Global Warming: The Science is NOT Settled
Rick Bradford, 1st September 2019

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1. Introduction

I have long maintained that there is an enormous gulf between predictions of change in global average temperature and the wider (and often wilder) predictions of climate change and its human impacts. However, even the attribution of global warming to CO_2 is more uncertain than the impression given to the public. So much so, in fact, that the oft-repeated claim in the media that "the science is settled" gives a false impression. There is ample room for reasonable doubt that CO_2 is to blame.

My concern over the inaccurate representation of the scientific position is considerably heightened by the increasingly intemperate language which is being used in popular discourse. Apparently we now have a "climate emergency". A picture is being painted by some pundits of imminent Armageddon, of global mass starvation and the like. Some sections of the public have become scared witless as a result, thus promoting activism which is by no means as well motivated by the science as people have been led to believe.

Here I address just one issue to illustrate the point: the dependence of current IPCC climate models on amplification of purely CO_2 effects by water vapour driven feedbacks. My purpose is not to make definitive claims but only to illustrate how fragile are existing model estimates to well-founded criticisms and alternative data.

But first, let's dispose of some preliminaries…

2. Is Global Average Temperature (GAT) Increasing?

Yes.

The temperature in question is that of the lower atmosphere (lower troposphere), and the "average" relates to averaging over the whole globe, and over annual variations. Broadly three diverse sources of temperature data are available: satellites, weather balloons and ground or sea based measurements. All these sources of raw data require heavy processing to convert to °C and to correct for physical inaccuracies. Satellites, for example, do not really measure temperature but radiance at various wavelengths. There is ample scope for error. Enormous amounts of effort have been expended both in attempting to do a good job of data sanitisation – and in criticising other research groups' efforts at the same.

The bottom line, though, is that diverse methods and independent research groups all identify upward trends in GAT over the last 40 to 60 years. In a separate file I have summarised the data from six groups/datasets, which give trends between 0.145 and 0.20 °C per decade. Given the diversity of method, and often passionate competition between research groups, this spread of trend rates of warming is rather modest.

Total GAT increase from 1850-1880 to 2018 is about 1.0°C to 1.1°C.

A few years ago some datasets were indicating a hiatus in the apparent warming. For example, the UAH dataset (see here) seemed to suggest no warming between 1995 and 2012. However, even the UAH dataset in its July 2019 release is showing warming, and other datasets never showed the hiatus (see here).

Sceptics may be suspicious that vested interests and 'group think' might have led to a convergence of warming curves which has resulted more from a convergence of mindset than from objective evidence. However, taking the published data at face value, the evidence for global warming over the last 40-60 years seems clear now. That the UAH dataset is now showing warming, albeit at the lowest end of the estimated rate (0.145°C/decade), is of particular note as the principal architects of the UAH analysis are themselves sceptics (and have come in for some stick from other groups as a result).

3. Is Atmospheric CO_2 Increasing?

Yes.

This is the easiest one to dismiss with certainty. CO_2 is very easily measured, with great accuracy – and it has been increasing steadily for decades. We need not dwell further on this.

The pre-industrial concentration of CO_2 in the lower troposphere was 278 vppm and reached 400 vppm in about 2015. Now (2019) it is 410 vppm.

4. Is the Increase in Atmospheric CO_2 Anthropogenic?

Very probably.

But not absolutely certainly.

There is a substantial sceptical literature which suggests that atmospheric CO_2 increases may not be anthropogenic. I critiqued some of these arguments previously (http://rickbradford.co.uk/AtmosphericCO2Modelling.pdf). But modelling CO_2 increases is relatively easy compared to modelling temperatures. I produced a simple, if amateurish, model in that link. Since it is so easy to explain the observed increases in CO_2 using reasonable data assumptions and a sensible, simple dynamic model, it seems perverse to look for more complicated explanations.

5. Is the Global Warming Caused by the CO_2 Increases?

Ah, now *that* is the question.

There is no logically secure way of identifying the cause of global warming.

All that can be done is to look for possible causes and produce models of how much warming they would cause. Whilst a logician would not be impressed, a pragmatic person might be content with the following,

- Draw up a list of all potential causes;
- For each postulated cause, model how much warming it would predict;
- Is there a postulated cause which predicts the observed rate of warming?
- Is there only one such potential cause?

An immediate criticism of the anthropogenic CO_2 theory of global warming is that this assumption has deflected attention away from other possible causes. So the above reasonable schema has not been followed. Natural causes such as variations in the Sun, or the intrinsically chaotic nature of the climate, may have been unfairly neglected as potential explanations. And recall, once the anthropogenic CO_2 theory took root, it might prove very difficult for research groups to obtain funding to investigate alternative mechanisms.

This criticism would apply however convincing might be the anthropogenic CO_2 theory. But the criticism takes on greater force if, in fact, there are significant weaknesses in the anthropogenic CO_2 theory. I think there are, and so we come, finally, to the burden of this article…

6. How Well Do the Climate Models Based on CO_2 Increases Work?

Ostensibly, if one takes IPCC at face value, the answer is that the climate models work very well indeed.

Figure 1: IPCC Comparison between Climate Model Predictions and Observed Global Average Temperatures, 1900 - 2010

