Carbon, Climate, and Self-Control: Prophetic Teachings of the Biosphere

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Christian faith and wider world society are challenged by wide-spread degradation of creation from adverse human actions and by ongoing creation and expansion of forces that promote an economy independent of the biospheric economy—forces that work to make the biosphere conform to its rules.[1] Christian faith and its institutions, undergirded with belief in God as Creator and Owner and in the biblical commission to care for creation, must now respond with sufficient power and authority to redirect institutions that degrade the biospheric economy and human society. At the center of this task is restoring the long-standing Christian stewardship tradition that served well for centuries until it faded with the industrial revolution. This response of Christian faith requires restoring the human economy fully within the biospheric economy in policy and deed. We have come to understand that we live in the biosphere, yet are adversely affecting it and its people in many ways, including destabilization and disruption of earth's climate system. Our stewardship commission—once local and regional—has become biospheric.

Describing the Present.—As we come to understand this integral stewardship, we find it difficult to describe the present. First, immense effort is needed and we are inexperience in describing our global reality. We have taken the gift of creation *for granted*, never thinking it would, unforgivingly, "bite back." We confess that the intricacies and operating scope of creation's extremely complex life-support system are so beyond our grasp that we really do not want to know how it all works. We want the freedom and security it has given, but without need for knowledge; we never expected we ever would have to understand the system that supports and sustains us. Second, we do not want to know what we are coming to discover about ourselves and the biosphere. Not liking the looks of what we see, we are reluctant to speak about it, for fear of being called "alarmist." We see troubling changes in creation within a mere decade or two that contrast with formerly mainly anticipated features and futures. Yet, there remain the seasons, sunrises and sunsets, the providence of earth's atmosphere, ocean, and landscapes, and its regular exchanges of carbon, hydrogen, oxygen, and nitrogen of earth and its life.

Elemental and Oxidized Carbon.—Among these provisions for an abundant and flourishing creation is carbon—the element that provides the molecular backbone of all living creatures. Distributed everywhere throughout the atmosphere with great consistency and regularity as carbon dioxide, it is captured physiologically from the air and the seas and incorporated as the basic structural component of every living creature, eventually to return to the atmosphere or be sequestered in biomass, detritus, peat, coal, bitumen, and petroleum. Atmospheric concentration of carbon dioxide—returned sooner or later to the atmosphere by respiration, oxidation, and combustion—is remarkably well-regulated. Not too little, not too much. If it removed as an atmospheric constituent, this source of carbon that structures all life would be gone, all green plants would perish, along with every living thing depending upon them. But there is no need to worry; for 10,000 years it has been right on the mark; kept at or very near 2.8 hundredths of one per cent, 280 parts per million (ppm).

Creation's Economy.—Since Eden, people knew that life was marvelously fit for its environment, and that this fitness is a gift of God's providence. But a century ago in a "flash realization" the eminent biochemist and physiologist, Lawrence J. Henderson furthered our wonder about this gift, discovering *mutual fitness* went in both directions: reciprocally between life and environment. In his *The Fitness of the Environment*[2] (1913) he marveled at five materials: carbon, hydrogen, oxygen, and their combinations as water (H_2O) and carbon dioxide (CO_2). It dawned upon him as he descended a New Hampshire mountain that these five are *simultaneously* (1) vital for life's physiological and biochemical regulation; and (2) essential to Earth's environmental and meteorological regulation. Life, thoughtfully considered by Henderson, must possess both complexity and durability, features made possible only when conditions inside and outside of the organism are stable. This makes it essential that there are automatic regulations of the *external environment* of living beings together with the possibility of regulation of the *internal environment*—the conditions within the organism. This, says Henderson, included "at least rough regulation of temperature, pressure, and chemical constitution of environment and organism." More marvelous still was his realization that all five pre-exist life on Earth! Vital to all life, yet pre-dating it! Amazed, and unable to explain this scientifically, he concluded, "*Matter and energy have an original property, assuredly not by chance, which organizes the universe in space and time. This is in very truth a metaphysical doctrine...*"[3]

This original property permeates the Earth System and its "biospheric economy." Stemming from the celebrated economy of Eden, similar fitness was admired in *De Oeconomia Naturae* (1749) by Carolus Linnaeus who explained: "By the economy of nature, we understand the all-wise disposition of the Creator in relation to natural things, by which they are fitted to produce general ends and reciprocal uses."[4] This provident economy includes the five materials vital for life's and earth's regulations celebrated by Henderson; it is beautifully expressed in the Earth System; it is admired by human beings whom God endowed with the ability to learn from creation;[5] and, it is confessed by those who pursue their commission to serve and protect their habitations as imagers of God's wisdom and love for the world. Earth System economics, dedicated to understanding and living responsively within the biospheric economy, is a quantitative science that seeks a full accounting of biospheric and atmospheric budgets of matter and energy.[6] As in the monetary economy, it begins with measurement of gains, transfers, and losses. And as an informative discipline, it uses material and energy budgets to evaluate how well we and our institutions are doing in performing our stewardship commission to *avad* and *shamar*[7] God's biospheric economy, "from garden to globe"[8] and points us to what we must do to correct our behavior and foster a flourishing fruitful creation.

