National Environmental Satellite, Data, and Information Service

Calibration Issues in Reprocessing SSM/I Climate Data Records

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NOAA/NESDIS

NOAA-NIST Meeting on Calibration for Climate Data Record

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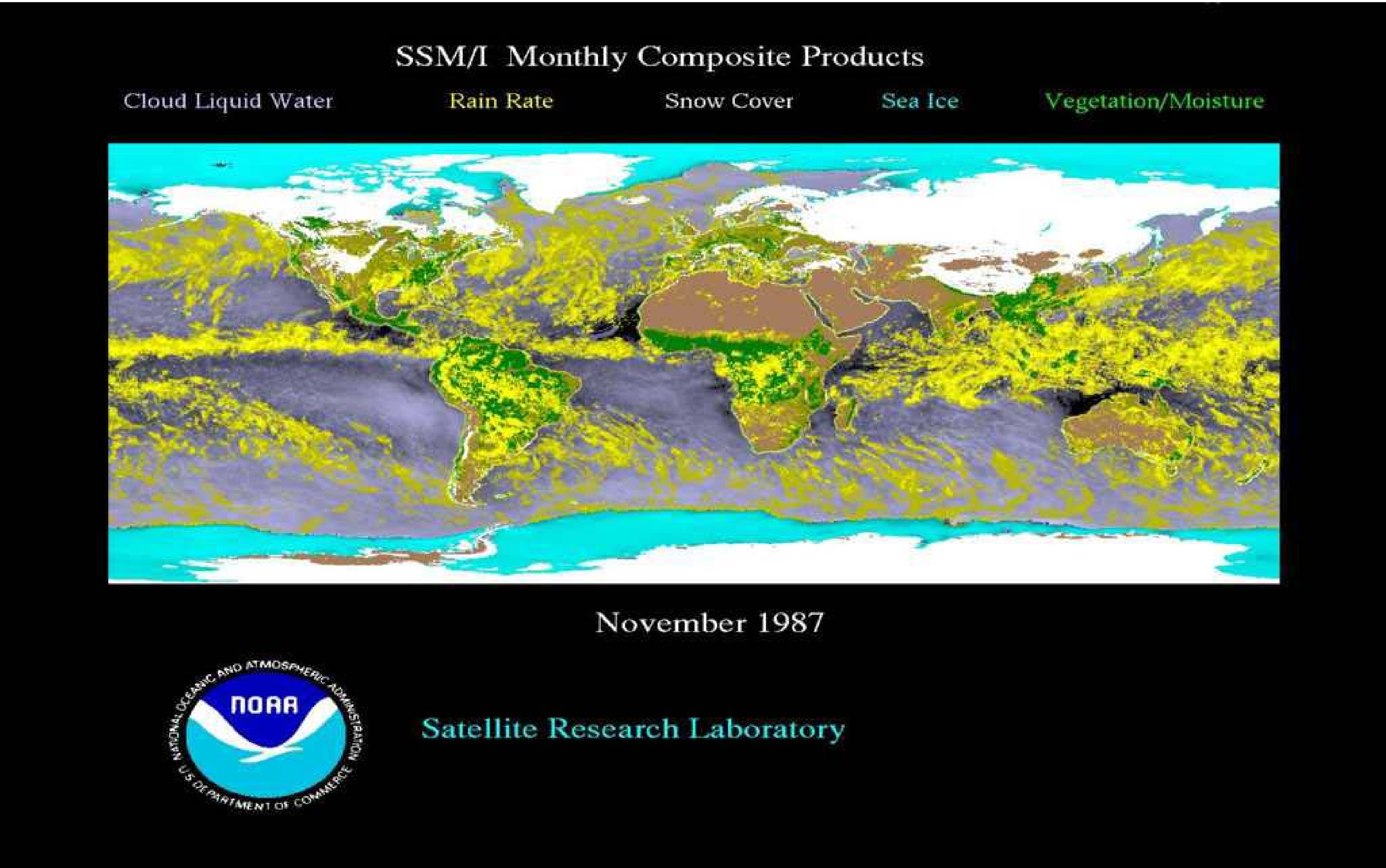
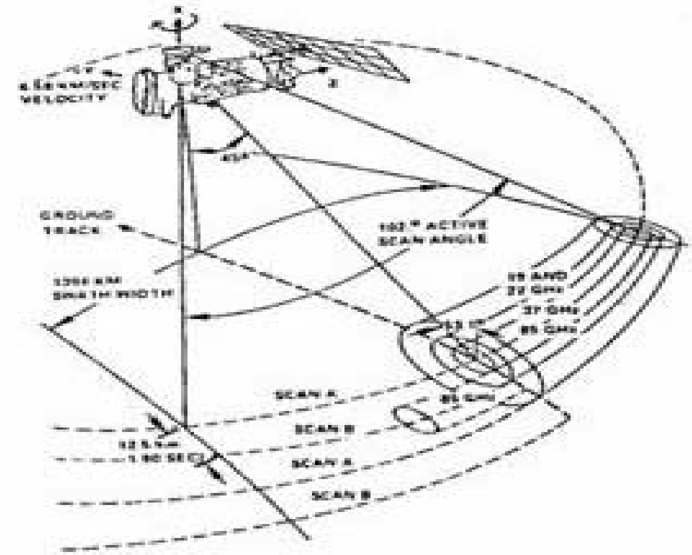
The SSM/I Climate Records Generated Since 1987 at NOAA/NESDIS



SSMI Characteristics

- **The most robust standing passive microwave time series**
  - 19+ years and growing
  - 14+ years dual-satellite
  - 10+ years tri-satellite
  - Sensor stability
  - Full time duty cycle
  - 1400+ km swath width
- **Seven channels**
- **10+ derived products**

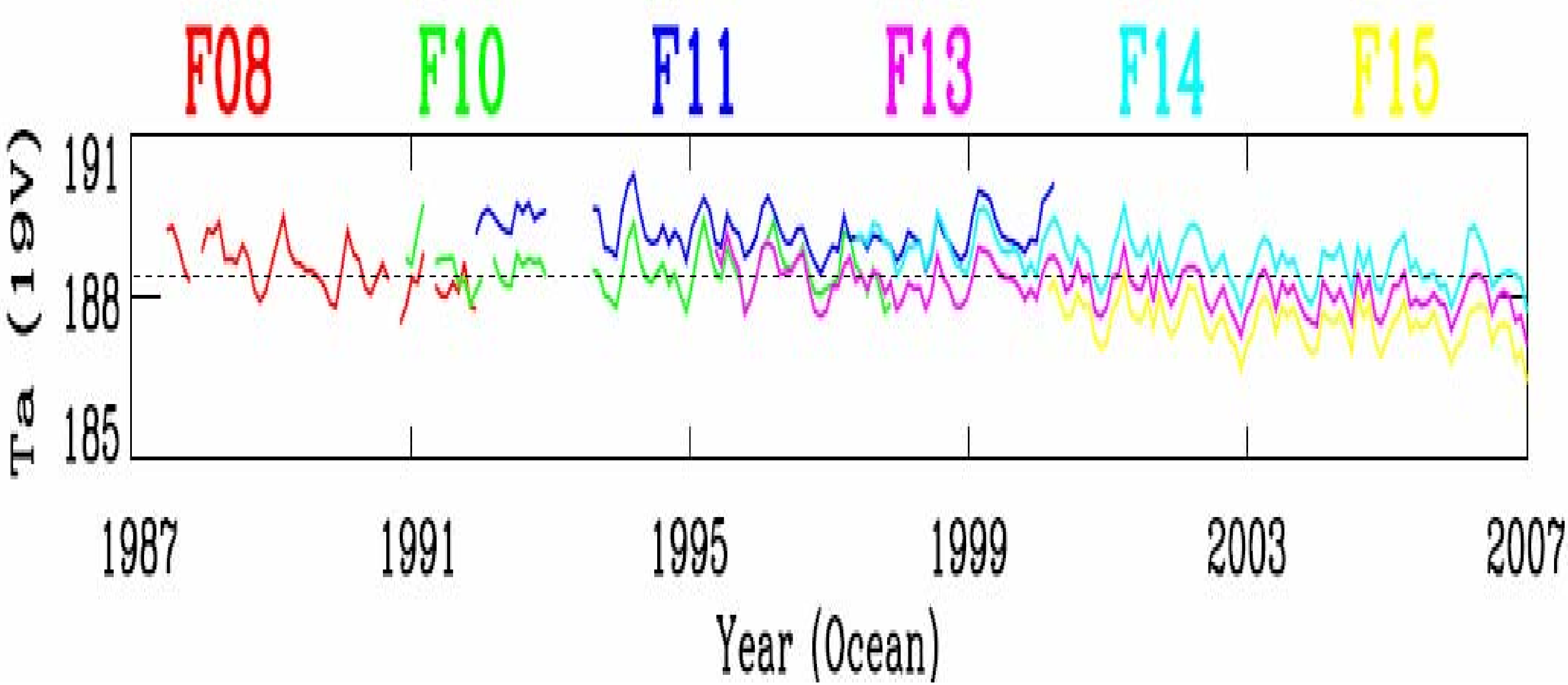


Center Frequencies(GHz)	19.35	19.35	22.235	37.0	37.0	85.5	85.5
Polarization	V	H	V	V	H	V	H
Bandwidth (MHz)	250	250	250	1000	1000	1500	1500
Sensitivity (K)	0.6	0.6	0.6	0.6	0.6	1.1	1.1
IFOV (km x km)	69 x 43	69 x 43	60 x 40	37 x 28	37 x 29	15 x 13	15 x 13
Sampling Interval (km x km)	25 x 25	25 x 25	25 x 25	25 x 25	25 x 25	12.5 x 12.5	12.5 x 12.5
Integration Time (msec)	7.95	7.95	7.95	7.95	7.95	3.89	3.89
Main Beam Efficiency (%)	96.1	96.5	95.5	91.4	94.0	93.2	91.1
Beamwidth (half-power, degrees)	1.87	1.87	1.65	1.10	1.10	0.43	0.45

SSM/I TDR Rescue Status (1987~present)

note: green means data complete for that year
pink means incomplete
blank means not in operation
F13,F14,F15 and F16 are complete.

