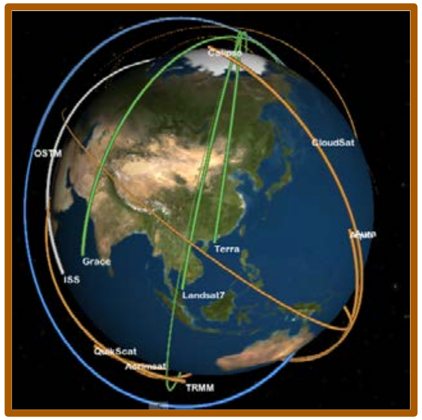
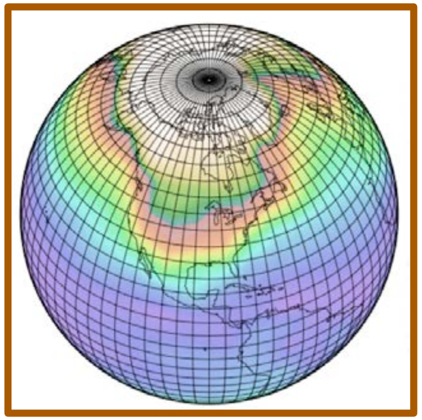
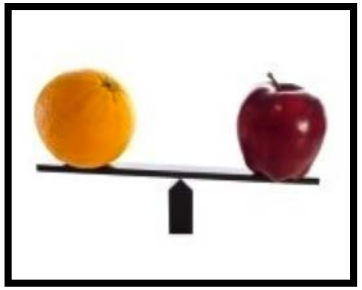
Satellite observations for CMIP5/IPCC Model Evaluation







Wikipedia: A comparison of **"apples and oranges"** occurs when two items or groups of items are compared that cannot be validly compared.

Duane Waliser, JPL/Caltech; WGCM, Boulder, CO; October 2011

Acknowledgements

D. Waliser, J. Teixeira, R. Ferraro, D. Crichton, L. Cinquini, others....

Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA

P. Gleckler, K. Taylor, D. Williams

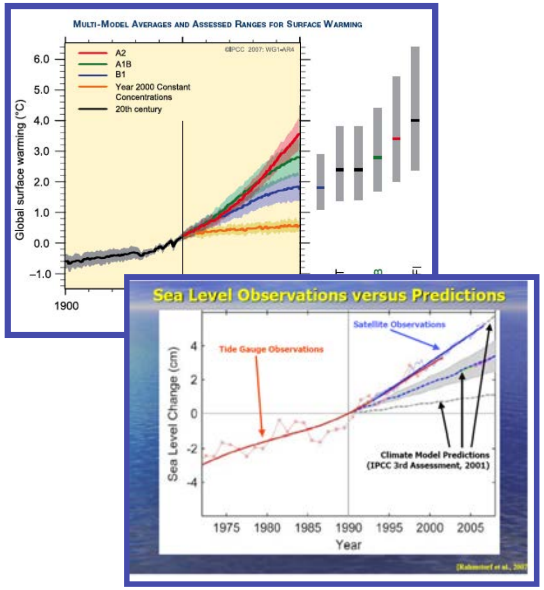
Program on Climate Modeling Diagnostics and Intercomparison (PCMDI/DOE), Livermore, CA

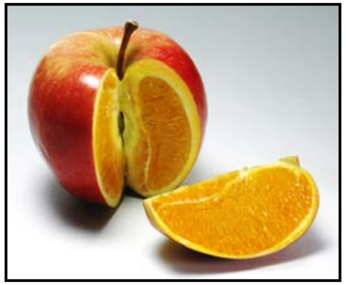
Tsengdar Lee, Jack Kaye, Martha Maiden, Steve Berrick

