Remapped ATMS Radiance and its Validation for the Suomi NPP Mission

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Introduction

The Cross-track Infrared and Microwave Sensor Suite (CrIMSS) on the Suomi NPP satellite is comprised of the Cross-track Infrared Sounder (CrIS) and the Advanced Technology Microwave Sounder (ATMS). The primary purpose of CrIMSS is to produce measurements of the atmospheric temperature and moisture profiles to support weather forecasting applications. The microwave instrument ATMS provides a stable initialization for the retrieval when only minor cloud obstruction is present, and a backup product when substantial cloud is present which prevents a successful use of infrared data. The synergistic use of CrIS and ATMS measurements requires the footprints of the two instruments to cover nearly identical areas on the Earth's surface. Since the 22 channels of ATMS have different sizes of footprints, as shown in Figure 1, the requirement of a common footprint is met by the production of the remapped ATMS brightness temperature with prescribed footprints as represented by the gray areas in Figure 1.

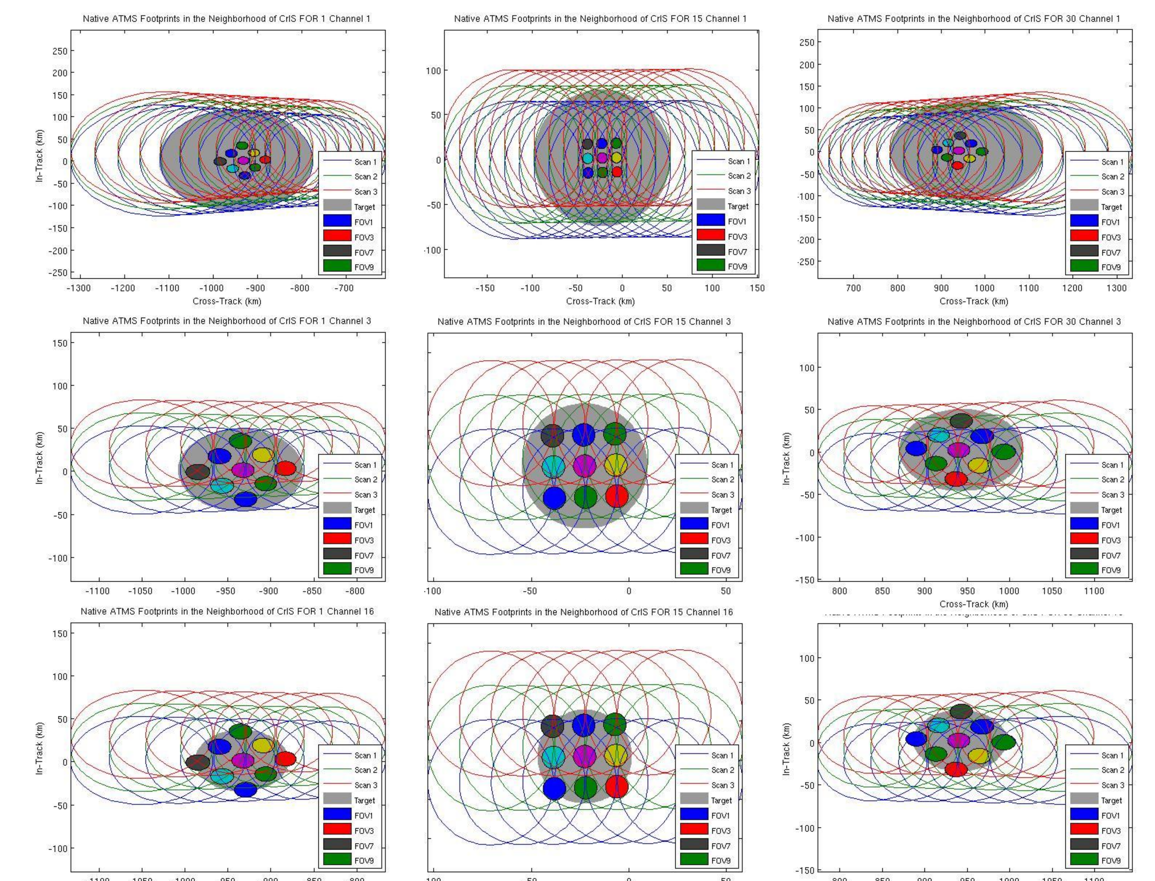

Figure 1. Nominal positions of CrIS and ATMS footprints and the target footprints for the remapped ATMS for channels 1 -2(top row), 3-10 (middle row) and 11-22 (bottom row) and FOR 1 (left column), 15 (middle column) and 30 (right column).

