

Status of the NOAA Unique CrIS/ATMS Processing System (NUCAPS)

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Abstract

This paper describes the status of the NOAA Unique Combined Atmospheric Processing System (NUCAPS). We provide an overview of the algorithm characteristics and retrieval product performance. Our current research aims towards the development of a robust retrieval algorithm suitable for both near real time regional forecast applications and long term climate analysis.

Introduction

NUCAPS is the NOAA operational algorithm for hyper spectral sounders (Gambacorta et al., 2012a, 2013, 2015). It responds to NOAA's mandate of a weather ready nation, by ensuring state of art inversion methods and highest computational efficiency, two necessary prerequisites for maximizing the utilization of large volumes of hyper spectral data.

NUCAPS is a globally applicable, mathematically sound (land/ocean, day/night, all season, all sky, TOA-surface) hyper spectral sounding retrieval code that can fully exploit all assets currently available on operational polar sounders: infrared, microwave, visible. This system generates a full suite of retrieval products: cloud cleared radiances, skin temperature, vertical profiles of temperature, water vapor, O₃, CO, CH₄, HNO₃, N₂O, SO₂, CO₂ (future: NH₃). These retrieval products are accessible in near real time (about 3 hour delay) through the NOAA Comprehensive Large Array-data Stewardship System. Since February 2015, NUCAPS retrievals have been also available to the science community with unprecedented low latency (less than 0.5 hours) through Direct Broadcast.

Our current research aims towards the development of a robust retrieval algorithm suitable for both near real time regional forecast applications and long term climate analysis. This paper presents an overview on the architecture of the retrieval system, with a highlight on the retrieval algorithm statistical performance and its applications.

Overview of the NUCAPS algorithm

NUCAPS is a modular design mainly organized in 4 sub-modules, as described below.

I. A microwave retrieval module, which computes temperature, water vapor and cloud liquid water (Rosenkranz, 2000)

II. A fast eigenvector regression retrieval that is trained against ECMWF analysis and CrIS all sky radiances. This step computes temperature and water vapor (Goldberg et al., 2003) profiles used as an input for the cloud clearing step.

III. A cloud clearing module (Chahine, 1974) which removes the spectral signature of clouds to generate a cloud free radiance spectrum.

IV. A second fast eigenvector regression retrieval that is trained against ECMWF analysis and CrIS cloud cleared radiances. This is used as first guess for the physical retrieval.

V. The final infrared physical retrieval based on a regularized, weighted and iterated least square minimization to retrieve temperature, water vapor, trace gases (O₃, CO, CH₄, CO₂, SO₂, HNO₃, N₂O) (Susskind, Barnet, Blaisdell, 2003), using a dedicated selection of channels [Gambacorta and Barnet, 2012].

