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

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11/18/2015

Aquarius calibration issues

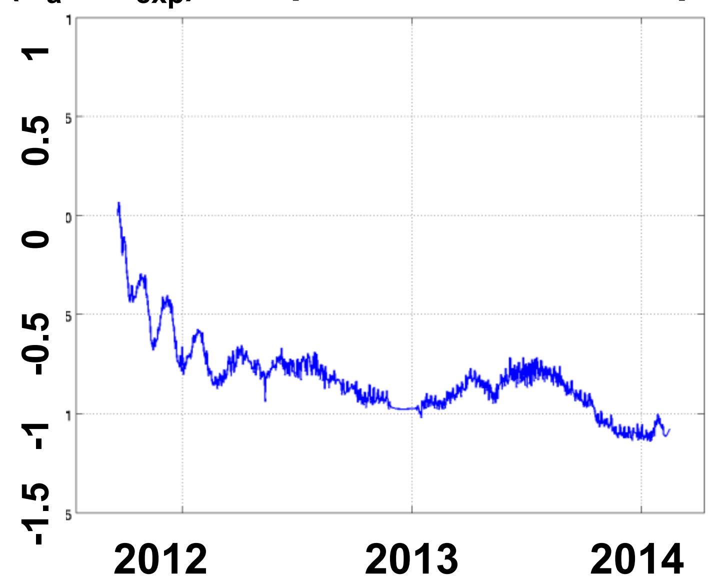
- **Drift:**
  - All six channels of the Aquarius radiometer have indicated a drift with respect to ocean model
  - Exponential correction applied to noise-diode temperature to correct drift

- **"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**

$(T_a - T_{exp})$ – Aquarius beam 2 – V pol



(1) 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

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

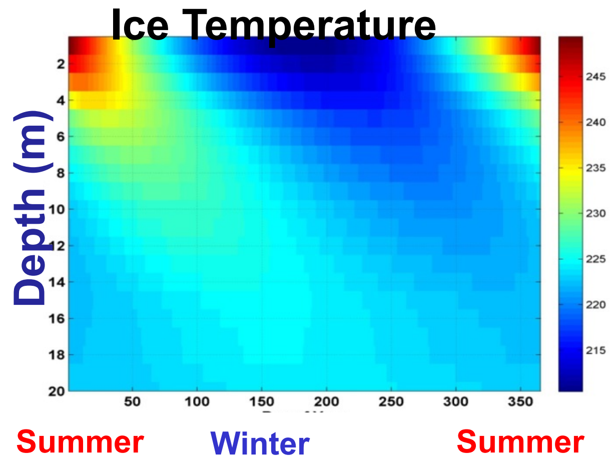
6 unknowns

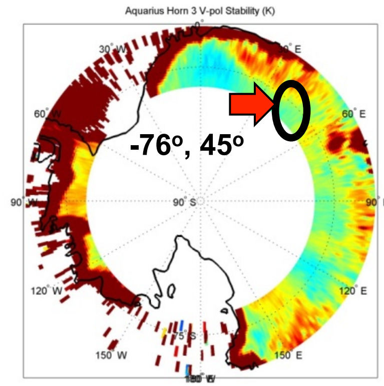
5 equations

- 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

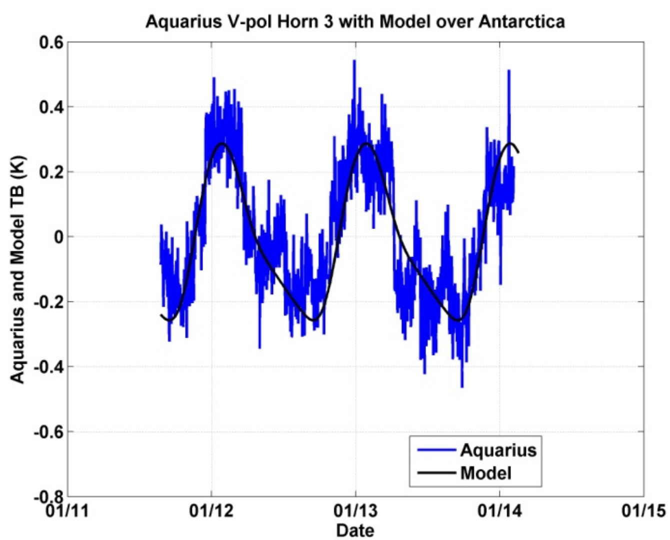
(1) Drift correction
Ice model

- **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)

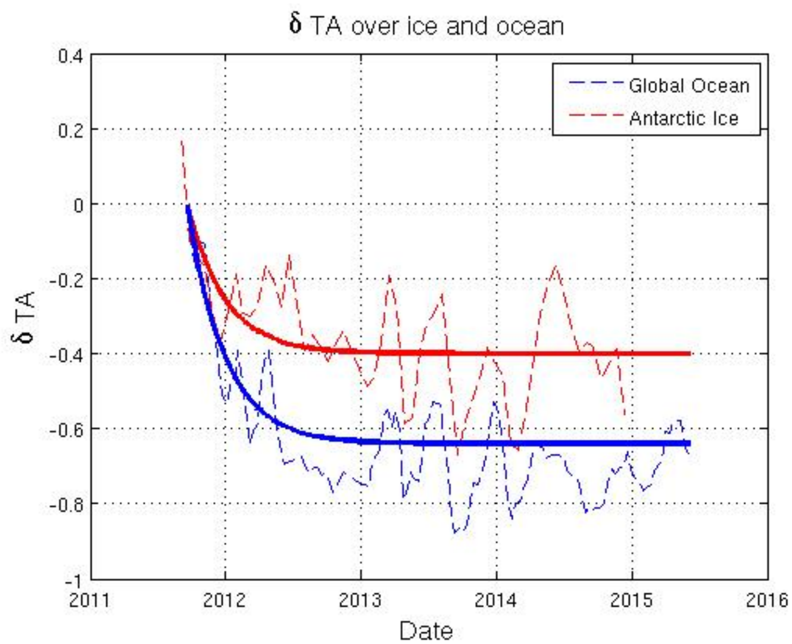




- **Tuned using multi-frequency AMSR-E TBs and in situ surface temperature data**
  - Generated random snow layer structures to find a realization that gave best fit 6-37 GHz V&H-pol TBs
  - Ice dielectric model from Tiuri et al., (1984) gave best fit AMSR-E data



(1) Drift correction
Vicarious Drift Correction + Double Difference



$T_{A,v3\_ice}$ — $T_{Amodel,v3\_ice}$

Solve for exponential fit on ice
$T_{A,v3\_ice} - T_{Amodel,v3\_ice}$

Calculate Tnd correction from fit – apply to ocean
$T_{A,v3\_ocn,new}$

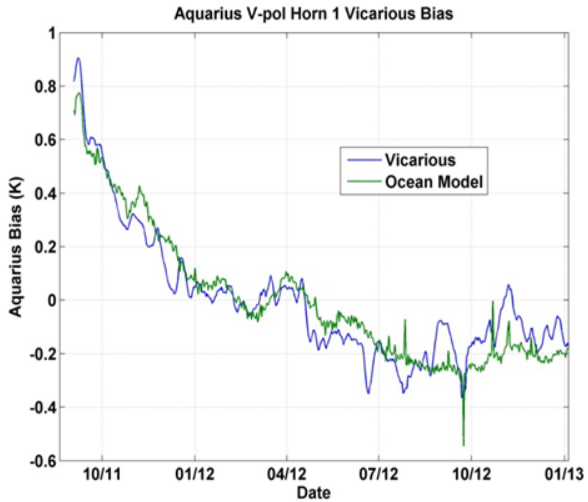
$bias_{A,v3\_ocn} = T_{A,v3\_ocn,old} - T_{A,v3\_ocn,new}$

