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

Hu(Tiger) Yang[1], Fuzhong Weng[2], Ninghai Sun[2]
Wanchun Chen[2], Lin Lin[2] , Miao Tian[1]

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

May 12, 2014

Introduction

NOAA request a full radiance based calibration algorithm for consistent calibration for historical, present and future microwave sounding instruments

- Weather forecast application require continuous improving for satellite instrument calibration accuracy
- Satellite climate study need to develop and implement a robust, sustainable and scientifically defensible calibration system to producing and preserving climate records from satellite data

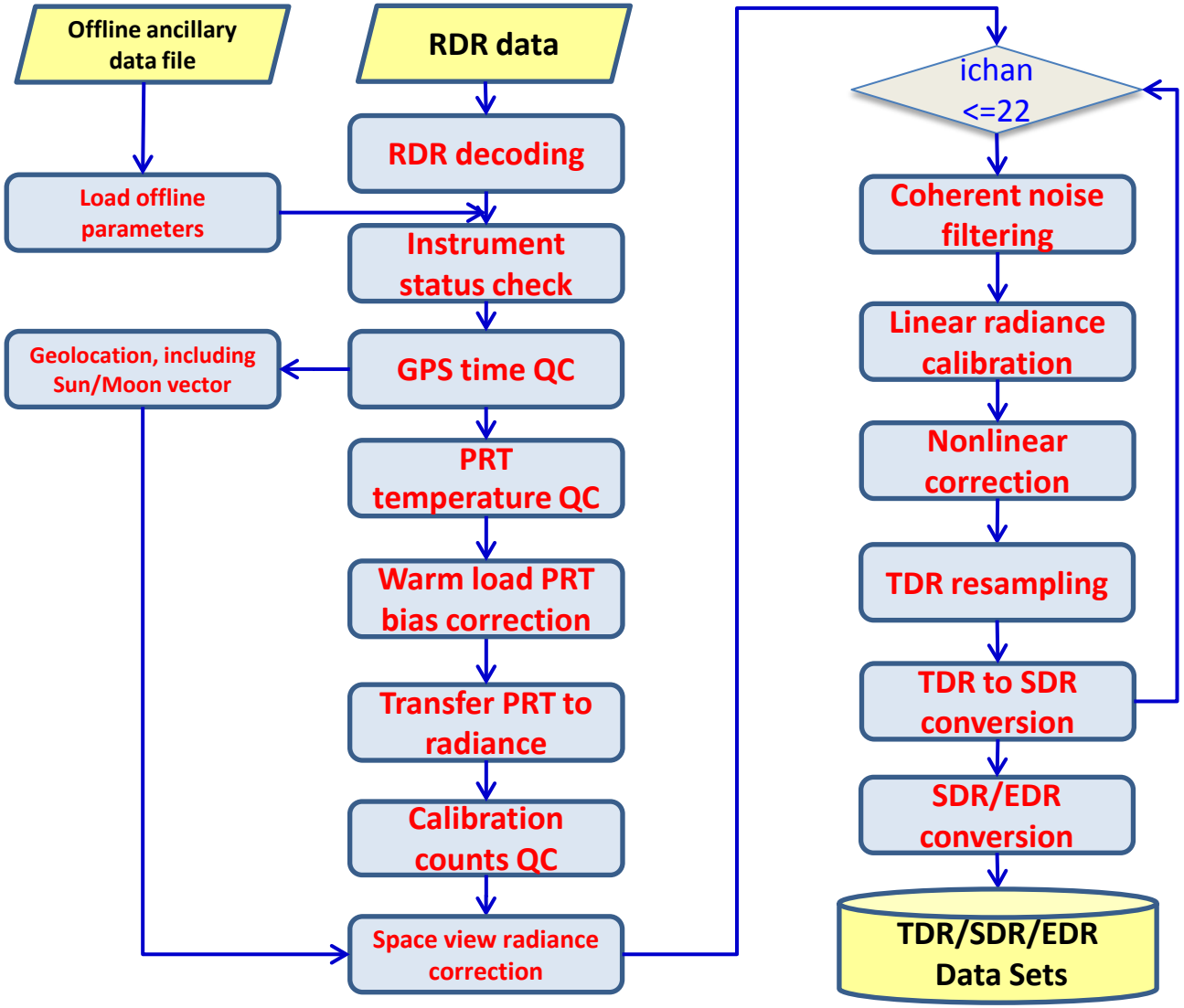
Present microwave calibration system is derived in temperature space, which is not consistent with historical full radiance calibration system developed in NOAA

- R-J approximation corrected calibration algorithm will cause scene dependent calibration error
- New sciences established from solid study of SNPP ATMS are need to be included to improve the calibration accuracy

An Advanced Radiance Transformation System (ARTS) is developed for microwave sounding instruments in JPSS era

- Full radiance calibration system applicable to different sensors
- New science for improving the calibration accuracy

