Development and Predicted Performance of the Advanced Technology Microwave Sounder for the NPOESS Preparatory Project

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Outline

- NPP ATMS overview
- Pre-launch testing
- Post-launch cal/val
- Summary

NPOESS Preparatory Project

NPP (NPOESS Preparatory Project)
~2011 Launch

- **Launch site: Vandenberg AFB**
- **Launch vehicle: Boeing Delta II**
- **Spacecraft: Ball Aerospace Commercial Platform 2000**
- **Instruments: VIIRS, CrIS, ATMS, OMPS, & CERES**
- **Orbits: 824 km (NPP); sun-synchronous with a 10:30 a.m. local-time descending node crossing**

National Polar-orbiting Operational Environmental Satellite System ⟶ Joint Polar Satellite System

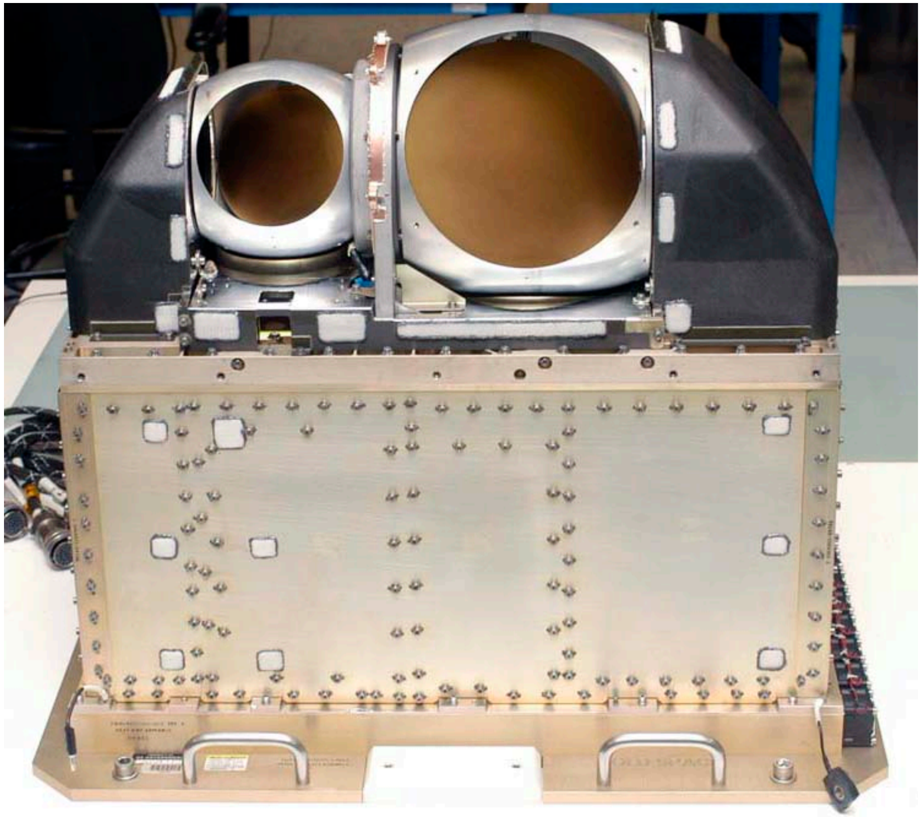
ATMS Development

- ATMS NPP unit (“PFM” – ProtoFlight Module) developed by NASA/Goddard
  - Sensor builder: Northrop Grumman Electronic Systems (formerly Aerojet)
  - ATMS NPP unit delivered in 2005
  - ATMS NPOESS C1 unit currently in development

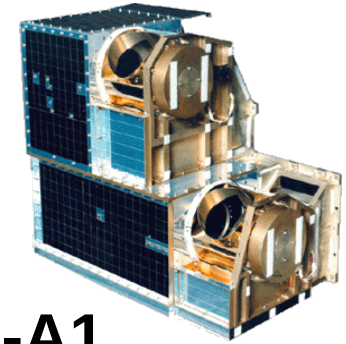
- Principal challenges/advantages:
  - Reduced size/power relative to AMSU
    - Scan drive mechanism
    - MMIC technology
  - Improved spatial coverage (no gaps between swaths)
  - Nyquist spatial sampling of temperature bands (improved information content relative to AMSU-A)

Advanced Technology Microwave Sounder

- ATMS is a 22 channel passive microwave sounder
- Frequencies range from 23-183 GHz
- Total-power, two-point external calibration
- Continuous cross-track scanning, with torque & momentum compensation
- Thermal control by spacecraft cold plate
- Contractor: Northrop Grumman Electronics Systems (NGES)



ATMS Design Challenge

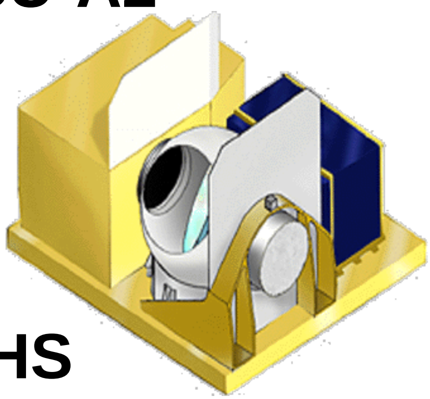


AMSU-A1

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

AMSU-A2

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

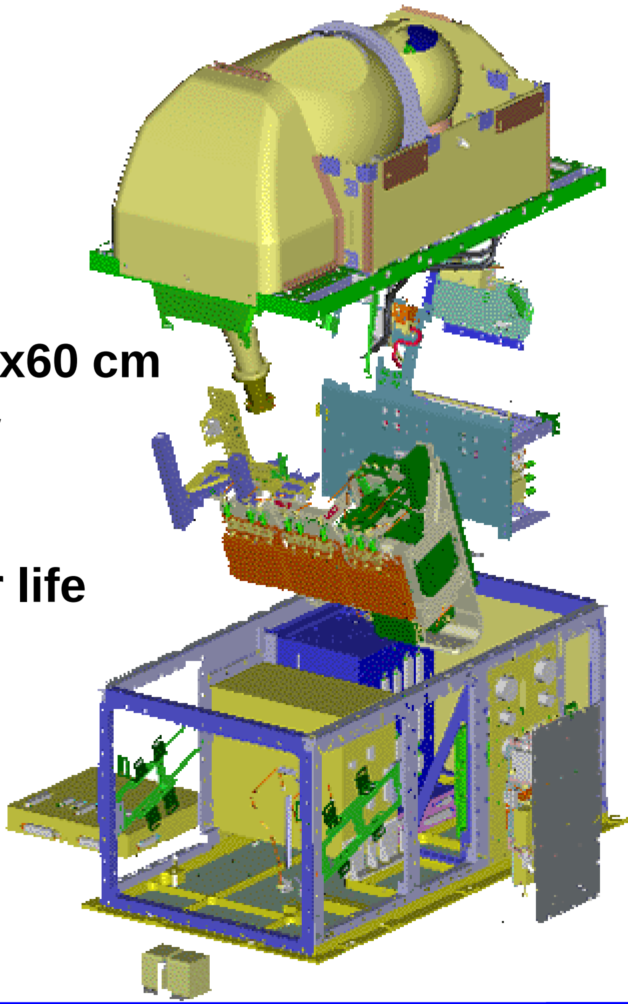


MHS

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

Reduce the volume by 3x

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



Spectral Differences: ATMS vs. AMSU-A

Ch	Center Freq. [GHz]	Pol	Ch	Center Freq. [GHz]	Pol
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	16	88.2	QV

