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California Institute
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Progress on Retracked TOPEX Data for the Climate Data Record

OSTST October 2017
Miami, Florida

Phil Callahan on behalf of the
TOPEX Reprocessing Team

Jet Propulsion Laboratory
California Institute of Technology

Outline / Overview

- A Brief History of TOPEX Altimeter Issues
  - Waveform Leakages
  - Waveform Weights (not shown)
  - Alt-A PTR Changes and Cal Data
  - Noise Bins
  - WFF Range Calibration (internal Cal-1)

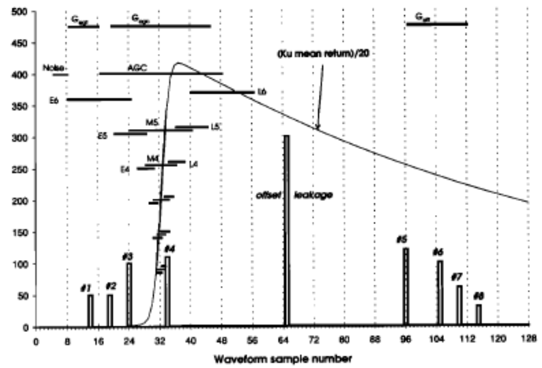

Figure 6. TOPEX Ku altimeter gates, mean return, and center locations of waveform leakage spikes.

- Revised Plan to create new RGDR with retracking corrections
  - Restart with original SDR, GDR. Recompute some items.
  - Update format to be more compatible with Jason-2 Ver E, including 20Hz range from SDR
  - Use latest POE from GSFC (ITRF2014), new environmental corrections & geophysical fields from CNES, reprocessed TMR data
  - Update Sea State Bias for revised data

- Investigations to be done
  - Ku, C –band PTR comparisons
  - Oscillator Drift Correction from Time Correlation Data
  - Sigma0 calibration to ECMWF wind speeds
  - 59 day Variations
  - Comparisons to Jason-1 during collinear phase

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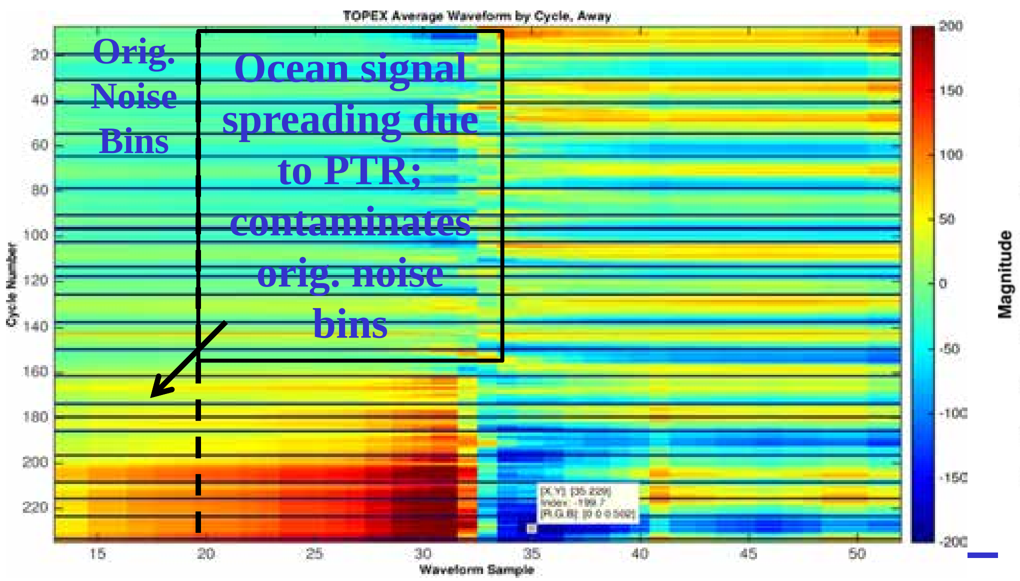
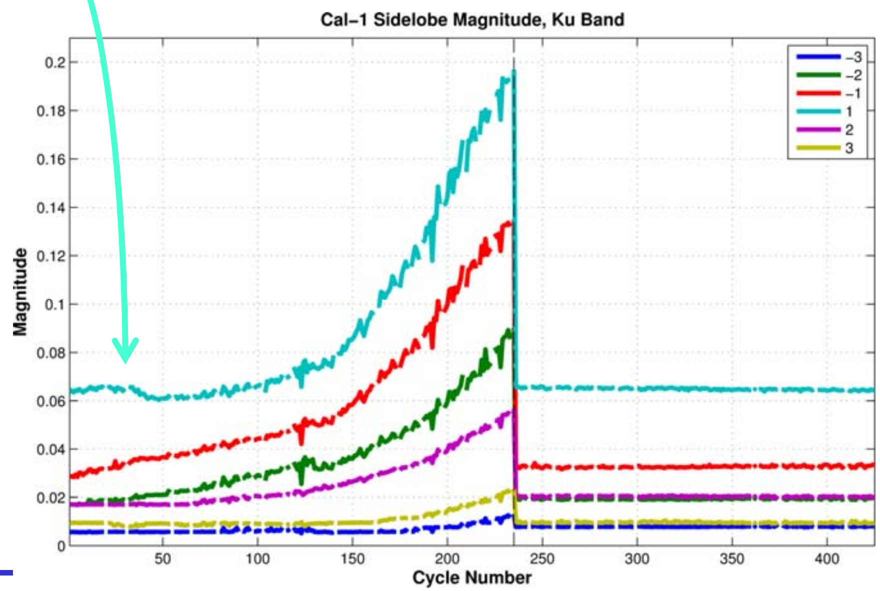
TOPEX History – Alt-A PTR Changes

- 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 good retracking consistent with PTR changes (increase in sidelobes, asymmetry for +/- sidelobes, missing lobes caused by increasing phase imbalance)
- 2016: 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





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.

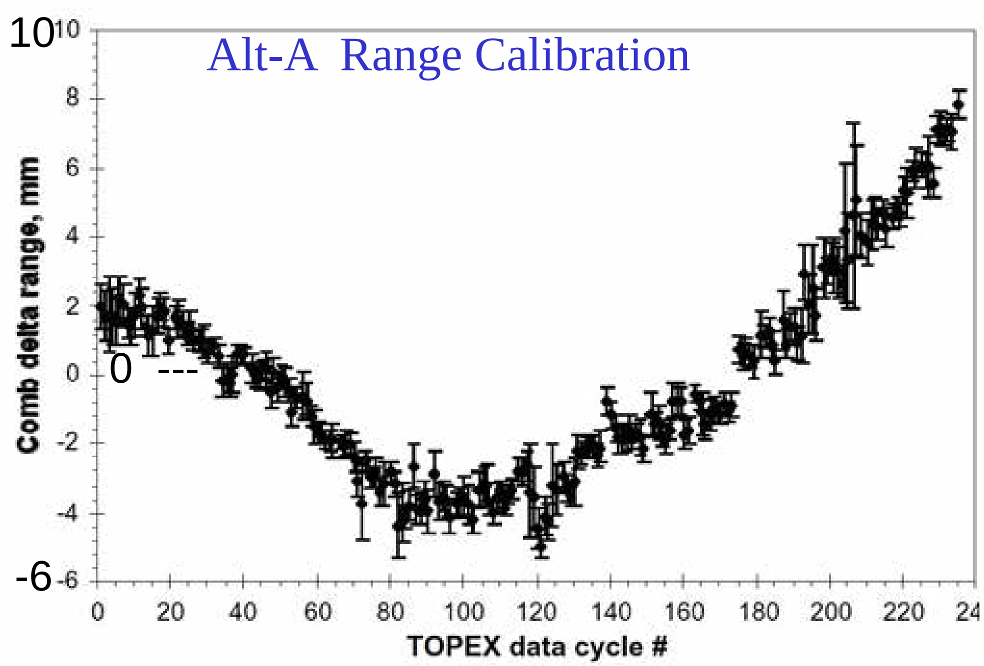


Figure 3-2 Combined (Ku & C) Delta Range vs. Cycle - With UCFM Temperature Correction

Slope of Alt-A Range Calibration 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 determined mm level values.

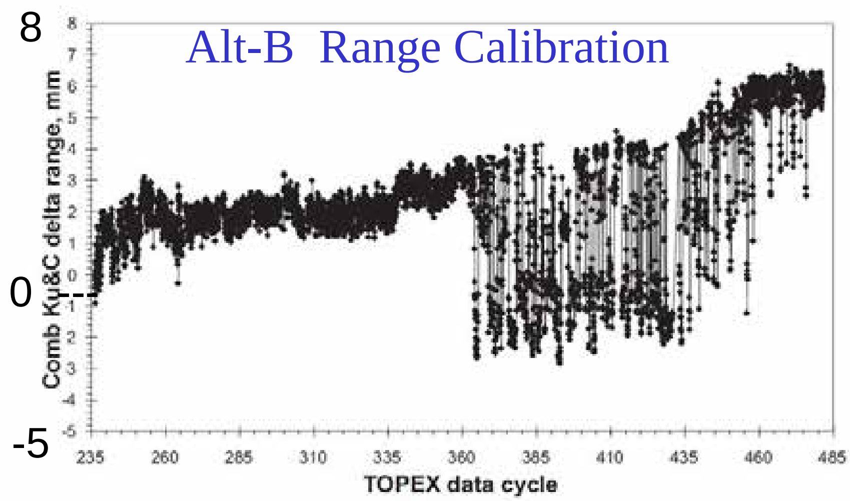


Figure 3-7 Side B CAL1 Step-5 Combined dRange vs. Cycle after Correction for Receiver AGC Temperature

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Beckley Comparison of Altimeter and Tide Gauges

2017 Results Accepted for publication

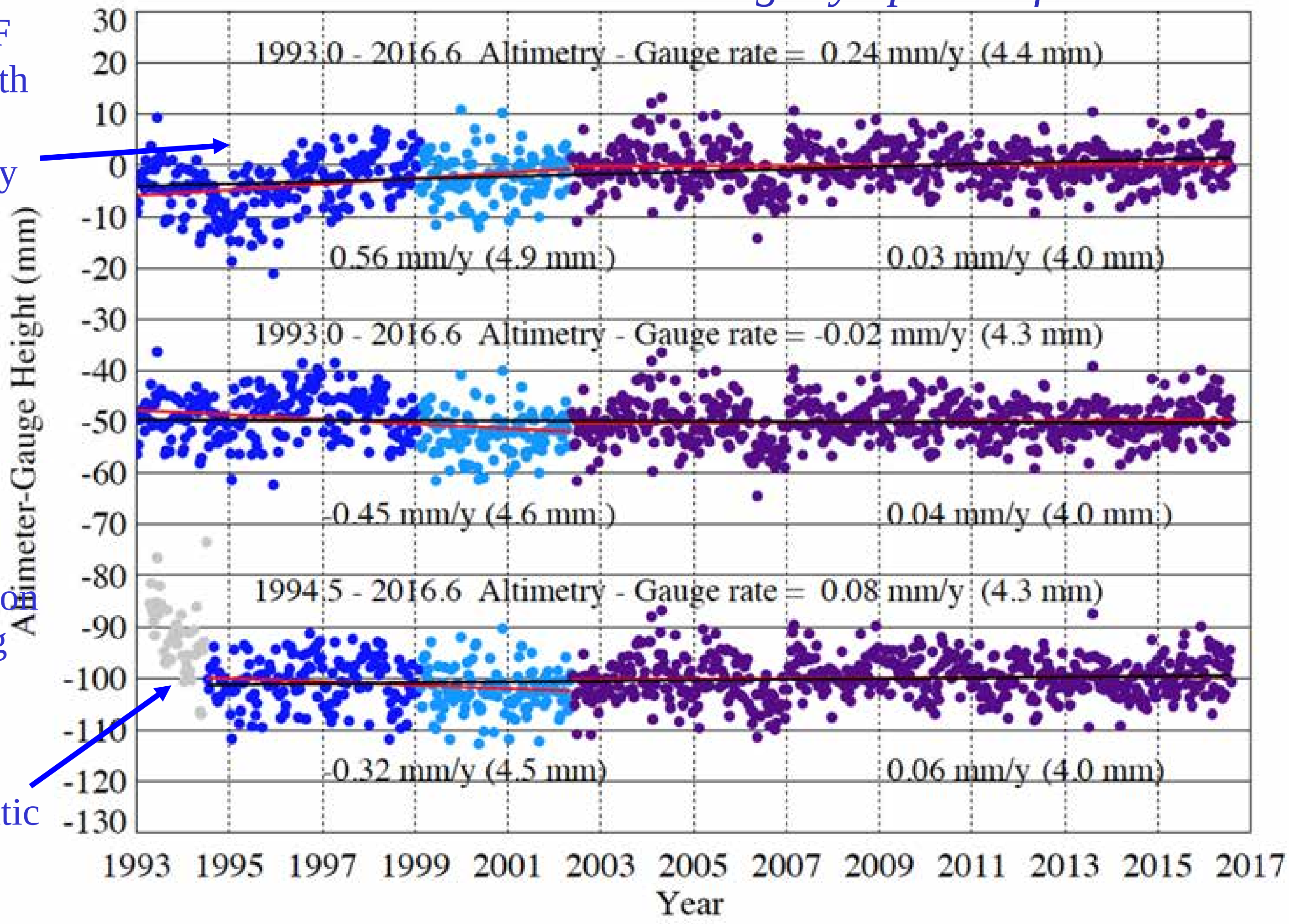
- Beckley et al comparison of altimetry to global tide gauge network (2016 and accepted paper)
- Alt-A without WFF Range Calibration but with retracking seems to be more consistent with overall data set
  - Without Cal shows some bias between Alt-A/Alt-B

