

**AIRS IMPACT on Tropical
Cyclone Analysis and
Forecast**
*over the Atlantic, Pacific and Indian
Oceans*

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J. Susskind,
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National Aeronautics
and Space Administration

Outline

- Short summary of previous work: AIRS impact on a) midlatitude winter dynamics, b) tropical cyclone Nargis; c) tropical cyclones in the Atlantic
- Global AIRS impacts in boreal *winter, spring, summer* and **(NEW)** *fall* conditions in **four** different years
- **NEW:** Focus on the TC analysis. Improvement in tropical cyclone position and **structure**, leading to improved forecast track, **over all basins**
- **NEW:** AIRS impact on TC precipitation analyses and **precipitation forecast**

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
- The improvement comes from the assimilation of **quality-controlled AIRS retrievals obtained under partially cloudy conditions**

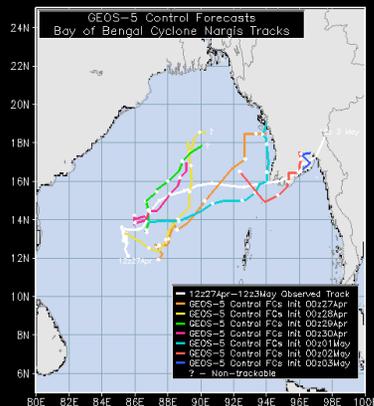
Reale, O., J. Susskind, R. Rosenberg, E. Brin, E. Liu, L.P. Riishojgaard, J. Terry, J.C. Jusem, 2008: Improving forecast skill by assimilation of quality-controlled AIRS temperature retrievals under partially cloudy conditions. Geophys. Res. Lett., 35, L08809, doi: 10.1029/2007GL033002

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

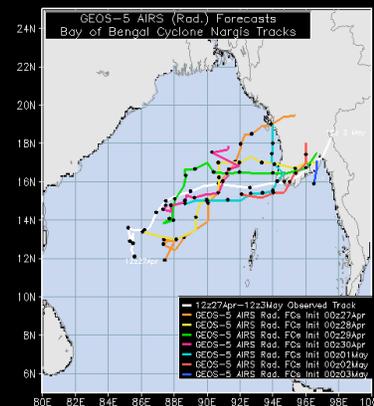
- Work published in **2009** shows enormous improvements in analysis over the *tropics* in the GEOS-5 DAS and forecasting model. Periods chosen: **15Apr-15May 2008** (boreal spring) to overlap with the catastrophic cyclone Nargis which hit Myanmar causing devastating loss of life
- Tropical Cyclones 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

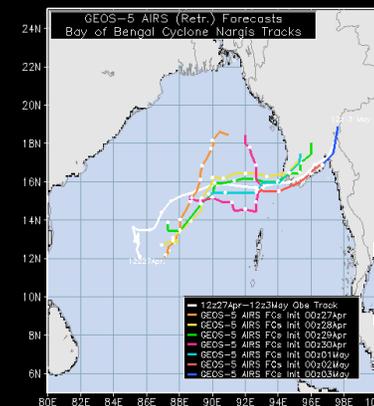
Previous work: track improvement for tropical cyclone Nargis (2008) consequent to AIRS retrieval assimilation



Control



AIRS clear-sky radiances



AIRS cloudy retrievals

5 out of 7 forecasts initialized from the analyses in which AIRS **cloudy retrievals** are ingested produce a displacement error at landfall of **about 50km**. **Clear-sky radiances** have a slight positive impact on the representation of TC Nargis in the GEOS-5, but **substantially inferior** than the retrievals (Reale et al., 2009, *Geophys. Res. Lett.*)

Ongoing work: Global Impact of Clear-sky Radiances versus QC-ed cloudy Retrievals

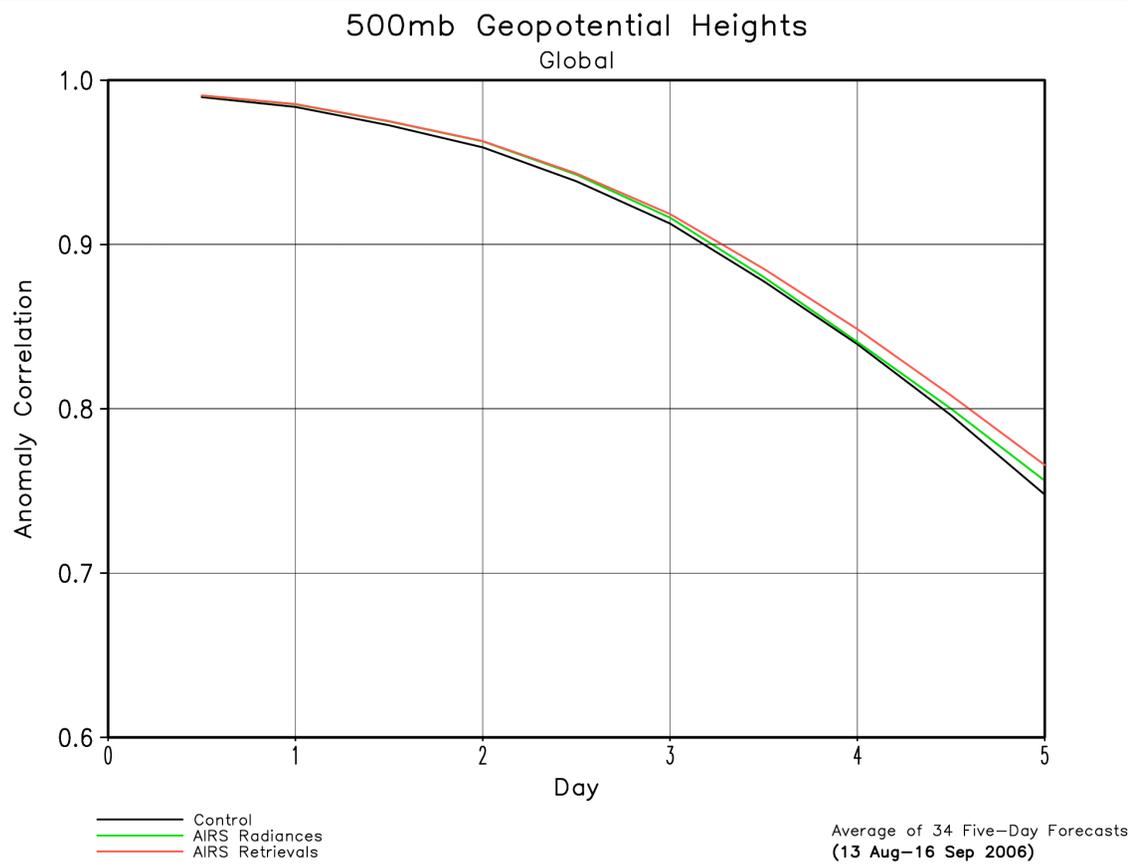
- A small fraction of AIRS data is still retained in operational weather systems, where the only AIRS data assimilated are radiance observations of channels unaffected by clouds. **This imposes a severe limitation on the horizontal distribution of the data.**
- Susskind (2007) strategy, based upon previous 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 **four different seasons, four 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** (Nargis)
- **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 0.5 degrees (and 0.25 for NAMMA)



GEOS-5 2.0.2 **Boreal Summer** Conditions: *global impact* of cloudy retrievals (tight QC) vs. clear-sky radiances



