Suomi NPP ATMS SDR Provisional Product Highlights

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Suomi NPP SDR Product Review
NOAA Center for Weather and Climate Prediction (NCWCP)
5830 University Research Park, College Park, Maryland
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Outline

- Team Membership
- ATMS calibration requirements
- ATMS calval task network
- Provisional product highlights
- Lessons Learned and path forward
- Summary

ATMS Team Membership

PI Name	Organization	Team Members	Funding Agency	FY13 Task
Fuzhong Weng	NOAA/STAR	N. Sun, T. Mo, X. Zou, Lin Lin, Li Bi	NJO	Support NPP/J1 Calval
Edward Kim	NASA	Joseph Lyu	NJO	Support NPP/J1 Calval
William Blackwell	MIT/LL	V. Leslie, C. Cull, I. Osaretin, R. Czerwinski, J. Samra, M. Tolman	NJO	Support NPP/J1 Calval
Neal Baker	DPA	M. Denning	NJO	Support NPP/J1 Calval
Kent Anderson	NGES	M. Landrum	NASA	Support NPP/J1 Calval
Degui Gu	NGAS	A. Foo, G. Amici	NASA	Support Transition
Wael Ibrahim	Raytheon		NASA	Support NPP/J1 Calval
Kris Robinson	USU/SDL		NJO	Support NPP/J1 Calval

ATMS Calibration Requirements

#	Channel Freq.(MHz)	Polarization	Bandwidth Max. (MHz)	Freq. Stability (MHz)	Calibration Accuracy	Nonlinearity Max. (K)	NEΔT (K)	3-dB BW* (deg)
1	23800	QV	270	10	0.83	0.1	0.5	5.2
2	31400	QV	180	10	0.83	0.1	0.6	5.2
3	50300	QH	180	10	0.67	0.075	0.7	2.2
4	51760	QH	400	5	0.67	0.075	0.5	2.2
5	52800	QH	400	5	0.67	0.075	0.5	2.2
6	53596±115	QH	170	5	0.67	0.075	0.5	2.2
7	54400	QH	400	5	0.67	0.075	0.5	2.2
8	54940	QH	400	10	0.67	0.075	0.5	2.2
9	55500	QH	330	10	0.67	0.075	0.5	2.2
10	f_o=57290.344	QH	330	0.5	0.67	0.075	0.75	2.2
11	f_o ± 217	QH	78	0.5	0.67	0.075	1.0	2.2
12	f_o ±322.2±48	QH	36	1.2	0.67	0.075	1.0	2.2
13	f_o ±322.2±22	QH	16	1.6	0.67	0.075.	1.5	2.2
14	f_o ±322.2±10	QH	8	0.5	0.67	0.075	2.2	2.2
15	f_o ±322.2±4.5	QH	3	0.5	0.67	0.075	3.6	2.2
16	88200	QV	2000	200	0.95	0.1	0.3	2.2
17	165500	QH	3000	200	0.95	0.1	0.6	1.1
18	183310± 7000	QH	2000	30	0.95	0.1	0.8	1.1
19	183310± 4500	QH	2000	30	0.95	0.1	0.8	1.1
20	183310± 3000	QH	1000	30	0.95	0.1	0.8	1.1
21	183310± 1800	QH	1000	30	0.95	0.1	0.8	1.1
22	183310± 1000	QH	500	30	0.95	0.1	0.9	1.1

ATMS CalVal Task Network

Index	Organizations	Task Name/Number	Objective
#1	MITLL(S) NGES(P) NASA(S)	ATMS Activation sequence / SEV-1	Activate ATMS by safely powering up, initiating a scan profile, and to start collecting science packet data
#2	NOAA/STAR(P)	ATMS Long Term Trending / SEV-2	Trend a multitude of ATMS data to monitor the health, anomalies, and the response of external influences on the instrument
#3	MITLL(S) NGES(P) NASA(S)	ATMS Functional Evaluation	Evaluate that the sensor is operating as expected and was undamaged during the launch phase
#4	NOAA/STAR(CP) MITLL(CP) NASA(CP)	ATMS Space View Sector Selection / TUN-1	Determine which of the pre-determined space view angles have the least interference from the spacecraft or Earth intercept
#5	MITLL(CP) NASA(CP)	ATMS NPP intra-satellite interference evaluation / SEV-4	Determine ATMS RFI susceptibility to instruments and transmitters on NPP
#6	MITLL(CP) NASA(CP)	ATMS NPP Terrestrial Interference Evaluation / SEV-5	Identify RFI from ground sources
#7	MITLL(S) NGES(P) NASA(S)	ATMS Dynamic Range Evaluation / SEV-6	Verify that the radiometric counts do not exceed the specified maximum allowable for the instrument's Analog-to-Digital conversion
#8	MITLL(S) NGES(P) NASA(S)	ATMS Scan Angle Evaluation / SEV-7	Verify that the reflector's scan position in the science data packet matches the expected scan position
#9	NOAA/STAR(S) NGES(P) MITLL(S) NASA(S)	ATMS Radiometric Sensitivity Evaluation / VER-1	Evaluate the on-orbit radiometric sensitivity (NEΔT)
#10	NOAA/STAR(S) NGES(P) MITLL(S) NASA(S)	ATMS Temperature Stabilization / SEV-8	Allow the sensor's temperature to reach equilibrium
#11	MITLL(CP) NASA(CP)	ATMS RF Shelf to Cold Plate LUT Verification / TUN-2	Verify the SDR algorithm LUT then covert the RF Shelf temperature to an appropriate cold plate temperature. Such LUT is used to determine the nonlinearity correction factor based on the present RF Shelf temperature
	MITLL(CP)	ATMS Performance Evaluation: Short Stare & Dwell	Evaluate sensor performance through the sensor's Power Spectral Density (PSD)

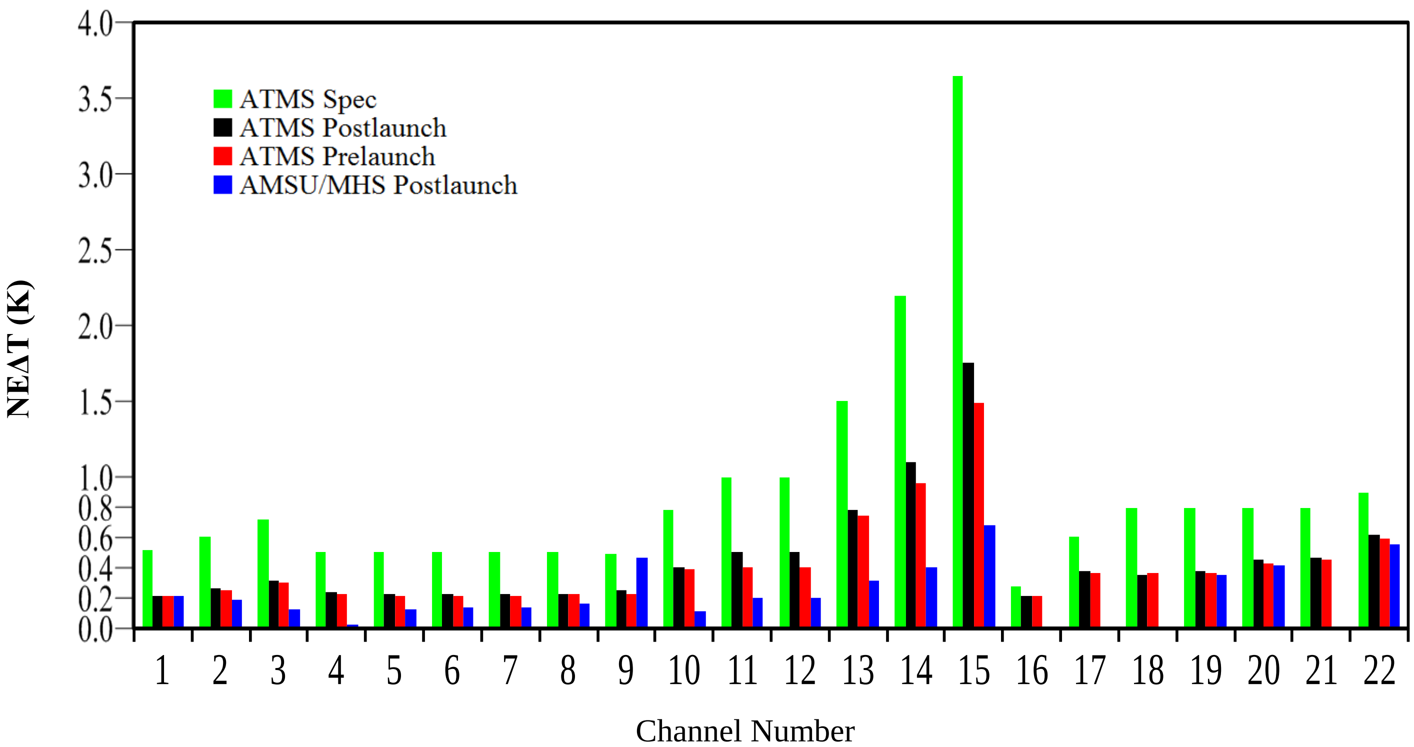
ATMS CalVal Tasks

Index	Organizations	Task Name/Number	Objective
#15	NOAA/STAR(S) MITLL(P) NASA(S)	Roll/Pitch Maneuvers / TUN-4, TUN-5, TUN-6	Characterize the cross-track scan bias dependence and determine at least part of any asymmetries that may exist toward the anti-sun side of the bus
#16	NOAA/STAR(S) SDL(P)	Geolocation Verification / VER-2	Evaluate the pitch, roll, and yaw accuracy of the native ATMS FOVs
#17	MITLL(P)	ATMS Central Frequency Stability / SEV-9	Verify the frequency stability of the opaque 57.29-GHz channels
#18	NOAA/STAR(P) MITLL(S)	SDR Correction Analysis / TUN-7	Calculate the two SDR tunable parameters called the beam efficiency and scan-dependent bias correction factors
#19	NOAA/STAR(S) MITLL(P)	ATMS Resampling Validation using CrIS / VER-3	Validate the ATMS FOV resampling to the CrIS FOR
#20	NOAA/STAR(P)	Ascend/Descend comparisons / VER-4	Determine pointing, navigation, and asymmetry errors by binned and averaged 0.5x0.5 lat-lon boxes for ascending and descending nodes
#21	NOAA/STAR(P) NASA(S)	Simultaneous Nadir Overpass (SNO) / VER-5	Inter-calibrate polar orbiting radiometers across satellites to achieve the consistency and traceability required for long term climate studies from the more than 20 years of NOAA satellite data. In addition, the calibration of current operational radiometers should be linked to those of the next generation meteorological satellites such as NPOESS
#22	NOAA/STAR(P)	Double Difference / VER-6	Inter-calibrate polar orbiting radiometers across satellites.
#23	NOAA/STAR(S) SDL(P) MITLL(S)	ATMS SDR validation by RAOB / VER-7	Assemble a “golden set” of a few hundred matchups of Radiosonde and CrIMSS FOR’s over clear-sky area and validate ATMS SDR
#24	NOAA/STAR(P) MITLL(S)	ATMS SDR validation by NWP / VER-8	Identify SDR and remap SDR bias using NCEP GFS/GDAS data
#25	MITLL(P) NASA(S)	High-Altitude Aircraft Validation Campaigns / VER-9	Compare high-resolution and high altitude aircraft brightness temperature images with those from coincident satellite overpasses.

ATMS SDR Provisional Product Highlights

- Stable instrument performance and calibration
- All the ATMS channels have noises much lower than specification
- ATMS processing coefficients table (PCT) are updated with nominal values
- Quality flags (e.g. spacecraft maneuver and scanline, calibrations) are checked and will be updated in the MX7.0
- Geolocation errors for all the channels are quantified and meet specification
- Remap SDR coefficients are updated using on-orbit CrIS data (e.g. CrIMSS now fully synchronized) and RSDR biases are assessed
- On-orbit absolute calibration is explored using GPS RO data, LBLRTM and ATMS SRF. All the sounding channels have biases much less than specification of accuracy
- A theory for converting from DR to SDR is fully developed and tested for ATMS. ATMS scan bias correction coefficients are derived.

