ATMS Striping Assessment and Mitigation

THE VALUE OF PERFORMANCE.

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With contributions from
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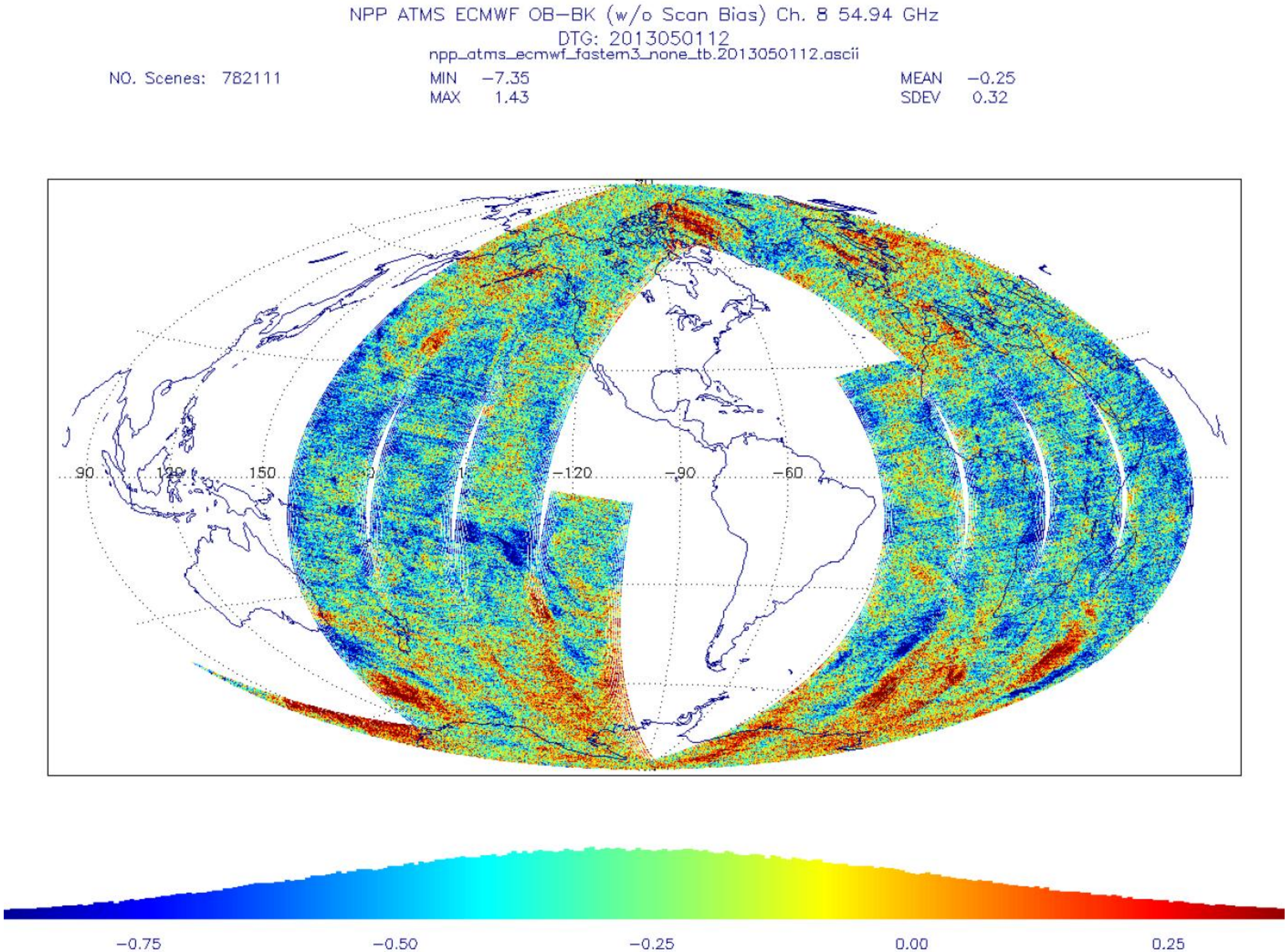
Outline

- Striping noise observations
  - O-B biases
  - Raw counts
- Root-cause analysis
  - Comparison with AMSU-A/B and MHS
  - Calibration data noise characteristics
  - Inter-channel correlation
- Quantification and mitigation
  - Striping Index (SI)
  - Optimization of calibration filter
    - TVAC data
    - Maneuver data
    - Operational data
- Summary
  - Findings
  - Recommendations

Examples of ATMS Striping Noise (1)

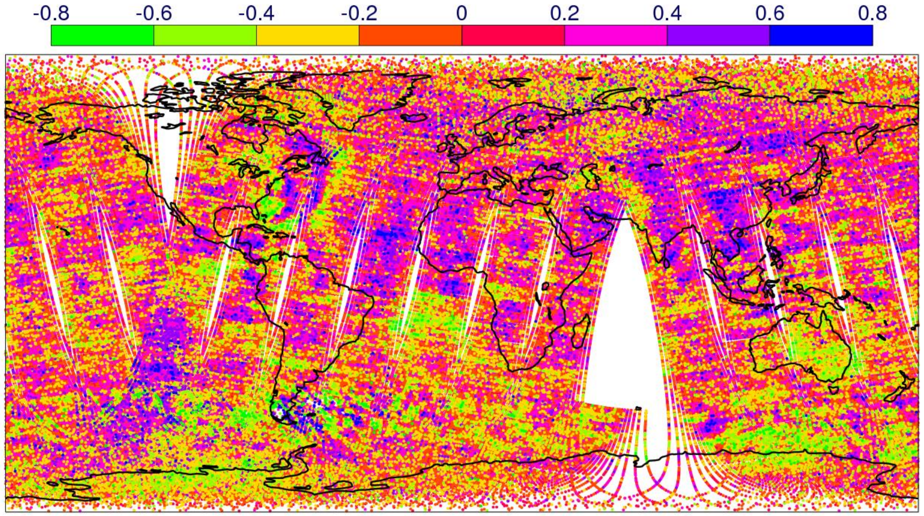


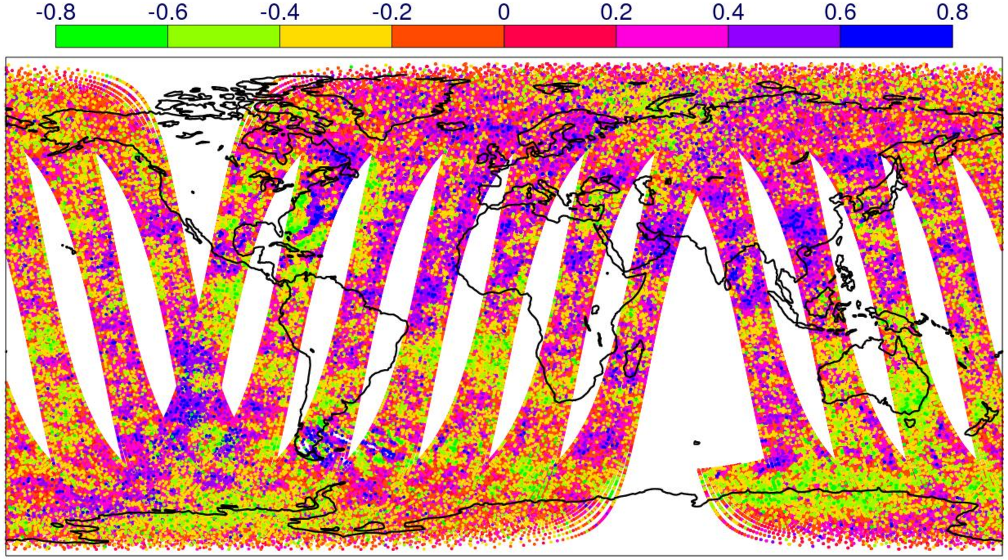
(Swadley et al, NRL)

Examples of ATMS Striping Noise (2)

Weak cross-track striping effect, especially for stratospheric temperature-sounding channels.

ATMS, ch 12, Obs-background [K]

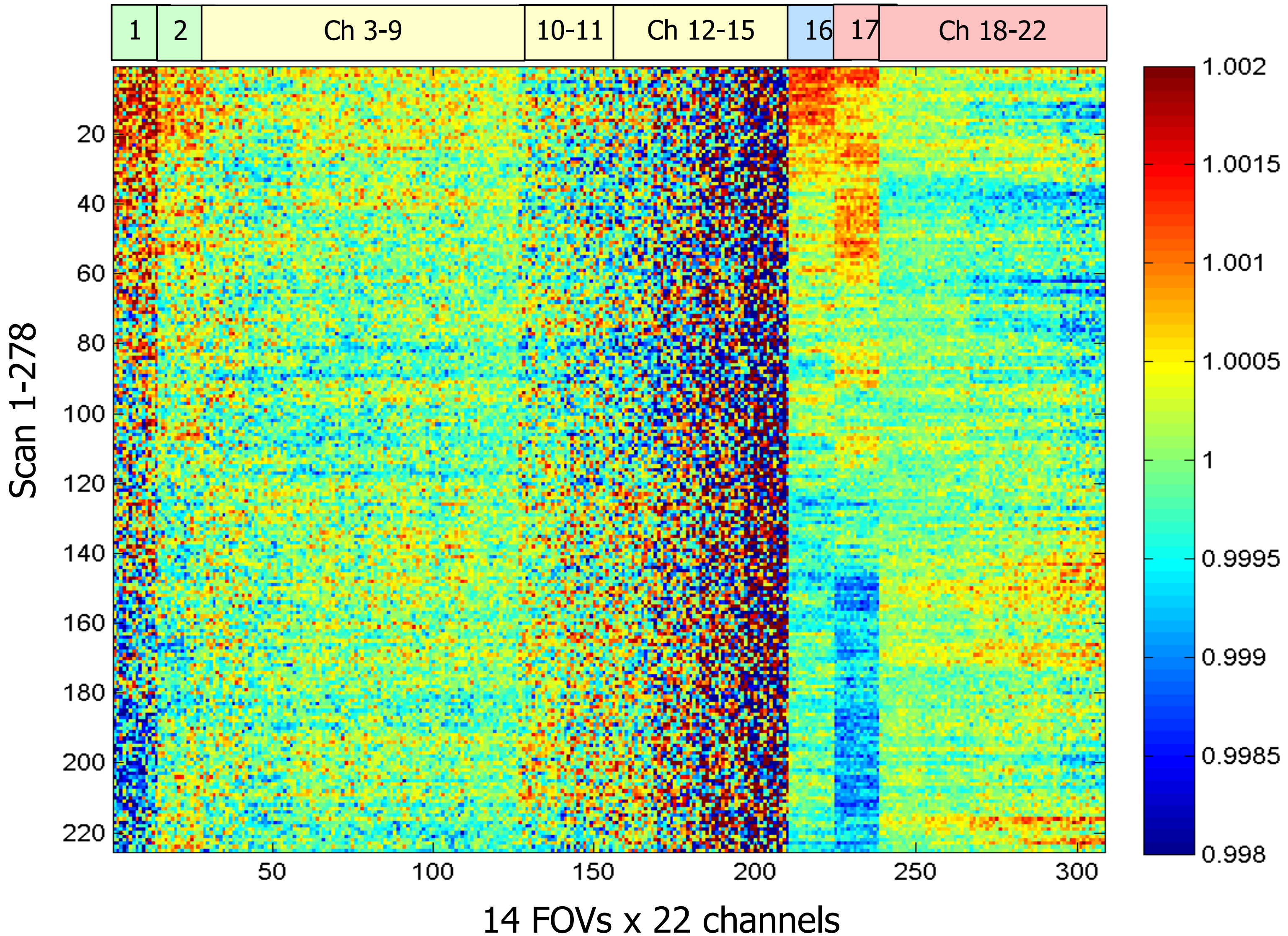




(Bormann et al, ECMWF)