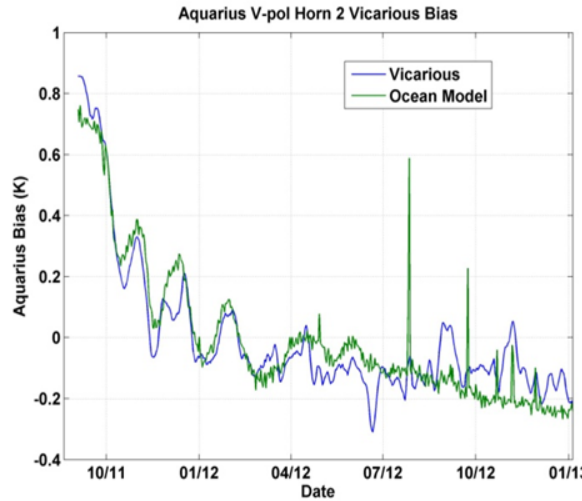
$bias_{A,pb\_ocn}$
=
$[T_{Amodel,v3\_ocn} - T_{amodel,pb\_ocn}] - [T_{A,v3\_ocn,old} - bias_{A,v3\_ocn} - T_{A,pb\_ocn,old}]$

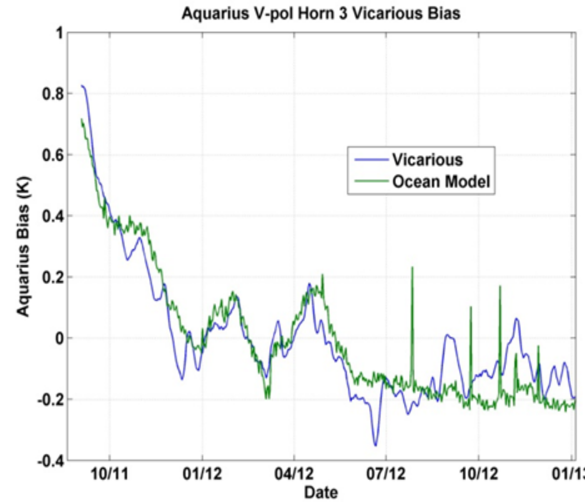
Solve for exponential fit for other channels using
$bias_{A,pb\_ocn}$

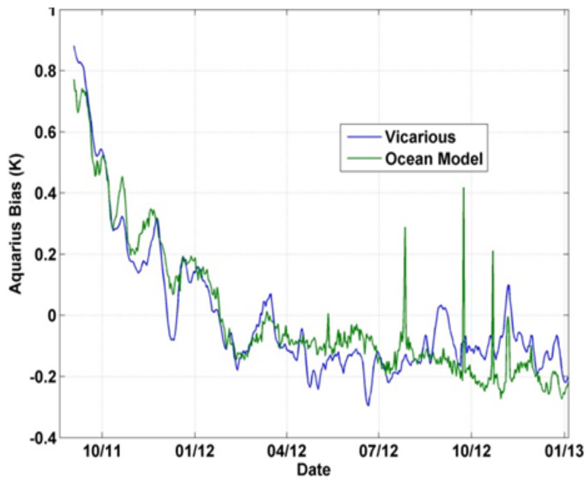
Exponential fit derived over ice for V3 once scaled by the ratio Tocean/Tice fits ocean ΔTA exactly

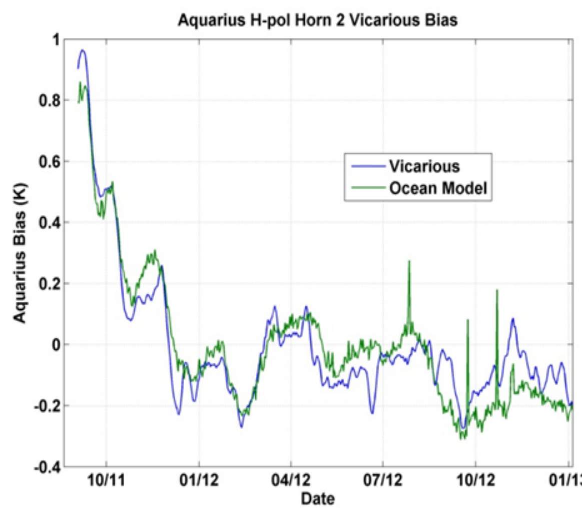
(1) Drift correction
Vicarious Drift Correction + Double Difference

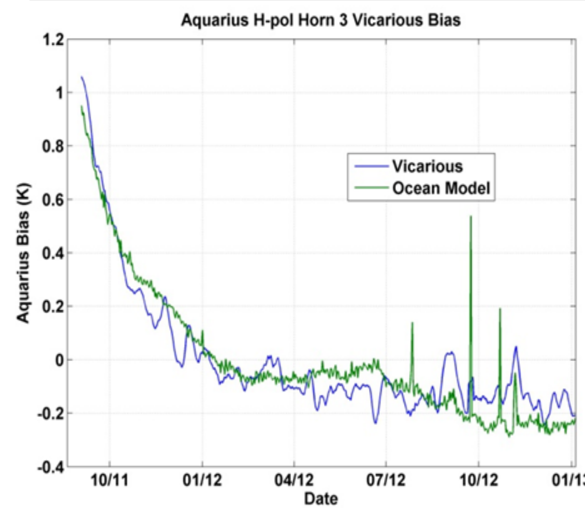












Plots above give an example of drift correction derived off the ice – vicariously fit to the other channels and compared to the ocean model

(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)

Tr (K)

→ Va/r → VFC → Fa/r → Counter → Ca/r

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

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

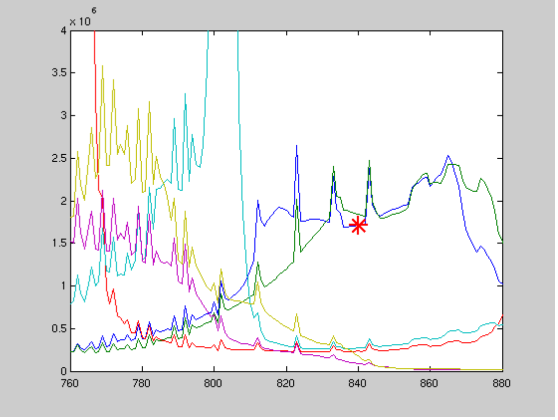
(3) Causing locked counts even though T is changing

