Recent Advances in Forecast Skill and Understanding Climate Process Using AIRS Version-5 Products

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SPIE Optics & Photonics 2012

Infrared and Remote Sensing and Instrumentation XX

Paper 8511-25

August 14, 2012

San Diego, California

AIRS/AMSU on Aqua

AIRS/AMSU launched on EOS Aqua May 5, 2002

AIRS is a multi-detector array grating spectrometer

2378 channels between 650 cm-1 and 2760 cm^{-1}

Channel spacing ≈ $\nu/2400$ (0.25 cm^{-1} – 1.1 cm^{-1})

Resolving power $\nu/\Delta\nu$ ≈ 1200 (0.5 cm^{-1} – 2.2 cm^{-1})

AIRS Field of View (FOV) 13 km x 13 km at nadir

AMSU is a microwave sounder with a nadir 45 km x 45 km Field of Regard (FOR)

AMSU-A has flown on previous satellites

3 x 3 AIRS FOV's within an AMSU-A FOR

One AIRS/AMSU sounding is produced per AMSU-A FOR

Overview of AIRS/AMSU Retrieval Methodology

Physically based retrieval system

Independent of GCM except for surface pressure - used to compute expected radiances

Uses cloud cleared radiances $\hat{R}_i$ to sequentially determine the solution for different geophysical parameters

$\hat{R}_i$ represents what AIRS would have seen in the absence of clouds

All AIRS/AMSU retrievals have error estimates which are used for Quality Control

Goddard DISC has been analyzing AIRS/AMSU data using AIRS Version-5 algorithm

Retrievals are near real time

Analyzed data from September 2002 through the present

AIRS Version-6 algorithm is finalized – see paper 8510-29 Wed. at 11:20 a.m.

AIRS Version-6 will become operational in late 2012 for forward processing

All previous data will be re-analyzed to produce a consistent climate data set

AIRS/AMSU Products

Surface and Atmospheric Products – one set per AMSU FOR (45 km)

- Sea/land skin temperature T_s
- Temperature profile T(p) to 1 mb
- Water vapor profile q(p) to 100 mb
- O_3, CO, CH_4,CO_2 profiles
- Cloud Cleared Radiances $\hat{R}_i$

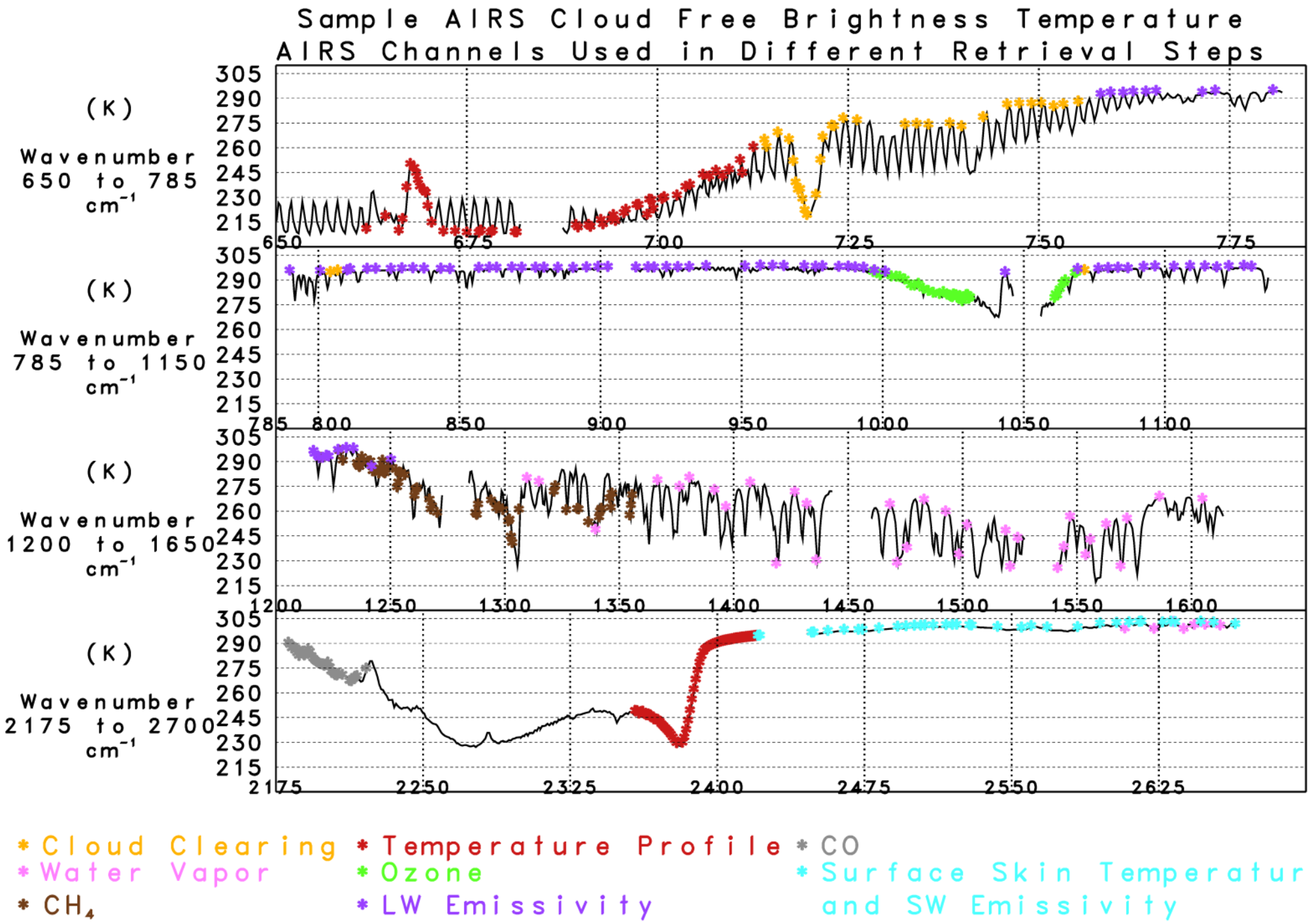
Cloud Products – one set per AIRS FOV (13 km).

- Radiatively effective cloud fraction $\alpha\varepsilon$ for up to two cloud layers
  - α is geometric fractional cloud cover
  - ε is cloud emissivity at 11 μm
- Cloud top pressure p_c for up to two cloud layers.

Outgoing Longwave Radiation (OLR) is computed using $\alpha\varepsilon$, p_c, and retrieved parameters.

Cloud clearing theory says that

1) Longwave channels should be used to determine $\hat{R}_i$ for all channels.
2) T(p) and T_s should be determined using $\hat{R}_i$ only in shortwave channels and longwave channels not sensitive to clouds.


Sample AIRS Cloud Free Brightness Temperature
AIRS Channels Used in Different Retrieval Steps
(K)
Wavenumber 650 to 785 cm-1
(K)
Wavenumber 785 to 1150 cm-1
(K)
Wavenumber 1200 to 1650 cm-1
(K)
Wavenumber 2175 to 2700 cm-1
305
290
275
260
245
230
215
650
675
700
725
750
775
785
800
850
900
950
1000
1050
1100
1200
1250
1300
1350
1400
1450
1500
1550
1600
2175
2250
2325
2400
2475
2550
2625
* Cloud Clearing
* Water Vapor
* CH4
* Temperature Profile
* Ozone
* LW Emissivity
* CO
* Surface Skin Temperature and SW Emissivity

Objectives of AIRS/AMSU

- Provide real time observations to improve numerical weather prediction.
  Could be $\hat{R}_i$ (used by NCEP, ECMWF) or T(p), q(p).
  Accuracy of $\hat{R}_i$ T(p), q(p) degrades slowly with increasing cloud fraction.
  There is a trade-off between accuracy and spatial coverage.
    Using soundings or radiances only in clear cases limits utility of the data.

