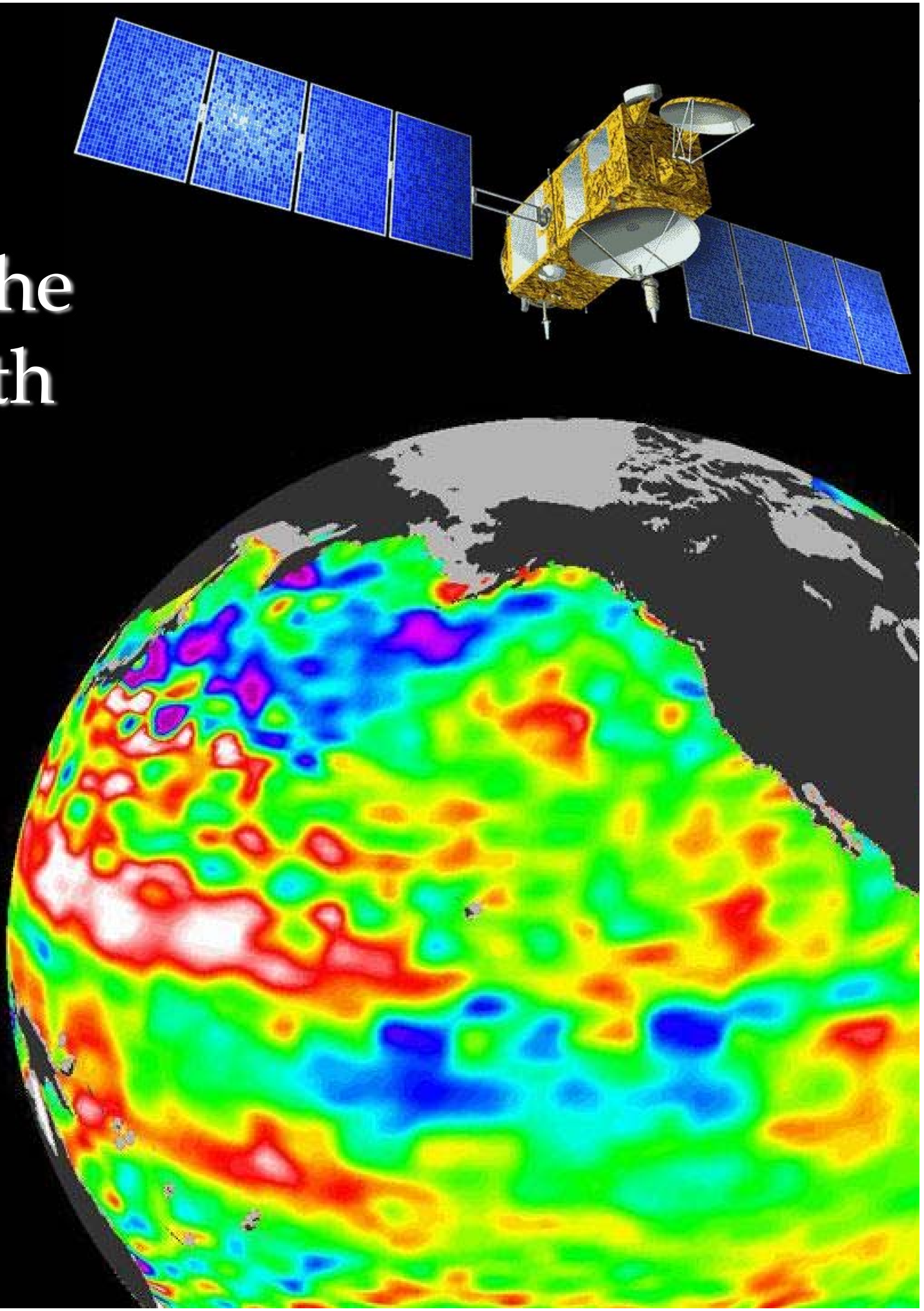
Error Structures in Altimetry Data from the Wet Tropospheric Path Delay Correction



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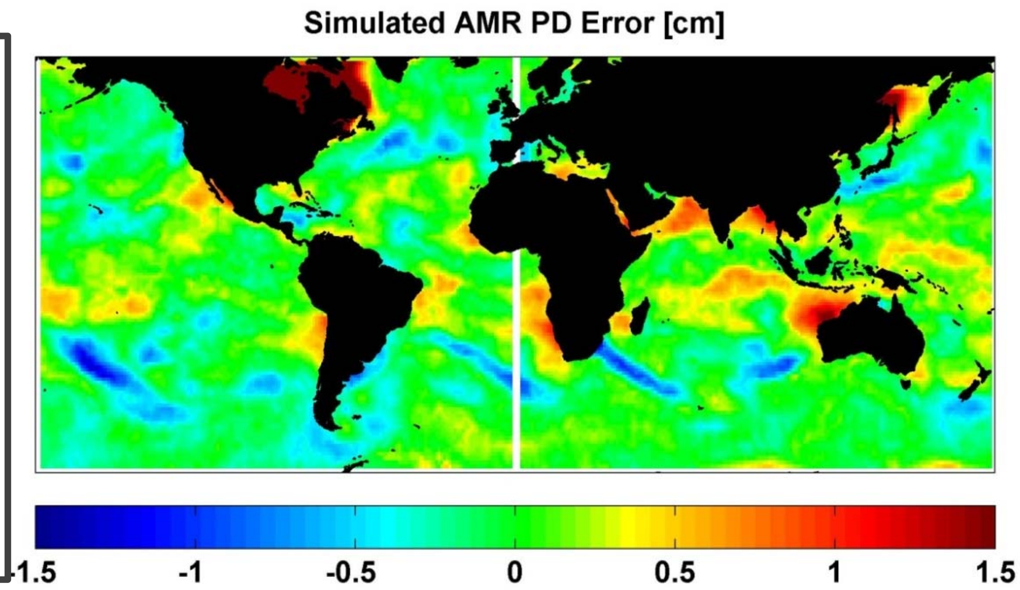
OSTST - Lisbon, Portugal
October 18-20, 2010

Error Structures In Wet PD Measurements

- On-going study to characterize the error structures from the wet PD measurement
  - **Calibration of the raw radiometer measurements to an antenna temperature**
    - Typically have error scales on orbital, yaw steering and long term (> 1yr) time scales
  - **Removal of antenna pattern sidelobe contributions**
    - Seasonal and large spatial scale (> 100 km)
  - **Limitations of the geophysical retrieval algorithm**
    - Errors correlated with geophysical state (e.g. weather conditions)

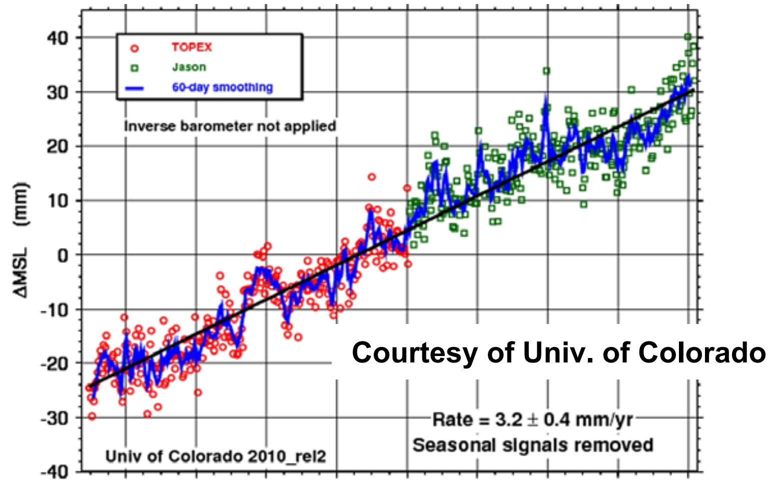
Example for retrieval algorithm errors

- Retrieval algorithm errors generally less than 1 cm for single measurement
- Occur on synoptic spatial scales (100-300 km)
- Average down to < 3 mm on long time scales

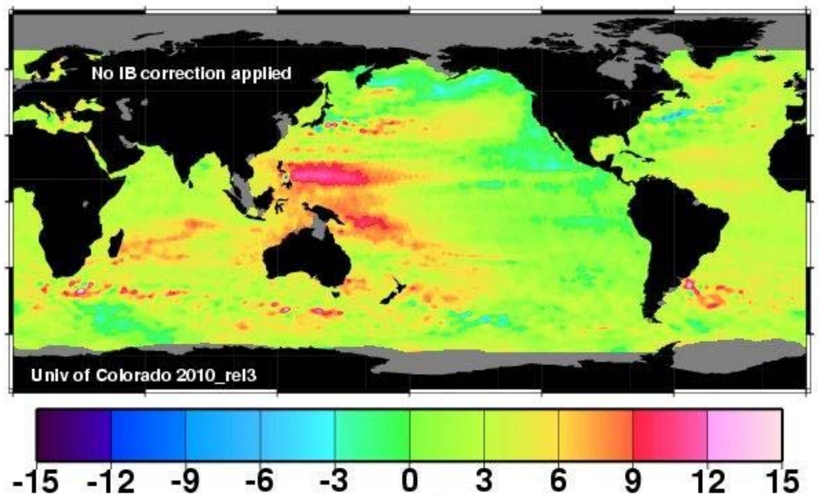


Long Time Scale Errors (> 1yr)

- Radiometer hardware stability dominates long time scale systematic errors (e.g. instrument drift)
- Altimeter radiometers are use relative internal calibration references and are not referenced to any calibration standard
- Any long term drift must be detected and accounted for in post processing

