CrIMSS Error Modeling with ATMS Proxy Data

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NASA Sounding Science Meeting

May 4-7, 2009

This work was sponsored by the National Oceanic and Atmospheric Administration under contract FA8721-05-C-0002. Opinions, interpretations, conclusions, and recommendations are those of the author and are not necessarily endorsed by the United States Government.

Successful Postlaunch NPP Cal/Val: 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)**
  - **Postlaunch radiance/product characterization**
  - **Refinement of error models/budgets based on observations**

Major Components of ATMS Cal/Val

- **ATMS/CrIMSS System Error Model/Budget**
  - **RDR ➔TDR ➔SDR ➔EDR+IP**
  - **Derived and evaluated with three data sources:**
    Thermal Vac; Simulated data; Proxy data
- **Post-Launch Cal/Val Planning**
- **Development of Cal/Val Tools**
  - **Neural network EDR algorithm**
  - **Matchup/RadTran comparison tools (SDR)**
  - **Raw radiance assessment tools (RDR)**
- **NAST-M Aircraft Comparisons**
- **Improved Pre-Launch Characterization (C1, but maybe PFM)**

ATMS/CrIMSS RDR/SDR/EDR Error Modeling

- **There is a need for simple, accurate error models with budgets for accuracy and precision resulting from:**
  - **Scan biases, nonlinearity, calibration biases, NEdT, pointing errors, polarization impurity, many others…**
- **RDR error model based on radiometric math model and thermal vacuum environmental testing**
- **SDR error model (calibration, geolocation, resampling)**
  - **Based on Phil Rosenkranz's radiative transfer package**
  - **Backus-Gilbert footprint processing**
- **EDR error modeling is much more difficult (highly nonlinear and dependent on scene conditions)**

ATMS Proxy Data Background

- **"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**

- **MIT-LL 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**

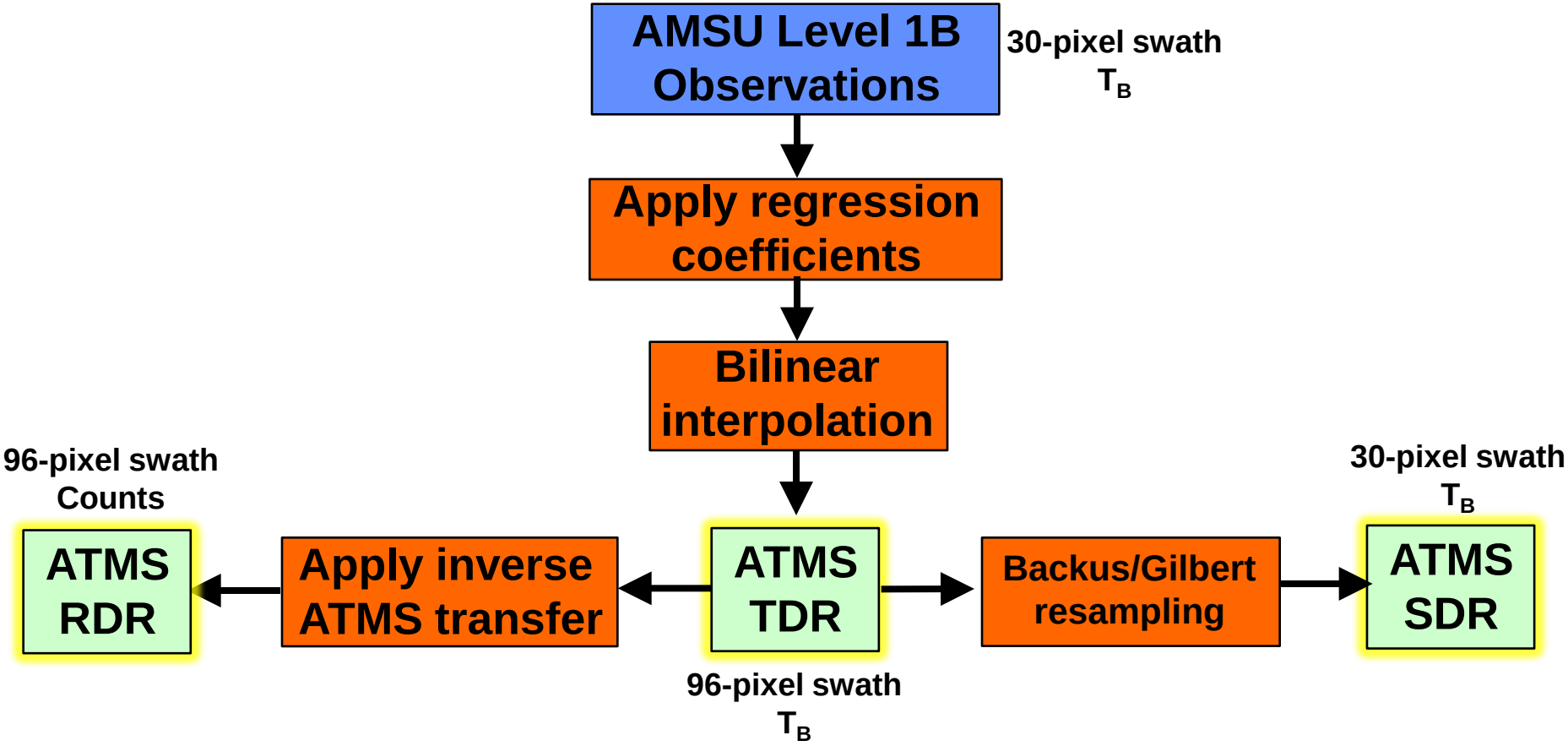
Generation of ATMS Proxy Data

- **AMSU-A/B observations can be transformed (spatially and spectrally) to resemble ATMS observations**
  - **11 channels are identical**
  - **5 channels are identical EXCEPT for polarization**
  - **6 channels are new, but can be estimated [with some error]**

  - **Footprint sizes and spatial sampling are different for frequencies < 89 GHz**
  - **ATMS measures wider swath angles**

  - **Orbits altitudes are slightly different**

ATMS Proxy Data Generation Flow Chart



Overview of 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.