Atmospheric Providence.—Recently, I bought a hand-held radiometer at a local hardware store, and enjoyed measuring temperatures around my yard with a simple "point and click." In doing this, I was reflecting on the good work of an early colleague of mine at the University of Wisconsin, meteorologist Verner Suomi—the first to address this question using radiometers he designed and installed on Earth-orbiting satellites.[9] Radiometers—now widely available as inexpensive "non-contact thermometers"—can be pointed at anything to measure surface temperature. Pointed at Earth from a Suomi satellite, it would record radiation of 240 watts per square meter (240 w/m^2)[10] a value that it calculates to its temperature equivalent—about minus 18 degrees Celsius, or 4/10 of a degree Fahrenheit (0.4F)![11] Cold! On a day in mid-March I used my hand-held radiometer outside, finding that temperatures ranged widely depending upon when and where I pointed. I searched for a spot that read 15 degrees C—the temperature that the eminent Swedish physicist and chemist, Svante Arrhenius, estimated was Earth's average surface temperature—and found this temperature for a sunny patch of lawn. I pressed the conversion button, and found it equal to 59 F.[12] This temperature translates into a radiation of 390 watts per square meter. The measurements by Suomi and estimated by Arrhenius raise a remarkably informative question: Why the difference between the TOA temperature and Earth's average surface temperature (from 0.4 to 59F)—a difference of about 33 degrees on the Celsius scale? Why the difference of 150 w/m^2 between the two radiometer readings (from 390 w/m^2 to 240 w/m^2)? The remarkably informative answer is: *Earth's atmosphere*.[13] For the first decades of my life I had simply taken the atmosphere for granted, not appreciating it for what it was: a primary life-sustaining gift of God's providence for this remarkably habitable Earth. But it truly is atmospheric providence—a beautiful expression of God's bountiful love and care as it "breathes in the air and shines in the light." *Atmospheric Providence!*

Selective Absorption—"A great deal has been written on the influence of the absorption of the atmosphere upon the climate", wrote Arrhenius in 1896. Concluding from measurements made by others that this influence was due to water vapor and carbon dioxide, he wrote: "The selective absorption of the atmosphere is, according to the researches of Tyndall, Lecher and Pernter, Röntgen, Heine, Langley, Ångström, Paschen, and others... not exerted by the chief mass of the air, but in a high degree by aqueous vapour (water vapor) and carbonic acid (carbon dioxide), which are in the air in small quantities."[14] Absorption of incoming sunlight by the atmosphere is "comparatively small" but great for outgoing infrared radiation (IR), and thus water vapor and carbon dioxide "must be of great importance in the transmission of rays from the earth."[15] John Tyndall, whom Arrhenius credited above, gave a remarkable lecture in 1859 at the Royal Institution "On the Transmission of Heat of different qualities through Gases of different kinds."[16] He projected light through a prism of rock salt to produce a spectrum. Measuring temperatures across the projection screen he showed elevated temperatures across the spectrum and surpirsed his audience by showing elevated temperatures in the invisible area below red—now known as "infrared radiation." Next, he described how light projected through a three-foot tube sealed at both ends with plates of polished rock-salt[17] passed freely through nitrogen, oxygen, water vapor and carbon dioxide. However, IR was blocked by water vapor and 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... and the result is a tendency to accumulate heat at the surface of the planet."

What makes these two gases such effective absorbers of IR? Tyndall, in another lecture said, "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..."[18] Physical chemists today measure these "ringing frequencies" or "resonances," not for sound, but for gas molecules responding to various frequencies of IR. The chemical bonds that hold atoms together in molecules act much like tiny springs[19]—vibrating both by "stretching" and "bending" as they absorb IR across particular frequencies.[20] Di-atomic molecules have only a "stretching vibration" and are IR active only if the two atoms are of different elements; thus the most abundant atmospheric gases, nitrogen (N≡N) and Oxygen (O=O) are IR inactive.[21] Mono-atomic elements—like Argon, the third most abundant atmospheric gas[22]—have no bonds and thus are IR inactive. More powerful absorbers of IR have "bending vibration" occurring in gas molecules with three or more atoms—like carbon dioxide (O=C=O) and water (H-O-H), whose central "elbow" allows flexing above or below the "normal" angle of 180 degrees for carbon dioxide and 105 degrees for water vapor. All gas molecules with three or more atoms absorb IR including atmospheric methane (CH_4), nitrous oxide (NO_2), ozone (O_3), and chlorofluorocarbons (CFCs). Professor Ramanathan, who follows me in this section of the seminar, studied the IR-active properties of CFCs, finding some CFCs on a per-molecule basis, about 10,000 times more absorptive of IR radiation that CO_2. These, together with methane, nitrous oxide, and ozone contribute about 5% of atmospheric IR absorption and are non-condensing. He will be able to provide good source material for studying these further.

