Optimization and Validation of ATMS Climate Data Records

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NOAA CDR Workshop

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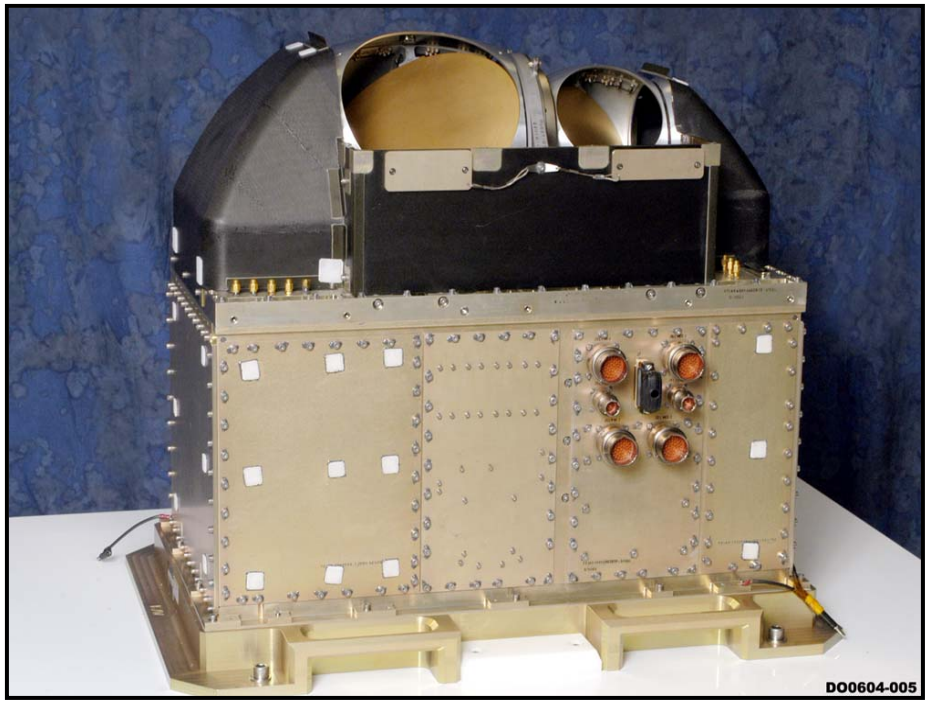
Outline

- Overview of ATMS (October 2011 Launch)
- Pre-launch testing
- Focus on CDRs
  - What is “climate quality”?
  - Implications/examples
    - LO stability
    - Polarization efficiency
- Summary

Advanced Technology Microwave Sounder

- ATMS is a 22 channel MW sounder
- Frequencies range from 23-183 GHz
- Total-power, two-point external calibration
- Continuous cross-track scanning, with torque & momentum compensation
- Orbits: 833 km (NPOESS); 824 km (NPP); sun-synchronous
- Thermal control by spacecraft cold plate
- Contractor: Northrop Grumman Electronics Systems (NGES)



