Advanced Radiance Transformation System (ARTS) For Space-borne Microwave Instruments

Hu(Tiger) Yang¹, Fuzhong Weng², Ninghai Sun¹
Wanchun Cheng², Lin Lin², Miao Tian¹

1. Earth Science System Interdisciplinary Center, University of Maryland
2. NOAA Center for Satellite Applications and Research, USA

huyang@umd.edu
Jan 29, 2014
Objective

• Develop a generic calibration system for microwave sounding instruments onboard the various satellites operated by NOAA and other space agencies

• Apply the system for processing the microwave data from past, present and future satellites to produce consistent climate data records for use in weather and climate applications

• The system is designed with an end-to-end capability (e.g. TDR, SDR, RSDR and EDR).
- Module based design makes different sensors easy to be fitted in the system.
- Brightness temperature is computed from full Planck function in radiance space.
- Error budget in calibration is traceable.
## Supported Platforms

<table>
<thead>
<tr>
<th>OS</th>
<th>C compiler</th>
<th>C++ compiler</th>
<th>Fortran 90 compiler</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIX 5.3.0.0 or later</td>
<td>IBM XL C/C++ Enterprise Edition for AIX, V10.1</td>
<td>IBM XL C/C++ Enterprise Edition for AIX, V10.1</td>
<td>IBM XL Fortran Enterprise Edition for AIX, V12.1</td>
</tr>
<tr>
<td>LINUX (Red Hat Enterprise 5)</td>
<td>GCC 4.3.2</td>
<td>GCC 4.3.2</td>
<td>Intel Fortran version 11 or later</td>
</tr>
<tr>
<td>Windows XP/Vista running Cygwin</td>
<td>GCC 4.3.2</td>
<td>GCC 4.3.2</td>
<td>gfortran</td>
</tr>
</tbody>
</table>

ARTS supports both big and little endian hardware platforms
Main ARTS Modules

- GPS data and two line element data based geolocation
- Full radiance calibration
- Near-field radiation correction
- Coherent noise filtering for calibration counts
- Lunar contamination correction
- TDR B-G resampling
- TDR to SDR conversion
For example, for the window channel (ch.1), the land/ocean boundary matches very well with the predetermined coastline map, indicating a good accuracy of the geolocation results.
The noise power (radiance) from scene can be expressed as

\[ P_s = \delta \cdot (P_h - P_c) + P_c \]

Under R-J approximation, the noise power can be expressed as

\[ P = k \cdot B \cdot T \]

Therefore we can get the two point calibration expressed in temperature as below:

\[ T_s = \delta (T_h - T_c) + T_c + (\Delta T_c - \Delta T_s) \]

- There is a scene temperature dependent term and constant term of bias in R-J calibration equation.
- Even the correction term being included in calibration equation, there is still temperature and frequency dependent residual error in calibrated temperature.
- When scene temperature is close to deep space temperature, large bias will be arise by applying the R-J calibration equation with Tc correction.
Near Field Radiation Modeling

• An analysis of the ATMS antenna gain measurements reveals that the efficiencies of both ATMS antenna side lobes and cross polarization are frequency-dependent.

• From the ATMS pitch-over maneuver data, it is found that the contributions of spacecraft radiation through the near-field side lobes are significant and dominate the scan angle dependent features in the ATMS antenna temperatures.

• A theoretical model is developed for the conversion from antenna to sensor brightness temperatures, including the angular dependent terms derived from the pitch-over maneuver data.

\[ \Delta T^{Q_v} = \eta_0 + \eta_1 \cdot \sin^2 \theta \]

\[ \Delta T^{Q_h} = \eta_0 + \eta_1 \cdot \cos^2 \theta \]

Since the near field radiation has contribution to radiance of cold space view and warm load view, it need to be considered in calibration. The correction correction only can be done in full radiance based calibration system

Corrected Two Point Calibration Equation in ARTS

For Vertical Polarization Channel:

\[ R_s = \delta [(R_h - R_c) + \beta_1 (\sin^2 \theta_h - \sin^2 \theta_c)] + R_c + \beta_1 (\sin^2 \theta_s - \sin^2 \theta_c) \]

For Horizontal Polarization Channel:

\[ R_s = \delta [(R_h - R_c) + \beta_1 (\cos^2 \theta_h - \cos^2 \theta_c)] + R_c + \beta_1 (\cos^2 \theta_s - \cos^2 \theta_c) \]

Rs: Calibrated antenna radiance  
Rh: Warm load radiance  
Rc: Cold space radiance (2.73K)  
\( \Theta_h \): Scan angle in warm load position  
\( \Theta_c \): Scan angle in space view position  
\( \Theta_s \): Scan angle in Earth view position of each FOV  
\( \delta \): (Cs - Cc)/(Ch - Cc), with Ch/Cc/Cs are receiver output counts of warm load, cold space and earth view
Coherent Noise Filtering

