

**AIRS impact on analysis and forecast  
of extreme precipitation events  
in the tropics  
with a global data assimilation and  
forecast system**

*Oreste Reale (GESTAR/USRA)*

*W. K. Lau (NASA), J. Susskind (NASA)*

*Robert I. Rosenberg (SAIC)*

*Yaping Zhou (GESTAR/MSU)*

*Lena Iredell (SAIC), John Blaisdell (SAIC)*



National Aeronautics  
and Space Administration

# Outline

## Previous work - AIRS impact on:

- midlatitude winter dynamics
- global AIRS impacts in all seasons
- tropical cyclone Nargis (2008)
- Analyses and Forecasts of Extreme Precipitation in the tropics associated with TCs (Nargis, Helene, Wilma)

## New - AIRS impact on:

- Precipitation Analysis for the 2010 floods along the Indus river (Pakistan)
- Conclusions, ongoing and future work
- Acknowledgements

# Global Impact of Clear-sky Radiances versus Quality Controlled cloudy Retrievals (AIRS v5)

- A small fraction of AIRS data is still retained in operational weather systems, where the only AIRS data assimilated are radiance observations of channels unaffected by clouds. This imposes a severe limitation on the horizontal distribution of the data.
- Susskind et al (2011) document the AIRS version 5 retrieval algorithm. Key elements are the use of information from partly cloudy areas and the ability *to generate case-by-case and level-by-level error estimates and use them for quality control*
- This team has been performing a very large number of experiments, comparing AIRS retrievals and radiances in all seasons, five different years, with different quality controls, looking at both global impacts and individual high-impact weather systems

# AIRS Experiments settings

- **GEOS-5 DAS**: versions **2.1.2, 2.1.4** (close to **MERRA**)
- Periods chosen: **Jan 2003** (active boreal winter); **8/10/06 to 9/15/2006** (NAMMA), **10/15/2005 to 11/15/2005** (Active TC Atlantic season), **4/15/2008 to 5/15/2008** (TC Nargis), **7/15/2010-8/31/2010** (Pakistan floods, anomalous boreal summer blocking over Eurasia)
- **Control assimilation**: assimilating all conventional and satellite data, but no AIRS-derived information
- **AIRS RET**: Same data as control plus AIRS version 5 retrievals added as rawinsonde temperature profiles
- **AIRS RAD**: AIRS clear-sky radiances from NESDIS
- **Forecasts** at 0.25 or 0.5 degrees

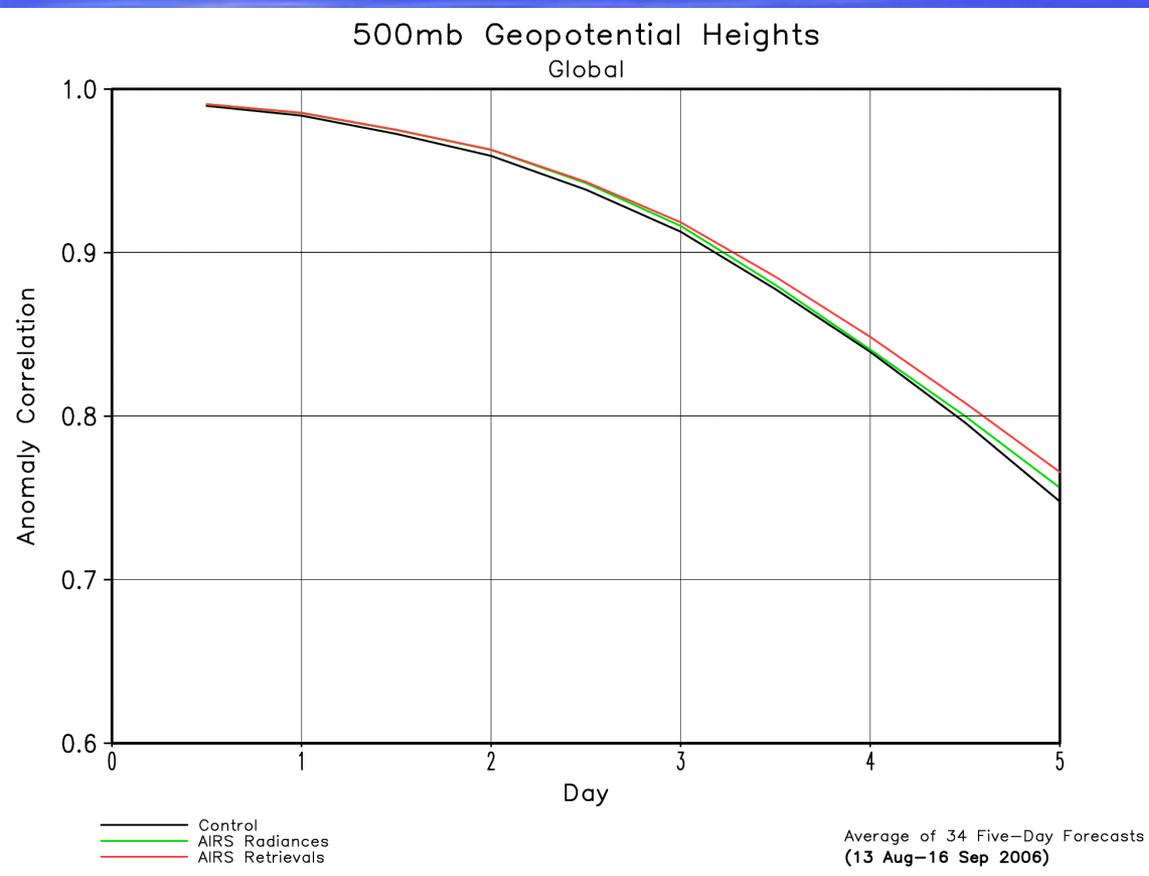


# Impact of AIRS in the GEOS-5 Data Assimilation and Forecasting System in **boreal winter conditions**

- Previous work published in 2008 (Reale et al., 2008) has shown substantial improvement in analysis and forecasts over the **northern hemisphere extratropics in boreal winter conditions**, due to an improved representation of the lower-mid tropospheric thermal structure in the high latitudes and consequently an **improved polar vortex**.
- The improvement comes from the assimilation of **quality-controlled AIRS retrievals obtained under partially cloudy conditions (AIRS version 5)**

*Reale, O., J. Susskind, R. Rosenberg, E. Brin, E. Liu, L.P. Riishojgaard, J. Terry, J.C. Jusem, 2008: Improving forecast skill by assimilation of quality-controlled AIRS temperature retrievals under partially cloudy conditions. Geophys. Res. Lett., 35, L08809, doi: 10.1029/2007GL033002*

# Example of GEOS-5 2.0.2 study of AIRS global impact in **Boreal Summer** (2006) conditions: cloudy retrievals (tight QC) vs. clear-sky radiances



Strong **global** impact of AIRS retrievals (red).

Smaller impact of AIRS clear-sky radiances (green).

In addition, representation of **individual weather systems** in the tropics are strongly impacted by AIRS.

**Consistent results obtained for Also Winter 2002, Spring 2008, Fall 2005** (Summer 2010 being run at this time)

Anomaly Correlations computed from **90S to 90N**

# Published AIRS impact study on **tropical cyclone Nargis** (2008) emphasizes the difficulty of analysing TCs over the Indian Ocean and compares performance of AIRS clear-sky radiances against cloudy retrievals.

- Work published in 2009 shows improvements in analysis over the *tropics* in the GEOS-5 DAS and forecasting model consequent to assimilation of AIRS-derived information in **CLOUDY** areas. Case chosen: **catastrophic cyclone Nargis which hit Burma causing devastating loss of life**
- Tropical Cyclones in the Northern Indian Oceans are extremely difficult to analyze: operational global analyses often do not represent these cyclones' **position** (or **even the TCs' very existence**) accurately. **Forecasts are penalized by these poor analyses**

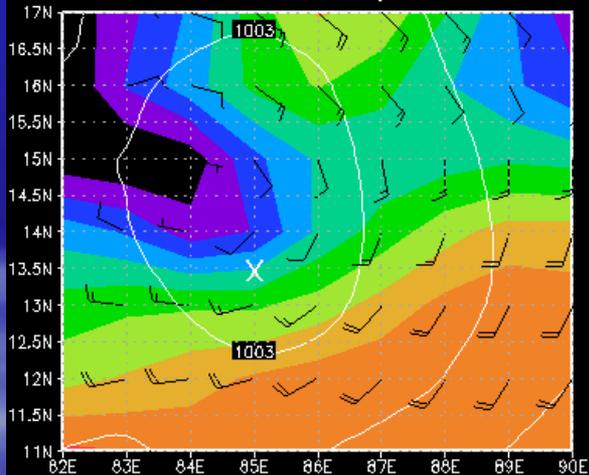
*Reale, O., W. K. Lau, J. Susskind, R. Rosenberg, E. Brin, E. Liu, L.P. Riishojgaard, M. Fuentes, R. Rosenberg, 2009: AIRS impact on the analysis and forecast track of tropical cyclone Nargis in A global data assimilation and forecasting system.*

