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Retracked TOPEX Climate Data Record

OSTST November 2016

La Rochelle, France

Phil Callahan on behalf of the
TOPEX Reprocessing Team

Outline / Overview

- A Brief History of TOPEX Altimeter Issues
  - Waveform Leakages
  - Waveform Weights
  - Alt-A PTR Changes and Cal Data
  - Noise Bins
  - WFF Range Calibration (internal Cal-1)
- Results for new retracking with adjusted noise bins, same PTR as 2015 (fit to Cal-1 +/-6 lobes, extend to 30 lobes), original waveform weights from WFF (GDR; used in 2015)
- Work to go
  - Some items to investigate
  - Update format to be more compatible with Jason-2 Ver E
  - Apply new environmental corrections from CNES
  - Sea State Bias Update - Doug Vandemark, Hui Feng to use standard method to provide

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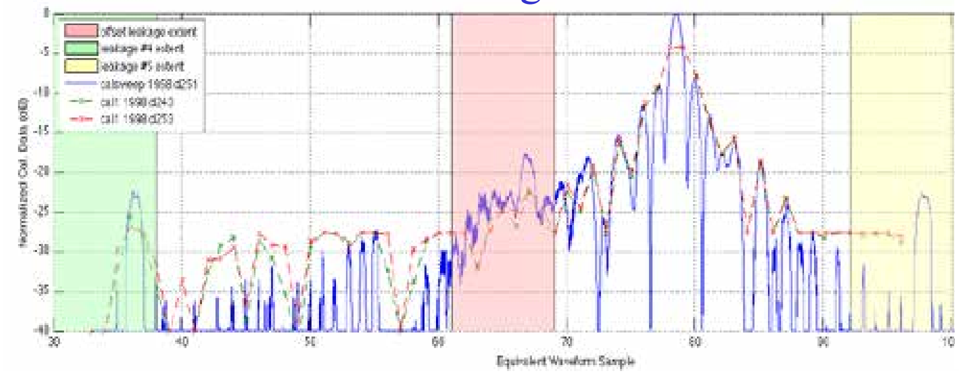
TOPEX History – Leakages

- Leakages (x20) in the TOPEX Alt-A waveform from Hayne et al., 1994, JGR, ***99*****,** 24,941 shown below
  - o Move over several bins with range rate giving North/South Ascending/Descending ("toward" / "away" from equator) differences
  - o Onboard gates used to estimate parameters shown as bars
  - o Need correction in processing via masking or "weights" on WF gates
  - o Limit range of Cal-1 data that can be used for PTR estimate to +/-6 lobes

- Waveform "teeth" observed in test data are well corrected by waveform weights
  - o 2015 onward using original WFF/GDR weights

Cal Sweep and Cal-1 Data, 1998
with Leakage areas



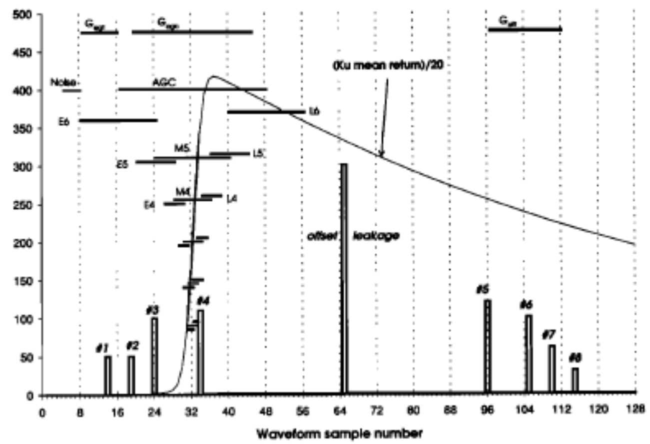


Figure 6. TOPEX Ku altimeter gates, mean return, and center locations of waveform leakage spikes.

TOPEX History – Alt-A PTR Changes

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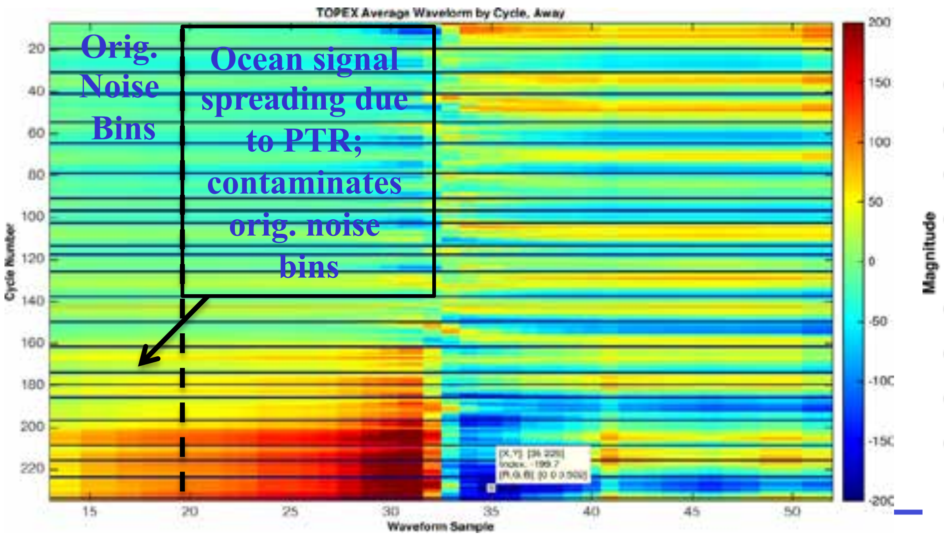
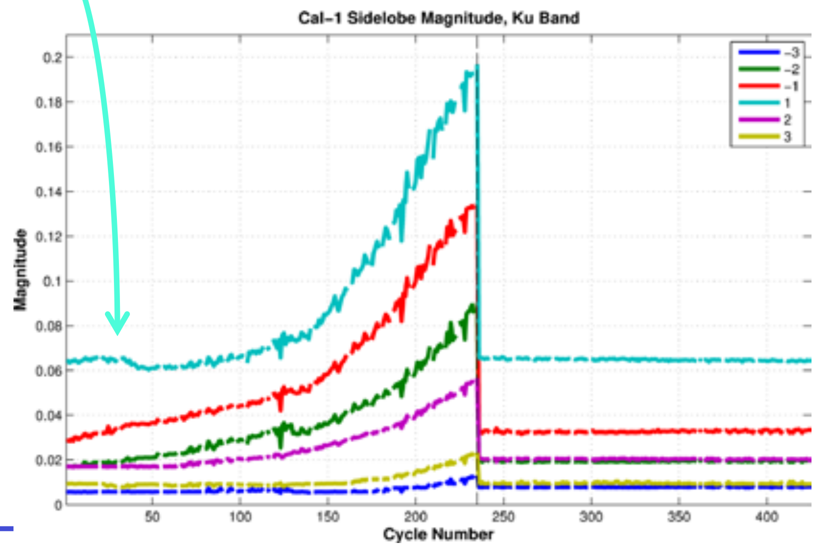
- Reviewed Cal data transfer through signal path. (Note: Cal-1 data are just Nyquist sampled.)
  - Right: Changes in sidelobes near cycle 50 (sidelobe +1) seem to produce anomalous SSH in early data
- Fit PTR to +/-6 lobes, extend to +/-30 lobes needed for retracking consistent with PTR changes (increase in sidelobes, missing lobes with increasing phase imbalance)
- *NEW: Alt-A PTR changes spread signal from leading edge into noise bins. Moved noise estimate from 7-12 to 5-7
  - Lower noise estimate will affect SWH and Range estimates directly and through correlations





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WFF Range Calibration

- During analysis of the Jan 2015 version of the retracked data, we were reminded that MGDR-B contains the WFF Range Calibration. It was not used in original GDRs.
- This calibration from the Cal-1 data produces a significant addition to the GMSL slope for Alt-A from about cycle 100 to 235.

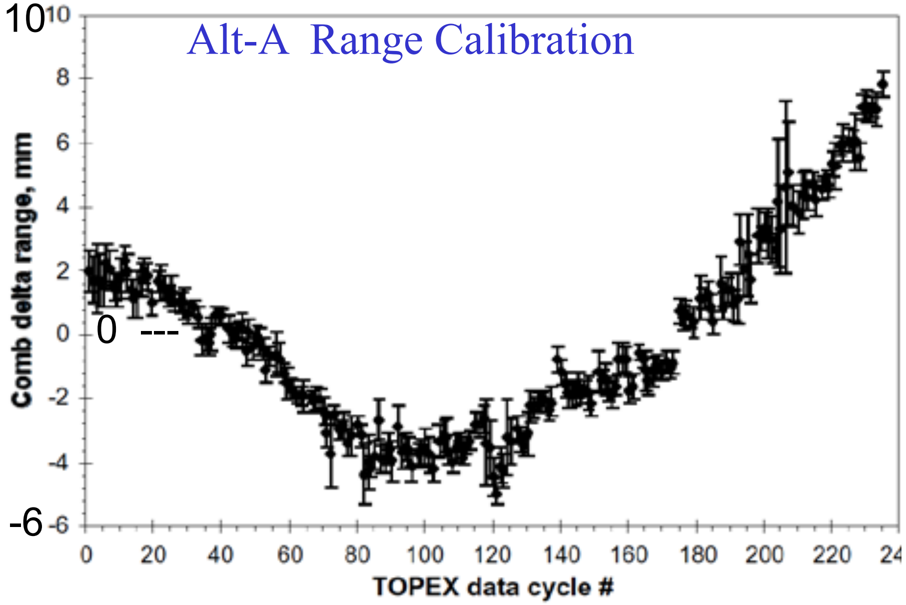

Figure 3-2 Combined (Ku & C) Delta Range vs. Cycle - With UCFM Temperature Correction

Slope from cycle 101 to 235 is 2.95 mm/yr

- Calibration is nominally quantized at 7 mm (see below), but through an undescribed process WFF was able to determine mm level values.

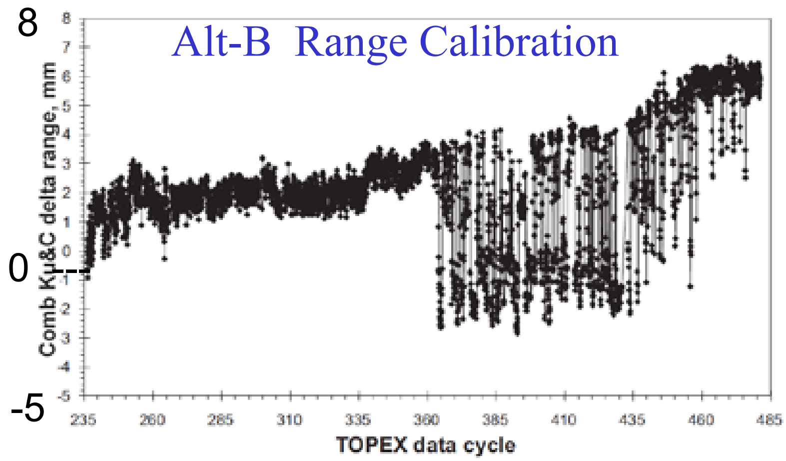

Figure 3-7 Side B CAL1 Step-5 Combined dRange vs. Cycle after Correction for Receiver AGC Temperature

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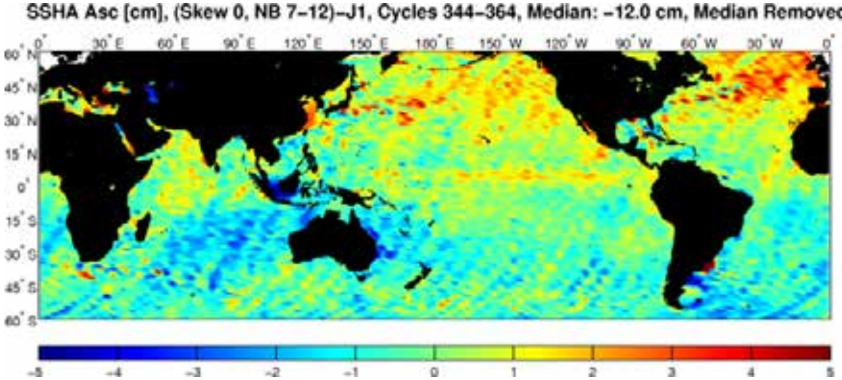
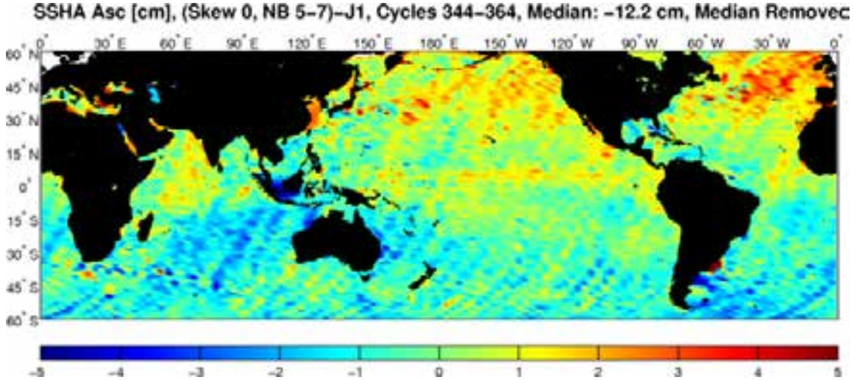
Difference (TPX-J1), SSHA Ascending, Cycles 344-364

