First Eurocongress on the Solar Cycle and Terrestrial Climate

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1. Some Difficulties in Simulating Climate Variables
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2. Expected Outcomes of CO_2 Forcing
    - The range of modeled global warmings for CO_2 doubling
    - Non-robustness of predicted changes for North Atlantic thermohaline circulation
3. Comments

Good morning! My name is Willie Soon. Before I start, let me first acknowledge that this presentation is a joint-effort with four of my colleagues as listed in the title. They are Sallie Baliunas, Kirill Kondratyev, Sherwood Idso, and Eric Posmentier. I also wish to thank Manolo Vazquez for his truly very kind invitation for me to speak to you today.

In the next 30 minutes or so, I hope to make clear for you the scientific difficulties and hurdles that prevent us from knowing the precise global and regional climate responses to the carbon dioxide human add to the air. I will show you evidence on why our knowledge on modeling climate processes or even specific climate variables such as temperature, precipitation and clouds is still rather crude.

And I find this fact to be INCOMPATIBLE with the type of quantitative detail required for effective public policy decisions regarding human impacts on global climate. What worries me is the political will in some nations or super-national organizations to prefer ineffective action, despite the scientific facts or unknowns of climate science!

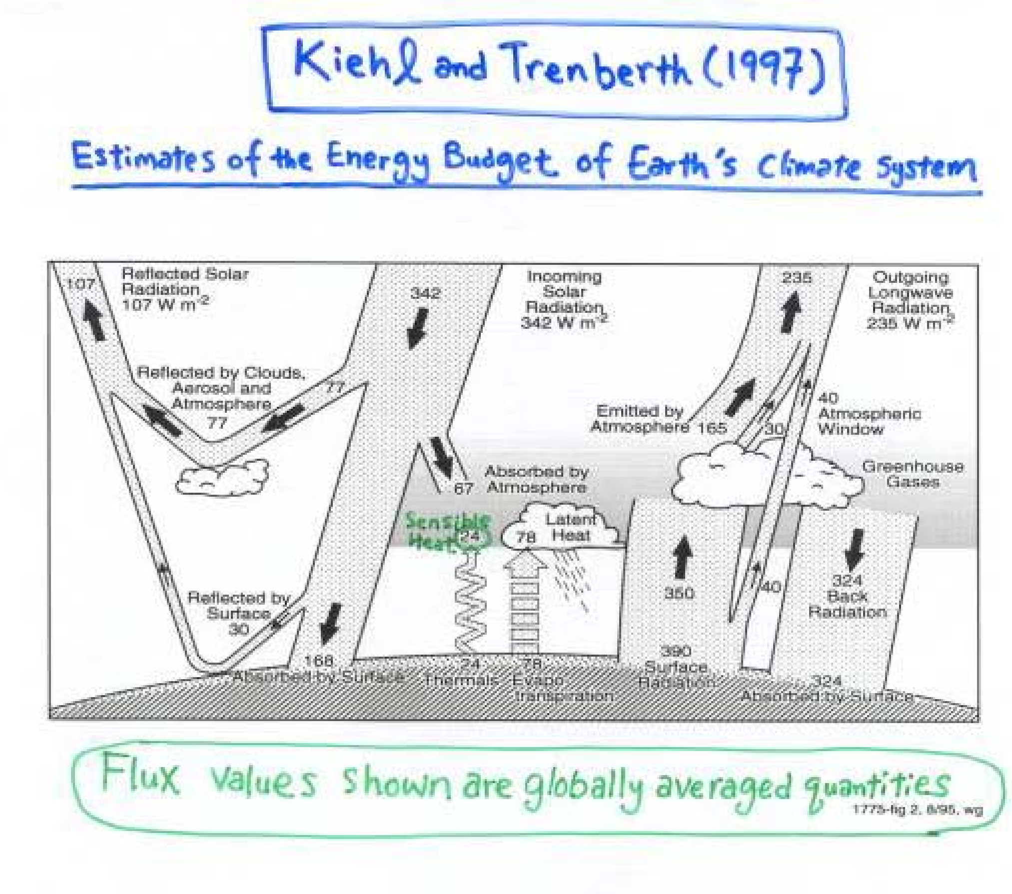
My presentation consists of 3 parts.

1. First, I shall illustrate some systematic difficulties in simulating several climate variables. We will look at surface, tropospheric and stratospheric temperatures, precipitation and cloud cover.
2. In the second part, I shall go over a recent attempt to quantify the range of expected global warming by doubling CO_2 in the climate model. I also hope to show you one example of the non-robustness of predicted changes for the North Atlantic thermohaline circulation that is currently the subject of a serious debate.
3. Finally, I shall wrap up my talk with one or two comments.

1. Some Difficulties in Simulating Climate Variables

Let us start with two key numbers. The first one is the nominal value of 2.5 W m^{-2} associated with the total greenhouse gases radiative forcing since the dawning of the Industrial Revolution. The second one is the estimated radiative change from a doubling of CO2 concentration[i], which adds about 4 W m^{-2} to the surface and troposphere system.

In order to appreciate the scientific difficulties associated with the task of finding climatic changes induced by the anthropogenic CO_2 forcing, one may start by examining the energy budget of Earth's climate system.


Kiehl and Trenberth (1997)

Estimates of the Energy Budget of Earth's Climate System

Flux values shown are globally averaged quantities

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This sketch by Jeff Kiehl and Kevin Trenberth of NCAR (1997) illustrates how various solar and terrestrial energy flux components are apportioned globally in the climate system.

Look towards the left of the chart below. About 107 W m^{-2} or one third of the incoming solar radiation is reflected back to space, some 67 W m^{-2} remains in the atmosphere; and almost 170 W m^{-2} of the solar shortwave radiation gets absorbed at the surface. Moving to the right hand-side of the chart, one sees the significant amount of energy flux attributed to the surface latent and sensible heats. At the top of the atmosphere, the outgoing longwave radiation is deduced by Earth Radiation Budget Experiment satellite measurements to be about 235 W m^{-2}. As for the longwave radiation balance within the surface, one sees that the NET longwave emission from terrestrial surface to the atmosphere is about 66 W m^{-2} (This net value comes from the 390 W m^{-2} up from surface subtracted by the 324 W m^{-2} back down from the atmosphere).

But looking at such a simplified picture alone is quite misleading. Next, one really needs to ask how well each flux components are constrained or even if the individual flux components may be directly measured from the real world.

