Variability and trends in tropospheric water vapor

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Special thanks to Kevin Trenberth

Aspects of the Water Cycle:

1. Water vapor
2. Cloud
3. Precipitation: amount, intensity, frequency, duration,type
4. Temperature-Precipitation relations
5. Evaporation
6. Runoff
7. E-P
8. Drought (PDSI)
9. Soil moisture
10. Streamflow, river discharge
11. Atmospheric moisture budget
12. Ocean fresh water budget
13. Total hydrological cycle

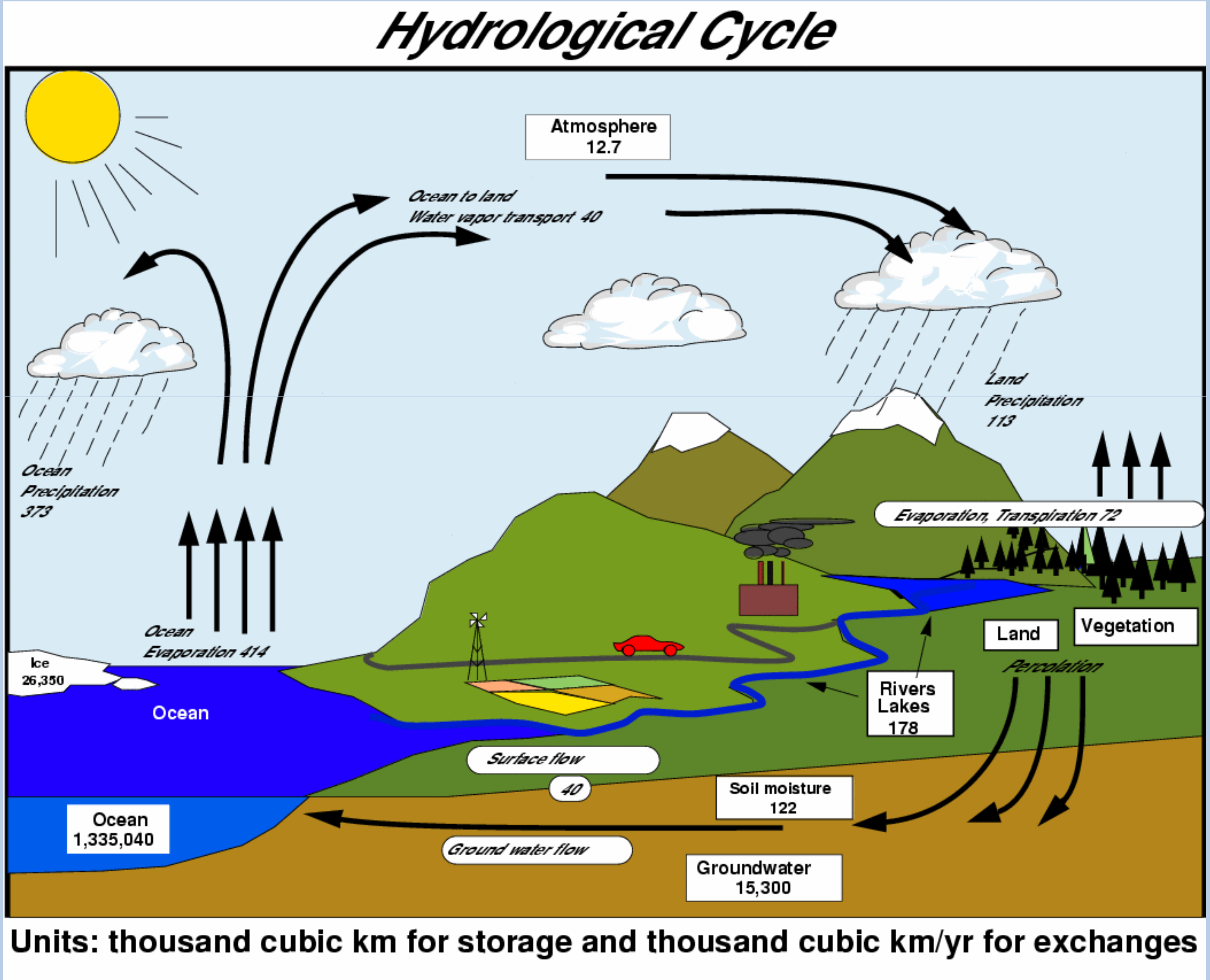
Hydrological cycle:

1. Mean
2. Annual cycle
3. Trends

Can we quantify components for each month of the year?

For each region?

Can we construct reliable time series?



Water vapor:

- Dominant feedback in climate system
- Most important greenhouse gas
- Provides main source of moisture for precipitation:

As global warming progresses, water vapor increases (faster than evaporation), it potentially leads to increases in intensity of precipitation and decreases in frequency.

More floods and droughts?

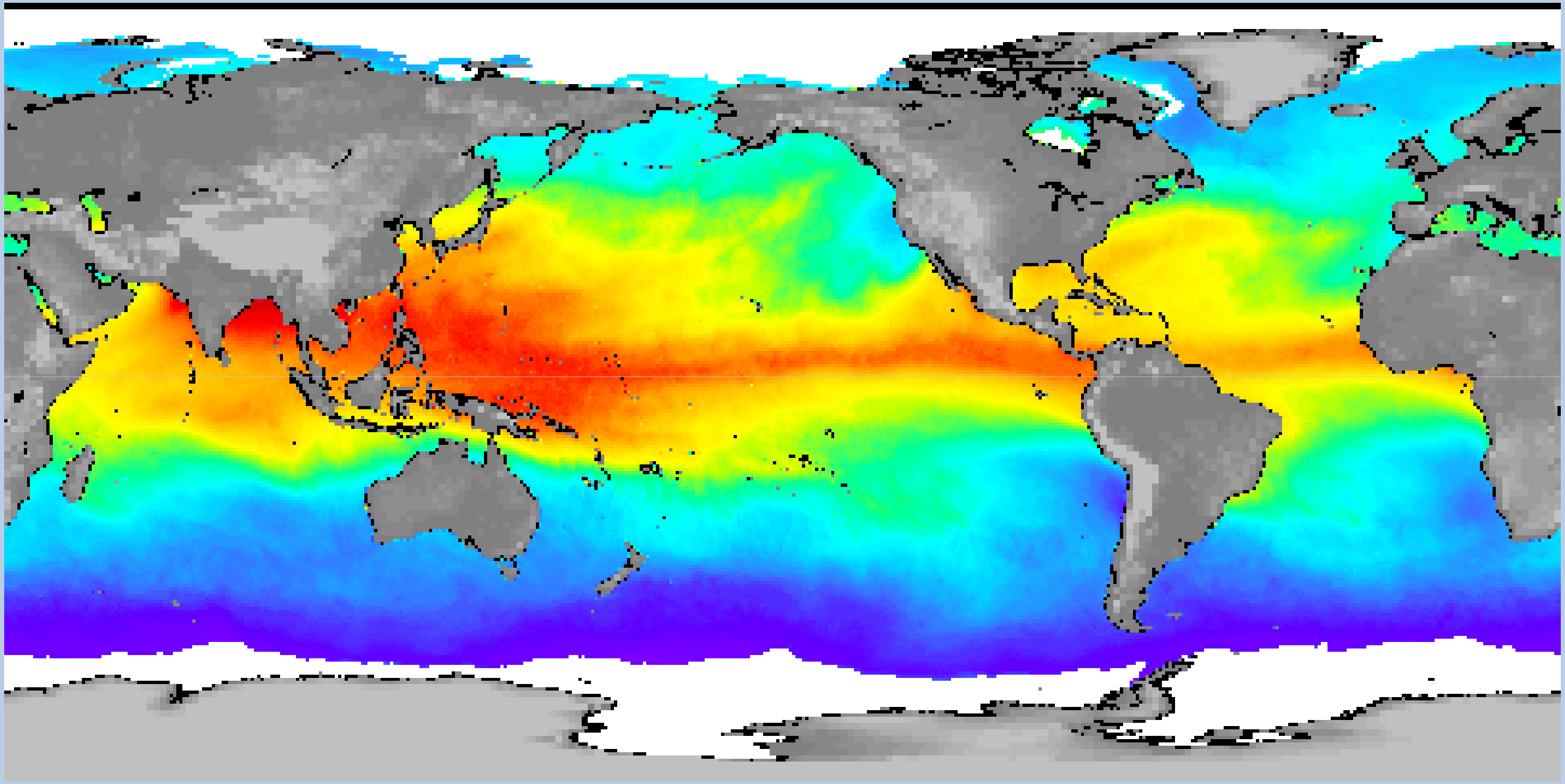
Trends and variability in column-integrated water vapor

Trenberth, K. E., J. Fasullo, and L. Smith, 2005: *Clim. Dyn.*
DOI 10.1007/s00382-005-0017-4.

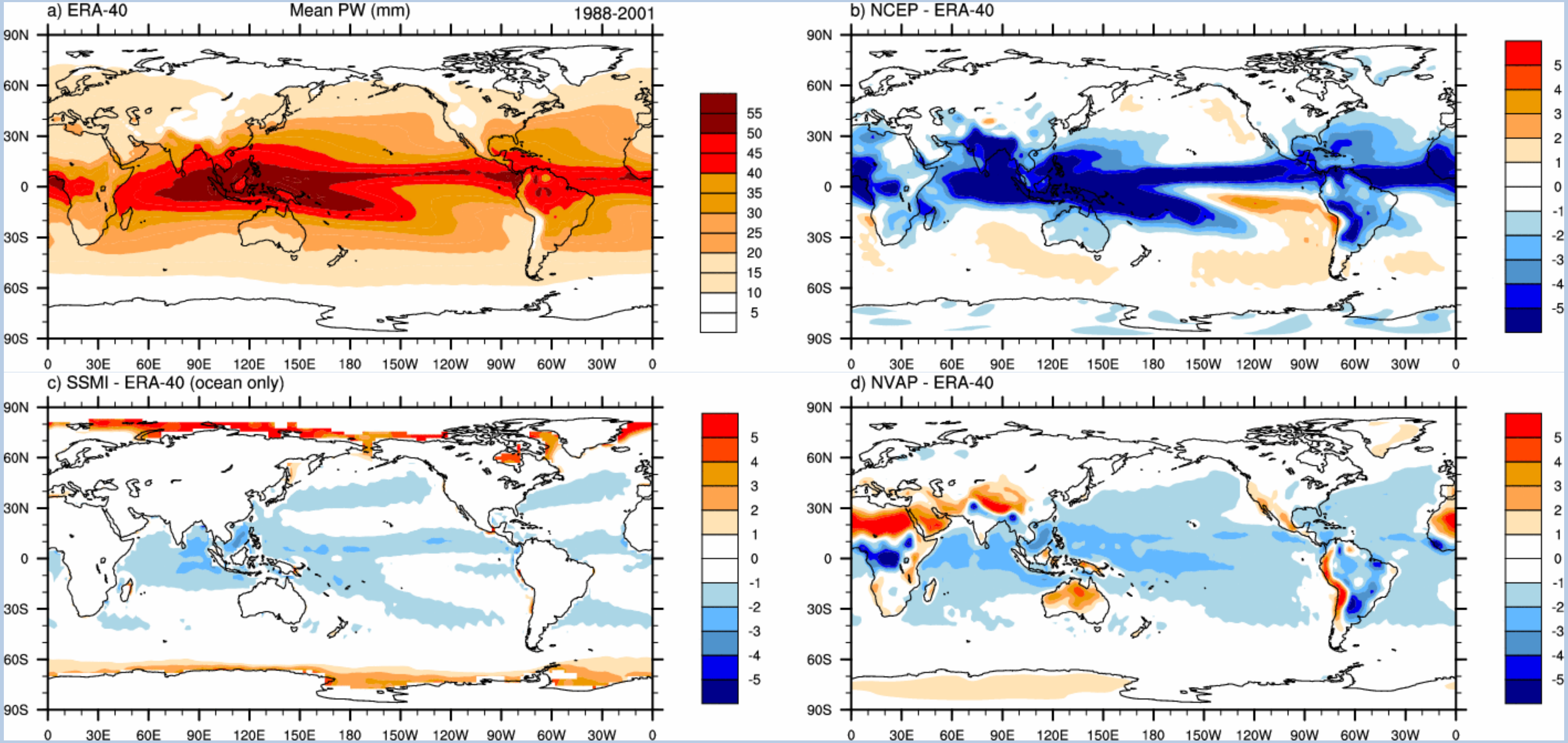
Global data sets:

- **NVAP**
- **NCEP reanalyses**
- **ERA-40**
- **SSM/I v5 (RSS)**
- **radiosondes**

