Balancing the Hydrologic Cycle on Decadal Time Scales

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How much more rain will global warming bring?
Wentz, Ricciardulli, Hilburn, Mears, *Science*, July 13, 2007;
Published online on *Science Express*, May 31, 2007.

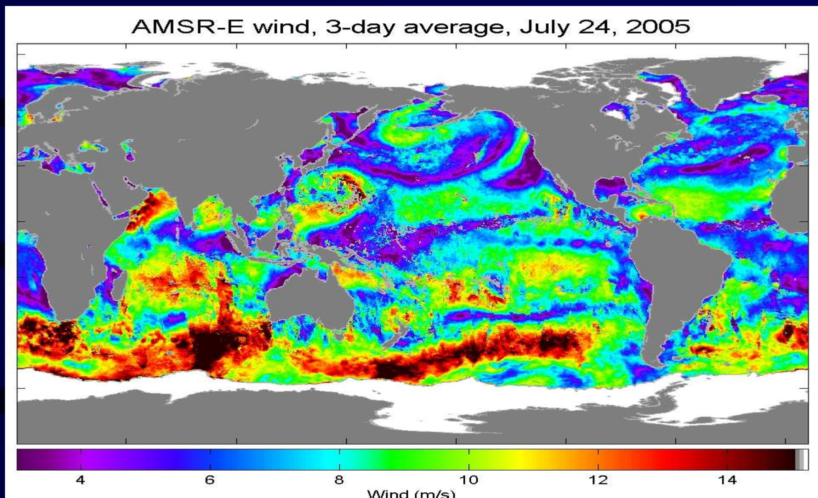
* This work was supported by NASA Earth Science Division

OVWST Meeting, Amsterdam, September 2007

What do MW radiometers tell us about changes to the global hydrologic cycle in the past 20 years?

- MW radiometers provide simultaneous observations of geophysical variables linked to the hydrologic cycle: Water (vapor and liquid), precipitation, surface wind.
- Using wind data we also evaluated evaporation.
- Data record from 6 different SSM/I, from 1987 to current.
- A long record is necessary but not sufficient for climate change detection: data has to be continuous and undergo extensive calibration and validation to allow detection of small signals.
- Remote Sensing Systems recently released a new version SSM/I V6 that has been CAREFULLY calibrated to remove intersatellite offsets and instrumental drifts and is suitable for climate studies (available at www.remss.com).
- Retrievals of precipitation (P), water vapor (WV), wind speed (U) and evaporation (E) rely on different methods and channels, therefore their uncertainties can be considered independent.