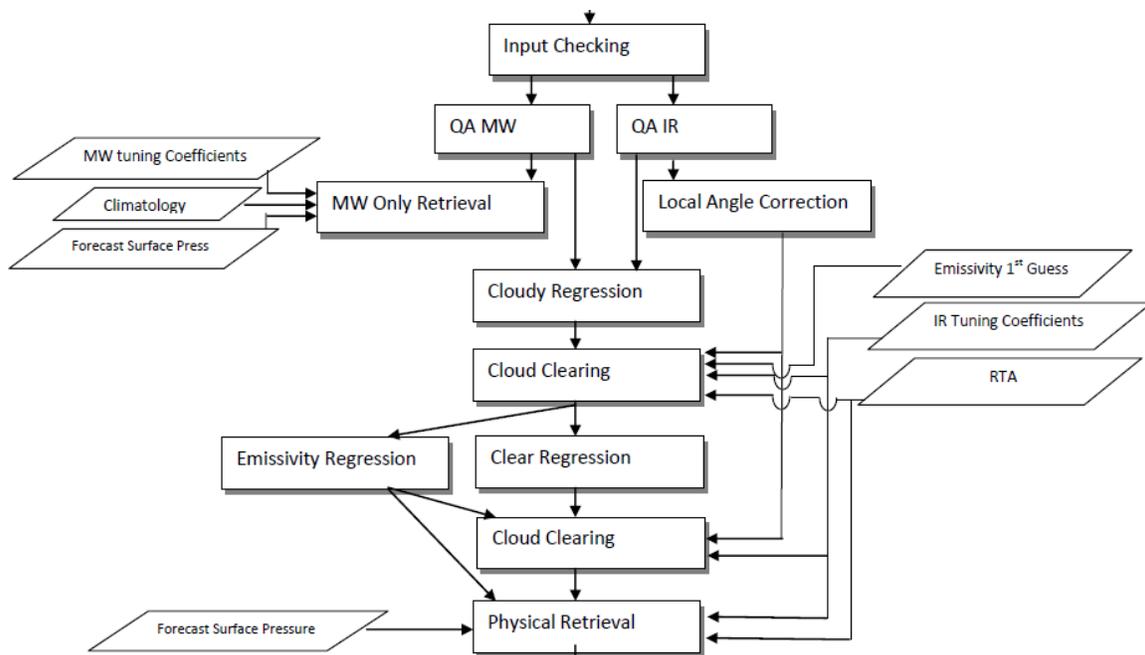


Figure 1. Algorithm flow diagram of the NUCAPS System. See text for explanation.

NUCAPS is the NOAA operational algorithm heritage of the AIRS Science Team (AST) code, with additional unique components. It was designed, from the beginning, to be product-centric rather than sensor-centric, a NPP Science Team priority recommendation. The AIRS/AMSU, IASI/AMSU/MHS, and CrIS/ATMS are processed with literally the same NUCAPS code, with the same underlying spectroscopy. The system is instrument agnostic: specific items are file-driven, not hardwired and retrieval components are programmable via name-lists. This condition lays the

foundation for a long-term uniform multi-satellite atmospheric data record. It is also advantageous in that it allows quick comparisons of retrieval enhancements and/or methodologies and fast transitions from research to operations.

NUCAPS uses an open framework, another NPP Science Team priority recommendation. This enables other researchers to link other algorithms for the core products and new algorithms for ancillary products (e.g., cloud microphysical products, trace gases, etc.) and new retrieval products, such as ammonia, formic acid (HCOOH), and peroxyacetyl nitrate (PAN). The NUCAPS system is designed to use all available sounding instruments. It employs a climatological startup and the only ancillary information used is surface pressure from GFS model. Microwave radiances are used in microwave-only physical retrieval, “allsky” regression solution, “cloud cleared” regression and downstream physical T(p) and q(p) steps. Visible radiances can be used to characterize sub-pixel inhomogeneity.

A fundamental characteristic of NUCAPS rests in the attempt to maximize the high-information content of the hyper-spectral infrared – both radiances and physics. Its sequential physical algorithm allows for a robust and stable system with minimal dependence on the a priori information. It utilizes forward model derivatives to help constrain the solution. Furthermore, all channels are used in the linear regression first guesses.

NUCAPS employs a physically based channel selection. The methodology for selecting the retrieval channels gives highest priority to spectral purity, vertical sensitivity properties, and minimization of noise sources. A detailed description of the methodology can be found in Gambacorta and Barnett, 2012b and Susskind et al., 2003. This methodology has been employed to build the NASA AIRS and the NOAA IASI and CrIS nominal and full spectral resolution operational channel selections. Information content analyses have indicated that this methodology is capable of fully representing the total atmospheric variability contained in the original spectrum, up to instrumental noise. These results ensure that the replacement of the full spectrum in favor of these channel selections have no detrimental effects on data assimilation and retrieval performance. The same methodology has been also employed for the selection of the CrIS operational channel selection, employed by the NOAA National Center for Environmental Prediction (NCEP). Figure 2 shows the CrIS operational channel selection employed by NUCAPS. 610 channels compose this selection. Their principal sensitivity to thermodynamic and composition species is indicated by the color code. Figure 3 (courtesy of Andrew Collard) shows the CrIS operational channel selection employed by NCEP. The latter varies from the former by a larger emphasis put on the thermodynamic species over the atmospheric composition ones, to better suit 4DVAR data assimilation requirements.