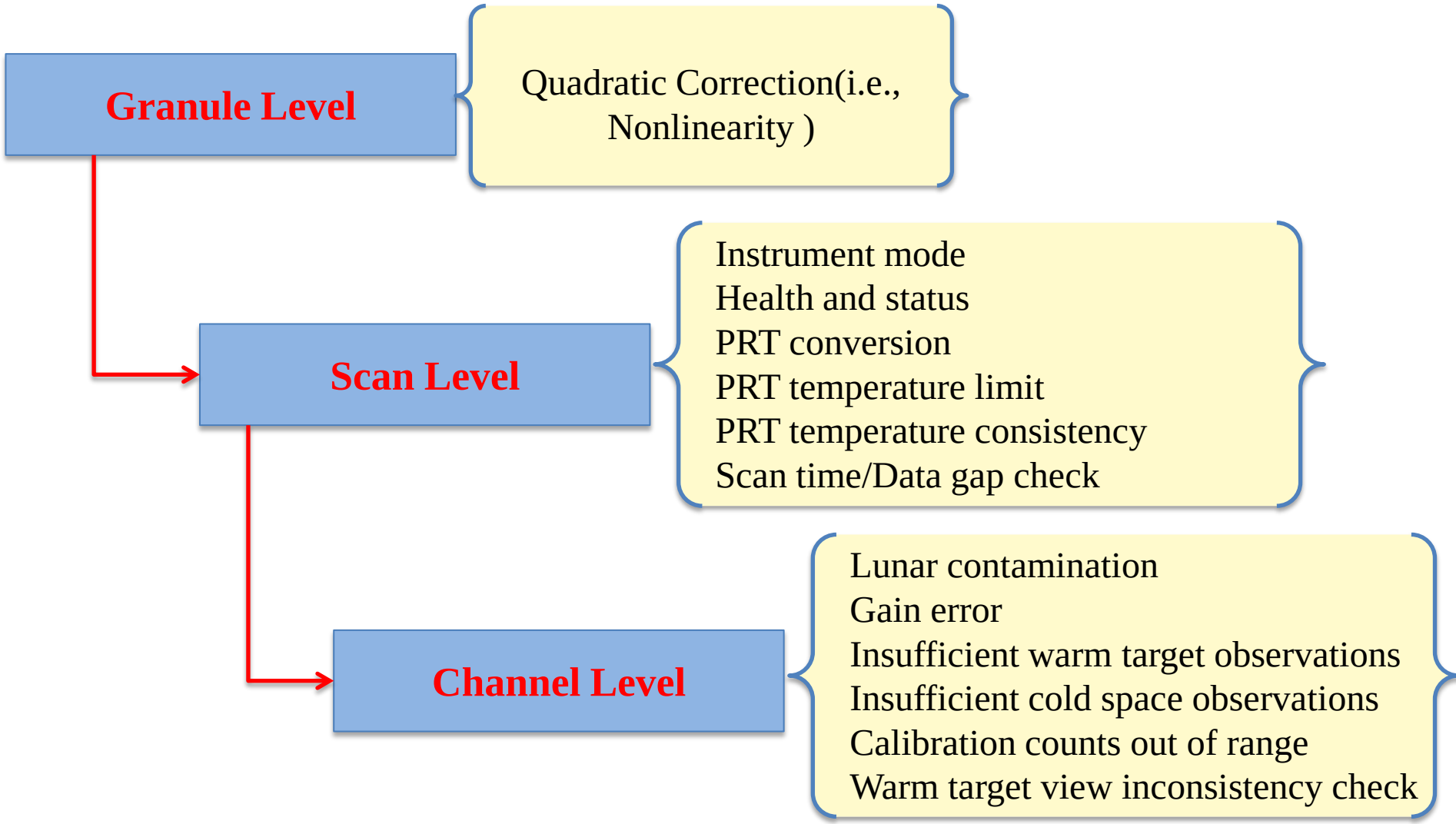
ARTS System and Software Engineering



- Consistent calibration algorithm for different sensors
- Full radiance calibration system with improved two-point calibration algorithm
- Data resampling ability to generate TDR with different spatial resolutions

Quality Control in ARTS

Different level of Quality control with PCT as inputs makes system being sustainable



Supported Platforms

- Supports both big and little endian platforms
- Comparable processing efficiency with IDPS

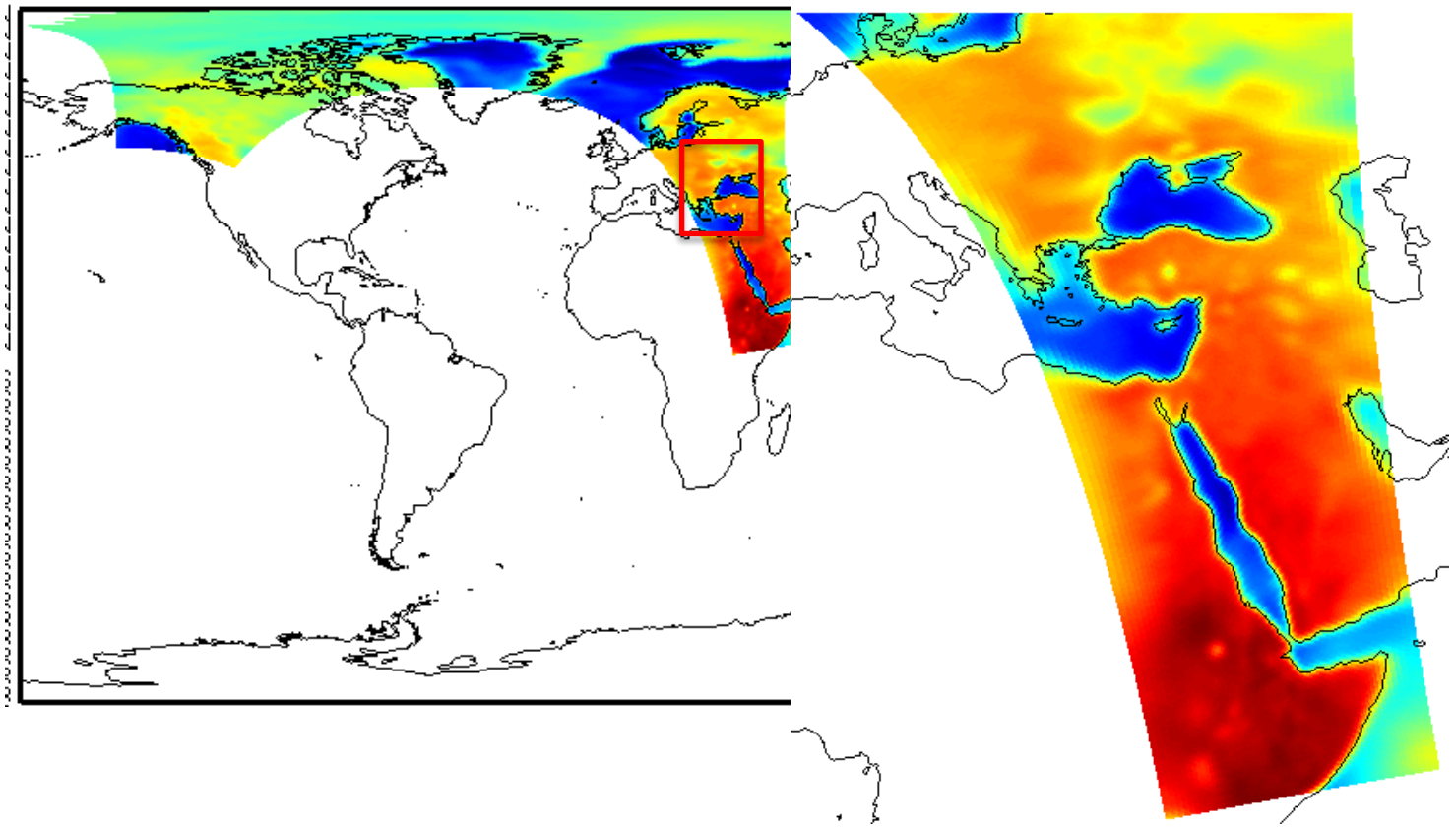
OS	C compiler	C++ compiler	Fortran 90 compiler
AIX 5.3.0.0 or later	IBM XL C/C++ Enterprise Edition for AIX, V10.1	IBM XL C/C++ Enterprise Edition for AIX, V10.1	IBM XL Fortran Enterprise Edition for AIX, V12.1
LINUX (Red Hat Enterprise 5)	GCC 4.3.2	GCC 4.3.2	Intel Fortran version 11 or later
Windows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

Main ARTS Modules

- Satellite geolocation
- Full radiance calibration
- B-G resampling
- Coherent noise filtering
- Lunar contamination correction