Results slightly updated from 2016

MEaSURES v3.2. WFF Cal1-mode applied to both Side A & B
Cal signature shows clearly

MEaSURES v3.2. WFF Cal1-mode Not applied to both Side A & B

- TOPEX data retracked (version Aug, 2016)
- WFF cal1-mode correction Not applied in retracking process. No external "calibration" A/B bias applied
- First 50 cycles problematic



2016 Conclusions and Work to Go

- Systematic retracking gives stable results using
  - Original WFF/GDR waveform weights
  - PTRs fit to Cal-1 data for +/-6 lobes and extended to +/-30 lobes with sinc2 consistent with separate levels of +/-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
  - Ku, C –band PTR comparisons
  - Oscillator Drift Correction from Time Correlation Data
  - Sigma0 calibration
  - North/South Ascending/Descending effects are not symmetric
  - TMR vs JMR wet tropo
  - Cos(beta_prime) (59 day) variations

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New TOPEX RGDR Plan

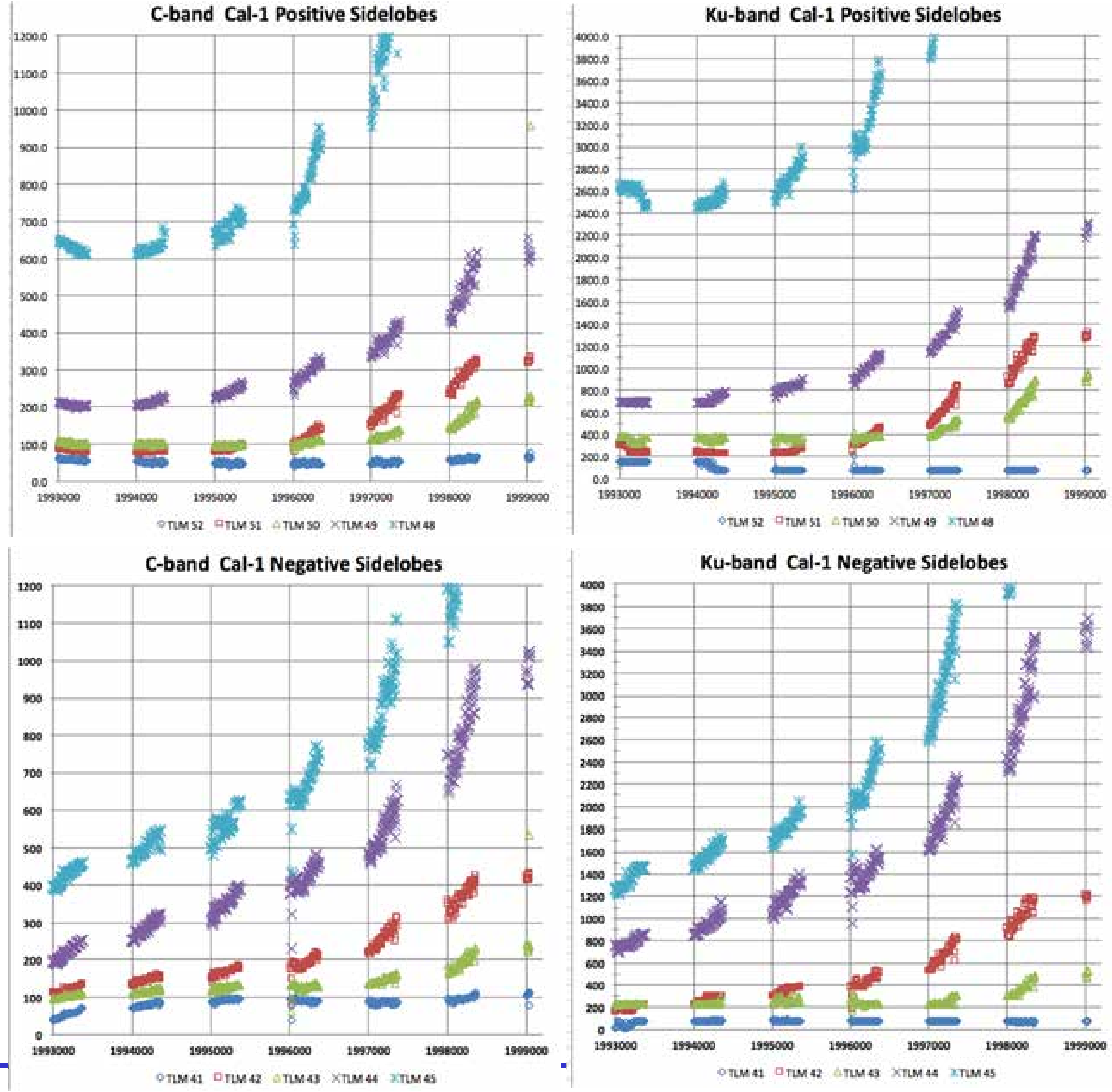
- Use original SDR, GDR
  - Search for missing cycles, pass data to make record as complete as possible. Both SDR and GDR are needed in retracking.
- Revisit Retracking code, process
  - Investigate use of same PTR for Ku, C
  - Validate with simulations
- Include additional parameters on record
  - 20Hz Range at both Ku, C as available on SDR. With time tags, locations. (Corrections still at 1 Hz)
  - Key parameters for both original GDR and Retracked
- Regenerate some corrections, flags
  - Oscillator drift from long term fit (TBD)
  - Doppler shift and acceleration corrections (TBD from orbit or altimeter data)
  - Rain, ice flags with Jason-like algorithms
- Use latest POE from GSFC (ITRF2014), new environmental corrections & geophysical fields from CNES, reprocessed TMR data
- Refit SSB with all above improvements
- Update format to Jason ver E

Investigations

- Oscillator Drift Correction
  - Original processing used piecewise oscillator frequency from time correlation data
    - Investigate differences for long-term fit
    - Possible source of 59-day variations
- Sigma0 Calibration
  - Original processing used piecewise calibration estimate from WFF
    - Various update products have used WFF long-term fit to apparent drift
    - Some datasets have/had erroneous jump at cycle 132. (Corrected on MGDR-B)
  - Check that trend-calibrated sigma0, corrected SWH give wind speeds that agree with ECMWF ERA
  - Review relation of empirical calibration to Cal-1 data and retrack amplitude
- 59 day Variations
- Comparisons to Jason-1 during collinear phase

Investigation: Use Separate Ku, C PTRs

- Most previous processing used same PTR for Ku and C bands
  - Most components that caused PTR change were common to Ku, C chains
  - Ku Cal-1 data had much better signal to noise
- Checks of same/different PTRs
  - Review of Cal-1 data
  - Ku, C SWH similar; Alt-A changes properly corrected



Backup Material

Beckley Comparison of Altimeter and Tide Gauges

2016 Results

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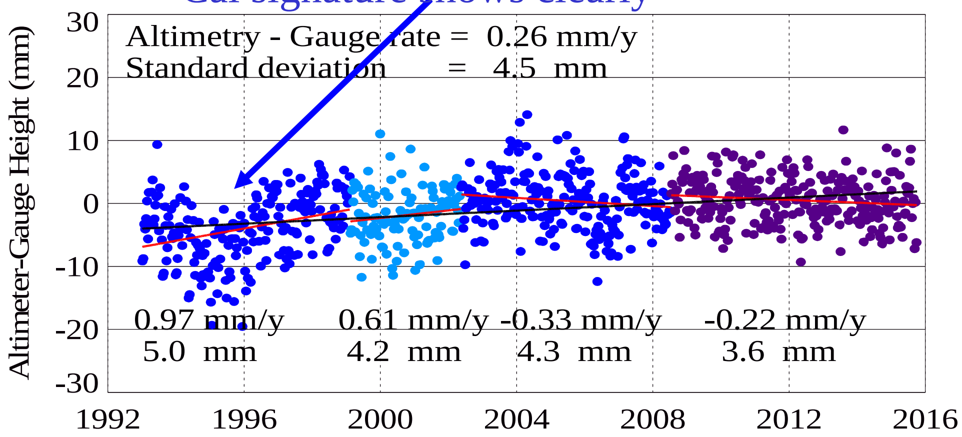
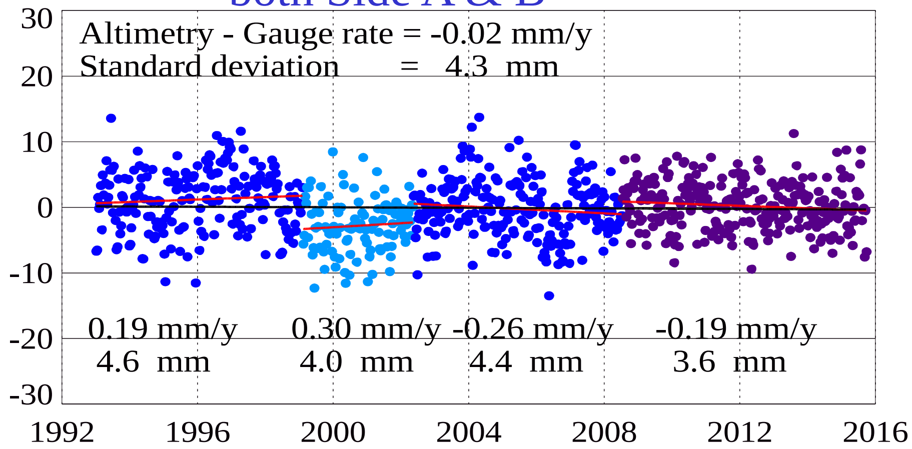
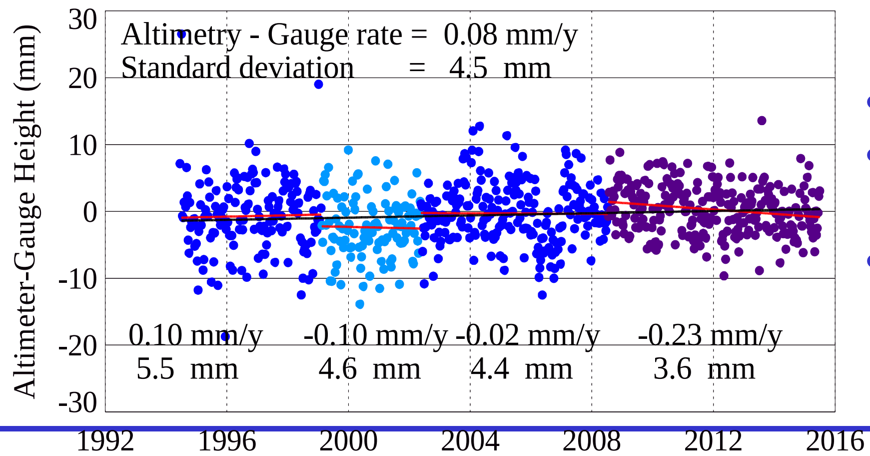
- Beckley et al comparison of altimetry to global tide gauge network (2016 and accepted paper)
- Alt-A without WFF Range Calibration but with retracking seems to be more consistent with overall data set
  - Without Cal shows some bias between Alt-A/Alt-B

