AIRS and MJO

Baijun Tian

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Judicious Use of AIRS Data for Climate Model Evaluation

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Outline

Tian, B., E. Fetzer, B. Kahn, J. Teixeira, E. Manning, and T. Hearty, 2013: Evaluating CMIP5 Models using AIRS Tropospheric Air Temperature and Specific Humidity Climatology, *J. Geophys. Res.*, **118**, D50117, 114-134, doi: 10.1029/2012JD018607.

Hearty, T., A. Savtchenko, **B. Tian**, E. J. Fetzer, Y. Yung, M. Theobald, B. Vollmer, E. Fishbein, Y.-I. Won, 2013: Estimating Sampling Biases and Measurement Uncertainties of AIRS/AMSU-A Temperature and Water Vapor Observations using MERRA Reanalysis, *J. Geophys. Res.,* **119**, D?????, doi: 10.1029/2013JD0212205, in press.

Part 1

Tian, B., E. Fetzer, B. Kahn, J. Teixeira, E. Manning, and T. Hearty, 2013: Evaluating CMIP5 Models using AIRS Tropospheric Air Temperature and Specific Humidity Climatology, *J. Geophys. Res.*, **118**, D50117, 114-134, doi: 10.1029/2012JD018607.

CMIP5 and Obs4MIPs

- The model outputs from the CMIP5 experiments provide the basis for the IPCC-AR5.
- To help evaluate the CMIP5 model experiments, NASA and DOE have initiated an Obs4MIPs project to collect well-established and well-documented datasets that have been organized according to the CMIP5 model output requirements and made available on the PCMDI Earth System Grid (ESG) - Center for Enabling Technologies (ESG-CET).

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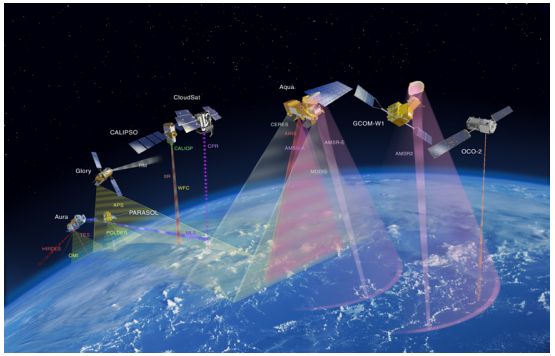
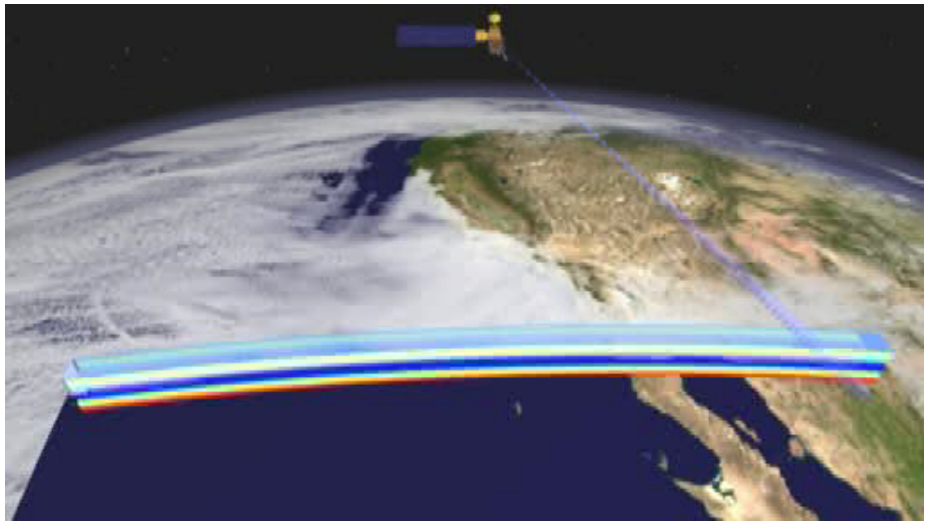
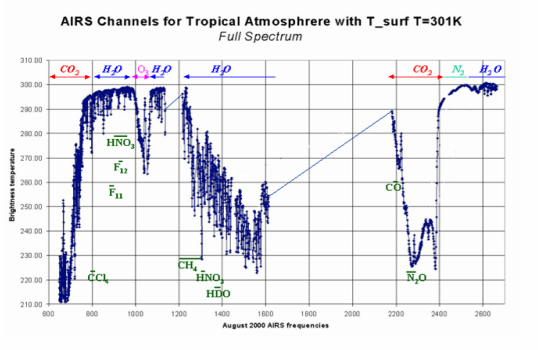
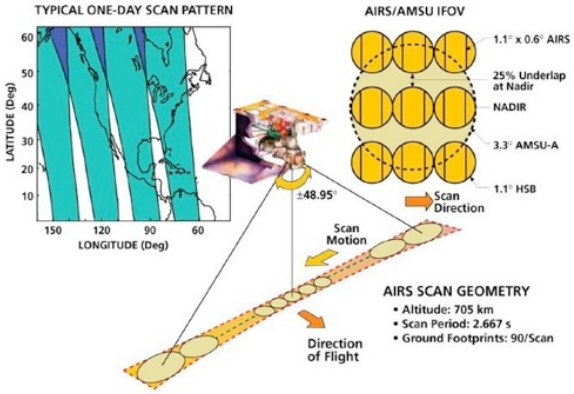
Atmospheric Infrared Sounder

The AIRS/AMSU Instruments









On the NASA A-Train Aqua satellite, AIRS/AMSU is one of several advanced temperature and moisture sounding systems in space now. Through multispectral coverage in infrared and microwave channels, the AIRS/AMSU system obtains vertical profiles of tropospheric temperature and water vapor with vertical resolution of around 2 km, horizontal resolution of 45 km at nadir, twice daily temporal resolution, global coverage, and for cloud cover up to about 70%. Thus, AIRS is a valuable dataset to evaluate climate models in terms of **the vertical structure of tropospheric temperature and water vapor**.

AIRS/AMSU and Obs4MIPs

- The NASA AIRS project produced monthly averaged tropospheric air temperature (ta) and specific humidity (hus) products:
  - For each month from Sept 2002 to May 2011 (time)
  - On a global spatial grid (lon, lat) at 1 degree by 1 degree resolution
  - On the CMIP5 mandatory vertical pressure levels (plev) from 1000 hPa to 300 hPa
- Key Strengths:
  - Global coverage with high horizontal and vertical resolutions and frequent sampling
  - Co-located temperature and humidity measurements
  - Validated against radiosondes, radio occultation data and reanalyses
- Key Weaknesses
  - Inconsistent sampling with latitude
  - Incomplete diurnal cycle coverage
  - Low sampling in cloudy regions

Objective

- The main purpose of this paper is to compare the tropospheric air temperature and specific humidity climatologies between AIRS and CMIP5 model simulations for CMIP5 model evaluation.

16 CMIP5 Models

#	Modeling Center (or Group)	Institution ID	Model Name	Type	Horizontal Resolution	Vertical Resolution	Reference
1	Beijing Climate Center, China Meteorological Administration	BCC	BCC-CSM1.1	ESM	2.8°X2.8° (T42L26)	17 standard pressure levels	Wu et al. (2011)
2	Canadian Center for Climate Modeling and Analysis, Canada	CCCMA	CanESM2	ESM	2.8°X2.8° (T63L35)	22 pressure levels (17 std + 5 ext)	Arora et al. (2011)
3	National Center for Atmospheric Research	NCAR	CCSM4	AOGCM	1.25°X0.9°	17 standard pressure levels (L26)	Gent et al. (2011)
4	Centre National de Recherches Meteorologiques / Centre Europeen de Recherche et Formation Avancees en Calcul Scientifique	CNRM-CERFACS	CNRM-CM5	AOGCM	1.4°X1.4° (T127L31)	17 standard pressure levels	Voldoire et al. (2011)
5	Australian Commonwealth Scientific and Industrial Research Organization in collaboration with Queensland Climate Change Centre of Excellence	CSIRO-QCCCE	CSIRO-Mk3-6-0	AOGCM	1.875°X1.875° (T63)	17 standard pressure levels (L18)	Rotstayn et al. (2010)
6	NOAA Geophysical Fluid Dynamics Laboratory	NOAA GFDL	GFDL-CM3	AOGCM	2.5°X2.0°	23 pressure levels (17 std + 6 ext)	Griffles et al. (2011)
7	NASA Goddard Institute for Space Studies	NASA GISS	GISS-E2-H	AOGCM	2.5°X2.0°	17 standard pressure levels (L40)	
8	NASA Goddard Institute for Space Studies	NASA GISS	GISS-E2-R	AOGCM	2.5°X2.0°	17 standard pressure levels (L40)	Schmidt et al. (2006)

16 CMIP5 Models

#	Modeling Center (or Group)	Institution ID	Model Name	Type	Horizontal Resolution	Vertical Resolution	Reference
9	Met Office Hadley Centre	MOHC	HadGEM2-CC	ESM	1.875°X1.25°	23 pressure levels (17 std + 6 ext)	Jones et al. (2011)
10	Met Office Hadley Centre	MOHC	HadGEM2-ES	ESM	1.875°X1.25°	17 standard pressure levels	Jones et al. (2011)
11	Institut Pierre-Simon Laplace	IPSL	IPSL-CM5A-LR	ESM	3.75°X1.9°	17 standard pressure levels (L39)	
12	Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Atmosphere and Ocean Research Institute (AORI) (The University of Tokyo), and National Institute for Environmental Studies (NIES)	MIROC	MIROC4h	AOGCM	0.56°X0.56° (T213L56)	22 pressure levels (17 std + 5 ext)	Sakamoto et al. (2011)
13	AORI, NIES, and JAMSTEC	MIROC	MIROC-ESM	ESM	2.8°X2.8° (T42L80)	23 pressure levels (17 std + 6 ext)	Watanabe et al. (2011)
14	Max Planck Institute for Meteorology	MPI-M	MPI-ESM-LR	ESM	1.8°X1.8° (T63L47)	25 pressure levels (17 std + 8 ext)	Raddatz et al. (2007)
15	Meteorological Research Institute	MRI	MRI-CGCM3	AOGCM	1.1°X1.1° (T159L48)	23 pressure levels (17 std + 6 ext)	Yukimoto et al. (2011)
16	Norwegian Climate Centre	NCC	NorESM1-M	ESM	2.5°X1.9° (f19L26)	17 standard pressure levels	

Different Sampling btw Satellite Observation and Climate Model Output

- Climate models are sampled on regular spatial and temporal grids while satellite observations are not.
- The AIRS/AMSU instrument suite is on the Aqua spacecraft in a Sun-synchronous low Earth orbit (LEO) with a limited swath width and its sampling of the diurnal cycle and synoptic events is incomplete.
- The AIRS/AMSU instrument suite is mainly an infrared instrument and its sampling is affected by clouds, aerosols, coastlines, and other factors that affect its ability to perform successful retrievals.
- These sampling differences can affect comparisons between the AIRS/AMSU retrievals and climate model outputs.

