Aquarius Instrument-Only Calibration: Correcting Drift, “Wiggles” and Pseudo-random biases

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Aquarius calibration issues

• Drift:
  – All six channels of the Aquarius radiometer have indicated a drift with respect to ocean model
  – Exponential correction applied to noise-diode temperature to correct drift

• “Wiggles”
  – Pseudo-periodic oscillation in the data that are different for all six channels
  – Root cause – backend Voltage to Frequency Converter (VFC) locking issue impacts reference load counts

• Systematic pseudo-random bias
  – There is a potential that the same phenomenon that causes wiggles also causes bias in the measured antenna temperature that would appear pseudo-random in nature – but is in fact systematic

• Correction and status of all three discussed here

![Graph](image-url)
Drift correction

\[ TA = \left( \frac{C_A - C_R}{C_{RND} - C_R} \right) T_{ND} + T_R \]

- Drift potentially caused by out-gassing during the first couple of months
- Directly impacts noise-diode of all channels

\[ C_A = G\left( T_A + T_{RX} \right) + C_{off} \]
\[ C_R = G\left( T_R + T_{RX} \right) + C_{off} \]
\[ C_{RND} = G\left( T_R + T_{ND} + T_{RX} \right) + C_{off} \]
\[ C_{AND} = G\left( T_A + T_{ND} + T_{RX} \right) + C_{off} \]
\[ C_{ACND} = G\left( T_A + T_{CND} + T_{RX} \right) + C_{off} \]

- Impossible to calibrate the calibrator using instrument only parameters
- Need an external constraining source
- Prefer NOT use Ta ocean model
- Antarctic model used for relative calibration
(1) Drift correction
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
  - Surface temperature values obtained from near by AWS station (JASE) used as top boundary condition
  - Thermal diffusivity increases as a function of density (Paterson, 2000)

- 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
(1) Drift correction
Vicarious Drift Correction + Double Difference

Exponential fit derived over ice for V3 once scaled by the ratio Tocean/Tice fits ocean ∆TA exactly
Plots above give an example of drift correction derived off the ice – vicariously fit to the other channels and compared to the ocean model.
(2) Wiggle Correction & (3) Pseudo-random bias

VFC locking and Aquarius

Ca = antenna counts, Cr = reference load counts, G = counts/K, Tr = reference temperature,

Ta (K) → Va/r → VFC → Fa/r → Counter → Ca/r

(1) VFC has a propensity to lock up at frequencies

(2) Causing locked frequency outputs even though V is changing

(3) Causing locked counts even though T is changing

(4) Resulting in noisy reference counts to be biased towards a locked count when averaged

Histogram of counts

Reference load wiggles
Systematic antenna bias

$T_A = \frac{C_A - C_R}{G} + T_R$
Antenna Counts Histogram

\[ TA = \left( \frac{C_A - C_R}{G} \right) + T_R \]
(2) Wiggle Correction
TA correction

Examples shown for 2 out of 6 channels

- Wiggles corrected
- Residuals remaining
(3) Pseudo-random ocean bias correction
Antenna Counts Histogram

\[ TA = \left( \frac{C_A - C_R}{G} \right) + T_R \]
(3) Pseudo-random ocean bias correction
Impact on Antenna Counts

- Antenna counts have a much larger dynamic range (from land to ocean) than the reference load counts.

- The offset error introduced due VFC locking on the Antenna counts varies as a function of,
  - Brightness temperature scene changes
  - Seasonal temperature changes
  - Salinity changes
  - Counts drift

- Due to multiple factors involved, the offset error would look random in nature

- Even though the noise looks random, it introduces systematic errors in the antenna temperature measurements
  - locally the antenna counts exhibit a similar stability as the reference load counts with additional varying factors
  - This locally introduces a non-random systematic bias to the science measurements that is also temporal in nature.
(3) Pseudo-random ocean bias correction
Identifying Lock Points

Black and White – For Easier Visualization
Counts vs. Days – Lock points – Aquarius 6 receivers
Above figures show a simulated example of bias introduced to mean ocean TAs due to backend VFC locking.

