Water Vapor and Lapse Rate Feedbacks of Climate Models

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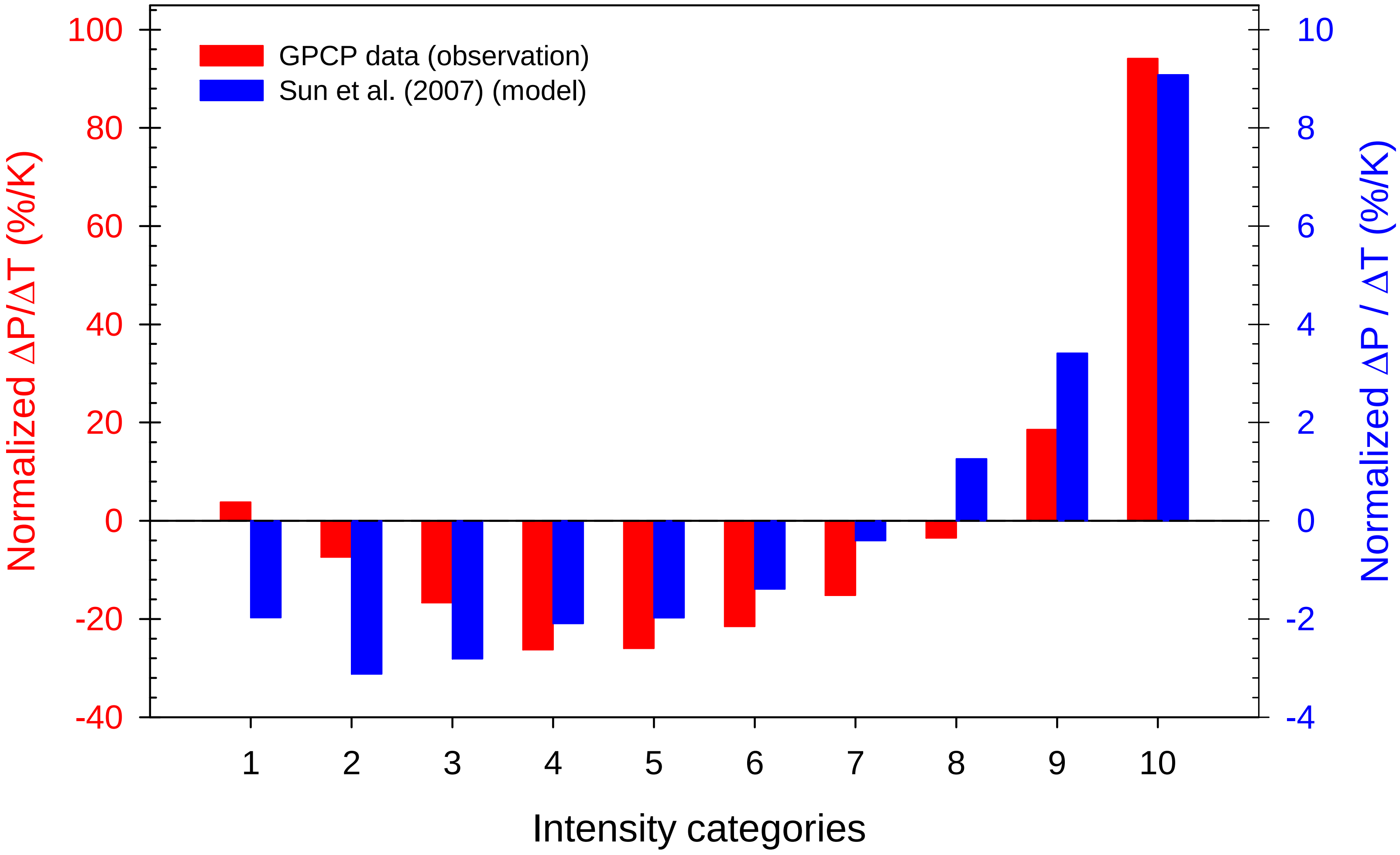
- It is well-known that most of the atmospheric warming in response to increases of greenhouse gases is contributed by climate feedbacks of water vapor, lapse rate (negative), clouds, and albedo.
- In the following we examine the climate feedbacks of water vapor and lapse rate by using the inter-annual variation method we developed recently.

Changes in global annual precipitation intensity as a function of global temperature

Results from an ensemble of 11 coupled climate models (Sun et al., 2007)

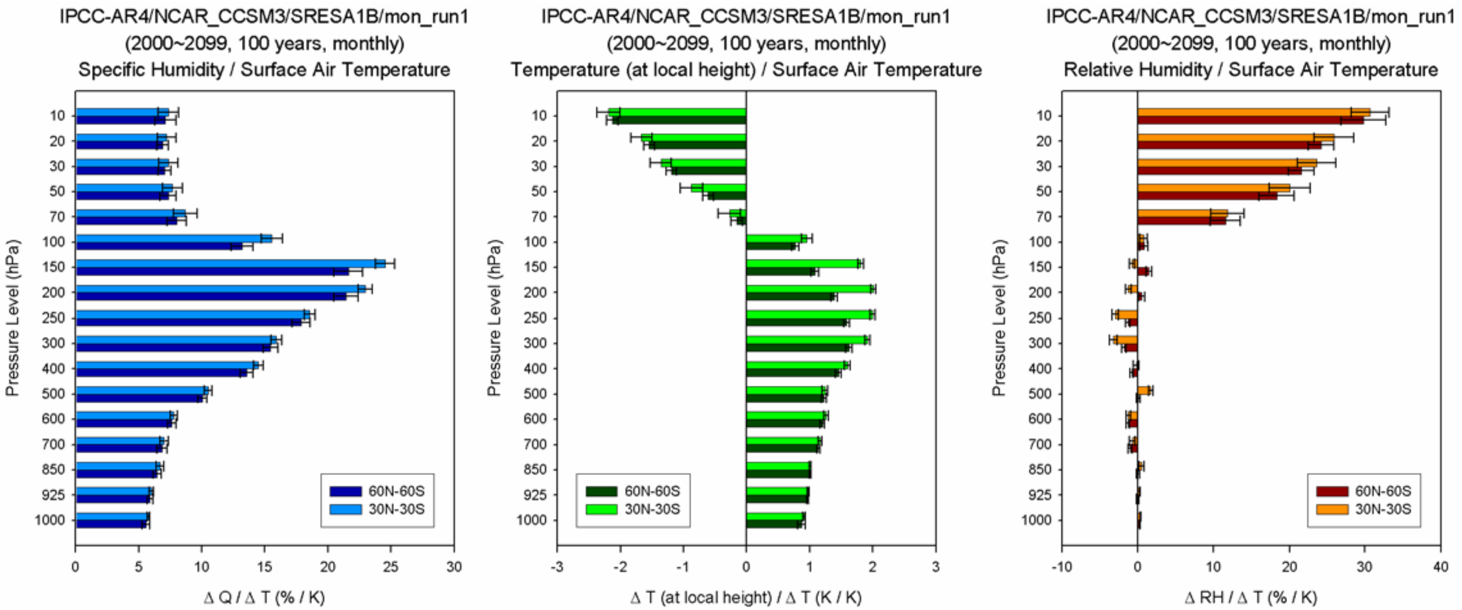
GPCP data: 1979-2007, 60N~60S, 2.5º x 2.5º, 5-day average



