VALIDATION OF CROSS-TRACK INFRARED SOUNDER (CRIS) PROFILES OVER EASTERN VIRGINIA

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Abstract

The Cross-Track Infrared Sounder began its mission to measure temperature and water vapor profiles in late October 2011. Weather balloon launches, from Hampton University, were coordinated with the satellite overpasses and used in validating the retrieved atmospheric profiles against in-situ measurements. Results show that temperature retrievals have a standard deviation of the difference, between the retrievals and radiosondes, between 1 and 2 K with a root mean square difference between 1 and 3 K for most pressure levels used. The mean difference between the two profiles stayed relatively small between 0 and 1 K except for a -3 K jump in the boundary layer. Mixing ratio and relative humidity results showed a similar pattern with statistics between 1 and 3 g/kg, and 10 and 30 percent, respectively. Statistics were also computed using satellite retrievals adjusted for the time and location discrepancy with the corresponding radiosonde. The time and location adjusted results showed improvement for temperature and mixing ratio. This indicates that time and space differences could be a source of the initial differences obtained. These results are consistent with another study which compared the Infrared Atmospheric Sounding Interferometer satellite instrument profile retrievals with radiosonde data.

Introduction

Passive remote sensing of the earth’s atmosphere using satellite based instruments is essential for atmospheric research and operational meteorology. The successful flight of TIROS-1 in 1960 marked the beginning of the era of satellites being used for meteorological information. Since then advances in satellite technology have lead to more capable instruments such as the Atmospheric Infrared Sounder (AIRS) and the Infrared Atmospheric Sounding Interferometer (IASI), both currently operational on the Aqua and MetOp satellites, respectively. Information from these instruments is currently used for weather forecasting, and for understanding weather and climate processes.

The Suomi National Polar-orbiting Partnership (NPP) satellite was launched on October 28 2011. One of the instruments on the Suomi NPP is the Cross-Track Infrared Sounder (CrIS). CrIS is a Fourier transform spectrometer that produces high resolution temperature and moisture profiles in three dimensions. CrIS has 1305 spectral channels with three infrared (IR) ranges, longwave-IR between 9.14 and 15.38 microns, mediumwave-IR between 5.71 and 8.26 microns, and shortwave-IR between 3.92 and 4.64 microns. The swath width of CrIS is 2200 km spanning +/- 50 degrees. The footprint consists of 9 fields of view in a 3x3 array of 14 km diameter spots.

This study focused on the validation of CrIS profile retrievals using in-situ measurements from weather balloons. Overpasses of the CrIS instrument were coordinated with radiosonde launches during the Hampton University Ground-based Remote Atmospheric Sounding Project (GRASP) in April 2012. The coordinated overpasses allowed for comparing the satellite retrieved profiles to those measured by radiosondes which were launched near the time of the satellite overpasses of HU. These
comparisons serve to show deficiencies in the CrIS profiles and provide insight on areas of improvement.

**Satellite Retrieval Background**

This paper describes results of comparing satellite retrieved profiles to radiosonde profiles of atmospheric parameters. Since a satellite instrument does not directly measure atmospheric parameters, atmospheric parameters at multiple vertical levels must be retrieved from observed radiance spectra through the inverse solution of the radiative transfer equation. Information regarding the magnitude and structure of atmospheric profiles is contained in the spectral radiance magnitude and its variation with wavelength.

Satellite instruments are designed with sensors to detect atmospheric radiance data in different parts of the electromagnetic spectrum, depending on the intended observation. Temperature and moisture retrievals use radiances observed in numerous spectral channels of the infrared spectrum. Past efforts used a small number, on the order of tens, of wavelength/wavenumber channels. The 1305 spectral channels used on the CrIS instrument categorize it as an ultraspectral instrument, which has improved accuracy and vertical resolution. The definition of ultraspectral is provided by Smith et al. (2012) as the term used for instruments with a spectral resolution better than 1% and processing more than 1000 spectral channels of radiance information.

