The NOAA Unique CrIS/ATMS Processing System (NUCAPS): first light retrieval results

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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 hyper spectral sounders. We present "first light" temperature and water vapor retrieval results from the NOAA Unique CrIS/ATMS Processing Systems. A comparison with respect to collocated ECMWF analysis and AIRS/AMSU retrieval profiles shows good stability in the retrieval performance statistics, already at this early stage of the post launch 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 at this early stage of the post launch mission (Spring 2012). The focus of this paper is an overview of these "first light" temperature and water vapor retrieval results which are atmospheric key parameters of the JPSS mission. The accuracy of temperature and water vapor 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 this preliminary 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 physical retrieval which employs the previous regression retrieval as a first guess.

The final IR 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 vapor, 53 ozone, 27 carbon monoxide, 54 methane, 53 carbon dioxide, 24 N_2O, 28 HNO_3 and 24 SO_2 sounding channels. Grey cross symbols on Figure 1 indicates the location of all 1305 channels present in the original spectrum of the CrIS instrument. Superimposed colored 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 modeling 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.*, 2012, part I and II] employs a global ocean night mid latitude sample of ATMS and CrIS clear sky observations to compute channel by channel differences 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. 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. Here we have plotted a preliminary bias tuning file obtained from the first available CrIS global data set, acquired on February 24^{th}, 2012 (green curve). Superimposed the the second version obtained from a more stable and calibrated stage of CrIS radiance measurements acquired on May 15^{th}, 2012. For comparison, we also show the IASI bias tuning, currently used in operations.

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 vapor 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 vapor retrieval results. Section 3 is divided in two parts. Part I shows “first light results” of the NUCAPS retrieval algorithm, already available at the time of the ITWG conference (March 2012, *i.e.* 5 months after launch). Part II of section 3 describes the improvement obtained from a more mature and calibrated state of the CrIS instrument achieved at the seventh month after launch of the instrument (May 2015).

3. NUCAPS retrieval results

3.1 NUCAPS “first light” results

The first global “focus day” of CrIS data has been collected on February 24^{th}, 2012. We used this same focus day to implement the infrared brightness temperature bias tuning. At this stage, data were still undergoing calibration improvements, while ATMS data had been already considered stable since the last previous ATMS global focus day, acquired on December 7^{th}, 2011, which was also use to compute the ATMS brightness temperature bias tuning.

Here we show the “first light” results of a preliminary non optimized early stage of the NUCAPS algorithm, where the microwave retrieval is used in replacement of the first and second regression steps. 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 improvement over the current operational version 5 in that it has an improved regression training and does not utilize several AMSU channels that have recently degraded.

Figure 3 shows standard deviation results for temperature (left) and water vapor (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. The larger temperature bias in the lower troposphere is under investigation. For water vapor in the tropical and nid-latitude regions, the standard deviation statistics are almost superimposed, while the bias differences generally don't exceed 10%.

The main source of difference in the NUCAPS and AIRS/AMSU performances rest in the non- fully calibrated status of the CrIS radiances, in the lack of a robust first guess solution (the microwave retrieval is not fully optimized yet, AIRS algorithm employs a regression solution) and in a non completed optimization of the least square inversion parameters. Also, the relatively poor performance of the polar region is likely due to a preliminary infrared tuning computed over a small sample of tropical ocean night granules. A more matured and improved status has been achieved at the time of the second full global focus day acquisition, as the results in sub-section 3.2 will demonstrate.

3.2 NUCAPS at launch + 7months results

The second global focus day of CrIS data has been collected on May 15th, 2012. At the time of this second acquisition, more stable and calibrated radiance data were available. We have also used this second focus day to implement an improved brightness temperature bias tuning, based on a more global training data set. Results are shown in figure 4a and 4b. Here we compare this new baseline statistics (green) to the previous NUCAPS results shown in figure 3 (red). As in figure 3, solid is for tropical, dash is for mid-latitude and dash-dot is polar regimes. The temperature statistics undergoes a general improvement in both standard deviation and bias, with the exception of the bias polar region which is under investigation. The water vapor standard deviation statistics undergoes a considerable improvement, especially in the polar region, which is mainly attributable to the improved bias tuning. The negative impact on the bias polar statistics is likely to arise from the degradation of the temperature bias polar statistics and is a subject of future investigation as well.

