1

Global Climate Models and Their Limitations

Introduction

Because the earth-ocean-atmosphere system is so vast and complex, it is impossible to conduct a small-scale experiment that reveals how the world's climate will change as the air's greenhouse gas (GHG) concentrations continue to rise. As a result, scientists try to forecast the effect of rising GHG by looking backwards at climate history to see how the climate responded to previous "forcings" of a similar kind, or by creating computer models that define a "virtual" earth-ocean-atmosphere system and run scenarios or "story lines" based on assumptions about future events.

The Intergovernmental Panel on Climate Change (IPCC) places great confidence in the ability of general circulation models (GCMs) to simulate future climate and attribute observed climate change to anthropogenic emissions of greenhouse gases. It says "climate models are based on well-established physical principles and have been demonstrated to reproduce observed features of recent climate … and past climate changes … There is considerable confidence that Atmosphere-Ocean General Circulation Models (AOGCMs) provide credible quantitative estimates of future climate change, particularly at continental and larger scales" (IPCC, 2007-I, p. 591).

To be of any validity, GCMs must incorporate all of the many physical, chemical, and biological processes that influence climate in the real world, and they must do so correctly. A review of the scientific literature reveals numerous deficiencies and shortcomings in today's state-of-the-art models, some of which deficiencies could even alter the sign of projected climate change. In this chapter, we first ask if computer models are capable *in principle* of producing reliable forecasts and then examine three areas of model inadequacies: radiation, clouds, and precipitation.

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1.1. Models and Forecasting

J. Scott Armstrong, professor, The Wharton School, University of Pennsylvania and a leading figure in the discipline of professional forecasting, has pointed out that forecasting is a practice and discipline in its own right, with its own institute (International Institute of Forecasters, founded in 1981), peer-reviewed journal (*International Journal of Forecasting*), and an extensive body of research that has been compiled into a set of scientific procedures, currently numbering 140, that must be used to make reliable forecasts (*Principles of Forecasting: A Handbook for Researchers and Practitioners*, by J. Scott Armstrong, Kluwer Academic Publishers, 2001).

According to Armstrong, when physicists, biologists, and other scientists who do not know the rules of forecasting attempt to make climate predictions based on their training and expertise, their forecasts are no more reliable than those made by nonexperts, even when they are communicated through complex computer models (Armstrong, 2001). In other words, forecasts by scientists, even large numbers of very distinguished scientists, are not necessarily *scientific* forecasts. In support of his position, Armstrong and a colleague cite research by Philip E. Tetlock (2005), a psychologist and professor of organizational behavior at the University of California, Berkeley, who "recruited 288 people whose professions included 'commenting or offering advice on political and economic trends.' He asked them to forecast the probability that various situations would or would not occur, picking areas (geographic and substantive) within and outside their areas of expertise. By 2003, he had accumulated more than 82,000 forecasts. The experts barely if at all outperformed non-experts and neither group did well against simple rules" (Green and Armstrong, 2007). The failure of expert opinion to lead to reliable forecasts has been confirmed in scores of empirical studies (Armstrong, 2006; Craig *et al.*, 2002; Cerf and Navasky, 1998; Ascher, 1978) and illustrated in historical examples of incorrect forecasts made by leading experts (Cerf and Navasky, 1998).

In 2007, Armstrong and Kesten C. Green of Monash University conducted a "forecasting audit" of the IPCC Fourth Assessment Report (Green and Armstrong, 2007). The authors' search of the contribution of Working Group I to the IPCC "found no references … to the primary sources of information on forecasting methods" and "the forecasting procedures that were described [in sufficient detail to be evaluated] violated 72 principles. Many of the violations were, by themselves, critical."

One principle of scientific forecasting Green and Armstrong say the IPCC violated is "Principle 1.3 Make sure forecasts are independent of politics." The two authors write, "this principle refers to keeping the forecasting process separate from the planning process. The term 'politics' is used in the broad sense of the exercise of power." Citing David Henderson (Henderson, 2007), a former head of economics and statistics at the Organization for Economic Cooperation and Development (OECD), they say "the IPCC process is directed by non-scientists who have policy objectives and who believe that anthropogenic global warming is real and danger." They conclude:

> The forecasts in the Report were not the outcome of scientific procedures. In effect, they were the opinions of scientists transformed by mathematics and obscured by complex writing. Research on forecasting has shown that experts' predictions are not useful in situations involving uncertainty and complexity. We have been unable to identify any scientific forecasts of global warming. Claims that the Earth will get warmer have no more credence than saying that it will get colder.

Scientists working in fields characterized by complexity and uncertainty are apt to confuse the output of *models*—which are nothing more than a statement of how the modeler believes a part of the world works—with real-world trends and forecasts (Bryson, 1993). Computer climate modelers certainly fall into this trap, and they have been severely criticized for failing to notice that their models fail to replicate real-world phenomena by many scientists, including Balling (2005), Christy (2005), Essex and McKitrick (2007), Frauenfeld (2005), Michaels (2000, 2005, 2009), Pilkey and Pilkey-Jarvis (2007), Posmentier and Soon (2005), and Spencer (2008).

Canadian science writer Lawrence Solomon (2008) interviewed many of the world's leading scientists active in scientific fields relevant to climate change and asked them for their views on the reliability of the computer models used by the IPCC to detect and forecast global warming. Their answers showed a high level of skepticism:

- Prof. Freeman Dyson, professor of physics at the Institute for Advanced Study at Princeton University, one of the world's most eminent physicists, said the models used to justify global warming alarmism are "full of fudge factors" and "do not begin to describe the real world."

- Dr. Zbigniew Jaworowski, chairman of the Scientific Council of the Central Laboratory for Radiological Protection in Warsaw and former chair of the United Nations Scientific Committee on the Effects of Atomic Radiation, a world-renowned expert on the use of ancient ice cores for climate research, said the U.N. "based its global-warming hypothesis on arbitrary assumptions and these assumptions, it is now clear, are false."

- Dr. Richard Lindzen, a professor of meteorology at M.I.T. and member of the National Research Council Board on Atmospheric Sciences and Climate, said the IPCC is "trumpeting catastrophes that couldn't happen even if the models were right."

- Prof. Hendrik Tennekes, director of research at the Royal Netherlands Meteorological Institute, said "there exists no sound theoretical framework for climate predictability studies" used for global warming forecasts.

- Dr. Richard Tol, principal researcher at the Institute for Environmental Studies at Vrije Universiteit and adjunct professor at the Center for Integrated Study of the Human Dimensions of Global Change at Carnegie Mellon University, said the IPCC's Fourth Assessment Report is "preposterous ... alarmist and incompetent."

- Dr. Antonino Zichichi, emeritus professor of physics at the University of Bologna, former president of the European Physical Society, and one of the world's foremost physicists, said global warming models are "incoherent and invalid."

