Observations for Model Intercomparison Projects (obs4MIPs): Facilitating the use of Satellite Data to Evaluate Climate Models

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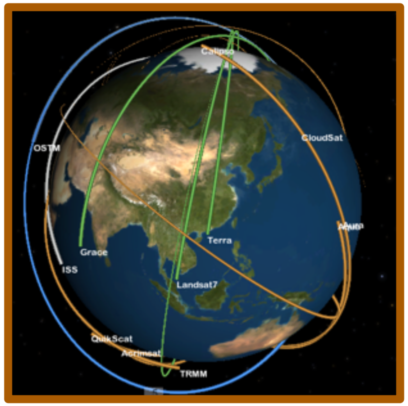
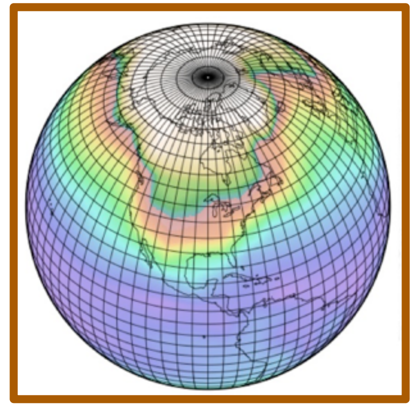


Obs4MIPs



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NASA obs4MIPs Working Group
NASA HQ (Tsengdar Lee and Jack Kaye)
ESG development (DeanWilliams, Luca Cinquini, Dan Crichton, etc.),
Satellite mission teams (e.g. CERES, AIRS, TES, MLS, MODIS, OVWs, REMSS, AVISO, TRMM)

WDAC, Darmstadt, Germany, March 2013

IPCC/CMIP Successes & Challenges

Motivation

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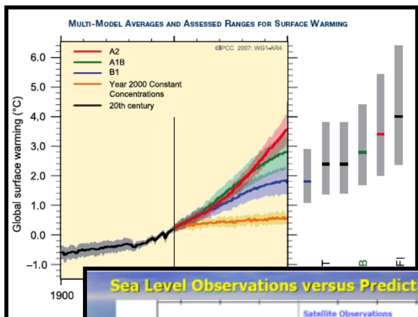

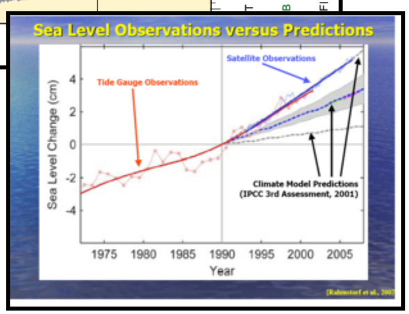

- National and international assessments (e.g. NCA, IPCC AR5) rely on models & coordinated CMIP modeling activities.
- Significant model errors still evident; implying climate projection uncertainties – need to be reduced.
- Models continuing to evolve in complexity and need (multi-variate) evaluation.
- Satellite observations have been under utilized by the model-analysis community.
- New observations on horizon and need to be fully exploited for model evaluation.

Satellite Data &CMIP/IPCC: Better Linkage

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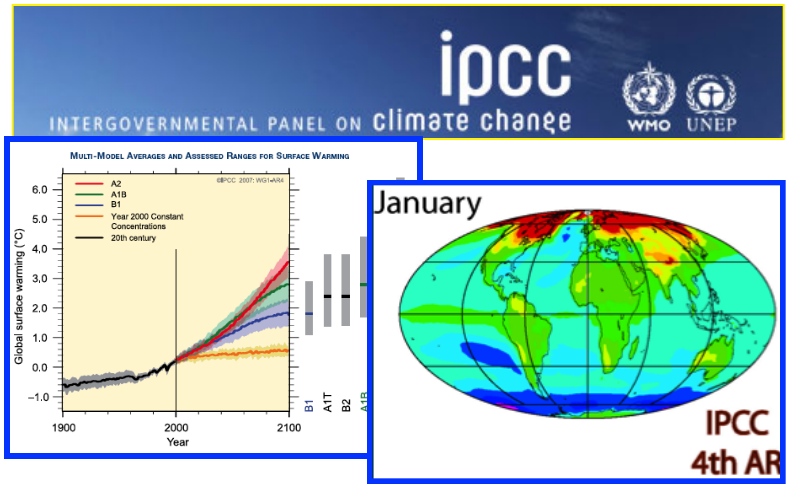

