Creation Stewardship Task Force

Note: A full-color version of this Creation Stewardship Task Force report is available for download at crcna.org/synodresources in order to view the charts contained in Appendix A in color.

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I. Introduction

We acknowledge that "the earth is the LORD's, and everything in it" (Psalm 24:1), taking seriously our task of imaging God's love for the world and all creation (cf. Gen. 1:26). We acknowledge and honor our Creator as we serve and keep his creation (cf. Gen. 2:15), ever seeking to act justly, love mercy, and walk humbly with our God (cf. Micah 6:8). We are stewards of God's gifts, stewards of God's world. The foundation for our stewardship is the Bible, through which we come to know God's will for our lives (cf. 2 Tim. 3:16-17) and for creation (cf. Rom. 8:18-25). Scripture also explains that creation is an eloquent proclaimer of God's glory (Psalm 19:1)—a revelation so convicting that not a single human being has a valid excuse for not knowing God's everlasting power and divinity (Rom. 1:20).

It is with gratitude to God for the blessings of his Word and his creation that we convey this, our task force report on caring for God's creation, to Synod 2012 of the Christian Reformed Church in North America in response to its mandate of 2010 (see *Acts of Synod 2010*, pp. 870-72).

II. The mandate: history, analysis, and approach

The committee carefully reviewed its mandate and its approach to these issues to ensure it stayed true to the intentions of Synod 2010:

> That synod instruct the Board of Trustees to assemble a task force that will report to Synod 2012, to identify a biblical and Reformed perspective of our position on creation stewardship, including climate change, applicable to this millennium, for congregations, society, and our global gospel partners.
>
> *Grounds:*
> a. *Our World Belongs to God*, paragraph 51—"We commit ourselves to honor all God's creatures and to protect them from abuse and extinction, for our world belongs to God"—makes clear our responsibility to address this concern.
> b. Sufficient relevant material already exists from which we may draw to create such a position statement.
> c. A great deal of the science on this subject elicits widely varying opinions that often retard any active response.
> d. There is an urgent need to focus on the biblical and Reformed perspective so that we may unify our community around common ground and enable the formulation of concrete positive action strategies.
>
> (*Acts of Synod 2010*, p. 871-72)

In order that our work be of maximum assistance to the Christian Reformed Church, we also noted the immediate and longer term denominational contexts in which our task force came to be.

The immediate event that precipitated the formation of our task force by Synod 2010 was a divided synodical advisory committee. This "pre-advice"

committee, assigned to review segments of the work of the Board of Trustees, could not agree on recommending ratification of the Board of Trustees' previous endorsement of the "Declaration on Creation Stewardship and Climate Change." This declaration, the product of a 2009 Micah Network[1] conference in Limuru, Kenya, was signed by senior staff of CRWRC and the Office of Social Justice and was subsequently endorsed both by the executive committee of CRWRC and by the Board of Trustees of the CRCNA. The core concern of a significant segment of the committee was the declaration's assertion that human activity has contributed to the degradation of creation and the potentially dangerous warming of earth's climate. Neither the science nor the theology behind this assertion was clear to them—thus the recommendation to form a task force. Similar concerns were raised by individual members of the church, illustrating the urgency and timeliness of this issue.

At the same time that Synod 2010 was dealing with objections and disagreements arising from climate change issues, it was instructing denominational staff to do more to raise the awareness of members of the CRC around creation stewardship issues.

Widening our historical lens a bit, we observe that the CRC has a long history of making significant intellectual, theological, and spiritual contributions toward environmentally responsible living. Because of our Reformed, Christian view of this world and of God's plan for its redemption, CRC members have the theological roots to affirm a commitment to work vigorously to protect and heal the creation for the glory of the Creator, as we wait for the restoration of the creation to wholeness. Long before "ecology," "environmental protection," and "creation care" became buzzwords, CRC members were living out a deep commitment—in their callings and in their lives—to the respectful treatment of God's earth, honoring the claim of Psalm 24:1 that "the earth is the LORD's, and everything in it."

However, the prophetic voice calling us to fulfill our appointment by the Creator as "earthkeepers and caretakers to tend the earth, enjoy it, and love our neighbors" (*Our World Belongs to God*, para. 10) has often come more from faithful individuals, congregations, and scholars than from a prophetic consensus at the level of the denomination or its agencies and institutions.

There is good anecdotal evidence to conclude that for decades CRC members and congregations have examined their behavior in light of the biblical calling to be stewards of God's creation and resources. They have found both small and large ways to resist the allure of wastefulness and overconsumption by making personal lifestyle choices to reduce, reuse, and recycle. They have contributed much to assisting others in times of distress and in developing their potential.

CRC scholars also had, and still have, a prophetic voice for creation care, producing much helpful information and suggesting many practices for sustainable development and responsible living. Already three decades ago, the Calvin Center for Christian Scholarship researched and produced the book *Earthkeeping* (Loren Wilkinson, Peter DeVos, Calvin DeWitt, Eugene Dykema,

[1] The Micah Network is a global coalition of approximately 350 Christian, evangelical relief, and development organizations that meet periodically to discuss and cooperate around major issues confronting the poor and disenfranchised. Both CRWRC and the CRC Office of Social Justice are members and active participants.

and Vernon Ehlers [Eerdmans, 1980]), a pioneer publication in the field of Christian environmental stewardship.

Several synods have made an effort to address creation care. First, in response to various overtures in the early 1990s, the synodical Task Force on CRC Publications and the Environment examined the use of resources at the denominational level, and synod commissioned CRC Publications to produce study guides on the ethical framework of environmental stewardship. This resulted in the publication of the first edition of *Earthwise: A Biblical Response to Environmental Issues* in 1994 by CRC Publications, published again in second (2007) and third (2011) editions by Faith Alive Christian Resources. The task force has cited and used material from the third edition, *Earthwise: A Guide to Hopeful Creation Care*, at various places in this report. Second, Synod 1997 alerted churches to the Reformed Ecumenical Council's report "The Just Stewardship of Land and Creation," which includes guidelines and recommendations that can be used by churches, classes, and institutions.

In 2008, in response to an overture from Classis Niagara requesting synod to consider stewardship guidelines, synod instructed the Board of Trustees to establish and maintain a webpage with up-to-date eco-justice resources. The overture requested clear guidelines for CRC institutions, agencies, and congregations to implement practices that respect God's creation. Such a request came out of the strong concerns that CRC members, congregations, and institutions engage in excessive levels of consumption similar to the rest of our affluent society.

All three of synod's actions on creation care over the past two decades served to help the denomination to embrace the work already undertaken by many individuals and congregations. The Creation Stewardship Task Force hopes to expand on this important work in this report.

Climate change

Despite the strong tradition of stewardship in our Reformed worldview and significant involvement on the part of CRC members whose vocation places them directly at the core of the scientific inquiry process, the denomination has, until recently, not engaged one of the most pressing stewardship issues of today—climate change.

In fact, as noted earlier, the public engagement of this issue on the part of denominational staff and leaders is the precipitating event bringing about the creation of our task force and the report that follows.

Given the mandate of the task force and the context briefly outlined above, the task force believes the report must focus on helping the CRC reach a consensus on these issues that is rooted in our commitment to the care of creation and in Reformed theological and scientific knowledge. This in turn must support and inspire constructive engagement that is urgently required by the reality of a warming world. We hope that the work of the task force can serve as a guide to shape denominational ministry with partners around the world and the education of CRC members, as well as to inform an effective advocacy response from individuals, agencies, and the denomination itself.

The task force is confident that its work is rooted deeply in the biblical and Reformed heritage we all share, and will therefore resonate deeply with the CRC. We are also aware that the topic of climate change generates intense

passion and diverse opinions on many levels, and that some of our conclusions may draw opposition. Nevertheless, it is our hope that the report may serve to enhance and deepen the critical conversations and engagement of the wider church and society. Our hope is that this report will at least serve to unify our community around common principles and understandings regarding care for God's creation. We also deeply desire that the in-depth information about the science of climate change and potential implications will serve to enable and motivate the participation of Christians of all political and cultural affiliations in their formulation of concrete positive action strategies.

III. Laying the foundation

There is a great deal of perceived conflict between science and religion. Some of this can be traced to differences in what philosophers call epistemology. Epistemology is the study of knowledge: what it is, how it is acquired, and how we know what we know. Our knowledge of God is acquired differently from our knowledge of the natural world. Knowledge of God must be revealed to us by God in some way. Knowledge of the structure and operation of the physical world can be discovered through human investigation using the gifts of investigation given by God.

A. Knowledge of God

Psalm 19:1-2 tells us, "The heavens declare the glory of God; the skies proclaim the work of his hands. Day after day they pour forth speech; night after night they reveal knowledge."

Basic to theology is the notion of revelation, the idea that God reveals knowledge of himself to humans. Revelation is the only way humans can acquire knowledge of God. In other words, unless God condescends to make himself known to us, humans will not know God. This is in contrast to how we acquire knowledge of the physical world. God does not need to reveal the structure and function of the physical world to us. We have direct access through our senses to the physical world. We observe some aspect of the physical world, test those observations, and draw conclusions based on those observations. But in order to know anything at all about God, God has to reveal himself. Following the teaching of Scripture, the Belgic Confession identifies two ways that God has chosen to disclose himself to human persons: through creation (general revelation) and through Scripture (special revelation).

God reveals himself through creation. Paul indicates in Romans 1:20 that God's "invisible qualities—his eternal power and divine nature" can be clearly seen all around us. John Calvin writes that God, "in order that none might be excluded from the means of obtaining felicity" has been pleased "so to manifest his perfections in the whole structure of the universe, and daily place himself in our view, that we cannot open our eyes without being compelled to behold him" (*Institutes of the Christian Religion*, 1.5.1). As a result, humans are without excuse for not acknowledging God and praising God for his wisdom and glory.

Despite the clarity of God's self-revelation in creation, sin has distorted the human ability to acquire true knowledge of God through creation alone. Paul explains that humans inevitably distort what they see in creation and

end up worshiping something less than the true God as he has revealed himself. Calvin elaborates this sentiment, writing that although God's glory shines in creation like "bright lamps lighted up to show forth the glory of its Author," these lamps are "altogether insufficient of themselves to lead us into the right path" (*Institutes*, 1.5.14). As a result, God graciously gives humans God's own Word, which both clarifies the knowledge of God available in creation and explains the way humans are able to have a right relationship with their Creator. Because God is incomprehensible, humans will never know God completely. But Scripture, along with the inward testimony of the Holy Spirit, enables human persons to know as much as they need to about God in this life to be in a restored relationship with God.

Creation, therefore, is one of the two ways or "books," as the Belgic Confession says, through which God has chosen to reveal himself to humanity. In fact, for many people creation may be the first encounter they have with the eternal power and divine nature of God. Creation is thus an evangelical witness to the power and glory of God. Given this understanding of creation, Christians should be compelled to ask whether the degradation of creation distorts this powerful witness. Can a smog-filled atmosphere and polluted lakes point to the Creator in the same way as a pristine river and clear blue sky? Does a person in a large city looking through the brown haze at seemingly dulled stars feel the same awe as the psalmist who, observing the beauty of the unpolluted night sky, exclaimed, "What is mankind that you are mindful of them?" (Ps. 8:4). Clearly, no small part of our concern for creation should be a concern to preserve this glorious theater of God's might and glory.

B. Knowledge of the natural world

Scientific Method

Knowledge of the natural world comes about through our observing what happens, and discovering universal laws that explain what we see. Scientists develop hypotheses—from a combination of knowledge and imagination—to explain what they see in reality. Hypotheses are testable because they make predictions of future events based on past events. Some hypotheses regarding climate change are tested against pre-historic records of geologic and climate changes. A hypothesis is refined over time through testing and debate. This process hones the hypothesis into a clearer statement of reality, often aided by mathematical formulae. Although, in some sense, a hypothesis can never be fully proven, its certainty can be raised to very high levels by this ongoing process. The result is that the hypothesis progresses to a theory and then, infrequently, to a law.[2] This is the scientific method.

Science is a search for an understanding of how the physical universe operates. It spans a range of disciplines including physics, chemistry, biology, geology, meteorology, oceanography, ecology, and cosmology, all of which are relevant to the biosphere in which we live. Science has developed theories such as gravity, electromagnetic radiation (explaining the behavior of light, radio waves, microwaves, X-rays, etc.), and the relativity of space

[2] The definition of what is meant by a "scientific law" varies with scientific discipline and is itself worth a philosophical discussion. We use it here to simply identify those theories that have progressed to such a level of maturity that we accept them as true in our everyday life. For example, we ignore the Law of Gravity at our peril.

and time. Some of these theories are codified as laws, such as Newton's law of universal gravitation or the laws of electromagnetism.

Explanations of phenomena develop over time and are changed with new developments in knowledge. For example, both Newton's laws of motion and Einstein's theory of relativity explain the behavior of objects influenced by gravity. Both predict very closely the same behavior for most of what we observe every day, but for applications where greater precision is required (for example, GPS technology or interplanetary space flights) it becomes clear that Einstein's theory is superior, more fully explaining the behavior of gravity.

Science may be considered a search for truth where truth is not capitalized and is understood by scientists to always be, to some extent, provisional. Science has an element of uncertainty, but this uncertainty is quantifiable and, for the most part, reducible in time. In our daily life, we often say that the outcome of an event, such as a sports game, is uncertain, and we may argue that the uncertainty is quantifiable because there are some odds associated with the outcome based on expected team performance. Ultimately, however, that event is uncertain until the game is played and then all uncertainty is removed.

Scientific uncertainty becomes more difficult to quantify as phenomena become more complex and may change with time. For example, the uncertainty in tomorrow's weather forecast is well understood and actually quite small, but the uncertainty in the forecast for ten days from now is substantially greater and considerably more difficult to quantify.

Uncertainty is the focus of scientific research; consequently, scientists speak often about uncertainty. This may lead the public to think that all science is totally uncertain. That is far from the truth. Scientists rarely discuss science that is certain because it is uninteresting in the sense that it is well understood. Scientists should speak more clearly about uncertainty, but the public should understand that the cutting edge of science is about defining what the limits of uncertainty are and how to go about reducing that uncertainty.

Scientists speak to each other by reporting their research in peer reviewed articles, or "primary literature."[3] Submitted articles are reviewed by carefully chosen peer scientists who can provide a scholarly review of the submission. Articles are only published when they pass the review process and earn the approval of the journal editor. This process is designed to keep researchers precise, honest, and thorough in reporting their results. Over time, published articles can be used to track the progression of scientific ideas.

In addition to peer reviewed articles, science is reported in "gray literature" and "popular literature." Gray literature consists of reports from federal or state agencies, colleges and universities, think tanks, institutes, and foundations. This literature is important, but it is not considered as authoritative as primary literature because it typically does not undergo the same kind of disciplined peer review. Popular literature consists of newspapers, magazines, leaflets, and brochures. Like gray literature, it also is important and, while it may be useful, is not normally considered authoritative. Many people use the gray or popular literature to learn about scientific issues and

[3] The information in this and the following paragraph is expanded in Appendix B. We think that it is very important for the broader community to understand the distinctions drawn here, and we encourage a careful reading of that appendix.

to inform their opinions. This literature is often easier to read and understand, and it may be written in a less technical or a non-technical way.

Arguably the most contentious area between religion and science is the nature of authority. Much of religious and theological discussion is concerned with the nature of divine authority and how we humans are to understand that authority. Science appeals to authority but *only* in the sense of an appeal to the consensus of the scientific community. There is no appeal to a higher, absolute authority. When a scientist begins a sentence about science with "We believe . . . ," he or she is making a statement about the consensus that the scientific community has reached on the subject. To use an overly simplistic situation, consider a scientist who says that "we believe the earth is spherical." He or she means that the consensus of the scientific community based on both observation and theory is that the earth is spherical, and the statement is an appeal to the authority of the community. The flat-earth society, which exists and maintains that the earth is flat, is not viewed as authoritative because that position is not credible within the context of scientific understanding (and uncertainty) and, hence, not part of the consensus.

The scientific method is limited to explanations of causes and effects among natural events or "phenomena"—that is, events or aggregate processes that are observable in one way or another. It can explain how things happen, but it cannot address deeper questions such as the meaning of life or the existence of God. Since scientific tests of hypotheses must be repeatable, science also cannot address the existence of miracles that are exceptions to the normal laws of nature. Furthermore, science works from the presupposition that nature operates on the basis of fixed, predictable, universal laws. It cannot explain the origin of those laws, but it can help us understand how those laws affect the created order and life within that order.

C. Unity of knowledge

God is the creator of everything that exists—spiritual and physical. The fixed, predictable, universal laws of nature were put in place by God. The doctrine of providence teaches not only that God created the world with these laws but also that his ongoing care of the world includes sustaining the world through these laws. This does not mean God is bound in some way to the laws of nature. God can and does at times supersede these universal laws. Scripture testifies to this in numerous stories—but perhaps most dramatically in the resurrection of Jesus Christ. Ordinarily, however, God uses the laws of nature as the means for his continuous care of the world.

Faith in God includes recognition of the means God uses to providentially care for creation. The fact that God is sustaining creation through the laws of nature ensures, at least to some degree, the reliability of the scientific method. Scientists are trained to recognize the ordered patterns in nature, and to test their investigations of various parts of the creation by means of these patterns that God continues to maintain. Thus scientific findings should be considered reliable, insofar as they are dealing with the realm of observable phenomena.

Scientific knowing, then, is one way God has given humans to learn about the world around them. Christians should wholeheartedly affirm the work of scientists who, through their investigation of the physical world, offer information that may enhance human flourishing and insights about creation that further display God's invisible qualities and offer opportunities to praise God.

IV. Biblical principles on caring for creation

A. A biblical, contemporary testimony

The CRC's *Our World Belongs to God: A Contemporary Testimony* provides an excellent framework for examining the biblical principles that underlie creation care. By following the biblical story of creation, fall, redemption, and new creation, we hope to make clear that the gospel message includes the entire creation.

With biblical principles firmly in hand, we are equipped to think about what the response of individuals and the church as a whole ought to be. Confession of our participation in the degradation of creation is one aspect of our response. Commitment to discipleship that develops Christian character is another aspect. Character that is oriented around love for God and neighbor reflects a desire to care for the world God has entrusted to us and those around us for the benefit of all of creation.

We therefore present portions of the Contemporary Testimony as a reflection of biblical teaching on creation care, outlining what this teaching means for how we live as stewards of God's world.

1. Creation

> 7. Our world belongs to God—
> not to us or earthly powers,
> not to demons, fate, or chance.
> The earth is the Lord's.

God alone is Creator.
The earth is the Lord's.

Reflecting Scripture, the Contemporary Testimony affirms God as Creator of all that is. God's ultimate ownership of everything is implied from the fact of his creating, and is also taught directly in Scripture (Ps. 24:1; 50:9-12). Because the world belongs to God, humans do not have the right to use creation as they please. Rather, humans are stewards, caretakers of the earth that is the Lord's. All the things that we can say we own—our land, our homes, our cars, our copyrights, and our patents—ultimately belong to God.

> 8. In the beginning, God—
> Father, Word, and Spirit—
> called this world into being
> out of nothing,
> and gave it shape and order.
> *See Genesis 1, where Creator, Word, and Spirit call creation into order. For the role of the Word in creation and Jesus as the Word, see John 1:1-14.*

> 9. God formed sky, land, and sea;
> stars above, moon and sun,
> making a world of color, beauty, and variety—
> a fitting home for plants and animals, and us—
> a place to work and play,
> worship and wonder,
> love and laugh.
> God rested
> and gave us rest.
> In the beginning
> everything was very good.
> *On creation, besides Genesis 1 and 2, see Psalm 19; 33:6-9; and 104.*

All of creation is created good.

10. Made in God's image
to live in loving communion with our Maker,
we are appointed earthkeepers and caretakers
to tend the earth, enjoy it,
and love our neighbors.
God uses our skills
for the unfolding and well-being of his world
so that creation and all who live in it may flourish.
For the image of God, see Genesis 1:26-27; 9:6; Ephesians 4:24; Colossians 3:10; and James 3:9.

Humans are both an inseparable part of the created order and have a special role within and a unique responsibility for all parts of the biosphere.

As imagebearers of God, humans are entrusted with taking care of the creation. Scripture presents this responsibility as both a gift and a command. Living as God intended includes taking this responsibility seriously.

2. Fall

13. In the beginning of human history,
our first parents walked with God.
But rather than living by the Creator's word of life,
they listened to the serpent's lie
and fell into sin.
In their rebellion
they tried to be like God.
As sinners, Adam and Eve feared
the nearness of God
and hid.
For the fall of humanity into sin, see Genesis 3. On the serpent, see, in addition to Genesis 3, Revelation 12:9 and 20:2.

In our fallen condition we are alienated from God and creation.

In trying to be like God, Adam and Eve sinned and were removed from the presence of God. This alienated humanity from God, each other, and the rest of creation.

The legacy of human sin is not merely about disobedience but also about an inherited deformity all humans live with. This deformity affects everything we do and even how we think. We no longer acknowledge the true God (Rom. 1). We no longer recognize how we are supposed to live. As a result, we fail to take seriously the gift of stewardship. We are inclined to corrupt our proper dominion of God's world into domination and abuse.

15. When humans deface God's image,
the whole world suffers:
we abuse the creation or idolize it;
we are estranged from our Creator,
from our neighbor,
from our true selves,
and from all that God has made.
On the defacing of God's image, see Romans 1:21-23; for the restoration of the image in Christ, see Romans 8:29, 2 Corinthians 3:18, Ephesians 4:22-24, and Colossians 3:10.

Human sin affects all of creation.

The history of exploration of the "new world" has taught us that when humans attempt to dominate other people and cultures, the mindset of domination can stretch to the environment as well. Abuse of our fellow human

beings reflects an overall attitude of disrespect for creation as a whole. Repenting from this attitude and seeking restoration with each other, including native cultures, opens the door to restoring a right relationship with creation.

3. Redemption

> *God's plan of salvation includes the restoration and reconciliation of all creation.*

18. While justly angry,
God did not turn away
from a world bent on destruction
but turned to face it in love.
With patience and tender care
the Lord set out
on the long road of redemption
to reclaim the lost as his people
and the world as his kingdom.
For God's response to sin, see Genesis 3:9-15, John 3:16, and Luke 1:68-75; for the aim to restore the kingdom, see Revelation 11:15.

23. Remembering the promise
to reconcile the world to himself,
God joined our humanity in Jesus Christ—
the eternal Word made flesh.
He is the long-awaited Messiah,
one with us
and one with God,
fully human and fully divine,
conceived by the Holy Spirit
and born of the virgin Mary.
For Jesus as the incarnate Son of God, see Luke 1:31-35, John 1:1-14, and Hebrews 1:2-3.

The fact that the eternal Christ was made flesh affirms the goodness and value of the created world. Against the many ancient religions that promoted escape from the material world, Christians affirmed the material world because the second person of the Trinity chose to take on flesh, becoming fully human so that humanity could become like him.

> *We look to Jesus as our example.*

24. As the second Adam,
Jesus chose the path we had rejected.
In his baptism and temptations,
teaching and miracles,
battles with demons
and friendships with sinners,
Jesus lived a full and righteous human life before us.
As Go's true Son,
he lovingly obeyed the Father
and made present in deed and word
the coming rule of God.
In Romans 5:12-21, Christ is designated the second Adam. Hebrews 2:10-18 and 4:14-5:2 teach about his life of righteous humanity; the announcement of the kingdom is found, among other places, in Mark 1:1, 14, 15.

25. Standing in our place,
Jesus suffered during his years on earth,
especially in the tortures of the cross.
He carried God's judgment on our sin—
his sacrifice removed our guilt.
God raised him from the dead:
he walked out of the grave,
conqueror of sin and death—
Lord of Life!

We are set right with God,
given new life,
and called to walk with him
in freedom from sin's dominion.
For Jesus' lifelong suffering, see Hebrews 5:7-10. All four of the gospel passion accounts portray the depths of his suffering on the cross. Jesus' resurrection victory is proclaimed often, especially in Matthew 28:1-10 and 1 Corinthians 15:20-28.

Because of Christ's work on our behalf, Christians are now able to live as God intended. No longer slaves to sin, we are now slaves to Christ. Our minds and hearts have been healed through Christ's atoning sacrifice. We are enabled to hear God's call to follow Christ and his mission in the world. Of primary importance is the call to go, preach the gospel, and make disciples of all nations.

Discipleship entails teaching others all that Christ has commanded (Matt. 28:20). This includes the command to be caretakers of the creation. Caring for God's world is part of our task as Christians. We need not despair that this command is too difficult or too much for us to accomplish. God is with us always and enables us to follow him in all that God commands through the empowering work of the Holy Spirit within us. God has called us, and God will work in and through us to accomplish what he intends (Phil. 1:6; 4:13).

4. The mission of God's people

Given what the Bible teaches about the goodness of creation, the task of humans to care for creation, the effects of sin on our ability to know how to exercise proper stewardship of creation, and God's gracious sacrifice of Jesus Christ that offers the restoration of proper human dominion of creation, we may then ask how we, as followers of Jesus Christ, should live in light of God's command to care for his world. Once again, the Contemporary Testimony offers a biblically based starting point for considering how humans should fulfill our task as earthkeepers.

43. Jesus Christ rules over all.
To follow this Lord is
to serve him wherever we are
without fitting in,
light in darkness,
salt in a spoiling world.
On the rule of Christ over the whole world, see Philippians 2:9-11, Colossians 1:15-20, and Revelation 11:15; on being light, salt, and not fitting in, see Matthew 5:13-16 and Romans 12:1-2.

44. Life is a gift from God's hand,
who created all things.
Receiving this gift thankfully,
with reverence for the Creator,
we protest and resist
all that harms, abuses, or diminishes the gift of life,
whether by abortion, pollution, gluttony,
addiction, or foolish risks.
Because it is a sacred trust,
we treat all life with awe and respect,
especially when it is most vulnerabl—
whether growing in the womb,
touched by disability or disease,
or drawing a last breath.

All life is a gift from God and should be treated with respect and dignity.

When forced to make decisions
at life's raw edges,
we seek wisdom in community,
guided by God's Word and Spirit.
On respect for all life, see Deuteronomy 5:17 and Psalm 104:14-30 and 139:14-16. Our very bodies are temples of the Holy Spirit: 1 Corinthians 6:19-20.

50. Grateful for advances
in science and technology,
we participate in their development,
fostering care for creation
and respect for the gift of life.
We welcome discoveries that prevent or cure diseases
and that help support healthy lives.
We respect embryonic life,
approaching each new discovery,
whether of science or of medical technique,
with careful thought,
seeking the will of God.
In Genesis 1:28-31 and 9:1-7, God gives to humanity the right and responsibility to develop and care for creation; for a reflection on the limitations of human technology and need for divine wisdom, see Job 28; for the continuing goodness of creation and the need for a prayerful approach to what we use of it, see 1 Timothy 4:4-5.

51. We lament that our abuse of creation
has brought lasting damage
to the world we have been given:
polluting streams and soil,
poisoning the air,
altering the climate,
and damaging the earth.
We commit ourselves
to honor all God's creatures
and to protect them from abuse and extinction,
for our world belongs to God.
Genesis 1:28-29; 7:1-5; Psalm 8; and Romans 8:18-25 teach that we are entrusted with caring for the earth.

As we are convicted by the Holy Spirit, we need to confess and repent of actions that degrade the biosphere.

5. New creation

We recognize that our efforts to care for creation will not bring in a new creation. We also recognize that there are many challenges in our world to God's rule, but we believe that we should confront those challenges by seeking to do God's will on earth, as it is in heaven. We must be responsible in our creation care even as we know that God's plans cannot and will not be thwarted by human actions. God is sovereign, and the earth will endure—"seedtime and harvest . . ." (Gen. 8:22)—until at a time known only to the Father (Matt. 24:36), Christ returns in triumph to complete what his resurrection started: the restoration of the heavens and earth. Thus our ultimate motivation in creation care is not any secular notion of "saving the planet"; salvation is through Christ alone. The Christian's ultimate motivation for creation care is love for God and neighbor. This love for our neighbor includes both this generation and generations to come because we do not know the time of Christ's return.

55. Our hope for a new creation is not tied
to what humans can do,
for we believe that one day
every challenge to God's rule
will be crushed.
His kingdom will fully come,
and the Lord will rule.
Come, Lord Jesus, come.
On this hope, see 1 Peter 1:3-12, 2 Peter 3:3-13, 1 Thessalonians 4:13-5:11, and Revelation 11:15.

We are not required nor even able to "save the world," but we are called to be disciples of Jesus Christ, the one who has and is setting things right, in joyful love and service to God and our neighbors.

56. We long for that day
when our bodies are raised,
the Lord wipes away our tears,
and we dwell forever in the presence of God.
We will take our place in the new creation,
where there will be no more death
or mourning or crying or pain,
and the Lord will be our light.
Come, Lord Jesus, come.
For the coming of the kingdom of God, see Matthew 24, Acts 1:10-11, 1 Thessalonians 4:13-5:11, and Revelation 19:11-16. 1 Corinthians 15 speaks of the resurrection of the body, Revelation 21:4 of the wiping away of tears, and Revelation 21:22-27 of the light of heaven.

57. On that day
we will see our Savior face to face,
sacrificed Lamb and triumphant King,
just and gracious.
He will set all things right,
judge evil, and condemn the wicked.
We face that day without fear,
for the Judge is our Savior,
whose shed blood declares us righteous.
We live confidently,
anticipating his coming,
offering him our daily lives—
our acts of kindness,
our loyalty, and our love—
knowing that he will weave
even our sins and sorrows
into his sovereign purpose.
Come, Lord Jesus, come.
Revelation 5 describes the Lion and the Lamb. For the just judgments of the Lord, see Revelation 19:1-10. A picture of the multitude of those declared righteous in Christ is found in Revelation 7:9-17. The concept of God weaving all things together is found, among other places, in Romans 8:28-39.

Our being set right with God is eagerly anticipated by all of the created order (Romans 8).

58. With the whole creation
we join the song:
"Worthy is the Lamb, who was slain,
to receive power and wealth
and wisdom and strength
and honor and glory and praise!"
He has made us a kingdom of priests
to serve our God,
and we will reign on earth.
God will be all in all,
righteousness and peace will flourish,
everything will be made new,
and every eye will see at last

"Praise God, from whom all blessings flow. . . ."

that our world belongs to God.
Hallelujah! Come, Lord Jesus!
For the imagery of this paragraph, see Exodus 19:5-6, Isaiah 40, 1 Peter 2:9-10, and Revelation 4-5.

B. Basic principles for earthkeeping

Some basic principles for earthkeeping naturally follow from our understanding of Scripture as outlined in the Contemporary Testimony. The following principles are a summary of the principles given in *Earthwise: A Guide to Hopeful Creation Care*, third edition (Faith Alive Christian Resources, 2011), pp. 72-80; used and adapted with permission.

1. Earthkeeping principle

   a. As the Lord keeps and sustains us, so we must keep and sustain our Lord's creation.

   b. Genesis 2:15 tells us that Adam and Adam's descendants were expected to *serve* the garden and to *keep* it.

   c. The Hebrew word *'abad* ("serve") in this passage occurs 290 times in the Old Testament, and it is most often translated as "serve," as in Joshua 24:15: "Choose for yourselves this day whom you will serve. . . . As for me and my household, we will serve the LORD."

   d. God also expected Adam and his descendants to meet the needs of the garden of creation so that it would persist and flourish. The word for *keep* (*shamar*) is sometimes translated as "guard," "safeguard," "take care of," and "look after," indicating a loving, caring, sustaining kind of keeping.

   e. When we fulfill God's mandate to serve and to keep the creation, we make sure that the creatures and other living things under our care are maintained so that they can flourish. They must remain connected with members of the same species, with the many other species with which they interact, and with the soil, air, and water they depend on.

   Earthkeeping

   As the Lord keeps and sustains us, so we must keep and sustain our Lord's creation.

   f. As God *keeps* those who believe, so God's people should *keep* his creation.

2. Fruitfulness principle

   a. We should enjoy but not destroy creation's fruitfulness.

   b. God's blessing of fruitfulness is for the whole creation. In Genesis 1, God declares, "Let the water teem with living creatures, and let birds fly above the earth across the vault of the sky" (1:20). And God blesses these creatures with fruitfulness: "Be fruitful and increase in number and fill the water in the seas, and let the birds increase on the earth" (1:22).

c. While we are expected to enjoy creation and its many fruits, we may not destroy the *fruitfulness* that creation's fullness depends on. Like Noah, we must preserve and care for God's many species whose interactions and relationships with each other and with land and water make up the fabric of the biosphere.

Fruitfulness

We should enjoy but not destroy creation's fruitfulness.

d. We must let the profound admonition of Ezekiel 34:18 echo in our minds: "Is it not enough for you to feed on the good pasture? Must you also trample the rest of your pasture with your feet? Is it not enough for you to drink clear water? Must you also muddy the rest with your feet?"

3. Sabbath principle

a. We must provide for creation's *Sabbath* rests. In Exodus 20 and Deuteronomy 5, God commands us to set aside one day in seven as a day of rest for people and for animals. God commands, "Six days you shall labor and do all your work, but the seventh day is a Sabbath to the LORD your God. On it you shall not do any work, neither you, nor your son or daughter, nor your male or female servant, nor your animals, nor any foreigner residing in your towns" (Ex. 20:9-10). This Sabbath day is given to help us all get "off the treadmill," to protect us all from the hazards of continuous work, to help us pull our lives together again. It's a time for rest and for expressing appreciation to God for the creation resources given for human use. In the New Testament, Jesus affirms and clarifies the meaning of Sabbath; the Sabbath is made for those who are served by it—not the other way around (Mark 2:27).

Sabbath

We must provide for creation's Sabbath rests.

b. Not only will every seventh day be set aside for rest for humans and animals, but every seventh year is also to be set aside to give rest to the land. "For six years sow your fields, and for six years prune your vineyards and gather their crops. But in the seventh year the land is to have a year of Sabbath rest, a Sabbath to the LORD" (Lev. 25:1-7). The land is not to be relentlessly pressed either.

c. Does this command create a problem for people? Leviticus 25:20-21 says, "You may ask, 'What will we eat in the seventh year if we do not plant or harvest our crops?'" God's answer: "I will send you such a blessing in the sixth year that the land will yield enough for three years." God was instructing people to trust his provision. Blessing and fruitfulness come from God. "If you follow my decrees and are careful to obey my commands, I will send you rain in its season, and the ground will yield its crops and the trees their fruit" (Lev. 26:3-4).

d. Sabbath, therefore, is deeply connected to the flourishing of all of creation. This Sabbath is not a legalistic requirement; it's a profound

principle. In some farming regions, the land is allowed to rest every *second* year, while in others, practices like conservation tillage and cover crops are used, without any "year off." The good steward will use practices specific to local conditions that are best suited to sustaining the soil. The key is the intent to keep the resource fruitful for the generations to come. The Sabbath applies to all of the resources of creation that we use.

4. Discipleship principle: We must be disciples of Jesus Christ—the Creator, Sustainer, and Reconciler of all things.

   a. No question about it—the Bible calls us to be disciples of, or *followers after,* someone. But we are not to be disciples of the Adam of Genesis, who neglected to serve (*'abad*) and keep (*shamar*) the creation. The Bible tells us that we must be disciples of "the last Adam," Jesus Christ (1 Cor. 15:45).

   b. All who follow Jesus follow the example of the one who makes all things new, the one who makes all things right again (Rev. 21:5). Colossians 1:19-20 puts it this way: "God was pleased to have all his fullness dwell in him, and through him to reconcile to himself *all things*" (emphasis added).

   Discipleship

   We must be disciples of Jesus Christ—the Creator, Sustainer, and Reconciler of all things.

   c. Who is this Christ we are to follow? He is the one *in whom* and *for whom* all things were created (Col. 1:16). He is the one *through whom* God made the universe and *through whom* God redeems his people (John 1:3; Col. 1:16, 20; Heb. 1:3).

   d. God reaches out sacrificially to make things right again. Jesus Christ, the final Adam, undoes the damage done by the first Adam and his followers. While followers of Adam bring death and degradation, Christ brings life and restoration (Rom. 5:12-17). The children of God work as followers and disciples of the final Adam. People who are happy being Christ's servant stewards are people for whom the whole creation is eagerly looking (Rom. 8:19).

5. Kingdom priority principle: We must seek first the kingdom of God.

   Our culture today proclaims, "Seek first a job (money, success), and all other things will be yours as well." It is tempting to yield to this message and to follow people whose highest priority is to gather up immense material gains. But Jesus advises us to seek first the kingdom of God and God's way of doing things; then everything else we need will be given to us as well (Matt. 6:33). In seeking God's kingdom, we discover that happiness and joy are *by-products* of our stewardship; fulfillment comes as a *result* of seeking the kingdom. It first is our calling, our vocation. We affirm this calling whenever we pray as

   God's kingdom

   We must seek first the kingdom of God.

