Introduction of Advanced Radiance Transformation System (ARTS) Software Package For Space-borne Microwave Instruments

Hu(Tiger) Yang
CISESS, University of Maryland

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Documents Supporting for ARTS Calibration Algorithm

Calibration Algorithm

- H. Yang et al., "ATMS Radiance Data Products Calibration and Evaluation," in IEEE Transactions on Geoscience and Remote Sensing, vol. 60, pp. 1-11, 2022, Art no. 5302211, doi: 10.1109/TGRS.2021.3123576.
- H. Yang et al., "On Study of Error Sources in Microwave Thermal Vacuum Non-Linearity Test and on-Orbit Verification," IGARSS 2020 - 2020 IEEE International Geoscience and Remote Sensing Symposium, 2020, pp. 6449-6452, doi: 10.1109/IGARSS39084.2020.9324629.
- J. X. Yang and H. Yang, "A New Algorithm for Determining the Noise Equivalent Delta Temperature of In-Orbit Microwave Radiometers," in IEEE Transactions on Geoscience and Remote Sensing, vol. 60, pp. 1-11, 2022, Art no. 5301611, doi: 10.1109/TGRS.2021.3097594.
- Fuzhong Weng, Xiaolei Zou, Ninghai Sun, Hu Yang, Xiang Wang, Lin Lin, Miao Tian, and Kent Anderson, 2013, "Calibration of Suomi National Polar-Orbiting Partnership (NPP) Advanced Technology Microwave Sounder (ATMS) ", Journal of Geophysical Research, Vol.118, No.19, PP. 11,187~11,200
- Weng, F. and Yang, H., 2016. Validation of ATMS calibration accuracy using Suomi NPP pitch maneuver observations. Remote Sensing, 8(4), p.332

Antenna Correction

- Hu Yang and Fuzhong Weng, Kent Anderson, 2016, "Estimation of ATMS Antenna Emission from Cold Space Observations", , IEEE Geoscience and Remote sensing, 10.1109/TGRS.2016.2542526"
- Fuzhong Weng, Hu Yang, Xiaolei Zou,2013, "On Convertibility From Antenna to Sensor Brightness Temperature for ATMS", IEEE Geoscience and Remote sensing Letters, 2012, Vol.99, pp 1-5

Remapping SDR

- Hu Yang and Xiaolei 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.

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

Vicarious calibration and Long-term stability Monitoring

- Hu Yang, Ninghai Sun, Kent Anderson, Quanhua Liu, Ed Kim, 2018, "Developing vicarious calibration for microwave sounding instruments using lunar radiation", EEE Transactions on Geoscience and Remote Sensing
- H. Yang, "Millimeter Lunar Microwave Radiance: Model Simulation and Satellite Observations," 2021 IEEE International Geoscience and Remote Sensing Symposium IGARSS, 2021, pp. 7704-7707, doi: 10.1109/IGARSS47720.2021.9554373.
- H. Yang et al., "2-D Lunar Microwave Radiance Observations From the NOAA-20 ATMS," in IEEE Geoscience and Remote Sensing Letters, vol. 18, no. 11, pp. 2021-2024, Nov. 2021, doi: 10.1109/LGRS.2020.3012518.
- Yang, H.; Burgdorf, M. A Study of Lunar Microwave Radiation Based on Satellite Observations. *Remote Sens.* **2020**, *12*, 1129. https://doi.org/10.3390/rs12071129

Geolocation Validation

- J. Zhou, H. Yang and K. Anderson, "SNPP ATMS On-Orbit Geolocation Error Evaluation and Correction Algorithm," in IEEE Transactions on Geoscience and Remote Sensing, vol. 57, no. 6, pp. 3802-3812, June 2019, doi: 10.1109/TGRS.2018.2887407.
- Zhou, J. and Yang, H.: A study of a two-dimensional scanned lunar image for Advanced Technology Microwave Sounder (ATMS) geometric calibration, Atmos. Meas. Tech., 12, 4983–4992, https://doi.org/10.5194/amt-12-4983-2019, 2019.

Outline

Improved radiance calibration algorithm in ARTS

- Reflector emission correction
- lunar intrusion correction
- APC correction

on-orbit calibration performance

- Geolocation accuracy evaluation
- TDR/SDR calibration accuracy evaluation

Introduction of the software package

- Instrument oriented design for future expansion
- Modulated calibration/geolocation function
- Public access

Improved Radiance Calibration Algorithm

H. Yang et al., "ATMS Radiance Data Products' Calibration and Evaluation," in IEEE Transactions on Geoscience and Remote Sensing, vol. 60, pp. 1-11, 2022, Art no. 5302211, doi: 10.1109/TGRS.2021.3123576.

The ATMS radiometric calibration for antenna brightness temperature is derived as

$$R = R_c + (R_w - R_c)\left(\frac{C_s - \overline{C_c}}{\overline{C_w} - \overline{C_c}}\right) + Q$$

Q is the calibration non-linearity term

$$Q = \mu (R_w - R_c)^2 \frac{(C_s - \overline{C_w})(C_s - \overline{C_c})}{(\overline{C_w} - \overline{C_c})^2} = 4Q_{\max}(x - x^2)$$

Major Improvements:

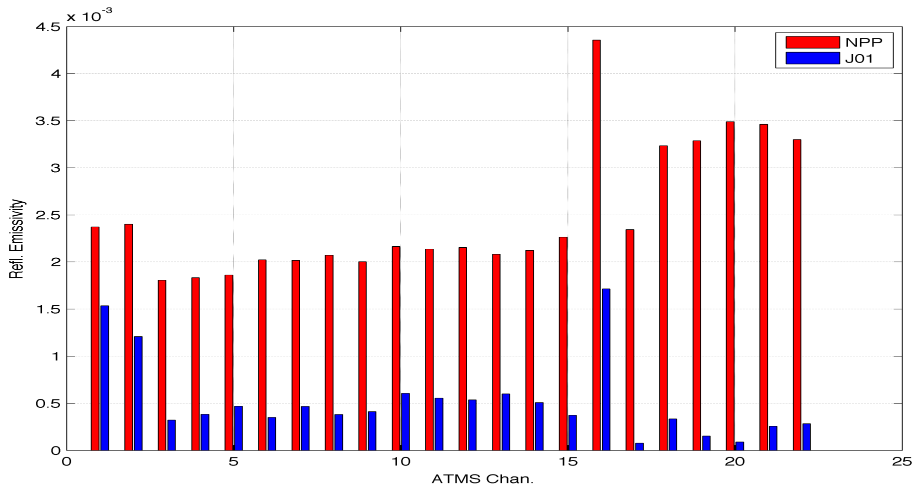
- Replaced the R-J approximation with full radiance based calibration in linear calibration and nonlinearity correction
- Applied antenna reflector emission correction for both calibration targets and the Earth scene
- Implemented the revised lunar intrusion correction scheme and correction model

Reflector Emission Correction

Yang, H., Weng, F. and Anderson, K., 2016. Estimation of ATMS antenna emission from cold space observations. IEEE Transactions on Geoscience and Remote Sensing, 54(8), pp.4479-4487.