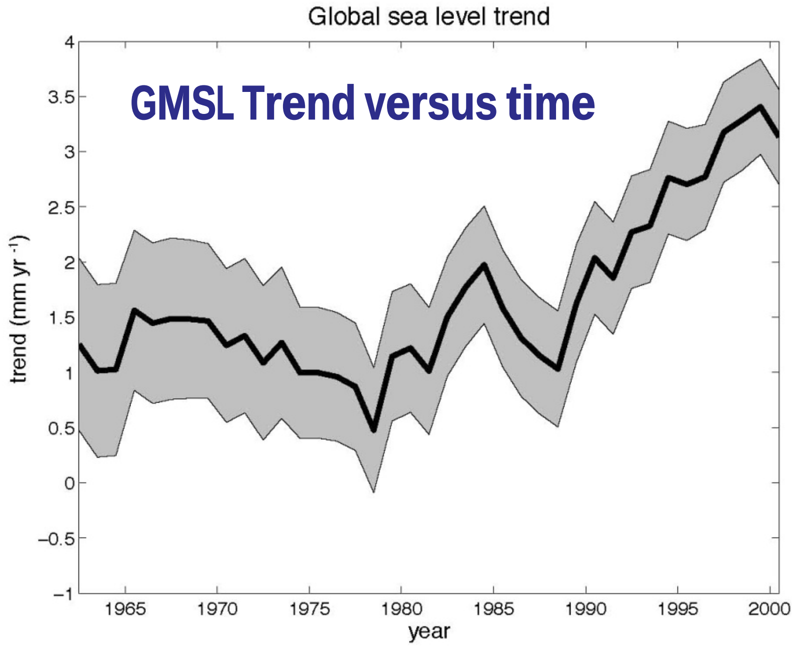


Regional GMSL Trends



mm/yr

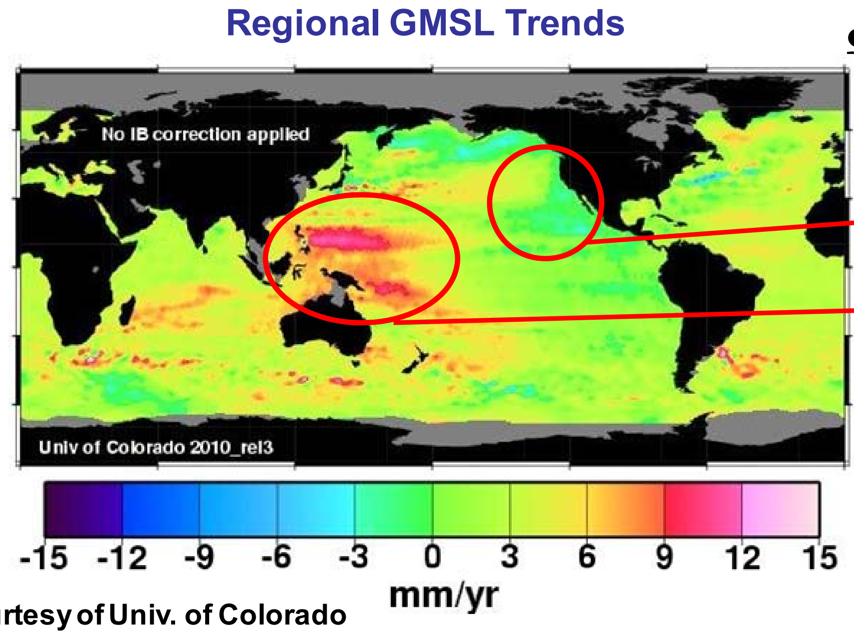
Courtesy of Univ. of Colorado



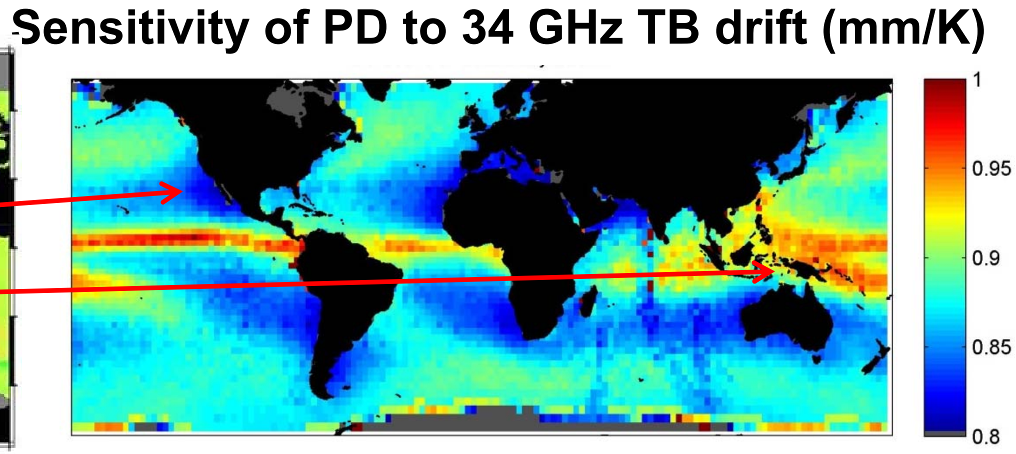
From Merrifield et al., *J. Climate*, 2009

Example: Bias Drift

- Drift in radiometer bias creates regional trends



Courtesy of Univ. of Colorado



Jason-2 Long Term Calibration

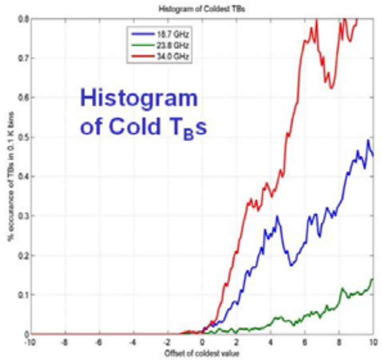
- **On-orbit calibration for Jason-2 AMR divided into operational and off-line (research) segment**

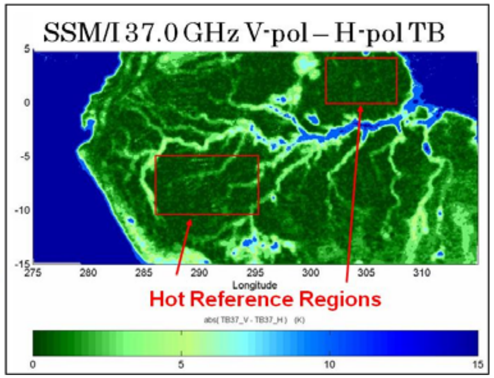
- **Autonomous Radiometer Calibration System (ARCS) performs end-to-end on-orbit system calibration for AMR to remove gross errors with < 60-day latency**
  - **Does not produce “climate quality” calibration**

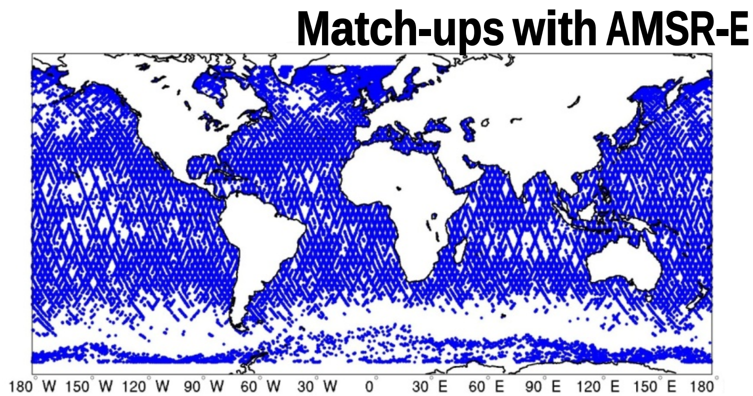
- **1 mm/yr stability goal (requirement) can only be met through rigorous on-orbit calibration using long time series**

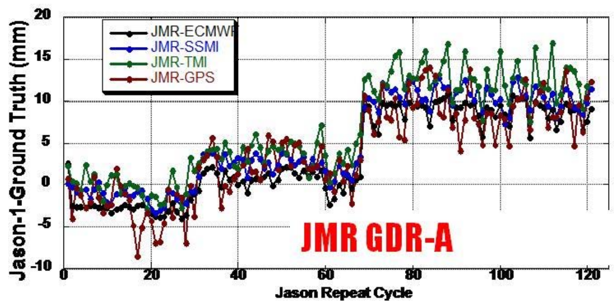
Methods for Long Term Monitoring

- Compare radiometer to on-Earth hot and cold T_B references
  - Vicarious Cold Reference
  - Amazon pseudo-blackbody regions
- Inter-sensor TB comparisons
  - AMSR-E, SSMI, TMI, JMR
  - Requires model to transfer one sensor's measurement to another
- Compare geophysical retrievals to in-situ measurements, models and other sensors
  - ECMWF, NCEP, SSMI, TMI, AMSR-E, GPS, RaOb, JMR
- Look for consistency between comparisons to assess and maintain stability to 0.1K/yr or 1mm/yr level





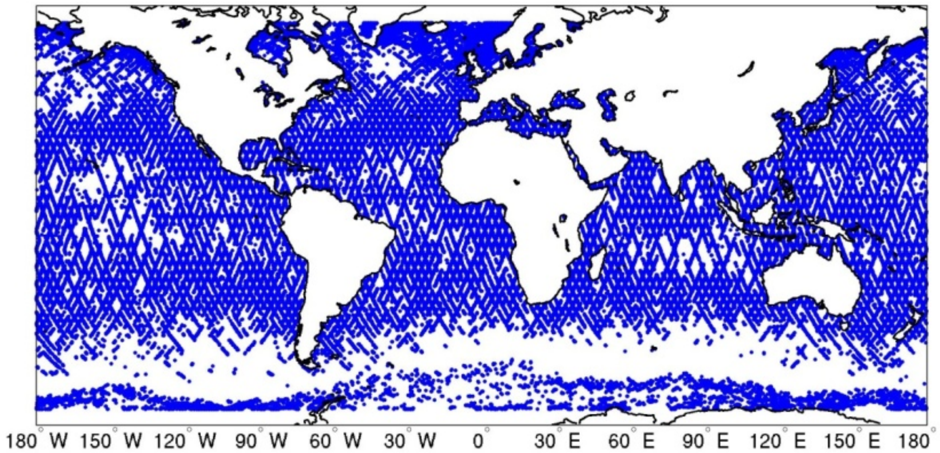


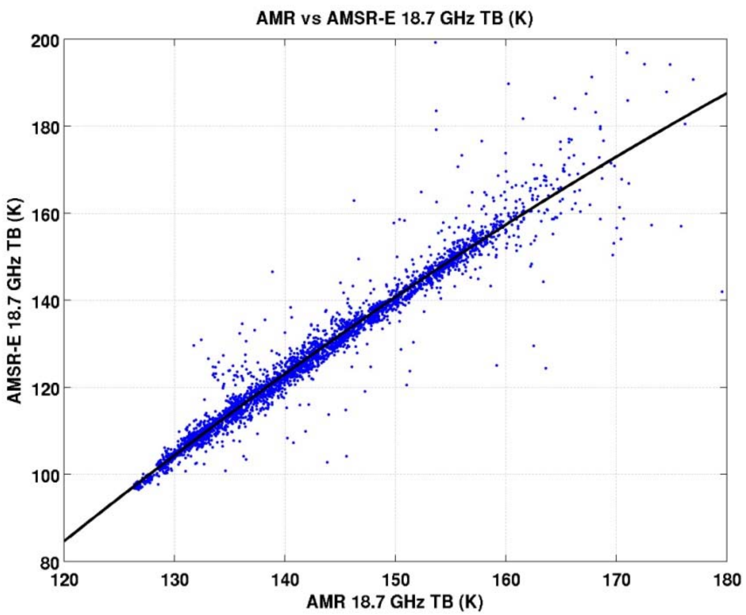


Inter-sensor TB Comparisons

- Transfer calibration of other microwave radiometers to AMR through co-incident observations
- Large number of globally distributed match-ups due to crossing orbits