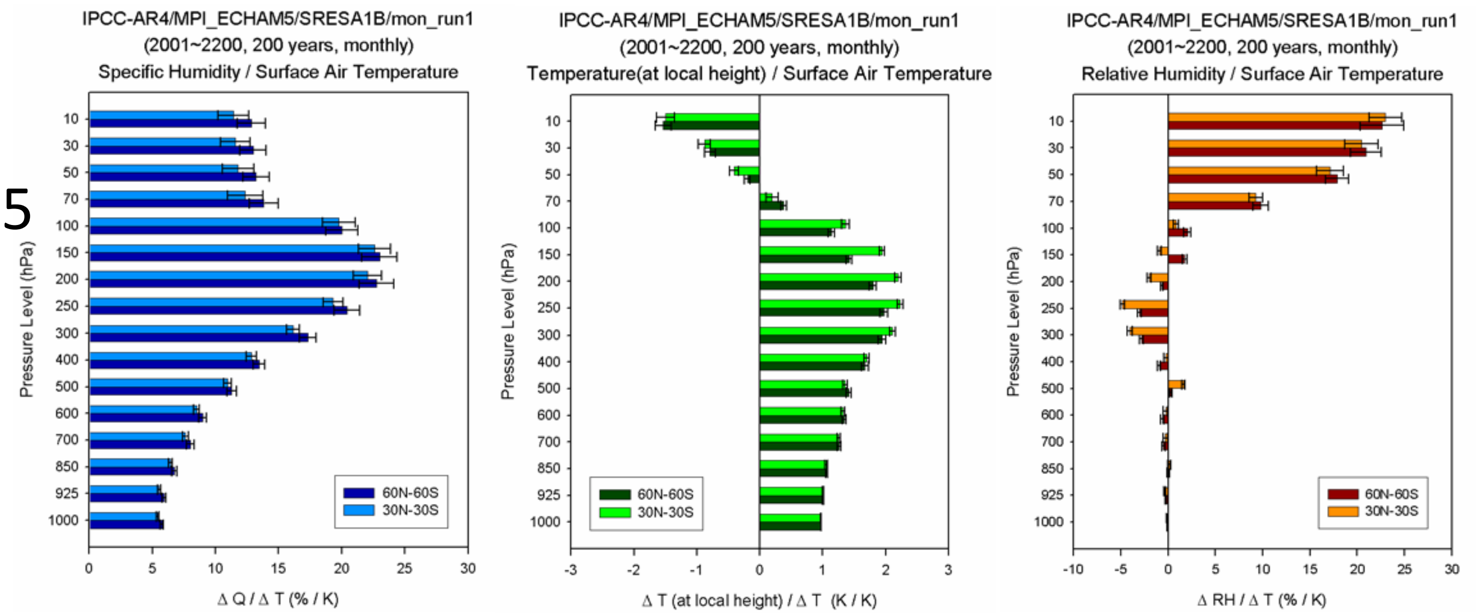
From Liu et al. (2009)

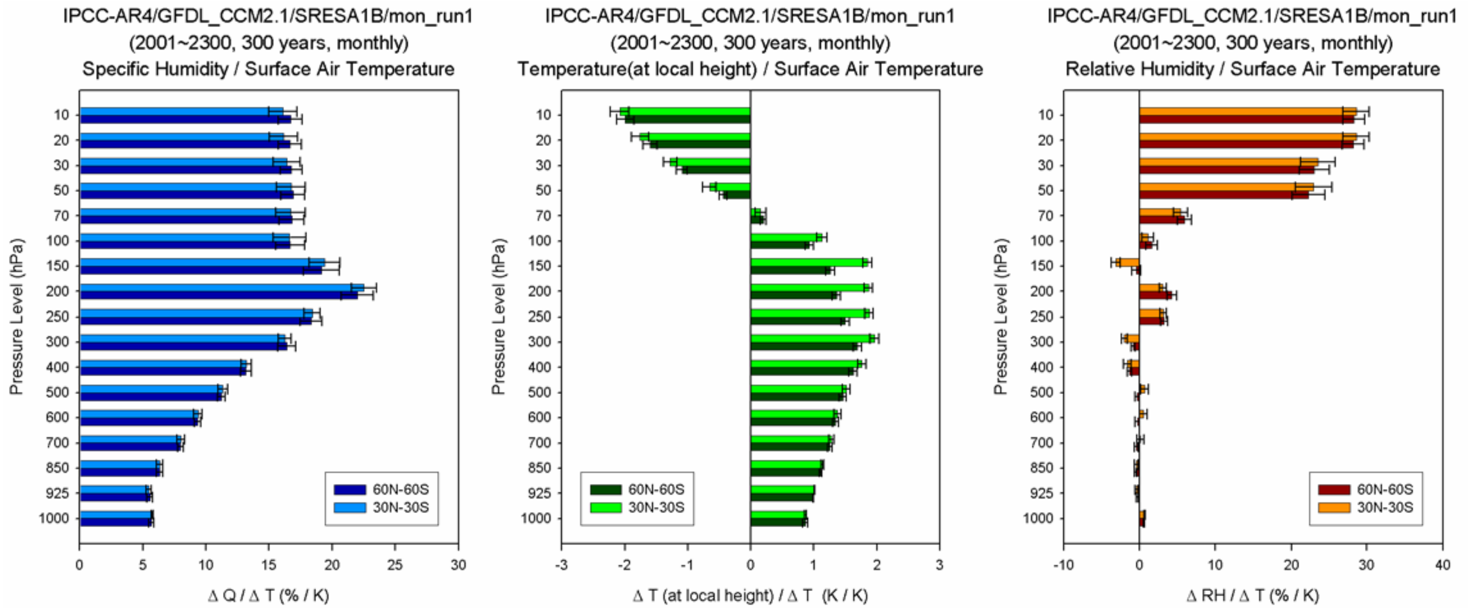
- Heavy precipitation is dominated by convective precipitation.
- It is well known that climate models tend to underestimate convections.
- It follows that the heat and moisture transported to the upper troposphere by convections may be underestimated. So the feedbacks of water vapor and lapse rate could be underestimated.

AR4
NCAR
CCSM3
A1B



AR4
MPI
ECHAM5
A1B



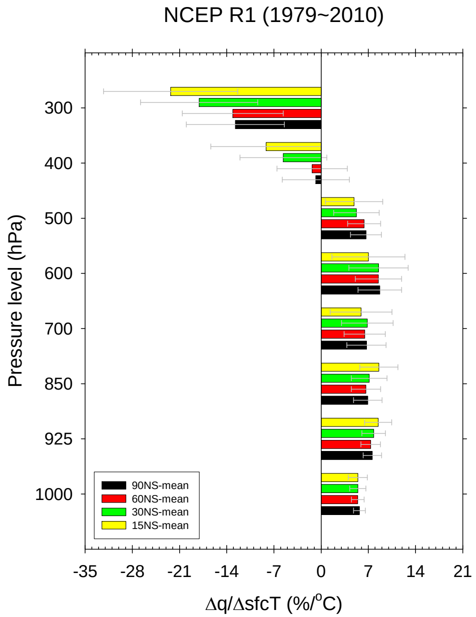


AR4 GFDL CCM2.1 A1B

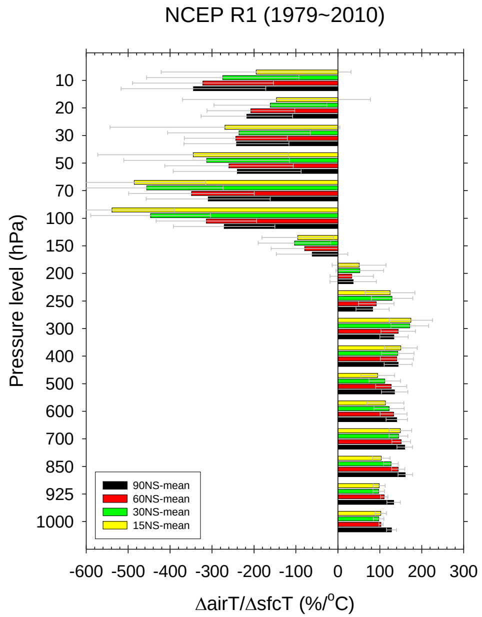
Feedbacks of water vapor and lapse rate

- A critical idea behind the water vapor feedback is that, when the atmospheric temperature changes, the specific humidity would change proportional to the saturation humidity which is governed by the Clausius-Clapeyron equation. I.e. relative humidity stays constant. All climate models of AR4 have this characteristics.
- This idea is well supported by extensive observations in the lower atmosphere, e.g. NCEP/NCAR R1.
- In the upper troposphere (>500 mb), there has been extensive debates with controversial results because the water vapor instrument of radiosondes is not reliable.

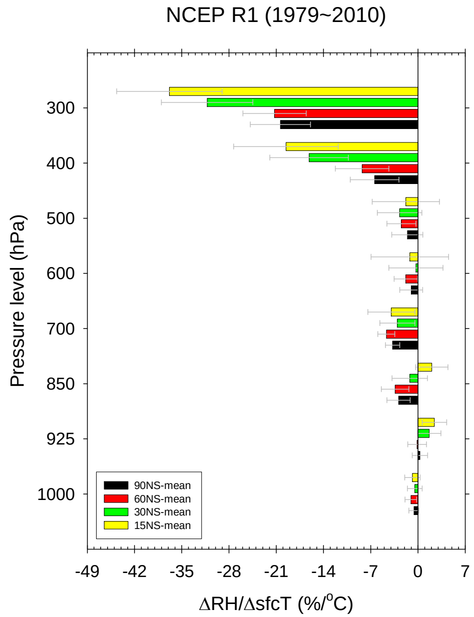
NCEP/NCAR R1



NCEP R1 (1979~2010)
Pressure level (hPa)
300
400
500
600
700
850
925
1000
90NS-mean
60NS-mean
30NS-mean
15NS-mean
-35
-28
-21
-14
-7
0
7
14
21
Δq/ΔsfcT (%/°C)