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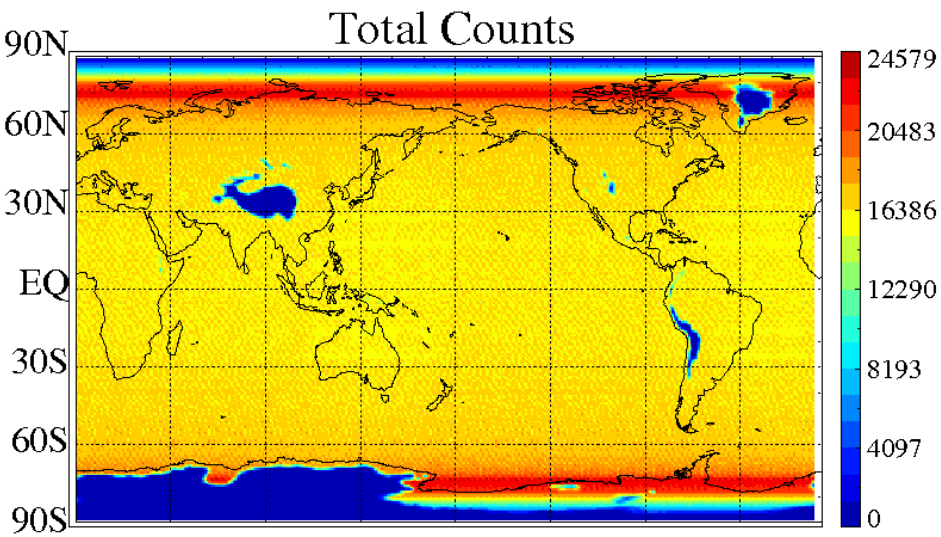
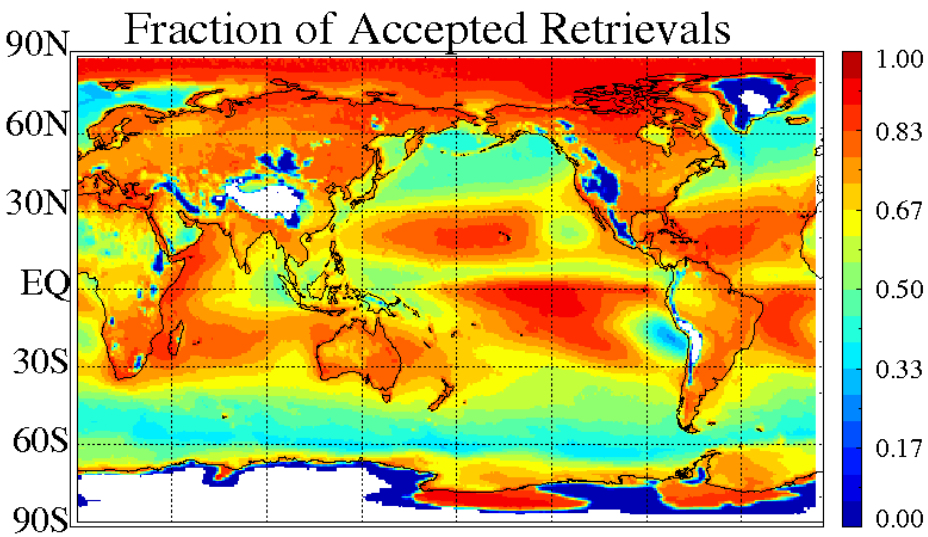
AIRS Sampling Issue





The left panel shows the number of attempted AIRS temperature retrievals at 850 hPa that are included in the 9 year average climatology. The right panel shows the fraction of attempted retrievals that were accepted by the AIRS/AMSU quality control algorithm.

AIRS Data Validation

- We also compare the tropospheric air temperature and specific humidity climatologies between AIRS and Modern Era Retrospective analysis for Research and Applications (MERRA) for data validation and to quantify the AIRS/AMSU satellite observation uncertainties. In this study, we assume the differences between AIRS or MERRA are their combined uncertainties.

Comparison Methodology

- Climatology from AIRS, MERRA and the multi-model ensemble mean (MMEM) of 16 CMIP5 models
- AIRS and MERRA climatology: 9-year mean (09/2002-05/2011)
- CMIP5 model climatology: 20-year mean (01/1986-12/2005) from historical experiments for each model.
- CMIP5 MMEM climatology: the multi-model ensemble mean (MMEM) of 16 CMIP5 model climatology
- On common spatial grid: 3X3 long-lat grids
- On 8 CMIP5 mandatory vertical pressure levels (plev) from 1000 hPa to 300 hPa

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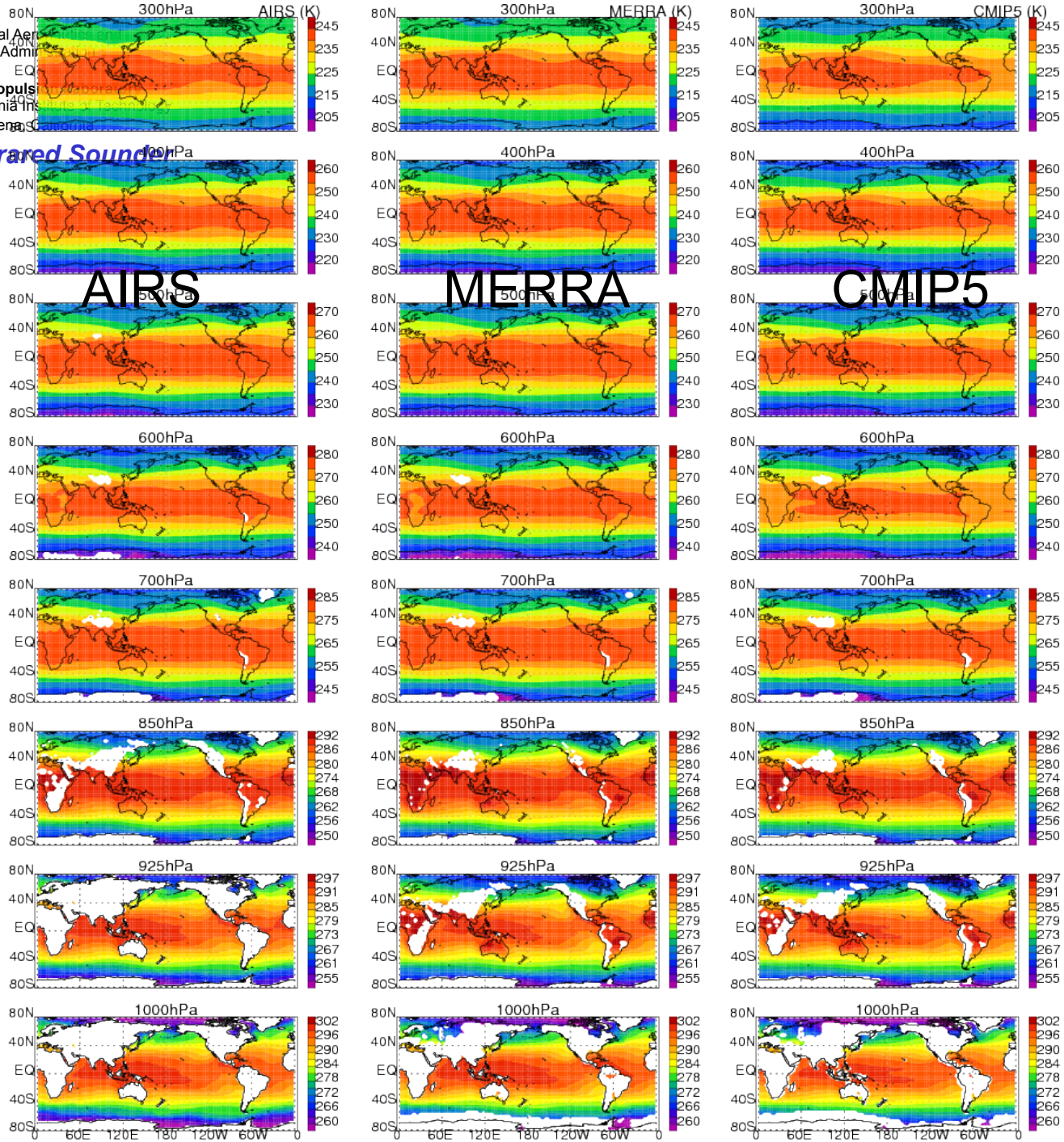


AIRS

MERRA

CMIP5

Temperature (K)

300 hPa

400 hPa

500 hPa

600 hPa

700 hPa

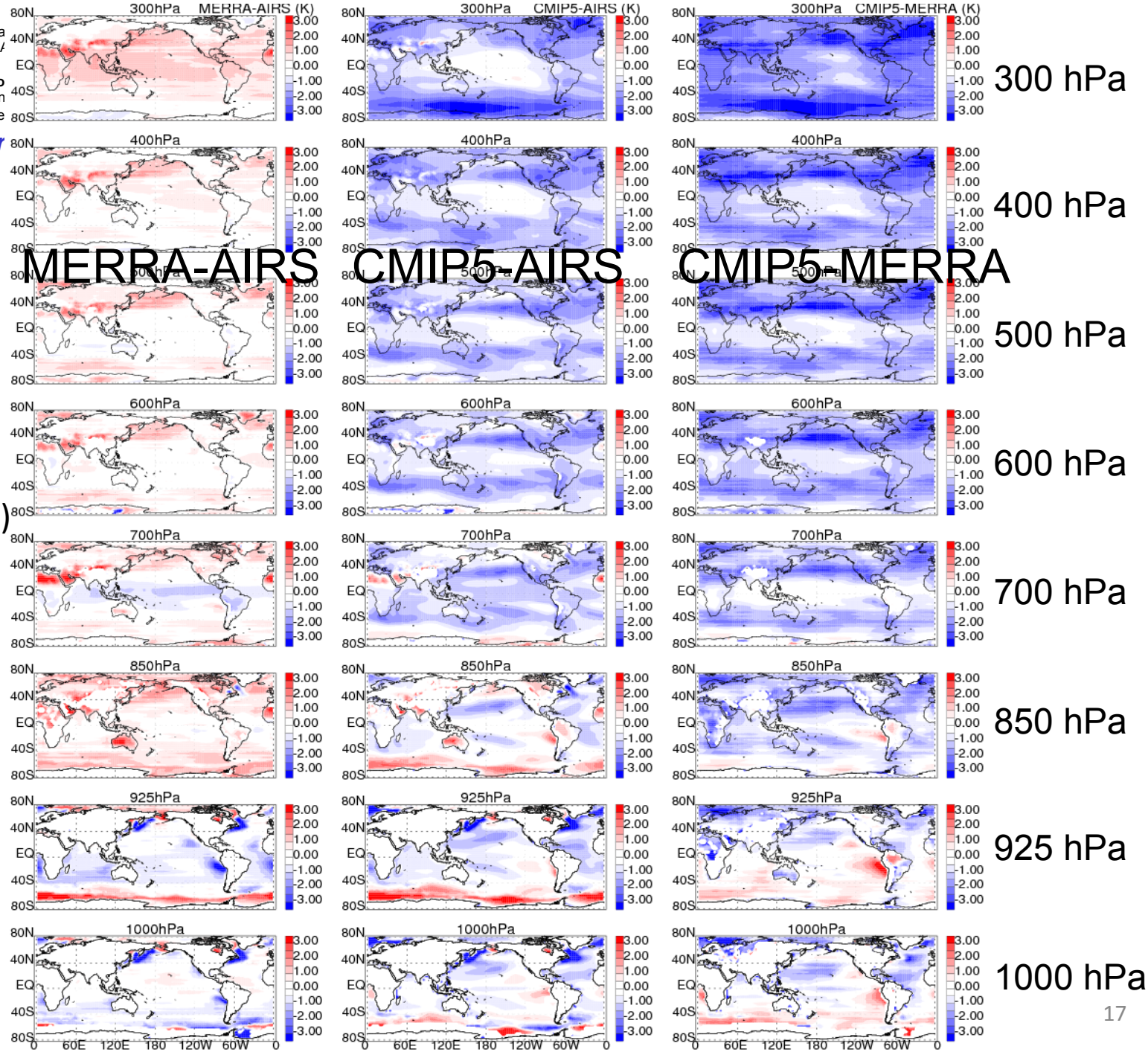
850 hPa

925 hPa

1000 hPa

Atmospheric Infr

Temperature Differences (K)