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



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





- TOPEX data retracked (version Aug, 2016)
- WFF cal1-mode correction not applied in retracking process
- No external “calibration” A/B bias applied

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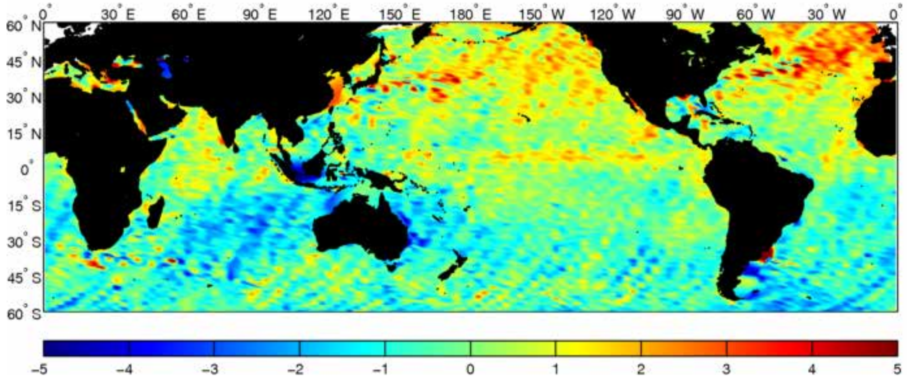
Difference (TPX-J1), SSHA Ascending, Cycles 344-364

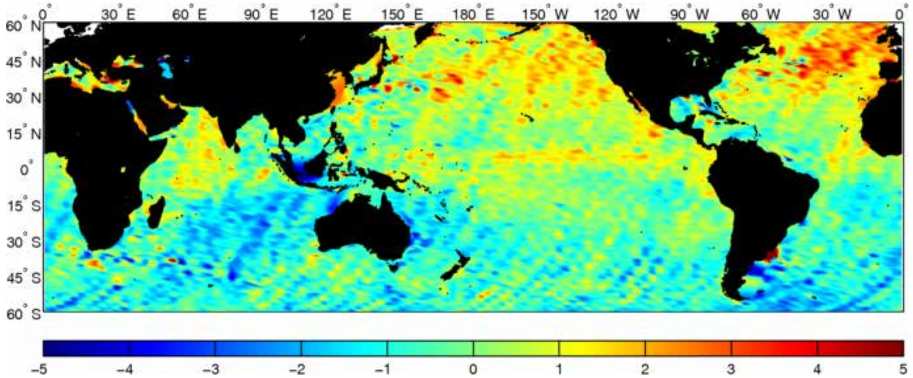
Noise 7-12 | Noise 5-7

Skew 0

SSHA Asc [cm], (Skew 0, NB 7–12)–J1, Cycles 344–364, Median: –12.0 cm, Median Removed

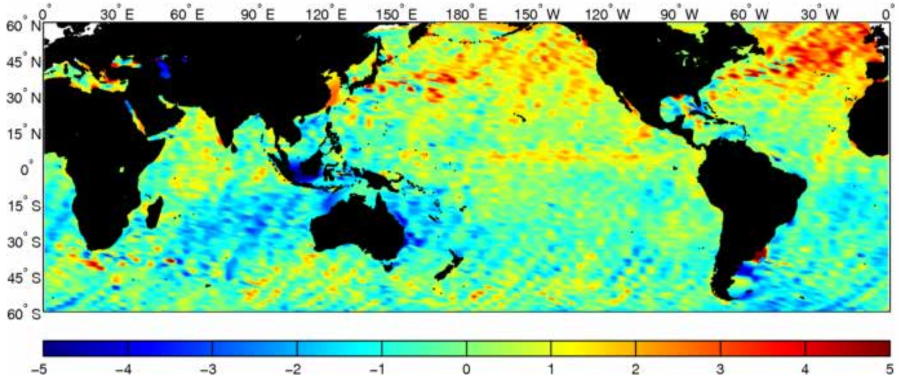


SSHA Asc [cm], (Skew 0, NB 5–7)–J1, Cycles 344–364, Median: –12.2 cm, Median Removed

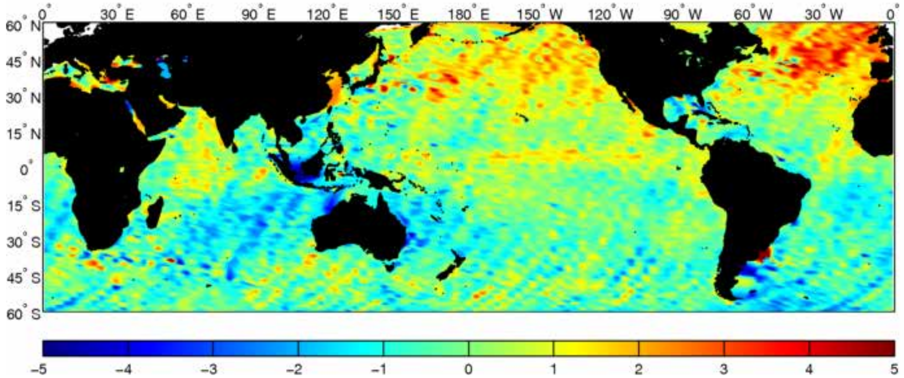


Skew 0.1

SSHA Asc [cm], (Skew 0.1, NB 7–12)–J1, Cycles 344–364, Median: –11.6 cm, Median Removed

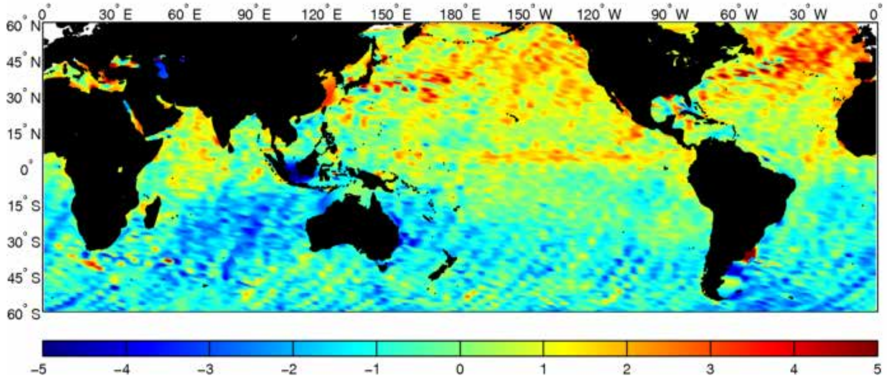


SSHA Asc [cm], (Skew 0.1, NB 5–7)–J1, Cycles 344–364, Median: –11.8 cm, Median Removed

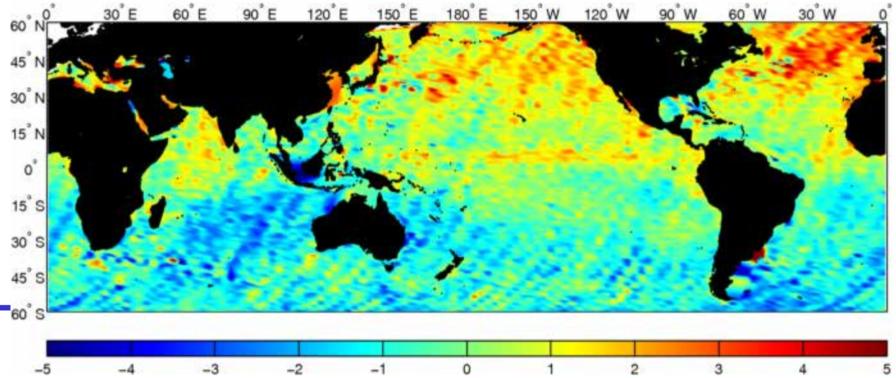


Skew Solve

SSHA Asc [cm], (Skew Solve, NB 7–12)–J1, Cycles 344–364, Median: –12.1 cm, Median Removed



SSHA Asc [cm], (Skew Solve, NB 5–7)–J1, Cycles 344–364, Median: –12.2 cm, Median Removed



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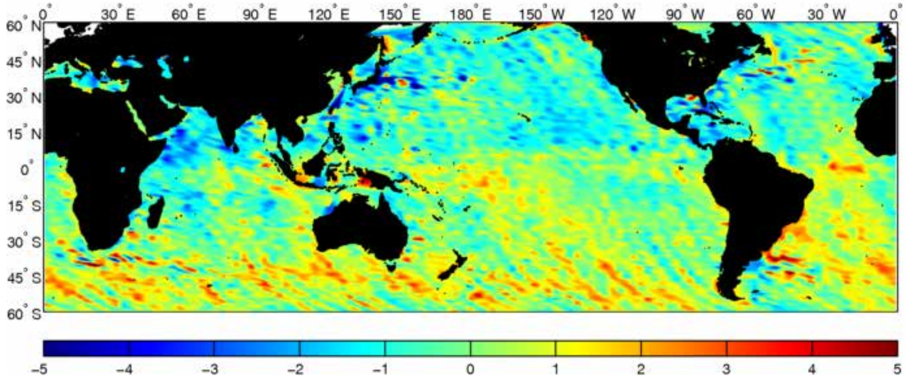
Difference (TPX-J1), SSHA Descending, Cycles 344-364

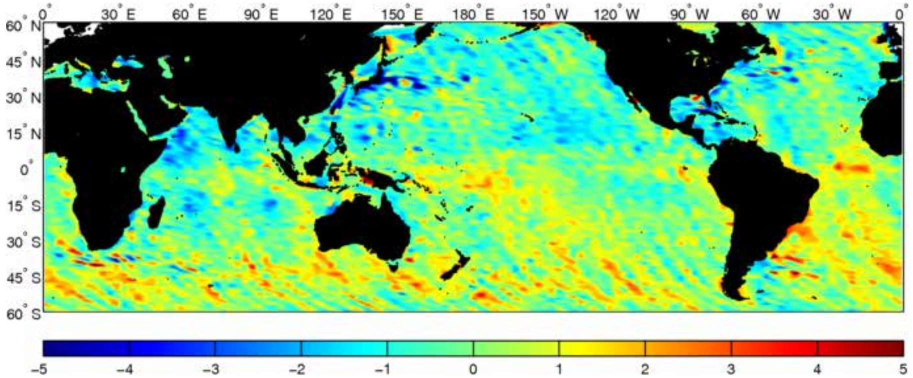
Noise 7-12 | **Noise 5-7**

Skew 0

SSHA Des [cm], (Skew 0, NB 7–12)–J1, Cycles 344–364, Median: −11.5 cm, Median Removed

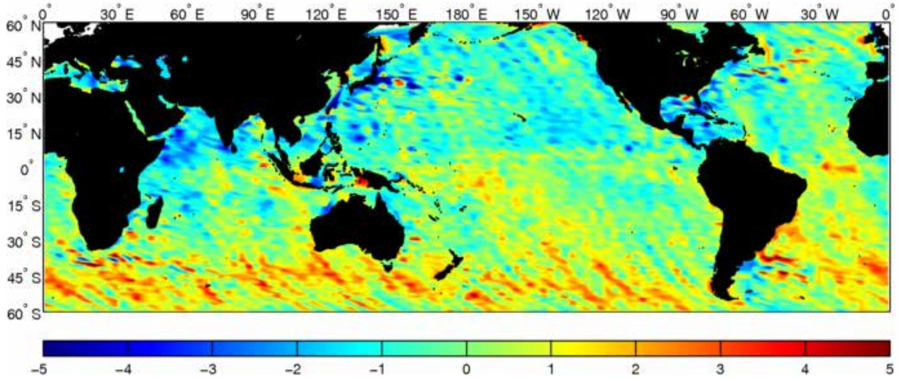


SSHA Des [cm], (Skew 0, NB 5–7)–J1, Cycles 344–364, Median: −11.7 cm, Median Removed

