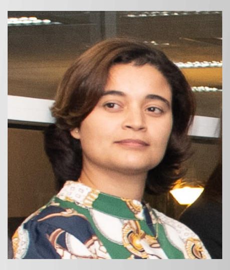

Implementing Atmospheric Infrared Sounder (AIRS) and Cross-Track Infrared Sounder (CrIS) Cloud-Clearing Algorithm into the NASA GEOS: Focus on the 2017 Atlantic Tropical Cyclone season.

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INTRODUCTION

Importance of hyperspectral infrared sounders

Satellite hyperspectral infrared (IR) sounders observe the thermodynamical structure of the atmosphere. The use of IR radiances in numerical weather prediction (NWP) has significantly increased (AIRS, CrIS and IASI[1]). However, they are underutilized in cloudy regions, and this is a major limitation.

Increased hurricane intensity: role of IR hyperspectral data

The 2017 Atlantic Hurricane Season was very active with 30 named storms of which 13 became hurricanes. Harvey, Irma (category 4 Hurricane) , and Maria (Category 5 Hurricane) were very devastating and caused property damage and loss of life in the southern United States and U.S. territories. The socio-economic impacts of the 2017 Atlantic hurricane season were over $130 billion (Lee, 2021).




Photos credit: https://www.nbcnews.com/news/us-news/2017-hurricane-season-finally-ends-how-bad-was-it-will-n825816

Cloud-Clearing methodology: an efficient approach to assimilate hyperspectral IR observations in cloudy areas

This team works to improve the assimilation of hyperspectral IR satellite observations in the presence of clouds, through the **cloud-clearing methodology**, to benefit analysis and forecasts with an emphasis on Tropical Cyclones (TCs) (Reale et al., 2018, McGrath-Spangler et al., 2021, Ganeshan et al., 2022).

Cloud-cleared methodology offers a potential benefit for NWP centers by allowing the use of radiances affected by clouds. Currently, many NWP centers are exclusively assimilating IR radiances over channels unaffected by clouds (clear-sky radiances).

IR cloud-cleared radiances (CCRs) have not been operationally used because of 1) latency and 2) external dependencies.

The essential work done by this team, to make CCRs usable by the operational community is:

- The AIRS and CrIS cloud-cleared algorithms have been ported on NASA HEC[2] systems and implemented into the NASA GEOS[3] to reduce latency, remove external dependencies and demonstrate their portability.
- The first guess to start the iterative process is now taken from the NASA GEOS instead of a product obtained via neural networks from ECMWF-derived fields.
- The channel selection was tailored to the GEOS and can be adapted to any other forecast system.
- The AIRS and CrIS cloud-cleared algorithms were parallelized for computational efficiency purposes (one entire month represented by 7440 AIRS granules can now processed in about 5 hours instead of 370.5 hours (gain factor of 70), which means that radiances needed for one analysis time can be processed in about 3 minutes).

This makes the internally produced AIRS and CrIS CCRs customizable, portable, independent, and potentially usable in a real-time forecast framework.

Overview of Cloud-clearing methodology

I. Co-located Thermal & Microwave in Cloudy Scenes

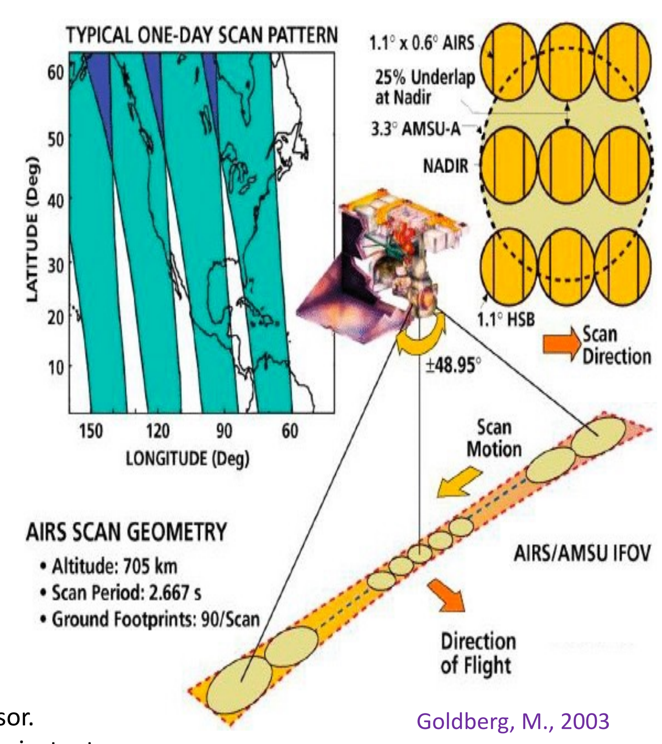
- The basic assumption of cloud-clearing is that within a retrieval field of regard (FOR) the cloud formation characteristics are constant and only the cloud fraction, α, of each cloud type varies over the FOR.
- FOR is defined by the size of 3*3 of IR footprints.

