# Suomi NPP ATMS Status and J1 ATMS Cal/Val Readiness

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# Outline

- **Major Achievements in SNPP ATMS Calibration Science**
  - Radiance calibration
  - TDR to SDR conversion
  - Reflector emission correction
  - Lunar contamination correction
  - TDR remapping
- **SNPP ATMS Instrument Status**
  - Channel noise NEdT
  - Calibration accuracy
  - Long-term gain drift
- **J1 ATMS Ground Test Datasets Processing for PCT**
  - Band correction coefficients from SRF measurements
  - APC coefficients from antenna ground measurements
  - Nonlinearity correction coefficients from TVAC
  - Antenna pointing error and instrument mounting matrix
- **J1 ATMS Post Launch Cal/Val Readiness**
  - ARTS software package for radiance and geometric calibration
  - ACIP software package for ground geolocation accuracy evaluation/correction
  - CRTM/LBL package for calibration bias assessment
  - ISCP software package for inter-satellite cal/val

# ATMS Block2.0 Radiance Calibration Algorithm

*Weng, Fuzhong, and Hu Yang. 2016: Validation of ATMS calibration accuracy using Suomi NPP pitch maneuver observations. Remote Sensing, vol.8, no. 4 (2016): 332*

The following calibration algorithm, which takes into account any nonlinear contribution due to an imperfect square law detector, is employed to convert observed Earth-viewing counts to radiances

$$R_b = R_{b,I} + Q_b \quad ,$$ **W•m$^{-2}$•sr$^{-1}$•Hz$^{-1}$**

where $R_b$ is the scene radiance and $R_{bI}$ and Qb are the Planck radiances corresponding to the linear part and nonlinear part. The linear part can be calculated from radiance of calibration targets Rw,Rc and receiver output counts Cw,Cc and Cs

$$R_{b,I} = R_w + G_b^{-1}(C_s - C_w)$$

$$G_b = \frac{C_w - C_c}{R_w - R_c}$$

The nonlinear part can be calculated from 'u' parameters following equation below

$$Q_b = Q^{\max}[4 \cdot (x - 0.5)^2 - 1]$$
$$Q^{\max} = \frac{1}{4} \cdot \mu \cdot (R_w - R_c)^2$$
$$x = \frac{C_s - C_c}{C_w - C_c}$$

"μ" is a function of instrument temperature and can be determined from TVAC test

$$\mu = aT_{shelf}^2 + bT_{shelf} + c$$

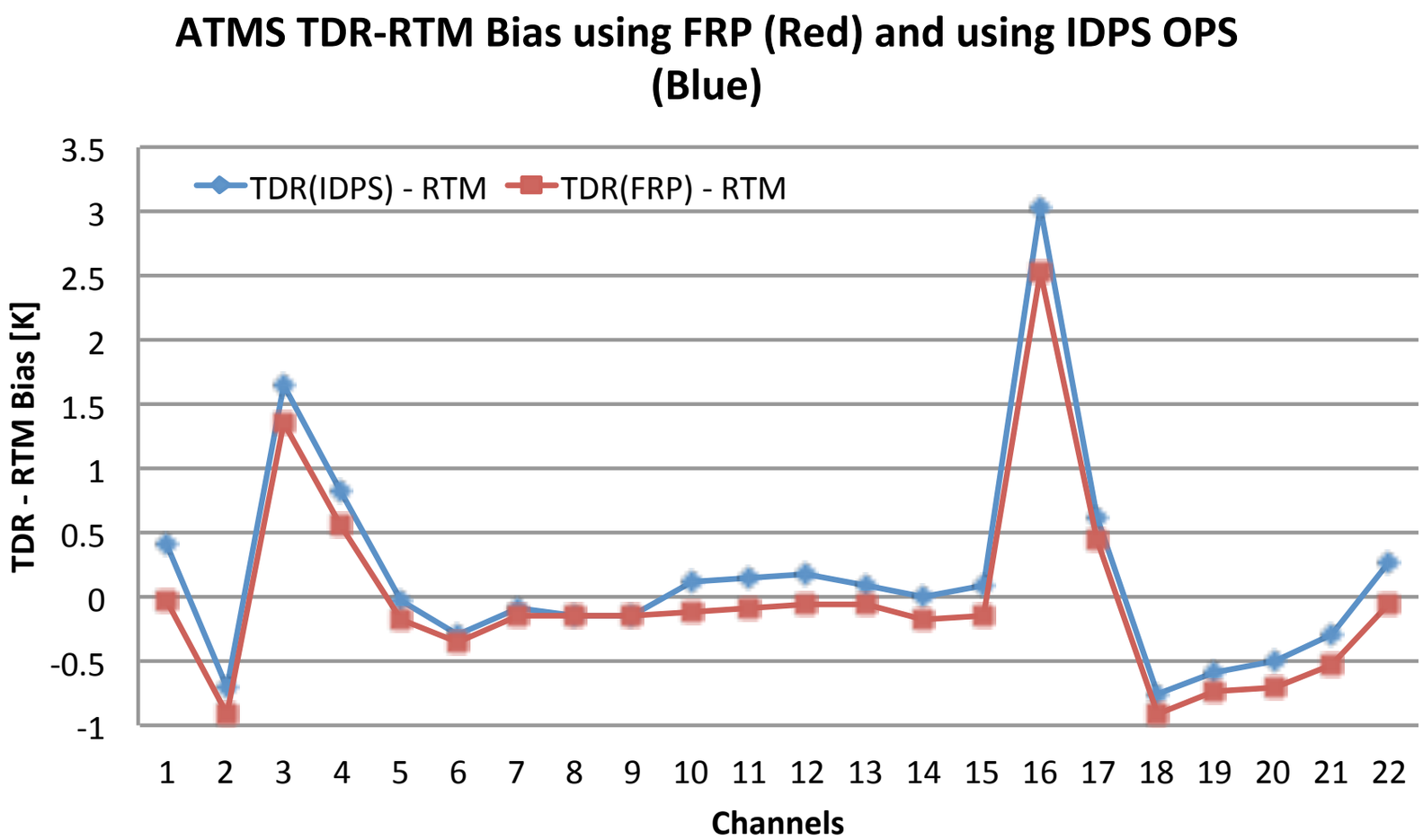
The Radiance can then be transferred to temperature by using inverse Planck function

$$T_b = \frac{B^{-1}(R_b) - C_1}{C_0}$$

Where B is Planck function, C0 and C1 are band correction coefficients, which can be derived by using SRF measurements for each channel