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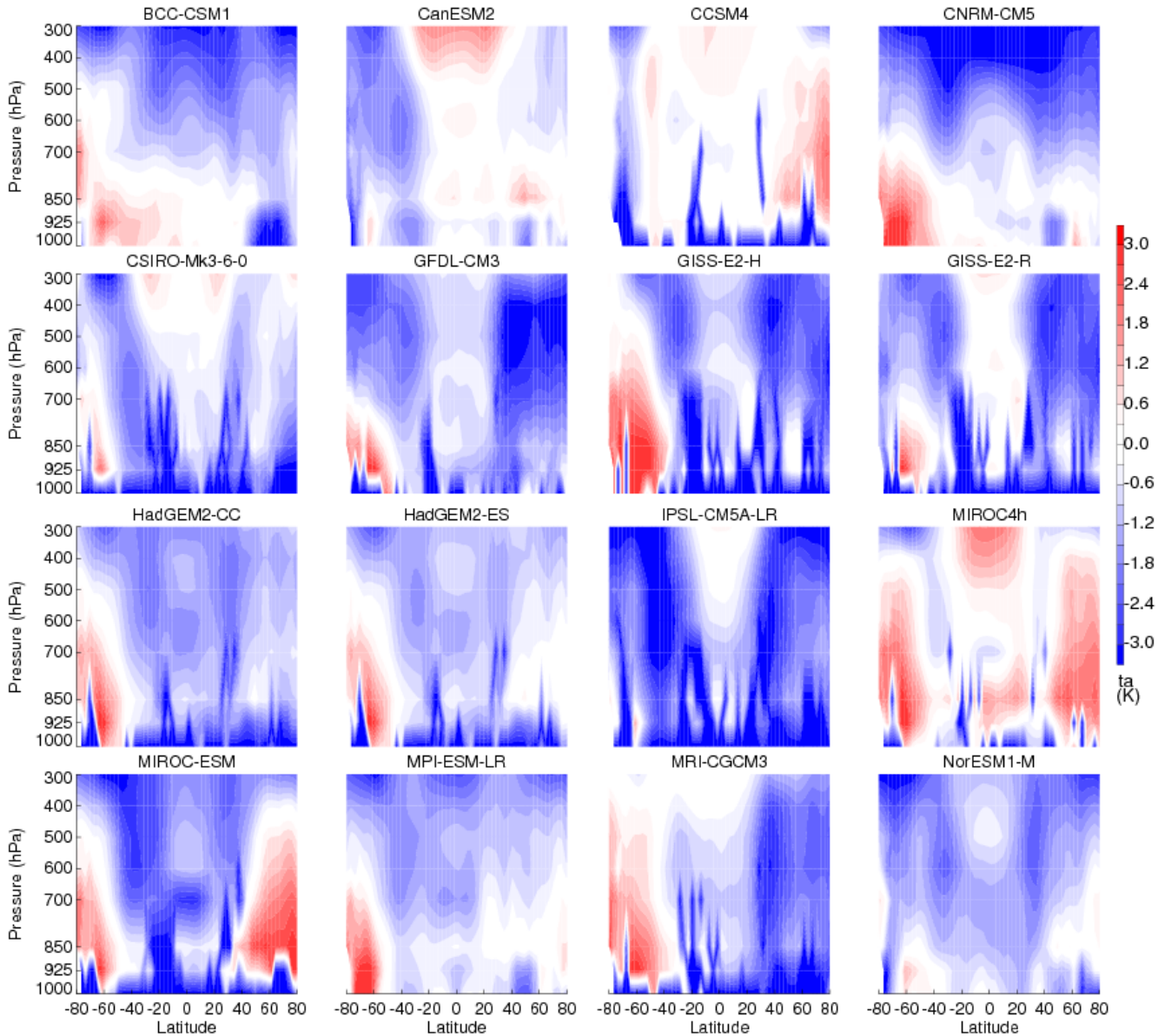
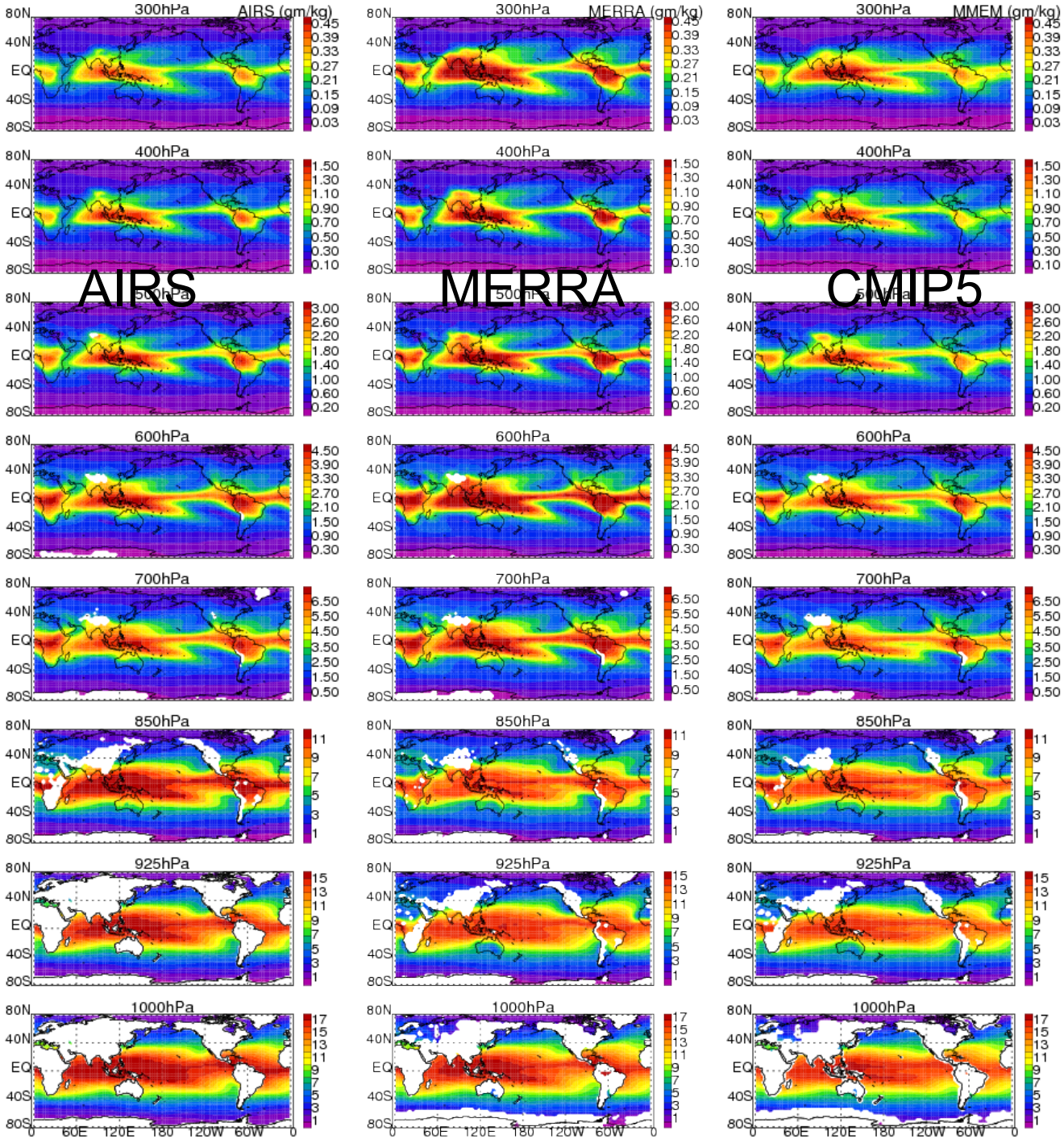
CMIP5-AIRS Temp Differences (K)



Atmospheric Infr

Specific Humidity (g/kg)



300 hPa

400 hPa

500 hPa

600 hPa

700 hPa

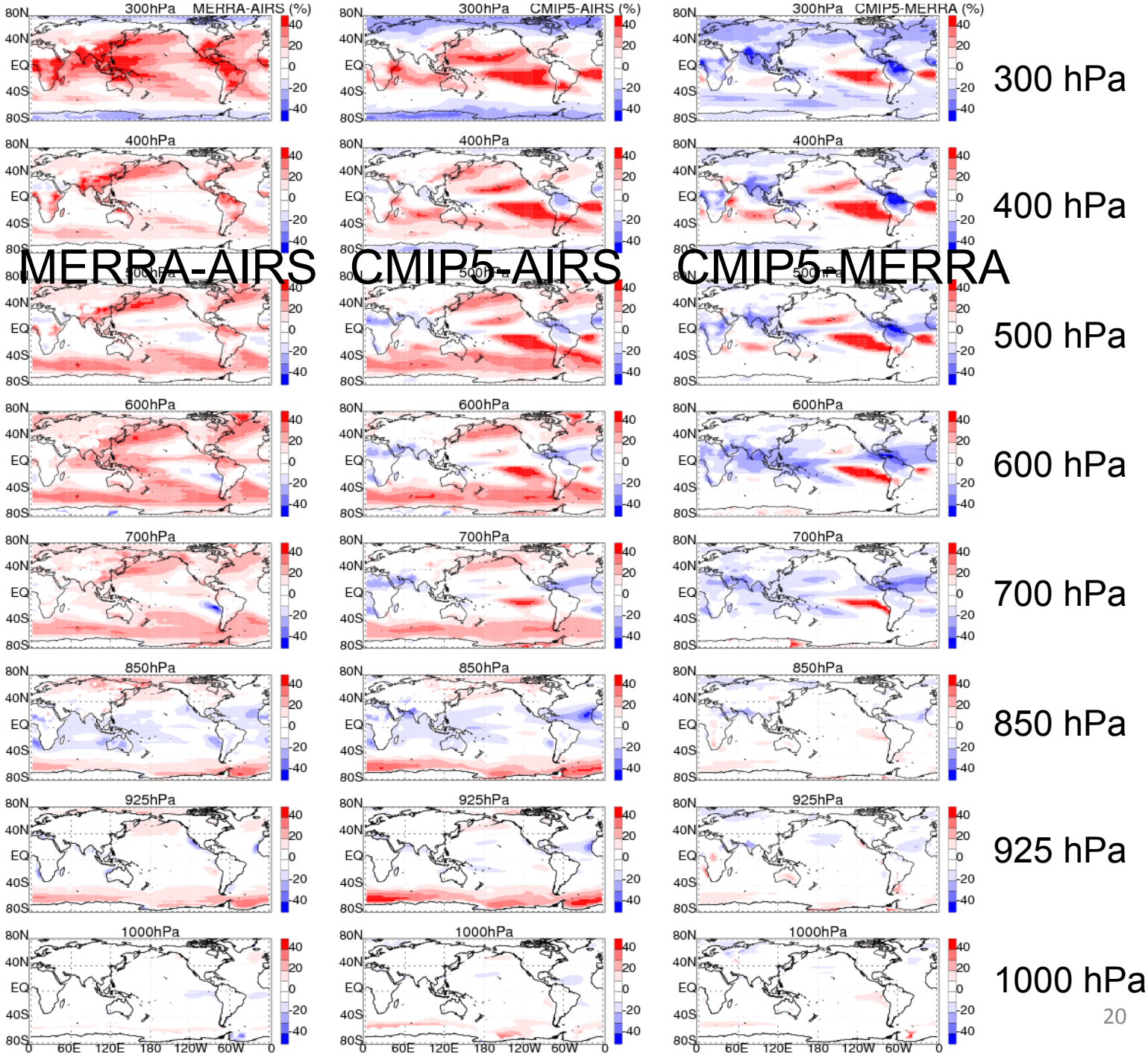
850 hPa

925 hPa

1000 hPa

Atmospheric Infr

Specific Humidity Differences (%)



