Overview of AMSU-A Inter-satellite Calibration Bias Analysis Using the SNO Method

March 2, 2011

NOAA CDR Workshop, 2011    College Park, MD

Robert Iacovazzi, Jr. (ERT, Inc.), Changyong Cao (NESDIS/StAR) and Sid-Ahmed Boukabara (NESDIS/StAR)
Outline

- AMSU-A instrument characteristics and AMSU-A intersatellite bias detection utilizing the SNO method

- SNO-ensemble avg. biases between AMSU-A instruments at sounding channels (Chs 3-14)

- The impact of data collocation method on SNO bias uncertainty estimates

- SNO-ensemble biases inferred for NOAA-14 MSU and NOAA-15 AMSU-A

- Summary
Outline

- AMSU-A instrument characteristics and AMSU-A intersatellite bias detection utilizing the SNO method
- SNO-ensemble avg. biases between AMSU-A instruments at sounding channels (Chs 3-14)
- The impact of data collocation method on SNO bias uncertainty estimates
- SNO-ensemble biases inferred for NOAA-14 MSU and NOAA-15 AMSU-A
- Summary
Advanced Microwave Sounding Unit-A Instrument Characteristics

During each eight second in-orbit scan line, the AMSU-A views three different types of targets:

- 30 Earth view (EV) positions,
- 2 views of the internal warm target (~300K), and
- 2 views of cold space (~2.73K).

**Frequencies:** 15 Channels @ 24, 31, 50-57, and 89 GHz

Typical Simultaneous Nadir Overpass (SNO)

Example SNO between NOAA-15 and NOAA-16 at 4:42:00 UTC on Aug. 18, 2002, located at 78.83 deg N and 87.00 deg W

Cao et. al., J. Atmos. Ocn. Tech., 2004
AMSU-A SNO Dataset Collocation

Satellite 2 Footprints

Satellite 1 Footprints

150 km

200 km

50 km
Outline

- AMSU-A instrument characteristics and AMSU-A intersatellite bias detection utilizing the SNO method
- SNO-ensemble avg. biases between AMSU-A instruments at sounding channels (Chs 3-14)
- The impact of data collocation in SNO bias estimation uncertainty
- SNO-ensemble biases inferred for NOAA-14 MSU and NOAA-15 AMSU-A
- Summary
**Operational AMSU-A SNO Ensemble Dataset**

**Time Period:** May 21, 2005 to July 31, 2006

**Locations:** Typically Around $80^\circ$ North and South

**SNO Time Threshold:** 30 Seconds

**Number of SNOs:**

<table>
<thead>
<tr>
<th></th>
<th>Aqua/N15</th>
<th>Aqua/N16</th>
<th>Aqua/N18</th>
<th>N15/N16</th>
<th>N15/N18</th>
<th>N16/N18</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Northern Hemisphere (NH)</strong></td>
<td>63</td>
<td>57</td>
<td>58</td>
<td>57</td>
<td>60</td>
<td>54</td>
</tr>
<tr>
<td><strong>Southern Hemisphere (SH)</strong></td>
<td>65</td>
<td>53</td>
<td>55</td>
<td>55</td>
<td>57</td>
<td>54</td>
</tr>
<tr>
<td><strong>Globe</strong></td>
<td>128</td>
<td>110</td>
<td>113</td>
<td>112</td>
<td>117</td>
<td>108</td>
</tr>
</tbody>
</table>
AMSU-A SNO Uncertainty Relative to NEDT

Avg. Percentage of SNO Bias Variance due to NEDT

\[ V_{\text{NEDT}} = 100 \times \sum_{N=1}^{N_{\text{sno}}} \frac{\sigma^2_{\text{NEDT}}(\text{Sat1}) + \sigma^2_{\text{NEDT}}(\text{Sat2})}{\sigma^2_{N}(\text{Sat1} - \text{Sat2})} \] \bigg/ N_{\text{sno}}

<table>
<thead>
<tr>
<th>AMSU-A Channel Number</th>
<th>Avg. VNEDT (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Avg Aqua-N18</td>
</tr>
<tr>
<td>2</td>
<td>Avg Aqua-N16</td>
</tr>
<tr>
<td>3</td>
<td>Avg Aqua-N15</td>
</tr>
<tr>
<td>4</td>
<td>Avg N15-N18</td>
</tr>
<tr>
<td>5</td>
<td>Avg N16-N18</td>
</tr>
<tr>
<td>6</td>
<td>Avg N15-N16</td>
</tr>
</tbody>
</table>
Aqua and N15 AMSU-A Individual SNO Mean Bias Time Series

Ch 5: 53.6 GHz

(Aqua-N15)

AMSU-A Brightness Temp. Bias (K)

Date (Year)

