The End-of-Mission Climate Quality Calibration for the JMR

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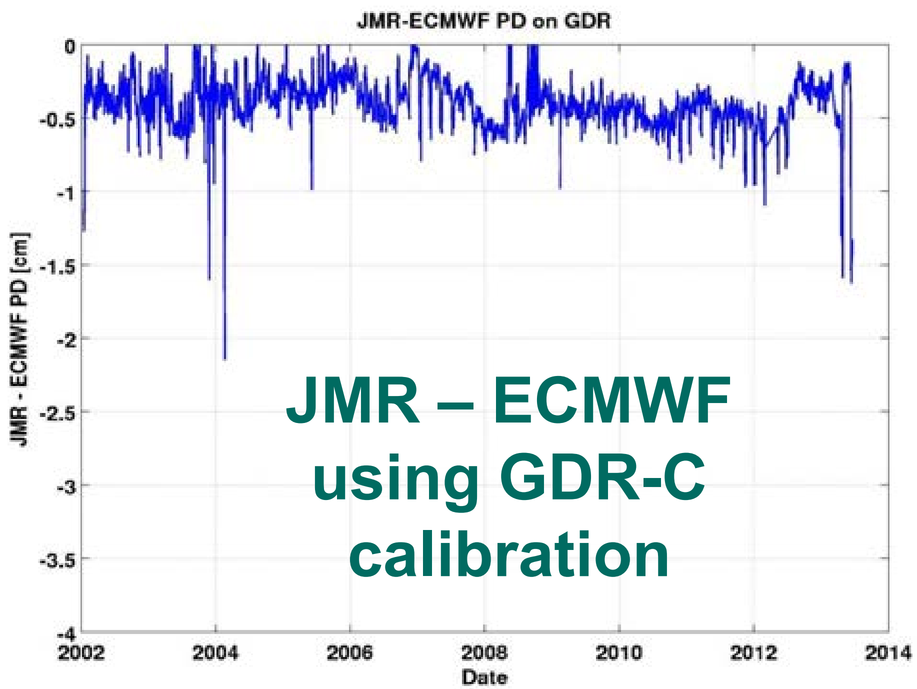
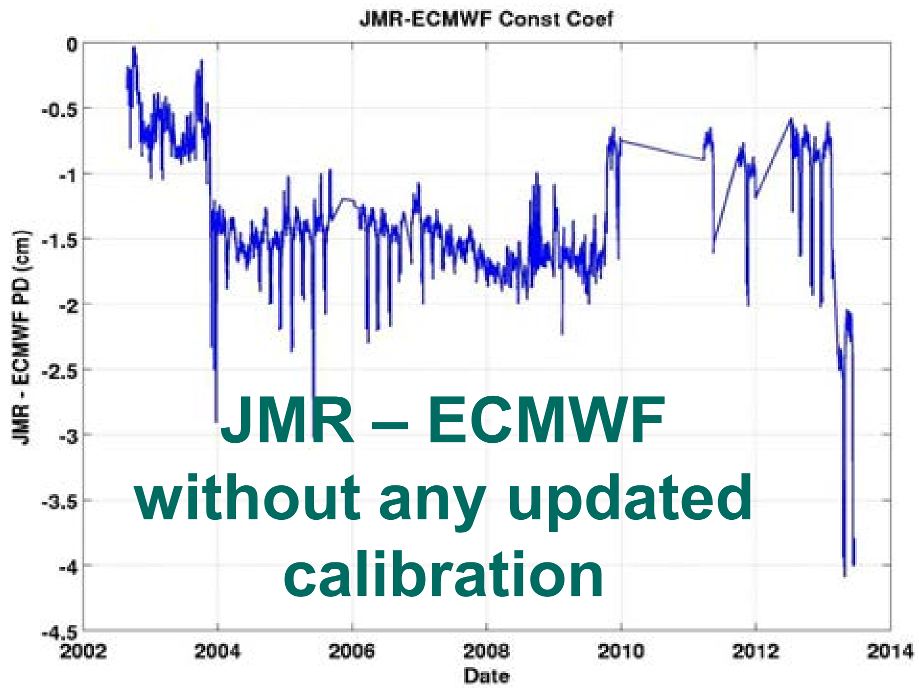
Overview of JMR GDR-C Calibration

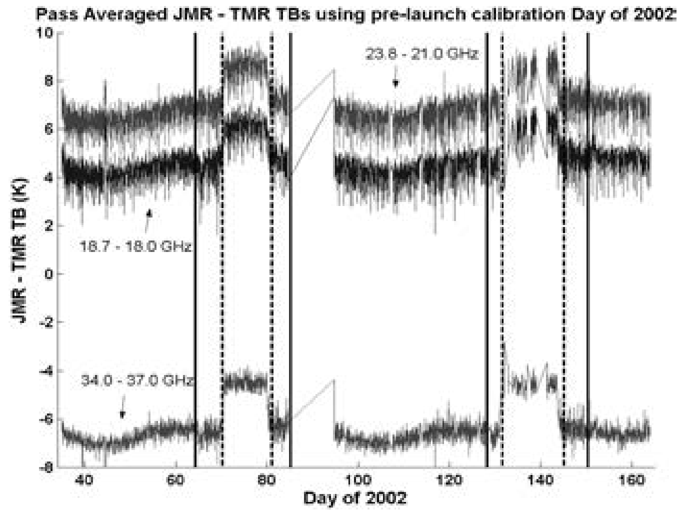
- JMR calibration updated several times during the mission to remove calibration shifts
- 2-4 cm change in PD over mission would be present if nothing had been done



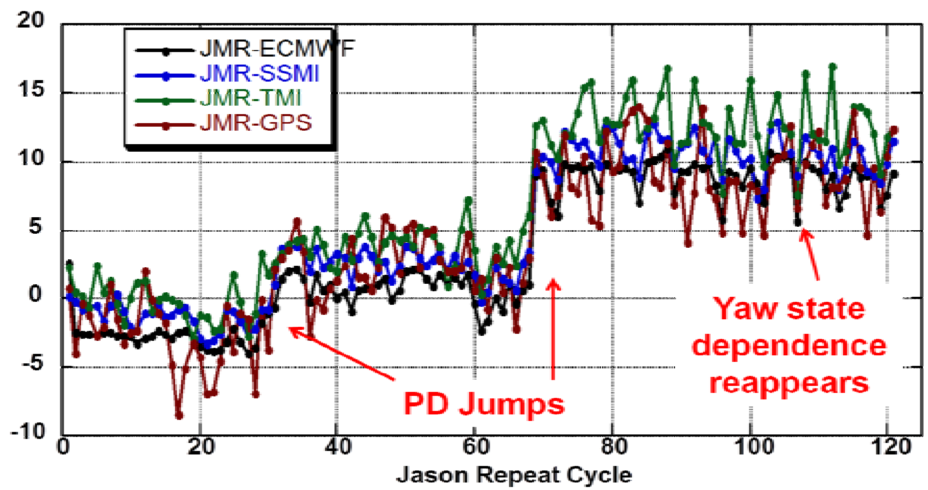


Overview of JMR Calibrations To Date

- **July 2002 - GDR-A**
  - Pre-launch calibration updated after cal/val phase to remove biases relative to TMR and remove "yaw state" dependence



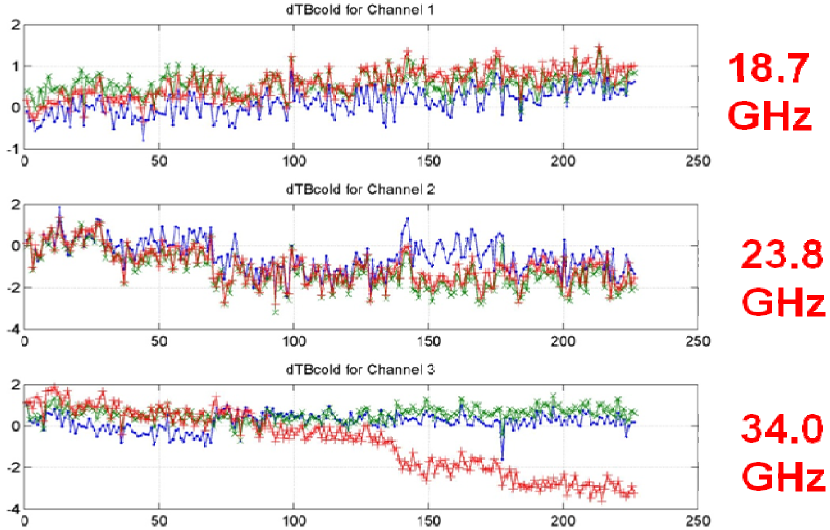
- **September 2005 - GDR-B**
  - Corrected calibration shifts after cycle 30 and cycle 69 using three sets of calibration coefficients.
    - Cycles 1-30, 31-69, 70-present.
  - Updated APC algorithm to mitigate geographically correlated errors ~200-500 km from land

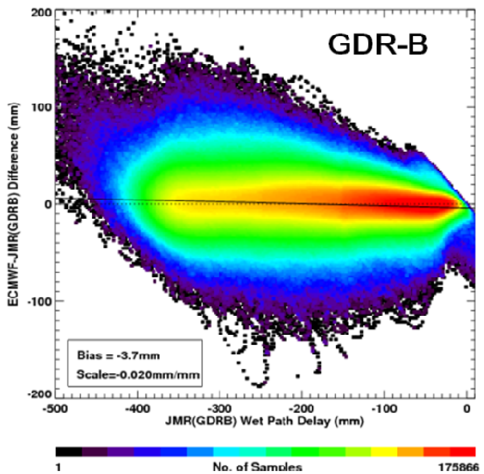


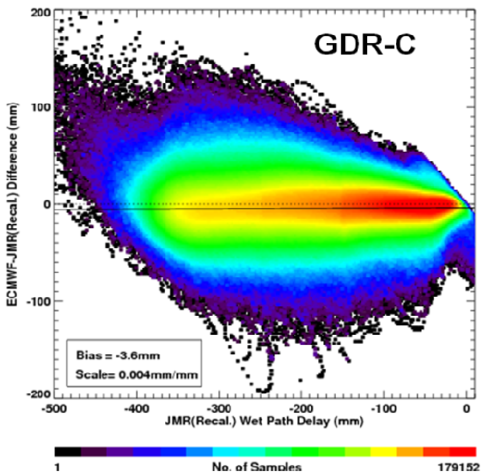
Overview of JMR Calibrations To Date

- **April 2008 - GDR-C**
  - Implemented time-variable calibration coefficients with new coefficients once per cycle.
    - Once per cycle coefficients derived from moving 30-day data window.
  - Adjusted path delay algorithm coefficients to remove scale error
    - Error in coefficients carried over from an error in the post-launch calibration of the TMR.

