AIRS contribution towards improved forecasts of flood-producing precipitation

within a global data assimilation and forecasting system

Oreste Reale (GEST/UMBC)
W. K. Lau (NASA), *J. Susskind* (NASA)
Yaping Zhou (GEST/UMBC)
Robert I. Rosenberg (SAIC), *Lena Iredell* (SAIC), *John Blaisdell* (SAIC)
Laboratory for Atmospheres

National Aeronautics and Space Administration

Outline

Previous work - AIRS impact on:

- midlatitude winter dynamics; global AIRS impacts in all seasons
- tropical cyclone Nargis (2008)
- tropical cyclogenesis and extra-tropical transitions in the Atlantic

New - AIRS impact on:

- Analyses and Forecasts of Flood-producing Precipitation (Nargis, Wilma)
- Precipitation Analysis for the 2010 floods along the Indus river (Pakistan)
- Conclusions, Future Work and Acknowledgements

Understanding and improving the impact of AIRS in the GEOS-5 Data Assimilation and Forecasting System

- 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

Reale, O., J. Susskind, R. Rosenberg, E. Brin, E. Liu, L.P. Riishojgaard, J. Terrry, 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

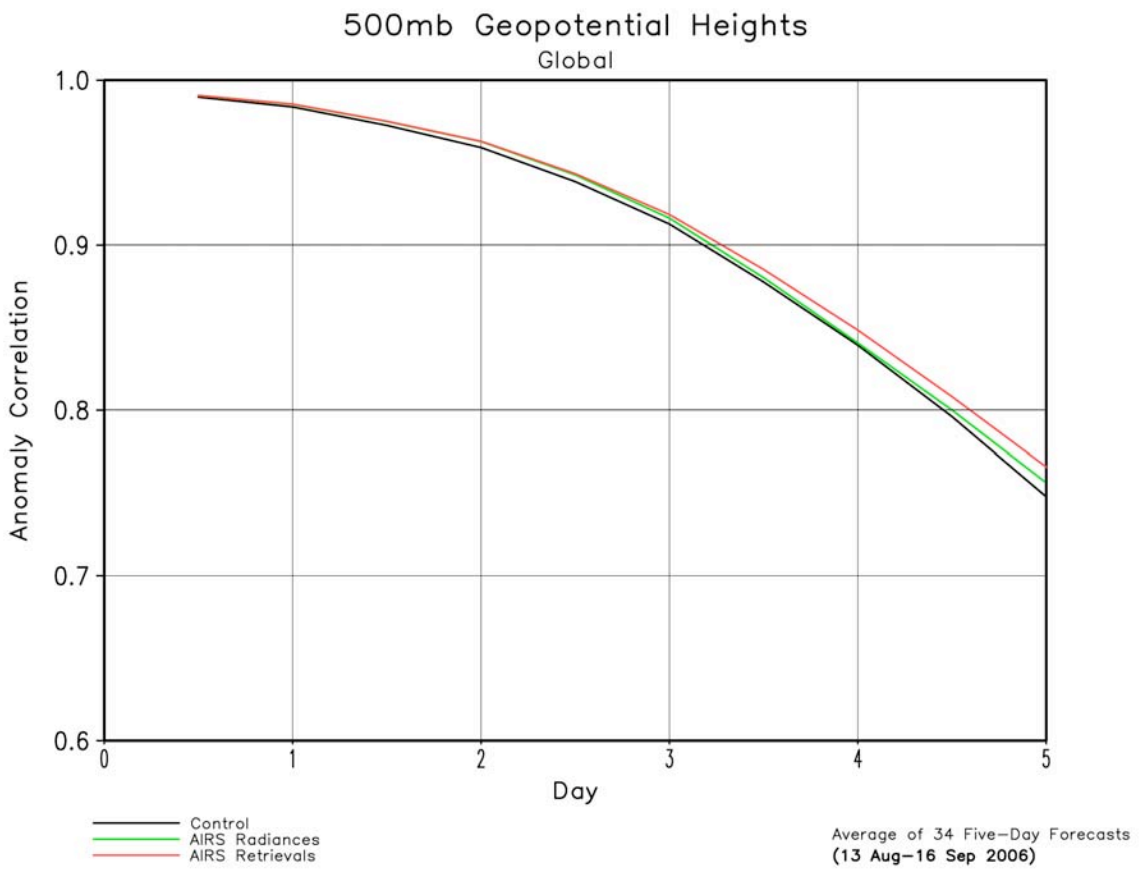
Global Impact of Clear-sky Radiances versus Quality Controlled cloudy Retrievals

- 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 (2007, 2010) strategy, based upon previous work by Chahine, allows improvement of soundings in partly-cloudy conditions: a key element is 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 five different 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 2.0.2, 2.1.2, 2.1.4
- Control assimilation (CNTRL): assimilating all conventional and satellite data, but no AIRS retrievals, from 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**)
- AIRS ``standard'' QC RET: Same data as control plus AIRS version 5 retrievals with "standard" quality control added as rawinsonde temperature profiles.
- AIRS ``medium'' QC RET: More restrictive QC for AIRS ret
- AIRS ``tight'' QC RET: Most restrictive QC for AIRS ret
- AIRS RAD: AIRS clear-sky radiances from NESDIS
- Forecasts at 0.25 or 0.5 degrees

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

In addition to global skill, AIRS affects the depiction of tropical weather systems

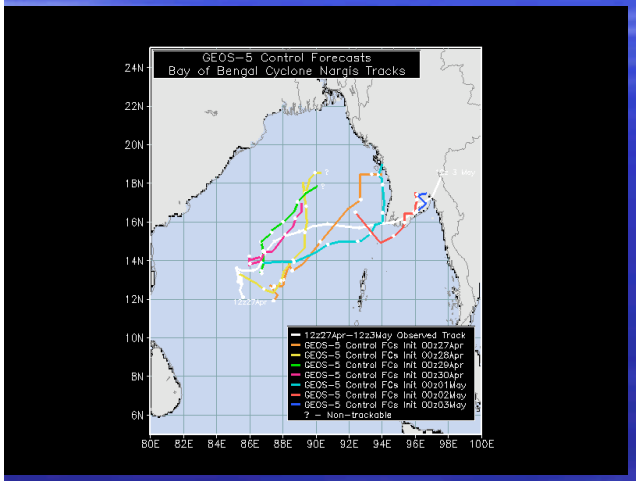
- AIRS cloudy retrievals change particularly the depiction of developing and transitioning tropical cyclones
- AIRS impact on Tropical Cyclones in the GEOS-5 has been studied over the Atlantic, Indian and Pacific Oceans
- AIRS improves the Tropical Cyclone ANALYSIS in GEOS5-DAS in terms of intensity, confinement and position
- The cause of the improvement arises from tight, strong upper-tropospheric positive thermal anomalies detected over organized convection
- No or minimal improvement derives from the assimilation of clear-sky radiances

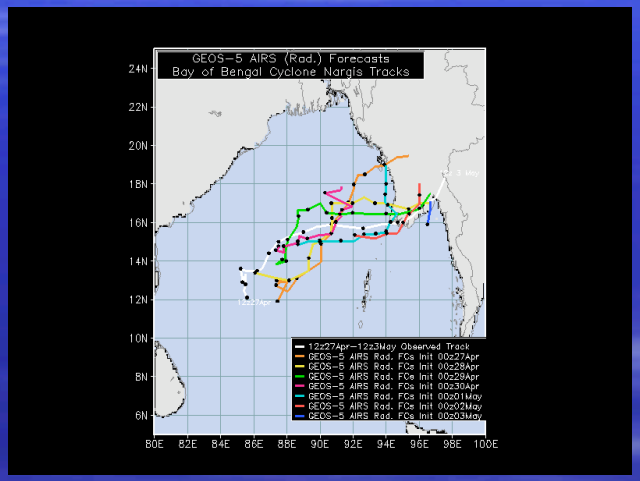
Published study on the impact of AIRS in the GEOS-5 Data Assimilation and Forecasting System: comparing clear-sky radiances with cloudy retrievals on a *very difficult* tropical cyclone

