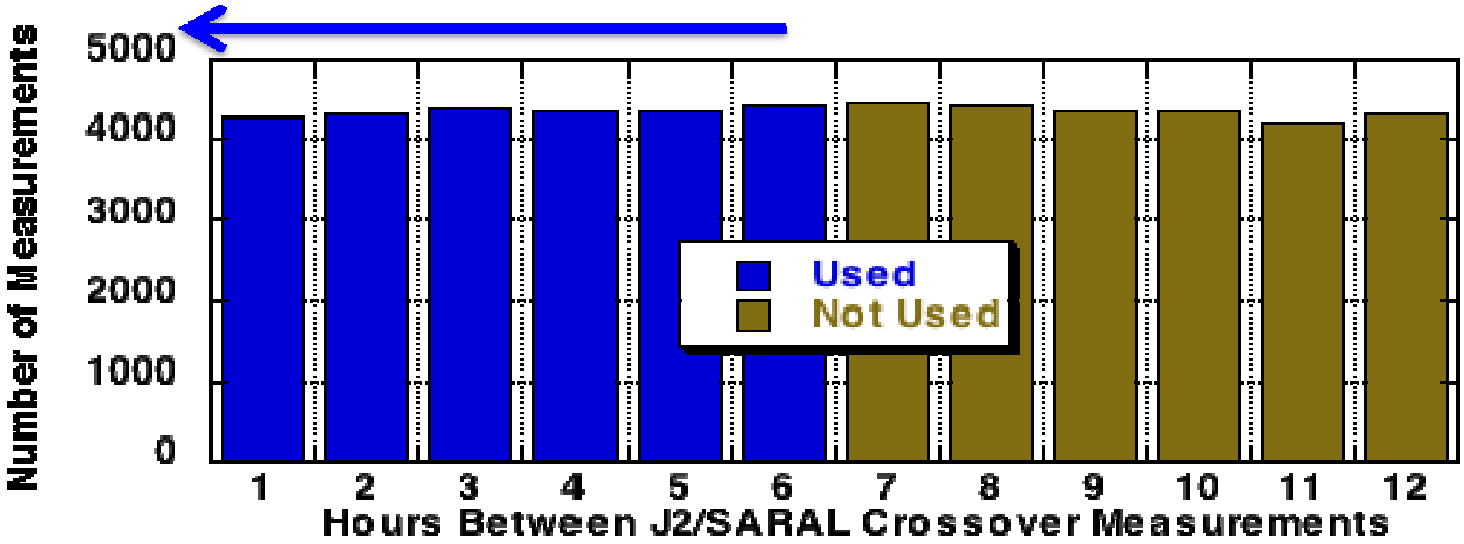
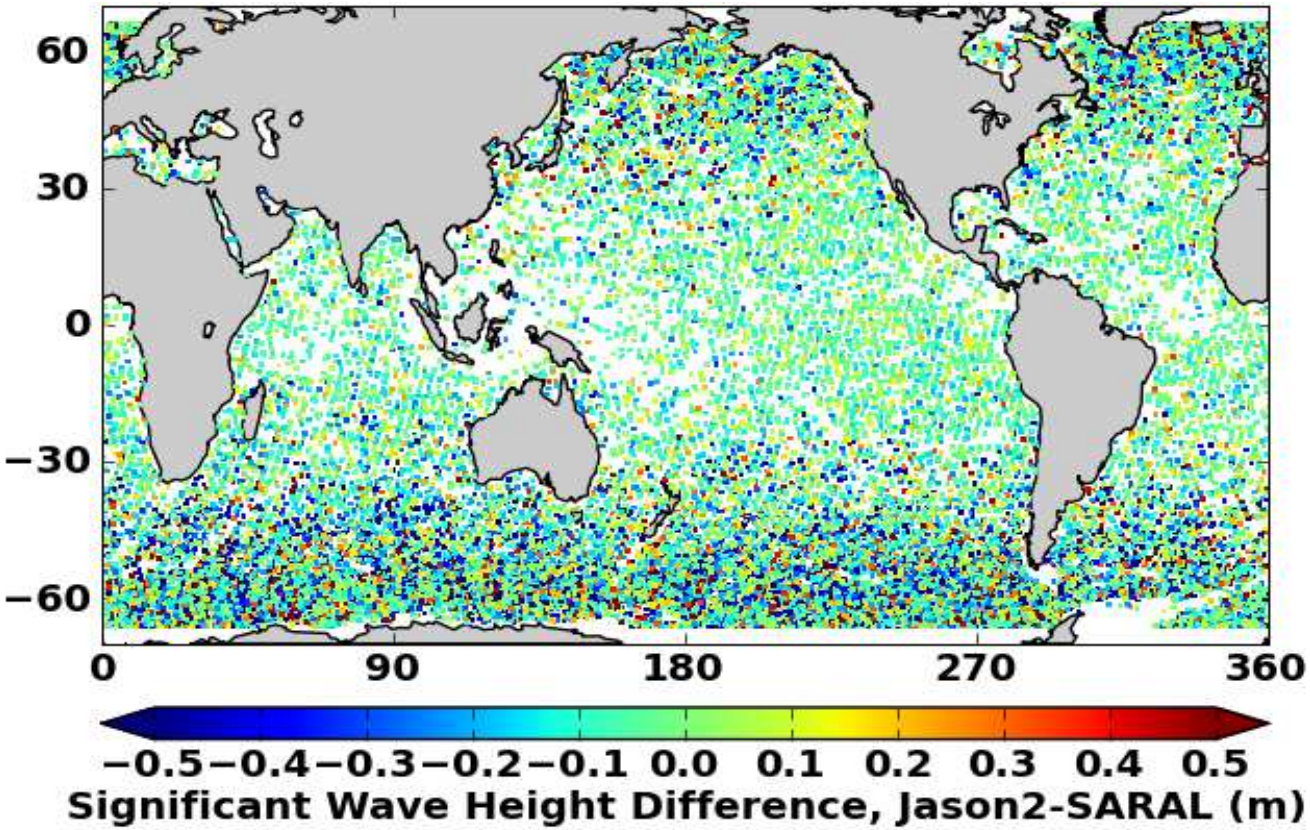
Cross-Calibration Approach

- Difference Jason-2 and SARAL measurements at crossover locations.
- Use 17 months of data since SARAL launch.
  - SARAL GDR-T: Cycles 1-15
  - Jason-2 GDR-D: Cycles 172-225
- Within each SARAL cycle, ~290 inter-satellite additional crossover points for every hour between measurements.
  - With 15 cycles, additional ~4300 crossovers for each hour apart.
- **Only use crossovers < 6 hours apart.**



