2

Forcings and Feedbacks

Introduction

In a paper that appeared in the 15 October 2010 issue of *Science*, Lacis et al. (2010) claim atmospheric CO_2 is the "principal control knob governing earth's temperature." Using models that employ only physical principles, they profess to have proven that carbon dioxide—not water vapor—should hold the title of "principal controller of earth's temperature" because water vapor, being a condensable greenhouse gas at current temperatures, is a "fast responder" to temperature changes induced by variations in both solar radiation intensity and non-condensable greenhouse gas concentrations, the most significant of which is CO_2. Therefore, by meekly "following in the footsteps" of CO_2 (decreasing in concentration when the atmosphere's CO_2 content drops and air temperatures cool), water vapor's potential role as an instigator of climate change is essentially preempted.

All else being equal, their conclusion might be correct. However, "all else being equal" is rarely the case in the real world, and in the case in point CO_2 affects Earth's climate in several more ways than through its thermal radiative properties. CO_2 promotes plant growth both on land and throughout the surface waters of the world's oceans, and this vast assemblage of plant life has the ability to affect Earth's climate in several ways, almost all of them tending to counteract the heating or cooling effects of CO_2's thermal radiative forcing as its concentration either rises or falls, thereby helping to maintain Earth's temperature within a range that is conducive to the continued existence and indeed flourishing of the planet's myriad life forms.

For example, Earth's plants—ranging from unicellular algae in the sea to grasses, shrubs, and majestic trees on land—emit copious quantities of gases that are converted to particles in the atmosphere, forming aerosols that reflect significant amounts of incoming solar radiation back to space, thereby cooling the planet, or that serve as condensation nuclei for cloud droplets that create more numerous, more extensive, longer-lasting, and brighter clouds that also cool the globe. Therefore, depending on whether the air's CO_2 content is increasing or decreasing, these phenomena result in changes in global radiative forcing similar in magnitude, but generally opposite in sign, to the direct thermal forcing induced by the increases or decreases in the atmosphere's CO_2 concentration.

Many of these phenomena are discussed in detail in *Climate Change Reconsidered*, the 2009 report of the Nongovernmental International Panel on Climate Change (Idso and Singer, 2009). In the subsections that follow, we provide brief reviews of related research that has subsequently been conducted on these and other climate forcing and feedback phenomena.

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2.1. Aerosols

Aerosols are an important factor in global temperature because they serve as condensation nuclei for clouds; clouds are important because they affect Earth's energy budget through their ability to reflect and scatter light and their propensity to absorb and radiate thermal radiation.

Roesler and Penner (2010) employed a microphysical model to explore how the chemical composition and size of aerosols affects the concentration and size of cloud droplets over the United States (using aerosol composition measurements from 1988–2004), while varying the strength of atmospheric vertical motions lifting initially saturated air parcels over a distance of about 300 meters in order to induce cloud formation. As vertical motion increased in their model, the number of cloud droplets increased. In addition, they found that larger aerosols, though fewer in number, were more soluble as they formed cloud droplets, as opposed to smaller, less-soluble aerosols that were more numerous, the end result being that the larger aerosols were better at producing cloud droplets than were the smaller aerosols. As an added complexity, they found the all-important size of the aerosols depended on their chemical composition, which varied by region and by season. Consequently, the two scientists concluded, "a global model using an empirical relationship based on regional measurements could over or under predict droplet concentrations when applied to other regions depending on differences in [aerosol] composition," thus demonstrating the great need for complex time- and location-dependent empirical data regarding the physical and chemical characteristics of aerosols as input to general circulation models (GCMs).

In a contemporaneous study of aerosols, Carslaw et al. (2010) write, "the natural environment is a major source of atmospheric aerosols, including dust, secondary organic material from terrestrial biogenic emissions, carbonaceous particles from wildfires, and sulphate from marine phytoplankton dimethyl sulphide emissions." These aerosols "have a significant effect on many components of the Earth system, such as the atmospheric radiative balance and photosynthetically available radiation entering the biosphere, the supply of nutrients to the ocean, and the albedo of snow and ice. With this background in mind, the authors reviewed "the impact of these natural systems on atmospheric aerosols based on observations and models, including the potential for long term changes in emissions and feedbacks on climate."

Based on their review, the seven scientists report, "the number of drivers of change is very large and the various systems are strongly coupled," noting "there have therefore been very few studies that integrate the various effects to estimate climate feedback factors." However, they add, "available observations and model studies suggest that the regional radiative perturbations are potentially several watts per square meter due to changes in these natural aerosol emissions in a future climate," which is equivalent to the magnitude of climate forcing projected to result from increases in greenhouse gases but typically of the opposite sign.

Arriving at their ultimate conclusion, therefore, Carslaw et al. state, "the level of scientific understanding of the climate drivers, interactions and impacts is very low." This is difficult to reconcile with the great degree of confidence the IPCC attaches to the conclusions it reaches about Earth's climatic future.

Some scientists believe aerosols could have a warming effect. Kiendler-Scharr et al. (2009) "present evidence from simulation experiments conducted in a plant chamber that isoprene can significantly inhibit new particle formation." The significance of this finding derives from the fact that "the most abundant volatile organic compounds emitted by terrestrial vegetation are isoprene and its derivatives, such as monoterpenes and sesquiterpenes," and the fact, as described in the "This Issue" abstract section of the *Nature* issue in which the paper appeared (p. 311), that "these compounds are involved in the formation of organic aerosols [the 'new particles' mentioned by them], which act as 'seeds' for cloud formation and hence as cooling agents via an effect on radiative forcing." Ziemann (2009), in a "News & Views" article that discusses the Kiendler-Scharr et al. paper, writes that "clouds formed at higher CCN [cloud condensation nuclei] concentrations have more and smaller drops than those formed at lower concentrations, and so reflect more sunlight and are longer-lived—effects that, at the global scale, enhance the planetary cooling that counteracts some of the warming caused by greenhouse gases." Thus, if vegetative isoprene emissions were to increase, driven directly by rising temperatures and/or indirectly by warming-induced changes in the species composition of boreal forests (as further suggested by Ziemann), the resulting decrease in CCN concentrations "could lead to increased global-warming trends," as suggested by Kiendler-Scharr in a "Making the Paper" article in the same issue of *Nature* (p. 313).

The rather convoluted story propounded by these four related items may sound like a blow to those familiar with data showing negative feedbacks are likely to maintain the temperature of the planet within bounds conducive to its own continued existence. However, and almost as an afterthought, Ziemann writes that some consideration should also be given to what he describes as "the potential suppression of terpene emissions by elevated carbon dioxide concentrations." When this is done, it is readily evident, as demonstrated by the multiple sets of observational data plotted in Figure 2.1, that rising atmospheric CO_2 concentrations will *decrease* isoprene emissions and thus *increase* CCN concentrations and lead to a cooling of the planet. These facts have yet to be sufficiently addressed by the IPCC.