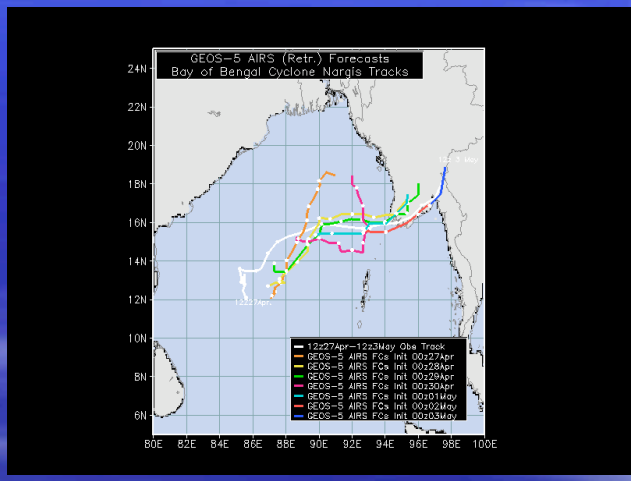
- Work published in 2009 shows enormous improvements in analysis over the *tropics* in in the GEOS-5 DAS and forecasting model. Case chosen: catastrophic cyclone Nargis which hit Burma causing devastating loss of life
- Tropical Cyclones in the Northern Indian Oceans are more difficult, partly because of short lifespan and erratic tracks. In addition, automated operational global analyses often do not represent these cyclones' position accurately.

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

Spectacular forecast track improvement for tropical cyclone Nargis (2008) consequent to qc-ed AIRS cloudy retrieval assimilation







Control

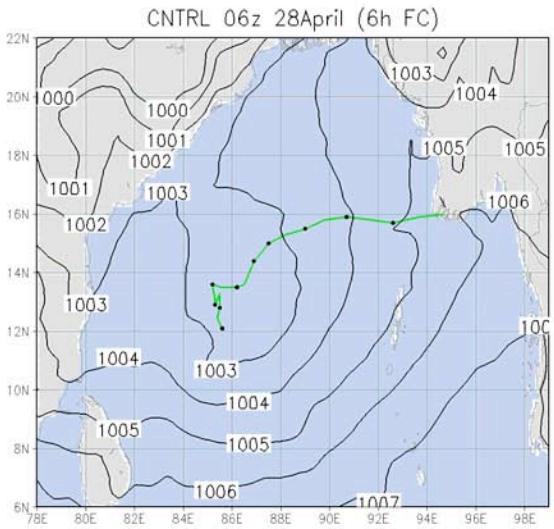
AIRS clear-sky radiances

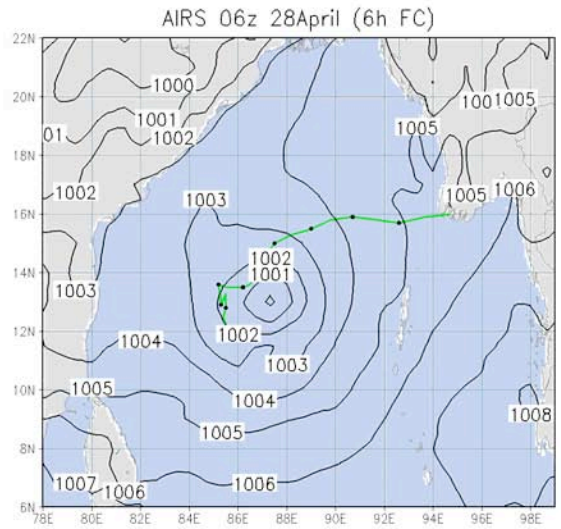
AIRS cloudy retrievals

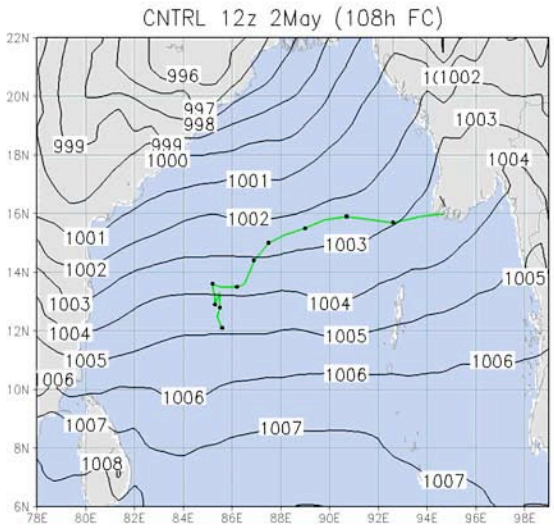
5 out of 7 forecasts initialized from the improved analyses have a displacement error at landfall of about 50km (Reale et al., 2009, *Geophys. Res. Lett.*)

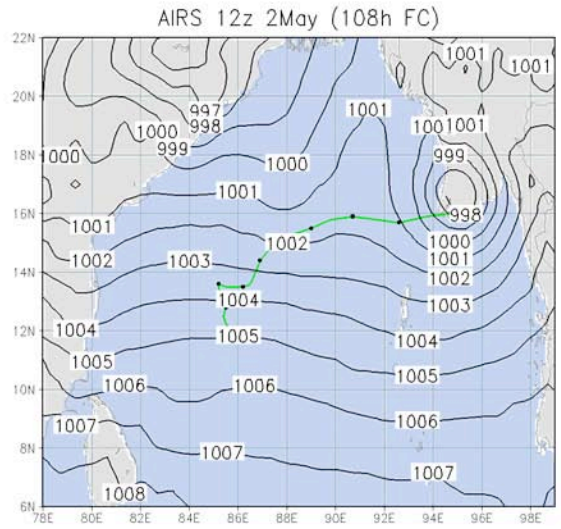
Assimilation of clear-sky radiances produce minimal improvement

