METHODOLOGY AND VALIDATION OF AMSU-A LIMB ADJUSTMENT

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1. INTRODUCTION

The Advanced Microwave Sounding Unit-A (AMSU-A) is the new generation of polar-orbiting cross-track microwave sounders operated by the National Ocean and Atmospheric Administration (NOAA). The first AMSU-A was launched on May 13, 1998 and measures outgoing radiation from the earth's surface and/or atmosphere in 15 spectral regions (4 window channels at 23.8, 31.4, 50.3, and 89 GHz and 11 temperature sounding channels from 52.8 to 58 GHz). The temperature sounding channels are used to derive atmospheric temperature profiles from the surface to an altitude of about 40 km in most situations. The exception is in regions of precipitation which can cause erroneous estimates of temperature in the lower troposphere (Goldberg, 1999). The window channels receive energy primarily from the surface and the boundary layer, and are used in deriving total precipitable water, cloud liquid water, snow cover, sea ice concentration and precipitation rate (Grody et al.,1999).

A feature of a cross-track sounder is the variation of the measurement along the scan line due to the change in the optical path length between the earth and the satellite. The AMSU-A scans between +- 48.33 degrees off nadir with 30 beam position per scan line and a swathwidth of about 2300 km. The variation of the measurement as a function of beam position is called the limb effect and can be as much as 30 K for the 23.8 GHz window channel and 15 K for the atmospheric temperature channels (53 – 58 GHz). In this paper, beam position, field of view (fov), and spot have the same meaning. Limb adjusting the measurement to a fixed view angle is a common practice at NOAA (Wark, 1993) and is important for a number of applications. Regression algorithms that depend on collocated observations of satellite data and in situ data, such as radiosonde reports of temperature, to derive the statistical relationship used to estimate geophysical parameters, such as atmospheric temperatures, from satellite observations are simplified if the satellite data are normalized to a fixed angle, since otherwise there would be difficulty in achieving a reasonable and similar sample size for each beam position. Physical retrieval algorithms often retrieve along the optical path, but generally some sort of beam position dependent bias adjustment is needed to remove spot- to-spot systematic biases caused by asymmetry of the observations (Fig. 1) or angular-dependent biases in the radiative transfer algorithm. If the limb adjustment procedure produce accurate limb adjusted data, then a physical retrieval would be simplified since there would be no need for spot dependent bias adjustments. Finally, averaging satellite observations to a given grid map (e.g., monthly 1 x 1 degree latitude/longitude, zonal bands, etc.) require that the data are limb adjusted prior to averaging, otherwise the data averaged will be associated with different atmospheric weighting functions. Observations representative of a fixed weighting function are critical for climate monitoring (Goldberg and Fleming, 1995).

The purpose of this paper is to describe a limb adjustment procedure for AMSU-A. Our limb adjusted AMSU-A observations have been used in deriving daily temperature time series at various levels in the troposphere and stratosphere (Goldberg, 1999) and to estimate the strength of tropical storms (Kidder et al., 2000) ,(DeMaria et al., 2000).

2. AMSU-A OBSERVATIONS AND LIMB ADJUSTMENT

The AMSU-A consists of two separate modules, A1 and A2. The A1 component has 12 channels (3-14) between 50 and 58 GHz in the oxygen band and a 89 GHz channel. The A2 has two window channels at 23.8, and 31.4 GHz. There are 30 measurements per scan line; positions 15 and 16 have near nadir angles of 1.35 degrees, while positions 1 and 30 are at the extreme scan positions. The fov size is 48 km in diameter at the near nadir positions and grows gradually to about 150 km at positions 1 and 30. Fig. 1 illustrates the asymmetry present in AMSU-A brightness temperatures. Plotted in this figure is the difference between beam positions with the same off-nadir angle, that is the mean difference of measurements from fov 30 and fov 1 to fov 16 and fov 15. The means were computed from data collected over oceanic regions between +- 60 degrees latitude and for the time period of May 1 - 5, 1999. All figures presented in this paper, unless otherwise noted, are derived from this time period . If there was no asymmetry the difference should be zero for each pair. The exact cause of the asymmetry remains unclear, however nearly all of the asymmetry is removed by the limb adjustment procedure.