Global SNO-ensemble Mean Bias = -0.05 K

SH: Southern Hemisphere
NH: Northern Hemisphere
POES and Aqua AMSU-A SNO-ensemble Mean Biases and 99% Confidence Intervals

A) Aqua-N15

B) Aqua-N16

C) Aqua-N18
Estimated and Observed and AMSU-A SNO biases using Aqua/AMSU-A as a Calibration Transfer Radiometer

- AMSU-A Channel
  - Tb Bias (K)
  - Avg N15-N18
  - Avg (Aqua-N18) - (Aqua-N15)

- AMSU-A Channel
  - Tb Bias (K)
  - Avg N15-N16
  - Avg (Aqua-N16) - (Aqua-N15)

- AMSU-A Channel
  - Tb Bias (K)
  - Avg N16-N18
  - Avg (Aqua-N18) - (Aqua-N16)
MetOP-A AMSU-A SNO-ensemble Mean Biases and 99% Confidence Intervals
AMSU-A SNO Mean Biases and STD
MetOP-A/NOAA16 Ch 4

METOP-A - NOAA16

Tb Bias (K)

Date


SH_Bias
SH_STD_Bias
NH_Bias
NH_STD_Bias
Outline

- AMSU-A instrument characteristics and AMSU-A intersatellite bias detection utilizing the SNO method
- SNO-ensemble avg. biases between AMSU-A instruments at sounding channels (Chs 3-14)
- The impact of data collocation method on SNO bias uncertainty estimates
- SNO-ensemble biases inferred for NOAA-14 MSU and NOAA-15 AMSU-A
- Summary
Operational AMSU-A SNO Ensemble Dataset

**Satellites**: NOAA18 and EOS-Aqua

**Time Period**: 21 May 2005 - 31 January 2007

**Locations**: Typically Around $80^0$ North and South

**SNO Time Threshold**: 30 Seconds

**Number of SNOs**:  
89 Northern Hemisphere  
85 Southern Hemisphere
Nearest-Neighbor Data Collocation
AMSU-A Ch 1 SNO Mean Bias Time Series
Using Nearest-neighbor Collocation

A) No Interpolation

Channel 1
Aqua - N18

SH: Southern Hemisphere
NH: Northern Hemisphere
AMSU-A SNO Mean Bias Uncertainties Using Nearest-neighbor Collocation
Bilinear Interpolation Data Collocation

Satellite 2 Footprints

Satellite 1 Footprints

SNO
AMSU-A Ch 1 SNO Mean Bias Time Series
Using Bilinear Interpolation Collocation
AMSU-A SNO Mean Bias Uncertainties Using Bilinear Interpolation Collocation
Screening SNO Events for Anomalous Scene Inhomogeneity

Establish a maximum brightness temperature (Tb) difference threshold around a given observation using

1) Assume a target SNO Bias STD (without NEΔT) at a given channel

2) Relate target SNO Bias STD to scene-average maximum difference

\[
\delta T_{b,\text{max}} = \text{slope} \times \left\{ 3 \times \sqrt{NE\Delta T_{\text{instr1}}^2 + NE\Delta T_{\text{instr2}}^2} \right\} \]

Target SNO Bias STD
AMSU-A Ch 1 SNO Mean Bias Time Series
After Data Quality Control

Number of events decreased on average from about 87 to 48 each for the NH and SH.
AMSU-A SNO Mean Bias Uncertainties After Data Quality Control
Outline

- AMSU-A instrument characteristics and AMSU-A intersatellite bias detection utilizing the SNO method
- SNO-ensemble avg. biases between AMSU-A instruments at sounding channels (Chs 3-14)
- The impact of data collocation method on SNO bias uncertainty estimates
- SNO-ensemble biases inferred for NOAA-14 MSU and NOAA-15 AMSU-A

Summary
Microwave Sounding Unit (MSU) and Advanced MSU Series-A (AMSU-A) Comparison