II. General formulation

The radiance for channel n in the field of view j (FOV_j), $R_j(n)$, can be given in terms of a clear component of the radiance, $R_{clr}(n)$ and a cloud component of the radiance, $R_{cld}(n)$, both of which are constant over the FOR, as follows:

$$R_j(n) = (1 - \alpha_j) * R_{clr}(n) + \alpha_j * R_{cld}(n)$$

where, α_j is the cloud fraction in FOV_j.



Goldberg, M., 2003

The field of regard (FOR) is the total area that can be captured by a movable sensor.
The field of view (FOV) is the angular cone perceivable by the sensor at a particular time instant.

Assimilating AIRS and CrIS CCRs into NASA GEOS

To study the impact of the assimilation of AIRS and CrIS CCRs on the global forecast skill and TC representation, a vast set of experiments (more than 13 experiments each with 80 days of analysis and forecast; validation of 50 ten-day forecasts after discarding spinup) were run in the GEOS hybrid 4DEnVar data assimilation framework with a focus on the 2017 hurricanes season: *Harvey, Irma and Maria*.

The goal of those experiments was:

- To compare the internally produced AIRS and CrIS CCRs with the AIRS CCRs product distributed by the NASA GES DISC[4] and CrIS CCRs distributed by NOAA CLASS[5] .
- To explore the sensitivity of AIRS and CrIS CCRs to different thinning levels in order to find the optimal data density.

AIRS and CrIS CCRs assimilation experiments setting

This poster shows the results of five data assimilation experiments carried out for the period of July 31st to October 20th, 2017 .

The reference, RAD, assimilates clear-sky AIRS and CrIS radiances with 180km thinning level (as operationally done).

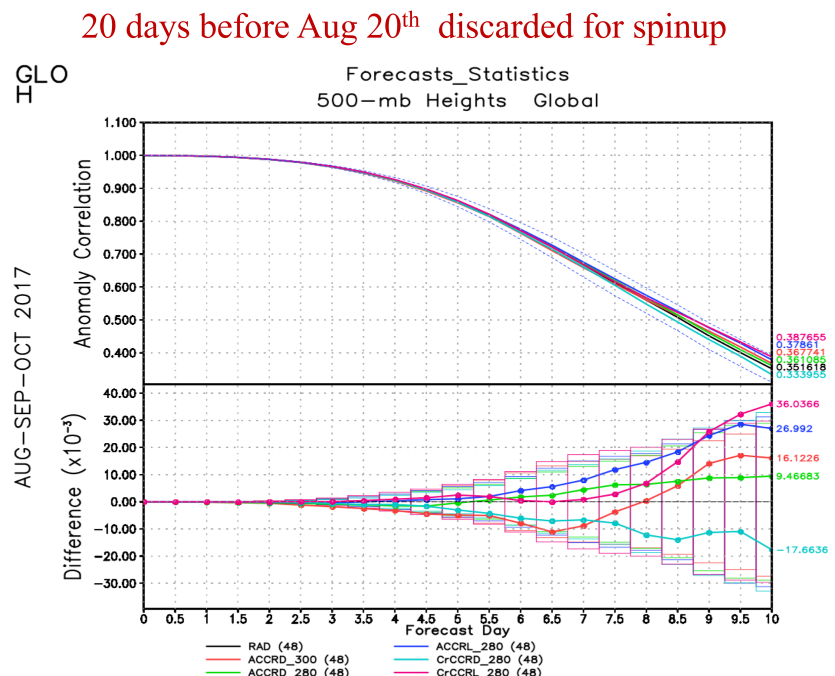
Exp Description	Global Thin Box (km)
ACCRD CrIS clear sky	300 180
ACCRL CrIS clear sky	280 180
CrCCRD AIRS clear sky	280 180
CrCCRL AIRS clear sky	280 180
RAD AIRS & CrIS clear sky	180 180

(1) AIRS CCRs from NASA DAAC, (2) Locally produced AIRS CCRs, (3): CrIS CCRs from NOAA CLASS, (4) locally produced CrIS CCRs, (5) AIRS CCRs from NASA DISC.

