

Laudato Si' and Climate Change: The Current State of Scientific Understanding

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“Christianity and the ideas that lay behind it is a religion and a philosophy of creation.” (Glacken, 1967). Christianity is this and more because of its wide embrace of God’s revelation both in creation and scripture. As such, it is dedicated to holding all God’s truth together and consequently makes major contributions to understanding creation and providence, including the integrity of the biosphere and the unity of knowledge. In this it celebrates God’s provisions for a habitable earth including its “climes”—“inclinations” that “incline” it to be warmer or cooler at various sun angles with earth’s surface. These climes interplay with planetary energy exchange, joining with atmospheric and oceanographic processes, biogeographic and trophic dynamics, biogeochemical cycles, carbon cycling, and fossil carbon sequestration conceptually to emerge as “earth’s climate system”—a system that is inseparably integrated within the wholeness of “the earth system” (Steffen et al. 2004).

Our Scientific Understanding

This paper is a contribution to a day-long consultation on faith and science presented by The Committee on Doctrine of the United States Conference of Catholic Bishops and The Catholic University of America on Pope Francis’ encyclical letter *Laudato Si’ “on Care for Our Common Home.”* Its focus is on “The Current State of Scientific Understanding of Climate Change” as part of this consultation’s “conversation on faith and science” as a response to invitation of Pope Francis to enter into dialogue (*Laudato Si’* ¶ 3, 14). More specifically, this paper places climate change into the context of “integral ecology,” “responsible stewardship” and what may be called “The Biblical Stewardship Commission” of Genesis 2;15 as it addresses current scientific understanding of Earth’s radiative energy exchange with our star, the Sun, selective absorption by atmospheric gases including water vapor and carbon dioxide, molecular resonance of atmospheric gases, the different “roles” or “offices” of water vapor and carbon dioxide, atmospheric water dynamics, atmospheric carbon dioxide for 250, 2000, and 10000 years, the oceans and oceanic providence, physical climate models, RCP (representative concentration pathways) scenarios, and what RCP scenarios tell us about atmospheric providence and stewardship. This paper next anticipates movement toward global “decarbonization” and a “culture of care” in restoring earth’s long-standing carbonic temperature regulation and concludes that the current transition in knowledge and action makes *Laudato Si’* required reading as the only comprehensive treatise on understanding and caring for the earth system as our common home.

Reductionism and Fragmentation

Up until the 1870s, American colleges were dedicated to wholeness of God’s truth and designed to promote “the essential synergy between science and religion” (Roberts and Turner, 2000).

This changed however as “specialization” and “reductionism” became broadly endorsed, with division and subdivision of knowledge into disciplines, including widespread breaking off most seminaries as separate institutions. Reductionism fragmented the sciences, and this soon linked them “to skepticism as an operative principle” thereby limiting “the opportunity for religious truths to be ‘grounded’ in scientific claims.” This made it difficult to maintain knowledge of earth as an integral system, much less to express gratitude for it. No longer would a scientific treatise conclude as did astronomer Frank W. Very’s *Atmospheric Radiation* in 1900: “we find the atmosphere playing the part of a conservator of thermal energy, and must gratefully admire the beneficent arrangement which permits the Earth to be clothed with verdure and abundant life.” Soon thereafter the atmosphere would simply be taken for granted, without awe, wonder, or appreciation.

Holding All God’s Truth Together

Dedication to holding all God’s truth together resurged with remarkable strength on June 18, 2015 in a broadly integrative treatise, *Laudato Si’—On Care for Our Common Home*. This encyclical letter from Pope Francis published worldwide in a single day embraced God’s revelation both in creation and scripture with clear purpose: “faced as we are with global environmental deterioration, I wish to address every person living on this planet.” Grounded biblically and scientifically, it addressed climate change, biodiversity loss, ocean degradation, atmospheric pollution, and social degradation in 246 paragraphs—reintegrating disciplines and specialties created in the 20th century. In proposing an “integral ecology” the pope asserted that “fragmentation of knowledge and the isolation of bits of information can actually become a form of ignorance, unless they are integrated into a broader vision of reality” (§ 138). Each specialty promotes its “isolation and the absolutization of its own field of knowledge”—all of which “prevents us from confronting environmental problems effectively” (§ 201).