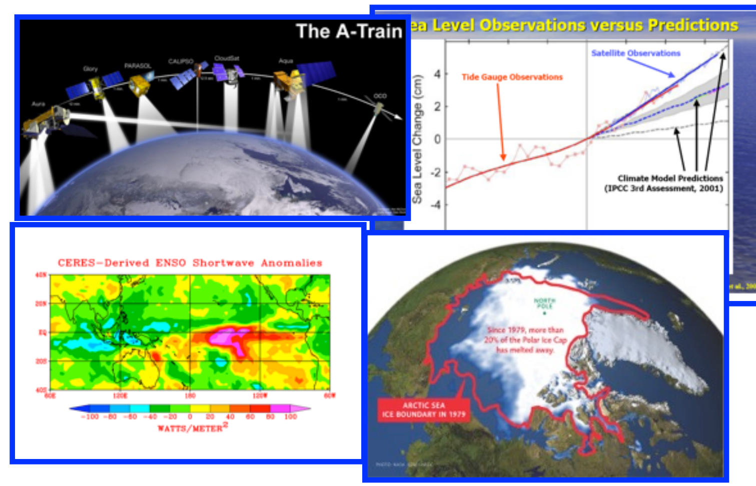

How to bring as much observational scrutiny as possible to the IPCC process?

How to best utilize the wealth of satellite observations for the IPCC process?

Model and Observation Overlap

For what quantities are these comparisons viable?

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

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

<u>Over 300 Variables in (monthly) CMIP Database</u> ⟷ <u>Over 1000 satellite-derived quantities</u>

Some Basic Tenets of this Activity

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1. Use the CMIP5 simulation protocol (Taylor et al. 2009) as guideline for deciding which observations to stage in parallel to model simulations.
   Target: monthly avg (e.g. OMON, AMON, LMON) products on 1^{o}x1^{o} grid
2. Convert Satellite Observations to be formatted exactly the same as CMIP Model output
   CMOR output, NetCDF files, CF Convention Metadata
3. Includes a 6-8 page Technical Note describing strengths/weaknesses, uncertainties, dos/don'ts regarding interpretations comparisons with models. (at graduate student level)
4. Hosted side by side on the ESG with CMIP5
5. Advertise availability of observations for use in CMIP5 analysis.



Some Basic Tenets of this Activity

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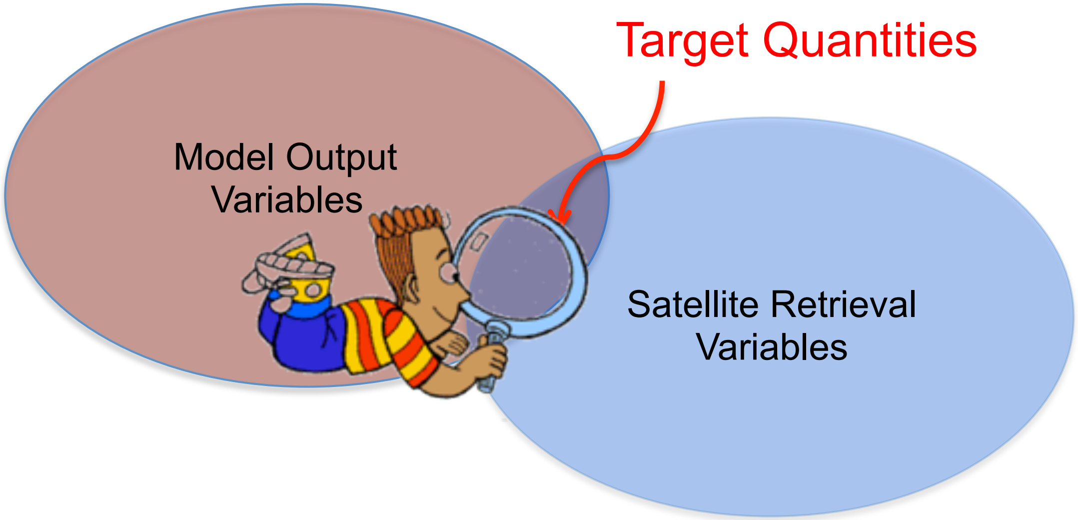