Princeton's Freeman Dyson has written elsewhere, "I have studied the climate models and I know what they can do. The models solve the equations of fluid dynamics, and they do a very good job of describing the fluid motions of the atmosphere and the oceans. They do a very poor job of describing the clouds, the dust, the chemistry, and the biology of fields and farms and forests. They do not begin to describe the real world that we live in" (Dyson, 2007).

Many of the scientists cited above observe that computer models can be "tweaked" to reconstruct climate histories after the fact, as the IPCC points out in the passage quoted at the beginning of this chapter. But this provides no assurance that the new model will do a better job forecasting *future* climates, and indeed points to how unreliable the models are. Individual climate models often have widely differing assumptions about basic climate mechanisms but are then "tweaked" to produce similar forecasts. This is nothing like how real scientific forecasting is done.

Kevin Trenberth, a lead author along with Philip D. Jones of chapter 3 of the Working Group I contribution to the IPCC's Fourth Assessment Report, replied to some of these scathing criticisms on the blog of the science journal *Nature*. He argued that "the IPCC does not make forecasts" but "instead proffers 'what if' projections of future climate that correspond to certain emissions scenarios," and then hopes these "projections" will "guide policy and decision makers" (Trenberth, 2007). He says "there are no such predictions [in the IPCC reports] although the projections given by the Intergovernmental Panel on Climate Change (IPCC) are often treated as such. The distinction is important."

This defense is hardly satisfactory. As Green and Armstrong point out, "the word 'forecast' and its derivatives occurred 37 times, and 'predict' and its derivatives occurred 90 times in the body of Chapter 8" of the Working Group I report, and a survey of climate scientists conducted by those same authors found "most of our respondents (29 of whom were IPCC authors or reviewers) nominated the IPCC report as the most credible source of forecasts (not 'scenarios' or 'projections') of global average temperature." They conclude that "the IPCC does provide forecasts." We agree, and add that those forecasts are unscientific and therefore likely to be wrong.

Additional information on this topic, including reviews of climate model inadequacies not discussed here, can be found at http://www.co2science.org/subject/m/subject_m.php under the heading Models of Climate.

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1.2. Radiation

One problem facing GCMs is how to accurately simulate the physics of earth's radiative energy balance. Of this task, Harries (2000) says "progress is excellent, on-going research is fascinating, but we have still a great deal to understand about the physics of climate."

Harries says "we must exercise great caution over the true depth of our understanding, and our ability to forecast future climate trends." As an example, he states that our knowledge of high cirrus clouds is very poor, noting that "we could easily have uncertainties of many tens of Wm^{-2} in our description of the radiative effect of such clouds, and how these properties may change under climate forcing." This state of affairs is disconcerting in light of the fact that the radiative effect of a doubling of the air's CO_2 content is in the lower single-digit range of Wm^{-2}, and, to quote Harries, "uncertainties as large as, or larger than, the doubled CO_2 forcing could easily exist in our modeling of future climate trends, due to uncertainties in the feedback processes." Because of the vast complexity of the subject, Harries says "even if [our] understanding were perfect, our ability to describe the system sufficiently well in even the largest computer models is a problem."

A related problem is illustrated by the work of Zender (1999), who characterized the spectral, vertical, regional and seasonal atmospheric heating caused by the oxygen collision pairs $O_2 \cdot O_2$ and $O_2 \cdot N_2$, which had earlier been discovered to absorb a small but significant fraction of the globally incident solar radiation. In addition, water vapor demers (a double molecule of H_2O) shows strong absorption bands in the near-infrared of the solar spectrum. Zender revealed that these molecular collisions lead to the absorption of about 1 Wm^{-2} of solar radiation, globally and annually averaged. This discovery, in Zender's words, "alters the long-standing view that H_2O, O_3, O_2, CO_2 and NO_2 are the only significant gaseous solar absorbers in earth's atmosphere," and he suggests that the phenomenon "should therefore be included in ... large-scale atmospheric models used to simulate climate and climate change."

In another revealing study, Wild (1999) compared the observed amount of solar radiation absorbed in the atmosphere over equatorial Africa with what was predicted by three GCMs and found the model predictions were much too small. Indeed, regional and seasonal model underestimation biases were as high as 30 Wm^{-2}, primarily because the models failed to properly account for spatial and temporal variations in atmospheric aerosol concentrations. In addition, Wild found the models likely underestimated the amount of solar radiation absorbed by water vapor and clouds.

Similar large model underestimations were discovered by Wild and Ohmura (1999), who analyzed a comprehensive observational dataset consisting of solar radiation fluxes measured at 720 sites across the earth's surface and corresponding top-of-the-atmosphere locations to assess the true amount of solar radiation absorbed within the atmosphere. These results were compared with estimates of solar radiation absorption derived from four GCMs and, again, it was shown that "GCM atmospheres are generally too transparent for solar radiation," as they produce a rather substantial mean error close to 20 percent below actual observations.

Another solar-related deficiency of GCMs is their failure to properly account for solar-driven variations in earth-atmosphere processes that operate over a range of timescales extending from the 11-year solar cycle to century- and millennial-scale cycles (see Section 4.11, Solar Influence on Climate). Although the absolute solar flux variations associated with these phenomena are rather small, there are a number of "multiplier effects" that may significantly amplify their impacts.

According to Chambers *et al*. (1999), most of the many nonlinear responses to solar activity variability are inadequately represented in the global climate models used by the IPCC to predict future greenhouse gas-induced global warming, while at the same time other amplifier effects are used to model past glacial/interglacial cycles and even the hypothesized CO_2-induced warming of the future, where CO_2 is not the major cause of the predicted temperature increase but rather an initial perturber of the climate system that according to the IPCC sets other more powerful forces in motion that produce the bulk of the ultimate warming. There appears to be a double standard within the climate modeling community that may best be described as an inherent reluctance to deal even-handedly with different aspects of climate change. When multiplier effects suit their purposes, they use them; but when they don't suit their purposes, they don't use them.

Ghan *et al*. (2001) warn that "present-day radiative forcing by anthropogenic greenhouse gases is estimated to be 2.1 to 2.8 Wm^{-2}; the direct forcing by anthropogenic aerosols is estimated to be -0.3 to -1.5 Wm^{-2}, while the indirect forcing by anthropogenic aerosols is estimated to be 0 to -1.5 Wm^{-2}," so that "estimates of the total global mean present-day anthropogenic forcing range from 3 Wm^{-2} to -1 Wm^{-2}," which implies a climate change somewhere between a modest warming and a slight cooling. They conclude that "the great uncertainty in the radiative forcing must be reduced if the observed climate record is to be reconciled with model predictions and if estimates of future climate change are to be useful in formulating emission policies."