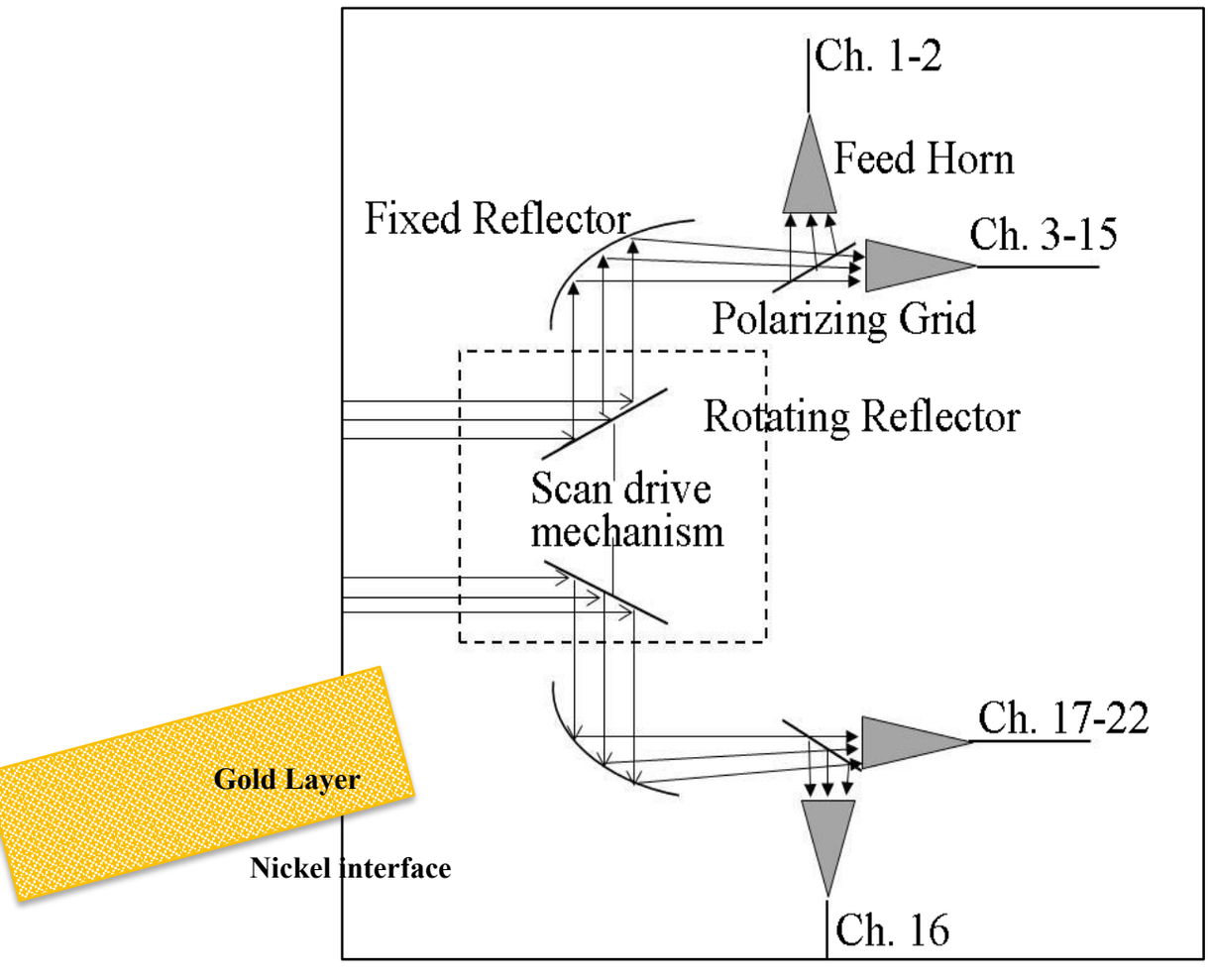
# Global Mean TDR-RTM Bias

- Calibrated scene temperature from ADL-Full radiance are consistently lower than IDPS at all ATMS channels
- Major cause of the difference is due to the incorrect application of nonlinearity correction in IDPS



# Reflector Emission Correction

*Hu Yang, Fuzhong Weng, Kent Anderson, 2016: Estimation of ATMS antenna emission from cold space observations, IEEE Transactions on Geoscience and Remote Sensing,Vol.54, No.8, PP. 4479-4484*




At an incident angle of 45o, a corresponding relation exists between V/H polarization reflection coefficients of flat reflector:

$$r_h^2 = r_v$$

$$e_v = 1 - r_v,\ e_h = 1 - r_h$$

From the Mueller matrix of reflection and transmission at 45° angle for a non-lossless, bulk-material polarized rotating reflector, we derived a full vector expression for reflected radiation from calibration target (non-polarized)

$$\begin{bmatrix} R_{Qv} \\ R_{Qh} \\ R_{Q3} \\ R_{Q4} \end{bmatrix} = \begin{bmatrix} R_s + \underbrace{e_h(R_{rfl} - R_s)}_{\beta_0} + \underbrace{[(R_{rfl} - R_s)(e_v - e_h)]}_{\beta_1} sin^2\theta \\ R_s + e_h(R_{rfl} - R_s) + [(R_{rfl} - R_s)(e_v - e_h)] cos^2\theta \\ (R_{rfl} - R_s) \cdot e_h \cdot (1 - e_h) \cdot sin2\theta \\ 0 \end{bmatrix}$$

# SDR Conversion Algorithm

*Fuzhong Weng, Hu Yang, Xiaolei Zou, 2012: On Convertibility From Antenna to Sensor Brightness Temperature for ATMS, IEEE Geoscience and Remote sensing Letters,, Vol.99, pp 1-5*

***For Quasi-V :***

$$T_b^{Qv} = [T_a^{Qv} - (\eta_{sc}^{vv} + \eta_{sc}^{hv})T_c - S_a^{Qv}] / [\eta_{me}^{vv} + \eta_{se}^{vv} + A^v(\eta_{me}^{hv} + \eta_{se}^{hv})]$$

***For Quasi-H:***

$$T_b^{Qh} = [T_a^{Qh} - (\eta_{sc}^{hh} + \eta_{sc}^{vh})T_c - S_a^{Qh}] / [\eta_{me}^{hh} + \eta_{se}^{hh} + A^h(\eta_{me}^{vh} + \eta_{se}^{vh})]$$

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

For window and near-surface channels (i.e., ch.1-5 and 16)

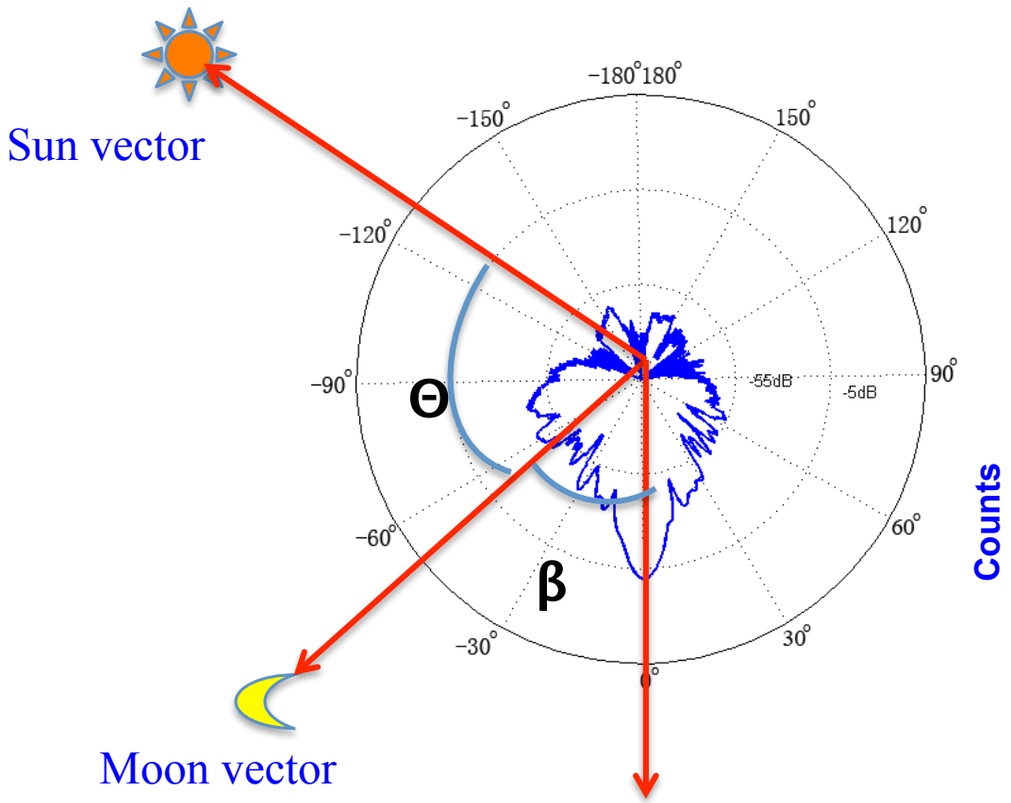
$A^q$ can be obtained from linear regression between $T_b^{Qv}$ and $T_b^{Qh}$

$$T_b^{Qv} = A^h(\theta)T_b^{Qh} \qquad T_b^{Qh} = A^v(\theta)T_b^{Qv}$$

For atmosphere opaque channels, $A^q = 1$

# Lunar Contamination Correction

*Hu Yang* and Fuzhong Weng, **2016**, "On-Orbit ATMS Lunar Contamination Corrections", IEEE Transactions on Geoscience and Remote Sensing, Vol. 54 Issue: 4, page(s): 1-7




- LI happens when $\beta' = \beta - \alpha_l \leq 1.25 \cdot \theta_{3dB}$
- 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**

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

**Antenna response function:**

$$G = e^{\frac{-(\beta' - \alpha_0)^2}{2\delta^2}}, \ with\ \delta = \frac{0.5 \cdot \theta_{3dB}}{\sqrt{2 \cdot log2}}$$

**Weights of the Moon in antenna pattern:**

$$\Omega_{moon} = \frac{\pi\left(\frac{r_{moon}}{D_{moon}}\right)^2}{\iint G(\theta,\varphi)d\theta d\varphi}$$

