

# Impact of AIRS and AMSU/A data assimilation on tropical cyclones and extreme precipitation events

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# Outline

## Past work: *'Those were the days'*

### Impact of assimilated **version 5** retrievals 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) and 2010 season
- Precipitation Analysis for the 2010 **floods** along the **Indus river** (Pakistan)

## Current work: *'The day after'*

### Impact of assimilated **version 6** retrievals

- New GEOS-5 experiments with **AIRS v6** on TC genesis, structure, intensity
- Focus on 2010 season.
- Results and implications
- Acknowledgements

# AIRS experiments settings

- **GEOS-5 DAS**: versions **2.1.4** (old, close to **MERRA**) and **5.7p4** (current)
- Periods chosen: **Jan 2003** (active boreal winter); **2006 Season**, (NAMMA), **2005 Season** (Hyper-active TC Atlantic season), **Spring 2008** (TC Nargis), **Summer 2010** (Pakistan floods and TC season), **Oct 2012** (Sandy)
- **CNTRL**: assimilating all conventional and satellite obs, but no AIRS-derived information (only AMSU)
- **AIRS RAD**: As CNTRL but adding AIRS **clear-sky radiances**
- **AIRS RET**: All control assimilated in CNTRL, but AIRS retrievals added as rawinsonde temperature profiles
- **AMSU AIRS** experiments **RET** or **RAD** to which AMSU/A data are either added or subtracted
- **Forecasts** at 0.25 (after 2012) or 0.5 (before 2012) degrees



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.

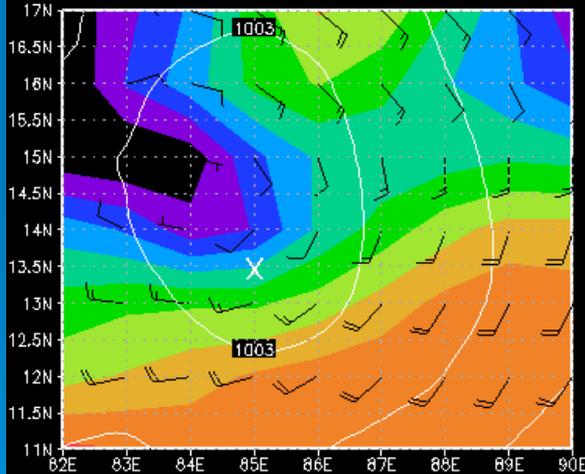
- Work published in 2009 shows improvements in the GEOS-5 DAS and forecasting model consequent to assimilation of AIRS-derived information in **CLOUDY** areas. Case chosen: **catastrophic cyclone Nargis which hit Burma causing devastating loss of life**
- Tropical Cyclones in the Northern Indian Oceans 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*

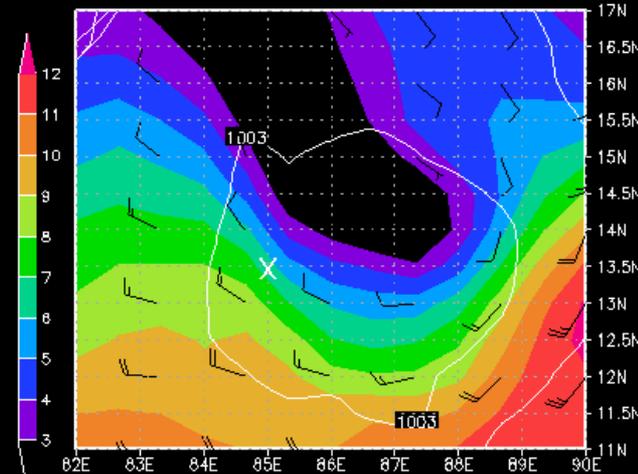
Complete miss of TC Nargis (2008) in both operational NCEP and MERRA analyses at a time when the storm had hurricane-level winds (JTPC and IMC statements)

COMPLETELY FLAT PRESSURE FIELD

NCEP 06z 28Apr 2008



MERRA 06z 28Apr 2008



WINDS DO NOT REACH 12m/s

WINDS DO NOT FORM A CLOSED CIRCULATION

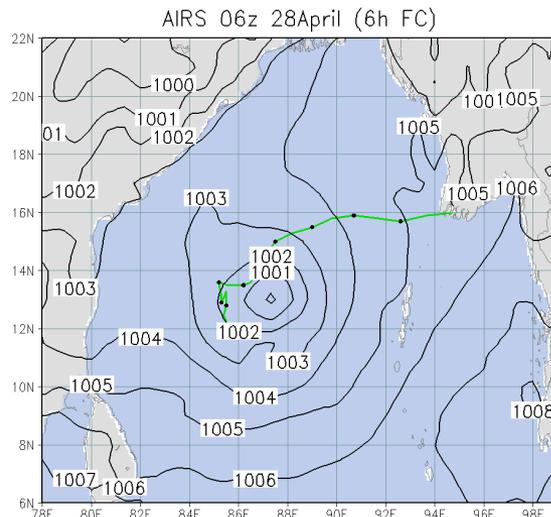
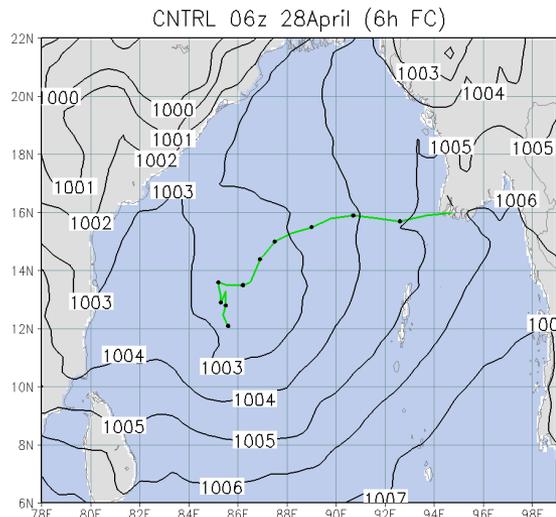
800x600km  
Contours  
every 1hPa

WINDS DO  
NOT FORM  
A CLOSED  
CIRCULATION

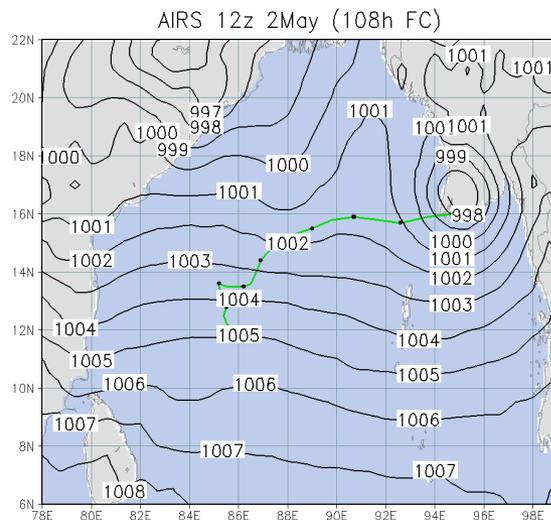
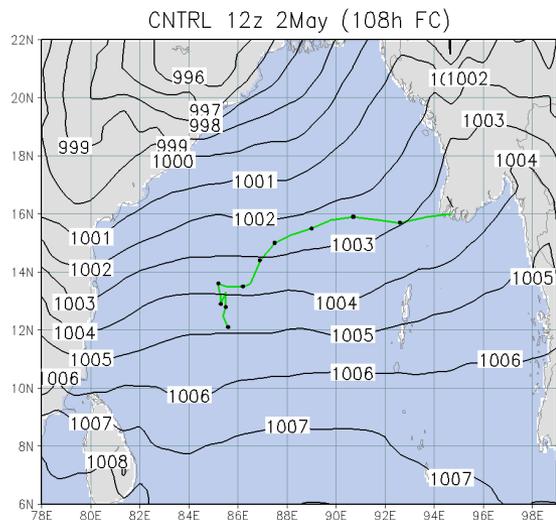
800x600km  
Contours  
every 1hPa