*Geophys. Res. Lett., 36, L06812, doi: 10.1029/2008GL037122*

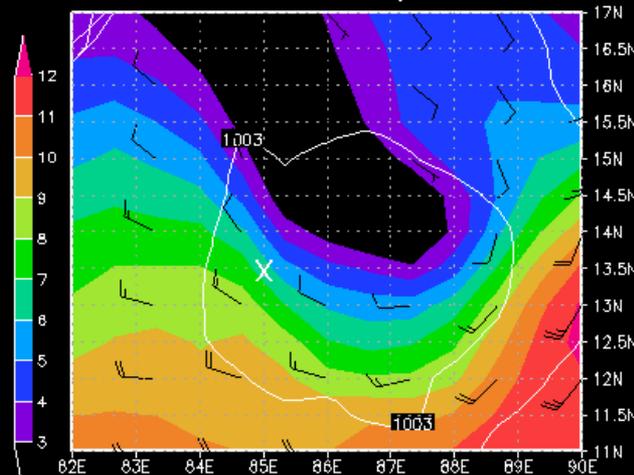
# Complete miss of TC Nargis (2008) in both operational NCEP and MERRA analyses at a time when is declared having **hurricane-level winds** by the JTPC and IMC

## COMPLETELY FLAT PRESSURE FIELD

NCEP 06z 28Apr 2008



MERRA 06z 28Apr 2008



800x600km  
Contours  
every 1hPa

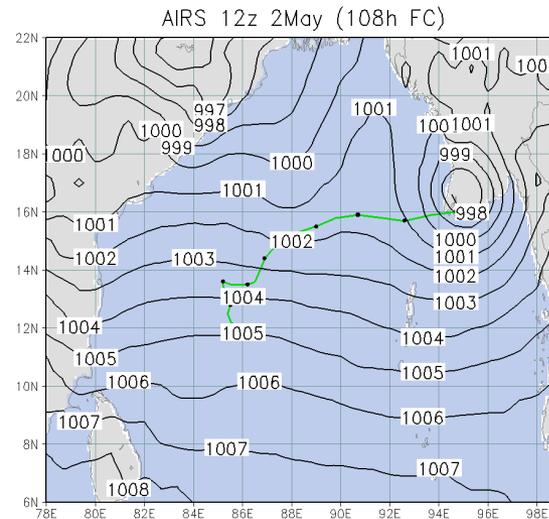
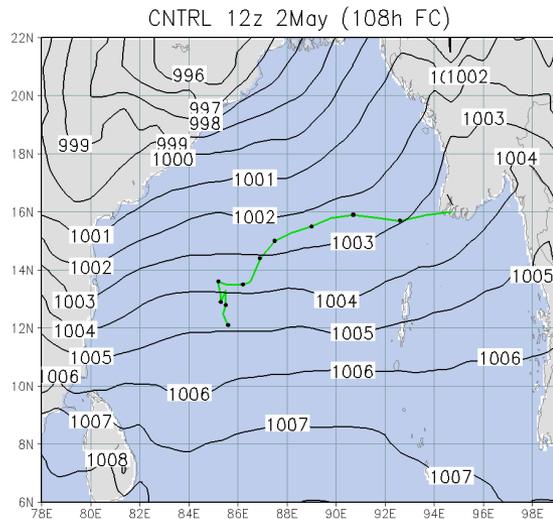
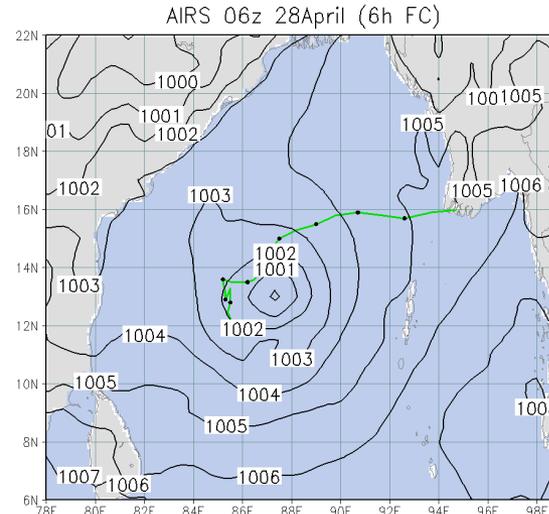
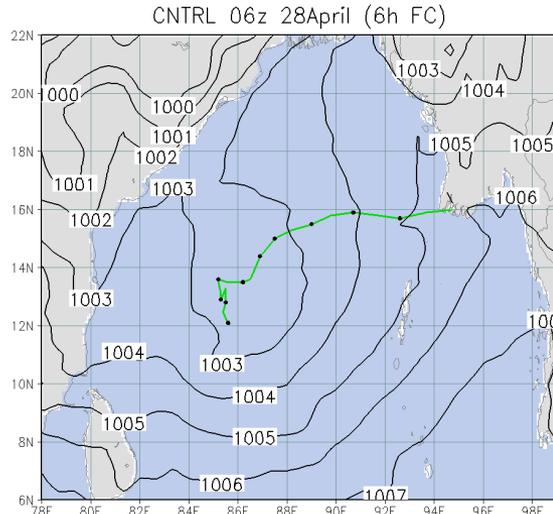
WINDS DO  
NOT FORM  
A CLOSED  
CIRCULATION

800x600km  
Contours  
every 1hPa

X observed  
cyclone's  
center

WINDS DO NOT REACH 12m/s  
WINDS DO NOT FORM A CLOSED CIRCULATION

# AIRS v5 impact on TC Nargis definition



AIRS  
Analysis  
**Well-defined  
Cyclone**  
Green:  
Observed  
Track

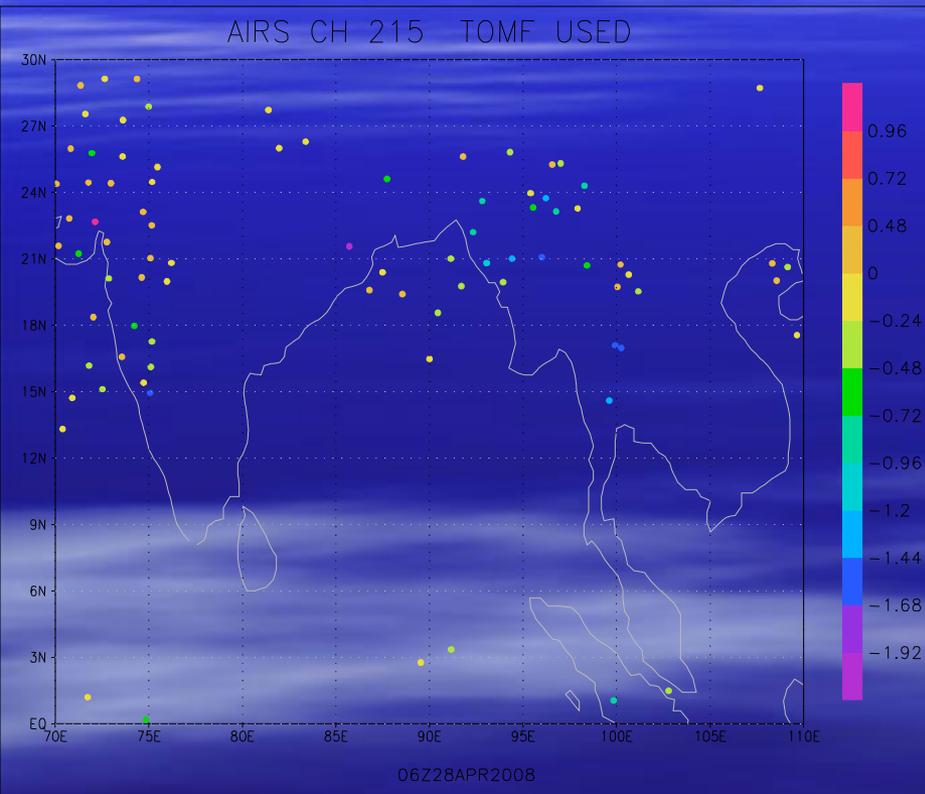
AIRS 108-  
hour  
Forecast (slp)  
Green:  
Observed  
Track