The limb effect is caused by the increase in optical path as the instrument scans from near nadir to larger angles, which causes the peak of the channel weighting functions to increase in altitude. The weighting functions, which gives the vertical contribution of atmospheric temperature to the outgoing radiance measured by the instrument, are shown for AMSU-A channels 3 - 14 at its near nadir angle of 1.67 degrees and far angle position of 48.33 degrees (dashed curves) in Fig. 2. Over the ocean, brightness temperatures for a given window channel increase with increasing view angle, because the channels is seeing less of the cold microwave surface (microwave surface emissivity over the ocean is approximately 0.5) Over land, because the emissivity is closer to unity, the mean variation in the window channel measurements, as a function of fov , is very small). Limb cooling arise in channels peaking in the troposphere because the temperature profile generally decreases with height. In the stratosphere, the opposite occurs because the temperature is now generally increasing with height. The mean difference of brightness temperatures between each fov position and the average of positions 15 and 16 (there is no true nadir position) for each channel are given in Fig. 3, and for some channels are quite large. The purpose of limb adjustment is to remove the scan angle dependency.

Limb adjustment can be derived by either physical, statistical and/or combinations of physical and statistical approaches. In a purely physical approach, one would solve for coefficients that combine weighting functions from the off nadir position to best fit the nadir weighting functions. This procedure was carried using the technique described in Goldberg and Fleming(1995). The physically combined and the true near nadir weighting functions are shown in Fig. 4. Clearly the AMSU-A data can be limb adjusted since the respective weighting functions in Fig. 4 are quite close. However, because of the asymmetry shown in Fig. 1 , we cannot use a purely physical approach.

We first experimented with a purely statistical approach, similar to one first suggested by Wark (1993). However, we found that for a few channels the coefficients from the statistical method were quite different from coefficients derived from a physical method. For example, for limb adjusting channel 5, we use channels 4, 5 and 6 as predictors. The statistical coefficient for the channel 5 predictor was much larger than the channel 4 predictor for fov #1 (the largest off-nadir angle), however as implied from Fig.2 the coefficient for channel 4 should dominate, since the channel 4 weighting function at fov #1 is similar to the channel 5 near nadir weighting function. Our latest approach is to use physically derived coefficients as a constraint in the statistical model. The technique is a constrained least-squares procedure and is similar to those in Goldberg and Fleming (1995) or Crone et al (1996).

Thirty one days of data from July 1 - 31, 1998 were used to compute mean brightness temperatures within two degree latitude bands for each fov. Large samples are used to assure that differences in brightness temperatures between two given fovs are due to view angle and not due to atmospheric variability. Using the above mean values, the physically constrained regression coefficients are then computed to adjust measurements from a given fov to "look like" the average of beam positions 15 and 16 (there is no true nadir observation). That is, the mean brightness temperatures at the angle are the predictor or independent variables and the average of the mean brightness temperature of positions 15 and 16 is used as the response or dependent variable A global set of coefficients is used for channels 6 - 14. Sea and non-sea coefficients are used for channels affected by the surface - channels 1- 5 and 15. The predictors are generally the channel itself plus the adjacent channel whose weighting functions peak below and above. In other words ,to limb adjust channel 6, we use unadjusted channels 5 , 6 and 7 observations as predictors. The exceptions are: channel 14 uses channels 12, 13 and 14; channel 3 uses channels 3, 4 and 5; channel 1 and 2 both use channels 1 and 2, and channel 15 uses channels 1 and 15. Since the regression is carried out on mean values the usual measures such as R^2 (coefficient of determination) or S_ε (mean squared error) do not have their standard meaning. This model assumes that the limb effect can be adjusted using linear combinations of the channels at a given angle. The largest model limb adjustment model error, usually associated with the furthest off-nadir positions, are given in Fig. 5. Also shown for comparison are the instrumental noise and a parameter we call combined atmospheric and instrument noise. This parameter is the root mean square (rms) difference between the same fov position of adjacent scanlines within tropical region where the temperature variability is assumed negligible. To get an unbiased estimate of the noise in a single fov, the rms was divided by square root of two. The sample size for computing this parameter was approximately 10000 for each fov. For the temperature sounding channels the atmospheric/instrumental noise is nearly identical to the instrument noise. For the window channels the atmospheric/instrumental noise is much larger due to variability of water vapor and cloud liquid water. For all channels the limb adjustment model errors are much lower than the atmospheric/instrumental noise. The larger model errors associated with the window channels are small relative to the observed range of these channels

3. VALIDATION

The goal of a good limb adjustment procedure is to produce global fields of limb adjusted brightness temperatures with negligible fov dependent systematic biases. We are highly confident that this goal has been met. AMSU brightness temperatures were computed for nadir viewing from the NCEP analysis for May 2, 1999. Fig. 6 shows the bias between the limb adjusted and computed values for channels 5 through 14. The average of fov positions 15 and 16 were used to remove systematic differences between measured and computed values, which results in a near zero bias for the near nadir positions. The remaining channels are not computed because they are significantly influenced by cloud liquid water effects. Clearly the bias is quite small, which is one indication that the limb adjustment procedure is working quite well. Examples of our products are at *http://orbit-net.nesdis.noaa.gov/crad/st/amsuclimate/amsu.html*

