AIRS impact on global analysis and forecast in the tropics:

The Case of Tropical Cyclone Nargis.

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Ongoing collaborative effort aimed at optimizing the impact of AIRS in the GEOS-5 Data Assimilation and Forecasting System

- Previously published work (Reale et al., 2008) showed 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
- Current work shows improvements in analysis over the *tropics* in in the GEOS-5 DAS and forecasting model *vs. 2.0.2 and 2.1.2* at 0.5x.5 and 0.25x0.25. Periods chosen: boreal summer and boreal spring
- Forecast skill increases (austral winter and fall) also in the southern hemisphere

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

- AIRS has long been recognized as an important contributor in atmospheric data assimilation. However, a small fraction of AIRS data is retained in operational weather systems. In addition to effects of thinning and quality control, 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) documents a new strategy that 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 control and use them for quality control
- The analyses produced by assimilating temperature retrievals obtained under partly cloudy conditions provide a substantially different thermal representation of the low-midtroposphere in the higher latitudes during boreal winter conditions, which produce better GEOS-5 forecasts (Reale et al., 2008)

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Analysis in the tropics

- The fact that AIRS improves the representation of the thermal structure of the atmosphere should be beneficial also in the tropics
- In particular, developing tropical lows are better defined and confined with the ingestion of AIRS temperature retrievals under partly cloudy conditions
- Experiments were initially done to cover the NAMMA period (15Aug-15Sep 2006) and confirmed substantially better defined TCs in the Atlantic in response to AIRS data ingestion

AIRS Experiments: (Boreal Summer) settings

- GEOS-5 DAS: 2.0.2
- Control assimilation (CNTRL): assimilating all conventional and satellite data, but no AIRS retrievals, from 8/10/06 to 9/15/2006 (to overlap the SOP-3 phase of NAMMA).
- "AIRS": Same data as control plus AIRS version 5 retrievals with "medium" quality control added as rawinsonde temperature profiles.
- "RAD": AIRS clear-sky radiances from NESDIS
- TWO sets of forecasts, and 0.25 and 0.5 degrees, for both CNTRL and AIRS runs

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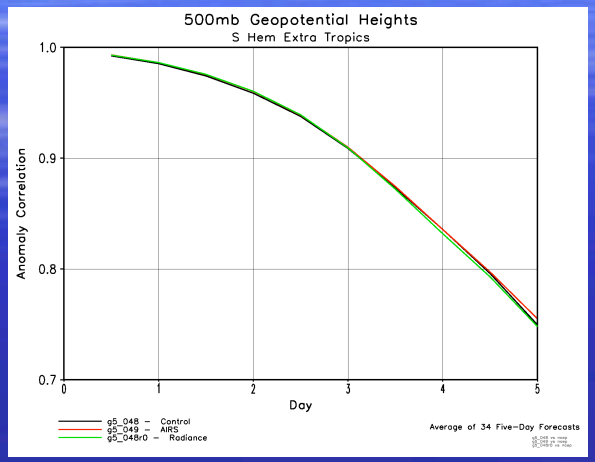
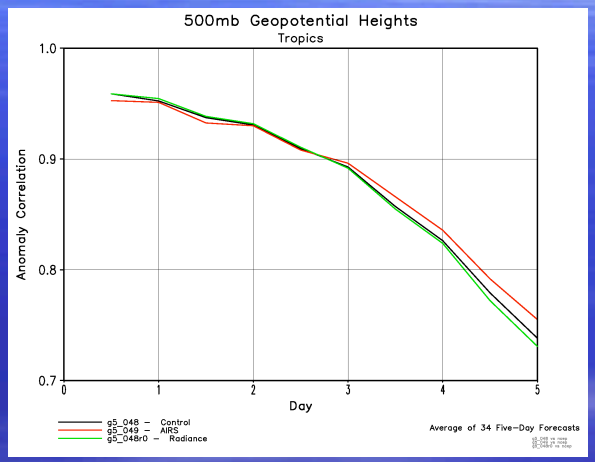
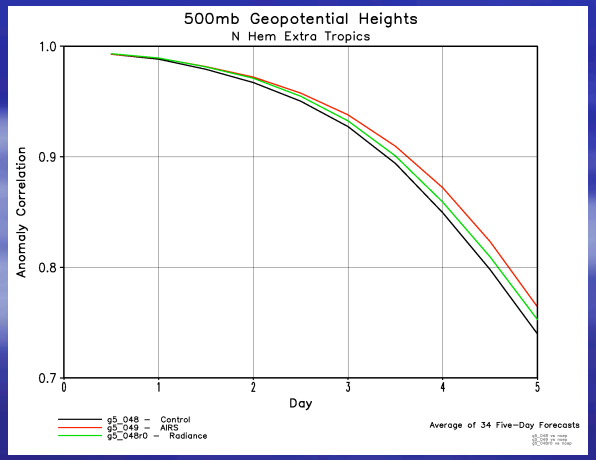
GEOS-5 2.0.2 Boreal Summer run







Strong AIRS impact on N.Hem ET Boreal summer, negligible in S.Hem Boreal winter. `Tropics': negligbible except for retrievals on days 3-5 [lat. band 15S-45N]

However, representation of individual weather systems in the tropics are strongly impacted by AIRS