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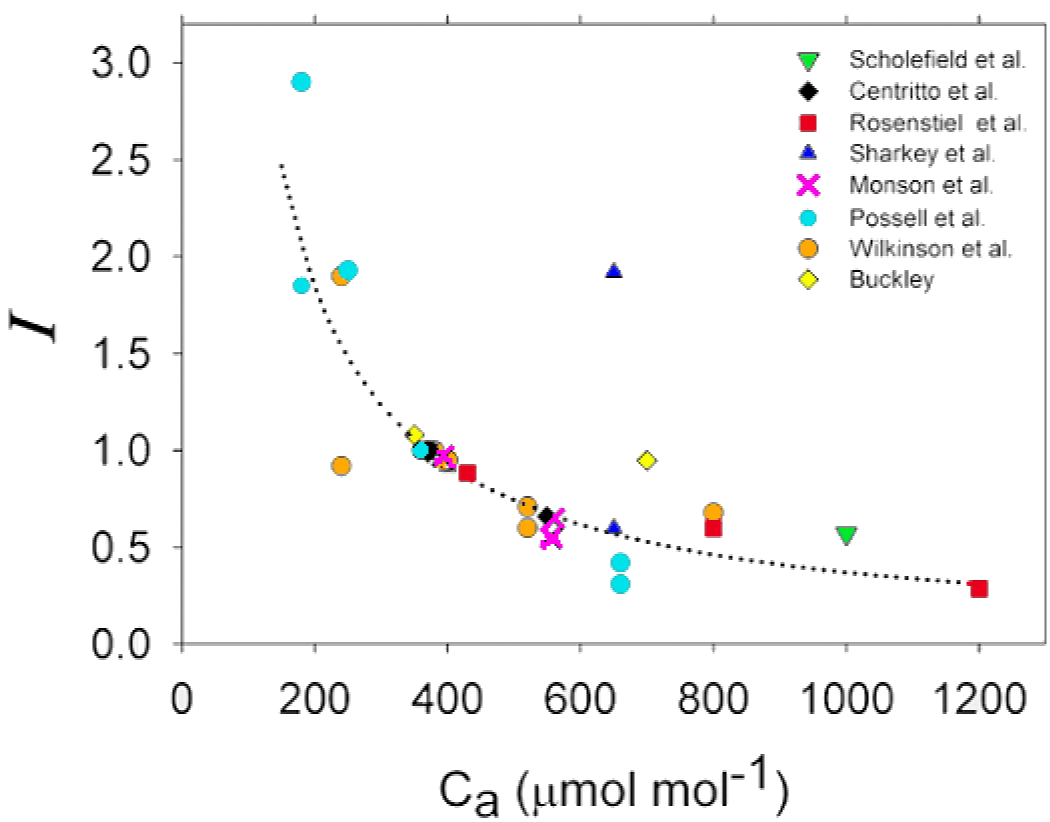

Figure 2.1. Field and laboratory observations of leaf isoprene emissions from plants grown in a variety of atmospheric CO_2 concentrations (Ca), normalized to a value of unity at Ca = 370 μmol mol^{-1} (= 370 ppm). Adapted from Young et al. (2009).

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2.2. Dimethyl Sulfide

In the 2009 NIPCC report, Idso and Singer (2009) discussed the plausibility of a multistage negative feedback process whereby warming-induced increases in the emission of dimethyl sulfide (DMS) from the world's oceans tend to counteract any initial impetus for warming. The basic tenet of this hypothesis is that the global radiation balance is significantly influenced by the albedo of marine stratus clouds (the greater the cloud albedo, the less the input of solar radiation to the Earth's surface). The albedo of these clouds, in turn, is known to be a function of cloud droplet concentration (the more and smaller the cloud droplets, the greater the cloud albedo and the reflection of solar radiation), which is dependent upon the availability of cloud condensation nuclei on which the droplets form (the more cloud condensation nuclei, the more and smaller the cloud droplets). And in completing the negative feedback loop, the cloud condensation nuclei concentration often depends upon the flux of biologically produced DMS from the world's oceans (the higher the sea surface temperature, the greater the sea-to-air flux of DMS).

Since the publication of the 2009 NIPCC report, additional empirical evidence has been found to support the several tenets of the DMS feedback process. Qu and Gabric (2010), for example, introduce their contribution to the subject by stating, "dimethylsulfide (DMS) is the main volatile sulfur [species] released during the formation and decay of microbial ocean biota" and "aerosols formed from the atmospheric conversion of DMS to sulfate and methanesulfonic acid can exert a climate cooling effect directly by scattering and absorbing solar radiation and indirectly by promoting the formation of cloud condensation nuclei and increasing the albedo of clouds, thus reflecting more solar radiation back into space."

Working with climate and DMS production data from the region of the Barents Sea (70–80°N, 30–35°E) obtained over the period 1998 to 2002, Qu and Gabric employed a genetic algorithm to calibrate chlorophyll-a measurements (obtained from SeaWiFS satellite data) for use in a regional DMS production model. Then, using GCM temperature outputs for the periods 1960–1970 (pre-industry CO_2 level) and 2078–2086 (triple the pre-industry CO_2 level), they calculated the warming-induced enhancement of the DMS flux from the Barents Sea region.

The two researchers report, "significantly decreasing ice coverage, increasing sea surface temperature and decreasing mixed-layer depth could lead to annual DMS flux increases of more than 100% by the time of equivalent CO_2 tripling (the year 2080)." In commenting on their findings, they state, "such a large change would have a great impact on the Arctic energy budget and may offset the effects of anthropogenic warming that are amplified at polar latitudes." What is more, they write, "many of these physical changes will also promote similar perturbations for other biogenic species (Leck et al., 2004), some of which are now thought to be equally influential to the aerosol climate of the Arctic Ocean." Thus it can be appreciated that DMS production in a warming world—especially when augmented by analogous biogenic phenomena—may provide a large moderating influence on the primary impetus for warming that is produced by mankind's emissions of CO_2 and other greenhouse gases.

Kim et al. (2010) write that DMS "represents 95% of the natural marine flux of sulfur gases to the atmosphere (Bates et al., 1992; Liss et al., 1997)," and they say it "may be oxidized to form non sea-salt sulfate aerosols, which are known to act as cloud condensation nuclei and thereby exert a cooling effect by absorbing or scattering solar radiation." They cite Charlson et al. (1987), who first described the intriguing and important chain of events. They also note "DMS is generated by intracellular or extracellular enzymatic cleavage of DMSP [dimethylsulfoniopropionate] by DMSP-lyase, which is synthesized by algae and bacteria, following DMSP secretion from producer cells or release following autolysis or viral attack," while noting that "grazing activity can also result in DMSP conversion to DMS if DMSP and DMSP-lyase are physically mixed following grazing," citing Stefels et al., 2007, and Wolfe and Steinke, 1996.

Working in the coastal waters of Korea from 21 November to 11 December 2008, the 14 Korean scientists utilized 2,400-liter mesocosm enclosures to simulate, in triplicate, three sets of environmental conditions—an ambient control (~400 ppm CO_2 and ambient temperature), an acidification treatment (~900 ppm CO_2 and ambient temperature), and a greenhouse treatment (~900 ppm CO_2 and ~3°C warmer-than-ambient temperature)—and within these mesocosms they initiated phytoplankton blooms by adding equal quantities of nutrients to each mesocosm on day 0. For 20 days thereafter they measured numerous pertinent parameters within each mesocosm. This work revealed, as they describe it, that "total accumulated DMS concentrations (integrated over the experimental period) in the acidification and greenhouse mesocosms were approximately 80% and 60% higher than the values measured in the control mesocosms, respectively," which they attribute to the fact that, in their experiment, "autotrophic nanoflagellates (which are known to be significant DMSP producers) showed increased growth in response to elevated CO_2" and "grazing rates [of microzooplankton] were significantly higher in the treatment mesocosms than in the control mesocosms." In the concluding paragraph of their paper, they write, "the key implication of our results is that DMS production resulting from CO_2-induced grazing activity may increase under future high CO_2 conditions," concluding that "DMS production in the ocean may act to counter the effects of global warming in the future."

