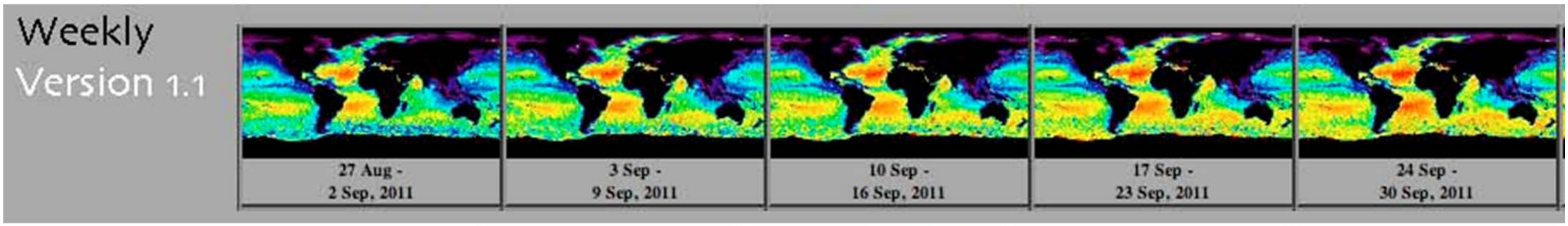
Characterization and Correction of the Aquarius TB Drift using On-Earth References

Shannon Brown and Sidharth Misra
Jet Propulsion Laboratory, California Institute of Technology

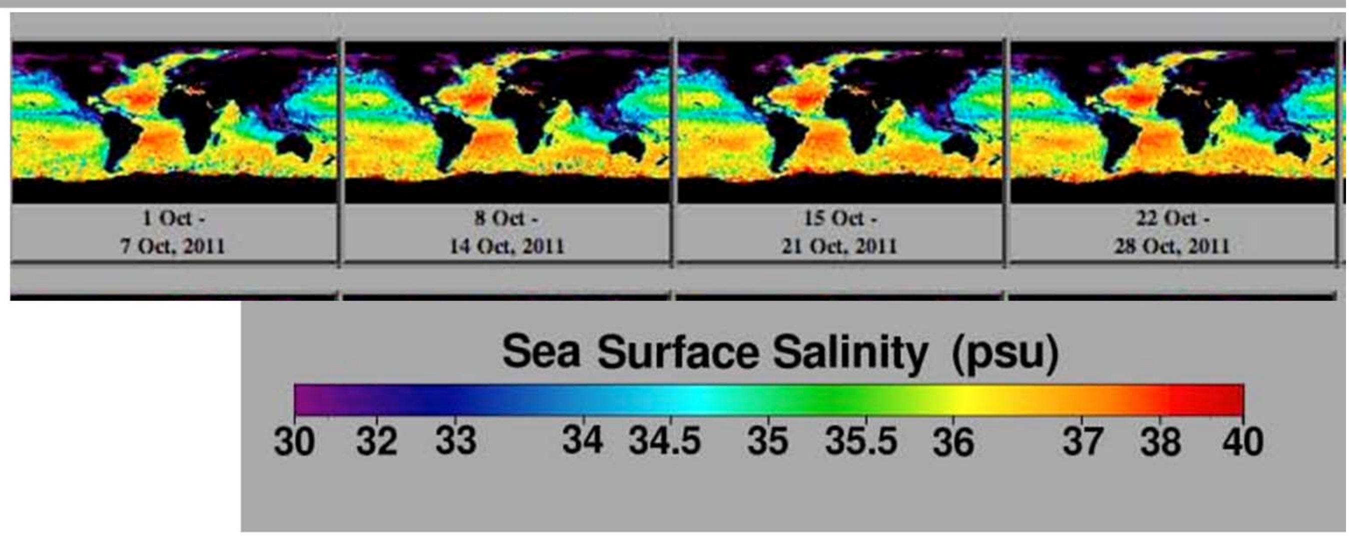
SMOS/Aquarius Workshop
April 16, 2013

Need for Stability

- A main mission objective is for Aquarius to provide monthly global salinity maps for climate studies
  - Critical that any spatial or temporal systematic biases be characterized and corrected to < 0.2 psu
  - Requires TB stability of about 0.1K, which is a challenging requirement for the radiometer

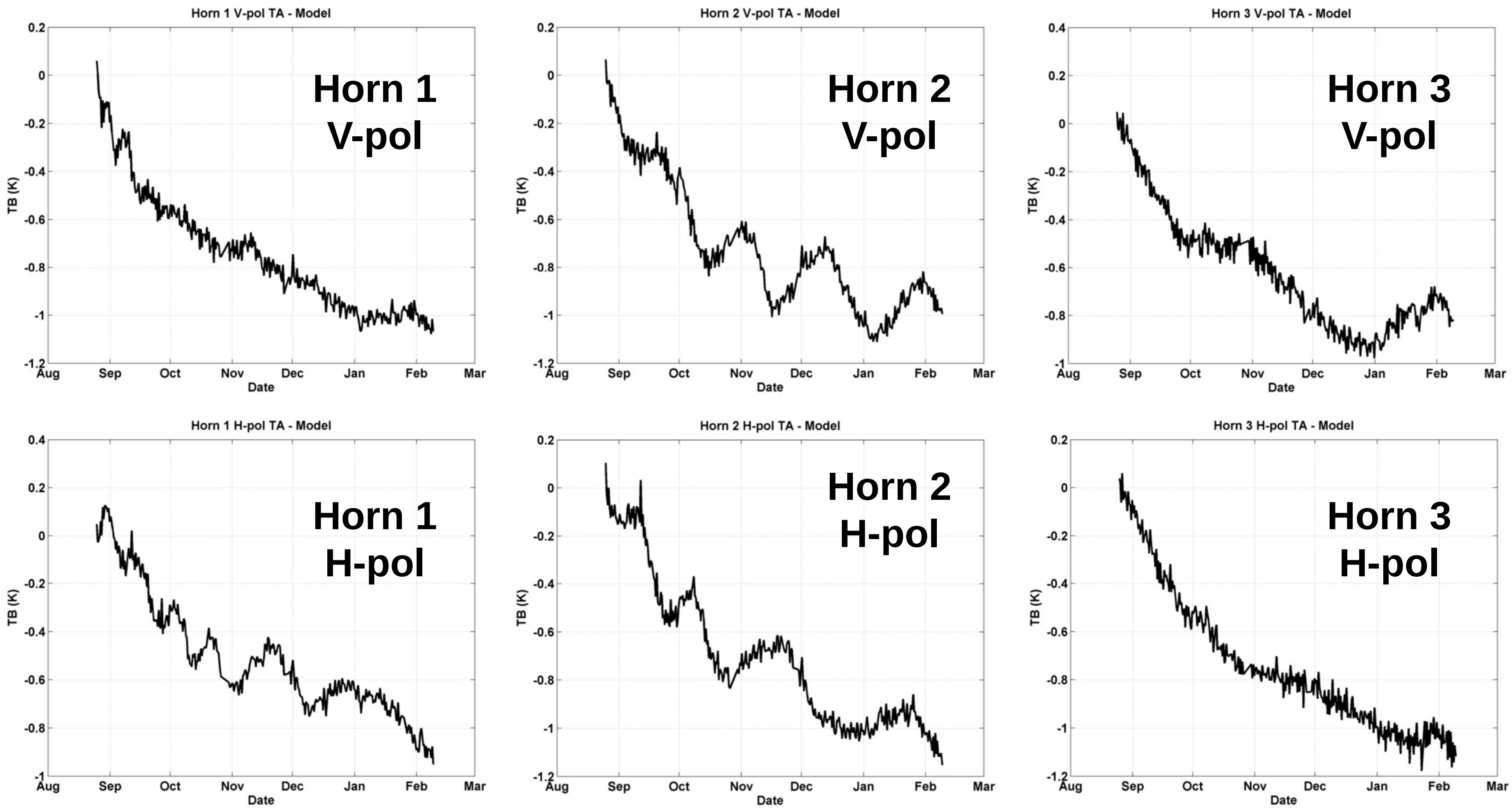


- Initially, Aquarius revealed increasingly more saline oceans with time
- Significant Aquarius drift became evident within the first few weeks



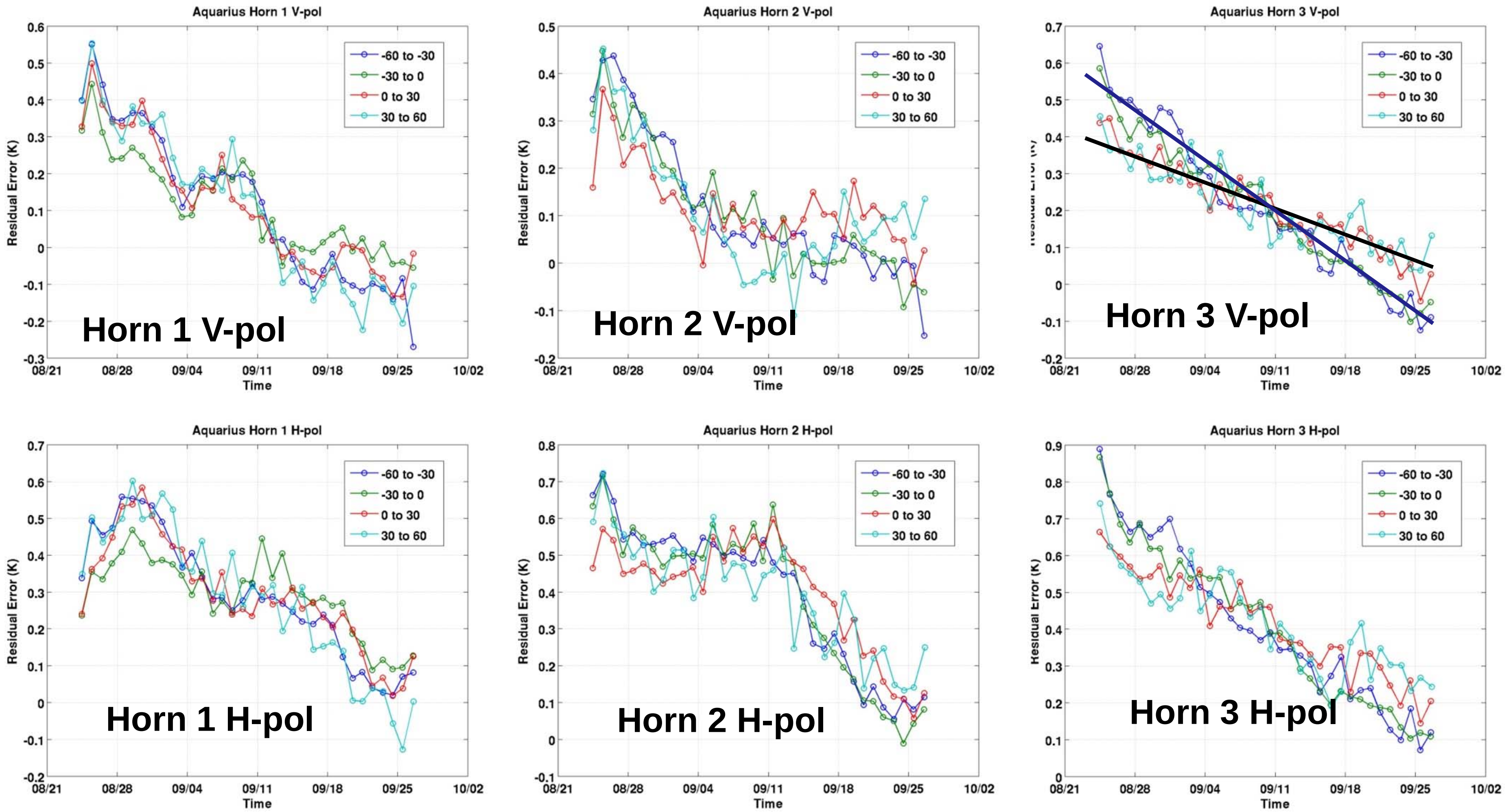
Aquarius Drift Relative to Ocean Model

- **Global average difference between observed and modeled TBs using HYCOM salinity reveals drift in all channels**
  - Data filtered for low wind conditions, negligible galactic contribution and weak faraday rotation



But which is the true drift?

