THE NOAA UNIQUE CRIS/ATMS PROCESSING SYSTEM (NUCAPS): ONE YEAR IN ORBIT

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Abstract

Launched on board the Joint Polar Satellite System (JPSS) Suomi National Polar-orbiting Partnership (NPP) platform on October 28th 2011, the Cross-track Infrared Sounder and the Advanced Technology Microwave Sounder represent the US next generation of polar-orbiting operational hyperspectral sounders. This paper focuses on global temperature and water vapour retrieval results from the NOAA Unique CrIS/ATMS Processing Systems. A comparison with respect to collocated ECMWF analysis and AIRS/AMSU retrieval profiles shows comparable results and a general good stability in the NUCAPS retrieval performance statistics already at this early stage (one year after launch) of the NPP mission.

1. Introduction

The Cross-track Infrared Sounder (CrIS) is a Fourier transform spectrometer with a total of 1305 infrared sounding channels covering the longwave (655-1095 cm^-1), midwave (1210-1750 cm^-1), and shortwave (2155-2550 cm^-1) spectral regions. The Advanced Technology Microwave Sounder (ATMS) sounder is a cross-track scanner with 22 channels in spectral bands from 23 GHz through 183 GHz. These two instruments together represent the latest addition to a long series of atmospheric satellite sounders that originated in the late 1970's [http://www.ipo.noaa.gov, 2011]. CrIS has been designed to continue the advances in atmospheric observations and research that started with the Atmospheric Infrared Sounder (AIRS) launched on the Aqua platform in 2002 and followed by the Infrared Atmospheric Sounding Interferometer (IASI), launched on the Metop-B platform in 2006. ATMS will similarly continue the series of observations that started with the Advanced Microwave Sounding Unit (AMSU) first launched by NOAA in 1998.

NOAA/NESDIS/STAR has processed AIRS data in near real-time since AIRS became operational in October 2002 by employing the NASA Science Team retrieval algorithm. Using this same retrieval algorithm (including spectroscopy), STAR has also processed IASI data since IASI became operational in August 2008. STAR is currently developing the NOAA-Unique CrIS/ATMS Product System (NUCAPS) which will employ the AIRS/IASI heritage retrieval algorithm and spectroscopy to operationally process CrIS/ATMS data and produce cloud cleared radiances and trace gas products.
The robust modular design of the NOAA implementation of the NASA Science Team algorithm has permitted a quick and efficient acquisition of CrIS and ATMS data, allowing retrieval processing results to be already available since the early stage of the post launch mission (Spring 2012, [Gambacorta et al., 2012a]). The focus of this paper is an overview of the current status (one year after launch) of the NUCAPS temperature and water vapour retrievals, two atmospheric key parameters of the JPSS mission. The accuracy of temperature and water vapour retrievals is also a fundamental requirement for the success of NUCAPS trace gas retrieval products, which are scheduled to become operational in January 2013.

The following part of this paper is organized in 3 sections. Section 2 presents an overview of the NUCAPS retrieval algorithm theoretical basis. Section 3 focuses on the validation assessment of the current status of the NUCAPS retrievals. Conclusions are summarized in section 4.

2. NUCAPS Retrieval Algorithm Theoretical Basis

NUCAPS is an iterative regularized least squares minimization algorithm, based on the approach described by Susskind, Barnet, Blaisdell (2003) and originally implemented for the AIRS/AMSU suite of instruments. This retrieval scheme includes: 1) A microwave retrieval module which derives cloud liquid water flags and microwave surface emissivity uncertainty; 2) A fast eigenvector regression retrieval for temperature and moisture that is trained against ECMWF analysis and CrIS all sky radiances [Goldberg et al., 2003]; 3) A cloud clearing module that combines a set of microwave and IR channels (along with, in the future, visible observations provided by the onboard VIIRS instrument) to produce cloud-cleared IR radiances [Chanine, 1974]; 4) A second fast eigenvector regression retrieval for temperature and moisture that is trained against ECMWF analysis and CrIS cloud cleared radiances [Goldberg et al., 2003]; 5) The final infrared physical retrieval, which employs the previous regression retrieval as a first guess.

