Facilitating the Use of Satellite Observations for Evaluating CMIP5/IPCC Simulations

Converting NASA Satellite Datasets for the CMIP5/IPCC Assessment

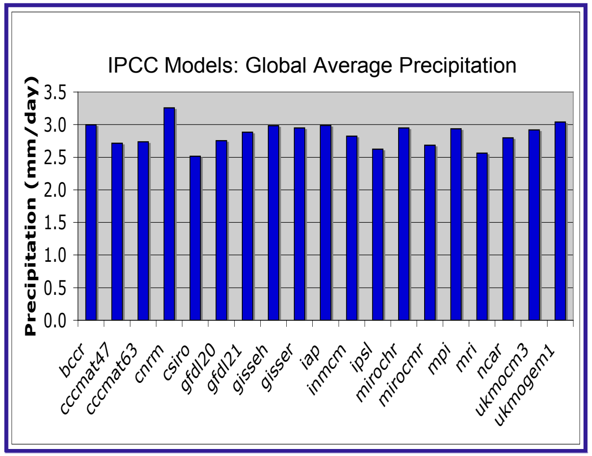
Robert Ferraro, Duane Waliser, Joao Teixeira

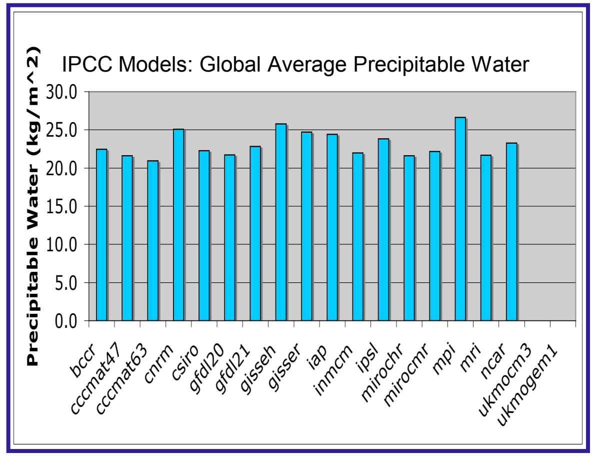
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA

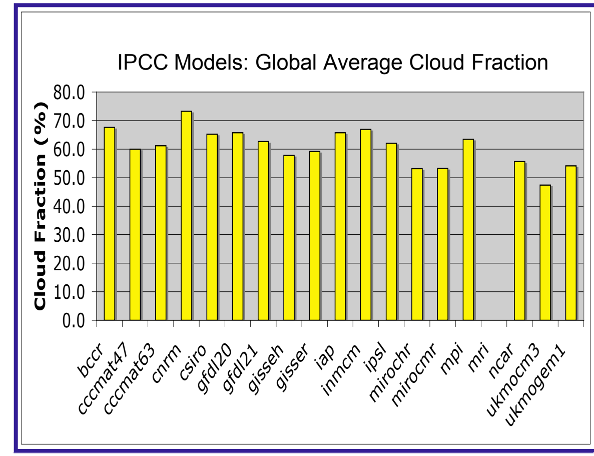
Peter Gleckler, Karl Taylor

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

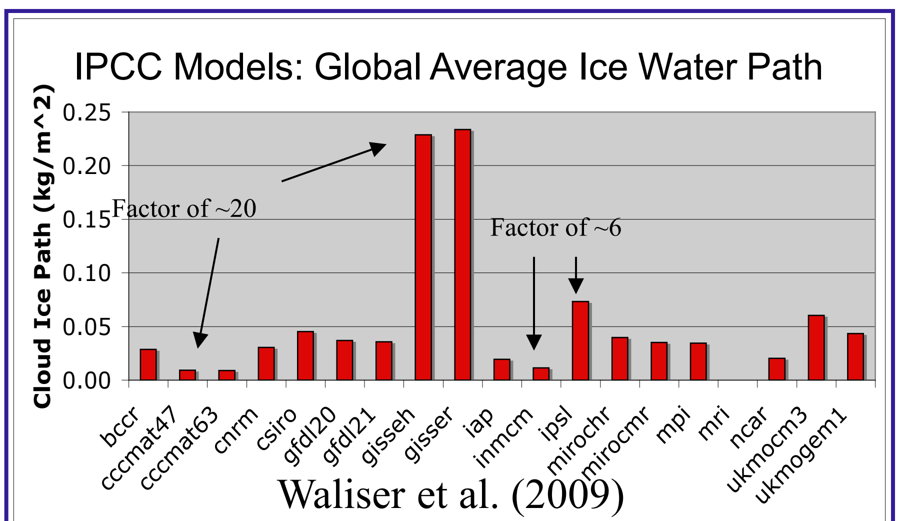
Motivation: Examples of Where Satellite Data Have Helped and Where They Have Been Missing







NASA/NOAA/DOD have produced observations of Precipitation (e.g., TRMM-NASA), Column Water Vapor (e.g. SSM/I - DOD), and Cloud Frequency (ISCCP-NASA/NOAA) that have led to RELATIVELY good model-model and model-obs (not shown) agreement.