NCEP R1 (1979~2010)
Pressure level (hPa)
10
20
30
50
70
100
150
200
250
300
400
500
600
700
850
925
1000
90NS-mean
60NS-mean
30NS-mean
15NS-mean
-600
-500
-400
-300
-200
-100
0
100
200
300
ΔairT/ΔsfcT (%/°C)



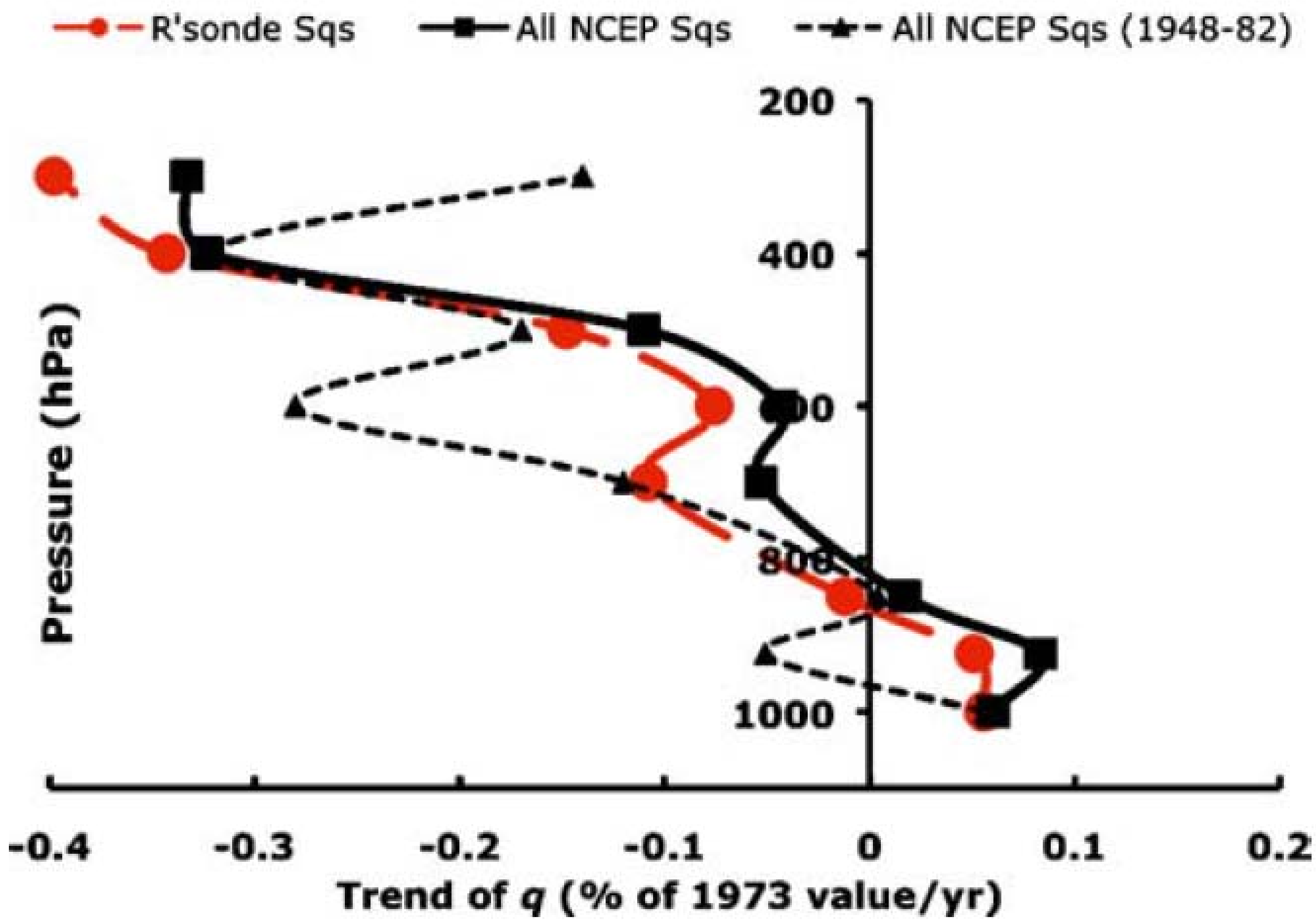
NCEP R1 (1979~2010)
Pressure level (hPa)
300
400
500
600
700
850
925
1000
90NS-mean
60NS-mean
30NS-mean
15NS-mean
-49
-42
-35
-28
-21
-14
-7
0
7
ΔRH/ΔsfcT (%/°C)

Take 300 mb as an example

- **Surface T up → atmospheric T up → atmospheric H2O up → T further up due to IR absorption by H2O (more so in the upper troposphere).**
- **The temperature increases by about 2 K for each 1 K increase at the surface. The specific humidity increases by about 15% for each 1 K increase at the surface. It is essentially ~7% K-1.**
- **It looks that the water vapor of the entire atmosphere is simply governed by the Clausius-Clapeyron equation, i.e. by saturation/precipitation processes rather than thermodynamics.**

- Paltridge et al. (2009) found that specific humidity in the (NCEP/NCAR) reanalysis declined between 1973 and 2007, particularly in the tropical mid and upper troposphere, the region that plays the key role in the water vapor feedback. If borne out, this result would suggest serious problems in the consensus view of a positive water vapor feedback.
- Dessler and Davis (2010) analyzed 5 reanalyses and found that, in response to decadal climate fluctuations, the NCEP/NCAR reanalysis is unique in showing decreases in tropical mid and upper tropospheric specific humidity as the climate warms. All other reanalyses show that the warming is accompanied by increases in mid and upper tropospheric specific humidity.

From Paltridge et al. (2009)