- **Different trends observed when data are binned zonally**
- **<u>Need to ensure that drift calibration doesn't remove real signal not captured in the ocean model</u>**



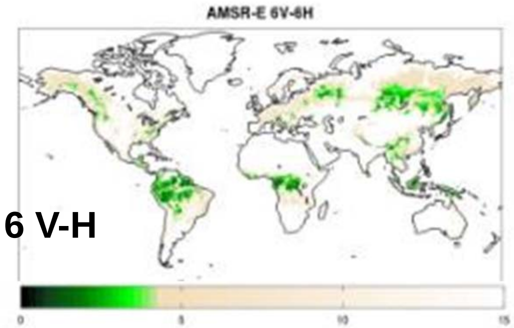
Drift Characterization and Correction Approach

- **Extend a technique originally developed to stabilize the climate calibration of the water vapor radiometers on the NASA altimeter missions**
  - **Use known reference targets at several brightness temperature levels to track both the gain and offset stability of the radiometer *-> important for soil moisture applications***
  - **Look for consistency between references to isolate instrument contribution from systematic model errors**
- **Develop model references suitable for L-band and characterize their uncertainty at various time scales**
  - **Particular to Aquarius, this implies assessing the timescale for which the model uncertainty is less than 0.1K**

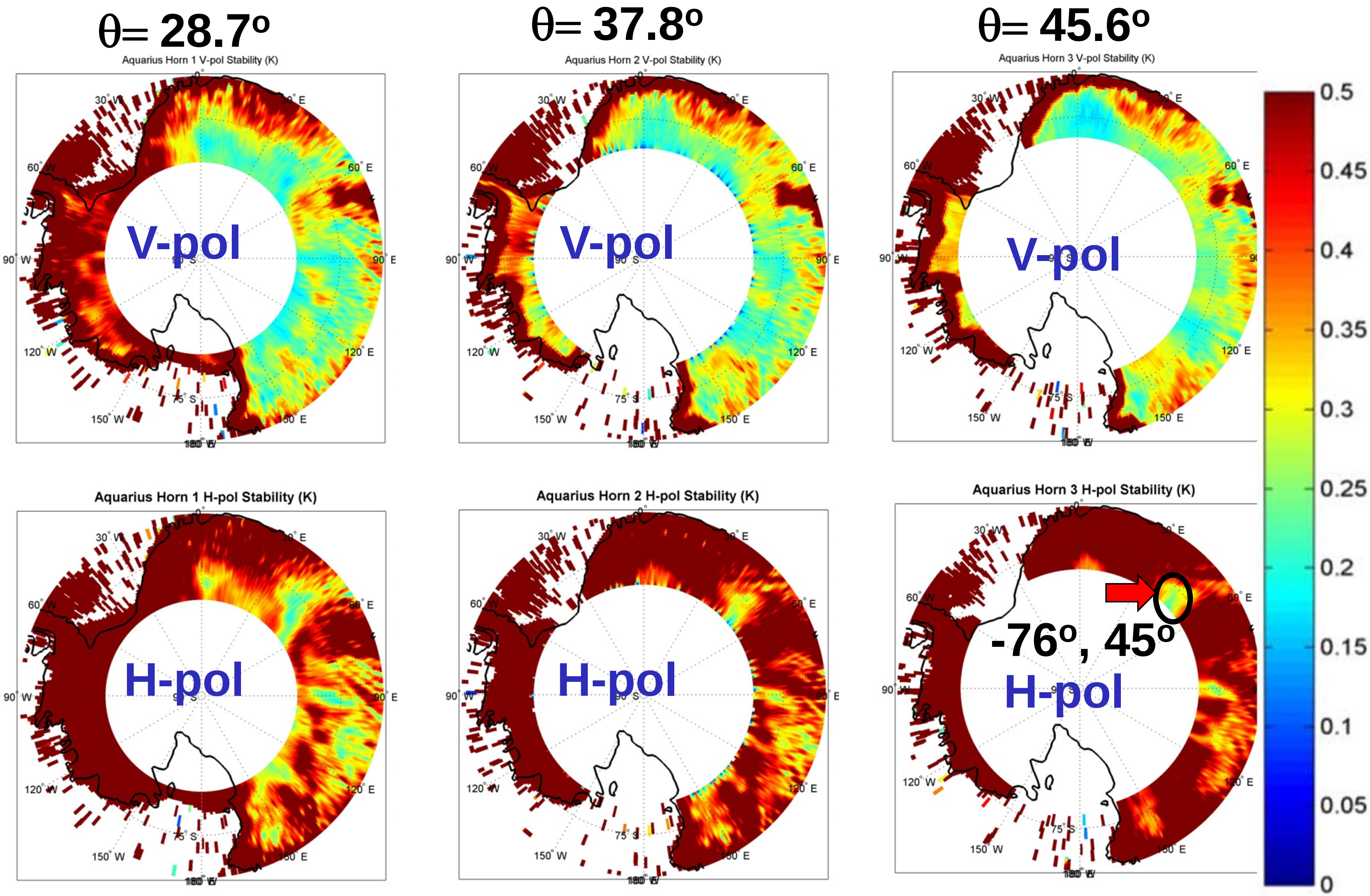
Natural On-Earth Calibration Targets for Stability Tracking

- **Antarctica (mid-range TB ~200K)**
  - Select areas with stable temperature (V-pol TB) and snow structure (H-pol TB)
  - Radiative transfer model used to determine L-band TB over time using in-situ temperature and higher frequency microwave observations as input

- **Rainforest (warm end TB ~280K)**
  - Select depolarized heavily vegetated areas within the Aquarius swath
  - Use ancillary data to determine canopy temperature to track Aquarius calibration



Aquarius L-band Temporal Stability (Sep’11-July’12)



Antarctica Ice Model

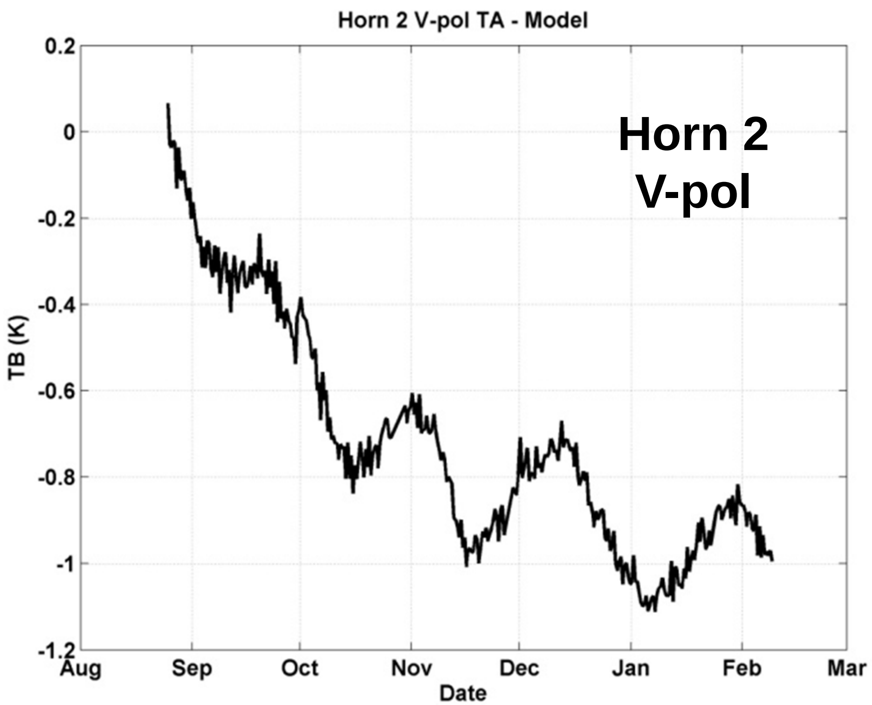
- **Coupled thermodynamic/radiative transfer model**
  - **MEMLS model (Wiesmann and Matzler, 1999) used to compute upwelling TB**
  - **Heat transport equation solved for ice T(z,t) profile**

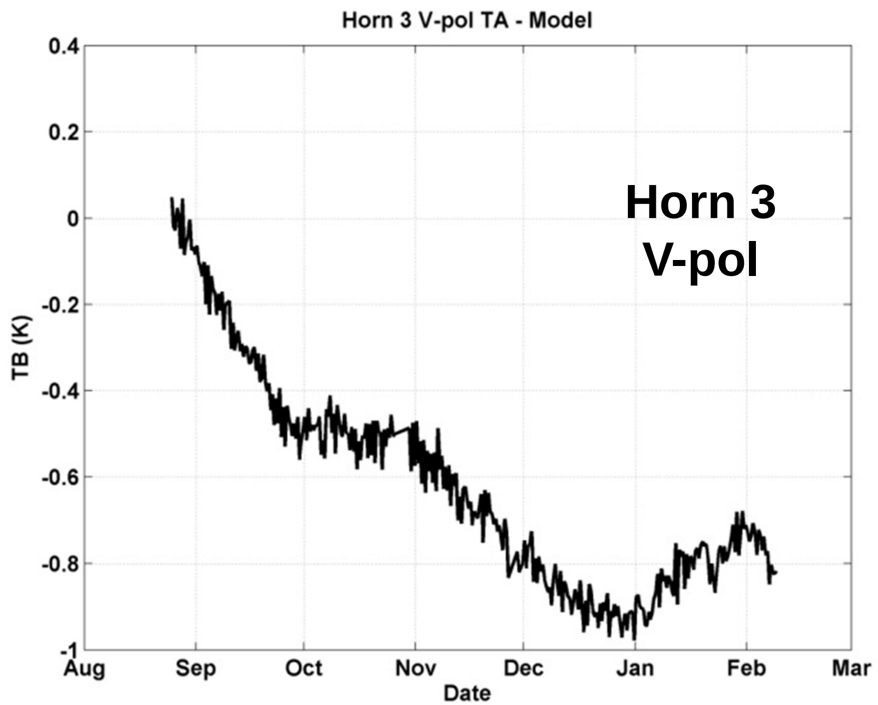
- **Tuned using multi-frequency AMSR-E TBs and in situ surface temperature data**
  - **Generated random snow layer structures to find a realization that gave best fit 6-37 GHz V&H-pol TBs**
  - **Ice dielectric model from Tiuri et al., (1984) gave best fit AMSR-E data**

- **Dynamic and static versions of model**
  - **Snow structure assumed constant in static model**
    - Limits ability for H-pol, particularly at higher incidence angle
  - **Dynamic model varies surface layer temperature and snow density to fit daily 6-37 GHz observations (e.g. WindSat, AMSR-2)**

Nature of the Drift

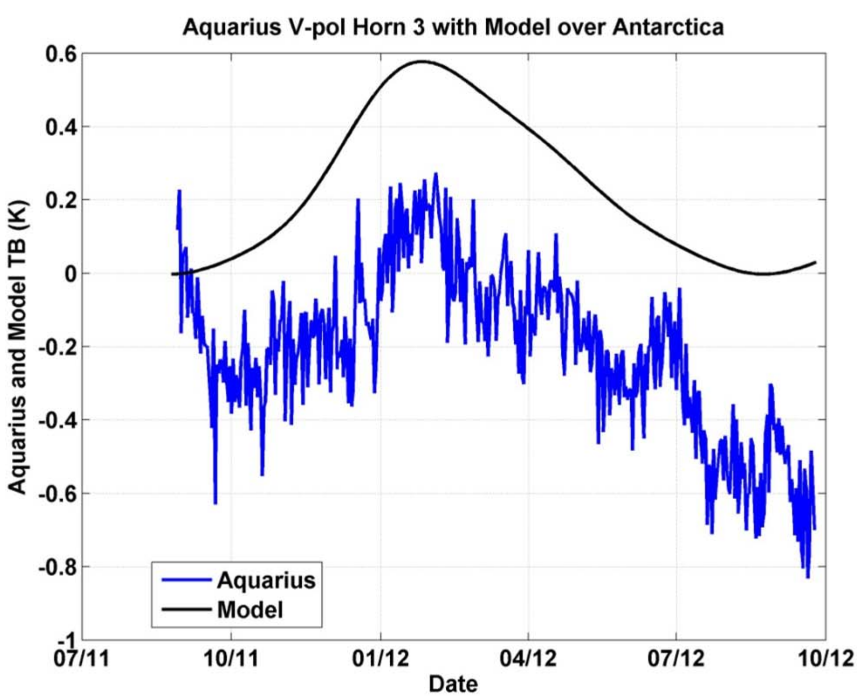
- **Ocean comparisons show long period exponential trend (~1K level) and shorter period oscillations (~0.2 K level)**
  - **Are these observed in the Antarctic and rainforest comparisons?**
  - **If so, do they have the same magnitude (-> offset) or are they scaled (-> gain)?**
    - Gain drift will be ~0.5x over Antarctica (~0.5K) and ~0.05x (~0.05K) over rainforest since Aquarius calibration referenced to internal ~300K load

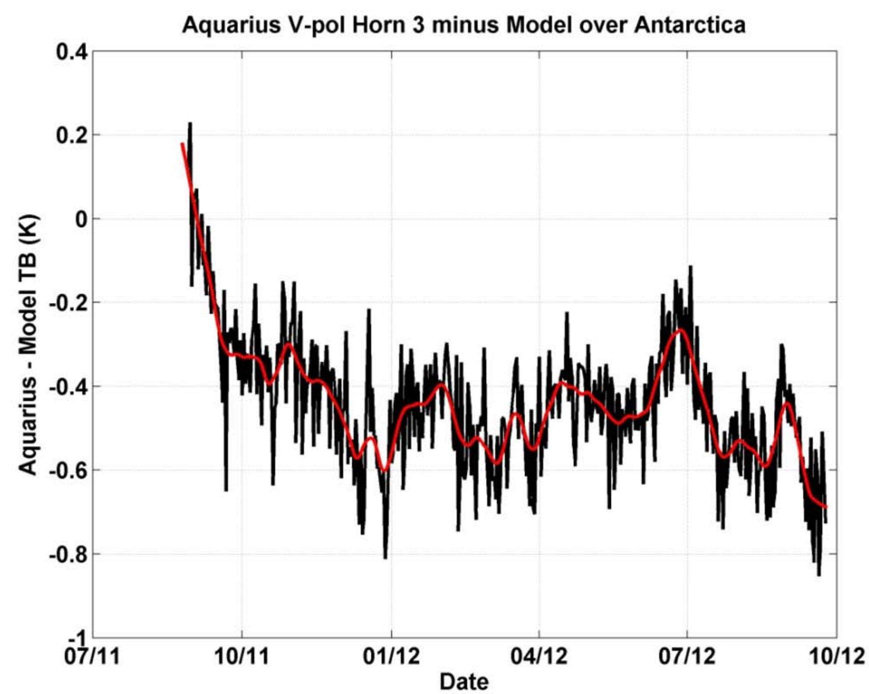




Aquarius – Antarctica TB Model

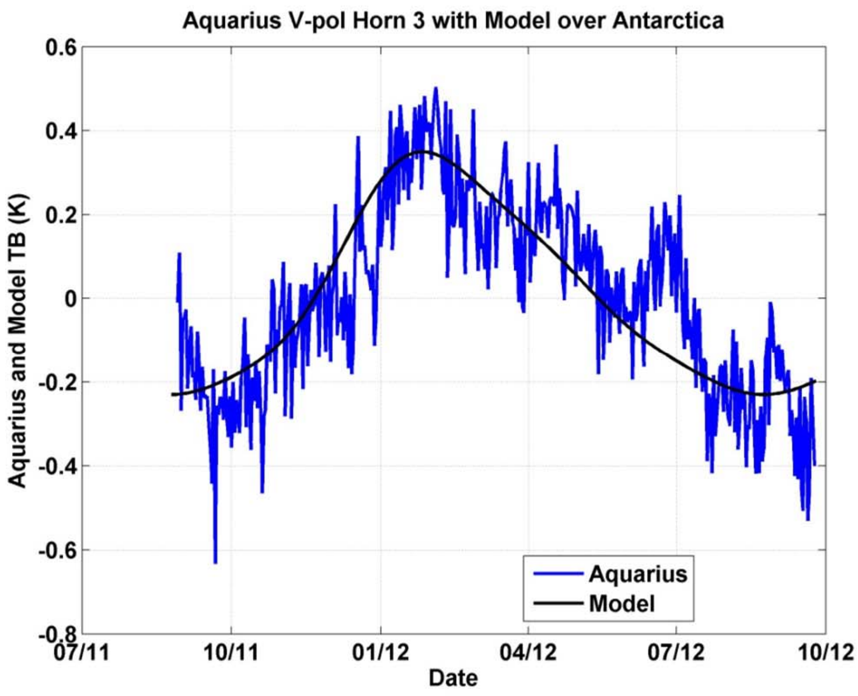
- **Difference between Aquarius and Antarctica TB model shows ~0.5K long term drift, but similar magnitude short term oscillations**
  - **Horn 3 V-pol shown here as an example since ice model performs best near Brewster angle (minimizes sensitivity to surface variability, wind crusts)**
- **Long term drift consistent with a gain drift**
  - **first implemented a long term exponential gain correction fit to ocean model**

