Utilizing Aura MLS and other A-Train Datasets for IPCC AR5 Climate Model Evaluation

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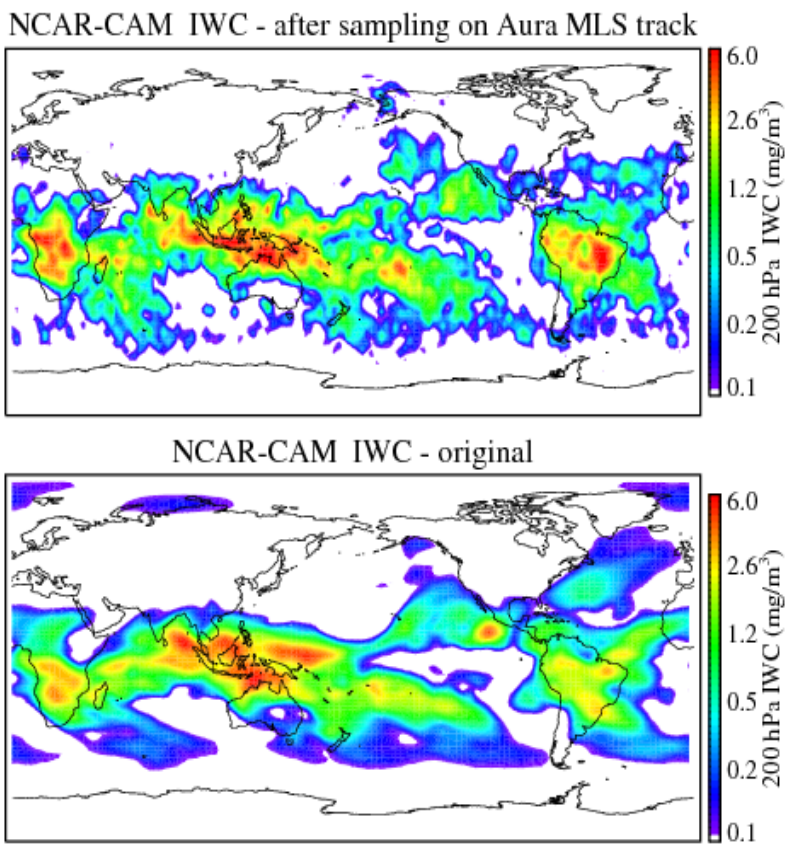
Objective

To utilize A-Train datasets to evaluate model simulations of water vapor and clouds in the CMIP5 and thus contribute to the IPCC AR5

- **Comparing collocated model output with A-Train observations**
  - Sampling 3-hourly (or, less ideally, 6-hourly) model output in A-Train measurement locations in space and time
  - Applying vertical averaging kernels
  - Creating gridded data (e.g. monthly mean) for both the collocated model output and satellite observations
    - Perform model-observation comparisons in terms of global (and tropical) distributions (monthly and longer-time averaged maps, zonal-mean and tropical mean profiles) and temporal evolutions (latitude-time section, height-time section, longitude-time section)
    - Examine relationships among different parameters and also with large-scale variables (e.g. SST).
- **Conditional Sampling: Sorting collocated modeled and observed parameters by large-scale variables to study the linkage of clouds and water vapor with environmental conditions**
  - Sorting by multiple parameters
  - Examining joint distributions of multiple parameters
  - Decomposing the dynamic and thermodynamic components

