Impact of Assimilating Adaptively Thinned AIRS Cloud-Cleared Radiances in the GEOS

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Outline

1. Short summary of work on AIRS published in 2018: Impact of adaptively thinned AIRS cloud-cleared radiances (CCRs) on TCs and global skill with GEOS 3DVAR (2014 TC season, from Sep 1st to Nov 10th)
2. Impact of AIRS CCRs on the analyzed temperature structure over the Arctic region
3. Adaptive thinning strategy tested on other sensors (CrIS and IASI)
4. New experiments with the Hybrid 4DEnVar GEOS system (2017 TC season)

Part 1
Adaptive Thinning

- Clear-sky infrared satellite observations are uniformly thinned globally prior to assimilation to reduce computational cost and the incidence of horizontal error correlation
- Liu and Rabier (2003), in a theoretical framework, found that "increased observation density with uncorrelated errors always increases the analysis accuracy"; however, "an increase in observation density degrades both the analysis and forecast if the error correlation between adjacent observations is greater than a certain threshold"
- Several studies have shown that adaptive thinning (with fewer observations in slowly evolving inactive areas, and more observations within rapidly evolving features characterized by steep gradients) could substantially improve both the analysis and the forecasts (e.g. Ochotta et al., 2005, Lazarus et al., 2010). However, "a suboptimal analysis is often a necessary choice because of the difficulty and cost" (Bondarenko 2007).
- A very simple TC-centered adaptive thinning approach, assimilating additional observations in a moving domain activated by Tropical Cyclone tracks, is presented

Two major findings

Published in August 2018, article summarizing the improvements obtained by assimilating *adaptively thinned AIRS cloud-cleared radiances* over *homogeneously thinned clear-sky radiances.*

Reale, O., E. McGrath-Spangler, W. McCarty, D. Holdaway, R, Gelaro, 2018: Impact of adaptively thinned AIRS cloud-cleared radiances on tropical cyclone representation in a global data assimilation and forecast system. *Weather and Forecasting, 33, 908-931.*

1. Assimilation of cloud-cleared AIRS radiances is a substantial improvement relative to clear-sky because the areas affected by clouds are meteorologically more active. However, CCRs must be thinned more aggressively because of higher information content

2. Assimilating *more data around TCs (small scale, strong gradients and rapid evolution)* and *less globally*, improves TC structure and intensity forecast, without damaging global skill.

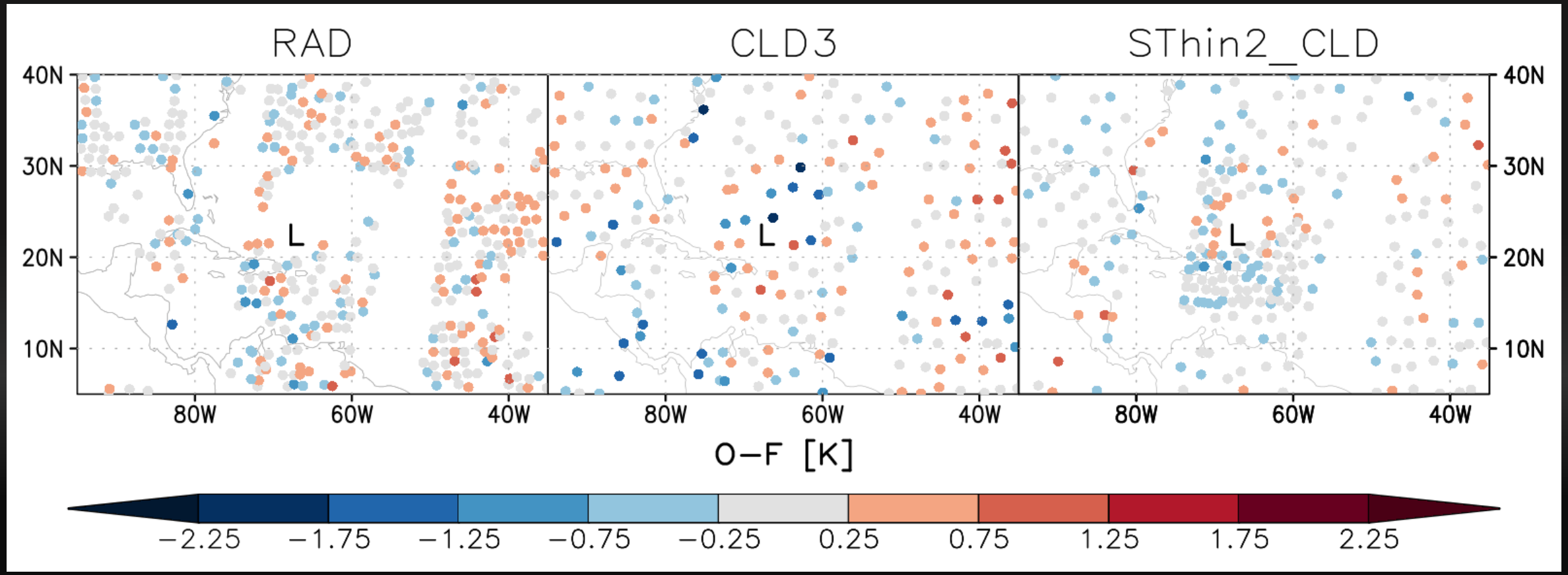
Experiments setup

GEOS, version 5.13, using 3DVar data assimilation of all operational observations, simulating boreal fall 2014, differing only on AIRS data types or thinning

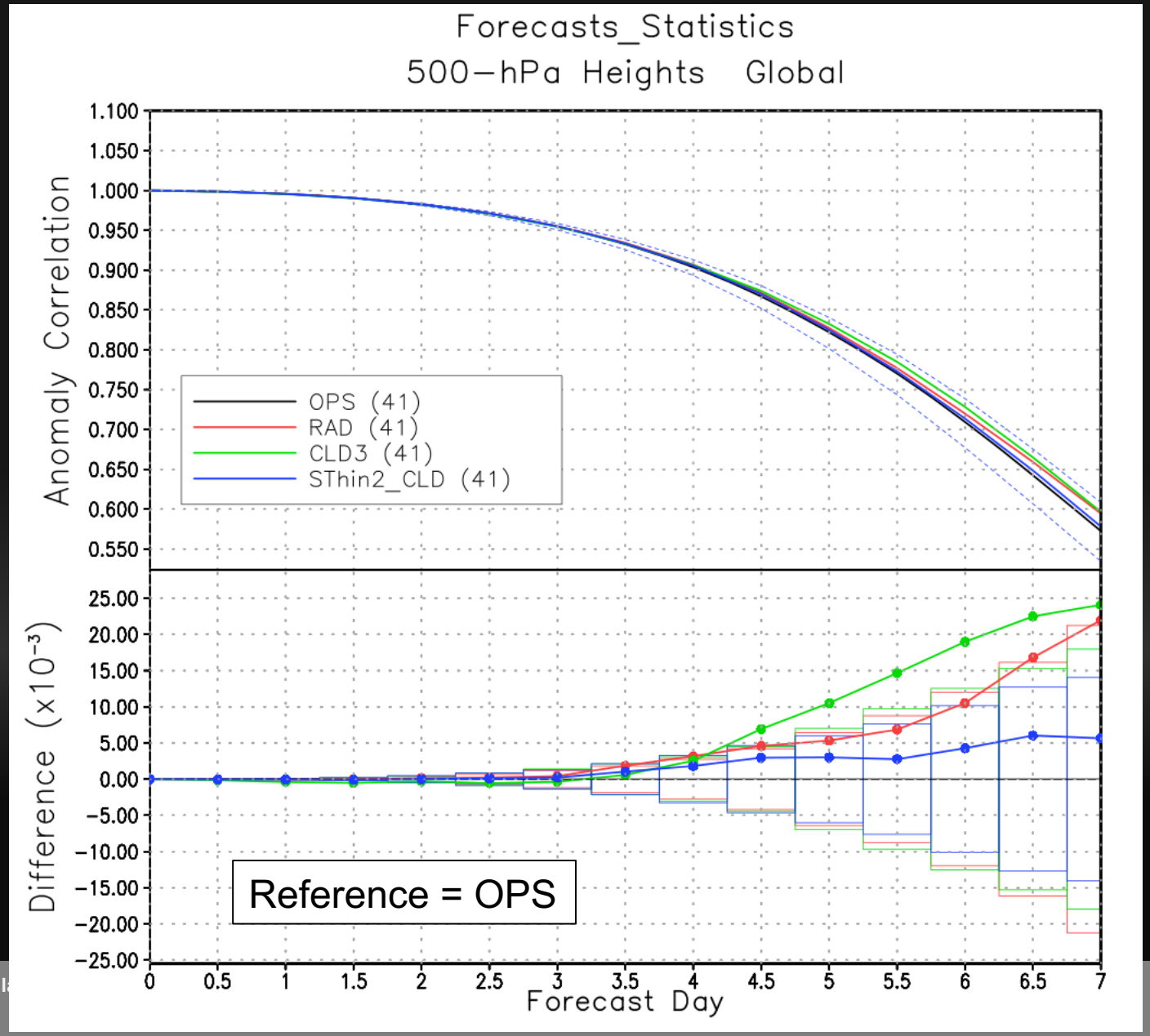
60 daily 10-day forecasts initialized at 00Z starting Sep 10th until Nov 10th

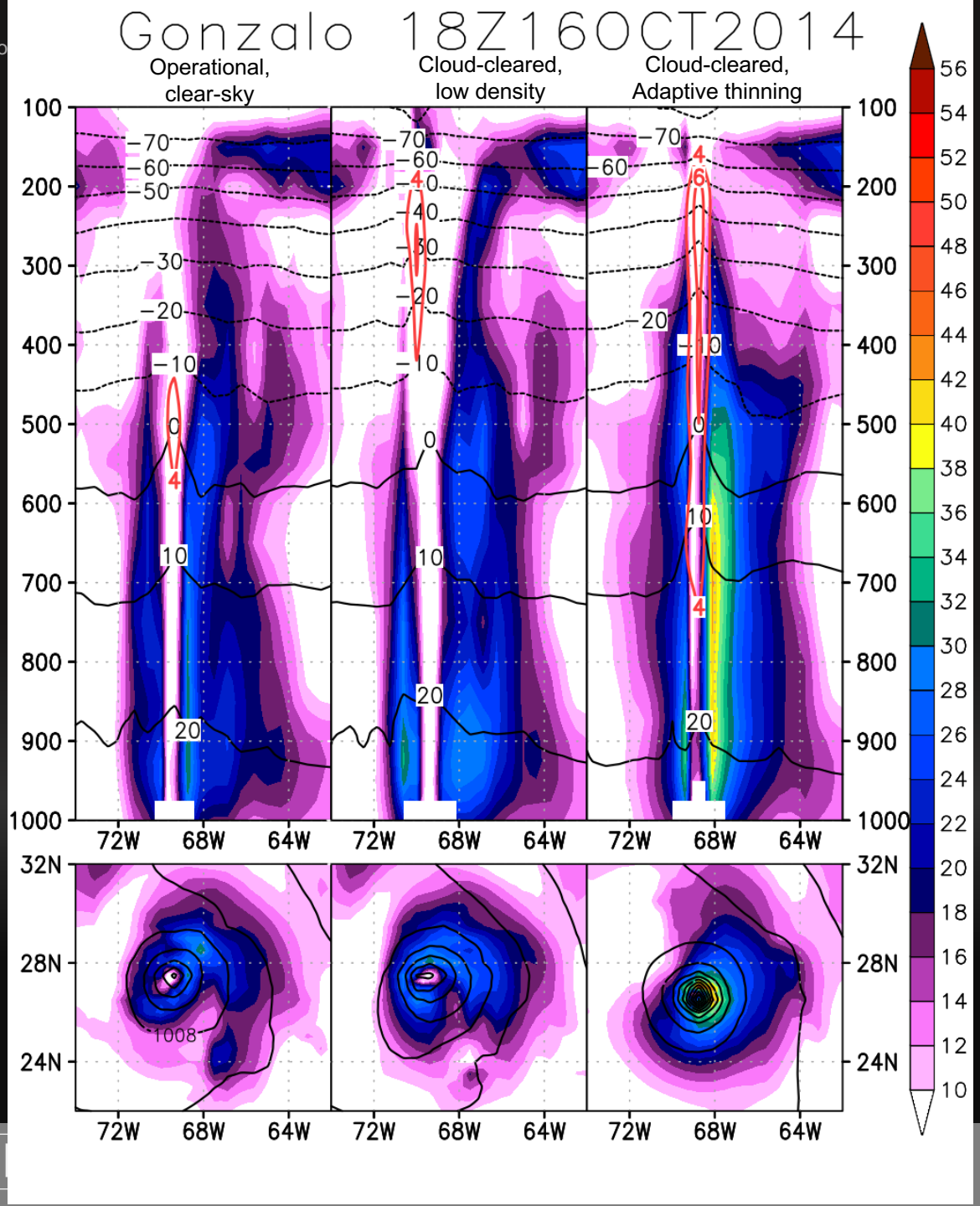
- OPS: Clear-sky AIRS radiances, version used quasi-operationally by the GMAO
- RAD: Clear-sky AIRS radiances, equivalent to OPS except with the vortex relocator turned off
- CLD3: Cloud-cleared AIRS radiances, globally assimilated at about ¼ of clear sky density
- SThin2_CLD: Cloud-cleared AIRS radiances, adaptively thinned with lower global density, but higher density surrounding TCs using a moving `TC' domain that is activated with TC-vital or Best Track information
- SThin2CLD_SThin2CrIS_SThin2IASI: Cloud-cleared AIRS radiances AND clear-sky CrIS and IASI radiances assimilated using adaptive thinning, a comprehensive thinning approach for ALL hyperspectral infrared radiances