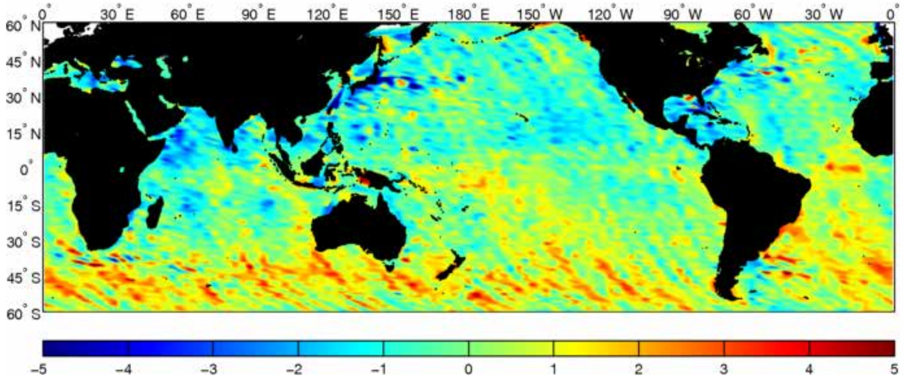


Skew 0.1

SSHA Des [cm], (Skew 0.1, NB 7–12)–J1, Cycles 344–364, Median: −11.1 cm, Median Removed

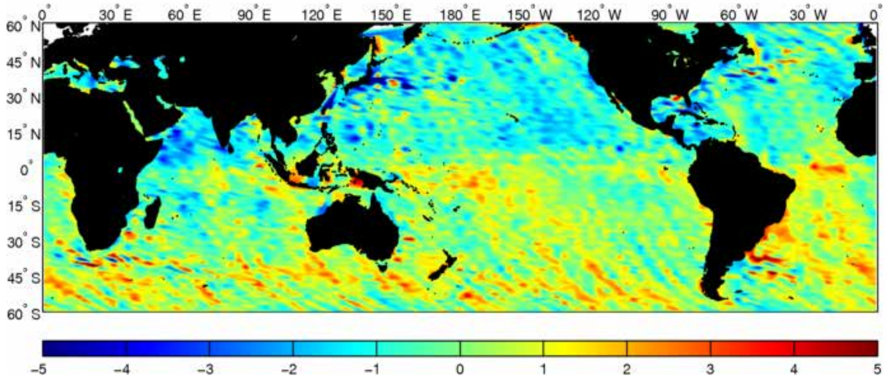


SSHA Des [cm], (Skew 0.1, NB 5–7)–J1, Cycles 344–364, Median: −11.3 cm, Median Removed

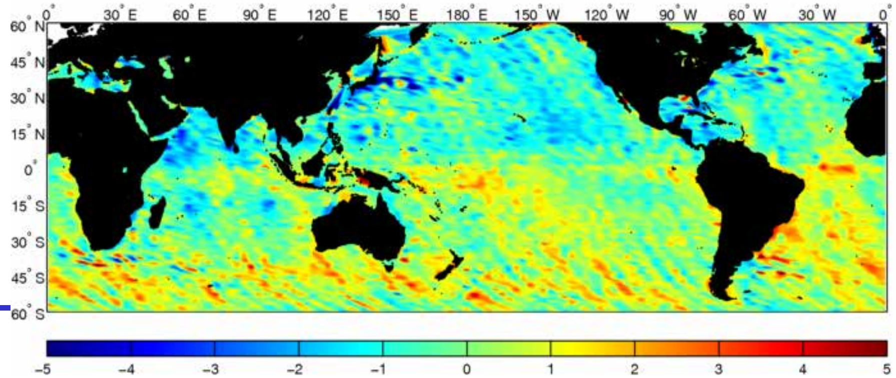


Skew Solve

SSHA Des [cm], (Skew Solve, NB 7–12)–J1, Cycles 344–364, Median: −11.5 cm, Median Removed



SSHA Des [cm], (Skew Solve, NB 5–7)–J1, Cycles 344–364, Median: −11.7 cm, Median Removed



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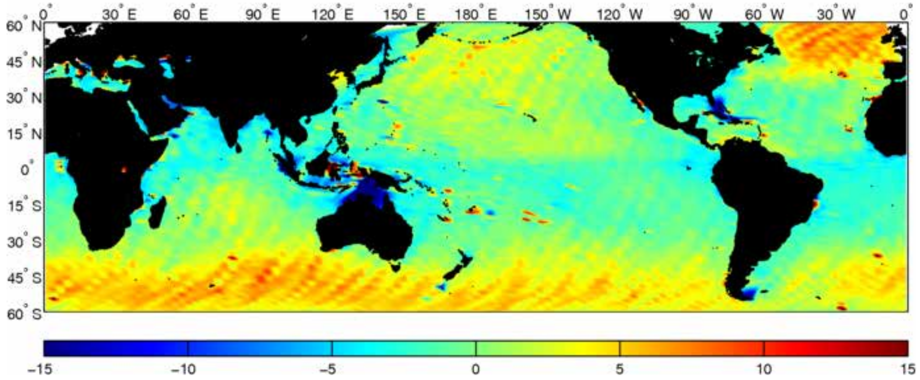
Difference (TPX-J1) (only SSB), SSHA Ascending, Cycles 344-364

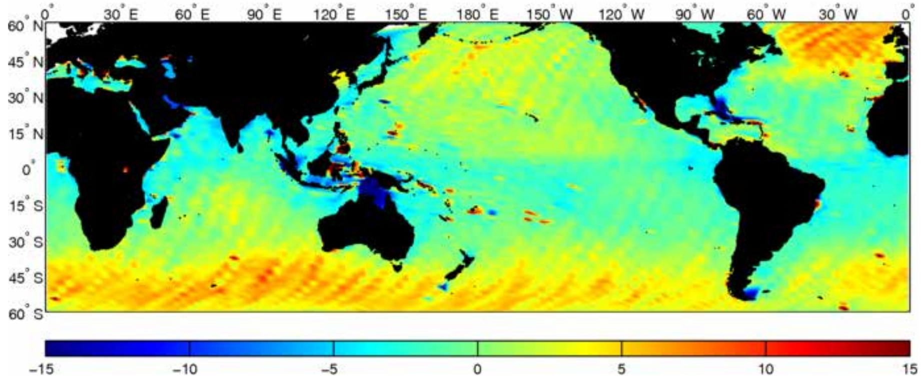
Noise 7-12 | Noise 5-7

Skew 0

SSHA Asc [cm], (Skew 0, NB 7–12)–J1, Cycles 344–364, Median: 0.9 cm, Median Removed

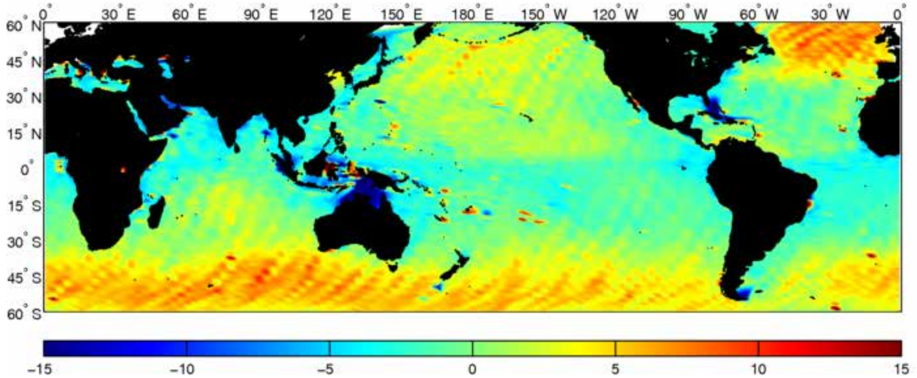


SSHA Asc [cm], (Skew 0, NB 5–7)–J1, Cycles 344–364, Median: 0.7 cm, Median Removed

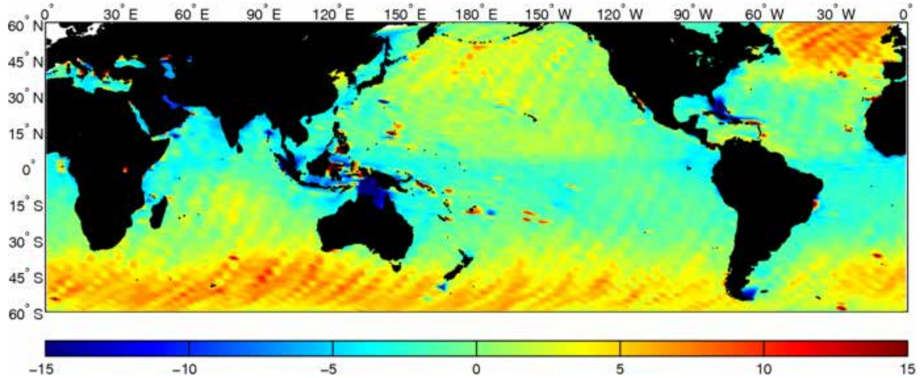


Skew 0.1

SSHA Asc [cm], (Skew 0.1, NB 7–12)–J1, Cycles 344–364, Median: 1.5 cm, Median Removed

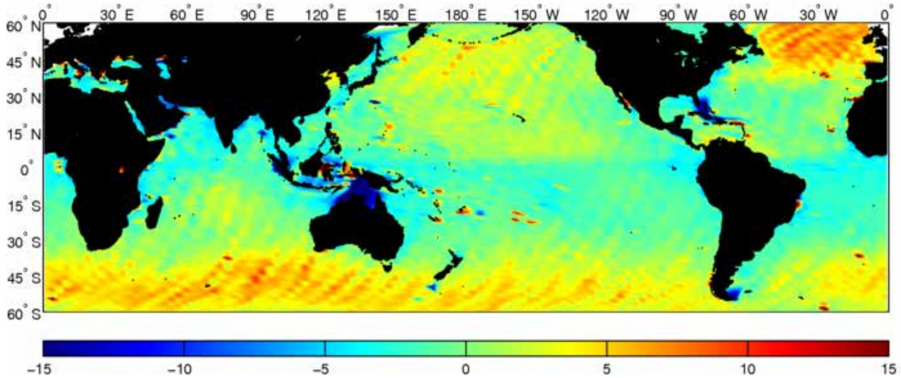


SSHA Asc [cm], (Skew 0.1, NB 5–7)–J1, Cycles 344–364, Median: 1.1 cm, Median Removed

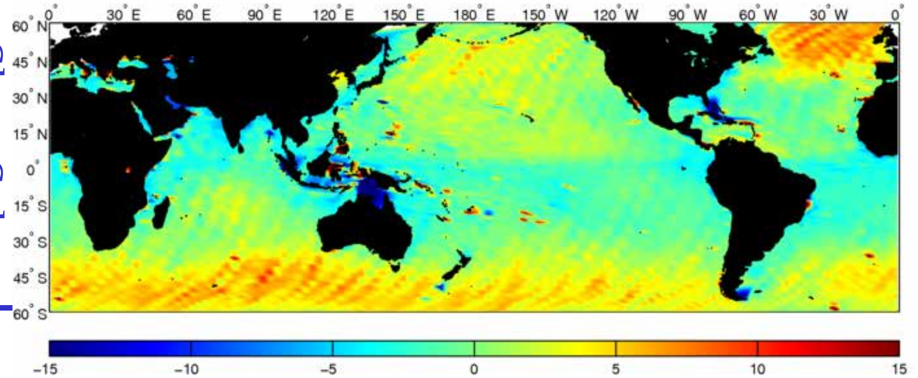


Skew Solve

SSHA Asc [cm], (Skew Solve, NB 7–12)–J1, Cycles 344–364, Median: 1.1 cm, Median Removed



SSHA Asc [cm], (Skew Solve, NB 5–7)–J1, Cycles 344–364, Median: 0.6 cm, Median Removed