The final infrared retrieval module is an iterated regularized least squared minimization performed on a selected subset of infrared channels. This channel selection follows the methodology described in Gambacorta and Barnet (2012) and is a physically-based procedure where channels are selected solely upon their spectral properties: high priority is given to spectral purity, avoidance of redundancy and vertical sensitivity properties, along with low instrumental noise and global optimality. This channel selection is composed of a total of 399 channels consisting in 24 surface temperature and emissivity sounding channels, 87 temperature sounding channels, 62 water vapour, 53 ozone, 27 carbon monoxide, 54 methane, 53 carbon dioxide, 24 \( \text{N}_2\text{O} \), 28 \( \text{HNO}_3 \) and 24 \( \text{SO}_2 \) sounding channels. Grey cross symbols on Figure 1 indicate the location of all 1305 channels present in the original spectrum of the CrIS instrument. Superimposed coloured cross symbols indicate the 10 channel subsets forming the complete channel selection, as indicated in the figure caption. Test studies [Gambacorta and Barnet, 2012] have shown that this selection is capable of significantly reducing the execution time of routine operations, while still retaining the bulk of the atmospheric variability contained in the original 1305 channel spectrum, up to instrumental noise. Hence, no detrimental impacts are to be expected on data assimilation and retrieval applications.
During the least square residual minimization, radiative transfer calculations are performed by mean of the microwave MIT [Rosenkranz, 2003] and infrared SARTA forward model [Strow et al., 2003] and there is a need for identifying and removing those components of the residuals arising from modelling and calibration errors. This process, commonly referred to as brightness temperature tuning, is fundamental to achieve retrieval performance accuracy, in that it removes artificial systematic biases that could be otherwise ascribed to the atmospheric source of interest and erroneously confused with climatic trend signals. The NUCAPS brightness temperature tuning methodology [Gambacorta et al., 2012b, part I and II] employs a global ocean night mid latitude sample of ATMS and CrIS clear sky observations to compute an average channel by channel difference with respect to correlative brightness temperature forward calculations. The microwave differences are computed also at each viewing angle. These calculations employ a combination of collocated climatology, un-tuned retrieval and ECMWF analysis profiles, describing the full atmospheric state input for the forward calculations. The obtained microwave and infrared OBS-CALC global average differences represent the microwave and infrared bias residual tuning respectively. For brevity we only show the infrared bias tuning spectrum for the CrIS instrument, in figure 2. Figure 2 shows the bias tuning file obtained from a global focus day acquired on May 15\textsuperscript{th}, 2012 which represented a fully stable and calibrated stage of CrIS radiance measurements (red curve). For comparison, we also show the current operational AIRS (green) and IASI (black) bias tuning, using the same spectroscopic radiative transfer model (SARTA version 10, [Strow et al., 2033]). Separate tests (not shown for brevity) have shown that the removal of these biases from the least square residuals improves the retrieval performance of temperature and water vapour by 0.5K and 10% RMS, respectively.

For a complete description of the retrieval algorithm theoretical basis, the reader can also refer to the AIRS Algorithm Theoretical Basis Documentation (2006) and the IASI Algorithm Theoretical Basis Documentation (2012).

The retrieval output consists of cloud cleared radiances, surface emissivity and temperature, vertical profiles of temperature, water vapour and trace gases, along with OLR, cloud fraction and pressure. As anticipated in the introduction, the focus of this paper is an overview of temperature and water vapour retrieval results. Section 3 describes the current status (one year after launch) of the NUCAPS temperature and water vapour retrievals using data from a global focus day acquired on May 15\textsuperscript{th}, 2012.

### 3. NUCAPS retrieval results

We show validation results of a non-fully optimized stage of the NUCAPS algorithm, where the microwave retrieval is temporarily used in replacement of the first and second regression steps (whose implementation is in progress). We perform a validation analysis with respect to collocated ECMWF atmospheric profiles. We section the statistics in latitudinal bands, showing the tropical (solid line), mid-latitude (dash line) and polar (dash-dot line) regime statistics separately. NUCAPS results are shown in red. For completeness, we provide a comparison with the AIRS/AMSU retrieval results for the same focus day (blue curves). For this comparison, we have used AIRS retrieval algorithm version 5.9 which represents an upgrade over the current operational version 5 in that it employs improved regression
training and does not utilize several AMSU channels that have recently undergone a significant degradation.