Jesus taught us: "Our Father in heaven, hallowed be your name, your kingdom come, your will be done *on earth* . . ." (Matt. 6:9-10).

6. Contentment principle: *We must seek true contentment.*

   a. Everyone's prayer today should be that of Psalm 119:36: "Turn my heart toward your statutes and not toward selfish gain." Relentless pressing of land and life to produce more and more seriously degrades God's creation.

   b. In 1 Timothy 6:6 we learn that "godliness with contentment is great gain." Contentment means aiming to have the things that will sustain us while not pressing beyond that. An Amish saying based on this passage goes like this: "To desire to be rich is to desire to have more than what we need to be content." Hebrews 13:5 puts it this way: "Keep your lives free from the love of money and be content with what you have, because God has said, 'Never will I leave you; never will I forsake you.'"

   Contentment

   We should seek godliness with contentment.

   c. Being content helps us personally, and it helps preserve creation's integrity. All the things we use, all the things we make, everything we manipulate, everything we accumulate derives from creation itself. If we learn to seek godly contentment as our great gain, we will take and shape less of God's earth. We will demand less from the land. We will leave room for God's other creatures. We will be responsible stewards, caretakers, keepers of creation. We will regularly allow creation to heal and perpetuate its fruitfulness, to the glory and praise of its Maker.

7. Praxis principle: We must practice what we believe.

   a. Scripture admonishes us to act on what we know is right. The failure of people to act on what they know is right is well-documented—and the shortcoming challenged—in the pages of Scripture:

   "My people come to you, as they usually do, and sit before you to hear your words, but they do not put them into practice. Their mouths speak of love, but their hearts are greedy for unjust gain. Indeed, to them you are nothing more than one who sings love songs with a beautiful voice and plays an instrument well, for they hear your words but they do not put them into practice" (Ezek. 33:31-32).

   Praxis

   We must practice what we believe.

   "Why do you call me, 'Lord, Lord,' and do not do what I say?" (Luke 6:46).

   b. Merely knowing God's requirements for stewardship is not enough. Merely believing in God is not enough, for Scripture tells us that even demons believe in God (James 2:19). We must practice God's require-

ments, or they do no good. Creation care is an integral part of the church's evangelical witness to the world.

8. The con-servancy principle: *We* must return creation's service to us with service of our own.

   a. This principle overarches all the others. The word *conservancy* refers to conservation and often denotes an organization that regulates fisheries and/or protects other natural resources. In this discussion this word is hyphenated to draw attention to its root meaning—*con + serve* means "to serve with."

   b. We already know from experience that the creation serves us with good food, beauty, herbs, fiber, medicine, pleasant microclimates, continual soil-making, nutrient processing, and seed production. The garden and the larger biosphere provide what ecologists call "ecosystem services," such as water purification by evaporation and percolation, moderation of flood peaks and drought flows by river-system wetlands, development of soils from the weathering of rocks, and moderation of local climates by nearby bodies of water. Yet Genesis addresses *our* service to the garden.

   Con-Servancy

   We must return creation's service to us with service of our own.

   c. The garden's service *to us* is implicit; service *from us* to the garden is explicit. Like Adam, we are expected to return the service of the garden with service of our own. This is a reciprocal service, a "service with"—in other words, a *con-service*, a *con-servancy*, a *con-servation*. This reciprocal service defines an engaging relationship between garden and gardener, between the biosphere and its safeguarding stewards. Our love of our Creator God, God's love of the creation, and our imaging this love of God—all join together to commission us as *con-servers* of creation.

V. History of caring for creation

A. The habitable world

1. The earth is the Lord's

This is a proclamation given throughout Scripture. "To the LORD your God belong the heavens, even the highest heavens, the earth and everything in it" (Deut. 10:14), "for the foundations of the earth are the LORD's; upon them he has set the world" (1 Sam. 2:8b). God is the landlord, and we are God's tenants (Lev. 25:23), for "the earth is the Lord's, and everything in it" (1 Cor. 10:26).

In Psalm 24:1 it is written, "The earth is the LORD's, and everything in it, the world, and all who live in it." This biblical announcement, going back some 3,000 years, makes explicit that the *physical earth* and the *biosphere* are the Lord's. The Hebrew words here are *eretz* for "earth" and *tebel* for "the habitable world." First written in Hebrew, Psalm 24:1 was translated into Greek by rabbis for the library at Alexandria in the time of Alexander

the Great. That translation, the Septuagint, renders these words this way: The *ge* is the Lord's and the fullness thereof, the *oikoumene* and all who dwell in it.

Ge is the root for our word *geology,* and *oikoumene* is the root for our word *ecumenical*. The *oikoumene*, in antiquity, was used to refer to "the habitable world" or "habitable earth," the earthly abode for us and all living creatures. The word *oikoumene* comes from the Greek word *oikos,* meaning "house" or "household." In our day, that remarkable interwoven fabric of life-sustaining habitats, the *oikoumene*, is called the biosphere.

There are more words whose root is *oikos,* including ecology ("oikology"—study of the household) and economics ("oikonomics"—management of the household). Most important for our task and privilege of caring for creation is the word *oikonomia,* the biblical translation for which is usually "stewardship."

2. *Oikoumene:* loving God and neighbor

Throughout history we have been increasing our understanding of the *oikoumene*. In the sense of its being the biosphere we have come to understand it as the remarkable system of processes and materials through which God sustains the habitable earth. In the sense of its being ecumenical we are coming to understand its meaning as it extends beyond "our own kind of people" to all people with whom we share the biosphere. In doing this we increasingly are putting into practice the biblical message on neighborliness, with its principal text being the reply of Jesus to one of his questioners: "'Love the Lord your God with all your heart and with all your soul and with all your mind.' This is the first and greatest commandment. And the second is like it: 'Love your neighbor as yourself.' All the Law and the Prophets hang on these two commandments" (Matt. 22:37-40; also see Lev. 19:18, 34; Matt. 19:19; Mark 12:28-31; Luke 10:27; Rom. 13:8-10; Gal. 5:14; James 2:8).

As we have broadened our understanding of who our neighbor is, we have embraced different kinds of people as part of *humankind*, and we have come to work more *ecumenically* across denominations in our vocations and Christian mission. This includes the recent union of the Reformed Ecumenical Council with the World Alliance of Reformed Churches to form the World Communion of Reformed Churches (WCRC), of which the Christian Reformed Church in North America is a member. This ecumenical communion of Reformed churches spreads across 108 countries and consists of Congregational, Presbyterian, Reformed, and United churches that share roots in the 16th-century Reformation led by John Calvin, John Knox, and other Reformers. Our broadened communion is helping us through God's grace to proclaim the message of Psalm 24 and to present a convicting witness and service to the world as followers of Jesus Christ in proclaiming the good news to all creation. And, considered in the context of what we are learning about the biophysical world, our understanding of *ecumenical* goes well beyond the WCRC to embrace the whole of the habitable earth, the whole biosphere, in witness and in caring service.

From antiquity, the habitable world has been viewed as a great gift and a highly ordered abode within which people are to live in harmony. This

gift of the biosphere enrobes earth, even as earth hangs in orbit within our solar system and thus operates within the ineffable immensity and grandeur of the highly ordered system of systems we call the universe. The grand entirety of our universe has been given the beautiful name *cosmos*—the Greek word that affirms creation's order and embraces *all things*. And this is the cosmos that God loves (John 3:16). It is no wonder that in imaging God's love for the cosmos, we also can love the world as God does! "Of course not in its strivings . . ." as Abraham Kuyper wrote, but "because God has thought it out; because God has created it; because God has *maintained* it and *maintains* it to this day." We cannot love God without loving what God loves.

Our world-and-life view, our way of seeing ourselves, the world, the biosphere, the creation, the cosmos—in space and in time—ranges from individual to provincial to biospheric to cosmic; it expands from microscopic to macroscopic, local to global, planetary to all things! In our time, standing as we are on earth and in its biosphere, our widening biospheric world-and-life view is illumined by images of God's *oikoumene* seen through the lens of an orbiting satellite and of God's inspired Word.

Accordingly, our stewardship extends to embrace God's *oikoumene*, reaching as far as God's love for the world; reaching as far as all things we affect and the world that affects us. Our stewardship is as wide, as deep, and as extensive as the systems we affect, and with which and within which we interact. Our stewardship images God's wide-embracing love, bringing good news that meets creation's expectation of the coming of the children of God (Rom. 8:20-22).

B. A just, ordered, and lawful creation

As we continue to understand the meaning of stewardship in our day, we continue to be affirmed in our biblical faith in the order and lawfulness of the cosmos—from its greatest components to its tiniest. God's law is present at the dawn of creation, and it is by faith in God's Word that we trust God's law. And flowing from God's law is God's justice, not only in the dynamic structure and operations of creation, but also as prescribed to human beings as basic to responsible living in wholesome relationship with other people, other creatures, and the whole creation. Jesus Christ comes as the Son of Man not to abolish, but to fulfill God's law (Matt. 5:17).

C. The Word made flesh and the covenantal context of creation care

Christianity derives its pervasive strength by translation of God into the flesh in Jesus Christ and by the translation of Holy Scripture into various languages in various cultures.[4] Not only does God proclaim that God's work is "very good" in the narrative of Genesis 1, but God takes on human flesh, joining with creation for the purpose of redeeming it. And similarly, as we translate the ancient understanding of God's *oikoumene* (οΘκουμένη) into its scientific understanding as God's *biosphere*, we come to understand the full-orbed beauty of God's love for the cosmos. In this beauty we also come to understand the meaning of caring for creation in our time. Principles on the care of creation, gleaned from the overall canon of Scripture, reverber-

[4] Andrew F. Walls, *The Missionary Movement in Christian History: Studies in the Transmission of Faith*, Maryknoll, New York: Orbis Books, 1996, p. 26.

ate in Jesus Christ, the *Logos* (Word) through whom the whole creation has its integrity. Locating ourselves within the canonical drama of Adam and on through Israel to Jesus crucified, risen, and commemorated in the Lord's Supper, we come to understand, in adopting the mind of Christ, that we participate with Christ in the reconciliation of all things.

D. Misappropriation of dominion

Human and cultural degradation needs particular attention in our study, because every one of the problems and challenges confronted in caring for creation has to do with people, both as the source of these problems and challenges and as those affected. This is particularly true in regard to land. The relationship of the ancient people of Israel with God focuses largely on the promise, expectation, and reality of receiving the promised land. In the biblical and Christian perspective the human-land relationship is interconnected with the Creator and Redeemer. Land relationships always have three major components: land, people, and the Lord. So it must be from this three-party perspective that we engage our thinking and action about land in our present day, for the earth continues to belong to the Lord.

Our first attention, therefore, is on this relationship. And as we consider the idea of land from this Christian perspective, we quickly recognize that farmers and agrarian cultures remain a pervasive segment of our world, with 2.5 billion people (among a world population of about 7 billion) gaining their livelihood from the land. This large agrarian population is entrusted with the land, as it has been for centuries and even millennia past. For them, stewardship of land held in trust over the generations remains the cultural and ethical norm. Holding the land in trust, however, as stewards and as cultures that transfer land from generation to generation, is being seriously threatened by external factors. These are forces that increasingly push agrarian people to the margins, even eliminating them and their agrarian culture altogether. Agrarian culture is being degraded and destroyed worldwide, and long-standing traditions of tending the land are being supplanted by new dominant agents whose purpose is not to "grow the soil" or sustain agrarian society but to achieve present and immediate gains. Local knowledge and local investment in land and soil are being discarded widely. And the pleasure of living on the land, the wholesomeness of agrarian culture, and the beauty of the earth are thereby diminished.

A 2008 *New York Times* article titled "Food is Gold, So Billions Invested in Farming"[5] helps to illustrate this transformation of land from trust to commodity as it reports, "Huge investment funds have already poured hundreds of billions of dollars into booming financial markets for commodities like wheat, corn, and soybeans. But a few big private investors are starting to make bolder and longer-term bets that the world's need for food will greatly increase—by buying farmland, fertilizer, grain elevators, and shipping equipment. . . . And three institutional investors . . . are separately planning to invest hundreds of millions of dollars in agriculture, chiefly farmland,

[5] Diana B. Henriques, "Food is Gold, So Billions Invested in Farming," *New York Times*, June 5, 2008, http://www.nytimes.com/2008/06/05/business/05farm.html?scp=1&sq=%22Food%20is%20Gold%22&st=cse.

from sub-Saharan Africa to the English countryside."[6] This article went on to announce the "ambitious plans" of a major firm "to invest in farmland in sub-Saharan Africa, where it plans to consolidate small plots into more productive holdings . . ." explaining that Africa was chosen because "land values are very, very inexpensive." In this revolutionary transformation of agrarian landscapes into investments in industrial-scale production, food becomes money, land becomes commodity, and "investors" are distanced from land as the place and habitat for people who are engaged in life and living.

This revolution is difficult to confront, in part because we may be among its "investors," but, more important, because the interests that pursue this new expansive concept of "dominion" have no visible person who is responsible to the one whose land this is. As God's Word says, "Do not take advantage of each other. . . . The land must not be sold permanently, because the land is mine and you reside in my land" (Lev. 25:17, 23). It also says that the land must be returned to the poor and meek (Lev. 25:28). As for the new entities that appropriate dominion of the land from people who live on the land, a related passage from Scripture takes on important relevance as it tells us "even the stork in the sky knows her appointed seasons, and the dove, the swift and the thrush observe the time of their migration. But my people do not know the requirements of the LORD" (Jer. 8:7).

Of course, most Christian missions, Christian relief and development agencies, and other institutions protect, help, and support this one-third of the world's people with another concept of dominion: dominion as service, dominion as stewardship, dominion as ministry. And we expect that caring for creation practiced as caring for the land and caring for peoples will continue to grow and confront dominion as domination.

Misappropriation of dominion—taking from the meek to further empower the strong—has been repeated throughout history. In the medieval church this misappropriation took form in the "Doctrine of Discovery," a misappropriation that continues to the present in many forms. This interpretation and understanding of dominion affected application of the great commission given by Christ: "All authority in heaven and on earth has been given to me. Therefore go and make disciples of all nations, baptizing them in the name of the Father and of the Son and of the Holy Spirit, and teaching them to obey everything I have commanded you. And surely I am with you always, to the very end of the age" (Matt. 28:18-20). In fulfilling this mandate, the church, acting through European Christian nations, began to explore the entire world, bringing the gospel and, along with it, European culture and values. Its expression is well represented by this statement by the pope in 1455 to the king of Portugal:

> The Roman pontiff, successor of the key-bearer of the heavenly kingdom and vicar of Jesus Christ, contemplating with a father's mind all the several climes of the world and the characteristics of all the nations dwelling in them and seeking and desiring the salvation of all, wholesomely ordains and disposes upon careful deliberation those things which he sees will be agreeable to the Divine Majesty and by which he may bring the sheep entrusted to him by God

[6] One of these funds, the Blackrock World Agricultural Fund, was launched in 2010 and by August 2011 had invested more than $600 million dollars. *Fact Sheet, BGF World Agriculture Fund*, available at http://www.blackrocklatam.com/content/groups/latinamericansite/documents/literature/1111111656.pdf.

> into the single divine fold, and may acquire for them the reward of eternal felicity, and obtain pardon for their souls. This we believe will more certainly come to pass, through the aid of the Lord, if we bestow suitable favors and special graces on those Catholic kings and princes, who, like athletes and intrepid champions of the Christian faith, as we know by the evidence of facts, not only restrain the savage excesses of the Saracens and of other infidels, enemies of the Christian name, but also for the defense and increase of the faith vanquish them and their kingdoms and habitations, though situated in the remotest parts unknown to us, and subject them to their own temporal dominion, sparing no labor and expense, in order that those kings and princes, relieved of all obstacles, may be the more animated to the prosecution of so salutary and laudable a work. (From the papal bull *Romanus Pontifex* [Nicholas V], January 8, 1455.)[7]

The understanding of dominion as reflected in this papal bull affected the medieval church's understanding of the great commission and also its understanding of the cultural mandate (Gen. 1:25-28). This was applied to Africa and the New World in *Romanus Pontifex* and *inter caetera* (1493), which allowed Portugal and Spain to claim dominion and sovereignty over all lands they "discovered." England, France, and the Netherlands also relied on the doctrine in their own exploration of the "New World." According to Native American Robert Williams, a professor of law at the University of Arizona, the rights given by *Romanus Pontifex* and *inter caetera* served as the legal basis for appropriation of indigenous lands, resources, and rights over subsequent centuries. For example, in the 1823 case of *Johnson v. M'Intosh*, the United States Supreme Court relied on the doctrine of discovery in finding that legal title to land flowed from English grants, while Native Americans merely held a right of occupancy. And these two papal bulls continued to empower other nations in their "discovery" of lands new to them.

The doctrine of discovery is closely related to Manifest Destiny, the idea that Europeans and European culture were destined to expand across all of North America. Due to the conflict between Manifest Destiny and indigenous sovereignty and individual rights, the United States government passed a number of laws to facilitate the expansion of European people and culture, including the Indian Removal Act of 1831, the Dawes Act of 1887, and the Education Act.[8] As a result of these actions, indigenous peoples were denied the right to exercise sovereignty over their own affairs, were forcibly relocated to new and sometimes undesirable locations in the United States[9]

[7] This papal bull gave Portugal the authority to claim Africa as their domain of discovery. The quotation given here is reprinted in William H. Worger, Nancy L. Clark, Edward A. Alpers, *Africa and the West: A Documentary History, Vol. 1, From the Slave Trade to Conquest, 1441-1905*, Oxford: Oxford University Press, 2010, p.14.

[8] The conflict between European and indigenous culture is perhaps best embodied in the words of Richard Pratt, an army officer who founded the first Indian boarding schools under the Education Act. His purpose was to "Kill the Indian in him, and save the man." See, for example, Charla Bear, "Indian Boarding Schools Haunt Many," National Public Radio (May 12, 2008), http://www.npr.org/templates/story/story.php?storyId=16516865.

[9] (a) Cherokees, Creeks, and Choctaws; *Trail of Tears* documents move from Georgia to Eastern Oklahoma (1831); (b) Navajo; *Long Walk* reports removal of Navajos to Fort Sumner, New Mexico (1893).

(and sometimes were relocated again when the lands became valuable),[10] and were required to abandon their own culture and language and assimilate into the surrounding culture of the European majority.[11] These actions diminished the ability of indigenous people to know God through general revelation and deprived them of the ability to exercise stewardship over their own lands in a manner consistent with their cultural values.

In the same way that the church, and society as a whole, has reconsidered its formerly held views with respect to the exercise of dominion over creation, it has reconsidered, to a degree, the policies through which it exercised dominion over indigenous people, who are also part of creation and image-bearers of God. In some places, such as India, colonial powers constituted a small minority, and indigenous persons have since reasserted sovereignty over their own lands. In other places—including the United States—indigenous persons comprise a small minority and exercise sovereignty, if at all, in small areas that do not reflect their heritage as independent and sovereign nations. In the United States some steps have been taken to redress the effect of past policies that harmed indigenous persons by the taking away of their individual rights. For example, at a December 2010 Tribal Nations Conference, President Obama announced that the United States would reverse its previous policy and support the United Nations Declaration of Rights of Indigenous People. Also in 2010, the United States settled a class action lawsuit regarding alleged mismanagement of trust fund assets held on behalf of Native Americans, agreeing to pay $3.4 billion to class members. Similarly, some religious institutions have recognized past abuses. For example, in 2009 the General Convention of the Episcopal House of Delegates passed a resolution titled "Repudiate the Doctrine of Discovery." By adopting this resolution, the House of Delegates gave support to the indigenous people in their ongoing efforts to assert their inherent sovereignty and fundamental human rights as peoples to be respected.

This of course raises the important commandment "Love your neighbor as yourself" and the great commission, "Go and make disciples of all nations." This also raises the divine claim, "The earth is the LORD's. . . ."

We know that discord in society and over land has a long history, beginning already in the garden when Adam decided to violate his God-given stewardship. Much of it comes from humans' striving to claim the garden, claim the earth, claim creation—for themselves. As we look into the history of our dealing with each other and the earth, we find truth in this statement of Robert Williams: "The conquest of the earth is not a pretty thing when you look into it too much."

[10] After initially designating the entirety of the Black Hills as part of the Great Sioux Reservation in the Fort Laramie treaty, the United States reversed course and appropriated that land after gold was discovered in 1874. In 1980, the United States Supreme Court, in United States v. Sioux Nation of Indians, found that this appropriation was an illegal taking of the Sioux Nation's land and awarded it more than $100 million in compensation. Subsequently, the Dawes Act forced individual land ownership of each tribe. This created both haves and have-nots and diminished the capacity of indigenous people to exercise stewardship over their lands in a manner consistent with their culture.

[11] This was enacted through the Education Act of the federal government by placing children of these displaced people into boarding and residential schools that were sometimes supervised by church organizations.

The forced and violent transformation of nearly all indigenous communities into colonies of Western nations here and elsewhere around the globe by "discovery" of their lands by European "explorers" washed much, but not all, indigenous knowledge away. An example is in south India, where contour-hugging terraces step down the mountain slopes. Once functional in growing rice for their builders and descendants, providing habitat for birds and frogs and wetland plants, fostering lives of many species intertwined with human life and sustenance, many have been transformed into tea plantations. Conversations with local people reveal that in many cases they no longer have knowledge of the rice that once flourished there. And as they are asked about what once were rice paddies, they counter by saying they are tea plantations. Yet, in select places in India where indigenous knowledge combines with functional and productive terraced rice paddies, the indigenous stewardship ethic remains strong, as the famed medical doctor to Indian lepers, Paul Brand, reminds us in his essay "Handful of Mud."[12] In Cameroon the marvelous uses being made by native people of native plants for veterinary medicines are ancient discoveries that have recently been rediscovered by Western veterinary medicine and pharmaceutical companies.

VI. The current status of creation

A. Degradation of the earth's habitability

Creation's *oikoumene*, the biosphere, is the system provided by God that sustains us and all life on earth. We have good reason to celebrate God's remarkable provisions for the habitable earth and to bring to God our continued praise for these. We appreciate how the biosphere relates to the rest of creation through the atmosphere—earth's great spherical gaseous envelope. And we are awed by God's sustaining grace that permeates the whole of creation. The biosphere is a remarkable gift to all of us and to all of life. For a long time we have taken this gift of the biosphere and its gaseous envelope for granted. And this was particularly true of the atmosphere that seemed so large that we believed we could not change or degrade it. Today, however, we know that we cannot take the biosphere and its atmosphere for granted, and the reason is that we are in the process of changing it—with serious consequences. In the book *Earthwise: A Guide to Hopeful Creation Care*, the changes being made are described as "Seven Degradations of Creation." These are briefly summarized with permission, in the following (see *Earthwise*, third edition [Faith Alive Christian Resources, 2011], pp. 44-55, for additional detail and references):

1. Alteration of earth's energy exchange

   Earth's atmosphere is a "crowning jewel" of the biosphere—whose beauty and transparency sustains life on earth and mediates energy flows between earth and space. Yet human beings are responsible for its degradation locally, regionally, and globally through the injection of pollutant chemicals and compounds into earth's atmosphere. Beyond the many consequences of this degradation on our lungs and breathing—like asthma, emphysema, and lung cancer—we are responsible for injecting

[12] In: Wesley-Granberg Michaelson, *Tending the Garden: Essays on the Gospel and the Earth*, Grand Rapids: Eerdmans, 1987, pp. 136-50.

into the atmosphere various greenhouse gases beyond the capacity of the biosphere to absorb them, a topic considered more fully later in this report (see section VII and Appendix A). One of the major chemical corporations, DuPont, has responded to this degradation by eliminating the production of Freon, the effects of which included creating the hole in earth ozone layer, and by saying, "We believe the scientific understanding of climate change is sufficient to compel prompt, effective actions to limit emissions of greenhouse gases. We believe that to be successful these actions will require concerted engagement by the world's governments, along with technological innovations by businesses, and individual actions by all citizens."

2. Soil and land degradation

   During the latter half of the twentieth century, nearly one-third of arable lands worldwide were lost to erosion and taken out of production. In Asia, Africa, and South America annual soil loss was about 8 tons per acre, and in the United States and Europe the loss was about 6 tons per acre—these deficits contrast sharply with annual soil formation rates that average about 0.4 tons per acre.[13] Soil erosion losses are compounded by associated reductions of water infiltration, soil water-holding capacity, topsoil thickness, soil carbon sequestration, organic matter and nutrients, soil biota, and productivity; by associated increases of water run-off, surface water eutrophication, and siltation of rivers and streams; and by reduction of hydroelectric capacity by siltation of reservoirs. Many farmers sustain their soils through good stewardship, but they also continue to struggle to reconcile the tension between the short-term and long-term economic and environmental dimensions of their sustainability.

3. Consumption, waste, and ecosystem dysfunction

   In our day, 870,000 different chemicals are being used in commercial quantities, most of them brand-new to the creation. Many and perhaps most of these are part of the environment in which we and other organisms live. Yet these are materials that living organisms have not had experience with in the past. Unlike chemicals made by organisms and the earth, some of these chemicals leave living things defenseless. Some are even specifically designed to destroy life: biocides, pesticides, herbicides, avicides, and fungicides.

4. Land conversion and habitat destruction

   Since 1850 people have converted 2.2 billion acres of natural lands for human uses (8.9 million square km, an area slightly smaller than China's total land area of 9.2 million square km). Compare this with earth's total of 16 billion acres of land that support some kind of vegetation (a nearly equal area consists of ice, snow, and rock) and a current world cropland of 3.6 billion acres. The greatest land conversion under way today is tropical deforestation, which removes about 25 million acres of primary forest each year—an area the size of the state of Indiana.

[13] R. Lal, "Soil erosion and the global carbon budget," *Environment International* 29 (2003): 437-50.

5. Species extinctions

   There are some 10,000 known bird species, of which about one goes extinct each year. Research predicts that by the end of this century as many as 10 species of birds will go extinct each year. Without action to preserve birds, 12 percent of all known bird species are predicted to become extinct by the year 2099. And, if needed action is not taken, 23 percent of mammals, 25 percent of conifers (pines, spruces, and relatives), and 32 percent of amphibians will be threatened with extinction during this century. In addition, 70 percent of the world's coastal fish stocks are overexploited or collapsed, and 90 percent of the biggest fish have been wiped out. Further, habitats are lost around us so that even butterflies, once so common in everyday life, are being destroyed.

6. Global toxification

   Of the thousands of chemical substances people have created, hundreds have been injected into the atmosphere, discharged into rivers and oceans, and leaked into groundwater by means of "disposal" systems and by pollution from our vehicles, homes, chemical agriculture, and industry. Some have joined global circulations, with substances like DDT showing up in Antarctic penguins. Cancer has become pervasive in some herring gull populations and is increasingly prevalent in our communities and congregations. Globally circulating toxins disrupt ecosystems, and hormone-mimicking chemicals create reproductive disorders and negatively affect development in animals and people.

7. Human and cultural degradation

   Among the most severe reductions of creation's richness are the degradation and extinction of cultures that have lived peaceably and sustainably on the land for centuries. Many Amish and Mennonite farming communities in North America, for example, operate under severe pressure from increasing land taxes and encroaching urban development. In many cases these pressures compel them to abandon their farms. In the tropics, longstanding cultures living cooperatively with the forest are being wiped off the land by force, death, and legal procedures devised to deprive these people of their traditional lands. As they are run off or extinguished, so is their rich heritage of unwritten knowledge. Successful ways of living in harmony with the land are forgotten, names of otherwise undescribed forest creatures are lost, and information on the uses of a wide array of tropical species for human food, fiber, and medicine is wasted.

B. Environmental complexity and solutions

As outlined in the previous section, there is no doubt that humans have modified and are modifying their environment in ways that are more extensive than those of any other living species. Here we take a brief look at the integrated response to these degradations.

We begin by noting that human-induced environmental changes do not always impair the ability of other living species to live or of the ecosystem to function. Human population increases and the desire for different lifestyles have led to alterations in ecosystems (such as forest removal), expansion of and changes in agricultural practices, management of hydrological systems to provide clean water, sanitation systems, transportation networks, and many

other changes. The changes altered the landscape and the balance of species in the ecosystem, favoring grasslands (pasture) and crops over forest and wetlands, as well as favoring domesticated animals over wild animals. These changes allowed human society to flourish in sometimes healthy and sometimes unhealthy relationships with ecosystems. The changes in the world in which we live would have been barely imaginable 100 years ago and beyond comprehension 200 years ago. In the absence of human activity, however, ecosystems tend to change much more slowly in response to factors such as climate variability, growth of plant and animal populations, and species migrations. These processes occur generally on time scales that are much longer than the rate of human development and landscape modification.

There is ample evidence that human modifications of the environment have led and continue to lead to environmental degradation. As summarized above, these include air pollution; water pollution; species extinction; the introduction of foreign compounds into the environment; depletion of natural resources, including fresh water, problems with waste disposal and sanitation, potential climate change, and many others. In some cases, we have alleviated problems, reducing their impact on the environment and human health. For example, the air quality in the Los Angeles Basin is now much better than it was 30 to 35 years ago. This improvement is principally the result of a variety of regulations that have been put in place, including catalytic convertors on automobiles, restrictions on certain types of stationary combustion engines, and removal of power generation facilities to outlying areas.

Many of these environmental problems have common root causes and, therefore, solutions for one can help solve another. Solutions are often a combination of regulation and voluntarily adopted practices. For example, in agricultural crop production, farmers have long recognized the benefits of building up organic matter in soil to keep it well-structured, healthy, and productive. The greenhouse gas issue provides an additional reason to maintain high organic matter soil, because it keeps carbon out of the atmosphere.

In some instances however, solving one problem can make another worse. For example, when chlorofluorocarbons (CFCs) were introduced as alternatives to ammonia in home refrigerators, they solved a risk to human health and made automobile air conditioning possible, but they introduced a risk to the environment, since CFCs are powerful greenhouse gases (and they deplete stratospheric ozone).

It is increasingly evident that we need to look for integrated solutions to environmental problems that simultaneously address interlocking issues. Power generation provides an interesting example. Power generation in North America is heavily dependent on the use of carbon-based fuels like coal, oil, and natural gas. Combustion of these fuels produces air pollutants such as sulfur dioxide, nitrogen oxides, and particulate matter, as well as carbon dioxide, and in some cases it creates serious waste products and contamination of local fresh water. In the United States, fuel imports burden the economy and are linked to issues of national security. Thus, reducing both total power usage by conservation and reducing the fraction of that power produced by carbon-based fuels through the use of renewable sources can simultaneously address multiple environmental problems.

Ecosystems are often negatively affected by human activities. Some changes, such as the conversion of the eastern North American forests to

crop lands and the use of trees for fuel, were almost inevitable during early settlement. It is interesting to note that some of this land, such as large parts of Michigan and central Pennsylvania, is now being allowed to return to forest, although the new forest most often is a far different ecosystem from the previous forest. Other changes, such as the draining of wetlands and the loss of fish spawning grounds through development, might have been prevented had the importance and ecosystem services of these wet lands and riparian zones been widely appreciated at the time. Marine ecosystems continue to experience degradation due to a wide variety of causes. Ocean ecosystems suffer from the removal of peak predator species by overfishing, while great estuaries, such as Chesapeake Bay and Puget Sound, suffer from contamination by toxic substances and sewage due to run off and dumping. Increasing carbon dioxide concentrations in the atmosphere lead to increased amounts of carbon dioxide in the upper ocean, which in turn increases ocean acidification, which is harmful to many organisms, especially those that depend on carbonaceous shells, such as mollusks, and carbonaceous skeletons, such as corals.

It is not the intent of this report to address each and all of these problems. Each represents an assault on the environment that has been given to us by God and of which we have been commanded to be good stewards. The majority of these environmental problems are recognized by the community as serious problems that need to be addressed by a combination of personal and societal actions. The task force strongly encourages the Christian community broadly and members of the Christian Reformed Church specifically to be active in addressing these issues.

One issue in particular, namely climate change, has become a matter of substantial concern and controversy in the United States and Canada. This issue was specifically identified in the task force mandate because of its importance and because of the controversy surrounding it. The following sections address climate, climate change, and how we should respond to it.

VII. Climate change

A. The climate system[14]

1. Physical climate system

The average temperature of earth is maintained by a balance of absorbed solar radiation and thermal radiation emitted to space. Solar absorption occurs primarily at the earth's surface. In the absence of an atmosphere, the amount of solar radiation absorbed by earth would be only enough to heat the planet (surface plus atmosphere) to an average temperature of about -18° C (0° F), which we know both from straightforward physics and satellite observations. Thermal emission, which is the loss of energy from the earth system, occurs primarily from the middle levels of the atmosphere, typically 5 to 10 km (3 to 6 miles) above the surface. The atmosphere, like any warm body, emits thermal radiation in all directions, both up toward space and downward toward the earth surface. The earth surface, because it is warmed by both absorbed solar

[14] This section is a synopsis of a longer section on climate and climate change included as Appendix A.

radiation and emitted thermal radiation from the atmosphere, is much warmer (by about 15° C or 60° F) than the average temperature of the planet. This warming of the earth surface by downward thermal radiation from the atmosphere has been named the "greenhouse effect." Although the physics of what keeps a greenhouse warm is actually different, the name captures the sense of a surface that is warmed by the presence of an overlying, absorbing atmosphere.

If the greenhouse effect were not operating—that is—if the atmosphere were not emitting thermal radiation, life as we know it would not be possible on the surface of earth because it would be too cold. Each of us has experienced this greenhouse effect. On humid summer nights, the temperature remains high because the large amount of thermal radiation from a moist atmosphere prevents cooling of the earth surface. On clear nights, locations at a higher elevation cool more quickly and to lower temperatures than those at lower elevations because the atmosphere is less dense at a higher altitude and therefore radiates less energy. In winter, clear nights are usually colder and cloudy nights are usually warmer, because clouds increase downward thermal emission.

The three principal absorbers (and emitters) of thermal radiation in the atmosphere are the molecules of water vapor (H_2O), carbon dioxide (CO_2), and ozone (O_3). Water vapor absorption and emission is by far the most important contributor to greenhouse warming, with carbon dioxide second and ozone a distant third, along with all other absorbing gases. Although water vapor is the most important greenhouse gas, carbon dioxide is the key regulator of the magnitude of the earth's greenhouse effect because removal mechanisms for carbon dioxide are very slow and its residence time, therefore, is very long (hundreds of years on average).

Atmospheric water vapor concentrations are strictly controlled by temperature. Water vapor is removed from the atmosphere by precipitation, which forms when air cools to the dew point temperature (or condensation point) and clouds are formed. For any air parcel, the condensation point is only a function of temperature. Therefore, the atmosphere cannot hold an unlimited amount of water vapor. From the perspective of the atmosphere, the ocean provides an infinite source of water vapor, so that, on a global average, the relative humidity (the ratio of the water vapor in an air parcel relative to the maximum water vapor amount that could be in the parcel at saturation) of the atmosphere remains constant, maintained by an approximate equilibrium between evaporation from the ocean (and from the land surface, to a lesser extent) and condensation and precipitation.

If the average temperature of the atmosphere rises, then the amount of water vapor in the atmosphere will also increase. But, since water vapor is a greenhouse gas, adding water vapor to the atmosphere increases the absorption and emission of thermal radiation by the atmosphere, which increases the downward thermal radiation from the atmosphere and further warms the surface. This process is called a *positive feedback—positive* in the sense that the initial direction of change (warming of the surface and atmosphere) is further enhanced over the initial change itself, and *feedback* in the sense that the initial response (more water vapor) actually drives a larger change.

Carbon dioxide is the regulator of earth climate on the time scale of a century. When carbon dioxide is added to the atmosphere, some fraction of that increase remains in the atmosphere from centuries to millennia. Because carbon dioxide is a greenhouse gas, the surface warms. Because the surface warms, the atmosphere warms as well, and more water vapor is added to the atmosphere. Because water vapor is an even more efficient greenhouse gas than carbon dioxide, the surface warms further, additionally warming the atmosphere and allowing more water vapor to be added to the atmosphere. This process of positive water vapor feedback amplifies the initial change due to carbon dioxide, but the carbon dioxide itself is the regulator because of its long lifetime in the atmosphere.

Clouds both reflect solar radiation, which cools the earth, and absorb infrared radiation, which warms it. On average for the current climate, clouds cool earth by reflecting more energy than they absorb. Cloud processes are quite complex, but a great deal is known about these processes at the scales both of individual clouds and of aggregate cloud systems. The difficult question, however, is, How will clouds change in a warmer world? Although the answer to this question is uncertain, some general statements can be made. A warmer atmosphere with more water vapor is not necessarily an atmosphere with more clouds, because clouds are the result of dynamical motions. However, the clouds in a warmer atmosphere may be thicker (have more condensed water in them) than in a cooler atmosphere. If cloud properties do change in a warmer world, then the question is, Will they produce a net negative feedback (more additional reflection than absorption) or a net positive feedback (more additional absorption than reflection)? Answering this question is complicated and can only be done with the use of global climate models, because there are no currently available data that provide a definitive answer. The consistent answer from a variety of modeling studies is that cloudiness increases slightly in a warmer world but, more significantly, the changes in cloud properties produce a positive feedback, further warming an already warmer world.

