Written evidence submitted by Professor Richard Lindzen (IPC0047)

I have come to be rather hesitant in discussing the IPCC WG1 reports. The reason for this is that almost noone asking my opinion seems to actually care what is in the report or even what is in the summary. Although the document certainly is biased against criticism of models, it is otherwise not particularly alarmist. For that matter neither is the iconic statement that characterizes the press release. The claim that 51% of the small warming over the past 60 years is due to man's activities is completely consistent with there being no problem worth bothering about. The concern arises because of the claim that models with high sensitivity can still be fudged (by cancelling much of the warming due to greenhouse gases with cooling due to the essentially unknown effect of aerosols) to replicate the observed warming. Somehow, the environmentalist assumption seems to be that human responsibility for warming, however small, is tantamount to disaster. However, the IPCC WG1 isn't really saying this.

Of course, even the attribution of most of the small warming to man is faulty and inconsistent. However, dwelling on this lends gravitas to a statement that, while wrong, is relatively innocuous.

The claim of consensus is frequently hurled at those who question alarm, but the consensus is generally about trivial and unalarming matters such as that the globe has warmed a bit since the end of what is referred to as the little ice age, or that man contributes something to climate change. As concerns the more serious questions such as what the sensitivity of the climate is or what the relationship is between global warming and various purported disasters, even the IPCC generally admits to ignorance. In fact, ignorance is a purely defensive posture.

As the attached paper notes, virtually all observational tests point to sensitivity less than that of any models, and there is no evidence of any relationship between extreme weather and global warming though theoretically one does expect warming to be associated with a reduction of extratropical storminess.

The fact that the focus of climate alarm keeps changing (from global cooling to global warming to climate change to extreme weather to ocean acidification to ......) is suggestive of an agenda in search of a scientific rationale. Given the destructive, expensive and corrupting nature of the proposed (or, alas, implemented) policies (as well as their demonstrable irrelevance to climate) leaves one with a disturbing view of the proposed agenda. It would appear that the privileged members of the global society regard as dogma that the rest of humanity is a blight on the planet, and all effort should be devoted to preventing their economic improvement and development. If this selfish and short-sighted view is what the privileged regard as morality, then God help us all.

WIREs CLIMATE CHANGE

Article type: **Opinion**

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Authors:

Full name and affiliation; email address if corresponding author; any conflicts of interest

First author
Richard S. Lindzen, Dept. of Earth, Atmospheric and Planetary Sciences, MIT.
rlindzen@mit.edu

Abstract.

It is noted that since models are not theories, the concept of falsification is not generally applicable. Models may be clearly incorrect in some respects, but that does not guaranty that they are incorrect in other respects. In this paper, I examine the matter of climate sensitivity (and very briefly the issue of extreme weather). Overall, evidence seems more consistent with low sensitivity, and there seems little evidence for high sensitivity.

1. Introduction.

The notion of 'falsification' plays a central role in science when applied to a theory which is a coherent chain of reasoning where each step depends on the preceding step. Theories frequently lead to models, but, unfortunately, climate models do not constitute a theory. Rather, the models at issue are attempts to solve the relevant equations for motion, energy, composition, etc. using numerical methods with inadequate resolution, where unresolved processes like boundary layer turbulence, convection, clouds, gravity waves, etc. are parameterized. The parameterizations are generally ad hoc devices designed to behave in a manner that is thought to be appropriate where 'appropriate' sometimes simply means that the parameterization is designed to compensate for obvious model problems. In addition, fundamental model inputs such as aerosol distributions and properties, solar forcing, and even the radiative forcing by important greenhouse gases are, at best, only approximate, and are sometimes almost completely unknown. In the latter case, they become little more than adjustable parameters. The problem, from the perspective of 'falsification' is that the resulting models get many things demonstrably wrong, but that does not mean that they get everything wrong. Thus, it is possible that though models may fail to predict something like global mean temperature over extended periods of time, they might still be right concerning the long term impact of greenhouse gases. Falsification, thus, does not simply mean showing that models fail for many things, but rather that specific aspects of the models are wrong. With respect to climate concerns, there are several aspects that are of central importance:

1) The sensitivity of global mean temperature anomaly to increasing greenhouse forcing.

2) The relation of global mean temperature anomaly to the various other features that are the current focus of much of our climate change concerns: extreme weather, sea level rise, etc.

It should be noted that the above concern models for which increases in greenhouse gases have been specified, and do not specifically concern the origins of these increases. There may be legitimate questions as to how much of the increase is due to emissions, but these are not addressed in the present context.

Also, the above implicitly assumes that global mean temperature anomaly is a uniquely appropriate metric for climate, and, more importantly, that climate forcing can be represented by a single annually and globally averaged quantity. This may be appropriate for climate change forced by increasing well mixed greenhouse gases, but it is likely to be inappropriate for the cycles of ice ages that are forced (not triggered) by the Milankovitch mechanism (Edvardsson et al, 2003 [1], Lindzen, 2012 [2]). The crucial point here is that the clouds (and other processes), that play a crucial role in the feedbacks that determine the above described climate sensitivity, depend on many factors other than surface temperature, and can serve as effective degrees of freedom whereby climate can adjust to achieve energy balance for such forcings as those produced by the seasonal and regional characteristics of orbital variations involved in the Milankovitch mechanism.

Item 1 above will be the primary focus of this essay. Item 2 does not really lead to falsification of models since models make no unambiguous predictions for such matters; rather, claims for extreme events are largely environmental speculations. However, I do offer some comments on this in Section 7.

2. The temperature record as evidence.

Attempts to relate climate sensitivity to the observed record of global mean temperature are common. However, for such issues as sensitivity and attribution, as well as for the purpose of falsifying models, this record is virtually useless. The main issues are the potential importance of such unknown factors as aerosols and solar variability and forcing, and the fact that current models inadequately account for alternative causes of climate change such as ENSO, the Pacific Decadal Oscillation and the Atlantic. Indeed, the matter of natural internal variability represented by these phenomena is one where the models are obviously falsified.