<u>But look at Cloud Ice – No Robust Satellite Measurements (Until Very Recently). This leads to poor model-model agreement and thus implicitly model-obs agreement.</u>

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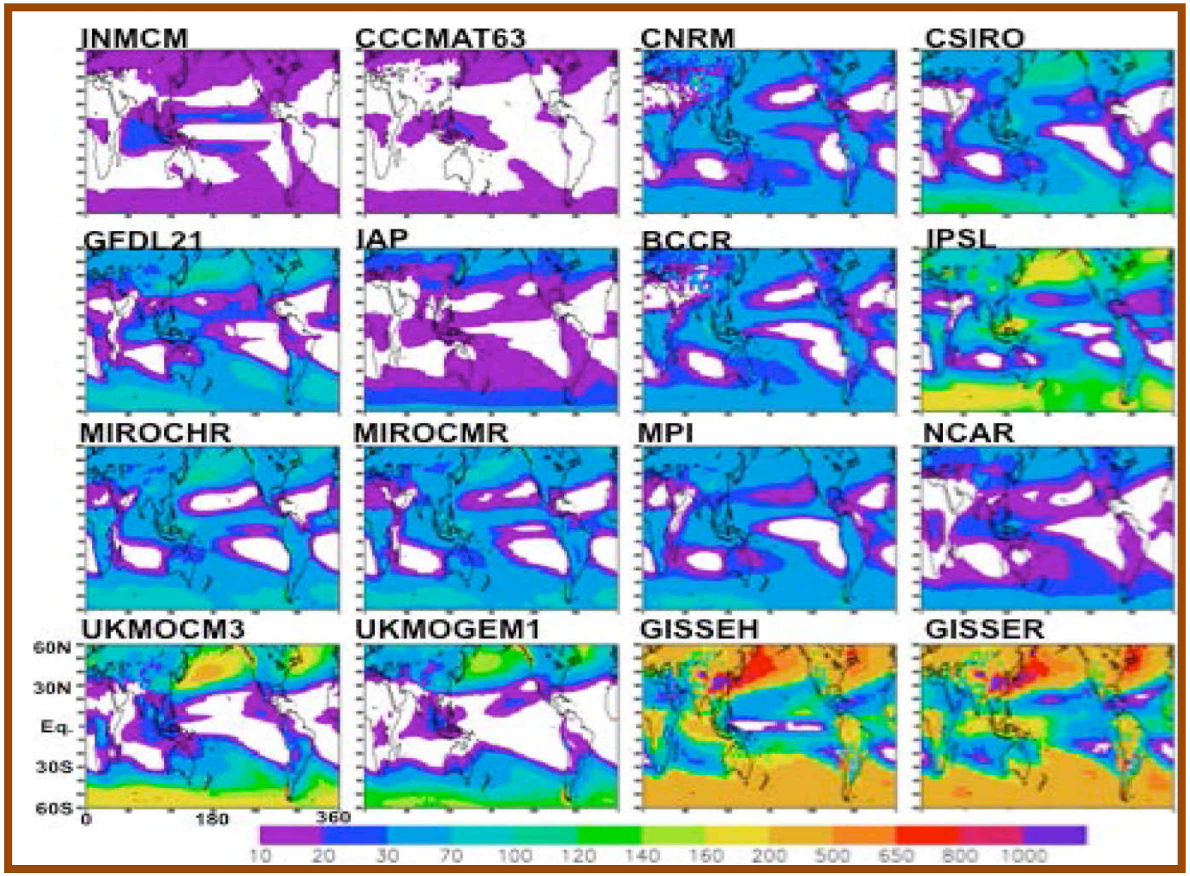
<u>**UNCERTAINTY IN CLIMATE PROJECTIONS**</u>

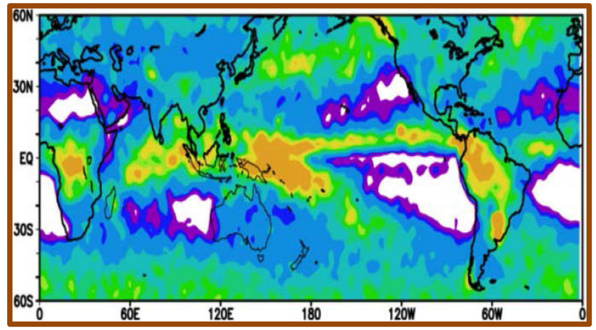
Motivation: Examples of Where Satellite Data Have Helped and Where They Have Been Missing



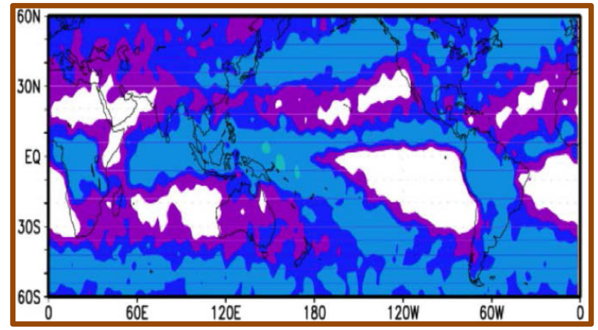
Mean *Cloud* IWP from 16 IPCC Contributions of 20th Century Climate : Color scale ~ log10:

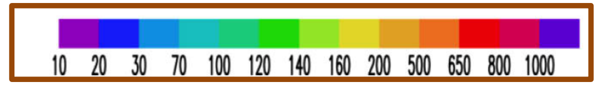
We need to use our observations to reduce this uncertainty.