Results

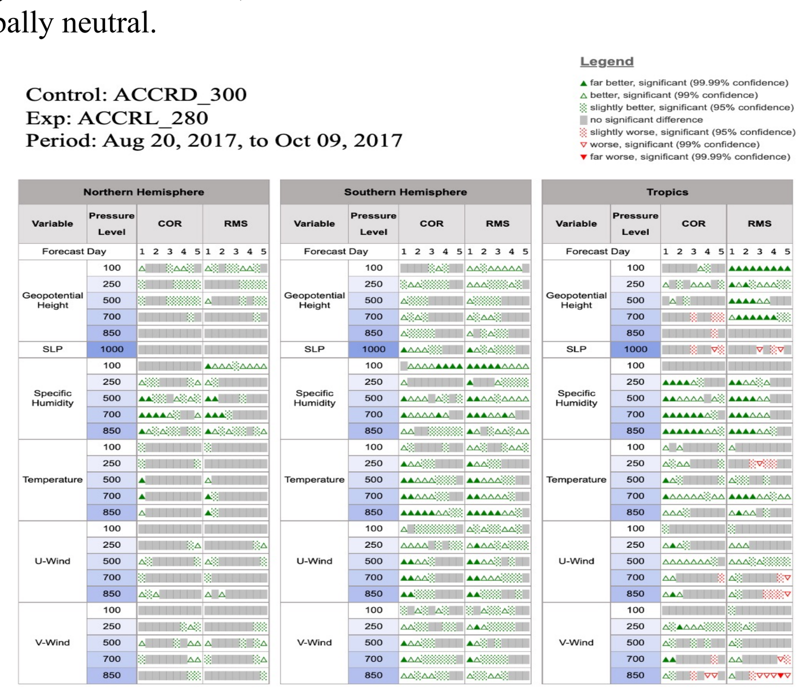
Forecast Skill results

20 days before Aug 20th discarded for spinup



The global 500-hPa geopotential height anomaly correlation is computed from 51 forecasts; The assimilation of AIRS and CrIS CCRD or CCRL has low impact on the global skill compared to RAD;

However, the assimilation of customized AIRS shows an improvement compared to AIRS CCRs data from the GES DISC (ACCRD). An example is illustrated by the following scorecard-based diagnostics. For CrIS, the scorecard of CrCCRD and CrCCRL is globally neutral.