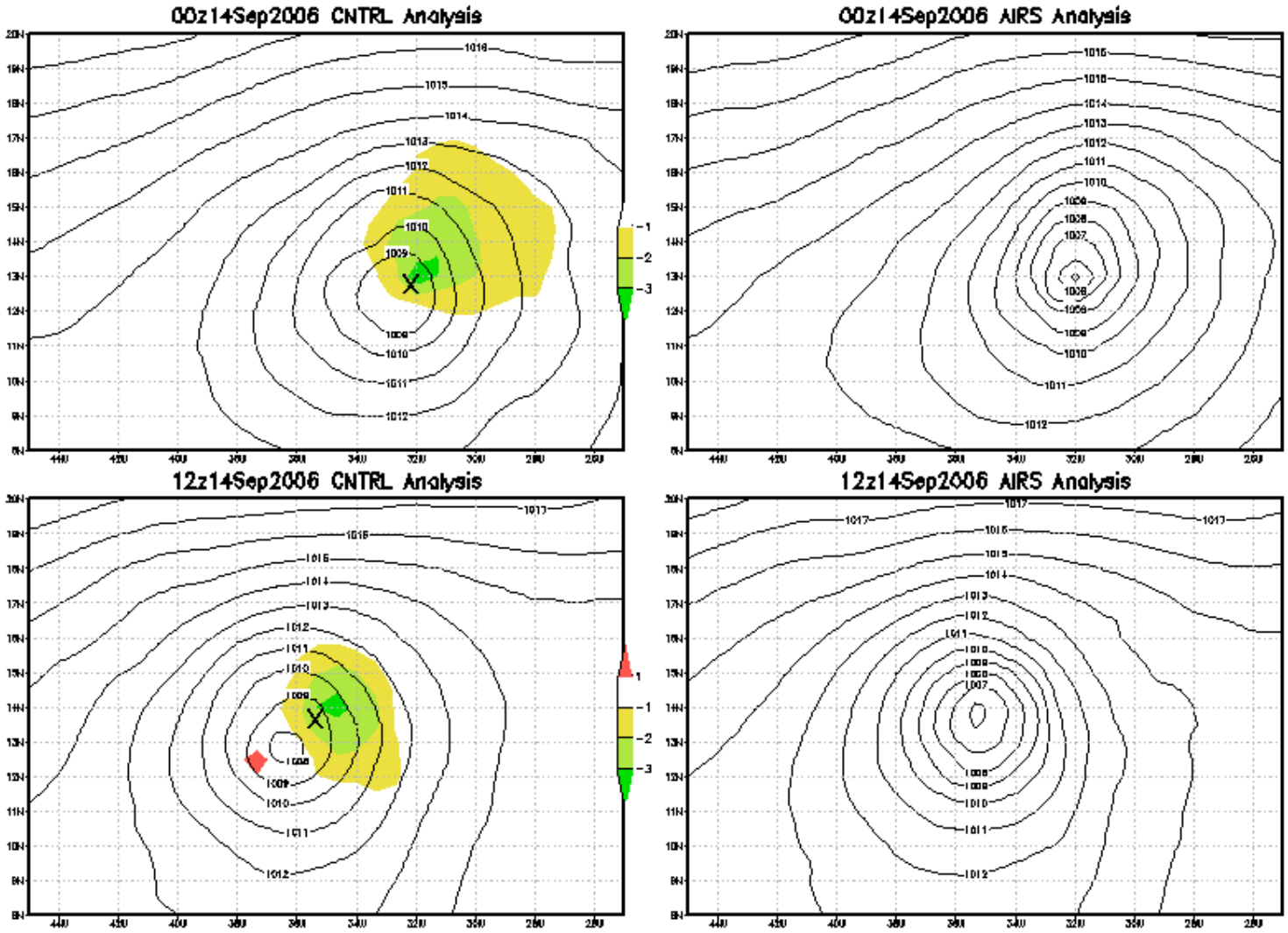
AIRS affects the depiction of developing tropical weather systems

- AIRS changes substantially the depiction of developing and/or weak tropical cyclones
- 6 cyclones during NAMMA period are studied
- AIRS improves the ANALYSIS in GEOS5-DAS at all times

Example: Analysis of TC Helene (2006)

CONTROL

AIRS



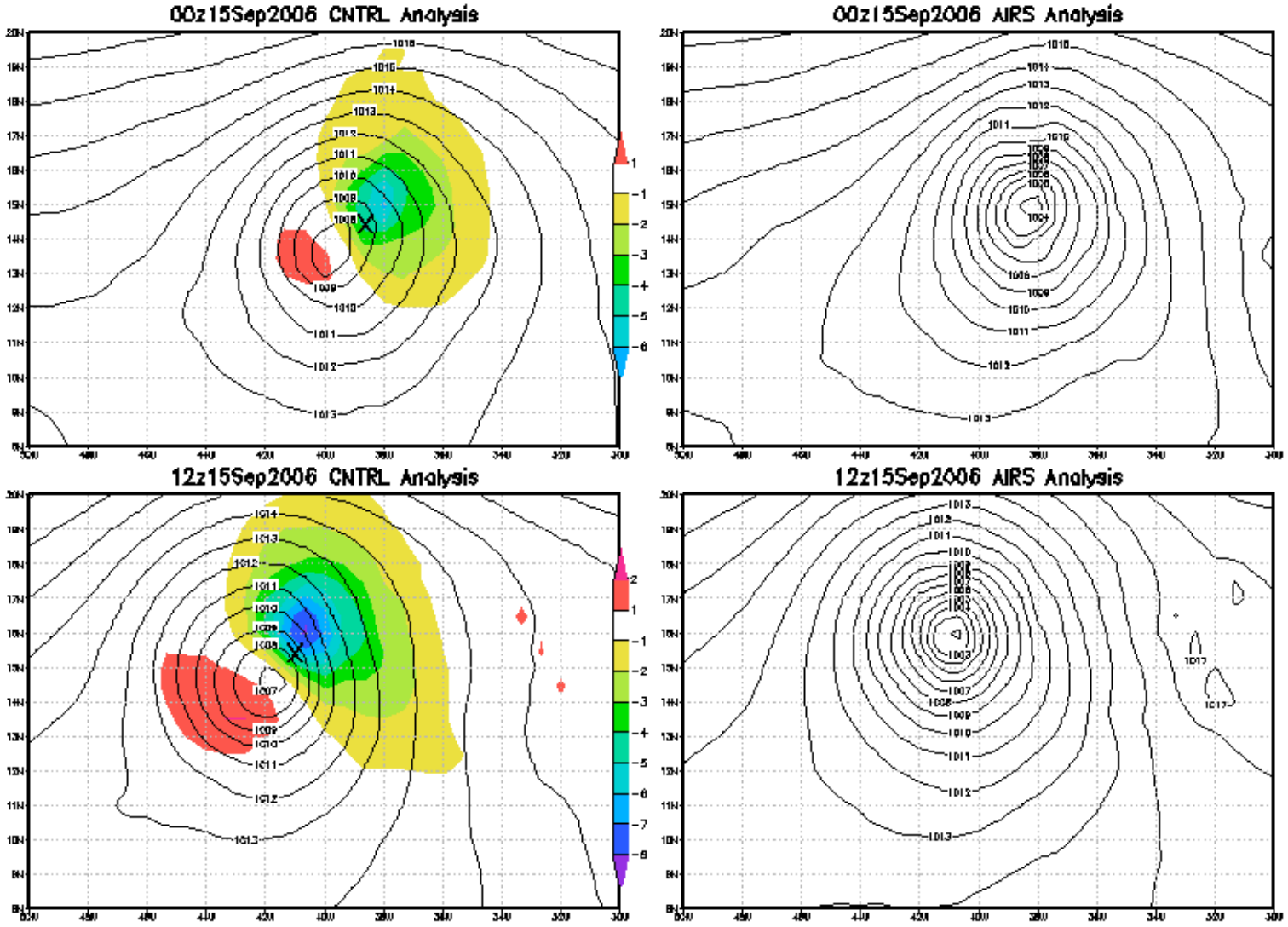
The shading indicates drastic improvement in the definition of TC Helene during its genesis stage.

Sea level pressure (hPA, solid) and AIRS minus CNTRL anomaly (shaded)

TC Helene (cont.)