Density of AIRS coverage around Hurricane Gonzalo (2014)



Global 500 hPa height anomaly correlation





- # H. Gonzalo (2014)
  - Vertical cross section: Wind magnitude (shaded), Temperature (°C, black), Temp. Anomaly (°C, red)
  - 850 hPa winds (shaded), slp (contours)

Homogenously thinned cloud-cleared radiances (CLD3) improve the global skill but not TC structure

Adaptively thinned cloud-cleared radiances produce large improvements in vertical and horizontal TC structure, without degrading the global skill

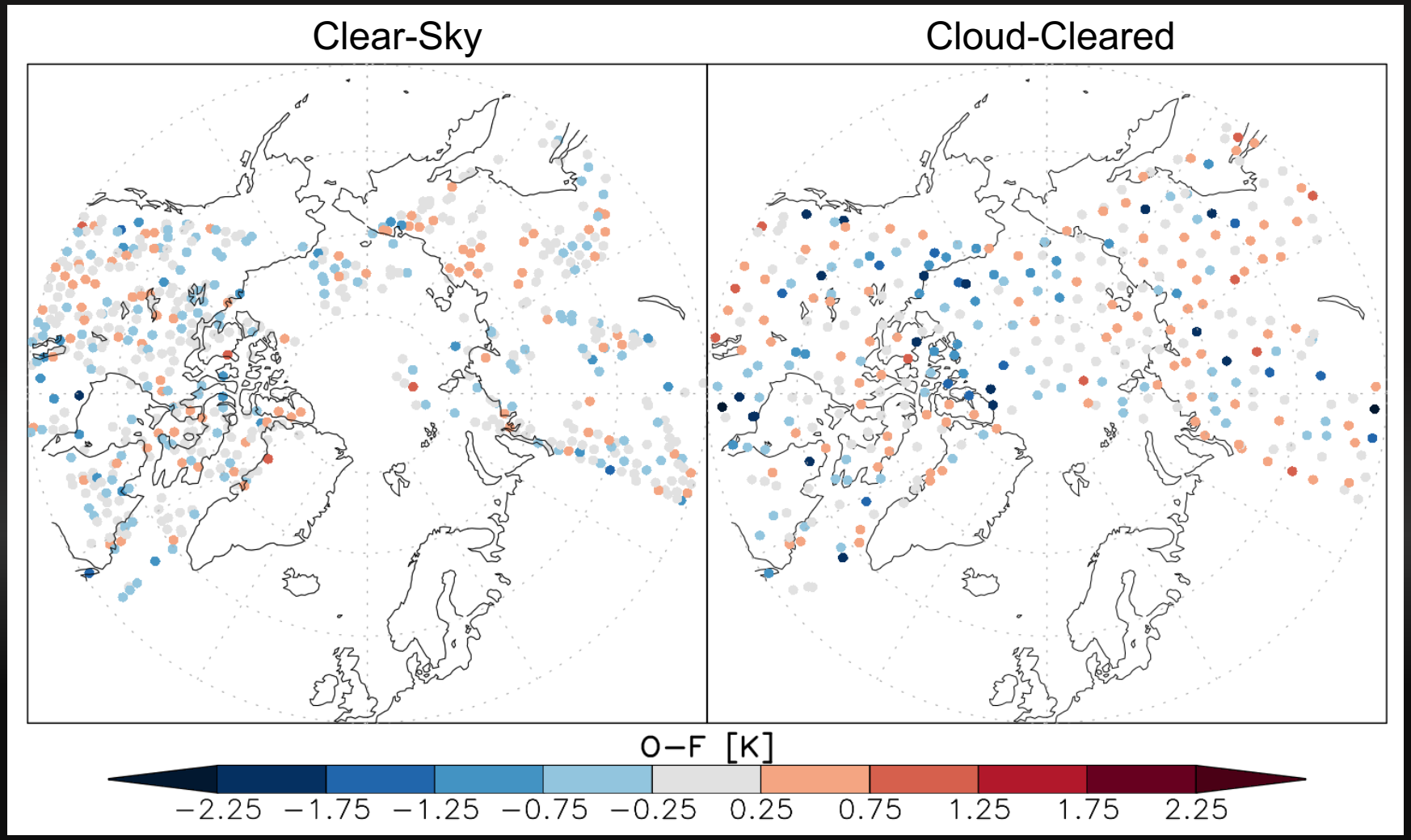
Specifically: more compact scale, stronger wind speeds, lower minimum pressure, stronger warm core

Limits: only TCs with good AIRS coverage were affected; TCs with very short lifespans were difficult to improve

Part 2:
Impact of cloud-cleared AIRS radiances on temperature structure in the Arctic

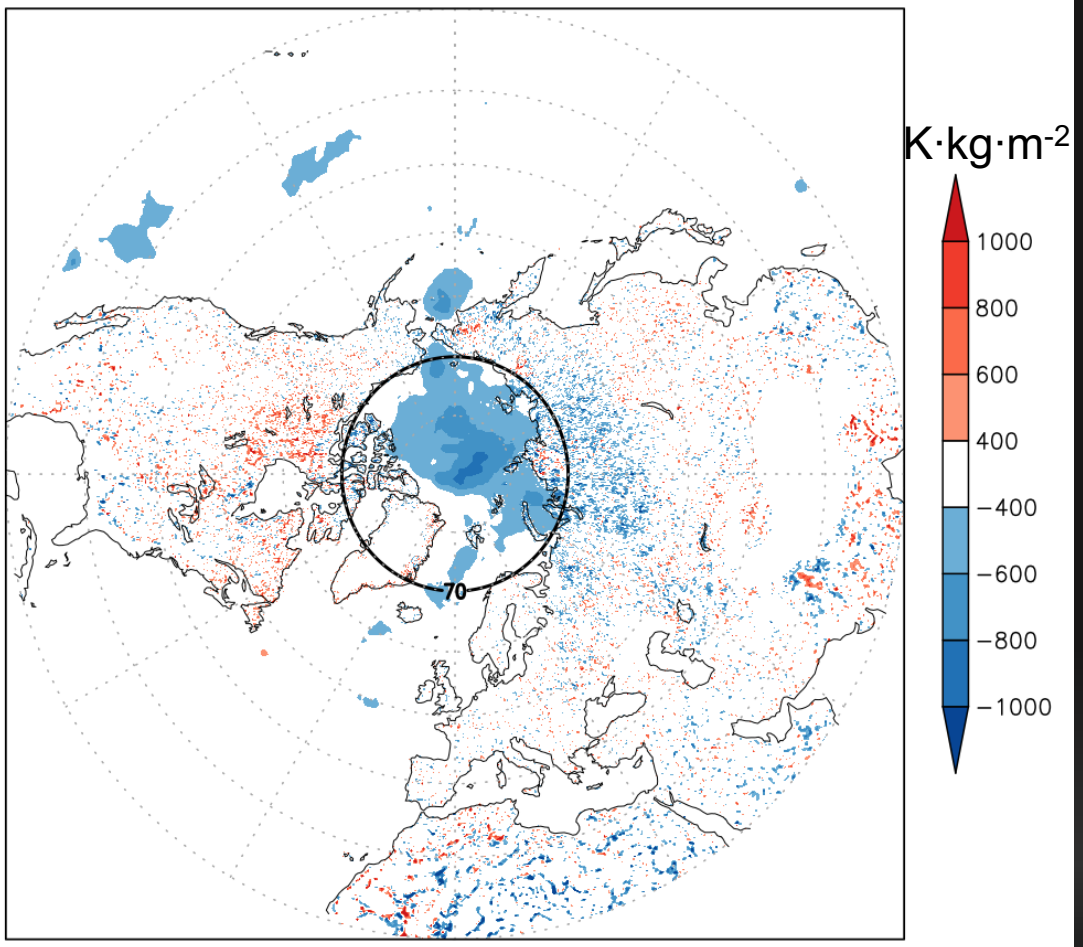
- Aside from the impact on convectively driven cyclones worldwide (including Polar Lows), based on an improved representation of their thermal structure, assimilation of AIRS CCRs produces also another very different impact on a regional scale.
- The Arctic region is extremely data scarce. Low-level stratus clouds limit the assimilation of clear-sky radiances. The analyzed thermal structure of the low-troposphere is very sensitive to the assimilation of AIRS CCRs

