Horizontal variability of water and its relationship to cloud fraction near the tropical tropopause

Using aircraft observations of water vapor to improve the representation of grid-scale cloud formation in GEOS-5

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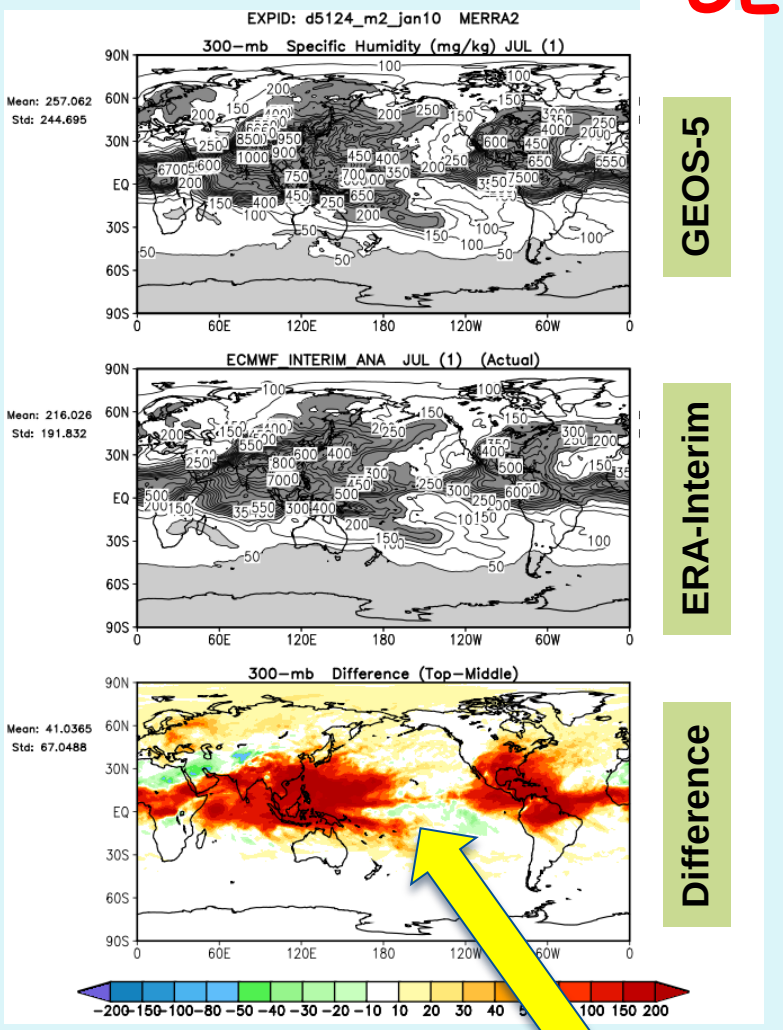
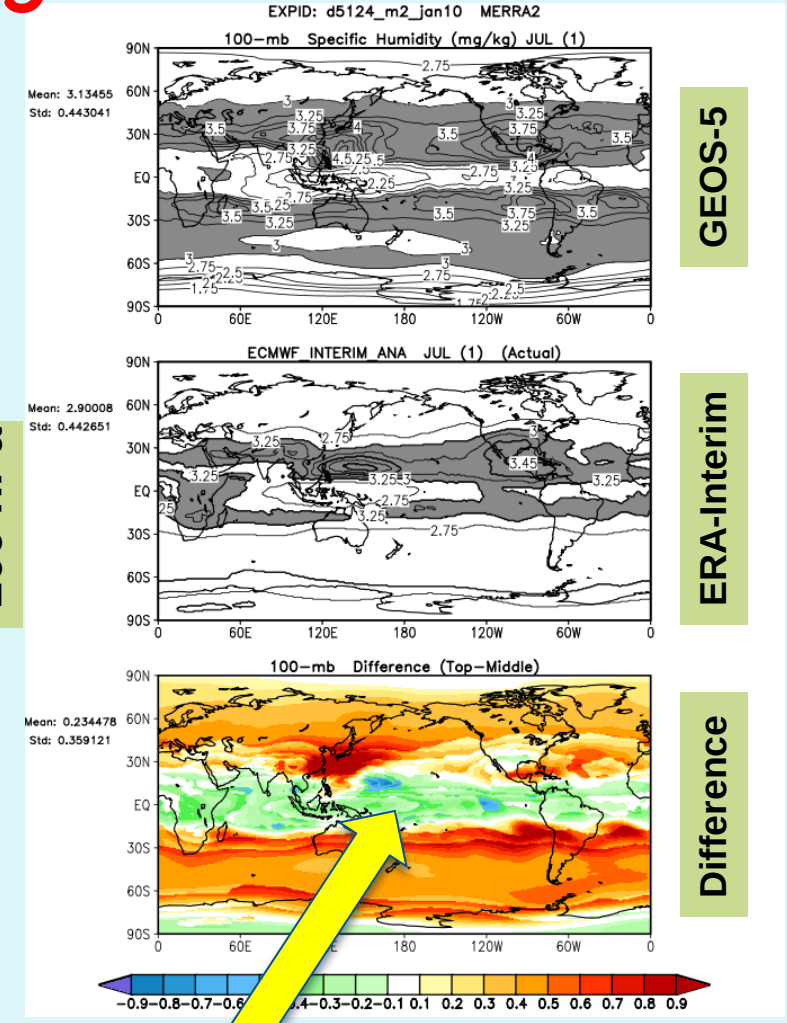
Talk topics