4. Summary and 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 (Spring 2012). In this paper we have presented an overview of the "first light" temperature and water vapor retrieval results from the NOAA Unique CrIS/ATMS Processing Systems. Vertical profile of atmospheric temperature and water vapor are key parameters of the JPSS mission. The accuracy of temperature and water vapor 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, already at this early stage of the post launch mission. Future improvements to the algorithm include the possibility of an improved first guess solution (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.

NOAA/NESDIS is currently engaged in an intense cal/val activity involving numerous operational retrieval products from the AIRS/AMSU and IASI/AMSU/MHS instruments. The aim of this cal/val activity is to perform a thorough assessment of the CrIS/ATMS retrieved atmospheric products, with a particular focus on temperature and water vapor profiles. Along with algorithm validation and improvement, the ultimate goal of this activity is to generate an inter-calibrated long term data record of AIRS, IASI and CrIS climate quality atmospheric variables.

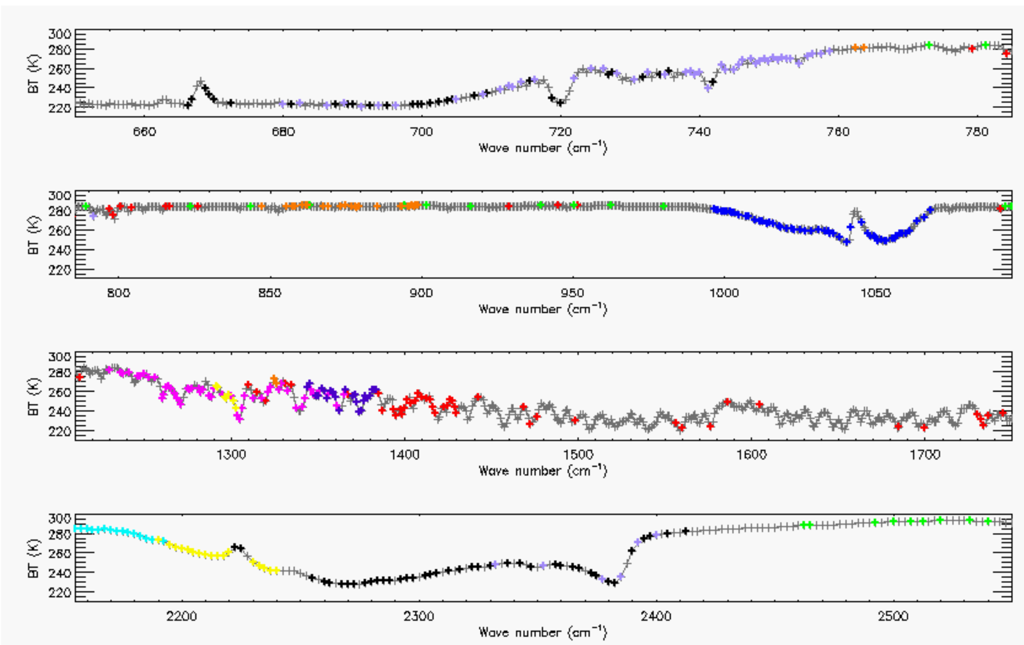

Figure 1. Operational CrIS channel selection. Grey symbols indicated unselected channels. Colored cross symbols indicate the 10 channel subsets forming our final channel selection. The final selection is composed of 24 surface temperature and emissivity sounding channels (green), 87 temperature sounding channels (black), 62 water vapor (red), 53 ozone (blue), 27carbon monoxide (cyan), 54 methane (magenta), 53 carbon dioxide (light purple), 24 *N2O* (yellow), 28 *HNO3* (orange) and 24 *SO2* (dark purple) sounding channels. The total number of channels is 399.