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2.3. Solar Forcing of Climate

Solar forcing of climate during the Current Warm Period has long been discounted by climate alarmists and the IPCC as being of insufficient magnitude to cause the observed rise in late twentieth and early twenty-first century temperatures. In contrast, the 2009 NIPCC report (Idso and Singer, 2009) made a strong case for solar forcing. In this section we present findings of additional papers that support a significant influence of this celestial body on Earth's climate, beginning with a discussion of the study of Helama et al. (2010).

The study of sun-climate connections long has been plagued by the lack of suitably extensive and continuous data for solar activity and climatic variables. Helama et al. (2010), however, overcame some of those difficulties by examining the sun-climate relationship in unprecedented detail from the Mid- to Late-Holocene, beginning a new exploration of sun-climate co-variations on bimillennial and millennial timescales. In conducting their study, for example, they produced a well-dated and annually resolved tree-ring proxy temperature reconstruction from 5500 BCE to 2004 CE, which was representative of the high Arctic region of Northern Lapland, Finland, and Norway (68–70°N, 20–30°E), after which they employed the reconstructed sunspot series for the past 11,000 years that was developed by Solanki and colleagues in 2004 as a proxy for their solar activity index. Although Helama et al. were able to confirm relevant temperature oscillations on centennial and bicentennial timescales, they chose to focus their study on bimillennial and millennial timescale variations.

Figure 2.3.1 shows the band-pass filtered (900–1100 years) millennial-scale variations of the sunspot number series and reconstructed tree-ring temperature series are very well correlated if one introduces a time lag of about 70 years. The statistical correlations between the two sun-climate variables change with time but become more significant during the last 2,000 years with r = 0.796 and p = 0.0066. In contrast, the authors cannot demonstrate similar positive or significant correlations for the sun-climate variables for bimillennial (band-pass filtering of 1,150 to 3,000 years) scale variations for the last two thousand years (late Holocene), but stronger correlations (with r = 0.877 and p = 0.0121) were shown to exist between sunspot activity and temperatures at high-latitude Lapland for the Mid Holocene interval at the bimillennial timescale (not shown).

Helama et al. (2010) suggest the statistical correlations for the sun and temperature series on millennial timescales depicted in the figure above are probably realistic and physically meaningful, especially if one takes into account the time lag of 60–80 years. They explain that the probable scenario for explaining this relationship would be that solar activity could have driven the advection of cold surface waters southward and eastward in the subpolar North Atlantic and that cold water

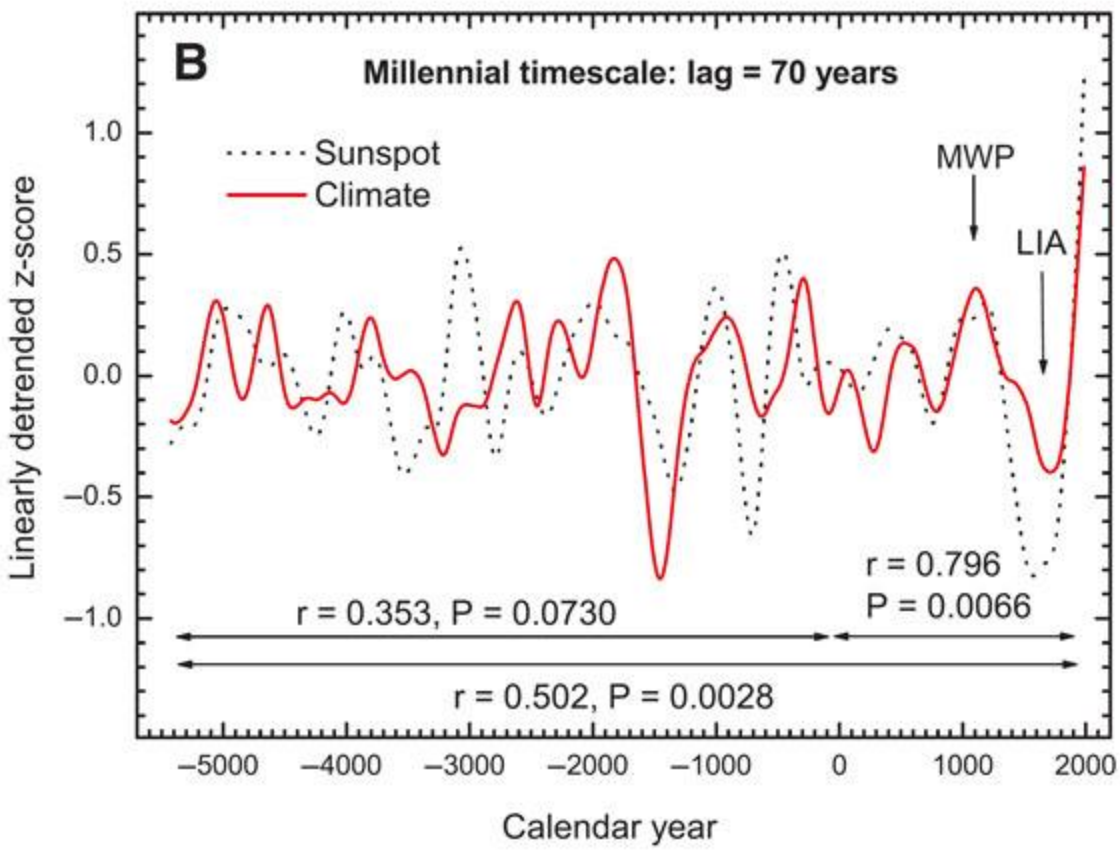

Figure 2.3.1. Band-pass filtered (900–1100 years) millennial-scale variations of the sunspot number series and reconstructed tree-ring temperature series lagged by 70 years. From Helama et al. (2010).

perturbation may ultimately influence the production of the North Atlantic deep water down to a depth of 2,000 meters. This chain of processes would probably need to include a time delay for actions within the high Arctic to propagate further south to affect the formation and working of the famous North Atlantic oceanic flywheel known as the North Atlantic Meridional Overturning Circulation. It also should be noted that such physical time delays, although in a shorter time range of five to 30 years, have been pointed out to be necessary for a physical connection between changes in the Sun and climatic conditions around Europe and North and tropical Atlantic regions by Eichler et al. (2010) and Soon (2009).

The authors also provide a brief discussion of plausible sun-climate mechanisms through the atmosphere, invoking changing tropospheric-stratospheric temperature gradients. But they ultimately conclude that a pathway and mechanism involving the ocean for both memory and redistribution of heat are probably needed to explain what they observed for bimillennial and millennial temperature variations during the Mid to Late Holocene in the high Arctic.

Finally, it is important to note Helama et al.'s observation that "the near-centennial delay in climate in responding to sunspots indicates that the Sun's influence on climate arising from the current episode of high sunspot numbers [which are the most pronounced of the entire record] may not yet have manifested itself fully in climate trends," and "if neglected in climate models, this lag could cause an underestimation of twenty-first-century warming trends."