Example of AIRS impact on forecast track









AIRS Analysis Well-defined Cyclone Green: Observed Track

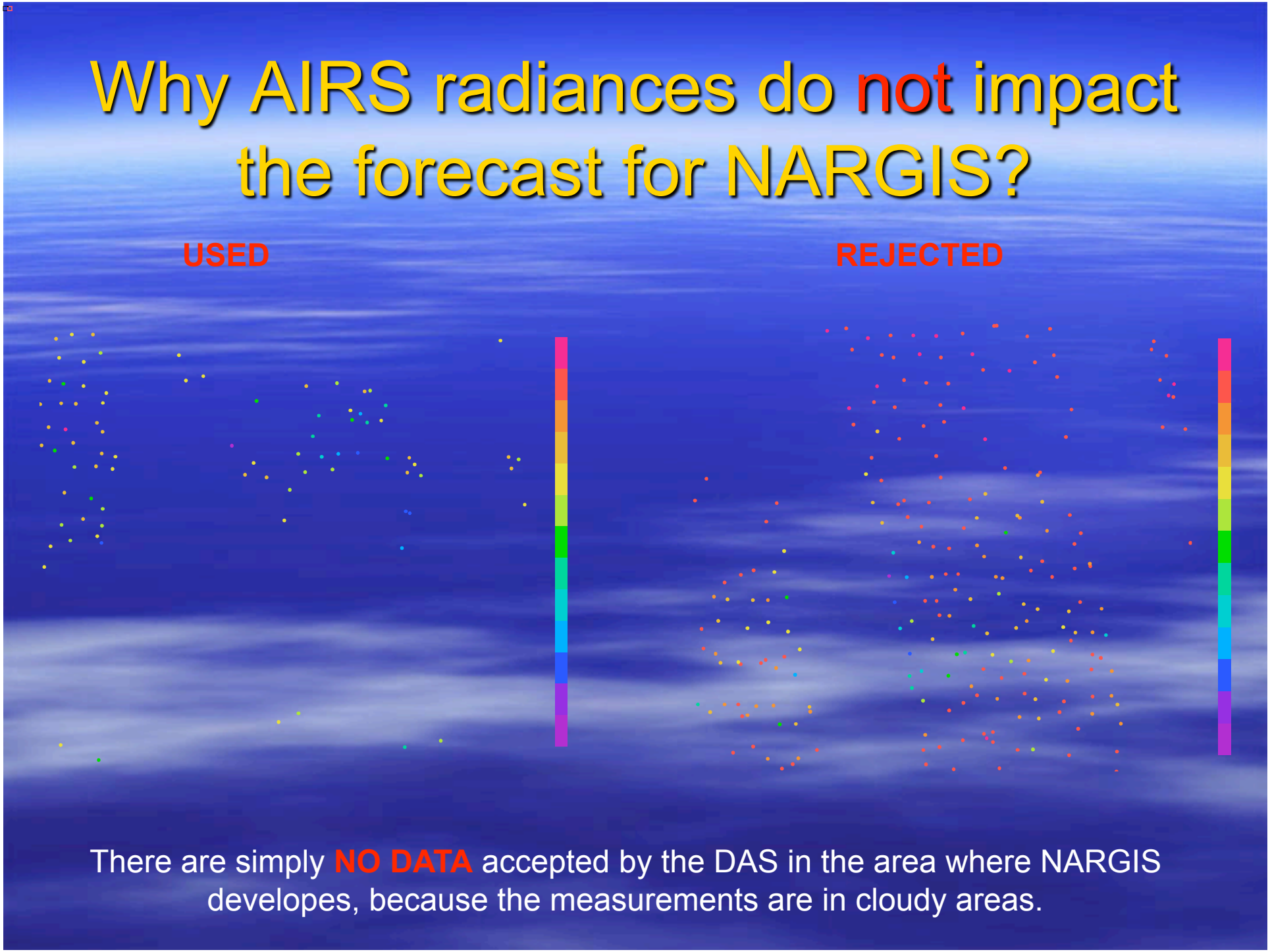
AIRS 108-hour Forecast (slp)

Green: Observed Track

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

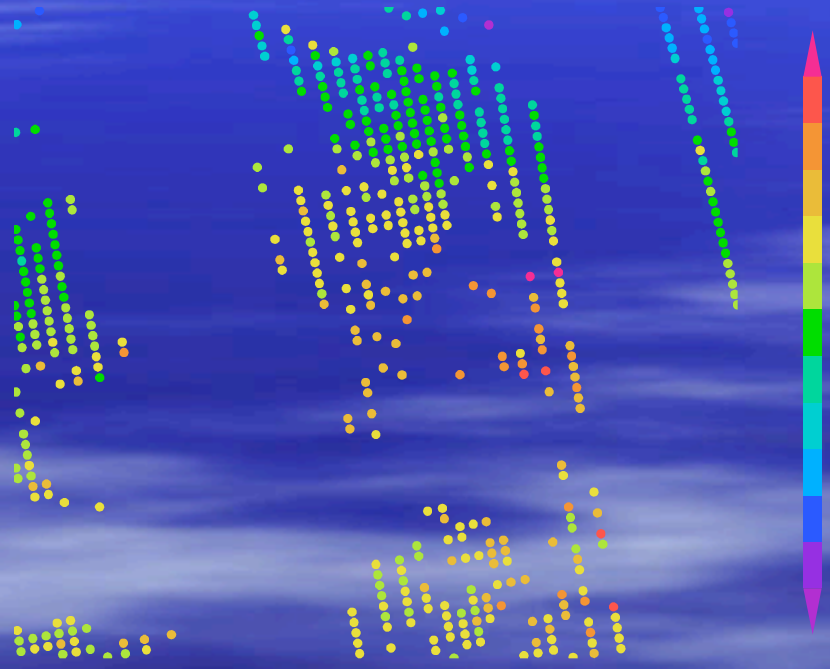
Accurate landfall is produced in the forecasts initialized with AIRS: (Reale et al., 2009, *Geophys. Res. Lett.*)

Why AIRS radiances do not impact the forecast for NARGIS?



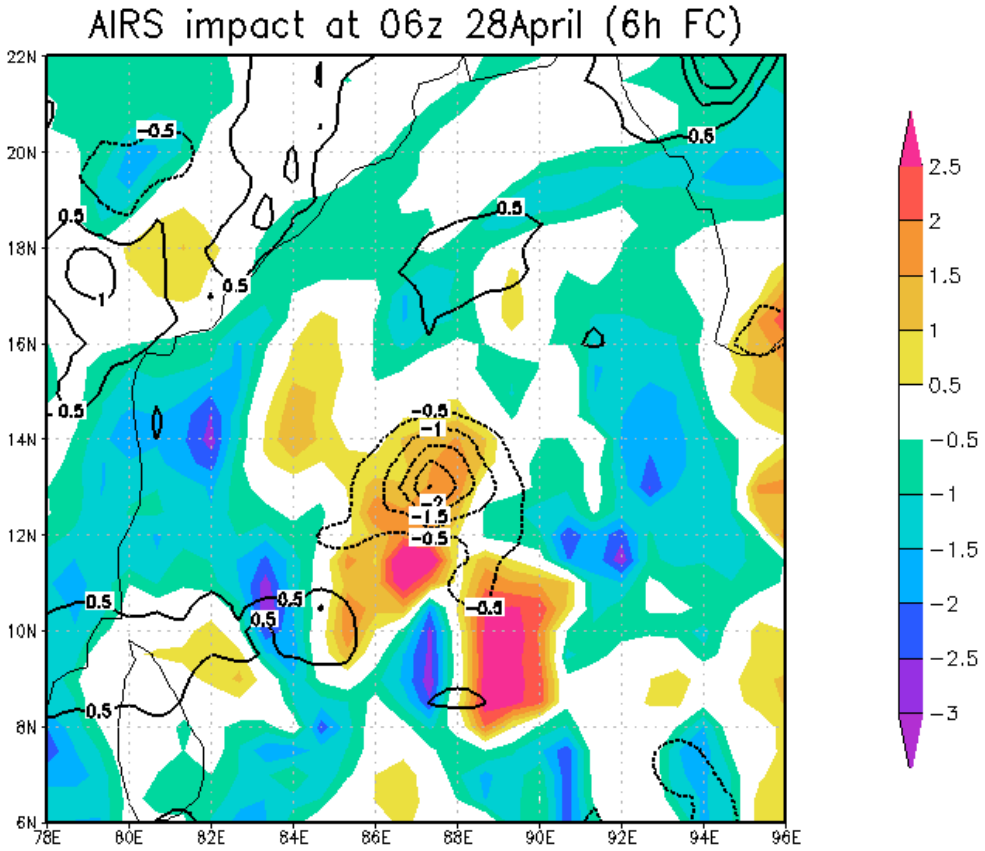
There are simply **NO DATA** accepted by the DAS in the area where NARGIS developes, because the measurements are in cloudy areas.