Geolocation

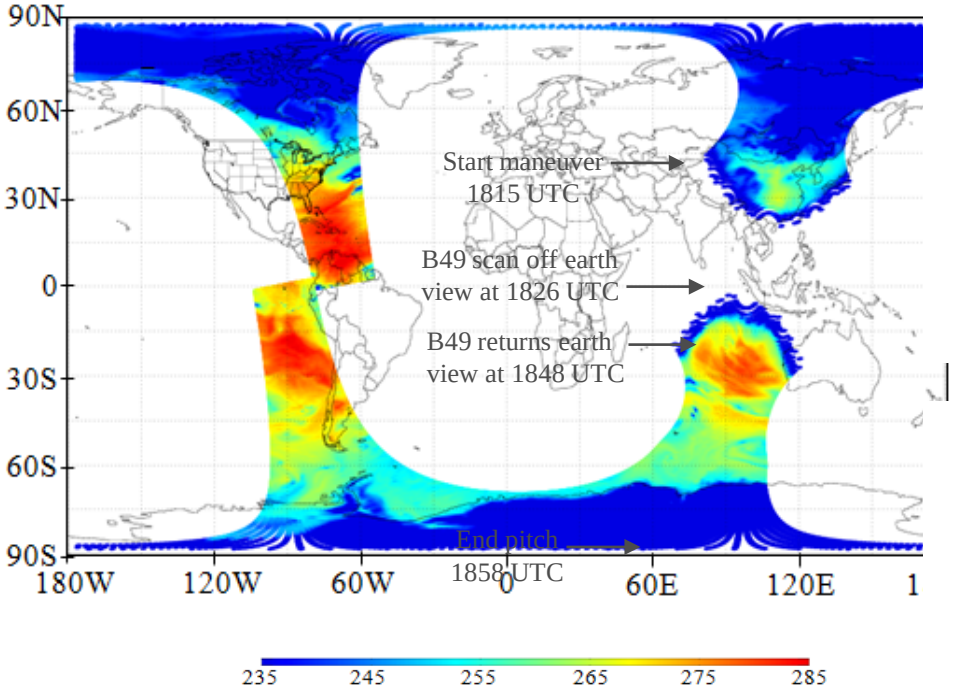
- Geolocation module includes GPS based and TLE based algorithms
- Primary algorithm uses GPS measurements of satellite position/velocity
- TLE is used as backup when no GPS data or large data gap exists in raw data
- ATMS geolocation error relative to VIIRS is about 3-4km



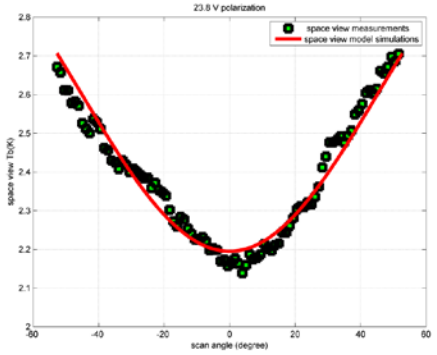
Full Radiance Calibration

- Calibrated space view scene brightness temperatures from IDPS are not equal to the cosmic background temperature 2.73K
- Abnormal scan angle dependent feature existed in calibrated TDR products

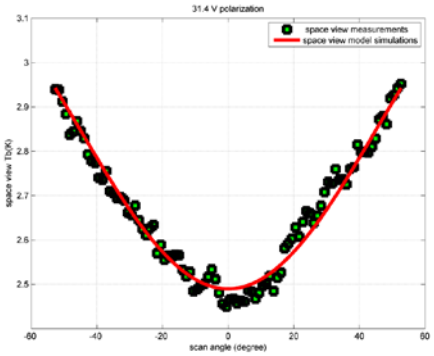
ATMS TDR at Ch18 on February 20, 2012



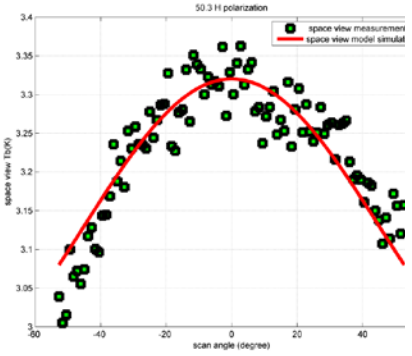
Channel 1



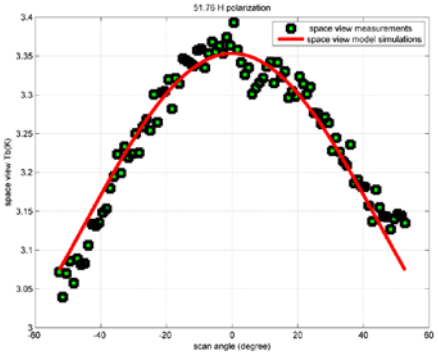
Channel 2



Channel 3



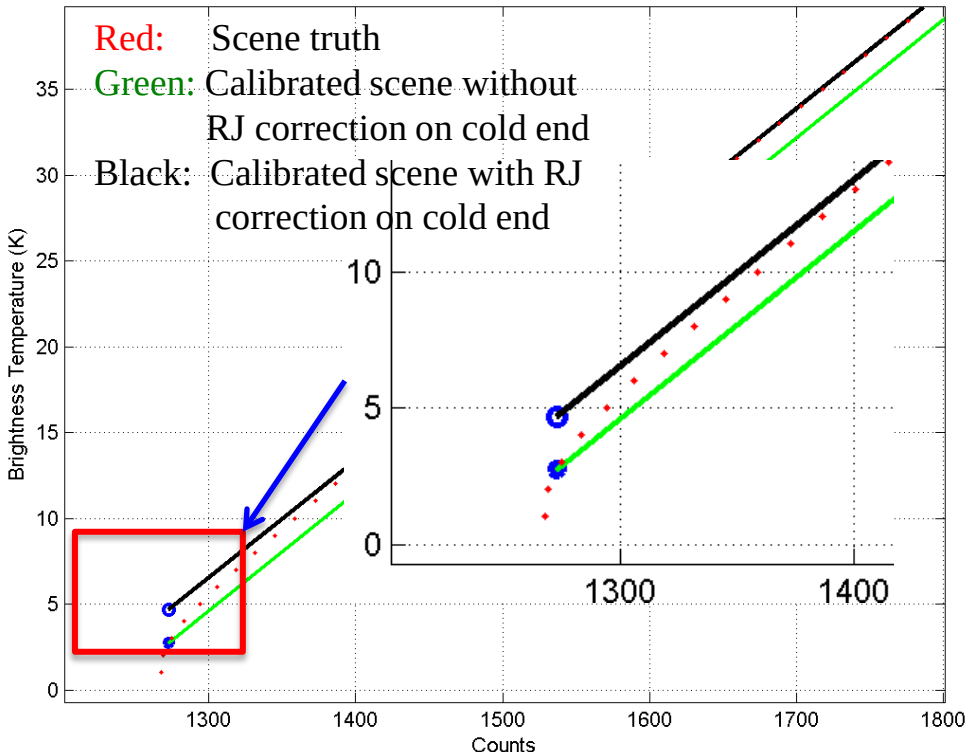
Channel 4



Calibration Error in IDPS

- Normally, a scene temperature dependent term and a constant bias term are used in R-J calibration equation
- However, after applying correction by them it will still have residual errors that are dependent to temperature and frequency in the corrected calibrated temperature
- Especially, when the scene temperature is close to cosmic background temperature, large bias will present when applying the R-J calibration equation with Tc correction.