X observed  
cyclone's  
center

# AIRS v5 retrievals impact on TC Nargis analysis



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

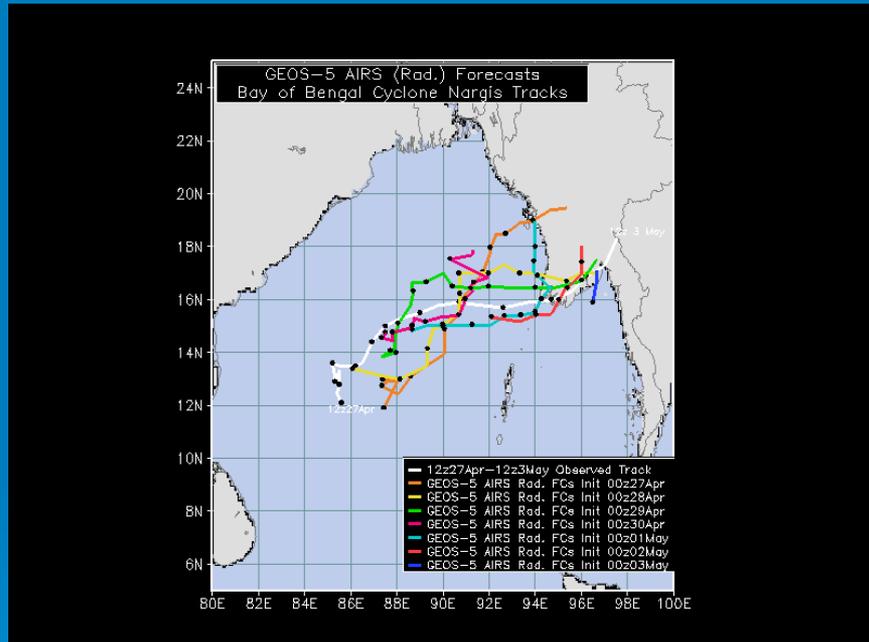


AIRS 108-  
hour  
Forecast (slp)  
Green:  
Observed  
Track

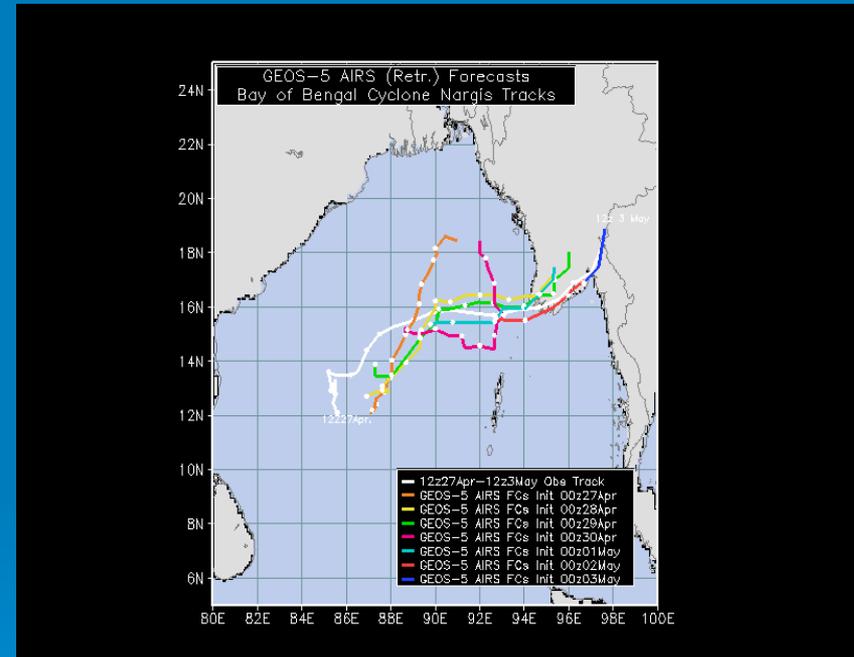
CNTRL Analysis (above)  
And forecast (below): **No Cyclone**

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

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



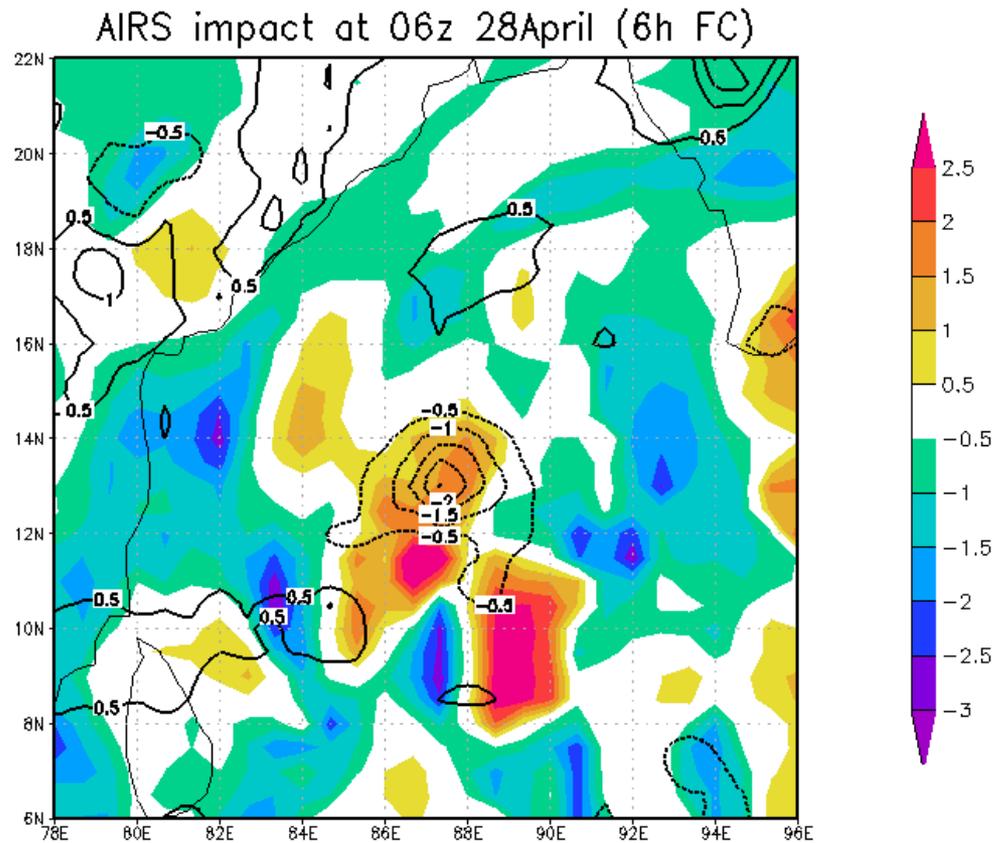
AIRS clear-sky **radiances**



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.*)

# Mechanism: AIRS retrievals improve the structure 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

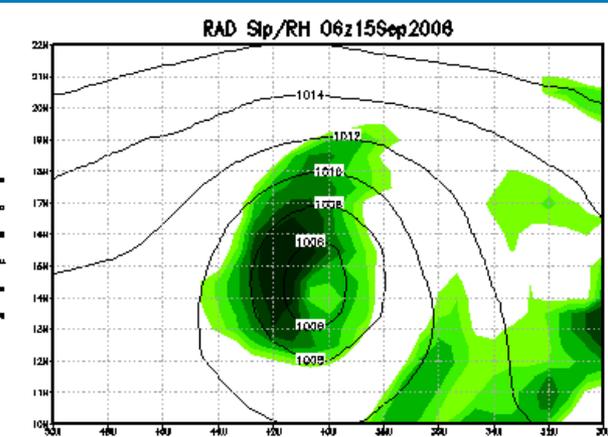
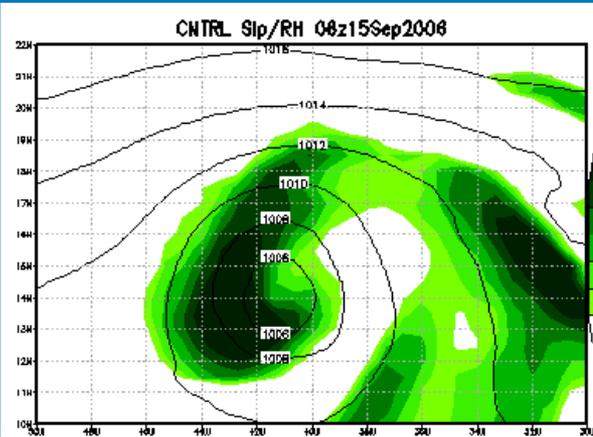
Shaded: 200 hPa AIRS minus CNTRL temp anomaly  
Contour: AIRS minus CNTRL slp anomaly (Reale et al., 2009)

Other past work showed improvement in TC **cloud/moisture distribution** caused by **AIRS v5 retrievals**

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

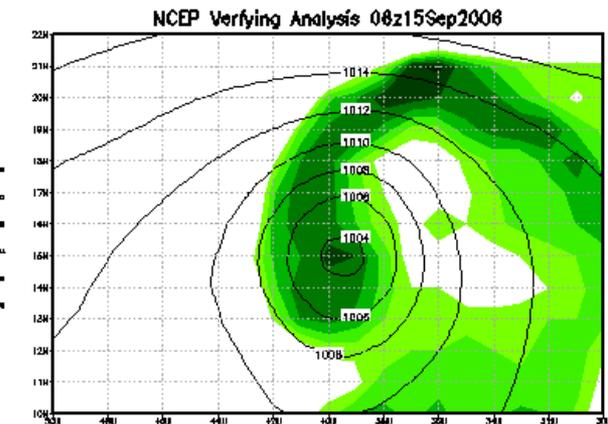
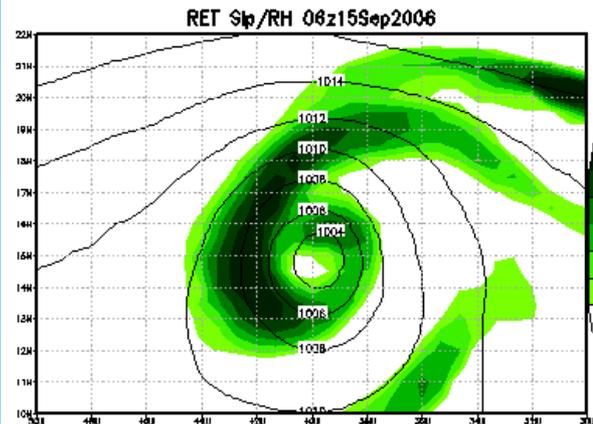
*800 hpa relative humidity, sea level pressure (hPa)*

CNTRL



RADIANCES  
*Do NOT produce an Eye-like feature*

RETRIEVALS  
**Produce an Eye-like feature**



NCEP  
Operational  
Analyses,  
Very poor

Past published AIRS impact study on **precipitation** associated with **tropical cyclones** compares performance of AIRS clear-sky radiances against v5 retrievals.