- Provide observations to measure and explain interannual variability and trends.
  Must provide very good spatial coverage but also be unbiased
  Can be less accurate than needed for data assimilation.

- Error estimates and quality flags provide options for use in either weather or climate applications.

AIRS/AMSU Version-5 Quality Control

All AIRS/AMSU retrievals and cloud cleared radiances have level-by-level and channel-by-channels error estimates. Thresholds of error estimates are used for Quality Control (QC) of all retrievals – determines pressure p_{best} down to which T(p) is acceptable.

Version-5 used Standard QC Thresholds, optimized to give a best middle ground for Data Assimilation (highest accuracy) and Climate (best spatial coverage). Tighter QC thresholds perform better for Data Assimilation (DA).

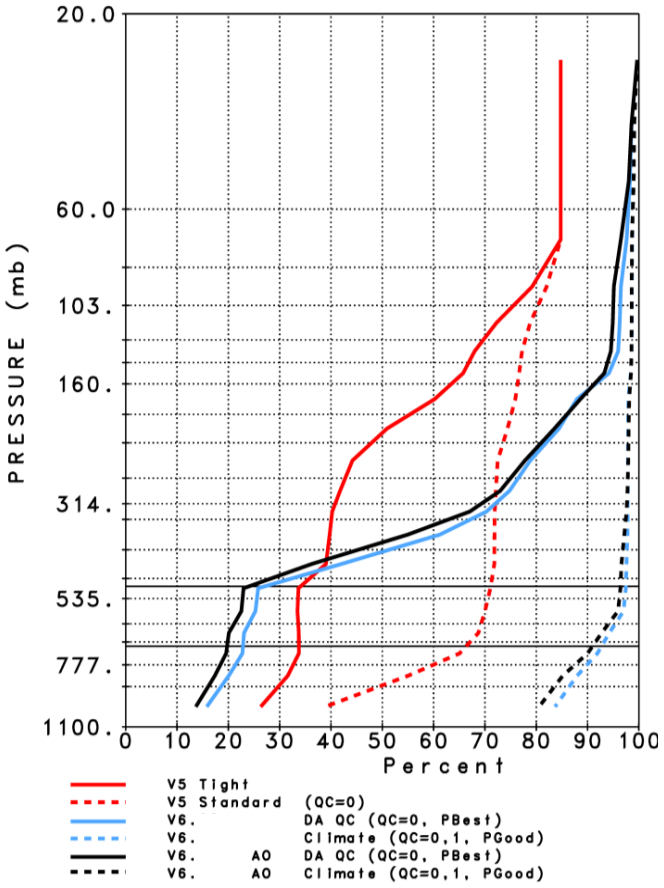
Much outstanding science has been conducted using AIRS Version-5 products.

I will show two studies related to: 1) improving forecast skill and 2) explaining why global and tropical mean OLR has decreased recently.

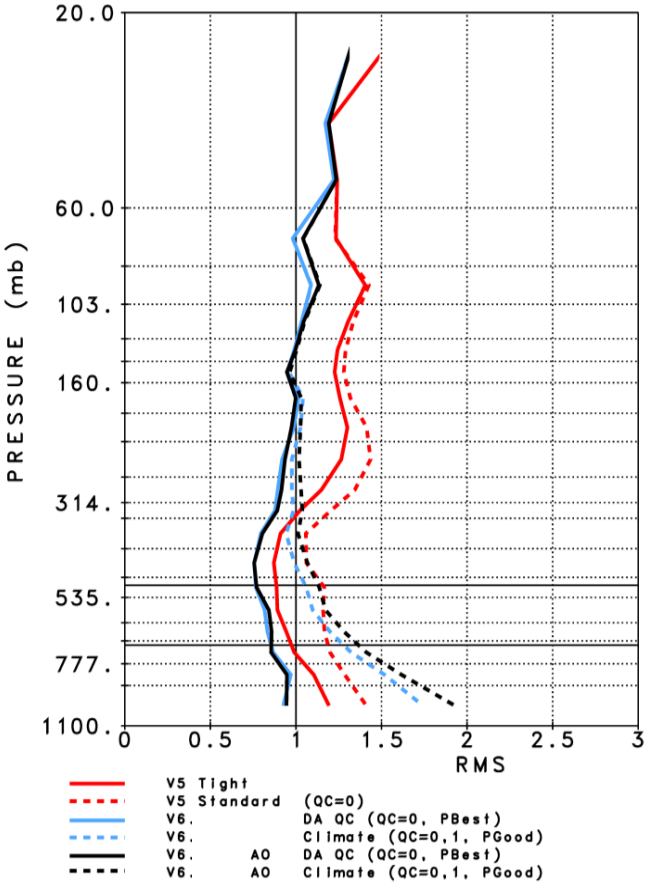
Version-6 will have further improvements, including separate sets of thresholds optimal for weather and climate applications and an "AIRS Only" (AO) mode to serve as a back-up should AMSU-A continue to degrade.

Global Temperature Profile Statistics

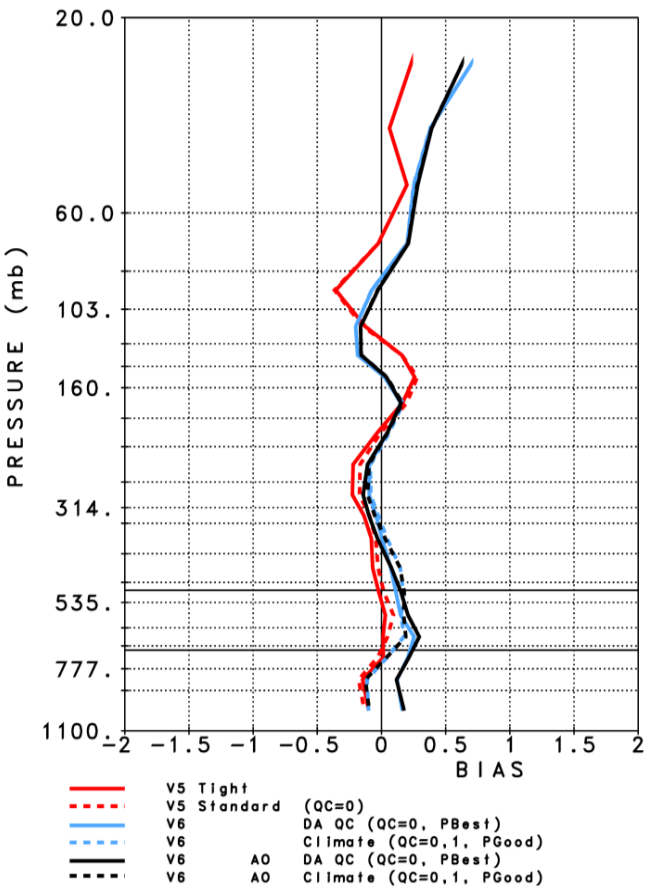
Percent of All Cases Accepted



1 km Layer Mean RMS (°K) Differences from ECMWF



1 km Layer Mean BIAS (°K) Differences from ECMWF



Version-6 T(p) retrievals with DA QC have RMS errors ≤ 1K throughout troposphere

Version-6 T(p) retrievals with Climate QC have much greater yield than Verison-5 with small biases

Differences between Version-6 and Version-6 AO are small

Data Assimilation Experiments

Ran experiments with GMAO GEOS-5 Data Assimilation System (DAS).