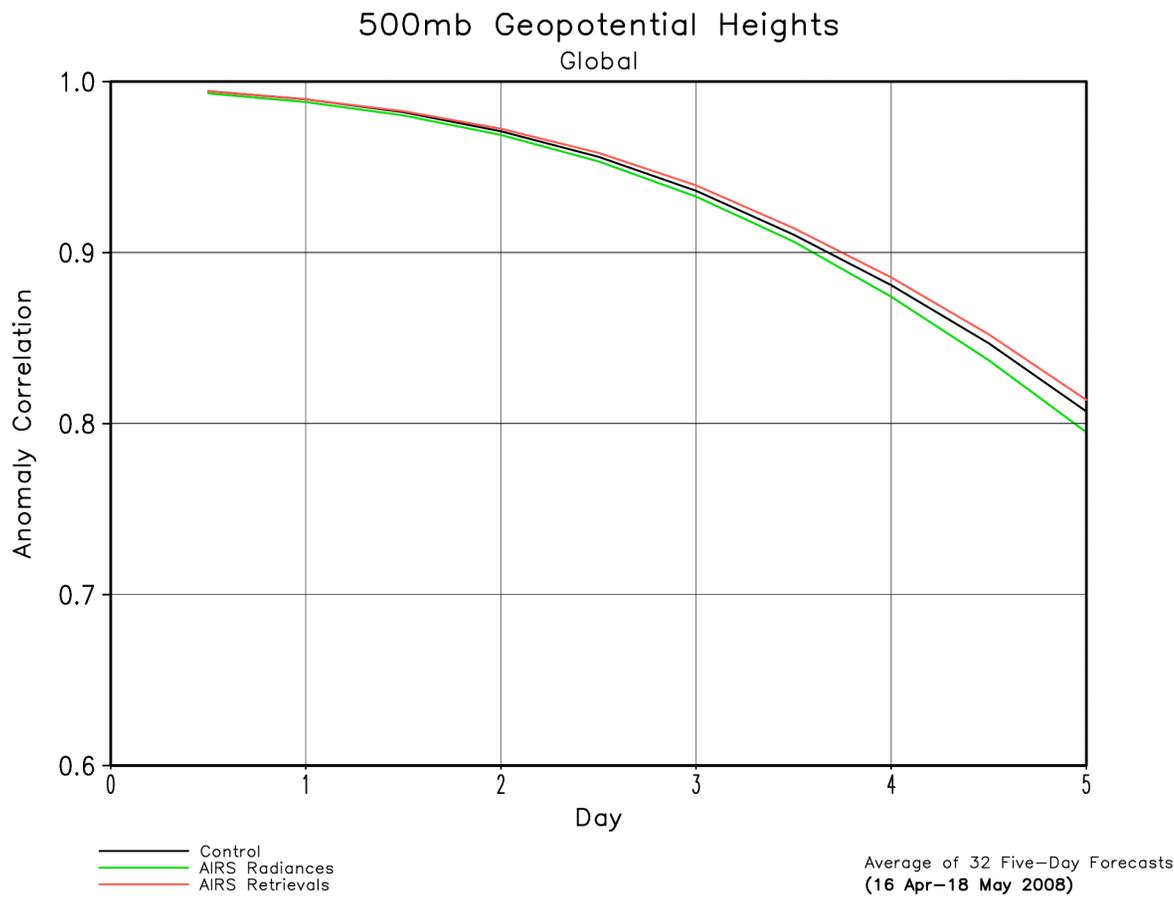
Strong **global** impact of AIRS retrievals (red).

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

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

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

GEOS-5 2.0.2 Boreal Spring Conditions: *global impact* of cloudy retrievals (tight QC) vs. clear-sky radiances



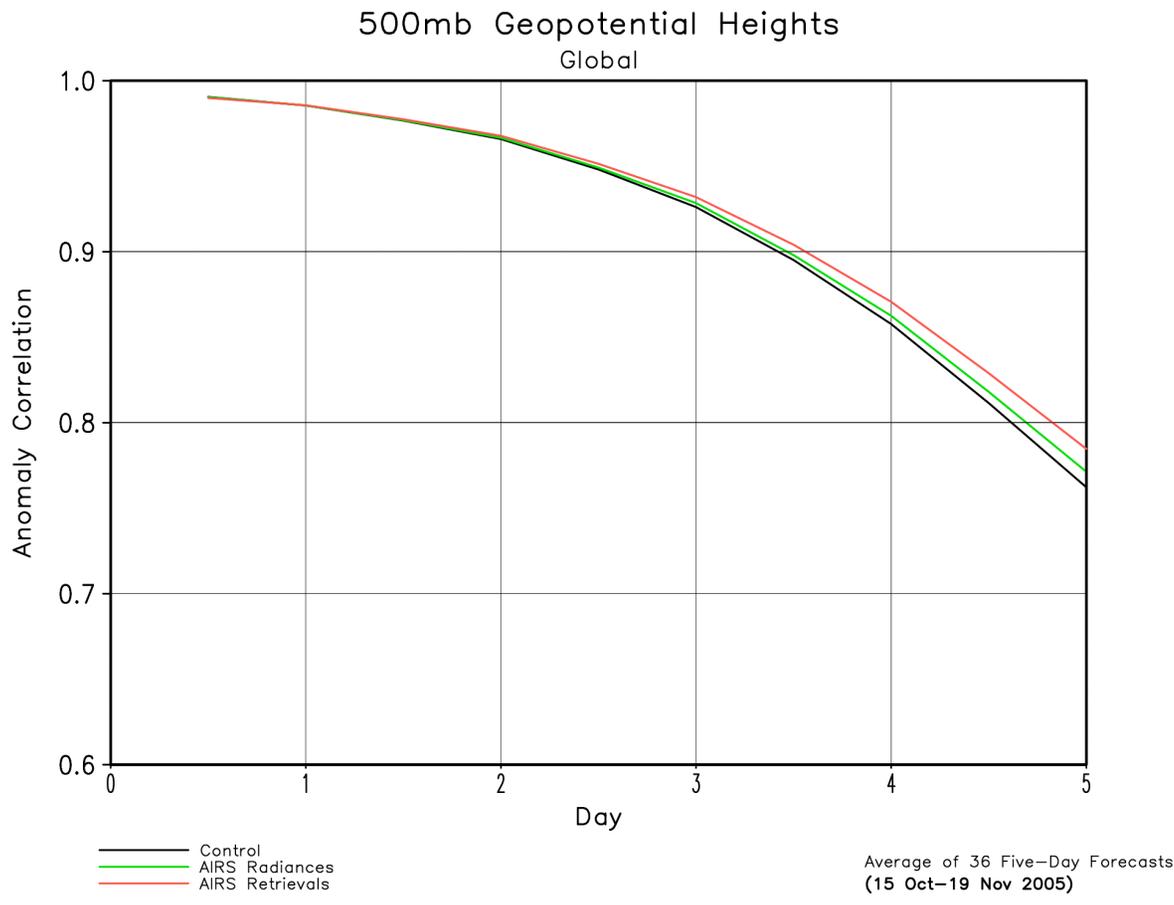
Positive **global** impact of AIRS retrievals (red).

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

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

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

GEOS-5 2.0.2 **Boreal Fall** Conditions: *global impact* of cloudy retrievals (tight QC) vs. clear-sky radiances



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

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

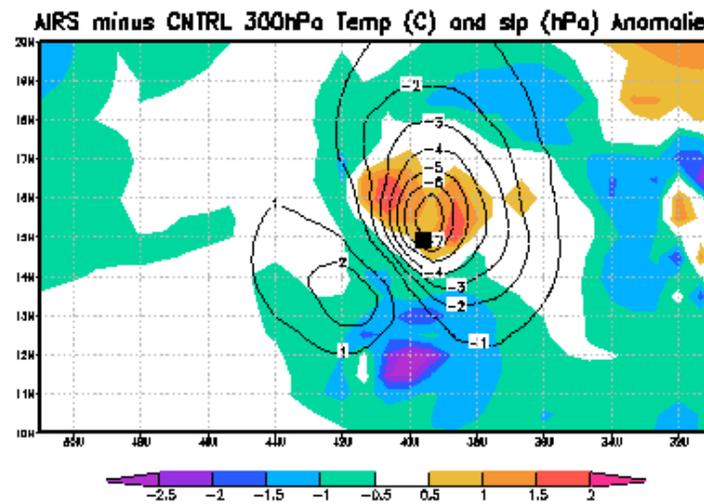
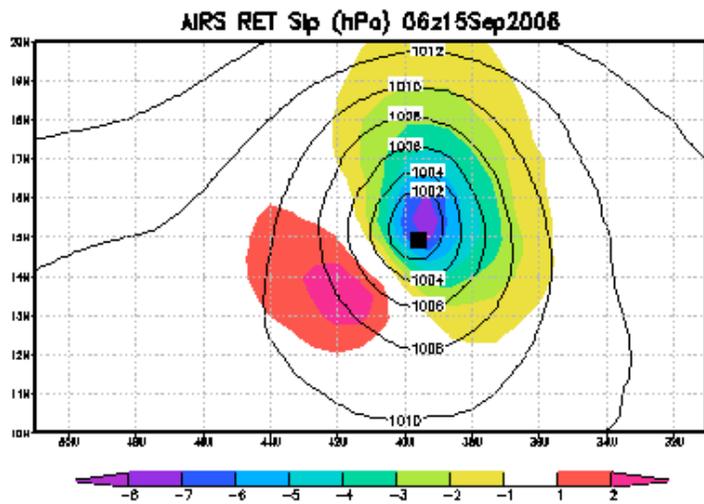
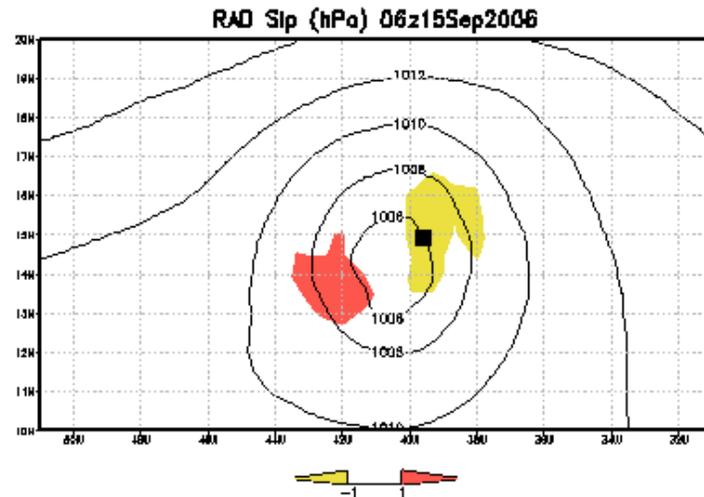
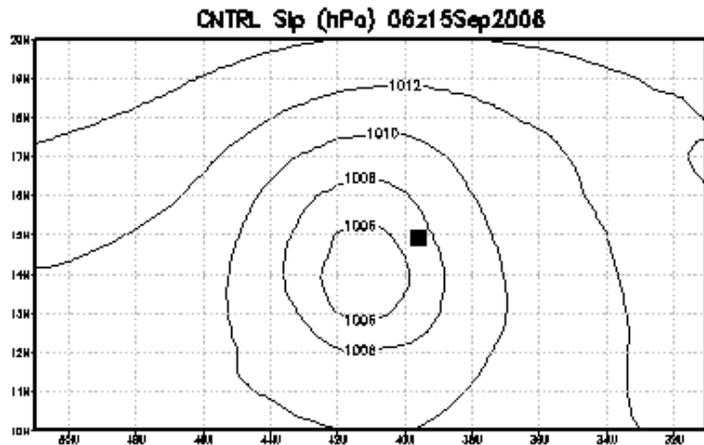
In addition, representation of **individual weather systems** in the tropics are strongly impacted by AIRS.