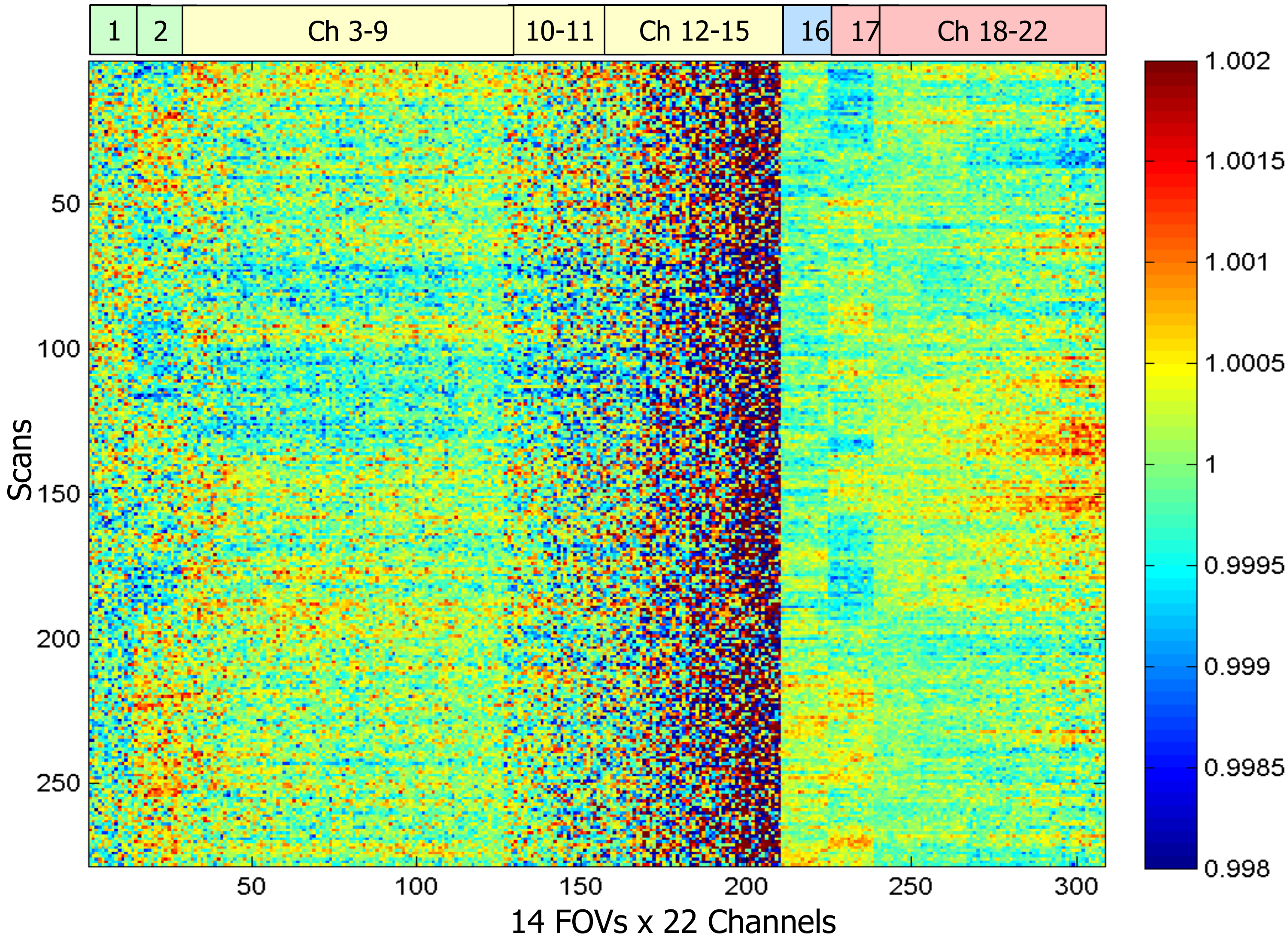
Examples of ATMS Striping Noise (4)

Composite image of ATMS pitch-over maneuver data – normalized counts



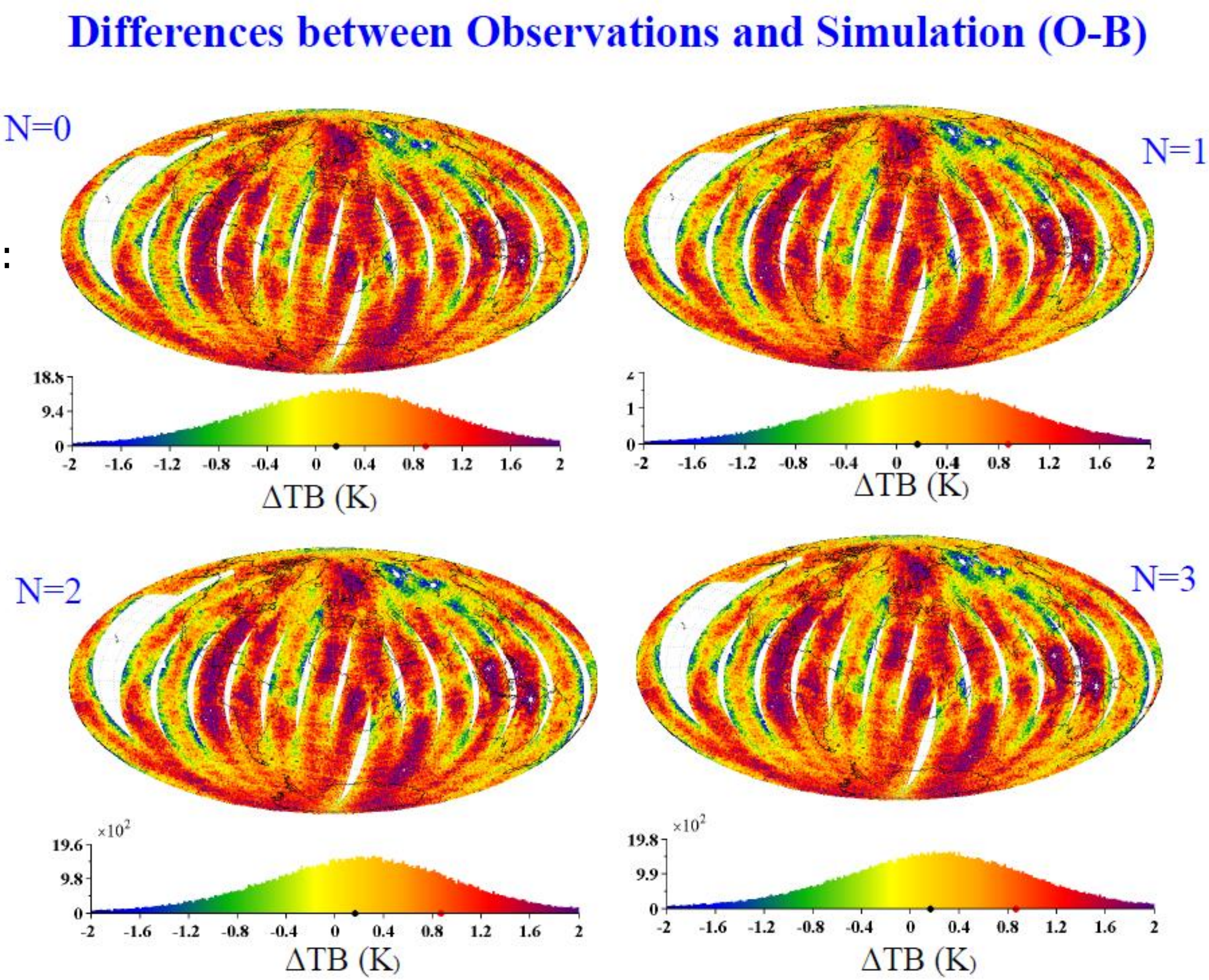
Examples of ATMS Striping Noise (4)

Composite image of ATMS TVAC test data – normalized counts, 230K, RC1



Striping Effectively Removed by Calibration in AMSU-A Calibrated Radiance Data

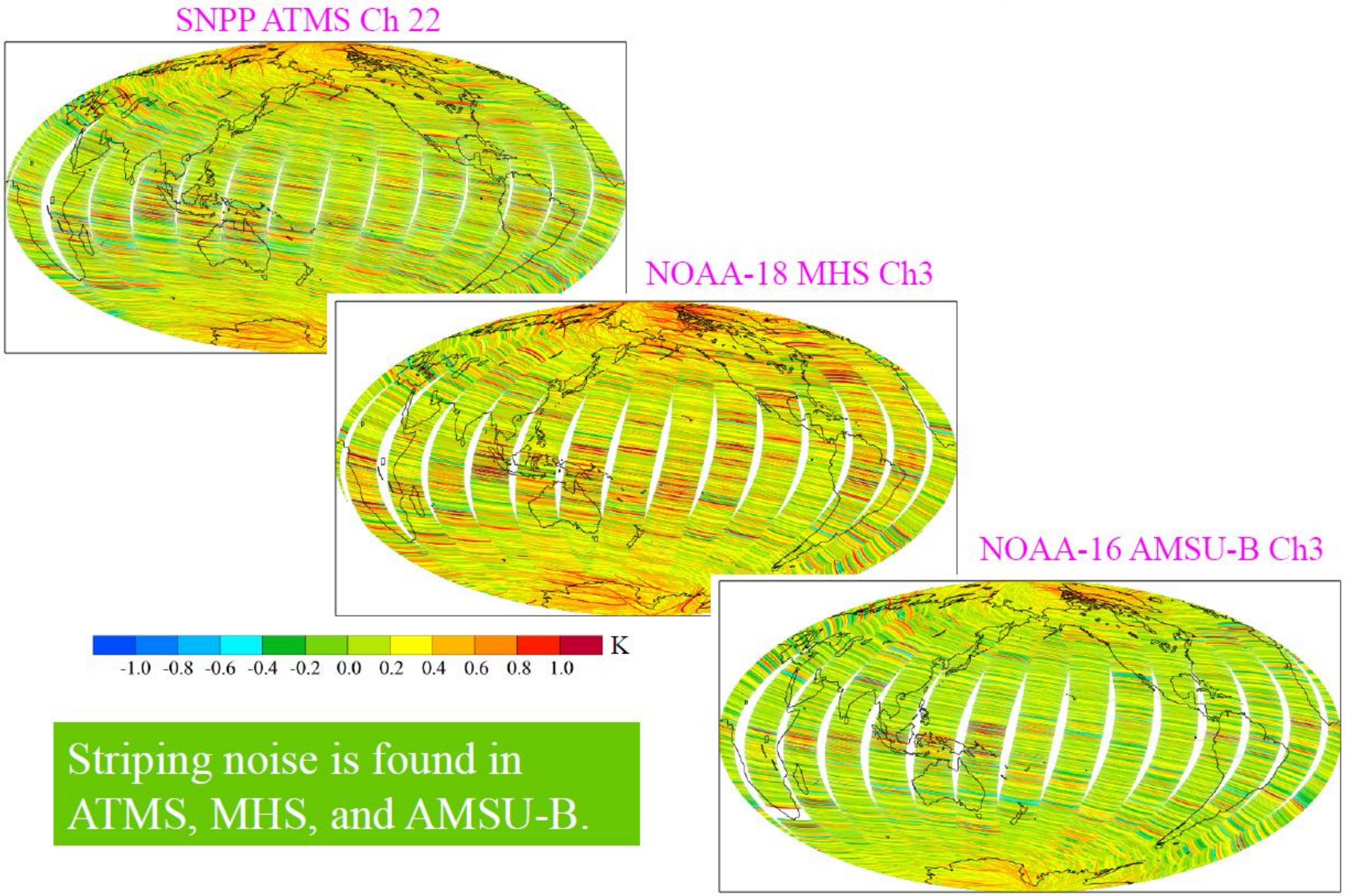
Calibration window size: 2N+1 scans



(Xiaolei Zou et al, FSU)

Striping in Moisture Sounding Channels/Instruments

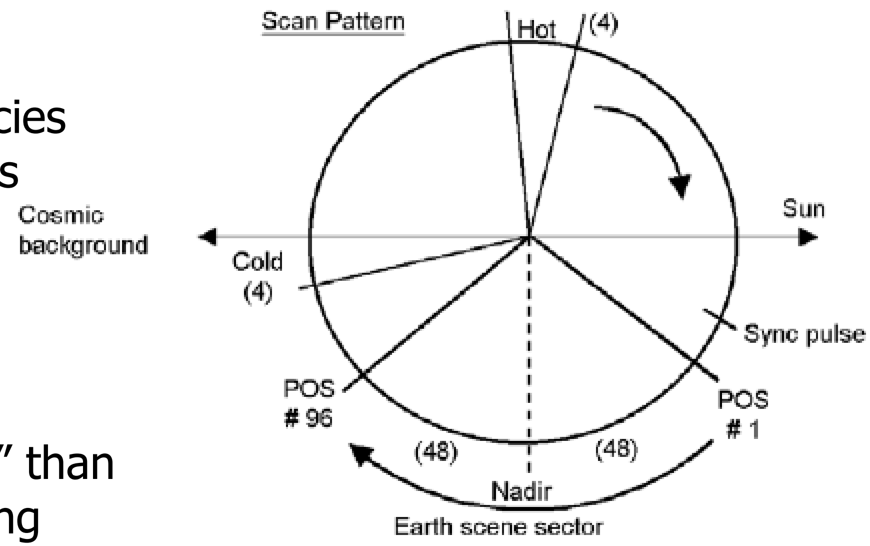
Global Distribution of Striping Noise



(Xiaolei Zou et al, FSU)