The "Offices" of Water Vapor and Carbon Dioxide.—For the two major atmospheric IR-active gases that are my focus it is important both to understand how greatly they differ in their respective "offices."[23] Carbon dioxide has a steady and continuous "carbonic presence" throughout the atmosphere, its concentration tightly regulated around the earth irrespective of time or place—by what we may call "carbonic regulation." In contrast, water vapor varies widely, with concentrations ranging in time and place from very wet warm air over the tropical oceans and to polar climes where it closely approaches and reaches zero. Importantly, water vapor has a temperature-dependent physical "cap"—a "saturation capacity" that is cut approximately in half for every 10 deg C (18 deg F) fall in temperature. This upper saturation limit—in grams of water vapor per kilogram (g/kg) of dry air—is about 49 at 40^o C, 15 at 20^o, 3.8 at 0^o, 0.75 at -20^o, 0.1 at -40^o, and 0.01 at -60^o C. Polar air may drop below this cap to zero g/kg.[24]

Atmospheric Water Dynamics and Dramatics.—The temperature-dependence of the water vapor saturation cap also means that going up temperature scale it is raised by about 7% for every 1 Celsius degree rise in temperature— equivalent to its increasing at "compound interest." Thus, when there is a good water source, as over the tropical ocean and equatorial forests, water vapor increases to very high levels and as an IR-active gas amplifies surface heating in an escalating "positive feedback loop." As it condenses to form clouds, it releases the heat removed from ocean and land surfaces by evaporation below to the air above—and by currents moving poleward—to mid-latitudes and polar regions. It thus serves as a tremendous heat pump. And as condenses out with great release of latent heat, is rapidly restored as it takes up water vapor again and again toward it temperature-dependent saturation limit. Its latent heat of evaporation is great, with 540 calories needed to change a gram of water from liquid to vapor—heat that otherwise could raise the temperature of gram of water by 540 degrees C! And, as a condensing gas, it soon is transformed back to liquid—a vertical and horizontal distant from its source—where this heat is released thereby warming other places. And since atmospheric water vapor capacity in warm tropical climes is higher, greater amounts of water vapor move upward there than elsewhere,[25] soon to release its latent hear in areas of the earth not so vertically inclined. Latent heat is strongly engaged in condensation, evaporation, freezing, and thawing—processes that are extremely vital to earth's climate and habitability. Latent heat also includes the heat taken up by ice in its transformation from solid to liquid—heat equivalent to what otherwise would have raised its temperature by 80 degrees C (144 degrees F). During this restructuring from solid to liquid, its temperature remains the same—zero degrees C (32F). Heating without warming—a process we know for a glass of ice water.) And when liquid water is restructured into solid ice, it holds at zero C (32F) until it all freezes—heat loss that otherwise would have dropped its temperature to 80 degrees C below zero!

Water vapor dynamics are impressive and often boisterous: thunder, lighting, storms, rushing winds, gentle dewfall, ascending mists, pelting rains, bouncing hail. By contrast, the other major IR-active gas—carbon dioxide—is but a "small voice."[26] Remove the water vapor from the atmosphere and it comes back; add water to the atmosphere and it precipitates out, with the average atmospheric residence time of about 10 days. Not so with carbon dioxide, whose atmospheric residence time ranges from about 4 and 10 years.[27]