The antenna reflector emission correction are applied to both the calibration targets and the scene

SNPP/N-20 ATMS Antenna Reflector Emissivity



The reflector emission corrected antenna radiance can be expressed as:

$$Ra' = C_0 + C_1 \times Ra$$

For QV channels:

$$C_0 = \frac{-R_{rfl} \times \epsilon\,(1 + (1-\epsilon))\sin^2\theta_s}{(1-\epsilon)\left(1-\epsilon\sin^2\theta_s\right)}$$

$$C_1 = \frac{1}{(1-\epsilon)\left(1-\epsilon\sin^2\theta_s\right)}$$

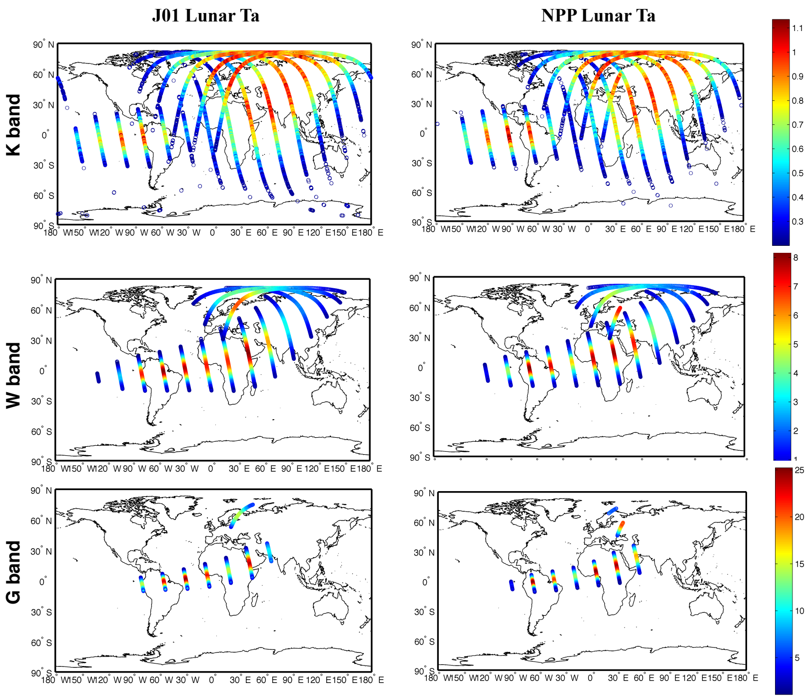
For QH channels:

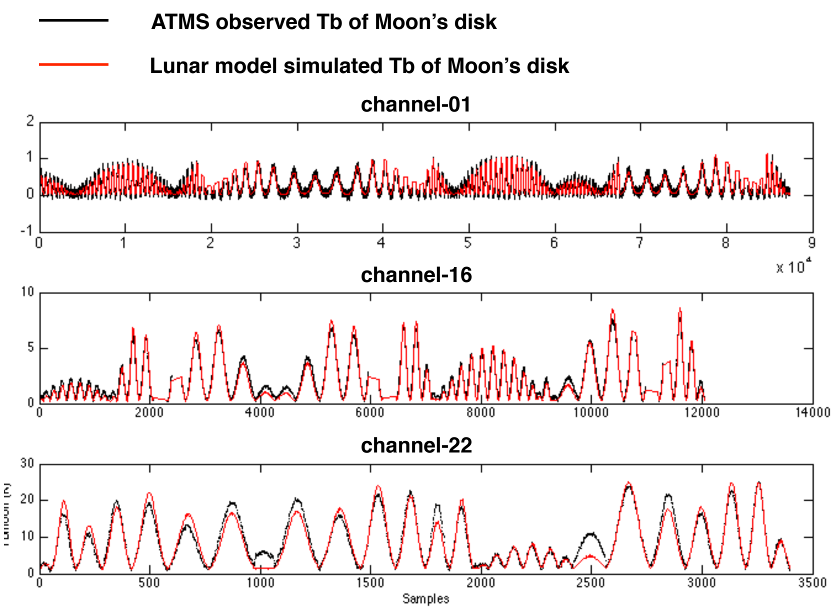
$$C_0 = \frac{-R_{rfl} \times \epsilon\,(1 + (1-\epsilon))\cos^2\theta_s}{(1-\epsilon)\,(1-\epsilon\cos^2\theta_s)}$$