SSM/I water vapor Sept. 7-14, 2009

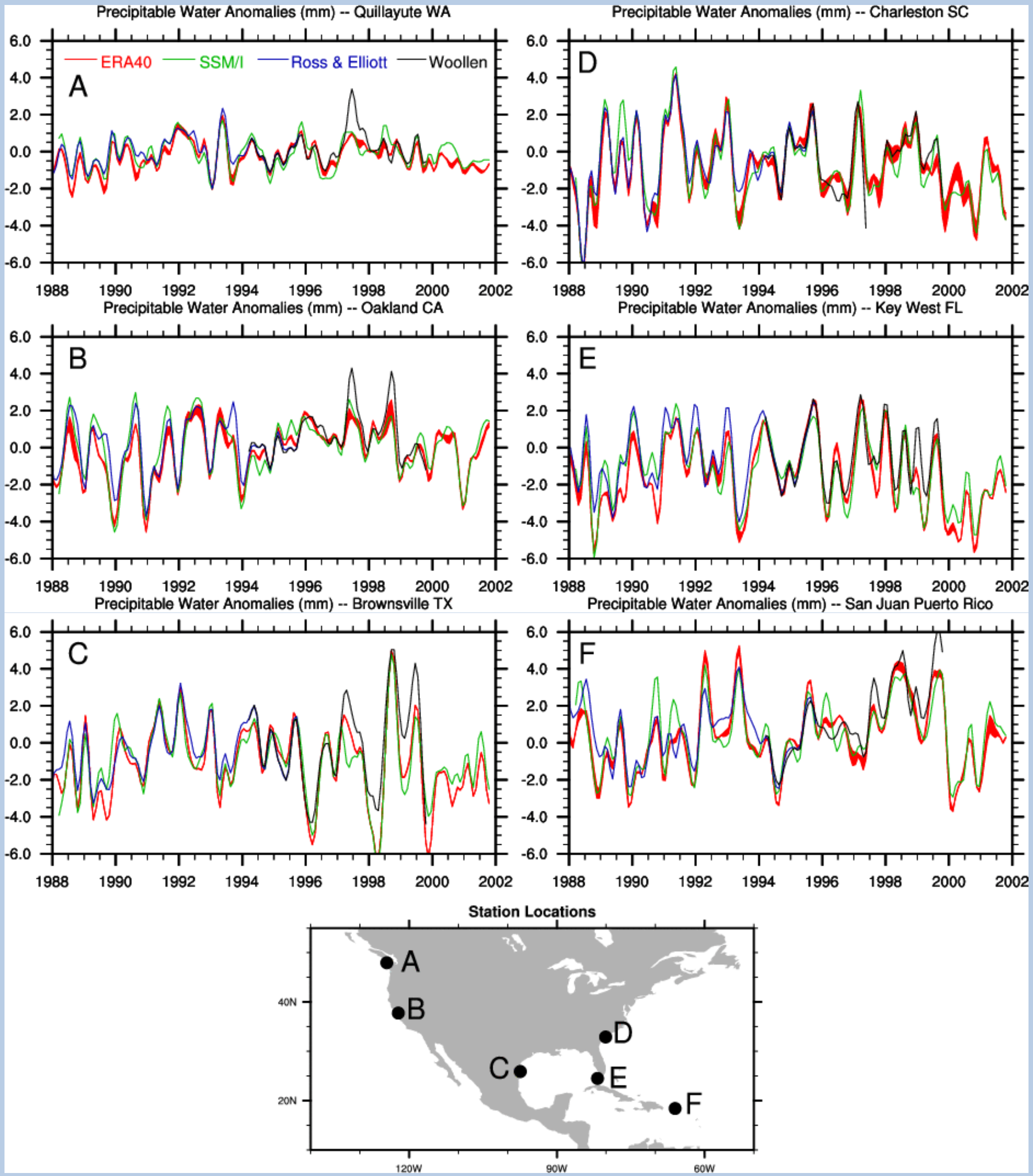


ERA-40 Mean and Differences



Time series of monthly data:

1. Sonde data
2. RSS SSM/I at the nearest grid point,
3. ERA-40 at both

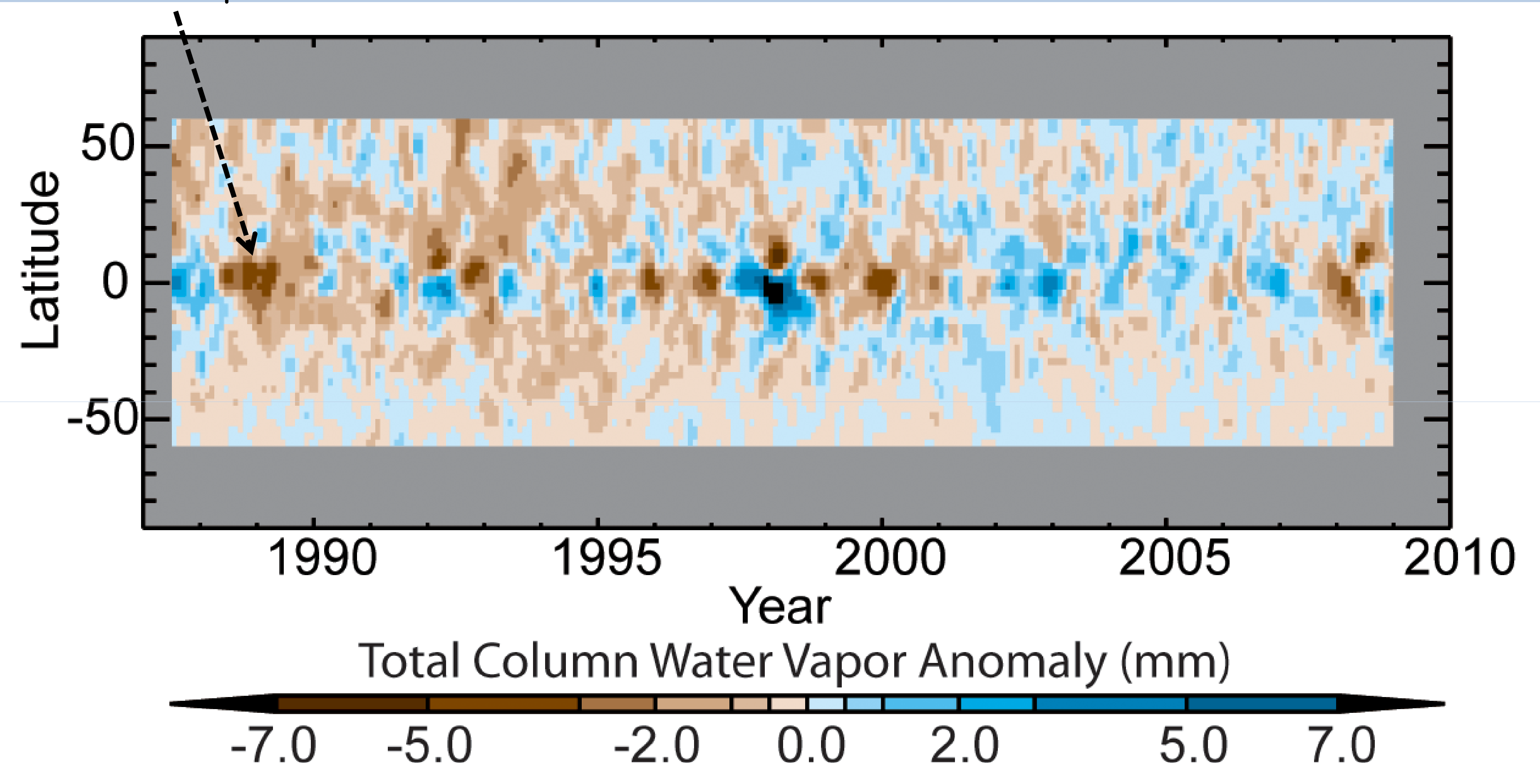


- Both **NCEP** reanalyses are deficient over ocean: the mean, the variability and trends, and the structures of variability are not very realistic. Stems from the lack of assimilation of water vapor information from satellites into the analyses and the model biases.
- The **NVAP** dataset suffers from major changes in processing at the beginning of 1993 and 2000 that upsets analysis of trends and variability. Major problems in mountain areas and also regions over land where radiosonde data are not prevalent.
- The **ERA-40** dataset appears to be quite reliable over land and where radiosondes exist, but suffers from substantial problems over the oceans; values too high for two years following the Mount Pinatubo eruption in 1991 and again in 1995-96. The trends are generally not very reliable.
- The **RSS SSM/I** dataset is realistic in terms of means, variability and trends over the oceans, although questions remain at high latitudes in areas frequented by sea ice.

- **It is recommended that RSS should be used for analyses of precipitable water.**