Many of these factors are more easily seen using a simple energy balance model described in Lindzen and Giannitsis (1998 [3]). This model consists in an ocean with a mixed layer and a diffusive thermocline that is forced at the surface by the radiative forcing. The model also allows distinction between oceans and land. The radiative forcing refers to the top of the atmosphere forcing, but given that dynamics largely constrains the vertical structure of the temperature, this should also be the forcing at the surface, although the forcing at the surface is mostly due to evaporation rather than radiation. The time dependent forcing used is shown in figure 1. This is essentially the forcing due to CO_2, but it has been multiplied by 1.75 to account for the fact that other increasing greenhouse gases like methane, nitrous oxide and freons also contribute substantially (IPCC FAR [4]). Our approach is oversimplified but adequate for present purposes. We have also included the radiative forcing due to volcanoes using the Sato (2013 [5]) model for forcing. This is shown in figure 2. We then calculate the response of the model for various choices of climate sensitivity (defined as the equilibrium response to the radiative forcing produced by a doubling of CO_2. The response through 2000 is shown in figure 3 where we also show the observed global mean temperature anomaly. Clearly, the more sensitive models overpredict, though not by as much as the difference in sensitivity would have suggested. This is because ocean delay increases with climate sensitivity. This is a matter that the next section will focus on. However, there remains the matter of aerosols. These have been introduced to compensate for the overprediction. As noted by Kiehl (2007, [6]), each model chooses values for aerosols needed to reduce its response. Figure 4 shows results with aerosol 'corrections,' while Table 1 shows the fraction of the greenhouse gas radiative forcing that had to be cancelled. Again, it is because of ocean delay that the amount of cancellation increases only slowly with sensitivity (once sensitivity becomes large).

Finally, it should be noted that the above seeks to explain all warming on the basis of greenhouse gas forcing. But, as a number of papers have noted (Zhou and Tung, [7], Wang et al, [8]), a significant fraction of the observed warming can be attributed to natural internal variability which is commonly associated with phenomena like ENSO, the PDO and the AMO. This would, in turn call for even more aerosol cancellation in sensitive models. Oddly, a recent paper (Santer et al, 2012 [9]) notes that model internal variability does not project on global warming, and uses this result to argue that only greenhouse gas forcing could lead to the observed warming. What they seemed to have found, instead, was that model internal variability bears little relation to observed internal variability.

All the above problems with using temperature to assess sensitivity are even more true for the use of paleoclimate to assess sensitivity – especially when in the case of phenomena such as the cycles of orbitally forced cycles of glaciations, the whole paradigm of climate forcing by a single annually and globally averaged radiative imbalance is inappropriate.

3**. Response time as evidence.**

We have already referred to response time in Section 2. The reason that sensitivity is intimately related to response time is simple. Sensitivity is the ratio of temperature change, ΔT, to radiative forcing, ΔF. High sensitivity means that a small ΔF is associated with a large ΔT, but, ultimately, it is ΔF that causes temperature change. Thus, the large ΔT takes longer to occur. This suggests that response time is a direct measure of climate sensitivity. Lindzen and Giannitsis (1998 [3]) suggested the impact of sensitivity on the response to a sequence of volcanoes might permit a test of model sensitivity. This is evident in Figures 3 and 4 where sensitive models show a much more pronounced and prolonged response to volcanoes than is indicated in the observations. The effect is more clearly illustrated in Figure 5 which shows the response to volcanoes alone. We see that for low sensitivity, the response to volcanoes consists in just short term cooling events, but for high sensitivity, there is a prolonged response to the sequences of volcanoes between 1883 and 1920 and between 1961 and 1992. Moreover, the sequence of volcanoes in the case of high sensitivity contributes a substantial net cooling (~0.3C), which compensates a bit for the excessive warming associated with high sensitivity. Although response time depends not just on climate sensitivity but also on the rate of ocean vertical heat transport, the above results remain approximately the same for a wide range of thermocline diffusivities.

Roger Cohen (personal communication) notes the following concerning volcanic responses. Suppose major volcanic eruptions are random with a mean time between eruptions τ. Then if the climate sensitivity is large such that the response time is larger than τ, the climate will settle down to some steady state cooling value plus fluctuations. The steady state cooling will be something like… <Forcing> x Sensitivity x Response Time/τ, which is more or less proportional to Sensitivity squared. The high sensitivity curves in Fig 5 look like they are headed in that direction, starting from zero. On the other hand if the response time is less than τ, the climate will usually return to its unperturbed temperature before the next eruption, as hinted at in the low sensitivity curves. Thus, for high sensitivity, we would apparently live in a world that was perpetually cooling due to the effect of all past volcanoes. Note that the clustering of volcanoes in Figure 2 is characteristic of a random process.

Roe (2009, [10]) made the interesting suggestion that a phenomenon like the PDO could provide an estimate of the response time. He noted that the PDO actually behaved like an AR(1) time series characterized by a response time, t, that was on the order of 15 months +/- 8 months. It has been noted that the PDO index is not significantly different from the average temperature of the North Pacific Ocean, which is an easier metric to track. We did this for the period 1900-2005, and found that for this period, t was 12 mos. Note that including the period 1854-1900, changes this result somewhat, but, given the change of instrumentation that occurred in this period, we felt it better to exclude this period. In order to compare this with model results, we chose the so-called preindustrial runs from the CMIP studies. Our reason for this choice is that the other runs included time dependent adjustments, and it would be unclear as to whether we were looking at the properties of the models or the adjustments. It turned out that we were only able to assess 5 models. The results are shown in Figure 6. Although the results are not unambiguous (because of the uncertainties in the AR(1) matches), the response times in the models are at least twice as long as the observed response times.

The above certainly point to the models being excessively sensitive, and this is confirmed by Gregory (2010 [11]) who found that Krakatoa was still biasing the results of UKMO model. It seems highly unlikely that the above results would allow the higher model sensitivities that have been reported.

The above also suggest a test that has not, so far, been made. It has been claimed that in order for models to have the 'correct' magnitude for internal variability, they need high sensitivity. However, as noted in section 2, internal variability in models seems to have little resemblance to observed internal variability. According to Newman et al (2009 [12]), the modeling of phenomena like ENSO, PDO, and AMO depend on the coupling of the atmosphere and the ocean. As has just been noted, this coupling increases as sensitivity decreases. It would be interesting to see if models where sensitivity is reduced (by changing the parameterization of high cirrus for example) would better simulate the observed phenomena.

4. Outgoing radiation as evidence.

Given that climate sensitivity depends on the ability of added greenhouse gases to elevate the emission level, and hence reduce the radiative cooling, one might suppose that observations of radiation from space might offer evidence of the existence of positive or negative feedbacks. In general, we would expect that, in the absence of feedbacks, an increase in temperature (extending throughout the troposphere due to dynamics) would correspond to the increase in Planck black body radiation from the characteristic emission level. Greater net outgoing radiation would imply negative feedback while less outgoing radiation would imply positive feedback. Although there have been a number of attempts to check this (Dessler, 2010 [13], Forster and Gregory, 2006 [14], Trenberth et al, 2010 [15]), the situation is more complicated than it seems at first glance. For example, for temperature changes that occur over time scales that are greater than or of the order of the response time (such as warming due to increased greenhouse gases), the system will have approximately equilibrated so that there is no longer any radiative imbalance at the top of the atmosphere associated with the change in temperature. This would involve a powerful misleading bias toward positive feedback. Most studies ignored this problem.