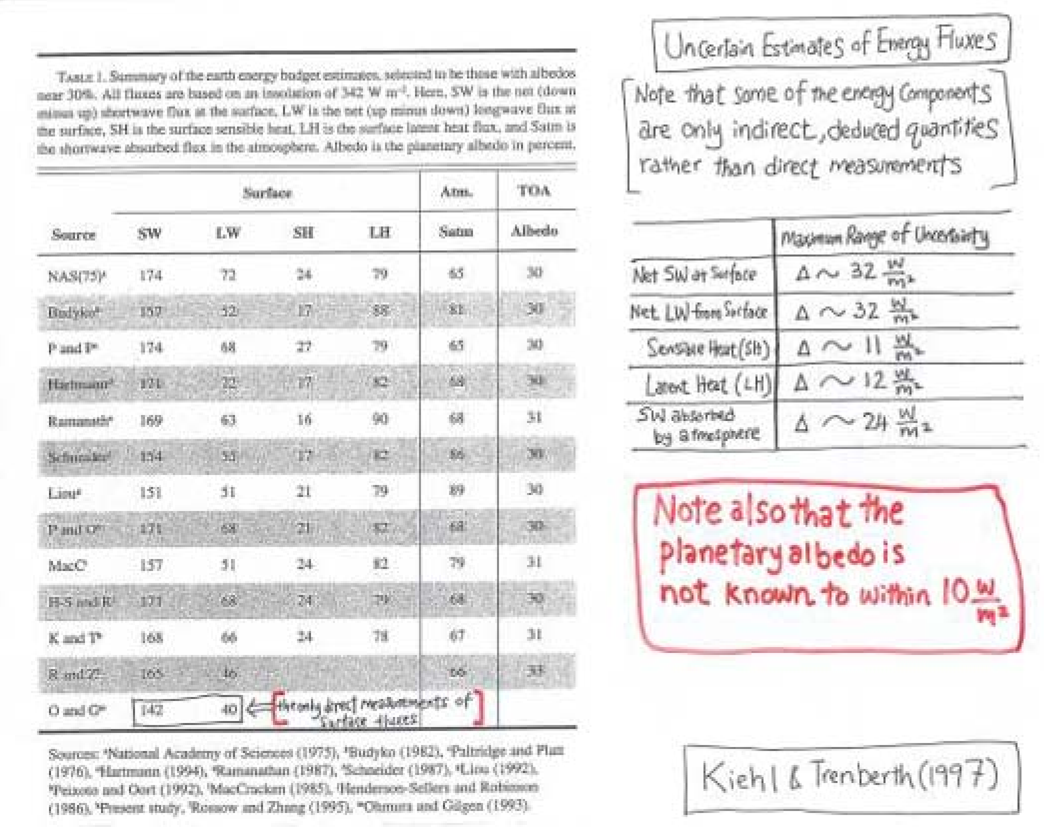


TABLE 1. Summary of the earth energy budget estimates, selected to be those with albedos near 30%. All fluxes are based on an insolation of 342 W m^{-2}. Here, SW is the net (down minus up) shortwave flux at the surface, LW is the net (up minus down) longwave flux at the surface, SH is the surface sensible heat, LH is the surface latent heat flux, and Satm is the shortwave absorbed flux in the atmosphere. Albedo is the planetary albedo in percent.

	Surface				Atm.	TOA
Source	SW	LW	SH	LH	Satm	Albedo
NAS(75)[a]	174	72	24	79	65	30
Budyko[b]	157	52	17	88	81	30
P and P[c]	174	68	27	79	65	30
Hartmann[d]	171	72	17	82	68	30
Ramanath[e]	169	63	16	90	68	31
Schneider[f]	154	55	17	82	86	30
Liou[g]	151	51	21	79	89	30
P and O[h]	171	68	21	82	68	30
MacC[i]	157	51	24	82	79	31
H-S and R[j]	171	68	24	79	68	30
K and T[k]	168	66	24	78	67	31
R and Z[l]	165	46			66	33
O and G[m]	142	40				

the only direct measurements of surface fluxes

Sources: [a]National Academy of Sciences (1975), [b]Budyko (1982), [c]Paltridge and Platt (1976), [d]Hartmann (1994), [e]Ramanathan (1987), [f]Schneider (1987), [g]Liou (1992), [h]Peixoto and Oort (1992), [i]MacCracken (1985), [j]Henderson-Sellers and Robinson (1986), [k]Present study, [l]Rossow and Zhang (1995), [m]Ohmura and Gilgen (1993).

Uncertain Estimates of Energy Fluxes

Note that some of the energy Components are only indirect, deduced quantities rather than direct measurements

	Maximum Range of Uncertainty
Net SW at Surface	$\Delta \sim 32 \frac{W}{m^2}$
Net LW from Surface	$\Delta \sim 32 \frac{W}{m^2}$
Sensible Heat (SH)	$\Delta \sim 11 \frac{W}{m^2}$
Latent Heat (LH)	$\Delta \sim 12 \frac{W}{m^2}$
SW absorbed by atmosphere	$\Delta \sim 24 \frac{W}{m^2}$

Note also that the planetary albedo is not known to within $10 \frac{W}{m^2}$

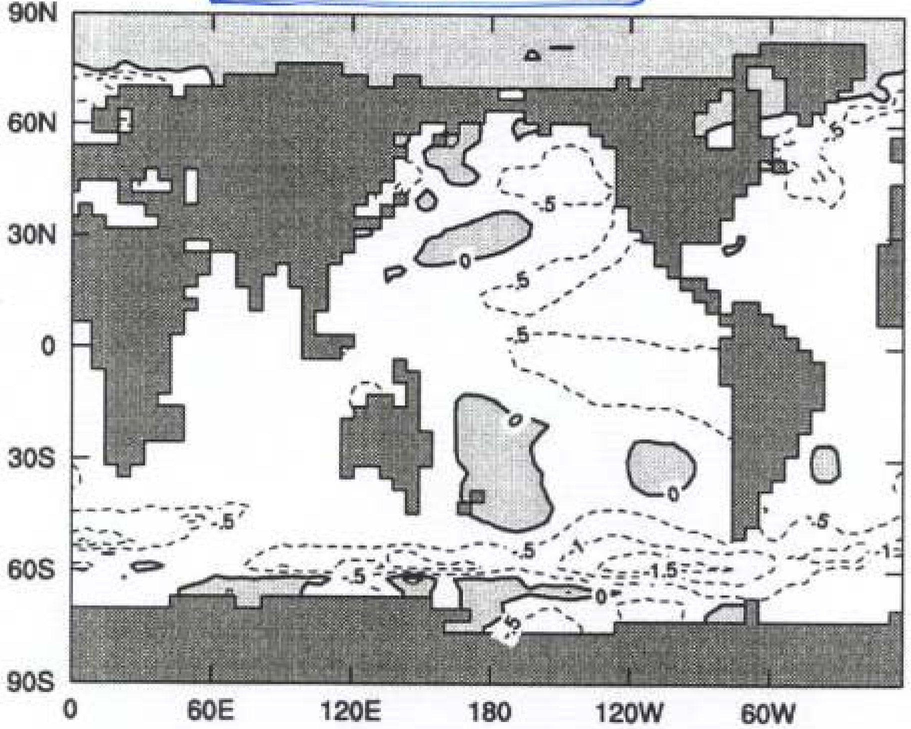
Kiehl & Trenberth (1997)