A native ATMS measurement can be written as an inner product between the ATMS gain pattern $g_{FOR,Band}$ projected onto the Earth's surface and the Earth's emission intensity E_{Band}:

$$R_{FOR,Band} = \int_{\Omega} g_{FOR,Band}(x) \cdot E_{Band}(x) \cdot d\Omega. \quad (1)$$

A resampled ATMS radiance is a convex combination of the native ATMS measurements. The coefficients in the linear combination are obtained by the well-known Backus-Gilbert method. This method consists of minimizing the difference between the desired gain pattern for the resampled data and the composite gain pattern for the weighted averaged data plus a regularization term

$$L(w_1, \cdots, w_n) = \gamma \int_{\Omega} \left\| g_{FOR,Band}^{Desired}(x) - \sum_{k=1}^{n} w_k g_{k,Band}^{Native}(x) \right\|^2 d\Omega + \beta \sum_{k=1}^{n} w_k^2, \quad (2)$$

subject to the condition that the sum of w_k is equal to 1. The solution of this optimization problem is given in an explicit form by the standard Lagrange multiplier technique defined as follows:

$$\vec{w} = Z^{-1}\left(\vec{v} + \frac{1}{\vec{u}^T Z^{-1} \vec{u}}\left(1 - \vec{u} Z^{-1} \vec{v}\right) \cdot \vec{u}\right), \qquad Z_{i,j} = \gamma \int_{\Omega} g_{i,Band}^{Native}(x) \cdot g_{j,Band}^{Native}(x) \cdot d\Omega + \delta_{i,j}\beta, \quad (3)$$

$$v_i = \gamma \int_{\Omega} g_{FOR,Band}^{Desired}(x) \cdot g_{j,Band}^{Native}(x) \cdot d\Omega, \qquad u_i = 1.$$

The key in obtaining resampled radiance that accurately represents the projection of the Earth's emission over the desired footprint is a detailed and faithful model for the effective footprint $g_{FOR,Band}$ for a native ATMS measurement.

Modeling of Effective ATMS Footprint

The resampling algorithm used in the generation of the remapped ATMS SDR uses a set of coefficients w_k specific for each CrIS FOR and each ATMS band independent of the orbital position of the satellite. The factors taken into consideration in the modeling of the effective footprints include:

a. Synchronization between CrIS and ATMS scans;
b. Alignments of the two instruments measured prior to NPP-launch;
c. Projections of the antenna pattern for each channel measured during the prelaunch TVAC test, shown in Figure 2, at each FOR position, and
d. The continuous scan mode of the ATMS measurement.

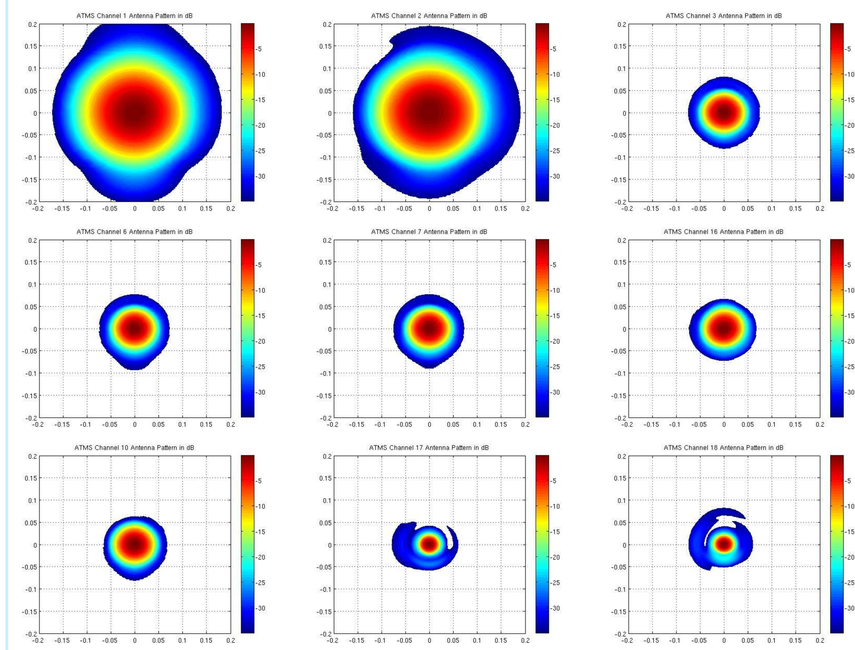

Figure 2. Prelaunch measurements of antenna patterns for 9 ATMS Channels from left to right and top to bottom: 1, 2, 3, 6, 7, 8, 10, 17 and 18.