CloudSat Total IWP



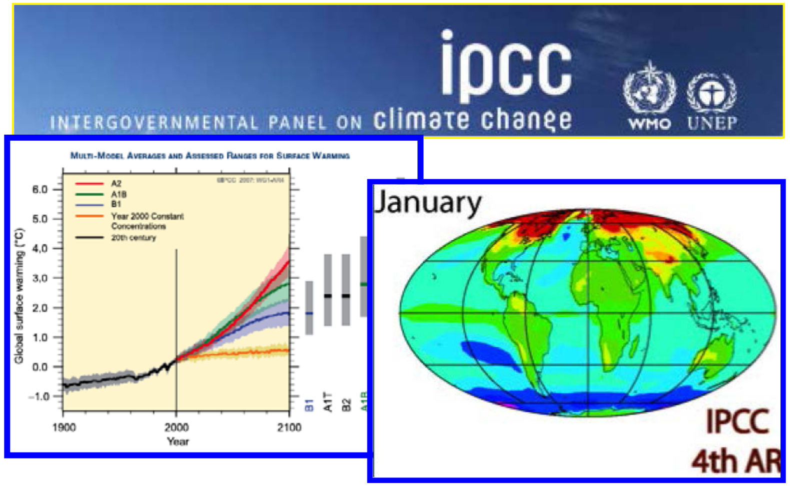
CloudSat IWP Conditionally Filtered to better Approximate/Validate GCM-modeled Cloud IWP



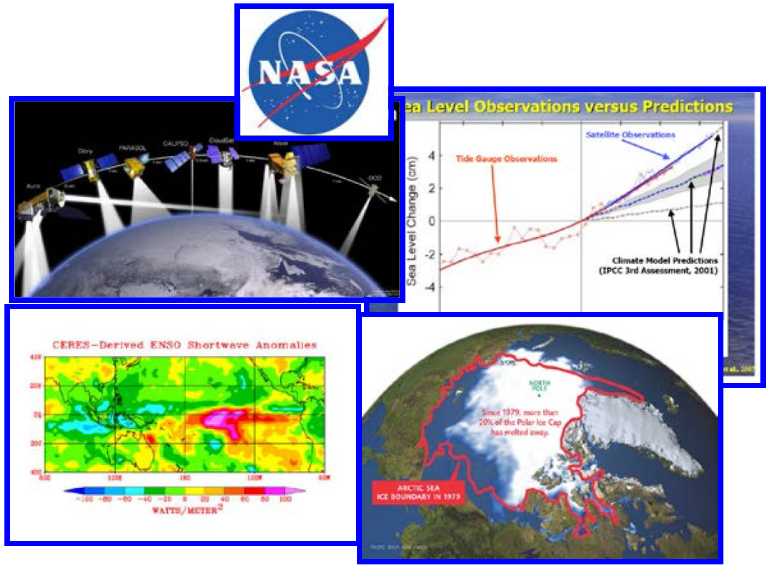


Waliser et al. 2009

NASA and CMIP/IPCC: Better Linkage



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



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

Modelers, PCMDI, JPL/NASA, Community
Who does what?

Produce Simulations & Projections (HUGE job; focus on model development – not analyses or observations)

Modeling Centers

Model output archived in a uniform fashion to facilitate access and analysis. (Far from trivial – see below)

Sophisticated development and application of model diagnostics for evaluation (Observations needed here, but which ones?)

PCMDI

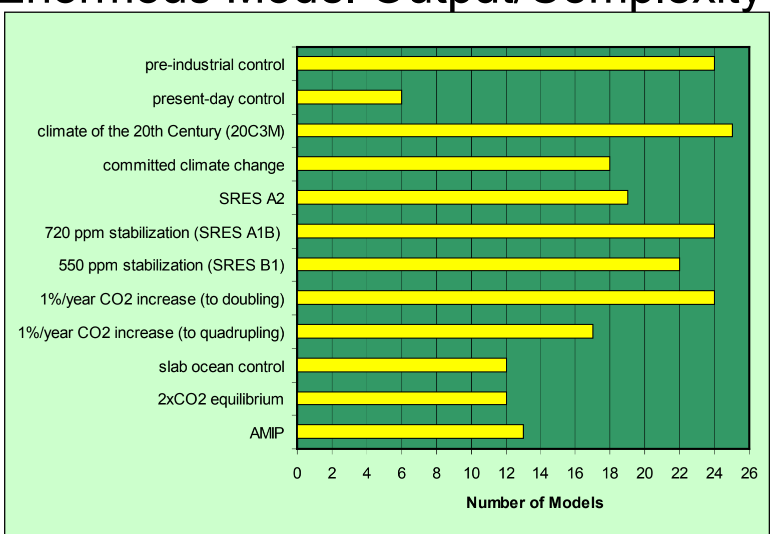
Identify and deliver/archive observations in form useful for model analysis (Requires model, obs and IT expertise)

Weak Link

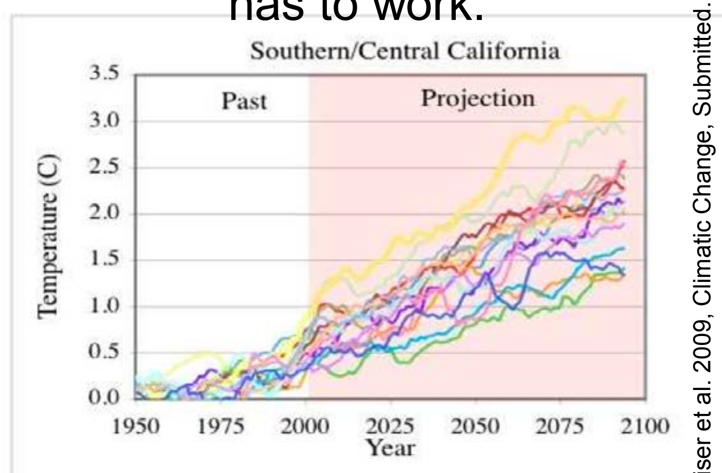
Develop global observations relevant to climate change research (Focus on hardware, retrievals, delivery)

NASA & JPL

Enormous Model Output/Complexity



To quantify and reduce uncertainty, this chain has to work.