Clear-sky vs cloud-cleared coverage

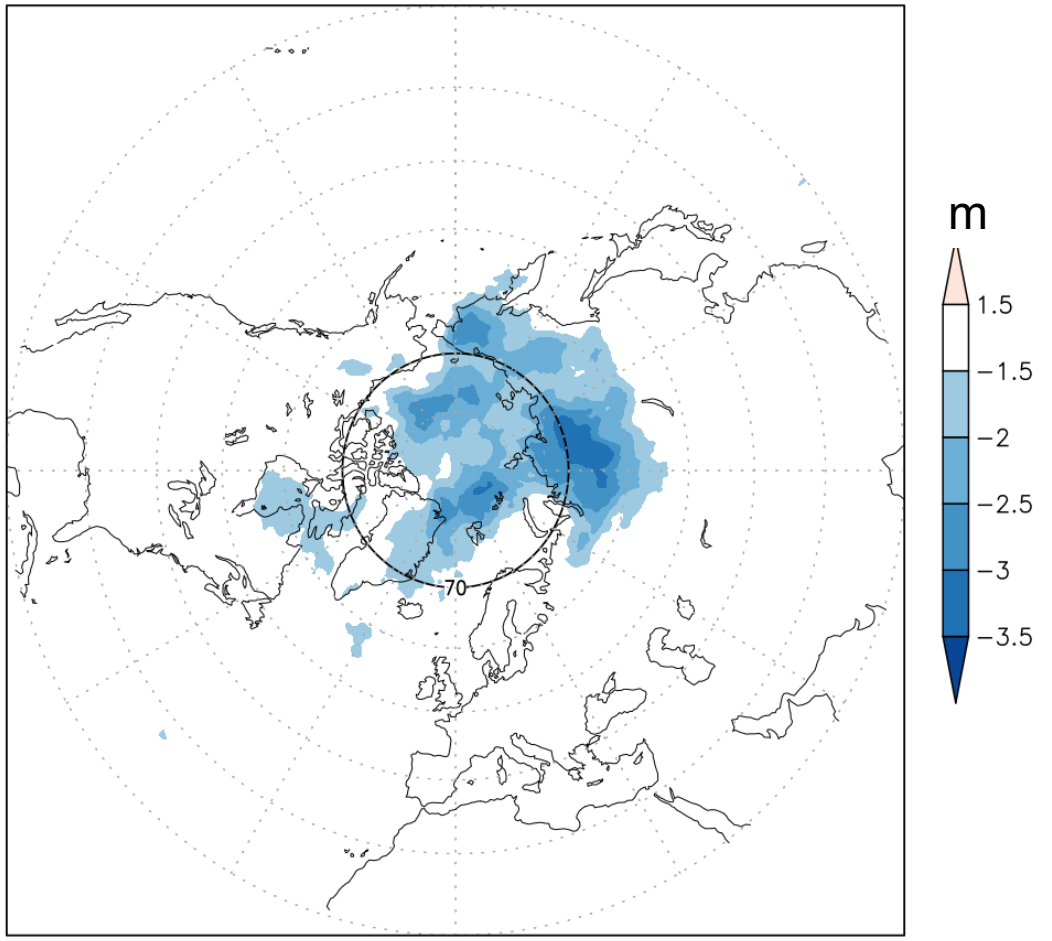


Nation

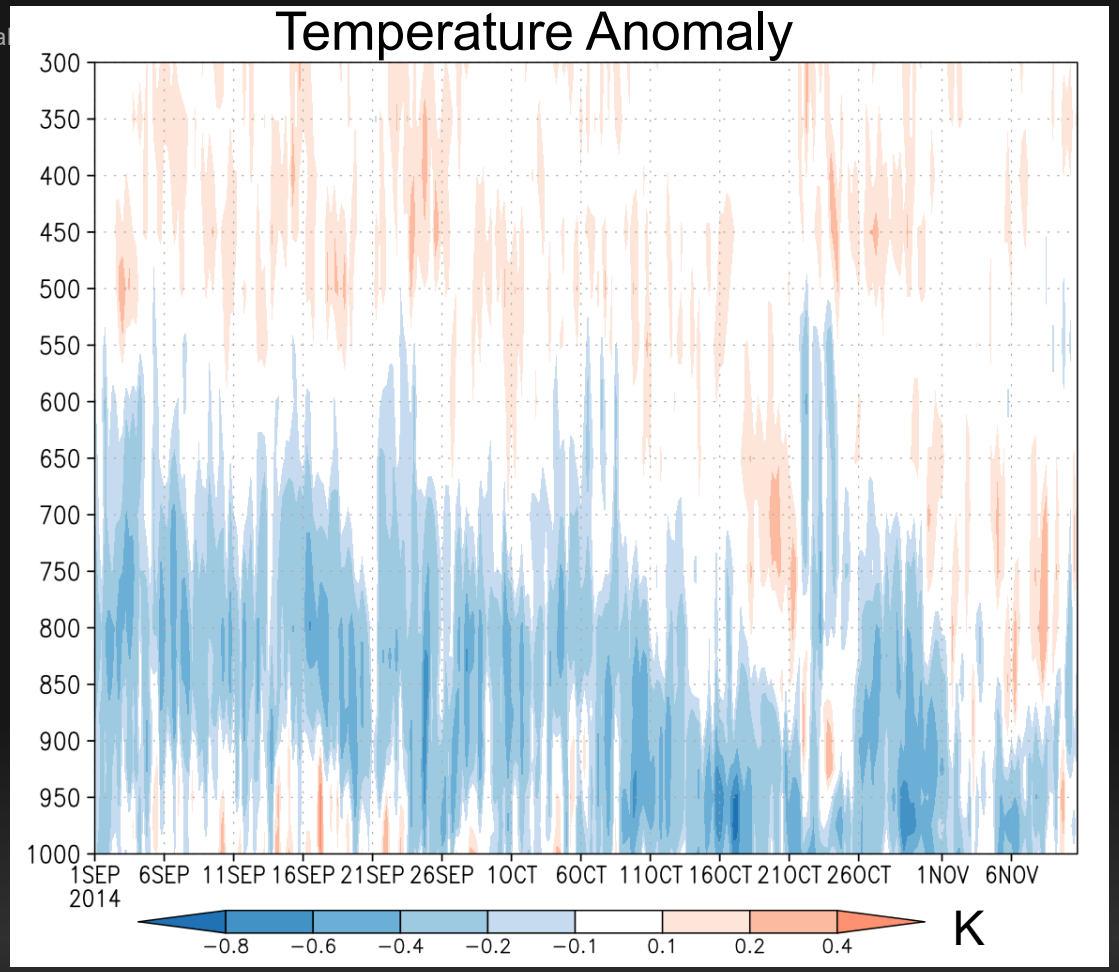
Vertically Integrated Temperature Anomaly

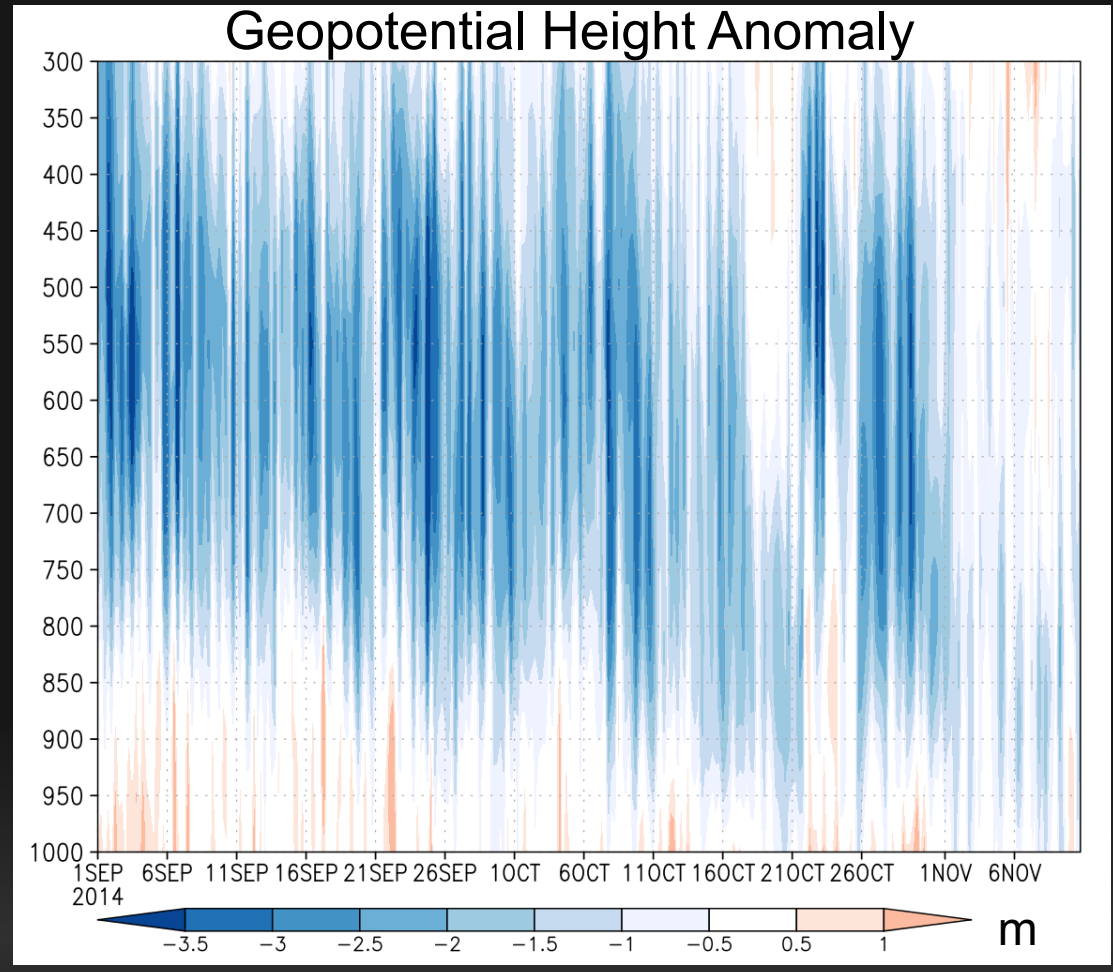


500-hPa Geopotential Height Anomaly

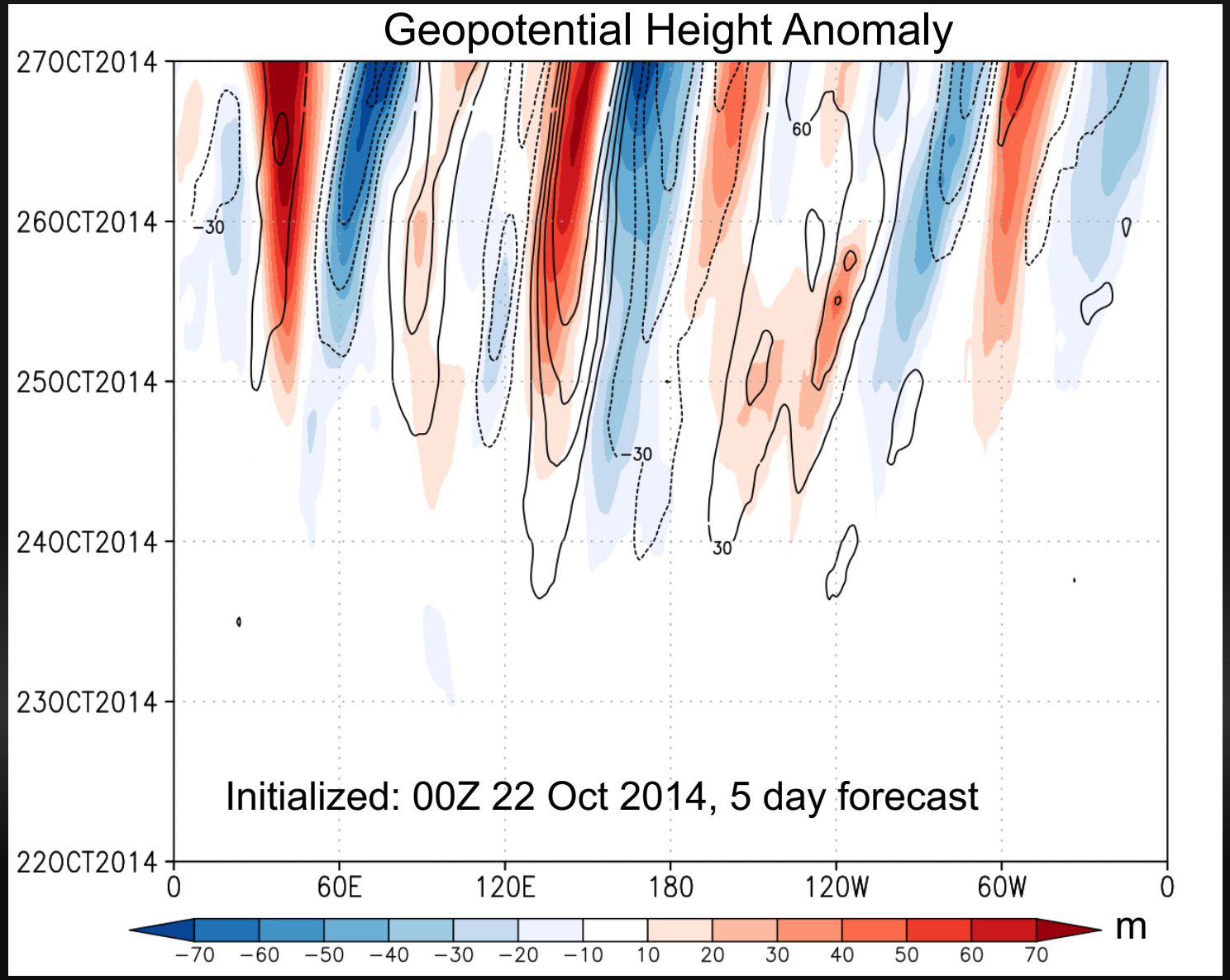


- *Cloud-cleared* minus *clear-sky* vertically integrated (sfc to 800-hPa) temperature and 500-hPa geopotential height anomalies in a two month-long analysis
- Large, spatially coherent temperature anomaly over Arctic induces negative mid- and upper-tropospheric geopotential height anomalies due to hydrostatic adjustment





- *Time series (Sep1st – Nov 10th) of cloud-cleared* minus *clear-sky* anomalies averaged 70ºN – 90ºN
- Persistent low-tropospheric cooling induced by assimilation of cloud-clear radiances over large area (over 15 million sq. km) lowers mid-troposphere geopotential height field
- The anomaly propagates into a small average improvement in forecast skill over the northern hemisphere, originating from a few individual forecasts in which the difference in skill between CLD3 and RAD is very large.