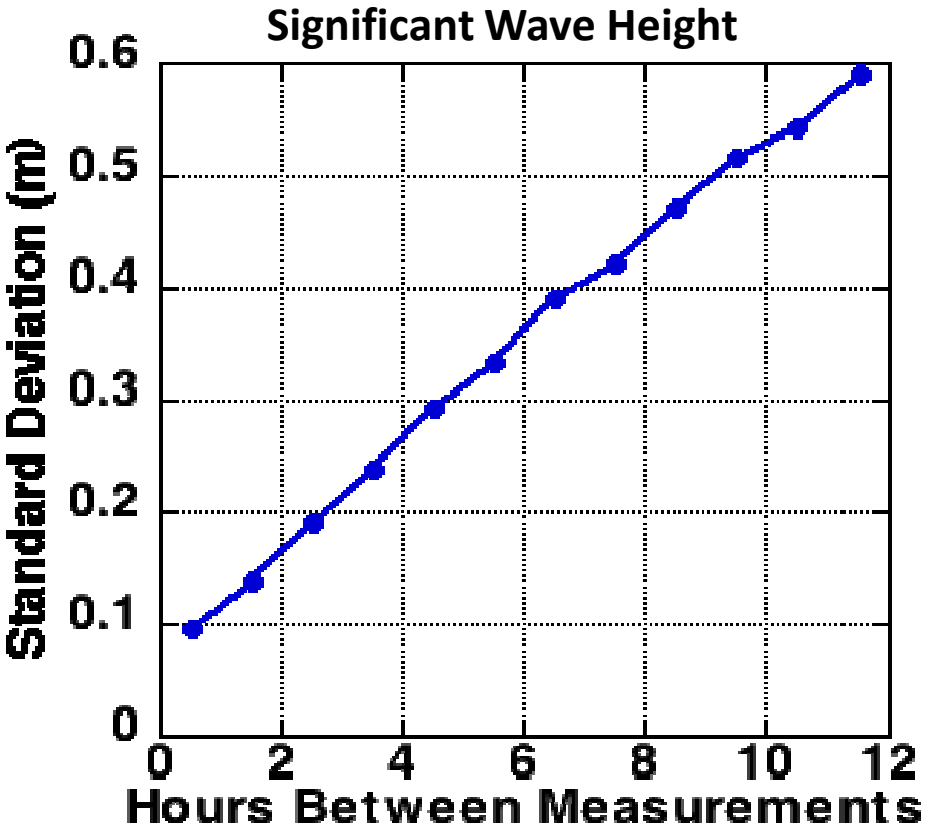
Global Coverage of Crossovers

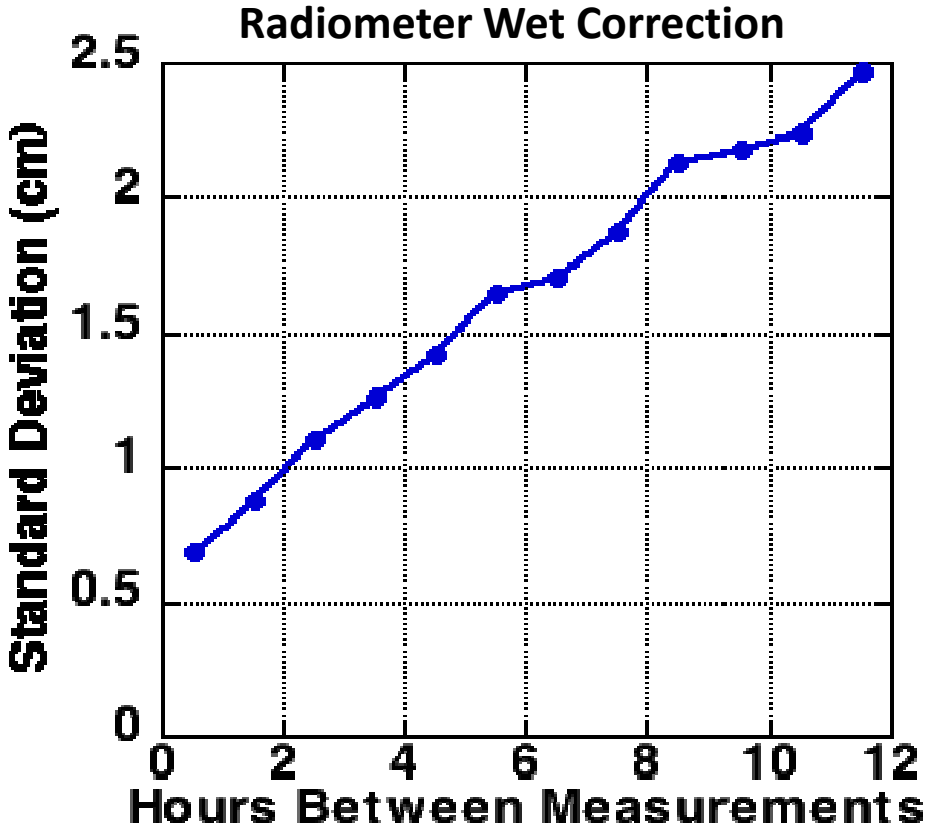
SARAL Cycle 1-15: ~26000 crossovers < 6 hours apart.



- **~26000 inter-satellite crossovers < 6 hours apart, over 15 cycles.**
- Good global coverage despite low number samples.

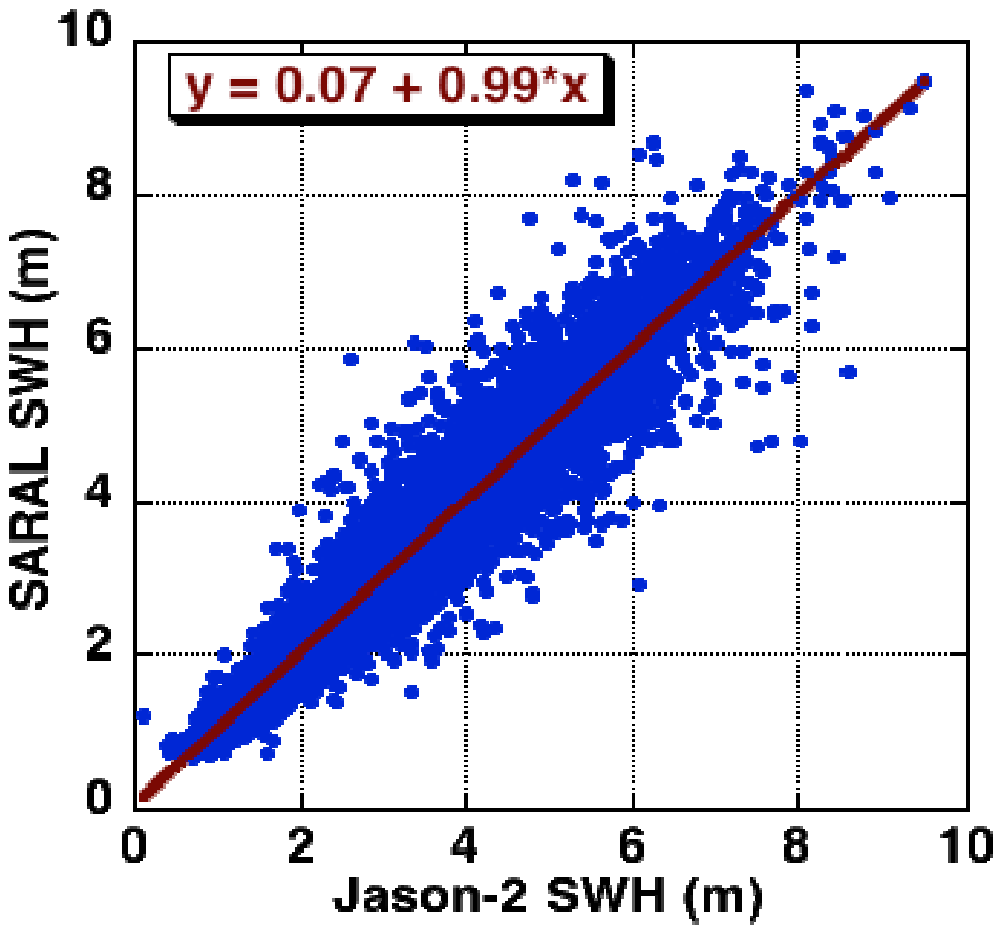
Data Noise





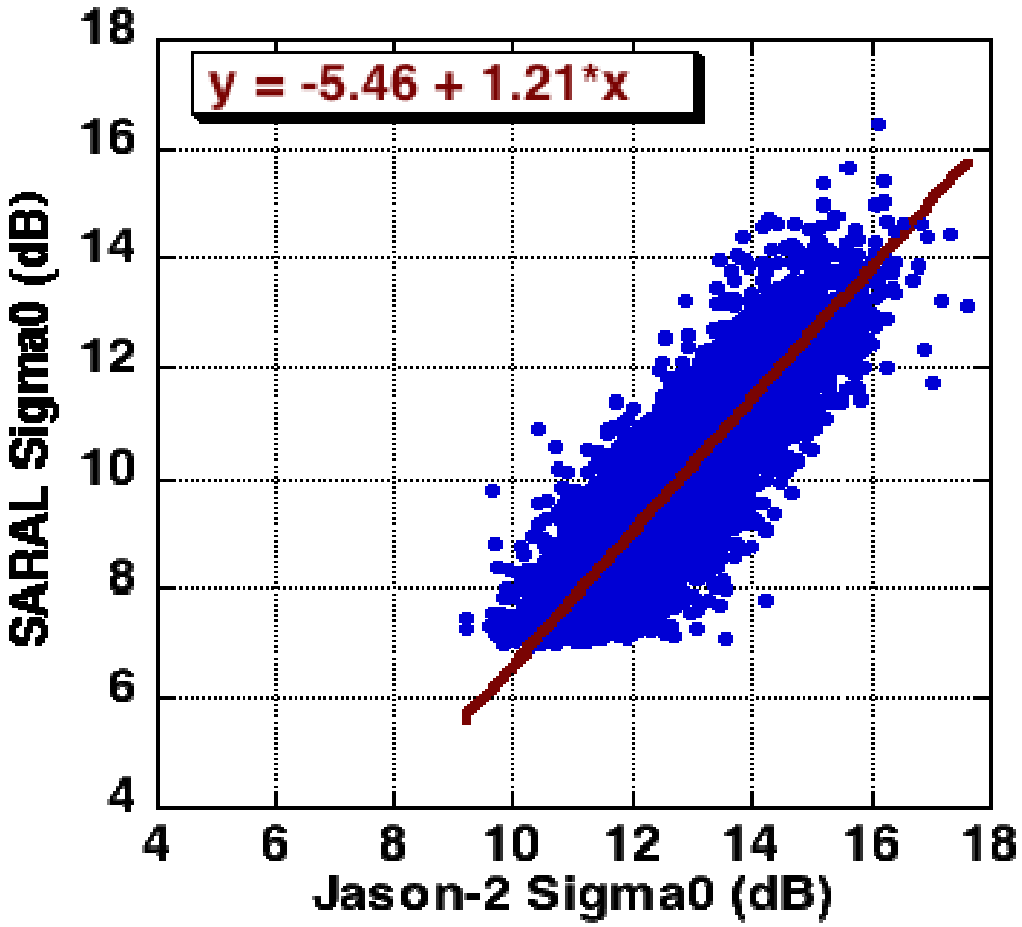
- Std. Dev. of differences linearly dependent on time between measurements.
- Provides proxy for data noise in two measurement systems.
  - e.g., 10 cm for SWH, and 7 mm for radiometer wet correction.