Let us look briefly at this table. This table gives a summary of the energy estimates obtained by 13 different studies. The key fact to note here is that individual energy flux components like solar shortwave radiation absorbed at surface and atmosphere or longwave radiation emitted by Earth's surface are all uncertain. This table shows that all the empirically deduced fluxes within the surface-atmosphere system are not known to within 10 W m^{-2}. Some uncertainties as in the case of solar shortwave radiation absorbed at the surface and atmosphere are as large as 20 to 30 W m^{-2}.

In addition, let us also contemplate the issue of the so-called "artificial flux adjustments"[ii] in General Circulation Models or GCMs. This is a problem related to the artificial energy flux correction of as large as 50 to 100 W m^{-2} locally, that are often used by GCMs to minimize unwanted drift in the ocean-atmosphere coupled system.

It should also be mentioned that despite the use of flux adjustment, most models with coupled ocean and atmosphere still show substantial climate drifts and biases.

Cai & Gordon (1999)



Geographical distribution of the SST drift:
over Southeastern Pacific – drift is up to 1.5°C (cooling)
The cooling drift over the Southern Ocean caused the Antarctic ice volume to increase from 10×10^3 km³ to 12.3×10^3 km³ by year 100.

Drift of the Sea Surface Temperatures (SST), despite the use of flux adjustment: the drift is ~0.3°C averaged over globe

The effects of such an artificial model result is shown here in this plot in terms of the drift in the ocean surface temperatures after the first 100 years of coupling the ocean to atmosphere without added forcing or feedback of any kind. So the drift problem is really an artificial model result. One can see that indeed the effects are quite significant: regionally, over the Southeastern Pacific the artificial cooling drift of the sea surface temperature can be as large as 1.5 degree C. The authors of this GCM study, Wenju Cai and Hal Gordon also noted that over the Southern Ocean, the cooling caused an artificial increase of the Antarctic ice volume from TEN thousands to 12.3 thousand cubic kilometers.

The globally averaged cooling drift of the sea surface temperature in this figure turns out to be about 0.3 degree C and this amount is clearly significant if one compares it to the observed global surface thermometers' warming over the past century of about 0.5 to 0.6 degree C.

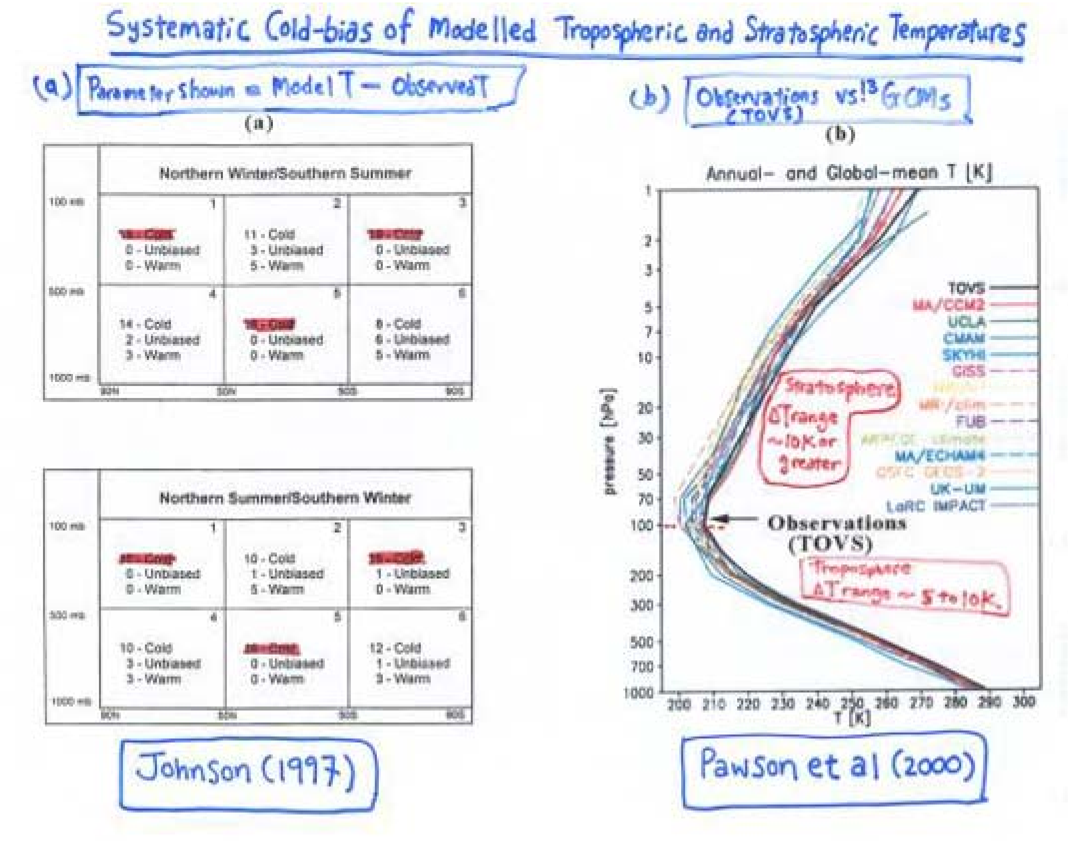
Finally, even if one tries to avoid flux adjustment completely, problems still persist because there seems to be no clear rule on how to couple the world's land surfaces, oceans and the atmosphere together.

My point here is that these artificially-modified and uncertain energy flux components SHOULD impose severe constraints on our ability to find the global and regional climate imprints of a mere 4 W m^{-2} expected for anthropogenic CO_2 forcing on timescales of about 100 years or so.

Rather than talk more about the details of finding fingerprints of carbon dioxide forcing, let us now move on to the issue of climate model validation as mentioned in the title of my talk.

1.1 Temperature

How well do General Circulation Models (GCMs) actually simulate atmospheric temperatures?