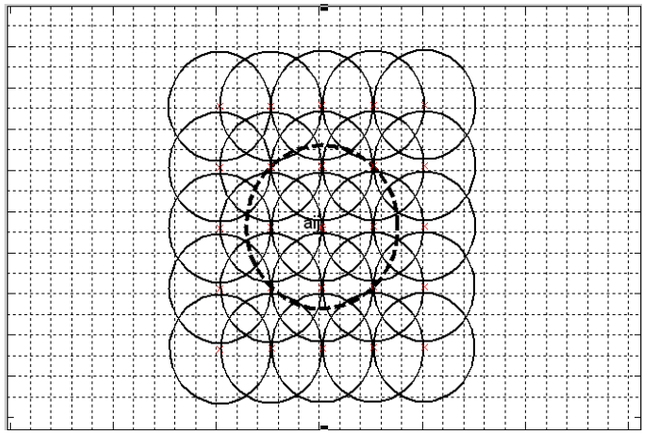
**Brightness temperature of the Moon**

$$TB_{moon} = a_0(f) + a_1(f)\cos(\varphi - 45^o)$$

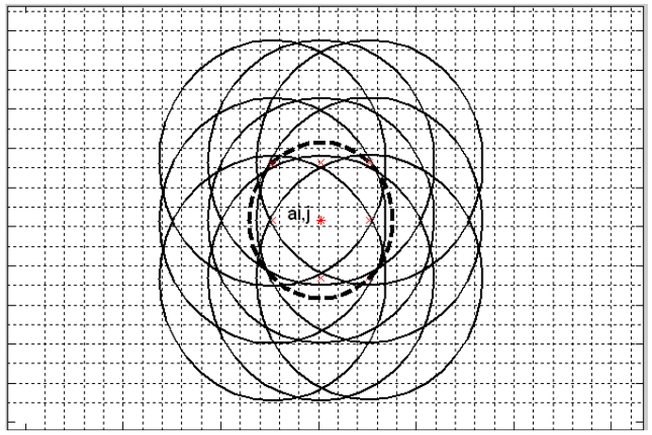
# TDR Remapping

*Yang, H., Zou, X, **2014**. Optimal ATMS remapping algorithm for climate research. Geoscience and Remote Sensing, IEEE Transactions on Geoscience and Remote Sensing, 52(11), 7290-7296*

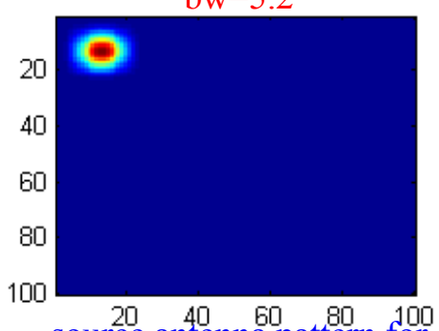
Resolution Reduction



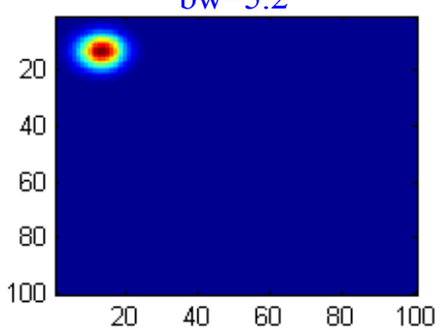

Resolution Enhancement



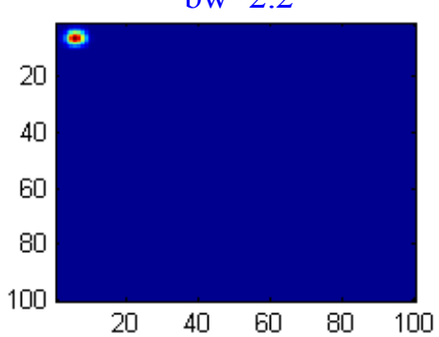

Rebuilt antenna pattern for bw=5.2

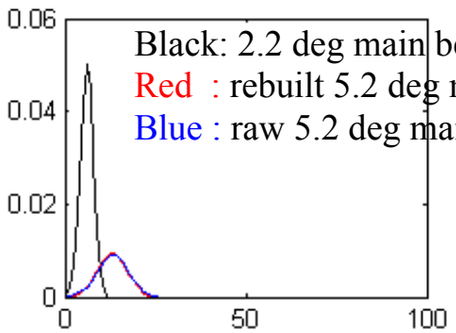



target antenna pattern for bw=5.2




source antenna pattern for bw=2.2




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

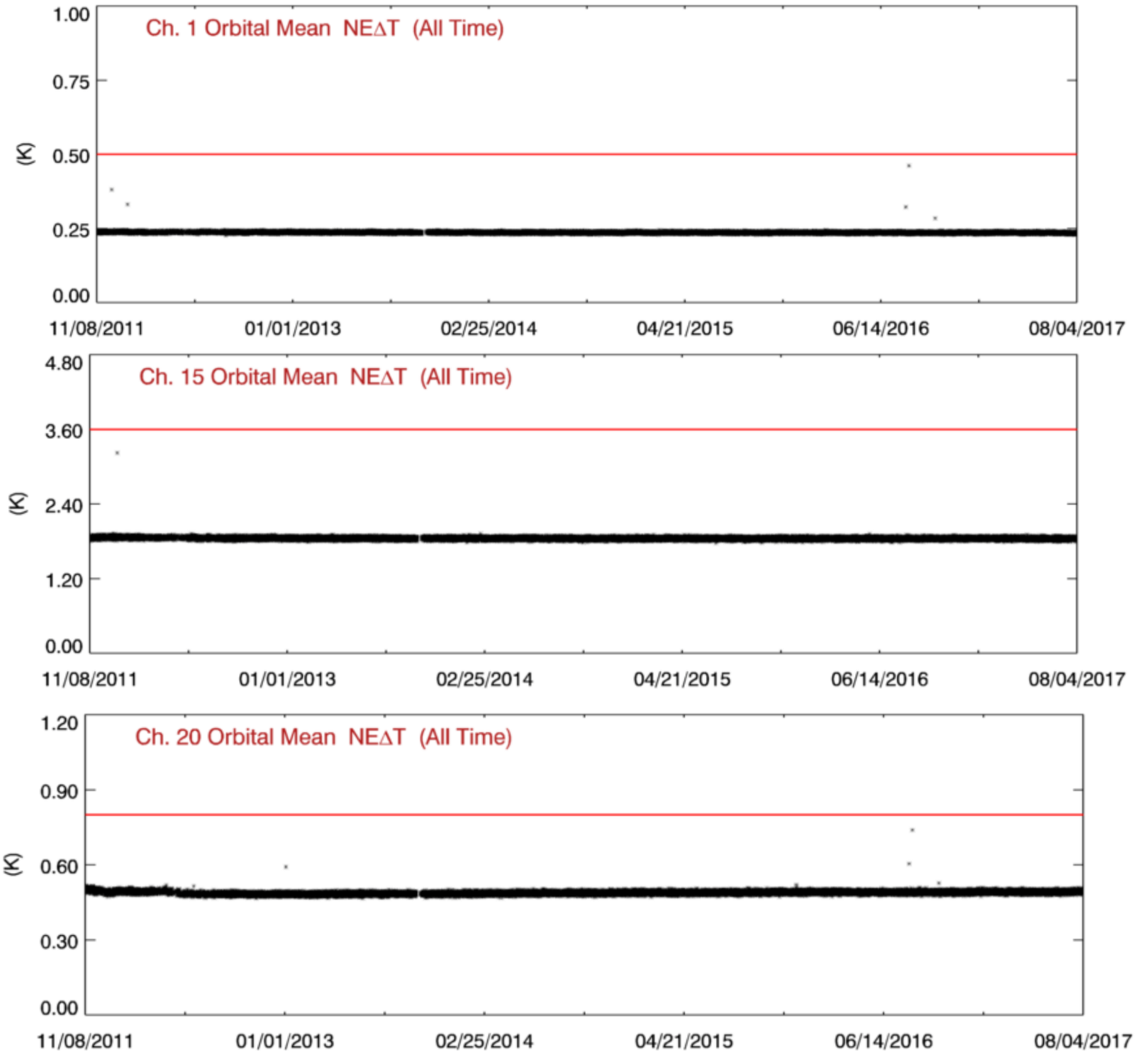
$$Q_0 = \int \left[ \sum_{i=1}^{n} a_i G_i(\rho) - F(\rho) \right]^2 J(\rho) dA$$