NASA HQ

AIRS, AMSR-E, CERES, MLS, MODIS, OSTM, OVW, TRMM, (PO)DAAC, others…

Continued Challenges & New Opportunities

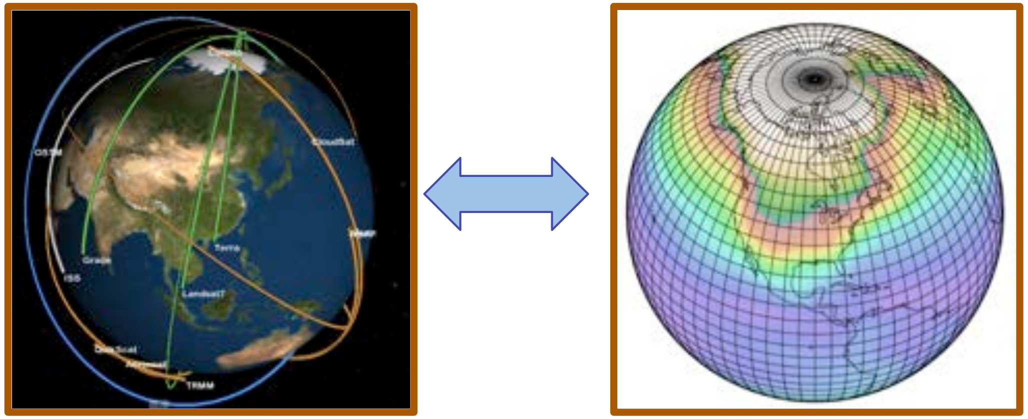


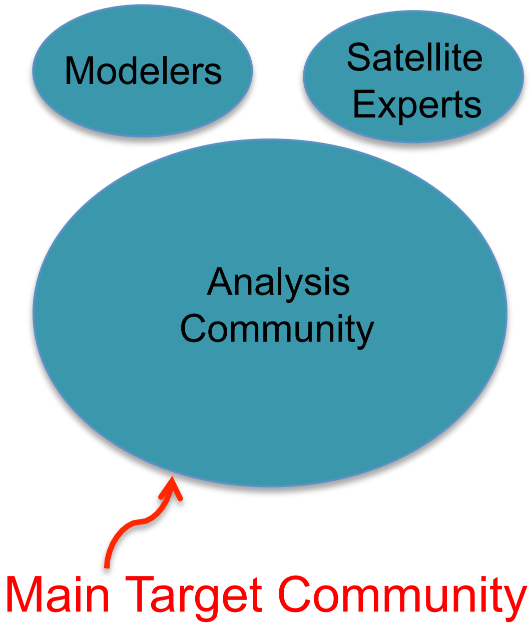


- More national and international assessments planned (e.g. NCA, IPCC AR5) that will rely on CMIP-like activities.
- Significant model errors still evident
- Model errors imply climate projection uncertainties – can these be reduced?
- Models continuing to evolve in complexity and need evaluation.
- Satellite observations have been under utilized by the model and model-analysis community.
- New observations becoming available.

Making Better Use of Observations for IPCC

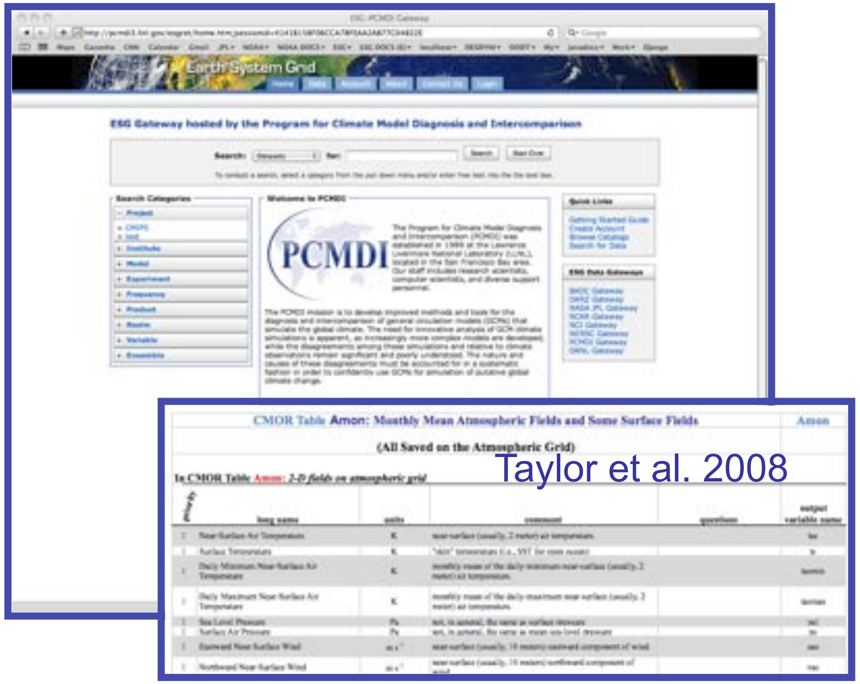
- JPL/NASA is leading an effort with PCMDI/DOE to identify and deliver a number of NASA satellite data tailored for IPCC model-data comparison.
- Community to have simultaneous access to model output and satellite observations similarly formatted to facilitate model evaluation.
- Need by Summer/Fall 2011 for model evaluations and timely submission of research articles –> IPCC AR5 to be published in 2013.





Model and Observation Overlap

For what quantities are these comparisons viable?



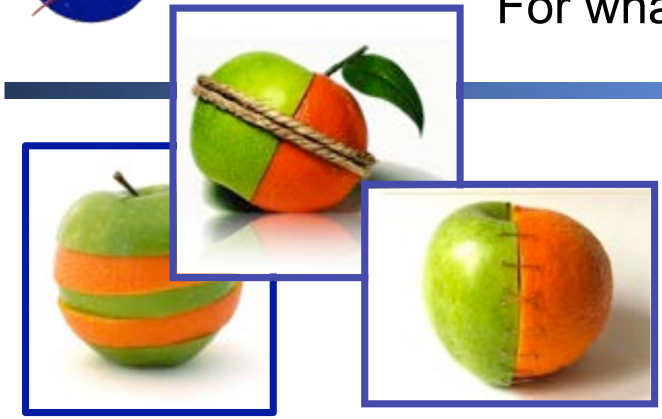
~120 ocean
~60 land
~90 atmos
~50 cryosphere

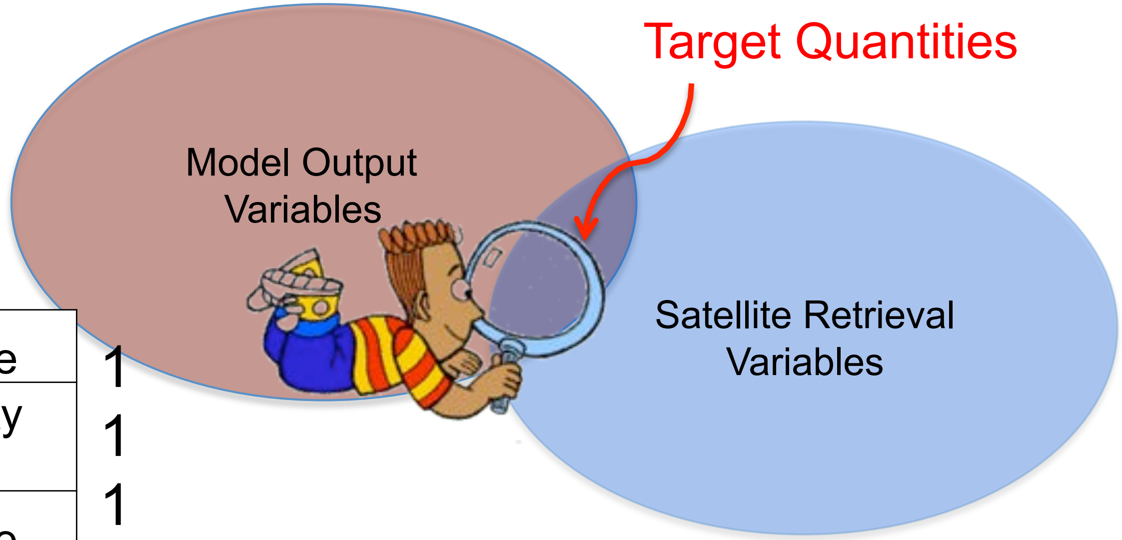
Current NASA Missions ~14
Total Missions Flown ~ 60
Many with multiple instruments
Most with multiple products (e.g. 10-100s)
Many cases with the same products

