

Status of the NOAA Unique CrIS/ATMS Processing System (NUCAPS): algorithm development and lessons learned from recent field campaigns.

Antonia Gambacorta (1), Chris Barnet (1), Mitch Goldberg (3)

(1) Science and Technology Corporation (STC), Columbia, MD, USA/ NOAA JPSS

(2) NOAA JPSS

Abstract

This paper describes the status of the NOAA hyper spectral retrieval system, with a focus on the NOAA Unique CrIS/ATMS Processing System (NUCAPS). We provide an overview of the algorithm characteristics and a general assessment of the temperature and water vapor retrieval products. 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 talk is organized into two main foci: building a robust a priori term and a formal computation of error estimates.

Introduction

The NOAA operational hyper spectral retrieval system was developed to produce cloud-cleared radiances and atmospheric temperature, water vapor and trace gas profiles from hyper spectral infrared sounders such as CrIS, IASI and AIRS, in conjunction with microwave sounders, such as ATMS, AMSU and MHS. 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, the NOAA Unique CrIS/ATMS Processing System (NUCAPS) [Gambacorta et al. 2012, Gambacorta and Barnet, 2012] 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 talk is organized into two main foci. We first present an overview on the status of the retrieval system, with a highlight on the latest enhancements to the algorithm. Secondly, we discuss some of the lessons learned during recent intensive field campaigns targeted at validating our products and engaging new user applications.

Overview and current status of the NUCAPS system

The NUCAPS system is a modular design mainly organized in 4 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 and CrIS all sky radiances which computes temperature and water vapor (Goldberg et al., 2003)

III. A cloud clearing module (Chahine, 1974)

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 iterated least square minimization: temperature, water vapor, trace gases (O₃, CO, CH₄, CO₂, SO₂, HNO₃, N₂O) (Susskind, Barnett, Blaisdell, 2003), using a dedicated selection of channels [Gambacorta and Barnett, 2012].

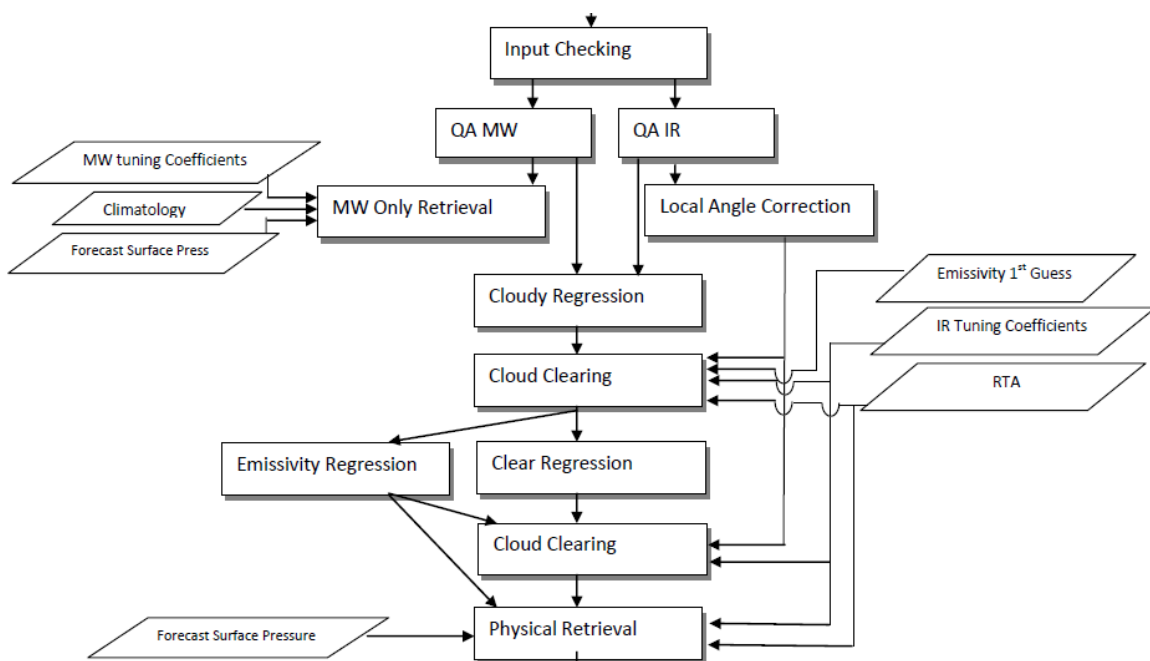


Figure 1. Algorithm flow diagram of the NUCAPS System. See text for explanation.