ATMS vs. AMSU

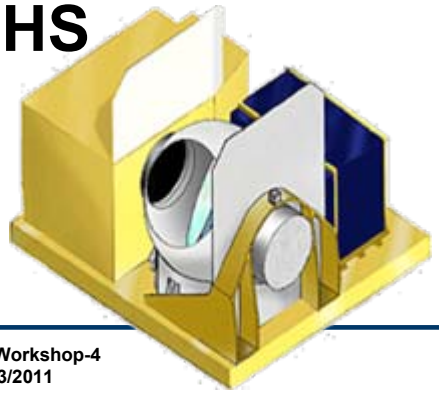
AMSU-A1

- 73x30x61 cm
- 67 W
- 54 kg
- 3-yr life

AMSU-A2

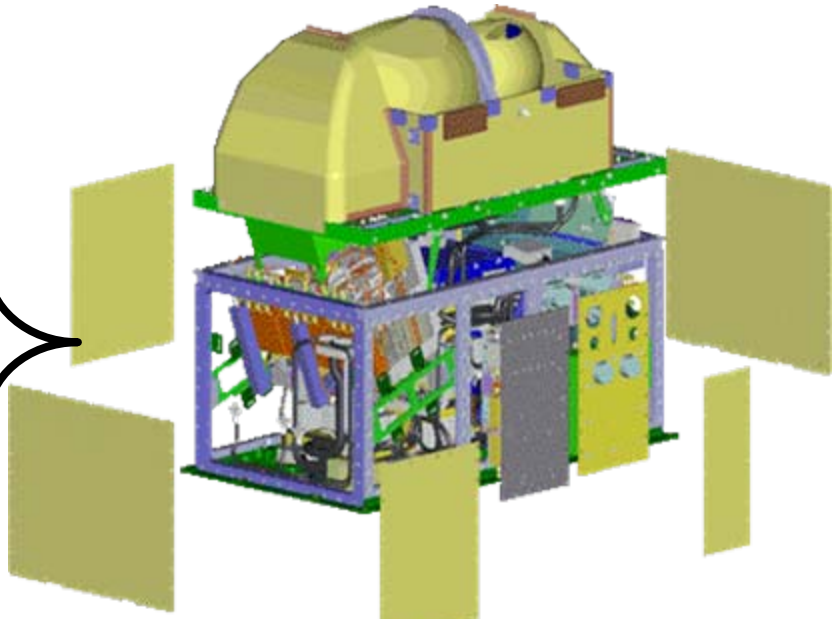
- 75x70x64 cm
- 24 W
- 50 kg
- 3-yr life

MHS



- 75x56x69 cm
- 61 W
- 50 kg
- 4-yr life

1/3 volume of AMSU



- 70x40x60 cm
- 110 W
- 85 kg
- 7 year life

Spectral Differences: ATMS vs. AMSU/MHS

	AMSU/MHS			ATMS		
	Ch	GHz	Pol	Ch	GHz	Pol
AMSU-A	1	23.8	QV	1	23.8	QV
	2	31.399	QV	2	31.4	QV
	3	50.299	QV	3	50.3	QH
				4	51.76	QH
	4	52.8	QV	5	52.8	QH
	5	53.595 ± 0.115	QH	6	53.596 ± 0.115	QH
	6	54.4	QH	7	54.4	QH
	7	54.94	QV	8	54.94	QH
	8	55.5	QH	9	55.5	QH
	9	fo = 57.29	QH	10	fo = 57.29	QH
	10	fo ± 0.217	QH	11	fo ± 0.3222 ± 0.217	QH
	11	fo ± 0.3222 ± 0.048	QH	12	fo ± 0.3222 ± 0.048	QH
	12	fo ± 0.3222 ± 0.022	QH	13	fo ± 0.3222 ± 0.022	QH
	13	fo ± 0.3222 ± 0.010	QH	14	fo ± 0.3222 ± 0.010	QH
	14	fo ± 0.3222 ± 0.0045	QH	15	fo ± 0.3222 ± 0.0045	QH
	15	89.0	QV			
MHS	16	89.0	QV	16	88.2	QV
	17	157.0	QV	17	165.5	QH
	18	183.31 ± 1	QH	18	183.31 ± 7	QH
	19	183.31 ± 3	QH	19	183.31 ± 4.5	QH
	20	191.31	QV	20	183.31 ± 3	QH
				21	183.31 ± 1.8	QH
				22	183.31 ± 1	QH

- **ATMS has 22 channels and AMSU/MHS have 20, with polarization differences between some channels**
  - **QV = Quasi-vertical; polarization vector is parallel to the scan plane at nadir**
  - **QH = Quasi-horizontal; polarization vector is perpendicular to the scan plane at nadir**

Exact match to AMSU/MHS
Only Polarization different
Unique Passband
Unique Passband, and Pol. different from closest AMSU/MHS channels

Spatial Differences: ATMS vs. AMSU/MHS

Beamwidth (degrees)

	ATMS	AMSU/MHS
23/31 GHz	5.2	3.3
50-60 GHz	2.2	3.3
89-GHz	2.2	1.1
160-183 GHz	1.1	1.1

Spatial sampling

	ATMS	AMSU/MHS
23/31 GHz	1.11	3.33
50-60 GHz	1.11	3.33
89-GHz	1.11	1.11
160-183 GHz	1.11	1.11
Swath (km)	~2600	~2200