Significant Wave Height (SWH)



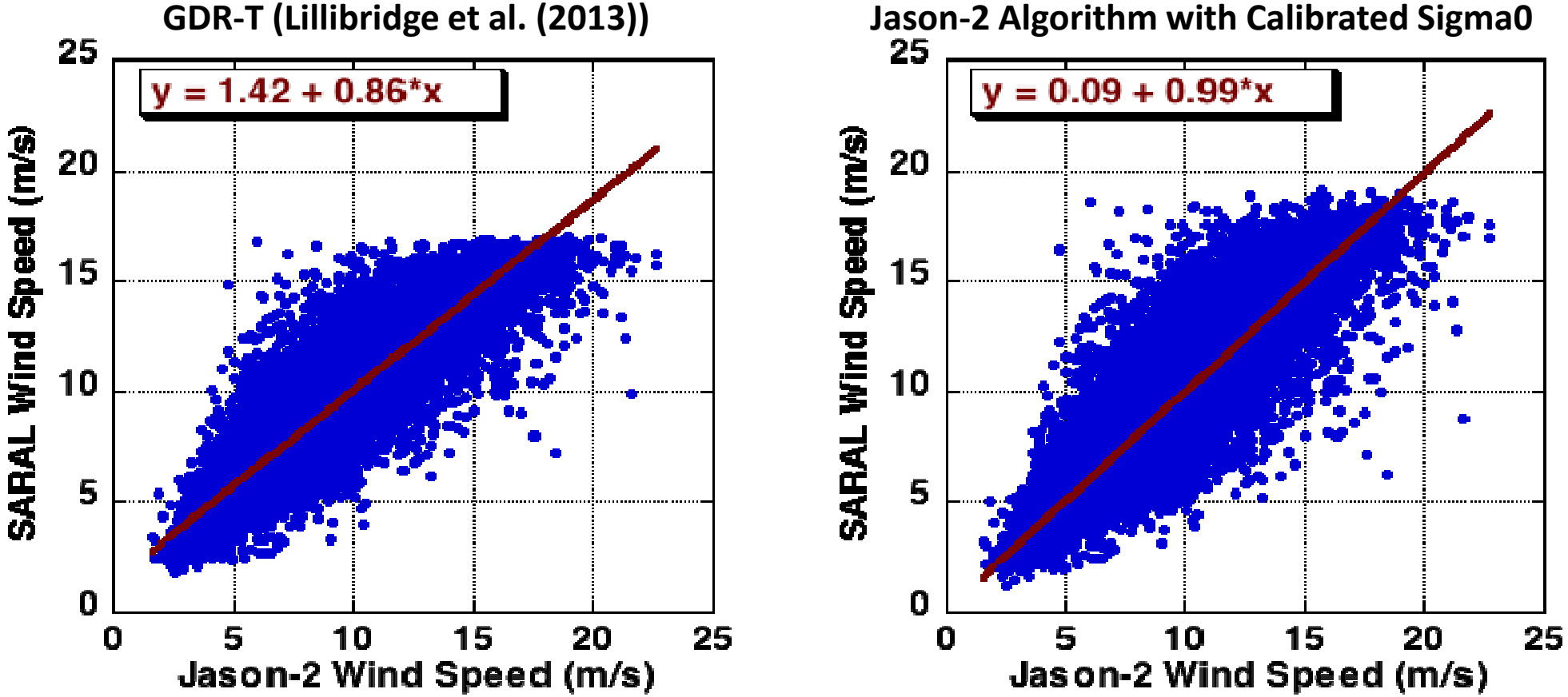
- Weighted linear regression to scatter between measurements from two systems.
  - Weighting function: 1/Δt
  - Δt = Time difference between measurements.
  - **Using only measurements with Δt < 6 hours.**
- Jason-2 and SARAL have very good agreement in SWH.
  - Bias: < 10 cm.
  - Slope: 0.99
  - Std. Dev.: 10 cm

Backscatter: Sigma0



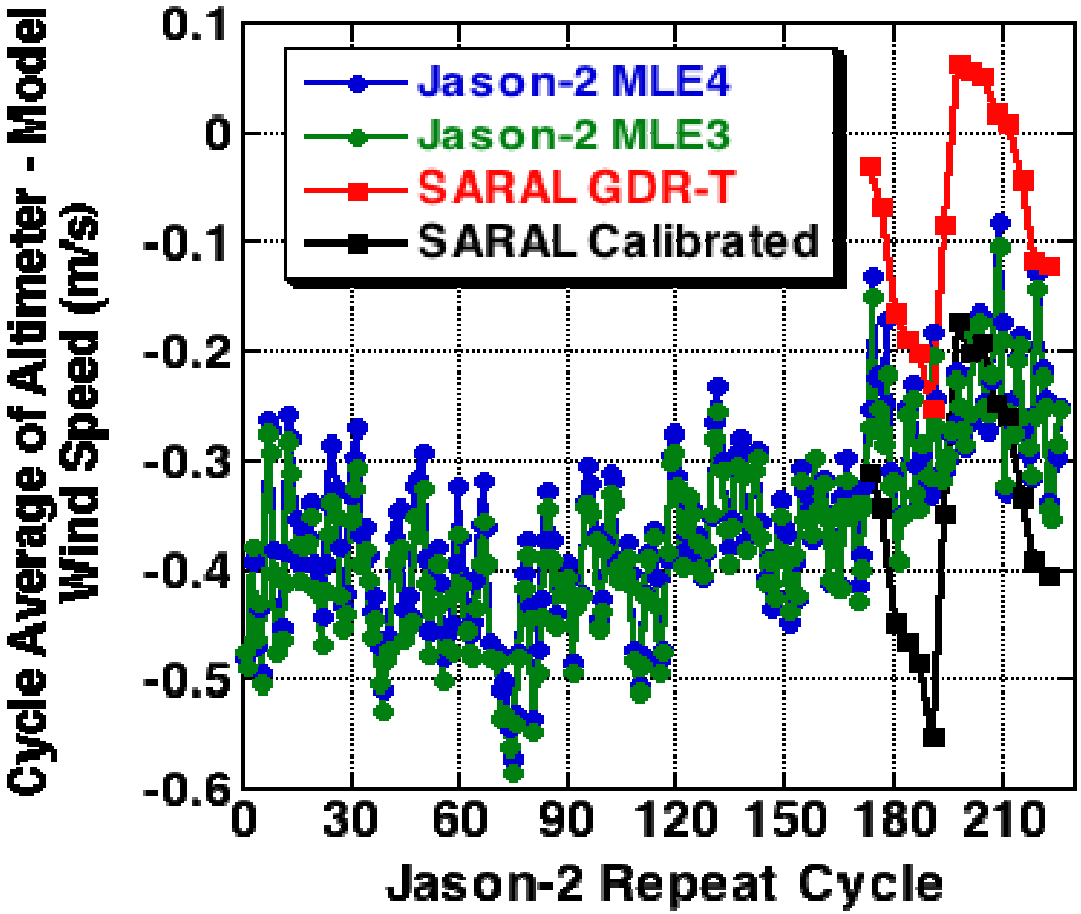
- Expect systematic differences between Ku- and Ka-band altimeters.
  - Bias = -5.46 dB
  - Slope: 1.20
  - Std. Dev.: 0.22 dB.
- Use linear regression as proxy for Ka- to Ku- calibration function.
- Facilitates application of Jason-2 Ku-band wind speed algorithm (Collard).
  - Referred to as “calibrated” SARAL wind speed.