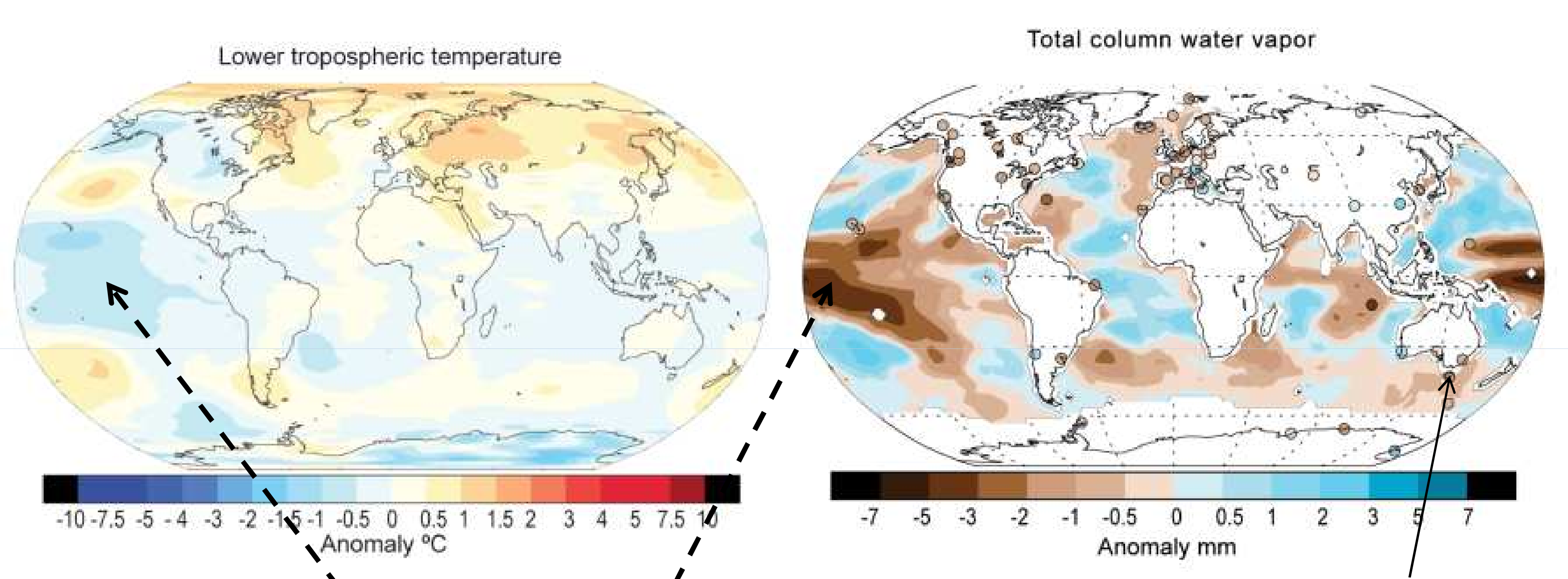
SSM/I water vapor anomalies

largest variations
in the tropics



Moisture increases over time

2008 SSM/I water vapor anomalies

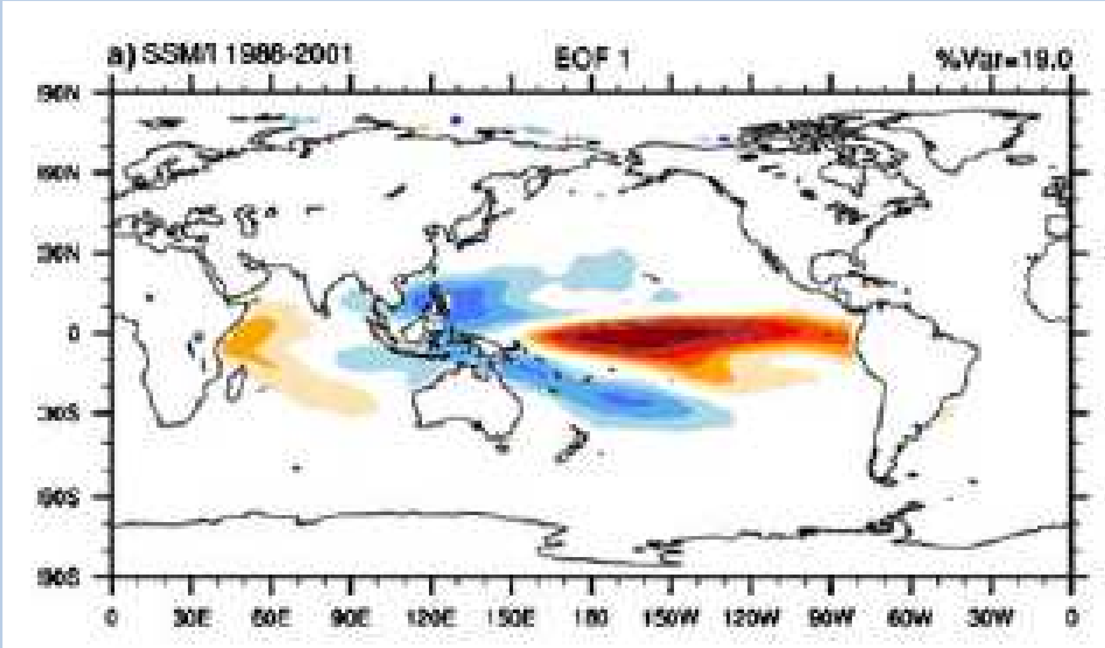


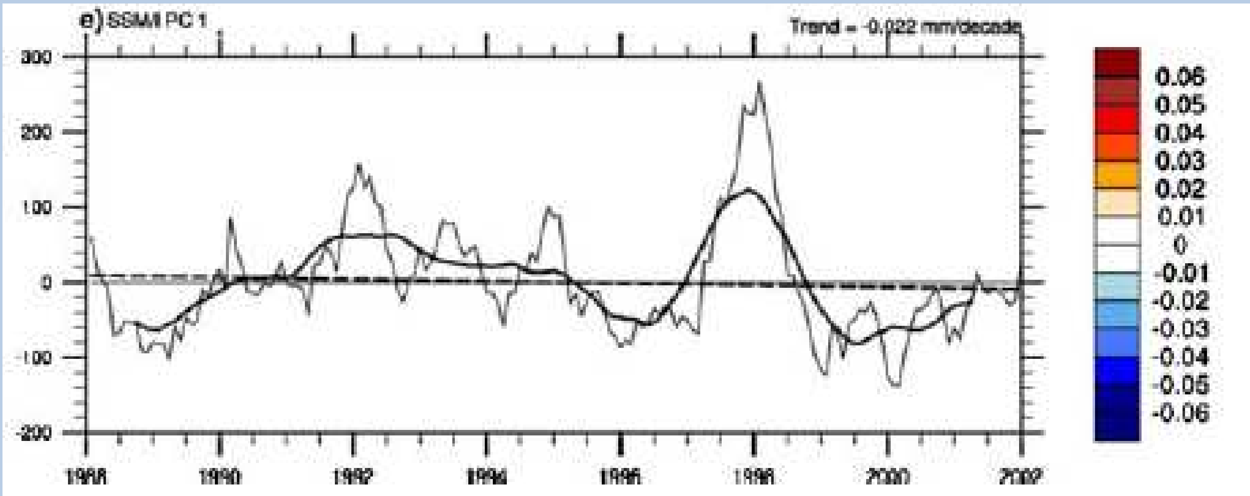
Cool and dry conditions associated with 2008 La Nina

GPS measurements

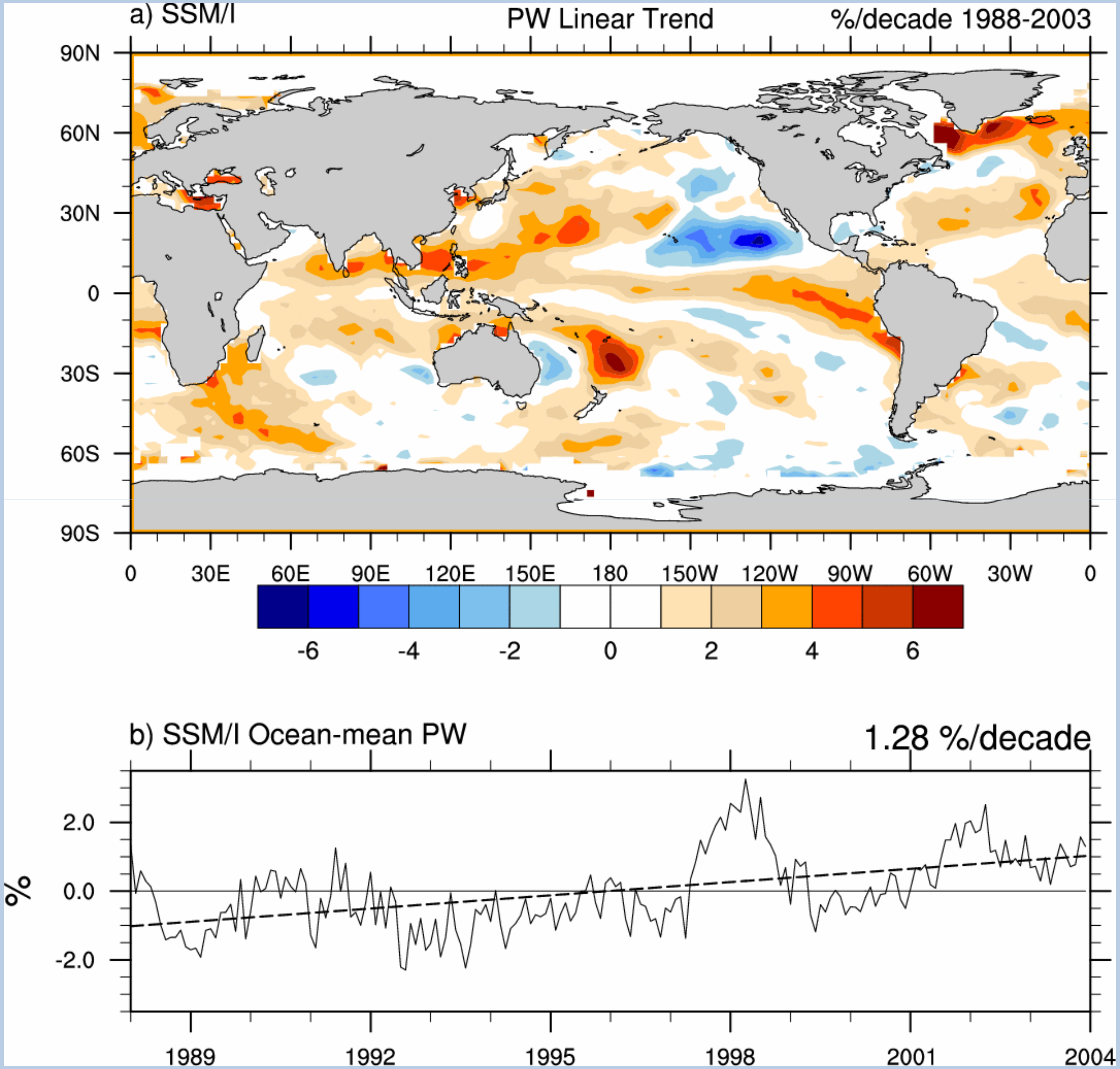
ENSO variations in water vapor

(follows SST's)