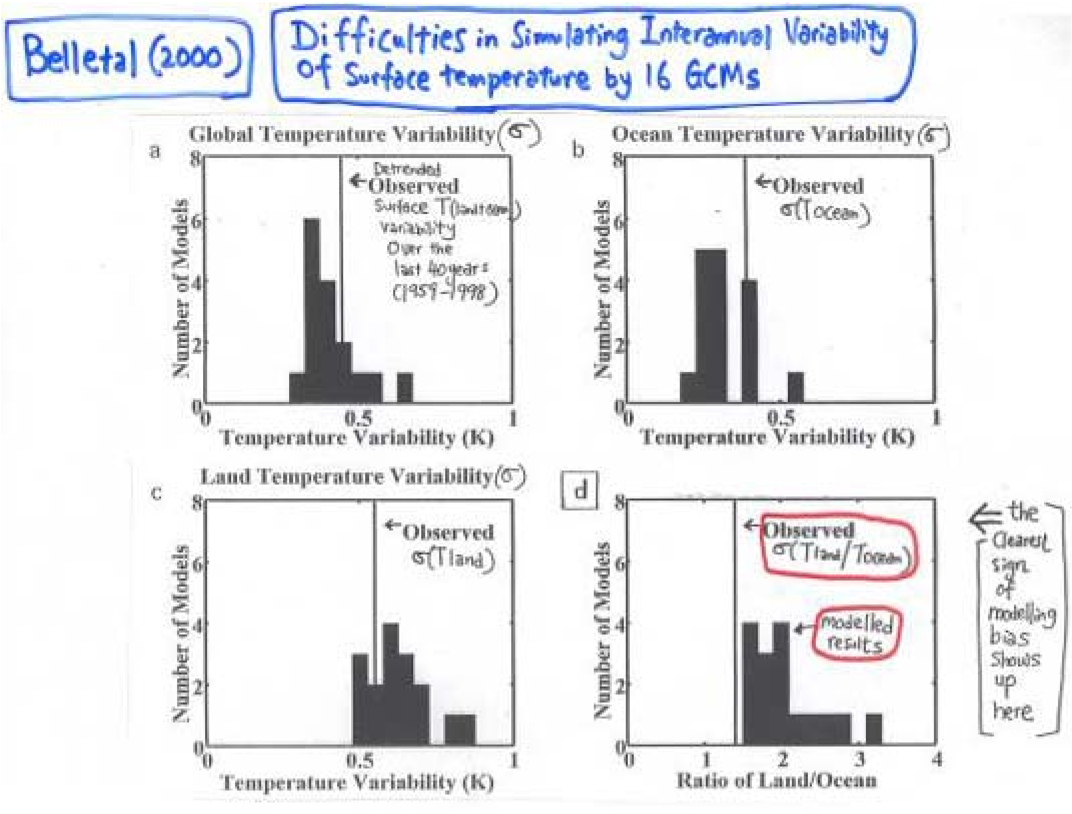
My first example is that emphasized by Prof. Donald Johnson (1997) at the University of Wisconsin. It has been known since the Intergovernmental Panel on Climate Change report of 1990 that all GCMs suffer from the so-called "general coldness problem," particularly in the lower tropical and upper polar troposphere. This point is clearly highlighted in PANEL (a) of this chart. Turn your attention to regions 1, 3 and 5 of the troposphere: we get almost unanimous verdicts for the models' cold bias relative to observed temperatures. And also note that this cold-bias problem persists regardless of the season.

In fact, George Boer, Klaus Arpe (the previous speaker in this morning's session) and several colleagues in their 1992 paper have already labeled such common deficiencies as 'universal,' 'tenacious,' or 'systematic.'

But: what could possibly be the reason for such systematic errors? Detailed analysis by Johnson (1997) suggested that temperature responses of GCMs could suffer from extreme sensitivity to systematic aphysical entropy sources introduced by spurious numerical diffusion, Gibbs oscillations and inadequacy of sub-grid-scale parameterizations.

Note that the coldness problem also extends to the stratosphere. Look at PANEL (b) of this figure. You can see here that almost all the GCMs stratospheric temperature curves lie to the left of the observed temperature line marked as TOVS (or the TIROS Operational Vertical Sounder) here, so the model temperatures are indeed systematically cooler.

In this case, Steve Pawson and his colleagues (2000) recently showed that the cold bias in the stratosphere is more uniformly distributed. Therefore, they suggest that this particular coldness problem is more likely associated with problems in physics like the under-estimation of radiative heating rates because models have too little absorption of solar radiation by ozone in the near infrared. Or perhaps there is too much longwave emission in the middle atmosphere, so that the climate models over-cool their stratosphere. I have also indicated the maximum range of the cold bias in the tropospheric and stratospheric temperatures in this plot. They are about 5 to 10 degree K at troposphere and greater than 10 degree K for stratosphere.

