Exploring the role of correlated errors in the assimilation of adaptively thinned AIRS cloud-cleared radiances

Impact on tropical cyclone analysis and forecast in the NASA GEOS-5

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Outline

- Previous published work showed that assimilation of cloud-cleared retrievals improve representation of high-impact weather systems (Reale et al. 2008; 2009a, 2009b, 2012)
- Investigating problems affecting the assimilation of AIRS radiances as done by operational centers (suboptimal thinning; limitation to clear-sky)
- Assimilation of adaptively-thinned **clear-sky radiances**
- Use of the adjoint-based forecast sensitivity observation impacts (FSOI) methodology (Langland and Baker 2004)
- Assimilation of adaptively-thinned **cloud-cleared radiances to improve TC analysis and forecast**
- Current and Future work

Statement of the problem

Operational assimilation of AIRS radiances and other infrared sensors are affected by 2 problems

1. Horizontally correlated errors "*Increasing the observation density for the uncorrelated-error case can generally improve the analysis and forecast. However, for correlated observation errors…an increase in the observation number...degrades the analysis and the forecast*" (Liu and Rabier 2003)
2. Clear-sky radiances: "*assimilation is limited to channels thought to be unaffected by clouds". This poses a severe limitation to the coverage of high-impact weather systems (Reale et al. 2009, 2012)*

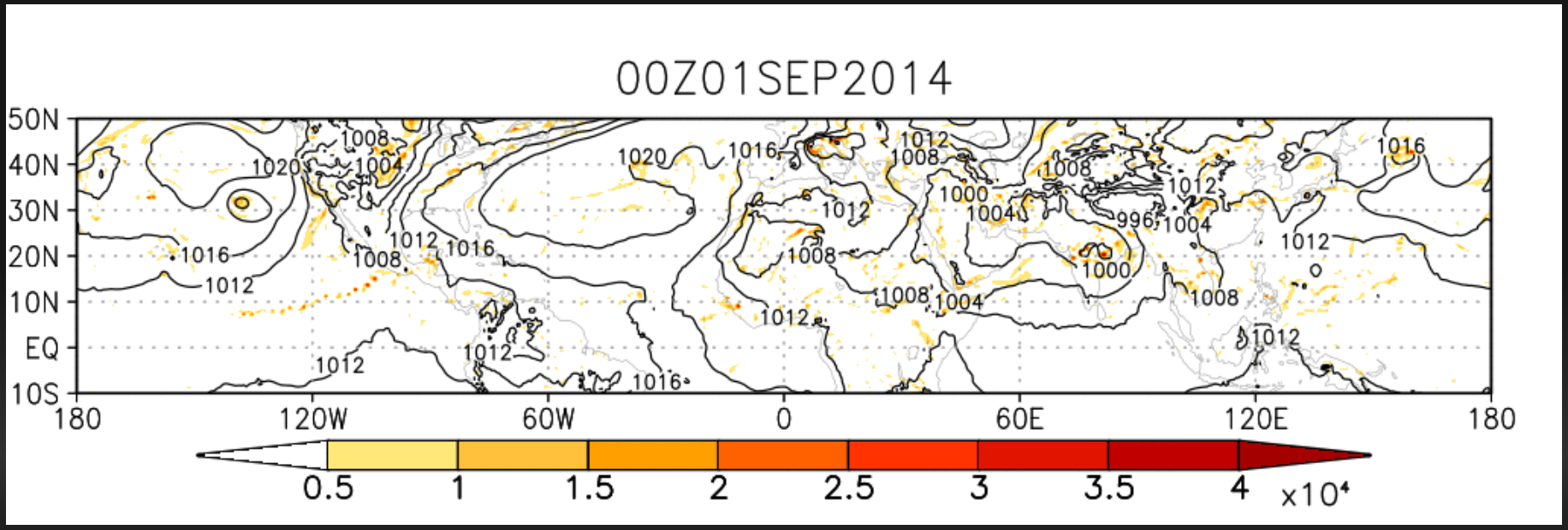
Consequences of these 2 problems and possible solutions

Apparent contrast between the goals of the instrument teams (promotes higher density data sets, better coverage, etc.) with the goals of data assimilation "*A high spatial and/or temporal data density can severely violate the assumption of independent observation errors*" - Ochotta et al. (2005)

Adaptive thinning has been seen as a long time as a possible solution (Morss, Emanuel and Snyder 2001). Many adaptive schemes have been proposed but none have been implemented because of their great complexity

- We have designed a very simple adaptive approach which uses best track or TC vitals data to identify location of worldwide TCs and activate a "TC domain" within which data are assimilated at a higher density and at a lower density elsewhere
- The rejection of data from cloudy areas is particularly detrimental to the forecast of extreme weather or high impact weather systems (Reale et al., 2009, 2012). We have applied the adaptive approach to cloud-cleared radiances as well.

TC domains for adaptive thinning



Shaded: 800 hPa vorticity
Contours: slp

Clear-sky experiments

GEOS-5 DAS version 5-13.0p1 run 1 Sep – 10 Nov 2014 with 10 day forecasts from 21 Sep – 31 Oct 2014

RAD: control experiment, identical to OPS except no vortex relocator, 145 km thinning box

RAD2: 75 km thinning box (~4x data)

RAD3: 300 km thinning box (~1/4x data)

SThin: 75 km thinning box within 15º×15º domain centered on TC, 300 km elsewhere

SThin2: 145 km thinning box within 15º×15º domain centered on TC, 300 km elsewhere

SThin3: 110 km thinning box within 15º×15º domain centered on TC, 300 km elsewhere

SThin4: 75 km thinning box within 7.5º ×7.5º domain centered on TC, 300 km elsewhere

SThin5: 75 km thinning box within 30º ×30º domain centered on TC, 300 km elsewhere