Pursuit of this goal, Ghan *et al.* say, requires achieving "profound reductions in the uncertainties of direct and indirect forcing by anthropogenic aerosols," which is what they set out to do in their analysis of the situation, which consisted of "a combination of process studies designed to improve understanding of the key processes involved in the forcing, closure experiments designed to evaluate that understanding, and integrated models that treat all of the necessary processes together and estimate the forcing." At the conclusion of this laborious set of operations, Ghan *et al*. came up with some numbers that considerably reduce the range of uncertainty in the "total global mean present-day anthropogenic forcing," but that still implied a set of climate changes stretching from a small cooling to a modest warming. They also provided a long list of *other* things that must be done in order to obtain a more definitive result, after which they acknowledged that even this list "is hardly complete." In fact, they conclude, "one could easily add the usual list of uncertainties in the representation of clouds, etc." Consequently, the bottom line, in their words, is that "much remains to be done before the estimates are reliable enough to base energy policy decisions upon."

Also studying the aerosol-induced radiative forcing of climate were Vogelmann *et al*. (2003), who report that "mineral aerosols have complex, highly varied optical properties that, for equal loadings, can cause differences in the surface IR flux between 7 and 25 Wm^{-2} (Sokolik *et al*., 1998)." They say "only a few large-scale climate models currently consider aerosol IR effects (e.g., Tegen *et al*., 1996; Jacobson, 2001) despite their potentially large forcing." Because of these facts, and in an attempt to persuade climate modelers to rectify the situation, Vogelmann *et al*. used high-resolution spectra to calculate the surface IR radiative forcing created by aerosols encountered in the outflow of air from northeastern Asia, based on measurements made by the Marine-Atmospheric Emitted Radiance Interferometer aboard the NOAA Ship *Ronald H. Brown* during the Aerosol Characterization Experiment-Asia. In doing so, they determined, in their words, that "daytime surface IR forcings are often a few Wm^{-2} and can reach almost 10 Wm^{-2} for large aerosol loadings," which values they say "are comparable to or larger than the 1 to 2 Wm^{-2} change in the globally averaged surface IR forcing caused by greenhouse gas increases since pre-industrial times." In a massive understatement of fact, the researchers concluded that their results "highlight the importance of aerosol IR forcing which should be included in climate model simulations." If a forcing of this magnitude is not included in current state-of-the-art climate models, what other major forcings are they ignoring?

Two papers published one year earlier and appearing in the same issue of *Science* (Chen *et al*., 2002; Wielicki *et al*., 2002) revealed what Hartmann (2002) called a pair of "tropical surprises." The first of the seminal discoveries was the common finding of both groups of researchers that the amount of thermal radiation emitted to space at the top of the tropical atmosphere increased by about 4 Wm^{-2} between the 1980s and the 1990s. The second was that the amount of reflected sunlight decreased by 1 to 2 Wm^{-2} over the same period, with the net result that more total radiant energy exited the tropics in the latter decade. In addition, the measured thermal radiative energy loss at the top of the tropical atmosphere was of the same magnitude as the thermal radiative energy gain that is generally predicted to result from an instantaneous doubling of the air's CO_2 content. Yet as Hartmann notes, "only very small changes in average tropical surface temperature were observed during this time." How did this occur?

The change in solar radiation reception was driven by reductions in cloud cover, which allowed more solar radiation to reach the surface of the earth's tropical region and warm it. These changes were produced by what Chen *et al*. determined to be "a decadal-time-scale strengthening of the tropical Hadley and Walker circulations." Another helping-hand was likely provided by the past quarter-century's slowdown in the meridional overturning circulation of the upper 100 to 400 meters of the tropical Pacific Ocean (McPhaden and Zhang, 2002), which circulation slowdown also promotes tropical sea surface warming by reducing the rate-of-supply of relatively colder water to the region of equatorial upwelling.

These observations provide several new phenomena for the models to replicate as a test of their ability to properly represent the real world. In the words of McPhaden and Zhang, the time-varying meridional overturning circulation of the upper Pacific Ocean provides "an important dynamical constraint for model studies that attempt to simulate recent observed decadal changes in the Pacific."

In an eye-opening application of this principle, Wielicki *et al*. (2002) tested the ability of four state-of-the-art climate models and one weather assimilation model to reproduce the observed decadal changes in top-of-the-atmosphere thermal and solar radiative energy fluxes that occurred over the past two decades. No significant decadal variability was exhibited by *any* of the models; and they *all* failed to reproduce even the cyclical seasonal change in tropical albedo. The administrators of the test kindly concluded that "the missing variability in the models highlights the critical need to improve cloud modeling in the tropics so that prediction of tropical climate on interannual and decadal time scales can be improved." Hartmann was considerably more candid in his scoring of the test, saying flatly that the results indicated "the models are deficient." Expanding on this assessment, he noted that "if the energy budget can vary substantially in the absence of obvious forcing," as it did over the past two decades, "then the climate of earth has modes of variability that are not yet fully understood and cannot yet be accurately represented in climate models."

Also concentrating on the tropics, Bellon *et al*. (2003) note that "observed tropical sea-surface temperatures (SSTs) exhibit a maximum around 30°C," and that "this maximum appears to be robust on various timescales, from intraseasonal to millennial." Hence, they say, "identifying the stabilizing feedback(s) that help(s) maintain this threshold is essential in order to understand how the tropical climate reacts to an external perturbation," which knowledge is needed for understanding how the global climate reacts to perturbations such as those produced by solar variability and the ongoing rise in the air's CO_2 content. This contention is further substantiated by the study of Pierrehumbert (1995), which "clearly demonstrates," in the words of Bellon *et al*., "that the tropical climate is not determined locally, but globally." Also, they note that Pierrehumbert's work demonstrates that interactions between moist and dry regions are an essential part of tropical climate stability, which points to the "adaptive infrared iris" concept of Lindzen *et al*. (2001), which is reported in Section 1.2.

Noting that previous box models of tropical climate have shown it to be rather sensitive to the relative areas of moist and dry regions of the tropics, Bellon *et al*. analyzed various feedbacks associated with this sensitivity in a four-box model of the tropical climate "to show how they modulate the response of the tropical temperature to a radiative perturbation." In addition, they investigated the influence of the model's surface-wind parameterization in an attempt to shed further light on the nature of the underlying feedbacks that help define the global climate system that is responsible for the tropical climate observations of constrained maximum sea surface temperatures (SSTs).

Bellon *et al*.'s work, as they describe it, "suggests the presence of an important and as-yet-unexplored feedback in earth's tropical climate, that could contribute to maintain the 'lid' on tropical SSTs." They say the demonstrated "dependence of the surface wind on the large-scale circulation has an important effect on the sensitivity of the tropical system," specifically stating that "this dependence reduces significantly the SST sensitivity to radiative perturbations by enhancing the evaporation feedback," which injects more heat into the atmosphere and allows the atmospheric circulation to export more energy to the subtropical free troposphere, where it can be radiated to space by water vapor.

This literature review makes clear that the case is not closed on either the source or the significance of the maximum "allowable" SSTs of tropical regions. Neither, consequently, is the case closed on the degree to which the planet may warm in response to continued increases in the atmospheric concentrations of carbon dioxide and other greenhouse gases, in stark contrast to what is suggested by the climate models promoted by the IPCC.