Now feedbacks depend on temperature fluctuations regardless of their origin. In order to assess feedbacks from space based measurements of outgoing radiation, one has to focus on temperature fluctuations that are short compared to response time of the ocean-atmosphere system, but longer than the time for feedbacks to occur. For current models, the feedbacks determining climate sensitivity involve water vapor and clouds (and ice albedo to a much smaller extent). Thus, they are associated with processes whose time scales are less than a month. The investigation of feedbacks should focus on temperature changes over a few months. This is what was done by Lindzen and Choi (2009 [16], 2011 [17]) as well as by Spencer and Braswell (2010 [18]). Although it has been common practice to consider feedbacks from water vapor and clouds separately, such a partitioning is problematic. Figure 7 illustrates the problem. Recall that greenhouse warming comes from elevating the emission level, but where high cirrus are present, they largely determine the emission temperature, and the impact of greenhouse gases, whose emission levels are below, has little impact. (This should, presumably, also impact the calculation of radiative forcing, though, as far as I can tell, it is not generally taken into account.) At the same time, the areal coverage of high cirrus is extremely variable (though typically on the order of 35%) so that disentangling the role of greenhouse gases from the infrared effect of high cirrus is essentially impossible. The appropriate approach is to simply consider the total long wave (infrared) feedback. Lindzen and Choi (2011 [17]) separately considered long and shortwave feedbacks. The use of lagged regressions is, as we will see, essential. The reader can find the details in the cited paper, but Figure 8 shows the essential result. We see that there is a unique indication of a modest negative feedback in the infrared (as confirmed by Trenberth and Fasullo, 2009 [19]; in a more recent paper, Fasullo and Trenberth (2012 [21]) attempt to argue that models with high sensitivity do better at replicating short wave feedbacks without noting that without the long wave feedback, these models no longer have high sensitivity.), but for the short wave feedback there appears to be a positive feedback that maximizes for negative lags, and a negative feedback that maximizes at positive lags (ie feedback lagging temperature). The positive feedback seems to extend to small positive lags, but as noted by Lindzen and Choi (2011 [17]), this is due to the finite decorrelation time for the temperature changes that were forced by cloud changes that were not due to temperature feedbacks. This has been shown in detail by Choi et al (2013 [20]). The presence of such 'noise' renders the determination of short wave feedbacks ambiguous. However, the result for the long wave feedback is, itself, of importance.

The usual representation for gain in terms of feedback is

$$\text{□□□□□□□} \quad . \qquad (1$$

$$\text{□} = \frac{1}{1-\text{□□}}$$

In current models, used by the IPCC, the long wave feedback, referred to as the water vapor feedback, contributes about +0.5 to f. This brings gain to 2, but, more importantly, now the addition of any small feedback due to the shortwave impact of clouds, leads to much greater gain. For example, a shortwave feedback of +0.3 brings the gain to 5. However, if one removes the longwave feedback (as observations suggest that one should), the impact of model shortwave feedbacks becomes small even if the model shortwave feedbacks are exaggerated. Once again, one can't completely rule out a net positive feedback, but the evidence pretty well rules out gains in excess of about 1.5 (which is well below what the IPCC suggests is the best guess; ie 3).

5. Other approaches.

Several papers have attempted to relate surface temperature changes to changes in ocean temperature (Shaviv, 2008 [22], Schwartz, 2007 [23]). One can then estimate the flux needed to produce the ocean temperature change. The ratio of the surface temperature change to this flux then should give the sensitivity. The results again point to a low sensitivity.

To the extent that dynamics fixes the vertical lapse rate, the radiative forcing at the top of the atmosphere should extend to the surface without significant divergence (ie, it should be the same at the surface as at the top of the atmosphere). Although the total flux may be non-divergent, the nature of the flux changes with height. At the top of the atmosphere, it is totally radiative, but at the surface, it is primarily evaporative. Wentz (2007 [24]), using satellite based data, estimated that evaporation changed about xx% per 0K while in models, it only changed by 1-3% per 0K. As noted in Lindzen (2012 [2]), the model response corresponds to climate sensitivities of between 1.5 and 4.5 C, while the observed value corresponds to a sensitivity of 0.8C. Moreover, Wentz discarded data that departed 'too much' from models so that there is some reason to believe the 0.8C is excessive. Stephens and Hu (2010 [25]) contested Wentz's results, but they based their criticism on models that had significant positive feedback. One might reasonably ask how evaporation can adjust to top of the atmosphere radiative forcing. The usual formula for evaporation is

$$E = C_D u_* L(q_s(T_*) - q(0)) \qquad (2$$

where q is specific humidity, CD is a drag coefficient, u* is a turbulent velocity, and L is the latent heat of vaporization. q_s, the saturation value of humidity, is determined by the Clausius-Clapeyron Equation. Ignoring temperature jumps at the surface (for purposes of order of magnitude estimates), we get

$$E \approx C_D u_* L q_s(T_*)(1-rh) \qquad (3$$

(where rh is the relative humidity of surface air). This is essentially the basis for the claim that E will increase in a warmer world. As we will note in the next section, small changes in relative humidity of surface air are sufficient to change evaporation significantly, and as Lindzen et al (1982 [26]) showed, such changes in surface air do occur to maintain global balances.

6. Other considerations.

Given, the importance of feedbacks for climate sensitivity, one might think that the relevant processes must change significantly in order to provide the large amplification found in some models. To see that this is not so, we need to compare the changes needed in these processes in order to produce radiative impacts on the order of the radiative forcing due to a doubling of CO_2. For order of magnitude purposes, it is sufficient to take this as ~3 Wm^{-2}.

We can readily estimate what sort of changes in upper level cirrus can produce a change in radiative balance of 3 Wm^{-2}. It turns out that a 10% change in area or a 500m change in altitude are sufficient to cause such changes in long wave radiation. Even smaller changes in the areal coverage of lower brighter clouds can cause such changes in the short wave radiation. Fluctuations of this magnitude or even much greater are common at all time scales. If such changes are caused by changes in surface temperature, they constitute climate feedbacks. However, there are many other factors that can cause such changes (for example, waves, including gravity waves, generated by a wide variety of meteorological phenomena, including hydrodynamic instability). Thus, such changes should really be looked on as 'degrees of freedom' whereby the climate system can adjust to any disequilibrating changes.

With respect to changes in evaporation, it is easy to show that a change in rh from 0.8 to about 0.83 is sufficient to counter the increase in q_s due to a warming of 3C, and such changes in rh are commonplace. Once again, this should be looked at as a 'degree of freedom' for the system to adjust to perturbations. Indeed, there is little empirical evidence that evaporation or rainfall have been increasing. It should be emphasized that the change in rh that we are referring to is the value in the thin boundary layer at the earth's surface. Changes above this thin layer can be very different.