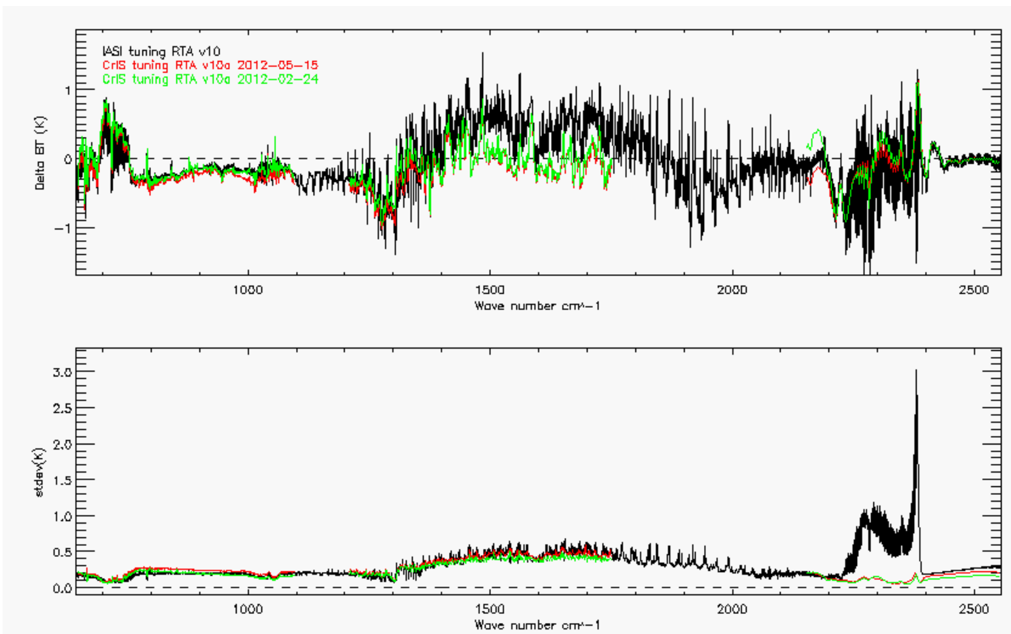

Figure 2. Brightness temperature bias tuning. Red curve is obtained from focus day May 15th, 2012. Green curve is obtained from focus day February 24th, 2012. Black curve is the currently operational IASI bias tuning.

