Introduction

We humans have sought spiritual understanding throughout our history. There is an innate impulse to worship something larger than us. As our ancestors became toolmakers, herders and farmers, their suspicion grew that the world around them had been fabricated by a Creator more skilled than any human. Even as our own fabrication skills progressed from flint axes to microchips, the world around us still dwarfs and amazes. I have been a seismologist for three decades, and can write my own computer codes to simulate earthquake-induced vibrations of the whole Earth to fair accuracy. Even so, I feel awed by the unpredictability of the largest earthquakes, by the tsunamis spawned by them, and by the near-total destruction that is left after the water recedes. Even as I struggle to model complex Earth processes, and sometimes succeed, I must acknowledge that my efforts will never duplicate Nature. Mankind's respect for the planet grows as it understands better its inner workings. Earth's physical processes sustain life as we know it, and life influences the expression of Earth's physical processes. In the 21st century, geoscience has achieved a tight focus on this symbiosis.

In this Essay, I a brief outline of the Earth-system paradigm for the geosciences, an emerging scientific revolution that has escaped the publicity of its revolutionary predecessor, the theory of Plate Tectonics. Plate tectonics explained the arrangement of earthquakes, volcanoes, mountain belts and curiously-matched coastlines at opposing sides of selected oceans. The Earth-system concept integrates plate tectonics into a larger picture of how our home planet works. Our planet's interwoven processes are truly far larger than humans and their civilizations, but not so large to but not so large to brush our activities aside. Despite advances in Earth science, the totality of Earth-system interactions remains somewhat mysterious and will retain its capacity for awe, even as more is discovered and explained by science. Both our scientific understanding and Earth's enduring mystery may be instrumental to our efforts to coexist within its limited resources.

Earth Science and the Earth System

Western science has its roots in the peculiar curiosity of the ancient Greeks in the natural world and the engineering prowess of their Roman successors. The flowering of modern scientific inquiry was fertilized in Christian Europe by religious inquiry, melding human creativity with inductive logic and the scientific method. In other religious cultures the belief in spiritual matters also left room for the development of abstract ideas and speculation on the evidence one can see all around us, e.g., mathematics in the medieval Muslim world. If one believes in a Creator, one must respect the evidence of Creation left to us. Although popular belief in the 21st-century holds that science and religion are opposed to each other, this opposition is artificial. Science is the application of human logic and human imagination, but science cannot entirely replace human faith as a tool for understanding our place in the universe. In theory, science and faith should address separate issues in human inquiry. In practice, science cordons off certain areas where observation and induction have adequate explanatory power. Many topics that our ancestors speculated to have supernatural causes have been shown by science to have natural causes. Nevertheless, many vexing questions of philosophy, such as "Is there a Plan?" and "How am I part of the Plan?" are likely forever to be matters of faith.

Part of what sustains a person's faith is evidence of order and purpose within Nature. Although human desire can impose order on almost any set of observations, the scientific method is a rigorous process for stripping away false assumptions and unworkable hypotheses. Many are suspicious of science because it is perceived to be impersonal, portraying the world as unpredictable, lacking a guiding hand. Such a view is outdated and should be discarded. Although many pleasingly ordered models for Earth's inner workings have been found wanting and discarded, those that remain validated by observation are, if anything, *more* pleasingly ordered. The world that geologists have imagined, and tested against data, is the opposite of the brutish incoherence that a faithful layperson might fear. Geologists in the 21st century work under the paradigm of the "Earth system," a working hypothesis that nearly all Earth processes are interconnected in the transport and interchange of chemical substances, and the balance of energy between Earth's solid interior, oceans, atmosphere and space.

Although our world is full of events that we perceive to occur by chance, myriad natural processes contribute to the Earth system, its breathable atmosphere, its equable planet, and the soil and seawater ecosystems that feed us. More than a mechanical interconnectedness, Earth-system processes rely upon life as well, involving organisms from the lowly microbe to the lofty palm tree. Organisms help to determine the type of sediment that forms at the bottom of the sea, and therefore expand the variety of sedimentary and metamorphic rocks that we see in hillsides and quarry for our built environment. Imagine how many free-floating plankton in some ancient ocean contributed to the block of marble that Michelangelo carved into a likeness of the biblical David! Although an atheist can be satisfied that the densely interconnected nature of the Earth system has emerged from the reductive, impersonal machinations of the scientific method, the theist can find persuasive support for faith in a Plan embodied in the natural world.

