AMSU navigation and geolocation errors

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Geolocation, mapping satellite data to the earth surface

- Geolocation is a very important part of the postlaunch calibration process.
- We combine different satellite and modeled data to retrieve geophysical variables like temperature, rainfall, water vapor, and etc. So it is critical to know the exact location of each measurement or simulation.

**Main sources of geolocation errors**

- 1. Poor spacecraft ephemeris data (right ascension, altitude, declination)
- 2. *Satellite and sensor pointing/attitude errors*
- 3. Time offset
How to quantify geolocation errors
The difference map for ascending/descending nodes

- The time difference between ascending/descending orbits is about 12 hours and normally one of them is daytime and the other one is nighttime.
- During day the surface temperature is hot and it is cold in night but the ocean surface temperature does not change that much.
- The difference map should not distinguish any difference at the coast lines
  - *negative alongtrack offset* => *northern coastlines will have a cold edge, and southern coastlines will have a warm edge.*
  - *negative crosstrack offset* => *western coastlines will have a cold edge and the eastern coastlines will have a warm edge*
  - *The reverse is also true*
NOAA15 AMSU-A Channel 1

Difference map created from one week data since 12/16/2010
NOAA15 AMSU-A Channel 1
RMSE = $\sqrt{\frac{\sum_{\text{pixels}} \Delta Tb^2}{n}}$

SD = $\sqrt{\frac{\sum_{\text{pixels}} (\Delta Tb - \overline{\Delta Tb})^2}{n}}$
Previous studies
An algorithm for correction of navigation errors in AMSU-A data

- used the cross correlation method and AMSU-B Channel 16 data, as the reference, to investigate the geolocation errors in AMSU-A Channels 1 and 2.

- They reported a roll angle of the order of 1 deg exists in the NOAA-15 AMSU-A Channels 1 and 2.
Table 4 shows the shift values calculated with the average of the pattern matching measurements shown in Figure 5.

Since the reference imagery of the pattern matching is AMSU-B channel 16,

1) if a line shift is positive, AMSU-A imagery has an offset to the direction of orbital velocity compared with AMSU-B.

2) if a pixel shift is positive, AMSU-A imagery has an offset to the scan direction compared with AMSU-B.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.15</td>
<td>-0.92</td>
<td>-0.26</td>
<td>0.20</td>
</tr>
</tbody>
</table>

Table 4. AMSU Image Shift Values expressed by AMSU-B Lines and Pixels.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pitch</td>
<td>Roll</td>
<td>Pitch</td>
<td>Roll</td>
</tr>
<tr>
<td>-3.1</td>
<td>18</td>
<td>-5.5</td>
<td>-3.8</td>
</tr>
</tbody>
</table>

Table 5. AMSU Correction Angles (milli-radians).
Figure 5a. NOAA-15 AMSU-A Line (along-track) Shift.
Figure 5b. NOAA-15 AMSU-A Pixel (cross-track) Shift.
NOAA-18 AMSU-A2 appears to be geolocated negative alongtrack and negative crosstrack.
NOAA-18 AMSU-A1-2 appears to be correctly geolocated

Thomas J. Kleespies, NOAA/NESDIS/ORA, 9 August 2005
Correction necessary to match coastlines