Importance of using collocated model output

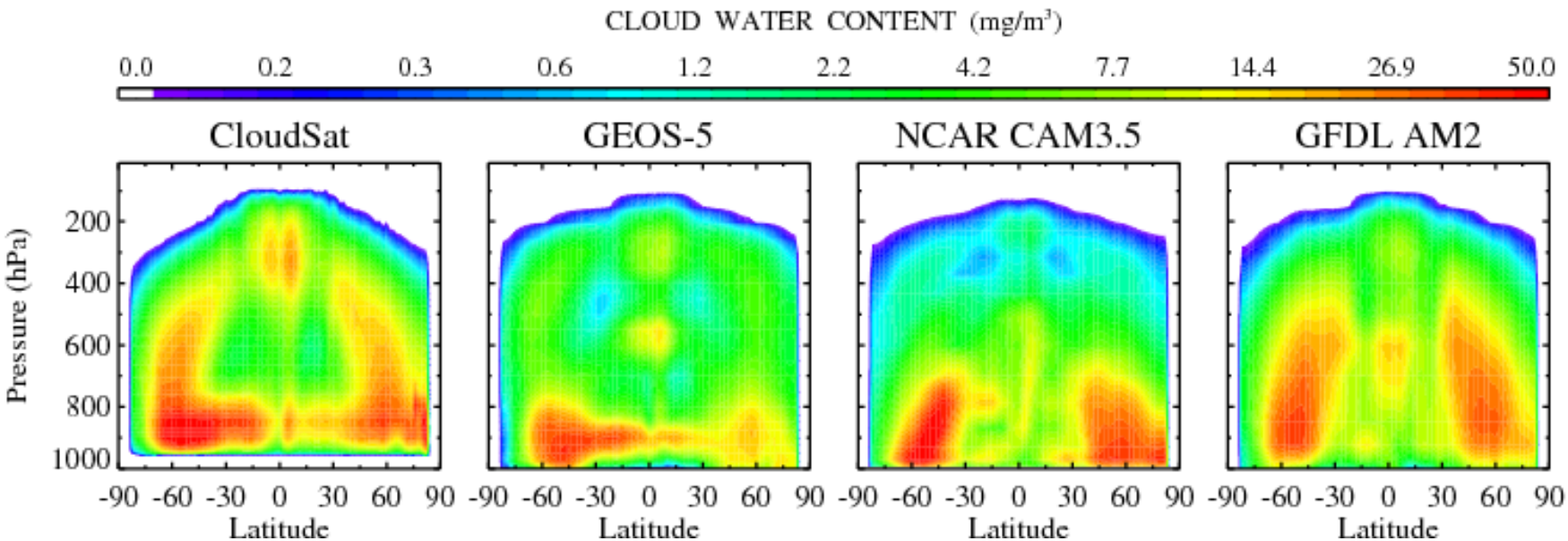


- **It is imperative to ensure consistent spatial and temporal samplings between model output and satellite measurements, and application of measurement averaging kernels to modeled vertical profiles, for a fair comparison**

- The differences between sampled and un-sampled model results are largest over land:
  - ΔIWC > 200%; ΔH_2O ~10-30%; ΔT ~ 0.5 K
- The difference between application of and non-application of vertical averaging kernels:
  - ΔIWC ~100%; ΔH_2O ~ 5 to 20%; ΔT ~ 1 K

These differences are preliminary estimates, which are model, instrument, and measurement dependent.