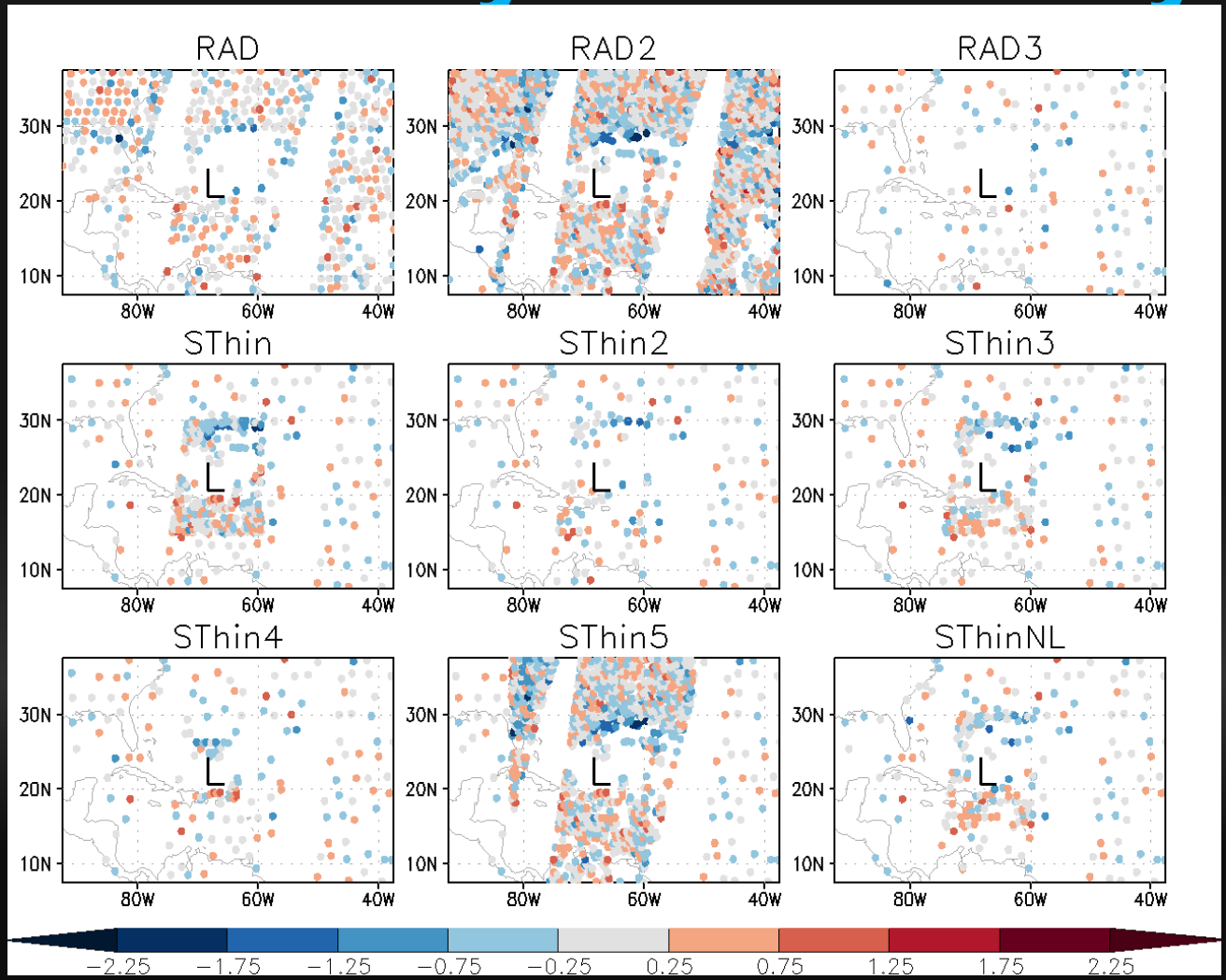
SThinNL: Same as SThin, but no AIRS data assimilated over land

These experiments do not investigate inter-channel correlations, only horizontal correlations