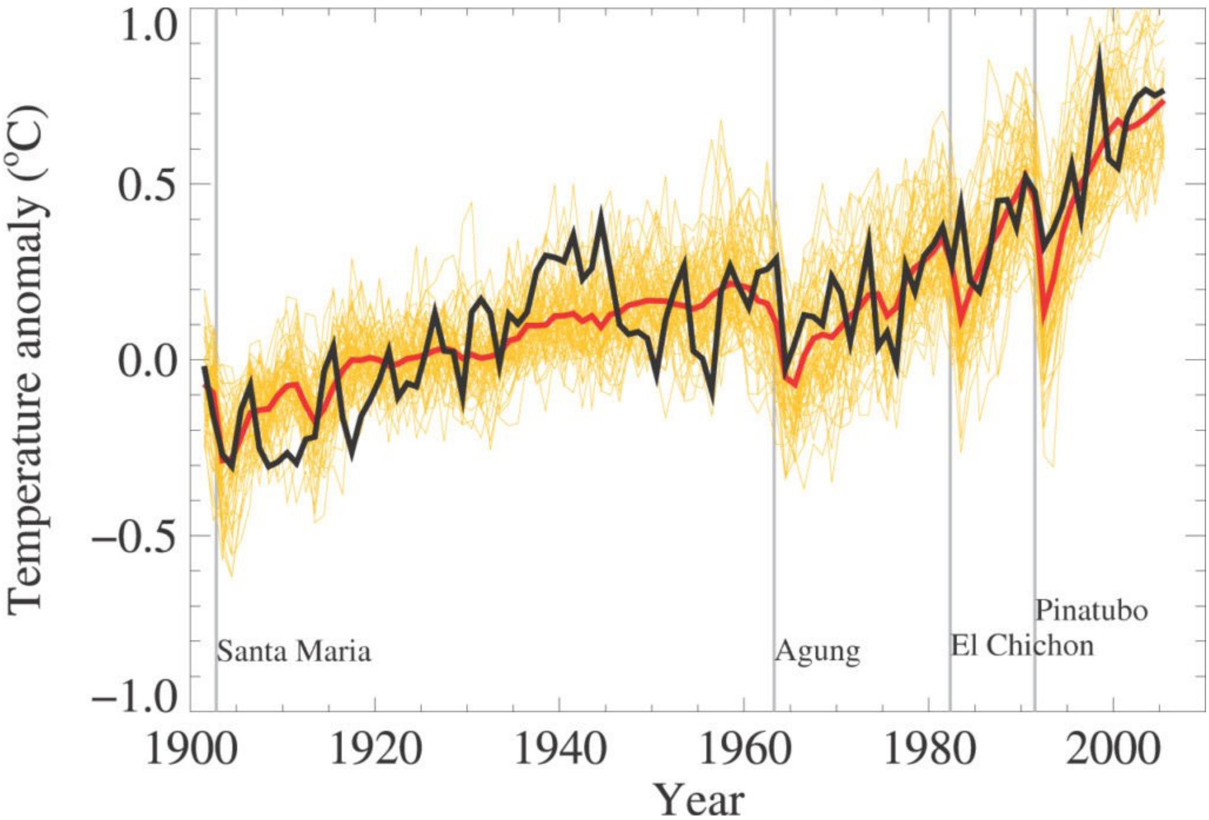


Figure 1 is taken from the fourth IPCC report (2007) Chapter 8. It compares the results of 58 simulations using 14 different climate models with temperature "measurements" over the period 1900 – 2010. The black line are the observed temperatures (using the UK's Hadley Centre dataset HadCru3) and the red line is the mean of the 58 simulations. (The yellow lines are individual model runs). It would seem that the mean of the models presents an impressively accurate prediction. Too impressive, perhaps.

But I question how much Figure 1 is really worth. The reason is that I suspect the climate models have many highly uncertain parameters which are simply tuned to reproduce the GAT history – hence the apparent agreement in Figure 1 means nothing. I cannot state categorically that this is the case, but a quote from the Fifth IPCC Report, Working Group 1 "The Physical Science Basis", Chapter 9, "Evaluation of Climate Models", Box 9.1 titled "Climate Model Development and Tuning" strongly suggests that this is the case. It states (omitting references)…

"…a small subset of model parameters remains to be adjusted so that the model adheres to large-scale observational constraints (often global averages). This final parameter adjustment procedure is usually referred to as 'model tuning'. Model tuning aims to match observed climate system behaviour and so is connected to judgements as to what constitutes a skilful representation of the Earth's climate.… The models used in this report almost universally contain adjustments to parameters in their treatment of clouds to fulfil this important constraint of the climate system…. With very few exceptions, modelling centres do not routinely describe in detail how they tune their models. Therefore the complete list of observational constraints toward which a particular model is tuned is generally not available.…. It has been shown for at least one model that the tuning process does not necessarily lead to a single, unique set of parameters for a given model, but that different combinations of parameters can yield equally plausible models. Hence the need for model tuning may increase model uncertainty. There have been recent efforts to develop systematic parameter optimization methods, but owing to model complexity they cannot yet be applied to fully coupled climate models.

Model tuning directly influences the evaluation of climate models, as the quantities that are tuned cannot be used in model evaluation. Quantities closely related to those tuned will provide only weak tests of model performance. Nonetheless, by focusing on those quantities not generally involved in model tuning while discounting metrics clearly related to it, it is possible to gain insight into model performance. Model quality is tested most rigorously through the concurrent use of many model quantities, evaluation techniques, and performance metrics that together cover a wide range of emergent (or un-tuned) model behaviour.

The requirement for model tuning raises the question of whether climate models are reliable for future climate projections. Models are not tuned to match a particular future; they are tuned to reproduce a small subset of global mean observationally based constraints. What emerges is that the models that plausibly reproduce the past, universally display significant warming under increasing greenhouse gas concentrations, consistent with our physical understanding."

One wonders how IPCC can possibly carry out a meaningful evaluation of the models given their observation that "*quantities that are tuned cannot be used in model evaluation*" and that also "*the complete list of observational constraints toward which a particular model is tuned is generally not available*". That appears to make the task impossible.

I should add that, in the same position, I'd have done the same thing. Of course one tunes uncertain parameters to known past outcomes. It provides a basis for prediction which is consistent with the past. A model which is not consistent with the past would have little credibility in predicting the future.

BUT – recall that the success of the models in estimating past GAT trends was to be used to validate the hypothesis that global warming is indeed due to CO_2 increases. Once tuning enters the picture – and assuming that the tuning makes a substantial difference to model predictions (it does) – then the "success" of the models can no longer be claimed to validate the CO_2 hypothesis.

That is the logical flaw in the process.

> The IPCC position may now be fairly criticised on the grounds that other postulated causes of GAT increase (which have received too little attention) may be just as successful, or more successful, in explaining the history of GAT (and hence provide equally credible future predictions) as a "fiddled CO_2 model". Importantly, models on an alternative physical basis may give very different forward projections.

7. Are There Obvious Candidates for What Parameters Might be Tuned?

Yes.

Recall that even IPCC do not know how the tuning is accomplished for most of the models they quote. However, there is an obvious quantity to target for tuning. It is the quantity which has the greatest effect upon GAT prior to global warming and is also that which is predicted to cause the greatest increase in GAT. It is the most important greenhouse gas in the atmosphere: water vapour in its various manifestations.

8. Is It CO_2 Which Directly Causes Most GAT Increase Even in CO_2-Based Models?

No.

The apparently oxymoronic nature of that answer is resolved by the word "directly".

Climate models include direct effects, or "radiative forcings", but also indirect effects. Thus, the direct effect of increasing greenhouse gases is to increase GAT. But then the resulting increased temperature can itself cause further effects, such as,

- Polar ice melting – which reduces albedo (causing further warming);
- Increased evaporation and hence potentially increased atmospheric humidity (and hence increased warming as water vapour is a greenhouse gas);
- Hence, perhaps increased (or decreased?) cloud cover – which increases (or decreases?) albedo - causing cooling (or warming?);
- Increased precipitation and hence potential implications for humidity and hence cooling or warming;

…and many other possibilities. These phenomena are known as feedbacks, as the magnitude of the initial temperature increase is subsequently modified by these consequential effects. Note that some of these effects will amplify the initial "CO_2 forcing" temperature increase (positive feedback), whereas others will act to decrease the initial temperature change (negative feedback).