ATMS scan period: 8/3 sec; AMSU-A scan period: 8 sec

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ATMS Prelaunch Testing

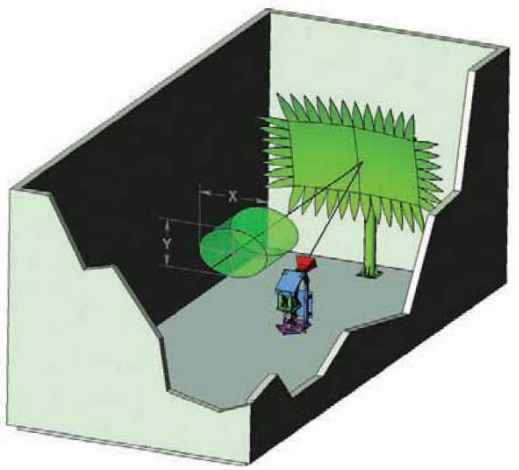
- A variety of prelaunch testing is performed to assess performance and reliability
  - EMI/RFI
  - Mechanical
  - Radiometric
  - Antenna
- Sensor parameters characterized during testing will be used in the calibration and retrieval algorithms
  - Linearity, frequency passbands, antenna patterns, etc.

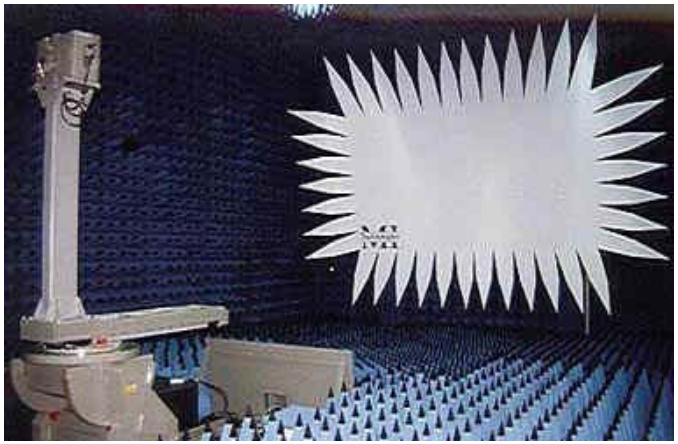
Key Radiometric Parameters

- Dynamic range (brightness temperature range of 3-300 K)
- NEΔT (sensitivity)
- Calibration accuracy (bias)
- Linearity (deviation from linear regression)
- Short term gain fluctuation (ΔG/G) (gain stability or 1/f noise)
- Hysteresis (repeatability)

Compact Antenna Range Testing

- **Compact Antenna Test Range**
  - RF source illuminates the Antenna Under Test (AUT), i.e., ATMS antenna subsystem
  - Uses a parabolic reflector to collimate the electromagnetic radiation to illuminate the AUT in the far-field region
  - AUT is attached to a positioner to rotate the AUT into the proper orientation
- **Test measures the power received by the AUT compared to a standard antenna with a known antenna gain pattern**
- **Specifications verified:**
  - Beam pointing accuracy
  - Beamwidth
  - Beam efficiency
  - Earth intercept





Thermal-Vacuum Radiometric Testing

- Fully characterize the radiometric performance of the sensor over a range of operating temperatures
- Access the stability and repeatability of radiometer performance
- Measure the calibration parameters that are needed by the SDR algorithm (e.g., non-linearity correction factor)
- Validate that the sensor meets performance requirements
- Provide pre-launch performance validation in a flight-like environment

Summary of ATMS Prelaunch Testing

- All key radiometric requirements were satisfied
- Radiometric accuracy is better than 1K
- Radiometric sensitivity exceeds requirements
  - Similar to AMSU for similar effective footprint sizes
- Linearity performance generally exceeds AMSU
  - Slight temperature-dependent nonlinearity for non-nominally high instrument temperatures
- Antenna pattern testing indicates good performance
  - Some G-band data are of questionable quality
  - Schedule/budget constraints prevented exhaustive testing
  - Opportunity for spacecraft maneuvers allows improved characterization of ATMS spatial response function

ATMS SDR Tunable Parameters (1 of 2)