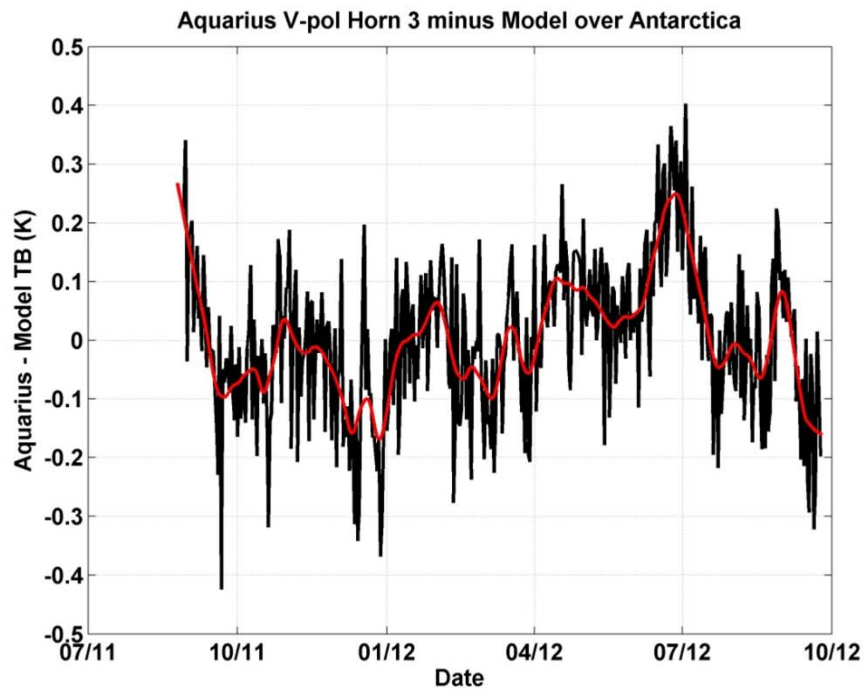


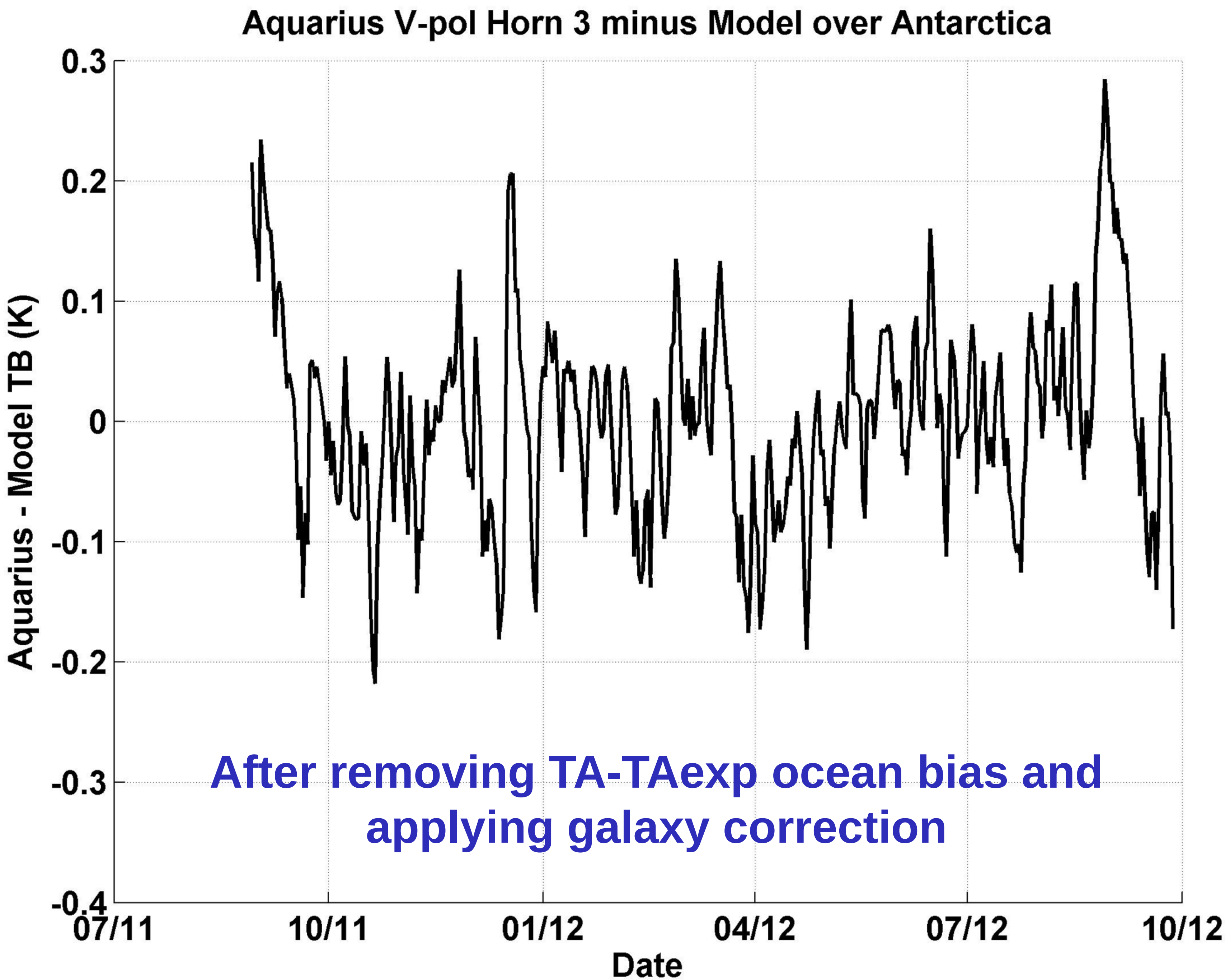


With Exponential Gain Correction

- **Exponential TND correction removes long term drift over Antarctica**
  - **Note, if offset correction was applied instead of a gain correction, a ~+0.5K drift would have been introduced over Antarctica**
- **Short term oscillations remain**
  - **Instrument or ice model?**



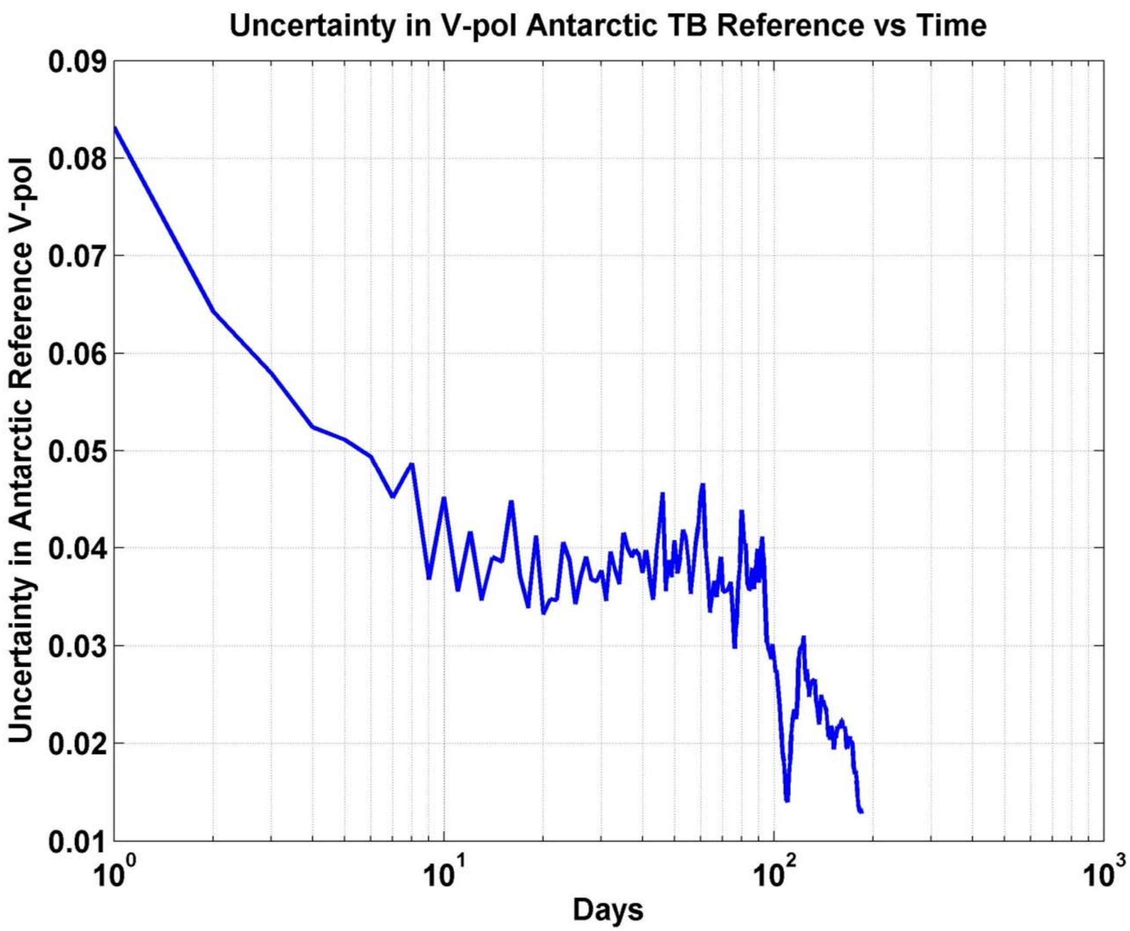




Aquarius V-pol Horn 3 minus Model over Antarctica
Aquarius - Model TB (K)
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
07/11
10/11
01/12
04/12
07/12
10/12
Date
After removing TA-TAexp ocean bias and applying galaxy correction

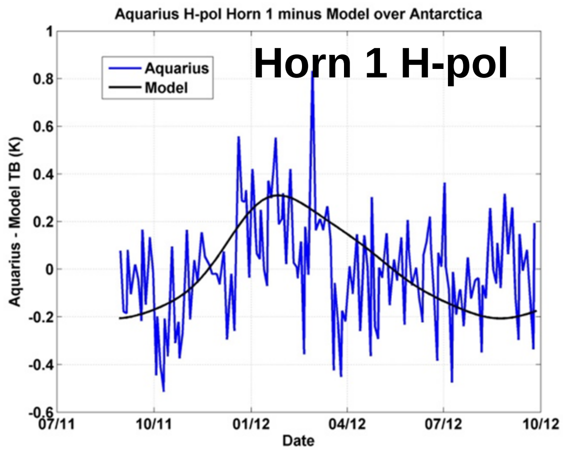
Uncertainty in Antarctic Reference: V-pol

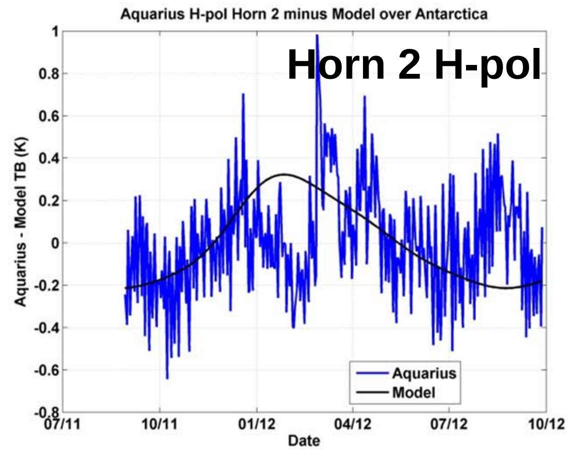
- **Antarctic reference for V-pol sensitive to 0.1K variability on daily time scales and <0.05K varability on > 10 day times scales**

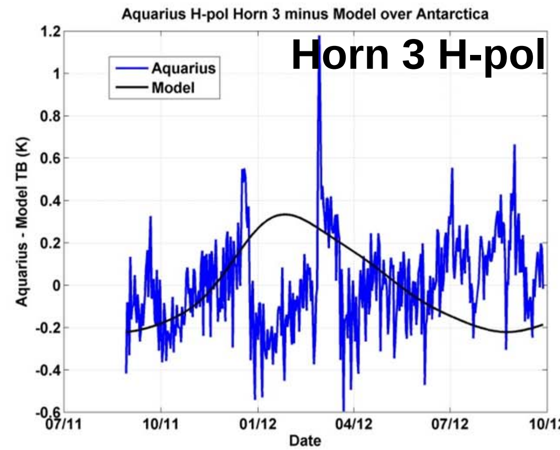


H-pol Channels after Exponential Gain Correction

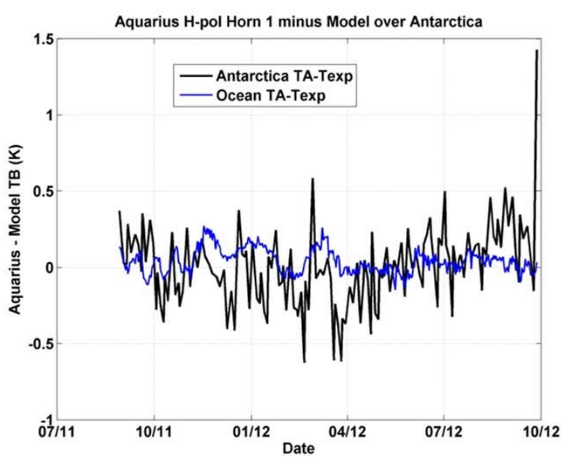
- **H-pol comparisons nosier due to ice surface variations not accounted for in model**
  - **Uncertainty ~ 0.25-0.5 K level**
  - **…but no evidence of residual drift**