$$Ts = \delta(Th - Tc) + Tc + (\Delta Tc - \Delta Ts)$$



New Two-Point Calibration Model in ARTS

Antenna emission including near-field radiation effect is modeled as function of scan angle and included in the calibration. Cold space observations from pitch maneuver operation are clean and used to derive model parameters for different channels. Such new algorithm can only be delivered in full radiance calibration system.

Corrected Two Point Calibration Equation in ARTS

For Vertical Polarization Channels:

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

For Horizontal Polarization Channels:

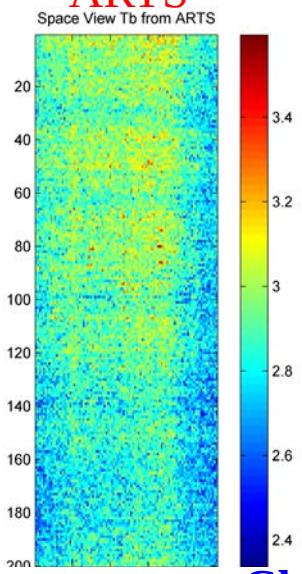
$$R_s = \delta[(R_h - R_c) + \beta_1(cos^2\theta_h - cos^2\theta_c)] + R_c + \beta_1(cos^2\theta_s - cos^2\theta_c)$$

Rs: Calibrated antenna radiance
Rh: Warm load radiance
Rc: Cold space radiance (equal to 2.73K)
θ_h: Scan angles of warm load measurements
θ_c: Scan angles of space view
θ_s: Scan angles of Earth view (i.e., each FOV)
δ: Defined as (Cs - Cc) /(Ch - Cc), where Ch/Cc/Cs are receiver output counts of warm load, cold space and earth view, respectively

