

Scan asymmetries in AMSU-B data

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[1] A simple method of averaging measurements for different scan positions was used to quantify scan asymmetries in AMSU-B brightness temperatures for the sensors on the satellites NOAA 15, 16, and 17. The method works particularly well for the sounding channels 18 to 20. The asymmetries are small in most cases. In particular, asymmetries for Channel 18 are below 1.90, -0.53, and 0.49 K for NOAA 15, 16, and 17, respectively. On the other hand, it was found that the instrument on NOAA 15 has significant asymmetries for Channels 19 and 20, which seem to be related to the known radio frequency interference problem for this instrument. The use of the appropriate set of interference correction coefficients significantly reduces the asymmetry. **Citation:** Buehler, S. A., M. Kuvatov, and V. O. John (2005), Scan asymmetries in AMSU-B data, *Geophys. Res. Lett.*, 32, L24810, doi:10.1029/2005GL024747.

1. Introduction

[2] Microwave humidity data from the polar orbiting satellite sensors SSM-T2 and AMSU-B play an important role in numerical weather prediction and in climate studies. For example, *Buehler and John* [2005] show how an upper tropospheric humidity (UTH) data product can be derived from AMSU-B data.

[3] The currently available microwave humidity sensors are cross-track scanners. This means that the instrument viewing angle is different for different pixels along the scan line. This leads to limb darkening or limb brightening in the data, which has to be taken into account in the data analysis. The atmospheric limb effect should depend only on viewing angle, and hence should be symmetric about the nadir point in the middle of the instrument scan. However, in the real world instrumental effects may lead to scan asymmetries. The instrumental origin of these asymmetries remains not fully understood. Possible explanations include a polarization misalignment or an antenna pointing angle error [*Weng et al.*, 2003].

[4] For the AMSU-A sensor, which is dedicated to temperature measurements, such asymmetries have been reported by *Weng et al.* [1999, 2003]. However, to our knowledge there is no published investigation of this issue for the humidity sensor AMSU-B. The issue is important, because uncorrected scan biases will introduce biases in humidity products derived from the data, for example humidity climatologies. The aim of the study described here is to close this gap, to estimate the scan dependent bias for the different channels of the different currently operational AMSU-B instruments, and to document the development of the biases with time.

[5] The paper is structured as follows: section 2 very briefly introduces the AMSU-B data, section 3 describes the methodology, section 4 contains the results and their discussion, and section 5 contains a summary and the conclusions.

2. AMSU-B Data

[6] AMSU-B is a cross-track scanning microwave sensor with channels at 89.0, 150.0, 183.31 ± 1.00 , 183.31 ± 3.00 , and 183.31 ± 7.00 GHz [*Saunders et al.*, 1995]. These channels are referred to as Channel 16 to 20 of the overall AMSU instrument. The instrument has a swath width of approximately 2300 km, which is sampled at 90 scan positions. The scan positions are defined such that, relative to the flight direction, position 1 is on the left edge of the scan, positions 45 and 46 are in the middle, and position 90 is on the right edge of the scan. The nadir viewing angle for the two innermost scan positions 45 and 46 is 0.55° , the nadir viewing angle for the two outermost scan positions 1 and 90 is 48.95° .

[7] The time period of data used for this study varies with the satellite. It is March 2000 to August 2005 for NOAA 15, September 2000 to August 2005 for NOAA 16, and September 2002 to August 2005 for NOAA 17. All three sensors continue to take data at the time of writing.

[8] The AMSU data were calibrated with the ATOVS and AVHRR Processing Package (AAPP) which is briefly described by *Atkinson and Whyte* [2003]. Data of NOAA 15 before March 2000 were discarded, because the AMSU-B instrument, especially Channels 17 and 19, suffered strongly from radio frequency interference (RFI) at the beginning [*Atkinson*, 2001]. (Our own analysis confirms this, showing unrealistic bias values for that period of time.) Even for later NOAA 15 data, RFI correction coefficients have to be applied to the AMSU-B data, to reduce the RFI problem. The procedure is described by *Atkinson* [2001]. Over time, ten sets of correction coefficients were made available by *NOAA* [2000]. These coefficients, their issue dates, and a brief description of each set of coefficients are given by *NOAA* [2000, Appendix M].

[9] These RFI correction coefficients are included in the AMSU level 1b data available from the Comprehensive Large Array-data Stewardship System (CLASS) and are used by the AAPP software when the data are calibrated, i.e., converted to level 1c data. However, users of the CLASS 1b data should be aware that although a new set of RFI coefficients was documented by *NOAA* [2000] on August 13, 2004, the coefficients in the 1b data were still the old ones as of writing this. This was discovered in the course of the study described here and is discussed further in Section 4.