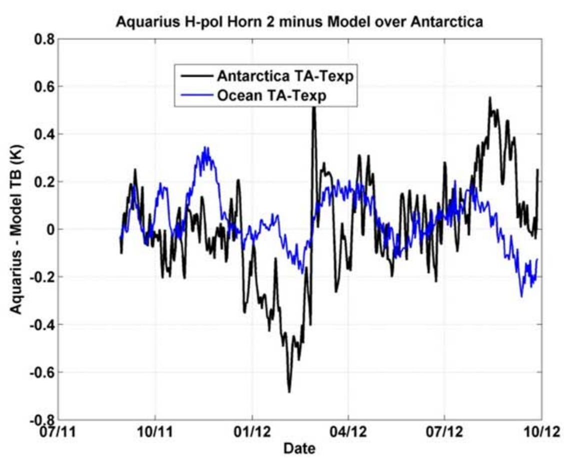


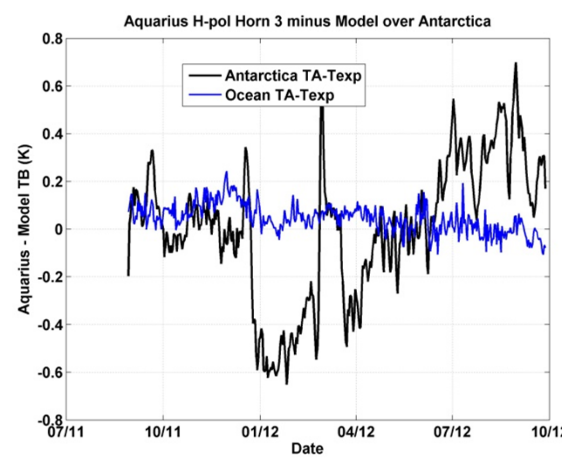


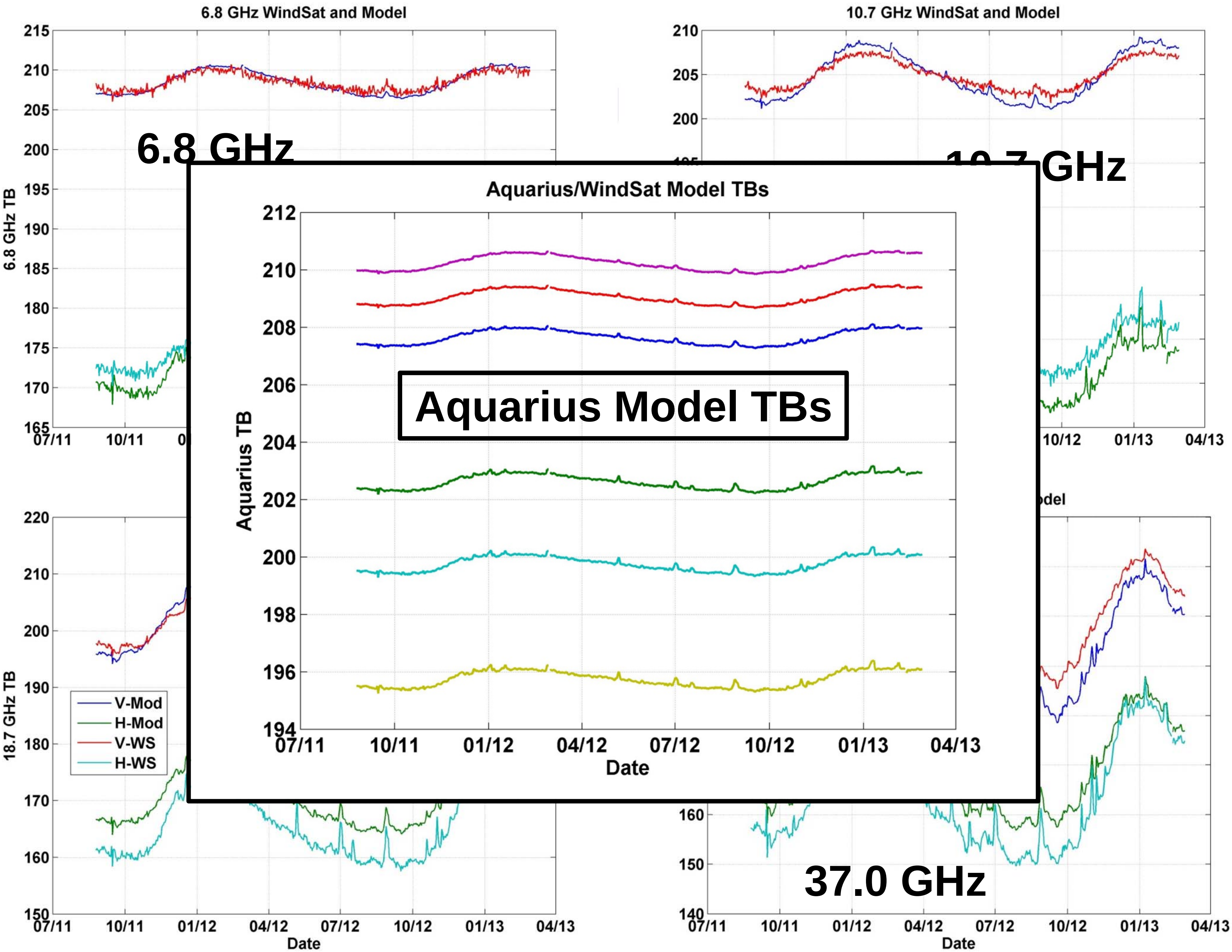


Aquarius- Model





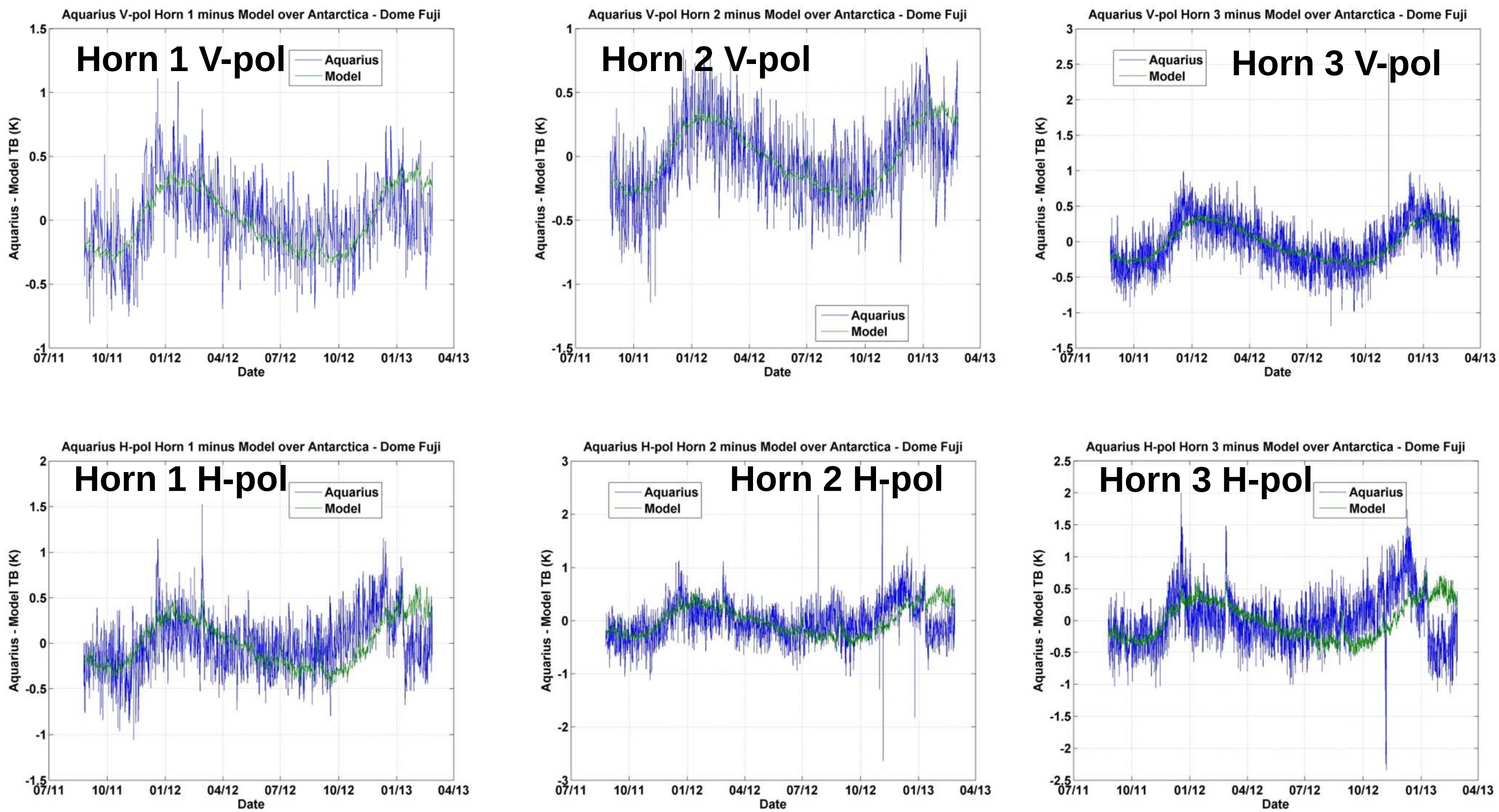


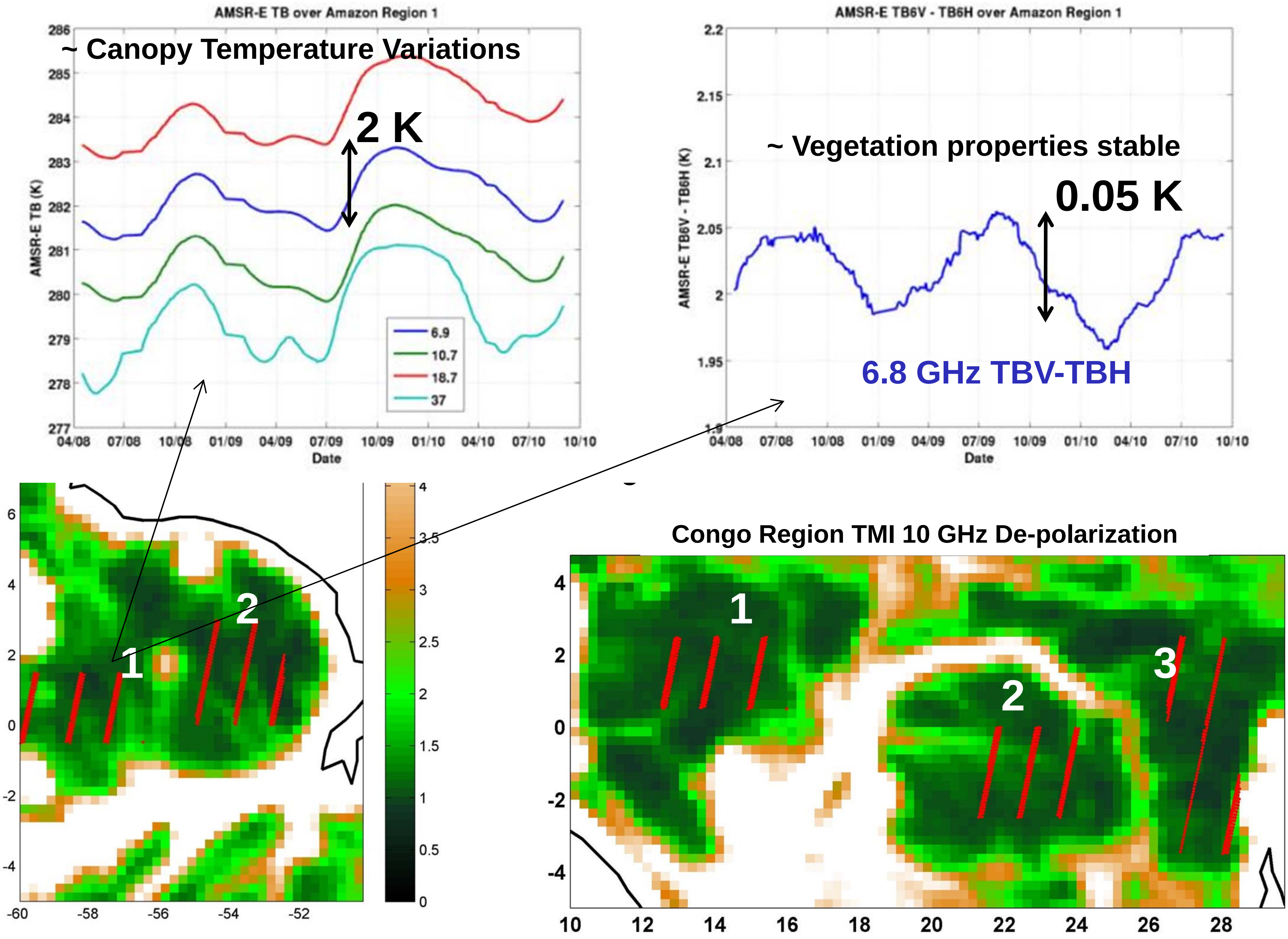


6.8 GHz WindSat and Model
6.8 GHz TB
6.8 GHz
10.7 GHz WindSat and Model
10.7 GHz
18.7 GHz TB
V-Mod
H-Mod
V-WS
H-WS
Date
37.0 GHz
Aquarius/WindSat Model TBs
Aquarius TB
Aquarius Model TBs
Date
07/11
10/11
01/12
04/12
07/12
10/12
01/13
04/13