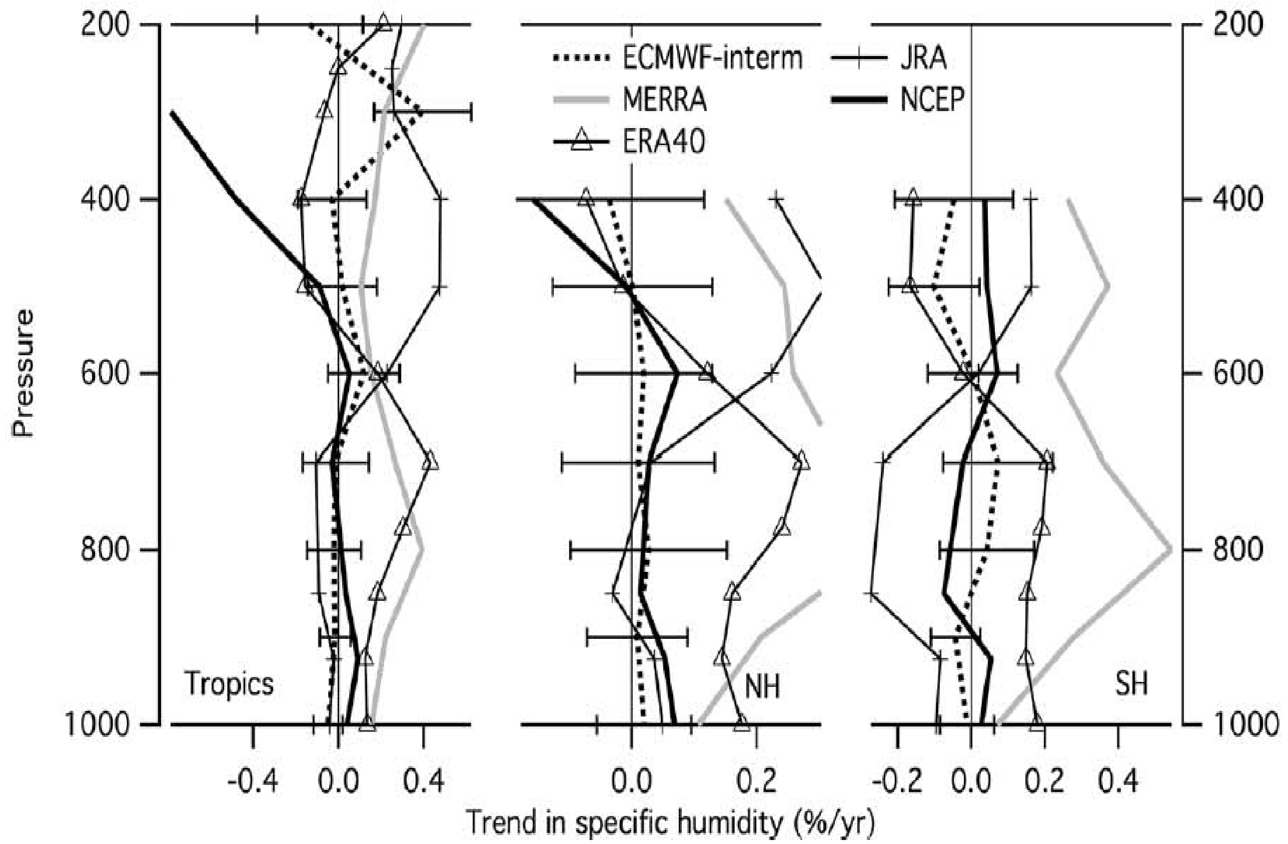
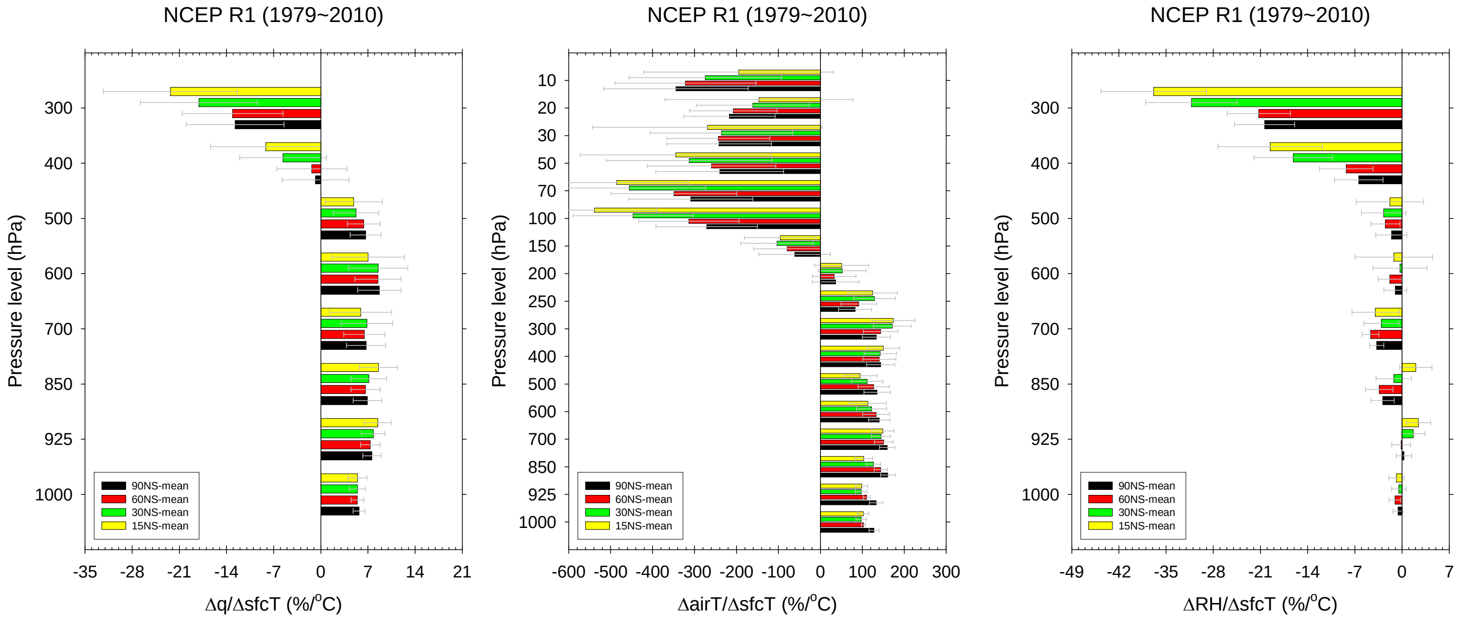
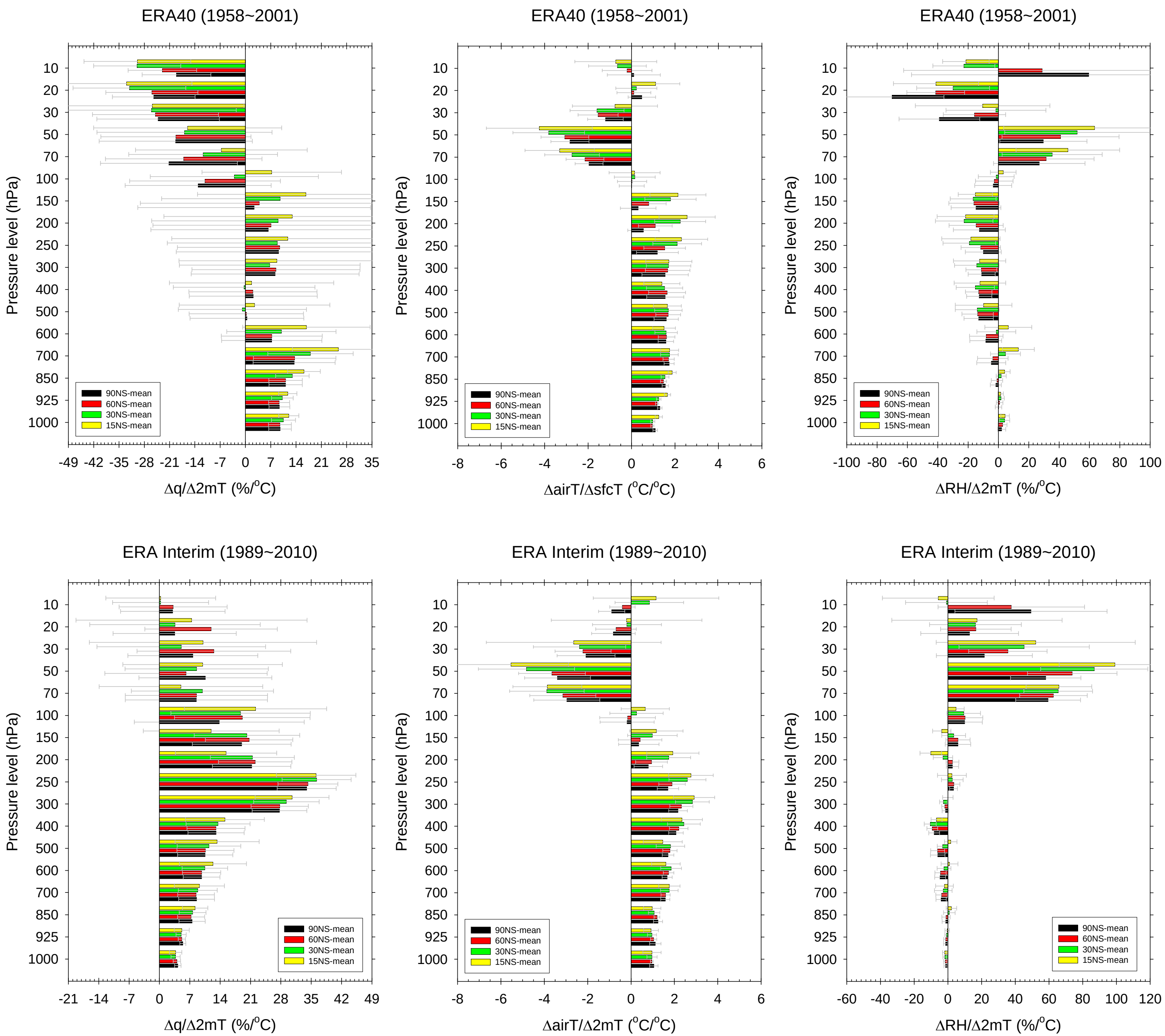


Figure 1. Plots of the trends in specific humidity in the different reanalyses, over the time periods discussed in the text (1979 onward, except for the ECMWF-interim, which begins in 1989). The plots are divided into three geographical regions: tropics (20°S–20°N), NH (20°N–50°N), and SH (20°S–50°S). Trends are divided by the average specific humidity over the entire time period, so they are expressed in percent per year. The 95% confidence interval for trends in the ERA-interim reanalysis are shown for illustration purposes.