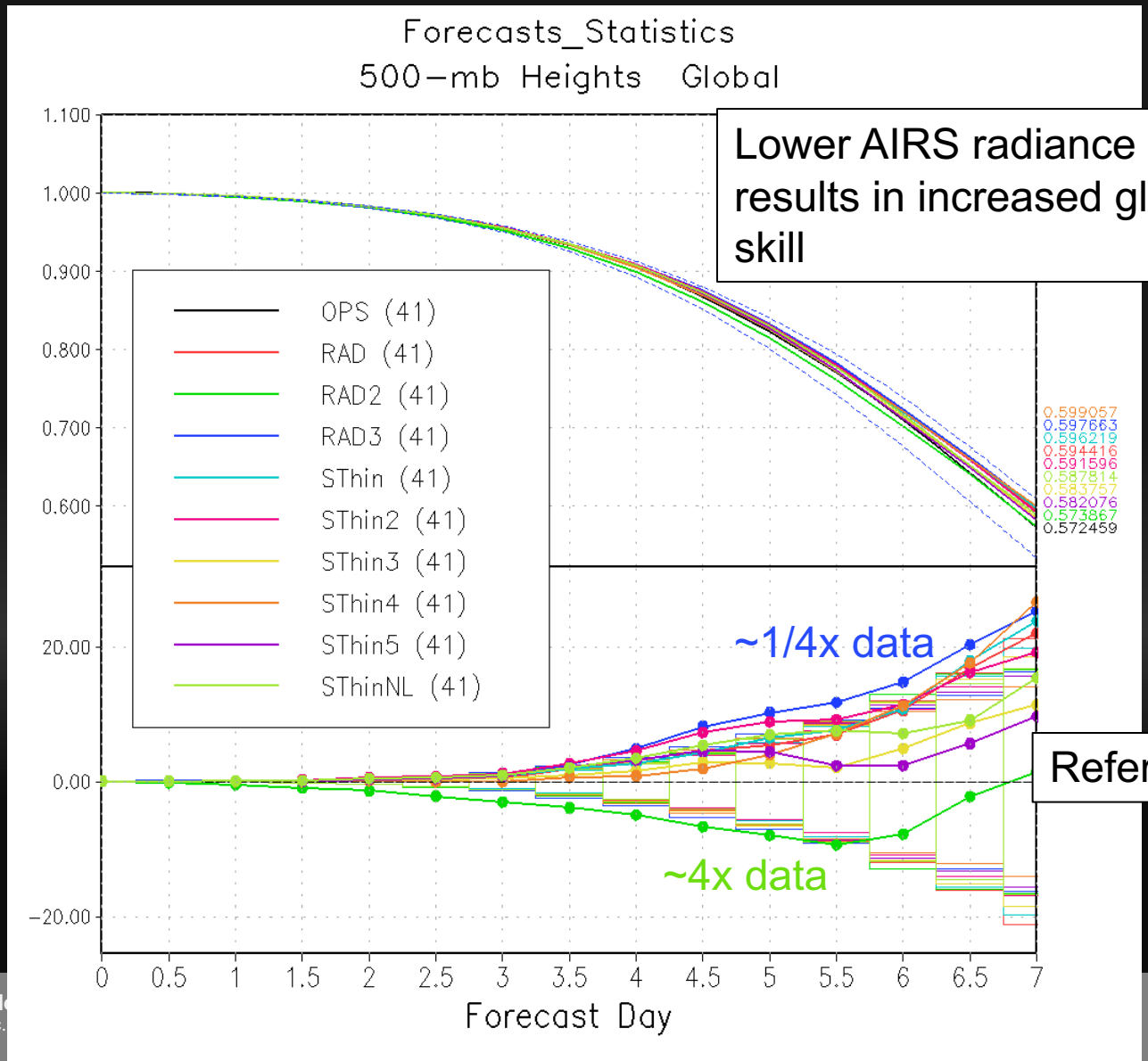
Clear-sky data density

Bounding

Adaptive Thinning



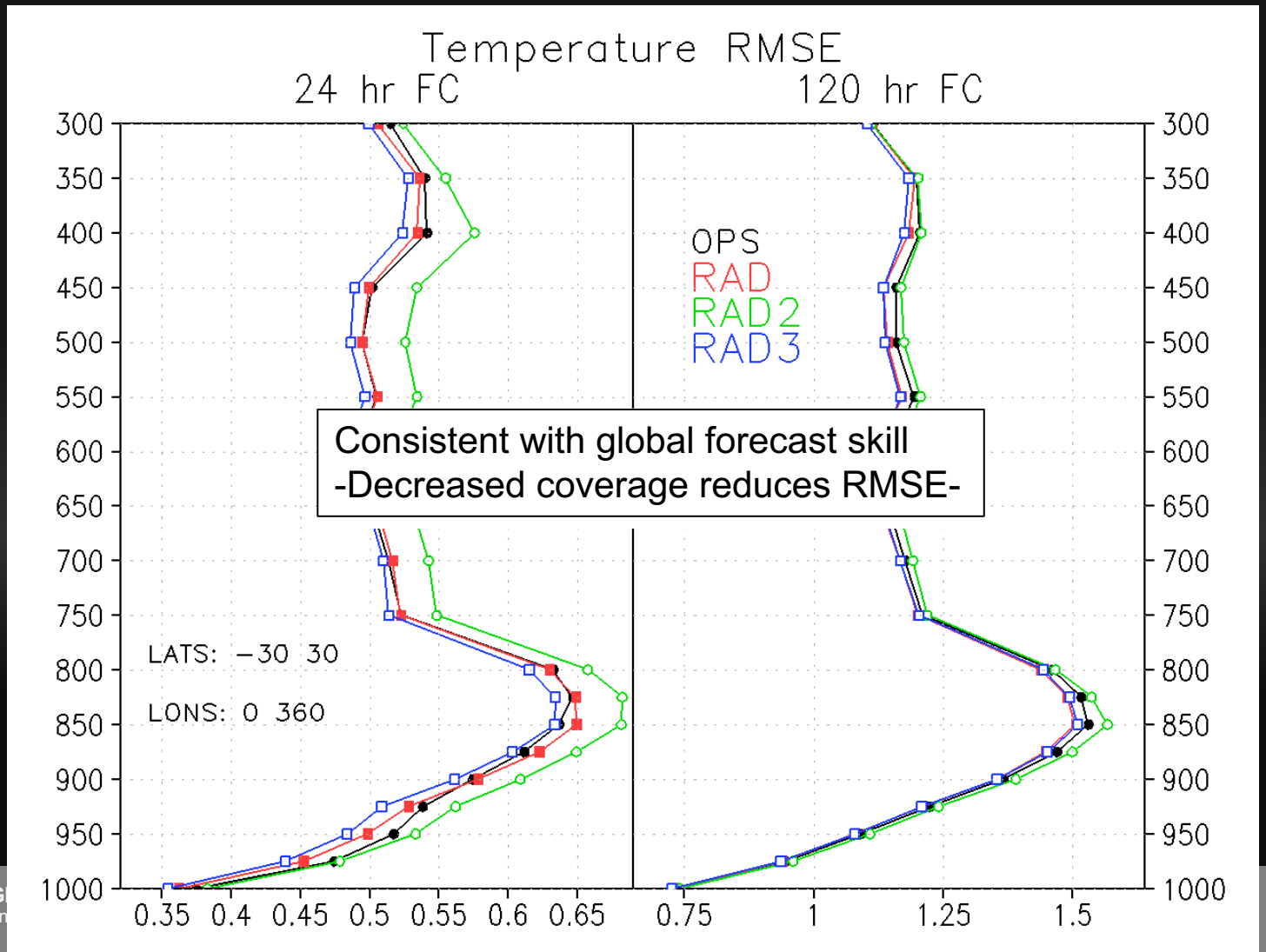
Global 500 hPa height anomaly correlation



Lower AIRS radiance data density results in increased global forecast skill

Reference = OPS

Tropical (30ºS - 30ºN) Temp. RMSE

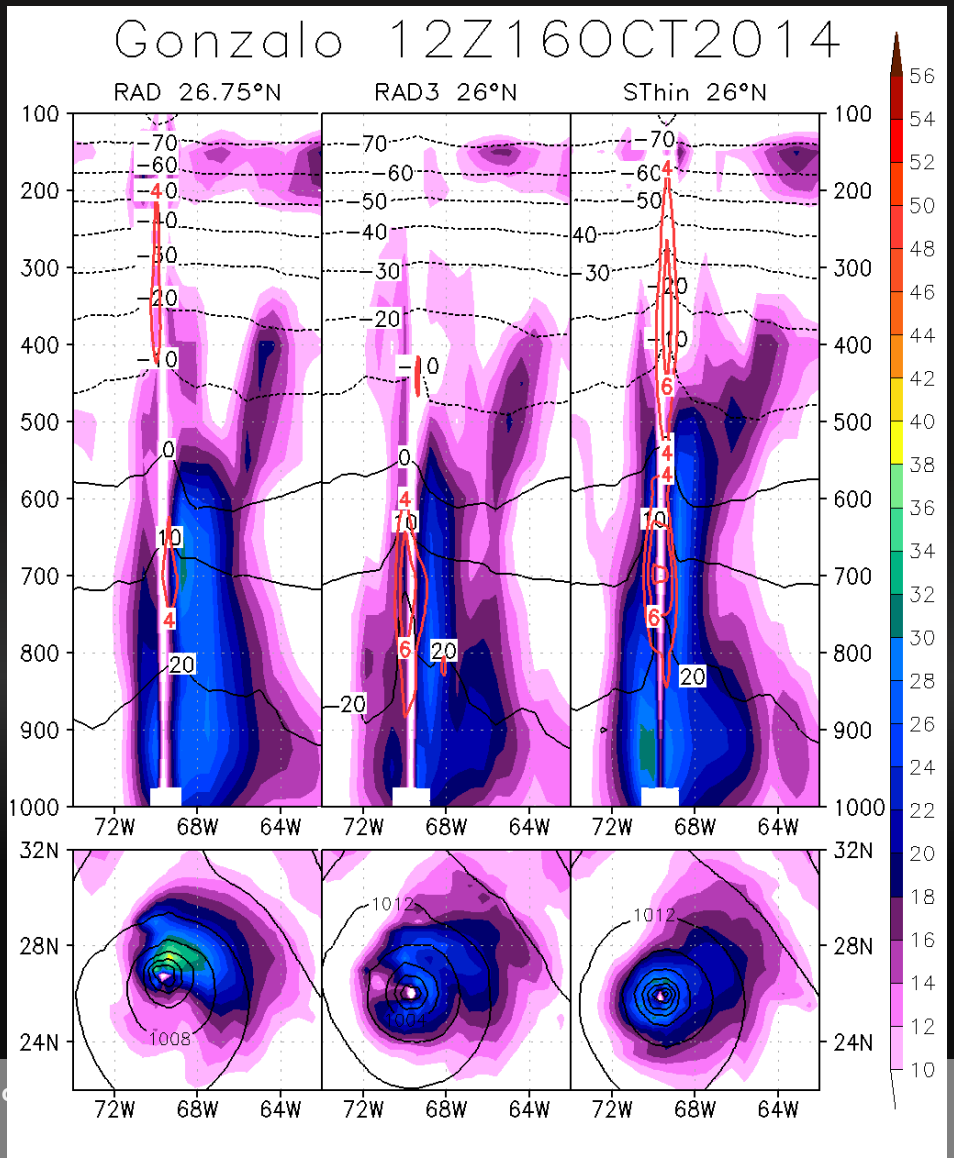


H. Gonzalo analysis

RAD shows reasonable structure, but too asymmetric

RAD3, while improving global forecast skill, degrades storm structure

Adaptive thinning shows increased warm core and symmetric structure while maintaining global forecast skill