- The chronic water vapor problem in the GEOS-5
- Two possible source and a potential remedy for one
- Motivating science questions
- Overview of cloud processes in GEOS-5
- Methodology: estimating RH_{crit} from aircraft data
- Initial results from TC4: DC-8 and WB-57
- Summary, long-term goals and future work

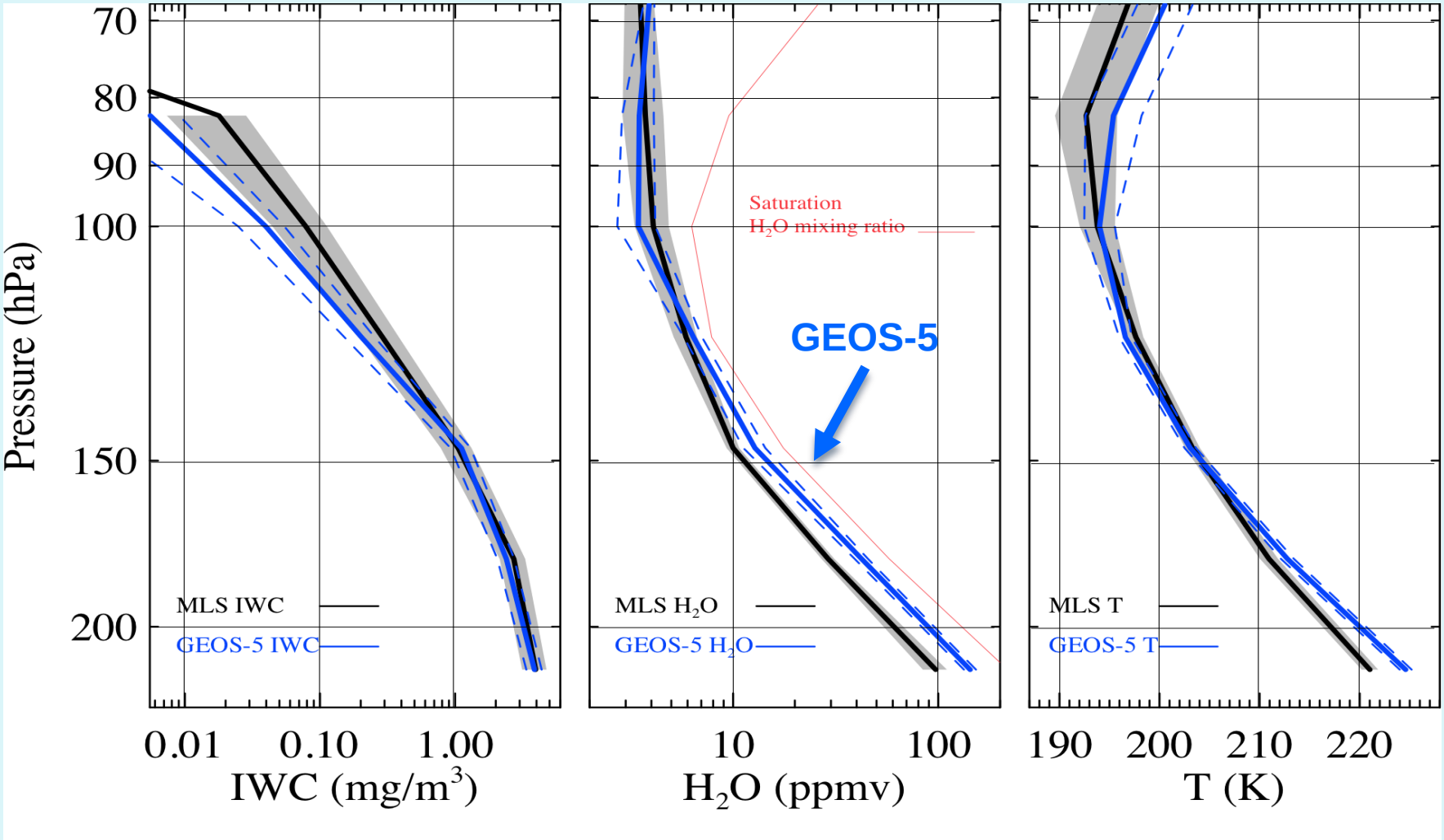
The chronic water vapor problem in the GEOS-5