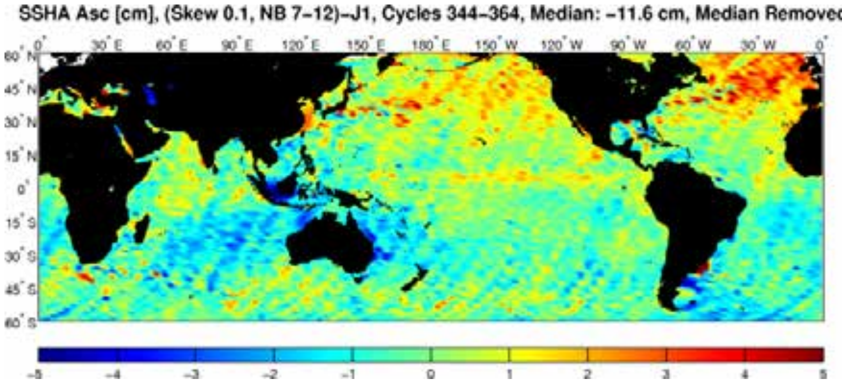
Noise 7-12 | **Noise 5-7**

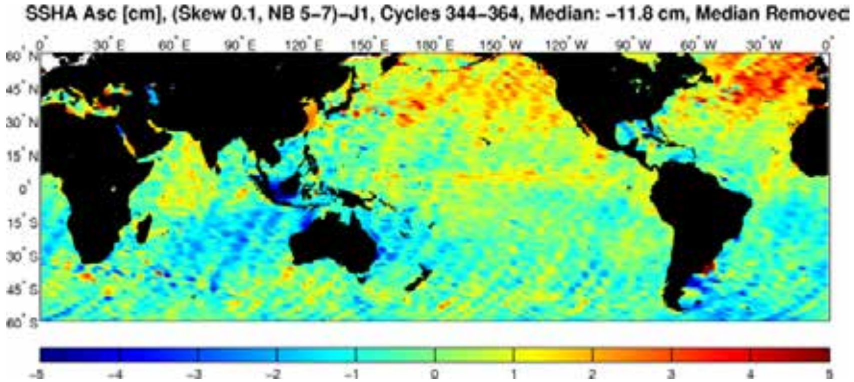
Skew 0



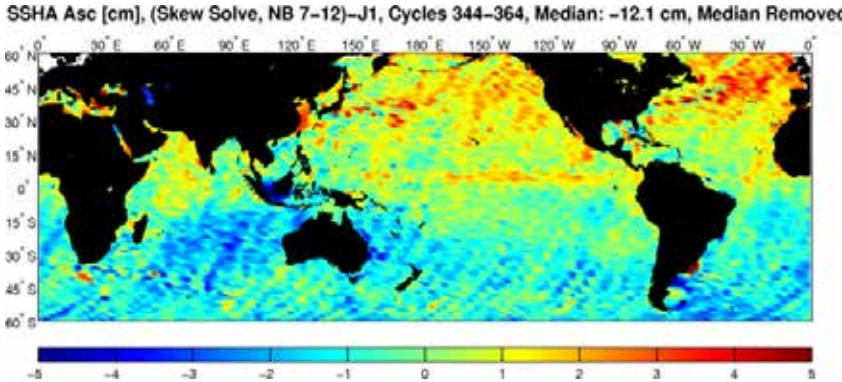


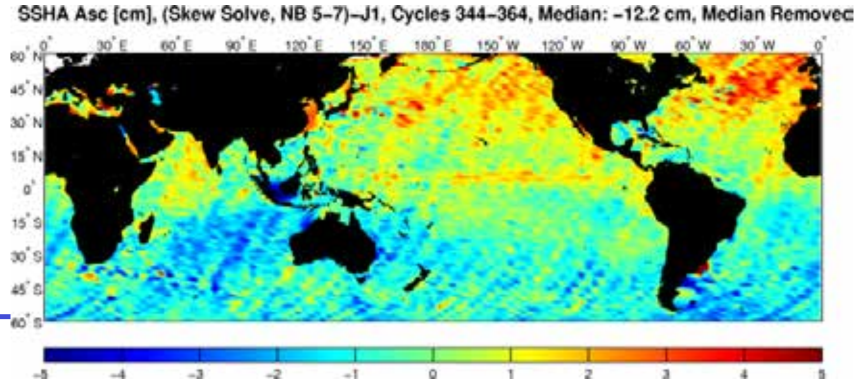
Skew 0.1





Skew Solve





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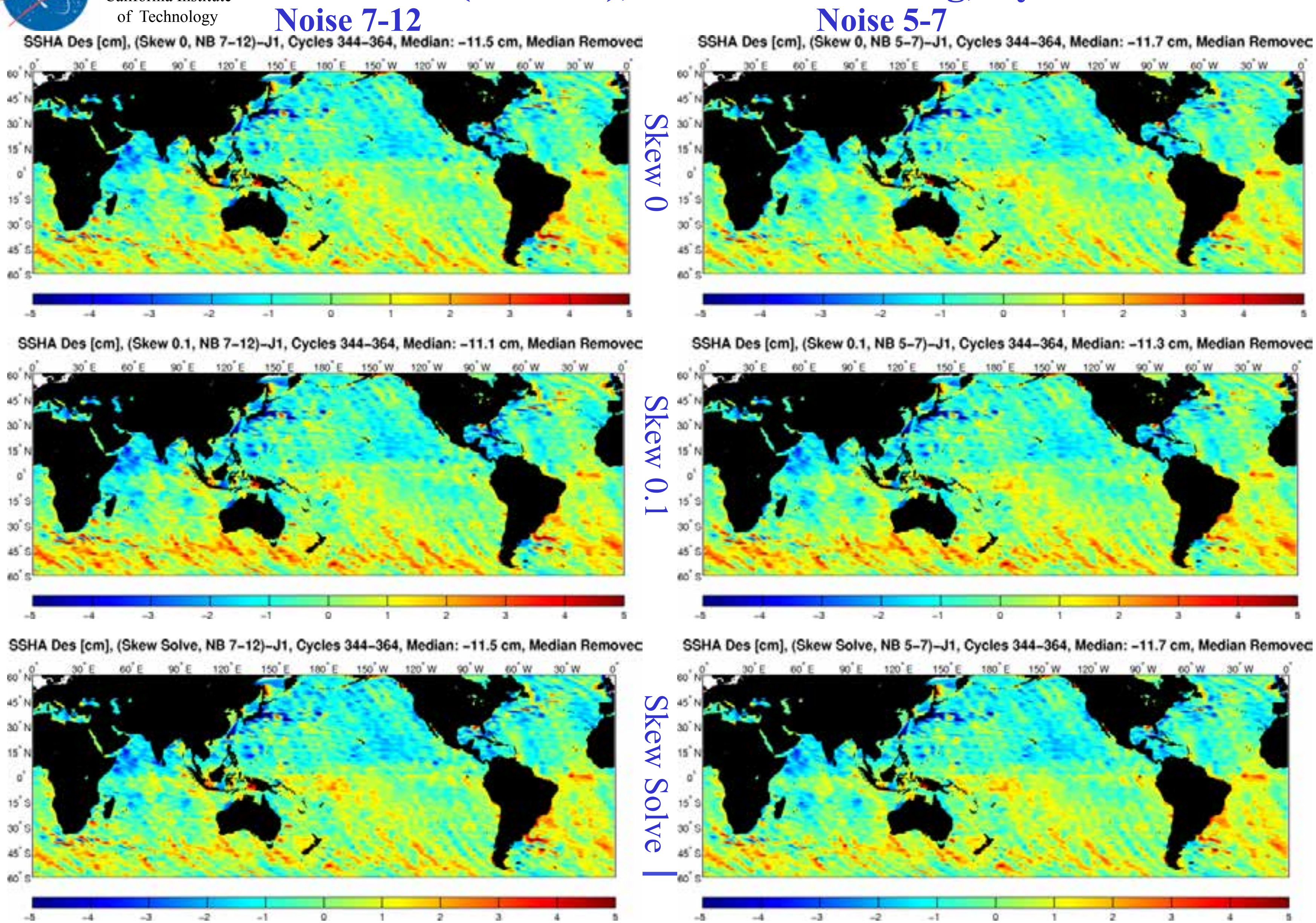
Difference (TPX-J1), SSHA Descending, Cycles 344-364



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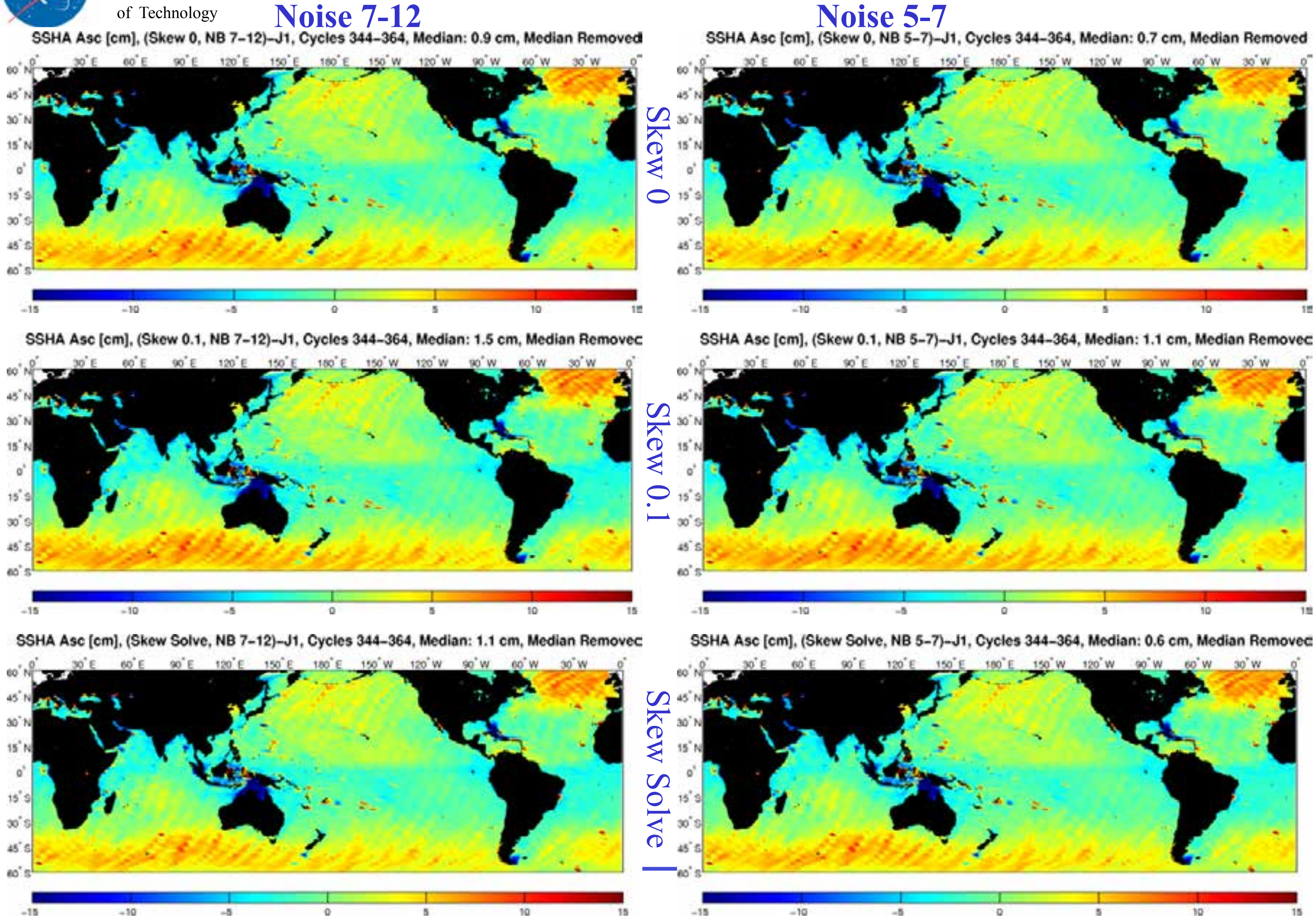
Difference (TPX-J1) (only SSB), SSHA Ascending, Cycles 344-364