- Uses NCEP Operational GSI Data Assimilation Methodology.
- Forecasts and NCEP GSI Analysis run at 0.5° x 0.625° resolution.

We compared forecasts from four assimilations:

Control	No AIRS
AIRS V5 temperature profile,	Standard QC
AIRS V5 temperature profile,	Tight QC
AIRS radiance assimilation	(Operational)

Control used all the data NCEP used operationally in 2003.

- Assimilates all satellite data but AIRS, including Aqua AMSU radiances

AIRS Radiance Assimilation (Operational procedure) adds observed AIRS radiances unaffected by clouds to Control – excludes most AIRS observations.

Control + AIRS (Standard or Tight) adds Version-5 global Quality Controlled temperature profile retrievals to Control.

- Assimilated as if radiosonde data.
- Error estimate of temperature profile is used as the level measurement error.

Forecast Impact Tests

Ran four sets of experiments, covering different seasons and years.

January 1 – January 31, 2003
October 15 – November 19, 2005
August 10 – September 16, 2006
April 15 – May 18, 2008 (Tropical Storm Nargis)

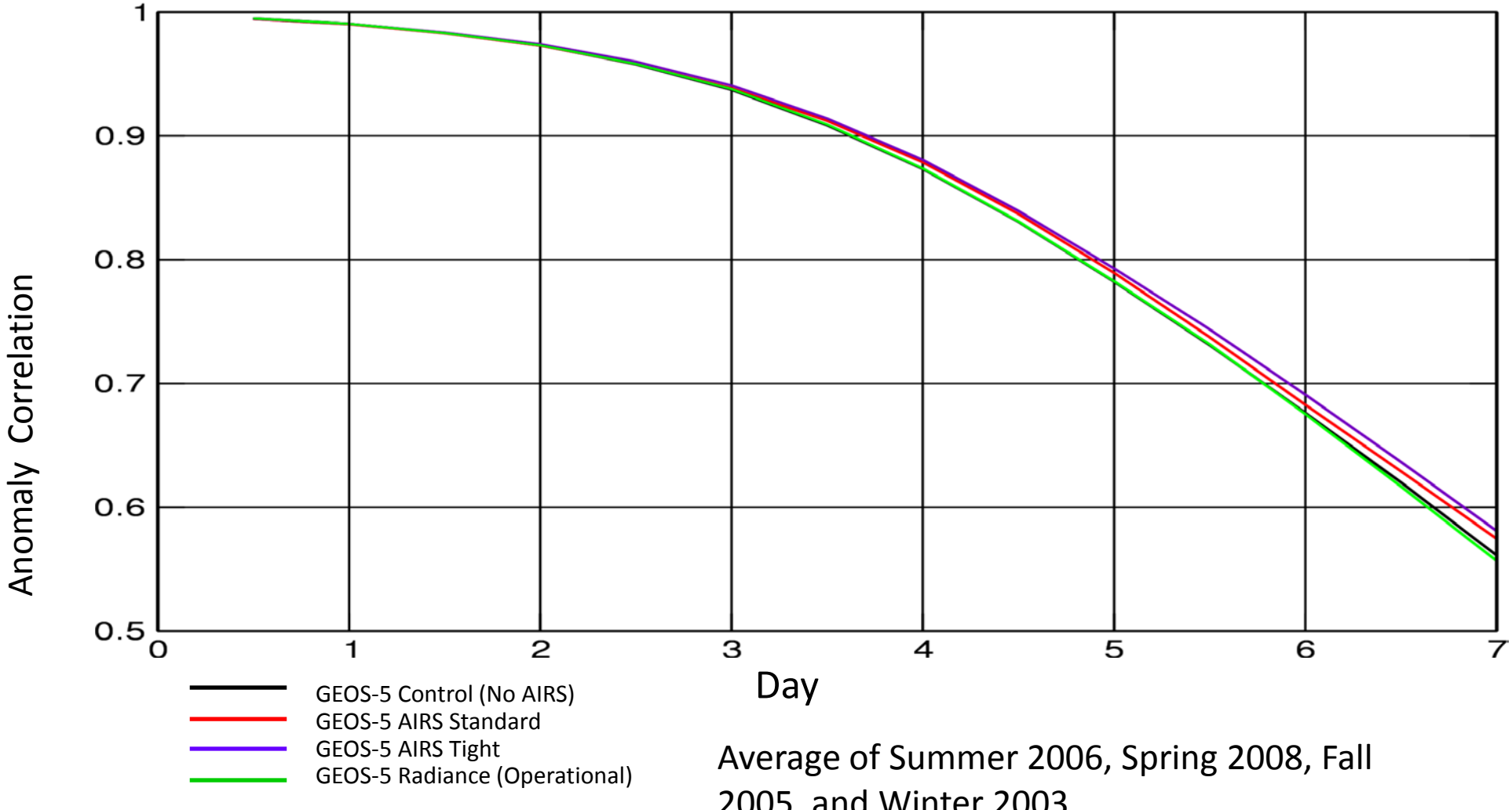
The AIRS temperature profiles are assimilated down to p_{best} determined using appropriate QC thresholds.

Seven day Forecasts run from each 0 Z Analysis for each experiment.

The accuracy is judged against anomaly correlation of 7-day forecasts vs. ECMWF Analysis for that time.

500mb Geopotential Heights

Northern Hemisphere Extra Tropics



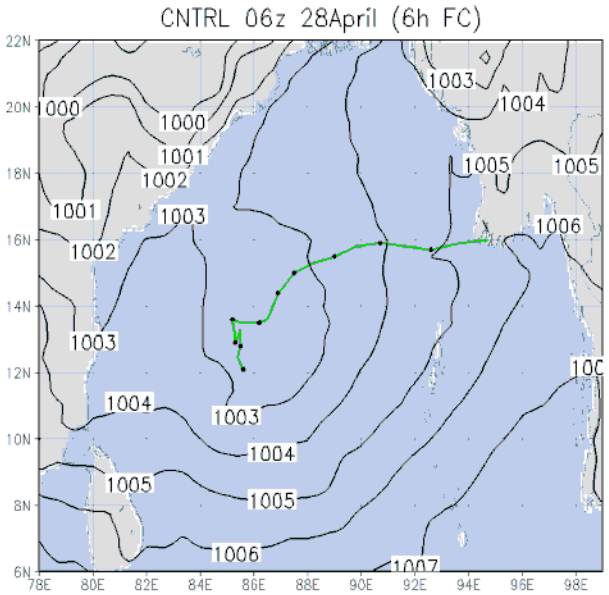
Average of Summer 2006, Spring 2008, Fall 2005, and Winter 2003