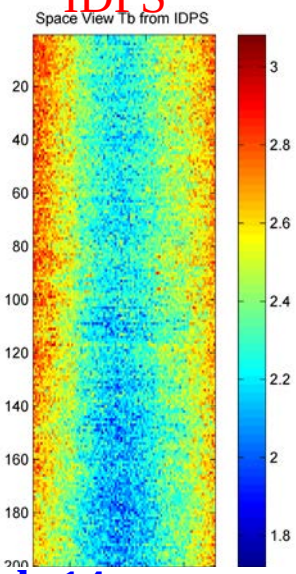
Space View BT Calibrated by ARTS

Channel -1

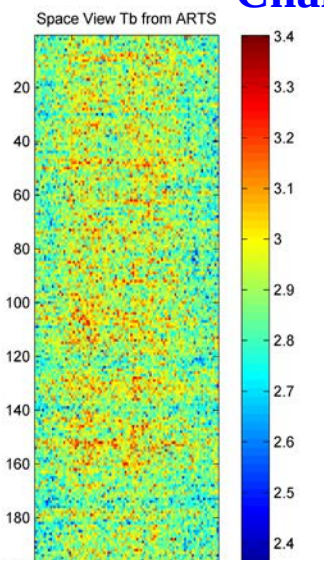
ARTS

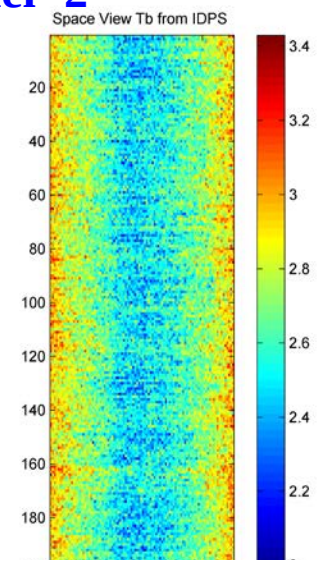


IDPS

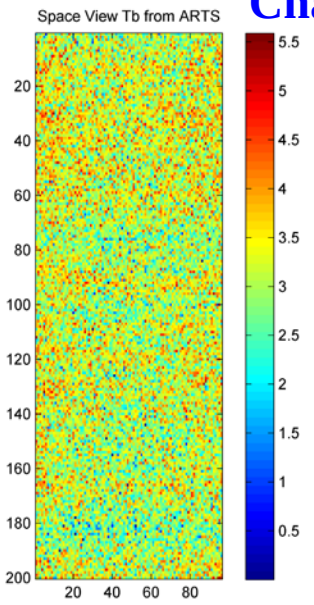


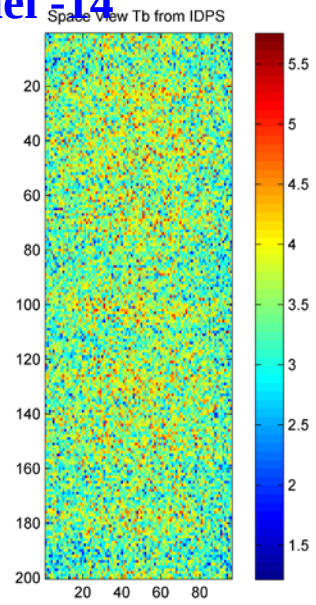
Channel -2



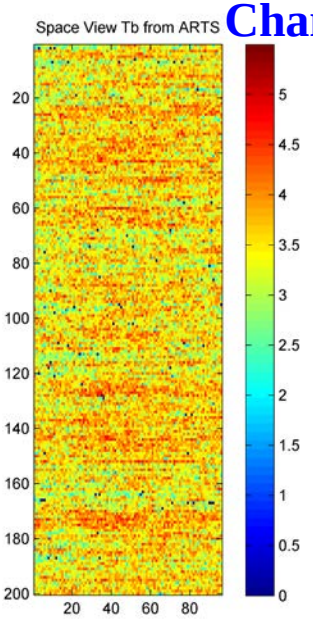


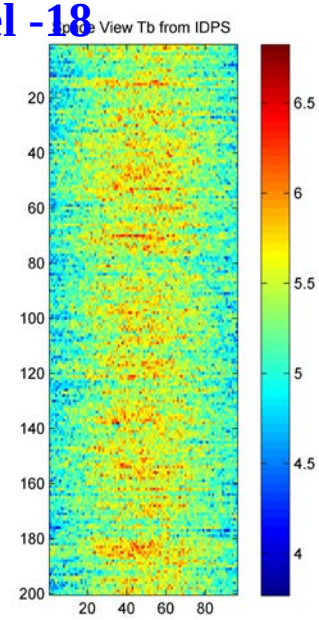
Channel -14





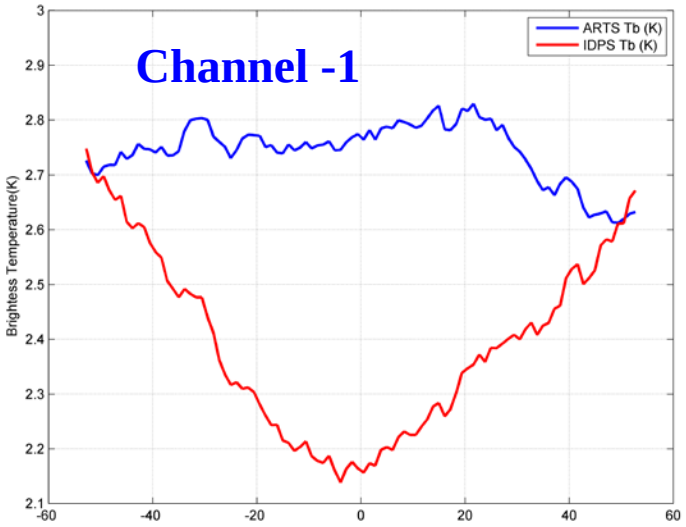
Channel -18

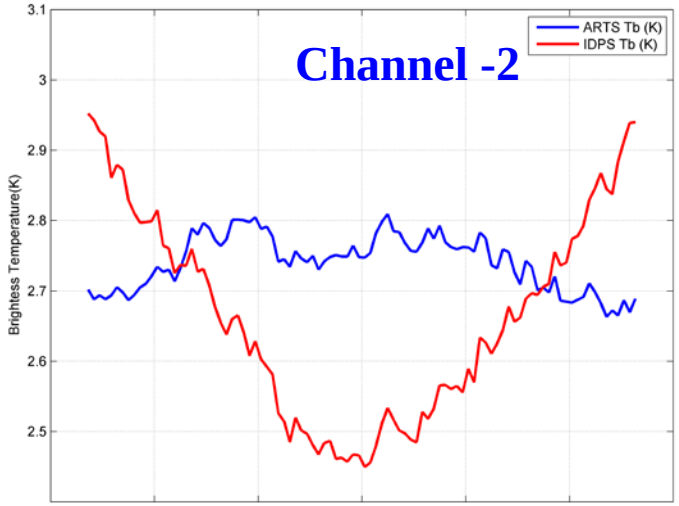


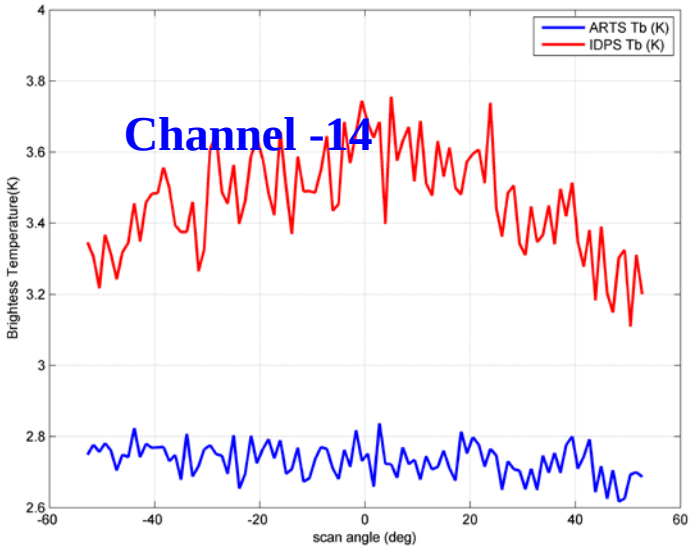


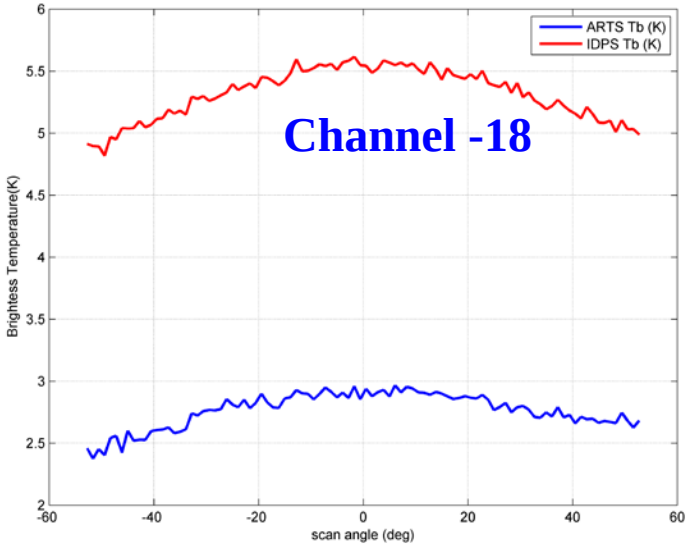
Scan Angle Dependent in TDR from ARTS

For space view BT corrected by ARTS: No scan angle dependent feature, and close to cosmic background 2.73K