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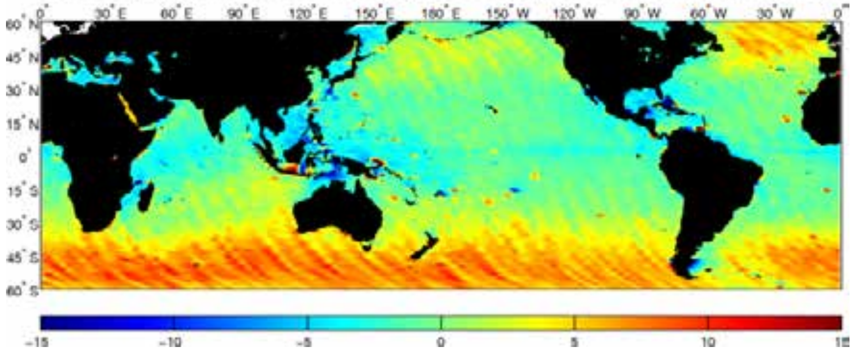
Difference (TPX-J1) (only SSB), SSHA Descending, Cycles 344-364

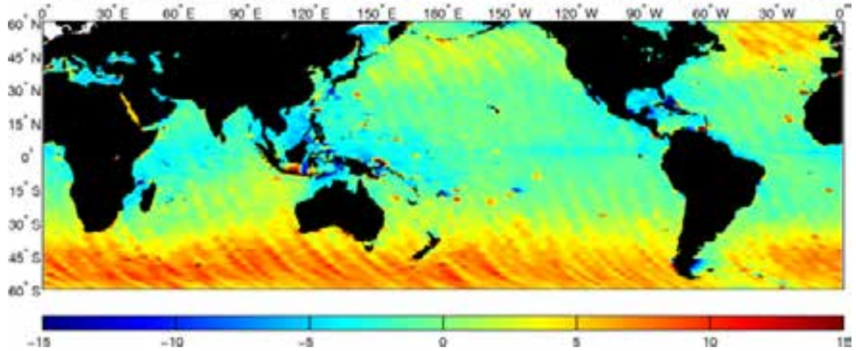
Noise 7-12 | Noise 5-7

Skew 0

SSHA Des [cm], (Skew 0, NB 7-12)-J1, Cycles 344-364, Median: 0.7 cm, Median Removed

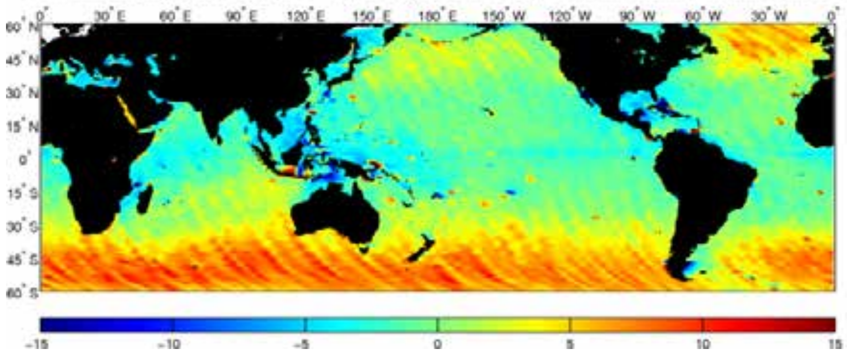


SSHA Des [cm], (Skew 0, NB 5-7)-J1, Cycles 344-364, Median: 0.5 cm, Median Removed

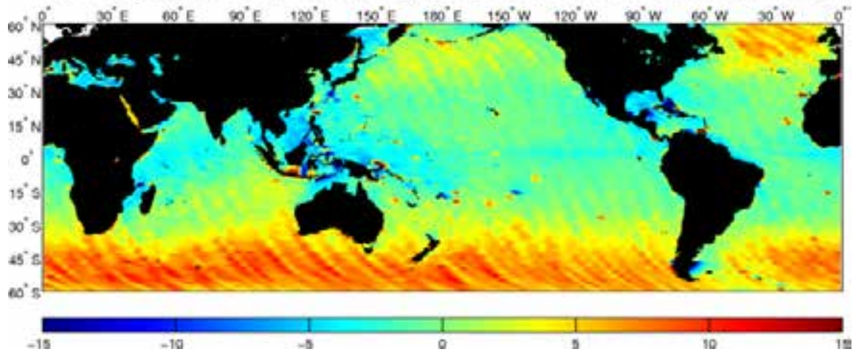


Skew 0.1

SSHA Des [cm], (Skew 0.1, NB 7-12)-J1, Cycles 344-364, Median: 1.3 cm, Median Removec

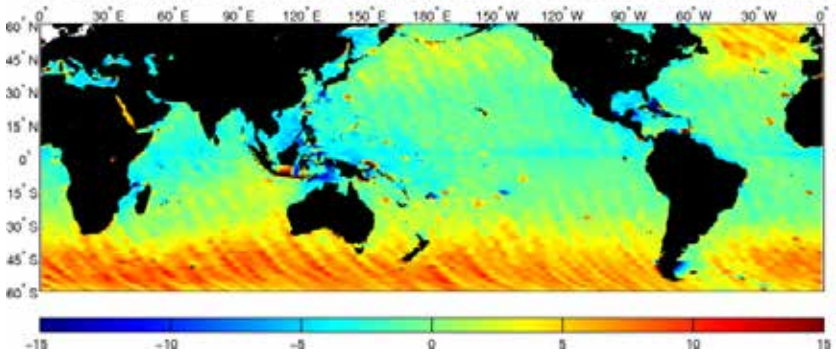


SSHA Des [cm], (Skew 0.1, NB 5-7)-J1, Cycles 344-364, Median: 0.9 cm, Median Removec

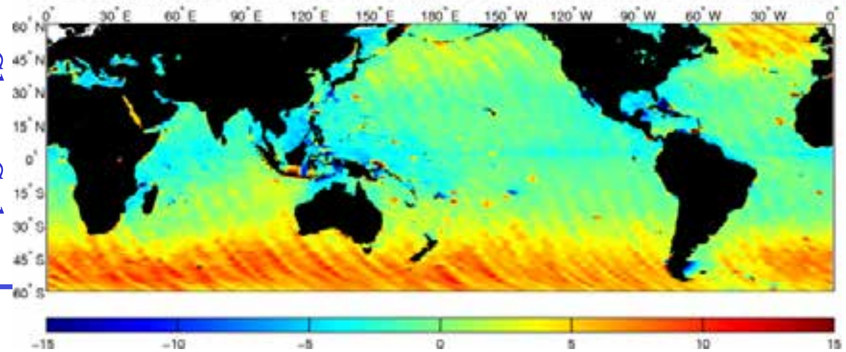


Skew Solve

SSHA Des [cm], (Skew Solve, NB 7-12)-J1, Cycles 344-364, Median: 0.9 cm, Median Removec



SSHA Des [cm], (Skew Solve, NB 5-7)-J1, Cycles 344-364, Median: 0.5 cm, Median Removec



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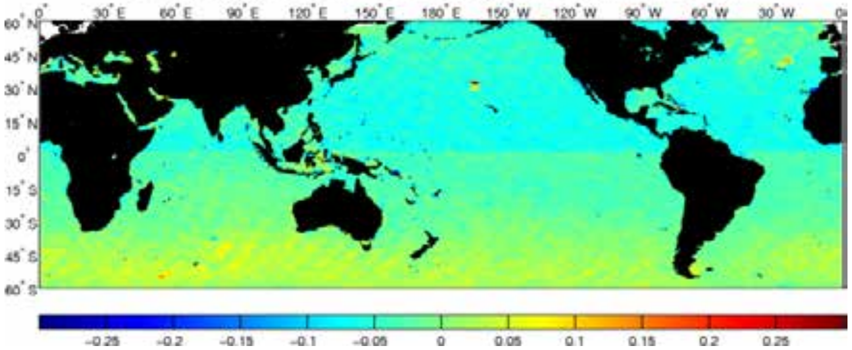
Difference (TPX-J1), SWH Ascending, Cycles 344-364

Noise 7-12

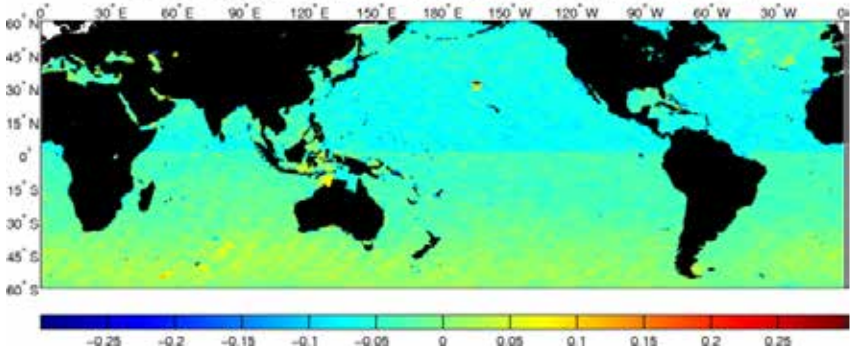
Noise 5-7

Skew 0

SWH Asc [m], (Skew 0, NB 7-12)-J1, Cycles 344-364, Median: -0.0 m

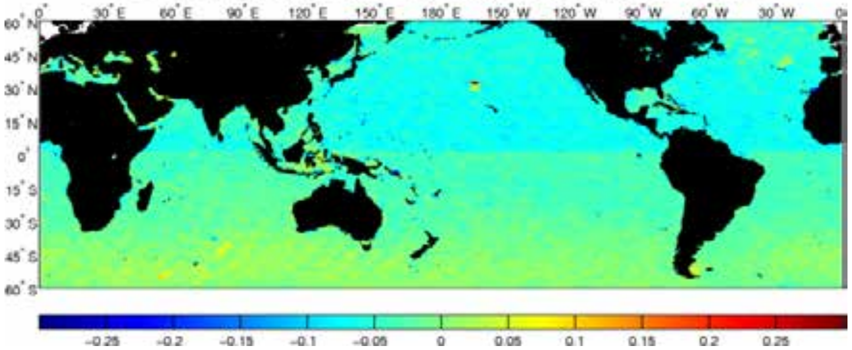


SWH Asc [m], (Skew 0, NB 5-7)-J1, Cycles 344-364, Median: -0.0 m

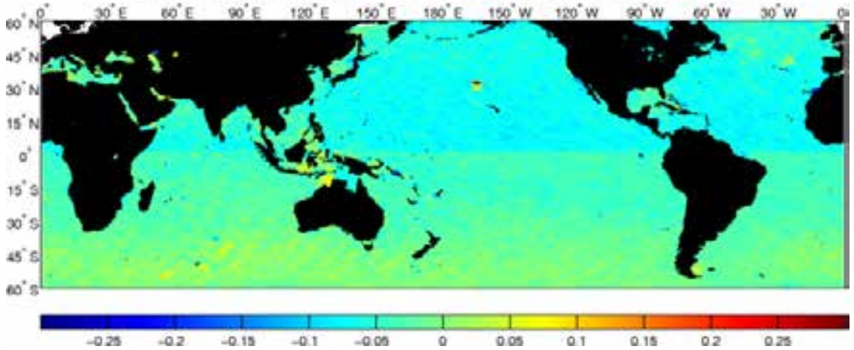


Skew 0.1

SWH Asc [m], (Skew 0.1, NB 7-12)-J1, Cycles 344-364, Median: -0.0 m

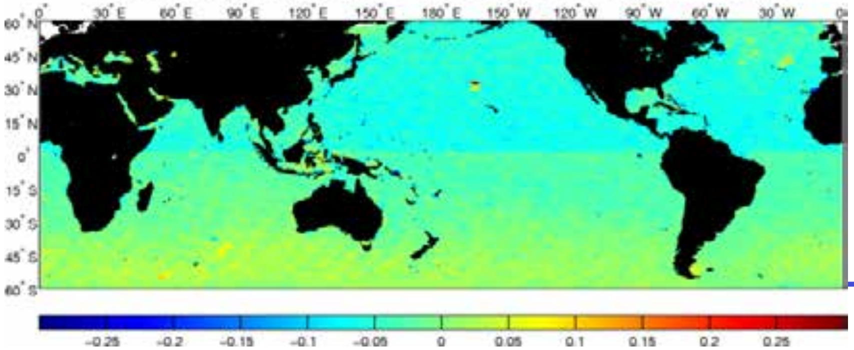


SWH Asc [m], (Skew 0.1, NB 5-7)-J1, Cycles 344-364, Median: -0.0 m

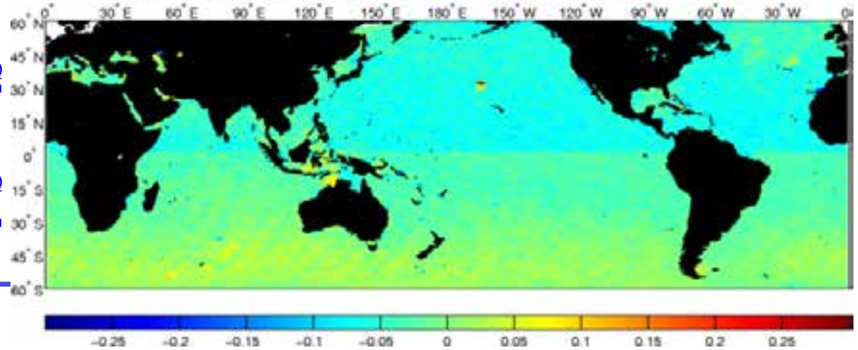


Skew Solve

SWH Asc [m], (Skew Solve, NB 7-12)-J1, Cycles 344-364, Median: -0.0 m



SWH Asc [m], (Skew Solve, NB 5-7)-J1, Cycles 344-364, Median: -0.0 m



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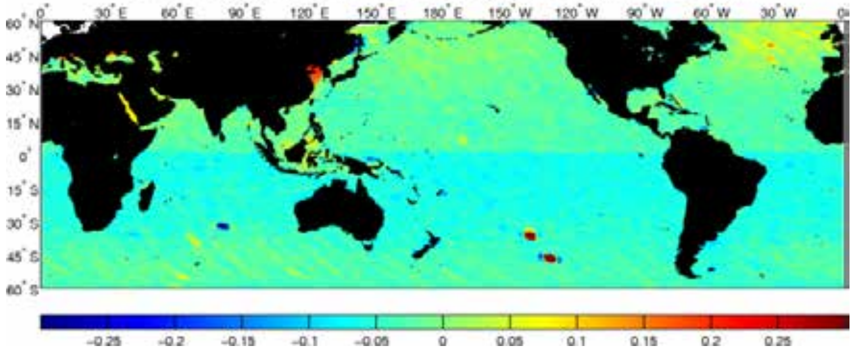
Difference (TPX-J1), SWH Descending, Cycles 344-364