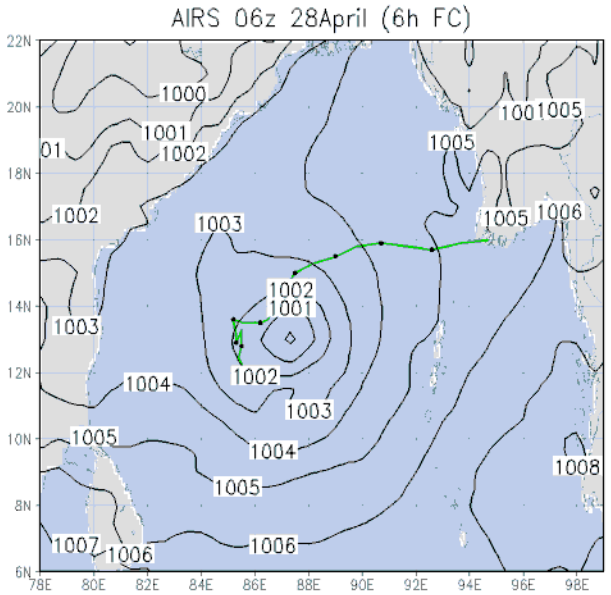
An anomaly correlation of 1.0 represents a perfect forecast

An anomaly correlation of 0.6 is the lower bound of a useful forecast

AIRS Tight improves seven day forecast skill by about five hours compared to No AIRS

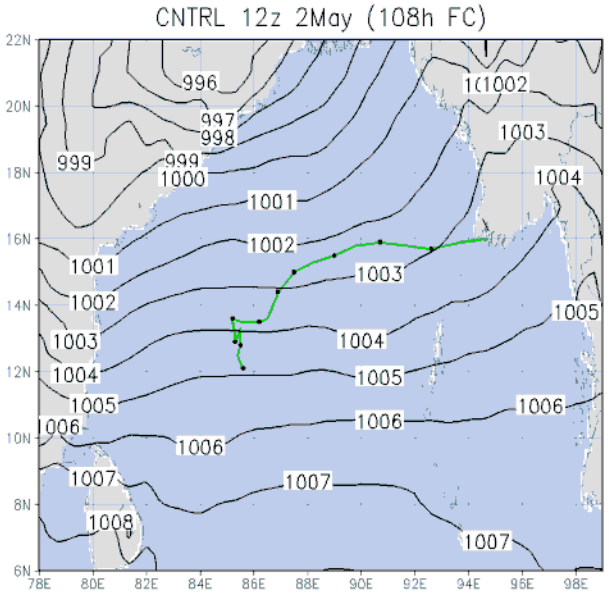
Example of AIRS Impact on Forecast Track

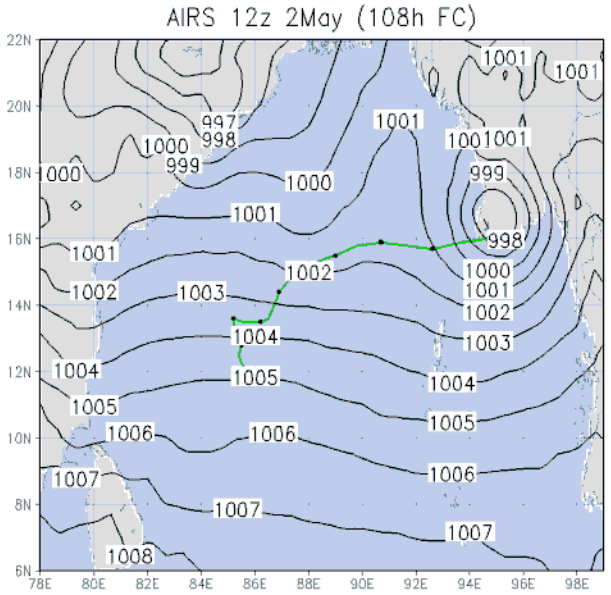




Tropical storm Nargis

AIRS Analysis Well-defined Cyclone Green: Observed Track





AIRS 108-hour Forecast (slp)

Green: Observed Track

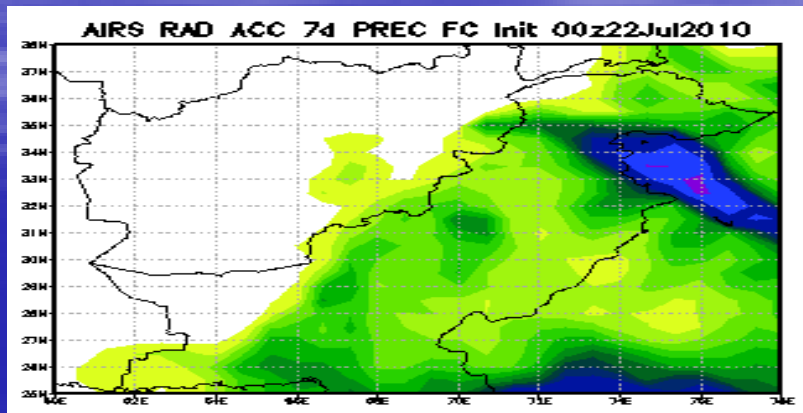
CNTRL Analysis (above) And forecast (below): No Cyclone

Accurate landfall is produced in the forecasts initialized with AIRS: *(Reale et al., 2009, Geophys. Res. Lett.)*

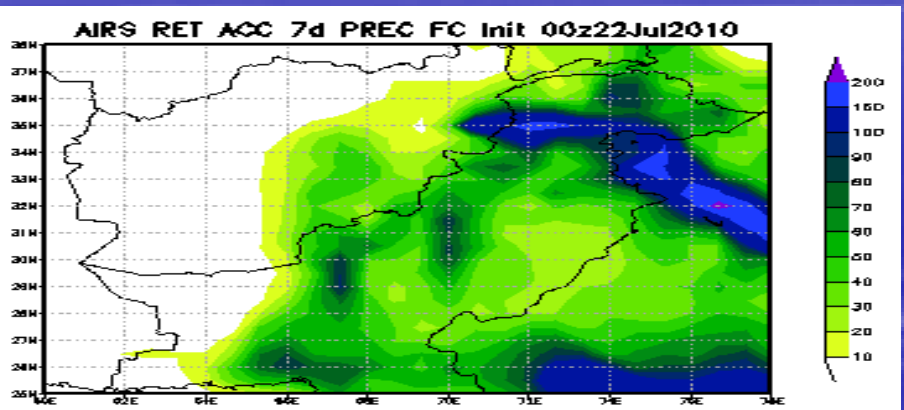
Reale, O., K. M. Lau, J. Susskind, and R. Rosenberg (2012), AIRS impact on analysis and forecast of an extreme rainfall event (Indus River Valley, Pakistan, 2010) with a global data assimilation and forecast system, J. Geophys. Res., 117,D08103, doi:10.1029/2011JD017093.

