A Fundamental Climate Data Record of Intercalibrated Brightness Temperature Data from SSM/I and SSMIS

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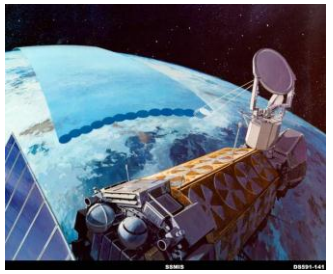
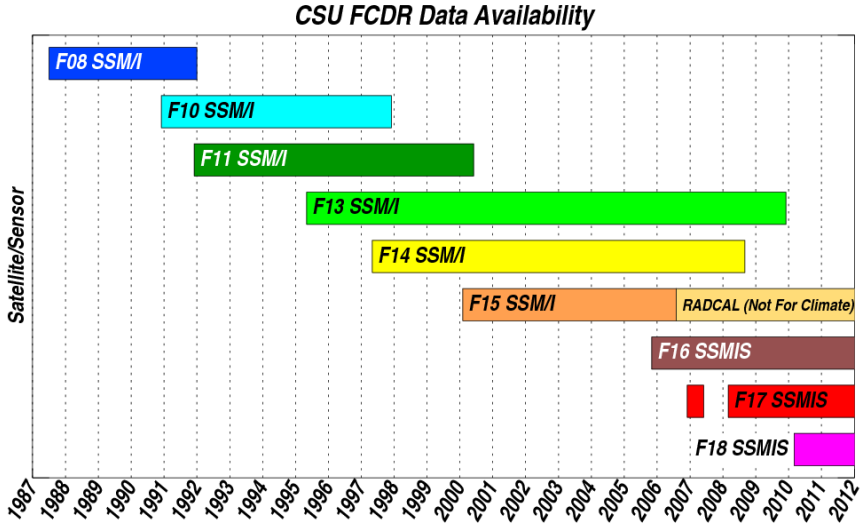
SSM/I and SSMIS

Fundamental Climate Data Record (FCDR)



- SSM/I and SSMIS are polar-orbiting passive microwave radiometers flying aboard DMSP satellites
- 6 SSM/I sensors starting in 1987
  - F08, F10, F11, F13, F14 and F15
- 5 SSMIS sensors
  - F16, F17, F18 currently available
  - F19 and F20 not yet launched
- Beta V5 SSM/I FCDR available
- Beta B4 SSMIS FCDR available.
- All sensors are calibrated to F13
- F15 RADCAL correction applied Aug 2006 forward (deemed not suitable for climate).

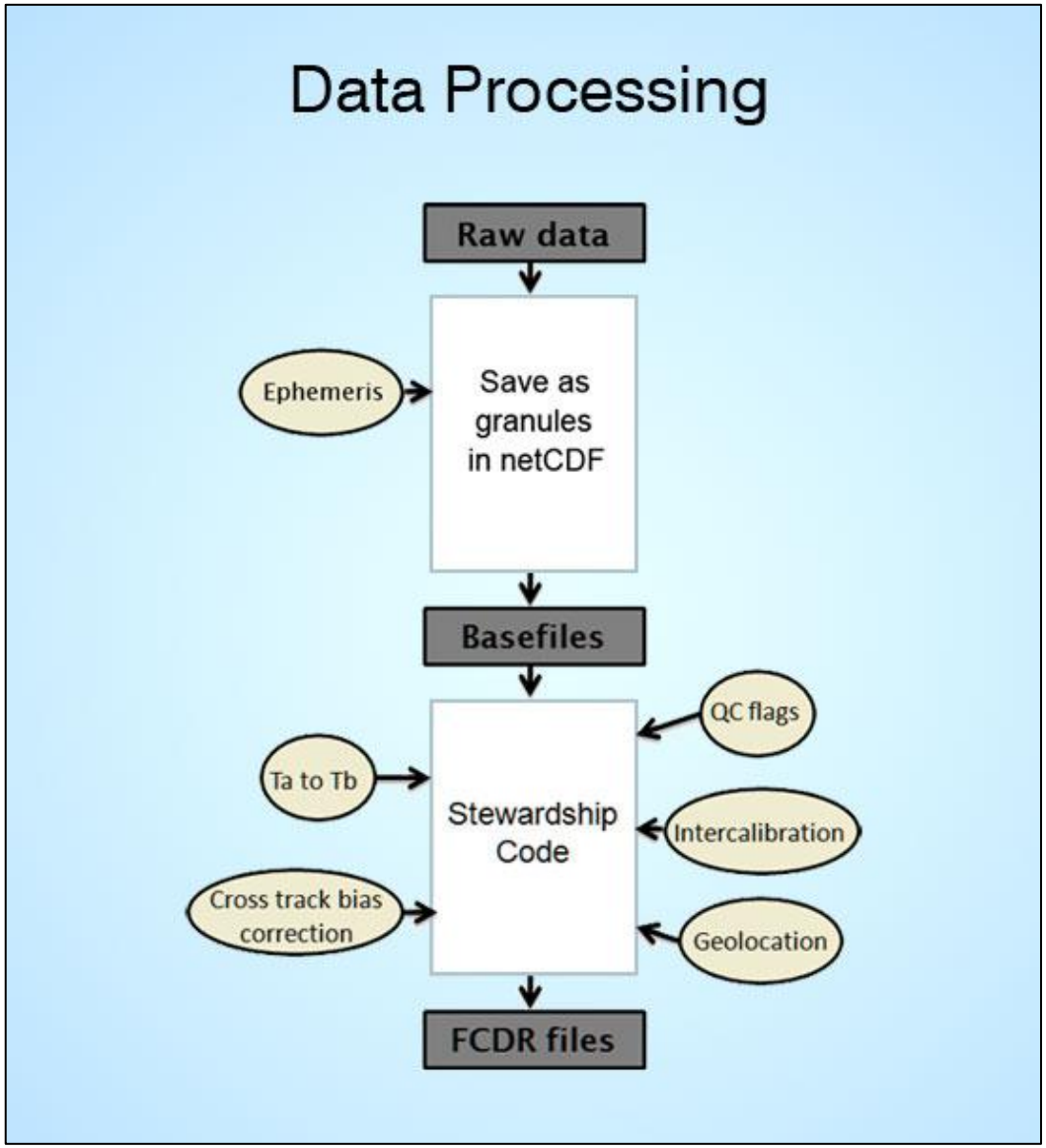
SSM/I: Special Sensor Microwave/Imager
SSMIS: Special Sensor Microwave Imager/Sounder