2. Carbon cycle and the biosphere[15]

Carbon is the central atom of the organic molecules that are essential to life. All living organisms on earth, including humans, have bodies that are based on carbon. Green plants are called producers, because they use energy from the sun to change carbon in the atmosphere into the organic forms that provide the building blocks and energy for the structure and function of all living organisms. All these organisms depend on the forms of carbon produced through photosynthesis by land plants and by phytoplankton in lakes and oceans.

Each year, plants on the surface of earth take in about 120 billion metric tons of carbon in the form of carbon dioxide and convert it to organic forms. Roughly the same amount is released back into the atmosphere by respiration from plants and animals, and from the decomposition of the organic carbon in their remains. Because most of earth's land mass and forests are in the northern hemisphere, there is an observable annual

[15] The source of the carbon budget estimates here is *IPCC Climate Change 2007: The Physical Science Basis,* pp. 511-33, updated to 2009 using data from Fig. 4 in Appendix A.

cycle in carbon dioxide concentrations, with a minimum in the northern hemisphere summer and a maximum in the northern hemisphere winter. This annual change in carbon dioxide, while actually large, is a near equilibrium process (the amount of carbon dioxide "breathed" in during the summer is the same amount "breathed" out in the winter, because the amount of vegetation is very nearly the same from year to year). Most natural ecosystems are close to equilibrium; the amount of organic carbon that has accumulated in the ecosystem is sufficiently large so that the amount decomposing each year is equal to the amount added each year.

The amount of carbon stored in organic form in the soils and plants of the world amounts to approximately 2,300 billion metric tons, and the annual cycle involves about 120 billion metric tons of carbon. The amount of carbon emitted to the atmosphere as carbon dioxide from human activities seems small in comparison to these numbers. Human activity adds a total of 8.8 billion metric tons annually (7.7 billion metric tons are from humanity's use of carbon-based fuels like coal, oil, and natural gas, and another 1.1 billion metric tons are from land-use change—mainly through the clearing of forests). However, the fact that atmospheric concentrations of carbon dioxide are rising is evidence that the world's biological systems are not capable of absorbing all these emissions on a net basis. Since preindustrial times the amount of carbon in the form of carbon dioxide in the atmosphere has grown from about 597 billion metric tons to about 762 billion metric tons today (see Fig. 4, Appendix A).

The increase in carbon dioxide in the atmosphere increases the primary productivity of plants that use the C_3 photosynthetic pathway.[16] While increasing concentrations of carbon dioxide may contribute to higher yields of many agricultural crops—such as wheat, soybeans, rice, and potatoes—not all crops are of the C_3 type. In many countries of Africa and Central America, as much as 50 to 88 percent of agricultural land is in C_4 crops, such as corn, sorghum, millet, and sugarcane. These C_4 crops are expected to respond to increased carbon dioxide with higher yields only under conditions of drought stress.

The increased carbon dioxide concentration can also alter the species composition of ecosystems. This occurs because some plant species exhibit a greater growth response to the increase than do others, changing their competitive ability. For example, a forest-scale experiment found that the plant species most responsive to free-air enrichment of carbon dioxide was poison ivy—and the plants had higher levels of skin irritant in their leaves. In another such experiment in Wisconsin, however, both birch and

[16] Plants of the C_3 type rely completely on the Calvin cycle for biochemical conversion of carbon dioxide to the sugars from which plant tissues are made. In this cycle, the rate-limiting enzyme is called "Rubisco"—short for ribulose bisphosphate carboxylase-oxygenase—which, owing to its low efficiency, often makes up as much as 50 percent of a plant's total leaf protein. C_4 plants have a more active enzyme—phosphoenolpyruvate carboxylase—that can more efficiently capture carbon dioxide for transfer to the Calvin cycle. Thus they are able to grow more effectively at low carbon dioxide concentrations, and during warmer temperatures and drought stress. J.R. Ehleringer and T.E. Cerling, "C3 and C4 Photosynthesis," 186-190 *in* H.A. Mooney and J.G. Canadell, eds., *Volume 2, The Earth System: Biological and Ecological Dimensions of Global Environmental Change*, Encyclopedia of Global Environmental Change, 2002.

aspen trees showed increased tolerance of heat stress in a carbon dioxide-enriched environment.

Increasing carbon dioxide in the atmosphere also leads to an increase in the carbon dissolved in the ocean. Carbon dioxide is soluble in sea water, and an increase in the amount (pressure) of carbon dioxide results in more carbon dioxide dissolved in the water. When carbon dioxide dissolves in water, it forms carbonic acid, the same acid found in carbonated beverages, and this shifts pH to being more acidic. Over the past several decades, consistent measurements have been made of the carbon dioxide in the atmosphere and the upper mixed layer (approximately the top 100 m) of the ocean. In addition, we know how much carbon dioxide has been produced by burning carbon-based fuels during this same period. Based on these measurements, roughly half of all the carbon dioxide produced by fuel consumption has dissolved into the ocean mixed layer. This dissolved carbon dioxide has made the ocean about 30 percent more acidic (less alkaline) over time. The process of ocean acidification is the result of simple, fundamental chemistry, and there is no way to prevent it. As long as carbon dioxide levels continue to increase in the atmosphere, the ocean will continue to become more acidic (see Appendix A for ocean acidification and pH).

So far, 244 billion tons of carbon in the form of fuels have been burned and emitted as carbon dioxide. Known conventional reserves of carbon in coal, oil, and natural gas add up to about 1,000 billion tons, and the total amount that eventually could be exploited may amount to 3,700 billion tons. So it is clear that humanity has the potential to continue increasing atmospheric carbon dioxide considerably!

B. Climate change: Is the earth warming?

1. Evidence for warming from natural systems

The climate of earth is warming, a statement which can be made on the basis of both observations of physical and biological phenomena and direct measurements. Each of us lives in contact with nature and, using a perceptive eye, we can observe some of this evidence for ourselves. Many natural systems around us integrate the effect of environmental variables. Observing and learning from trends in the behavior of these natural systems does not require mathematical models or detailed scientific analysis. For instance, the extent of ice in glaciers and ice sheets is a natural integration of a variety of climate variables such as temperature, precipitation, prevailing wind direction, and more. The observation that any of us can make via travel, historical photography, and anecdotal stories is that the majority of mountain glaciers around the world are in retreat, many drastically. Glaciers in some famous areas such as Glacier National Park in Montana are in danger of disappearing altogether. Similarly, the summer meltback of sea ice that covers the Arctic Ocean is easily monitored by satellite imagery, and meltback is on average significantly greater than in the past (see Fig. 7, Appendix A). Relevant satellite images and data are available on the Internet and can be viewed by anyone with an Internet connection. Continental ice sheets on Greenland and Antarctica, although still very extensive, are also experiencing significant melting and shrinkage, as confirmed by measurements on the ice sheets and from satellite.

Other natural systems that show evidence of global warming may be closer to home for us. The length of the growing season is increasing in most areas because the date of the last expected spring frost is steadily moving earlier and the date of the first fall frost is moving later. Published plant hardiness zones are shifting northward in the northern hemisphere. Plants are flowering earlier on average than in the past. Bird and insect migrations are occurring earlier in the spring and later in the fall, and the destination of migrating bird and insect populations is shifting northward in North America. These natural systems all point to an earth that on average is warming.

2. Evidence for warming from direct measurements

Many direct temperature measurements have been and are being made of both the atmosphere and the surface layer of the oceans. The longest records are thermometer measurements of surface air temperature and of ocean surface water temperature. These data are in one sense quite simple, because we all understand thermometer measurements, but in another sense the data can be complicated. Constructing a global temperature record requires accounting for changes in the number of measuring sites over time, the characteristics of the sites, and measurement techniques. Several different groups of scientists have analyzed the basic thermometer data to each construct a record of surface temperature over the past 100 to 150 years, and their results are very similar. The record shows quite clearly that the earth surface is warmer now (averaged over about a ten year period from 2001 to 2010) than at any other time in the past 150 years (see Fig. 5, Appendix A). A rapid rise in temperature occurred from about 1910 to 1940, and a slightly more rapid rise occurred from 1975 to the present. During the period from 1940 to 1975, the temperature was roughly constant. The total increase in temperature from 1900 to the present is about 0.8° to 0.9° C, or about 2° F.[17] This may seem like a small change, but it is not when compared to the estimated change in surface temperature of 5° to 7° C between the last glacial period (when much of North America was covered by a mile-deep sheet of ice) and the current interglacial period.

A word of caution is appropriate here. The earth's surface temperature fluctuates from year to year due to a variety of internal oscillations in the ocean-atmosphere system. The El Niño Southern Oscillation (ENSO) is perhaps the most widely publicized of these natural oscillations, but there are others that climate scientists know of and study. Consequently, it is very risky to argue that a particularly warm year is an indication of global warming or that a particularly cool year is an indication that global warming is not happening. Climate scientists tend to look at 10-year (decadal) averages, or even longer periods, to establish trends in surface temperature. Data from a single recent year (such as the relatively cold year of 2008 or the relatively warm year of 2010) cannot be used to extrapolate a trend; one can only wait for another few years to understand the decadal trend.

Satellite measurements of earth are available since about 1975. Satellites orbit far above earth's surface and its atmosphere; instruments on these satellites measure all or some portion of the thermal radiation emitted by

[17] A figure showing surface temperature for the past 150 years is included in Appendix A.

the planetary system. Because this radiation is emitted by both surface and atmosphere, measuring it is not the same as measuring an actual temperature with a thermometer. It is a challenging problem to reconstruct atmospheric temperature trends from these satellite measurements, and the process of doing so has generated quite of bit of debate over the past decade or so. The most recent evaluations, however, including one by the National Academy of Sciences, show that the satellite measurements are in general agreement with the trends from surface temperature measurements and from temperature measurements by routine atmospheric balloon soundings.

C. Cause of climate change

The principal driver of the earth's climate (and surface temperature) is solar energy. Thus it is logical to ask whether variations in solar energy output or changes in the amount of absorbed solar radiation are responsible for the observed warming climate. The other principal control on earth surface temperature is the downward thermal radiation received from the atmosphere. Thus, it is also logical to ask whether variations in atmosphere composition have occurred and whether they are responsible for the observed warming climate. A third possibility is that changes in earth surface temperature are driven by internal system variability occurring on time scales in excess of a hundred years. The climate science community has invested a great deal of time and energy during the past 20 years in trying to provide a definitive answer to these questions. The few paragraphs here and the expanded comments in Appendix A provide only a brief summary. Interested readers are referred to the extensive reports available from the U.S. Global Change Research Program, the National Academy of Sciences, and the Intergovernmental Panel on Climate Change (IPCC).

Variations in solar energy input over time are small but probably do play some role in the temperature increase seen in the past century. Total solar irradiance (TSI) is a measure of the amount of solar energy arriving at the earth. Precise measurements of this quantity have only been available since about 1975, when satellites could look at the sun from above the atmosphere. Prior to 1975, scientists can reconstruct an approximate value of TSI based on observations of sunspot number, since variations of sunspot number can be related to variations in TSI. TSI was increasing slightly from before 1900 to about 1960. It has been declining since 1960, and it dropped to its lowest level in more than 100 years in 2010 (see Fig. 8, Appendix A). It is very likely that the temperature increase from 1900 to 1940 was driven in part by this increase in TSI. However, the temperature *increase* since 1975 has occurred while TSI values have been *decreasing*. Further, it is precisely this period for which we have our most accurate measurements of TSI from satellite. Thus, we can certainly rule out solar variability as being the principal driver of temperature warming during the latter part of the past century, and it is probably only partially responsible for the earlier warming, as we shall see.

It is more difficult in a sense to rule out natural climate variability on timescales of a hundred years or more. The thermometer record only extends back about 100 to 150 years, so it is inadequate for this purpose. Longer term records going back 1,000 years or more have been constructed from temperature proxies (see Fig. 6, Appendix A). Proxies are constructed by measuring

temperature-sensitive properties of physical or biological systems and then by inferring temperature from the measured properties. Tree rings are one example of a proxy. Results from these proxy studies have generated a great deal of controversy over the past few years, much of it producing far more noise than clarity. The most straightforward conclusion from all this research and discussion is that global mean surface temperature was higher during the past few decades of the 20th century than during any comparable period since at least A.D. 1600.[18] This conclusion comes from a report prepared by the National Academy of Sciences as requested by the President of the United States and is supported by a wide range of science. Reconstructions of temperature further back in time are difficult due to the lack of adequate proxies and the increasing uncertainty in their interpretation.

Carbon dioxide concentrations and the concentrations of other greenhouse gases have been increasing at accelerating rates since the mid-1800s. Carbon dioxide concentrations alone have increased from 280 ppmv (parts per million by volume) around 1850 to about 390 ppmv today (see Fig. 2, Appendix A). We know that increasing greenhouse gas concentrations increase the absorbing potential of the atmosphere, which must lead to increasing downward thermal radiation and increasing surface temperatures. This is fundamental radiation physics that has been understood for more than 100 years. The principal question is whether the size of the increase in greenhouse gas concentrations is consistent with the amount of observed temperature increase. The answer to that question, based on extensive global climate model studies, is simply yes. Model simulations of temperature change over the past 150 years agree very well with observations when increasing greenhouse gas concentrations are included; they do not agree at all well when increasing concentrations are omitted (see Fig. 11, Appendix A). Increasing greenhouse gas concentrations (primarily carbon dioxide), as well as increased solar radiation contribute to the warming between 1910 and 1940; the warming since 1975 is principally the result of increasing greenhouse gas concentrations. The conclusion drawn from the observations and modeling studies is that the greenhouse gas increases are the primary driver of the warming temperatures.

The temperature plateau between 1940 and 1975 has been used by some to question this conclusion because greenhouse gas concentrations increased during this period as well. It is unrealistic to expect that the average earth surface temperature would be perfectly correlated with increasing greenhouse gas concentrations. Natural variability in the climate system produces oscillations in temperature that are unconnected with trends produced by changes in climate forcing such as greenhouse gases. It is perfectly possible—in fact, it is to be expected—that natural climate variability can mask increasing temperatures or enhance them on timescales of 10 to 20 years. In addition, rapid industrialization of the United States and Europe during and following World War II introduced increasing amounts of particulates into the atmosphere of the northern hemisphere. These particulates reflect solar radiation, effectively cooling earth. Concerns about air pollution and its

[18] National Research Council of the National Academies, *Surface Temperature Reconstructions for the Last 2,000 Years,* Washington, D.C.: National Academies Press, 2006, http://books.nap.edu/openbook.php?record_id=11676&page=R1.

effects on human health led to regulations that improved air quality in North America and Europe beginning in the 1970s. It is thought that the temperature plateau is in part related to this cycle of air pollution. It is interesting to contemplate whether the industrialization of China, India, and other developing countries in the past decade is producing a similar response.

1. Conclusions from the scientific community

   The scientific community has been asked on many occasions since about 1990 to evaluate the question of whether human activity, through increased greenhouse gas concentrations, is responsible for a warming climate. The Intergovernmental Panel on Climate Change (IPCC) was jointly established in 1988 by the United Nations Environment Programme and the World Meteorological Organization to conduct periodic assessments of the state of knowledge concerning global climate change. In its most recent assessment report, the Fourth, denoted AR4, the IPCC states,

   > Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations.

   Similar statements can be found in reports from the National Academy of Sciences in the United States and some twenty other national academies. Learned societies such as the American Geophysical Society and the American Meteorological Society in the United States, the Royal Society in the United Kingdom, and a host of other societies around the world are on record as supporting this statement. The scientific community has expended a great deal of effort to understand the causes of climate change (as well as to predict future trends involving global temperature and climate change). There is no ambiguity about these conclusions within the scientific community.

   So why do scientists keep talking about "climate change" if they agree that the global trend is warming? The reason is that "global warming" might be interpreted by many as a rather uniform increase in temperature. The actual situation is more unsettling. While the global average temperature is expected to increase, warming the world by increasing greenhouse gas concentrations will also change climate patterns, thereby increasing temperatures in some (probably most) regions while decreasing them in others. Even more surely, rainfall will increase in some areas and decrease in others. These uncertainties in future climate change add to the scope of the challenge of adaptation. So the term "climate change" is meant to express both an expected increase in global mean temperature, along with change in the distribution of temperatures, and variations in other climate quantities such as rainfall. For the remainder of this report, we use the term climate change with this understanding.

2. How should we understand these statements?

   As noted above, the conclusion of the broadly based scientific community is that anthropogenic—that is—human, activities are responsible for the majority of global warming, primarily due to the atmospheric buildup of carbon dioxide from the burning of carbon based fuels by modern society. This conclusion stems from an understanding of how carbon dioxide operates in the atmosphere based on well understood physical and

biological principles, measurements of increasing carbon dioxide in the atmosphere, and an estimation of how increasing carbon dioxide affects other related phenomena, such as water vapor and cloud cover, in the atmosphere and earth surface. Most of the pertinent physical interactions are very well understood. The scientific conversation today is not whether temperature will rise but the magnitude of the increase in the future.

The terminology used in the pertinent reports (such as that of the IPCC) is that human activity is "very likely" to be responsible for the observed change in temperature. In this particular case, scientists interpret "very likely" to mean a greater than 90 percent probability.

What does that "very likely" mean to us? If people were told that their houses had a 90 percent chance of burning down due to faulty wiring, nearly everyone would take immediate action. If they were told their cars had 1 chance in 10 of reaching their desired destination, few people would start out. If you were told that a new medicine helps 9 out of 10 people, you would probably rejoice and try the new drug. The term "very likely" is a call to action.

D. Whom do we believe?

For some readers of this document, the scientific conclusion that "the observed increase in anthropogenic greenhouse gas concentrations" is the very likely cause for most of global warming is controversial. Other voices in society question this conclusion and offer their own assessments. Some of these questions are helpful. They clarify issues and may appropriately highlight weaknesses. Many questions, however, stem from personal, political, or financial agendas and seek to obscure accepted and reasonable scientific conclusions. This is not a new phenomenon. For instance, the historical debate concerning tobacco and health involved much propaganda and misinformation driven by financial agendas. As in all things in this world, an observer must be astute and discerning in order to separate accepted fact from fiction.

Which voices deserve a hearing, and which should be ignored? In this contentious debate, whom should we believe? This may be difficult for the casual observer to determine. Credible conclusions should be based on objective observation and interpretation, and they should be as free as possible from competing agendas. Such conclusions may be offered by individuals or organizations that have experience and credentials supporting their status. Consensus statements by groups or consortiums should carry more weight than individual comments. Broad support within a respected and knowledgeable community should convey high credibility to their position.

It is true that scientists too are human; scientific conclusions may also contain error, exaggeration, or misstatement. As imperfect humans, this is unavoidable. In part, we should hold scientific conclusions with a light grip, because we know that new information may shift or modify our understanding. Nevertheless, when a broad community of experienced and reliable experts, utilizing the checks and balances implicit in scientific review, agrees on consistent conclusions over a period of several decades, it is reasonable to accept these broadly based conclusions and plan for the future. Each of us has personal experience in making decisions based on imperfect or evolving information as we deal with health, finance, and life issues. Delay also

carries risk, and when significant impacts are very likely, it is no longer sufficient to watch and wait.

VIII. Implications of climate change for the future

A. What are the impacts?

How will global warming affect our future? Increasing greenhouse gas concentrations will result in a warmer world. Temperature rise will be greatest in polar regions, especially the Arctic, which will experience loss of sea and land ice. Permafrost at high latitudes will warm and melt, altering the way of life of indigenous people and the animals on which they depend. Sea level will rise due to glacial runoff and water expansion associated with ocean warming. Increasing levels of dissolved carbon dioxide in sea water will cause increasing ocean acidification. Climatic and agricultural zones will continue their poleward shift. Most deserts will increase in size, primarily shifting poleward, while rainfall rates will intensify in already wet tropical areas. Shifts in large-scale precipitation patterns will occur, although the projections of such pattern shifts are uncertain at present.

For worldwide agriculture, there will be areas of winners and losers. Crops in subtropical areas such as the Sahel are expected to produce lowered yields due to increased temperatures and a more variable water supply. Based on temperature alone, the great grain belts of North America are likely to shift northward, leading to improved production on the northern boundaries but reduced production in the south. A warmer climate will almost certainly bring additional water stress on summer crops.[19]

Sea level rise will occur, caused by expansion of warmer water and melting of large ice sheets on land. The former effect is more easily understood and is expected to produce 2 to 3 feet of sea level rise by the end of the century. Understanding of the second is more limited, and estimates range from a few inches to another few feet. Sea level rise of 2 to 3 feet will have particularly negative effects on low-lying areas near the sea, such as most river delta regions, which will suffer from a combination of rising sea level and expected greater storm surge, leading to increased flooding, displacement of population, severe erosion, and the possibility of salt water incursion into delicate wetlands. Small island atolls may become uninhabitable due to loss of land surface area and possible destruction of coral reefs and their associated ecosystem.

Regardless of the magnitude of global temperature increases, ocean acidification will continue due simply to the solubility of carbon dioxide in water. A more acid ocean will have negative impacts on organisms with carbonate shells and skeletons, such as mollusks and corals, and perhaps others, at the lower levels of the ocean food web.

Planning and managing infrastructure for water resources, such as dams and reservoirs, will become more difficult because the statistical precipitation distributions on which these decisions are based will change with time. Water infrastructure is typically based on a combination of average flows and managing for extreme events, such as a "hundred year" flood. Such planning requires long-term records because extreme events are by definition

[19] IPCC, Climate Change 2007: Impacts, Adaptation, and Vulnerability.

rare. As climate changes, however, the distribution of events will change, and events that are rare now may become more frequent. Global climate models, because they do not have high spatial resolution, are not very good at predicting extreme events for the current climate or for the future. However, in cases where these global models have been adapted to regional levels, as for example in the Great Lakes Region and the eastern United States, they have been helpful. In addition to supporting such work, countries with both technical and financial resources, such as Canada and the United States, will have many more options for coping with coming challenges than will smaller and poorer countries. The agricultural sector, for example, is likely to manage these changes quite well in Canada and the United States by changing crop varieties and species and managing water usage.

Sea level rise in places like the Netherlands is managed in part by building levees and dikes, but these require massive investments that are not feasible in many developing countries.

The outlook for developing countries with weaker infrastructures, fewer cash reserves, and less technological capability is far more bleak. They most likely will not have the ability to adapt to change with technology, and, in some cases, as in small island states, they may experience population dislocation with no place for people to move. Reduced crop yields due to either persistent climate change or more variable weather may produce chronic malnourishment or episodic starvation.

B. Vignettes

The general description of climate change impacts does not do justice to impacts at the regional and local levels. While it is beyond our mandate to provide a comprehensive review of climate impacts, we have chosen to describe a few specific cases to illustrate what may happen if greenhouse gas emissions continue along their current trajectory. Despite their diversity, these cases share two common themes: they involve communities whose contributions to climate change have been relatively minor and, to the extent that adaptation is possible, they lack the economic and technical resources enjoyed by nations such as the United States and Canada.

1. Arctic communities

Average temperatures in arctic regions are expected to increase at nearly twice the global average rate, making potential impacts even more significant. Among the most likely impacts from climate change are declining snow and ice cover, increasing precipitation, rising sea levels, and thawing permafrost. Coastal communities will face an increased risk of erosion due to rising sea levels and reductions in sea ice. In some cases, entire villages may be displaced. Travel and commerce will also be affected in areas that depend on frozen land and water for transportation routes. In addition, thawing permafrost will result in land instability and will threaten the integrity of key infrastructure, including roads, buildings, and pipelines.

Aspects of this change are already in evidence. Arctic sea ice extent has been steadily decreasing over the past 30 years. The minimum sea ice extent record was set in 2007 and nearly reached again in 2011. The sea ice extent in 2011 was 35 percent below the average value from 1979 to 2000. Melting permafrost, loss of coastal ice, and increased melt water in rivers

has led to increased coastal erosion by destabilizing soil, enhancing wave activity from storm surge, and changing coastal drainage patterns. Entire coastal villages are being relocated because increased erosion is eating away at their foundations.

Changing climate impacts animal behavior and food resources for indigenous people. Ring seals, for example, serve as food for many species of higher predators, including polar bears and humans. The seals require ice sheets with snow cover for breeding dens. They carve a hole through the ice to create a small den in the snow layer on the ice. Reduced ice and snow cover will limit their habitable area and expose them to more predation. Migration and life cycle of large species such as caribou may be affected. Increased snow cover may make access to winter food more difficult, changing snow melt patterns may affect populations of harassing insects, and vulnerability to predators may increase due to deeper snows.

Indigenous peoples, who make up more than 50 percent of the arctic population in Canada, are particularly at risk. Indigenous communities have lived in the arctic for millennia and have adapted to its unique yet demanding climate. Many continue to rely on a subsistence economy and depend on the natural world for their livelihoods as well as their cultural and social identity. These communities are at particular risk as rising temperatures and encroachment from other species threaten the plant and animal communities on which their livelihoods and identities are based.

Further, the elders of the native communities provide a remarkable resource of knowledge about changing climate. Because of the intimate connection between each community and its environment and the oral traditions within the community, knowledge of environmental change is preserved collectively within the community. In a recent interview, Frank Logusik Jr., a member of the Togiak Traditional Council in Togiak, Alaska, reported that "in my early time, there used to be lots of snow. . . . Our ice used to stay in our bay until sometime in May, but now, in winter, our bay doesn't freeze up . . . winds break up the ice." [20]

2. African Sahel

Located on the southern edge of the Sahara desert, the Sahel is particularly vulnerable to climate change. The countries that make up the Sahel are among the poorest in the world, with economies heavily reliant on agriculture. The region is characterized by fragile soils that are low in carbon and plant nutrients, making it extremely vulnerable to environmental stresses as well as overgrazing and erosion.

Studies of the Sahel show the interlocking complexity of environmental and social issues. One such study concluded:

> Rainfall variability is a major driver of vulnerability in the Sahel. However, blaming the 'environmental crisis' on low and irregular annual rainfall alone would amount to a sheer oversimplification and misunderstanding of the Sahelian dynamics. Climate is nothing but one element in a complex combination of processes that has made agriculture and livestock farming highly unproductive. Over the last half century, the combined effects of population growth, land degradation (deforestation, continuous cropping

[20] The interview and additional information about Togiak is available at the North Pacific Research Board and National Science Foundation's website on "Understanding Ecosystems Processes in the Bering Sea," http://bsierp.nprb.org/fieldwork/2010/togiak_visit.html.

and overgrazing), reduced and erratic rainfall, lack of coherent environmental policies and misplaced development priorities, have contributed to transform a large proportion of the Sahel into barren land, resulting in the deterioration of the soil and water resources.[21]

The Sahel has been repeatedly stressed by lengthy droughts over the past several decades. Its rainfall is strongly influenced by large-scale patterns of atmospheric circulation and has been in a minimum phase from about 1970 to the present.[22] While the expectation is that a recent shift in the large-scale atmospheric circulation pattern will bring a period of increased rainfall, most climate models predict that in the coming century the Sahel will be even drier as a result of climate change.

As past experience has taught, droughts in the Sahel produce devastating results, including food insecurity and starvation, greater likelihood of disease, lost educational opportunities, and many other stresses. While indigenous resources and technologies such as crop diversification, harvest of wild fruits and tree products, shifting to animal husbandry, and migration to urban areas have mitigated some of the impacts of past droughts, they will likely be insufficient to address the challenges resulting from climate change, especially considering the current disarray in the Sahel. Instead, successful adaptation will require strategic partnerships providing the economic and technical resources to develop drought resistant crop varieties, improve soil and water conservation, and restore soil fertility in areas degraded by erosion and desertification.

3. Small island atolls: The Tarawa Atoll, Kiribati

Among the places most directly affected by climate change will be small island atolls. The Tarawa Atoll, a part of Kiribati located at 1° N latitude and 8° longitude west of the international dateline, provides an example of the potential impacts of climate change. The atoll comprises a series of islets with an average width of less than 450 meters, and most of the land is less than three meters above sea level. The total area is approximately 30 km^2, with a population of 35,000 that is growing at a rate of about 2 percent per year. The population density is stressing the local environment in a variety of ways, particularly in the areas of fresh water and sanitation.

Life on Tarawa Atoll, as on many other atolls, is largely supported by a small fresh water lens (layer) that accumulates in the subsurface from rainfall and runoff and floats on the denser salt water. This lens prevents the intrusion of salt water, allowing plants to grow, and can be tapped by wells for drinking water. As the population increases, the need for fresh water also rises, stressing the fresh water aquifer. If too much water is withdrawn or too much rainwater is used without allowing it to percolate into the lens, salt water can intrude into the lens and damage the island ecosystem. In addition, human and animal waste, if not properly

[21] Serigne Tacko Kandji, Louis Verchot, and Jens Mackensen, "Climate Change and Variability in the Sahel Region: Impacts and Adaptation Strategies in the Agricultural Sector," United Nations Environmental Programme and World Agroforestry Centre, 2006, http://www.unep.org/Themes/Freshwater/Documents/pdf/ClimateChangeSahelCombine.pdf.

[22] See here for data, plots, and discussion: Todd Mitchell, "Sahel rainfall index (20-10N, 20W-10E), 1900 - April 2011," Joint Institute for the Study of the Atmosphere and the Ocean, September 2011, http://www.jisao.washington.edu/data/sahel/.

managed, can enter the fresh water lens, leading to contamination and disease. Conflict over fresh water resources is already a problem in Tarawa.

One might think that a small, near-equatorial atoll would be largely unaffected by climate change but that is far from the case. While expected sea level rise is unlikely to completely submerge the atoll, the impacts of climate change will, most likely, be significant. Sea level rise coupled with storm surges could periodically inundate more than half of the atoll by late in this century. Such inundations would certainly substantially reduce the size of the existing fresh water lens and might render it unusable due to salt water intrusion. Possible increased evapo-transpiration and reduced precipitation may further threaten freshwater supplies for human consumption and agriculture. The inundations would destroy a substantial portion of the atolls' roads, including the causeways connecting the various islets. Inundation and associated erosion will reduce the amount of land available for agriculture, a primary economic driver on the atoll. Increasing ocean acidity and temperature may also harm the atolls' coral reefs, leading to depleted fisheries and the loss of an important buffer against wave action and erosion.[23]

While the risk of submersion is a common theme, it is clear that small island atolls such as Tarawa face many other challenges that are also extremely serious. With a per capita GDP of approximately $600 per year, Kiribati lacks the economic resources to take aggressive action to address the expected impacts. One estimate suggests that the cost of dealing with the infrastructure damage could be more than ten times the annual GDP of the atoll. It is likely that these communities will face permanent evacuation but that the populations will have no obvious place to go.

4. Orissa State, India

Orissa State is located on the east coast of India on the Bay of Bengal, just to the south and slight west of Calcutta. Flooding is an essential feature of Orissa, India; it replenishes groundwater, delivers valuable topsoil and nutrients for agriculture, and sustains valuable ecosystems. As we write this (September 2011), Orissa is being devastated by heavy monsoon rains that have produced the worst flooding in at least 30 years. Estimates are that more than 50 people have died and tens of thousands have been left homeless by rampaging floods and mudslides. Communities in Orissa have adapted to this sometimes volatile environment with agricultural systems based on flood-resistant rice, which are often supplemented with aquaculture, fishing, and some dairy farming.

Climate research suggests that climate change will result in increased temperatures, more variable rainfall, and an increased incidence of flash floods. In addition, sea level rise will create coastal inundation and increased susceptibility to storm surges associated with tropical storms and cyclones. Orissa is already prone to floods and coastal damage from monsoon systems and cyclones. Coupling the anticipated rise in sea level with

[23] A number of studies of Tarawa and its environment are available, including chapter four in the report "Cities, Seas, and Storms: Managing Change in Pacific Island Economies, Vol. IV, Adapting to Climate Change," World Bank, 2000, http://siteresources.worldbank.org/INTPACIFICISLANDS/Resources/4-VolumeIV+Full.pdf.

the strong likelihood of increasing strength of tropical storms (primarily due to warmer sea surface temperatures) suggests that coastal flooding and erosion can only become worse over the next century.

The impact of variable rainfall is hard to quantify, but is likely to result in reduced crop yields and loss of income for many in Orissa. With almost 60 percent of land devoted to rain-fed agriculture, and with water-dependent rice as its main crop, the agriculture sector is vulnerable. The crops are prone to frequent erosion, inundation, and salinization. Climate projections indicate that flood-prone areas, particularly in the subtropics, will be subject to more intense rain and flooding.

These communities, which have already taken significant steps to adapt to their flood-prone environment, may have few remaining options to build additional resiliency into their economy through adjustments to crop patterns and farming practices. Instead, these communities will be forced to rely on national and international aid to provide for immediate needs in the aftermath of floods and to develop comprehensive strategies to adapt to a changing and more variable world.

Scientists have warned that such impacts on agriculture could occur globally. "In the future, heat stress on crops and livestock will occur in an environment of steadily rising demand for food and animal feed worldwide, making markets more vulnerable to sharp price swings. High and variable prices are most damaging to poor households that spend the majority of their incomes on staple foods."[24]

The Orissa government has already produced a draft Climate Change Action Plan[25] that discusses these issues and possible responses. Addressing the question of why climate change is a serious issue for Orissa, they state:

> Continuing climate change variation is predicted to alter the sectoral origins of growth, including the ability of the poor to engage in the farm and non-farm sector, as well as increase inequality, and therefore to reduce the poverty elasticity of growth. The direct impacts of extreme climate-induced events could be the loss of life, livelihoods, assets and infrastructure. All of these will affect the state's economic growth and nullify the effectiveness of pro-poor macroeconomic policies, trade and private sector investment being pursued.

5. Concluding thoughts

These four vignettes illustrate the possible impacts of climate change on diverse communities in our world. While each story is unique, each is also representative. Frank Logusik Jr., could be speaking for hundreds of communities across the Alaskan and Canadian arctic, as well as for our Native American brothers and sisters in the American Southwest who see their own community life being threatened by increasing heat and drought. The complex environmental and social problems occurring in the Sahel and the likelihood that they will be exacerbated by climate change are similar to problems in Mexico and in the arid regions of central Asia. Tarawa is representative of many small island states across the Pacific

[24] D.S. Battisti, and R.L. Naylor, "Historical warnings of future food insecurity with unprecedented seasonal heat," *Science* 2009: 240.

[25] Draft dated 4 June 2010, produced by the Department of Forest and Environment, Government of Orissa, http://orissa.gov.in/portal/occap.pdf.

and Indian Oceans. Their societal issues associated with limited resources and overpopulation, which has resulted in part from improved health care provided by developed countries, are already daunting. Coupling them with environmental changes produced by climate change is likely to stress these small islands to the breaking point. Ocean acidification and its possible impacts on reef ecosystems also attacks the basic food supply of these small states. Orissa State in India represents dozens of similar locales in the subtropics that depend on monsoon rains for their very existence and yet are threatened by changes in the intensity and variability of these rains, as well as damage associated with a rising sea level.

The projected impacts are an extrapolation of what is being observed to happen today, coupled with impact assessment studies based on both global climate models and regional models, which are used to provide insight on smaller spatial domains. The magnitudes of the anticipated changes are uncertain because our knowledge of both physical (including biological) and social science is incomplete. Although climate change to date may have increased agricultural productivity in some areas, future impacts are highly uncertain, and the likely detrimental impacts may contribute to significant increases in extreme poverty. Further, we do not know exactly how societies will respond to the threats to food and fresh water that we can anticipate. It is not difficult to imagine that possible outcomes include armed conflict and outright war.

Unfortunately, it appears that global society is unlikely to change its current use of carbon based fuels and associated economic policies any time in the near future. We are left then to contemplate what we might do to mitigate these impacts.

C. Mitigation and adaptation

The world's population has been expanding exponentially in the past century, and emissions per capita are also still increasing, especially during times of growth in economic well-being. The two trends combine to form a prospect of a very rapid rate of increase in emissions if we let "business as usual" continue.

As we consider what should be our response to this problem, we first acknowledge God's grace in society. God has endowed humans with gifts to innovate: to dream, discover, develop, and deploy means of sustaining themselves from the provisioning of creation. Since God's providence has in the past allowed humans to innovate technologically to increase the abundance of food and material goods they enjoy today, we live in the expectation of the continuation of such providence. We recognize that God created humans as stewards of the biosphere, and we believe that if we take concerted action, God's grace will allow us to develop innovative solutions for mitigation and adaptation.