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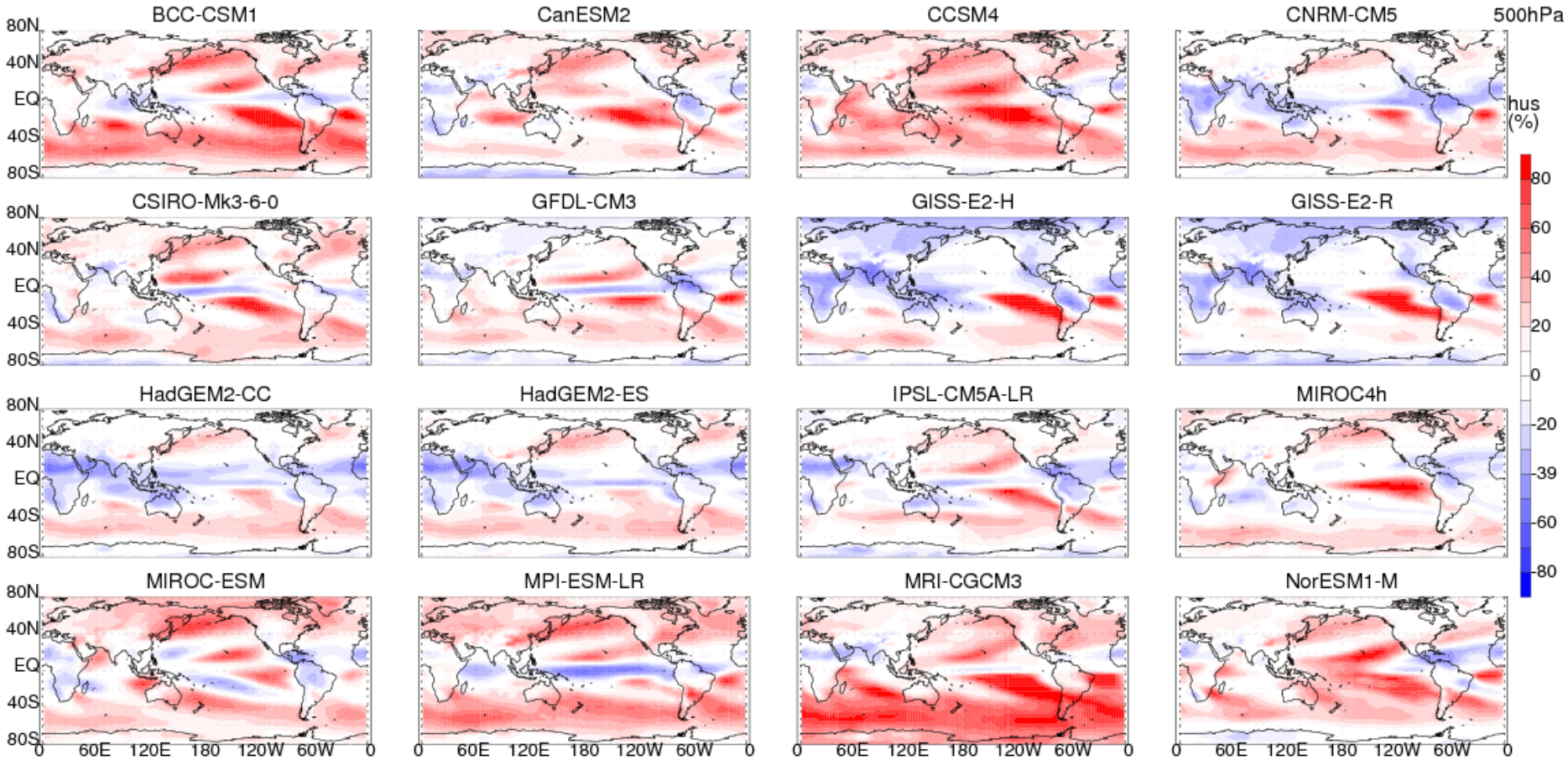
Atmospheric Infrared Sounder

CMIP5-AIRS Specific Humidity Differences (%) at 500 hPa



Summary - I

- For the 9-year climatology, MERRA is warmer than AIRS in the free troposphere but colder in the boundary layer with differences typically less than 1 K. MERRA is also drier (~10%) than AIRS in the tropical boundary layer but wetter (~30%) in the tropical free troposphere and the extratropical troposphere.
- In comparison to AIRS and MERRA, the 16 CMIP5 models can generally reproduce the climatological mean features of tropospheric air temperature and specific humidity well, but noticeable biases exist.
- The models have a tropospheric cold bias (around 2 K), especially in the extratropical upper troposphere, and a double-ITCZ problem in the troposphere from 1000 hPa to 300 hPa, especially in the tropical Pacific. These biases exist in the most or all models, are independent of the reference dataset used (AIRS or MERRA).

Part II

Hearty, T., A. Savtchenko, **B. Tian**, E. J. Fetzer, Y. Yung, M. Theobald, B. Vollmer, E. Fishbein, Y.-I. Won, 2013: Estimating Sampling Biases and Measurement Uncertainties of AIRS/AMSU-A Temperature and Water Vapor Observations using MERRA Reanalysis, *J. Geophys. Res.,* **119**, D?????, doi: 10.1029/2013JD0212205, in press.

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- These sampling differences can affect comparisons between the AIRS/AMSU retrievals and climate model outputs.

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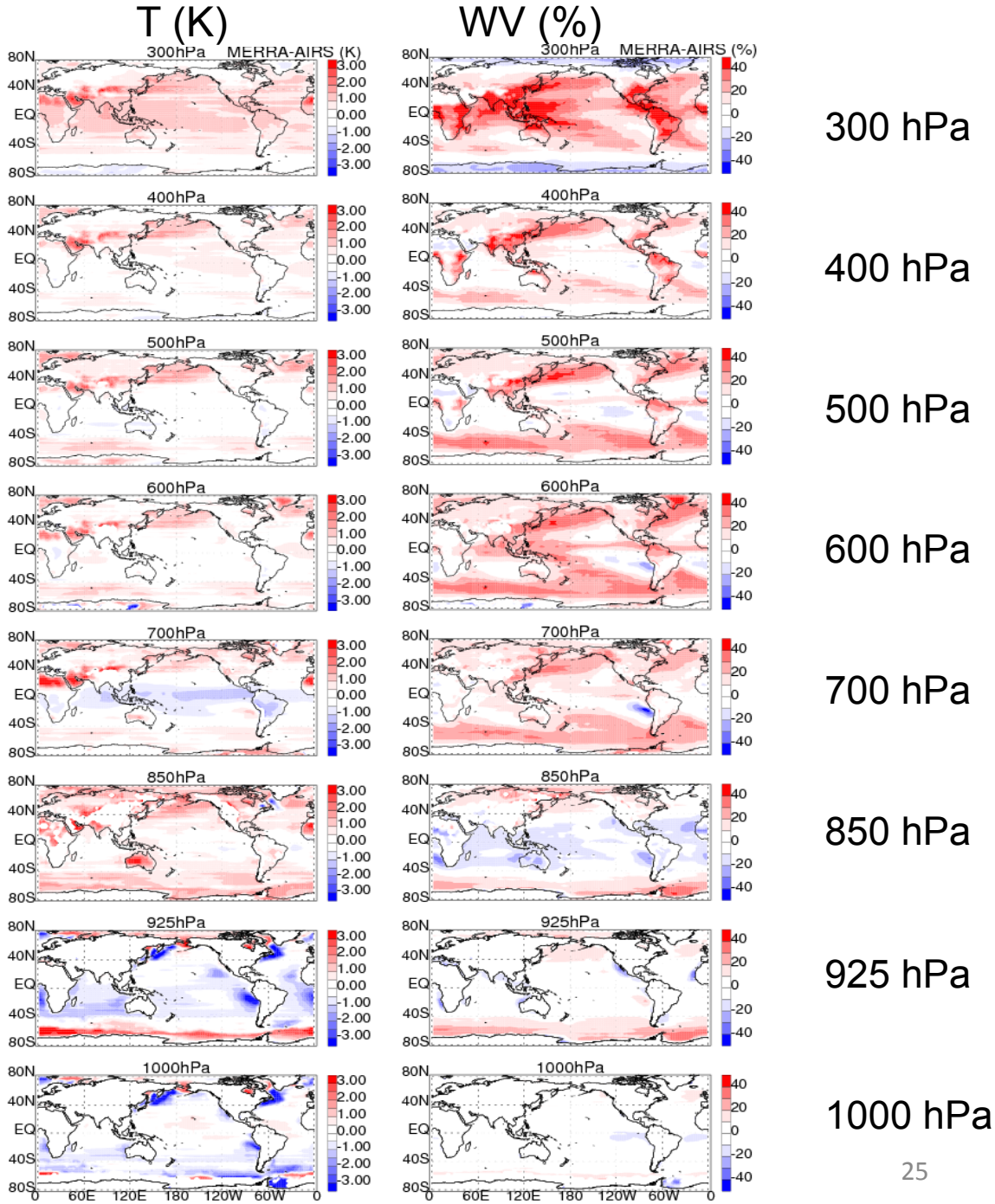
Temperature (left) and Specific Humidity (right) Differences (MERRA – AIRS)

Tian et al. [2013]



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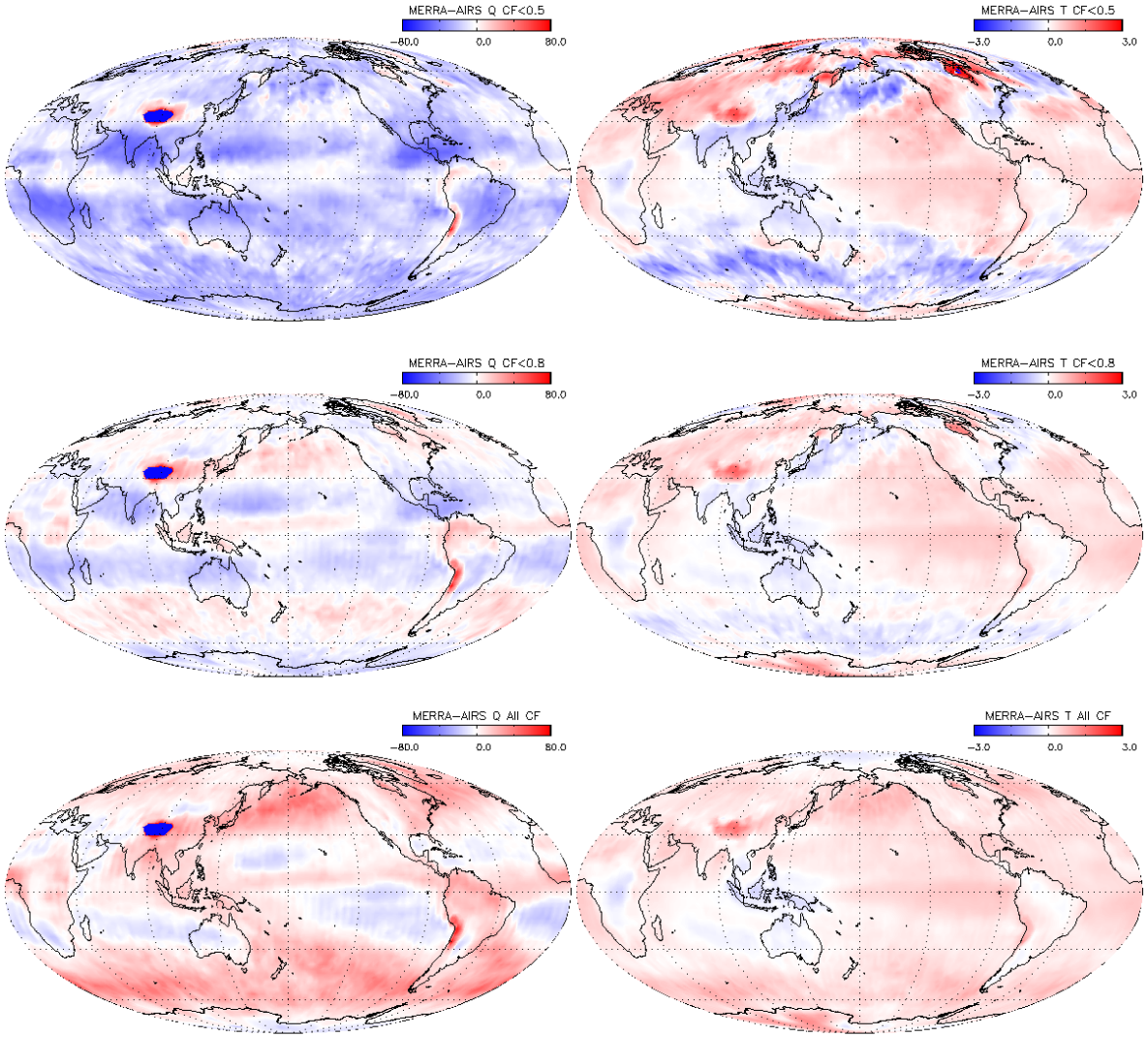
Atmospheric Infrared Sounder

Specific Humidity (left) and Temperature (right) Differences (MERRA – AIRS) at different MERRA cloud amounts

Tian et al. [2013]



Objectives

- To estimate ***the sampling biases*** of the AIRS/AMSU air temperature and specific humidity climatologies using MERRA data assuming that the MERRA data correctly samples the atmospheric state.