SSM/I has 7 Channels:
19 V&H, 22 V, 37 V&H, 85 V&H GHz
SSMIS has 24 Channels
7 correspond to SSM/I:
19 V&H, 22 V, 37 V&H, 91 V&H GHz

Approach

(from TDR to FCDR Files)



1. Reformat SSMI/SSMIS TDR files into NetCDF "**Base files**". These files contain **all** the original data and **nothing is modified** except to make orbit granules, add ephemeris and reformatted time, and reformat to NetCDF.

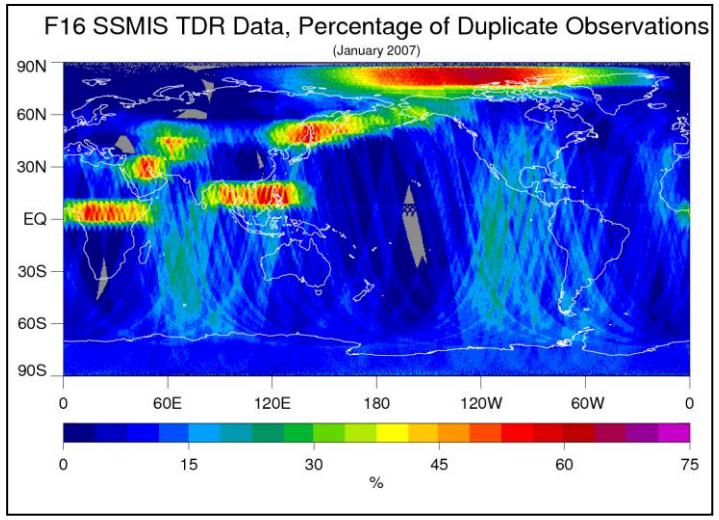
2. Create a **well documented software** package ("**Stewardship code**") that ingests the Base files, applies corrections and outputs the final FCDR in NetCDF for use by the broader community. Modules include the following.

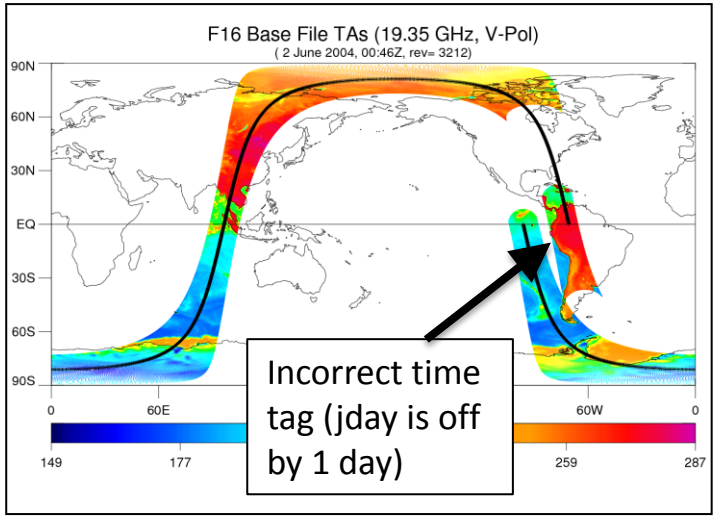
   - **Quality control:** (Sets/flags bad data to missing and flags potential problems)
   - **Cross-track bias correction:** (Adjusts for unphysical end-of-scan dropoffs)
   - **Warm/cold load contamination correction:** (Adjusts for intrusions into warm/cold loads)
   - **SSMIS antenna emission correction:** (Correction for emissive antenna, only SSMIS currently)
   - **Geolocation:** (Computes pixel geolocation based on attitude adjustments and TLE-based spacecraft ephemeris)
   - **Antenna temperature to brightness temperature:** (Accounts for antenna pattern including sidelobes and cross-pol)
   - **Intercalibration:** (Adjusts for sensor differences for both warm and cold TBs).

Quality Control

Examples of QC issues

- Duplicate scans removed from basefiles
  - These occur more often in some locations (problem for climate)
- Several QC checks are applied in stewardship code
  - Non-physical TBs and lat/lons
  - Climatology check
    - Remove scans with 30% pixels outside 3 sigma from climatology
  - Geolocation check
    - Compare original pixel lat/lon with calculated values; remove anomalies due to time tag issues
  - Check for spikes in warm/cold load values

