SSM/I and SSMIS Calibration Issues and Implications for Weather and Climate Applications

Fuzhong Weng and Ralph Ferraro

NOAA/NESDIS/ORA

STAR Science Forum
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DMSP SSMI&SSMIS SDS Team

Mitch Goldberg, Climate data record requirements for SSMI

Fuzhong Weng: Calibration and product algorithm science

Ralph Ferraro: Sampling issues, CDR assessments, algorithm validation,

Banghua Yan: Calibration algorithm

Wanchen Chen: Data recovery, archival and reformat

Ninghai Sun: Tests and implementation of SSM/I and SSMIS calibration algorithm

Hilawe Semunegus: NCDC SSM/I archival

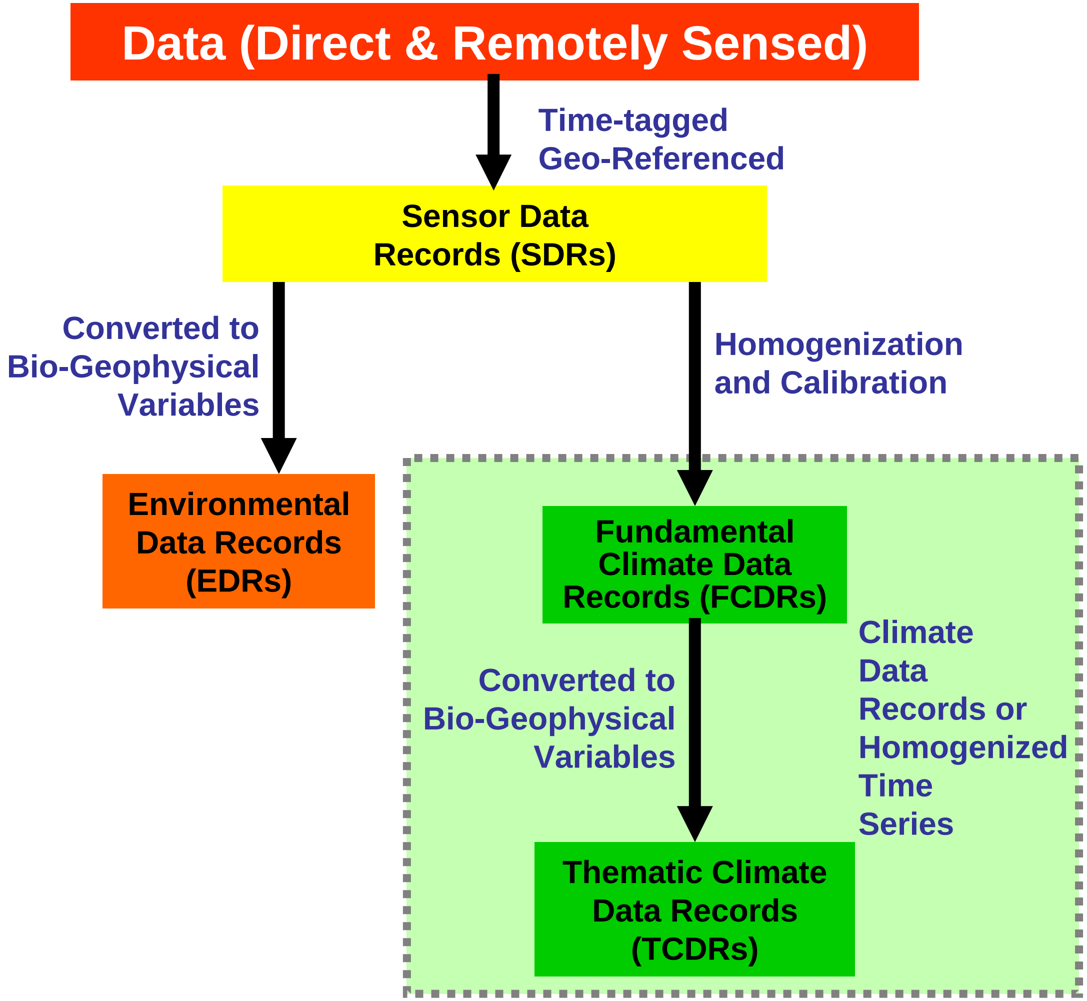
John Forsythe: CIRA SSM/I data recovery from 1987 to 1992

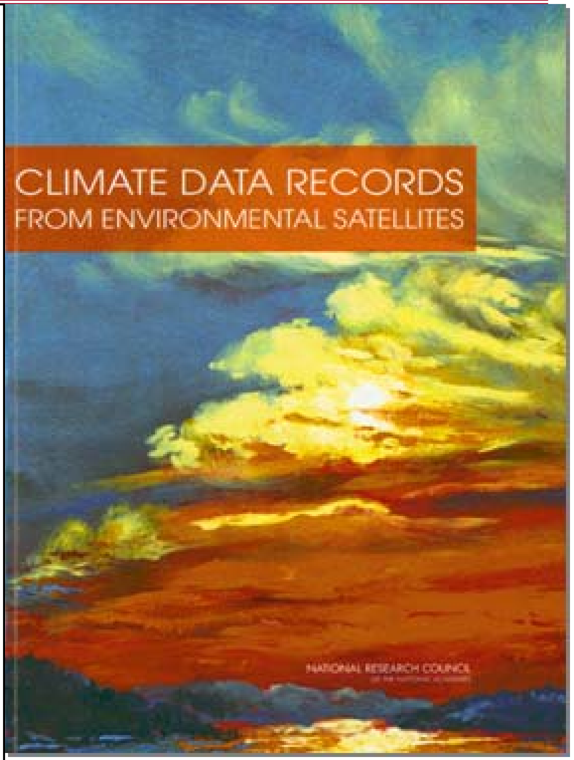
Outline

- **Scientific Data Stewardship Requirements**
  - Fundamental CDR (Level 1B, SDR)
  - Thematic CDR
- **SSMI and SSMIS Calibration Issues (Fuzhong Weng)**
  - Data rescue efforts
  - Newly discovered SSM/I calibration problem (calibration targets, angular dependant biases, beacon contamination)
  - SSMIS calibration problems
  - Reformat issues with new calibration information
- **SSM/I/S Products Issues (Ralph Ferraro)**
  - Some thoughts on "Climate" and trends
  - Orbit drifts & sampling problems
  - Old data format vs pixel level retrievals
  - SSM/I/S value added products
  - Parallel productions with SSM/I operational algorithms

NOAA Scientific Data Stewardship Program

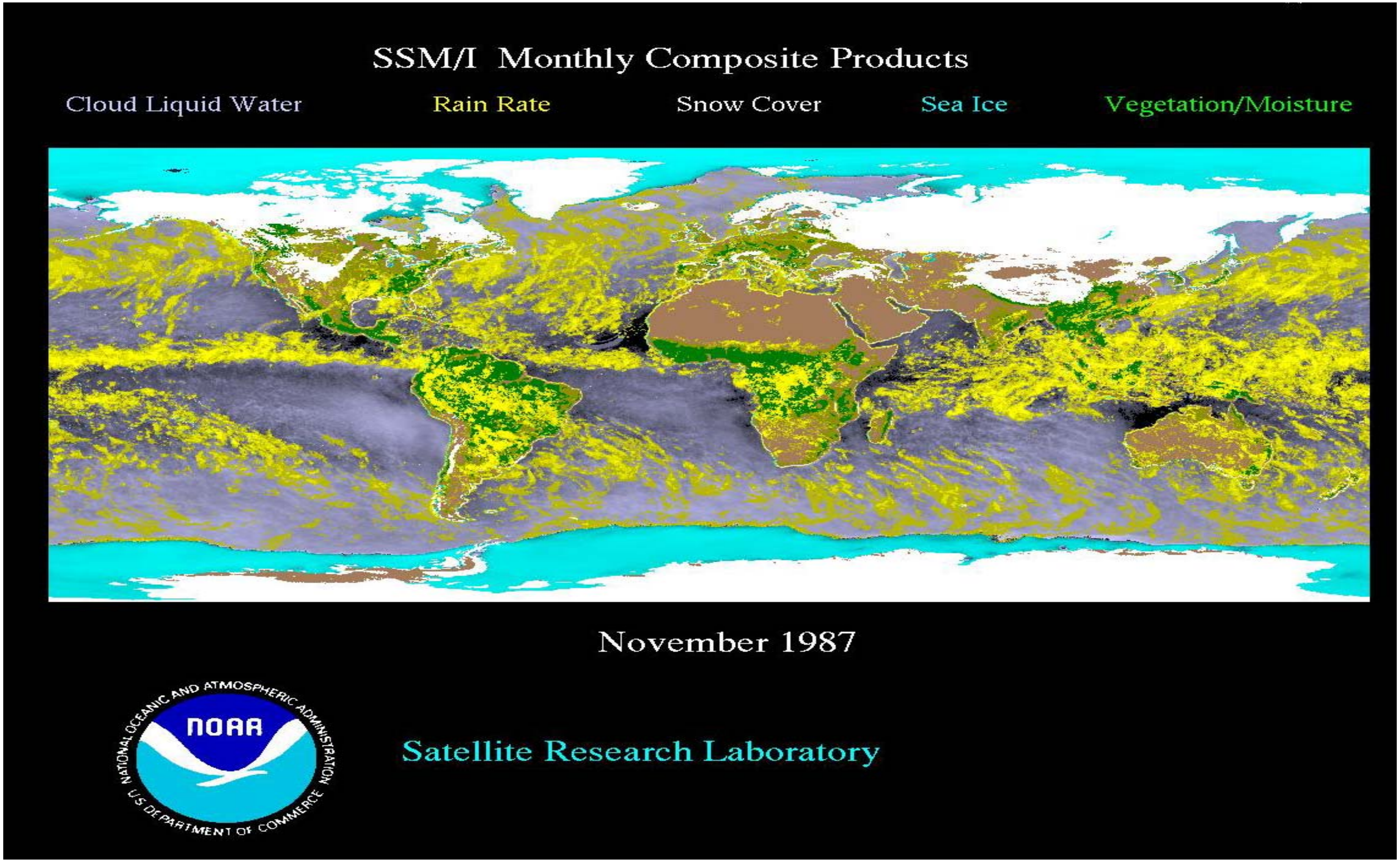
Climate Data Records





- •The program was initiated from NRC report and has been approved for FY06 fundng
- •FCDR and TCDR from SSM/I and SSMIS are identified as one of priorities
- •AO will be published in FFO
- •John Bates and Mitch Goldberg are leaders of the SDS program

NESDIS SSM/I Climate Data Records Began Since 1987



The SSM/I Time Series

- **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**

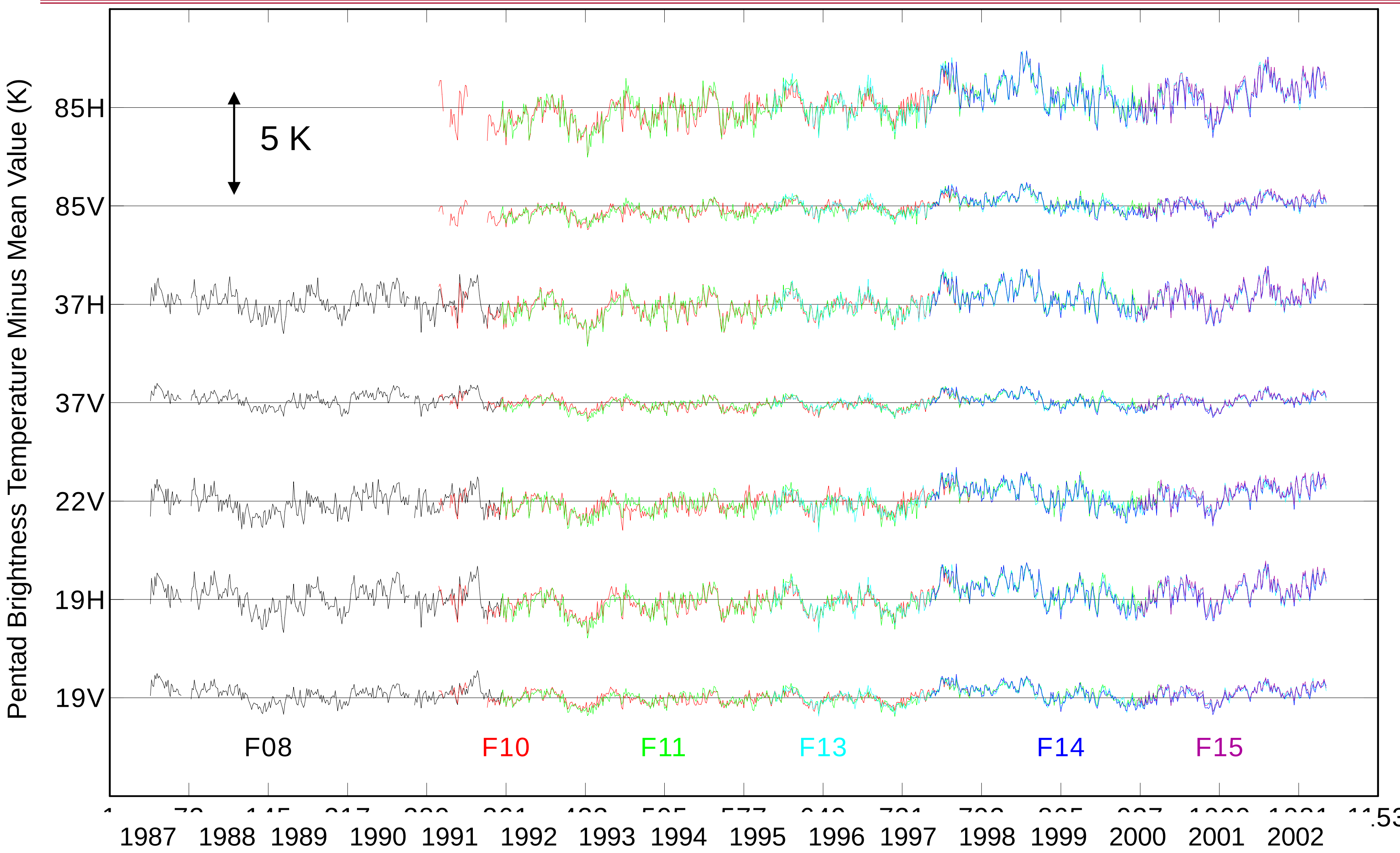
Month, Year	F8	F10	F11	F13	F14	F15	F16
1987	●	○	○	○	○	○	○
1988	●	○	○	○	○	○	○
1989	●	○	○	○	○	○	○
1990	●	○,●	○	○	○	○	○
1991	●	●	○,●	○	○	○	○
1992	○	●	●	○	○	○	○
1993	○	●	●	○	○	○	○
1994	○	●	●	○	○	○	○
1995	○	●	●	○,●	○	○	○
1996	○	●	●	●	○	○	○
1997	○	●	●	●	○,●	○	○
1998	○	○	●	●	●	○	○
1999	○	○	●	●	●	○,●	○
2000	○	○	●	●	●	●	○
2001	○	○	○	●	●	●	○
2002	○	○	○	●	●	●	○
2003	○	○	○	●	●	●	○,●
2004	○	○	○	●	●	●	●
2005	○	○	○	●	●	●	●
~07/2006	○	○	○	●	●	●	●

SSM/I TDR Data Rescue Status (1987~present)

	F8	F10	F11	F13	F14	F15	F16
1987	● (pink)						
1988	● (green)						
1989	● (green)						
1990	● (green)	● (green)					
1991	● (pink)	● (green)	● (green)				
1992		● (green)	● (green)				
1993		● (pink)	● (pink)				
1994		● (green)	● (green)				
1995		● (green)	● (pink)	● (green)			
1996		● (green)	● (pink)	● (green)			
1997		● (green)	● (green)	● (green)	● (green)		
1998			● (green)	● (green)	● (green)		
1999			● (green)	● (green)	● (green)	● (green)	
2000			● (green)	● (green)	● (green)	● (green)	
2001				● (green)	● (green)	● (green)	
2002				● (green)	● (green)	● (green)	
2003				● (green)	● (green)	● (green)	
2004				● (green)	● (green)	● (green)	
2005				● (green)	● (green)	● (green)	● (green)
2006				● (green)	● (green)	● (green)	● (green)

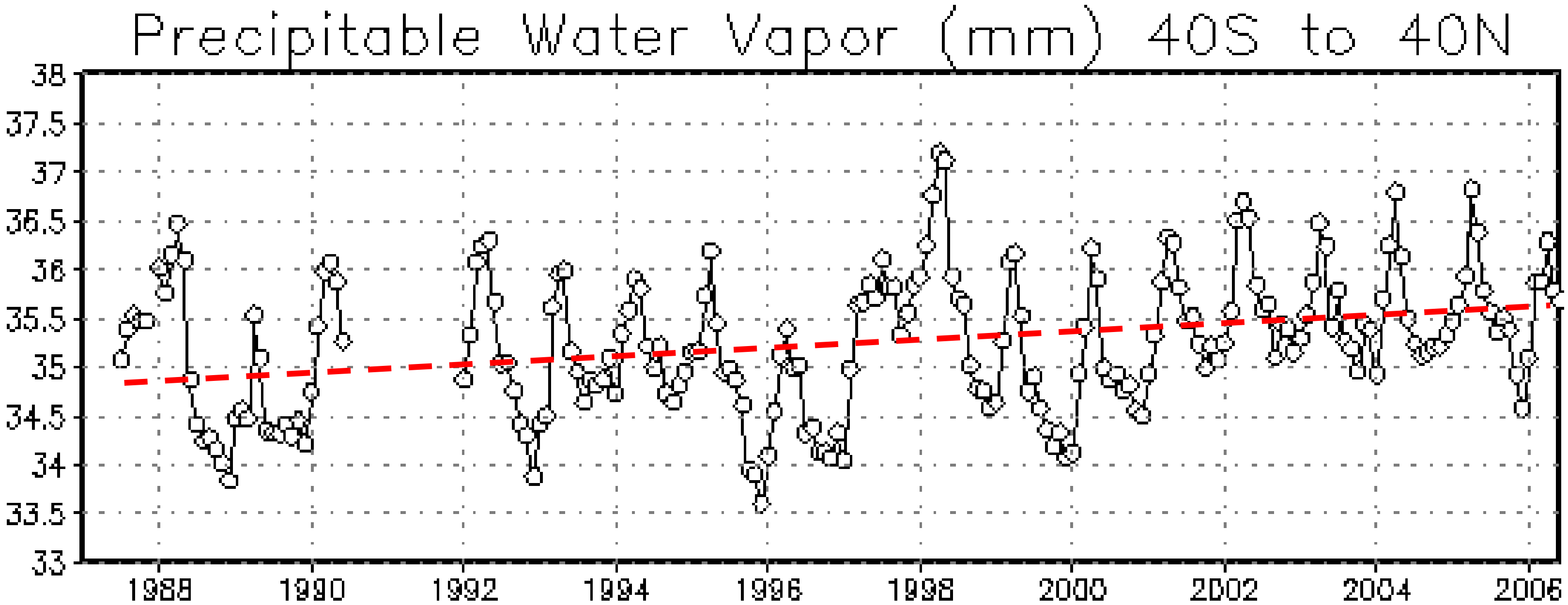
note: green means data complete for that year
pink means incomplete
blank means not in operation
F13,F14,F15 and F16 are complete.

SSM/I Brightness Temperature Time Series



(Wentz, 2006)

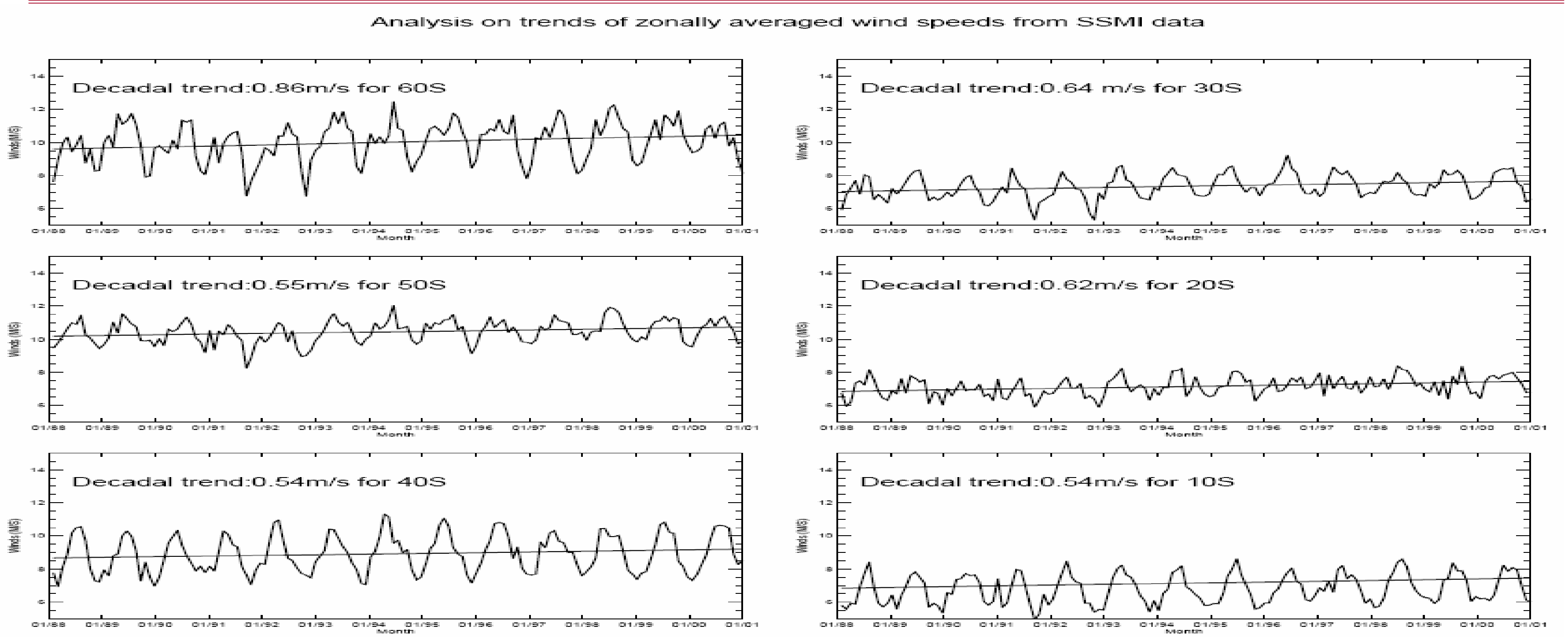
19 Years of SSM/I TPW



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?

19 Years of SSM/I Ocean Wind Speed



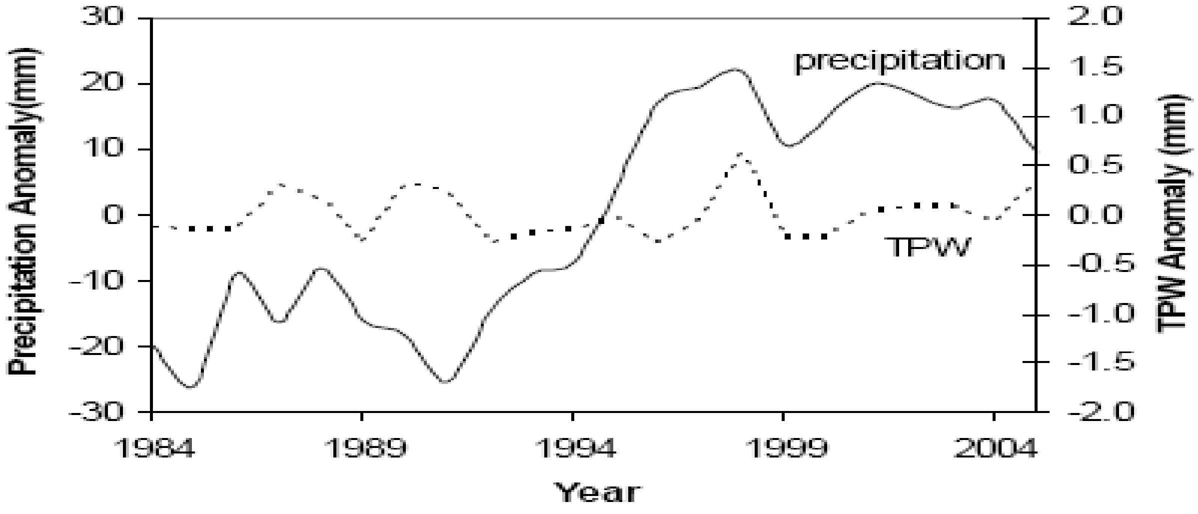
Tropical mean wind speed increases 0.5 m/s per decade. Is the recent increasing hurricane wind damage responding to this trend? How can we assure this trend not related to inter-satellite calibration and algorithms

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

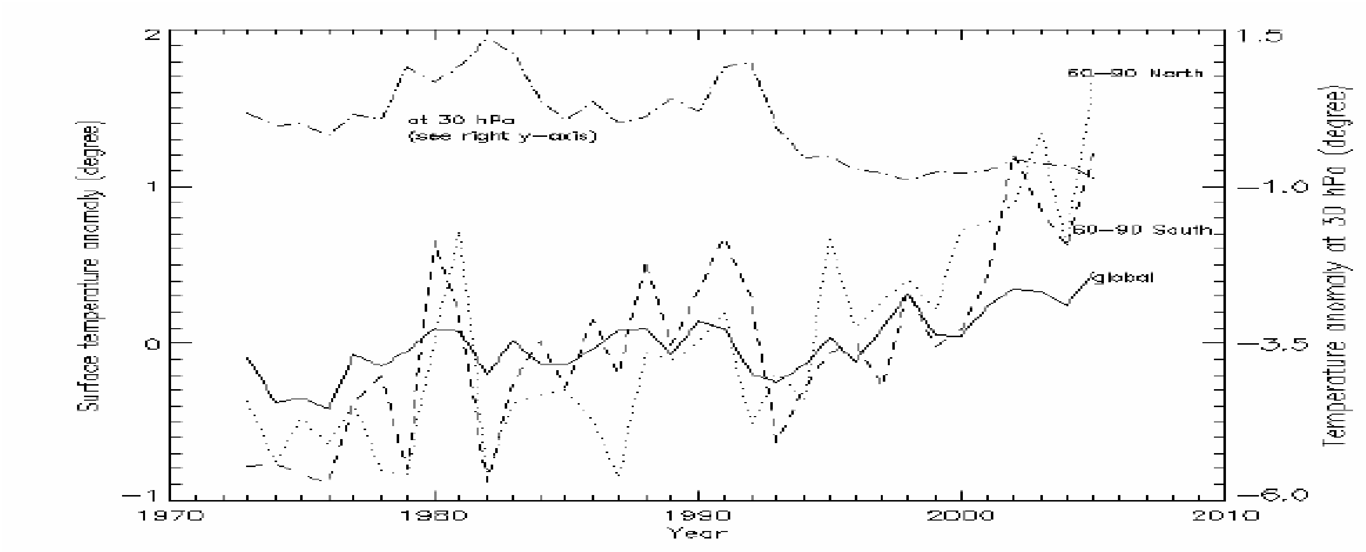
$$\frac{\partial W}{\partial T_b} = \frac{\partial W}{\partial \varepsilon} \frac{\partial \varepsilon}{\partial T_b} \approx \frac{1}{2.38 \times 10^{-3} (T_s - T_d)\tau}$$

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.