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 place at nadir**

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

Methodology Details

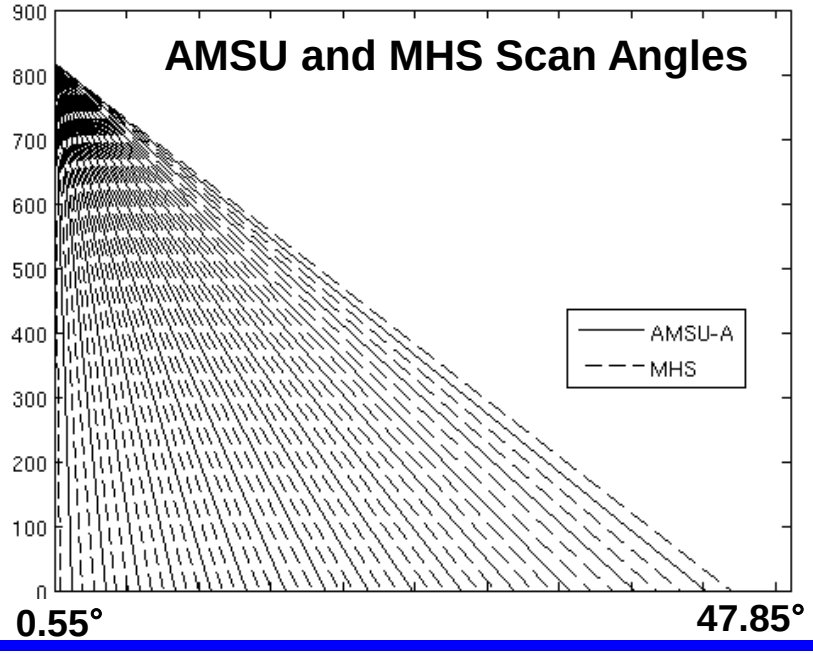
(Slide 1 of 3)

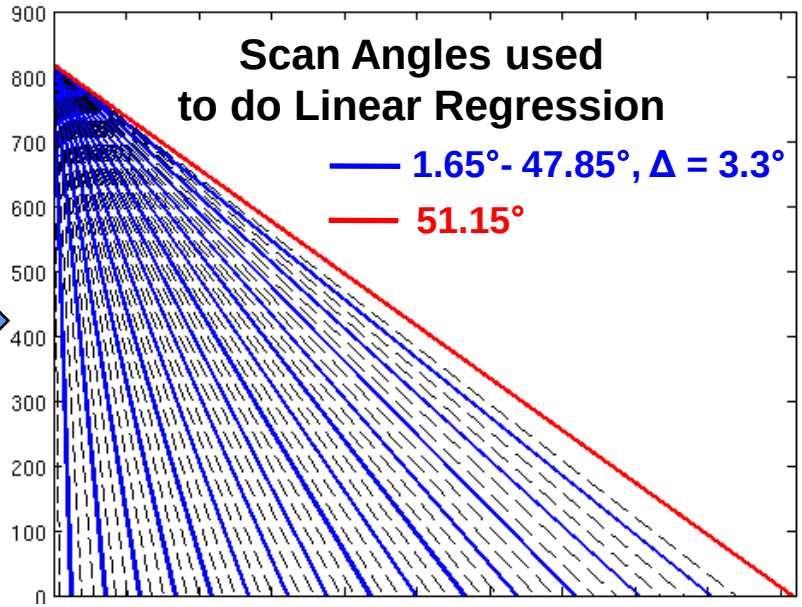
Three step procedure:

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**





Methodology Details

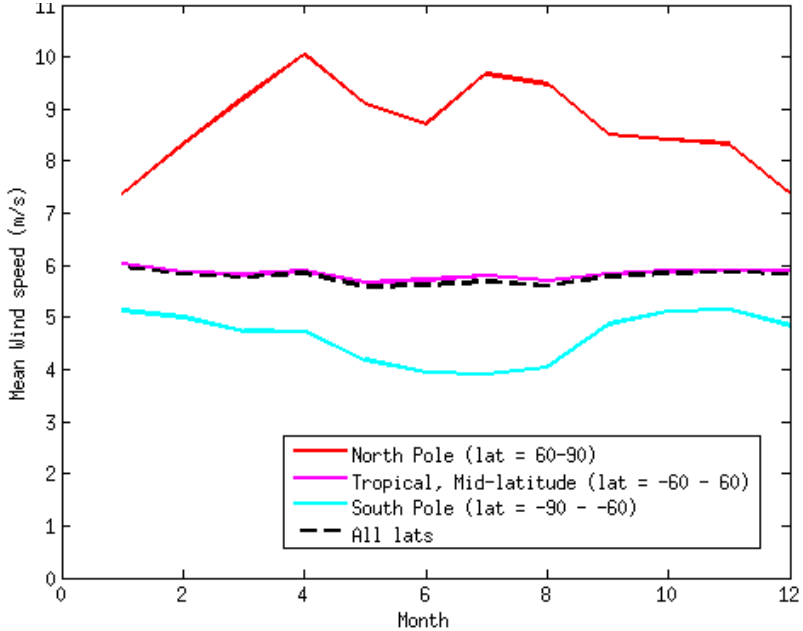
(Slide 2 of 3)

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

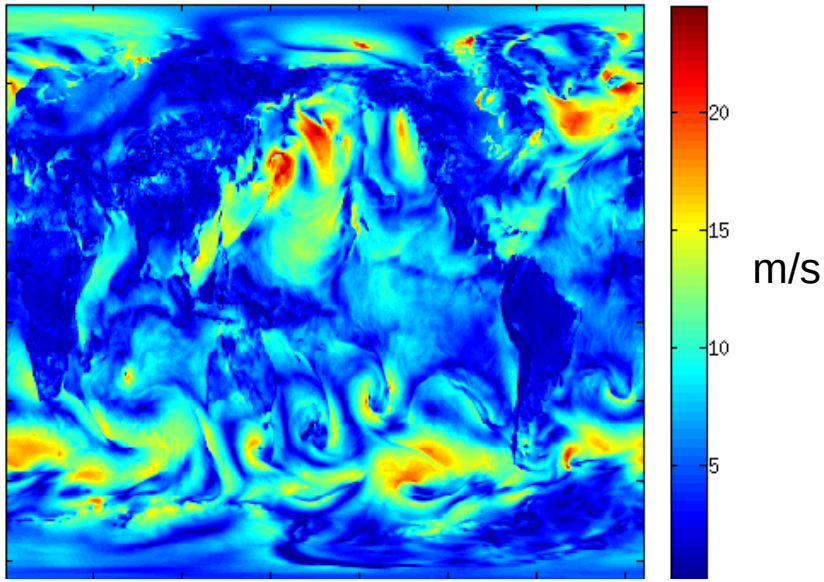
     For ocean, use fastem2* with wind speed based on ECMWF 2005 data

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

Mean Wind Speed Over Ocean, ECMWF 2005



ECMWF Horizontal Wind Speed at 10m
January 1st, 2005, 00hrs



*See English & Hewison 1998, Deblonde 2000

†Hewison 2001

Methodology Details

(Slide 3 of 3)