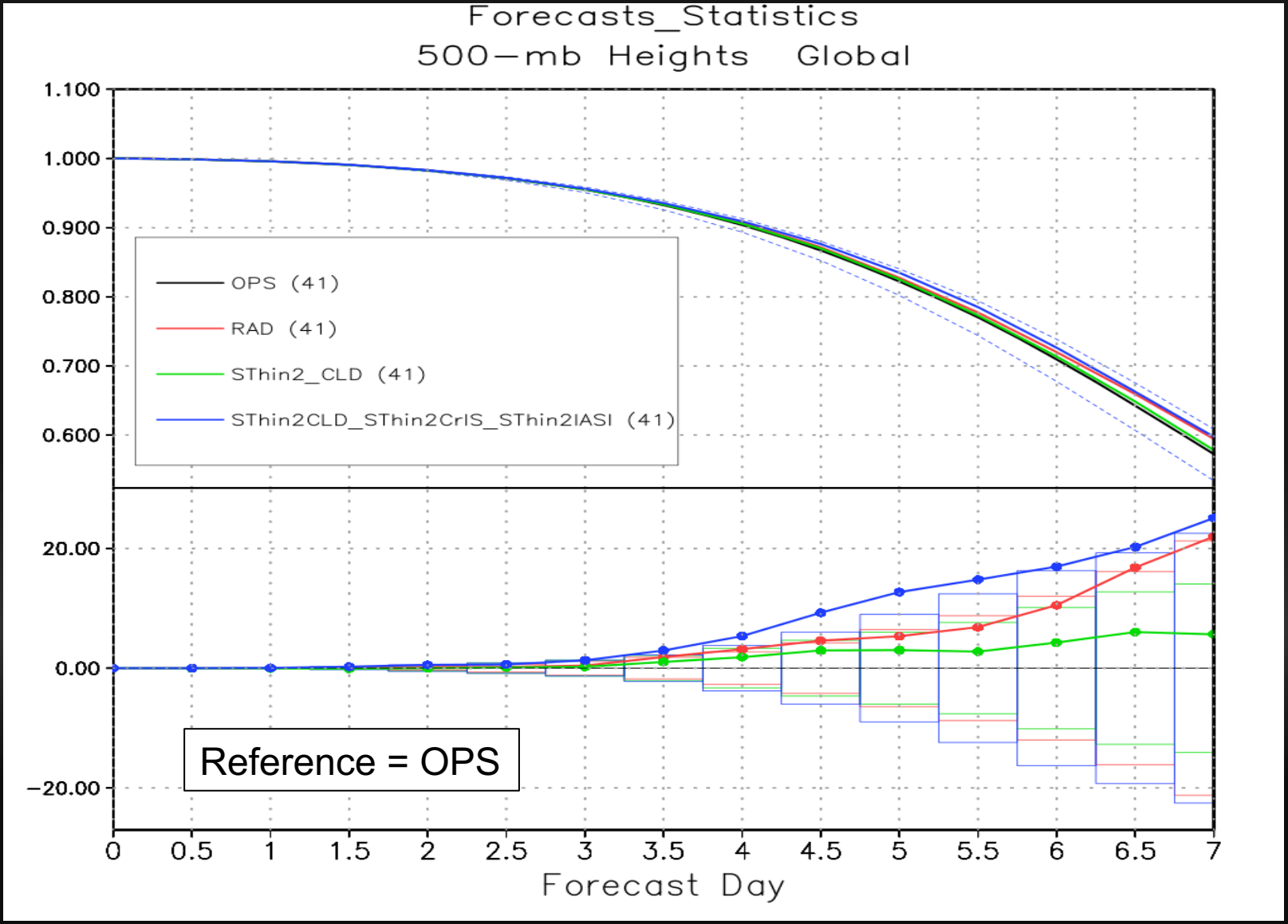


- Hovmöller diagram with 500 hPa geopotential height anomaly averaged from 40ºN – 80ºN
- Shaded: *cloud-cleared forecast* minus *clear-sky forecast*
- Contour: *NCEP analysis* minus *clear-sky forecast*
- Anomalies grow with time and travel with westerly mid-latitude waves
- Changes induced by cloud-clearing attempt to correct the forecast in the direction of the verifying analysis

Part 3: Impact of a comprehensive adaptive thinning strategy for all IR sensors together

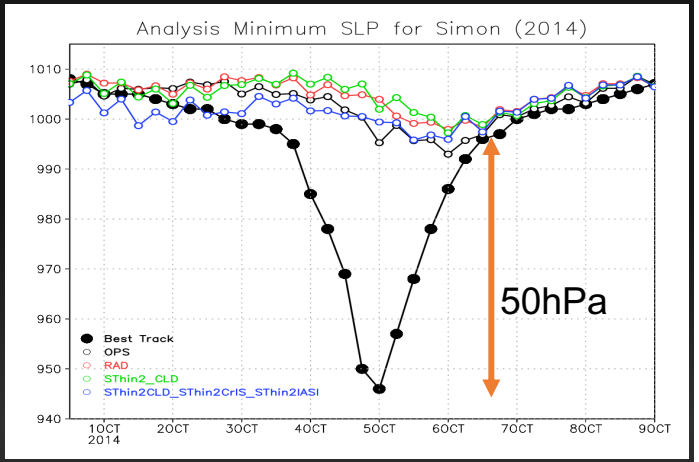
- Assimilation of low density AIRS CCRs brings a substantial improvement in global skill but negligible impact on TC structure
- Adaptively thinned AIRS CCRs bring a strong improvement on structure of many TCs, without damage to Global Skill
- Cloud-cleared CrIS and IASI are not yet available
- However, when the adaptive thinning strategy is *simultaneously applied* to ***all*** hyperspectral sensors ***together*** (Cloud-cleared AIRS and clear-sky CrIS and IASI) global and TC representation both improve substantially; even more TCs are positively affected

Global 500 hPa height anomaly correlation

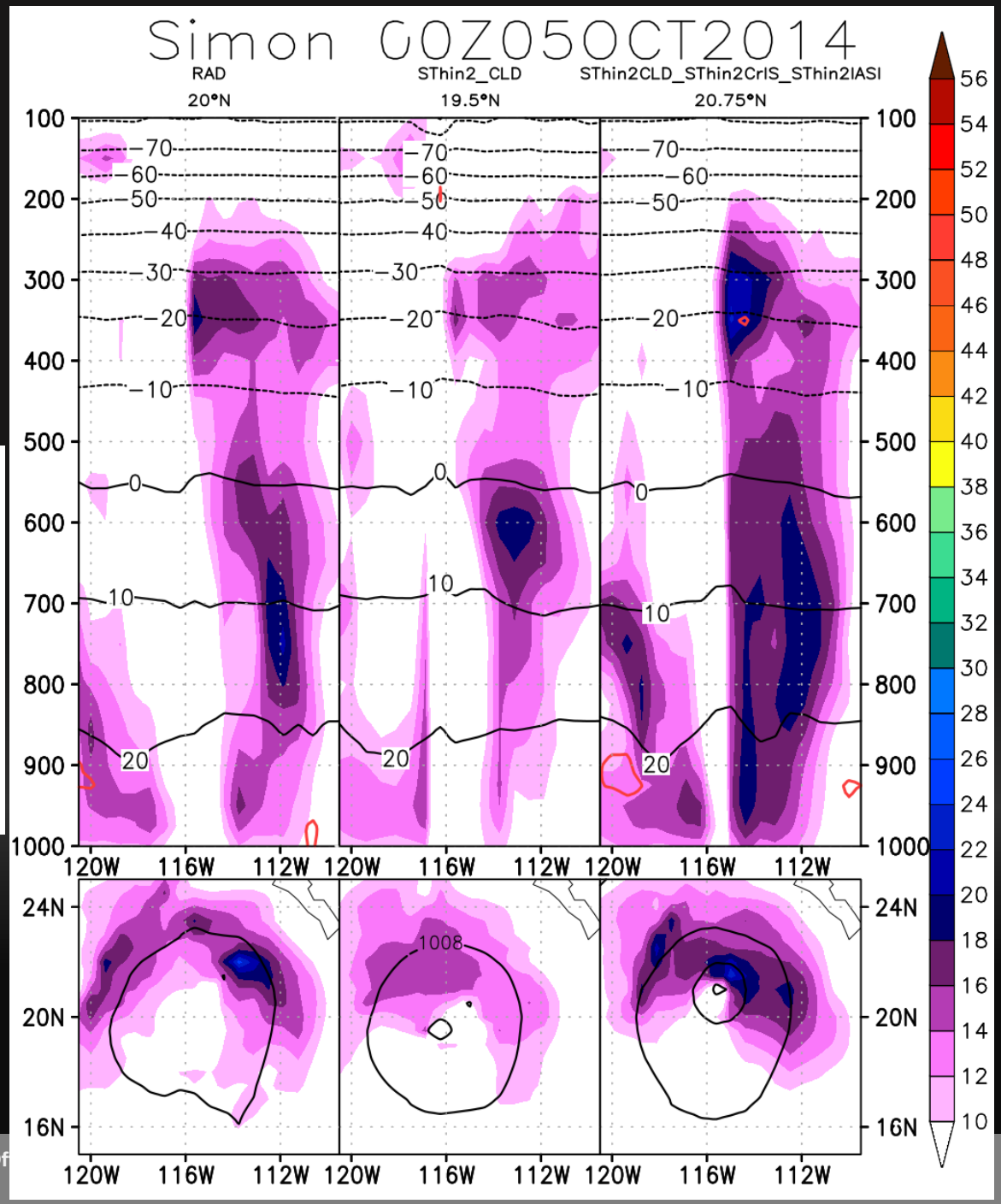


- A comprehensive, adaptive thinning approach for all hyperspectral infrared sensors, using cloud-cleared AIRS radiances, results in a statistically significant improvement in global forecast skill

H. Simon (2014)
East Pacific



Impossibly difficult TC:
extremely small,
rapid deepening and
rapid dissipation



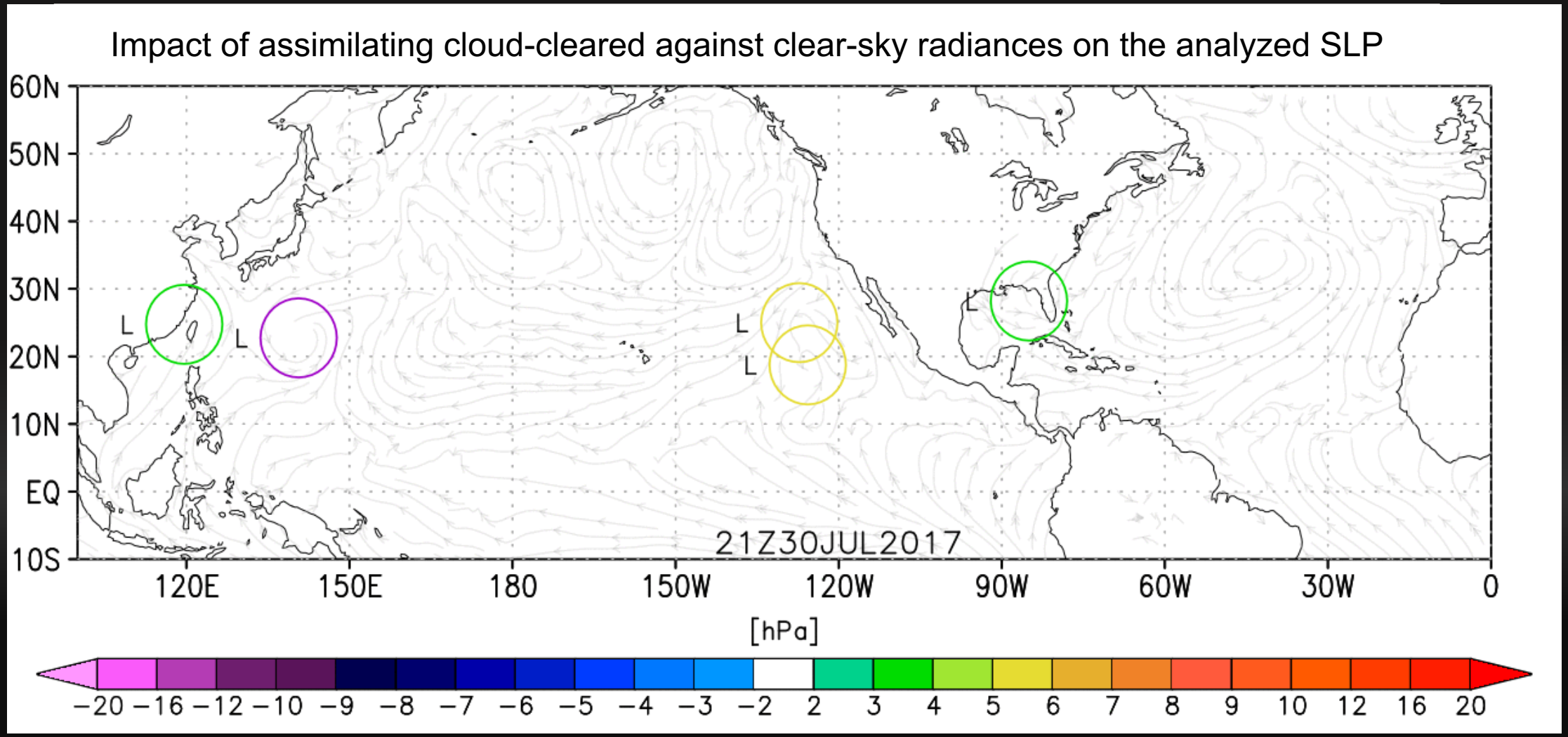
Vertical cross section
Wind magnitude (shaded)
Temperature (°C, black)
Temp. Anomaly (°C, red)

850 hPa winds (shaded)
slp (contours)

