STATUS OF NOAA ADVANCED MICROWAVE SOUNDING UNIT-B (AMSU-B) PRODUCTS
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1.0 INTRODUCTION
The National Oceanic and Atmospheric Administration (NOAA), National Environmental Satellite Data and Information Service (NESDIS) are currently validating the new Advanced TIROS Operational Vertical (ATOVS) sounder and derived products systems from the NOAA-15 polar orbiting satellite (launched in May, 1998). This report describes scientific activities concerning the measurements and products from the Advanced Microwave Sounding Unit-B (AMSU-B) instrument. The five channels for AMSU-B in frequency order are: 89 GHz, 150 GHz, 183+/1 GHz, 183+/3 GHz, and 183+/0 GHz.

The principal activity has focused on the required corrections of the AMSU-B measurements for unexpected Radio Frequency Interference (RFI). These are presented in the first part of this report. Their impact and the current status concerning NESDIS operational product systems for AMSU-B are presented in the remaining sections.

NOAA/NESDIS has traditionally provided global data sets of derived temperature and moisture sounding products to national and international users in support of numerical weather prediction (NWP) forecasts and climate research. The suite of sounding products planned from NOAA-15 includes the relatively new, high horizontal resolution moisture measurements and derived soundings from AMSU-B (up to 2.6 million soundings per day at full resolution). NESDIS product systems for AMSU-B are operated separately, and independent of those for the more traditional ATOVS sounding products planned from NOAA-15 (Reale, 1999). Future evaluations concerning the simultaneous processing of ATOVS and AMSU-B data are pending.

The “traditional” ATOVS products from NOAA-15 are scheduled to be operationally implemented by NESDIS in late April, 1999. However, these will not include the additional AMSU-B measurements and derived products. Their implementation primarily depends upon the status of RFI corrections and subsequent impacts on derived product systems.

2.0 RFI HISTORY

NOAA-15 was launched into an descending, morning (0730 LST) polar orbit configuration on May 13, 1998. It was immediately apparent that something was wrong with the calibrated data from the AMSU-B instrument. This was confirmed by other users, and determined to be a form of RFI contamination from data transmitters onboard NOAA-15. This led to a series of tests conducted by National Aeronautics and Space Administration (NASA) in August, during which the S-band transmitters (STX-1, STX-2, STX-3 and SARR) on the spacecraft were turned off and then reactivated in succession. Corresponding differences in channel count values at transition points were then tabulated for each channel. The United Kingdom Meteorological Office (UKMO), and Nigel Atkinson in particular, determined from these tests the level of interference (in counts) for each
S-band transmitter for each AMSU-B channel. The end result was a set of procedures and correction tables per transmitter, beam position and channel, to remove this "original" RFI from the earth views, space view and internal target temperatures in the scan (see Section 3.2).

The term "original" is used because a new RFI component appeared in the AMSU-B data on October 13, 1998. This new bias appeared to be more intense and intermittent than the original RFI, leading to a second series of NASA transmitter on/off tests in November of 1998 and in January of 1999. It was ultimately determined that the source of this new RFI was additional energy from the STX-1 antenna (which was degrading) being reflected off one of the AMSU-A antennas and into the AMSU-B instrument along the optical path. The gradual degradation of the STX-1 antennas was causing the intermittent characteristic of the observed RFI pattern, a characteristic which appeared to disappear after January 23rd suggesting that the degradation was complete. Furthermore, since the AMSU-B instrument scans three times in the eight seconds it takes for the AMSU-A instrument to complete one scan, this new STX-1 RFI was observed to vary in a three scan line cycle. The UKMO ultimately developed procedures to detect "events" of this additional STX-1 RFI, and three sets of correction tables for the earth views, space view and internal target temperatures (see Section 3.3).

Yet another source of RFI appeared on February 15th, 1999. This latest RFI appeared confined to descending orbit paths in the vicinity of the Wallops Island, Virginia, and Fairbanks, Alaska receiving stations. This led to a third series of NASA transmitter on/off tests in March, and the conclusion that this latest RFI was being caused by a degradation of the STX-3 antenna. Similar to the latest STX-1 RFI, this new STX-3 RFI was intermittent, requiring separate event detection procedures. It also appeared to propagate in a 3-scanline, but (unlike the new STX-1) only in the calibration points (mainly the space view). The UKMO ultimately derived procedures and correction tables to account for this latest component of STX-3 RFI (see Section 3.4).