SSM/I water vapor trends 1988-2003

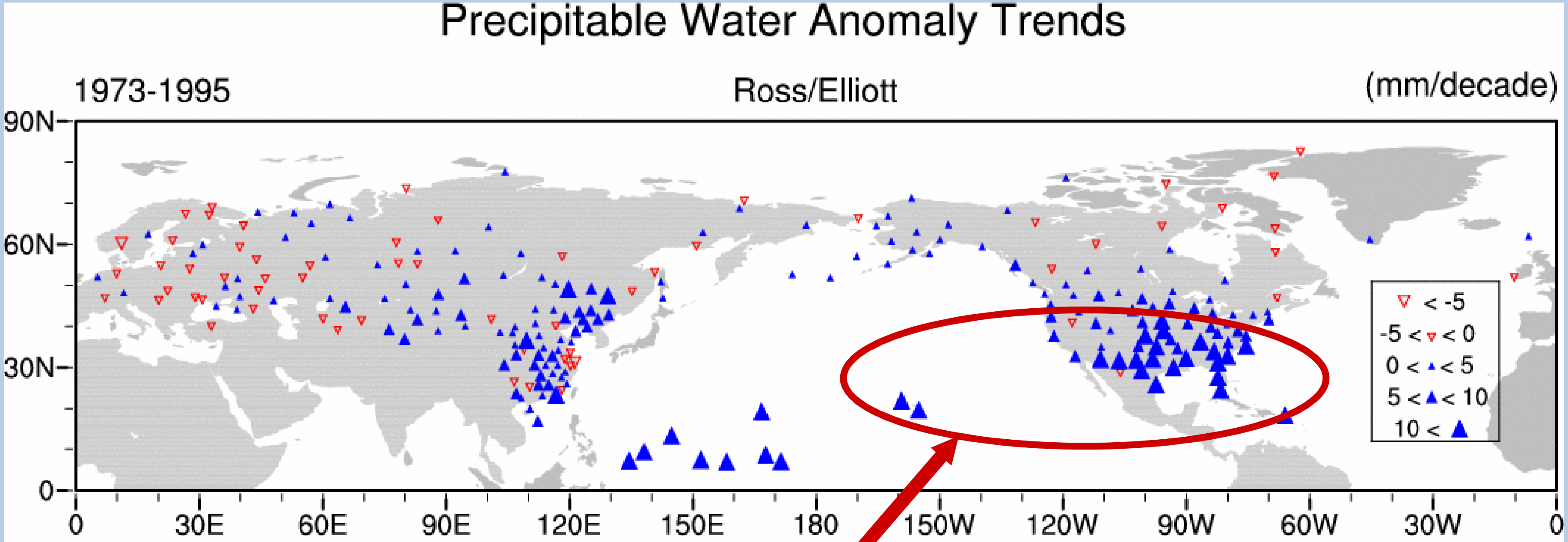


Best estimate of linear trends

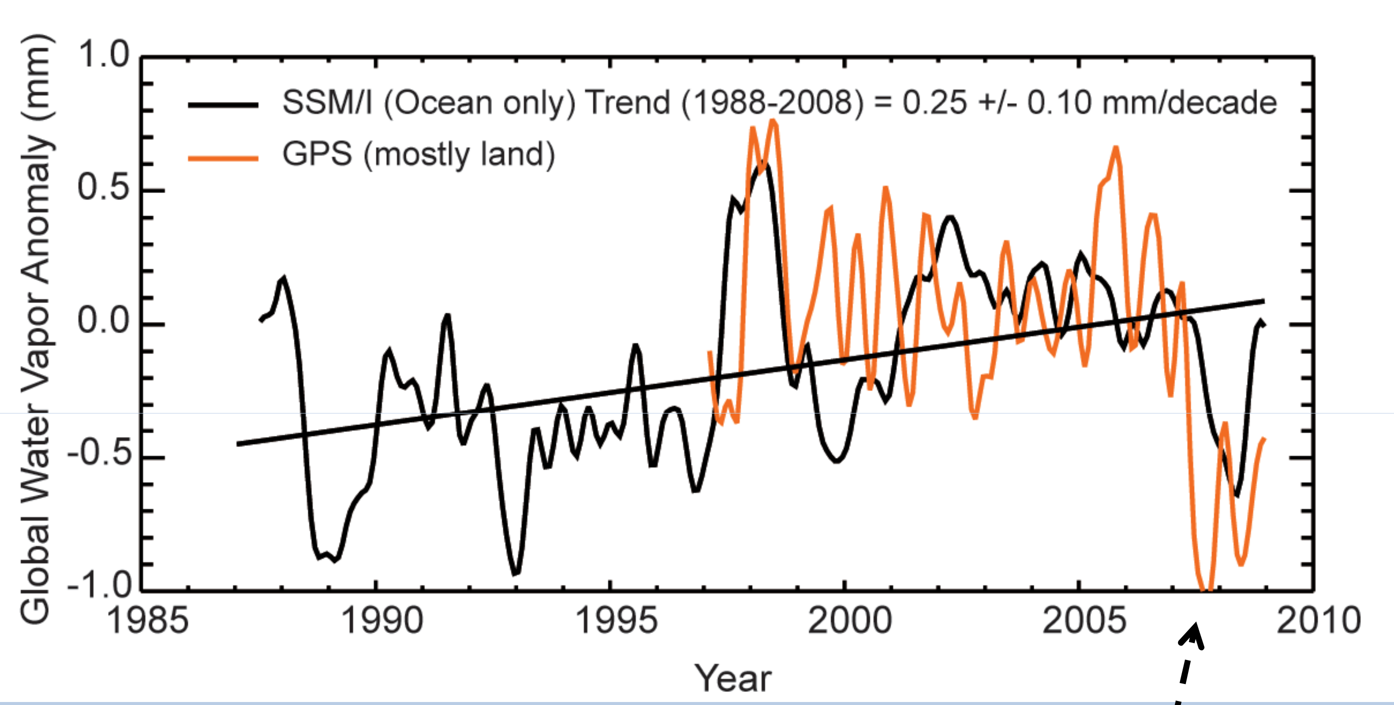
1.3±0.3% Per decade

95% C.L. includes sampling and merging satellites

Radiosonde water vapor trends



Trends up 8 to 15% over 23 years 1973-1995 updates to 2008



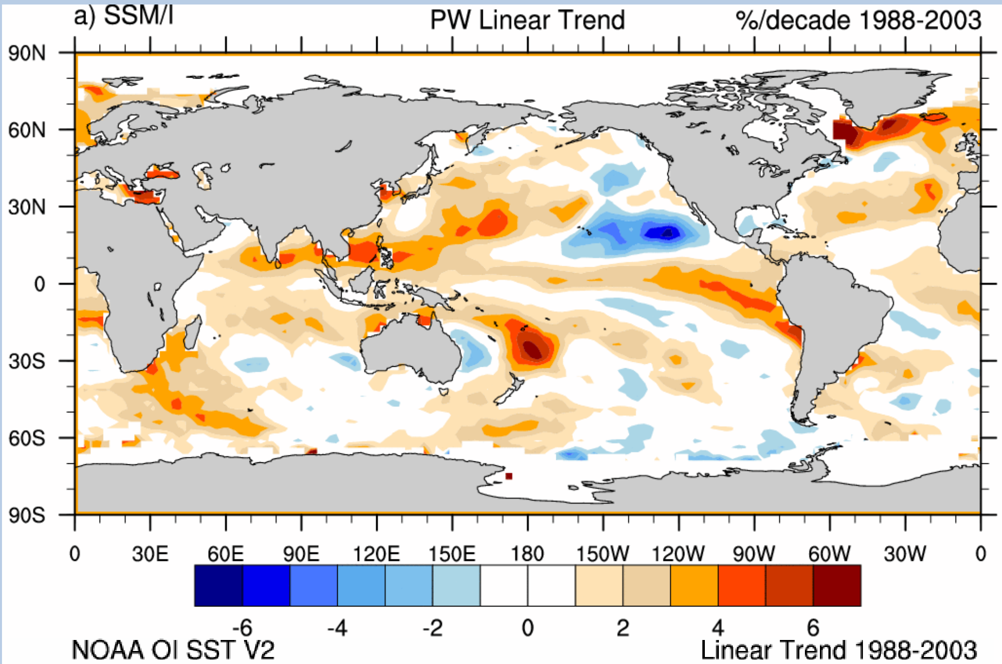
Dry anomalies from La Nina

Water Holding Capacity

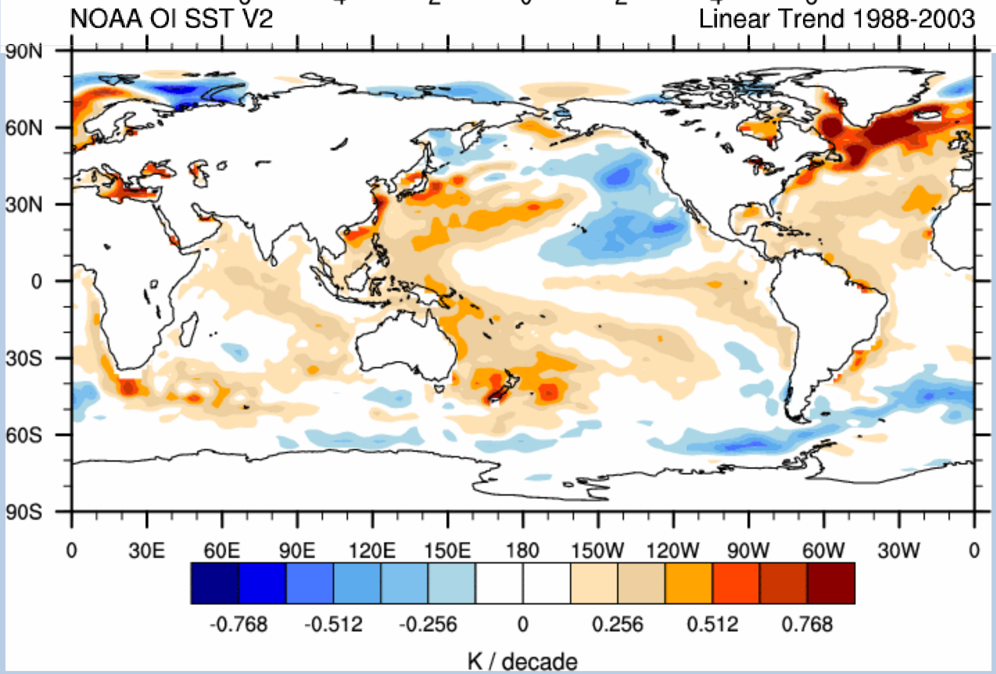
A basic physical law (the Clausius-Clapeyron equation) tells us that the water holding capacity of the atmosphere goes up at about 7% per degree Celsius increase in temperature.

How does this agree with observations?

Water vapor



SST's



Linear trends
SST – water vapor

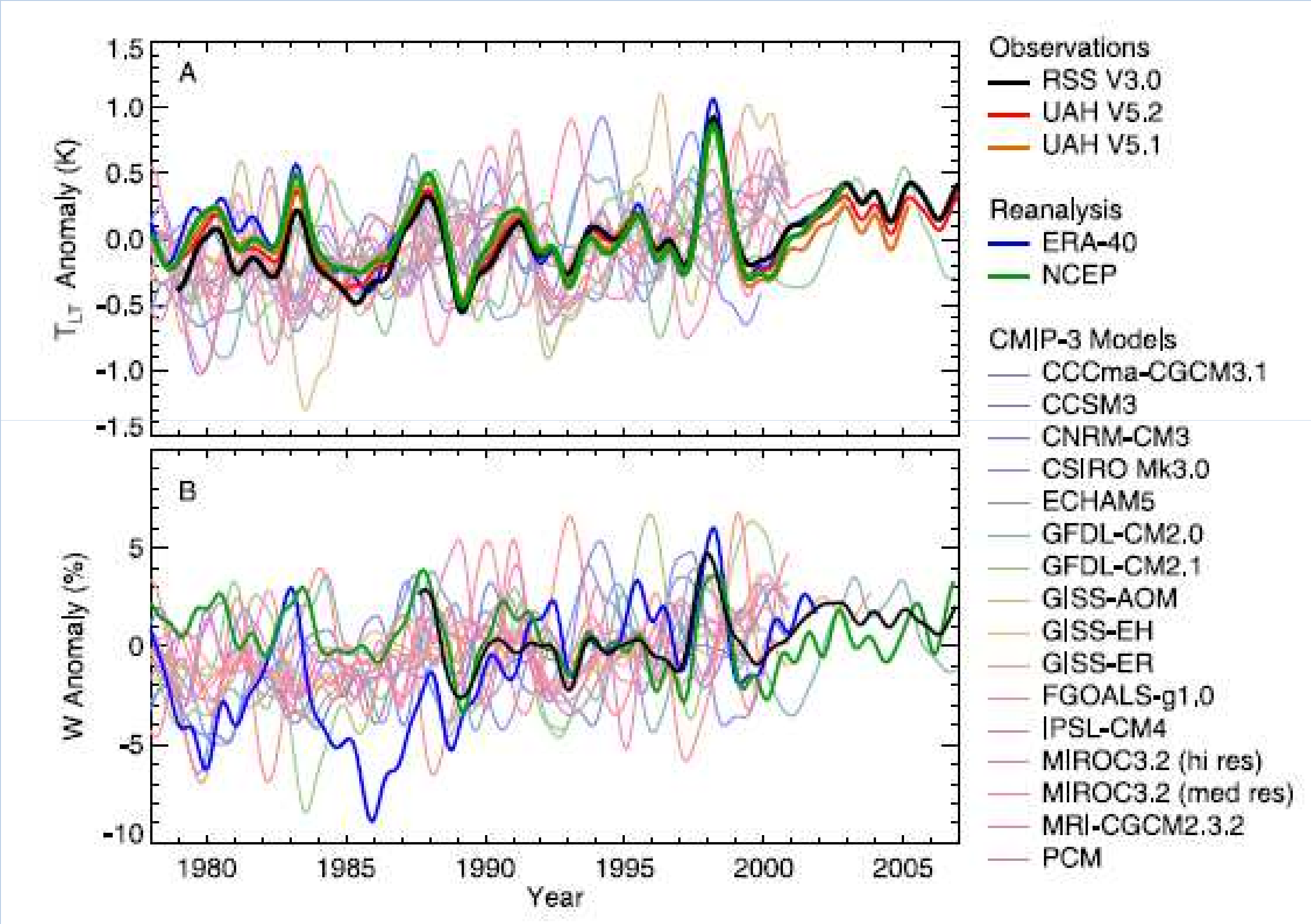
Temporal correlation (ocean 30N-30S) 0.84

Pattern correlation 0.65

Regression:
7.8%/K SST

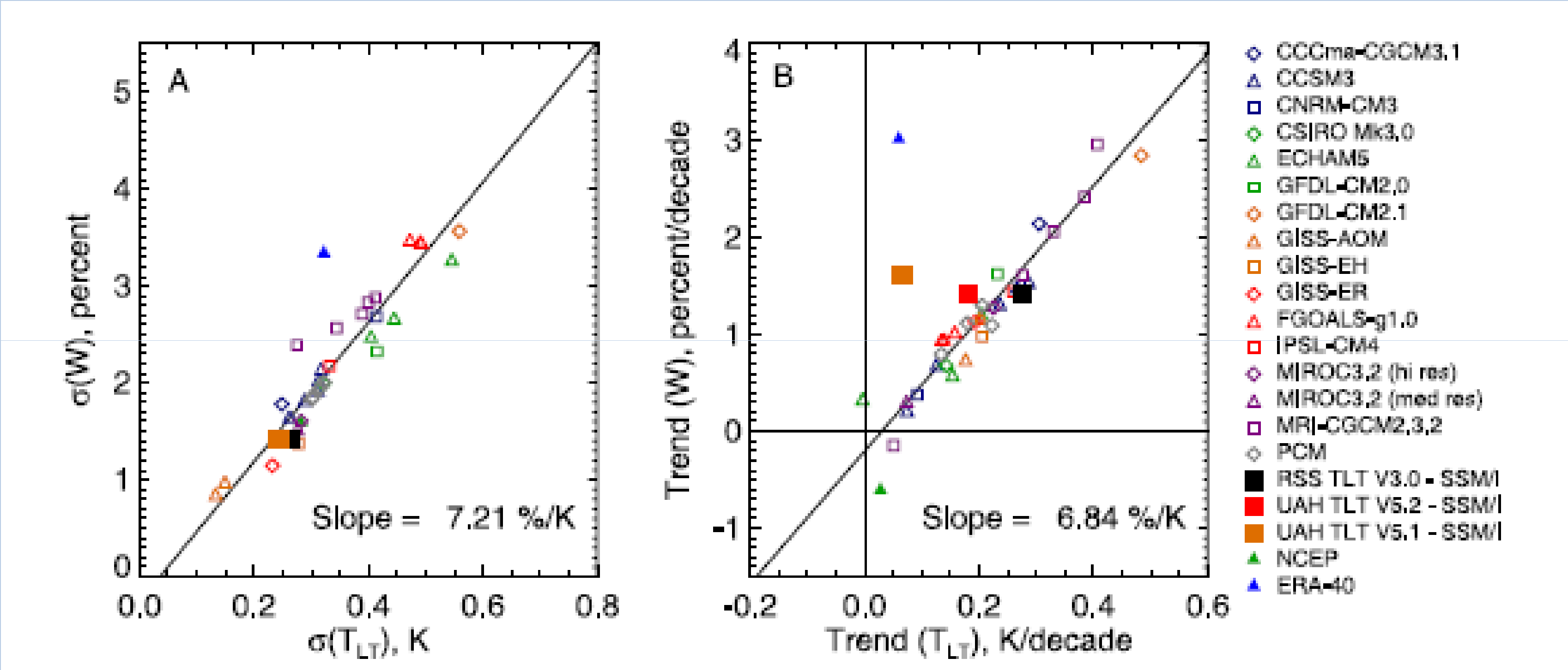
Implies ~5% increase in water vapor over 20th C.