In conclusion, there are a number of major inadequacies in the ways the earth's radiative energy balance is treated in contemporary general circulation models of the atmosphere, as well as numerous other telling inadequacies stemming from the non-treatment of pertinent phenomena that are nowhere to be found in the models. IPCC-inspired predictions of catastrophic climatic changes due to continued anthropogenic CO_2 emissions are beyond what can be soundly supported by the current state of the climate modeling enterprise.

Additional information on this topic, including reviews of newer publications as they become available, can be found at http://www.co2science.org/subject/m/inadeqradiation.php.

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1.3. Clouds

Correctly parameterizing the influence of clouds on climate is an elusive goal that the creators of atmospheric general circulation models (GCMs) have yet to achieve. One reason for their lack of success has to do with model resolution on vertical and horizontal space scales. Lack of adequate resolution forces modelers to parameterize the ensemble large-scale effects of processes that occur on smaller scales than their models are capable of handling. This is particularly true of physical processes such as cloud formation and cloud-radiation interactions. Several studies suggest that older model parameterizations did not succeed in this regard (Groisman *et al*., 2000), and subsequent studies suggest they still are not succeeding.

Lane *et al*. (2000) evaluated the sensitivities of the cloud-radiation parameterizations utilized in contemporary GCMs to changes in vertical model resolution, varying the latter from 16 to 60 layers in increments of four and comparing the results to observed values. This effort revealed that cloud fraction varied by approximately 10 percent over the range of resolutions tested, which corresponded to about 20 percent of the observed cloud cover fraction. Similarly, outgoing longwave radiation varied by 10 to 20 Wm^{-2} as model vertical resolution was varied, amounting to approximately 5 to 10 percent of observed values, while incoming solar radiation experienced similar significant variations across the range of resolutions tested. The model results did not converge, even at a resolution of 60 layers.

In an analysis of the multiple roles played by cloud microphysical processes in determining tropical climate, Grabowski (2000) found much the same thing, noting there were serious problems related to the degree to which computer models failed to correctly incorporate cloud microphysics. These observations led him to conclude that "it is unlikely that traditional convection parameterizations can be used to address this fundamental question in an effective way." He also became convinced that "classical convection parameterizations do not include realistic elements of cloud physics and they represent interactions among cloud physics, radiative processes, and surface processes within a very limited scope." Consequently, he says, "model results must be treated as qualitative rather than quantitative."

Reaching rather similar conclusions were Gordon *et al*. (2000), who determined that many GCMs of the late 1990s tended to under-predict the presence of subtropical marine stratocumulus clouds and failed to simulate the seasonal cycle of clouds. These deficiencies are extremely important because these particular clouds exert a major cooling influence on the surface temperatures of the sea below them. In the situation investigated by Gordon and his colleagues, the removal of the low clouds, as occurred in the normal application of their model, led to sea surface temperature increases on the order of 5.5°C.

Further condemnation of turn-of-the-century model treatments of clouds came from Harries (2000), previously cited in Section 1.1, who wrote that our knowledge of high cirrus clouds is very poor and that "we could easily have uncertainties of many tens of Wm^{-2} in our description of the radiative effect of such clouds, and how these properties may change under climate forcing."

Moving into the twenty-first century, Lindzen *et al*. (2001) analyzed cloud cover and sea surface temperature (SST) data over a large portion of the Pacific Ocean, finding a strong inverse relationship between upper-level cloud area and mean SST, such that the area of cirrus cloud coverage normalized by a measure of the area of cumulus coverage decreased by about 22 percent for each degree C increase in cloudy region SST. Essentially, as the researchers described it, "the cloudy-moist region appears to act as an infrared adaptive iris that opens up and closes down the regions free of upper-level clouds, which more effectively permit infrared cooling, in such a manner as to resist changes in tropical surface temperature." The sensitivity of this negative feedback was calculated by Lindzen *et al*. to be substantial. In fact, they estimated it would "more than cancel all the positive feedbacks in the more sensitive current climate models" that were being used to predict the consequences of projected increases in atmospheric CO_2 concentration.

Lindzen's challenge to what had become climatic political correctness could not go uncontested, and Hartmann and Michelsen (2002) quickly claimed the correlation noted by Lindzen *et al*. resulted from variations in subtropical clouds that are not physically connected to deep convection near the equator, and that it was thus "unreasonable to interpret these changes as evidence that deep tropical convective anvils contract in response to SST increases." Fu *et al*. (2002) also chipped away at the adaptive infrared iris concept, arguing that "the contribution of tropical high clouds to the feedback process would be small since the radiative forcing over the tropical high cloud region is near zero and not strongly positive," while also claiming to show that water vapor and low cloud effects were overestimated by Lindzen *et al*. by at least 60 percent and 33 percent, respectively. As a result, they obtained a feedback factor in the range of -0.15 to -0.51, compared to Lindzen *et al*.'s much larger negative feedback factor of -0.45 to -1.03.

In a contemporaneously published reply to this critique, Chou *et al*. (2002) stated that Fu *et al*.'s approach of specifying longwave emission and cloud albedos "appears to be inappropriate for studying the iris effect," and that since "thin cirrus are widespread in the tropics and ... low boundary clouds are optically thick, the cloud albedo calculated by [Fu *et al*.] is too large for cirrus clouds and too small for boundary layer clouds," so that "the near-zero contrast in cloud albedos derived by [Fu *et al*.] has the effect of underestimating the iris effect." In the end, however, Chou *et al*. agreed that Lindzen *et al*. "may indeed have overestimated the iris effect somewhat, though hardly by as much as that suggested by [Fu *et al*.]."

Although there has thus been some convergence in the two opposing views of the subject, the debate over the reality and/or magnitude of the adaptive infrared iris effect continues. It is amazing that some political leaders proclaim the debate over global warming is "over" when some of the meteorological community's best minds continue to clash over the nature and magnitude of a phenomenon that could entirely offset the effects of anthropogenic CO_2 emissions.

Grassl (2000), in a review of the then-current status of the climate-modeling enterprise two years before the infrared iris effect debate emerged, noted that changes in many climate-related phenomena, including cloud optical and precipitation properties caused by changes in the spectrum of cloud condensation nuclei, were insufficiently well known to provide useful insights into future conditions. His advice in the light of this knowledge gap was that "we must continuously evaluate and improve the GCMs we use," although he was forced to acknowledge that contemporary climate model results were already being "used by many decision-makers, including governments."

Although some may think that what we currently know about the subject is sufficient for predictive purposes, a host of questions posed by Grassl—for which we still lack definitive answers—demonstrates that this assumption is erroneous. As but a single example, Charlson *et al*. (1987) described a negative feedback process that links biologically-produced dimethyl sulfide (DMS) in the oceans with climate. (See Section 2.3 for a more complete discussion.) The basic tenet of this hypothesis is that the global radiation balance is significantly influenced by the albedo of marine stratus clouds, and that the albedo of these clouds is a function of cloud droplet concentration, which is dependent upon the availability of condensation nuclei that have their origin in the flux of DMS from the world's oceans to the atmosphere.