Mitigation, which means reducing the accumulation of greenhouse gases in the atmosphere, is defined as actions that change the net balance of emissions of carbon dioxide, methane, nitrous oxide, and several other specific substances that warm the planet. These actions include conservation (for example, more judicious use of energy) and more dramatic changes, such as further developing renewable fuels and switching to alternative technologies

and infrastructures. These changes will take real commitment and long-range planning on the part of our society and governments.

Conservation and efficiency yield immediate benefits and may be very low cost or no cost. Well-insulated homes, efficient heating and cooling systems, and higher vehicle mileage standards may cost little or nothing when the energy cost savings are included. Good stewardship mandates that we take these actions to reduce our use of natural resources. Because the construction of power facilities of any sort requires large amounts of energy, the lowest emissions always come from the power plant that was never built.

In the short term, we can substitute less polluting fuels for dirtier fuels. Natural gas emits about 40 percent less carbon dioxide than coal on an equal energy basis, and does not contain the heavy metal pollutants of coal. Large new reserves of natural gas have been discovered in the eastern and southern United States, and, to a lesser extent, Canada. Worldwide, there are many large natural gas fields currently unavailable because of distance to markets. We should support efforts to access these fields, particularly when accompanied by processes that remove carbon dioxide from power plant exhaust for processing or injecting into permanent underground storage. Another energy source, nuclear energy, can produce large amounts of carbon-free energy but has particular issues of safety and waste disposal. Wind and solar energy contain promise, but today they mainly supplement traditional energy sources and usually are dilute energy sources and often are intermittent. Solar energy production in North America is currently financially noncompetitive with other energy sources, but that promises to change with the ongoing development of improved solar energy cells. Increasing the use of renewable energy sources will require improvements in energy storage capability, as well as changes and improvements in the power distribution grid.

While mitigation strategies may be expensive, we should be careful of using cost as an excuse to shy away from doing what is right based on our understanding of the stewardship of creation. These strategies may be expensive in the short term but both cost effective and necessary in the longer term. Economic analyses often discount the cost of actions as they are moved into the future. Such analyses may well be inappropriate for climate change, in which the future costs are likely to be considerably higher because the effects become increasingly likely and more drastic as greenhouse gas concentrations rise.

Adaptation, which means dealing with the climate changes that have already occurred and will continue to occur, involves more changes than many of us can envision. In the near term, we can begin adapting infrastructure to account for anticipated changes. For example, the Netherlands and Germany are increasing the height of dikes along the North Sea to combat sea level rise and anticipated storm surges. Power companies along the Pacific Coast are planning to change reservoir storage capacity and hydroelectric generation capability in anticipation of enhanced winter rainfall and reduced winter snowpack.

While we work at reducing our emissions, we also need to recognize that we as humans need both provisioning and gainful employment. Simply doing less of the things we are currently doing would indeed reduce greenhouse gas emissions but could also lead to increased deprivation and unemployment. On the other hand, policies supporting research and innovation

can potentially lead, along with reduced emissions, to greater productivity through improved efficiency and to increased employment opportunities for skilled and educated workers.

For example, intensifying agriculture through investment in research and development of higher-yielding crops has been shown to have reduced greenhouse gas emissions. Globally, crop yields have more than doubled since 1961. The increased yields have made it possible to feed the world's growing population with much less increase in cropland area than would have been required otherwise. Had the yield increase not occurred, the larger conversion of forests to cropland would have resulted in higher emissions, globally on a net basis, amounting to 590 million metric tons of carbon dioxide equivalents.[26] As with other mitigation options, intensification may be associated with trade-offs in other environmental impacts, but it is recognized as a key factor to meet the dual objective of food production and climate mitigation.[27]

Intensification includes smallholder farms as well as large farms. There are examples of developing countries (including China, Costa Rica, El Salvador, and Vietnam) that have recently managed to increase both their forest cover and their agricultural production, showing that even in the face of economic globalization, sound polices and innovation can reconcile forest preservation with food production.[28] Such innovation is particularly needed in the tropics, where the carbon loss is greater and the gain in food production is often less per acre of land that is converted to agriculture.[29] Approaches to mitigation need to be assessed from a whole-landscape multisector perspective, including life-cycle analysis of technological options.

Anticipating and managing changes to infrastructure, energy production, and food production will demand serious attention to social justice issues. These issues arise from the fact that, as we have noted above, some groups of people will be more, perhaps much more, vulnerable to the impacts of climate change than others, and some groups will have more resources to use for adaptation than others. As Christians, we are called to love our neighbors and seek their good, which includes helping the poor and vulnerable to adapt to these anticipated changes.

IX. Translating knowledge and gratitude into responsible action and joyful service

As confessing Christians in the 21st century, what is our response to these issues of environmental degradation and the particular issue of human-induced climate change? The answer to this question is complex because the

[26] J.A. Burney, S.J. Davis, and D.B. Lobell. "Greenhouse gas mitigation by agricultural intensification," *Proceedings of the National Academies of the Sciences,* 107:26 (2010):12052-12057.

[27] R. DeFries, and C. Rosenzweig, "Toward a whole-landscape approach for sustainable land use in the tropics," *Proceedings of the National Academies of the Sciences* 107:46 (2010):19627-19632.

[28] Lambin, Eric F., and P. Meyfroidt, "Global land-use change, economic globalization, and the looming land scarcity. *Proceedings of the National Academies of the Sciences,* 108:9 (2011):3465-3472.

[29] Paul C. West, H.K. Gibbs, C. Monfreda, J. Wagner, C.C. Barford, S.R. Carpenter, and J.A. Foley, "Trading carbon for food: Global comparison of carbon stocks vs. crop yields on agricultural land," *Proceedings of the National Academies of the Sciences,* 107:46 (2010):19645-19648.

issues are complex. Moral responsibility and obligation are difficult concepts for issues that span global scales and decades of time; preventive and remedial actions require long-term commitment and international cooperation, both of which are difficult to achieve.

A. Previous declarations on creation care and climate change

We are not the first Christians to wrestle with these issues, so it is important for us to consider what has been done already. The committee has considered the following six documents:

- *The Evangelical Declaration on the Care of Creation* from the Evangelical Environmental Network
- *The Oxford Declaration on Global Warming*
- *An Evangelical Declaration on Global Warming* from the Cornwall Alliance
- *Climate Change: An Evangelical Call to Action* from the Evangelical Climate Initiative, which is associated with the Evangelical Environmental Network
- *The Micah Declaration on Creation Stewardship and Climate Change* developed at the Fourth Triennial Global Consultation held in Kenya by the Micah Network from July 13-18, 2009
- *African Church Leaders' Statement on Climate Change and Water* resulting from a meeting held in Nairobi, Kenya, in June 2008 under the auspices of the All Africa Council of Churches

Summaries of the six documents statements are provided below. The documents are included in their entirety in Appendix C for reference.

1. *The Evangelical Declaration on the Care of Creation*[30] was developed in 1994 by a conference of leaders of the evangelical community under the auspices of the Evangelical Environmental Network. It is a powerful statement calling God's people to renewal and commitment to care of creation. The declaration begins with a statement of worship for the Creator and acknowledgment of our sin and, in particular, that "we have failed in our stewardship of creation." It then describes the degradation of creation and the finite limits for creation against which we are pressing, and it asserts that "human poverty is both a cause and a consequence of environmental degradation." It follows with a call for confession and repentance and states that all humans have responsibility for creation. It concludes with several statements of purpose, among them:

> Therefore we call upon all Christians to reaffirm that all creation is God's; that God created it good; and that God is renewing it in Christ.
>
> We seek a deeper reflection on the wonders of God's creation and the principles by which creation works. We also urge a careful consideration of how our corporate and individual actions respect and comply with God's ordinances for creation.
>
> We recall Jesus' words that our lives do not consist in the abundance of our possessions, and therefore we urge followers of Jesus to resist the allure of wastefulness and overconsumption by making personal lifestyle choices that express humility, forbearance, self restraint and frugality.

[30] Those seeking a detailed discussion of this document are encouraged to read S.A. Berry, ed., *The Care of Creation: Focusing Concern and Action*, Leicester, UK: InterVarsity Press, 2000.

> We call on all Christians to work for godly, just, and sustainable economies which reflect God's sovereign economy and enable men, women and children to flourish along with all the diversity of creation. We recognize that poverty forces people to degrade creation in order to survive; therefore we support the development of just, free economies which empower the poor and create abundance without diminishing creation's bounty.
>
> We commit ourselves to work for responsible public policies which embody the principles of biblical stewardship of creation.

Before moving on to the declarations specifically dealing with global warming, we note that in 2000, in reaction to *The Evangelical Declaration on the Care of Creation*, the Cornwall Alliance[31] issued a *Declaration on Environmental Stewardship* that addressed some similar issues. The *Cornwall Declaration on Environmental Stewardship* claims to represent the perspective of a broader grouping of faiths. It states that it is written by a group of "Jews, Catholics, and Protestants, speaking for ourselves and not officially on behalf of our respective communities." Its expressed beliefs, presented as arising from a common Judeo-Christian heritage, are given without direct biblical references. It agrees with the evangelical declaration that "men and women were created in the image of God," but it places more emphasis on their "privileged place among creatures" and notes concern that "many people mistakenly view humans as principally consumers and polluters rather than producers and stewards. Consequently, they ignore our potential, as bearers of God's image, to add to the earth's abundance." Because of the absence of biblical references, presence of other ideologies commingled in its theological background, and outright denial of science on the issue of climate change, we do not discuss further the *Cornwall Declaration on Environmental Stewardship* or recommend it for study.

2. *The Oxford Declaration on Global Warming* arose from a meeting held in 2002 in Oxford, England. This meeting brought together climate scientists and evangelical leaders for mutual scientific and theological education at St. Anne's College. The outcome of this unprecedented gathering of leading scientists and evangelicals was the *Oxford Declaration on Global Warming*. This declaration is well rooted in biblical, theological, and scientific scholarship. Its three main points are

   a. Human-induced climate change is a moral, ethical, and religious issue.

   b. The earth's climate is changing, with adverse effects on people, communities, and ecosystems.

   c. Action is needed now, both to arrest climate change and to adapt to its effects.

   It then goes on to recommend actions by Christian denominations, churches, and organizations to increase awareness of climate change, set an example through our own actions, and urge action by national governments.

[31] A brief history and some additional perspective on the Cornwall Alliance is included in Appendix D.

3. *An Evangelical Declaration on Global Warming*, issued by the Cornwall Alliance in 2009 (hereafter referred to as the Cornwall Declaration on Global Warming) and authored largely by Calvin Beisner, provides a stark contrast to the previous two documents. Despite the placement of *evangelical* in the title, this document arises from an interfaith alliance (see Appendix D). This Cornwall Declaration includes both statements on "What We Believe" and "What We Deny." The principal belief of this declaration is that "earth and its ecosystems . . . are robust, resilient, self-regulating and self-correcting," a belief that is unsupported by science and observation. The Cornwall Declaration states that fossil and nuclear fuels are indispensable and that policies to create mandatory reductions in carbon dioxide will increase the cost of energy and will harm the poor. The declaration denies both that the "earth's climate system is vulnerable to dangerous alteration" and that human contributions to greenhouse gas concentrations are causing global warming. The declaration "Call to Action" is primarily a call to practice creation stewardship and to simultaneously abandon "fruitless . . . policies to control global temperature."

4. *Climate Change: An Evangelical Call to Action* was produced by the Evangelical Climate Initiative (ECI) in January 2006. The ECI is "a group of senior evangelical leaders in the United States who are convinced it is time for our country to help solve the problem of global warming." The Call to Action has four main claims:

   a. Human-induced climate change is real.

   b. The consequences of climate change will be significant and will hit the poor the hardest.

   c. Christian moral convictions demand our response to the climate change problem.

   d. The need to act now is urgent. Governments, businesses, churches, and individuals all have a role to play in addressing climate change—starting now.

5. *The Micah Declaration on Creation Stewardship and Climate Change* synthesizes the findings of the Fourth Triennial Global Consultation held in Kenya by the Micah Network from July 13-18, 2009. The meeting attracted members of the Micah Network from 38 countries, and the declaration arose from their deliberations. It recognizes that God established just relationships among all of creation, including the establishment of women and men as stewards. It acknowledges that through our sin we have failed to be faithful stewards, but that God "is already at work to renew all things." It specifically identifies global warming as a result of human activity and enumerates the potential impacts of that warming. It then challenges individuals to "teach and model care of creation" and calls on "local, national, and global leaders to meet their responsibility to address climate change and environmental degradation." It concludes with the statement "We will labour with passion, persistence, prayer and creativity to protect the integrity of all creation, and hand on a safe environment and climate to our children and theirs."

6. *The African Church Leaders' Statement on Climate Change and Water* was developed by the All Africa Council of Churches at a meeting held in Kenya in 2008. The Statement affirms "the reality and urgency of climate change and the adverse negative impact it has on entire humanity and particularly on poor and vulnerable communities in Africa." It goes on to state that greenhouse gas emissions have arisen and continue to arise largely from industrialized countries while the negative consequences of [global warming] are felt largely in the global south. It calls upon the governments of the global north to reduce greenhouse gas emissions, support adaptation in the global south, offer financial and technological support, promote and implement low carbon strategies, and compensate developing countries for damage already done. The statement also appreciates "the efforts of churches and faith-based organizations in advocating for the rights of the poor and vulnerable communities in the continent [of Africa]" and further challenges them to "recognize the reality of climate change" and to "stand in solidarity with communities that are currently suffering from the negative impacts of climate change." It also challenges churches and faith-based organizations to develop curricula and training modules that help integrate climate change issues into educational material and to establish "eco-congregations" that have a focus on "checking consumerism through behavior change."

B. What can we learn from these declarations?

These documents provide contrasting views on evangelical Christian responses to creation stewardship and climate change. Four of them—*The Evangelical Declaration on the Care of Creation*, *The Oxford Declaration on Global Warming*, *Climate Change: An Evangelical Call to Action*, and *The Micah Declaration*—are quite similar in tone, although the first deals with the general creation care issue, while the latter three deal more specifically with climate change. *The Evangelical Declaration on the Care of Creation*, which the Christian Reformed Church signed in 1994, provides a broader and richer perspective on the creation care issue than any of the other documents. *The Oxford Declaration* and *The Call to Action* have a similar perspective on climate change. Both state that climate change is real and occurring now, has moral and ethical implications, affects the poor more than the rich, and requires urgent action. *The Micah Declaration* is similar in tone but places a somewhat stronger emphasis on social justice issues, particularly as they affect future generations. Each of the latter three documents emphasizes the need for the Christian church to be engaged in the discussion of climate change impacts and to act to mitigate impacts, as well as plan for adaptation to them.

The African Church Leaders' Statement is similar to these documents in its recognition of the reality and urgency of climate change, and it has, like the *Micah Declaration*, a strong emphasis on social justice. Its focus, however, is much more on the relationship between the global north being responsible for greenhouse gas emissions and the global south suffering the impacts of global warming. The statement specifically calls out global warming as affecting domestic and agricultural water and food security and is alone among the statements in drawing a possible connection between global warming and resource-based conflicts. Its contention that "a third of the African population has already fallen prey to droughts, flood and resource-based

conflicts resulting from global warming" is difficult to document, likely because of the difficulty in specifying the impacts of climate change that have occurred thus far. Nonetheless, the potential for disasters and conflict associated with climate change in Africa is high.

The Cornwall Declaration on Global Warming takes a completely opposite point of view, challenging not only the idea that human influence on climate change is occurring but even the possibility that creation could be harmed by human activity. In addition, it states that actions to mitigate climate change are neither warranted nor useful and, if taken, will harm the poor.

How can we resolve this apparent dilemma? Which of these alternatives is the pole toward which our denomination should gravitate? We think that the following three primary questions need to be addressed in order to decide:

- Does earth have such a robust climate that human activity cannot alter that climate?
- Is climate changing due to human activity?
- Will climate change affect the poor more negatively than the rich, and will policies enacted to mitigate climate change do the same?

1. Does the earth have such a robust climate that human activity cannot alter that climate?

   Scripture testifies that God created the earth, including both the physical and biological components of creation, good. Creation and our relationship to it, however, have been warped and distorted by sin. Sin resulted in changes in land productivity and ecosystems (Gen. 3:17-19; Rom. 8:18-22). The answer to this first question, therefore, is no, and we must consider instead the degree to which the earth can be altered by human activity. While human activity cannot produce a result so calamitous that the entire human race is wiped out (Gen. 9:15), there is no biblical basis to assert that climate (or any part of creation) is so robust that humans cannot damage their environment in ways that produce pain and loss, including the loss of human life.

   This position is borne out by the history of the past century. Even leaving aside the terrible tragedies and genocide associated with the wars and purges of the past century, we can identify many examples of human activity that have had and are having serious impacts on the environment and human life. In many of these cases, but certainly not all, the initial actions were not the product of sinful intent, but the consequences were a manifestation of evil. Thalidomide was introduced as a helpful drug to combat nausea associated with morning sickness, but it caused terrible birth defects. Chernobyl was built to provide nuclear power to the Ukraine, but an explosion and fire, possibly the result of human negligence, produced the worst nuclear power plant disaster in history. The radioactive products devastated both humans and the environment, with effects that will continue for many years. At Love Canal near Niagara Falls, New York, the burial of over 21,000 tons of known toxic waste led to an environmental wasteland and lingering health impacts. Lead was added to gasoline to aid combustion and engine performance, but it contributed to lead poisoning in people and the environment.

   Many more examples of similar regional disasters could be cited. But, is there an example of human activity having a global climate impact?

The ozone hole provides an illustrative case in point. As early as the 1920s, chlorofluorocarbon (CFC) compounds were recognized as highly effective refrigerants to replace ammonia and other toxic gases, and as efficient fire-fighting compounds and propellants. The rapid rise in CFC usage, which began in the 1960s, caused atmospheric CFC concentrations to rise from zero to a few thousand ppt (parts per trillion; basically a few thousand molecules of various CFC compounds per trillion air molecules) by 1990. In the early 1980s, two atmospheric chemists alerted the world to the fact that these compounds could affect the atmospheric ozone layer that protects life from the harmful effects of high energy solar radiation. Further research confirmed that this was indeed the case, and the first impacts of ozone loss were identified in the Antarctic stratosphere (some 6 to 10 miles above the surface), perhaps the remotest part of the earth's atmosphere and seemingly the least likely to be affected by human activity. The confirmation of this environmental degradation already in progress led in 1987 to the signing of the Montreal Protocol, which limited the production and use of CFCs. CFC concentrations are now declining, but it will be several more decades before CFCs are reduced to near-zero levels and the ozone layer is healed.

The ozone hole is an interesting example of a problem created by human activity, recognized as such by the scientific community, and then successfully addressed by the international political community through negotiation and regulation. It indicates quite clearly that humans have the capability through their actions to impact the environment both regionally and globally. Although earth's climate is robust and resilient, it is not immune to human activity.

2. Is climate changing due to human activity?

   We have addressed this question in Section VII and Appendix A. The scientific community is strongly in support of the Intergovernmental Panel on Climate Change (IPCC) finding, which states that

   > Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations.

   The term "very likely" implies certainty at the 90 percent level of probability.

3. Will climate change affect the poor more negatively than the rich, and will policies enacted to mitigate climate change do the same?

   This question regarding the impact of climate change is really two questions that are often entangled, resulting in poorly constructed answers. First, climate change as we understand its consequences will indeed impact the poor more negatively than the rich, particularly at the level of individual countries. Geographically small countries with limited financial resources will have very little opportunity to adapt to climate change. Their populations cannot move to a more benign climate, and they do not have the resources to adapt technologically to anticipated changes. We have provided some examples of these impacts in Section VII, and the scientific studies of which we are aware confirm this general conclusion. While various arguments can be made to the contrary

(e.g., the poor have less to lose; the rich are more susceptible to the social unrest and rebellions that may arise from the impacts of climate change), it is clear to us that there is indeed a social justice issue associated with potential climate change. The African church leaders make this point very forcefully in their statement. Our actions toward reducing emissions of greenhouse gases can be an expression of the love for our neighbors that God requires of us.

The second half of the question asks whether policies to reduce greenhouse gases will affect the poor more negatively than the rich. This is really the question posed in The Cornwall Declaration on Global Warming. It is an economics and policy question that is somewhat beyond the scope of our mandate but deserves a few comments. The conclusion that these policies unfairly affect the poor seems to arise, in part, from the assumption that the only path to a higher standard of living is to follow the highly energy intensive route taken by the United States and other developed countries. This is by no means correct, especially for countries that lack carbon-based fuel reserves or the financial resources with which to pay for them.

In addition, it assumes that we as individual nations and as an international community are unable to implement policies that will address these inequities. This is not the case. In recent years during cold winters in the United States, the price of fuel oil for heating reached disastrous levels for many poor and elderly residents, particularly in the northeast. The government has chosen to provide subsidies for the purchase of heating oil to prevent loss of life because that is the moral course of action. The 1987 Montreal Protocol contained provisions for poorer countries to phase out use of CFCs more slowly to limit disruption to their economies, particularly in refrigeration. It will be incumbent on the more technologically advanced countries to provide technological and financial help for poorer countries. This has happened in the past and can happen in the future.

Effective climate change mitigation will be a significant undertaking and will undoubtedly come at a cost. But the costs of mitigation and their distribution among countries and individuals are separate issues that should not be conflated. As the examples above demonstrate, concerns about the distribution of costs of mitigation can be addressed through financial and technological aid, differentiated responsibilities, and other means. Further, the costs of failing to act will also impact the poor more negatively than the rich. And these costs are likely to be greater (and more difficult to redistribute) than the costs of mitigation. While we must be ever mindful of the costs that our choices have on the poor, those considerations alone are not a reason to avoid taking action.

Further, it is difficult, perhaps impossible, to predict technological advances that will change our energy future. A recent example is the ability to drill horizontal wells followed by artificial fracturing to produce natural gas from tight shale formations. This technology can potentially develop vast reserves of natural gas that a few years ago were considered inaccessible. Advances in technology and decreases in costs may change our energy future for a variety of energy sources in ways we cannot predict. These future advances too are a part of God's continuing providence and provision.

There is an additional, important moral issue relating to future generations. The amount of carbon-based fuels on earth is finite, and our generation is consuming them at an ever increasing rate. Estimates of the amount of fuel remaining and the length of time before it is effectively consumed vary widely. There can be no doubt, however, that our children and grandchildren, and their children, will experience more of the risks and less of the benefits of the greenhouse gas emitting practices that we are employing today.

Our analysis of the statements on climate change and their implicit questions leads us to conclude, in terms of the climate change issue, that we most strongly identify with the positions expressed by *The Evangelical Declaration on the Care of Creation*, *The Oxford Declaration on Global Warming*, *Climate Change: An Evangelical Call to Action,* and *The Micah Declaration on Creation Stewardship and Climate Change.* These statements align with our understanding of biblical principles, theology, and environmental science. The positions expressed in the Cornwall Declaration are in general inconsistent with our perception of biblical stewardship and with our observations of what is occurring in our world today.

C. Position statement on climate change

The Christian Reformed Church Creation Stewardship Task Force submits the following position statement on climate change.

We re-affirm *The Evangelical Declaration on the Care of Creation.*

Its statement of the relationship between God and all of creation, including humanity; the degradation of creation through the effects of our sin; the need for repentance and renewal; and the call for action are as true today as they were in 1994, when it was adopted by the Christian Reformed Church.

We affirm the following statements:[32]

1. Climate change is occurring and is very likely due to human activity.

   Observations of natural systems and collection of scientific data confirm that the earth on average is warming. Careful scientific research consistently identifies human-induced greenhouse gases as the very likely (90% probable) primary cause of observed global warming.

2. Human-induced climate change is a moral, ethical, and religious issue.

   God created the earth and continues to sustain it. Made in God's image, human beings are to care for people and all creation as God cares for them. The call to "love the Lord your God" and "love your neighbor" (Matt. 22:37–39) takes on new implications in the face of present and projected climate change.

3. Human-induced climate change poses a significant threat to future generations, the poor, and the vulnerable.

   As higher levels of greenhouse gases accumulate in the atmosphere with time, average global temperature will increase and rainfall will become more variable. Future generations will inherit climate change driven

[32] Our statements follow closely some parts of *The Oxford Declaration on Global Warming* and of *Climate Change: An Evangelical Call to Action.*

by emissions of today. Changing climate and rising sea level will particularly impact low-lying coastal areas and small islands. Poor societies will have fewer options and resources than wealthier societies to adapt to these changes.

4. Human-induced climate change poses a significant challenge to us all.

   Climate change will occur globally and will require adjustments and changes for all people. The changes required to our lifestyles and to our economic goals are most likely large and potentially underestimated. The God-given gifts of human innovation and resourcefulness, as well as a renewed commitment to stewardship, need to be applied in a concerted manner to mitigate and adapt to climate change.

5. Urgent action is required to address climate change.

   Action is needed at the personal, community, and political levels toward reducing human causes of climate change and mobilizing ourselves in urgent assistance to those who are forced to adapt to its negative effects.

   We have an opportunity now to reduce the future impact of climate change by reducing the emission of greenhouse gases. These emissions are increasing at an exponential rate. Waiting to act until more data accumulate limits our ability to reduce future impacts and ensures that future climate change will be greater rather than smaller.

D. Walking the talk

1. Reflection

   Moving forward from our position statement to concrete actions requires that we all begin with prayer, individually and communally, asking God for forgiveness for the sins of arrogance, pride, and greed that cause us to fail in our roles as stewards of creation, consume more than we need or ought, and ignore the plight of the poor and vulnerable. We must all pray for discernment regarding the answers to the difficult questions that the issue of global warming raises and for loving spirits that allow us to seek a right path together.

   In this spirit, we commend item 8 of the *Micah Declaration* to the churches for reflection and commitment:

> Before God we commit ourselves, and call on the whole family of faith, to bear witness to God's redemptive purpose for all creation. We will seek appropriate ways to restore and build just relationships among human beings and with the rest of creation. We will strive to live sustainably, rejecting consumerism and the resulting exploitation. We will teach and model care of creation and integral mission. We will intercede before God for those most affected by environmental degradation and climate change, and will act with justice and mercy among, with and on behalf of them.

2. A first step: awareness, appreciation, and stewardship[33]

   What does it mean to act with justice and mercy among, with, and on behalf of those most affected by environmental degradation? The simple yet profound response to this question is this: "Love God as Redeemer

[33] This section on awareness, appreciation, and stewardship is excerpted from *Earthwise: A Guide to Hopeful Creation Care* (Faith Alive 2011), pp. 122-23, with permission.

and Creator, acknowledge God's love for all creation, and act upon this by following Jesus—the one who created, upholds, and reconciles all things."

But a serious problem remains: it is difficult to love, uphold, and care for a world that we really do not know. Thus many will first have to become aware of creation and its God-declared goodness. As believers in Christ, we are called to share this good news and invite others to come to know the one true personal God and Savior, and to have them join us in working to live rightly and to spread the joy of right living. Once we are aware of creation and God's love for the world, we can move on to appreciation and stewardship.

Our ultimate purpose is to honor God as Creator in such a way that Christian environmental stewardship—caring for creation—is part and parcel of everything we do. Our goal is to make "tending the garden"—our striving to safeguard and renew the life of all creation—an unquestioned and all-pervasive part of our service to each other, to our community, to God's world.

We can move in our response from awareness to appreciation to stewardship, as follows.

a. Awareness

In a time when so much calls for our attention—international affairs, local politics, our work or schooling, family needs, church commitments, and other busyness—we might only barely notice the natural and environmental aspects of creation in our surroundings. We might take time to notice and learn things about creation only when we have a day off or when we take a vacation trip—and even then our impressions may be seriously obscured. We must consciously make ourselves aware of what is happening in God's creation.

Awareness involves seeing, naming, identifying, and locating different parts of God's creation. It means taking off blinders that we or society may put on us to keep us focused on our pursuits in life. It means providing ourselves with enough quiet, reflection, and learning time that we can notice and identify a tree or mountain, bird or river. It means entering the natural world intentionally in order to locate and find God's creatures that we sing about in a favorite doxology: "Praise God . . . all creatures here below."

b. Appreciation

From awareness comes appreciation; we cannot appreciate something we are unaware of. At the very least, appreciation means tolerating what we are aware of. We may tolerate, for example, worms and hyenas. But appreciation can also involve respect. We certainly respect a large bear, but we can also develop respect for a lowly worm as we learn of its critical importance to the rest of creation. We can move, as well, from toleration to respect to valuing. The earth and everything in it has value because God made it so. As we become aware of the order of creation, we will image God's valuing of all his works. And this will build even further until we even esteem and cherish much of what we discover.

c. Stewardship

Appreciation must lead to stewardship. Stewardship takes us beyond appreciation to restoration. We now work for the restoration of what has been degraded in the past. Beyond restoration, stewardship means serving. As we understand that God through creation is in so many ways serving us, we grow to willingly return this service with our own. This service includes a loving and caring keeping of what God has given us to hold in trust. And our service in creation will eventually involve entrusting others with what we have served, kept, and restored.

Christian environmental stewardship—our loving care and keeping of creation—is a central, joyful part of the human task. As communities of God's stewards—as the worldwide body of the one who redeems and reconciles all things—our churches and our lives can and must be vibrant testimonies to our Redeemer and Creator. "You are worthy, our Lord and God, to receive glory and honor and power, for you created all things, and by your will they were created and have their being" (Rev. 4:11).

3. Getting your congregation talking and walking

Each congregation is different. There may already be things that you are doing for other reasons that are helping care for creation by default, or you may be a congregation who has integrated creation care into all aspects of your church life. No matter where you are on the awareness, appreciation, and stewardship continuum, the following suggestions will help you become better caretakers of the place where God has planted you. One of the best places to start is to take an inventory of where your church is at, then brainstorm ideas of where you could go from there; choose one or two activities that you can implement and finally go about the work of doing it. Remember, environmental stewardship is not talk. Environmental stewardship is action.

a. Take an inventory

Take some time to look at your creation care activities in the context of the following:

- Worship
- Theology
- Education programs
- Property management
- Finance and purchasing
- Church activities
- Church grounds
- Personal lifestyle
- Community outreach
- Global outreach

The Office of Social Justice has created a simple church checklist to help with this process, and it is reprinted in its entirety in Appendix E.

b. Brainstorm ideas

Once you have a sense for where your church is at, have a brainstorming session of what you could do to become better stewards. Remember that this is a time to dream and share every crazy idea you have. Do not block ideas because of perceived roadblocks; just get it all down on paper. You will have time to narrow things down later. The mini-workshop printed in Appendix E is an excellent tool for skimming ideas from your group.

c. Choose one or two actions

Choose a couple things or maybe one area that you would like to work on for the next twelve months and start putting together a plan for how you will go about accomplishing that action. This may include finding more people to be involved in the process (council, the congregation, the education committee, and so forth), learning more about a certain topic or the area where you live, or even finding others in your church who are interested in joining you. Be careful not to try to do too much at once, but do something!

d. Get cracking

Do the work you have set out to do. Pray. Gather with other like-minded people. Encourage each other, share your stories, and keep going. Remember that each step you take glorifies your Creator and helps reconcile you and others to the creation, no matter how big or small the action.

4. What are others doing?

There are many examples of individuals, congregations, and denominations that are doing wonderful work on caring for creation. Appendix E lists many ideas that were gleaned from churches who did the brainstorming activity outlined there. You can also look at the eco-justice group at www.justiceseekers.ning.com to find out what CRC congregations are doing around the world. Join in and share your ideas, support each other, and ask questions about eco-justice.

X. Recommendations

A. That synod grant the privilege of the floor to Dr. Calvin B. DeWitt, chair, and Dr. Thomas Ackerman, member of the task force, when the report of the Creation Stewardship Task Force is addressed.

Ways of Knowing

B. That synod declare that both Scripture and continually emerging scientific knowledge are necessary and valid ways of knowing that should guide our response to creation stewardship issues, including climate change.

Grounds:

1. God reveals himself through Scripture and creation. As creation suffers, God's revelation is diminished.
2. God's revelation in Scripture and creation has integrity and compatibility. These revelations are complementary and mutually supportive if understood correctly.
3. The ability to learn through science and personal observation is part of God's gift of general revelation.

Affirmation of Biblical Principles

C. That synod declare that an important way in which Christians reflect their love of God and neighbor is through their expression of creation care. Caring for creation, therefore, becomes an integral part of the church's evangelical witness to the world.

Ground: 1 Peter 2:12 urges us to remember that all our actions should lead others to glorify God.

D. That synod affirm the biblical principles of earthkeeping, fruitfulness, Sabbath, discipleship, kingdom priority, contentment, praxis, and con-servancy (see section IV, B) and that it urge congregations, denominational staff, leaders, and members to strive to live by these principles.

Statements on Climate Change

E. That synod affirm the following findings (see section IX, C) concerning climate change and that it commend them to the churches as guides to prayer, discussion, direct action, and advocacy:

1. Climate change[34] is occurring and is very likely due to human activity.
2. Human-induced climate change is a moral, ethical, and religious issue.
3. Human-induced climate change poses a significant threat to future generations, the poor, and the vulnerable.
4. Human-induced climate change poses a significant challenge to us all.
5. Urgent action is required to address climate change. This includes actions at the personal, community, and political levels toward reducing human causes of climate change and mobilizing ourselves to urgent assistance of those who are forced to adapt to its negative effects.

Call to Action

F. That synod call upon the churches and their members to examine our energy choices in our homes, lives, businesses, farms, and institutions from a perspective of stewardship, challenging ourselves to use less energy and to use it more wisely in order to reduce our individual and collective carbon footprint on the environment. (Reducing greenhouse gas emissions is the first step; ultimately, control of climate change will likely require low or zero net emissions.)

[34] Climate change here refers to global warming.

G. That synod call upon the churches, their members, and appropriate denominational agencies and institutions to respond with generosity and compassion to people and places affected by climate change, as well as to make efforts to mitigate it. This includes advocating with our governments to commit the necessary financial resources in an effective global framework to assist populations that are bearing the brunt of the negative effects of climate change while being the least able to cope.

H. That synod call upon the churches, members, and denominational bodies to be voices for justice and public examples in the effort to live sustainably within our God-given resources, to promote stewardship in our own communities and our nations, and to seek justice for the poor and vulnerable among us and for future generations.

I. That synod direct the BOT to ensure that educational resources and programs are developed and made widely available to congregations, schools, and other groups in order to promote participation in the urgent global conversation concerning care for the creation. This particularly includes how we can, now and in the future, significantly reduce our greenhouse gas emissions, including the need for energy conservation and efficiency, the need to substitute cleaner fuels for dirtier fuels, and the need for publicly supported investment to replace fossil fuels with better alternatives.

J. That synod request the BOT to review the operational practices of major CRC agencies and institutions in the light of this report's conclusion concerning the urgent need to exercise robust leadership in caring for the creation and addressing a changing climate, including the need to reduce our denominational carbon footprint.

K. That synod request the BOT to facilitate placing several appropriate creation care organizations on the list of those recommended for financial support.

L. That synod accept this report as fulfilling the mandate of the Creation Stewardship Task Force and dismiss the task force.

XI. Items for further study and action

In the course of its work, the task force noted at least two items that it believes merit further study, consideration, or implementation by appropriate denominational bodies:

1. The "Doctrine of Discovery" (see section V, D) should be examined in the light of its connection to injustice committed against indigenous peoples and how the church and the Reformation may have been involved in the process. This is not just an issue of past injustices; in multiple, modified forms the doctrine continues to persist today. Although this is a large, complex, and difficult issue, the task force believes the integrity and unity of our CRC community of faith requires us to confront it.

2. The task force suggests that a type of "seed grant" program—from denomination to churches—would encourage small groups within churches to act creatively in responding to the findings and recommendations within this report. The best ideas often come from the local level. The availability of a small amount of concrete funding can catalyze local energy and support for creative and innovative projects. These in turn become the seeds for others.

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Appendix A
A Climate Change Primer

Note: A full-color version of this Creation Stewardship Task Force report is available for download at crcna.org/synodresources in order to view the charts contained in Appendix A in color.

The science of climate change is complex and has been the subject of extensive investigation, discussion, and debate, particularly over the past three decades. It is impossible to do full justice to the extent of this subject in a few pages; the intent here is to provide an overview of the principal scientific issues. For each issue, multiple scientific papers could be cited, but here references are provided to a few seminal papers, reports, and books that are intended for a more general audience. Interested readers are strongly encouraged to read these reports and books to extend the discussion presented here.

A. Earth's greenhouse effect

All warm bodies emit electromagnetic radiation. If the temperature of the body is high, such as that of a star like our sun, radiation is emitted at wavelengths that our eyes can see, as well as at wavelengths both shorter and longer than what is visible to us. If the temperature of the body is lower, similar to the normal range of temperature on earth, then this radiation is emitted at infrared wavelengths (also referred to as longwave radiation). Human bodies, the earth surface, clouds, and the atmosphere all emit infrared radiation.