7. Associated phenomena.

Impacts of changes in global mean temperature anomalies have received much emphasis in the public discussion of climate issues, but models frequently cannot deal with such impacts. Models differ radically in their forecasts for regional change, and models deal poorly or not at all with phenomena whose scales they cannot even resolve. Observations are frequently contradictory to the claims. Thus, there is little that is ready for falsification.

Nonetheless, it may be worth examining how warming might affect 'extreme' weather. For example, the main driver of extratropical cyclones is baroclinic instability. This depends on the temperature difference between high and low latitudes. Also, the range of extreme temperatures seen at any midlatitude location depends as well on this difference. But, if warming is greater at high latitudes than at lower latitudes, then this difference is expected to decrease – not increase – in a warmer world. What has frequently been claimed instead is that in a warmer world, there will be more evaporation, and hence, more rainfall. The latent heating associated with the rain will presumably provide more energy to disturbances, and lead to flooding, etc. All of this is speculation, and, as we have seen, even the claim of increased evaporation is open to question. Moreover, latent heating is primarily of importance in the tropics, and is only one of many factors involved in hurricanes. There is little observational basis for the claims, but, to be fair, the small amount of warming seen thus far, is unlikely to be a major factor in any case.

8. Conclusions.

One cannot rigorously rule out **significant** global warming due to increasing greenhouse gases. Indeed, it is logically impossible to prove anything to be absolutely impossible. It nonetheless seems peculiar to base policy on something for which there appears to be no evidence. Quite the contrary, all independent tests of climate sensitivity point to low sensitivity. The main support for high sensitivity is that models with high sensitivity can simulate past behavior of global mean temperature anomaly. However, such ability depends, as we have seen, on having adjustable allegedly almost unconstrained parameters. Although the IPCC FAR [4] doesn't mention it in the Summary for Policymakers, aerosols can provide positive as well as negative forcing. Thus, even models with arbitrarily small sensitivity can be made to simulate past climate.

Moreover, we have seen that the processes that act as feedbacks depend on much other than global mean temperature, and constitute some of the probably more numerous degrees of freedom whereby the climate system can adjust to the numerous forcings that do not necessarily adhere to the paradigm of annually and globally averaged radiative forcing. Understanding this would almost certainly lead to a deeper understanding of the climate system.

As to the association of warming (whatever its cause) with extreme weather, the main driver of extratropical weather systems, baroclinicity, is expected to be diminished rather than increased in a warmer world. The claim that increased evaporation will occur depends on assuming surface relative humidity remain precisely constant, but there is little basis for such an assumption.

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Figure Captions

Figure 1. Radiative forcings from IPCC FAR [4]. A line has been added to indicate the aerosol impact on the cloud greenhouse forcing associated with cold upper level cirrus. This was discussed in the IPCC WG1 report, but not shown on the original chart.

Figure 2. Radiative forcing due to volcanoes since 1850 from Sato [5]

Figure 3. Response of global mean temperature to greenhouse forcing and volcanoes (without aerosol adjustment).

Figure 4. Response of global mean temperature to greenhouse forcing and volcanoes (with aerosol adjustment).

Figure 5. Response of global mean temperature to volcanoes alone.

Figure 6. a. Response time for North Pacific Temperatures derived from typical coupled IPCC models. b. Response time for North Pacific Temperatures derived from observations.

Figure 7. Schematic of longwave emissions to space from surface, greenhouse gases and upper tropospheric cirrus clouds.

Figure 8. Lagged regressions of longwave and shortwave radiation (measured from space0 with respect to short term fluctuations in SST (sea surface temperature). Also shown are corresponding correlations. From Lindzen and Choi (2011 [17])

Table Caption

Table 1. Aerosol cancellation called for by models as a function of climate sensitivity assuming all warming of past century due to anthropogenic greenhouse emissions.

Tables

Sensitivity in ^{0}C (for doubling of CO_2)	Fraction of GHG forcing cancelled by 'aerosols'
0.75	0
1.5	0.25
3.0	0.481
4.0	0.525
5.0	0.543