JMR TB Drift Before Calibration







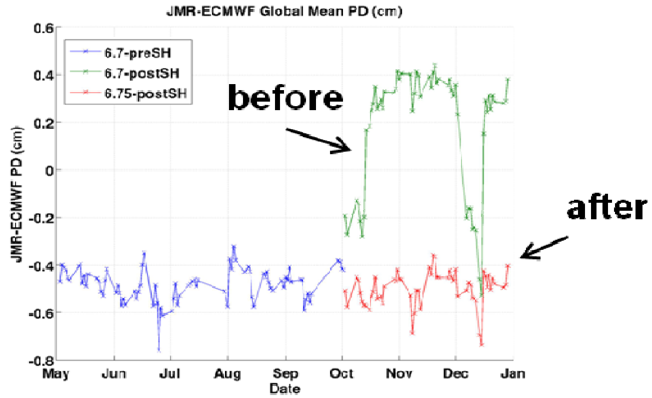
Overview of JMR Calibrations To Date

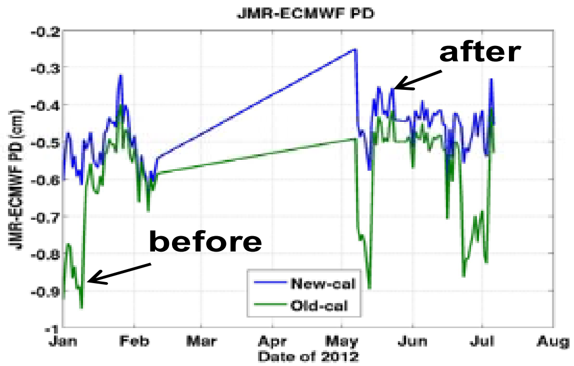
- **January 2010**
  - ~1cm path delay jump observed after September 2009 safehold event
  - 23.8 GHz TB calibration corrected prior to GDR processing

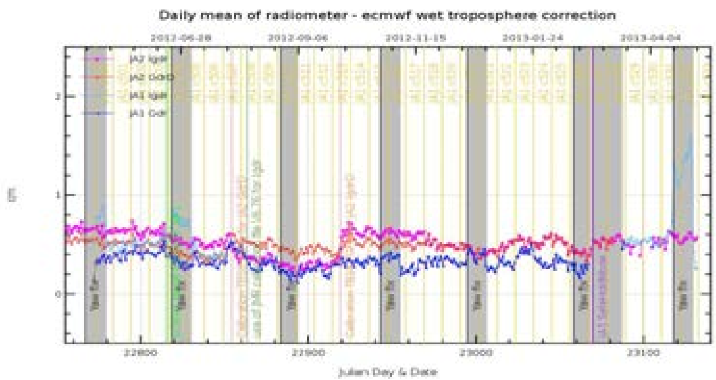
- **July 2012**
  - Corrected 23.8 GHz calibration after Feb/March 2012 safehold event to remove ~4mm yaw state dependence

- **July 2013**
  - Adjusted calibration after February 2013 safehold to remove 7mm yaw state bias

PD Error

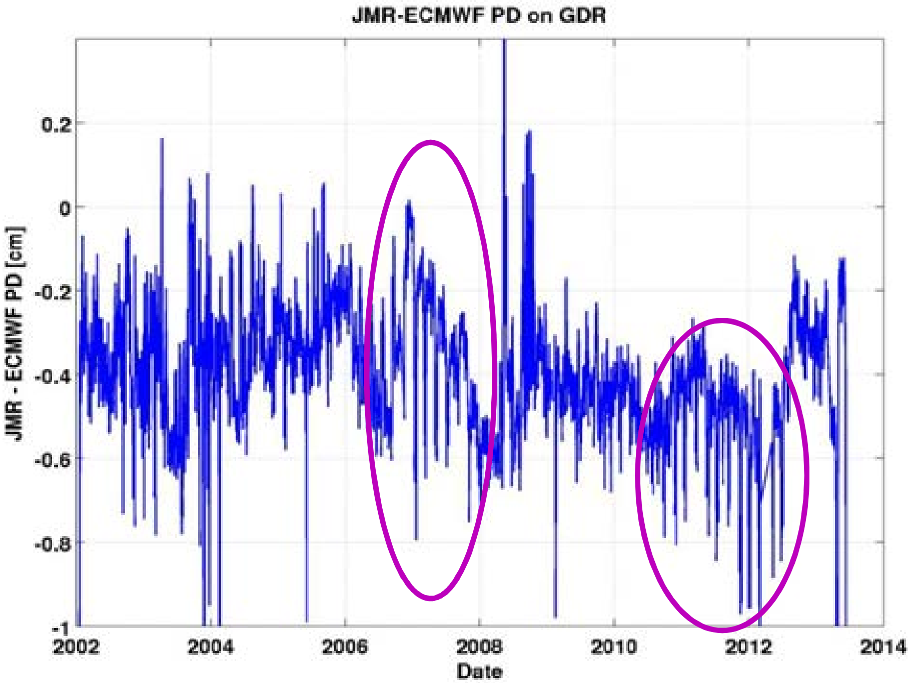






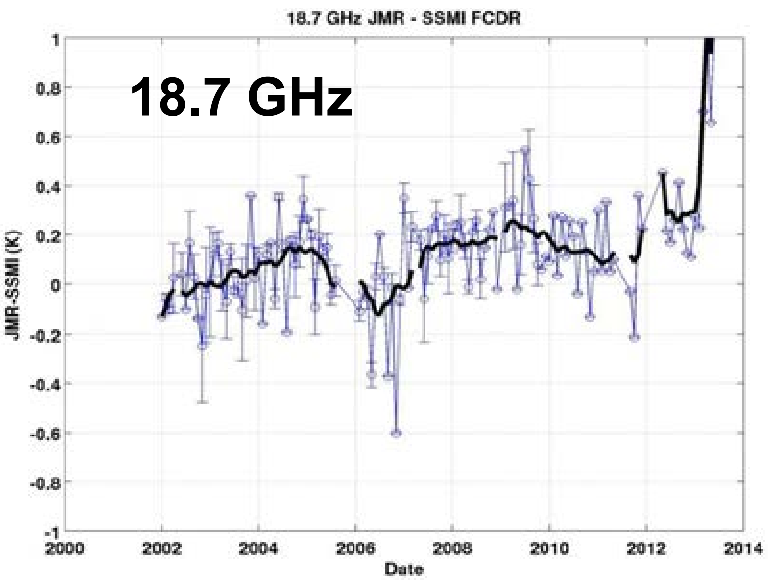
End-of-Mission Calibration

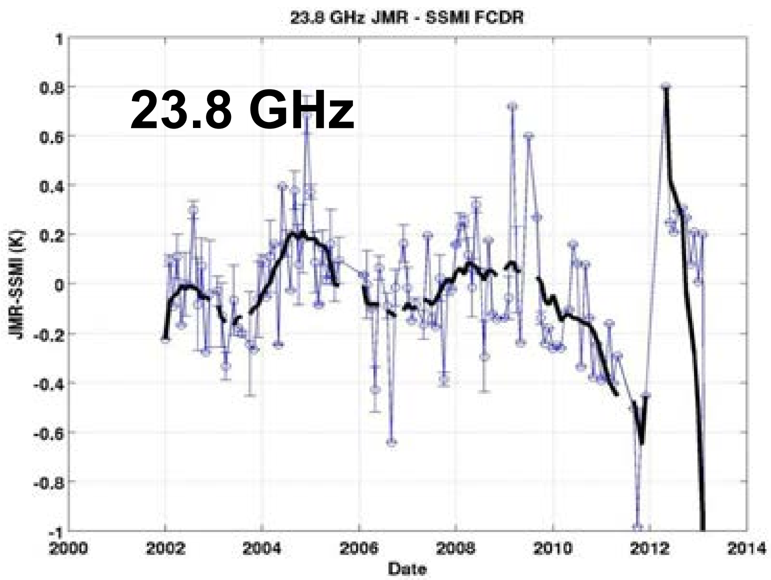
- End of mission re-calibration builds on previous calibration that has been done (e.g. applied on top of existing corrections)
- Remaining issues are to address both short term and long term residual calibration instability evident in the data
  - Long term drift addressed by calibrating the TBs to the SSM/I FCDR
  - Residual yaw state errors derived using PD and WS model comparisons
- Additionally, the algorithms are brought to Jason-2 AMR GDR-D standards



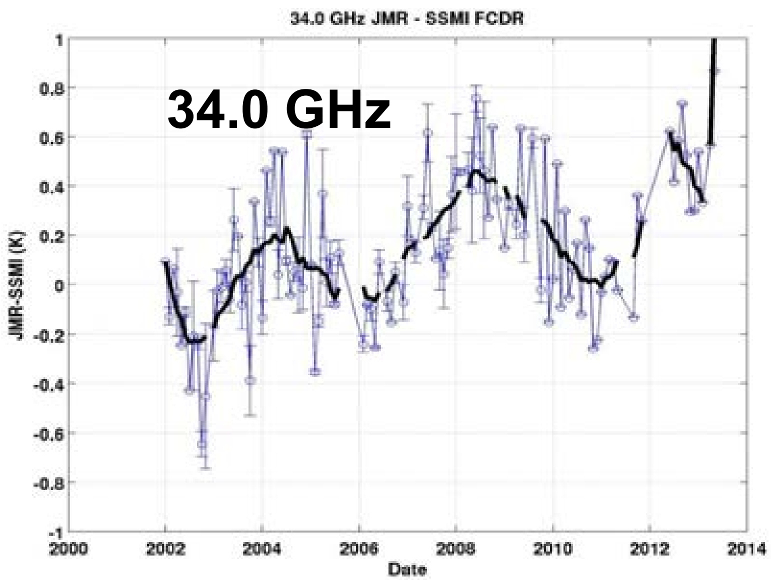
Both long term drifts and yaw state errors remain

Cold End TB Drift (Ocean Data)