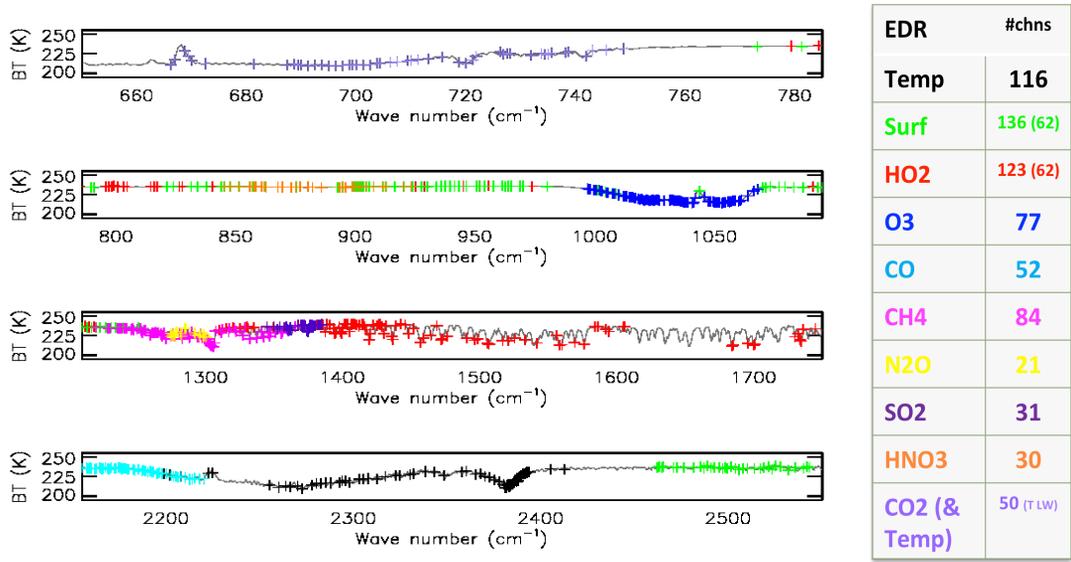


Figure 2. The CrIS full spectrum resolution operational channel selection used in the NOAA Unique Combined Atmospheric processing System (NUCAPS)

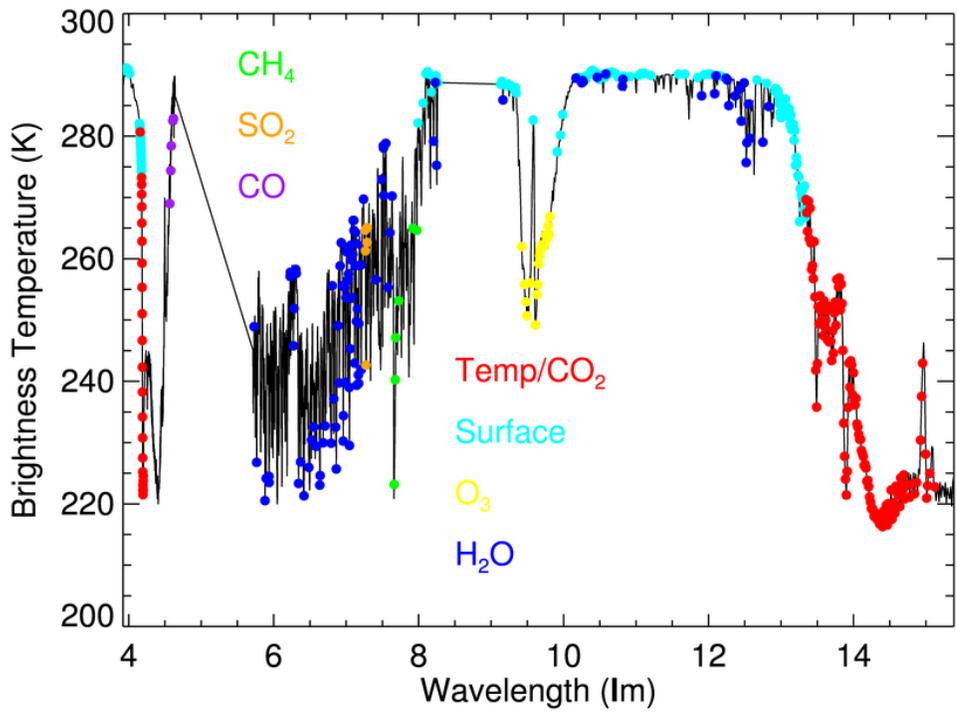


Figure 3. The CrIS full spectrum resolution operational channel selection employed by the NOAA National Center for Environmental Prediction (NCEP).