Figure 1

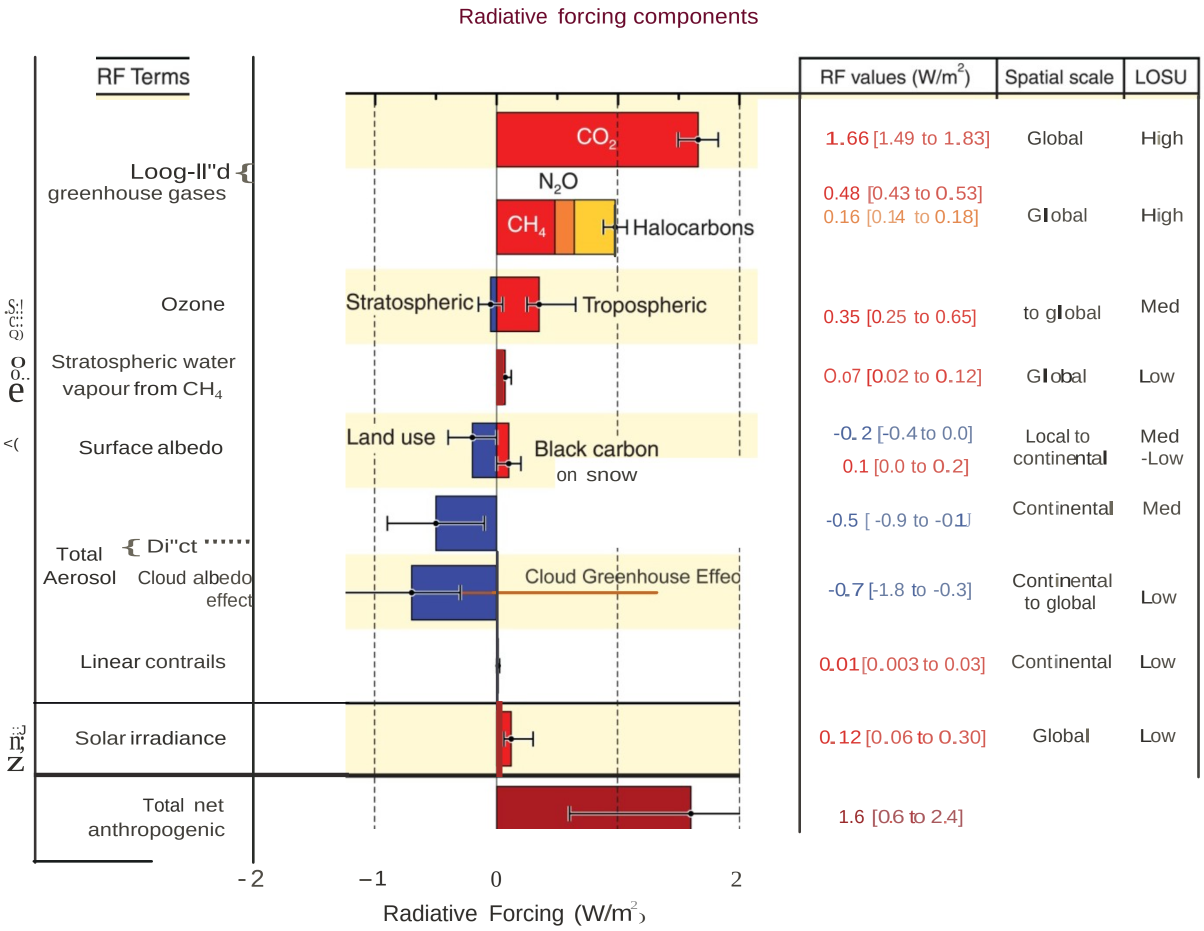

Radiative forcing components
RF Terms
RF values (W/m^2)
Spatial scale
LOSU
Loog-ll"d
greenhouse gases
CO$_2$
1.66 [1.49 to 1.83]
Global
High
N$_2$O
CH$_4$
Halocarbons
0.48 [0.43 to 0.53]
0.16 [0.14 to 0.18]
Global
High
Ozone
Stratospheric
Tropospheric
0.35 [0.25 to 0.65]
to global
Med
Stratospheric water
vapour from CH$_4$
0.07 [0.02 to 0.12]
Global
Low
Surface albedo
Land use
Black carbon
on snow
-0.2 [-0.4 to 0.0]
0.1 [0.0 to 0.2]
Local to
continental
Med
-Low
Total
Aerosol
Di"ct
-0.5 [-0.9 to -0.1]
Continental
Med
Cloud albedo
effect
Cloud Greenhouse Effec
-0.7 [-1.8 to -0.3]
Continental
to global
Low
Linear contrails
0.01 [0.003 to 0.03]
Continental
Low
Solar irradiance
0.12 [0.06 to 0.30]
Global
Low
Total net
anthropogenic
1.6 [0.6 to 2.4]
-2
-1
0
2
Radiative Forcing (W/m^2)

Figure 2

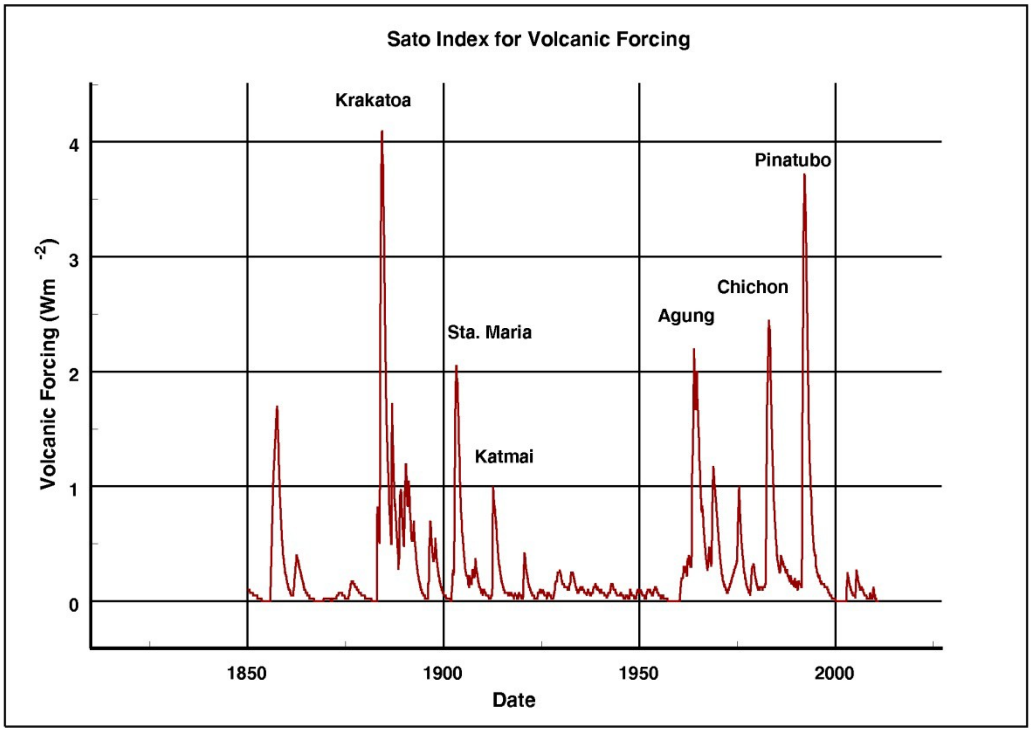

Sato Index for Volcanic Forcing
Volcanic Forcing (Wm -2)
4
3
2
1
0
Krakatoa
Sta. Maria
Katmai
Agung
Chichon
Pinatubo
1850
1900
1950
2000
Date