Examining the sun-climate connection on a much-reduced time scale were Le Mouel et al. (2010a). The team of Professors Jean-Louis Le Mouel, Vincent Courtillot, and colleagues has been particularly inspired and productive of late in publishing papers revealing more evidence and information about how the sun's variable magnetic activity may affect various terrestrial phenomena, including weather and climate (see for example Kossobokov et al. 2010; Le Mouel et al. 2010b). And their 2010 publication (Le Mouel et al. 2010a) adds even more remarkable evidence and insight to the topic.

Figure 2.3.2, for example, displays some rather unexpected and surprising correlations between the long-term variation in the amplitude (A) of the solid Earth rotation parameter (here they have adopted its well-detected semiannual variation) called length-of-day, and two candidate solar activity measures: sunspot number (SN) and neutron count (NC, a proxy for incoming galactic cosmic rays), obtained from a station in Moscow, Russia. They point out that A and NC are inversely correlated with SN, the solar activity index, which leads A by about one year. And since galactic cosmic rays are also inversely related to sunspot number with a delay of one to two years or so, A is directly correlated to NC.

Le Mouel et al. (2010a) explain the correlations in the figure above as being due to a plausible physical link of the 11-year solar activity cycle to a systematic modulation of tropospheric zonal wind (since winds above 30 km contribute less than 20 percent of Earth's angular momentum, as proxied by A). They also make the important point that although the IPCC and others usually rule out the role of solar irradiance impact on terrestrial climate because of the small interannual changes in the solar irradiance, such an argument does not apply to the plausible link of the large seasonal incoming solar radiation in modulating the semiannual oscillations in the length-of-day amplitude. Therefore, Le Mouel et al. (2010a) say their paper "shows that the Sun can (directly or indirectly) influence tropospheric zonal mean-winds over decadal to multidecadal time scales." And noting "zonal mean-winds constitute an important element of global atmospheric circulation," they go on to suggest, "if the solar cycle can influence zonal mean-winds, then it may affect other features of global climate as well, including oscillations such as the NAO and MJO, of which zonal winds are an ingredient." Thus, "the cause of this forcing," as they describe it, "likely involves some combination of solar wind, galactic cosmic rays, ionosphere-Earth currents and cloud microphysics."

Contemporaneously, Scafetta (2010) investigated lesser-explored solar-planetary interactions and how they might also be capable of influencing Earth's climate. Using the pattern of perturbations of the sun's motion relative to the center of the solar system as a measure of the internal gravitational interactions of the sun-planet system, he identified—via spectral analysis and other means—a number of clear periodic signals. A spectral decomposition of Hadley Centre climate data shows similar spectra, with the results of a spectral coherence test of the two histories being highly significant. On the other hand, the spectral pattern of climate model simulations does not match the solar and climatic variability patterns, whereas the

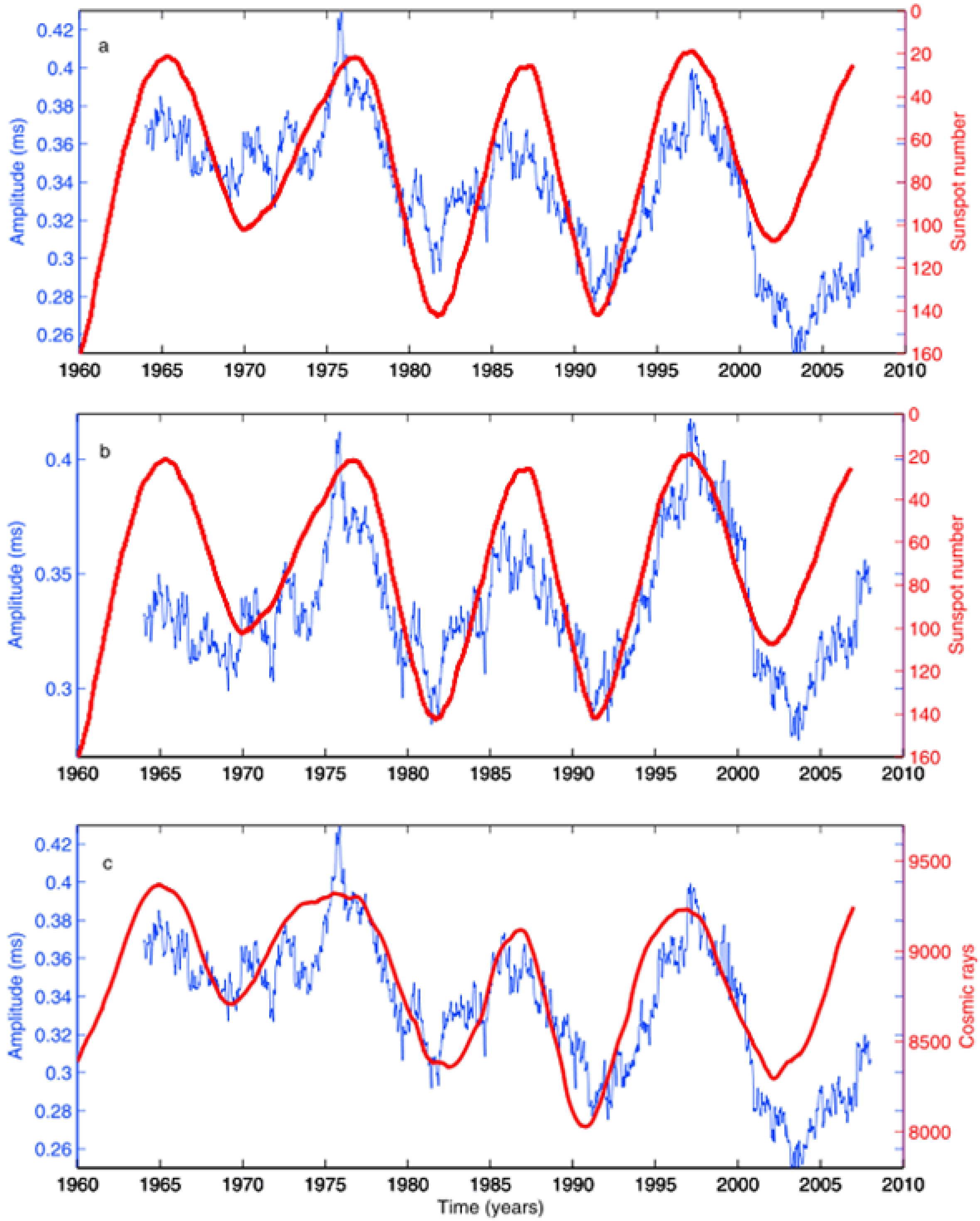

Figure 2.3.2. Correlation between the amplitude of the semiannual oscillation in length-of-day (blue curves with middle panel as detrended data with both top and bottom panels as original data) and various solar activity measures (sunspot numbers and proxy for galactic cosmic rays: red curves) from 1962–2009. A four-year moving-average filter was used to smooth the data series. Adapted from Le Mouel et al. (2010).

output of a model based on astronomically forced cycles does match global temperature data well, and it matches ocean temperature data even better.

The mechanism behind the newly discovered suite of relationships appears to be a combination of planetary gravitational effects upon the sun that influence both direct solar irradiance and the sun's magnetic field, plus an interaction of the magnetic fields of the other planets with Earth's magnetic field and the solar wind. Through these means the solar-terrestrial magnetic field experiences oscillations of several different frequencies that each exert an influence on the intensity of cosmic rays reaching the Earth and the subsequent generation of climate-changing clouds. As for the significance of the hypothesized sun-planets-Earth-(and moon) interactions, Scafetta notes failure to include these natural cyclical components of climate in current state-of-the-art climate models has resulted in at least a 60 percent overestimate of the degree of anthropogenic-induced greenhouse warming between 1970 and 2000.