Impact on the representation of a Tropical Cyclone

Harvey

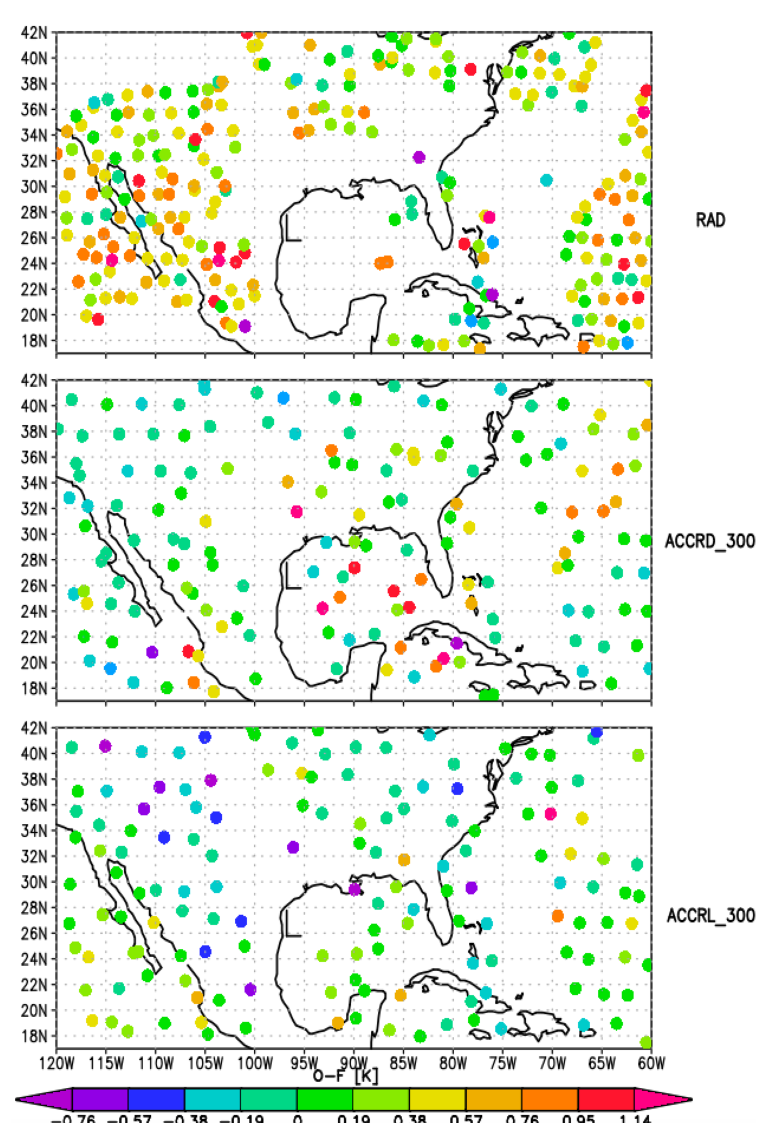


Fig 1. Hurricane Harvey spatial distribution of data assimilated in RAD, AIRS cloud-cleared radiances from NASA GES DISC (ACCRD) and the internally produced AIRS CCRs (ACCRL). The dots indicate locations of assimilated observations minus forecast (OmF, K) for channels 215 (14,06 µm, 711 cm^{-1}) on August 25th, 2017, at 18z.

AIRS cloud-cleared radiances assimilate more data around TC comparing to RAD which produce more realistic atmospheric representation in the analysis.

Irma

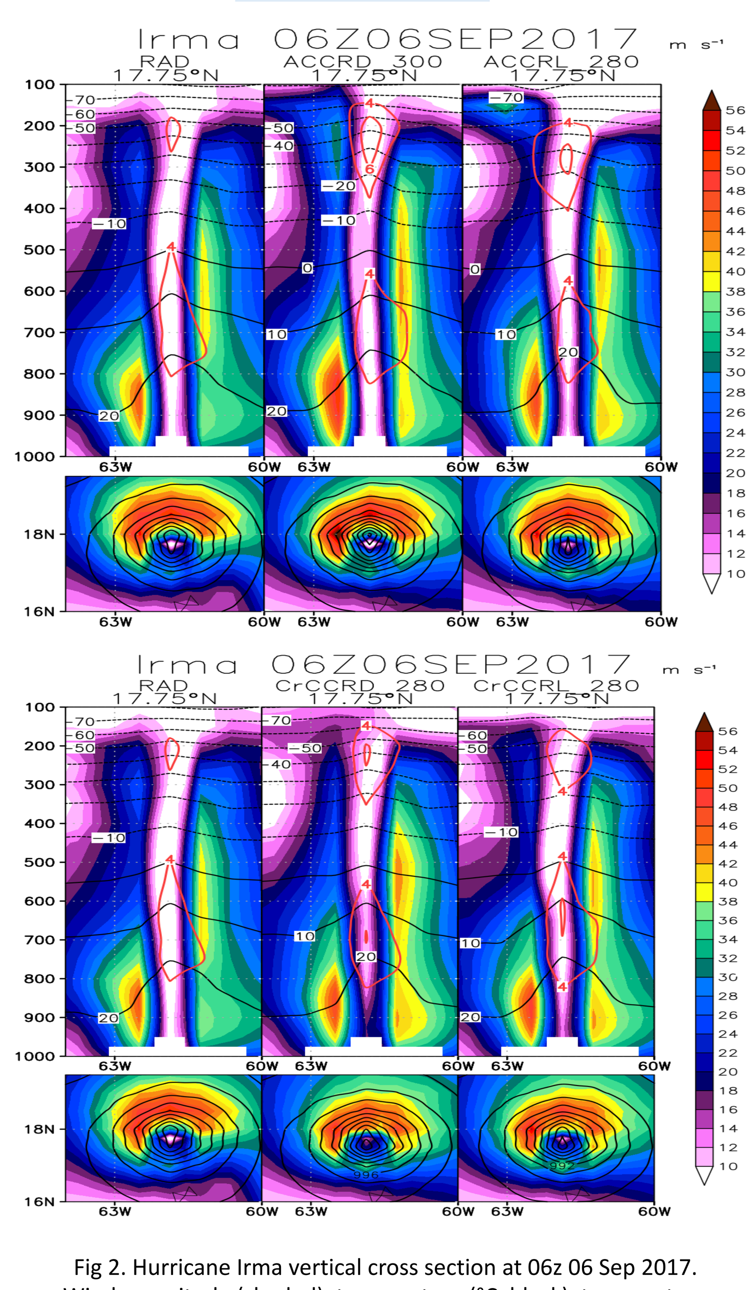
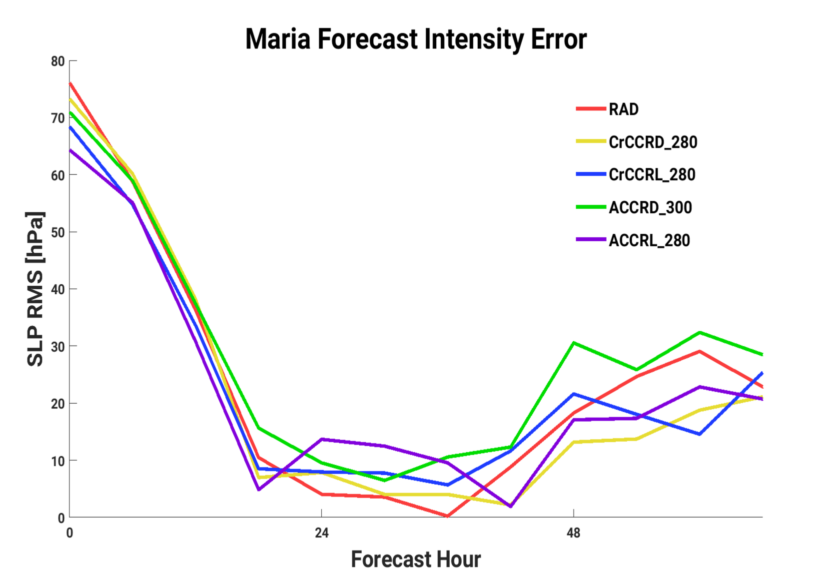