Unfortunately, this was not the final hurdle concerning the RFI. During late March, the intermittent characteristic of the new STX-1 RFI discussed earlier returned. At first, this was thought to be of little consequence, since the procedures to handle intermittency were already developed. However, this latest episode also appeared to affect the ascending and descending orbit paths differently, a feature not observed in the past. Current thinking is that this latest STX-1 RFI can be attributed to solar heating differentials between the daytime and nighttime passes. Investigations continue, with the possibility (likelihood) that additional procedures and corrections may be required.

3. RFI CORRECTION METHODOLOGY

3.1 Background

The RFI correction algorithms were developed in response to the three phases as described above. These algorithms require three basic steps:

- determine which transmitters are on for a given scan line,
- adjust the space view and target temperatures and compute the primary calibration coefficients (mainly for direct readout users),
- adjust the earth views and apply calibration coefficients (for direct readout and 1b users).
Chalfant, et.al, Status of NOAA AMSU-B...

The two user groups referenced are those processing either the direct readout broadcast or the NESDIS operational 1b level data, respectively.

Direct readout users must determine the active transmitter configuration using the telemetry data contained in the broadcast, adjust (using the correction tables) the calibration points, and calculate the calibration coefficients. NESDIS 1b level users already have the adjusted calibration coefficients, but along with direct readout users must adjust (using correction tables) the earth views prior to calibration. Specific procedures are presented in Sections 3.2 to 3.4.

The RFI correction tables for level-1b users are provided on the header record of the 1b file. Corrections for each transmitter are provided at a predefined subsample of the (90) earth views, for the space (91) and for the internal target (92) temperatures. The earth view corrections must be expanded (ie, spline function) to attain values for each beam position.

Direct readout users and any level 1b users who wish to use them, can access expanded RFI correction tables (at each beam position) over the Internet:


The algorithms below were extracted from correspondence with Nigel Atkinson of the UKMO and uses channel numbering conventions where the five AMSU-B channels are numbered from 16 to 20 (following AMSU-A channels 1 to 15). The frequencies for channels used in the detection algorithm are:

- channel 16 @ 89 Ghz,
- channel 17 @ 150 Ghz, and
- channel 20 @ 183+/-.7 Ghz.

3.2 Original RFI

Baseline correction tables for the original RFI from the STX-1, STX-2, STX-3 and SARR transmitters, respectively, for each AMSU-B channel, are defined at each fifth earth view spot (and for spots 91, the space view, and 92, the internal target) on the header record of the NESDIS level 1b file, and must be expanded. Already expanded values exits at the Internet URL listed above.

To compensate for the possibility that the power for a given transmitter may change over time, a "reference power level" for each transmitter is also included in the level 1b header. For direct readout users the mean power levels in counts at the time the tables were derived are:

- STX-1 @ 111.3,
- STX-2 @ 114.3,
- STX-3 @ 95.0, and
- SARR @ 209.9
Chalfant, et.al, Status of NOAA AMSU-B...

The methodology to correct for the original RFI in a scan line are listed below:
- extract the transmitter power counts for STX-1, STX-2, STX-3, and SARR.
- compute a power ratio for each active (nonzero power) transmitter by dividing the observed power by the reference power level.
- multiply the baseline correction tables for each active transmitter by its power ratio to get the final adjustments tables for the scan line,
- add the values from the RFI adjustment table (for active transmitters) to the observed counts for the space view and the internal target views.
- recompute primary calibration coefficients (already done for 1b users), and
- adjust the earth views using the appropriate correction tables and calibrate.

The last two steps are only done if the STX-1 and STX-3 transmitters are not active, otherwise go to Sections 3.3 and 3.4.