AMSU-A | ATMS

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

Spectral Differences: ATMS vs. MHS

MHS Ch	MHS Center Freq. [GHz]	MHS Pol	ATMS Ch	ATMS Center Freq. [GHz]	ATMS Pol
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

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

- Green: Exact match to MHS (ATMS 20, 22)
- Yellow: Only Polarization different
- Gray: Unique Passband (ATMS 16, 19, 21)
- Red: Unique Passband, and Pol. different from closest MHS channels (ATMS 17, 18)

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

ATMS Data Products

Data Product	Description
RDR (Raw Data Record)	FOV[1] antenna temperature (counts)
TDR (Temperature Data Record)	FOV[1] antenna temperature (K)
SDR (Sensor Data Record)	FOR[1] brightness temperature (K)
EDR (Environmental Data Record)	P/T/WV profile
CDR (Climate Data Record)	"Climate-optimized" product
IP (Intermediate Product)	Used to generate EDR/CDR

[1]FOV = ATMS "Field of View"; FOR = CrIMSS "Field of Regard"

ATMS Performance Validation: Intellectual Framework

- **Goals:**
  - Error *characterization* of radiances and derived products that is:
    - Extensive (global, seasonal, all channels, etc.)
    - Comprehensive (wide assortment of meteorological conditions, ground truth, etc.)
  - Error *attribution* to atmospheric, sensor, or algorithm mechanisms

- **Necessary Ingredients:**
  - Prelaunch sensor testing and calibration
  - Prelaunch algorithm evaluation
  - Error models and budgets (including ground truth)
  - Post-launch radiance/product characterization
  - Refinement of error models/budgets based on observations

- **Detailed validation plans for SDRs and EDRs**

Major Components of ATMS Post-Launch Calibration/Validation

- ATMS/CrIMSS system error model/budget
  - RDR ➔TDR ➔SDR ➔EDR+IP
  - Derived and evaluated with four data sources:
    Thermal Vac; Simulated data; Proxy data; Observed data
- Development of Cal/Val “machinery”
  - Teams: close-knit, multi-agency, multi-national
  - Plans: clear, actionable, prioritized, coordinated
  - Resources: ground truth, other data/sensors, tools, etc.
- Planned spacecraft maneuvers offer unique opportunity for detailed characterization of ATMS antenna pattern
- NAST-M aircraft comparisons
- Improved pre-launch characterization of future sensors

ATMS Pre-Launch Testing

- **Essential for two objectives:**
  - **Ensure sensor meets performance specifications**
  - **Ensure calibration parameters that are needed for SDR processing are adequately and accurately defined**

- **PFM testing revealed several issues that will require calibration corrections in the SDR:**
  - **Non-linearity (temperature-dependent for 31.4-GHz channel)**
  - **Cross-polarization (sometimes 10X higher than AMSU)**
  - **Antenna beam spillover from secondary parabolic reflector approaching 2% for some channels**

- **EDR specifications may still be met (evaluation in progress) if pre-launch corrections are "valid" on-orbit**

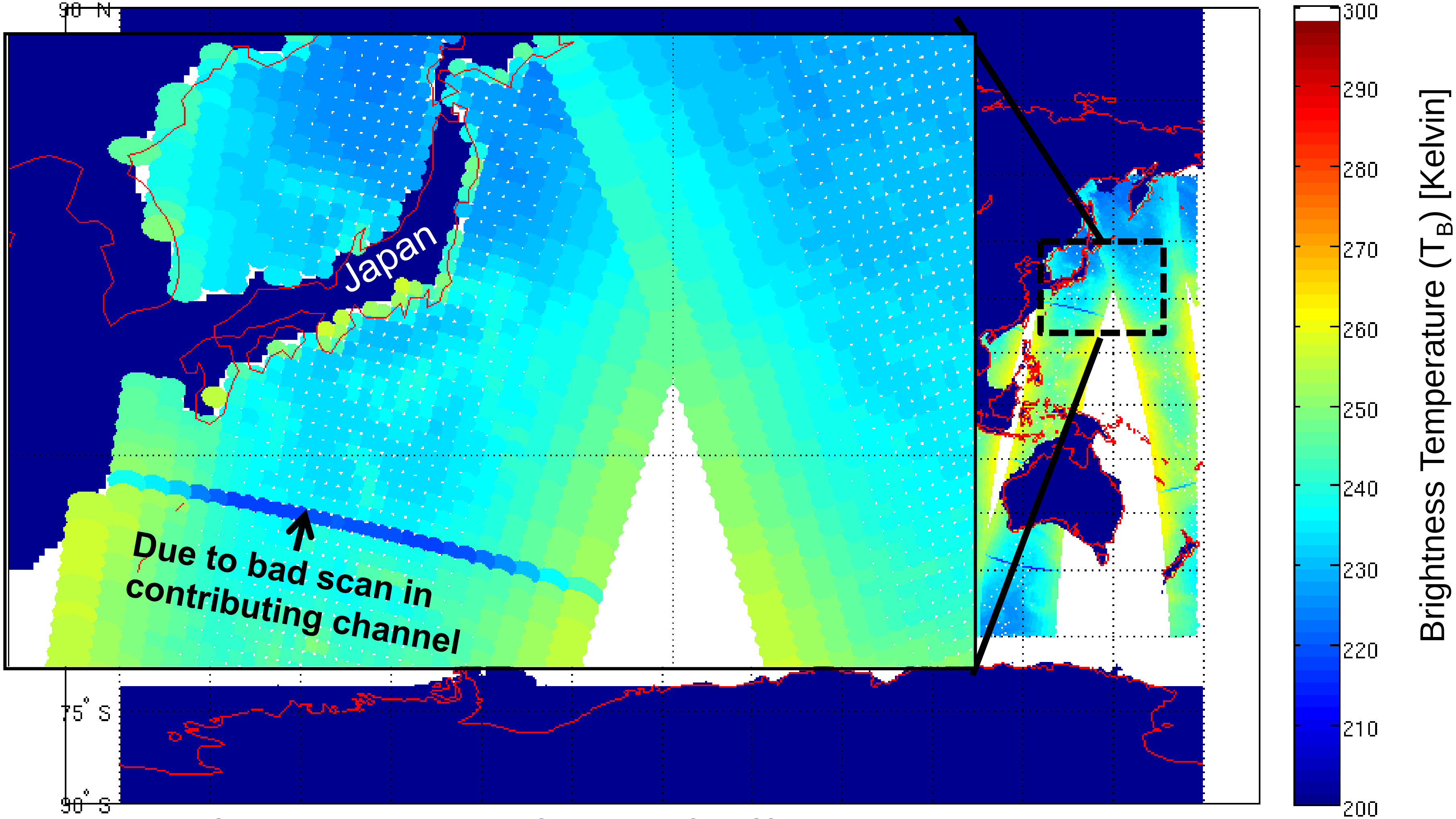
- **On-orbit spacecraft maneuvers for NPP could provide improved calibration parameters to correct any scan bias**