[10] It should be noted that the RFI problem is most affecting the AMSU-B instrument on NOAA 15. The AMSU-B instrument on NOAA-17 also suffers RFI problems to a small extend, with a maximum of 2 K for Channel 19 and 1 K for Channel 18. Correction coefficients for that instrument were issued on July 12, 2002 [NOAA, 2000]. The error due to RFI for AMSU-B on NOAA-16 is within the instrument noise level, therefore no correction is applied.

3. Methodology

[11] For an individual instrument scan line, it is quite obvious that there will be a natural cross-track asymmetry, due to the inhomogeneity of the atmosphere and the surface. Different pixels along the scan line sample different atmospheric and surface states. However, one can assume that this natural variability cancels out when a large amount of data over a sufficiently long period of time is averaged.

[12] We define the asymmetry ΔT_b for a particular viewing angle as the mean brightness temperature for the scan position corresponding to this viewing angle on the left side of the scan minus the mean brightness temperature for the scan position corresponding to this viewing angle on the right side of the scan. So,

$$\begin{aligned} \Delta T_b(0.55^\circ) &= \overline{T}_{b45} - \overline{T}_{b46} \\ &\vdots \\ \Delta T_b(48.95^\circ) &= \overline{T}_{b1} - \overline{T}_{b90} \end{aligned} \quad (1)$$

where T_b means brightness temperature, indices indicate the scan position, and the overbar denotes the mean.

[13] If similar atmospheric states are observed by both sides of the scan on average, then the effect of atmospheric inhomogeneities should cancel out. The polar regions will violate that condition, since the meteorological conditions at the winter pole, which is favored by one side of the scan, are very different from those at the summer pole, which is favored by the other side of the scan. Our analysis is therefore restricted to the tropical region, i.e., ± 30 degrees of latitude. One can then assume that biases are mostly of instrumental origin, except for those channels with strong surface influence, as will be discussed in section 4.

[14] For the study, the available data were divided into three-monthly sub sets: March-April-May (MAM) 2000, June-July-August (JJA) 2000, September-October-November (SON) 2000, December-January-February (DJF) 2000/2001, MAM 2001, JJA 2001, ..., MAM 2005, JJA 2005. Each sub-set contains about 1,000,000 data points for each scan position.

4. Results and Discussion

[15] Figure 1 shows ΔT_b , the scan angle dependent asymmetry in mean brightness temperature, as a function of nadir viewing angle. This is the data version available from CLASS, i.e., RFI correction coefficients available in the level 1b data were applied. Different sub-plots display results for different satellites and channels. The different lines represent different three-monthly time periods of the

data, the lines for recent data are darker. As a help in interpreting these curves, rough estimates of the radiometric noise for each channel are displayed as horizontal lines. Noise estimates for NOAA 15 and 16 are from *Buehler et al.* [2004], noise estimates for NOAA 17 are copied from NOAA 16. To check the influence of different surface types, data were sorted into land and sea data. As expected, for the sounding channels both classes lead to similar results, so that only global data are shown in Figure 1, but for the surface channels 16 and 17 the results depend somewhat on surface type therefore both classes are shown separately.

[16] The dependence of the asymmetry curve on the surface type for the surface channels indicates that the assumption that inhomogeneities are random and therefore average out does not hold completely for these channels. The further discussion will therefore focus on the three sounding channels.

[17] In general, observations close to nadir (viewing angle 0°) have the smallest asymmetries, as expected. The largest asymmetries tend to occur towards the edge of the scan, but not always directly at the edge. The figure confirms that the simple method used to calculate the asymmetry is stable, in the sense that the shape of the asymmetry curve for each satellite and channel is remarkably similar for the different time periods studied, except for a slow evolution in some cases. We will come back to the time evolution of the asymmetry later.

[18] The different asymmetry shapes for the same channels of different instruments suggest that each instrument has its particular signature. The oldest AMSU-B instrument on NOAA 15 is most strongly affected by scan asymmetries. Its sounding channels 18 to 20 suffer significantly, with asymmetries reaching ΔT_b values of approximately 1.9, 9.7, and 3.0 K, respectively. Hence, particularly the newer data from Channel 19 of this instrument should be used only with caution.

[19] The AMSU-B instrument on NOAA 16 is much less affected by scan asymmetries. The ΔT_b values are mostly below 1 K, except for the edge of the scan for Channel 19, where they reach 1.4 K and for Channel 20, which shows significant asymmetries reaching negative values down to almost 1 K and positive values of approximately 2 K. As a rough help in interpreting these numbers, consider that according to *Buehler and John* [2005] a brightness temperature difference of 1 K for Channel 18 corresponds approximately to a relative difference in upper tropospheric relative humidity of 7%. Sensitivities can be assumed to be of the same order of magnitude for the other humidity sounding Channels 19 and 20. Hence, the asymmetry in Channels 19 and 20 is large enough to introduce significant humidity errors, if neglected. In contrast, the asymmetry in Channel 18, with an absolute value below 0.5 K, can most likely be safely ignored compared to other sources of uncertainty.