Wind Retrieval is Not Robust

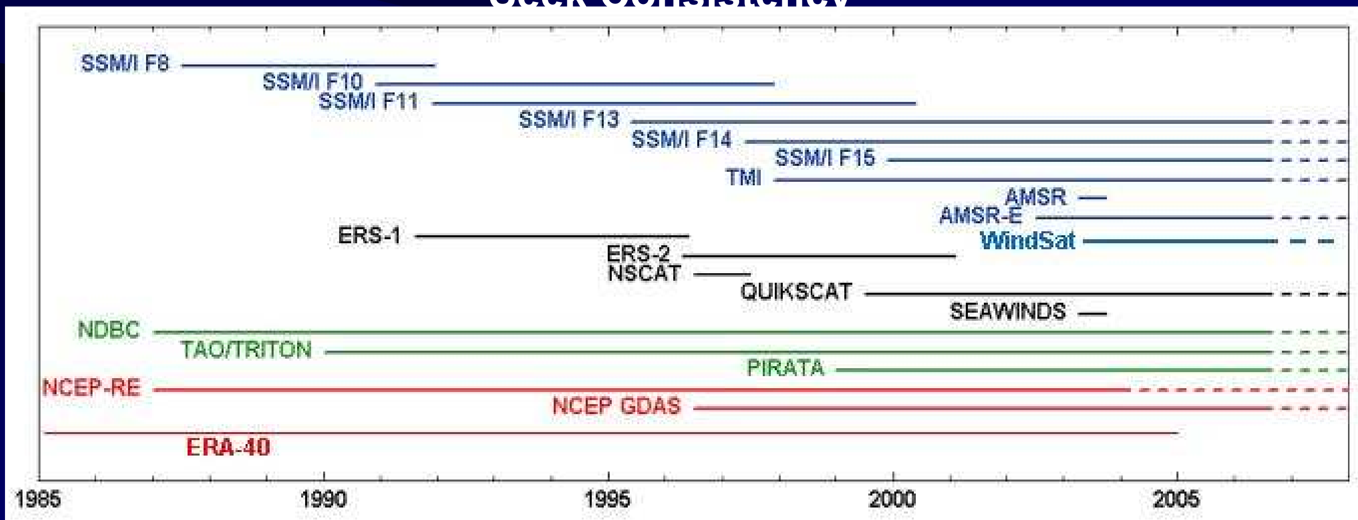


Objective: Trend error = 0.1 m/s/decade
Retrieval Algo: W = H – 2V
Required TB error = 0.05 K/decade
Required inc. ang. error = 0.02 deg/decade

Problems with Version 5 Winds:

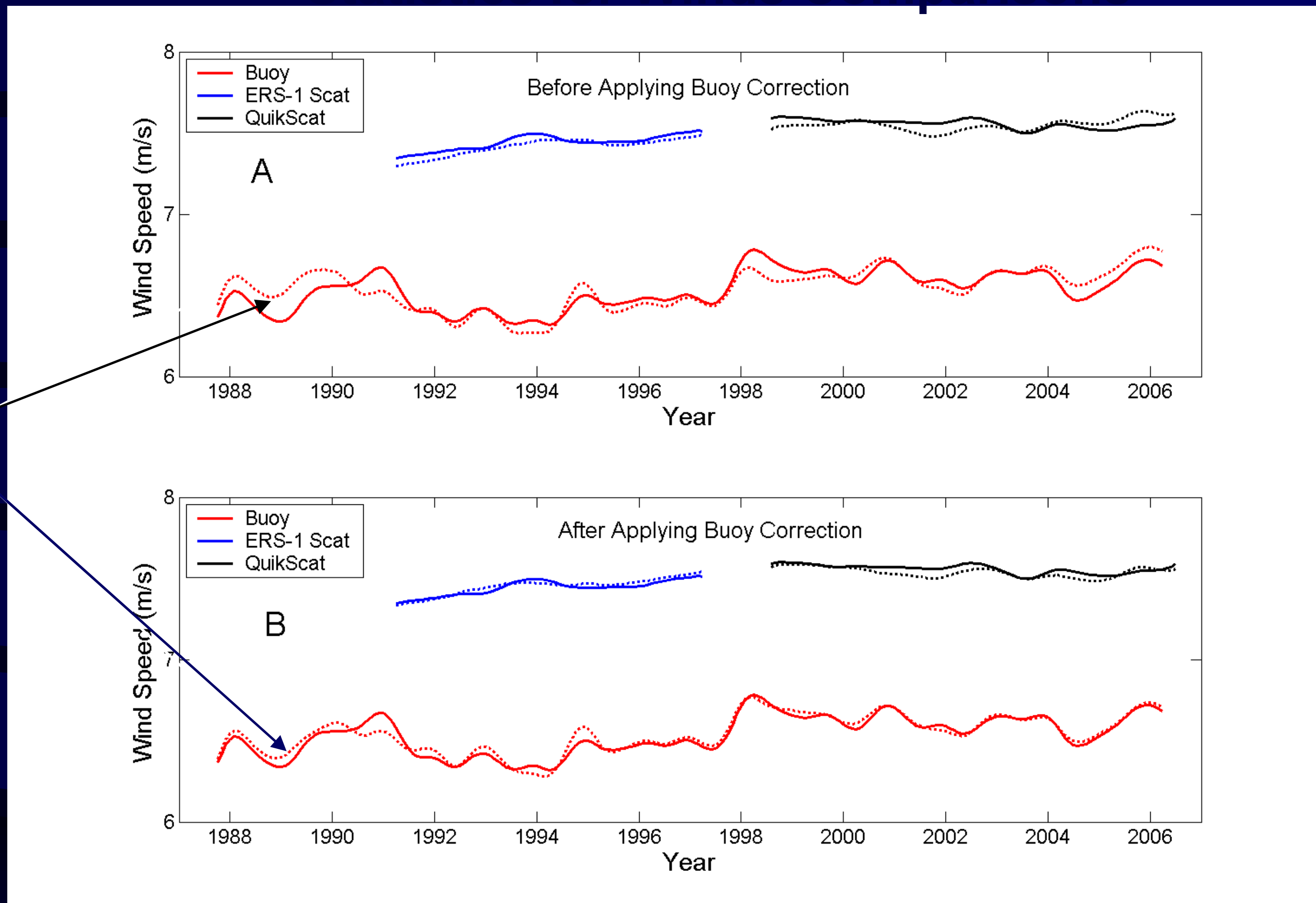
1. F10 did not agree with ERS-1 (0.3 m/s/decade)
1. SSMI trend did not agree with buoys (0.2 m/s/decade)
2. Radical change in F14 thermal environment