In the next sections, I elaborate on the major components of the Earth system, how life figures into the paradigm, how the concept of steady state should replace equilibrium as our conception of our preferred situation in Nature, and what how an appreciation of our own place in the Earth system advises us toward sustainable practices. It is possible to articulate practical motivations for embracing a harmony between human society and the Earth system. However, spiritual motivations have the potential for greater alignment with human nature, and therefore a longer-lasting adherence to practices that are harmonious with our environment.

Plate Tectonics and Geochemical Cycles

Tremble, thou earth, at the presence of the Lord,
at the presence of the God of Jacob;
Which turned the rock into a standing water,

the flint into a fountain of waters.
Psalm 114

Water is central to life. Water figures prominently in faith traditions. Water covers most of Earth's surface. An imbalance of heavy oxygen isotopes in the oldest known Earth minerals suggests the presence of an ocean at Earth's surface shortly after its accretion from meteorites in the early solar system. Liquid water is key to the habitability of our planet. It is less familiar that water within the rocks of Earth's surface and interior -- enough water to refill the world's oceans more than once – is equally crucial to our planet's benign surface environment. Water and other simple chemical substances, such as carbon dioxide (CO_2), sulfur dioxide (SO_2), sulfuric acid (H_2SO_4) and halogen gasses (F_2,Cl_2,Br_2), react chemically with minerals to weaken bonds within crystal structures, or to form new crystalline structures. A granite block left in an open meadow will experience weathering when feldspar minerals react with rainwater and carbon-based acids to form clay. At the atomic level, water within mineral crystals induces weaker chemical bonding. At the macroscopic level "wet" minerals are easier to deform than "dry" minerals. Wherever water infiltrates solid rock and forms chemical bonds within its minerals, or converts dry minerals like olivine to wet minerals like serpentine, the rock weakens and can more easily be torsioned, sheared and bent.

Earth is layered, with a thin crust atop a rocky mantle that extends a bit less than halfway to Earth's center. Earth's core is solid metal, mostly iron, at its center (inner core), surrounded by a thick shell of liquid metal (also mostly iron, the outer core). Heat from Earth's interior rises from the core to the planetary surface via convection, the upward motion of hot rock. High temperatures cause solids to expand, and this expansion and lowered density go hand in hand. Less dense rock tends to rise, even though nearly all rising rock within Earth is solid. The physical properties of rocks within Earth's mantle were long predicted theoretically to allow convection, but until the 1960s many geologists, especially in the United States, resisted the idea that internal convection could force massive changes in Earth's surface landscape. Evidence for the slow lateral motion of continental land masses grew through midcentury until a geometric system was devised to explain such motion in terms of a finite collection of thin spherical-shell fragments, called plates. Semi-rigid everywhere but at their edges, the "tectonic" plates jostle and scrape each other at their edges. This leads to numerous earthquakes in a lacework of narrow belts within Earth's crust and shallow mantle, which together form the lithosphere, literally "rock-sphere," matching "atmosphere" and hydrosphere.

Earth's system of tectonic plates comprises the lithosphere. The solid rock immediately beneath is called the asthenosphere, and is hotter, weaker and less dense than the plates above. When two plates collide in slow-motion geologic time, it often happens that one piece of lithosphere sinks, or is shoved, into the asthenosphere. As long as sinking lithosphere is cooler than surrounding mantle, it will be more dense and will keep sinking. One of the spectacular confirmations of the plate-tectonics model for Earth is that earthquakes are found to occur in narrow, steeply-dipping zones beneath many of the boundaries where plates converge, tracing the path of the sinking lithosphere from the surface to depths approaching 700 kilometers. (The average thickness of continental crust is only 40 kilometers.) The lateral drift and downward "subduction" of lithospheric plates recasts the starring role in the epic blockbuster of mantle convection. Energetically speaking, the subduction of plates, that is, the descent of cool mantle rock in 150-km thick sheets, is more important than the rise of hot mantle rock, which tends to form narrow (diameter ~100 km) plume columns.