Figure 3

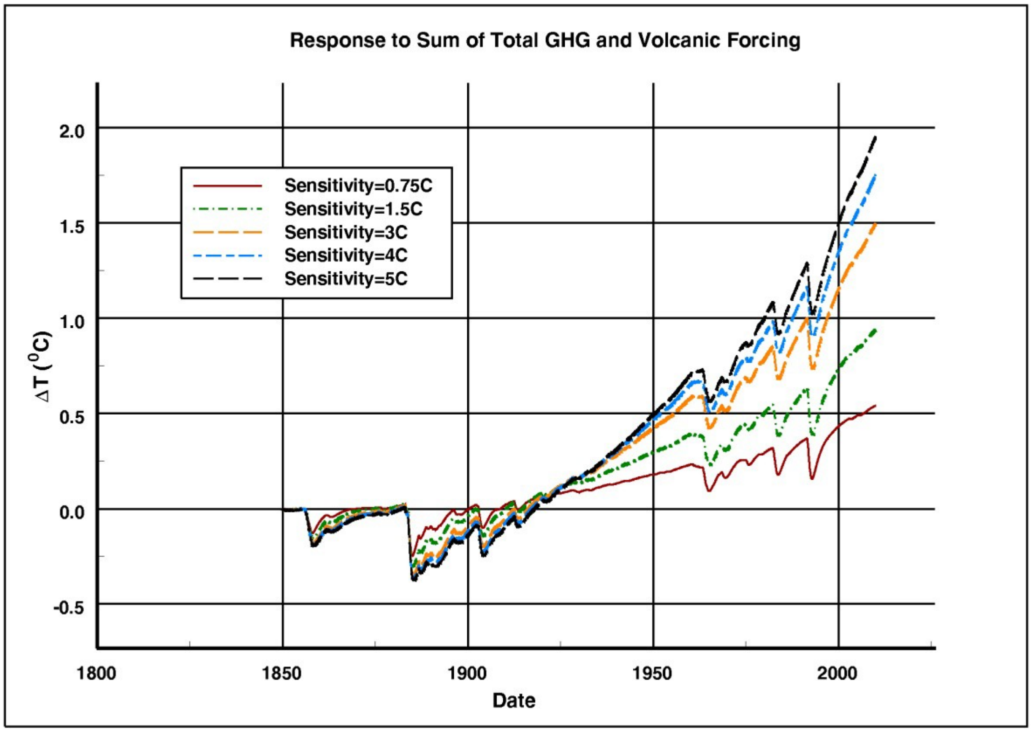

Response to Sum of Total GHG and Volcanic Forcing
Sensitivity=0.75C
Sensitivity=1.5C
Sensitivity=3C
Sensitivity=4C
Sensitivity=5C
ΔT (⁰C)
2.0
1.5
1.0
0.5
0.0
-0.5
1800
1850
1900
1950
2000
Date

Figure 4

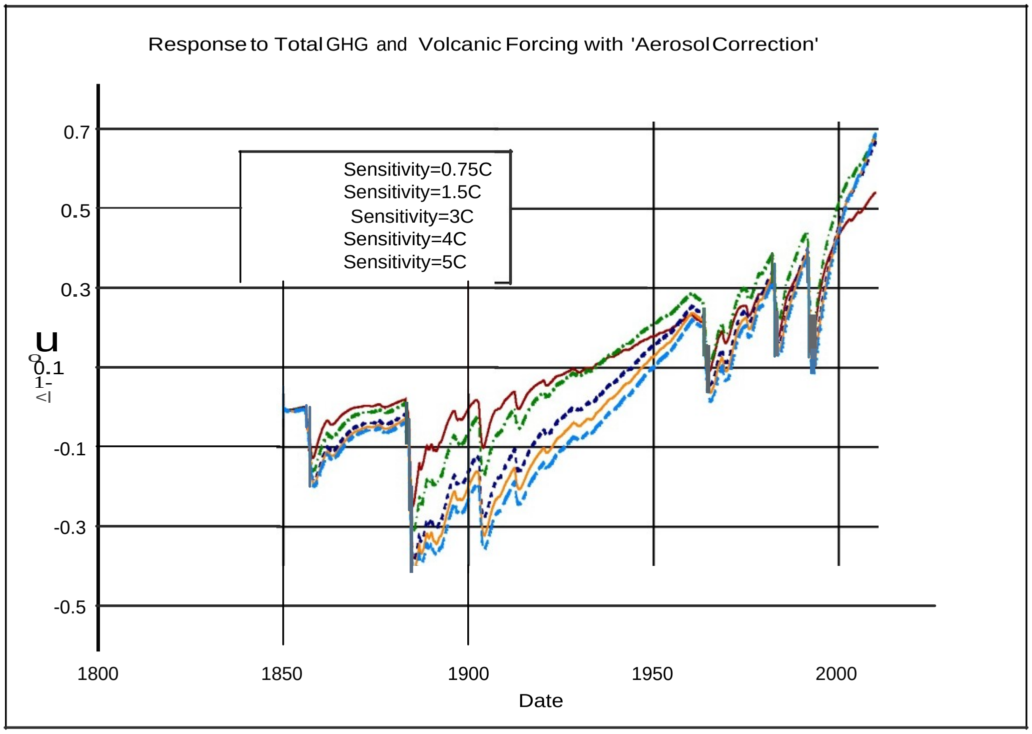

Response to Total GHG and Volcanic Forcing with 'Aerosol Correction'
Sensitivity=0.75C
Sensitivity=1.5C
Sensitivity=3C
Sensitivity=4C
Sensitivity=5C
0.7
0.5
0.3
0.1
-0.1
-0.3
-0.5
1800
1850
1900
1950
2000
Date

Figure 5

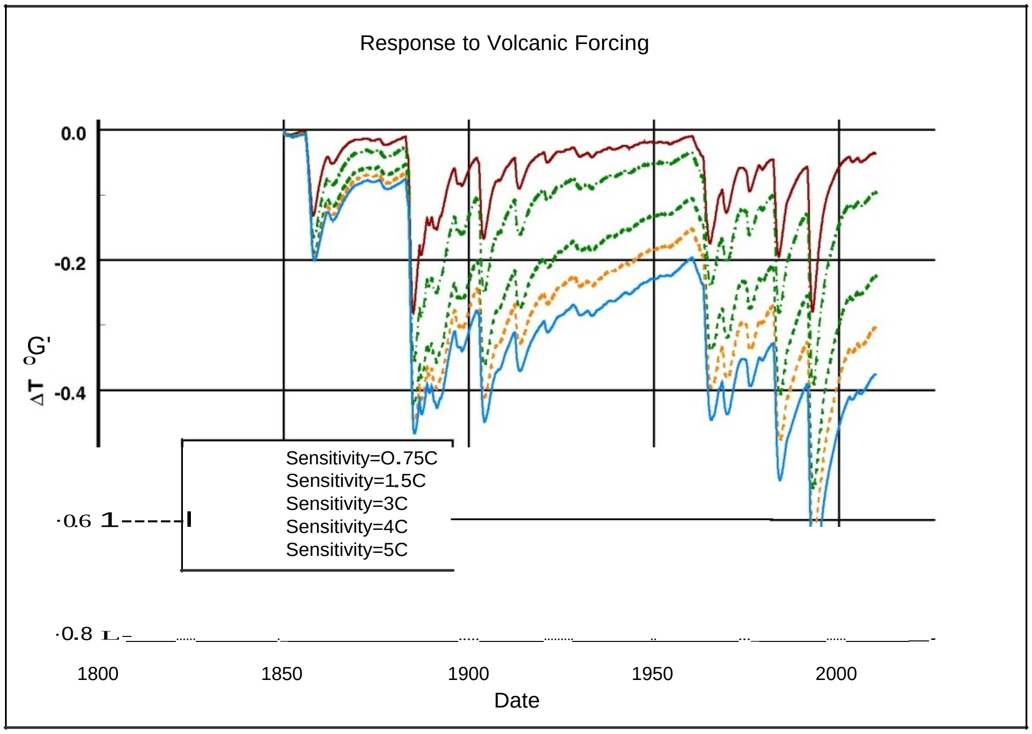

Response to Volcanic Forcing
0.0
-0.2
-0.4
-0.6
-0.8
ΔT °C
1800
1850
1900
1950
2000
Date
Sensitivity=0.75C
Sensitivity=1.5C
Sensitivity=3C
Sensitivity=4C
Sensitivity=5C