Vertical cross section
Wind magnitude (shaded)
Temperature (ºC, black)
Temp. Anomaly (ºC, red)

850 hPa winds (shaded)
slp (contours)

Use of the adjoint of the forecast model

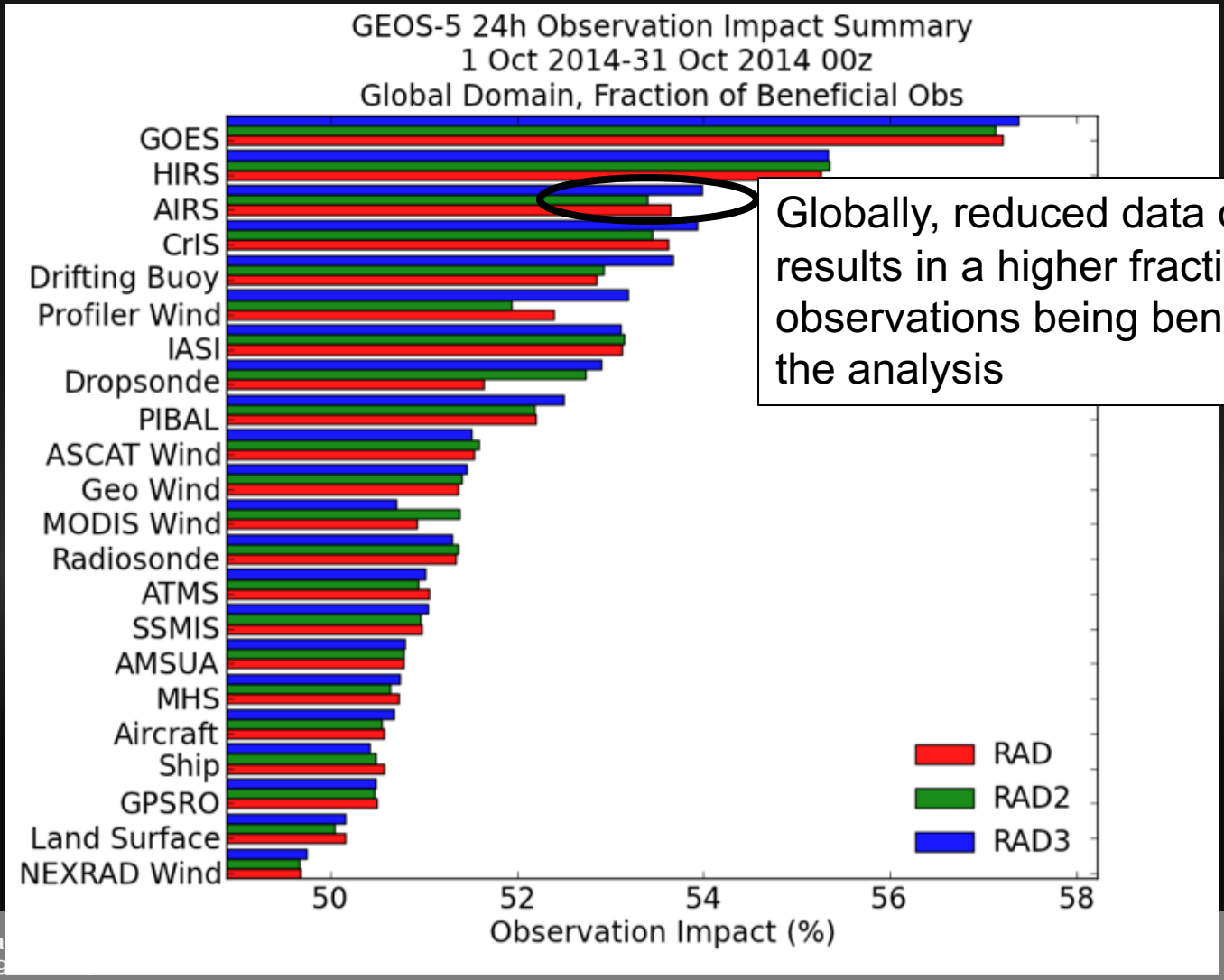
AIRS radiance errors seem to be globally correlated at the current operational thinning levels

The greater forecast skill of RAD3 (less dense coverage) relative to RAD2 (denser coverage) suggests that errors are less correlated in RAD3 globally.

However, the fact that higher data density is beneficial around TCs, suggests that error correlations are much smaller on TC scales

We use the adjoint of the forecast model to further investigate this possibility, following Gelaro and Zhu (2009) and Gelaro et al (2010).