Although the predominance of cool subduction over hot plumes is supported well by observations, it complicates attempts to model Earth's interior processes faithfully with computer models. Without special treatment, the surface of a simulated, convecting planet will not break apart into plates. More importantly, the surface rocks of a simulated planet drift, stretch and converge, but do not recycle into Earth's interior. Instead, blobs of rock form along the bottom boundary of the stiff outer lithosphere and drip or peel off into the asthenosphere. The unbroken-shell convection style resembles what NASA scientists observed after the Magellan space mission radar-imaged the surface of Venus. There was little evidence of plate tectonics: no long ridges to match Earth's midocean ridge system, no parallel lines of volcanoes and surface trenches to match Earth's subduction zones. Evidence for rising plumes of hot rock were found, confirming the prediction the Venusian mantle convects, but in a manner different from Earth. Differences in convection are mirrored by differences in atmosphere and surface environment. Although Venus has size and composition that closely resemble Earth, its surface environment is dominated by the runaway greenhouse effect of a carbon-dioxide atmosphere nearly 100-times more dense than Earth's nitrogen-dominated atmosphere.

Although it is expected that the Venusian surface is hotter than Earth's surface, by virtue of Venus being closer to the Sun, its extreme surface conditions (>500°C) suggest that more than proximity is at fault. Carbon dioxide is a greenhouse gas, a leading factor in maintaining Earth's surface temperature in a range benign to life. As with French fries, however, one can have too much of a good thing. The Earth system maintains atmospheric carbon dioxide at far lower levels than Venus by reacting it with rocks to weather minerals, photosynthesizing CO_2 to fuel plant growth, and absorbing CO_2 via the ocean into the calcium carbonate shells of one-celled plankton, clamshells, and skeletal material of many other organisms. Earth's partial pressure of CO_2 has varied roughly from 0.0001 to 0.03 times atmospheric pressure during the Phanerozoic Era, more than 500 million years of the history of life. During this time the greenhouse effect has risen or fallen to induce expanded tropics or expanded ice sheets, respectively, but life has prospered throughout, or at least survived. By contrast, the CO_2 partial-pressure today on Venus approaches 100 atmospheres. Compared to lifeless Venus, surely, Earth is blessed.

The above is not the entire story of carbon dioxide within the Earth system. To sustain Earth's life-friendly climates, more CO_2 must enter the atmosphere to balance its consumption by rock weathering and life processes. The Earth system needs a carbon cycle in order to maintain this balance. Hydrous clay minerals and calcium carbonate shells settled into sedimentary traps and form shales and limestones. Undecayed organic matter, nearly all derived originally from the photosynthesis of CO_2, is buried to form coal, oil and gas deposits. Locked into rocks, these reservoirs of carbon cannot be tapped to re-invigorate the greenhouse effect. Without recycling, atmospheric CO_2 would dwindle, the greenhouse effect would falter, and Earth's chill would snuff out life as we know it.

Earth's carbon cycle is completed by plate tectonics. Laid down at the ocean bottom or at the margin of a continent, carbon-rich surface rocks follow downgoing plates into subduction zones. Under increasing pressure and temperature, the chemical reactions that bound CO_2 and water into minerals and organic compounds can reverse and liberate CO_2 and water to rise into the crust and mantle rocks within the overriding plate. These and other volatile compounds bond within new minerals within hotter rock, weakening chemical bonds and lowering the melting temperature of the deep rock. Wherever volatile-assisted melting occurs in a subduction zone, buoyant melt percolates toward Earth's surface, transporting most of the volatile CO_2, water and other substances that had induced the melting in the first place. Although science does not grant volition to a water molecule, poetry could narrate how a water molecule encouraged rock melting to satisfy her yearning to reunite with her liquid friends in the atmosphere and hydrosphere. After ascending while dissolved in a channel of molten rock, water, CO_2 and sulfur compounds exsolve from the melt as they near Earth's surface and vent forcefully at Earth's volcanoes, many of which lie directly above the subducting slab. Earth's most violent volcanic eruptions are propelled largely by the escape of gasses long locked away chemically within rocks.