Seek Consistency



Statistics for Winds Comparisons

Dotted lines are SSM/I Winds



Individual overpasses: RMS variation of SSMI minus bouy difference = 1.0 m/s
Monthly Averages: RMS variation of SSMI minus bouy difference = 0.1 m/s (lag-1 correlation =0.46)
Estimate error bar is 0.05 m/s/decade at 95% confidence
SSM/I trend minus the buoy trend is 0.02 m/s/decade.

Yearly corrections (0.05-0.10 m/s) are applied to SSMI winds for climate studies.

WIND TREND MAP (1988-2005)

SSM/I

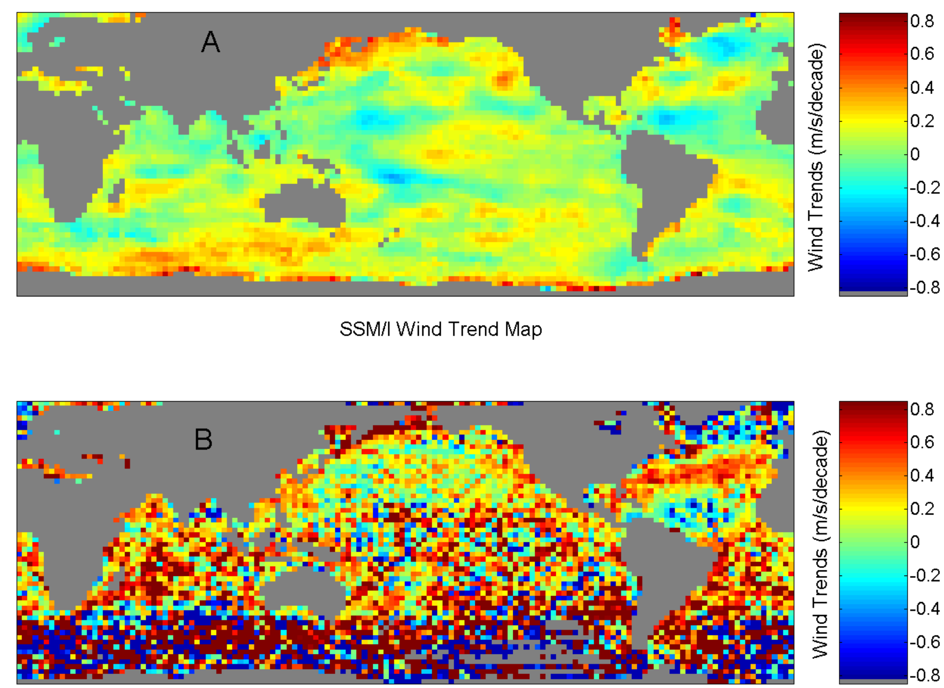
global trend over ocean

- 0.07 m/s/decade =1%/decade

ICOADS

global trend over ocean

- 0.25 m/s/decade =3.3%/decade



SSM/I Wind Trend Map

ICOADS Wind Trend Map

Wind is important for derivation of Evaporation. Because of the nature of ship observations, ICOADS is not good enough to calculate evaporation for climate studies.