ATMS, AMSU-A/B and MHS Scan Sequences

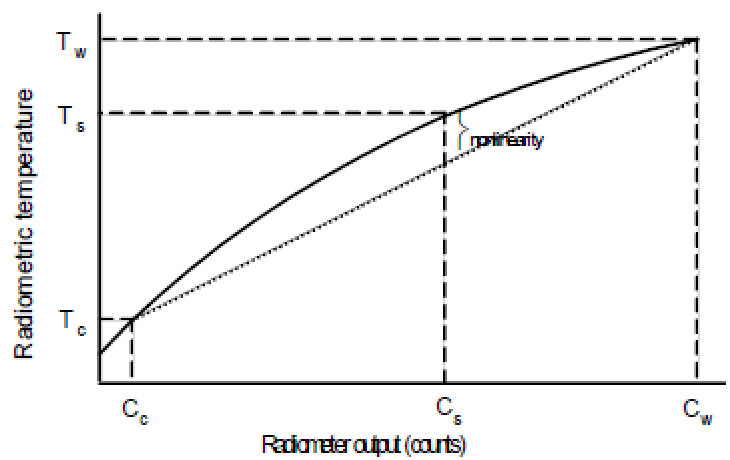
- Scan period
  - ATMS and MHS/AMSU-B: 8/3seconds
  - AMSU-A: 8 seconds
  - Impact: Noise at intermediate frequencies (1/8-3/8Hz) have different appearances
- Calibration data integration time
  - ATMS and MHS/AMSU-B: ~65ms
  - AMSU-A: 370ms
  - Impact: ATMS calibration data "noisier" than AMSU-A and more susceptible to striping



- TDR/SDR calibration

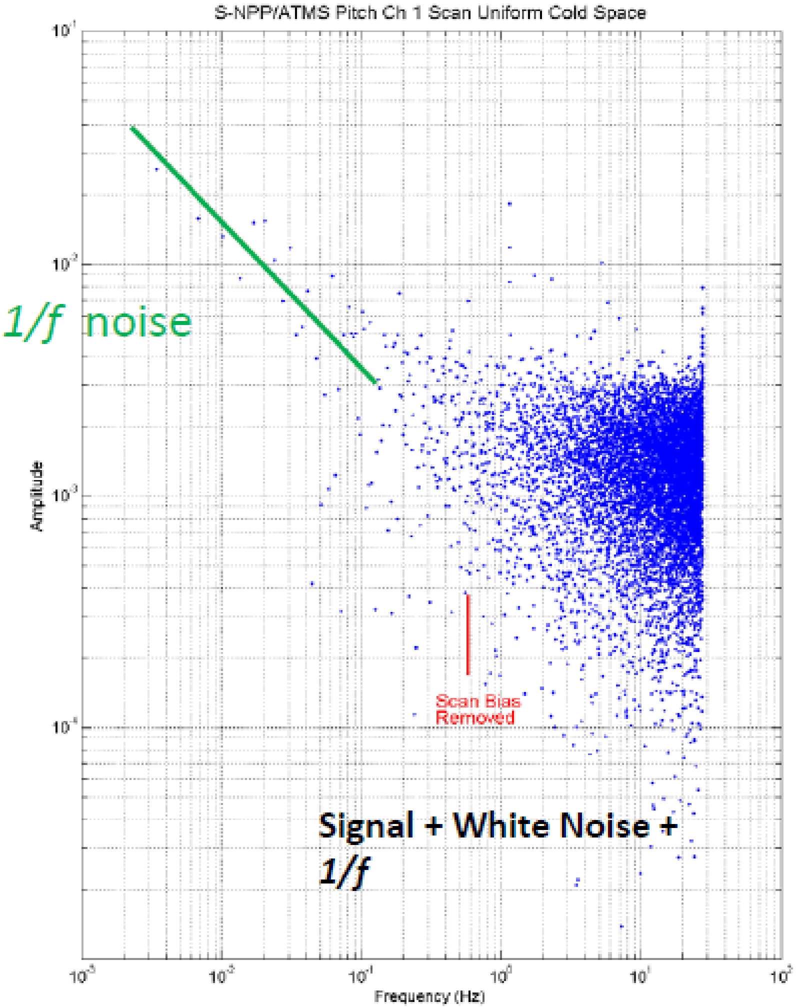
$$T_B = \underbrace{T_w + (T_w - T_c)\left(\frac{C_s - \overline{C_w}}{\overline{C_w} - \overline{C_c}}\right)}_{T_{BL}} + Q$$

nonlinearity correction



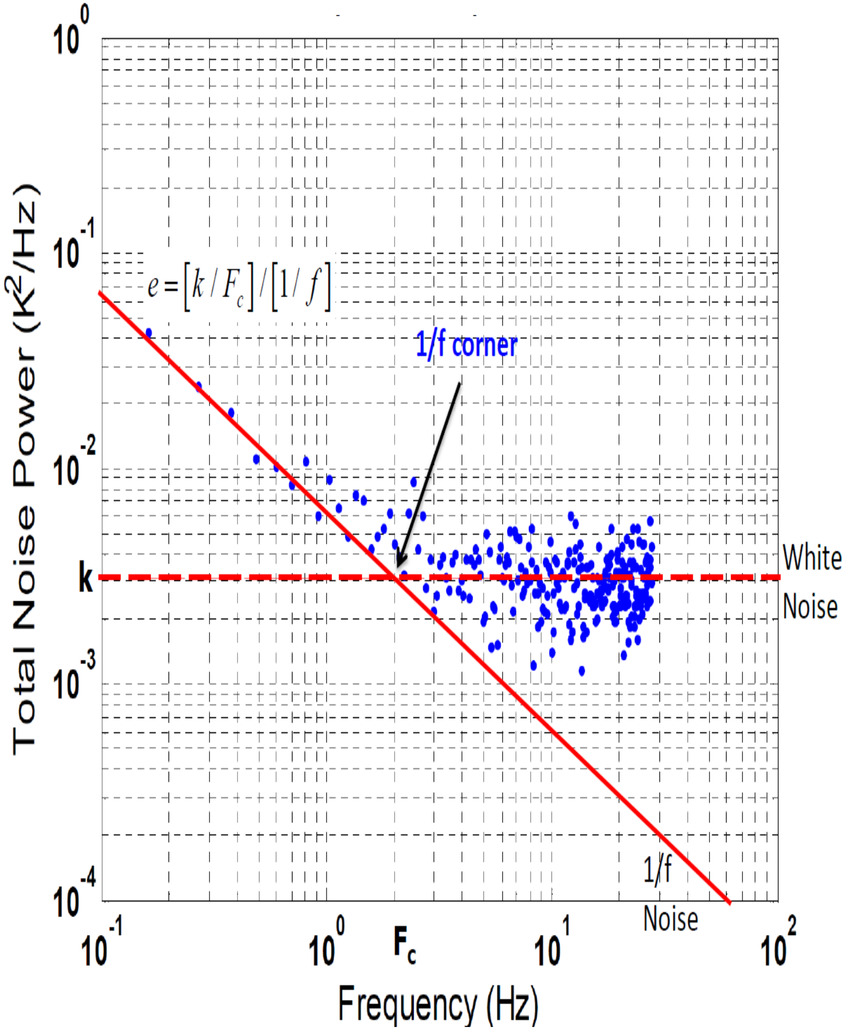
Flicker Noise (1/f) Evident in ATMS Data

Maneuver data PSD



(Lyu and Kim, NASA)

TVAC data PSD

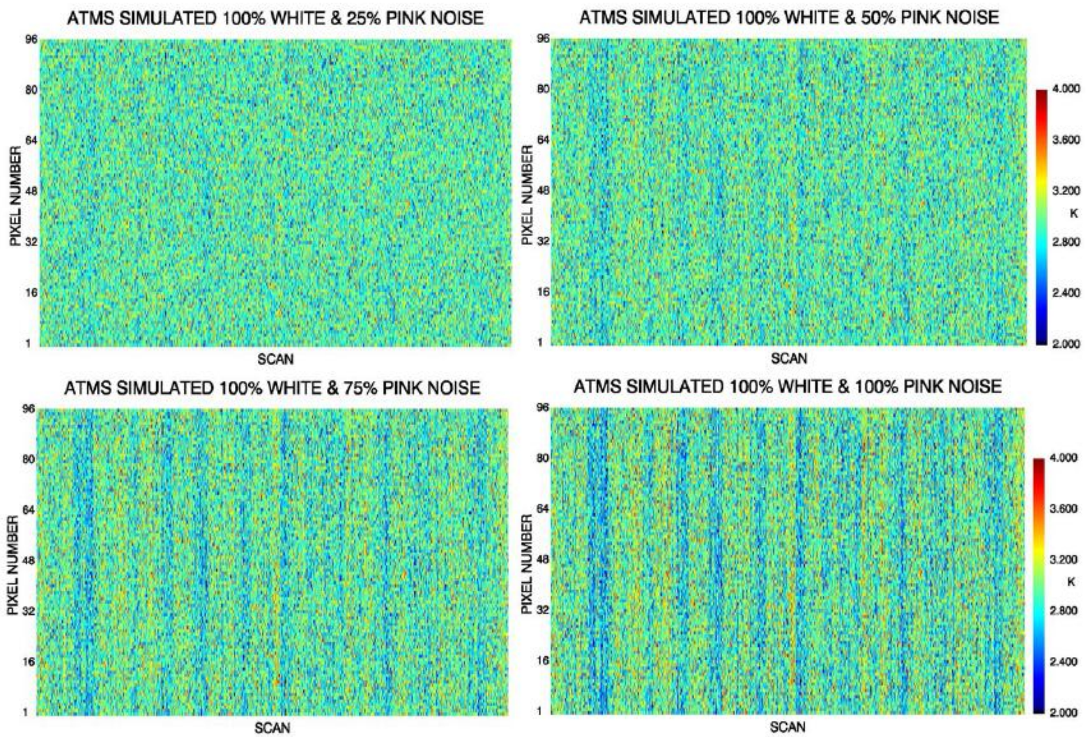


(Blackwell and Leslie, MIT-LL)

NRL Simulated Striping from White and 1/f Noises

NRL Analysis Strategy (In time domain)

