SENATOR THE HON KIM CARR

MINISTER FOR INNOVATION, INDUSTRY, SCIENCE AND RESEARCH

The Hon Danna Vale MP
Federal Member for Hughes
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22 FEB 2010

Dear Ms Vale Danna

Thank you for your letter of 14 December 2009, concerning CSIRO-Bureau of Meteorology climate models and your concerns about apparent discrepancies with the work of Paltridge *et al.* (2009) and Wentz *et al.* (2007).

I would like to reaffirm the statement in my previous letter that the observations cited in these two papers do not disprove the underlying theories on which the Global Climate Models (GCMs) are based nor do they invalidate the outputs from those models. I also confirm that this statement has the endorsement of the CSIRO's Chief Executive, Dr Megan Clark.

In summary the primary science concerns raised in your letter appear to be that:

- The papers by Paltridge *et al.* (2009) and Wentz *et al.* (2007) report observations that contradict contemporary theory of the feedbacks between global warming, due to increasing levels of atmospheric carbon dioxide, and atmospheric water content.
- The existing GCMs including those used in preparation of the Garnaut Review (2007) are based on contemporary theories of climate and atmospheric physics and so may be in error if the interpretations of Paltridge *et al.* and Wentz *et al.* are correct.
- The GCMs are based primarily on assumptions that have not been tested against empirical evidence.

CSIRO has provided a detailed analysis of each of these matters in the enclosed document which I commend to you. In summary their analysis notes that:

- The inconsistencies cited in Paltridge *et al.* (2009) and Wentz *et al.* (2007) were substantially qualified with caveats by the authors and alone do not provide consistently convincing evidence sufficient to overturn the findings of the many other peer-reviewed papers published in the climate science literature. Indeed both papers contain substantive observational results that are consistent with the theoretical underpinnings of current GCMs.
- There is no observational data in either of the two papers that categorically disproves the underlying theories on which the CSIRO's GCMs are based, or would invalidate outputs from those models. It would thus be inappropriate to re-configure the contemporary GCMs on the basis of these two publications as their results are arguably inconsistent *in places* with the majority of evidence-based theory and the wealth of other research that has informed these models and which has been used repeatedly to test their assumptions and predictions.

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- There generally is very good agreement between predictions of theories of the atmospheric water cycle in a warming environment and published empirical evidence.
- Outputs from GCMs are regularly tested against available observational evidence. Further the ability of GCMs to replicate an extremely wide range of observed features of past and current climate and climate variability is continually reported in the peer reviewed literature, along with analyses of model – data differences and the quality of the observed datasets themselves.

Climate change and the uncertainties surrounding it are subject to much public and scientific debate. It is not unusual for new scientific studies to report findings that are to some degree at odds with the majority of available, rigorous evidence and this appears to be the case with the papers by Wentz *et al.* and Paltridge *et al.* It is a normal part of the testing and challenging of established scientific theory that contributes to the rigor of the scientific method. However science does not advance on the result of a few inconsistent findings alone and the overturning of existing theory only occurs after a rigorous review of such observations to ensure that they are sufficiently robust to justify a change in theory. The role of CSIRO scientists in providing rigorous peer reviewed science is important in providing decision makers with the best available scientific knowledge, advancing the underpinning science and continually improving model performance.

Wentz *et al.* has attracted considerable subsequent examination but this has not resulted in a re-writing of the theoretical underpinnings of GCMs because the review process has not verified that the partial differences from other observations are sufficiently robust to overturn existing theory. Paltridge *et al* will no doubt receive similar rigorous examination in the peer reviewed literature in due course and any tested and substantiated implications for GCMs would be taken into consideration at that time as part of the systematic evolution of GCMs.

In addition to the enclosed analysis by CSIRO of Paltridge *et al.* and Wentz *et al.*
I would encourage you to read CSIRO's review of common climate change science questions at http://www.csiro.au/resources/Climate-questions-science-facts.html which includes references to published, peer-reviewed papers on this important topic.

If it would be helpful, CSIRO staff would be able to give you an oral briefing on these issues. Please contact Kimberley Shrives on 02 6276 6682 or at Kimberley.Shrives@csiro.au if you'd like to arrange a meeting.