Waliser et al. 2009, Climatic Change, Submitted.

What to do about the weak link?

- Taylor et al (2009) have defined the protocol for the CMIP5 simulations that will be used for the next IPCC Assessment Report, AR5.
- The protocol defines the scope of simulations that will be undertaken by the participating modeling groups.
- For several of the prescribed retrospective simulations (e.g, decadal hindcasts, AMIP and 20th Century coupled simulations) observational data sets can be used to evaluate and diagnose the simulation outputs.
- However, to date, the pertinent observational data sets to perform these particular evaluations have not been optimally identified and coordinated to readily enable their use in the context of CMIP5.

Observations may match model variables but usually differ in file format, metadata standard, and may have subtle characteristics that are not obvious to the non-expert

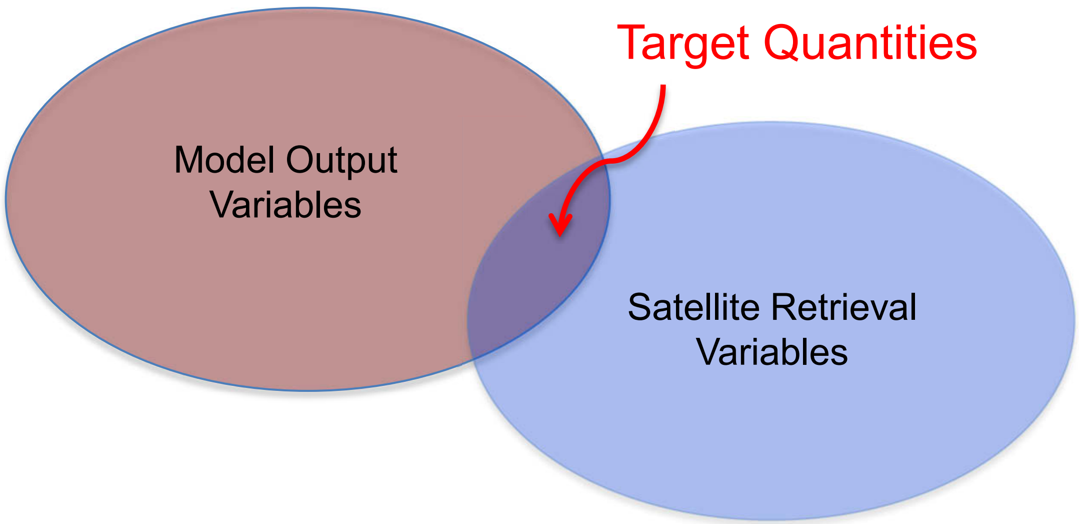
Observational Scientists make datasets for process studies – not for model evaluation

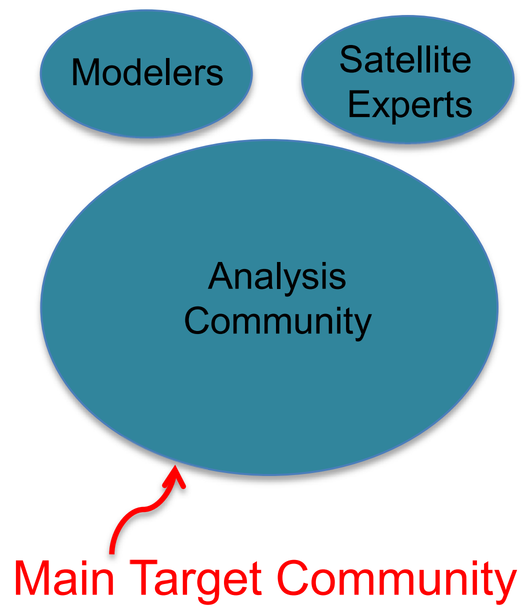
Satellite Observations for CMIP5 Simulations
Some Basic Tenets of this Activity

- To provide the community of researchers that will access and evaluate the CMIP5 model results access to ***analogous sets*** (in terms periods, variables, temporal/spatial frequency, dissemination) of satellite data.

- To be carried out in close coordination with the corresponding CMIP5 modeling entities and activities – in this case PCMDI and WGCM.

- To directly engage the observational (e.g. mission and instrument) science teams to facilitate production of the corresponding data sets and documentation.





IPCC AR5 – Making Better Use of Observations

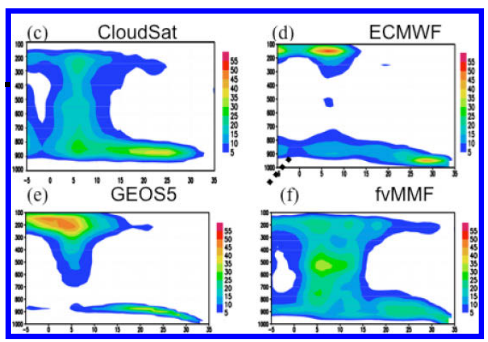
Characterizing and Reducing Uncertainties

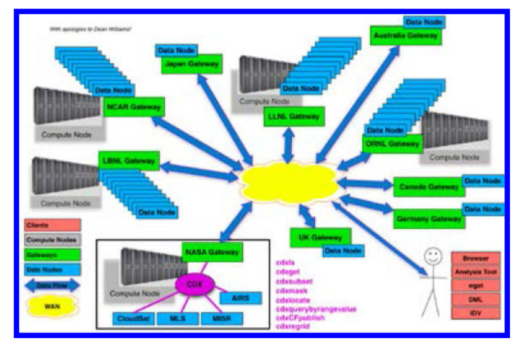
PCMDI

- JPL/NASA is leading an effort with PCMDI/DOE to identify and deliver a number of NASA satellite datasets tailored for IPCC model-data comparison.
- Community to have simultaneous access to model output and satellite observations similarly formatted to facilitate model evaluation.
- Use observation-based "metrics" to assess model capabilities of representing past climate -> use to weight models' climate projections.
- Need by Spring/Summer 2011 for model evaluations and timely submission of research articles –> IPCC AR5 to be published in 2013.