#	SDR Tunable Parameter	Size	Comments	Source or Task
1	Space View Sector	4	6.66°, 8.33°, 10°, 13.33°	TUN-1
2	Warm target PRT weights	8 (or 7 WG) PRTs × # of scans	Uniform for 9 scans	prelaunch
3	Warm target bias	# of coef. × # of chan. (Telemetry: 5 bands)	Eq. 20 SDR rad. cal. ATBD Telem: Eq. 3-3 RE-12110D	prelaunch
4	Cold space bias	# of Space View Sectors × # of chan. (Telemetry: 5 bands only)	Only primary SVS (6.66°) has values	prelaunch TUN-4 & 5
5	Warm target multi-scan weight factors	# scans × # chan.	MIT LL ATMS PFM T/V Cal. Data Analysis	prelaunch
6	Cold space multi-scan weight factors	# scans × # chan.	MIT LL ATMS PFM T/V Cal. Data Analysis	prelaunch

ATMS SDR Tunable Parameters (2 of 2)

#	SDR Tunable Parameter	Size	Comments	Source or Task
7	Non-linearity correction factor	# of cold plate temp. × # of redundancy config. × # of chan. (Telemetry: # of chan.)	Table 10-26 PFM Cal. Data Book	prelaunch
8	Cold plate to RF-shelf temperature conversion LUT	# cold plate temp. × # shelf temp.	Table 10-28 PFM Cal. Data Book	TUN-2
9	Cold Space Brightness Temp.	# of chan.	Eq. 22 SDR rad. cal. ATBD	prelaunch
10	Lunar contamination threshold	# of chan.	0.2	TUN-3
11	Antenna boresight alignment	# of chan. × 3 beam pos. (1,48, & 96) × 3 attitudes (Telemetry: 5 bands × 3 × 3)	Table 6-1 & 6-2 PFM Cal. Data Book	prelaunch
12	Backus-Gilbert resampling coefficients	# of ATMS FOV × 30 FOR	AER Inc. deliverable	prelaunch
13	Beam efficiency correction factor	# of chan. × # of beam pos.		TUN-7
14	Scan-dependent correction factor	# of chan. × # of beam pos.		TUN-7

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Specifications (What is "climate quality"?)

- JPSS Level 1 Requirements Document contains "Long-term stability" over seven-year mission life
  - Water vapor: 2% (threshold), 1% (goal)
  - Tropospheric temperature: 0.05K (threshold), 0.03K (goal)
  - Stratospheric temperature: 0.10K (threshold), 0.05K (goal)

- Level 1 requirements need to be flowed into sensor reqts.

- Relevant ATMS sensor parameters:
  - LO frequency
  - Filters
  - Reflectors
  - Calibration targets

Example: ATMS LO stability

- From ATMS sensor specification (for "tropospheric" channels):
  - Channel 5: 5 MHz
  - Channel 6: 5 MHz
  - Channel 7: 5 MHz
  - Channel 8: 10 MHz
- LO stability needed to achieve 0.03K stability:
  - Channel 5: 3 MHz
  - Channel 6: 2 MHz
  - Channel 7: 2 MHz
  - Channel 8: 3 MHz
- Punchline: ATMS LO stability specifications are inadequate by a factor of about 2-3
- Good news: ATMS LO stability performance is expected to exceed specifications by a factor of about 2-3