[20] For the AMSU-B instrument on NOAA 17 we can draw only preliminary conclusions, since not as much data are available as for the other instruments. The data available so far looks very promising, with asymmetry values even smaller than for NOAA 16. The only notable exception here is Channel 20, which can have asymmetries up to 2.3 K.

[21] While the development of the asymmetry with time has a random nature for some channels, for others the asymmetry is steadily increasing with time. For example,

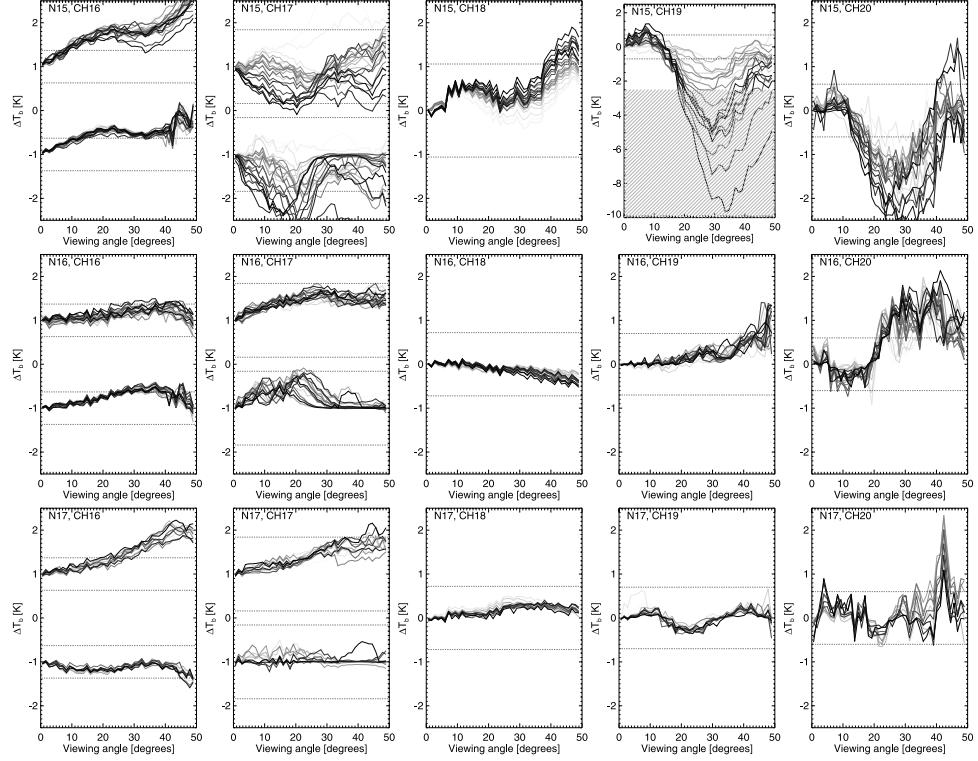


Figure 1. The asymmetry ΔT_b (left side minus right side in flight direction) as a function of viewing angle. Nadir is at zero degree viewing angle. The rows of plots from top to bottom correspond to the satellites NOAA 15, 16, and 17, the columns from left to right correspond to the AMSU-B channels 16, 17, 18, 19, and 20. Note that the y-axis scale for Channel 19 on NOAA 15 is different from the others. The different lines correspond to different three-monthly time periods, the lines for recent data are darker. Horizontal lines indicate the noise equivalent temperature. The two sets of lines for Channel 16 and 17 are data over land (plus 1 K offset) and sea (minus 1 K offset).

one can see from Figure 1 that the asymmetry for Channel 19 of NOAA 15 has significantly increased to -9.7 K for the most recent data. One can observe the same behavior for Channel 18 of the same instrument. To show the evolution more clearly, Figure 2 shows the maximum asymmetry for each three-monthly time period as a function of time for each channel and instrument.

[22] The most striking feature of this figure is the steadily increasing asymmetry for the AMSU-B instrument on NOAA 15. It can be observed for all channels except Channel 16. The increase can be approximately described

by a linear trend, as indicated in the figure. The most likely cause of this problem is a change in the characteristics of the radio-frequency interference that the AMSU-B instrument on this satellite has experienced from the start, as mentioned in section 2. The figure also shows the impact of different RFI correction coefficients. The coefficients published by NOAA [2000] on August 13, 2004 do significantly reduce the asymmetry. Note that these coefficients were not implemented in the 1b data, so they have to be manually applied. As shown by Figure 2, the latest coefficients also significantly reduce the asymmetry in data before August 13,