Earth’s Climate System as a Common Good

Importantly Pope Francis confronted “an excessive anthropocentrism” handed us as “a Promethean vision of mastery over the world, which gave the impression that the protection of nature was something that only the faint-hearted cared about” (§ 116). Contrary to such mastery, he cited the biblical commission of Genesis 2:15 that “should be understood more properly in the sense of responsible stewardship” (§ 116)—as a “culture of care” (§ 14). Such caring relationship opens us to awe and wonder, speaks of fraternity and beauty, and unites us intimately with all that exists (§ 11). It sees earth’s climate system as “a common good, belonging to all and meant for all... a complex system linked to many of the essential conditions for human life” (§ 23).

Endorsement of Laudato Si’

The largest organization of professional ecologists, the Ecological Society of America (ESA), commended Pope Francis—“clearly informed by the science underpinning today’s environmental challenges”—for his “insightful encyclical on the environment... an eloquent plea for responsible Earth Stewardship.” The largest U.S. environmental religious consociation, the National Religious Partnership for the Environment also commended Pope Francis, with links to supportive denominations, one of which is entitled, “Christian Reformed Church Celebrates Pope’s Call to Climate Action”—that “welcomes Pope Francis’s encyclical on environmental

stewardship, integral ecology, and climate change.” Affirming that “human-induced climate change is a moral, social justice and religious issue” the CRC statement calls on “its institutions, churches, and individual members to take steps to address it” and in accord with the pope’s focus on Genesis 2:15, this CRC release says “a central component of this task includes taking seriously God’s command in Genesis 2:15 to serve and to protect the rest of the created order and to exercise responsible stewardship.”

The Biblical Stewardship Commission

This “God’s command in Genesis 2:15”—the “biblical stewardship commission”—fosters a “culture of care” (§ 231) that implies a reciprocal relationship (“relación de reciprocidad”)—“a relationship of mutual responsibility between human beings and nature” (§67). This commission expects human beings to return the services of the garden with services of their own—practicing stewardship as “con-service.” But this reciprocal relationship can be broken by excessive anthropocentrism, circumstance, or specialization, resulting in carelessness, indifference, and consequent degradation. Stewardship is a practice not reducible to a single word, is a *realm of stewardship*. Thus both “to till” and “not to till” (as in no-till agriculture) may serve the garden. Beyond con-service, this commission of Genesis 2:15 requires “*guardening*”—providing a *realm of safe-guarding*. The realm of stewardship incorporates the realms of con-serving and safe-guarding as a comprehensive stewardship—while keeping in mind, that “realities are more important than ideas.” (§ 110).

Atmospheric Providence

In dealing with realities, scientific measurement is important. One such measurement is the temperature at the top of earth’s atmosphere (TOA). My colleague at Wisconsin Verner Suomi, who first used radiometers on earth-orbiting satellites to measure outgoing TOA radiation found along with later scientists this to be 240 watts per square meter (240 w/m²). The “Stefan-Boltzmann Law” computes this as equivalent to a minus 18° C (0.4° F). Yet, earth’s surface on average is about 15° C (59° F)—which computes as outgoing radiation of 390 w/m². The reason for this difference? *Earth’s atmosphere*. Clearly a life-sustaining gift of God’s providence, *earth’s atmosphere makes life on earth possible and sustains it*.

How is this achieved? “A great deal has been written on the influence of the absorption of the atmosphere upon the climate”, wrote Arrhenius in 1896. “The selective absorption of the atmosphere is, according to the researches of John Tyndall not exerted by the chief mass of the air, but in a high degree by aqueous vapour and carbonic acid [i.e., carbon dioxide], which are in the air in small quantities.” Absorption of sunlight by the atmosphere is “comparatively small” but is great for outgoing infrared radiation (IR) and this keeps the earth warmer than it would otherwise be. Thirty-seven years earlier, in 1859, physicist John Tyndall spoke at London’s Royal Institution “On the Transmission of Heat of different qualities through Gases of different kinds.” Passing light through a prism of rock salt onto a screen he showed elevated screen temperatures across the visible spectrum and surprisingly also in the invisible area below red (infrared, or IR). He next described constructing a three-foot tube sealed at both ends with plates of polished rock-salt through which he projected visible light—finding it to pass freely when filled with nitrogen, oxygen, water vapor or carbon dioxide. IR light also passed freely with the tube filled with nitrogen or oxygen, but blocked when filled with water vapor or carbon dioxide.

“The bearing of this experiment upon the action of planetary atmospheres is obvious,” he said. “The solar heat possesses...the power of crossing an atmosphere; but, when the heat is absorbed by the planet, it is so changed in quality that the rays emanating from the planet cannot get with the same freedom back into space. Thus the atmosphere admits of the entrance of the solar heat, but checks its exit; and the result is a tendency to accumulate heat at the surface of the planet.”