DMSP SSM/I Time Series at 19 GHz



SSM/I shows a clear trend in brightness temperature with noticeable intersensor biases. Mean brightness is around 188 K at 19 GHz

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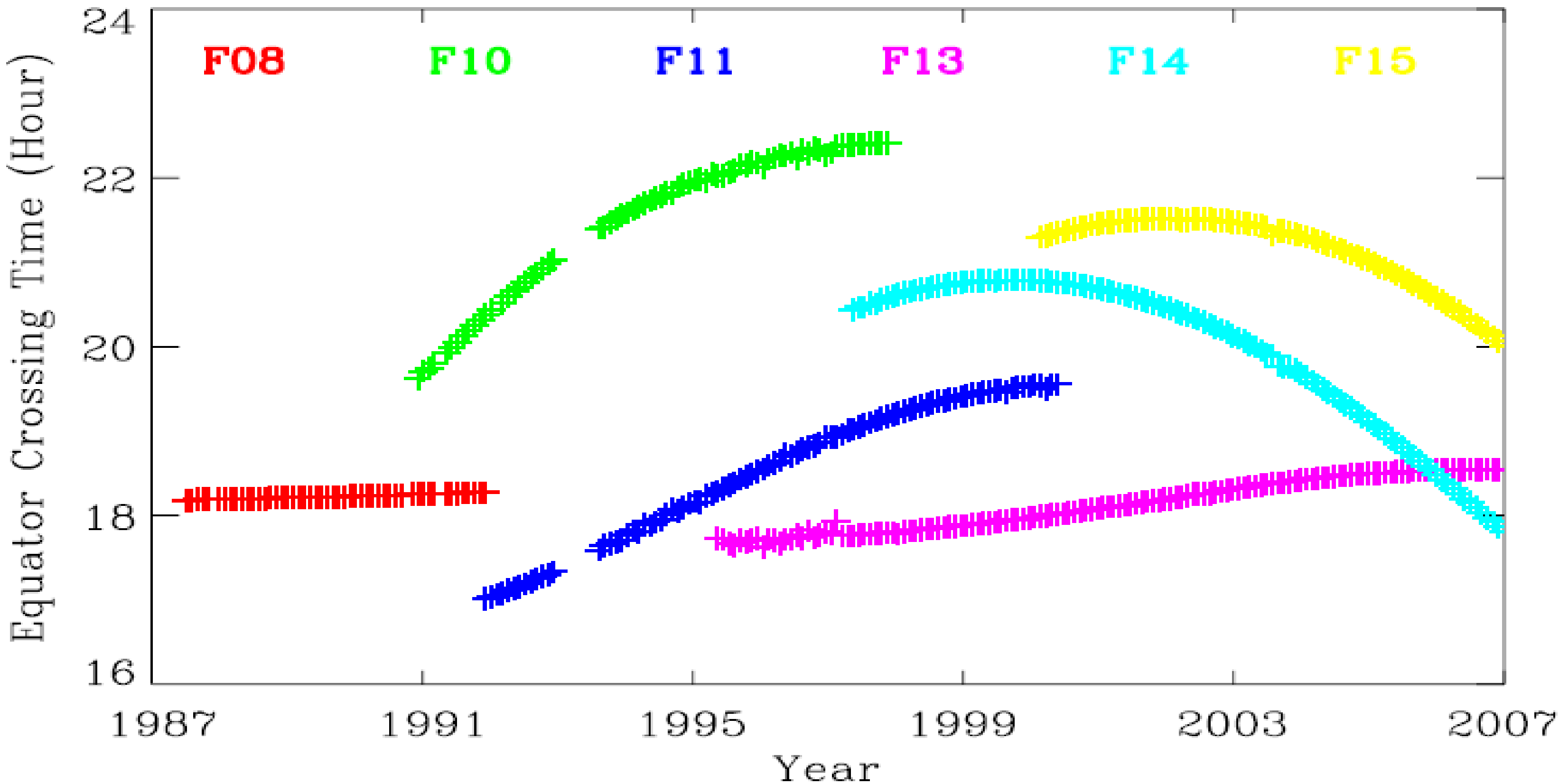
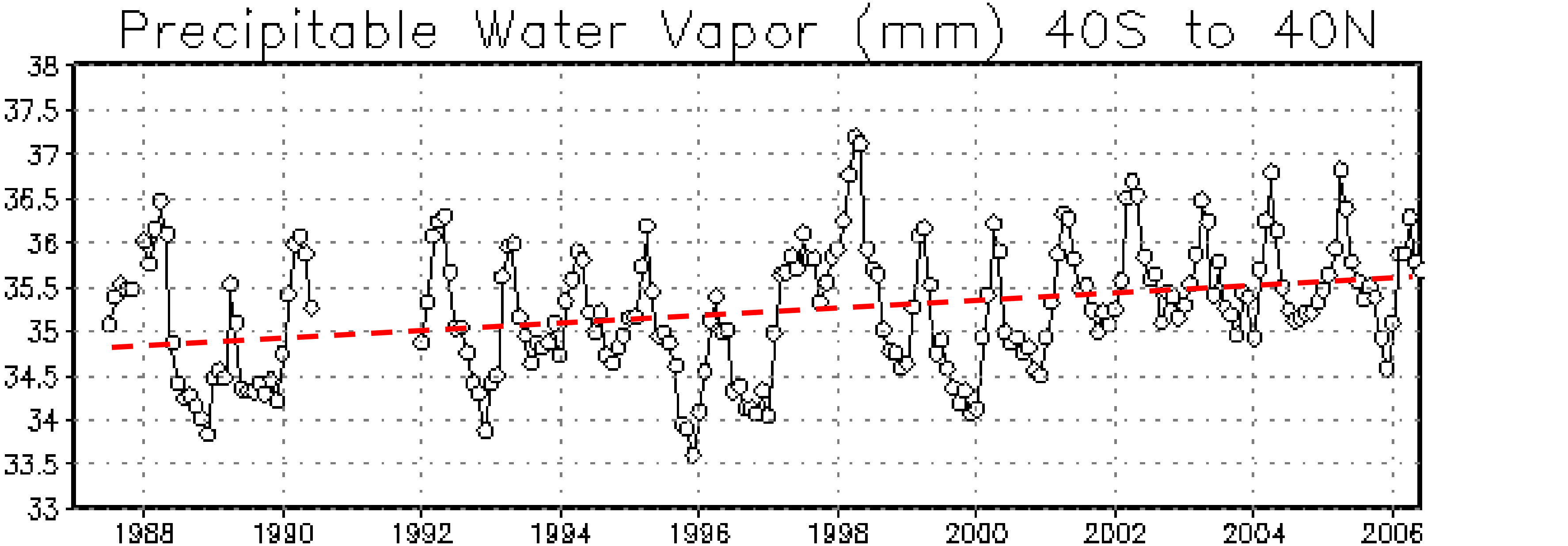
SSM/I Orbit Drift



F13 provides the stable and longest time series for inter-sensor calibration

19 Years of SSM/I Total Precipitable Water



Example:

If 1% TPW uncertainty (~0.35 mm/month) with a trend ~ 0.05 mm/year (or 0.004 mm/month), is this a trend or just uncertainty in retrieval?

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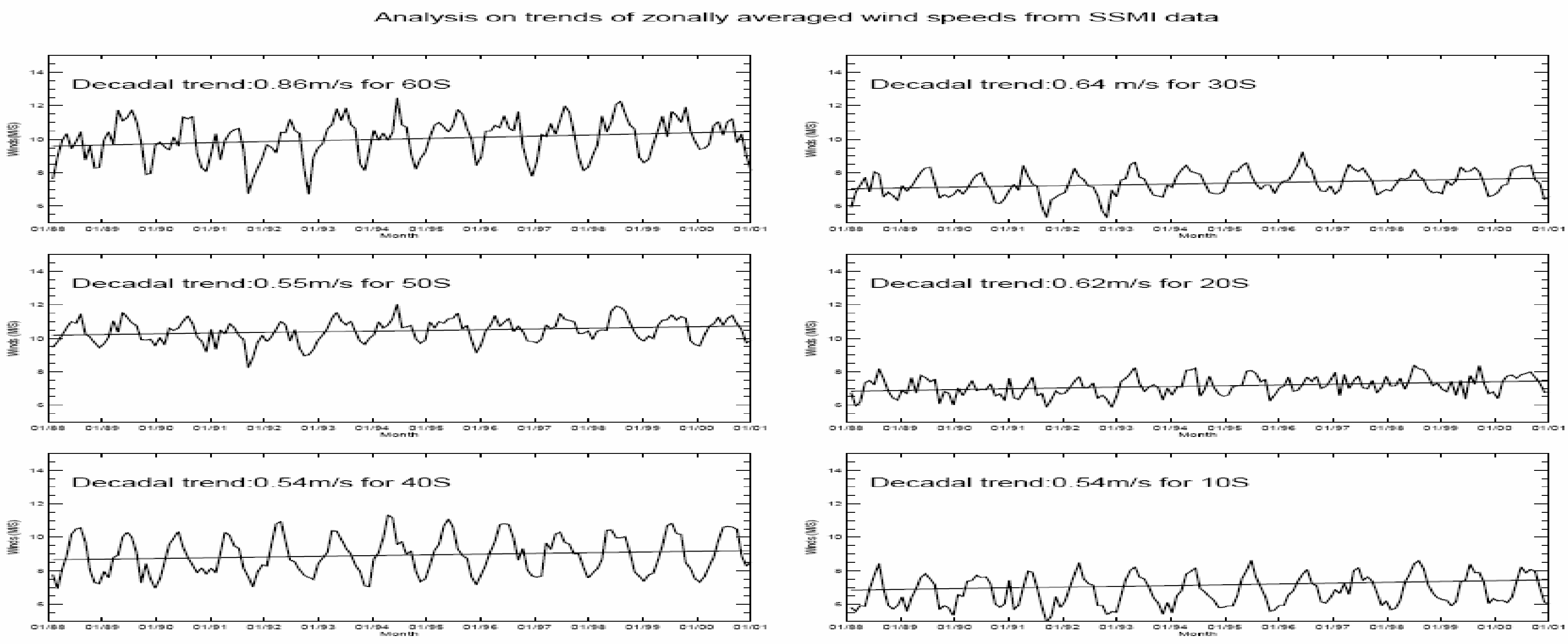
19 Years of SSM/I Ocean Wind Speed



Tropical mean wind speed increases 0.5 m/s per decade. Is the recent increasing hurricane wind damage responding to this trend? How can we assure this trend not related to inter-satellite calibration and algorithms