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

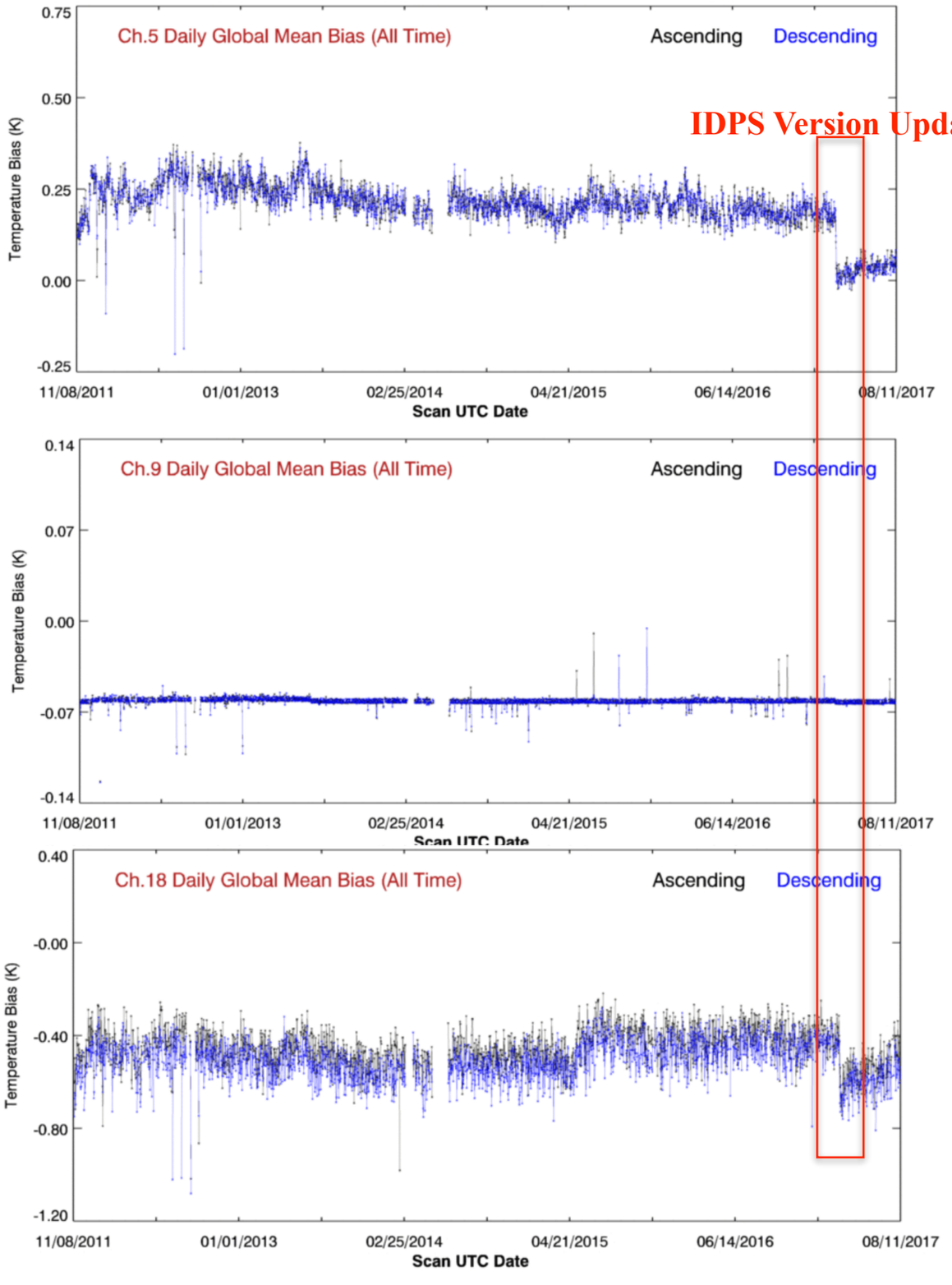
$$T_B = \sum_{i=1}^{n} a_i \overline{T_{Bi}} = \int T_B(\rho) \sum_{i=1}^{n} a_i G_i(\rho) dA$$

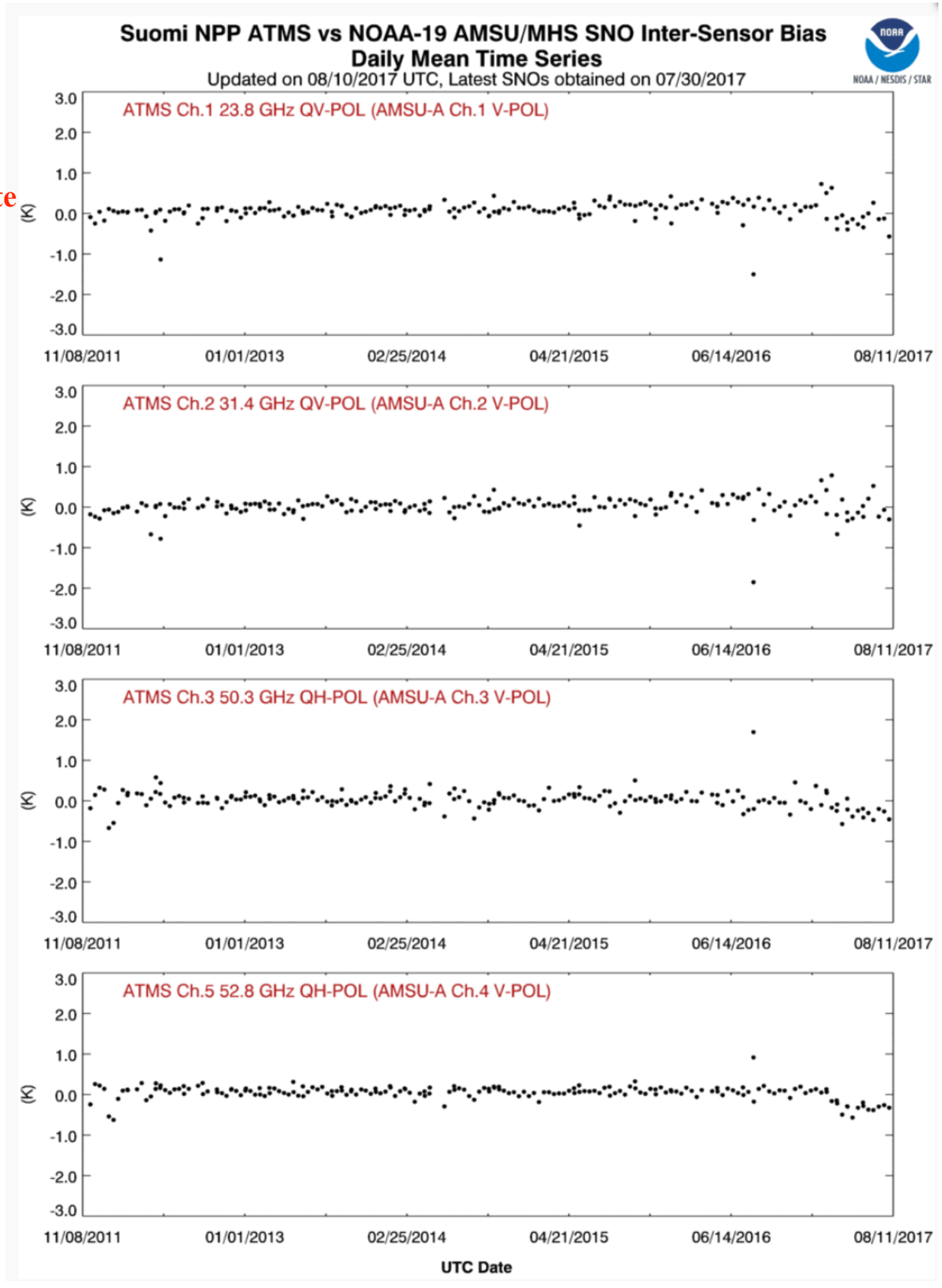
# SNPP ATMS Status—NEdT

- Warm load and cold sky observations are used to calculate on-orbit instrument NEdT
- Instrument performance is stable, channel noise is kept in a lower level