$$C_1 = \frac{1}{(1-\epsilon)\,(1-\epsilon\cos^2\theta_s)}$$

Lunar Intrusion Mitigation Test

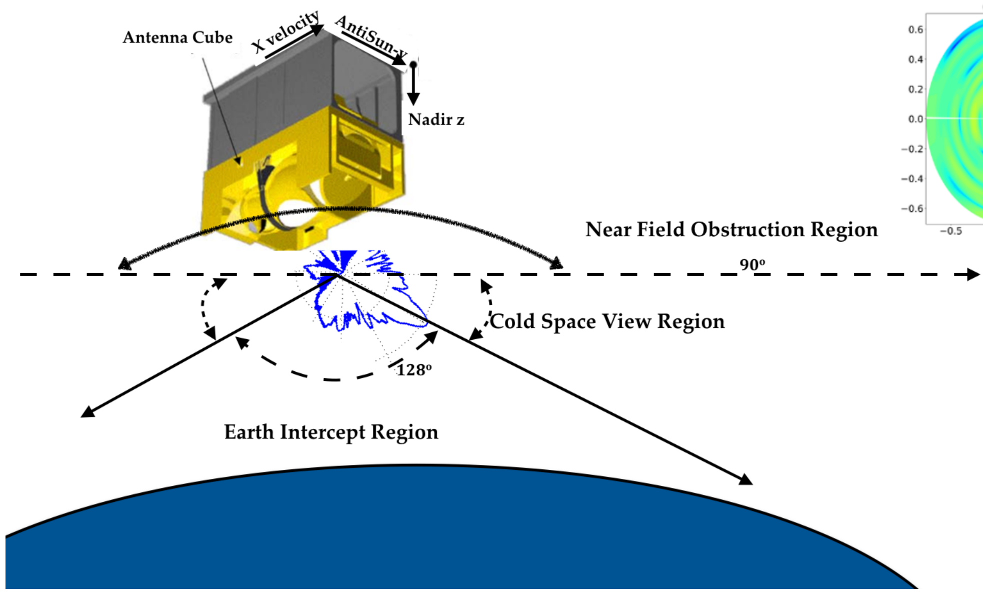
Hu Yang and Fuzhong Weng, 2016, "On-Orbit ATMS Lunar Contamination Corrections", IEEE Transactions on Geoscience and Remote Sensing, Vol. 54 Issue: 4, page(s): 1-7

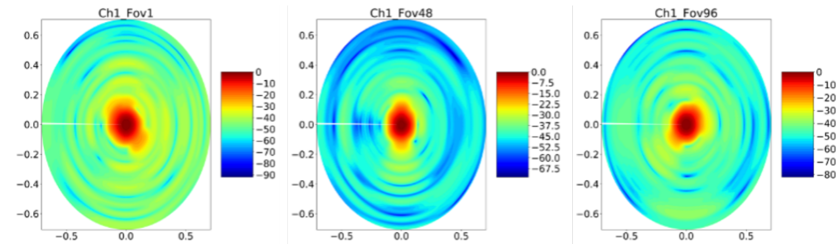




Improved Antenna Pattern Correction (SDR correction) Algorithm

H. Yang et al., "ATMS Radiance Data Products' Calibration and Evaluation," in IEEE Transactions on Geoscience and Remote Sensing, vol. 60, pp. 1-11, 2022, Art no. 5302211, doi: 10.1109/TGRS.2021.3123576.





$$Tb = \frac{Ta - \eta_c \cdot Tc}{\eta^{pp} + \eta^{pq}}$$

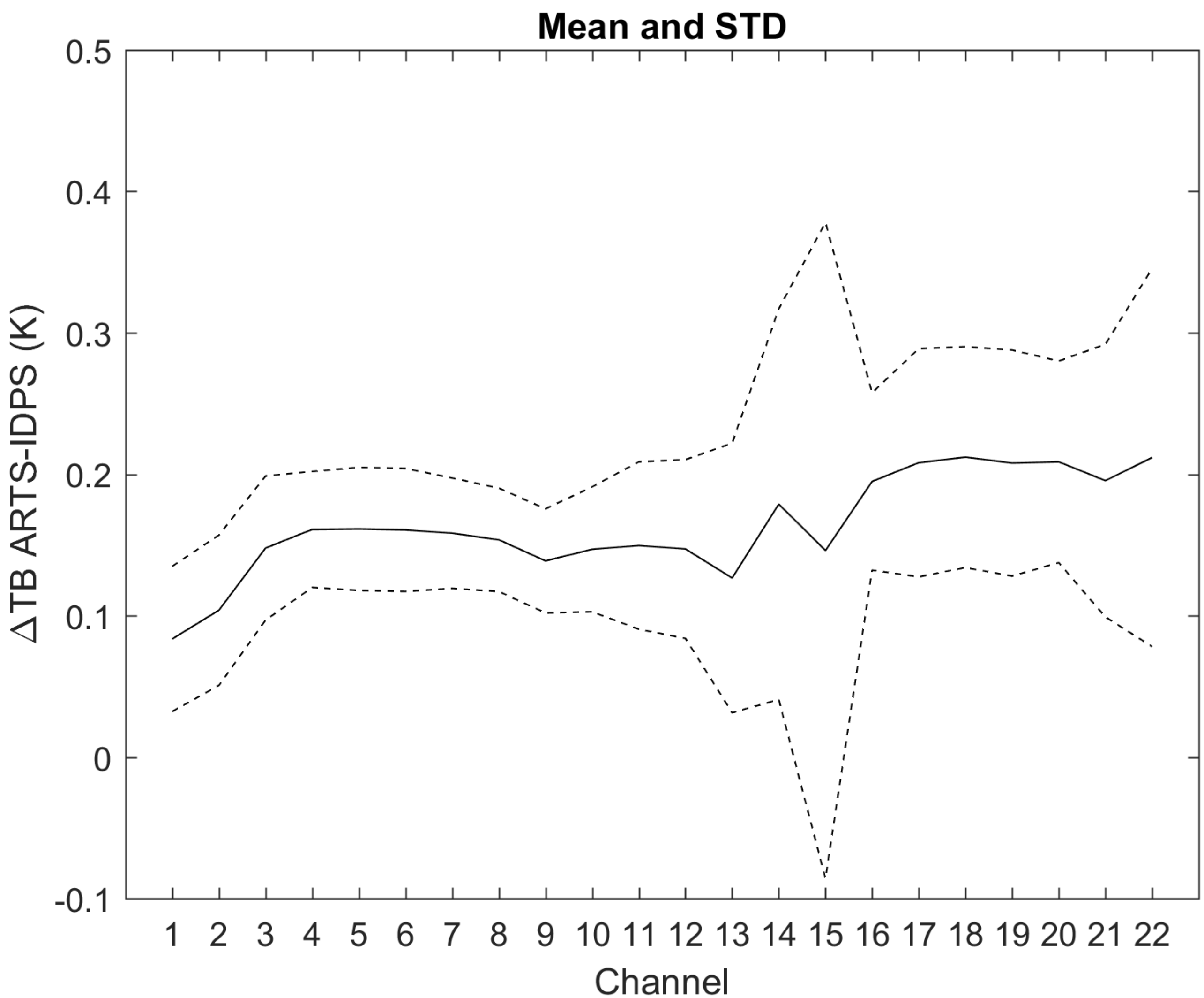
$$\eta^{pp} = \frac{\int_{\Omega_E} G^{pp}(\theta, \phi)\, d\theta d\phi}{G_{total}}$$