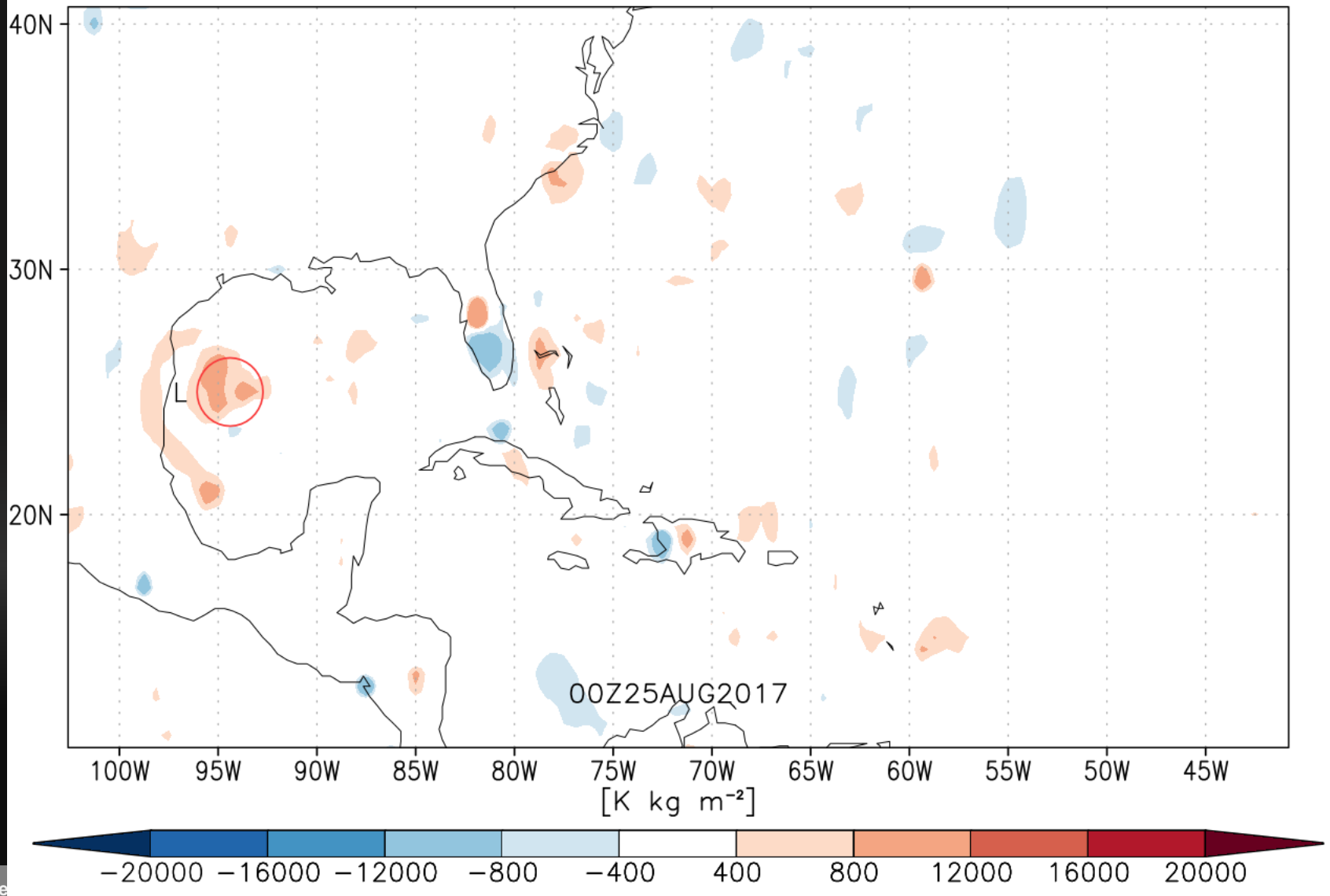
Part 4: Hybrid 4DEnVar experiments and results

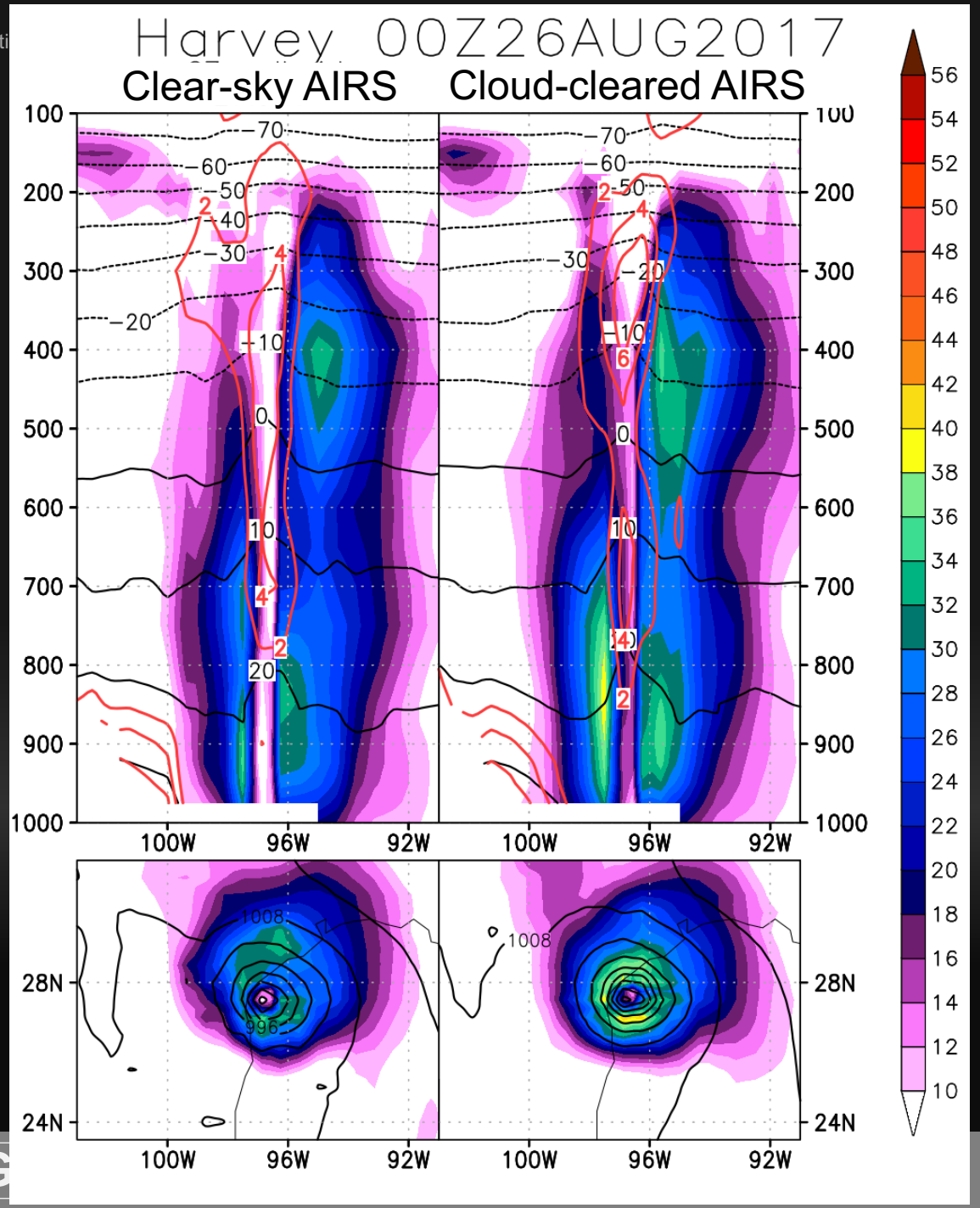
- GEOS, version 5.17 experiments, using hybrid 4DEnVar data assimilation, simulating boreal late summer – early fall 2017
- 80 daily 10-day forecasts initialized at 00Z from July 31st to October 19th
- RAD: Clear-sky AIRS radiances, as used operationally
- CLD3: Cloud-cleared AIRS radiances, globally assimilated at a lower density (~1/3 of RAD)
- CLD3 shows an improvement in global forecast skill after day 6

Impact of assimilating cloud-cleared against clear-sky radiances on the analyzed SLP



H. Harvey (2017) Cloud-cleared minus Clear-sky Vertically Integrated Temperature Anomaly (300 to 200 hPa)





- # H. Harvey (2017)
  - Vertical cross section: Wind magnitude (shaded), Temperature (°C, black), Temp. Anomaly (°C, red)
  - 850 hPa winds (shaded), slp (contours)
- Increased warm core structure, stronger wind speeds and lower sea level pressure and an overall improvement in vertical and horizontal structure result from assimilation of cloud-cleared AIRS radiances assimilated at low global resolution
- Both track and intensity forecast improve (not shown)

Conclusions

- Previous work has shown the strong positive impact of assimilating adaptively thinned AIRS cloud-cleared radiances (CCRs) on TC representation, with no loss of global skill
- More recent findings show that the increase in mid-latitude forecast skill is caused by a strong sensitivity of the Arctic region to assimilation of AIRS CCRs.
- A comprehensive thinning approach (which adaptively thins *all hyperspectral infrared radiances together*) results in improved global forecast skill and better TC representation than when applied to AIRS radiances alone
- Ongoing experiments with the newer Hybrid 4DEnVar data assimilation system continue to show the strong sensitivity of TC representation to assimilation of CCRs and appear very promising
- Future work will involve assimilation of CrIS CCR and further exploring the sensitivity to adaptive thinning in the Hybrid 4DEnVar system

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AIRS team at JPL and the Sounder Research Team at NASA GSFC

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.