CONTROL

AIRS

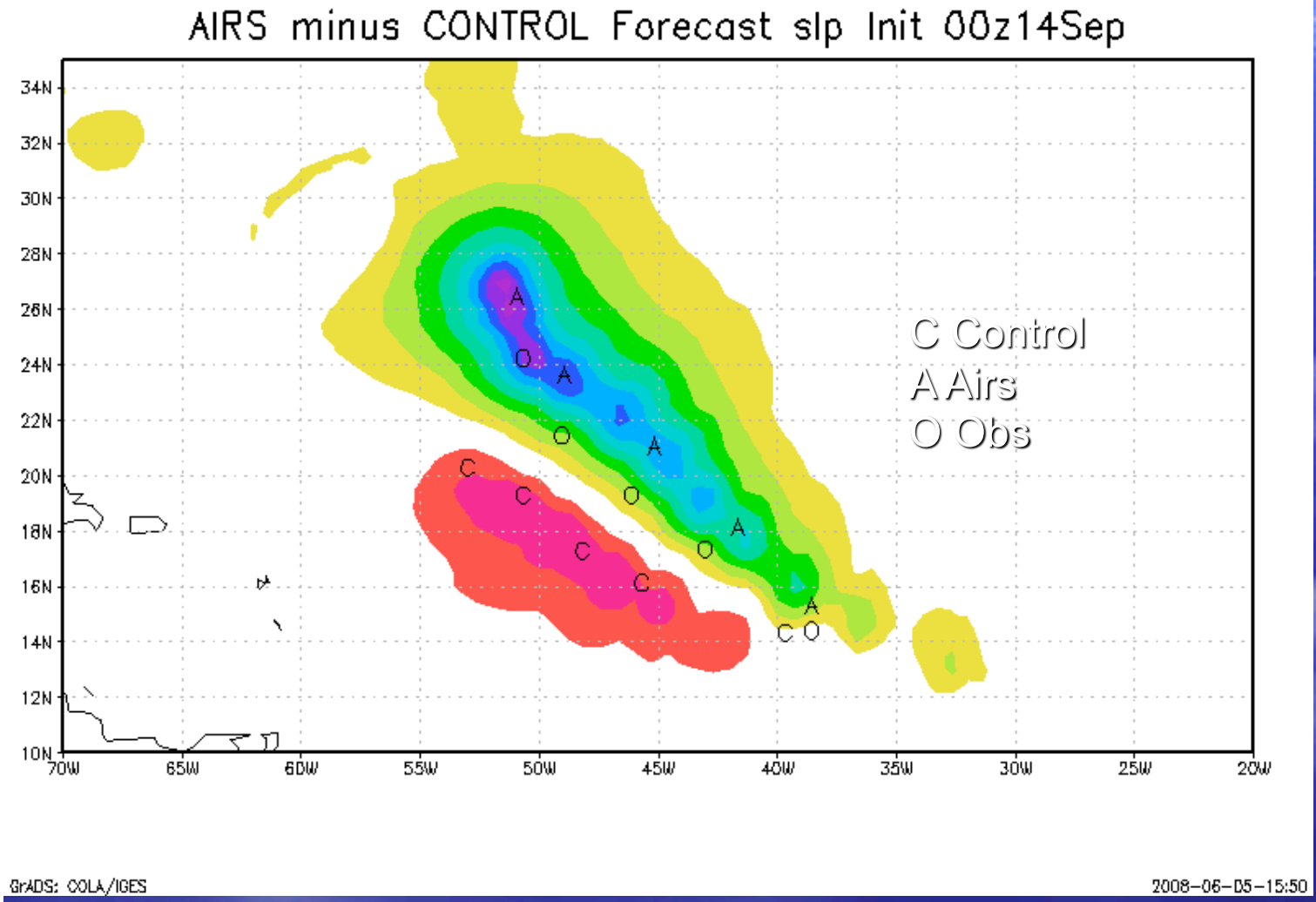


Sea level pressure (hPA, solid)

AIRS minus CNTRL anomaly (shaded)

X Obs center

GEOS-5 Forecast of TC Helene



Sea level pressure AIRS minus CNTRL anomaly (shaded)

Substantial improvement in track and definition of the storm

Thermal structure is important in the tropics

- Results from the Atlantic Ocean confirm that AIRS retrievals can improve the representation of a developing low
- The improvement consists of a more confined and tight circulation
- Why not attempting to see AIRS impact also on very difficult cyclones?

Tropical Cyclones on the northern Indian Ocean

- Unlike other tropical basins, Tropical Cyclones are relatively rare over the northern Indian Ocean. They typically occur either in the pre-monsoon phase or at the very end of the monsoon. However, they are possibly the most catastrophic natural disasters in terms of life loss (300,000 deaths in Bangla Desh, 1970; at least 100,000 in Myanmar, 2008)
- TCs over the Arabian Sea and Bay of Bengal are the most difficult to analyze (i.e., well developed lows do *not* appear in the analyses or appear misplaced of hundreds of km.)
- As a consequence of poor initialization, forecasts model often perform less-than-optimally

Why TCs over the N Indian Ocean are so difficult?

- In addition to the problems related with data-poor areas, the particular thermal structure in the lower-mid troposphere with very hot Deccan plateau in the pre-monsoon and relatively cool temperatures over the Ocean lead to very sharp thermal gradients which are generally not captured in the analyses.
- Very strong vertical shear associated throughout the warm season. Easterly Tropical Jet at 150 hPa, westerly jet at 700-800 hPa, low-level jets associated with strong thermal contrast between the Deccan and the Bay of Bengal
- TCs form only when occasional breaks in the vertical shear occur over the ocean.
- TCs' tracks are very erratic, display loops and singularities

Tropical Cyclone NARGIS (2008)

- The catastrophic cyclone Nargis (Apr 27th -May 3rd) is one of the most deadly natural events in recorded history
- It appeared as a convective cluster on the 25th, and was named as tropical cyclone 1B at 12z 27Apr 2008 by the Joint Typhoon Center
- Erratic track and intensity fluctuations made forecast quite difficult (initially forecasted to hit Bangladesh or even West Bengal)
- Landfall occurred after a period or rapid intensification at about 12z 2May over Myanmar

Experiment settings

- GEOS-5 DAS: 2.1.2 at 0.5 resolution.
- 3 Sets of Analyses are produced
- Control assimilation (CNTRL): assimilating all conventional and satellite data, but no AIRS retrievals or radiances, from April 15th to May 18th 2008, to include TC Nargis (4/27-5/3) but also assess the overall behavior of the system in boreal spring conditions
- "AIRS": Same data as control plus AIRS version 5 retrievals (added as rawinsonde temperature profiles) from the DAAC
- "RAD": AIRS clear-sky radiances from NESDIS
- 5-day forecasts run from April 16th to May 18th 2008 for each set of analyses

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- 3 sets of 34 5-day forecasts, initialized at 00Z each day, from April 16th to May 18th 2008:
  - "CNTRL" forecasts initialized from control assimilation
  - "AIRS" forecasts initialized from AIRS assimilation
  - "RAD" forecasts initialized from RAD assimilation
- All three sets verified against NCEP analysis