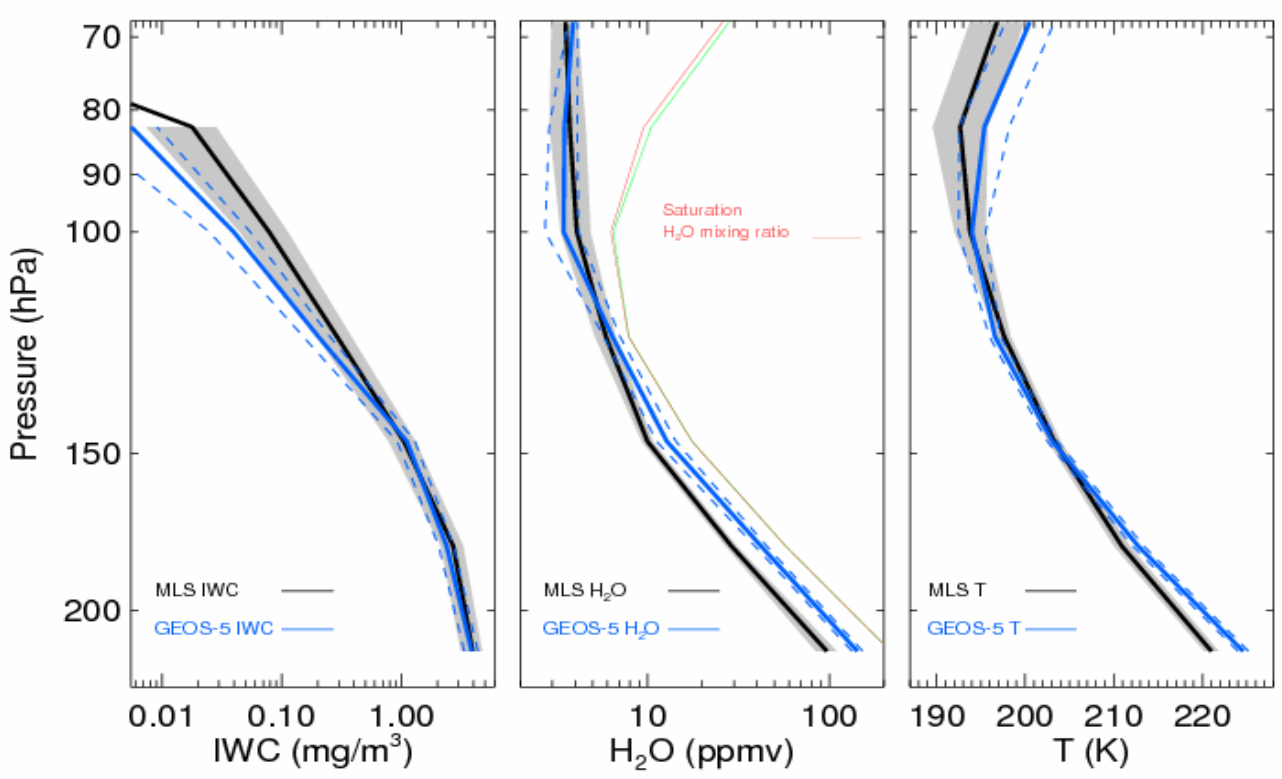
Vertical Profiles



- Global measurements of cloud vertical profiles were not available before A-Train
- Substantial differences exist between observation and model, as well as among the models.
  - Models underestimate the amount of IWC in the tropics. (Based on comparisons of model IWCs with those from MLS, CloudSat & CALIPSO)
  - In the tropics, simulated middle level clouds have different vertical structure among three models, while observation suggests less mid-level clouds.
  - The tropical LWC has an asymmetry between the NH and SH, with larger LWC in the SH. This feature is approximately produced only in GEOS-5.
  - In the mid- and high latitudes, Large CWC values extend beyond the melting-level into the upper troposphere in CloudSat and AM2, while GEOS5 and CAM3 are more confined below 500 hPa.
- It is important to document uncertainties and errors for the observed parameters.

Su, H. et al., Comparison of Regime-Sorted Tropical Cloud profiles Observed by CloudSat with General Circulation Model Simulations, *J. Geosphys. Res.*, 2010, submitted.