Noise 7-12

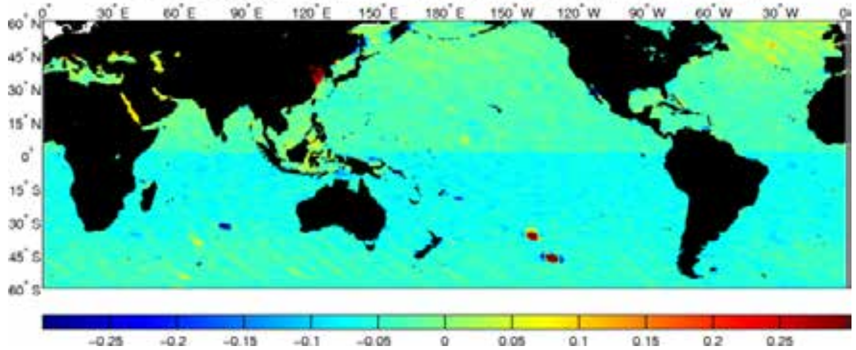
Noise 5-7

Skew 0

SWH Des [m], (Skew 0, NB 7-12)–J1, Cycles 344–364, Median: –0.0 m

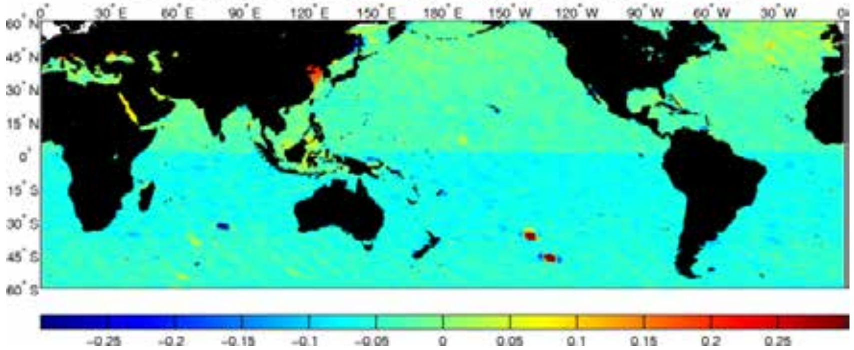


SWH Des [m], (Skew 0, NB 5-7)–J1, Cycles 344–364, Median: –0.0 m

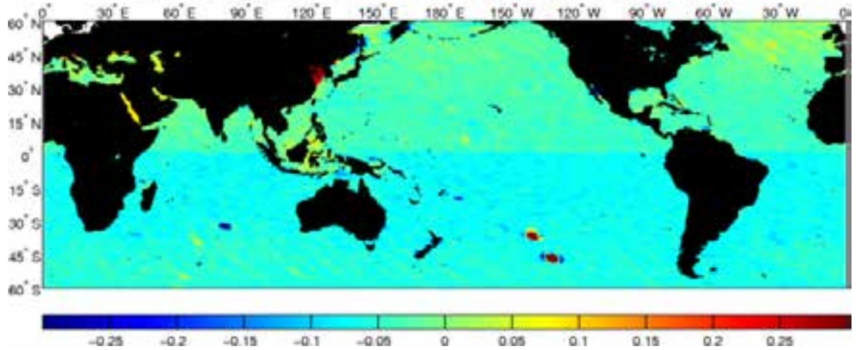


Skew 0.1

SWH Des [m], (Skew 0.1, NB 7-12)–J1, Cycles 344–364, Median: –0.0 m

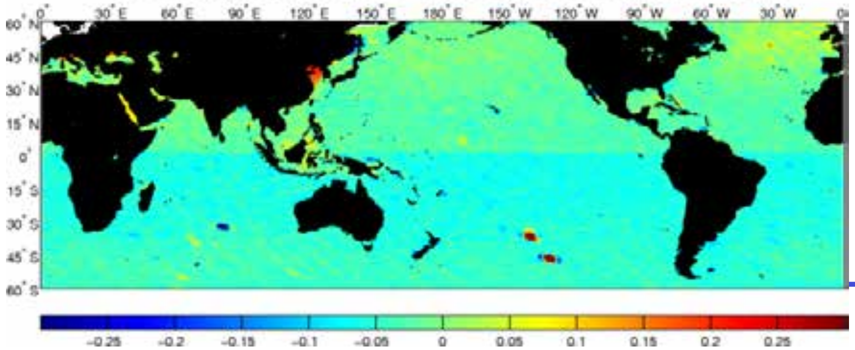


SWH Des [m], (Skew 0.1, NB 5-7)–J1, Cycles 344–364, Median: –0.0 m

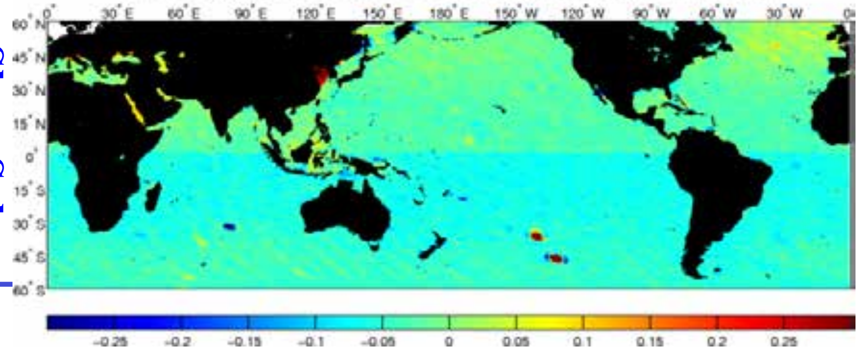


Skew Solve

SWH Des [m], (Skew Solve, NB 7-12)–J1, Cycles 344–364, Median: –0.0 m



SWH Des [m], (Skew Solve, NB 5-7)–J1, Cycles 344–364, Median: –0.0 m



Observations on TOPEX-Jason-1 Differences

- Difference between with/without corrections (but note scale change)
  - Appears to be most like wet tropo – Need to check Radiometer corrections
  - Have obtained latest environmental corrections from CNES for TOPEX for use in final product
- Differences for North/South Ascending/Descending occur for all skewness, both noise estimates
  - Descending SSB-only SSH and Ascending SWH are more sensitive to North/South. Not clear why not symmetric – further investigate leakage effects
  - SSH differences could indicate a timing bias in addition to leakage effect. Not clear if separable.
- Differences between noise bins 7-12 and 5-7 are relatively small
  - ~2-4 mm median SSHA difference
  - Noise 5-7 is somewhat more consistent across skewness types, especially for SWH
  - Noise 5-7 North/South differences somewhat larger (or sensitivity to average SWH)

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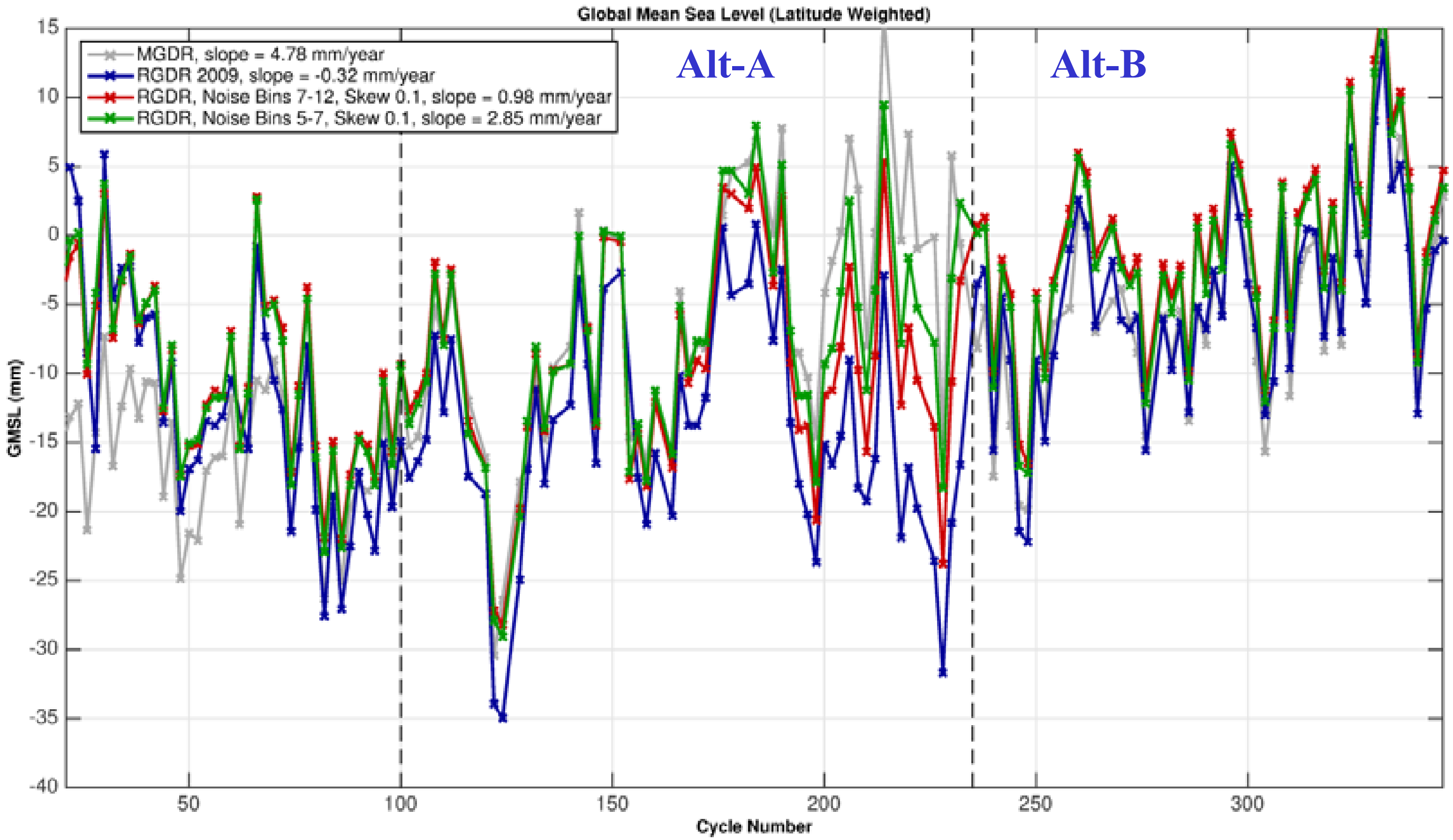
Comparison of Global Mean Sea Level Estimates

- 2009 retracking (blue) used different (empirical) waveform bin weights
- Note divergence of Red (Noise 7-12) – Green (Noise 5-7) curves in latter part of Alt-A: Very similar to WFF Range Calibration (used original GDR waveform weights)