Plate tectonics helps to complete Earth's carbon cycle, and thus prevents a runaway greenhouse effect on the cold side, that is, the opposite extreme to the scorching surface conditions of Venus. Plate tectonics also recycles water from surface rocks to replenish the oceans. The deep-Earth hydrologic cycle is less-appreciated because Earth's oceans are too large to be consumed by chemical reactions in Nature, at least in the current global climate. Critically, the relation of plate tectonics with water is symbiotic. Subduction transports water into the shallow mantle to be recycled via volcanic activity, and water facilitates rock fracture in earthquakes and rock deformation via weak or weakened hydrous minerals. The latter effect may be the missing ingredient that allows Earth's mantle to convect in a manner driven by lithospheric subduction. Plate tectonics recycles surface rocks, unlike convection in a tank of heated corn syrup or within Venus, which does not recycle surface rocks.

In Exodus (17:6) God instructed Moses to strike a rock, and water gushed to quench the thirst of the Israelites. In the Earth system, water not only sustains life and fills the ocean, but it also facilitates plate tectonics. The recycling of surface rocks helps to maintain Earth's greenhouse effect, suggesting that the cycling of water and CO_2 both slaked the Israelites' thirst *and* kept them warm. Subduction maintains these and other geochemical cycles essential to the Earth system and to life. This means that the catastrophes associated with subduction, such as the enormous 11 March 2011 Tohoku megathrust earthquake, can be seen as having a larger purpose: to recycle useful chemical substances from Earth's surface rocks into its interior and then back in volcanic venting or eruptions. Scientific understanding of the Earth system assures us that this disaster is neither random nor evil, but in the long view contributes to our welfare.

Life processes and the geochemical cycles

Life plays a crucial role in the Earth system, mainly as a facilitator of its geochemical cycles. Life processes, such as photosynthesis, clearly play a role in the carbon cycle. Rock weathering can proceed with only the carbonic acid formed by the combination of carbon dioxide and water (carbonic acid $H_2CO_3 \leftrightarrow H_2O+CO_2$), but it proceeds faster when a plant is involved. Plant roots produce organic acids in stronger concentrations than in rainwater, and are adapted by natural selection to liberate nutrients from rocks via weathering reactions. Organisms from free-floating foraminifera to sand-burrowing clams produce carbonate minerals for skeletal material, consuming dissolved CO_2 to form the minerals aragonite and calcite. These two minerals share the same chemical formula (calcium carbonate $CaCO_3$) but with different atomic lattices. Evolution has enabled biological systems to crack the code of two independent mineral lattices with the same chemical composition. Other organisms, such as planktonic radiolarians and diatoms, secrete silica, a glassy form of quartz (SiO_2). Humans and other mammals produce apatite (calcium phosphate $CaPO_4$) to form their teeth and bones.

The greatest biological role in the Earth system is arguably photosynthesis, the chemical trick of extracting CO_2 from the atmosphere to generate raw material for an organism, and simultaneously to generate energy for the organism's growth. The chemical reactions of photosynthesis have a slight preference for carbon atoms that are lighter. As a result, all organic matters that derives from photosynthesis, that is, plants and the animals that eat them, have a slight enrichment of carbon atoms with six neutrons, relative to carbon atoms with seven neutrons. This imbalance of carbon atoms is a clue to the presence of life in ancient rocks, even when no fossil can be found. Evolution produced more than one chemical pathway to photosynthesis, and each has a different preference for light over heavy carbon atoms. One can trace the encroachment of grasses, which use a geologically recent pathway to photosynthesis, into regions of forest and shrubland, whose plants use an older chemical process. Evidence for the floral change can be detected in the teeth of animals that ate the plants. We are what we eat, in an isotopic as well as a chemical sense.

Fossil fuels are critical for modern civilization, but their supply is limited ultimately by the total fossil organic material that lies at or near Earth's surface. All proven resources of hydrocarbons on Earth arise from biologic activity, most, but not all, associated with photosynthesis. Seams of coal are stratigraphic layers that typically contain beautiful plant fossils. Natural gas is methane typically produced by the underground microbes that decompose dead organisms. Most oil is formed from the organic matter preserved from algae and other photosynthetic plankton in ancient seas. Going back hundreds of millions of years, the black muck that spawns our fossil fuels has preserved an array of surprisingly complex organic molecules that match molecules found in present-day plants and animals. It is this commonality of life chemistry, coupled with the myriad genes shared by all living organisms in their DNA, that argue for a long-term stability in the basic processes of Earth life and in the symbiosis of life with Earth's surface environment.