$$TA = \left(\frac{C_A - C_R}{G}\right) + T_R$$

Reference load wiggles

Systematic antenna bias

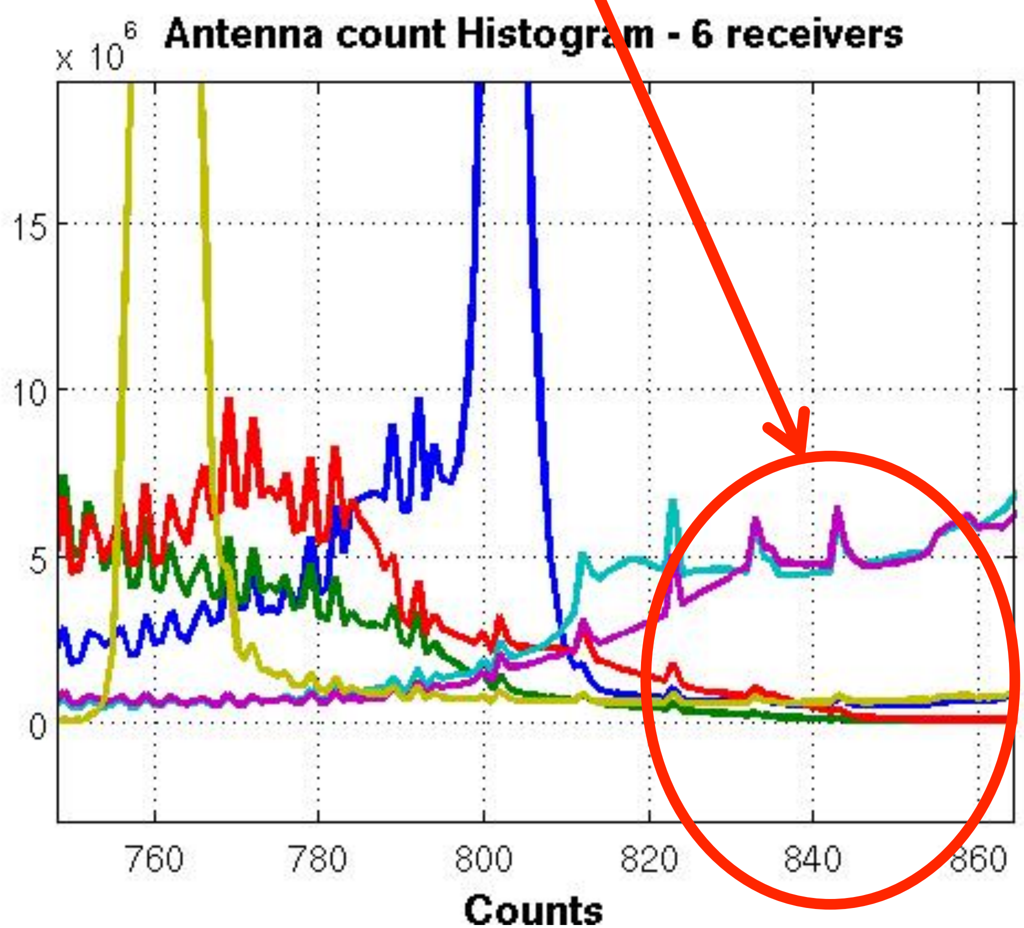
Histogram of counts



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

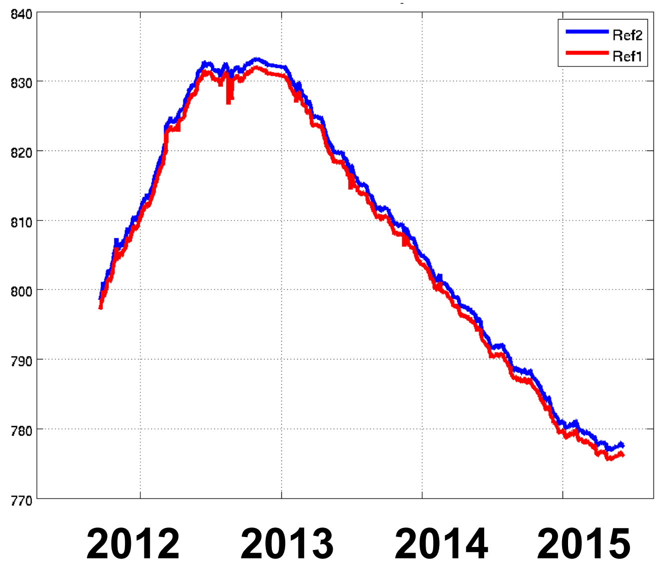
(2) Wiggle Correction
Antenna Counts Histogram

$$TA = \left(\frac{C_A - C_R}{G} \right) + T_R$$

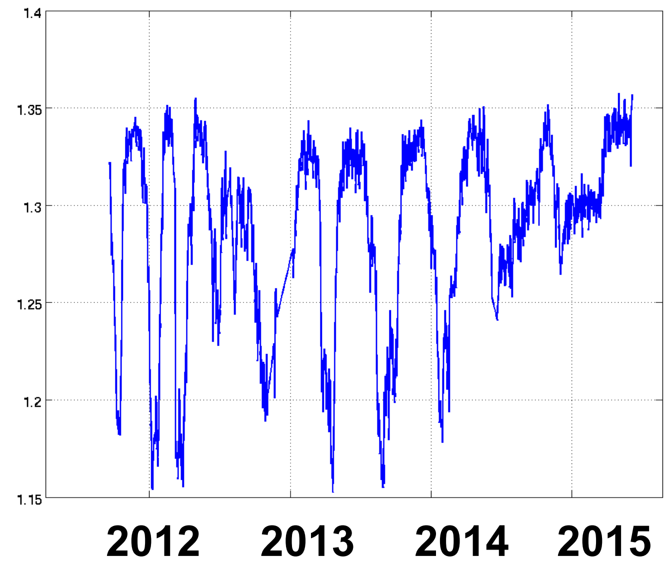


(2) Wiggle Correction
Correction Derivation

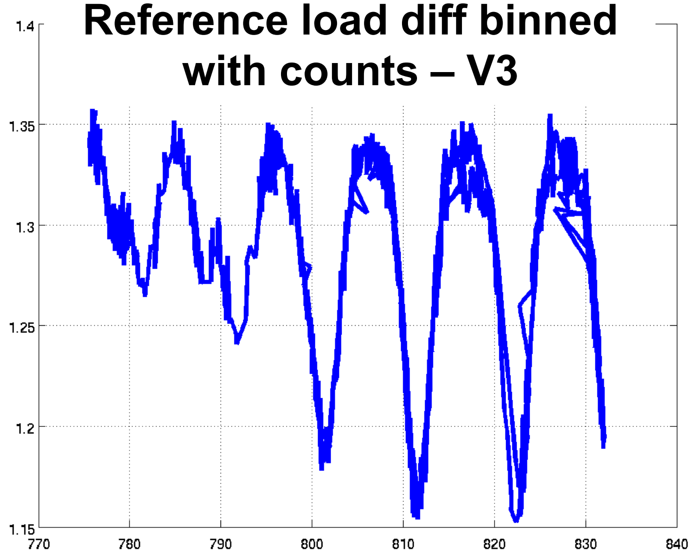
Reference load – V3



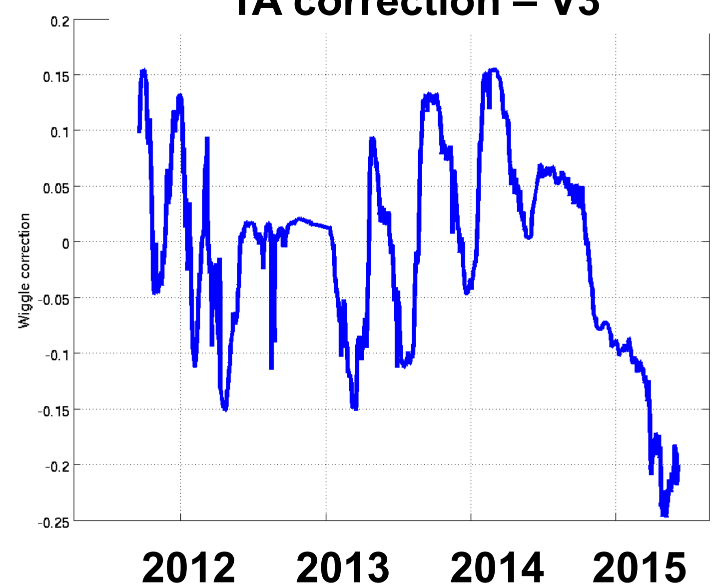
Reference load diff – V3



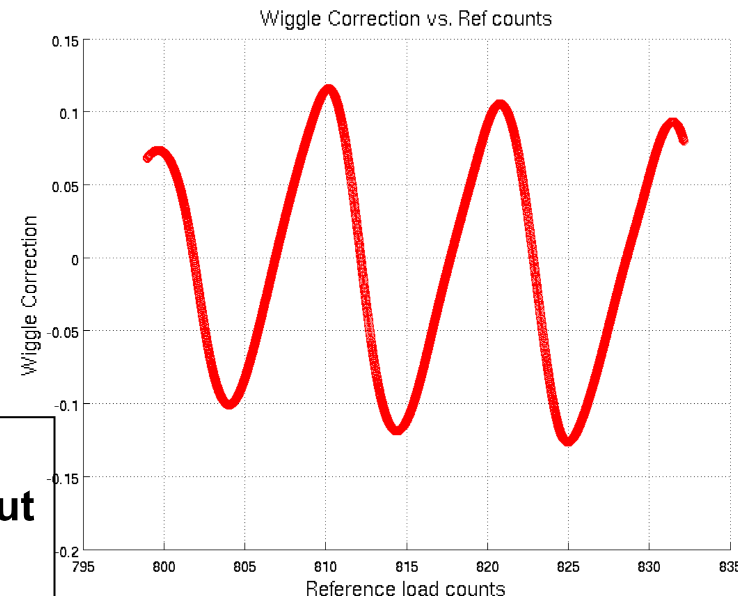
Reference load diff binned with counts – V3