3.3 Additional RFI from STX-1 (Part-1)

Similar to the procedure for “original” RFI, correction tables for scan lines contaminated by additional STX-1 can be extracted from the level 1b header, but are defined for every third spot (as opposed to at every 5th for original RFI). These must be expanded or use the expanded table available on the Internet.

The steps to detect whether additional STX-1 RFI exists are:
- for channels 16, 17, and 20, respectively, calculate the mean difference in counts (dc) for pixels 1 to 10 minus pixels 11 to 20, for each scan; the results are dc (16), dc (17), and dc (20),
- calculate the term \( X_1 = y_{17} - y_{20} - 0.3 \cdot y_{16} \),
- \( X_1 \) typically varies between +/-200, if greater than 600 the additional STX-1 is present.

No power ratio adjustment needs to be made for additional STX-1 RFI.

As discussed, the additional STX-1 RFI varies over a 3 scan line cycle, requiring three sets of correction tables. The three sets correction tables associated with the additional STX-1 RFI are referred to as SCAN(1), SCAN(2), and SCAN(3), respectively. The steps to correct for additional STX-1 RFI are:
- determine which of the three correction tables, SCAN(LINE#), to use, where \( \text{LINE#} = \text{MOD(scanline-1,3)} + 1 \),
- if a direct readout user, use the selected table to adjust space view, and internal target view counts (already adjusted for original RFI) and compute calibration coefficients,
- adjust the earth view counts using the appropriate table(s) and calibrate.

Also as discussed, the additional STX-1 RFI appeared to de-stabilize during March, this time portraying an ascending versus descending orbit path characteristic. This is not accounted for in the above procedures and is currently under investigation.
3.4 Additional RFI from STX-3

As of this document, the correction table for additional STX-3 RFI has not yet been included in the level 1b header. However, this is expected in the near future, with an RFI correction table defined for every fifth earth view spot, the space view and internal target temperature.

The steps to detect whether STX-3 RFI exists are:
- for channels 16, 17, and 20, respectively, calculate the mean difference in counts (dc) for pixels 41 to 45 minus pixels 76 to 80 for each scan; the results are dc (16), dc (17), and dc (20),
- calculate the term \( X_3 = dc (17) - dc (20) - 0.3 \times dc (16) \),
- If \( X_3 \) is greater than 1100 the STX-3 RFI is present.

The necessity to provide three sets of correction tables is pending, with preliminary indication that they may only be needed for the space and internal target views. If necessary selection procedures will be similar to those for the additional STX-1 RFI. No power ratio adjustments are required.

The steps in correcting for STX-3 RFI are:
- use the STX-3 RFI table to adjust the space view, and internal target view counts (that have already been adjusted for any original RFI and additional STX-1 RFI),
- for direct readout users (and level 1b users until incorporated on 1b header), use the adjusted space and internal target views to generate calibration coefficients,
- adjust and calibrate the earth views.

3.5 RFI Correction Table Maintenance

Users can anticipate that additional transmitter turn-off tests will be conducted periodically to determine the stability of the RFI over time. For level 1b users who elect to read the correction tables from the level 1b file header, any table corrections made as a result of these stability tests will be transparent. Direct readout users and level 1b users who elect to download the expanded correction tables from the


Internet web page (see Section 3.1), will want to visit that site regularly to check the date stamp on the correction table files and download any updates.

4.0 RFI RESULTS

The series of transmitter on/off tests conducted by NASA during July and August (1998) were used to characterize the original RFI observed in the AMSU-B measurements after launch (May, 1998). The UKMO used these data to quantify the level of interference in counts for each AMSU-B channel corresponding to each of the S-band transmitters, and compiled RFI correction tables. Figure 1 shows plots of the total correction across the scan for each AMSU-B channel, due to "original" RFI from STX-1, STX-3, and SARR transmitters.

Similar plots of the additional RFI from STX-1, which first appeared on October 13, 1998, are shown for each AMSU-B channels in Figure 2. The RFI was more intense, intermittent, and varied over a 3-scan line cycle.
Figure 1. AMSU-B corrections for original STX-1, STX-3, and SARR RFI

Figure 2. AMSU-B corrections for Additional STX-1 RFI (Scan 2)

Figure 3. AMSU-B corrections for additional STX-3 RFI
Figure 4: Radiance temperature (K) at 183+/-3 GHz for uncorrected AMSU-B (upper left), original RFI adjusted AMSU-B (upper right), the original RFI corrections (lower left), and concurrent SSM/T2.