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

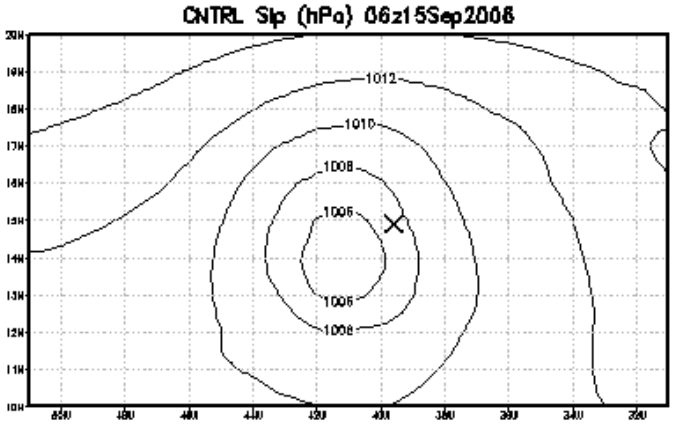
How AIRS retrievals improve the analysis of a TC?

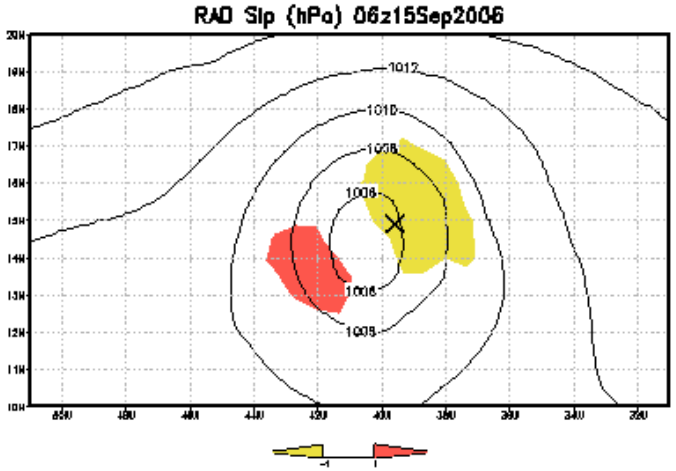


The localized, intense Upper-Level heating induced by AIRS data in correspondence to organized convection deepens the low-level cyclonic circulation of TC Nargis

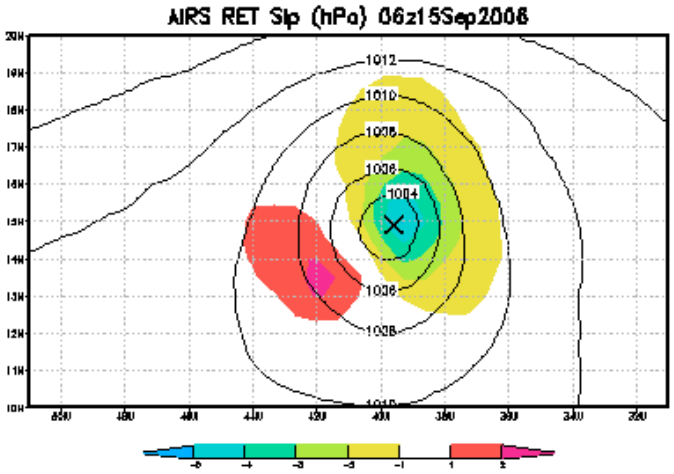
Shaded: 200 hPa AIRS minus CNTRL temp anomaly
Contour: AIRS minus CNTRL slp anomaly (Reale et al., 2009)

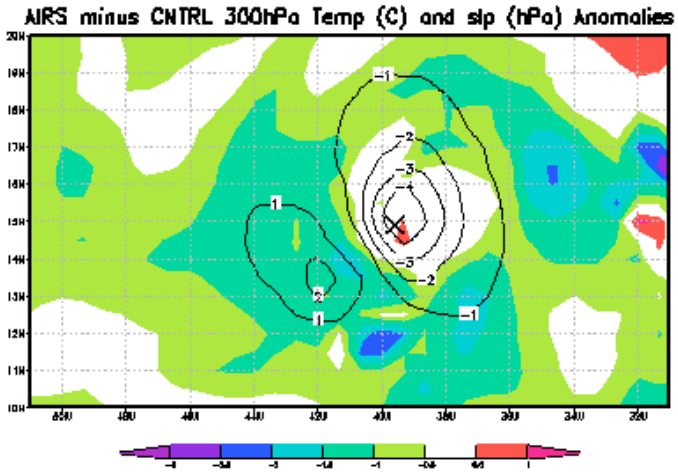
AIRS TIGHT QC CLOUDY RET improves TC position in the Analysis of Helene (2006)





Slp RAD analysis (contour)
RAD slp impact (shaded)
X: observed Helene position



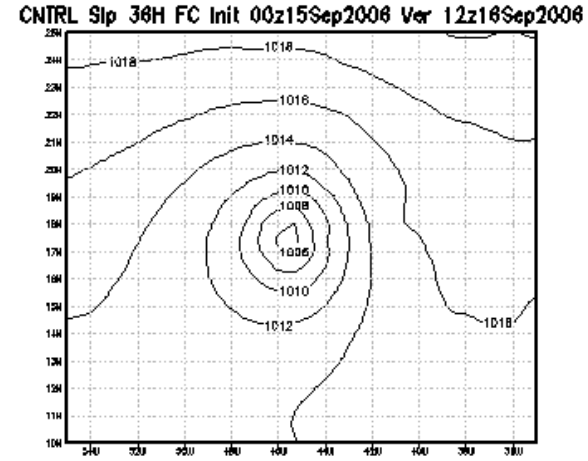


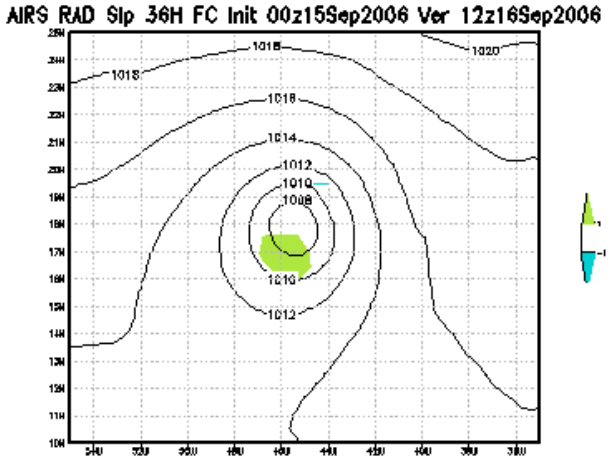
300 hPa Temp Impact (ret minus Control, shaded)
And slp impact (contour)

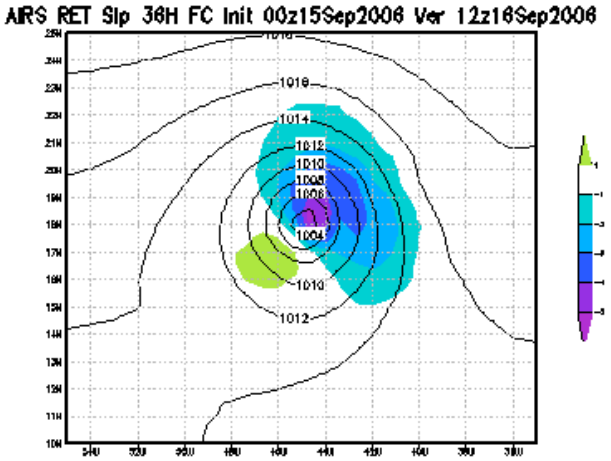
Slp RET analysis (contour)
RETRIEVALS slp impact (shaded)