- Assimilation of **AIRV v5 retrievals** produced **better precipitation forecast** than the assimilation of **clear-sky radiances**, contrary to expectation
- **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

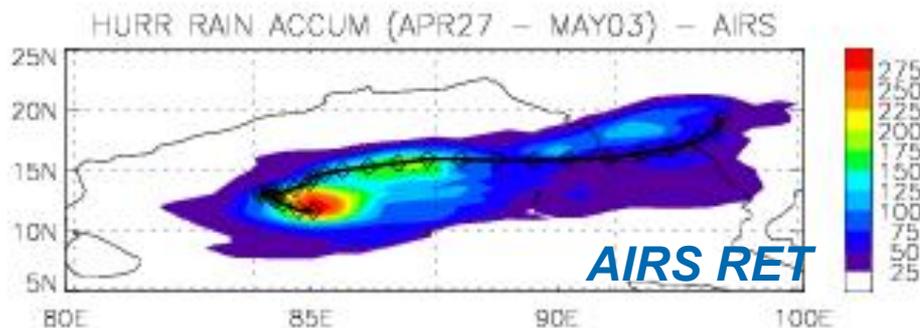
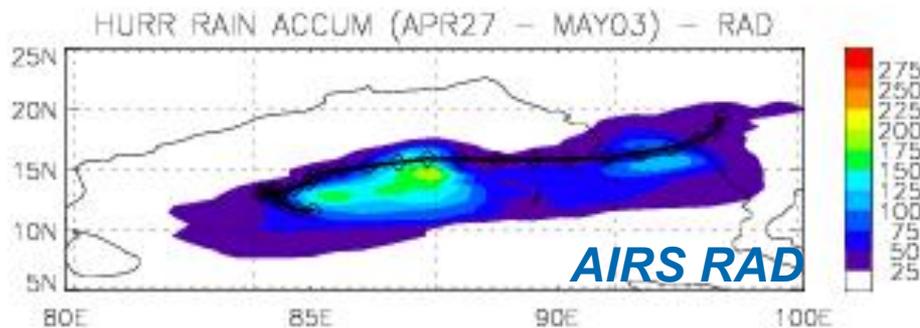
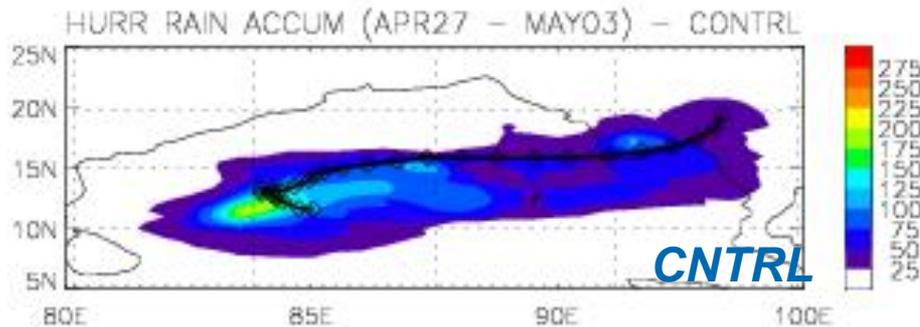
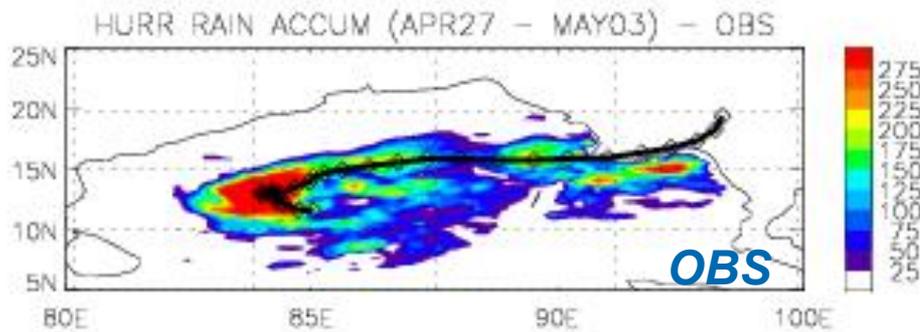
## for Nargis

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

The assimilation containing AIRS v5 retrievals –which improves Nargis structure- also produces **the best precipitation 'analysis' and forecast.**

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

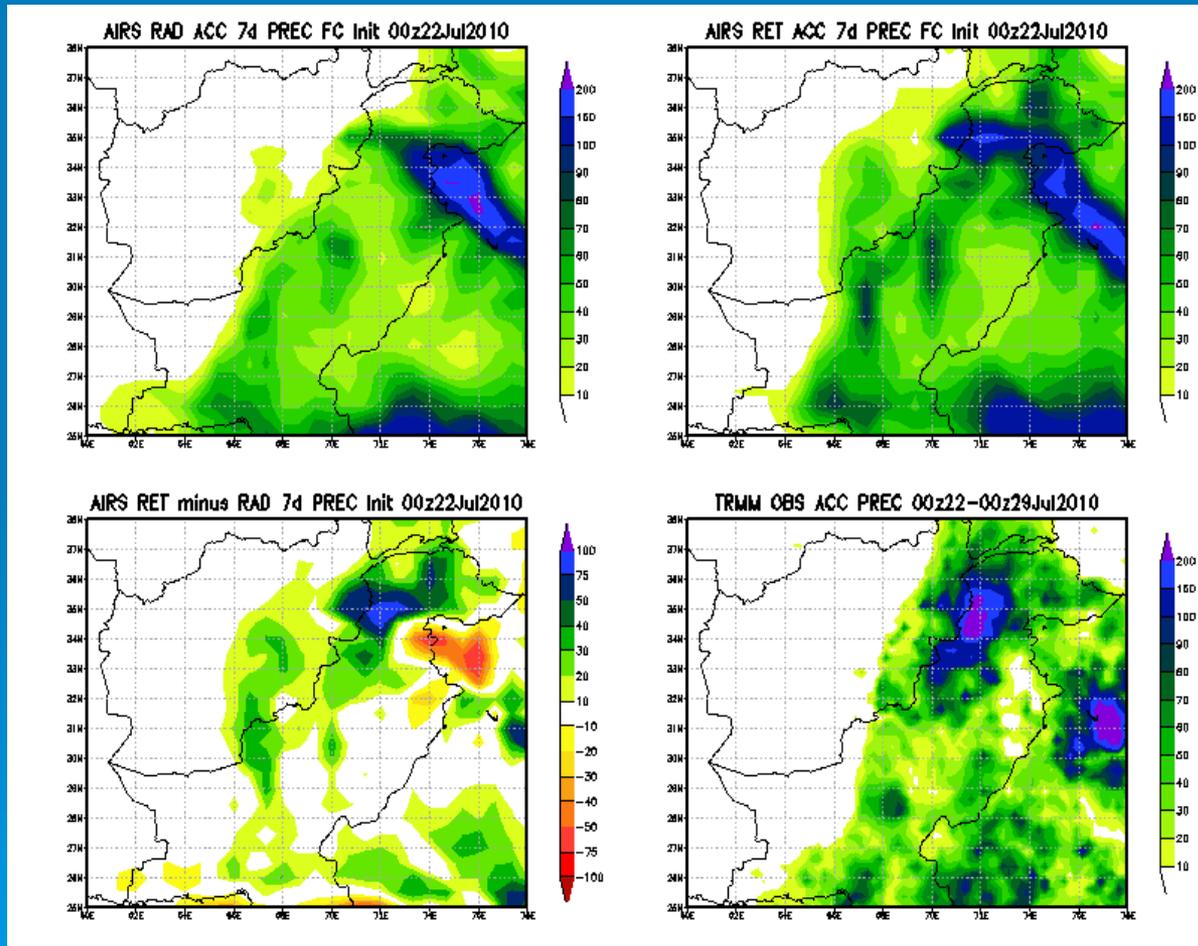
Zhou, Y., W. K. Lau, O. Reale, R. Rosenberg, 2010: AIRS Impact on precipitation analysis and forecast of tropical cyclone in a global data assimilation and forecasting system. *Geophys. Res. Lett.*, 37, L02806, doi.1029/2009GL041494



