Comment on "How much more rain will global warming bring?"

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Wentz *et al.* (Reports, 13 July 2007, p. 233) present a satellite estimate of global-mean rainfall that increases with global warming faster than predicted by climate models. An independent estimate of global-mean evaporation provides additional support, but critical assumptions on relative humidity and the air-sea temperature difference changes are made that do not have adequate observational basis and are inconsistent with climate models.

Wentz *et al.* (*1*) claim that the strength of the global hydrological cycle is increasing faster than the rate predicted by climate models as the Earth warms. Whereas water vapor in the atmosphere is projected to increase rapidly with increasing temperatures following the temperature dependence in the Clausius-Clapeyron (C-C) relation, the strength of the hydrological cycle, the global mean precipitation and evaporation, is projected to increase more slowly. This difference has consequences for the atmospheric circulation (*2*), (*3*). Wentz *et al.* (*1*) interpret satellite measurements as indicating that the global hydrological cycle is, in fact, increasing at close to the C-C rate. We focus here on the estimation of global mean evaporation in (*1*) .

Using the standard bulk formulation, evaporation from the ocean surface E may be calculated as

$$E = C^* U q_s(T_s) \left[1 - r q_s(T_s - \delta T)/q_s(T_s)\right], \tag{1}$$

where T_s is the surface temperature, q_s is the saturation mixing ratio, δT is the temperature difference between the surface and the near-surface air, r is the near-surface atmospheric relative humidity, U is the effective surface wind speed and C^* is an effective transfer coefficient, which will be assumed constant for the sake of this discussion.

Wentz *et al.* (*1*) make an estimate of the temporal evolution of E under the approximation that the term in the square brackets in Eq. 1 does not change. In this case, small changes (Δ) in evaporation are given by

$$\frac{\Delta E}{E} = \frac{\Delta U}{U} + \frac{1}{q_s} \left.\frac{\partial q_s}{\partial T}\right|_{T_s} \Delta T_s \tag{2}$$

The second term on the rhs is determined by the C-C relation, which is globally associated with an increase of 5.7% per degree K of surface warming and in itself generates a 1.1% increase per decade over the 1987-2006 period (*1*). Average wind speeds U also increase over this period, enhancing the estimated increase in E to 1.3% per decade or 6.8% per degree of global surface warming (*1*).

Wentz *et al.* (*1*) hypothesize that the explanation for the slower rate of increase in global evaporation predicted by climate models for the future (around 2% per degree of global near-surface warming; (*3*)) lies in a deficiency in the estimation of surface wind speed, which they assume to be *decreasing* significantly in the climate models, instead of increasing as the satellite data indicates. However, this is not the case of the GFDL AM2 model forced with observed sea surface temperature (SST) for a similar period, as the modeled surface wind speed has a positive trend, although weaker than the SSM/I data used by (*1*), in part due to the underestimation of the peak in 1998-1999 (Figure 1). Furthermore, examination of the WCRP CMIP3 archive of global model projections for the future (*4*) shows that the sign of the projected trend in global mean surface wind speed is not a robust result among climate models, so wind speed decreases cannot consistently play the role of weakening the evaporation increase in climate models, as argued by (*1*) . The strength of vertical circulations does decrease robustly in these models, consistent with the trend in the strength of the hydrological cycle being weaker than the trend in water vapor (*5*). The relationship between this weakening and the surface wind speed changes is complex and requires further investigation, but there is no simple one-to-one relation between the two.

The difference between the changes in evaporation estimated by (*1*) and the model predictions lie in the term in the square brackets in Eq. 1. Assuming typical values of relative humidity, r, and air-sea temperature difference, δT, either an increase in r of 0.01 or a reduction in δT of 0.2 K would lead to a reduction in E of around 5%. The observational trends in these quantities are uncertain, as indicated by (*1*), but this high sensitivity suggests that we cannot assume that they are negligible. In fact, an estimate of global evaporation based on the monthly data from the GFDL model run with observed SSTs following (*1*), shows that assuming climatological values for r and δT enhances the trend in E by 45% and 25%, respectively.

Thus, the assumption that r and δT are constant, which results in evaporation changes following closely the C-C relation, cannot be made *a priori* and should be considered as a hypothesis about nature that requires observational validation. We do not address the estimated global mean precipitation trend in (*1*), but emphasize that enhanced confidence in this trend due to apparent consistency with independent estimates of the global mean evaporation trend is not warranted. Furthermore, we note that the confidence interval given by (*1*) for their trends is large and overlaps with the range in the trends from the GFDL prescribed-SST ensemble run, suggesting that the length of the SSM/I record might be too short for the validation of the long-term behaviour of climate models.

References and Notes

1. F. J. Wentz *et al.*, *Science* **317**, 233 (2007). Supporting online material at http://www.sciencemag.org/cgi/content/full/1140746/DC1

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4. World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model database, archived by the Program for Climate Model Diagnosis and Intercomparison (PCMDI) and supported by the Office of Science, U.S. Dept. of Energy.

5. G. A. Vecchi, B. J. Soden, In press in *J. Climate* (2007).

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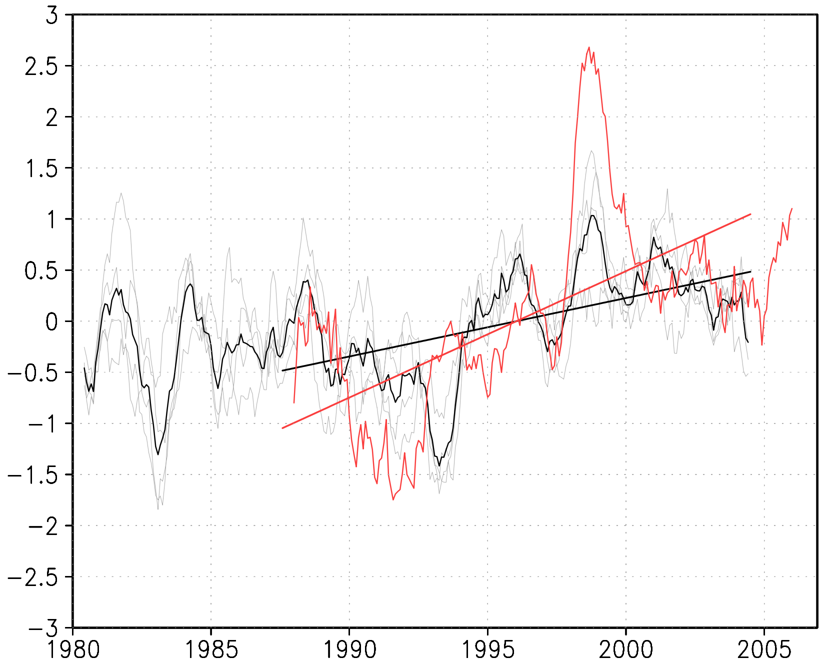

Figure 1: Global oceanic surface wind speed anomaly (%) with respect to the period August 1987-July 2004 from SSM/I data (Wentz et al., 2007; red; trend = 1.2%/decade) and from the four-member ensemble mean of the GFDL AM2 atmospheric model run with observed SST (black; trend=0.6%/decade; individual members in grey). The linear fits for August 1987-July 2004 are also included. 12-month running mean was applied to the data.