- To estimate the residual ***measurement uncertainties*** of AIRS/AMSU and MERRA data when they are both similarly sampled.

Sampling Bias Definition and Calculation

Component	Definition	Calculation
Total	The under-sampling of temporal (especially diurnal) and spatial variations of the atmosphere of the AIRS/ AMSU data due to all reasons.	MSAQC – MMM
Temporal	Caused by the Aqua spacecraft's Sun-synchronous low Earth orbit and the limited swath width of the AIRS/ AMSU instrument suite.	MSA – MMM
Instrumental	Caused by the AIRS/AMSU quality control imposed in regions where the AIRS/AMSU algorithm cannot successfully perform retrievals.	MSAQC – MSA

MERRA Climatology Definition	
MSAQC	MERRA Sampled Like AIRS/AMSU with the AIRS/AMSU Quality Control
MSA	MERRA Sampled Like AIRS/AMSU w/o the AIRS/AMSU Quality Control
MMM	MERRA Monthly Mean or MERRA sampled like a climate model

Measurement Uncertainty Definition and Calculation

Definition	Calculation
Difference of AIRS/AMSU and MERRA climatologies independent of sampling and caused by the AIRS/AMSU algorithm or MERRA model assimilation.	AIRS/AMSU – MSAQC

Data

- AIRS V5 L2 air temperature and specific humidity profile data from September 2002 to August 2011: twice daily, 45 km FOV, and 8 vertical pressure levels/layers.

- MERRA air temperature and specific humidity profile data for the same AIRS period: 3-hour, 1.25°x1.25° longitude-latitude grids, and 42 vertical pressure levels.

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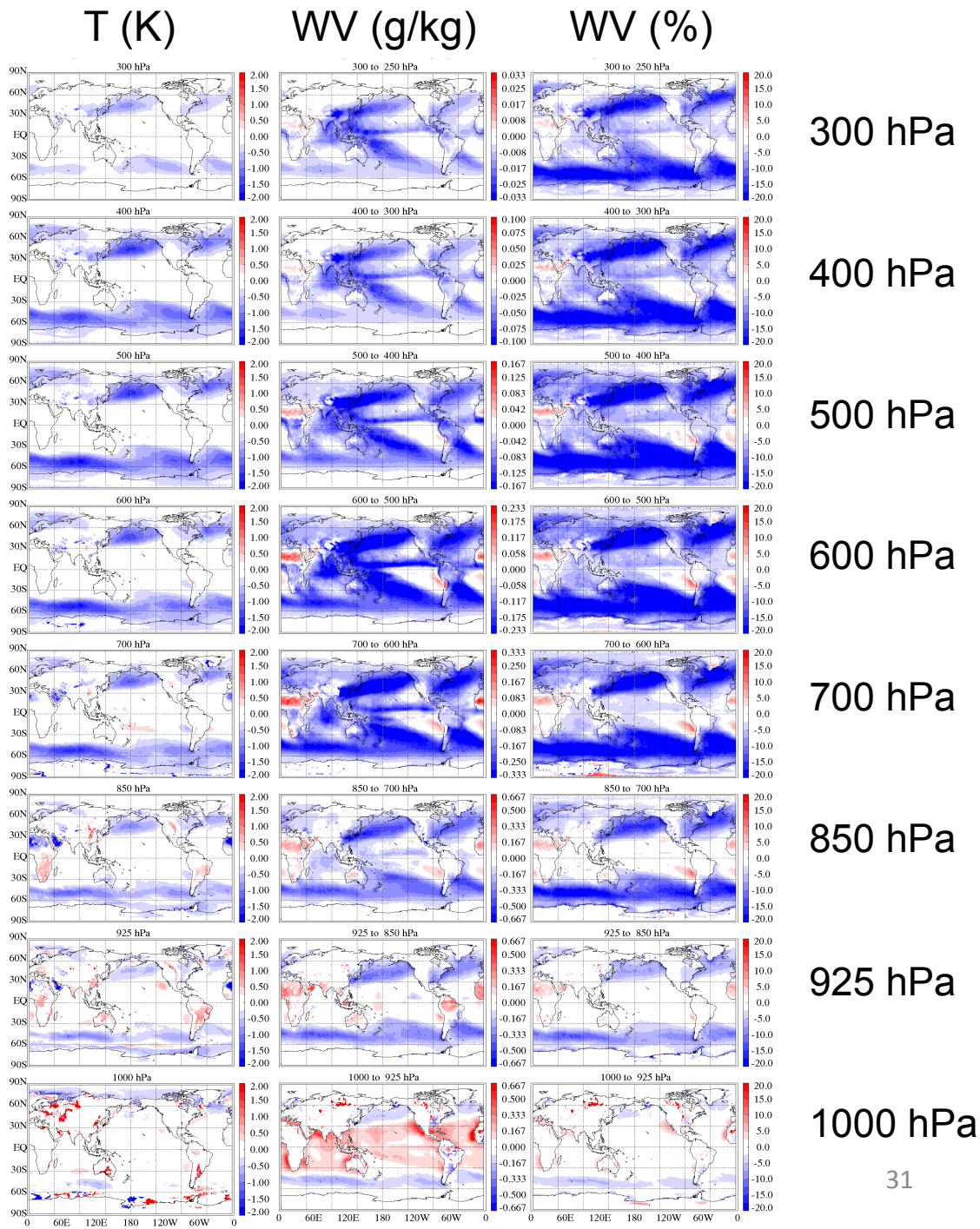
Total Sampling Bias

- The total sampling biases are significant in some regions/ levels.
- Cold/dry biases throughout the troposphere over the mid-latitude storm tracks.
- Dry bias in the free troposphere over the tropical convective regions.
- Wet bias throughout the troposphere over the Sahara, Sahel, and the Arabian Peninsula.
- Either warm or cold biases in the boundary layer over land.
- Wet bias in the boundary layer over the tropical/sub-tropical ocean.



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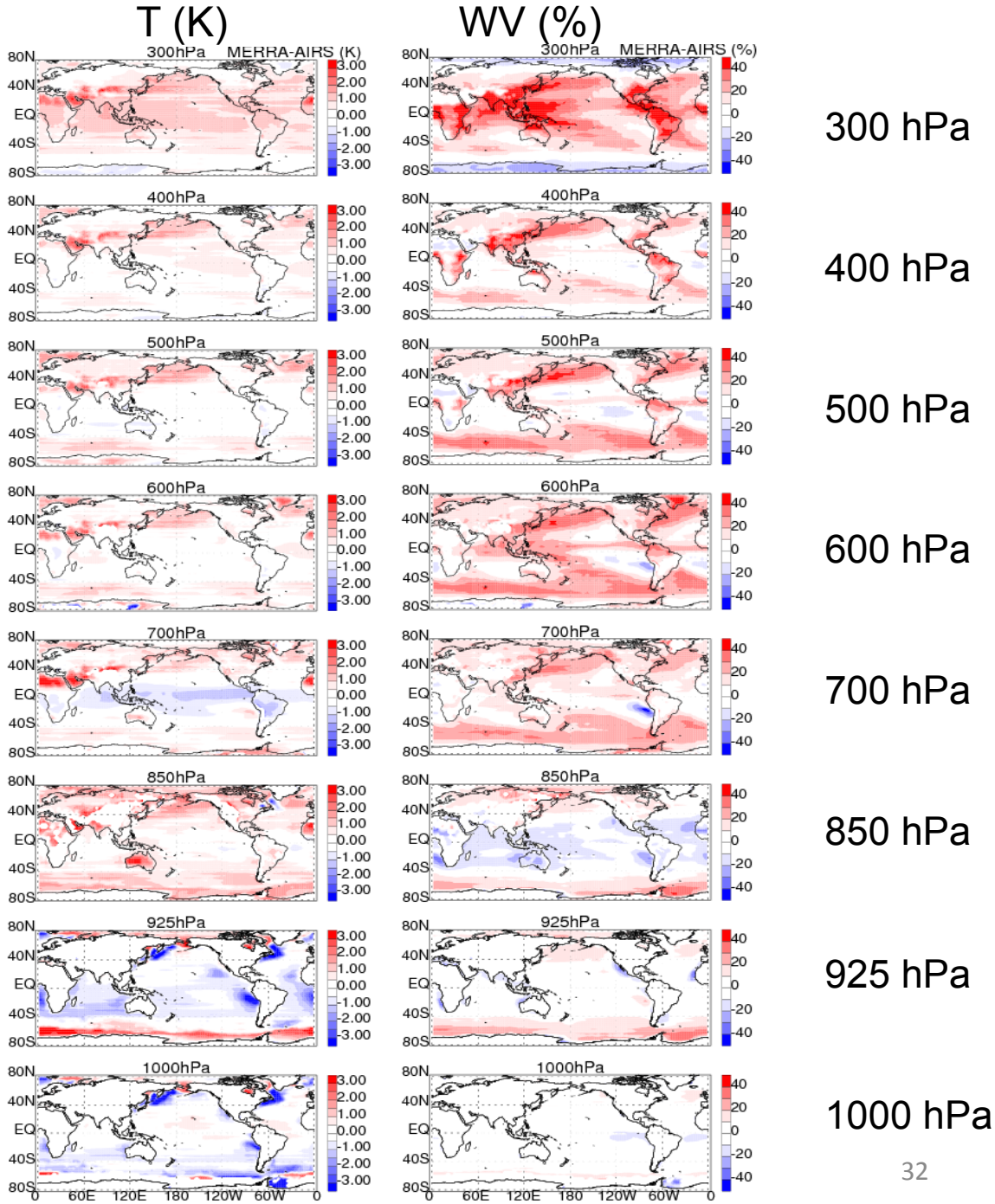
Atmospheric Infrared Sounder

Temperature (left) and Specific Humidity (right) Differences (MERRA – AIRS)

Tian et al. [2013]



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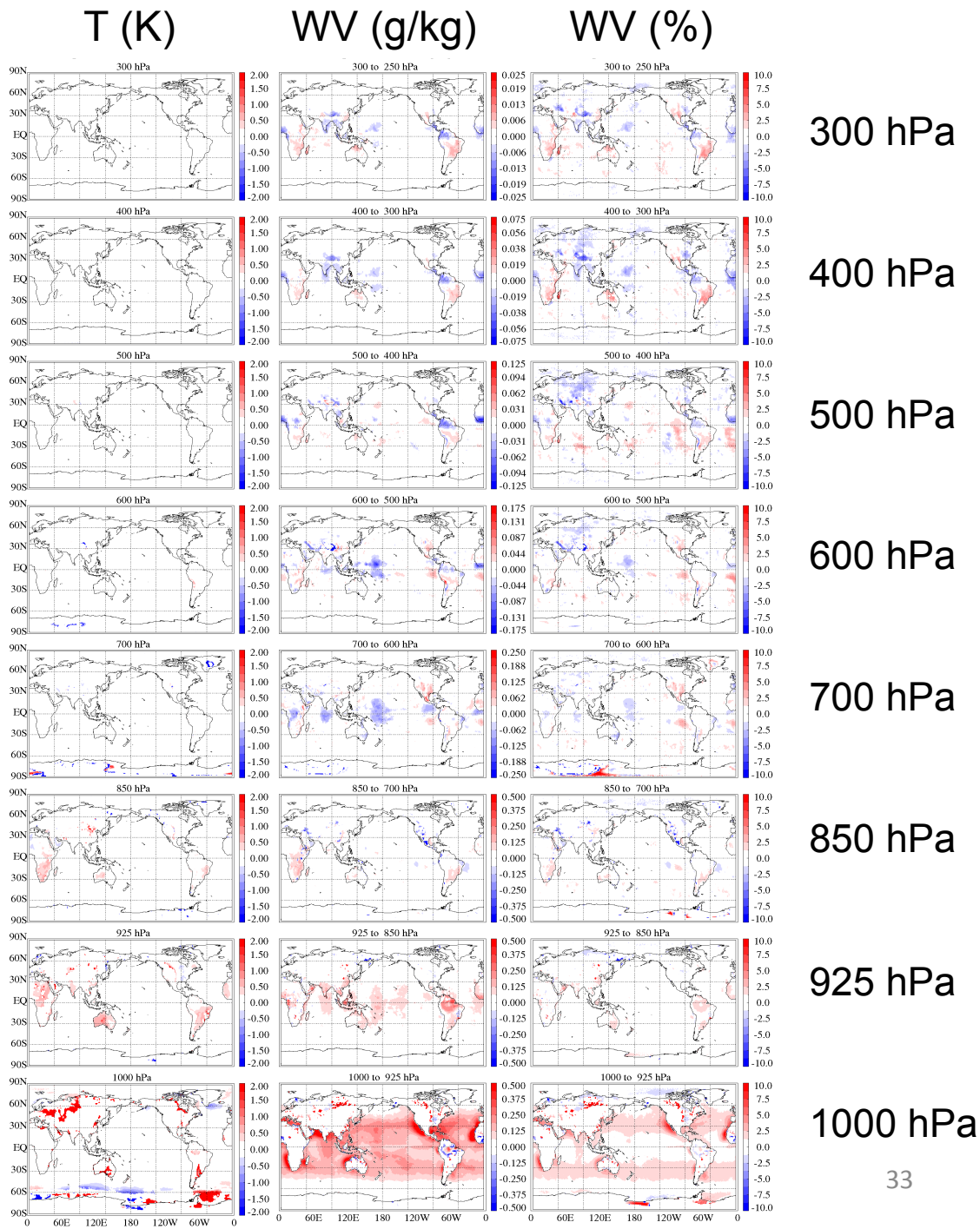
Atmospheric Infrared Sounder