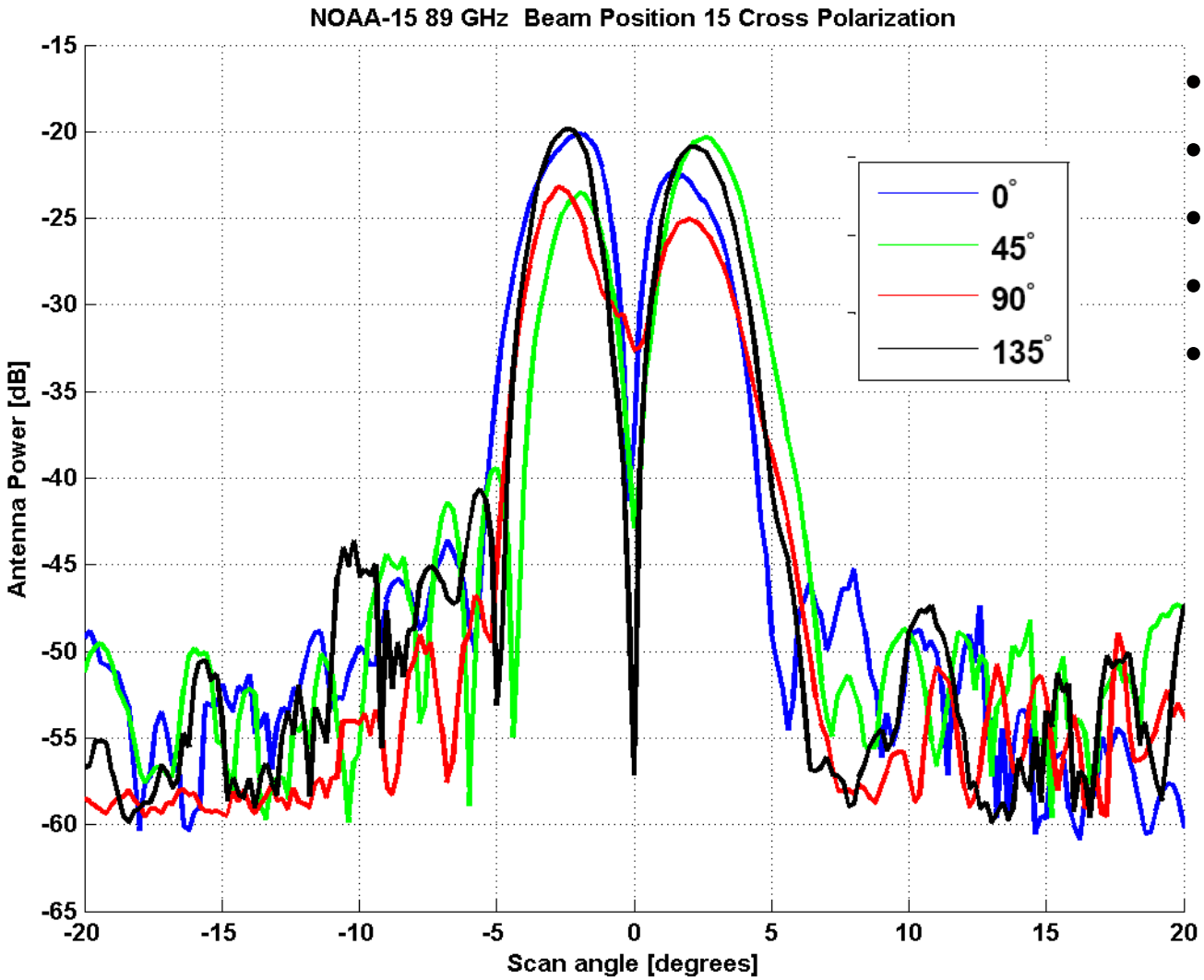
AMSU-A Cross-Polarization Efficiency

NOAA-15

Channel Number	Channel Frequency		Cross Polarization Beam Efficiency
	Specification (MHz)	Measured * (MHz)	
1	23800	23800.37	1.57%
2	31400	31400.42	1.23%
3	50300	50299.91	2.24%
4	52800	52799.39	1.21%
5	53596 ± 115	53595.41 ± 115	1.38%
6	54400	54399.53	1.65%
7	54940	54940.64	1.47%
8	55500	55498.70	1.44%
9	fo = 57290.344	fo = 57290.33	1.29%
10	fo ± 217	fo ± 217	
11	fo ± 322.2 ± 48	fo ± 322.2 ± 48	
12	fo ± 322.2 ± 22	fo ± 322.2 ± 22	
13	fo ± 322.2 ± 10	fo ± 322.2 ± 10	
14	fo ± 322.2 ± 4.5	fo ± 322.2 ± 4.5	
15	89000	88997.00	1.38%