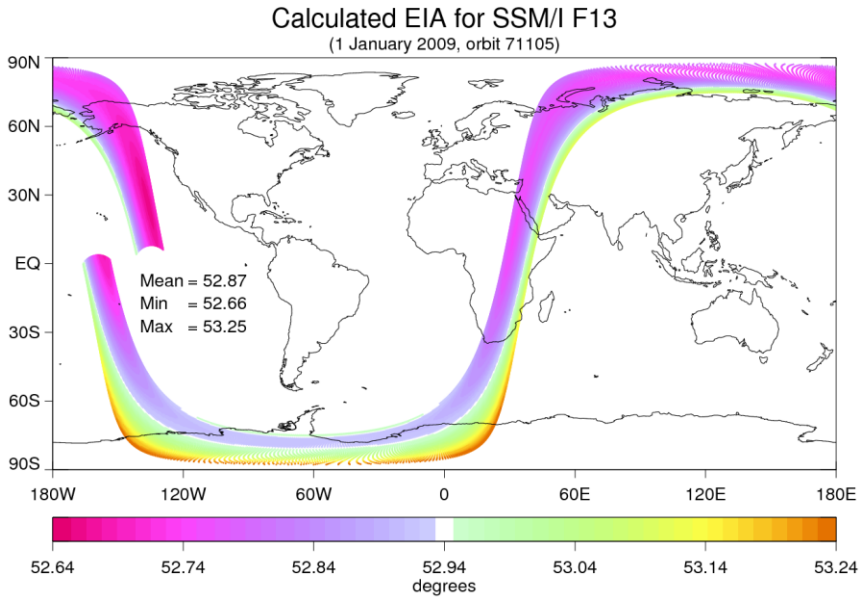


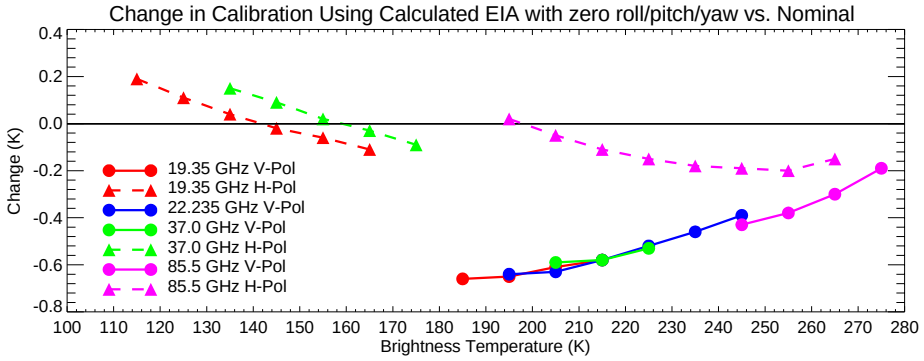


Geolocation and View Angle

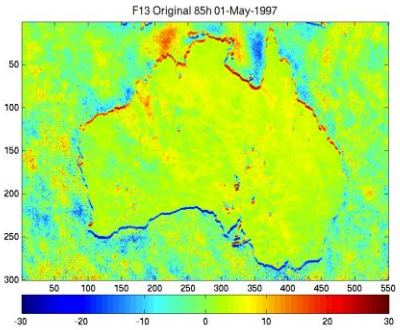
Estimation of Satellite Attitude

- Spacecraft ephemeris computed using two-line element data and NORAD SDGP4 code
- Satellite attitude roll, pitch, and yaw offsets required to accurately calculate geolocation
- Earth Incidence Angle (EIA) was not included in original data
  - EIA is needed for intercalibration and geophysical retrievals
  - Estimates of EIA are grossly inaccurate without satellite attitude estimates
- Attitude is relatively stable over the life of each spacecraft
  - F08 and F10 are less stable than F11-F15
  - Yields Time varying attitude with estimated accuracy within ~0.1 degrees.
- Determination of high-frequency changes not possible with this approach
  - Expected impact for climate is generally negligible