Selective Absorption

In 1865, Tyndall noted, “If you open a piano and sing into it, a certain string will respond. Change the pitch of your voice; the first string ceases to vibrate, but another replies.” Modern physical chemists measure these “ringing frequencies” or “resonances” for gas molecules as they respond to various frequencies of IR. Acting much like tiny springs, bonds that hold atoms together as gas molecules vibrate both by “stretching” and “bending” as they absorb IR at specific resonant frequencies. Di-atomic molecules have only a “stretching vibration” and are IR active only if the two atoms are different—thus the most abundant atmospheric gases, nitrogen ($N\equiv N$) and Oxygen ($O=O$) are IR inactive. The element Argon has no bonds, thus also is IR inactive. All gas molecules with three or more atoms are IR active—like atmospheric carbon dioxide ($O=C=O$) and water vapor ($H-O-H$), whose central “elbow” allows “bending vibrations” that flex above or below the “normal” angle of 180 degrees for carbon dioxide and 105 degrees for water vapor. Others with three or more atoms are methane (CH_4), nitrous oxide (NO_2), ozone (O_3), and chlorofluorocarbons (CFCs). Professor Veerabhadran Ramanathan’s research on CFCs at the Scripps Institution, found some CFC molecules about 10,000 times more absorptive than CO_2 . These five contribute about 5% of atmospheric IR absorption of which methane prevented and manufacture of CFCs can be eliminated, leaving two major IR

active gases, carbon dioxide and water vapor.

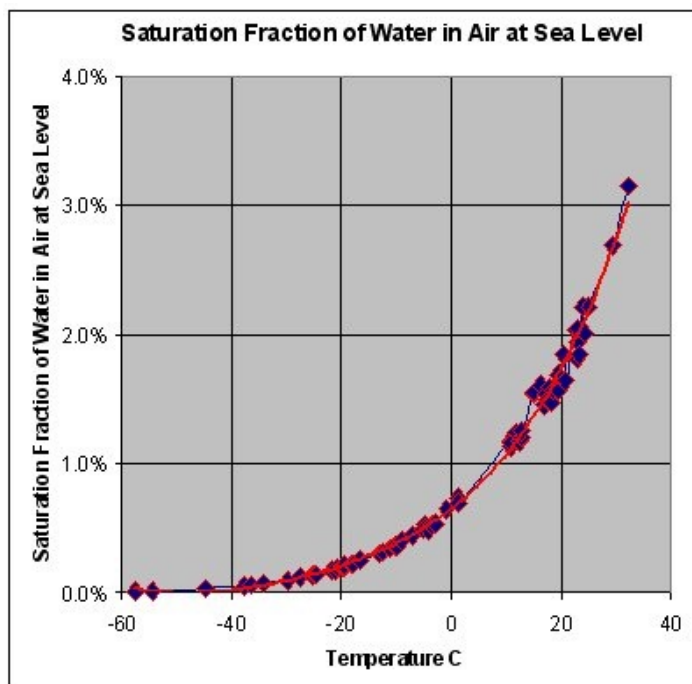


Figure 1. Saturation capacity vs. Temperature
Credit: Chemistry Stack Exchange

The “Offices” of Atmospheric Water Vapor and Carbon Dioxide

These two major atmospheric IR-active gases differ greatly in their respective “offices.” Carbon dioxide has a steady and continuous “carbonic presence” throughout the atmosphere at all temperatures. But water vapor varies widely in time and place from very high concentrations above tropical oceans to very low concentrations in polar climes where it can reach zero. Water vapor is a condensing gas and it has a temperature-dependent physical “cap”—a “saturation capacity” that compels it to condense into liquid when it reaches this temperature limit. Water vapor’s “cap” is cut

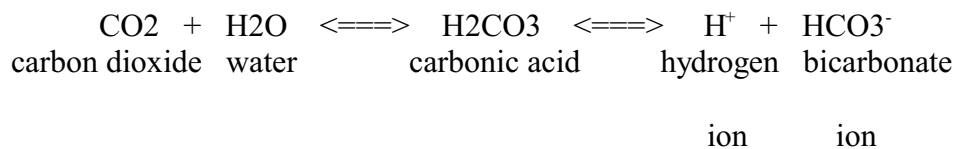
approximately in half for every 10° C (18 ° F) fall in temperature. In grams of water vapor per kilogram (g/kg) of dry air, it is about 49 at 40° C, 15 at 20°, 3.8 at 0°, 0.75 at -20°, 0.1 at -40°, and 0.01 at -60° C. In polar air it may drop below this cap to 0 g/kg (Bloch and Karasiński, 2014). In contrast, carbon dioxide does not condense, has no cap, and is everywhere present in earth's atmosphere.