Acknowledging that the roles played by DMS oxidation products within the context described above are indeed "diverse and complex" and in many instances "not well understood," Ayers and Gillett (2000) summarized empirical evidence supporting Charlson *et al*.'s hypothesis that was derived from data collected at Cape Grim, Tasmania, and from reports of other pertinent studies in the peer-reviewed scientific literature. According to their findings, the "major links in the feedback chain proposed by Charlson *et al*. (1987) have a sound physical basis," and there is "compelling observational evidence to suggest that DMS and its atmospheric products participate significantly in processes of climate regulation and reactive atmospheric chemistry in the remote marine boundary layer of the Southern Hemisphere."

The empirical evidence analyzed by Ayers and Gillett highlights an important suite of negative feedback processes that act in opposition to model-predicted CO_2-induced global warming over the world's oceans; and these processes are not fully incorporated into even the very best of the current crop of climate models, nor are analogous phenomena that occur over land included in them, such as those discussed by Idso (1990). (See also, in this regard, Section 2.7 of this report.)

Further to this point, O'Dowd *et al*. (2004) measured size-resolved physical and chemical properties of aerosols found in northeast Atlantic marine air arriving at the Mace Head Atmospheric Research station on the west coast of Ireland during phytoplanktonic blooms at various times of the year. In doing so, they found that in the winter, when biological activity was at its lowest, the organic fraction of the submicrometer aerosol mass was about 15 percent. During the spring through autumn, however, when biological activity was high, they found that "the organic fraction dominates and contributes 63 percent to the submicrometer aerosol mass (about 45 percent is water-insoluble and about 18 percent water-soluble)." Based on these findings, they performed model simulations that indicated that the marine-derived organic matter "can enhance the cloud droplet concentration by 15 percent to more than 100 percent and is therefore an important component of the aerosol-cloud-climate feedback system involving marine biota."

As for the significance of their findings, O'Dowd *et al*. state that their data "completely change the picture of what influences marine cloud condensation nuclei given that water-soluble organic carbon, water-insoluble organic carbon and surface-active properties, all of which influence the cloud condensation nuclei activation potential, are typically not parameterized in current climate models," or as they say in another place in their paper, "an important source of organic matter from the ocean is omitted from current climate-modeling predictions and should be taken into account."

Another perspective on the cloud-climate conundrum is provided by Randall *et al*. (2003), who state at the outset of their review of the subject that "the representation of cloud processes in global atmospheric models has been recognized for decades as the source of much of the uncertainty surrounding predictions of climate variability." They report, however, that "despite the best efforts of [the climate modeling] community ... the problem remains largely unsolved." What is more, they say, "at the current rate of progress, cloud parameterization deficiencies will continue to plague us for many more decades into the future."

"Clouds are complicated," Randall *et al*. declare, as they begin to describe what they call the "appalling complexity" of the cloud parameterization situation. They state that "our understanding of the interactions of the hot towers [of cumulus convection] with the global circulation is still in a fairly primitive state," and not knowing all that much about *what goes up*, it's not surprising we also don't know much about *what comes down*, as they report that "downdrafts are either not parameterized or crudely parameterized in large-scale models."

With respect to stratiform clouds, the situation is no better, as their parameterizations are described by Randall *et al*. as "very rough caricatures of reality." As for interactions between convective and stratiform clouds, during the 1970s and '80s, Randall *et al*. report that "cumulus parameterizations were extensively tested against observations without even accounting for the effects of the attendant stratiform clouds." Even at the time of their study, they had to report that the concept of detrainment was "somewhat murky" and the conditions that trigger detrainment were "imperfectly understood." "At this time," as they put it, "no existing GCM includes a satisfactory parameterization of the effects of mesoscale cloud circulations."

Randall *et al*. additionally say that "the large-scale effects of microphysics, turbulence, and radiation should be parameterized as closely coupled processes acting in concert," but they report that only a few GCMs have even attempted to do so. Why? Because, as they continue, "the cloud parameterization problem is overwhelmingly complicated," and "cloud parameterization developers," as they call them, are still "struggling to identify the most important processes on the basis of woefully incomplete observations." To drive this point home, they say "there is little question why the cloud parameterization problem is taking a long time to solve: It is very, very hard." In fact, the four scientists conclude that "a sober assessment suggests that with current approaches the cloud parameterization problem will not be 'solved' in any of our lifetimes."

To show that the basis for this conclusion is robust, and cannot be said to rest on the less-than-enthusiastic remarks of a handful of exasperated climate modelers, we report the results of additional studies of the subject that were published *subsequent* to the analysis of Randall *et al*., and which therefore could have readily refuted their assessment of the situation if they felt that such was appropriate.

Siebesma *et al*. (2004) report that "simulations with nine large-scale models [were] carried out for June/July/August 1998 and the quality of the results [was] assessed along a cross-section in the subtropical and tropical North Pacific ranging from (235°E, 35°N) to (187.5°E, 1°S)," in order to "document the performance quality of state-of-the-art GCMs in modeling the first-order characteristics of subtropical and tropical cloud systems." The main conclusions of this study, according to Siebesma *et al*., were that "(1) almost all models strongly underpredicted both cloud cover and cloud amount in the stratocumulus regions while (2) the situation is opposite in the trade-wind region and the tropics where cloud cover and cloud amount are overpredicted by most models." In fact, they report that "these deficiencies result in an overprediction of the downwelling surface short-wave radiation of typically 60 Wm^{-2} in the stratocumulus regimes and a similar underprediction of 60 Wm^{-2} in the trade-wind regions and in the intertropical convergence zone (ITCZ)," which discrepancies are to be compared with a radiative forcing of only a couple of Wm^{-2} for a 300 ppm increase in the atmosphere's CO_2 concentration. In addition, they state that "similar biases for the short-wave radiation were found at the top of the atmosphere, while discrepancies in the outgoing long-wave radiation are most pronounced in the ITCZ."

The 17 scientists who wrote Siebesma *et al*., hailing from nine different countries, also found "the representation of clouds in general-circulation models remains one of the most important *as yet unresolved* [our italics] issues in atmospheric modeling." This is partially due, they continue, "to the overwhelming variety of clouds observed in the atmosphere, but even more so due to the large number of physical processes governing cloud formation and evolution as well as the great complexity of their interactions." Hence, they conclude that through repeated critical evaluations of the type they conducted, "the scientific community will be forced to develop further physically sound parameterizations that *ultimately* [our italics] result in models that are capable of simulating our climate system with increasing realism."

In an effort to assess the status of state-of-the-art climate models in simulating cloud-related processes, Zhang *et al*. (2005) compared basic cloud climatologies derived from 10 atmospheric GCMs with satellite measurements obtained from the International Satellite Cloud Climatology Project (ISCCP) and the Clouds and Earth's Radiant Energy System (CERES) program. ISCCP data were available from 1983 to 2001, while data from the CERES program were available for the winter months of 2001 and 2002 and for the summer months of 2000 and 2001. The purpose of their analysis was two-fold: (1) to assess the current status of climate models in simulating clouds so that future progress can be measured more objectively, and (2) to reveal serious deficiencies in the models so as to improve them.