The average temperature of any planet is maintained by a balance of incoming and absorbed solar radiation and outgoing radiation emitted to

space. The solar radiation reaching earth is a function of the average surface temperature of the sun (approximately 5,700 degrees Kelvin) and the distance of earth from the sun. About 30 percent of this energy is reflected by earth and its atmosphere, and the remainder is absorbed, primarily at earth's surface (see Fig. 1). In the absence of an atmosphere, the amount of solar radiation absorbed by earth would be only enough to heat the planet (surface plus atmosphere) to an average temperature of about -18° C (0° F), something we can learn from straightforward physics and satellite observations. In order to maintain a stable planetary temperature, absorption of incoming solar energy needs to be balanced by outgoing thermal radiative energy. The outgoing thermal energy is radiated primarily from the middle levels of the atmosphere, typically 5 to 10 km (3 to 6 miles) above the surface. The atmosphere, like any warm body, emits thermal radiation in all directions, both up toward space and downward toward the earth surface. The earth surface, because it is warmed by both absorbed solar radiation and emitted thermal radiation from the atmosphere, is much warmer—about 15° C (60° F)—than the average temperature of our planet.

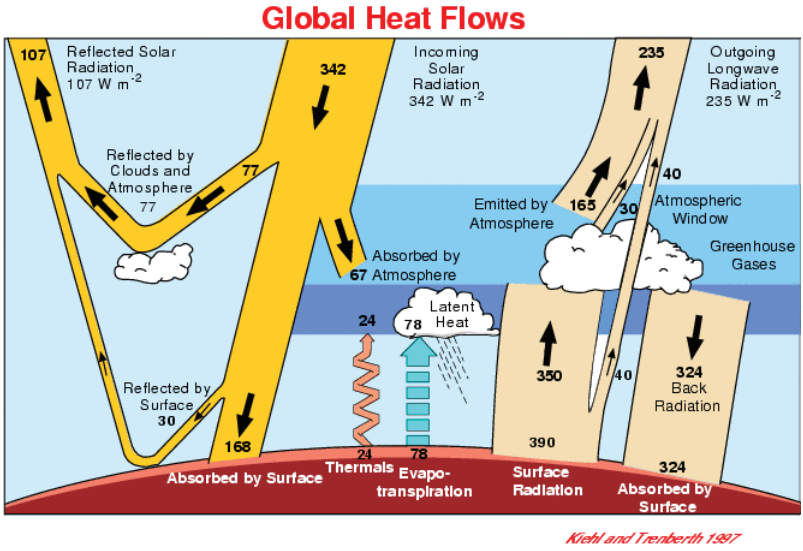

Figure 1. Globally averaged heat flow in the earth climate system expressed in units of Watts per square meter. This figure was taken from an article on the greenhouse effect (http://www.windows2universe.org/earth/climate/greenhouse_effect_gases.html) at Windows to the Universe, an educational website operated under the auspices of the University Corporation for Atmospheric Research. This is an excellent site from which to obtain information about the science of weather and climate.

The warming of the earth surface by downward radiation from the atmosphere has been named the "greenhouse effect," even though the physics of what keeps a greenhouse warm is quite different. The term "greenhouse

effect" does capture the fact, however, that the earth surface is kept warm due to the presence of an overlying, absorbing atmosphere. Atmospheric greenhouse effects occur on both of our neighboring planets. Venus has a far larger greenhouse effect and a very hot surface, while Mars has a much smaller greenhouse effect and colder surface.

The physics of the greenhouse effect has been known for more than 150 years, beginning with the work of John Tyndale in 1861 and Svente Arrhenius in 1896.[1] Given knowledge of the composition of an atmospheric column, the downwelling infrared radiation, or greenhouse effect, can be calculated by standard computer codes to an absolute accuracy of better than 1 percent when compared with measurements.[2] Perhaps surprisingly, this accuracy is better than the absolute accuracy with which solar radiation transmitted through the earth atmosphere can be calculated.

The primary constituents of the atmosphere are nitrogen (78%), oxygen (21%) and argon (about 1%). Nitrogen and oxygen each occur naturally as a "diatomic" molecule consisting of two identical atoms, and argon is a single atom. Single atoms and diatomic molecules are very poor absorbers of thermal radiation, and thus none of these three contribute to the greenhouse effect. The greenhouse effect is due entirely to molecules consisting of three or more atoms, and for our atmosphere, these are principally three different molecules: water vapor (H_2O), carbon dioxide (CO_2), and ozone (O_3). Water vapor absorption and emission is by far the most important contributor to greenhouse warming, with carbon dioxide second, and ozone a distant third. There are other naturally occurring greenhouse gases (e.g., nitrous oxide and methane), the concentrations of which are augmented by human activity, as well as some greenhouse gases produced only by human activity (e.g., Freon and related compounds).

Although water vapor is the most important greenhouse gas, carbon dioxide is the key regulator of the magnitude of earth's greenhouse effect because of its long residence time in the atmosphere. Earth's carbon cycle is complex, and processes operate on time scales that are very short (seasonal)

[1] An excellent history of global warming had been compiled by Spencer Weart under the auspices of the American Institute of Physics and is available on line at http://www.aip.org/history/climate/summary.htm.

[2] In general, it is much more difficult to make an absolute measurement than to make a comparison measurement. For example, a radar gun can easily be used to determine with high precision which of two cars is traveling faster down the highway. Determining the exact miles per hour that a car is traveling is considerably more difficult because the radar gun accuracy must be determined by calibration. The 1 percent accuracy mentioned here applies to the agreement of a computed quantity vs. a measured quantity, in this case the downwelling thermal radiation.

Absolute accuracy is limited by accurate knowledge of the properties of the atmosphere (for example, the amount and distribution of water vapor in the atmosphere), the accuracy of the instrument itself (typically on the order of 0.5 percent for thermal radiometers), and the accuracy of the radiation model. The absolute accuracy of the radiation model can be estimated in a variety of ways, but can ultimately be determined only by comparison with observations. The precision of the model (e.g., the ability to correctly calculate the *change* in the downward thermal radiation when the amount of CO_2 in the column is increased) is much better, typically hundredths of a percent, and is due only to the small uncertainties in the basic physics of the radiation model.

to very long (millennia and beyond). During the present interglacial period (the past 10,000 years) but prior to the industrial revolution, the carbon content of the atmosphere (primarily as carbon dioxide) was approximately constant at about 280 parts per million by volume (ppmv).[3] This concentration was maintained for more than 10,000 years by a balance between increases due to volcanic out gassing and decreases due to biological activity, primarily the formation of calcium carbonate shells by small ocean animals. When additional carbon dioxide is added to the atmosphere, roughly half of it dissolves into the upper layer of the ocean on the time scale of a few years. This process creates carbonic acid in the ocean and leads to an increasing acidification of the upper 100 meters (about 300 feet) of the ocean. (The harmful impacts of this acidification on ocean life are discussed briefly at the end of this section.) The remaining carbon dioxide stays in the atmosphere for periods ranging from many decades to millennia.

Atmospheric water vapor concentrations are strictly controlled by temperature. Think of a parcel of air as in a balloon (but without the actual balloon membrane) containing some amount of water vapor. If we slowly cool the parcel, condensation will occur at some point, and the water vapor will be converted to liquid water (or possibly ice). This occurs regularly in the atmosphere and produces clouds and, sometimes, precipitation, because air parcels cool as they rise in the atmosphere. The point at which condensation occurs is known as the dewpoint temperature; the dewpoint is only a function of temperature and can be predicted very accurately.[4] Consequently, the atmosphere cannot hold an unlimited amount of water vapor because the water vapor concentration is controlled by atmospheric temperature. Since the ocean provides an unlimited source of water vapor for the atmosphere, one can see that, on a global average, the amount of water vapor in the atmosphere is held constant by an equilibrium between evaporation from the ocean (and from the land surface, to a lesser extent) and condensation and precipitation.

Since the maximum amount of water that can be held in an air parcel increases with temperature, the amount of water vapor in the atmosphere will increase if the average atmospheric temperature increases. But, since water vapor is a greenhouse gas, adding water vapor to the atmosphere increases the absorption and emission of thermal radiation by the atmosphere, which increases the downward thermal radiation from the atmosphere and further warms the earth surface. This process is called a *positive feedback*, *positive* in the sense that the initial direction of change (warming of the surface and atmosphere) is further enhanced by the initial change itself, and *feedback* in the sense that the initial response (more water vapor) actually drives a larger change.

The role of carbon dioxide as the regulator of earth climate therefore becomes clear. When carbon dioxide is added to the atmosphere, some fraction of that increase remains in the atmosphere from decades to centuries.

[3] 1 ppmv of carbon dioxide means that there is one molecule of carbon dioxide in a million molecules of dry air.

[4] Dewpoint temperature, the temperature at which condensation occurs, can be calculated from the Clausius-Clapeyron equation with great accuracy. This relationship was deduced in the early 1800s and can be derived from the equations of moist thermodynamics.

Because carbon dioxide is a greenhouse gas, the surface warms. Because the surface warms, the atmosphere warms as well, and more water vapor is added to the atmosphere. Because water vapor is a more efficient greenhouse gas than carbon dioxide, the surface warms further, warming the atmosphere still more, allowing more water vapor to be added to the atmosphere. This process of positive water vapor feedback amplifies the initial change due to carbon dioxide. However, the carbon dioxide itself is the regulator because of its long lifetime in the atmosphere.

Two additional subjects need to be addressed. The first is the annual biological cycle of carbon dioxide. Each year, earth's vegetation "breathes" carbon dioxide in during the summer growing season and releases it to the atmosphere by plant respiration and material decay during the full year. Because most of the earth's land mass and forests are in the northern hemisphere, there is an observable annual cycle in carbon dioxide concentrations, with a minimum in the northern hemisphere summer and a maximum in its winter. This annual change in carbon dioxide is actually quite large but is a process in which the amount of carbon dioxide "breathed" in during the summer is very nearly the same amount "breathed" out in the winter, because the amount of vegetation is very nearly the same from year to year. However, deforestation in the tropics in recent years has partially upset the balance, leading to a small overall increase in atmospheric carbon dioxide concentrations.

The second subject is clouds and cloud feedback. As air parcels rise in the atmosphere, they cool until condensation occurs, at which point liquid water condenses onto small particles that are always present in the atmosphere. Small water droplets coalesce into larger droplets, which eventually become large enough to become rain drops. Cloud processes are far more complex than what is described in these few sentences; nonetheless, a great deal is known about cloud properties and the processes that form them. From a climate perspective, the problem is that many cloud processes occur on very small spatial scales (micrometers, or tiny fractions of an inch) so, although they can be understood at this small scale and models of individual clouds can be created, it is not possible to model all cloud processes on a global scale. Thus, a detailed knowledge of how clouds will respond to a warmer world is uncertain.[5]

However, some clear statements about global cloud response can be made. A warmer atmosphere with more water vapor is not necessarily an atmosphere with more clouds because cloud formation depends on air motions and relative humidity,[6] not on the actual water vapor concentration. So, why do we care if there are more or fewer clouds in a warmer world? Clouds both cool and warm the atmosphere simultaneously. They cool by reflecting solar radiation and they warm by absorbing thermal infrared radiation radiated from the surface of the earth, thereby adding to the atmospheric greenhouse effect (Fig. 1). If cloud properties change in a warmer world, then the question is, Will they change to produce a net negative feedback

[5] "Uncertain" does not mean "unknown" but, rather, "known with less certainty." See discussion below.

[6] Relative humidity is the ratio of the actual water vapor concentration to the water vapor concentration required for saturation (at which point condensation occurs). Since the saturation vapor pressure increases with temperature, warming an air parcel actually lowers its relative humidity, all other things being equal.

(more reflection than absorption) or a net positive feedback (more absorption than reflection)? Answering this question is complicated and can only be determined using global climate models, because there are no data that provide a definitive answer.[7] The consistent answer from a variety of modeling studies is that cloudiness increases slightly in a warmer world but, more significantly, the changes in cloud properties produce a positive feedback, further warming an already warmer world. The uncertainty about cloud response to a warmer world is the leading cause of differences among model projections of future earth temperature.

Much more can be said about the current understanding of climate and the role that the greenhouse effect plays in maintaining earth's climate. Detailed discussions are available in the references cited at the end of this appendix for readers who may wish to pursue the topic in more detail.

B. Greenhouse gas concentrations over time

Human activity is increasing the atmospheric concentration of carbon dioxide and many other greenhouse gases, such as methane, nitrous oxide, and chlorofluorocarbons (CFCs). All these gases have similar effects on thermal infrared radiation and the greenhouse effect, but they play a lesser role than carbon dioxide, so our discussion here focuses only on carbon dioxide. Detailed discussions of the life cycle and concentrations of these other gases can be found in the 2007 IPCC report.

In 1957 Charles David Keeling began making measurements of atmospheric carbon dioxide concentrations at an observatory located at about 12,000 feet above sea level on Mauna Loa on the island of Hawaii. Keeling chose the Mauna Loa observatory because of its elevation and lack of any significant local sources of carbon dioxide at that altitude.[8] These measurements, which are continued to the current day by the National Oceanographic and Atmospheric Administration (NOAA), are shown in Fig. 2. The two obvious features are the annual cycle produced by the "breathing" of the biosphere, discussed earlier, and the consistent upward trend of the record. The values measured at the start of the record in 1957 were about 315 ppmv, while the most recent measurements are nearing 390 ppmv. Similar records, but shorter in time, are available from a worldwide set of sites ranging from Pt. Barrow, Alaska, to American Samoa to the South Pole. All records show the same consistent increase in carbon dioxide concentration, but with differing annual cycles, depending on location.

[7] Directly observing climate feedbacks requires watching (i.e., collecting useful data on) the climate system for a sufficiently long period that both the changing conditions (increasing CO_2 concentrations) and the response (changes in cloud properties) can be seen unambiguously. Global cloud records of sufficient accuracy only exist for about the past decade, and the natural climate variability in the earth system is too large for the response to be measured over such a short time. One can try to estimate cloud feedbacks from the response of clouds to internal variability (such as the annual cycle of warming and cooling), but this approach is fraught with difficulty because system responses to internal variability are not the same as responses to external variability. This is an area of current research and discussion within the scientific community.

[8] Some may find this confusing because Mauna Loa is an active volcano, and active volcanoes emit carbon dioxide. The vents on Mauna Loa, however, are on the lower flanks of the volcano, far below the observatory. Care is taken to avoid contamination of the measurements by up-slope winds that might carry natural or local human emissions of carbon dioxide.

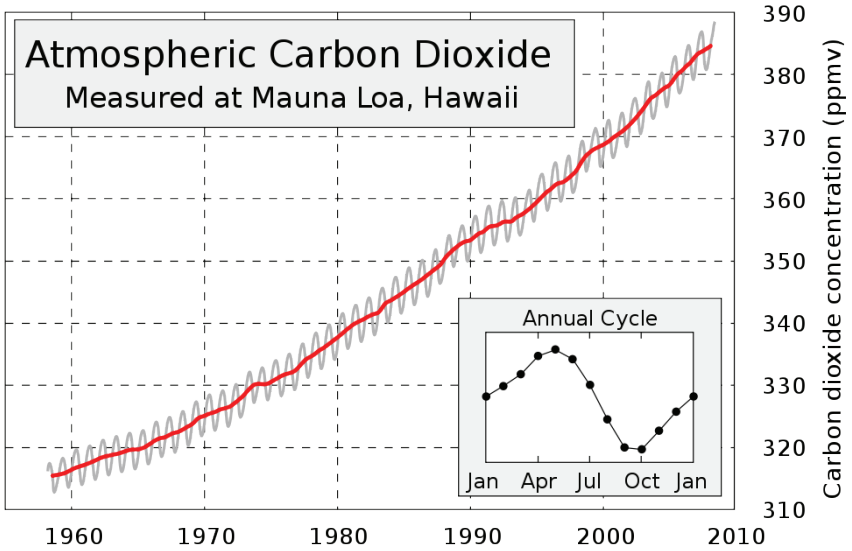

Figure 2. Measurements of atmospheric carbon dioxide taken at Mauna Loa Observatory since 1957. This measurement series was begun by David Keeling and continued to the present day by NOAA. Data may be obtained at http://www.esrl.noaa.gov/gmd/ccgg/trends/. The figure is taken from the Wikipedia Commons.

A longer trend of carbon dioxide concentration can be obtained by extracting ice cores from glaciers on Greenland and Antarctica and measuring the carbon dioxide concentration in air bubbles trapped in the ice. The ice core can be dated exactly over the past few millennia by counting annual layers (much like tree rings) and by other means. Because carbon dioxide and nitrogen molecules are large relative to the crystal dimensions of ice, they cannot escape, meaning that their concentration is unchanged with time. Data for the last millennia (Fig. 3) show that carbon dioxide concentrations were constant at about 280-285 ppmv until about 1850, which is approximately the start of the industrial revolution. The annual rate of change has steadily increased since that time, which simply means that, each year, the change in carbon dioxide ppmv is greater than that of the year before.

The data suggest that the increase in carbon dioxide concentrations is associated with human activity. But can that be proven? Chemically, all carbon-based fuels are made up of some combination of carbon and hydrogen, as well as, in some cases, oxygen. When burned in the presence of oxygen, the chemical end product of carbon-based fuel combustion is water vapor and carbon dioxide. Gas, oil, and coal producers keep very accurate records of fuel production and usage. Thus, one can make an accurate calculation of the carbon dioxide produced by combustion and how that production would alter observed atmospheric concentrations over time.

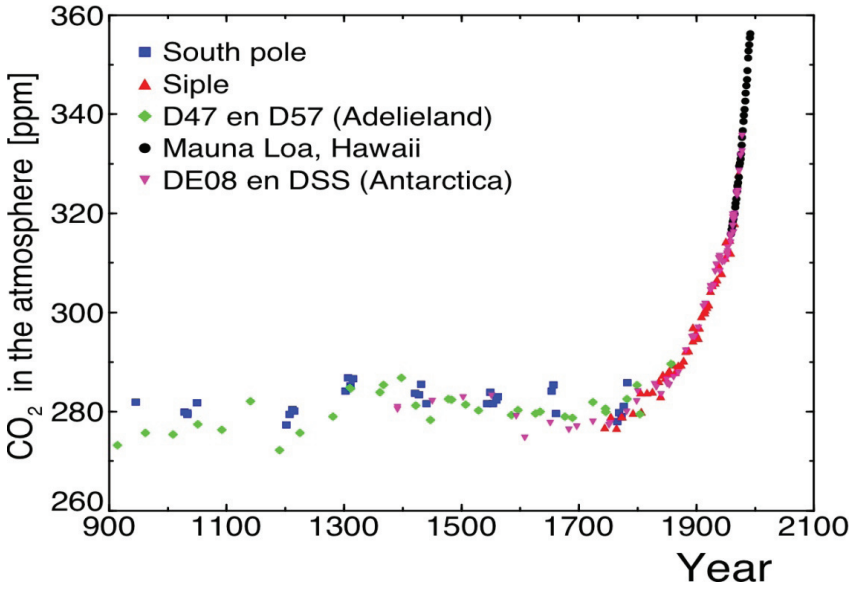

Figure 3. Atmospheric carbon dioxide concentrations obtained from ice core measurements taken in Antarctica. Ice core data are available from a number of locations, such as http://www.ncdc.noaa.gov/paleo/icecore.html.

Fig. 4 illustrates the fluxes of carbon into and out of the atmosphere. The two primary sources are emission from fuel combustion and from land-use changes, the latter being essentially the burning of forests. The sinks are atmospheric storage (increasing carbon dioxide concentrations in the atmosphere), solution in the ocean, and storage in the biomass. It is interesting to note that the land-use source and the land storage terms are comparable and, over the past decade, the latter is twice the former. The land storage term is the most uncertain term in the budget. It represents carbon stored in standing biomass, including root systems (e.g., trees), and stored as organic carbon in soils. While tropical biomass burning has introduced carbon into the atmosphere, regrowth of forests in North America, particularly in suburban areas and areas once logged for fuel, has removed carbon at a nearly comparable rate.

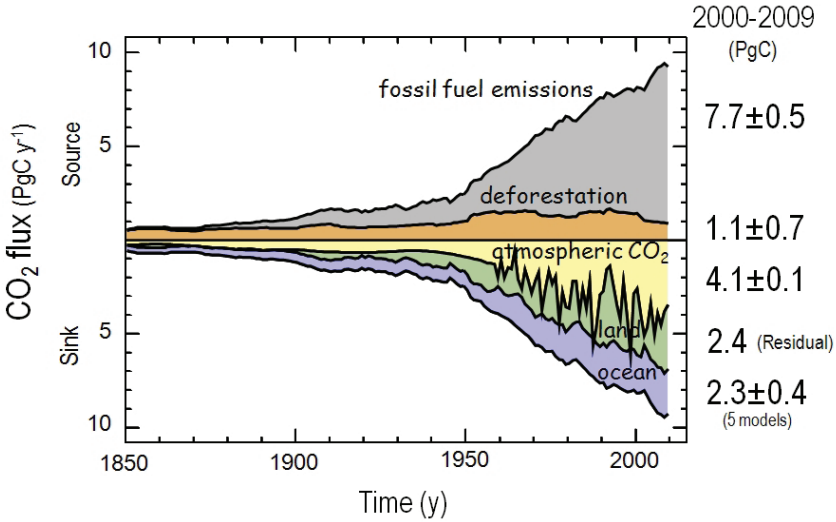

Figure 4. Carbon dioxide fluxes into (source terms) and out of (sink terms) the atmosphere for the past 150 years. Units are petagrams of carbon per year. (See Glossary for definitions.) Budget data are supplied as follows:

Atmospheric CO_2: Data from the U.S. National Oceanic and Atmospheric Administration Earth System Research Laboratory. Accumulation of atmospheric CO_2 is the most accurately measured quantity in the global carbon budget, with an uncertainty of about 4 percent.

Emissions from CO_2 fossil fuel: CO_2 emissions from fossil fuel and other industrial processes are calculated by the Carbon Dioxide Information Analysis Center of the U.S. Oak Ridge National Laboratory. For the period 1958 to 2007 the calculations were based on United Nations Energy Statistics and cement data from the U.S. Geological Survey, and for the years 2008 and 2009 the calculations were based on BP energy data. Uncertainty of the global fossil fuel CO_2 emissions estimate is about ±6 percent (currently ±0.5 PgC). Uncertainty of emissions from individual countries can be several-fold bigger.

Emissions from land-use change: CO_2 emissions from land-use change are calculated by using a bookkeeping method with the revised data on land-use change from the Food and Agriculture Organization of the United Nationals Global Forest Resource Assessment 2010. Uncertainty on this flux is the highest of all budget components.

Ocean CO_2 sink: The global ocean sink is estimated using an ensemble of five process ocean models. Models are forced with meteorological data from the U.S. national Centers for Environmental Prediction and atmospheric CO_2 concentration. Current uncertainty is about 0.4 PgC y-1.

Land CO_2 sink: The terrestrial sink is estimated as the residual from the sum of all sources minus the ocean+atmosphere sink. The sink can also be estimated using terrestrial biogeochemical models as in previous carbon budget updates.

More information on data sources, uncertainty, and methods is available at http://lgmacweb.env.uea.ac.uk/lequere/co2/carbon_budget.htm. Figure from the Global Carbon Budget, http://www.globalcarbonproject.org/carbonbudget/.

Over the past decade, the average emission into the atmosphere from burning carbon based fuels was 7.7 Pg of carbon[9] per year. This is a very large amount of carbon; it is perhaps helpful to understand that burning 1 U.S. gallon of gasoline produces about 5.3 lbs. (2.4 kg) of carbon in the form of carbon dioxide. An additional 1.1 Pg of carbon was added to the atmosphere by land-use changes. The observed increase in atmospheric carbon dioxide averaged over the decade from 2000 to 2009 is about 1.9 ppmv per year, which is about half of what would be expected from the source terms in Fig. 4. Thus, about 50 percent of the carbon dioxide produced by human activity is now in the atmosphere. The remainder of the emitted carbon dioxide is either dissolved in the surface ocean layer or taken up by the biosphere.

The final piece of the argument is based on carbon isotopes. Carbon in our atmosphere exists as ^{12}C, ^{13}C, or ^{14}C. (The small numbers indicate the atomic weight of a carbon atom, the sum of its protons [6] and neutrons [the remainder, either 6, 7, or 8].) The vast majority of atmospheric carbon (about 99%) is the stable isotope ^{12}C, with most of the remaining 1 percent being ^{13}C. ^{14}C is a naturally occurring radioactive form of carbon produced by cosmic ray radiation in our atmosphere. Its concentration is very small, about 1 out of a trillion carbon atoms in the atmosphere, and it decays with a half-life of about 5,700 years.[10]

Plants have a preference for using lighter isotopes of carbon, so the ratio of ^{13}C to ^{12}C is lower in plants than in the atmosphere. Fuels derived from coal, oil, and natural gas have a reduced $^{13}C/^{12}C$ ratio as well. Measurements of the atmospheric $^{13}C/^{12}C$ ratio show that it begins to decrease at the same time that the overall concentration of atmospheric carbon dioxide begins to increase—at the beginning of the industrial revolution. Thus the source of the increasing carbon dioxide must be relatively lacking in ^{13}C and therefore must have come from the fuels we have burned.

A similar story comes from measurements of the $^{14}C/^{12}C$ ratio. Carbon-based fuels buried in the earth are devoid of ^{14}C. Measurements of the $^{14}C/^{12}C$ ratio show that it is also decreasing with time, indicating that the source of the increasing carbon dioxide must be lacking in ^{14}C. The only possible explanation is that this carbon dioxide comes almost entirely from burning carbon based fuels. The conclusion, therefore, is that human activity,

[9] A petagram (Pg) is 10^{15} grams or 1 billion metric tons. Carbon budgets such as shown in Fig. 4 typically refer to the amount of carbon by mass rather than the mass of carbon compounds. Since carbon has an atomic mass of 12 and oxygen has an atomic mass of 16, the ratio of mass of carbon to mass of carbon dioxide is 12 / (12 + 16 + 16) = 12 / 44 = 0.27. Thus, the 7.7 Pg of carbon emission corresponds to 28 Pg of carbon dioxide in the atmosphere.

[10] Half-life measures the rate of radioactive decay of a collection of radioactive atoms. If one starts with 100 radioactive molecules of ^{14}C, in about 5,700 years, 68 of them will have "decayed" (e.g., emitted a pair of neutrons) and become ^{12}C atoms. In another 5,700 years, 68 percent of the remaining 32 will have decayed, etc. This rate of decay can be measured very accurately and is statistically certain.

principally the burning of carbon based fuels, is responsible for the bulk of the increasing carbon dioxide concentration in the atmosphere.

C. Earth climate variability

Discussions of earth's climate variability over time usually focus on surface air temperature (typically defined by meteorologists as the air temperature measured 4-6 feet above the earth surface) because long-term measurements are only available at the surface. Climate scientists consider the recent temperature record on three different timescales, the modern era of the past 50 years or so, the period of the past 150 years for which a measure of global temperature can be computed from thermometer measurements, and the past millennia or two during which temperature can be determined from proxy measurements—measurements of other variables that are related to temperature. From roughly 1950 to the present, a variety of measurements in the atmosphere are available, first from balloon-borne instruments (which are still released twice daily all around the globe), then aircraft, and now satellites, that allow atmospheric scientists to construct the state of the atmosphere in three dimensions as a function of time. The quality and quantity of the data record, and hence the understanding of the atmosphere, has increased dramatically during this period but especially in the past two decades.

Sometime in the late 1800s, sufficient surface temperature measurements both on land and by ship became available to make it possible to construct an average global surface temperature record. Constructing this record requires a considerable amount of research because the measurements are not uniform in accuracy and are not uniformly distributed around the world. Several different research groups have ongoing research programs to construct this long-term record and provide independent checks on the overall record. The record developed by the Hadley Centre, a component of the British Meteorological Service, is shown in Fig. 5. The vertical axis in the figure represents the temperature anomaly[11] (difference) with respect to a 30-year average from 1961-1990. Each red bar marks the difference between the annual average temperature for that year and the 30-year average. The range (maximum minus minimum) of anomaly values is 0.8° to 1.0° C (about 1.5° to 2° F). While this may seem like a small value, it is large in climate terms. The change in global surface temperature from the end of the last ice age (about 20,000 years ago) and the current interglacial period is between about 5° and 8° C, so a change of 0.8° to 1.0° C in 100 years is a significant amount.

[11] *Anomaly* is a term regularly used by earth scientists to refer to the difference between some particular measurement and some long-term average of that quantity. Thus, an annual "temperature anomaly" is the difference between the annual average temperature and the temperature averaged over a longer period. For historical reasons, this longer period is conventionally taken to be a 30-year interval from 1961 to 1990.

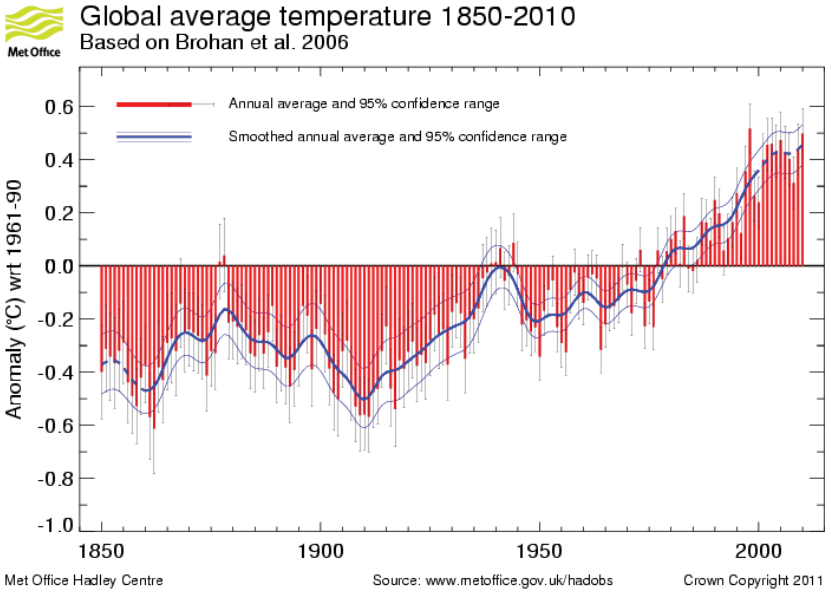

Figure 5. Global average surface temperature constructed by the Hadley Centre. The red bars represent annual average surface temperatures, and the gray extensions denote the 95 percent confidence level of the data. The dark blue line is a smoothed curve based on a running mean of between 1 and 2 decades. The light blue lines indicate the 95 percent confidence level of the smoothed data. "95 percent confidence" means that based on statistical tests, there is a 95 percent chance that the actual value of the temperature lies with the error bars and a 5 percent chance that it is either higher or lower. Typically as one averages longer periods, the confidence goes up and the error bars are reduced in size. The dotted portions at each end of the blue curve indicate that the smoothing curve is influenced by the treatment of the end-points. Additional information and figures can be found at http://www.metoffice.gov.uk/hadobs/hadcrut3/diagnostics/comparison.html.

Over the past 1,500 to 2,000 years, temperature variability can be derived from proxy records. Proxies are measurements of some quantity that is proportional to temperature and is recorded in biological systems (e.g., tree rings), physical systems (e.g., oxygen isotopes in ice cores or bore holes in the earth crust), or mixed systems (e.g., pollen deposition in lake sediments). Converting these proxy measurements to equivalent temperature is challenging but can be done with careful research and comparison among proxies. A variety of proxy records have been developed in recent years and show comparable changes during the past 1,000 to 2,000 years.

A graphical summary of most of the available proxy data is provided in Fig. 6, a very complex diagram. The curves in this figure are based on a database of 1,209 proxy series which come from tree rings, marine sediments, stalagmites in caves (speleothems), lake sediments, ice cores, corals,

bore holes, glacier extent, and historical documentary series.[12] The curves are constructed from multiple proxy series using a variety of statistical methods. The references for the various curves in the figure are not given here but are available in the paper by Mann, et al.

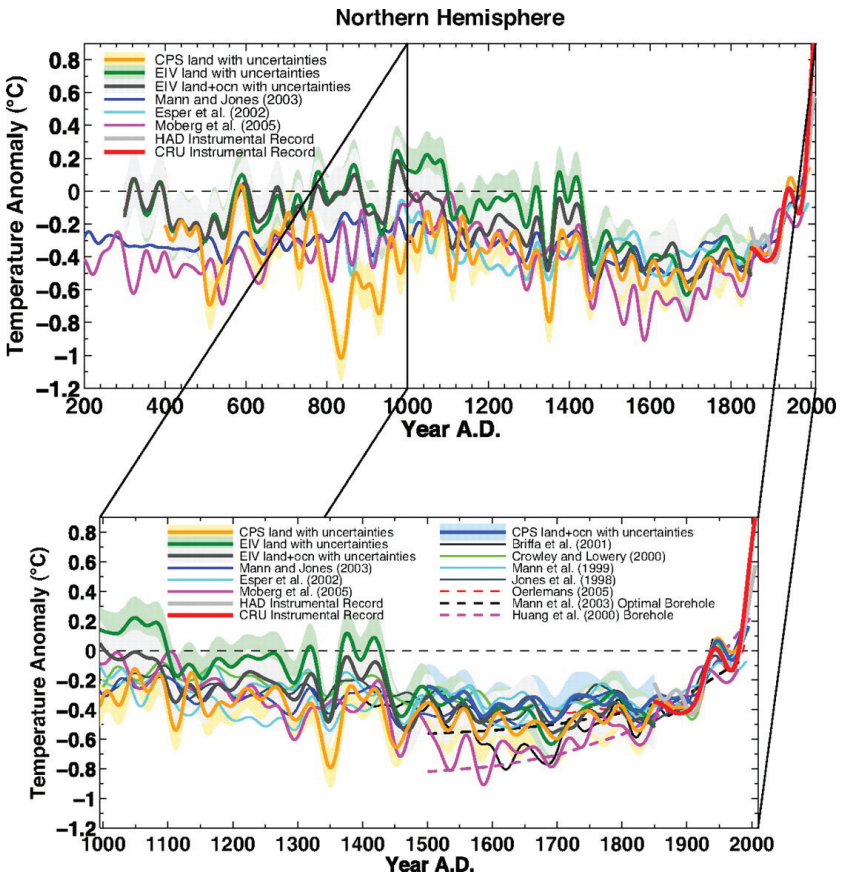

Figure 6. Temperature anomaly curves for the past 1,800 years (upper) and past 1,000 years (lower) based on proxy series from multiple sources. The shadings represent 95 percent confidence levels. The figure is from Mann, et al. (see footnote), and the references cited in the figure are given there. The instrument records (same as in Fig. 5) are shown in red and gray at the latter end of the curve. All curves have been smoothed using a 40-year period.

[12] Mann, M. E., Z. Zhang, M. K. Hughes, R. S. Bradley, S. K. Miller, S. Rutherford, and F. Ni, 2008: Proxy-based reconstructions of hemispheric and global surface temperature variations over the past two millennia, Proceedings of the National Academy of Sciences, pp. 13252–57.

Several inferences can be drawn from these figures. As seen in Fig. 5, temperature varies a great deal from one year to the next. Even the smoothed curve shows variability on time scales of a decade or so, with extended periods of temperature increase and others of relatively little change. On the longer time period (Fig. 6), there is again a great deal of variability, and the different proxies do not always vary in the same way. Despite this variability, however, Fig. 5 shows that surface temperature has warmed considerably in the past 40 years compared to the previous 100 years; Fig. 6 suggests that it is now significantly warmer than at any time in the preceding 1,000 years.

The two figures also show that climate change cannot be assessed using short period records. Some have argued that surface temperature has been constant in the past 10 years. If one looked only at the past 10 years, one might be tempted to agree. Looking at the longer period record, however, indicates that the temperatures in the past few years have been on a small plateau, similar to others that have occurred in the past, but that the longer-term trend continues upward.

Fig. 6 (or similar plots) has generated a great deal of confusion in the past few years, much of it due to a lack of clarity in understanding and interpretation. One should not read too much into the details of proxy records; they generally show relative change, not absolute change. The long-term variations that produced a warming around 1,000 A.D. and a cooling period around 1,500 A.D. are not well understood in terms of causation but are most probably due to variations in the amount of solar radiation reaching earth and, possibly, variations in volcanic activity. Lacking measurements of both long-term solar variations and atmospheric particles and lacking a well-understood mechanism make it difficult to provide a completely satisfactory explanation of these longer term features. The global extent of such features is also difficult to determine because proxy records are principally available in the northern mid and polar latitudes and on land; very few records are available in the tropics and in the southern hemisphere. As a result, proxy temperature changes may be exaggerated because they are only regional in extent. Thus there is considerable uncertainty about global temperatures over the past two thousand years, but the available evidence indicates that current global temperatures are higher now than they have been at any time during this period.