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Orbit</th>
<th>Des/Asc</th>
<th>Cross-Track [MHS FOVS]</th>
<th>Along-Track [MHS Scan lines]</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMSU-A1 89 GHz</td>
<td></td>
<td></td>
<td>-0.60 (-=10.2 km @ nadir)</td>
<td>-0.40 (-=6.8 km @ nadir)</td>
</tr>
<tr>
<td>AMSU-A2 23 GHz</td>
<td>D05172 S0244</td>
<td>D</td>
<td>+0.30 +0.50</td>
<td>+0.50 +0.70</td>
</tr>
<tr>
<td></td>
<td>D05172 S0952</td>
<td>A</td>
<td>-0.10 -0.10</td>
<td>+0.70 +0.80</td>
</tr>
<tr>
<td></td>
<td>D05172 S0434</td>
<td>A</td>
<td>+0.50 +0.30</td>
<td>+0.80 +0.80</td>
</tr>
<tr>
<td></td>
<td>D05172 S1747</td>
<td>D</td>
<td>+0.40 +0.30</td>
<td>+0.60 +0.70</td>
</tr>
<tr>
<td>A2-Average</td>
<td></td>
<td></td>
<td>+0.26 (+=4.7 km@nadir)</td>
<td>+0.70 (+=12.5 km@nadir)</td>
</tr>
<tr>
<td>AMSU-A1 50 GHz</td>
<td>D05172 S0244</td>
<td>D</td>
<td>+0.20 +0.20</td>
<td>-0.30 -0.35</td>
</tr>
<tr>
<td></td>
<td>D05172 S0952</td>
<td>A</td>
<td>-0.20 -0.10</td>
<td>+0.00 +0.00</td>
</tr>
<tr>
<td></td>
<td>D05172 S0434</td>
<td>A</td>
<td>+0.20 +0.30</td>
<td>0.00 0.00</td>
</tr>
<tr>
<td></td>
<td>D05172 S1747</td>
<td>D</td>
<td>+0.20 +0.20</td>
<td>+0.20 +0.00</td>
</tr>
<tr>
<td>A1-Average</td>
<td></td>
<td></td>
<td>+0.13 (+=2.2 km@nadir)</td>
<td>+0.06 (+=1.0 km@nadir)</td>
</tr>
<tr>
<td>MHS 89 GHz</td>
<td>D05172 S0244</td>
<td>D</td>
<td>+0.35 +0.35</td>
<td>-1.00 -1.00</td>
</tr>
<tr>
<td></td>
<td>D05172 S0952</td>
<td>A</td>
<td>+0.10 +0.00</td>
<td>-0.90 -0.90</td>
</tr>
<tr>
<td></td>
<td>D05172 S0434</td>
<td>A</td>
<td>+0.10 +0.10</td>
<td>-0.70 -0.80</td>
</tr>
<tr>
<td></td>
<td>D05172 S1747</td>
<td>D</td>
<td>+0.20 -0.20</td>
<td>-0.80 -1.20</td>
</tr>
<tr>
<td>MHS-Average</td>
<td></td>
<td></td>
<td>+0.18 (+=3.2 km@nadir)</td>
<td>-0.92 (+=16.4 km@nadir)</td>
</tr>
</tbody>
</table>
AM1012/AM2012 NOAA-19 AMSU Geolocation Study
Thomas J. Kleespies

AMSU-A2 offset

~3-4 km uptrack, xtrack OK

AMSU-A1-2 offset

~8-9 km uptrack xtrack OK

AMSU-A1-1 offset

~ 4-5 km uptrack xtrack probably OK
AMSU-A channel 1 image over the west coast of California. The striking contrast between land and ocean from microwave window channel is normally used for a sanity check for geolocation. It appears that there is one pixel offset in AMSU earth location in both E-S and N-S directions. This offset is being under investigation.
AMSU
Pointing/Attitude Errors
Flight dynamics parameters in 3D Euclidian space are known as Pitch, Roll and Yaw but in mathematics they are often known by their mathematical name, **Euler angles**.
Methodology

Rotating the coordinate system (Wikipedia)

\[
L = \begin{bmatrix}
\cos \theta_1 & 0 & \sin \theta_1 \\
0 & 1 & 0 \\
-\sin \theta_1 & 0 & \cos \theta_1
\end{bmatrix} \begin{bmatrix}
1 & 0 & 0 \\
0 & \cos \theta_2 & -\sin \theta_2 \\
0 & \sin \theta_2 & \cos \theta_2
\end{bmatrix} \begin{bmatrix}
\cos \theta_3 & -\sin \theta_3 & 0 \\
\sin \theta_3 & \cos \theta_3 & 0 \\
0 & 0 & 1
\end{bmatrix}
\]

\[
\theta_1 = \Delta R \\
\theta_2 = \Delta Y \\
\theta_3 = \Delta P
\]
Rotation matrix (Kigawa and Weinreb, 2002)

Corrected pointing vector in the platform coordinates is given by

\[
\begin{pmatrix}
    x_{cpp} \\
    y_{cpp} \\
    z_{cpp}
\end{pmatrix} =
L \begin{pmatrix}
    \cos \theta \\
    0 \\
    \sin \theta
\end{pmatrix}
\]