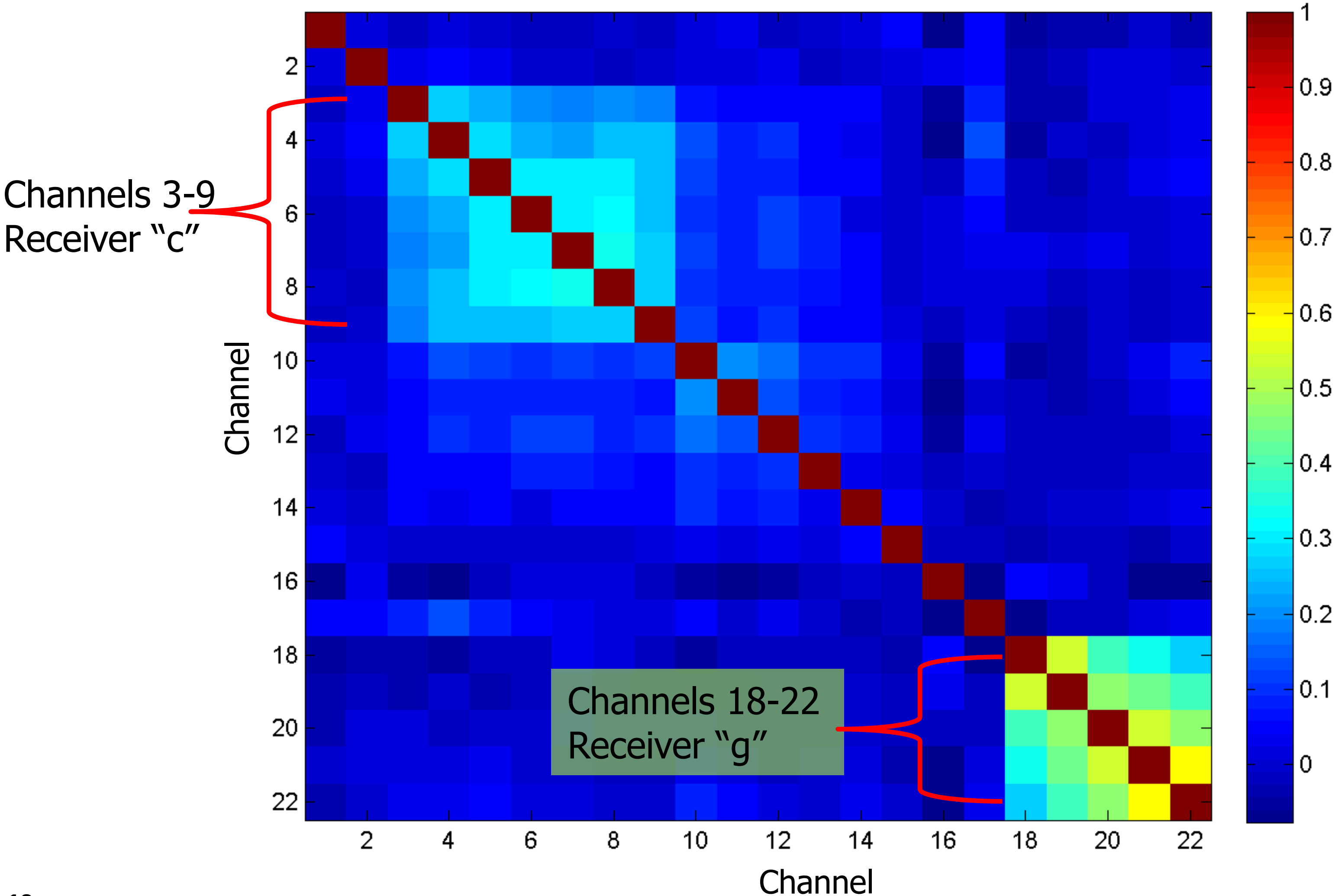
1. White noise + scale factor × $1/f$ noise (scale factor = 1, 0.75, 0.5, 0.25)
2. Time series data were chopped into 8/3 second "scans"
3. Powers of the white and $1/f$ noises were designed to be comparable
4. Background is assumed to be cold space (using 3K to represent)



(Steve Swadley, NRL)

Inter-Channel Correlation

Inter-channel correlation in uncalibrated raw counts (TVAC)



Striping Index Proposed to Quantify Striping Noise

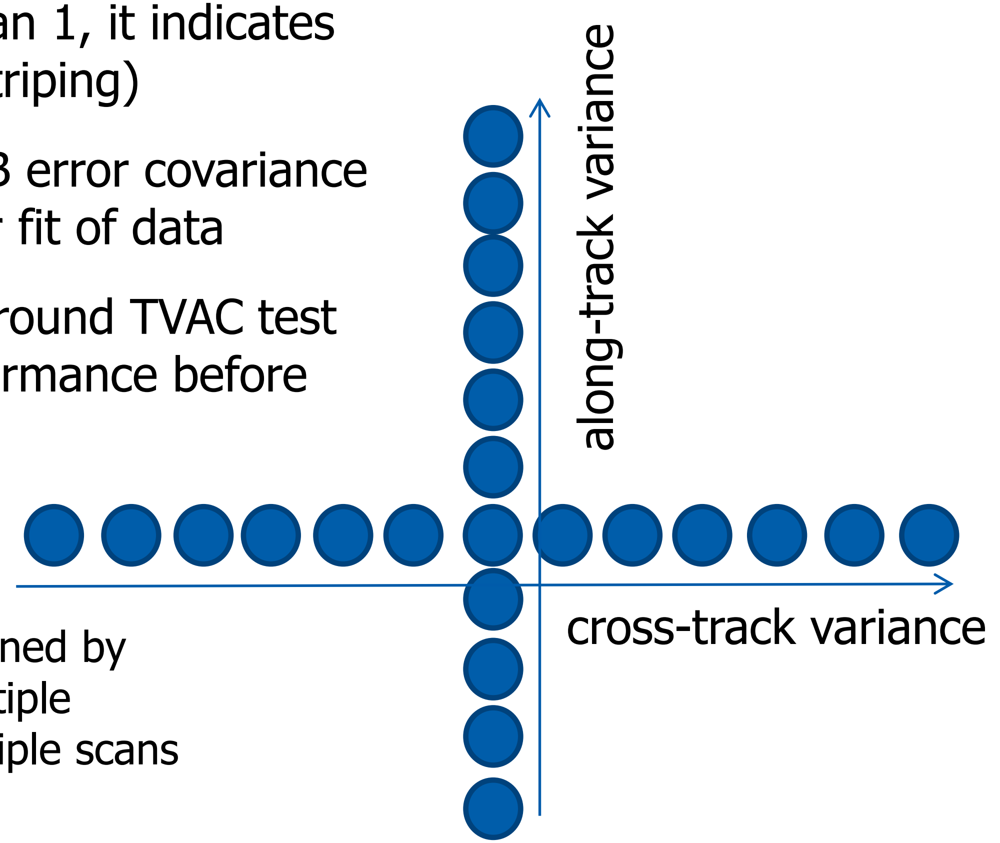
Striping Index (SI) is defined as the ratio of along-track variance to cross-track variance of the observed brightness temperatures

$$SI = V_{AT} / V_{CT}$$

If this index is significantly larger than 1, it indicates additional scan-to-scan variability (striping)

This index can be used to inflate O-B error covariance for NWP assimilation to prevent over fit of data

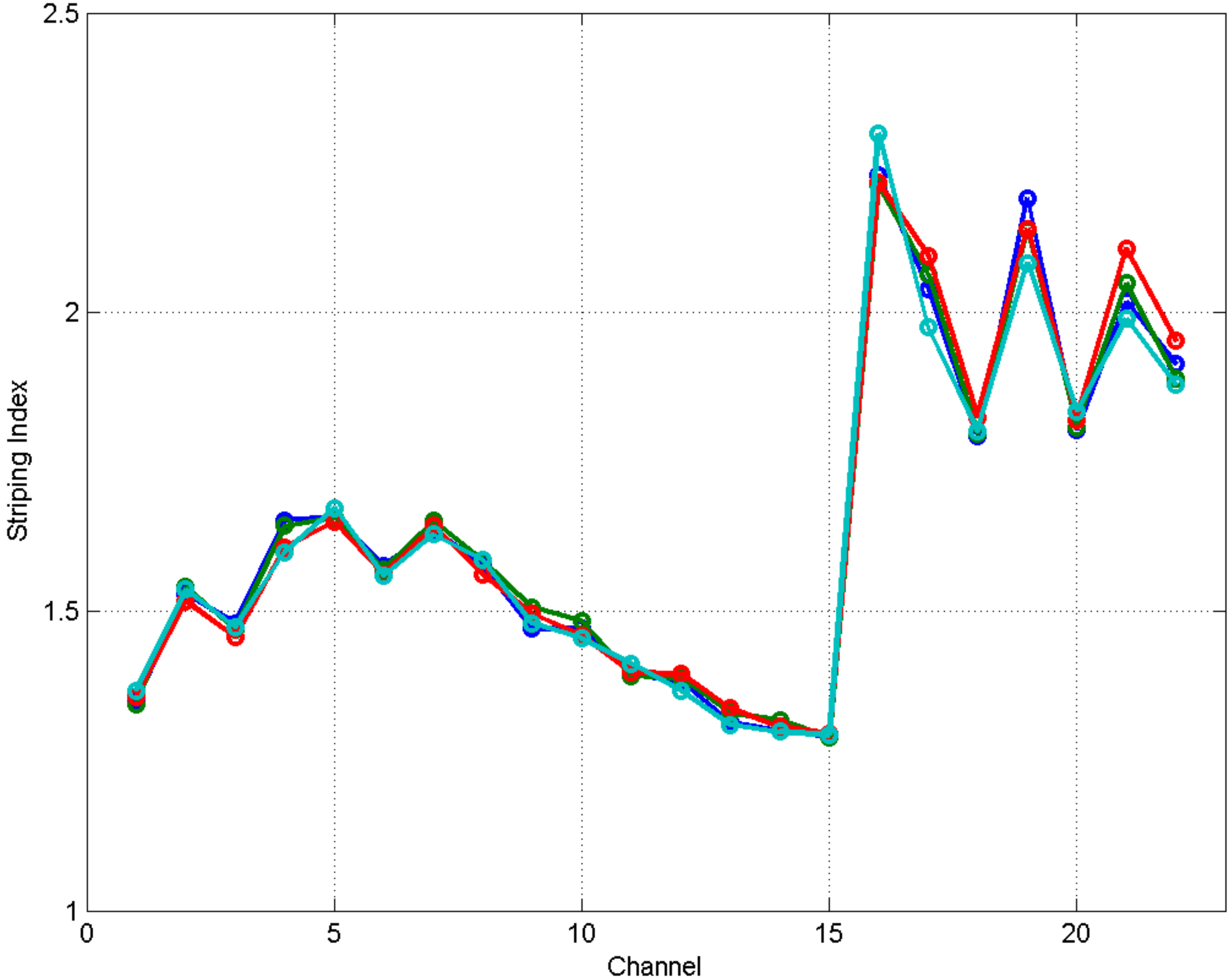
This index can be computed using ground TVAC test data to verify sensor hardware performance before launch



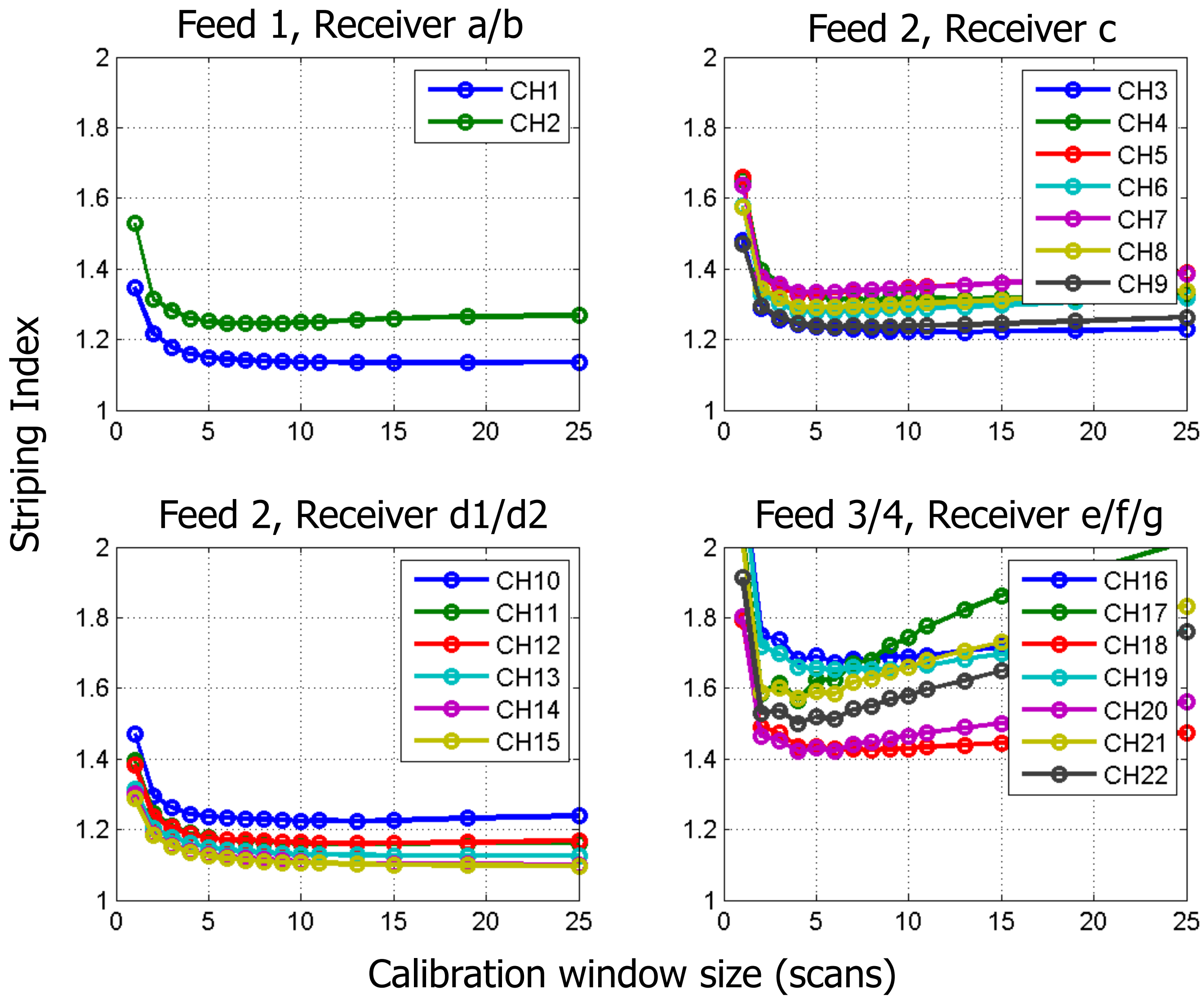
More precise estimate of SI can be obtained by averaging along-track variance over multiple FOVs and cross-track variance over multiple scans