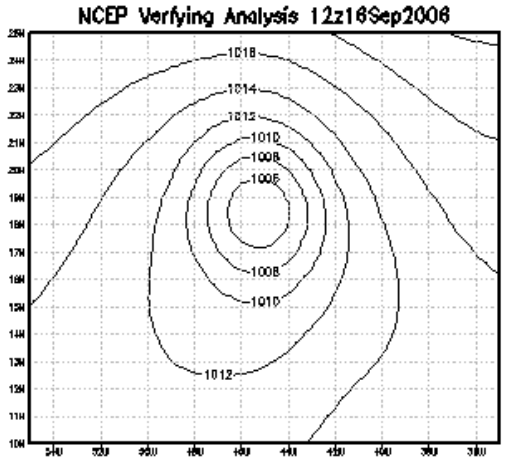
AIRS TIGHT RET produces a **PERFECT** position for Helene and a deeper storm

Even larger improvement in the genesis forecast of Hurricane Helene genesis with `tight QC' cloudy retrievals









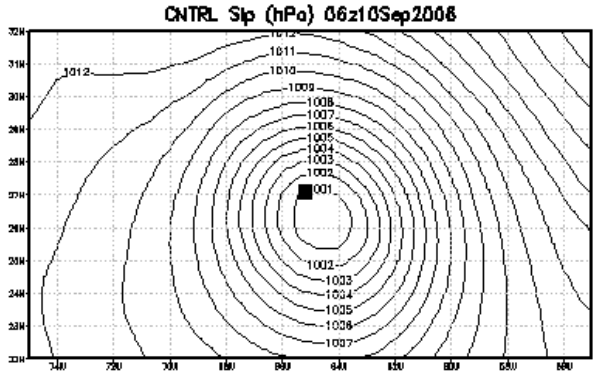
Comparison
Of 36-h
Forecasts
of AIRS TIGHT RET
(lower left)
with AIRS RAD
(upper right)

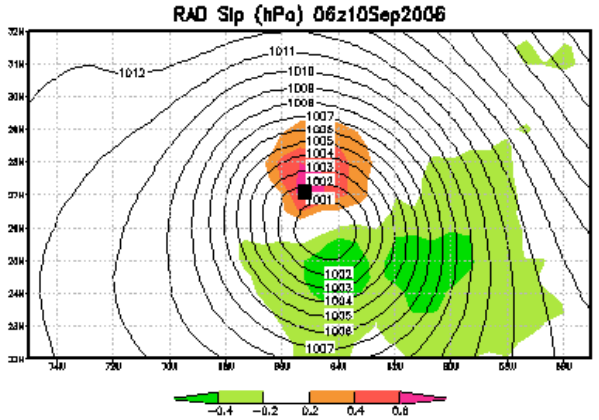
Forecasts from Analysis in which AIRS TIGHT RET are assimilated improve Helene's Formation as a hurricane (12z 16Sep). Improvement is minimal in RAD case

AIRS impact on extra-tropical transitions: a difficult problem.

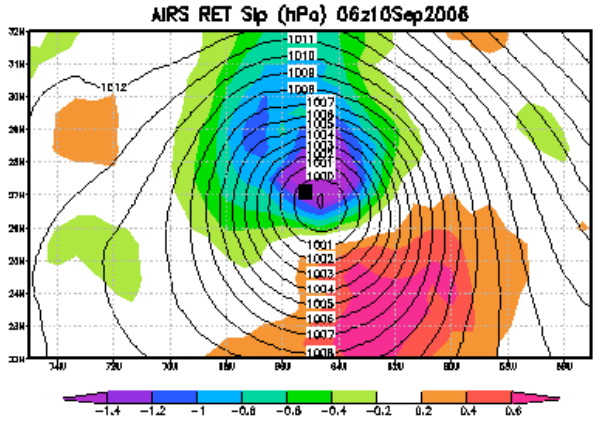
- Rapid changes in dynamics from tropical to baroclinic
- Very strong asymmetric vertical shear
- Rapid acceleration of the systems
- Small errors in TC location before transition lead to large forecast track errors
- Small errors in the thermal structure of the atmosphere before transition lead to large misrepresentations of storm intensity
- AIRS quality-controlled cloudy retrievals positively impact EXTRA TROPICAL TRANSITIONS

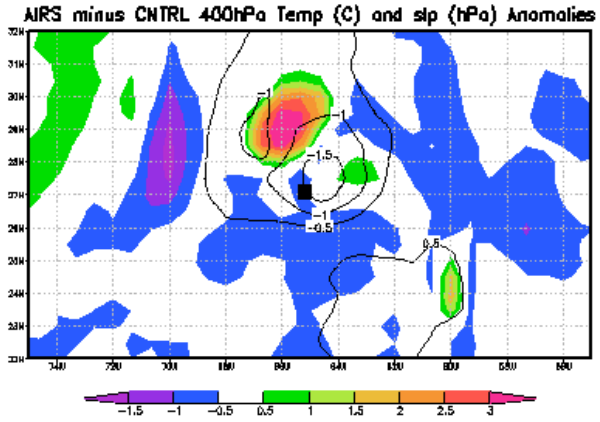
Extra-tropical transition of Hurricane Florence (2006): improving the analysis before transition 06z10Sep2006





RAD slp analysis (contour)
And difference from
CNTRL.. Negative impact
From assimilation of clear-sky
Radiances.





400 hPa AIRS RET-induced
Temp anomaly (shaded)
And impact on slp (contour)

AIRS RET slp analysis (contour)
and difference from CNTRL (shaded)

AIRS RET improves location and intensity also at subsequent times; FORECASTS from the improved analyses are much superior.

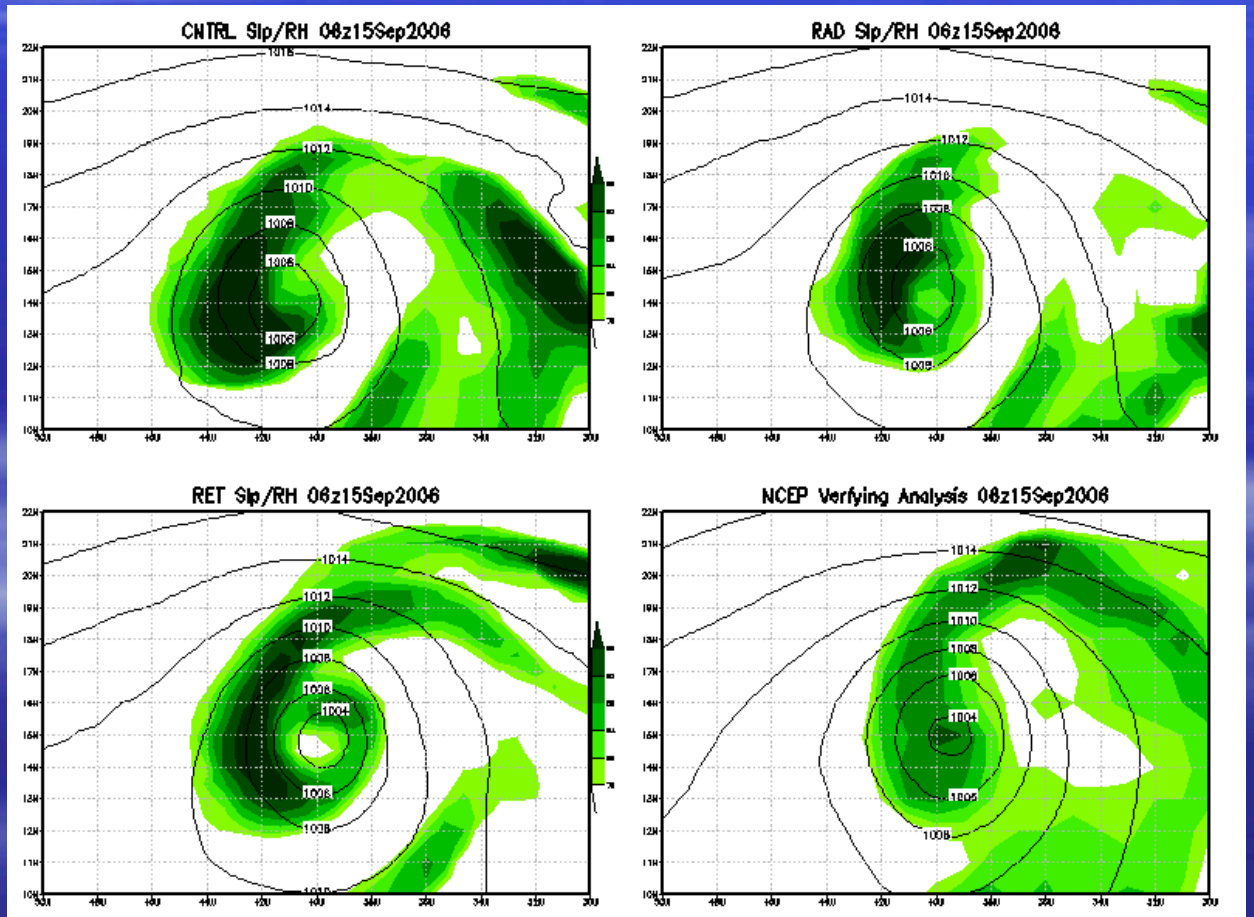
Improvement in **cloud structure** caused by AIRS retrievals