Water vapor – temperature relationships in observations and models



Mears et al, GRL, 2007

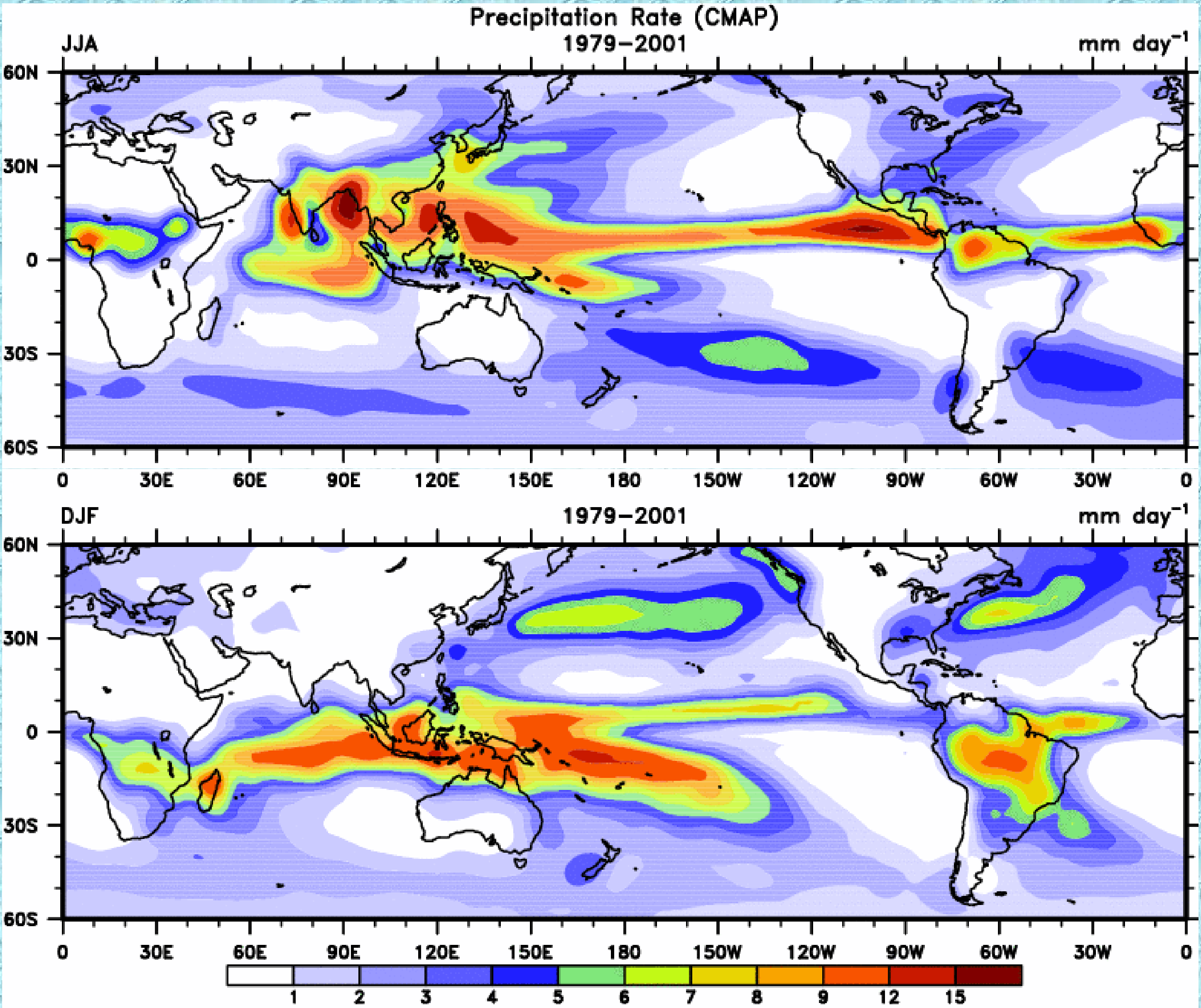
Variability Trends



Mears et al, GRL, 2007

- global water vapor variability is dominated by tropics (where SST's are warmest)
- ENSO is largest component of variability
- Observed increasing trends of ~1.3% / decade
- Strong space-time coherence with SST's; excellent quantitative agreement with Clausius-Clapeyron