4. REFERENCES

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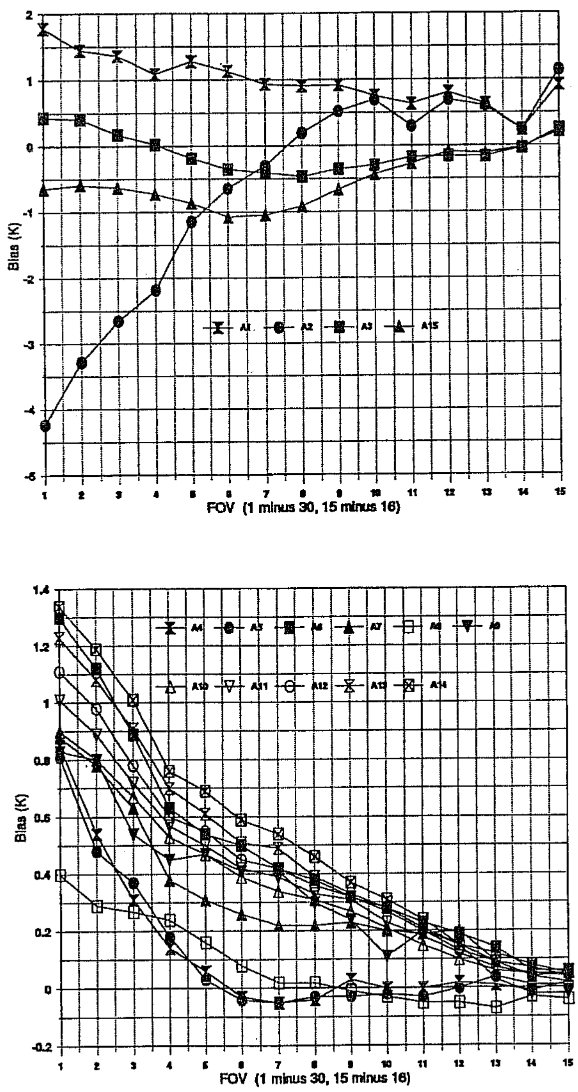
5. Figures



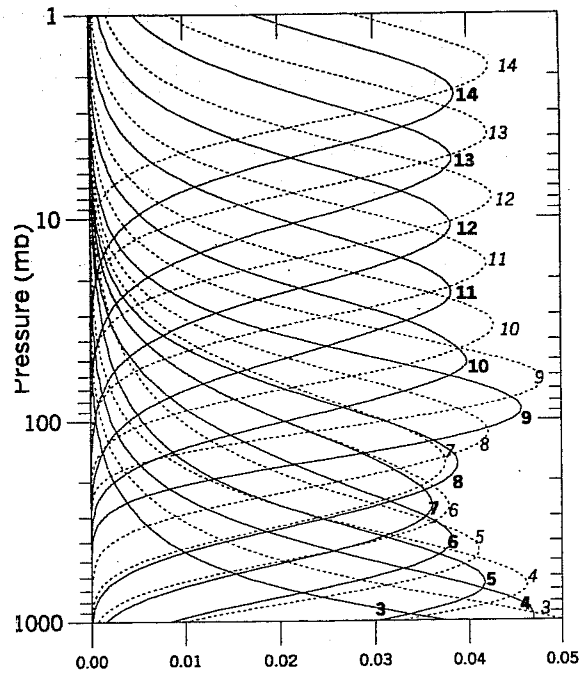


Fig. 1. The mean bias (i.e. asymmetry) between unadjusted brightness temperatures from field of views with the same off-nadir angles. Top panel shows the bias from the window channels, lower panel shows the bias from the atmospheric channels.

Fig. 2. AMSU-A channels 4 - 14 weighting functions for two view angles: near nadir angle of 1.35 (solid curves) and the largest angle of 47.85 (dashed curves).