Atmospheric Water Dynamics and Dramatics

Thus, water vapor concentration increases to higher levels in warmer air and as it moves upward and is blown to cooler places it condenses into liquid water, releasing its latent heat and forming mists, clouds, and precipitation. The energy released—its “latent heat of condensation”—is equal to its “latent heat of evaporation” that earlier was required for its transformation from liquid to vapor: 540,000 calories per kilogram. Once water vapor is thus removed it is soon restored by more evaporation into air that again moves upward and blown to cooler areas—its water vapor moving towards its temperature-dependent saturation cap. Water vapor thus serves as a powerful heat pump, moving immense amounts of energy from warmer to cooler places. In this movement, atmospheric and water vapor dynamics are often boisterous—in thunder storms, rushing winds, pelting rains, and bouncing hail—and calming in gentle dewfall, ascending vapor, and rising mists. Remove this vapor from the atmosphere and it comes back; add water vapor and it condenses out, with an average atmospheric residence time of about 10 days. By contrast, the other major IR-active gas—carbon dioxide—is steady and consistent with residence time ranging about 4 to 10 years.

It is an easy thing to take water vapor and carbon dioxide and their “offices” in the atmosphere for granted. But there is wonder here—well beyond what might be expected. Many of us who are scientists experience what might be called an “invitation to wonder!” It is an invitation that comes from the very things we observe, measure, and work to make sense of. And so it is very helpful to our thinking about and responding to the way the world works to join with scientists and others who respond to this “invitation.” One such person is Lawrence J. Henderson, an eminent biochemist and physiologist at Harvard University who at one point was descending Mount Monadnock in New Hampshire shortly before he would be teaching his course in the history of science. It was then, a century ago, that in a “flash realization” he realized that the fitness of life for its environment worked in parallel with the fitness of the environment for life—making fitness a mutual relationship between living creature and nature. He marveled at five materials: carbon, hydrogen, oxygen, and their combinations as water (H₂O) and carbon dioxide (CO₂). Wonderfully, he realized, these five are *simultaneously* (1) vital for life's physiological and biochemical regulation; and (2) essential to Earth's environmental and meteorological regulation. More marvelous still, Henderson realized that all five pre-exist life on Earth. Amazed, and unable to explain this scientifically, he concluded in his book *The Fitness of the Environment* (1913) that emerged from this realization, “*Matter and energy have an original property, assuredly not by chance, which organizes the universe in space and time.*” And, unable to explain this scientifically, wrote, “*This is in very truth a metaphysical doctrine...*”

And quite remarkably, this fine professor and thinker about the world he inhabited investigated carbon dioxide (then called carbonic acid) in aqueous solutions to discover the “extraordinary capacity of carbonic acid to preserve neutrality in an aqueous solution”—both in the blood and the oceans. By neutrality he is referring to its maintaining a particular level of pH (a measure of acidity and alkalinity). Remarkably, “no other substance shares this power,” thus making it remarkably fit for life, both within the organism and in the oceans. This is the “carbon dioxide-bicarbonate buffer system” whose precision is essential for all bodily functions and for stability of chemistry of the world’s oceans. This impressive system can be shown in this reversible equation:



The CO₂, on the left, can be exchanged with the atmosphere—directly from the atmosphere or via lungs and gills—while the bicarbonate (HCO₃⁻), on the right, can be excreted by the organism’s gills or kidneys, or it can react with calcium ions in the oceans to form a calcium carbonate precipitate. Remarkable here is that if strong acids or bases are added to this system, the pH remains nearly constant at an “equilibrium pH.” It is “buffered”—and Henderson, expert as he was in chemistry and physiology, was absolutely amazed by the fitness of this for life. It is also important also to realize here that the pH of the blood or water is buffered at a higher level or lower level depending upon how well the carbon dioxide (on the left of the equation) and bicarbonate ion (on the right) can be discharged into the environment. For CO₂, this depends on the difference in concentration of carbon dioxide of the air into which it is being discharged. A higher “outside” concentration means that CO₂ is discharged less readily, and vice versa. In our day, the rise in atmospheric CO₂ has shifted the equilibrium pH such that the upper water of the world ocean are 30% more acidic than it has been during the last 10,000 years.