Over 300 Variables in (monthly) CMIP Database ⟷ Over 1000 satellite-derived quantities

Model and Observation Overlap

For what quantities are these comparisons viable?





AIRS (≥ 300 hPa)	Atm temp profile	1
	Specific humidity profile	1
MLS (< 300 hPa)	Atm temp profile	1
	Specifc humidity profile	1
QuikSCAT	Ocean surface winds	1
TES	Ozone profile	~4
AMSR-E	SST	1
TOPEX/JASON	SSH	1
CERES	TOA radiation fluxes	1
TRMM	Total precipitation	~6
MODIS	Cloud fraction	1
	Net primary production	1
		3

After much scrutiny and two workshops, only ~20 variables were identified as being "safely" comparable in this first round – although still with caveats!

- Continue to consider additional datasets
- **Model-pull for additional satellite observations**
- **Model-push for additional model output variables.**

Atmospheric Infrared Sounder (AIRS) Specific Humidity Description

1. Intent of This Document

This document is intended to describe AIRS specific humidity observation data, which are specially prepared for scientists who would be engaged in using IPCC model data and observational data for model-to-observation comparisons, climate model diagnostics and evaluations, and climate changes and variability studies for the IPCC 5th assessment report (AR5). In particular, the document provides the user of the data with critical caveats of using the AIRS specific humidity observation data for those activities in comparison with CMIP5 model outputs.

2. Data Field

This data product is a regularly gridded, monthly averaged specific humidity measured by AIRS during 2002-2010. The product contains temporal and geometric fields (time, latitude, longitude, and vertical pressure levels) and atmospheric parameter (specific humidity). The time is given in terms of Julian day for the start of the month. The latitude (lat) and longitude (long) are regularly gridded in a 1 degree by 1 degree box. The longitude starts at 0.5 degree and ends at 359.5 degree. The latitude starts at -89.5 degree and ends at 89.5 degree. The vertical pressure levels (plev) include all the CMIP5 mandatory levels from 1000 hPa to 10 hPa. However, we only provide the data up to 300 hPa. For this version of the retrieval, the tropospheric moisture resolution ranges between 2.7 km near the surface and 4.3 km near the tropopause [1]. The specific humidity variable is reported as "hus(time, plev, lat, long)" and is in units of 1 (kg/kg).

3. Data Origin

The AIRS specific humidity is not an *in situ* measurement. The infrared emission radiations emitted by different Earth scenes are remotely sensed by a spectrometer. Among the 2378 spectral channels, 49 are especially used to sense water vapor, in the range 1250 to 1650 cm^{-1} [2]. First, measurements are transformed into calibrated radiances for all footprints and all channels. Then, physical quantities such as the specific humidity are derived from these geolocated radiance products. The physical quantities are then averaged over different periods, typically a month. At this stage, the water vapor is reported in terms of layer averages. In order to convert from layer amounts to level amounts, we treat the original layer averages at level amount at the midpoint (in log(pressure) of the layers and then logarithmically interpolate in log(pressure) to the desired levels. For the 1000 hPa level this interpolation is replaced by an extrapolation. The values reported are means of the day and night values, provided there are enough observations in each category to make the values statistically significant. The minimum is 20 observations each, except for latitudes beyond +/- 80 degrees, where we relax the limits to compensate for a much lower number of observations.

4. Validation

AIRS retrievals have been validated against a variety of in situ data (radiosondes, airborne sun photometer, ship based measurements), other remote measurements from other satellites and model-generated data (fully coupled global ocean- atmosphere General Circulation Models, collocated model forecasts compared with radiosondes). The table below summarizes these findings and can be found in reference **Error! Reference source not found.**.

Geophysical Conditions Studied	Uncertainty Estimate
Ocean, surface to 300 hPa	15-25% / 2 km
Non-polar land 2 km to 300 hPa.	15-25% / 2 km
Non-polar land, surface to 1-2 km	30-40% / 2 km
Polar land.	30-40% / 2 km
Tropical upper troposphere.	25% / 2 km
Middle and high latitude upper troposphere.	30-50% / 2 km

Table 1: uncertainty estimate for different conditions.

The uncertainty estimates are calculated based on the difference between AIRS retrievals and radiosonde observations. The horizontal resolution is 45km.

4. Consideration for Model-Observation Comparisons

Because this data product is observational data, there are several aspects that distinguish this product from model outputs. The user of this data product should be aware of them in order to make judicious model-observation comparisons.