TA correction – V3

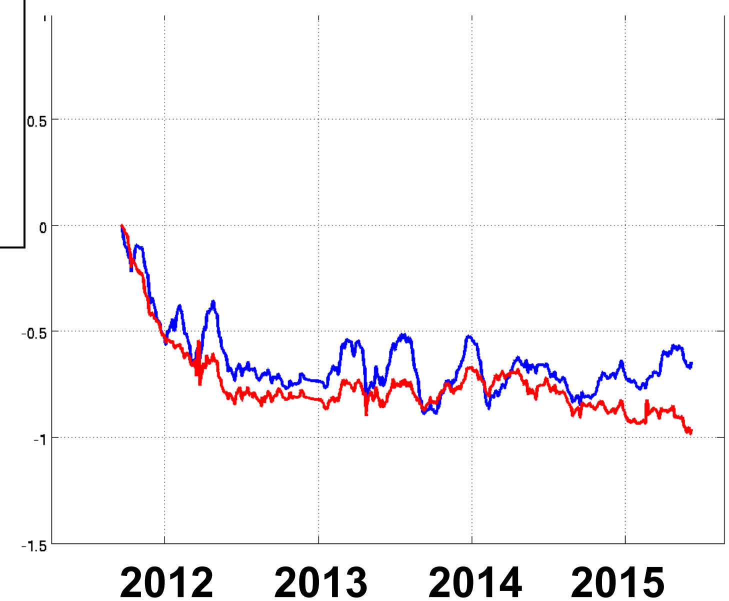


(2) Wiggle Correction
TA correction



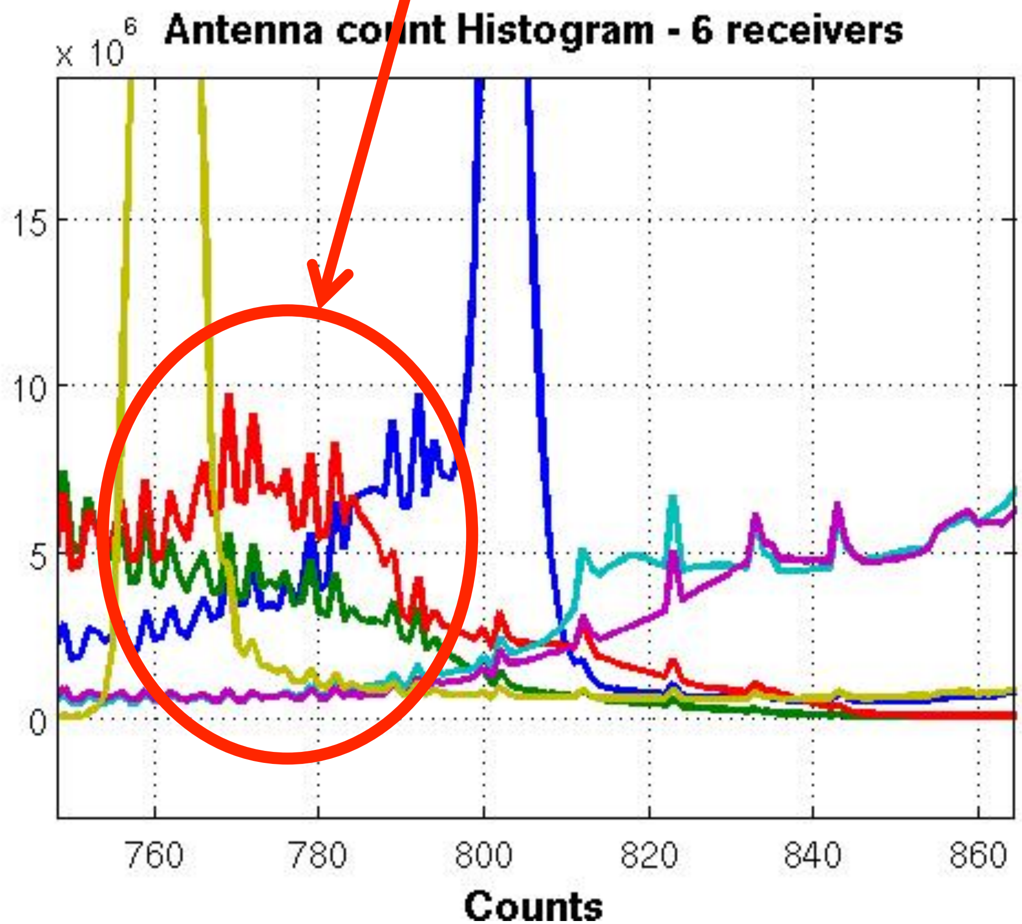
Examples shown for 2 out 6 channels

- **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

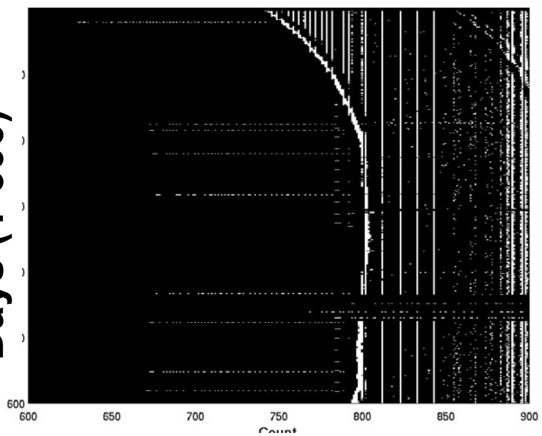
- Due to multiple factors involved, the offset error would look random in nature

- 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.

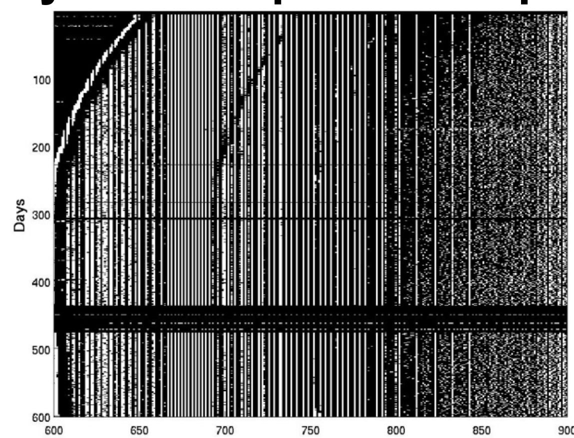
(3) Pseudo-random ocean bias correction
Identifying Lock Points

Black and White – For Easier Visualization
Counts vs. Days – Lock points – Aquarius 6 receivers

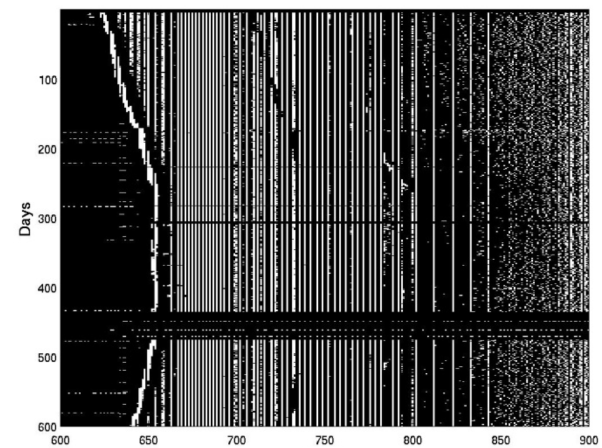
Days (1-600)