<table>
<thead>
<tr>
<th>Ch #</th>
<th>Ch f (GHz)</th>
<th># Bands</th>
<th>Nominal Bandwidth (GHz)</th>
<th>Nominal Beamwidth (degrees)</th>
<th>NEΔT (K) (Spec.)</th>
<th>Nadir Polarization</th>
<th>Subunit</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSU 1</td>
<td>50.30</td>
<td>1</td>
<td>0.20</td>
<td>7.5</td>
<td>0.30</td>
<td>V</td>
<td>N/A</td>
</tr>
<tr>
<td>AMSU 3</td>
<td>50.30</td>
<td>1</td>
<td>0.18</td>
<td>3.3</td>
<td>0.40</td>
<td>V</td>
<td>A1-2</td>
</tr>
<tr>
<td>MSU 2</td>
<td>53.74</td>
<td>1</td>
<td>0.20</td>
<td>7.5</td>
<td>0.30</td>
<td>H</td>
<td>N/A</td>
</tr>
<tr>
<td>AMSU 5</td>
<td>53.596 ± 0.115</td>
<td>2</td>
<td>0.17</td>
<td>3.3</td>
<td>0.25</td>
<td>H</td>
<td>A1-2</td>
</tr>
<tr>
<td>MSU 3</td>
<td>54.96</td>
<td>1</td>
<td>0.20</td>
<td>7.5</td>
<td>0.30</td>
<td>V</td>
<td>N/A</td>
</tr>
<tr>
<td>AMSU 7</td>
<td>54.94</td>
<td>1</td>
<td>0.40</td>
<td>3.3</td>
<td>0.25</td>
<td>V</td>
<td>A1-1</td>
</tr>
<tr>
<td>MSU 4</td>
<td>57.95</td>
<td>1</td>
<td>0.20</td>
<td>7.5</td>
<td>0.30</td>
<td>H</td>
<td>N/A</td>
</tr>
<tr>
<td>AMSU 9</td>
<td>57.29</td>
<td>1</td>
<td>0.33</td>
<td>3.3</td>
<td>0.25</td>
<td>H</td>
<td>A1-1</td>
</tr>
</tbody>
</table>

Note: H indicates horizontal and V indicate vertical polarization
Microwave Sounding Unit (MSU) and Advanced MSU Series-A (AMSU-A) Comparison
MSU/AMSU-A SNO Dataset Collocation

AMSU-A Footprints

MSU Footprints

150 km
NOAA-14 MSU and NOAA-15 AMSU-A Tb Biases
NOAA Microwave Integrated Retrieval System (MIRS) and Community Radiative Transfer Model (CRTM)

- NOAA MIRS (Boukabara et al. 2006) is a microwave instrument retrieval software engineered around the CRTM (Han et al. 2006)

- CRTM utilizes atmospheric soundings and surface parameters from the National Centers for Environmental Prediction (NCEP) Global Data Assimilation System (GDAS).
For the 14th or 15th day of each month of 2007, GDAS soundings and surface parameters interpolated in time and space to AMSU-A footprint geolocations

CRTM used in the forward model mode to simulate both N14 MSU and N15 AMSU-A measurements

Simulations for four nearest-nadir AMSU-A scan positions give about 3,400 (3,000) simulated MSU and AMSU-A data values for the Northern (Southern) Hemisphere region poleward of 75 deg N (75 deg S) in a given month

Differences between simulated MSU and AMSU-A measurements for similar channel pairs is only due to their frequency and band width differences
NOAA-14 MSU and NOAA-15 AMSU-A Tb Biases
Projected from MIRS/CRTM for 2007 (MSU/AMSU-A center frequency
and band width differences only) and Raw Data for 1998-2006

South Hemisphere

AMSU-A 3 - MSU 1

AMSU-A 5 - MSU 2

AMSU-A 7 - MSU 3

AMSU-A 9 - MSU 4

North Hemisphere
NOAA-14 MSU and NOAA-15 AMSU-A Tb Biases
Estimated after MIRS/CRTM Adjustments to Raw Data

AMSU-A 3 - MSU 1
South Hemisphere
AMSU-A 5 - MSU 2
AMSU-A 7 - MSU 3
AMSU-A 9 - MSU 4

South Hemisphere
North Hemisphere

AMSU-A Ch 3 - MSU Ch 1 (SH)
AMSU-A Ch 5 - MSU Ch 2 (SH)
AMSU-A Ch 7 - MSU Ch 3 (SH)
AMSU-A Ch 9 - MSU Ch 4 (SH)

AMSU-A Ch 3 - MSU Ch 1 (NH)
AMSU-A Ch 5 - MSU Ch 2 (NH)
AMSU-A Ch 7 - MSU Ch 3 (NH)
AMSU-A Ch 9 - MSU Ch 4 (NH)
## NOAA-14 MSU and NOAA-15 AMSU-A Tb Biases
Estimated after MIRS/CRTM Adjustments to Raw Data