***Life Chiefly Atmospheric*.—**The fitness of water vapor and carbon dioxide for life on earth we know as a great provision for making the earth habitable, as is the whole of earth's atmosphere. For not only is heat accumulated at Earth's surface because of atmospheric carbon dioxide, water vapor and other IR-active gases, and heat redistributed vertically and horizontally by water vapor as latent heat, but life in its very substance is chiefly atmospheric—with carbon dioxide and water being the principal materials for making all living creatures, based in the process of photosynthesis. This was admired by Thomas C. Chamberlin, a prominent geologist and avid scientist of natural history, who in his three-volume Geology, described how the combinations of carbon, hydrogen, and oxygen in water (H2O) and carbon dioxide (CO2) were exchanged with the atmosphere through photosynthesis and respiration:

$$6CO2 + 6H2O \longrightarrow C6H12O6 + 6O2$$

where photosynthesis goes from left to right and respiration right to left. This enables and enlivens all living creatures—exchanging carbon and water in composing and decomposing life's carbon-based structure of life. In company with this exchange, carbon dioxide and water vapor work atmospherically to let most of the sun's energy move through the atmosphere to warm the Earth's surface, while restricting and delaying the movement of Earth's radiation of infrared "light" to the TOA from which it radiates into space. This dual role of carbon dioxide and water provides a remarkable fitness for life—internally in tissues and vital fluids and externally in climate and widespread carbon-availability—calling for admiration "in honour to the world's great Author." All this is important in evaluating our stewardship, especially as we have become accustomed to using Earth's atmosphere as a dump.

Even More Mutual Fitness—A creational focus embraces the atmosphere as God's testimony. Earth's atmosphere is remarkably fit for life! But the beauty of Creation only begins here. Our progression from weather, to climate, to the climate system, and to the Earth System brings us to understand that climate embraces the totality of Earth's habitability. In describing the life-sustaining fitness of water for regulating temperature, Lawrence Henderson wrote: "The specific heat of water, and the high freezing point all contribute to the restriction of temperature range within the organism, in the waters, and over the whole surface of the earth." And with this he marveled at the fitness provided to life by water's thermal conductivity, expansion before freezing, expansion in freezing, solvent power, dielectric constant, ionizing power, surface tension, latent heat, vapor pressure, and its latent heats of fusion and vaporization. And all three phases of water—liquid, ice, and vapor—are widely distributed around the globe with latent heats of transition between these phases having great consequence for stability of temperature.28

Hospitability in the Body and Biosphere.—What keeps the biosphere so hospitable to microbes, plants, animals, human beings and human society? To answer this question it is helpful to ask a similar question for 'the internal environment' of the body, as did physiologist, Claude Bernard. With his prescient statement, "La fixite du milieu interieur est la condition de la vie libre" ("Regulation of the internal environment is the condition for a free life."),[29] he provided a highly important dictum that not only applies to living creatures, but also provides the foundation for the science of cybernetics and control systems. As a statement about freedom, it is informed by the controls that regulate body temperature, blood sugar levels, alkalinity, pH, and other physiological processes. "La fixite du milieu interieur" gives freedom to the body, allowing it to live without the need to think moment-to-moment about these critical internal factors. And we are now coming to know that "la fixité du milieu extérieur" gives freedom to live joyfully and fruitfully in the biosphere.

We are coming to realize a remarkably unified and integrated system endowed by its Creator with a remarkable complex interplay of coordinated regulatory systems. Inter-connected controls maintain the habitability of the land, atmosphere and oceans even as similar controls maintain the "internal environments" of every living creature. The American Chemical Society website correctly states that "It's true that water vapor is the largest contributor to the Earth's greenhouse effect. On average, it probably accounts for about 60% of the warming effect. However, water vapor does not control the Earth's temperature, but is instead controlled by the temperature...The greenhouse effect that has maintained the Earth's temperature at a level warm enough for human civilization to develop over the past several millennia is controlled by non-condensable gases, mainly carbon dioxide, CO_2, with smaller contributions from methane, CH_4, nitrous oxide, N_2O, and ozone, O_3. Since the middle of the 20th century, small amounts of man-made gases, mostly chlorine- and fluorine-containing solvents and refrigerants, have been added to the mix. Because these gases are not condensable at atmospheric temperatures and pressures, the atmosphere can pack in much more of these gases. Thus, CO_2 (as well as CH_4, N_2O, and O_3) has been building up in the atmosphere since the Industrial Revolution..."

Oceanic Providence.—Henderson thought through the chemistry of carbon dioxide—this basic material of life—in both the “internal environment” and the “external environment.” He was occupied “with various aspects of the problem of the neutrality or faint alkalinity of the organism”— especially as it was achieved in the blood. In parallel, he studied “the neutrality or faint alkalinity of the ocean”—particularly as this involved carbon dioxide. What he discovered in his work on *Fitness* was the “extraordinary capacity of carbonic acid to preserve neutrality in an aqueous solution...”—both in the blood and the oceans—neutrality meaning its maintaining a particular level of pH (a measure of acidity and alkalinity). Remarkably, he found that “no other substance shares this power,”[30] thus making it remarkably fit for life, both within the organism and in the oceans. (*Fitness*, p 152) This is the “carbon dioxide-bicarbonate buffer system” that works, with precision, to regulate pH (acidity-alkalinity) both within organisms and in the oceans. Its precision is essential for all bodily functions and for stability of chemistry of the world’s oceans. This impressive buffer system can be shown in this reversible equation:

CO_2	+	H_2O	$\rightleftharpoons$	H_2CO_3	$\rightleftharpoons$	H^+	+	HCO_3^-
carbon dioxide		water		carbonic acid		hydrogen ion		bicarbonate ion

in which the CO_2, on the left, can be exchanged with the atmosphere, directly from to the atmosphere or via lungs and gills—and the bicarbonate (HCO_3^-), on the right, can be excreted by the organism’s gills or kidneys, or react with calcium ions in the oceans to form a calcium carbonate precipitate. What is remarkable here is that if strong acids or bases are added to this system, the pH remains nearly constant—it is “buffered”—and Henderson, expert as he was in chemistry and physiology, was absolutely amazed by the fitness of this for life, as I am also! What is important also to realize in this buffering is 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 CO_2, this depends on the difference in concentration of carbon dioxide of the air into which it is being discharged and its concentration in blood or the sea water—called the CO_2 “concentration gradient.” A higher “outside” concentration means that CO_2 is discharged less readily, and vice versa. So, depending upon how freely the CO_2 on the left side of this equation can be exchanged with the atmosphere, and that the bicarbonate can be freely excreted or precipitated as a carbonate salt like calcium carbonate. And in our present day for the world ocean the rise in atmospheric CO^2 has shifted the equilibrium point to be 30% more acidic than it has been during the last 10,000 years and more.

Atmospheric Carbon Dioxide for 2000 and 10000 Years.—And so in our biospheric accounting, “we measure...” using a psychrometer for water vapor and finding it rising toward 100 % relative humidity, the per cent of the way it has gone in reaching its cap, finding this to be widely variable and changing dramatically in time and place—continually restored by evaporation by earth’s land and water surfaces and transpiration by plants. Clearly, water vapor is constrained by its upper limit, its saturated water vapor capacity, but it is not regulated at a particular concentration. Instead, its cap is regulated by air temperature—a cap that is increased by about

7% for every 1 degree C rise in air temperature. Beneath this cap it varies widely in time and place; it does not rise above its temperature-dependent cap.

In our biospheric accounting it clear that we must measure the concentration of atmospheric carbon dioxide, particularly because unlike water vapor which varies greatly, carbon dioxide varies but slightly, suggesting that it is a controlled variable. But how do observe and measure the atmospheric concentration of carbon dioxide, and how can we measure this over a long enough period to observe whether or not it exhibits regularity? Measurement of carbon dioxide concentration began in 1958 on Mauna Loa in Hawaii by Charles David Keeling, and today measurements are made worldwide using similar methods as developed by Keeling. More recently, other scientists measured carbon dioxide in a set of three ice cores from Law Dome, Antarctica, obtaining measurement that shows "unparalleled age resolution and extends into recent decades." Because these measurement data are freely available, I downloaded them for the last 2000 years,[1] first analyzing these for 0 to 1600 years A.D, I found that 43 records during this period have an average CO_2 concentration of 279.5 ppm and range 8 ppm between 276 to 284 ppm.[2] I next selected data from the Vostoc ice cores also from Antarctica, from 2342 to 10,123 years before the present (BP) for which there are 7 records, finding that for approximately 8 millennia before Christ atmospheric concentrations of carbon dioxide range from 254.6 and 284.7 ppm with a median of 262.2 ppm.[3] We can conclude that carbon dioxide has been maintained with remarkable regularity during the last 10,000 years—at about 280 ppm.[4] For the past 2000 year, see Fig. 1 along with data for the remainder of this 2000-year period.

Since these data bring us back only 2000 years, I also selected data from a 2342 to 10,123 years BP of another set of data from Antarctica, the Vostok ice cores, for which there are 7 records. From these limited records we find for approximately 8 millennia B.C. that atmospheric concentrations range from 254.6 and 284.7 with a median of 262.2 again with remarkable regularity, but somewhat less and at slightly lower concentrations than from the Law Dome cores.[5] The Antarctic Law Dome and Vostok ice cores show that carbon dioxide has been maintained with remarkable regularity during the last 10,000 years.[6] This remarkable regularity has given climatically what physiological regulation has given us bodily: the freedom not to have to think about it. In our day, however, we are at 400ppm atmospheric carbon dioxide, leading us to ask: can this regularity of atmospheric carbon dioxide be overwhelmed? If so, what is being called "climate change" is more than mere change of climate; it is disruption of the carbonic regulation of the Earth System's climate.