Figure 6a

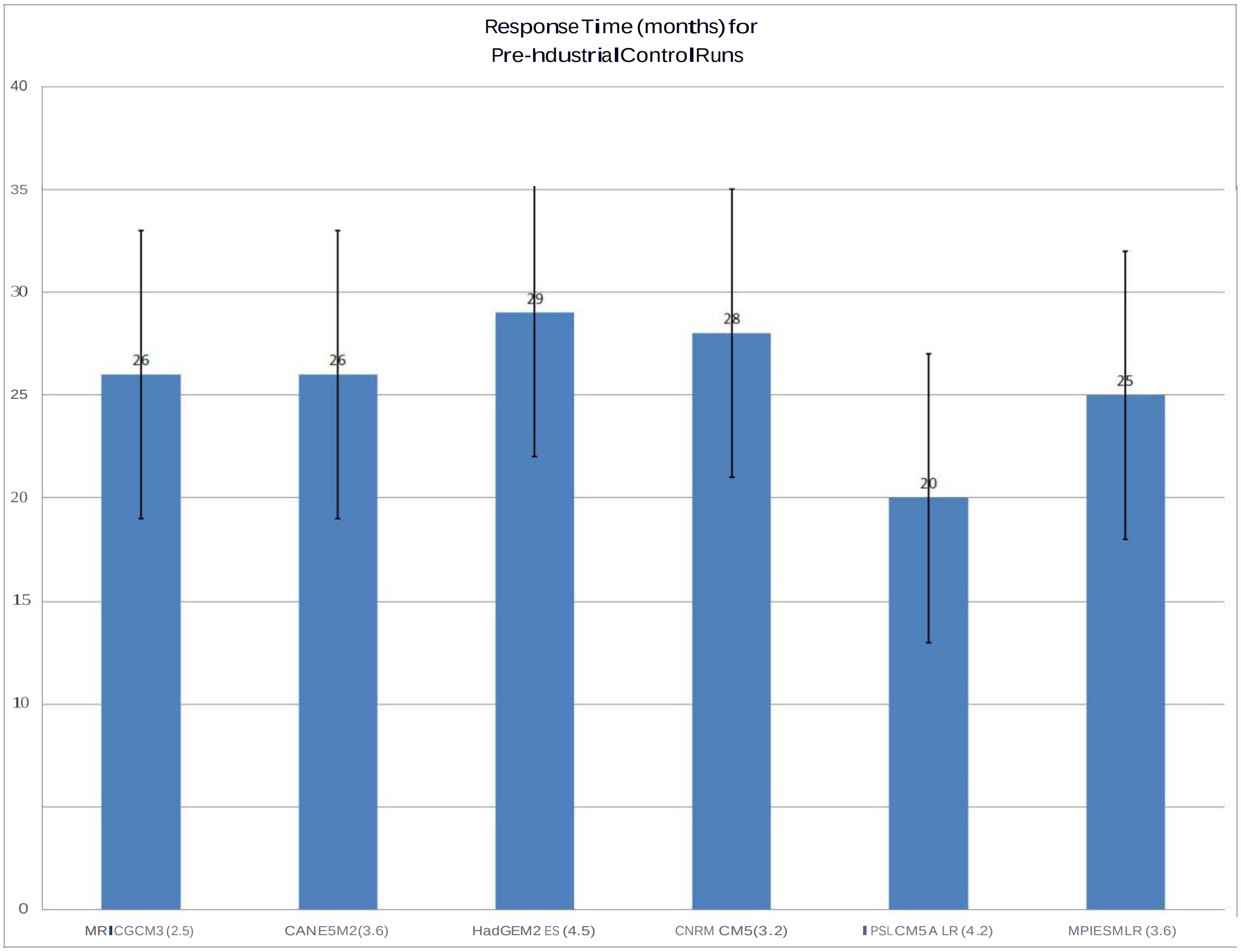

Response Time (months) for
Pre-Industrial Control Runs
40
35
30
25
20
15
10
0
26
26
29
28
20
25
MRI CGCM3 (2.5)
CANE5M2 (3.6)
HadGEM2 ES (4.5)
CNRM CM5 (3.2)
IPSL CM5A LR (4.2)
MPIESMLR (3.6)