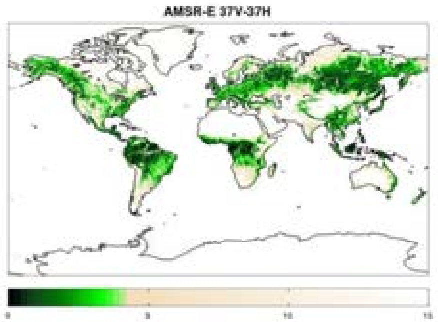


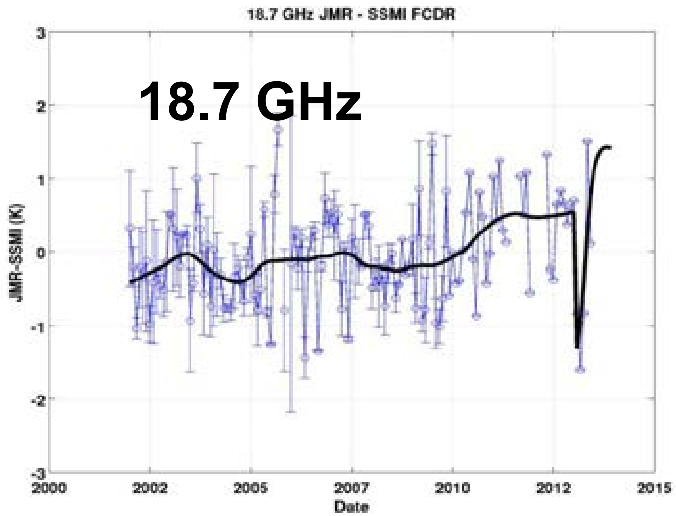


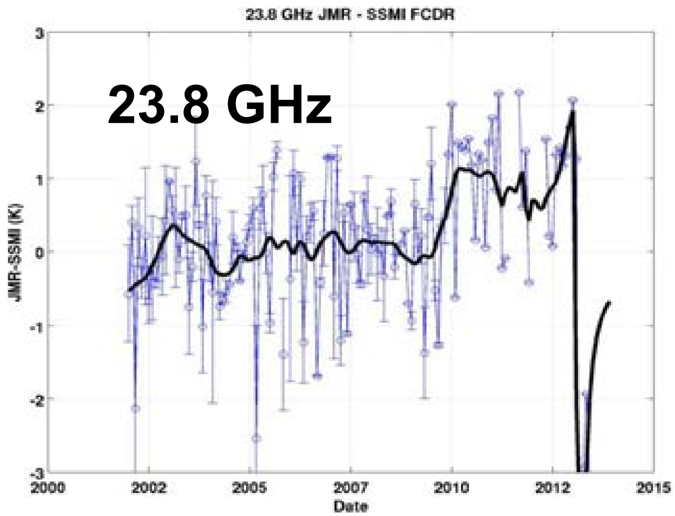
- For each month, computed average JMR calibration bias using SSMI FCDR over ocean
- Applied 12-month running average to isolate long term component
  - Short term component removed separately



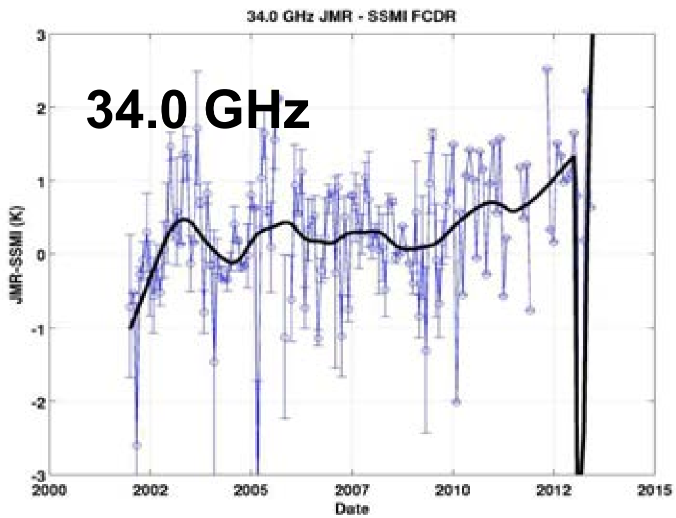
Warm End TB Drift (Rainforest Data)







- Computed differences between JMR TBs and SSMI over heavily vegetated land regions (e.g. rainforest) to constrain the warm end TB drift (~280K)
- Warm end comparisons noisier
  - 2-year running average fit to data
- Largest change (during prime mission) was 1K jump in the 23.8 GHz channel in 2010



Drift Correction

- Drift correction is applied to final GDR –C calibration

- Takes the form of a time variable scale and offset correction

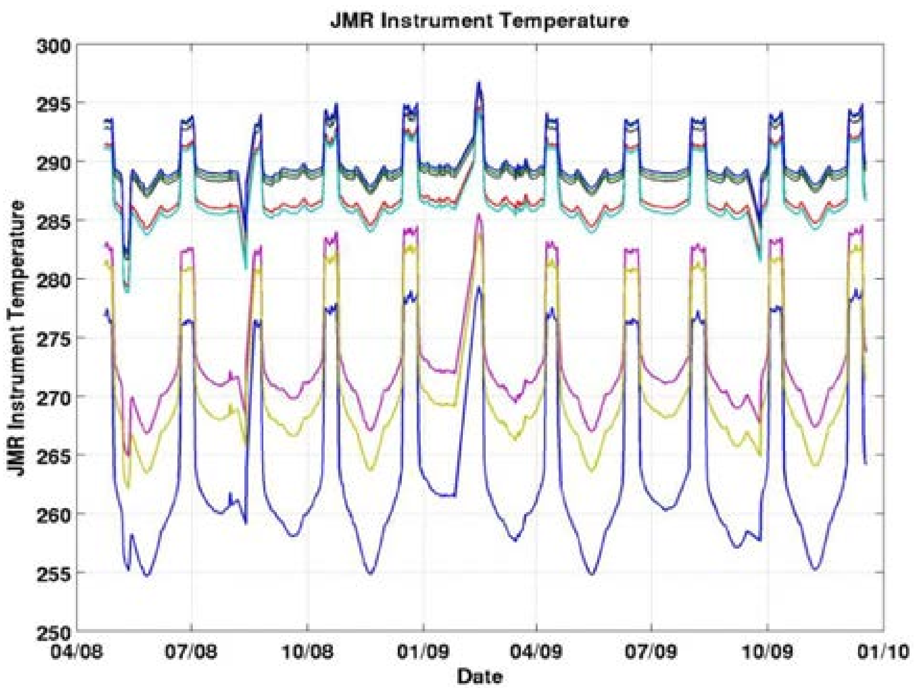
$$TB(ch,t)_{corrected} = TB(ch,t)_{uncorrected} - \Delta T_B(ch,t)$$

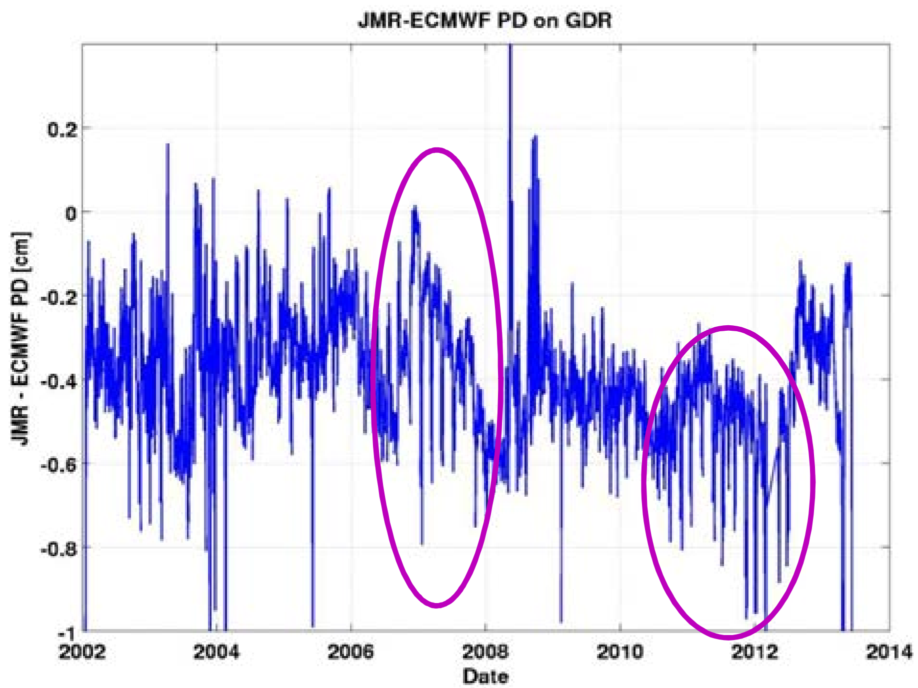
$$\Delta T_B(ch,t) = c_0(ch,t) + c_1(ch,t)TB(ch,t)_{uncorrected}$$

- Coefficients are derived by forcing agreement with the running average of the SSM/I FCDR biases over the ocean (cold end) and over the rainforest (warm end)

Instrument Temperature Correction

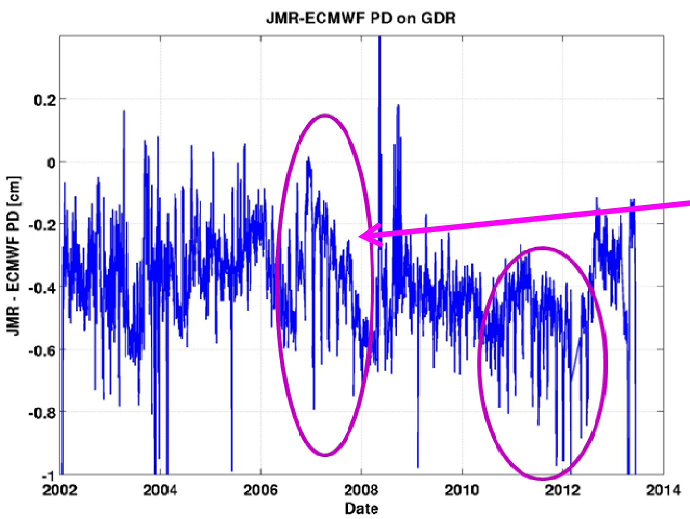
- “Yaw-state” dependence periodically resurfaces (creates 60-day signal)
- Results from instrument temperature dependency of calibration changing over time