Yours sincerely

Kim Carr

Paltridge *et al.* (2009) and Wentz *et al.* (2007) and the validity of Global Climate Models (GCMs)

Introduction

The papers referred to by the Hon Danna Vale, MP in her letter of 14 December 2009 are:

"Trends in middle and upper-level tropospheric humidity from NCEP reanalysis data" by Paltridge, G., Arking, A. and Pook, M., Theor. Appl. Climatol. (2009), 98, 351 - 359

"How much more rain will global warming bring" by Wentz, F.J., Ricciardulli, L. and Mears, C. Science (2007), 317, 233 – 235.

The primary concerns of science raised by Ms Vale's letter appear to be as follows:

- Papers by Paltridge *et al.*(2009) and Wentz *et al.*(2007) report observations that contravene contemporary theory of the feedbacks between global warming, due to increasing levels of atmospheric carbon dioxide, and atmospheric water content.
- Existing Global Climate Models (GCMs) including those used in preparation of the Garnaut Review (2007), are based on contemporary theories of climate and atmospheric physics and so may be in error if the interpretations of Paltridge *et al.* and Wentz *et al.* are correct.
- It is also suggested that the GCMs are based primarily on assumptions without test against empirical evidence.

Responses to each matter follow.

Observations

Water vapour feedback and humidity in the atmosphere (Paltridge *et al.* 2009)

The paper by Paltridge *et al.* relates to the water vapour feedback, whereby global warming will lead to increased humidity in the atmosphere which, in turn could cause further warming because water vapour itself is a greenhouse gas. If this is occurring, then there should be an increasing trend of water vapour, measured as specific humidity, in the troposphere (the lower 10 or so km of the atmosphere).

The results from Paltridge *et al.* confirm this for the lower part of the atmosphere; finding that the trend in specific humidity over the 35 years from 1973 to 2007 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*". This confirmation is consistent with other observed data sets and demonstrates that the water vapour feedback is occurring as expected in the lower 1 – 2 kilometres of the troposphere. This is consistent with current climate theories.

Paltridge *et al.* find a decreasing trend in humidity in the upper troposphere, based on analysis of balloon-borne radiosonde measurements. They note that this result is inconsistent with satellite-based observations and importantly they provide the caveat that "*radiosonde-derived humidity data must be treated with great caution, particularly at altitudes above 500 hPa*". This caveat acknowledges that analyses of trends in upper troposphere moisture based on radiosonde observations alone are highly uncertain, a point that is well documented in the climate science literature.

Many studies in the peer-reviewed scientific literature (for example: Spencer and Braswell, 1997; Allan *et al.*, 2003) have concluded that radiosonde moisture data are highly uncertain in the upper troposphere, due to a range of factors including: i) poor instrument response at very low humidities; ii) changes in instrumentation over time, and iii) the extremely poor spatial coverage over the globe - for example, the Southern hemisphere is mostly ocean and so poorly sampled by

balloon-borne radiosonde sensors. These data are therefore unreliable for analysing even the *mean* climate of the upper tropospheric humidity, and so any analysis of *trends* will be highly uncertain.

The conclusions of such studies are summarised well by the IPCC Fourth Assessment Report (Working Group I, p. 273) where it is stated that "*In general the radiosonde trends are highly suspect owing to the poor quality of, and changes over time in the humidity sensors. Comparisons of water vapour sensors during recent intensive field campaigns have produced a renewed appreciation of random and systematic errors in radiosonde measurements of upper tropospheric humidity...*".

Thus, the result from Paltridge *et al.* for the upper troposphere is not alone sufficient to falsify current water vapour feedback theory, and the theory continues to be consistent with the other peer reviewed observational evidence.