> The most important issue, which is not advertised to the public and which lies deeply buried in the mass of IPCC reports, is that *most* of the GAT increase predicted by the models is due to positive feedback – *not* due to the CO_2 "forcing" directly.

The Executive Summary of the Fifth IPCC Report, Working Group 1 "The Physical Science Basis", Chapter 9, "Evaluation of Climate Models" states,

"*The Coupled Model Intercomparison Project Phase 5 (CMIP5) model spread in equilibrium climate sensitivity ranges from 2.1°C to 4.7°C and is very similar to the assessment in the AR4 (Assessment Report 4)*"

Section 9.7.1 of the same 2014 Fifth IPCC Report states,

"*Equilibrium climate sensitivity (ECS) is the equilibrium change in global and annual mean surface air temperature after doubling the atmospheric concentration of CO2 relative to pre-industrial levels. In the AR4, the range in equilibrium climate sensitivity of the CMIP3 models was 2.1°C to 4.4°C, and the single largest contributor to this spread was differences among modelled cloud feedbacks. These assessments carry over to the CMIP5 ensemble without any substantial change (Table 9.5).*"

In fact the Fourth IPCC Report, WG1 The Physical Science Basis, Chapter 8, Climate Models and Their Evaluation, (2007) Section 8.6.2.2, gives the mean equilibrium climate sensitivity to be 3.2ºC, with lower and upper bounds as stated above: 2.1ºC to 4.4ºC. Section 8.6.2.3 states,

"*The diagnosis of global radiative feedbacks allows better understanding of the spread of equilibrium climate sensitivity estimates among current GCMs (Global Climate Models). In the idealised situation that the climate response to a doubling of atmospheric CO2 consisted of a uniform temperature change only, with no feedbacks operating (but allowing for the enhanced radiative cooling resulting from the temperature increase), the global warming from GCMs would be around 1.2°C.*"

To emphasise what this is saying: the GAT temperature increase due to CO_2 directly, ignoring feedbacks, due to an increase in CO_2 from pre-industrial levels (278 vppm) to double that level (556 vppm) is given by the models to be only 1.2ºC.

The Fourth IPCC Report, WG1 The Physical Science Basis, Chapter 8, Climate Models and Their Evaluation, (2007) Section 8.6.2.3 continues,

"*The water vapour feedback, operating alone on top of this, would at least double the response. The water vapour feedback is, however, closely related to the lapse rate feedback and the two combined result in a feedback parameter of approximately 1* $Wm^{-2}°C^{-1}$*, corresponding to an amplification of the basic temperature response by approximately 50%. The surface albedo feedback amplifies the basic response by about 10%, and the cloud feedback does so by 10 to 50% depending on the GCM. Note, however, that because of the* *inherently nonlinear nature of the response to feedbacks, the final impact on sensitivity is not simply the sum of these responses. The effect of multiple positive feedbacks is that they mutually amplify each other's impact on climate sensitivity.*

Using feedback parameters from Figure 8.14, it can be estimated that in the presence of water vapour, lapse rate and surface albedo feedbacks, but in the absence of cloud feedbacks, current GCMs would predict a climate sensitivity (±1 standard deviation) of roughly 1.9°C ± 0.15°C (ignoring spread from radiative forcing differences). The mean and standard deviation of climate sensitivity estimates derived from current GCMs are larger (3.2°C ± 0.7°C) essentially because the GCMs all predict a positive cloud feedback (Figure 8.14) but strongly disagree on its magnitude."

To paraphrase: of the mean 3.2ºC climate sensitivity predicted by the models due to doubling CO_2, only 1.2ºC is due directly to the CO_2 and 2.0ºC in total is due to various feedbacks, of which water vapour plus its manifestation as clouds (and hence albedo) are the strongly dominant components.

At 2019 CO_2 levels of 410 vppm, a climate sensitivity of 1.2ºC would imply a GAT rise of only 0.57ºC due to CO_2 effects directly without feedbacks. This is only half the observed GAT increase to-date (since 1880), of about 1.0ºC to 1.1ºC. Hence ignoring feedbacks would make the climate models inconsistent with observed temperature changes.

If feedback effects were actually substantially smaller (or even negative), but have been artificially inflated in models to-date as a result of tuning to past temperature data, then the climate models based on the CO_2 hypothesis would fail to correctly predict the observed rising GAT.

9. Is Enough Known with Confidence About the Effect of Warming on Water Vapour and Clouds to Justify the Large Positive Feedback in the Models?

No.

This is the denouement of this article. The truth is that the effect of warming on water vapour is extremely uncertain, especially when it is noted that it is the water vapour at high altitude which matters most. Moreover, knowledge of the effect of warming on cloud cover and cloud albedo is more uncertain still. In fact either or both of these key phenomena could produce a negative, rather than a positive, feedback mechanism. Yet all the models include large positive feedbacks. It is hard to avoid the suspicion that this has been done because it is what results in agreement with past GAT data. But what if there were other causes of warming which have been neglected?

The rest of this article considers the available evidence which conflicts with the presumption of positive feedback due to water vapour. I will not be attempting a complete and balanced account of all the data – that would be a formidable task. I seek only to show that credible evidence exists to cast doubt on the IPCC models presumption of a large positive feedback.

In fact, there is credible evidence the feedback might be negative – and, if so, the CO_2 hypothesis fails.

10. The Effect of Global Warming on Water Vapour & Its Feedback Effect

Before turning to the evidence from the literature, it worth emphasising that it is water vapour at high altitudes which matters most – and this is despite the specific humidity at the lower temperatures which prevail in the upper troposphere being far smaller than near ground level. This quote from the Fourth IPCC Report, WG1 The Physical Science Basis, Chapter 8, Climate Models and Their Evaluation, Box 1 of Section 8.6.2.3, explains why,

"*The radiative effect of absorption by water vapour is roughly proportional to the logarithm of its concentration, so it is the fractional change in water vapour concentration, not the absolute change, that governs its strength as a feedback mechanism….Under such a response, for uniform warming, the largest fractional change in water vapour, and thus the largest contribution to the feedback, occurs in the upper troposphere*."

(1) Garth Paltridge, Albert Arking & Michael Pook, "Trends in middle- and upper-level tropospheric humidity from NCEP reanalysis data", Theor Appl Climatol (2009) 98: 351.