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

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

- AIRS cloudy retrievals change substantially the depiction of developing and/or weak tropical cyclones
- 6 Atlantic cyclones during NAMMA period have been studied so far
- 1 Cyclone over the Indian Ocean (Nargis)
- 1 Typhoon over the Pacific (Shanshan)
- AIRS improves the Tropical Cyclone ANALYSIS in GEOS5-DAS at in **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**

AIRS standard QC RET impact on the Analysis of Helene (2006)



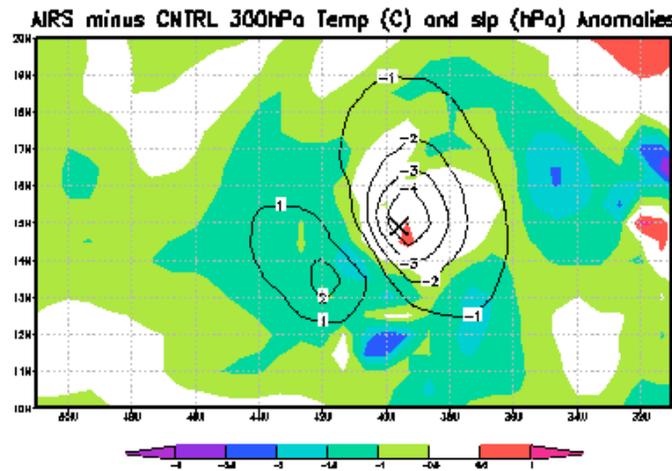
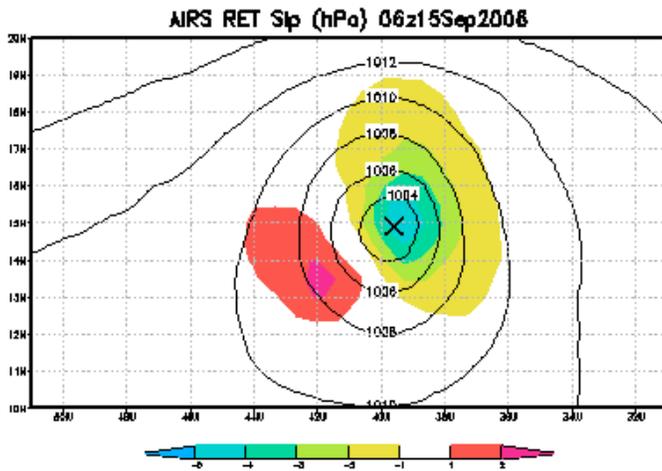
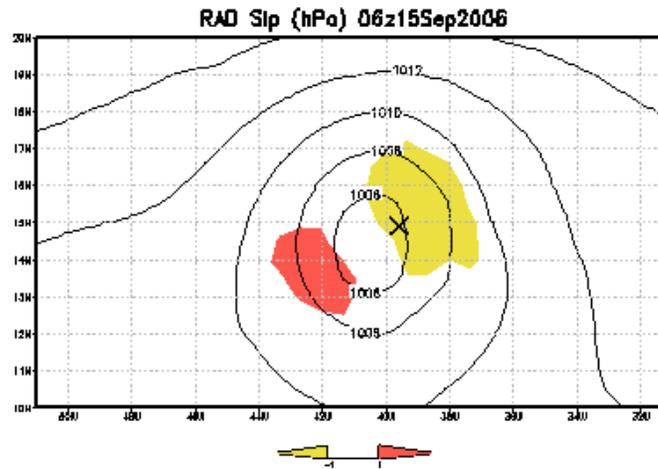
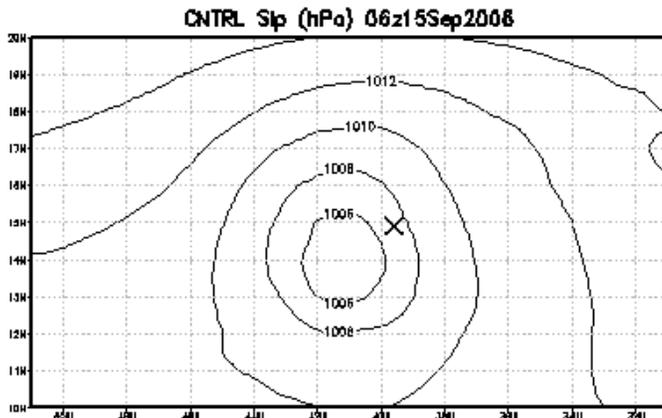
Slp RAD analysis (contour)
 RAD slp impact (shaded)
 Square: observed Helene position

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

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

AIRS RET improves position and intensity of Helene

NEW: AIRS TIGHT QC RET further improves TC position in the Analysis of Helene (2006)



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

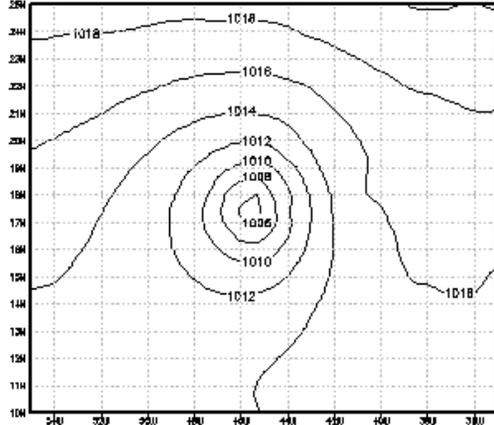
300 hPa Temp Impact (ret minus Control, shaded)
 And slp impact (contour)

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

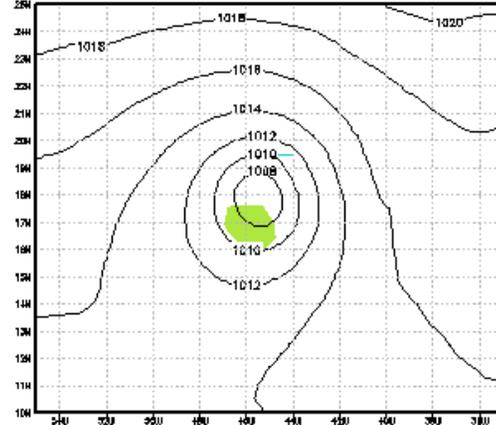
AIRS TIGHT RET produces a **PERFECT** position for Helene

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

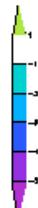
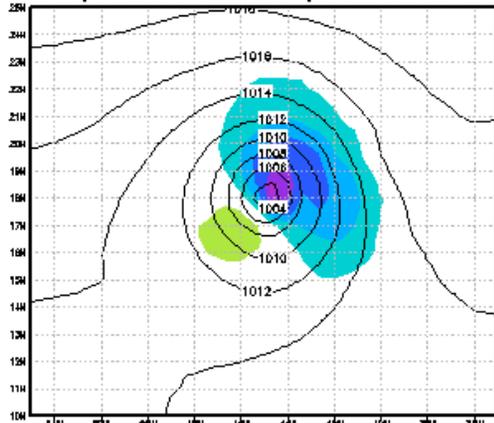
CNTRL Slp 36H FC Init 00z15Sep2006 Ver 12z16Sep2006



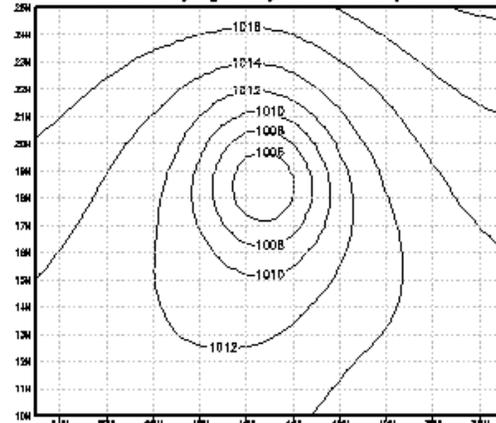
AIRS RAD Slp 36H FC Init 00z15Sep2006 Ver 12z16Sep2006