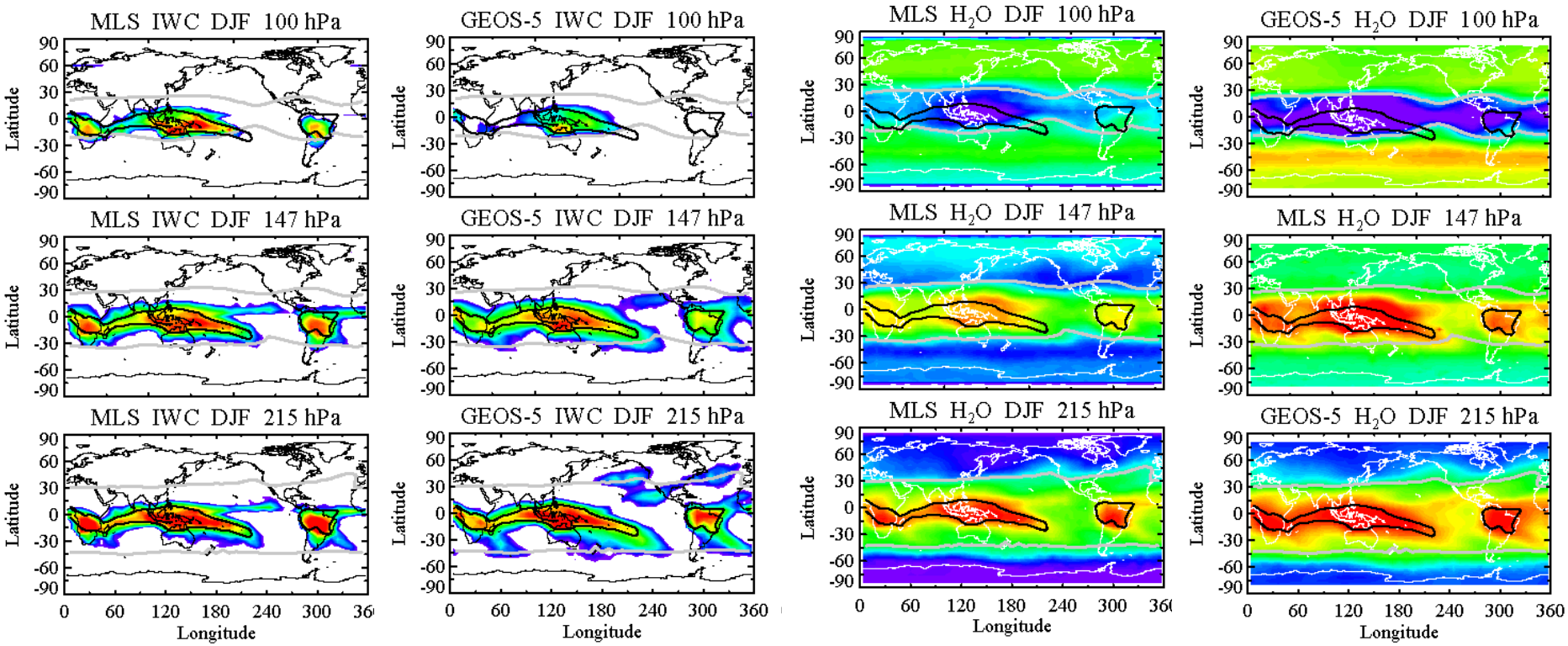
Upper Tropospheric IWC, H_2O, T



- **IWC:** Agreement between MLS and GEOS-5 at 215 hPa to 147 hPa are within 15%. At 100 hPa, GEOS –5 produces ~50% less IWC. (*MLS IWC uncertainty is 200%*)
- **H_2O:** GEOS-5 H_2O is ~50% and ~30% larger than MLS values. At 100 hPa, GOES-5 produces 15% less H_2O and ~20% more H_2O in the extratropics. (*MLS H2O accuracy is ~ 20%*)
- **T:** GEOS-5 tropical mean T is higher by ~ 3 K than MLS T at 215 hPa . But the agreements ate within 0.5 K at 147 hPa to 100 hPa. (*MLS T has low bias of ~2 K at 215 hPa and of ~0.5 K at 147 hPa*)

Jiang et al., Five-year (2004-2009) Observations of Upper Tropospheric Water and Cloud Ice from MLS and Comparisons with GEOS-5 analyses, *J. Geosphy. Res.*, doi: 10,1029/2009JD13256, 2010