GEOS-5 tropics are too wet at 300 hPa but too dry at 100 hpa

GEOS-5 vs. MLS


Pressure (hPa)
70
80
90
100
150
200
MLS IWC
GEOS-5 IWC
0.01
0.10
1.00
IWC (mg/m3)
Saturation
H2O mixing ratio
GEOS-5
MLS H2O
GEOS-5 H2O
10
100
H2O (ppmv)
MLS T
GEOS-5 T
190
200
210
220
T (K)

Two possible causes of the problem:

- ***Convective scheme not lofting condensate high enough***
  - **Evidence from ice water**
  - **Evidence from CO**
  - **Suggestions from TOA radiative balance (OLR, SW)**
  - ***At high-res (7 km) with RAS turned way down, problem goes away!***
- ***Vertical distribution of condensation processes not properly captured***
  - **Currently extrapolating AIRS results into UT where AIRS provides little information**
  - **Need more observations in upper troposphere**

Motivating Science Questions

- What physical processes control the water budget in the upper troposphere and lower stratosphere?
- What is the relationship between thin, cold clouds and supersaturation?
- Given depletion of vapor by numerous small ice particles, are there really extended regions of supersaturation?
- What are the causes of the fine structure of water vapor and what are the implications for cloud formation?
- How will each of these respond to a warming atmosphere?