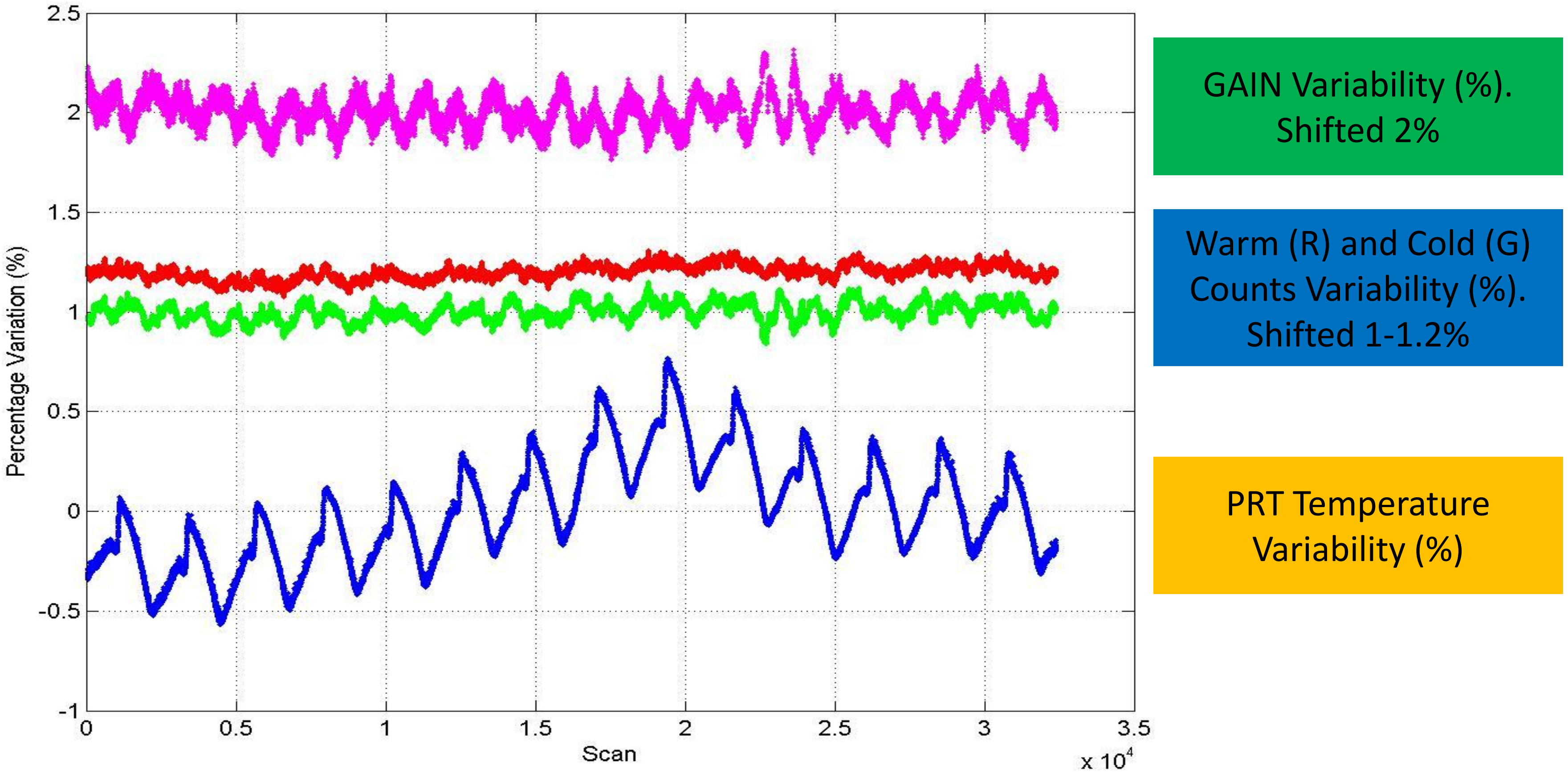
Channel Noise Characterization



All Channels are within Specifications

Slide courtesy of STAR

Calibration Target Consistency Check

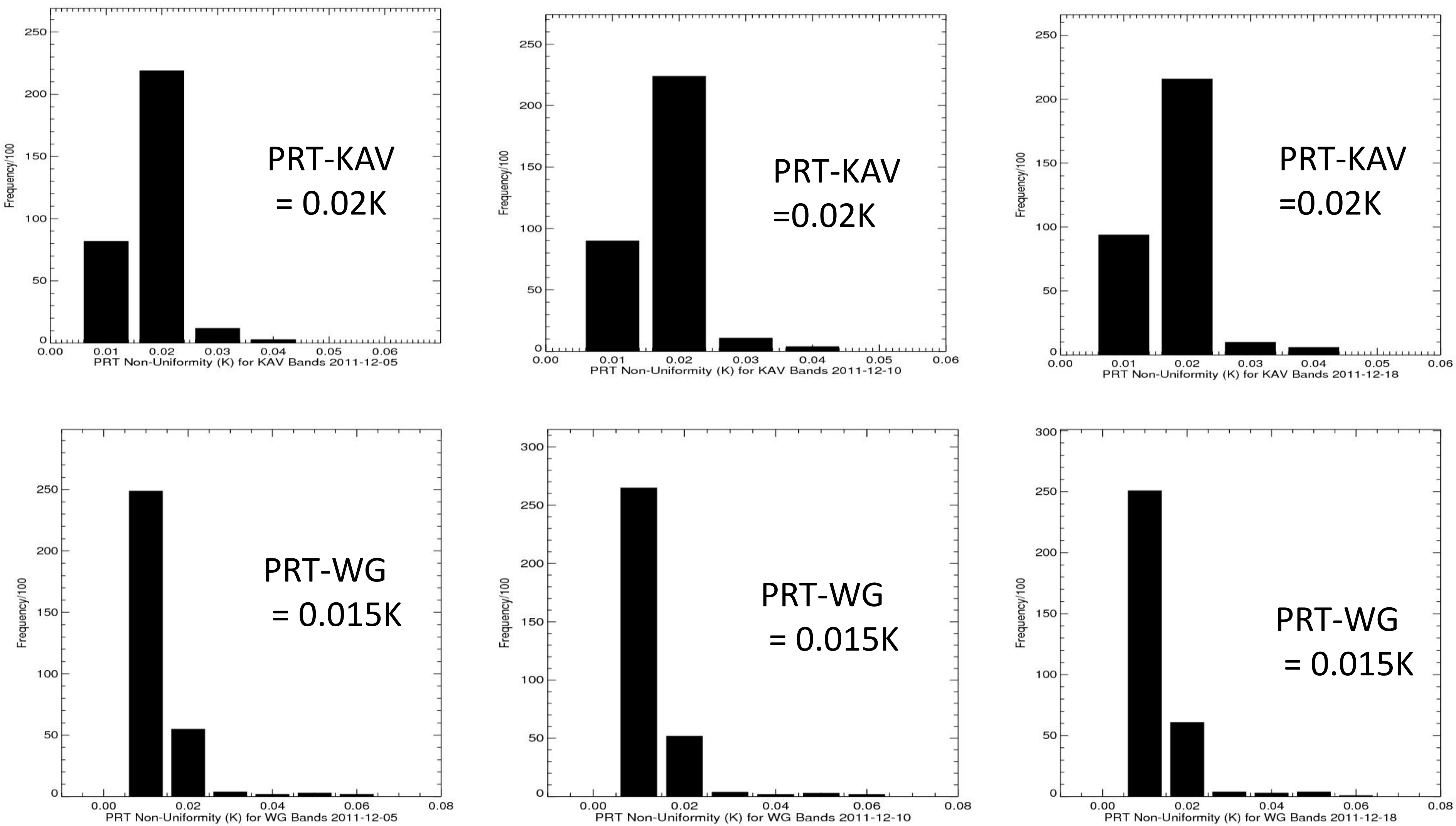


ATMS calibration data consistency check. Channel 16. Nov 18, 2011. Data downloaded from GTP. Cold counts have more variability than warm counts, and gains also show significant variability. Need further investigation and assessment of impact on SDR quality

Slide courtesy of NGAS

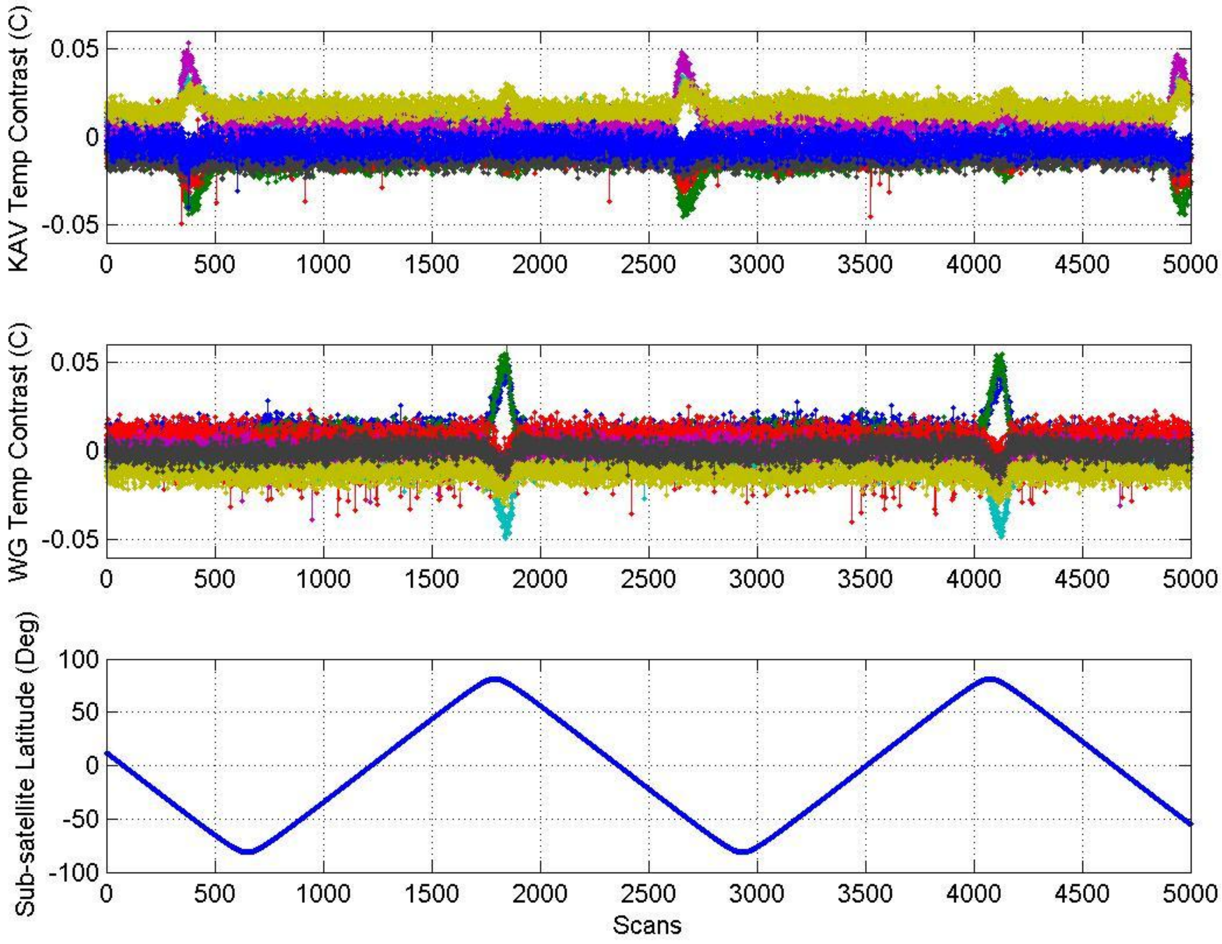
ATMS PRT Uniformity Check

12-05-2011 | 12-10-2011 | 12-18-2011



Slide courtesy of STAR

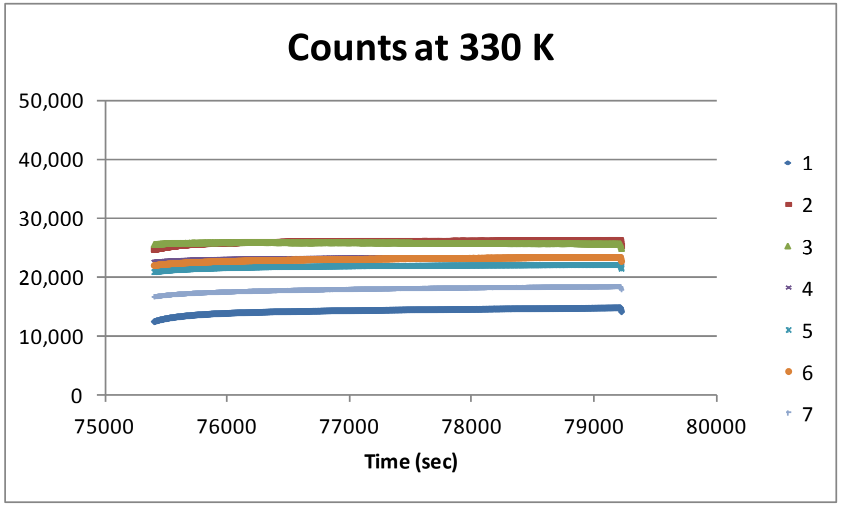
PRT Temperature Uniformity Check

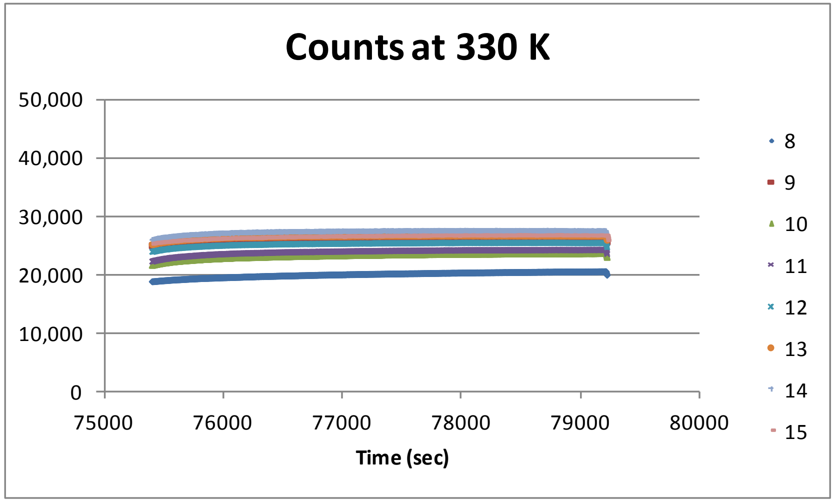


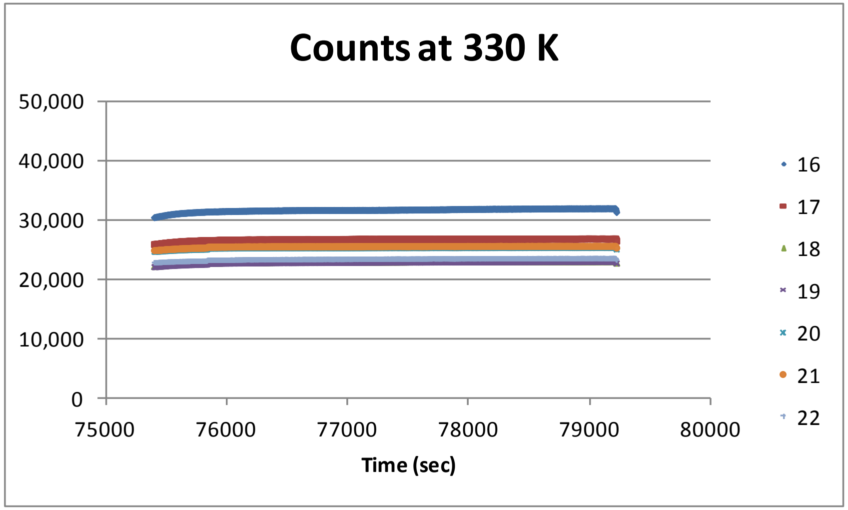
Warm load PRT temperature contrast spiked around the north pole for the WG bands. Similar spikes occurred at ~45 degree south for the KAV bands

Slide courtesy of NGES

ATMS Dynamic Range Count (Warm)





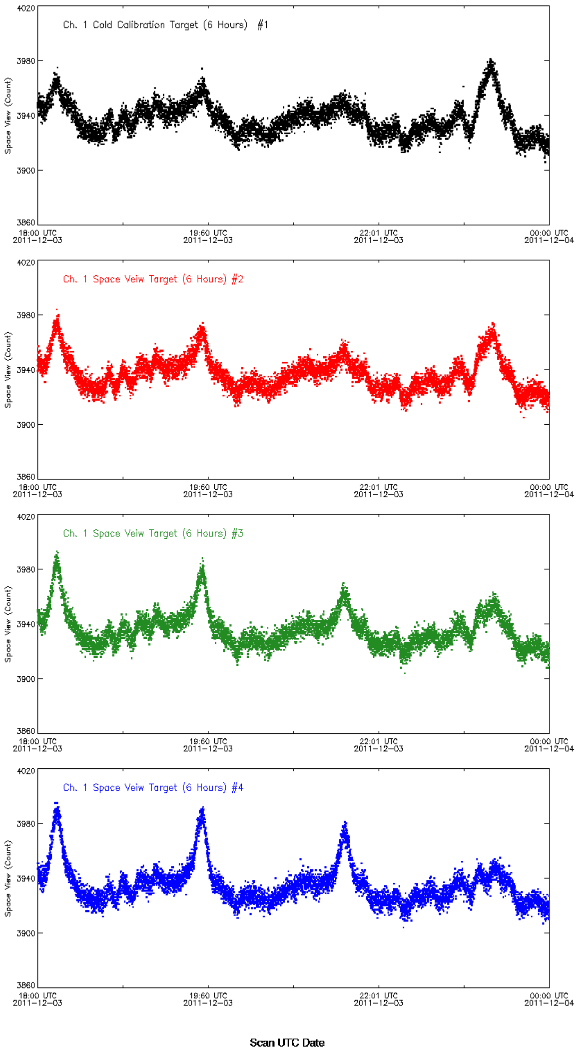


- **Dynamic range is assessed by comparison to requirement that maximum allowable radiometric counts, for any channel, shall be < 45,150**
- **The dynamic range assessment is done by extrapolating the warm target counts to a 330 K temperature, using gains computed from on-orbit data.**
- **As shown in chart, for orbit 163, all channels consistently met the criterion that counts (330K) < 45,150. Over 13,100 counts margin relative to 45,150 limit. Dynamic range requirements are satisfied**