Further, the current state of the science with regard to drying in the upper troposphere is well presented by both the IPCC Fourth Assessment Report (see Chapter 8 of Working Group 1), and the recent paper by Dessler and Sherwood (2009) published in Science. Dessler and Sherwood's main points are:

- The water vapour feedback is controlled by humidity changes in the tropical upper troposphere (see also Held and Soden, 2000), where humidity levels are forced mostly by large-scale wind and temperature fields. As climate models predict these large-scale fields well, using the fundamental equations for fluid mechanics and thermodynamics, there is much less uncertainty in their predictions of the sign of the water vapour feedback.
- While climate models may vary to an extent in their predictions of the magnitude of the water vapour feedback effect due to differences in predicted warming, the net feedback magnitude is relatively insensitive to these model differences (Soden and Held, 2006).
- Crucial observational evidence has been hampered by acknowledged limitations of radiosondes to accurately measure humidity levels in the upper troposphere (as explained above). Observational evidence for the upper troposphere and ocean regions is therefore based mostly on satellite data. Studies (for example Soden et al, 2002 and 2005; Forster and Collins, 2004; Dessler et al, 2008; Inamdar, 1998) have analysed both long-term trends (over the ~ 20 year satellite record) and shorter-term responses of atmospheric humidity to climate variations that arise from natural causes such as El Nino or volcanic eruptions to demonstrate "atmospheric humidity changing in ways consistent with those predicted by global climate models" (Dessler and Sherwood, 2009).
- Quoting from Chapter 8 (Section 8.6.3.1.2) in the IPCC Fourth Assessment Report, based on papers such as those listed above: "*Confidence has also increased in the ability of GCMs to represent upper-tropospheric humidity and its variations, both free and forced. Together, upper-tropospheric observational and modelling evidence provide strong support for a combined water vapour/lapse rate feedback of around the strength found in GCMs.*"

These points are based on a large volume of peer-reviewed literature and are not inconsistent with the findings of Paltridge et al, who also demonstrate the need to develop and maintain a high quality record of atmospheric humidity in the upper troposphere.

Indeed Paltridge *et al.* do not conclude that their radiosonde observations disprove a positive water vapour feedback effect, stating in their Abstract that the inconsistency found in their analysis should be explored to "*... establish what (if any) aspects of the observed trends survive detailed examination of the impact of past changes of radiosonde instrumentation and protocol within the various international networks*".

Global precipitation (Wentz *et al.* 2007)

The goal of this paper by Wentz *et al.* is to investigate whether the global water cycle is intensifying i.e. whether the observed rates of global precipitation and evaporation are increasing. Using a combination of satellite and rain gauge observations (for the global precipitation) and model estimates (for evaporation) for the decade from 1987 to 2006, their goal was to quantify

the size and sign of the trend in the global water cycle and compare this to predictions from the GCMs used in the IPCC's Fourth Assessment.

The motivation for the study is the apparent discrepancy between the response of atmospheric humidity to global warming and the response of the water cycle to global warming. Climate models, theory and observations all agree that specific humidity increases at 5 - 7% per degree Kelvin of global warming (referred to as the Clausius-Clapeyron, or C-C, rate). Climate models, however, predict that global mean precipitation and evaporation change at the much slower rate of about 1–3% per degree Kelvin of global warming. This issue is widely reported and discussed in the climate science literature (see for example not just Wentz *et al.*but also Held and Soden, 2006; Liepert and Previdi, 2009; Soden and Held, 2006). As a result it is now well established that this discrepancy arises from the fact that the global water cycle is constrained by the atmospheric energy balance and not the availability of moisture (i.e. atmospheric water vapour which must increase at the rate dictated by the Clausius-Clapeyron equation) - see Mitchell *et al.* (1987); Allen and Ingram (2002); Feichter *et al.* (2004); and John *et al.* (2009).

The Wentz *et al.* analysis shows that the observed trend in global precipitation from 1987 to 2006 is close to the C-C rate. For the slightly shorter period (1987 – 2001), the GCMs predicted an increasing but smaller trend, and a dampening of the inter-annual variability. They conclude that *"the reason for the discrepancy between the observational data and the GCMs is not clear"* and suggest it could result from:

1. the time period chosen may being too short for extrapolating trends; and/or
2. errors in the observed data set due to problems with satellite retrievals; and/or
3. the possibility that the climate models are in error.

Analyses of long-term trends in global precipitation from observations do have uncertainties, as noted in numerous peer-reviewed papers (see for example Liepert and Previdi, 2009, Adler *et al.*, 2008, Stephens and Ellis, 2008) and in the IPCC Fourth Assessment Report.

There have been many papers published citing Wentz *et al.* 2007 (65 citations on ISI) that shed further light on the reasons for the apparent discrepancy between the response of atmospheric humidity to global warming, and that of the observed and predicted global water cycle.