Atmospheric Carbon Dioxide for 250, 2000 and 10000 Years

Atmospheric carbon dioxide is measured at observatories—as at Mauna Loa, Hawaii where “flask measurements” began in 1958—and from gas inclusions in ice. An ice core from Law Dome, Antarctica shows average CO₂ concentration of 43 records for 0 to A.D. 1600 (pre-Industrial Revolution) as 279.5 ppm (range: 276 to 284 ppm) as shown in Figure 2.

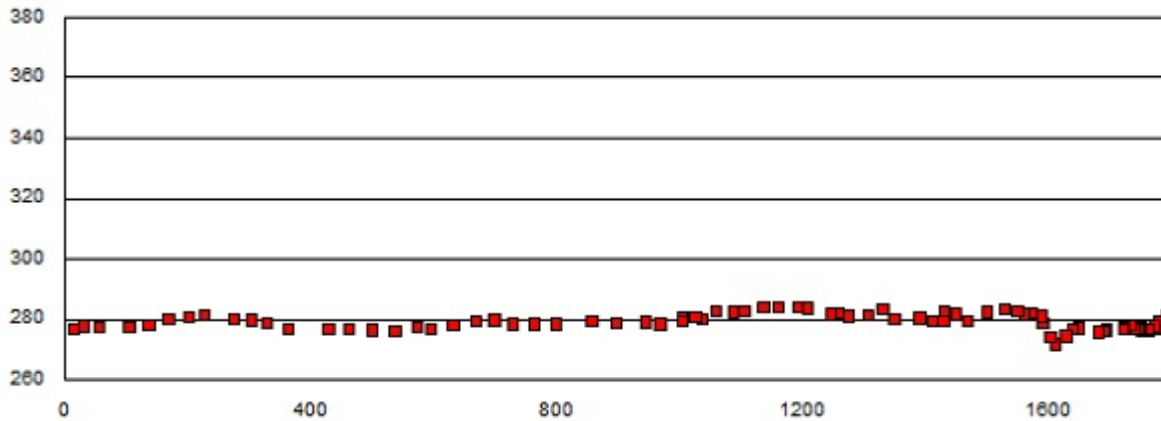


Figure 2. Carbon dioxide concentration (ppm) for the first 1600 years A.D.

Ice core records And Antarctic Vostoc cores show 7 measurements from 2,342 to 10,123 ago from 254.6 to 284.7 ppm (average: 266.2 ppm). These data show CO₂ maintained with remarkable regularity during recorded human history to about 1600 A.D.—near 280 ppm. This regularity gave human civilization climatically what physiological regulation gives bodily regulation: the freedom not to have to think about it. Over some 250 years of the industrial revolution, however, the atmosphere was given an additional role as a sink for airborne wastes and by-products of human industry, including carbon dioxide and nitrogen oxides. Measurements of atmospheric carbon dioxide concentrations, begun in 1958 by Charles Keeling on Maunas Loa, Hawaii, found a largely-unexpected continual increase. I have added data for this period of about 2050 years both from the Law Dome ice cores and the data from Mauna Loa shown to Figure 2, with the result shown in Figure 3.

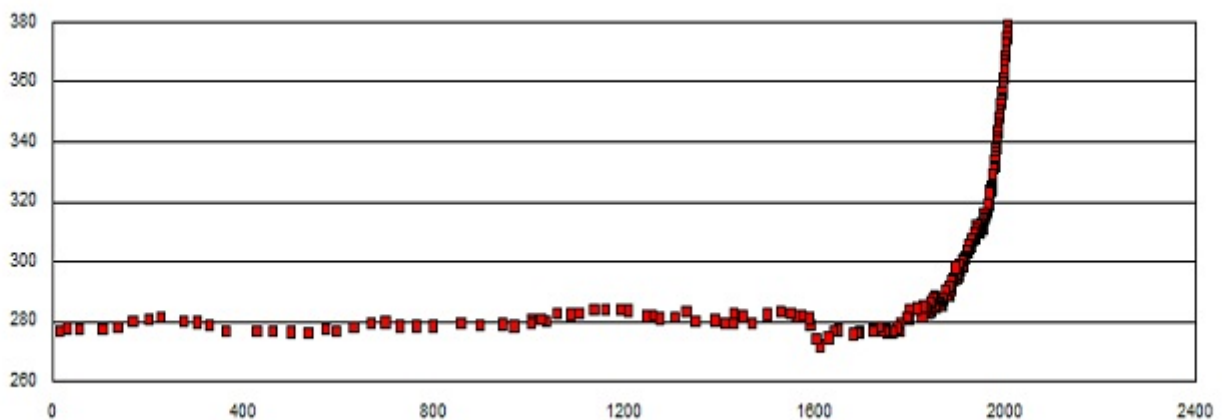


Figure 3. Carbon dioxide concentration (ppm) for the past 2000 years.