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

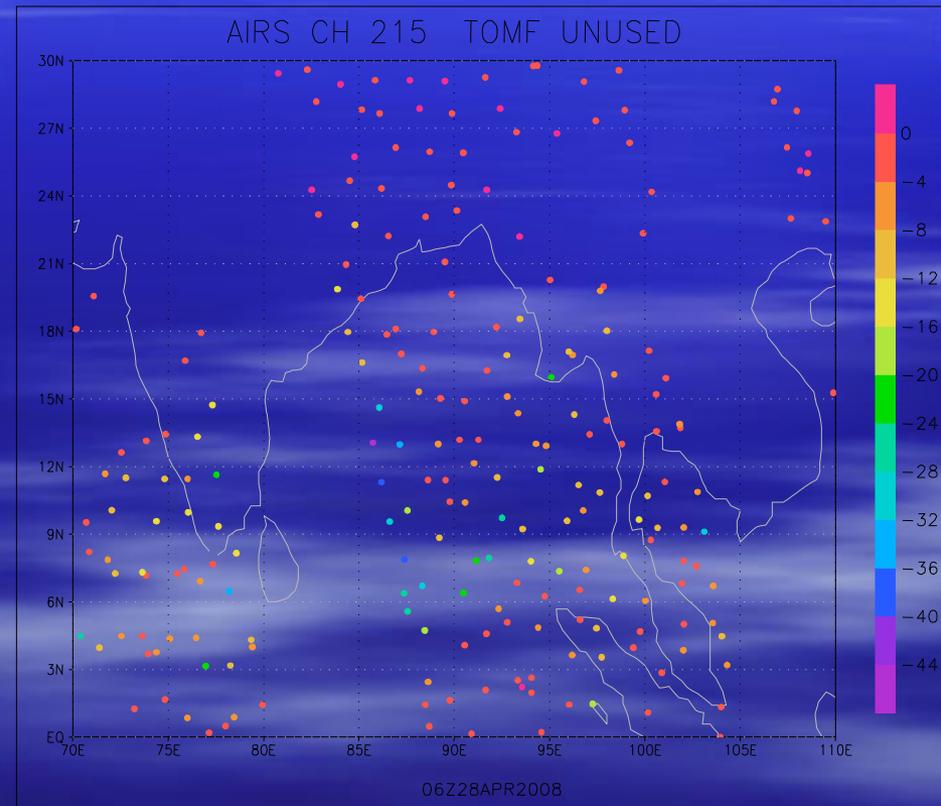
Accurate landfall is produced in the forecasts initialized  
with AIRS: (Reale et al., 2009, *Geophys. Res. Lett.*)

# Why AIRS radiances do **not** impact the forecast for NARGIS?

**USED**

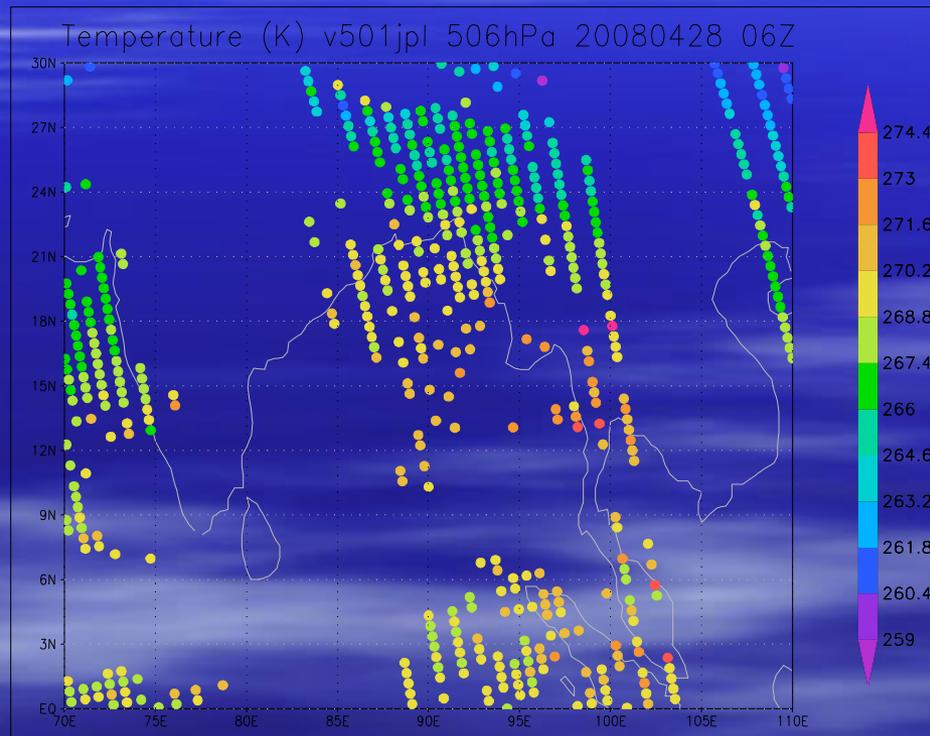


**REJECTED**



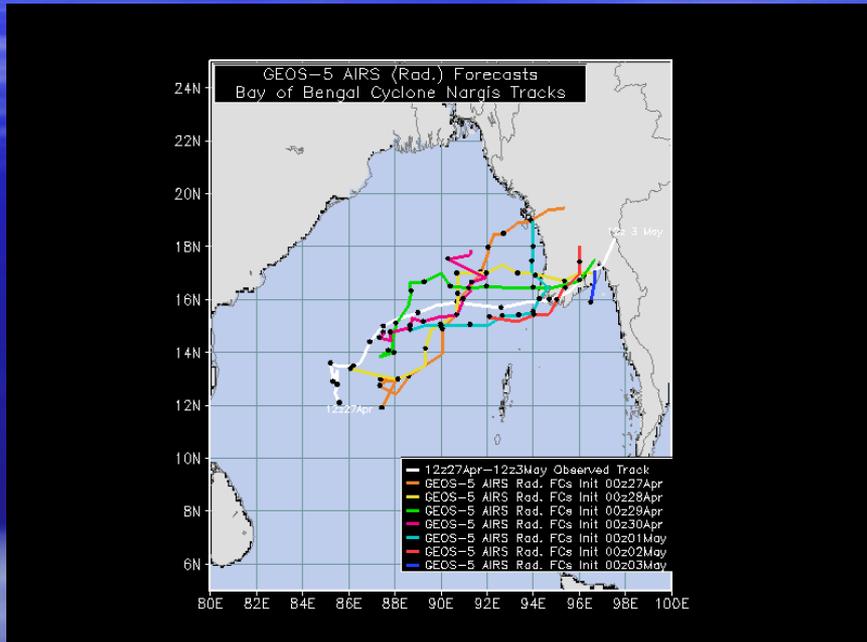
There are simply **NO DATA** accepted by the DAS in the area where NARGIS develops, because the measurements are in cloudy areas.

# QC-ed AIRS cloudy retrievals provide substantial coverage over the area

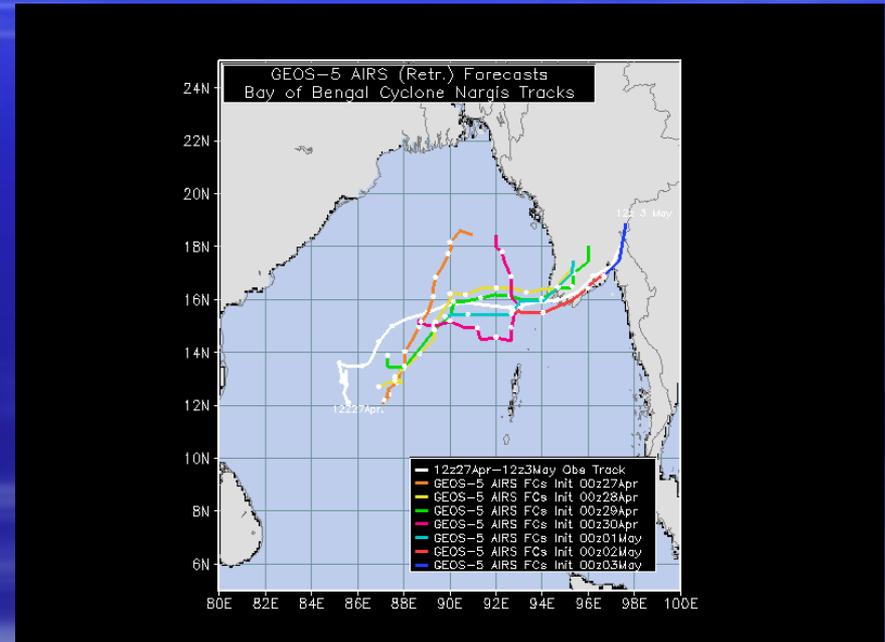


The temperature information provided by cloudy AIRS retrievals where the storm is developing leads to improved analyses and forecasts

# Large forecast track improvement for tropical cyclone Nargis (2008) consequent to AIRS v5 cloudy retrieval assimilation, compared to assimilation of clear-sky radiances