# SNPP ATMS Status—Calibration Accuracy



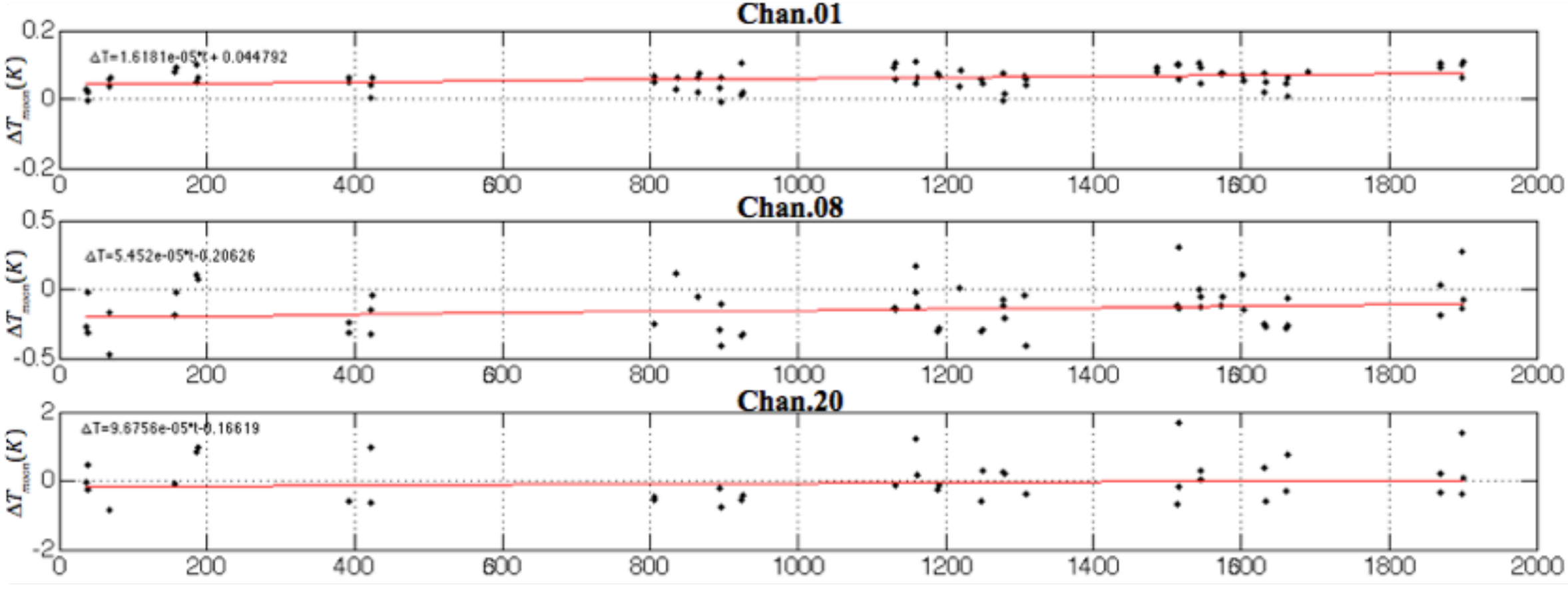
# SNPP ATMS Status—Long-Term Calibration Stability

*Hu Yang and Fuzhong Weng, 2017, Assessing Calibration Stability Using Moon Observations from microwave instruments, IGARSS 2017*

- Radiation from Moon's disk was used as reference to evaluate ATMS life-time calibration stability from December 03, 2011 to January 13, 2017. Panels from top to bottom are variation of daily average for channel 1, 8, and 20.

- The linear fitting line of verses days passed after launch was also presented. It shows that for ATMS, the observed lunar Tb is highly consistent with reference lunar Tb, with a mean bias of less than 0.5K.

- SNPP ATMS shows a highly stable calibration status after 6 years on-orbit operation, with less than $10^{-5}$K / day drift magnitude. Similar results can be derived for other channels.



# J1 ATMS Ground Test Datasets Processing—SRF

- J1 ATMS channel 1-17 receiver bandpass characteristics was analyzed by using SRF measurements provided by NASA
- Real measured SRFs were used to generate band correction coefficients for channel 1-17, boxcar assumption was used for other channels without measurements
- J1 ATMS band correction coefficients were generated for PCT update

| Chan. | f0 | a | b |
|---|---|---|---|
| 1 | 2.37954E+10 | -2.01700E-05 | 1.00001E+00 |
| 2 | 3.13952E+10 | -1.05200E-05 | 1.00000E+00 |
| 3 | 5.03019E+10 | -3.09000E-06 | 1.00000E+00 |
| 4 | 5.17558E+10 | -1.50100E-05 | 1.00000E+00 |
| 5 | 5.27990E+10 | -1.53600E-05 | 1.00000E+00 |
| 6 | 5.35819E+10 | -1.95200E-05 | 1.00001E+00 |
| 7 | 5.44045E+10 | -1.52100E-05 | 1.00000E+00 |
| 8 | 5.49383E+10 | -1.54900E-05 | 1.00000E+00 |
| 9 | 5.55005E+10 | -9.31000E-06 | 1.00000E+00 |
| 10 | 5.72939E+10 | -1.03500E-05 | 1.00000E+00 |
| 11 | 5.72898E+10 | -5.72000E-05 | 1.00001E+00 |
| 12 | 5.73286E+10 | -1.21220E-04 | 1.00003E+00 |
| 13 | 5.73462E+10 | -1.22840E-04 | 1.00003E+00 |
| 14 | 5.73239E+10 | -1.22700E-04 | 1.00003E+00 |
| 15 | 5.72782E+10 | -1.24470E-04 | 1.00003E+00 |
| 16 | 8.80971E+10 | -2.34710E-04 | 1.00004E+00 |
| 17 | 1.65493E+11 | -3.47710E-04 | 1.00003E+00 |
| 18 | 1.83310E+11 | -1.84621E-02 | 1.00146E+00 |
| 19 | 1.83310E+11 | -7.61881E-03 | 1.00061E+00 |
| 20 | 1.83310E+11 | -3.32909E-03 | 1.00027E+00 |
| 21 | 1.83310E+11 | -1.15156E-03 | 1.00009E+00 |
| 22 | 1.83310E+11 | -3.53080E-04 | 1.00003E+00 |

# J1 ATMS Ground Test Datasets Processing—Antenna Pattern

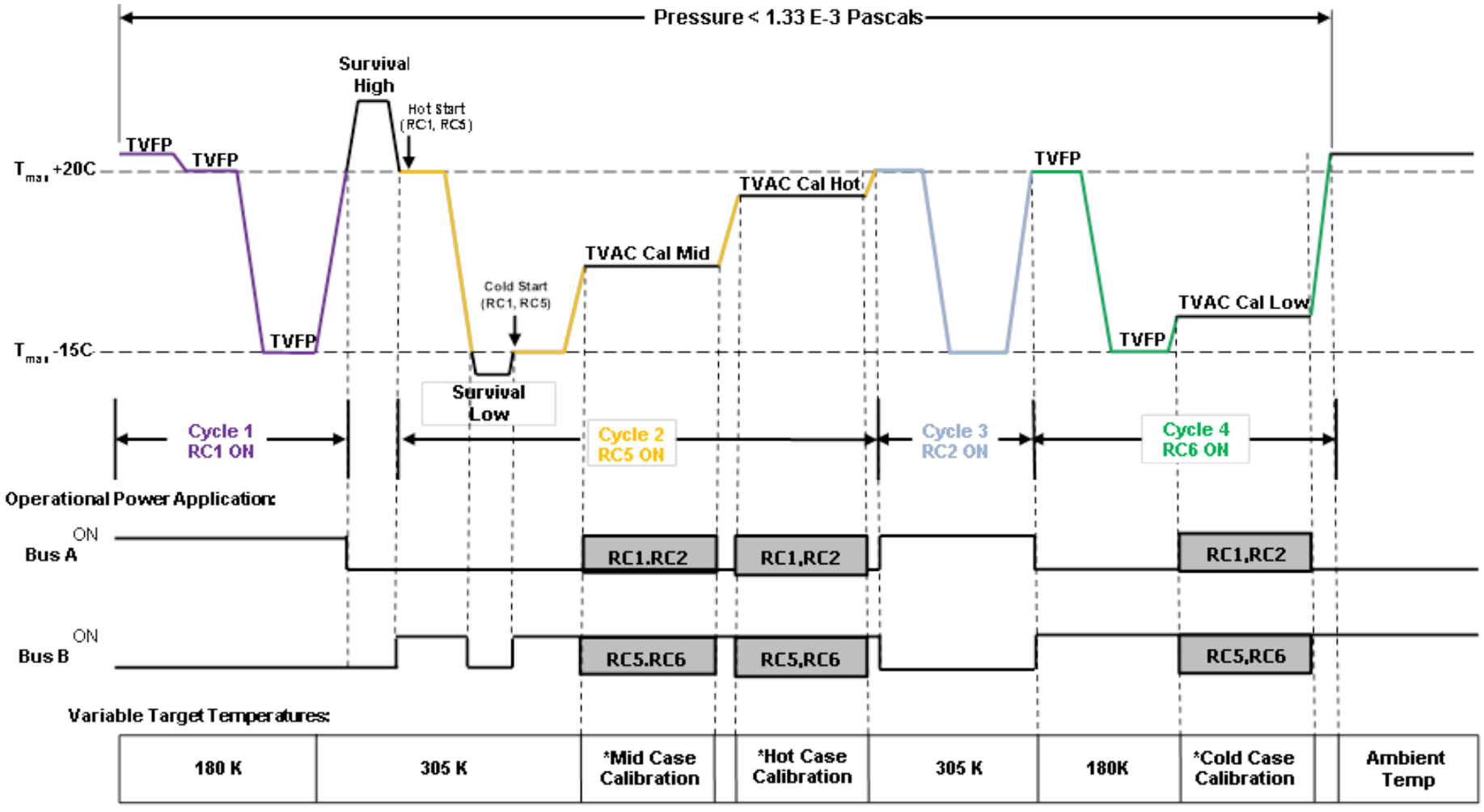
## APC Coefficients at Nadir (FOV 49)