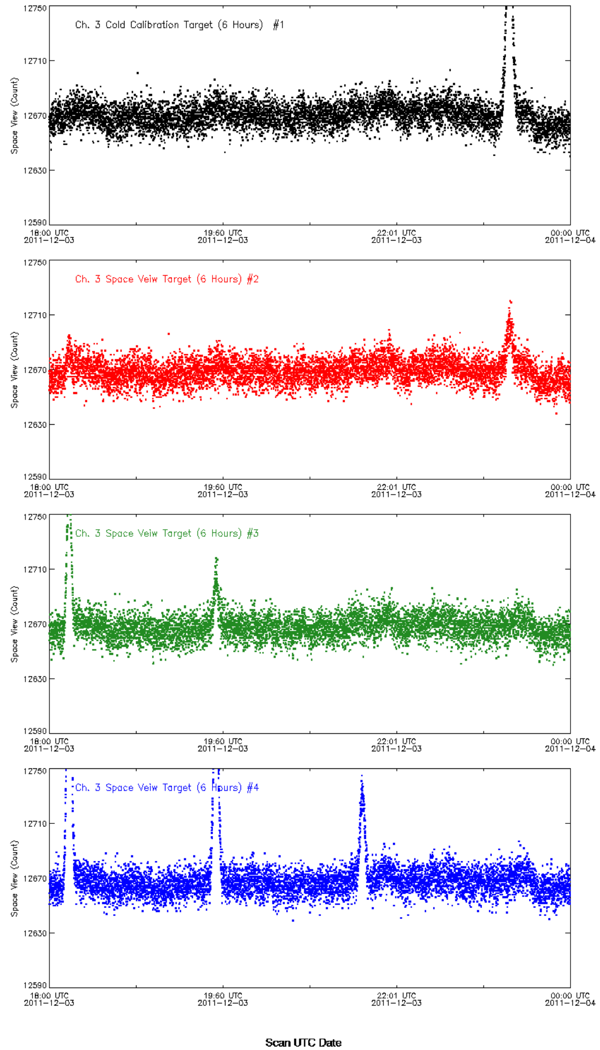
Slide courtesy of NGES

Lunar Intrusion Detection

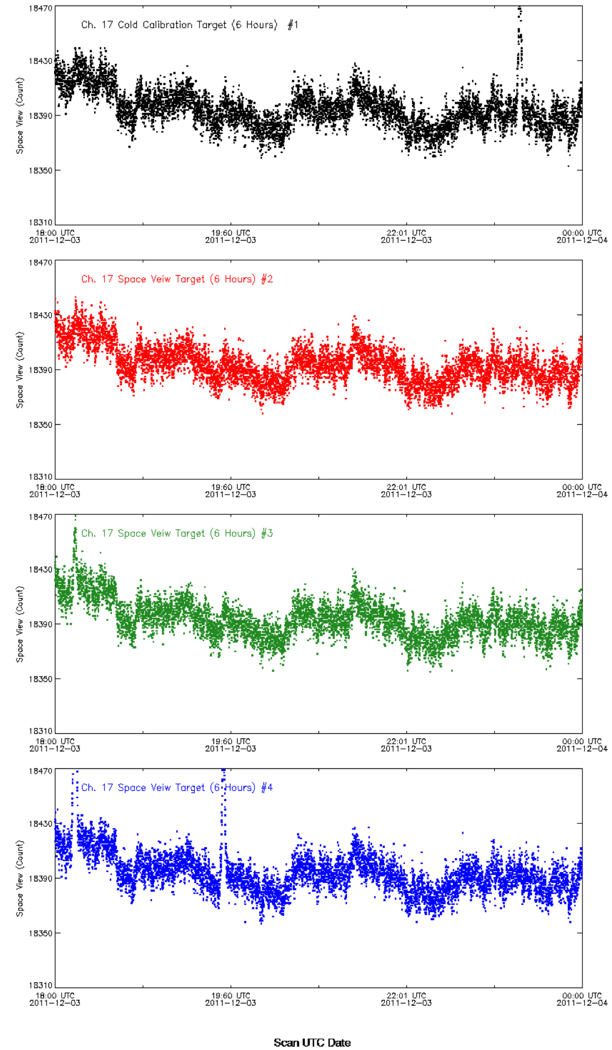
Channel 1 (FOV Size:5.2)



Channel 3 (FOV Size: 2.2)

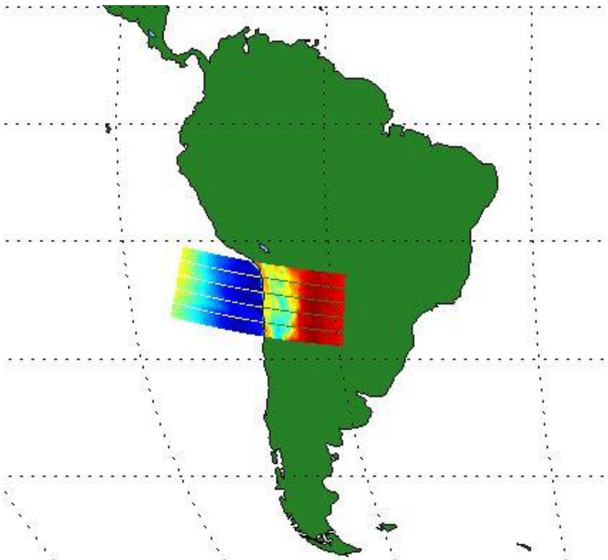


Channel 17 (FOV Size: 1.1)

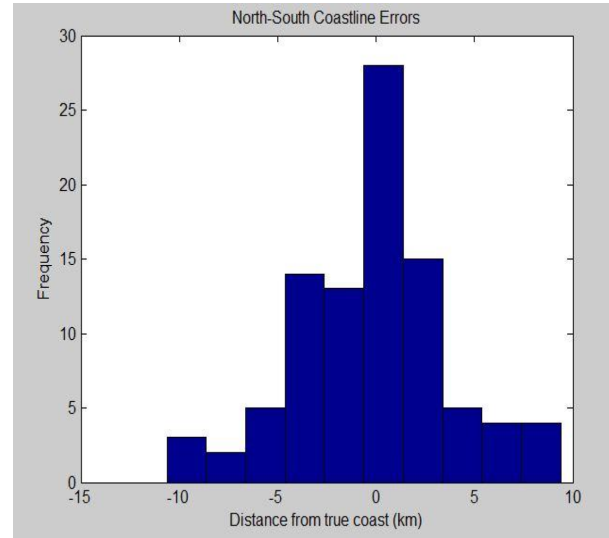


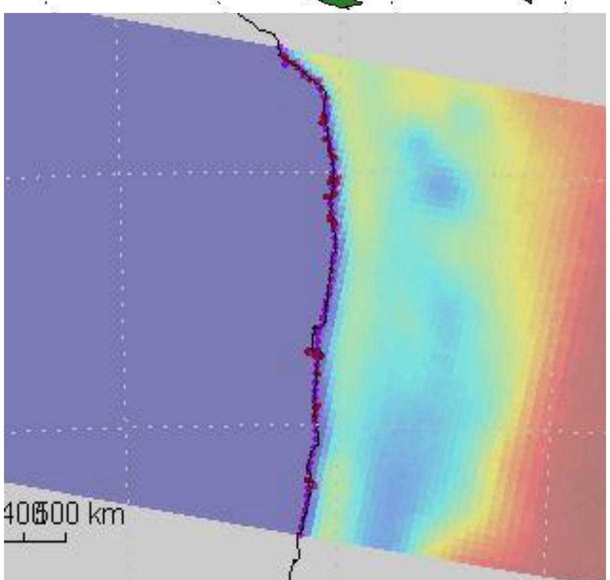
Slide courtesy of STAR

Geolocation Verification

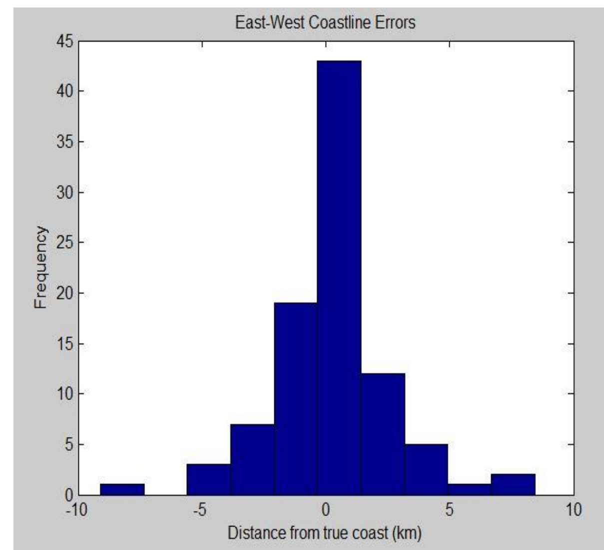


North – South
Mean -0.15km
0.01°
Std. Deviation
3.98km 0.28°



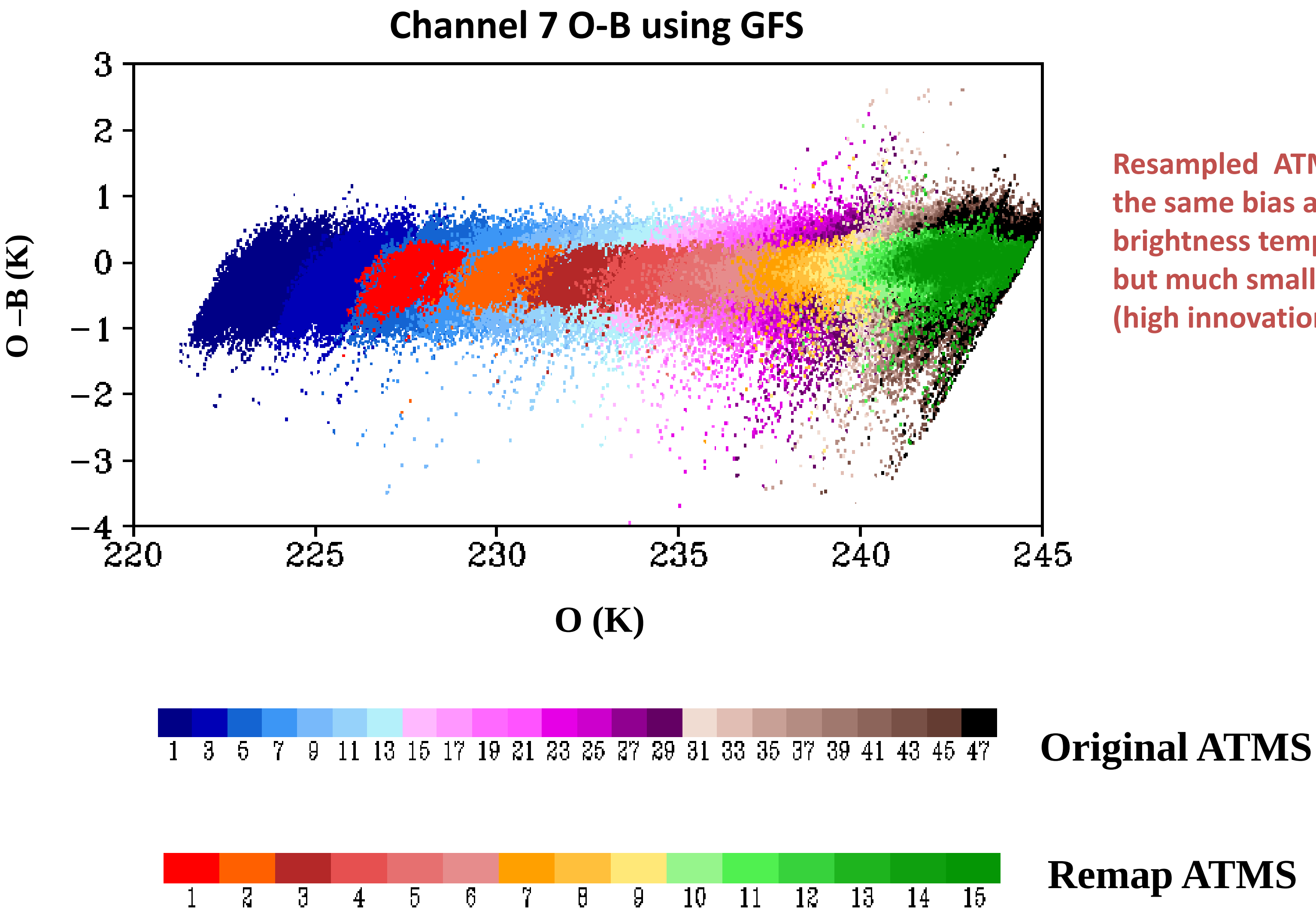


East – West
Mean -.027km
0.02°
Std. Deviation
2.34km 0.16°



Slide courtesy of SDL

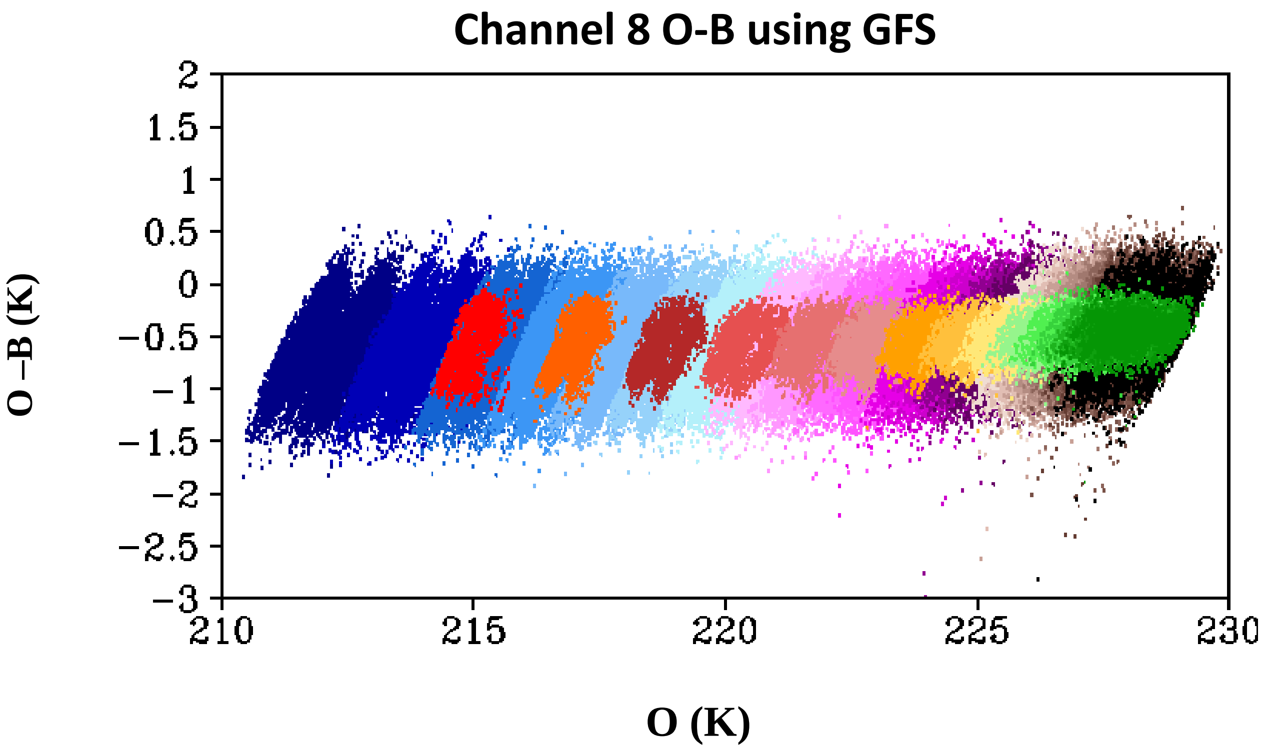
Assessments of ATMS Remap SDR (RSDR)