AIRS RET Slp 36H FC Init 00z15Sep2006 Ver 12z16Sep2006



NCEP Verifying Analysis 12z16Sep2006



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

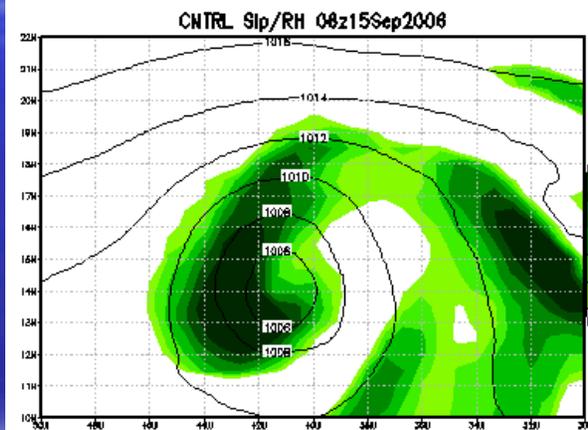
NEW: Dramatic improvement in cloud structure caused by AIRS retrievals

TS Helene Analysis at 06z 15Sep2006

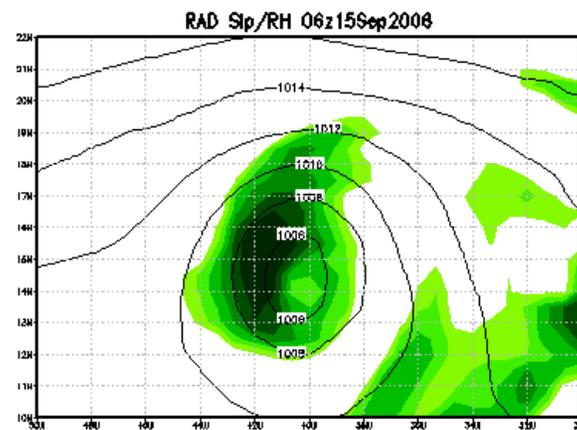
30 hours before becoming a hurricane

800 hpa relative humidity, sea level pressure (hPa)

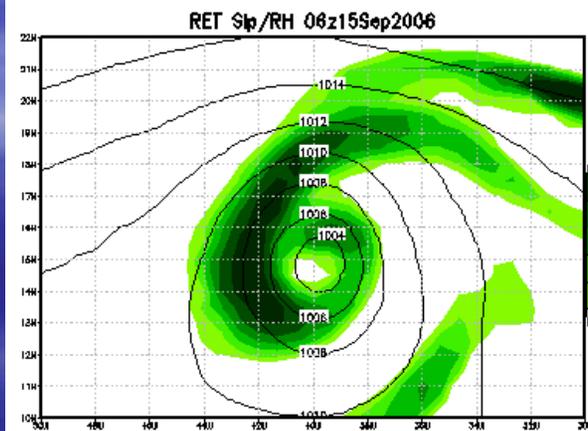
CNTRL



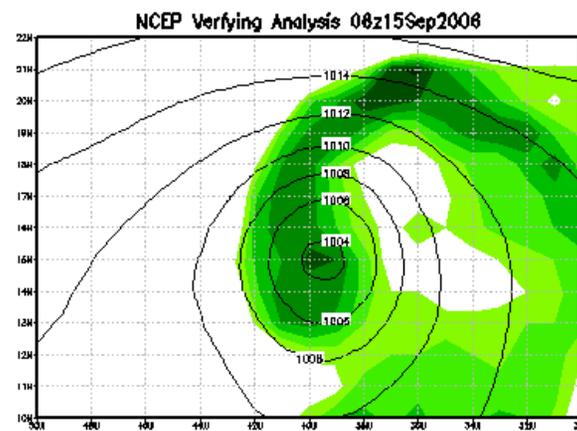
RAD



RETRIEVALS
Display an
Eye-like feature



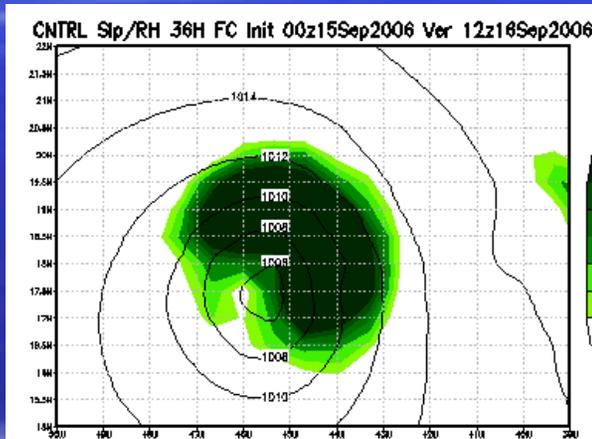
NCEP
Operational
Analyses,
Very poor



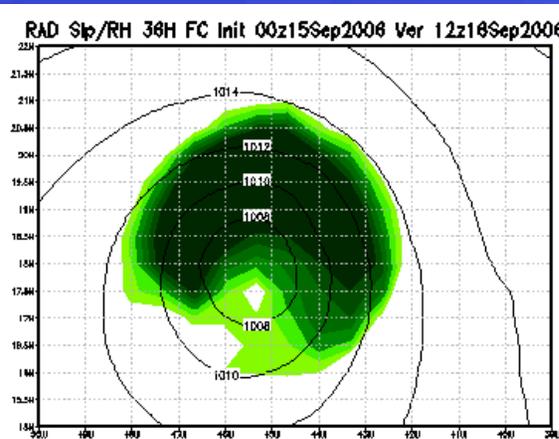
The 36-hour **forecast** initialized from AIRS retrievals is the only one that produce an **eye**, a closed circulation, and a reasonable scale **Helene at 12z 16Sep2006, upgraded to hurricane**

850 hpa relative humidity, sea level pressure (hPa)