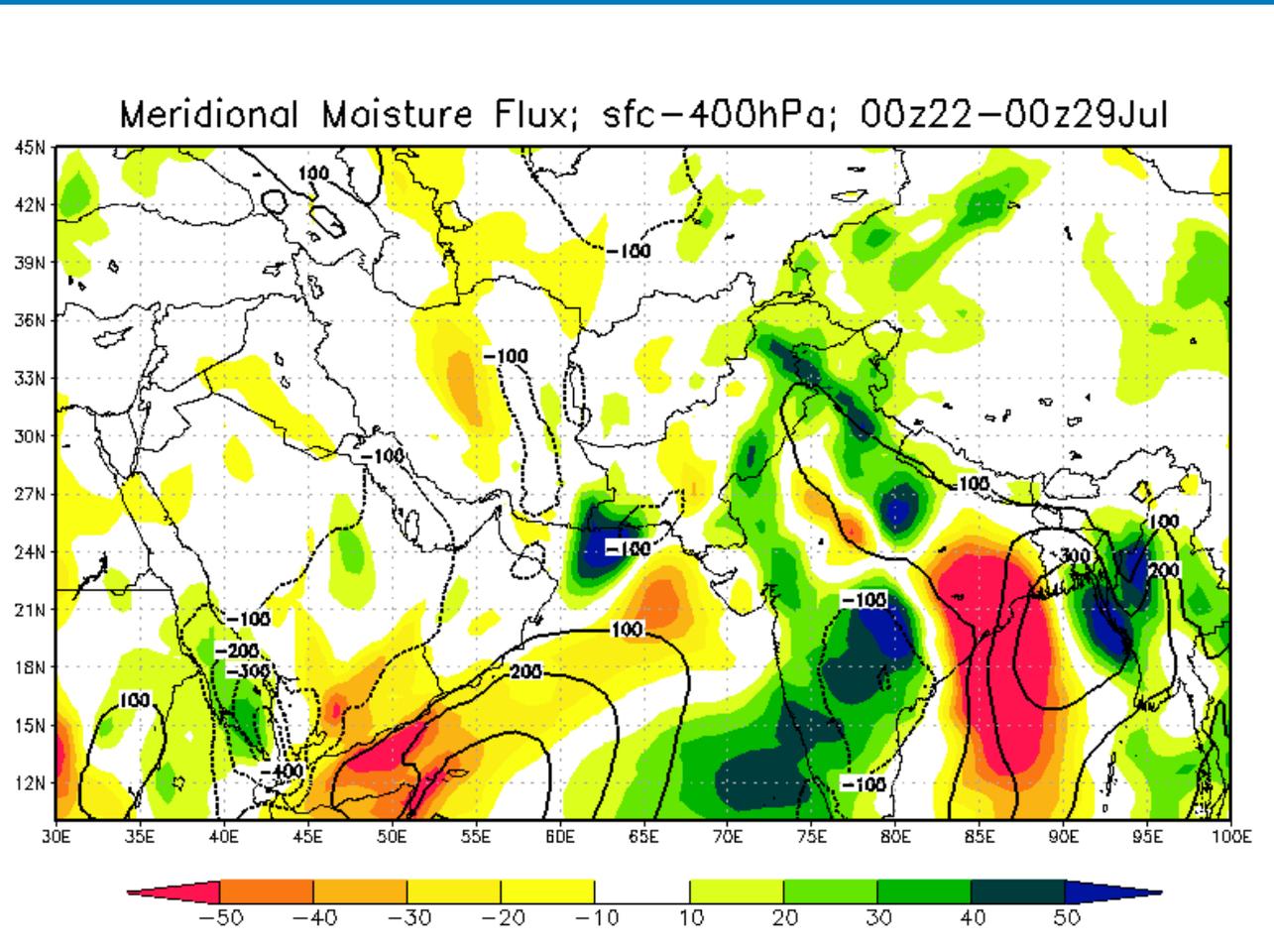
Reale, O., K. M. Lau, J. Susskind, and R. Rosenberg (2012), AIRS impact on analysis and forecast of an extreme rainfall event (Indus River Valley, Pakistan, 2010) with a global data assimilation and forecast system, J. Geophys. Res., 117, D08103, doi:10.1029/2011JD017093.

- Another of the few studies studying the impact of AIRS on PRECIPITATION
- Focus on a set of catastrophic floods that affected the Indus River Valley (Pakistan) in 2010
- The importance of data obtained in partly cloudy areas became more evident.

# AIRS v5 retrievals improve the 7-day accumulated precipitation forecast with respect to AIRS radiances at the peak of the event



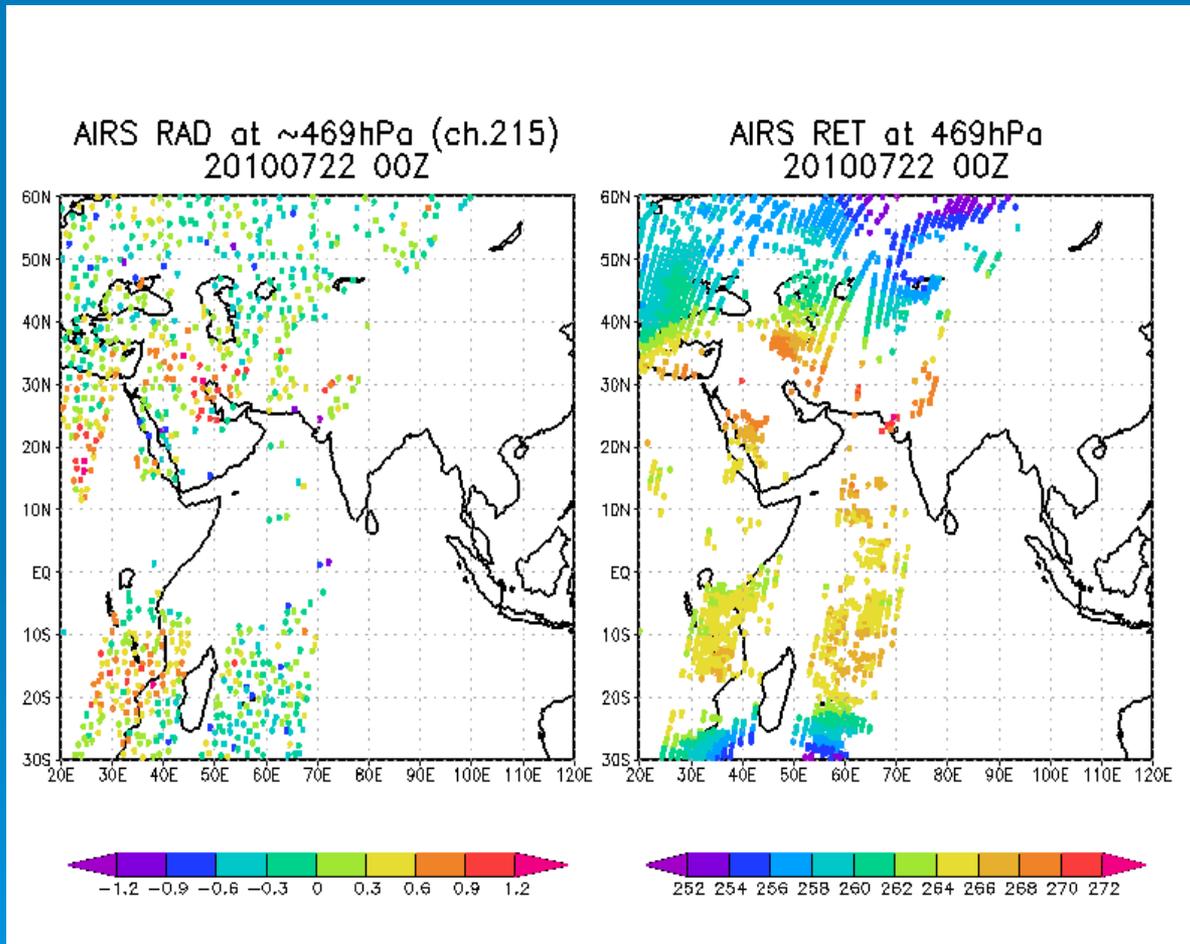
# Mechanism: AIRS retrievals increases the 7-day average moisture transport with respect to AIRS radiances



Solid: 7-day avgd vertically integrated meridional moisture transport (RAD)

Shaded: RET minus RAD departure

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



## Current work: Impact of assimilation of AIRS v6 against v5 and clear-sky radiances in a higher resolution DAS

### Two separate problems:

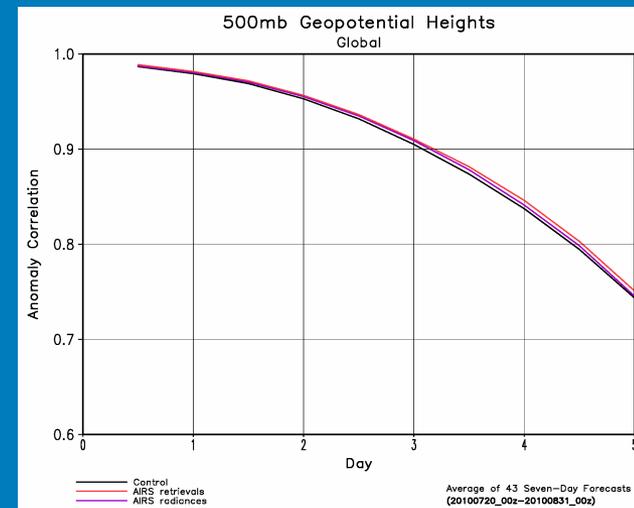
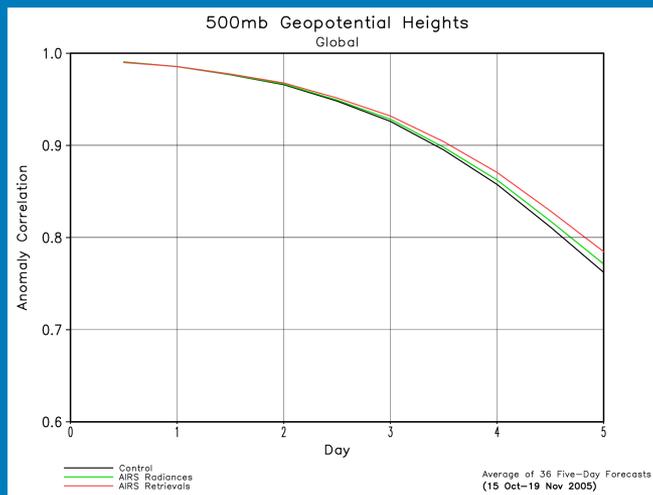
- The **impact on global skill of an individual data set**, when assessed through 500 hPa anomaly correlation, **becomes smaller**. This is true for **any** instrument, because of the enormous constraint exerted by all the other observing systems ( $10^7$ ) and by the improvements in the DAS and forecast system (whose skill goes up). However, regional or event-focused impacts can still be very strong.
- AIRS version 6 does not noticeably affect the global skill (minor improvement), but represents a degradation with respect to version 5 from an **event-specific** (i.e., **TCs**) perspective