Match-ups with AMSR-E

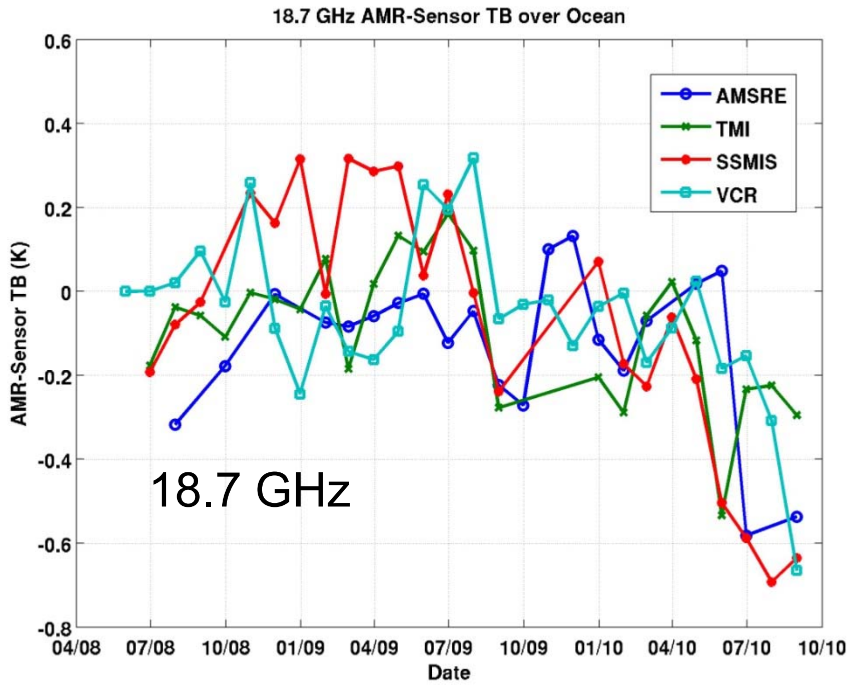


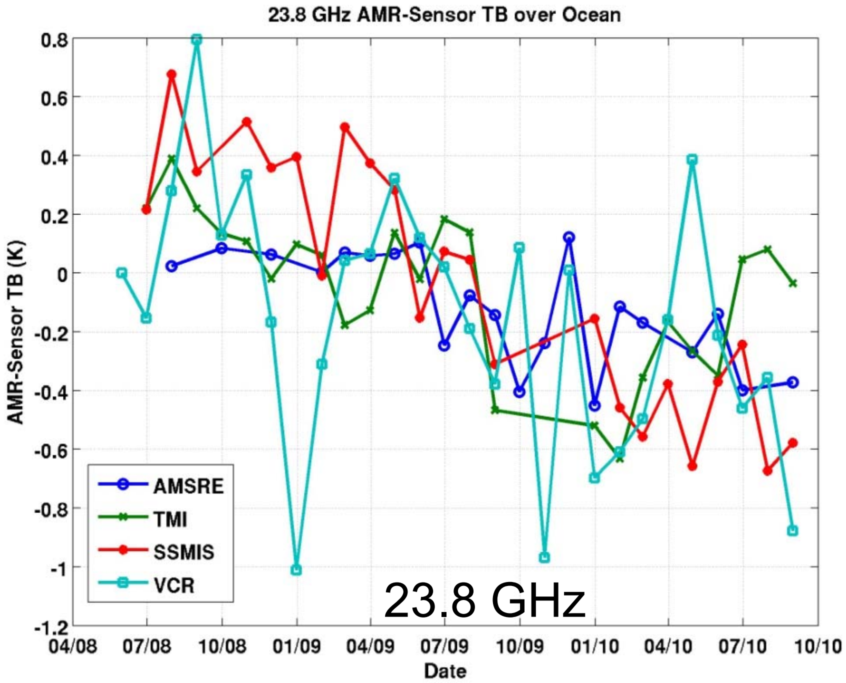


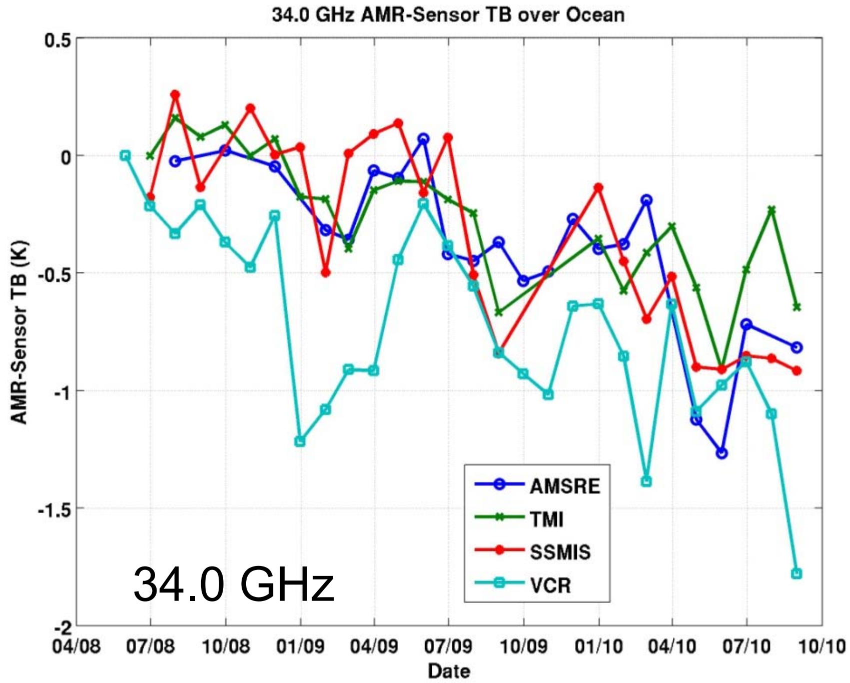
- Other sensors operate at different frequencies with different viewing geometry than the AMR
- Requires mapping function to go from other sensor’s TB to AMRs TB
  - Mapping function determined empirically – suitable for looking at long term trends

AMR TB Stability

- Monthly averaged AMR-Sensor differences shown
- Multiple independent observations of TB stability required to have confidence at 0.1K/yr level

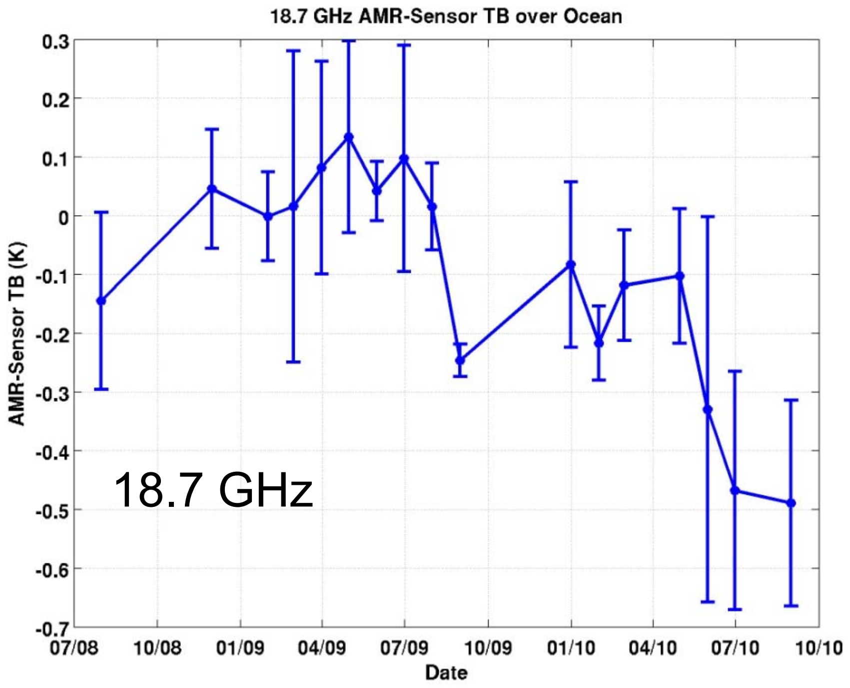


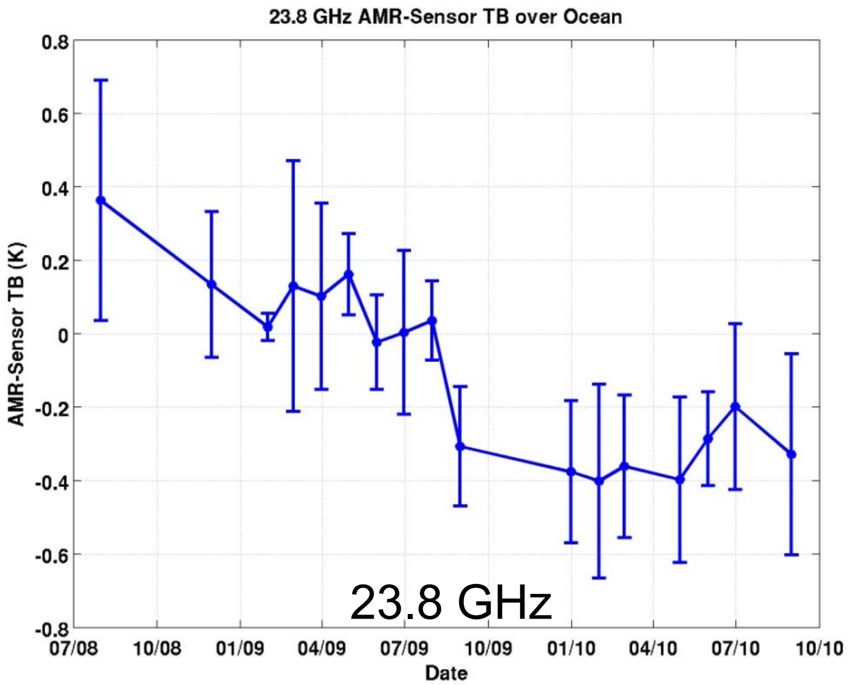


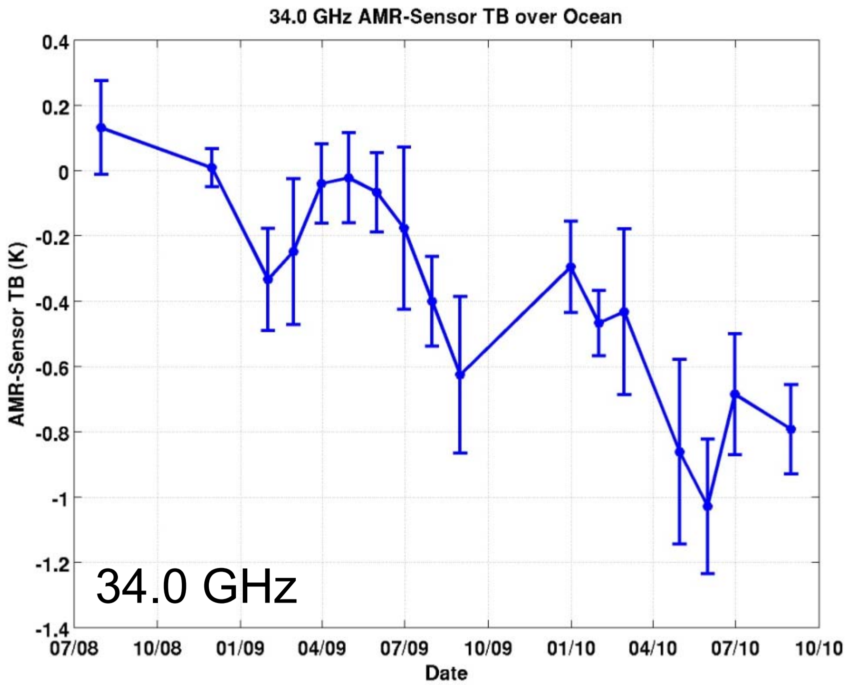


Consensus TB Offsets

- Computed monthly averages from all comparisons to get consensus calibration
- 18.7 GHz channel exhibited small drift until 7/2009, followed by small jump
- 23.8 GHz channel exhibited ~0.4K jump after 7/2009
- 34 GHz channel has residual drift of about 0.5K/yr – reduced from ~2K/yr by ARCS