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

$\mathbf{X}$ = simulated ensemble of AMSU and MHS radiances

$\mathbf{Y}$ = simulated ensemble of ATMS radiances

$\mathbf{N}$ = AMSU and MHS noise

Linear regression of **X** and **Y**:

$$\mathbf{C} = \frac{\mathrm{Cov}(\mathbf{X}, \mathbf{Y})}{\mathrm{Cov}(\mathbf{X}) + \mathbf{N}}$$

Transformation matrix is applied to real AMSU/MHS data:

$$\underset{\rightarrow}{\mathbf{v}}_{proxy}^{ATMS} = \mathbf{C} \cdot (\underset{\rightarrow}{\mathbf{v}}_{real}^{AMSU,MHS} - \overline{\mathbf{X}}) + \overline{\mathbf{Y}}$$

Results

(ocean, mid-latitude)

ATMS

Ch	GHz	Pol
1	23.8	QV
2	31.4	QV
3	50.3	QH
4	51.76	QH
5	52.8	QH
6	53.596 ± 0.115	QH
7	54.4	QH
8	54.94	QH
9	55.5	QH
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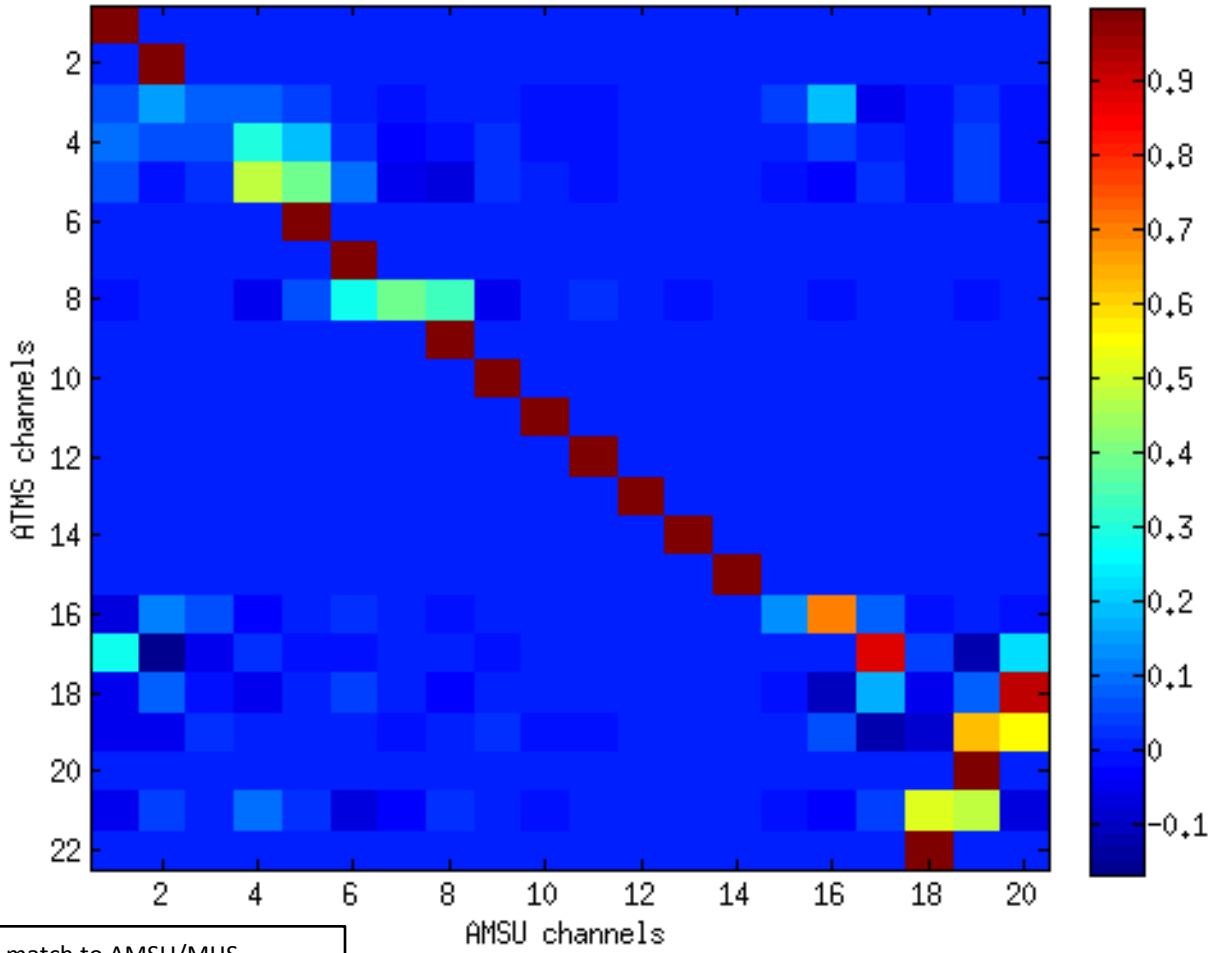
15	fo± 0.3222±0.0045	QH
16	88.2	QV
17	165.5	QH
18	183.31 ± 7	QH
19	183.31 ± 4.5	QH
20	183.31 ± 3	QH
21	183.31 ± 1.8	QH
22	183.31 ± 1	QH