This paper considers data from the National Centers for Environmental Prediction (NCEP) on tropospheric humidity for the period 1973 to 2007. The authors acknowledge the limitations in this radiosonde-derived humidity data, particularly at altitudes above the 500 hPa pressure level. (NB: hPa is the same as millibars, and a guide to altitude is that 850 hPa corresponds to the top of Ben Nevis, 4,779 feet; 300 hPa corresponds to the top of Everest at just over 30,000 feet, while the pressure drops to 100 hPa then 60 hPa at 52,000 and 64,000 feet). Extracts from the Abstract are,

"*…the face-value 35-year trend in zonal-average annual-average specific humidity q is significantly negative at all altitudes above 850 hPa (roughly the top of the convective boundary layer) in the tropics and southern midlatitudes and at altitudes above 600 hPa in the northern midlatitudes. It is significantly positive below 850 hPa in all three zones, as might be expected in a mixed layer with rising temperatures over a moist surface. The results are qualitatively consistent with trends in NCEP atmospheric temperatures (which must also be treated with great caution) that show an increase in the stability of the convective boundary layer as the global temperature has risen over the period.*

The upper-level negative trends in q are inconsistent with climate-model calculations and are largely (but not completely) inconsistent with satellite data. Water vapor feedback in climate models is positive mainly because of their roughly constant relative humidity (i.e., increasing q) in the mid-to-upper troposphere as the planet warms. Negative trends in q as found in the NCEP data would imply that long-term water vapor feedback is negative—that it would reduce rather than amplify the response of the climate system to external forcing such as that from increasing atmospheric CO_2."

To paraphrase: the paper observes there is data which indicates water vapour concentrations have reduced at the higher altitudes where it matters most, which would indicate water vapour to provide a negative feedback to GAT changes.

(2) Ferenc Miskolczi, "The Stable Stationary Value of the Earth's Global Average Atmospheric Planck-Weighted Greenhouse-Gas Optical Thickness", Energy & Environment, **21** 4 (2010) 243-262

The author analyses radiosonde data from hundreds of weather balloons. An extract from the Abstract reads,

"*In the 1948-2008 time period the global average annual mean true greenhouse-gas optical thickness is found to be time-stationary. Simulated radiative no-feedback effects of measured actual CO_2 change over the 61 years were calculated and found to be of magnitude easily detectable by the empirical data and analytical methods used. The data negate increase in CO_2 in the atmosphere as a hypothetical cause for the apparently observed global warming. A hypothesis of significant positive feedback by water vapor effect on atmospheric infrared absorption is also negated by the observed measurements. Apparently major revision of the physics underlying the greenhouse effect is needed*."

In a subsequent paper by the same author, "The Greenhouse Effect and the Infrared Radiative Structure of the Earth's Atmosphere", Development in Earth Science, **2** (2014) 31-52, Miskolczi draws the following conclusions,

"*Many authors have proposed a greenhouse effect due to anthropogenic carbon dioxide emissions. The present analysis shows that such an effect is impossible*."

"*Climate modelers are using diverse - and not very transparent - H_2O feedback processes to match their predicted ΔOLR (change in outgoing longwave radiation) with the reality*."

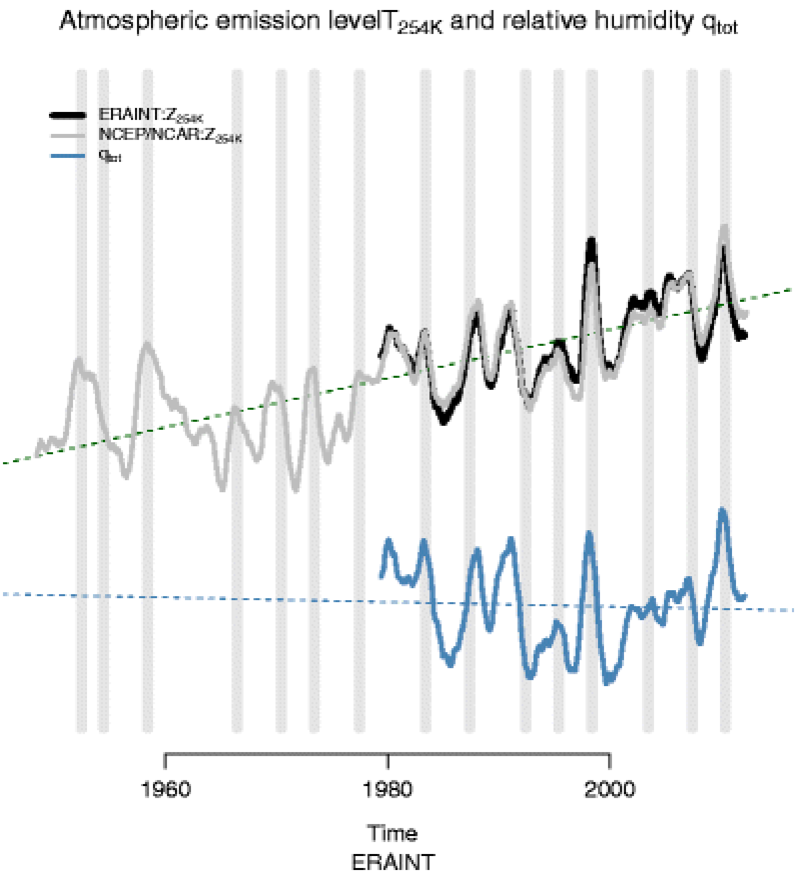
The latter confirms my suspicion.

(3) Rasmus E. Benestad, "A mental picture of the greenhouse effect", Theoretical and Applied Climatology, May 2017, **128** 3–4, 679–688

The paper presents a trend line for relative humidity from 1980 to 2012, reproduced as Figure 2 below. This shows relative humidity to be trending downwards, contrary to IPCC models which invariably assume constant relative humidity (and hence increasing specific humidity as temperatures rise).

The trend in total precipitable water (TPW), Qtot, was also negative, -0.018 ± 0.017 kg/m^2 per decade, from a mean of 29kg/m^2 (a condensed water column of 2.9cm). Hence this also contradicts the IPCC models, which assume increasing total water (increasing specific humidity).

Figure 2: Blue line shows downward trend in relative humidity from Benestad. (Grey bands are El Nino years)



(4) Gregory King, (2013) "NASA satellite data shows a decline in water vapor" (web article)

The NASA water vapour project (NVAP) uses multiple satellite sensors to create a standard climate dataset to measure long-term variability of global water vapour. Data for 1988 to 2001 was provided by King and is reproduced as Figure 3 below. (The NVAP site now has data to 2009 but I have not yet accessed it). The logarithmic scale of Figure 3 is appropriate as the feedback effect relates to percentage change, not absolute change. The graph shows a significant percentage decline in upper and middle layer water vapour from 1995 to 2001, suggesting water vapour would have a negative feedback effect on GAT changes.