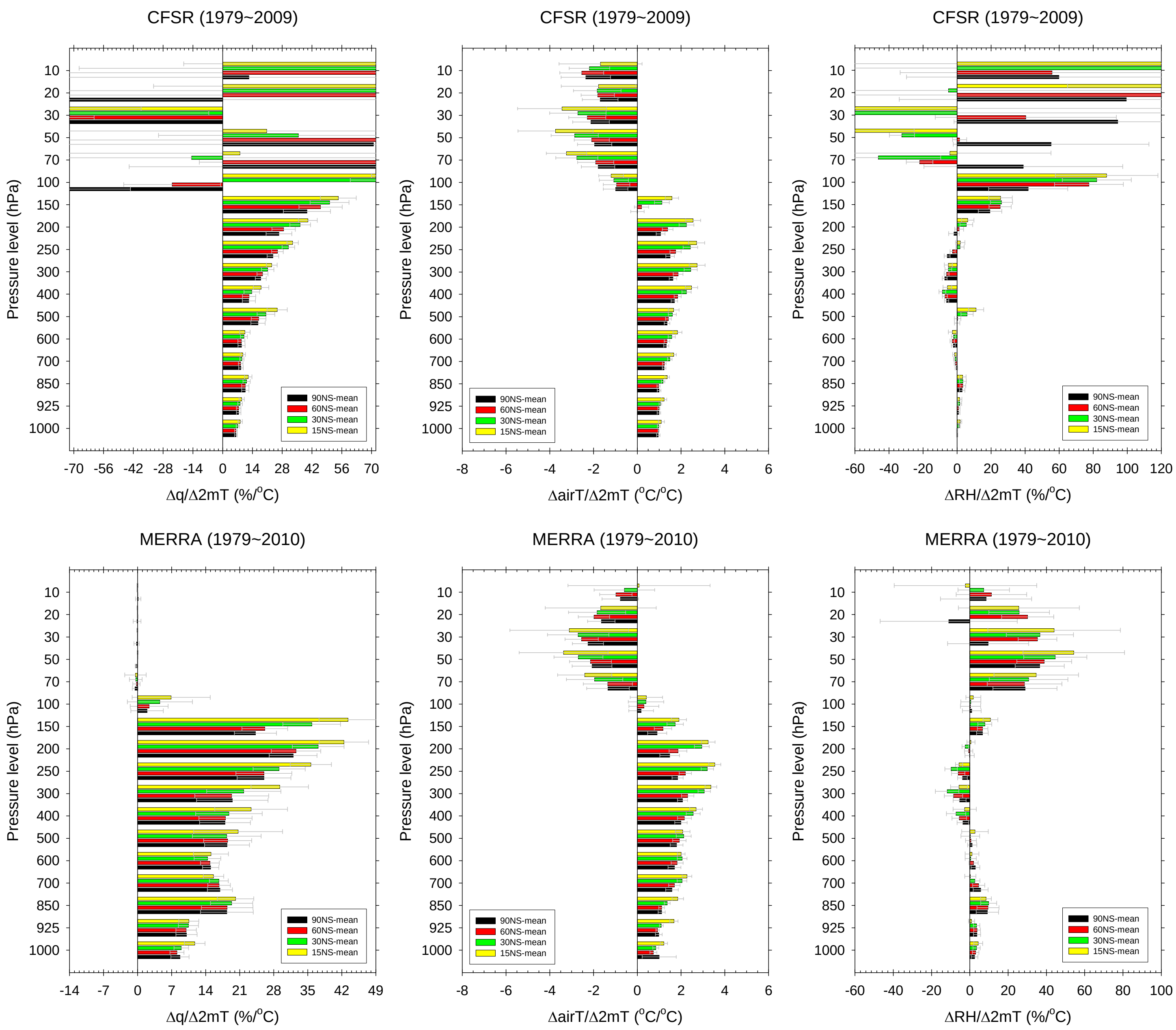
From Dessler and Davis (2010)

NCEP/NCAR R1

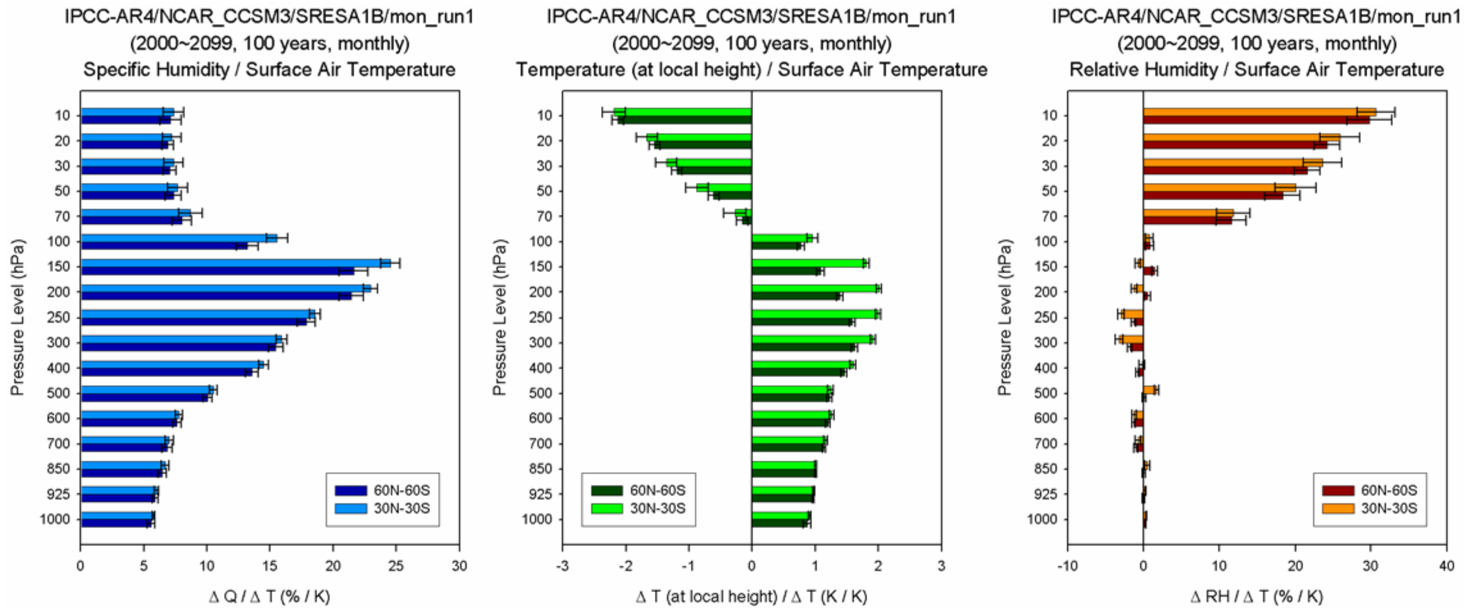

NCEP R1 (1979~2010)
Pressure level (hPa)
300
400
500
600
700
850
925
1000
90NS-mean
60NS-mean
30NS-mean
15NS-mean
-35 -28 -21 -14 -7 0 7 14 21
Δq/ΔsfcT (%/°C)
NCEP R1 (1979~2010)
Pressure level (hPa)
10
20
30
50
70
100
150
200
250
300
400
500
600
700
850
925
1000
90NS-mean
60NS-mean
30NS-mean
15NS-mean
-600 -500 -400 -300 -200 -100 0 100 200 300
ΔairT/ΔsfcT (%/°C)
NCEP R1 (1979~2010)
Pressure level (hPa)
300
400
500
600
700
850
925
1000
90NS-mean
60NS-mean
30NS-mean
15NS-mean
-49 -42 -35 -28 -21 -14 -7 0 7
ΔRH/ΔsfcT (%/°C)


ERA40 (1958~2001)
Pressure level (hPa)
Δq/Δ2mT (%/°C)
ΔairT/ΔsfcT (°C/°C)
ΔRH/Δ2mT (%/°C)
ERA Interim (1989~2010)
ΔairT/Δ2mT (°C/°C)
90NS-mean
60NS-mean
30NS-mean
15NS-mean