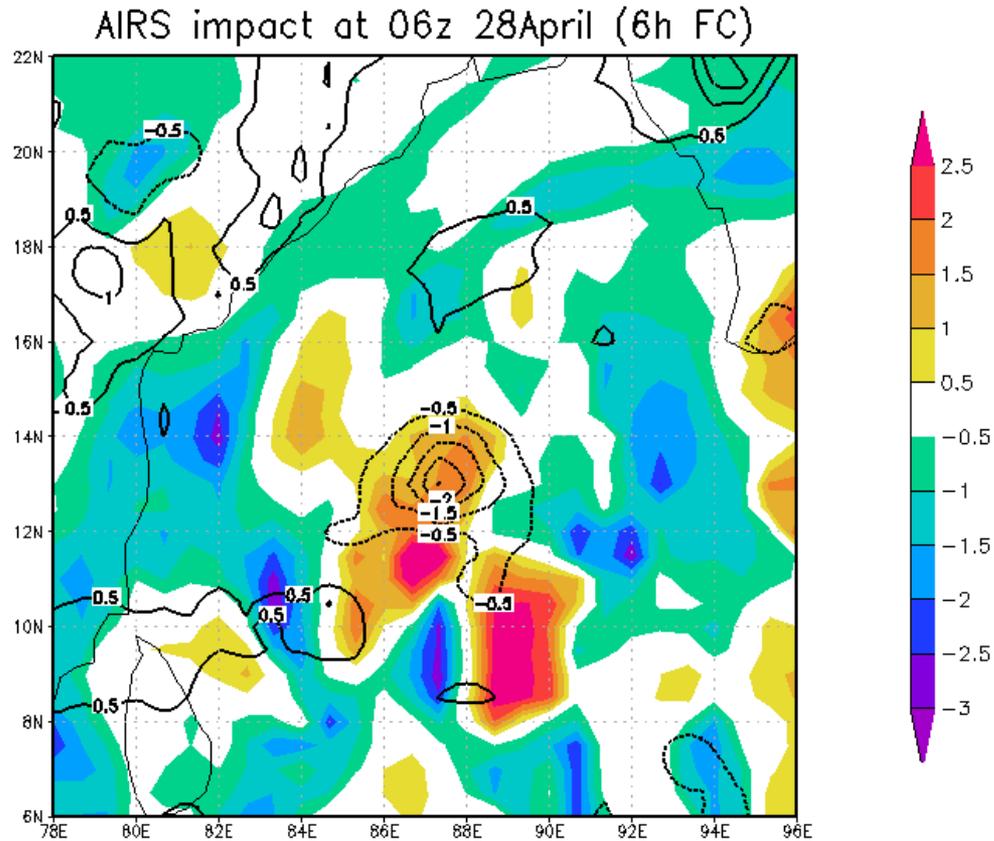
AIRS clear-sky radiances



AIRS v5 cloudy retrievals

5 out of 7 forecasts initialized from the improved analyses have a displacement error at landfall of about 50km (Reale et al., 2009, *Geophys. Res. Lett.*)

# How AIRS retrievals improve the analysis of a TC?



The localized, intense Upper-Level heating induced by AIRS data in correspondence to organized convection deepens the low-level cyclonic circulation of TC Nargis

Shaded: 200 hPa AIRS minus CNTRL temp anomaly  
Contour: AIRS minus CNTRL slp anomaly (Reale et al., 2009)

# Published AIRS impact study on precipitation associated with tropical cyclones compares performance of AIRS clear-sky radiances against cloudy retrievals.

- Assimilation of AIRV v5 retrievals produces better precipitation forecast than the assimilation of clear-sky radiances
- 3 TCs selected in different seasons, Atlantic and Indian Oceans

Zhou, Y., W. K. Lau, O. Reale, R. Rosenberg, 2010:  
AIRS Impact on precipitation analysis and forecast of  
tropical cyclone in a global data assimilation and  
forecasting system.

*Geophys. Res. Lett.*, **37**, L02806, doi.1029/2009GL041494

# Precipitation Analysis

## for Nargis

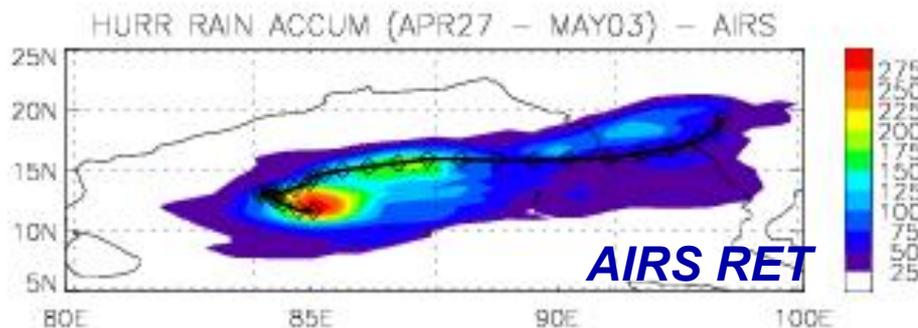
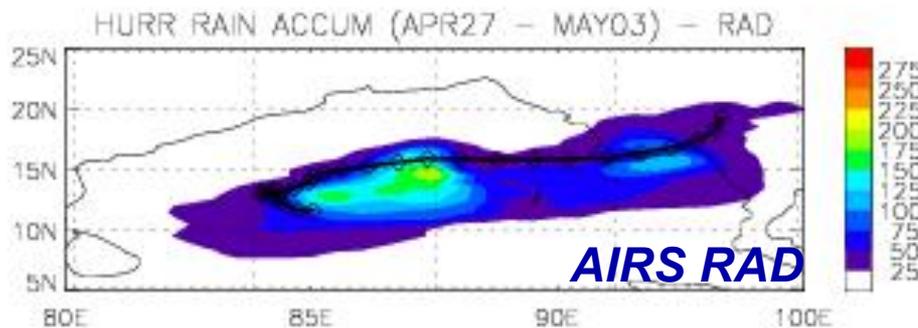
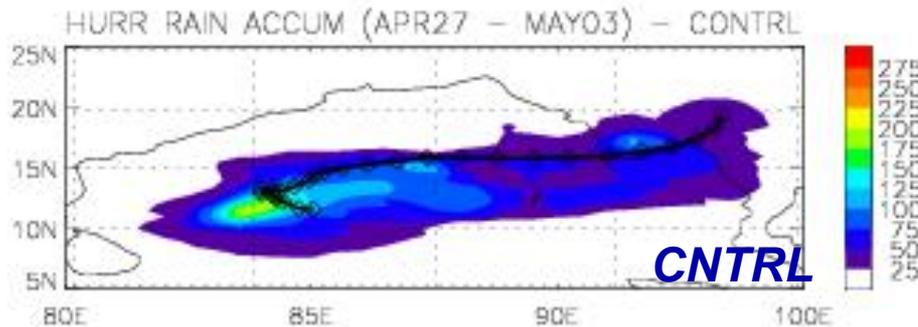
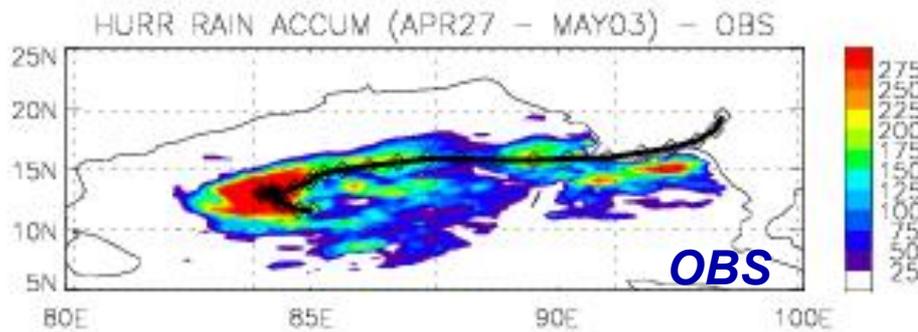
No precip data are assimilated. Precip comes from the 'corrector sequence' and is essentially a set of very short term forecasts strongly constrained by observations.

The assimilation containing AIRS retrievals –which improves Nargis structure- also produces the **best precipitation 'analysis' and forecast.**

**Validation is made against SSM/I, AMSU and TMI data**

Zhou, Y., W. K. Lau, O. Reale, R. Rosenberg, 2010: AIRS Impact on precipitation analysis and forecast of tropical cyclone in a global data assimilation and forecasting system.

*Geophys. Res. Lett.*, **37**, L02806, doi.1029/2009GL041494



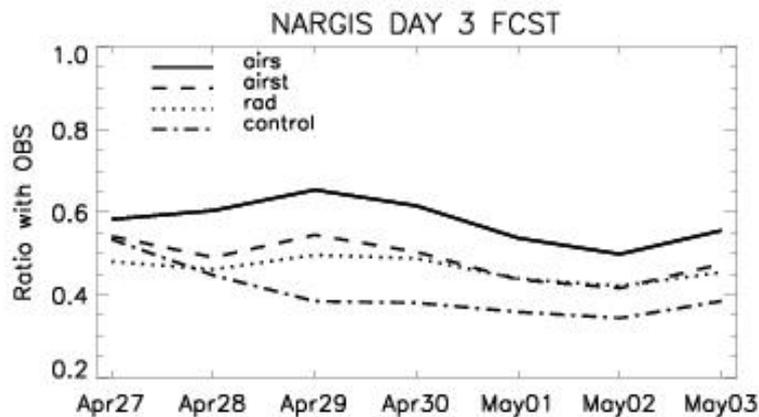
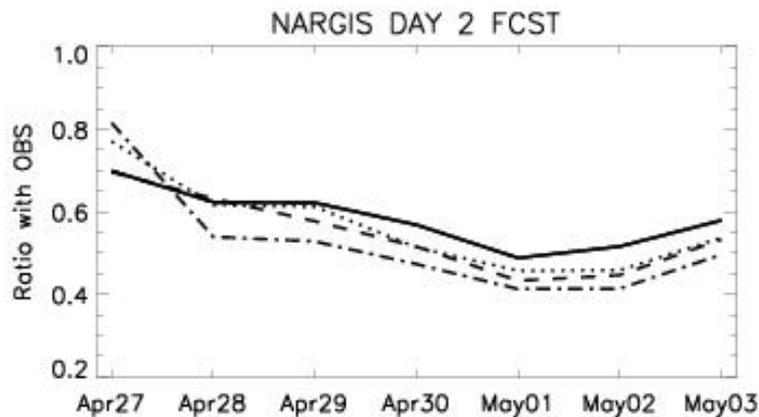
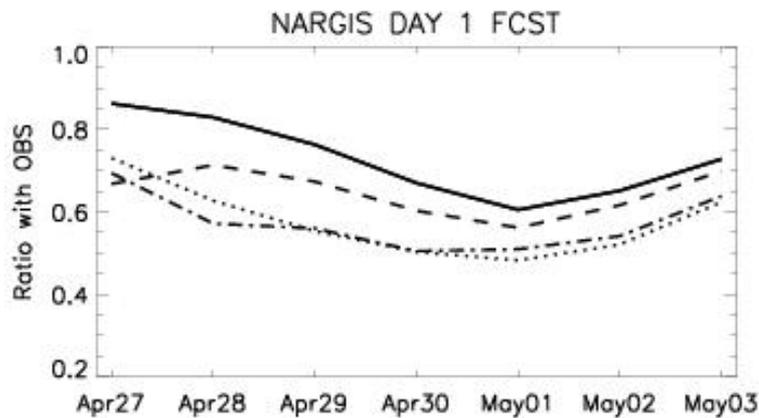
# Precipitation Forecast for Nargis

Forecasts computed along track and validated with SSM/I data.