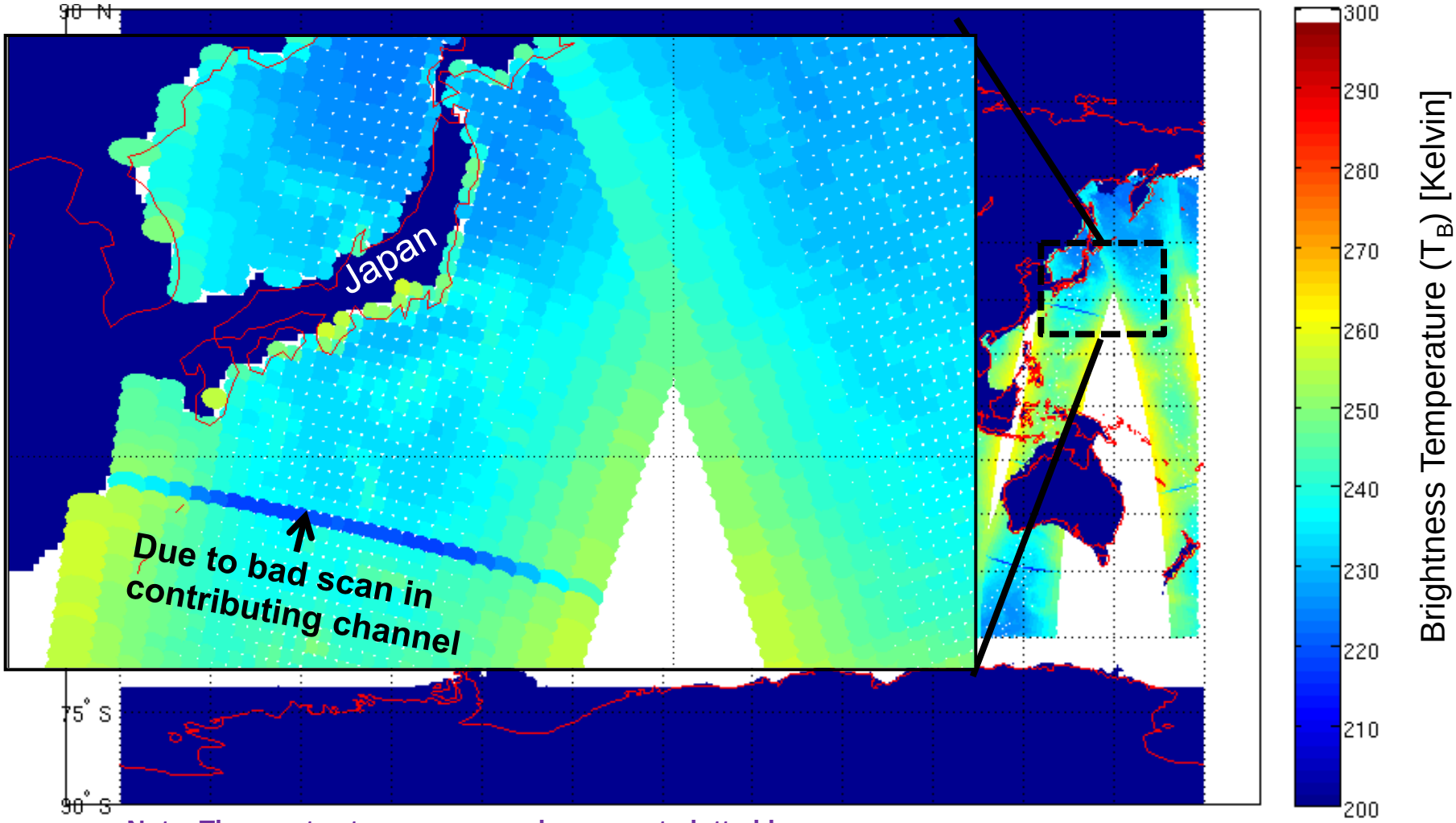
Transformation matrix for nadir (1.65°)



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

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

Validation Plan

- **Use observed data to validate our proxy data, with two existing operational sensors with similar (but not identical) spectral characteristics (like ATMS relationship to AMSU/MHS)**
  - **→ AMSU-B and MHS**
  - **→ Use coincident data from NOAA-17 and METOP from 2008**

AMSU-B			MHS		
Ch	GHz	Pol	Ch	GHz	Pol
1	89.0± 0.9	QV	1	89.0	QV
2	150.0± 0.9	QV	2	157.0	QV
3	183.31 ± 1	QV	3	183.31 ± 1	QH
4	183.31 ± 3	QV	4	183.31 ± 3	QH
5	183.31 ± 7	QV	5	191.31	QV

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

ATMS Proxy Data Deliverables and Schedule

- We are using Oct. 19, 2007 MetOp-A observations for initial validation
- HDF format will be used (compatible with PEATE?)
- We plan to deliver code (Fortran) and coefficients to PEATE
- Focus days to be specified
- Schedule: Initial delivery of “beta release” for testing
  - Target date is June 1st

ATMS Proxy Data Development Status

- General baseline code complete
  - Pipeline of components for modeling ATMS, generating regression coefficients, applying coeffs to AMSU/MHS data, then co-locating to ECMWF (for sanity checking)
- Generation of C matrices for all stratifications is underway
  - "beta" release will include data at all scan angles and a subset of stratifications
  - Ocean "tropical + mid-latitude" matrices complete
  - Land "tropical + mid-latitude" matrices in progress
- Validation underway using AMSU-B and MHS
- Initial beta release soon: HDF output format planned