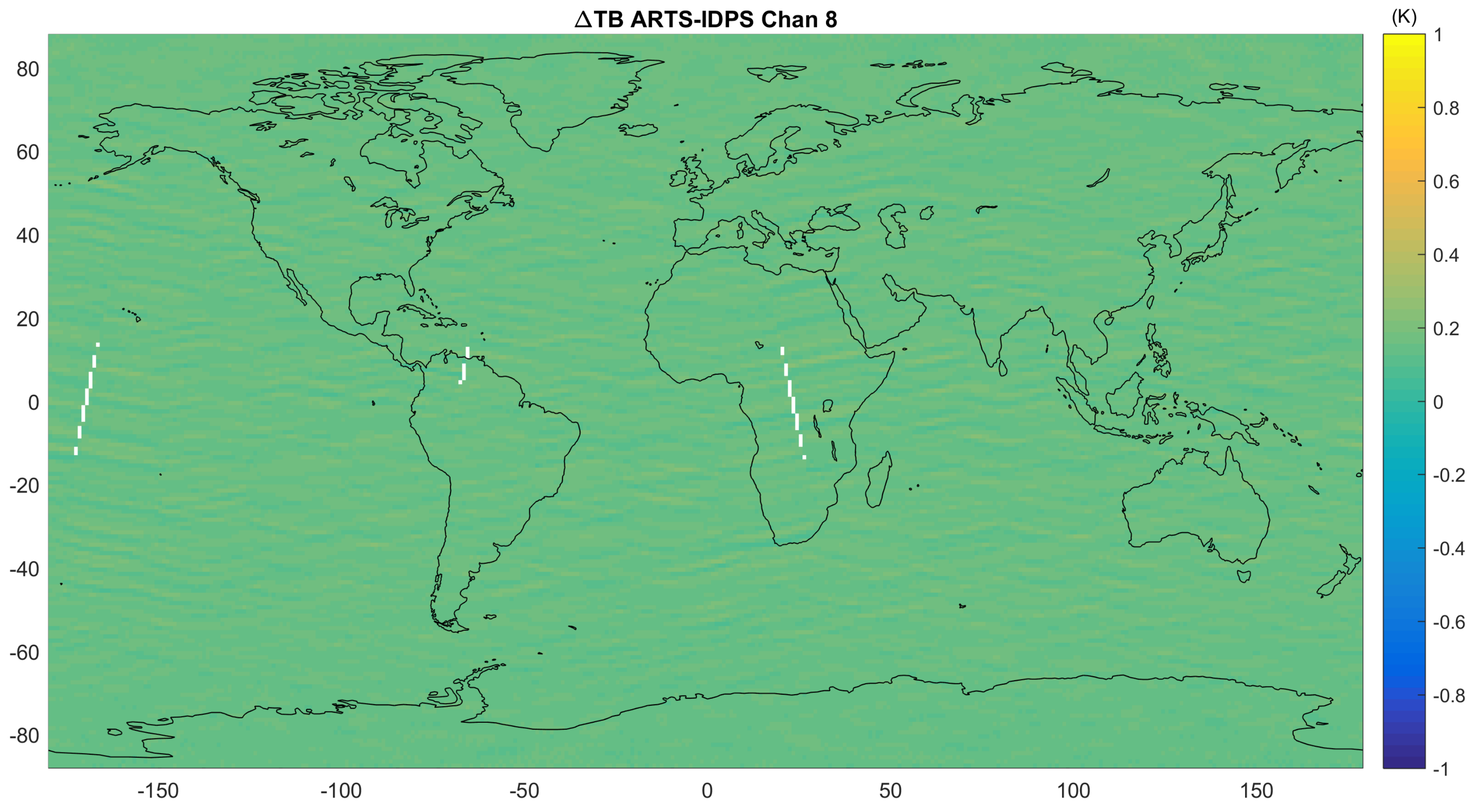
$$\eta^{pq} = \frac{\int_{\Omega_E} G^{pq}(\theta, \phi)\, d\theta d\phi}{G_{total}}$$

Major Updates

- Use hyper-antenna pattern to generate the APC coefficients
- Revised algorithm to account for FOV inhomogeneity
- Side lobe spill-over correction based on post-launch special scan