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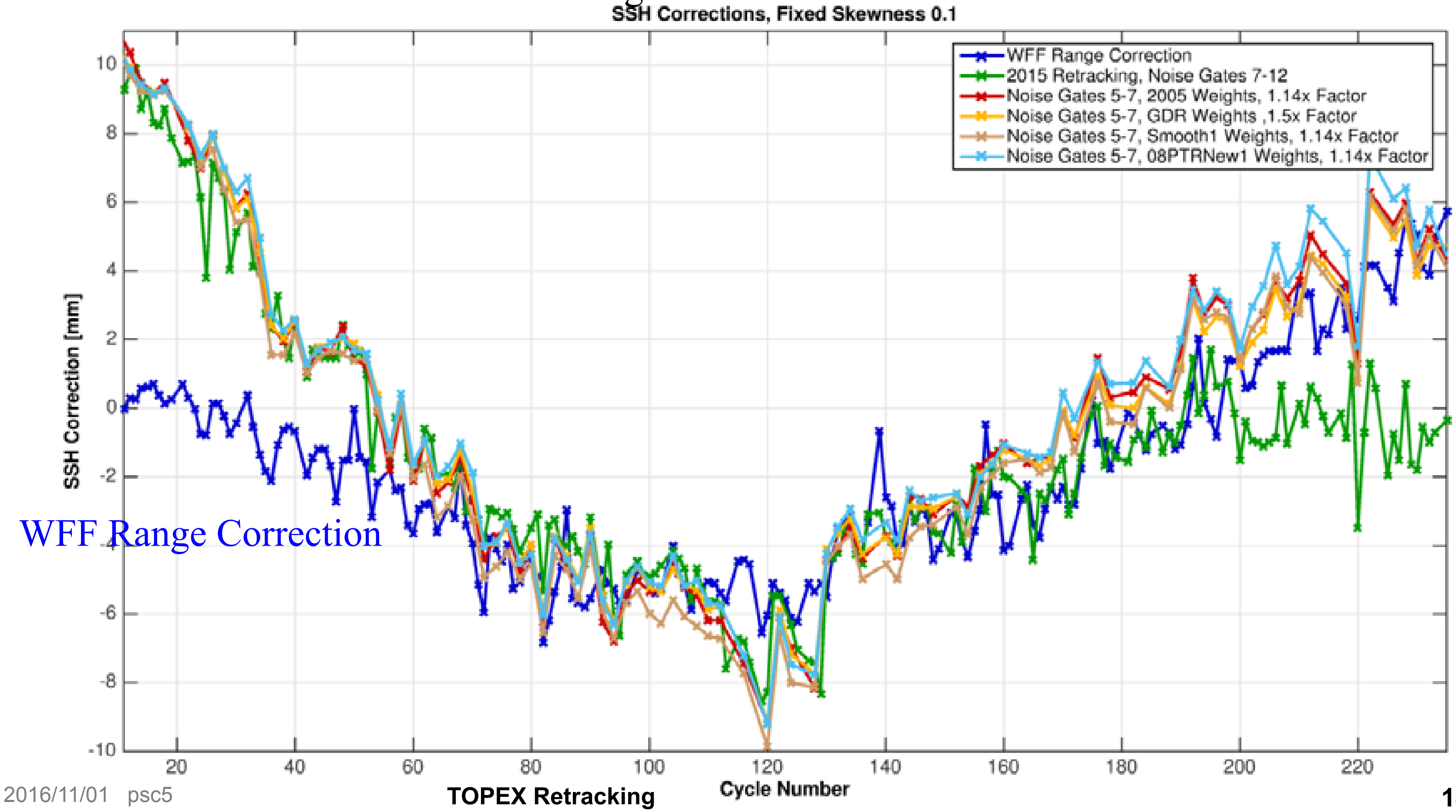
Comparison of Global Mean Sea Level Estimates: Alt-A

- 2015 retracking noise estimation used bins = 7-12 (telemetry bins) (Green)
- Found that Noise estimate using bins 6-7 had too variation (noise), so used bins 5-7
  - Empirically estimated factor to make behavior similar to bins 7-12
  - Tested various waveform weights



TOPEX Retracking

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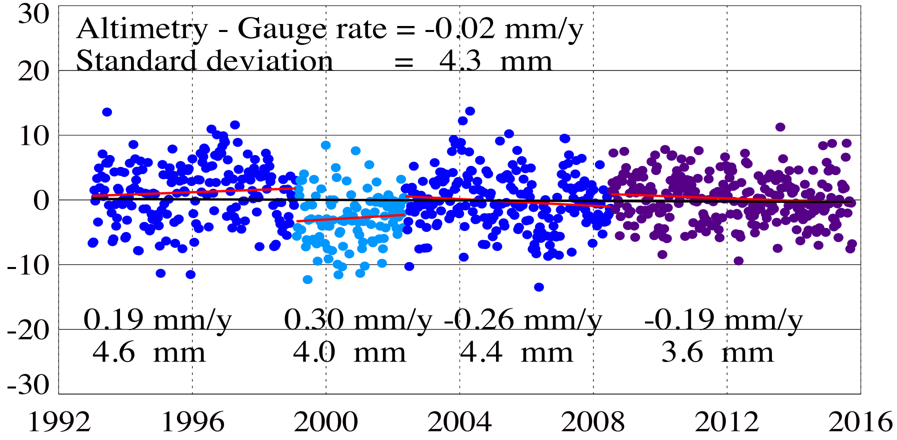
Beckley Comparison of Altimeter and Tide Gauges

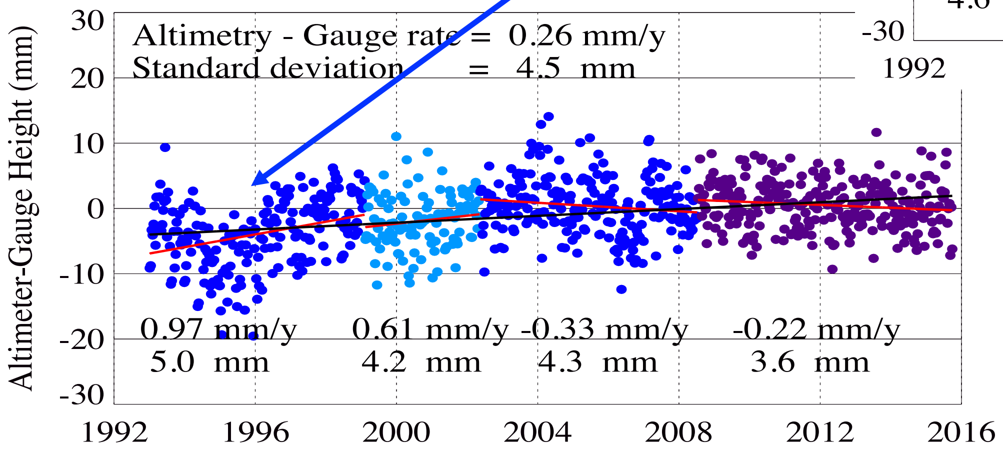
- Beckley et al showing comparison to altimetry to global tide gauge network (this meeting)
- Alt-A with and without WFF Range Calibration seems to be more consistent with overall data set <u>without</u> Cal
  - Without also shows some bias between Alt-A/Alt-B

WFF Cal1-mode Not applied to both Side A & B



See Beckley et al for the Exciting conclusion !

WFF Cal1-mode applied to both Side A & B
Cal signature shows clearly



Conclusions

- Systematic retracking gives stable results using
  - Original WFF/GDR waveform weights
  - PTRs fit to Cal-1 data for +/-6 lobes extended to +/-30 lobes consistent with +/-6
  - Noise bins 5-7 slightly scaled
  - Fixed skewness of 0.1
- WFF Range Calibration appears to give a signature relative to tide gauge calibration (Beckley et al)
- Differences for North/South Ascending/Descending occur for all skewness, both noise estimates
- Effects to be investigated
  - North/South Ascending/Descending effects are not symmetric
  - TMR vs JMR wet tropo
- Work to go for final climate data records
  - Update format to Jason ver E
  - Apply new environmental corrections supplied by CNES
  - Refit SSB

Backup Material

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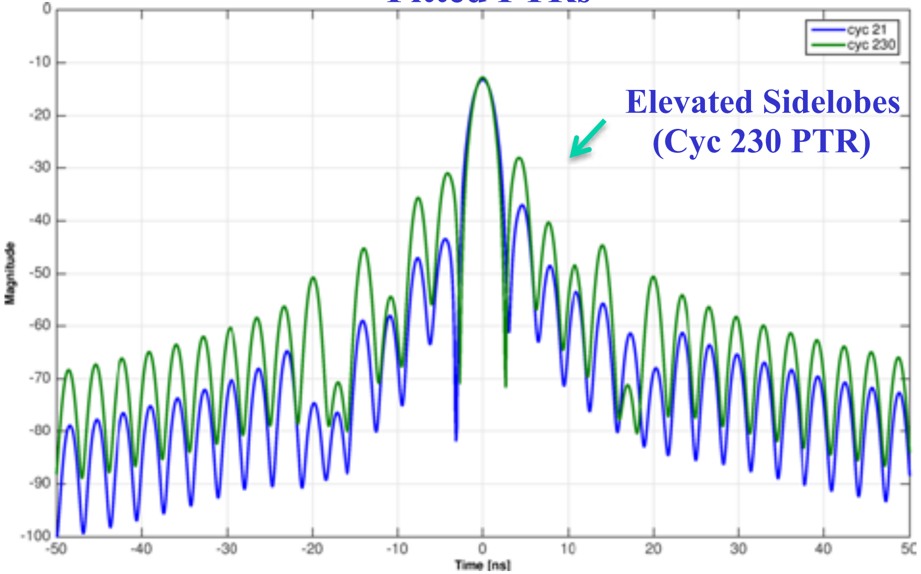
Simulated Waveform Return from Broadened PTR

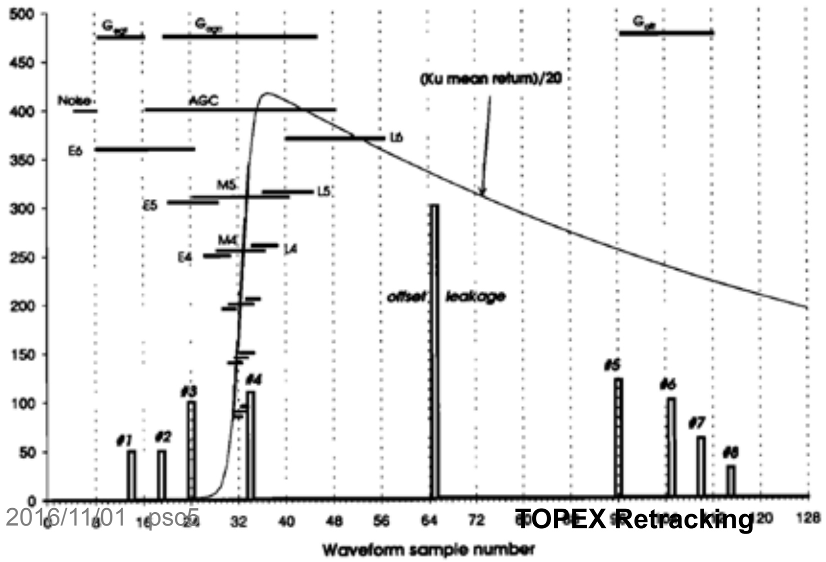
Joe McMichael, JPL

Fitted PTRs

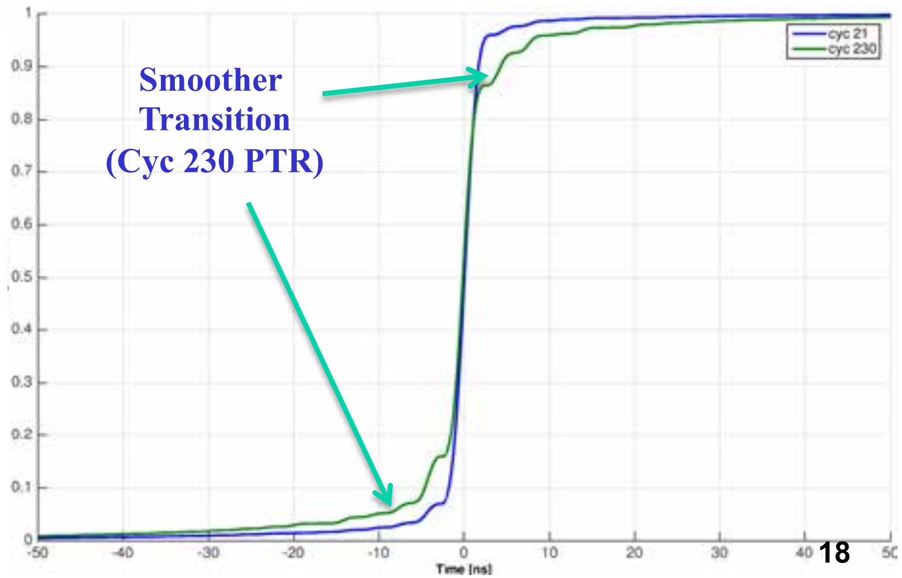


- PTR energy leaks from main lobe to sidelobes at the end of Alt-A
- As a result, the ocean backscatter waveform has an artificially smoothed transition from low to high
- Noise estimate is contaminated by signal energy from spread PTR

TOPEX Waveform Diagram



Simulated Ocean Backscatter Return



TOPEX Data Conclusions

- Waveform leakages cannot be directly corrected. Could not determine from on-orbit data (low wave height, low range rate)
  - **Lesson:** Checkout the test data. WF “teeth” corrected by weights.
- Point Target Response (PTR) changes can be determined from Cal-1 data to correct Alt-A changes
  - All versions of retracking correct Alt-A SWH for PTR change
  - No obvious changes in Alt-B data
- Range Calibration data are not well understood and contribute to sea level signal
  - **Lesson:** Calibration process should be part of algorithm development, open, widely understood
- Retracked data show different SWH behavior than Jason-1, but Alt-B is more similar than MGDR (Vandemark, Feng analysis)
  - Separate SSB corrections bring data into agreement
- One year is barely long enough average to get SSB. Observed interannual variations in SSB.