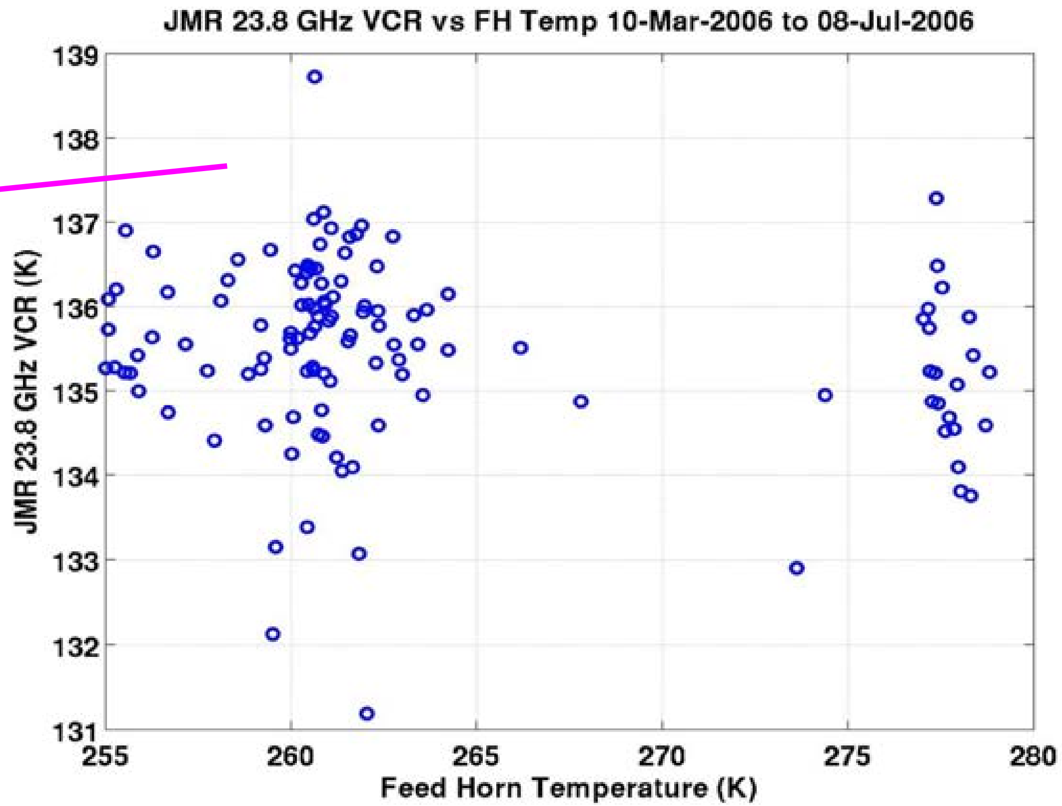




Instrument Temperature Correction

- This effect can be typically removed by binning TB references as a function of instrument temperature and removing the slope
- Because the time period was short, and the temperature dependency was a variable with time, the TB comparisons were too noisy to use this approach



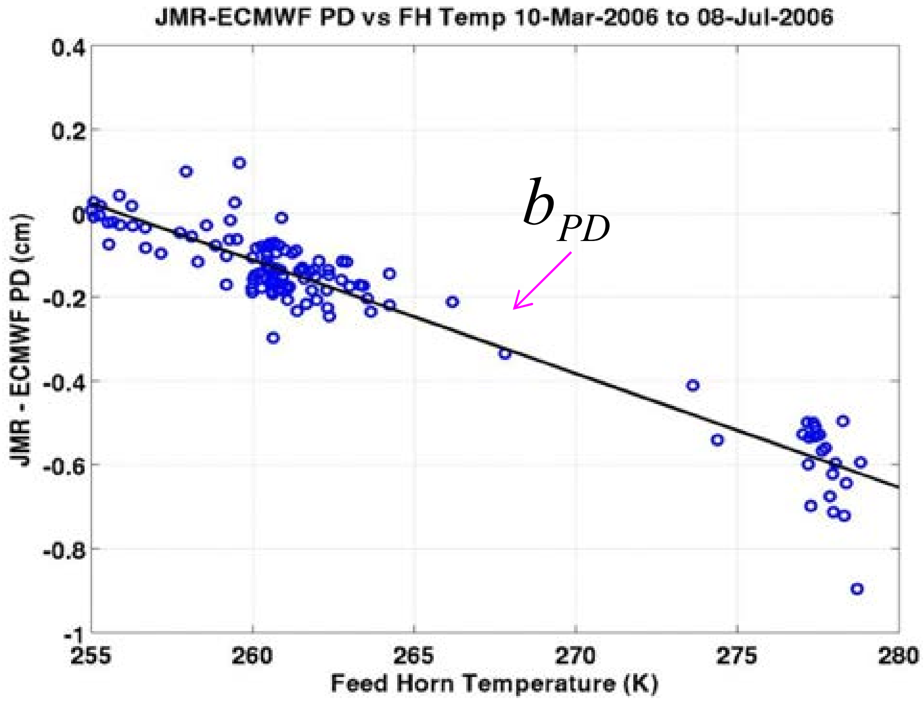


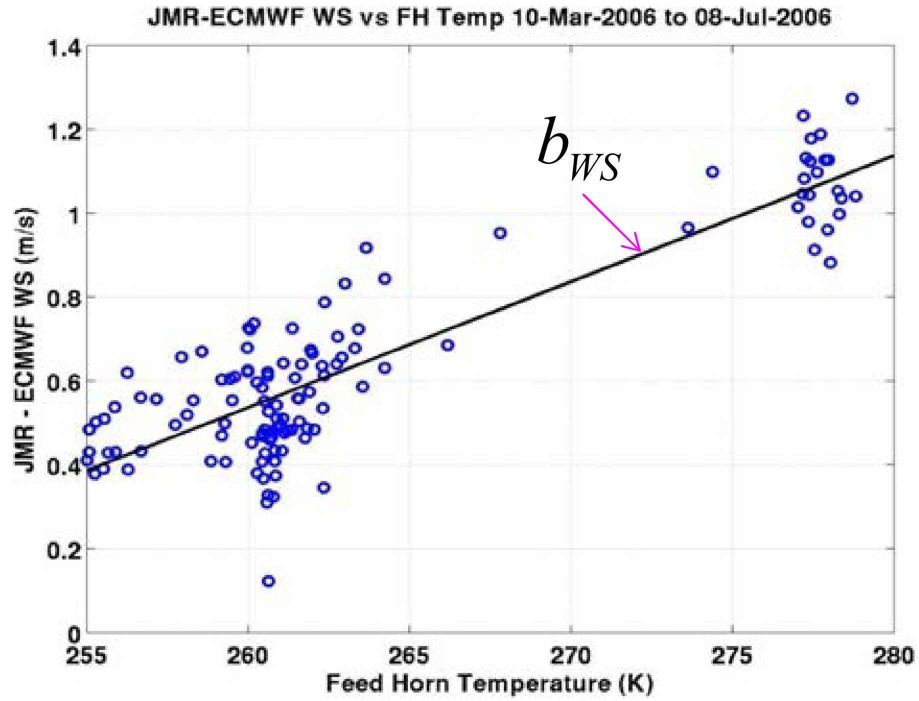
Instrument Temperature Correction

- Alternative approach was developed using both the path delay and wind speed comparisons to the model to determine TB instrument temperature dependency

$$\begin{bmatrix} b_{TB18} \\ b_{TB23} \end{bmatrix} = \begin{bmatrix} c_{18}^{PD} & c_{23}^{PD} \\ c_{18}^{WS} & c_{23}^{WS} \end{bmatrix}^{-1} \begin{bmatrix} b_{PD} \\ b_{WS} \end{bmatrix}$$

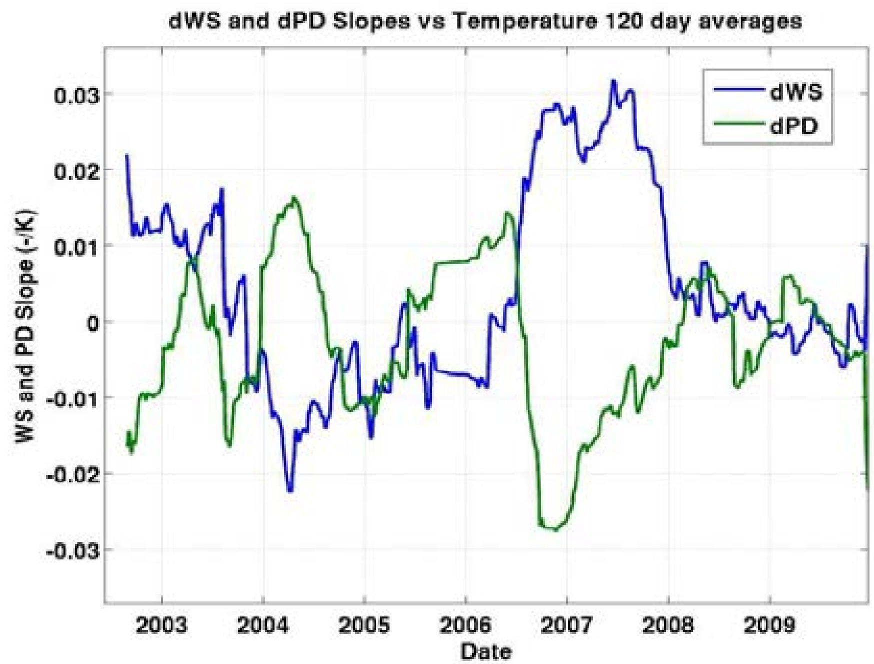
Coefficients are from linearized global retrieval algorithm

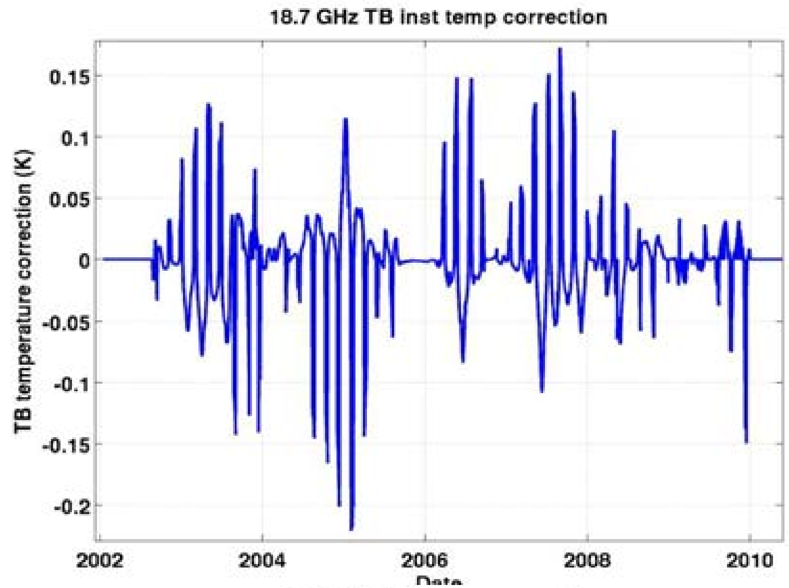


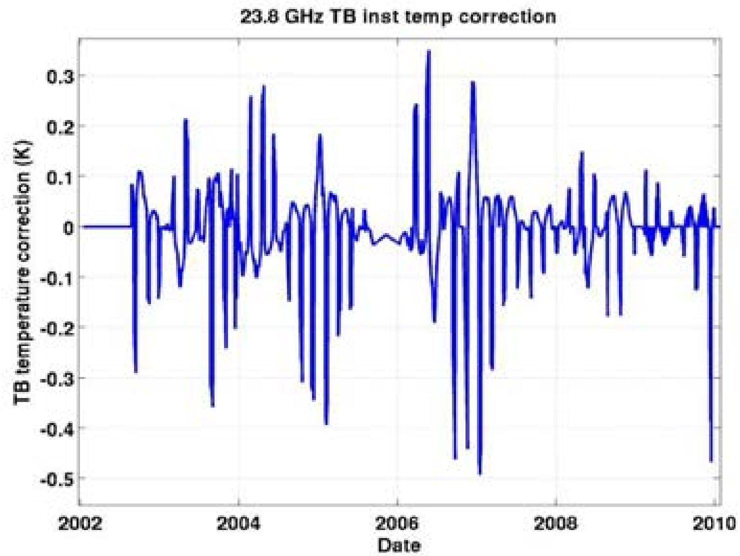


Instrument Temperature Correction

- Slopes computed using running 120-day window
- Applied to TB time series in addition to long term drift
  - < 0.2K correction in 18.7 GHz channel
  - Up to 0.4K in 23.8 GHz channel