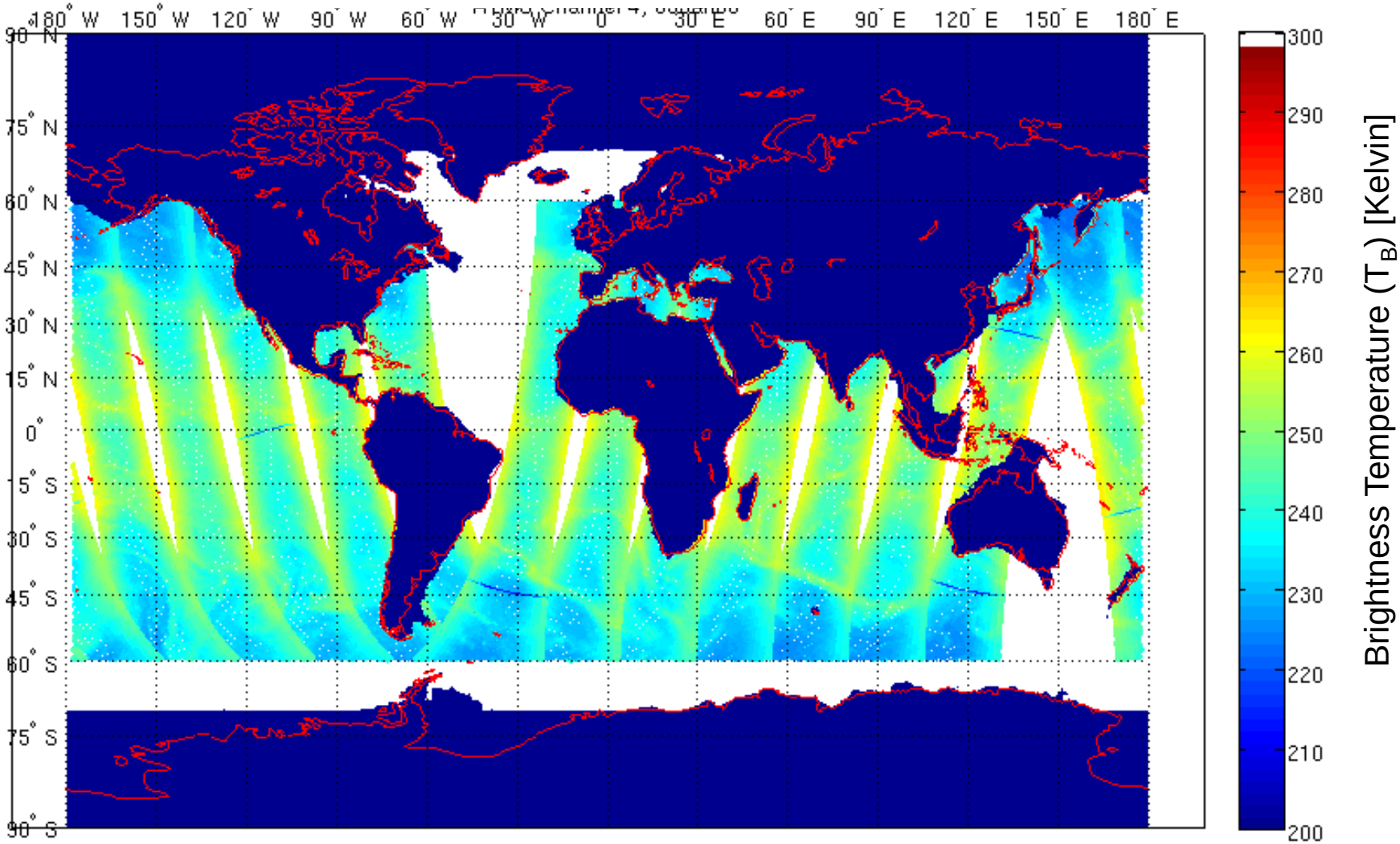
Summary

- ATMS/CrIMSS error models/budgets are being developed to predict on-orbit performance and sensitivities
- Error models/budgets will be used during cal/val to characterize performance and help attribute sources
- ATMS proxy data is a critical component of prelaunch testing
- ATMS proxy data generator will be delivered to Sounder PEATE
  - Beta testing in progress, preliminary version ready in June
  - We'll work with PEATE and sounding science team to maximize utility and compatibility

Backup Slides

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 land mask (used to identify ocean pixels)

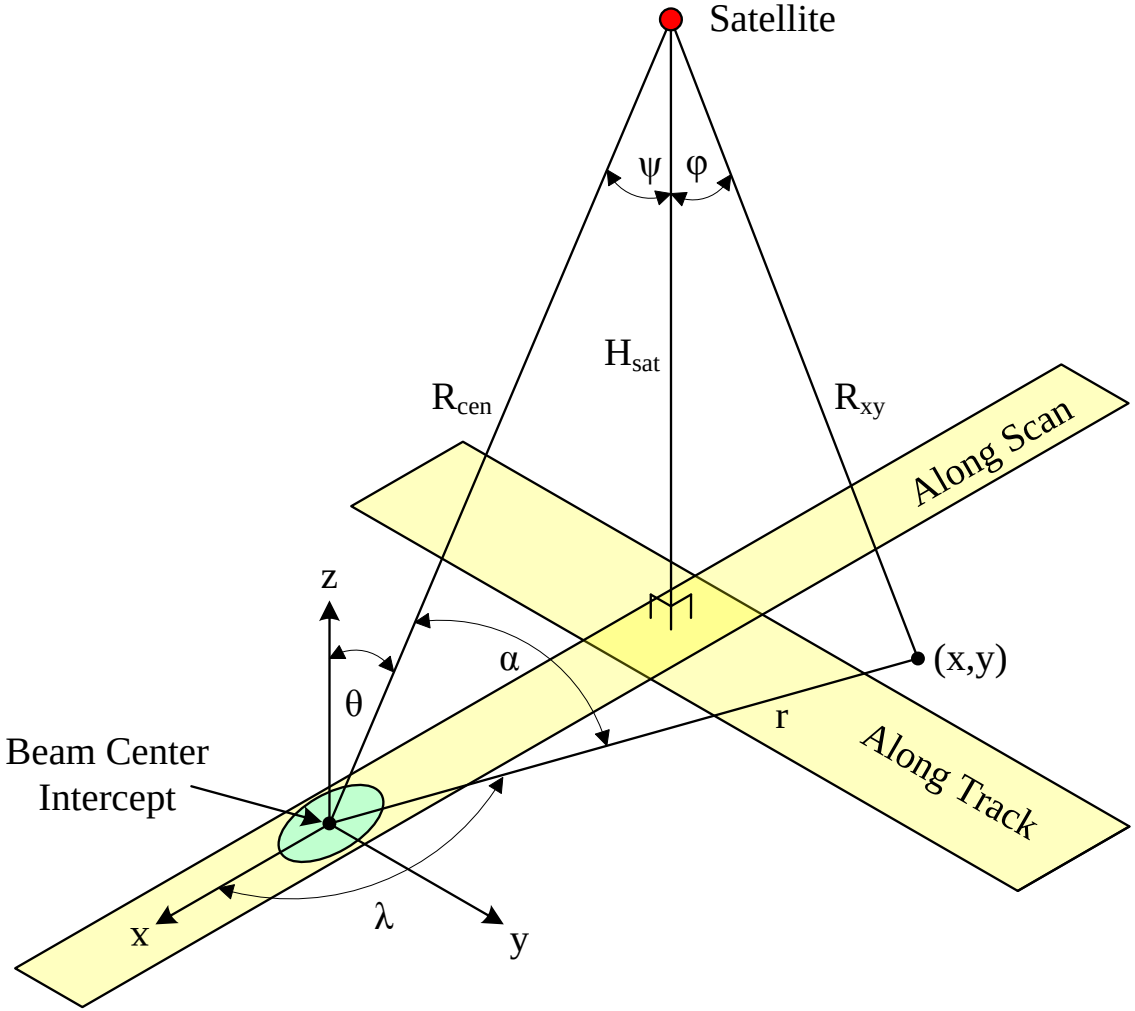
ATMS “Footprint Matching”

Jenna Samra and Bill Blackwell

Overview

- **Resampling algorithm**
  - **Projection geometry**
  - **Scan geometry**
  - **Backus-Gilbert coefficients**
- **Example of results**
  - **ATMS channels 1-2 (5.2° BW)**
  - **ATMS channels 3-16 (2.2° BW)**
  - **ATMS channels 17-22 (1.1° BW)**
- **Next steps**