| Chan | co-pol coef. | x-pol coef. | spillover coef. |
|---|---|---|---|
| 1 | 0.982 | 0.014 | 0.003 |
| 2 | 0.987 | 0.010 | 0.003 |
| 3 | 0.982 | 0.015 | 0.002 |
| 4 | 0.984 | 0.014 | 0.002 |
| 5 | 0.983 | 0.014 | 0.002 |
| 6 | 0.985 | 0.013 | 0.002 |
| 7 | 0.985 | 0.013 | 0.002 |
| 8 | 0.985 | 0.012 | 0.002 |
| 9 | 0.985 | 0.012 | 0.002 |
| 10-15 | 0.987 | 0.011 | 0.002 |
| 16 | 0.949 | 0.048 | 0.003 |
| 17 | 0.946 | 0.050 | 0.002 |
| 18-19 | 0.953 | 0.042 | 0.002 |
| 20-22 | 0.954 | 0.040 | 0.002 |

- Ground measured J1 ATMS antenna pattern datasets was analyzed and compared with NPP ATMS
- Except for J1 ATMS K band, beam width of J1 ATMS is consistent with NPP and meet the requirements
- G band antenna beam efficiency of J1 ATMS is much higher than NPP measurement results
- Space view Earth side lobe contamination correction term calculated from J1 antenna pattern is trustworthy and can be applied to on-orbit calibration, while the side lobe for NPP ATMS need to be reevaluated
- Antenna pattern correction coefficients are calculated for each of 96 FOVs, cross polarization is high in W and G bands

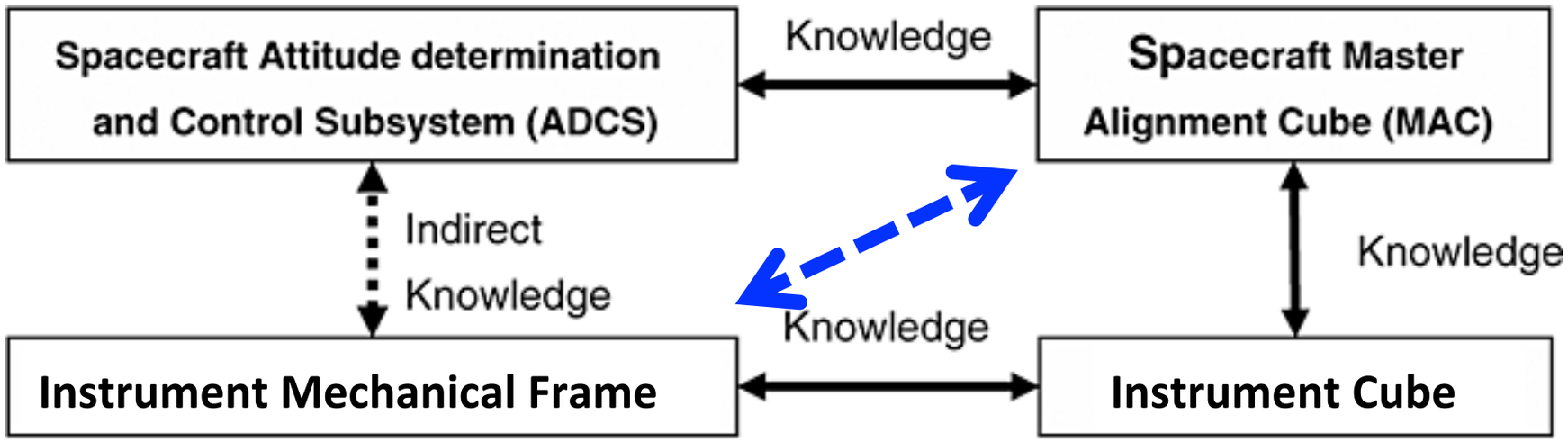
# J1 ATMS Ground Test Datasets Processing—TVAC

- Instrument performance at CPT Mid/Hot/Low was studied by using calibration cycle test and pointing&staring test datasets
- Low frequency spike were not obvious in channel 18 and 19
- Channel correction between channel 18 and 19 still exist
- Striping noise is about the same level with 2015 TVAC test
- Channel NEdT meet the requirement
- Maximum calibration accuracy (TVAC) is 0.3K for all channels and RCs after reflector correction
- There is no improvement in ATMS nonlinearity after rework
- Calibration parameters from TVAC are need to be calculated to conform to Block2.0 radiance algorithm
- Nonlinear parameter "μ" was modeled as a function of instrument temperature and has been updated to PCT



# J1 ATMS Ground Test Datasets Processing—Mounting Matrix

- All measurements used in computation are from Ball Systems Engineering Report: DOC NO. 2463159
- All reported angles are XYZ Fixed angles, also known as instantaneous angles
- Need to build transformation matrix based on instantaneous angles instead of Euler angles
- All computation results are need to be updated by using final measurements