SDR Comparison Results with IDPS

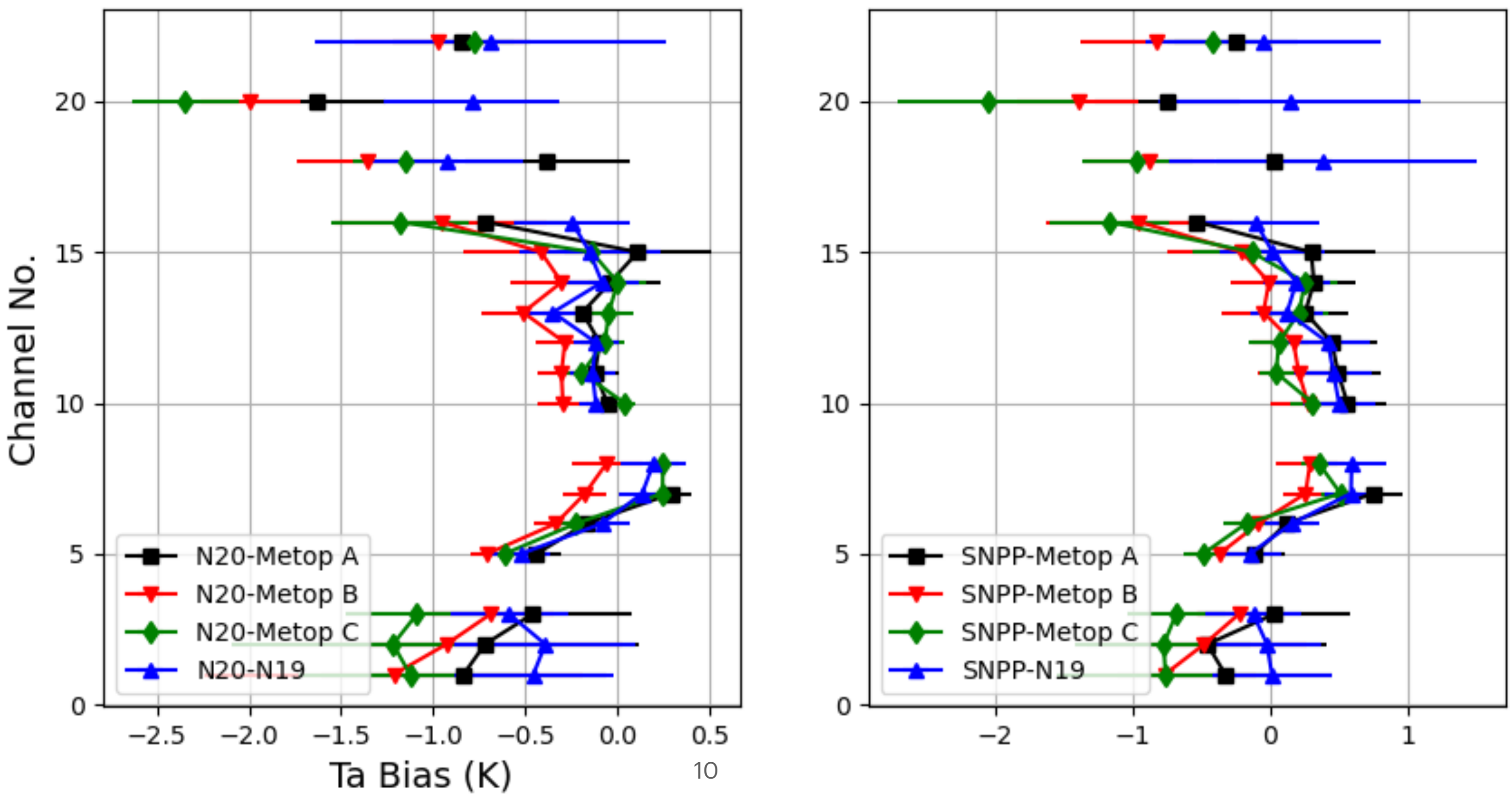




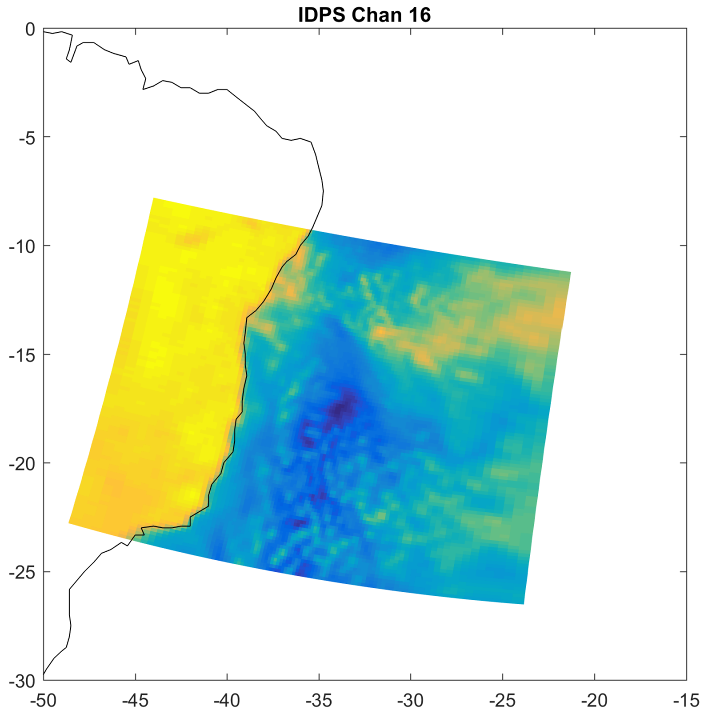
ΔTB ARTS-IDPS Chan 8
(K)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
80
60
40
20
0
-20
-40
-60
-80
-150
-100
-50
0
50
100
150

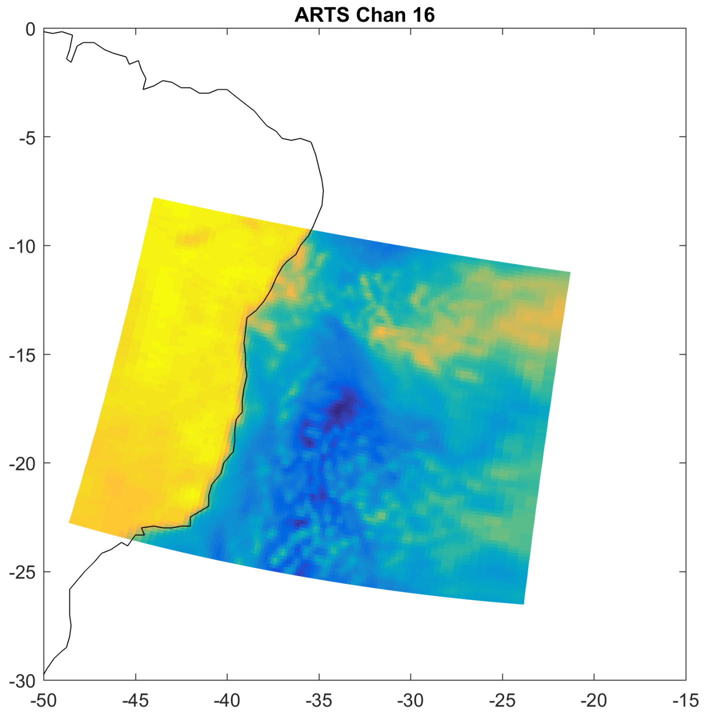
SNO Calibration Accuracy Evaluation

- The simultaneous nadir overpass (SNO) method was explored to investigate the calibration difference between S-NPP/ NOAA-20 ATMS and AMSU/MHS onboard Metop-A, B, and C and NOAA-19
- For sounding channels 5 to 15, the calibration are more consistent between ATMS and AMSU/MHS, the differences are around ±0.5 K
- For window channel and 183 GHz channels, larger calibration differences are observed between ATMS and AMSU/MHS, and among AMSU/MHS onboard different satellites