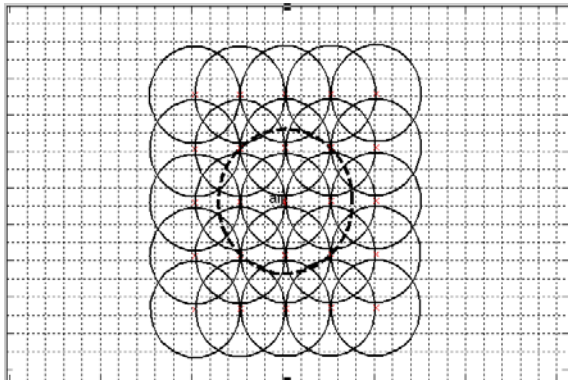




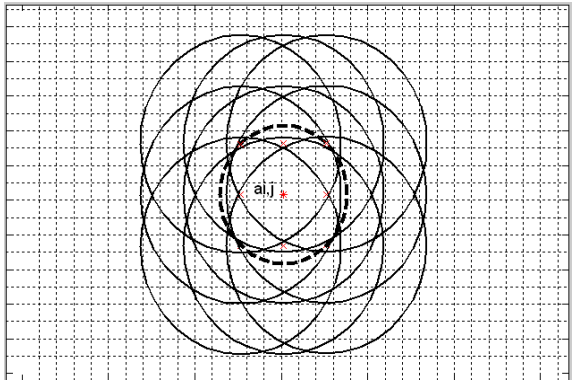


Resampling TDR

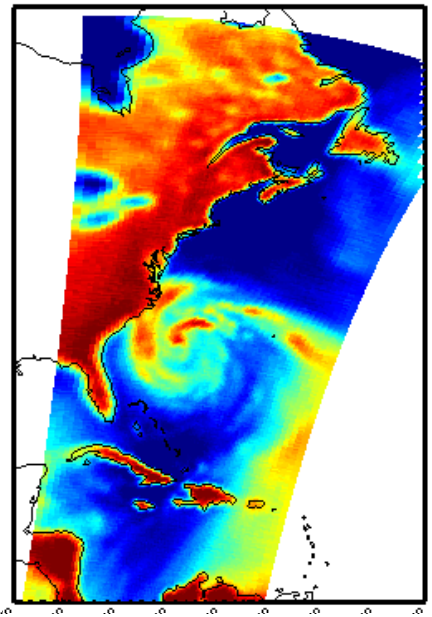
Resolution Reduction



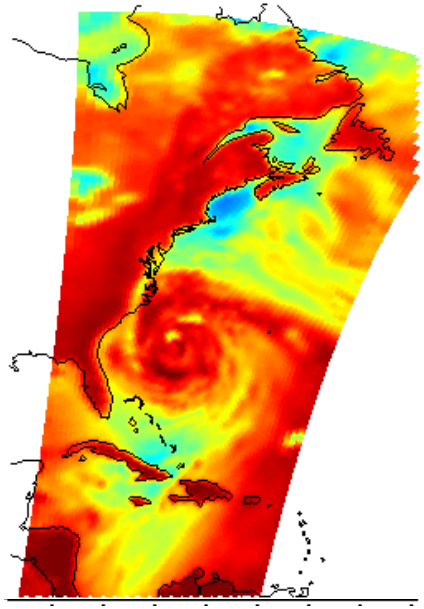
Resolution Enhancement



FOV 2.2°



FOV 3.3

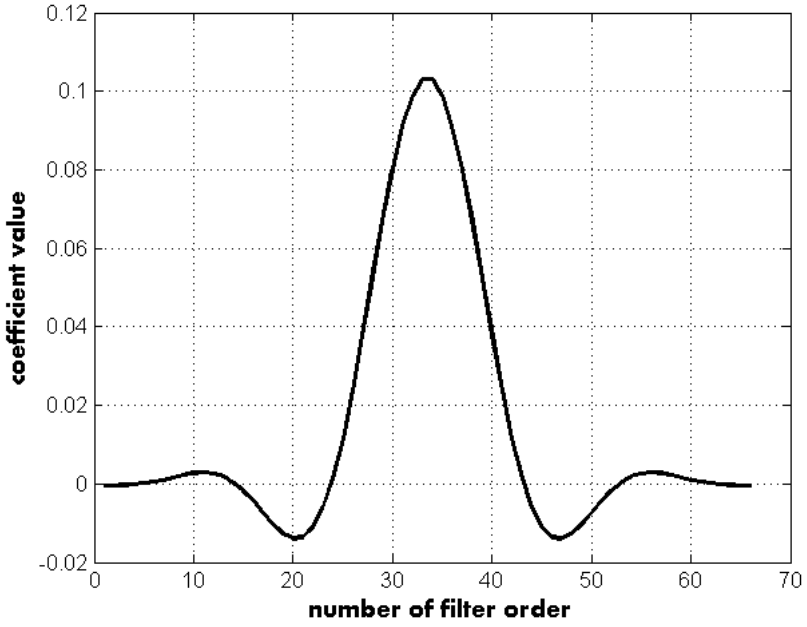


- Explore the potential of the oversampling characteristic of ATMS observations and generate observations at different frequencies with consistent FOV size
- Backus-Gilbert observation reconstruction algorithm is used for remapping TDR to expected spatial resolution
- Remapping coefficients are tuned to ensure the remapped TDR products are in best balance between noise and spatial resolution

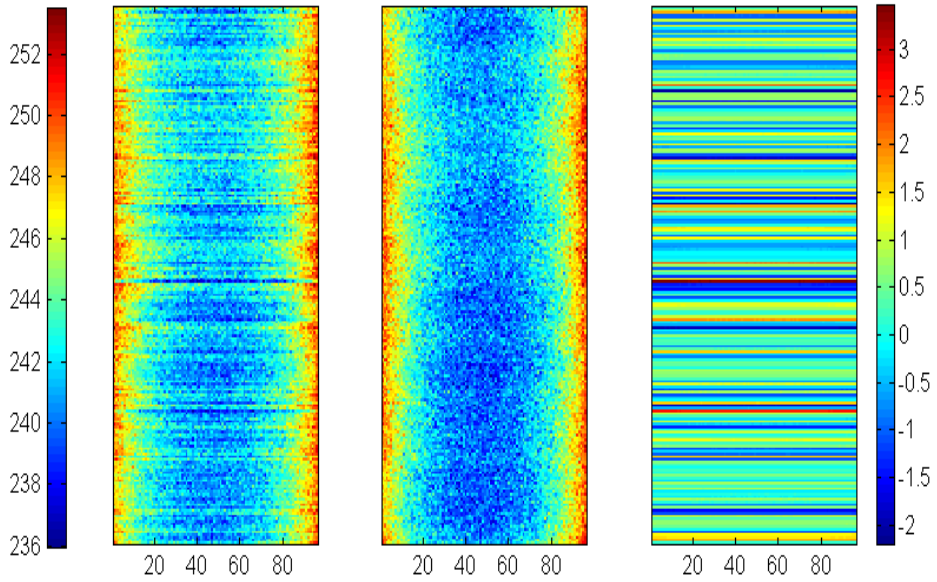
Coherent Noise Filtering

Based on frequency spectrum analysis of the receiver output calibration counts, a low-pass filter with sinc window function is developed to effectively remove the high-frequency components (rapid fluctuations) while keep the low-frequency components (gain variations) unchanged.