The corrected pointing vector in the earth fixed coordinates is expressed as

\[
\begin{pmatrix}
    x_{cp} \\
    y_{cp} \\
    z_{cp}
\end{pmatrix} =
\begin{pmatrix}
    x_{yaw} \\
    y_{yaw} \\
    z_{yaw}
\end{pmatrix} x_{cpp} +
\begin{pmatrix}
    x_{roll} \\
    y_{roll} \\
    z_{roll}
\end{pmatrix} y_{cpp} +
\begin{pmatrix}
    x_{pitch} \\
    y_{pitch} \\
    z_{pitch}
\end{pmatrix} z_{cpp}
\]
The corrected view vector \((X'_p, Y'_p, Z'_p)\) directed from the platform to the point of interest is given by:

\[
\begin{align*}
    a &= (1 - f)^2(x_{cp}^2 + y_{cp}^2) + z_{cp}^2 \\
    b &= (1 - f)^2(X_o \cdot x_{cp} + Y_o \cdot y_{cp}) + Z_o \cdot z_{cp} \\
    c &= (1 - f)^2(X_o^2 + Y_o^2 - Re^2) + Z_o^2 \\
    k &= \frac{-b \pm \sqrt{b^2 - ac}}{a} \\

    \text{(smaller absolute value should be employed)}
\end{align*}
\]

\[
\begin{pmatrix} X'_p \\ Y'_p \\ Z'_p \end{pmatrix} = \begin{pmatrix} X_o \\ Y_o \\ Z_o \end{pmatrix} + k \begin{pmatrix} x_{cp} \\ y_{cp} \\ z_{cp} \end{pmatrix}
\]

(44)

2.12 Corrected latitude and longitude

The corrected latitude and longitude of the point of interest are given by

\[
\varphi' = \tan^{-1} \left( \frac{Z'_p}{(1 - f)^2 \sqrt{(X'_p)^2 + (Y'_p)^2}} \right)
\]

(45)

\[
\lambda' = \tan^{-1} \left( \frac{Y'_p}{X'_p} \right)
\]

(46)
Results
mid-latitude Pitch = 1.000  Roll = 1.000  Yaw = 1.000
mid-latitude Pitch = 0.500  Roll = 0.500  Yaw = 0.500

Tropical
High Latitude
Mid-Latitude
NOAA 16 – AMSU-A2 Channel 1
The pixel and line shifts for AMSU-B seem to be less variable than AMSU-A2
What’s next

❖ Calculating roll, pitch and yaw errors for each week and then correcting the current values of latitude and longitude.
❖ Correcting LZA and LSA using new pitch, roll and yaw
❖ Including time offset corrections
❖ Quantifying the uncertainty from satellite ephemeris data.
End
**AMSU-A Characteristics**

http://www2.ncdc.noaa.gov/docs/klm/html/c3/sec3-3.htm

<table>
<thead>
<tr>
<th>Channel No.</th>
<th>Frequency (GHz)</th>
<th>Polarization at nadir</th>
<th>Atmospheric transmission (tropical)</th>
<th>Atmospheric transmission (winter subarctic)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>23.8</td>
<td>V</td>
<td>0.78</td>
<td>0.99</td>
</tr>
<tr>
<td>2</td>
<td>31.4</td>
<td>V</td>
<td>0.89</td>
<td>0.96</td>
</tr>
<tr>
<td>3</td>
<td>50.3</td>
<td>V</td>
<td>0.63</td>
<td>0.68</td>
</tr>
<tr>
<td>4</td>
<td>52.8</td>
<td>V</td>
<td>0.29</td>
<td>0.32</td>
</tr>
<tr>
<td>5</td>
<td>53.596 ± 0.115</td>
<td>H</td>
<td>0.11</td>
<td>0.13</td>
</tr>
<tr>
<td>6</td>
<td>54.40</td>
<td>H</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>7</td>
<td>54.94</td>
<td>V</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>8</td>
<td>55.50</td>
<td>H</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>9</td>
<td>57.290 = ν</td>
<td>H</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>10</td>
<td>ν ± 0.217</td>
<td>H</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>11</td>
<td>ν ± 0.322 ± 0.048</td>
<td>H</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>12</td>
<td>ν ± 0.322 ± 0.022</td>
<td>H</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>13</td>
<td>ν ± 0.322 ± 0.010</td>
<td>H</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>14</td>
<td>ν ± 0.322 ± 0.0045</td>
<td>H</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>15</td>
<td>89.0</td>
<td>V</td>
<td>0.61</td>
<td>0.91</td>
</tr>
</tbody>
</table>

Difference map created from one week data since 12/16/2010
Thickest lines denote GPCP calibrator.

Image by Eric Nelkin (SSAI), 20 October 2010, NASA/Goddard Space Flight Center, Greenbelt, MD.