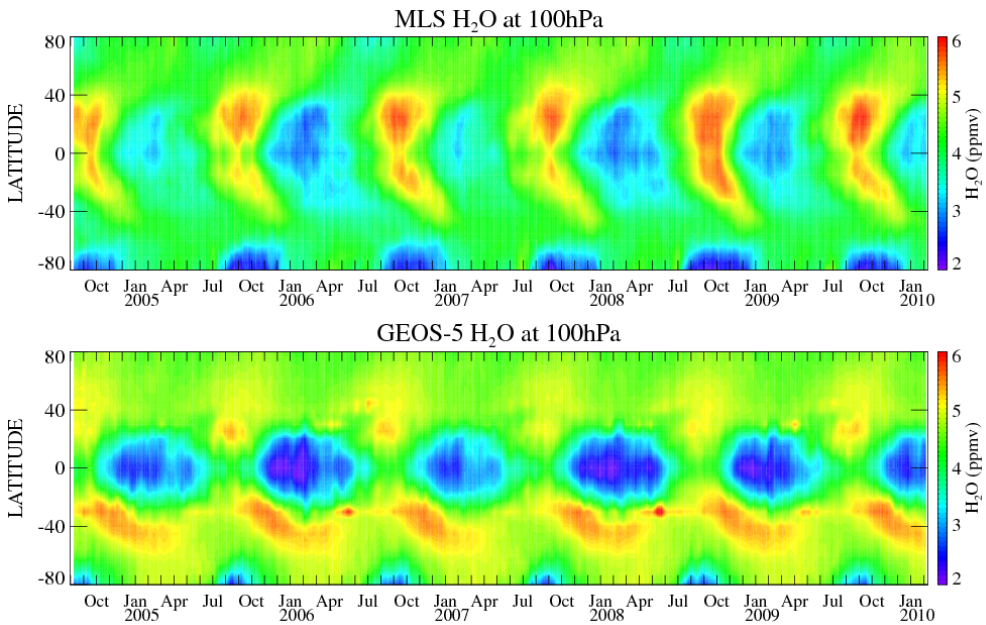
Global Distributions



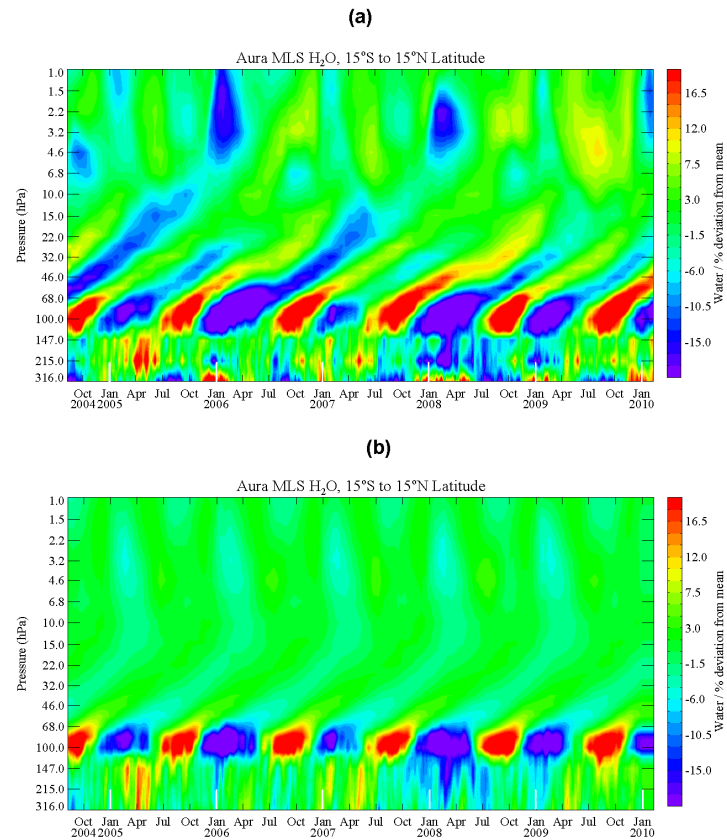
- **IWC:** GEOS-5 produces weaker convection over the land (e.g. South America) and weaker ITCZ than MLS
- **H_2O:** GEOS-5 H_2O is ~50% (215hPa) and ~30% (147hPa) larger than the MLS values. At 100hPa, GOES-5 produces 15% less H_2O in the tropics. The high H_2O in the subtropics seen in the GEOS-5 is unrealistic.

Jiang et al., Five-year (2004-2009) Observations of Upper Tropospheric Water and Cloud Ice from MLS and Comparisons with GEOS-5 analyses, *J. Geosphy. Res.*, doi: 10,1029/2009JD13256, 2010.

Time series



- Latitudinal transport is evident in MLS H_2O observations, but not captured by GEOS-5.



- Vertical transport is captured by GEOS-5, but the attenuation of the "tape-recorder" signal in GEOS5 arises because of its relaxation of stratospheric water vapor to zonal-mean monthly averages.

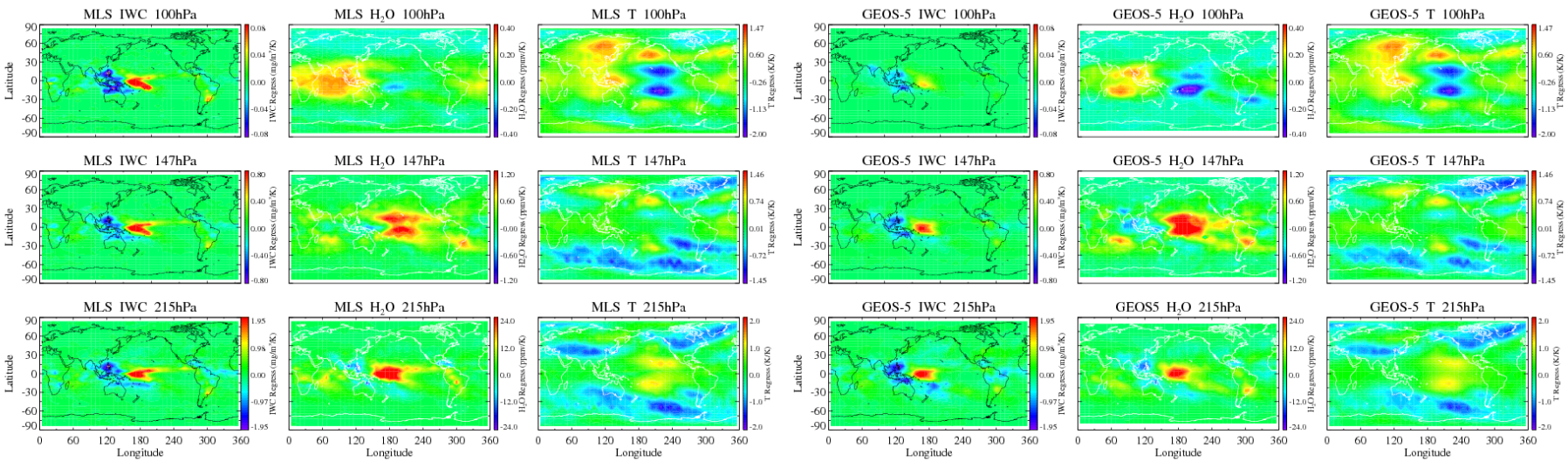
Jiang et al., Five-year (2004-2009) Observations of Upper Tropospheric Water and Cloud Ice from MLS and Comparisons with GEOS-5 analyses, *J. Geosphy. Res.*, doi:10,1029/2009JD13256, 2010.