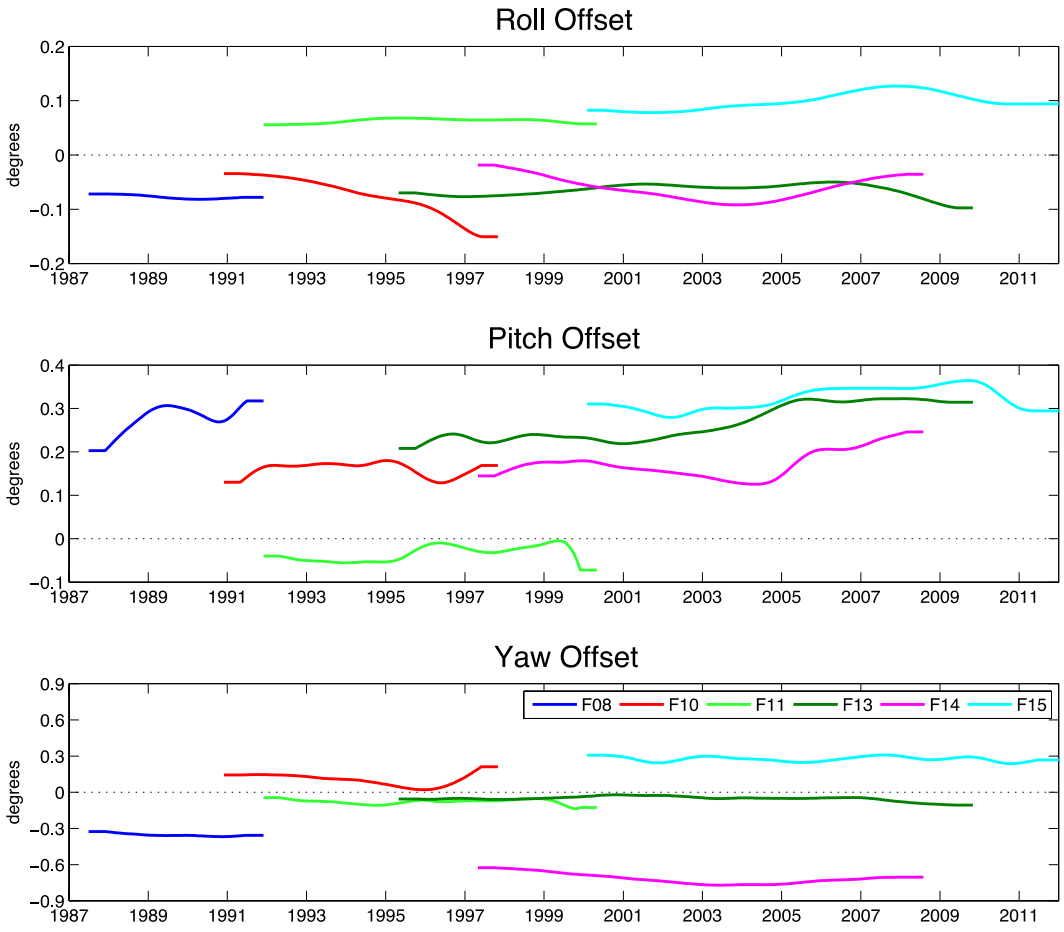




Estimation of Satellite Attitude



Before attitude correction

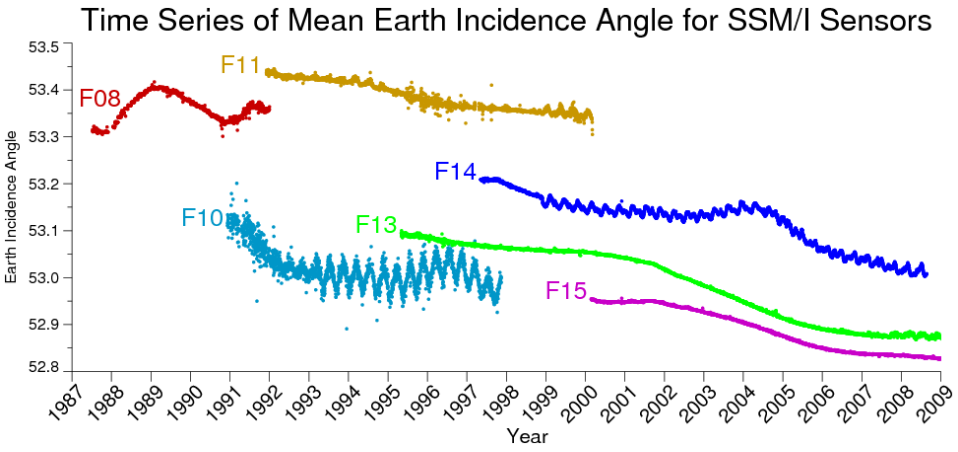


- Roll offset estimates are calculated based on slope of the mean Tb across the scan
- Pitch and yaw estimated by minimizing RMSE of mean ascending-descending Tb
  - Pitch/yaw errors are reflected by A-D due to land/ocean contrast

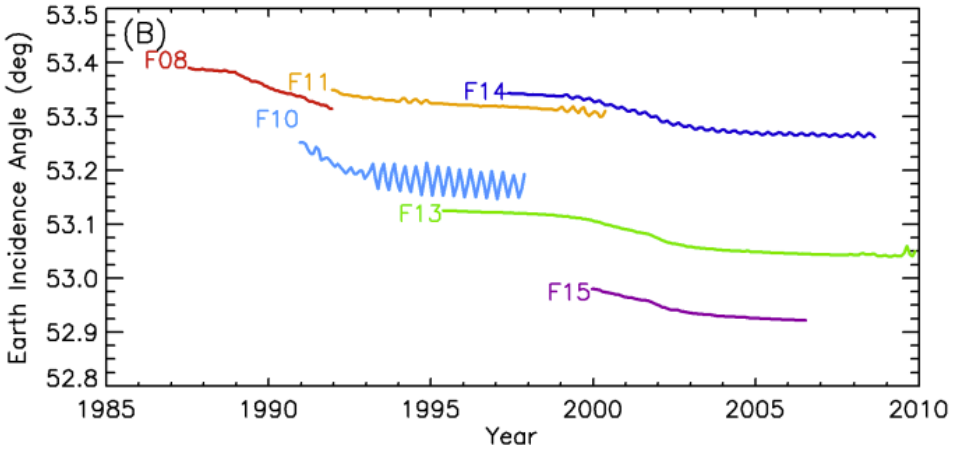
- Time-dependent variations are small, but there are significant differences between sensors

Variation in Mean EIA over Time

CSU FCDR

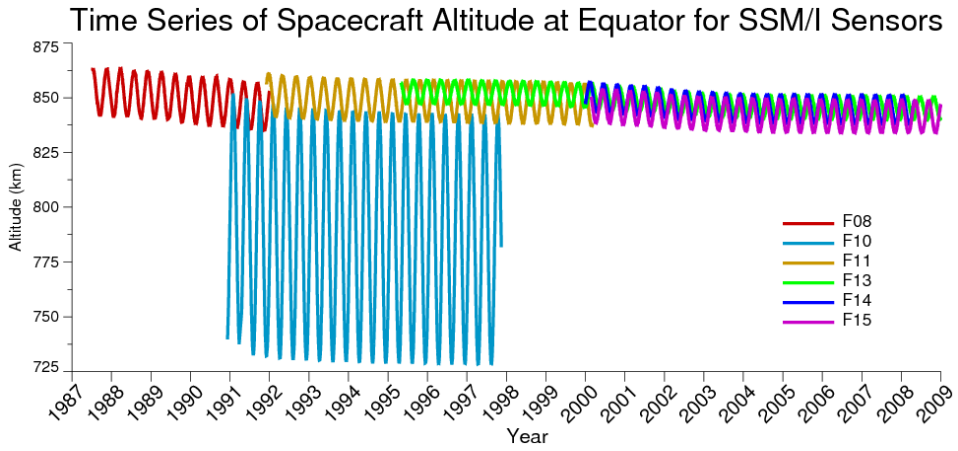


RSS FCDR



from Hilburn and Shie, 2011, RSS Technical Report.