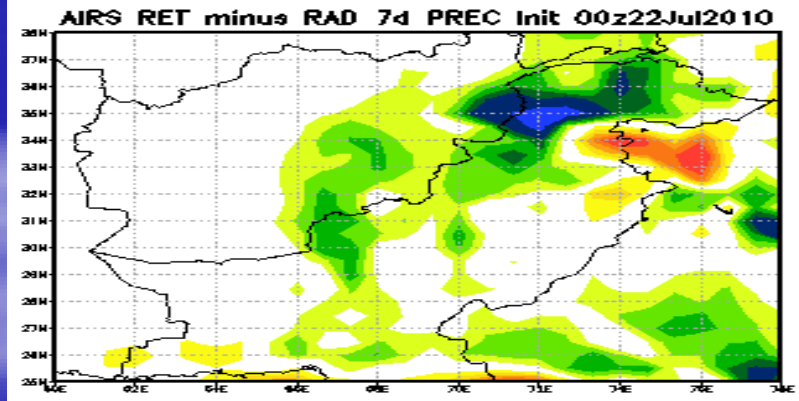
7-day accumulated precipitation forecast initialized at July 22, 2010 00z

GEOS-5 Forecast using v5 Clear-sky radiances (RAD)

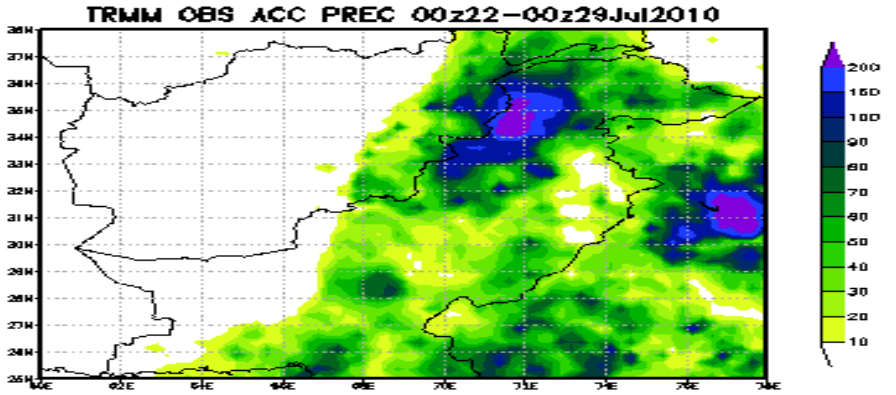


GEOS-5 Forecast using v5 Retrievals (RET)





RET minus RAD



OBS (TRMM)

Assimilation of AIRSv5 retrievals goes in the direction of the observations

First Experiment Using NCEP GFS

Lou Uccellini, Director of NCEP, was very impressed with the potential of this methodology to improve operational forecast skill.

New methodology must be first tested with the GFS system used operationally at NCEP.

Lou Uccellini, together with Tsengdar Lee (HQ) arranged to have the NCEP GFS ported to GSFC.

We have just started to run the first experiment assimilating AIRS Version-5 T(p) in GFS.

Covers the period July-August 2010, containing Pakistan flood.

Results are encouraging but too preliminary to be shown at this time.

Future experiments will contain

- Tests with other time periods.
- Optimization of DA QC thresholds for use in GFS.
- Experiments assimilating Version-6 T(p) retrievals.

Example of Climate Research

- Comparison of AIRS and CERES anomaly time series of OLR.
- Explanation of recent decreases in global and tropical mean values of OLR.

Data sets used

AIRS Science Team Version-5 monthly mean data obtained from Goddard DISC (level-3).

OLR, T_{skin}, q_{500}, cloud fraction $\alpha\varepsilon$.

Data products extend to July 2012.

CERES Science Team monthly mean data obtained from Langley ASDC

CERES Terra EBAF (Energy Balanced And Filled) Edition 2.6r.

Data products extend to June 2011.

CERES is considered the “gold standard” for OLR

AIRS/CERES comparisons are shown for the period September 2002 through June 2011.

Definition of Anomalies, ARCs and ENCs

Eight-year monthly climatologies were generated for each 1˚x 1˚ grid box by averaging data for eight Januaries, eight Februaries, ……

The monthly anomaly for each grid box is the difference of the monthly mean value for that month from its climatology.

The Average Rate of Change (ARC) for a grid box is the slope of the straight line passing through the monthly anomaly time series.

Values of ARCs depend on the extent of the time series used.

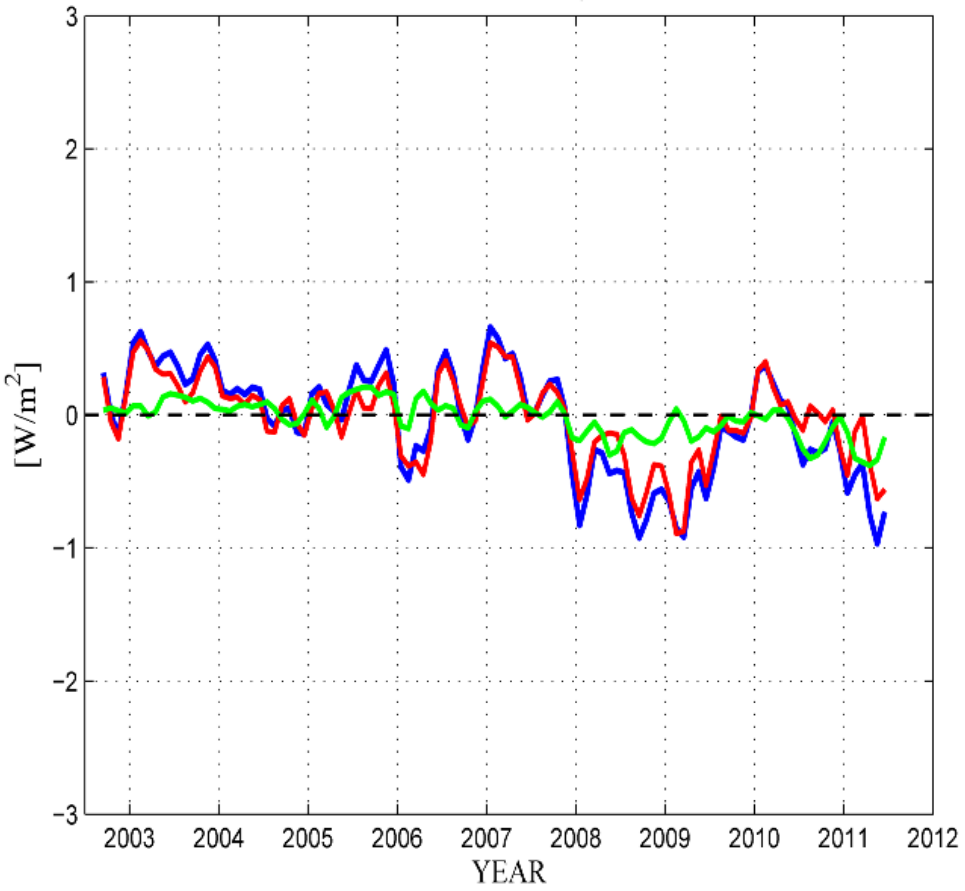
Spatial patterns are more important than precise values.

An area mean ARC is the cosine latitude weighted average ARC over the area.

The El Niño Correlation (ENC) for a given grid point is the temporal correlation of the anomaly time series for that grid point with the El Niño Index. ENCs should be less time period dependent.