Altimeter Wind Speed



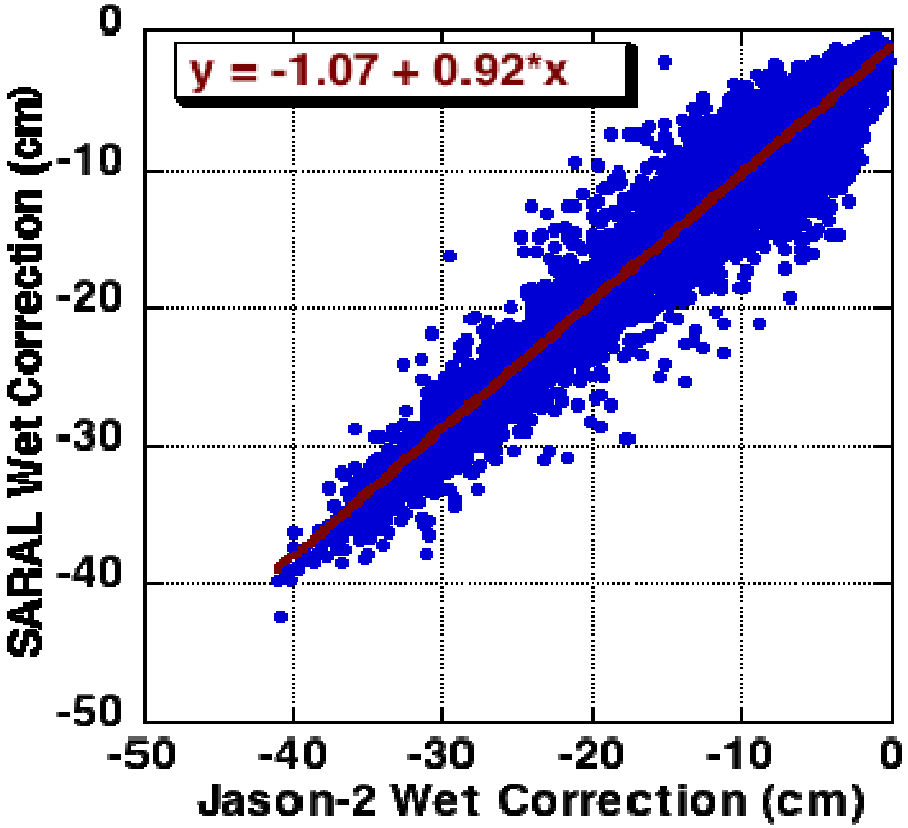
- As expected, improved consistency when using same Jason-2 wind speed algorithm (Collard et al.).
  - Not a measure of relative accuracy.

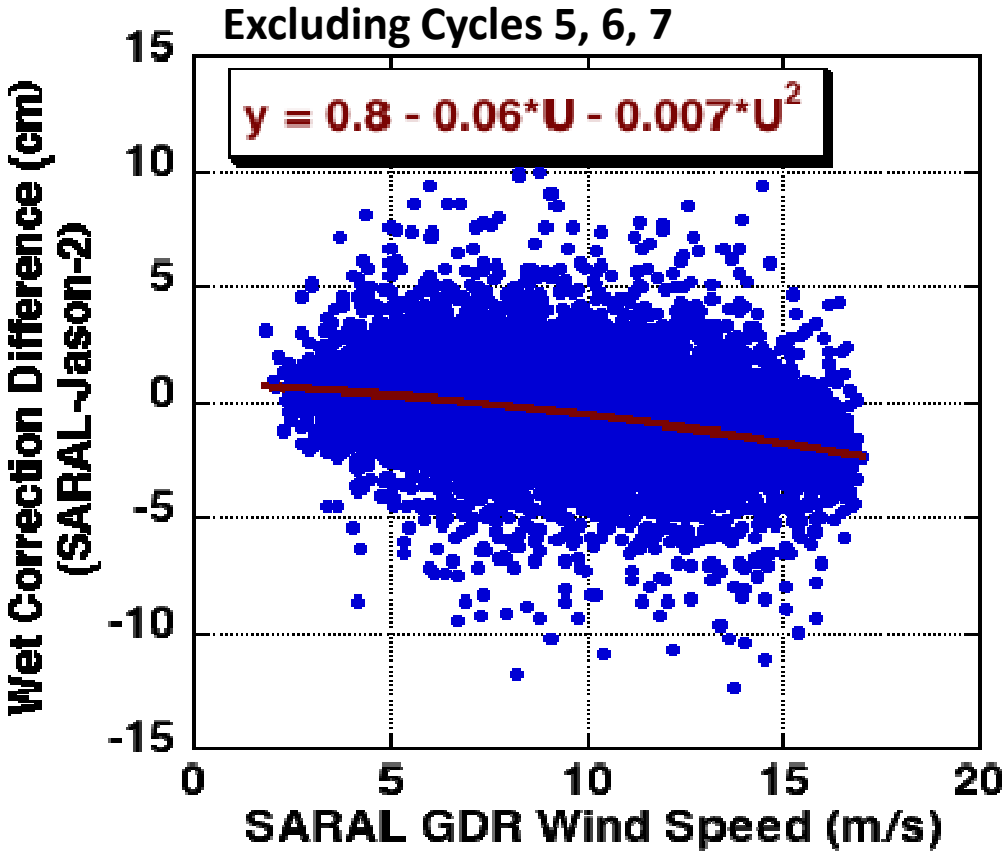
Wind Speeds: Altimeter versus ECMWF



- Relative drift between Jason-2 altimeter and ECMWF wind speeds.
  - ~0.1 – 0.2 m/s offset at least since cycle 180.
- Calibrated SARAL wind speed provides similar average of differences to model.
- SARAL has higher standard deviation of cycle averages.