Proxy Background

- Pre-launch SDR/EDR testing is in progress
- "Proxy" ATMS data is needed to test operational software
  - Observed data from on-orbit microwave sensors AMSU-A and MHS are transformed spatially/spectrally to resemble ATMS data
  - Captures real-world atmospheric variations better than simulations based on imperfect/incomplete surface, atmospheric, and radiative transfer models
  - Caveats: Radiometric characteristics of original sensor are embedded in proxy data
- Lincoln's roles:
  - Generate ATMS proxy data and provide it to "NPOESS community"
  - Coordinate with other proxy data providers to ensure consistency
  - Solicit feedback from community to improve/extend data set

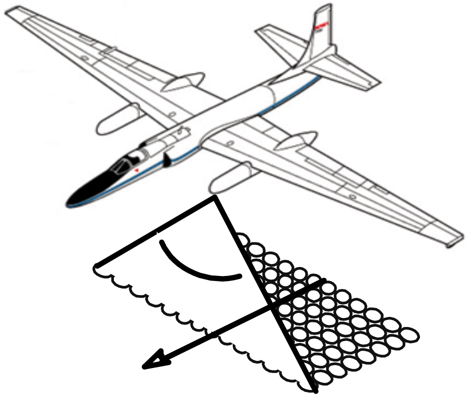
Example of ATMS proxy data

ATMS Channel 4, ocean, mid-latitude, January 5th, 2008 (12hrs)



Note: The most extreme scan angles are not plotted here

Utility of Aircraft Underflights

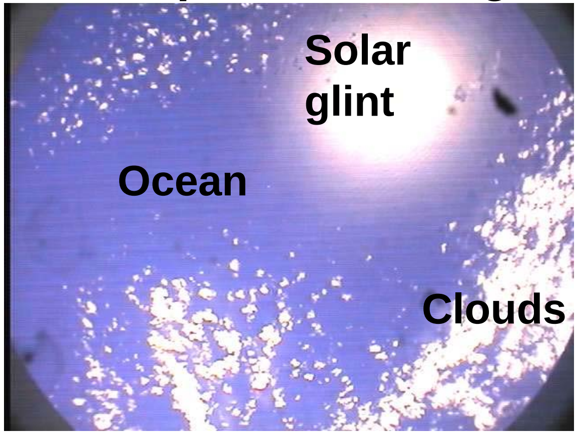


What do aircraft measurements provide that we cannot get anywhere else?

- Why not just compare to radiosondes or NWP?

- Direct radiance comparisons
  - Removes modeling errors
- Mobile platform
  - High spatial & temporal coincidence achievable
- Spectral response matched to satellite
  - With additional radiometers for calibration
- Higher spatial resolution than satellite
- Additional instrumentation deployed
  - Coincident video data
  - Dropsondes