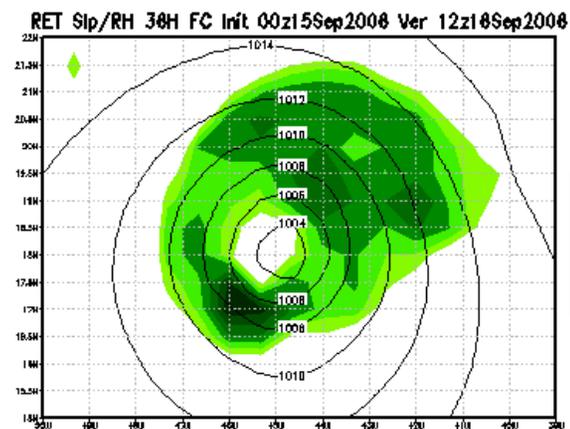
CNTRL



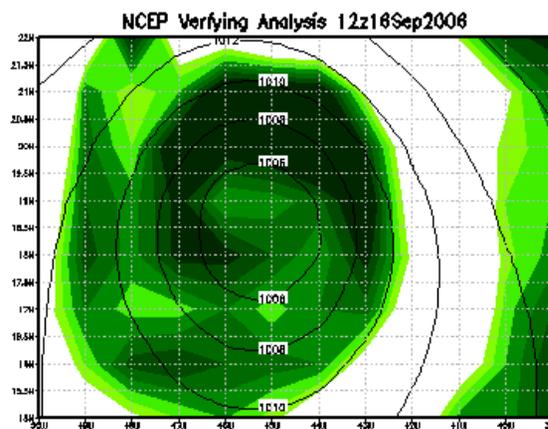
RAD



RETRIEVALS
*Clear eye-like
feature*



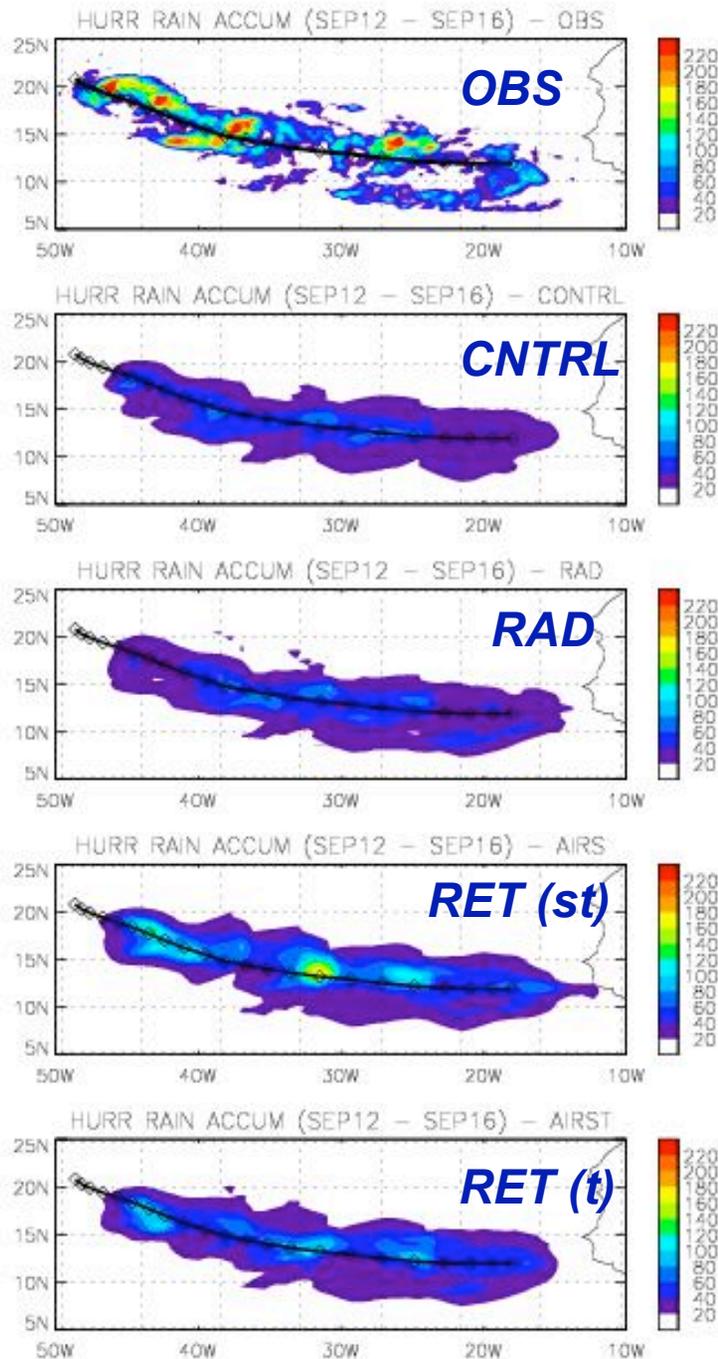
NCEP
analyses
*Too broad
wrt to obs*

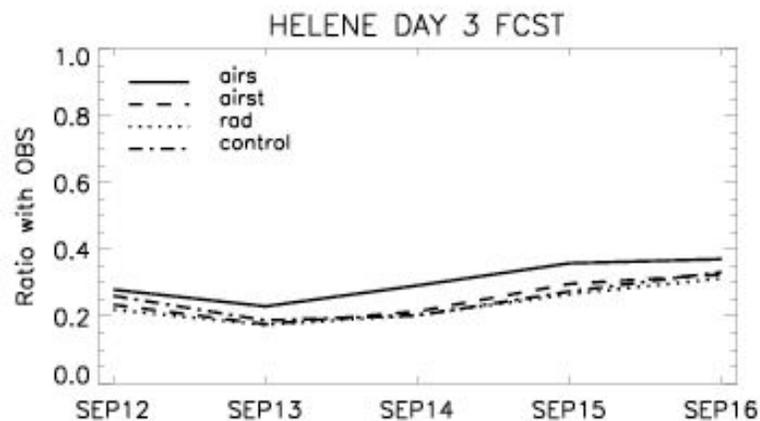
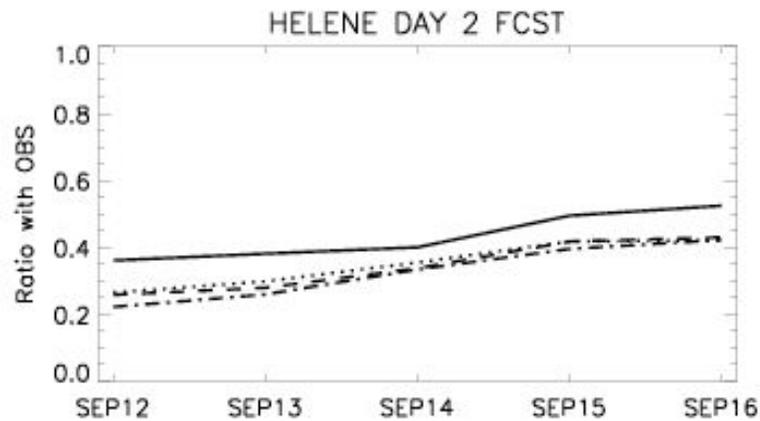
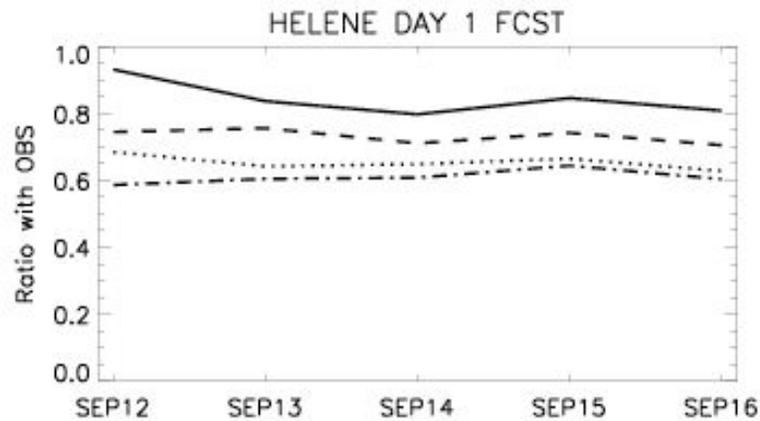


NEW: Precipitation “analysis” for Helene (2006)

Not a true precipitation analysis since 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, besides improving Helene’s structure, also produces the **best accumulated precipitation**





Precipitation Forecast for Helene

Precipitation forecast computed along track and validated with SSM/I data. **Ingestion of AIRS retrievals cause the GEOS-5 to have best skill.** Improvement with respect of CNTRL caused by AIRS retrievals is about 30%, radiances only 15% for 1-day forecasts. Overall skill is **very good in the 1-day** forecasts, **reasonable at day 2**, but drops at day 3.

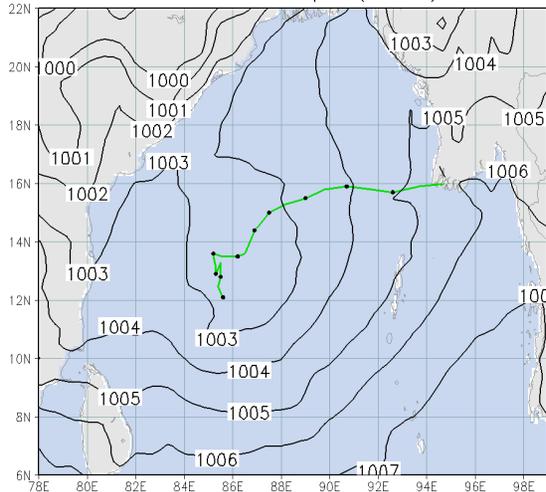
Previous work on TC Nargis

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

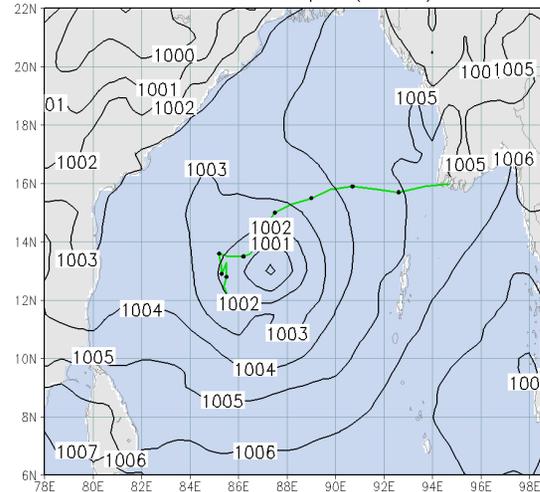
AIRS 108-
hour
Forecast (slp)

Green:
Observed
Track

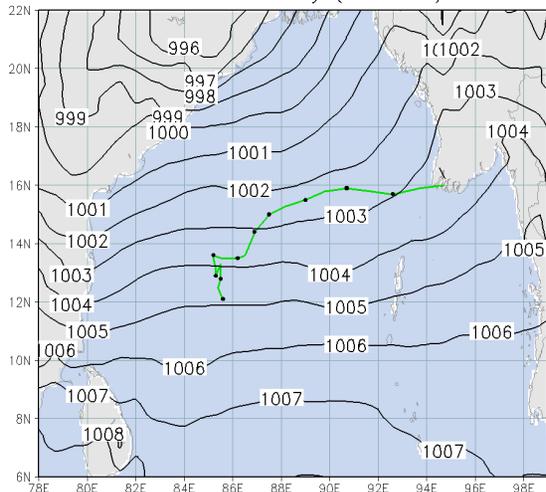
CNTRL 06z 28April (6h FC)