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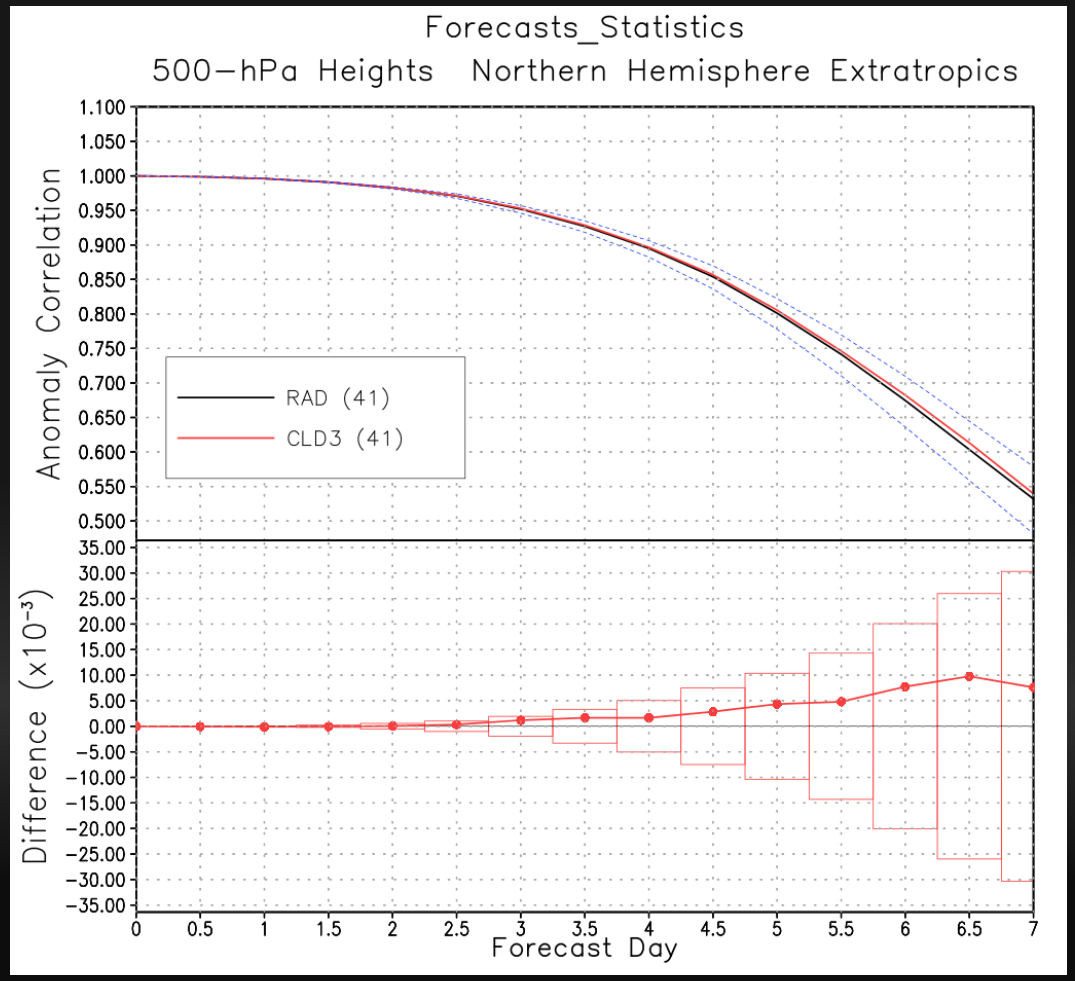
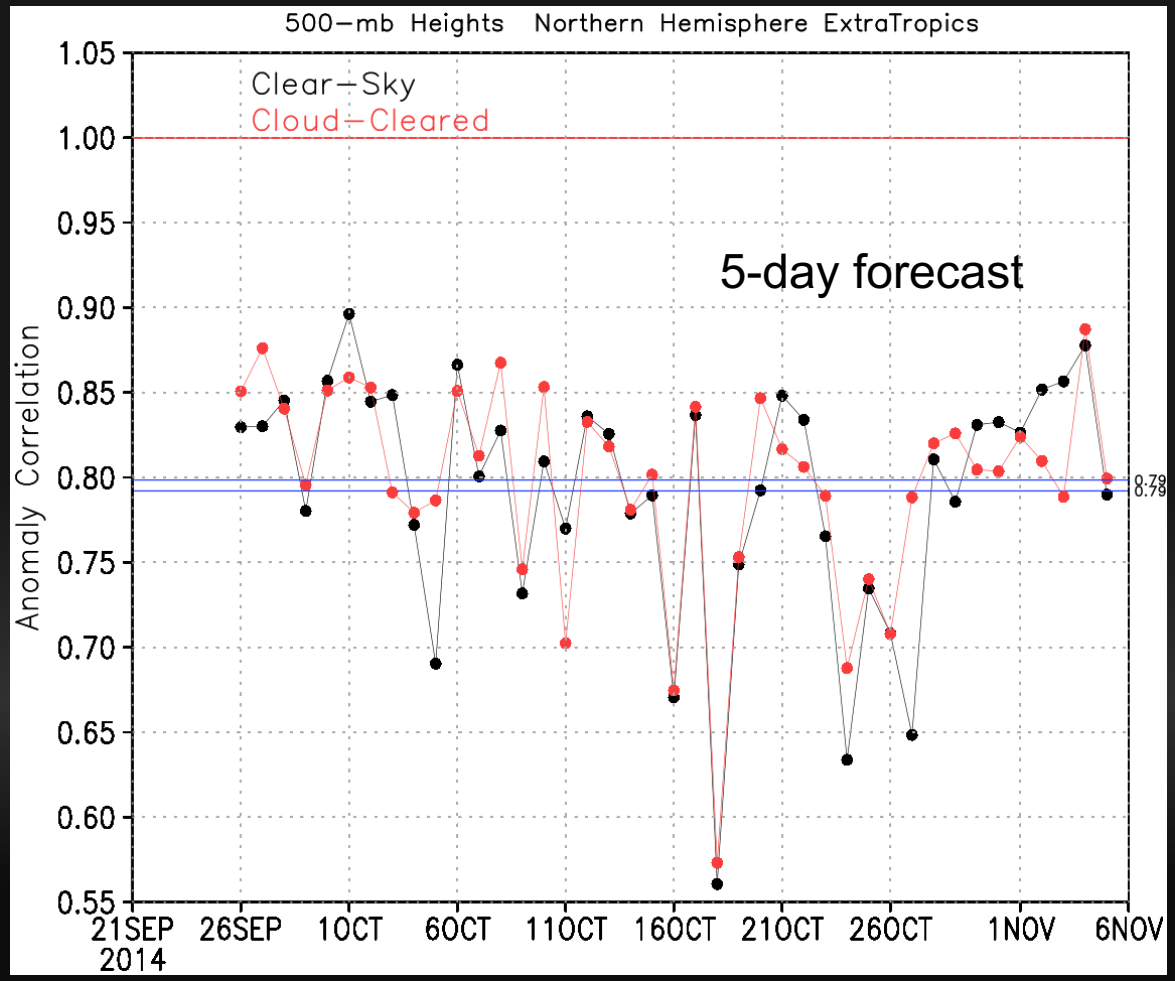
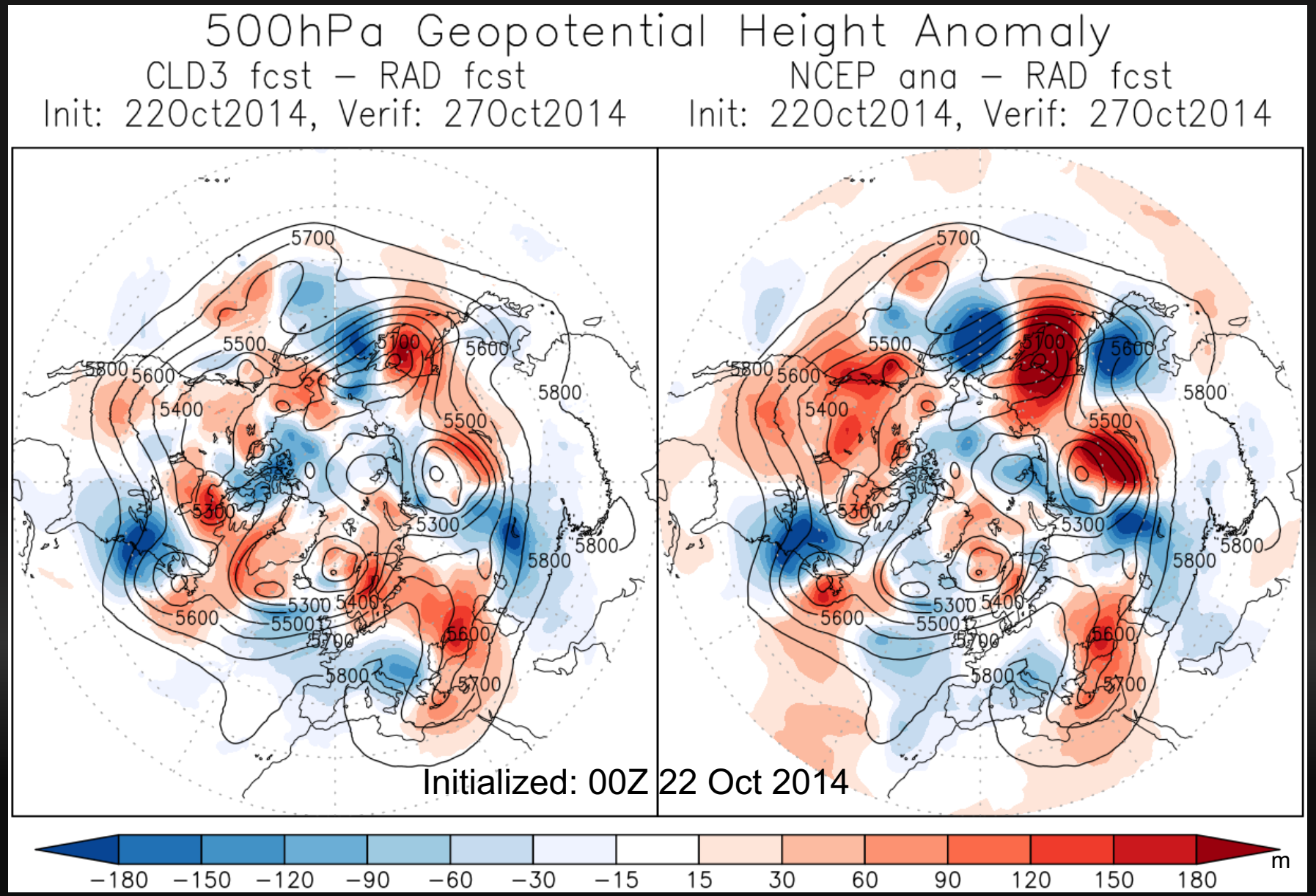
Reale, O., E. McGrath-Spangler, W. McCarty, D. Holdaway, R, Gelaro, 2018: Impact of adaptively thinned AIRS cloud-cleared radiances on tropical cyclone representation in a global data assimilation and forecast system. Weather and Forecasting, 33, 908-931.