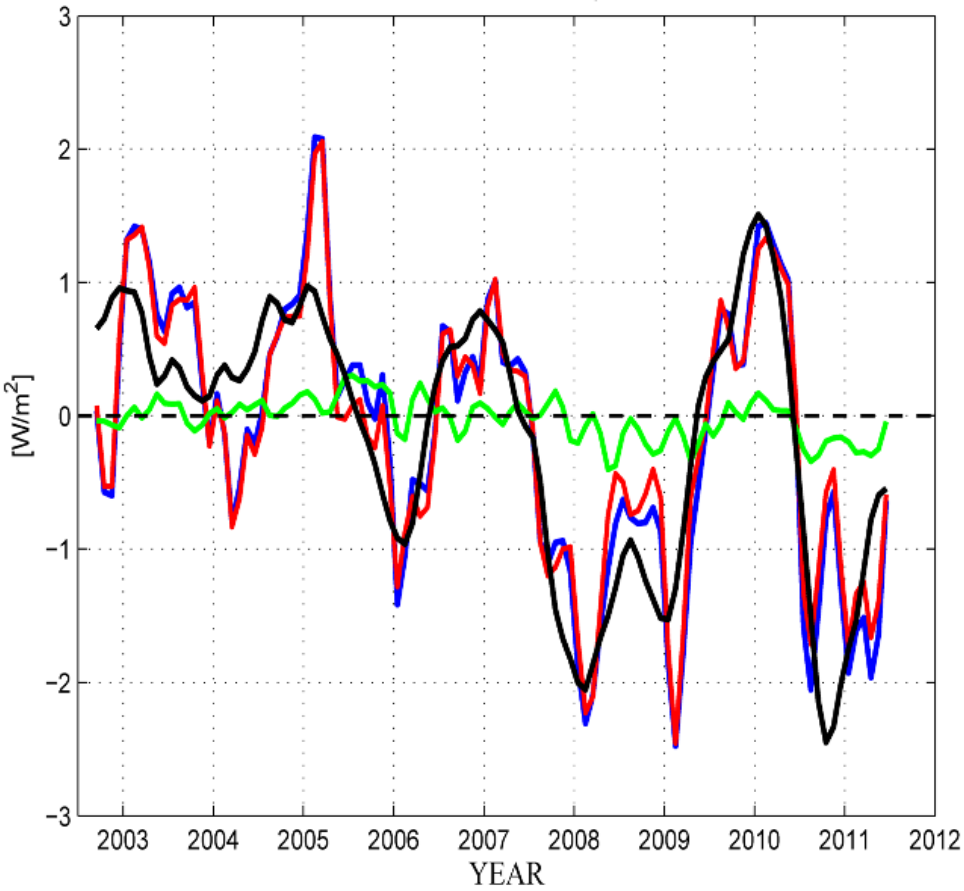
OLR Anomaly Time Series
September 2002 through June 2011

Global Mean



AIRS
CERES
AIRS minus CERES

Tropical Mean



AIRS
CERES
AIRS minus CERES
1.5 times the El Niño Index
El Niño Index ARC = -0.123 ± 0.046 K/yr

OLR Anomaly Time Series Comparison
September 2002 through June 2011

Data Set	Global	Tropical
AIRS ARC ($W/m^2/yr$)	−0.094 ± 0.026	−0.183 ± 0.070
CERES Terra ARC ($W/m^2/yr$)	−0.059 ± 0.022	−0.154 ± 0.066
AIRS Minus CERES STD (W/m^2)	0.136	0.155
AIRS/CERES Correlation	0.955	0.991
AIRS ENC	0.587	0.830
CERES ENC	0.523	0.813

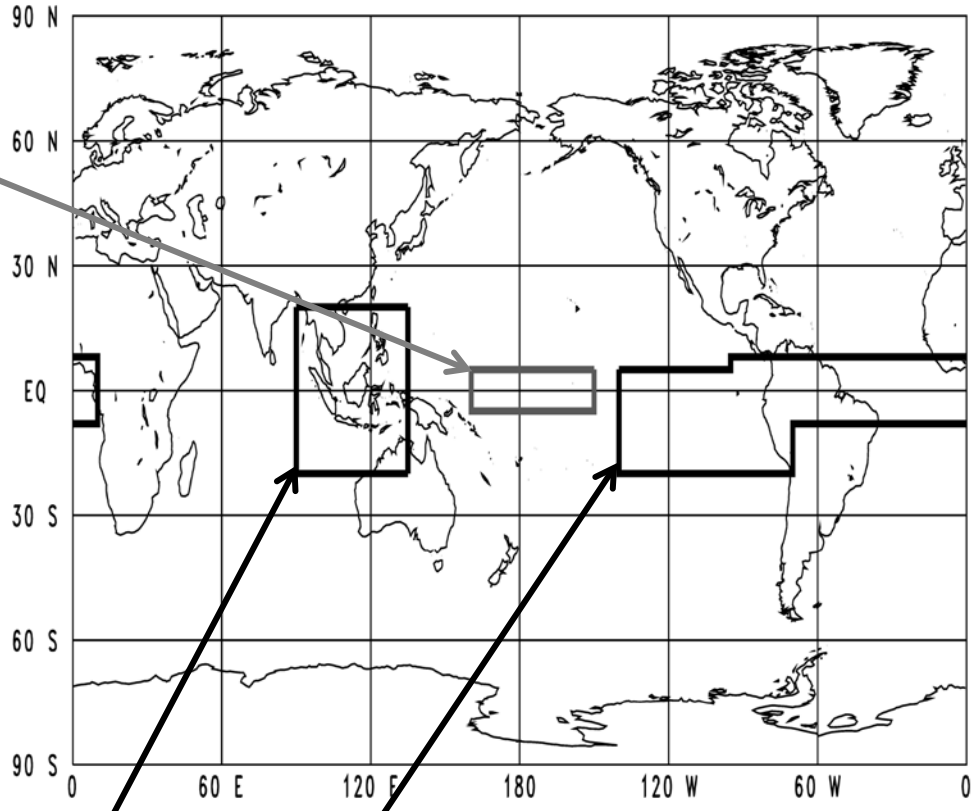
AIRS and CERES global mean and tropical mean anomaly time series agree very closely with each other.

Both show that global, and especially tropical, mean OLR have decreased over the time period under study.

Important Highlighted Regions in Subsequent Figures

NOAA Niño-4 Region:

We define the El Niño Index as the NOAA monthly mean T_{skin} anomaly, compared to 8-year climatology, averaged over the NOAA Niño-4 region 5°N to 5°S, 150°W, westward to 160°E



Warm Pool Maritime Continent (WPMC) region:

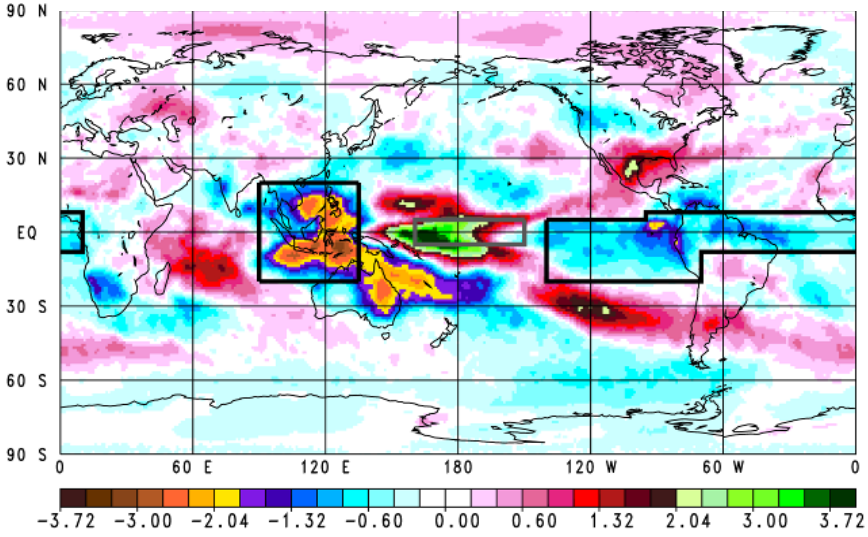
West of Niño-4 region

Equatorial Eastern Pacific and Atlantic (EEPA) region:

East of Niño-4 region

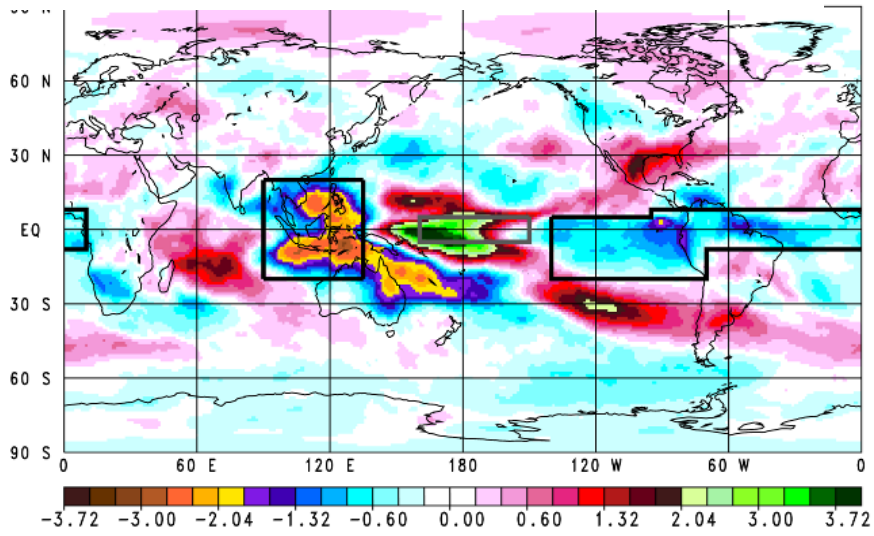
ARCs and ENCs of OLR Anomaly Time Series
September 2002 through June 2011

a) AIRS ARCs



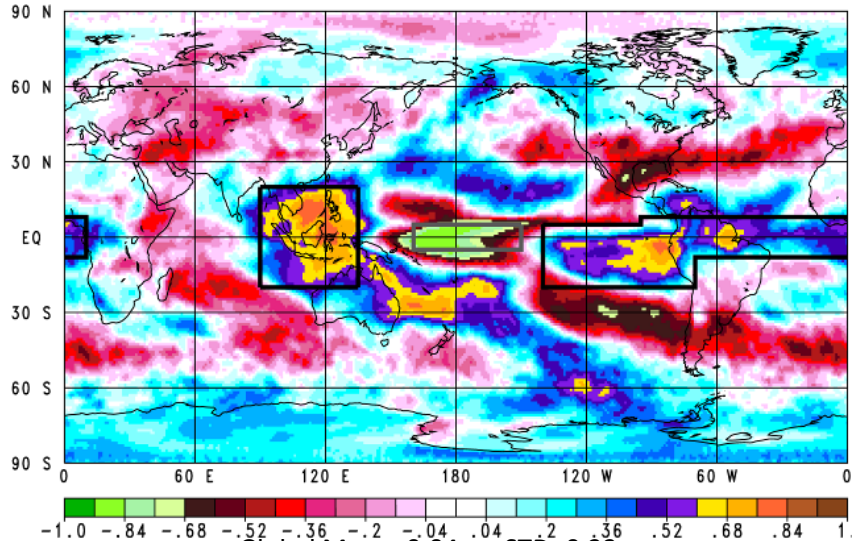
Global Mean=-0.094 STD= 0.82

b) CERES ARCs



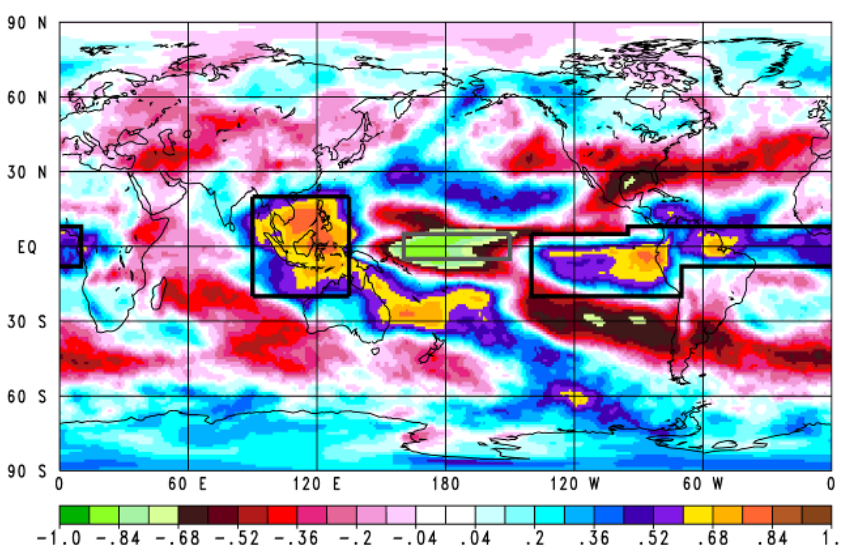
Global Mean=-0.059 STD=0.82

a) AIRS ENCs



Global Mean=0.04 STD=0.33

b) CERES ENCs



Global Mean=0.03 STD=0.36

OLR ARCs are very negative over the WPMC and EEPA regions (blue, yellow).

OLR ENCs are very positive over the WPMC and EEPA regions (blue, yellow).

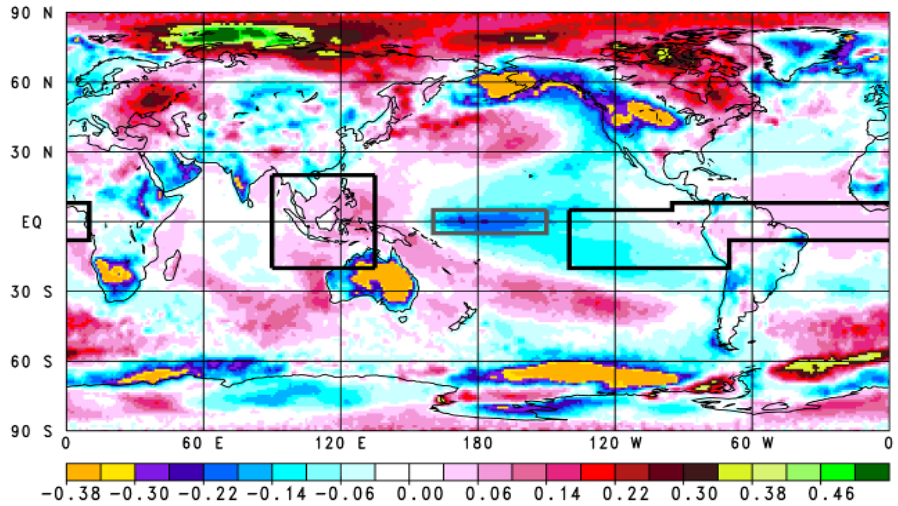
Area Mean Statistics for AIRS and CERES OLR
September 2002 through June 2011