Aquarius with Dynamic Antarctic Model

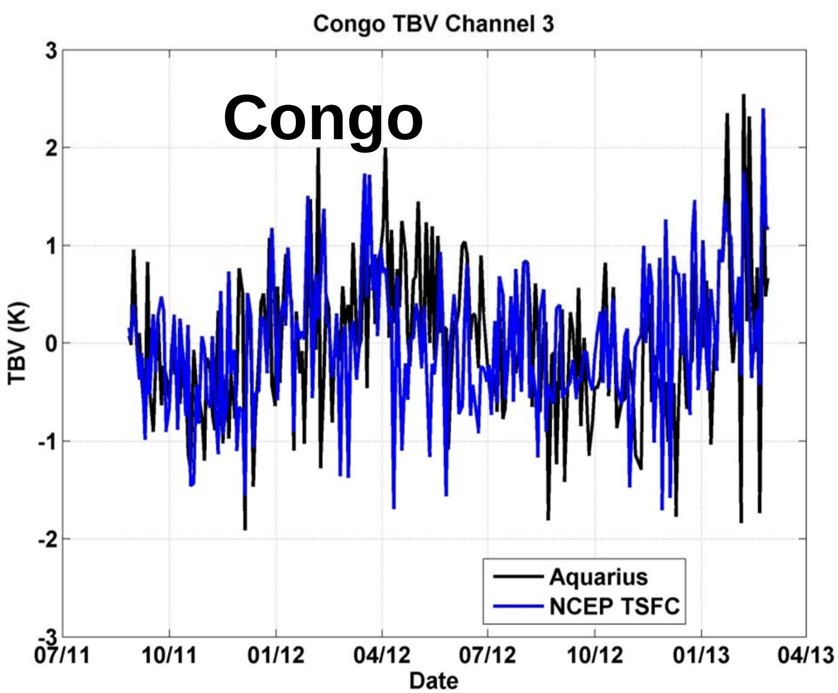
- **Dynamic model offers some improvement for H-pol, but doesn't capture all variability**
- **Future work will attempt to improve dynamic model, but we still have the rainforest comparisons…**

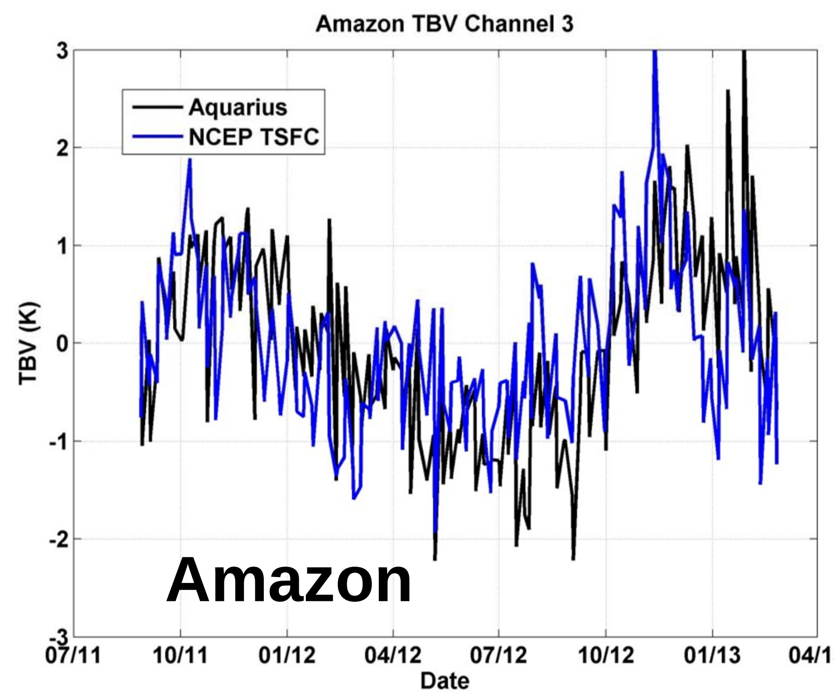



AMSR-E TB over Amazon Region 1
~ Canopy Temperature Variations
2 K
AMSR-E TB (K)
Date
6.9
10.7
18.7
37
AMSR-E TB6V - TB6H over Amazon Region 1
~ Vegetation properties stable
0.05 K
AMSR-E TB6V - TB6H (K)
6.8 GHz TBV-TBH
Congo Region TMI 10 GHz De-polarization
1
2
3

Aquarius TB and NCEP Surface Temperature

- Slightly larger seasonal signal observed over Amazon
- NCEP surface temperature scaled by approximate surface emissivity of 0.94 for large woody volume forests (Vecchia et al. 2010)
- Good correlation observed on long time scales

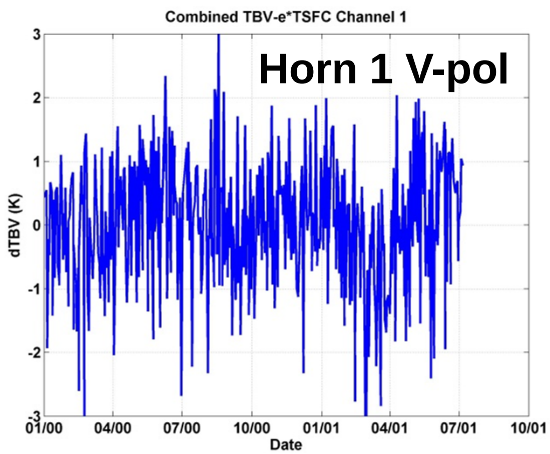


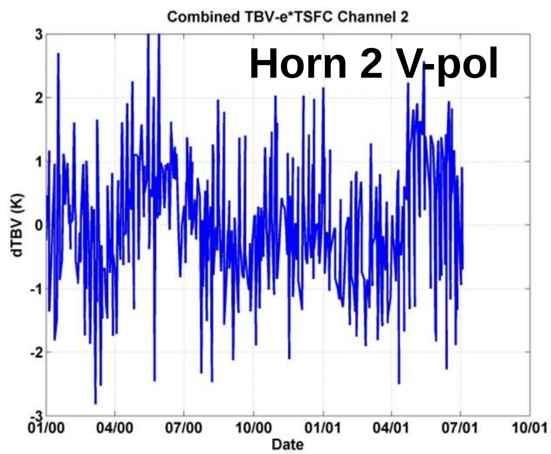


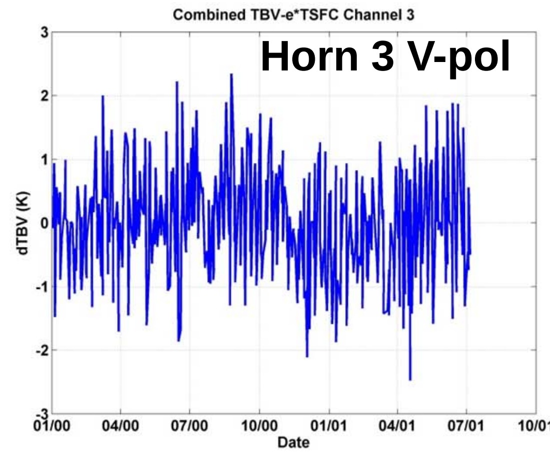
Aquarius – Rainforest (Congo+Amazon)

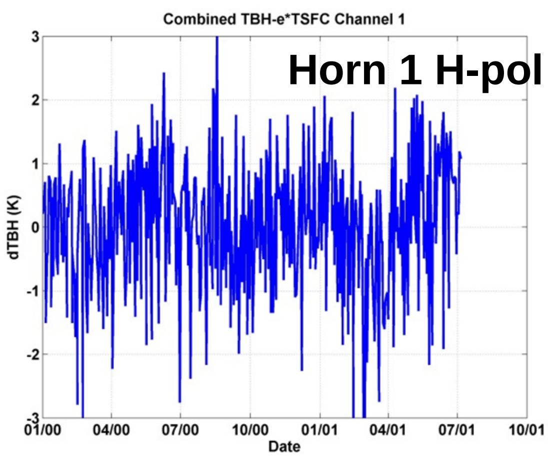
- **Individual channel comparisons too noisy to assess short period oscillations**

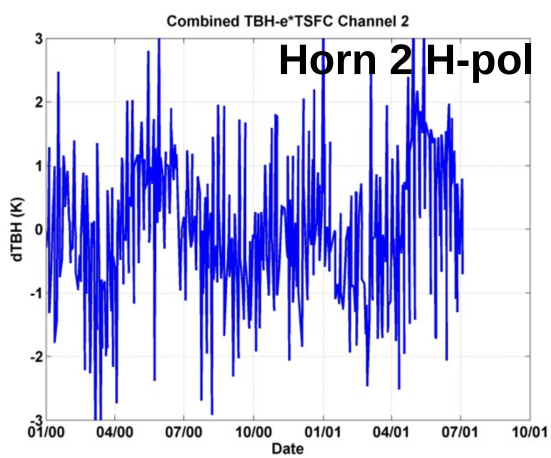
- **Though, can be used for tracking long term drift**
  - **Absence of long term drift exponential drift consistent with gain drift**

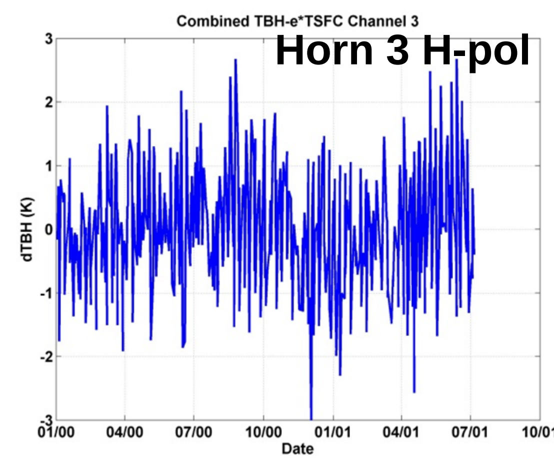






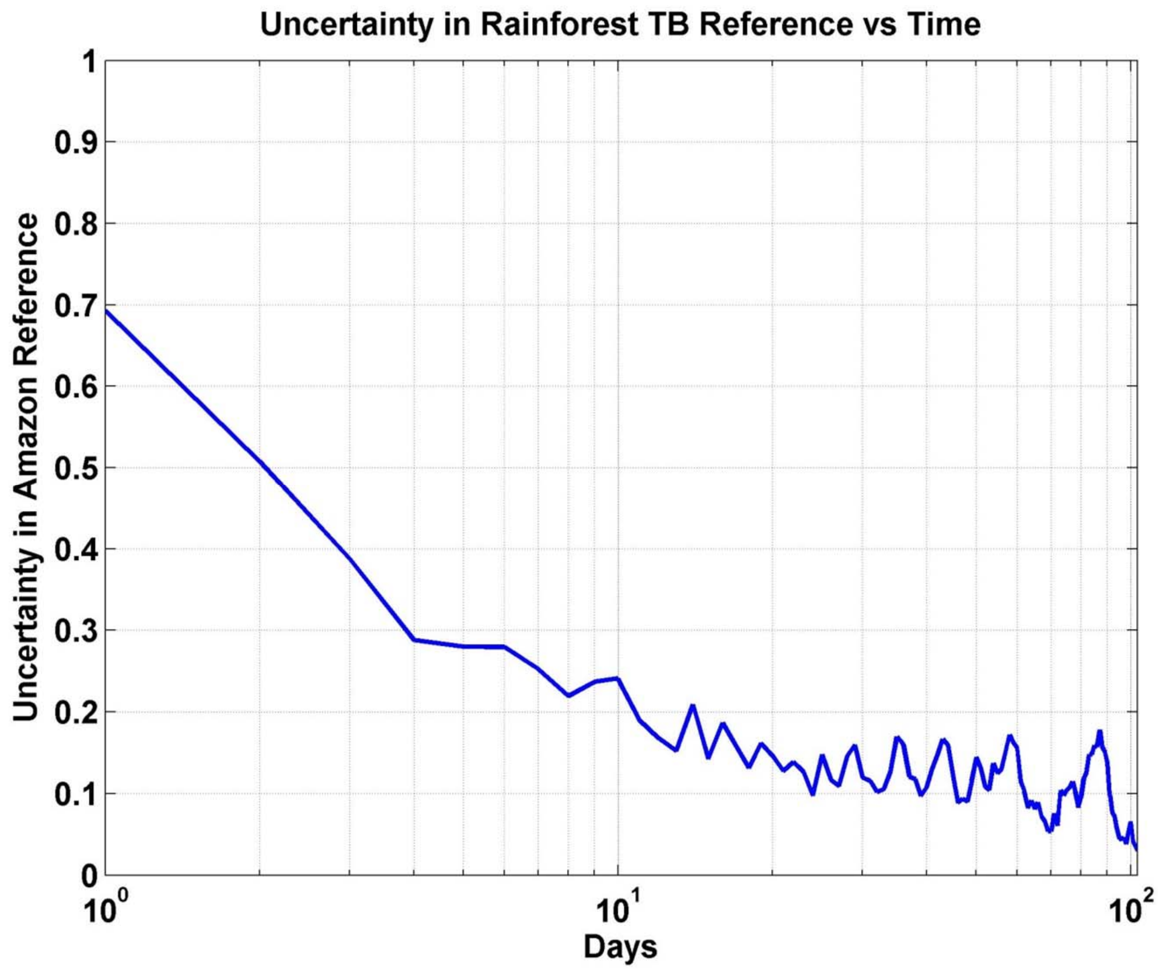






Uncertainty in Rainforest Reference

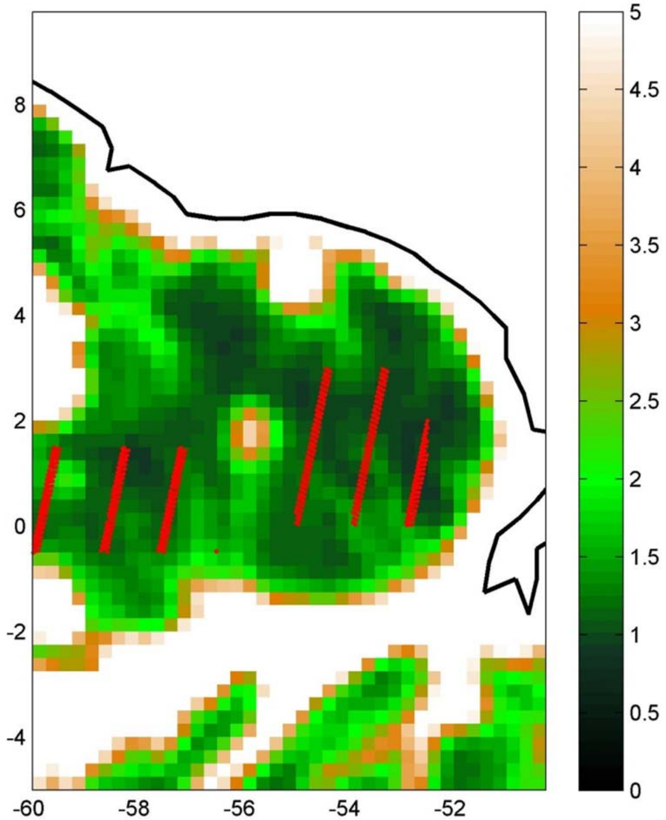
- **Rainforest reference only reaches 0.1K level uncertainty on > 60 day time scales**
  - **Not good enough for analyzing quasi-monthly variability**