**Ingestion of AIRS retrievals cause the GEOS-5 to have better skill.** Improvement with respect of CNTRL caused by **AIRS cloudy retrievals (tight QC)** is **about 20%**. The impact of radiances is negligible. Overall skill is very good in the 1-day forecasts. Skill **still reasonable at day 3**.

**Since the largest amount of casualties caused by Nargis were due to FLOODs, this result has prominent implications**

**Zhou et al., (2010)** also show **consistent** AIRS impact on **Wilma (2005), Helene (2006)**

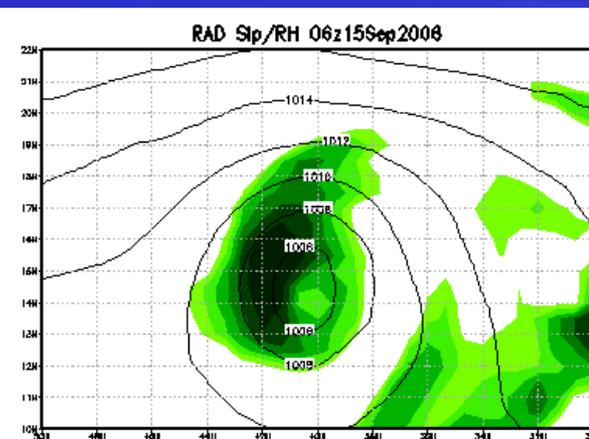
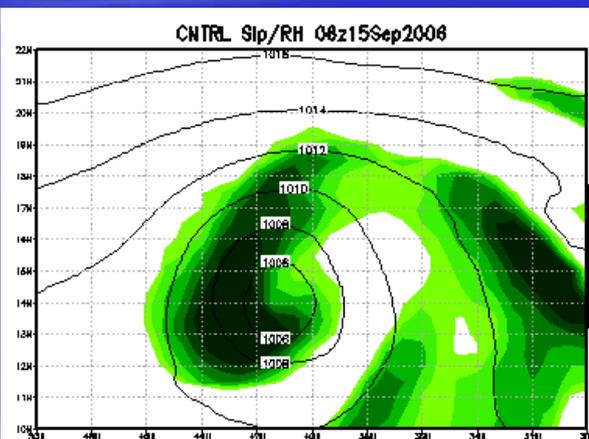


# Improvement in TC cloud/moisture distribution caused by AIRS v5 retrievals

## Example: TS Helene Analysis at 06z 15Sep2006 30 hours before becoming a hurricane

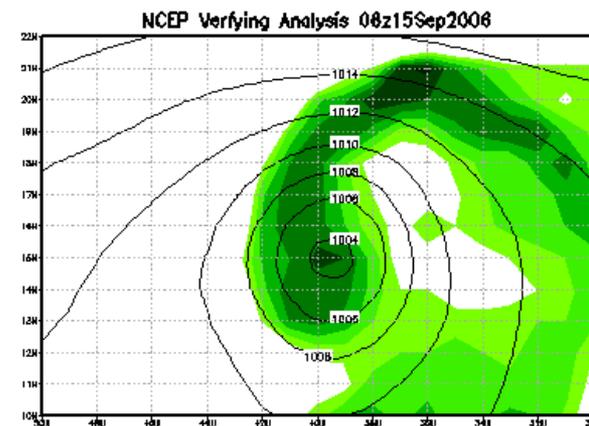
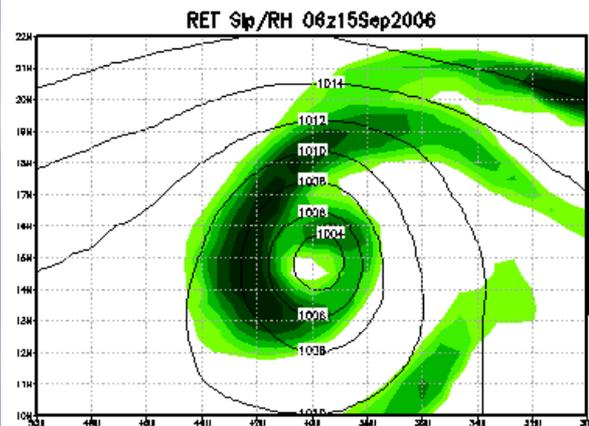
800 hpa relative humidity, sea level pressure (hPa)

CNTRL



RADIANCES  
*Do NOT produce an Eye-like feature*

RETRIEVALS  
*Produce an Eye-like feature*



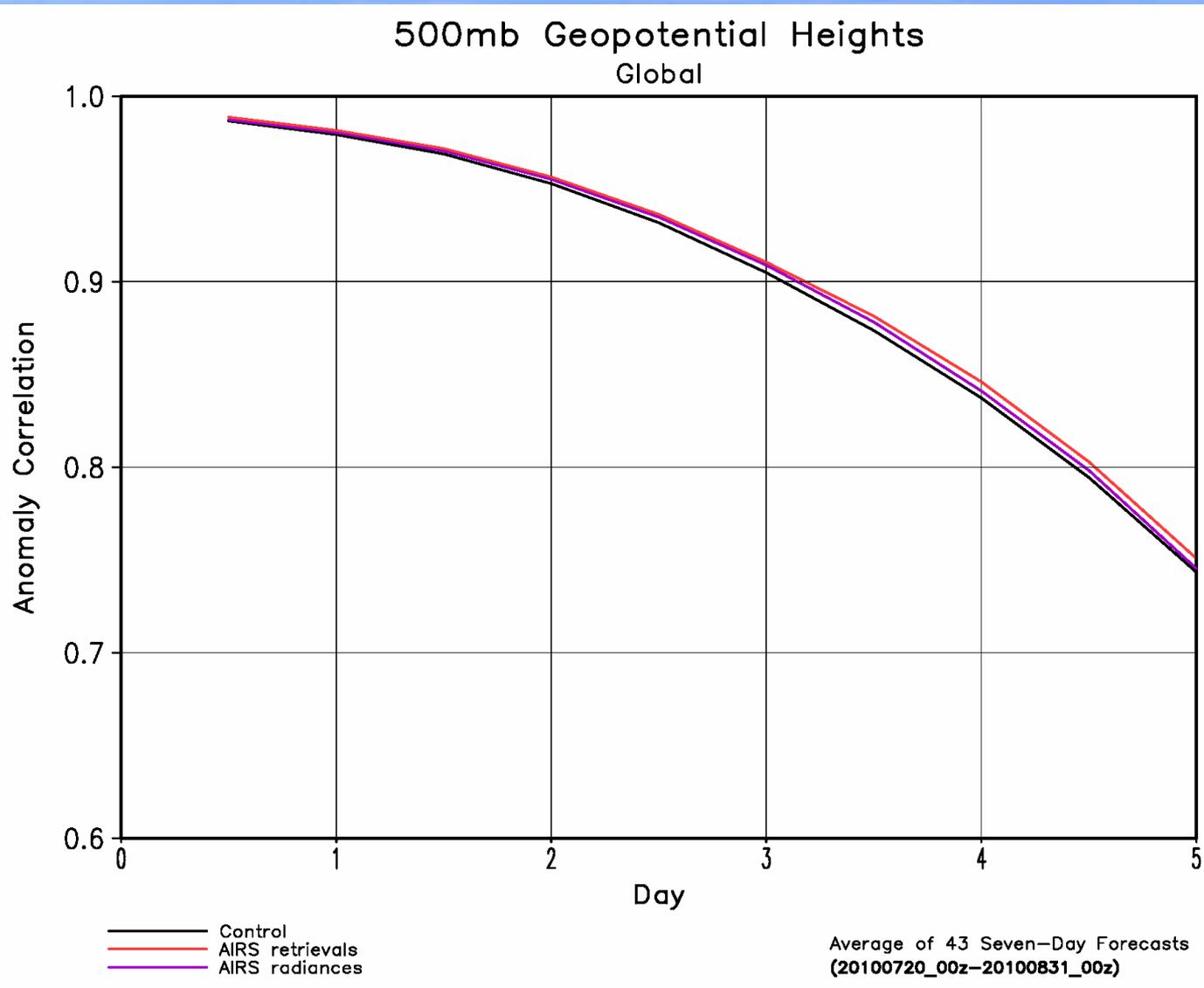
NCEP  
*Operational Analyses, Very poor*