GLOBAL WATER BUDGET

- MW retrievals are ocean-only. However, we want to focus on GLOBAL water cycle because it is regulated by basic physical principles, on which climate models are based.

- 20 years of data is probably not enough to detect local changes as they are more influenced by interannual and decadal variability.

LOCAL WATER BUDGET

Small storage term

Moisture flux

$$\frac{\partial q}{\partial t} + \nabla \cdot (\rho v q) = E - P$$

GLOBAL WATER BUDGET, TIME AVERAGE

$$P = E$$

Evaporation and precipitation balance on global scale

How did we calculate global E and P maps, having only MW retrievals over ocean?

1. Precipitation: we use GPCP precipitation (Adler et al, 2003), over land and ice

2. Ocean Evaporation: EVAPORATION BULK FORMULA (from Large and Pond 1981, CAM3 (CCSM))

$$\mathbf{E} = \rho_A \cdot C_E(T_{Air}) \cdot \mathbf{U} \cdot [q_{Sat}(T_{surface}) - RH \cdot q_{Sat}(T_{Air})]$$

   we use SSMI wind, ICOADS RH, Reynolds SSTs, and marine nighttime air temperatures from the Hadley center (MOHMAT43). For (T_{Air}-SST) and RH we use maps of monthly climatology.

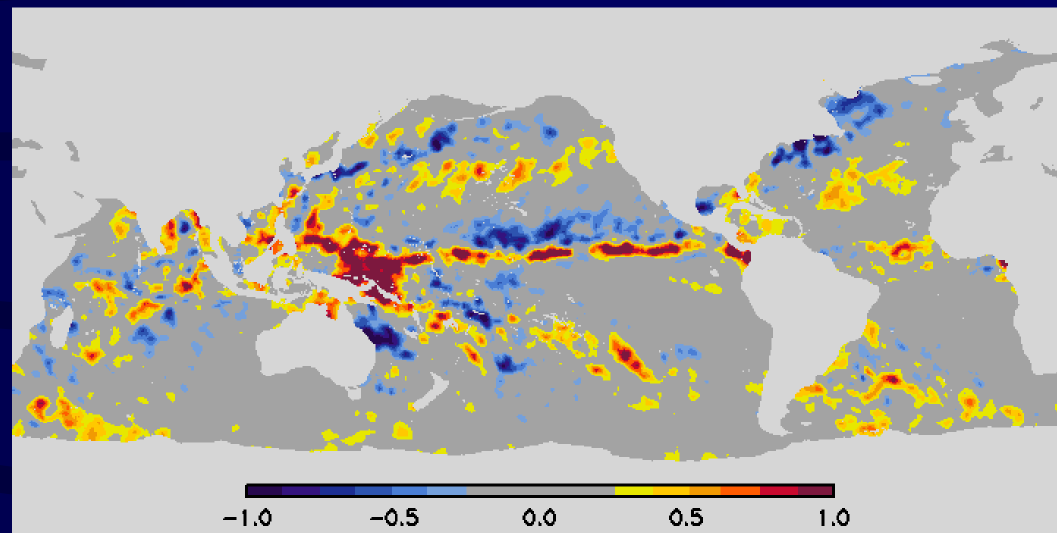
3 Land and Ice Evaporation: constant values from literature (rather uncertain, however land/ice evaporation contributes on 14% to global average, and its observed trends are very uncertain)

PRECIPITATION TREND MAP (1988-2005)