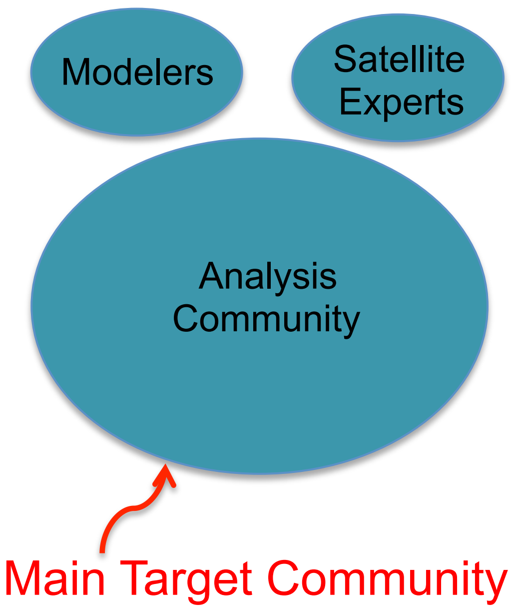

Oct 2010 : Workshop I at PCMDI
Nov 2010 : Workshop II at GSFC

About 15 variables identified as being “safely” comparable in the first phase.

Significant IT work with ESG and data delivery/ formatting by missions teams followed.

Model and Observation Overlap

Initial Data Sets and Ongoing Efforts

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Initial Phase

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

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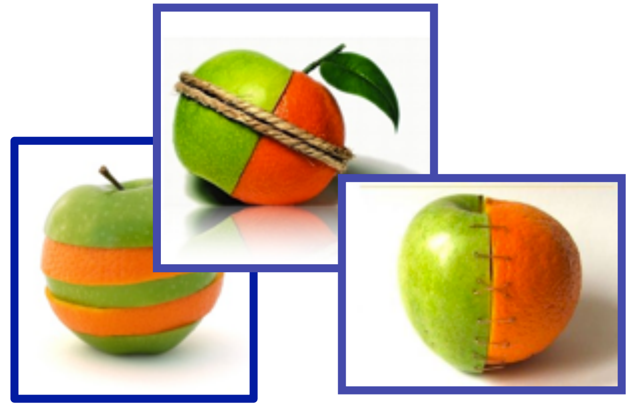

<u>Present efforts are working to provide:</u>

- CFMIP cloud-related products <u>(much of this completed)</u>
- MISR (land) and MODIS (ocean) AOD
- Sea Ice (NSIDC)
- CALIPSO Aerosol Optical Extinction Profile
- CERES surface radiation budget
- MODIS Land (e.g. albedo, LAI, FPAR)

Continued Discussions with ESA's CMUG & CEOS Climate Working Group to expand holdings.