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

800 hpa relative humidity, sea level pressure (hPa)

CNTRL

RETRIEVALS
Display an Eye-like feature



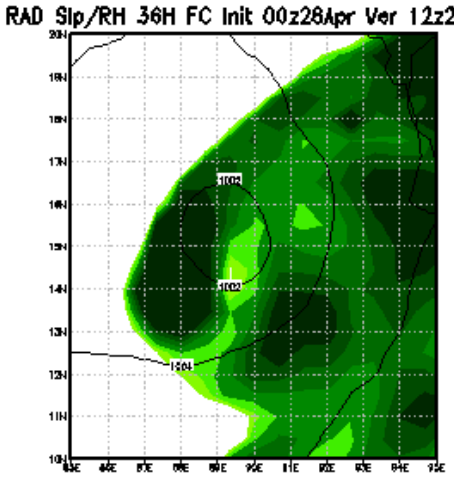
RADIANCE

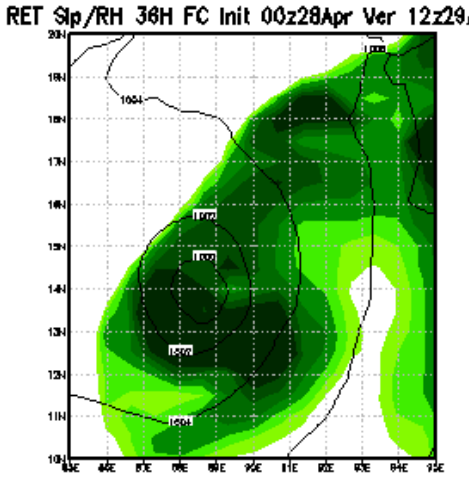
NCEP Operational Analyses, Very poor

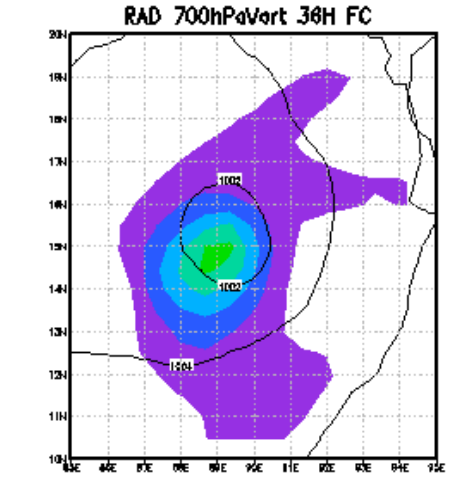
AIRS cloudy retrievals impact the forecast of Nargis **structure more** than clear radiances

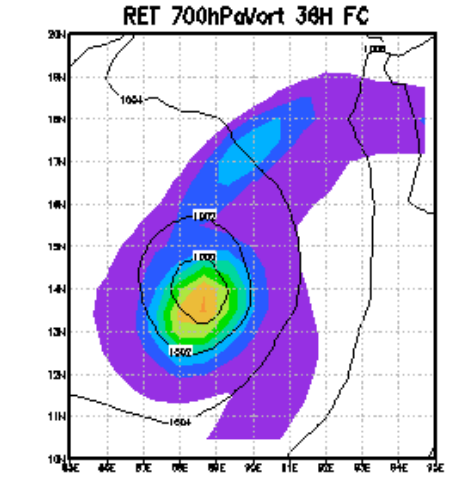
Radiances: ***very poor structure:***
Two unconnected convective systems without a deep circulation