<table>
<thead>
<tr>
<th>Channel Pair</th>
<th>Northern Hemisphere</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\delta T_b$ (K)</td>
<td>$\delta T_b$ (K)</td>
<td>$\delta T_b$ vs. time</td>
</tr>
<tr>
<td></td>
<td>*Conf. Int. (K)</td>
<td>*Conf. Int. (K)</td>
<td>Slope (Kdecade⁻¹) /</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>*Significant</td>
</tr>
<tr>
<td>MSU Ch 1 / AMSU-A Ch 3</td>
<td>0.38</td>
<td>0.36</td>
<td>-0.32 / No</td>
</tr>
<tr>
<td>MSU Ch 2 / AMSU-A Ch 5</td>
<td>0.11</td>
<td>0.08</td>
<td>0.08 / No</td>
</tr>
<tr>
<td>MSU Ch 3 / AMSU-A Ch 7</td>
<td>-0.13</td>
<td>0.06</td>
<td>0.17 / No</td>
</tr>
<tr>
<td>MSU Ch 4 / AMSU-A Ch 9</td>
<td>-0.24</td>
<td>0.07</td>
<td>-0.15 / No</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Channel Pair</th>
<th>Southern Hemisphere</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\delta T_b$ (K)</td>
<td>$\delta T_b$ (K)</td>
<td>$\delta T_b$ vs. time</td>
</tr>
<tr>
<td></td>
<td>*Conf. Int. (K)</td>
<td>*Conf. Int. (K)</td>
<td>Slope (Kdecade⁻¹) /</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>*Significant</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MSU Ch 1 / AMSU-A Ch 3</td>
<td>0.46</td>
<td>0.18</td>
<td>0.69 / Yes</td>
</tr>
<tr>
<td>MSU Ch 2 / AMSU-A Ch 5</td>
<td>-0.07</td>
<td>0.09</td>
<td>0.10 / No</td>
</tr>
<tr>
<td>MSU Ch 3 / AMSU-A Ch 7</td>
<td>-0.05</td>
<td>0.05</td>
<td>0.03 / No</td>
</tr>
<tr>
<td>MSU Ch 4 / AMSU-A Ch 9</td>
<td>-0.52</td>
<td>0.08</td>
<td>0.41 / Yes</td>
</tr>
</tbody>
</table>

*All confidence levels are defined at the 0.01 significance level.*
Examination of Residual Biases

Regressions of Adjusted Tb Biases with respect to Calibration-related parameters:

- Tb
- Solar zenith angle
- Instrument space view and blackbody target counts
- Temperatures of the blackbody, antenna, scan motor, RF shelf, local oscillator, MSU dicke load, etc

Largest regressions coefficients were: Tb Bias versus

- Solar Zenith Angle (0.35 in Southern Hemisphere for MSU4/AMSU-A9)
- Tb (0.32 in Southern Hemisphere for MSU2/AMSU-A5)
- MSU Space View Counts (0.31 in Southern Hemisphere for MSU4/AMSU-A9)
Examination of Residual Biases

Adjusted AMSU-A5-MSU2 $\delta T_b$ (Dots)
MSU2 $T_b$ (Squares)

MSU4 (Dots)
AMSU-A9 (Squares)
Outline

- AMSU-A instrument characteristics and AMSU-A intersatellite bias detection utilizing the SNO method
- SNO-ensemble avg. biases between AMSU-A instruments at sounding channels (Chs 3-14)
- The impact of data collocation method on SNO bias uncertainty estimates
- SNO-ensemble biases inferred for NOAA-14 MSU and NOAA-15 AMSU-A

Summary
Summary

High radiometric consistency exists between concurrently operating AMSU-A instruments, with biases ~0.5 K or less.

AMSU-A1-1 on N18 and Aqua, and AMSU-A1-2 on N16, show significant biases across all platforms. Large noise anomaly found in N16 Ch. 4.

Main source of uncertainty of SNO-inferred biases in surface-influenced channels is surface emissivity and temperature inhomogeneities, and in other channels it is NEDT.

Bilinear interpolation with QC reduces N18/Aqua SNO-ensemble mean Tb bias confidence intervals (STD) at AMSU-A surface-influenced channels by nearly 68 % (76 %) on average over nearest-neighbor collocation.

Need a sufficient population (> 50 – 60 SNO events)

Calibration and diurnal-cycle related Tb biases must be estimated for all pairs of MSU and/or AMSU-A instruments used to make a time series.

Frequency and band width differences between similar MSU and AMSU-A instrument channels must be carefully evaluated as a function of season and earth location.

Further analysis of Tb bias residuals with respect to sensor data must be done to isolate Tb bias related to radiative transfer model and initial condition errors, as well as instrument affects.
Backup Slides
Development of MSU/AMSU-A Fundamental Climate Data Records

What was done

- Isolated calibration-related biases for NOAA-14 MSU and NOAA-15 AMSU-A

What needs to be done

- Using MIRS/CRTM, create a LUT of MSU/AMSU-A center frequency and band width difference Tb biases as a function of earth coordinates and season

- Estimate diurnal cycle related MSU/AMSU-A Tb biases resulting from intersatellite orbit differences and drifts. Can be estimated using a climate model (Mears, 2003) or could use ocean-only data where the diurnal cycle is very small (Zou et al., 2006)

- Cumulatively remove net frequency and band width difference, calibration and diurnal time-dependent Tb biases between each successive co-orbiting MSU, MSU/AMSU-A, or AMSU-A instrument pair from the first satellite in the time series to the last

- Perform a residual analysis