2015: TOPEX RGDR, Skew 0.1 - Jason 1

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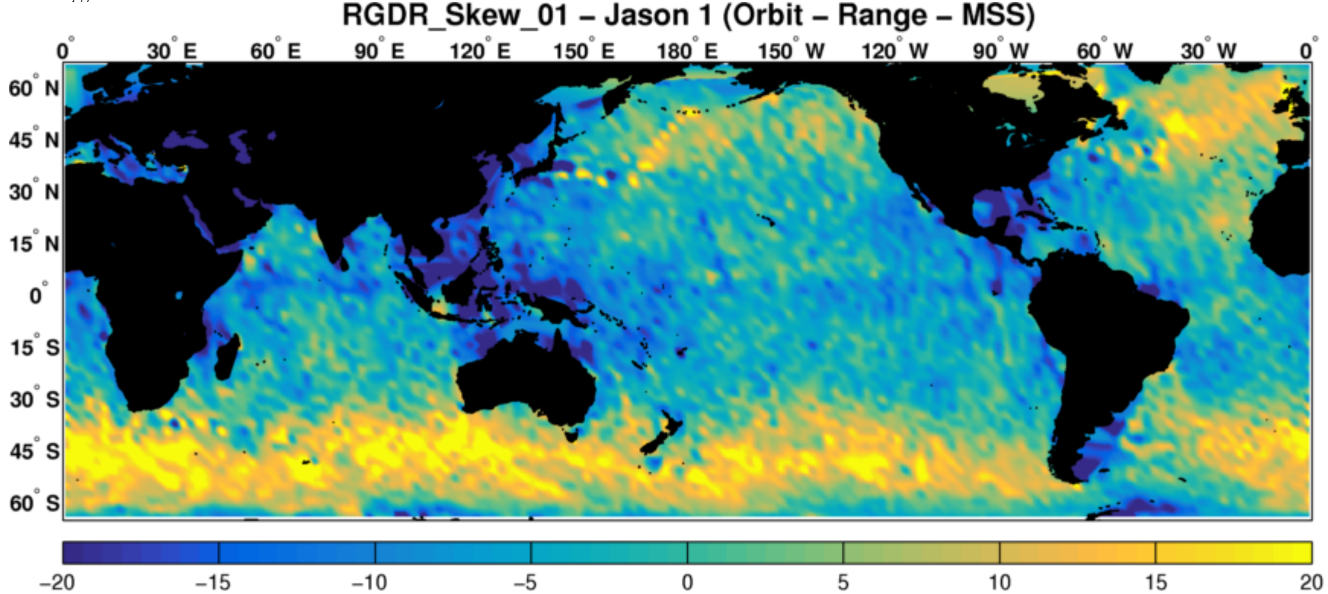
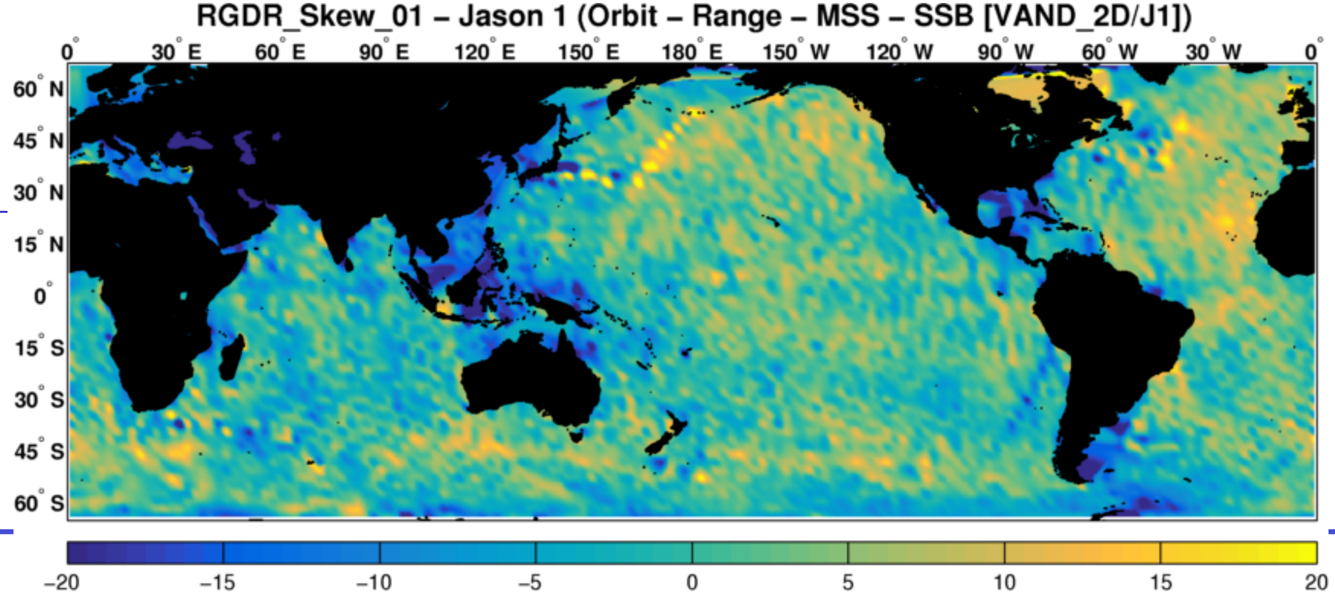
Orbit – Range – MSS



Bias removed: -56 mm

Orbit – Range – MSS – SSB



Bias removed: -82 mm

2015: TOPEX RGDR, Skew Solve - Jason 1

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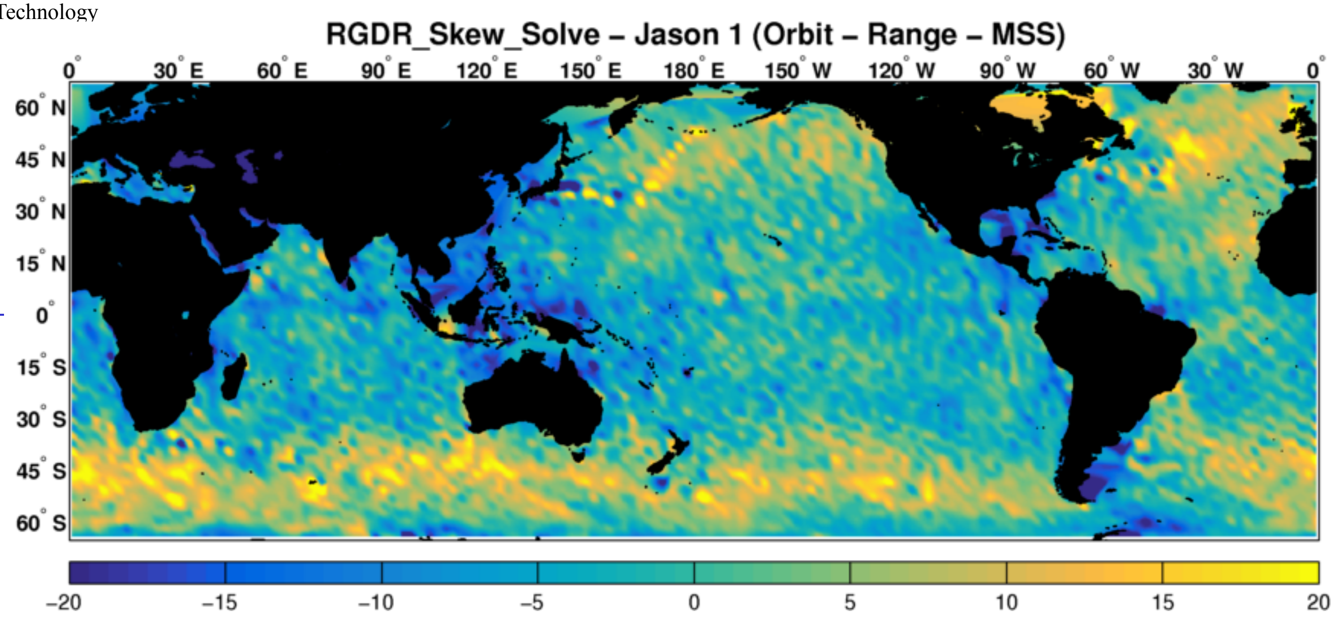
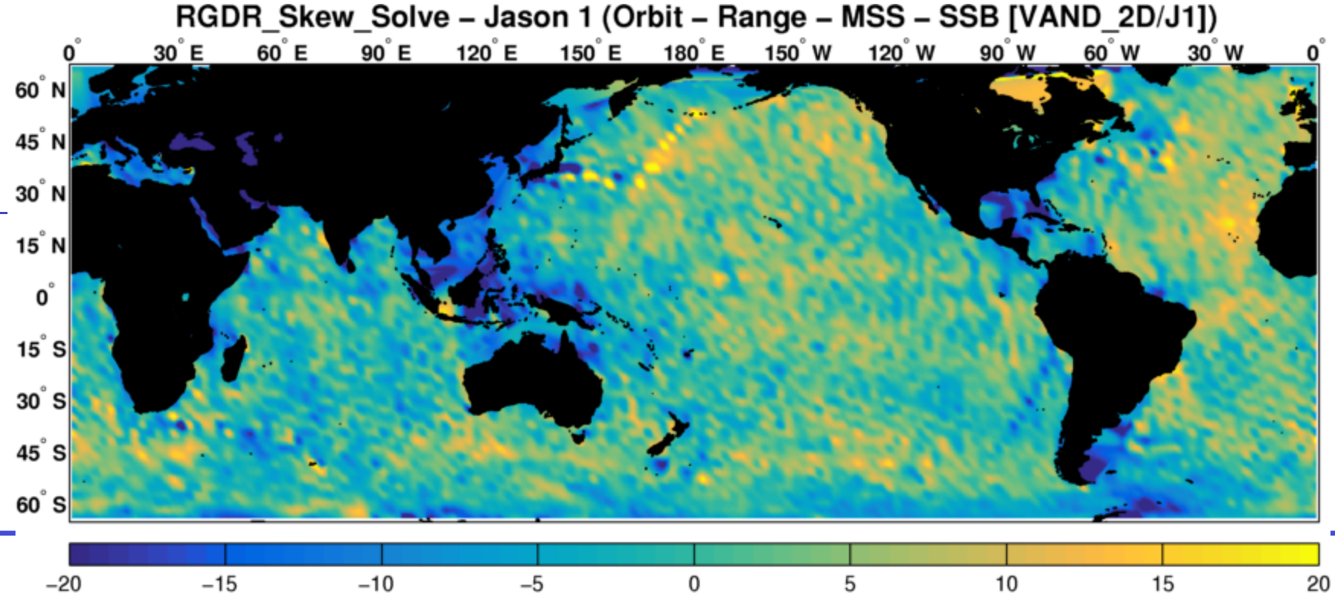
Orbit – Range – MSS



Bias removed: -62 mm

Orbit – Range – MSS – SSB



Bias removed: -85 mm

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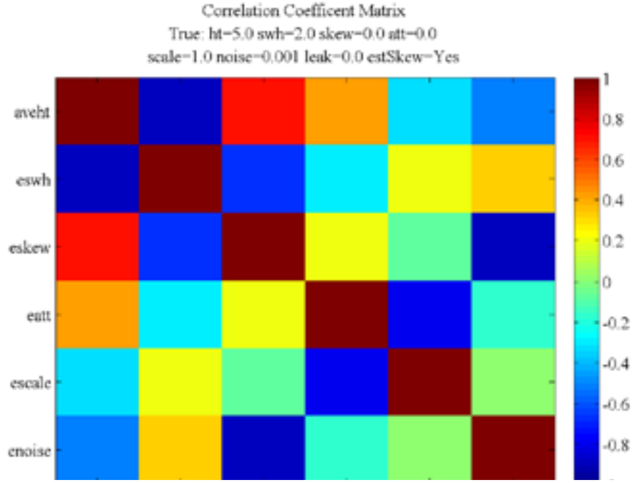
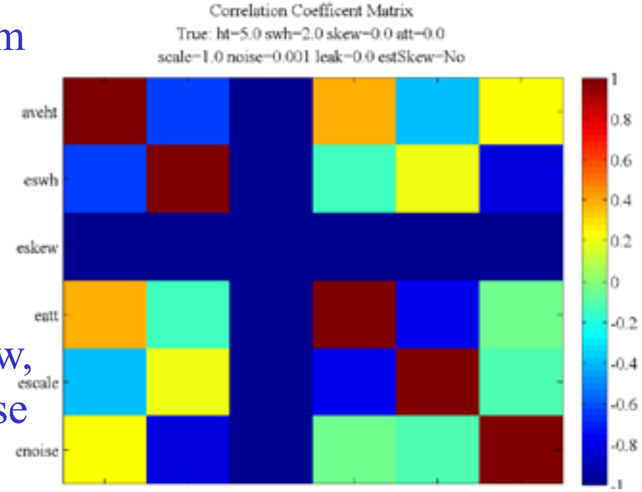
Simulation Results