Trends from NCEP/NCAR Reanalysis

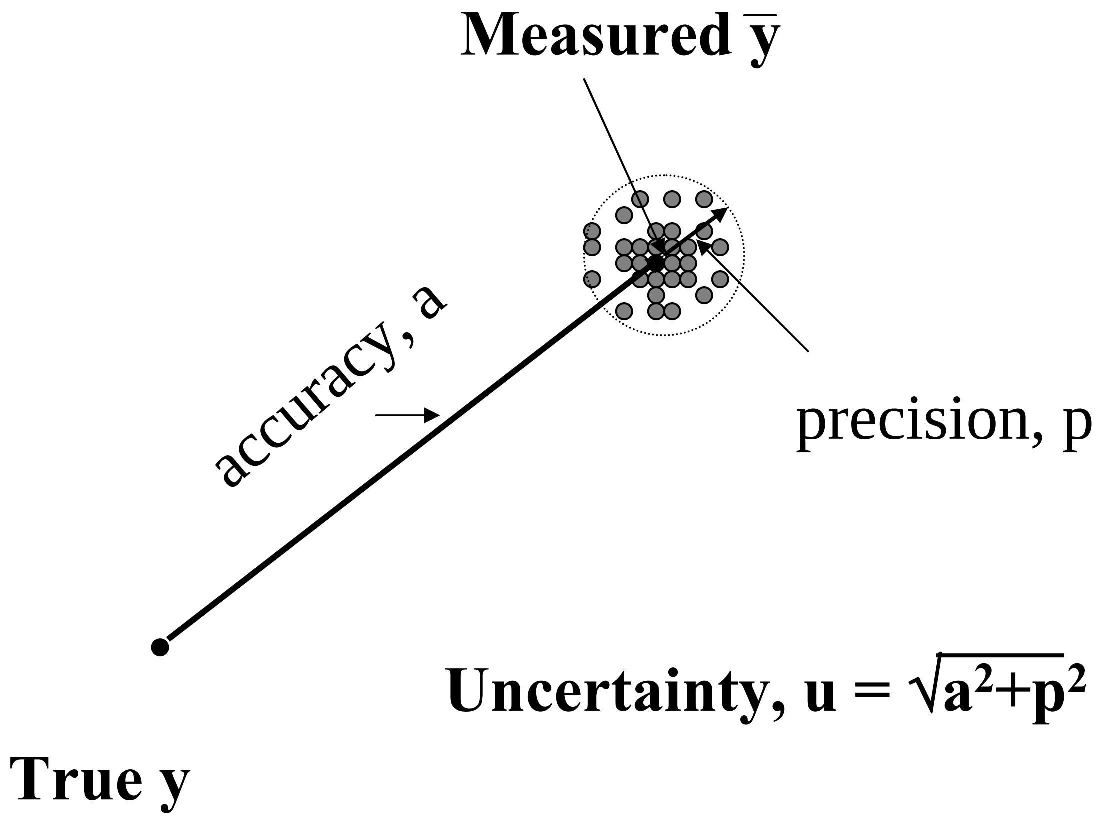


TPW/Precip



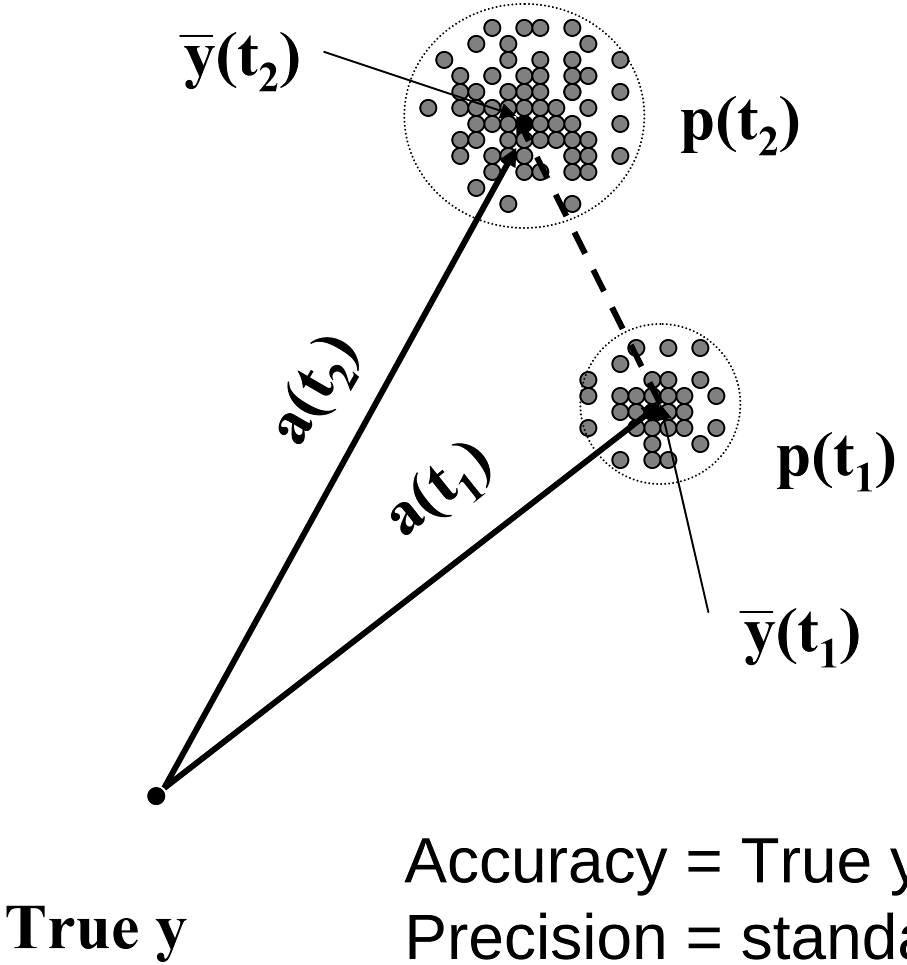
SST

Traits: Accuracy, Precision and Uncertainty (After Stephens)



Uncertainty, $u = \sqrt{a^2+p^2}$

Accuracy, Precision, Stability (after Stephens)

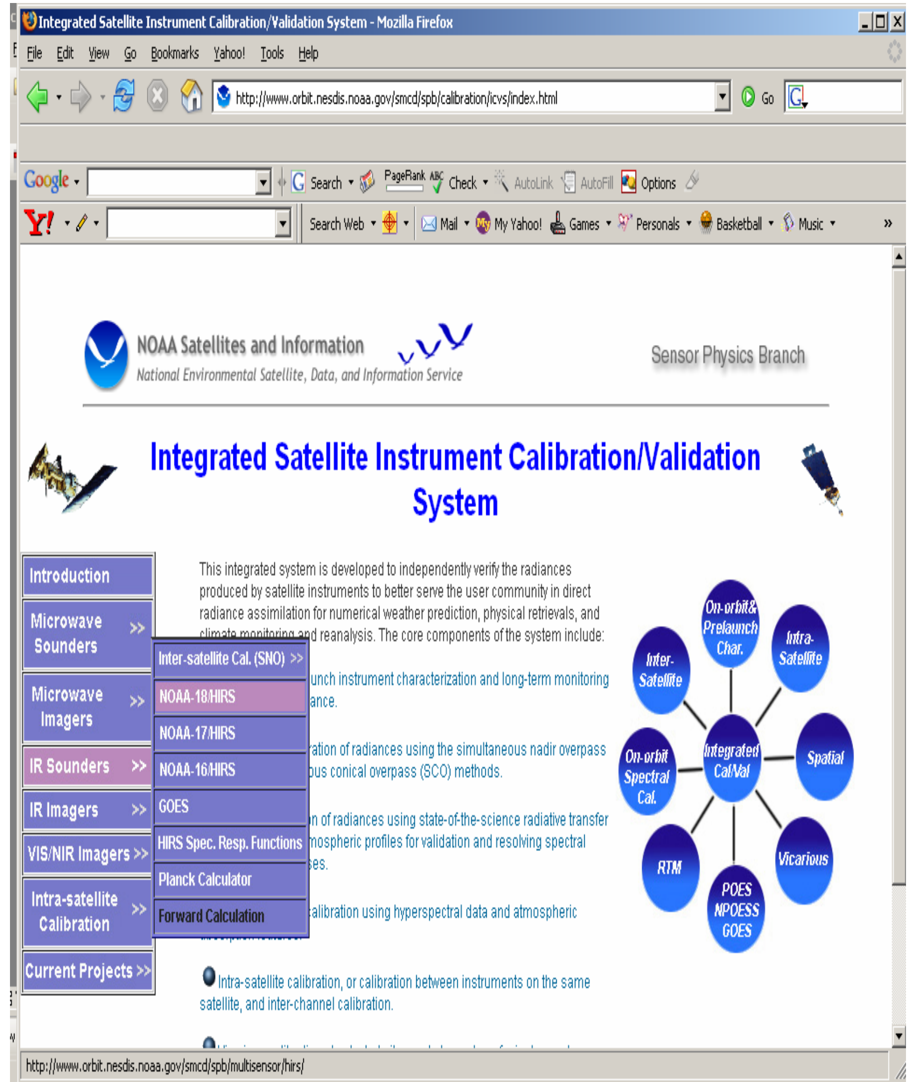


Accuracy = True y - mean y
Precision = standard deviation of y
Stability = change of accuracy with time

National Environmental Satellite, Data, and Information Service

NOAA Integrated Cal/Val System

- **Characterize the biases between instruments through inter-satellite and intra-satellite calibration, and rigorous forward modeling (RTM) with NWP model outputs**
- **Monitor and quantify instrument noise by analyzing calibration target and space view measurements (on-orbit & prelaunch)**
- **Monitor instrument performance stability and update calibration coefficients through vicarious calibration**
- **Monitor on-board calibration targets and eliminate anomalous signals from stray lights and other sources**
- **Quantify post-launch instrument spectral response function (on-orbit spectral)**
- **Validate against ground, ocean and aircraft observations**
- **Monitor the stability of intrument calibration accuracy**



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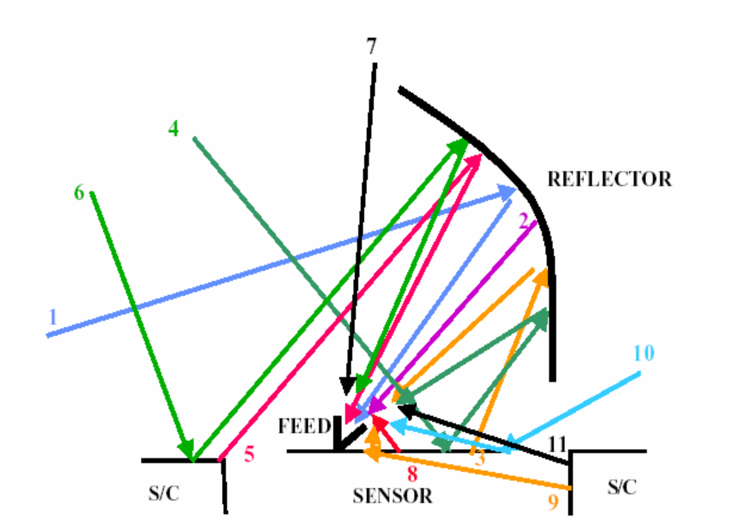
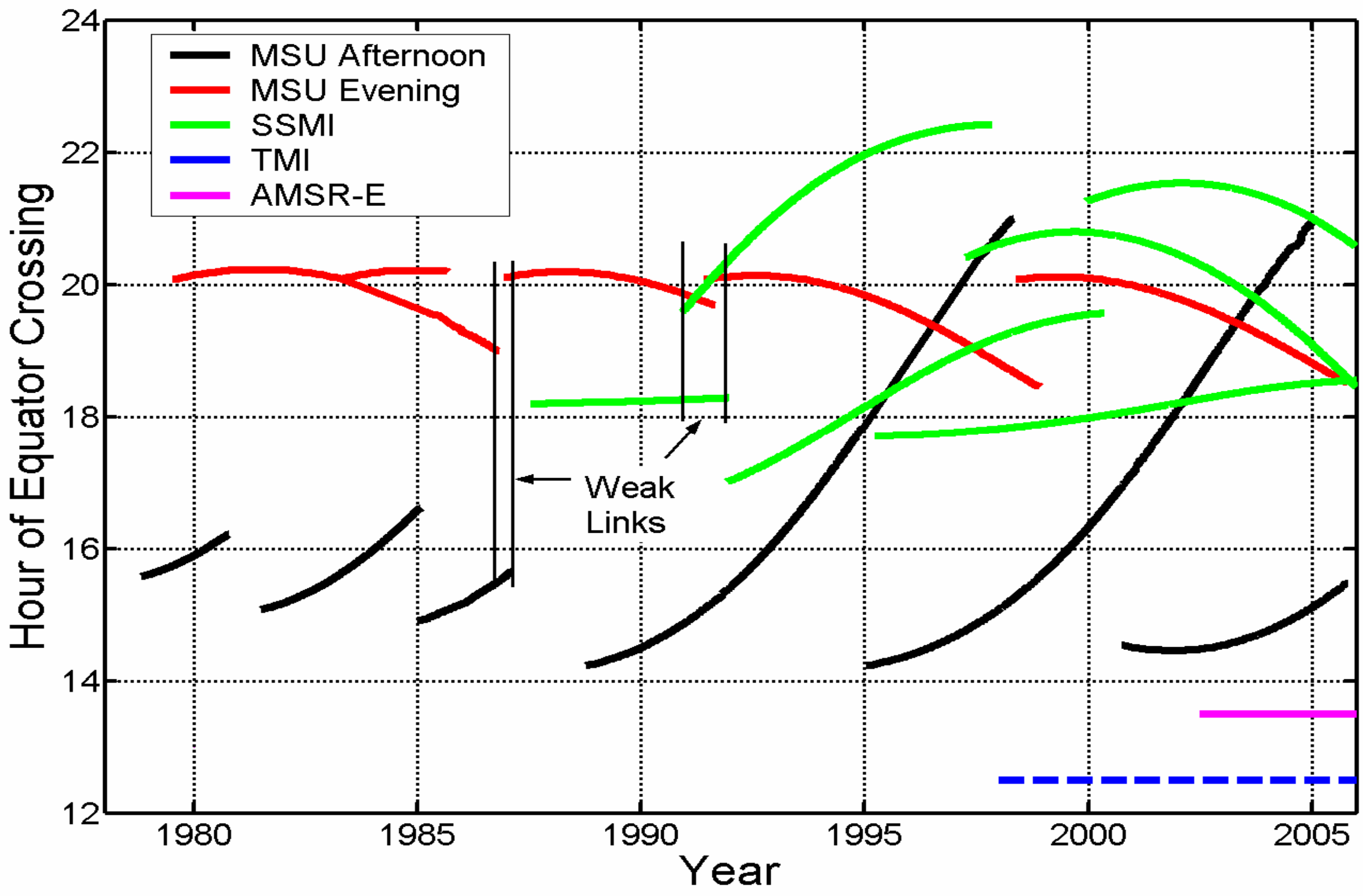
Microwave Instrument Calibration Components

Energy sources entering feed for a reflector configuration

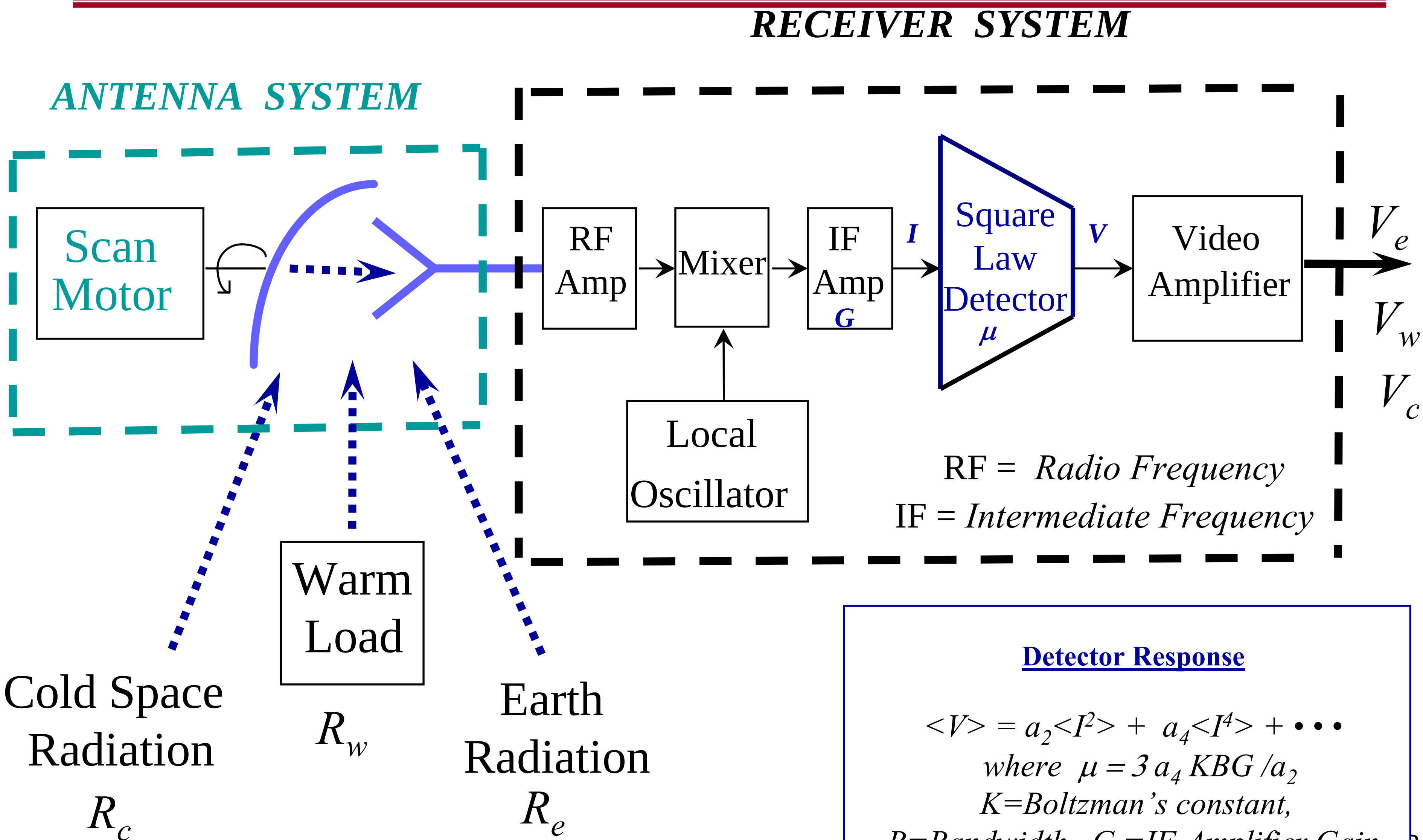
1. Earth scene Component,
2. Reflector emission
3. Sensor emission viewed through reflector,
4. Sensor reflection viewed through reflector,
5. Spacecraft emission viewed through reflector,
6. Spacecraft reflection viewed through reflector,
7. Spillover directly from space,
8. Spillover emission from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



Linking Together Multiple MW Instruments



Microwave Radiometer



Detector Response

$<V> = a_2<I^2> + a_4<I^4> + \cdots$

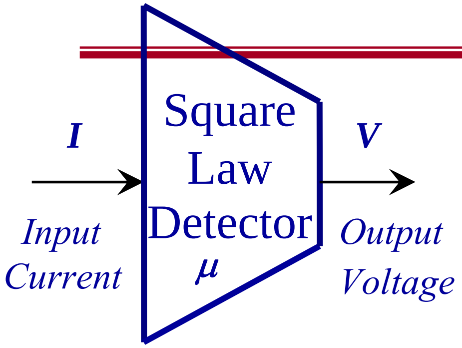
where $\mu = 3\,a_4\,KBG/a_2$

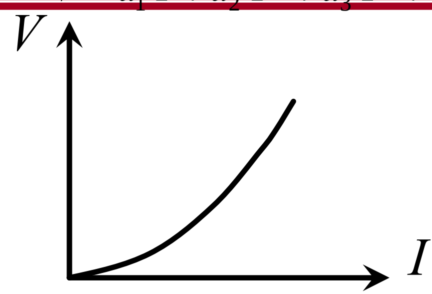
K=Boltzman's constant,

B=Bandwidth, G =IF-Amplifier Gain

Example: Non-Linear Calibration

$$V = a_1 I + a_2 I^2 + a_3 I^3 + a_4 I^4 + \cdots$$





K=Boltzman's constant
G=Amplifier gain, B=Bandwidth
T=Amplifier temperature, T_e *= Radiometric temperature*

$$b_o = [a_2 + 3a_4 KBGT]\, KBGT \qquad b_1 = [a_2 + 6a_4 KBGT]\, KBG$$

$$\mu = 3a_4 \frac{KBG}{a_2 + 6a_4 KGBT} \quad (nonlinear\ parameter)$$

Time-averaged voltage :

$$\langle V \rangle \cong \left(a_2 + 3a_4 \langle I^2 \rangle \right) \langle I^2 \rangle \qquad [1]$$

Nyquist theorem :

$$\langle I^2 \rangle = KBG\left[R(T_A) + R(T)\right] \qquad [2]$$

Combining [1] and [2] :

$$\langle V \rangle = b_o + b_1\, R(T_A)\left[1 + \mu R(T_A)\right] \qquad [3]$$

Two-point radiometer calibration eliminates b_o **and** b_1 **from <V> *(output in counts)* so that**

$$R_A = R_C + S(C_A - C_C) + \mu S^2 (C_A - C_C)(C_A - C_W)$$

At microwave region: $T_A = T_C + S(C_A - C_C) + \mu S^2 (C_A - C_C)(C_A - C_W)$

Linear and Non-linear Calibration

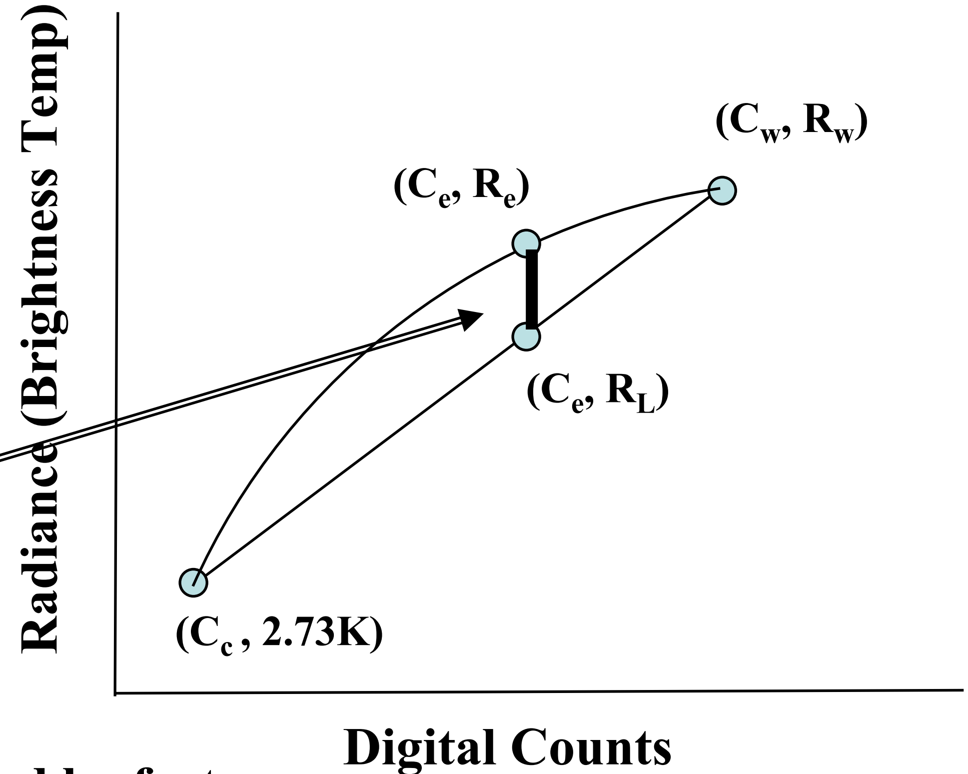
Two Point Radiometer Linear Calibration:

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

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

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

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

Calibration Issues for MW Imager/Sounder

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 et al, ASIC3, 2006)