Counts

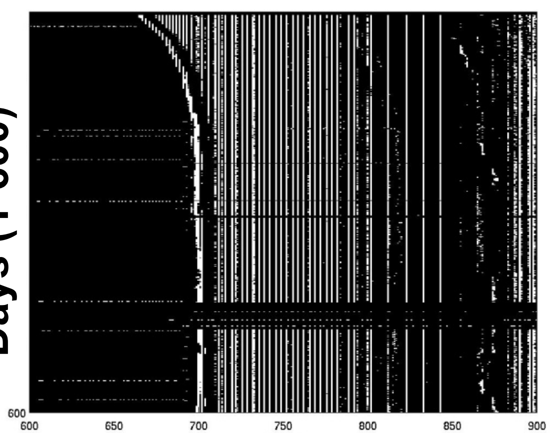


Counts

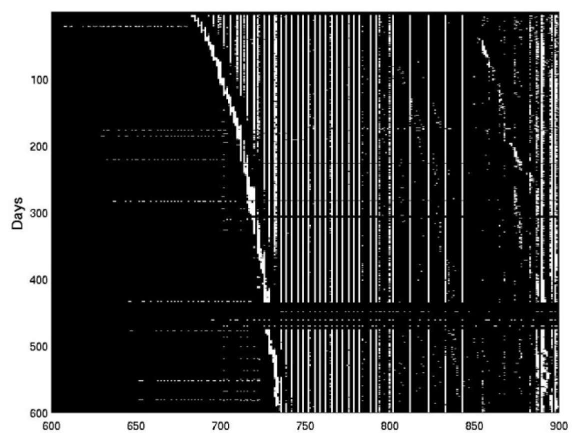


Counts

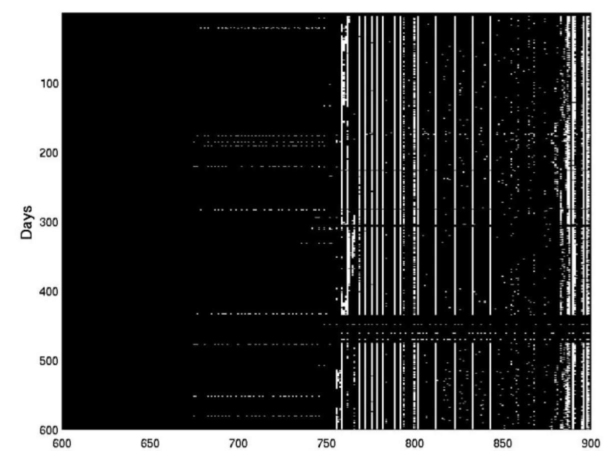
Days (1-600)



Counts

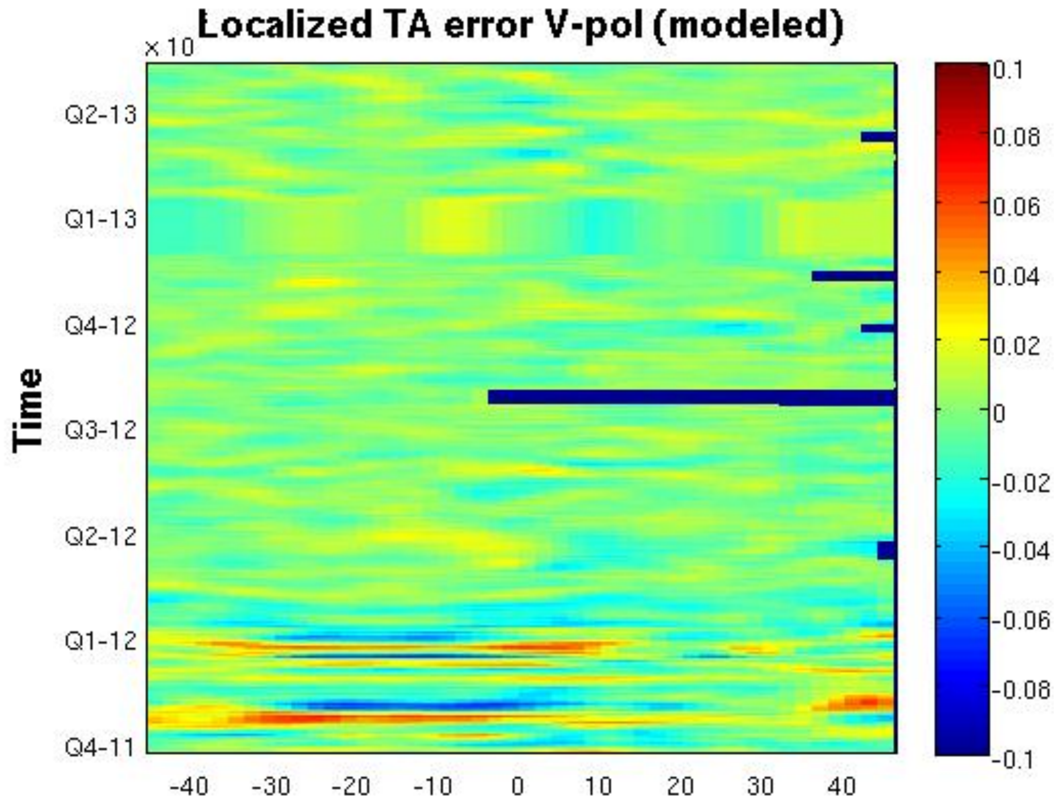


Counts



Counts

(3) Pseudo-random ocean bias correction TA impact



- 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

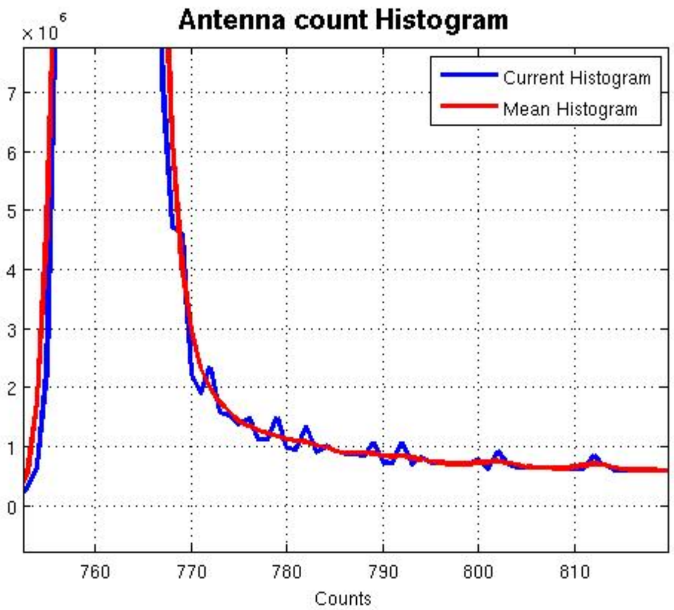
1. "Wiggle" Correction
   - Correction currently being implemented at GSFC
   - Will be evaluated over next couple of weeks
   - Secondary calibration issues previously hidden might come through

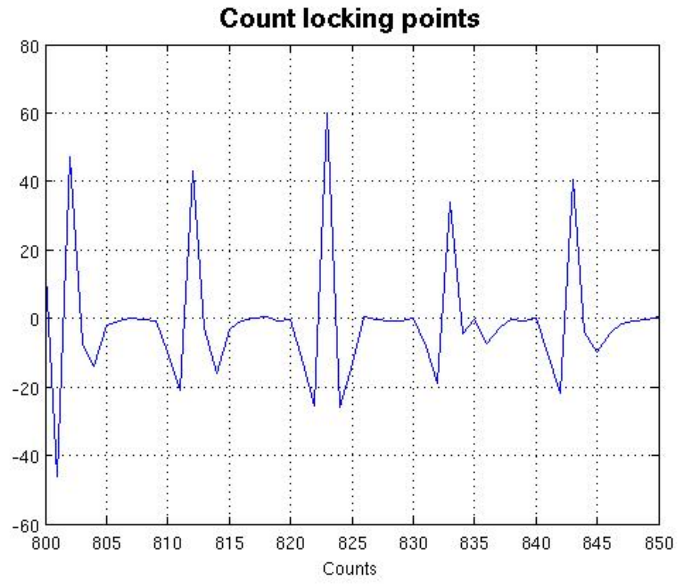
2. Drift Correction
   - Current initial drift correction based off HYCOM exponential fit
   - We've demonstrated that an exponential fit using Antarctic Ice model scales with respect to ocean drift for V-pol beam 3
   - This correction can be vicariously applied to other channels and polarizations