Life is affected by more than one geochemical cycle. Recognizing this fact is critical to our successful management of our future. Life needs phosphorous, and modern agriculture is spending rapidly the geologic bank account of this element by mining phosphate deposits for fertilizer. Life needs nitrogen as well, but cannot easily obtain nitrogen from its closest source, the air we breathe. In this case human activity is creating an over-abundance of biologically available nitrogen, as another ingredient in our fertilizers, and this overabundance pollutes the environment. Sustainable agriculture is not simply a rejection of pesticides, but will require a thoughtful management of phosphorous, nitrogen, and other chemical resources that are alive within the Earth system.

What the Earth System Teaches Us: Steady State Versus Equilibrium

One of the ways to approach the Earth system in a spiritual manner is to appreciate the balancing fluxes of matter and energy within in it. According to tradition, the 6th-century BCE Greek philospher Heraclitus argued that "*Everything changes and nothing remains still. You cannot step twice into the same stream.*" Any geologist who studies rivers and floods knows this to be true, and that the riverbed changes as well. Each time a river floods, the increased flow scours sediment from its bed, and new sediment from upstream arrives to replace it. Nevertheless, it is common for the river and its bed to appear to be unchanging, year after year. This phenomenon of simultaneous change and stasis is called "steady state" or "dynamic equilibrium."

Steady state differs from simple equilibrium. An equilibrium state is defined as a situation that a system will return to if it is disturbed to a modest extent. An apt metaphor for equilibrium is a ball in a circular bowl. Pushed up the sides of the bowl, the ball will tend to return to its state of lowest potential energy, at the bottom of the bowl. This concept of equilibrium is static, not dynamic, because the final state of the ball does not change over time. In millions of living rooms across America, a similar metaphor determines the motions of US citizens: feeling thirst, a couch potato rises to fetch a beer, and then sits back down in front of the TV. The application of equilibrium thinking leads many people to believe that environmental problems do not need active attention from either individuals or their governments, that, left alone, the environment will return to its pre-historic state.

There is no monopoly of equilibrium thinking on either side of political and cultural debates. A select community of self-described conservatives believe that mankind can alter the world's landscape to its wishes, add unlimited greenhouse gasses to the atmosphere and Nature will respond quickly to absorb the damage, growing larger trees and adding new snowdrifts to melting glaciers. A select community of environmentalists subscribe to a extreme version of the Gaia Hypothesis originally articulated (in a less-extreme formulation) by the scientists James Lovelock and Lynn Margules, in which biological organisms act quickly to counteract any deleterious environmental change from outside forces, bringing Earth back into a state benign to life. (Articulated in this way, these two opposed groups seem to have much in common!) The Earth system would indeed be Paradise, or close to it, if the environment within which human civilizations grow were indeed an equilibrium state.

Geologic observations contradict equilibrium thinking. The Earth-system paradigm rejects equilibrium for the steady-state model. A sandy beach manifests a balance between coastal erosion and the supply of fresh sand from nearby beaches, eroding cliffs or river-sediment transport. If coastal erosion increases, say, from an increase in winter storm activity, its effect on the beach will not necessarily be counteracted by an increase in sand supply from rivers, cliffs and nearby beaches. Rather, the beach will shrink until diminished erosion from its diminished extent will be balanced by the unchanged supply of sand. The beach will change until a steady state is re-instated. Similarly, if developers build seawalls to halt cliff erosion or dam nearby rivers to manage fresh-water supplies, the beach will also shrink, even if coastal erosion processes are unchanged. In both cases, there is no equilibrium state for the beach, rather, a steady state that depends on a balance of Earth-system processes. In the worst case, achieving a steady state is impossible and the beach disappears or transforms to a different type of coastline. I have illustrated only changes that adversely affect a beach, but other changes, natural or anthropogenic, could also cause it to grow. A growing beach will also reach a new steady state, if it has enough time.