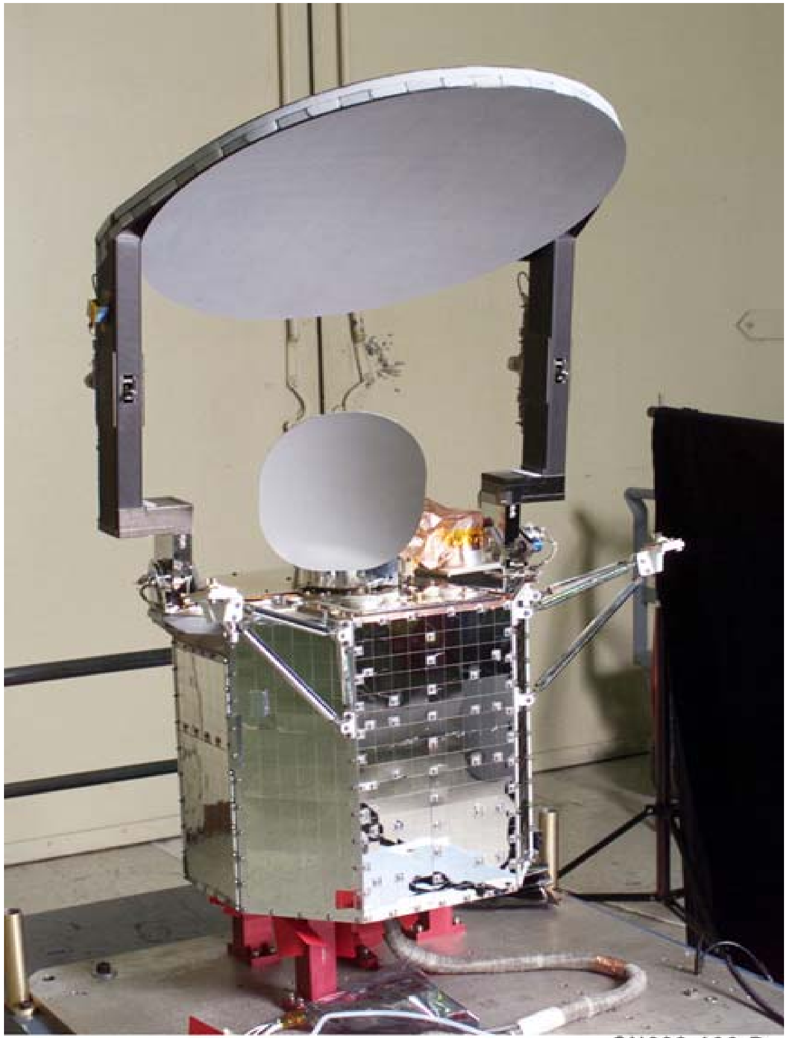
Major Impediments to Microwave Sensor Calibration

- Difficult to Correct for satellite orbit drift in trend analysis
- Calibration uncertainty from instrument non-linearity
- Anomalous emission from unknown targets
- Warm load instability and solar and stray slight contamination
- Difficult to characterize the radio frequency interference in particular wavelengths
- Pre-launch characterization, antenna patterns, brightness temperature standard, and well characterized target

(Weng et al, ASIC3, 2006)

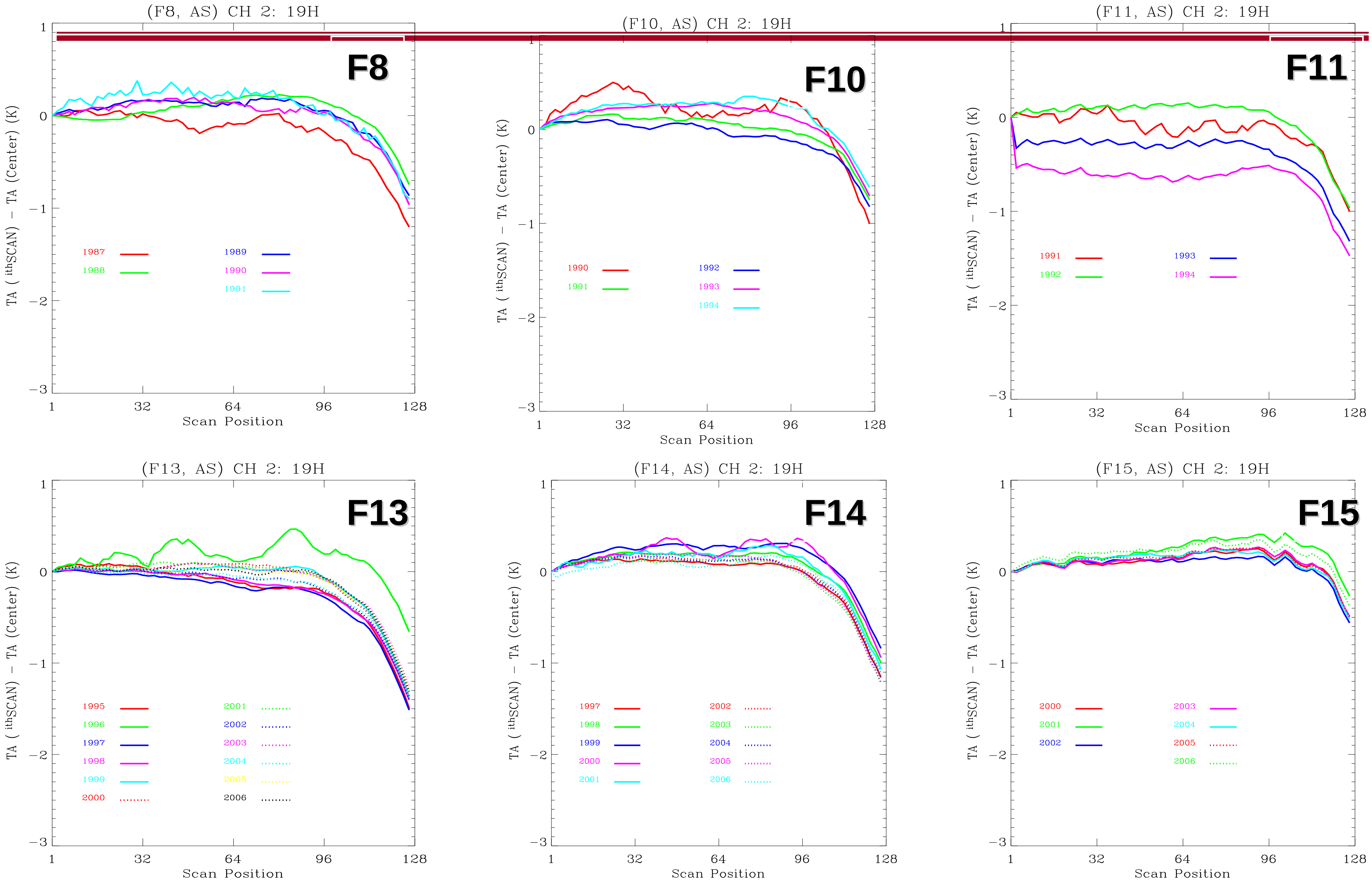
SSM/I and SSMIS Antenna Systems

- Main-reflector conically scans the earth scene
- Sub-reflector views cold space to provide one of two-point calibration measurements
- Warm loads are directly viewed by feedhorn to provide other measurements in two-point calibration system
- Warm load calibration is contaminated by solar and stray lights
- Lunar contamination on space view



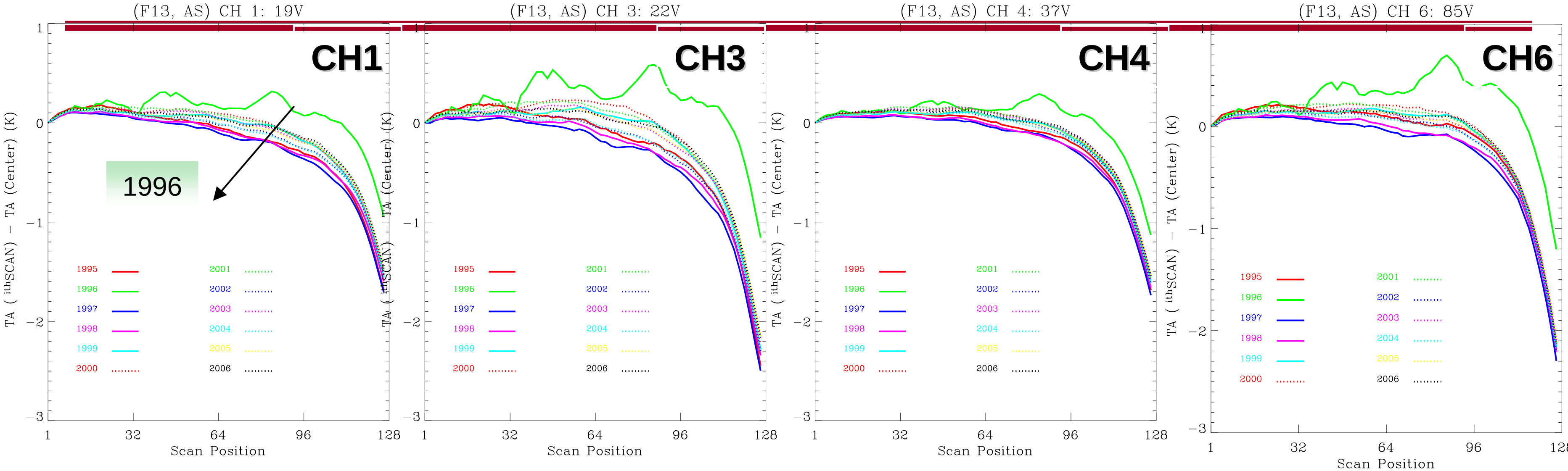
CN600-136-D

Scan Dependant Biases

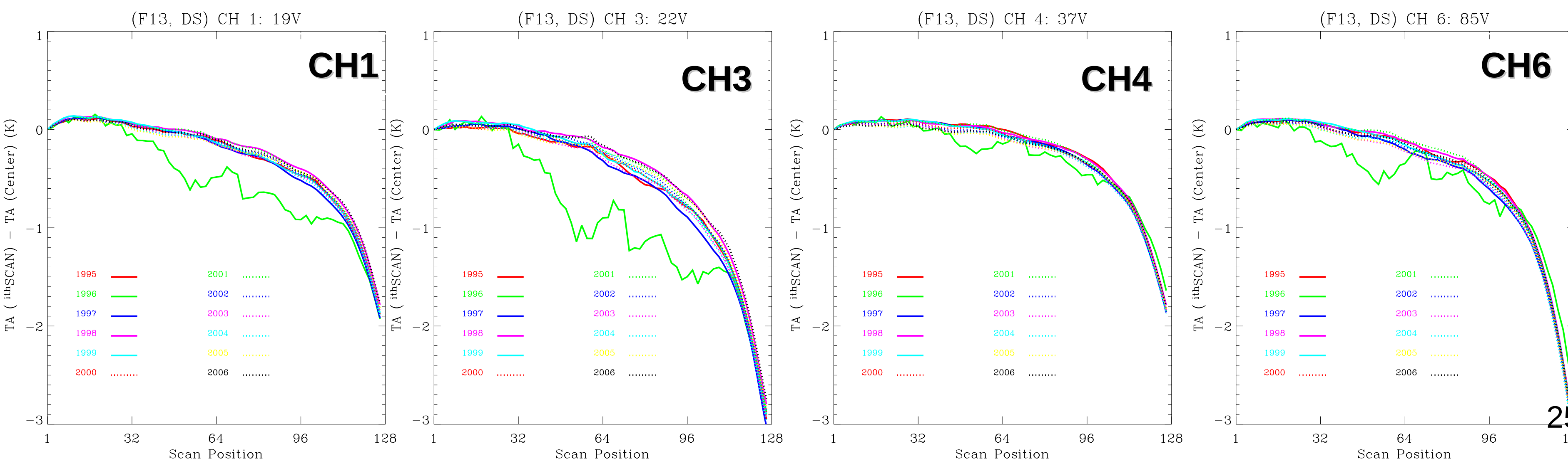


F13 Scan Dependant Biases

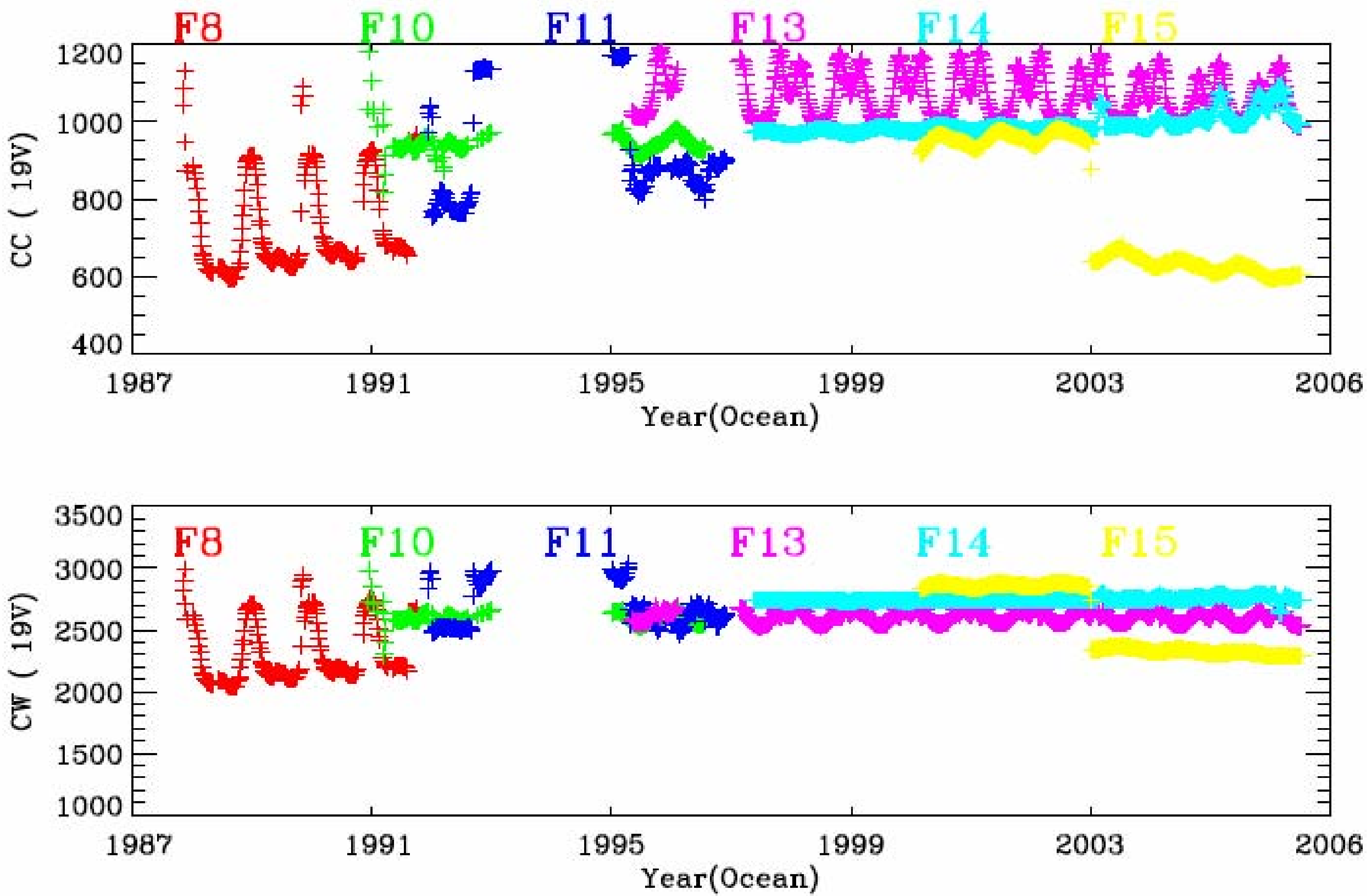
Ascending node:



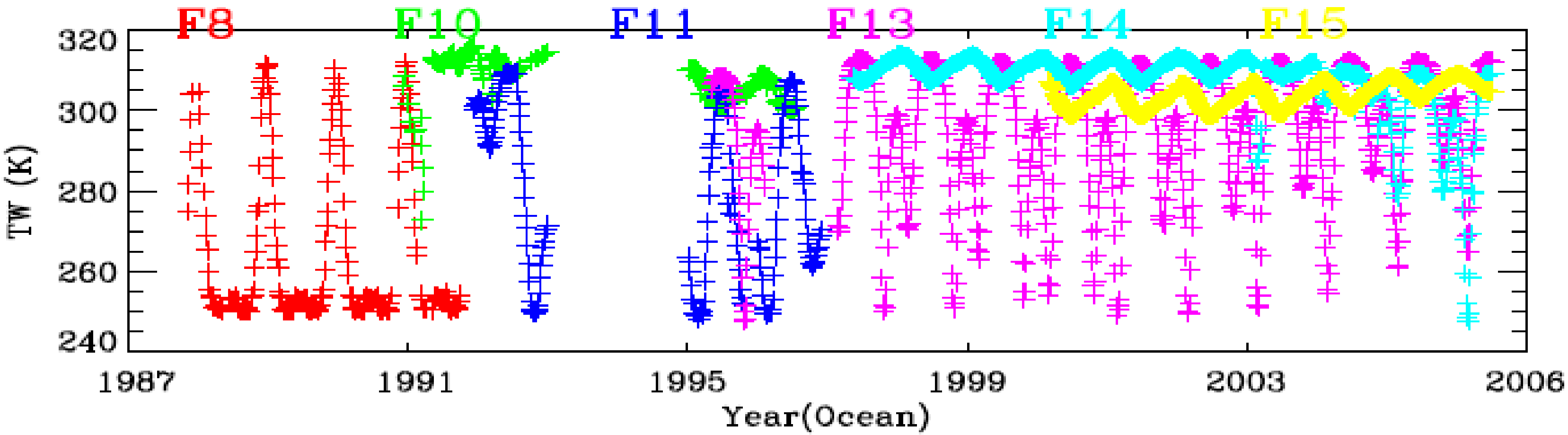
Descending node:

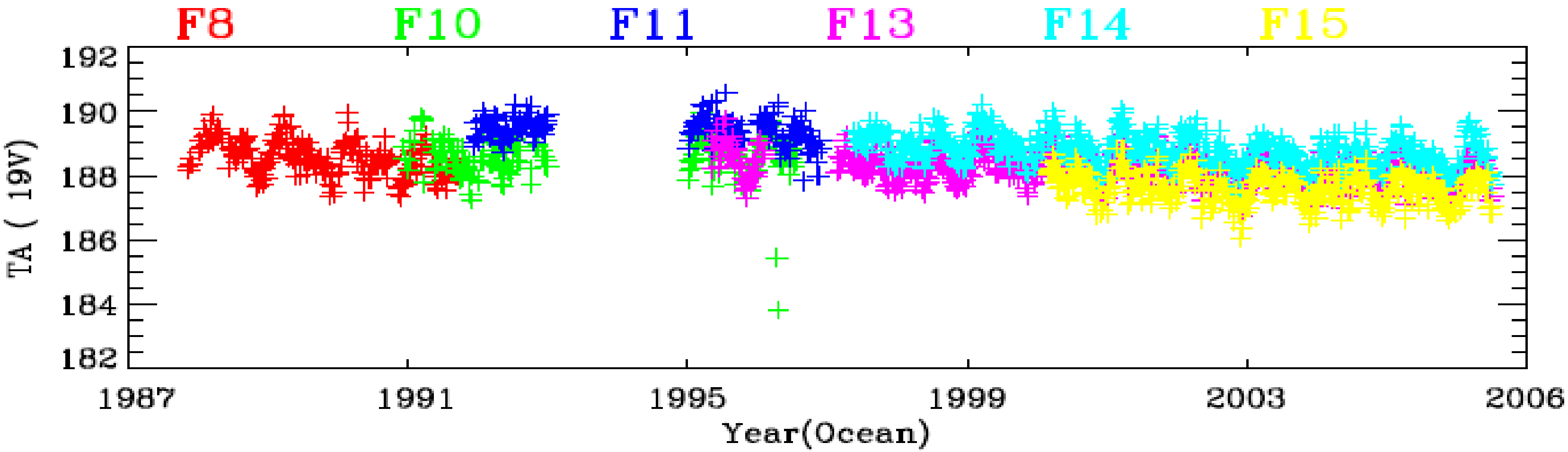


Cold and Warm Load Trend

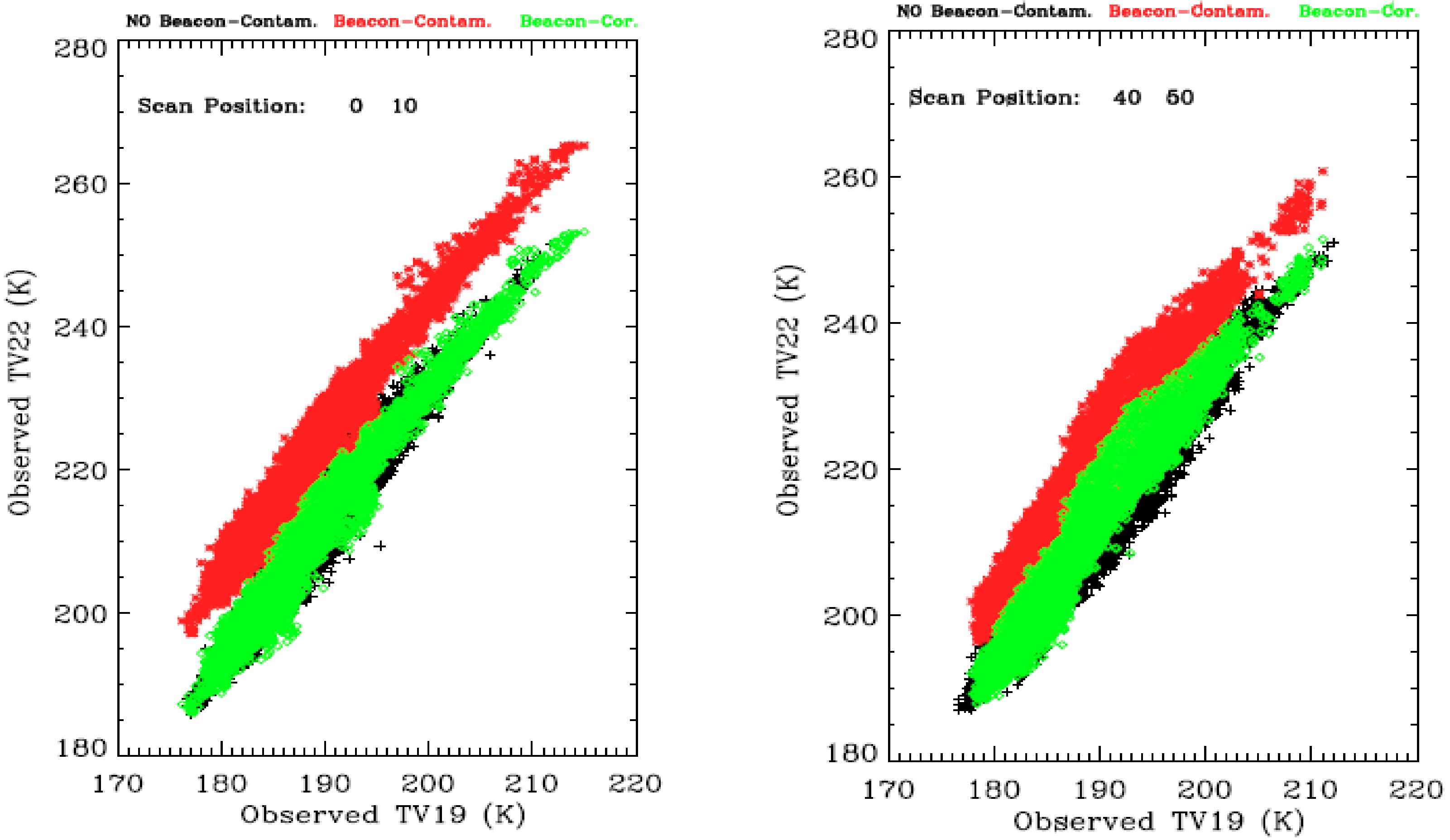


Platinum Resistance Thermometers (PRT) Trend

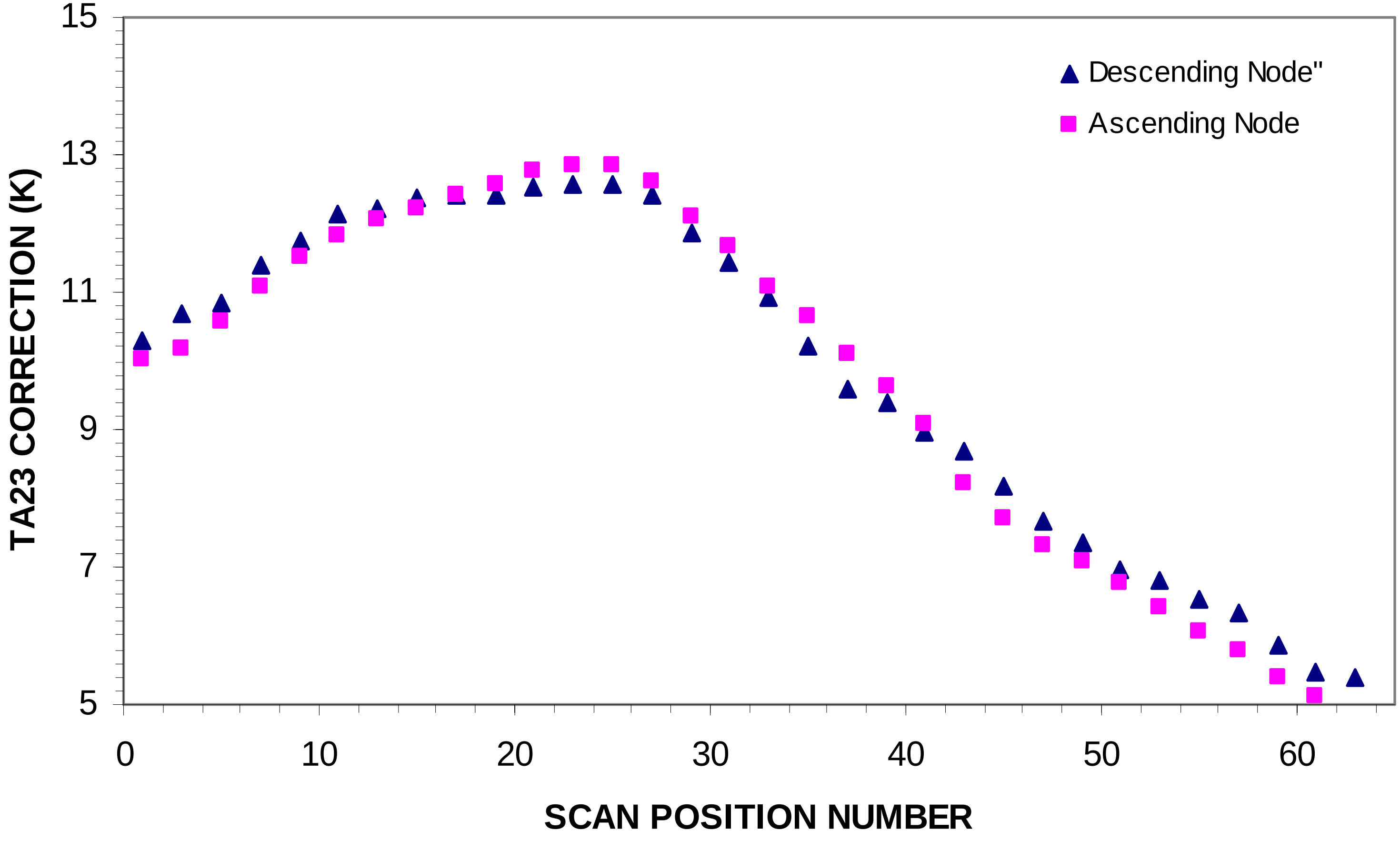




F15 SSM/I Radcal Beacon Interference

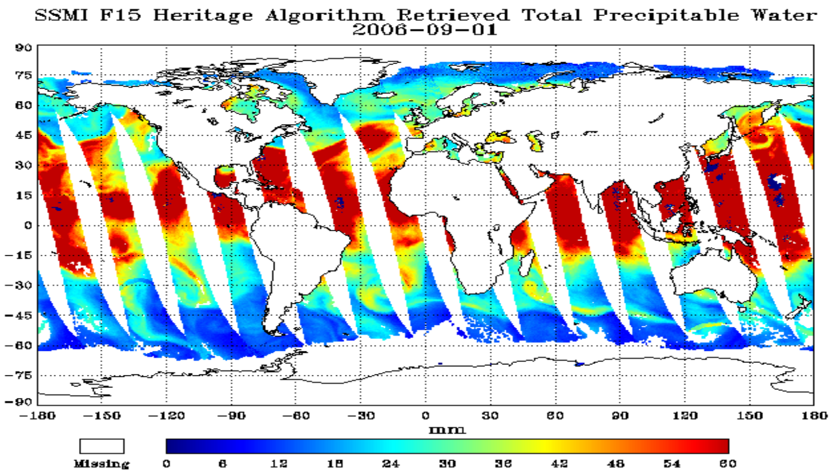


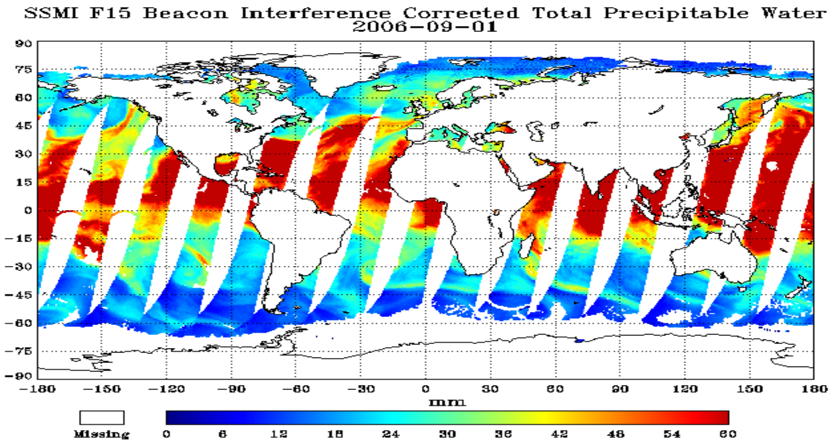
F15 SSM/I Radcal Beacon Interference



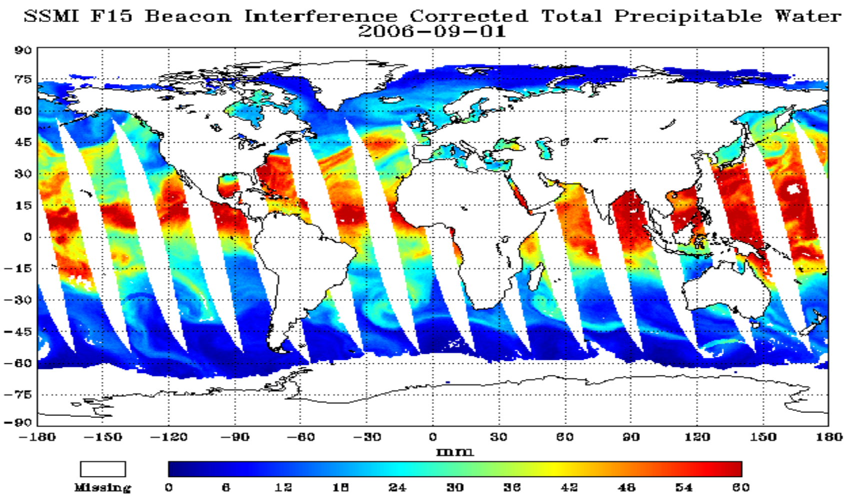
Total Precipitable Water (TPW) from F15 SSM/I

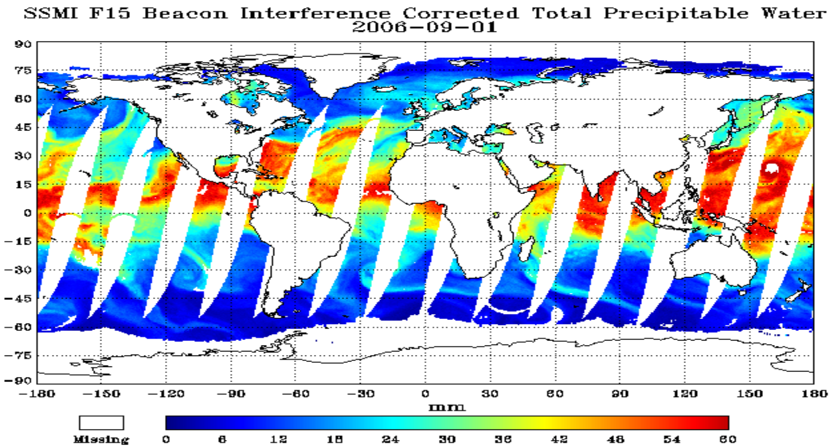
TPW (beacon signal contaminated)





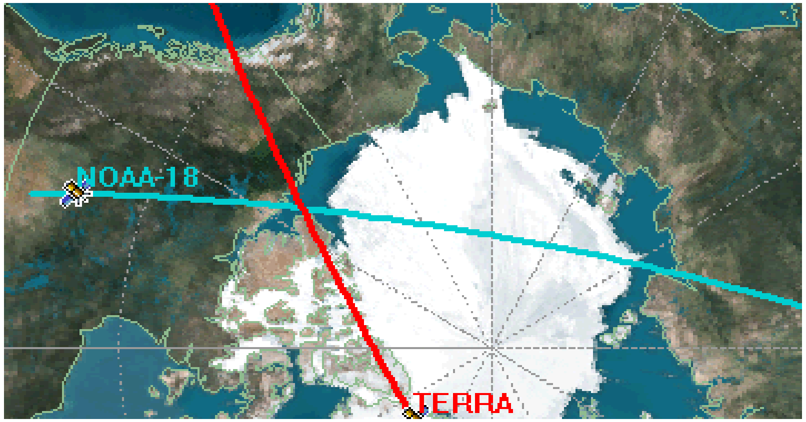
TPW (beacon signal removed)

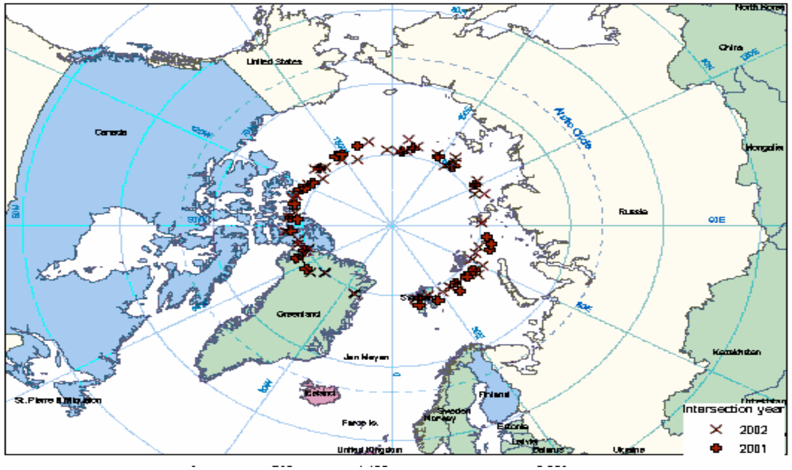




Intersatellite Calibration Using the Simultaneous Nadir Overpass (SNO) Method

- **SNO – every pair of POES satellites with different altitudes pass their orbital intersections within a few seconds regularly in the polar regions (predictable w/ SGP4)**
- **Precise coincidental pixel-by-pixel match-up data from radiometers provides reliable long-term monitoring of instrument performance**
- **The SNO method has been used for operational on-orbit longterm monitoring of AVHRR, HIRS, AMSU and for retrospective intersatellite calibration from 1980 to 2003 to support climate studies**
- **The method is expanded for SSMI with the Simultaneous Conical Overpass (SCO) method**





SNOs occur regularly in the +/- 70 to 80 latitude

Inter-satellite Calibration for SSM/I Data

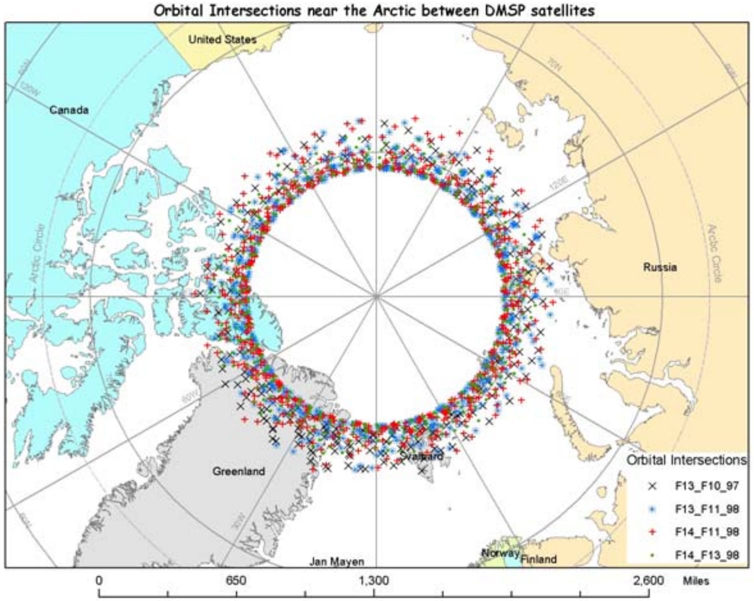
- Read and extract TDR data array
- Find the intersecting point when two pixels are within 12.5 km with a stand time difference < 60 degree
- Perform pixel-by-pixel match and image remapping for the mid-scan pixels with the same surface features
- Comparison of antenna temperatures with the mean for biases and standard deviation
- Produce plots showing time series of biases and regression line and mean antenna temperature for each SCO

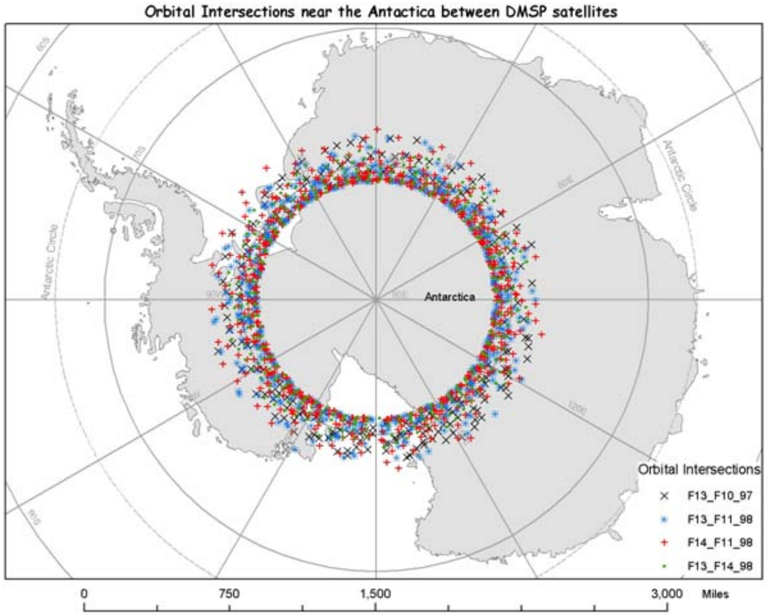
Frequency of Simultaneous Conical Overpasses

	Orbital Period (min)	Time between successive SCOs (Days) F-08	F-10	F-11	F-13	F-14	F-15
F-08	101.7062						
F-10	100.4645	5.7145					
F-11	101.8109	68.6968	5.2757				
F-13	101.8979	N/A	4.9597	82.8006			
F-14	101.8832	N/A	5.0102	99.5613	491.8503		
F-15	101.8061	N/A	N/A	1518.6125	78.5195	93.4356	
F-16	101.8833	40.6325	5.0099	99.4616	494.2989	99291.1703	93.4184

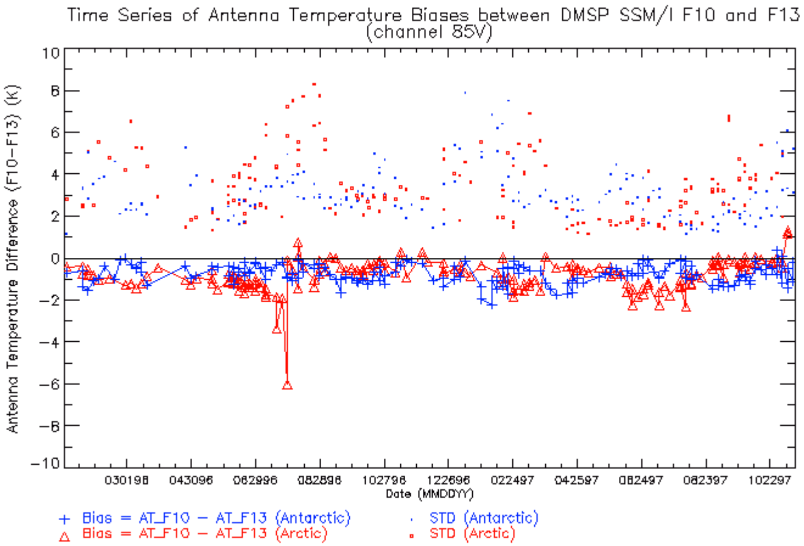
Note: Orbital periods derived from two-line-elements for December 15, 1999. except the TLE for F-16 was on Oct. 20, 2003.

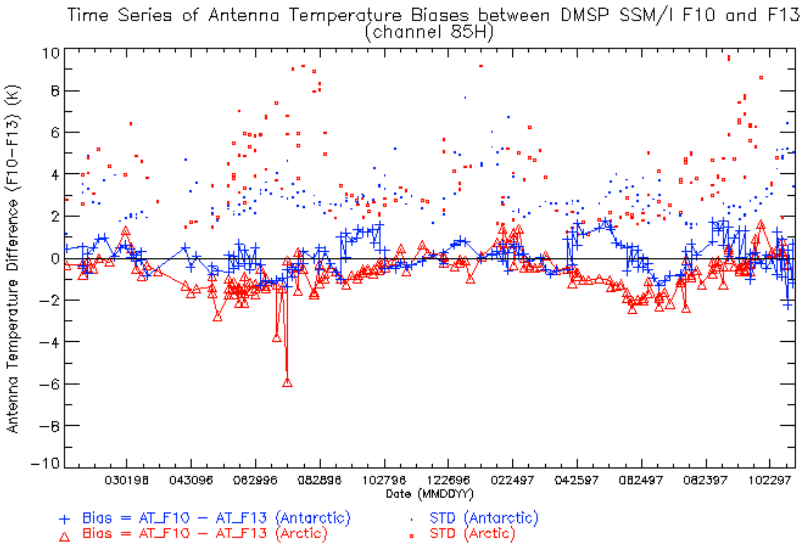
SSM/I SCO Distribution

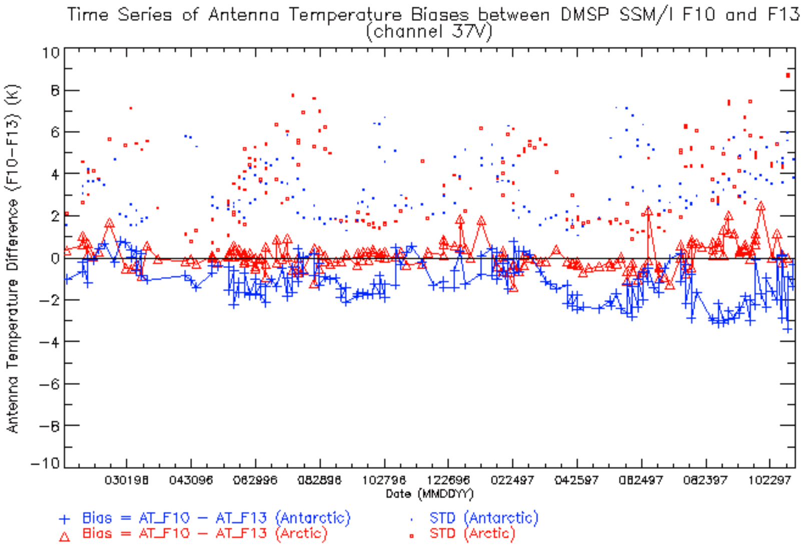


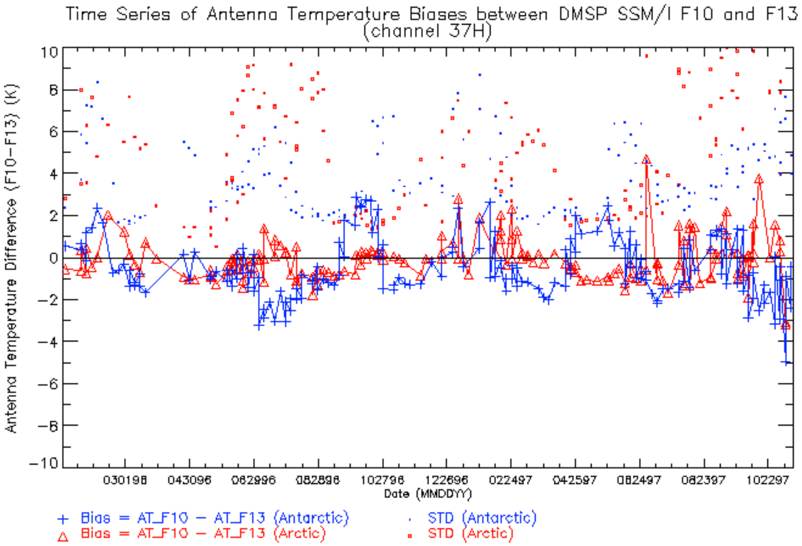


F-10 vs. F-13 SSM/I SCO Matching
(37- 85 GHz Channels)

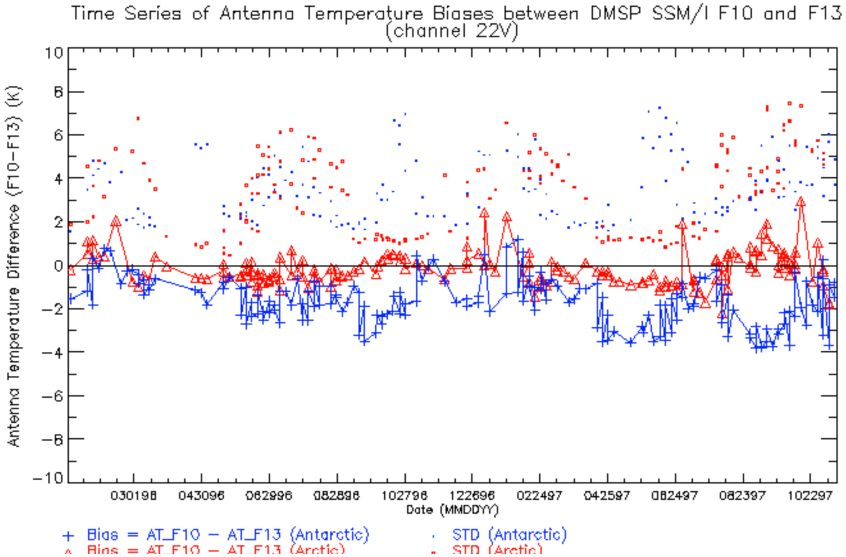


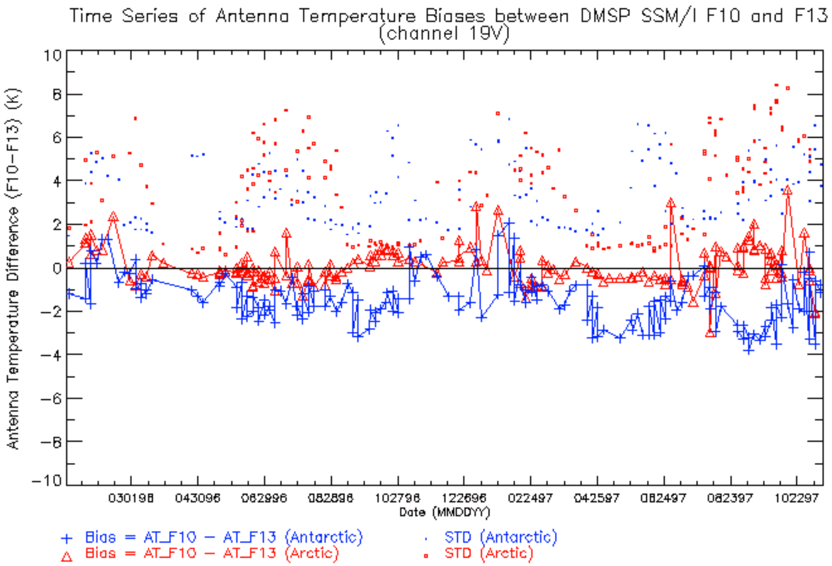


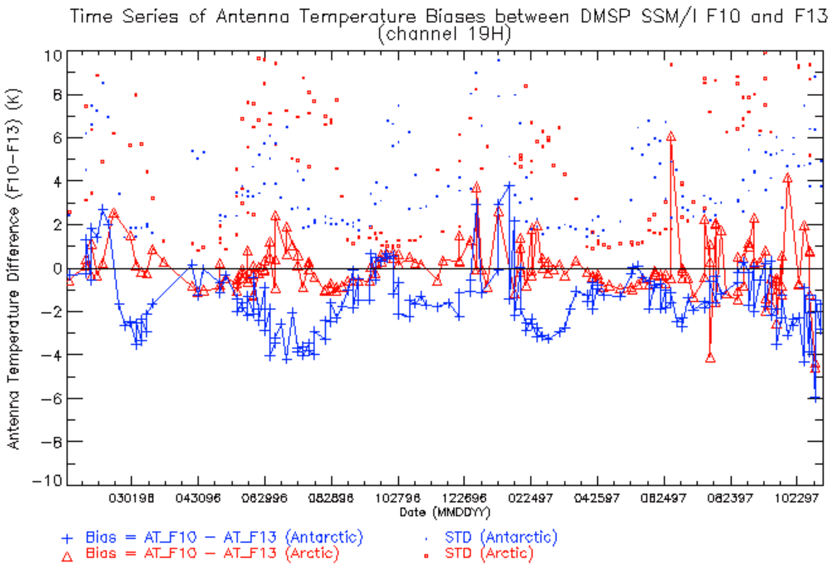




F-10 vs. F-13 SSM/I SCO Matching (19-22 GHz Channels)



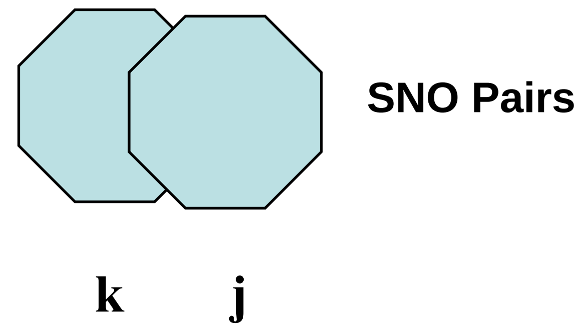




SNO Time Series Used for Deriving Intersatellite Bias and Nonlinearity

$$R_k = R_{L,k} - \delta R_k + \mu_k Z_k$$

$$R_j = R_{L,j} - \delta R_j + \mu_j Z_j$$



We would like to have zero bias between two satellites, $R_k = R_j$

$$\Delta R_L = \Delta \delta R - \mu_k Z_k + \mu_j Z_j$$

For many pairs of SNO, multivariable linear regression will resolve $\Delta\delta R$ *(intersallite bias)*, μ_k and μ_j (non-linearity parameters for k, j satellites, respectively

(Zou et al, 2006, JGR)

SSM/I Algorithms for Non-Linearity

Non-linear calibration:

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

Simultaneous conical overpass:

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

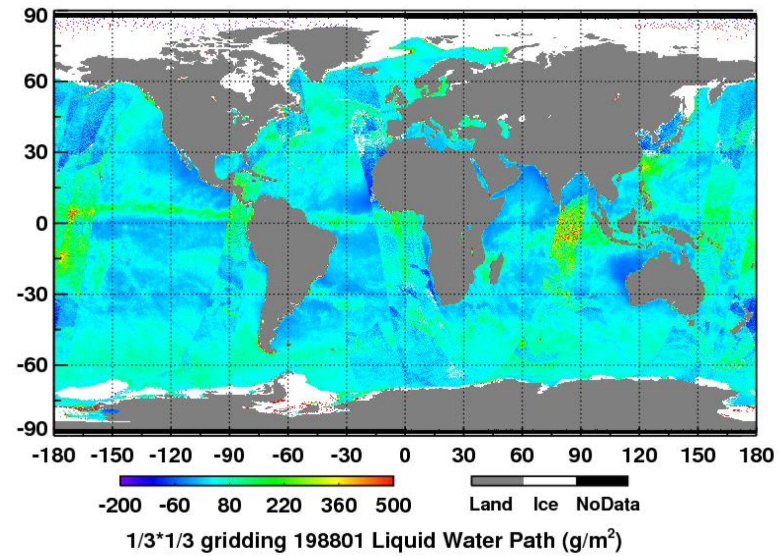
North and South Pole matching:

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

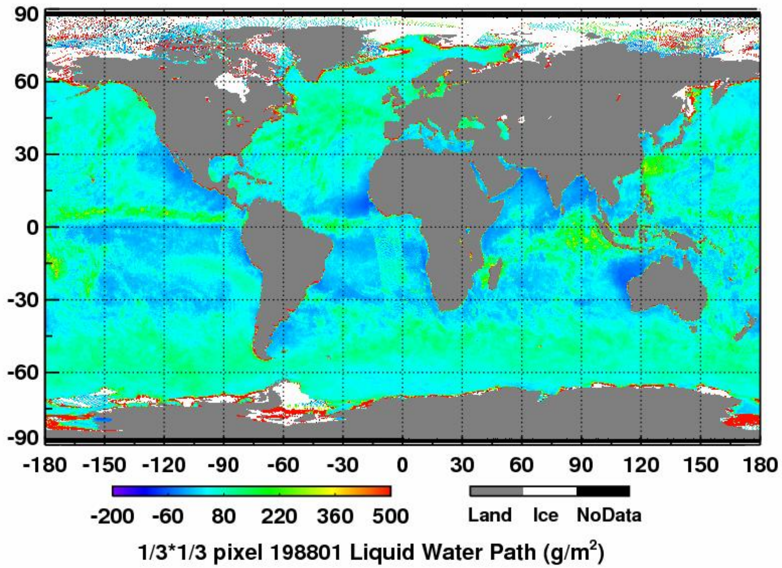
$$\mu_j Z_{j,S} - \mu_k Z_{k,S} = \Delta T_{L,S}(j,k)$$

Impacts of SSMIS Data Bit Accuracy

Single Byte Retrieval



Two Bytes Retrieval

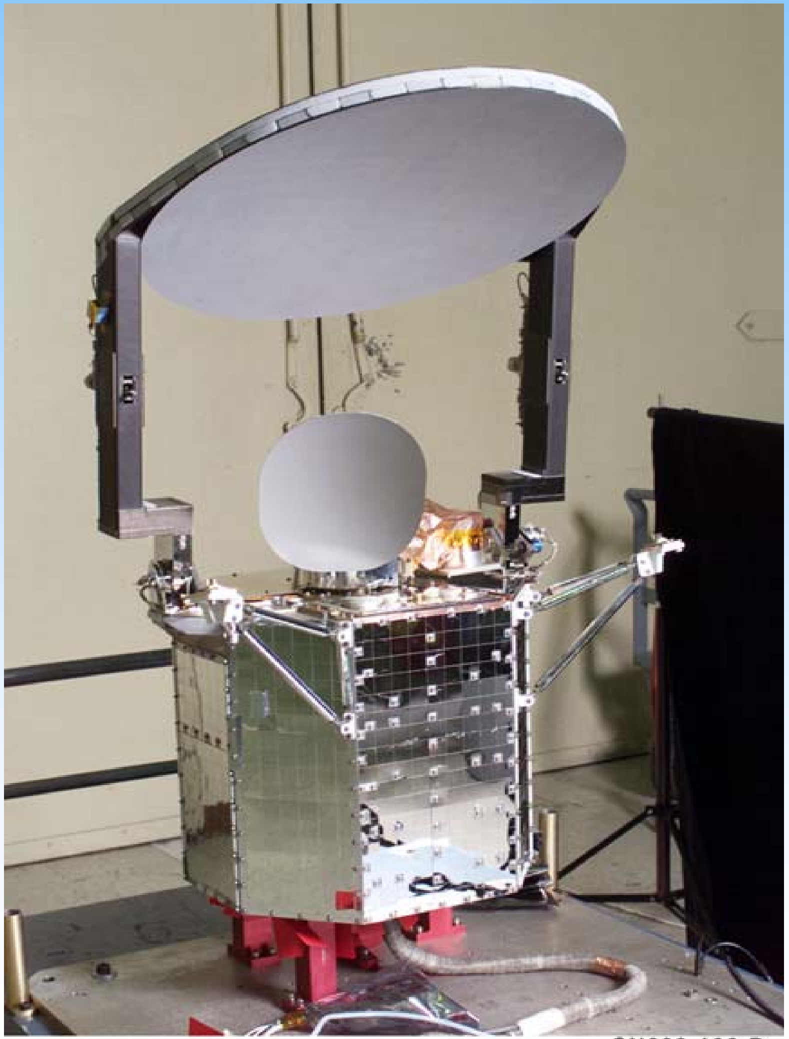


Major SSM/I Calibration Issues

- Scan dependent biases: rapid fall-off near end of scan within 3 K,
- Sensor to sensor variation in calibration information (e.g., RF gain, count range…),
- Some possible trends in calibration targets,
- Improper on-board averaging of calibration information (e.g. PRT averaging),
- No nonlinearity term in calibration process,
- Known and unknown contamination processes: radcal beacon interference (RFI), solar intrusion to warm load

SSMIS Antenna System and Calibration

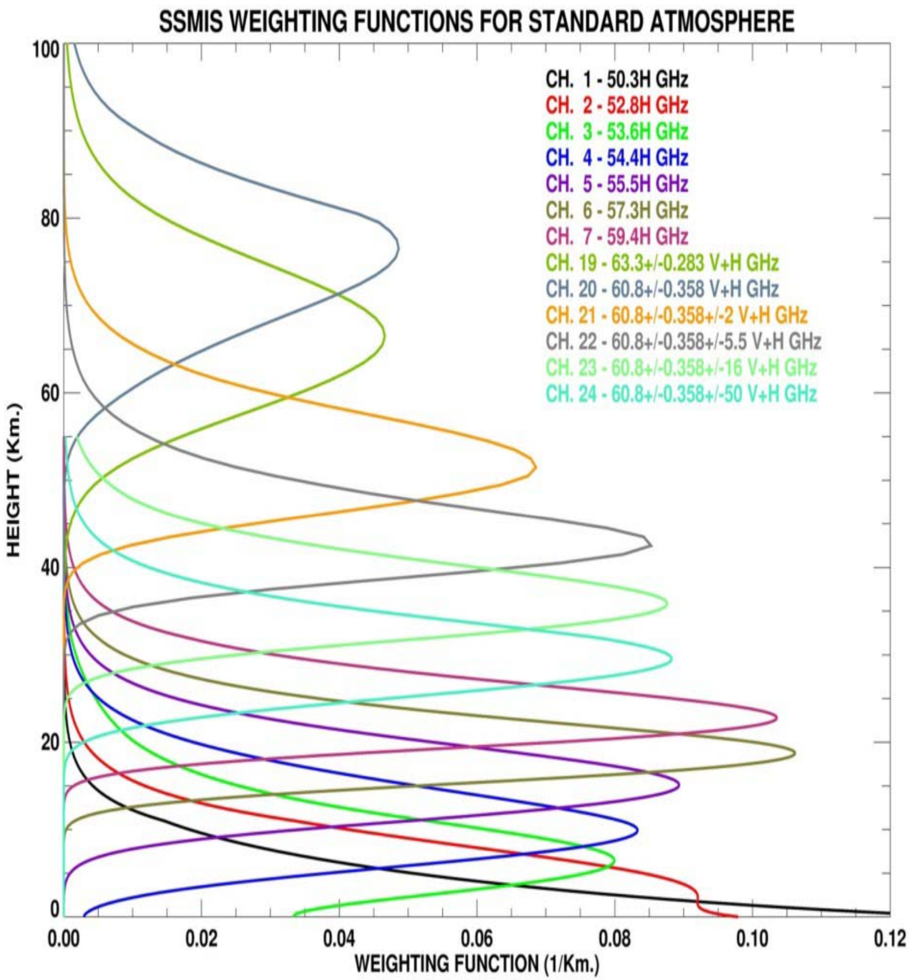
- **Main-reflector conically scans the earth scene**
- **Sub-reflector views cold space to provide one of two-point calibration measurements**
- **Warm loads are directly viewed by feedhorn to provide other measurements in two-point calibration system**
- **The SSMIS main reflector emits radiation from its coating material**
  - **SiOx VDA (coated vapor-deposited aluminum)**
  - **SiOx and Al VDA Mixture**
  - ***Graphite Epoxy***
- **Warm load calibration is contaminated by solar and stray Lights**
  - **Reflection Off of the Canister Top into Warm Load**
  - **Direct Illumination of the Warm Load Tines**
- **Lunar contamination on space view**



CN600-136-D

National Environmental Satellite, Data, and Information Service

SSMIS Provides Sounding at Higher Altitudes



SSMIS vs. AMSU-A
Weighting Functions
Oxygen Band Channels

SSMIS 13 Channels Sfc – 80 km

AMSU-A 13 Channels Sfc - 40 km

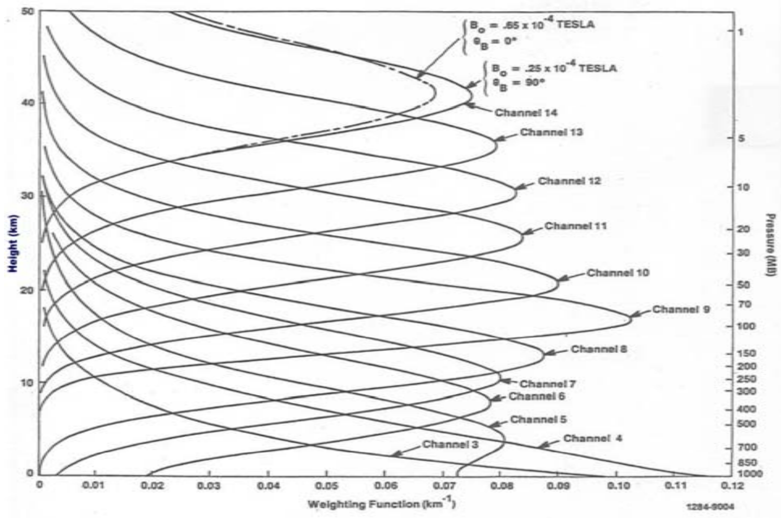
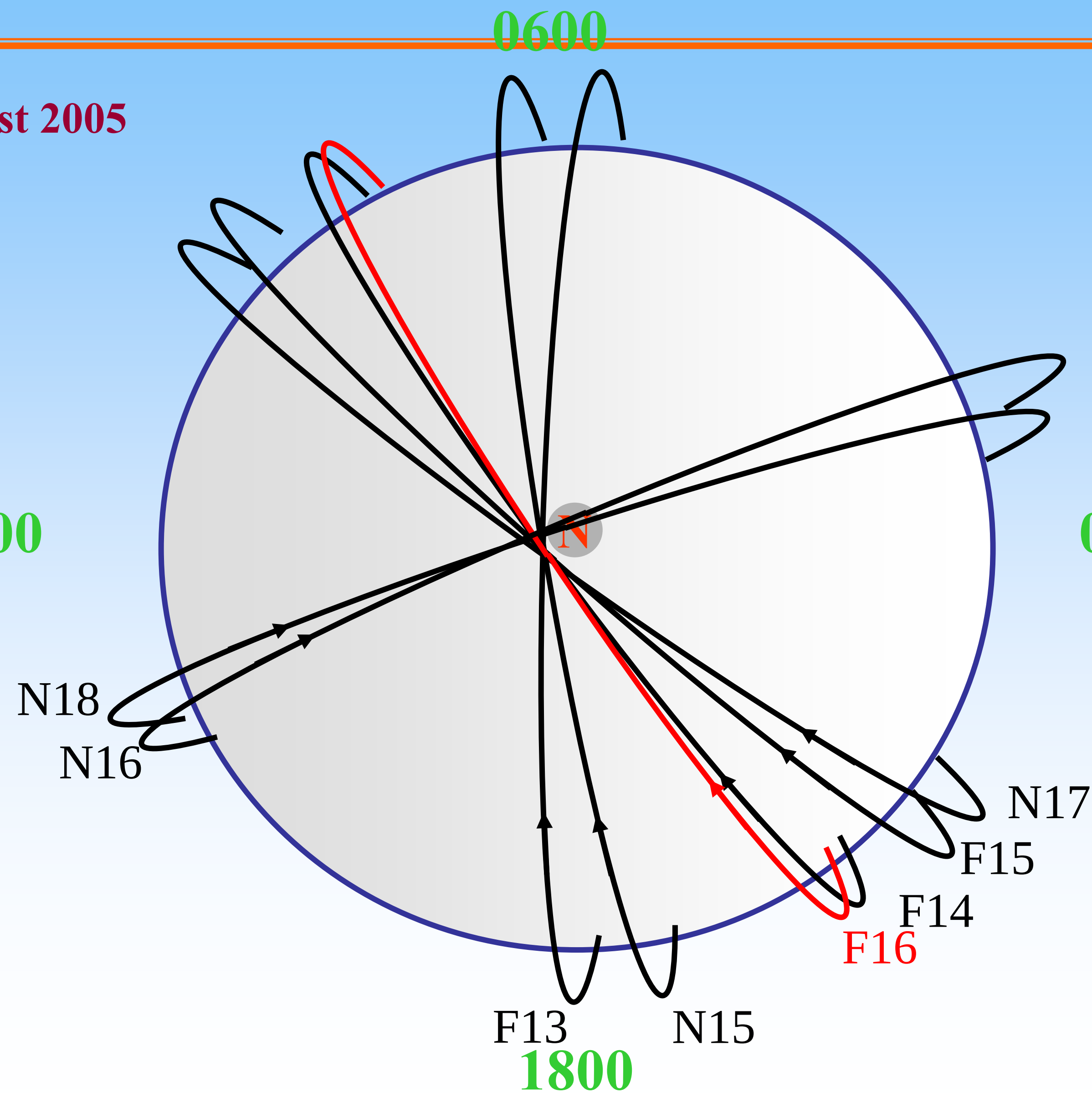


Figure A-5 Channel 3-14 Weighting Functions (Beam Positions 15 and 16, Calm Ocean Background)

Critical Operational Constellation from DMSP and NOAA Satellites

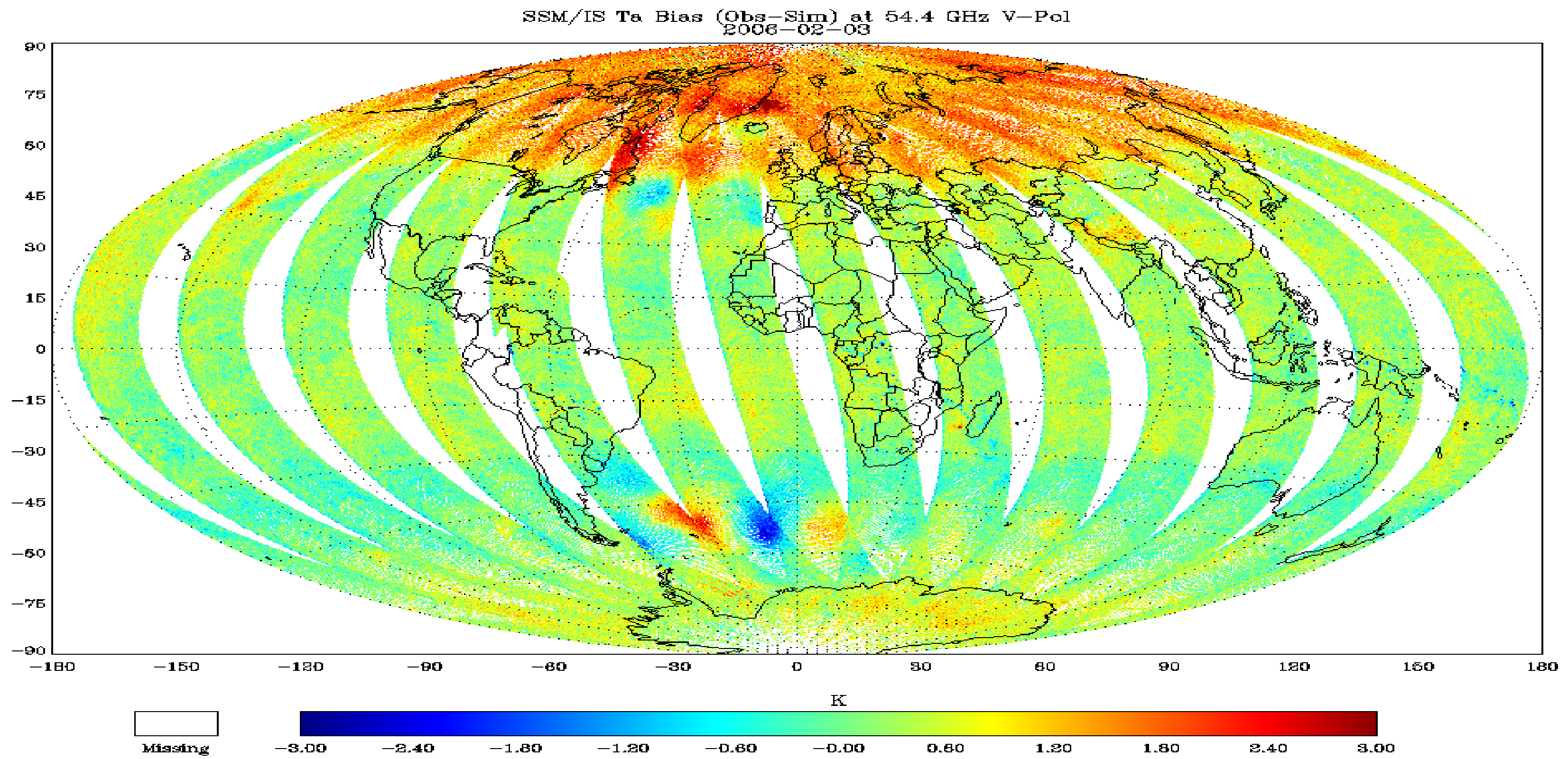
- As of August 2005



DMSP LTANs
F13 1818
F14 2012
F15 2130
F16 2000

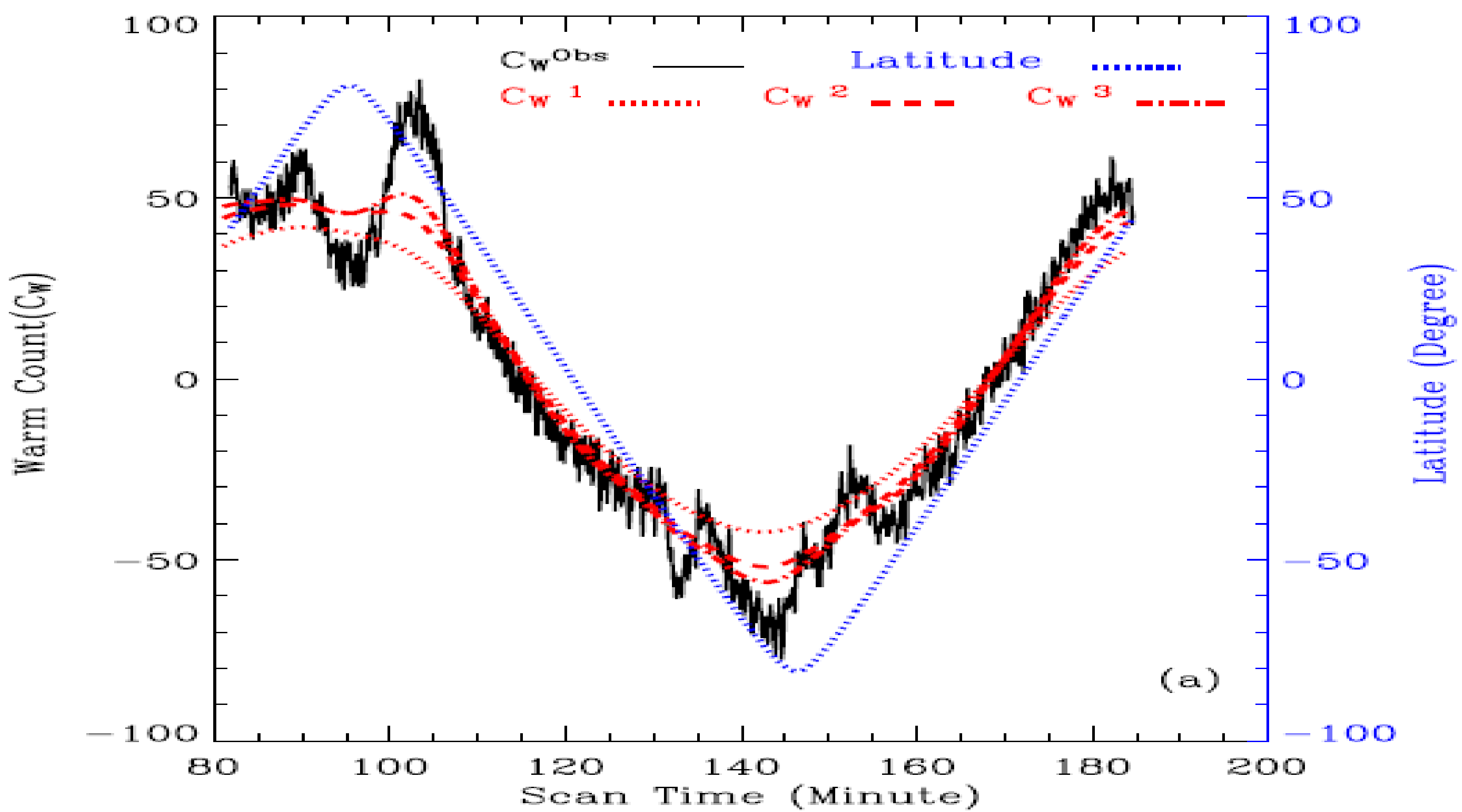
NOAA LTANs
N15 1903
N16 1430
N17 2204
N18 1359

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.