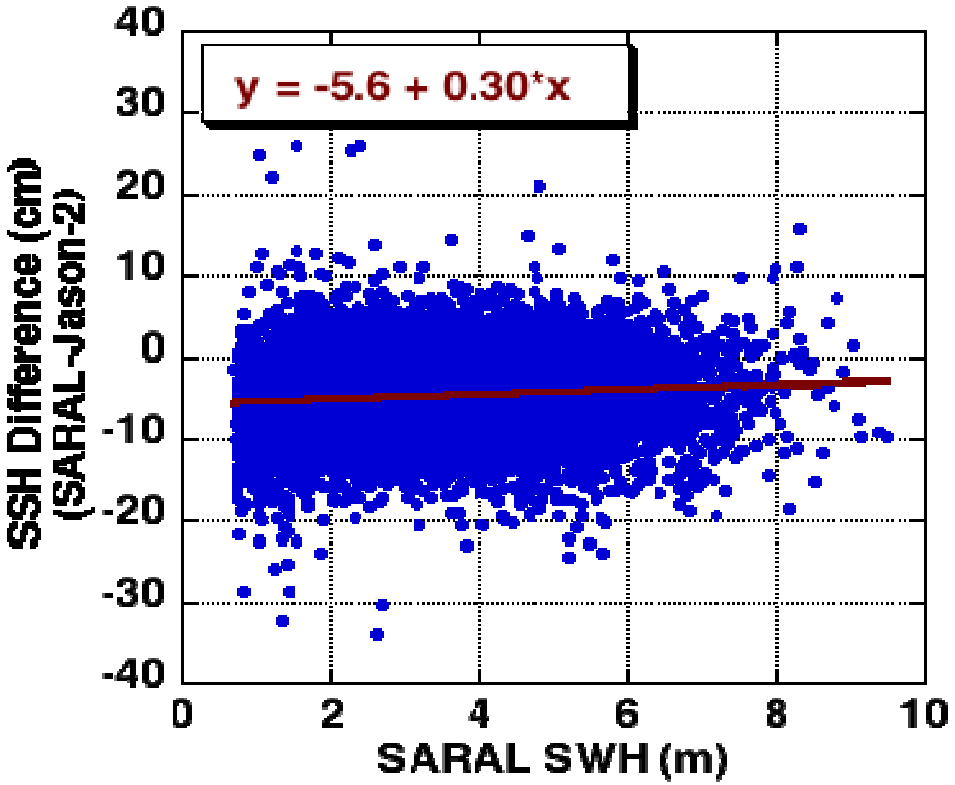
Radiometer Wet Troposphere Correction

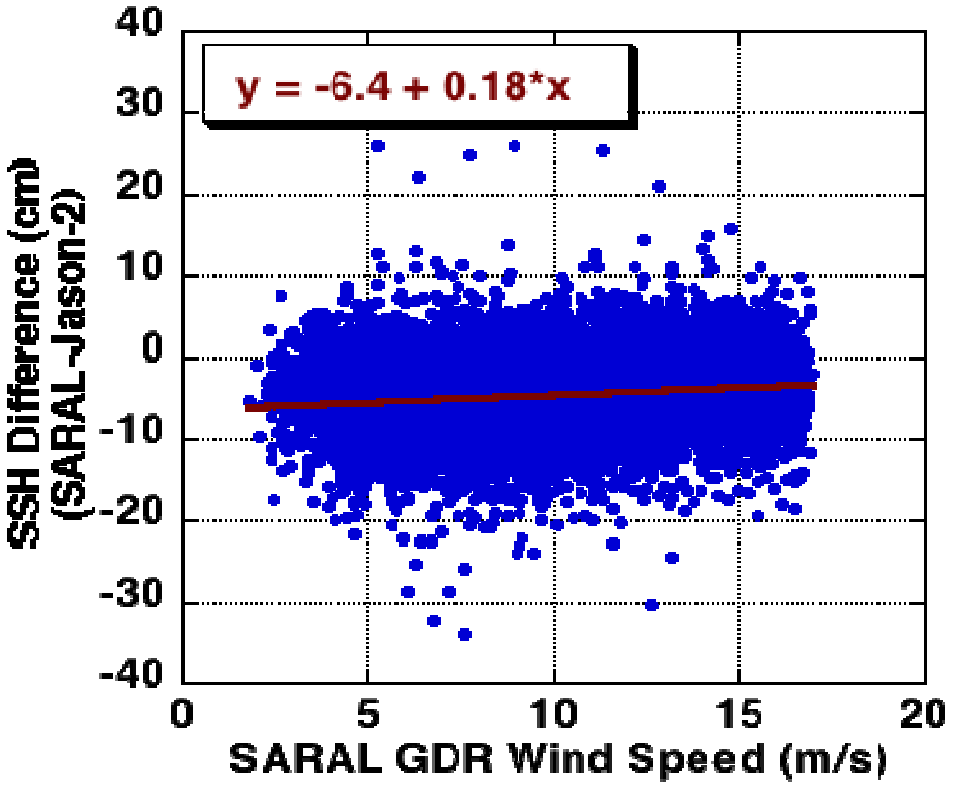




- Differences have dependency on wind speed.
  - Similar dependency on calibrated wind speed.
- Perhaps related to SARAL two- versus Jason-2 three-frequency radiometers.

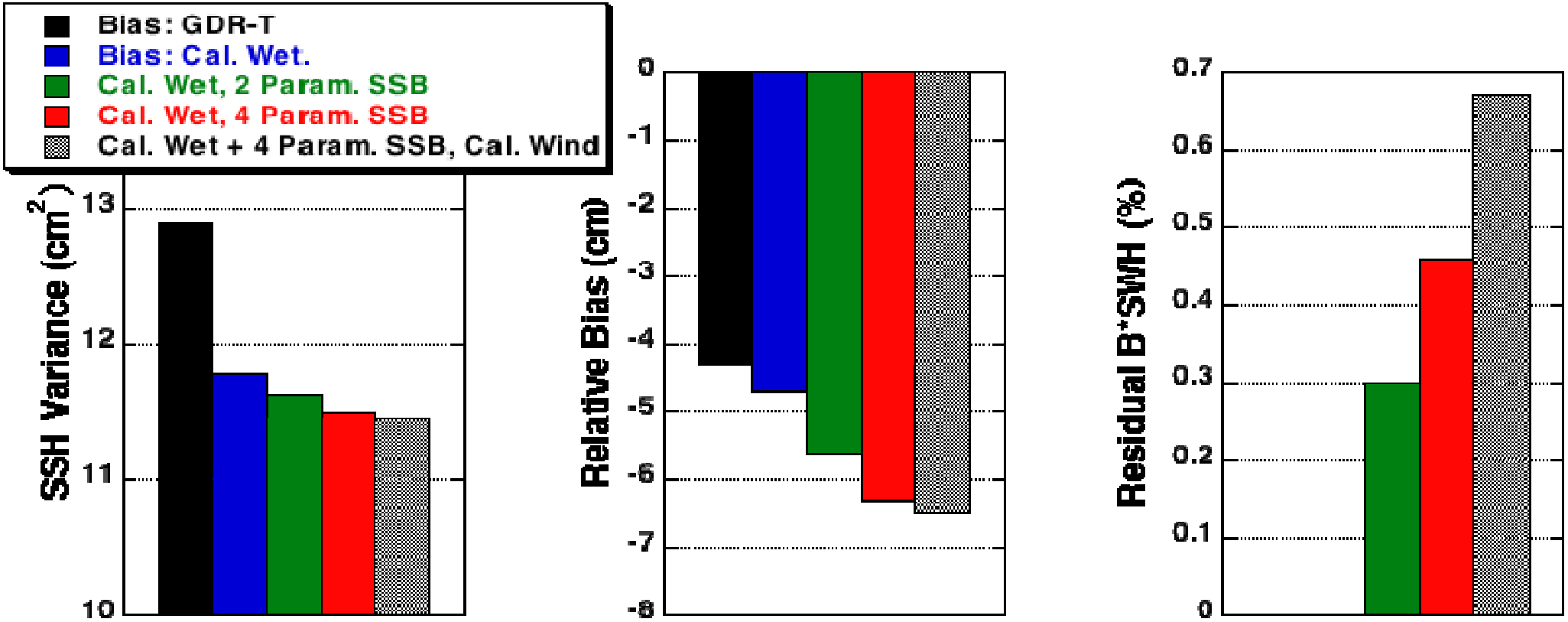
Sea Surface Height and Sea State Bias





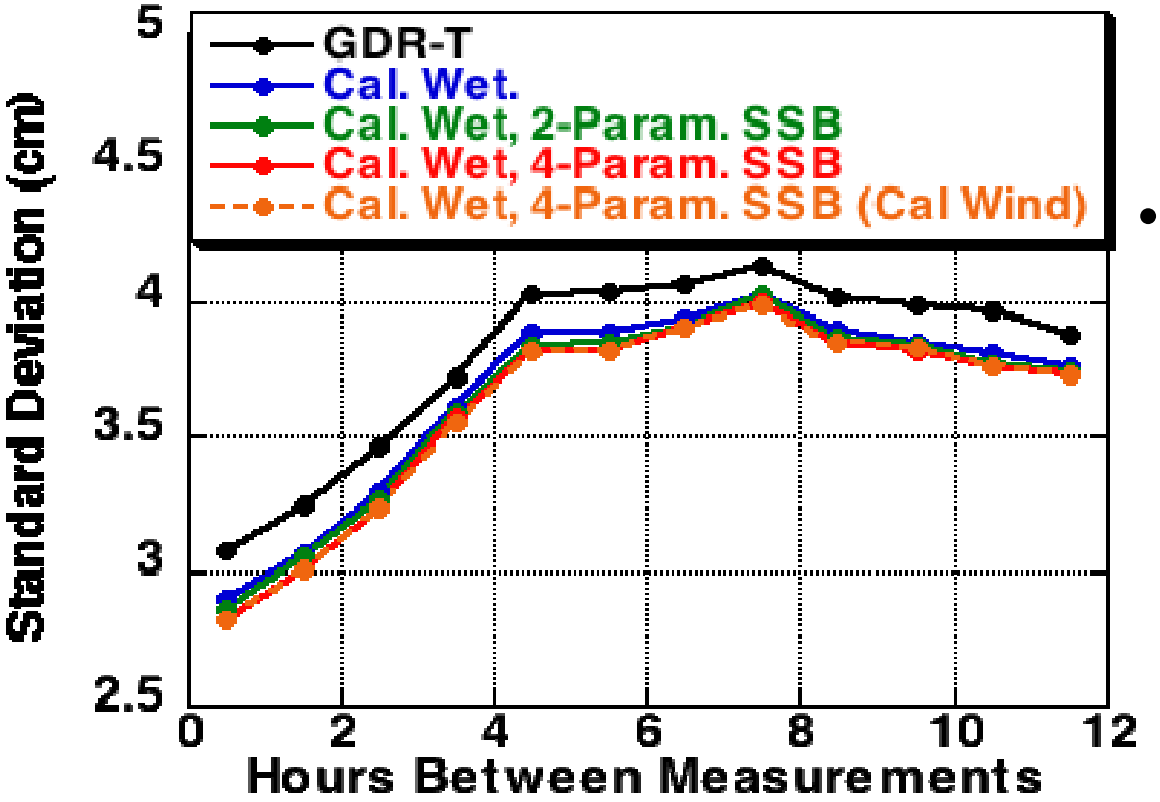
- Remaining dependency on SWH and wind speed after applying SARAL GDR-T sea state bias model.
  - GDR-T model derived from only 6 months of data, and independent of wind speed.