Science + Observations + IT

- NASA funded JPL pilot project to identify & deliver selected satellite data
- JPL led organization of two workshops
  1) Mission/Science -> Data Sets
  2) Mission/IT -> Infrastructure
- Hoping for future NASA Program





Satellite Observations for CMIP5 Simulations

Main Tasks for CMIP5

1. Use the CMIP5 simulation protocol (Taylor et al. 2009) as guideline for deciding which observations to stage in parallel to model simulations.

   Target is monthly averaged (CMON, AMON) products on 1 x 1 degree grid

2. Work with satellite community to identify data sets [e.g., AIRS, MLS, TES, QuikSCAT, CloudSat, Topex/Jason, CERES, TRMM, AMSR-E, TRMM]

3. Work with observational teams to produce 4-5 page Technical Note describing strengths/weaknesses, uncertainties, dos/don'ts regarding interpretations comparisons with models. (at graduate student level)

4. Transform satellite observations into CMIP5 compliant format (to the greatest extent possible – should look like model output)

   Not new products, but reformatted existing products, with perhaps some interpolation

5. Provide a strategy for accessing them that has close parallels to the model data archive (e.g. ESG).

6. Advertise availability of observations for use in CMIP5 analysis.

NASA Recommended Datasets for CMIP5

Match up of available NASA datasets to PCMDI priority list

Model	Dataset	Time Period	Comments
Atm Temperature (200,850hPa)	AIRS (≥ 300 hPa) MLS (< 300 hPa)	9/02 – 8/04 -	AIRS +MLS needed to cover all pressure levels
Zonal and meridional wind (200,850 hPa)	No obvious match		Reanalysis is the best product
Specific humidity (200, 850 hPa)	AIRS (≥ 300 hPa) MLS (< 300 hPa)	9/02 – 8/04 -	AIRS +MLS needed to cover all pressure levels
Sea level pressure	No obvious match		Reanalysis is probably the best product match
Surface (10m) zonal and meridional wind	QuikSCAT CCMP	1999 – 2009 7/87 – 12/09	Oceans only. No land products. CCMP is a multi-sensor variational analysis product
Ocean surface zonal and meridional wind stress	QuikSCAT CCMP	1999 – 2009 7/87 – 12/09	Oceans only. No land products. CCMP is a multi-sensor variational analysis product
Sea surface temperature	AMSR-E	6/02 -	SST science team recommends multiple products
TOA reflected shortwave radiation and OLR	CERES	3/00 -	
TOA longwave and shortwave TOA clear-sky fluxes	CERES	3/00 -	
Total precipitation	TRMM GPCP	1997 - 2/79 – 4/08	GPCP is an analysis product
Cloud cover	MODIS	2/00 -	
Precipitable water	SSM/I	7/87 -	
Sea surface height	TOPEX/JASON series	10/92 -	Project scientist recommends converting the AVISO product
Sea ice	NSIDC		microwave product would be best. More investigation is needed.

Satellite Observations for CMIP5 Simulations
"Technical Note"

Target audience is modeling community members who have little experience with NASA 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

Guidance documents (and project related stuff) posted at

http://oodt.jpl.nasa.gov/wiki/display/CLIMATE

Satellite Observations for CMIP5 Simulations
Example Technical Note – AIRS

Atmospheric Infrared Sounder/Advance Microwave Sounding Unit (AIRS/AMSU)

Air Temperature Description

1. Intent of This Document

1a) This document is intended for users who wish to compare satellite derived observations with climate model output in the context of the CMIP5/IPCC historical experiments. Users are not expected to be experts in satellite derived Earth system observational data. This document summarizes essential information needed for comparing this dataset to climate model output. References are provided at the end of this document to additional information for the expert user.

This NASA dataset is provided as part of an experimental activity to increase the usability of NASA satellite observational data for the model and model analysis communities. This is not a standard NASA satellite instrument product. It may have been reprocessed, reformatted, or created solely for comparisons with the CMIP5 model. Community feedback to improve and validate the dataset for modeling usage is appreciated.

Dataset File Name (as it appears on the ESG):
ta_Amon_AIRS_amip_r1i1p1_200209-201006.nc

1b) Technical point of contact for this dataset: Baijun Tian, Baijun.Tian@jpl.nasa.gov

2. Data Field

This data product is a regularly gridded, monthly averaged air temperature measured by AIRS during 2002-2010.

CF variable name, units: ta, K
Vertical resolution: CMIP5 mandatory levels
Horizontal resolution: 1 degree
Temporal resolution and extent: monthly averaged between September 2002 and June 2010.
Coverage: Global

The vertical pressure levels (plev) include all the CMIP5 mandatory levels from 1000 hPa to 10 hPa. However, we only provide the valid data up to 300 hPa and assign a missing value (1e-20) for levels above 300 hPa because AIRS measurements are not as reliable for levels above 300 hPa as other instruments such as Microwave Limb Sounder (MLS), which is specially designed for the accurate measurements of the atmospheric profiles in the upper troposphere and lower stratosphere. The MLS measurements for levels above 300 hPa are provided as a separate dataset. It is therefore highly recommended for a user to combine the AIRS and MLS datasets to create a complete temperature profile from 1000 hPa to 10 hPa.