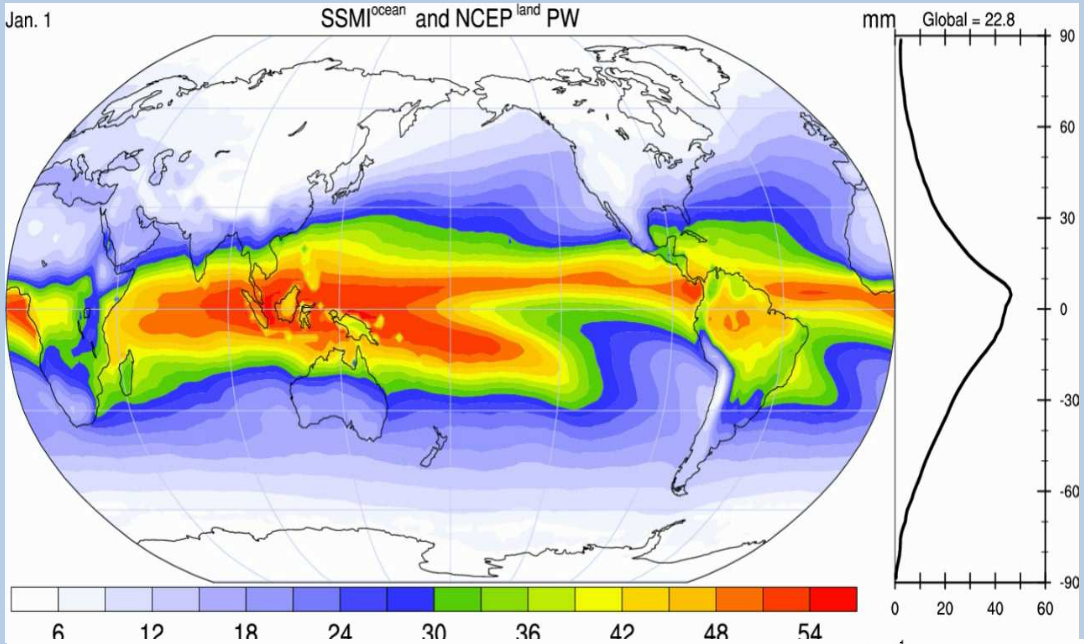
Climatology of precipitation



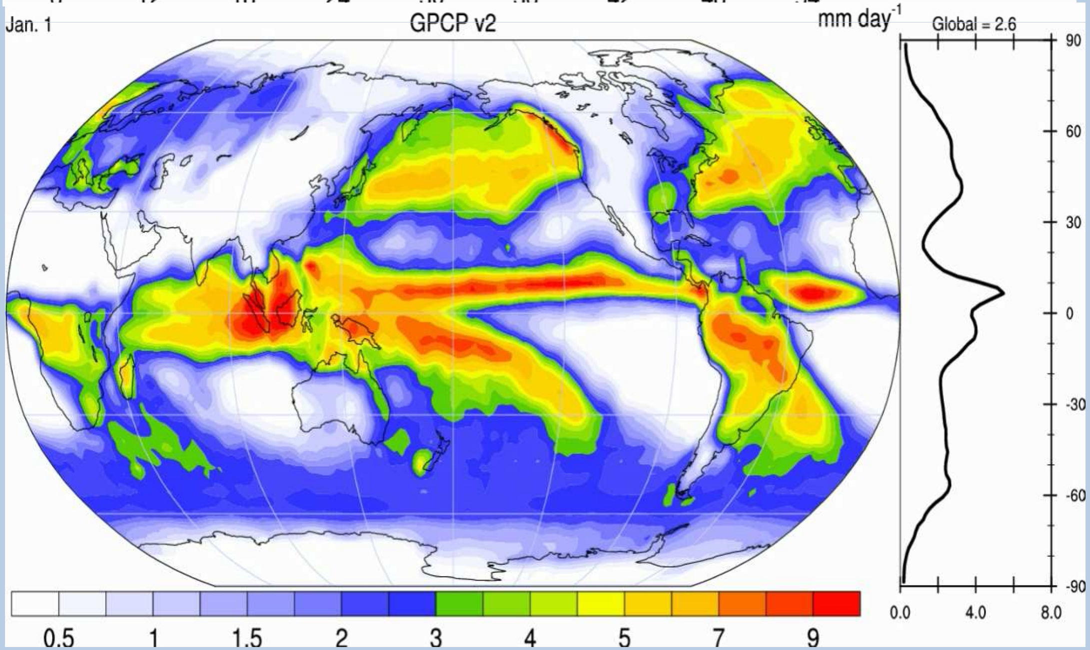
JJA

DJF

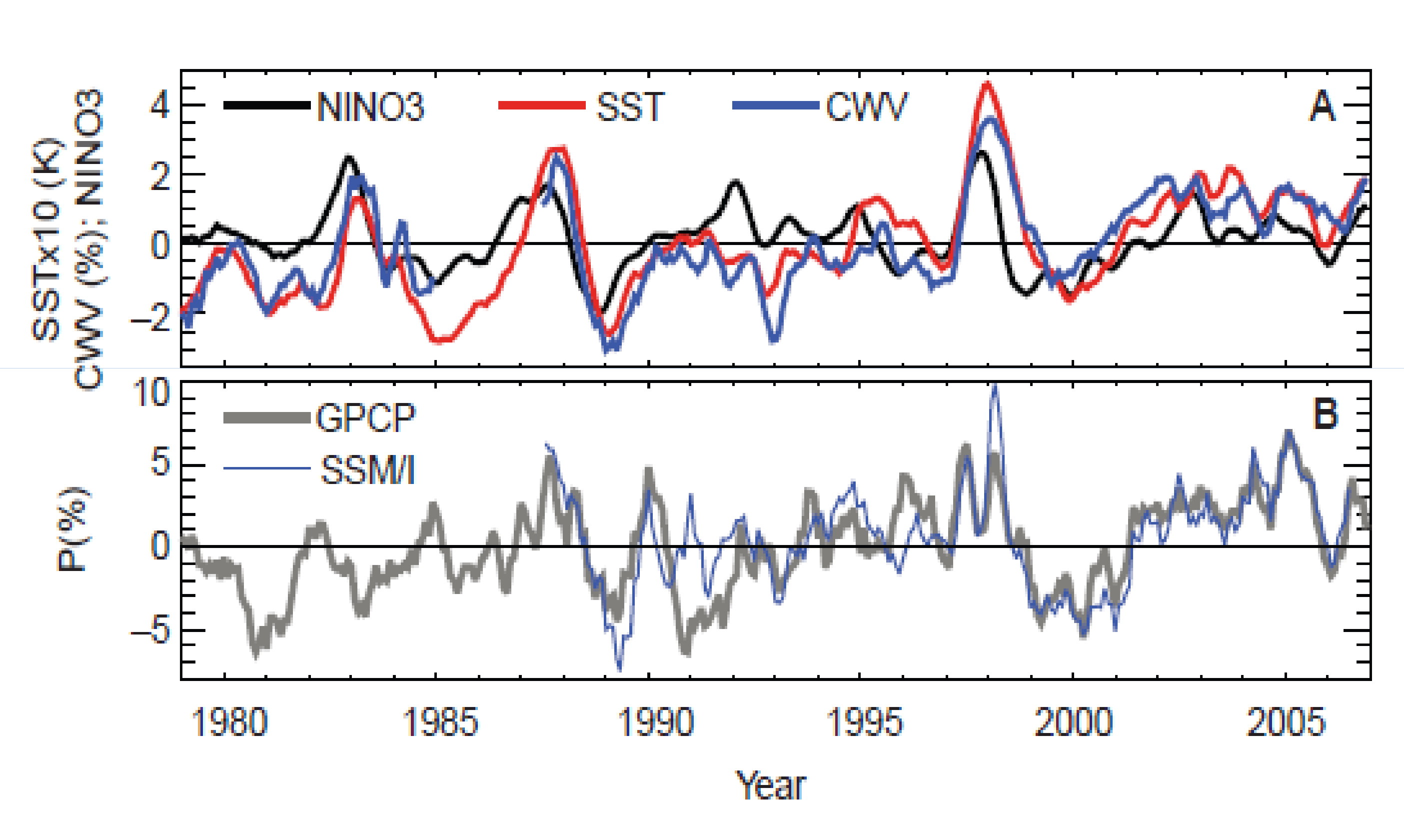
Precipitable water



Precipitation



Precipitation closely follows temps and water vapor



water vapor, SST's

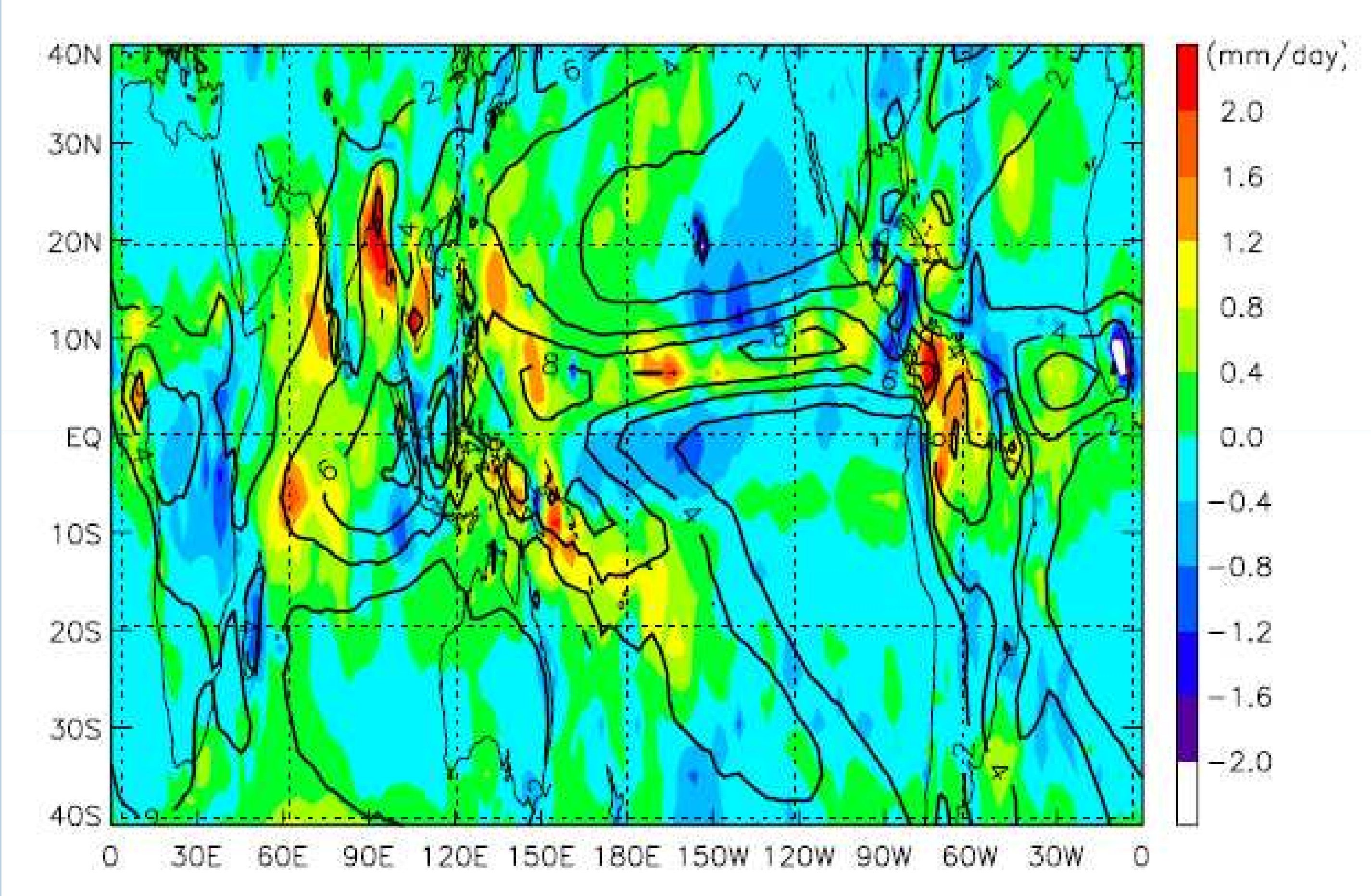
Precip.

Allan and Soden, Science, 2008

Trends in precipitation 1979-2007 (GPCP data)

Contours: climatology

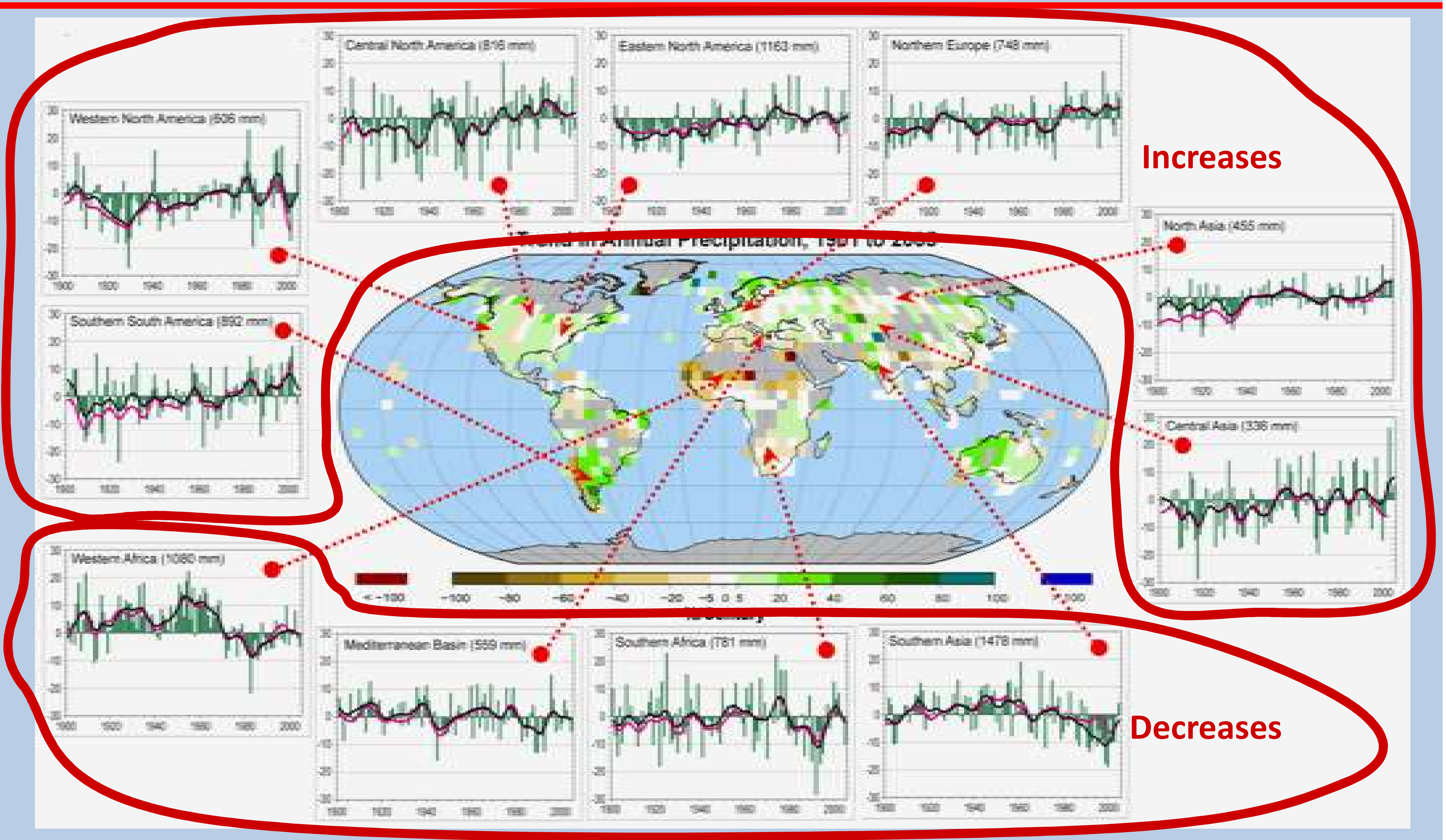
Colors: trends



-> increases in maxima

Zhou et al, 2009

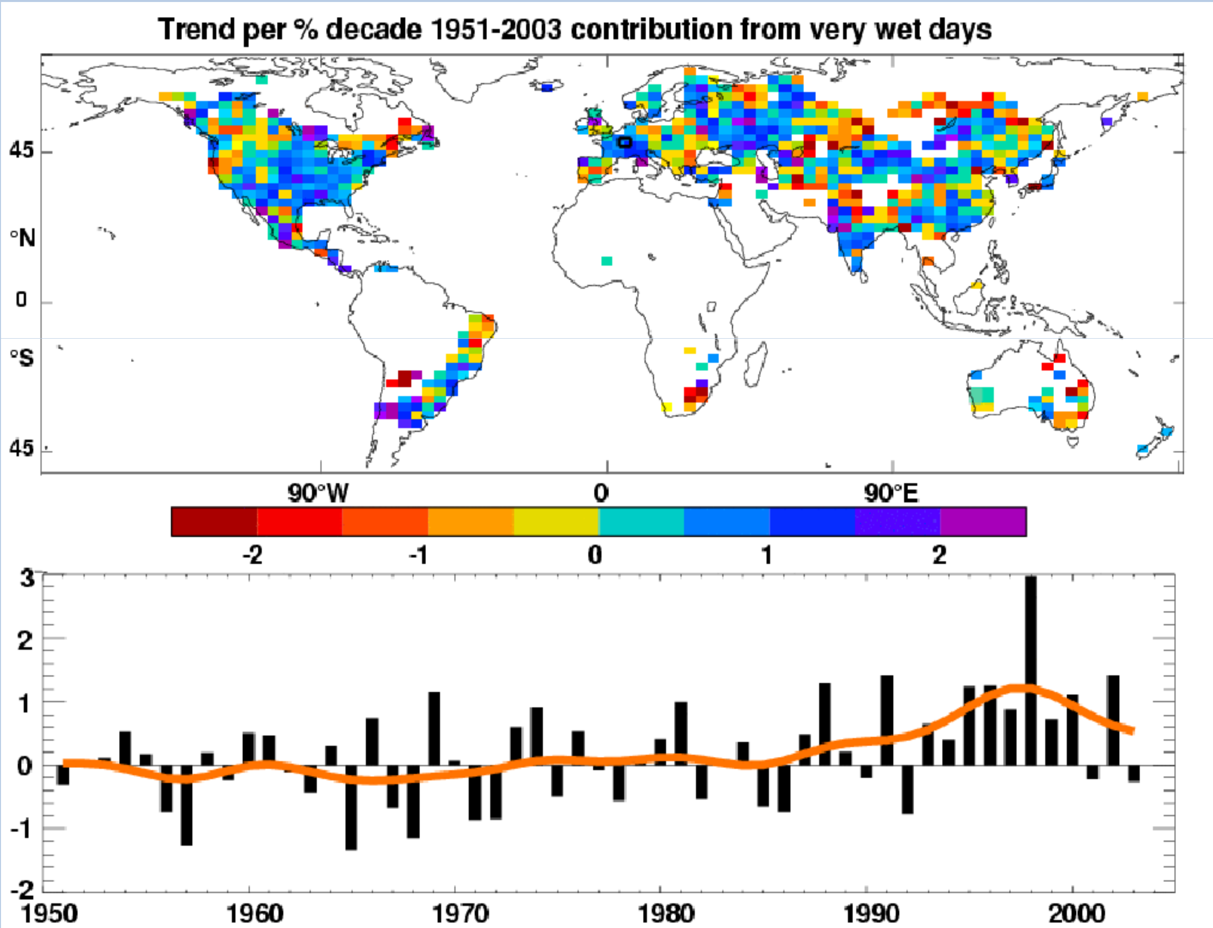
Land precipitation is changing significantly over broad areas



Smoothed annual anomalies for precipitation (%) over land from 1900 to 2005; other regions are dominated by variability.

IPCC

Heavy precipitation days are increasing even in places where precipitation is decreasing.