Retrievals: *Realistic 2-band structure comparing well with satellite*



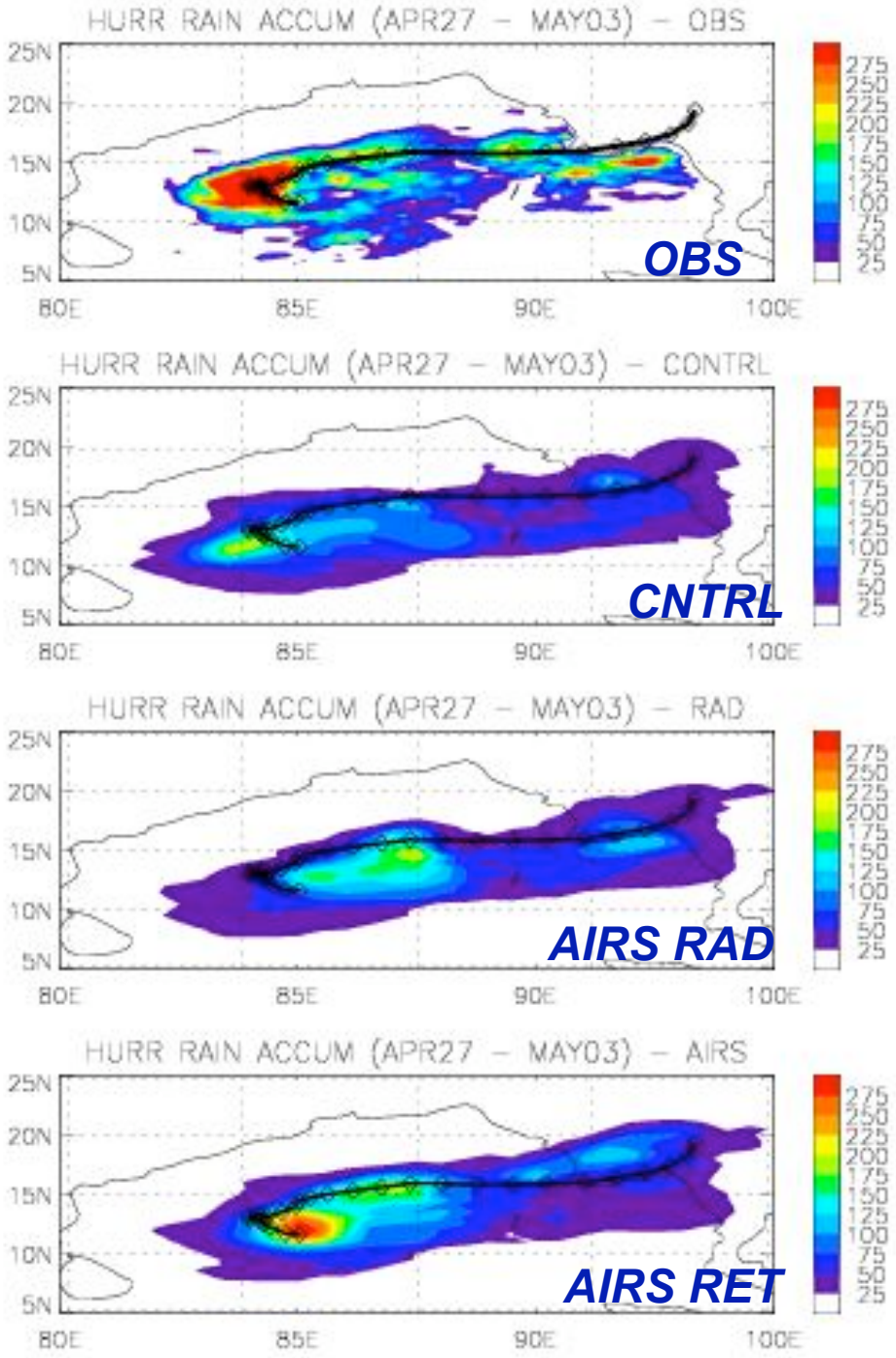






Radiances
Very weak System, ***low Vorticity***

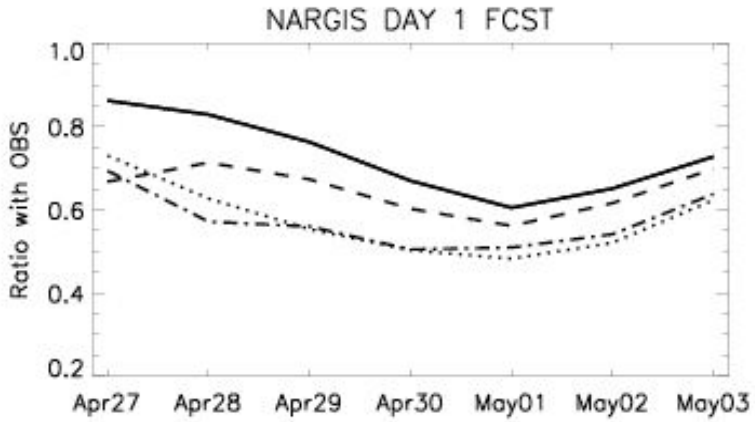
Retrievals
Much ***higher (100%) Vorticity***

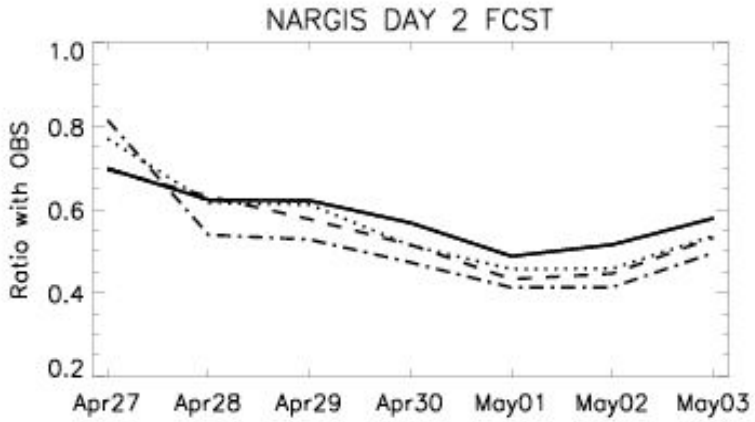


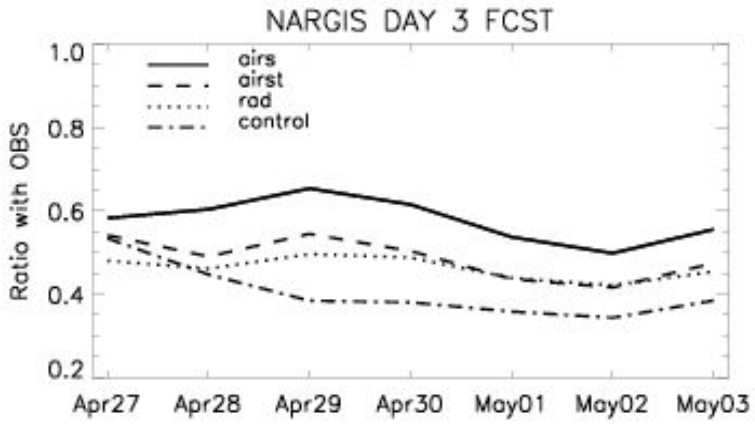
Precipitation``Analysis'' for Nargis

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

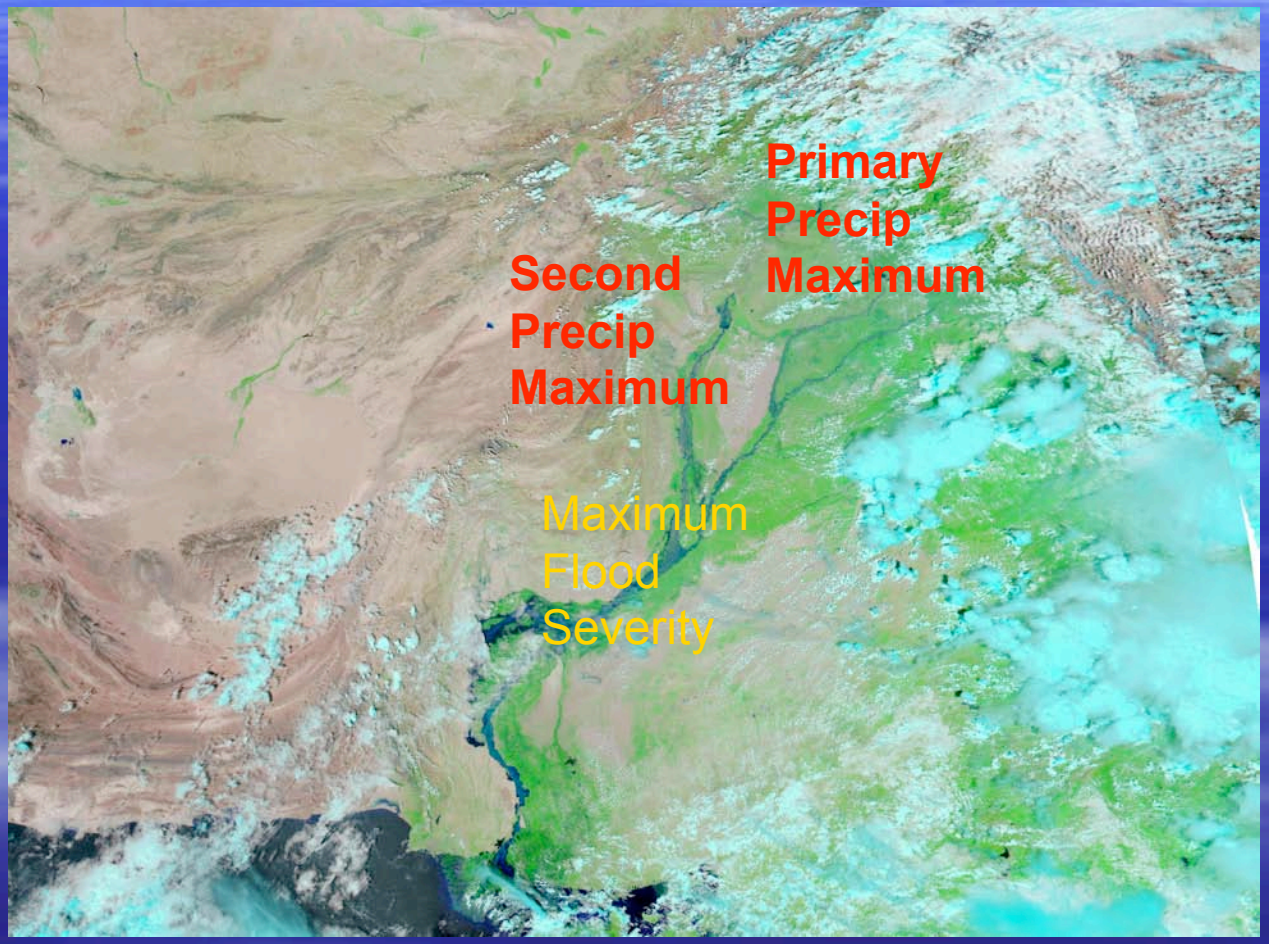
Zhou et al., (2010)

also show consistent AIRS impact on Wilma (2005), Helene (2006)