Impact of Calibrating Wet Troposphere and Residual SSB (A + B*SWH + C*SWH^2 + D*SWH*U)



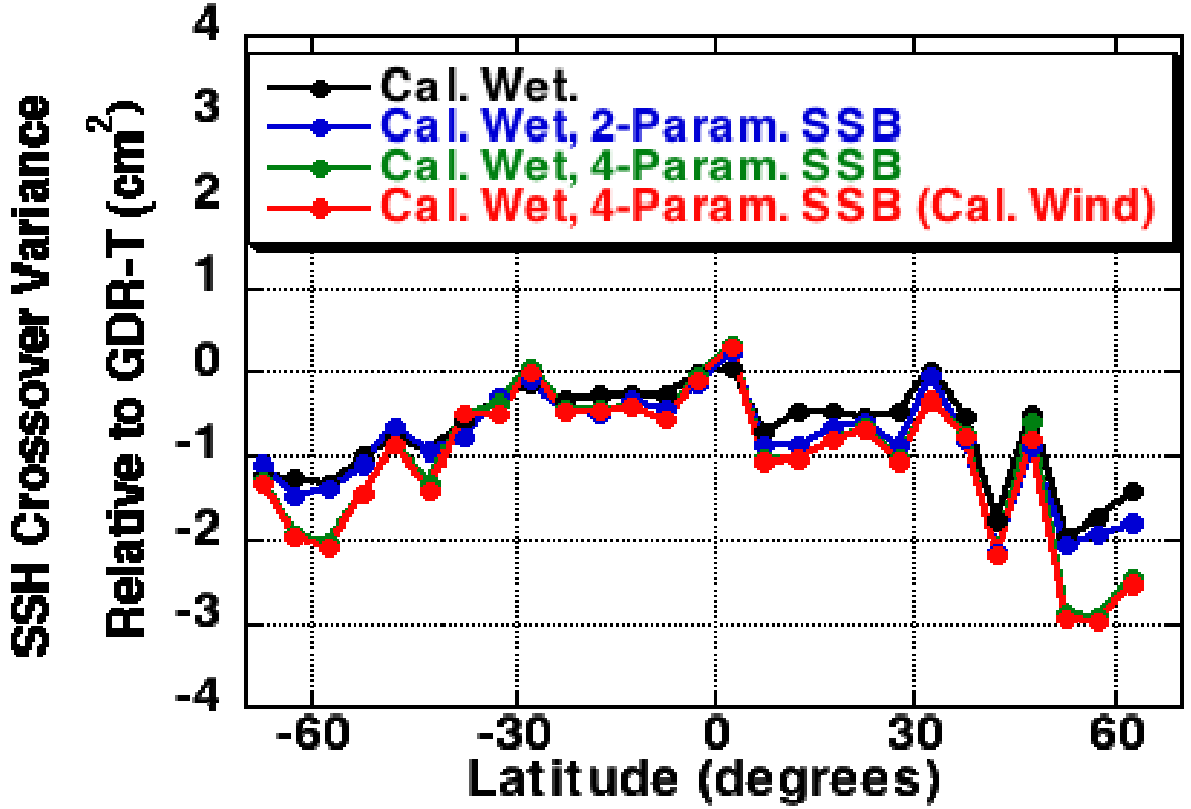
- Most significant variance reduction (9%) from calibrating SARAL radiometer wet troposphere correction.
- Relative bias of -4 to -6 cm (SARAL measuring low), depending on SSB model.
- Residual dependence on SWH of 0.3% to 0.7% of SWH.

Sea Surface Height Anomaly: Inter-Satellite Consistency



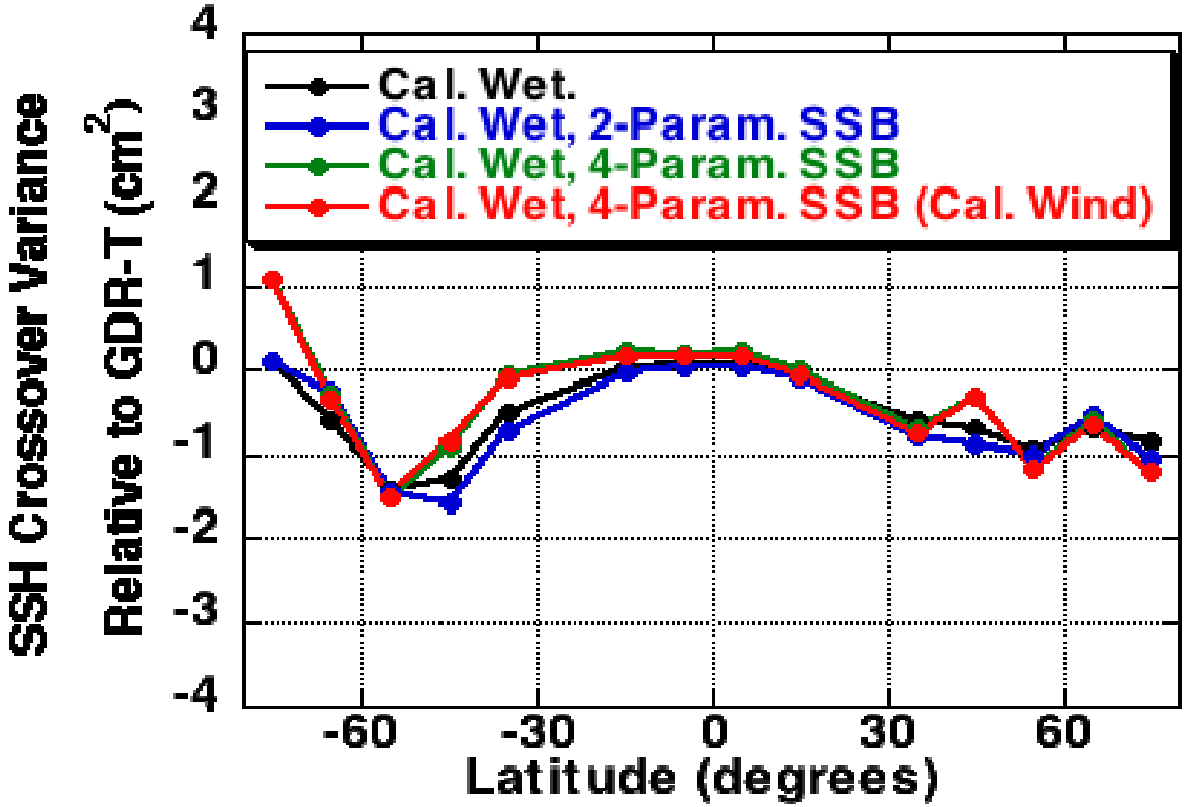
- Most significant improvement from calibrating radiometer wet troposphere correction.
- Small improvement from additional SSB correction to SARAL data.
  - 4-parameter models provide best consistency.
  - Residual dependency on both SWH and Wind.
  - Very small but detectible improvement from using calibrated wind speed.

Calibrated Inter-Satellite Cross Over Variance (Relative to SARAL GDR-T)



- |latitudes| > 30 degrees: Variances reduction from calibrating radiometer wet troposphere correction.
- |latitudes| > 50 degrees: Additional variance reduction from residual SSB model that includes wind speed and quadratic SWH term.

Calibrated SARAL ONLY Cross Over Variance (Relative to SARAL GDR-T)

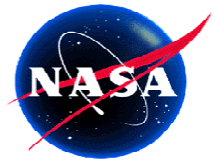


- Variance reduction at |latitudes| > 30 degrees.
  - Primarily from calibrating wet troposphere correction.
- Exposes sub-optimal parametric residual SSB model.
  - Perhaps better to use collinear variance reduction (e.g., Feng, Vandemark et al).