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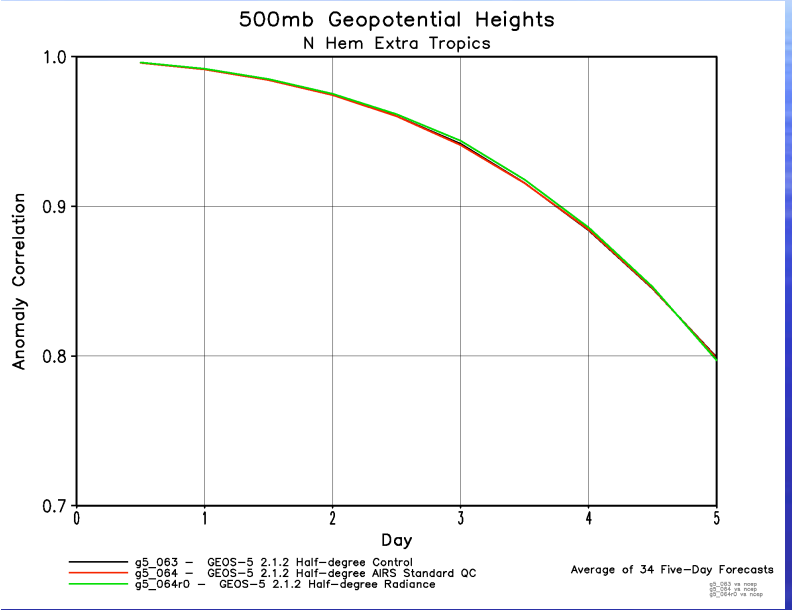
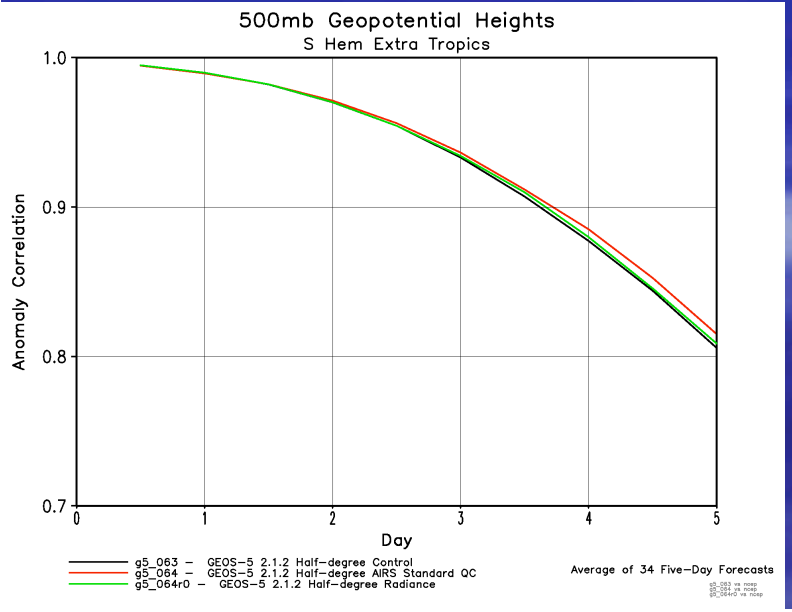
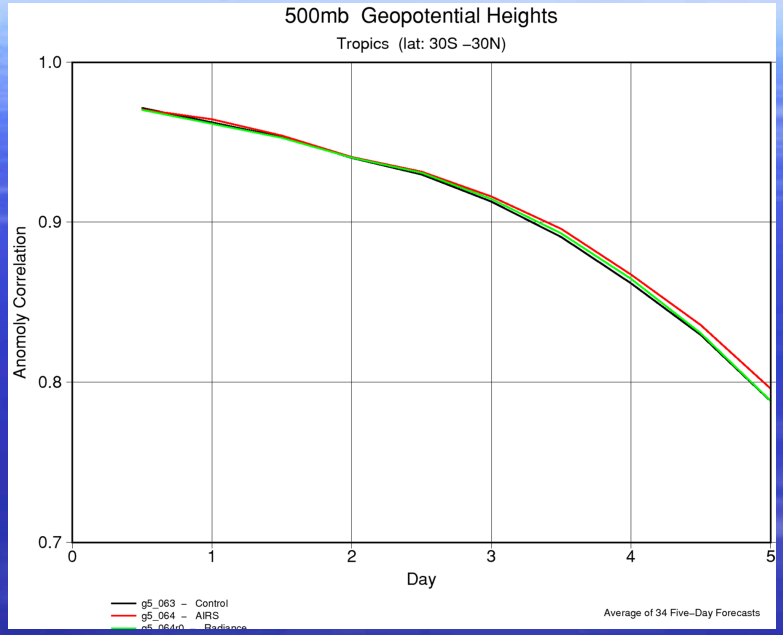
AIRS impact in boreal spring conditions: extratropics vs tropics





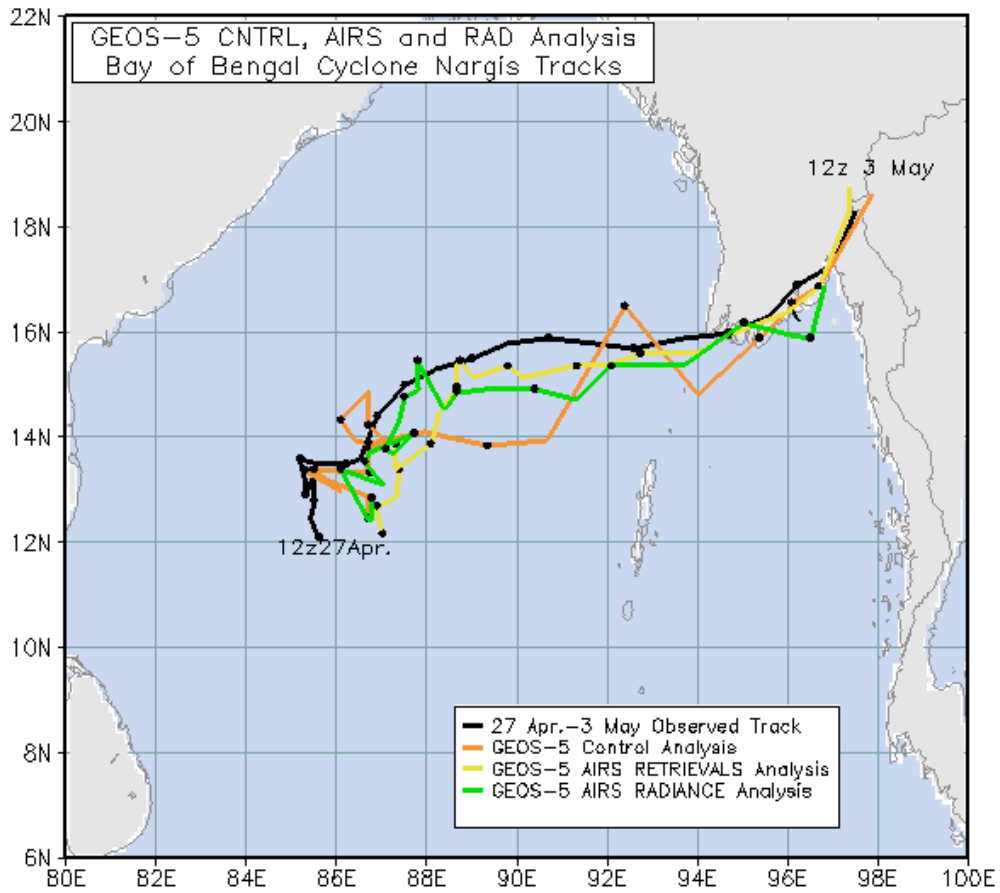


Substantial improvement in the Southern Hemisphere

Negligible (non-negative) impact in the northern hemisphere

Some positive impact in the tropics at days 3-5 (retrievals only)