Additional Slides

NHE Forecast Skill

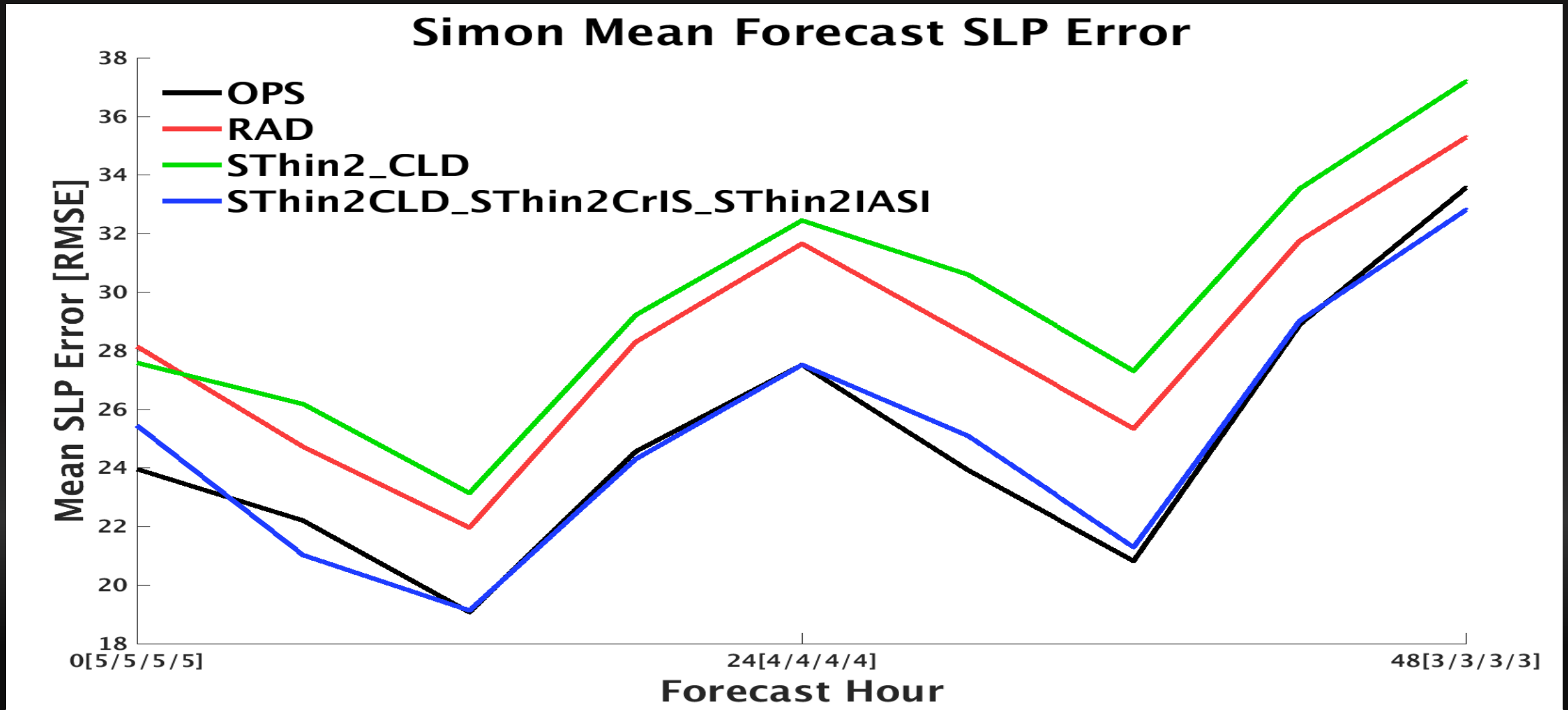




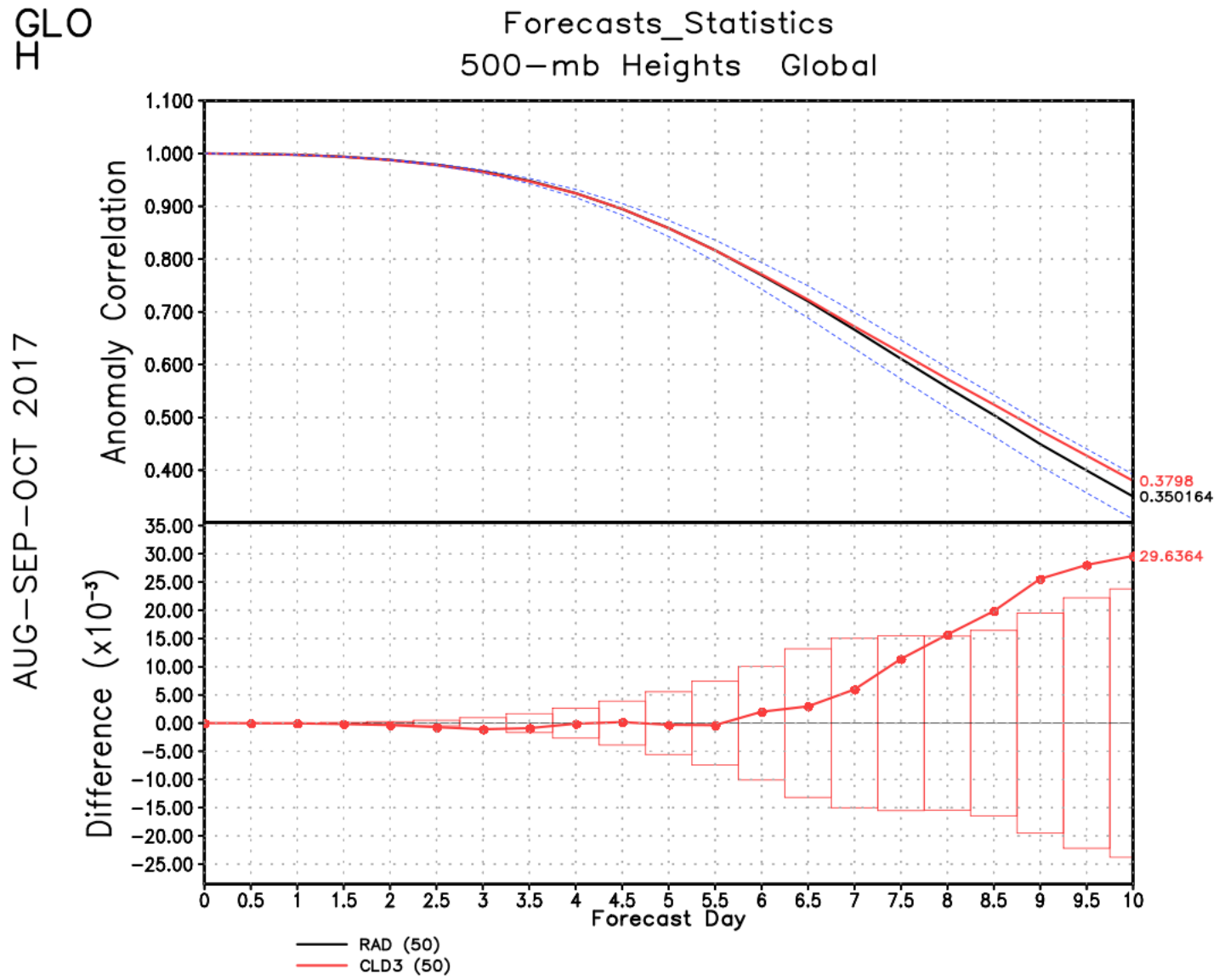


- 5 day forecast geopotential height anomalies
- All valid 00Z 27 Oct. 2014.
- Left: *Cloud-cleared forecast* minus *clear-sky forecast*
- Right: *NCEP operational analysis minus clear-sky forecast*
- Similar to Hovmöller, shows assimilation of cloud-cleared radiances reduces error growth in the forecast.

H. Simon intensity forecast



Intensity forecast for this difficult storm is identical to the one obtained with vortex relocator



- Assimilation of cloud-cleared AIRS radiances, more aggressively thinned, does not degrade the global forecast skill and produces an improvement after 6 days

x27_cld3hy4d GEOS Scorecard

Comparison of scores of **x27_radhy4d** (Control) and **x27_cld3hy4d** (Experiment) experimental runs for the period of **August 1, 2017 to October 9, 2017**.

Legend

- ▲ far better, significant (99.99% confidence)
- △ better, significant (99% confidence)
- ⁘ slightly better, significant (95% confidence)
- not really any difference
- ⁘ slightly worse, significant (95% confidence)
- ▽ worse, significant (99% confidence)
- ▼ far worse, significant (99.99% confidence)

Northern Hemisphere

Variable	Pressure Level	COR					RMS				
Forecast Day		1	2	3	4	5	1	2	3	4	5
Geopotential Height	100										
	250										
	500										
	700										
	850										
Specific Humidity	100		⁘	⁘							
	250										
	500	⁘									
	700										
	850										
Temperature	100										
	250										
	500										
	700										
	850										
U-Wind	100										
	250										
	500										
	700										
	850										
V-Wind	100										
	250										
	500										
	700										
	850										

Southern Hemisphere

Variable	Pressure Level	COR					RMS				
Forecast Day		1	2	3	4	5	1	2	3	4	5
Geopotential Height	100										
	250										
	500										
	700										
	850										
Specific Humidity	100										
	250										
	500										
	700										
	850										
Temperature	100										
	250										
	500						⁘				
	700										
	850										
U-Wind	100										
	250										
	500										
	700										
	850										
V-Wind	100										
	250										
	500										
	700										
	850										

Tropics

Variable	Pressure Level	COR					RMS				
Forecast Day		1	2	3	4	5	1	2	3	4	5
Geopotential Height	100										
	250										
	500										
	700										
	850										
Specific Humidity	100										
	250	▲	△	⁘			▲	▲	△	⁘	
	500	▲	⁘				▲	△	⁘		
	700	△	⁘	⁘			▲	△	⁘		
	850	△	⁘				△	⁘			
Temperature	100										
	250	⁘					⁘	⁘			
	500	⁘					▲				
	700						⁘				
	850	⁘	△				△	△	⁘	⁘	⁘
U-Wind	100										
	250										
	500						⁘				
	700										
	850										
V-Wind	100										
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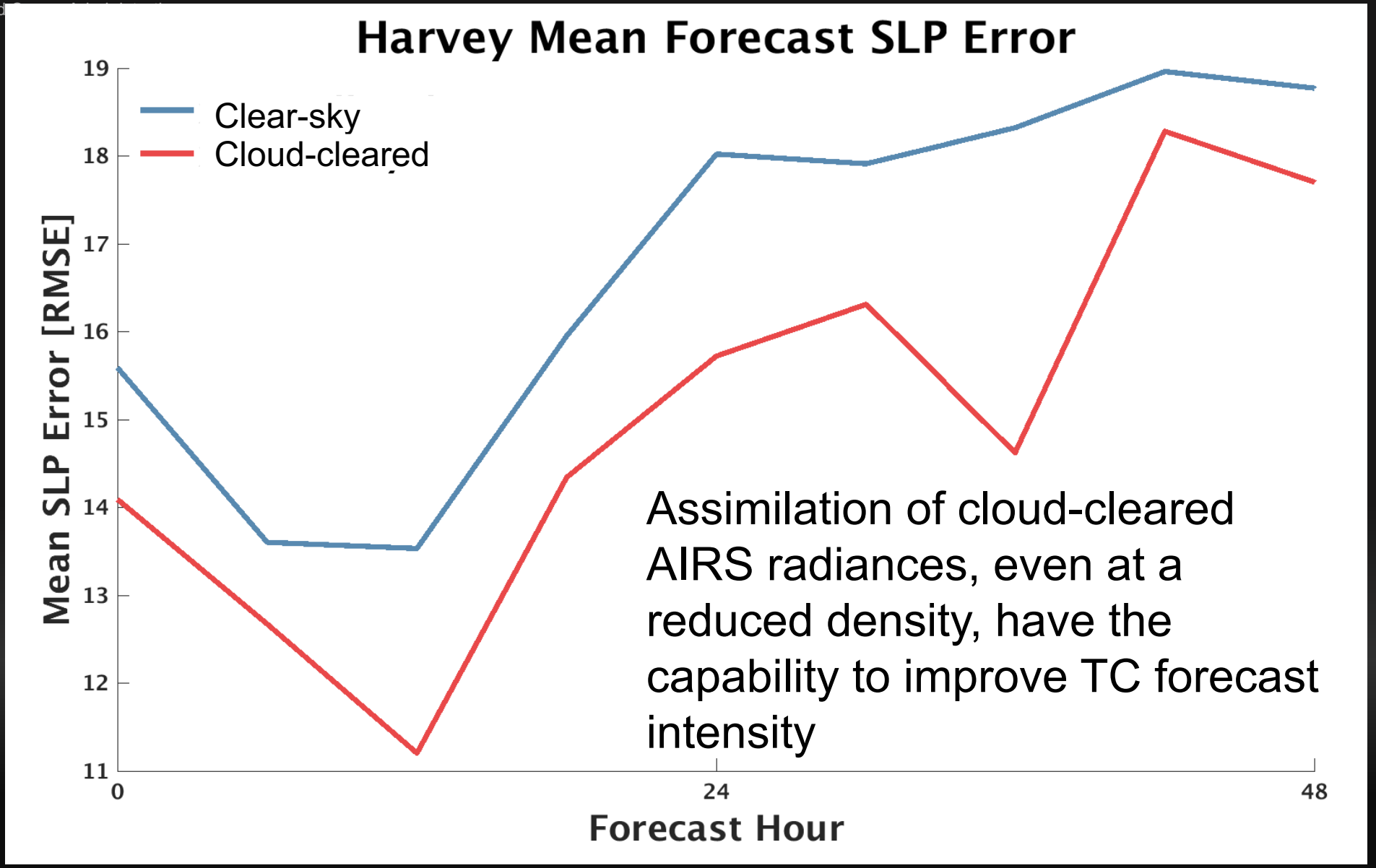
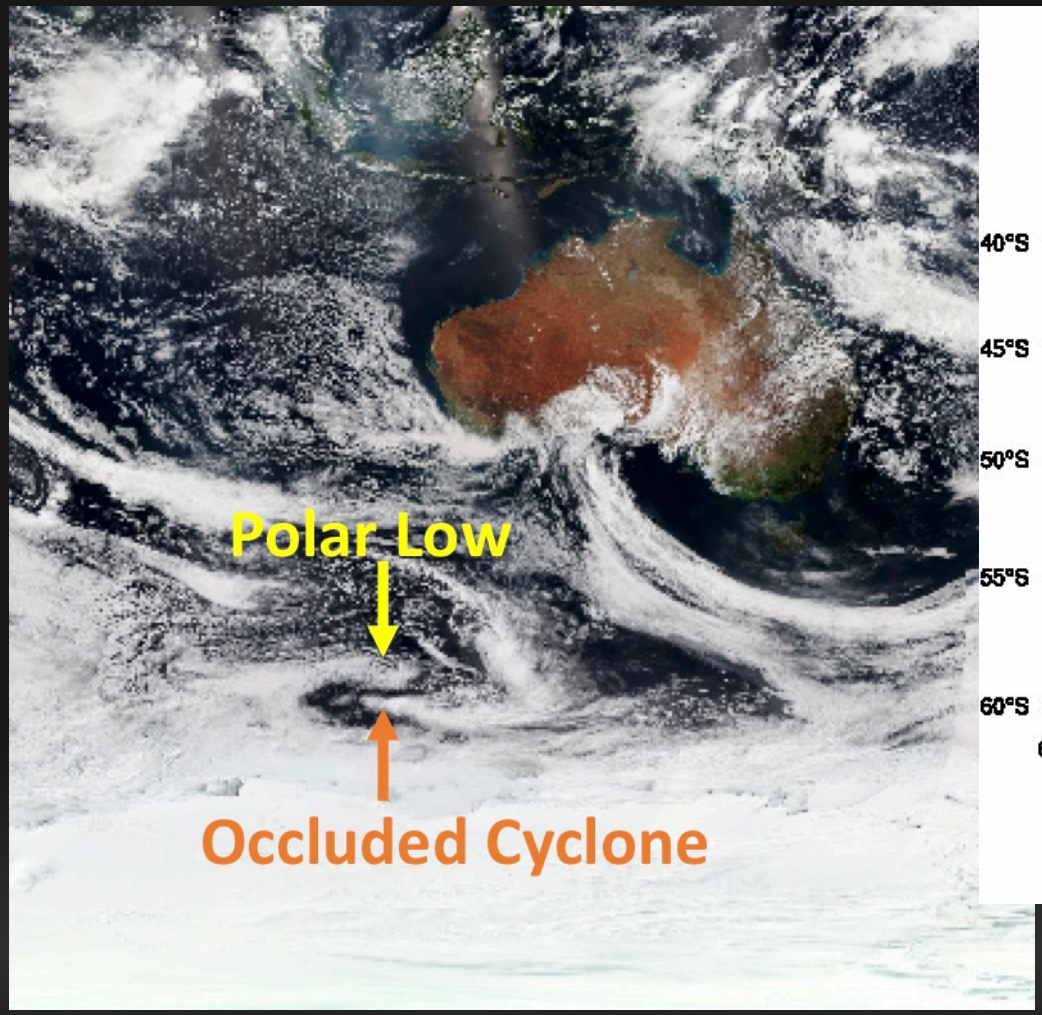
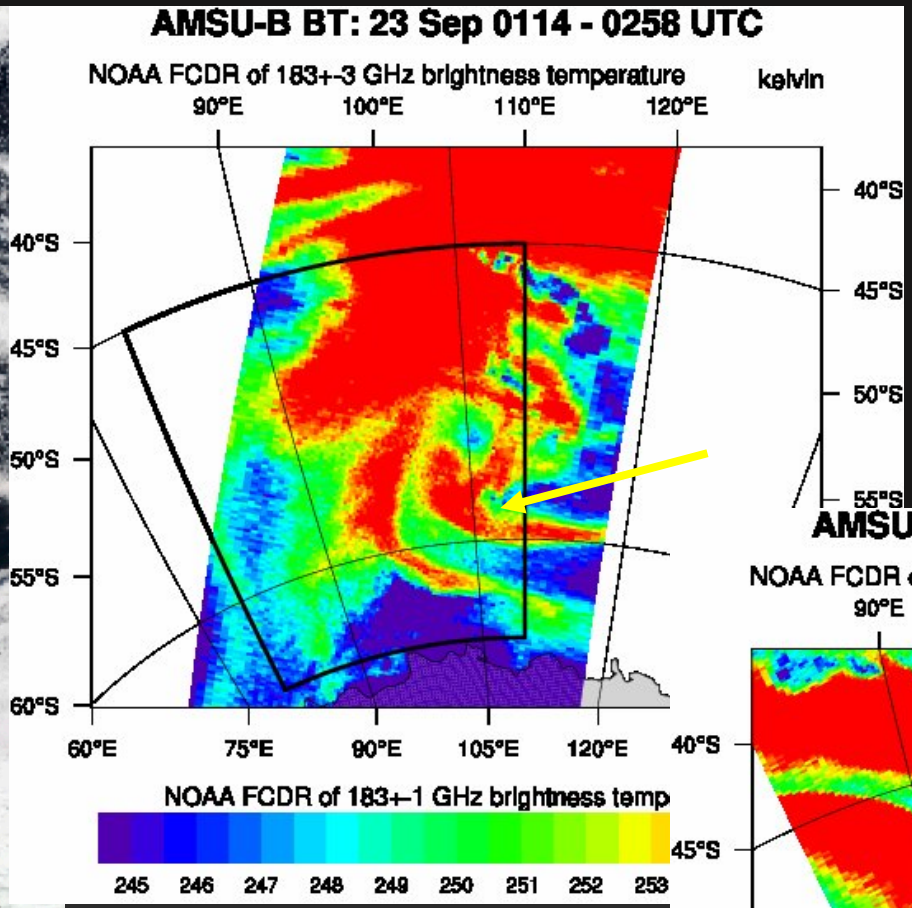
	500						⁘				
	700						⁘				
	850										