Sinc Window Function



Calibrated Tb with and without calibration counts noise filtering



Lunar Contamination Correction

Brightness temperature increment arising from lunar contamination is modeled as function of lunar solid angle, antenna response and radiation from the Moon

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

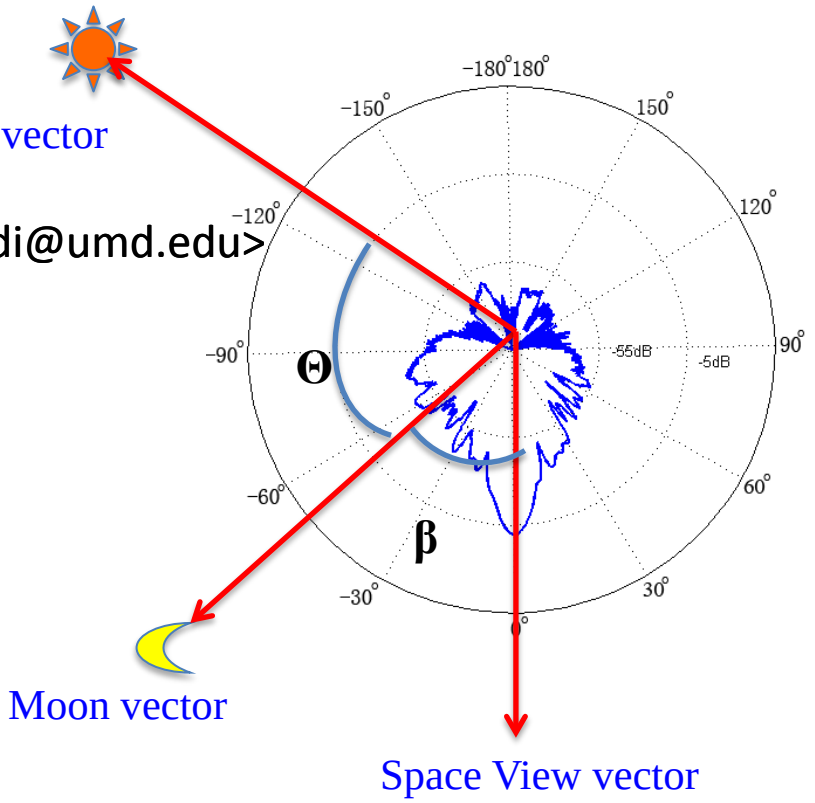
G: Antenna response function

Ω_{moon} Weights of the Moon in antenna pattern:

T_{moon}: Brightness temperature of the Moon

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

Sketch plot of lunar contamination in space view



Isaac Moradi <imoradi@umd.edu>

ATMS SDR Lunar Intrusion Identification and Correction Activities and Results

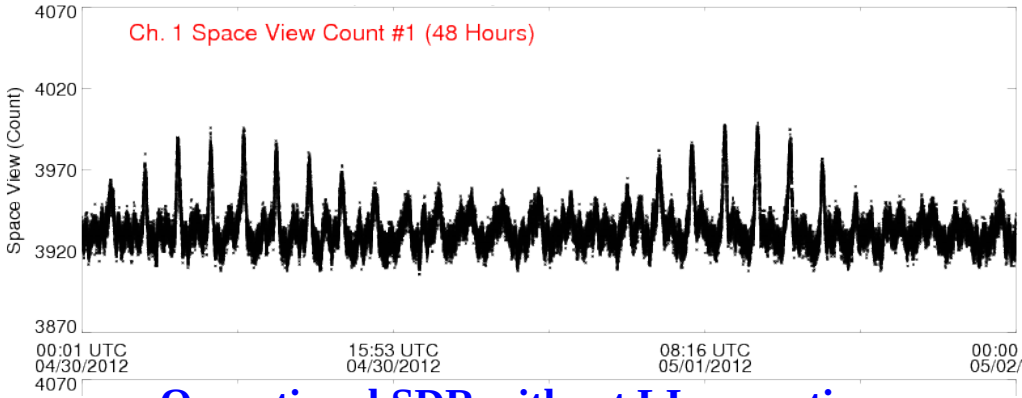
Activities

- ATMS RDR dataset was re-processed using the latest ATMS SDR algorithm code and PCT to evaluate lunar intrusion (LI) detection and correction performance
- The potential impact of current TDR with LI on NWP model was evaluated in GSI
- New metrics and physical model was developed for LI identification and correction
- Different approaches for LI correction was compared and tested in ARTS, optimal algorithm was selected and implemented in current operational calibration system

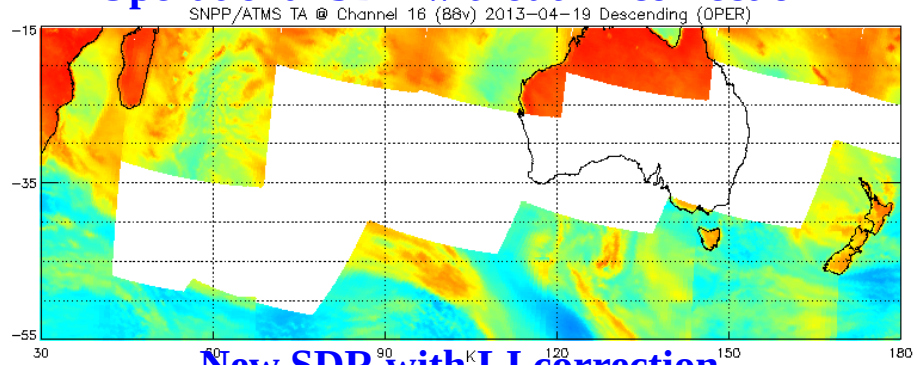
Results

- Lunar intrusion was accurately identified and correctly flagged in SDR datasets
- Data gap was removed after LI correction, residual correction error is below the instrument noise
- New scheme for LI detection and correction was developed for future improvement of current IDPS

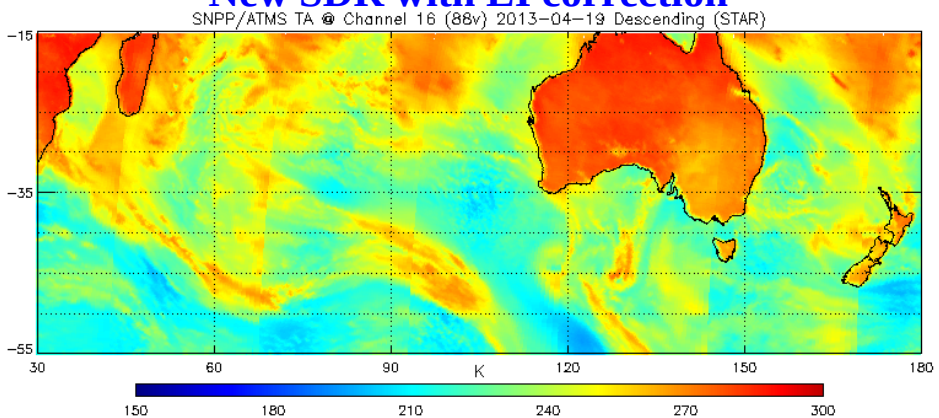
ICVS Monitoring Results of Lunar Intrusion