4.1 Clouds influence

AIRS coverage is limited by the presence of optically thick clouds because it is an infrared instrument. Since microwaves can penetrate through most clouds, accurate moisture profile retrievals in the presence of clouds can be obtained with a combined analysis of AIRS infrared and AMSU microwave radiances **Error! Reference source not found.**. AMSU is a microwave instrument flown together with AIRS on AQUA.

up to about 70% **Error! Reference source not found.**. This limitation of the infrared measurement makes the observation scene dependent and in turns, causes a spatially inhomogeneous sampling as illustrated on Figure 1. The AIRS sampling is low (~40) in cloudy regions, such as the Intertropical Convergence Zone (ITCZ) (e.g., the

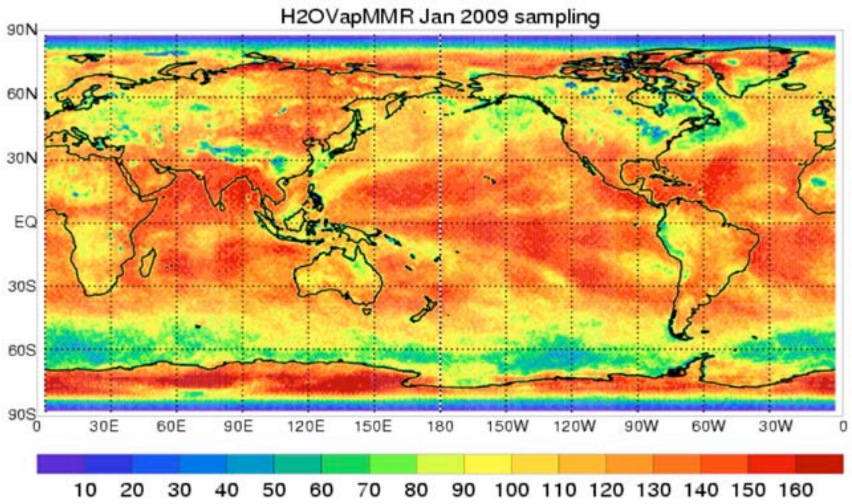


Figure 1: Water vapor sampling repartition at 550 hPa for the month of January 2009.

equatorial western Pacific warm pool) and the midlatitude storm tracks (e.g., north Pacific, north Atlantic and 60S latitude belt). The AIRS sampling is high (~150) in clear regions, such as subtropics and midltitude land regions.

4.2 Time Sampling Bias

Because AIRS is on board the Aqua satellite with a sun-synchronous polar orbit, it samples at the two fixed local solar times at each location (e.g. 1:30 AM and 1:30 PM at the equator) and does not resolve the diurnal cycle. AIRS observations at a given latitude on either the ascending (north-going) or descending (south-going) portions of the orbit have approximately (to within several minutes) the *same* local solar time throughout the mission. In contrast, typical model monthly averaged outputs contain the averaged values over a time series of data with a fixed time interval (e.g. every 6 hours). For many constituents in the upper atmosphere, this difference is not likely a problem although for regions influenced by deep convection and its modulation of the diurnal cycle (e.g. tropical land masses), this time sampling bias should be considered.

Because the monthly averaged value in this AIRS data product is an average over observational data available in a given grid cell, the number of samples used for averaging varies with the geo-location of the cell. Because of the convergence of longitude lines near the poles, the time range of data collection broadens as one moves from the equator toward either pole, with the ranges in the polar regions including all times of day and night **Error! Reference source not found.**. So, there are more observations near in the regions near the poles (~50° to ~85°) than the rest of the area.

5. Instrument Overview

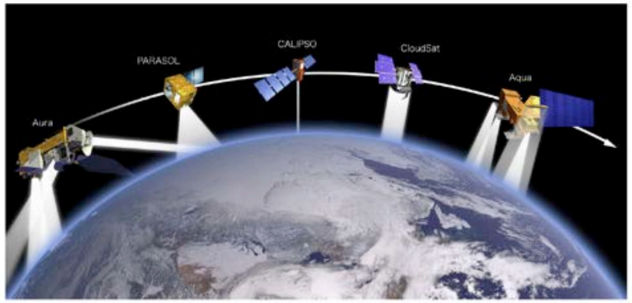


Figure 2: NASA's A-train group of Earth observing satellites.

Launched into Earth-orbit on May 4, 2002, the Atmospheric Infrared Sounder, AIRS, is one of six instruments on board the Aqua satellite, part of the NASA Earth Observing System. AIRS along with its partner microwave instrument, Advanced Microwave Sounding Unit (AMSU-A), observe the global water and energy cycles, climate variation and trends, and the response of the climate system to increased greenhouse gases. The term "sounder" in the instrument's name refers to the fact that temperature and water vapor are measured as functions of height**Error! Reference source not found.**.

AIRS and AMSU-A share the Aqua satellite with the Moderate Resolution Imaging Spectroradiometer (MODIS), Clouds and the Earth's Radiant Energy System (CERES), and the Advanced Microwave Scanning Radiometer-EOS (AMSR-E). Aqua is part of NASA's "A-train" satellite constellation (see Figure 2), a series of high-inclination, Sun-synchronous satellites in low Earth orbit designed to make long-term global observations of the land surface, biosphere, solid Earth, atmosphere, and oceans.

Satellite Observations for CMIP5 Simulations

Technical Documentation

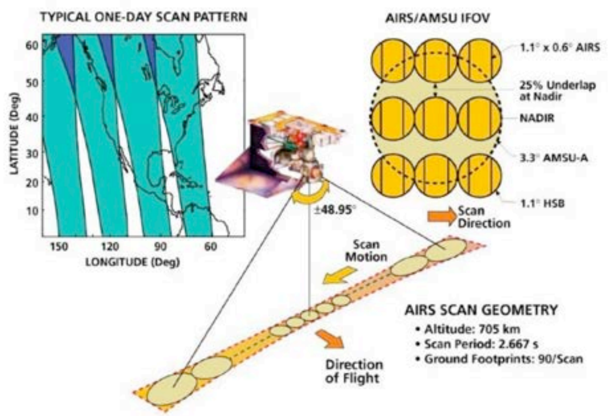


Figure 3: AIRS scanning and coverage geometry.