CSU FCDR



- Differences in Mean EIA are small for some sensors (i.e. F11, F13, F15), but as much as 0.2 degrees or more for F10 and F14.
- Both CSU and RSS show similar trends in EIA over time (F08 is the exception).
- EIA trend due primarily to decrease in spacecraft altitude over time. Due to the larger eccentricity of the F10 orbit its variability over time is significantly larger.

Intercalibration

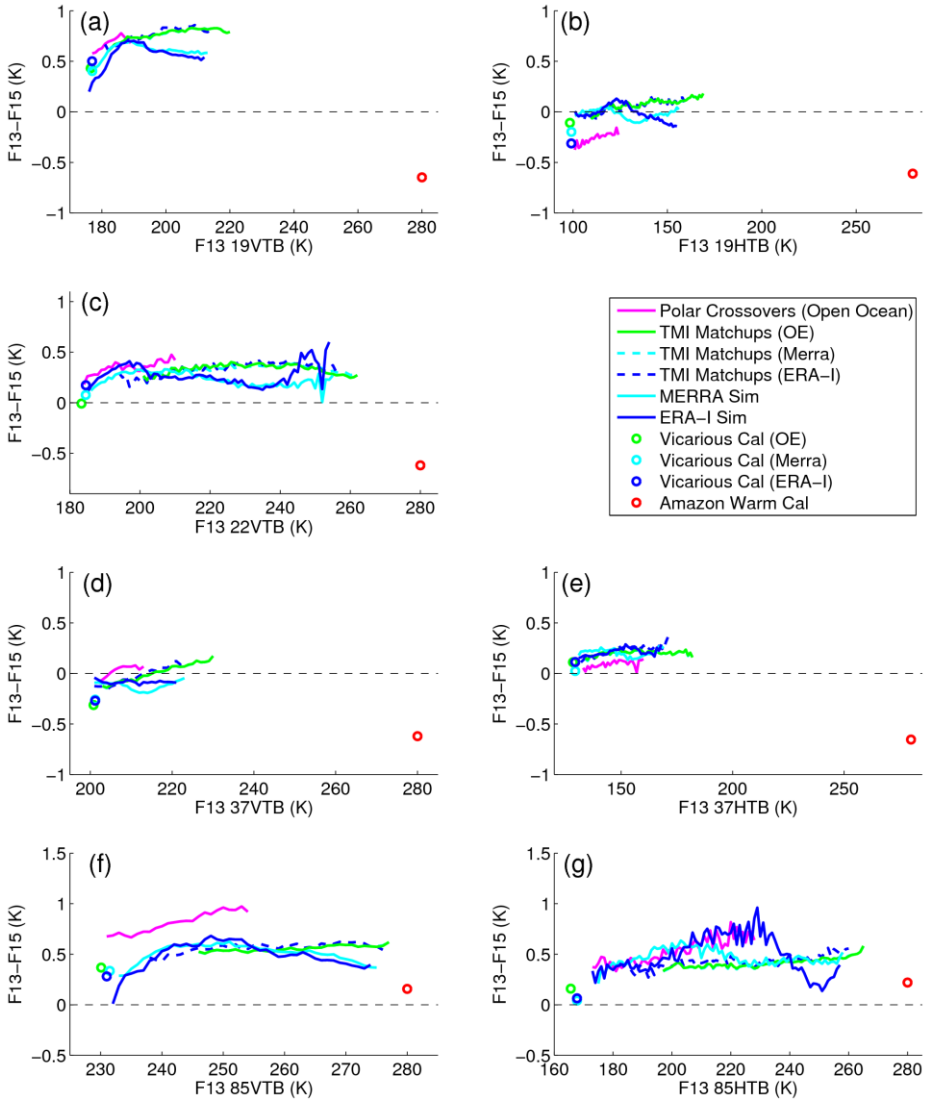
- Intercalibration is required to reduce erroneous climate trends due to calibration differences
  - Used 5 distinct techniques for SSM/I (total 10 implementations)
  - No warm-end calibration done yet for SSMIS sensors
  - Seek agreement between methods and use to estimate uncertainty of intercal
- Small EIA differences lead to intercal biases approaching size of intercal estimates
  - Must therefore remove differences due to EIA differences

Technique	Simulation of EIA differences	Sensors covered	Notes
Polar Matchups	ERA-I (on 1° equal area grid)	All except F08	Direct overlaps near poles; restricted to open ocean only (No overlap of F08 with any other sensor)
Reanalysis Transfer	Merra, ERA-I (both on 1° grid)	All Sensors	Simulate Tb from reanalysis matched to SSM/I; model is transfer standard
TMI Matchups	Merra, ERA-I, Optimal Estimation (all on 1° grid)	F11, F13, F14, F15, F16, F17, F18	Crossovers between TMI and SSM/I; used TMI as a transfer standard (Dec 97 forward only)
Vicarious Cold	Merra, ERA-I, Optimal Estimation (at native res.)	All Sensors	Estimate stable minimum Tb over clear-sky open-ocean
Amazon Warm	Physical model developed by Brown and Ruf (2005] (at native resolution)	F13, F14, F15	Done by Darren McKague (Univ. Michigan) Used homogeneous Amazon warm target; used TMI as a transfer standard to remove diurnal cycle

SSM/I Intercalibration Results

- Plot shows intercal estimates for F13-F15 as a function of F13 Tb
  - Vicarious Cold cal and Amazon warm cal are valid only for single Tb values
- Agreement is extremely good
  - Spread amongst colder techniques ~0.5K for most channels
  - Amazon Warm cal in less good agreement, but has 0.57K error
  - Larger (~1K) for F08 and F10 (not shown)