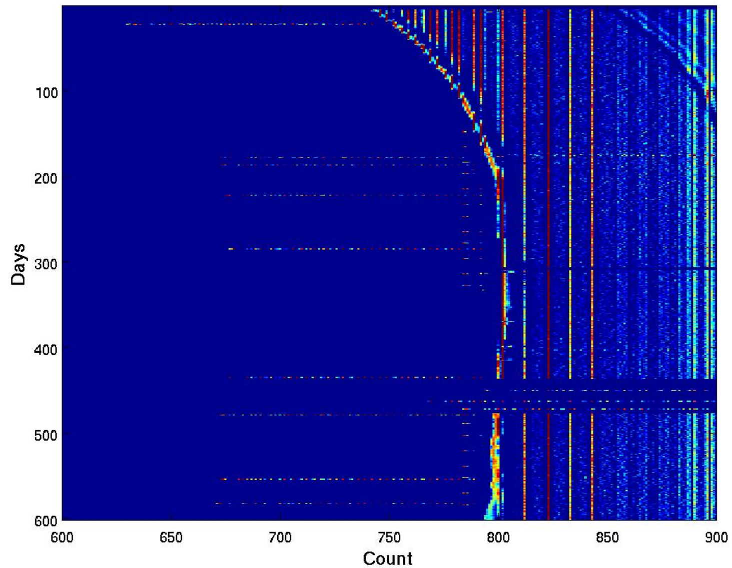
3. Pseudo-random ocean bias
   - There does exist a systematic offset bias that is dependent on salinity, surface temperature, instrument count drift – and varies over time
   - Correction of such bias is possible but not trivial
   - Initial simulations of bias generally <0.08K and this TA impact can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

Backup

Identifying Lock Points

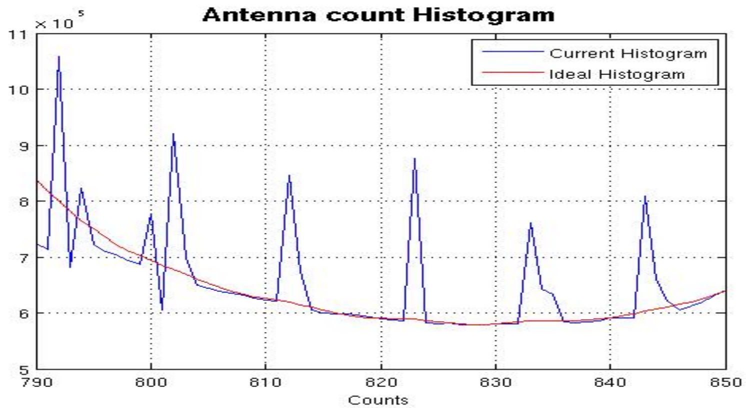


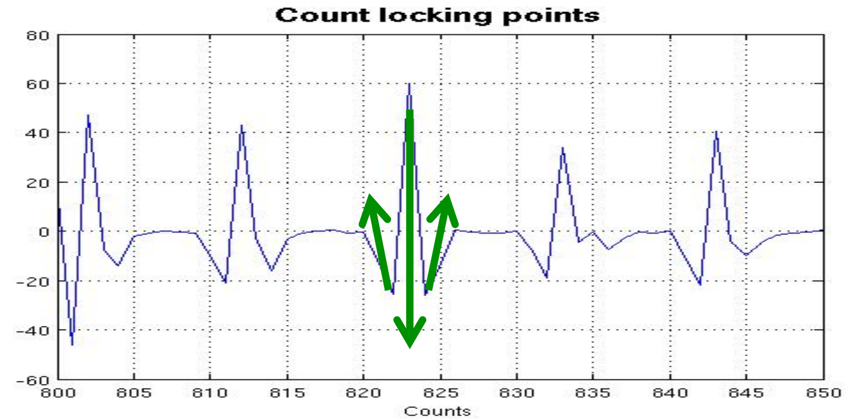




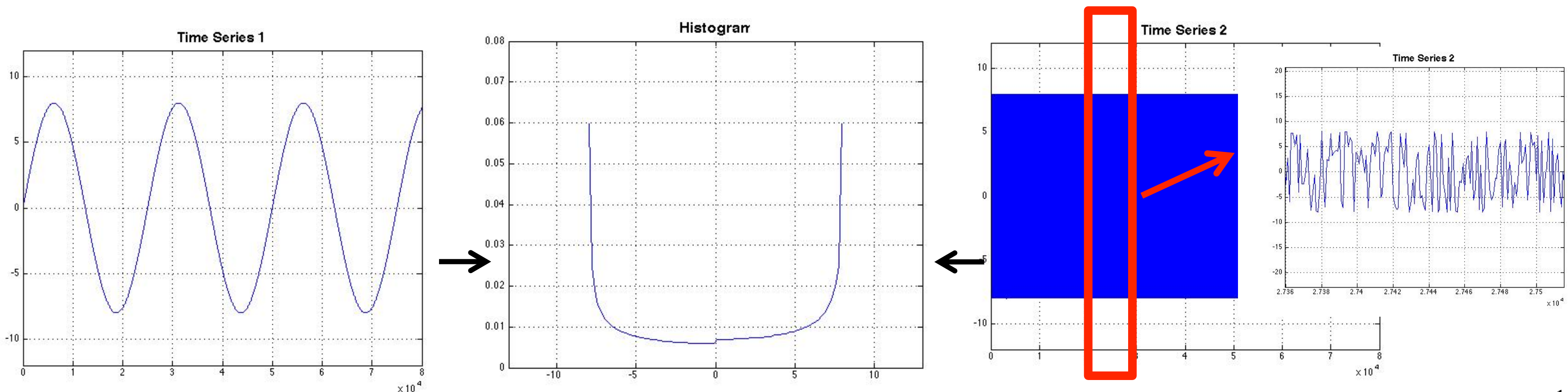
Deriving a distribution based correction

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





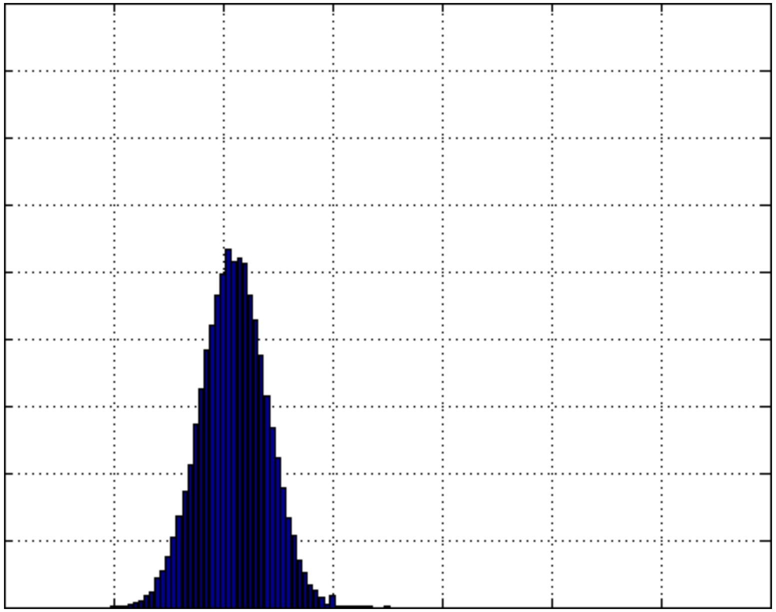
- **A temporal behavior can not be directly derived from a distribution correction**