AIRS coverage is pole-to-pole and covers the globe two times a day. Because the swaths (scanning sweeps) do not overlap at low latitudes, some points near the equator are missed. However, these points are eventually scanned within 2-3 days. As depicted on Figure 3, AIRS scans laterally with respect to its direction of flight. With the scanning angle being 49.5 degree about nadir, the swath width is 1650 km. One orbit period is 98.8 minutes **Error! Reference source not found.**.

6. References

[1] Eric S. Maddy *et al.*, "Vertical Resolution Estimates in Version 5 of AIRS Operational Retrievals", IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 46, NO. 8, AUGUST 2008, page 2375.

[2] Joel Susskind *et al.*, "Accuracy of geophysical parameters derived from Atmospheric Infrared Sounder/Advanced Microwave Sounding Unit as a function of fractional cloud cover", J. Geophys. Res., 111, D09S17, doi:10.1029/2005JD006272.

[3] V5_CalVal_Status_Summary.pdf, p8.

[4] Hartmut H. Aumann *et al.*, "AIRS/AMSU/HSB on the Aqua Mission: Design, Science Objectives, Data Products, and Processing Systems", IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 41, NO. 2, FEBRUARY 2003.

[5] Joel Susskind *et al.*, "Retrieval of Atmospheric and Surface Parameters From AIRS/AMSU/HSB Data in the Presence of Clouds", IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 41, NO. 2, FEBRUARY 2003, page 390.

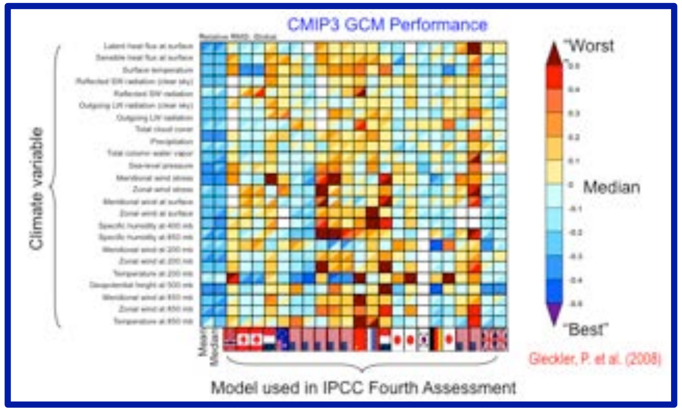
[6] Claire L. Parkinson, "Aqua: An Earth-Observing Satellite Mission to Examine Water and Other Climate Variables", IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 41, NO. 2, FEBRUARY 2003.

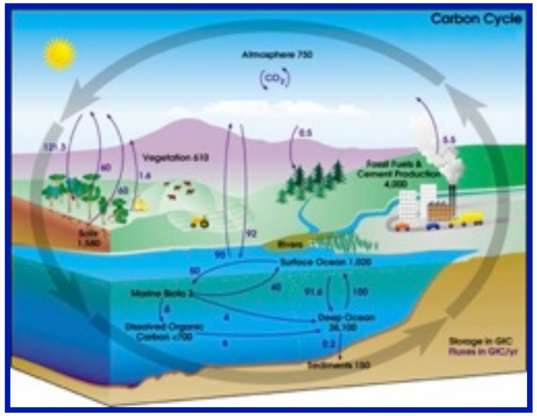
[7] http://airs.jpl.nasa.gov/instrument/coverage/

Satellite Observations for CMIP and IPCC ARs

Why is this timely for AR5 and beyond?

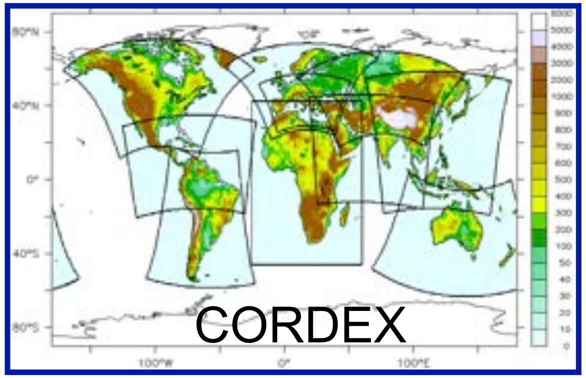
Model Scoring w/ Observations: "1 model – 1 vote" to weighting projections based on obs metrics (e.g. WGCM/WGNE Metrics Panel)





Earth System Modeling (e.g. Coupled Carbon-Climate): added complexity, more degrees of freedom, need for observational constraints; many assets here / on horizon (e.g. CO_2 : AIRS, TES, MODIS, OCO-2, OCO-3, ACE, Ascends, L-Band SAR).