In fact, due to the continuous scan of the ATMS during the capturing of an Earth scene, the effective footprints are larger in the cross-track direction than the instantaneous projection of the ATMS antenna pattern at any nominal FOR position as shown in Figure 3. On the other hand, the need to have a constant set of resampling coefficients requires us to assume a spherical satellite orbit and a spherical Earth without self-rotation.

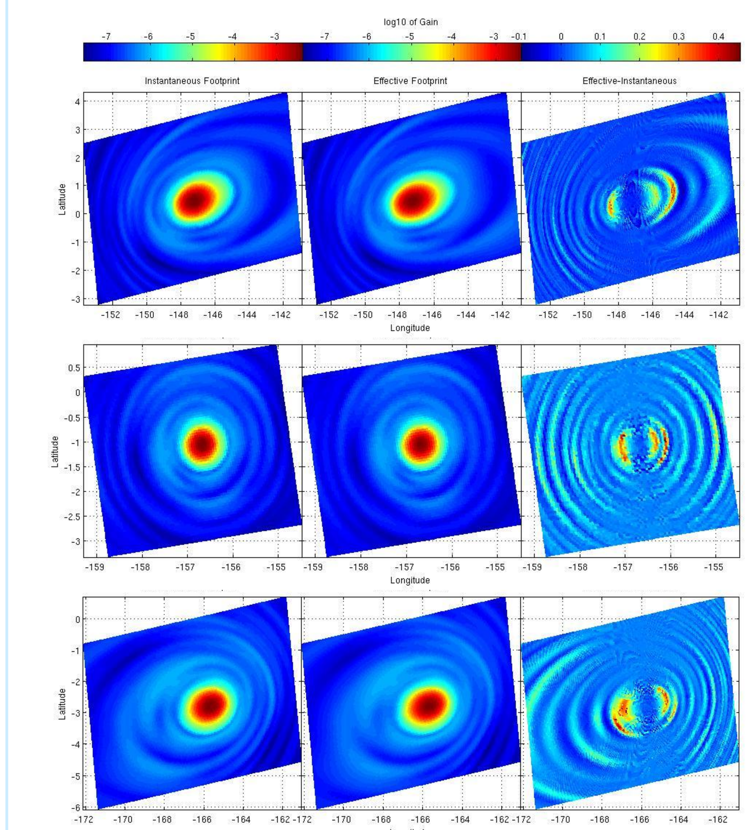

Figure 3. Effects of continuous scan mode on the effective ATMS footprints. The instantaneous footprints (left column) are in general narrower in the scan direction than the effective footprint (middle column) for FORs 1 (top), 15 middle and 30 (bottom). The right column shows the difference in FOR gain patterns between effective and instantaneous footprints.

Validation

A preliminary part of the validation consists of examination of the optimal composite gain pattern in comparison with the desired gain pattern. As shown in Figure 4, the composite gain patterns given by the optimal resampling coefficients provide reasonably accurate representation of the desired gain patterns for all FORs and bands. However, there are still significant differences between the desired and optimal composite gain patterns. In fact, the actual antenna gain does not decrease as rapidly as the desired Gaussian gain pattern when the view angle moves away from the center of a FOR. On the other hand, Figure 4 also demonstrates the necessity of the resampling because the gain pattern of the nearest native ATMS FOR is much poorer representation of the desired gain pattern than the composite gain, especially for channels with small footprints such as channel 17 shown in Figure 4.