Retrieval performance and applications

Figure 4 shows a global RMS error statistics of NUCAPS microwave only (green), microwave + infrared first guess (red) and microwave + infrared retrievals. Comparisons were made against ECMWF analysis. Left figure is temperature, center figure is water vapor and right figure is ozone. Figure 5 shows the same type of results using an infrared only version of the NUCAPS system. The comparison of figure 4 and 5 demonstrates the gain obtained from the use of the microwave sounder, in terms of statistical performance. The temperature RMS error degrades by 1 degree Kelvin in the lower troposphere. The water vapor statistics degrades by roughly 5 to 10% along the full atmospheric column.

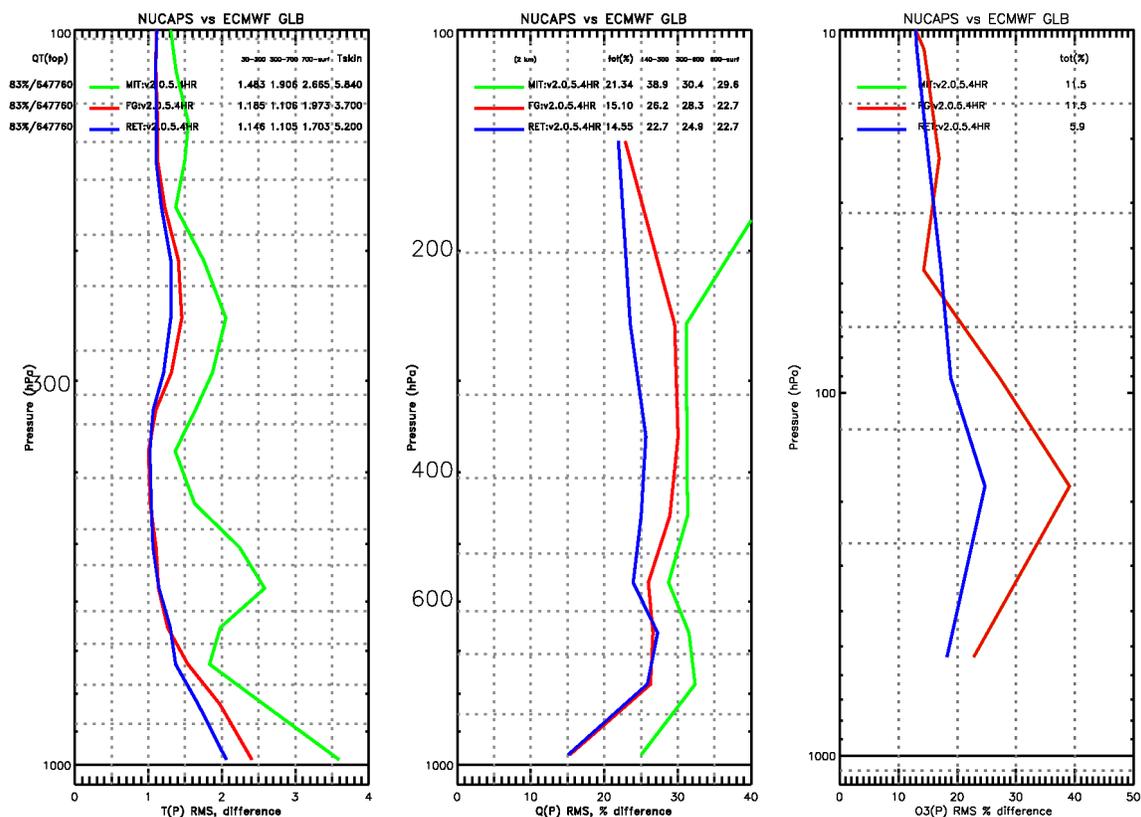


Figure 4. Global RMS error statistics of NUCAPS microwave only (green), microwave + infrared first guess (red) and microwave + infrared retrievals. Comparisons were made against ECMWF analysis. Left figure is temperature, center figure is water vapor and right figure is ozone.