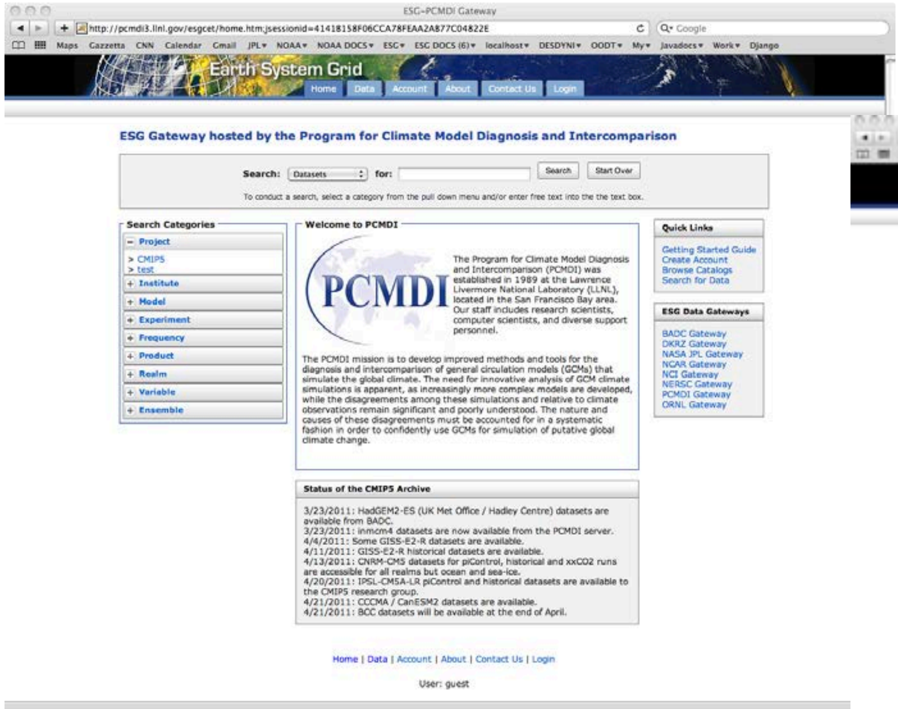
Decadal Predictions: Downscaling GCMs with regional models is key to many decision-support issues; systematic application of observations for regional model evaluation is even less mature than for GCMs.



Satellite Observations for CMIP5 Simulations

Data Available Now on Earth System Grid

- NASA Infrastructure (Gateway and Data Node) is ready to receive observation datasets from science teams.
- First datasets (AIRS,CERES, MLS, etc) delivered.
- Federated access via the Earth System Grid – side by side w/ GCM data.

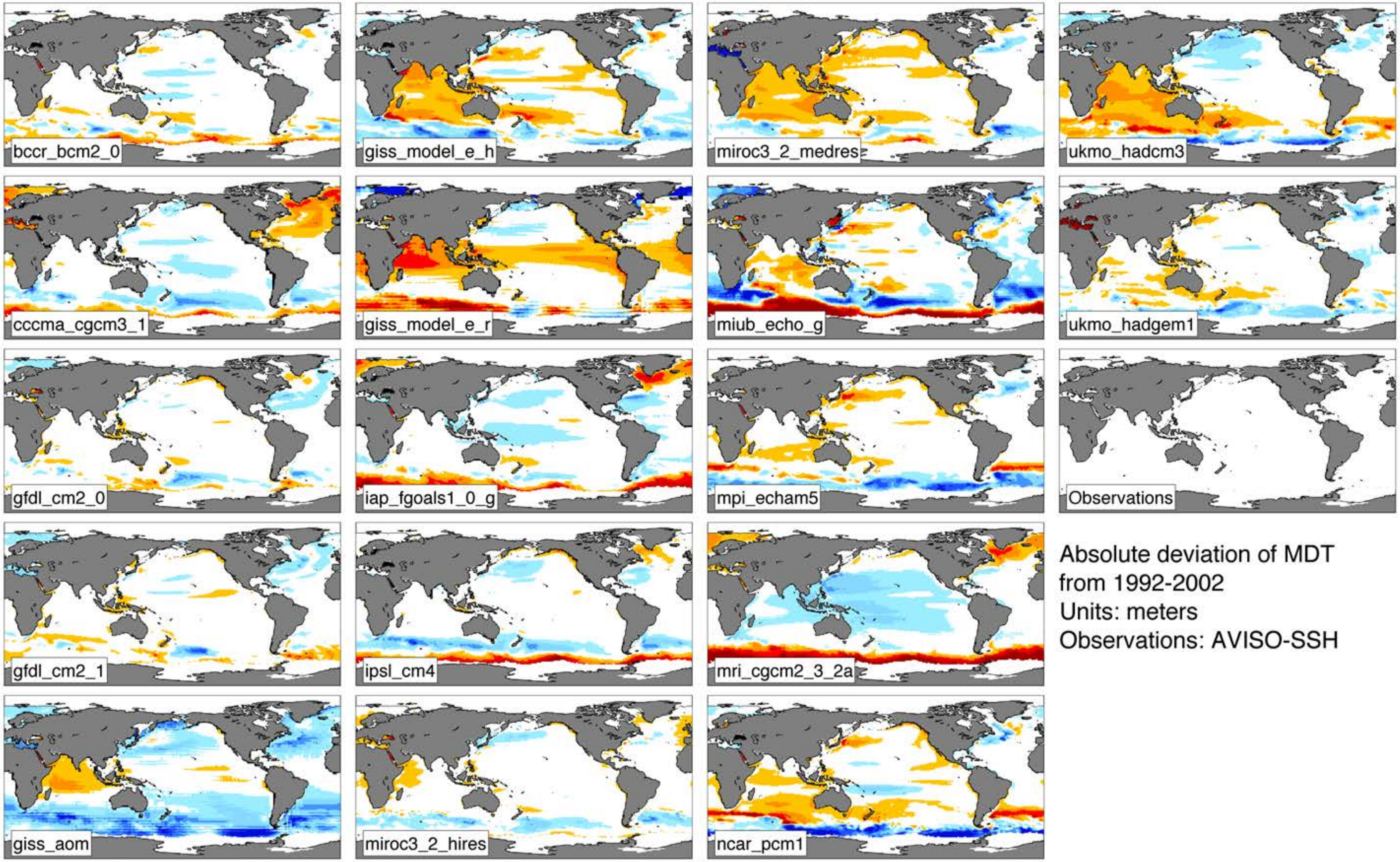


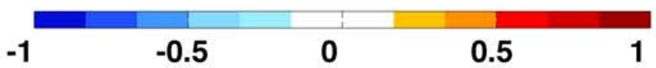
PCMDI Gateway

NASA Gateway

CMIP3 Sea Level vs TOPEX/JASON

Mean dynamic topography (GCMs 1992-2002); Obs: Maximenko et al. [2005]) Absolute values (each field has zero mean)