**Data**

Radiosonde data gathered during GRASP consisted of 17 balloon launches over several days. The balloon launches were coordinated with satellite overpasses of the CrIS, IASI, and AIRS instruments. Only the launches nearest to CrIS overpasses were used in this study. Balloons were launched from the same area each day at HU with the latitude and longitude of 37.03N and 76.34W. Radiosonde data files had very high vertical resolution with a measurement being provided every few meters. These measurements typically reached an altitude of greater than 10 km with pressure levels less than 100 hPa.

CrIS data was provided in level 1 (L1) and level 2 (L2) format from the University of Wisconsin, Community Satellite Processing Package. The L1 data was processed into L2 data using a dual regression retrieval technique developed by Smith et al. (2012). This L2 data format consisted of various atmospheric parameters at the 101 CrIS pressure levels, ranging from 1100 to .05 hPa, for specific radiance measurement locations.

Global Data Assimilation System (GDAS) data was obtained from the National Climatic Data Center (NCDC). This data are available every 6 hours at 00, 06, 12, and 18 UTC with small vertical pressure spacing. For the data to be useable in this study, it had to be interpolated to the specific latitude and longitude and time (HHMMSS) of both the satellite retrieval and the radiosonde data.

**Method**

The first step involved finding the CrIS profiles closest to the radiosonde time and space locations. A space tolerance of 100 km and the time tolerance of near one hour were imposed for “matching” the satellite retrievals to the radiosonde profiles. These same criteria were used by Kwon et al. (2012) for comparing radiosonde data to satellite retrievals. Nine comparisons fit these criteria and were used in the analysis. Table 1 provides information on these pairs, while figure 1 provides a map showing the location of each CrIS profile and the balloon launch site.
Table 1: CrIS/Radiosonde pair information. Time in UTC (HHMMSS). Distance is great circle distance in km between the launch site and corresponding CrIS profile. Time diff in HH:MM:SS.

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<th>Radiosonde Time</th>
<th>Time Diff.</th>
<th>Distance</th>
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</table>

Figure 1: Location map of radiosonde launch site (Green) and CrIS retrieved profiles (Red). From figure 1 it can be seen that all of the CrIS profiles (red) are relatively close to the HU balloon location (green) and all are within close proximity to a large body of water.

The initial comparisons between the profiles were done on an individual basis so as to identify any significant differences. The three parameters compared were atmospheric temperature, mixing ratio, and relative humidity. The CrIS profiles were plotted against both the raw radiosonde data and the radiosonde data interpolated to the satellite retrieval pressure scale. Specifically, radiosonde data was interpolated to the 101 quadrature pressure levels used for the CrIS retrievals. Because of a known vertical resolution difference, it was expected that the radiosonde profile would reveal smaller scale features in the vertical than would be resolved by the satellite profiles. Interpolation allowed the two profiles to be compared for the same pressure levels.

Root mean square difference (RMSD), standard deviation (STD), and mean difference (MD) statistics were computed for each pressure level and for each parameter across all pairs. For this analysis the radiosonde data was interpolated to the CrIS pressure levels. This however caused some limitations of which pressure levels could be analyzed. Because the CrIS pressure levels go much higher in altitude than the radiosonde observes, the interpolated radiosonde data was limited to the altitude extent of the radiosonde. This limited the analysis to the troposphere. Specifically the pressure levels used ranged from the surface to 160 hPa.

GDAS data was used to account for the time and location difference between the CrIS profile and the radiosonde profile. This method was applied to see if any significant differences in the STD, RMSD, and MD statistics arose from including an adjustment factor to account for time and space differences in the comparisons. Equation 1 was used to account for the CrIS and radiosonde time and space differences,

\[
RTVL(xo,yo,to) = RTVL(x,y,t) + (GDAS(xo,yo,to) - GDAS(x,y,t))
\]

Where RTVL is the CrIS retrieval, “xo, yo, to” are the radiosonde time and location, and “x, y, t” are the retrieval time and location.