3. Data Origin

The data used to make this product was obtained from the Goddard Earth Science (GES) DISC data access [1].

The AIRS/AMSU instrument suite is carried on the NASA Aqua spacecraft, in a sun-synchronous orbit at 1:30 local time. The southward/northward moving observations are obtained during daytime/nighttime. (See Section 6 below for an Overview of the AIRS/AMSU instrument suite.) The AIRS/AMSU air temperature is derived from infrared and microwave radiances measured from space, so is not an *in situ* measurement. The infrared emission radiations emitted by different Earth scenes are remotely sensed by a spectrometer, and the microwave observations are obtained by a radiometer [2]. Among the 2378 infrared spectral channels, 147 channels are used in the first temperature profile retrieval; an additional seven channels are used in the second temperature profile retrieval; 12 or 15 microwave channels are utilized for temperature sounding [3]. First, measurements are transformed into calibrated radiances for all footprints and all channels [4]. Then, physical quantities such as the air temperature are derived ('retrieved') from these geolocated radiance products [5]. The retrieved physical quantities are then averaged over a month [6]. The data we obtained from the GES DISC [1] was at this last processing level. We then applied an additional processing step to adapt the data according to the CMIP5 model output format.

The values described here are means of the daytime and nighttime 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. Since clouds have a significant effect on observed infrared radiances (see section 4-1 below), the retrieval process includes steps to retrieve the temperature from radiance in the presence of clouds [3]. The horizontal resolution of each AIRS/AMSU scene is 45 km, and the instrument sample in a swath 30 scenes wide (see Figure 3 below), yielding 324,000 scenes per day. However, the atmospheric temperature can be inferred in about 70% of these scenes, with the remainder affected by thick clouds or precipitation.

This data product is the monthly average of the AIRS/AMSU retrieved temperature profiles in the regularly gridded 1 degree by 1 degree latitude and longitude boxes. The AIRS/AMSU temperature profile is originally in 28 pressure levels that are the superset of the CMIP5 mandatory levels. The temperature values at only the CMIP5 levels are included in this data product.

Satellite Observations for CMIP5 Simulations
Example Technical Note – AIRS

Jet Propulsion Laboratory
California Institute of Technology

PCMDI

4. Validation

AIRS retrievals have been validated against a variety of in situ data (radiosondes, ship-based measurements), other remote measurements, from other satellites, and model-generated data. The table below summarizes these findings and can be found in reference [7].

Geophysical Conditions Studied	Uncertainty Estimate
Ocean, surface to lower stratosphere	1K
Non-polar land, 1-2 km to lower stratosphere	1K
Non-polar land, surface to 1-2 km	1-2 K
Polar land.	1-2 K

Table 1: uncertainty estimate for different conditions.

The uncertainty estimates are calculated based on the difference between AIRS retrievals and radiosonde observations and are valid in the troposphere, between the boundary layer and 300 mbar.

5. 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.

5.1 Clouds influence

AIRS/AMSU coverage is limited by the presence of optically thick clouds because AIRS is an infrared instrument. The combination of infrared and microwave radiances allows retrieval of high-resolution temperature profiles for infrared cloud fraction (the product of emissivity and coverage) up to about 70% [3]. While AMSU retrievals based purely on microwave observations are currently available, they are not included with the AIRS/AMSU retrievals because of significantly lower vertical resolution. This limitation of the infrared measurement makes the AIRS/AMSU observation scene dependent and in turn, 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 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. See reference [8] for more on the implication of cloud-induced sampling in AIRS/AMSU observations.

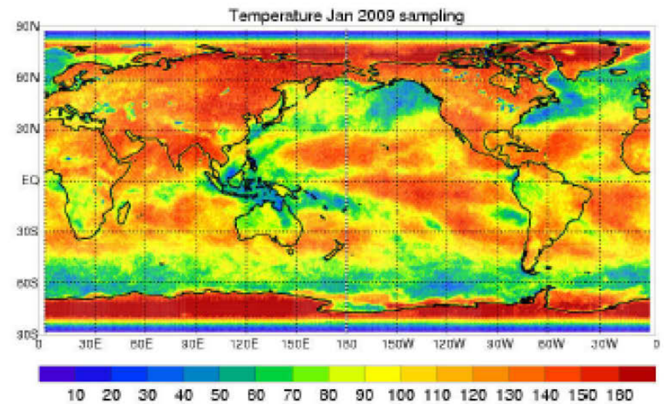


Figure 1: Temperature sampling at 500 hPa for the month of January 2009.

5.2 Temperature bias trend

There is a spurious trend in AIRS temperature retrievals, giving an apparent cooling of the lower troposphere of ~100 mK/year. This is suspected to come from incorrect handling of rising atmospheric CO_2 levels [9], and should be reduced in the next release of AIRS data.

5.3 Asynoptic Time Sampling

Because Aqua satellite with a sun-synchronous polar orbit, it samples at two fixed local solar times (e.g. 1:30 AM and 1:30 PM at the equator) so cannot resolve the diurnal cycle. AIRS observes at a given latitude at the *same* local time (to within several minutes). In contrast, typical model monthly averaged outputs contain the averaged values over a time series of data within a fixed time interval (e.g. every 6 hours). For temperature 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.

5.4 Inhomogeneous Sampling

Because the monthly averaged value in this AIRS data product is an average over observational data available in a given grid cell (see Figure 1), 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 [10]. So, there are more observations in the regions near the poles (~70° to ~85°) than the rest of the area.