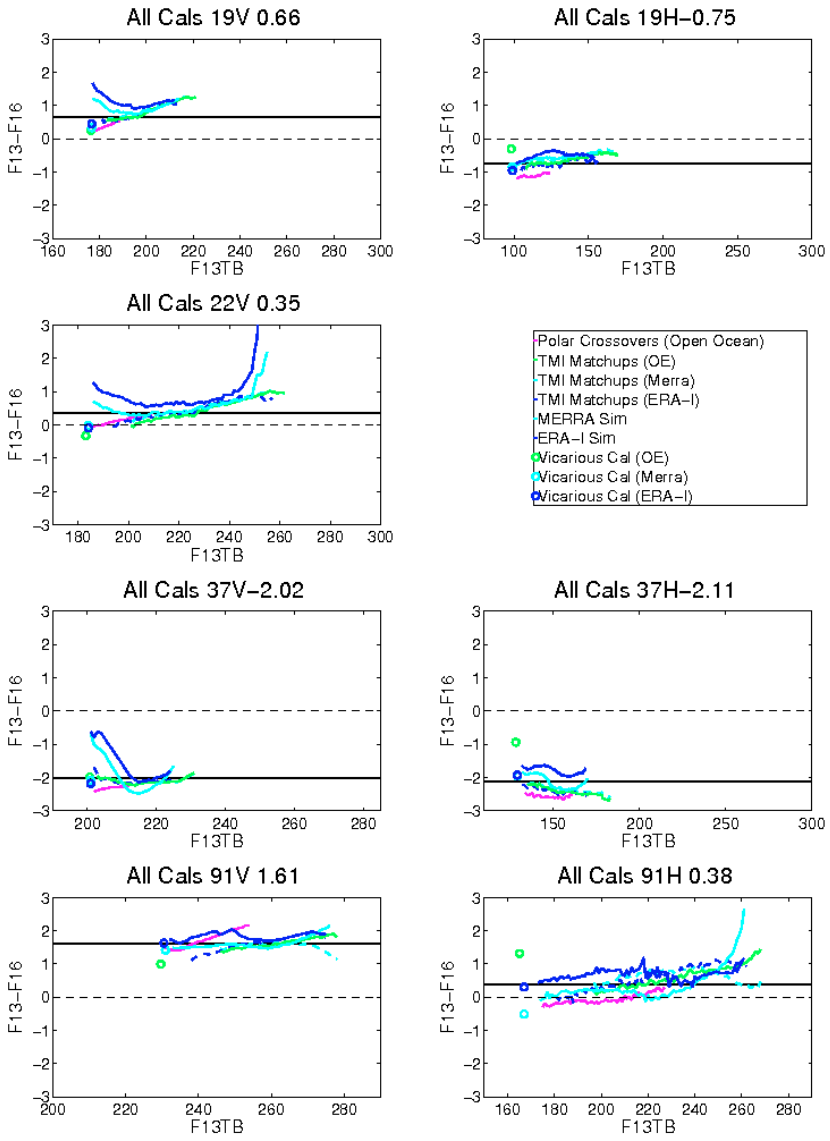
F13-F15



SSMIS Intercalibration Results

- SSMIS has several major, known issues
  - Worse for F16 than for F17, F18
  - Preoperational data not used currently
- Applied corrections for
  - Solar/lunar Intrusions
  - Emissive antenna
- Estimated attitude for EIA calculation
  - SSMIS has 6 feedhorns: use common satellite attitude with a fixed sensor alignment offset for each feedhorn
- Spillover and cross-pol corrections from operational code used, but not scene-dependent correction.
- SSMIS intercalibration
  - Same approach as used for SSM/I. Only applied to the 7 SSM/I equivalent channels
  - Beta SSMIS numbers look good.
  - Differences with F13 are slightly larger than for other SSM/I sensors, but consistent

F13-F16



SSMI/SSMIS Intercalibration

Mean Difference

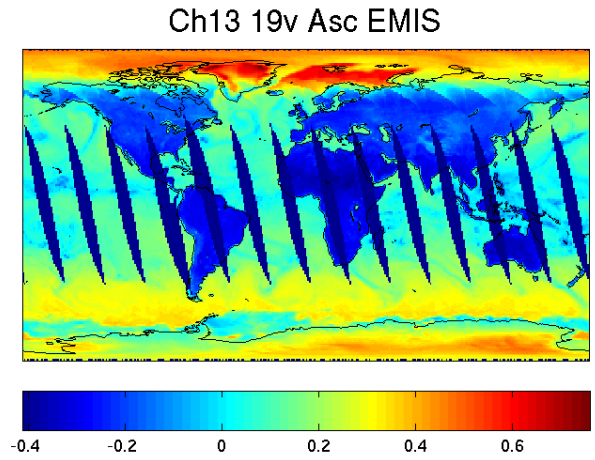
Sat	19V	19H	22V	37V	37H	85V/91V	85H/91H
F08	0.65	0.16	1.42	0.82	1.64	1.91	-0.52
F10	0.05	0.16	1.27	-0.21	0.48	0.37	0.11
F11	0.19	-0.16	0.15	0.67	0.36	-0.55	-1.22
F13	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F14	0.34	-0.20	0.06	-0.20	0.00	0.45	0.35
F15	0.29	-0.26	-0.13	0.24	0.00	0.26	0.09
F16	0.67	-0.75	0.36	-2.04	-2.13	1.59	0.38
F17	0.25	-0.95	-0.40	-2.39	-1.54	3.59	2.51
F18	0.73	0.28	0.12	-1.38	-0.76	3.01	2.28