King also provides a graph of relative humidity between 1948 and 2012 taken from the NOAA Earth System Research Laboratory and based on data from weather balloon and satellites (Figure 4). The relative humidity shows downward trends at all altitudes, in conflict with IPCC models which assume constant relative humidity.

Figure 3: NASA-NVAP Project, Precipitable Water Vapour by Altitude

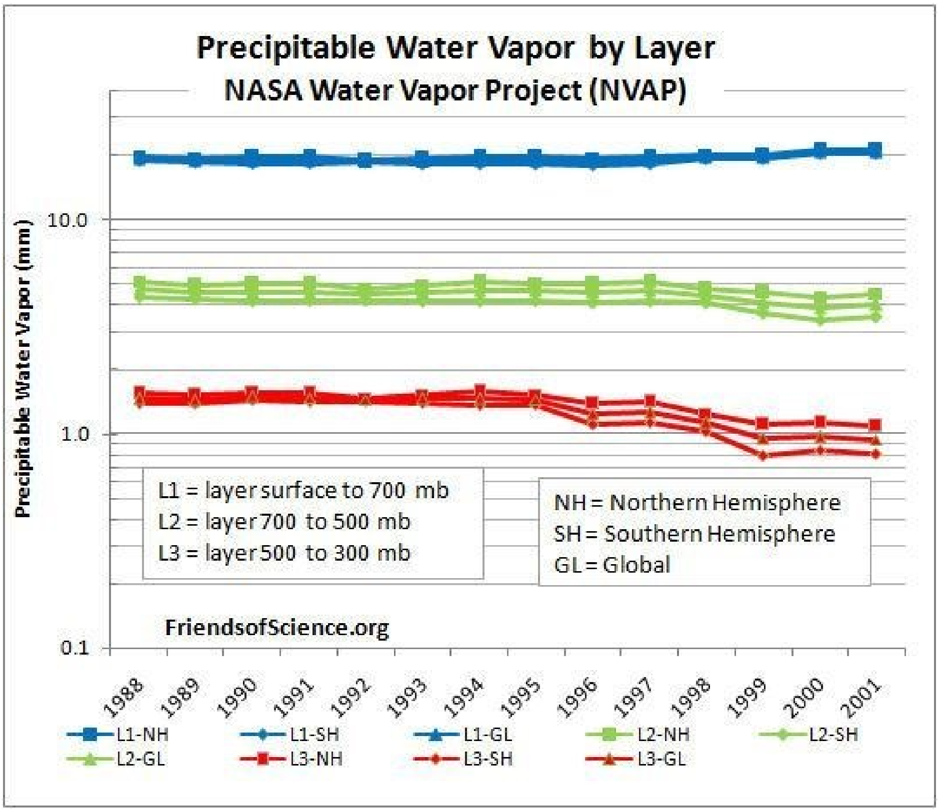
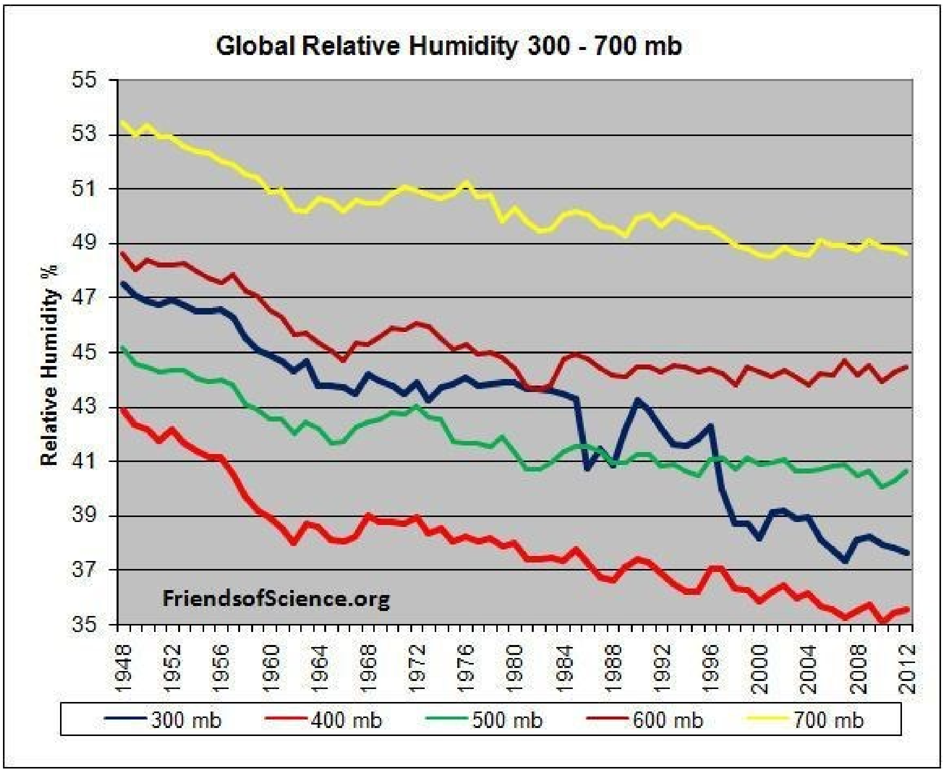
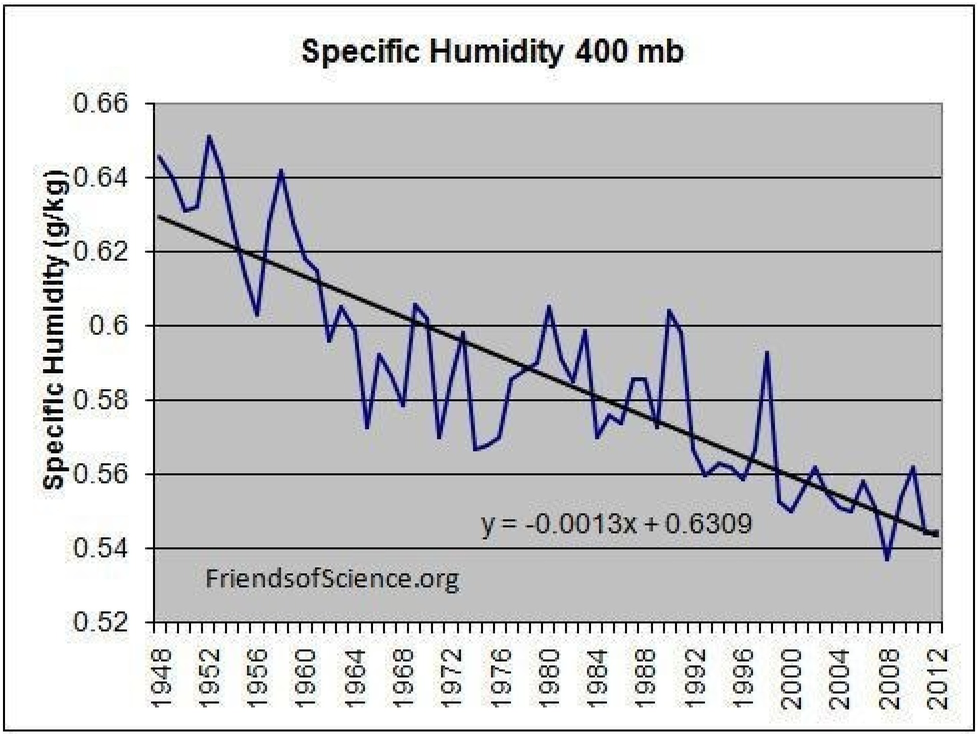