SSM/I

global trend over ocean

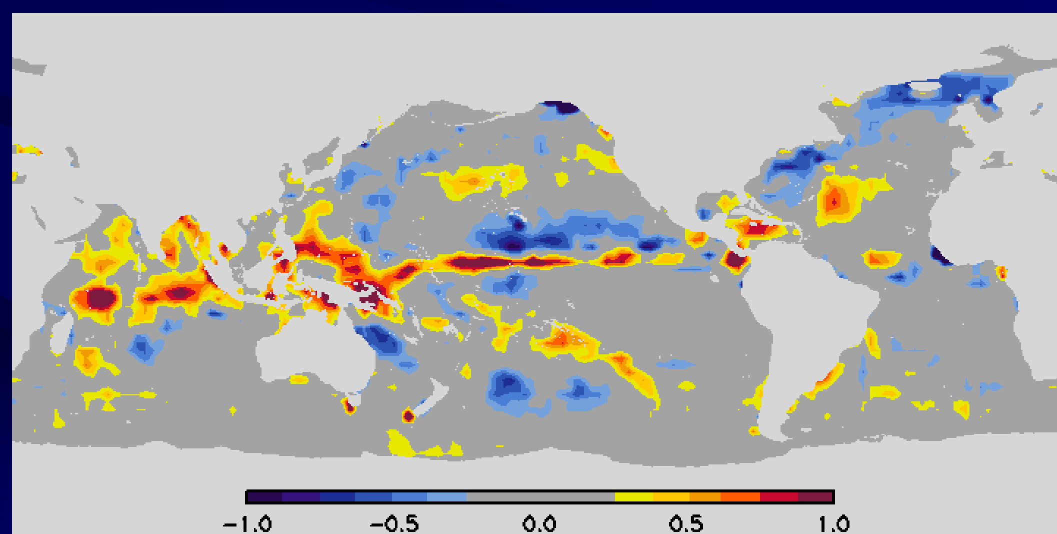
≈ 1.8 %/decade



GPCP

global trend over ocean

≈ 1.5 %/decade



(mm/day/decade)

From Hilburn and Wentz, 2007, J. Appl. Meteor. Clim., in press

HOW DOES GLOBAL WARMING AFFECT THE WATER CYCLE?

WATER VAPOR

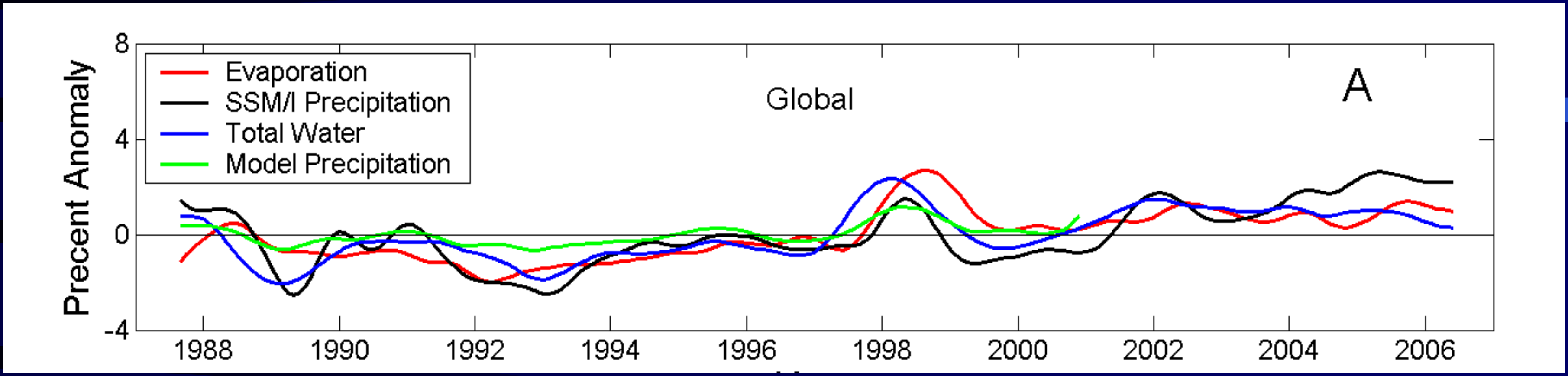
- q_{SAT} increases according to Clausius Clapeyron (C-C), by approximately 7% per degree of warming .
- q_{SAT} increases but surface RH stays approximately constant, therefore WV also increases as C-C.
- Satellite retrievals and climate models agree on this aspect (Wentz and Schabel, 2000; Trenberth et al, 2005; Soden et al, 2005)

PRECIPITATION AND EVAPORATION

- In the climate models, P and E are regulated by availability of energy, not moisture. Their changes are regulated by tropo-spheric energy budget (i.e., radiative cooling; Boer, 1993; Allen and Ingram, 2002). In theory, they are not constrained by C-C.