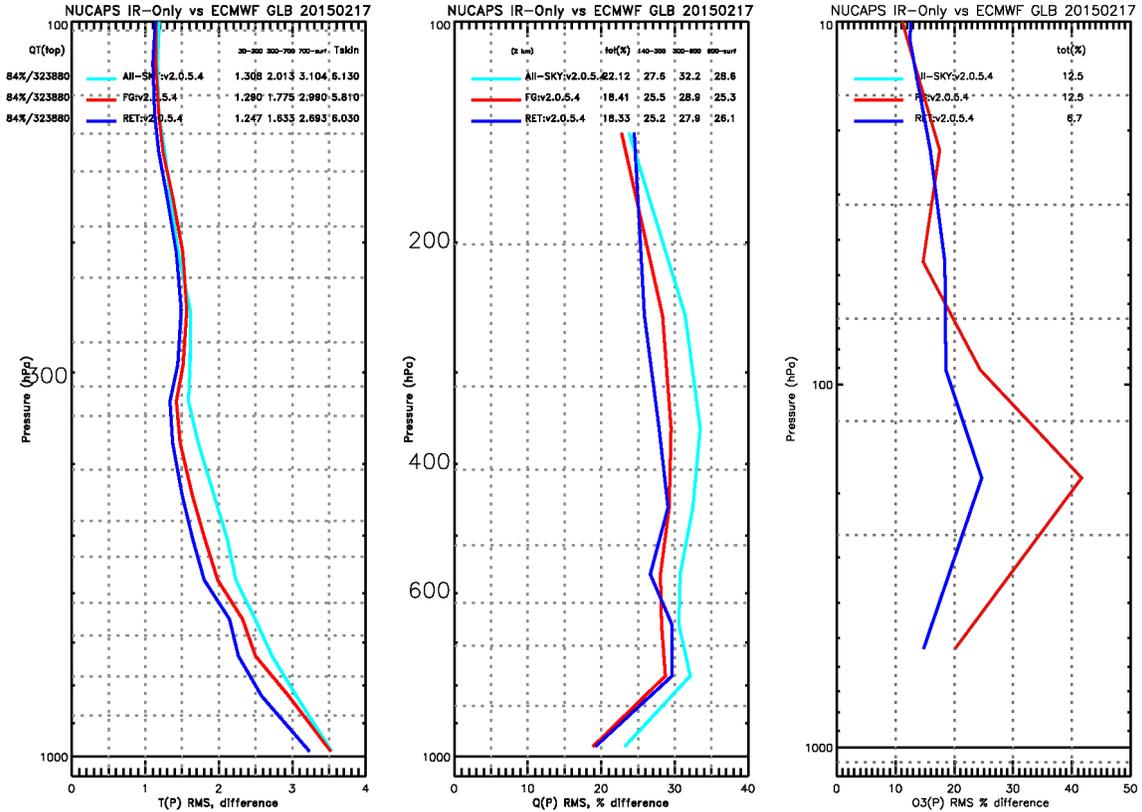


Figure 5. Global RMS error statistics of NUCAPS all sky retrievals (cyan), infrared only first guess (red) and infrared retrievals. Comparisons were made against ECMWF analysis. Left figure is temperature, center figure is water vapor and right figure is ozone.