Figure 5: AMSU-B radiance temperature (K) at 150 GHz for orbit segment with additional STX-3 RFI.
Chalfant, et al., Status of NOAA AMSU-B...

Given the transmitter on/off data from the NASA tests in November of 1998 and January of 1999, the UKMO ultimately compiled three sets of RFI correction tables to account for the 3-scan line cycle. The Figure 2 plots are for scan line 2.

UKMO derived plots of the additional RFI from STX-3, which first appeared on February 15, 1999, are shown for each AMSU-B channel in Figure 3. This additional STX-3 RFI was also intermittent, appearing in the descending path (concurrent with STX-3 transmissions) in the vicinity of the Wallops Island, Virginia and Fairbanks, Alaska receiving stations. Although the RFI did not appear to vary in a 3-scan line cycle for earth views, a 3-scan cycle in the calibration points was observed.

The four panels of Figure 4 show examples of net, original RFI interference and corrections across a portion of an orbit for the 183 +/- 3 GHz sounding channel, in equivalent radiance temperature units (ie, calibrated counts converted to radiance temperature). These represent the RFI contamination as they initially appeared to NESDIS scientists. Shown (clockwise beginning upper left) are original RFI contaminated AMSU-B data, the corrected data, concurrent Special Sensor Microwave/Moisture (SSM/T2) from the Defense Meteorological Satellite Program (DMSP) F-13 polar orbiting satellite, and in the lower left panel the RFI corrections applied. The SSM/T2 is identical to AMSU-B except at a lower spatial resolution (47km). The NOAA-15 and F-13 satellites are coincident within one hour. Although the magnitude of the RFI is significant, the good agreement between the RFI corrected AMSU-B and corresponding SSM/T2 radiance temperature fields is very encouraging.

Figure 5 shows an example of the additional STX-3 RFI across an orbit segment in the vicinity of Wallops Island Virginia for the AMSU-B 150 GHz channel. The warm bias due to the RFI is well defined, but not always present when STX-3 is active. Also notice the 3 scan line cycle variations embedded in the measurements (attributed to the 3-scan line cycle in the calibration points). It also appears that the RFI pattern changes abruptly along the west Gulf coast, but that is an illusion.

5.0 AMSU-B OPERATIONAL PRODUCT SYSTEMS

The current status of AMSU-B processing systems at NESDIS is described below. As mentioned, these systems operate independent from the more traditional AMSU-A and HIRS sounding product systems.

The impact of the RFI on AMSU-B measurements had a significant impact on the NESDIS capability to validate the operational product systems, since they were unexpected and resulted in unrealistic measurements for generating products. However, the decision to completely account for RFI in front-end processing during the generation of the 1b-level dataset, allowed the undertaking of a strictly system validation of the orbital and offline support systems which was successfully completed by August of 1998. However, the actual tuning of the operational product systems and the generation of reliable products require accurate radiometric measurements (ie, those which have been suitably corrected for RFI). It is also likely that additional orbital processing modifications will be needed if and when the FRI correction is finalized, but this is expected to be minimal.
Figure 6 – AMSU-B Processing System, showing the On-Line (orbital) processing, the Off-Line Daily jobs, the Off-Line Weekly jobs, and As Needed.
Chalfant, et.al, Status of NOAA AMSU-B...

Figure 6 presents a schematic diagram of the planned AMSU-B operational sounding products generation system. The chart shows the orbital processing system components in red, and the daily, weekly and as needed offline tuning components in green, blue and black respectively. The processing systems for AMSU-B are similar to those operated by NESDIS for the SSM/T2 (Reale, 1998), and planned for ATOVS (Reale, 1999).

5.1 Online Orbital Processing

The online orbital processing of AMSU-B products consists of four major components:
- calibration and earth location
- precipitation screening,
- radiance adjustments, and
- first guess/retrieval

Given that the RFI adjustments have been done, all scan lines in the vicinity of transmitter on/off activity will need to be screened. The remaining procedures are nearly identical to those for the SSM/T2.