Large-scale cloud processes and sub-grid scales in GEOS-5

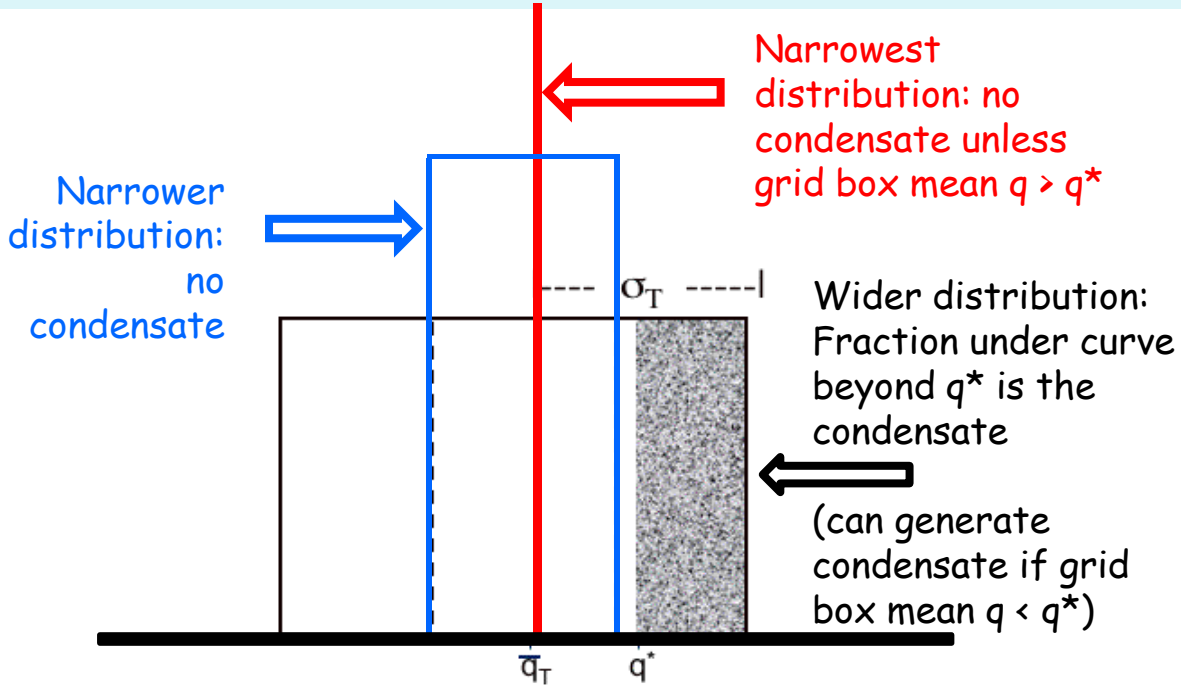
- Like many AGCMs, in GEOS-5 a simple, two-parameter "Top-hat" PDF distribution relates grid-scale q and cloud fraction to subgrid-scale variations of q
- Vertical variation of top hat PDF width obtained with information from AIRS
- But AIRS provides no real information above 300 hPa, so current PDF falls back to a simple extrapolation

The PDF formalism

- q_T - total specific humidity
- $q^*(T)$ - grid-box mean saturation specific humidity
- $P(q_T)$ – the distribution of q_T within the grid box
- Cloud fraction (C_f)
  - the portion of a model grid box where $q_T > q^*(T)$
  - formally expressed as integral of P(q) from q* to infinity
- PDFs such as the "Top Hat" are simplification of $P(q_T)$
  - Width of PDF is standard deviation of q_T or $sigma_T$
  - Define $RH_{crit} = 1 - sigma_T / q^*(T)$

=> RH_{crit} is the threshold for condensation in a grid box expressed in terms of the grid-scale quantities, i.e. condensation if RH > RH_{crit}