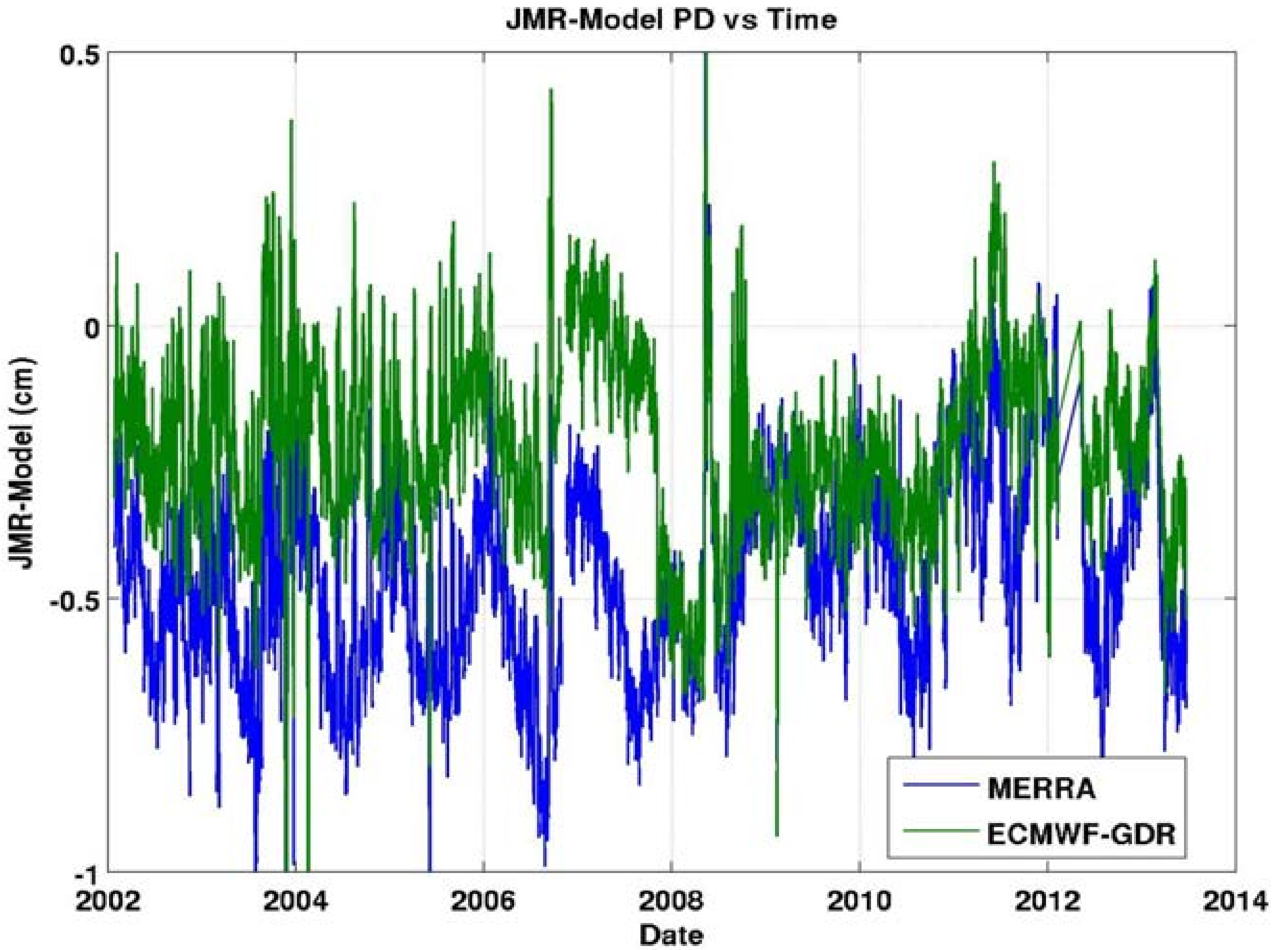






PD Validation

- PD compared to time series from ECMWF and MERRA
- Long term drift < 1mm/decade compared to these models

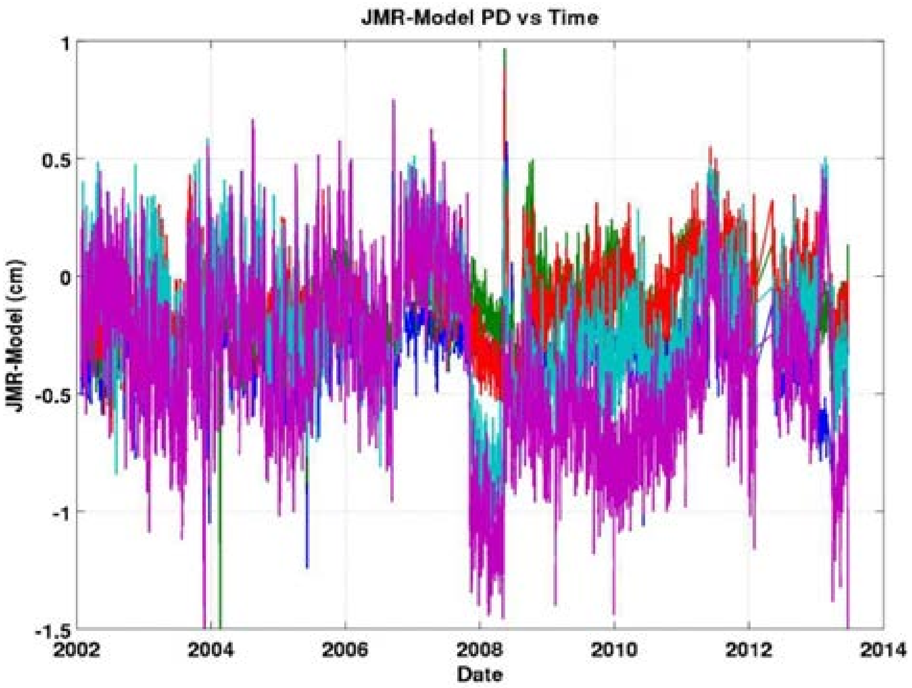


ECMWF-GDR
MERRA

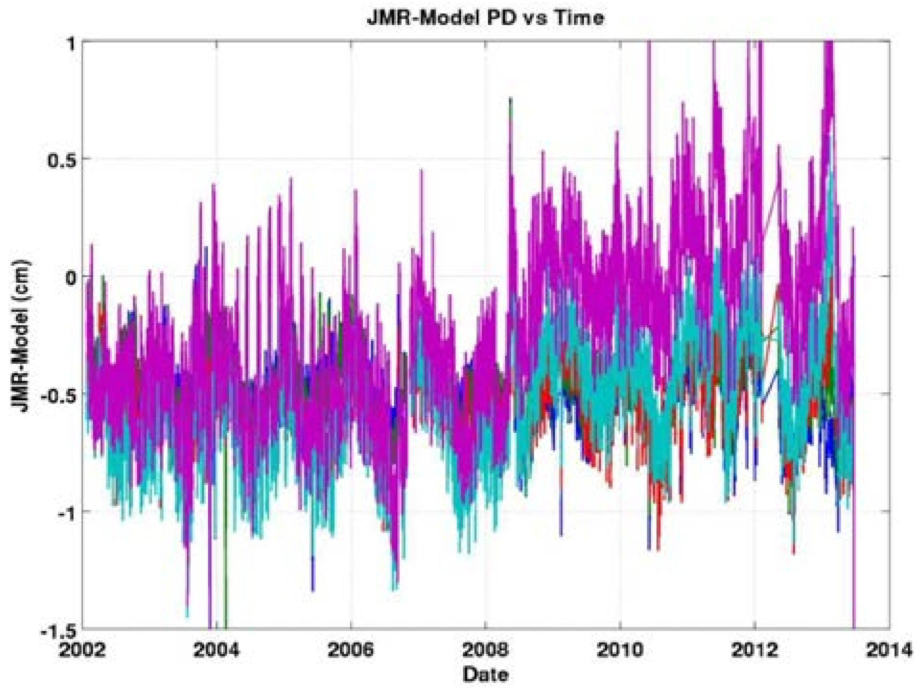
PD Validation Stratified

- PD compared to model for low, medium and high PD ranges to assess any geographically correlated drift
- No definitive drift over all PD ranges