Temporal Sampling Bias

- Negligible biases in the free troposphere.
- Either warm or cold biases in the boundary layer over land.
- Wet bias in the boundary layer over the tropical/sub-tropical ocean.



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Total Sampling Bias

- The total sampling biases are significant in some regions/ levels.
- Cold/dry biases throughout the troposphere over the mid-latitude storm tracks.
- Dry bias in the free troposphere over the tropical convective regions.
- Wet bias throughout the troposphere over the Sahara, Sahel, and the Arabian Peninsula.
- Either warm or cold biases in the boundary layer over land.
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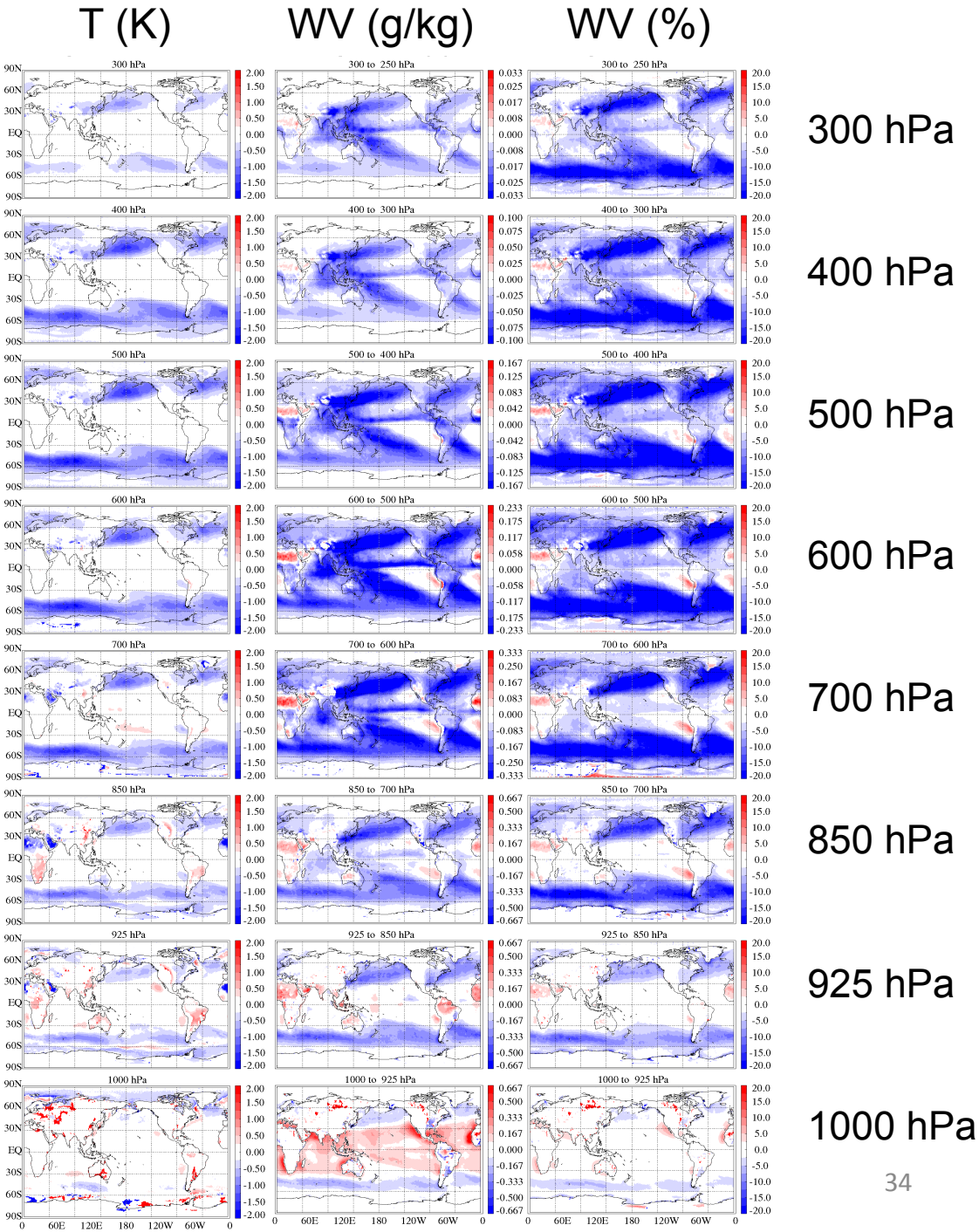

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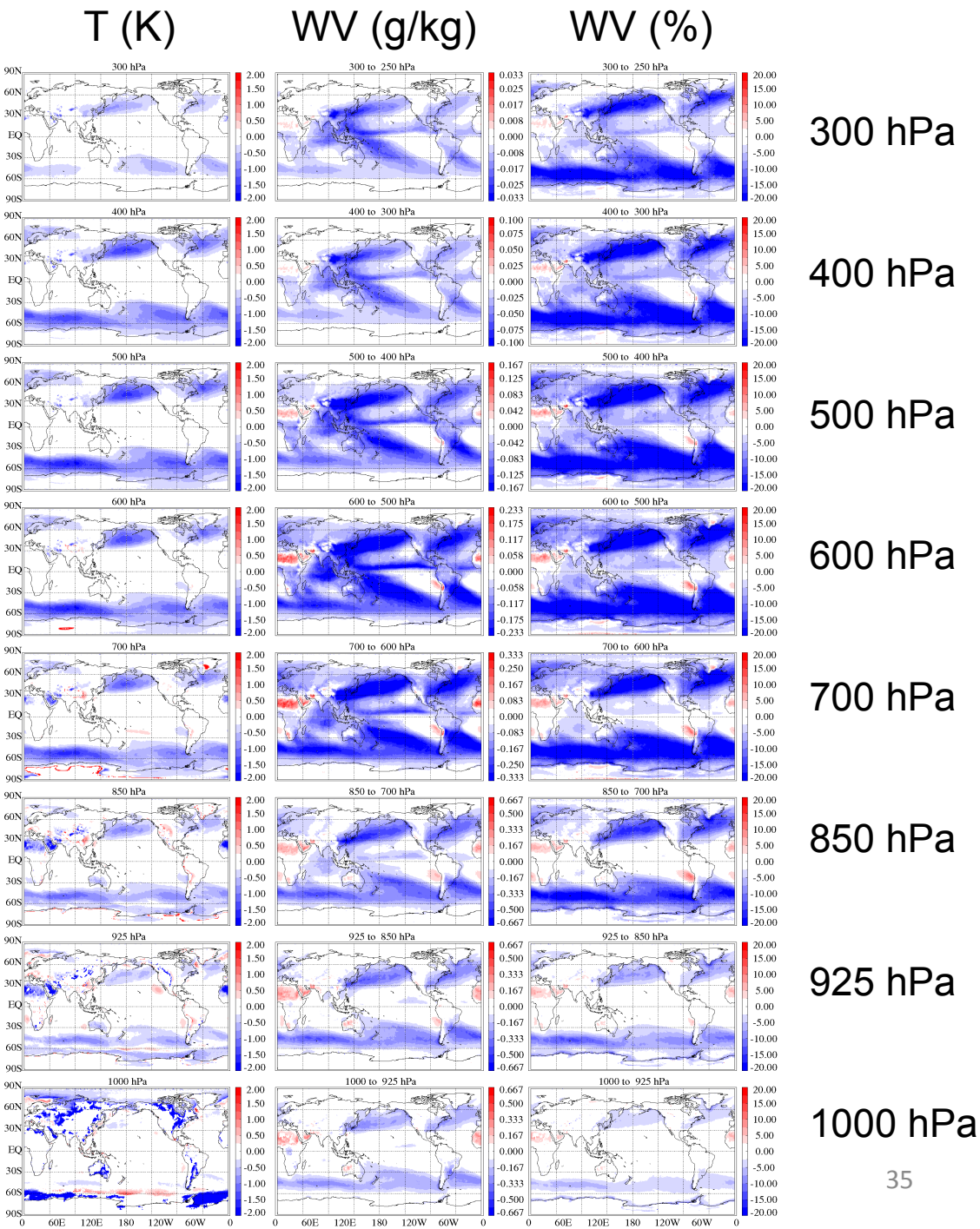
Instrumental Sampling Bias

- The instrumental sampling biases are the main contributor to the total sampling biases.
- Cold/dry biases throughout the troposphere over the mid-latitude storm tracks.
- Dry bias in the free troposphere over the tropical convective regions.
- Wet bias throughout the troposphere over the Sahara, Sahel, and the Arabian Peninsula.



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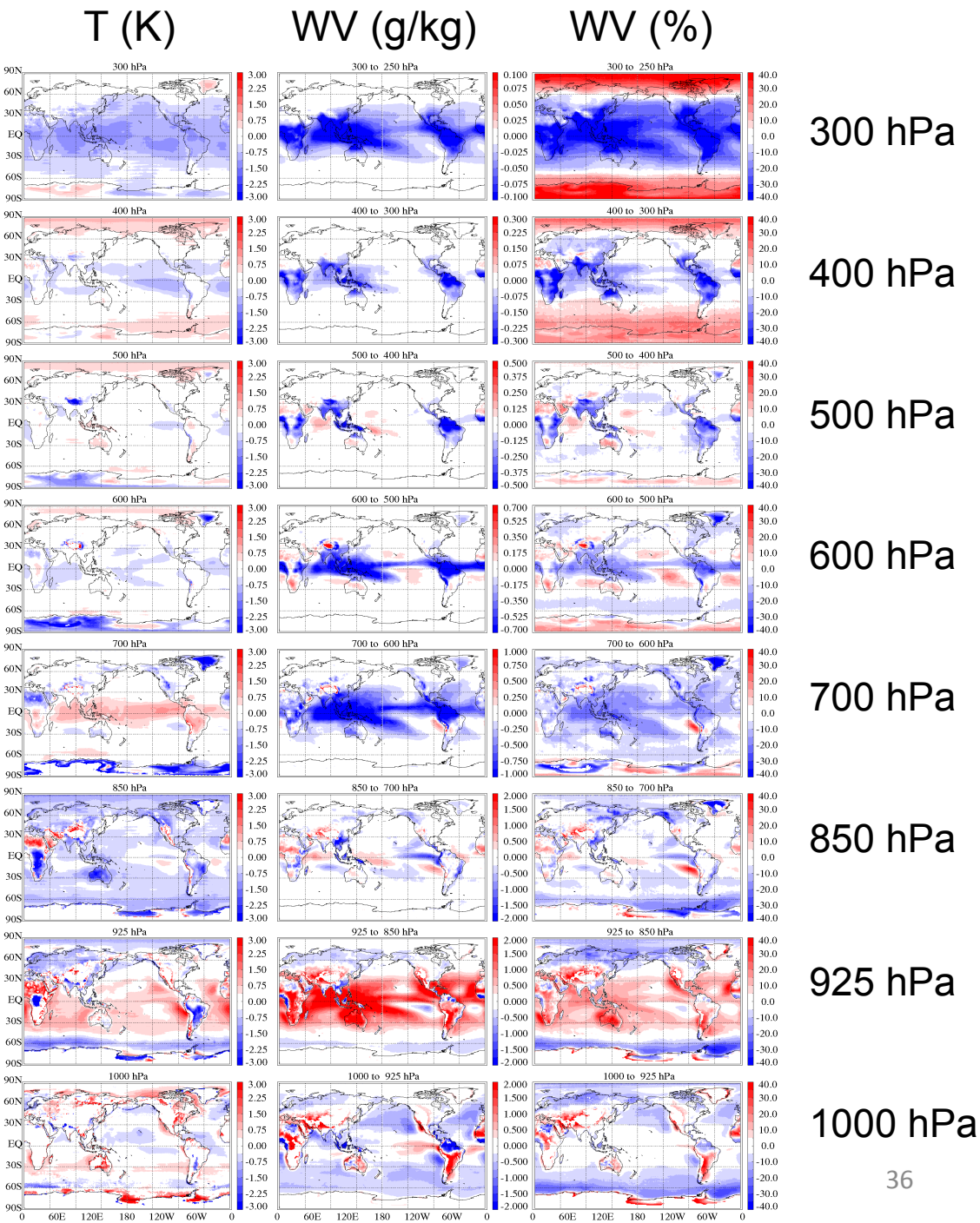
Measurement Uncertainties