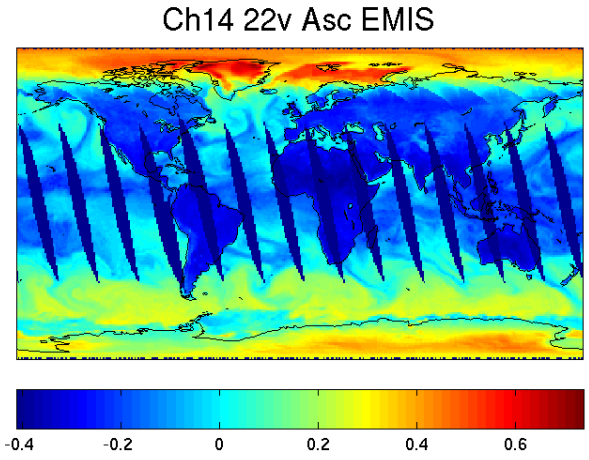
Standard Deviation

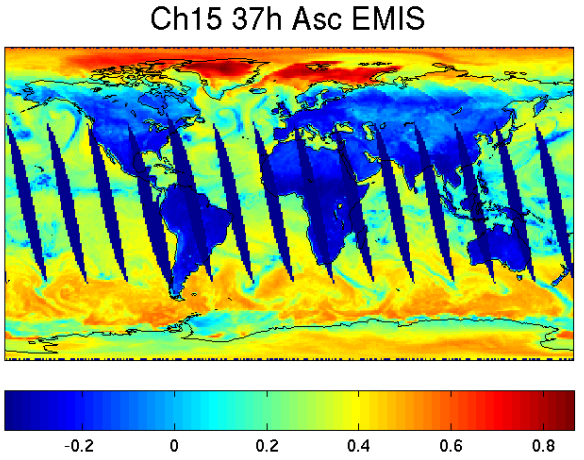
Sat	19V	19H	22V	37V	37H	85V/91V	85H/91H
F08	0.05	0.05	0.07	0.03	0.05	0.41	0.20
F10	0.03	0.04	0.09	0.01	0.04	0.07	0.13
F11	0.01	0.03	0.05	0.02	0.02	0.05	0.11
F13	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F14	0.11	0.05	0.08	0..05	0.07	0.04	0.04
F15	0.09	0.02	0.07	0.05	0.03	0.07	0.04
F16	0.10	0.05	0.12	0.05	0.11	0.06	0.08
F17	0.04	0.05	0.06	0.06	0.09	0.04	0.10
F18	0.06	0.08	0.06	0.05	0.09	0.07	0.08

Emissive Antenna Correction
SSMIS Only

- Reflector coating on F16 (and F17) is degraded
  - Emissivity is 1-2% (graphite epoxy)
- Correction was implemented in UPP code (primarily used for model ingest)
  - Antenna temperature not available, so lagged reflector arm temperature used
- Maps show magnitude of correction for three channels
  - Correction is generally around -0.5 to 2K for F16
- Currently investigating this correction due to seasonal variations in ascending vs. descending Tb values found by UCF as part of XCAL



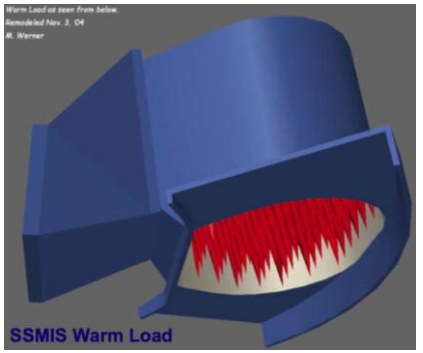




Solar/Lunar Intrusion Correction

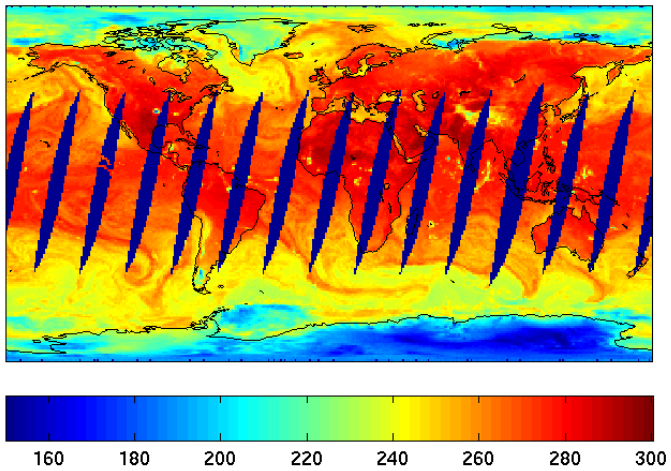
SSMIS Only

- Solar intrusion into warm load was detected for F16
  - Intrusions rapidly heat warm load tines (ie: the pyramids), but this is not well characterized by warm load temperature sensor
- Direct and indirect reflections into warm load for F16
  - Indirect intrusion only on F17 and F18
- Lunar intrusion into cold sky reflector also a problem
- Correction based on FFT smoothing of gain implemented
  - Magnitude of correction often low, but this is dependent on the size of anomaly
- Currently investigating impact of warm load intrusion on F16 37h channel (currently no correction applied to this channel).