Further examining the cosmic ray/climate hypothesis, Shaviv (2008) writes as background for his study, "climatic variations synchronized with solar variations do exist, whether over the solar cycle or over longer time-scales," citing numerous references in support of this fact. However, it is difficult for some scientists to accept the logical derivative of this fact, that solar variations are driving major climate changes, the prime problem being that measured or reconstructed variations in total solar irradiance seem far too small to be able to produce the observed climatic changes.

One potential way of resolving this dilemma would be to discover some type of amplification mechanism, but most attempts to identify one have been fraught with difficulty and met with much criticism. In this particular instance, however, Shaviv makes a good case for at least the existence of such an amplifier, and he points us in the direction of a sensible candidate to fill this role.

Shaviv "use[d] the oceans as a calorimeter to measure the radiative forcing variations associated with the solar cycle" via "the study of three *independent* records: the net heat flux into the oceans over 5 decades, the sea-level change rate based on tide gauge records over the 20th century, and the sea-surface temperature variations," each of which can be used "to consistently derive the same oceanic heat flux."

In pursuing this path, Shaviv demonstrates "there are large variations in the oceanic heat content together with the 11-year solar cycle." He also reports the three independent datasets "consistently show that the oceans absorb and emit an order of magnitude more heat than could be expected from just the variations in the total solar irradiance," thus "implying," as he describes it, "the necessary existence of an amplification mechanism, although without pointing to which one."

Finding it difficult to resist pointing, however, Shaviv acknowledges his affinity for the solar-wind modulated cosmic ray flux (CRF) hypothesis, suggested by Ney (1959), discussed by Dickinson (1975), and championed by Svensmark (1998). Based on "correlations between CRF variations and cloud cover, correlations between non-solar CRF variations and temperature over geological timescales, as well as experimental results showing that the formation of small condensation nuclei could be bottlenecked by the number density of atmospheric ions," this concept, according to Shaviv, "predicts the correct radiation imbalance observed in the cloud cover variations" that are needed to produce the magnitude of the net heat flux into the oceans associated with the 11-year solar cycle. Shaviv thus concludes the solar-wind modulated CRF hypothesis is "a favorable candidate" for primary instigator of many climatic phenomena.

Moving the hypothesis forward one year later, Knudsen and Riisager (2009) proposed the galactic cosmic ray (GCR) climate theory involves a solar forcing of the climate that significantly amplifies the forcing owing to solar irradiance. Noting "the GCR flux is also modulated by earth's magnetic field," they speculated, "if the GCR-climate theory is correct, one would expect not only a relatively strong solar-climate link, but also a connection between earth's magnetic field and climate." Thus, they went on to "compare a new global reconstruction of the Holocene geomagnetic dipole moment (Knudsen et al., 2008) with proxy records for past low-latitude precipitation (Fleitmann et al., 2003; Wang et al., 2005)," the first of which proxy records was derived from a speleothem $\delta^{18}O$ record obtained from stalagmite Q5 from Qunf cave in southern Oman, and the second of which was derived from a similar record obtained from stalagmite DA from Dongge cave in southern China.

The two researchers report the various correlations they observed over the course of the

Holocene "suggest that the Holocene low-latitude precipitation variability to some degree was influenced by changes in the geomagnetic dipole moment." More particularly, they say the general increase in precipitation observed over the past 1,500 years in both speleothem records "cannot be readily explained by changes in summer insolation or solar activity," but that it "correlates very well with the rapid decrease in dipole moment observed during this period." This relationship is largely explained by the fact that "a higher dipole moment leads to a lower cosmic ray flux, resulting in reduced cloud coverage and, ultimately, lower precipitation."

Knudsen and Riisager also state, "in addition to supporting the notion that variations in the geomagnetic field may have influenced earth's climate in the past," their study provides support for a link "between cosmic ray particles, cloud formation, and climate, which is crucial to better understand how changes in solar activity impact the climate system."

In an intriguing paper published in *Physics Reports*, Qing-Bin Lu (2009)—who is associated with three different departments of Canada's University of Waterloo (physics and astronomy, biology, and chemistry)—injects a new dimension into the debate over what has been the cause of late twentieth-century global warming and its apparent early twenty-first-century cessation.

The bulk of Lu's paper is dedicated to describing the new cosmic-ray-driven electron-induced reaction mechanism—or CRE model—of ozone depletion, which he contrasts with the conventional photochemical model of ozone depletion. Near the end of his discussion of this other important subject, however, he makes some original observations about the possible effects of chlorofluorocarbons (CFCs) and cosmic-ray-driven ozone depletion on global climate change. This subsidiary analysis gives one reason to suspect the IPCC has long been focused on the wrong greenhouse gas, CO_2.

Lu begins by noting ozone-depleting CFCs are also greenhouse gases but that the IPCC has considered them to provide only about 13 percent of the total radiative forcing produced by all of the atmosphere's well-mixed greenhouse gases. He then goes on to challenge the low value of this assessment, stating emphatically (as indicated by his use of italics), "*these conclusions were based on climate model simulations rather than direct observations*." He then proceeds to describe and consider certain real-world measurements in ways that have not been done before.

In plotting yearly mean global temperature deviations (ΔT, relative to the 1980 mean value) vs. equivalent effective stratospheric chlorine concentrations (EESC, normalized to their 1980 value) over the period 1970–2008, for example, Lu found the former parameter was a well-defined function of the latter, as may be seen in Figure 2.3.3, where the correlation coefficient (R) of the linear relationship between the two parameters is 0.89 at a probability level (P) of < 0.0001.

Of course, correlation does not prove causation, as must also be admitted to be the case when examining the similar relationship between ΔT and the atmosphere's CO_2 concentration over the latter part of the twentieth century and early part of the twenty-first century. However, Lu makes an important point in noting that following the implementation of the Montreal Protocol, the total halogen level in the lower atmosphere was observed to peak in 1994, while the EESC over Antarctica was estimated to peak around the year 2000, after which it actually began to decline, as did global temperature, as shown in Figure 2.3.4. And based on the estimated trend of EESC over the next four decades, Lu's analysis suggests the Earth could well continue to cool—as it has been gradually doing for the past decade—until the middle of the current century or more.

As for what it all means, Lu states in the concluding paragraph of his lengthy treatise that the "observed data point to the possibility that the global warming observed in the late 20th century was dominantly caused by CFCs, modulated by CRE-driven ozone depletion" and "with the decreasing emission of CFCs into the atmosphere, global cooling may have started since 2002." Lu does not contend this must be the case; he states only that "this is likely a subject deserving close attention." The question now is: Will other scientists and the IPCC provide that close attention?