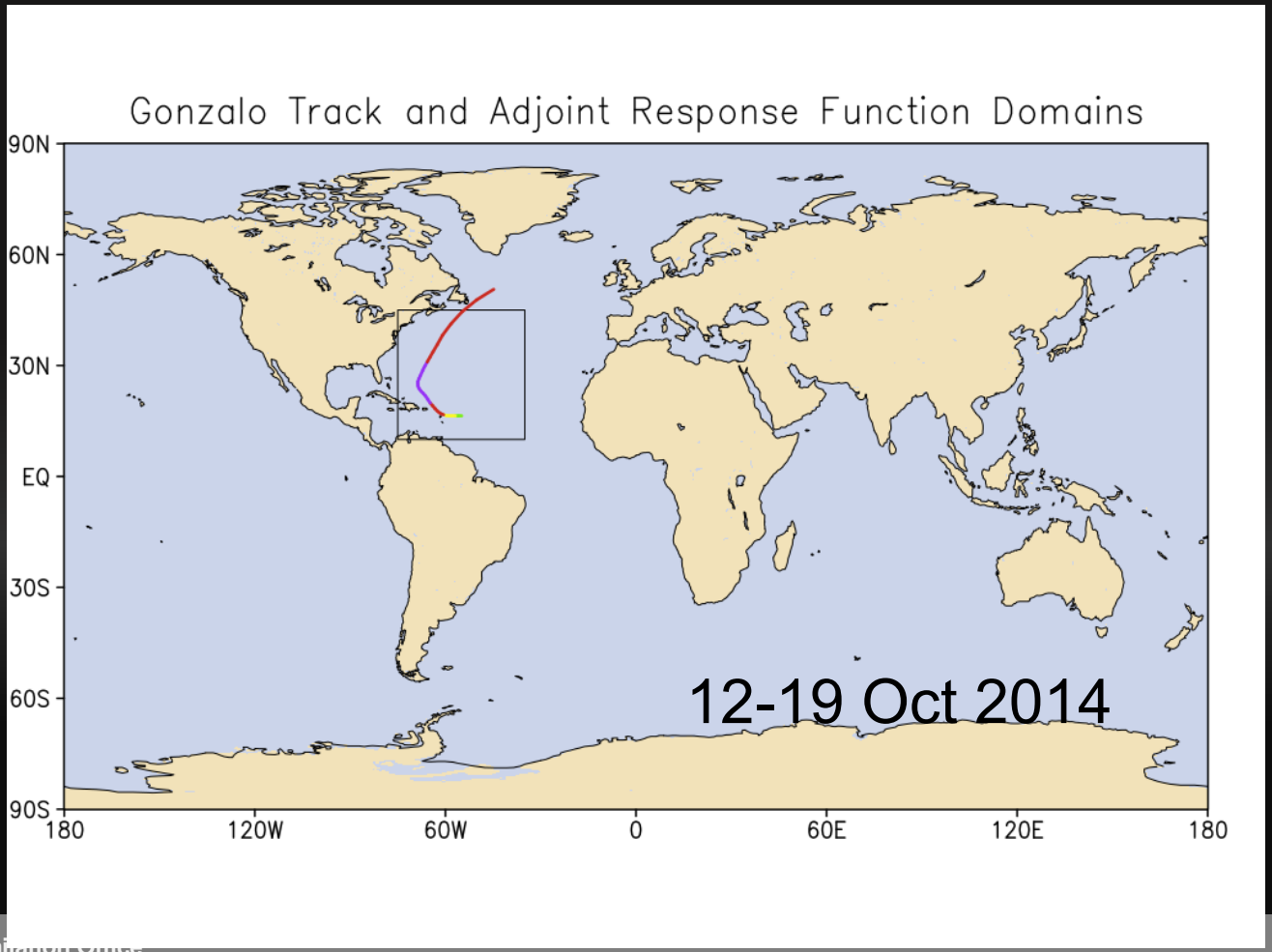
Clear-sky global adjoint results



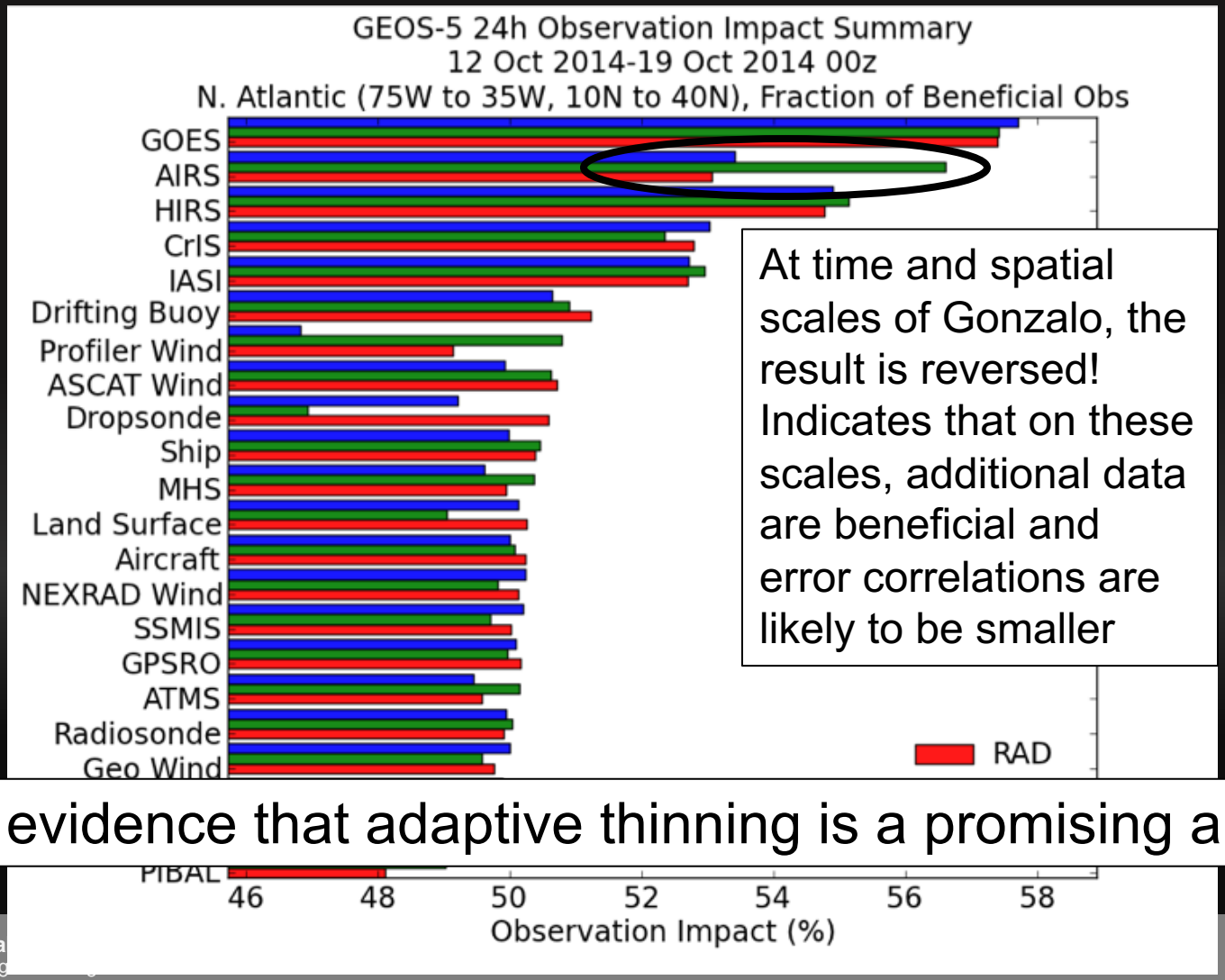
Globally, reduced data density results in a higher fraction of observations being beneficial to the analysis

Adjoint response on TC scale

To justify use of adaptive thinning, compute the fraction of beneficial observations on the spatiotemporal scale of a TC



Clear-sky, regional adjoint results



At time and spatial scales of Gonzalo, the result is reversed! Indicates that on these scales, additional data are beneficial and error correlations are likely to be smaller

Further evidence that adaptive thinning is a promising approach

Potential of cloud-cleared radiances

Prior work has shown potential of assimilating AIRS retrievals over partially cloudy regions to improve global forecast skill, TC intensity, and extreme precipitation forecasting (Reale et al., 2009a,b,2012)

Resistance from the operational community to consider retrievals

Cloud-cleared radiances have been available through the GSFC DAAC for more than a decade

However, very few successful attempts to assimilate AIRS cloud-cleared radiances are documented (e.g., Pangaud et al. 2009)

Evidence that the error correlation of cloud-clear radiances could be radically different from clear-sky

Cloud-cleared experiments

GEOS-5 DAS version 5-13.0p1 run 1 Sep – 10 Nov 2014 with 10 day forecasts from 21 Sep – 31 Oct 2014