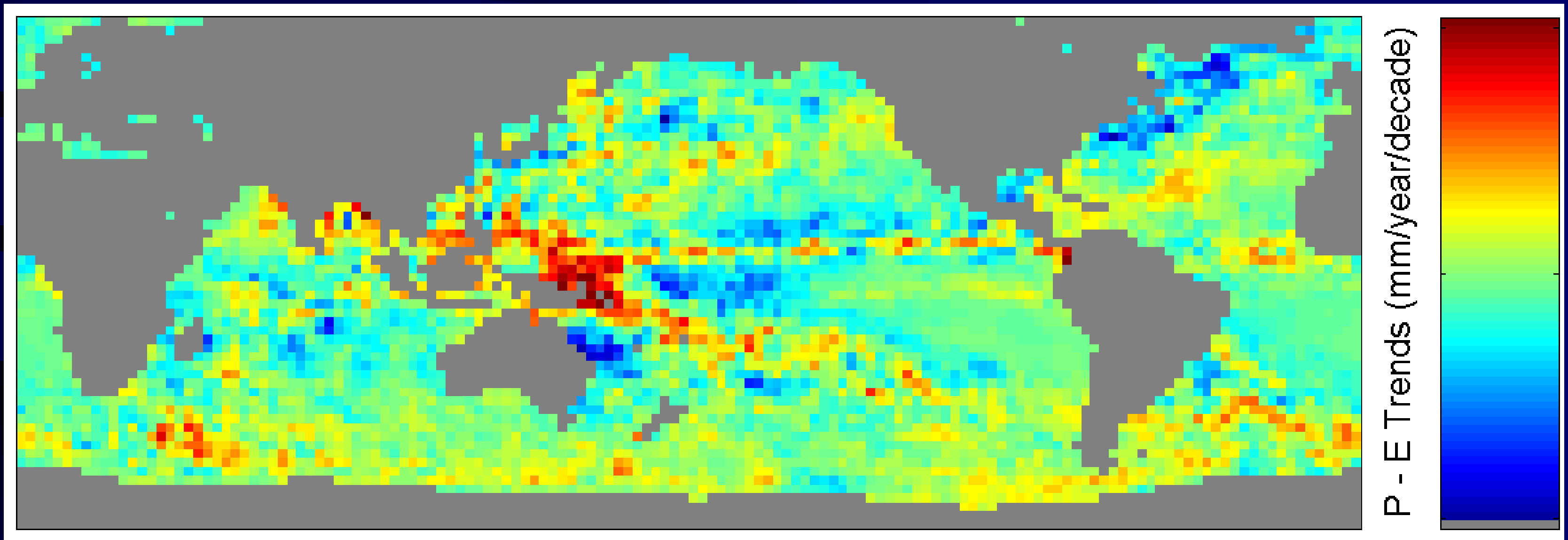
- Do models and observations agree?

1987-2006 SATELLITE OBSERVATIONS OF WATER CYCLE



	Mean	Trend (retrievals uncertainty ~0.5%/dec)	Scaling factor
EVAPORATION	961 mm/yr	1.3 %/decade	6.5 %/C
SSMI PRECIPITATION	950 mm/yr	1.4 %/decade	6.9 %/C
SSMI TOTAL WATER (over ocean only)	28.5 mm	1.2 %/decade	6.2 %/C
MODEL PRECIPITATION (AMIP, 9 models)	1048 mm/yr	0.4 %/decade	2 %/C

P-E TREND (from MW satellites)