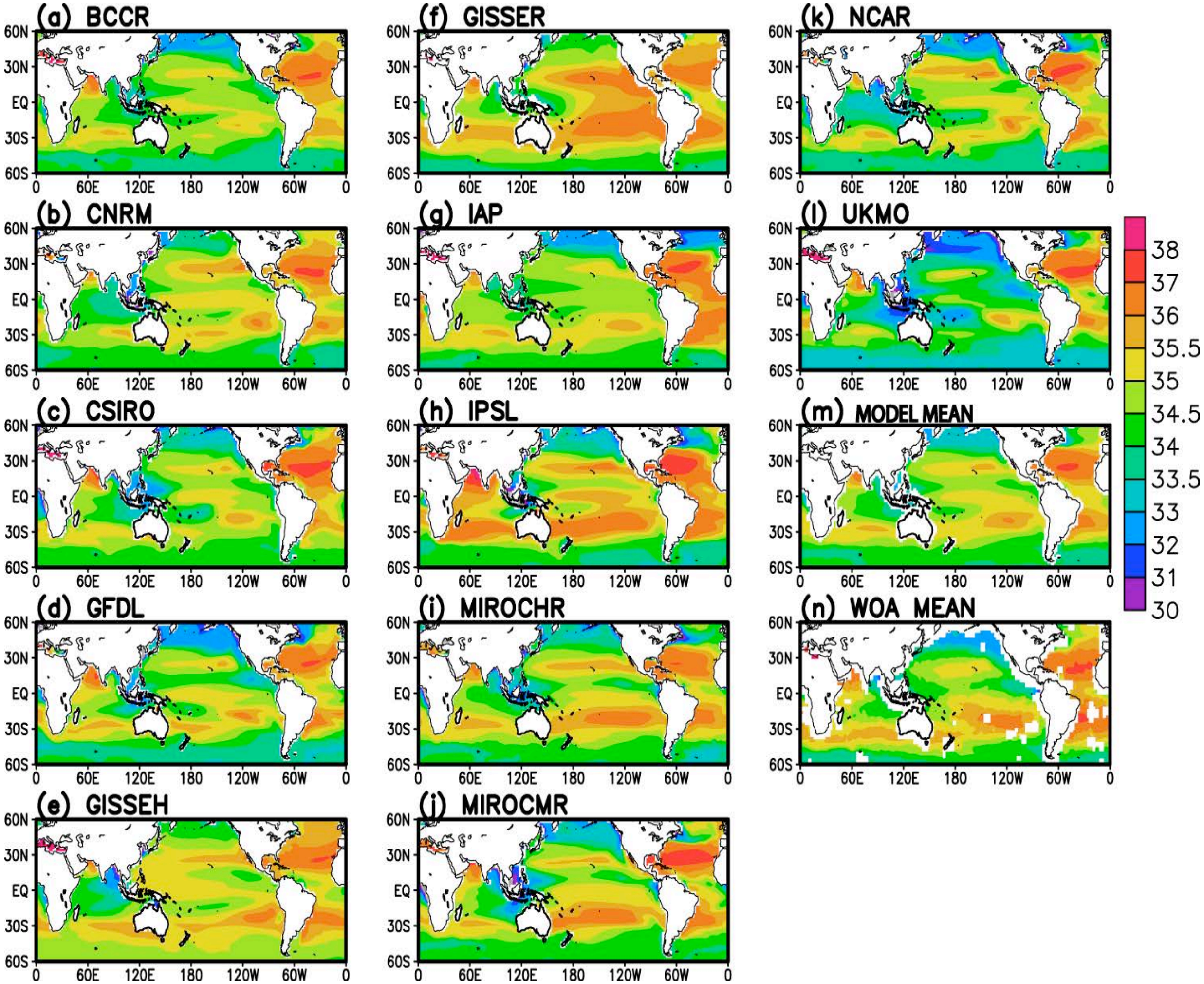




Courtesy F. Landerer (JPL)

F. Landerer: 24-Aug-2011

Next NASA Earth Science Mission: Aquarius – June 2011 – Ocean Salinity



Mean *Salinity* from 12 CMIP3 Model Simulations of 20th Century Climate: POOR MODEL AGREEMENT

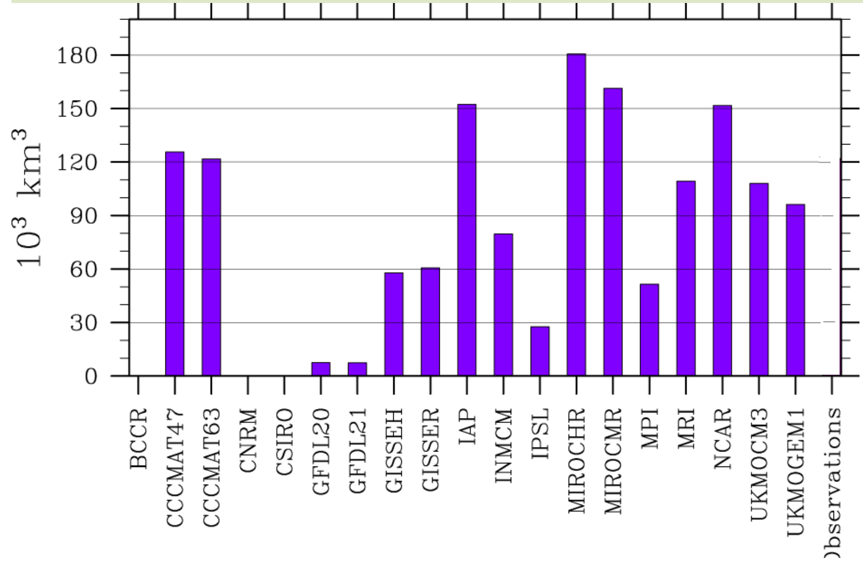
Aquarius will provide the first NASA spaceborne global data of salinity.