FFT Analyses of Warm Counts (54.4 GHz)



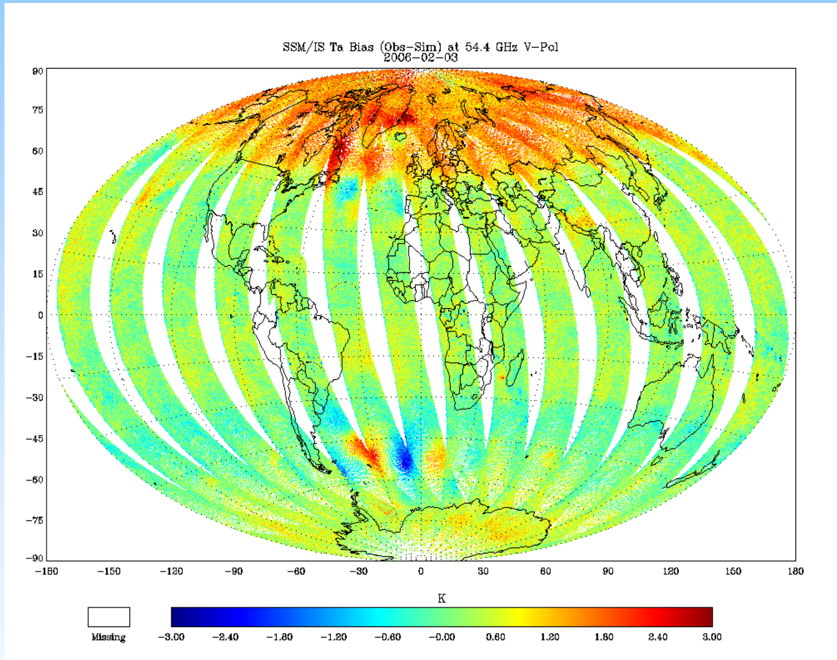
Anomalous jumps in warm load counts result from direct solar illumination and stay light to calibration. These anomalies can be detected and filtered out through FFT analysis

SSMIS Anomalies Correction Algorithms

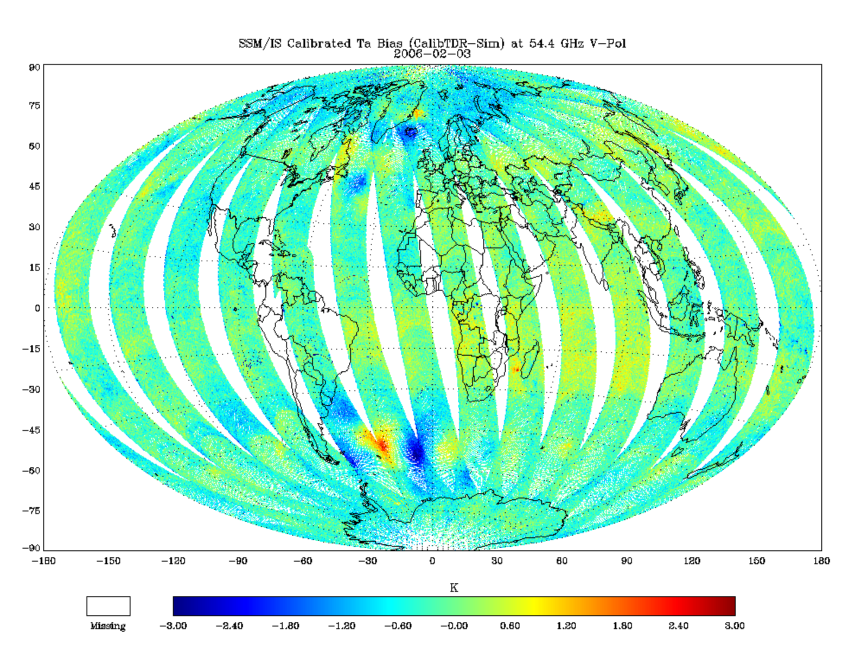
Anomaly Causes	Anomaly Mitigation Process
1. Antenna is not a pure reflector. It emits radiation with a very small emissivity and its own temperature. This additional radiation is called as an antenna emission anomaly	1. Use the emissivity from NRL antenna model and the temperature measured from the thermister mounted on antenna arm as approximation
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	2. Analyze the time series of warm load counts together with PRT and define the anomaly locations in terms of the FFT harmonics
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.	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

SSMIS Antenna Temperature Bias February 3, 2006

Before anomaly correction

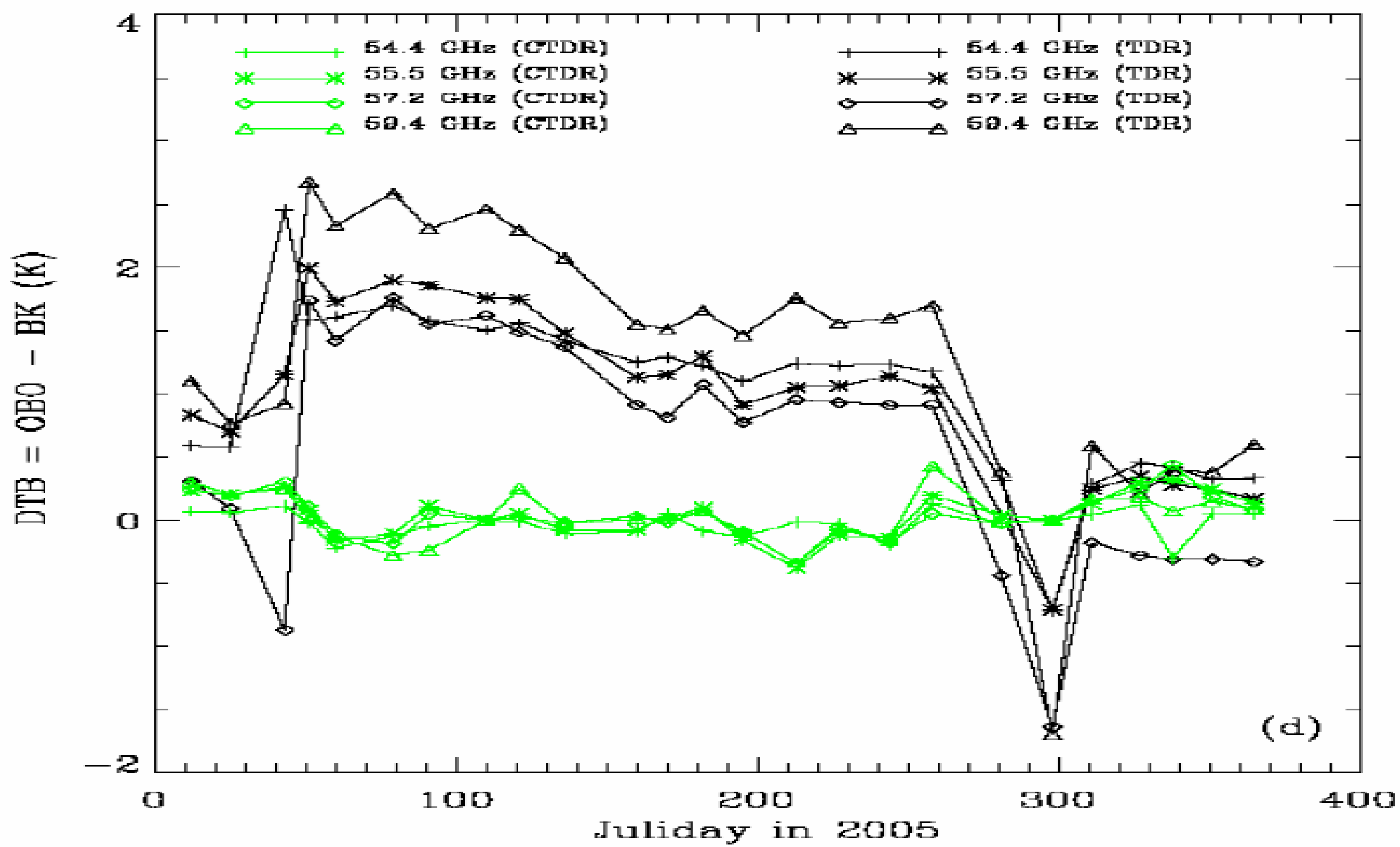


After anomaly correction



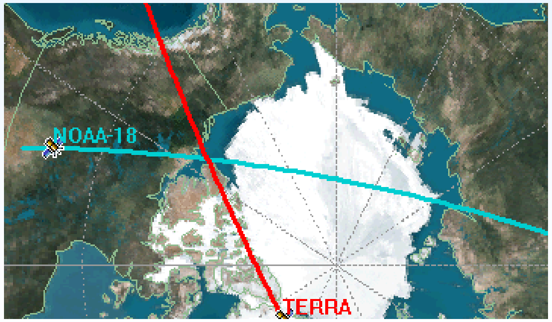
After removal of antenna emission and solar contamination to warm load. Global biases approach constant. Temperature biases from TDR and SDR space are related through the slope coeff. for spill-over correction, Tb = a*Ta + b

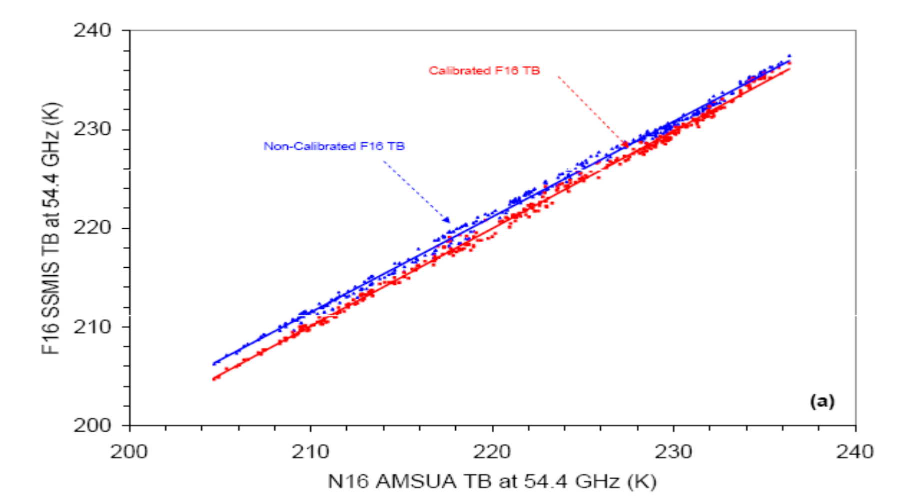
SSMIS Bias Trending

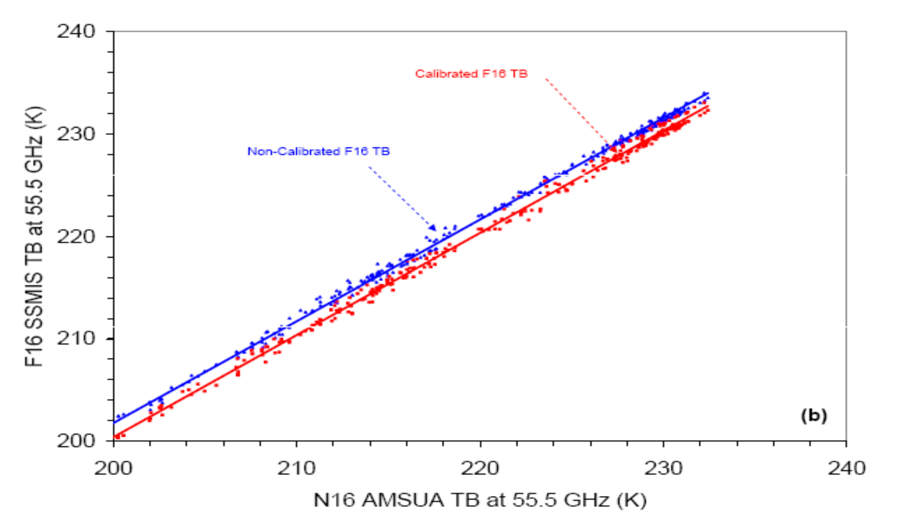


AMSU vs SSMIS Matching through Simultaneous Conical Matching

- SNO – every pair of POES satellites
- with different altitudes make orbital intersections within a few seconds regularly in the polar regions (predictable w/ SGP4)
- Precise coincidental pixel-by-pixel match-up data from radiometer pairs provide reliable long-term monitoring of instrument performance
- The SNO method (Cao et al., 2005) is used for on-orbit long-term monitoring of imagers and sounders (AVHRR, HIRS, AMSU) and for retrospective intersatellite calibration from 1980 to 2003 to support climate studies
- The method has been expanded for SSM/I with Simultaneous Conical Overpasses (SCO)

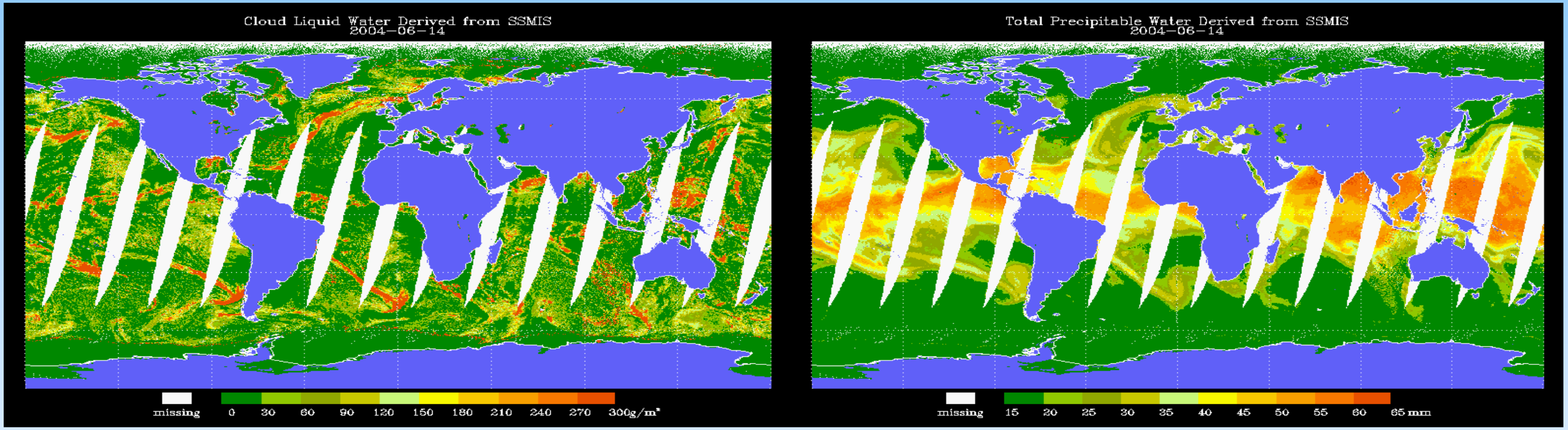




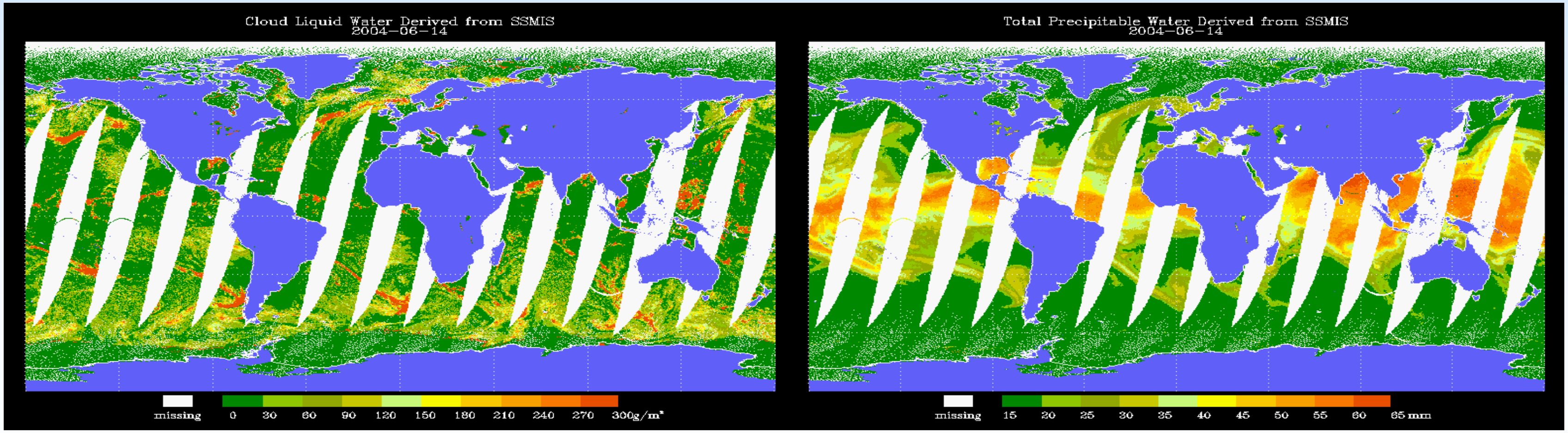


SSMIS vs. SSM/I Products

Cloud Liquid Water | **Total Precipitable Water**



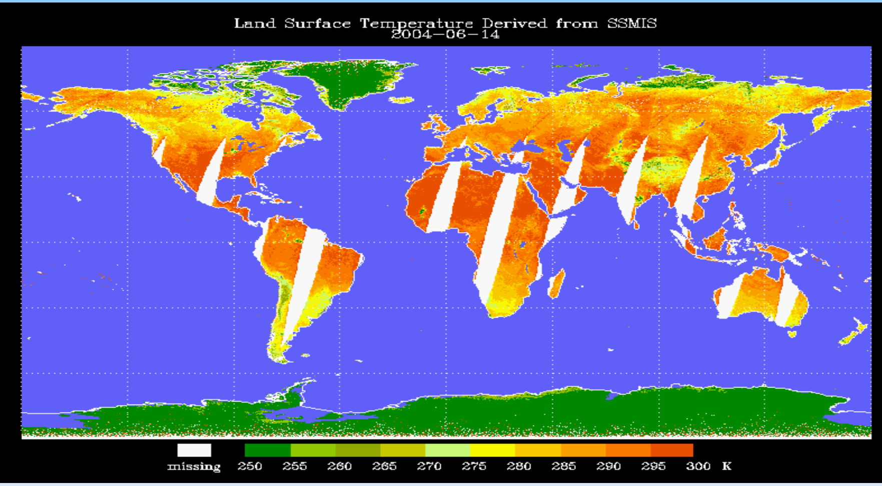
SSMIS-F16

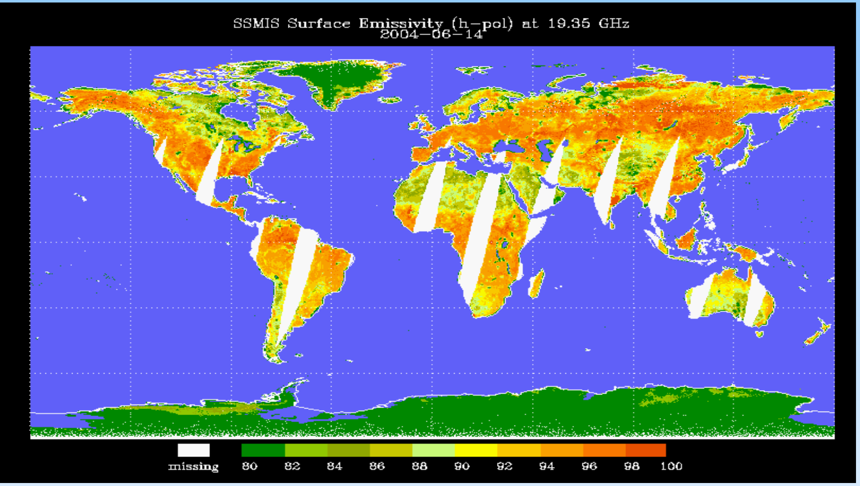


SSM/I-F15

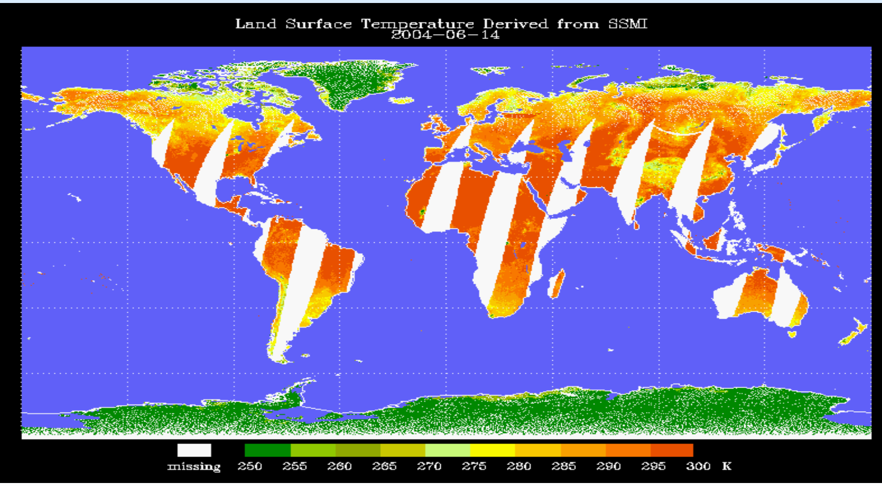
SSMIS vs. SSM/I Products

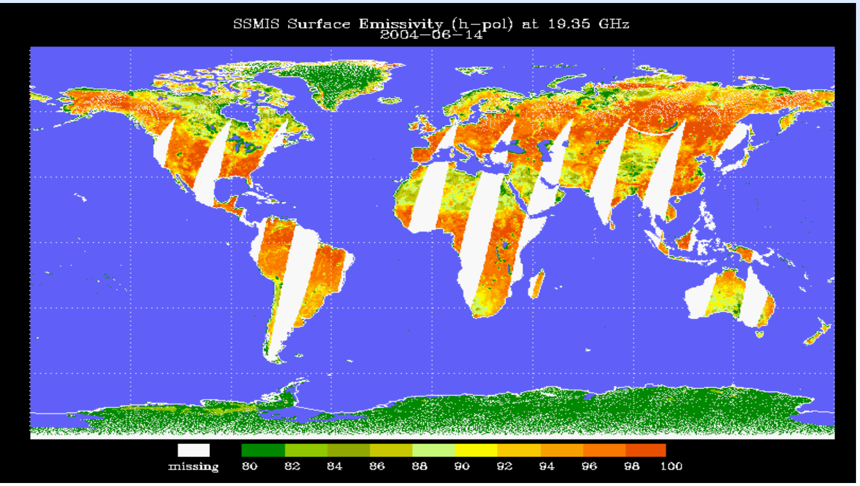
Land Surface Temperature | **Land Surface Emissivity**





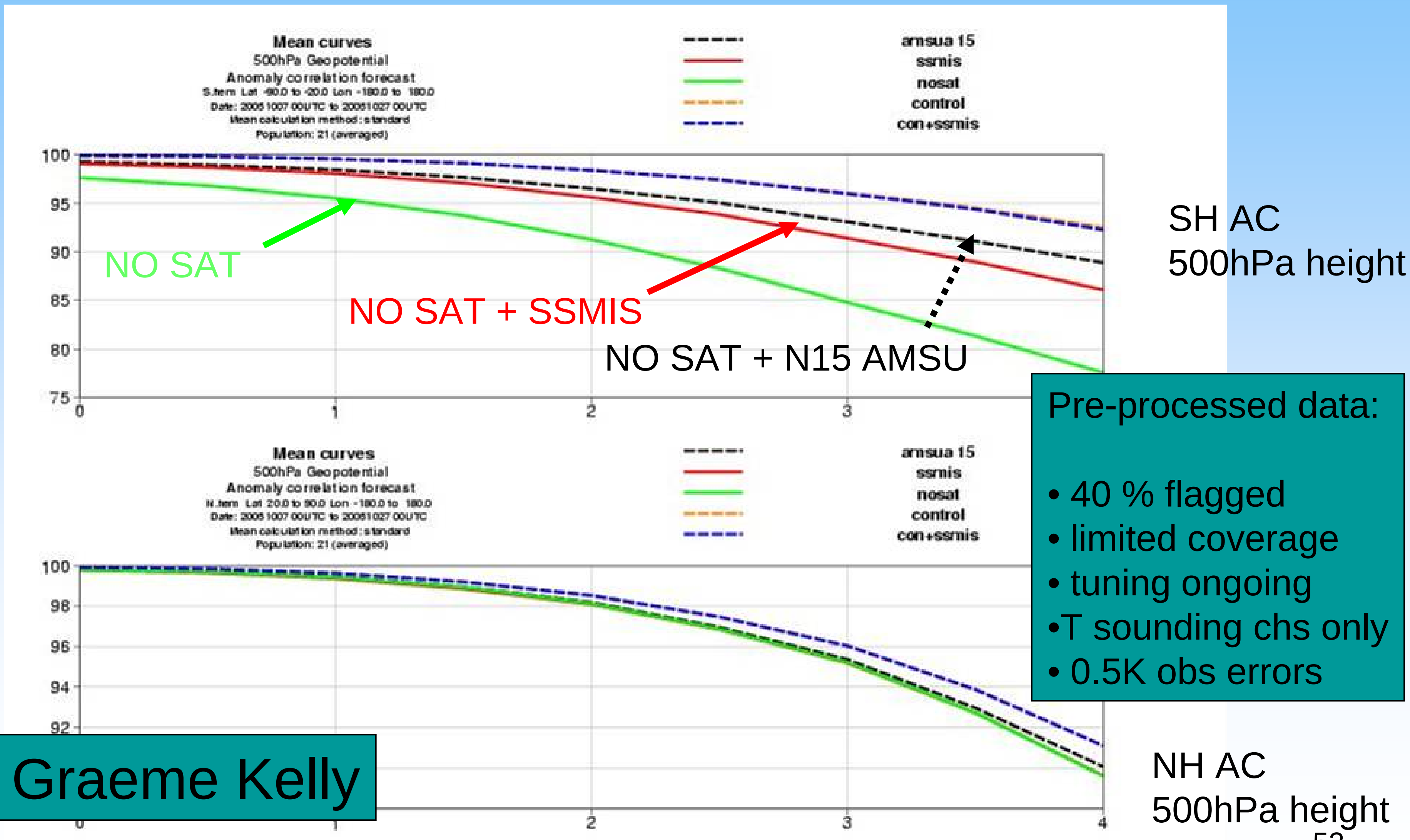
SSMIS-F16





SSM/I-F15

SSMIS Assimilation Trials at ECMWF



Pre-processed data:

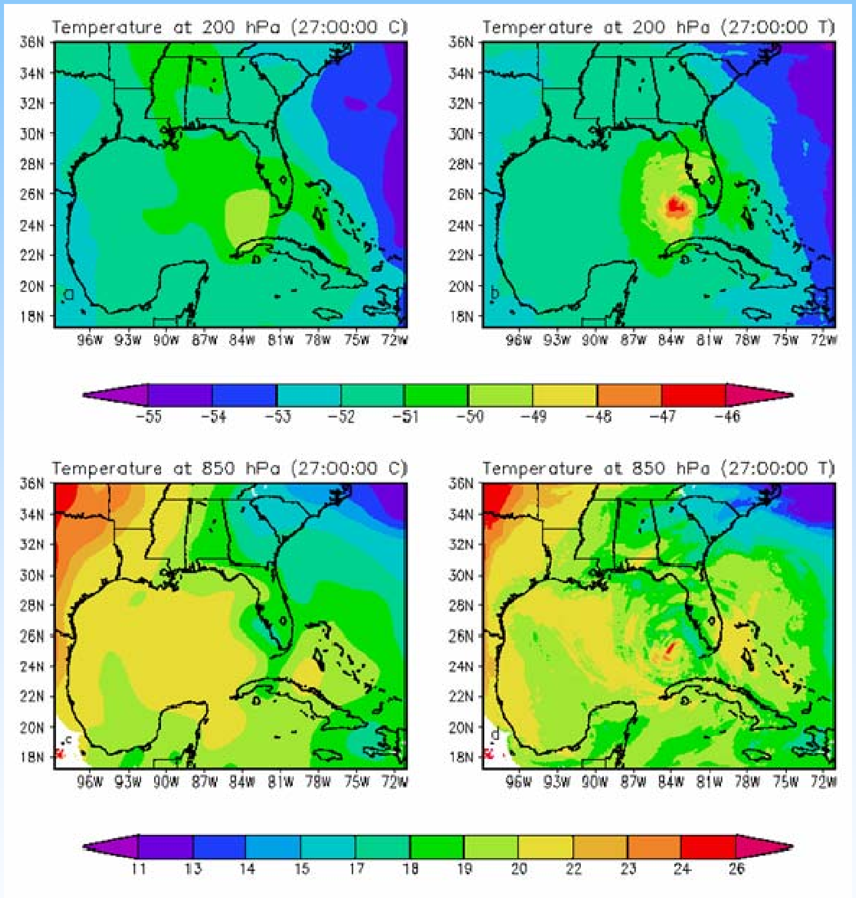
- 40 % flagged
- limited coverage
- tuning ongoing
- T sounding chs only
- 0.5K obs errors