Projection to Earth's Surface



Transformation Equations

$$\lambda = \tan^{-1}\frac{y}{x}$$

$$\varphi = \sin^{-1}\left[\frac{r\sin\alpha}{R_{xy}}\right]$$

$$\alpha = 90° + \theta\cos\lambda$$

$$r = \sqrt{x^2 + y^2}$$

$$R_{xy}^2 = R_{cen}^2 + r^2 - 2R_{cen}r\cos\alpha$$

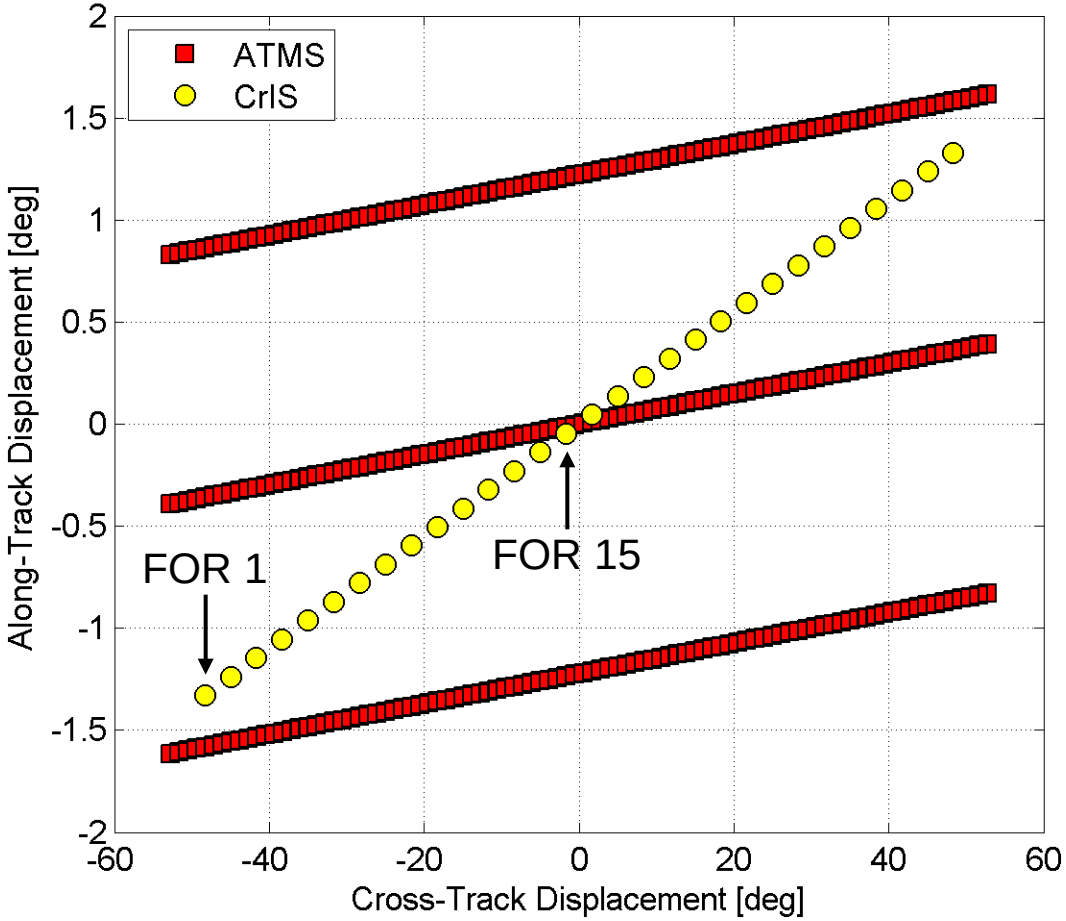
$$\frac{\sin\varphi}{r} = \frac{\sin\alpha}{R_{xy}}$$

CrIS and ATMS Scan Parameters

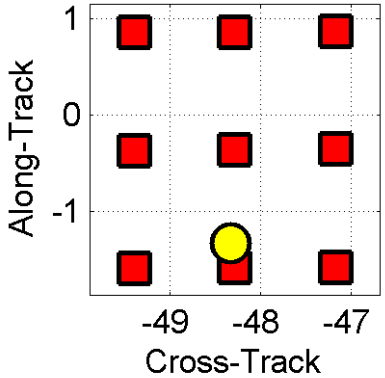
Parameter	CrIS	ATMS
-3 dB beam width [deg]	3.3	1.1, 2.2, 5.2
Step time [ms]	200	18.018
Full scan period [s]	8	8/3
Angular velocity [deg/s]	0.458	0.458
Step angle [deg]	10/3	1.11
Number of earth views	30	96

- **Δ cross-track displacement = step angle**
- **Δ along-track displacement = angular velocity x step time**
- **Scan separation = angular velocity x scan time**

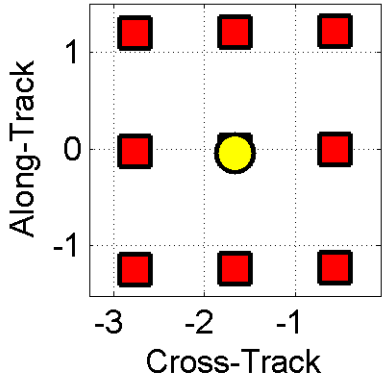
Resampling Grid



FOR 1

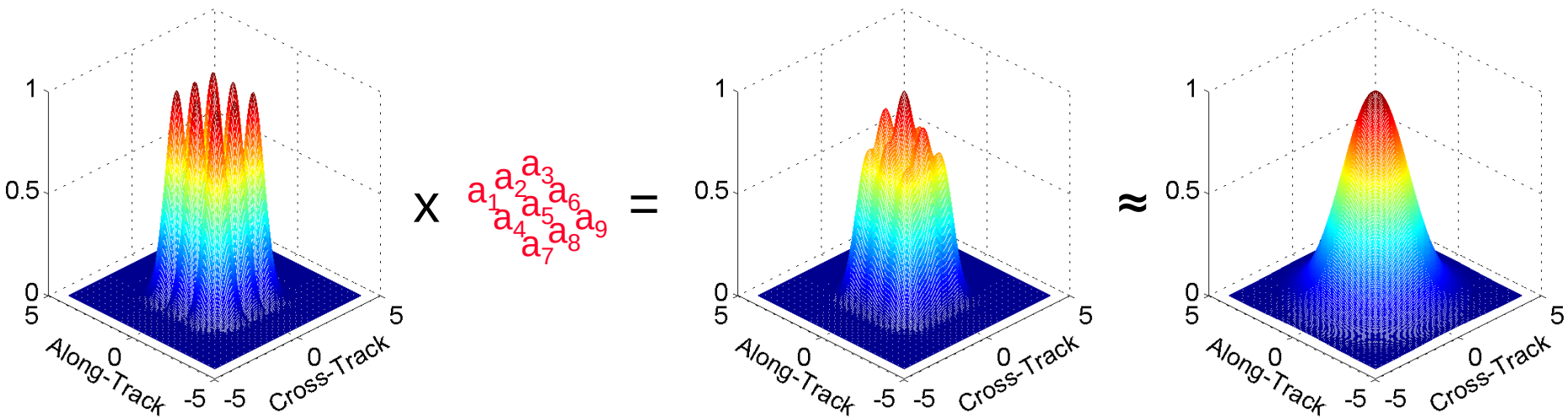


FOR 15



Backus-Gilbert Methodology

- **Backus-Gilbert coefficients a_i scale ATMS brightness temp to approximate CrIS brightness temp**