Summary - II

- The sampling biases of the AIRS/AMSU data are significant in some regions/levels.
- The temporal sampling bias are generally small except in the boundary layer.
- The instrumental sampling biases are the main contributor to the total sampling biases and caused mainly by clouds over mid-latitude storm tracks, tropical deep convective and stratus cloud regions and also by surface emissivity/temperature over deserts.
- There are significant measurement differences between AIRS/AMSU and MERRA.
- These sampling biases and measurement uncertainties have to be considered when comparing the AIRS/AMSU satellite observations with CMIP5 model outputs.

Future Work

- Removing the sampling biases of the AIRS/AMSU data when comparing the AIRS/AMSU satellite observations with CMIP5 model outputs.

- Perform similar analysis for AIRS/AMSU tropospheric relative humidity data.

Thank You !

Tian, B., E. Fetzer, B. Kahn, J. Teixeira, E. Manning, and T. Hearty, 2013: Evaluating CMIP5 Models using AIRS Tropospheric Air Temperature and Specific Humidity Climatology, *J. Geophys. Res.*, **118**, D50117, 114-134, doi: 10.1029/2012JD018607.

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http://www.gps.caltech.edu/~btian/

Backup Slides

Caveats

- MERRA may not be able to correctly represent the atmosphere due to its limited spatial (1.25X1.25) and temporal (3-h) resolutions and model uncertainty. Thus, the sampling bias estimates of AIRS/AMSU based on MERRA could be flawed. Similar studies using other reanalyses are needed.
- MERRA assimilates AIRS/AMSU clear-sky radiances but this probably has little effect on the sampling bias estimates.
- The MSAQC and MSA climatologies are not sampled exactly like AIRS/AMSU due to different temporal and spatial resolutions of MERRA and AIRS/AMSU.
- The sampling biases may be larger for any given daily or monthly average than the current 9-year climatology.

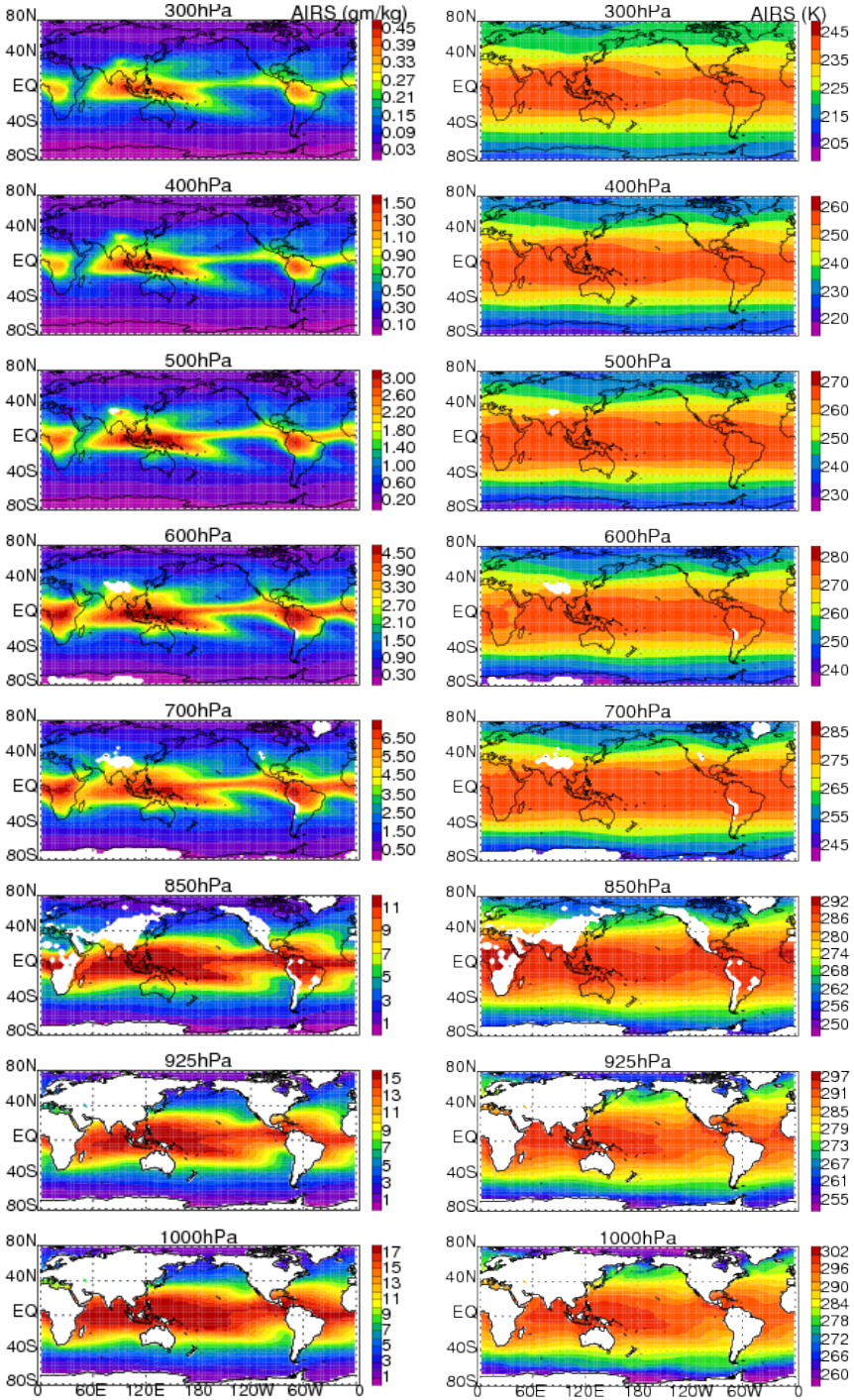
National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Atmospheric Infrared Sounder

AIRS
Specific Humidity (left)
and Temperature (right)
Climatologies

[Tian et al. 2013]