Precipitation

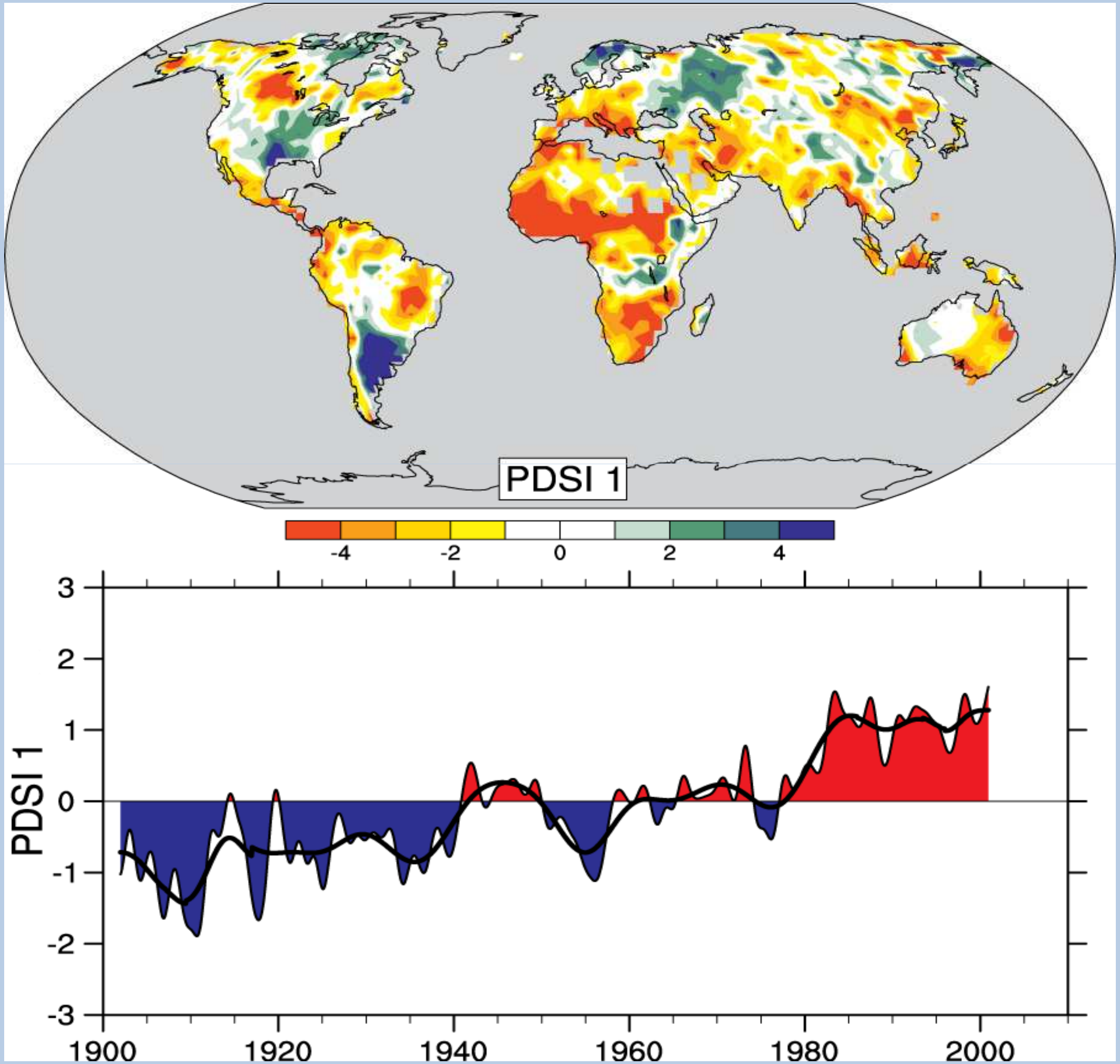
Observed trends (%) per decade for 1951-2003 contribution to total annual from

very wet days

> 95th %ile.

Alexander et al 2006
IPCC AR4

Drought is increasing most places

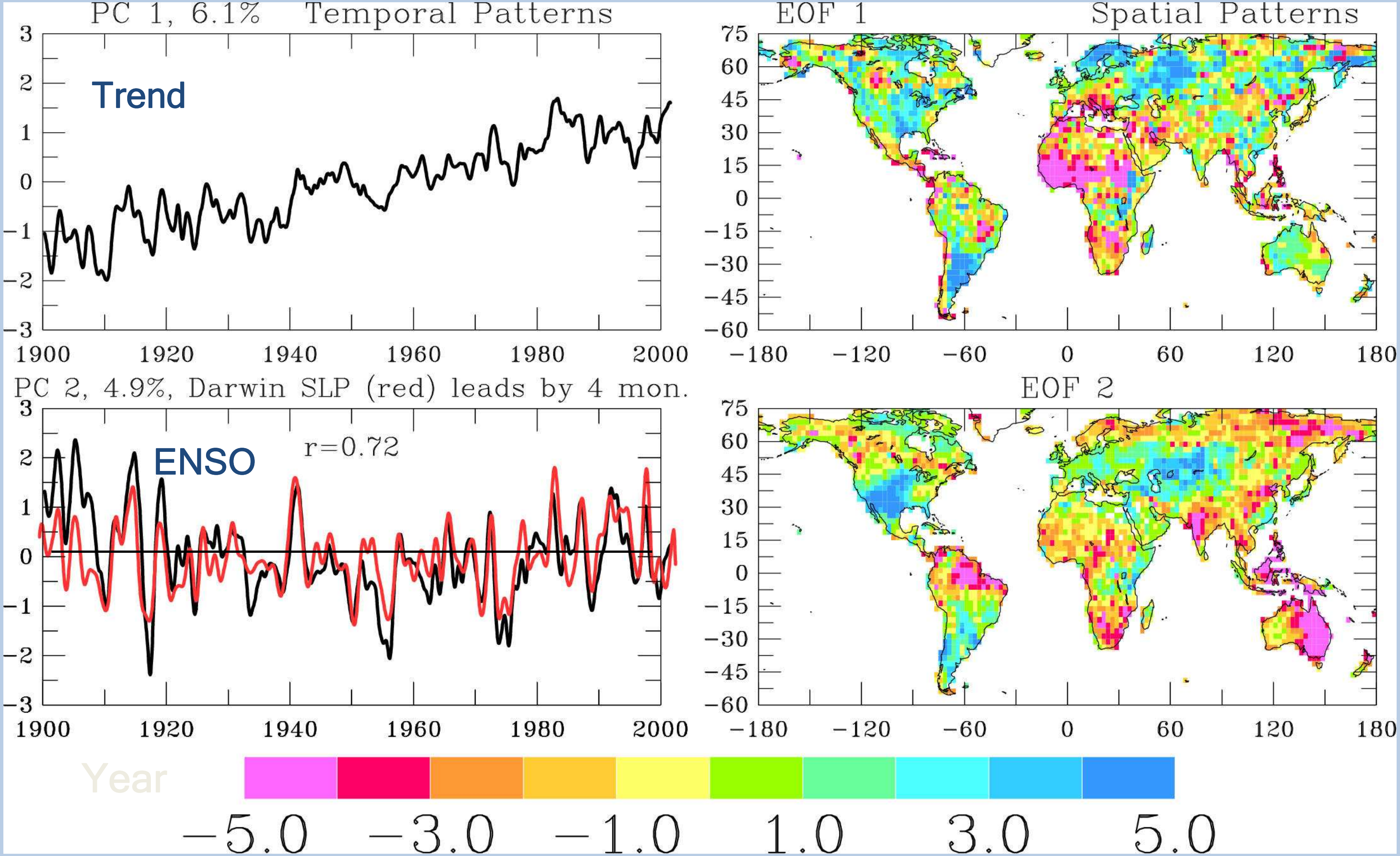


The most important spatial pattern (top) of the monthly Palmer Drought Severity Index (PDSI) for 1900 to 2002.

The time series (below) accounts for most of the trend in PDSI.

IPCC 2007

Leading Modes of PDSI Variations

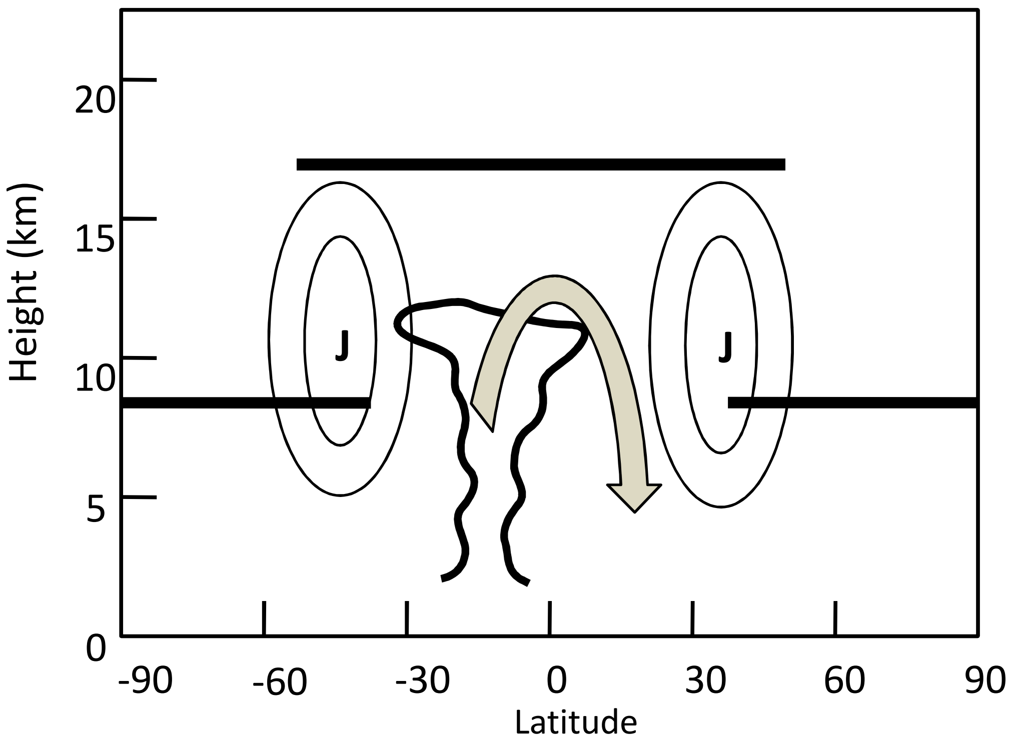


Precipitation is dominant contributor

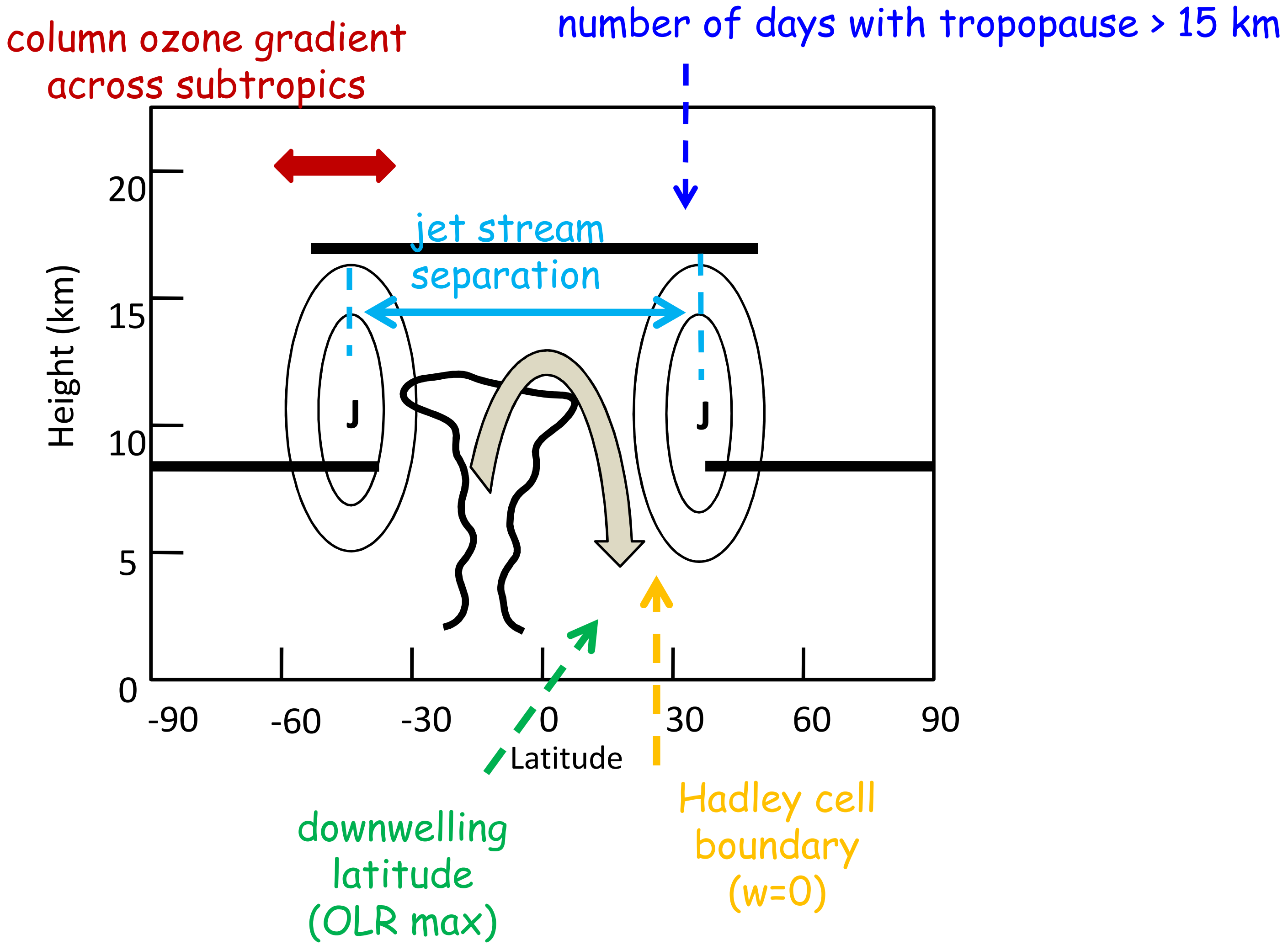
Dai et al 2004
J Hydromet

- Global precipitation closely linked with atmospheric water vapor (and surface temps.)
- observed increasing trends in precipitation
- increases in heavy precipitation days
- increases in droughts