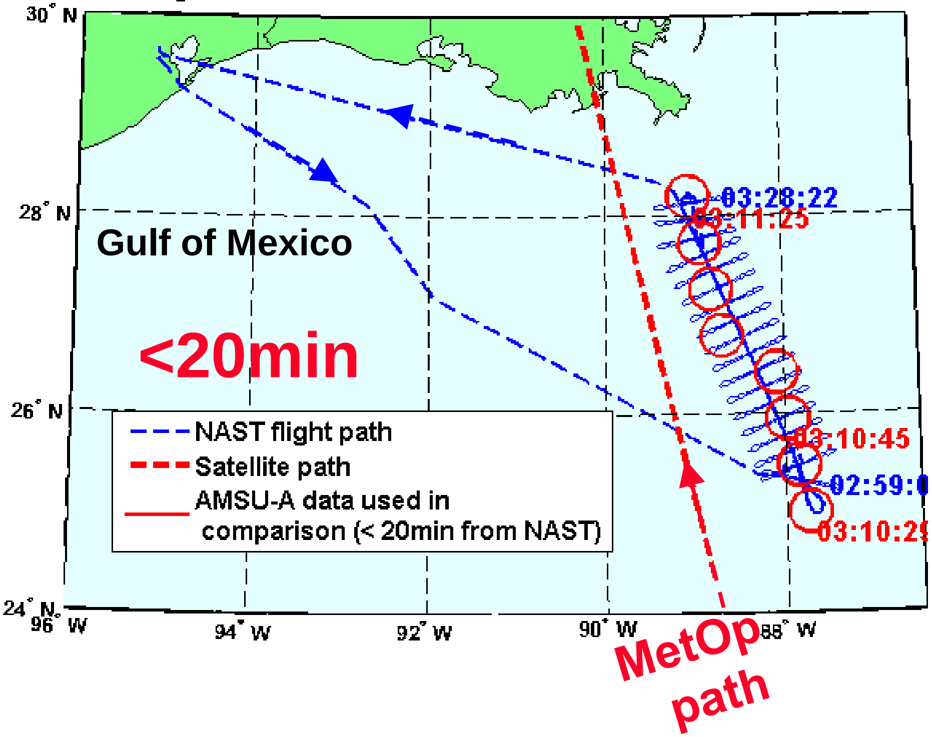
Example video image

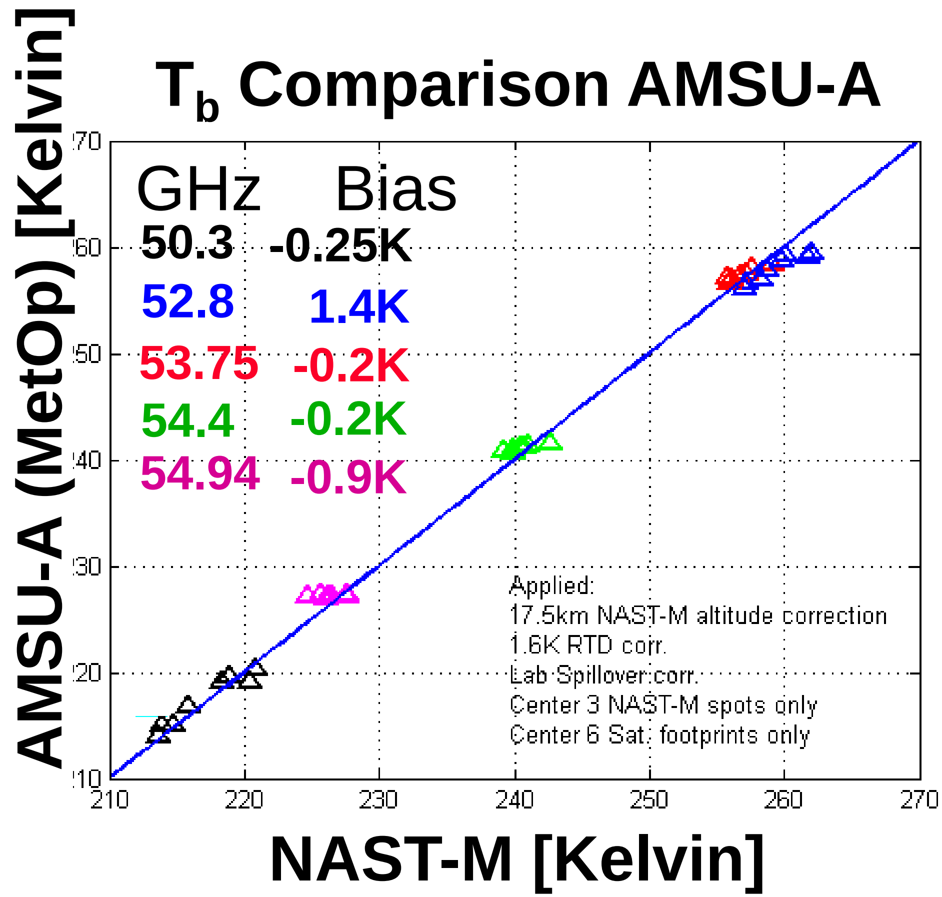


MetOp Satellite Validation

JAIVEx

April 20th, 2007 collection





ATMS On-Orbit FOV Characterization

- Spacecraft maneuvers (constant pitch up or roll, for example) could be used to sweep antenna beam across vicarious calibration sources
  - Moon (probably too weak/broad for pattern assessment)
  - Earth's limb (requires atmospheric characterization)
    - Focus of today's presentation
  - Land/sea boundary (good for verification of geolocation)
- With knowledge of the atmospheric state, the antenna pattern can be recovered with deconvolution techniques
- Objectives of this study - quantitatively assess:
  - The benefits of various maneuvers
    - How accurately can the pattern be recovered?
  - The limitations of this approach
    - How much roll/pitch is needed for an adequate measurement?
    - The error sources and their impact

Summary

- **ATMS will continue and improve the data record provided by MSU and AMSU**
  - **ATMS for NPP delivered in 2005**
  - **NPP has a tentative launch in Oct. 2011**
  - **NPOESS C1 unit scheduled for testing in 2010 and delivery in ~2011**
- **Prelaunch testing has revealed excellent ATMS performance**
- **Planned post-launch validation activities will confirm performance and offer opportunities for improvement**
  - **Community involvement is critical**
  - **Conflation of different user perspectives enhances the process**

Backup Slides

NPOESS Airborne Sounder Testbed

OBJECTIVES

- *Satellite calibration/validation*
- Simulate spaceborne instruments (i.e. CrIS, ATMS, IASI)
  - Preview high resolution products
  - Evaluate key EDR algorithms

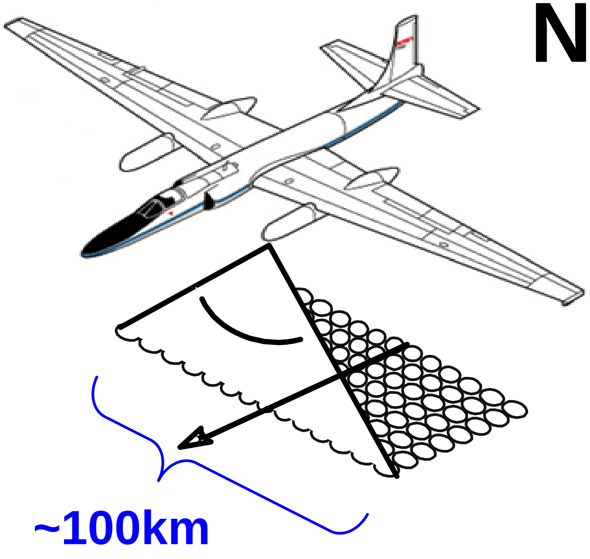
INSTRUMENTS: NAST-I & NAST-M

NAST- I: IR Interferometer Sounder

NAST- M: Microwave Sounder

- 4 Bands: 54, 118, 183, 425 GHz

NAST



Cruising altitude: ~17-20 km

Cross-track scanning: - 65º to 65º

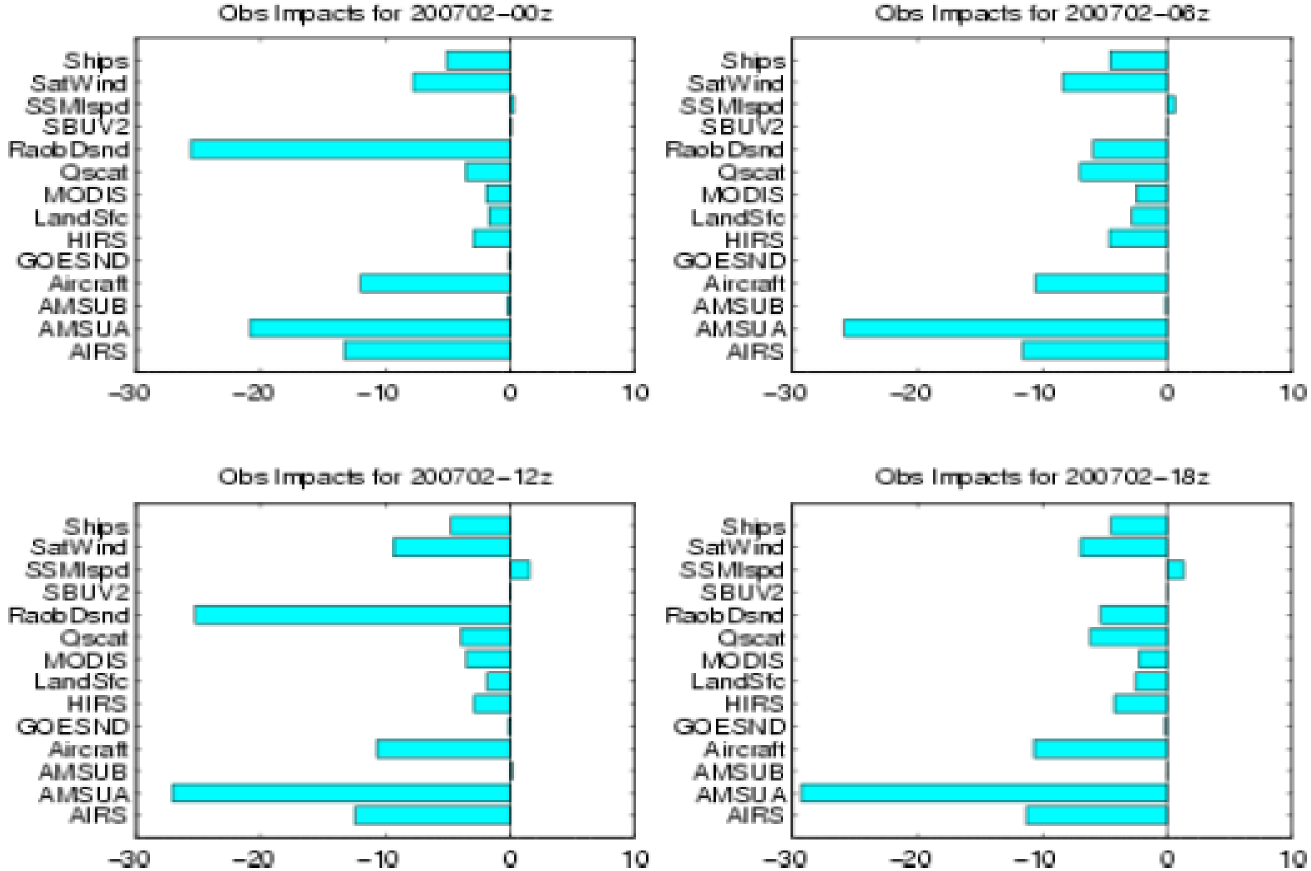
Summary of ATMS Prelaunch Testing

- All key radiometric requirements were satisfied
- Radiometric accuracy exceeds 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