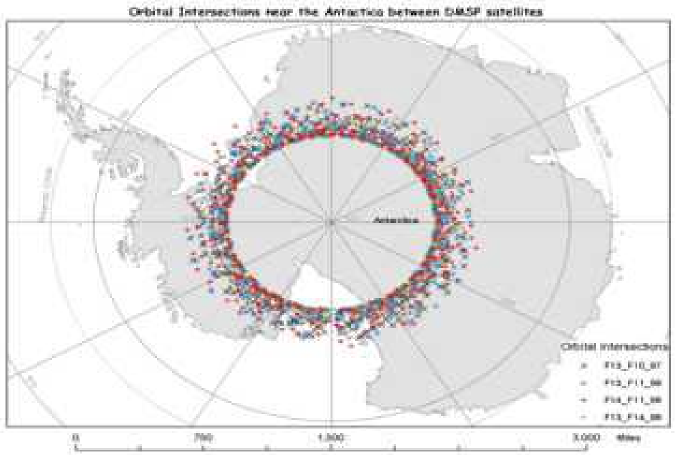
$$T_b = \varepsilon (T_s - T_d)\tau + T_u + T_d \tau$$

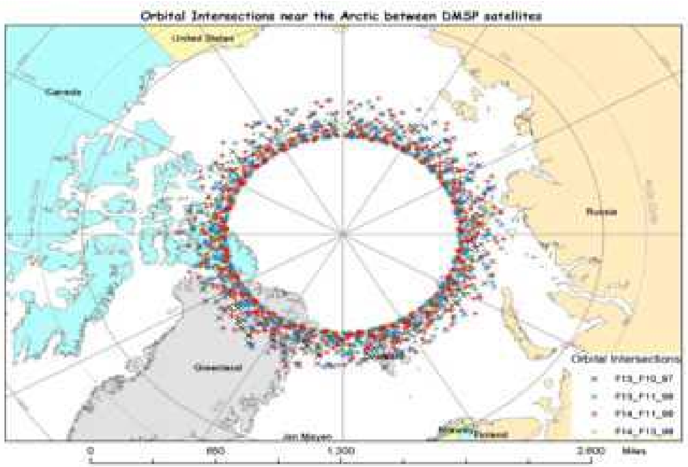
$$\frac{\partial W}{\partial T_b} = \frac{\partial W}{\partial \varepsilon}\frac{\partial \varepsilon}{\partial T_b} \approx \frac{1}{2.38 \times 10^{-3} (T_s - T_d)\tau}$$

This is the case for SSM/I 37 GHz, V-Pol, surface wind > 12 m/s. The sensitivity of wind speed to brightness temperature is about 1. – 3 m/s/K.

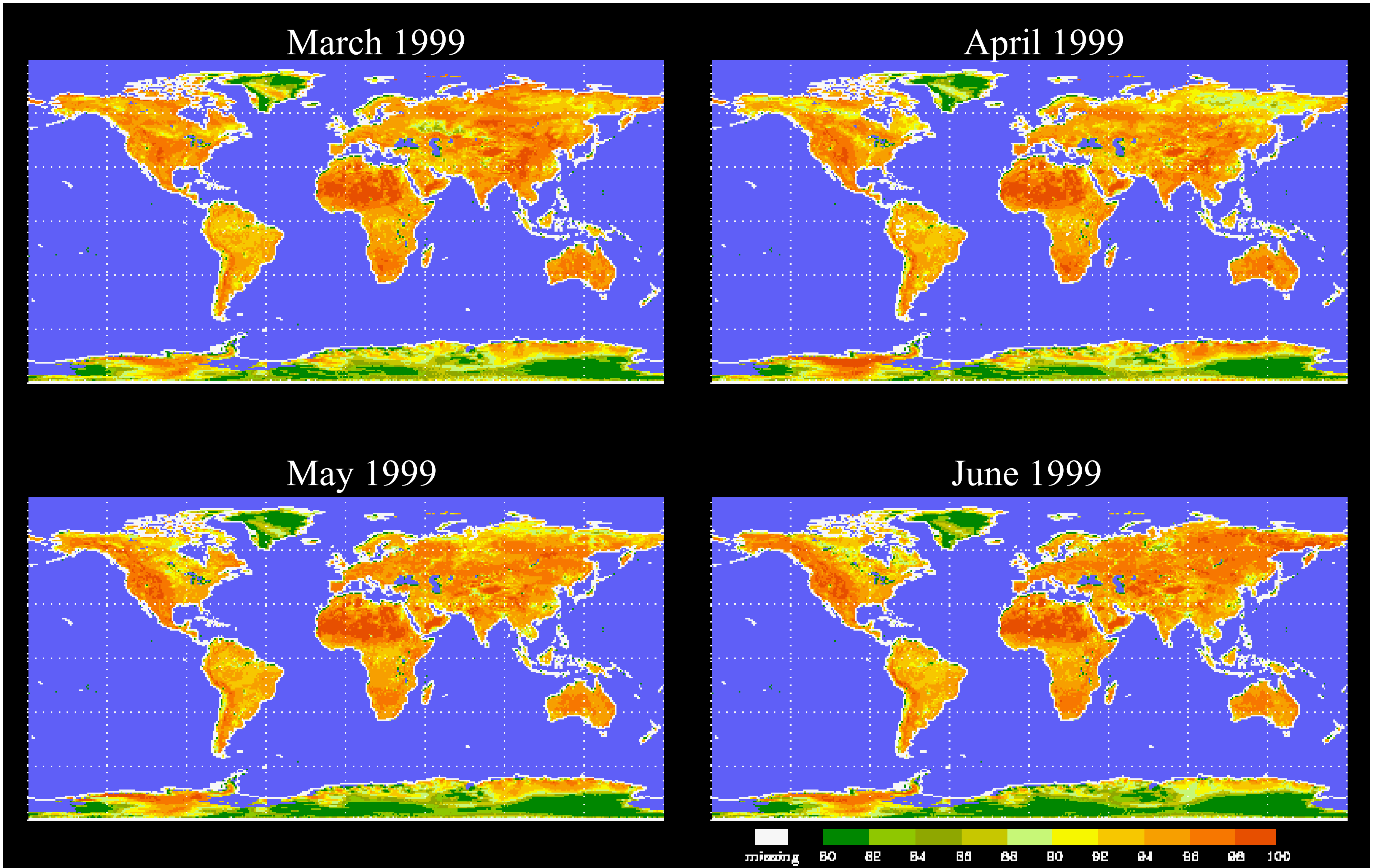
Specific Considerations in SSM/I SCO Processing

- SCO – every pair of POES satellites with different altitudes pass their orbital intersections within a few seconds regularly in the polar regions
- Conical instruments produce more chances in matching duo to their constant viewing angle
- Strong emissivity variation at high latitudes requires stringent check in surface homogeneity - sigma tests
- Time constraints are significant for microwave sensors