6. Instrument Overview

Satellite Observations for CMIP5 Simulations
Example Technical Note – AIRS

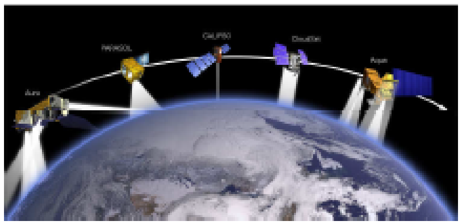


Figure 2: NASA's A-train group of Earth observing satellites.

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.

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.

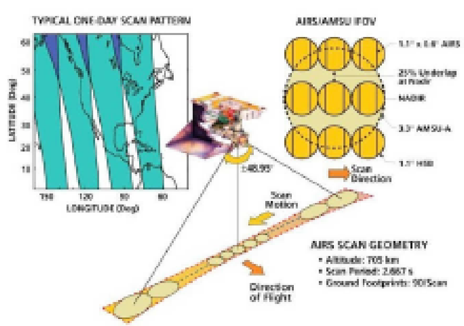


Figure 3: AIRS scanning and coverage geometry.

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 [11].

7. References

[1] http://disc.sci.gsfc.nasa.gov/AIRS/data-holdings

[2] 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.

[3] 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.

[4] Level-1B AIRS IR

[5] Level-2 Standard Products Quick Start

[6] Level-3 Standard 1x1° Gridded Products Quick Start

[7] V5_CalVal_Status_Summary.pdf, p8.

[8] Fetzer, E. J., *et al.*, (2006), Biases in total precipitable water vapor climatologies from Atmospheric Infrared Sounder and Advanced Microwave Scanning Radiometer, *J. Geophys. Res., 111*, D09S16, doi:10.1029/2005JD006598.

[9] Murty G. Divakarla *et al.*,"Validation of Atmospheric Infrared Sounder temperature and water vapor retrievals with matched radiosonde measurements and forecasts", JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 111, D09S15, doi:10.1029/2005JD006116, 2006, page 18.

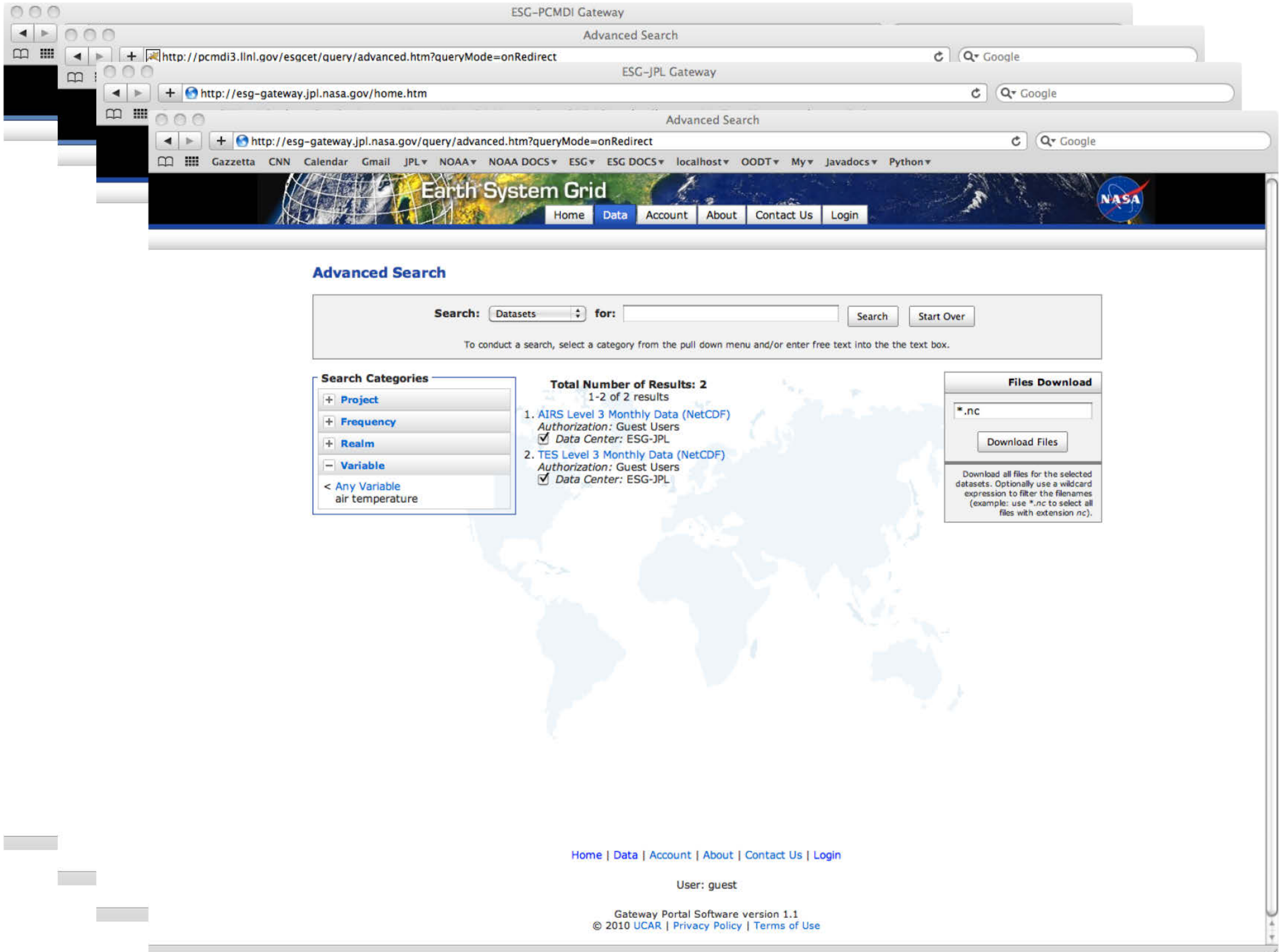
[10] Claire L. Parkinson, "Aqua: An Earth-Observing Satellite Mission to Examine Water and Other Climate Variables", IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 41, NO. 2, FEBRUARY 2003.