Inter-channel Differences over Rainforest

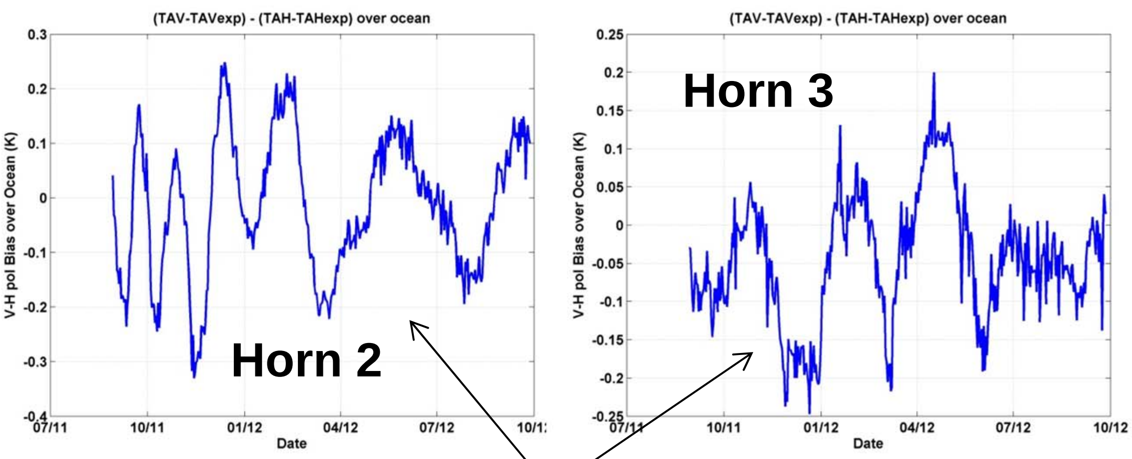
- Offset error should be apparent in rainforest comparisons
- Uncertainty in TA over rainforest regions at > 0.1K level on time scales < 30 days mainly due to uncertainty in T_{canopy}, but…

Amazon Region TMI 10 GHz De-polarization



these uncertainties largely cancel if looking at inter-channel differences

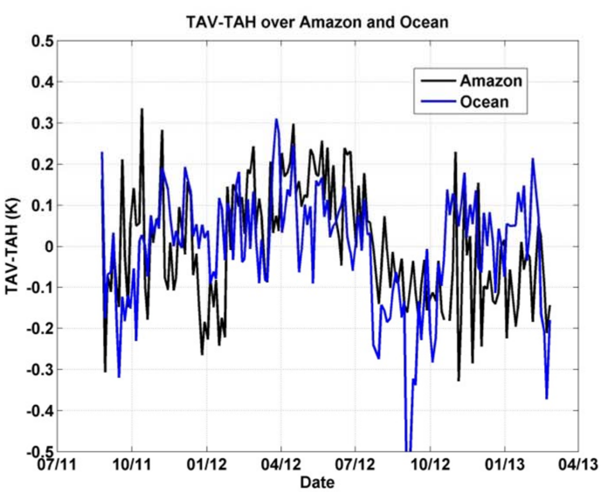
Inter-channel biases relative to ocean model



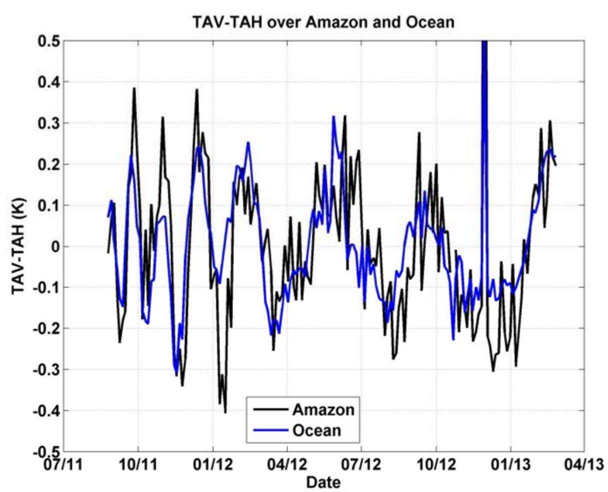
$$\left(T_V - T_{V\_Expected}\right) - \left(T_H - T_{H\_Expected}\right)$$

Inter-Channel Differences over Rainforest

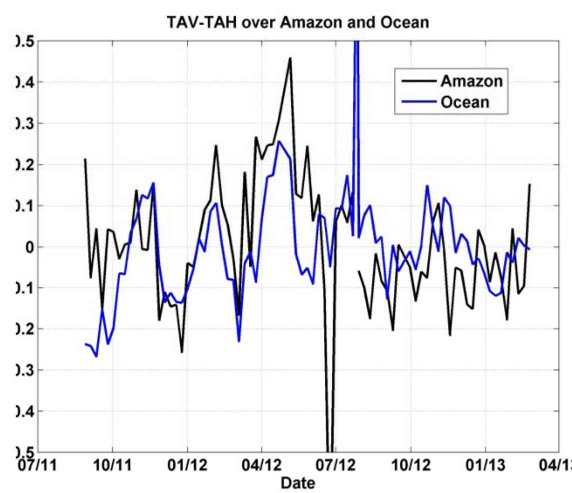
- **Uncertainty in T_{canopy} largely cancels in V-pol – H-pol difference over the rainforest regions**
- **Assuming that surface emissivity is stable (and depolarized), then these inter-channel differences allow us to assess relative offsets compared to ocean**
  - **Uncertainty at 0.1K level on times scales < 10 days**



Horn 1



Horn 2



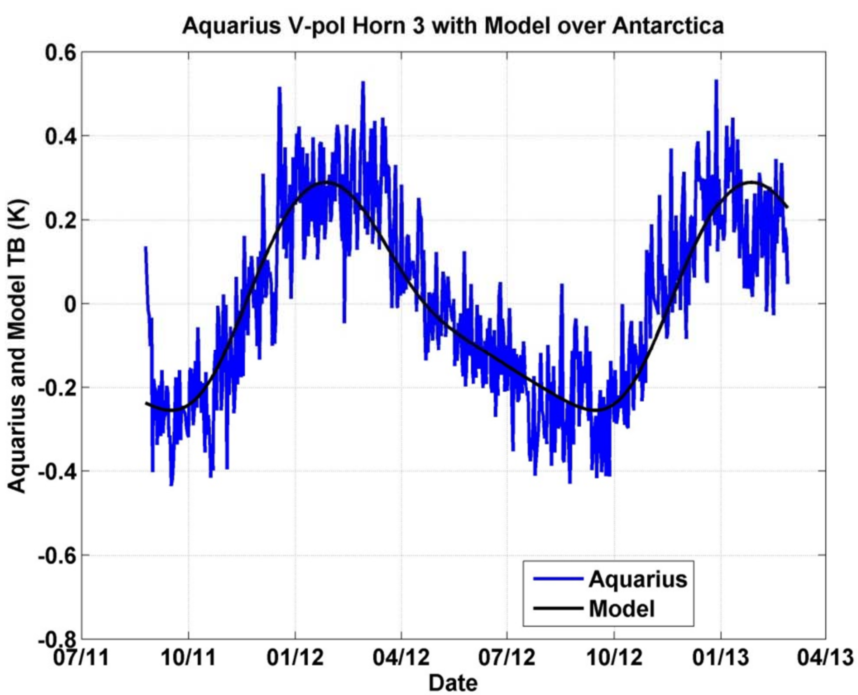
Horn 3

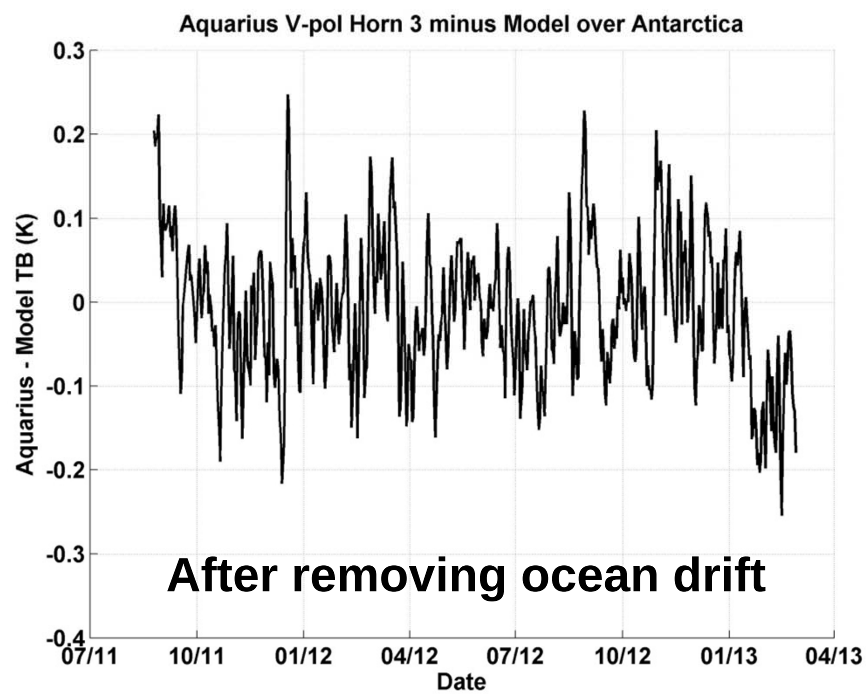
Aquarius Version 2 Drift Correction Approach

- **Empirical exponential gain correction fit to > 1yr time series of ocean model differences**
- **Residual TA oscillations removed by extracting a common component from ocean model time series computed for different regions and subtracted as an offset**
- **Corrections only made to V & H pol channels, not 3rd stokes**

Version 2 Aquarius – Antarctica TB : TBV horn3

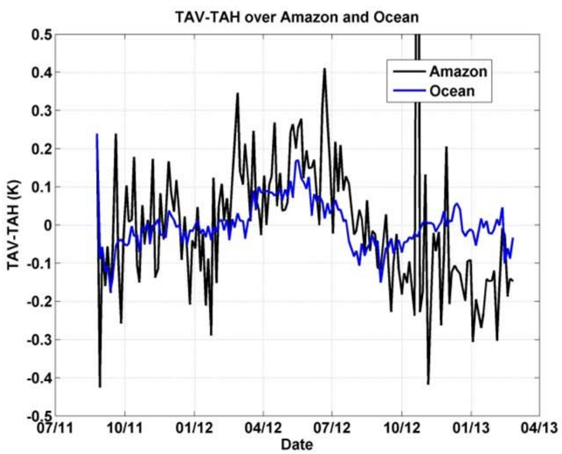
- **Version 2 calibration removes most all drift, but residual instrument calibration variability at 0.05-0.1 K still apparent**



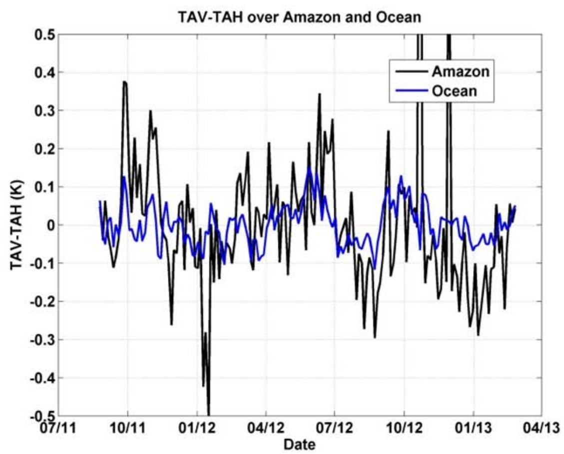


Version 2 Aquarius TV-TH over Rainforest

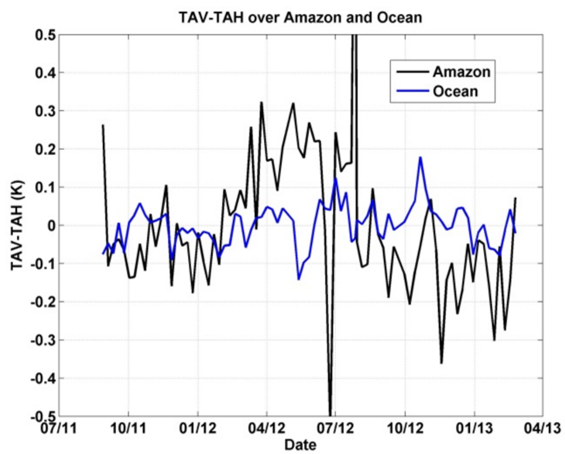
- **Some residual error remains in inter-channel differences as well**
  - **Correlated between ocean and rainforest**