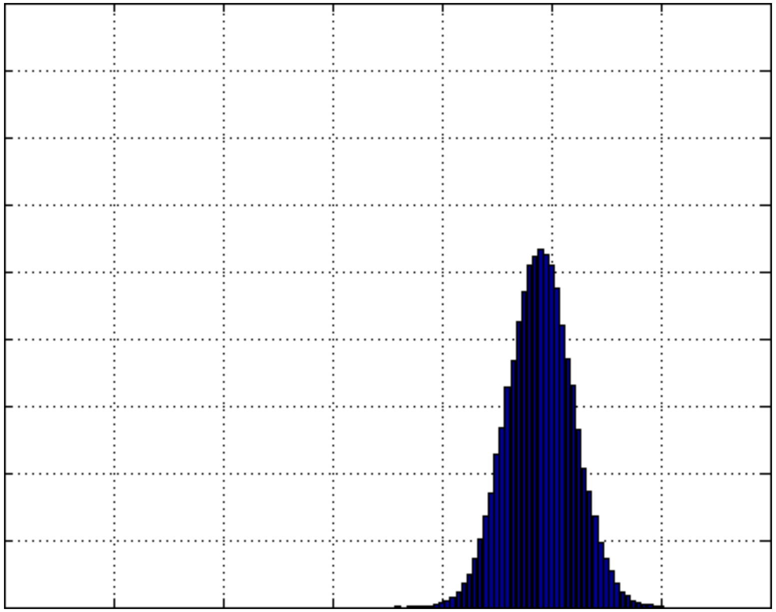


Removing the Lock Points

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

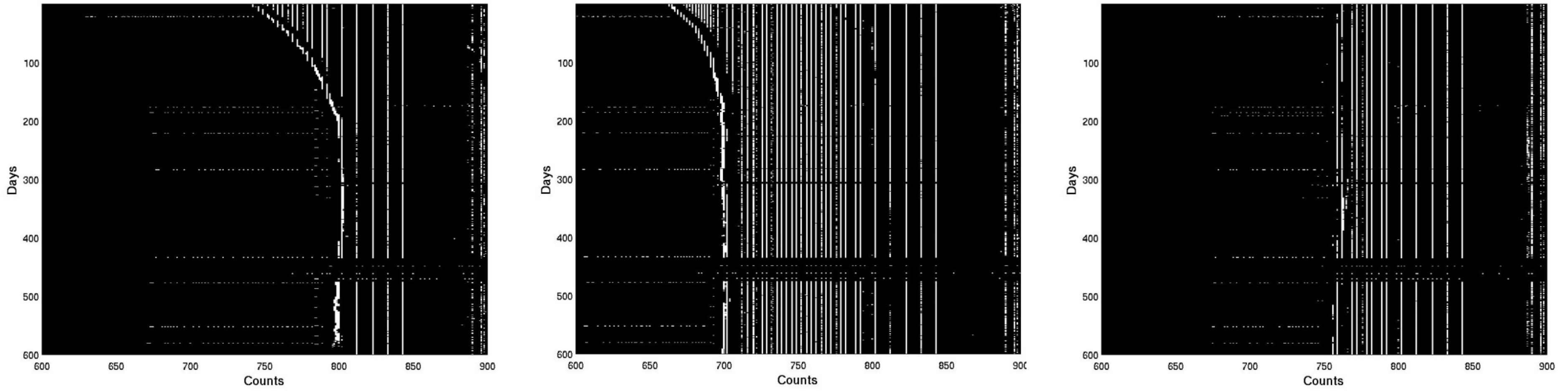
- We calculate the slope of the time domain signal at every locking point
- If the signal is rising, chances are the signal is locked higher (left figure) and vice-versa (right figure)
- We optimize for the slope value *p* to redistribute the histogram