"Top-hat" PDF parameterization



$RH_{crit} = 1 - sigma_T / q^*(T)$

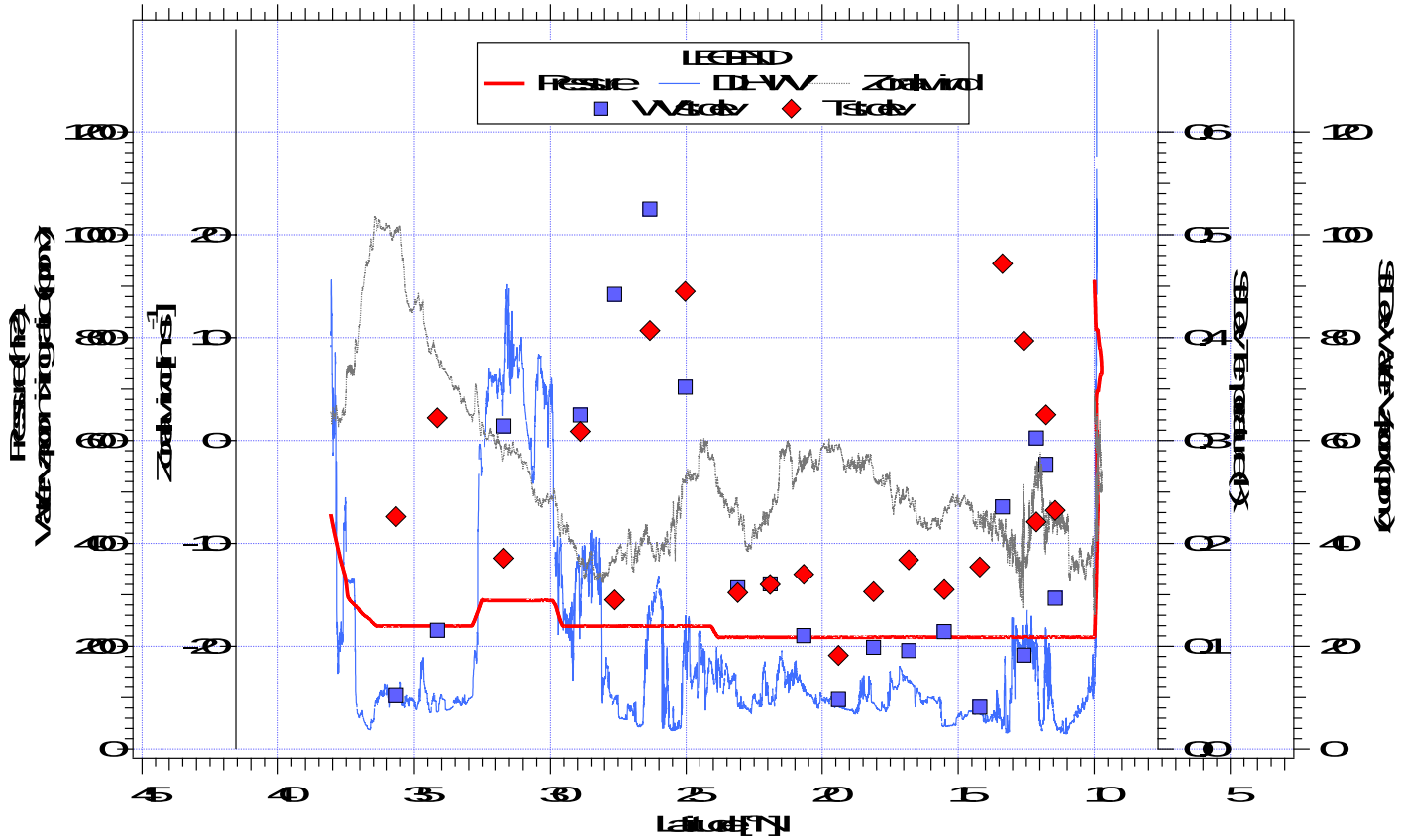
Other distributions in the literature, but derived parameters from CRM:

- **Triangular – need 3 parameters (assymetry)**
- **Beta – need 4 parameters**

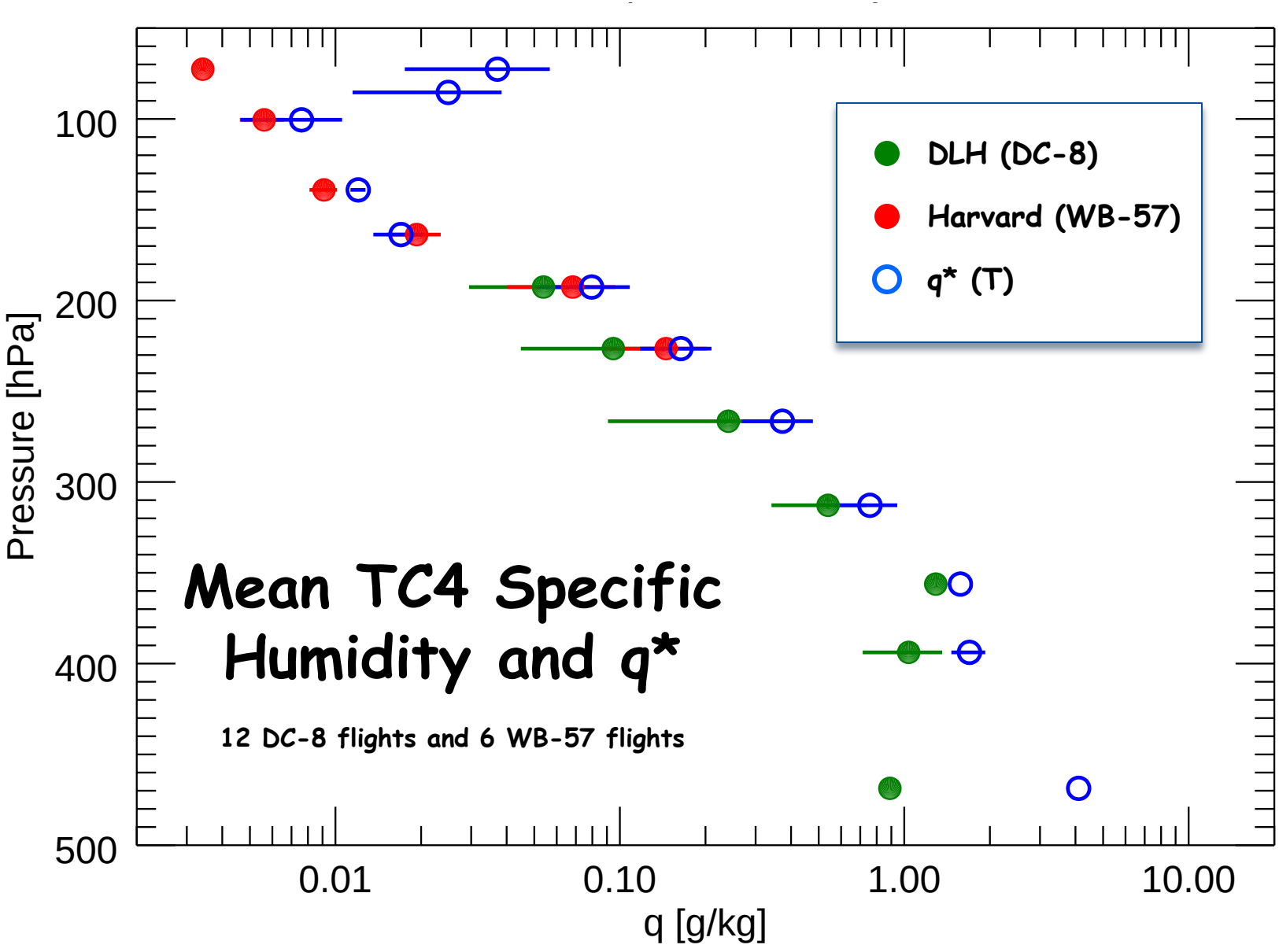
Estimating RH_{crit} with aircraft observations