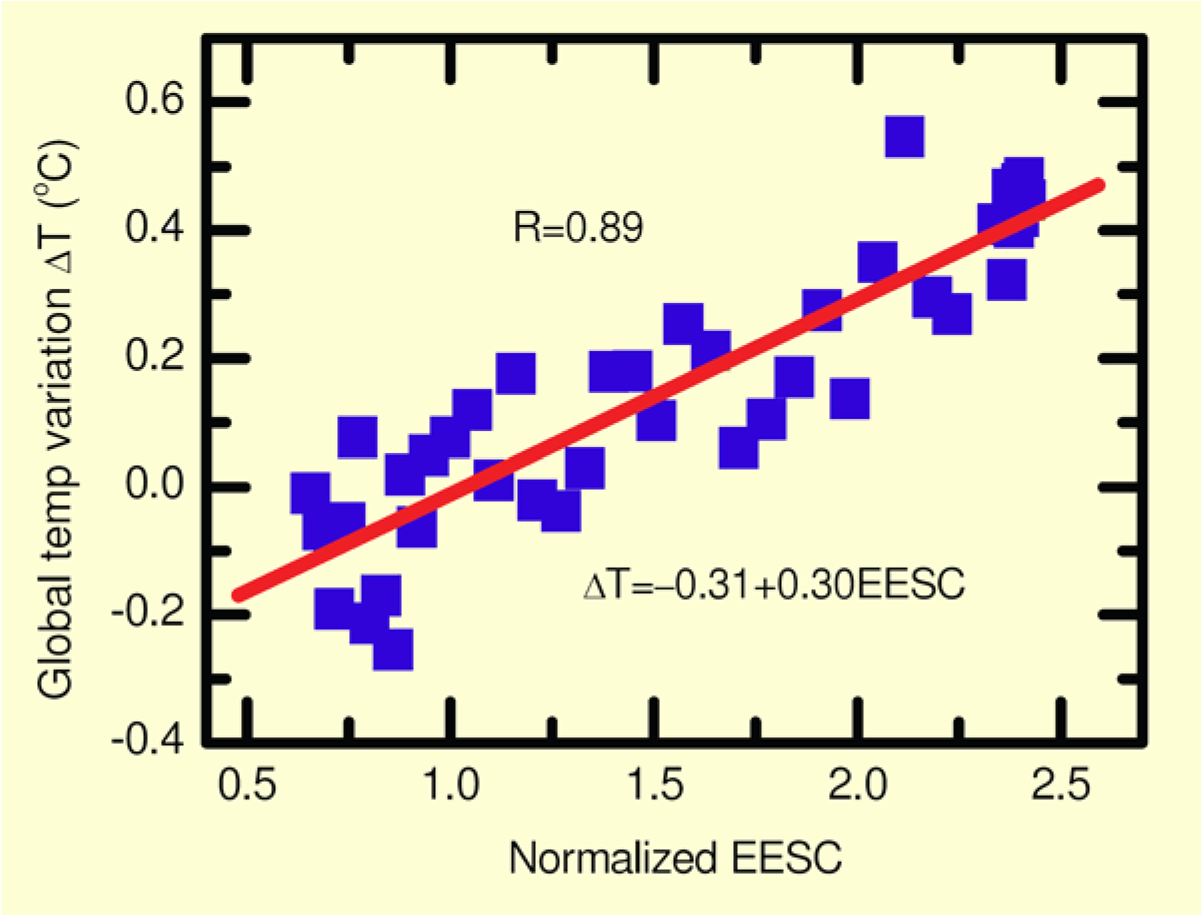

Figure 2.3.3. Yearly global temperature relative to its 1980 value (ΔT) vs. yearly equivalent effective stratospheric chlorine concentrations (EESC) normalized to its 1980 value. Adapted from Lu (2009).

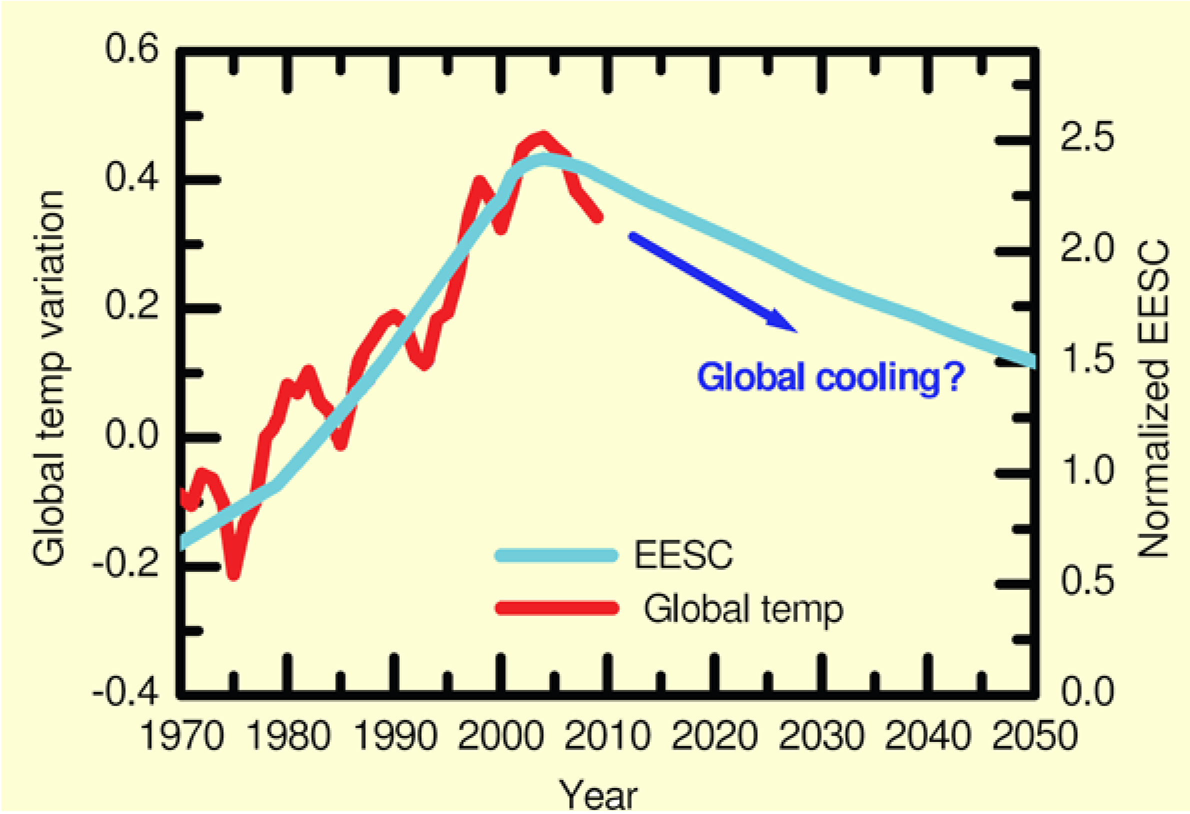

Figure 2.3.4. Yearly global temperature relative to its 1980 value (ΔT) and yearly EESC normalized to its 1980 value vs. time. Adapted from Lu (2009).

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2.4. Other Forcings and Feedbacks

Researchers have identified other forcings and feedbacks about which little is currently known (or acknowledged by the IPCC), but which may ultimately prove to be important drivers of climate change. In this section we examine some of those phenomena that have been described in the peer-reviewed scientific literature.

2.4.1 Stratospheric Water Vapor

Solomon et al. (2010) write, "the trend in global surface temperatures has been nearly flat since the late 1990s despite continuing increases in the forcing due to the sum of the well-mixed greenhouse gases (CO_2, CH_4, halocarbons, and N_2O), raising questions regarding the understanding of forced climate change, its drivers, the parameters that define natural internal variability, and how fully these terms are represented in climate models." In an effort to improve our understanding of climate forcing, they used observations of stratospheric water vapor concentration obtained over the period 1980–2008, together with detailed radiative transfer and modeling information, to calculate the global climatic impact of this important greenhouse gas and compare it with trends in mean global near-surface air temperature observed over the same time period.