AMSU-A: Large, Positive Forecast Impact

Observation impact: 3dVar DAS & Forecasts

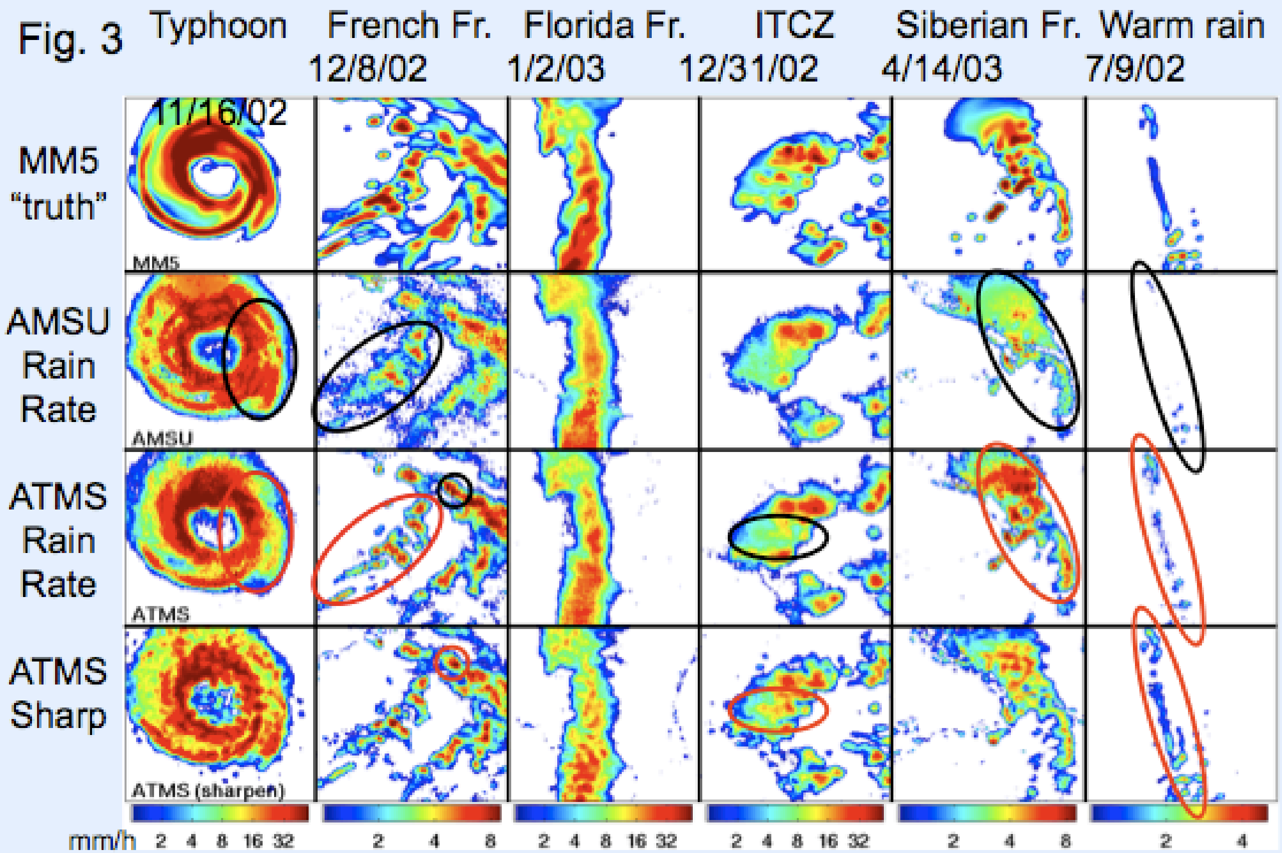
Accumulated forecast error reduction due to various observing instruments for the 24-forecasts for February 2007 - 1/2degree system



Source: Gelaro, Rienecker et al., 2008, NASA GMAO

ATMS Storm Mapping: Improvements Relative to AMSU

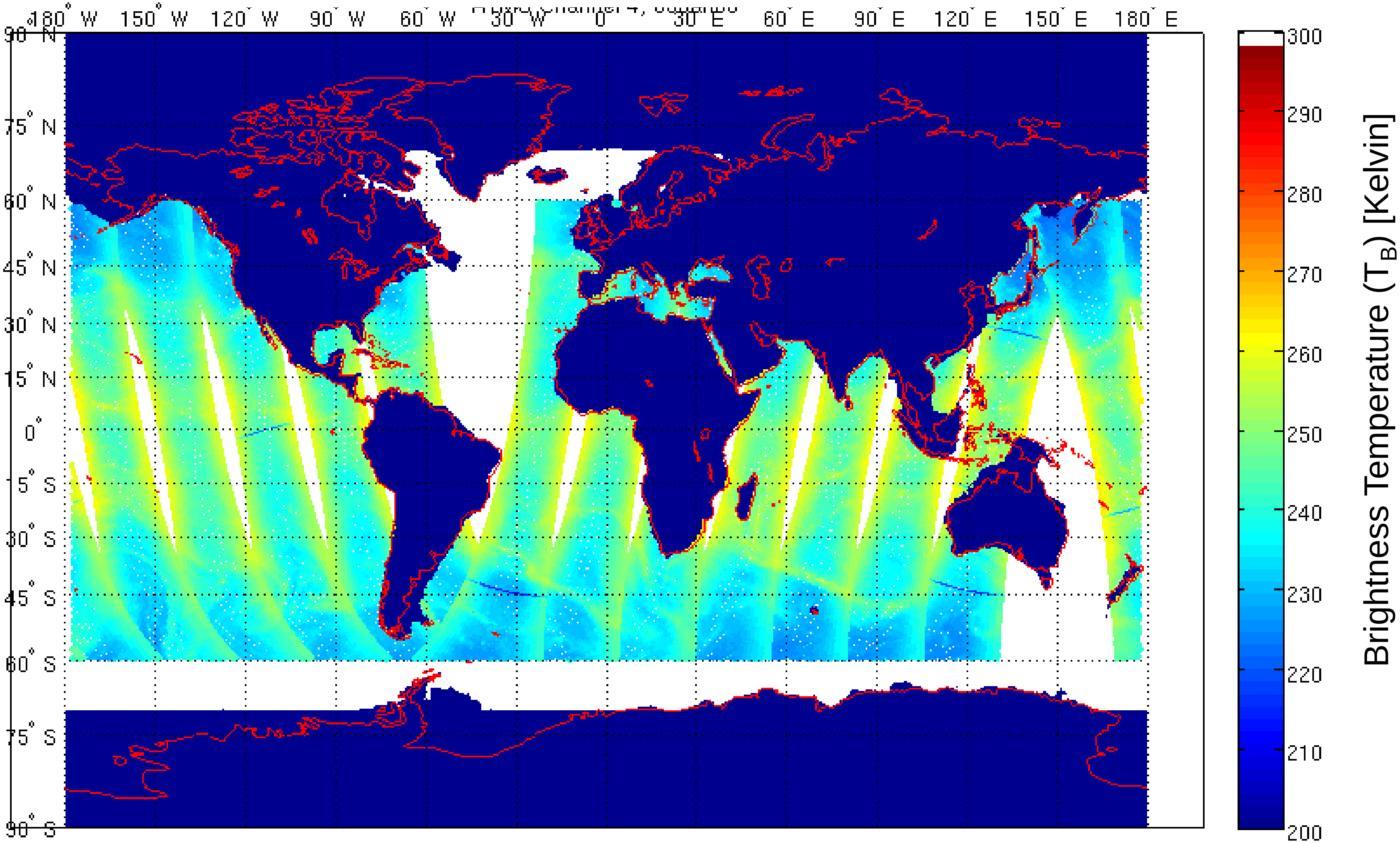
Black and red circles highlight "before" and "after" differences between AMSU and ATMS, and between ATMS and ATMS-sharpened, for six simulated storms validated with AMSU. Note the better definition of strong convective cells with ATMS due to its 33-km resolution and Nyquist sampling, and the better recovery of the warm rain with sharpening