CLD: identical to RAD except uses cloud-cleared AIRS radiances, 145 km thinning box

CLD2: 75 km thinning box (~4x data)

CLD3: 300 km thinning box(~1/4x data)

SThin_CLD: 75 km thinning box within 7.5º×7.5º domain centered on TC, 300 km elsewhere

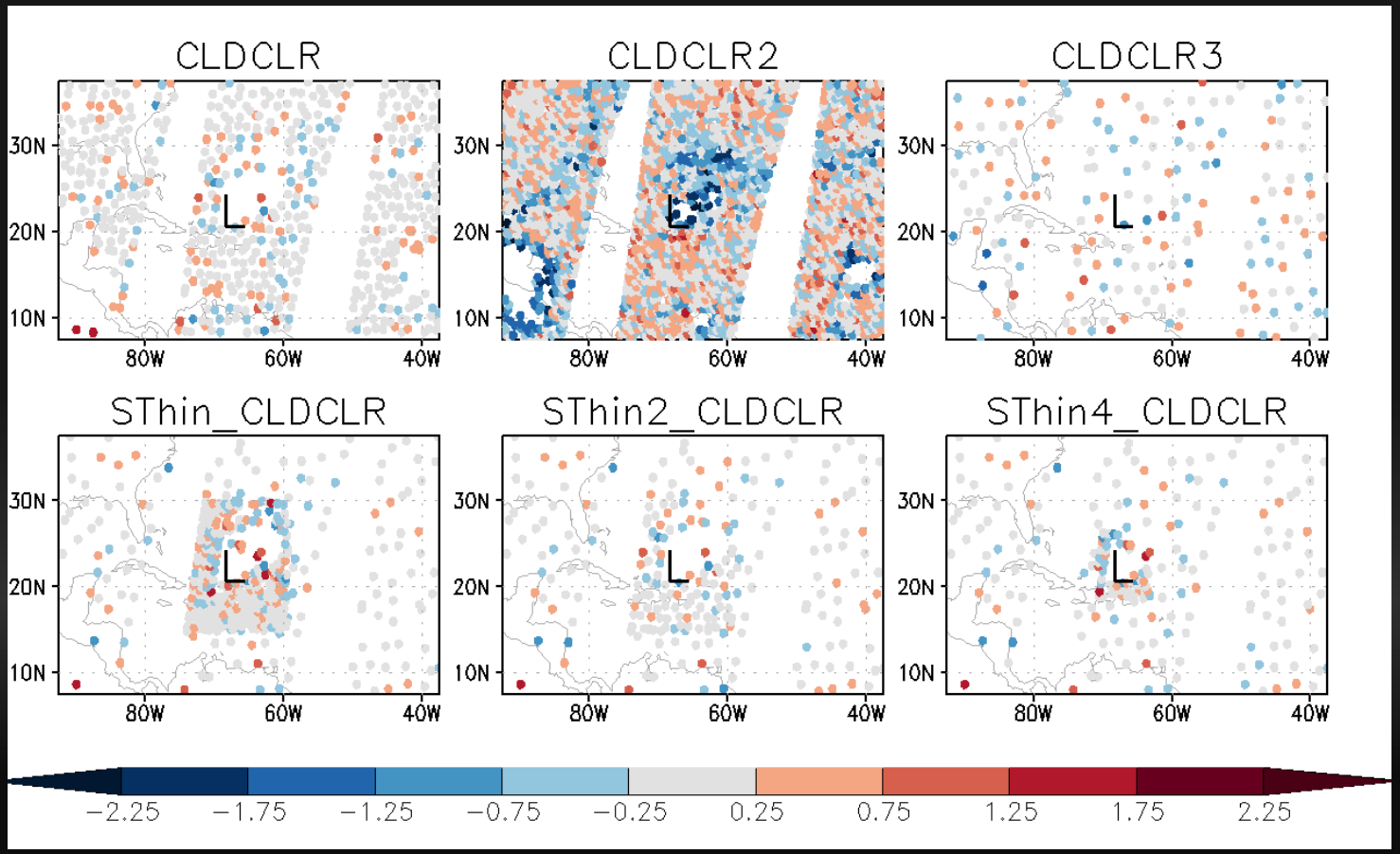
SThin2_CLD: 145 km thinning box within 7.5º×7.5º domain centered on TC, 300 km elsewhere

SThin4_CLD: 75 km thinning box within 3.75º×3.75º domain centered on TC, 300 km elsewhere