Evidence for a warming climate is not limited to temperature and temperature proxy measurements. There is a wide range of additional scientific evidence, as well as correlative evidence from natural systems. Perhaps the most dramatic evidence for a warming climate comes from measurements of Arctic sea ice extent. Satellite measurements have been used to track the September minimum ice extent in the Arctic since 1979 (Fig. 7).[13] Sea ice extent has decreased steadily, reaching an all-time minimum in 2007. It recovered somewhat in 2009 but reached a near-record low again in 2011. Sea ice extent is an integrator of many factors, including atmospheric and oceanic temperature and circulations. The approximately 40 percent decrease in minimum sea ice extent since 1979 is strongly indicative of an overall polar warming.

[13] National Snow and Ice Data Center, Boulder, Colo., http://nsidc.org/arcticseaicenews/.

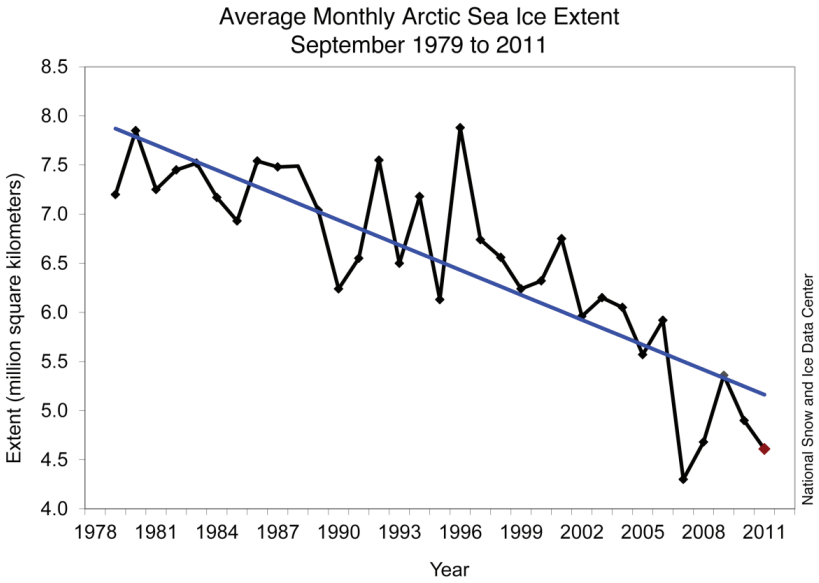

Figure 7. Monthly September ice extent for 1979 to 2011 measured by satellite. The data show a decline of 12.0% per decade.

The National Climate Data Center cites evidence of warming from sea level rise, global ocean heat content, decreasing snow cover in the northern hemisphere, and shrinking glacier volume.[14] Sea level has been rising slowly since measurements began in the late 1800s, but it has accelerated in recent years. Current rates of rise are small (3.5 mm/year, or about 1/8 inch/year) but are expected to increase as the ocean warms. The heat content of the upper ocean provides a way to measure its average temperature. The heat content has increased steadily since the mid-1980s, although it has been on somewhat of a plateau for the past five years. The rise in heat content is consistent with increasing sea level rise.

Ecological systems provide another way of identifying a warming climate. The observed behavior of these natural systems is important because they integrate multiple climate parameters into a single observable result. For many of us, these natural systems are easier to understand and are more compelling than the results of complex climate models which by their nature include assumptions and complicated calculations.

There are many examples of ecological change that have been observed in the past 50 to 100 years. Many of the records come from amateur enthusiasts who record bird and butterfly migration patterns, the time of spring flowering for plants, or the appearance of new species. Other studies relate to the appearance of warm-water fish species at more northerly latitudes along the Pacific Coast and the poleward migration of mammals. Another evidence of change is the upward migration of plant and animal communities in alpine areas.

[14] NOAA National Climate Data Center, Asheville, N.C., http://www.ncdc.noaa.gov/indicators/.

Summaries of these changes can be found in review articles,[15] and we summarize a few here. Spring arrival of migratory birds in Europe and North America has advanced by 1 to 5 days per decade over the past 30 to 50 years. During the same period, plants are flowering and unfolding leaves earlier at a rate of 1.5 to 3 days per decade. Alpine vegetation is moving upward in the Alps at approximately 1 to 4 meters (3 to 12 feet) per decade. Although any one of these indicators may not be conclusive, they collectively testify to an earth climate that has warmed significantly over the past 40 years.

D. The causes of climate variability and change

It is useful to consider earth climate records in terms of climate variability and climate change. Climate variability, the short-period oscillating behavior seen in climate records, is principally the result of internal interactions in the climate system that occur because the physical links between ocean, atmosphere, and ice sheets are complex and happen at different timescales. This internal variability is largely unpredictable on a year to year basis (at least at present), but analyzing past variations provides estimates of the expected magnitude and frequency of the variations. Trends or changes in climate cannot be detected using short-term measurements but must be considered on longer time scales (typically more than a decade) because of this internal variability. It is incorrect to argue that a very warm year such as 1998 demonstrates global warming is occurring; it is equally incorrect to argue that a relatively cool year such as 2008 demonstrates that it is not occurring.

Some climate variability can occur due to external forces on the climate system, some of which are episodic and some of which are oscillatory. Volcanic eruptions produce episodic change. Mount Pinatubo erupted in the Philippine Islands in 1991, and the resulting cloud of volcanic particles produced a noticeable cooling of the earth surface in the following two years. When the particles disappeared after a couple of years, the surface temperature recovered quickly to pre-eruption levels. This response is typical of volcanic eruptions and is predictable given knowledge of the time and size of an eruption. Solar radiation varies very slightly in intensity on an 11-year cycle driven by internal behavior of the sun and drives small oscillations in climate (see discussion below).

Climate change is the climate response to changes in external forces on the earth system that occur on timescales that are longer than decades. For the time period of a century to a millennium, there are only a handful of potential causes of climate change: (1) solar variability, (2) atmospheric particles or aerosol, and (3) greenhouse gases. Climate scientists have considered these forcings in great detail and conclude that all three play a role in understanding climate change on this timescale.

It is important in this context to distinguish between *climate forcing* and *climate feedbacks*. *Climate forcing* refers to a process that affects the long-term radiation balance of the planet, but the forcing agent is somewhat isolated

[15] See, for example, G. Walther, E. Post, P. Convey, A. Menzel, C. Parmesank, T.J.C. Beebee, J.M. Fromentin, O. Hoegh-Guldberg, and F. Bairlein, 2002: "Ecological responses to recent climate change," *Nature*, vol. 416, p. 389; available at http://eebweb.arizona.edu/courses/Ecol206/Walther%20et%20al%20Nature%202002.pdf. This article summarizes numerous studies and contains a reference list of over 90 articles on the subject.

from the climate system itself. This is easy to understand in the case of the sun, where changes in the solar output are not affected in any way by earth climate. It is a little harder to understand in the case of a greenhouse gas like carbon dioxide. An increase in the atmospheric carbon dioxide concentration is essentially unaffected by any climate change that it may force, because carbon dioxide remains in the atmosphere for long periods of many decades to centuries and millennia. This statement is not correct, however, for changes on much longer periods because carbon dioxide can be removed from (or added to) the atmosphere by geological activity on timescales of tens and hundreds of thousands of years. *Climate feedbacks* are responses within the climate system to external forces that in turn affect climate. For example, a warming climate will increase the melt rate of snow and ice sheets, which makes earth less reflective and more absorbing, thus amplifying the original warming. A feedback process requires an initial push to the system, however, from an external forcing, and then it responds to that push.

The fundamental driver of earth climate (or the climate of any planet) is the absorption of incoming solar radiation, which is in turn a function of the amount of solar radiation reaching the planet. Thus, it is logical to assume that variations in the solar energy reaching earth may be responsible for recent variations in earth climate. Solar energy emitted by the sun varies in two ways. There is an 11-year cycle associated with magnetic field activity and sunspot movement on the surface of the sun, and there are longer term aperiodic fluctuations that modulate the actual number of sunspots at any given time. Specific measurements of the solar radiation reaching earth are only available since the advent of satellites in the late 1970s. Prior to that, solar radiation variations can only be estimated by counting sunspots and correlating that number with expected variations in solar energy. The satellite measurements of solar variability show that the solar energy varies by only 0.1 percent during an 11-year cycle.

Trends in sunspot number, carbon dioxide concentration, and surface temperature are shown in Fig. 8. Some fraction of the warming between 1910 and 1940 is likely related to an increase in solar irradiance associated with the increased number of sun spots. The fact that solar irradiance continued to increase (based on sunspot correlation) until 1960, while temperatures decreased slightly, and then solar irradiance decreased from 1960 to the present, while temperatures increase substantially, indicates that surface temperature is not driven by solar irradiance alone. Satellite measurements of total solar irradiance at the top of the atmosphere confirm that total solar irradiance has decreased during the period from 1970 to the present, while it has oscillated during the sun spot cycle with a variation in received energy of about 0.1 percent. Calculations show that the time lag (the amount of time between a variation in solar heating and a corresponding change in earth temperature) in heating due to these small variations is less than a decade. Hence, solar variability cannot account for the temperature rise since 1960.

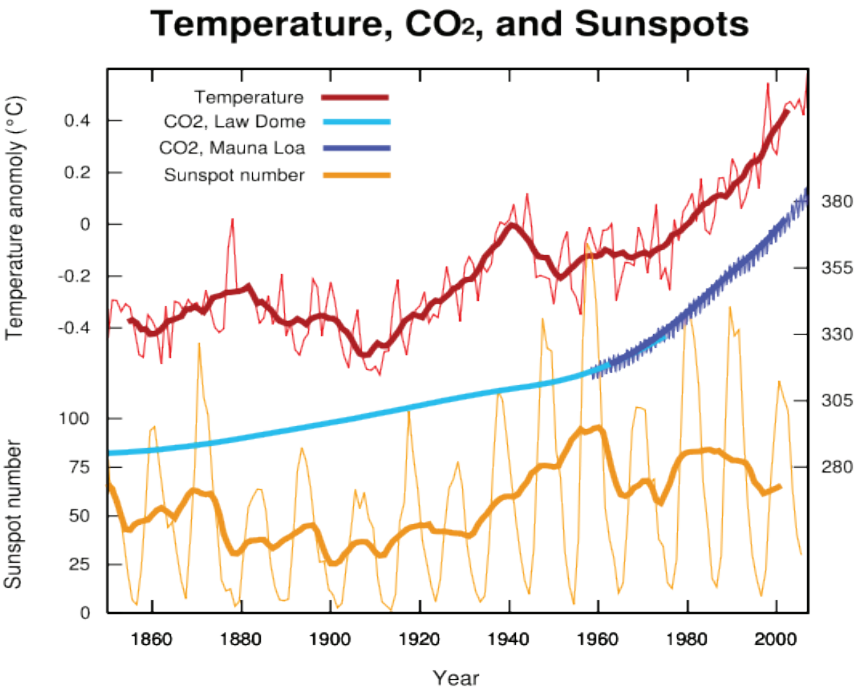

Figure 8. Variations in earth surface temperature (red lines), atmospheric carbon dioxide concentration (blue lines), and sunspot number (gold lines). The thin red and gold lines show annual averages, while the thicker lines are decadal moving averages. The 11-year sunspot cycle is clearly evident in the thin gold line. Plot taken from the Stanford Solar Observatory, Stanford University.

Atmospheric particles result from both natural and human causes. Natural causes include catastrophic events like volcanic eruptions, as well as more routine events such as dust storms and sea spray and certain types of biological emissions. Human causes are primarily related to combustion and industrial processes. Biomass burning, whether natural or human caused, is also a major contributor. Reliable records of particle amount in the global atmosphere are available since the advent of satellite measurements in the mid-1970s. Prior to that, global estimates can be constructed from a variety of ground-based measurements made by astronomers and atmospheric scientists and by estimates of production by industrialization and burning. Since particles have a relatively short residence in the atmosphere, typically a few days to a month in the lower atmosphere and a year or two in the stratosphere, estimates of production can be used to estimate concentrations as well. As a general rule, an increasing number of particles leads to a cooling of the climate system because the particles reflect solar energy back to space.

Particle concentrations, particularly in the northern hemisphere, increased following World War II due to rapid industrialization of North America and the rebuilding of Europe and Japan. Air quality concerns in the 1960s and 1970s led to regulations on vehicle emissions and industrial plants that

reduced particle concentrations thereafter. Satellite measurements show no trend in global particle concentrations since 1980 and very little variation other than the spike associated with the eruption of Mt. Pinatubo in the Philippine Islands in 1991 (see Fig. 9).

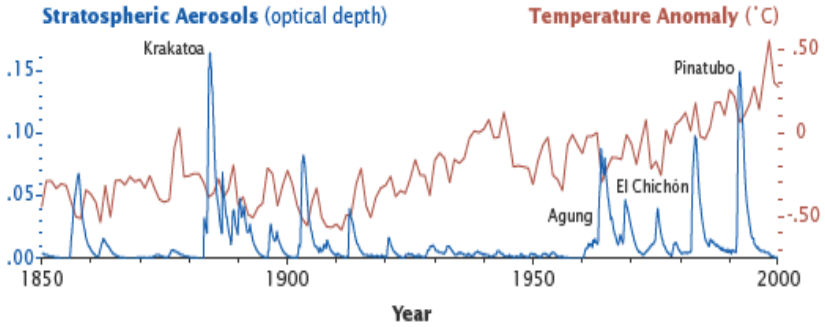

Figure 9. The optical depth of stratospheric aerosol (particles) and the global temperature anomaly as a function of time from 1850 to the present. Optical depth is a measure of the amount of aerosol expressed in terms of its potential to scatter sunlight. A greater optical depth means a greater ability to reflect sunlight and cool the earth. The record since 1950 identifies several known volcanic eruptions but no long-term trends. The global temperature tends to decrease after each eruption and then recover to pre-eruption level in a year or two. Data are from http://earthobservatory.nasa.gov/Features/Aerosols/page3.php, which includes a more detailed discussion of aerosol effects.

As seen in Fig. 2, carbon dioxide concentrations have been increasing since the mid-1800s with an accelerating rate of increase in the past several decades. The concentrations of other greenhouse gases are also increasing. These increasing concentrations lead to an increasing thermal opacity of the atmosphere, with a corresponding increase in absorption of thermal radiation emitted from the earth surface and increased thermal emission by the atmosphere, resulting in a warmer surface. The physics of this process is well understood and measured. The surface warming that has occurred since about 1960 matches well with the observed rise in the concentration of carbon dioxide and other related gases, leading to the conclusion that the most likely cause of recent warming is greenhouse gas forcing. Additional support for this conclusion comes from climate modeling, which is discussed below.

E. Climate change on short geologic timescales

Ice cores from Antarctica can be used to infer the climate of earth for at least the past 800,000 years, using their long record of measurements of carbon dioxide concentrations and temperature variations, the latter based on oxygen isotopes as a proxy thermometer. During this period the earth experienced ice ages with durations of about 100,000 years. The record shows long, slow temperature decreases as ice sheets grew to their maximum extent, followed by very rapid (in geological terms) warming to an interglacial period

(Fig. 10). Global temperature in the Holocene, our current interglacial period, began warming about 15,000 years ago and reached its current value about 10,000 years ago.

Temperature and carbon dioxide concentrations are obviously correlated in the long-term ice-age record (Fig. 10). In the original analyses of these records, the time resolution of the record (the shortest period of time that could be resolved in the record) was poor, and many people made the assumption that carbon dioxide changes were forcing (or *leading*) the temperature change. Better analytic methods have allowed scientists to improve the time resolution of the record, and it now appears that temperature begins to change before the carbon dioxide concentrations change. In other words, carbon dioxide changes lag *behind* temperature changes. This has led some to argue that carbon dioxide concentration changes do not cause temperature changes, which cannot be true according to the laws of physics. The explanation of the geologic record in Fig. 10 is actually much more complex and interesting than a simple lead or lag theory.

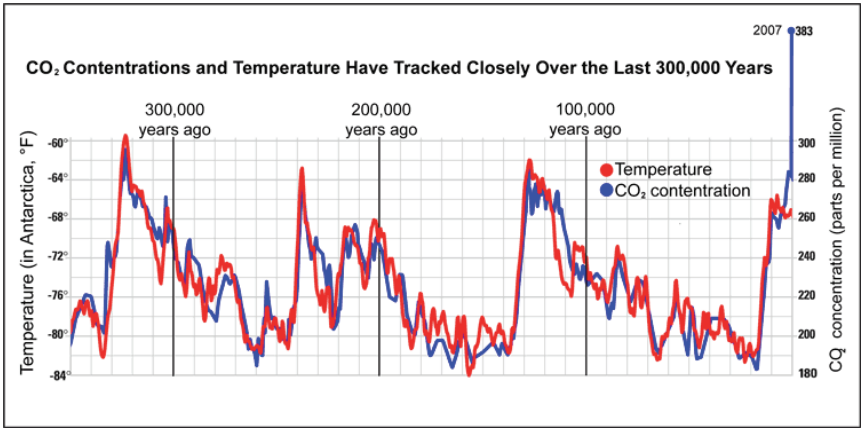

Figure 10. Carbon dioxide concentrations and temperature changes over the past 300,000 years, deduced from ice core measurements. The data show a similar relationship going back at least 800,000 years. The 2007 carbon dioxide concentration value of 383 is from current atmospheric measurements. Image is modified and courtesy of the Marian Koshland Science Museum of the National Academy of Sciences.

In earth's climate, carbon dioxide and temperature are tightly coupled due to feedback processes. The coupling occurs through a complex set of processes that include volcanism, carbon dioxide solution in the ocean, biological uptake of carbon dioxide in the ocean, and weathering. A detailed explanation of these processes is beyond the scope of this discussion, but a few summary points are helpful.

– The amount of carbon dioxide dissolved in seawater depends on the temperature; warmer water contains less carbon dioxide than colder water.

– Carbon dioxide in the atmosphere very rapidly comes into equilibrium with carbon dioxide dissolved in sea water on timescales of months to a few years.
– Annual volcanic emissions of carbon dioxide are very small and are balanced by biological uptake of carbon dioxide in the ocean via shell and coral building. These are slow processes that balance each other on long timescales of centuries to a millennium.
– Weathering of minerals is an extremely slow process that controls carbon dioxide concentrations on very long time scales of millennia to ice ages.

So what does this mean for ice ages? The best current explanation for these long-term cycles is that small changes in the orbital relationship between the earth and sun (the so-called Milankovitch cycles) produce a small warming or cooling. In the case of a small warming, the ocean warms and carbon dioxide is pushed from the ocean into the atmosphere, because carbon dioxide is less soluble in warmer water. An increase in atmospheric carbon dioxide concentrations increases the downward thermal radiation from the atmosphere, which then further warms the surface. This positive feedback is then amplified by increased water vapor concentration in the atmosphere. As the earth warms, the ice sheets begin to melt, allowing additional solar radiation to be absorbed by a now darker planetary surface. The interaction of biological processes with this physical feedback cycle is complex; the interested reader may refer to one of the introductory textbooks listed in the references for additional explanation.

The onset of an ice age is similarly related to changes in the orbit of the earth. We think that when changes in the tilt of the earth's axis coincide with its month of closest approach to the sun, which together produce cooler northern hemisphere summers, winter snow fails to melt during the cooler summers and ice sheets grow slowly across the northern land masses. The growing ice sheets reflect more sunlight, reinforcing the direction of change—cooling in this case. Cooling water dissolves more carbon dioxide, thus drawing down atmospheric concentrations and further cooling the surface. It is readily apparent in Fig. 10 that the time required to grow ice sheets is much longer than the time to melt them. This is consistent with the idea that ice sheets can only grow by the amount of snowfall in a year, but melting can occur at a much more rapid pace. It is important to note that the timescale for ice sheet melt is still long. It took between 5,000 and 10,000 years to go from the last glacial maximum (the period of greatest ice sheet extent) to the current interglacial period (the period of minimum ice sheet extent), which began about 10,000 years ago.

The recent rise in carbon dioxide concentration is depicted at the very right of Fig. 10. In the past 150 years, mostly in the past 100 years, the carbon dioxide concentration has increased by more than 100 ppmv. Coincidently, this is very similar to the range of carbon dioxide concentration variations between glacial and interglacial periods. To put this in slightly different terms, the rate of increase in carbon dioxide concentration for the past 40 years has been greater than 1.5 ppmv per year (Fig. 2); for the past 150 years, the rate of increase has been about 0.67 ppmv per year (Fig. 3). About 15,000 years ago, the carbon dioxide concentration was close to 200 ppmv, so the

rate of increase between then and 1850 (prior to the industrial revolution) was about 0.005 ppmv per year. Most of this change in carbon dioxide concentration occurred prior to 10,000 years ago, so changes over the past 10,000 years have been even smaller (on the order of only 0.002 ppmv per year). During such long periods of stability, biological feedback processes work to maintain relatively constant carbon dioxide levels.

How much can past climate relationships between temperature and carbon dioxide tell us about the response of current climate to current carbon dioxide increases? The answer, unfortunately, is not all that much. During the past ice ages, temperature changes and carbon dioxide changes occurred together, with temperature changes due to changes in earth's orbit and carbon dioxide changes in response to warming or cooling ocean water (as well as weathering, which we have not discussed). The result is that temperature change occurred first, and carbon dioxide changes amplified the temperature change. The changes occurred rapidly on geological timescales but slowly relative to human history. Today, we have introduced a new player into the climate equation—namely, the large amounts of carbon dioxide produced from the burning of carbon-based fuels. This additional carbon dioxide from combustion has overwhelmed the ability of biological and geological processes to moderate carbon dioxide concentrations. In the past 800,000 years, these processes have limited the buildup of carbon dioxide in the atmosphere to less than about 290 ppmv, but it is now above 380 ppmv and growing every year. Predicting climate and climate change over this century requires understanding the impact of this growing concentration from combustion. The lagged feedback relationship between temperature and carbon dioxide on geological timescales, while certainly of great interest to climate scientists, is largely irrelevant in the context of current climate change. Increasing carbon dioxide concentrations must act to warm the earth, as they have done in the past and are doing now. Geological processes may either moderate or enhance that warming, but only on very long timescales of millennia.

F. Projecting future climate change

One very important way that scientists try to understand complex system behavior is by constructing mathematical models of the system that can be solved by either analytical or computational means. In order to be useful, these models must (a) incorporate the important processes that control system behavior, (b) simulate the way the system currently behaves as determined from observations, and (c) predict the future behavior of the system. Weather models provide a useful example. National and international weather centers have been working on improving numerical atmospheric weather models for more than 50 years. These models continue to grow in complexity as new processes are added and the representation of existing processes is improved through greater understanding. The output of these models is compared with observations on a daily basis, which helps scientists understand both how the weather system works and where a specific model may require improvement. And, of course, the models are used to predict the weather.

Climate modeling follows this standard scientific strategy. Starting in the 1960s with rudimentary computer models based on simple physics, climate

scientists have now developed sophisticated models based on the best current understanding of climate physics; these models are able to simulate the large-scale features of atmosphere and ocean climate with excellent fidelity. Interested readers may refer to the IPCC Fourth Assessment Report (AR4; 2007), which devotes an entire chapter to discussions of current models and their ability to simulate current climate.

Ideally, one would like to emulate weather model evaluation by making multiple climate forecasts and then comparing them to actual climate. Unfortunately, the currently unpredictable features of natural climate variability add "noise" to climate observations and models, so evaluation of prediction requires periods well in excess of a decade. Thus, the only real opportunity available to evaluate climate models is to ask how well they do in simulated climate change over the past century or so. (The lack of data going back more than 100 to 150 years makes it difficult to evaluate model performance over longer periods.)

A useful strategy to evaluate climate models is to apply the same climate forcing history to multiple independent models and to ask how well the simulations agree. The result of such a test is shown in Fig. 11, taken from IPCC AR4. Panel a shows a set of thin yellow lines, each one representing the surface temperature from a climate model run for the 20th century, and a thicker red line that is the average of those runs. The black line is the observed temperature (same as Fig. 5). The spread in the yellow lines gives an indication of the differences among models due to model internal variability and model differences. This is not the same as a traditional measure of scientific uncertainty but is as close as can be achieved for climate models. The fact that the average of the models agrees well with the observations is a strong indication that the forcing (including increasing carbon dioxide concentrations) applied to the models and the model responses is correct. The model runs in panel b (in blue) are identical to those in panel a, except that the carbon dioxide concentration in each model run is held constant, rather than being allowed to increase as observed. The resulting model average (dark blue line) no longer agrees with the observations in the latter part of the time series.

The results in Fig. 11 show that the current generation of climate models successfully reproduces global surface temperature changes over the past century when observed climate forcings, including solar variability and aerosol changes, are applied. When observed carbon dioxide changes are not included, the models cannot reproduce the warming of the past 40 years. These models are built on fundamental physical relationships that are well understood, expressed mathematically, and solved computationally. While uncertainties remain, as evidenced by the spread in model runs, the overall model trend matches very well with the observations, giving us confidence in the understanding of climate physics.

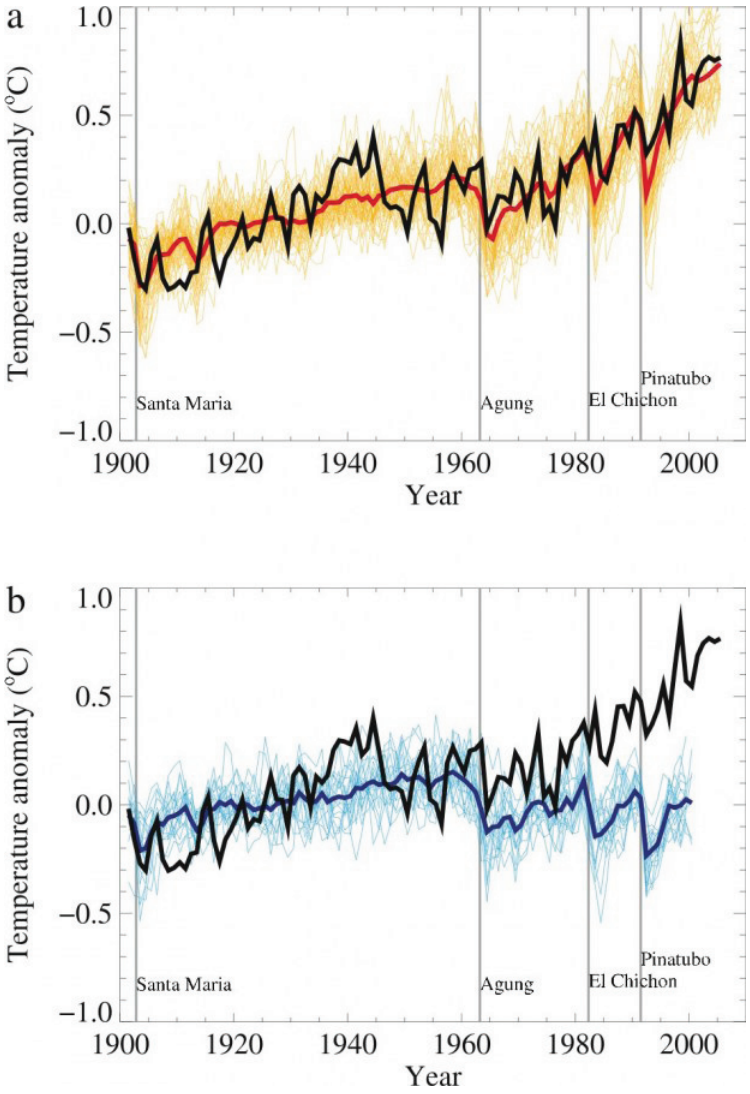

Figure 11. Climate model runs for the 20th century using (a) all forcings and (b) all forcings except for increasing greenhouse gas concentrations. The "all forcings" case includes solar activity, aerosol variations from volcanic eruptions and human activity, land-use changes, and greenhouse gas concentration changes. The vertical axis of temperature anomaly is simply the change in temperature measured against a 30-year average temperature from 1960 to 1990. It is a simple way of understanding temperature change.

These same models have been run through the 21st century using estimates of carbon dioxide emissions and consequent atmospheric carbon dioxide concentrations. The emissions estimates are based on estimates

of population growth, energy consumption per capita, and projections of energy emissions. Since the estimates of these factors vary, the estimated atmospheric carbon dioxide concentrations also vary. Current estimates of the carbon dioxide concentration in the year 2100 range from a low of about 550 to a high of about 1,000 ppmv. The lower number assumes drastically reduced carbon-based fuel usage over time, while the higher number assumes "business as usual," where energy consumption per capita and population continue to increase rapidly with time. We are aware that the assumptions employed in developing these scenarios are open to criticism. It is, however, the impacts of generally increasing greenhouse gas concentrations that we wish to understand. Fine details of the scenarios and the resulting impacts should not be considered because of their large inherent uncertainty.

G. What are the projected changes and what confidence do we have in the projections?

Climate model projections based on the estimated carbon dioxide emissions produce a range of average model changes in global surface temperature of about 2° to 4° C (4° to 8° F). For the lowest estimated carbon dioxide concentrations, no model shows changes less than 1.5° C (3° F); for the larger carbon dioxide estimates, projected changes can be as large as 6° C (11° F). This asymmetry in projected changes is often unappreciated. Based on even modest greenhouse gas emission scenarios and our current understanding of the climate system, there is virtually no chance that the warming by the end of this century will be less than 3° to 4° F, globally averaged. While the median value of expected temperature changes for high end emissions is 7° to 8° F, there is a real possibility that the changes could be as high as 10° to 11° F! When thinking about risk and response, this asymmetry is an important factor.

Because of the sensitivity of polar environments to warming, the Arctic in particular is expected to warm about twice as much as the average global warming. Thus, global average warmings of 4° to 8° F are expected to produce warmings of 8° to 15° F in the Arctic. These changes will result in large changes in summer ice extent, most probably producing extended summer periods of an ice free Arctic, unprecedented stresses on the Arctic biosphere, and significant changes in the traditional lifestyles of indigenous people. Arctic warming will also begin to melt permafrost, which is everywhere extensive at high latitudes. Melting permafrost allows additional greenhouse gases, particularly carbon dioxide and methane, to escape into the atmosphere.

Global warming is expected to produce important changes in large scale atmospheric and oceanic circulations. Due to circulation changes, wet regions in the tropics are expected to get wetter (more precipitation), while dry regions are expected to receive even less precipitation. Expected consequences include increased erosion and landslides in tropical regions and additional water stress in the dry subtropical regions such as the African Sahel. Changes in the mid-latitudes are expected to be somewhat less stressful, with warmer winters and hotter summers. Areas such as much of the Pacific Coast that depend heavily on winter snowpack and summer melt for fresh water will see reduced winter snow and thus more competition for reduced summer runoff. Warmer summers may increase crop productivity in the American

northern plains and Canadian plains, depending on the availability of rain, which is difficult to predict.

Sea level is expected to rise by at least 2-3 feet by 2100, based simply on the warming of the ocean, since water expands as it warms. Additional warming due to melting of land-based ice, such as the Greenland ice sheet or the West Antarctic ice sheet, is expected to add at least another foot and quite possibly more. Although the current understanding of ice sheet dynamics is limited, sea levels have been much higher during past interglacial periods, with only modestly warmer temperatures. Increased sea level will result in increased flooding of low-lying areas, coastal erosion, and damage to coastal infrastructure from storms and storm surge.

Increasing carbon dioxide emissions will inevitably lead to increased ocean acidity. Roughly half the carbon dioxide emitted to date resides in the ocean mixed layer, reducing the measured pH from 8.2 to 8.1.[16] Small increases in ocean acidity can prevent ocean organisms from producing carbonate and aragonite shells because the shells dissolve in the slightly more acidic water. The impact of increasing acidification on ocean food chains and coral communities is currently largely uncertain. Over longer times (centuries), one might expect ocean communities to adjust to a more acidic environment. Over short times, it is likely that there will be extensive damage to the bottom end of the ocean food chain, with corresponding damage to larger predators. Given severe existing stresses to ocean predators due to overfishing and pollution, the resulting damage to ocean fisheries may be devastating.

The uncertainty in these predictions is significant and difficult to express quantitatively because of uncertain emissions and possible ranges of climate responses. This is not to say, however, that the predictions are incorrect or useless. The direction of change in each case is clear and the mid to upper range of predictions is large and represents significant risk. Increasing carbon dioxide must result in a warmer world. A warmer world will result in a considerably warmer Arctic and a significant reduction in Arctic sea ice and land ice. Warming of the ocean and melting of land-based ice will result in sea level rise. Increased carbon dioxide will result in increasing ocean acidification. All of these statements are true and based on well understood physics. The only argument is about the magnitude of response in each case. All climate models, from the simplest to the most complex, predict that estimated carbon dioxide concentrations of 500 ppmv by the end of this century will result in a *minimum* of 3° F global warming by 2100. Upper end estimates of the warming for this same low carbon dioxide estimate are 7° to 8° F. Higher carbon dioxide emissions will result in increased warming. Future research may well reduce the range of predicted responses and provide better estimates of uncertainty. It is highly unlikely, however, that future research will change the direction of the responses or reduce the magnitudes to a trivial amount.

[16] Because the pH scale is logarithmic, pH 7 is ten times more acidic than pH 8, and 100 times more acidic than pH 9. This translates into an increase in acidity of 30 percent when the pH shifts from 8.2 to 8.1.

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Appendix B
Refereed, Gray, and Popular Literature

The material in this appendix is excerpted and adapted with permission from *Earthwise: A Guide to Hopeful Creation Care,* third edition (Faith Alive Christian Resources, 2011), pp. 43-44.

In understanding how scientists come to know what they know about how the world works, it is helpful to explain the meaning of "refereed literature." We know how referees are used in sports—they make sure the game is played by the rules. Similarly, refereed literature is read carefully by referees before it is published. Referees are carefully chosen for the depth and breadth of their knowledge and expertise, for their discernment and judgment, for their record of fairness, and for being free from the influence of sponsors and spectators.

The editors of refereed or "primary" literature normally use three referees to critically evaluate each article or "paper" (as professional research articles usually are called). For scientific literature, these referees are scientists who are peers of the scientist who is submitting a particular paper, have expertise in the particular field covered by the paper, and are not given the identity of the other two referees. After reading the paper, each of the three referees makes an independent and anonymous report to the editor and recommends whether to "reject," "publish," or "publish with revisions." If the editor gets a mixed review, the paper may be sent to still other qualified referees. If the paper must be revised, each revision is again reviewed by three referees in the same manner. Articles that pass these peer reviews are published periodically in professional journals, usually by a professional society of scientists to whom the editor is responsible. This highly disciplined procedure is designed to keep researchers precise, honest, and thorough in reporting about what they discover, in how they interpret their findings, and in how they place these in the context of what is known, and not known as this is published by other scientists in their refereed publications. While mistakes and exaggeration can still occur in reviewed articles, the review process operates to minimize mistakes. Also, particularly early in an investigation as more information is discovered, accepted ideas on a topic may shift over time to reflect new data. Thus, over time, published articles can be used to track the evolution and progression of scientific ideas.

Despite this careful process, some deeply flawed, and perhaps intentionally misleading, articles do get published. A particular strength of the scientific process is that the work of a scientist is usually duplicated by another, often because the latter wishes to extend the work of the former. Flawed science is

found when the work cannot be duplicated or inconsistent results are found. A few years ago, several scientists announced the discovery of cold fusion, a process that if true would provide enormous amounts of cheap energy. The reported results, however, could not be reproduced by other scientists. The result was disgrace and loss of respect and positions for the scientists who initially reported the discovery.

There are two other kinds of literature we should know about: "gray literature" and "popular literature." Gray literature consists of reports from government agencies such as the Environmental Protection Agency and state departments of natural resources, from colleges and universities, from granting agencies, and from think tanks, institutes, and foundations. This literature also is important, but it is not considered as authoritative because it does not undergo the same kind of disciplined peer review as does primary literature. Gray literature often uses different standards and is more susceptible to outside influences, and it may have items on its agenda that go beyond reporting new knowledge. As a result, it generally is not relied upon by professional researchers for a basic understanding of how the world works and what is happening to it. Popular literature consists of newspapers, magazines, leaflets, and brochures. Like the gray literature, it also is important, but while it may be useful, it is not normally considered to be authoritative.

Many people use the gray or popular literature to learn about scientific issues and to inform their opinions. This literature is often easier to read and understand, and may be written in a less technical or a non-technical way. This literature is fine as long as it accurately reflects the primary literature and accepted scientific conclusions based on the primary literature. However, gray or popular literature is often biased by political or financial agendas, and the data are spun to support their position. For instance, tobacco companies for many years denied the health effects of smoking. Pro-nuclear interests may seek to minimize the effect of radiation on health and environment. At the same time, anti-nuclear interests may overstate the risks associated with small doses of radiation or long-term storage of nuclear waste.

Appendix C
Declarations on Creation Care and Climate Change

A. The Evangelical Declaration on the Care of Creation (http://www.creationcare.org/blank.php?id=39)

The earth is the Lord's, and the fullness thereof — Psalm 24:1.