Salinity: Characterization of ocean thermohaline circulation and global water budget

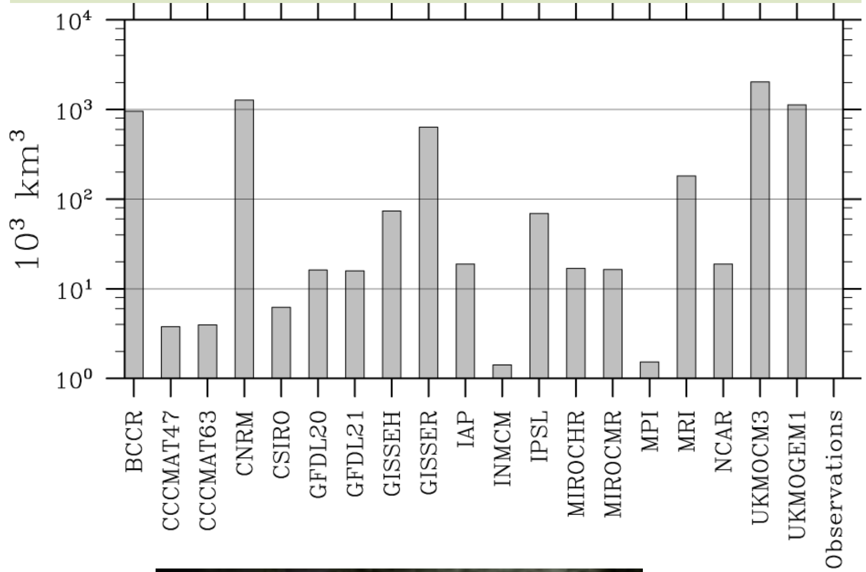
Courtesy D. Waliser, Y. Chao & F. Li

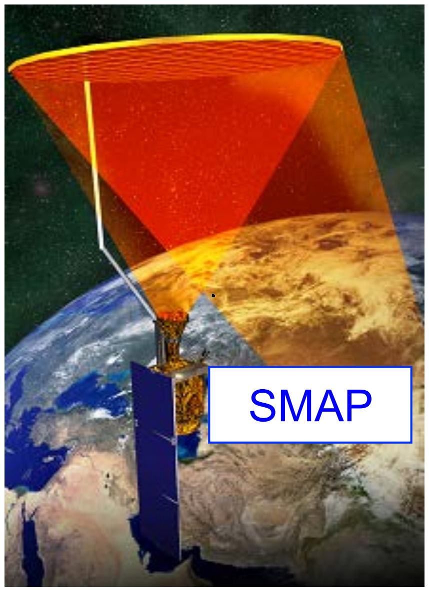
Other Critical Climate Variables:
Model Disagreement & Future Mission Horizon

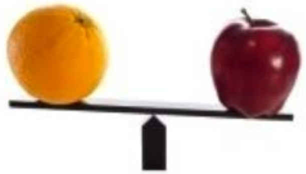
CMIP3 Models: Global Average Soil Moisture

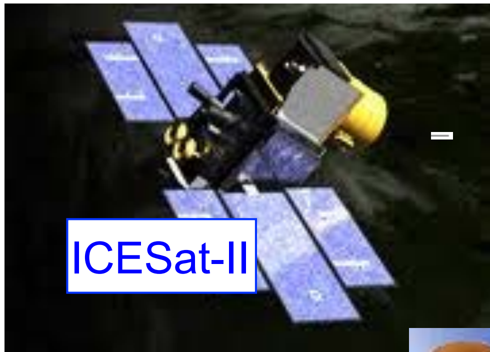


CMIP3 Models: Global Average Snow/Ice Mass









Satellite Observations for IPCC / Climate Modeling

Summary

- Establish a NASA-wide capability for the climate modeling community to support model-to-observation intercomparison. This involves IT, satellite retrieval, data set, modeling and science expertise.

- Establish science "bridge" between models and satellite observations to facilitate model improvement and reduce projection uncertainty. This is also a focus of the new JPL Center for Climate Science.

- Utilize feedback/community collaboration to develop future climate-critical satellite missions. The modeling community has yet to be galvanized to provide feedback to the satellite-development community.

This project is on course to deliver NASA satellite data sets for the evaluation of CMIP5 climate model archive and impact the IPCC AR5.

"PCMDI, major modeling centers, and a very large community of scientists involved in model evaluation would jump on this resource!" PCMDI Thoughts (via P. Gleckler); *Oct 2010 NASA/JPL +DOE/PCMDI Sponsored Workshop*

Satellite Observations for IPCC / Climate Modeling

Future Emphases and Needs

- Identify additional observations to include in this activity.
- Make links to WGCM/WGNE Climate Metrics Panel.
- Identify suites of observations for directions in earth system modeling.
- Develop analogous capabilities within the regional modeling community.
- Encourage the missions to provide the modeling community with forward models / satellite simulators for more direct comparisons with observed quantities (e.g. CFMIP).
- Continue to work with the ESG community and PCMDI to facilitate the means to utilize the satellite data.
- Continue to develop cultivate collaboration / data utilization from NOAA and international (e.g. ESA CCI) partner data sets.
- Encourage missions to develop products analogous to model output.
- Encourage modeling community to develop the means to output quantities analogous to satellite retrieved quantities.
- Cultivate more coherent input from the modeling community on observations critical to model development/evaluation and reducing projection uncertainties.