Conclusion

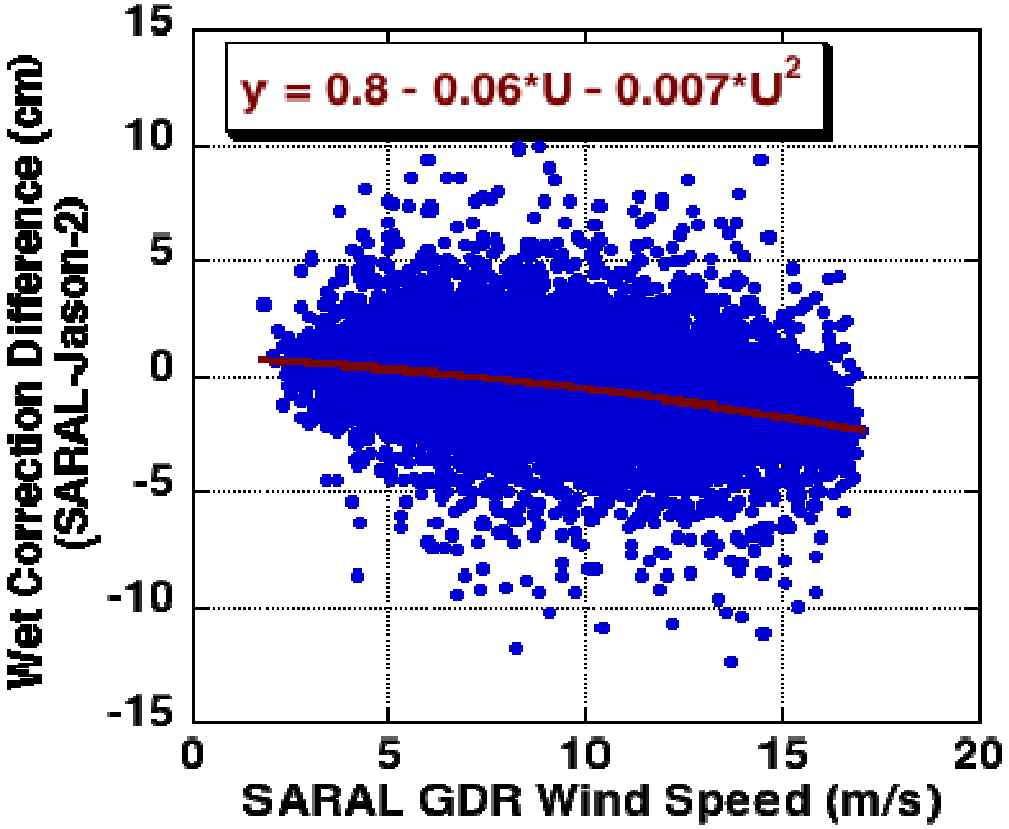
- Jason-2/SARAL crossovers provide powerful inter-satellite calibration approach.
  - Good global distribution, and sampling of wind/wave conditions.
  - Despite relatively few crossover measurements available.
- Residual wind-dependent inconsistency in SARAL radiometer wet troposphere correction.
- Inconsistency between Jason-2 and SARAL altimeter wind speeds.
- Residual sea state bias error (~0.5% of SWH) in SARAL GDR-T products.

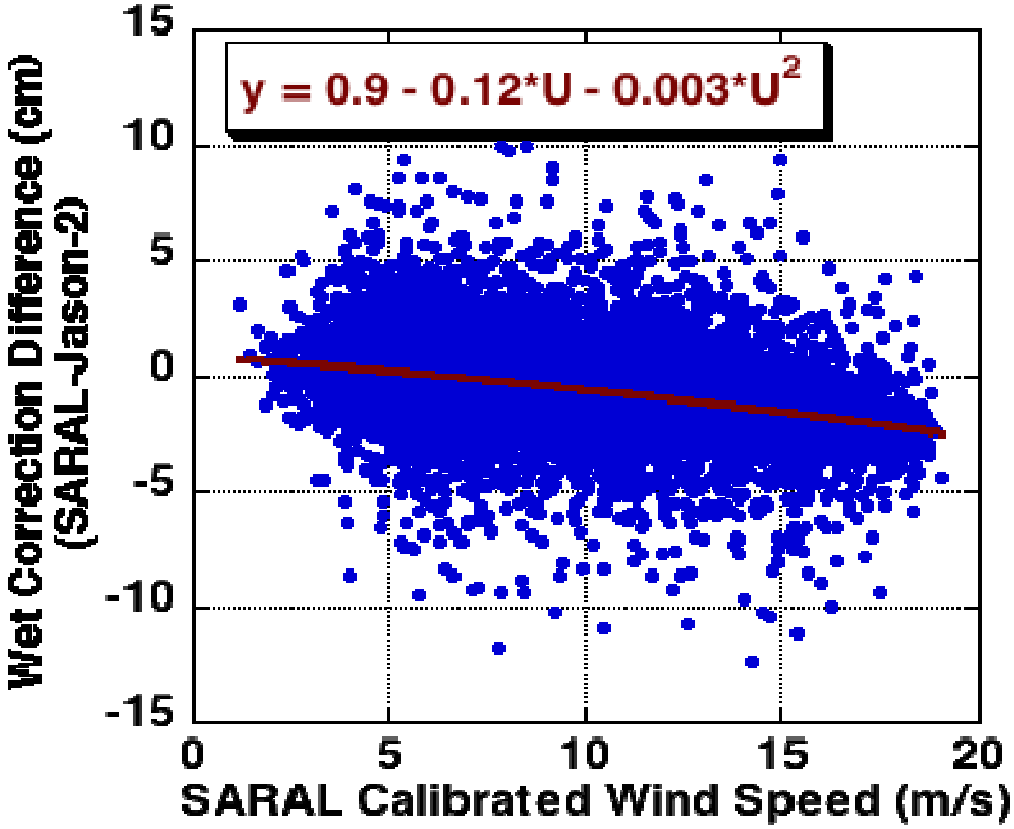
Parameter	Std. Dev. of Cross Over Differences
Significant Wave Height	0.10 m
Backscatter Coefficient	0.22 dB
Radiometer Wet Correction	0.68 cm
Sea Surface Height (GDR-T)	3.08 cm
Sea Surface Height (Calibrated)	2.81 cm



Back-Up Slides

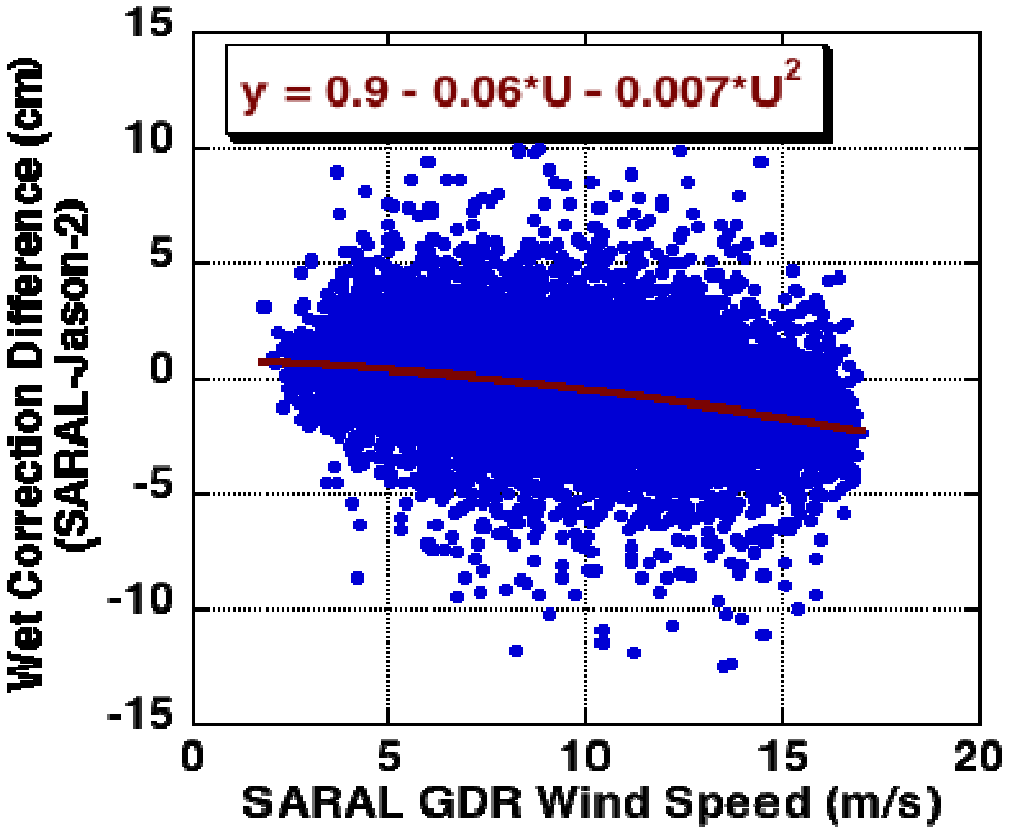
Radiometer Wet Correction: Dependency on Wind Speed (Excluding cycles 5-7)