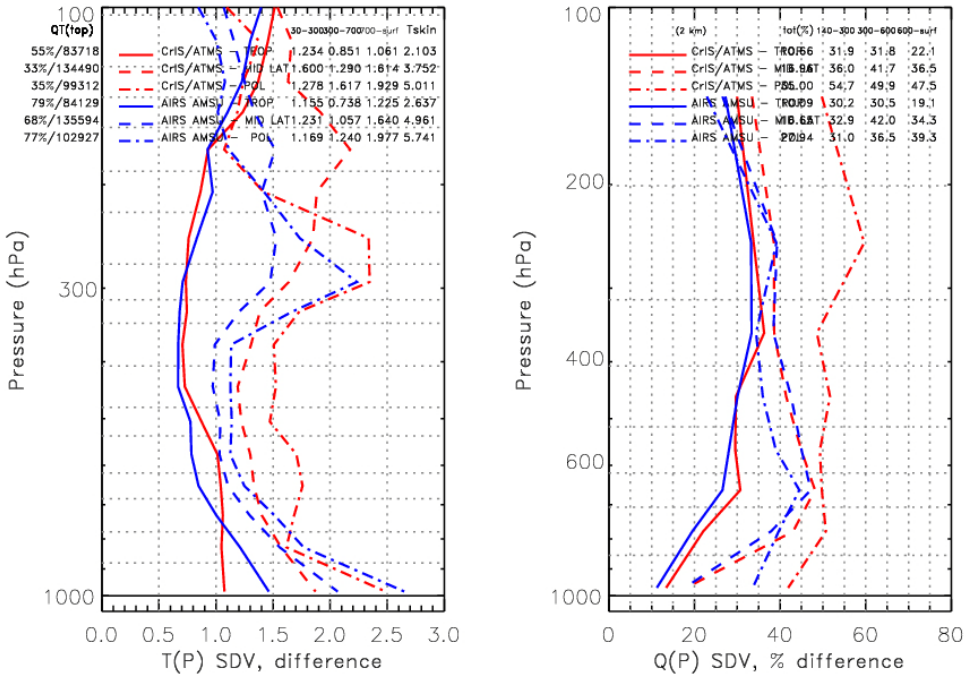

Figure 3a. Standard deviation staatistics of NUCAPS (red) and AIRS/AMSU (blue) retrievals versus correlative ECWMF collocated measurements. Left is temperature, right is water vapor statistics. Solid line is for tropical, dash line is for mid-latitude and dash-dot is for polar regimes. The text in the topleft corner indicates the acceptance yield.Text on the figure indicates a coarse layer statistics.

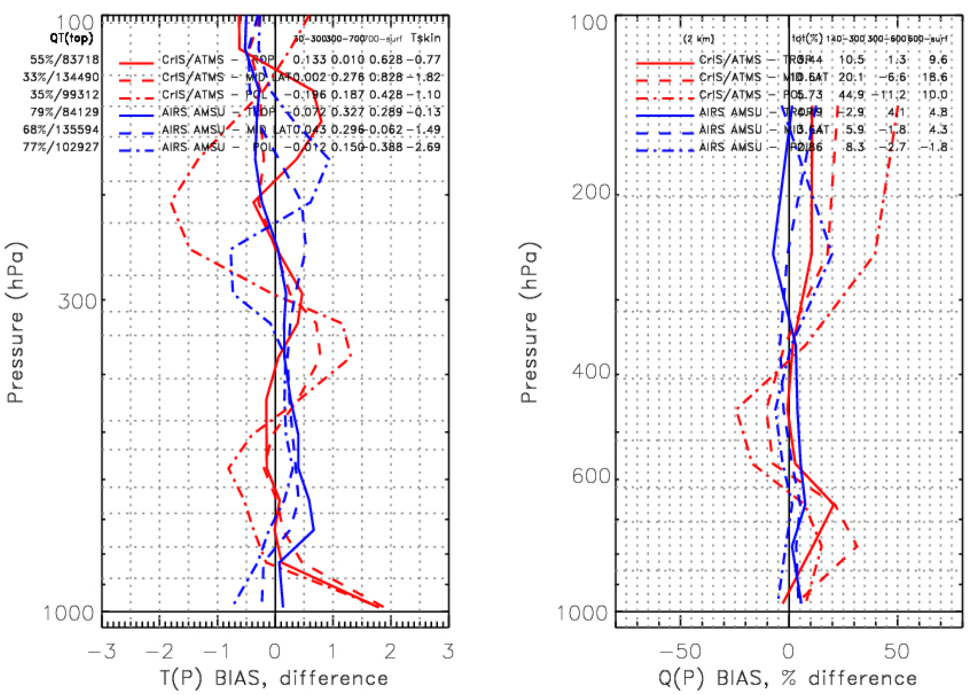

Figure 3b. Same as figure 3a, for the bias statistics.