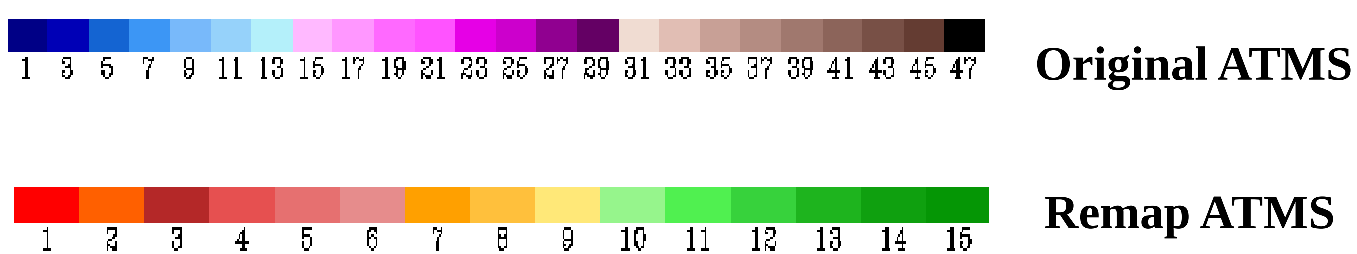
Resampled ATMS has the same bias at all brightness temperatures but much smaller spread (high innovation)

Slide courtesy of STAR

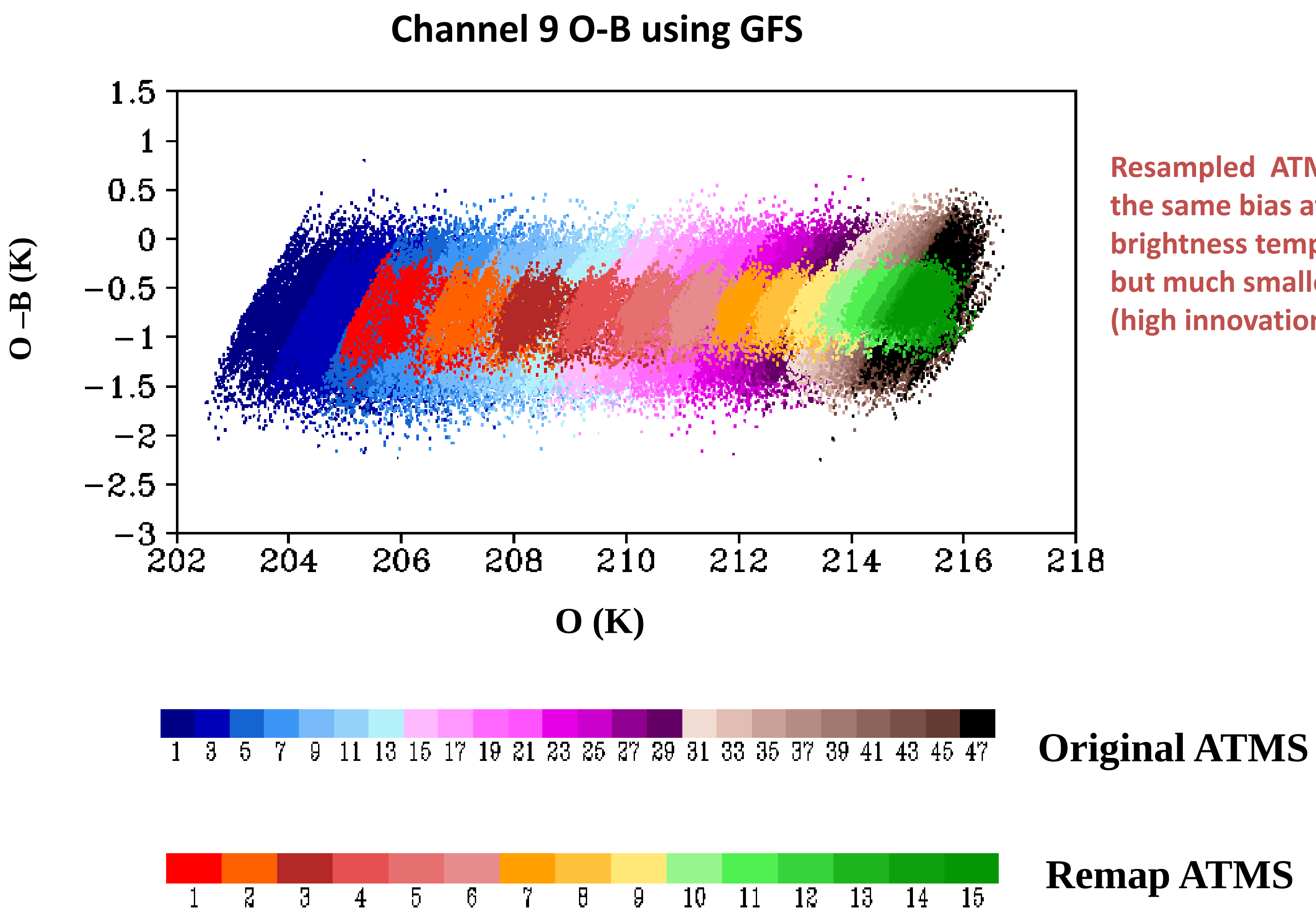
Assessments of ATMS Remap SDR (RSDR)



Resampled ATMS has the same bias at all brightness temperatures but much smaller spread (high innovation)



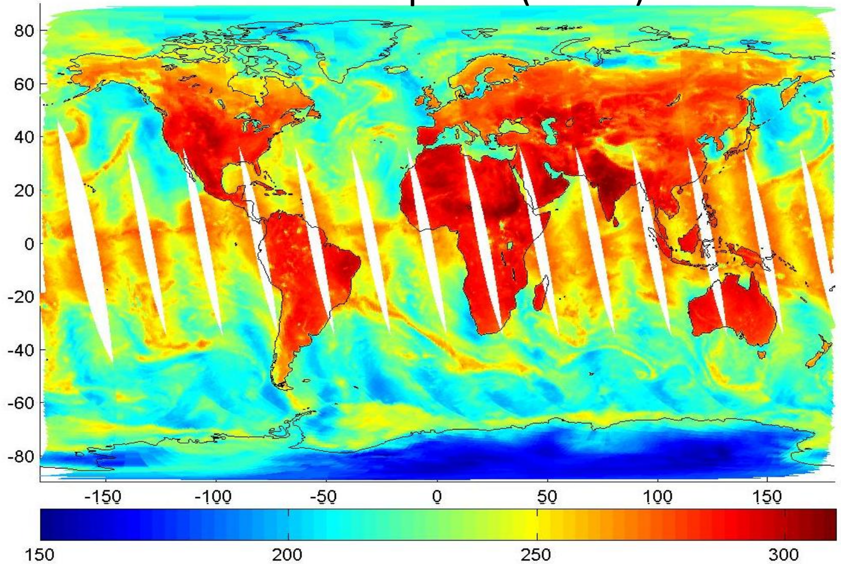
Assessments of ATMS Remap SDR (RSDR)



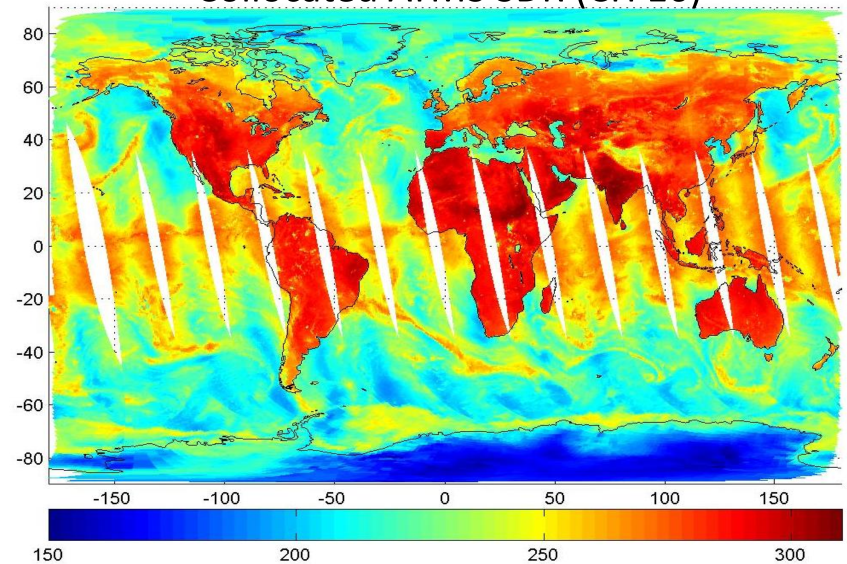
Resampled ATMS has the same bias at all brightness temperatures but much smaller spread (high innovation)

ATMS Remap SDR Evaluation

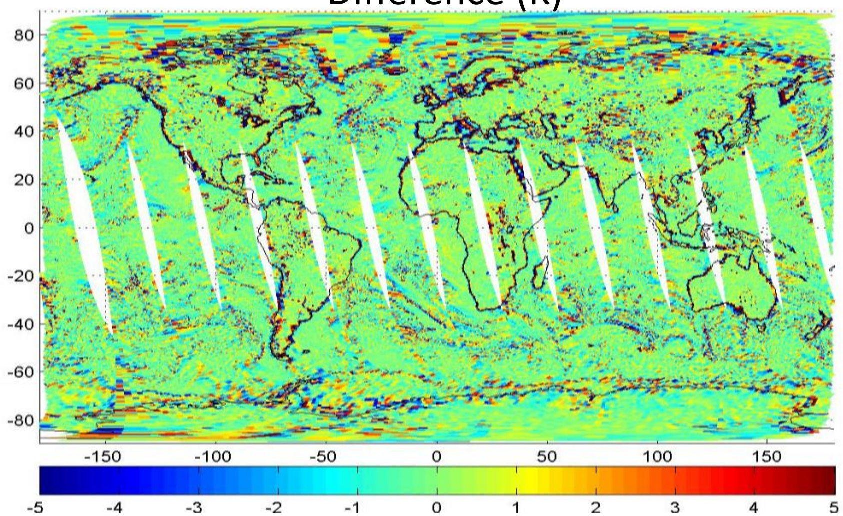
IDPS Remap SDR (CH 16)

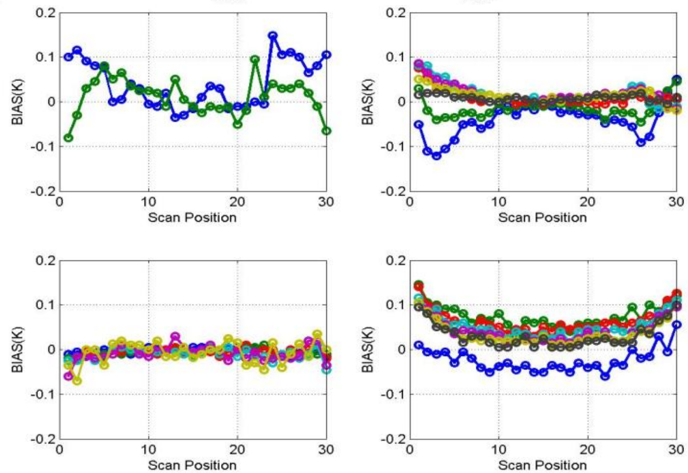


Collocated ATMS SDR (CH 16)



Difference (K)





No Significant Biases Between Remapped SDRs and Collocated ATMS SDRs

Slide courtesy of NGAS

ATMS Calibration Accuracy Assessment Using GPSRO

- **Time period of data search:**

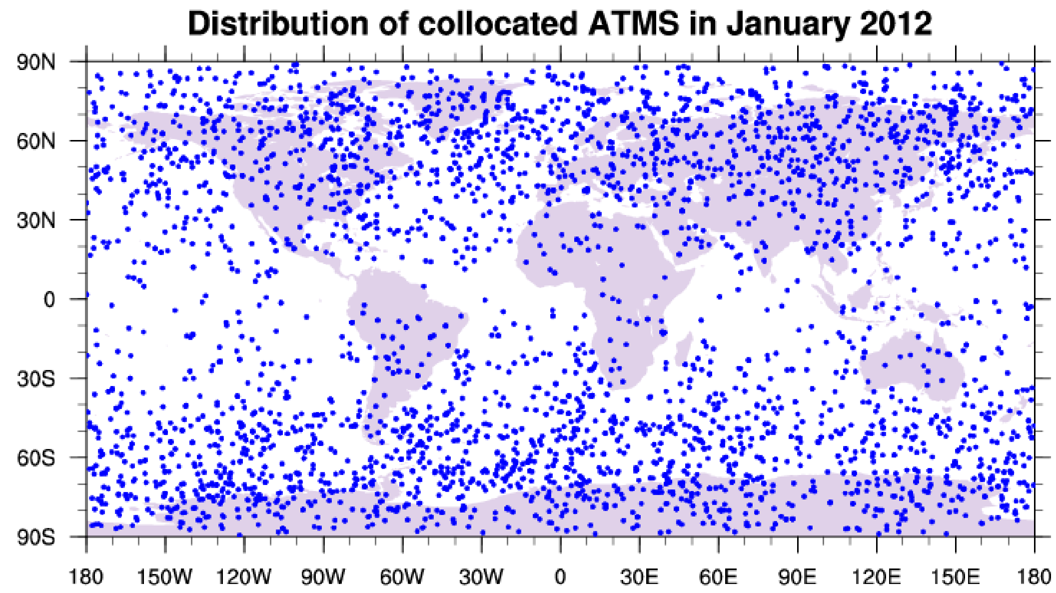
  January, 2012

- **Collocation of CloudSat and COSMIC data:**

  Time difference < 0.5 hour

  Spatial distance < 30 km

(GPS geolocation at 10km altitude is used for spatial collocation)