Biospheric Carbon Budget.— The steady and continuous presence and regulation of atmospheric carbon dioxide is a major focus of Earth System economics as it accounts for gains, transfers, and losses among the atmosphere, the world ocean, and the land. Two measures of its mass are gigatonnes and petagrams of carbon—both equal to 10^{15} grams (the number 1 followed by 15 zeroes), expressed as GtC and PgC. The measure of its concentration is parts per million by volume, expressed as ppmv or simply ppm. March 2015 was the first month CO_2 concentration rose above 400 ppm at sites around the globe. This value is easily converted to the total mass of carbon in GtC by multiplying it by 2.120, which computes at

848 GtC. This compares with the long-standing 10,000-year value of 280 ppm x 2.120 of 254 GtC. Evaluation of carbon emissions into the atmosphere from fossil-carbon used as fuels between 1750 and 2011 was somewhere between 470 and 640 GtC—about 555 GtC—with 240 GtC of this going to the atmosphere by 2011 and 254 GtC by 2015.[7] This amount in the atmosphere is about 42% with about 28 per cent absorbed by the oceans, and 29% by the land and its surface waters. This explains why the CO_2 emitted by human activities, at about 7.4 GtC per year, produces an increase in atmospheric CO_2 in the atmosphere by about 3.1 GtC per year.

A good entry to this topic is the Carbon Dioxide Information Analysis Center (CDIAC) of the U.S. Department of Energy. At its website (http://cdiac.ornl.gov/GCP/) global carbon budgets and explanatory papers and documentation are easily accessed. One of these is a downloadable paper (2014 Budget v1.1) by Le Quéré et al. More information on carbon budgets is easily accessible from the Global Carbon Atlas: www.globalcarbonatlas.org/, including interactive maps and figures. Two other good sources are "A synthesis of carbon dioxide emissions from fossil-fuel combustion" and "Carbon and other biogeochemical cycles" that can be downloaded free [8]

Carbon, Climate, and Self-Control.---Carbon, Climate, and Self-Control.---Life must possess both complexity and durability, features made possible only when conditions inside and outside of the organism are stable. This insight of Henderson requires that these features must have regulations, both within the physiological economy, and the biospheric economy without—automatic regulations that provide not only the conditions for life and community, but also provide life and community the freedom to live, move, and have their being. In our day these automatic regulations no longer are appreciated or respected. And with this, these automatic regulations are themselves being degraded and disrupted. Principal among these are the carbonic regulations of the atmosphere and oceans that assure the habitability of the life of the land, the atmosphere, and the sea. Beyond this disrespect are the ongoing creation and expansion of forces that promote an economy independent of the biospheric economy that degrade the capacity for self-control that holds society withing the embrace of a supportive biosphere.

Christian faith and wider world society are challenged by these forces that presume an economy that subsumes creation's economy. Christian faith and its institutions, undergirded with belief in God as Creator and Owner and in the biblical commission to care for creation, must now respond with sufficient power and authority, to redirect institutions that degrade the biospheric economy and human society. And through this also to restore the possibility of self-control.

Endnotes

1. See John Gowdy, Charles Hall, Kent Klitgaard and Lisi Krall. 2010. The End of Faith-Based Economics. *The Corporate Examiner* 37(4-5):5-11. (Published by Interfaith Center on Corporate Responsibility, New York.) They present "Some fundamental myths of Neo-classical Welfare

Economics" as follows: 1. A theory of production can ignore physical and environmental realities; 1a. The economy can be described independently of its biophysical matrix; 1b. Economic production can be describe without reference to physical work; 2. A theory of consumption can ignore actual human behavior; 2a. *Homo economicus* is a scientific model that does a good job of predicting human behavior; and 2b. Consumption of market good can be equated with well-being and money is a universal substitute for anything. Most importantly for policy on biospheric components such as the climate system is their statement, "Where reality and the neoclassical model disagree, reality is increasingly forced through policy to conform to the neoclassical model..." John M. Gowdy is Rittenhouse Professor of Humanities and Social Science, Department of Economics, Rensselaer Polytechnic Institute in Troy, New York.

[2]. Lawrence J. Henderson 1913. The fitness of the environment: an inquiry into the biological significance of the properties of matter. New York: Macmillan. Also a paper by the same title and year, published in *American Naturalist* 47(554): 105-115.

[3]. *Fitness*, p 308. Italics mine. This accords beautifully with Genesis 1, and example of which is the position of God's statement "Let the earth sprout vegetation, plants5 yielding seed, and fruit trees bearing fruit in which is their seed, each according to its kind, on the earth" in Genesis 1:11. Another example is the conclusion of theologian John Walton regarding readying creation for God taking up residence in the cosmic temple (*The Lost World of Genesis One*, 97-98; 121-123).