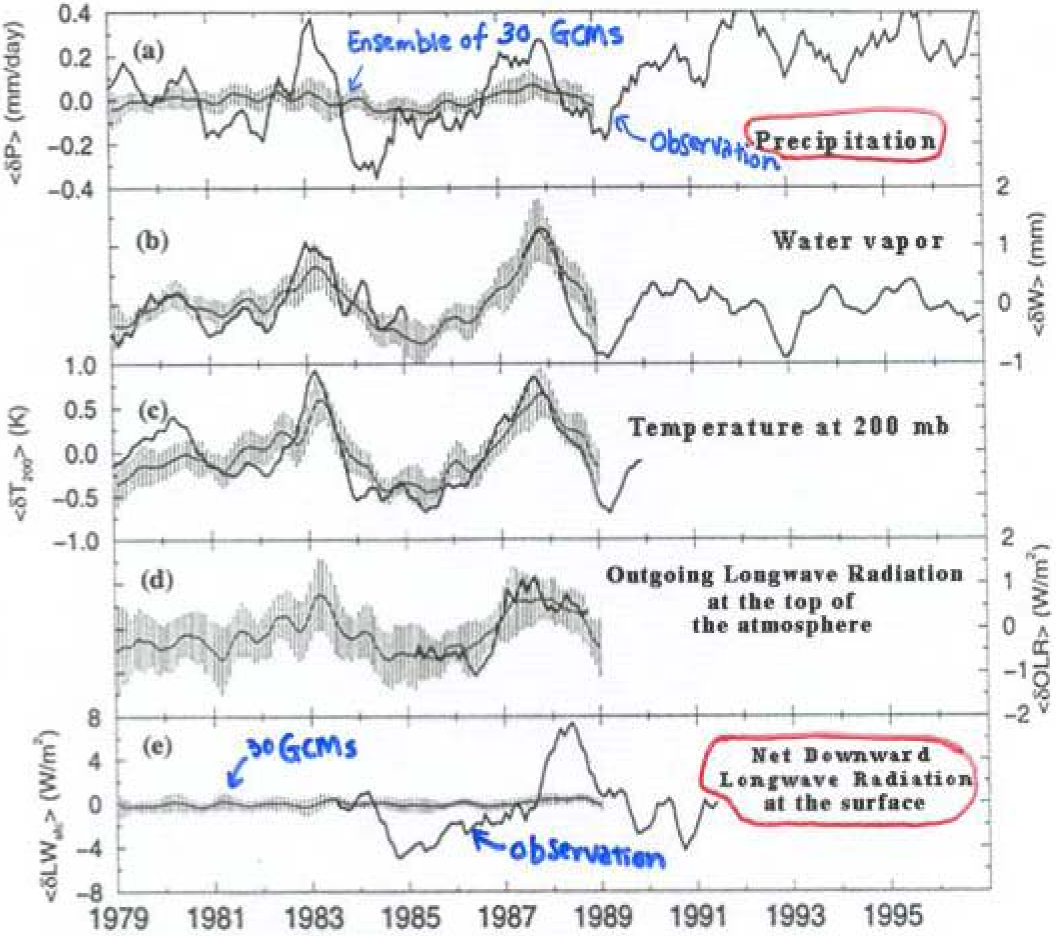


What about surface temperatures? Most interesting for discussion now are the latest results by Jason Bell, Curt Covey and colleagues (2000). Here, Bell and colleagues carefully examined the control or unforced results of interannual changes in the surface temperature from16 of the latest coupled ocean-atmosphere GCMs and compared them with the detrended, observed temperatures[iii]. Bell and colleagues found that the majority of the GCMs significantly underestimate the observed global surface temperature variability over the oceans (panel b in this viewgraph) while overestimating the variability over the land (panel c here). The most decisive illustration of the biased GCMs results comes from the ratio of the land to ocean temperature variability in panel (d) of this viewgraph. Bell and colleagues found that modeled ratio of land over ocean temperature variability in all 16 GCMs are indeed systematically higher than the observed ratio as shown here.

To look for the possible causes of the systematic discrepancy between observed and GCM-predicted interannual temperature variabilities: Bell and colleagues carefully thought about potential factors like forcing agents including CO_2 solar variability and volcanic eruption. They also considered GCMs' underestimation of El Niño - Southern Oscillation variability for the problem of ocean temperature variability. But they eventually pinned the discrepancy PRIMARILY to non-physical representations of land surfaces. Bell and colleagues concluded that GCMs with non-physical land surfaces have lead to low soil moisture, which then yields artificially greater land temperature variability than observed. This idea makes qualitative sense because the parameterization of specific land processes (which involve also the biosphere and cryosphere) is known to be notoriously complex and difficult. (If you are interested in other known problems on modeling land processes, please see more of the discussion in the written portion of our contribution.)

1.2 Precipitation

Systematic Difficulty in Simulating
interannual Changes in precipitation field
over the Tropics (30°N - 30°S)
(by 30 GCMs)



Soden (2000)

For the case of precipitation: I want to point your attention now to the latest analysis by Brian Soden of Princeton's Geophysical Fluid Dynamics Lab shown in this figure.

Here, Soden documented another puzzling behavior in the current generation of GCMs.

In this case, the systematic problem comes from the inability of the ensemble of 30 atmospheric GCMs to produce the interannual changes in the precipitation observed over the tropics (See panel a of this plot). The GCMs results cover the interval 1979-1989 while the observed quantities are plotted year to year from 1979 to 1997 when available.

This figure highlights the important CONTRAST of the agreements and disagreements in the GCM simulations. One sees that the amount of water vapor, tropospheric temperature at 200 mb and outgoing longwave radiation (OLR) are very well simulated. But this is not the case for precipitation and net downward longwave radiation to the surface (panel e here).

Soden explained that the agreements are mostly fortuitous because the atmospheric GCMs were forced with observed sea surface temperatures (SSTs), while the modeled interannual variabilities of the precipitations are seriously underestimated by a factor of three to four.

From the hint of the relatively constant value of the downward longwave flux reaching the surface (as shown in panel e), Soden points to possible systematic problems in the current GCM representations of low-altitude boundary layer clouds.

1.3 Clouds

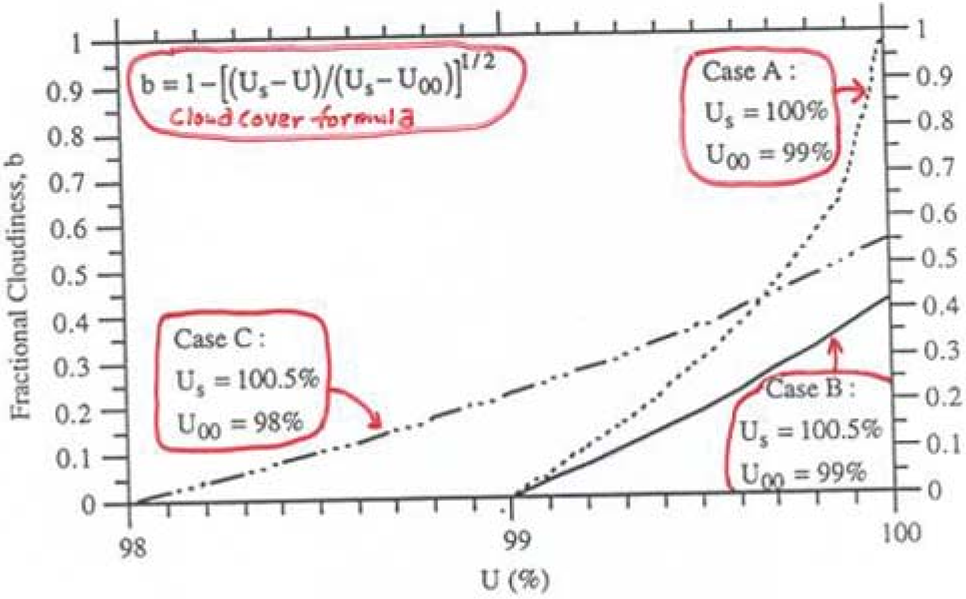
Parameterization of large-scale formation of Cloud-cover in a GCM

Illustrations of great sensitivity to:

U_s — the saturated relative humidity within Clouds

U_{00} — the threshold relative humidity at which Condensation begins

and U is the actual relative humidity in a grid cell

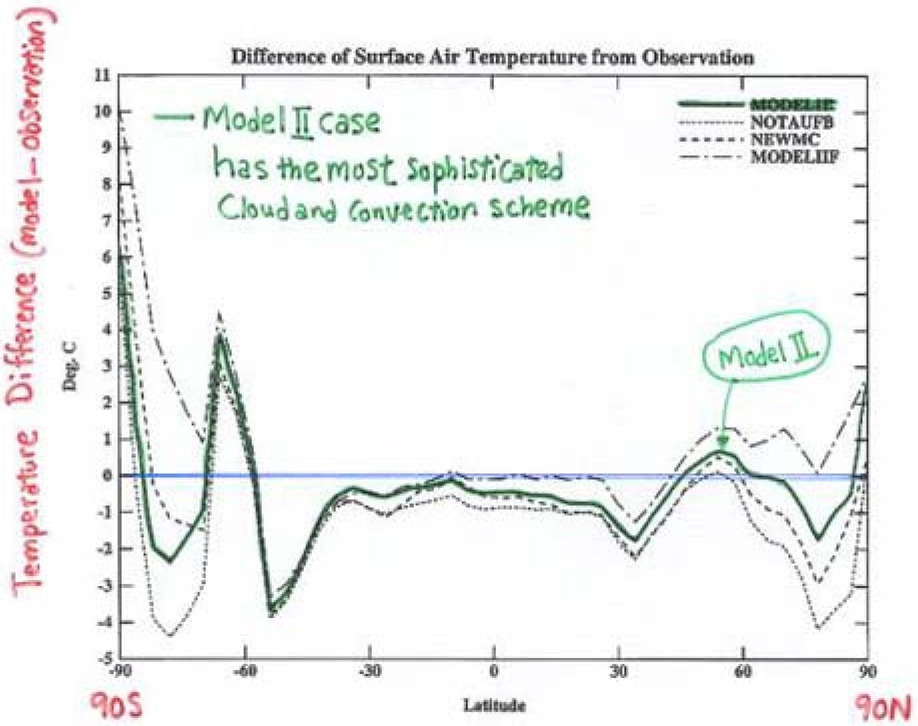


Yang et al (2000)

What about clouds? As an illustration of how clouds are represented in GCMs, we show in this plot the parameterization of the large-scale formation of cloud cover that is used in one state-of-the-art GCM. The particular example used here is from the work by Fanglin Yang and Mike Schlesinger at University of Illinois.

Here one can see that cloud cover in the MODEL is indeed very sensitive to relative humidity, U, and also to values of U_S, which is the saturated relative humidity within the cloud, and U_{00}, the threshold relative humidity at which condensation begins. The sensitivity is highlighted by the three cases of parameters shown in this figure. Just consider how drastic the cloud cover changes with a very small change in U_S and U_{00}

Yang and colleagues discuss in their paper how such cloud cover formula is used to tune the formation of clouds by 20-30% through large-scale condensation, especially near polar regions in order to try to match available observations.



Comparison of the observed surface air temperature with modelled results from 4 cloud and moist convection parameterization schemes

Yao & Del Gino (1999)

The next chart I show here gives us another hint on how poor the current generation of GCMs perform in terms of their abilities to simulate clouds and their impacts on surface temperature. Shown in the viewgraph is the zonal-mean surface temperature distribution from south to north. The plotted results are for the difference between model temperatures and observations. This is a plot from the study by Yao and Del Genio that attempts to assess how various cloud parameterization schemes work.

Yao and Del Genio emphasized that even for the scenario using the most sophisticated and realistic cloud and convection schemes (this case is emphasized by the green line in this viewgraph): [their GCM model results] are still about 6 degrees C warmer than the observed temperature at the South Pole, and about 2 degrees C cooler elsewhere in both northern and southern polar regions. The model is also noted to be too warm at sea-ice margins but perhaps, too cold in the poorly observed southern midlatitudes. Finally, Yao and Del Genio tell us that the model results are within 1 degree C at the tropics because the ocean heat transports in their GCM were tuned to give roughly consistent sea surface temperatures as observed. So the agreement here in the tropic is not an evidence of model's intrinsic skills.

Therefore, it is reasonable to conclude that the parameterization of cloud or convection processes in a GCM remains a major challenge. It is also clearly a serious challenge to calculate precipitation as well as to resolve the systematic biases for GCM simulations of surface and atmospheric temperatures.

2. Expected Outcomes of CO_2 Forcing

We will now move on to the second part of the talk. Many questions remain open regarding what one can firmly deduced from the current generation of GCMs about the potential CO2-induced modifications of Earth's climate. This is simply so because the real ocean and atmosphere have a very large number of degrees of freedom that are not guaranteed to be captured or modeled by the general circulation models.

In fact, even the range of global warming remains large and not PHYSICALLY well constrained in climate models. For example, the IPCC 1995 gave global climate sensitivity that ranges from 1.5 to 4.5 degrees C (e.g., p. 34 of IPCC 1996) for an equilibrium response to a doubling of atmospheric CO_2 concentration.

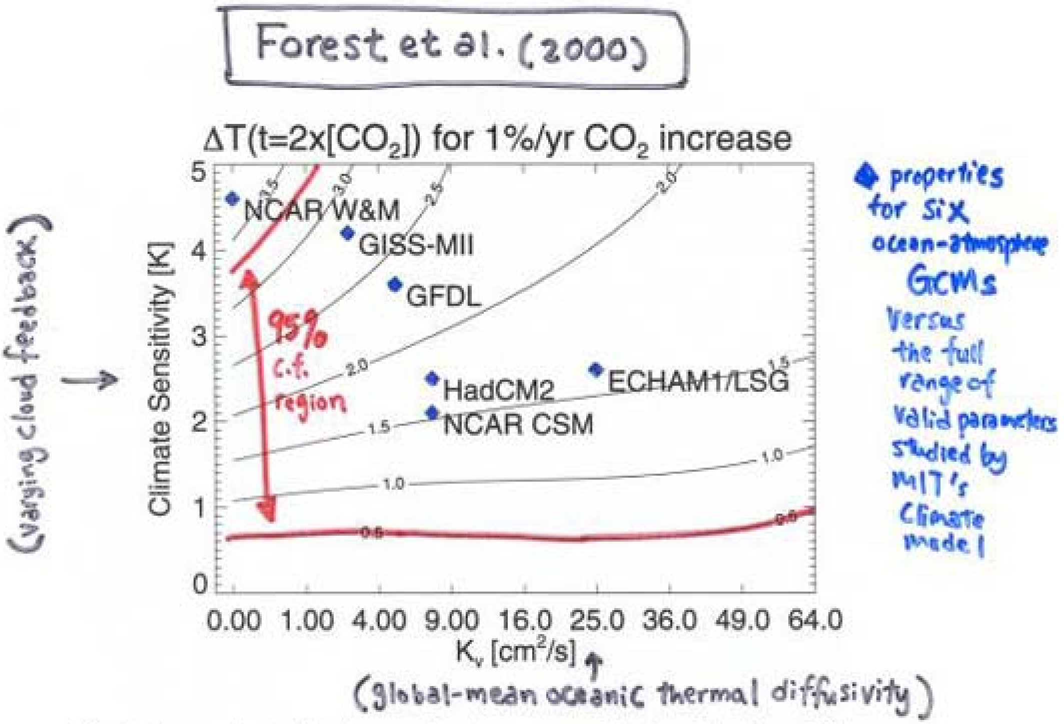


Fig. 2. Response in the global mean surface temperature at the time of doubling of CO_2 for simulations with 1%/year increase in CO_2 concentration. The corresponding S and K_v values for six AOGCMs are shown.