Operational SDR without LI correction



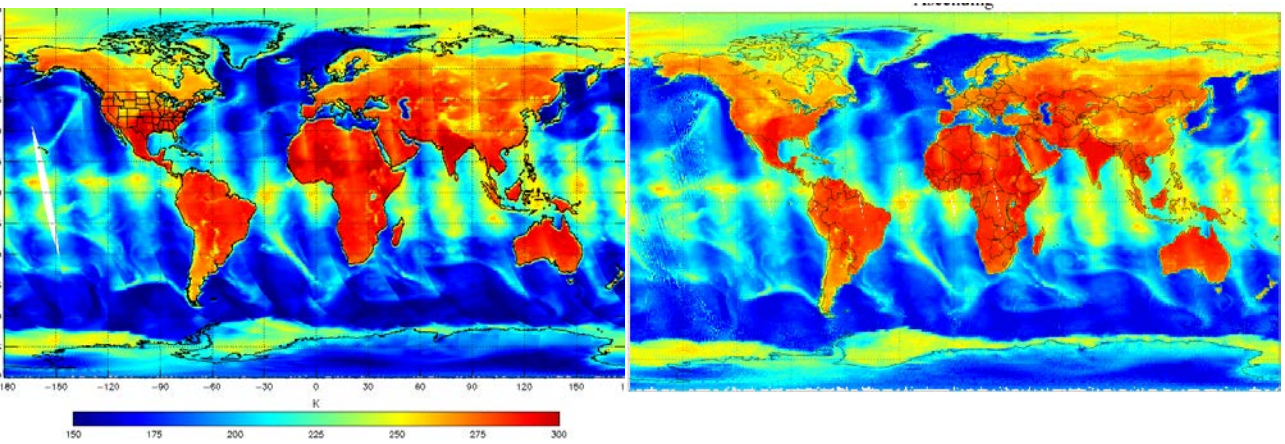
New SDR with LI correction

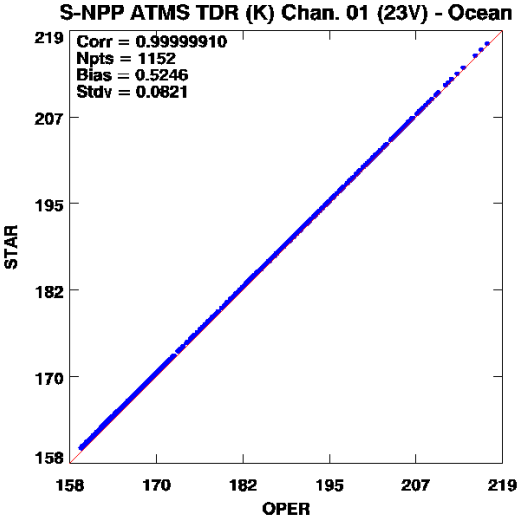


TDR Products from ARTS

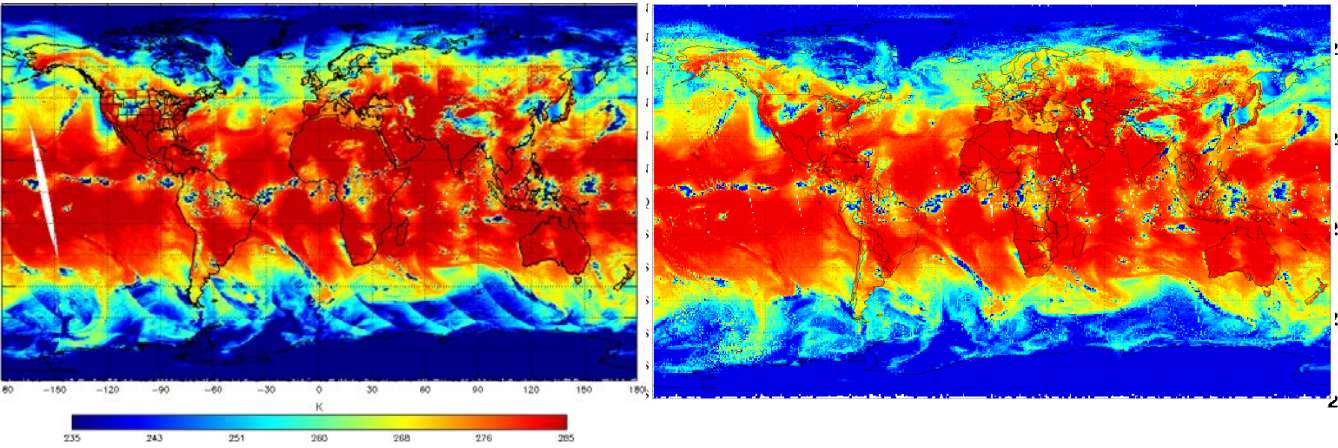
- TDR products are generated on the daily basis
- TB difference ARTS and IDPS is scene and frequency dependent.

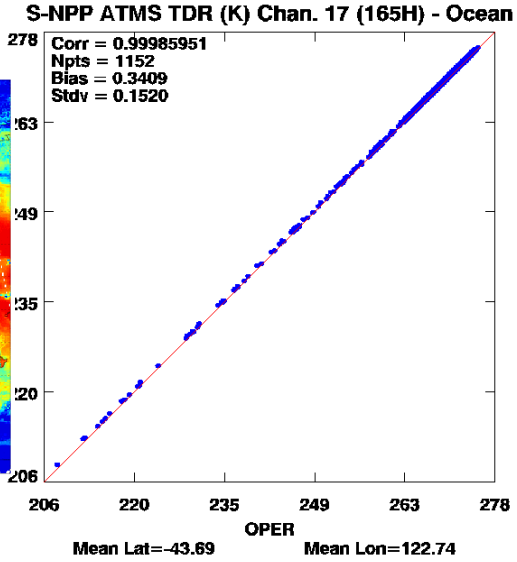
TDR from ARTS ATMS Channel-01 TDR from IDPS





ATMS Channel-17





Conclusions and Future Works

- ARTS is a full radiance calibration system designed for microwave sounding instruments. With new sciences developed from solid study of SNPP ATMS, the calibration accuracy of TDR products from future JPSS satellite will be improved

- ARTS is designed as a robust, sustainable and scientifically defensible operational calibration system for future JPSS satellite, and also can be used as test bed for developing new algorithm.

- Future work will focus on reprocessing SNPP ATMS data using ARTS, generating 2.2^{o} resolution TDR products for use in weather and climate study

Pertinent Publications

- 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

- 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

- Fuzhong Weng, Xiaolei Zou, 2013, “Errors from Rayleigh-Jeans approximation in satellite microwave radiometer calibration systems”, 52 (3) PP. 505-508

- Hu Yang and Xiaolei Zou, 2014, “OPTIMAL ATMS REMAPPING ALGORITHM FOR CLIMATE RESEARCH”, IEEE Transaction on Geoscience and Remote sensing, in print

- Xiaolei Zou, Fuzhong Weng, and Hu Yang, 2014, “Connection the Time Series of Microwave Sounding Observations from AMSU to ATMS for Long-Term Monitoring of Climate Change”, Journal of Climate, accepted for publication

- Hu Yang and Fuzhong Weng, 2014, “On-Orbit ATMS Lunar Contamination Corrections”, Submitted to IEEE Transaction on Geoscience and Remote Sensing