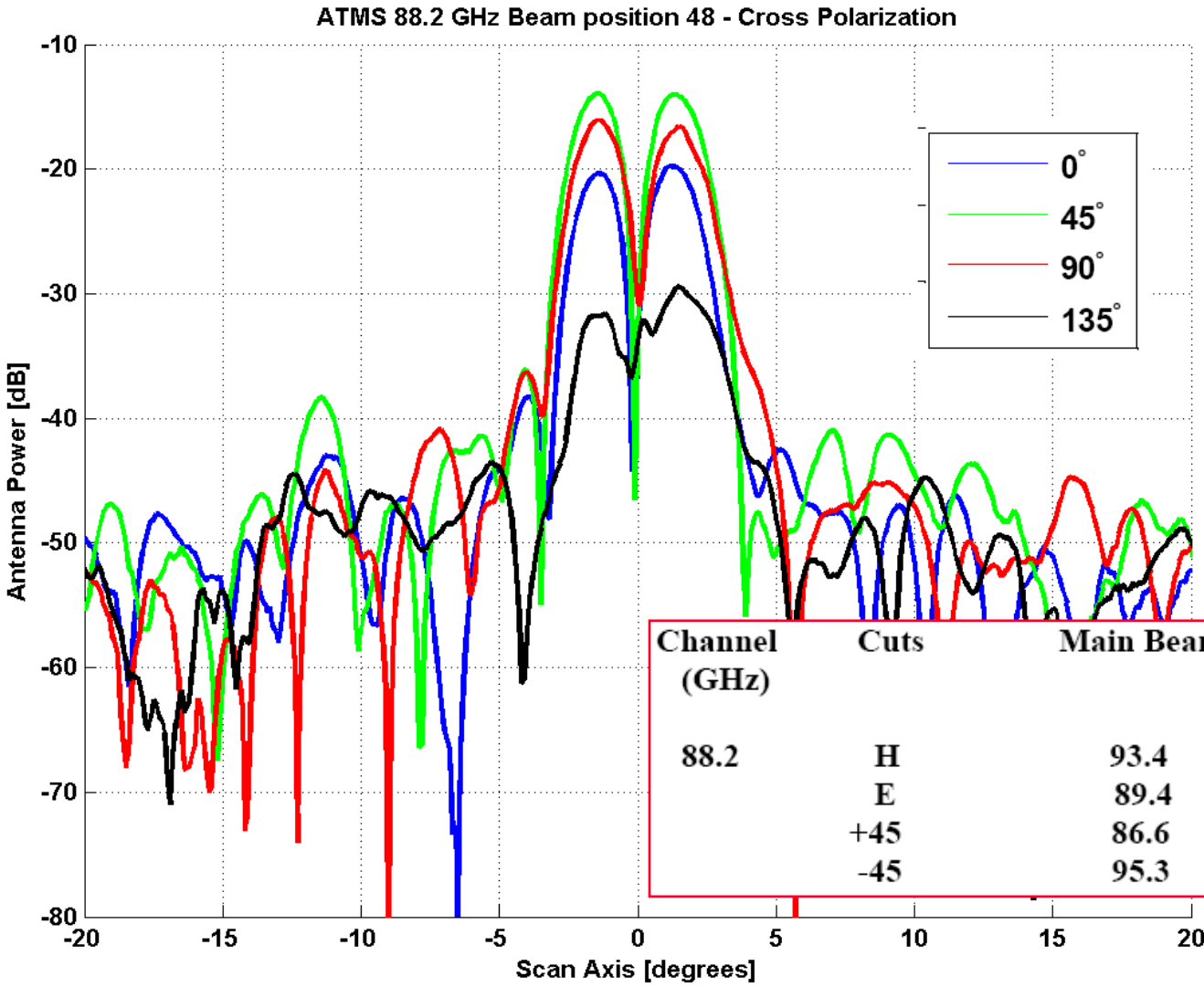
Tsan Mo, "AMSU-A Antenna Pattern Corrections," TGARS, Vol. 37, No. 1, Jan. 1999; NOAA-15 (K)

AMSU Antenna Pattern Measurement (89 GHz)



- NOAA-15
- AMSU-A1
- 89 GHz
- Beam position 15
- Cross polarization

ATMS Antenna Pattern Measurement (89 GHz)