According to the seven scientists, stratospheric water vapor concentrations decreased by about 10 percent after the year 2000, and their analysis indicates this decrease should have slowed the rate of increase in global near-surface air temperature between 2000 and 2009 by about 25 percent compared to what would have been expected on the basis of climate model calculations due to measured increases in carbon dioxide and other greenhouse gases over the same period. In addition, they found, "more limited data suggest that stratospheric water vapor probably increased between 1980 and 2000, which would have enhanced the decadal rate of surface warming during the 1990s by about 30% [above what it would have been without the stratospheric water vapor increase]."

In their concluding paragraph, Solomon et al. thus write it is "not clear whether the stratospheric water vapor changes represent a feedback to global average climate change or a source of decadal variability." In either case, their findings elucidate a hugely important phenomenon not previously included in any prior analyses of global climate change. They also write that current climate models do not "completely represent the Quasi Biennial Oscillation [which has a significant impact on stratospheric water vapor content], deep convective transport [of water vapor] and its linkages to sea surface temperatures, or the impact of aerosol heating on water input to the stratosphere." Consequently, in light of (1) Solomon et al.'s specific findings, (2) their listing of what current climate models do not do (which they should do), and (3) the questions they say are raised by the flat-lining of mean global near-surface air temperature since the late 1990s, it is premature to conclude that current state-of-the-art models know enough to correctly simulate the intricate workings of Earth's climate regulatory system.

2.4.2 Volcanic and Seismic Activity

Tuffen (2010) writes, “there is growing evidence that past changes in the thickness of ice covering volcanoes have affected their eruptive activity.” He states, “the rate of volcanic activity in Iceland accelerated by a factor of 30–50 following the last deglaciation at approximately 12 ka (Maclennan et al., 2002)” and “analyses of local and global eruption databases have identified a statistically significant correlation between periods of climatic warming associated with recession of ice and an increase in the frequency of eruptions (Jellinek et al., 2004; Nowell et al., 2006; Huybers and Langmuir, 2009).” Thus he asks the next logical question: “Will the current ice recession provoke increased volcanic activity and lead to increased exposure to volcanic hazards?”

In response to his self-interrogation, Tuffen—a researcher at the Lancaster Environment Centre of Lancaster University in the United Kingdom—proceeds to “analyze our current knowledge of how ice thickness variations influence volcanism” and to “identify several unresolved issues that currently prevent quantitative assessment of whether activity is likely to accelerate in the coming century.”

At the conclusion of his review and analysis, Tuffen finds “ice unloading may encourage more explosive eruptions” but “melting of ice and snow may decrease the likelihood and magnitude of meltwater floods.” On the other hand, he writes, there is (1) “uncertainty about the time scale of volcanic responses to ice unloading,” (2) “poor constraint on how ice bodies on volcanoes will respond to twenty-first century climate change,” (3) “lack of data on how past changes in ice thickness have affected the style of volcanic eruptions and associated hazards,” and he notes (4) “the sensitivity of volcanoes to small changes in ice thickness or to recession of small glaciers on their flanks is unknown,” (5) “it is not known how localized ice withdrawal from stratovolcanoes [tall, conical volcanoes with many layers (strata) of hardened lava, tephra, and volcanic ash] will affect shallow crustal magma storage and eruption,” and (6) “broader feedbacks between volcanism and climate change remain poorly understood.”

The U.K. researcher concludes, “in order to resolve these problems, both new data and improved models are required.” In the data area, he states, “existing databases of known volcanic eruptions need to be augmented by numerous detailed case studies of the Quaternary eruptive history of ice-covered volcanoes.” Regarding models, he writes, “improved physical models are required to test how magma generation, storage and eruption at stratovolcanoes are affected by stress perturbations related to the waxing and waning of small-volume ice bodies on what is commonly steep topography.” Last, he suggests “feedbacks between the mass balance of ice sheets and glaciers and volcanic activity need to be incorporated into future earth-system models.” Hence, it is clear that much is known about the subject, but it is equally clear that much is still to be learned.

O. Molchanov (2010) of the Russian Academy of Sciences’ Institute of the Physics of the Earth, headquartered in Moscow, Russia, makes a case for the hypothesis that, at least partially, global climate changes and corresponding activity indices such as the ENSO phenomenon are induced by similar variations in seismicity. Molchanov (1) calculates the cumulative annual seismic energy released by large earthquake events originating from depths of 0 to 38 km, based on data archived by the U.S. Geological Survey for the 35-year time interval of 1973–2008 for various earthquake activity zones spread across the tropical and western Pacific—including the Chilean subduction zone; the Tonga-Kermadec zone; the Sunda, Philippine, and Solomon Sea zones; and the Mariana, Japan, and Kuril-Kamchatka zones—and (2) compares the then-evident periodicity of seismic energy production with that of sea surface temperature oscillations that occurred over the same 35-year period within the Niño zones 1+2 (0–10°S, 90–80°W), 3 (5°N–5°S, 150–90°W), and 4 (5°N–5°S, 160°E–150°W).

It was first determined that the “climate indices show expected ENSO variation” and “amazingly,” as Molchanov describes it, the earthquake indices demonstrate “similar quasi-ENSO variations.” So the next question was obviously: which is the action and which is the reaction? From a number of other factors, the Russian researcher concludes it is “more probable” that earthquake activity is “forcing the ENSO variation in the climate” than vice versa.

In concluding his paper, Molchanov states, “trends in the climate and seismic variations are similar to each other” and “it is rather probable that the climate ENSO effect is at least partially induced by seismicity with a time lag of about 1.5 years,” leaving it up to others to further study and debate the issue.

2.4.3 Carbon Sequestration

Lin et al. (2010) observe that "most models predict that climate warming will increase the release of carbon dioxide from the terrestrial biosphere into the atmosphere, thus triggering positive climate-terrestrial carbon feedback which leads to a warmer climate." However, they state the "stimulation of biomass accumulation and net primary productivity of terrestrial ecosystems under rising temperature (Rustad et al., 2001; Melillo et al., 2002; Luo et al., 2009) may enhance carbon sequestration and attenuate the positive feedback between climate warming and the terrestrial biosphere."

In an effort to find out which view is correct, Lin et al. conducted a meta-analysis of pertinent data from 127 individual studies published before June 2009, in order to determine whether the overall impact of a substantial increase in the air's CO_2 concentration on terrestrial biomass production would likely be positive or negative.

The three scientists report that for the totality of terrestrial plants included in their analysis, "warming significantly increased biomass by 12.3%" and there was a "significantly greater stimulation of woody (+26.7%) than herbaceous species (+5.2%)." They also found the warming effects on plant biomass production "did not change with mean annual precipitation or experimental duration" and "other treatments, including CO_2 enrichment, nitrogen addition, drought, and water addition, did not alter warming responses of plant biomass." Given such findings, the Chinese researchers conclude, "results in this and previous meta-analyses (Arft et al., 1999; Rustad et al., 2001; Dormann and Woodin, 2002; Walker et al., 2006) have revealed that warming generally increases terrestrial plant biomass, indicating enhanced terrestrial carbon uptake via plant growth and net primary productivity." Thus, we can logically expect that (1) the ongoing rise in the air's CO_2 content will soften its own tendency to increase global temperatures, while simultaneously (2) enhancing Earth's terrestrial vegetation with greater growth rates and biomass production, both in the agricultural arena and throughout the planet's many natural ecosystems.