Results

Individual Cases

The first analysis involved comparing vertical temperature, mixing ratio, and relative humidity profiles from CrIS and the corresponding radiosonde on a case by case basis. It is known that the radiosonde data has a higher vertical resolution which will cause a
higher likelihood of picking up smaller features in the vertical. Because of this, the CrIS/radiosonde pairs were plotted first with raw radiosonde data, then again with radiosonde data that was interpolated to the 101 CrIS pressure levels. The goal was to reduce some of the noise in the radiosonde measurements and compare the two profiles using the same vertical scale. Figure 2 shows an example temperature, mixing ratio, and relative humidity profile comparison.

![Figure 2: Example profiles of individual cases, Left: Temperature, Center: Mixing Ratio, Right: Relative Humidity. Y-axis is in log scale. Temperature and mixing ratio use data from Table 1 row 2. Relative humidity is from Table 1 row 3.](image)

In the left panel of figure 2 (temperature) the radiosonde data stops around 150 hPa as it reached its vertical extent, while the CrIS profile extends to 0.05 hPa. As expected, the raw radiosonde data shows more detail in temperature, specifically in the lower troposphere between the surface and 700 hPa. The radiosonde data picks up a small temperature inversion around 800 hPa extending to 700 hPa while the CrIS profile is showing a steady decrease in temperature. Above the inversion level, agreement in profile shape and magnitude exists up to 250 hPa. Above this level some disagreement exists in the highly structured tropopause region. These features were present in eight of nine cases studied.

The center panel of figure 2 shows an example vertical profile of mixing ratio for the CrIS and radiosonde data. For seven of nine cases the CrIS profile showed a larger value of mixing ratio below 750 hPa. The profile for both sources drops off with height as the water vapor content becomes very small with increases in altitude.

The relative humidity results, figure 2 right panel, varied greatly from case to case. The only similarity was that both profiles followed a similar profile shape. No definitive similarities of magnitude differences were noticed for the different cases.

**All Pairs**

Statistics were calculated at each of the CrIS pressure levels across all of the CrIS/radiosonde pairs. The radiosonde profiles were interpolated to the CrIS pressure levels for the numerical comparison. In these results the radiosonde data was used as “truth” as it is an in-situ measurement. The first set of statistics used all nine profile pairs. To keep consistency between pressure levels, only the levels where all nine pairs had data available were included in the statistics. The bottom pressure level is 986.0666 and the top pressure level is 160.4959. Figure 3 displays the STD, RMSD, and MD at each pressure level for temperature, mixing ratio, and relative humidity.
The temperature STD stays between 1 and 2 K for most pressure levels. The lower level maximum is at similar levels to the inversions discussed from figure 2. High STD values are also found near the surface and above 300 hPa. This is consistent with the results previously shown for individual cases. The MD temperature plot shows a strong negative bias, near a 3 K difference, from the surface to around 750 hPa. Above this there is a weak negative bias close to 0 K. The RMSD temperature profile shows values between 1 and 2 K for most of the pressure levels, with a large jump to 3.3 K near the base of the inversions as seen for individual cases.

The mixing ratio STD ranged between 1 and 3 g/kg from the surface through 600 hPa. Above this the curve approaches zero. This is merely due to the mixing ratio values being very close to zero such that differences are also near zero. The MD shows a generally positive bias with some variation to negative around 700 hPa. The difference values stayed between -1 and 3 g/kg. The mixing ratio RMSD was larger near the surface and decreased with altitude as the water vapor content approached zero.

The STD and RMSD for relative humidity stayed between 10 and 30 % RH (percent of relative humidity) for all of the pressure levels. The MD shows positive bias between 0 and 25 % RH for most pressure levels.
The next set of results used GDAS data to adjust the CrIS retrieval to the time and location of the radiosonde data. Also, only seven pairs are used of the nine because GDAS data was not available on April 29, 2012.

A) Temperature

Figure 4 shows that both the temperature and mixing ratio STD and RMSD decrease after the adjustment from the surface through 800 hPa and again above 600 hPa. In the layer between 800 and 600 hPa the adjustment increased the STD and RMSE values for the temperature profile. This is the layer where inversions were found for individual cases and could be caused by GDAS model errors in inversion identification. The temperature MD shows after the adjustment the negative bias was slightly weaker compared to that shown by the original statistics.

