Progress toward a comprehensive cloud-cleared AIRS-CrIIS radiance assimilation strategy

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Outline

• Short summary of past, published work on AIRS
  • Impact on TCs and global skill, caused by adaptive thinning of AIRS cloud-cleared radiances (CCRs)
• Impact of AIRS CCRs on high latitude atmospheric dynamics
• Impact of AIRS CCRs on representation of high-latitude convective cyclones (Arctic, Antarctic, and polar lows)
• Expanding the adaptive thinning strategy to other sensors (CrIS and IASI)
  • Best impact on global skill and on TC analysis and forecast
• New experiments with the Hybrid 4DEnVar GEOS system
• Focus on Hurricane Harvey (2017)
Recent past work: Two major findings

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


1) Cloud-cleared AIRS radiances are a substantial improvement over clear-sky radiances, but 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.

Limits: only TCs with good AIRS coverage were affected; strong improvement on TC structure and intensity but negligible on forecast track; TCs with very short lifespans were difficult to improve
Experiments setup

GEOS, version 5.13, using 3DVar data assimilation, simulating boreal fall 2014

- **OPS**: Clear-sky AIRS radiances, version used quasi-operationally by the GMAO
- **RAD**: Clear-sky AIRS radiances, equivalent to operationally run version except with the vortex relocator turned off
- **CLD3**: Cloud-cleared AIRS radiances, globally assimilated at a lower density
- **SThin2_CLD**: Cloud-cleared AIRS radiances, adaptively thinned with lower global density, but higher density surrounding TCs using a `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
Adaptively thinned, cloud-cleared radiances produce large improvements in vertical and horizontal structure. Specifically: more compact scale, stronger wind speeds, lower minimum pressure, stronger warm core, at no expense to global forecast skill.

- H. Gonzalo (2014)
  - Vertical cross section: Wind magnitude (shaded), Temperature (°C, black), Temp. Anomaly (°C, red)
  - 850 hPa winds (shaded), slp (contours)
Impact of cloud-cleared AIRS radiances on high latitudes

• The Arctic region is extremely data scarce and low-level stratus clouds limit the assimilation of clear-sky radiances. Therefore, it appears extremely sensitive to the assimilation of AIRS CCRs.

• The positive impact on mid-latitude forecast skill is investigated with a plausible cause found.

• A large and persistent temperature anomaly in the lower-mid troposphere is induced by the assimilation of CCRs, propagating to the mid troposphere in the form of a large geopotential adjustment.
• *Cloud-cleared* minus *clear-sky* vertically integrated (sfc to 800-hPa) temperature and 500-hPa geopotential height anomalies in the **analysis**

• Large, spatially coherent temperature anomaly over Arctic induces negative mid- and upper-tropospheric geopotential height anomalies due to hydrostatic adjustment
• *Cloud-cleared* minus *clear-sky* anomalies averaged 70°N – 90°N
• Persistent cooling over large area (over 15 million sq. km) and over 2 month time period produces lowering of geopotential height field
• The anomaly slopes downward, transitioning into the cold season
• Result of assimilating cloud-cleared AIRS radiances
NHE Forecast Skill

5-day forecast

Forecasts_Statistics
500-hPa Heights Northern Hemisphere Extratropics

500-mb Heights Northern Hemisphere Extratropics

Clear-Sky
Cloud-Cleared

Anomaly Correlation

Difference ($\times 10^{-3}$)

Forecast Day

21SEP 2014 26SEP 10CT 15CT 20CT 25CT 30CT 31CT 01NOV 06NOV
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

Initialized: 00Z 22 Oct 2014, 5 day forecast
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
Maximum vertically integrated cyclonic vorticity and a vertically aligned eye-like feature occur when adaptively thinned AIRS CCRs are used around a polar low.
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, but negligible improvement on Global Skill.
- However, when the adaptive thinning strategy is *simultaneously applied* to *all* hyperspectral sensors *together*, global and TC representation both improve; 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

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

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

850 hPa winds (shaded)
slp (contours)
H. Simon intensity forecast

Intensity forecast for this difficult storm is identical to the one obtained with vortex relocator.
Hybrid 4D-EnVar experiments and results

- GEOS, version 5.17 experiments, using hybrid 4D-EnVar data assimilation, simulating boreal late summer – early fall 2017
- **RAD**: Clear-sky AIRS radiances, as used operationally
- **CLD3**: Cloud-cleared AIRS radiances, globally assimilated at a lower density (~1/3 of RAD)
Assimilation of cloud-cleared AIRS radiances, more aggressively thinned, does not degrade the global forecast skill and produces an improvement after 6 days.
Cloud-cleared minus Clear-sky SLP anomaly
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
Assimilation of cloud-cleared AIRS radiances, even at a reduced density, have the capability to improve TC forecast intensity.
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. This causes a large negative lower tropospheric temperature anomaly in the Arctic, which induces a mid-upper tropospheric height anomaly that propagates to the mid-latitudes and improves the forecasts of individual waves.

• Adaptively thinned AIRS CCRs also improve the analysis of polar lows (stronger vorticity columns, more pronounced warm cores, and better vertical alignment).

• 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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