"Technical Note"

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Each Dataset has an accompanying Technical Note

Target audience is modeling and model-evaluation community members who have little experience with satellite datasets

Content

- Intent of the Document/POC
- Data Field Description
- Data Origin
- ➡ Validation and Uncertainty Estimate
- ➡ Considerations for Model – Observation Intercomparison
- Instrument Overview
- References
- Revision History

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

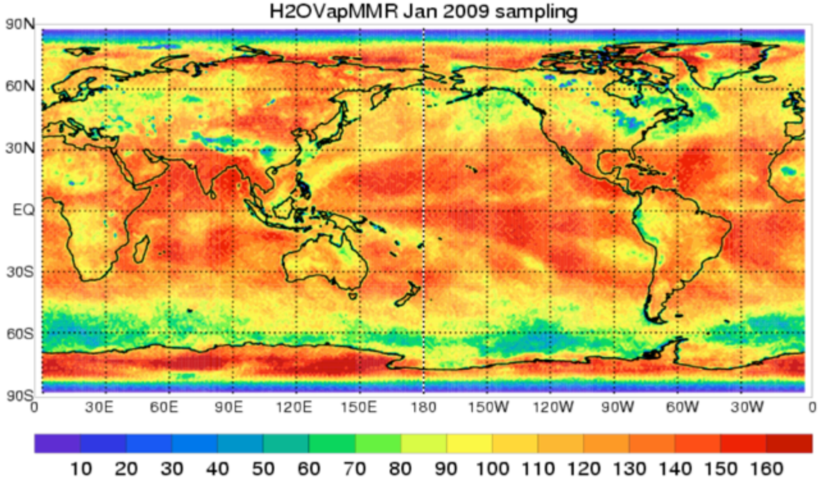

Figure 1: Water vapor sampling repartition at 550 hPa for the month of January 2009.

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

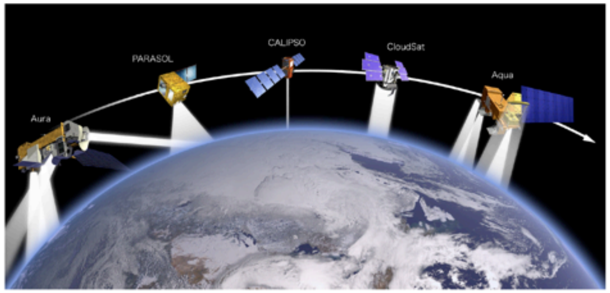

Figure 2: NASA's A-train group of Earth observing satellites.

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

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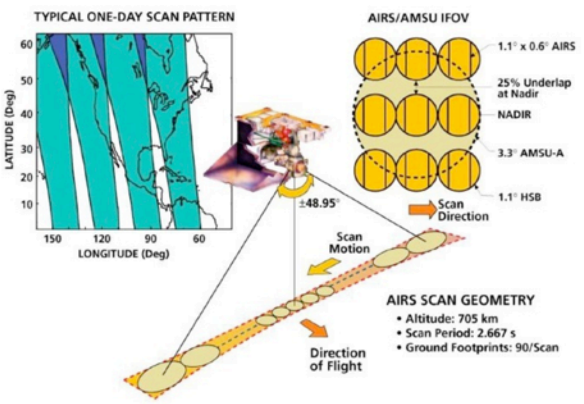

Figure 3: AIRS scanning and coverage geometry.