↕ 95% confidence regions for transient responses at time of 2x CO_2 are between 0.5 and 3.3°C

Forest et al (2000) concluded that "Climate change projections based on current GCMs do not span the range of possibilities consistent with the recent climate record."

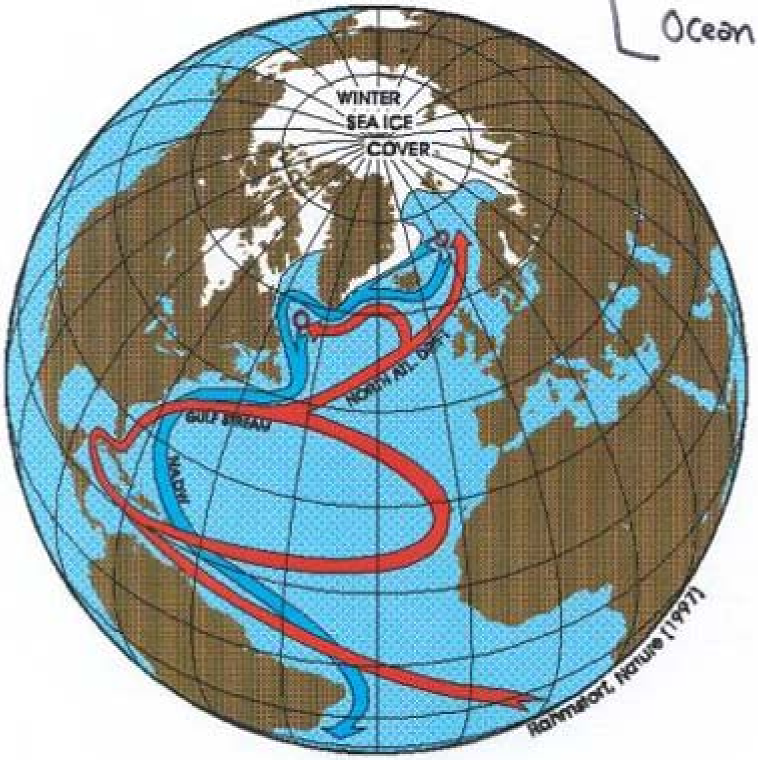
Next I want to show you the new results by Chris Forest, Myles Allen, Peter Stone and colleagues at MIT. Essentially Forest and company used the best version of the MIT statistical and dynamical climate model or the so-called intermediate complexity GCM to quantify the probability of expected CO_2 doubling outcomes by performing a very large number of sensitivity runs, i.e., by varying the climate sensitivity parameter through cloud feedback (expressed on this vertical axis here) and the rate of heat uptake by the deep ocean (shown by the horizontal axis here). Forest and colleagues define the statistical range of permissible outcomes by constraining model results to observed pattern of vertical temperature changes over the last 40 years or so. Forest also highlighted the properties used by six current ocean-atmosphere GCMs as the blue dots in this plot in order to emphasize the very WIDE range of sensitivity and ocean diffusivity parameters studied by him and his colleagues.

Forest found that the IPCC's range of equilibrium climate sensitivity of 1.5 to 4.5 degrees C corresponds roughly to ONLY an 80% confidence interval under a particular optimal value of vertical thermal diffusivity of the world's oceans. The 95% probability range for the equilibrium climate sensitivity for doubling atmospheric CO_2 is quantified to be 0.7 to 5.1 degrees C.

In the final analysis, Forest gave the more DIRECTLY relevant results for transient responses to a doubling of atmospheric CO_2 shown in this summary plot. The range turns out to be an increase in global temperatures between 0.5 and 3.3 degrees C at the 95% confidence level as bounded between the two red curves marked in this plot. In light of this more complete results, we agree with Forest's main scientific conclusion that: “climate change projections based on current general circulation models do not span the range of possibilities consistent with the recent climate record.” (p. 569 of Forest *et al*., 2000)

We have studied several other examples regarding the expected climate outcomes of CO_2 forcing in the written portion of our contribution. But in order to save time, let us look here ONLY at the case concerning changes of the oceans.

The Atlantic Thermohaline Ocean Circulation



Surface currents are in Red, the flow of North Atlantic Deep Water (~~at~~ with maximum overturning flow at ~ 2000m) in Blue

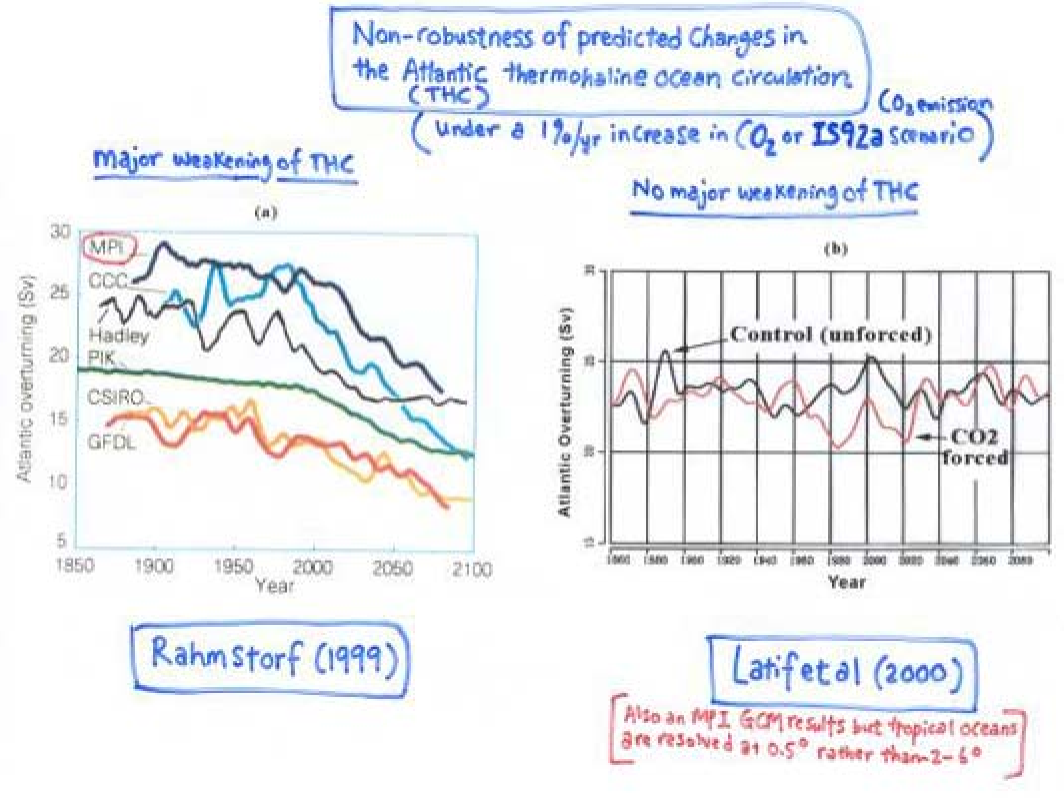
o two main areas of deep water formation (Greenland/Norwegian and Labrador Seas)