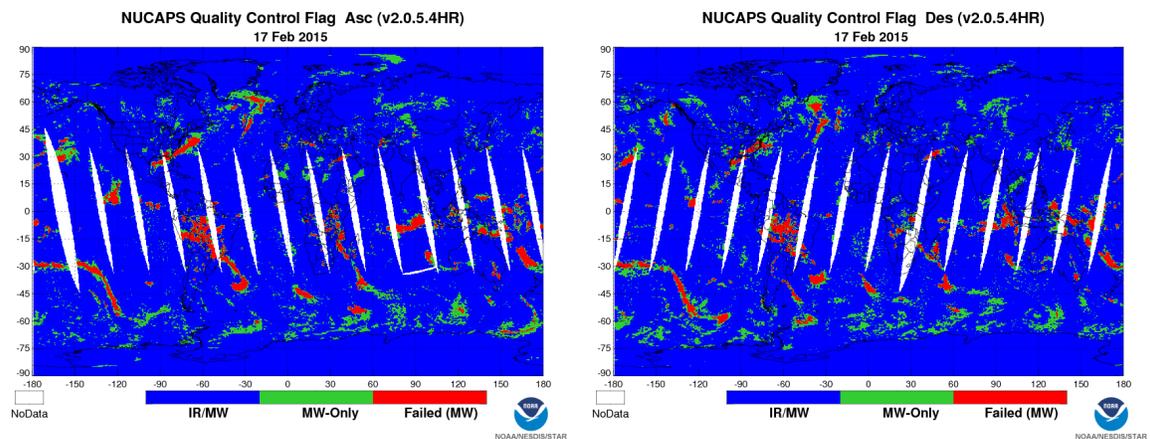


Figure 6. NUCAPS global acceptance yield upon cloud clearing. Red regions are failed microwave retrievals, mostly due to precipitation. Green are regions solely accepted by the microwave retrieval step but rejected by the infrared step. Blue regions are accepted cases by both the microwave and microwave + infrared step.

Another fundamental characteristic of NUCAPS is cloud clearing. Cloud clearing enables soundings from the top of atmosphere to the surface. It is computationally fairly simple in that it does not require any radiative or microphysics treatment of clouds. Cloud clearing is the very first step of the retrieval chain and is greatly advantageous in that it considerably helps improving linearization of the inversion problem. The downside of cloud clearing rests in the degraded spatial resolution since it relies on a cluster of IR and microwave co-located field of views to extract one final retrieval. Nonetheless, it enables removing the typical clear sky biases of inversion algorithms and ad hoc switches between clear sky-only and cloudy sky single field of view algorithms. This enables a uniform and global coverage in the data record. Figure 6 describes NUCAPS global acceptance yield upon cloud clearing.

The correct propagation of the cloud clearing error is a key aspect of the cloud clearing methodology. Cloud clearing noise is used to weigh the contribution of the infrared measurement during the inversion. High cloud clearing noise is expected under uniform cloud cover across the cluster of field of views. Under these circumstances, the cloud clearing error term in the measurement noise error covariance matrix will tend to suppress the infrared measurement in favor of the microwave one. This helps stabilizing the retrieval solution by allowing a smooth transition from infrared + microwave to microwave-only dominated types of retrievals. As a result, this algorithm favors the possibility of a smoother data fusion between microwave only retrievals (accepted under overcast, non-precipitating cloud formations) and microwave + infrared retrievals. Figure 7 shows an example of data fusion of this kind. The figure shows NUCAPS total precipitable water during Hurricane Katya (left side of the Gulf of Mexico) and Irma (as it makes landfall over the Caribbean archipelago). Top part is obtained using only accepted microwave + infrared retrievals. Bottom figure was obtained by using accepted microwave + infrared retrievals and microwave only retrievals when microwave + infrared retrievals fail (white areas in the top figure). The composite yield increases to ~95%, against the infrared + microwave yield of ~70%. This enables a more comprehensive synoptic representation that can ultimately provide improved situational awareness during an extreme event of societal importance.

Conclusions and future steps

This paper provides an overview of the architecture and status of the NUCAPS operational algorithm. In August 2017, the system underwent a major operational upgrade to enable processing of the Suomi-NPP CrIS full spectral sampling mode. This activity lays the foundation for future implementation of NUCAPS applied to NOAA-20 CrIS/ATMS. NOAA-20 was successfully launched on November 18th, 2018. NUCAPS retrievals from NOAA-20 CrIS/ATMS promise to advance near real time weather applications and extend the data record of environmental variables necessary for long-term climate analysis.