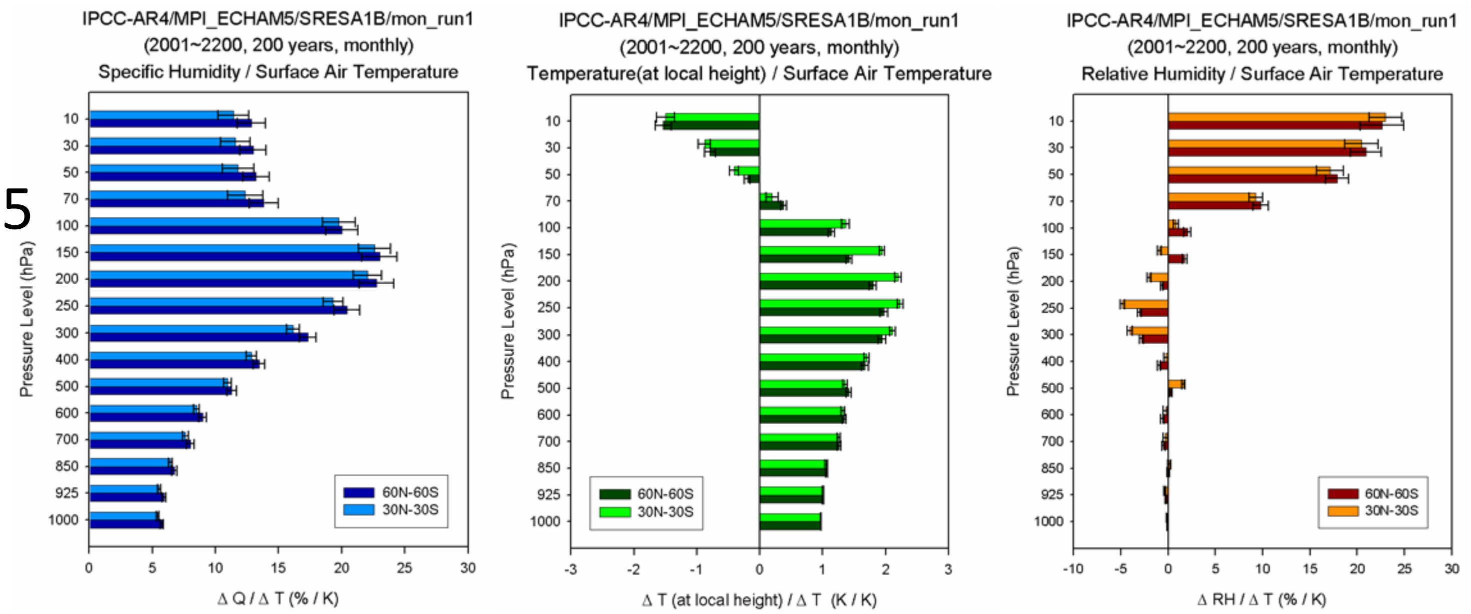
Two more Reanalyses: MERRA and CFSR



AR4
NCAR
CCSM3
A1B



AR4
MPI
ECHAM5
A1B

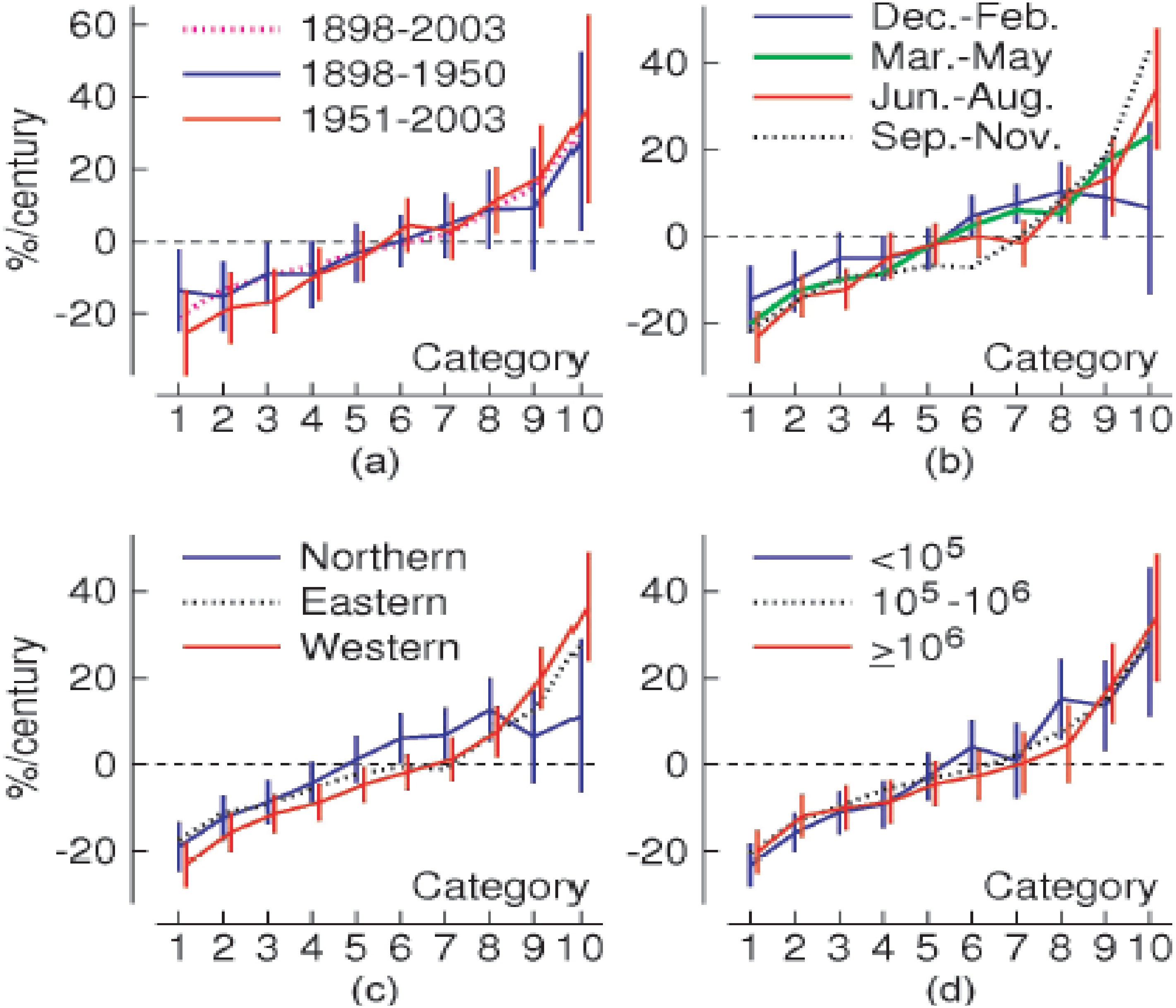


Conclusions

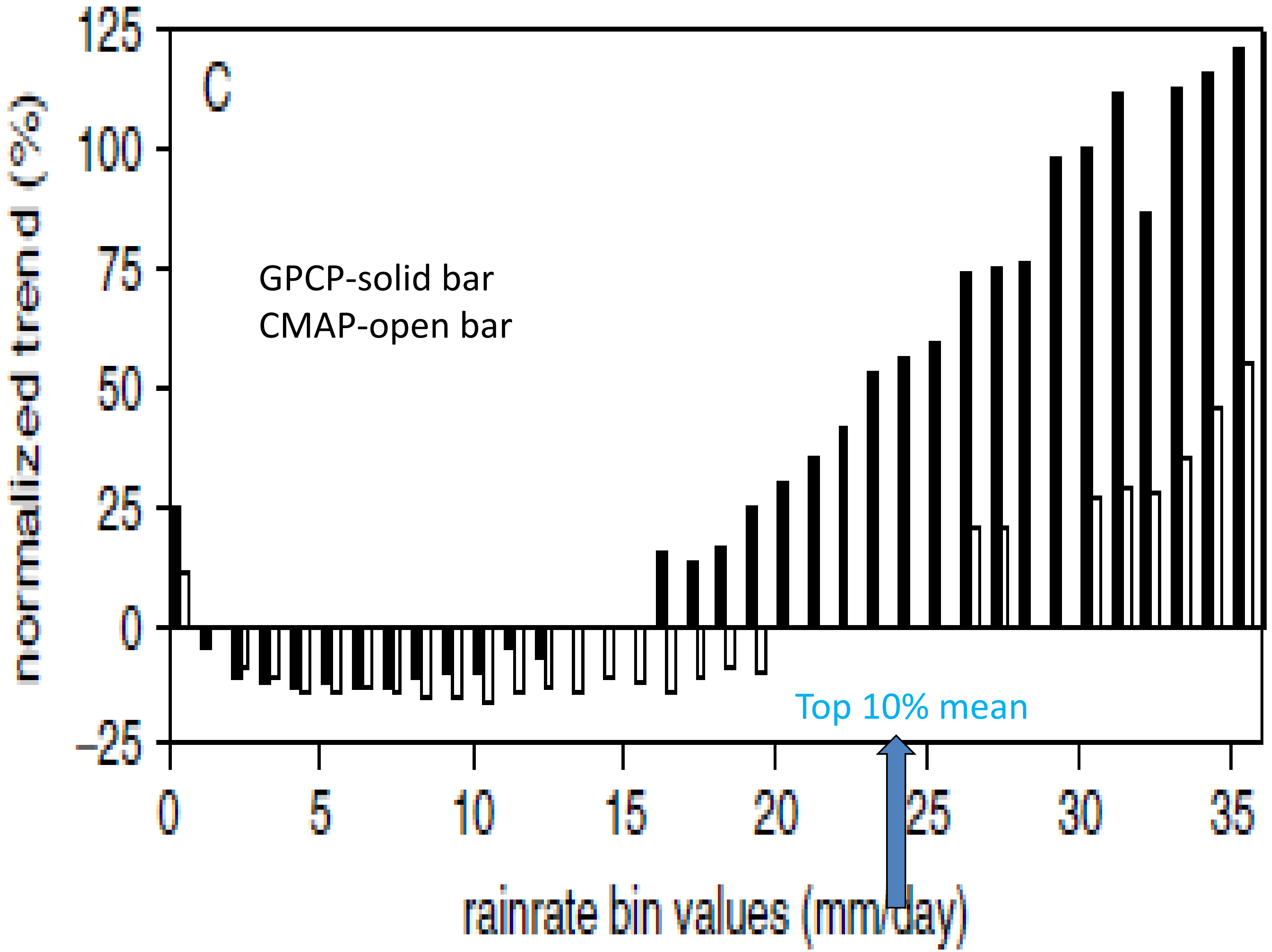
- When recent satellite data, particularly the AIRS data, are taken into account, the reanalyses show that the water vapor in the mid and upper troposphere increases significantly with global surface temperature.
- There are also significant increases of temperature in the mid and upper troposphere.
- The increases of water vapor and temperature in the mid and upper troposphere are in quantitative agreement with projections of climate models used for AR4.
- This agreement provides a key validation for the climate models, as the feedbacks of water vapor and lapse rate are among the largest climate feedbacks.