In the past, it was easy to get a clear global impact by assimilating AIRS radiances or retrievals in all seasons and different years (GEOS-5.1.4 at 0.5 degrees) **with retrievals being somewhat superior to radiances.**

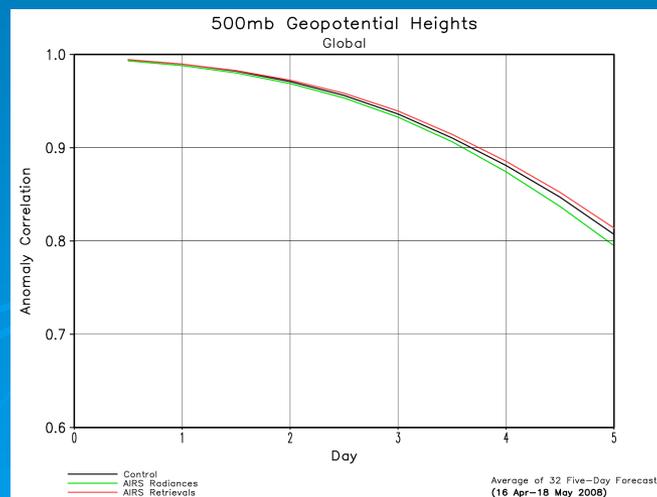
Metric used: 500 hPa anomaly correlation  
computed from 90S to 90 N

FALL 2005

SPRING 2008



SUMMER 2010



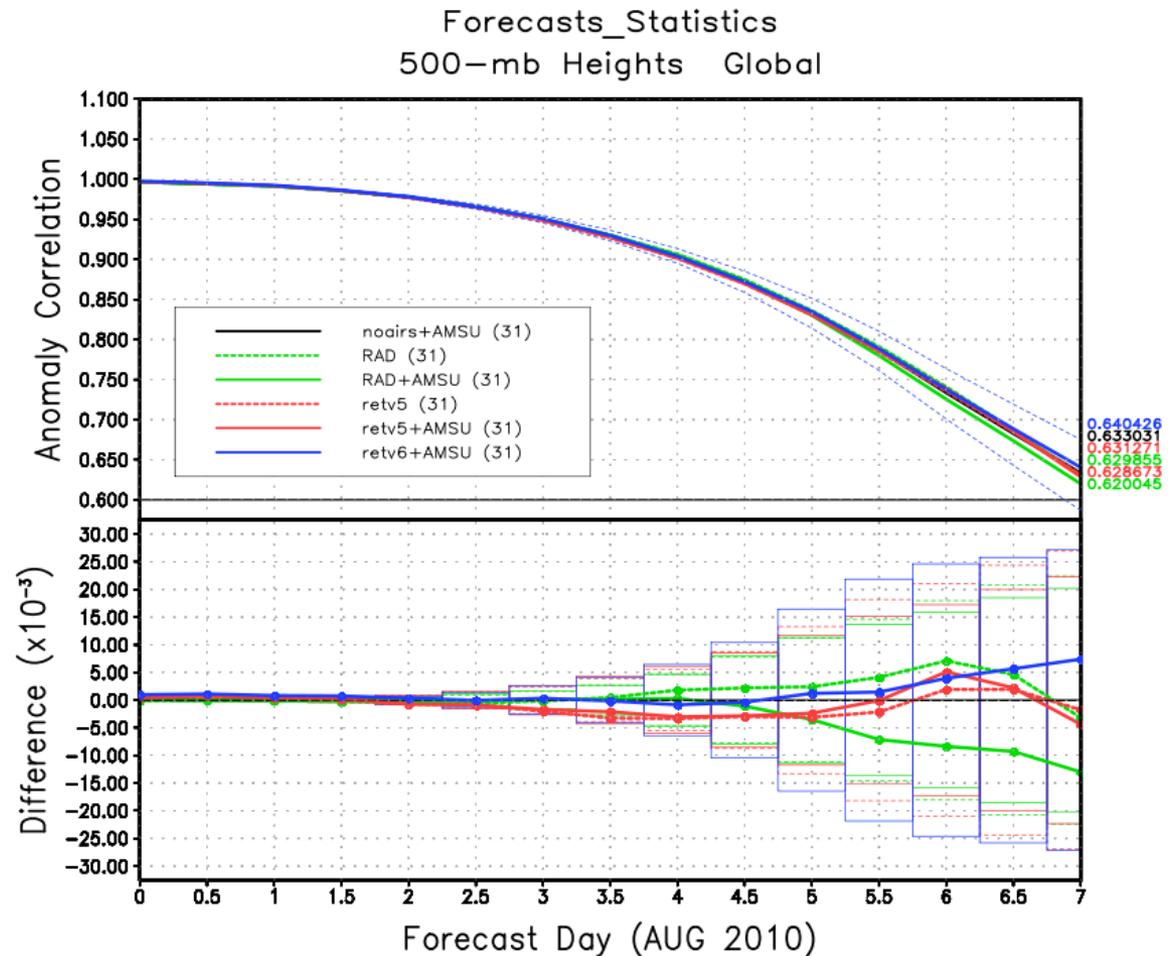
With a more current model, increased data assimilation resolution, and many new instruments, and increased model's skill, the global impact becomes negligible

**when assessed as 500-hPa anomaly correlation**

- Experiments with GEOS-5.7p4, at 0.25 resolution
- AIRS v5 and v6 data (with or without AMSU), competing against many new instruments and  $10^7$  observations, do not impact the global skill
- However, impact can **still be strong on a regional scale or even more, on an event-specific scale (TCs)**

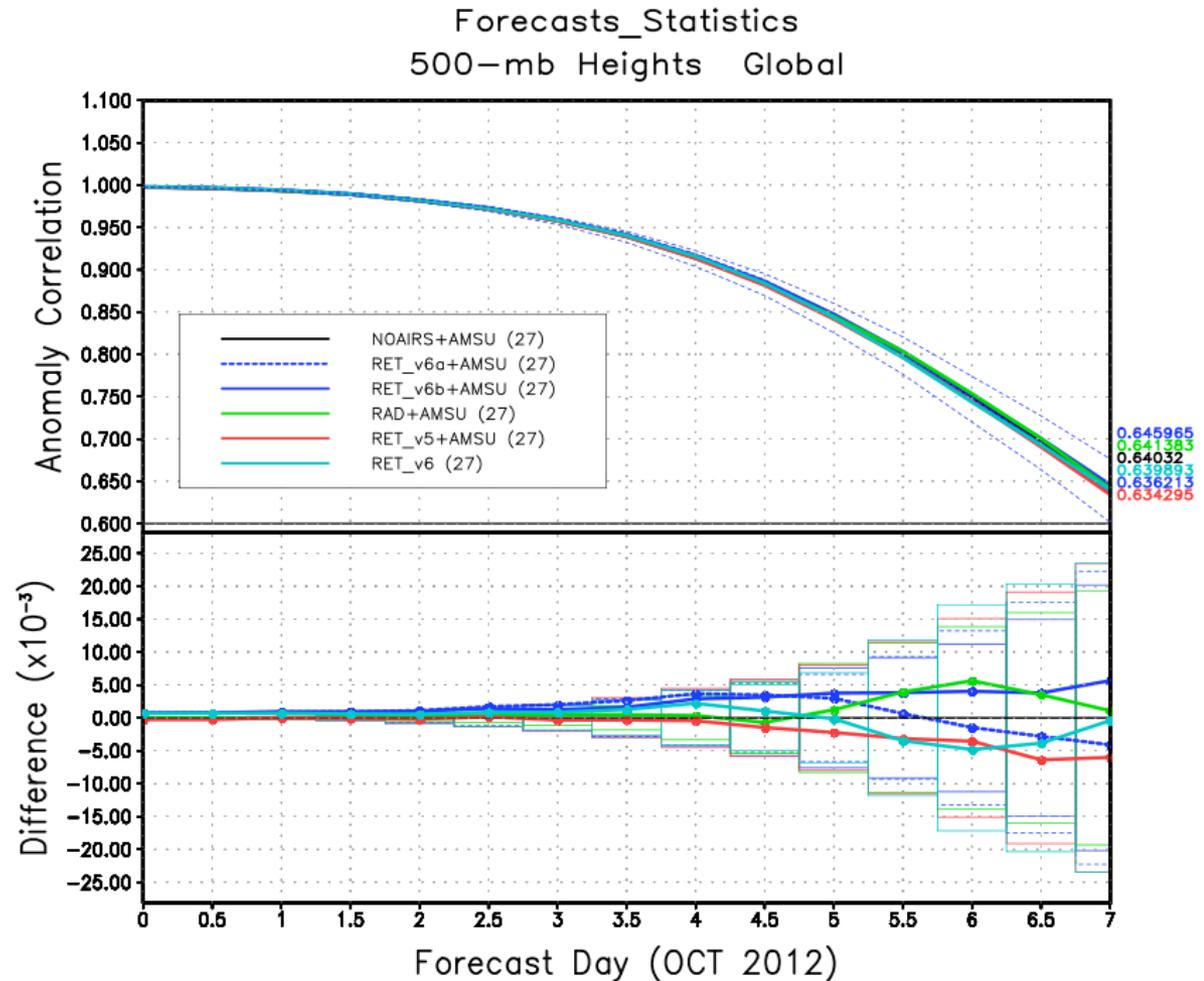
Six experiments, forecast extended to **7 days** (Retv6, Clear-Sky Rad, Retv5 with or without AMSU, AMSU alone).  
**Virtually no difference until day 5, minimal difference after.**