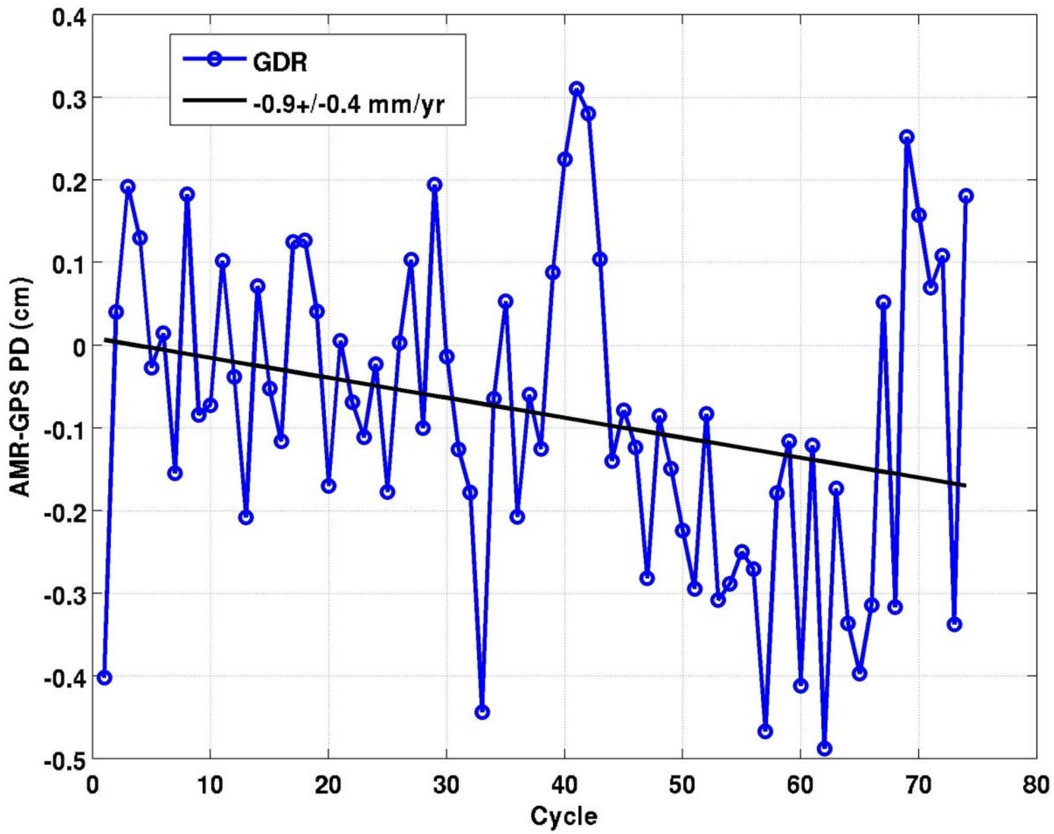


PD Observations

- TB comparisons suggest drift rate of -1mm/yr should be expected
  - Drift would be +3mm/yr without ARCS
- PD compared to ECMWF, GPS[1], SSMI, TMI, and AMSRE

Cycles 1-79	mm/yr
GPS	-0.9 ± 0.4
ECMWF	-0.5 ± 0.1
AMSR-E	-1.0 ± 0.1
TMI	-0.9 ± 0.1
SSMI	-1.1 ± 0.1

AMR – GPS PD [cm]

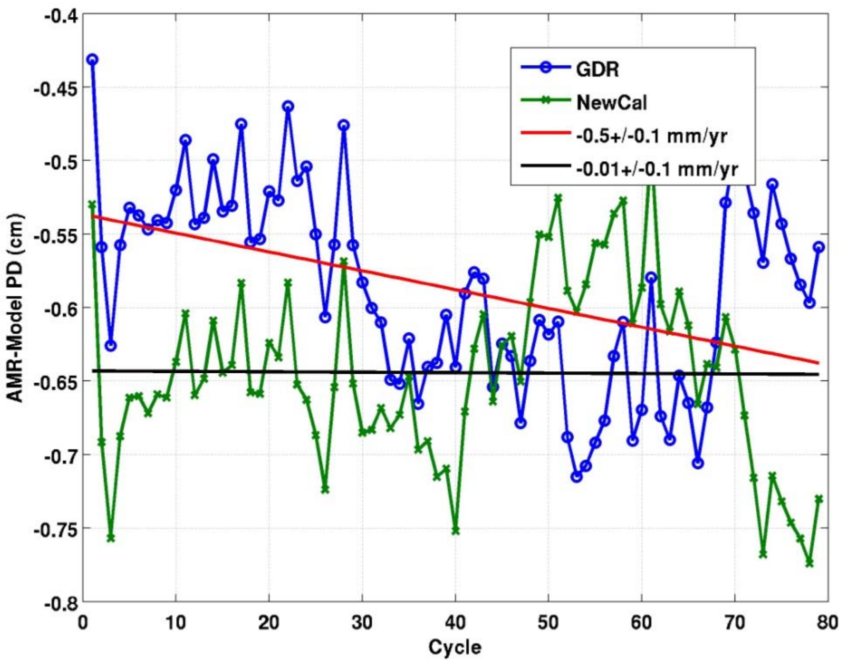


[1] *Only completely independent comparison*

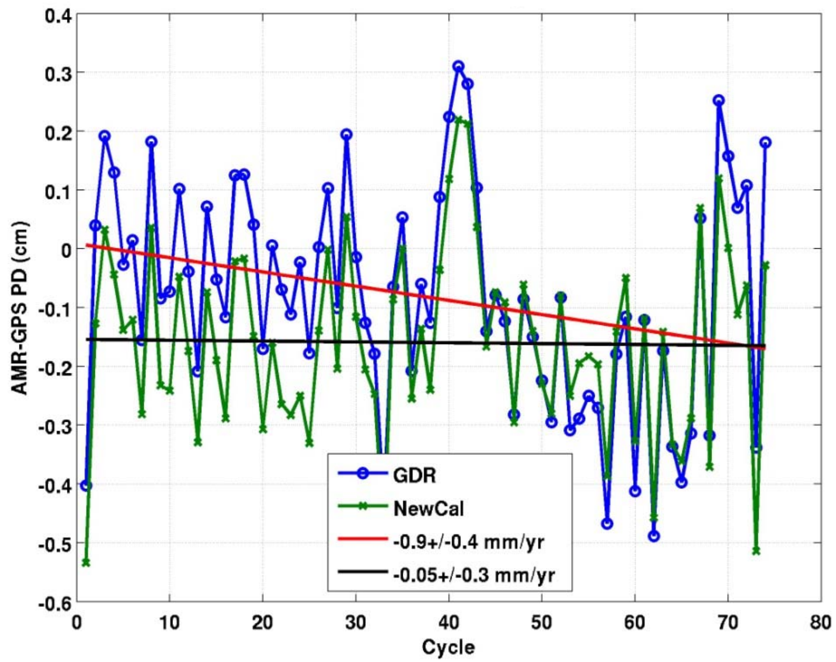
GDR-C Recalibration

- GDR-C is first opportunity to update the AMR calibration for the entire record
- Adjusted AMR calibration to remove consensus TB offsets
- Validated through PD, WS and CLW comparisons
  - GDR-C calibration shows negligible PD drift compared to GPS and ECMWF
  - Drift in AMR WS compared to altimeter removed with GDR-C calibration

AMR – ECMWF PD [cm]



AMR – GPS PD [cm]



Summary

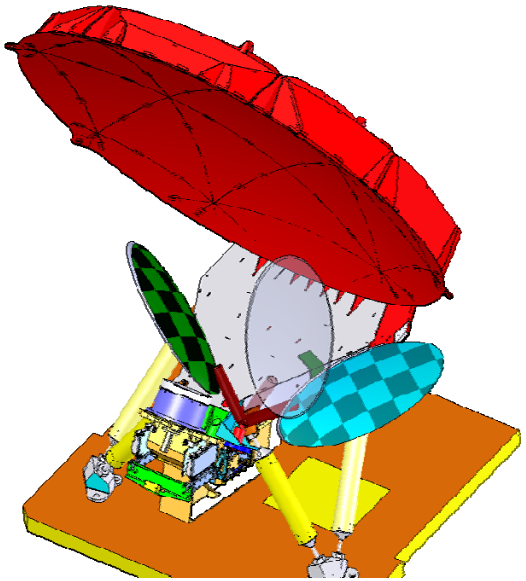
- Drift in GDR wet PD estimated to be about -1mm/yr
- ARCS successful is reducing drift from 3mm/yr to 1mm/yr
- Recalibration performed for GDR-C reduces drift over cycles 1-79 to a negligible level
- GDR-C will also include new processing to produce valid PDs in the coastal zone in addition to radiometer rain and sea ice flags
  - Currently available on AMR enhanced product (via PO.DAAC)

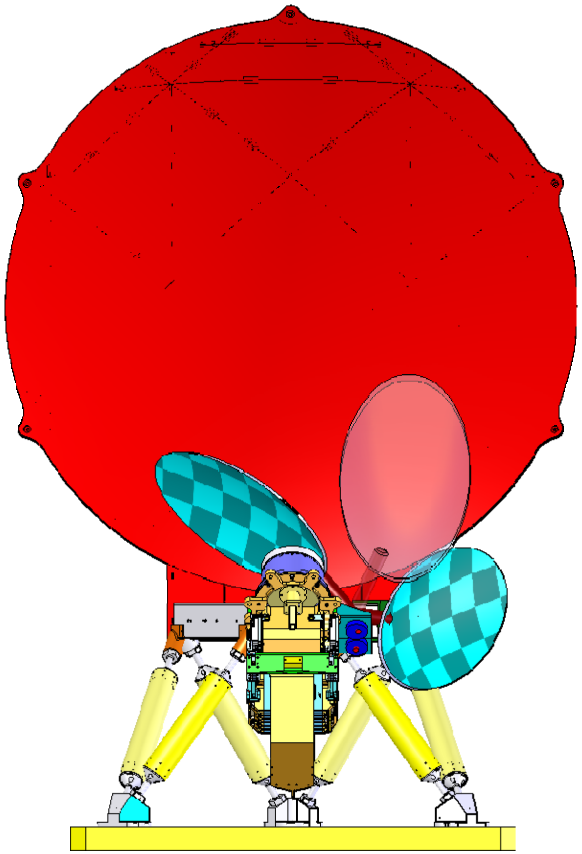
- Based on science team recommendation, study on-going to add calibrator to radiometer for Jason-3 to mitigate drift issue altogether
- Should also be considered for Jason-CS