Graeme Kelly

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

Summary

- DMSP SSM/I data scattered in the community from 1987 to 2006 has been recovered and archived at NESDIS
- Critical calibration problems affecting SSM/I CDR generation has been identified
- DMSP SSMIS is becoming a major data source for NWP data assimilation and provide vital constellation to NOAA POES operation
- The NESDIS beta-version calibration algorithm has significantly eliminated most of SSMIS radiance anomalies (e.g. antenna emission, warm load anomaly…)
- Impacts of SSMIS radiances on NCEP analysis field are significantly positive. SSMIS observations are assimilated under all weather conditions through JCSDA Community Radiative Transfer Model (CRTM)

SSMI Product Issues will be the future forum by Ralph Ferraro

Stay tuned

Next few slides are the preview for his talk

National Environmental Satellite, Data, and Information Service

Outline

- **Scientific Data Stewardship Requirements**
  - Fundamental CDR (Level 1B, SDR)
  - Thermatic CDR
- **SSMI and SSMIS Data Issues (Fuzhong Weng)**
  - Data rescue efforts
  - Newly discovered SSM/I calibration problem (calibration targets, angular dependant biases, beacon contamination)
  - SSMIS calibration problems
  - Reformat issues with new calibration information
- **SSM/I/S Products Issues (Ralph Ferraro)**
  - Some thoughts on “Climate” and trends
  - Orbit drifts & sampling problems
  - Old data format vs pixel level retrievals
  - SSM/I/S value added products
  - Parallel productions with SSM/I operational algorithms

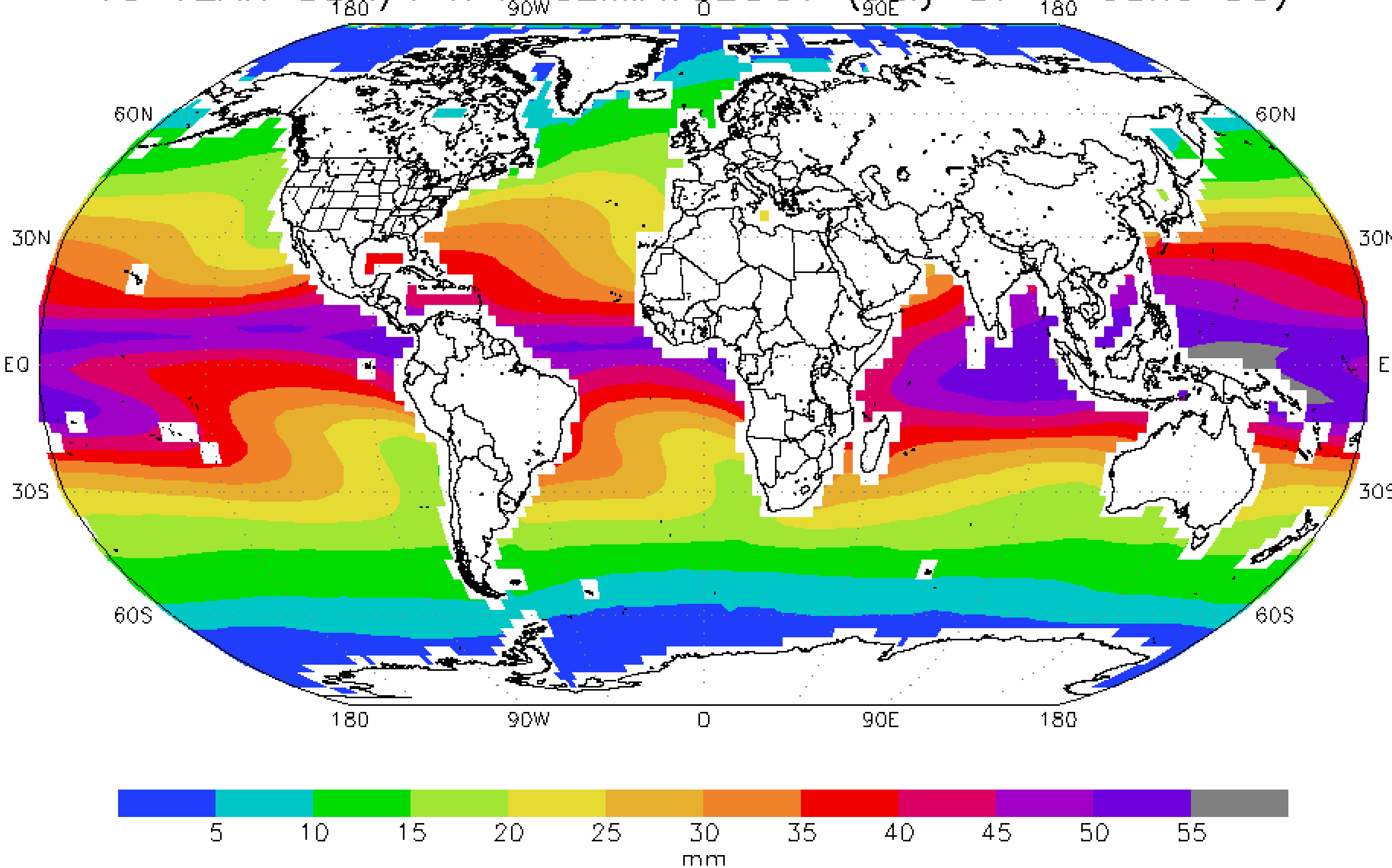
What Defines Climate & Variability?

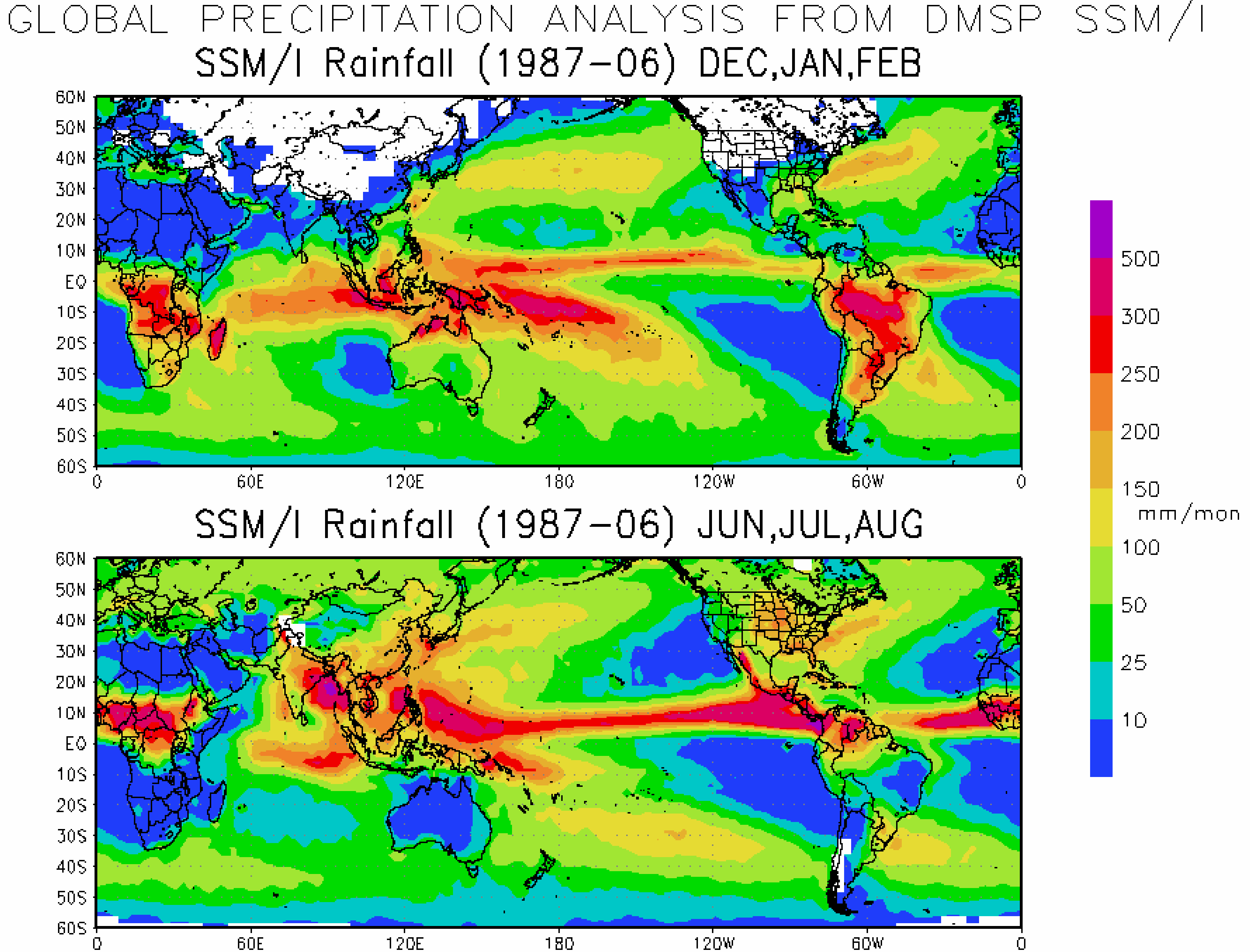
Easy

- **Mean state of surface and atmosphere (last 30 years)**
- **Seasonal to interannual variability (and its spatial variability)**
- **Fluctuations in shorter term phenomenon (that may "average" in longer term)**
- **Discernable trend in time series (above noise/confidence level)**

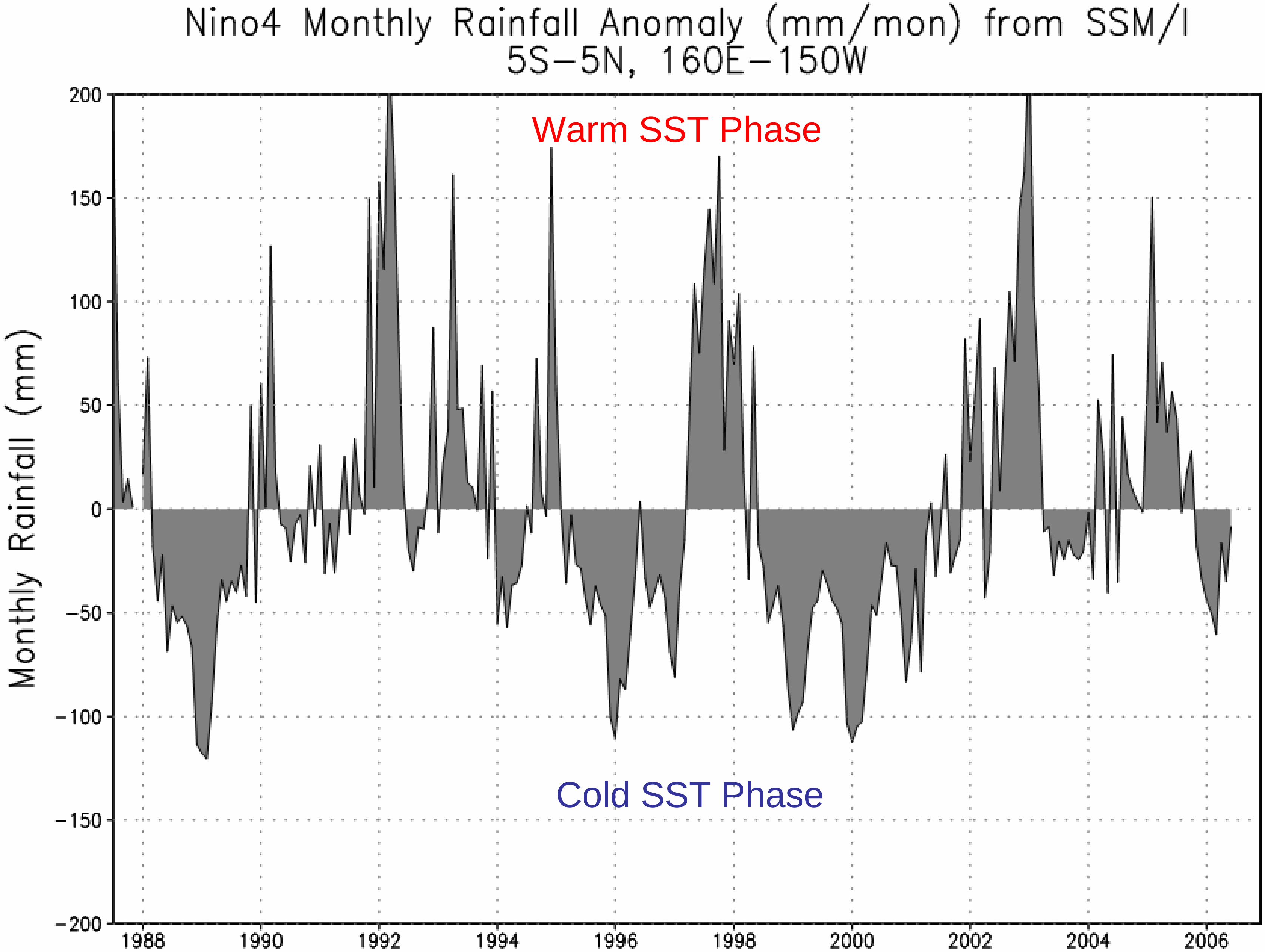
Difficult

19 YEAR SSM/I TPW CLIMATOLOGY (July 87 – June 06)





GLOBAL PRECIPITATION ANALYSIS FROM DMSP SSM/I
SSM/I Rainfall (1987-06) DEC,JAN,FEB
SSM/I Rainfall (1987-06) JUN,JUL,AUG
60N 50N 40N 30N 20N 10N EQ 10S 20S 30S 40S 50S 60S
0 60E 120E 180 120W 60W 0
500 300 250 200 150 100 50 25 10
mm/mon

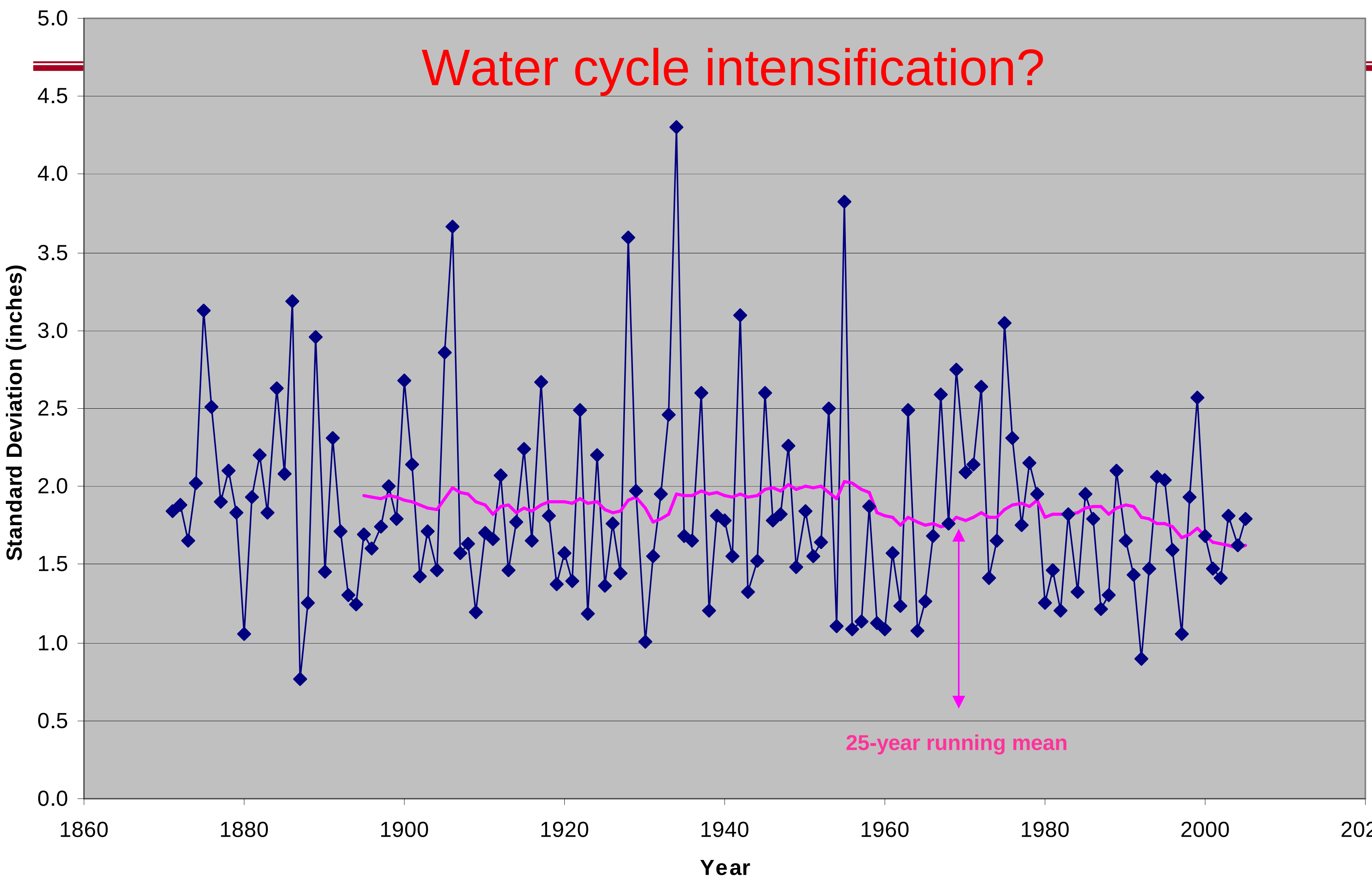


Nino4 Monthly Rainfall Anomaly (mm/mon) from SSM/I
5S-5N, 160E-150W
Warm SST Phase
Cold SST Phase
Monthly Rainfall (mm)
200
150
100
50
0
-50
-100
-150
-200
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006

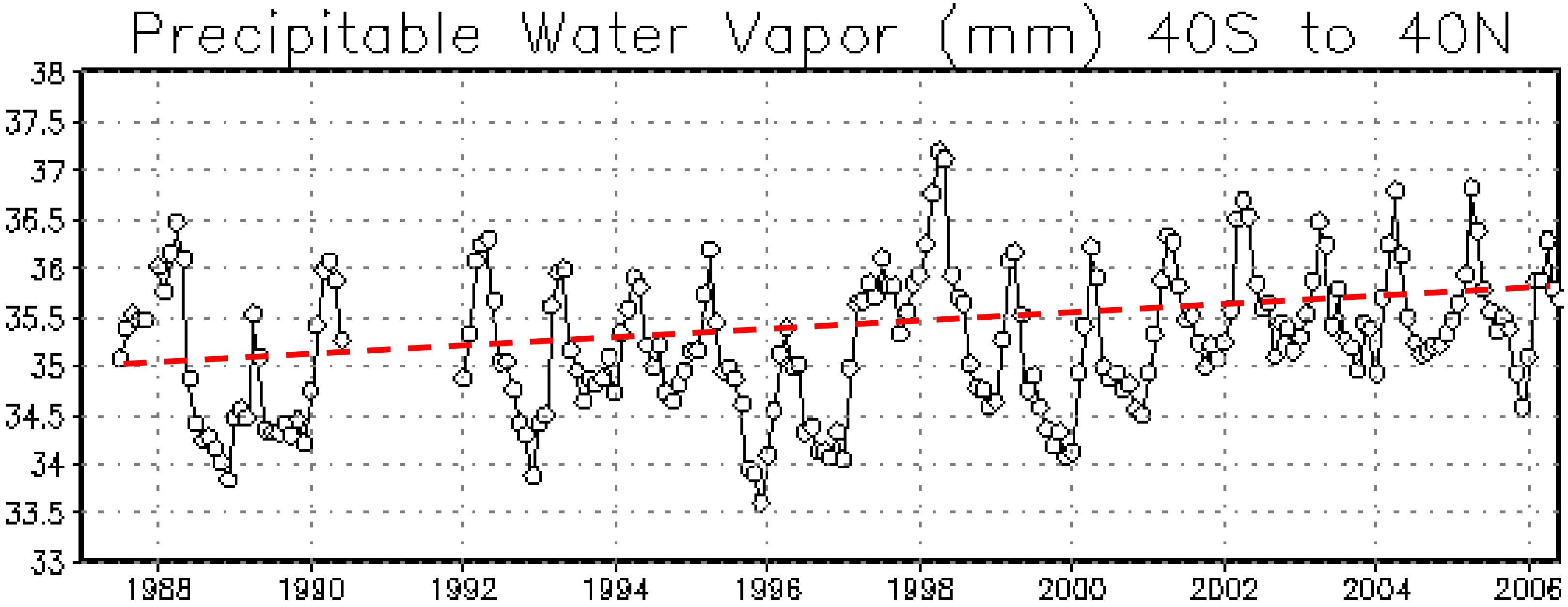
National Environmental Satellite, Data, and Information Service

Standard Deviation of Monthly Rainfall at DCA

(Courtesy of Bob Kuligowski, NOAA/NESDIS)



19 years of SSM/I TPW



Example:

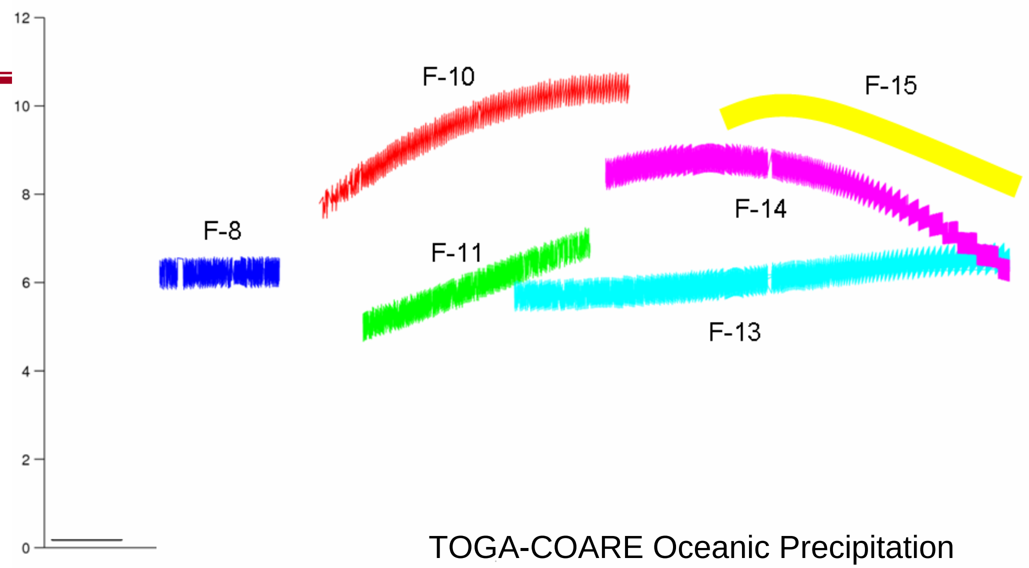
If 1% TPW uncertainty (~0.35 mm/month) with a trend ~ 0.05 mm/year (or 0.004 mm/month), is this a trend or just uncertainty in retrieval?