August 2010



# No significant global impact also on a different month/year (Oct 2012)

October 2012

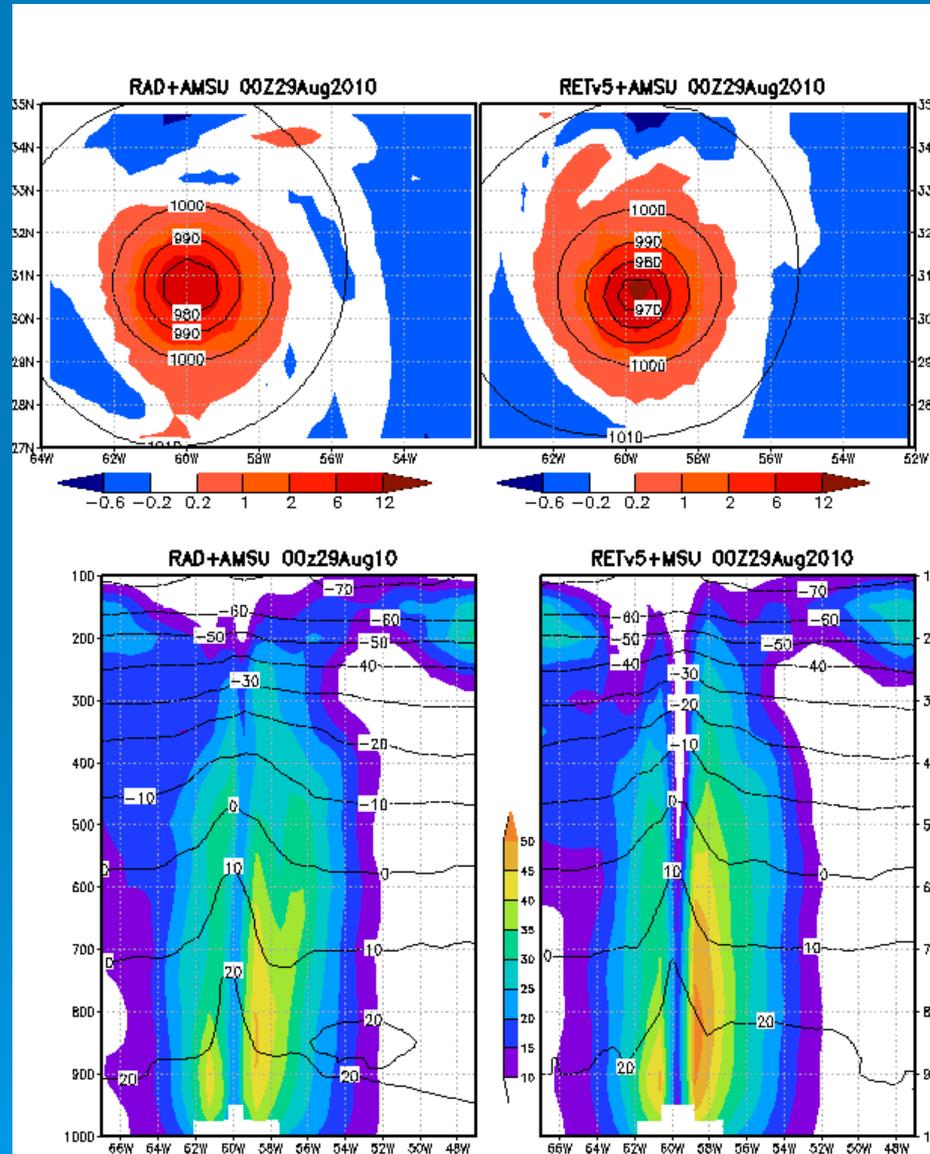


# Focus on TCs

- Particularly on **tropical cyclones**, AIRSv5 retrievals obtained under cloudy conditions produced a spectacular impact even with the most recent versions of the GEOS-5
- Improvements affected track, structure and intensity (center pressure, max wind, vertical structure)
- Impact on other events could be noted as well when using appropriate metrics (and not just 500 hPa anomaly correlations)

AIRS version 5 retrievals had large event-specific impact, and impact on regional scale: enormous improvement on Hurricane Danielle (2010) with respect to radiances.