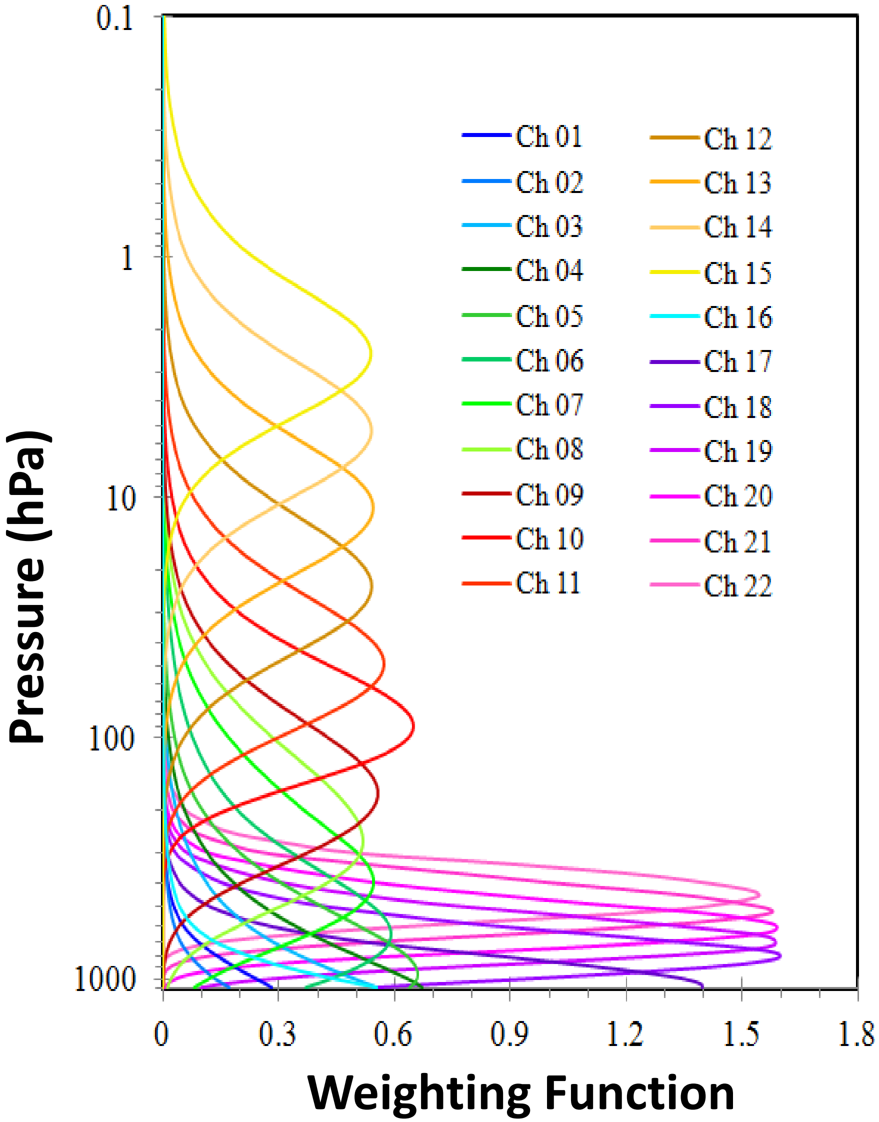


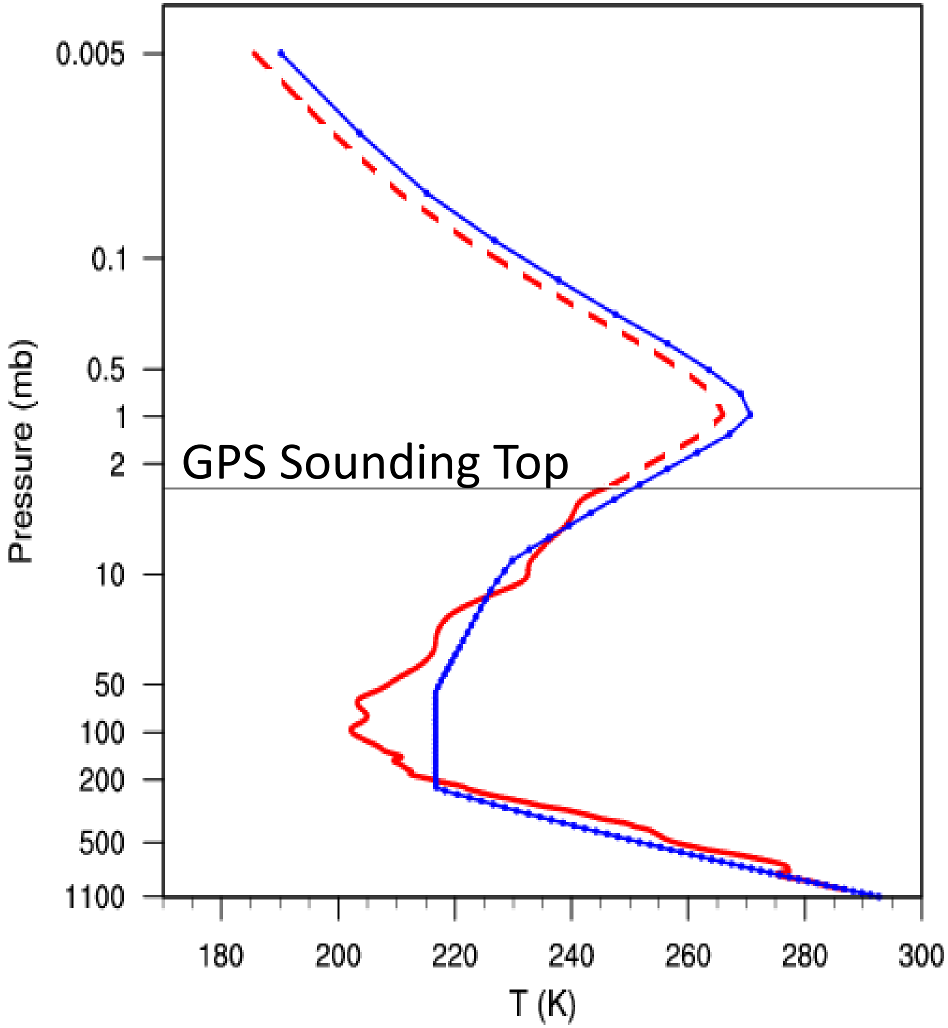
3056 collocated measurements

Slide Courtesy of STAR

ATMS WF (U.S. Standard Atmosphere)

Add 1976 U.S. Standard Atmosphere State to GPS Soundings

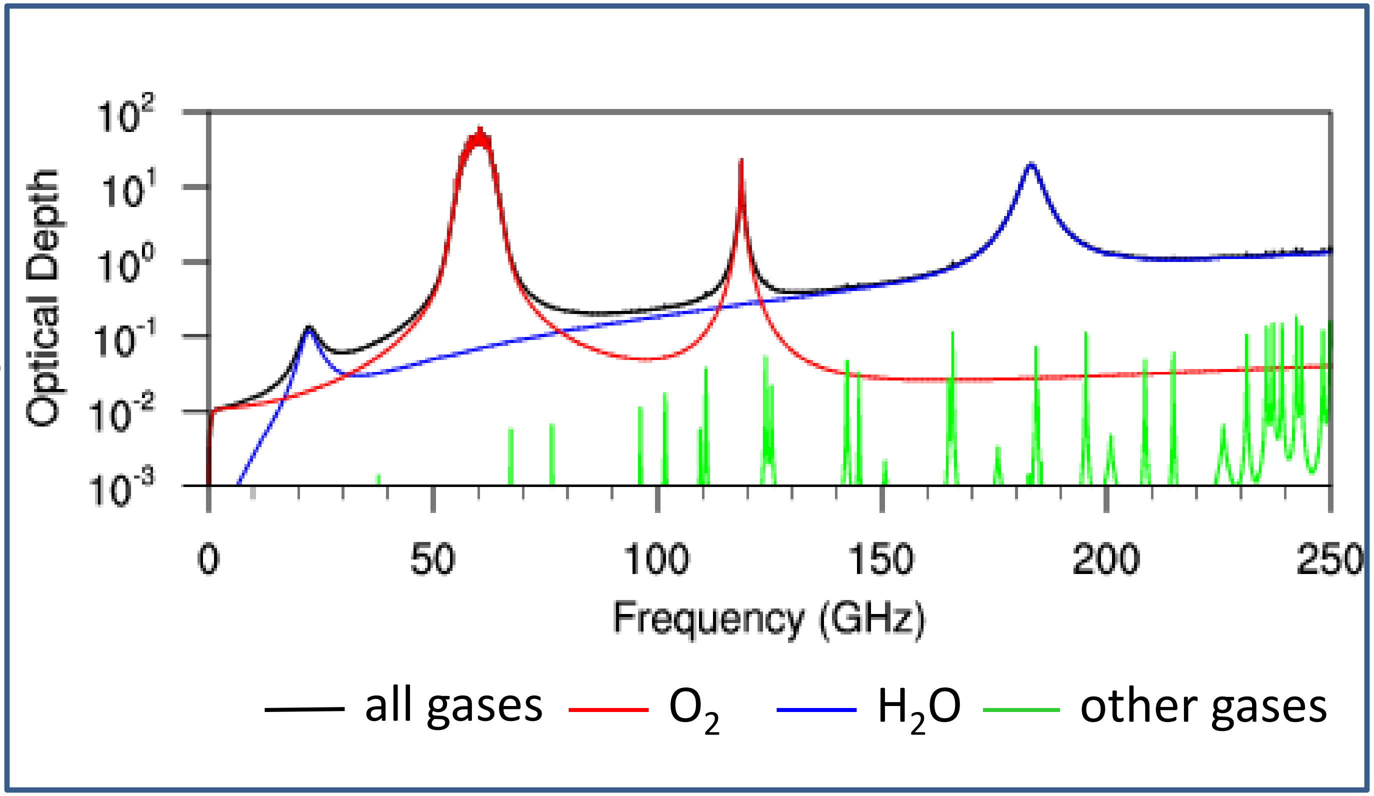




1051 UTC on January 1, 2012

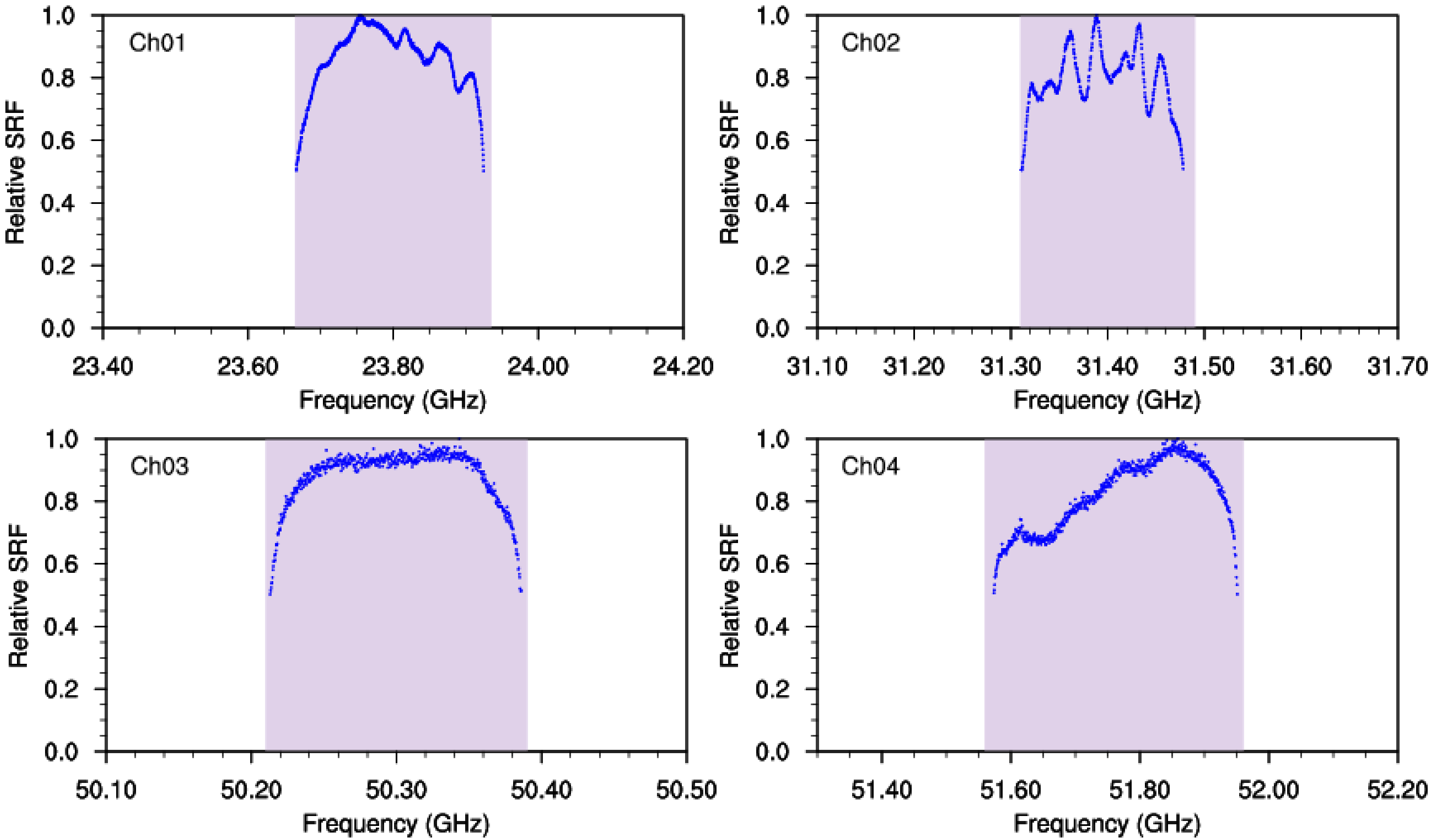
Line by Line RTM

- Perform a line by line radiative transfer calculation
- Accurate atmospheric spectroscopy data base
- Only gaseous absorption
- Vertical stratification