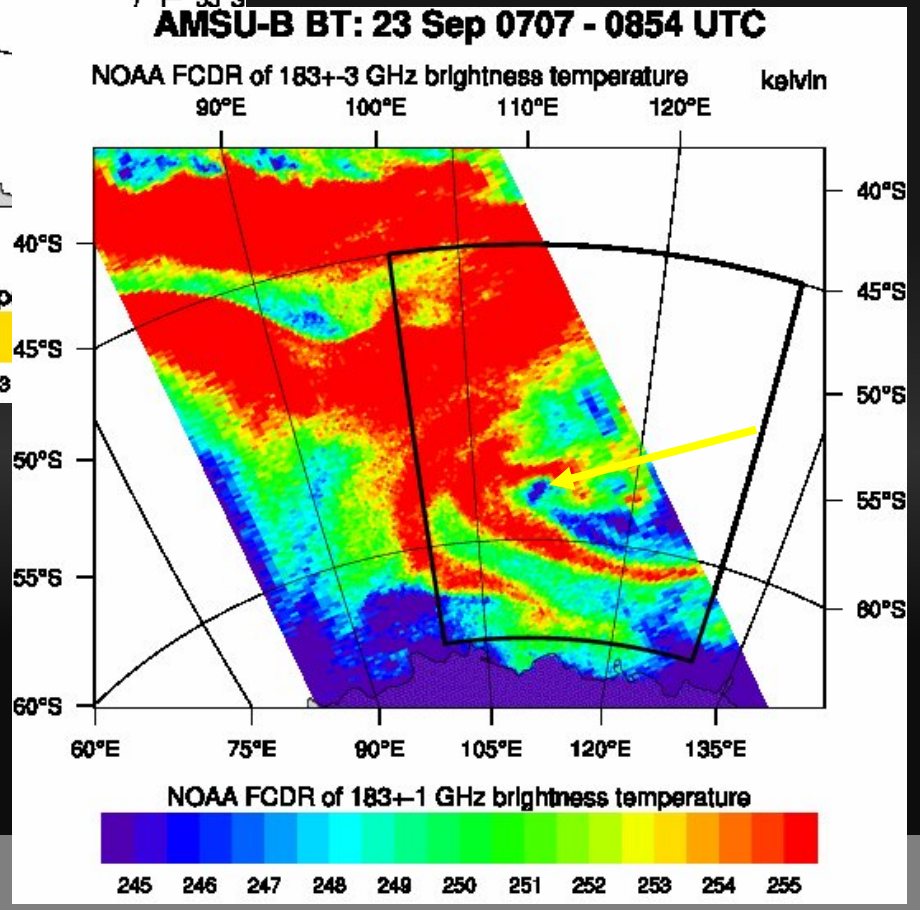

Harvey Mean Forecast SLP Error
Clear-sky
Cloud-cleared
Mean SLP Error [RMSE]
19
18
17
16
15
14
13
12
11
0
24
48
Forecast Hour
Assimilation of cloud-cleared AIRS radiances, even at a reduced density, have the capability to improve TC forecast intensity

Investigating Polar, Arctic, and Antarctic Lows

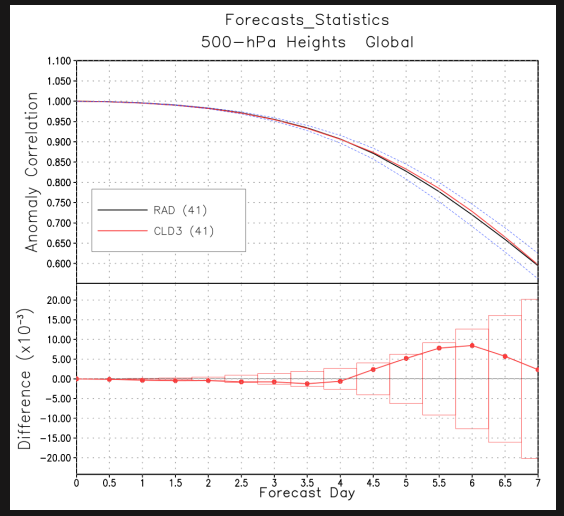
- Based on positive results obtained for TCs, we explore the sensitivity of Polar Lows (PLs) to the adaptive thinning methodology
- Unlike TCs, polar lows are generally not tracked in real time on a global scale (i.e., there is no TC vital-like information for PLs)
- This limits the operational applicability of the methodology as of now
- Adaptive thinning experiments are attempted to investigate whether the methodology could be applicable
- SThinPL_CLD: 'PL domains' (in which higher density AIRS cloud-cleared radiances are used around PLs) are constructed as TC domains, but based on satellite information (AMSU-B) only
- Results are promising and show strong sensitivity to assimilation of additional data in proximity to the storms

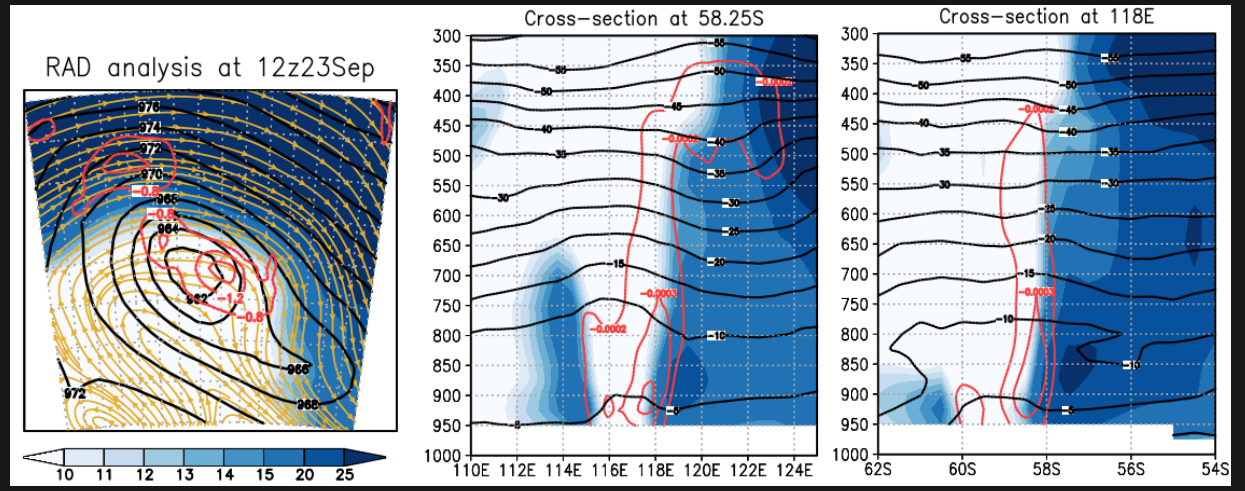






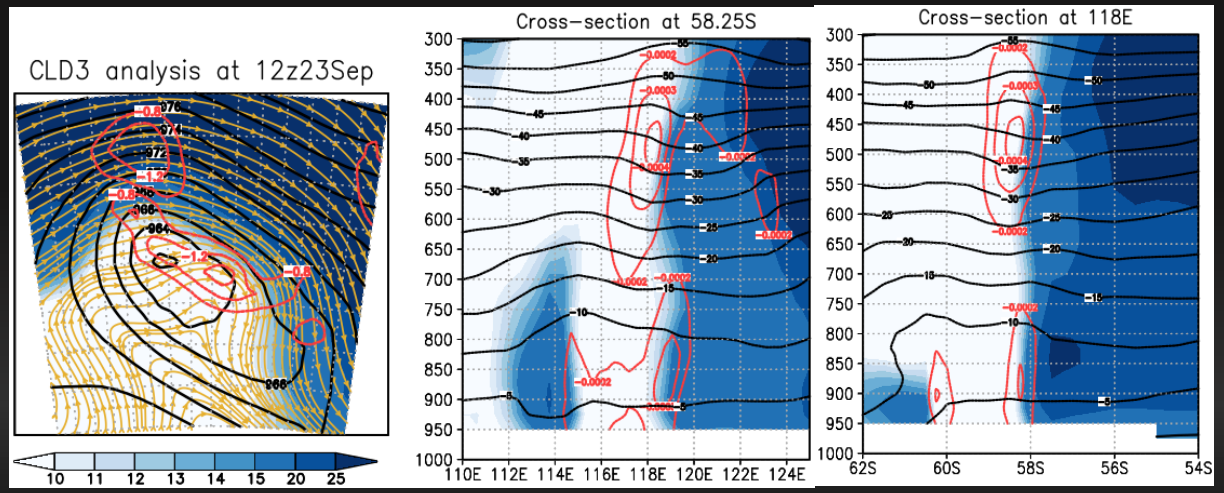
Satellite detection of polar low on 23 Sep. 2014

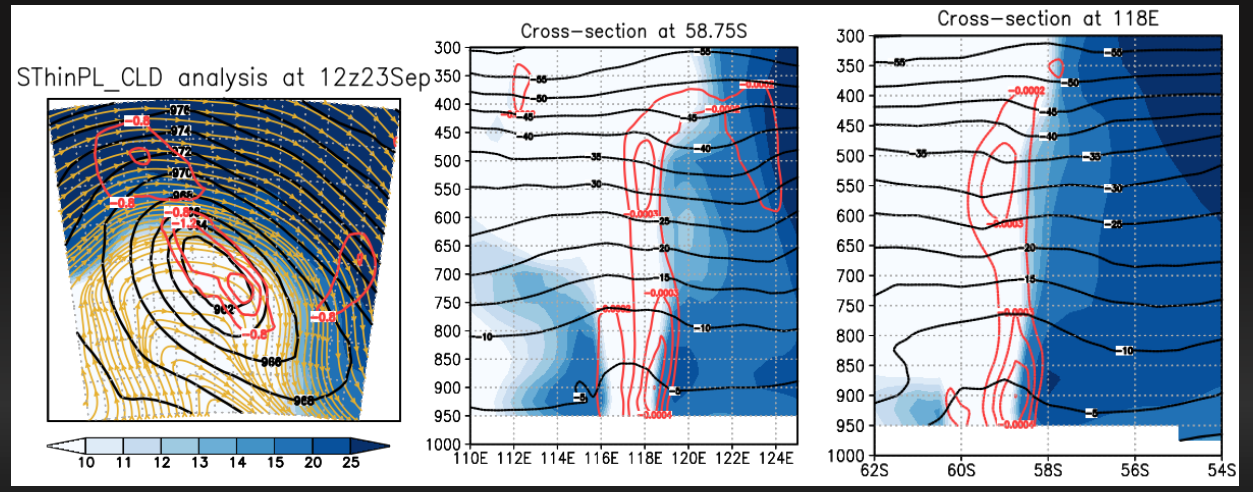




Horiz.: 300hPa winds (shaded), Vert. Integ. vorticity (red), slp (black)

Vert: Winds (shaded), vorticity (red), temperature (black)





Maximum vertically integrated cyclonic vorticity and a vertically aligned eye-like feature occur when adaptively thinned AIRS CCRs are used around a polar low