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. Indeed, 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. Indeed, the operational code is a “filtered” version of the science code.

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 of maximizing 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. In this framework, errors from previous steps are mapped into an error estimate from interfering parameters. Furthermore, all channels are used in linear regression first guesses.

Another fundamental characteristic of NUCAPS is cloud clearing. Cloud clearing is what makes NUCAPS meeting the requirement of sounding all the way down 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. 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.

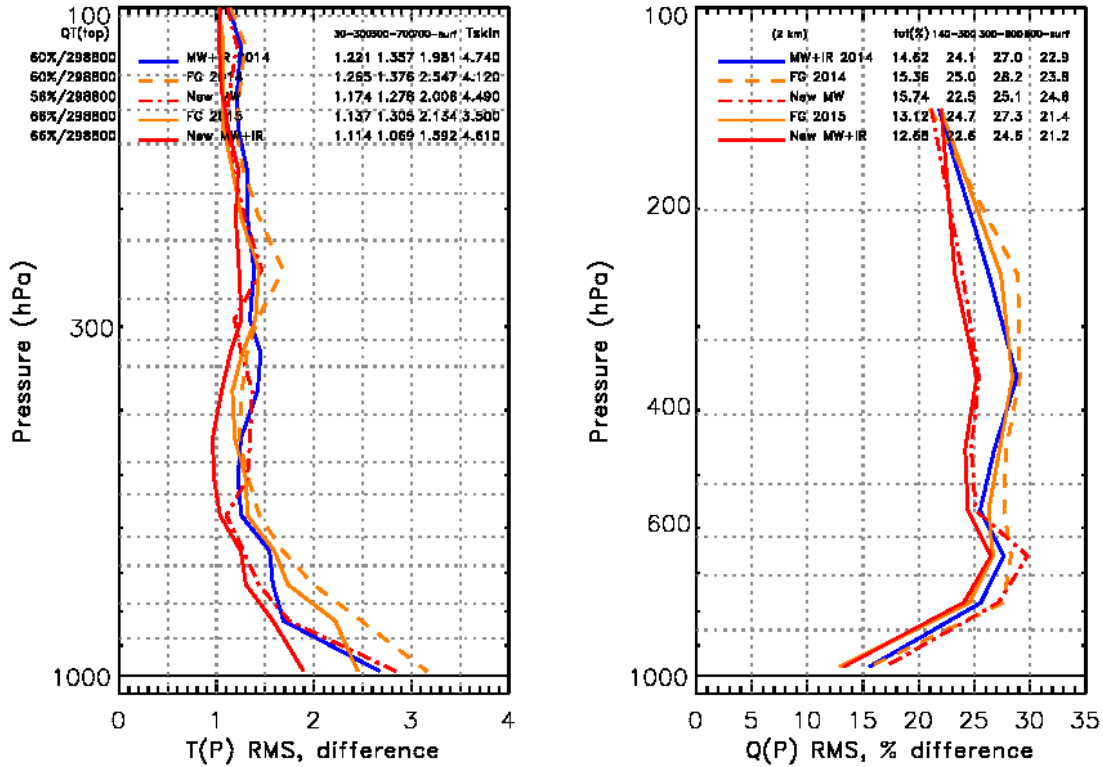


Figure 2. Global statistical retrieval performance assessment for the final physical retrieval (“MW+IR” step). We show the rms statistics for temperature (left) and water vapor (right). See text for explanation on the color codes.

Figure 2 shows the results of a global statistical retrieval performance assessment for the final physical retrieval (“MW+IR” step). We show the rms statistics for temperature (left) and water vapor (right). In blue, we show the status of the retrieval as of August 2014. These results allowed NUCAPS to pass the JPSS stage 1 validation review. In orange we show the 2014 (dash) and the recently updated (solid) regression solution that is used as first guess for the physical retrieval. In dot-dash red, we show the MW-only solution. In solid red we show the current retrieval results. Improvements over the 2014 system are due to a new RTA error and bias tuning file, an improved MW noise instrument and the aforementioned updated first guess. The system now fully meets JPSS retrieval requirements.