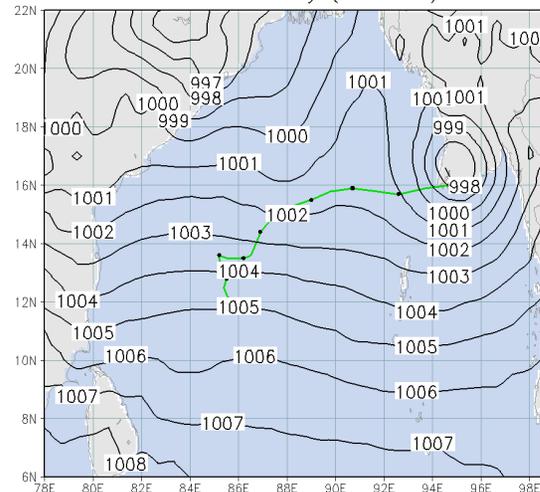
AIRS 06z 28April (6h FC)



CNTRL 12z 2May (108h FC)



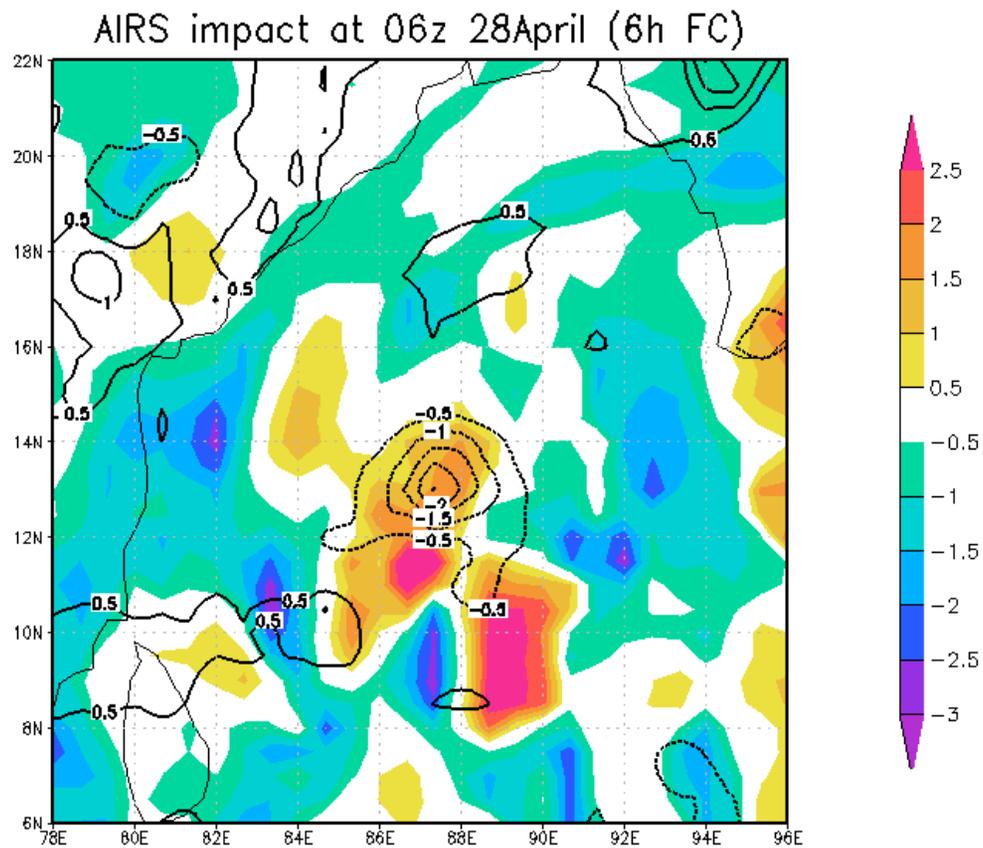
AIRS 12z 2May (108h FC)



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.*)

Reminder: why 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**

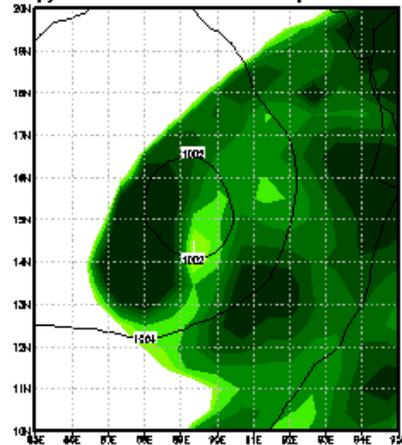
Shaded: 200 hPa AIRS minus CNTRL temp anomaly
Contour: AIRS minus CNTRL slp anomaly (Reale et al., 2009)

NEW: AIRS cloudy retrievals impact Nargis structure much better than radiances

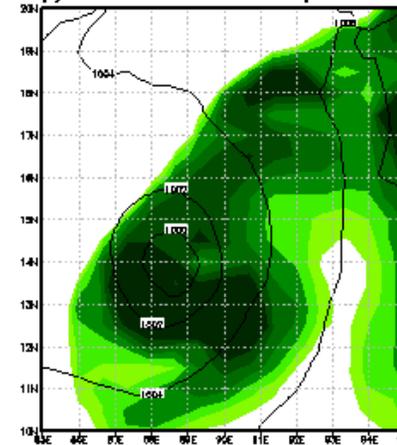
Radiances: very poor structure:
Two **unconnected** convective systems
without a deep circulation

Retrievals: Realistic 2-band
structure comparing well with
satellite

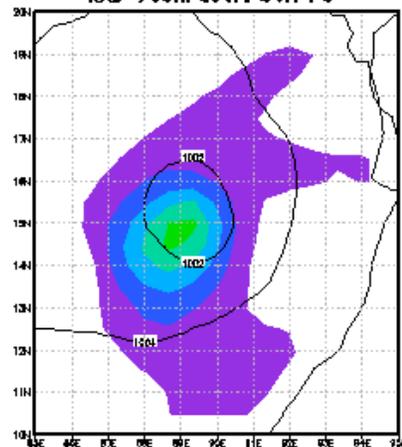
RAD Slp/RH 36H FC Init 00z28Apr Ver 12z29Apr



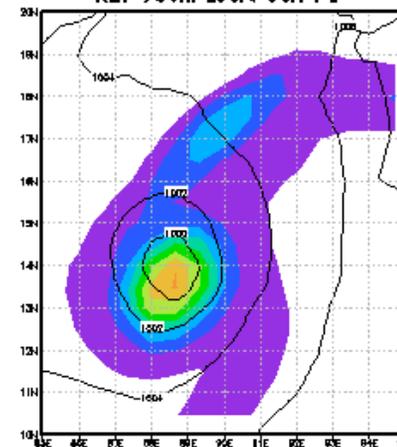
RET Slp/RH 36H FC Init 00z28Apr Ver 12z29Apr