As March 2015 became the first month in recorded human history that CO₂ concentration rose above 400 ppm at observatories around the globe, interest in the role of this atmospheric gas has increased greatly.

“Integral Ecology” —Getting it All Together

The consequences of these atmospheric additions are coming to be more fully understood, assisted by successively-improved physical climate models that cross relevant disciplines. Assessment Reports by the IPCC in 1990, 1995, 2001, 2007, 2014 (continuing at 6-7 year intervals) progressively gave an “up to date view of the current state of scientific knowledge relevant to climate change” (IPCC, 2015). The joining of these physical models with the “RCP scenario approach” extended their scope. Four RCPs published by 19 researchers of the Netherlands Environmental Assessment Agency in 2011 included one (RCP2.6) that held global average temperature increase below 2 °C (3.6 °F)—thereby meeting a principal goal of the 2010 international Cancun Agreements (van Vuuren et al. 2011). This scenario reduced had the global society—all nations—reduce global IR-active gas emissions by 70% from 2010 to 2100 and by more than 95% in 2100—a “technically feasible goal.” The Institutional Investors Group on Climate Change (IIGCC)—representing US\$24 trillion in assets—supported this goal in its “Global Investor Statement on Climate Change” in September 2014 (IIGCC 2014; Symon, 2013). And this was paralleled by two other major initiatives that integrated “human ecology” with “natural ecology”: the ESA’s “Earth Stewardship” initiative (Chapin et al. 2015) and *Laudato Si’*.

Praised Be...

Wonderfully, we are not only finding that earth has magnificent fitness for life, but also the vital role of the atmosphere in maintaining this fitness. This is widely celebrated, and increasingly so. And in this celebration is the re-discovered startling scientific recognition by the eminent physiologist and biochemist, Lawrence J. Henderson. In his *The Fitness of the Environment* (1913) he celebrates five materials—carbon, hydrogen, oxygen, and combinations as water (H₂O) and carbon dioxide (CO₂)—that are absolutely essential biochemical, physiological, environmental, and meteorological regulation. And even more wonderfully, all of these were present before life on earth!

And as we have been finding these and many other regulations being seriously compromised by adverse human actions a century later—resulting in increased earth temperature, increased frequency and intensity of storms, decreased pH in the world ocean, biogeographic and trophic restructuring of the biosphere, and compromised atmospheric carbonic regulation—we are discovering that as our actions have had consequences not only for the garden but for the globe—that like it or not, “...for the first time in history ***we have become stewards of the biosphere***” (DeWitt, 2003).

Significantly, the Ecological Society of America has launched a major initiative on “Earth Stewardship” to foster engagement for sustaining the earth (Chapin et al. 2015). And this is among many other stirrings and movements that accord well with Pope Francis’s *Laudato Si’* as

it addresses “fragmentation” of knowledge, “absolutization” of specialized disciplines” (§ 201) and a culture of stewardship (§ 116). Christianity and science are together poised to make important contributions toward Earth Stewardship, and *Laudato Si’*—as the only comprehensive treatise published worldwide, *Laudato Si’* has become required reading for dialogue and implementation, even as its title reminds people to “praise God from whom all blessings flow” for God’s and provisions for “our common home” and our commission in “integral ecology” that hears both the cry of the earth and the cry of the poor.

Laudato Si’

World ecology and economy are now moving toward global “decarbonization” and a “culture of care.” This transition has been in many ways a stormy one, described well by climatologist, atmospheric physicist, and Christian leader Sir John Houghton’s *The Eye of the Storm* (2015). Despite the storms, and perhaps also because of them, society is coming to understand earth’s climate system and its inseparable integration within the earth system. And society has begun to work seriously toward restoration of earth’s long-standing atmospheric carbonic temperature regulation. Every person on earth, and every one of our institutions are now invited into dialogue, even as we “gratefully admire the beneficent arrangement which permits the Earth to be clothed with verdure and abundant life.”

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