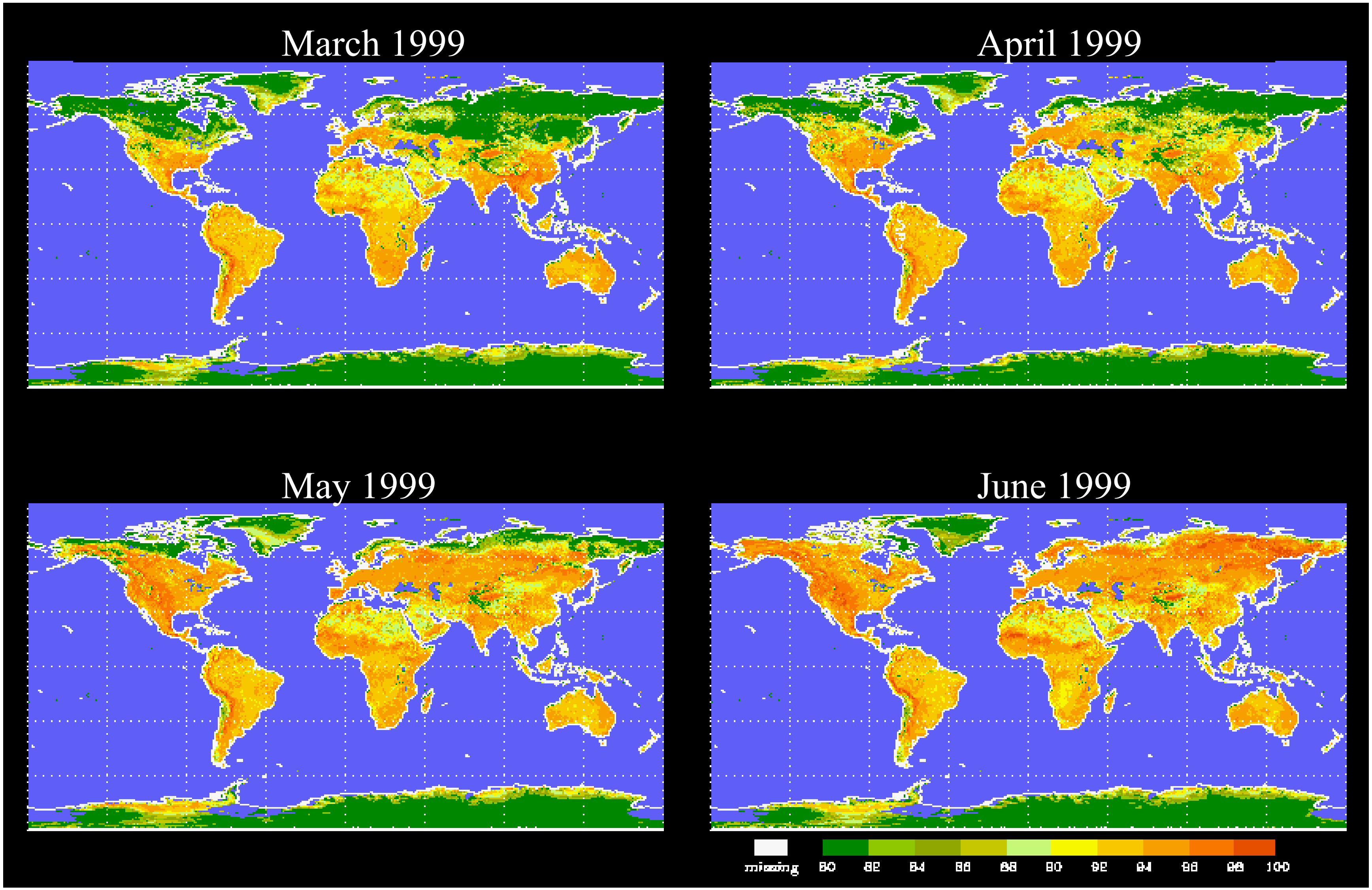




Land Surface Emissivity at 19 GHz Derived from SSM/I



Land Surface Emissivity at 85 GHz Derived from SSM/I



F13 and F14 SCO Bias vs. Quality Control

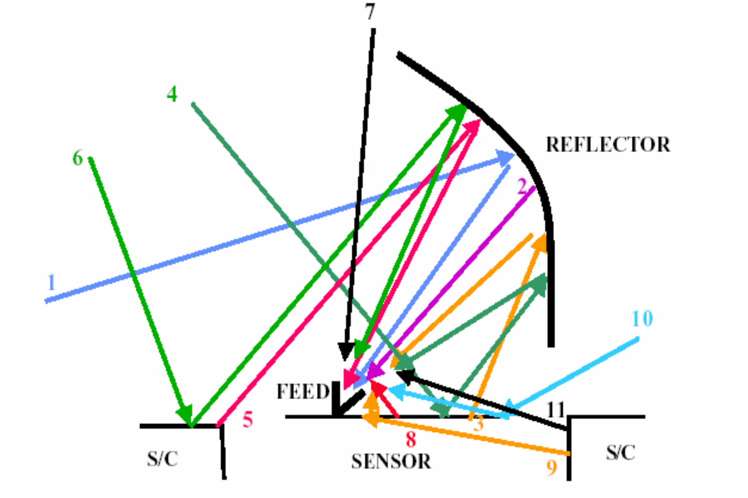
Channel & Polarization			19V	19H	22V	37V	37H	89V	89H
Bias	Land	QC1	2.55	3.56	2.42	1.41	2.28	1.07	1.62
		QC2	1.74	2.23	1.74	0.95	1.32	1.00	1.29
	Ice	QC1	0.29	0.78	0.39	-0.09	0.40	0.40	0.70
		QC2	0.05	0.84	0.10	-0.25	0.48	0.29	0.65
	Water	QC1	-0.02	0.21	0.14	-0.26	0.17	0.51	0.72
		QC2	-0.17	-0.03	-0.04	-0.38	0.06	0.44	0.62
Standard Deviation	Land	QC1	9.61	16.75	8.29	7.32	13.09	6.82	9.54
		QC2	7.55	12.88	6.76	6.08	10.18	5.88	7.82
	Ice	QC1	2.04	3.74	1.87	1.49	2.54	2.98	2.98
		QC2	1.49	1.97	1.57	1.58	1.89	2.87	2.96
	Water	QC1	3.96	6.88	3.31	2.90	5.48	2.71	3.66
		QC2	4.29	7.16	3.50	2.83	5.33	2.54	3.42
Quality Control Criteria			QC1: $\Delta d \leq 12.5$ km, $\Delta t \leq$ 60 seconds QC2: $\Delta d \leq 12.5$ km, $\Delta t \leq$ 10 seconds						

Channel & Polarization			19V	19H	22V	37V	37H	89V	89H
Bias	Land	QC1	1.74	2.23	1.74	0.95	1.32	1.00	1.29
		QC2	0.28	0.59	0.31	-0.32	0.26	0.12	0.20
	Ice	QC1	0.05	0.84	0.10	-0.25	0.48	0.29	0.65
		QC2	0.16	0.46	0.32	-0.28	0.13	0.64	0.67
	Water	QC1	-0.17	-0.03	-0.04	-0.38	0.06	0.44	0.62
		QC2	-0.16	0.28	0.22	-0.43	0.22	0.15	0.65
Standard Deviation	Land	QC1	7.55	12.88	6.76	6.08	10.18	5.88	7.82
		QC2	1.66	1.45	1.80	1.54	1.45	1.17	1.09
	Ice	QC1	1.49	1.97	1.57	1.58	1.89	2.87	2.96
		QC2	0.58	0.88	0.99	0.46	0.58	0.86	0.79
	Water	QC1	4.29	7.16	3.50	2.83	5.33	2.54	3.42
		QC2	0.63	0.57	0.88	0.69	0.86	0.94	1.15
Quality Control Criteria			QC1: $\Delta d \leq 12.5$ km, $\Delta t \leq$ 60 seconds QC2: $\Delta d \leq 12.5$ km, $\Delta t \leq$ 10 seconds Plus $\sigma \leq 2K$						

Microwave Instrument Calibration Components

Energy sources entering feed for a reflector configuration

1. Earth scene Component,
2. Reflector emission
3. Sensor emission viewed through reflector,
4. Sensor reflection viewed through reflector,
5. Spacecraft emission viewed through reflector,
6. Spacecraft reflection viewed through reflector,
7. Spillover directly from space,
8. Spillover emission from sensor,
9. Spillover reflected off sensor from spacecraft,
10. Spillover reflected off sensor from space,
11. Spillover emission from spacecraft



Calibration Error Sources for Microwave Conical Instruments

Sensors	Full Capability	Current Capability	Major Impediments	Recommendations & Solutions
SSMI SSMIS WindSat AMSR-E	•NEDT (monitoring and trending) •Non-linearity •Bias characterization •Spectral response function •Warm load anomaly correction •Field of view impingements •Calibration target stability •Antenna emission level/stability •Polarization knowledge •Pointing knowledge •Reduce/eliminate On-board averaging •Antenna patterns •Characterize Antenna emissivity •Measure antenna Surface Temperature •On-board averaging •Correcting for Orbital Drift •Bias characterization for all channels	•NEDT measurements •Bias characterization •Spectral response function not characterized adequately fro all channels •Solar-driven gradients •Residual errors large w/r/t signals •Sounding channels have on-board averaging •Limited pre-launch characterization of antenna patterns •Antenna arm temperature •Average antenna FOV on-orbit •Frank Wentz using GCM (3 hour temporal resolution) Bias Correction for few sounding channels only (surface blind)	•Variable calibration observations depending on footprint size, channel NEDT and ΔG •Warm load (RF and thermal) modeling •Warm load design •Antenna model on emissivity and energy distribution function •Simulation and RF model of s/c and antenna interaction •Physics of antenna emissivity issue •Complete characterization of polarization and cross-pol •Data rate and interface issues •Lack of full temperature monitoring of antenna surface •Better characterize non-linearity pre-launch and in design phase •Insufficient time period information •Bias correction in window channel (surface emissivity)	•High temporal NWP also TMI •Complete root cause investigation on reflector emissivity – improve coating with respect to considerations of microwave radiometry •Shading the warm load from solar intrusion; thermally isolating the warm load; •Non-linearity characterization for SSM/I and SSMIS ; Matching and overlapping Simultaneous Conical Overpass •Develop standards for noise injection •Develop antenna FOV models to aid determining scan dependent biases •Thermally stable radiometers – add to gain stability; Front-end; LNA for 183 GHz •RFI – mitigation; detection; correction

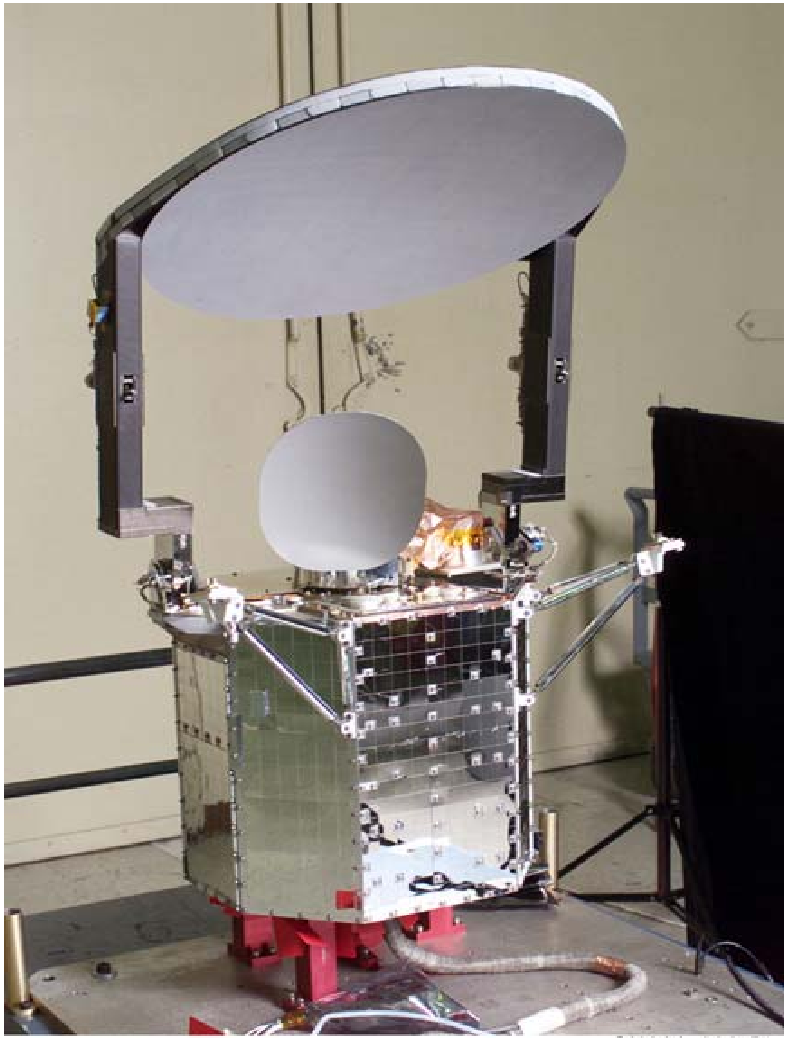
Weng, Kunkee and St. Germain, 2006, in the report of Workshop on Achieving Satellite Instrument Calibration for Global Climate Change (ASIC3) by Ohring et al

Sources of Errors in SSM/I Calibration

- Indirect calibration system
- Spill-over corrections
- Scan dependent bias
- Specific contamination
- Antenna emission
- Non-linearity

SSM/I Calibration System

- **Main-reflector conically scans the earth scene**
  - Reflector emissivity is nozero
- **Warm load is viewed by feedhorn to provide one of measurements in two-point calibration system**
  - Temperature gradient in load due to solar heating
- **Sub-reflector views cold space to provide other one point**
  - Lunar signal
  - RFI from other spacecrfats