RAD 700hPaVort 36H FC



RET 700hPaVort 36H FC

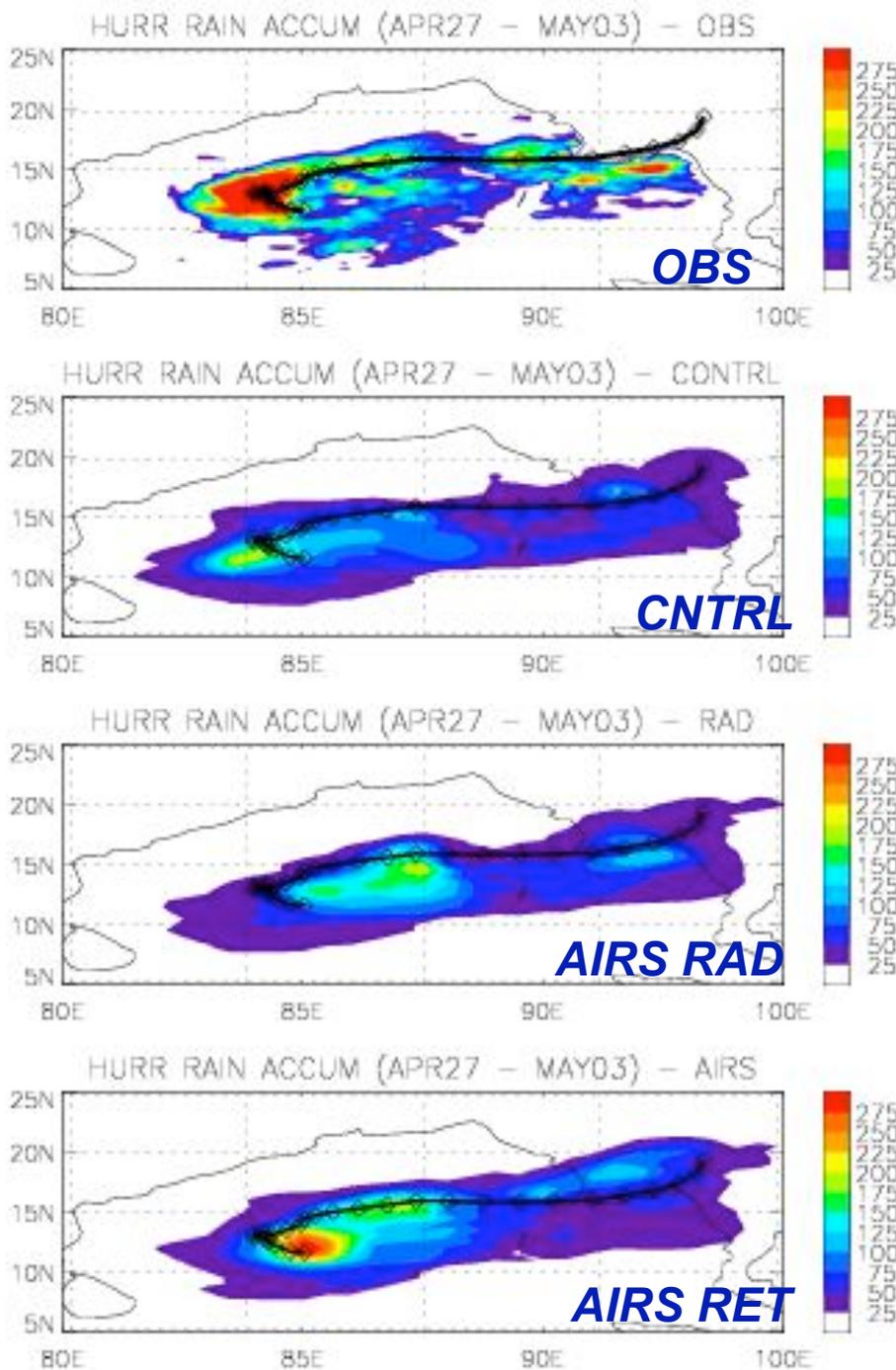


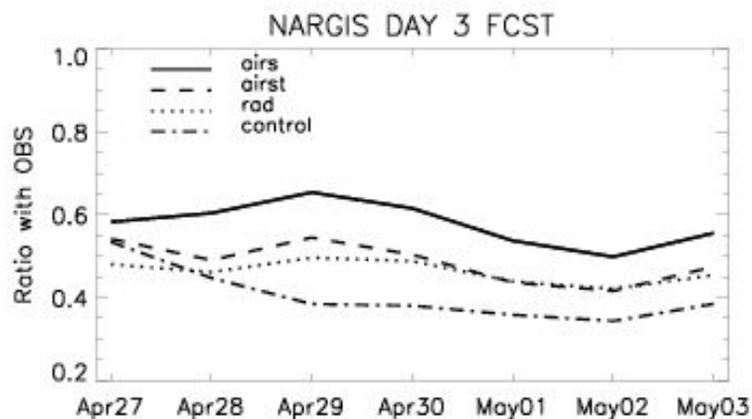
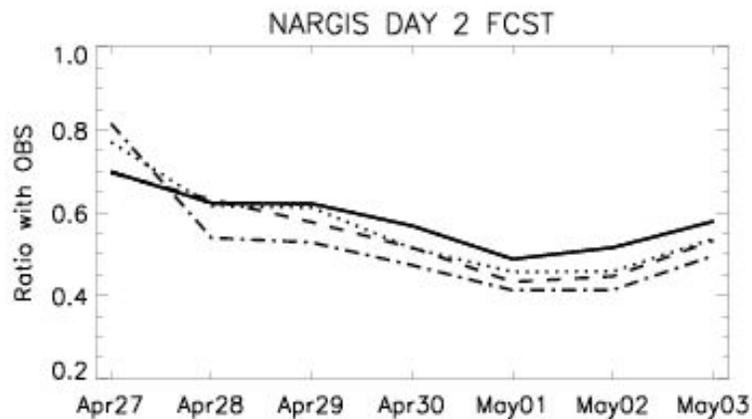
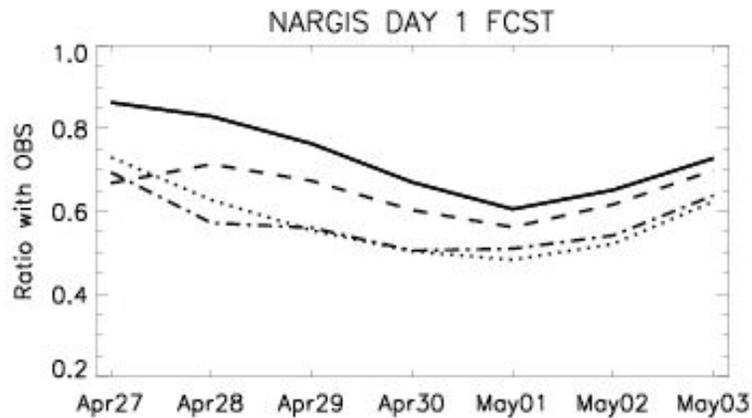
Radiances
Very weak
System, low
Vorticity

Retrievals
Much
higher
(100%)
Vorticity

NEW: Precipitation “Analysis” for Nargis

Not a true precipitation analysis since 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’**. Validation is made against SSM/I, AMSU and TMI data





Precipitation Forecast for Nargis

Precipitation forecast computed along track and validated with SSM/I data.

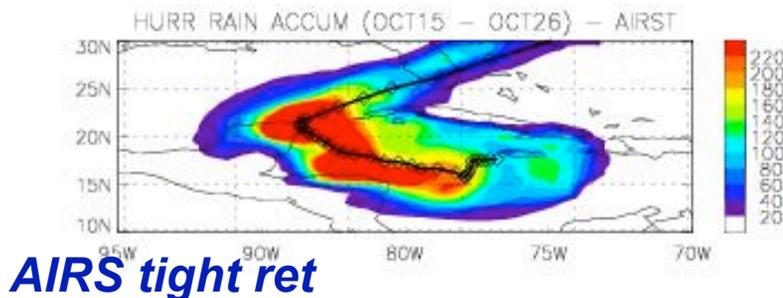
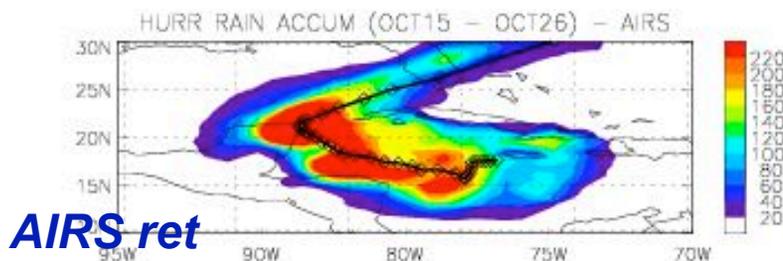
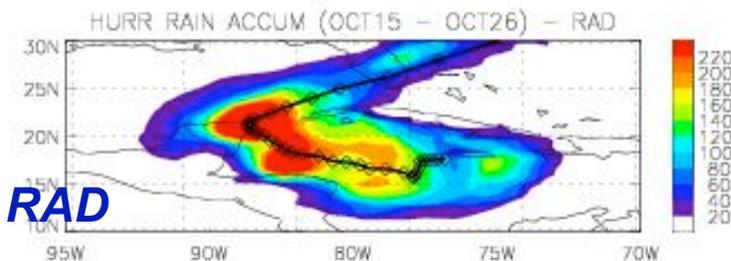
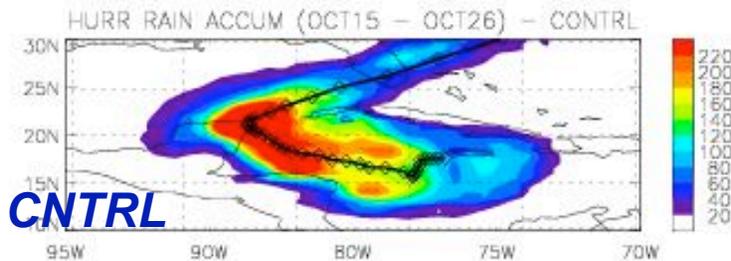
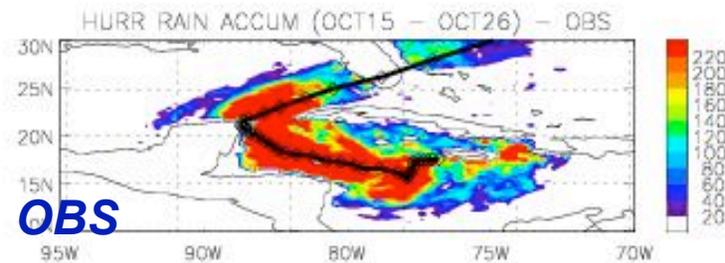
Ingestion of AIRS retrievals cause the GEOS-5 to have best skill. Improvement with respect of CNTRL caused by AIRS (tight QC) retrievals is about 20%, radiances impact is negligible. Overall skill is very good in the 1-day forecasts. Skill **still reasonable at day 3.**