Figure 6b

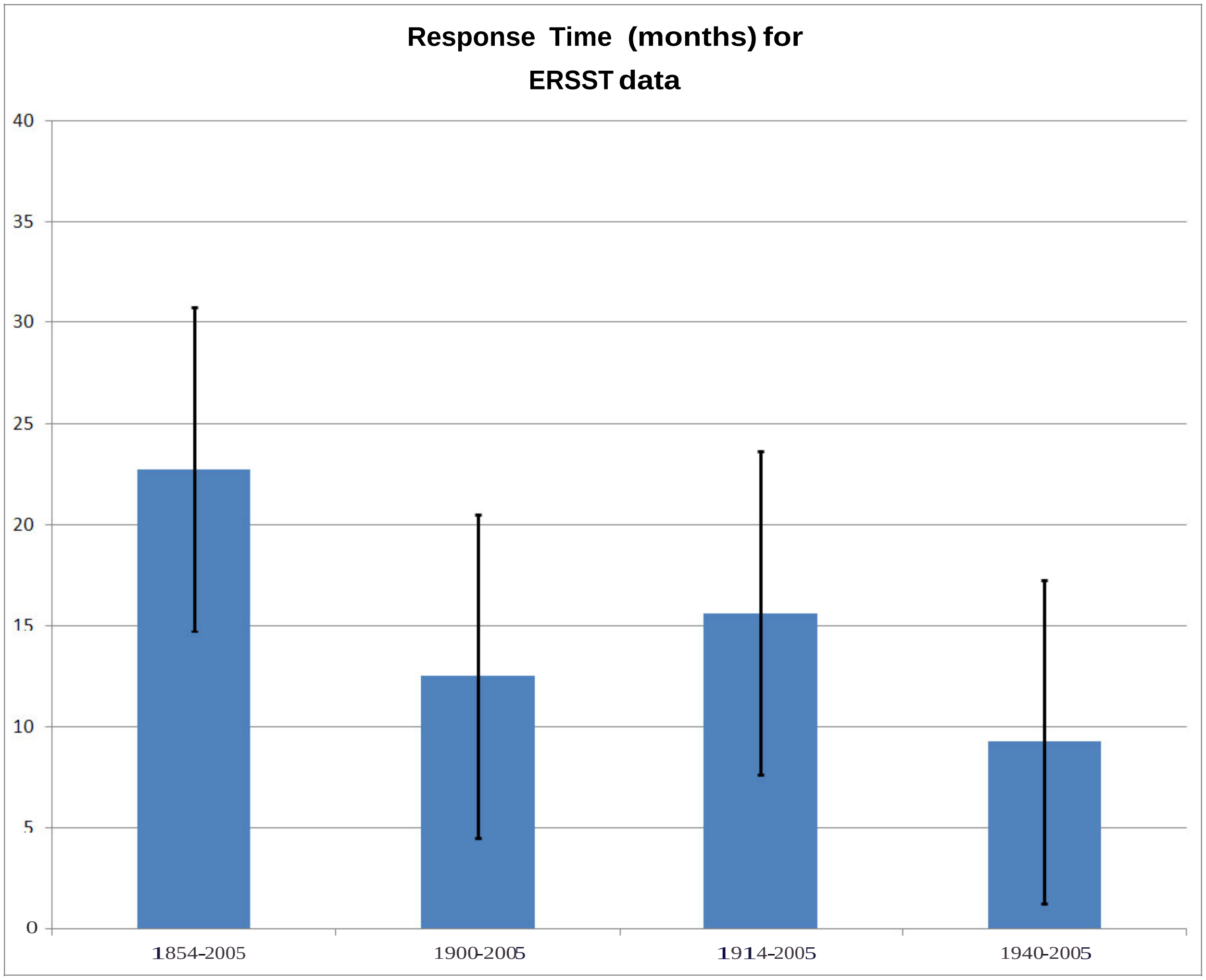
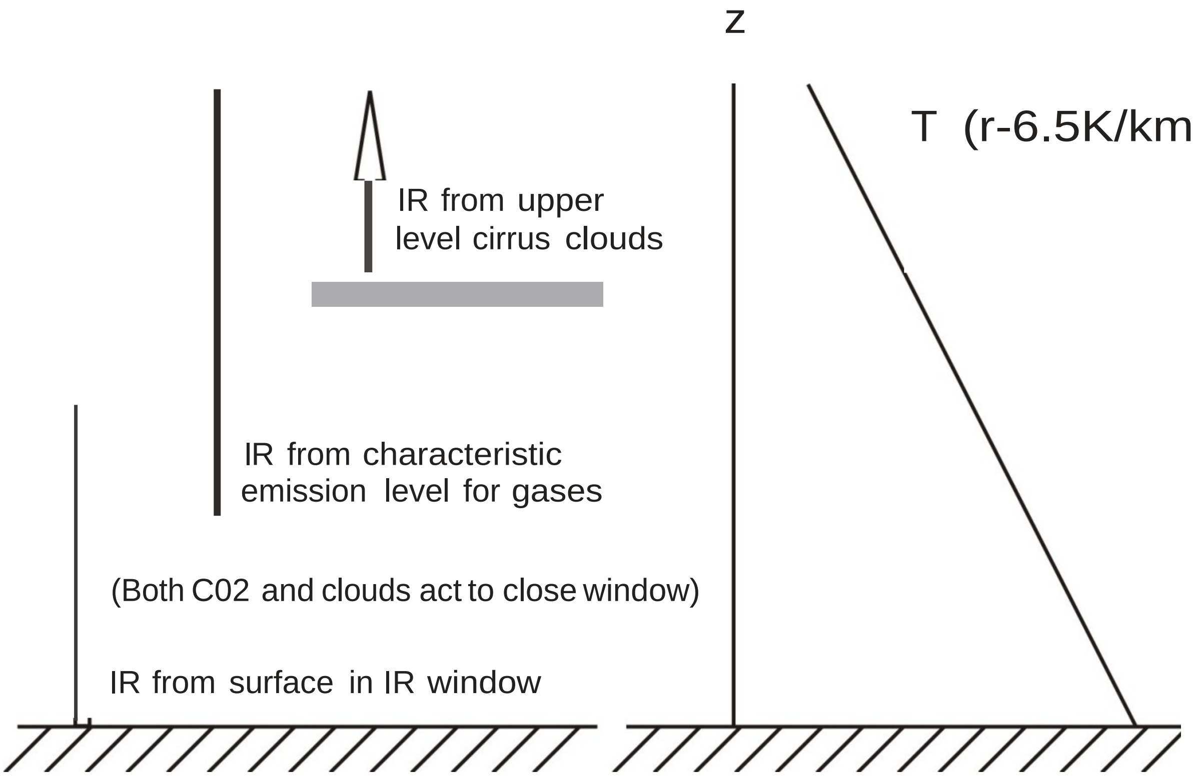

Response Time (months) for
ERSST data
40
35
30
25
20
15
10
5
0
1854-2005
1900-2005
1914-2005
1940-2005

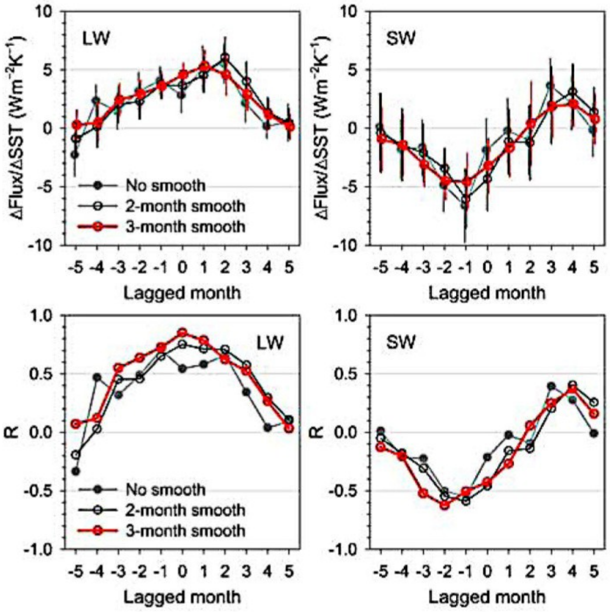
Figure 7



Comments concerning clouds

1. Clouds also reflect shortwave radiation.
2. Thin upper level cirrus often have substantial IR opacity with **little** reflectivity.
3. When clouds are below the characteristic emission level for gases, they do not impact gaseous greenhouse effect.

Figure 8


LW
SW
ΔFlux/ΔSST (Wm^-2K^-1)
10
5
0
-5
-10
-5 -4 -3 -2 -1 0 1 2 3 4 5
Lagged month
No smooth
2-month smooth
3-month smooth
R
1.0
0.5
0.0
-0.5
-1.0