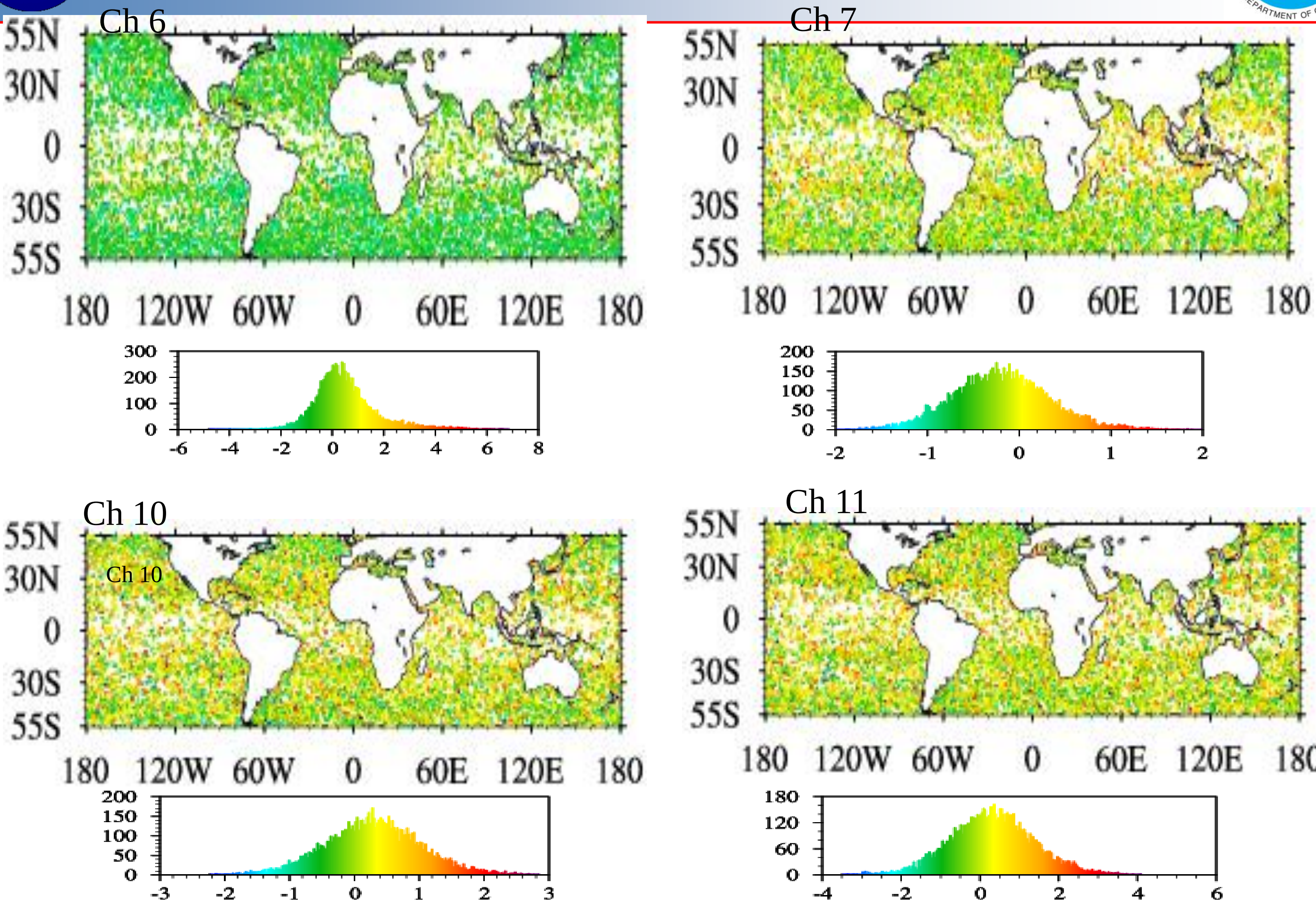
Microwave sounding channels at 50-60 GHz O_2 absorption band can be best simulated under a cloud-free atmosphere using line by line calculation

Effects of ATMS Spectral Response Function



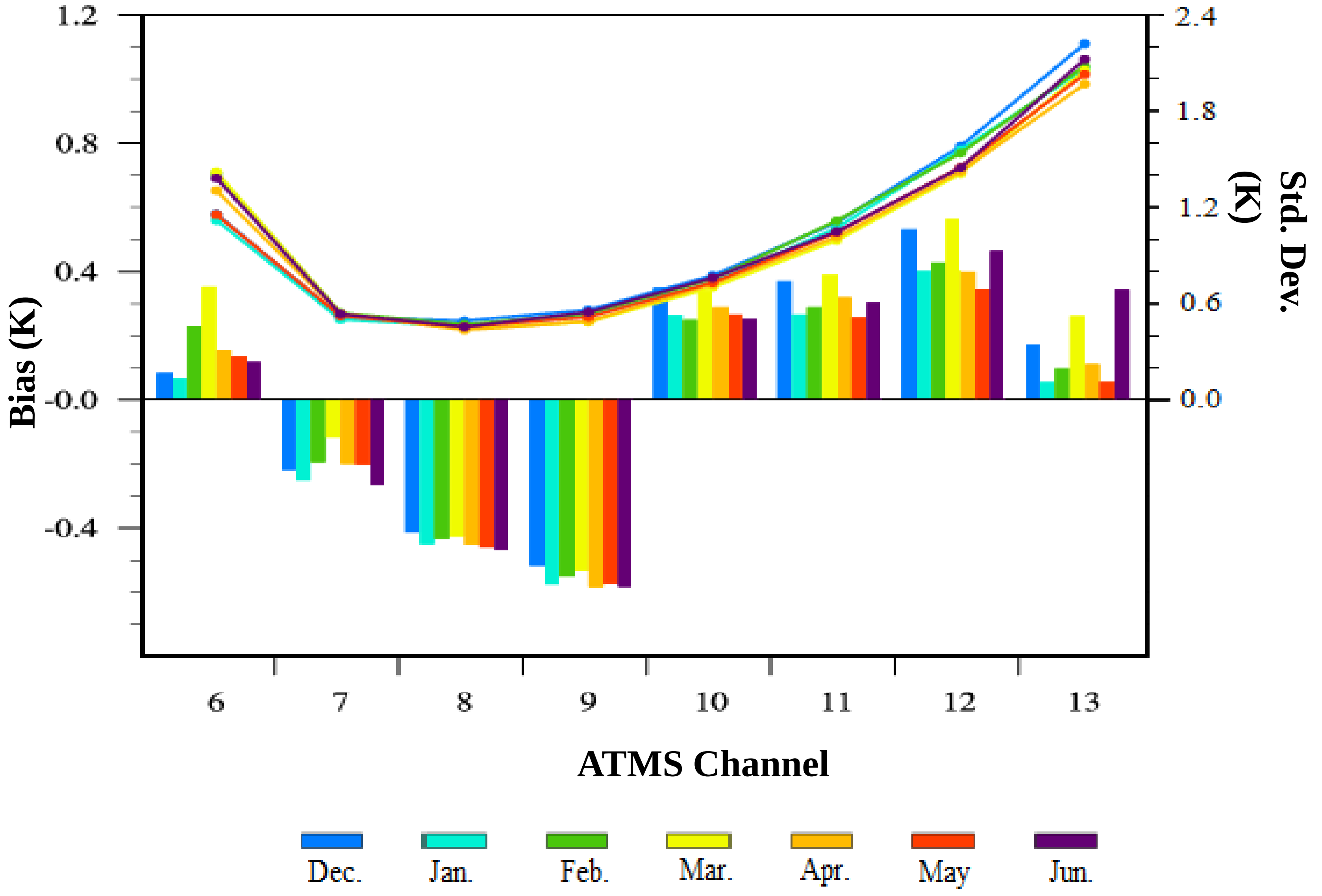
Slide courtesy of STAR

ATMS Bias Obs (TDR) - GPS Simulated



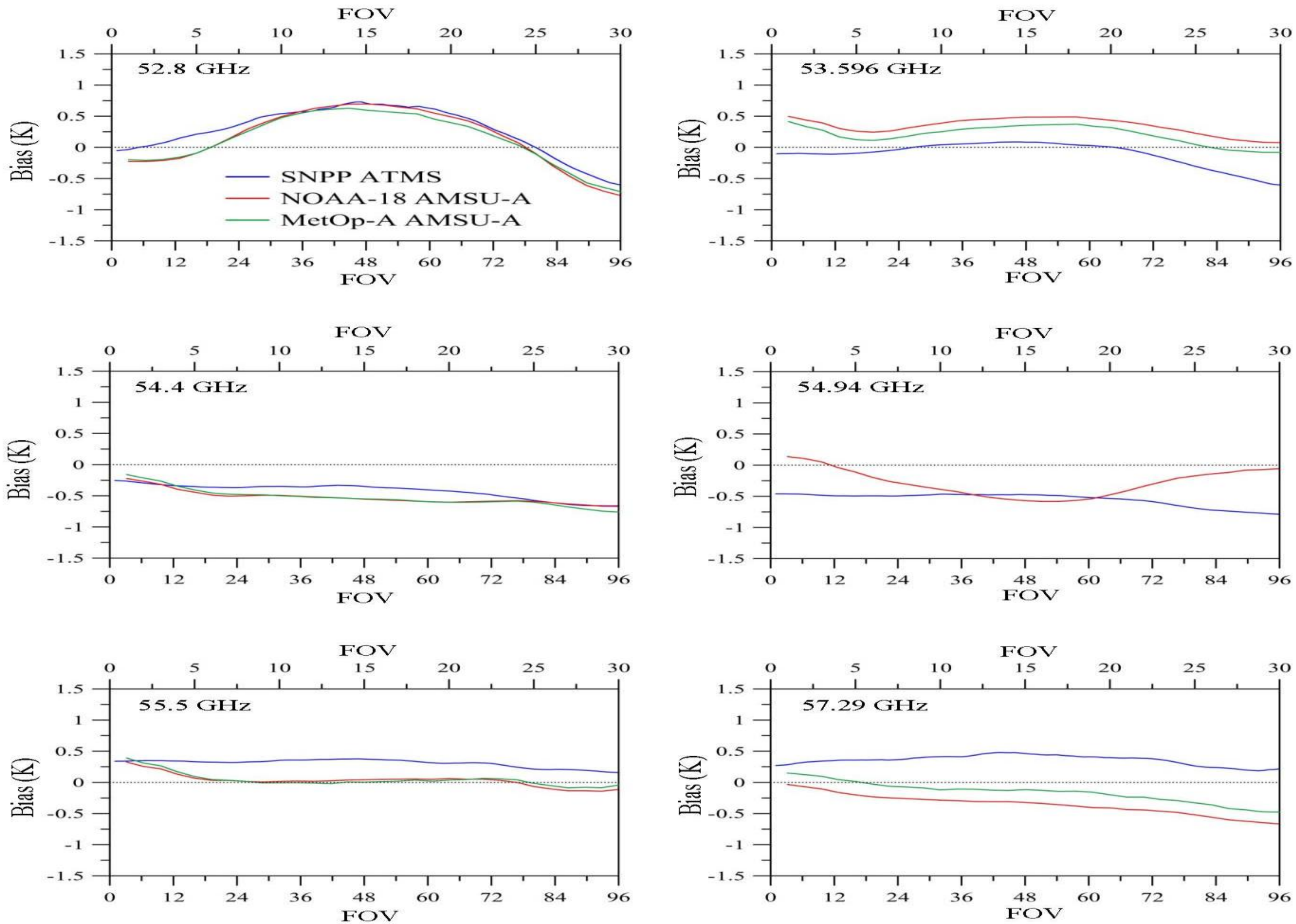
O-GPS (K) *Slide courtesy of STAR* O-GPS (K)

ATMS Bias Obs - Sim (GPSRO)



Slide courtesy of STAR

ATMS Bias Compared to AMSU-A



Slide courtesy of STAR

ATMS SDR Algorithm Formulation

SDR

TDR

$$T_a^{Qv} = \eta_{me}^{vv} T_b^{Qv} + \eta_{me}^{hv} T_b^{Qh} + \eta_{se}^{vv} E_b^{Qv} + \eta_{se}^{hv} E_b^{Qh} + \eta_{sc}^{vv} C_b^{Qv} + \eta_{sc}^{hv} C_b^{Qh} + S_a^{Qv}$$

SDR

$$T_a^{Qh} = \eta_{me}^{hh} T_b^{Qh} + \eta_{me}^{vh} T_b^{Qv} + \eta_{se}^{hh} E_b^{Qh} + \eta_{se}^{vh} E_b^{Qv} + \eta_{sc}^{vv} C_b^{Qv} + \eta_{sc}^{hv} C_b^{Qh} + S_a^{Qh}$$

Weng et al., 2012, GRSL

The first two terms are Quasi-V and Quasi-H brightness temperature from earth in the main beam (main lobe earth), the 3rd/4th terms are those from the side-lobe earth, the 5/6th terms are the side-lobe cold space, the last term is the near-field satellite radiation

$$T_b^{Qv} = T_b^{v} \cos^2\theta + T_b^{h} \sin^2\theta \qquad T_b^{Qh} = T_b^{v} \sin^2\theta + T_b^{h} \cos^2\theta$$

Under a polarized earth scene, the side lobe together with cross-polarization term can result in large errors in computing SDR from TDR data if the antenna has a significant spill-over effect and the cross-polarization term is neglected.

Convertibility Issues from TDR to SDR

- Need to correct side-lobe radiation from far-field earth and near-field satellites
- For un-polarized surface and atmospheric conditions, the inversion from TDR to SDR is possible with a single polarization measurement.
- For an instrument with a significant cross-polarization spill-over, an inversion from TDR to SDR is problematic if a single polarization measurement is available.

ATMS Antenna Beam Efficiency

Frequency (GHz)	θ_{3dB} (degree)	η_{me}^{pp} (%)			η_{me}^{pq} (%)			$\eta_{se}^{pp}+\eta_{sc}^{pp}+\eta_{ss}^{pp}$ (%)		
		B1	B48	B96	B01	B48	B96	B01	B48	B96
23.8	5.25	99.48	99.61	99.53	0.52	0.39	0.46	0.003	0.0002	0.0025
31.4	5.35	99.59	99.60	99.60	0.40	0.40	0.39	0.003	0.0003	0.0024
50.3	2.20	99.43	99.39	99.56	0.57	0.61	0.44	0.001	0.0006	0.0008
51.8	2.25	99.45	99.47	99.73	0.55	0.53	0.27	0.001	0.0004	0.0007
52.8	2.25	99.48	99.46	99.36	0.51	0.54	0.64	0.001	0.0004	0.0010
53.6	2.20	99.49	99.43	99.31	0.51	0.57	0.68	0.001	0.0004	0.0008
54.4	2.15	99.51	99.51	99.55	0.49	0.49	0.44	0.001	0.0006	0.0006
54.9	2.20	99.48	99.49	99.21	0.51	0.51	0.78	0.001	0.0004	0.0007
55.5	2.15	99.50	99.52	99.54	0.50	0.48	0.46	0.001	0.0004	0.0007
57.3	2.20	99.48	99.49	99.48	0.52	0.51	0.52	0.001	0.0006	0.0007
88.2	2.05	97.73	97.70	97.92	2.27	2.30	2.07	0.002	0.0012	0.0035
166.5	1.16	98.00	97.77	96.92	1.98	2.21	3.06	0.013	0.0147	0.0085
176.31	1.10	97.92	97.77	96.17	2.07	2.21	3.81	0.009	0.0115	0.0075
183.31	1.10	97.69	98.48	98.86	2.29	1.50	1.12	0.009	0.0108	0.0083
190.31	1.07	98.23	97.94	97.80	1.75	2.03	2.18	0.011	0.0138	0.0111

From STAR' calculation

ATMS SDR Algorithm

For Quasi-V :

$$T_b^{Qv} = (T_a^{Qv} - \beta_0^v - \beta_1^v \sin^2\theta) / \eta_m^{vv}$$

For Channels 1, 2, 16

For Quasi-H:

$$T_b^{Qh} = (T_a^{Qh} - \beta_0^h - \beta_1^h \cos^2\theta) / \eta_m^{hh}$$

For Channels 4~15, and 17~22

$$\eta_m^{pp} = \eta_{me}^{pp} + \eta_{se}^{pp}$$

Caveats: Cross-polarization spill-over is neglected. The main contribution from the side-lobe earth is next to the main beam. Atmosphere is also unpolarized and both side-lobe earth and spill-over are included in the main beam efficiency which is close to 1.0

Status of ATMS Discrepancy Reports

25 DRs Opened

9 DRs Closed

3 DRs remain open for provisional version

- 4811 - PRT consistency check (analysis is done in ADL4.0)
- 4593 – ATMS DQTT (draft values accepted, RTN will test)
- 4806 – Scan bias correction (convertibility theory/draft values proposed)