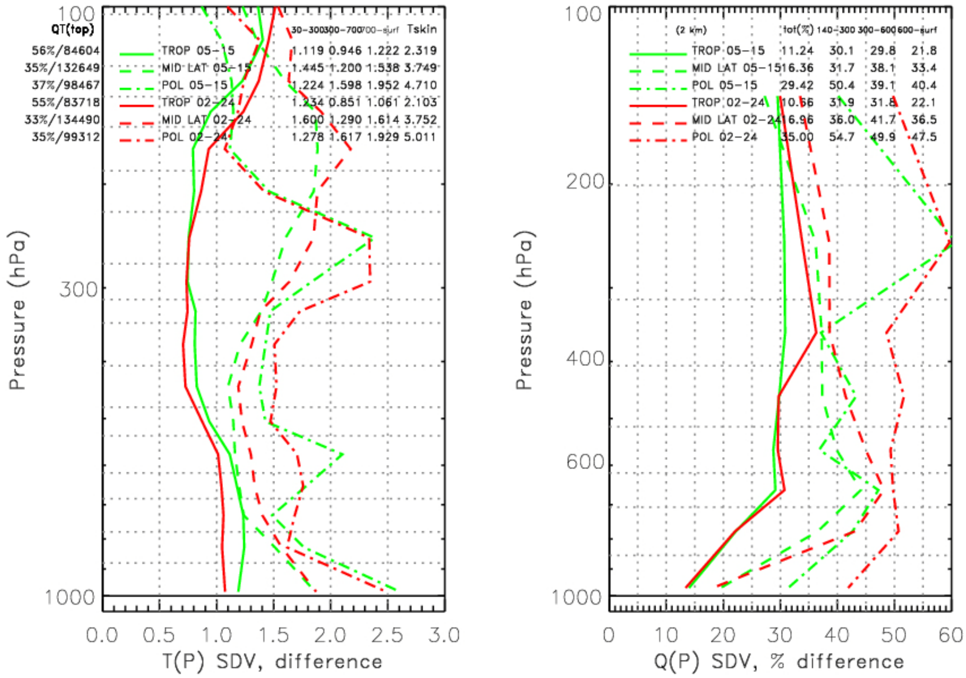

Figure 4a. Standard deviation statistics omparison between first light retrieval results obtained from focus day February 24th, 2012 (red curves) and latest baseline results obtained from focus day May 15th, 2012 (green curves). See text for details.

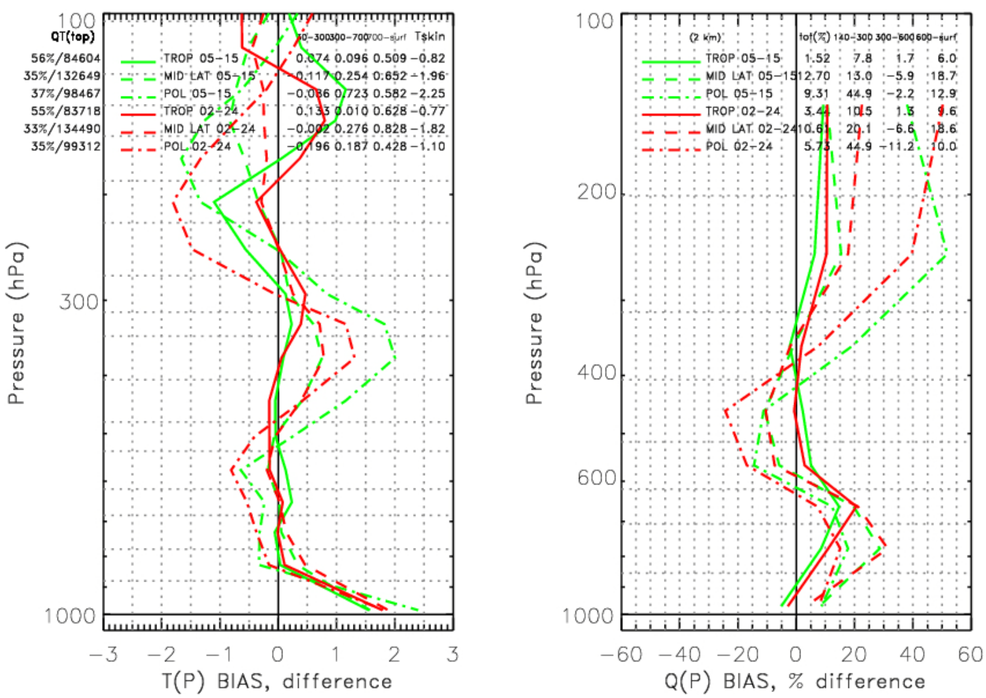

Figure 4b. Same as figure 4a, but for bias statistics.

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