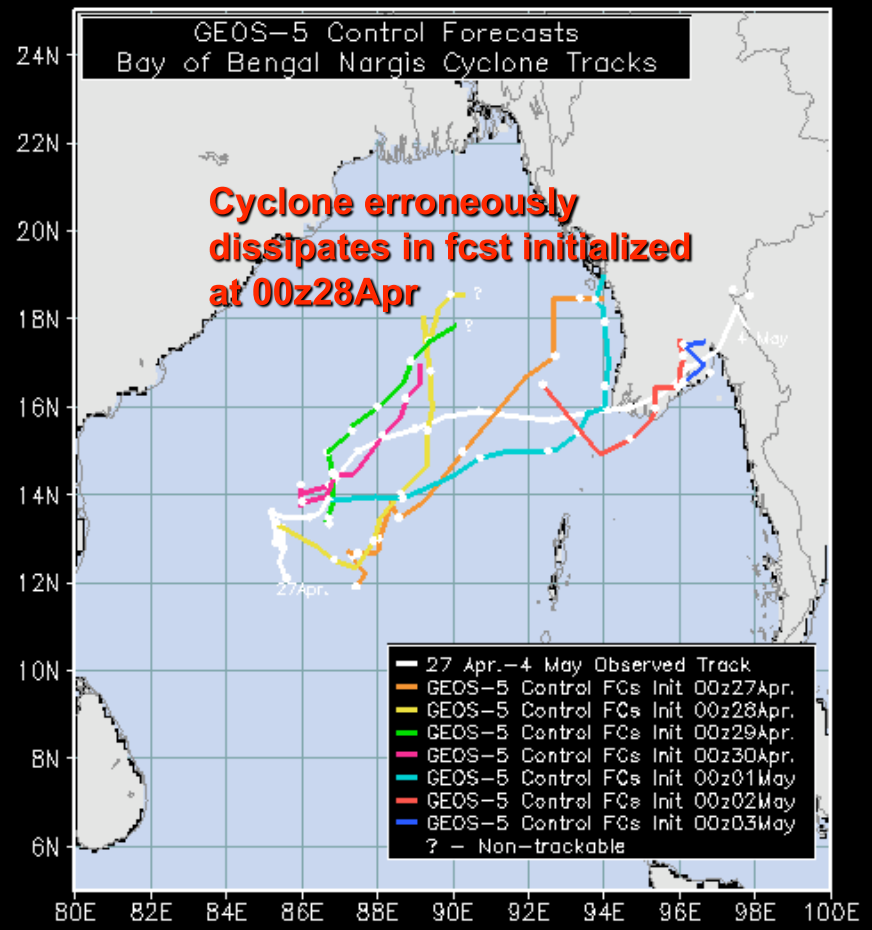
AIRS improves the ANALYSIS of Nargis



The 3 tracks are obtained by tracking the center of Nargis in the 3 sets of ANALYSES produced by the CNTRL, RAD and AIRS Assimilations.

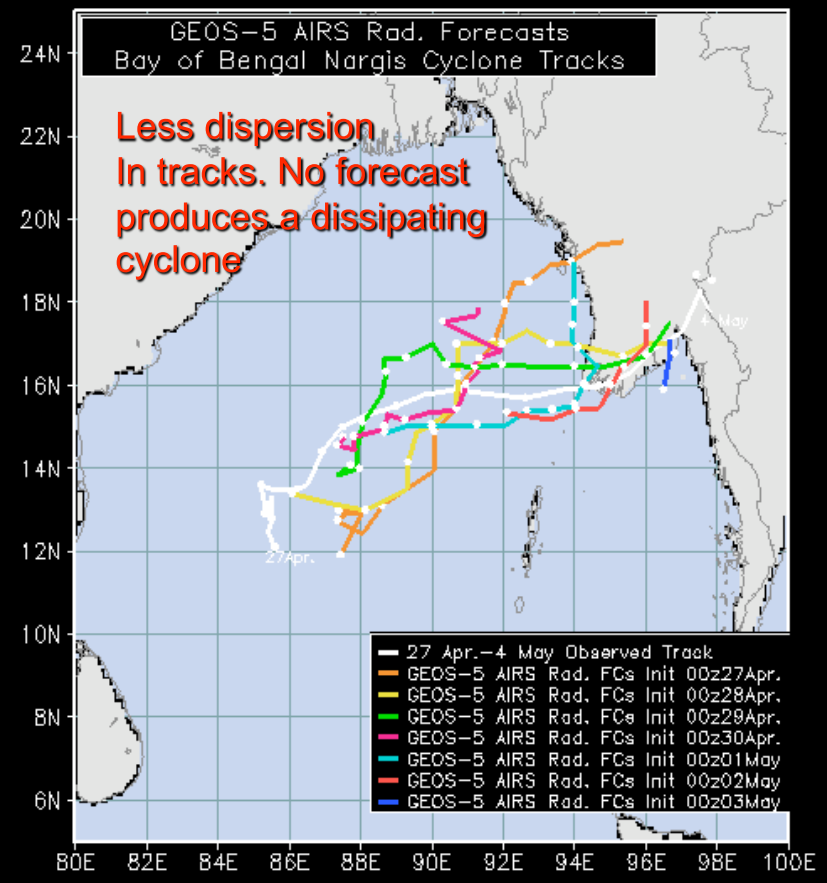
The displacement error in the CNTRL Analysis often exceeds 150km but is substantially mitigated by AIRS.

Very poor forecast track skill in the CONTROL Run

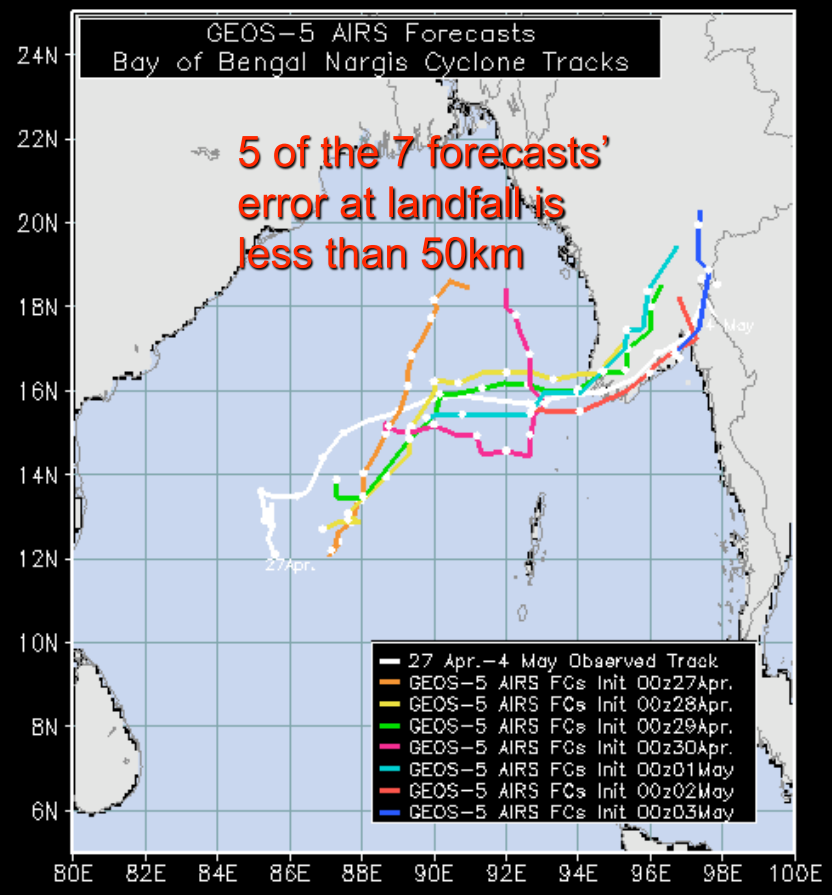


Consequent to poor representation of Nargis in the CNTRL analyses the forecasts initialized with the CNTRL analyses produce large track errors and some do not even produce trackable cyclones