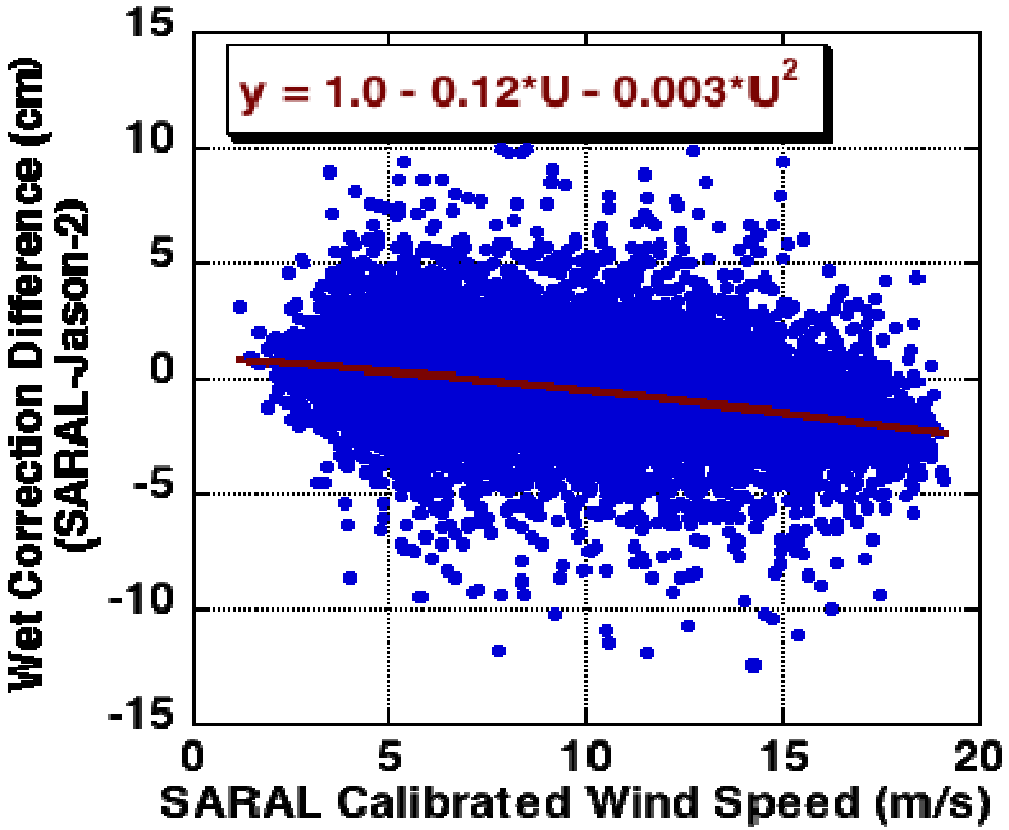




- Dependency on wind speed observed with GDR or Calibrated Wind Speed.

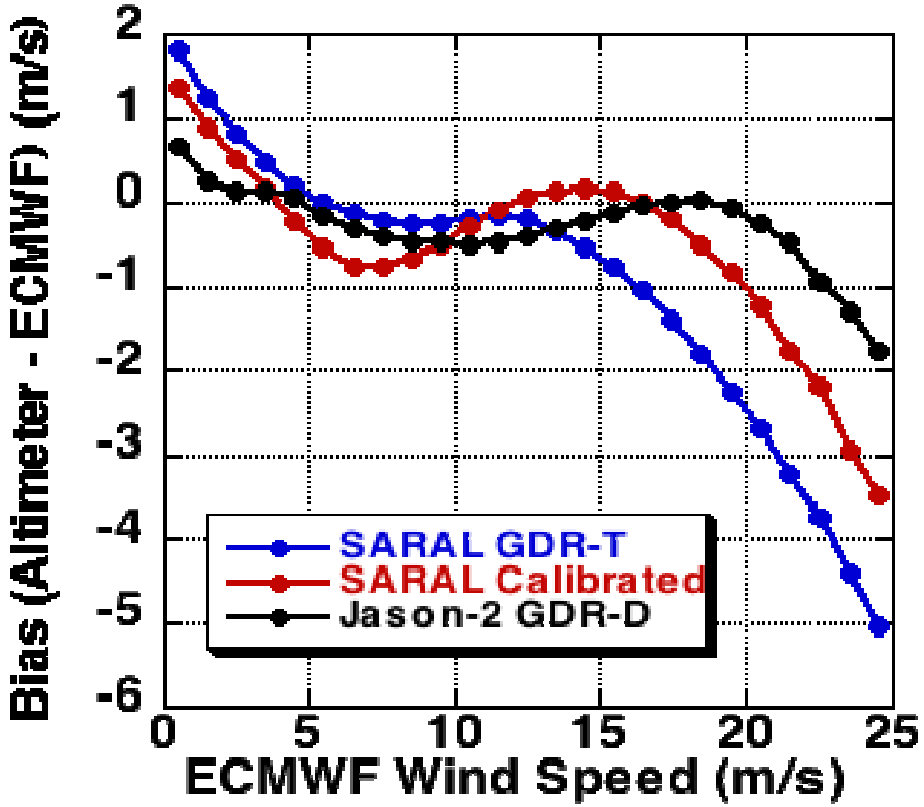
Radiometer Wet Correction: Dependency on Wind Speed (Including cycles 5-7)

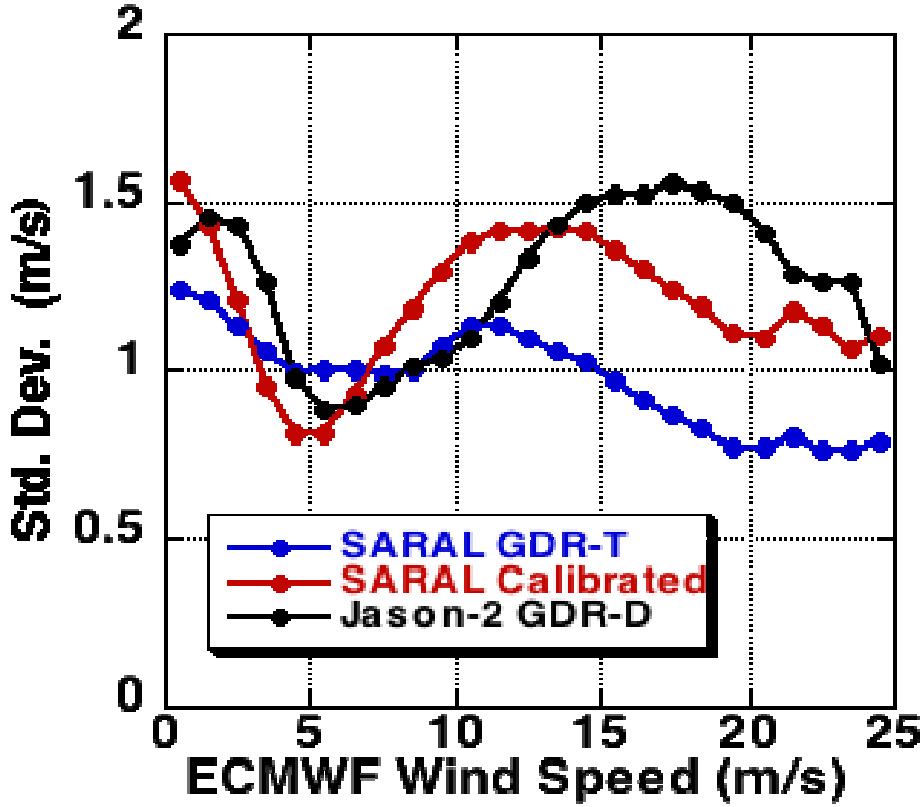




- Dependency on wind speed observed with GDR or Calibrated Wind Speed.

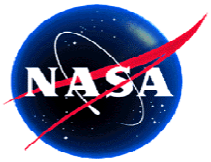
Comparisons to ECMWF Model Wind Speed





- Jason-2 wind speed has smallest bias versus ECMWF.
  - Calibrating SARAL wind speed reduced bias at high wind conditions.
- SARAL GDR-T wind speed has smallest standard deviation.

Empirical Models for Residual Sea State Bias



Residual SSB = A + B*SWH + C*SWH^2 + D*U*SWH

A (m)	B (m/m^{-1})	C (m/m^2)	D (m/(m. m/s))	Residual SSH Variance (cm^2)	
-0.043				12.89	GDR-T
-0.047				11.78	Wet. Calibration
-0.056	0.0030			11.62	SSB Model 1
-0.063	0.0046	-0.0017	0.0007	11.48	SSB Model 2
-0.065	**0.0067**	**-0.0016**	**0.0005**	**11.45**	**SSB Model 3 (Cal. Wind)**

- Models are in addition to SSB model on GDR-T product.
  - Subtracted from sea surface height anomaly (added to range).
- SARAL measuring SSH low relative to Jason-2 by 4-6 cm.
  - Potential residual dependence on SWH of ~0.5%.
  - Impact of residual SSB on inter-satellite bias is ~2 cm.
  - Calibrated wind speed provides slightly improved consistency.
    - Increases SWH dependency by 0.2%*SWH (from 0.0046 to 0.0067).