ATMS Grid BG Coeffs CrIS Estimate CrIS Target

Choosing BG Coefficients

Goal: **find coefficient vector a to minimize cost function Q**

$$Q = Q_0(a(\gamma))\cos\gamma + we^2(a(\gamma))\sin\gamma$$

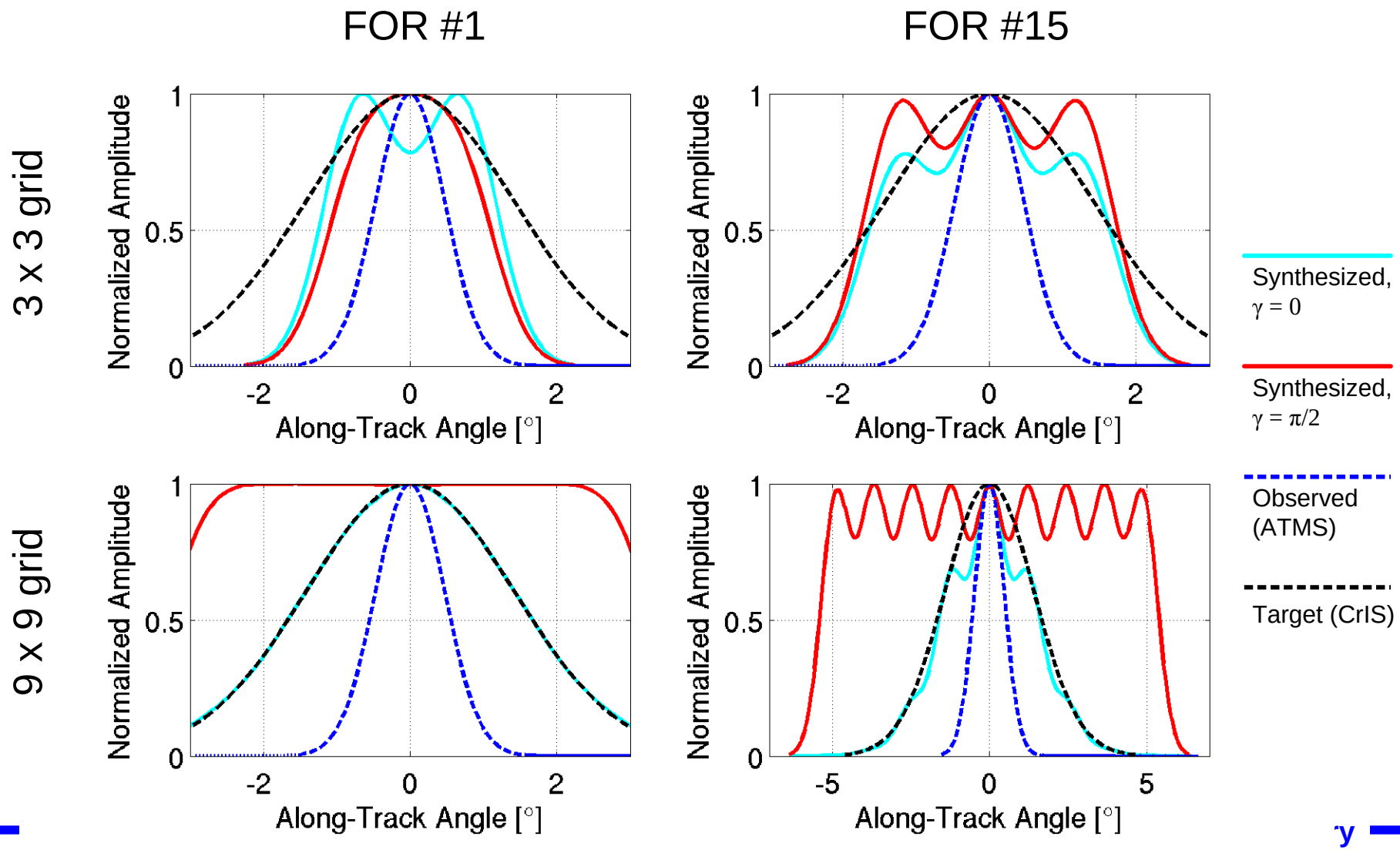
- **Minimizing Q_0 → highest accuracy**
- **Minimizing e^2 → lowest noise amplification**
- **γ chosen as tradeoff between best fit and lowest noise**