Fig 2. Hurricane Irma vertical cross section at 06z 06 Sep 2017. Wind magnitude (shaded), temperature (°C, black), temperature anomaly (°C, red), 850 hPa (winds shade) and slp (contours).

The internally produced AIRS and CrIS CCRs, when adaptively thinned, produce large improvements in vertical and horizontal TC structure, without degrading the global skill.

Maria



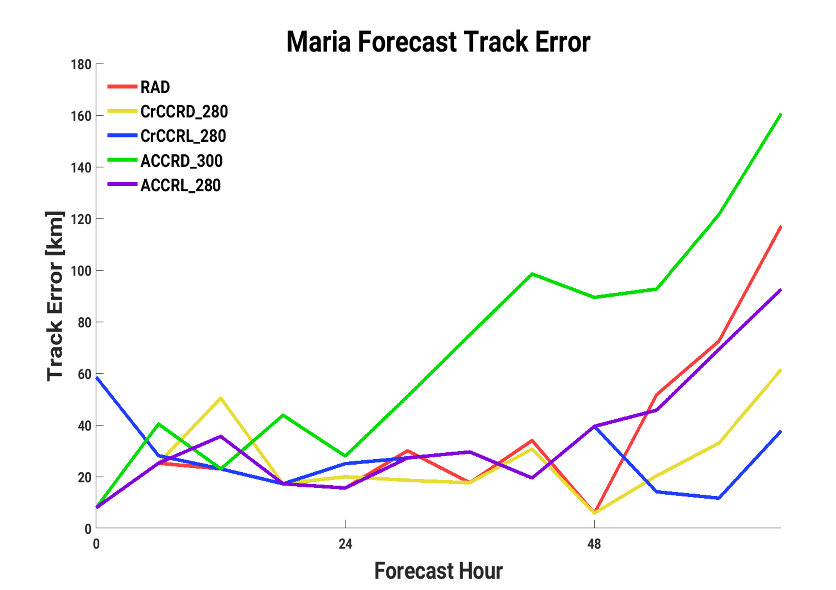


Fig 3. Hurricane Maria forecast intensity error and forecast track error

The assimilation of the internally produced AIRS and CrIS CCRs improve the forecast for both track and intensity beyond day 3.

Summary and future work

- Positive impact obtained when assimilating the internally produced AIRS and CrIS CCRs on TCs analysis and forecast in the GEOS hybrid 4DEnVar.
- Better results using the internally generated AIRS and CrIS CCRs compared to AIRS CCRs product distributed by NASA GES DISC and CrIS CCRs from NOAA CLASS.

Next, we will be focusing on:

- Exploring TC-centered adaptive thinning strategies on all hyperspectral IR sensors by investigating domain selections denser data assimilation around TCs using machine learning techniques.
- Expanding the concept of AIRS and CrIS CCRs towards other IR hyperspectral sensors such as IASI.
- Preparing the foundation for an all-sky IR assimilation.

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- NASA GES DISC and NOAA CLASS.

[1]Infrared Atmospheric Sounding Interferometer
[2]High-End Computing
[3] Goddard Earth Observing System Model
[4] Goddard Earth Sciences Data and Information Services Center
[5]Comprehensive Large Array-data Stewardship System

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