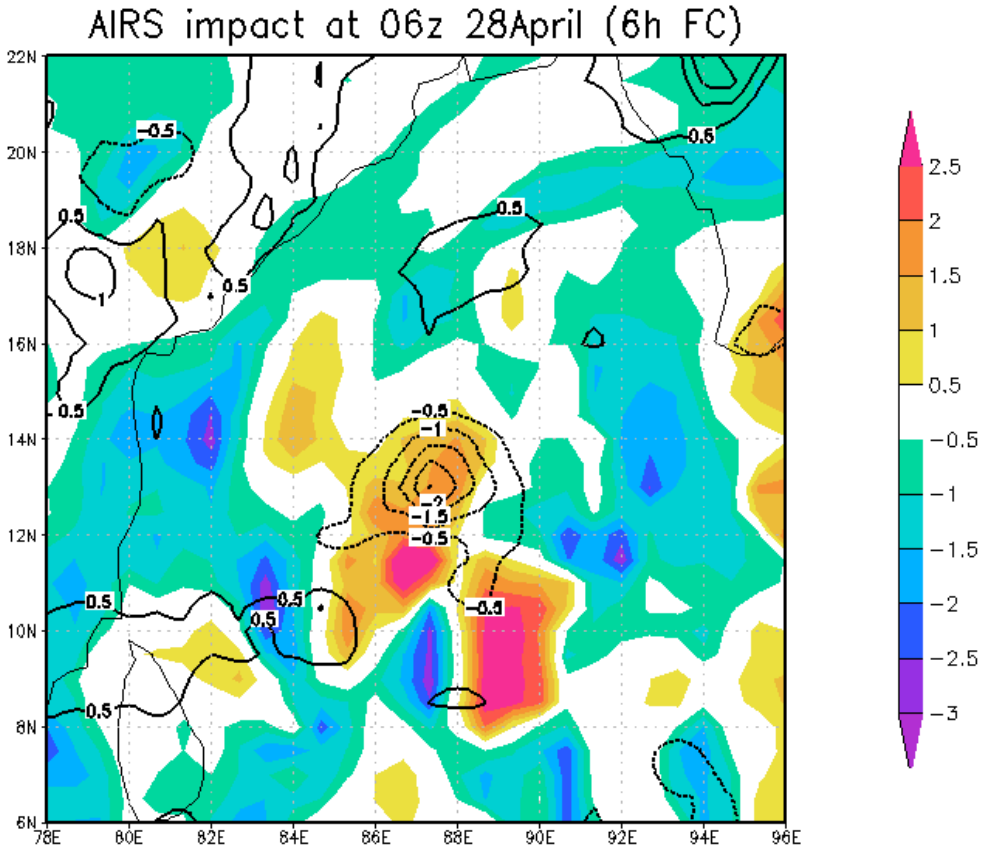
Improved forecast skill in the RAD



Superior Forecast Skill in the AIRS



How AIRS changes the analysis

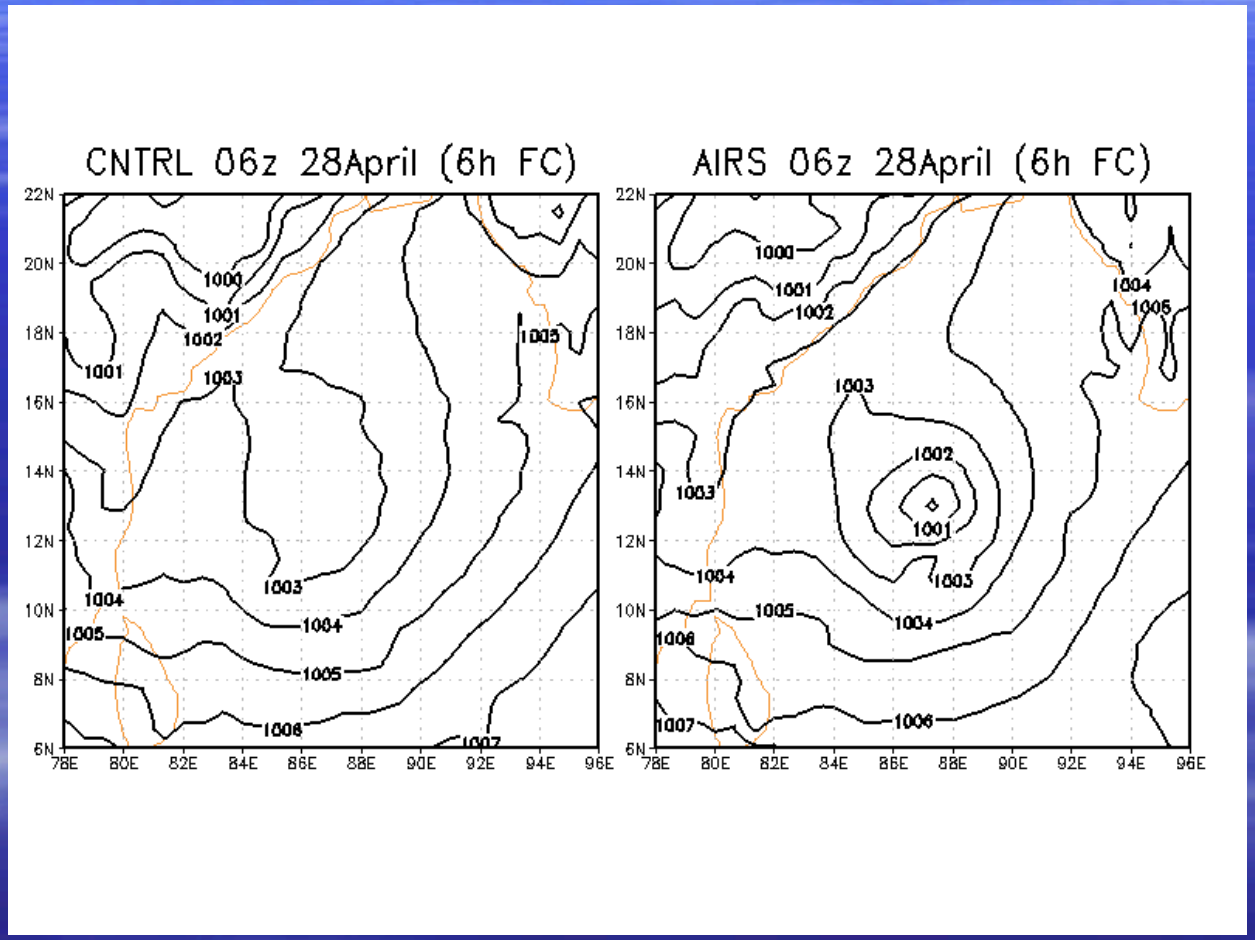


The Upper Level heating induced by AIRS data deepens the low-level cyclonic circulation