Response to El Nino

Regression of UT DJF IWC, H_2O, and T anomalies to Nino3.4 SST

MLS

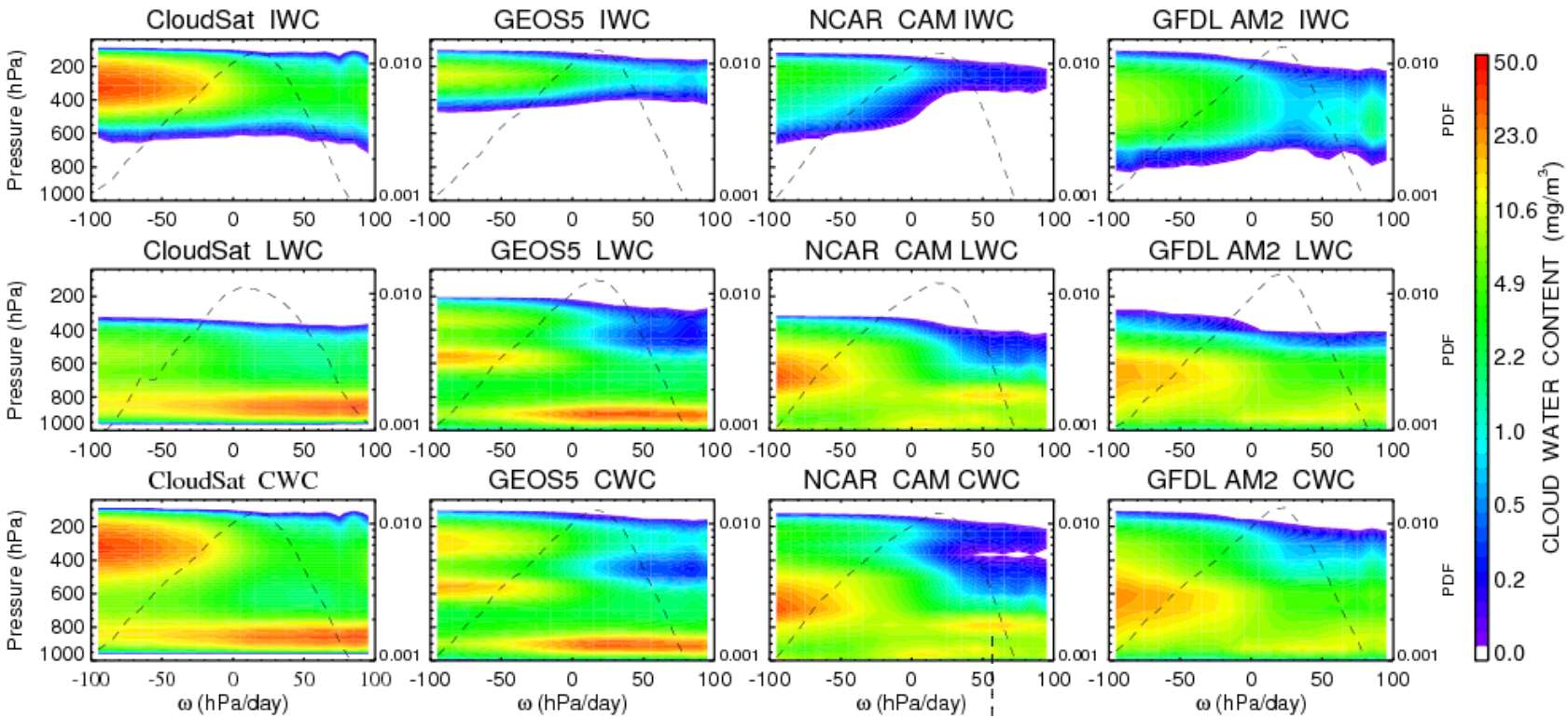
GEOS-5



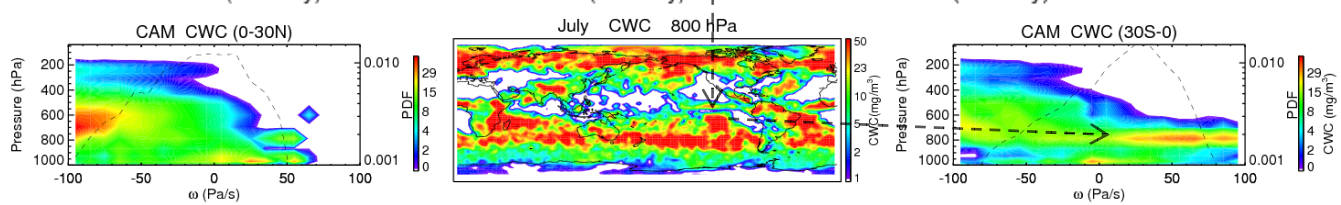
- The upper tropospheric IWC, H_2O and T interannual variations, from both MLS and GEOS-5, show clear ENSO imprint
- A typical dipole pattern is seen in IWC and H_2O at 215 hPa and 147 hPa with positive anomaly in the central Pacific and negative in the western Pacific.
- At 100 hPa, a positive IWC anomaly and a negative H_2O anomaly in the central Pacific are accompanied by anomalies of opposite sign in the western Pacific.
- GEOS-5 captures the ENSO response but with different magnitudes.