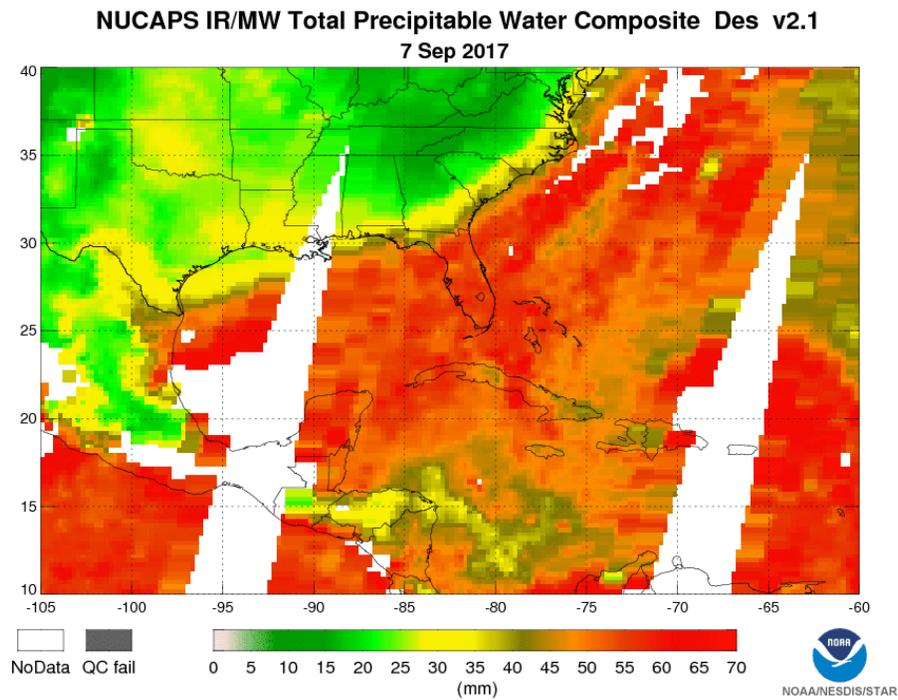
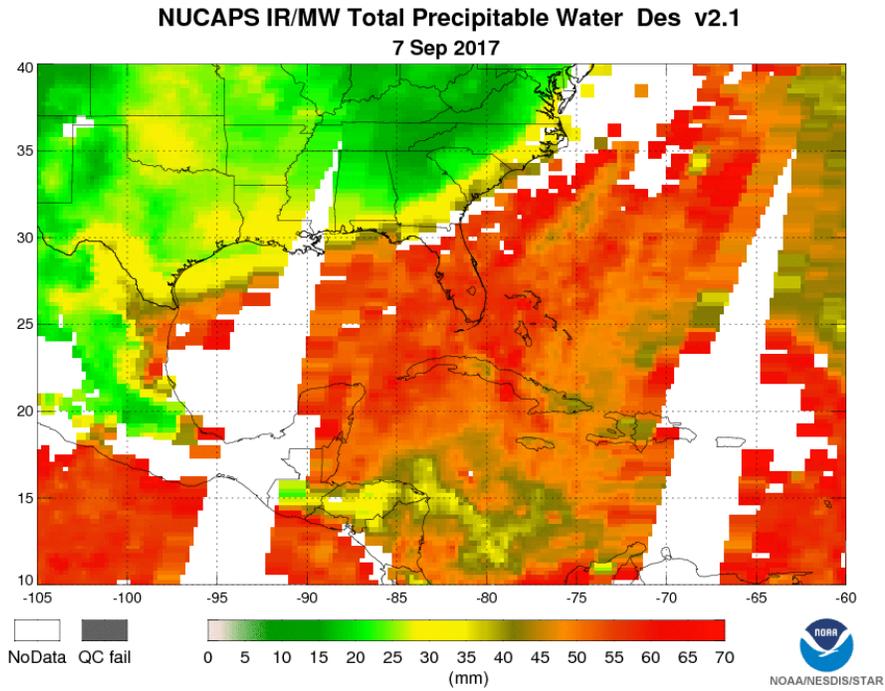


Figure 7. NUCAPS total precipitable water during Hurricane Katya (left side of the Gulf of Mexico) and Irma (as it makes landfall over the Caribbean archipelago). Top is accepted microwave + infrared. Bottom is accepted microwave + infrared and accepted microwave only where microwave + infrared failed (white areas in the top figure).

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