**Sinc Window Function**

![Sinc Window Function Graph](image)

**Calibrated Tb with and without calibration counts noise filtering**

Based on the frequency spectrum analysis of the receiver output calibration counts, a sinc window function based low-pass filter is developed to effectively remove the high-frequency components (rapid fluctuations) while keep the low-frequency components (gain variations) unchanged.
Physical Modeling For LI Correction of Cold Space Brightness Temperature

- LI happens when $\beta' = \beta - \alpha_I \leq 1.25 \cdot \theta_{3dB}$
- Lunar contamination to the four space view counts are different.
- The increased brightness temperature due to the lunar contamination can be accurately identified and quantified from model.

Brightness temperature increment arising from lunar contamination can be expressed as function of lunar solid angle, antenna response and radiation from the Moon

Space view radiance increment

$$\Delta T_{moon} = G \cdot \Omega \cdot T_{moon}$$

Antenna response function:

$$G = e^{-\frac{(\beta'-\alpha_I)^2}{2\delta^2}}, \text{ with } \delta = \frac{0.5 \cdot \theta_{3dB}}{\sqrt{2 \cdot \log 2}}$$

Weights of the Moon in antenna pattern:

$$\Omega_{moon} = \frac{\pi (r_{moon}/D_{moon})^2}{\int \int G(\theta,\phi)d\theta d\phi}$$

Brightness temperature of the Moon:

$$T_{moon} = 95.21 + 104.63 \cdot (1 - \cos \Theta) + 11.62 \cdot (1 + \cos 2\Theta)$$
Construct a cost function, in which the antenna pattern is used as source and target function, and should be minimized with respect to a set of optimal remapping coefficients

\[ Q_0 = \int \left[ \sum_{i=1}^{n} a_i G_i(\rho) - F(\rho) \right]^2 J(\rho) dA \]

Applying the coefficients to source observations, the resampled observations with expected FOV size can be derived as:

\[ T_B = \sum_{i=1}^{n} a_i T_{Bi} = \int T_B(\rho) \sum_{i=1}^{n} a_i G_i(\rho) dA \]
For channel-01, more details of observation are presented in remapping results, but the results seem more noisy; For channel-16, lost some detail but the noise is decreased.
TDR to SDR Conversion

For conversion from TDR to SDR, corrections to the Earth contamination entering from side-lobe and the near-field contamination from ambient radiation are needed.

- For un-polarized surface and atmosphere, the TDR to SDR conversion is possible with a single polarization measurement.
- For an instrument with a significant cross-polarization spill-over, the conversion can be carried out by using synthetic datasets.

For Quasi-V:

$$R_{b}^{Qv} = \left[ R_{a}^{Qv} - (\eta_{sv}^{vv} + \eta_{sv}^{hv})R_{c} \right] / \left[ \eta_{me}^{vv} + \eta_{se}^{vv} + A^{v}(\eta_{me}^{hv} + \eta_{se}^{hv}) \right]$$

For Quasi-H:

$$R_{b}^{Qh} = \left[ R_{a}^{Qh} - (\eta_{sc}^{hh} + \eta_{sc}^{vh})R_{c} \right] / \left[ \eta_{me}^{hh} + \eta_{se}^{hh} + A^{h}(\eta_{me}^{vh} + \eta_{se}^{vh}) \right]$$

$A^{q} , q = v,h$ is cross polarization correction coefficients.

For the window and near surface channels (i.e., channel 1,2,16), $A^{q}$ can be derived from regression between $R_{b}^{Qv}$ and $R_{b}^{Qh}$

$$R_{b}^{Qv} = A^{h}(\theta)R_{b}^{Qh} \quad R_{b}^{Qh} = A^{v}(\theta)R_{b}^{Qv}$$

For other sounding channels, $A^{q}=1$.

F.Weng et al., 2013, “Calibration of Suomi-National Polar-Orbiting Partnership (NPP) Advanced Technology Microwave Sounder”, JGR (Revised)
Evaluation of ARTS SDR Products

O: ARTS SDR
B: CRTM simulations of ATMS using ECMWF 91-level analysis data
Case: April 19, 2013

O(SDR)- B at Channel 15
Future Works

- Comparison of ARTS products with those from IDPS
- Validation of ARTS products with radiosondes and GPS RO data
- Uses of ARTS data in global and regional NWP
- Reprocess SNPP ATMS data using ARTS
- Test for JPSS-1 ATMS applications