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

8. Revision History

Rev 0 – 03/07/2011

Satellite Observations for CMIP5 Simulations
ESG-JPL Gateway : Side by Side Archive



IPCC AR5
New Emphases, Opportunities, & Needs

Model Scoring against Observations:

"one model – one vote" to weighting of projections based on metrics.
(e.g. WGCM/WGNE Metrics Panel)

Earth System Modeling (e.g. Coupled Carbon-Climate models):

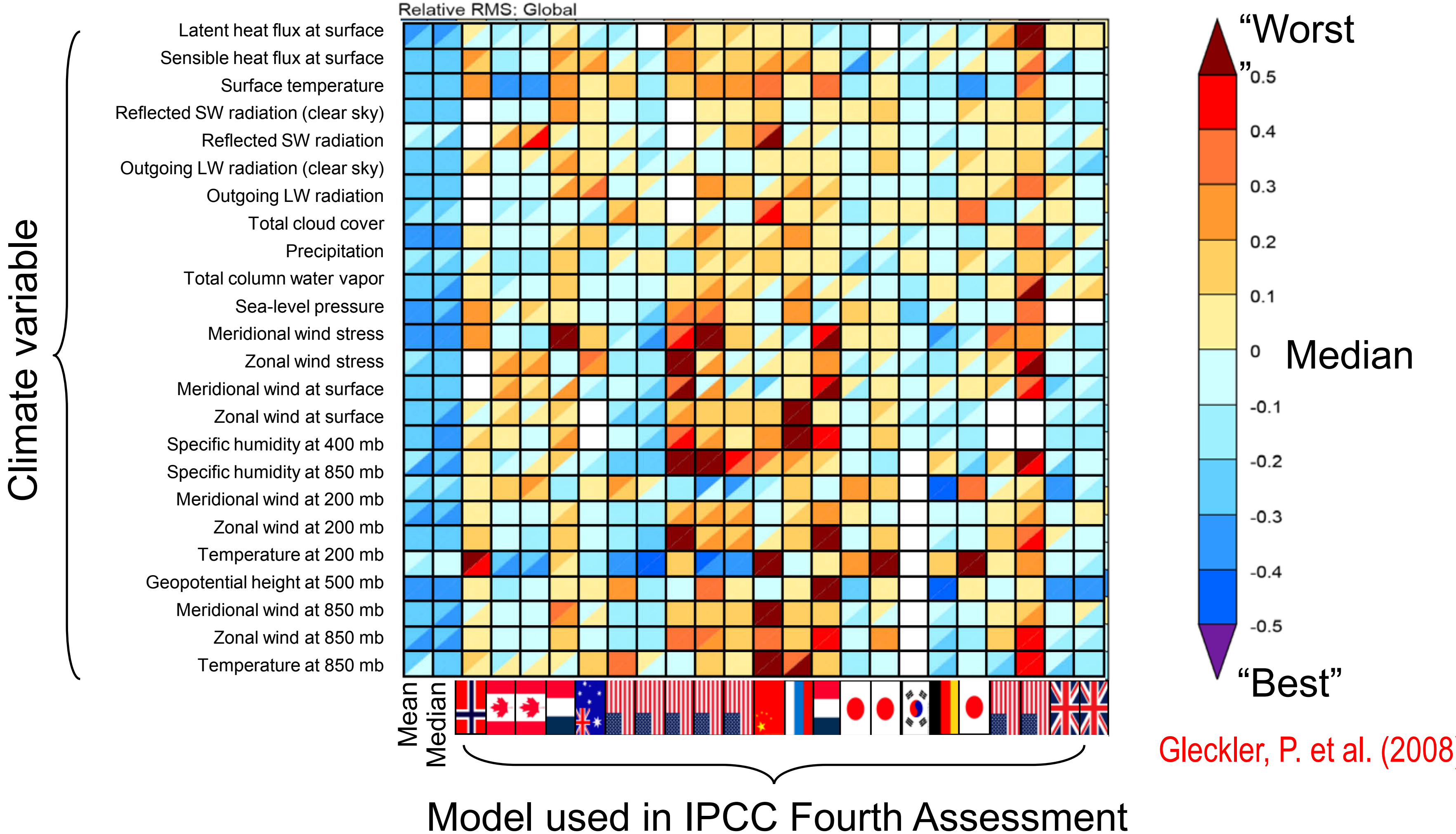
added complexity, more degrees of freedom, greater need for observational constraints (e.g. CO_2, carbon).

Decadal Predictions:

- more directly related to societal decisions and investment needs
- typically augmented with regional models that provide downscaling with added processes/realism.
- such models need observational scrutiny too.

IPCC AR5 - New Emphases, Opportunities, & Needs: Model "Scoring" Based on Measures of Model Quality

CMIP3 GCM Performance



Gleckler, P. et al. (2008)

New WGCM & WGEN Metrics Subpanel: Use observation-based "metrics" to assess model representations of past climate -> use to weight models' climate projections

Satellite Observations for Climate Modeling
SUMMARY

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

Longer Term

- Provide a 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.

Ultimately

- 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 by the end of May for the evaluation of CMIP5 climate model archive and impact the IPCC AR5.