For example, Liepert and Previdi (2009) analyse the trend in global mean precipitation for the same decade as Wentz *et al.*(July 1987 to August 2006), using two observed datasets. They find an increase of 1.4% ± 0.50% per decade and 1.14 ± 0.65% per decade, which confirms Wentz *et al.*(2007) and is *"close to the Clausius–Clapeyron rate that describes the dependence of water vapour saturation pressure on temperature."* Their analysis of global ocean evaporation rates is consistent with this observed increase in global precipitation. The predictions of eight GCMs analysed in their study underestimate this observed increase in precipitation, however the difference was not always statistically significant. They conclude that the GCMs used in the IPCC Fourth Assessment Report are able to predict the increasing trend in the global water balance, but over larger time scales and that global precipitation changes in a *"given 20-yr period may not be representative of the changes that will occur on longer time scales"*. These conclusions are consistent with the caveat stated by Wentz *et al.*

These papers suggest that the discrepancy identified by Wentz *et al.* (2007) does not point to an error in the GCMs. Some of the factors cited are:

- The large inter-decadal variability in the sensitivity of the global water cycle to warming in GCMs, especially for 20th century simulations. This partly arises because of differences in the nature of the climate forcing i.e. changing greenhouse gas concentrations compared to aerosols or volcanic emissions. The decade 1987 to 2006 analysed by Wentz *et al.* includes several volcanic eruptions that are likely to have affected the observed precipitation response.
- It is possible that the dampened response of precipitation and evaporation may arise from systematic changes in surface wind, humidity and temperature (Richter and Xie, 2008).

- Ongoing concerns about the quality of the long-term observations of the global hydrological cycle, as already noted (e.g. Liepert and Previdi, 2009, Adler *et al.*, 2008, Stephens and Ellis, 2008).

Based on the current science, there is no consistent and substantive evidence of a model error that would invalidate the projected climate change stated in the IPCC Fourth Assessment or the more recent Garnaut Report.

In summary, given the uncertainties in observed global precipitation trends and the recent analyses by Liepert and Previdi (2009) and others, the paper by Wentz *et al.* does not invalidate contemporary theory behaviour of the atmospheric water cycle and its response to atmospheric warming.

The Global Climate Models

The GCMs referenced in the IPCC Fourth Assessment Report and those used in the preparation of the Garnaut Review are based on contemporary climate theory, developed on the bases of a long history of climate observations and fundamental theories of physics. GCMs routinely are run to produce outputs covering historical periods (as well as future projections) and the outputs for the past tested against empirical evidence from the same periods to verify that the models credibly mimic the available empirical evidence. The cycle of model refinement, prediction, and test against observations is a robust, rigorous and peer-reviewed process that ensures that the custodians of GCMs are constantly accountable to earth system observations.

The papers of Paltridge et al. (2009) and Wentz et al. (2007) contain substantive observational results that are consistent with the theoretical underpinnings of current GCMs. The cited inconsistencies of some of their observations with predictions of current theory are substantially qualified with caveats by the authors and are not consistent with the majority of equally rigorous and peer reviewed publications describing observations and upon which contemporary climate models are based. There is no observational data in either of the two papers that categorically disproves the underlying theories on which the existing GCMs are based, or would invalidate outputs from those models. Re-configuring the contemporary GCMs on the basis of two publications with results arguable inconsistent in places with the majority of evidence-based theory would be to ignore the wealth of other research with which those GCMs are consistent.

Outputs from GCMs are regularly tested against available observational evidence and their skill in replicating an extremely wide range of observed features of past and current climate and climate variability is continually reported in the peer reviewed literature along with analyses of model – data differences and the quality of the observed datasets themselves.

Summary

The papers by Paltridge *et al.* (2009) and Wentz *et al.* (2007) do not provide consistently convincing evidence sufficient to overturn the findings of many other peer-reviewed papers.

There generally is very good agreement between predictions of theories of the atmospheric water cycle in a warming environment and published empirical evidence.

Outputs from GCMs are regularly tested against available observational evidence and their skill in replicating an extremely wide range of observed features of past and current climate and climate variability is continually reported in the peer reviewed literature along with analyses of model – data differences and the quality of the observed datasets themselves.

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