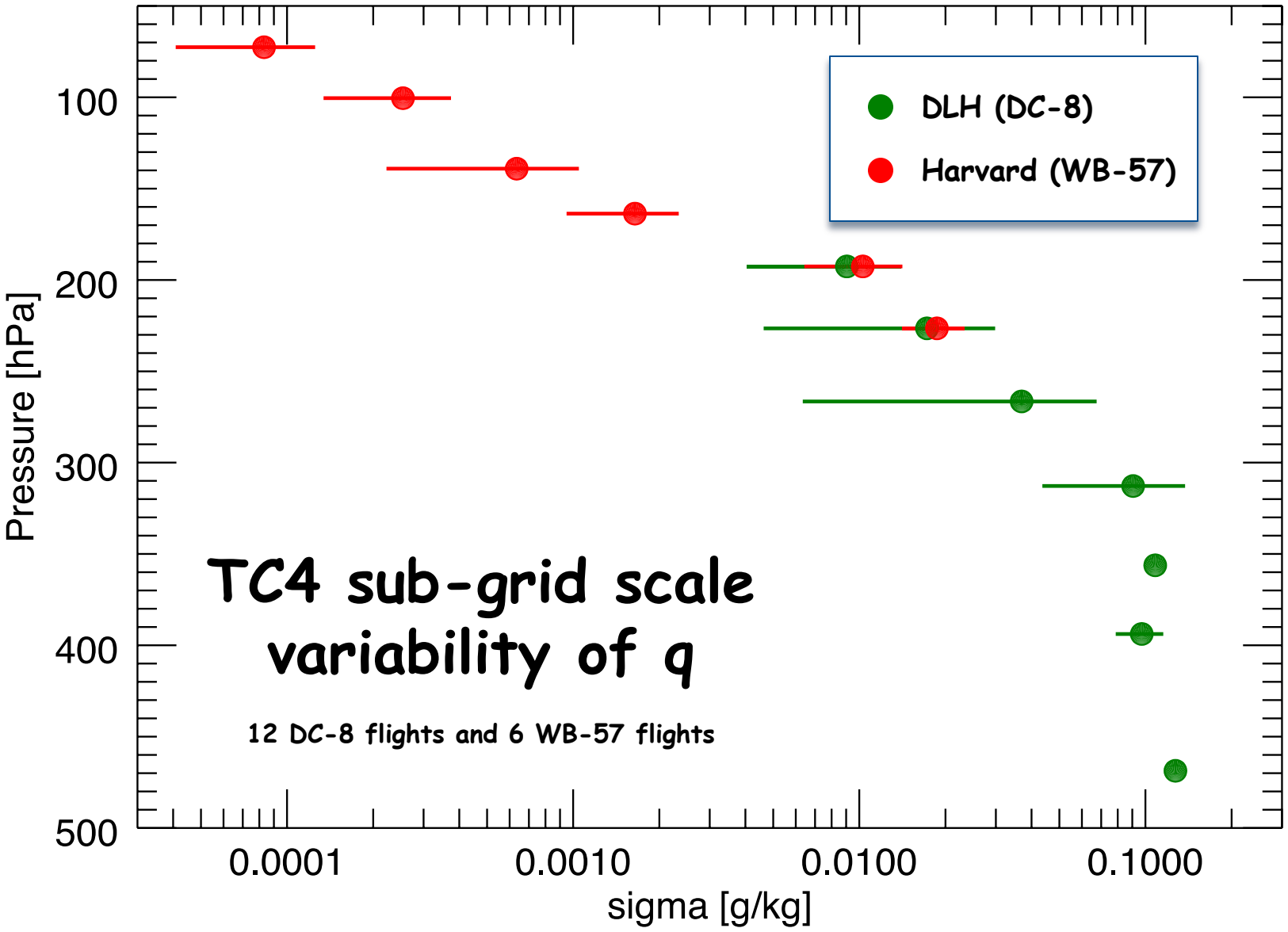
1. Break aircraft flights into level-leg segments equal to model resolution (e.g. 100 km for 1° x 1°)
2. Estimate sub-grid scale variability in segment with sigma, the standard deviation of specific humidity q
3. Estimate large-scale saturation specific humidity q* in segment
4. Derive RH_{crit} = 1- sigma/q*