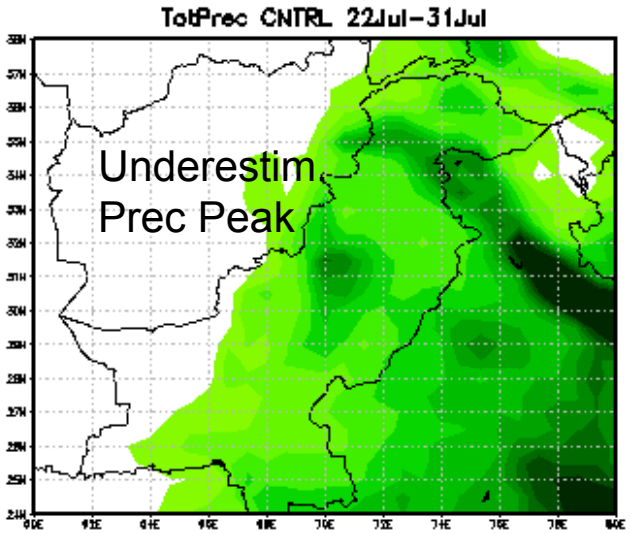
Indus River Floods (Pakistan, 2010)

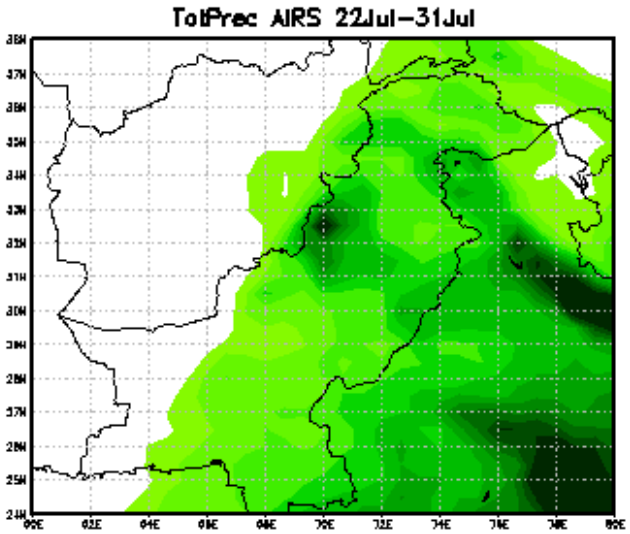
- From 200 to 400mm fell between 27 July and 31 July 2010 over several locations where the seasonal mean is on the same magnitude or less
- Floods arise out of a combination of precipitation on a certain spatial domain within a precise time scale proper of each basin (small basins respond to high rain rates over short times, large basins respond more to spatial extent of moderate rain rates)
- Global operational weather forecasts produced generally from 20% to 50% of the total measured precipitation
- Of the two relevant peaks of precipitation occurred, particularly critical is a maximum on the mountains southwest of Peshawar, on the Afghan border, being missed in most forecasts.
- That peak contributes to the flooding of the central part of the Indus, which is the most severe

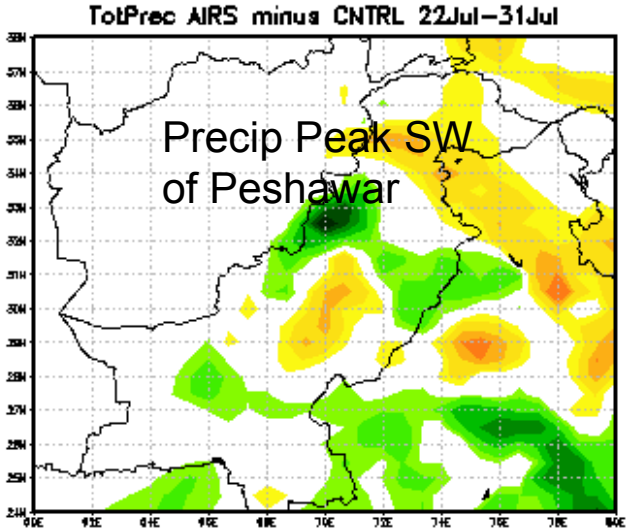
The Indus waterhsed and observed precip maxima

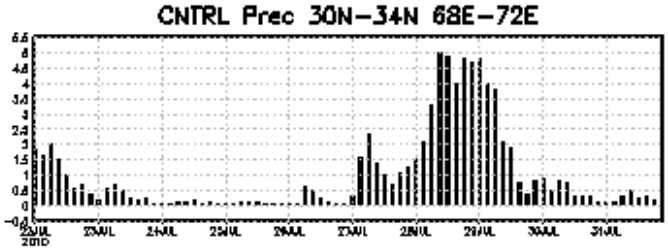


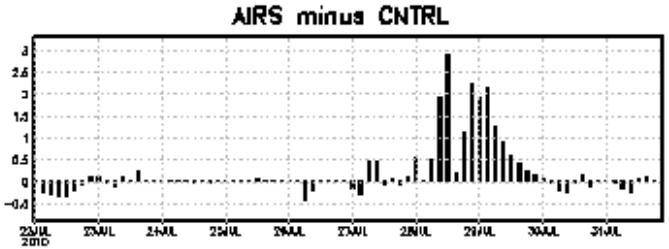
AIRS impact on the Precip Analsysis











AREA AVERAGED 3-hourly PRECIP

The precip SW of Peshawar Improves of 60% As a consequence Of AIRS retrievals ingestion

Preliminary results on the experiments on the Indus-river floods (2010)

- Preliminary assessment of the moisture sources shows a transport of moisture during the week preceding the event from the Indian ocean
- Information provided from AIRS cloudy retrievals allow an improved representation of the low- and mid-level moist atmospheric flow
- Control GEOS-5 Analysis produce 2 peaks of precip of about 120 mm in agreement with obs, but the southern maximum is strongly underestimated and misplaced (as in most of operational forecasts)
- Assimilation of Quality Controlled AIRS cloudy retrievals improve the analysis of the southern precipitation maximum to 200mm and improves its location
- The analysis improvement indicates good potential for improved forecasts of precipitation and thus hydrological forecasts

Conclusions and Future Work

- Sets of data assimilation experiments without AIRS, with AIRS cloudy retrievals (at two different quality controls) 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 all sets of analyses, for a total of about 600 forecasts
- The overall skill of forecasts initialized from analyses in which retrievals are assimilated is higher in every season
- Consistent improvements in the analysis of Tropical Cyclones are noted as a consequence of AIRS retrievals ingestion
- **The improvements affect FORECAST TRACK and TC PRECIPITATION FORECASTS**
- **Preliminary results from the Pakistan floods show substantial improvements in the Precip Analysis.**
- **Forecasts are being completed at this time**
- **The importance of not rejecting AIRS-derived information from cloudy areas becomes even more evident**

Acknowledgments

- **Dr. Ramesh Kakar** *for support to proposal ``Relationships among precipitation characteristics, atmospheric water cycle, climate variability and change''* (PI: **Dr. W. K. Lau**)
- **Dr. Tsengdar Lee** for generous allocations of NASA High End Computer resources
- **AIRS team** at JPL and the **Sounder Research Team** at NASA GSFC

National Aeronautics and Space Administration