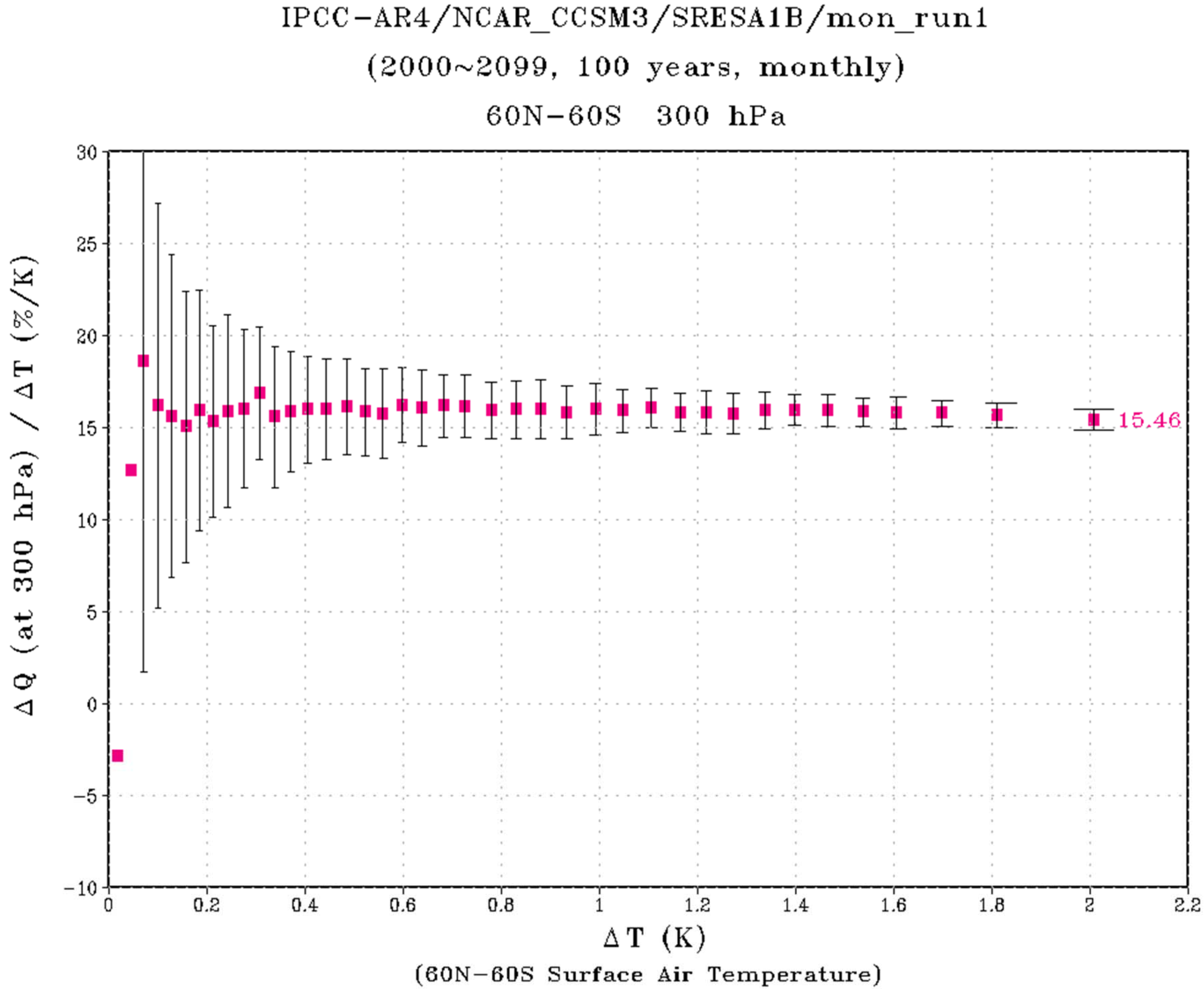
Thank you for your attention!

Linear trends of precipitations at different intensities in Japan, (a) for 3 time periods, (b) for 4 seasons, (c) for 3 regions, and (d) for 3 urban population ranges. (Fujibe et al., 2005)

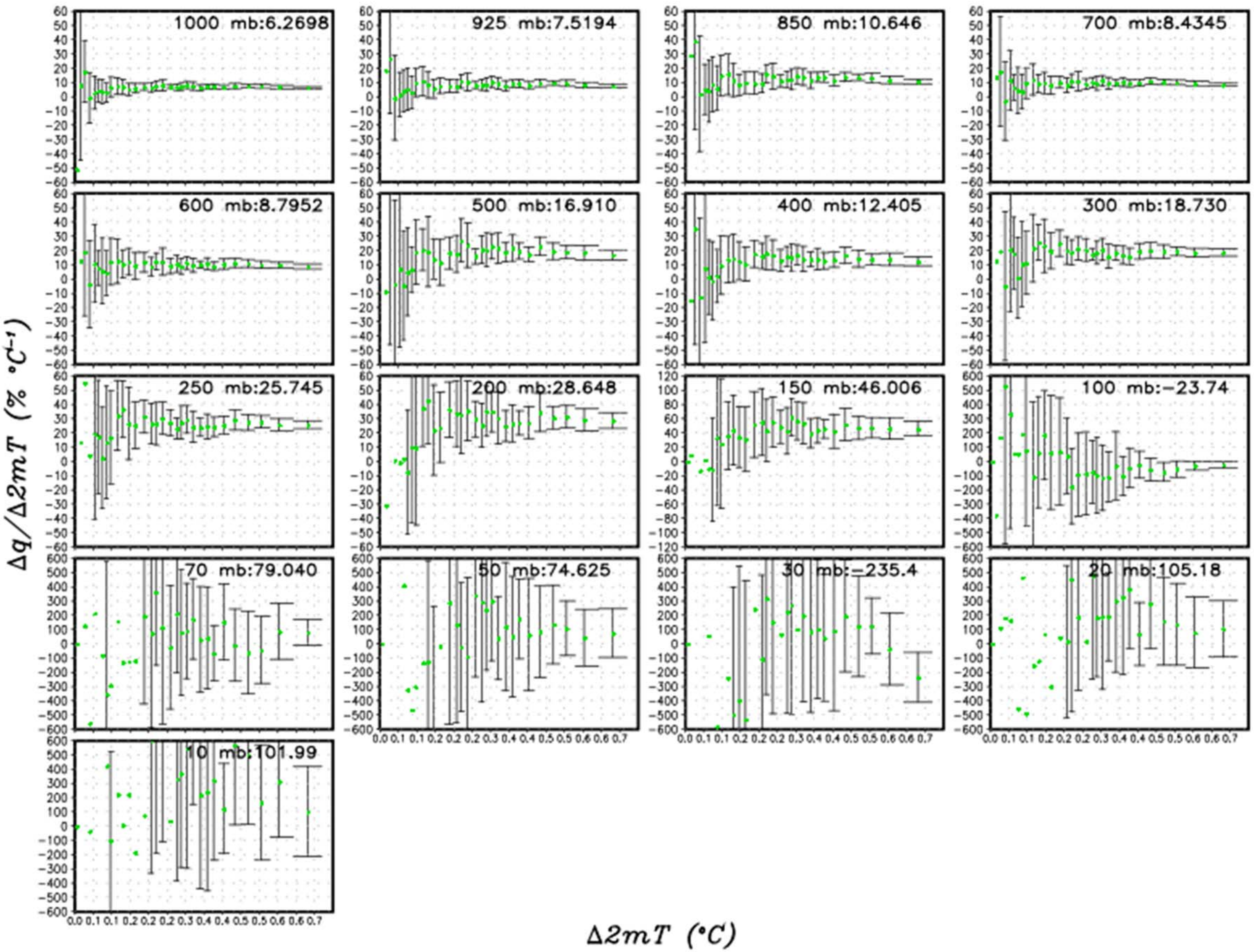


From Lau and Wu (2007)