# New study on: Indus River Floods (Pakistan, 2010)

- From 200 to 400mm fell between 27 July and 31 July 2010 over several locations where the seasonal mean is on the same magnitude or less
- Most operational systems failed to predict accurate **spatial distribution** of rainfall over Pakistan because of the poor representation of **cloudiness distribution** (Houze et al 2011)
- **Accurate spatial/temporal distribution of rainfall** the **most important parameter** to predict **watershed response**: floods arise with precipitation occurring on spatial and temporal scales proper of each basin (**small watersheds** respond to **high intensity- smaller duration** rain episodes, **large watersheds** respond to **lower intensity - longer duration**)
- Lau and Kim (2011) emphasized **tropical-extratropical teleconnections**
- **New: 3 sets of 48-day** assimilation experiments (CNTRL, RET and RAD) and corresponding **3 sets of 43 7-day forecasts** were performed.
- **Precipitation analysis and forecast**, and changes in the **moist circulation** consequent to the **different assimilation strategies** were assessed (Reale et al. 2011, submitted)

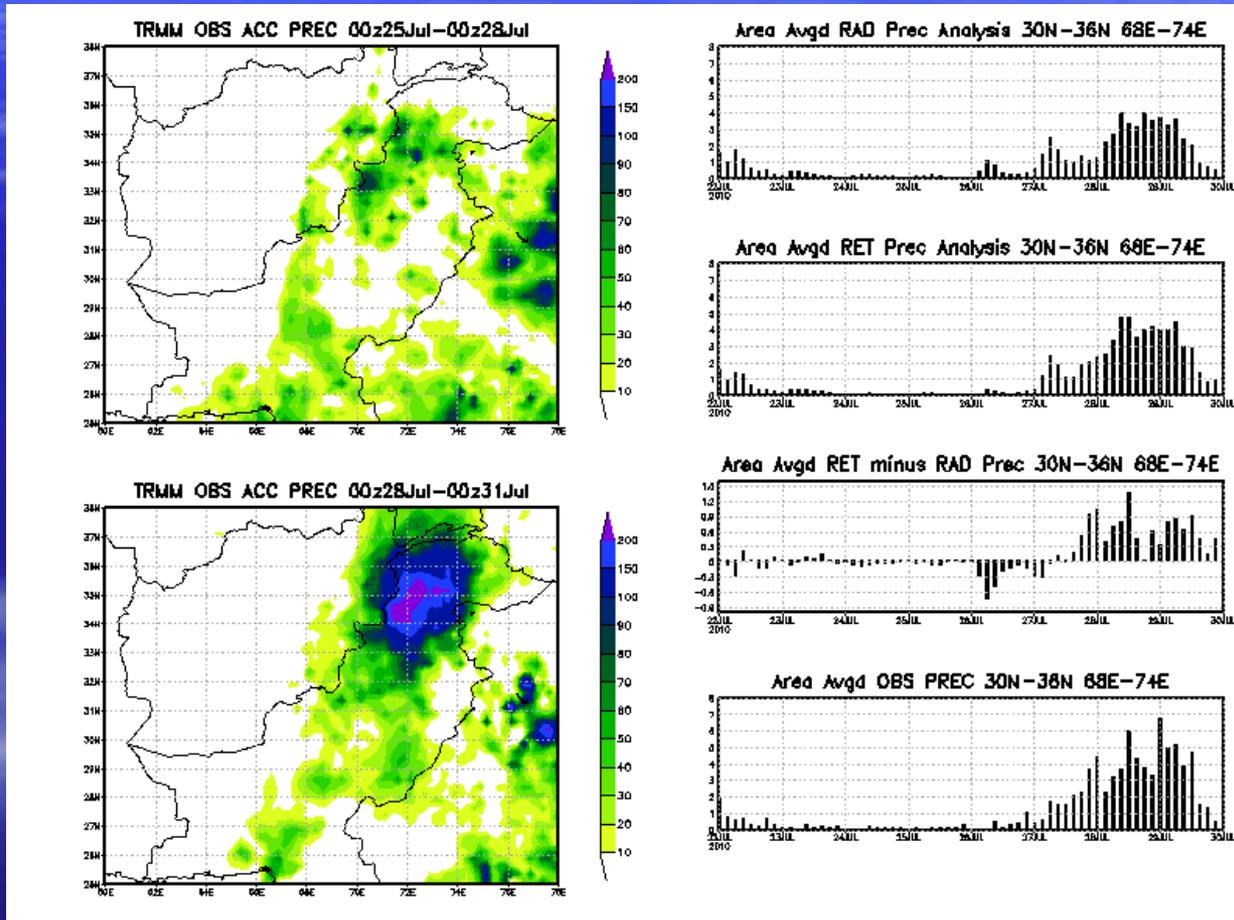
Reale, O., W. K. Lau, J. Susskind, R. Rosenberg, 2011: AIRS Impact on analysis and forecast of an extreme rainfall event (Indus River Valley, Pakistan, 2010) with a global data assimilation and Forecast system. Submitted.