12 DRs remain open for validated version

Lesson Learned from NPP ATMS

- Uncertainty in the current ATMS radiometric calibration
  - Uses of Rayleigh-Jeans approximation result in significant uncertainty in calibration although empirical corrections are applied
- Uncertainty related to ATMS antenna cross polarization
  - Current ATMS antenna has 1 to 2% cross-polarization spill-over for some channels. Over oceans where the surface is polarized, TDR to SDR conversion would have a large uncertainty due to neglecting cross-pol spill-over
- Uses of Backus-Gilbert for channel 1 to 2 enhancement
  - ATMS noise is very low and the FOV enhancements for ch 1 and 2 seem to be likely for better depicting the storm structure
- Channel dependent calibration procedure for reducing the striping
  - Need to further reduce the ATMS striping for the upper-level channels

ATMS Radiometric Calibration Using Rayleigh-Jeans (RJ) Approximation: Ill-Posted Approach in IDPS

$$R_s = \delta_c (R_w - R_c) + R_c$$

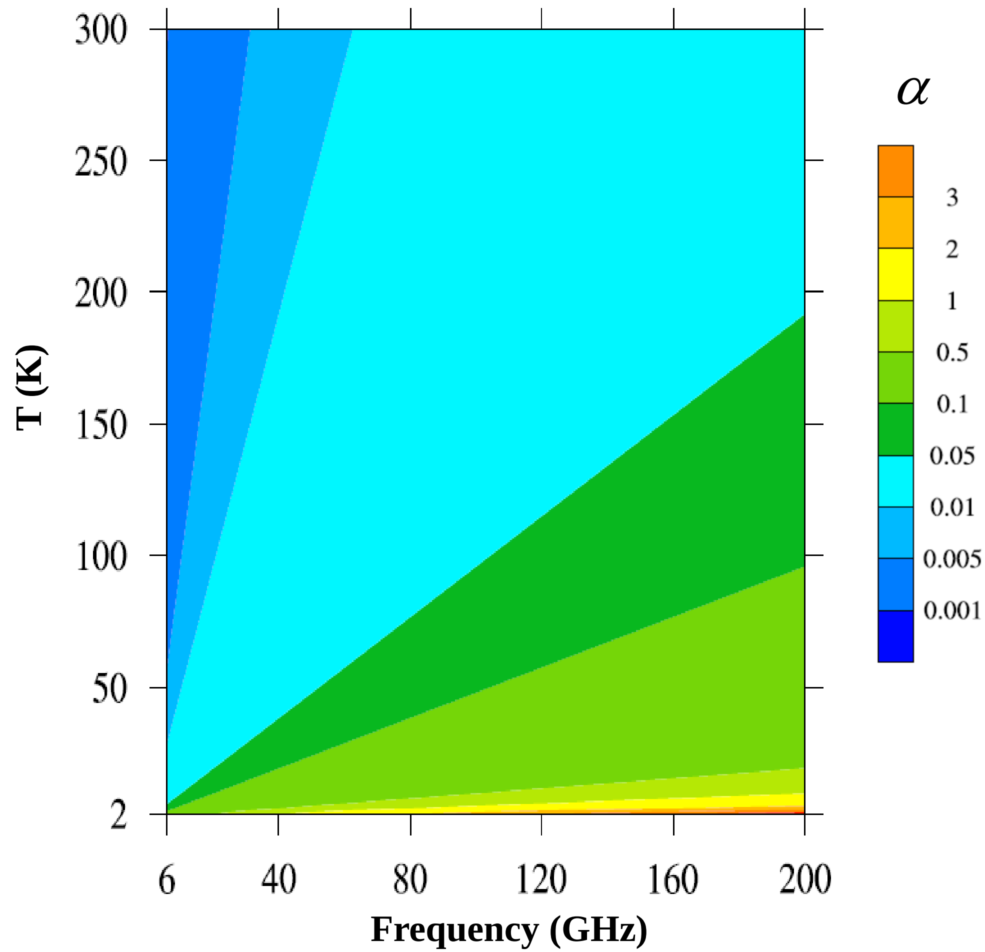
$$d_c = \frac{\overline{C}_s - \overline{C}_c}{\overline{C}_w - \overline{C}_c}$$

$$R_\upsilon(T) = \frac{C_1 \upsilon^3}{\exp\left(\frac{C_2 \upsilon}{T}\right) - 1}$$

When $\alpha = \frac{C_2 \upsilon}{T} \ll 1$

$$R_\upsilon^{RJ}(T) = \frac{C_1 \upsilon^2}{C_2} T$$

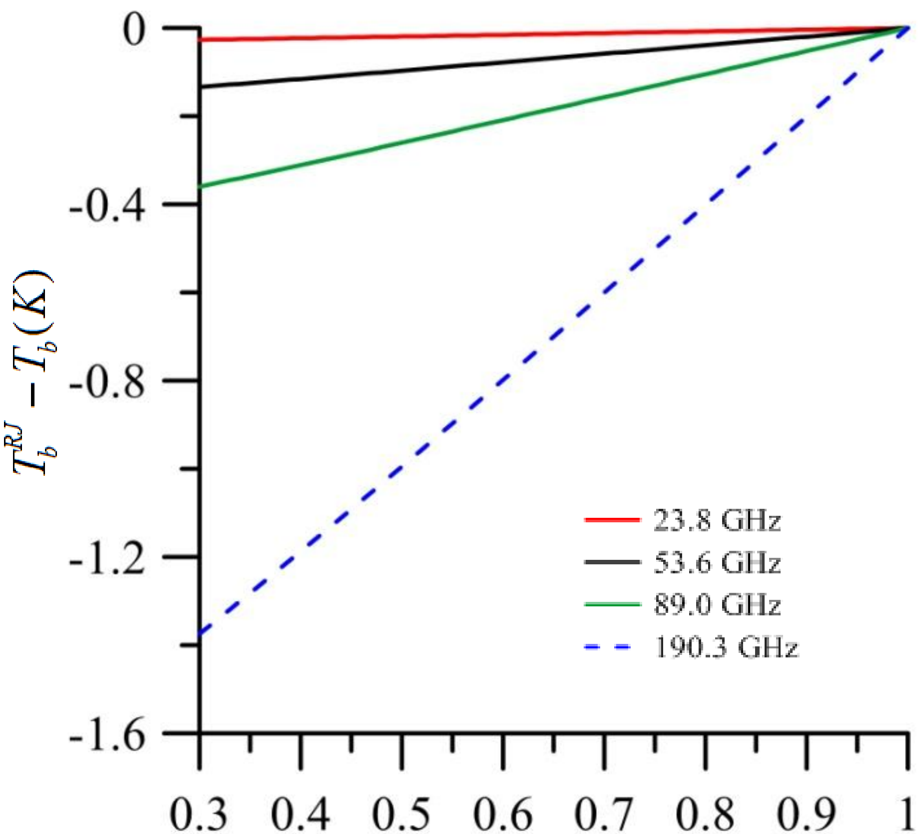
$$T_{b,s} = d_c \left(T_{b,w} - T_{b,c}\right) + T_{b,c}$$



In ATMS frequency range , this condition is not valid in cold space view !

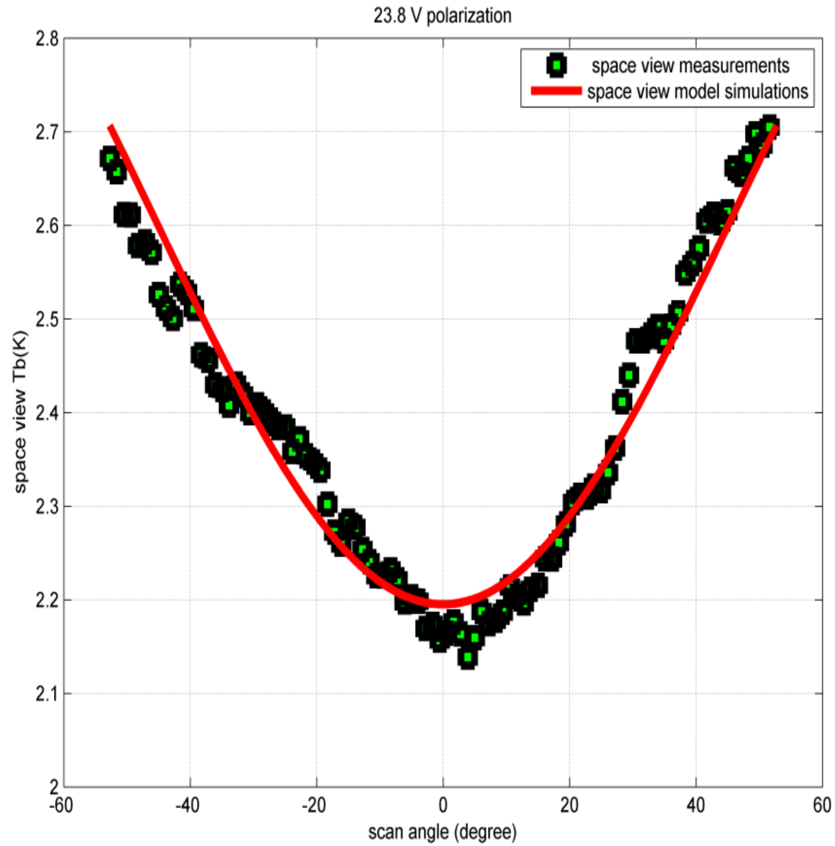
ATMS Radiometric Calibration Errors from RJ vs. Pitch Maneuver Data

Error from RJ Approximation



$$d_c = \frac{\overline{C_s} - \overline{C_c}}{\overline{C_w} - \overline{C_c}}$$

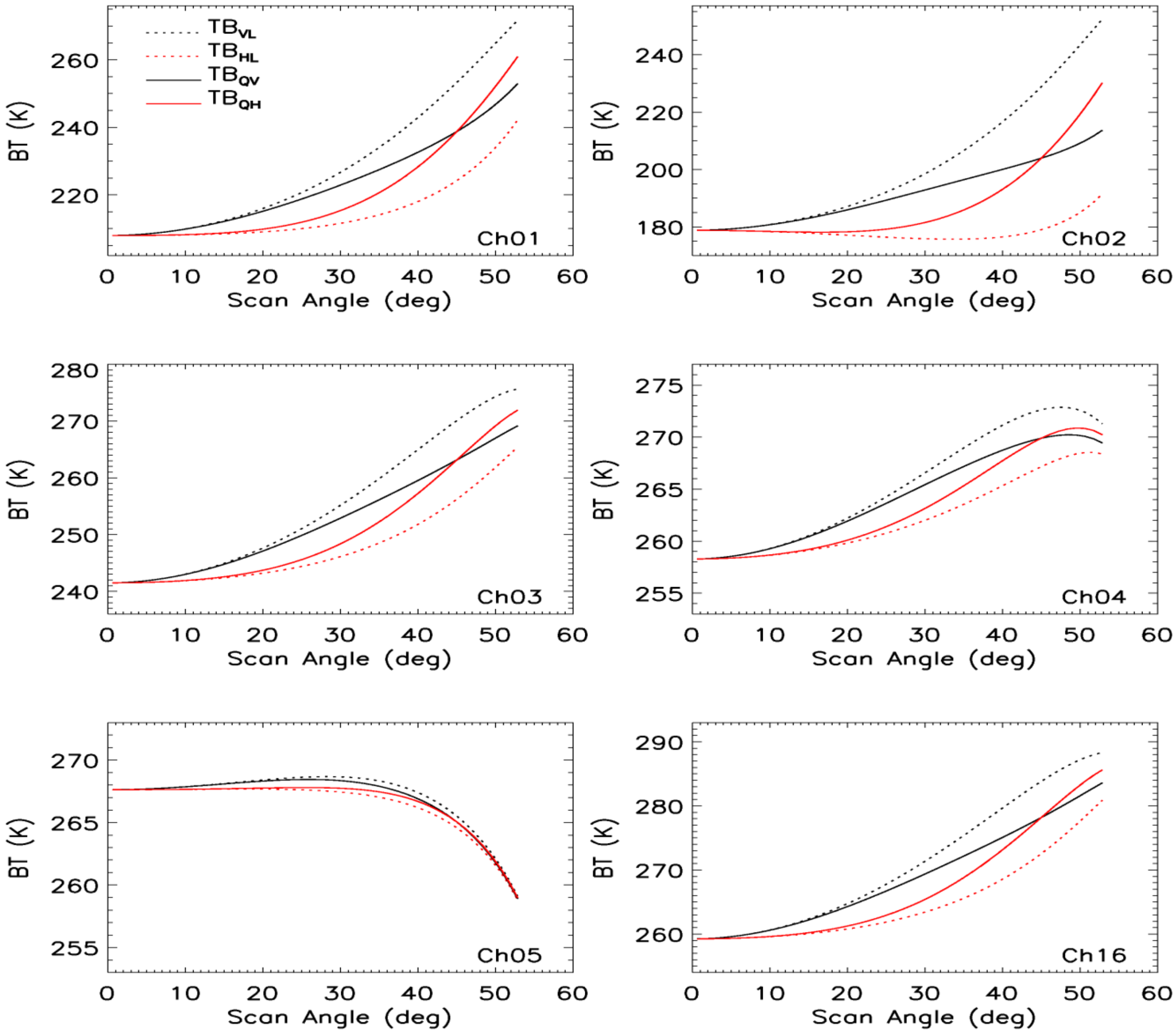
ATMS Pitch Maneuver Data



It is a mystery why Tb is significantly than 2.73K. The bias is due probably to uses of Rayleigh Jeans approximation