Horn 1



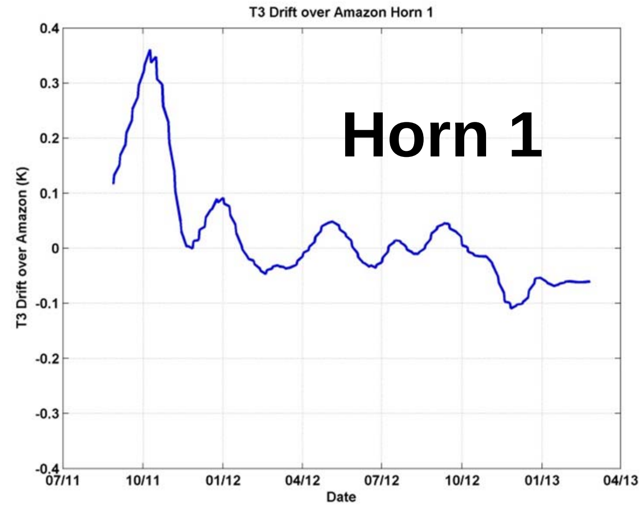
Horn 2



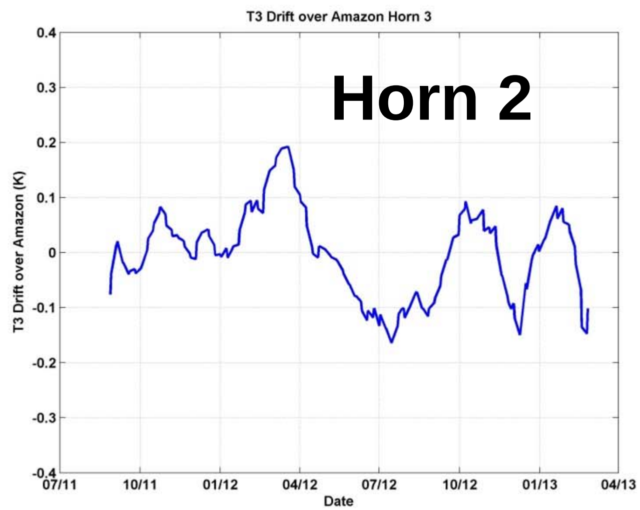
Horn 3

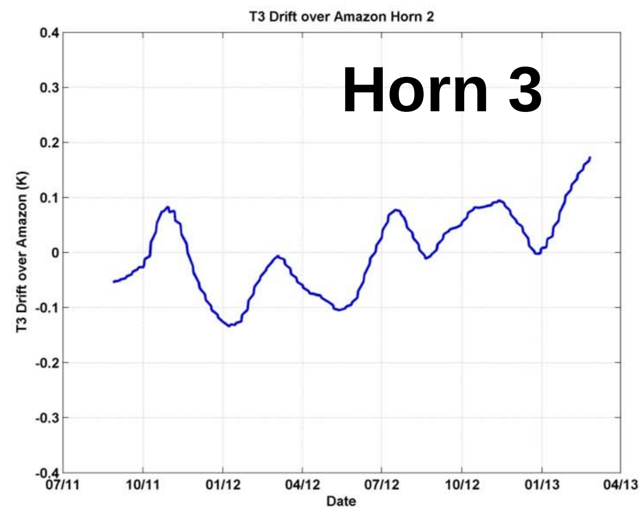
Version 2 3rd Stokes Calibration Variability

- **3rd stokes should be near zero and stable over rainforest**
  - Consistent variability observed across 5 regions in Amazon and Congo
  - Variations between 0.1-0.4K observed
  - Introduces small time variability in Asc/Dsc regional differences and in global mean time series



- **Current correction implemented for V2 doesn't address drift/oscillations in 3rd stokes**





Summary

- **Antarctica and rainforest references used to characterize TB drift**
  - **Separated gain and offset components of Aquarius TB drift**
  - **Isolated instrument contributions though inter-reference consistency**

- **Reference model uncertainty:**
  - **Antarctica reference uncertainty < 0.05 K on >10-day time scales for V-pol, but not as reliable for H-pol (>1K uncertainty)**
  - **Rainforest reference uncertainty at 0.1K on > 60-day times scale for single channel observations**
  - **Uncertainty in inter-channel differences over rainforest (e.g. V-Hpol) <0.1K on 10-day times scales**
    - Including 3rd stokes

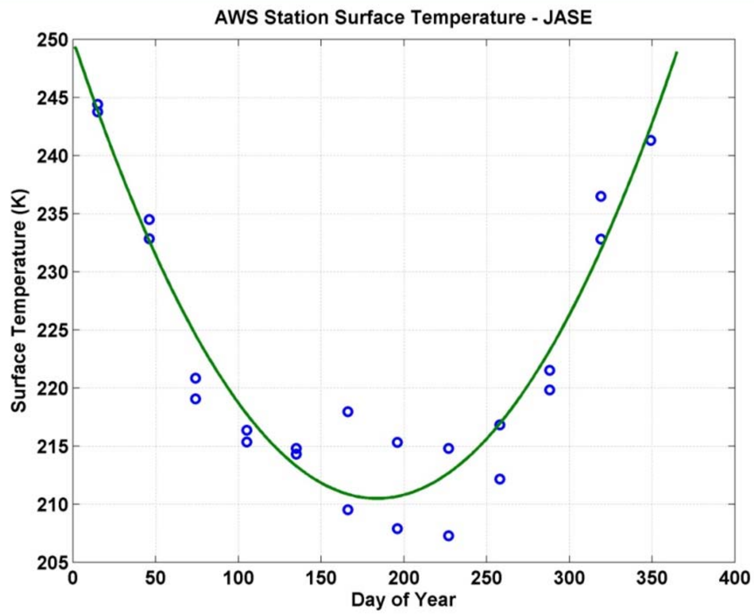
Next Steps: Toward Aquarius Version 3

- **Current drift correction approach doesn't completely remove all instrument variability nor correct 3rd stokes variability**

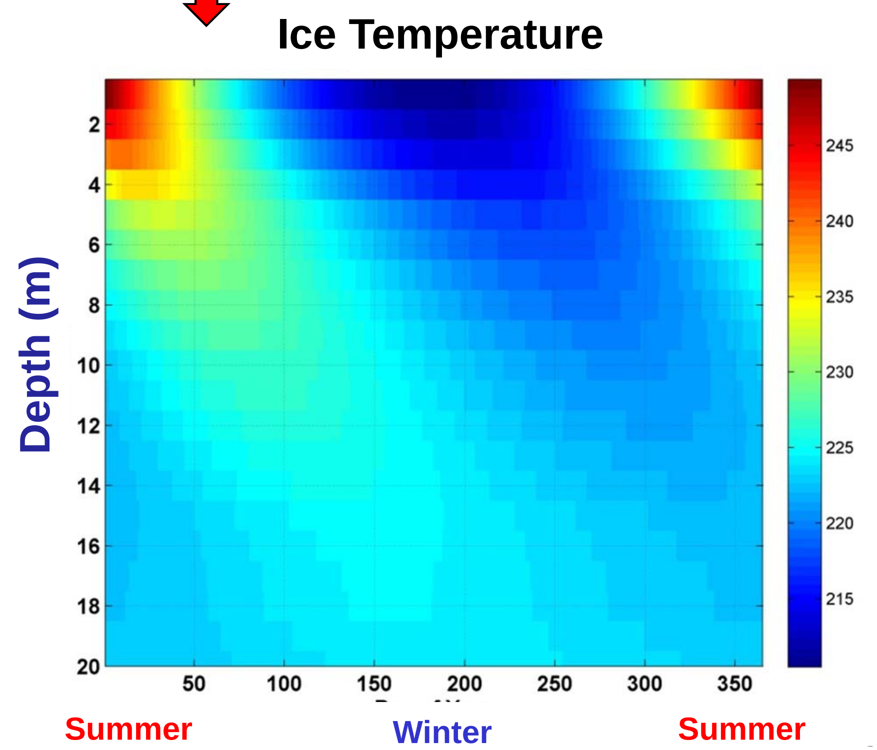
- **Recently, probable root cause for the long term drift and short term oscillations identified**
- **Move toward hardware constrained or hardware only solution**
- **Assess and apply corrections for all channels (including 3rd stokes)**

Backup

Thermal Profile



$$\frac{\partial T}{\partial t} = \alpha_T(\rho)\frac{\partial^2 T}{\partial z^2}$$

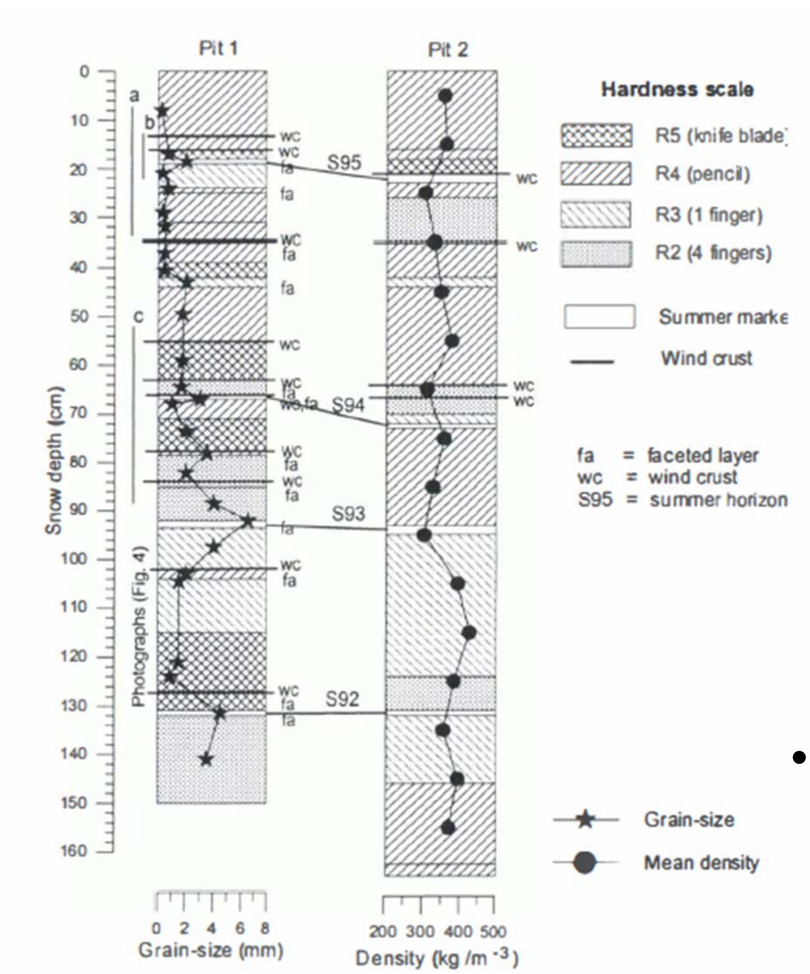


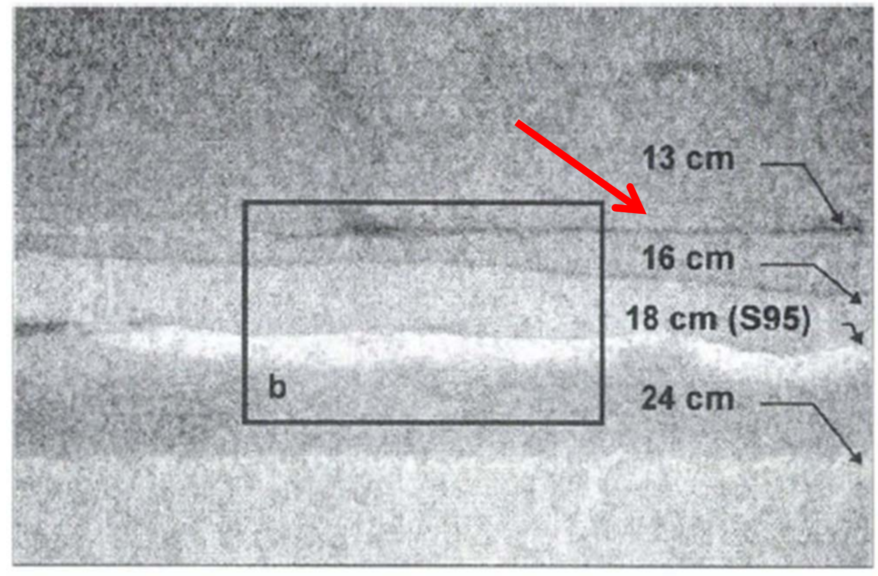
Surface temperature values obtained from near by AWS station (JASE) used as top boundary condition

Solved heat equation numerically to determine T(z,t) assuming only vertical heat transport

Thermal diffusivity increases as a function of density (Paterson, 2000)