Rahmstorf (1997)

We are now looking at the North Atlantic thermohaline circulation system that consists of the salinity-driven formation of the North Atlantic Deep Water that reaches down to the depth of 2000 meter. The deep water subsurface flow is indicated by the thick blue belt in this cartoon. Red arrows and loops show the pattern of the ocean surface currents, including of course the Gulf Stream which could moderates much of the fine weather and climate here over the Canaries Islands. The two red circles marked here are the main sites of sinking convective flow around the Greenland -Norwegian Sea and the Labrador Sea.

This thermohaline circulation pattern is known to play important role for heat and salinity budgets within the world oceans and hence an important modulator of the climate system. But the most urgent question debated today is indeed: would the added anthropogenic forcing strongly affect or even completely disrupt the inner workings of this natural circulation system?

Under an increased atmospheric CO_2 forcing scenario, the commonly expected transient response of the climate system is the weakening of the North Atlantic thermohaline circulation because of the net increase in freshwater fluxes say around the two main sinking regions I just pointed out.



Indeed the prediction appears to be true and robust if we focus our attention to PANEL (a) on this viewgraph. Shown in the Y-axis of this plot is the maximum volume flow rate of the North Atlantic deep waters. The flow rates are calculated from 1850 up to 100 years into the future. The qualitative agreements among all six different models showing the weakening of the flowrate over time, are in fact quite impressive and that would lead one to feel quite comfortable with the model prediction!

But look at PANEL b of this figure. Somewhat surprisingly, Mojib Latif and colleagues at Max Planck Institute (MPI) for Meteorology of Hamburg have just reported a new stabilization mechanism that results in no weakening of the thermohaline circulation.

What is the KEY difference between Latif's latest results and other previous findings?

Most important of all: Latif and colleagues use the MPI state-of-the-art coupled ocean-atmosphere GCM that resolved the tropical oceans at a finer meridional grid scale of half a degree rather than the more typical scale of two to six degrees, and that make the new MPI GCM better adapted in studying, for examples, feedbacks related to the tropical ENSO phenomenon and how the tropical Pacific and Atlantic Oceans interact with each others. (Also note from panel (a) that the coarser version of the MPI model actually predicted weakening of thermohaline circulation just like other models.)

Latif *et al*. explained that their model did not predict a collapse or large weakening of the thermohaline circulation because under the increased CO_2 scenario: there is an increased freshwater flux over the equatorial Pacific oceans because of increased El Niño frequency. And that excess freshening over the Pacifics in turns causes anomalously high salinity in the tropical Atlantic oceans, ultimately this tropical Atlantic saline anomalies were then advected poleward to the sinking region of the thermohaline system. And this saline advection effect is apparently sufficient to compensate for local increases in freshwater influx over the North Atlantic.

Therefore, with the additional stabilizing degree of freedom from the tropical oceans,
the thermohaline circulation remains stable in the increasing atmospheric CO_2 GCM experiment. So it seems that there is really no credible expectation of a "disastrous" change in the oceanic circulation over the North Atlantic under a CO_2-forced climate scenario.

3. Comments

Let me now take a few more minutes to finish up. In a way: this talk has been largely a public apology for my personal lack of understanding of Earth's climate system. To date, we do not know whether human-made CO_2 has caused, or will cause, the climate to change for better or for worse.

I have shown you evidence on why we really do not have much confidence in what the GCMs tell us about temperature, precipitation, clouds and changes in the oceans. By default, I also wish to emphasize that such climate model deficiencies also impact our understanding on how Earth's climate may response to other external forcing agents such as the natural variations of incoming radiant energies and particle fluxes linked to changes in our Sun which we have heard so much about throughout this meeting.

As scientists, we have to remind ourselves that it is really *impossible* to have a verified or a fully validated numerical climate model because natural systems like Earth's climate system are never closed. Model results are always non-unique. Therefore, the proper role of a model is to *challenge* existing formulations rather than to *predict* or project unconstrained scenarios of change by adding CO_2 to the model atmosphere. A climate model should best be built to test or single out certain proposed mechanisms of climate change rather than to yield consensus on any climate forcing scenarios. It is only then a realistic progress toward a falsifiable hypothesis of CO_2-global warming and related regional consequences may be expected.

Therefore, I conclude that it is high time for us to address the serious scientific question of whether human influences on climate could really be detectable on a global extent like that proposed by increasing CO_2 in the air. It is also very clear from the beginning that understanding global and regional climate change is not a matter of dealing with CO_2 alone. In fact, the enormous complexity and difficulty are knowing the precise roles of other forcing agents including the Sun, natural and anthropogenic aerosols, ozone and so on.

As a start, it would certainly be helpful for all climate scientists and many more from other domains of research, including economists, social scientists and law-makers interested in public policy, to begin working together to distinguish between what one may consider as climate uncertainties versus what one should admit as climate unknowns. While we, as private citizens of the world, can keep a constant vigilance that the case of human interactions with the environment is not merely a challenge of scientific research and testings.

I sincerely hope that what I have tried to tell you about the current problems of our climate models makes a common sense. More importantly, I hope that such an open critique and discussion of GCMs could serve as a good motivational point for accelerating the pace of our knowledge on climate science. Thank you.

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[i] The quantitative details and the rate at which this forcing is imposed upon our atmosphere ranges from the observed rate of increase of CO_2 concentration over the past 30 years of about 0.4% per year to the more inflated increment of 1% to 4% (!) per year in some GCM experiments, but that is not the primary concern of our discussion now.

[ii] In addition to the heat flux adjustment considered here, nonphysical flux adjustments for freshwater, salinity and wind stress (momentum) are also applied in many contemporary GCMs.

[iii] Coupled Model Intercomparison Project.