Jiang et al., Five-year (2004-2009) Observations of Upper Tropospheric Water and Cloud Ice from MLS and Comparisons with GEOS-5 analyses, *J. Geosphy. Res.*, doi: 10,1029/2009JD13256, 2010T

Relationship between cloud structure and large-scale dynamics



An investigation of CAM's two-layer low cloud structure



- **Observation:** Clear separation of high and low clouds in large-scale ascending and descending regimes;
- **GEOS-5:** A tri-modal cloud structure, high and middle liquid clouds are both in the ascending regime;
- **CAM:** Liquid mid-clouds in ascending regime; two low cloud layers (surface, 800 hPa), both in the descending regime;
- **AM2:** Liquid mid-clouds in ascending regime.

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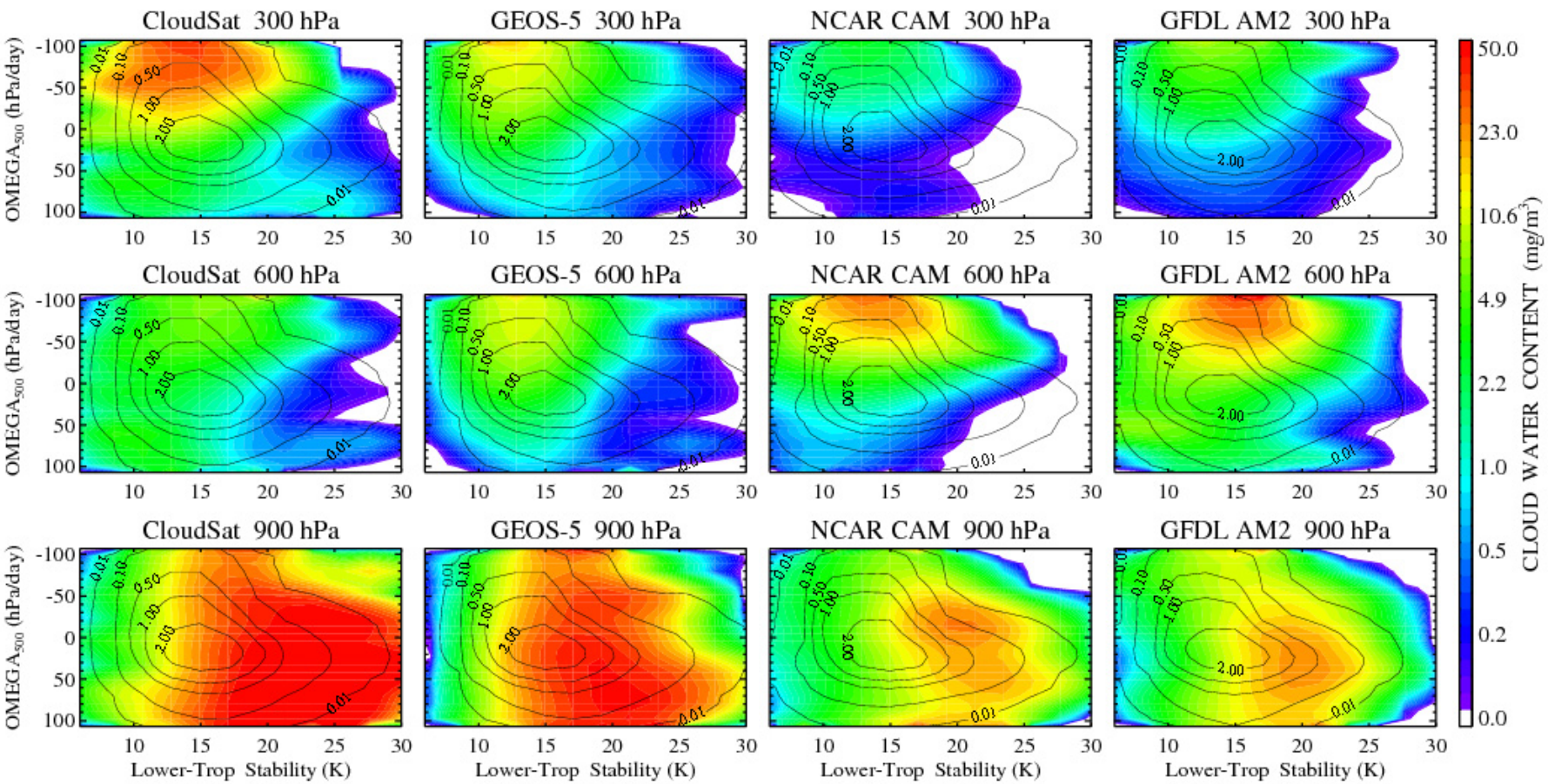
Bi-Variate Composite (BVC) analysis