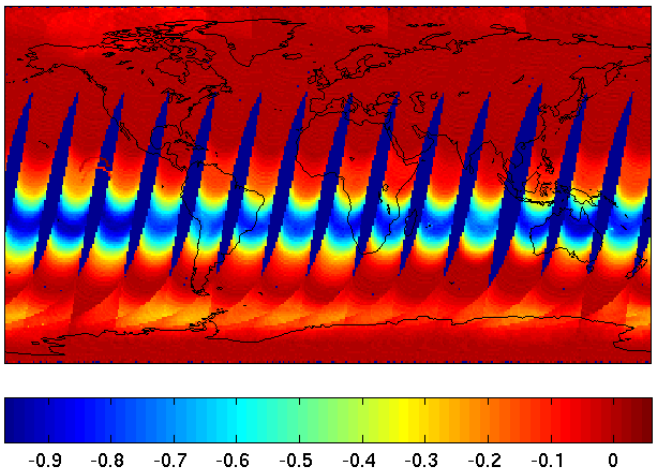


SSMIS F16 Cal/Val Document

91v Descending Mean TB

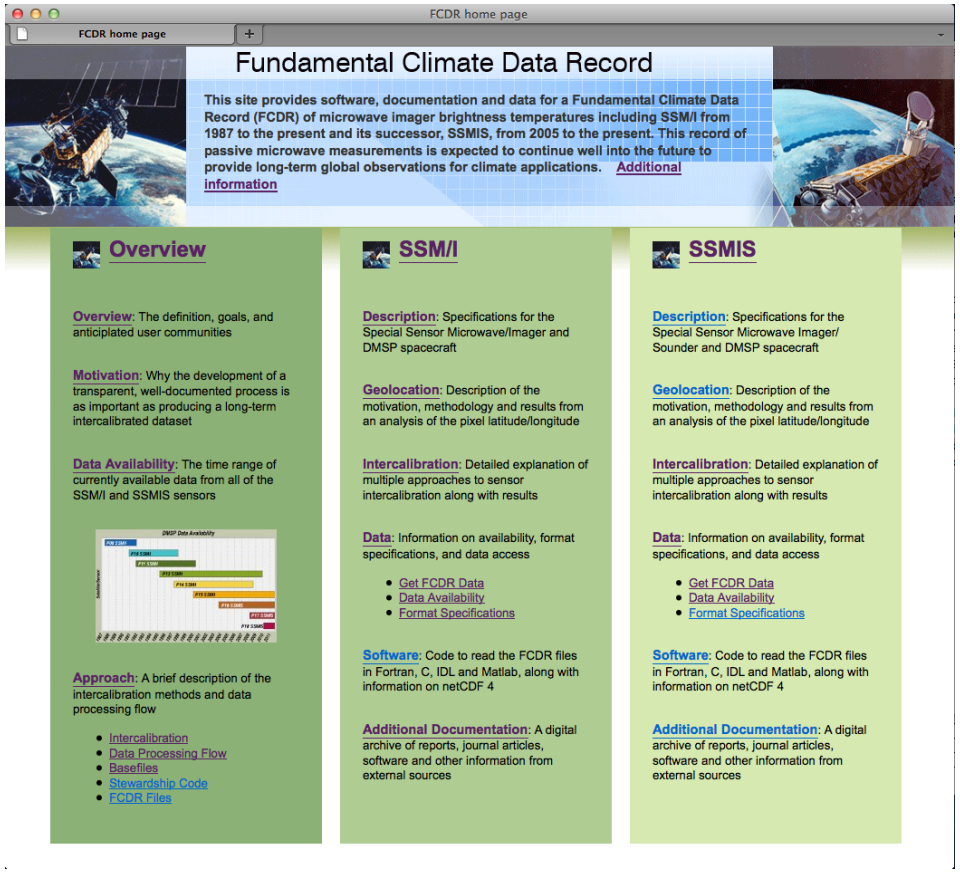


Magnitude of Solar Intrusion



Documentation

http://rain.atmos.colostate.edu/FCDR



- Goals
  1. Preserve existing record of satellite/sensor characteristics, known issues, cal/val activities etc. (This is critical before information on early SSM/Is is lost!)
  2. Provide sufficient documentation for transfer of FCDR processing to NCDC and for adapting processing code and techniques to future sensors
  3. Allow for future developments/improvements to FCDR processing through the use of well documented modular procedures.
- Progress
  1. Collect and digitize any available documentation on the sensor characteristics, dataset formats, cal/val activities, software etc.
  2. FCDR processing code is part of documentation. It will be clean, modular, well commented, and publically available.
  3. Fully document the QC, TA->TB, cross-track bias corrections, geolocation adjustments, intercalibration, etc. along with how all of the coefficients used in the processing code were derived (in PDF form kept with processing code).
  4. Documentation is available via web site. Note that this is a work in progress.

Summary

- Critical issues for construction of SSMI/SSMIS FCDR
  - Quality Control
  - Accurate estimation of EIA for each pixel
  - Intercalibration between sensors
- Beta version of SSM/I FCDR looks good
  - Clear signs that recalculation of EIA has lead to far more consistent record
  - Results from multiple intercalibration techniques are in excellent agreement
  - Sensor differences were found to be generally small. In particular, differences between cold and warm calibration results are small enough that decision was made to use simple offset adjustments to calibration.
- Beta version of SSMIS FCDR generally looks good
  - Currently revisiting warm-load intrusion and emissive antenna corrections (working with members of the PMM XCAL team)
  - Not surprisingly differences with F13 are somewhat larger than for other SSM/I sensors, but with the exception of 37 and 91 GHz channels are within 2K.
- Importance of soliciting feedback from users

Ta to Tb

- Two Ta to Tb techniques applied in operational FNMOC code
  - Spillover and cross-polarization: applied to all channels, except 19, 22, 37 and 91
  - "APC" correction – is actually a scene-dependent intercalibration procedure applied to channels 19, 22, 37 and 91
    - TAs for these channels are compared to SSM/I from F13, F14 or F15 TBs and offset/slope used to transform
    - Correction is slope and offset by surface type
- Note that we apply only the Spillover and cross-polarization correction and do our own intercalibration.