Part of the water vapor changes may be linked to
<u>widening of the tropical belt</u>

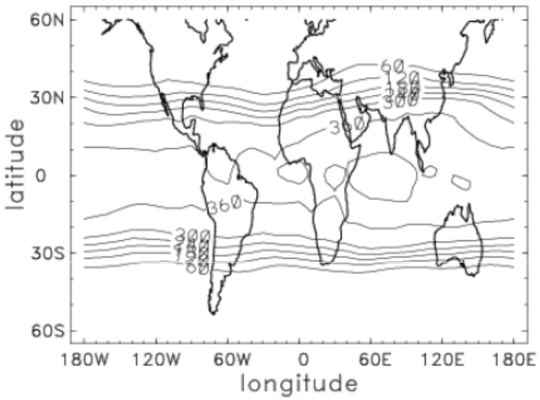


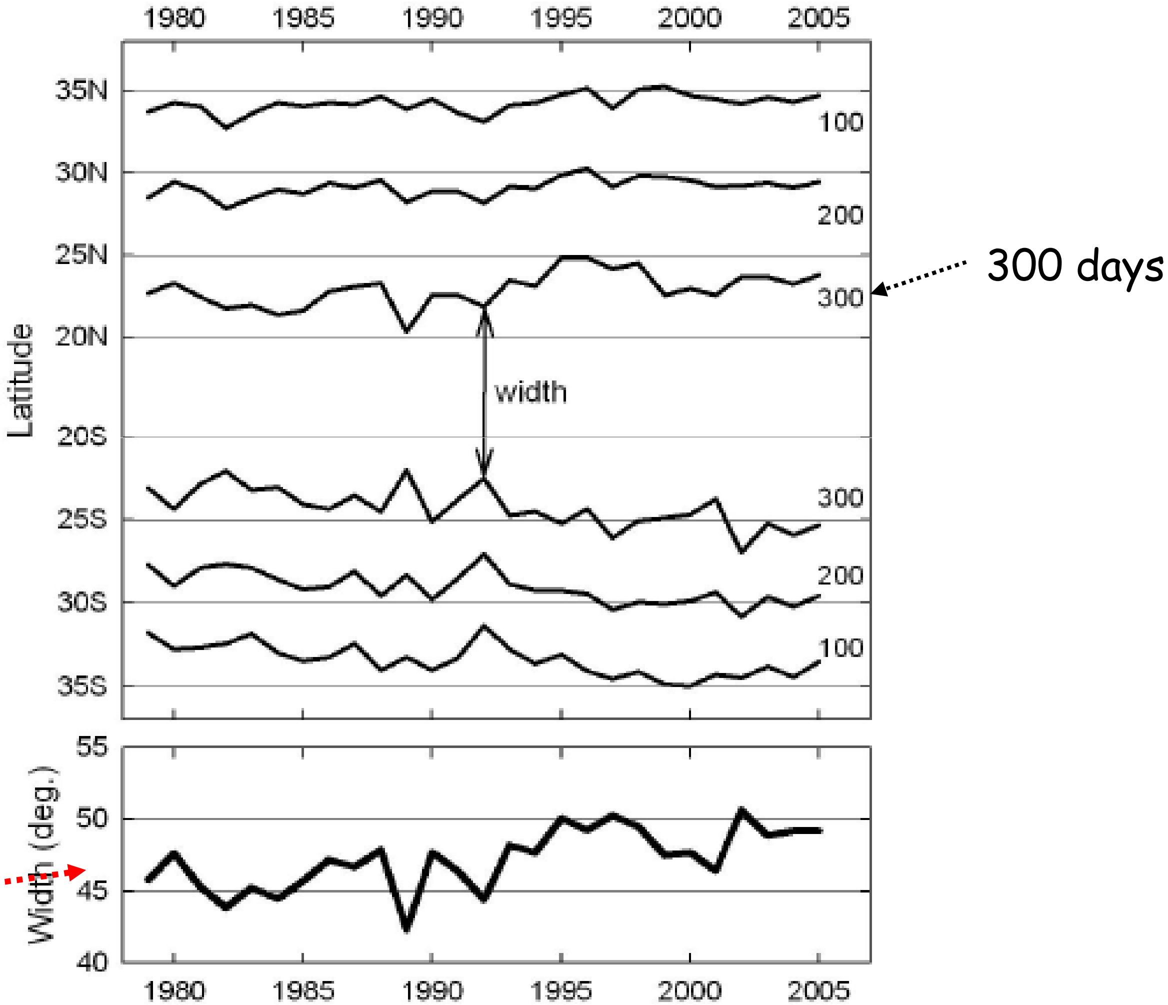
Metrics for width of the tropics:



latitudes where tropopause > 15 km for specific # days

<u>Climatology:</u> # days
where tropopause > 15 km

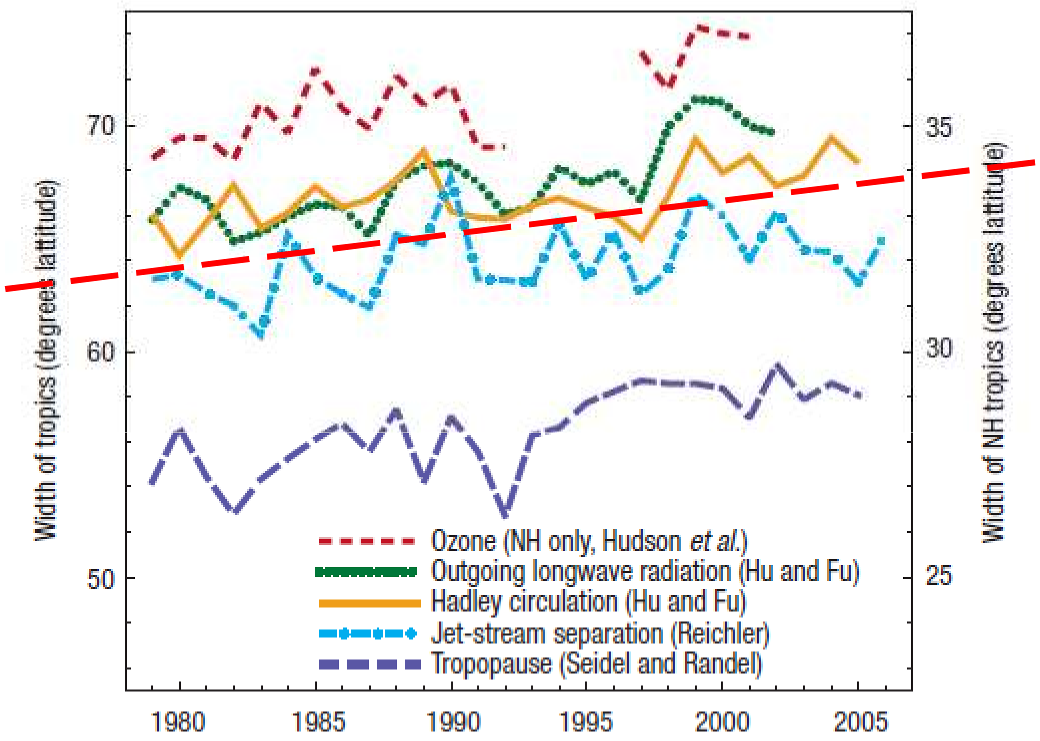




trend= 1.7 +/- 0.8
degrees/decade

Seidel and Randel, JGR, 2007

Evidence for widening of the tropics



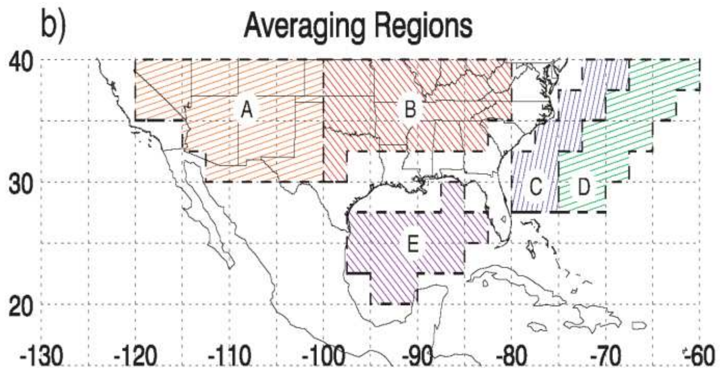
net change:
2 °- 4°

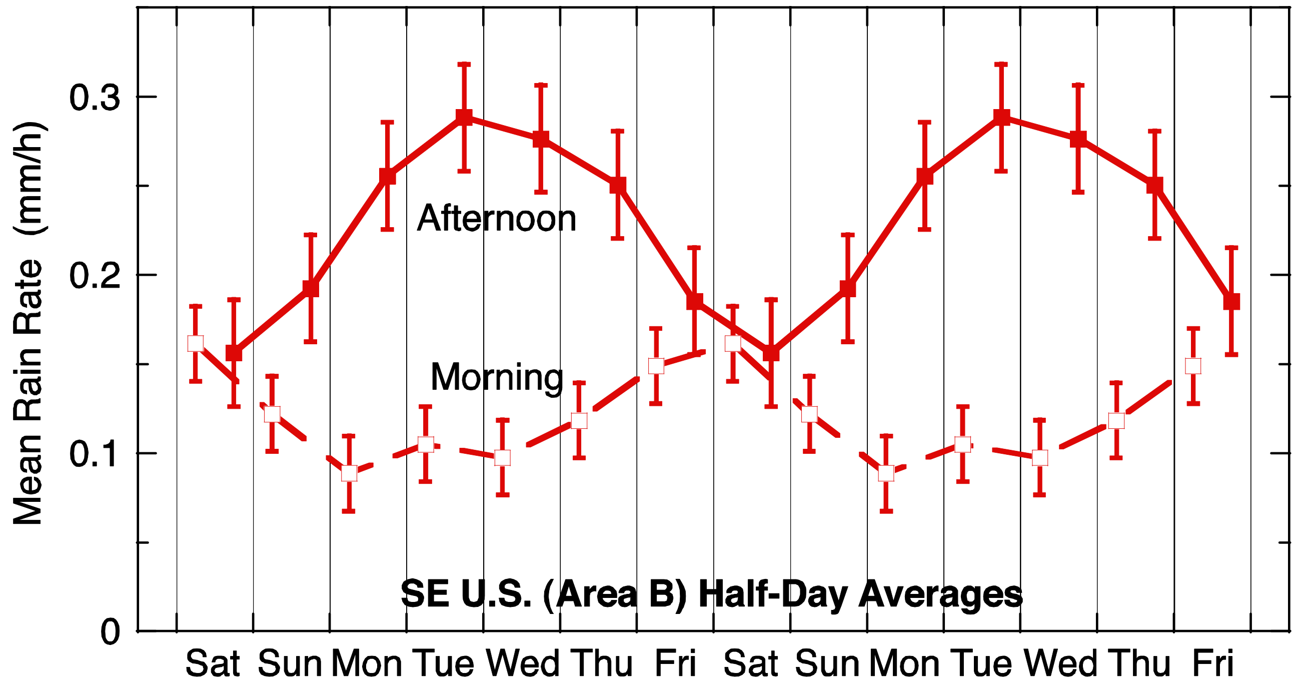
Seidel et al, Nature Geo., 2008

Midweek increase in U.S. summer rain and storm heights suggests air pollution invigorates rainstorms

Thomas L. Bell,[1] Daniel Rosenfeld,[2] Kyu-Myong Kim,[1,3] Jung-Moon Yoo,[4] Myong-In Lee,[1,3] and Maura Hahnenberger[5]

JGR, 2008






Thank you
Hurricane Bill, August 2009