RADIANCES

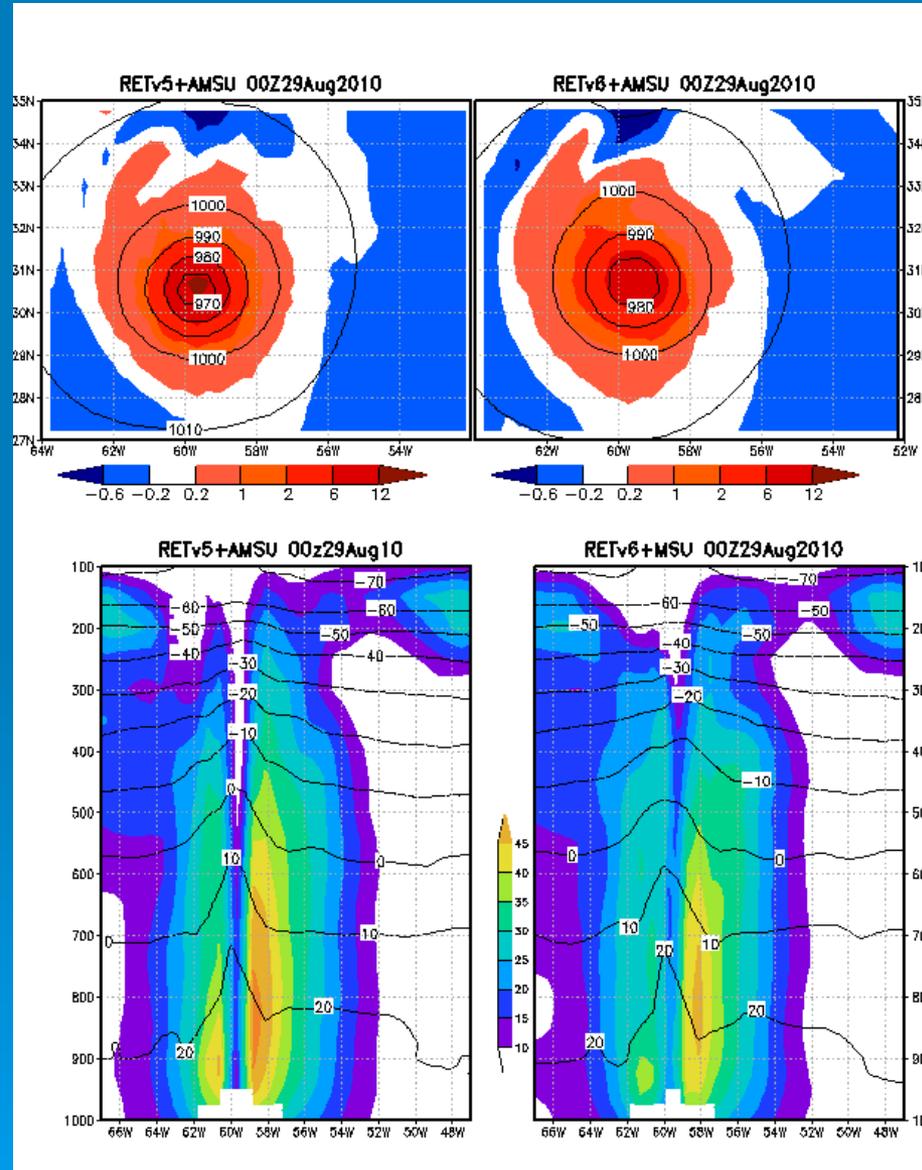


RETRIEVALS v5

00z29Aug2010

With the advent of version 6,  
that ability has been lost

RETRIEVALS v5



RETRIEVALS v6

# Version 5 retrievals used to deepen hurricanes at every step in the analyses, when compared to radiances

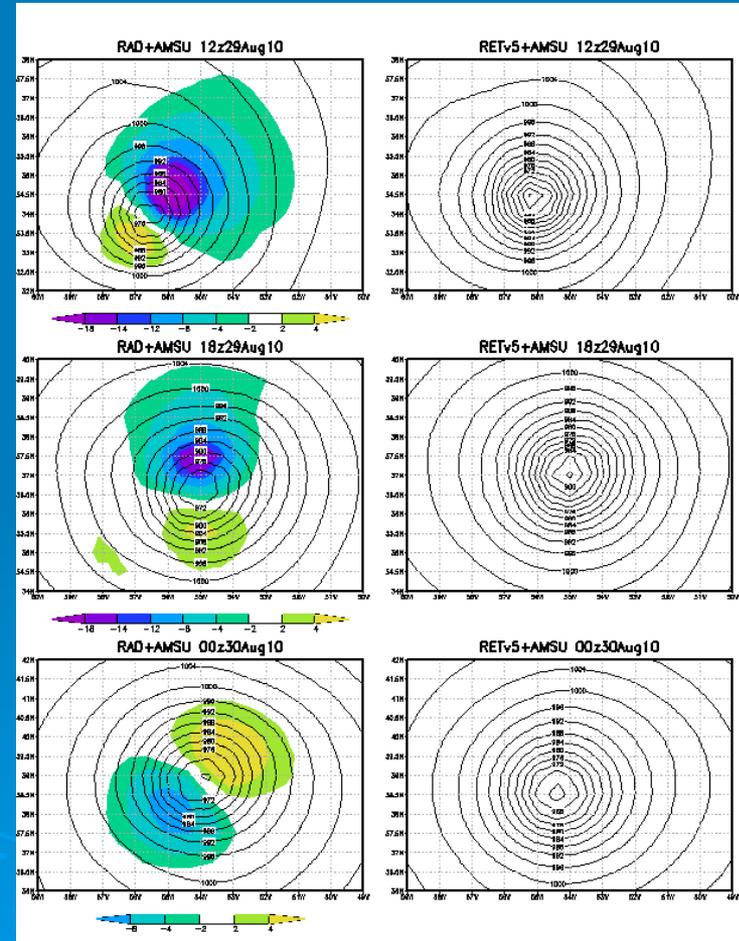
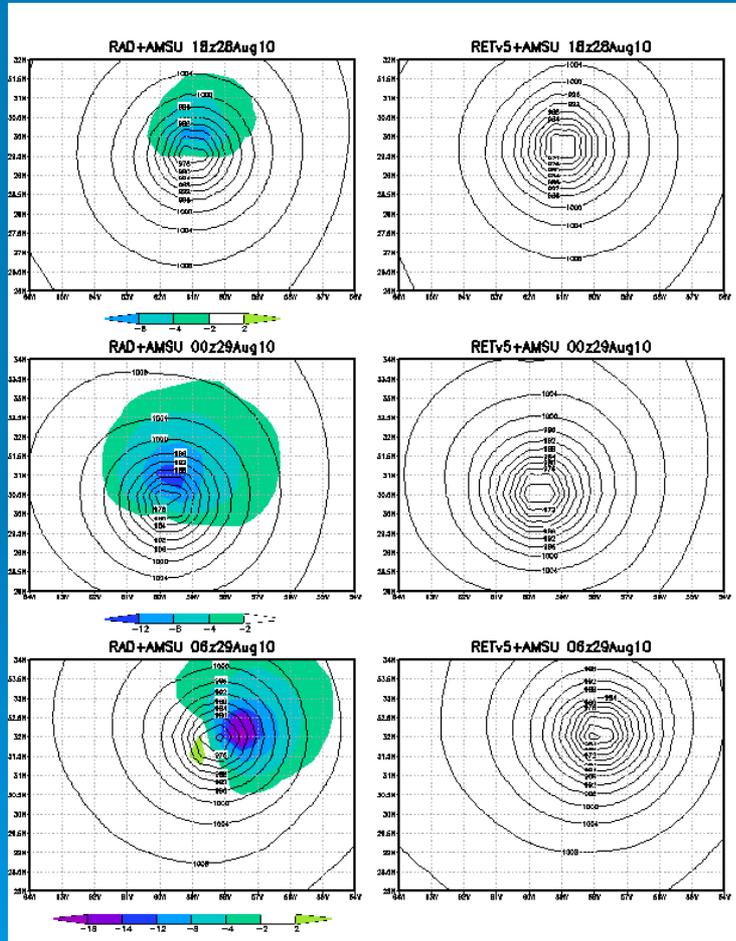
Shaded: **Impact RETv5 minus RAD slp (hpA)**

RAD

RET v5

RAD

RET v5



# However, version 6 retrievals act as a 'hurricane suppressant' against version 5

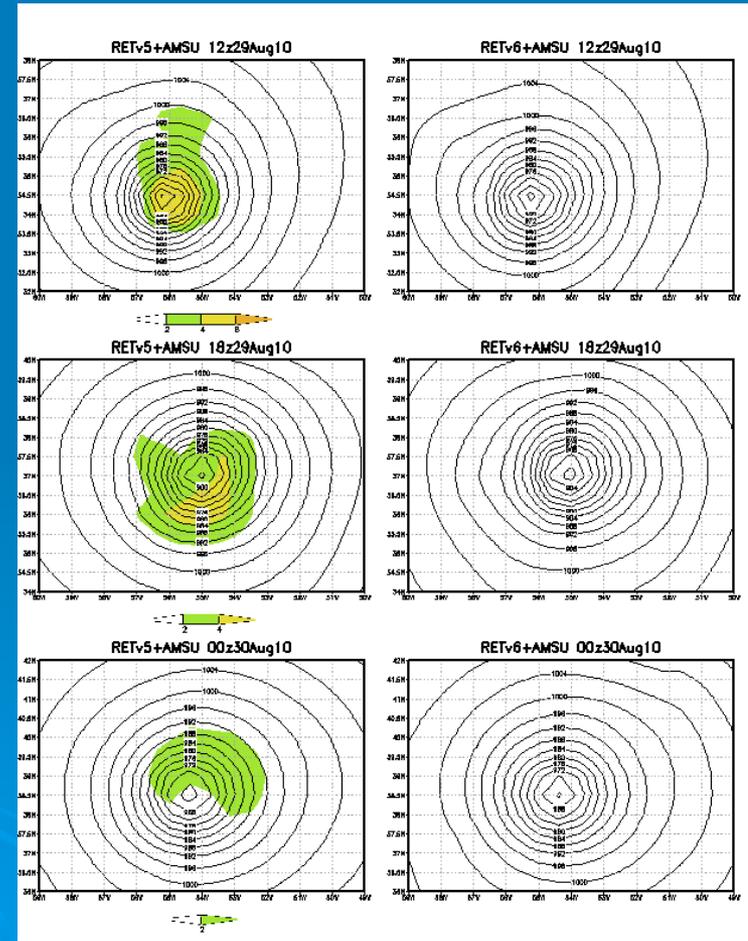
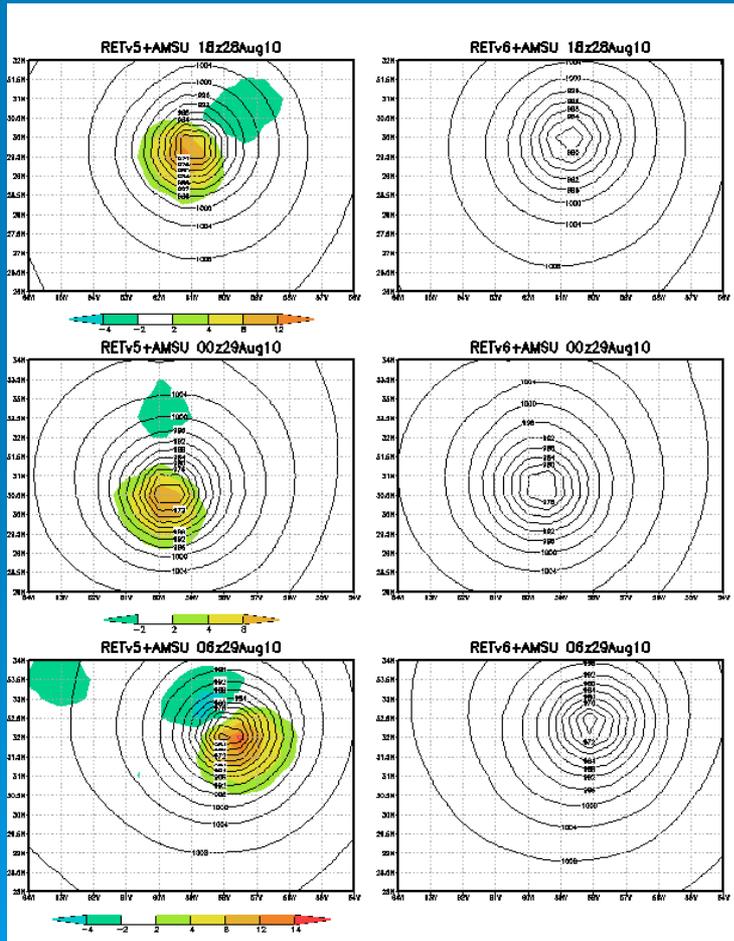
Shading: Impact RETv6 minus Retv5 slp (hpA)