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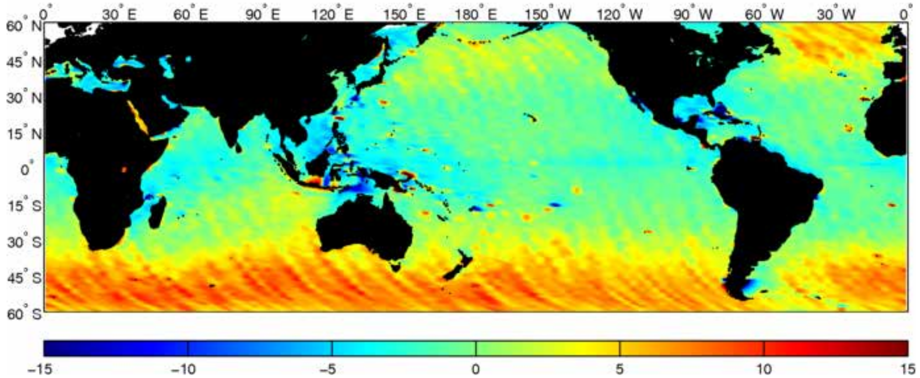
Difference (TPX-J1) (only SSB), SSHA Descending, Cycles 344-364

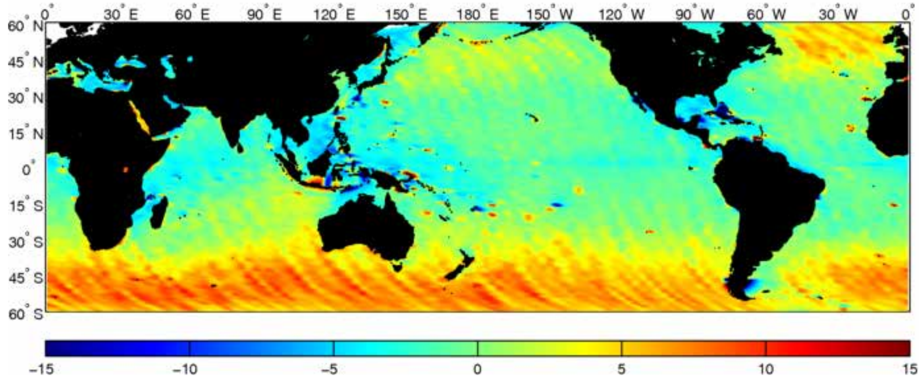
Noise 7-12 | Noise 5-7

Skew 0

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

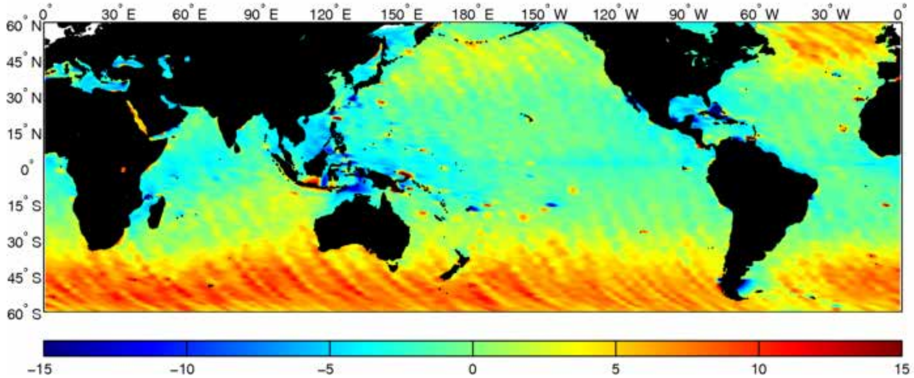


SSHA Des [cm], (Skew 0, NB 5–7)–J1, Cycles 344–364, Median: 0.5 cm, Median Removed

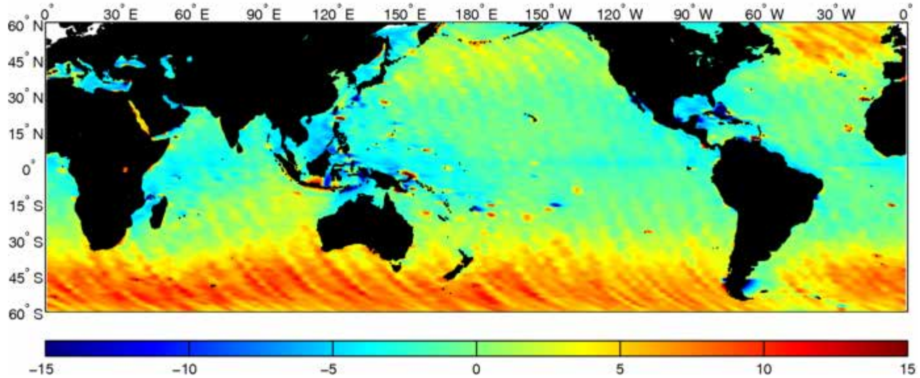


Skew 0.1

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

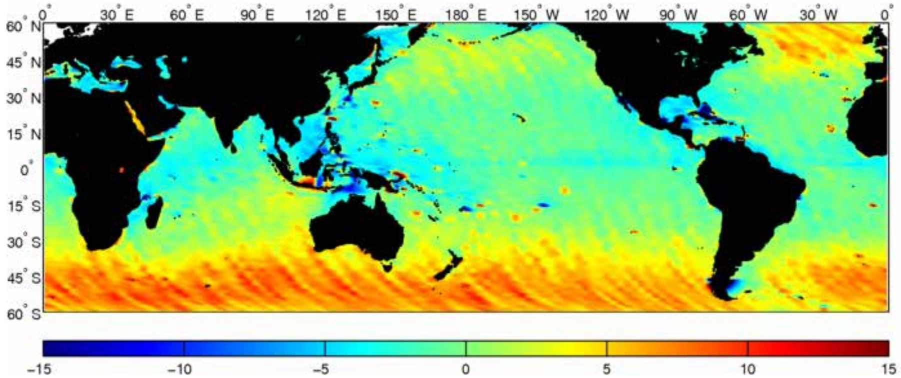


SSHA Des [cm], (Skew 0.1, NB 5–7)–J1, Cycles 344–364, Median: 0.9 cm, Median Removed

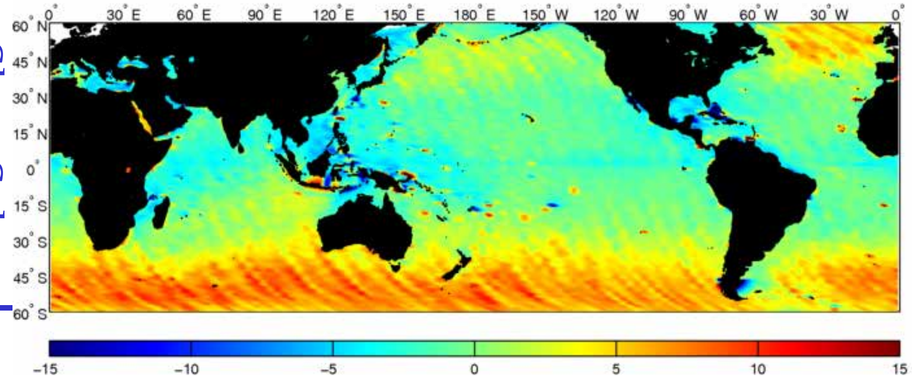


Skew Solve

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



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



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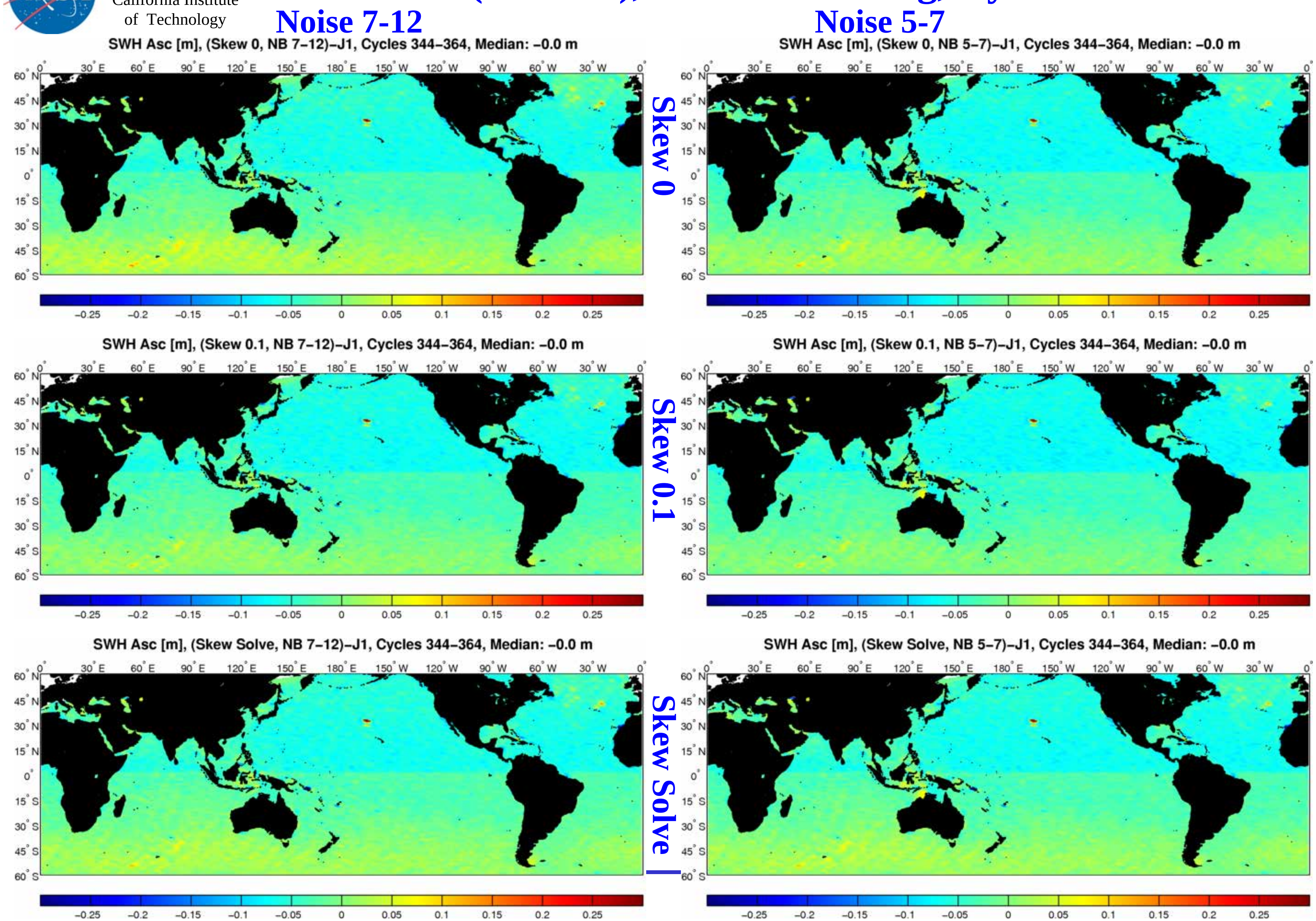
Difference (TPX-J1), SWH Ascending, Cycles 344-364