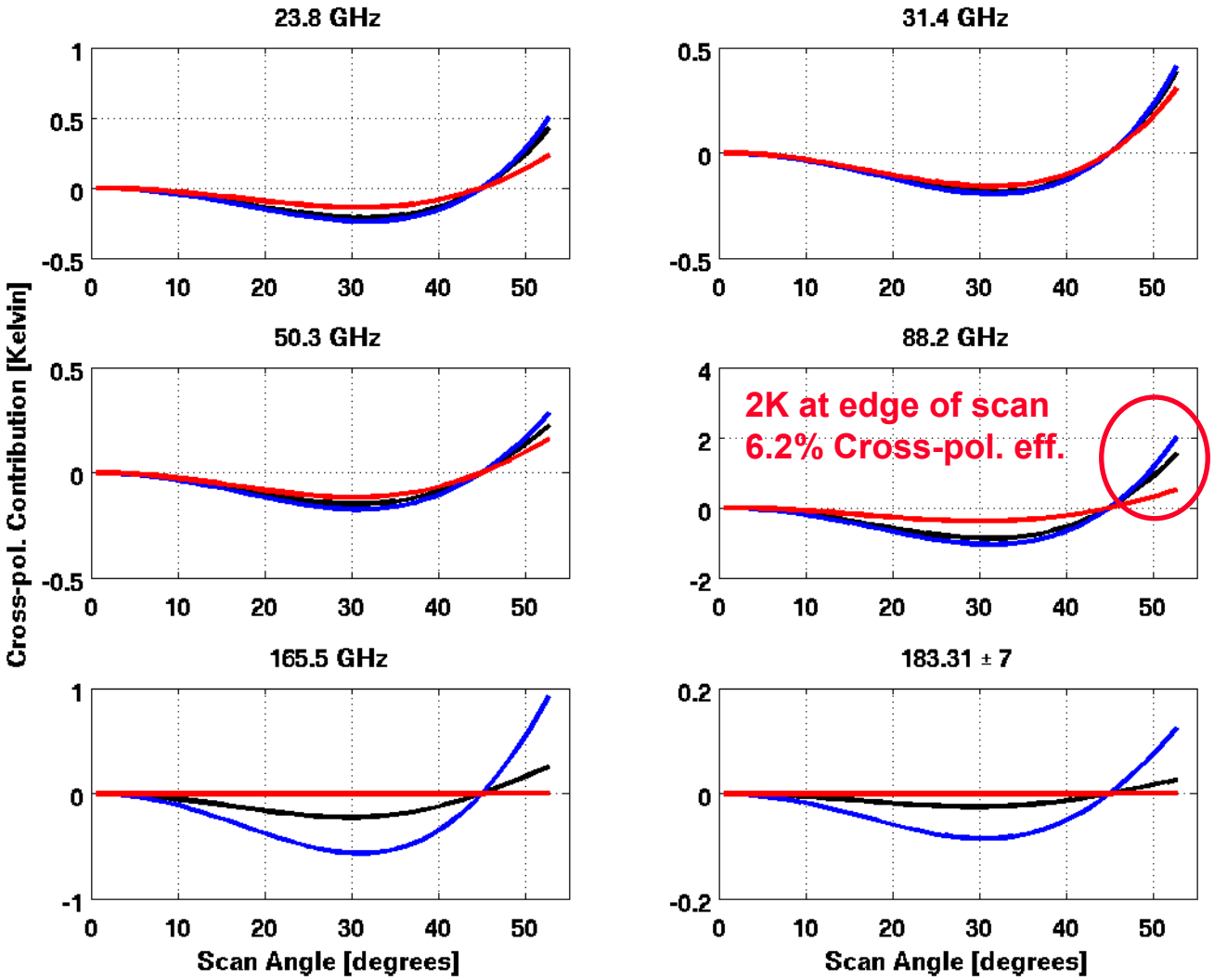
Channel (GHz)	Cuts	Main Beam(%)	Cross-Polarization(%)
88.2	H	93.4	3.9
	E	89.4	7.5
	+45	86.6	11.6
	-45	95.3	1.8