Example of DC-8 transit, Dryden to Costa Rica

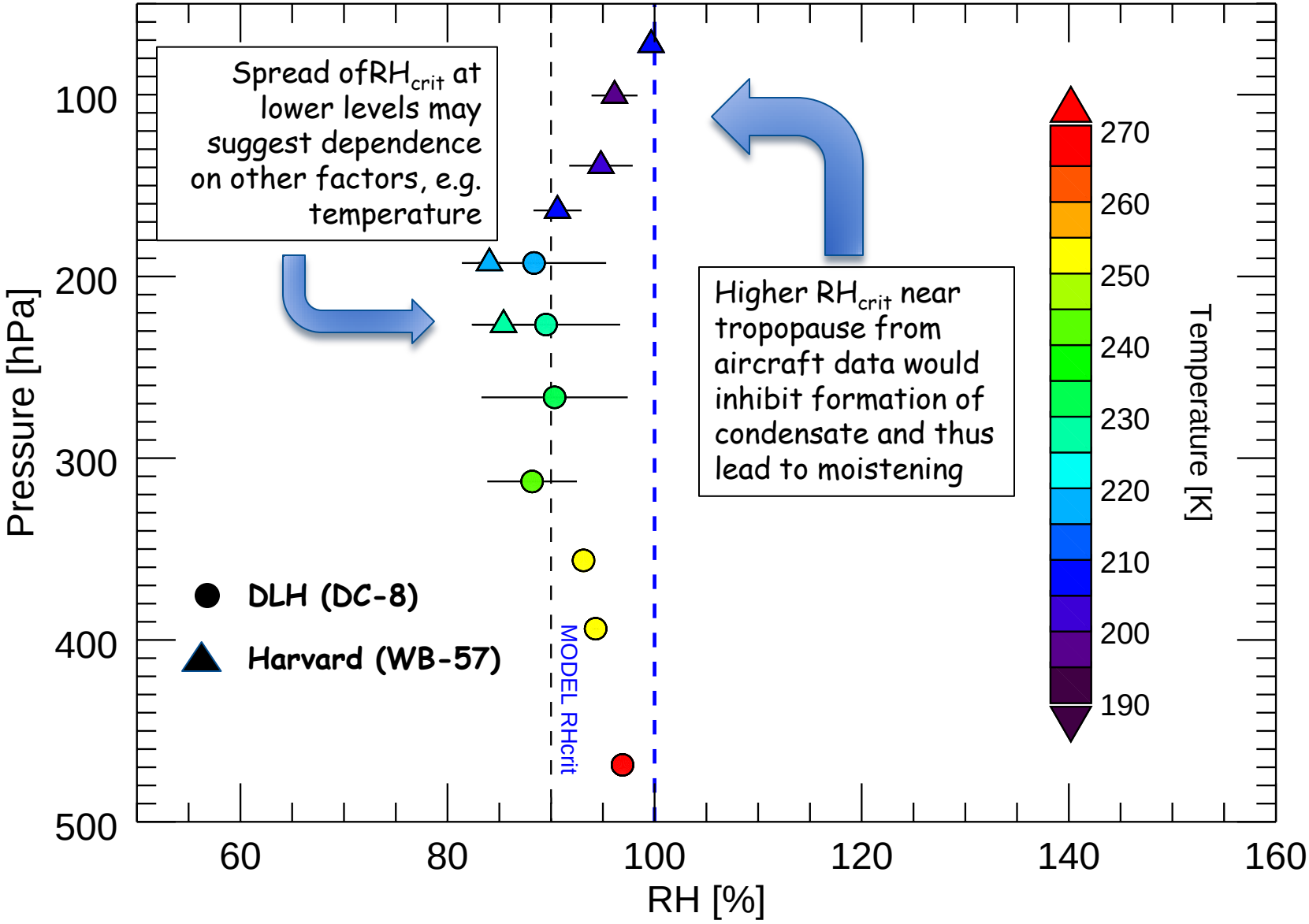


DLH WV mixing ratio and standard deviation (ST DEV) of water vapor and temperature for 200-km on the DC-8 transit, NASA Dryden to Costa Rica, 13 July, 2007. Also plotted are flight-leg pressure and the zonal wind.


Mean TC4 Specific Humidity and q*
12 DC-8 flights and 6 WB-57 flights
DLH (DC-8)
Harvard (WB-57)
q* (T)
Pressure [hPa]
100
200
300
400
500
0.01
0.10
1.00
10.00
q [g/kg]


DLH (DC-8)
Harvard (WB-57)
TC4 sub-grid scale variability of q
12 DC-8 flights and 6 WB-57 flights
Pressure [hPa]
100
200
300
400
500
0.0001
0.0010
0.0100
0.1000
sigma [g/kg]

RH_{crit} estimates from TC4



Summary

- GEOS-5 has a chronic problem of excess moisture at 300 hPa and above in tropics but too little at trop
- Improvement may come by informing PDF parameterization of condensation through estimates of RH_{crit} profile with aircraft water vapor measurements
- Have done this for a single tropical airborne mission (TC4)
- Encouraging results:
  - Higher RH_{crit} than AIRS-based estimate near the tropopause (above 200 hPa) should lead to moistening
  - Below 200 hPa seeing spread of estimates, suggesting different large-scale condensation regimes

Long-term goals

- Reduction of tropical UT wet bias of GEOS-5
- Improved TOA radiative balance
- Improve moisture at tropical tropopause
- With new microphysical scheme, achieve better understanding of water vapor budget & microphysical processes in tropical UT/LS
- Improved model fields for better interpretation of airborne measurements

Carrying on…

- ATTREX/CONTRAST/CAST provide an extraordinarily rich database of water vapor measurements, particularly in the "gap" between the DC-8 and high-altitude platforms
- Other missions, other environments & seasons: CR-AVE, MACPEX, SEAC4RS, HIPPO
- Model runs and validation with observational data
- Analysis of remote sensing data for sub-grid variability
  - CPL data
  - CALIPSO overpasses of opportunity
- Develop state-dependent PDF parameterization for large-scale models (probably not a simple top-hat)