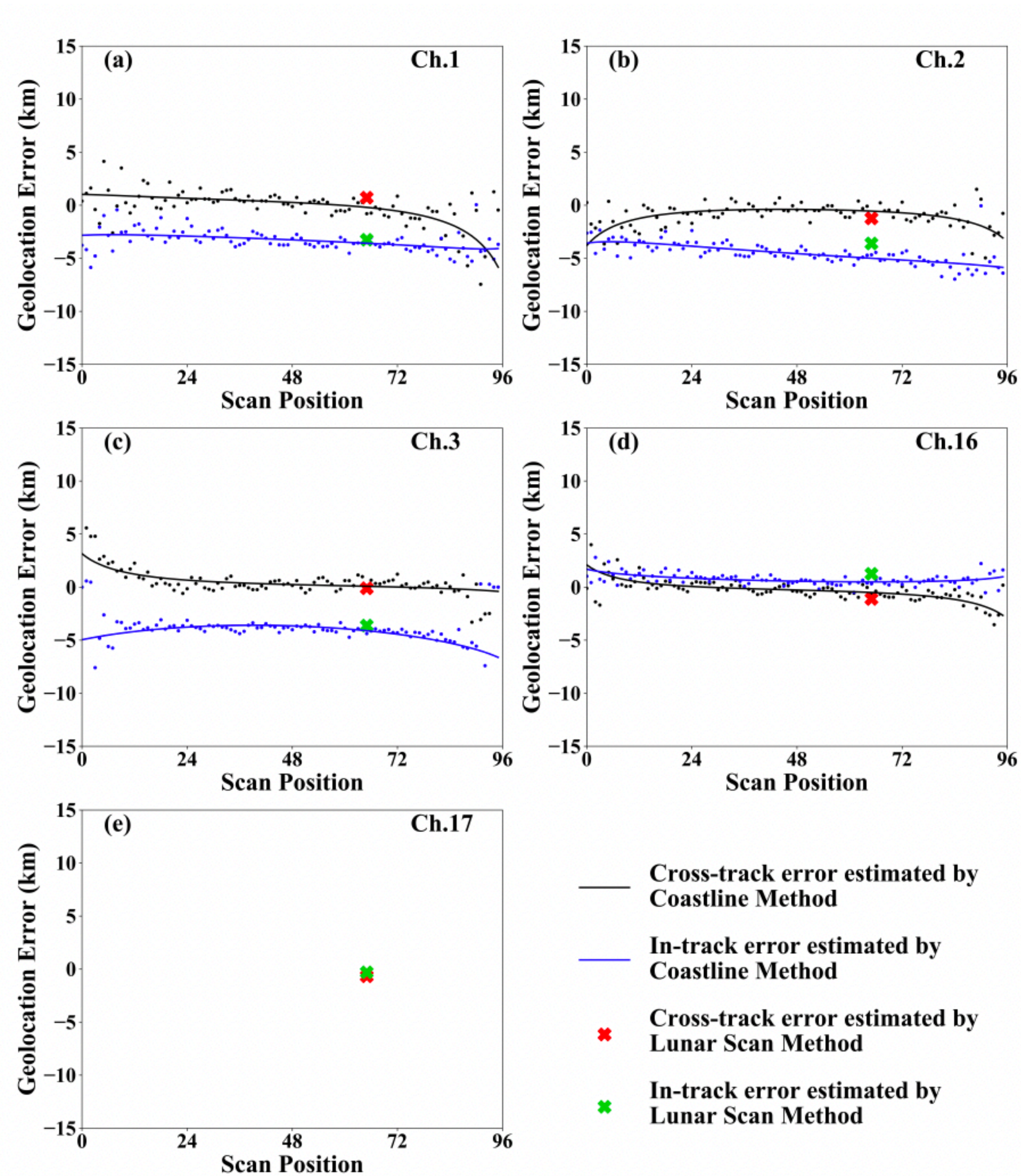


Geolocation Comparison Results between ARTS and IDPS





Geolocation Accuracy Evaluation Results



Summary of Evaluation Results for the Released Version

- One day NOAA-20 ATMS RDR dataset on 08/10/2019 was used as test data and being processed in ARTS. SDRs were generated and compared with operational products from IDPS on the same day.

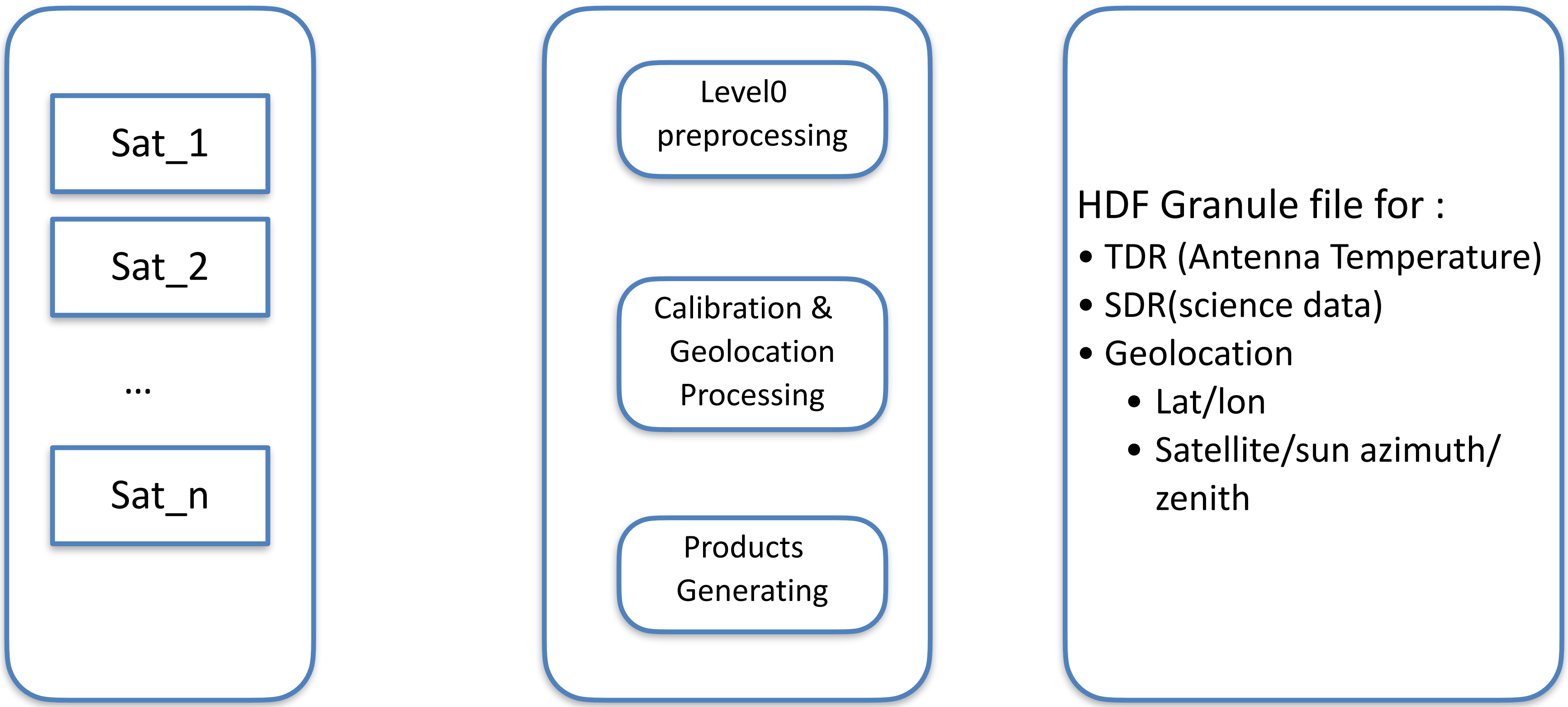
- Comparison results show that mean Tb difference between ARTS and IDPS is less than 0.2 K with a maximum Std less than 0.2K