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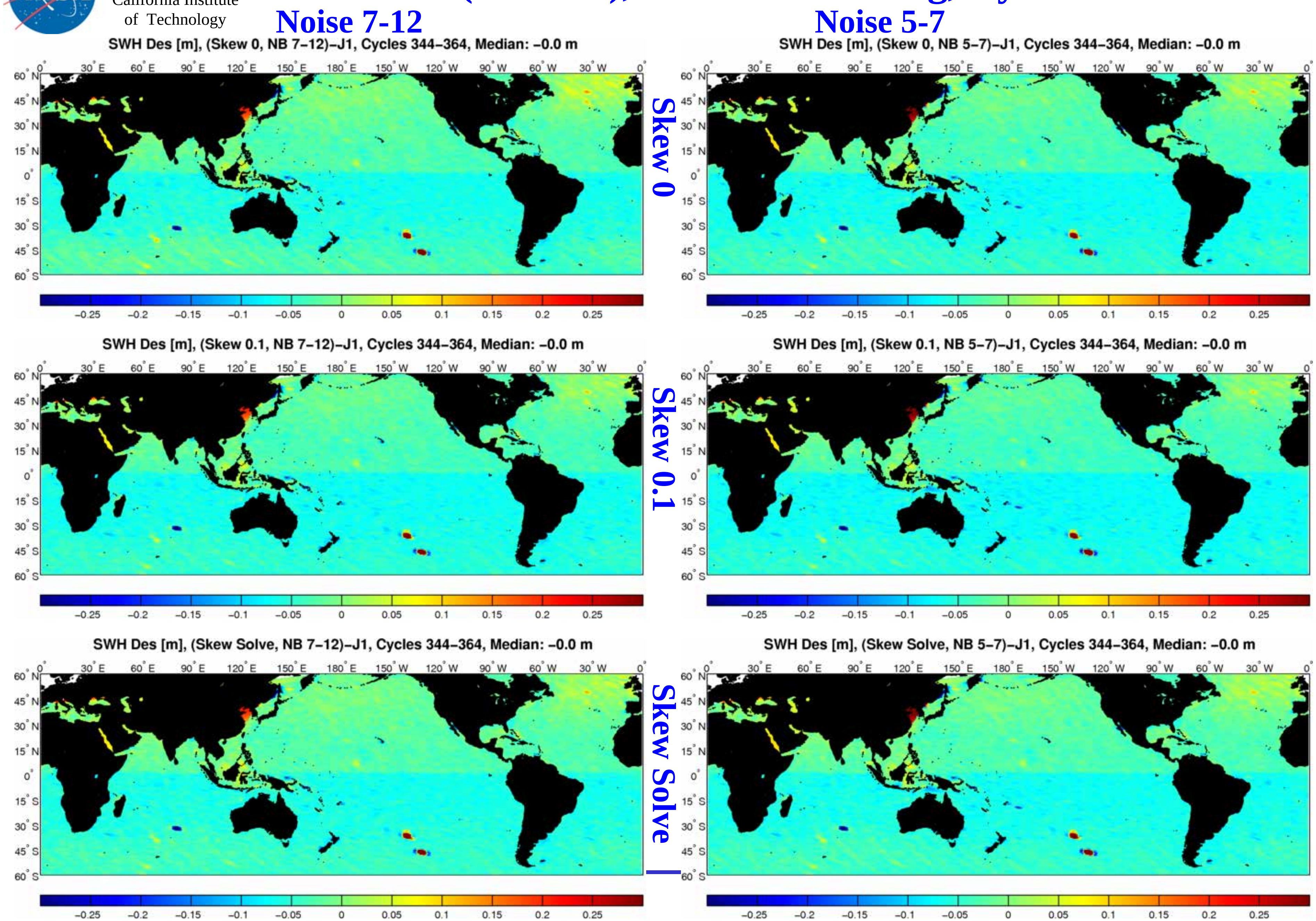
Difference (TPX-J1), SWH Descending, Cycles 344-364



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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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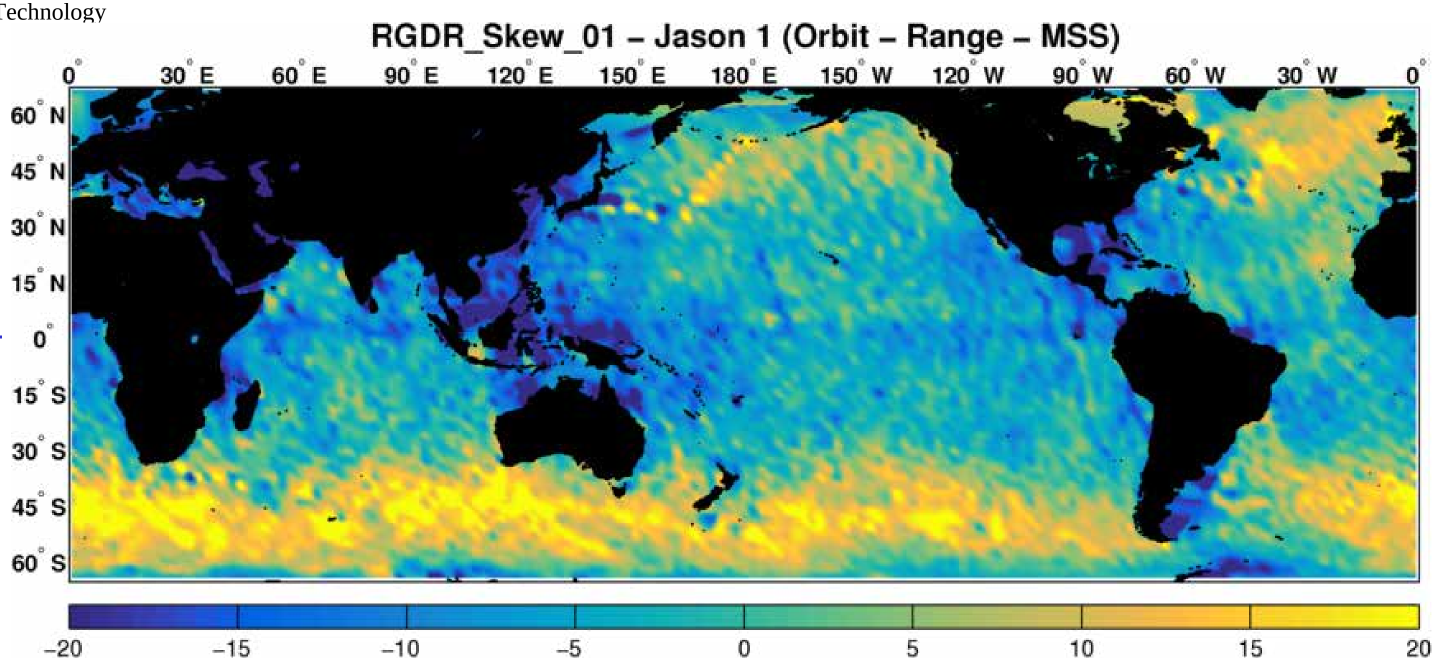
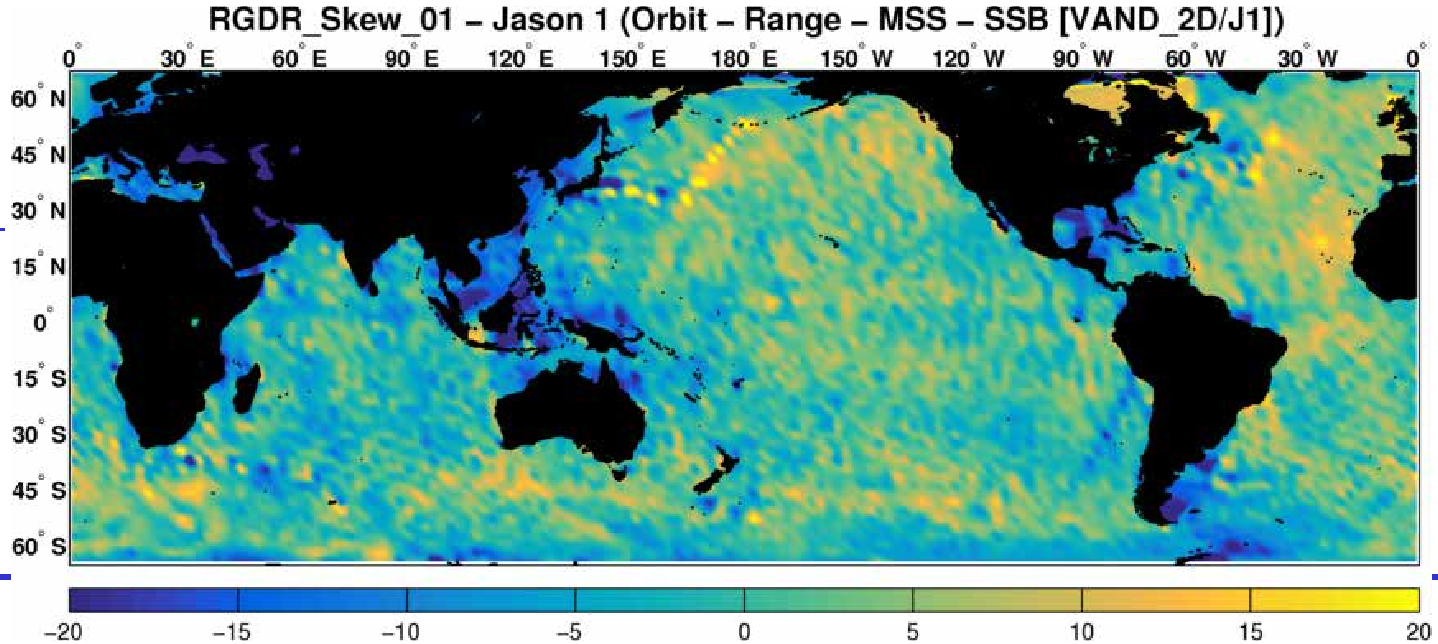
2015: TOPEX RGDR, Skew 0.1 - Jason 1

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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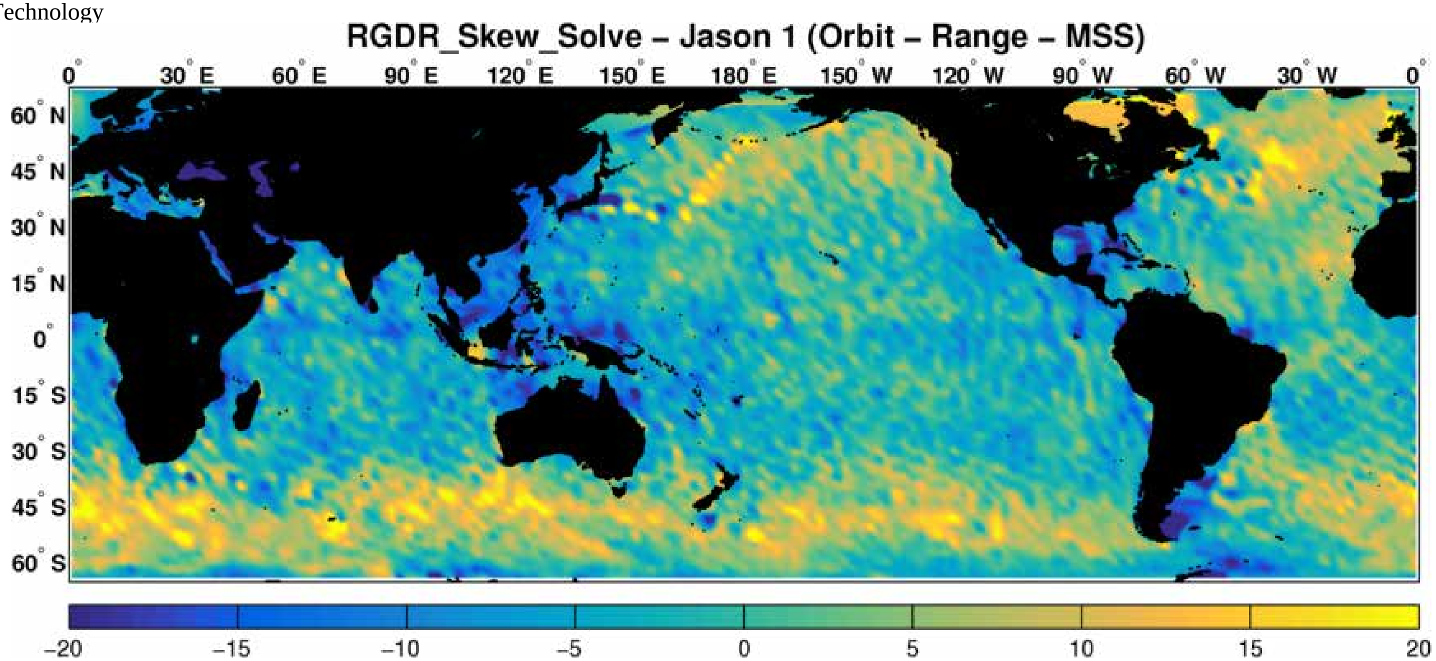
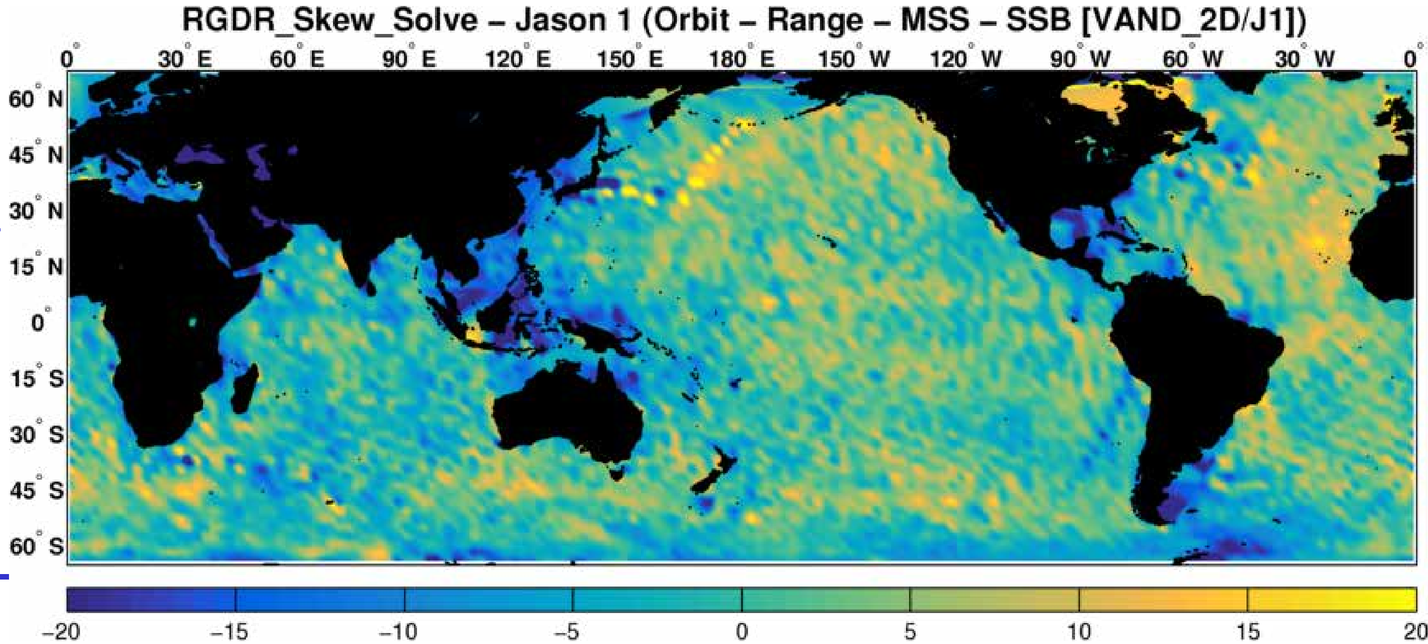
Orbit – Range – MSS