B) Mixing Ratio

The descriptive statistics shown for temperature and relative humidity are similar to those presented by a previous study comparing IASI data to radiosondes over eastern Asia. The RMSD and MD profiles show similar magnitudes between the two studies for coastal regions on clear days. Kwon et al. (2012) showed a temperature bias between 1 and 2 K near the surface with bias being a point measurement while the satellite is a volume measurement. An example of this is the recognition of small low level inversions present in the radiosonde data, but not in the CrIS data. The inability to resolve these small inversions with CrIS data is expected. The inversions missed are generally small with a 1 to 2 K difference over an approximately 50 hPa layer. The vertical resolution, though smaller than radiosonde resolution, is sufficient to resolve larger inversions and details that can have an impact on weather forecasting.

The descriptive statistics shown for temperature and relative humidity are similar to those presented by a previous study comparing IASI data to radiosondes over eastern Asia. The RMSD and MD profiles show similar magnitudes between the two studies for coastal regions on clear days. Kwon et al. (2012) showed a temperature bias between 1 and 2 K near the surface with bias
values between 0 and 1 K up through 250 hPa. This CrIS study showed differences near the surface with values being close to 0 K at 986 hPa, but reaching a -3 K difference near 800 hPa. Other than this large jump, the CrIS bias remains low between 0 and 1 K up through 250 hPa. Above this level the differences increase dramatically, unlike the IASI study. The RMSD for both studies was relatively large, between 3 and 4 K, below 900 hPa, in the boundary layer, and then between 1 and 2 K for the remainder of pressure levels.

The “all pair” results for relative humidity show a general positive bias with magnitudes between -10 and 25 %RH. Also it’s shown that the RMSD is between 10 and 30 %RH. This is different than the Kwon et al. (2012) results, which showed a smaller bias on the order of 0 to 10 %RH and RMSE values between 10 and 20 %RH for coastal regions. Between the two studies it would seem that the IASI instrument performed better for measuring relative humidity, but a definite conclusion cannot be drawn due to the very different soundings and sample sizes used for the two studies.

There are important differences between these studies that need to be considered. First, Kwon et al., (2012) used only the mandatory meteorological pressure levels for comparison while this study used a much higher number of pressure levels. This included pressure levels between the mandatory ones, allowing for more detailed statistics between the mandatory levels. Also, the Kwon et al., (2012) study used a much larger data set, with over 6000 pairs. This study was limited to the number of balloons launched and corresponding CrIS overpasses of HU during GRASP making the data set much smaller with only 9 pairs. Statistics are much more meaningful for larger data sets because they are less likely to be skewed by a few poor measurements.

The time and location adjustment improved precision and accuracy in the temperature and mixing ratio retrievals shown by the statistics. The STD, MD, and RMSD decreased in magnitude for most pressure levels for the temperature retrievals. The mixing ratio statistics also showed some improvement in STD and RMSD, but not a significant change in MD. This indicates that part of the difference between the retrievals and the radiosondes is due to time and space differences.

Future research will be conducted to improve the confidence in the results and understanding of the differences found. The plans include increasing the number of retrieval and weather balloon pairs which will improve the statistics. The AIRS and IASI profiles will also be included in future comparison studies. Also, the satellite retrievals will be compared to other atmospheric profiles such as those from the ASSIST (Atmospheric Sounder Spectrometer for Infrared Spectral Technology) instrument and the Hampton University LIDAR. Along with the statistical comparison of profiles, the satellite/radiosonde pairs will also be compared using radiance data. For this a radiative transfer model will be used to calculate the radiances corresponding to the radiosonde to compare with the observed CrIS, AIRS, and IASI radiances.

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References
   <cimss.ssec.wisc.edu/cspp/>
   <http://npp.gsfc.nasa.gov/cris.html>
5. National Aeronautics and Space Administration. “Suomi NPP Overview.”
   <npp.gsfc.nasa.gov/mission_details.html>