SOME CONSIDERATIONS…

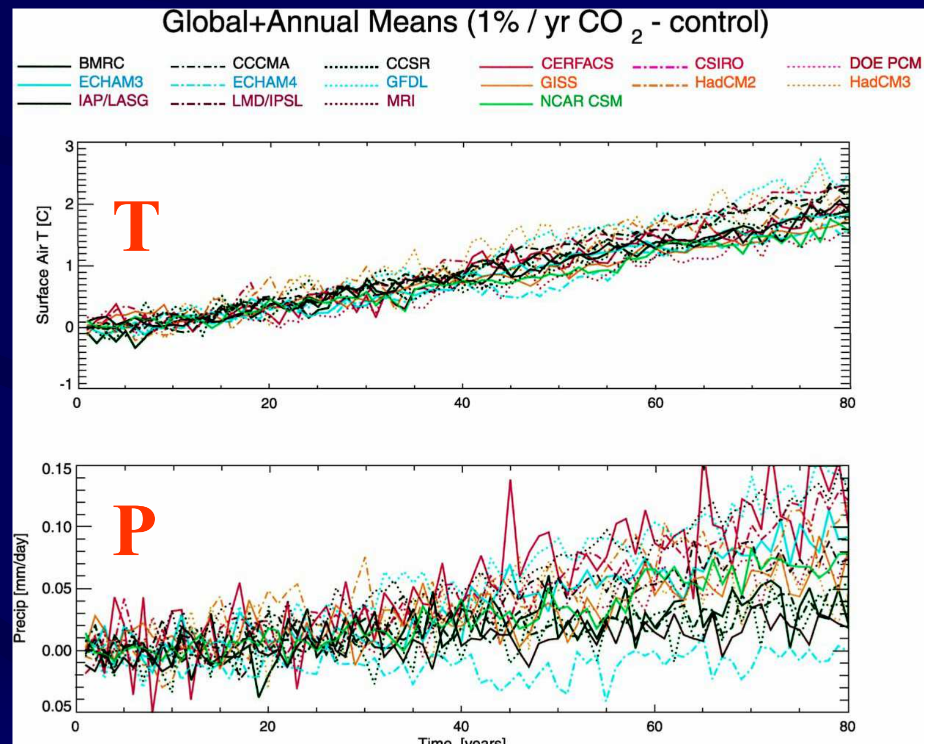
•20 years of satellite data are all we have. It might not be long enough to detect "trends". But the derived scaling relationship (percent change per degree warming) should be valid.

•Retrieved E and P have uncertainties, but they offer two independent estimates of changes to the hydrologic cycle. At global scale, they both increased at the same C-C rate of ~ 7%/C.

•Are RH or (Ta-Ts) changing?

•Models' response of hydrologic cycle to global warming varies according to the model (different treatment of convection, clouds and feedbacks). But they ALL show a remarkable similarity in predicting a muted response of P and E (1-3%/C) compared to WV. How can they all be wrong?

•Compared to P observations, climate models seem to significantly underpredict interannual variability and ENSO events (Soden, 2000, Wentz et al, 2007).



From Covey et al,2003; and Meehl et al, 2005

New Result

- X. Zhang *et al, Nature,* **448**, 461 (2007) *Detection of human influence on 20th century precipitation trends*.
- Last 75 years of Global Historical Climatology Network compared to climate models
- Model P trends a factor of 3 lower than observations

SUMMARY AND IMPLICATIONS FOR FUTURE RESEARCH

•Satellite retrievals show WV, E and P all increasing at the C-C rate for the past 20 years (about 7%/C)

•Climate models (AMIP or CMIP 21th century projections) predict a WV increase following C-C, but a reduced increase of P and E (Allen and Ingram, 2002; Meehl et al, 2005)

•Climate models seem to explain this P and E muted response to global warming with a reduced atmospheric circulation and an increase in WV residence time in the atmosphere (Held and Soden, 2006; Vecchi et al., 2006, Bosilovich et al., 2005)

•Our MW data do not show any evidence of slowing circulation: for the past 20 years ocean surface winds had a small positive trend (1%/decade).

•For a global warming of 3C by the end of the century, our results would implicate a 20% increase in rain versus a 6% increase predicted by the models.

•This significant discrepancy between satellite data and models needs to be resolved if we want to have confidence in model predictions (at the global and regional level)