Errors in general less than 0.05K (higher for H-pol)

Local bias larger during first couple of months of drift
(3) Pseudo-random ocean bias correction
Correction techniques

The impact on TA can be corrected in the following ways

1. Introduce random-noise to antenna counts to wash out impact of locking points on the antenna counts
   - Pros: Applied to all antenna counts
   - Pros: Does not introduce its own systematic bias
   - Cons: Increases the noise in the derived salinity data (have margin)

2. Apply correction based off similar shapes derived from “wiggle” correction by applying constrained probability theory (backup)
   - Pros: Does not increase white noise of the system
   - Cons: Correction might introduce its own systematic bias due to improper assumption
   - Cons: Very hard to verify

3. Alternate recommendation: Ignore systematic bias
   - Current simulated bias is 0.05K to 0.08K for both channels which is below Aquarius requirements
Summary

1. “Wiggle” Correction
   - Correction currently being implemented at GSFC
   - Will be evaluated over next couple of weeks
   - Secondary calibration issues previously hidden might come through

2. Drift Correction
   - Current initial drift correction based off HYCOM exponential fit
   - We’ve demonstrated that an exponential fit using Antarctic Ice model scales with respect to ocean drift for V-pol beam 3
   - This correction can be vicariously applied to other channels and polarizations

3. Pseudo-random ocean bias
   - There does exist a systematic offset bias that is dependent on salinity, surface temperature, instrument count drift – and varies over time
   - Correction of such bias is possible but not trivial
   - Initial simulations of bias generally <0.08K and this TA impact can potentially be ignored
Backup
Identifying Lock Points

Antenna count Histogram

Count locking points

[Graphs and plots showing data analysis and lock points identification]
Deriving a distribution based correction

- Aquarius antenna counts ultimately require the lock-point spikes in the distribution to reduce and it’s neighbors to increase.

- A temporal behavior can not be directly derived from a distribution correction.
Removing the Lock Points

\[ x_{\text{new}}(t_{\text{lock}}) = \begin{cases} 
  x_{\text{old}}(t_{\text{lock}}) - 1, & \text{if } \text{slp}(t_{\text{lock}}) > p \\
  x_{\text{old}}(t_{\text{lock}}) + 1, & \text{if } \text{slp}(t_{\text{lock}}) < -p 
\end{cases} \]

• We calculate the slope of the time domain signal at every locking point
• If the signal is rising, chances are the signal is locked higher (left figure) and vice-versa (right figure)
• We optimize for the slope value \( p \) to redistribute the histogram
Histogram Lock Points Detected

Pre-correction

Post-correction
Resulting systematic biases

Initial Analysis

- <0.1K peak to peak bias depending on channel being observed
Challenges Ahead

• Still ways to go before this correction can be implemented in Aquarius v5.0

• Verification is a big challenge
  – We do not want to add systematic bias of our own
  – We can not compare with the HYCOM model since we are correcting localized variations
  – Needs to be compared with localized ARGO regions
  – Is this even a problem?

• Lock point identification not complete
  – Channel 1 – Beam 2 – has the lowest ocean counts, making it very difficult to retrieve the locking points using above method
  – At certain locations due to high density of locking points, some lock points get missed
  – Locking spikes magnitude not completely equal
What is locking? (or “flat-spot”)

VFCs are responsible for converting voltage proportional to the Tb measurement to counts.

VFC (Voltage to Frequency Converter) can lock on certain frequencies due to the presence of an interfering clock signal.

- Spike translates to a “flat-spot” in VFC response. The signal gets locked on to a particular count value (voltage).

After launch, odd feature in histogram of Jason-2 AMR 34 GHz Tb observed.

Traced to VFC flat spot issue – proven by lab test with AMR spare hardware.

- VFC “locked” onto 9001 counts due to interference with another clock in the system.
- Biased noise diode measurements over ocean.

Jarnot et al., MLS calibration report.
• As an example, we derived simulated antenna counts from the model antenna temperature and measured gain and offset of the radiometers.

• We added an offset error to the simulated counts similar to the *wiggle* errors observed on the reference counts.

• We re-derived the antenna temperature values and subtracted the original antenna temperature samples.
Summary

• Aquarius’ Voltage to Frequency Converters (VFC) get “locked” at certain frequency locations and this impact is clearly observed in the histogram of the uncalibrated counts

• We have already applied a correction to the reference load counts causing TA “wiggles”

• Locking counts at the antenna scene counts causes non-random systematic temporal biases in the ocean salinity retrieval that is hard to detect

• We have developed a preliminary method to identify these counts and apply a correction from the counts distribution to temporal samples

• Method needs to be verified and tweaked further