300 hPa

400 hPa

500 hPa

600 hPa

700 hPa

850 hPa

925 hPa

1000 hPa

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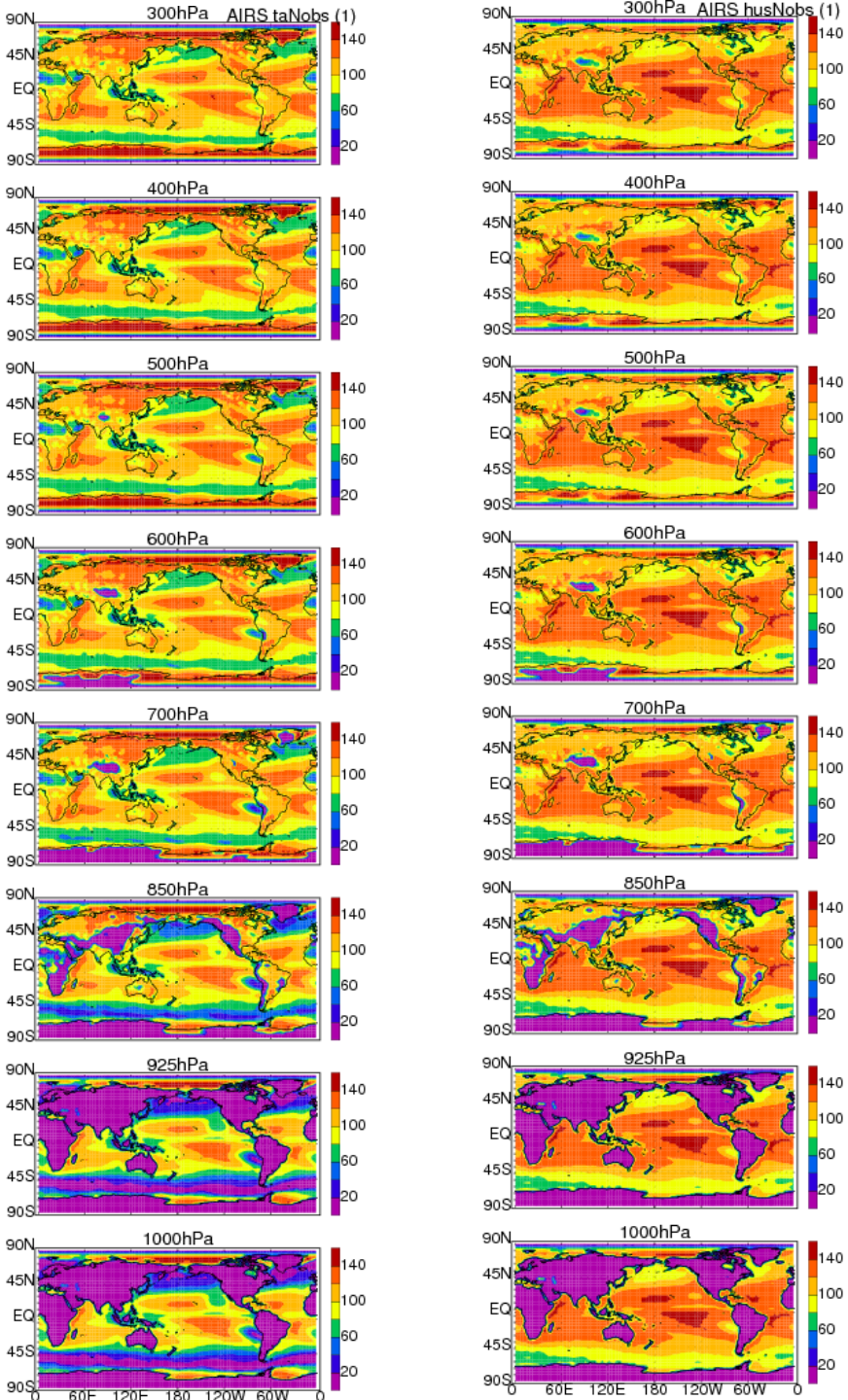
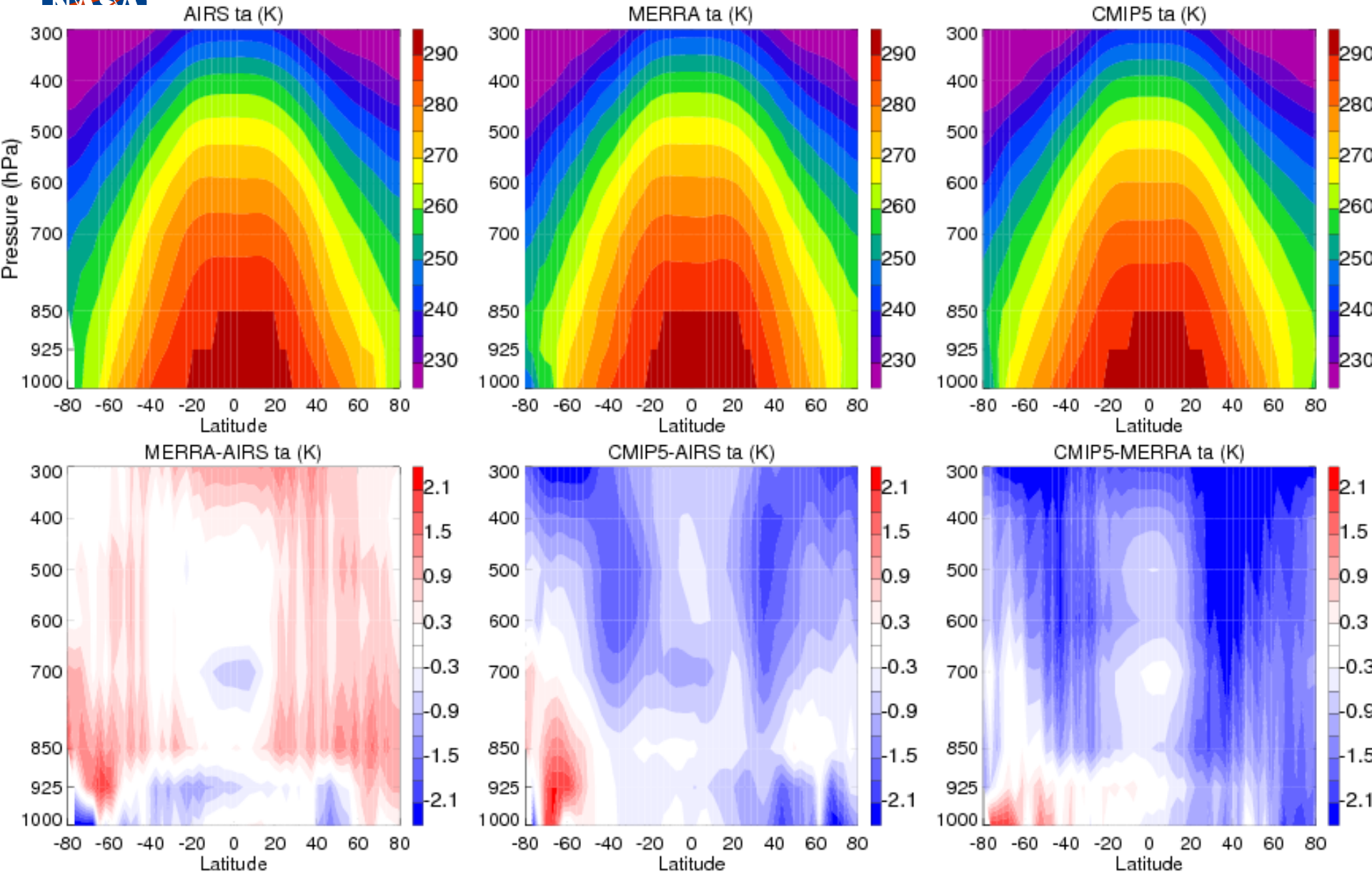
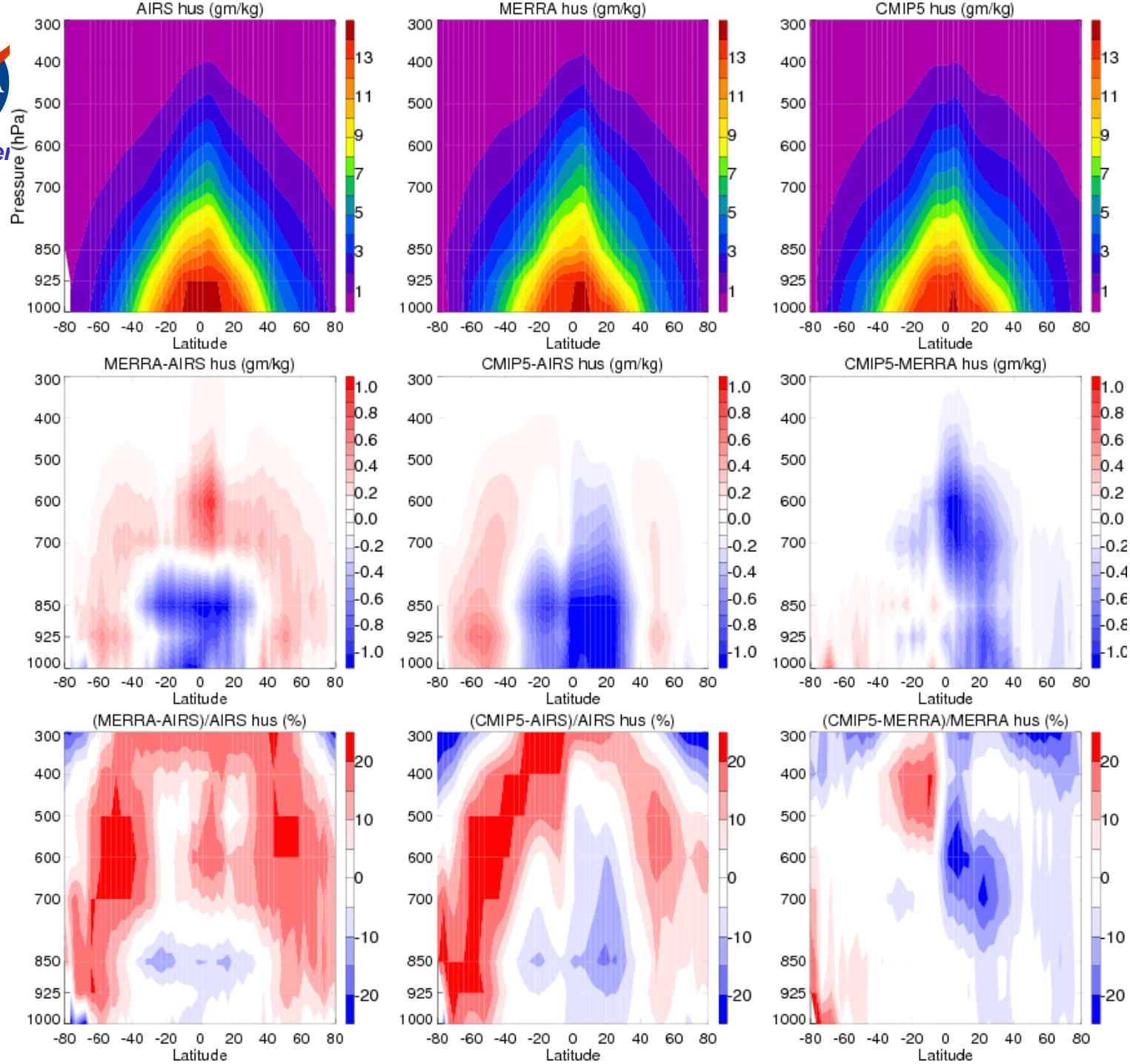
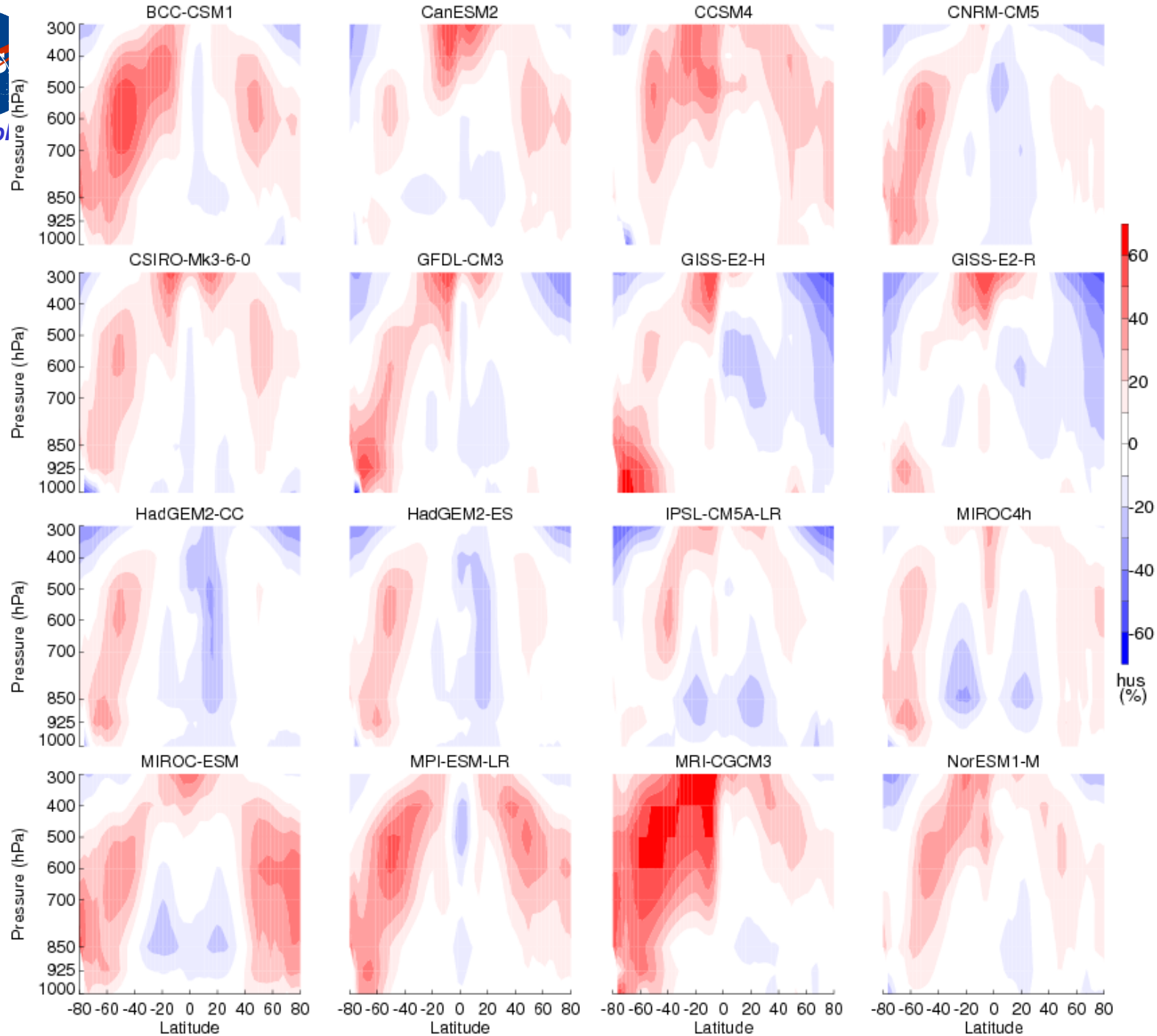
Atmospheric Infrared Sounder



National Aeronautics and Space Administration




AIRS hus (gm/kg)
MERRA hus (gm/kg)
CMIP5 hus (gm/kg)
MERRA-AIRS hus (gm/kg)
CMIP5-AIRS hus (gm/kg)
CMIP5-MERRA hus (gm/kg)
(MERRA-AIRS)/AIRS hus (%)
(CMIP5-AIRS)/AIRS hus (%)
(CMIP5-MERRA)/MERRA hus (%)
Pressure (hPa)
Latitude


BCC-CSM1
CanESM2
CCSM4
CNRM-CM5
CSIRO-Mk3-6-0
GFDL-CM3
GISS-E2-H
GISS-E2-R
HadGEM2-CC
HadGEM2-ES
IPSL-CM5A-LR
MIROC4h
MIROC-ESM
MPI-ESM-LR
MRI-CGCM3
NorESM1-M
Pressure (hPa)
300
400
500
600
700
850
925
1000
Latitude
-80 -60 -40 -20 0 20 40 60 80
60
40
20
0
-20
-40
-60
hus
(%)

Nationa
Space
Jet Pro
Californ
Pasade
Atmospheric Infl