Source: Surussavadee and Staelin, NASA PMM Presentation, July 2008

Example of ATMS proxy data

ATMS Channel 4, ocean, mid-latitude, January 5th, 2008 (12hrs)



Note: The most extreme scan angles are not plotted

coast

USGS landmask (used to identify ocean pixels)

Overview of Proxy Methodology

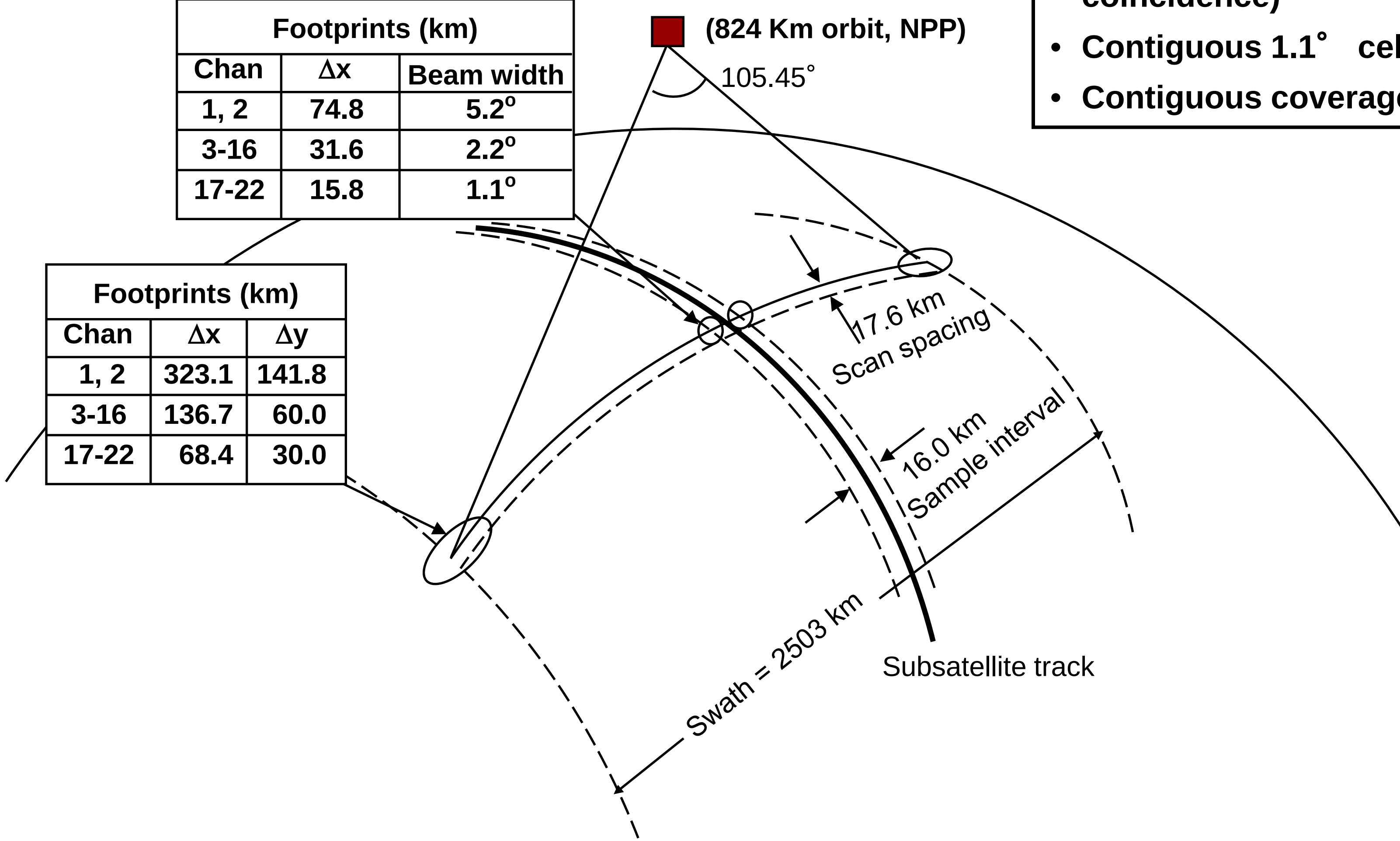
- Generation of ATMS proxy data is non-trivial due to spectral and spatial differences between AMSU/MHS and ATMS
- A linear relationship (regression) is derived between ATMS and AMSU channels that are not common to both sensors
- Simulated data are used to derive the regressions
- The simulated data are calculated using global AIRS Level2 profile data (Dec 2004 – Jan 2006), fastem 2.0 ocean surface model, and Phil Rosenkranz's radiative transfer package
- The relationships between ATMS and AMSU can vary as a function of lat/lon, surface topography, and sensor scan angle. Data stratification is used to improve the fit quality.