Ongoing developments

NUCAPS ultimate goal is to meet climate quality. The need for a climate quality retrieval algorithm rests in the necessity to build an independent data record to study atmospheric variability and feedbacks, to test Global Circulation Models (GCM) and understand current discrepancies.

Climate quality is met when a retrieval algorithm can be characterized by explicitly evaluating the *functional form* of the relationship between the retrieved profile, the true atmosphere, and the various error sources [Rodgers, 2000]. The computation of a formal error estimate passes through the measurement and a priori covariance matrices entering the minimization of the cost function. We currently only map the diagonal component of the retrieval error covariance into down-stream steps.

It has been shown that there is a robust way to pass the full 2D retrieval error covariance from one step to the next (Chris Barnet Mar. 23 2007 AIRS meeting, and Eric Maddy, AIRS meeting, Apr. 27, 2011). This is by compressing the retrieval error estimate covariance matrix and only propagating the significant eigenvalues and eigenvectors to the next step. From there the retrieval error covariance can be reconstructed and used to compute the measurement error covariance.

We have recently investigated the number of significant pieces of information needed to fully reconstruct the retrieval error covariance. As an example, Figure 3 shows that 6 eigenvectors are sufficient to fully reconstruct the temperature error covariance.

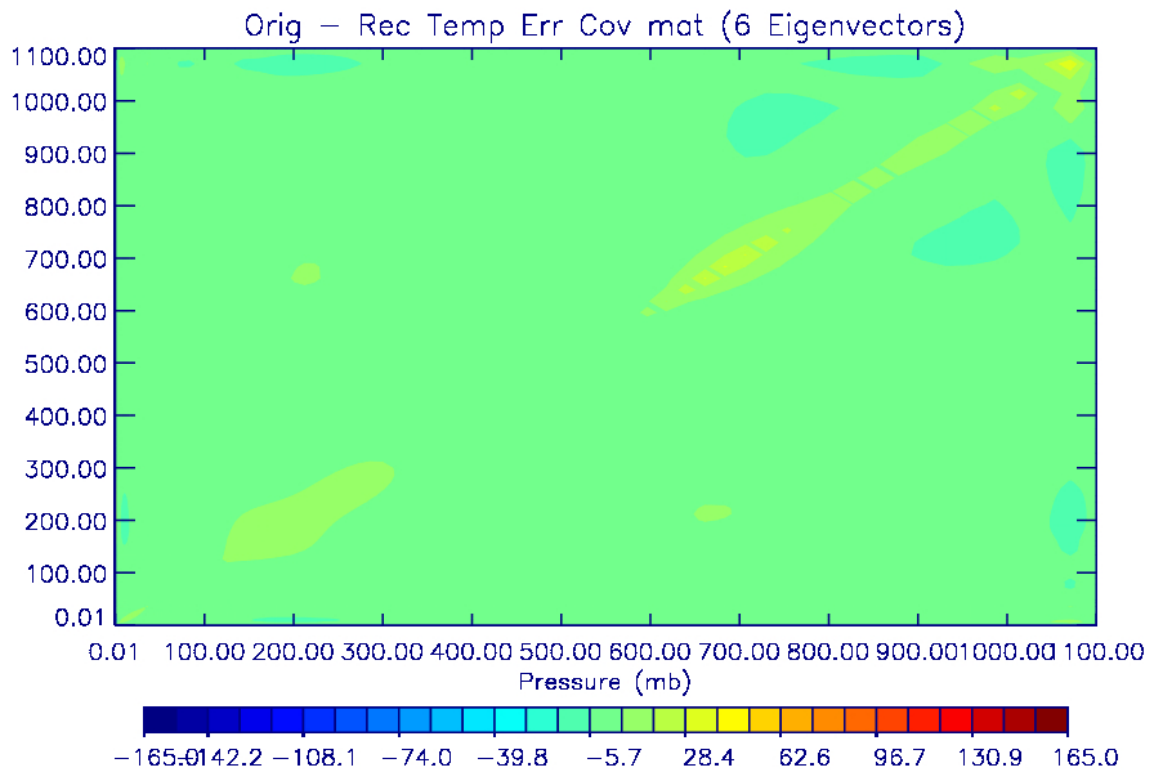


Figure 4. Original minus reconstructed temperature error covariance using only the first 6 eigenvectors.