Evidence from geology also informs environmental problems much larger than an isolated shoreline. Traces of past conditions embedded in the rock record tell us that the Earth system can easily reach and sustain a large range of CO_2 concentrations in its atmosphere, from as low as half the pre-industrial CO_2 concentrations to as high as ten times today's value. Many steady states are possible, so it is quite reasonable to forecast that today's high CO_2 concentration (nearly 400 parts per million, or 400 ppm, compared to the pre-industrial 270 ppm) will persist or continue to rise on the millennial time scale of human civilizations. On the other hand, the Earth system has operated for at least 600 million years to produce environments in which life has thrived, but the wide range of environments falsifies an extreme version of the Gaia Hypothesis, that is, that the organisms of Earth's biosphere conspire to maintain an environmental equilibrium. Rather, Earth history is divided into eras, periods and stages, recorded worldwide in sedimentary layers, in which distinct steady-state environments persisted, characterized by steady-state ecosystems of flora and fauna. The organisms of one geological period would not vote to switch environments and be replaced by a different flora and fauna. There is evidence that life processes can destabilize climate as well as stabilize it. In the Carboniferous period (300-360 Ma) the ecological dominance of land plants in coastal swamps is believed to have drawn down CO_2 levels sufficiently to induce ice-sheet growth, sea-level retreat and consequently the destruction of the plants' swamp habitats. Although land plants are not the only factor recognized by geologists in this ancient dance of climate change, it is a causative factor that could gradually reverse to generate an ice-sheet cycle. For example, destruction of swamp habitat would reduce CO_2 consumption, increase the greenhouse effect, induce warmer climates and return the Earth system to its starting point in the cycle.

Steady state conditions in the Earth system have facilitated life as we know it throughout the Phanerozoic Eon, spanning the last 540 million years. There are a handful of Phanerozoic mass-extinction events in which a large fraction of then-living species were wiped out, associated with extreme events such as massive meteorite strikes or enormous sustained volcanic eruptions. Shocking the Earth system far out of its steady state is not healthy for the biosphere. The fossil record demonstrates that a full recovery of biodiversity after a mass-extinction event can take millions, if not tens of millions of years.

Not all Earth-system steady states have been benign to life. Just prior to the Phanerozoic, between 650 and 800 Ma, while evolution was producing more diverse and complex multicellular life forms, a catastrophic disruption to the surface environment induced three or more episodes of what geologists Joseph Kirschvink and Paul Hoffmann named Snowball Earth, a persistent steady state of low greenhouse-gas concentrations and ice-bound continental surfaces. Although all contemporary life lived in water, not on land, the marine biosphere suffered as well, with carbon-isotope evidence for photosynthesis weakening in the sediments laid down during this time. Far from a fine-tuned machine, the Earth system is capable of running the biosphere into a ditch off its evolutionary road.

The Role of Mankind in the Earth System

If microbes, grass and trees can help maintain balance in the carbon cycle without any knowledge of their role in the Earth system, what can the human species accomplish, with or without full knowledge of the consequences? Quite a lot, actually. We currently harvest a large share of the total biological productivity of the oceans, by skimming off the fish and mollusks within the marine food chain. We alter the reflectivity of our planetary surface, by converting forests to farmland, and a fraction of farmland to desert. Our 21st-century civilization is not unique in its impact on the environment. Prehistoric societies altered their landscapes consciously before they had a written language to document their intentions, for instance, burning down forests to create a savannah environment dense with game animals. The Earth system will survive our worst mistakes, at least over time, but our culture, as we now know it, might not. Each civilization makes a leap of faith when it assumes that a successful life strategy, whether a hunter-gatherer band, a village agriculture, an irrigated river kingdom, a sailing-ship commercial empire, or a fossil-fuel metropolis, can be scaled up to sustain a rising population. Both history and pre-history are littered with human societies where this faith failed, where exhaustion of resources, or defeat by a superior technology, terminated a cultural lineage. Is it any wonder that generations of humans prayed to a higher spiritual power to intercede against the contingencies that could upset their very survival?