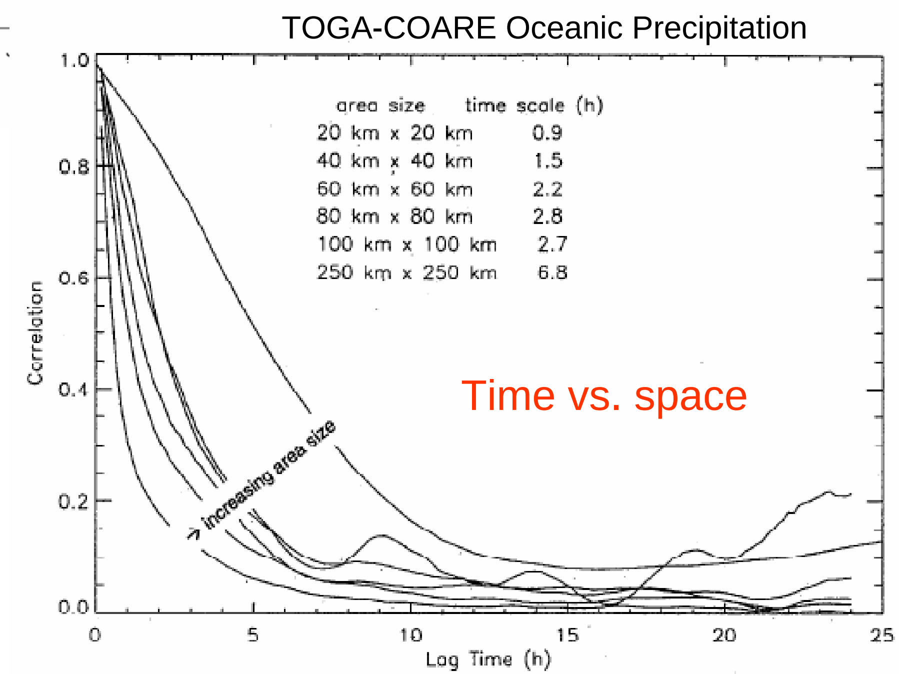
Moving towards TCDR's…

- **Sensor characterization and correction remain the highest priority**
  - Robust and rigorous approaches
  - Adjust to common "reference"
- **However, this does not solve the "climate" issue entirely for derived hydrological parameters**
  - Satellite drift & diurnal cycle
  - Non-linear processes in retrieval algorithms
  - Use/treatment of multiple satellites
  - Data sampling

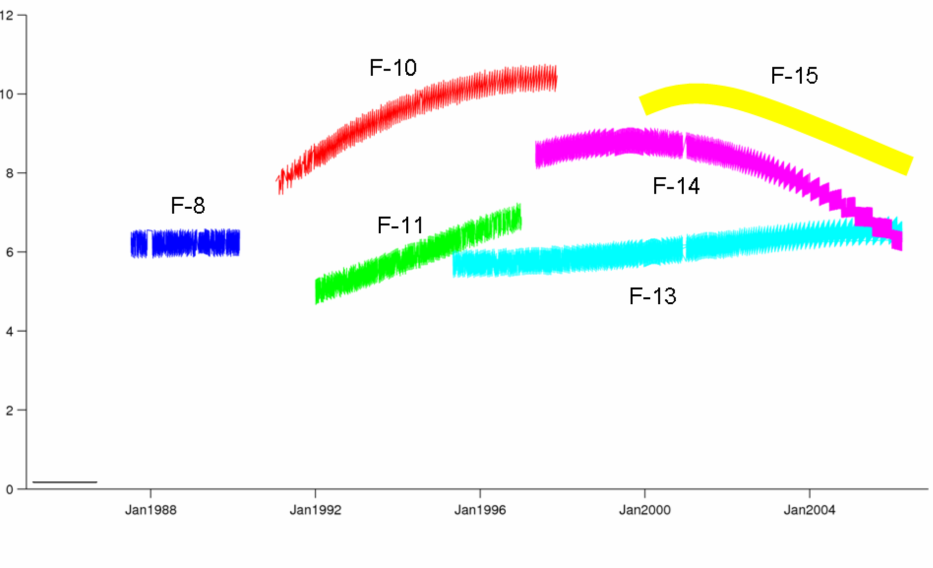
Satellite Drift

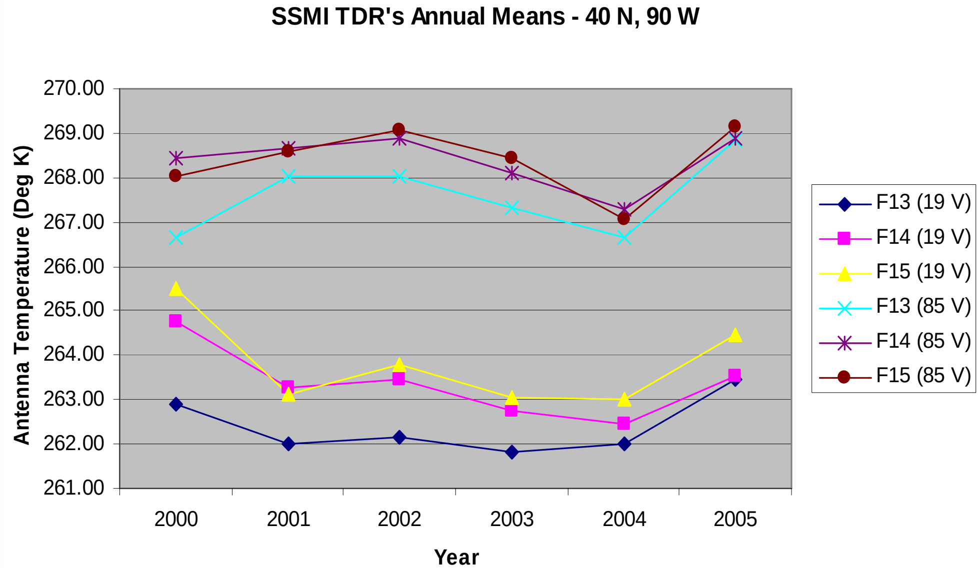
- **DMSP satellites can drift by over 2 hours during its lifespan**
- **Correcting drift to common time is desirable**
  - Caveat: autocorrelation of geophysical parameter is greater than drift
    - Affects spatial and temporal resolution of derived products





Satellite Drift (2)





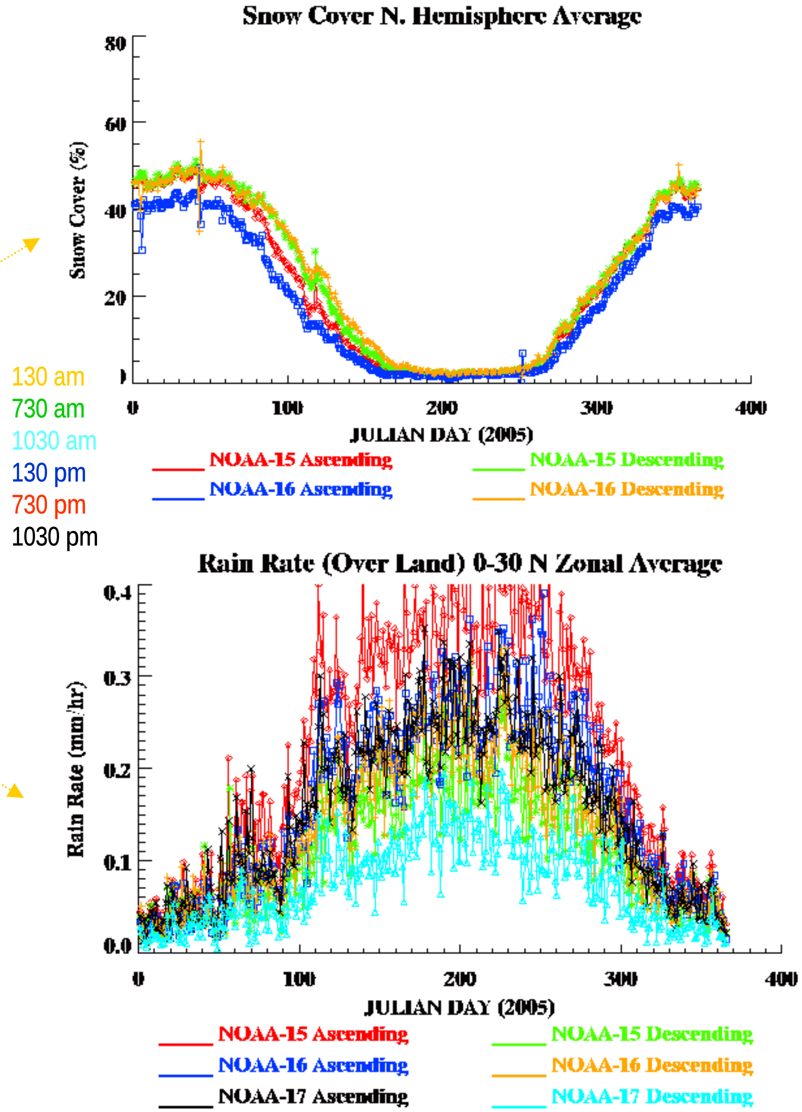
- Example: Satellite drift is confirmed at a land location
  - 19 V and 85 V annual mean values closely follow overpass time changes
  - Adjustment to a reference should compensate for drift
    - Geophysical products should respond properly
  - However, 85 V sensitive to episodic events (e.g., snow cover & rain)
    - Impact unknown on geophysical products

Improper calibration and compensation for drift & diurnal cycle can cause unreliable time series (and inferred trends)

Diurnal Cycle

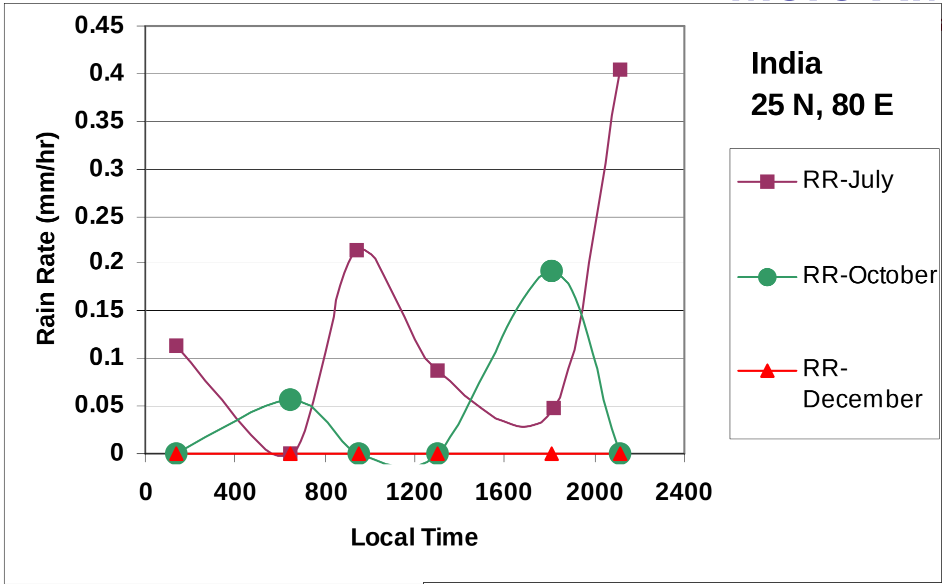
- **Adjustment of Tb to “reference” cannot compensate for missing diurnally driven events**
- **Impact on time series is parameter driven**
  - Snow and ice cover (low), rain and clouds (high)
  - Some remedies include using only specific nodes (e.g., snow cover), however, regional and seasonal variations can be quite different (next slide)!

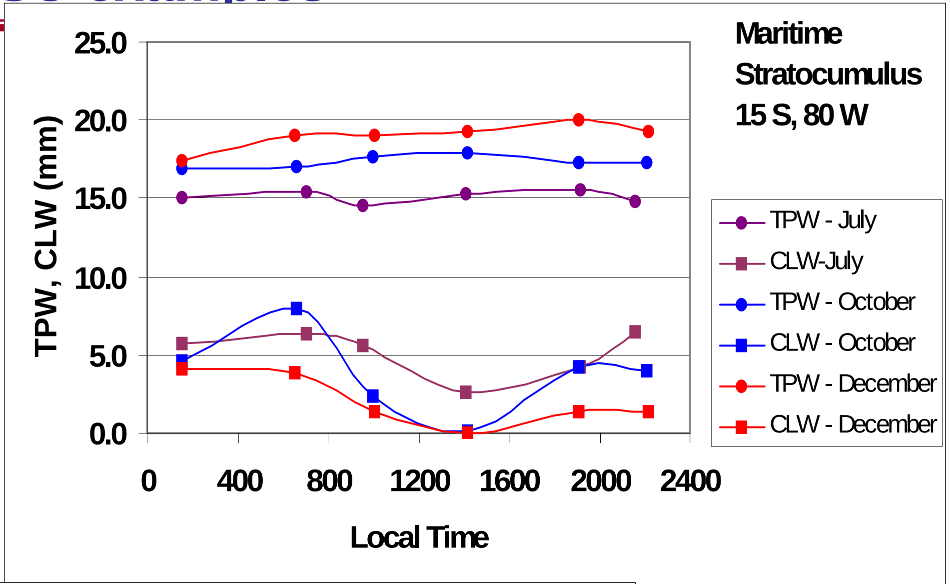
AMSU

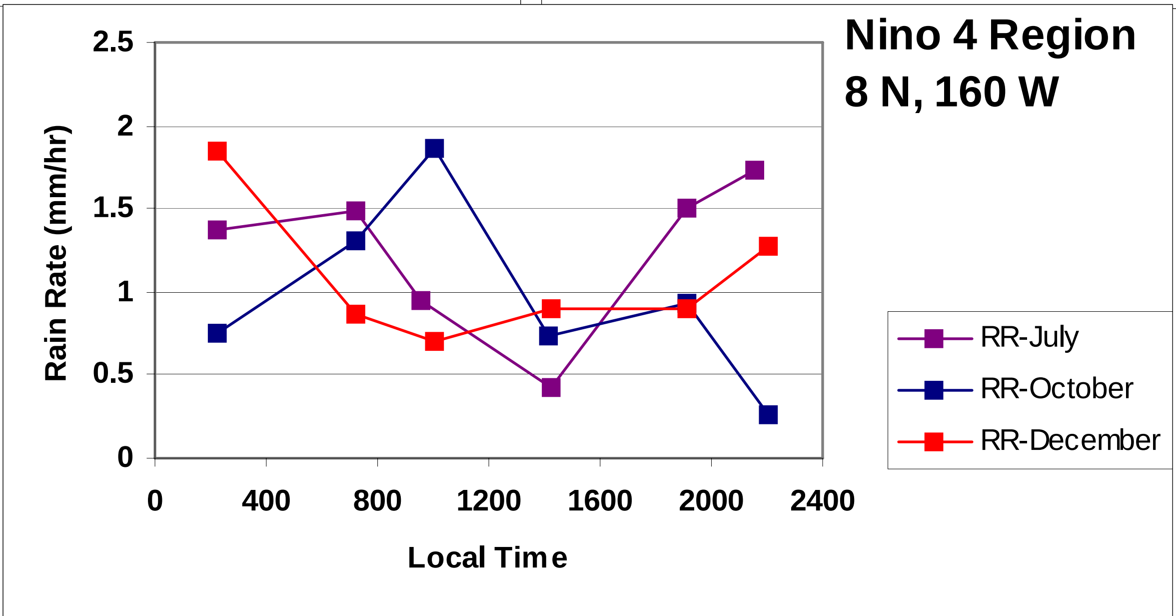


Diurnal Cycle (2)

More AMSU examples







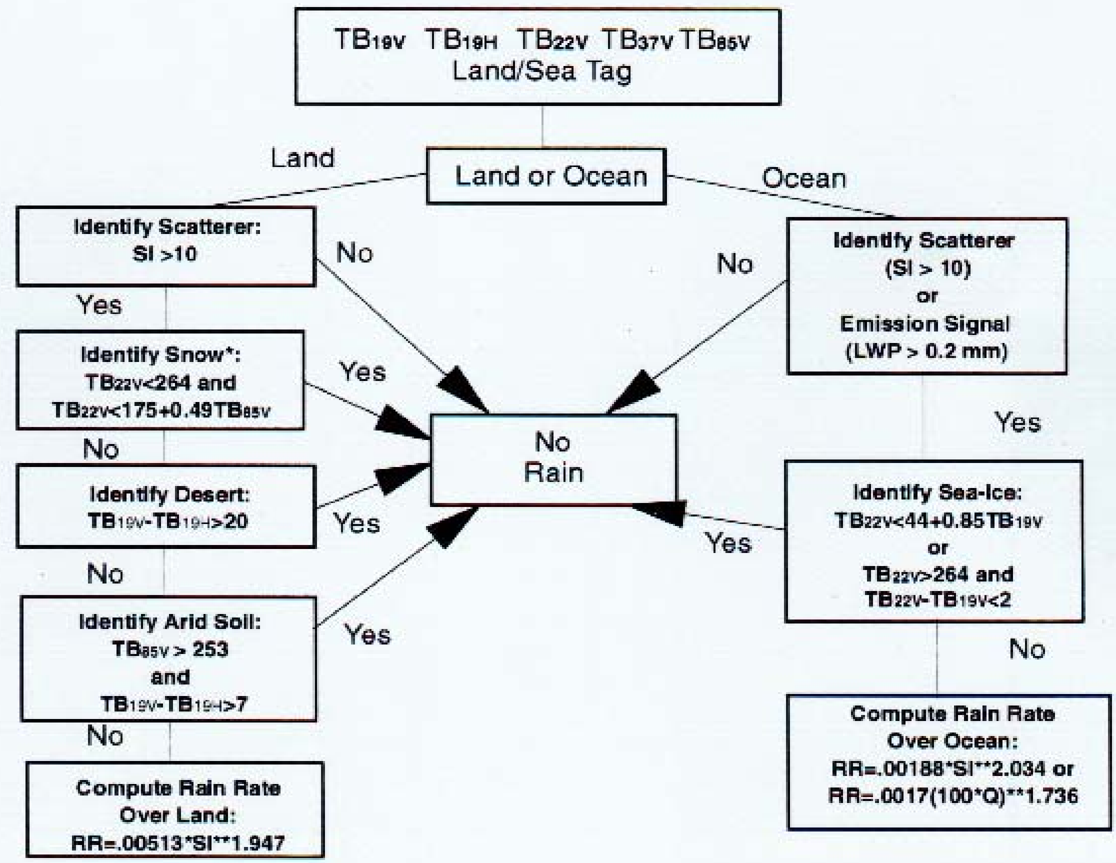
Non-Linear Processes

- **A physical relationship:**
  - $L = a_0\{ln[Ts - TB_2] - a_1 ln[Ts - TB_1] - a_2\}$
  - $V = b_0\{ln[Ts - TB_2] - b_1 ln[Ts - TB_1] - b_2\}$
- **Averaging methods (pentad, monthly, etc.)**
  - Generally assume normal distributions; may not be the case
- **Decision tree processes**
  - Individual steps may be linear, entire process is highly non-linear

Impacts of improper calibration on non-linear processes needs to be quantified before TCDR's are truly robust

SSM/I EDR Rain Algorithm

- **Bias in TB's will affect the "decision" in each step:**
  - SI
  - Snow cover
  - Desert
  - Arid Soil
  - Sea-ice
- **Ramifications unknown but likely severe for "climate change"**
  - However, defining mean climate and seasonal to interannual changes are less sensitive to such biases



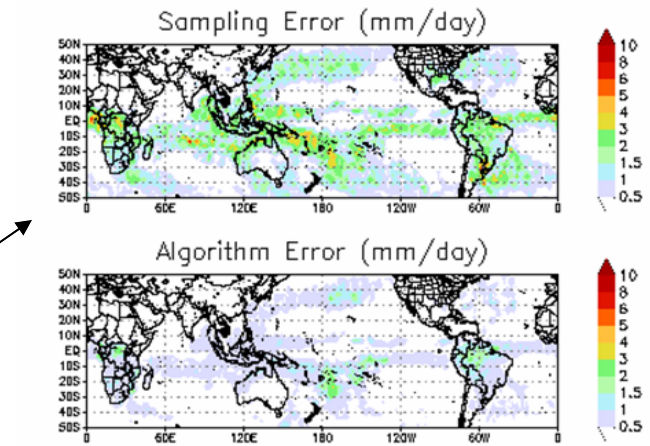
* An additional check is made for refrozen snow when for the following regions: January-March [Latitudes 25-90], April-May [Latitudes 40-90], June [Latitudes 60-90]

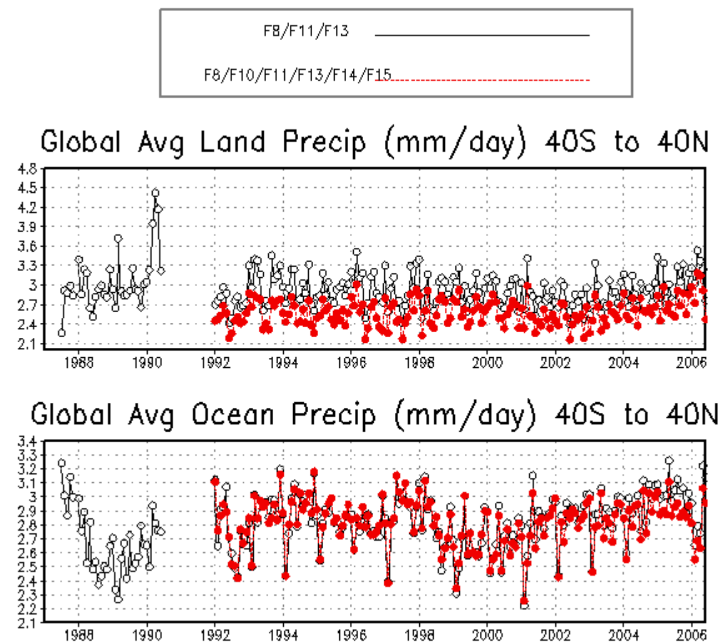
Refrozen snow is flagged if SI<60 and 264≤TB(22V)≤268

National Environmental Satellite, Data, and Information Service

Use of Multiple Satellites

- **Aside from F8, at least two SSM/I's in operation since 1991**
  - Nominal operating times 6 am/pm; 10 am/pm
- **For those parameters with largest diurnal variability, "sampling error" contributes largest source of overall error**
  - Can greatly reduce this using dual satellites
  - However, diurnal cycle and orbital drift need to be treated properly





Data Sampling Implications

- **Swath vs. Gridded**
  - Several “legacy” products were generated using sub-sampled and/or gridded products
    - Necessitated due to computer limitations in 1990’s
    - For continuity sake, procedures have changed very little
      - e.g., Ferraro/NCDC time series, GPCP, EASE grid
  - For most accurate climate products, swath data need to be used
    - Impact of using gridded and subsampled data needs to be carefully considered

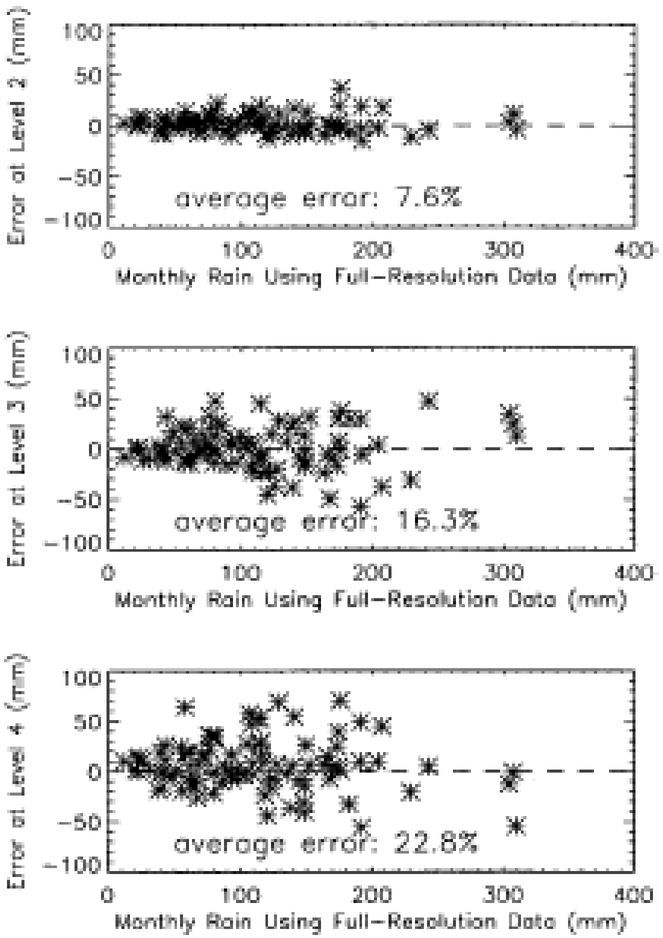


FIG. 6. Error in the estimate of 1° × 1° monthly rain at (top) 25-, (middle) 37.5-, and (bottom) 50-km resolutions, respectively, using SSM/I data and the scattering algorithm over TOGA COARE.

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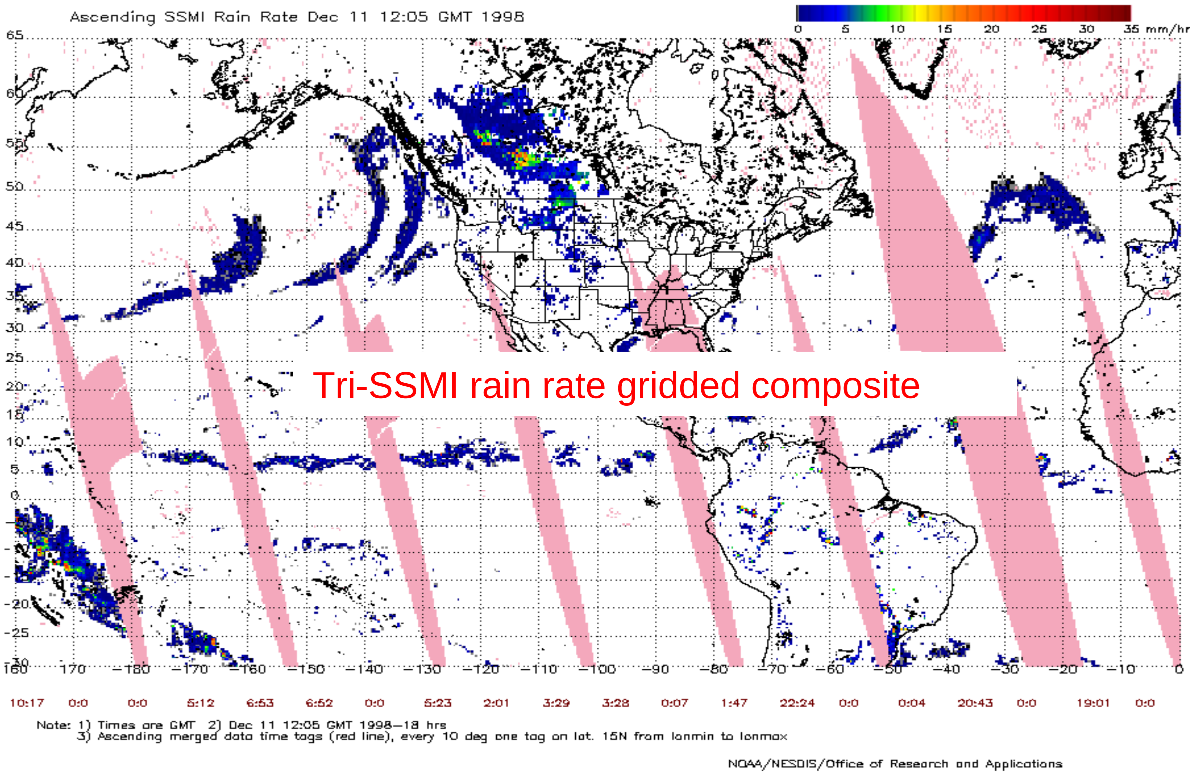
Data Sampling Implications (2)



- **Use of gridded TB's/L2 products can cause misrepresentation of derived fields**
  - Treatment of overlapping orbits
    - Average or composite?
  - Higher latitudes
    - Improved data sampling reduces retrieval errors, but, can cause aliasing affects

SSM/IS Value Added Products

- **Besides "legacy" TCDR's (rain, snow, TPW, CLW, Sea-ice, etc.), there is a host of enhanced products that can be produced from SSM/I**
  - Land surface emissivity
  - Land surface temperature
  - Soil moisture/wetness
  - Improved physical retrieval models for atmospheric and surface parameters
- **Inclusion of new TCDR's will be considered as part of SDS program. These will be compared with the reprocessed legacy products**

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Summary

- **Although sensor characterization and correction remain the highest priority for passive microwave satellite measurements, a number of other concerns need to be addressed before** robust **FCDR's can be generated:**
  - Satellite drift & diurnal cycle
  - Non-linear processes in retrieval algorithms
  - Use/treatment of multiple satellites
  - Data sampling
  - Others