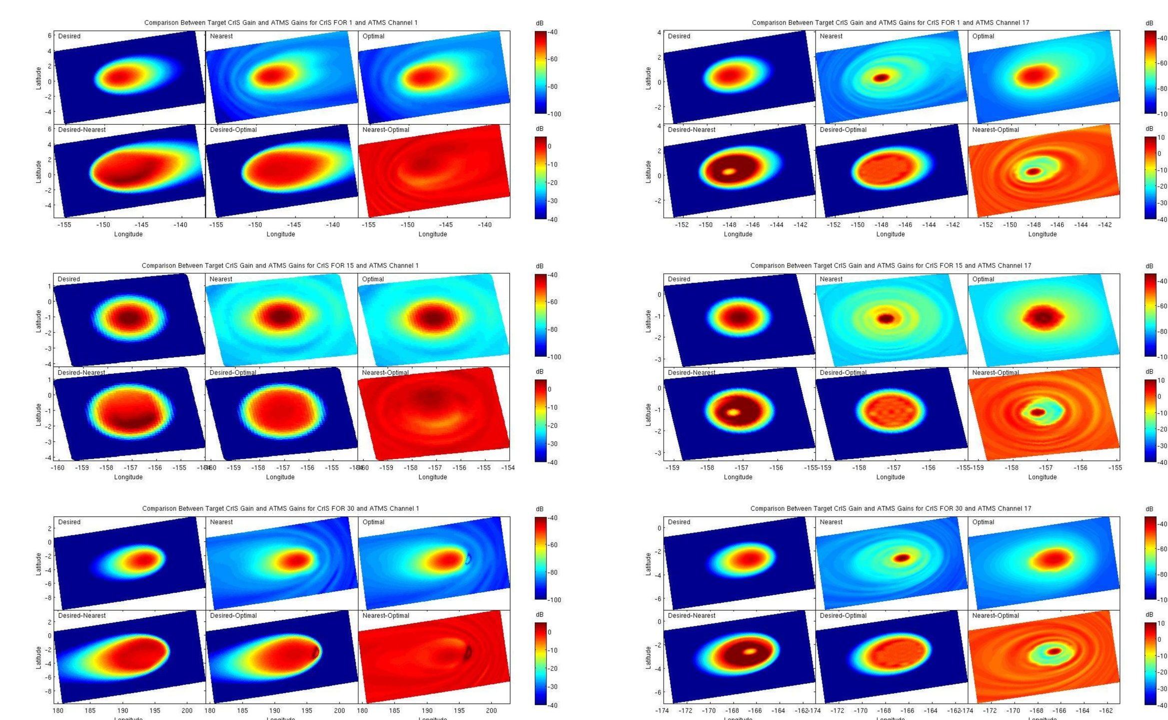

Figure 4. Comparison between desired gain pattern for the remapped ATMS radiances and the native ATMS and optimized composite ATMS gain patterns for ATMS channels 1 (left panel) and 17 (right panel) for FOR 1 (top), 15 (middle) and 30 (bottom).

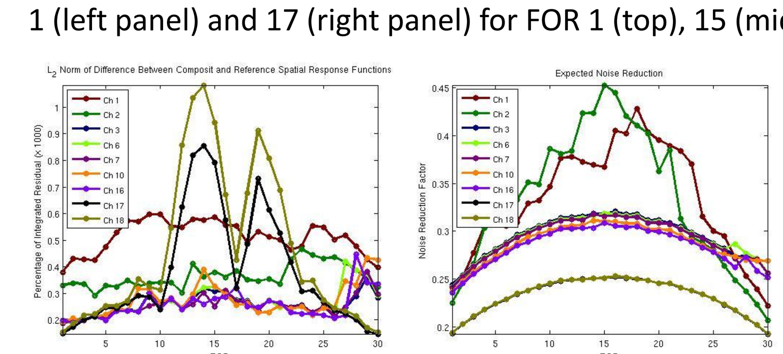

Figure 5. Model predicted mismatch between desired and the optimized remapped ATMS footprint patterns (left) and noise reduction factors (right).

In addition to gain pattern, we have also examined the integrated deviation between the optimal composite and the desired gain patterns, shown in Figure 5, left panel, and the predicted noise reduction factors shown in Figure 5, right panel. Both these quantities are higher for FORs close to nadir (FOR15,16) than FORs near the edges of a scan due to a reduced number of ATMS native FORs used to generate the remapped data.

Following the launch of the Suomi NPP satellite, we have used actual ATMS data to validate the remapped ATMS radiances in two ways. First, we compared remapped SDR to the radiances of the nearest native ATMS radiance as shown in Figure 6. We also examined the biases, shown in Figure 7, and the RMS of the differences between the two sets of radiances, shown in Figure 8. The results show near zero biases and expected levels for RMS differences.

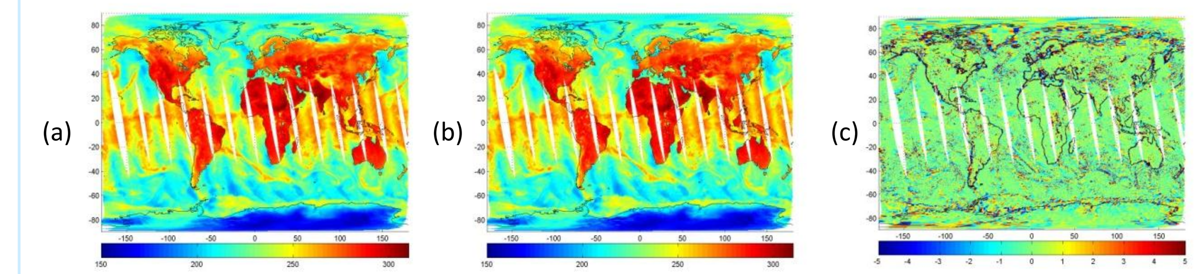

Figure 6. Comparison between the native ATMS brightness temperatures (a) and the resampled brightness temperatures (b) and their differences (c).