ECMWF-GDR

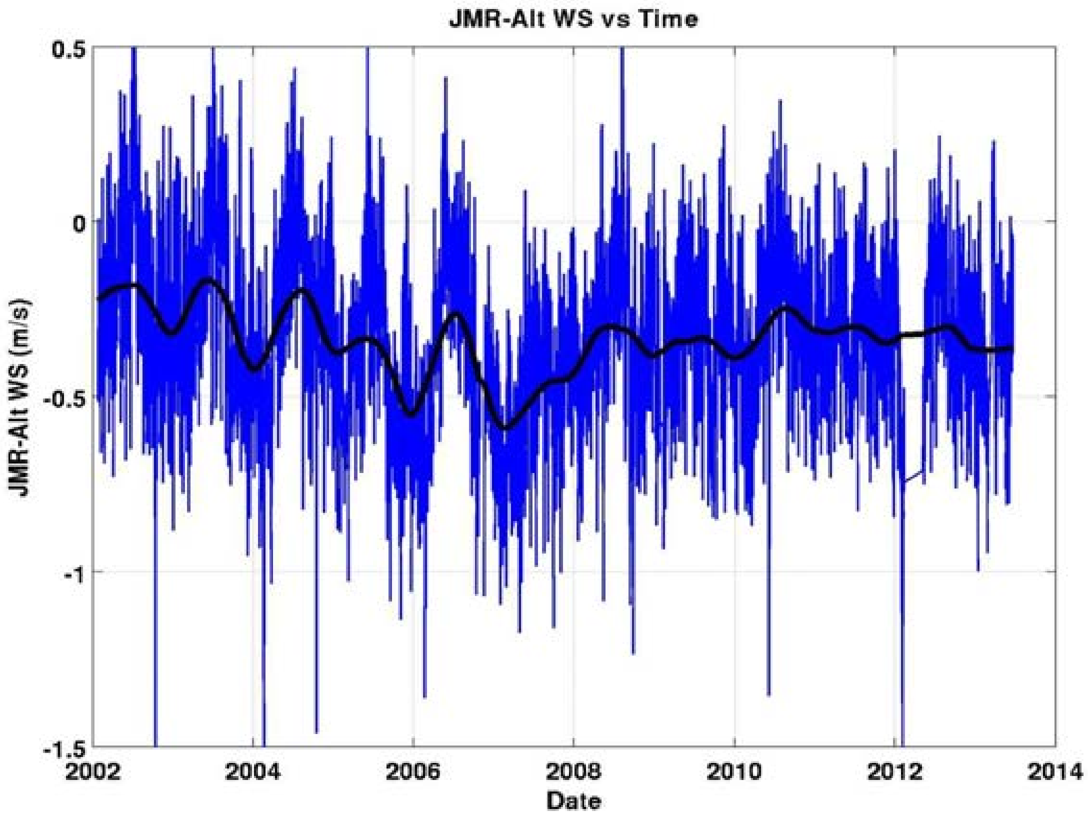


MERRA



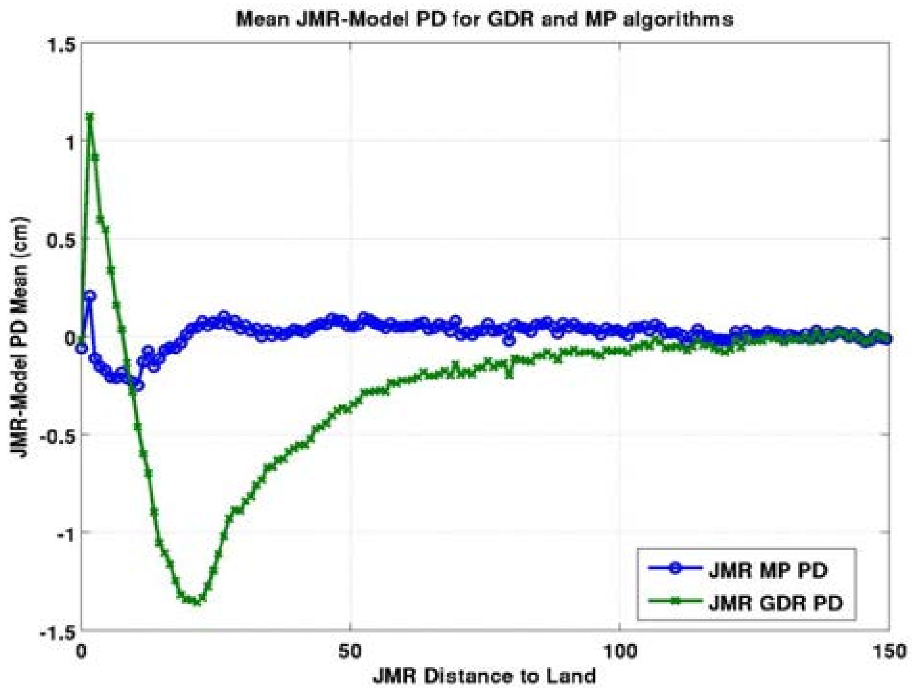
Wind Speed Time Series

- Wind speed compared to altimeter vs time shows < 0.2 m/s drift over mission
- Independent comparison that is consistent with < 1mm PD drift over mission

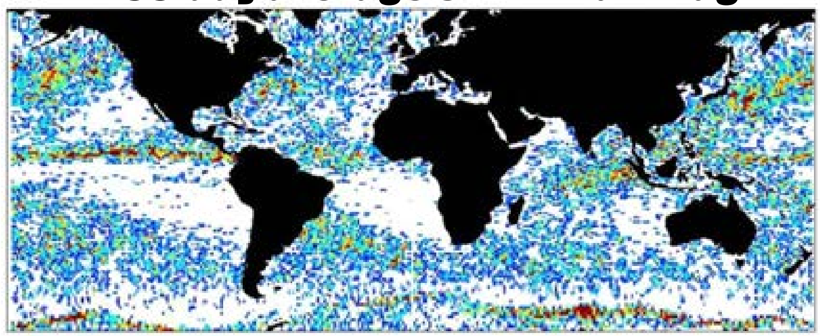


Algorithm Updates

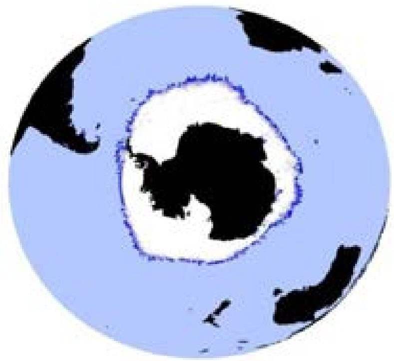
- JMR algorithms updated to Jason-2 AMR standards
  - All-weather sigma-0 attenuation correction algorithm
  - Consistent sea ice and rain flagging
  - Near land path delay retrieval algorithm



200-day average of AMR rain flag



Cycle 1-5 average of AMR sea ice flag



Summary

- JMR end-of-mission re-calibration effort is complete
  - Long term calibration constrained by inter-satellite calibration to the SSM/I FCDR and on-Earth references
  - Residual time variable yaw-state (60 day) dependencies removed

- Month-to-month calibration uncertainty about 0.2K (~2mm in PD)
  - 2 mm/yr uncertainty for any 1 year
  - < 1 mm/yr uncertainty for time spans greater than 2 years
  - << 1 mm/yr for mission

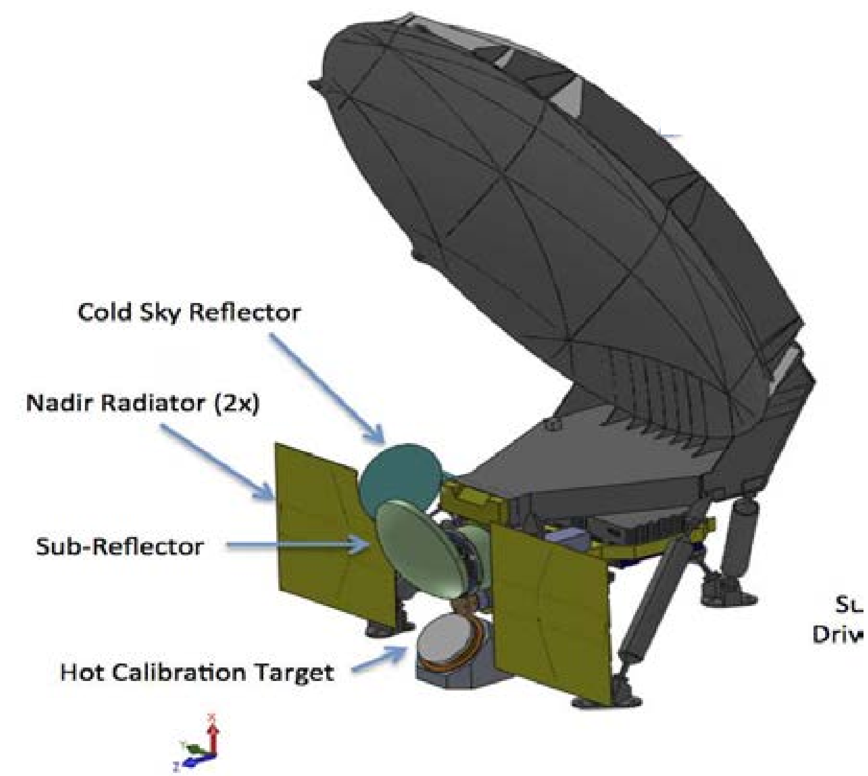
- Algorithms updated to Jason-2 GDR-D standard

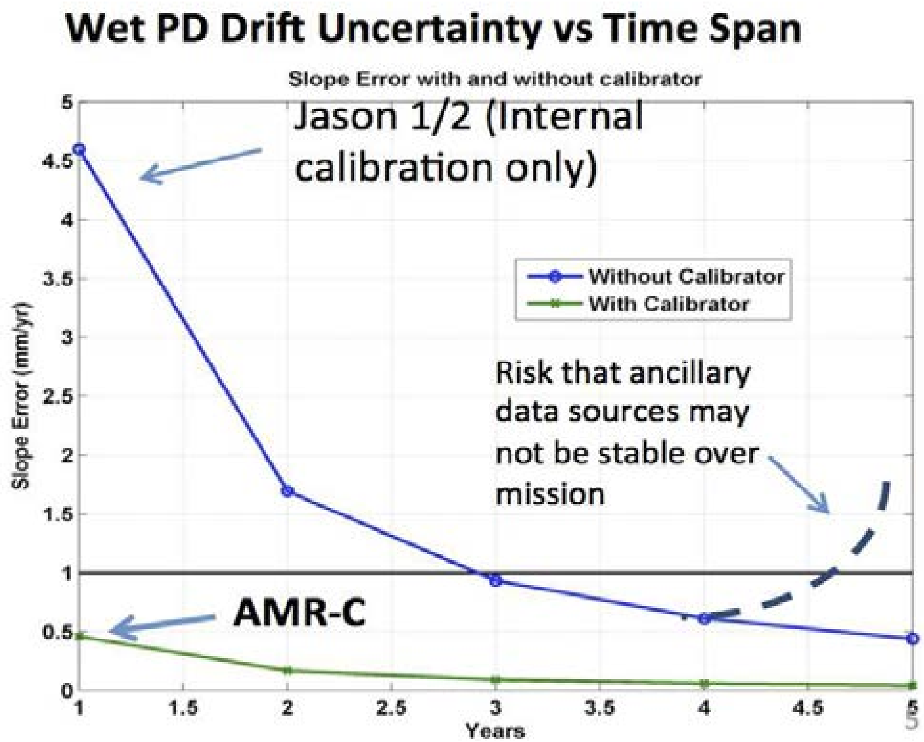
- **The need for this type of *a posteriori* calibration will be reduced for Jason-3 (cold sky calibration) and eliminated for Jason-CS (complete 2-point external calibration)**

Backup

Looking toward the Future

- AMR-C concept includes secondary reflector to perform end-to-end calibration using stable blackbody calibration targets similar to SSM/I, AMSR-E, AMSU, etc.
- Wet PD long term stability estimated to be better than 0.3mm for any one year period and <u>eliminates reliance on ancillary data sources for calibration</u>





Overview

- Current status of the JMR calibration
- End-of-mission recalibration approach
- Initial comparison with the SSMI FCDR

Jason-1 Jason Microwave Radiometer (JMR) 2002 - 2013

- **Jason-1 JMR maintained same measurement requirements as TMR**
  - 1.2 cm RMS error for PD measurement
  - No requirement for long term stability

- **JMR used noise diodes for calibration to eliminate the need for a cold sky horn**
  - First spaceborne radiometer to use NDs
  - Paved way for Aquarius, SMOS, SMAP and of course AMR
  - JMR ND implementation and thermal environment presents calibration challenges