Humans are changing Earth's climate via deforestation and the combustion of fossil fuels. Atmospheric CO_2 concentrations have risen from 270 ppm at the French Revolution to nearly 400 ppm today. Our civilization is capable of extracting and consuming every accessible scrap of oil, natural gas and coal within a few centuries. The best, though uncertain, estimates of climate response to a doubling of CO_2 in the atmosphere have hovered near 3°C since Svante Arrhenius extrapolated the effects of Earth's greenhouse effect in 1896. For a variety of reasons, scientists estimate that a global-average warming of 2°C can be tolerated by our ecosystems and civilization, but major disruptions are inevitable at higher values. These numbers offer some hope of reducing our current fossil-fuel usage before entering a danger zone of predicted effects. However, several researchers cite the ice-albedo feedbacks of our current geologic period as a neglected factor in previous estimates of climate sensitivity. In most numerical climate models and in ice-free periods of Earth history, climate response extends to greenhouse amplification, via water vapor, and rapid (decade or century scale) changes in land vegetation. Ice-sheet changes in most computer models are either neglected or modeled to occur quite slowly, at multi-century to multi-millennium time scales. However when ice-sheet changes are incorporated into estimates, or climate sensitivity is assessed only from glacial periods of Earth history, the climate response is amplified roughly by a factor of two. With a climate sensitivity of 6°C, we are already in the danger zone of damaging climate effects. We will not feel their full impact until the ice sheets of Greenland and Antarctica, and the glaciers of mountainous regions worldwide, fully respond to the change in the air. If the newer glacier-amplified climate scenarios are correct, the Earth system will not settle again into a steady state until, so to speak, our culture's goose is cooked.

In the worst-case scenario for climate, mankind's role in the Earth system would be to shove its climate state outside the range of the past few million years, escape the cycle of ice ages, and inaugurate a new era of drowned coastlines (from melted ice sheets), re-arranged deserts and forests, impoverished biodiversity, and a new human civilization on the ruins of the exhausted fossil-fuel economy. The journey to the new steady state would not be smooth, to say the least. With people, communities and nations all acting individually to advance their interests against the interests of competing people, communities and nations, the strongest units will survive and the weaker units will downsize or disappear. It is conceivable that natural selection could elevate one pool of human genes over all others, an eventuality that future paleontologists would recognize as a new species.

If we have sufficient scientific knowledge, and can articulate a policy to mitigate the problematic future of our place within the Earth system, what role can spirituality play? The answer is that spiritual values are the best defense against the raw, instinctive, mathematically-justified competition that, in a time of deteriorating environments, will consume souls as well as natural resources. The countervailing human instinct for cooperation, if expanded from family and tribe to include the entire Earth system and its diverse residents, is best harnessed by means of faith in a larger enterprise.

In the role of an ecological actor, the anthropologist Marcus Hamilton has characterized *Homo sapiens* as an invasive species that lacks the talents of most successful invaders. We are large, resource-hungry and slow to reproduce, but we have occupied, and eventually have dominated, nearly every ecosystem on Earth. We have not thrived in diverse and difficult environments by virtue of an absolute dedication to individualism and free markets. Most plants and animals survive or die alone, or in competition with each other, and their species have not matched the adaptability of Homo sapiens. Faced with this paradox, Hamilton and coworkers developed a mathematical model for human evolutionary fitness that allowed for cooperation among individuals, motivated by the observation from demographic data that socially-connected human groups tend to use resources more efficiently as the groups expand. Such a model helps to predict our successful invasions of new ecosystems. Knitted together by shared values, groups of primitive humans could cooperate to divide labor, brainstorm solutions to novel survival problems, and debate long-term goals. Modern humans could do the same, if they are not burdened with a rigidly individualist value system.

Individualism, at its most recalcitrant, stands apart from God. A God shared among a people implies a shared destiny, and shared values. Cooperative communities are rarely found that lack a spiritual kinship among members, even if several traditional religions are present side by side, for example, the success of nationalist movements in unifying the petty dukedoms of early-modern Europe. Post-Cold-War history has highlighted the reverse process, the successful propaganda to divide individuals within communities along cultural distinctions both subtle and sharp. Against this background, any call for us to recognize and develop a spiritual kinship between humans and the Earth system may seem foolish. However, the scale of the environmental challenges we face is too large to rely on human social cooperation based solely on kinship, friendship, religious sect, linguistic group or nationality. Split into competing groups, at whatever level, human societies are less likely to achieve the cooperative synergy that has allowed our species to surmount obstacles to its cultural evolution from merely the third great ape to the master of the planet. A shared understanding of how the Earth system works, and our place in it, is our best chance to bridge our most-cherished cultural divisions, and address our common predicament.