[4]. Twenty-seven years before publication of Adam Smith's The Wealth of Nations, Carolus Linnaeus, the great Swedish systematizer of life, wrote his *De Oeconomia Naturae* as a dissertation to be defended by his student Isacus J. Biberg in Uppsala, Sweden.

[5]. "The Creator, in providing for all people, has given us minds and the capacity for mindful nurture of worldviews that allow us to image how the world works, to understand our place in it, and to act on our understanding in wisdom." (*Earthwise*, 3rd ed., 38)

[6]. An example is the annual accounting of the principal material that makes up the "backbone" of all living creatures, and also contributes to Earth's habitability by its presence in the atmosphere. The latest budget is given in: C. Le Quéré 2014. Global carbon budget 2014. *Earth System Science Data* 7:521-610, written by 60 climate scientists from around the world, and accessible at: http://www.earth-syst-sci-data-discuss.net/7/521/2014/essdd-7-521-2014.html, accessed 21 February 2015.

[7]. The Hebrew words, *avad* and *shamar* are central to the commission of stewardship given people in Genesis 2:15—"The LORD God then took the man and settled him in the garden of Eden, to *avad* and *shamar* it."

[8]. See my three papers under the heading "Stewardship and Economic Harmony: Living Sustainably on Earth" in Melville Y. Stewart, ed., 2010. *Science and Religion in Dialogue*, Oxford: Wiley-Blackwell: Earth's Biospheric Economy (pp 631-644), The Steward and the Economist (pp 645-657), and Sustainable Living in the Biosphere (pp 658-670). These also are available in Chinese.

[9]. Verner Suomi built this radiometer, and along with his staff, the satellites that carried them at our Space Science and Engineering Center. They were put into space from rockets launched from Wallops Island, Virginia.

[10]. Suomi's radiometer measured radiation at the top of Earth's atmosphere (TOA) as 237 w/m^2. Next generation radiometers recorded this radiation as 240 w/m^2.

[11]. This temperature also is -18 deg C and compares with an average of measured surface temperatures from 15 deg C to 16.5 deg C. This is the Stefan-Boltzmann Law, $E=\sigma T^4$ where σ

= 5.67 x 10^{-8} and T^4 is the Absolute temperature raised to the 4^{th} power. This is the equation for an object that radiates as a "black body" which is the case for Earth.

[12]. My radiometer converted radiation of 390 watts per square meter into a temperature of 15 degrees Celsius which is 273+15 = 288 degrees Absolute. This is an easy conversion: just shift the decimal on the absolute two places to the left to get 2.88, multiply this by itself 4 times (2.88*2.88*2.88*2.88) to get 68.8, and then multiply this by 5.67 to get 390 watts per square meter. (This conversion is an expression of the Stefan Boltmann Law of Radiation: $E=\sigma T^4$ where σ = 5.67 x 10^{-8} and T^4 is the Absolute temperature raised to the 4^{th} power. This is the equation for an object that radiates as a "black body" which is the case for Earth.

[13]. And of course, this is the answer if earth's surface temperature is above 0.4 degrees F!

[14]. This "chief mass of the air" of course is nitrogen, N_2, at 78.09% and oxygen, O_2, at 20.95%, and Argon at 0.93%, totaling 99.97 %—for dry air.

[15]. Svante Arrhenius. 1896. On the influence of carbonic acid in the air upon the temperature of the ground. *Philosophical Magazine and Journal of Science* 41:237-276.

[16].John Tyndall. 1859. 'On the Transmission of Heat of different qualities through Gases of different kinds." Notice of the Weekly Evening Meeting, Friday, June 10, 1859. John Tyndall, Esq. F.R.S. Professor of Natural Philosophy, Royal Institution. *Notices of the Proceedings of the Royal Institution of Britain, Abstracts of the Discourses delivered at the Evening Meetings.* Vol 3 (1858-1862). London: William Clowes and Sons.

[17]. Rock salt is used because it is transparent both to visible and infrared radiation.

[18]. Tyndall follows this by writing, "And thus is sentient man sung unto by Nature, while the optic, the auditory, and other nerves of the human body are so many strings differently tuned and responsive to different forms of the universal power." Here I use this analogy to introduce the topic of molecular resonance to various frequencies of light. John Tyndall 1865. On Radiation: The "Rede" Lecture, delivered in the Senate House, before the University of Cambridge, England, on Tuesday, May 16, 1865.

[19]. Their behavior as "tiny springs" is so close to that of the springs we use in machines, appliances, and toys that it is describable using "Hooke's Law"—the long-standing law describing the stretching and compression of springs.