A formal error estimate computation requires a formal a priori. NUCAPS currently employs a linear regression solution. Statistical methods are in general very attractive for a number of reasons. They not require a radiative transfer model for training or application. Application of eigenvector and regression coefficients is very fast and for hyper-spectral instruments it is very accurate. Since real radiances are used the regression implicitly handles many instrument calibration (e.g., spectral offsets) issues. This is a huge advantage early in a mission. Also, since clouds are identified as unique eigenvectors, a properly trained regression tends to “see through” clouds. The major downside of statistical methods is that training requires a large number of co-located “truth” scenes. The regression operator does not provide any diagnostics or physical interpretation of the answer it provides. It can introduce sub-resolved structures in the retrieval. It is normally very difficult to assess errors in a regression retrieval without the use of a physical interpretation. Furthermore, The regression answer builds in correlations between geophysical parameters. For example, retrieved O_3 in biomass regions might really be a *measurement* of CO with a statistical correlation between CO and O_3 .

We are in the process of investigating new a priori solutions. We have started investigating three possible *a-priori*:

1) climatology built from a decade of ECMWF (this has already been constructed by the AIRS science team and will be tested)

2) ERA-interim; NCEP reanalysis; MERRA.

3) microwave-only retrieval. For CrIS/ATMS this has the potential to be an exceptional *a-priori*. For AIRS/AMSU and IASI/AMSU/MHS it is unlikely that the AMSU information content is sufficient.

To perform this investigation we are relying on an ensemble of in situ measurements collected during the CAIWater 2015 field campaign. For the context of this paper, we show results from a test case acquired on February 6th, 2015. A 4 hours flight with 4 transects across the river occurred that day, capturing pre, in and post river environment as the river quickly approached the US West coast. This case offered a good spatial and temporal matching with NPP (dropsonde location 19 in Figure 4 is ~ 3.2 minutes ahead of over pass).

Figure 5 shows a comparison of the dropsonde (top left), NUCAPS MW-only (top right), GFS (lower left) and NUCAPS linear regression (lower right) along the flight path of Figure 4. We can notice that the MW-only shows a more resilient behavior to the presence of this extreme weather event, while the linear regression is shown a large instability. Ongoing work is considering the development of an a priori profile and covariance from the MERRA Re-analysis to be used in the future development of NUCAPS.

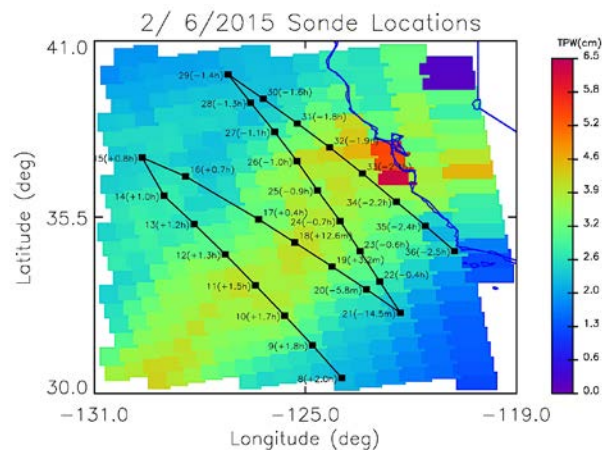


Figure 4. Dropsonde location from CalWater February 6th, 2015 flight. Numbers displayed next to each dropsonde location indicate the temporal mismatch from NPP overpass.