The work of 20 climate modelers involved in this exercise reveals a huge list of major model imperfections. First, Zhang *et al*. report a four-fold difference in high clouds among the models, and that the majority of the models simulated only 30 to 40 percent of the observed middle clouds, with some models simulating less than a quarter of observed middle clouds. For low clouds, they report that half the models underestimated them, such that the grand mean of low clouds from all models was only 70 to 80 percent of what was observed. Furthermore, when stratified in optical thickness ranges, the majority of the models simulated optically thick clouds more than twice as frequently as was found to be the case in the satellite observations, while the grand mean of all models simulated about 80 percent of optically intermediate clouds and 60 percent of optically thin clouds. And in the case of *individual* cloud types, the group of researchers reports that "differences of seasonal amplitudes among the models and satellite measurements can reach several hundred percent." As a result of these and other observations, Zhang *et al*. conclude that "much more needs to be done to fully understand the physical causes of model cloud biases presented here and to improve the models."

L'Ecuyer and Stephens (2007) used multi-sensor observations of visible, infrared, and microwave radiance obtained from the Tropical Rainfall Measuring Mission satellite for the period from January 1998 through December 1999, in order to evaluate the sensitivity of atmospheric heating—and the factors that modify it—to changes in east-west sea surface temperature gradients associated with the strong 1998 El Niño event in the tropical Pacific, as expressed by the simulations of nine general circulation models of the atmosphere that were utilized in the IPCC's most recent Fourth Assessment Report. This protocol, in their words, "provides a natural example of a short-term climate change scenario in which clouds, precipitation, and regional energy budgets in the east and west Pacific are observed to respond to the eastward migration of warm sea surface temperatures."

Results indicated that "a majority of the models examined do not reproduce the apparent westward transport of energy in the equatorial Pacific during the 1998 El Niño event." They also found that "the intermodel variability in the responses of precipitation, total heating, and vertical motion is often larger than the intrinsic ENSO signal itself, implying an inherent lack of predictive capability in the ensemble with regard to the response of the mean zonal atmospheric circulation in the tropical Pacific to ENSO." In addition, they reported that "many models also misrepresent the radiative impacts of clouds in both regions [the east and west Pacific], implying errors in total cloudiness, cloud thickness, and the relative frequency of occurrence of high and low clouds." As a result of these much-less-than-adequate findings, the two researchers from Colorado State University's Department of Atmospheric Science conclude that "deficiencies remain in the representation of relationships between radiation, clouds, and precipitation in current climate models," and they say that these deficiencies "cannot be ignored when interpreting their predictions of future climate."

In another recent paper, this one published in the *Journal of the Atmospheric Sciences*, Zhou *et al.* (2007) state that "clouds and precipitation play key roles in linking the earth's energy cycle and water cycles," noting that "the sensitivity of deep convective cloud systems and their associated precipitation efficiency in response to climate change are key factors in predicting the future climate." They also report that cloud resolving models or CRMs "have become one of the primary tools to develop the physical parameterizations of moist and other subgrid-scale processes in global circulation and climate models," and that CRMs could someday be used in place of traditional cloud parameterizations in such models.

In this regard, the authors note that "CRMs still need parameterizations on scales smaller than their grid resolutions and have many known and unknown deficiencies." To help stimulate progress in these areas, the nine scientists compared the cloud and precipitation properties observed from the Clouds and the Earth's Radiant Energy System (CERES) and Tropical Rainfall Measuring Mission (TRMM) instruments against simulations obtained from the three-dimensional Goddard Cumulus Ensemble (GCE) model during the South China Sea Monsoon Experiment (SCSMEX) field campaign of 18 May-18 June 1998.

The authors report that: (1) "the GCE rainfall spectrum includes a greater proportion of heavy rains than PR (Precipitation Radar) or TMI (TRMM Microwave Imager) observations"; (2) "the GCE model produces excessive condensed water loading in the column, especially the amount of graupel as indicated by both TMI and PR observations"; (3) "the model also cannot simulate the bright band and the sharp decrease of radar reflectivity above the freezing level in stratiform rain as seen from PR"; (4) "the model has much higher domain-averaged OLR (outgoing longwave radiation) due to smaller total cloud fraction"; (5) "the model has a more skewed distribution of OLR and effective cloud top than CERES observations, indicating that the model's cloud field is insufficient in area extent"; (6) "the GCE is ... not very efficient in stratiform rain conditions because of the large amounts of slowly falling snow and graupel that are simulated"; and finally, and in summation, (7) "large differences between model and observations exist in the rain spectrum and the vertical hydrometeor profiles that contribute to the associated cloud field."

Even more recently, a study by Spencer and Braswell (2008) observed that "our understanding of how sensitive the climate system is to radiative perturbations has been limited by large uncertainties regarding how clouds and other elements of the climate system feed back to surface temperature change (e.g., Webster and Stephens, 1984; Cess *et al.*, 1990; Senior and Mitchell, 1993; Stephens, 2005; Soden and Held, 2006; Spencer *et al.*, 2007)." The two scientists from the Earth System Science Center at the University of Alabama in Huntsville, Alabama then point out that computer models typically assume that if the *causes* of internal sources of variability (*X* terms) are uncorrelated to surface temperature changes, then they will not affect the accuracy of regressions used to estimate the relationship between radiative flux changes and surface temperature (*T*). But "while it is true that the processes that *cause* the X terms are, by [Forster and Gregory (2006)] definition, uncorrelated to *T*, the *response* of *T* to those forcings cannot be uncorrelated to *T* – for the simple reason that it is a radiative forcing that causes changes in *T* [italics in the original].” They ask “to what degree could nonfeedback sources of radiative flux variability contaminate feedback estimates?”

Spencer and Braswell use a “very simple time-dependent model of temperature deviations away from an equilibrium state” to estimate the effects of “daily random fluctuations in an unknown nonfeedback radiative source term *N*, such as those one might expect from stochastic variations in low cloud cover.” Repeated runs of the model found the diagnosed feedback departed from the true, expected feedback value of the radiative forcing, with the difference increasing as the amount of nonfeedback radiative flux noise was increased. “It is significant,” the authors write, “that all model errors for runs consistent with satellite-observed variability are in the direction of positive feedback, raising the possibility that current observational estimates of cloud feedback are biased in the positive direction.” In other words, as the authors say in their abstract, “current observational diagnoses of cloud feedback – and possibly other feedbacks – could be significantly biased in the positive direction.”

In light of these findings, it is clear that CRMs still have a long way to go before they are ready to properly assess the roles of various types of clouds and forms of precipitation in the future evolution of earth’s climate in response to variations in anthropogenic and background forcings. This evaluation is not meant to denigrate the CRMs, it is merely done to indicate that the climate modeling enterprise is not yet at the stage where faith should be placed in what it currently suggests about earth’s climatic response to the ongoing rise in the air’s CO_2 content.