- **Maintained same antenna design as TMR with partial blockage from struts**
  - Results in larger sidelobes (creates geographically correlated errors)

End-of-Mission Calibration Plan

- Previous calibration relied upon on-Earth hot and cold T_B references
  - Vicarious Cold Reference *(Ruf, 2000, TGARS)*
  - Amazon pseudo-blackbody regions *(Brown and Ruf, 2005, JTECH)*
  - On-orbit references sensitive to climate variability; require corrections; risk of aliasing geophysical signals

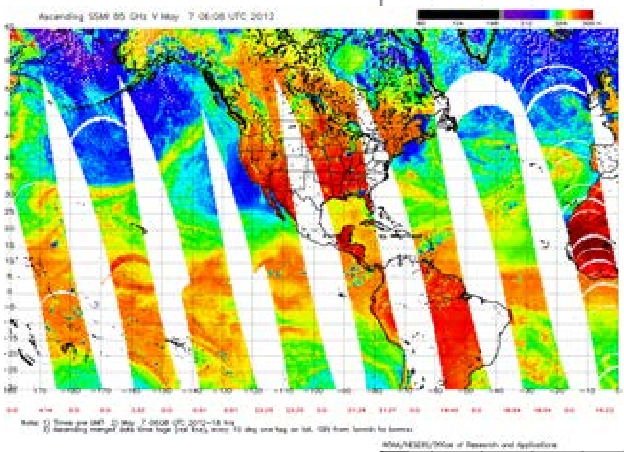
- Complementary inter-sensor TB calibration approach recently developed and applied to AMR (Brown, 2012, TGRS)
  - Uses polynomial regression to transfer one sensor's measurement to another
  - Requires stability of other systems
  - Presents independent means to monitor the long term TB calibration

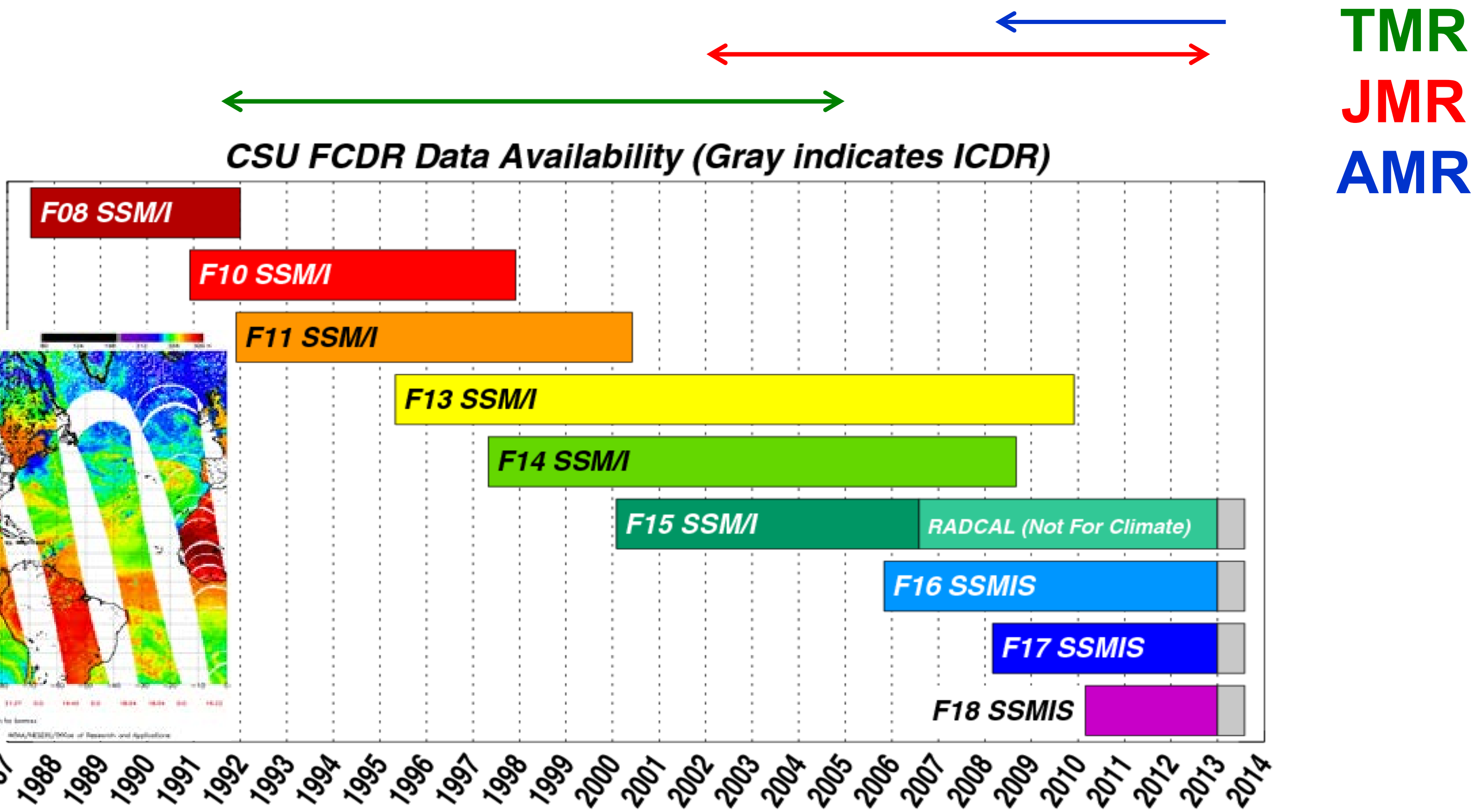
- Compare geophysical retrievals to in-situ measurements, models and other sensors
  - Dependent on long term stability of other sensors/models
  - Need to use re-analysis products from models to ensure a consistent long term record

- Demonstrated consistency between independent methods ensures a "climate-quality" long term calibration
  - the agreement, or lack thereof, between the different references provides a means to assess the uncertainty of the long term calibration

SSM/I FCDR

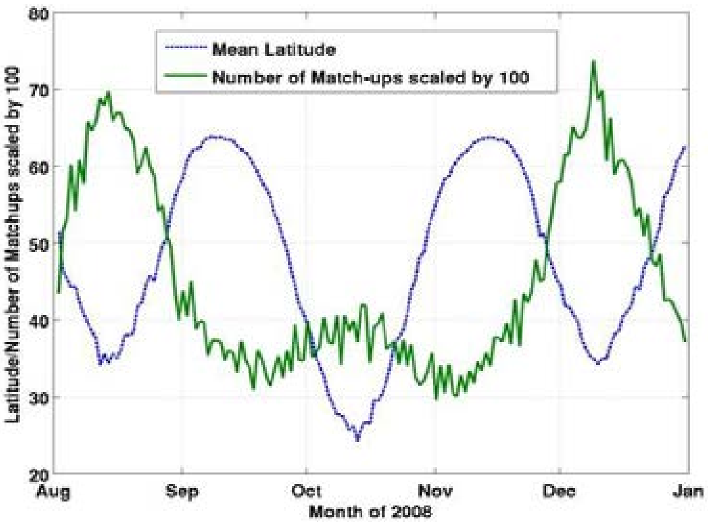
- The SSM/I series of radiometers have operated since 1987, spanning the Topex/Jason altimeter record
- A newly released SSM/I Fundamental Climate Data Record is a reprocessed well inter-calibrated record of brightness temperature ideal for inter-satellite calibration with JMR
- SSMI F13, F14 and F17 used in this analysis

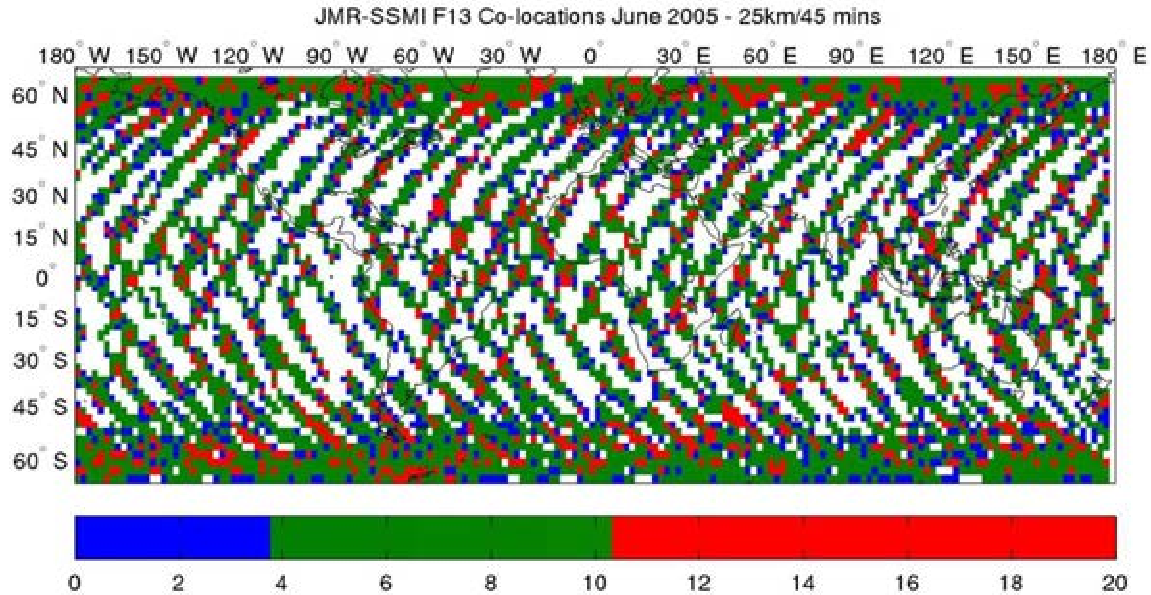




Match-up Process

- A database of co-locations is generated by finding JMR and SSMI observations that occur within 25 km and 45 minutes of each other
- The match-ups cluster between high and low latitudes as a function of time