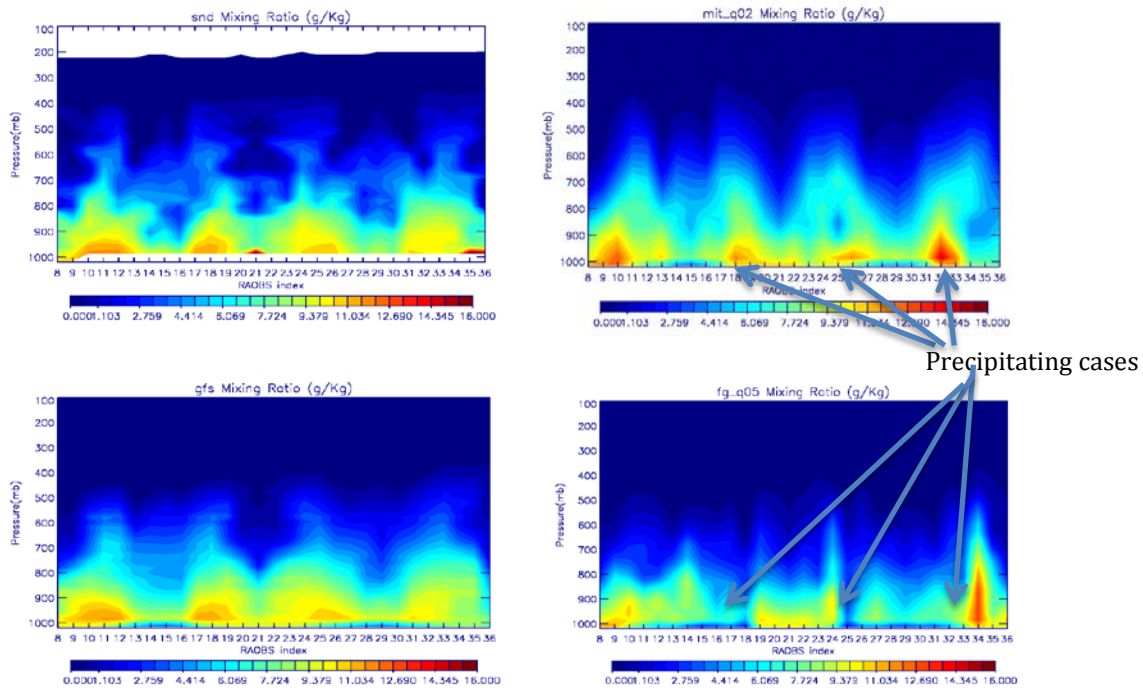


Figure 5. Top left is a water vapor (mixing ratio) cross section of dropsonde measurement along the flight path. Top right is same but from NUCAPS MW-only retrievals. Lower left is from the GFS model and lower right is from the linear regression solution.

Summary and future work

We will add error estimates in addition to current QC parameters in the NUCAPS output package. Error estimates are essential to provide the level of confidence on any climate application. In essence, computing formal error estimates represents the definition of a climate quality algorithm. “It can be argued that a retrieval method without an error analysis and characterization is of little value” (Rodgers, 2000).

References

Gambacorta A. et al., 2012, The NOAA Unique CrIS/ATMS Processing System (NUCAPS): First light retrieval results. Proceedings of ITSC-XVIII, Toulouse, France, International TOVS Working Group (ITWG).

Gambacorta A. and Barnet C.D., Methodology and information content of the NOAA NESDIS operational channel selection for the Cross-Track Infrared Sounder (CrIS), IEEE Transactions on Geoscience and remote Sensing, Vol. 51, Issue No. 6, pp3207-3216, 2012, DOI [10.1109/TGRS.2012.2220369](https://doi.org/10.1109/TGRS.2012.2220369).

Rosenkranz, P., Retrieval of Temperature and Moisture Profiles From AMSU-A and AMSU-B Measurements, IEEE Transactions on Geoscience and remote Sensing ,Vol. 39, No. 11, 2001.

Goldberg M., Qu, Y., McMillin, L.M., Wolf, W., Lihang Zhou, Divakarla, M., AIRS near-real-time products and algorithms in support of operational numerical weather prediction, IEEE Transactions on Geoscience and remote Sensing , Vol. 41, No. 2, pp. 379-389, 2003.

Susskind J., Barnet C.D. and Blaisdell J.M., Retrieval of atmospheric and surface parameters from AIRS/AMSU/HSB data in the presence of clouds, IEEE Transactions on Geoscience and remote Sensing , Vol. 41, No. 2, pp. 390-409, 2003.