Quantitative Assessment of Striping in TVAC Calibrated Radiances

Striping Indices of calibrated brightness temperatures without calibration filter applied. TVAC Data. All Redundancy Configurations



Striping Reduction by Increasing Calibration Window Sizes – TVAC Data



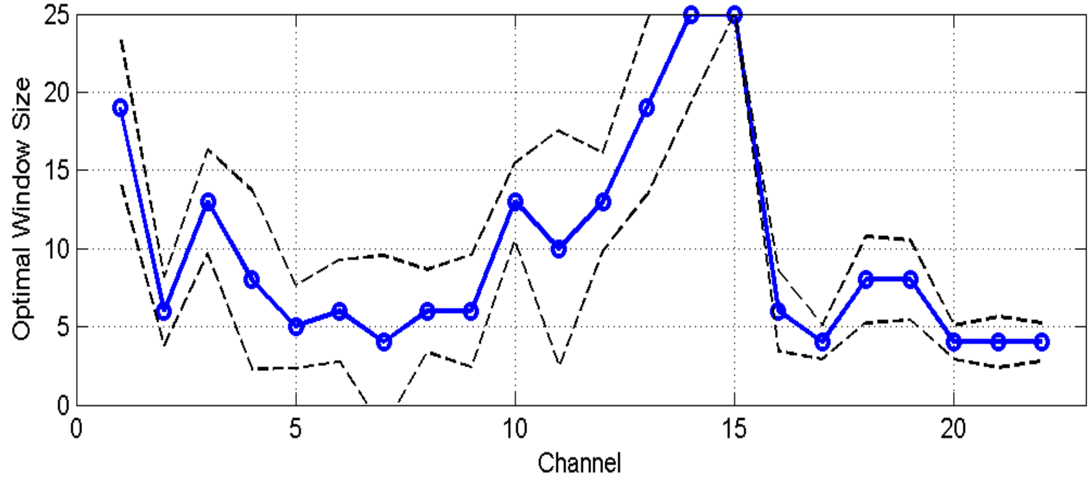
Optimal Window Sizes and Residual Striping – TVAC Data

Optimal window sizes correspond to the minimum SI averaged over all scene temperatures from 130K-280K. Dashed lines indicate ± 1σ uncertainty estimates

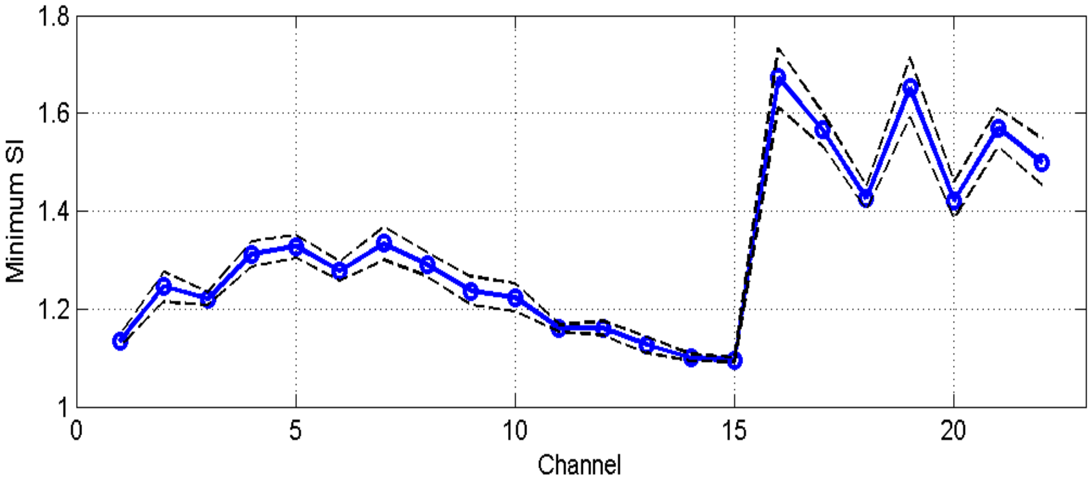
Redundant Configuration 1

Boxcar weighting functions

Optimal calibration window sizes



Residual striping noise estimates



Residual Striping in Calibrated Brightness Temperatures – TVAC vs Maneuver Data

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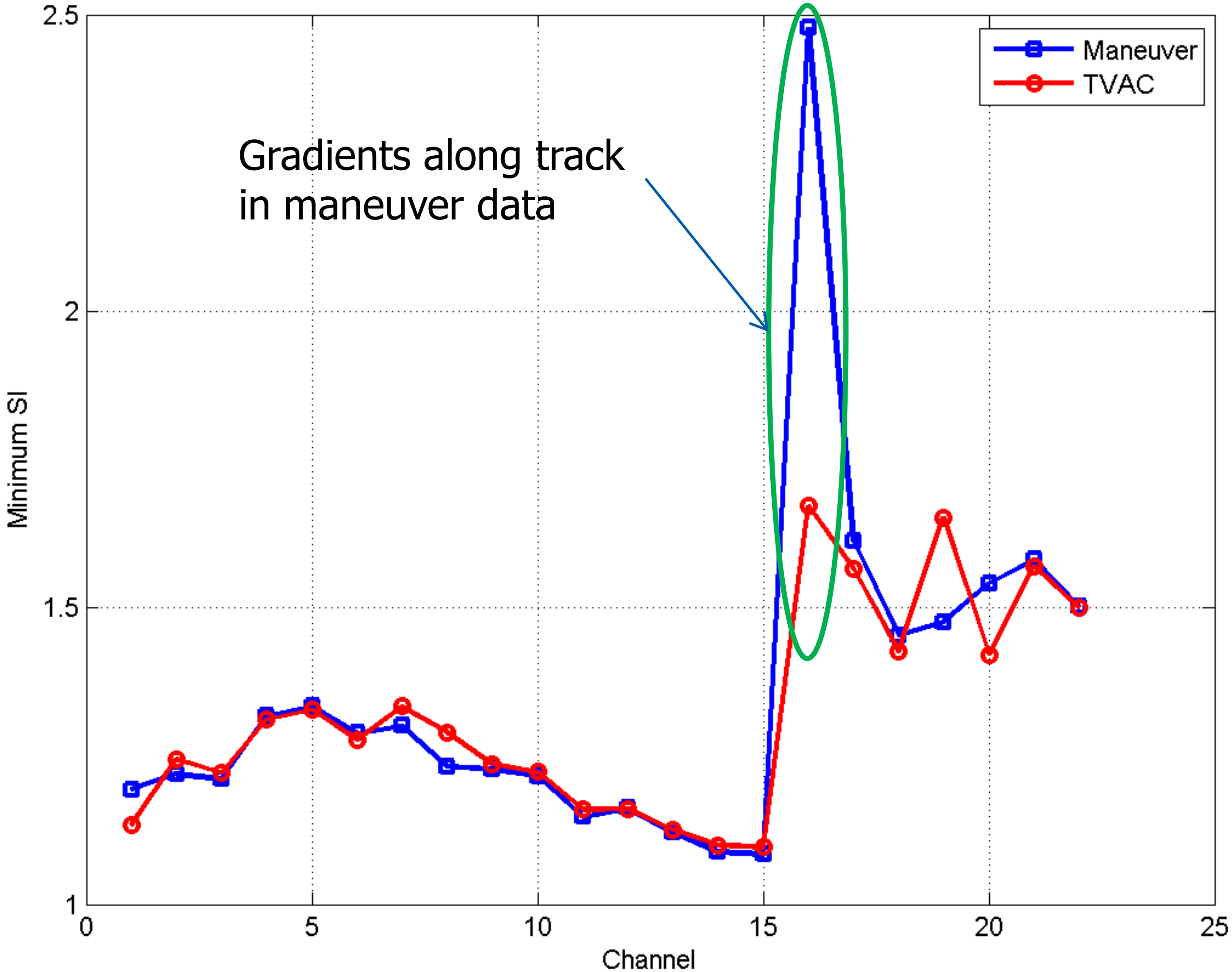
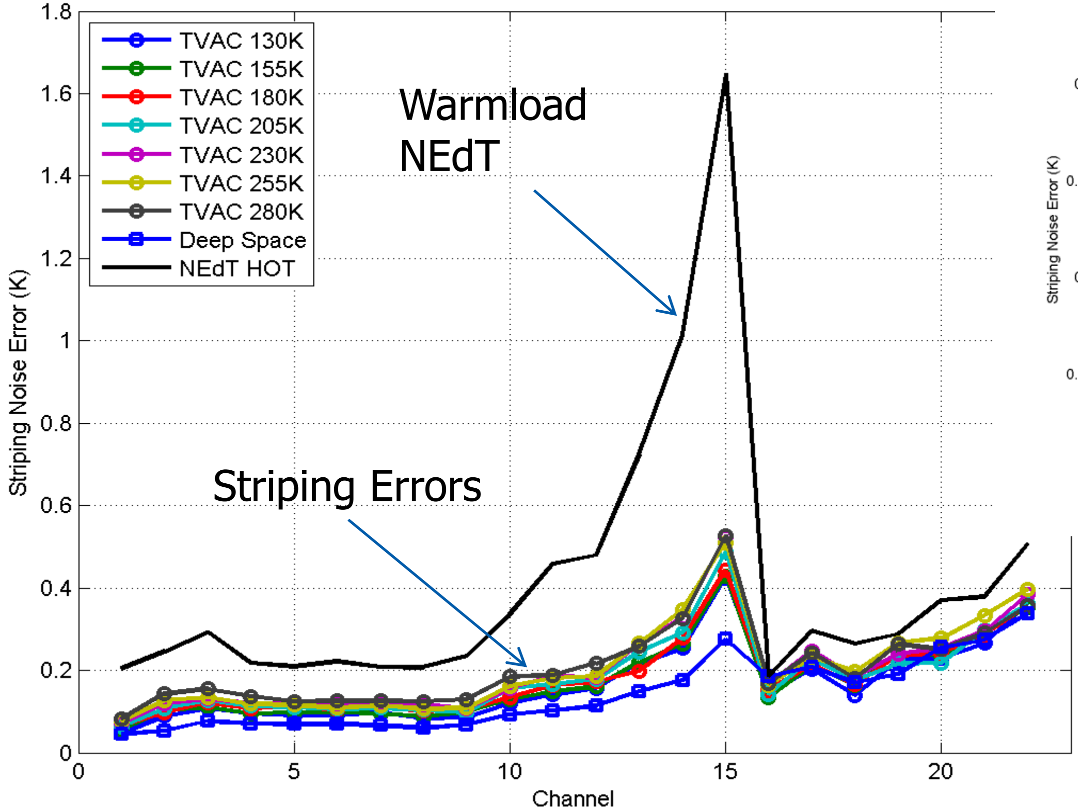
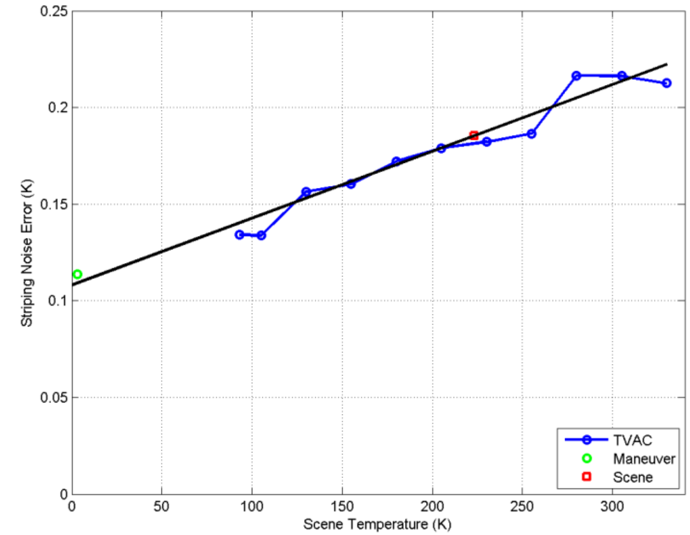