RET v5

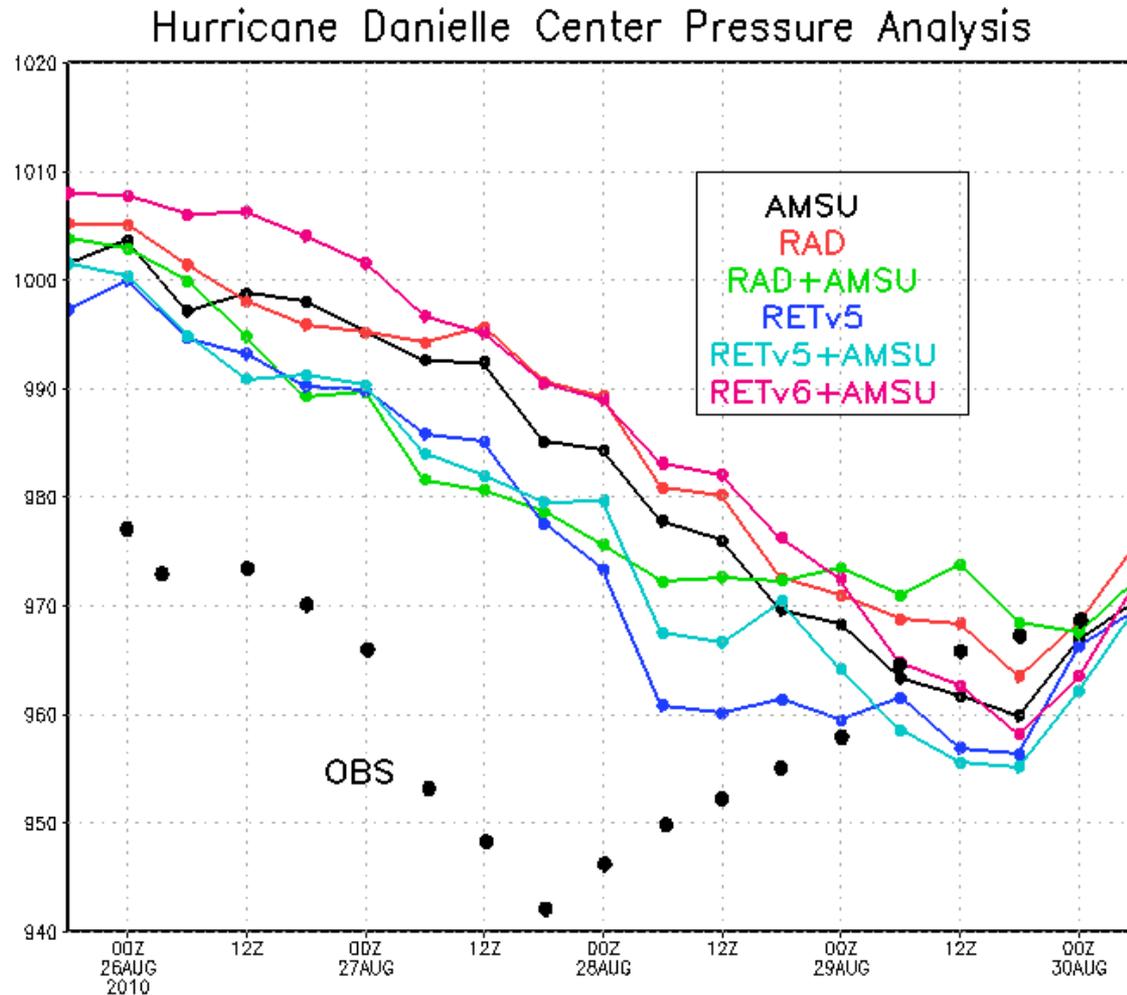
RET v6

RET v5

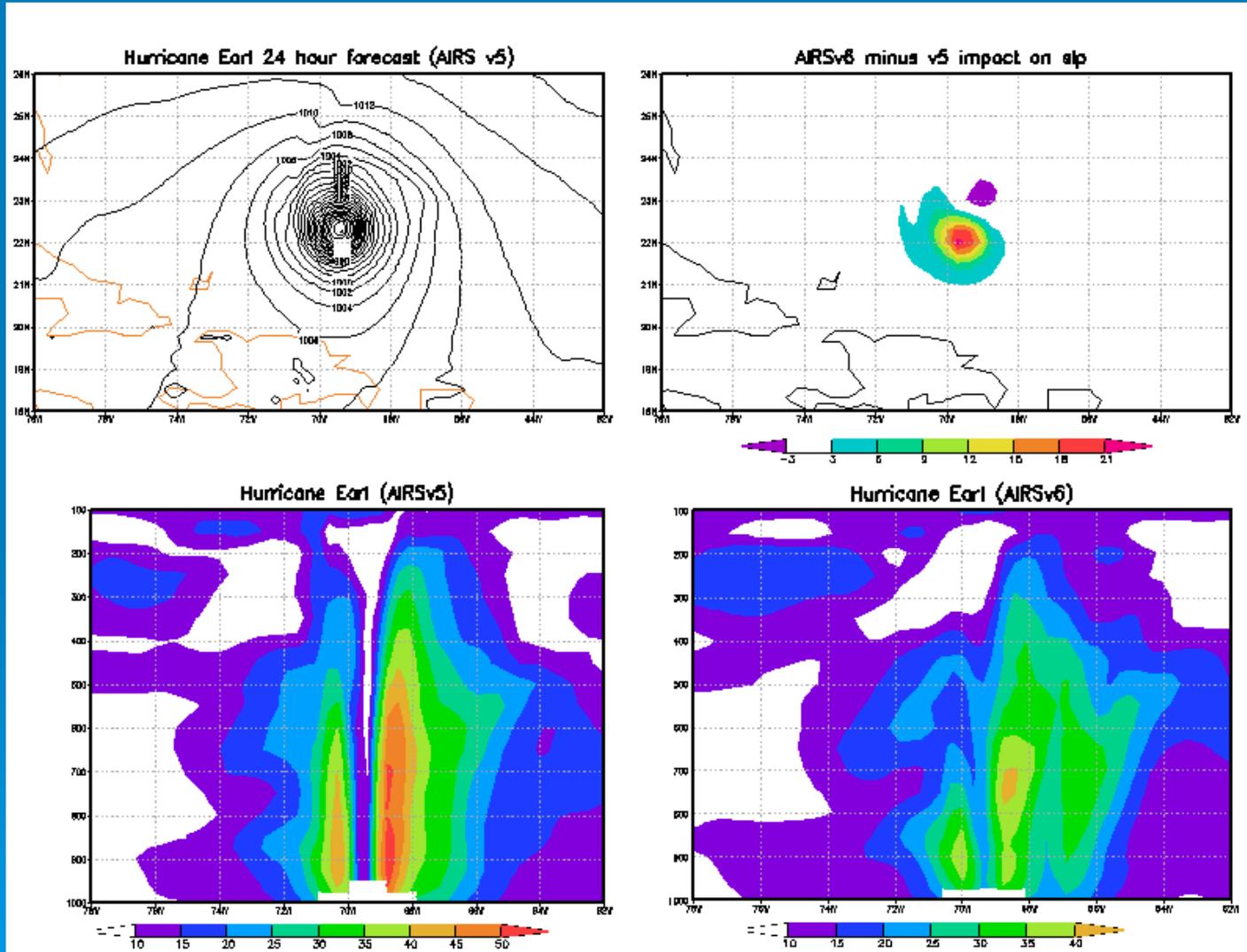
RET v6



Deepening rate for Danielle (2010):  
Analysis of center pressure, obtained from assimilation of **version 5**  
retrievals, **version 6 retrievals**, radiances  
(with or without AMSU)



# Comparison of a 24-h forecast for Hurricane Earl (2010) obtained from assimilation of v5 and v6



# Conclusion

- Sets of data assimilation experiments without AIRS, **with AIRS version 5 and version 6 retrievals**, AIRS clear-sky radiances were produced for **boreal winter, spring, four summer-fall** conditions, for a total of **about 1200 analysis-day**; 5- or 7-day forecasts were produced daily from **each set of analyses**
- Surprisingly, the **overall impact** on TC forecasts skill coming from **v5 retrievals** was **higher** than the corresponding impact of **radiances** in **every season, every year** and **every basin**, contrary to the well-established practice of assimilating clear-sky radiances
- **Four published articles** (3 GRL and 1 JGR) showed a larger impact from AIRS v5 retrievals in a variety of situations (**global, regional, event-focused, different years and seasons**), with the global impact improvement gradually decreasing with better versions of the model and more data, but the local impact on TCs always present or getting even better
- **Version 6 retrievals**, while causing a minor improvement in the global skill, **cannot produce a positive impact on TC analysis or forecast**. None of the results produced with version 5 can be replicated by version 6

# Future Work

- Funded research (June 2014-2017): AIRS impact on processes affecting **Tropical Cyclone structure** in global models and extreme precipitation
- Aside from the apparent difficulties with AIRSv6, the lesson learnt from previous research is the importance of assimilating data in cloudy areas, to improve the representation of TCs in the analysis
- A more confined and better placed TC in the analysis leads to better forecast.
- Improve analyses in cloudy regions also improve the moist low-level transport associated with extreme precipitation events.
- Will start working with **cloud-cleared radiances**
- **Starting** experiments soon

# 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 ending proposal *“Using AIRS data to understand processes affecting Tropical Cyclone structure in a Global Data Assimilation and Forecasting Framework (2011-2014)”*
- **Dr. Ramesh Kakar** for support to new proposal *“Using AIRS data to understand processes affecting TC structure and extreme precipitation in a Global Data Assimilation and Forecasting Framework (2014-2017)”* (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
- **Joel Susskind**, **Lena Iredell**, **John Blaisdell**, **Louis Kouvaris**
- **GES DISC** for their outstanding service to the community



# **AIRS-related articles published by this team**

**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. Geophysical Research Letters, 35, L08809, doi: 10.1029/2007GL033002.**

**Reale, O., W. K. Lau, J. Susskind, 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. Geophysical Research Letters, 36, L06812, doi:10.1029/2008GL037122.**

**Reale, O., W. K. Lau, K.-M. Kim, E. Brin, 2009: Atlantic tropical cyclogenetic processes during SOP-3 NAMMA in the GEOS-5 global data assimilation and forecast system. Journal of the Atmospheric Sciences, 66, 3563-3578.**

**Zhou, Y., W. K. Lau, O. Reale, R. Rosenberg, 2010: AIRS Impact on precipitation analysis and forecast of tropical cyclones in a global data assimilation and forecasting system. Geophysical Research Letters, 37, L02806, doi.1029/2009GL041494.**

**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.**