	AIRS		CERES	
Spatial Area	OLR ARC ($W/m^2/yr$)	OLR ENC	OLR ARC ($W/m^2/yr$)	OLR ENC
WPMC Region	-1.502 ± 0.525	0.871	-1.496 ± 0.529	0.870
Tropical outside WPMC Region	0.004 ± 0.054	0.050	0.034 ± 0.053	0.101
Global outside WPMC Region	-0.030 ± 0.028	-0.129	0.005 ± 0.027	-0.372
EEPA Region	-0.631 ± 0.158	0.767	-0.611 ± 0.154	0.761
Tropical outside EEPA Region	-0.037 ± 0.048	0.599	-0.011 ± 0.047	0.511
Global outside EEPA Region	-0.044 ± 0.020	0.256	-0.011 ± 0.019	0.039

ARCs of otherwise Tropical mean and Global mean OLR computed outside of either WPMC region or EEPA region are essentially zero.

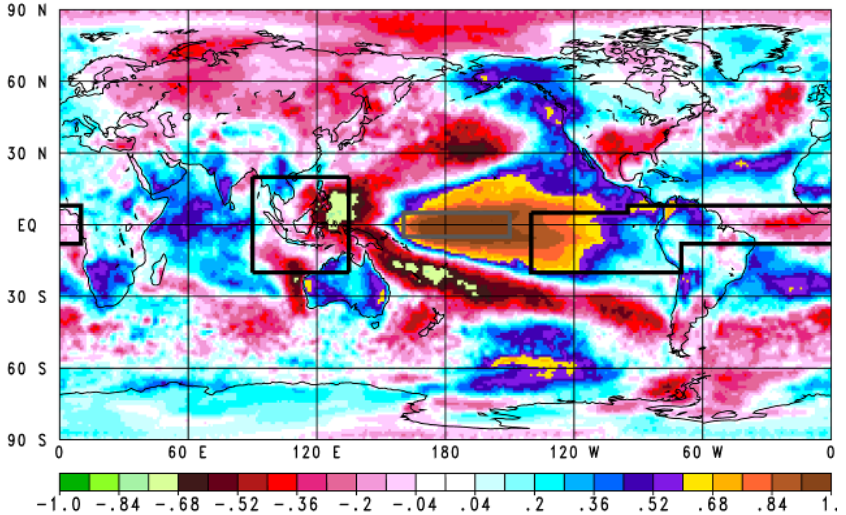
AIRS Products September 2002 through June 2011

a) T_{skin} ARCs (K/yr)



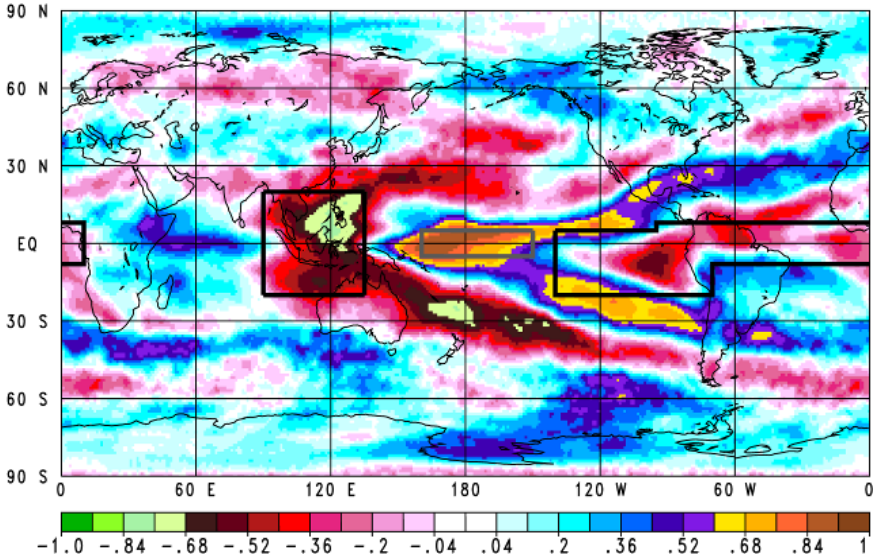
Global Mean = -0.01 STD = 0.10

b) T_{skin} ENCs



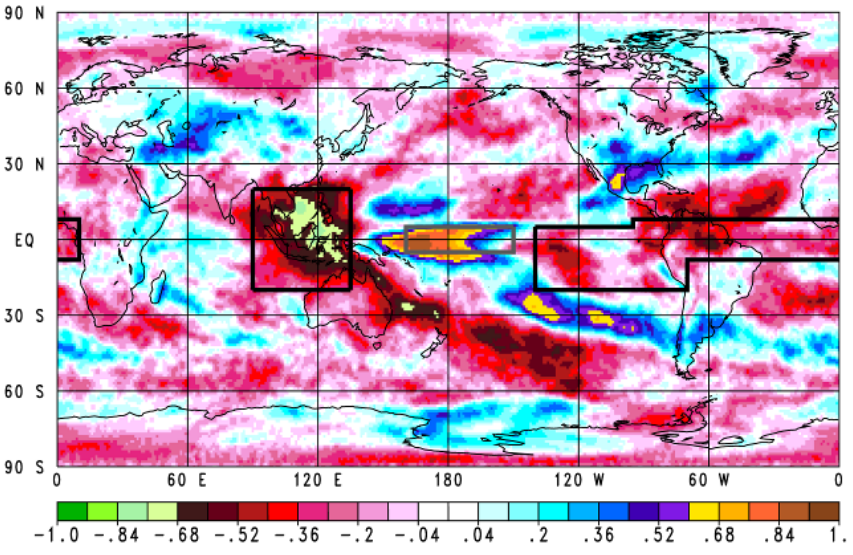
Global Mean = -0.08 STD = 0.35

c) 500 mb Specific Humidity ENCs



Global Mean=0.06 STD=0.34

d) Effective Cloud Fraction ENCs



Global Mean=-0.08 STD=0.28

T_{skin} ARCs and ENCs are for the most part of opposite sign (similar color). This shows most ARCs are El Niño driven, except near the North Pole.

ENCs of q_{500} and $\alpha\varepsilon$ are similar to each other and are both very negative over the WPMC and EEPA regions. This results in positive OLR ENC's in these regions.

Findings of Climate Study

Recent AIRS and CERES OLR anomaly time series are in very close agreement on a 1° spatial scale.

Both show a significant decrease in global mean and tropical mean OLR over the period September 2002 through June 2011.

The degree of agreement is remarkable, but the recent OLR decrease is not because it is the result of a transition from El Niño conditions to La Niña conditions. This implies nothing about long term changes.

The recent decrease in global and tropical mean OLR results from the very large negative correlations of water vapor and cloud cover in each of the WPMC and EEPA regions with the El Niño Index. This more than compensates for the reverse effect in the Niño-4 region.

AIRS is expected to last through the life of Aqua ≈2022.

This will allow for a 20 year AIRS Climate Data Set.

Version-6 climate products will be further improved over Version-5.


NASA