Bias removed: -62 mm

Orbit – Range – MSS – SSB



Bias removed: -85 mm

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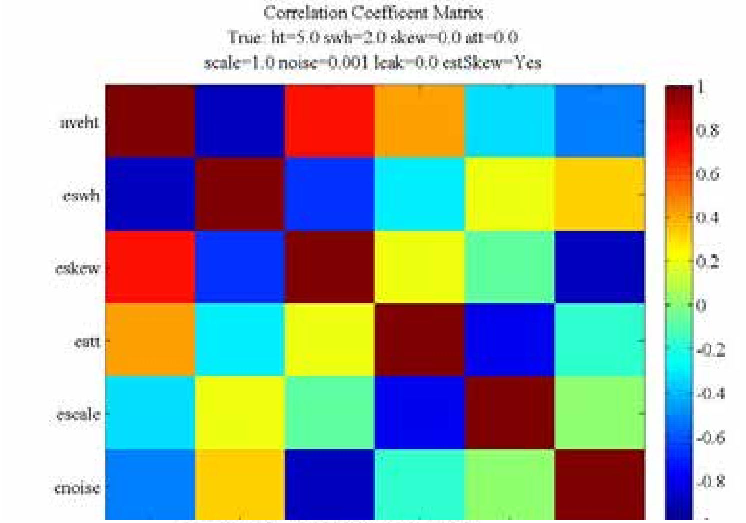
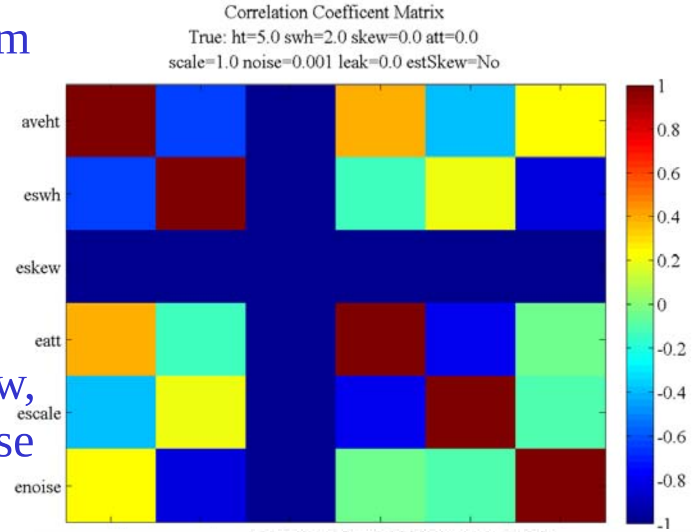
Simulation Results

Parameter Correlation Solving for Skewness

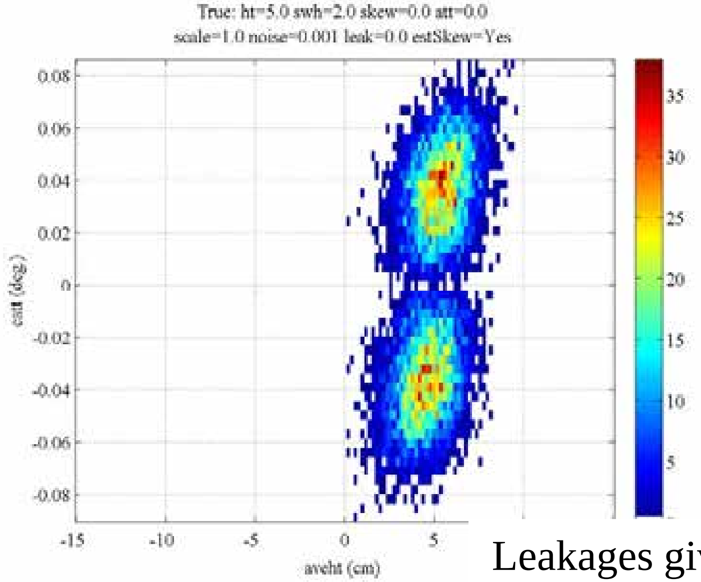


Parameter Correlation Not Solving for Skewness



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

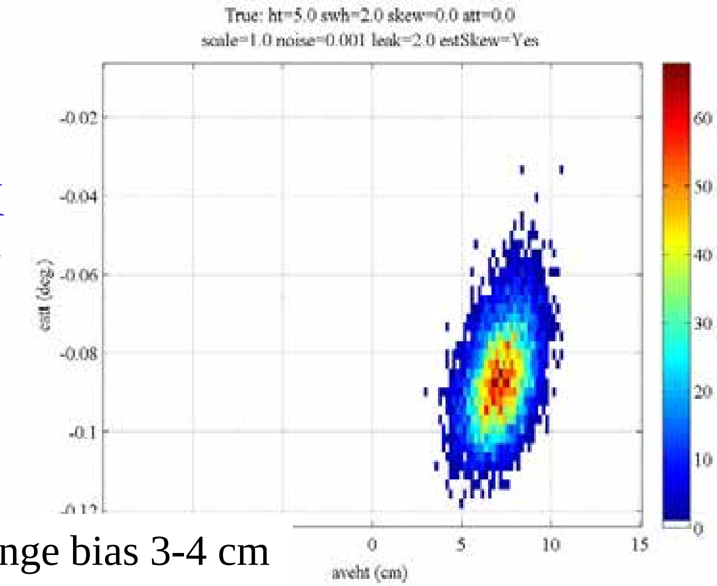
Parameters:
dH, SWH, Skew,
Att, Scale, Noise