Figure 3a shows standard deviation results for temperature (left) and water vapour (right). Figure 3b shows bias difference analogous results. The striking result is that even at this early stage of the NUCAPS algorithm, both performance statistics already compare well with the more mature and fully operational AIRS instrument, over all three geophysical regions. Except for the polar region, where NUCAPS largest uncertainties are found, both tropical and mid-latitude regimes only differ of less than half a Kelvin in both temperature statistics throughout the full upper and middle vertical profile. For both temperature and water vapour, the standard deviation statistics are almost superimposed, over all three regions. The bias statistics also fall in the same bulk range, with the exception of the polar region where differences between NUCAPS and AIRS/AMSU can go up to 2K for temperature and 10% for water vapour.

The main source of difference in the NUCAPS and AIRS/AMSU performances rest in the temporarily lack of a robust first guess solution (the microwave retrieval is not fully optimized yet, AIRS algorithm employs a regression solution) and of a fully optimization of the least square inversion parameters employed by the NUCAPS system. Both elements are part of an ongoing effort and will be fully implemented into the final NUCAPS operational delivery.

4 CONCLUSIONS

The robust modular design of the NOAA implementation of the NASA Science Team algorithm has permitted a quick and efficient acquisition of CrIS and ATMS data, allowing retrieval processing results to be already available at this early stage of the post launch mission (launch+1 year). In this paper we have presented an overview of the temperature and water vapour retrieval results from the NOAA Unique CrIS/ATMS Processing Systems. Vertical profile of atmospheric temperature and water vapour are key parameters of the JPSS mission. The accuracy of temperature and water vapour retrievals is also a fundamental requirement for the success of NUCAPS trace gas retrieval products which are scheduled to become operational in January 2013.

A comparison with respect to collocated ECMWF analysis and AIRS/AMSU retrieval profiles shows good stability in the retrieval performance statistics, of both temperature and water vapour. Future improvements to the algorithm will include an improved first guess (by mean of a regression solution), an improved cloud clearing module (by mean of visible channels) and an overall optimization of the least square minimization parameters. These efforts will be targeted towards the final operational delivery of the NUCAPS system.
Figure 1. Operational CrIS channel selection. Grey symbols indicated unselected channels. Colored cross symbols indicate the 10 channel subsets forming our final channel selection. The final selection is composed of 24 surface temperature and emissivity sounding channels (green), 87 temperature sounding channels (black), 62 water vapor (red), 53 ozone (blue), 27 carbon monoxide (cyan), 54 methane (magenta), 53 carbon dioxide (light purple), 24 $N_2O$ (yellow), 28 $HNO_3$ (orange) and 24 $SO_2$ (dark purple) sounding channels. The total number of channels is 399.

Figure 2. Brightness temperature bias tuning of the SARTA model applied to IASI (black), AIRS (green) and CrIS (red).
**Figure 3a.** Standard deviation statistics of NUCAPS (red) and AIRS/AMSU (blue) retrievals versus correlative ECWMF collocated measurements. Left is temperature, right is water vapor statistics. Solid line is for tropical, dash line is for mid-latitude and dash-dot is for polar regimes. The text in the top left corner indicates the acceptance yield. Text on the figure indicates coarse layer statistics results: 30mb – 300mb, 300mb – 700mb, 700mb – surface temperature statistics and skin temperature on the left figure; total column and 140mb – 300mb, 300mb – 600mb, 600mb – surface on the right figure.
Figure 3b. Bias statistics of NUCAPS (red) and AIRS/AMSU (blue) retrievals versus correlative ECWMF collocated measurements. Left is temperature, right is water vapor statistics. Solid line is for tropical, dash line is for mid-latitude and dash-dot is for polar regimes. The text in the top left corner indicates the acceptance yield. Text on the figure indicates coarse layer statistics results: 30mb – 300mb, 300mb – 700mb, 700mb – surface temperature statistics and skin temperature on the left figure; total column and 140mb – 300mb, 300mb – 600mb, 600mb – surface on the right figure.

References