- Backup

Meeting the Drift Requirement by Design for Jason-3

- Based on the science team recommendation, a design study to add an on-board absolute calibration reference to the AMR for Jason-3 was initiated and is to be completed this month
- Preliminary results indicate that a lightweight secondary reflector providing a periodic cold sky look can be accommodated by the existing AMR design.
- A concept review planned for end of October will provide an independent assessment of the proposed design



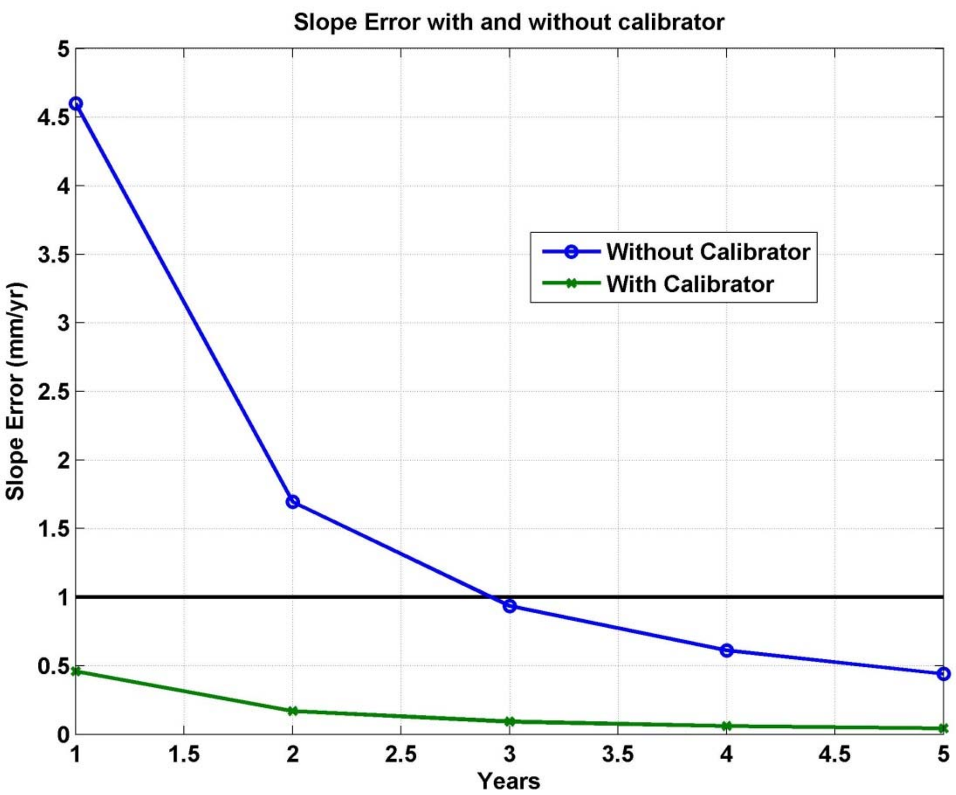


Estimated Calibrator Performance

- Wet PD slope uncertainty estimated for current on-orbit calibration approach and for calibrator approach as a function of time span
  - On-orbit calibration approach assumes no drift in “ground truth” – but this is not under project control and therefore verified posteriori
  - Calibrator approach assumes calibration performed once every 10 days

- 1 mm/yr uncertainty reached after 3 years assuming monthly 0.5K calibration uncertainty and no drift in “ground truth”

- Only a few months needed with calibrator to reach 1mm/yr uncertainty on slope error

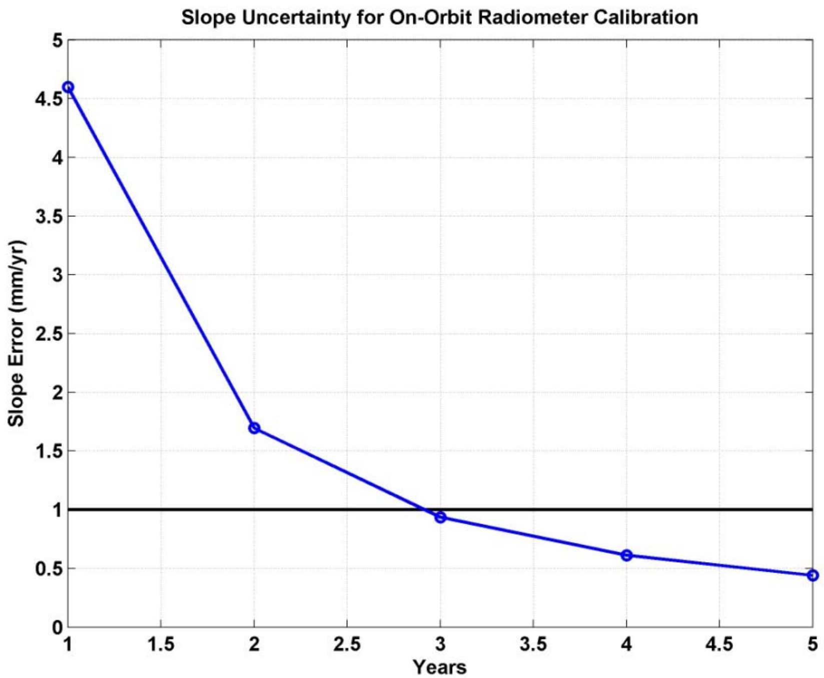


Radiometer Stability

- Radiometer PD stability on long time scales (>30 days) derived from ancillary sources
  - No control over "external references" (e.g. instrumentation change, geophysical signals in models)
  - References may not be stable over time and <u>no way to validate it</u>
  - External references should be used for validation, not calibration
- To perform climate measurements, future missions (e.g. Jason-3, Jason-CS…) must consider radiometer with capability for long term stability

Stability

- What level of stability is required and over what time scales (e.g. accelerations/decelerations)?
- What is the requirement on regional sea level change and on what time scale?



Uncertainty on Wet PD slope (mm/yr) versus time span assuming monthly 0.5K calibration uncertainty and no drift in “ground truth”

- Backup

ARCS Recalibration Decision Algorithm

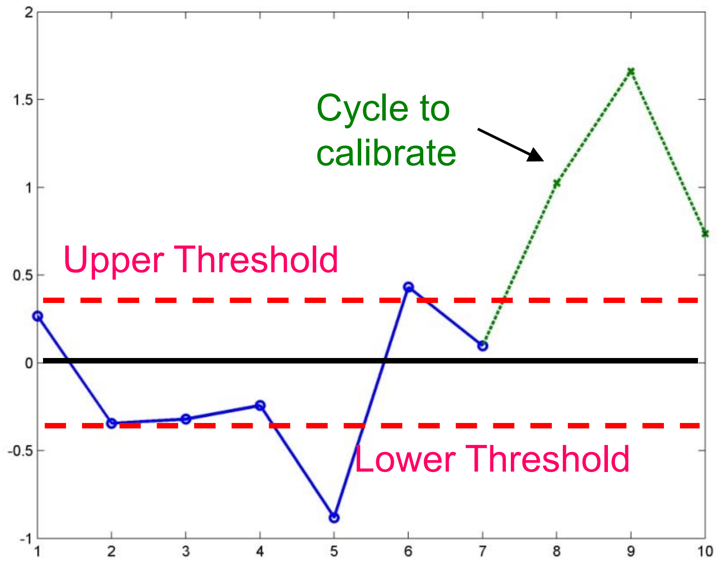
- ARCS uses a combination of path delay and TB residuals to determine is recalibration is needed
  - Uses current GDR processing cycle + future data

- Checks if TB or PD biases from the current cycle + 2 future cycles ALL exceed either upper or lower threshold or if current cycle > 3σ

- Re-calibrates if either TB or PD threshold check fails
  - Only uses TBs to recalibrate
  - PD comparisons used for detection and validation only

- Validates by performing threshold check after-recalibration
  - Error if thresholds still exceeded

Change detection example



False Alarm Rate/Probability of Detection

- Threshold setting allows ARCS to be aggressive or conservative
  - Balance False Alarm Rate (FAR) and Probability of Detection (POD)

Sensitive to changes at sub-mm level, high false alarm rate

Sensitive to changes at 2-4 mm level, low false alarm rate

Probability of detecting small change

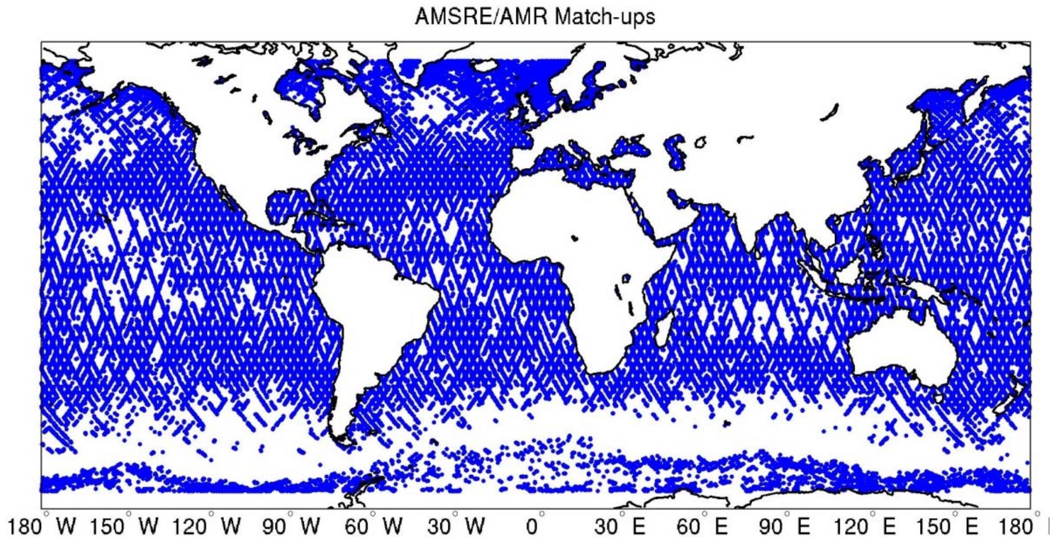
Probability of detecting large change

for N=3	T = 0.25σ	T = 0.5σ	T = 0.75σ	T = 1σ
False Alarm Rate (%)	12.9	5.9	2.3	0.8
POD (μ_{bias}=1σ) (%)	46.3	33.1	21.5	12.5
POD (μ_{bias}=2σ) (%)	88.5	81.3	71.5	59.6
POD (μ_{bias}=3σ) (%)	99.1	98.2	96.4	93.3