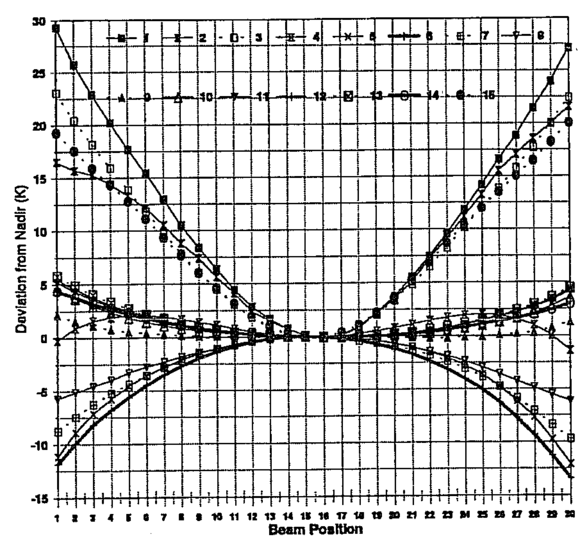


Fig. 3. The deviation of unadjusted brightness temperatures from nadir (average of positions 15 and 16) for all channels (ocean data).

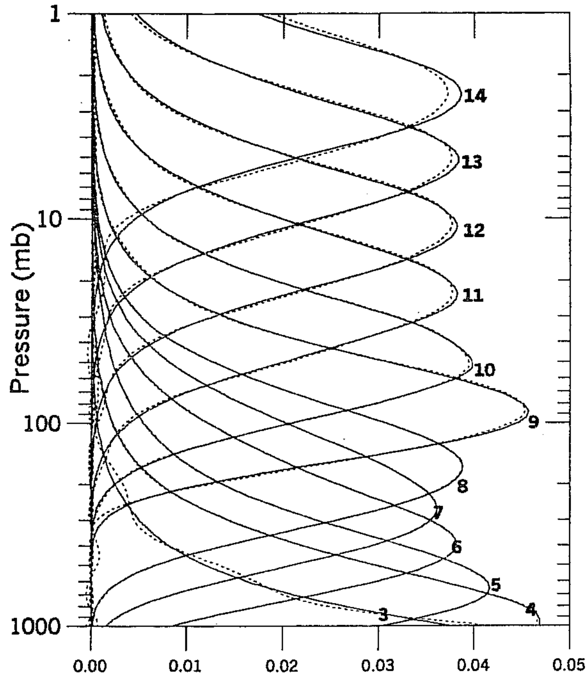


Fig. 4. AMSU-A channels 4 - 14 weighting functions for near nadir and physical estimated weighting functions from the largest off-nadir angle.

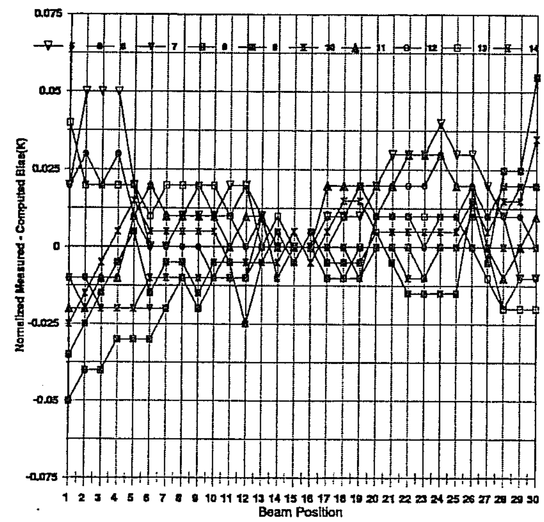


Fig. 6. Mean bias between limb adjusted brightness temperatures and brightness temperatures calculated from the NCEP 00 GMT analysis of May 2, 1999.

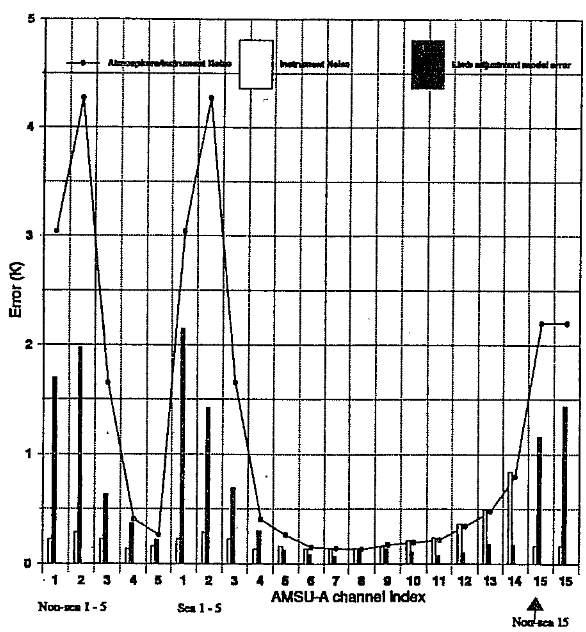


Fig 5. The limb adjustment model error for each channel, along with instrumental noise and a composite noise consisting of instrument and atmospheric noise.