Parameter Correlation Solving for Skewness

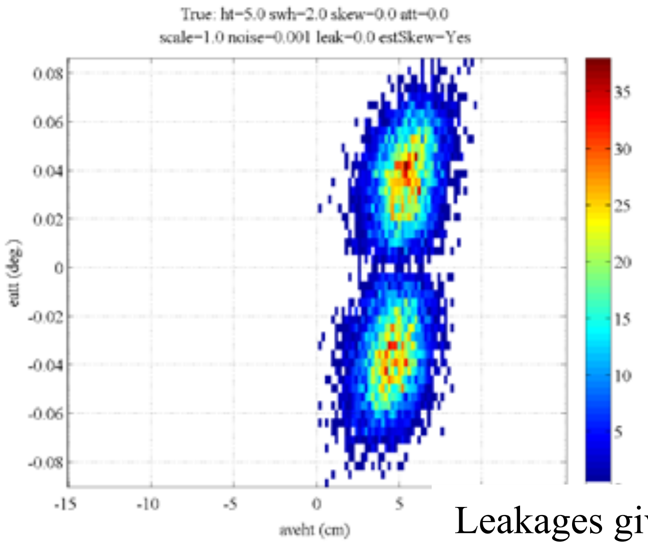


Parameter Correlation Not Solving for Skewness



All: SWH = 2 m
Att = 0
Skew = 0
dH = 5 cm

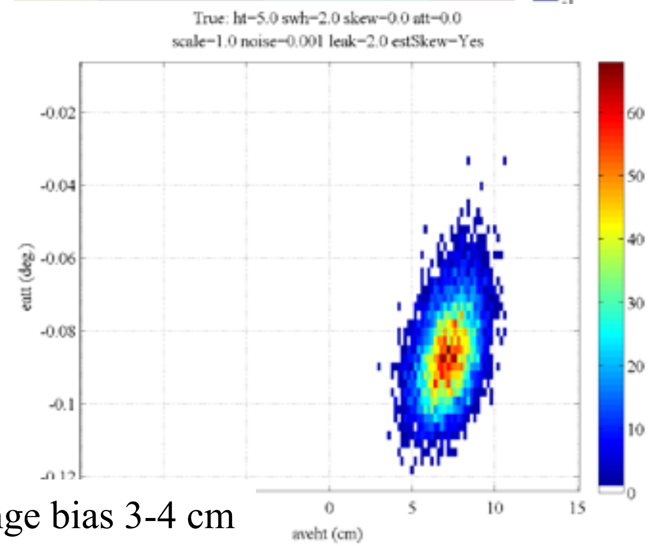
Parameters:
dH, SWH, Skew,
Att, Scale, Noise



← Leakage = 0

Leakage = 2X
→

2D Histogram:
Att / dH



Leakages give Att2 bias ~ 0.09, Range bias 3-4 cm

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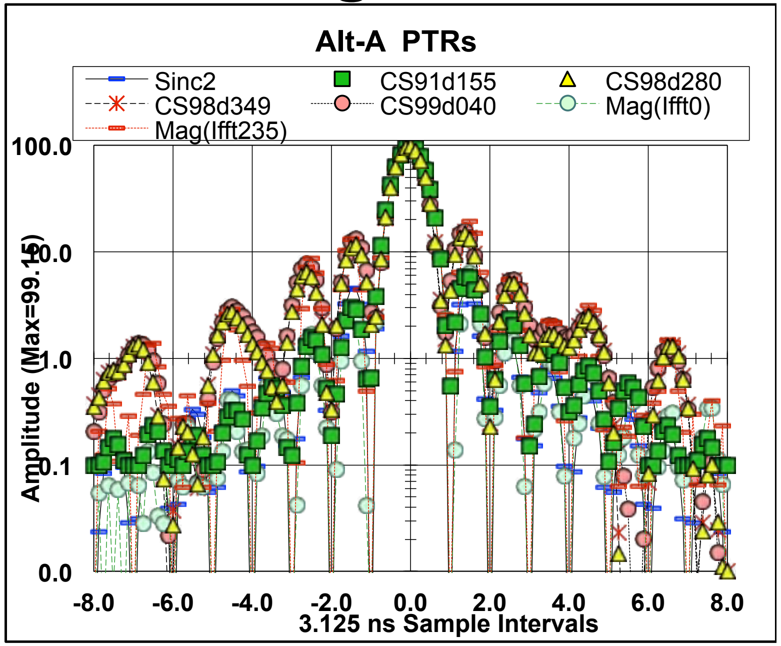
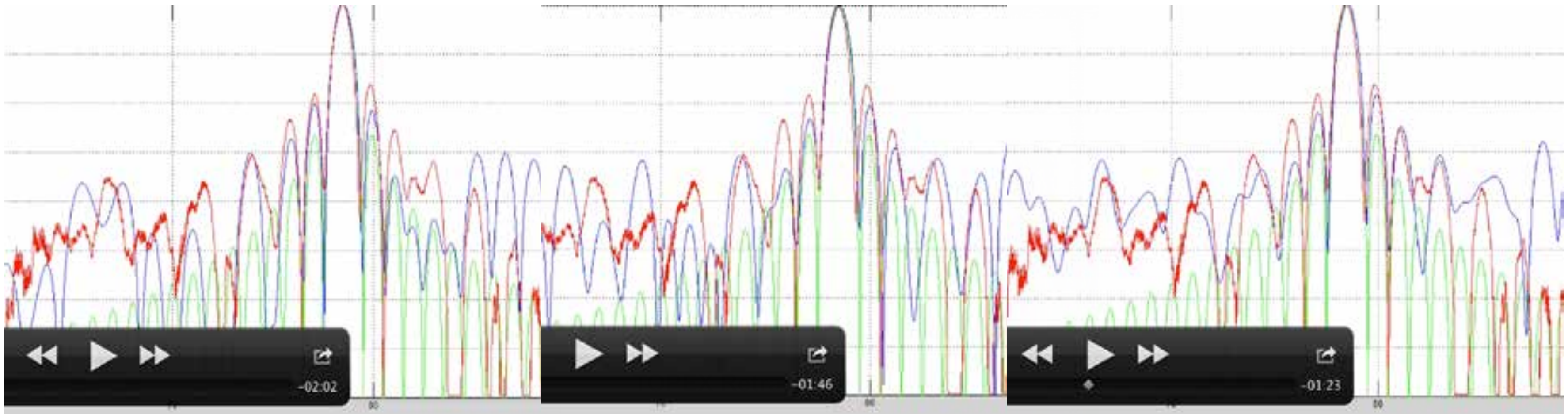
TOPEX Alt-A PTR Changes



- TOPEX Alt-A PTR degradation – increase and distortion of sidelobes likely caused by I/Q phase difference (Jensen analysis)
  - "Cal Sweeps" done only late in 1998
- Reproduced Jensen analysis
  - Effect depends on center location. Figures below show I/Q phase diff 18 deg, 3 different center locations
  - Observations and previous simulations by G. Hayne indicate that effect is not as large as suggested by model ➔ Modeling is not adequate to generate PTRs.



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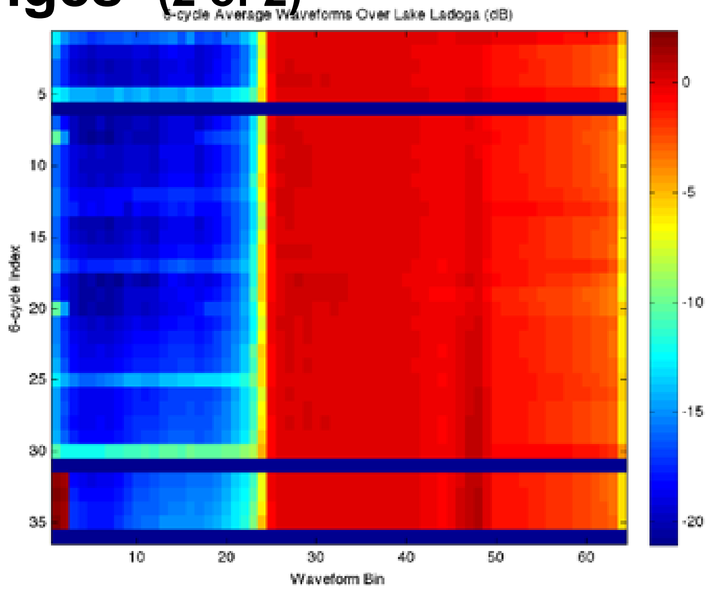
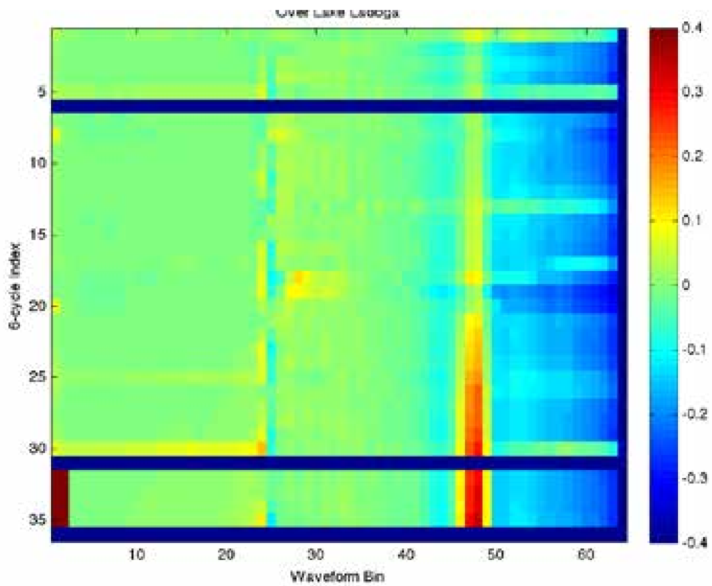
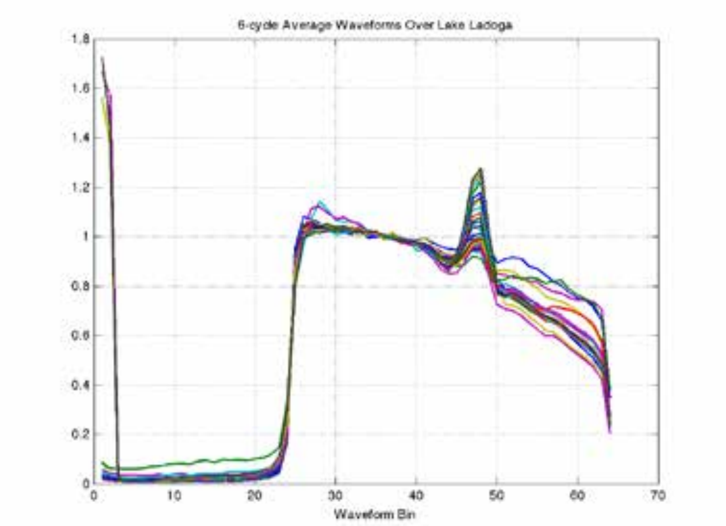
TOPEX Alt-A PTR Changes (2 of 2)

- Investigated changes in the PTR by using data over Lake Ladoga in western Russia. 6 Cycle averages of waveform
  - Below: Line plot – "zero frequency" leakage is prominent
  - Upper Right: Full waveform
  - Lower Right: Difference from first