Estimated ATMS TDR/SDR Striping Errors

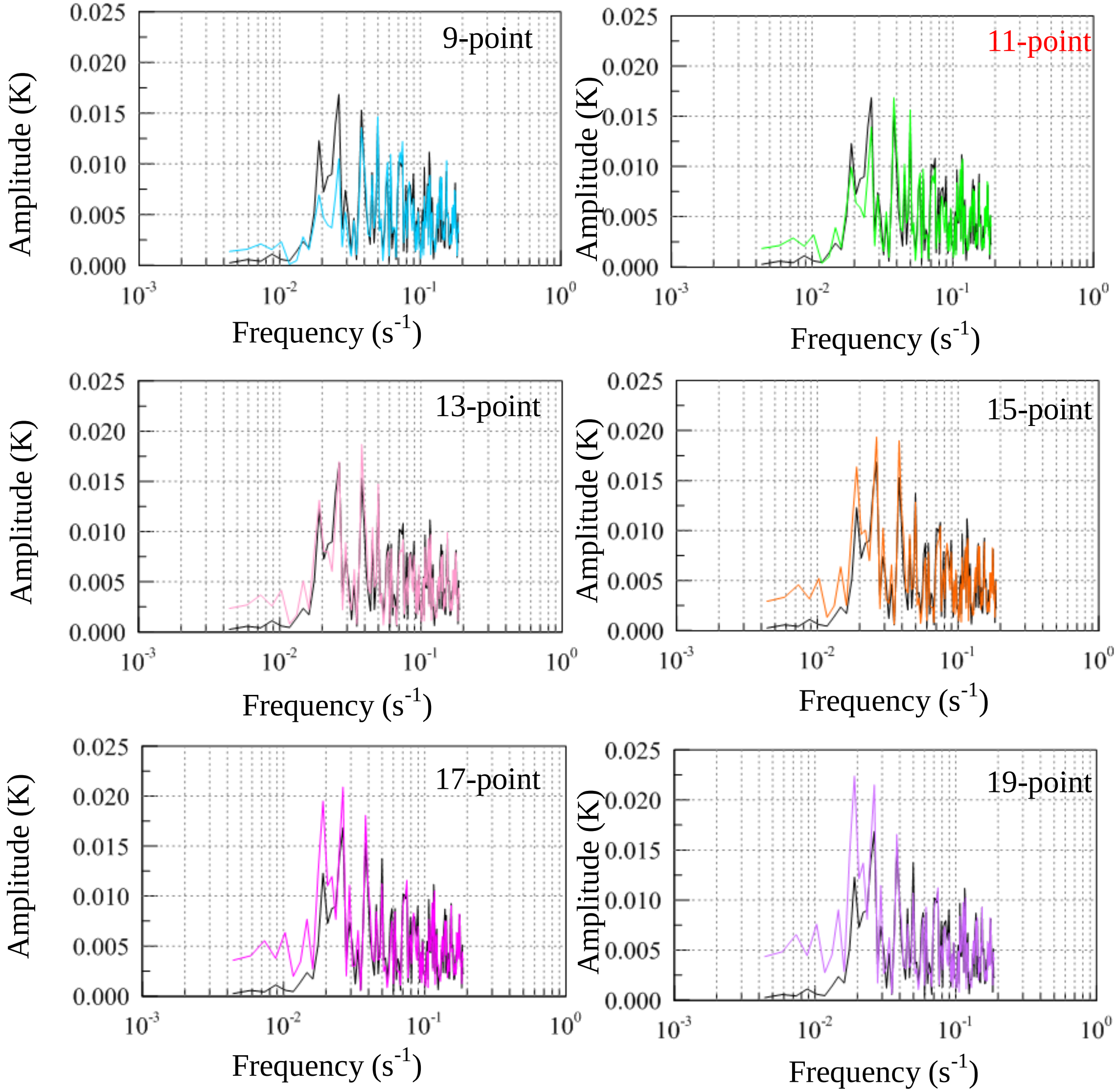
Striping errors at varying scene temperatures





Channel	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Avg Temp (K)	208	201	239	248	252	245	231	222	216	213	217	223	231	241	250	237	257	260	258	255	250	245
Striping (K)	.07	.11	.14	.12	.12	.12	.12	.11	.11	.15	.17	.19	.25	.32	.51	.16	.24	.19	.25	.26	.31	.37

Optimal Filters from Operational Data Analysis Using PCA/EEMD Technique



The spectral distribution of the sum of the first three Ensemble Empirical Mode Decomposition (EEMD) modes (black curve) and the difference between raw data and 9-point (sky blue curve), 11-point- (green), 13-point (pink), 15-point (orange), 17-point (magenta) and 19-point (little purple) boxcar filters of brightness temperature observations at nadir of the 1st PCA component of ATMS channel 10

Optimal filter size: 11-scan

(Xiaolei Zou et al, FSU)

Assessment of Residual Striping in ATMS Brightness Temperatures using IDPS and Updated Filters

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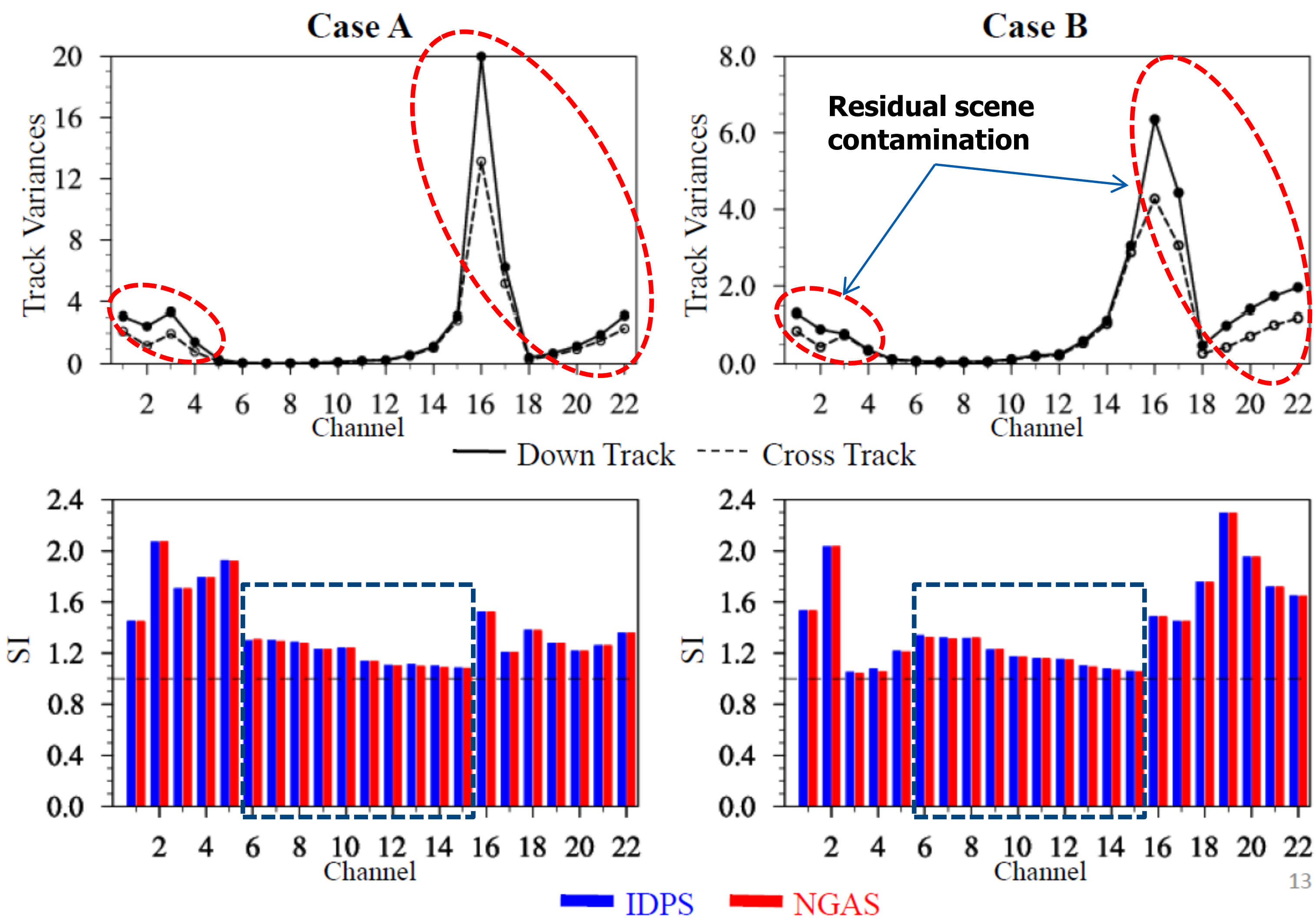
O-B Striping Index (SI)



(Lin Lin et al, STAR)

Summary

- ATMS TVAC test data, pitch-maneuver data, and operational data all show a certain degree of scan-to-scan variability (striping) in the calibrated brightness temperatures
- It's evident that both white noise and flicker noise (1/f) are present in ATMS measurements to have caused the striping
- Striping Index, defined as the ratio of cross-track variance to down-track variance, was proposed to measure and characterize the magnitude of striping
- Striping can be effectively reduced by averaging the calibration data over multiple scans, but not completely eliminated due to the presence of 1/f noise
- There are some correlation between channels that share the same front-end RF path, evident in both raw counts and calibrated brightness temperatures

Recommendations

- Recommendation 1: ATMS SDR team continue to refine radiometric calibration algorithms to reduce the impact of 1/f noise on TDR/SDR data products through specific filtering and wavelet analysis
- Recommendation 2: Add the striping index in TDR/SDR data products to provide users the needed information for proper handling of striping noise in their applications
- Recommendation 3: ATMS SDR team work with NWP centers to assess the impacts of striping on global medium-range forecasts and effectiveness of the implemented mitigation approaches
- Recommendation 4: ATMS SDR team proposed to NASA to revise the instrument specification on the short-term gain stability for future instruments
- Recommendation 5: ATMS instrument vendor and NASA instrument team investigate ATMS MMIC LNAs performance to compare with AMSU