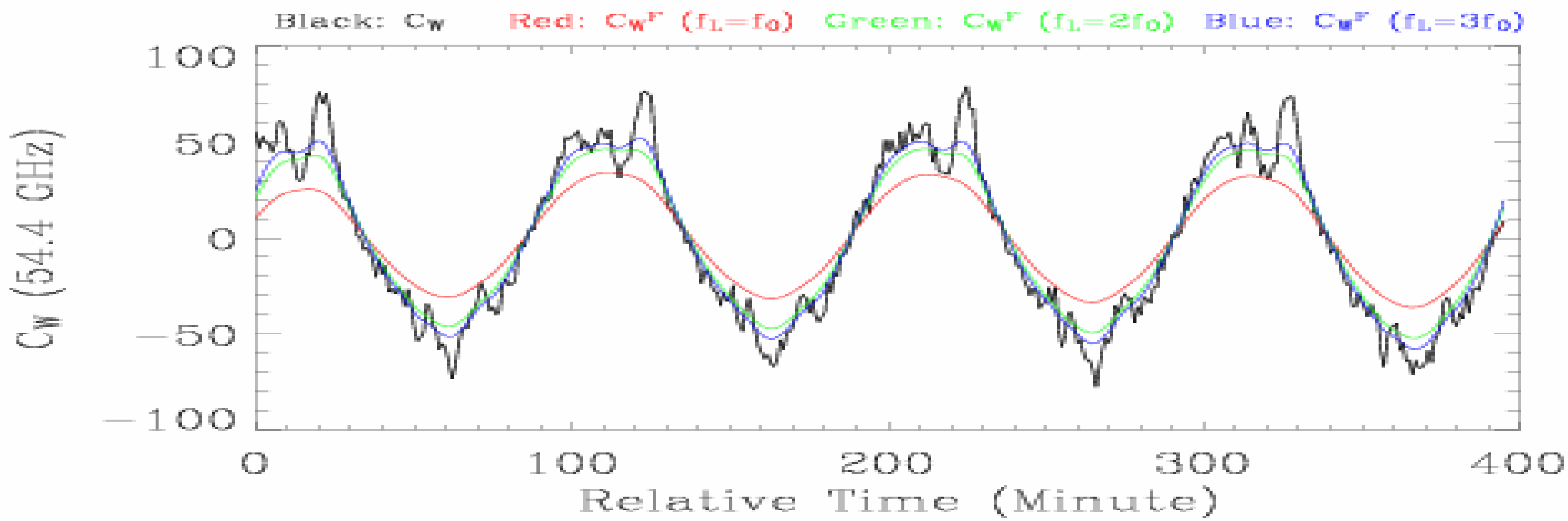
CN600-136-D

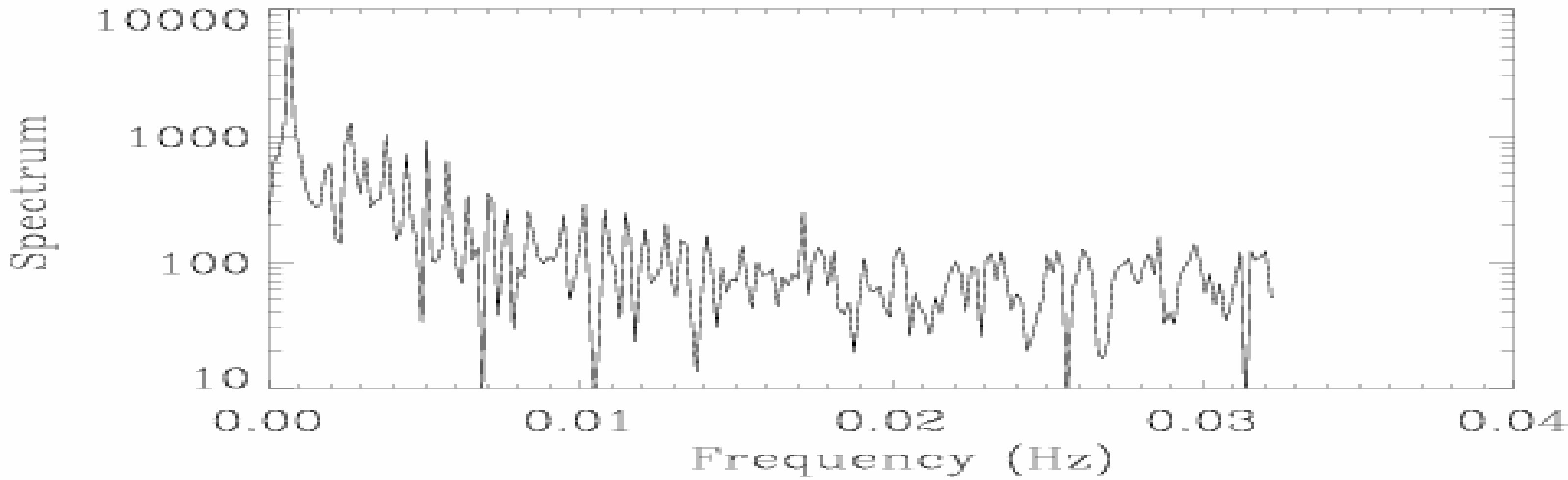
Theoretical SSMIS Reflector Surface Parameters

(NRL Multilayer Antenna Model)

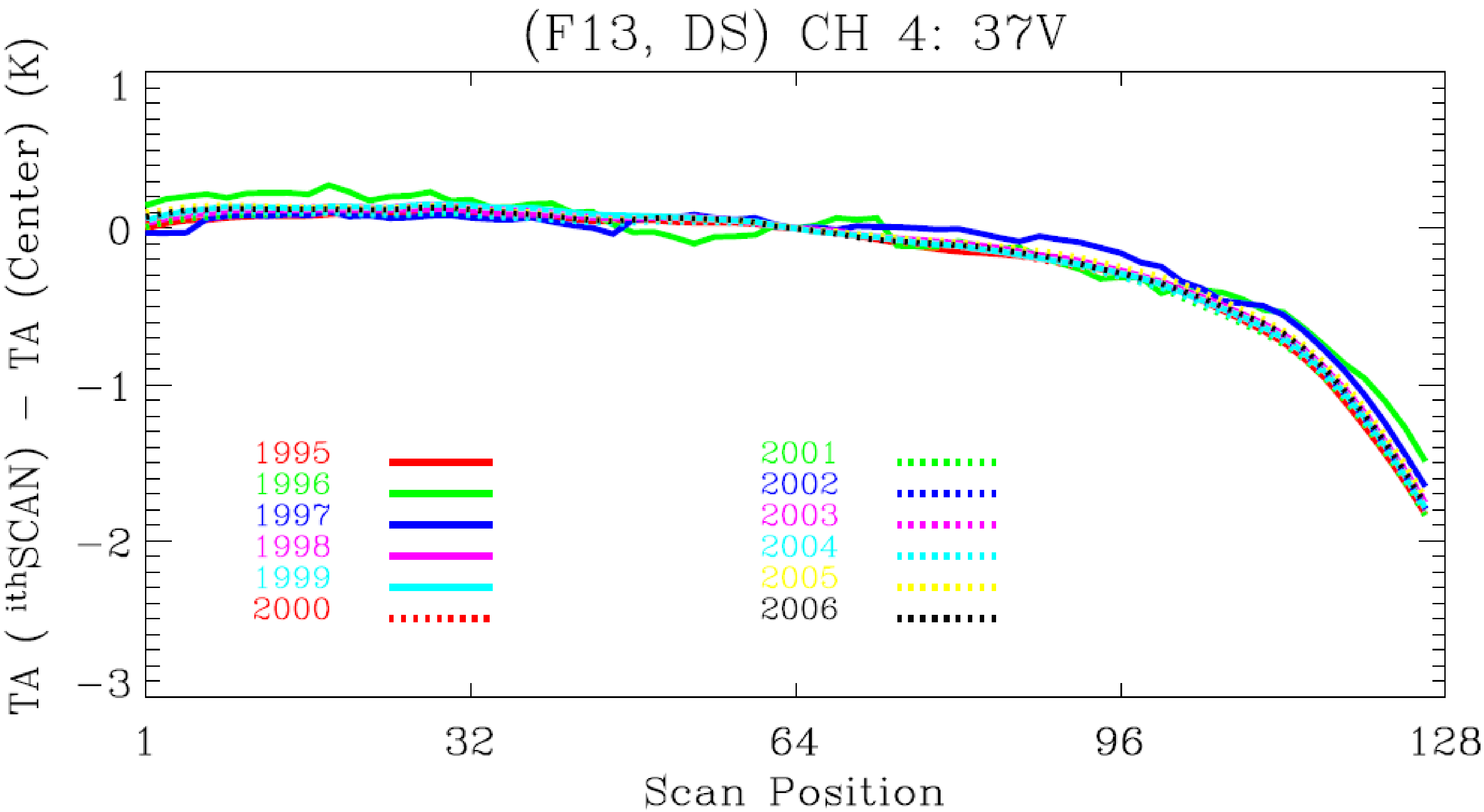
		Emissivity (V-pol/20deg) [$\in$ R]		
Freq. (GHz)	Al	GrEp	SiOx	SiOx/Al
19.35	0.00051	0.012	0.91	0.00051
37.0	0.00071	0.016	0.91	0.00071
60.0	0.00090	0.020	0.91	0.00090
91.65	0.00111	0.025	0.91	0.00111
183.0	0.00157	0.035	0.91	0.00157

Fluctuation of Warm Loads Count





SSM/I Scan Dependent Bias (F13)



All SSM/I shows scan dependent biases due primarily to intrusion of Glare Suppression System-B (GSS-B).