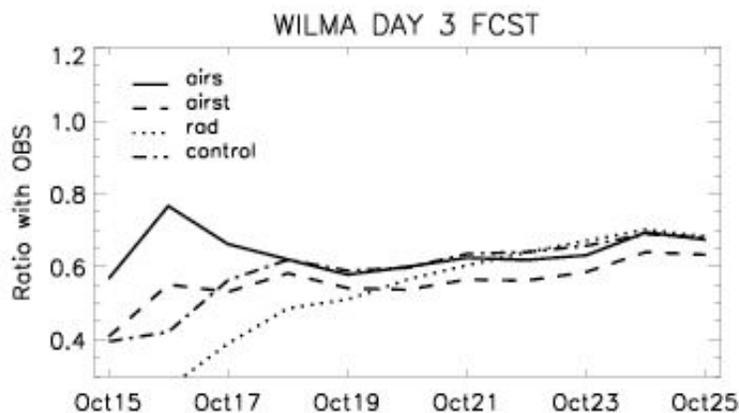
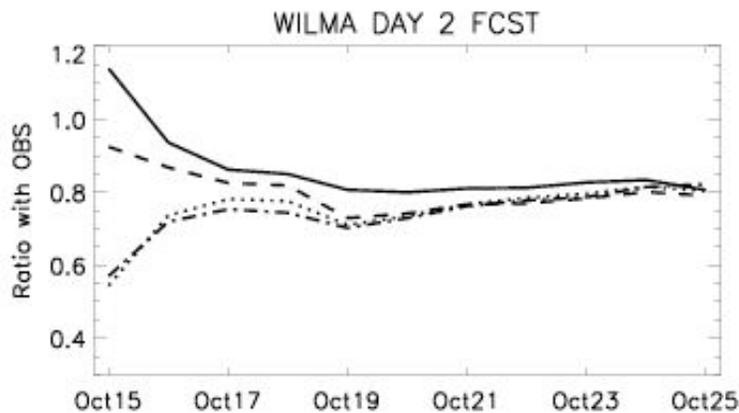
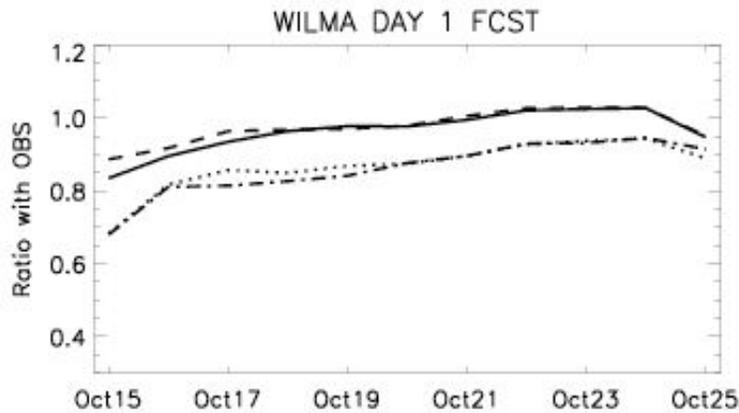
Since the largest amount of casualties caused by Nargis were due to FLOODs, this result has prominent implications

NEW: Precipitation “Analysis” for Wilma (2005)

Not a true precipitation analyses since 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 Wilma structure- also produces the **best precipitation ‘analysis’** in the earliest stages (east of 80W)





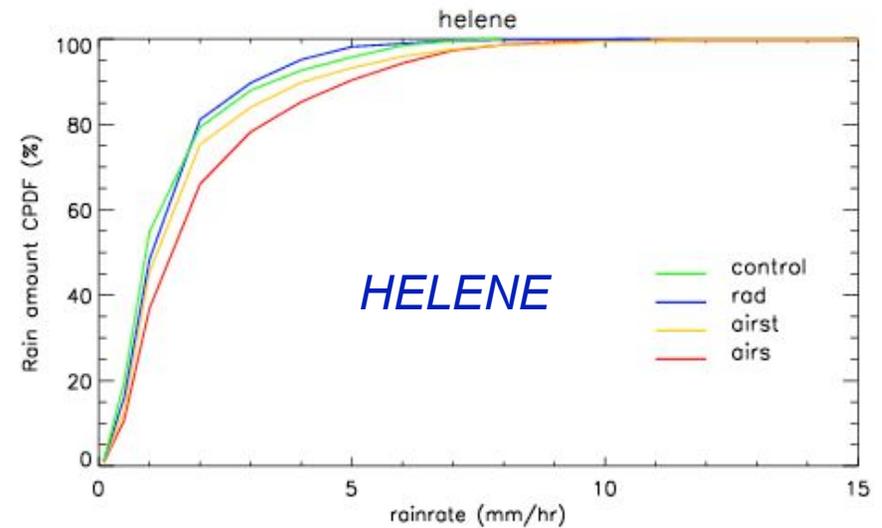
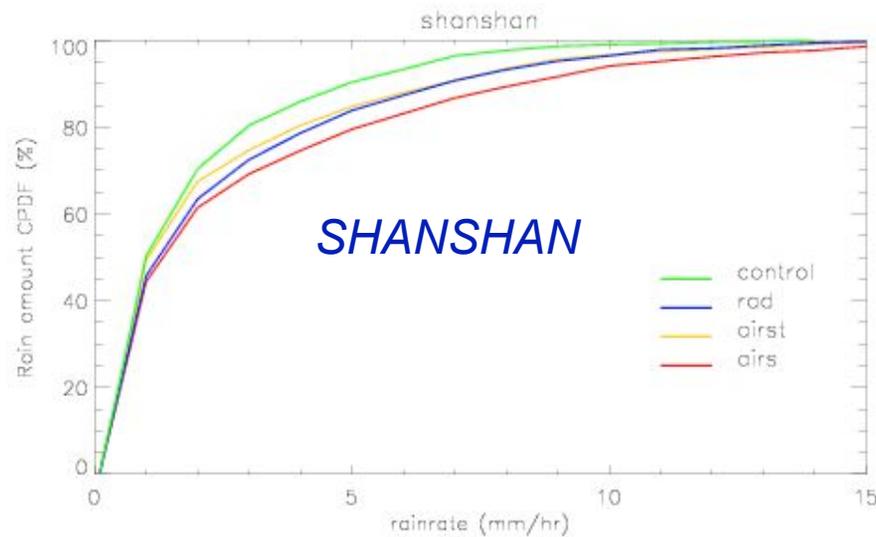
Precipitation Forecast for Wilma

Precipitation forecast computed along track and validated with SSM/I data.

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

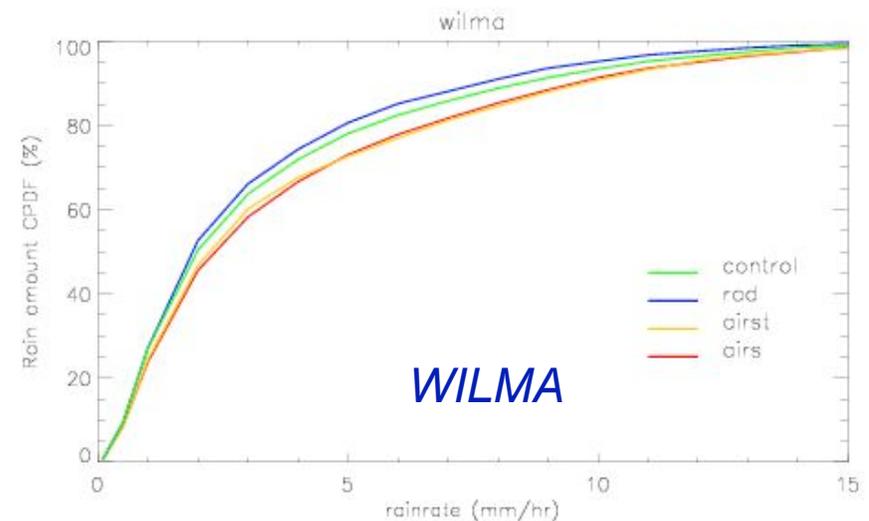
Since prominent damages caused by Wilma were due to FLOODs, this result has prominent implications

AIRS improves the precip probability distribution function



Even in cases in which AIRS brings *no improvement in precipitation analysis and forecast* (typhoon Shanshan, 2006) and generally in very strong, mature and large tropical systems, the assimilation of AIRs retrievals improves the *precipitation probability distribution function*.

THIS HAS PROMINENT IMPLICATIONS FOR FLOOD FORECASTING



Conclusions

- 30-day data assimilation experiments without AIRS, with AIRS cloudy retrievals (at two different quality controls) and with AIRS clear-sky radiances are produced for **boreal winter, spring, summer** and **fall** conditions, for a total of **about 480 days**
- 5-day forecasts are produced from all 3 sets of analyses, for a total of about **480 5-day forecasts**
- The overall skill of forecasts initialized from analyses in which retrievals are assimilated is higher in every season at both levels of quality control, being the 'tight' slightly higher
- **Spectacular improvements in the analysis of Tropical Cyclones are observed as a consequence of AIRS retrievals ingestion**
- The improvements affect **FORECAST TRACK** and **TC PRECIPITATION FORECASTS**
- Since **freshwater floods** are the **number one cause of deaths** associated with TCs, AIRS-caused improvement in TC precip analysis and forecasting is **extremely relevant**

Acknowledgments

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