The hope of the climate-modeling community of tomorrow resides, according to Randall *et al*., in something called “cloud system-resolving models” or CSRMs, which can be compared with single-column models or SCMs that can be “surgically extracted from their host GCMs.” These advanced models, as they describe them, “have resolutions fine enough to represent individual cloud elements, and space-time domains large enough to encompass many clouds over many cloud lifetimes.” Of course, these improvements mean that “the computational cost of running a CSRM is hundreds or thousands of times greater than that of running an SCM.” Nevertheless, in a few more decades, according to Randall *et al*., “it will become possible to use such global CSRMs to perform century-scale climate simulations, relevant to such problems as anthropogenic climate change.”

A few more decades, however, is a little long to wait to address an issue that nations of the world are confronting now. Hence, Randall *et al*. say that an approach that could be used very soon (to possibly determine whether or not there even is a problem) is to “run a CSRM as a ‘superparameterization’ inside a GCM,” which configuration they call a “super-GCM.” Not wanting to be accused of impeding scientific progress, we say “go for it,” but only with the proviso that the IPCC should admit it is truly needed in order to obtain a definitive answer to the question of CO_2-induced “anthropogenic climate change.” In other words, the scientific debate over the causes and processes of global warming is still ongoing and there is no scientific case for governments to regulate greenhouse gas emissions in an expensive and likely futile attempt to alter the course of future climate.

We believe, with Randall *et al*., that our knowledge of many aspects of earth’s climate system is sadly deficient. Climate models currently do not provide a reliable scientific basis for implementing programs designed to restrict anthropogenic CO_2 emissions. The cloud parameterization problem by itself is so complex that no one can validly claim that humanity’s continued utilization of fossil-fuel energy will result in massive counter-productive climatic changes. There is no justification for that conclusion in reliable theoretical models.

Additional information on this topic, including reviews of newer publications as they become available, can be found at http://www.co2science.org/subject/m/inadeqclouds.php.

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1.4. Precipitation

One of the predictions of atmospheric general circulation models (GCMs) is that the planet's hydrologic cycle will intensify as the world warms, leading to an increase in the frequency and intensity of extreme precipitation events. In an early review of the subject, Walsh and Pittock (1998) reported "there is some evidence from climate model studies that, in a warmer climate, rainfall events will be more intense," and that "there is considerable evidence that the frequency of extreme rainfall events may increase in the tropics." Upon further study, however, they were forced to conclude that "because of the insufficient resolution of climate models and their generally crude representation of sub-grid scale and convective processes, little confidence can be placed in any definite predictions of such effects."

Two years later, Lebel *et al*. (2000) compared rainfall simulations produced by a GCM with real-world observations from West Africa for the period 1960-1990. Their analysis revealed that the model output was affected by a number of temporal and spatial biases that led to significant differences between observed and modeled data. The simulated rainfall totals, for example, were significantly greater than what was typically observed, exceeding real-world values by 25 percent during the dry season and 75 percent during the rainy season. In addition, the seasonal cycle of precipitation was not well simulated, as the researchers found that the simulated rainy season began too early and that the increase in precipitation was not rapid enough. Shortcomings were also evident in the GCM's inability to accurately simulate convective rainfall events, as it typically predicted too much precipitation. Furthermore, it was found that "interannual variability [was] seriously disturbed in the GCM as compared to what it [was] in the observations." As for why the GCM performed so poorly in these several respects, Lebel *et al*. gave two main reasons: parameterization of rainfall processes in the GCM was much too simple, and spatial resolution was much too coarse.

Three years later, Woodhouse (2003) generated a tree-ring-based history of snow water equivalent (SWE) characteristic of the first day of April for each year of the period 1569-1999 for the drainage basin of the Gunnison River of western Colorado, USA. Then, because "an understanding of the long-term characteristics of snowpack variability is useful for guiding expectations for future variability," as she phrased it, she analyzed the reconstructed SWE data in such a way as to determine if there was anything unusual about the SWE record of the twentieth century, which the IPCC claims experienced a warming that was unprecedented over the past two millennia.

Woodhouse found "the twentieth century is notable for several periods that lack extreme years." Specifically, she determined that "the twentieth century is notable for several periods that contain few or no extreme years, for both low and high SWE extremes," and she reports that "the twentieth century also contains the lowest percent of extreme low SWE years." These results are in direct contradiction of what GCMs typically predict should occur in response to global warming. Their failure in this regard is especially damning because it occurred during a period of global warming that is said to have been the most significant of the past 20 centuries.

Two years later, and as a result of the fact that the 2004 summer monsoon season of India experienced a 13 percent precipitation deficit that was not predicted by any of the empirical or dynamical models regularly used in making rainfall forecasts, Gadgil *et al*. (2005) performed a historical analysis of the models forecast skill over the period 1932-2004. Despite model advancements and an ever-improving understanding of monsoon variability, they found the models' skill in forecasting the Indian monsoon's characteristics had not improved since the very first versions of the models were applied to the task some seven decades earlier. The empirical models Gadgil *et al*. evaluated generated large differences between monsoon rainfall measurements and model predictions. In addition, the models often failed to correctly predict even the *sign* of the precipitation anomaly, frequently predicting excess rainfall when drought occurred and drought when excess rainfall was received.

The dynamical models fared even worse. In comparing observed monsoon rainfall totals with simulated values obtained from 20 state-of-the-art GCMs and a supposedly superior coupled atmosphere-ocean model, Gadgil *et al*. reported that not a single one of those many models was able "to simulate correctly the interannual variation of the summer monsoon rainfall over the Indian region." And as with the empirical models, the dynamical models also frequently failed to correctly capture even the *sign* of the observed rainfall anomalies. In addition, the researchers report that Brankovic and Molteni (2004) attempted to model the Indian monsoon with a much higher-resolution GCM, but its output also proved to be "not realistic."

Lau *et al*. (2006) considered the Sahel drought of the 1970s-'90s to provide "an ideal test bed for evaluating the capability of CGCMs [coupled general circulation models] in simulating long-term drought, and the veracity of the models' representation of coupled atmosphere-ocean-land processes and their interactions." They chose to "explore the roles of sea surface temperature coupling and land surface processes in producing the Sahel drought in CGCMs that participated in the twentieth-century coupled climate simulations of the Intergovernmental Panel on Climate Change [IPCC] Assessment Report 4," in which the 19 CGCMs "are driven by combinations of realistic prescribed external forcing, including anthropogenic increase in greenhouse gases and sulfate aerosols, long-term variation in solar radiation, and volcanic eruptions."

In performing this analysis, the climate scientists found, in their words, that "only eight models produce a reasonable Sahel drought signal, seven models produce excessive rainfall over [the] Sahel during the observed drought period, and four models show no significant deviation from normal." In addition, they report that "even the model with the highest skill for the Sahel drought could only simulate the increasing trend of severe drought events but not the magnitude, nor the beginning time and duration of the events." All 19 of the CGCMs employed in the IPCC's Fourth Assessment Report, in other words, failed to adequately simulate the basic characteristics of "one of the most pronounced signals of climate change" of the past century—as defined by its start date, severity and duration."