Current setting

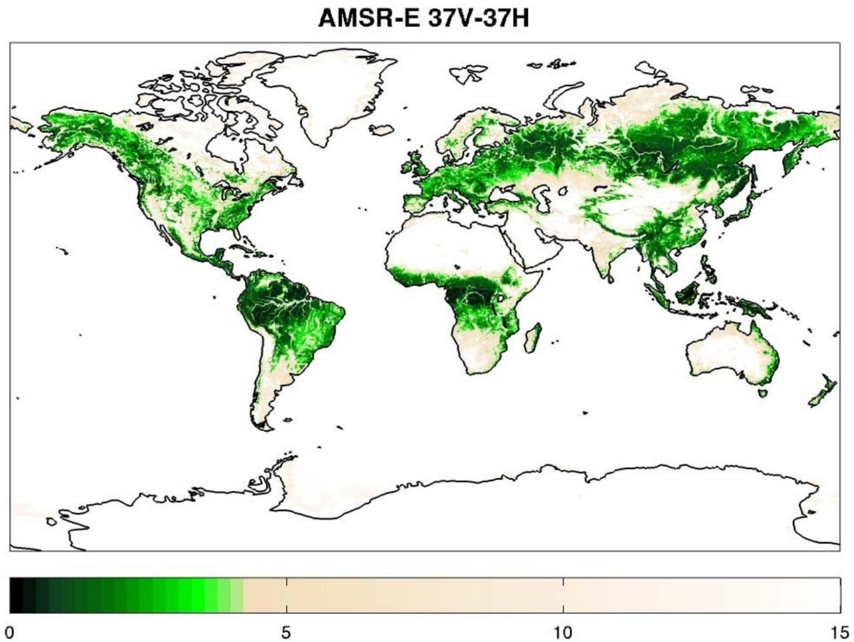
- ARCS currently set to be conservative to minimize unnecessary recalibration at the expense of missing potential small changes

Inter-Sensor TB Comparisons



- Intercomparison with AMSRE, TMI, SSMI, WindSat and SSMIS Level1C data
- Ocean match-ups to +/- 66 degrees
- Simple regression algorithm used to transfer TBs between similar channels
- Radar altimeter derived WS and radiometer CLW used to filter for clear, calm scenes
  – WS < 6 m/s, CLW < 0.05 mm

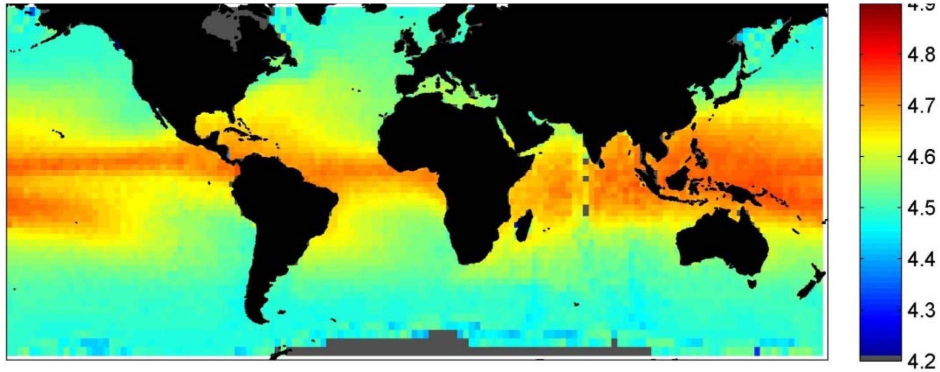
- Performing land comparisons globally over heavily vegetated regions
  - 18 to 37 GHz de-pol < 2K
  - Act like pseudo-blackbodies, with little polarization or incidence angle dependence
- No inter-sensor mapping currently done



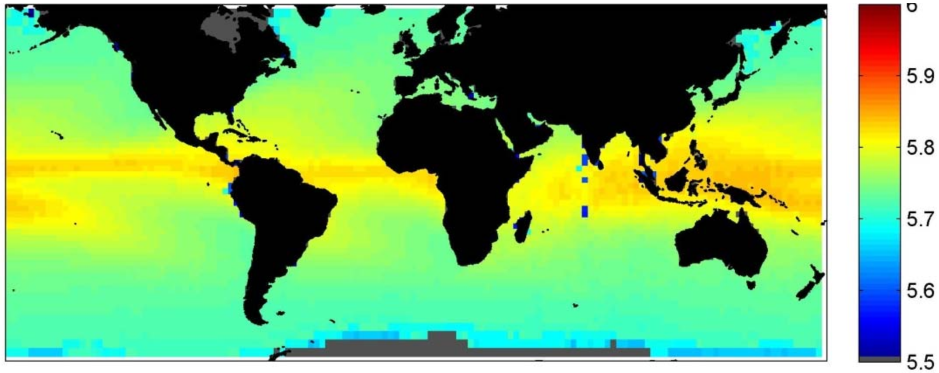
Gain Drift

- Structure of errors depends on whether the drift is in gain or bias
- Typical gain error from ND instability produces largest error for dry conditions

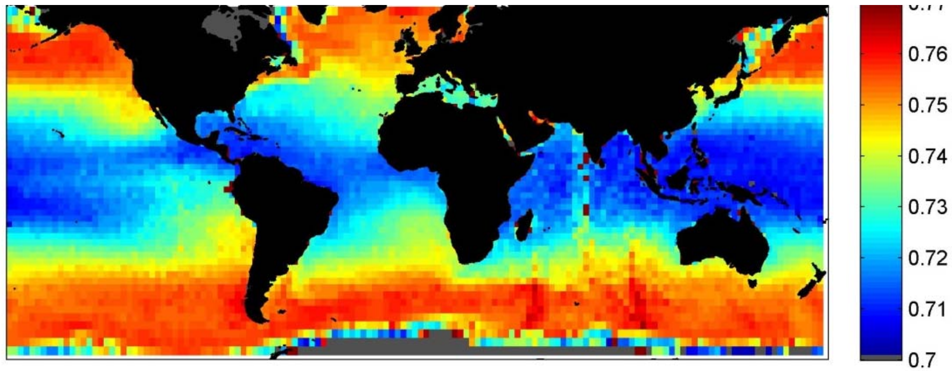
Sensitivity of PD to 18 GHz TB (mm/%)



Sensitivity of PD to 23 GHz TB (mm/%)



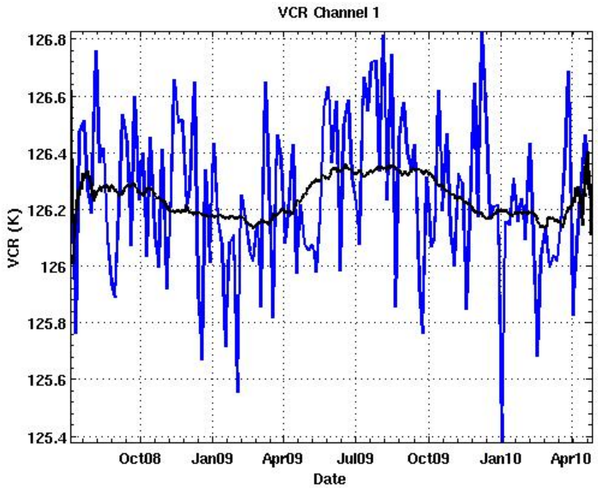
Sensitivity of PD to 34 GHz TB (mm/%)



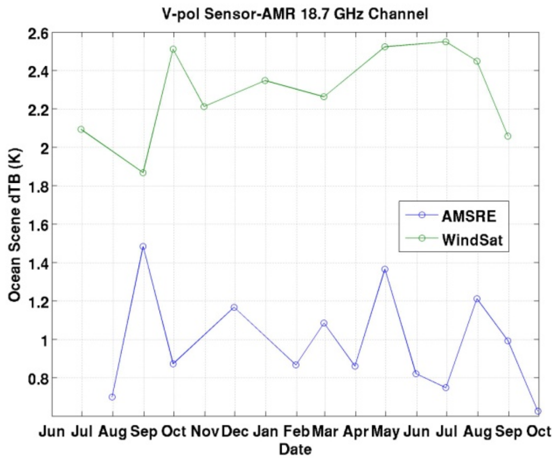
- Less geographical variation for typical gain errors

18 GHz Cold TBs

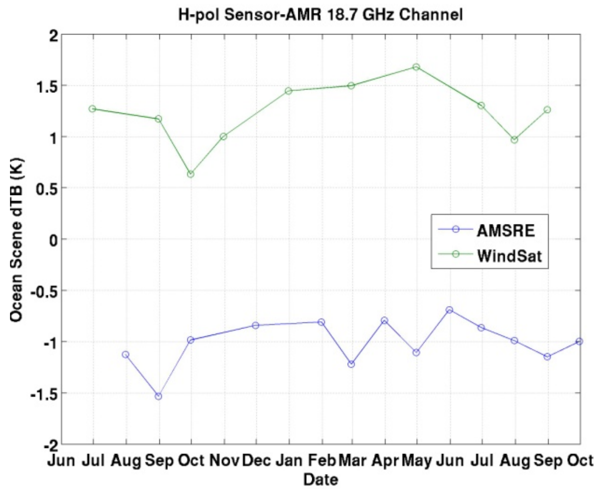
AMR Vicarious Cold Reference



AMR vs AMSR-E/WindSat V-pol



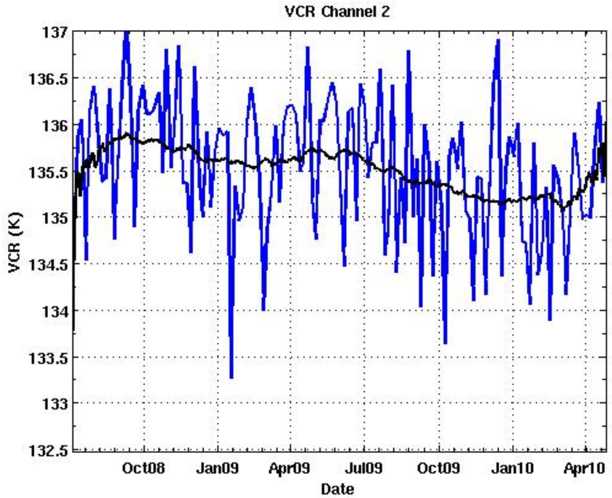
AMR vs AMSR-E/WindSat H-pol



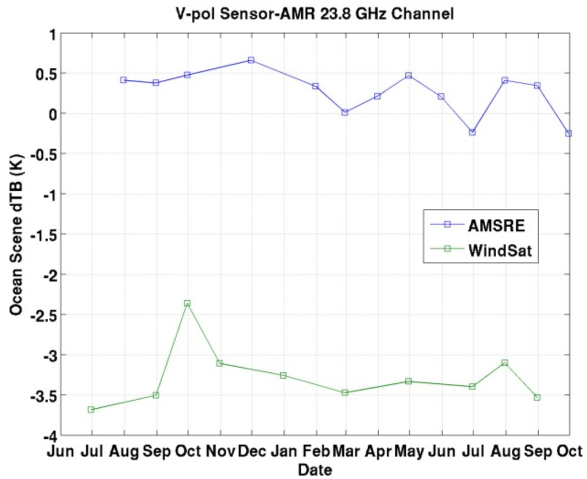
	1 yr [K/yr]	2 yr [K/yr]
Vicarious Cold	-0.1 ± 0.1	0.05 ± 0.04
AMSR-E 18.7 H	0.1 ± 0.1	0.04 ± 0.06
AMSR-E 18.7 V	0.06± 0.1	-0.08± 0.07
WindSat 18.7 H	0.2 ± 0.1	0.04 ± 0.07
WindSat 18.7 V	0.2± 0.2	0.1 ± 0.1