Precipitation screening is based on the calculation of cloud liquid water (clw), with appropriate thresholds (approximately 50 mm) to indicate precipitation contamination over sea. A land based precipitation indicator is also under investigation.

The radiance adjustments (applied to the final RFI adjusted data) include:
- limb adjustments (Allegrino, 1999),
- cloud liquid water adjustment, and
- radiative transfer bias adjustments

The first guess moisture and radiance temperature profiles are determined using a scaler closeness version of the library search approach. This requires a radiance covariance matrix which is updated weekly. All five channels of the AMSU-B are used to determine the first guess radiance temperature and moisture profiles. Over sea, all three radiance adjustments are applied to the AMSU-B data. Over land, all three adjustments are applied to the 183 GHz channels, but only limb adjustment for the two surface channels.

The retrieval solution is a statistical regression. The regression coefficients are separate for sea and nonsea cases, based on adjusted radiance temperatures for all five channels over sea, and the three 183 GHz channels over land. Temperature information is not required, and only moisture soundings are derived.

5.2 Offline Tuning Systems

The offline tuning systems include the routine compilation and updating of:
- collocated radiosonde and satellite observations,
- first guess libraries,
- radiative transfer bias adjustment coefficients,
- radiance covariance matrix, and
- retrieval regression coefficients
Chalfant, et.al, Status of NOAA AMSU-B...

The collocations are compiled daily, and are used to update longer term data sets of collocations which serve as input for the first guess libraries and the various coefficients. The first guess libraries are updated daily. Coefficients and the radiance covariance matrices are updated weekly.

The radiative transfer bias coefficients are the only point in the current AMSU-B operating system which requires temperature information (as provided by the radiosonde). This is needed to calculate (Kleespies, 1997) the radiance temperatures for the five channels of the AMSU-B, which are then regressed against the observations. The surface emissivity assumptions for these calculations is

- .60 over sea, and
- .95 over land (and sea-ice).

The AMSU-B measurements are simultaneously adjusted for cloud liquid water during the radiative transfer bias correction by including the cloud liquid water as an additional predictor.

The retrieval regression coefficients to compute the moisture profiles do not require temperature information, as they are based on regression of radiosonde water vapor mixing ratio (g/kg) and the AMSU-B adjusted radiometric data. All five channels are used over sea, and only the three 183 GHz channels are used over land.

6.0 RESULTS

Preliminary results from the sounding products generation systems are presented in the four panels of Figure 7. Shown are regional fields of "adjusted" 183 +/- 7 GHz radiance temperatures from the SSM/T2 (upper left) and AMSU-B (upper right), and corresponding water vapor mixing ratio products (lower left and right). The 183 +/- 7 GHz channel is most sensitive to lower tropospheric moisture, and the adjustments include limb, clw and radiative transfer bias.

Overall good agreement between the SSM/T2 and AMSU-B data is observed. Notable is the improved spatial coverage for AMSU-B (ie, reduced orbit gaps). Residual problems due to unaccounted RFI (mainly additional STX-3 which is not finalized) can be detected in AMSU-B. These similarly affect the measurements and products, indicating the importance of reliable RFI adjustments and the sensitivity of the products.

7.0 FUTURE PLANS

NESDIS remains optimistic concerning useful AMSU-B products from NOAA-15. We anticipate a successful conclusion of RFI correction activities, including the latest RFI from STX-1, and associated modifications to the products generation software system. Meanwhile, the scientific areas targeted for upgrade include:

- limb adjustment
- cloud liquid water and precipitation detection over land,
- use of temperature information from AMSU-A and HIRS, and
- a physical retrieval approach.

A specific problem for AMSU-B products is the extremely high data volume (up to 2.6 million soundings daily) and the inability of current data links to handle the load. User requirements are needed.
Figure 7: Composite fields of concurrent SSM/T2 and AMSU-B radiances at 183+/−7 GHz (upper) and derived 850 mb water vapor mixing ratio (lower).

8.0 REFERENCES


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