Wentz *et al*. (2007), in a study published in *Science*, noted that the Coupled Model Intercomparison Project, as well as various climate modeling analyses, predicted an increase in precipitation on the order of 1 to 3 percent per °C of surface global warming. They decided to see what had happened in the real world in this regard over the prior 19 years (1987-2006) of supposedly unprecedented global warming, when data from the Global Historical Climatology Network and satellite measurements of the lower troposphere indicated there had been a global temperature rise on the order of 0.20°C per decade.

Using satellite observations obtained from the Special Sensor Microwave Imager (SSM/I), the four Remote Sensing Systems scientists derived precipitation trends for the world's oceans over this period, and using data obtained from the Global Precipitation Climatology Project that were acquired from both satellite and rain gauge measurements, they derived precipitation trends for earth's continents. Appropriately combining the results of these two endeavors, they derived a real-world increase in precipitation on the order of 7 percent per °C of surface global warming, which is somewhere between 2.3 and 7.0 times *larger* than what is predicted by state-of-the-art climate models.

How was this huge discrepancy to be resolved? Wentz *et al*. concluded that the only way to bring the two results into harmony was for there to have been a 19-year decline in global wind speeds. But when looking at the past 19 years of SSM/I wind retrievals, they found just the opposite, an *increase* in global wind speeds. In quantitative terms, the two results were about as opposite as they could possibly be, as they report that "when averaged over the tropics from 30°S to 30°N, the winds increased by 0.04 m s^{-1} (0.6 percent) $decade^{-1}$, and over all oceans the increase was 0.08 m s^{-1} (1.0 percent) $decade^{-1}$," while global coupled ocean-atmosphere models or GCMs, in their words, "predict that the 1987-to-2006 warming should have been accompanied by a decrease in winds on the order of 0.8 percent $decade^{-1}$."

In discussing these results, Wentz *et al*. say "the reason for the discrepancy between the observational data and the GCMs is not clear." They also observe that this dramatic difference between the real world of nature and the virtual world of climate modeling "has enormous impact" and the questions raised by the discrepancy "are far from being settled."

Allan and Soden (2007) quantified trends in precipitation within ascending and descending branches of the planet's tropical circulation and compared their results with simulations of the present day and projections of future changes provided by up to 16 state-of-the-art climate models. The precipitation data for this analysis came from the Global Precipitation Climatology Project (GPCP) of Adler *et al*. (2003) and the Climate Prediction Center Merged Analysis of Precipitation (CMAP) data of Xie and Arkin (1998) for the period 1979-2006, while for the period 1987-2006 they came from the monthly mean intercalibrated Version 6 Special Sensor Microwave Imager (SSM/I) precipitation data described by Wentz *et al*. (2007).

The researchers reported "an emerging signal of rising precipitation trends in the ascending regions and decreasing trends in the descending regions are detected in the observational datasets," but that "these trends are substantially larger in magnitude than present-day simulations and projections into the 21st century," especially in the case of the descending regions. More specifically, for the tropics "the GPCP trend is about 2-3 times larger than the model ensemble mean trend, consistent with previous findings (Wentz *et al*., 2007) and also supported by the analysis of Yu and Weller (2007)," who additionally contend that "observed increases of evaporation over the ocean are substantially greater than those simulated by climate models." What is more, Allan and Soden note that "observed precipitation changes over land also appear larger than model simulations over the 20th century (Zhang *et al*., 2007)."

Noting that the difference between the models and real-world measurements "has important implications for future predictions of climate change," Allan and Soden say "the discrepancy cannot be explained by changes in the reanalysis fields used to subsample the observations but instead must relate to errors in the satellite data or in the model parameterizations." This same dilemma was also faced by Wentz *et al*. (2007); and they too stated that the resolution of the issue "has enormous impact" and likewise concluded that the questions raised by the discrepancy "are far from being settled."

Lin (2007) states that "a good simulation of tropical mean climate by the climate models is a prerequisite for their good simulations/predictions of tropical variabilities and global teleconnections," but "unfortunately, the tropical mean climate has not been well simulated by the coupled general circulation models (CGCMs) used for climate predictions and projections," noting that "most of the CGCMs produce a double-intertropical convergence zone (ITCZ) pattern," and acknowledging that "a synthetic view of the double-ITCZ problem is still elusive."

To explore the nature of this problem in greater depth, and in hope of making some progress in resolving it, Lin analyzed tropical mean climate simulations of the 20-year period 1979-99 provided by 22 IPCC Fourth Assessment Report CGCMs, together with concurrent Atmospheric Model Intercomparison Project (AMIP) runs from 12 of them. This work revealed, in Lin's words, that "most of the current state-of-the-art CGCMs have some degree of the double-ITCZ problem, which is characterized by excessive precipitation over much of the Tropics (e.g., Northern Hemisphere ITCZ, Southern Hemisphere SPCZ [South Pacific Convergence Zone], Maritime Continent, and equatorial Indian Ocean), and often associated with insufficient precipitation over the equatorial Pacific," as well as "overly strong trade winds, excessive LHF [latent heat flux], and insufficient SWF [shortwave flux], leading to significant cold SST (sea surface temperature) bias in much of the tropical oceans."

The authors further note that "most of the models also simulate insufficient latitudinal asymmetry in precipitation and SST over the eastern Pacific and Atlantic Oceans," and further, that "the AMIP runs also produce excessive precipitation over much of the Tropics including the equatorial Pacific, which also leads to overly strong trade winds, excessive LHF, and insufficient SWF," which suggests that "the excessive tropical precipitation is an intrinsic error of the atmospheric models." And if that is not enough, Lin adds that "over the eastern Pacific stratus region, most of the models produce insufficient stratus-SST feedback associated with insufficient sensitivity of stratus cloud amount to SST."

With the solutions to all of these long-standing problems continuing to remain "elusive," and with Lin suggesting that the sought-for solutions are in fact prerequisites for "good simulations/predictions" of future climate, there is significant reason to conclude that current state-of-the-art CGCM predictions of CO_2-induced global warming should not be considered reliable.

In conclusion, in spite of the billions of dollars spent by the United States alone on developing and improving climate models, the models' ability to correctly simulate even the largest and most regionally-important of earth's atmospheric phenomena—the tropical Indian monsoon—hasn't improved at all. The scientific literature is filled with studies documenting the inability of even the most advanced GCMs to accurately model radiation, clouds, and precipitation. Failure to model any one of these elements would be grounds for rejecting claims that the IPCC provides the evidence needed to justify regulation of anthropogenic greenhouse gas emissions.

Additional information on this topic, including reviews of newer publications as they become available, can be found at http://www.co2science.org/subject/p/precipmodelinadeq.php.

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