23 GHz Cold TBs

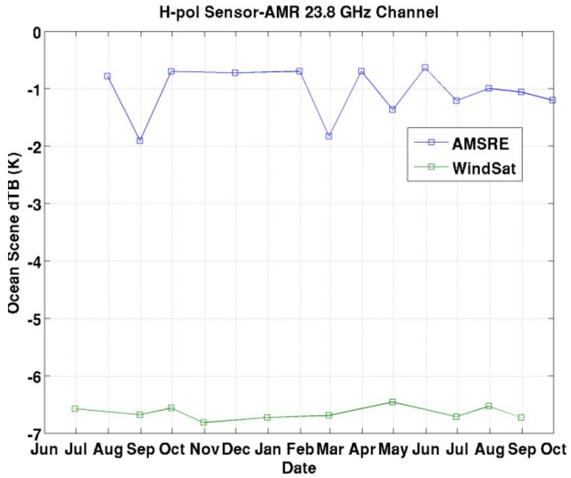
	1 yr [K/yr]	2 yr [K/yr]
Vicarious Cold	-0.3± 0.2	-0.4 ± 0.08
AMSR-E 23.8 H	-0.3 ± 0.2	-0.4 ± 0.08
AMSR-E 23.8 V	-0.4 ± 0.2	-0.4 ± 0.07
WindSat 23.8 H	-0.04 ± 0.6	-0.2 ± 0.2
WindSat 23.8 V	+0.1 ± 0.6	-0.3 ± 0.2



AMR Vicarious Cold Reference



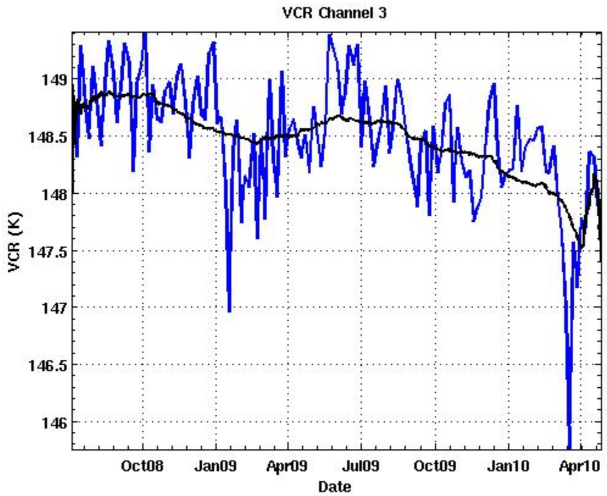
AMR vs AMSR-E/WindSat V-pol



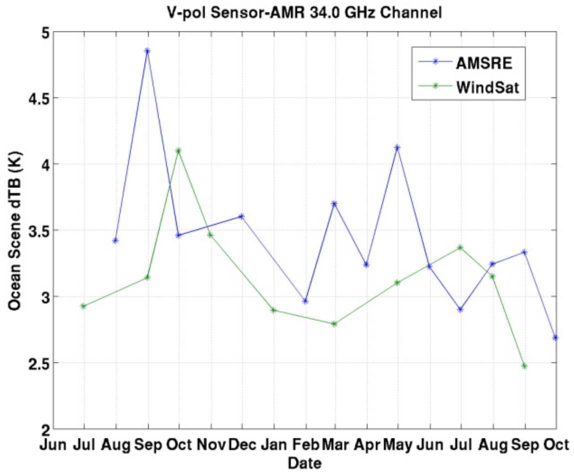
AMR vs AMSR-E/WindSat H-pol

34 GHz Cold TBs

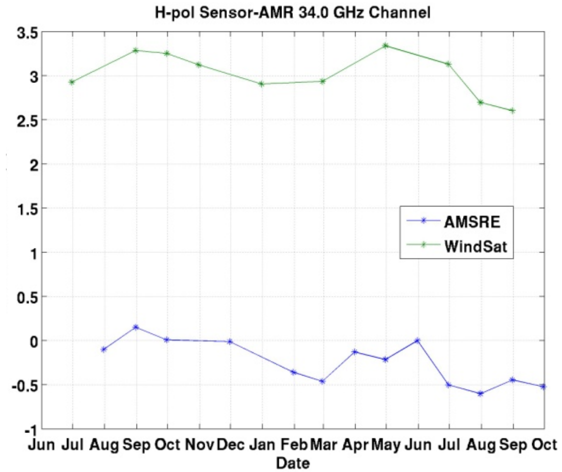
AMR Vicarious Cold Reference



AMR vs AMSR-E/WindSat V-pol



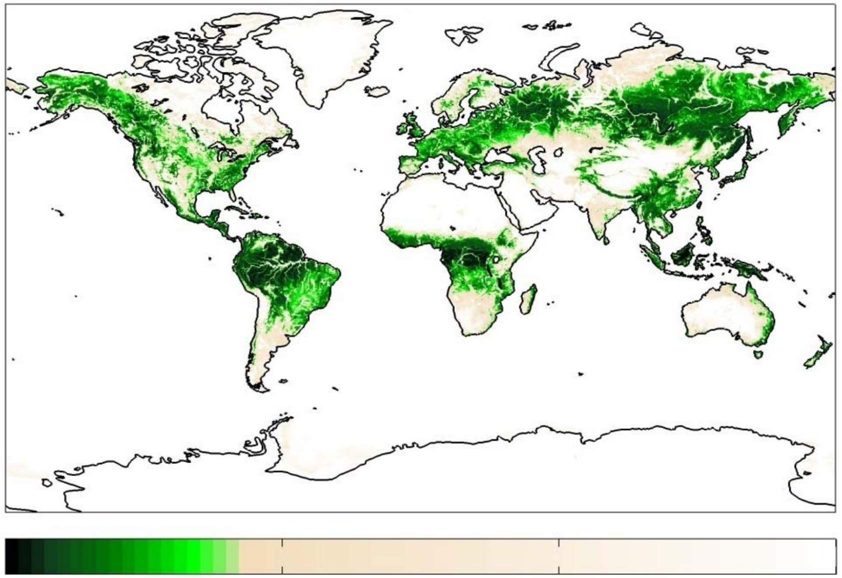
AMR vs AMSR-E/WindSat H-pol



	1 yr [K/yr]	2 yr [K/yr]
Vicarious Cold	-0.3 ± 0.2	-0.5± 0.05
AMSR-E 37 H	-0.3 ± 0.2	-0.3 ± 0.08
AMSR-E 37 V	-0.2 ± 0.2	-0.4 ± 0.09
WindSat 37 H	+0.6 ± 0.2	-0.4± 0.08
WindSat 37 V	-0.6 ± 0.3	-0.5 ± 0.1

Warm TB Inter-Sensor Drift

AMSR-E 37V-37H



AMR 18.7GHz	2 yr [K/yr]
Amazon Model	0.1 ± 0.2
AMSR-E 18 H	0.3 ± 0.2
AMSR-E 18 V	0.3 ± 0.2
WindSat 18 H	-0.01 ± 0.2
WindSat 18 V	-0.05± 0.1

AMR 23.8 GHz	2 yr [K/yr]
Amazon Model	-0.07 ± 0.2
AMSR-E 23 H	0.07 ± 0.2
AMSR-E 23 V	0.01 ± 0.2
WindSat 23 H	-0.3 ± 0.1
WindSat 23 V	-0.3 ± 0.1

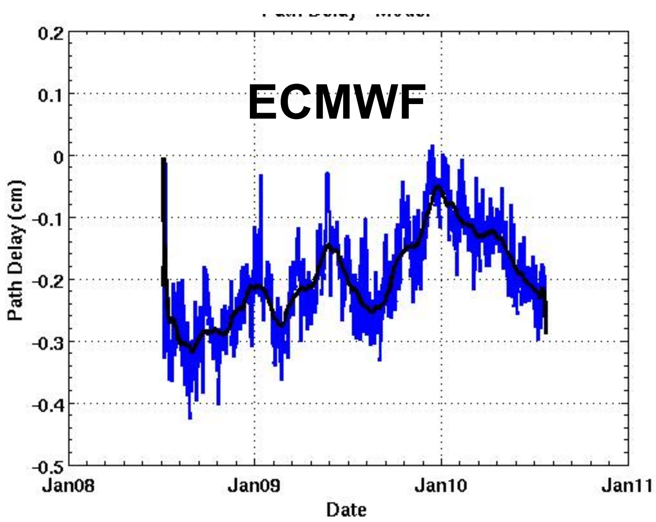
AMR 34.0 GHz	2 yr [K/yr]
Amazon Model	- 0.1 ± 0.2
AMSR-E 37 H	-0.2 ± 0.2
AMSR-E 37 V	-0.2 ± 0.2
WindSat 37 H	-0.2± 0.2
WindSat 37 V	-0.2 ± 0.2