**Instrument Cube to IMF: Rx, Ry, Rz**
**Instrument Cube to MAC: Rx, Ry, Rz**

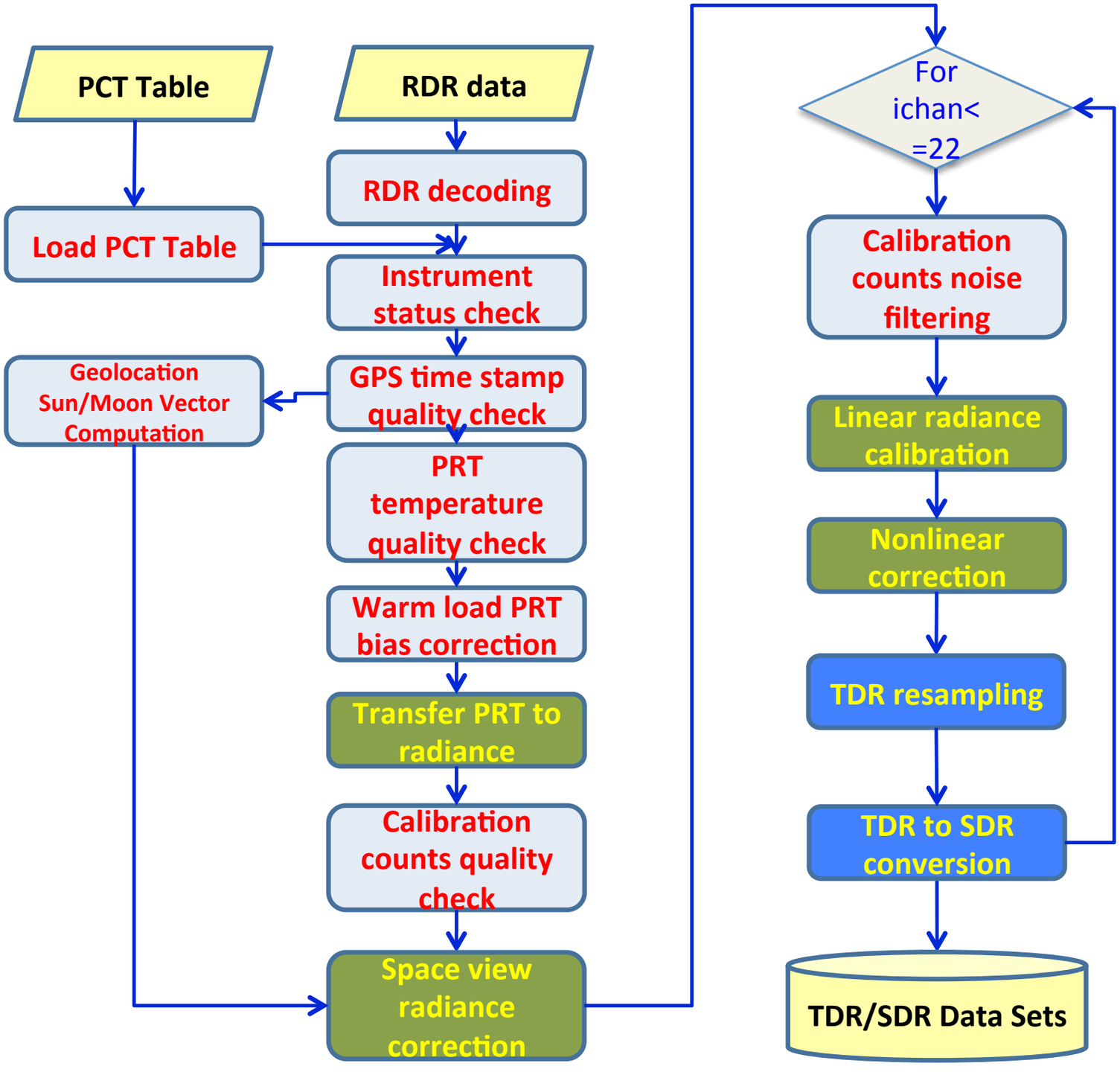
→ **Instrument IMF to MAC: Rx, Ry, Rz**

**ADCS to MAC: (all the instrument share the same value)**
**Rx', Ry', Rz' → (41, -601, -241-50) (Table 3+4)**

IMF to ADCS: **Transpose($T_{ADCS2Mac}$ (Rx', Ry', Rz')) * $T_{imf2mac}$ (Rx, Ry, Rz) = $T_{inst2spc}$**

# J1 ATMS Post Launch Cal/Val Readiness

## — ARTS software package for radiance and geometric calibration



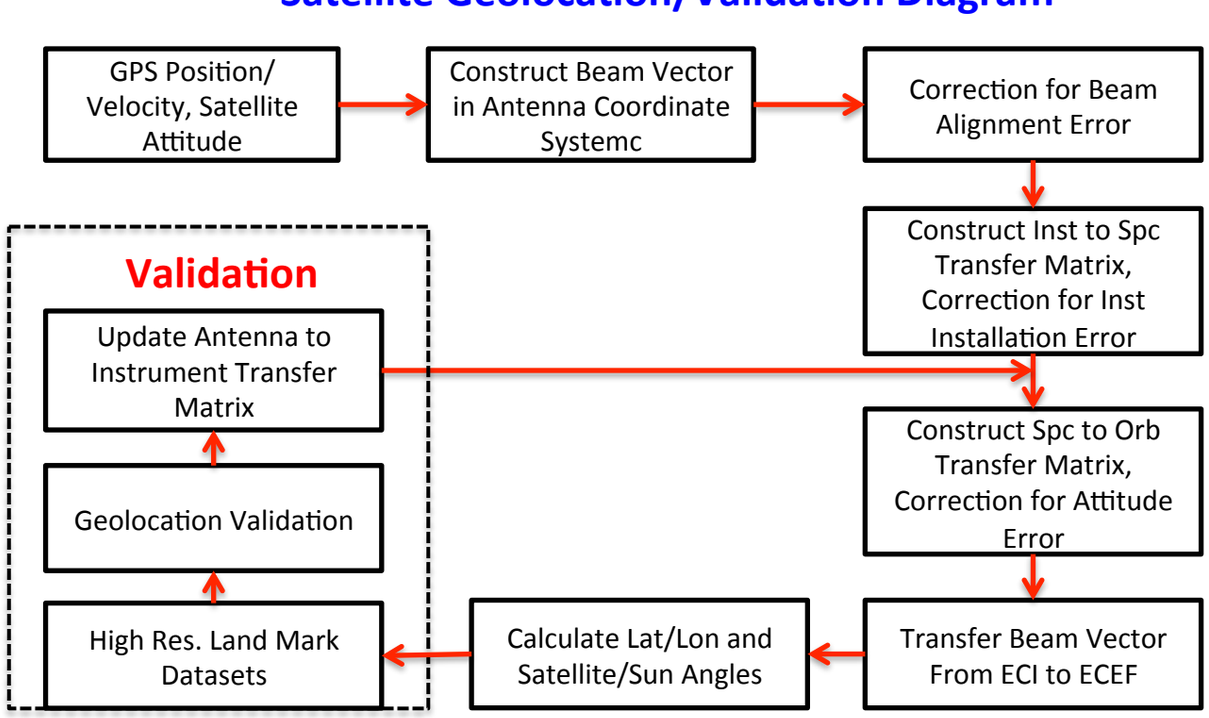

- ARTS is a radiance calibration software package for microwave radiometers developed in NOAA
- ARTS software is developed based on newest study results from SNPP ATMS. Its baseline calibration algorithm is identical to IDPS
- ARTS is module based system and flexible to be modified, new algorithm of calibration science can be easily integrated into the software
- Part of algorithm tested in ARTS has been implemented in IDPS. It can be used as testbed for current and future operational ATMS calibration system improvements

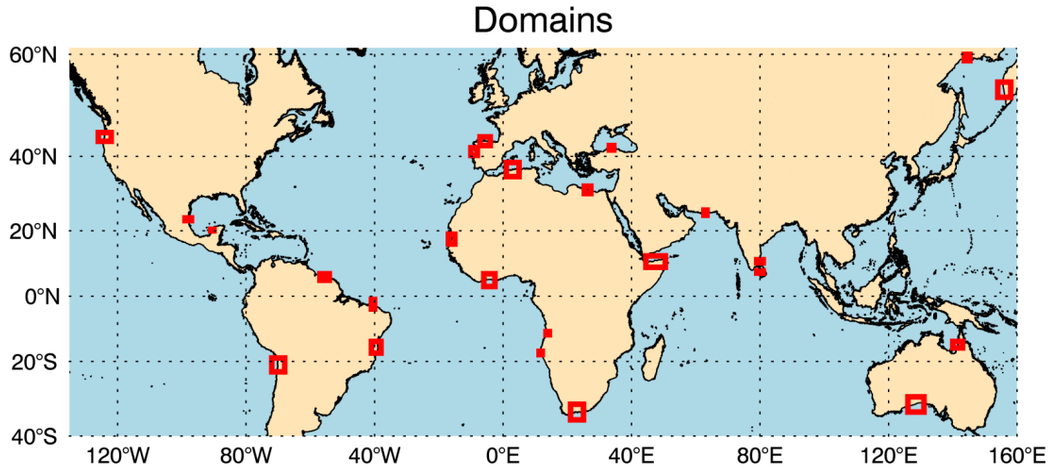
# J1 ATMS Post Launch Cal/Val Readiness

## — CIPSD software package for ground geolocation accuracy evaluation/correction

• Separate-domain technique is developed to obtain coastline inflection point from globally distributed 26 regions with coastlines parallel or vertical to ATMS scan directions
• Math model connecting boresight pointing error with ground geolocation error is connect SNPP ATMS ground geolocation error with ground measured pre-launch instrument pointing error
• New geolocation correction matrix can be build up from retrieved Euler angles and updated to IDPS geolocation module