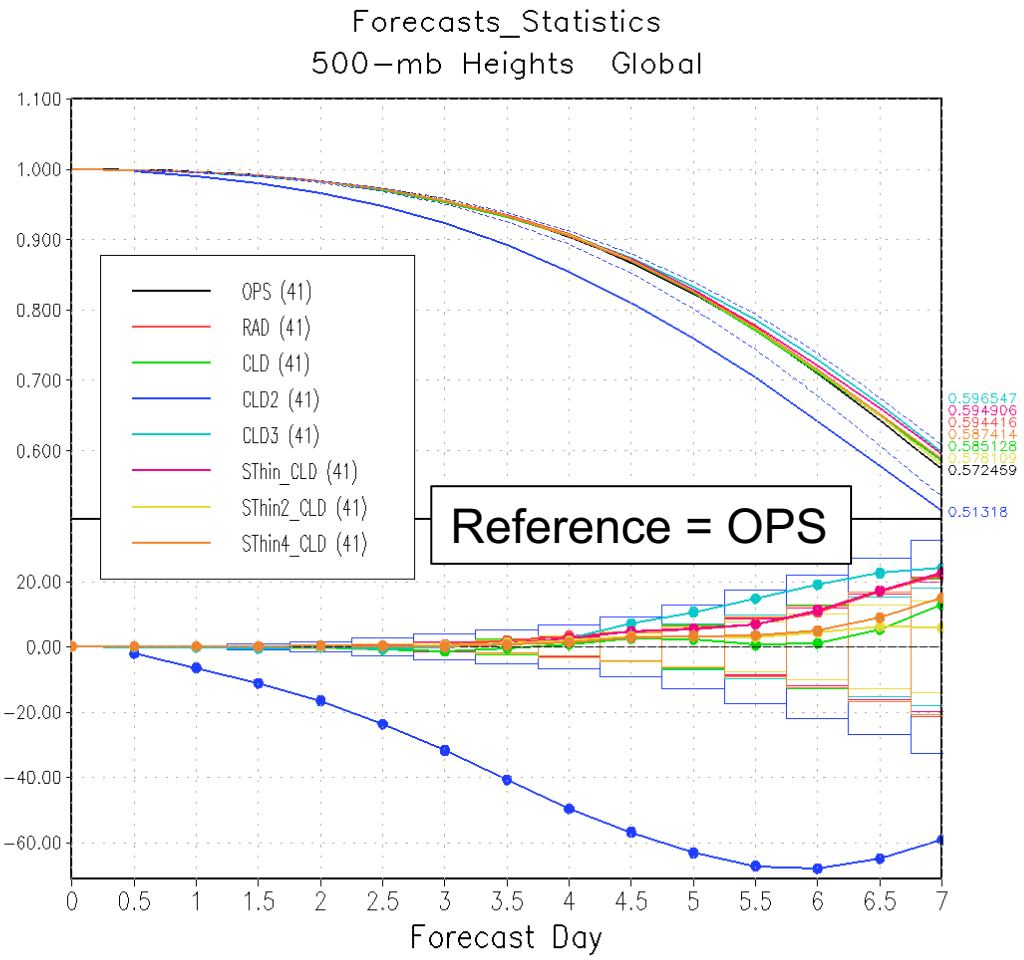
Cloud-cleared data density

Bounding

Adaptive Thinning



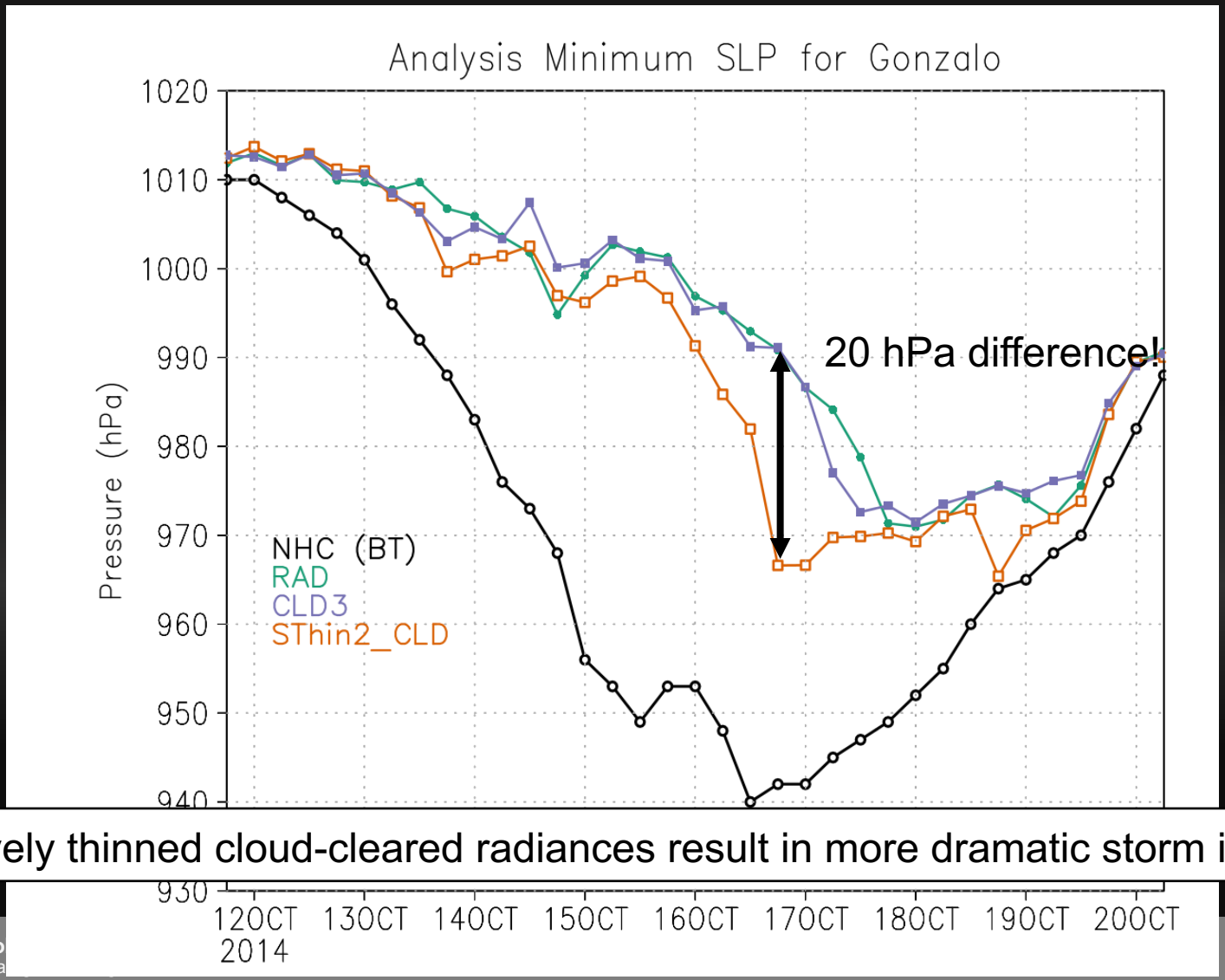
Global 500 hPa height anomaly correlation



Forecast skill of CLD3 (much greater thinning) is similar to RAD

Cloud-cleared AIRS radiances must be thinned much more aggressively to avoid degrading global forecast skill

H. Gonzalo analysis



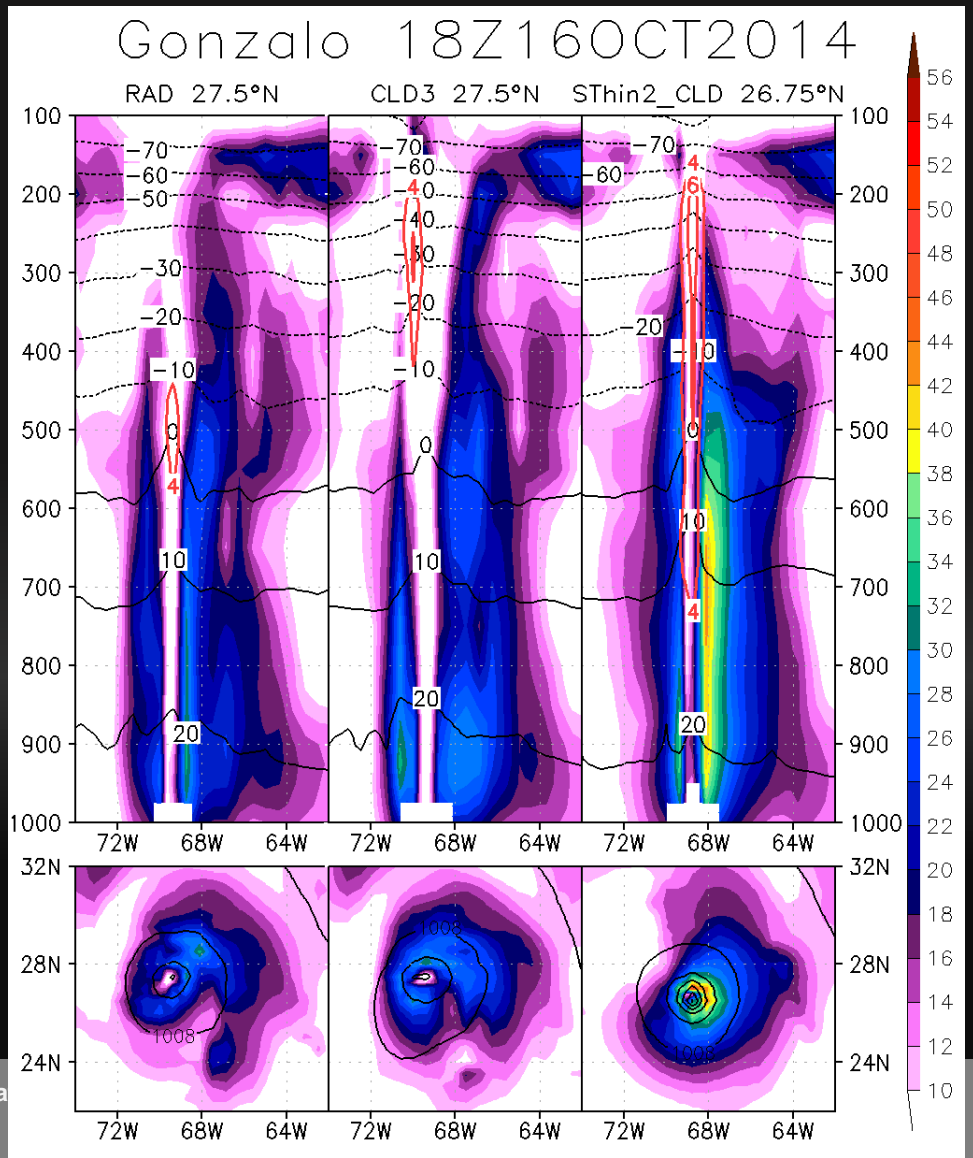
Adaptively thinned cloud-cleared radiances result in more dramatic storm intensificatio