Backup Charts

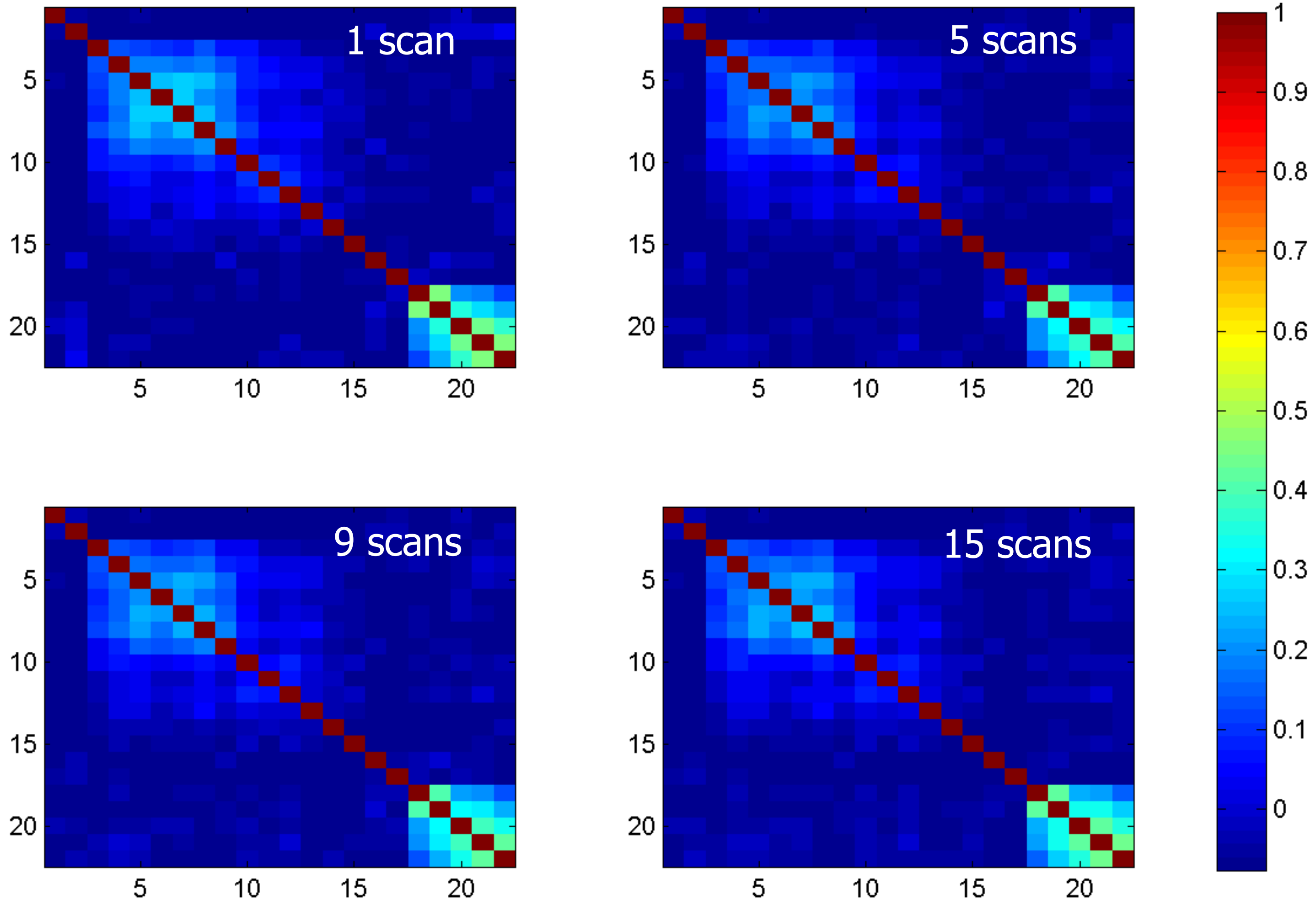
ATMS RF Path for Different Channels

Table 1. ATMS spectrometric and radiometric specifications

Ch	RF path			Center frequency [MHz]		Bandwidth [MHz]		NEDT [K]	Pol	Beamwidth [°]
	Ant	Feed	Rcvr	Value	Stab	Req	True	Req		Req
1	A	1	a	23800	<10	<270	1x270	0.5	V	5.2
2	A	1	b	31400	<10	<180	1x180	0.6	V	5.2
3	A	2	c	50300	<10	<180	1x180	0.7	H	2.2
4	A	2	c	51760	< 5	<400	1x400	0.5	H	2.2
5	A	2	c	52800	< 5	<400	1x400	0.5	H	2.2
6	A	2	c	53596±115	< 5	170	2x170	0.5	H	2.2
7	A	2	c	54400	< 5	400	1x400	0.5	H	2.2
8	A	2	c	54940	<10	400	1x400	0.5	H	2.2
9	A	2	c	55500	<10	330	1x330	0.5	H	2.2
10	A	2	d_1	57290.344 [f_0]	<0.5	330	2x155	0.75	H	2.2
11	A	2	d_1	f_0±217	<0.5	78	2x 78	1.0	H	2.2
12	A	2	d_2	f_0±322.2±48	<1.2	36	4x 36	1.0	H	2.2
13	A	2	d_2	f_0±322.±22	<1.6	16	4x 16	1.5	H	2.2
14	A	2	d_2	f_0±322.±10	<0.5	8	4x 8	2.2	H	2.2
15	A	2	d_2	f_0±322.±4.5	<0.5	3	4x 3	3.6	H	2.2
16	B	3	e	88200	<200	2000	1x2000	0.3	V	2.2
17	B	4	f	165500	<200	3000	2x1150	0.6	H	1.1
18	B	4	g	183310±7000	<30	2000	2x2000	0.8	H	1.1
19	B	4	g	183310±4500	<30	2000	2x2000	0.8	H	1.1
20	B	4	g	183310±3000	<30	1000	2x1000	0.8	H	1.1
21	B	4	g	183310±1800	<30	1000	2x1000	0.8	H	1.1
22	B	4	g	183310±1000	<30	500	2x 500	0.9	H	1.1

Inter-Channel Correlation in Calibrated Radiances

Inter-channel correlation in calibrated brightness temperatures (TVAC)



TVAC Data Collection Overview

This analysis focused on CPP5 cases

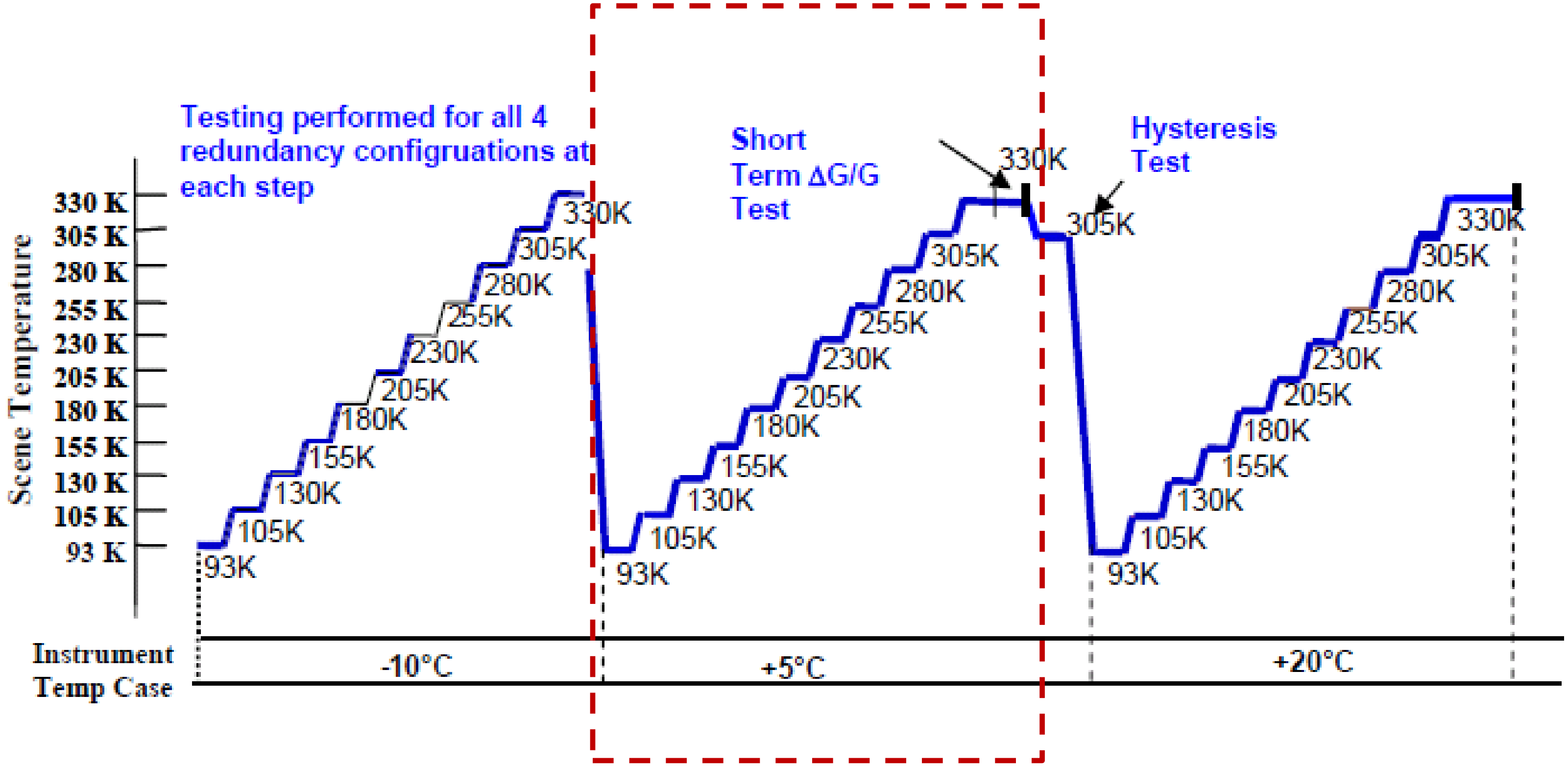
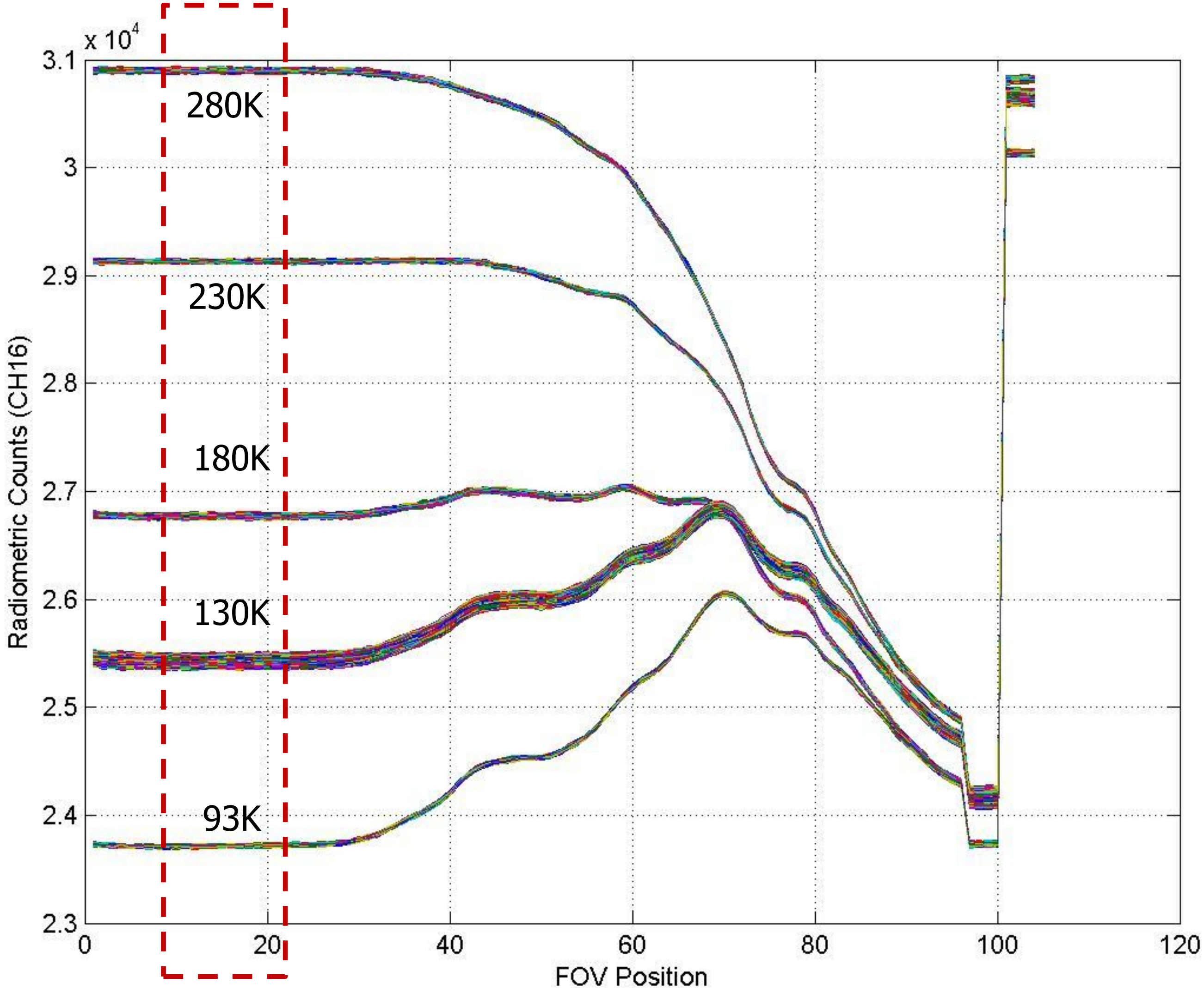