Scanning Characteristics

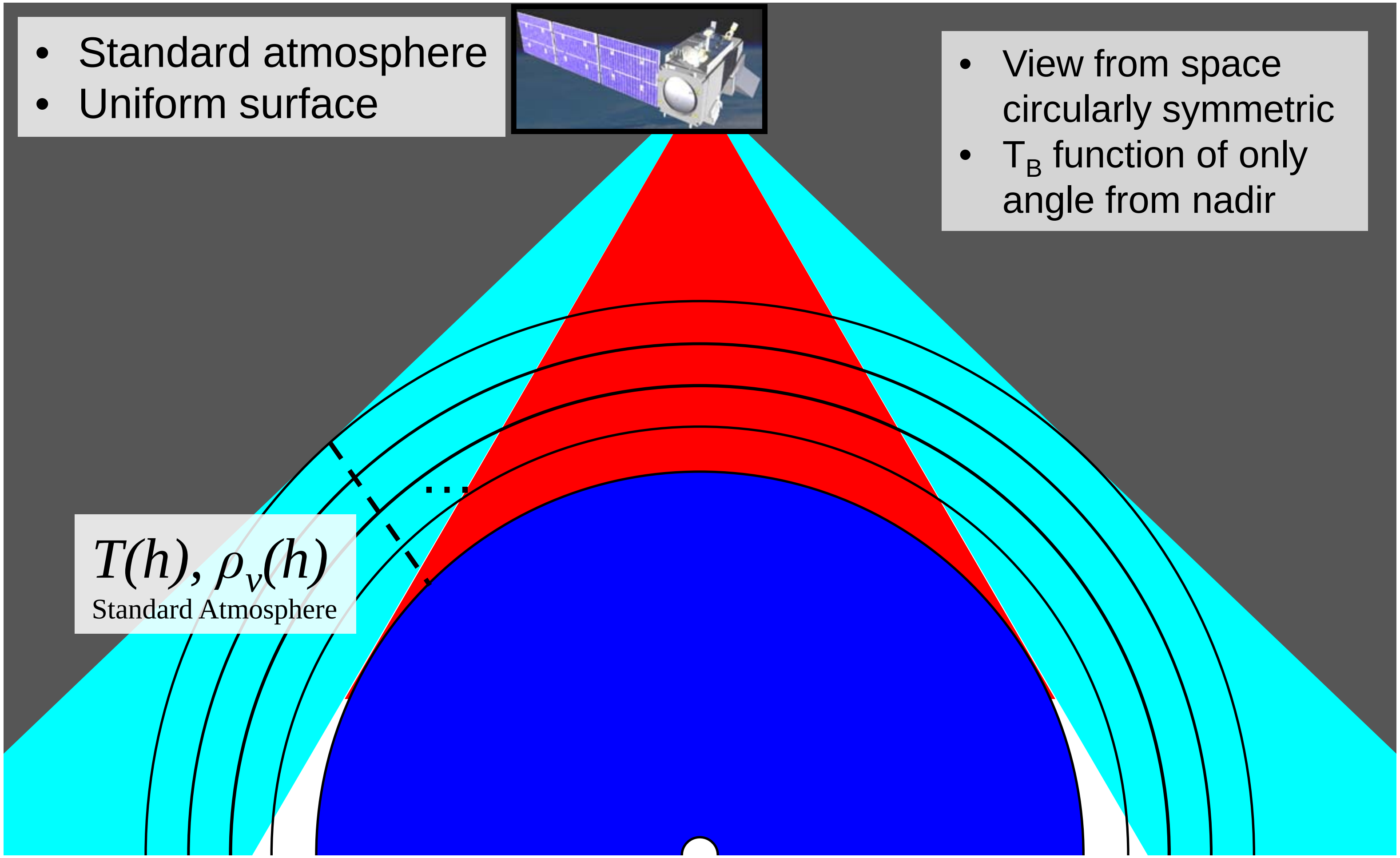
- Cross-track (for CrIS coincidence)
- Contiguous 1.1° cells
- Contiguous coverage at equator

Footprints (km)		
Chan	Δx	Beam width
1, 2	74.8	5.2°
3-16	31.6	2.2°
17-22	15.8	1.1°

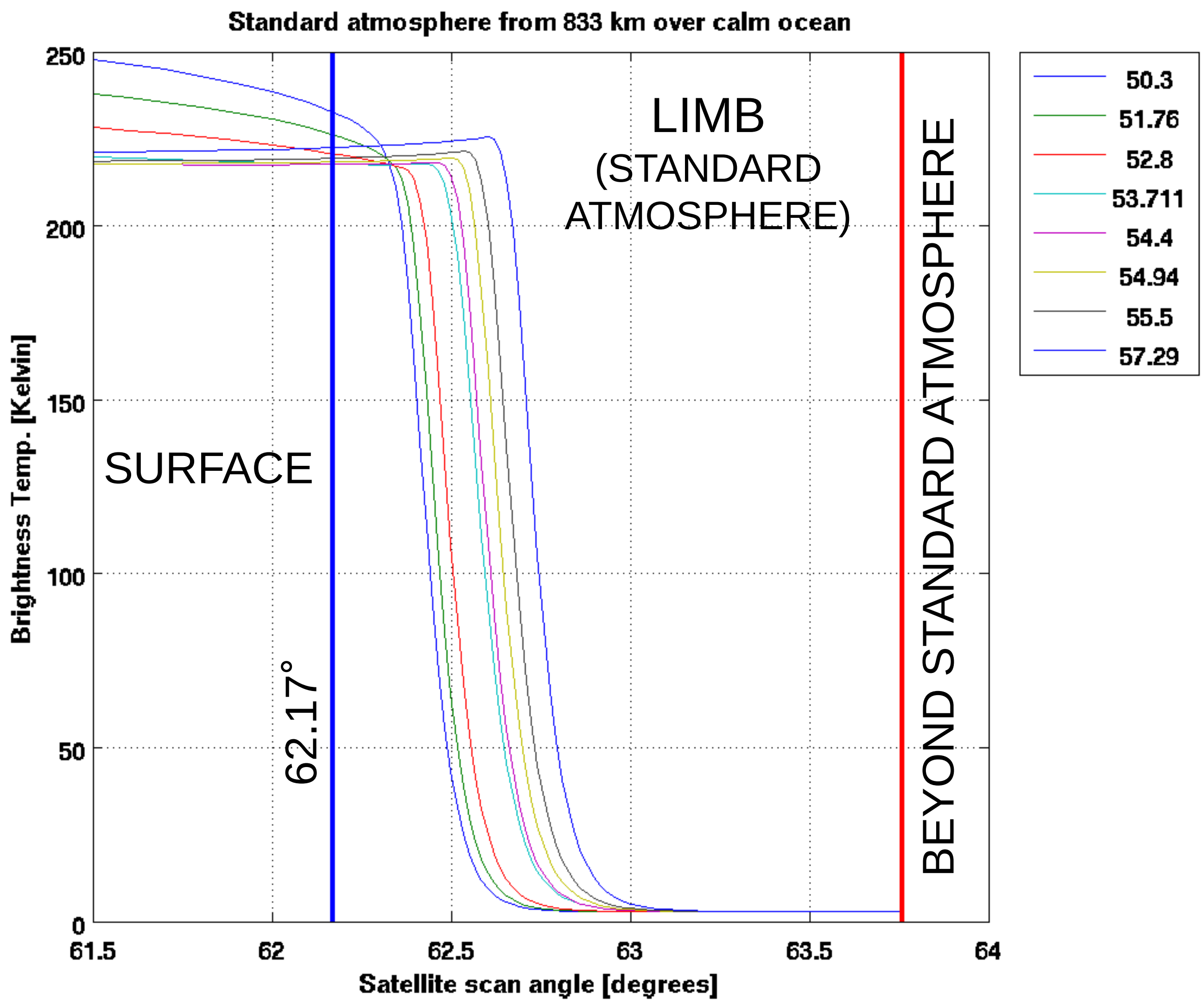
Footprints (km)		
Chan	Δx	Δy
1, 2	323.1	141.8
3-16	136.7	60.0
17-22	68.4	30.0



"Onion" Model of Earth

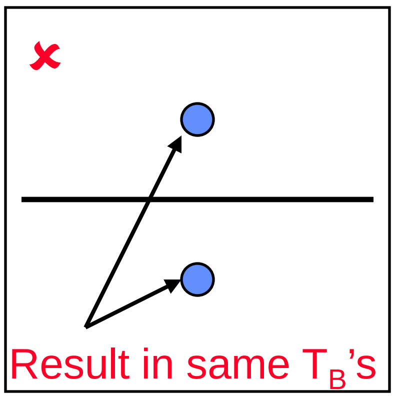


T_B's Across Earth/Space Transition

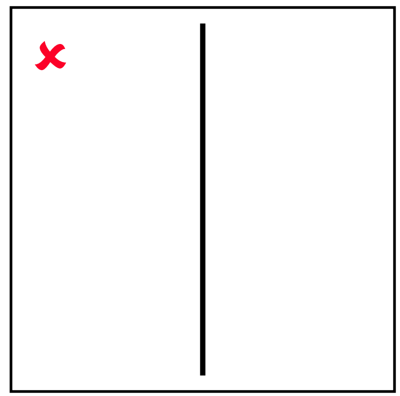


Results (with sensor noise)