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/

ESG Gateway : Side by Side Archive with CMIP

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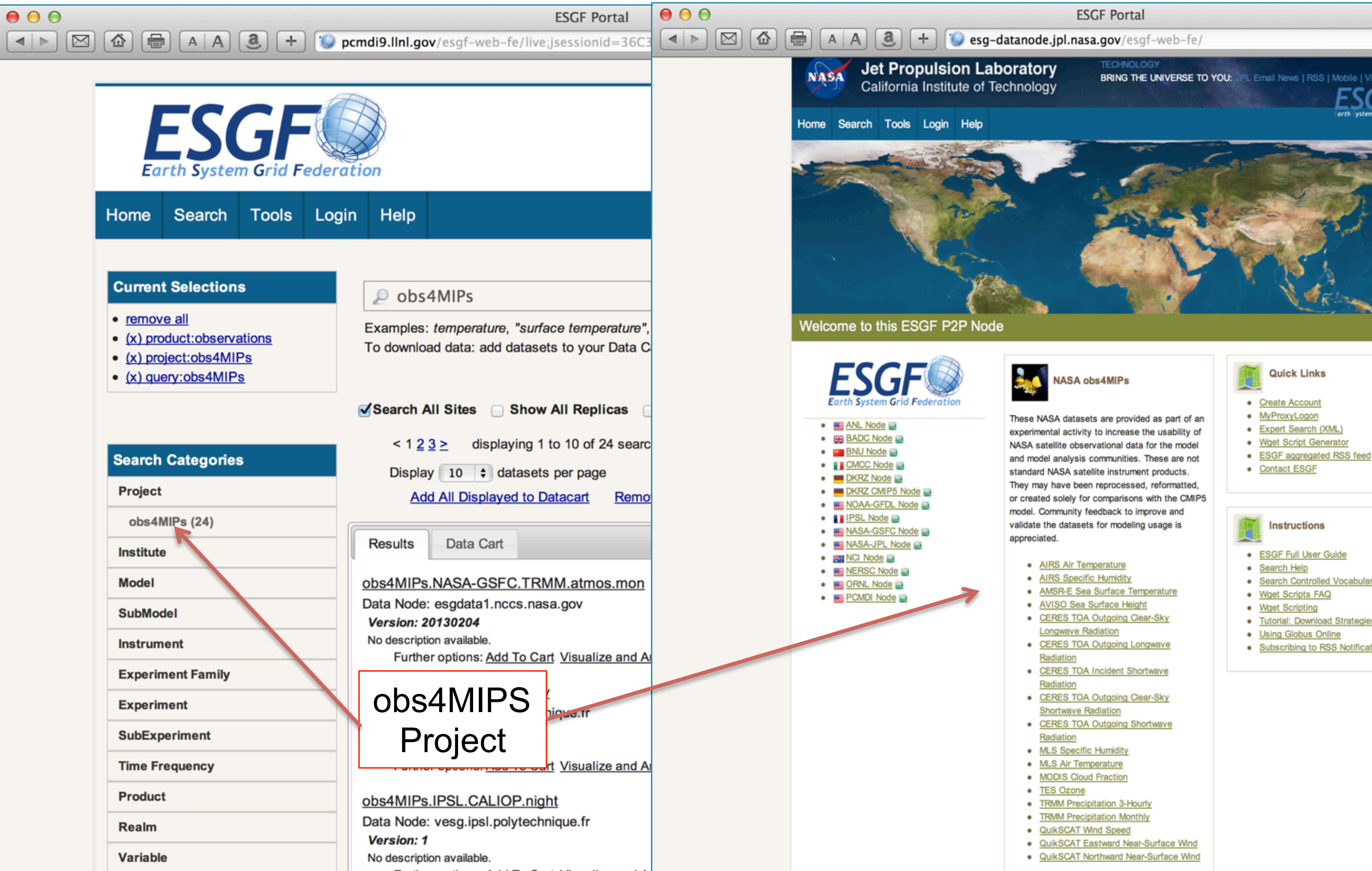