Snow Structure

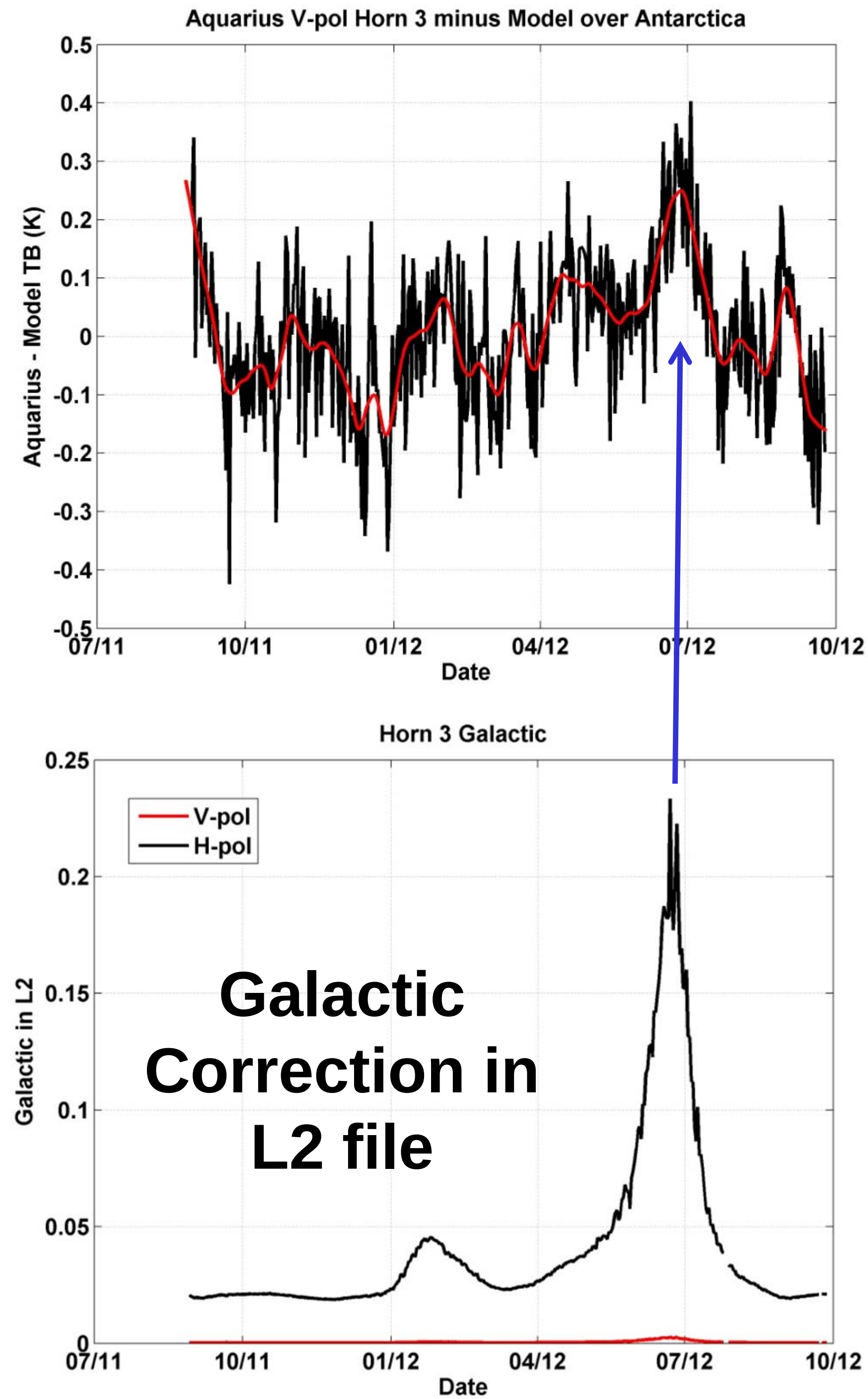




Steffen et al., 1999

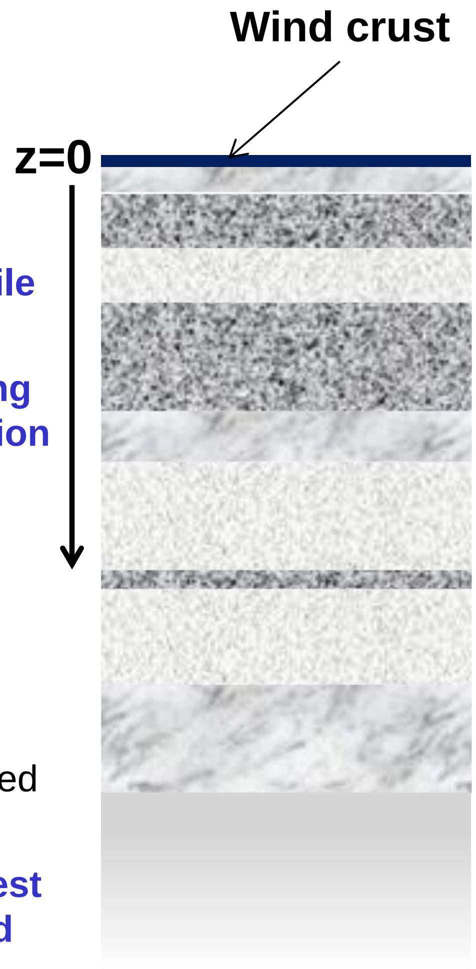
- **Snow structure near top surface contains layers with variable thickness, density and grain size (e.g. Steffen et al., 1999; Macelloni et al., 2006)**
- **Wind crusts (thin, high density) can be present**

- **Undercorrection of strong galactic reflection in July 2012 accounts for some of the oscillation**

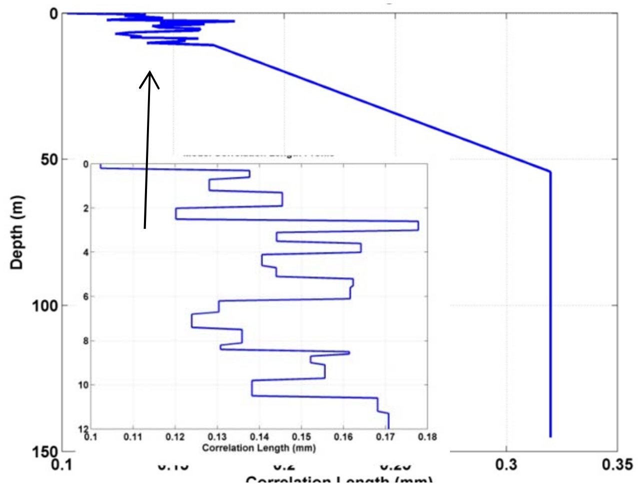


TB Model

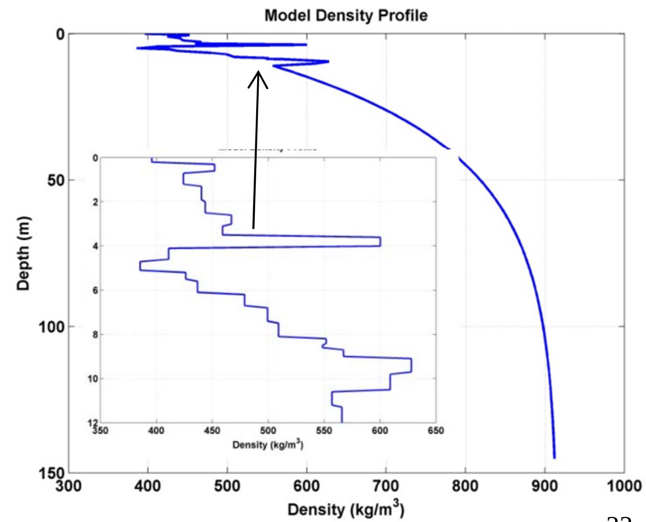
- **MEMLS model (Wiesmann and Matzler, 1999) used to compute upwelling TB**
  - **Started with exponentially increasing density profile and increasing correlation length profile**
  - **Generated multiple realizations of snow structure by randomly adding layers of varying density, correlation length and thickness to first 20 m**
    - Density variations based on measurements found in literature (e.g. Steffen et al., 1999; Paterson, 2000; Macelloni et al., 2007)
    - Correlation length profile based on Matzler (2002)
  - **Chose realization that provided best fit to AMSR-E 6.9 – 36.5 GHz V-and H-pol TBs**
  - **Ice dielectric model from Tiuri et al., (1984) gave best fit AMSR-E data**

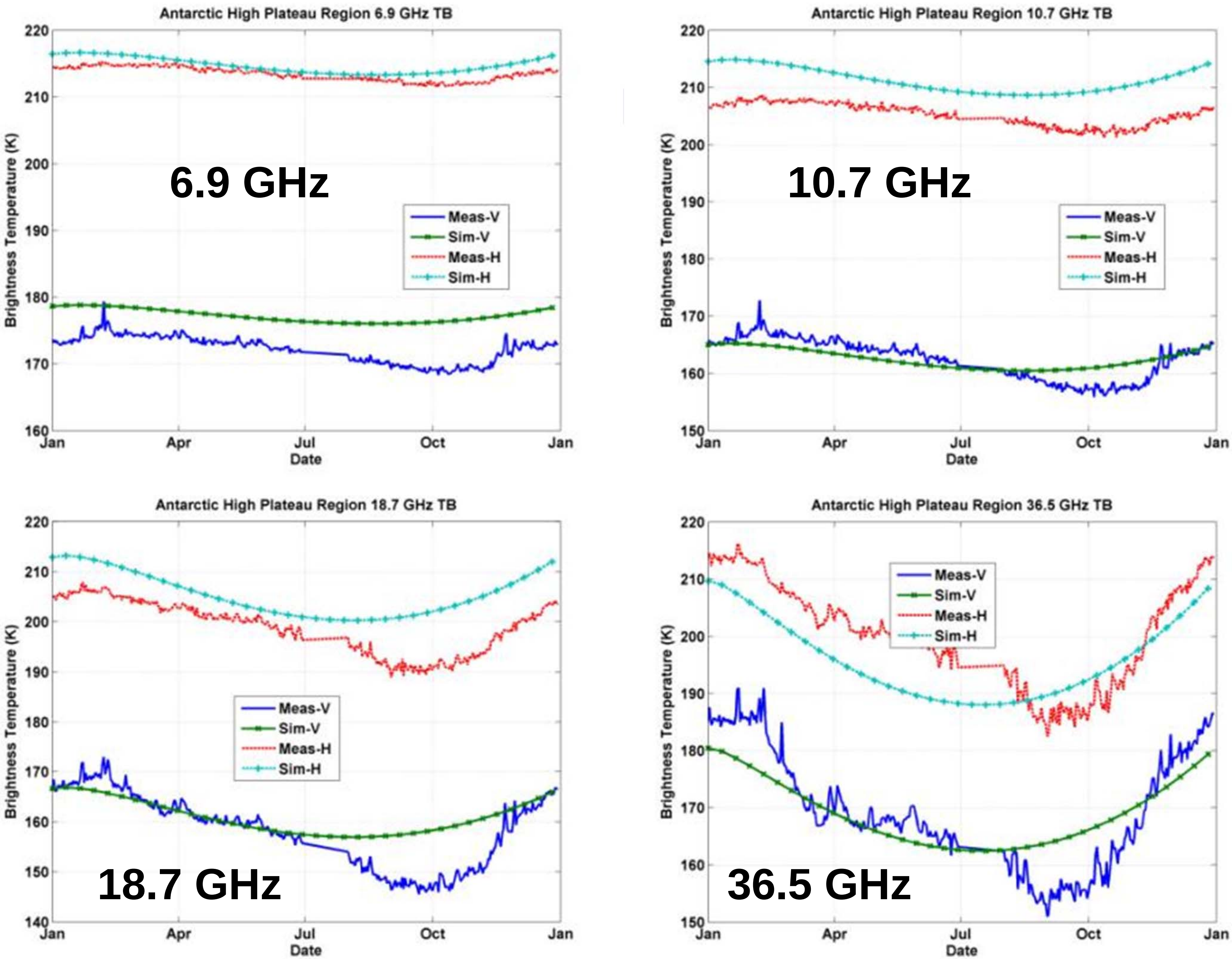


Correlation Length Profile



Density Profile



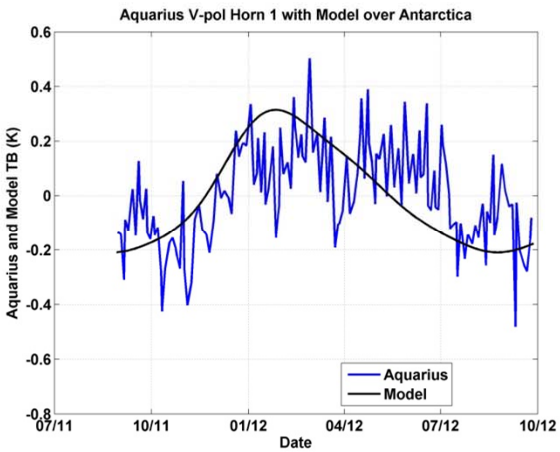

Antarctic High Plateau Region 6.9 GHz TB
6.9 GHz
Meas-V
Sim-V
Meas-H
Sim-H
Brightness Temperature (K)
220
210
200
190
180
170
160
Jan
Apr
Jul
Oct
Jan
Date
Antarctic High Plateau Region 10.7 GHz TB
10.7 GHz
Meas-V
Sim-V
Meas-H
Sim-H
Brightness Temperature (K)
220
210
200
190
180
170
160
150
Jan
Apr
Jul
Oct
Jan
Date
Antarctic High Plateau Region 18.7 GHz TB
18.7 GHz
Meas-V
Sim-V
Meas-H
Sim-H
Brightness Temperature (K)
220
210
200
190
180
170
160
150
140
Jan
Apr
Jul
Oct
Jan
Date
Antarctic High Plateau Region 36.5 GHz TB
36.5 GHz
Meas-V
Sim-V
Meas-H
Sim-H
Brightness Temperature (K)
220
210
200
190
180
170
160
150
Jan
Apr
Jul
Oct
Jan
Date

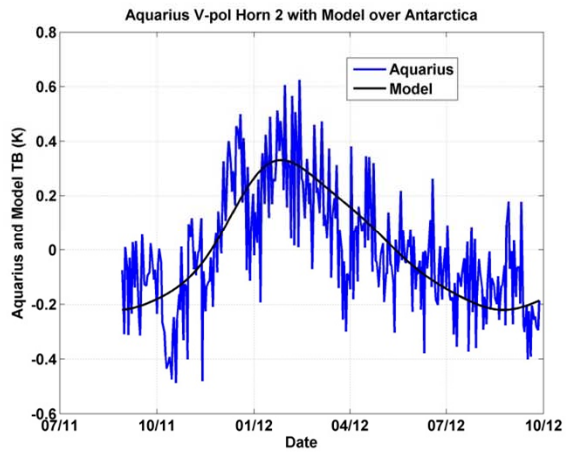
Summary

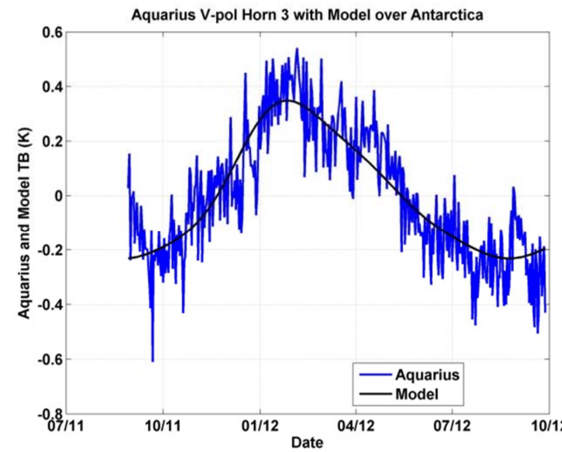
- **Exponential drift correction successfully removes observed long period drift over Antarctica**
  - **Confirms gain (e.g. noise diode) drift as source**
- **Calibration wiggles <u>are</u> observed in Antarctic model differences and have the same magnitude as those observed over the ocean**
  - **Suggests quasi-monthly variability observed in TA-TAexp over ocean is due to TA calibration drift**
  - **Suggests that correction should be implemented as an offset correction**
    - Could be related to instability in PIN diode switch or change in impedance balance between antenna and reference arm of switch

V-pol Channels after Exponential Gain Correction

- **All channels in good agreement with model after applying gain drift correction based on ocean TA drift estimates**







Aquarius- Model