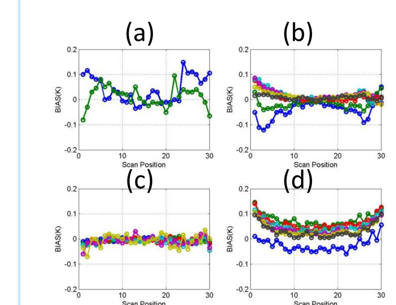

Figure 7. Biases between the native and resampled brightness temperatures of ATMS channels 1-2 (a), 3-9 (b), 10-15 (c) and 16-22 (d)

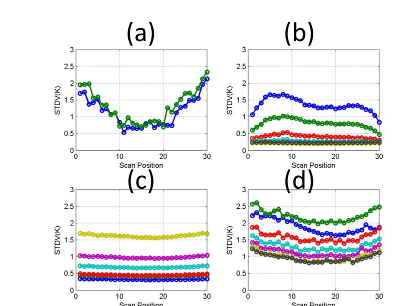

Figure 8. RMS of the differences between the native and resampled brightness temperatures of ATMS channels 1-2 (a), 3-9 (b), 10-15 (c) and 16-22 (d)

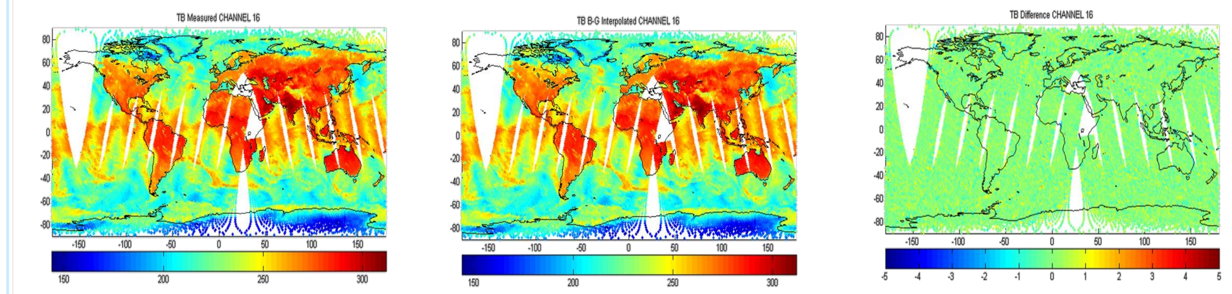

Figure 9. Comparison between the native ATMS brightness temperatures (a) and the resampled brightness temperatures from its neighboring FORs (b) and their differences (c).

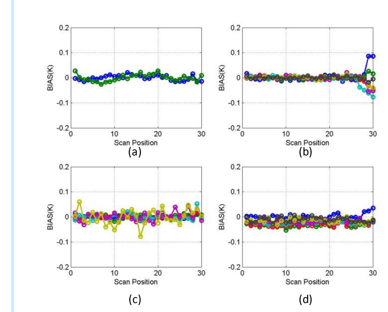

Figure 10. Biases between the native and resampled brightness temperatures using its neighboring FORs of ATMS channels 1-2 (a), 3-9 (b), 10-15 (c) and 16-22 (d)

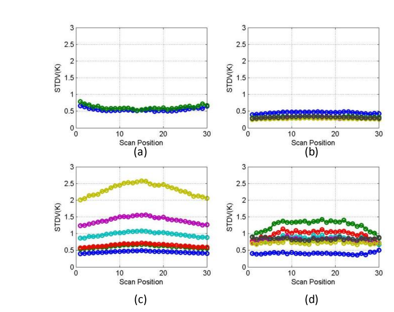

Figure 11. RMS of differences between the native and resampled brightness temperatures using its neighboring FORs of ATMS channels 1-2 (a), 3-9 (b), 10-15 (c) and 16-22 (d)

In a second validation effort, we generated a new set of resampling coefficients using the native ATMS gain pattern nearest to a CrIS FOR as the desired gain pattern and using the nearby ATMS FORs to regenerate the native ATMS data. This approach allows us to validate the basic technique of resampling. As shown in Figures 9-11, the resampled data accurately reproduced the native data with near zero biases and expected noise reduction.

Conclusion

Remapped ATMS SDR provides an accurate representation of microwave radiances with desired gain patterns. The methodology of the resampling has been validated by analyses, as well as, by on-orbit ATMS data. The remapped ATMS data is currently used in the generation of the CrIMSS EDR products.