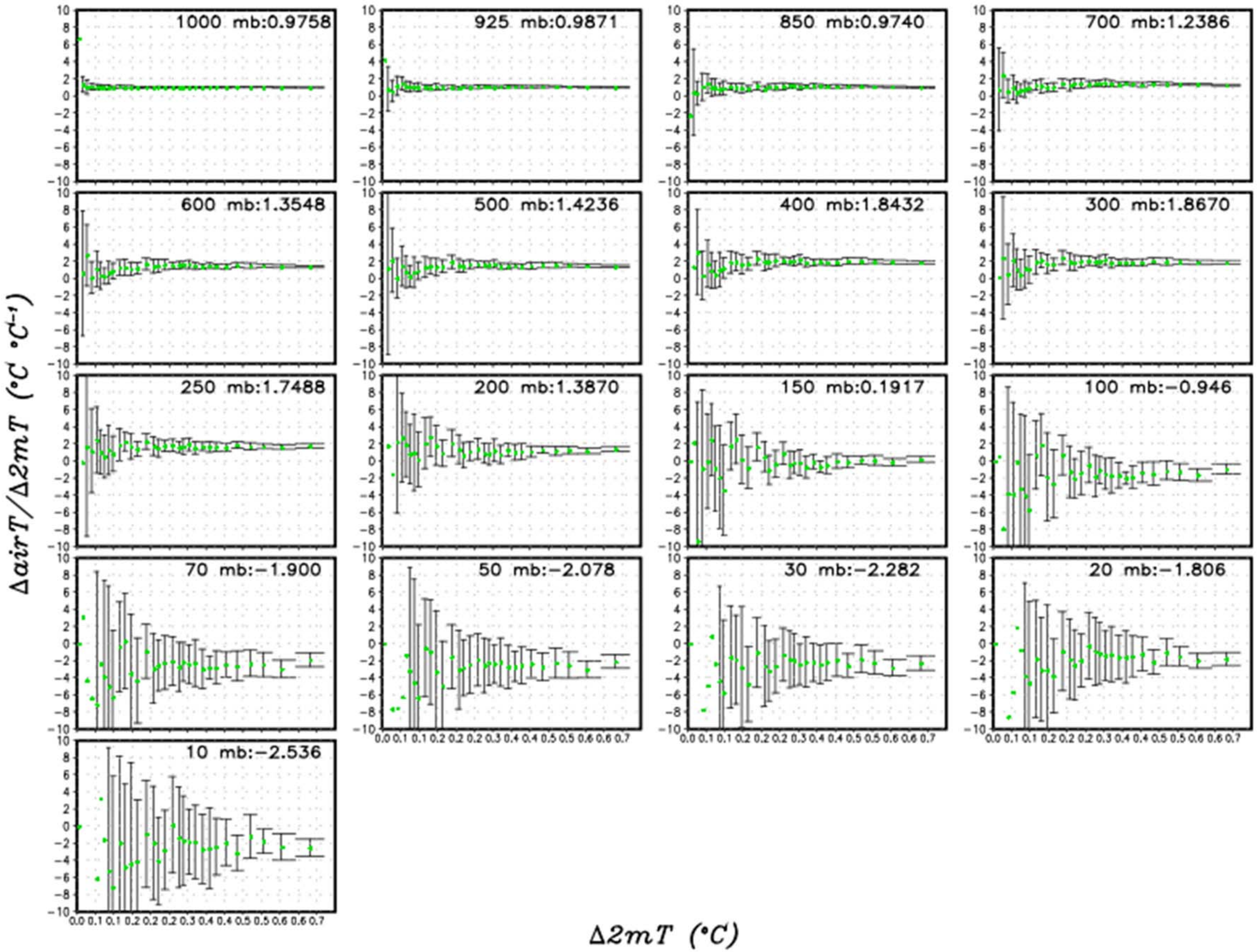

IPCC-AR4/NCAR_CCSM3/SRESA1B/mon_run1
(2000~2099, 100 years, monthly)
60N-60S 300 hPa
ΔQ (at 300 hPa) / ΔT (%/K)
ΔT (K)
(60N-60S Surface Air Temperature)
15.46
30
25
20
15
10
5
0
−5
−10
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2

CFSR (1979-2009)



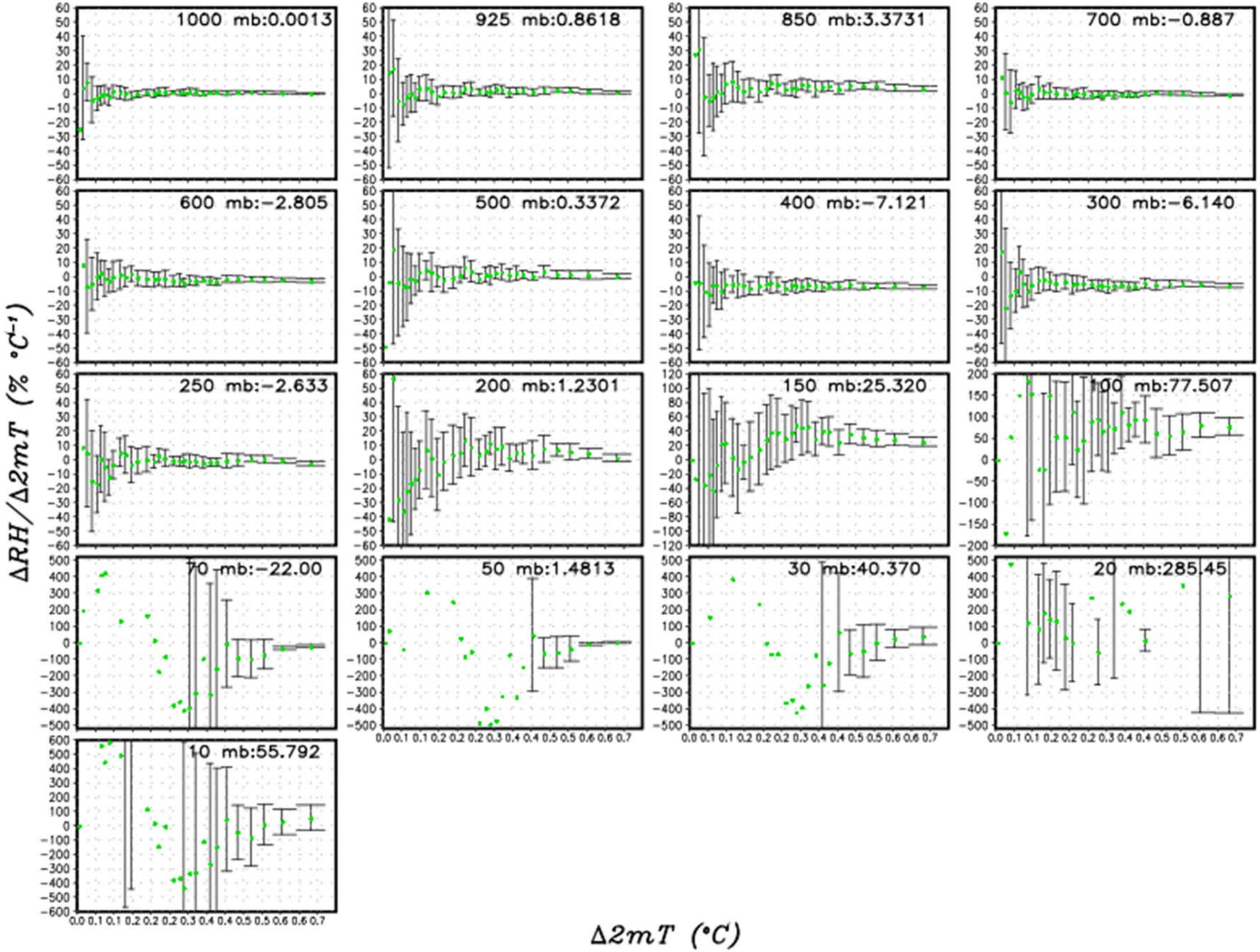
Note: Δq and Δ2mT are averaged within 60NS (% normalized to mean q)

CFSR (1979-2009)



Note: ΔairT and Δ2mT are averaged within 60NS

CFSR (1979-2009)



Note: ΔRH and Δ2mT are averaged within 60NS (% normalized to mean RH)

- The relationship of fluctuations in SST and upper tropospheric humidity can be derived directly from the Atmospheric Infrared Sounder (AIRS), and the results show that a typical GCM is capable of reproducing the positive rate of increase in specific humidity with increased SST of 10%–25% $^{o}C^{-1}$ (Gettelman and Fu, 2008).