Shaded: 200 hPa AIRS minus CNTRL temp anomaly
Contour: AIRS minus CNTRL slp anomaly

To improve the upper tropospheric thermal structure in the tropics is CRUCIAL

CNTRL slp



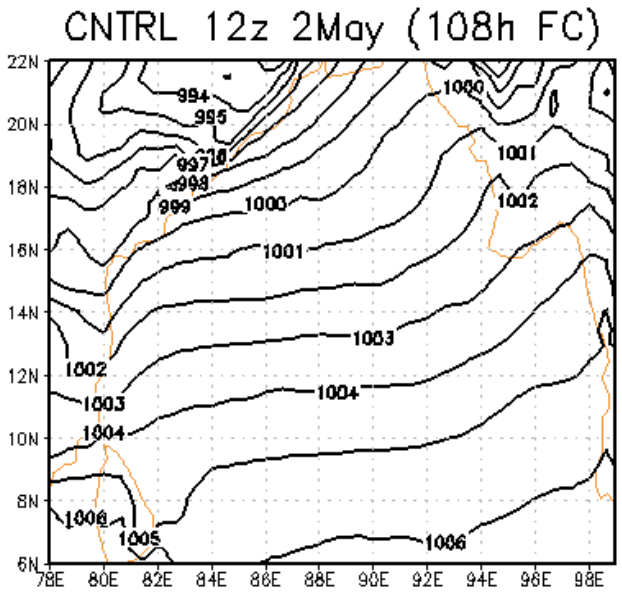
AIRS slp

No Cyclone

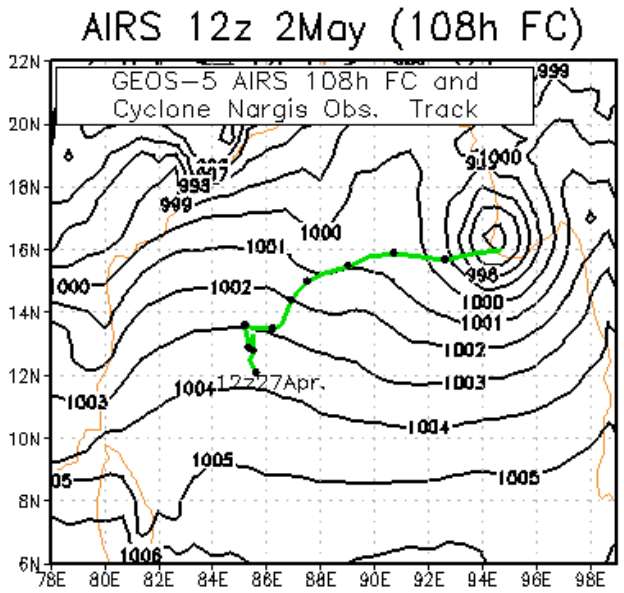
Well-defined cyclone

The forecast originated from the analysis in which AIRS is assimilated gives a 'perfect' landfall (error less than 50km)