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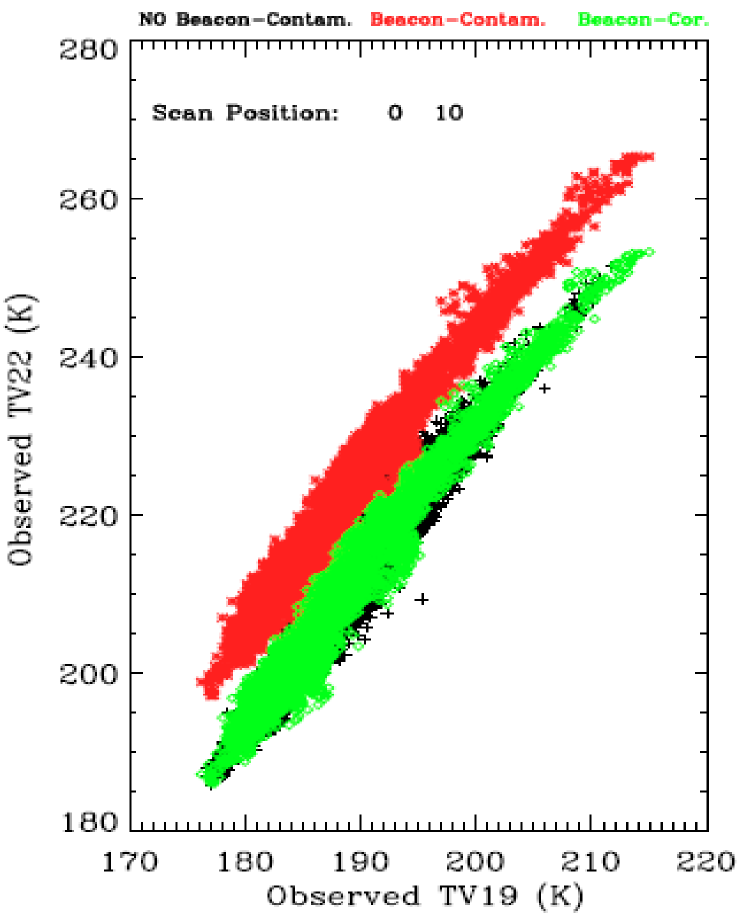
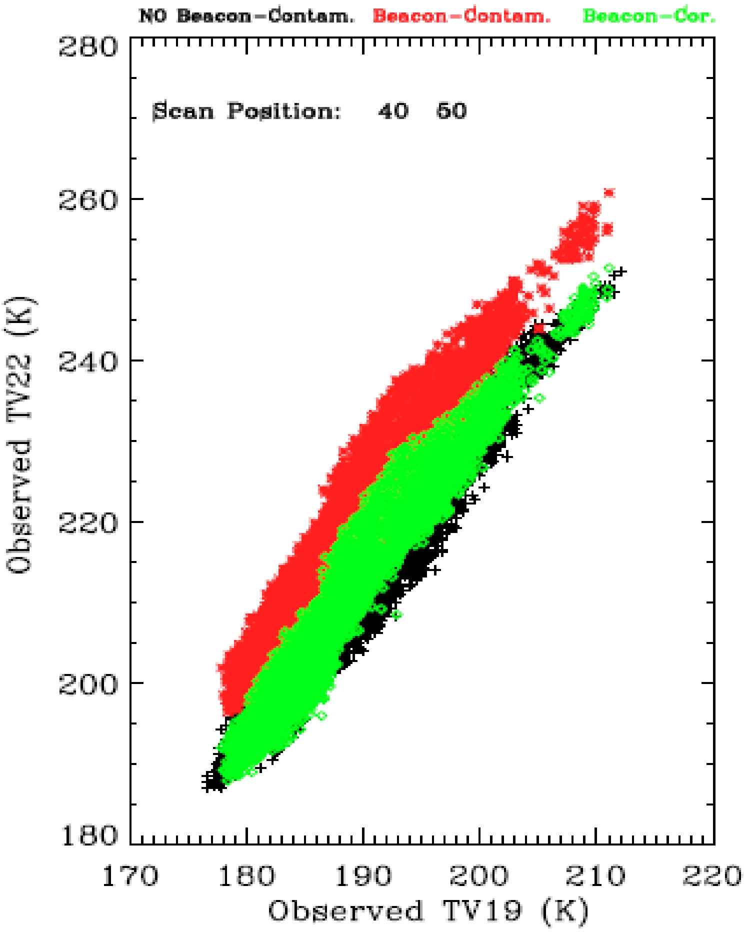
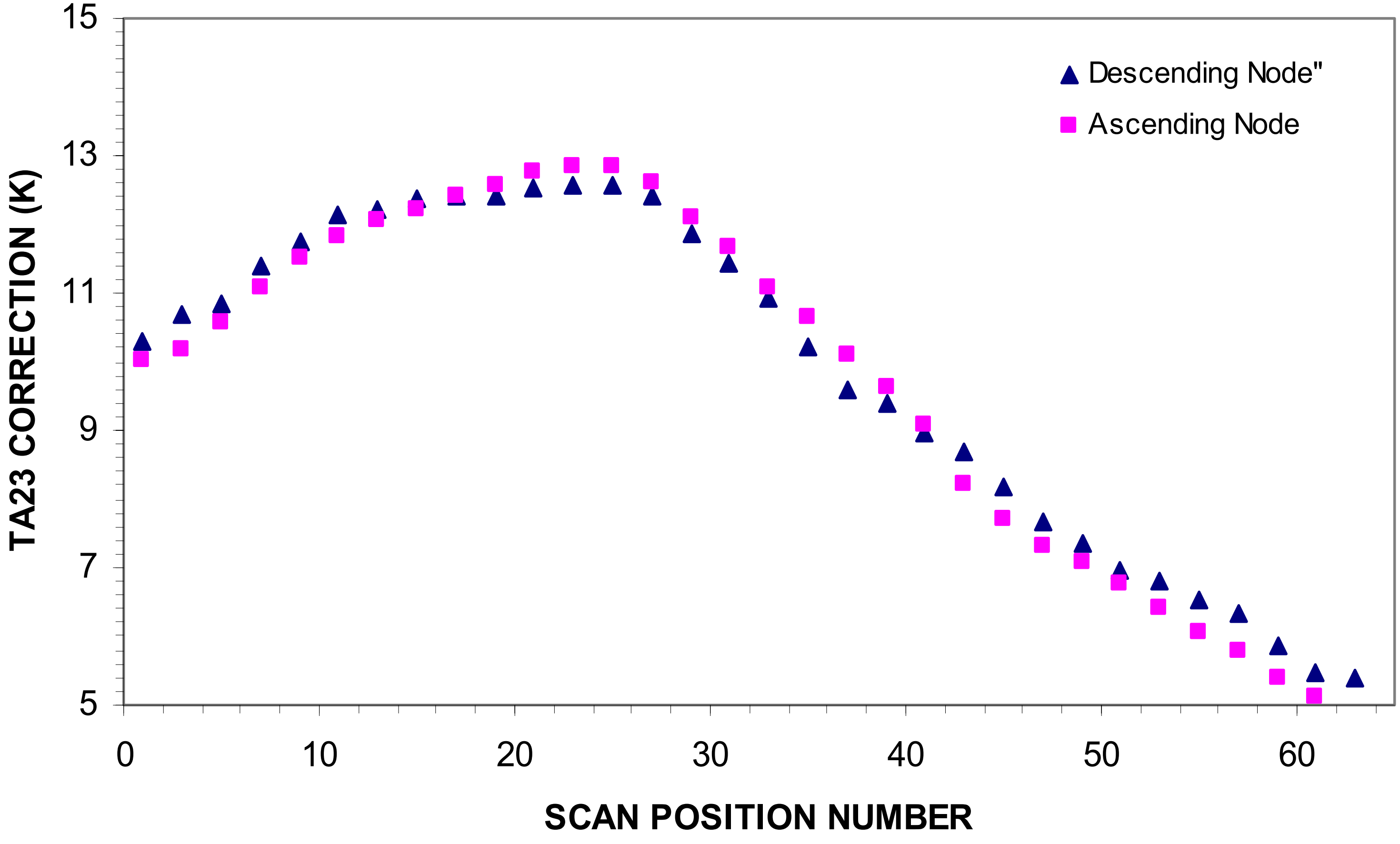
F15 SSM/I Radar calibration Beacon Interference





Starting from August 14, 2006, F15 SSM/I channel 3 (22V) is contaminated by radar calibration beacon

F15 SSM/I Radcal Beacon Interference



Antenna Spill-Over Corrections

$$T_{B,V} = \frac{1}{AP_V(1-BP_V)}T_{A,V} - \frac{BP_V}{AP_V(1-BP_V)}T_{A,H}$$

$$T_{B,H} = \frac{1}{AP_H(1-BP_H)}T_{A,H} - \frac{BP_H}{AP_H(1-BP_H)}T_{A,V},$$

Frequency (GHz)	AP		BP	
	F15 SSM/I	F16 SSMIS	F15 SSM/I	F16 SSMIS
19 V	0.9690	0.9720	0.00473	0.00441
19H	0.9690	0.9680	0.00415	0.00503
22V	0.9740	0.9820	0.01070	0.00292
37V	0.9860	0.9850	0.02170	0.00415
37H	0.9860	0.9810	0.02612	0.00343
85V (92V)	0.9880	0.9820	0.01383	0.01319
85H (92H)	0.9880	0.9780	0.01947	0.01876

→

Frequency (GHz)	ΔT_A^{APF}(K)
19.35 (V)	-0.72
19.35 (H)	0.17
22.235 (V)	-1.99
37 (V)	-0.18
37 (H)	1.60

SSM/I 22 GHz has largest uncertainty in spill-over correction from antenna to brightness temperature

Linear and Non-linear Calibration

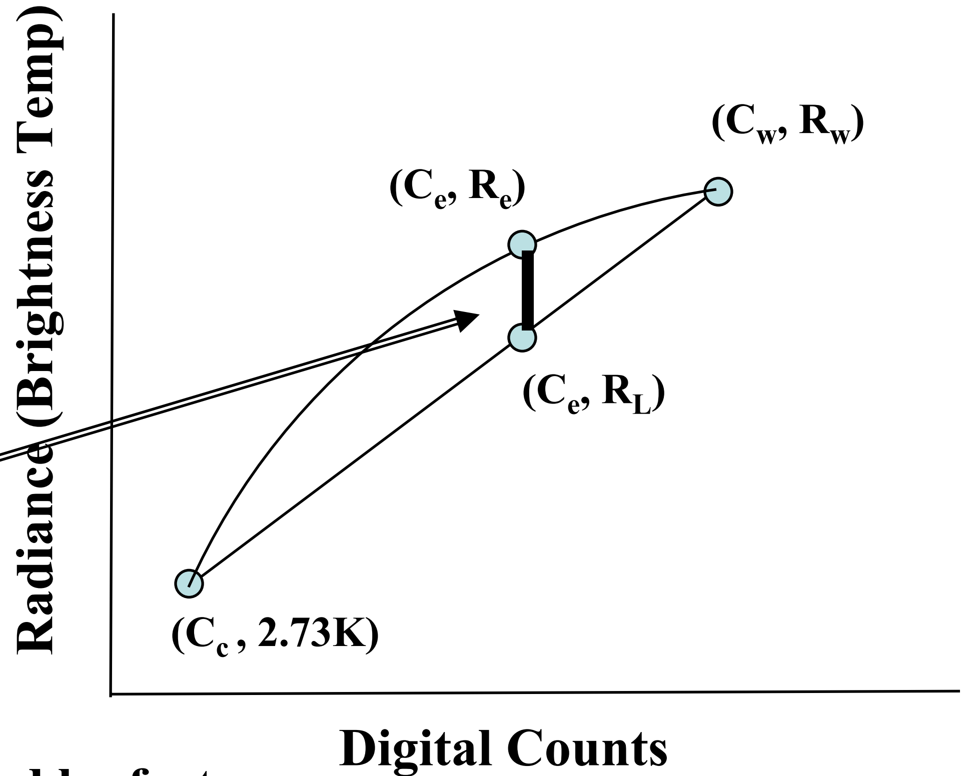
Two Point Radiometer Linear Calibration:

$$R_{e,L} = R_c + S(C_e - C_c)$$

$$S = \frac{R_w - R_c}{C_w - C_c}$$

Two Point Radiometer with Nonlinear Calibration Correction:

$$R_e = R_{e,L} + \mu Z - \delta R$$



where δR is the post-launch bias caused by factors other than non-linearity

$$Z = S^2 (C_e - C_c)(C_e - C_w)$$

SSM/I Algorithms for Non-Linearity

Non-linear calibration in brightness temp. :

$$T_A = T_{A,L} + \mu Z$$

Simultaneous conical overpass:

$$\Delta T_{A,L}(j,k) + \mu_k Z_k - \mu_j Z_j = 0$$

For two different surface types:

$$\mu_j Z_{j,N} - \mu_k Z_{k,N} = \Delta T_{L,N}(j,k)$$
$$\mu_j Z_{j,S} - \mu_k Z_{k,S} = \Delta T_{L,S}(j,k)$$

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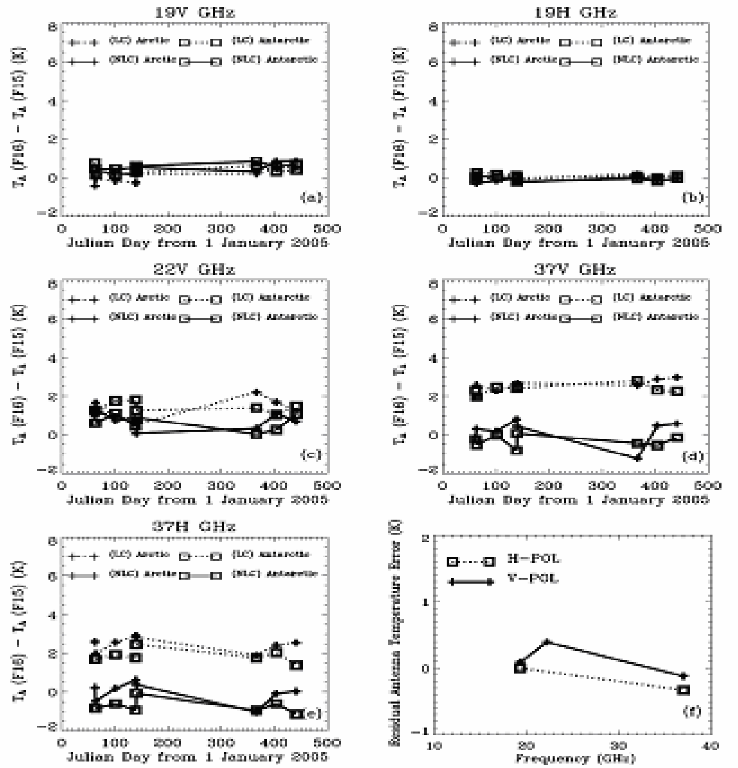
F15 and F16 Non-linearity Factors

Frequency (GHz)	Nonlinear Parameter (μ)	
	F15	**F16**
19.35 (V-POL)	-7.0449E-6	1.0913E-5
19.35 (H-POL)	-1.1059E-6	-1.0825E-6
22.235 (V-POL)	-5.4371E-5	6.7848E-5
37 (V-POL)	-5.6897E-5	7.1057E-5
37 (H-POL)	-1.7801E-5	2.2946E-5

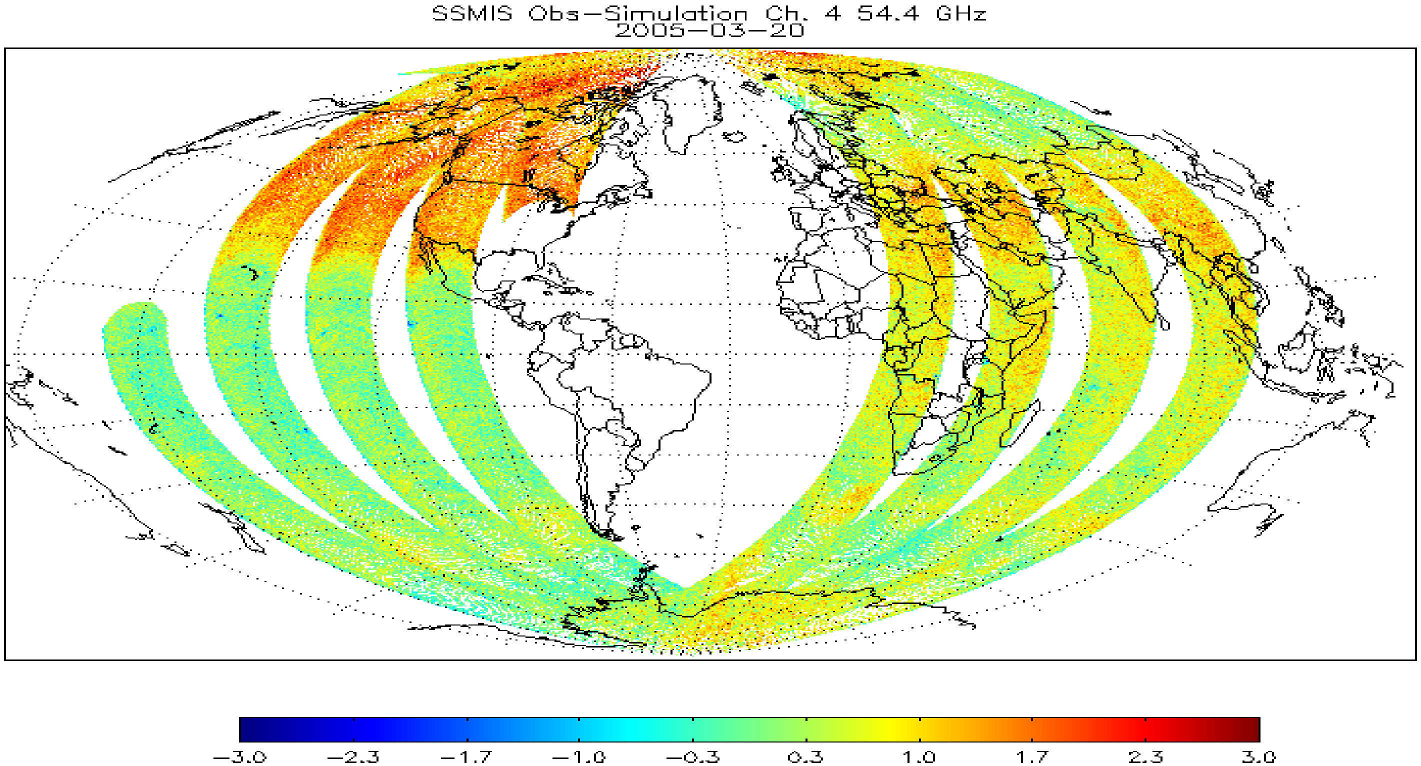


Yan and Weng, 2008; TGARS. The algorithm can be used for a pair of satellites when they are matched Over two distinct surface types (land and ocean). The correction is on an order of 0.5-1K. The caveat is this correction will combine all other bias sources into non-linearity

SSMIS Instrument Characteristics

- **The Defense Meteorological Satellite Program (DMSP) successfully launched the first of five Special Sensor Microwave Imager/Sounder (SSMIS) on 18 October 2003.**
- **SSMIS is a joint United States Air Force/Navy multi-channel passive microwave sensor**
- **Combines and extends the current imaging and sounding capabilities of three separate DMSP microwave sensors, SSM/T, SSM/T-2 and SSM/I, with surface imaging, temperature and humidity sounding channels combined.**
- **The SSMIS measures partially polarized radiances in 24 channels covering a wide range of frequencies (19 – 183 GHz)**
  - conical scan geometry at an earth incidence angle of 53 degrees
  - maintains uniform spatial resolution, polarization purity and common fields of view for all channels across the entire swath of 1700 km.

SSMIS Anomaly Distribution



Shown is the difference between simulated and observed SSMIS 54.4 GHz. The SSMIS is the first conical microwave sounding instrument, precursor of NPOESS CMIS. The calibration of this instrument remains unresolved after 2 years of the lunch of DMSP F16. The outstanding anomalies have been identified from three processes: 1) antenna emission after satellite out of the earth eclipse which contaminates the measurements in ascending node and small part in descending node, 2) solar heating to the warm calibration target and 3) solar reflection from canister tip, both of which affect most of parts of descending node.