In another study, Geibert et al. (2010) write, "the Southern Ocean (SO) plays a key role in modulating atmospheric CO_2 via physical and biological processes," but "over much of the SO, biological activity is iron-limited," which restricts the SO's ability to do its job in this regard. However, they note "new in situ data from the Antarctic zone south of Africa in a region centered at ~20°E–25°E reveal a previously overlooked region of high primary production." They sought to learn the cause of this anomalous production, which is an integral part of the globe's deep-ocean carbon transferal system, whereby massive quantities of CO_2-carbon recently absorbed from the atmosphere are photosynthetically incorporated into phytoplanktonic biomass, which either directly or indirectly—via marine food chains—is transported to the bottom layers of the sea, where it experiences long-term separation from the atmosphere.

Based on data obtained from expedition ANT XX/2 to the Weddell Gyre (WG) that took place from 24 November 2002 to 23 January 2003—carried out on the icebreaker RV *Polarstern*—Giebert et al. acquired "an in situ biogeochemical data set to complement indirect information from modeling and remote sensing techniques." This dataset included multiple water samples for analyses of nutrients, oxygen, phytoplankton species identification and pigment and chlorophyll-a concentration, as well as for measurements of particulate matter, temperature, salinity, and the radionuclides ^{234}Th and ^{238}U.

The 11 researchers—from Germany, New Zealand, South Africa, and the United Kingdom—determined that "sea ice together with enclosed icebergs is channeled by prevailing winds to the eastern boundary of the WG," where a sharp transition to warmer waters causes melting of ice that contains significant amounts of iron previously deposited upon it by aeolian transport of iron-rich dust. As the larger icebergs penetrate deeper into the sea, the researchers note, "they are exposed to warmer waters even during winter, when sea ice is present and growing," which means the "continuous melting of icebergs in winter will lead to rising fresher and potentially iron-enriched waters from below, in the immediate vicinity of icebergs," which meltwater "would spread under the sea ice as a thin lens of fresher water, where it can refreeze due to its comparatively low salinity, and it can undergo processes of sorption and biological uptake." This hypothesis, in their words, "is consistent with maxima of iron concentrations in the lowermost parts of sea ice prior to the onset of spring melting (Lannuzel et al., 2007)." Thus, they conclude, "this melting hot spot causes an enhanced input of iron and salinity-driven stratification of the surface waters," which are the ideal conditions for sustaining the "intense phytoplankton blooms" that characterize the waters they studied.

With respect to the significance of their work, Geibert et al. state their findings "imply that future changes in sea-ice cover and dynamics could have a significant effect on carbon sequestration in the SO." If those changes included enhanced melting of Antarctic sea ice and icebergs, such as climate alarmists claim will occur, the planet's deep-ocean carbon transferal system would shift into a higher gear and effectively sequester greater amounts of CO_2-carbon from the atmosphere, reducing its rate of rise and thereby reducing the strength of the CO_2 greenhouse effect.

Janssens et al. (2010) write that "atmospheric deposition of reactive nitrogen, originating mainly from fossil-fuel burning and artificial fertilizer applications, has increased three- to five-fold over the past century" and "in many areas of the globe, nitrogen deposition is expected to increase further." This phenomenon stimulates plant growth and the uptake of carbon from the atmosphere, contributing to climate change mitigation. They state that Magnani et al. (2007) demonstrated nitrogen deposition to be "the dominant driver of carbon sequestration in forest ecosystems," although there has been what they describe as "intense debate" about the magnitude and sustainability of the phenomenon and its underlying mechanisms.

In an effort designed to further explore the subject, Janssens et al. conducted "a meta-analysis of measurements in nitrogen-addition experiments, and a comparison of study sites exposed to elevated or background atmospheric nitrogen deposition." The work of the 15 scientists revealed, in their words, that "nitrogen deposition impedes organic matter decomposition, and thus stimulates carbon sequestration, in temperate forest soils where nitrogen is not limiting microbial growth." What is more, they find "the concomitant reduction in soil carbon emissions is substantial," being "equivalent in magnitude to the amount of carbon taken up by trees owing to nitrogen fertilization."

For those worried about the prospect of CO_2-induced global warming, these findings should be good news, for in the concluding sentence of their paper, Janssens et al. state, "the size of the nitrogen-induced inhibition of below-ground respiration is of the same order of magnitude as the forest carbon sink." And in the concluding sentence of their paper's introduction, they state, "this effect has not been included in current carbon-cycle models," suggesting that when it is included, it will contribute much to "climate change mitigation."

In one final study of note, Blok et al. (2010) write of "fears" that if Earth's permafrost thaws, "much of the carbon stored will be released to the atmosphere," as will great quantities of the greenhouse gas methane (further exacerbating warming), as is claimed is already happening—and at an accelerating rate—by many climate alarmists, such as Al Gore in his 21 March 2007 testimony before the United States Senate's Environment & Public Works Committee and Michael Mann and Lee Kump (2008) in their *Dire Predictions* book. Quite to the contrary, Blok et al. say "it has been demonstrated that increases in air temperature sometimes lead to vegetation changes that offset the effect of air warming on soil temperature," citing the studies of Walker et al. (2003) and Yi et al. (2007) as specific examples of the phenomenon.

Thus, in an attempt to explore the subject within the context of real-world experimentation, Blok et al. conducted a study within the Kytalyk nature reserve in the Indigirka lowlands of northeastern Siberia (Russia), where they measured the thaw depth or active layer thickness (ALT) of the soil, the ground heat flux, and the net radiation in 10-meter-diameter plots either possessing or not possessing a natural cover of bog birch (*Betula nana*) shrubs, the latter of which set of plots had all *B. nana* shrubs removed from their native tundra vegetation in 2007.

The Dutch, Swiss, and Russian researchers report, "experimental *B. nana* removal had increased ALT significantly by an average of 9% at the end of the 2008 growing season, compared with the control plots," which implies reduced warming in the shrub-dominated plots, and "in the undisturbed control plots with varying natural *B. nana* cover, ALT decreased with increasing *B. nana* cover," also "showing a negative correlation between *B. nana* cover and ALT," which again implies reduced warming in the more shrub-dominated plots.

Blok et al. say their results suggest "the expected expansion of deciduous shrubs in the Arctic region, triggered by climate warming, may reduce summer permafrost thaw" and the "increased shrub growth may thus partially offset further permafrost degradation by future temperature increases." The six scientists write (1) permafrost temperature records "do not show a general warming trend during the last decade (Brown and Romanovsky, 2008), despite large increases in surface air temperature," (2) during the decade before that, "data from several Siberian Arctic permafrost stations do not show a discernible trend between 1991 and 2000 (IPCC, 2007)," and (3) "a recent discovery of ancient permafrost that survived several warm geological periods suggests that vegetation cover may help protect permafrost from climate warming (Froese et al., 2008)." Last, they note this phenomenon "could feedback negatively to global warming, because the lower soil temperatures in summer would slow down soil decomposition and thus the amount of carbon released to the atmosphere."

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