CNTRL slp



No Cyclone

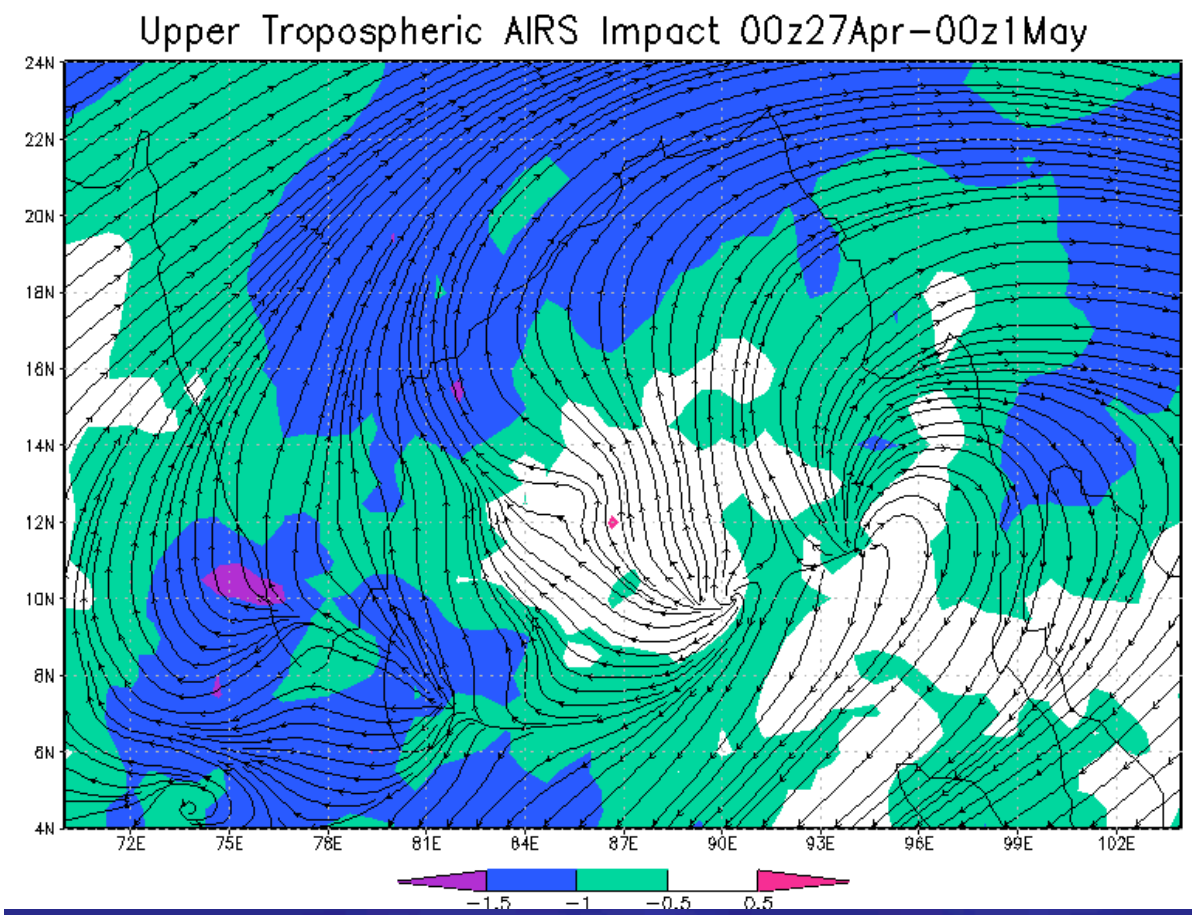


Perfect landfall location
Perfect landfall timing

AIRS slp

Green: Observed Track

AIRS affects the analysis *every* day

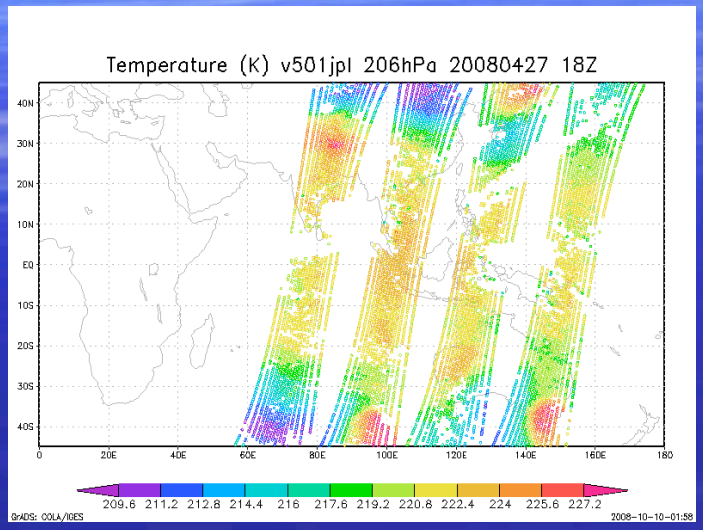


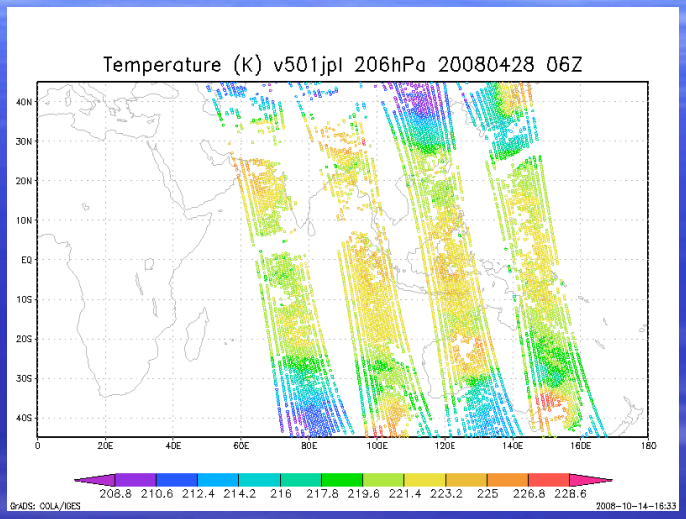
4-day average AIRS minus CNTRL 200hPa temp impact
4-day average mean CNTRL circulation at 200hPa

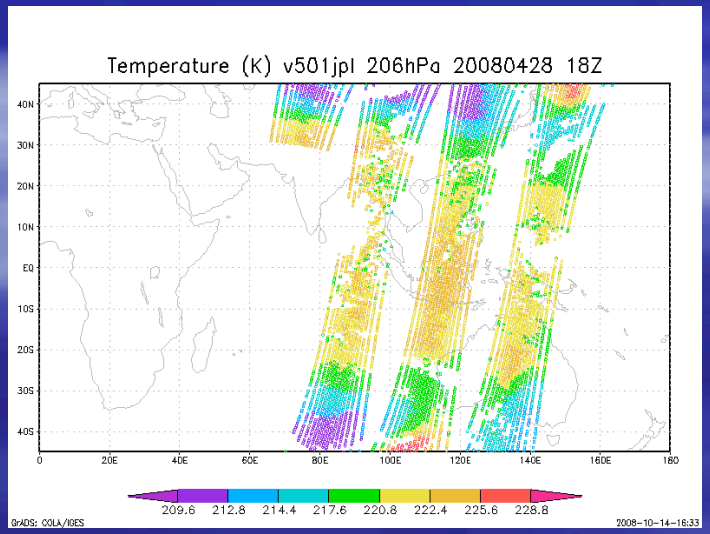
The general impact of AIRS on the analysis in the tropics is a slightly cooler upper Troposphere.

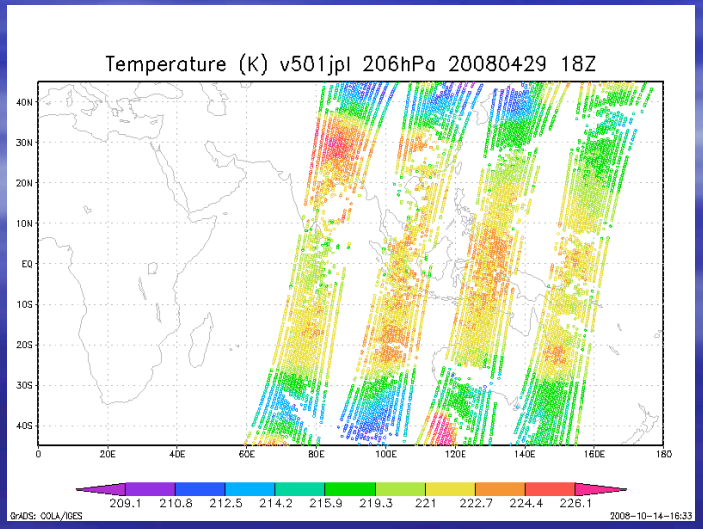
However, throughout the 4 days in which Nargis lingers over the Bay of Bengal, the impact of AIRS defines and isolates a less cool area in the upper Troposphere corresponding to an upper level anticyclonic flow. The upper-troposperic positive thermal anomaly causes sea level pressure to be lower, thus better defining Nargis. Preliminary evidence suggests that the same mechanisms occurs also In other basins.

Coverage over the Bay of Bengal









Summary of .5x.5 AIRS boreal spring (April 15th – May 18th) impact study

- AIRS retrieved temperature profiles in the GEOS-5 assimilation significantly improve the average 500 hPa an. correl. in SHXT , and in the tropics on days 3-5.
- AIRS clear-sky radiances also improve the forecast skill in the SH; negligible(non-negative) impact in the NH and tropics.
- Compensating scarcity of conventional obs, and providing a radically different thermal structure of the upper troposphere (generally cooler, but warmer in correspondence to *organized* convection), AIRS data dramatically improves the analysis of tropical cyclone Nargis
- 5 out of 7 forecasts initialized from the improved analyses have a displacement error at landfall of about 50km

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Ongoing Work

- Further investigation on the four sets of 2.0.2 GEOS-5 runs at 0.5 and 0.25 resolution with/without AIRS with focus over the African Monsoon and Tropical Atlantic region during the SOP-3 NAMMA period. In particular, the role of AIRS in improving the prediction of Tropical Cyclogenesis will be assessed
- More investigation of impacts of:
  - Assimilation of *retrieved temperatures* under partially cloudy conditions in different seasons
  - Assimilation of *clear sky radiances* (in collaboration with Lars P. Riishojgaard and Emily Liu)

Future work

- Assimilation of cloud-cleared radiances (in collaboration with Joel Susskind)
- Assimilate new AIRS version 6 retrievals when available
- Assimilating AIRS moisture retrievals and focus on 0.25 degree TC forecast in the Tropics (similar to [Wu et al., 2006] but from a global perspective)

Special Thanks

- Don Anderson for support through grant MAP/04-0180-0070 on OSEs and OSSEs
- Michele Rienecker and the GMAO for providing the GEOS-5 DAS and the technical support needed
- AIRS team at JPL and the Sounder Research Team at NASA Goddard

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