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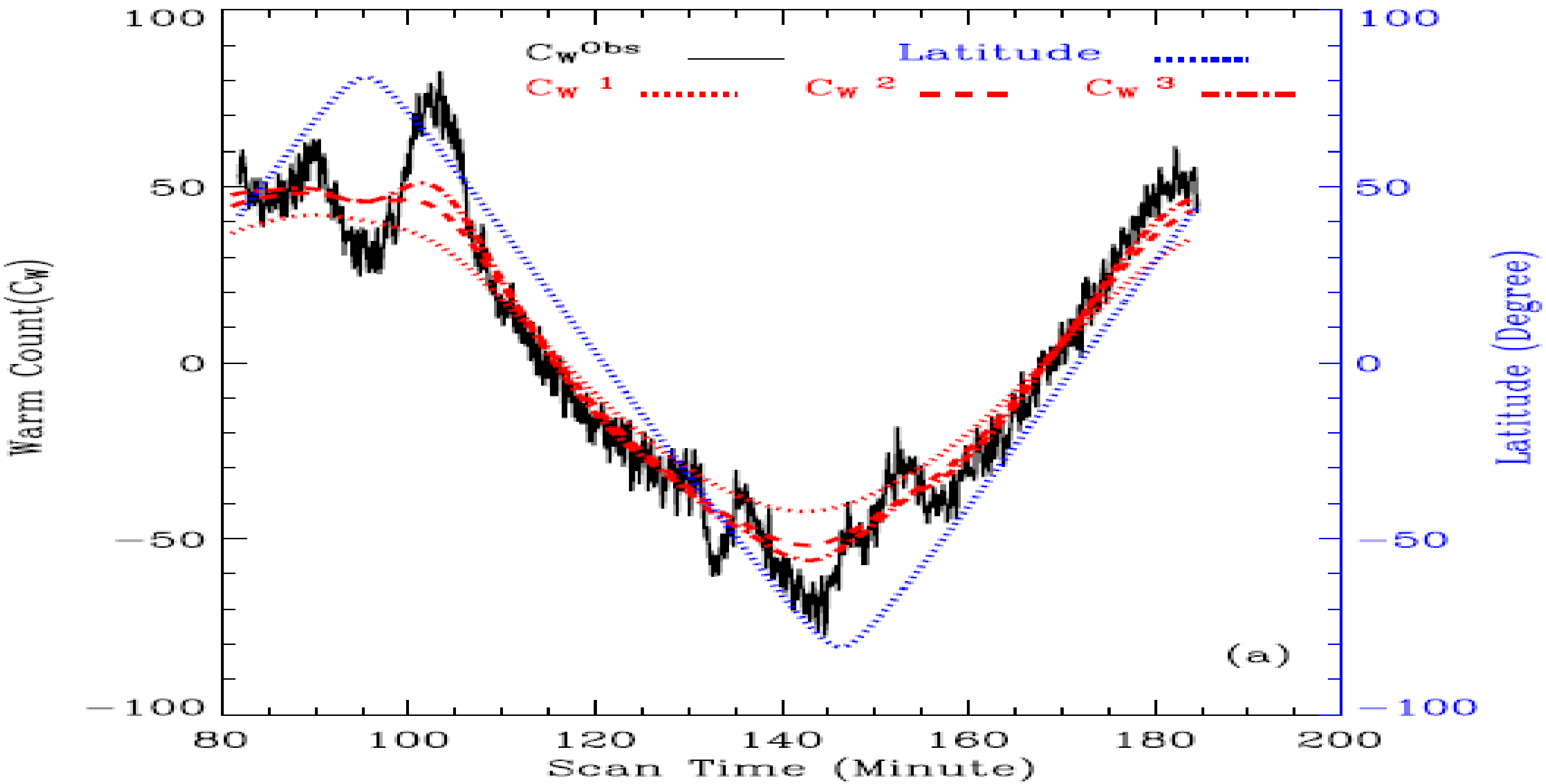
SSMIS Warm Load Anomaly at 54.4 GHz



Anomalous jumps in warm load counts result from direct solar illumination and stay light to calibration.

SSMIS Anomalies Correction Algorithms

Anomaly Causes

1. Antenna is not a pure reflector. It emits radiation with a very small emissivity and its own temperature. This additional radiation is called as an antenna emission anomaly
2. Warm load is heated by intruded solar radiation. The energy received through feedhorn does not match with the warm load physical temperature measured by the platinum résistance thermisters (PRT). This is referred as a warm load anomaly
3. The radiance from space view by the sub-reflector does not correspond to the sum of cosmic background temperature (2.73K) and pre-calculated correction values for each channel due to antenna side-lobe effort.

Anomaly Mitigation Process

1. Use the emissivity from NRL antenna model and the temperature measured from the thermister mounted on antenna arm as approximation
2. Analyze the time series of warm load counts together with PRT and define the anomaly locations in terms of the FFT harmonics
3. Analyze the time series of cold space view count and define the anomaly locations in terms of the FFT harmonics and cosmic temperature plus antenna correction

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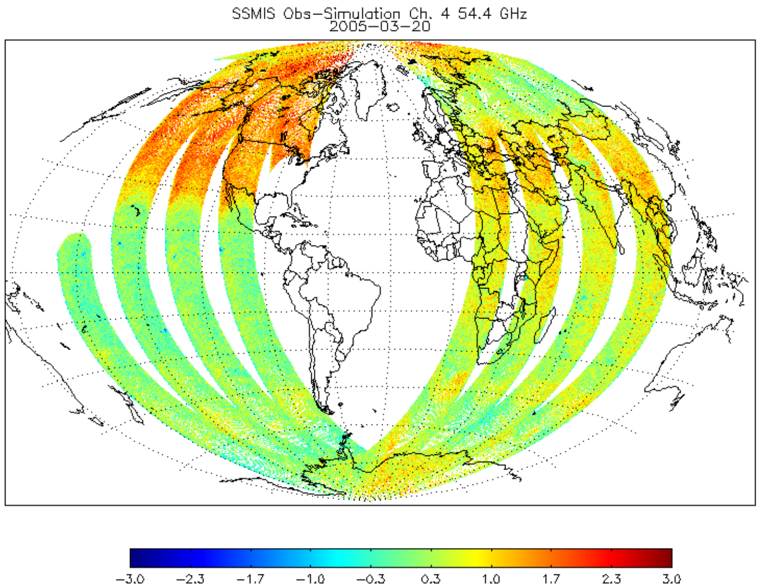
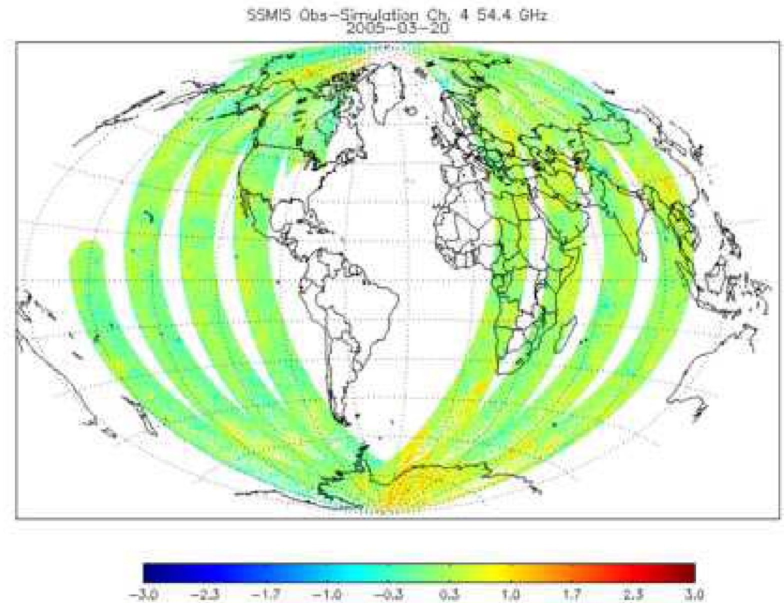
DMSP Special Sensor Microwave Imager and Sounder (SSMIS) Calibration

Before NOAA Calibration



After NOAA Calibration



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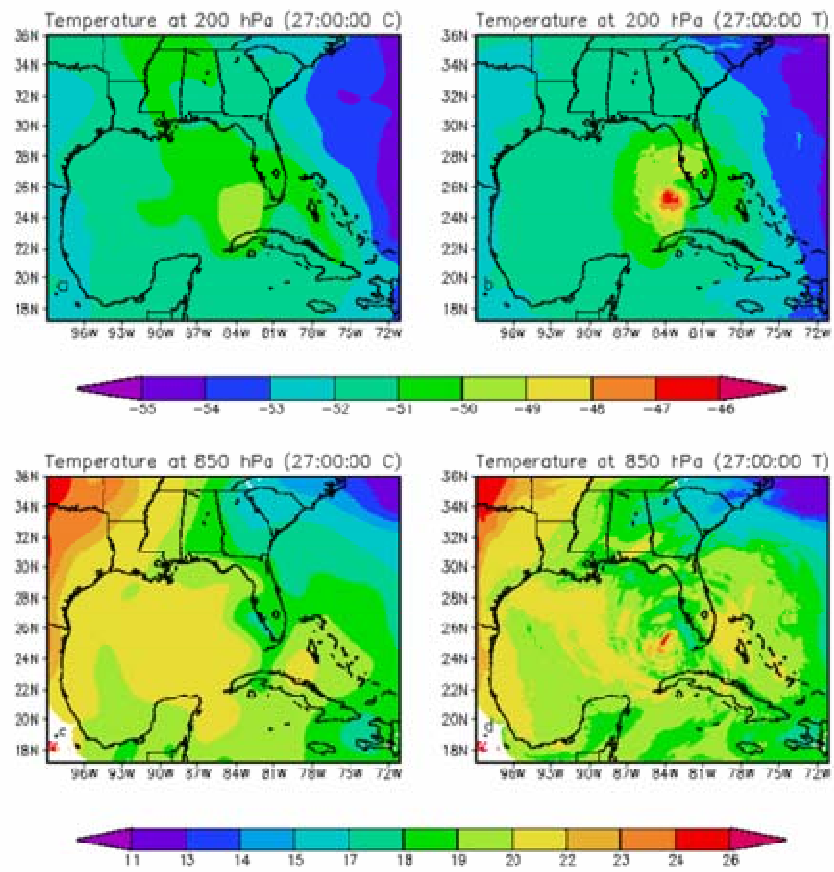
Correcting unintended instrument contamination is part of the cal/val process to provide accurate data for use in computerized weather forecast models

Direct SSMIS Cloudy Radiance Assimilation

DMSP F-16 SSMIS radiances is at the first time assimilated using NCEP 3Dvar data analysis. The new data assimilation improves the analysis of surface minimum pressure and temperature fields for Hurricane Katrina. Also, Hurricane 48-hour forecast of hurricane minimum pressure and maximum wind speed was significantly improved from WRF model

Significance: Direct assimilation of satellite radiances under all weather conditions is a central task for Joint Center for Satellite Data Assimilation (JCSDA) and other NWP centers. With the newly released JCSDA Community Radiative Transfer Model (CRTM), the JCSDA and their partners will be benefited for assimilating more satellite radiances in global and mesoscale forecasting systems and can improve the severe storm forecasts in the next decade



The initial temperature field from control run (left panels) w/o uses of SSMIS rain-affected radiances and test run (right panels) using SSMIS rain-affected radiances

Concluding Remarks

- SSM/I data has been fully recovered from 1987 to 2006.
- Critical calibration problems affecting SSM/I CDR has been identified
- Scan dependent biases can be characterized for each satellite
- Uncertainty in antenna spill-over corrections appears high at 22 GHz
- It is possible for correct some specific known sources of contamination such as radcal beacon interference
- Nonlinearity in calibration process can reduce the intersensor biases but must be applied when other bias sources are fully understood