- The Major difference may caused by different processing scheme in ARTS and IDPS. For ARTS, the RDR dataset is processed on hourly base(1354 scan lines), and in IDPS it is processed for every 36 scan lines (3 granules). Which will raise slightly difference in the calibration gain

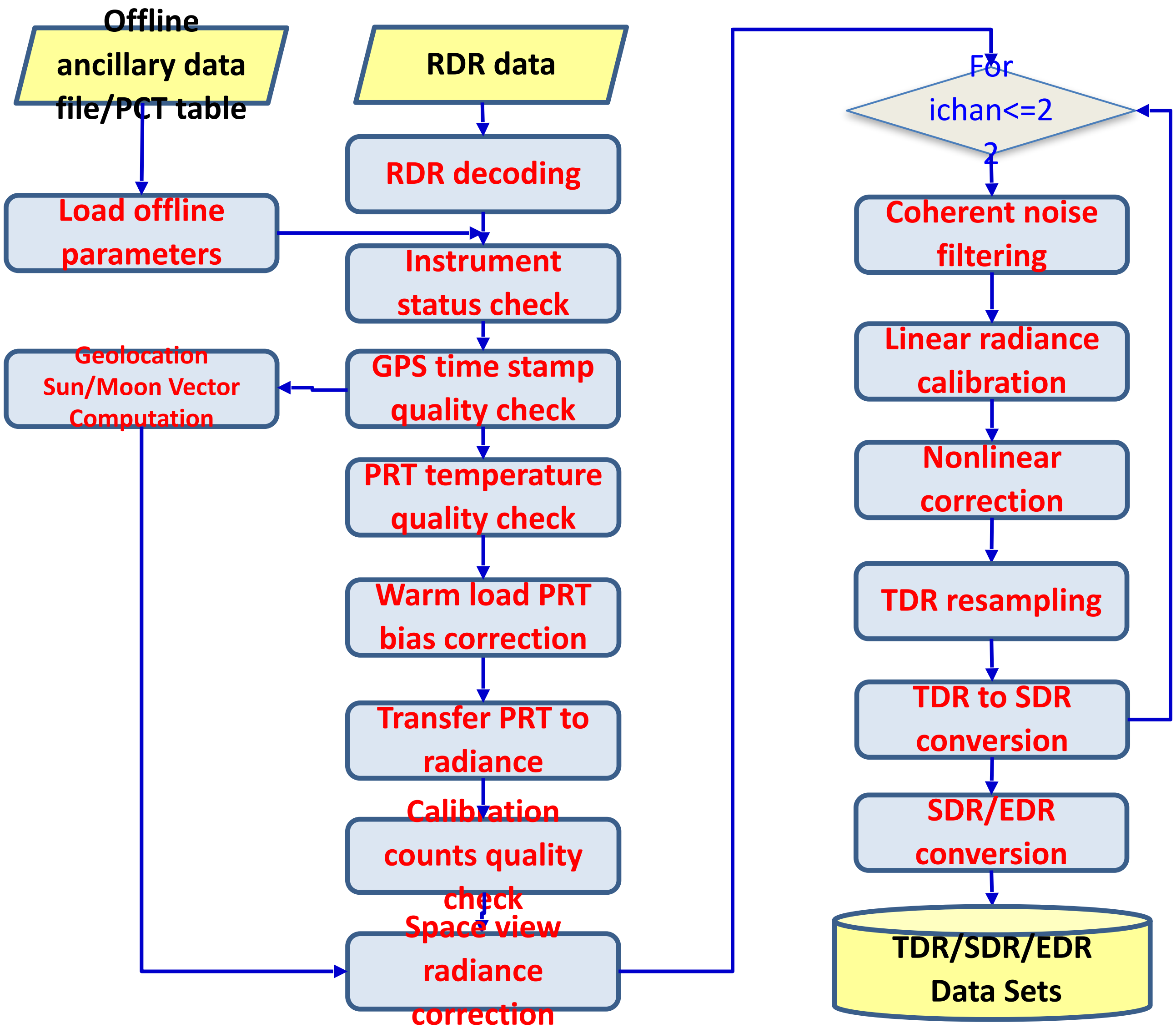
Main Feature of ARTS

- Module based design can be easily expanded to different instrument
- A PCT table is build for each individual instrument, make it flexible for maintenance and algorithm upgrade
- Up-to-date algorithm and consistent with ADL/IDPS

Parameter Configuration Table | **Common Processing Module** | **General Outputs**