- **Observation:** High/mid-clouds are mostly located in upwelling and low LTS regimes; Least cloud amount at 600hPa;
- **GEOS-5:** Closest match to the observation, although the amount of IWC is much less.
- **CAM:** Large mid-clouds; low clouds are distributed in a narrower range of ω_{500} and LTS than observation;
- **AM2:** Mid-cloud dominate, low clouds are distributed in a narrower range of ω_{500} and LTS than observation.

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Table 1: Available IPCC AR5 Models

Model	Center
BCC-AGCM2.1[Ŧ]	Beijing Climate Center, China
BCCR-BCM3	Bjerkes Centre for Climate Research, Norway
CCSM4[Ŧ]	**National Center for Atmospheric Research, USA**
CGCM4 (T47, T63)	Canadian Centre for Climate Modeling & Analysis, Canada
CNRM-CM4	Centre National de Recherches Meteorologiques, France
CSIRO-MK4	Commonwealth Scientific & Industrial Research Org., Australia
ECHAM6/MPI-OM	Max Plank Institute for Meteorology, Germany
ECHO-G	Meteorological Research Institute of the Korea, South Korea
FGOALS-g2	Institute of Atmospheric Physics, China
GEOS5-AGCM[Ŧ]	**NASA Goddard Space Flight Center/GMAO, USA**
GFDL-CM3[Ŧ]	**NOAA/Geophysical Fluid Dynamics Laboratory, USA**
GISS-ModelE[Ŧ]	**NASA/Goddard Institute for Space Studies, USA**
INM-CM4	Institute for Numerical Mathematics, Russia
IPSL-CM4	Institut Pierre Simon Laplace, France
MIROC4 (T106, T42)	Center for Climate System Research (U Tokyo) & JAMSTEC, Japan
MRI-CGCM3	Meteorological Research Institute, Japan
PCM	National Center for Atmospheric Research, USA
UKMO-HadCM4/GEM2	Hadley Centre for Climate Prediction & Research, UK

[Ŧ]The 3-hourly model outputs have been or will soon be provided to this project. We welcome all other AR5 models to provide 3-hr outputs of QI, QL, QV, T, LTS, WVP, WINDS (U,V, Omega), CAPE, SST, Precipitation to be evaluated by satellite observations.

Summary

- Collocated A-Train observations of clouds and H_2O are used to evaluate climate models, particularly for the CMIP5/IPCC AR5.
- It is important to interpolate time-resolved model output onto the A-Train satellite measurement locations in space and time, and apply measurement averaging kernels to modeled vertical profiles, for a fair comparison.
- Both the traditional comparison method (e.g. geographical distributions, zonal-mean and tropical mean profiles, and temporal evolutions) and the new conditional sampling technique are effective tools in model evaluations.