# Global skill resulting from assimilation of AIRS v5 retrievals better than from clear sky radiances.

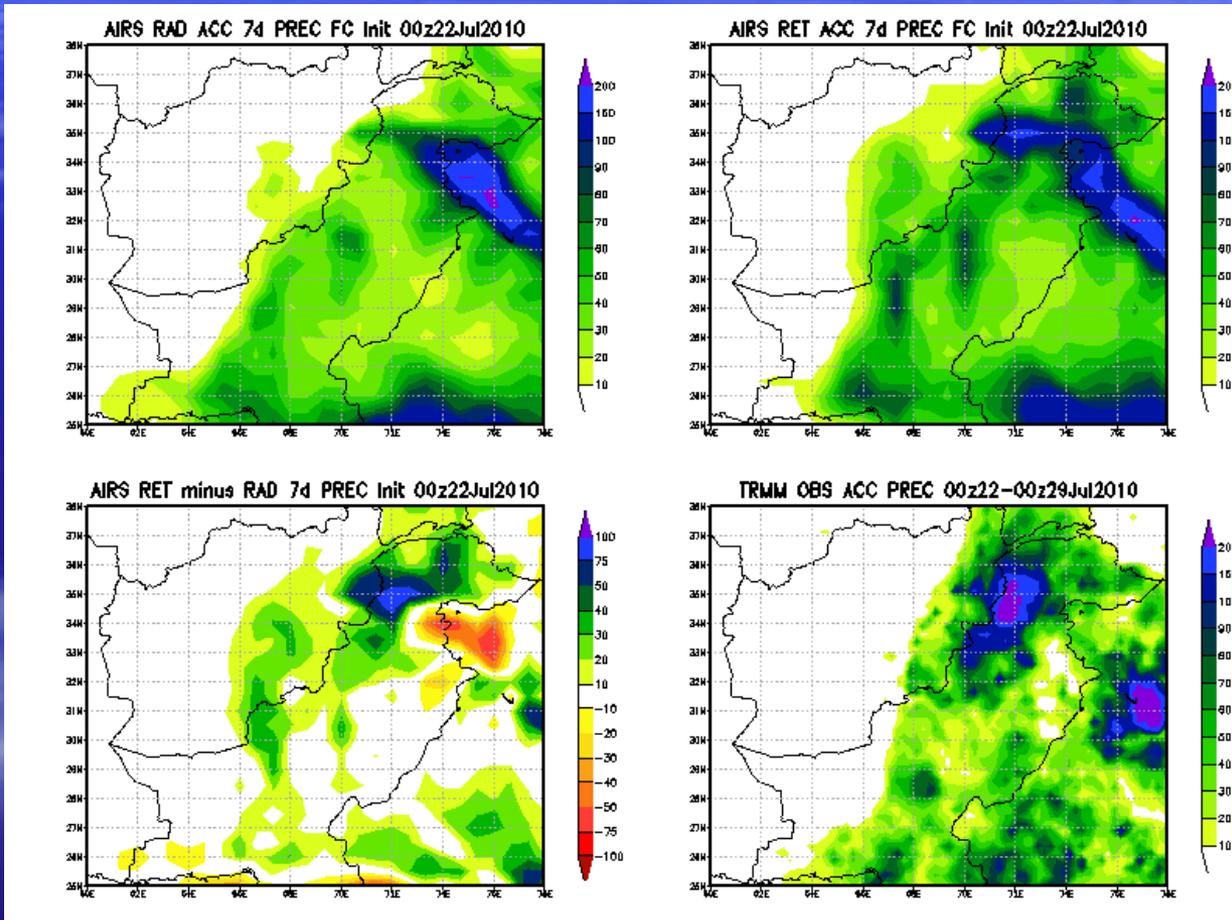


500 hPa  
anomaly  
correlation  
computed  
from 90S  
to 90 N

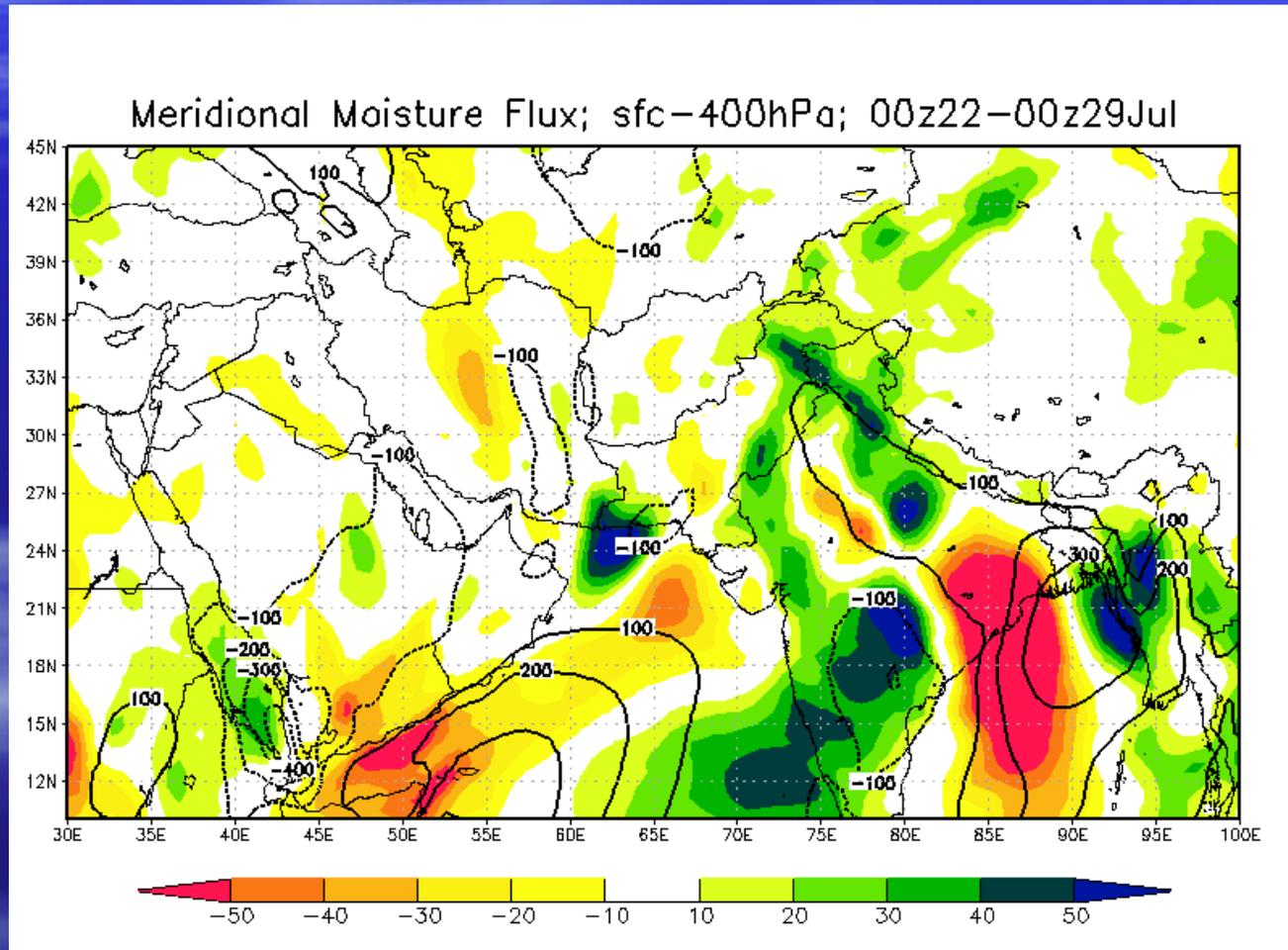
# AIRS retrievals improve the area-average precipitation analysis with respect to AIRS radiances