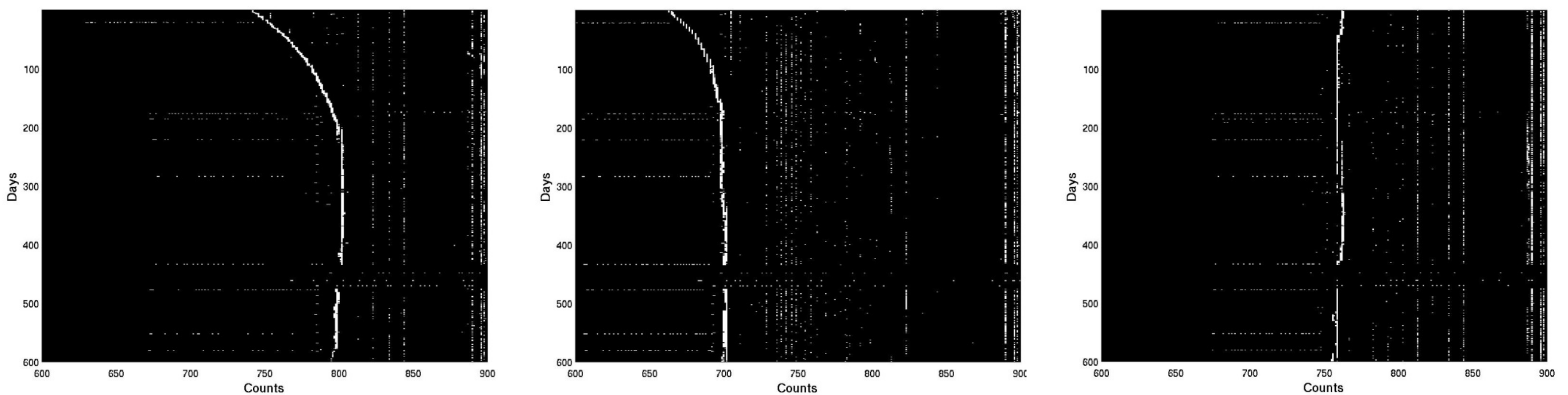


Histogram Lock Points Detected

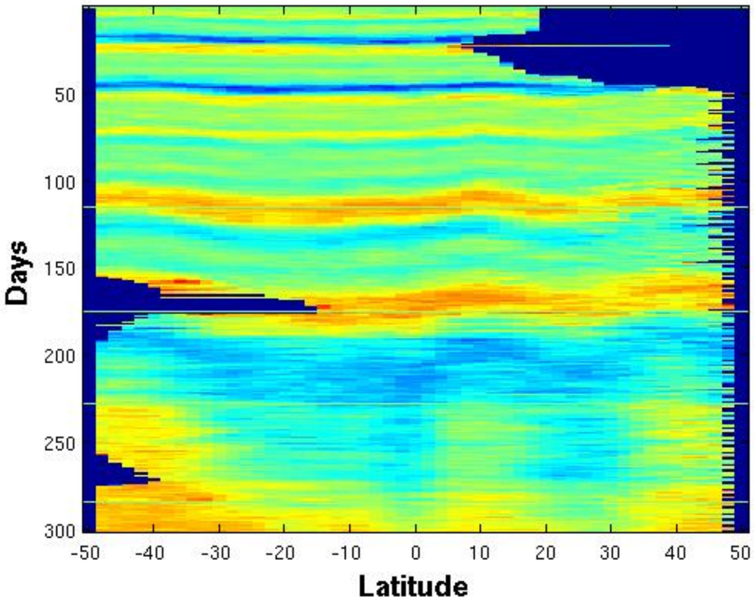
Pre-correction

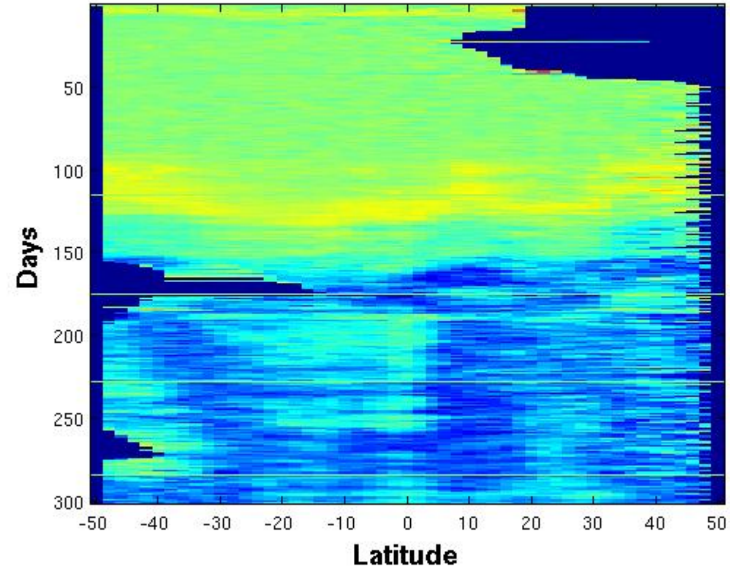


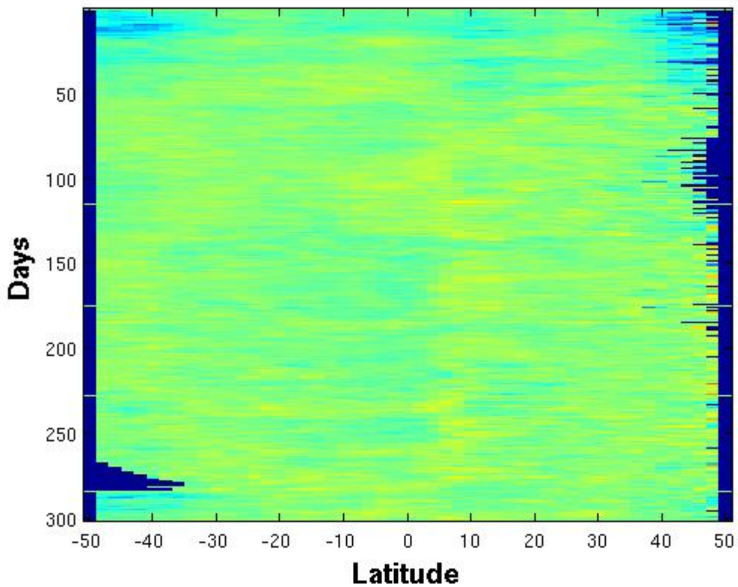
Post-correction



Resulting systematic biases Initial Analysis







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

Challenges Ahead

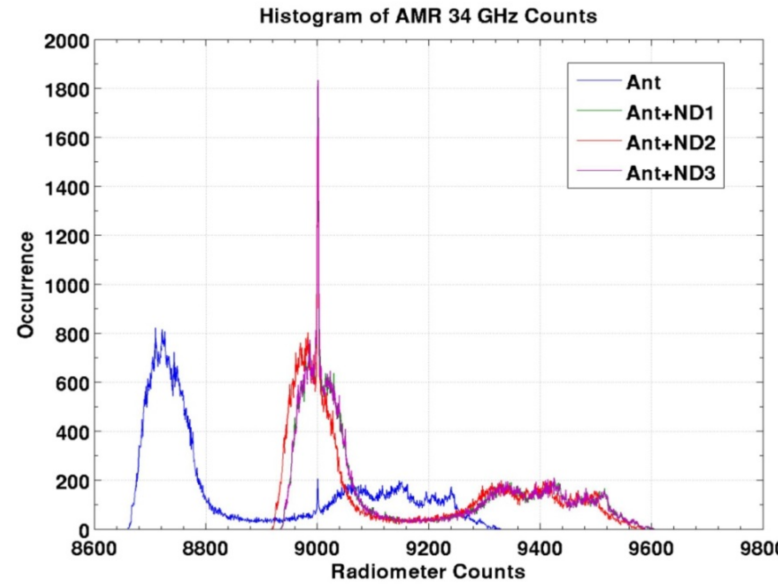
- Still ways to go before this correction can be implemented in Aquarius v5.0
- Verification is a big challenge
  - We do not want to add systematic bias of our own
  - We can not compare with the HYCOM model since we are correcting localized variations
  - Needs to be compared with localized ARGO regions
  - 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

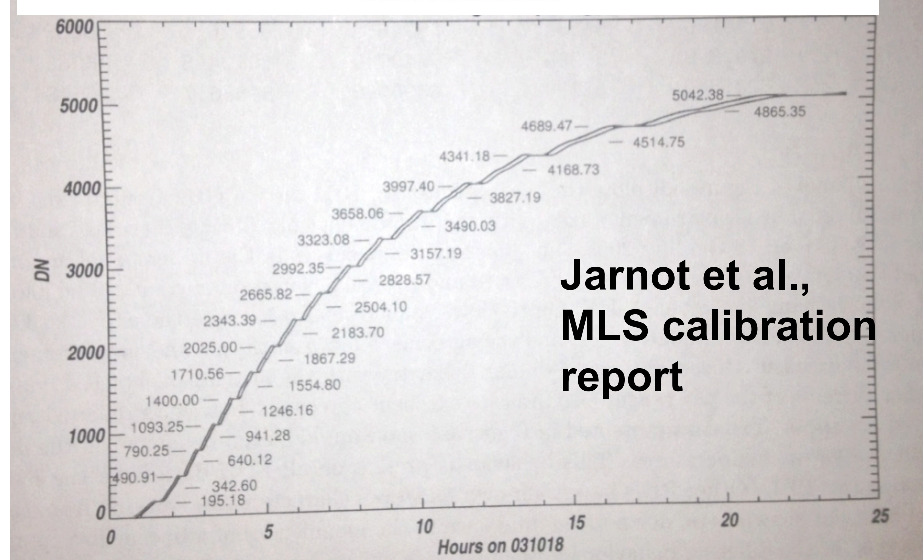
Backup

What is locking?
(or "flat-spot")

TB→(antenna)→TA→(radiometer front end+detector)→V→(VFC)→F→(counter)→C

- **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**

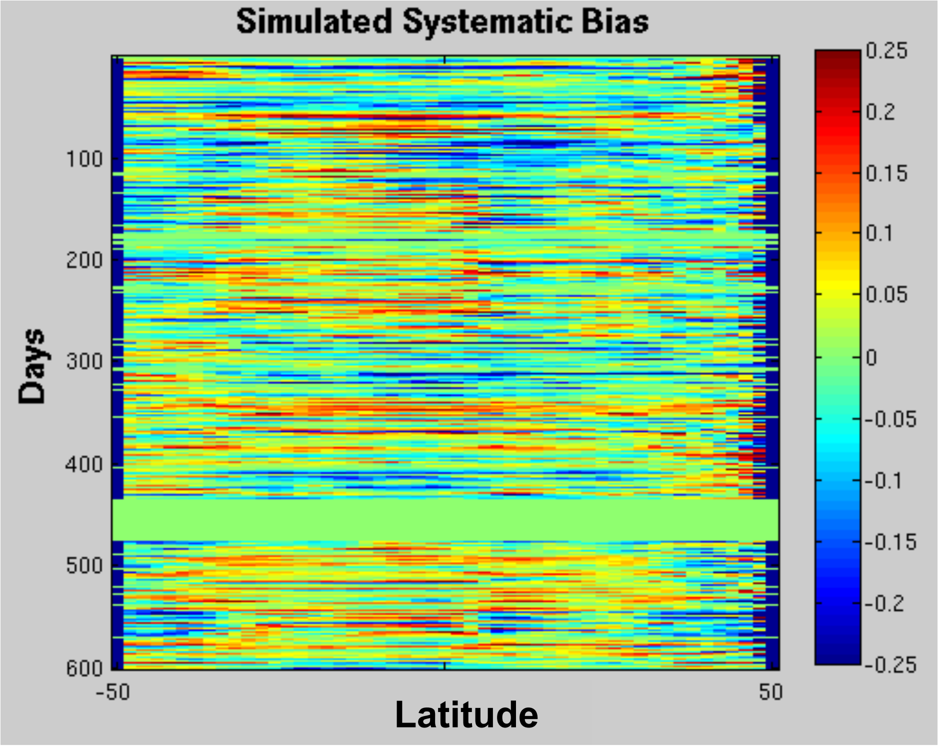




Jarnot et al., MLS calibration report

Simulated Locking Error on Antenna Temperature

- 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