Figure 4: NOAA ESRL Relative Humidity Data



King also provides a plot of the specific humidity at a height of 400 mb (7 km), which also trends downwards (Figure 5), contrary to IPCC models which have specific humidity increasing with increasing GAT.

Figure 5:



(5) Andy May (June 2018), "Does Global Warming increase total atmospheric water vapor (TPW)?" (web site)

I do not want to give the impression that all sources indicate downward trends in water vapour and hence negative feedback. Some sources show the opposite.

May has plotted data for total precipitable water (TPW) in various forms derived from NCEP (National Centers for Environmental Prediction). TPW is essentially an integration of specific humidity over a certain latitude range. The two sources are Reanalysis 1 and Reanalysis 2 with associated publications being Kalnay et al (March 1996), "The NCEP/NCAR 40-year reanalysis project", Bulletin of the American Meteorological Society, and Kanamitsu et al. (2002), "NCEP-DOE AMIP-II Reanalysis (R-2)", Bulletin of the American Meteorological Society. Note that NCEP is the same source as used by Paltridge et al, above.

Figure 6 plots this TPW data versus year, and in comparison with the rising GAT (grey line). Reanalysis 1 is plotted as the orange line and relates to the atmosphere up to a height of 8 km (350 mb). Reanalysis 2 is plotted as the yellow line and relates to the whole atmosphere. Reanalysis 1 shows no change in TPW between 1948 and the present, though there is a dip in the middle. Reanalysis 2 shows an increase in TPW.

However, recall that it is the percentage change in water vapour at higher altitudes that matters most, not the TPW. Figure 7 plots the high altitude data from Reanalysis 1 and shows a reducing trend, suggesting possible negative feedback due to water vapour.

Figure 6: Total Precipitable Water (TPW): Orange = NCEP Reanalysis 1 for atmosphere below 8km; Yellow = NCEP Reanalysis 2 for whole atmosphere; Blue = RSS; Grey = temperature (GAT, from HADCRUT4 dataset)

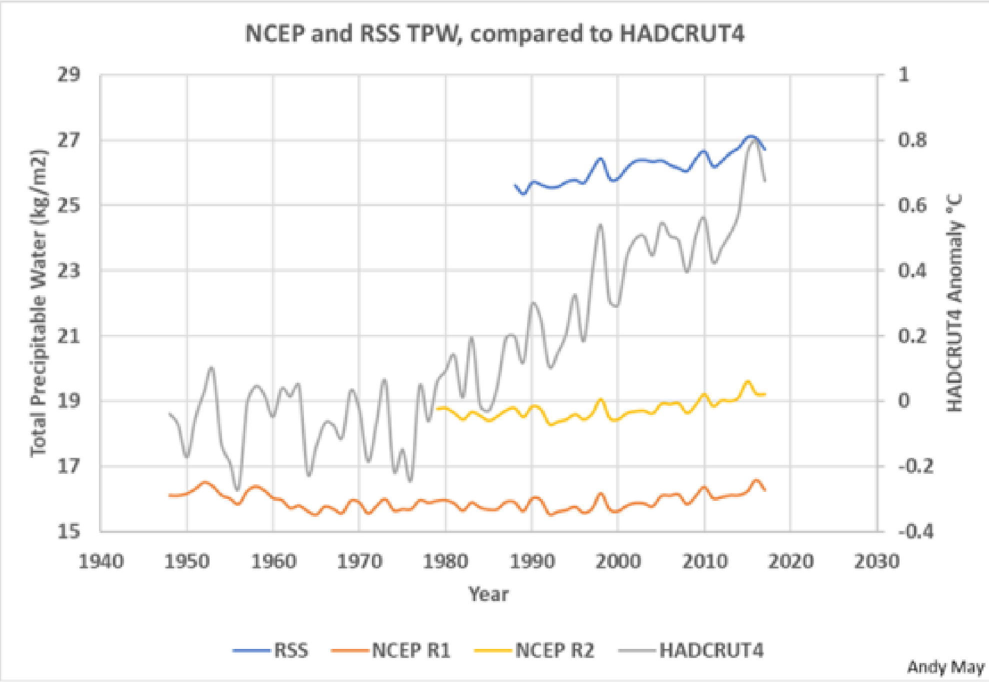
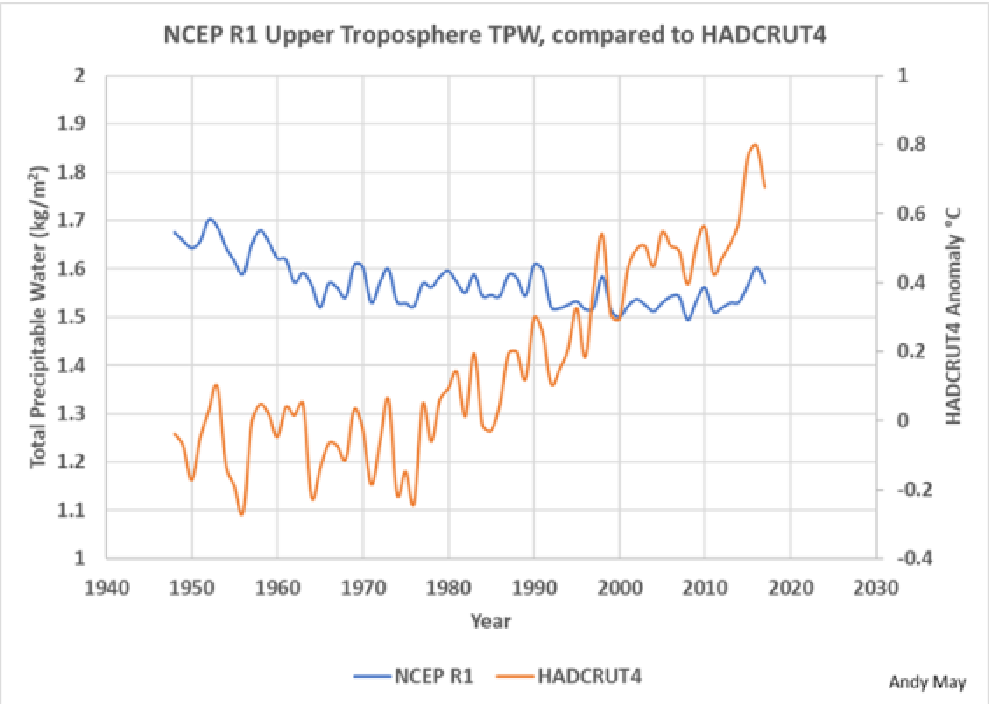