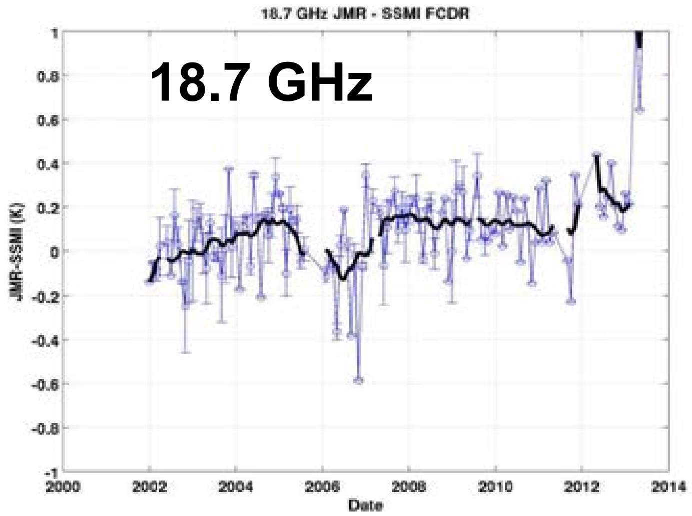
JMR Equivalent TBs from SSMI

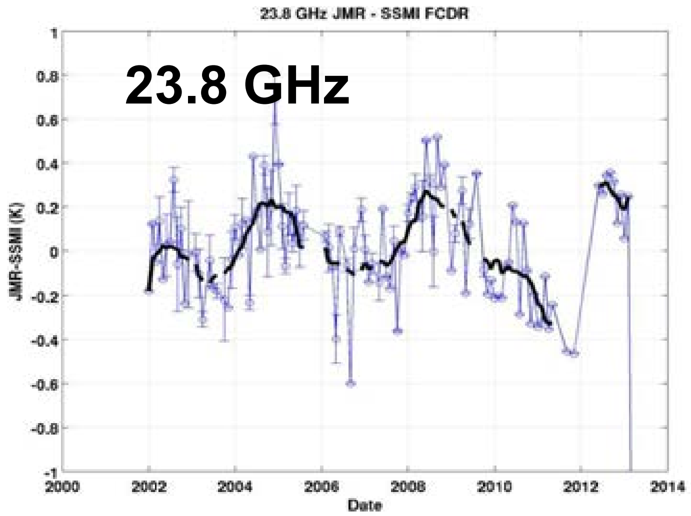
- Polynominal regression used to transfer SSM/I TBs to JMR equivalent TBs
  - Uses 19, 22 and 37 GHz TBs from SSMI
- Coefficients derived from AMR used in this analysis
  - Ensures consistent cross-calibration between AMR and JMR

$$T_{B\_ocean}^{AMR} = c_0 + c_1 T_B^{19V} + c_2 T_B^{19H} + c_3 T_B^{22/24V} + c_4 \left(T_B^{22/24V}\right)^2 + c_5 T_B^{37V} + c_6 T_B^{37H}$$

- JMR-SSMI biases correlated with latitude are removed to ensure no signals due to the sampling are aliased into the trend
  - Biases with latitude computed using the entire record
- JMR-SSMI TB differences greater than 8K (5-sigma) were removed from the match-up database

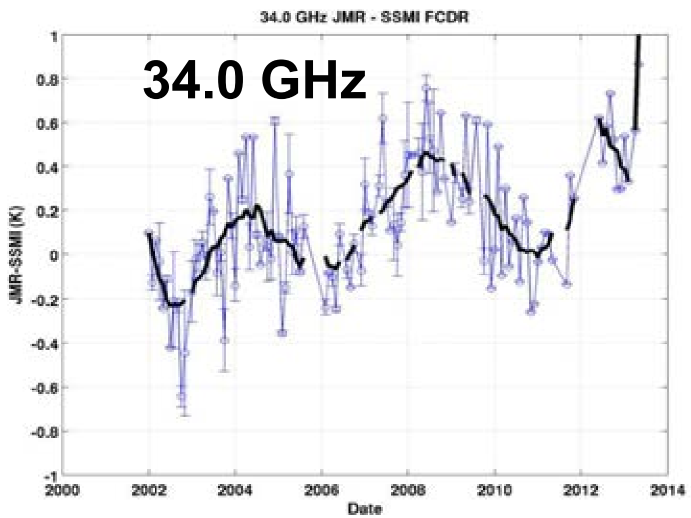
JMR-SSMI TBs





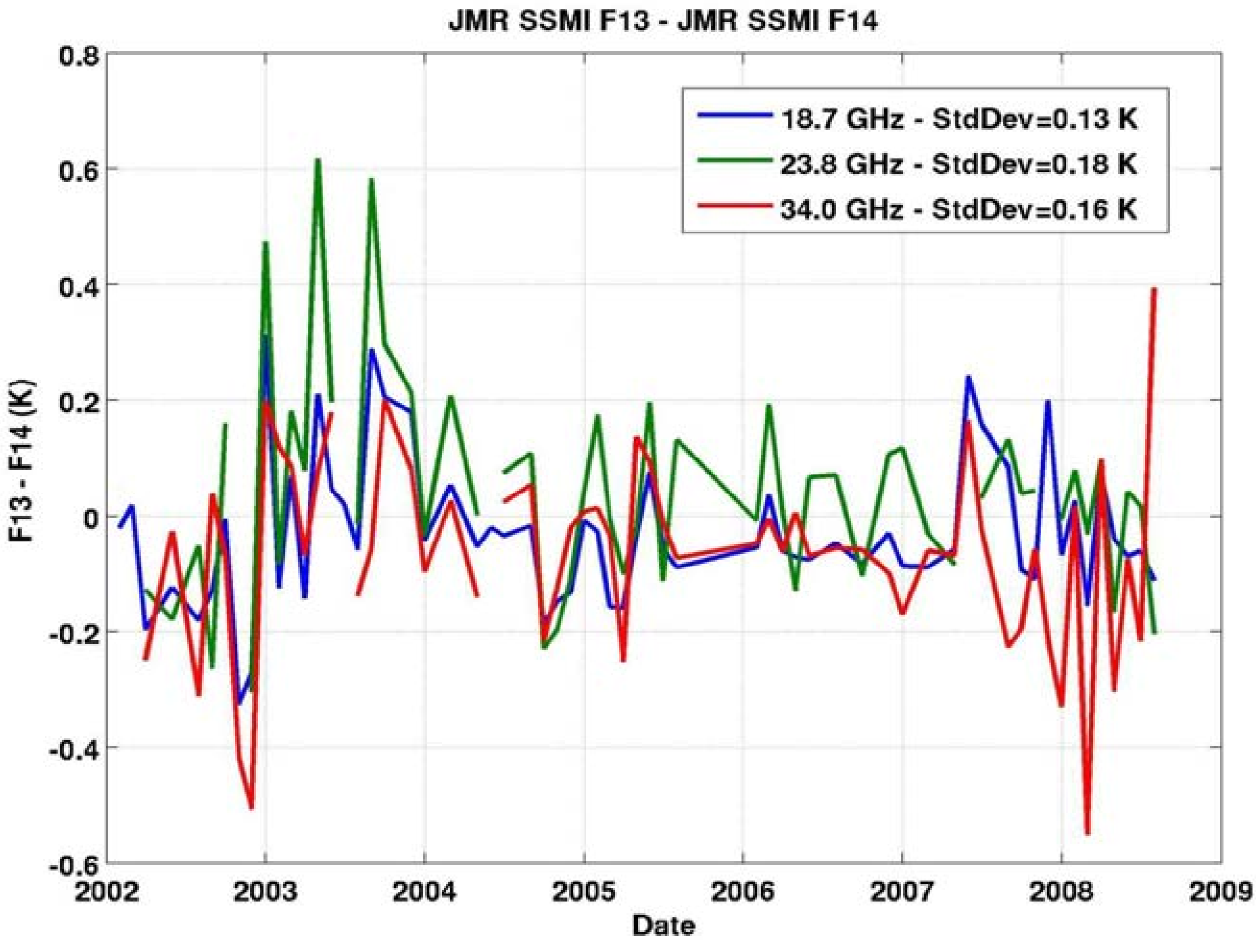
- Computed monthly averages of the JMR – SSMI TB bias for each channel
- Overall excellent consistency between SSMI F13 and F14

- **Small, but statistically significant, residual instability evident in all channels (< 0.5 K)**

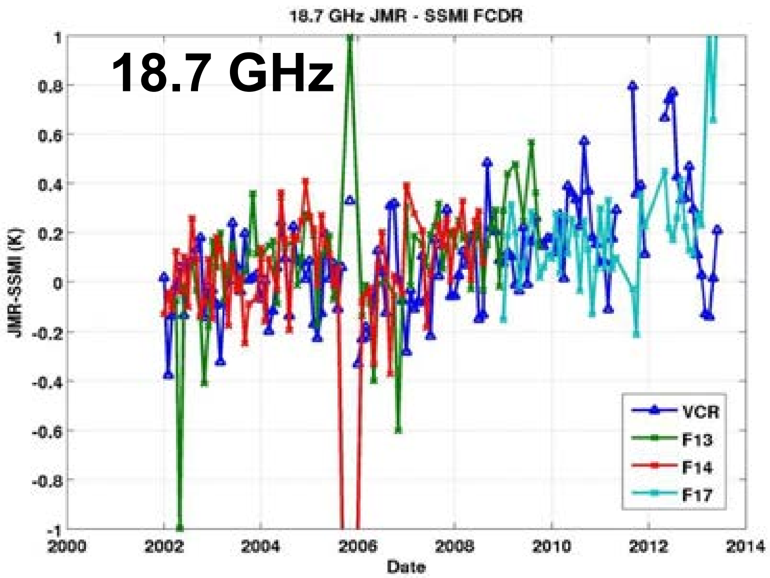


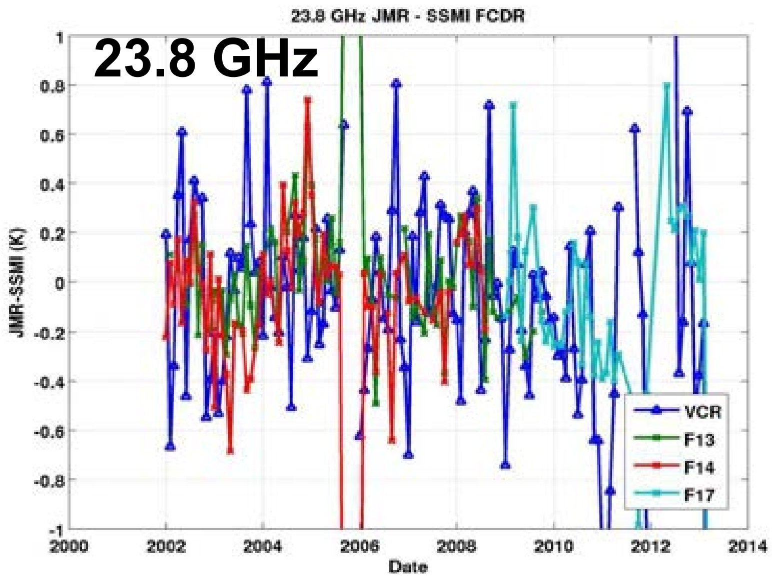
Monthly Consistency

- < 0.2K standard deviation of monthly JMR biases computed from SSMI F13 and F14 with no discernible trend



Comparison with Ocean Reference





- Dark blue line shows monthly averaged vicarious cold reference with biases from SSMI
- Consistency observed between these independent references increasing confidence in the long term trends