# AIRS retrievals improve the 7-day precipitation forecast with respect to AIRS radiances

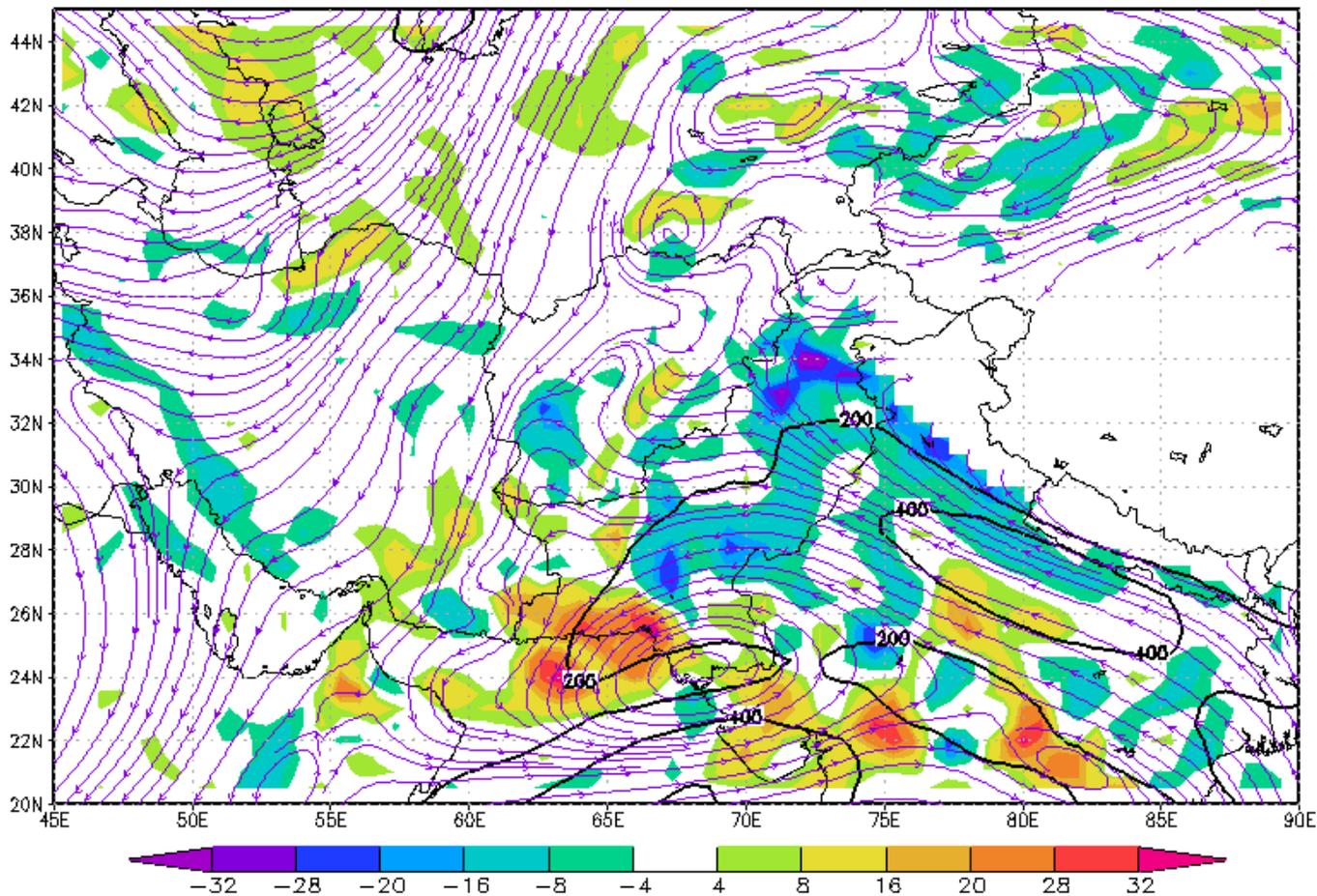


# AIRS retrievals increases the 7-day average moisture transport with respect to AIRS radiances

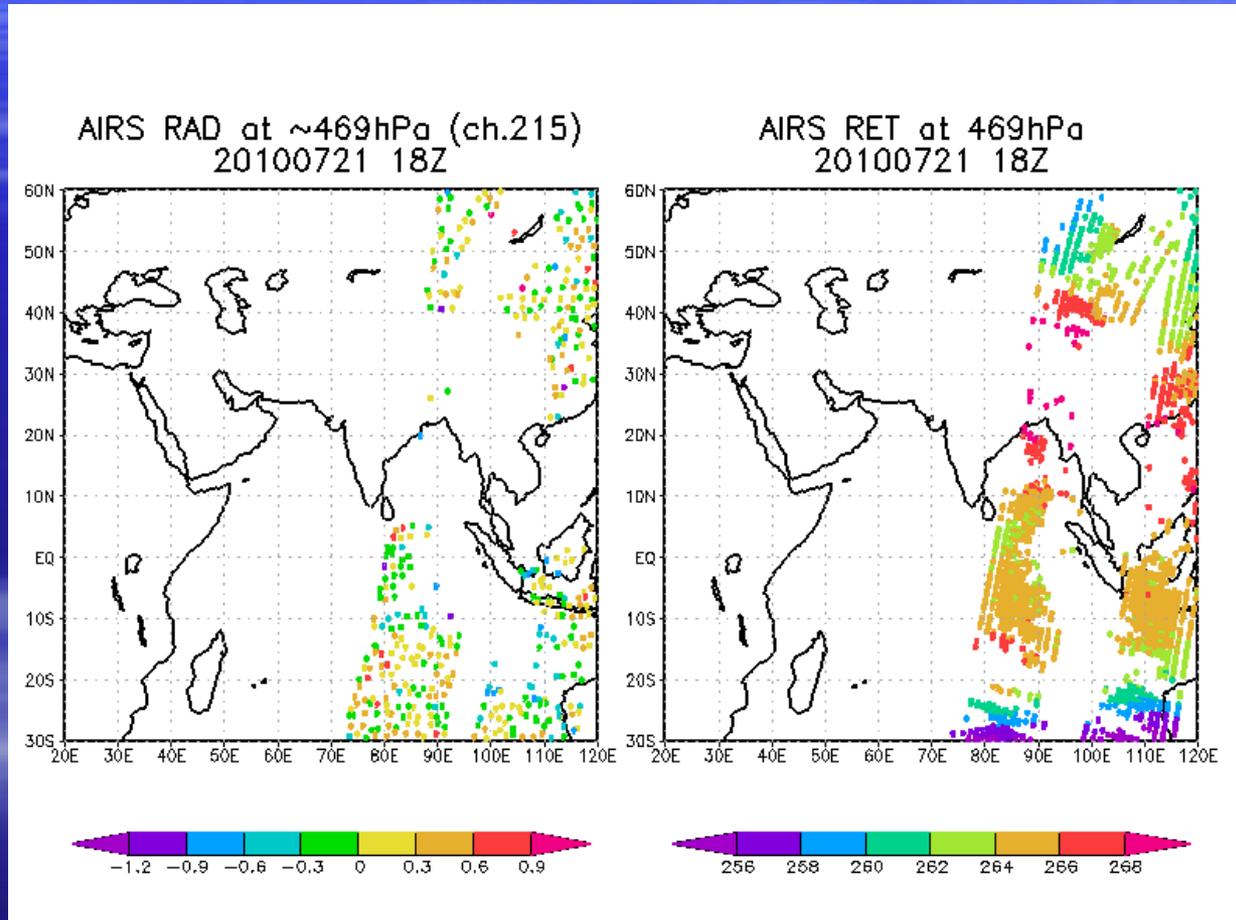


# AIRS retrievals increases the 2-day average moisture concentration with respect to AIRS radiances

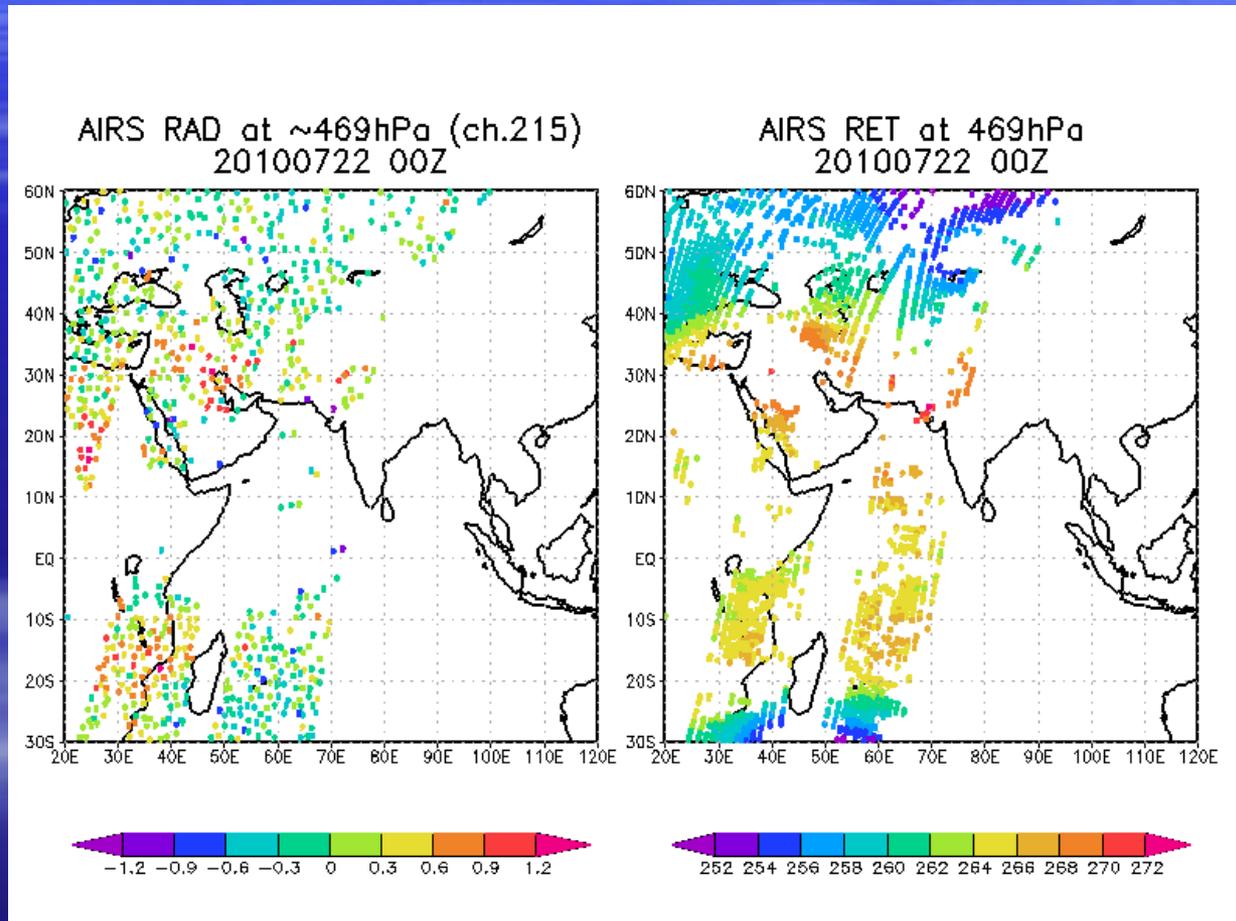
Moist Vint Transp and Div: sfc-600hPa; 00z27-00z29Jul



# Enormous difference in coverage between clear sky radiances and v5 retrievals: 18Z passes



# Enormous difference in coverage between clear sky radiances and v5 retrievals: 00z passes



# Summary of the impact study on the Indus-river floods (Pakistan, 2010)

- Information provided from AIRS v5 cloudy retrievals allow an improved representation of the low- and mid-level moist atmospheric flow from the Indian Ocean, on different time scales
- Assimilation of **AIRS version 5 cloudy retrievals** improve the analysis of **precipitation more than assimilation of AIRS clear-sky radiances**
- Improved precipitation analysis arise out of **an improved representation of cloudiness distribution, moisture transport and convergence.**
- The analysis improvement consequent to **AIRS v5 retrieval** assimilation produced **improved precipitation forecasts up to 7 days** with respect to assimilation of **AIRS clear-sky radiances**
- **Improved precipitation forecast** may enable **better hydrological forecasts**
- **Results submitted to JGR**

Reale, O., W. K. Lau, J. Susskind, R. Rosenberg, 2011: AIRS Impact on analysis and forecast of an extreme rainfall event (Indus River Valley, Pakistan, 2010) with a global data assimilation and Forecast system. Submitted.

# Conclusions of 3 years of work

- Sets of data assimilation experiments without AIRS, with AIRS version 5 retrievals and with AIRS clear-sky radiances were produced for boreal winter, spring, two summers and fall conditions, for a total of about 600 days; 5- or 7-day forecasts are produced from each set of analyses, for a total of about 600 forecasts
- The overall impact on forecasts skill coming from v5 retrievals is higher than the corresponding impact of radiances in every season and every year
- 3 GRL articles have been published demonstrating the superior impact of AIRS v5 retrievals in a variety of situations (global, regional, event-focused, different years and seasons)
- New AIRS impact study on Pakistan floods show substantial improvements, caused by assimilation of AIRS v5 retrievals, in the precip Analysis and 7 day forecast, with respect to clear-sky radiances.

# Ongoing and future Work

- Research started under new grant (June 2011-2014) on AIRS impact on processes affecting **Tropical Cyclone structure** in global models
- Current results show that AIRS improves the Tropical Cyclone ANALYSIS in GEOS5-DAS in terms of **intensity**, **confinement** and **position**; impact is particularly strong on **developing** and **transitioning** tropical cyclones
- AIRS impact on Tropical Cyclones in the GEOS-5 is being studied over the **Atlantic, Indian and Pacific Oceans**, **different years**, both hemispheres
- Tests on the **NCEP GFS** system have started in collaboration with Amidu Oloso, (SSSO, Tom Clune's group)
- Waiting for **AIRS version 6** when available

# Acknowledgments

- **Dr. Ramesh Kakar** for support to **previously funded** proposal ``*Relationships among precipitation characteristics, atmospheric water cycle, climate variability and change*'' (PI: Dr. W. K. Lau)
- **Dr. Ramesh Kakar** for support to **currently funded** proposal ``*Using AIRS data to understand processes affecting Tropical Cyclone structure in a Global Data Assimilation and Forecasting Framework*'' (PI: Dr. O. Reale)
- **Dr. Tsengdar Lee** for generous allocations of NASA High End Computer resources
- **AIRS team** at JPL and the **Sounder Research Team** at NASA GSFC