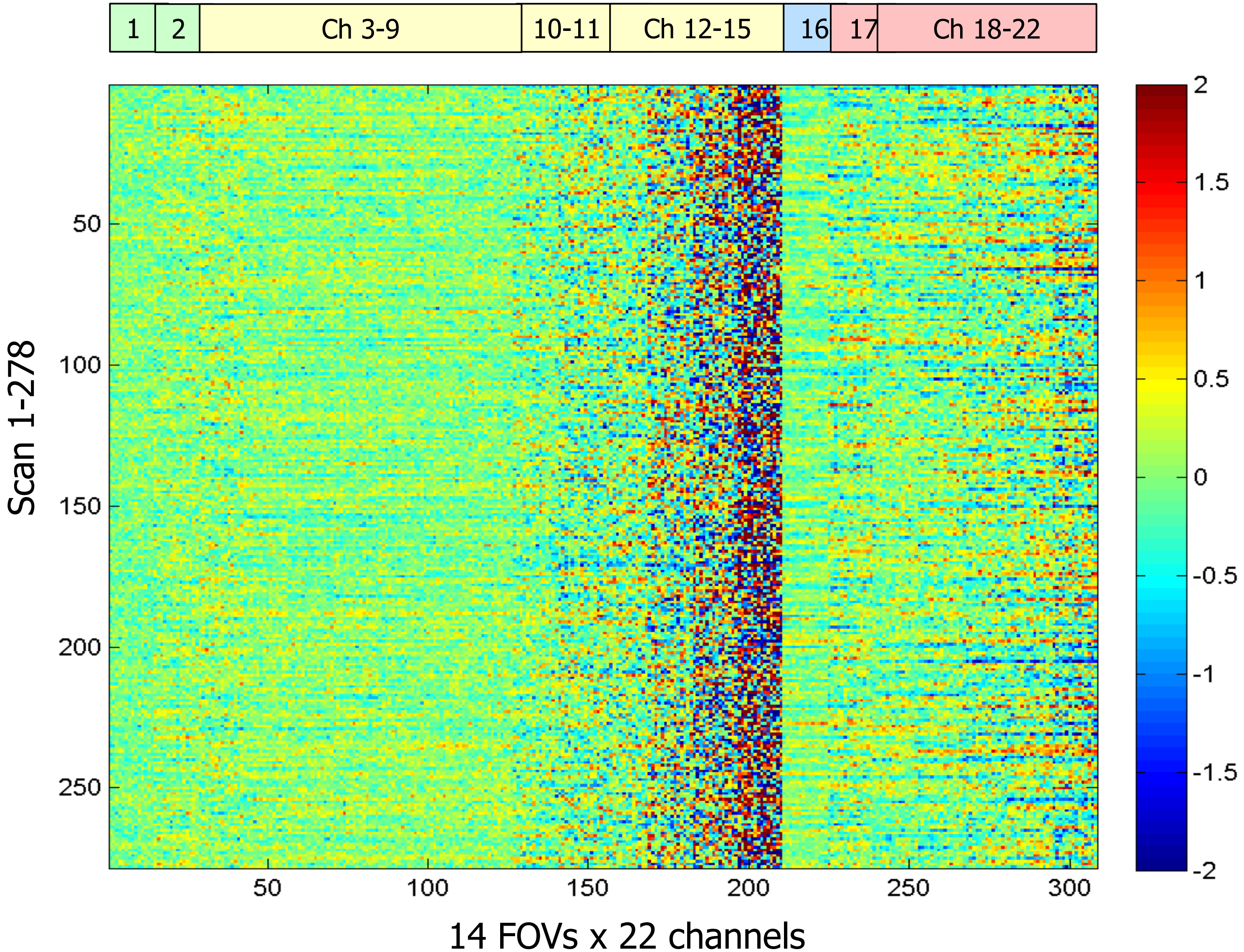
Figure 3-2 Calibration Test Cycles

Controlled Scene Target Identification

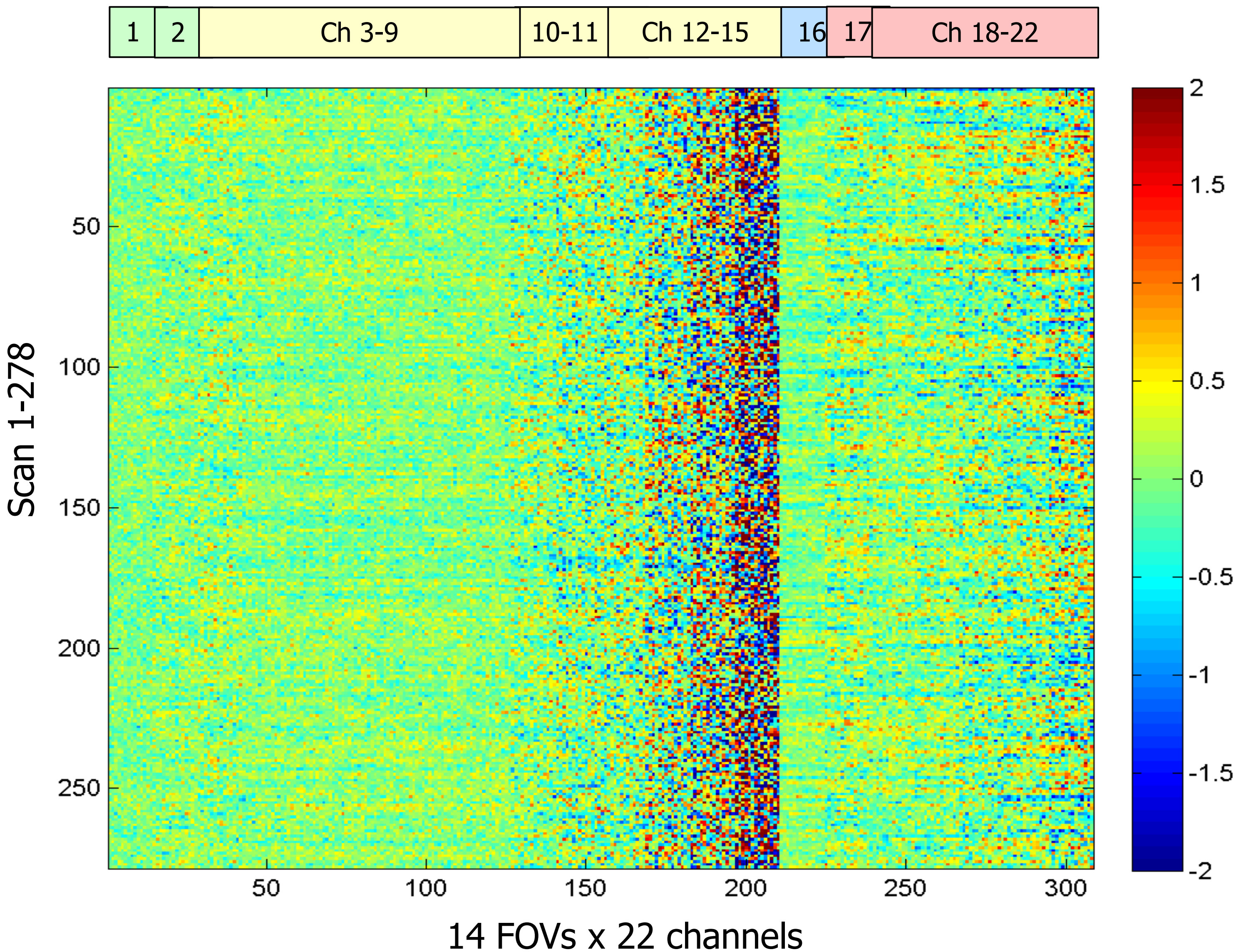
FOVs 9-22 are relatively uniform and used to analyze striping



Calibrated Brightness Temperature: No Averaging to Calibration Data



Calibrated Brightness Temperature: 5-scan Averaged Calibration Data



Calibrated Brightness Temperature: 9-scan Averaged Calibration Data

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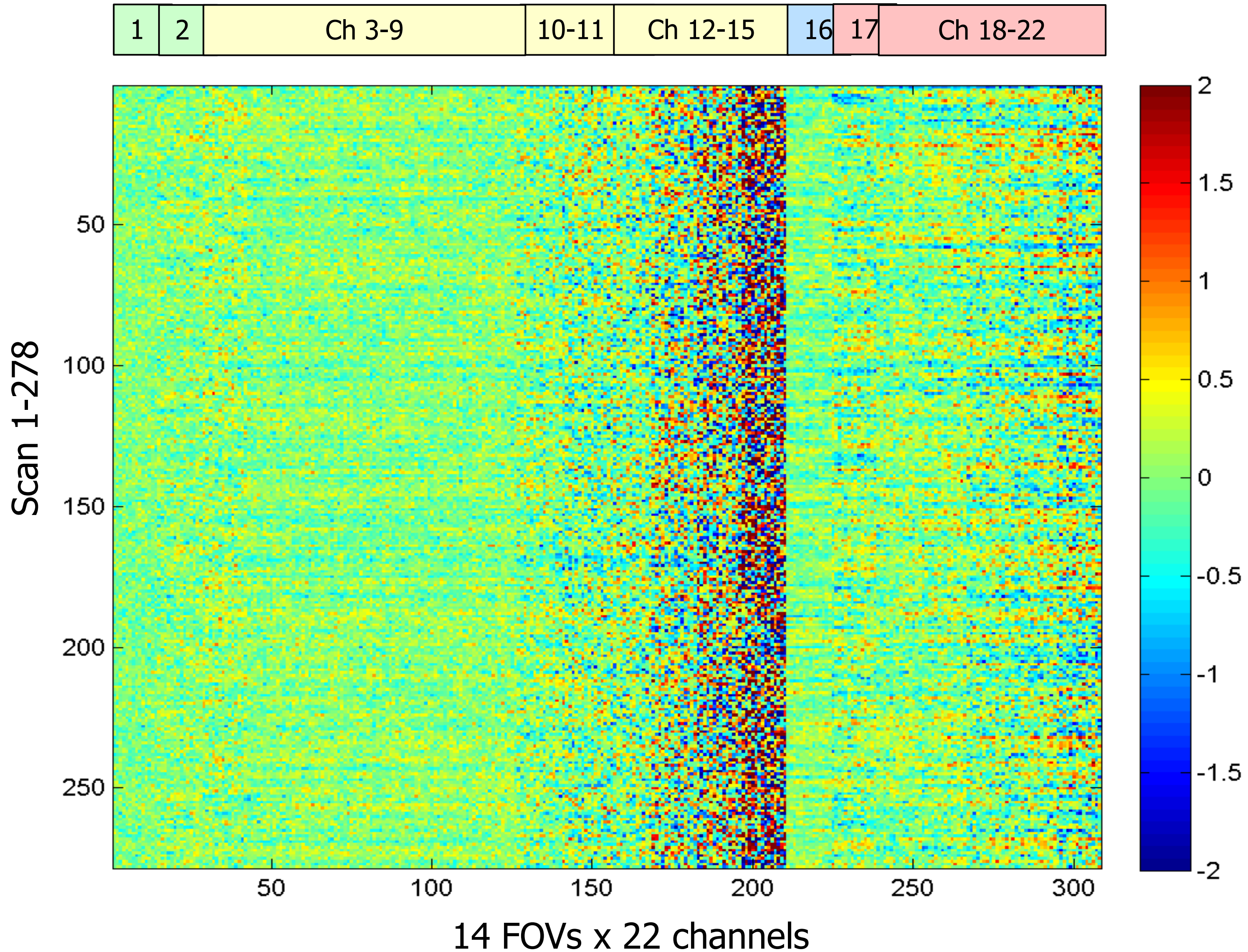

Calibrated Brightness Temperature: 15-scan Averaged Calibration Data