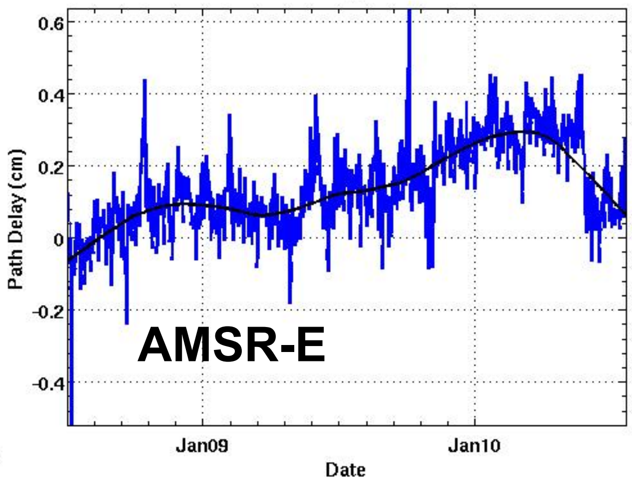
Summary of TB comparisons

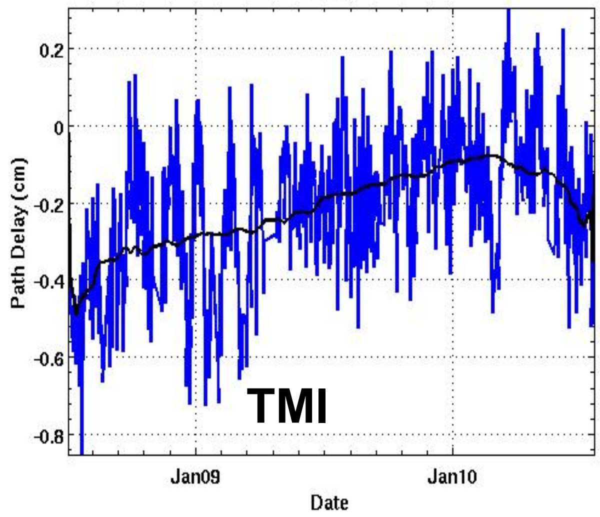
AMR	Cold TBs	Hot TBs
18.7	0.03 ± 0.07	0.1 ± 0.17
23.8	-0.34 ± 0.09	-0.18 ± 0.05
34.0	-0.42 ± 0.08	-0.1 ± 0.2

- Fairly good agreement between TB comparisons
- 23.8 and 34 GHz channels appear to have residual drift
- TB comparisons suggest PD drift rate of -1.5 ± 0.5 mm/yr

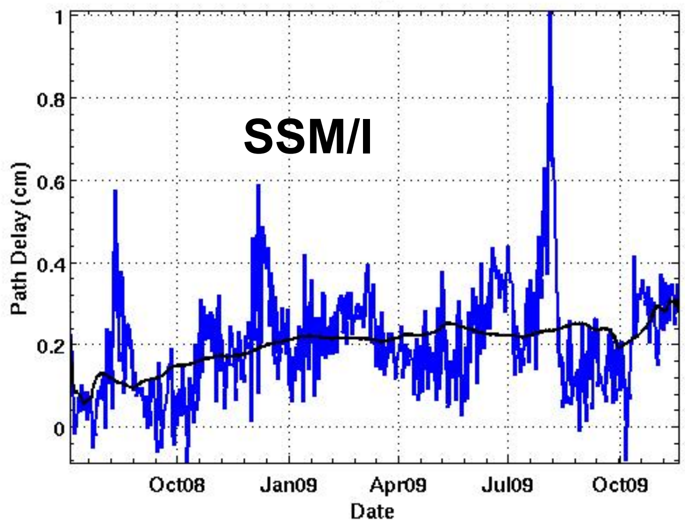
PD Inter-comparisons







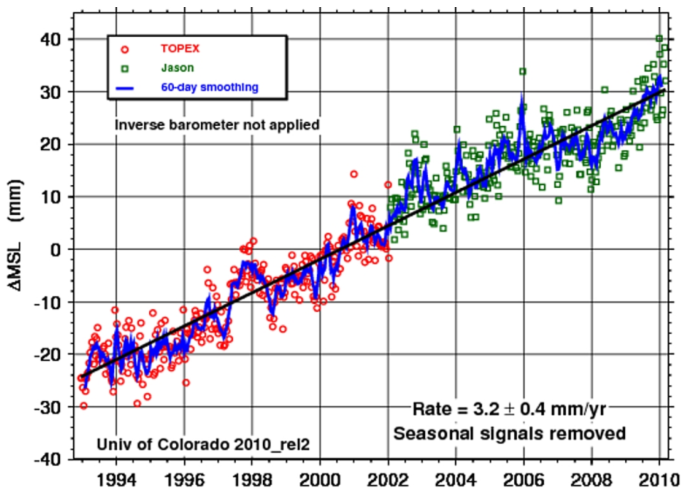
	1 yr [mm/yr]	2 yr [mm/yr]
PD ECMWF	-1.1 ± 0.1	-0.8 ± 0.04
PD AMSR-E	-1.0± 0.2	-1.2± 0.06
PD SSMI F13	-1.7 ± 0.2	-1.1± 0.1
PD TMI	-0.8± 0.4	-1.1± 0.1



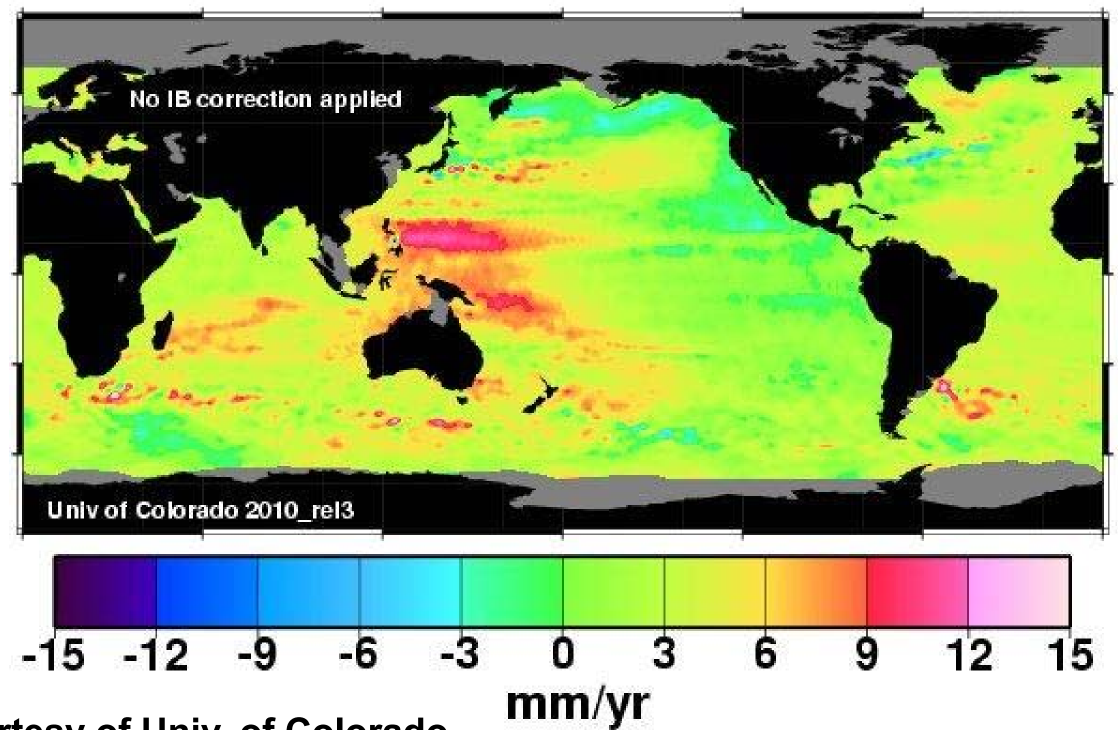
- Average from PD comparisons is -1.1 ± 0.2 mm/yr
- Consistent with TB comparisons within error bars

Regional Trends

- Observing regional trends also important
- Essential to understand impact of calibration drift on regional trends
- Different error structures arise due from instability in different channels and whether drift is gain or bias



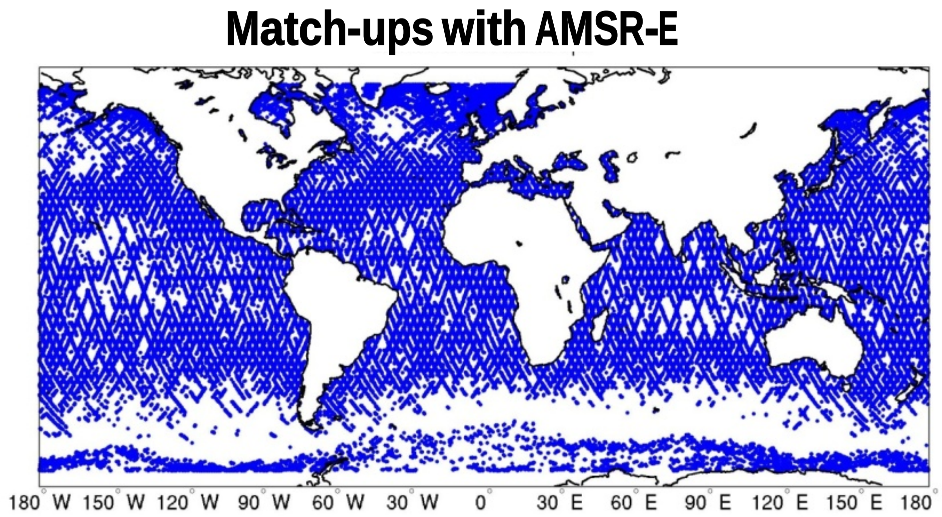
Regional GMSL Trends

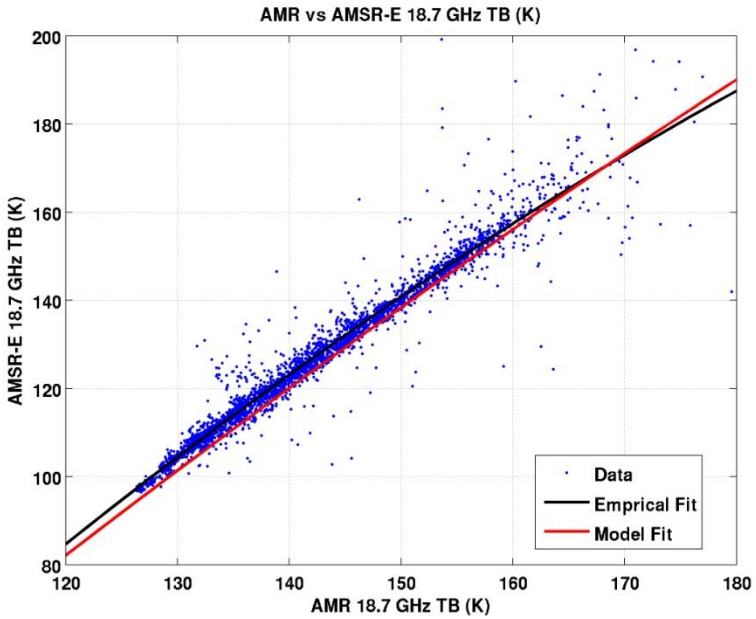


Courtesy of Univ. of Colorado

Inter-sensor TB Comparisons

- Transfer calibration of other microwave radiometers to AMR through co-incident observations





- Other sensors operate at different frequencies with different viewing geometry than the AMR
- Requires mapping function to go from other sensor's TB to AMRs TB
  - Mapping function determined empirically – suitable for looking at long term trends