[20]. The behavior of these bonds are pretty well-described by Hooke's Law, as this was discovered for the kinds of springs we are accustomed to using.

[21]. Molecules containing two atoms of the same chemical element such as nitrogen (N_2) and oxygen (O_2), and monatomic molecules like argon (Ar) do not have a net change in "dipole moment" when they vibrate and thus do not absorb IR.

[22]. The approximate per cent of the three major atmospheric gases are 78 for nitrogen, 21 for oxygen, and 1 for Argon.

[23]. The term "office" here is used in the sense of an assigned function, duty, or service." The widely-used term, "ecosystem services," as applied to what is accomplished by an ecosystem can be considered to be its "office."

[24]. See page 298 of Magdalena Bloch and Grzegorz Karasiński. 2014. Water vapor mixing ratio profiles over Harnsund, Arctic. *Acta Geophysica* 52(2):290-301.

[25]. A memoir, easily downloaded from the web, gives a much better grasp of water vapor and climate than modern accounts. Written a century ago by a prominent astronomer who with Samuel Langley measured infra-red radiation emitted by the moon through earth's atmosphere, it is: Frank W. Very. 1900. Atmospheric Radiation: A Research Conducted at the Allegheny

Observatory and at Providence, R.I. U.S. Department of Agriculture, Weather Bureau, Bulletin G, W.B. No. 221.

[26]. One way we sense carbon dioxide is by carbon-dioxide sensors in our blood circulatory systems where its increase signals the body to increase our respiratory rate, thereby to remove excesses by respiratory ventilation. And, we can see it in bubble form as it rises in a glass of soda water.

[27] Harmon Craig 1957. The natural distribution of radiocarbon and the exchange time of carbon dioxide between atmosphere and sea. *Tellus* 9(1):1-17.

[28]. When water changes phases, the arrangement of its molecules are changed but its temperature is not. If the new molecular arrangement has a higher level of energy, the substance absorbs energy to make the phase change. If it has a lower amount, it releases thermal energy. This "latent heat" for the ice-liquid phase change is equal to what otherwise would have changed its temperature by 80 degrees C (144 deg F) and for the vapor-liquid phase change it is equal to what otherwise would have changed its temperature by 540 degrees C (972 deg F).

[29].Bernard, Claude, 1865. Oevures xvi, 113 Phénomènes de la vie, tome i. Cited in J. M. D. Olmstead. Claude Bernard, Physiologist, p. 254. Harper & Brothers, New York, NY, 1938

[30]. *Fitness*, p 152.

[31] Mac Farling Meure, C..D. Etheridge, C. Trudinger, P. Steele, R. Langerfelds, T. Van Ommen, A. Smith, and J. Elkins. 2006. The Law Dome CO_2, CH_4 and N_2) Ice Core Records Extended to 2000 years BP. *Geophysical Research Letters* 33(14).

[32]. See the upper left panel of Figure 6.11 (p. 483) for these data plotted graphically in: Ciais, P., C. Sabine, G. Bala, L. Bopp, V. Brovkin, J. Canadell, A. Chhabra, R. DeFries, J. Galloway, M. Heimann, C. Jones, C. Le Quere, R. B. Myneni, S. Piao and P. Thornton, 2013: Carbon and Other Biogeochemical Cycles. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[33]. These points were determined by analyzing data from: Barnola, J.-M., D. Raynaud, C. Lorius, and N. I. Barkov. 2003. Historical CO_2 record from the Vostok ice core. In Trends: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A.

[34]. Ciais, et al. 2013, *op. cit.*, report that during the past 7000 years atmospheric CO_2 from ice cores shows only very slow changes (increase) from 260 ppm to 280 ppm.

[35]. These points were determined by analyzing data from: Barnola, J.-M., D. Raynaud, C. Lorius, and N. I. Barkov. 2003. Historical CO2 record from the Vostok ice core. In Trends: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A.

[36]. Ciais, et al. 2013, *op. cit.*, report that during the past 7000 years atmospheric CO_2 from ice cores shows only very slow changes (increase) from 260 ppm to 280 ppm.

[37]. C. Le Quéré, et al. 2014. Global carbon budget 2014. *Earth System Science Data* 7:521-610.

[38]. Andres, R. J., et al., 2012: A synthesis of carbon dioxide emissions from fossil-fuel combustion. Biogeosciences, **9**, 1845–1871, and P. Ciais, et al. 2013. Other Biogeochemical Cyles. In: *Climate Change 2013: The Physical Science Basis, Fifth Assessment Report*, *IPPC.* Cambridge: Cambridge University Press.