As followers of Jesus Christ, committed to the full authority of the Scriptures, and aware of the ways we have degraded creation, we believe that biblical faith is essential to the solution of our ecological problems.

Because we worship and honor the Creator, we seek to cherish and care for the creation.

Because we have sinned, we have failed in our stewardship of creation. Therefore we repent of the way we have polluted, distorted, or destroyed so much of the Creator's work.

Because in Christ God has healed our alienation from God and extended to us the first fruits of the reconciliation of all things, we commit ourselves to working in the power of the Holy Spirit to share the Good News of Christ in word and deed, to work for the reconciliation of all people in Christ, and to extend Christ's healing to suffering creation.

Because we await the time when even the groaning creation will be restored to wholeness, we commit ourselves to work vigorously to protect and heal that creation for the honor and glory of the Creator—whom we know dimly through creation, but meet fully through Scripture and in Christ. We and our children face a growing crisis in the health of the creation in which we are embedded, and through which, by God's grace, we are sustained. Yet we continue to degrade that creation.

These degradations of creation can be summed up as 1) land degradation; 2) deforestation; 3) species extinction; 4) water degradation; 5) global toxification; 6) the alteration of atmosphere; 7) human and cultural degradation.

Many of these degradations are signs that we are pressing against the finite limits God has set for creation. With continued population growth, these degradations will become more severe. Our responsibility is not only to bear and nurture children, but to nurture their home on earth. We respect the institution of marriage as the way God has given to insure thoughtful procreation of children and their nurture to the glory of God.

We recognize that human poverty is both a cause and a consequence of environmental degradation.

Many concerned people, convinced that environmental problems are more spiritual than technological, are exploring the world's ideologies and religions in search of non-Christian spiritual resources for the healing of the earth. As followers of Jesus Christ, we believe that the Bible calls us to respond in four ways:

First, God calls us to confess and repent of attitudes which devalue creation, and which twist or ignore biblical revelation to support our misuse of it. Forgetting that "the earth is the Lord's," we have often simply used creation and forgotten our responsibility to care for it.

Second, our actions and attitudes toward the earth need to proceed from the center of our faith, and be rooted in the fullness of God's revelation in Christ and the Scriptures. We resist both ideologies which would presume the Gospel has nothing to do with the care of non-human creation and also ideologies which would reduce the Gospel to nothing more than the care of that creation.

Third, we seek carefully to learn all that the Bible tells us about the Creator, creation, and the human task. In our life and words we declare that full good news for all creation which is still waiting "with eager longing for the revealing of the children of God," (Rom. 8:19).

Fourth, we seek to understand what creation reveals about God's divinity, sustaining presence, and everlasting power, and what creation teaches us of its God-given order and the principles by which it works.

Thus we call on all those who are committed to the truth of the Gospel of Jesus Christ to affirm the following principles of biblical faith, and to seek ways of living out these principles in our personal lives, our churches, and society.

The cosmos, in all its beauty, wildness, and life-giving bounty, is the work of our personal and loving Creator.

Our creating God is prior to and other than creation, yet intimately involved with it, upholding each thing in its freedom, and all things in relationships of intricate complexity. God is transcendent, while lovingly sustaining each creature; and immanent, while wholly other than creation and not to be confused with it.

God the Creator is relational in very nature, revealed as three persons in One. Likewise, the creation which God intended is a symphony of individual creatures in harmonious relationship.

The Creator's concern is for all creatures. God declares all creation "good" (Gen. 1:31); promises care in a covenant with all creatures (Gen. 9:9-17); delights in creatures which have no human apparent usefulness (Job 39-41); and wills, in Christ, "to reconcile all things to himself" (Col. 1:20).

Men, women, and children, have a unique responsibility to the Creator; at the same time we are creatures, shaped by the same processes and embedded in the same systems of physical, chemical, and biological interconnections which sustain other creatures.

Men, women, and children, created in God's image, also have a unique responsibility for creation. Our actions should both sustain creation's fruitfulness and preserve creation's powerful testimony to its Creator.

Our God-given, stewardly talents have often been warped from their intended purpose: that we know, name, keep and delight in God's creatures; that we nourish civilization in love, creativity and obedience to God; and that we offer creation and civilization back in praise to the Creator. We have ignored our creaturely limits and have used the earth with greed, rather than care.

The earthly result of human sin has been a perverted stewardship, a patchwork of garden and wasteland in which the waste is increasing. "There is no faithfulness, no love, no acknowledgment of God in the land...Because of this the land mourns, and all who live in it waste away" (Hosea 4:1,3). Thus, one consequence of our misuse of the earth is an unjust denial of God's created bounty to other human beings, both now and in the future.

God's purpose in Christ is to heal and bring to wholeness not only persons but the entire created order. "For God was pleased to have all his fullness dwell in him, and through him to reconcile to himself all things, whether things on earth or things in heaven, by making peace through his blood shed on the cross" (Col. 1:19-20).

In Jesus Christ, believers are forgiven, transformed and brought into God's kingdom. "If anyone is in Christ, there is a new creation" (II Cor. 5:17). The presence of the kingdom of God is marked not only by renewed fellowship

with God, but also by renewed harmony and justice between people, and by renewed harmony and justice between people and the rest of the created world. "You will go out in joy and be led forth in peace; the mountains and the hills will burst into song before you, and all the trees of the field will clap their hands" (Isa. 55:12).

We believe that in Christ there is hope, not only for men, women and children, but also for the rest of creation which is suffering from the consequences of human sin.

Therefore we call upon all Christians to reaffirm that all creation is God's; that God created it good; and that God is renewing it in Christ.

We encourage deeper reflection on the substantial biblical and theological teaching which speaks of God's work of redemption in terms of the renewal and completion of God's purpose in creation.

We seek a deeper reflection on the wonders of God's creation and the principles by which creation works. We also urge a careful consideration of how our corporate and individual actions respect and comply with God's ordinances for creation.

We encourage Christians to incorporate the extravagant creativity of God into their lives by increasing the nurturing role of beauty and the arts in their personal, ecclesiastical, and social patterns.

We urge individual Christians and churches to be centers of creation's care and renewal, both delighting in creation as God's gift, and enjoying it as God's provision, in ways which sustain and heal the damaged fabric of the creation which God has entrusted to us.

We recall Jesus' words that our lives do not consist in the abundance of our possessions, and therefore we urge followers of Jesus to resist the allure of wastefulness and overconsumption by making personal lifestyle choices that express humility, forbearance, self restraint and frugality.

We call on all Christians to work for godly, just, and sustainable economies which reflect God's sovereign economy and enable men, women and children to flourish along with all the diversity of creation. We recognize that poverty forces people to degrade creation in order to survive; therefore we support the development of just, free economies which empower the poor and create abundance without diminishing creation's bounty.

We commit ourselves to work for responsible public policies which embody the principles of biblical stewardship of creation.

We invite Christians—individuals, congregations and organizations—to join with us in this evangelical declaration on the environment, becoming a covenant people in an ever-widening circle of biblical care for creation.

We call upon Christians to listen to and work with all those who are concerned about the healing of creation, with an eagerness both to learn from them and also to share with them our conviction that the God whom all people sense in creation (Acts 17:27) is known fully only in the Word made flesh in Christ the living God who made and sustains all things.

We make this declaration knowing that until Christ returns to reconcile all things, we are called to be faithful stewards of God's good garden, our earthly home.

B. The Oxford Declaration on Global Warming (http://www.jri.org.uk/news/statement.htm)

Human-induced climate change is a moral, ethical and religious issue.

- God created the earth, and continues to sustain it. Made in God's image, human beings are to care for people and all creation as God cares for them. The call to "love the Lord your God and love your neighbour" (Matthew 22:37–39) takes on new implications in the face of present and projected climate change. God has demonstrated his commitment to creation in the incarnation and resurrection of Jesus Christ. Christ who "reconciles all things" (Colossians 1:20) calls his followers to the "ministry of reconciliation" (2 Corinthians 5:18, 19).
- Human induced climate change poses a great threat to the common good, especially to the poor, the vulnerable and future generations.
- By reducing the earth's biological diversity, human induced climate change diminishes God's creation.

Human induced climate change, therefore, is a matter of urgent and profound concern.

The earth's climate is changing, with adverse effects on people, communities and ecosystems.

- There is now high confidence in the scientific evidence of human influence on climate as detailed by the Intergovernmental Panel on Climate Change (IPCC) and endorsed by 18 of the world's leading Academies of Science.
- Human activities, especially the burning of coal, oil and natural gas (fossil fuels) are rapidly increasing the concentrations of greenhouse gases (especially carbon dioxide) in the global atmosphere. As a result the global climate is warming, with rising sea levels, changes in rainfall patterns, more floods and droughts, and more intense storms. These have serious social, economic and ecological consequences.
- The harmful effects of climate change far outweigh the beneficial ones:
  - In many arid and semi-arid areas, the quantity and the quality of fresh water will continue to decrease.
  - Although agricultural productivity may increase in temperate northern latitudes, it will decrease throughout the tropics and subtropics.
  - A greater incidence of diseases, such as malaria, dengue fever and cholera, is expected.
  - Sea-level rise and increased flooding is already displacing people and will eventually affect tens of millions especially in low income countries. Some island states are likely to disappear altogether.
  - Important ecosystems, such as coral reefs and forests, will be destroyed or drastically altered, undermining the very foundation of a sustainable world.

Action is needed now, both to arrest climate change and to adapt to its effects.

- We must take immediate steps to stabilize the climate. This means reducing global emissions of carbon dioxide (the most important greenhouse gas) to below 1990 levels well before the middle of the 21st century.
- While industrialized nations have largely caused the problem, its most severe effects fall upon the peoples of developing countries. Industrialized countries need therefore to make much greater reductions in emissions in order to allow for economic growth in developing countries.
  - We urge industrialized nations to take the lead in reducing their emissions. They have the technical, financial and institutional ability to do so now.
  - We urge industrialized countries to assist developing countries in gaining access to cleaner and renewable forms of energy
  - We urge that actions be taken to increase energy efficiency, in transportation, buildings and industry. Many actions can produce savings or be taken at little or no net cost. Examples were presented to the Forum of such actions by 38 major multinational companies.
  - We urge greater use and development of renewable sources of energy.
  - We urge increased financial investment and that banking initiatives be grasped to enable the necessary changes.
- The cost of inaction will be greater than the cost of appropriate action.
- Adapting to the impacts of climate change (e.g., droughts and flooding) is not an alternative to mitigation, but is essential given that the climate is already changing and further change is inevitable.

Christian denominations, churches and organizations need to take action to:

- increase awareness of the facts of global climate change and its moral implications;
- set an example through individual and collective actions that reduce greenhouse gas emissions;
- increase demand for technologies and products that produce less emissions of carbon dioxide;
- urge immediate and responsible action by national governments, in cooperation with other governments under the Framework Convention on Climate Change. This should be, first, to ensure the successful operation of the Kyoto Protocol (which some countries, including the United States, Canada and Australia, have not yet ratified) and, second, to establish an effective programme of emissions reductions in the period immediately following that covered by that Protocol.

C. *An Evangelical Declaration on Global Warming* from the Cornwall Alliance *(http://www.cornwallalliance.org/articles/read/an-evangelical-declaration-on-global-warming/)*

Preamble

As governments consider policies to fight alleged man-made global warming, evangelical leaders have a responsibility to be well informed, and then to speak out. *A Renewed Call to Truth, Prudence, and Protection of the Poor: An Evangelical Examination of the Theology, Science, and Economics of Global*

Warming demonstrates that many of these proposed policies would destroy jobs and impose trillions of dollars in costs to achieve no net benefits. They could be implemented only by enormous and dangerous expansion of government control over private life. Worst of all, by raising energy prices and hindering economic development, they would slow or stop the rise of the world's poor out of poverty and so condemn millions to premature death.

What We Believe

1. We believe earth and its ecosystems—created by God's intelligent design and infinite power and sustained by His faithful providence—are robust, resilient, self-regulating, and self-correcting, admirably suited for human flourishing, and displaying His glory. Earth's climate system is no exception. Recent global warming is one of many natural cycles of warming and cooling in geologic history.
2. We believe abundant, affordable energy is indispensable to human flourishing, particularly to societies which are rising out of abject poverty and the high rates of disease and premature death that accompany it. With present technologies, fossil and nuclear fuels are indispensable if energy is to be abundant and affordable.
3. We believe mandatory reductions in carbon dioxide and other greenhouse gas emissions, achievable mainly by greatly reduced use of fossil fuels, will greatly increase the price of energy and harm economies.
4. We believe such policies will harm the poor more than others because the poor spend a higher percentage of their income on energy and desperately need economic growth to rise out of poverty and overcome its miseries.

What We Deny

1. We deny that earth and its ecosystems are the fragile and unstable products of chance, and particularly that earth's climate system is vulnerable to dangerous alteration because of minuscule changes in atmospheric chemistry. Recent warming was neither abnormally large nor abnormally rapid. There is no convincing scientific evidence that human contribution to greenhouse gases is causing dangerous global warming.
2. We deny that alternative, renewable fuels can, with present or near-term technology, replace fossil and nuclear fuels, either wholly or in significant part, to provide the abundant, affordable energy necessary to sustain prosperous economies or overcome poverty.
3. We deny that carbon dioxide—essential to all plant growth—is a pollutant. Reducing greenhouse gases cannot achieve significant reductions in future global temperatures, and the costs of the policies would far exceed the benefits.
4. We deny that such policies, which amount to a regressive tax, comply with the Biblical requirement of protecting the poor from harm and oppression.

A Call to Action
In light of these facts,

1. We call on our fellow Christians to practice creation stewardship out of Biblical conviction, adoration for our Creator, and love for our fellow man—especially the poor.
2. We call on Christian leaders to understand the truth about climate change and embrace Biblical thinking, sound science, and careful economic analysis in creation stewardship.
3. We call on political leaders to adopt policies that protect human liberty, make energy more affordable, and free the poor to rise out of poverty, while abandoning fruitless, indeed harmful policies to control global temperature.

D. Climate Change: An Evangelical Call to Action from the Evangelical Environmental Network (2006)
(http://newevangelicalpartnership.org/?q=node/10)

Preamble
As American evangelical Christian leaders, we recognize both our opportunity and our responsibility to offer a biblically based moral witness that can help shape public policy in the most powerful nation on earth, and therefore contribute to the well-being of the entire world.[1] Whether we will enter the public square and offer our witness there is no longer an open question. We are in that square, and we will not withdraw.

We are proud of the evangelical community's long-standing commitment to the sanctity of human life. But we also offer moral witness in many venues and on many issues. Sometimes the issues that we have taken on, such as sex trafficking, genocide in the Sudan, and the AIDS epidemic in Africa, have surprised outside observers. While individuals and organizations can be called to concentrate on certain issues, we are not a single-issue movement. We seek to be true to our calling as Christian leaders, and above all faithful to Jesus Christ our Lord. Our attention, therefore, goes to whatever issues our faith requires us to address.

Over the last several years many of us have engaged in study, reflection, and prayer related to the issue of climate change (often called "global warming"). For most of us, until recently this has not been treated as a pressing issue or major priority. Indeed, many of us have required considerable convincing before becoming persuaded that climate change is a real problem and that it ought to matter to us as Christians. But now we have seen and heard enough to offer the following moral argument related to the matter of human-induced climate change. We commend the four simple but urgent claims offered in this document to all who will listen, beginning with our brothers and sisters in the Christian community, and urge all to take the appropriate actions that follow from them.

[1] Cf. "For the Health of the Nation: An Evangelical Call to Civic Responsibility," approved by National Association of Evangelicals, October 8, 2004.

Claim 1: Human-Induced Climate Change Is Real
Since 1995 there has been general agreement among those in the scientific community most seriously engaged with this issue that climate change is happening and is being caused mainly by human activities, especially the burning of fossil fuels. Evidence gathered since 1995 has only strengthened this conclusion.

Because all religious/moral claims about climate change are relevant only if climate change is real and is mainly human-induced, everything hinges on the scientific data. As evangelicals we have hesitated to speak on this issue until we could be more certain of the science of climate change, but the signatories now believe that the evidence demands action:

- The Intergovernmental Panel on Climate Change (IPCC), the world's most authoritative body of scientists and policy experts on the issue of global warming, has been studying this issue since the late 1980s. (From 1988—2002 the IPCC's assessment of the climate science was Chaired by Sir John Houghton, a devout evangelical Christian.) It has documented the steady rise in global temperatures over the last fifty years, projects that the average global temperature will continue to rise in the coming decades, and attributes "most of the warming" to human activities.
- The U.S. National Academy of Sciences, as well as all other G8 country scientific Academies (Great Britain, France, Germany, Japan, Canada, Italy, and Russia), has concurred with these judgments.
- In a 2004 report, and at the 2005 G8 summit, the Bush Administration has also acknowledged the reality of climate change and the likelihood that human activity is the cause of at least some of it.[2]

In the face of the breadth and depth of this scientific and governmental concern, only a small percentage of which is noted here, we are convinced that evangelicals must engage this issue without any further lingering over the basic reality of the problem or humanity's responsibility to address it.

[2] Intergovernmental Panel on Climate Change 2001, Summary for Policymakers; http://www.grida.no/climate/ipcc_tar/wg1/007.htm. (See also the main IPCC website, www.ipcc.ch) For the confirmation of the IPCC's findings from the U.S. National Academy of Sciences, see, Climate Change Science: An Analysis of Some Key Questions (2001); http://books.nap.edu/html/climatechange/summary.html. For the statement by the G8 Academies (plus those of Brazil, India, and China) see Joint Science Academies Statement: Global Response to Climate Change, (June 2005): http://nationalacademies.org/onpi/06072005.pdf. Another major international report that confirms the IPCC's conclusions comes from the Arctic Climate Impact Assessment. See their Impacts of a Warming Climate, Cambridge University Press, November 2004, p.2; http://amap.no/acia/. Another important statement is from the American Geophysical Union, "Human Impacts on Climate," December 2003, http://www.agu.org/sci_soc/policy/climate_change_position.html. For the Bush Administration's perspective, see Our Changing Planet: The U.S. Climate Change Science Program for Fiscal Years 2004 and 2005, p.47; http://www.usgcrp.gov/usgcrp/Library/ocp2004-5/default.htm. For the 2005 G8 statement, see http://www.number-10.gov.uk/output/Page7881.asp.

Claim 2: The Consequences of Climate Change Will Be Significant, and Will Hit the Poor the Hardest

The earth's natural systems are resilient but not infinitely so, and human civilizations are remarkably dependent on ecological stability and well-being. It is easy to forget this until that stability and well-being are threatened.

Even small rises in global temperatures will have such likely impacts as: sea level rise; more frequent heat waves, droughts, and extreme weather events such as torrential rains and floods; increased tropical diseases in now-temperate regions; and hurricanes that are more intense. It could lead to significant reduction in agricultural output, especially in poor countries. Low-lying regions, indeed entire islands, could find themselves under water. (This is not to mention the various negative impacts climate change could have on God's other creatures.)

Each of these impacts increases the likelihood of refugees from flooding or famine, violent conflicts, and international instability, which could lead to more security threats to our nation.

Poor nations and poor individuals have fewer resources available to cope with major challenges and threats. The consequences of global warming will therefore hit the poor the hardest, in part because those areas likely to be significantly affected first are in the poorest regions of the world. Millions of people could die in this century because of climate change, most of them our poorest global neighbors.

Claim 3: Christian Moral Convictions Demand Our Response to the Climate Change Problem

While we cannot here review the full range of relevant biblical convictions related to care of the creation, we emphasize the following points:

- Christians must care about climate change because we love God the Creator and Jesus our Lord, through whom and for whom the creation was made. This is God's world, and any damage that we do to God's world is an offense against God Himself (Gen. 1; Ps. 24; Col. 1:16).
- Christians must care about climate change because we are called to love our neighbors, to do unto others as we would have them do unto us, and to protect and care for the least of these as though each was Jesus Christ himself (Mt. 22:34-40; Mt. 7:12; Mt. 25:31-46).
- Christians, noting the fact that most of the climate change problem is human induced, are reminded that when God made humanity he commissioned us to exercise stewardship over the earth and its creatures. Climate change is the latest evidence of our failure to exercise proper stewardship, and constitutes a critical opportunity for us to do better (Gen. 1:26-28).

Love of God, love of neighbor, and the demands of stewardship are more than enough reason for evangelical Christians to respond to the climate change problem with moral passion and concrete action.

Claim 4: The need to act now is urgent. Governments, businesses, churches, and individuals all have a role to play in addressing climate change—starting now.
The basic task for all of the world's inhabitants is to find ways now to begin to reduce the carbon dioxide emissions from the burning of fossil fuels that are the primary cause of human-induced climate change.

There are several reasons for urgency. First, deadly impacts are being experienced now. Second, the oceans only warm slowly, creating a lag in experiencing the consequences. Much of the climate change to which we are already committed will not be realized for several decades. The consequences of the pollution we create now will be visited upon our children and grandchildren. Third, as individuals and as a society we are making long-term decisions today that will determine how much carbon dioxide we will emit in the future, such as whether to purchase energy efficient vehicles and appliances that will last for 10-20 years, or whether to build more coal-burning power plants that last for 50 years rather than investing more in energy efficiency and renewable energy.

In the United States, the most important immediate step that can be taken at the federal level is to pass and implement national legislation requiring sufficient economy-wide reductions in carbon dioxide emissions through cost-effective, market-based mechanisms such as a cap-and-trade program. On June 22, 2005 the Senate passed the Domenici-Bingaman resolution affirming this approach, and a number of major energy companies now acknowledge that this method is best both for the environment and for business.

We commend the Senators who have taken this stand and encourage them to fulfill their pledge. We also applaud the steps taken by such companies as BP, Shell, General Electric, Cinergy, Duke Energy, and DuPont, all of which have moved ahead of the pace of government action through innovative measures implemented within their companies in the U.S. and around the world. In so doing they have offered timely leadership.

Numerous positive actions to prevent and mitigate climate change are being implemented across our society by state and local governments, churches, smaller businesses, and individuals. These commendable efforts focus on such matters as energy efficiency, the use of renewable energy, low CO_2 emitting technologies, and the purchase of hybrid vehicles. These efforts can easily be shown to save money, save energy, reduce global warming pollution as well as air pollution that harm human health, and eventually pay for themselves. There is much more to be done, but these pioneers are already helping to show the way forward.

Finally, while we must reduce our global warming pollution to help mitigate the impacts of climate change, as a society and as individuals we must also help the poor adapt to the significant harm that global warming will cause.

Conclusion
We the undersigned pledge to act on the basis of the claims made in this document. We will not only teach the truths communicated here but also seek ways to implement the actions that follow from them. In the name of

Jesus Christ our Lord, we urge all who read this declaration to join us in this effort.

E. The Micah Declaration on Creation Stewardship and Climate Change
Developed at the Fourth Triennial Global Consultation held in Kenya by the Micah Network from July 13-18, 2009
(http://www.micahnetwork.org/sites/default/files/doc/library/micah_network_global_consultation_declaration_0.pdf)

We, members of the Micah Network[3], gathering together from 38 countries on all 5 continents, met at Limuru, Kenya from 13–18 July 2009 for its 4th Triennial Global Consultation. On the matter of Creation Stewardship and Climate Change, we sought God's wisdom and cried out for the Holy Spirit's guidance as we reflected on the global environmental crisis. As a result of our discussions, reflections and prayers, we make the following declaration:

1. We believe in God – Father, Son and Holy Spirit in community – who is the creator, sustainer and Lord of all. God delights in His creation, and is committed to it.[4]

2. In the beginning, God established just relationships amongst all of creation. Women and men – as image-bearers of God – are called to serve and love the rest of creation, accountable to God as stewards. Our care for creation is an act of worship and obedience towards the Creator.[5]

3. We, however, have not always been faithful stewards. Through our ignorance, neglect, arrogance and greed, we have harmed the earth and broken creation's relationships.[6] Our failure to be faithful stewards has caused the current environmental crisis, leading to climate change, and putting the earth's ecosystems at risk. All creation has been subjected to futility and decay because of our disobedience.[7]

4. Yet God remains faithful.[8] In Christ's incarnation, life, death and resurrection, God is at work to reconcile all of creation to Himself.[9] We hear the groaning of creation as in the pains of childbirth. This is the promise that God will act, and is already at work, to renew all things.[10] This is the hope that sustains us.

5. We confess that we have sinned. We have not cared for the earth with the self-sacrificing and nurturing love of God. Instead, we have

[3] Micah Network is a global network of Christian agencies and churches involved in relief, development and advocacy, and responding to poverty and injustice.

[4] Colossians 1:15-16; Romans 11:36

[5] Genesis 1:26-30; Genesis 2:15

[6] Genesis 3:13-24

[7] Romans 8:20

[8] Romans 8:21

[9] Colossians 1:19-20; Philippians 2:6-8

[10] Romans 8:22; Revelation 21:5

exploited, consumed and abused it for our own advantage. We have too often yielded to the idolatry that is greed.[11] We have embraced false dichotomies of theology and practice, splitting apart the spiritual and material, eternal and temporal, heavenly and earthly. In all these things, we have not acted justly towards each other or towards creation, and we have not honoured God.

6. We acknowledge that industrialization, increased deforestation, intensified agriculture and grazing, along with the unrestrained burning of fossil fuels, have forced the earth's natural systems out of balance. Rapidly increasing greenhouse gas emissions are causing the average global temperature to rise, with devastating impacts already being experienced, especially by the poorest and most marginalized groups. A projected temperature rise of 2°C within the next few decades will significantly alter life on earth and accelerate loss of biodiversity. It will increase the risk and severity of extreme weather events, such as drought, flood, and hurricanes, leading to displacement and hunger. Sea levels will continue to rise, contaminating fresh water supplies and submerging island and coastal communities. We are likely to see mass migration, leading to resource conflicts. Profound changes to rainfall and snowfall, as well as the rapid melting of glaciers, will lead to more water stress and shortages for many millions of people.

7. We repent of our self-serving theology of creation, and our complicity in unjust local and global economic relationships. We repent of those aspects of our individual and corporate life styles that harm creation, and of our lack of political action. We must radically change our lives in response to God's indignation and sorrow for His creation's agony.

8. Before God we commit ourselves, and call on the whole family of faith, to bear witness to God's redemptive purpose for all creation. We will seek appropriate ways to restore and build just relationships among human beings and with the rest of creation. We will strive to live sustainably, rejecting consumerism and the resulting exploitation.[12] We will teach and model care of creation and integral mission. We will intercede before God for those most affected by environmental degradation and climate change, and will act with justice and mercy among, with and on behalf of them.[13]

9. We join with others to call on local, national, and global leaders to meet their responsibility to address climate change and environmental degradation through the agreed inter-governmental mechanisms and conventions, and to provide the necessary resources to ensure sustainable development. Their meetings through the United Nations Framework Convention on Climate Change process must produce a fair, comprehensive, and adequate climate deal. Leaders must

[11] Colossians 3:5; Matthew 6:24

[12] Matthew 6:24

[13] Micah 6:8

support the efforts of local communities to adapt to climate change, and must act to protect the lives and livelihoods of those most vulnerable to the impact of environmental degradation and climate change. We recognize that among the most affected are women and girls. We call on leaders to invest in the development of new, clean technologies and energy sources and to provide adequate support to enable poor, vulnerable and marginalized groups to use them effectively.

10. There is no more time for delay or denial. We will labour with passion, persistence, prayer and creativity to protect the integrity of all creation, and hand on a safe environment and climate to our children and theirs.

For those with ears to hear, let them hear.[14]

17 July 2009

F. African Church Leaders' Statement on Climate Change and Water (http://onlinelibrary.wiley.com/doi/10.1111/j.1758-6623.2010.00060_2.x/full)

We Church Leaders representing National Christian Councils and Churches from the Fellowship of Christian Councils and Churches in Southern Africa [FOCCISA] and the Fellowship of Christian Councils and Churches in the Great Lakes and Horn of Africa [FECCLAHA] under the auspices of AACC [All Africa Council of Churches] met from 3rd–5th June 2008 to consult on the subject of climate change and water at the Archbishop Desmond Tutu Ecumenical Centre in Nairobi, Kenya.

1. [We] Affirm the reality and urgency of climate change and the adverse negative impact it has on all of humanity and particularly on poor and vulnerable communities in Africa. The current climate crisis is primarily spiritual and ethical with serious political, economic and justice implications. As human beings we have failed to appreciate the intrinsic worth of ourselves, other humans, other species and future generations. We have failed to acknowledge the fact that the earth sustains life because of the harmonious balance of the elements and all the creatures within it. Our pursuit of "happiness and high quality of life" need not endanger other peoples, nations, communities, species and future generations that are also entitled to survival and happiness. The earth has enough resources to satisfy everyone's need, but not enough resources for anyone's greed.

2. Believe that ecological sustenance can be assured only through the principle of being mindful of the welfare of others while we mind our own. That our survival is inextricably woven with that of others. And that in the long term, we cannot survive while others perish. (Do not wish for others that which you do not wish for yourself, nor promise that which you do not fulfill. Matthew 7:12.)

3. Believe, in line with the United Nations Framework Convention on Climate Change (UNFCCC) principle of common but differentiated

[14] Mark 4:23

responsibilities, that the costs of climate change mitigation and adaptation must be borne based on historical and actual responsibility and the ability to pay. In other words, there is an obligation of the industrialized countries to pay their carbon debts but more urgently to stop the emission of greenhouse gases.

4. Recognize that climate change has primarily been accelerated by emissions of greenhouse gases due to human activities. That these global emissions are not only historical but also actual current emissions by industrialized countries, thus global warming. The negative consequences of which are felt largely in the global south. And that climate change affects the availability of domestic and agricultural water and food security.

5. Appreciate the role of the United Nations Framework Convention on Climate Change (UNFCCC) in responding to the global environmental crisis as it provides a common negotiation platform for all nations and offers access for participation of non-governmental actors.

6. Reason that the current environmental and development crisis cannot be overcome through voluntary action only. That legally binding commitments are critical for the different issues of mitigation, adaptation, finance, development of technology and afforestation. It is therefore our view that the next eighteen months preceding the UNFCCC climate conference in Copenhagen in December 2009 (COP 15) are crucial to improving and strengthening the existing mechanisms.

7. Recognize that the Kyoto Protocol is an important step towards ensuring that industrialized countries commit themselves to legally binding emission reductions to 1990 levels. However, its implementation and the political commitment of the industrialized nations is absent. Some countries, notably the USA and New Zealand, have not even ratified the protocol, while most of the other countries with mitigation commitments are lagging too far behind their reduction targets.

We therefore urge African governments to propose and support principles based on justice, equity and responsibility in the climate change debate. These will go a long way to secure fair and just commitments for the post-2012 period. Unless decisive action is taken immediately, climate chaos will lead to increased human suffering and social upheaval, condemning millions of people to hunger, disease, misery and death. A third of the African population has already fallen prey to droughts, floods and resource-based conflicts resulting from global warming.

We urgently therefore:

A. Call on governments and industry in the industrialized countries, especially in the North, to:
   - Implement significant and immediate reduction measures of at least 80% on 1990 levels and at the same time secure the right of all people to reach a dignified level of human development.

- Rapidly execute emission reductions that they accepted in the Kyoto Protocol and to adopt new, more effective and legally binding post-2012 emission reduction obligations.
- Support adaptation strategies in the South through adequate financial and technological support as a way of owning up to their responsibility for the climate crisis.
- Avail new mechanisms for channelling significant sums of financial, technological and other support, in addition to the commitment made (and mostly not fulfilled) by developed countries to provide 0.7% of their Gross Domestic Product for Official Development Assistance (ODA).
- Promote and implement low carbon strategies for sustainable human development.
- Compensate developing countries for the damage already done and the lost opportunities based on the polluter-pays-principle.

B. Observe that the contribution of African countries to the total global emissions is very low and call upon the African governments to:
   - Affirm political will to address climate change and to allocate adequate public resources to education for increased resilience and adaptation initiatives.
   - Recognize the role of the churches and other civil societies, including other faith communities, in order to adequately respond to and support local efforts to adapt to the adverse consequences of climate change – particularly at community levels.
   - Define appropriate policy frameworks to support the innovation, contextualization and development of technologies for sustainable industrial development in their respective countries, giving priority to the promotion of indigenous inventions and innovations.

C. Appreciate the efforts of churches and faith-based organizations in advocating for the rights of the poor and vulnerable communities in the continent and challenge them to:
   - Recognize the reality of climate change and the urgency to create awareness, mobilize and promote their communities to engage in activities towards effective and sustainable adaptation to the crisis.
   - Stand in solidarity with communities that are currently suffering from the negative impacts of climate change and whose livelihoods have been compromised through encouraging diversified eating habits, homegrown long-term agriculture and food security programs.
   - Review curricula of theological institutions and develop in-service training for clergy and lay leaders to integrate the theme of climate change at all levels.
   - Engage faith communities in the North to demand binding commitments from their governments to pay their carbon debt, reduce emission of greenhouse gases and support adaptation initiatives in the South.
   - Continue to influence the UNFCCC negotiation process through joint lobbying and advocacy activities using equity-based frameworks like the "Greenhouse Development Rights" and other human rights–based approaches.

To collaborate with their partners in the North to establish eco-congregations that will also offer options for checking consumerism through behaviour change, thus reducing carbon emissions.
- Engage African governments to develop appropriate legislation and policy framework towards precaution, mitigation and adaptation against climate change.

We, church leaders present in this consultation, hereby commit ourselves to work, engage and challenge our constituents, African governments, partners, governments of industrialized countries, the African Union and United Nations and other stakeholders in ensuring that climate change and its adverse effects as already experienced or projected are reversed.

Appendix D
Background to the Cornwall Declaration

Because the declarations of the Cornwall Alliance are at variance with other declarations discussed in this report, we think it may be useful to provide a bit of background information on the Alliance and its members.

The Interfaith Council for Environmental Stewardship (ICES) was founded in April 2000 by Jewish, Catholic, and Protestant leaders promoting a public, theologically, and politically conservative religious agenda. These leaders argued that religiously informed moral action, rather than governmental controls, should guide behavior, and that the environment can best be sustained in a context of free market economics, strong property rights, and technological innovation. The ICES was conceived and established by the Acton Institute for the Study of Religion and Liberty, an advocacy and educational organization created in 1990 by Fr. Robert A. Sirico "to promote a society that embraces civil liberties and free-market economics." The flagship publication and defining document of the ICES is *The Cornwall Declaration on Environmental Stewardship*; its principal author is E. Calvin Beisner.[1] Beisner was involved in founding the ICES and is a founding member of the Interfaith Stewardship Alliance.

The Cornwall Declaration on Environmental Stewardship had its origin in October 1999 at a meeting held in West Cornwall, Connecticut, and attended by some 25 theologians, economists, environmental scientists, and policy experts. Apparently the driving force behind this meeting was the Acton Institute and a group of like-minded individuals from other faiths.

[1] Beisner's bio, available on his website, states that he is "general editor and a contributing author and reviewer of the Cornwall Alliance's *A Renewed Call to Truth, Prudence, and Protection of the Poor: An Evangelical Examination of the Theology, Science, and Economics of Global Warming*, a scholarly study released in December 2009, and of *The Cornwall Stewardship Agenda;* author of *The Evangelical Declaration on Global Warming;* co-author, with climatologist Roy Spencer, environmental economist Ross McKitrick, and energy analyst and ethicist Paul Driessen, of *A Call to Truth, Prudence, and Protection of the Poor: An Evangelical Response to Global Warming*, a technical paper released in July 2006 by the Interfaith Stewardship Alliance (now Cornwall Alliance); and editor of the Cornwall Alliance's electronic newsletter on environmental science, economics, theology, ethics, and policy; http://www.ecalvinbeisner.com/bio.pdf.

This group produced *The Cornwall Declaration on Environmental Stewardship* and then released it in early 2000 in conjunction with the founding of the ICES. The declaration acknowledges that "as concerns about the environment have grown in recent decades, the moral necessity of ecological stewardship has become increasingly clear." But it also claims that "certain misconceptions about nature and science, coupled with erroneous theological and anthropological positions, impede the development of a sound environmental ethic." It also states that "some unfounded or undue concerns include fears of destructive manmade global warming, overpopulation, and rampant species loss." *The Cornwall Declaration on Environmental Stewardship* is largely a distillation of arguments made by E. Calvin Beisner in his book *Where the Garden Meets Wilderness* (1997), according to David Larsen, whose doctoral thesis addressed evangelicals and the environment.[2]

The authors of *The Cornwall Declaration on Environmental Stewardship* then circulated it among church leaders and solicited signatures. While a number of evangelical, Jewish, and Catholic leaders have signed the document, they were not responsible for its drafting or content.

The Interfaith Stewardship Alliance (ISA) was formed in November of 2005. According to its website, it "formed to take the principles of the Cornwall Declaration and apply them to specific public-policy issues in the environmental dialogue. The group changed its name to the Cornwall Alliance for the Stewardship of Creation in May of 2007 to more clearly reflect the tenets of its flagship document."