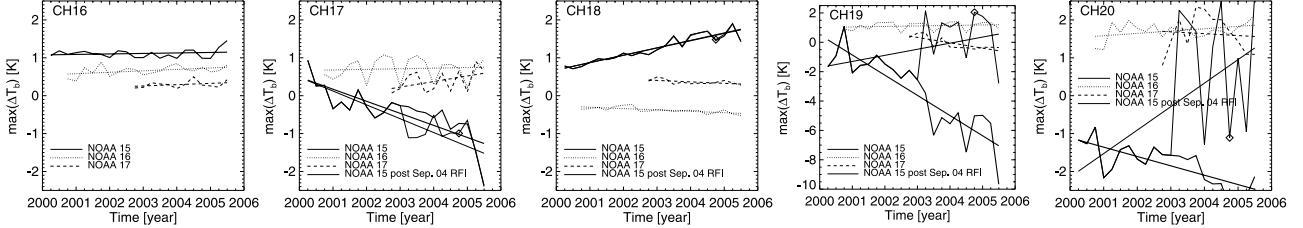


Figure 2. The time evolution of the maximum asymmetry for three-monthly time periods. The plots from left to right correspond to the AMSU-B channels 16, 17, 18, 19, and 20. Different line styles indicate different satellites: NOAA~15 (thick-solid), NOAA~16 (dotted), and NOAA~17 (dashed). The thin-solid line is for NOAA~15 where RFI correction coefficients as of August 13, 2004 are manually applied to level 1b data. The diamonds indicate the last, as of writing, RFI coefficients update date. Straight lines show linear fits.

Table 1. The Range of Maximum Absolute Brightness Temperature Asymmetries^a

Channel	NOAA 15	NOAA 16	NOAA 17
16	0.98–1.45	0.38–0.89	0.19–0.50
17	0.15–2.93	0.22–1.07	0.07–0.91
18	0.71–1.90	0.23–0.53	0.28–0.49
19	0.88–9.67	0.62–1.41	0.30–0.67
20	0.83–2.95	1.21–2.13	0.80–2.34

^aThis table summarizes Figure 2. The maximum of the absolute value of ΔT_b was calculated for three-monthly time periods for each channel and satellite. Given here are the smallest and largest of these numbers.

2004. From this study we recommend the use of the August 13, 2004 coefficients for Channel 19 data later than March 1, 2003.

[23] Compared to NOAA 15, the instruments on NOAA 16 and 17 show no significant trends. (The apparent trends for Channels 19 and 20 on NOAA 17 are not significant because the time series of data is not yet long enough.)

5. Summary and Conclusions

[24] Using a simple method of averaging the brightness temperatures for different instrument viewing angles, the scan asymmetry in measured brightness temperatures of the AMSU-B instrument was quantified. The exercise was carried out for all available data of NOAA 15, 16, and 17. For the three sounding channels the results are independent of the surface type. This gives a reasonable confidence that they show instrumental effects. For the two surface channels the results depend somewhat on the surface type and should therefore be regarded with caution.

[25] The development of the asymmetry over time was investigated by considering three-monthly averages. Table 1 summarizes the range of maximum asymmetries for the different satellites and channels.

[26] The AMSU-B instrument that suffers the most asymmetry is the one on NOAA 15, particularly its Channels 19 and 20, which have maximum asymmetry values of –9.67 and –2.95 K, respectively. Moreover, there is clear evidence that for Channels 17 to 20 of this instrument the asymmetry is steadily increasing with time. The most likely explanation for this increase are changes in the RFI characteristics, because the application of appropriate RFI correction coefficients significantly reduces the asymmetry. Updated coefficients were reported by NOAA [2000] on August 13, 2004, but were not implemented in the level 1b data from CLASS. We recommend to use this set of coefficients for NOAA 15, Channel 19 data after March 1, 2003.

[27] In contrast to NOAA 15, asymmetries for NOAA 16 and 17 are smaller and show no significant trend. Channels with maximum asymmetry exceeding 1 K on NOAA 16 are 17, 19, and 20. On NOAA 17 it is only Channel 20. The instrument on NOAA 17 has clearly the smallest asymme-

tries, but also the shortest time series so far. The asymmetries in some cases show a seasonal cycle, most pronounced for NOAA 16 Channel 17 with an amplitude of approximately 0.8 K.

[28] Of particular interest for our own ongoing activities is Channel 18 of all satellites, which we use to derive upper tropospheric humidity climate data products. To check its scan asymmetry was an important motivation for the presented study. The channel was found to be very well behaved, with maximum asymmetry values of 1.90, –0.53, and 0.49 K for NOAA 15, 16, and 17, respectively. Hence, with the exception of NOAA 15, asymmetries in Channel 18 can be neglected compared to other sources of error for most applications, since a brightness temperature difference of 0.5 K maps to a relative difference in relative humidity of only approximately 3.5%, according to *Buehler and John* [2005].

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