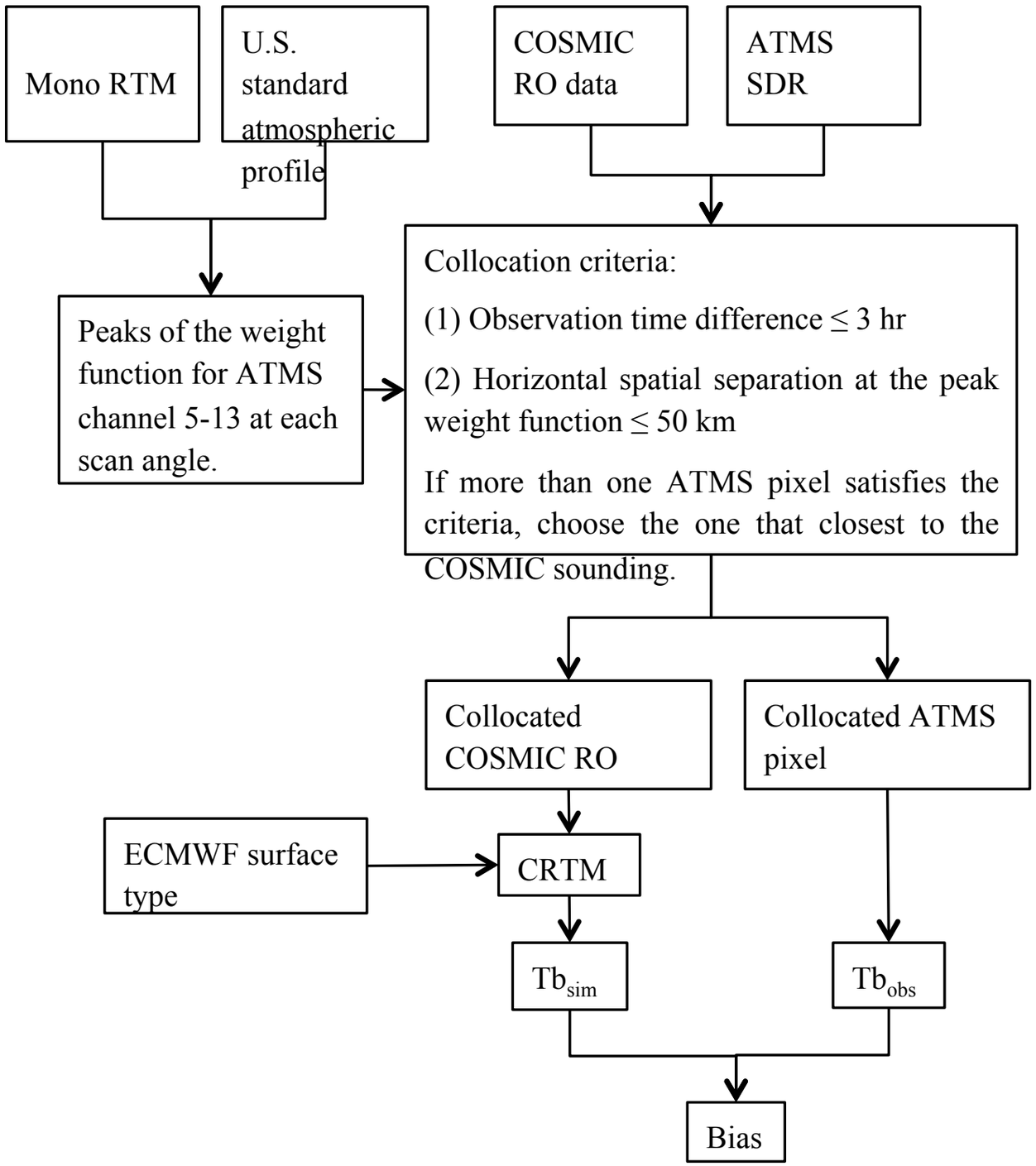
**Satellite Geolocation/Validation Diagram**



# J1 ATMS Post Launch Cal/Val Readiness

## —— RTM-GPSRO package for calibration bias assessment using GPS RO

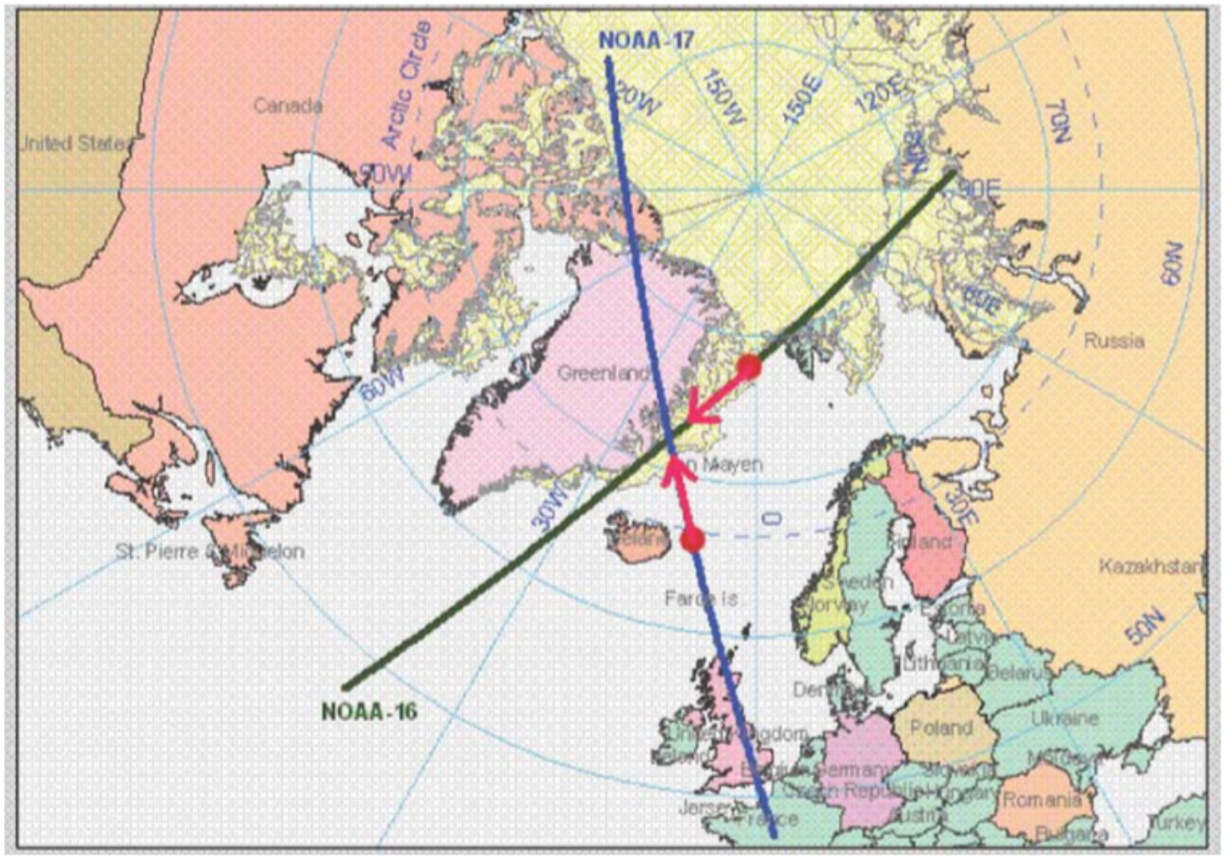



- RTM simulation with GPS RO profile as inputs can be taken as reference to evaluate calibration accuracy of ATMS channel 5-13
- Software package has been developed for GPS RO colocation and simulation
- Determine weighting height of channel 5-13 from MonoRTM simulations
- Spatial and temporal Colocation of GPS RO profiles from COSMIC with ATMS observations
- Obtain O-B feature by comparing CRTM simulation with ATMS TDRs

# J1 ATMS Post Launch Cal/Val Readiness

## —— ISCP software package for inter-satellite cal/val

- Mainly focus on inter-calibration between SNPP and J1 ATMS
- Validate TVAC derived nonlinearity parameters




- Collect collocated SNPP and J1 ATMS observations
- Perform linear calibration for J1 ATMS and SNPP ATMS
- Calculate Ta difference between linear calibrated J1 and fully calibrated SNPP ATMS
- The nonlinearity parameters then can be obtained from equation below:

$$\Delta T = (T_{\mathrm{AL},K} - T_{\mathrm{AL},J}) + (\mu_K Z_K - \mu_J Z_J)$$

$$Z = S^2 (C_S - C_C)(C_S - C_W)$$

# Conclusions and Future Work

- On-orbit performance of SNPP ATMS is still very stable, no degradation in calibration accuracy and long-term drift is below $10^{-5}$K /day

- PCT table for J1 ATMS ground processing system has been updated by using latest ground measurements

- Software packages and analysis tools have been developed in NOAA SDR team and ready for use in J1 post-launch cal/val activity

- Future work will focus on tasks listed on NOAA post launch cal/val plan