Result: **least-squares minimization yields**

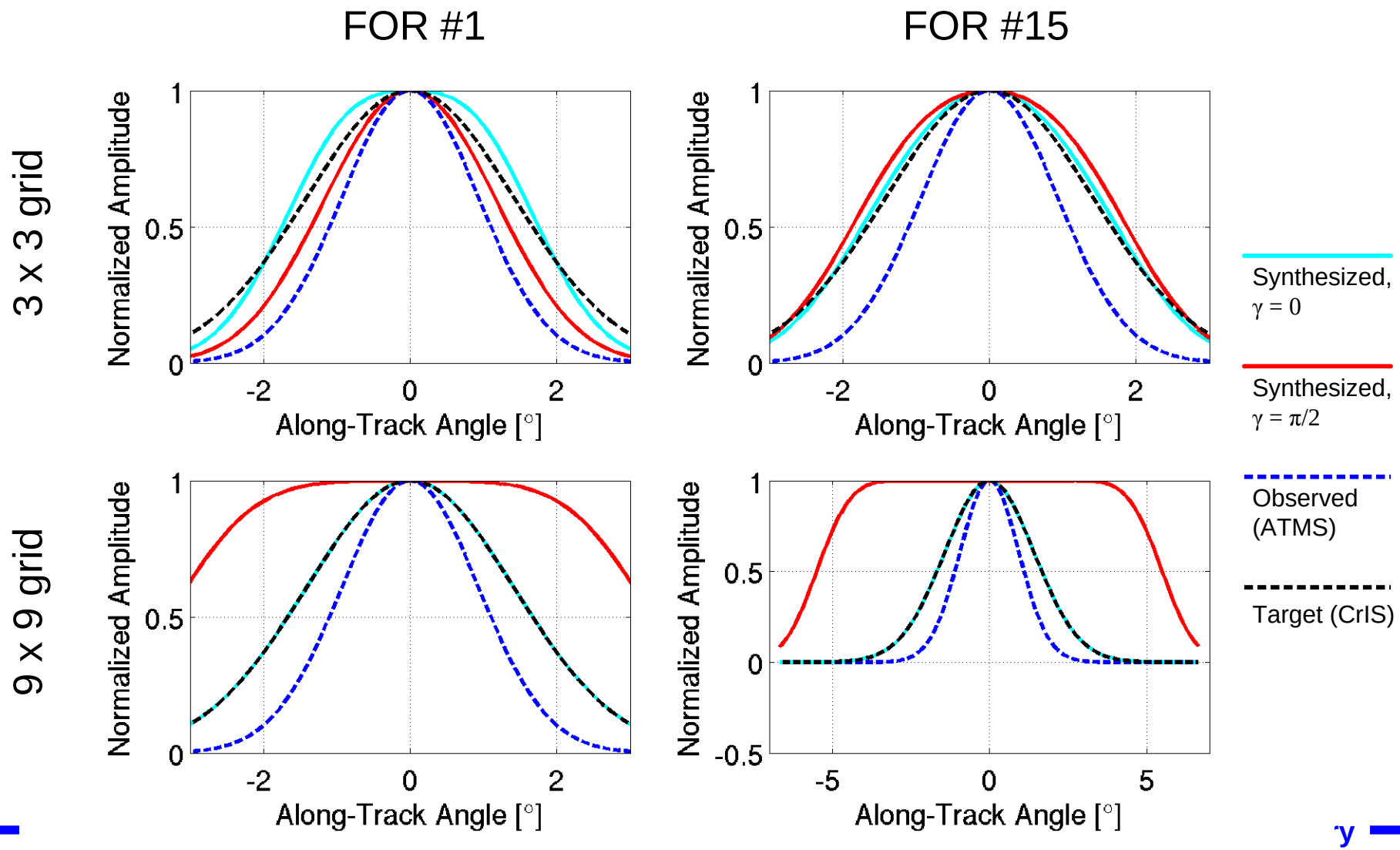
$$a = V^{-1}\left[\frac{\cos\gamma v + \left(1 - \cos\gamma u^T V^{-1} v\right)u}{u^T V^{-1} u}\right]$$

where u, v, and V are specified in Stogryn, 1978

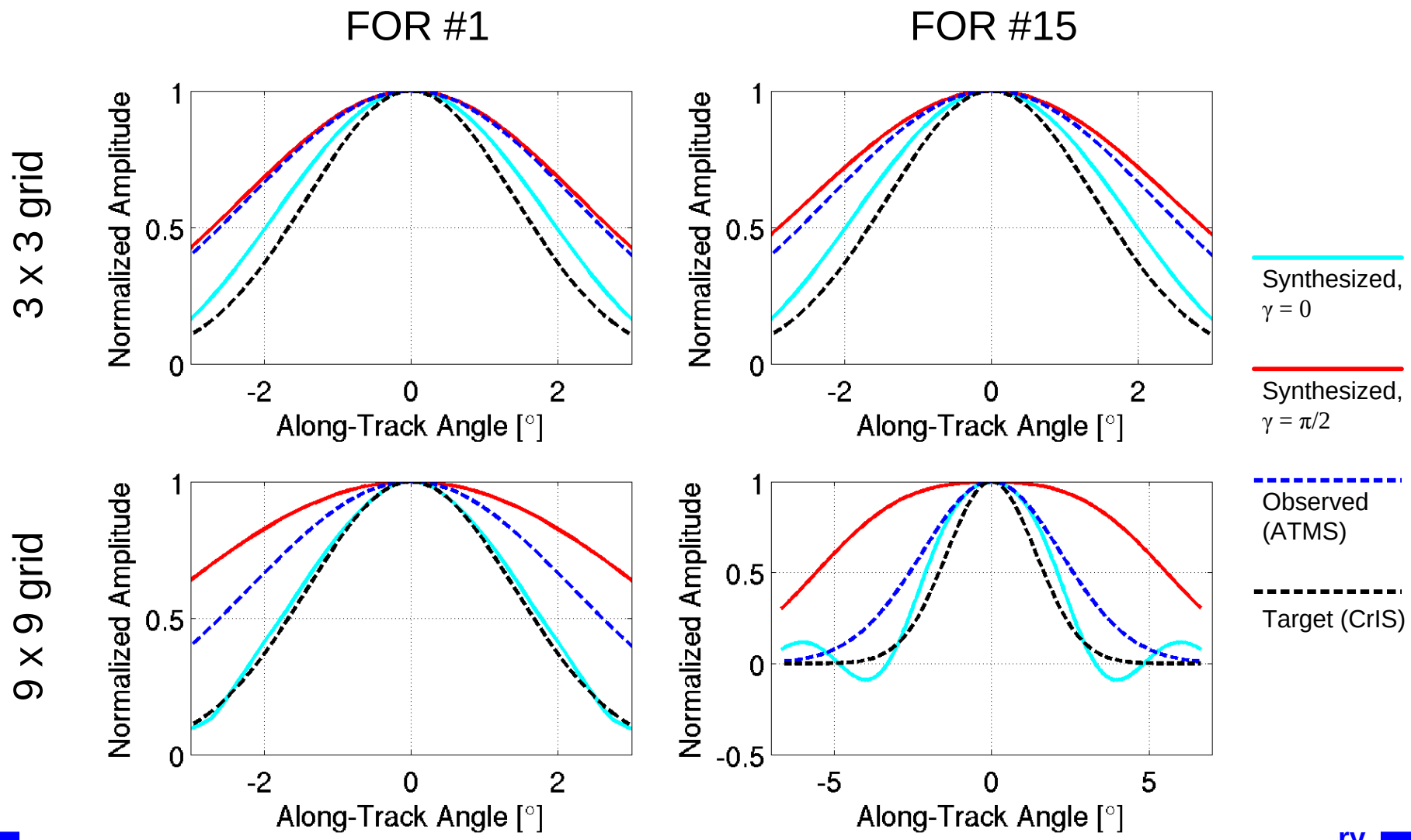
Along-Track Transects, 1.1° Beam Width



Along-Track Transects, 2.2° Beam Width



Along-Track Transects, 5.2° Beam Width



Next Steps

- **Evaluate AER coefficients**
  - **Noise amplification**
  - **Matching error**

- **Incorporate coefficients in TDR/SDR tools and error models**