CMIP3 Sea Level vs TOPEX/JASON

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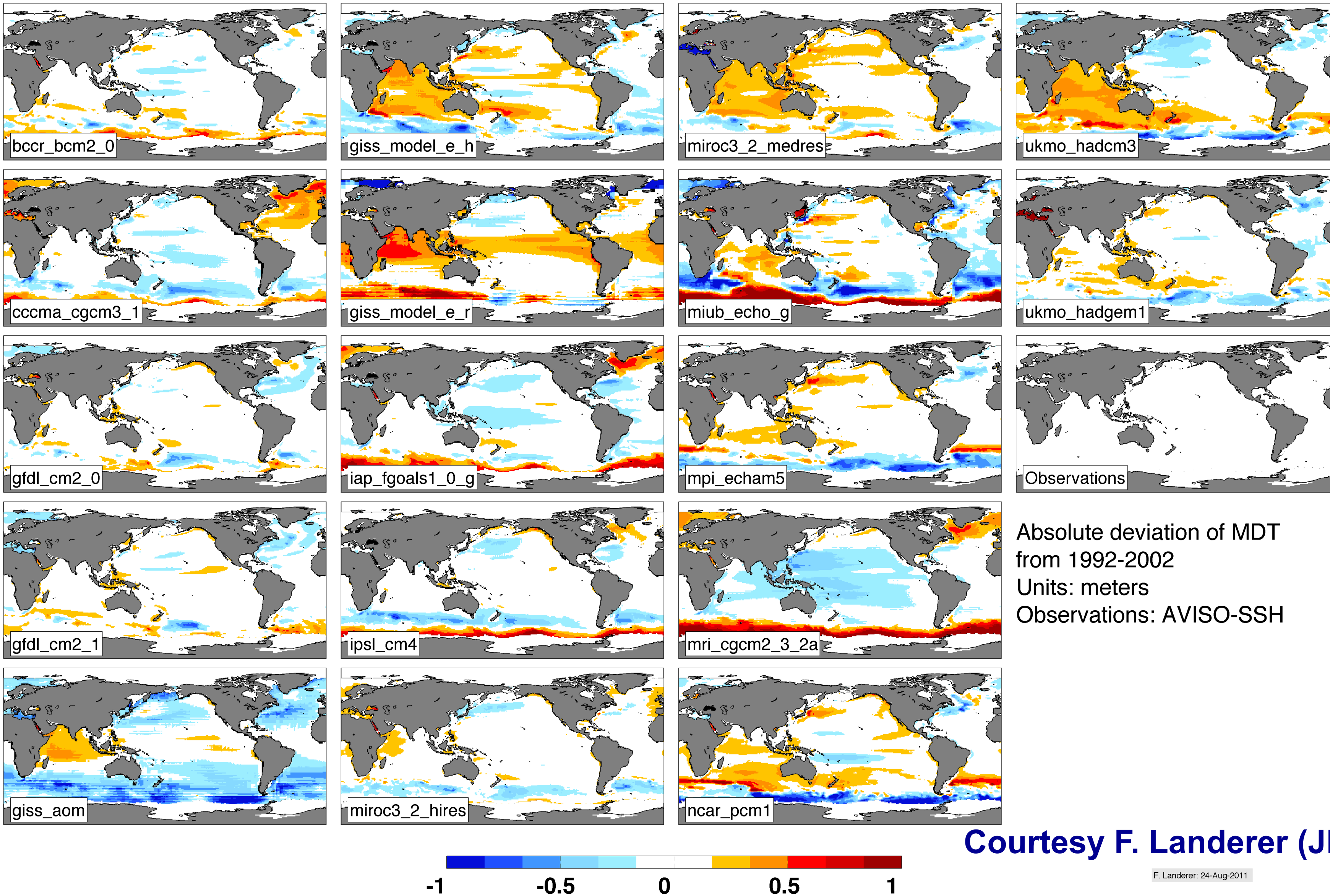
Mean dynamic topography (GCMs 1992-2002); Obs: Maximenko et al. [2005]) Absolute values (each field has zero mean)



Absolute deviation of MDT from 1992-2002
Units: meters
Observations: AVISO-SSH

Courtesy F. Landerer (JPL)

F. Landerer: 24-Aug-2011

Satellite Observations for CMIP and IPCC ARs

Why is this timely for AR5 and beyond?