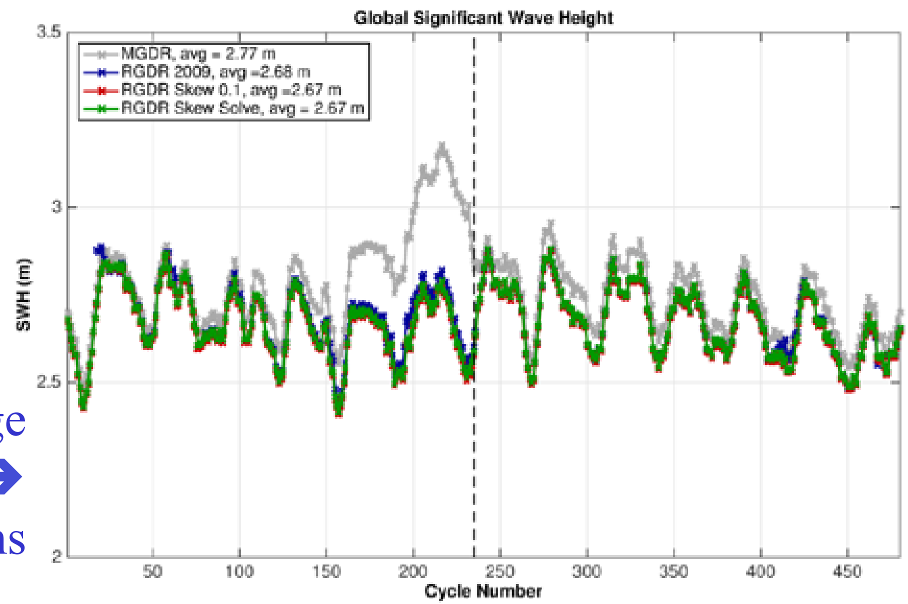




TOPEX Retracking Overview / History

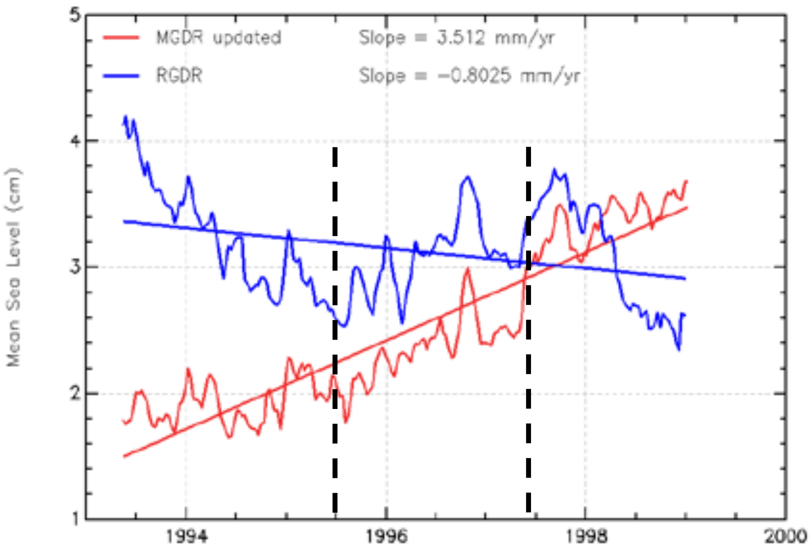
- TOPEX standard processing did not include retracking
- Alt-A had changes in Point Target Response (PTR) beginning about Cycle 140 (mid-1996)
  - Changes became clear in 1997 as apparent increase in SWH
  - Switch to Alt-B in Feb 1999 (Cyc 236). No apparent changes in Alt-B
- Previous versions of retracking in 2007, 2009
  - 2007 used original WFF waveform (WF) weights/gains, hand fit PTRs
  - 2009 used refit WF weights, systematically fit PTRs to Cal-1 data to 10 lobes
  - Analysis by Labroue '09 showed that 2007 agreed with MSL trend and improved agreement with Jason-1, while 2009 caused negative MSL trend and SSB was similar to original MGDR and rather different than that for Jason-1

Correction of SWH change from Retracking ➔ Similar in all versions

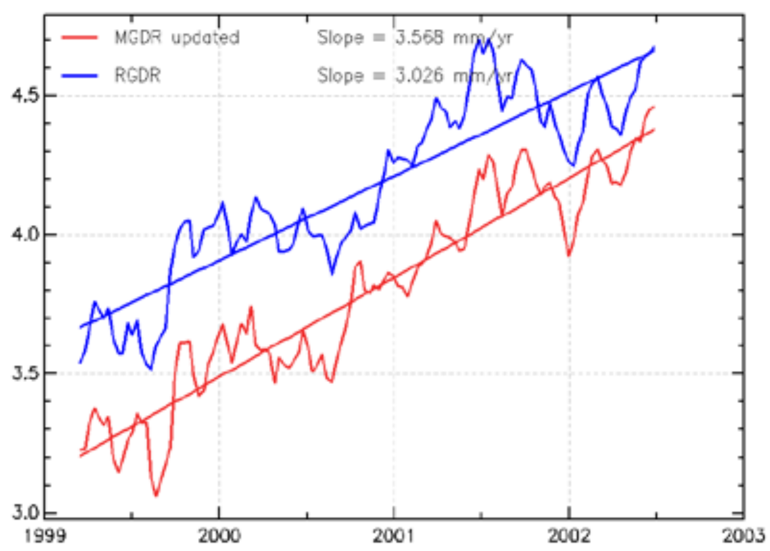


Mean Sea Level Analysis by S. Labroue (CNES) '09 OSTST

Side A MSL



Side B MSL



• Side A MSL with RDGR shows strong discrepancy with respect to MGDR MSL. RGDR exhibits a false curve and trend (-0.8 mm/year!!!!). The main differences appear at the beginning and the end of the time series.

• Side B MSL with RGDR data presents a trend lowered by 0.55 mm/year which is significant for MSL studies. We are more confident in MGDR MSL since side B is very stable (validated against in situ data and Jason-1 data)

Careful assessment of the PTR correction needs to be performed on the SSH (including PTR corrections on range and SWH (through SSB)). A SSB has been estimated on RGDR products for each altimeter.

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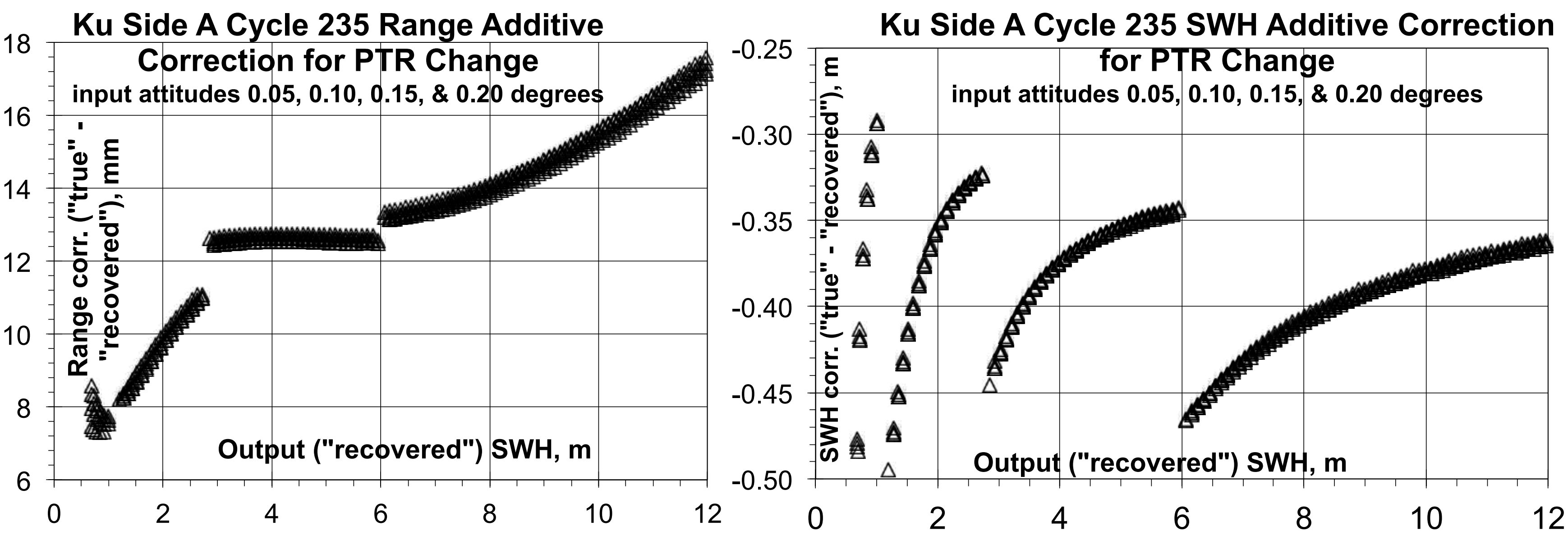
Alt-A PTR Change Simulation

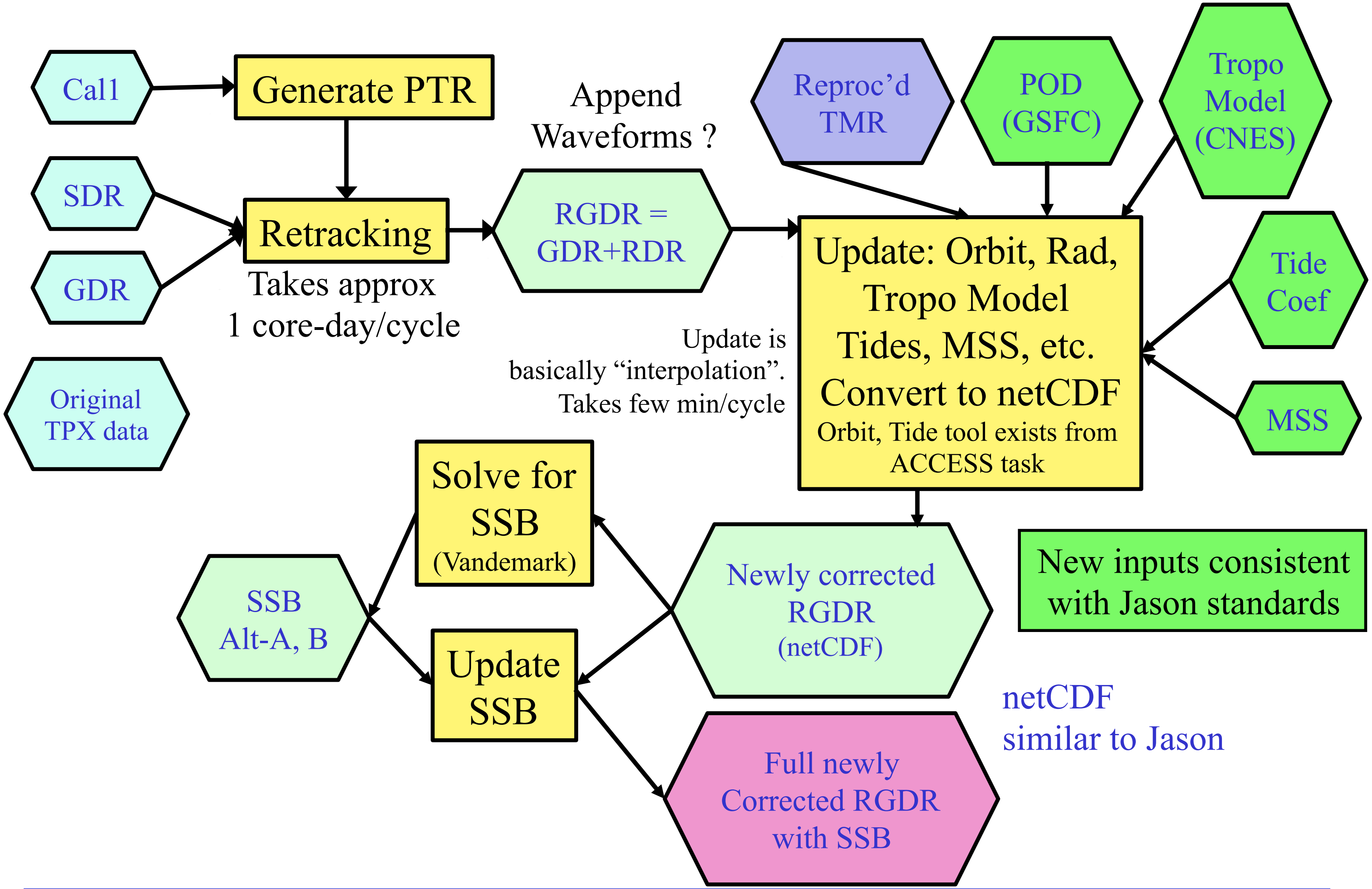
Simulation by G. Hayne (WFF) of change in Range and SWH as a function of SWH for PTR of Cycle 235 (discontinuities reflect internal altimeter function – change in adaptive gate widths).
Left: Range error of ~ 8-13 mm for typical SWH of 1.5 – 6 m.
Right: SWH error of ~ 0.4 m as observed (slide 4).
The change in apparent altimeter SWH will also change the calculated Sea State Bias correction.



TOPEX Climate Data Records

- TOPEX RGDR as similar as possible to Jason ver_E
  - NetCDF similar to Jason
  - Copy of original GDR
  - Retracking values for range, SWH, attitude
  - New GSFC orbits
  - New tide model GOT4.10C
  - Improved long period non-equilibrium tides
  - Updated MSS
  - Reprocessed TMR data (Shannon Brown: improved calibration, coastal resolution)
  - Corrected sigma0 properly for WFF determined changes
  - SSB fitted to Retracked Data by Doug Vandemark
  - New dry tropo correction and associated MOG2D values

TOPEX CDR Processing Flow



Three Generations of Retracking

- 1st Generation retracking (Rodriguez and Martin, JGR 94):
  - Decomposition of the PTR into sum of Gaussians
  - Arbitrary attitude angle (expansion to higher order terms)
  - Linearized least squares estimation, including Skewness
  - ➔10/frame range, 1/frame other parameters
- 2nd Generation retracking (Callahan and Rodriguez, MG 04)
  - Added iterative estimation of parameters until retracker fully converged
- 3rd Generation retracking: Maximum *a Posteriori* (MAP)
  - 1st and 2nd generation retrackers operated on 1 second frames without constraints
  - Retracker unbiased, but noisy and retrieved parameters could be highly correlated
  - MAP estimation constrains the parameter space for the inversion using *a priori* knowledge (data are still estimated from 1 sec frames)
    - Attitude varies slowly, SWH correlation distance ~100 km and known to better than 60cm, Track Point known to better than 20 cm, |skewness|<1