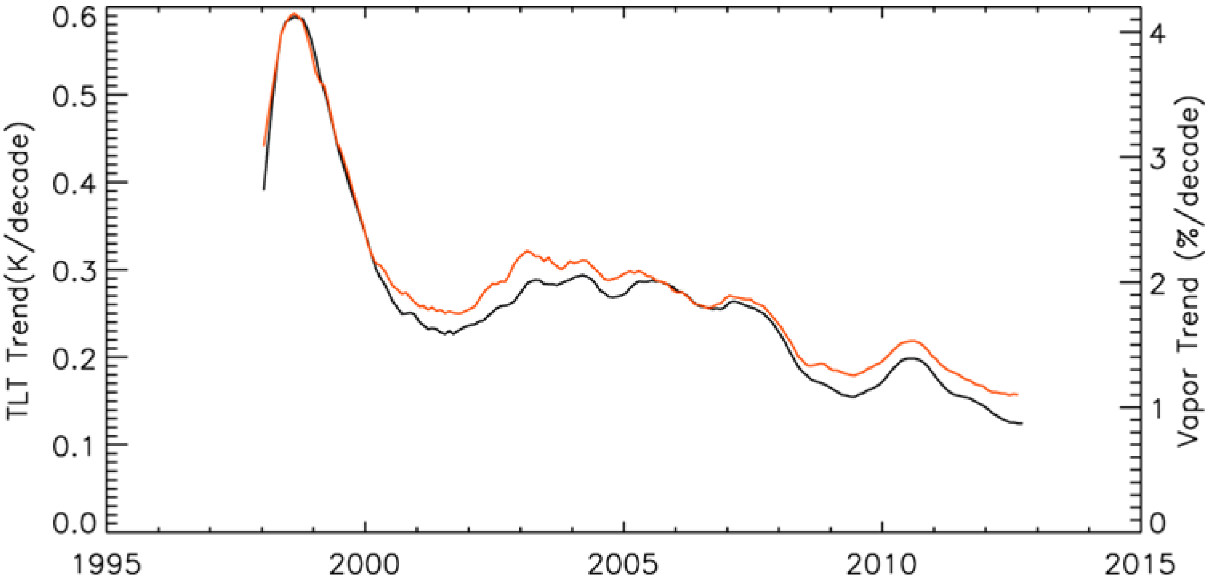
Figure 7: TPW from NCEP Reanalysis 1 in the Upper Troposphere (blue), cf GAT (orange)



Another source of TPW data is also plotted in Figure 6, namely RSS. Their data relates to oceans without sea ice only, not the whole globe, so are not directly comparable with NCEP. However, RSS data shows an upward trend. In fact, both the RSS and NCEP Reanalysis 2 data for TPW can be presented in a manner which makes it look like it tracks temperature closely, by choosing the scale appropriately. RSS themselves make a big play about this, plotting the data as shown in Figure 8. These TPW data are restricted to the deep tropics (+/-20 degrees latitude) and clear ocean regions only. What is plotted is not the data itself but the calculated linear trend starting from January 1988. This plot indicates an upward trend in TPW over tropical oceans. Why the trend itself should be trending downwards (i.e., why the rate of increase should be decreasing) I do not know – and one may ask the same about GAT as plotted on Figure 8.

An upward trend in TPW as reported by RSS can also be seen in their global distribution map given here.

Figure 8: RSS Trend in TPW above the Tropical Oceans (orange) cf Trend in GAT (black) (graphic downloaded from here).



The IPCC quote other sources indicating increasing TPW or increasing specific humidity. My purpose here is not to argue that either decreasing TPW or a negative H_2O feedback can necessarily be asserted with confidence, only that the reverse cannot be asserted with any great confidence either.

And yet the Executive Summary of the Fifth IPCC Report, Working Group 1 "The Physical Science Basis", Chapter 9, "Evaluation of Climate Models" states,

"*There is likewise very high confidence that, consistent with observations, models show a strong positive correlation between tropospheric temperature and water vapour on regional to global scales, implying a positive water vapour feedback in both models and observations*."

The IPCC's claim of *very high confidence* on this issue in the face of the contrary indications noted above is puzzling. Indeed, any confidence at all seems misplaced.

11. Clouds & Albedo

The IPCC emphasises that the effect of clouds is the chief cause of spread in model results. Rather than attempt an examination of the literature on the effect of warming on cloud cover I take here a simpler and more direct approach. Firstly a bit of a primer on how GAT may be calculated.

The heat flux from the Sun impinging on the outer layer of the atmosphere is S_0 =1367 W/m^2. However, a smaller heat flux actually impinges on the ground (or sea) due to reflection of some of the radiation. This smaller flux is written $S_{max} = (1-a)S_0$, where a is the albedo, i.e., the fraction of radiation reflected. The subscript denoting 'maximum' refers to the fact that S_{max} is the flux hitting the ground only at mid-day at the equator. The incident flux falls off as the cosine of the latitude (which is why the poles are cold) – and, of course, is zero at night. However, the total energy hitting the ground can be based on the maximum flux, S_{max} , so long as we use the projected area πr^2, where r is the radius of the Earth. So the total energy hitting the ground is $\pi r^2(1-a)S_0$.

The Earth is in almost precise energy balance. (Were it not, global warming would be happening on a timescale of hours or days, not decades). The Earth re-radiates energy back into space at infrared wavelengths. Taking T to be some suitably averaged temperature, the power flux radiated will be $\varepsilon\sigma T^4$ where σ is Stefan's constant and ε is some effective emissivity. The total power is radiated by the Earth is thus $4\pi r^2\varepsilon\sigma T^4$ (since the whole surface of the Earth radiates). After cancellation the energy balance equation is therefore,

$$4\varepsilon\sigma T^4 = (1-a)S_0 \qquad (1)$$

The devil lies in the values of the albedo, a, and the effective emissivity, ε. In a perfect vacuum, with no resistance to the passage of radiation, the emissivity would be unity. But the atmosphere resists free propagation of radiation and results in $\varepsilon < 1$. The average albedo of the Earth is about 0.3, and the GAT at the Earth's surface, or lower atmosphere, is T_s =15.2°C (288.35K). The heat balance equation, (1), therefore implies an effective emissivity of $\varepsilon = 0.61$ (Stefan's constant is 5.67 x 10^{-8} Wm^{-2}K^{-1}).