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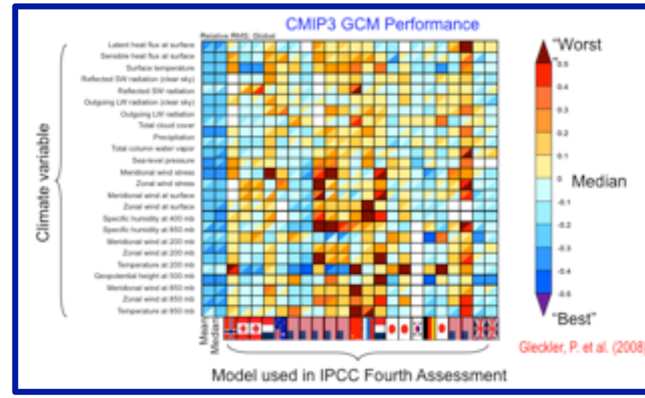
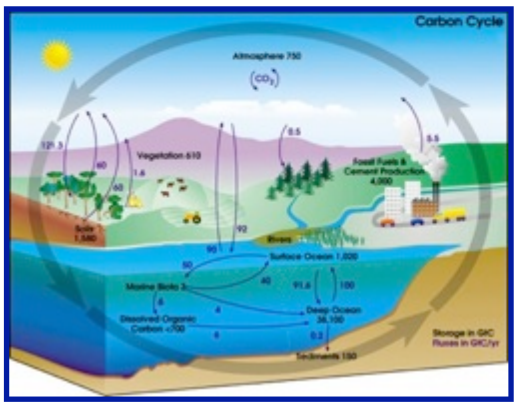
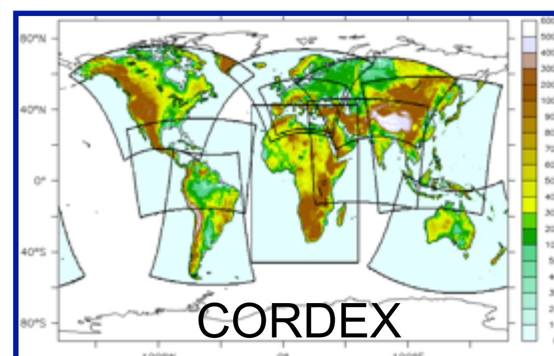
<u>Model Scoring w/ Observations</u>: "1 model – 1 vote" to weighting projections based on obs metrics (e.g. WGCM/WGNE Metrics Panel)





<u>Earth System Modeling</u> (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).

<u>Decadal Predictions:</u> 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 Evaluating CMIP5 SUMMARY

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- NASA-PCMDI pilot Project has established a (satellite) observation capability for the climate modeling community to support model-to-data intercomparison. This involves IT, satellite retrieval, data set, modeling and science expertise.
- ~20 satellite-based datasets currently available on the ESG – more coming.
- Interested in collaboration with other agencies, activities and international partners (e.g. IPSL/CFMIP – already contributed, ESA CMUG, ana4MIPs) to expand this for AR6 and related MIPs, and solicit feedback from model analysis community.
- NASA formed a obs4MIPs Working Group, including rep from PCMDI and NOAA to help guide the expansion and direction of this activity. We are hoping to have a component of WCRP (i.e. WDAC) shepherd it at the broadest level.
- This would not have been possible without help from AIRS, MLS, TES, QuikSCAT, MODIS, TRMM, REMSS, PODAAC, GSFC, and AVISO, plus ESGF, IPSL/CFMIP, etc – many people contributed to this effort

- Identify additional observations to include in this activity (broader participation). Hoping to do this in concert and with guidance with WCRP (e.g. WDAC, WMAC).
- Continue to work with the ESG community and PCMDI to facilitate the means to utilize the satellite data, as well as CMUG, Climate Metrics Panel, other MIPs, etc.
- Encourage missions to develop products analogous to model output, including satellite simulators for more direct comparisons with observed quantities (e.g. COSP, but for other processes/ES components).
- Encourage modeling community to develop the means to output quantities analogous to satellite retrieved quantities.
- Need: Future workshop (2013/2014) to begin planning for CMIP6 – CMIP architects, modeling, satellite and reanalysis leads, ESG developers, etc.