LL cross-pol. efficiency calculations

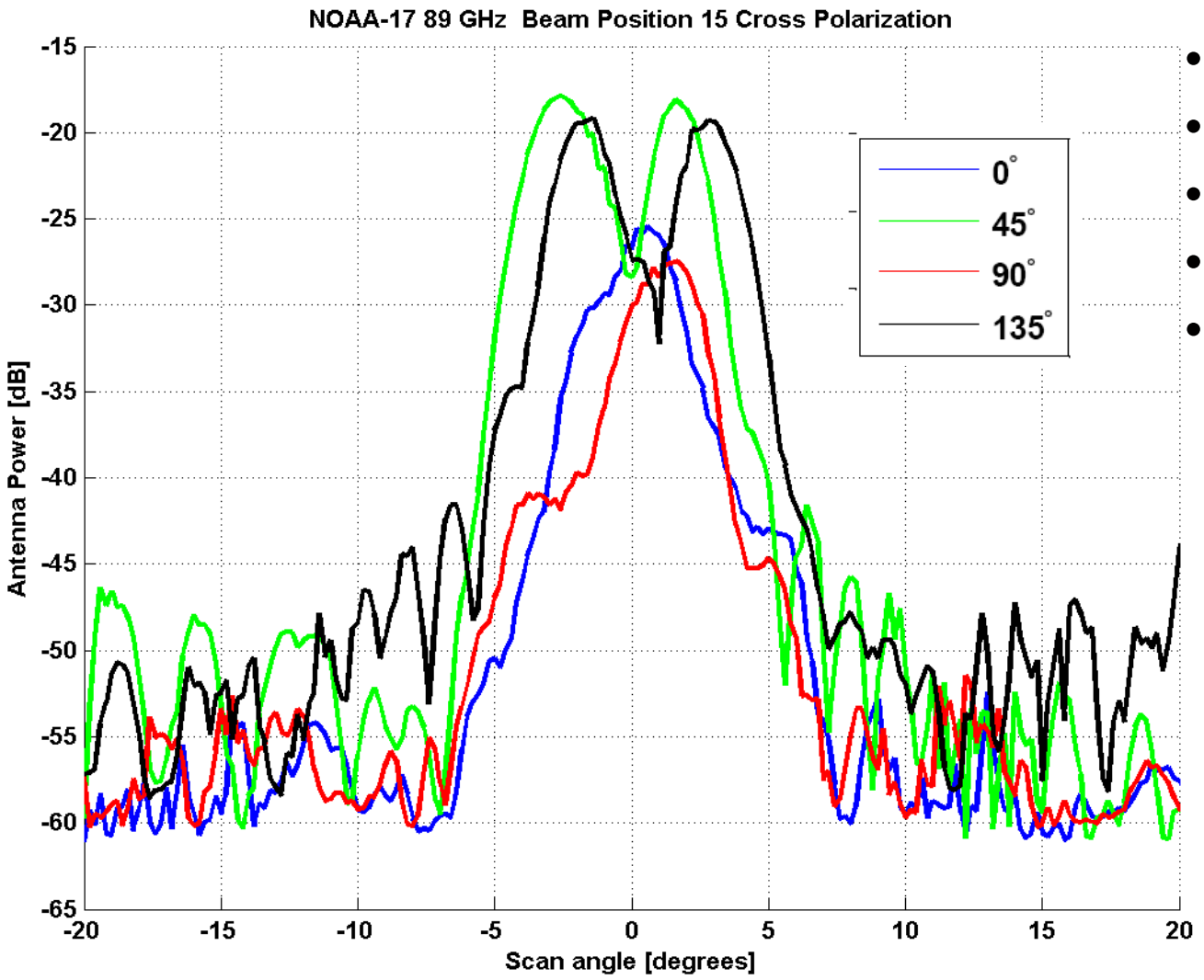
0°	3.91%
45°	11.64%
90°	7.50%
135°	1.82%
Avg.	6.15%

SDR Error Due to Polarization Impurity

Red: July 25° Lat. (summer)
Black: Standard Atmos. 1976
Blue: Mar. 46° Lat. (winter)
Ocean surface (fastem2)



AMSU Antenna Pattern Measurement (89 GHz)



- NOAA-17
- AMSU-A1
- 89 GHz
- Beam position 15
- Cross polarization

Summary

- ATMS is an excellent sensor
  - Well-calibrated
  - Improved performance
  - Improved reliability
- ATMS is not perfect (and characterization is not perfect)
  - Cross-track biases to be expected
  - Deep space maneuvers could help
  - Polarization correction probably needed for CDRs
- We have fought (somewhat successfully) for additional/improved testing for future ATMS builds
- Further room for improvement