Slide courtesy of STAR

Brightness Temperatures Simulated over Oceans

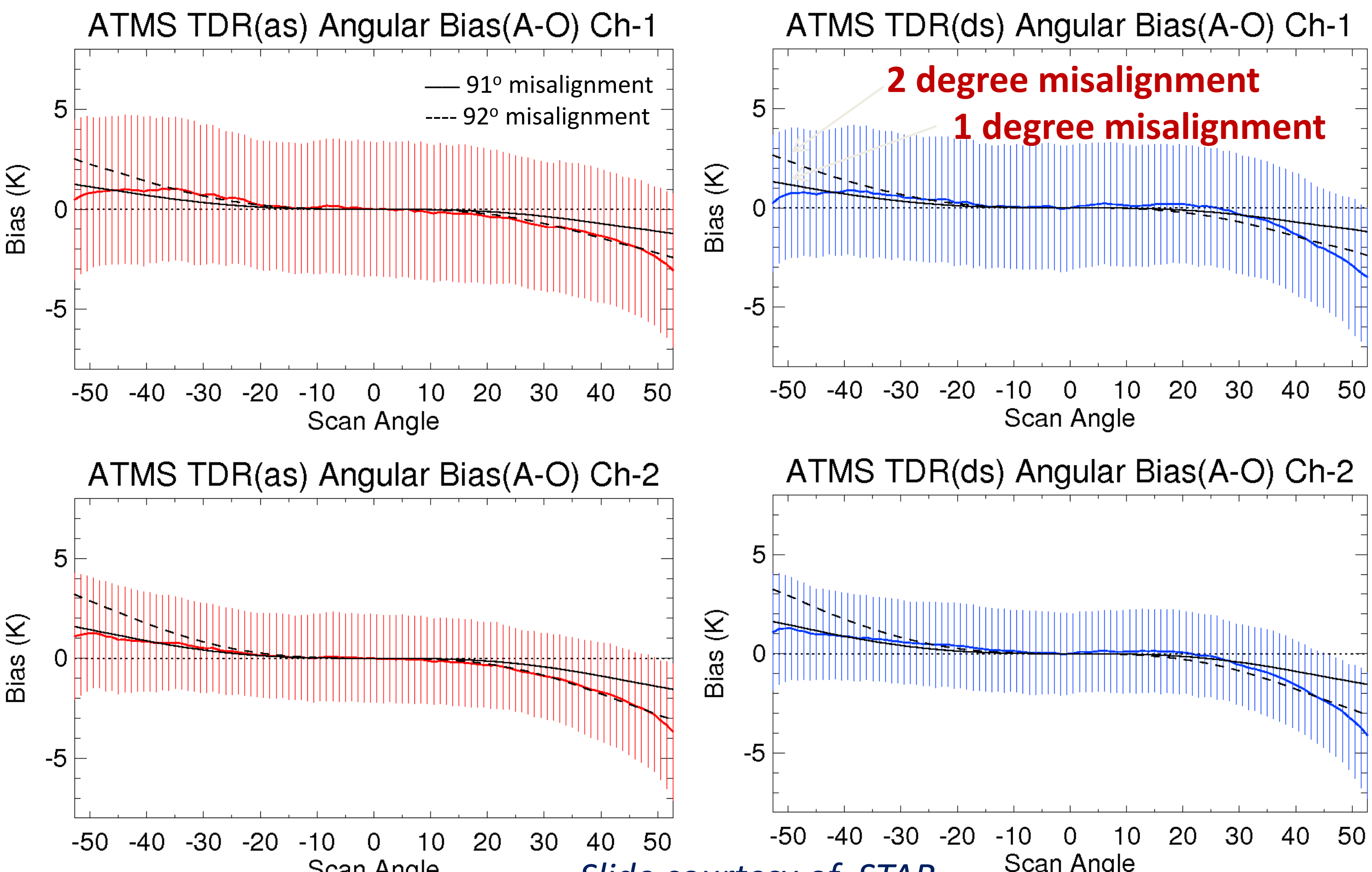


For a scan angle ranging from 15 to 45 degrees, ATMS brightness temperatures at ch1, 2, 3,4 and 16 are polarized over oceans. A conversion from TDR to SDR is also ill-posted problem if the antenna has a significant spill-over effect

Slide courtesy of STAR

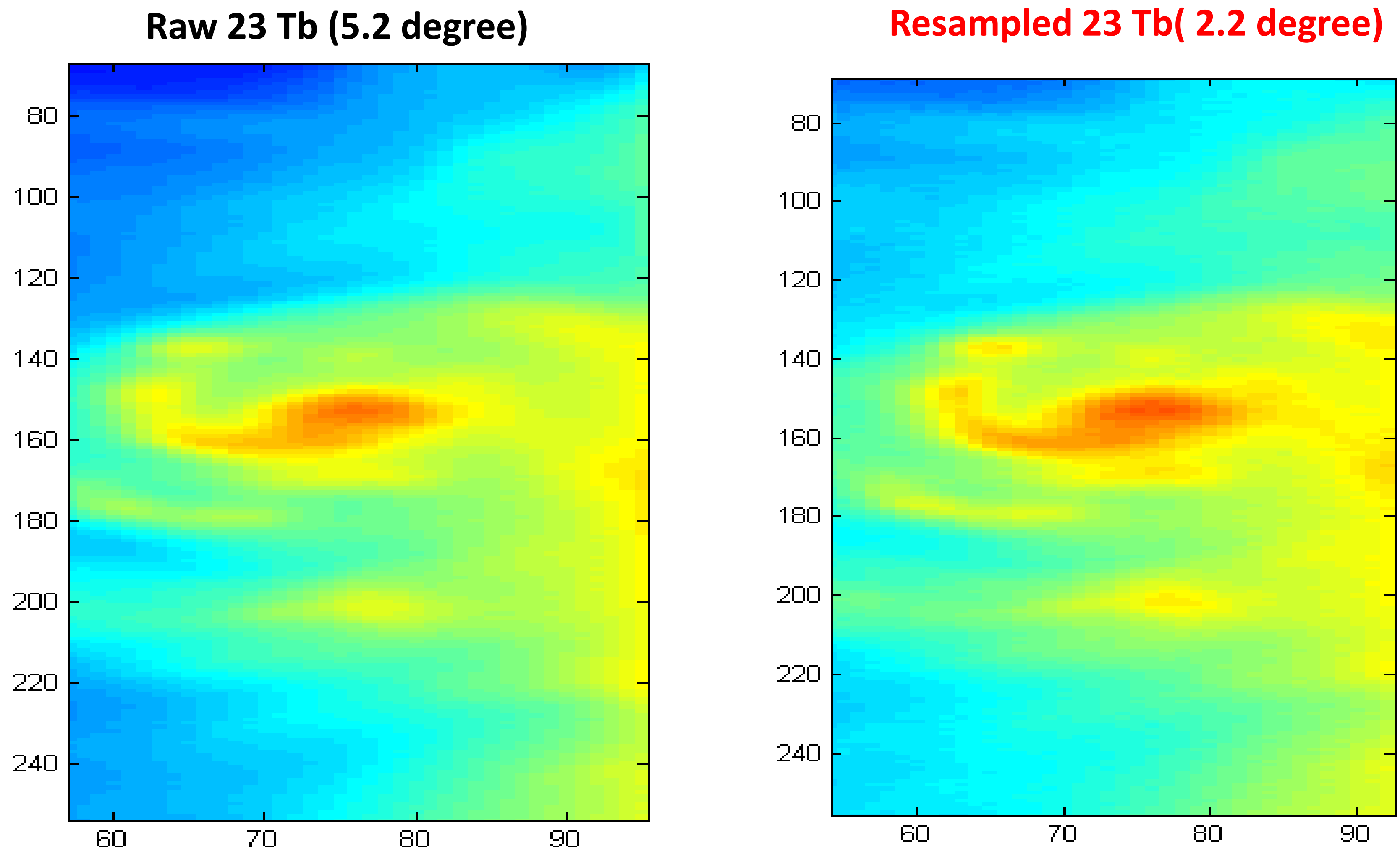
ATMS Polarization Twist Angle

Angular dependent bias (A-O) Dec, 16-22, 2011
CRTM Sim: GSI analysis field ; OBS: ATMS TDR



Slide courtesy of STAR

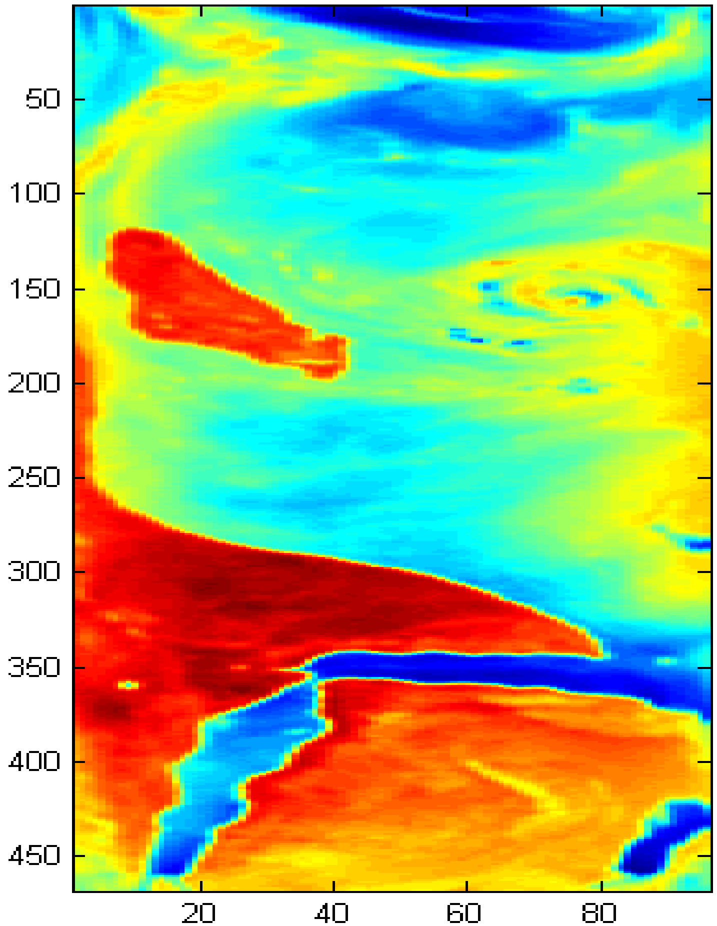
ATMS De-convolution from Low to High Resolution



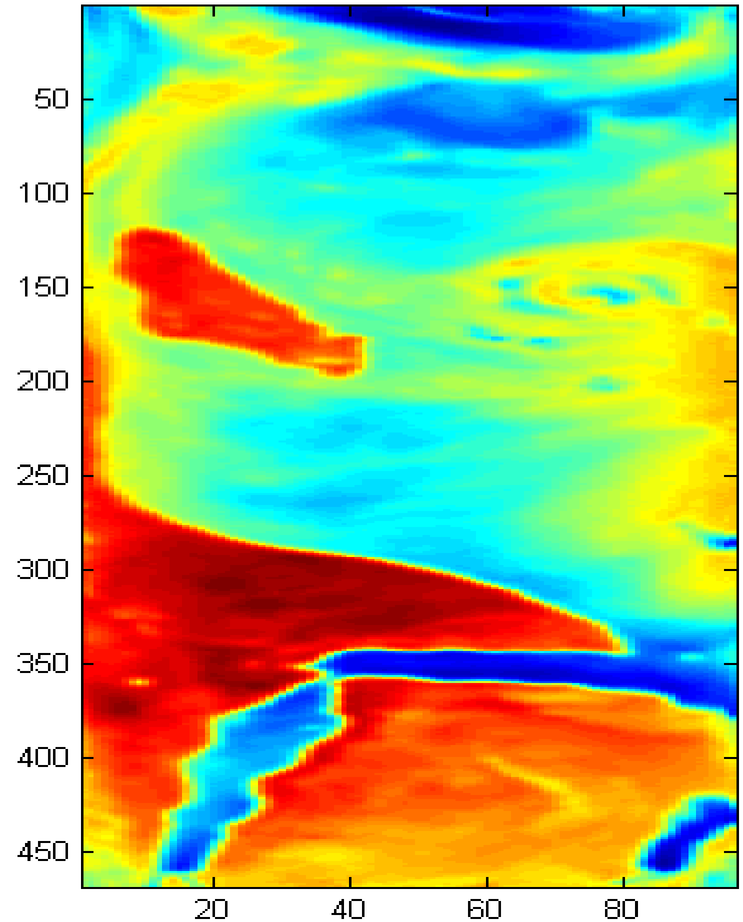
Slide courtesy of STAR

ATMS Convolution from High to Low Resolution

Raw 89 GHz Tb (2.2 degree)



Resampled 89 Tb(5.2 degree)

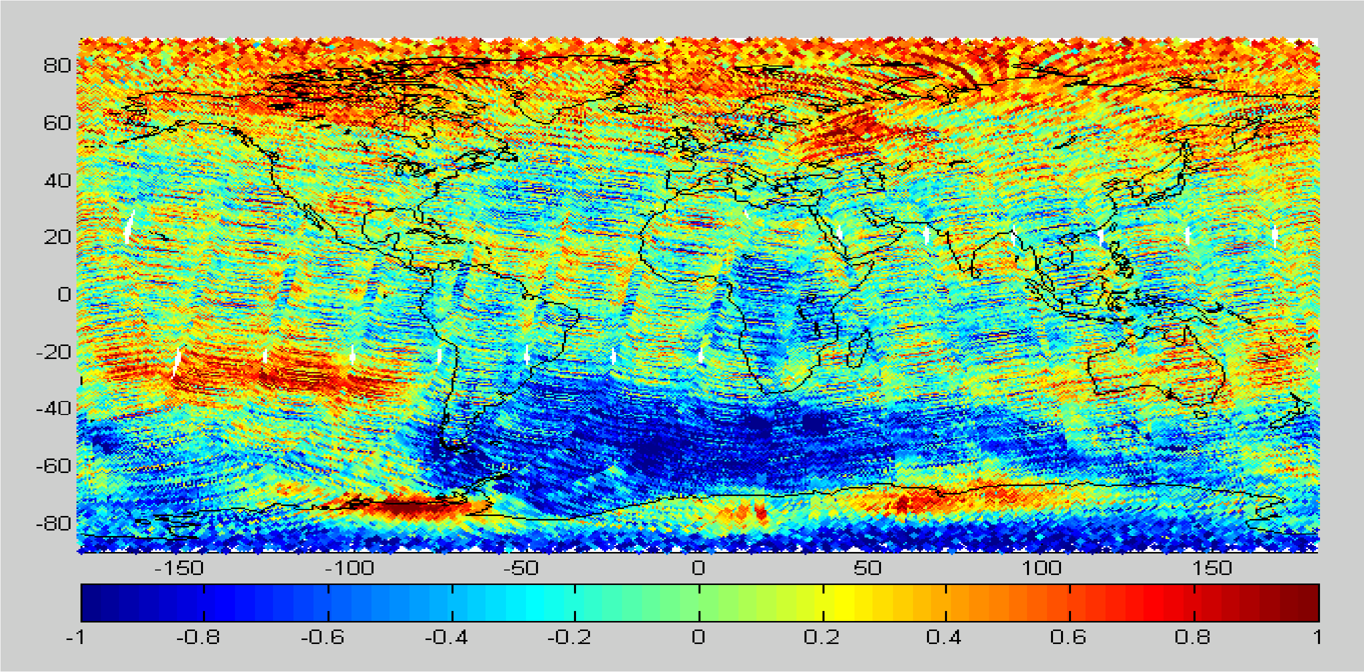


Slide courtesy of STAR

ATMS TDR Stripping Noise

- Striping is caused by ATMS SDR calibration noise, specifically the noise in the warm counts. Contributions to the overall calibration noise from cold counts and PRT readings are much smaller
- The level of the striping noise is insignificant and well within ATMS SDR noise spec level

ATMS Brightness Temperature Difference: Simulated – Observed



Slide courtesy of NGAS

Path Forward

- Update ATMS scan bias corrections for TDR to SDR conversion using the ATMS antenna efficiency and pitch maneuver data
- Work with NGES to better characterize ATMS antenna (side-lobe, xpol spill-over, polarization twist angle) for J1/J2 mission
- Revise ATMS radiometric calibration in full radiance to make the SDR data consistent with NOAA heritage approach
- Develop channel-dependent averaging of warm counts for reducing stripping

Summary

- ATMS TDR/SDR data has reached a provisional status.
  - NEDT (precision) at 22 channels meet specification
  - Bias (accuracy) at channels 5 to 13 are better than specification
- ATMS TDR to SDR conversion theory is well developed and applied for TDR to SDR conversion
  - Caveats : xpol spill-over is neglected for window channels. Performance is not optimal for clear oceans where there is significant polarization
- ATMS radiometric calibration theory needs to be further improved with full radiance processing