The "optical depth" of a given thickness of atmosphere refers to the degree of impedance to the passage of photons through it. Unit optical depth is defined as a depth equal to the mean free path of a photon, i.e., the average distance travelled by a photon before it is scattered by a molecule in the air. Any molecule can do the scattering: N_2, O_2, H_2O, CO_2, NH_4, etc., but some molecules have a far larger cross-section for scattering photons than others (which is just a way of saying they are far more likely to cause scattering, molecule for molecule). In particular, increasing the number of H_2O or CO_2 or NH_4 molecules per unit volume will reduce the mean free path of photons.

It can be shown that the position in the atmosphere at which the atmosphere which remains above it has unit optical depth acts with an effective emissivity of unity, $\varepsilon = 1$. It follows immediately from Equ.(1) that the average temperature of the position in the atmosphere at unit optical depth must be T_1 =254.9K (-18.3°C). Roughly speaking, from far away the Earth appears to be a black body radiating infrared at this temperature.

The surface of the Earth (or lower atmosphere) is hotter, i.e., $T_s > T_1$, because a temperature gradient is required to drive heat (or radiation, more precisely) through a resisting atmosphere – and this resistance is caused by the photon scattering. The effect of greenhouse gases is to increase scattering and hence to decrease the effective emissivity. In Equ.(1) deceasing ε causes an increase in T_s.

The two key feedback effects are caused by (a) changes in water vapour, and, (b) changes in cloud cover. Increasing water vapour reduces ε, because H_2O is a greenhouse gas, and hence increases GAT. We have noted above that this is sensitive to the altitude, such that changes in high altitude water vapour are far more important than changes at low altitude. Consequently even increases in total water vapour could lead to reductions in GAT (negative feedback) if high altitude specific humidity decreased.

The significance of cloud cover is in changing the albedo, a.

There are four major contributions to the Earth's average albedo: clouds, ice, cloudless land, and cloudless ocean. Ice occupies about 10% of the Earth's surface and has an albedo of 0.5 to 0.7, and might be as high as 0.9 if snow covered. At any one time, about two-thirds of the world's surface is cloud covered. Cloud has an albedo of 0.3 to 0.7. Perhaps 12% or so of the Earth's surface is cloudless land at any given time, with an albedo of about 0.2. Finally, cloudless ocean has an albedo of about 0.06 and accounts for the remaining 11% of surface area. The average albedo of 0.3 is thus made up as follows.,

$$a = 0.1 \times 0.5 + 0.67 \times 0.33 + 0.12 \times 0.2 + 0.11 \times 0.06 = 0.30 \qquad (2)$$

Cloud therefore accounts for 0.22 of the 0.30 average albedo, i.e., about three-quarters of the Sun's radiation which is reflected back into space, and hence not available to cause warming, is reflected off clouds. Clearly, any change in cloud cover is therefore going to be of paramount importance.

Consider what increase in average albedo would be needed to reduce the GAT by, say, 2^{o}C. Using the above illustrative data (keeping the effective emissivity unchanged) this would be accomplished by increasing the albedo from 0.30 to 0.32 – and this could be accomplished by increasing cloud cover from a notional 67% to 73%. This is well within the range of uncertainty of current percentage cloud cover.

In other words a 6% increase in cloud cover would be sufficient to negate most or all of the GAT increases predicted by the current climate models.

IPCC climate models at present are based upon a doubling of CO_2 producing a direct increase in GAT of 1.2^{o}C plus a positive feedback due to water vapour and clouds of an additional 2^{o}C. But a mere 6% increase in cloud cover alone would produce a negative feedback *reducing* GAT by 2^{o}C.

Thus, the models implicitly assume a *decrease* in cloud cover by just a few percent due to the 1.2^{o}C rise attributable directly to CO_2 – and this is sufficient to increase the climate sensitivity to 3.2^{o}C in total. But, had GAT not already increased, how many modellers would be confident of claiming that increasing GAT would cause decreased cloud cover? In truth this seems to be an assumption of convenience because it is what is required to make a CO_2 based model fit the GAT data.

There is serious doubt that our understanding of clouds is precise enough to predict whether an increase of GAT of around 1.2^{o}C would be more likely to result in a few percent increase or a few percent decrease in cloud cover. A similar remark might be made in respect of changes in mean cloud albedo. This observation alone casts doubt on whether net feedback effects can even be confidently asserted to be positive. This doubt overs clouds adds to the doubt over water vapour effects.

12. Conclusions

[1] Global average temperature (GAT) has been increasing over the last 40-60 years and is currently continuing to trend upwards.

[2] Atmospheric concentrations of CO_2 have been increasing, are continuing to increase, and are most likely to be of anthropogenic origin.

[3] The basic physics underlying the greenhouse gas phenomenon is well understood and increasing levels of CO_2 in the atmosphere would be expected to produce *some* increase in GAT.

[4] However, models consistently fail to predict the observed increases in GAT from direct CO_2 forcing alone.

[5] Consistency between model predictions and past GAT increases is achieved only because strong positive feedback effects are assumed, those involving water vapour and clouds being by far the most significant.

[6] Consistency between model predictions and past GAT increases, as claimed by IPCC, appear to be the result of "tuning", i.e., the agreement is not a result of accurate *ab initio* calculations but a result of tuning uncertain parameters to the measured data.

[7] Oddly, even IPCC appear not to be well informed about what parameters are "tuned", but the dominance of the feedback effects involving water vapour and clouds – together with the great uncertainty in these phenomena - implies that it is these aspects which are tuned.

[8] The literature regarding whether water vapour (or water vapour at the most sensitive altitudes) has increased or decreased is ambiguous, some sources claiming increase and some decrease. Hence there is ample reason to doubt that the water vapour effect is even a positive feedback at all.

[9] IPCC models invariably assume a strong positive feedback associated with cloud, which is implicitly an assumption of deceasing cloud cover with increasing GAT but the physical basis of this is obscure and may not exist.

[10] There is cause for concern that the determination to make CO_2 the sole root cause of GAT increases might have deflected attention from other possible contributory causes.

[11] Vested interests by research groups, and vested political capital, may now be making it very difficult to admit error. There is increasing pressure for radical, wholesale, global changes in industrial and economic infrastructure on the basis of a perception about the evils of carbon which is far less well founded than the public or politicians have been led to believe.