In 2009 in a media event at the Heritage Institute, the Cornwall Alliance released both *A Renewed Call to Truth, Prudence, and Protection of the Poor* and *An Evangelical Declaration on Global Warming*. Both documents were authored primarily by Beisner, but Roy Spencer, Paul Driessen, and Ross McKitrick were listed as contributing authors. Considering the limited number of authors and their lack of religious credentials, it is somewhat disingenuous to label these as evangelical documents. Once again, these documents have been circulated among church leaders for endorsements.

From all appearances, the Cornwall Alliance is the creation of E. Calvin Beisner and represents his views. He is the only person listed in association with press releases, media days, or other statements. Although the website lists an extensive Board of Advisors, there is no evidence that these advisors play an important role in its activities.

Appendix E
Recommended Publications and Resources for Action

A. Publications

Berry, R.J., ed. *The Care of Creation: Focusing Concern and Action.* Downers Grove, Ill.: IVP Academic, 2000. A book-length commentary on the Evangelical Declaration on the Care of Creation by a wide variety of scholars, including an account of the origin of this declaration.

[2] David K. Larsen, *God's Gardeners: American Protestant Evangelicals Confront Environmentalism, 1967-2000."* Ph.D. Dissertation, University of Chicago, 2001.

Basney, Lionel. *An Earth-Careful Way of Life: Christian Stewardship and the Environmental Crisis*. Downers Grove, Ill.: Intervarsity, 1994. Practical ways of living out Christian stewardship.

Bouma-Prediger, Steven. *For the Beauty of the Earth: A Christian Vision for Creation Care*. Grand Rapids, Mich.: Baker Academic, 2001. Caring for creation as a vital feature of Christian discipleship.

DeWitt, Calvin B. *Earthwise: A Guide to Hopeful Creation Care* (third edition). Grand Rapids, Mich.: Faith Alive Christian Resources, 2011. A study guide for churches and discussion groups, with suggestions for discussion leaders.

Glacken, Clarence. *Traces on the Rhodian Shore: Nature and Culture in Western Thought from Ancient Times to the End of the Eighteenth Century.* University of California Press, 1976. A preeminent treatise for scholars.

Granberg-Michaelson, Wesley. *Tending the Garden: Essays on the Gospel and the Earth*. Grand Rapids, Mich.: Eerdmans, 1987. Biblical and theological insights on the relation of God, humanity, and creation.

Houghton, John T. *Global Warming: The Complete Briefing* (fourth edition). Cambridge: Cambridge University Press, 2009. A comprehensive treatment by a pre-eminent climate scientist and evangelical Christian.

Koetje, David S., ed. *Living the Good Life on God's Good Earth*. Grand Rapids, Mich.: Faith Alive Christian Resources, 2006. Essays on practical living, with discussion questions for small groups.

White, Robert S. *Creation in Crisis: Christian Perspectives on Sustainability.* London: SPCK, 2009. The present state and future hope of the earth prepared by theologians, scientists, economists, and development experts as they together worked to address the root causes of unsustainability.

Wilkinson, Loren, Peter DeVos, Calvin DeWitt, Vernon Ehlers, and Eugene Dykema. *Earthkeeping: Christian Stewardship and Natural Resources (1980)* and *Earthkeeping in the Nineties: Stewardship of Creation* (1991), Grand Rapids, Mich.: Eerdmans.

B. Other resources

A Congregational Checklist (from http://www.crcna.org/pages/osj_creationcareresources.cfm)
This checklist comes from the Office of Social Justice of the Christian Reformed Church in North America. For more information, see www.crcna.org/osj.

WORSHIP

How often during the year are environmental concerns included in sermons?

☐ never ☐ occasionally ☐ special services (Earth Day) ☐ frequently

In your church's prayer life, do you . . .

☐ praise God as the Creator? ☐ give thanks to God for the gift of creation? ☐ ask forgiveness for the harm done to the earth? ☐ pray for the healing of creation?

Yes	No	Potential to develop	**THEOLOGY** *Does your church . . .*
☐	☐	☐	Include environmental issues in a teaching or preaching program?
☐	☐	☐	Encourage practicing Sabbath as a community / individuals?
☐	☐	☐	Educate parishioners re: Reformed eschatology as opposed to popular end-times beliefs?

Some-times	Never	Potential to develop	**CHILDREN'S PROGRAMS:** *Do the following programs include earthkeeping elements?*
☐	☐	☐	Kids church / children in worship / Sunday school
☐	☐	☐	Cadets / GEMS
☐	☐	☐	MOPS

Have done	Could consider	**YOUTH PROGRAMS**
☐	☐	Undertake a practical environmental/conservation project (trash pick-up, road adoption, etc.)
☐	☐	Assess how environmentally friendly the church is and make recommendations for action

Have done	Could consider	**ADULT EDUCATION/FORMATION**
☐	☐	Environmental Bible study / Sunday school class / speaker
☐	☐	Organize / participate in a carbon fast
☐	☐	Organize carpool schedule for church services / activities

Have done	Could consider	**PROPERTY MANAGEMENT**
☐	☐	Switch to green electricity (if offered by the electric company)
☐	☐	Commission an energy / environmental audit (free with membership in Interfaith Power and Light)
☐	☐	Encourage switching off unnecessary lights / equipment not in use; not leave items on stand-by (copier, etc.)
☐	☐	Install low-energy light bulbs where appropriate, replace lighting fixtures with timed or motion-sensitive lights
☐	☐	Check water faucets – fix drips / leaks, install aerators
☐	☐	Collect downspout water in rain barrels, use in garden
☐	☐	Install a bike rack

Have done	Could consider	**FINANCE & PURCHASING**
☐	☐	Use environmentally friendly cleaning materials and paint
☐	☐	Purchase recycled paper and envelopes
☐	☐	Purchase fairly traded products
☐	☐	Use local suppliers where possible

Have done	Could consider	KITCHEN
☐	☐	Use reusable cups / plates; corn-based rather than plastic
☐	☐	Use farmers markets and other local suppliers for food
☐	☐	Compost used coffee grounds / uncooked food scraps

Have done	Could consider	RESOURCE MINIMIZATION
☐	☐	Get a Paper Gator, www.papergatorrecycling.com
☐	☐	Reconsider the need to print materials (bulletins, mailings, etc.); ensure easy recycling for materials

Have done	Could consider	CHURCH GROUNDS
☐	☐	Native landscape responsible to watershed (rain gardens, omit pesticide/fertilizer), promote wildlife flourishing (birds, bees)
☐	☐	Trees planted for shade / wind protection, reducing the need to heat and cool building
☐	☐	Environmental consideration of church improvements (carpet, paint, bathrooms, green space, drainage for parking lots, etc.)
☐	☐	Compost yard waste

Have done	Could consider	PERSONAL LIFESTYLE
☐	☐	Publish green tips in church newsletter
☐	☐	Promote use of reusable shopping bags and coffee mugs
☐	☐	Encourage a Community Supported Agriculture, where local farmer provides weekly shares of crops
☐	☐	Promote a "Green Challenge" for lifestyle changes

Have done	Could consider	COMMUNITY OUTREACH
☐	☐	Participate in local environmental initiatives or policy formation (e.g., local watershed cleanup project, etc.)

Have done	Could consider	GLOBAL OUTREACH
☐	☐	Support the work of development agencies (CRWRC) and campaigns (Micah Challenge)
☐	☐	Support the work of international conservation and environmental agencies (e.g., A Rocha, WWF, Friends of the Earth, Care of Creation, etc.)

C. A mini-workshop

This mini-workshop is excerpted and adapted with permission from *Earthwise: A Guide to Hopeful Creation Care,* third edition (Faith Alive Christian Resources, 2011), pp. 100-11.

The procedure described on the following pages will help you generate lots of ideas for making your church, household, or larger community a Creation Care Center. It then guides you to choose the best ideas to put into action.

This procedure enables people to bypass initial roadblocking debates about the validity of ideas or budget and time constraints. It also helps bring specific ideas into an organized, coherent statement to present to church or community leaders who have the authority to move ahead with an action plan. The group or community therefore benefits from the undiluted strengths, talents, and abilities of everyone involved.

The procedure works best with a group of five to fifty people who already share a concern for and an understanding of the various degradations of creation. A one-hour session usually is sufficient to identify and screen ideas. Following the session, results should be summarized and gathered into a document for further development and implementation by your group, church, or community leaders.

Because this process begins with particular local issues and uses available local talent, each resulting Creation Care Center will have its own personality, identity, and character.

Procedure

A. General Setting and Room Arrangement

Set up the room with chairs in a single circle. Once people are seated, remove extra chairs so that no empty ones remain (but keep extra chairs handy for any who might arrive after you've begun). Bring a supply of index cards or similar-sized sheets of recycled paper. You'll need three cards for each person in the group. Have pencils or pens available for everyone.

B. Generating Initial Ideas

When the group is seated, explain that a Creation Care Center is a community, large or small, that intends to honor God as Creator and Sustainer in every way. This mini-workshop aims to help people discover how best to accomplish this goal in the community and region in which they live.

To begin, give two blank cards to each person, noting that people should write on one side only. Then ask, "What specific idea can you think of to make our group (or larger community) a Creation Care Center?"

Have people reflect for a few moments and then write their idea on one of the cards. Help group members to think broadly and deeply by asking some additional questions while they are reflecting:

- What is our situation here?
- What local environmental problems need to be addressed?
- How can we become a kind of "window on creation care"—a model of how to care for God's earth?
- What do we have going for us that other groups (communities) do not?
- What special contributions could we make toward the care and keeping of creation?

The purpose of asking these questions at various points while people are reflecting is to help them think creatively. This process can help to free people from real or imagined constraints of having too little money, already full schedules, or the need to "be practical." It encourages them to come up with their best ideas.

When participants have finished writing (after 3 to 5 minutes), ask them to think of another best idea and to write that on the other card. Again ask

questions to help people think creatively. Urge them to move beyond the obvious.

C. "Idea Skimming"

After group members have finished recording their ideas, have them pass both cards to the person on their right. Repeat this step so that the cards have been passed twice. Then have everyone read both cards carefully. Tell the group that when you say "Pass," they should pass the card with the better idea to the person on their right. If both ideas have equal merit, they should select either one to pass.

Again give the signal to pass a card—the better of the two that each person is holding. Repeat this process from three to seven times, but not so often that people might receive a card they had earlier. Explain that this process sifts out best ideas by using a screen of different perspectives. The best ideas will naturally endure the screening of different viewpoints.

When you've decided as a group that you're done passing cards, each person should read aloud the better of the two ideas in his or her hand. Without making comments on the ideas, thank everyone as you collect each card that is read. Continue around the circle until each person has read one idea. Stack together the "better idea" cards, and set them aside.

D. More Ideas

Pass out another blank card to each group member. (Each person will now have a blank card and the card from the previous round.) Now ask everyone to take into account all the ideas they read as they passed cards around earlier. They should also reflect for a minute or two on additional ideas they could write down. Here are some additional idea categories you could mention:

- use of liturgy, sermon, songs, order of worship
- building, grounds, parks, streets
- region, state, nation, world
- animals, plants, woods, fields, wetlands
- earth's energy exchange, soil and land degradation, ecosystem dysfunction, habitat destruction, species extinctions, global toxification, human and cultural abuse

Again ask questions to encourage creative thinking while everyone is reflecting. When everyone has written an idea on a blank card, repeat the passing procedure from three to seven times and conclude with the reading of the better ideas. Again collect each card after it is read, making a second pack to set aside.

E. Filling Remaining Gaps

Ask if any of the remaining cards has a good idea that has not yet been read. If so, group members should read such cards and hand them to you so that you can make a third pack.

At this point you will probably be ready to end this session, having completed the groundwork of your mini-workshop.

F. Preparing Results

Together as a group (or having two or three persons assigned to this task), prepare a document based on the contents of the card packs. Identify major

topics and sort the cards into those categories. Typical categories that may emerge are Creation Care Committee, other congregational committees, administration, liturgy and worship, building and grounds, community, and so on. Arrange the categories in a logical order, with those that address the administration of your Creation Care Center at the top. Type up the ideas, organized by categories, suggest action plans for implementing the ideas, and add a descriptive title to the document.

G. Distribution of the Results and Follow-Up

After obtaining necessary approvals, distribute the document to all who should receive it. For example, you may consider printing the results in your church newsletter, if that applies. Follow this by examining each identified category and bringing the content of each category to the attention of leaders, committees, or task forces who can follow up on your findings with concrete actions. Use the document together as you take steps to become a Creation Care Center.

IDEAS GLEANED FROM VARIOUS GROUPS

The following list of ideas should not be consulted until after group members have generated their own ideas. For additional helpful ideas in your ongoing work as a Creation Care Center, you may wish to consult this list, compiled from churches and other groups who implemented the preceding mini-workshop.

A. Creation Care Committee

1. Form a committee of interested people to advise the church to raise creation awareness, build an understanding of God as Creator, and assist people to become better stewards of our Lord's creation.
2. Publish information on Christian environmental stewardship in your newsletter.
3. Include a selection of books and materials on Christian environmental stewardship in your library, including those with biblical principles, practical suggestions for action, and local natural history and ecology.
4. Provide creation-focused materials for homebound members and residents of nursing homes, including audiotapes of birds, running waters, and weather; provide bird feeders for people's windows, and set up a schedule for keeping the feeders filled.

B. Worship and Liturgy

1. Designate one Sunday each season for recognizing our commitment to God's earth.
2. Request a sermon on creation care and keeping.
3. Devote a portion of each worship service to creation awareness and care. (For example, have at least one family report on something they are doing to help take care of God's creation.)
4. Encourage leaders and members to extend the principle of compassion to all living things (human beings, flora, fauna, and the biosphere).

5. Hold a well-planned outdoor worship service on environmental stewardship in a park or in an awe-inspiring creation setting, followed by a picnic.
6. Plan a multigenerational half-day or even two-hour field trip to regain appreciation and concern for God's creation. Include such things as star viewing and delighting in the life of a river.
7. Plant a new church that emphasizes general (natural) revelation—that is, learning from the "beautiful book" of God's creation as well as from the Bible (special revelation). Its mission statement could direct that all members practice creation stewardship and promote and honor the Lord of creation in all respects.
8. Emphasize how each person can give others an impression of creation awareness and creation care in their everyday work and living.

C. Building and Grounds

1. Use a building sign that emphasizes the importance of caring for creation.
2. Have an energy audit to find out ways in which your buildings could use energy more efficiently. Become an "Energy Star Congregation" (Google "energy star" on the Internet).
3. Use energy-efficient lighting and switches that turn off automatically when people are not present and when window light is adequate.
4. Assign someone the responsibility to see that all lights, fans, and air conditioning are turned off when the building is empty.
5. Remodel to save energy, doing such things as insulating, adding solar units, putting in a heat-pump water heater, and installing dropped ceilings where appropriate.
6. Research and develop ways to generate your own electricity (using wind, solar, geothermal, or other energy) and perhaps send surpluses back into the power grid.
7. Set up recycling bins for sorting metal, glass, plastics, paper, and so on. Post signs to remind people of your group's recycling program.
8. Hang appropriate banners and wall-hangings in the halls and meeting area to help raise people's awareness of creation care.
9. Make provisions that encourage people to appreciate creation: windows that open, clear glass panes in appropriate locations for viewing creation's beauty, trees and flowers planted at points where they can be seen from inside the building.
10. Develop a naturally self-sustaining park (garden) where people of the community can come to enjoy peace, quiet, plants, trees, animals, and the Lord. Have a sign that states the purpose of the park. Plant berry bushes, trees, and flowers that will attract birds and other animals.
11. Add an open-air covered picnic area to your grounds.

12. Add a rain-filled irrigation tank for watering plantings on the property.
13. Encourage people to use alternate means of travel to gather at your building. Aim for a parking lot that has as many bicycles as cars. (Let it be known that in connection with this idea, casual clothing would be accepted and considered appropriate.)

D. Stewardship Education

1. Make use of books and articles in your church library that focus on creation care for different age groups.
2. Identify your church's connection to its environment by answering questions like these: What materials make up the products that we use? Where does our food come from? Where does our waste go?
3. Hold a six- or seven-week miniseries to explain the degradations of creation. Most people are unaware of the actual problems. Some sessions could be used to develop ideas for righting the wrongs that have been identified.
4. Provide pastors and teachers an opportunity to complete a special course of study dealing with responsibility to God's creation.
5. Develop service projects that involve families: flower and tree planting, recycling programs, adopting a highway stewardship program, speaking to other area groups about stewardship.
6. Serve as a host for children from an inner-city setting for a week. Focus together on the wonders of God's creation, aiming to learn from each other.
7. Involve members in activities that support local agricultural efforts in soil stewardship, such as contour cropping, intensive rotational grazing, reduced chemical inputs, and improved animal care.
8. Fund and support people to act as environmental stewards to debate and influence public policy in the interest of maintaining and restoring creation's integrity.
9. Invite people in your community to be part of your Creation Care Center.
10. Offer community education classes on the how, what, and where of recycling and energy conservation in your area. Become an information center for source reduction and all kinds of recycling.
11. Provide information on environmentally sound practices, such as the efficient use of home thermostats, air conditioners, and coffee makers; the safe disposal of home cleansers, batteries, plastics, petroleum-based products, organic matter—and so on.
12. Make an inventory of all plant and animal communities within a half-mile radius of your church. Display this inventory pictorially as an exhibit.

13. Organize annual or semi-annual "Creation Rehabilitation Workdays" for planting trees, cleaning up a stretch of highway, landscaping a vacant lot, or buying some land and protecting it.

14. Reclaim a piece of land—an urban park, a city block, or some other area, and take care of it, modeling stewardship and involving area residents. Or adopt a wetland or woodland, keeping it, caring for it, and using it to educate yourselves and others.

15. Take a field trip to a local landfill to show people the waste we generate in our society.

E. Study Groups, Youth, and Christian Education

1. With others in your church, approach Bible study with an openness to receive the message of the Creator on creation care and keeping.

2. Hold vacation Bible school at a local county park, or hold the final celebration of the Bible school at a park, hosting a potluck dinner afterward. Bring students on walks for the purpose of discovering creation, learning awe and wonder, and developing an understanding of caring for creation.

3. Start an environmental awareness and creation care program with Sunday school students, involving them in an environmental cleanup or appreciation project each month.

4. Make creation awareness part of the church school curriculum. Involve adults of all ages in teaching lessons for the children about the need to preserve our world, and provide practical instruction in how to do this. Help children understand animals through pets under their care.

5. Gather a forum of interested business and science professionals in your church or wider community to discuss and propose solutions for alternative energy sources, renewable energy concepts, and improved energy use in support of creation care and keeping.

F. Congregational Life and Response to Creation

1. As a congregation, commit to living out your faith through caring for the part of God's creation in which you live. For example, commit to caring for a nearby creek or watershed, adopting a highway or endangered species, recycling the garbage you produce, and keeping your cars and homes as environmentally fit as possible.

2. Arrange for informal meetings of church families at a local park on a regular basis. Invite individuals who can give presentations on nature to help people notice and understand their natural surroundings.

3. Start a program that involves all family members in conducting whole-family environmental and conservation projects in and around their homes and neighborhoods.

4. Have each individual set a personal goal each month to transform talk into action.

5. Hold a Friday- or Saturday-evening retreat that includes nature study and star-watching.
6. Plan a multigenerational tree-planting event that involves entire families.

G. Resource Use and Conservation

1. Purchase glass or ceramic dinnerware and communion cups instead of throwaway paper and plastic products.
2. Arrange to have various meetings held at the same time to conserve heat and air conditioning.
3. Adopt a "no chemical use" policy for lawn and plant care.
4. Adopt a "no throwaway" policy for functions at which food and drinks are served.
5. Use cloth tablecloths for church functions.
6. Use recycled paper for church bulletins, publications, and correspondence.
7. Put timers on outside lights.
8. Put motion- and light-detecting wall switches in appropriate places so that lights automatically go out when people are not present or when natural lighting is adequate.
9. Develop a car pool or mass-transit arrangement for bringing members to church. Also include bicycle racks. This will reduce the need for a large parking lot and will allow you to turn part of it into a garden for trees, flowers, and other plants.

H. Personal Lives, Lifestyle, and Home

1. Encourage members to make their homes and workplaces into Creation Care Centers.
2. Provide opportunities for all members to commit themselves to stating what they will do as stewards of creation.
3. Arrange for a "pedal-power activity" and use it as a basis for discussing how you can help others, yourselves, and creation.
4. Adopt energy-efficient practices for the use of heaters, air conditioners, lights, and various appliances at home.
5. Continue to show and explain to others the importance of creation care displayed in your own life.

I. Cooperation with Other Groups

1. Search out other groups (churches, schools, businesses, neighborhood associations, community centers) and invite them to join you in forming a Creation Care Center. Publicize what you are doing to encourage others.

2. Form a team to glean from other groups the best ideas and approaches for developing a Creation Care Center, and share these concepts with your church leaders to stimulate thinking and response.
3. Plan a community-wide workshop on God's creation that involves all the organizations of the community. Follow up with projects on energy conservation, clean-up, materials use, and more.
4. Conduct a city-wide energy and waste audit of public-use buildings.

J. Providing Leadership in Society

1. Be leaders in speaking out against the degradation of creation.
2. Continue efforts with other groups in the community to form a task force to encourage concern about environmental issues, and work on things that the community as a whole can do to improve or properly take care of the environment (such as cleaning up a riverbank, lakeshore, or part of a highway).
3. Conduct a study of various occupations and how they affect creation, and then discuss these issues in a community forum, inviting businesses and workers and others to brainstorm about how to improve on or eliminate negative impacts.
4. Urge your community's or organization's governing bodies to make a statement about creation and the environment that offers practical application for daily living.
5. Use the connections you can make with websites to pull together statements on caring for creation that have been produced by other groups, and glean ideas for stewardship and action.

K. Yet More Ideas!

- Build window boxes, rooftop gardens, ground-level gardens; promote other environmentally conscious architecture.
- Build fish ponds with fluorescent night lights for insect feeding.
- Plant edible flowers (nasturtiums).
- Encourage or practice rotational grazing or regenerative gardening.
- Engage in native plant restoration, indigenous gardening, and forest garden techniques.
- Encourage seed and tree distribution.
- Reclaim creation terminology in liturgy, psalmody, hymnody, and sermons.
- Establish walking trails through woodlands, fields, and gardens; include signs that identify tree and plant varieties.
- Restore habitats around homes to provide for a large diversity of creatures.
- Develop lawns with biodiversity that fix their own atmospheric nitrogen and naturally recycle thatch.
- Assist on a farm; buy your meat "on the hoof" and have it processed.
- Purchase a hundred acres of tropical rainforest for preservation.
- Give environmental stewardship awards to deserving members of the community.

- Develop a paid summer stewardship mission experience for young people at the wages they might earn as a fast-food clerk.
- Make your setting a distribution center for native flowers and trees on Arbor Day.
- Make your setting a distribution center for vegetable seeds and related literature on food and the environment in late spring.
- Talk with a farmer about planting a crop for direct human consumption; help identify a market for it; direct any surplus food to a local food pantry.
- Develop a wheelchair nature loop at a retirement or nursing home.
- Conduct a food-source or hunger awareness dinner at church.
- Encourage a local restaurant to use placemats that show the relationship of menu items to the places where food is grown.
- Encourage a local newspaper to get involved in environmental issues.
- Organize the restoration of native vegetation along a stretch of roadside.
- Discuss the difference between tree planting and forest restoration and follow it with a restoration project.
- Buy a worn-out piece of land and redeem it for productive gardening or re-establishment of native species.
- Arrange for an "astronomy night" to help make Psalm 19 come alive.
- Spend a half-hour or more in autumn lying on a forest floor, listening to leaves fall and observing woodland creatures.

Appendix F
Glossary

Biosphere: The thin covering of our planet that contains all of life and is knit together by exchanges of material, energy, and information. It extends from the deepest parts of the sea upward to the outer limits of the atmosphere, but is concentrated within a few miles' elevation at the surface of our planet.

Biota: The totality of living things in a particular area or ecosystem.

Ecosystem: A particular system of interwoven and interacting living things with their physical environment that can be distinguished from its surroundings. Examples are wetland ecosystems, lake ecosystems, prairie ecosystems, and urban ecosystems. The largest ecosystem is the biosphere.

Ecosystem services: The services provided by an ecosystem; for example, flood control by wetland ecosystems along rivers, purification of water by plants as they move water from the soil into the atmosphere, and food production by photosynthesis.

El Niño Southern Oscillation (ENSO): This is a back-and-forth variation of surface air pressure between the eastern and western tropical Pacific Ocean, with pressure being high in the eastern tropical Pacific when it is low in the western tropical Pacific, and vice-versa. When the surface low pressure develops near northern Australia and Indonesia and the surface high pressure develops over the coast of Peru, trade winds over the Pacific Ocean move strongly from east to west, carrying warm surface waters westward,

bringing convective storms to Indonesia and coastal Australia; at the same time, along the coast of Peru cold bottom water rises to the surface to replace the warm water that is pulled to the west, bringing with it an upwelling of deeper ocean life that strongly affects the fish catch there. This oscillation has profound effects on the climate of the southern hemisphere and is a principal driver of year-to-year climate variability in the Pacific Northwest of Canada and the United States. The name given to the development of warm surface waters at the edge of the sea in Ecuador and Peru by fishermen there is El Niño (Spanish for "Christ child") because when it occurs, it is near Christmastime (for more information, see: http://www.physicalgeography.net/fundamentals/7z.html).

Exponential: Applied to something that is increasing (or decreasing) and does so by doubling (or halving) over a specific interval of time. An example is the population growth of the well-known bacterium *Escherichia coli* (*E. coli*) whose doubling time is 17 minutes when given the necessary combination of sugar and salt. The doubling time can be determined for any system by dividing the number 70 by the percent annual growth rate, meaning that a population, savings account, or GDP that is increasing at a rate of 1 percent annually will double in 70 years.

GDP (Gross domestic product): The market value of all final goods and services produced within a country in a given year.

Global south: Largely refers to the nations of Africa, Central and Latin America, and a majority of Asia. Although not divided solely by geographic boundaries (i.e., all countries south of the equator), most countries in the global south are located in the southern hemisphere. In general, these nations are less developed (socioeconomically) and may also bear the brunt of the challenges facing our world, including, but not limited to, climate change.

Units of Measure:

Mass (and weight):
- Kilogram (Kg): 1,000 grams = 2.2046 pounds
- Metric ton (tonne): 1,000 Kg = 1.102 tons (U.S.)
- Petagram (Pg): 1 billion metric tons = 1 gigaton
- Ton (U.S. measure): 2,000 pounds = 907 Kg
- Pound (lb.): 454 grams

Area:
- Hectare (ha): 10,000 square meters = 2.47 acres
- Acre (ac): 4,840 square yards = 4047 square meters = 0.405 hectares

Appendix G
Biographies of Contributors

Dr. Thomas Ackerman is Director of the Joint Institute for the Study of the Atmosphere and Ocean (JISAO) and Professor of Atmospheric Sciences at the University of Washington. From 1999 through 2005, he served as the Chief Scientist of DOE's Atmospheric Radiation Measurement (ARM)

Program and was a Battelle Fellow at Pacific Northwest National Laboratory in Richland, Washington. Dr. Ackerman was Professor of Meteorology at Pennsylvania State University from 1988 to 1999, as well as Associate Director of the Earth System Science Center. He has authored or co-authored more than 175 peer-reviewed journal articles on a wide range of climate-related topics and received several awards for his research papers. He is the recipient of the NASA Distinguished Public Service Medal and the Leo Szilard Award for Science in the Public Interest, awarded by the American Physical Society. Dr. Ackerman is a Fellow of the American Association for the Advancement of Science and a Fellow of the American Geophysical Union. He is a member of Sanctuary Christian Reformed Church in Seattle, Washington, and has served as a deacon and elder in CRC congregations and as elder in the Presbyterian Church of America and the Reformed Church of Australia. He has also served on and chaired a Christian school board. Further information available at http://www.atmos.washington.edu/~ackerman/.

Dr. Tom Bruulsema directs research and education programs in the Northeast region for the North American program of the International Plant Nutrition Institute, a not-for-profit, scientific organization dedicated to the responsible management of plant nutrition. Dr. Bruulsema is a Fellow in the American Society of Agronomy and the Soil Science Society of America, an Adjunct Professor in the Department of Plant Agriculture at the University of Guelph, and a Certified Crop Adviser. He has research experience in soil science with Cornell University and the University of Minnesota, and in Bangladesh agronomy with the Mennonite Central Committee. He is a member of New Life Christian Reformed Church in Guelph, Ontario, Canada, and has served for over nine years on local Christian school boards. Dr. Bruulsema holds a B.S. from the University of Guelph (1983, Agriculture), M.S. from the University of Guelph (1985, Crop Science), and Ph.D. from Cornell University (1994, Soil Science). For further information, see http://nane.ipni.net/staff/Director-Tom-Bruulsema.

Mr. Ted Charles is the son of Mr. and Mrs. John M. Charles, born into the Waters Flow Together clan and for the Bitter Water clan of the Navajo tribe on March 10, 1941, at Ft. Defiance, Arizona. Raised in Shiprock, New Mexico, he graduated from high school at Rehoboth Mission School in 1959. He attended Dordt College from 1959-1961; he subsequently joined the United States Marine Corps and served at home and abroad from 1961-1966. Mr. Charles returned to a degree program in 1966 and graduated from Biola College in 1970. He later received a M.A. from Northern Arizona University in Flagstaff, Arizona. He went on to work at Rehoboth Mission for seven years and later taught for twenty more years in the Gallup McKinley County School system, retiring in 1999. Mr. Charles subsequently assumed the position of pastor of the Ft. Wingate CRC and retired from church work in July 2011.

Dr. Calvin B. DeWitt is Professor of Environmental Studies Emeritus, Nelson Institute, University of Wisconsin-Madison, where he is a member of the graduate faculties of Environment and Resources, Conservation Biology and Sustainable Development, Water Resources Management, and Oceanography and Limnology. Dr. DeWitt is a Fellow of the University of Wisconsin Teaching Academy, recipient of the Chancellor's Award for Distinguished Teaching, and teaches Environmental Science. He is a member of the Ecological Society of America, the International Science Society for Science and

Religion, a Corresponding Editor of *Christianity Today*, a member of the editorial board of *Christians in Science*, and a recipient of the Connie Award of the National Wildlife Federation for his work as "a world-class conservationist" in Christian environmental stewardship. He is an elder in Geneva Campus Church and lives south of Madison on the Waubesa Wetlands in the Town of Dunn, where in the mid-1970s he served as Town Chair (Mayor) and helped bring his town to receive the RenewAmerica Award in 1995 and 2000. In 2002, he organized Climate Forum 2002 with his British colleague, Sir John T. Houghton, which produced the *Oxford Declaration on Climate Change,* a statement that has been particularly instrumental in bringing climate issues into the concerns of evangelicals and the wider public. His most recent book is *Earthwise: A Guide to Hopeful Creation Care*, third edition (Faith Alive Christian Resources, 2011). Another book, *Song of a Scientist* (Faith Alive), is scheduled for release in spring 2012.

Ms. Anoushka Martil works as an environmental scientist in the environmental assessment group at SENES Consultants Limited, Ontario, Canada. Her educational background includes a B.Sc. in Environmental Science and an M.A.Sc. in Environmental Applied Science and Management. Her thesis focused on environmental justice issues and its integration in project development using case studies in Sri Lanka. Ms. Martil holds certificates in Geographic Information Systems and Remote Sensing and Greenhouse Gas Verification and is currently earning a certificate in Renewable Energy. She is also a Certified Environmental Practitioner-in-Training, Canadian Environmental Certification Approvals Board, Calgary. Her experience in Sri Lanka includes working with consulting firms and international donor agencies such as the Asian Development Bank and the World Bank. Born in the city of Colombo, Sri Lanka, Ms. Martil has lived in Canada since 2001. She is a member at Friendship Community Church, Toronto. She is also very involved with Youth for Christ ministries, where she has served as a volunteer for more than eight years.

Dr. Mary L. VandenBerg is Associate Professor of Systematic Theology at Calvin Theological Seminary, Grand Rapids, Michigan. She has taught as an adjunct professor at Kuyper College in Grand Rapids and at Western Theological Seminary in Holland, Michigan. Her graduate work focused on atonement theology, and she is currently working in the areas of theological anthropology and soteriology. She is also interested in topics dealing with the intersection of theology and science. She has been married for thirty years and has three grown children. She is a member of LaGrave Avenue CRC in Grand Rapids, Michigan.

Mr. Peter Vander Meulen is the Coordinator for Social Justice and Hunger Action of the Christian Reformed Church in North America and previously worked for twenty-three years in managing community development projects in developing countries, including seven years in Africa with CRWRC. The focus of his work is with the agencies, congregations, and members of the Christian Reformed Church to help support and develop ministries to the poor and promote social justice through organizing and building social justice networks in CRC communities. Mr. Vander Meulen has served on the national board of Bread for the World, has been an elder in his local congregation, serves on the Immigration and Refugee Committee of Church World Service, and is recent Co-Chair of the Micah Challenge USA,

one of over 45 national anti-poverty coalitions rooted in global evangelical Christianity and inspired by Micah 6:8. He recently attended a CRWRC/World Missions conference titled "Restoring Creation: A Seminar on Environmental Degradation and Creation Care for Christian leaders in Bangladesh." During heavy rains and higher-than-usual flooding he learned how local populations are coping with rising environmental problems.

Ms. Amy Vander Vliet is a web editor at the Berkley Center for Religion, Peace, and World Affairs at Georgetown University. She joined the center in September 2006 as a research assistant, contributed to the report "Faith Communities Engage the HIV/AIDS Crisis: Lessons Learned and Paths Forward," and has offered editing support for numerous other Berkley Center publications, including *Embryo Politics: Ethics and Policy in Atlantic Democracies* (2011) and *Religion and Global Politics of Human Rights* (2011). She is a member of Washington, D.C., CRC and is currently serving her first term as deacon. Ms. Vander Vliet was also a youth observer to Synod 2009 and Synod 2010 and is part of the Leadership Exchange's young adult leadership team. She received her M.A. in Security Studies from Georgetown University and a B.A. in Political Studies and History from Dordt College.

Dr. Gerald K. Van Kooten is Professor of Geology at Calvin College, Grand Rapids, Michigan, and is a consultant for energy issues, particularly in Alaska. Dr. Van Kooten has work experience as an exploration and production geologist in geothermal, coal, and oil and gas. Before coming to Calvin College in 2004, he worked for ARCO in Dallas, Denver, and Anchorage. He has lived full- or part-time in Alaska for twenty-six years and has conducted exploration and geological field activities throughout Alaska. He also participated in ecosystem impact studies of Prince William Sound, Alaska, after the Exxon Valdez oil spill. At Calvin College, Dr. Van Kooten teaches the "hard rock" geology courses, including mineralogy, petrology, structure, and geochemistry. He also supervises student research and gives talks in the area on energy issues. As a geological consultant, he has worked for many clients, including small and large oil companies, the Federal Department of Energy, Alaska State resource agencies, Alaska Public Utilities, and various Alaska Native Corporations. Dr. Van Kooten holds B.S., M.S., and Ph.D. degrees in geology from the University of Washington (1973), Arizona State University (1975), and the University of California at Santa Barbara (1980). He is a member of Shawnee Park CRC in Grand Rapids.

Ms. Cindy Verbeek has worked as a volunteer and board member and has been a staff member of A Rocha Canada since 1996. A Rocha is an international conservation organization working to show God's love to all creation. She is now working as the Northern British Columbia representative and community mobilizer. Ms. Verbeek volunteers as a streamkeeper, farmer's market manager, and secretary for Healthy Options for People and the Earth (HOPE). She worked with Earthkeeping in Edmonton, Alberta, to produce the "Caring for Creation" study guide, worked on the *Birds of the McKenzie Delta* with her husband, and is currently working on a children's book called *There's a Salmon in My Classroom*. Ms. Verbeek is a B.S. graduate of the King's University College in Edmonton, Alberta, and a Naturalist Certificate graduate of the Au Sable Institute of Environmental Studies in Michigan. She attends Houston CRC, where she leads C4, a weekly women's

ministry, helps out with vacation Bible school, and coordinates the church's community garden.

Mr. Joel Visser practices environmental law in Washington, D.C. He graduated from Calvin College with a bachelor's degree in Chemistry. He holds a master's degree in religion from Yale University Divinity School and a master's degree in environmental policy from the University of Michigan School of Natural Resources and the Environment. Mr. Visser holds a juris doctor degree from the University of Michigan. He provides litigation and regulatory guidance with respect to a variety of environmental laws, including the Clean Air Act, Clean Water Act, Comprehensive Environmental Response, Compensation and Liability Act (Superfund), and National Environmental Policy Act. Mr. Visser currently attends Silver Spring (Md.) CRC.