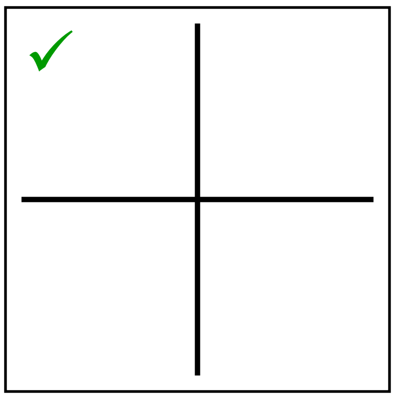
ROLL ONLY



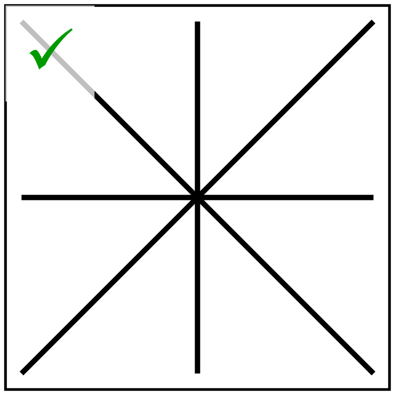
PITCH ONLY



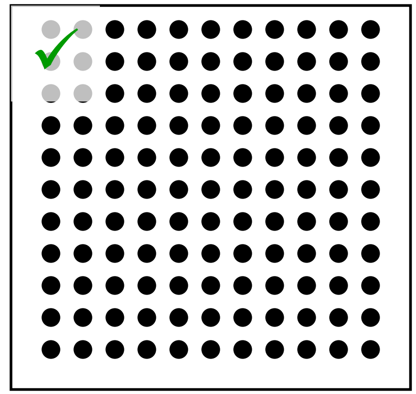
CROSS



STAR



2-D ARRAY



- Noise causes problems with width estimation
- Single dimension inadequate

Proxy Methodology Details

Three step procedure:

1. **Compile AIRS L2 profile ensembles for each stratification (~10,000)**
   - **Stratifications planned:**
     - **Scan angle (16 angles total, from nadir out to 51.15˚)**
     - **Ocean/Land**
     - **Latitude (North, Tropical and mid-latitude, South)**
     - **Surface pressure for Land (8 strats)**
     - **Total: 432 transformation matrices**

2. **Simulate ATMS, AMSU/MHS radiances with Rosenkranz radiative transfer model (RTM) software**
   - **Account for beamwidth and polarization per channel**
   - **Surface emissivity models:**

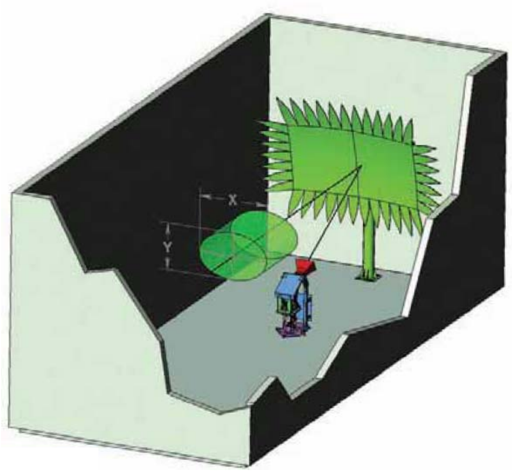
     For ocean, use fastem2*

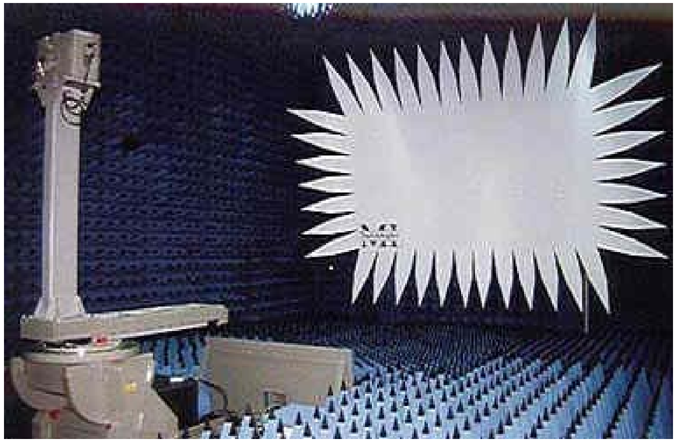
     For land, uniform distribution from [0.9 – 1]†

3. **Generate 22x20 transformation matrix ("C") via linear regression for each stratification**

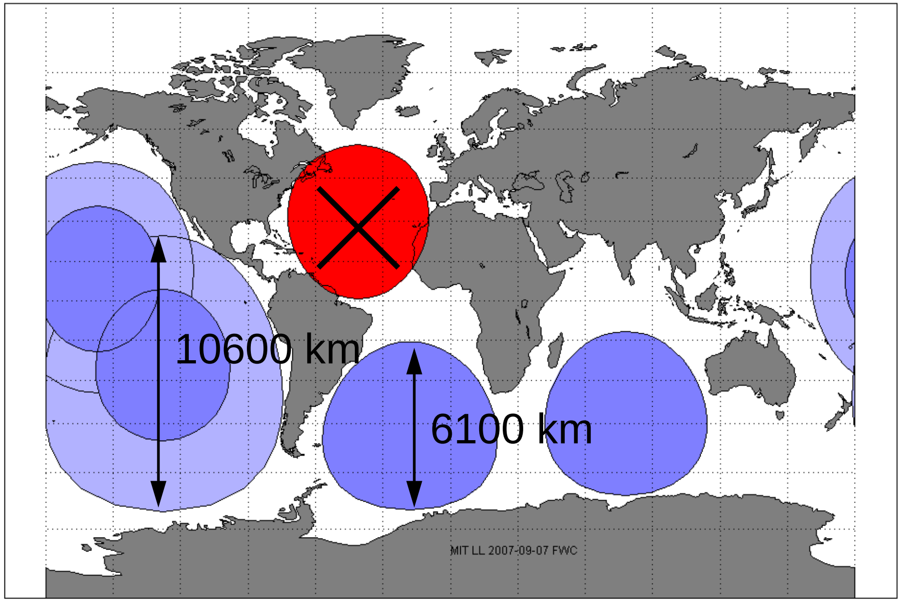
Compact Antenna Range Testing

- 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





Areas for Spacecraft Maneuvers with Ocean View



- Ocean has less surface emissivity variation than land
- Earth visible to 62.17° from nadir (dark blue), or 6100 km diameter
- Complete ocean view possible over Indian, S. Atlantic, Pacific
- Wide range of possibilities over Pacific (light blue)

Summary of Key Sensor Parameters

Parameter	PFM Measurement
Envelope dimensions	70x60x40 cm
Mass	75 kg
Operational average power	100 W
Operational peak power	200 W
Data rate	30 kbps
Absolute calibration accuracy	0.6 K
Maximum nonlinearity	0.35 K
Frequency stability	0.5 MHz
Pointing knowledge	0.03 degrees
NEΔT	0.3/0.5/1.0/2.0 K

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.**

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**