H. Gonzalo analysis

Adaptive thinning results in dramatic improvement structure

- 15 m s^{-1} wind speed increase
- Stronger warm core
- Narrower circulation

Data within the “TC domain” is less dense than was used in the clear-sky results, with a larger improvement!



Vertical cross section
Wind magnitude (shaded)
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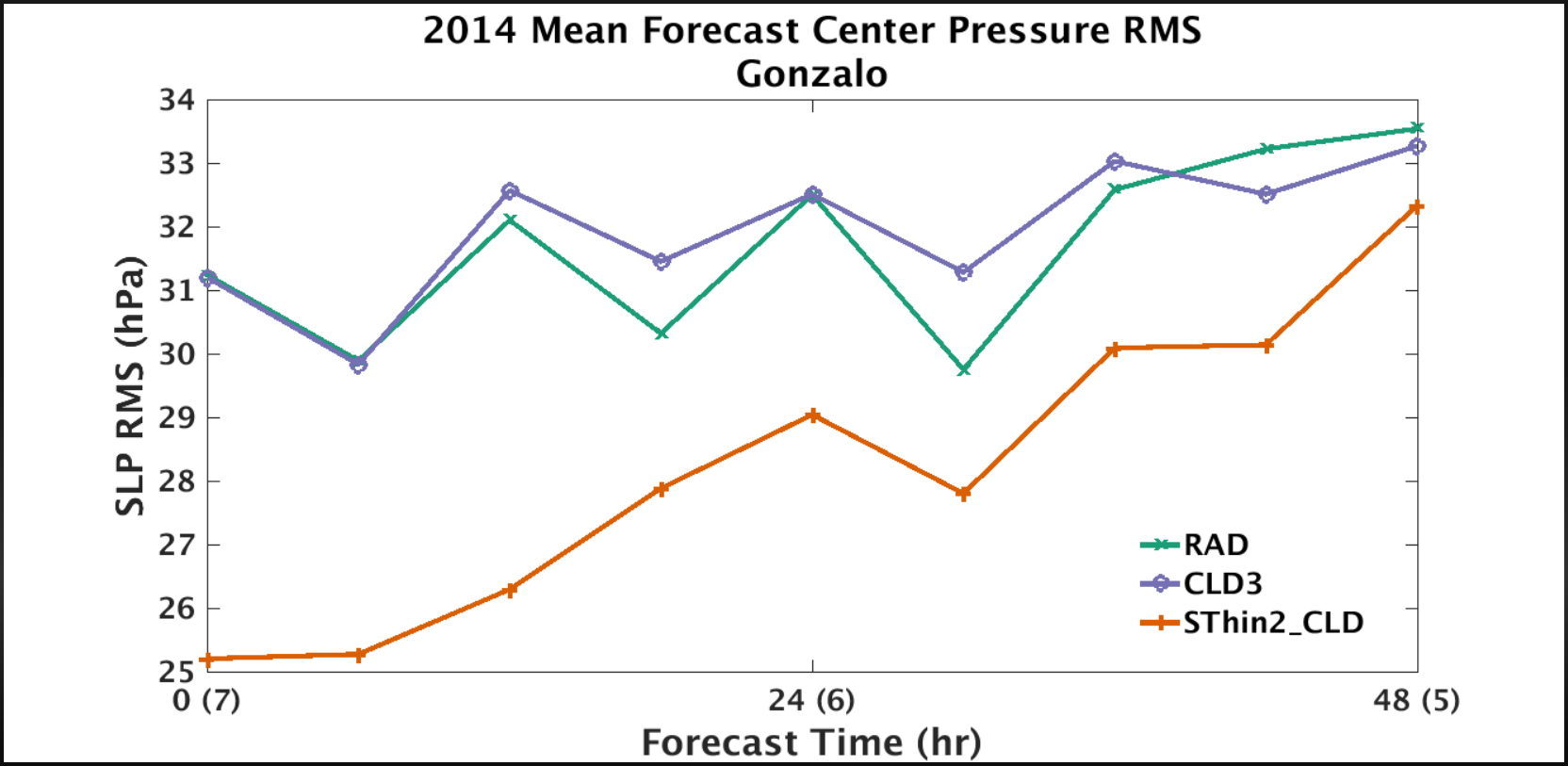
H. Gonzalo intensity forecast



Intensity forecast improve up to 48 hours when using adaptively thinned, cloud-cleared AIRS radiances

Summary

In agreement with Liu and Rabier (2003), we corroborate the understanding that error correlation is very important in the assimilation of AIRS radiances and that regular thinning is not a good choice

A very simple, easy to implement operationally,

TC-centered adaptive approach for AIRS is tested and found very beneficial in the assimilation of both clear-sky and cloud-cleared radiances.

AIRS cloud-cleared radiances are a **superior product,** improve global skill and should be used operationally, as long as they are thinned to at least ~1/4 the density of clear-sky or more.

Adaptive thinning of cloud-cleared radiances further improves TC analysis without damage to global skill (and without the need of a vortex relocator)

Current and future work

Currently investigating the impact of error correlation between instruments (AIRS, CrIS and IASI). We found evidence that the operational use of infrared radiances is affected by this problem [next talk]

Future: Investigating potentials of cloud-cleared CrIS radiances

Design adaptive thinning methodology for AIRS+CrIS+IASI together with the final goal of designing a comprehensive adaptive strategy for all infrared sensors in the GEOS-5.

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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.

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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.

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