Flow Chart for Radiance Calibration Module



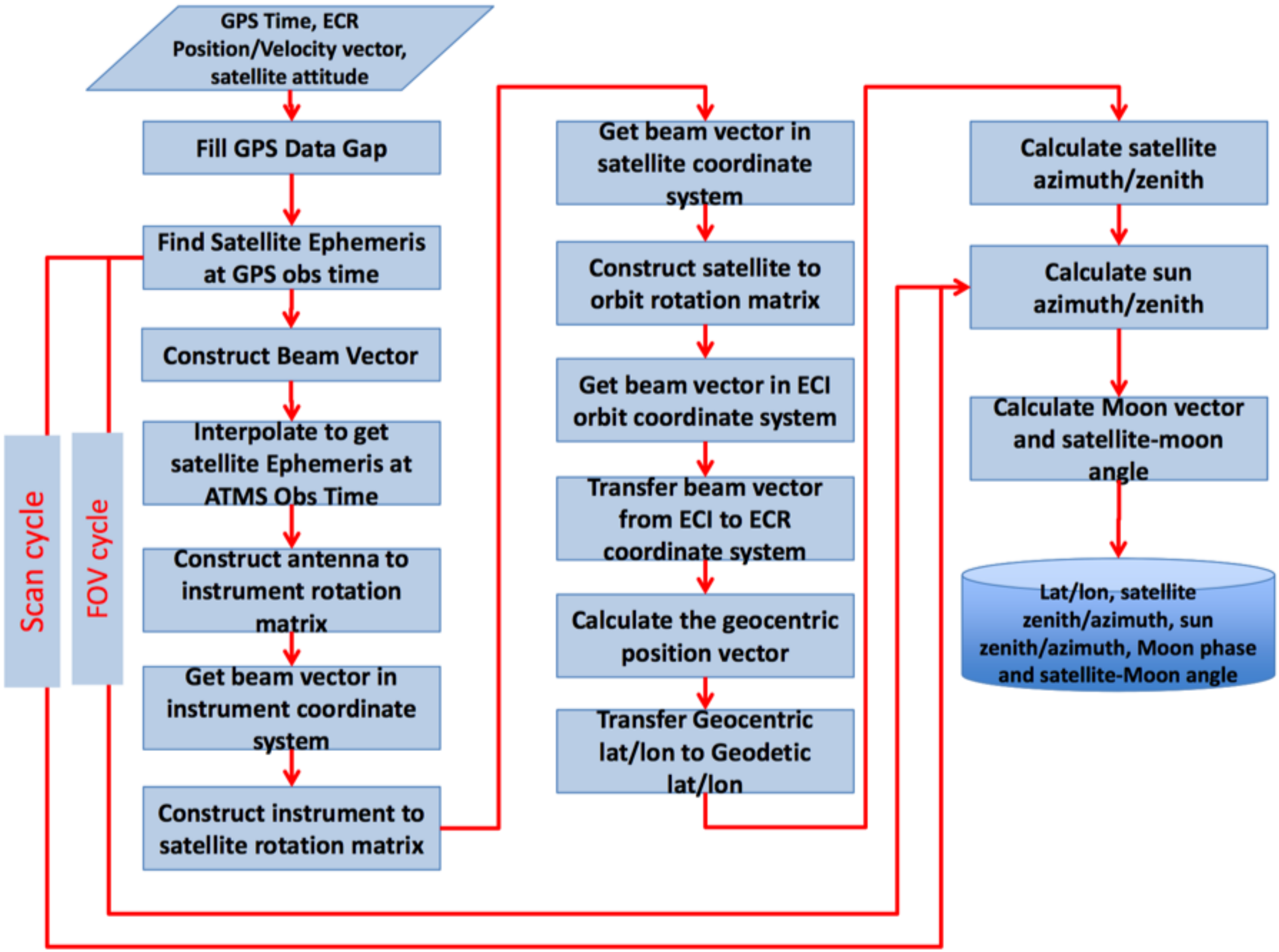
•Module based design make different sensor easy to be fitted in the system

•Brightness temperature is computed from full Planck function in radiance space

•System developed based on state-of-arts calibration algorithm.

•Error budget in calibration are traceable

Flowchart of ARTS Geolocation Module



```
THE ARTS TARBALL DIRECTORY STRUCTURE LOOKS LIKE:
    ./
     |-make.macros............compiling variables
     |-make.rules.............compiling environment variables
     |-bin....................Executable file
     |-log....................Diary files
     |-scripts................Script files
     |-data...................
       |-calancilary..........off-line ancilary files for calibration
       |-geoancilary..........off-line ancilary files for geolocation
       |-srf..................spectral response function files
       |-ContrlData...........Control files
       |-InputsData...........Input files
       |-figs.................Figures
       |-grid.................Grid files
       |-tdr..................TDR files(need to be reset by user)
       |-sdr..................SDR files(need to be reset by user)
     |-lib....................
       |-makefile.............
       |-cal..................calibration related function/subroutines
       |-geo..................geolocation related function/subroutines
       |-math.................mathematical function/subroutines
       |-dsp..................digital signal processing function/subroutines
       |-misc.................miscellinous functions
       |-const................constants
       |-io...................input/output functions/subroutines
     |-src....................main code file
```

```
1) SETUP
----------------------------------
   Compile make.macros file, set up compiling environment according to
   user's need.
   TO DO ( more details are needed here )

   Compile conf/conf.in to specify paths.
   Go to script directory, open atmsdpps_daily.bash, set dir_root according to user's need
   in the same directory, open atmsdpps_conf.bash, set dir_root, datadir, rdr1_path accordi
ng to user's need
   If it is the first run, set step1, step2, step3 to 1. if it is repeat run for the same d
ata, set step1=0, step2=1,step3=1


2) BUILD
----------------------------------
   cd src
   make
   3 executable files will be generated under bin/

   atmsdpps
   rdr_decode
   tdr_encode


3) RUN
----------------------------------
   Go to scripts directory,
   Open rundpps.bash and edit
   the script atmsdpps_daily.bash then can be run as:
   ./atmsdpps.bash  satid  sensorid   yyyy-mm-dd start-time end-time
```

Public Released Version in GitHub Repository Server

Access link: https://github.com/noaa-jpss-atms/ARTS

Send access request to POC below:

quanhua.liu@noaa.gov
ninghai.sun@noaa.gov
huyang@umd.edu

Conclusions and Future Work

- ARTS is flexible and can be expanded for on-orbit absolute calibration of microwave instrument from different satellite platform, including the SmallSAT and CubeSAT

- ARTS is written in C# and Fortran, and easy to be migrated to different platform

- Two line elements data based geolocation algorithm will be implemented in geolocation module as a mitigation measure when GPS data is missing

- Interface of ARTS system will be re-written in python to include the parallel computation function, which is expected to significantly reduce the processing time