← Leakage = 0

Leakage = 2X
→

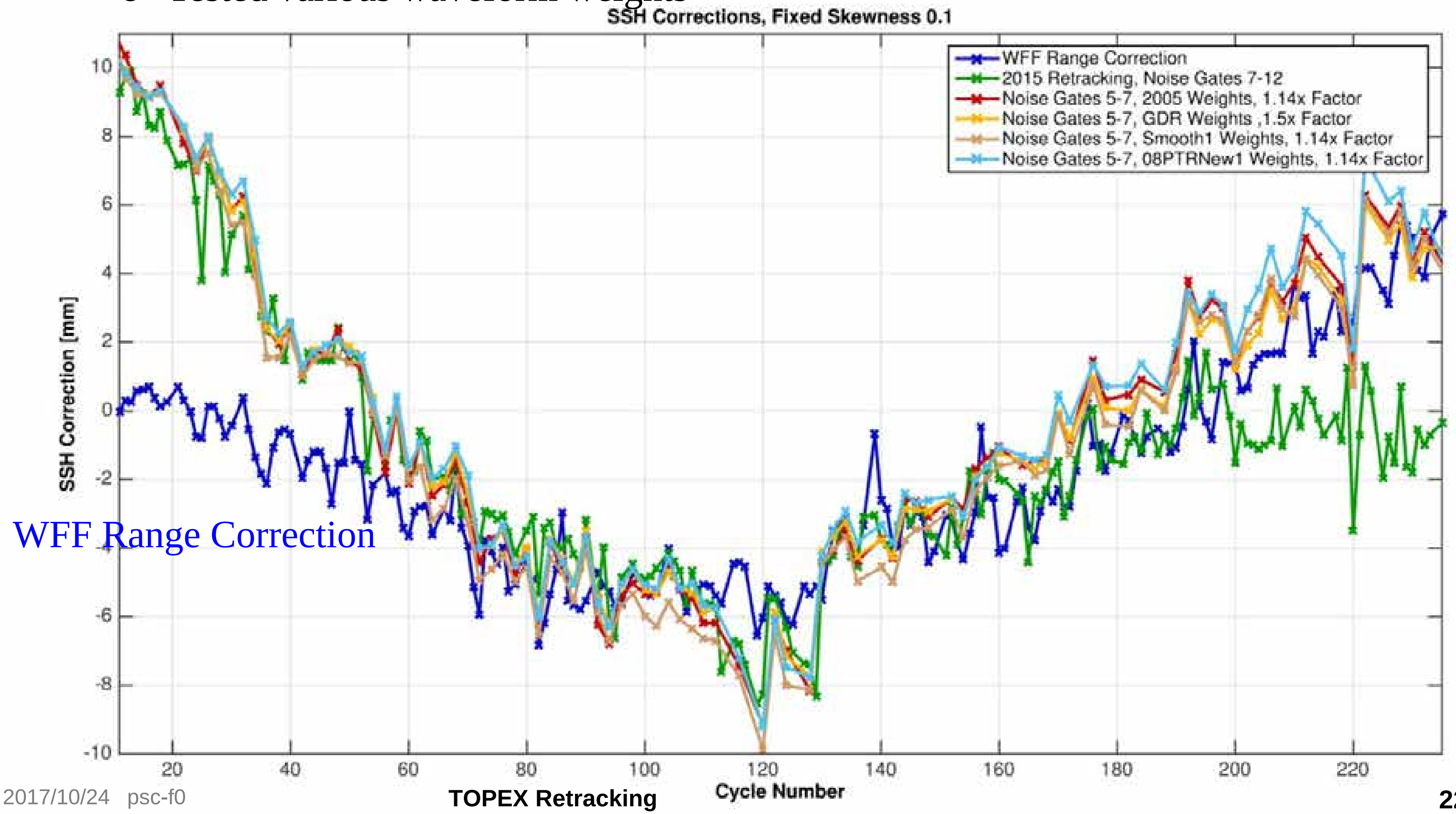
2D Histogram:
Att / dH



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

Comparison of Global Mean Sea Level Estimates: Alt-A

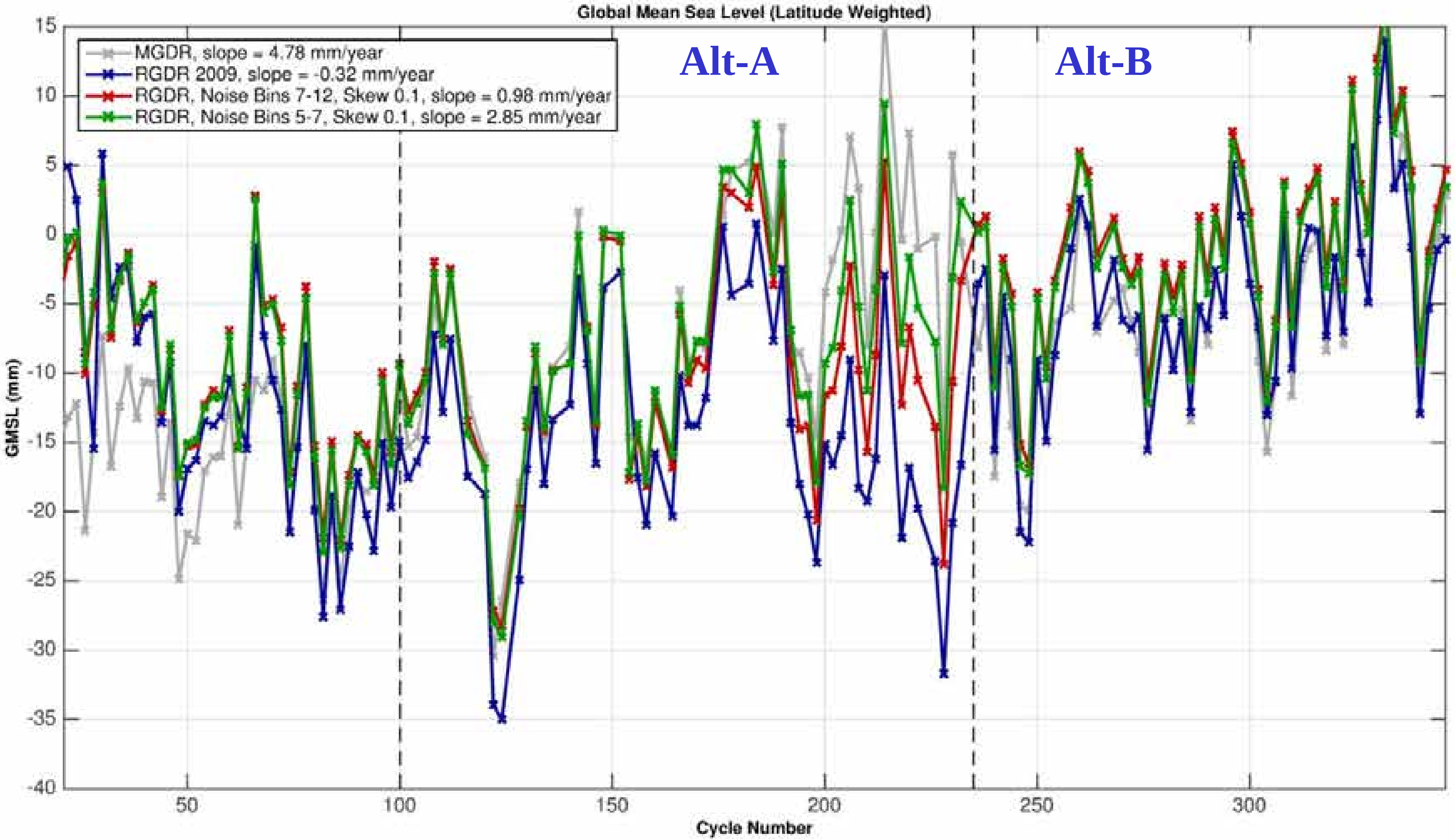
- 2015 retracking noise estimation used bins = 7-12 (telemetry bins) (Green)
- Found that Noise estimate using bins 6-7 had too variation (noise), so used bins 5-7
  - o Empirically estimated factor to make behavior similar to bins 7-12
  - o Tested various waveform weights



TOPEX Retracking

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)

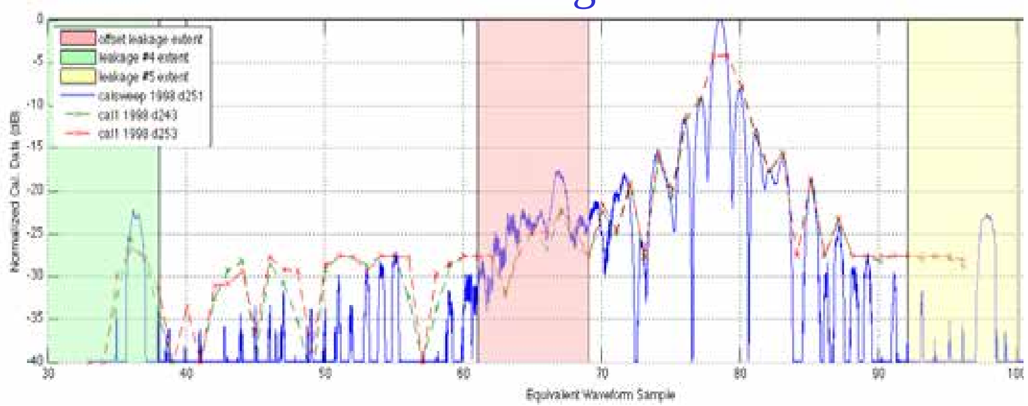


TOPEX History – Leakages

- Leakages (x20) in the TOPEX Alt-A waveform from Hayne et al., 1994, JGR, ***99,*** 24,941 shown below
  - Move over several bins with range rate giving North/South Ascending/Descending ("toward" / "away" from equator) differences
  - Onboard gates used to estimate parameters shown as bars
  - Need correction in processing via masking or "weights" on WF gates
  - 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
  - 2015 onward using original WFF/GDR weights

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



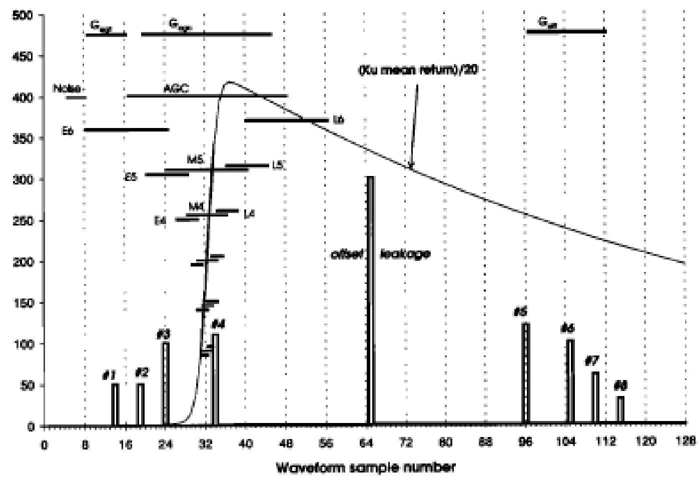


Figure 6. TOPEX Ku altimeter gates, mean return, and center locations of waveform leakage spikes.

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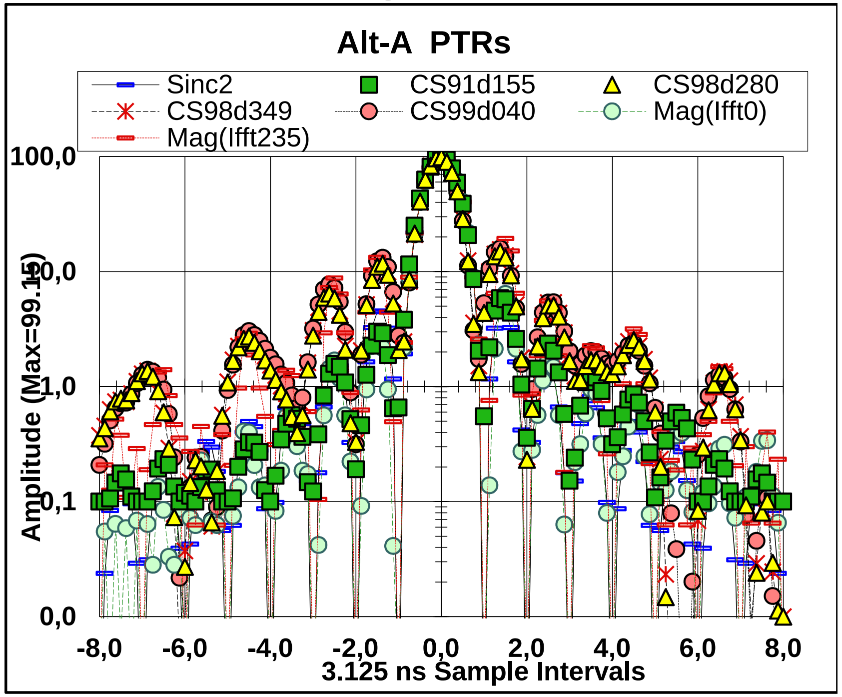
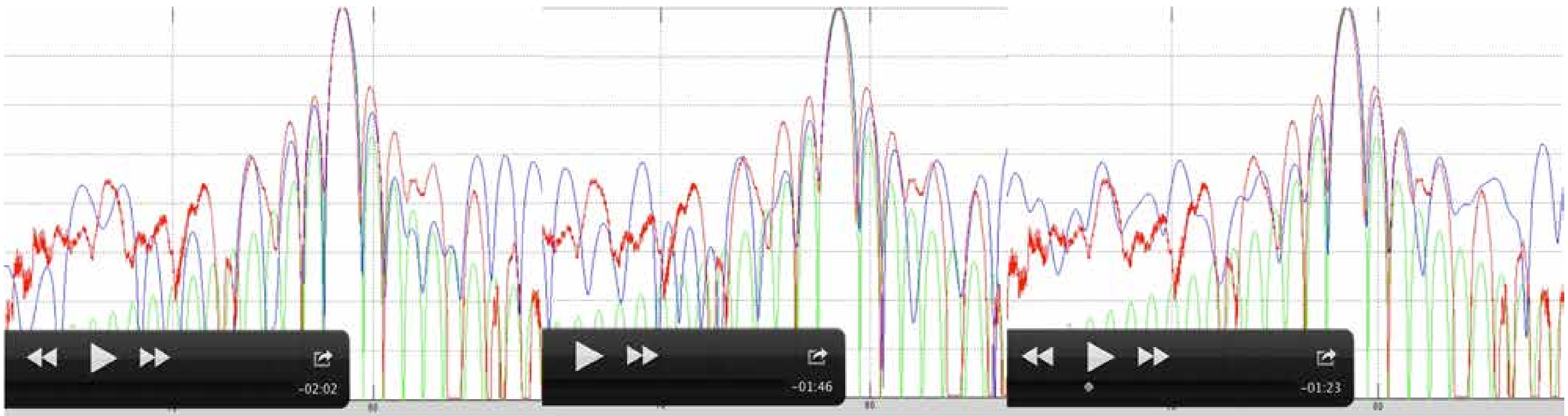
TOPEX Alt-A PTR Changes



- 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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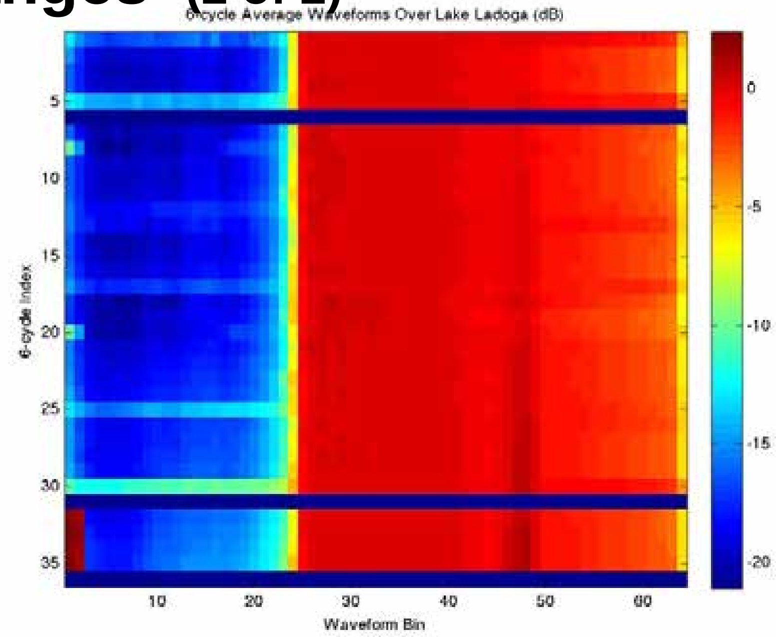
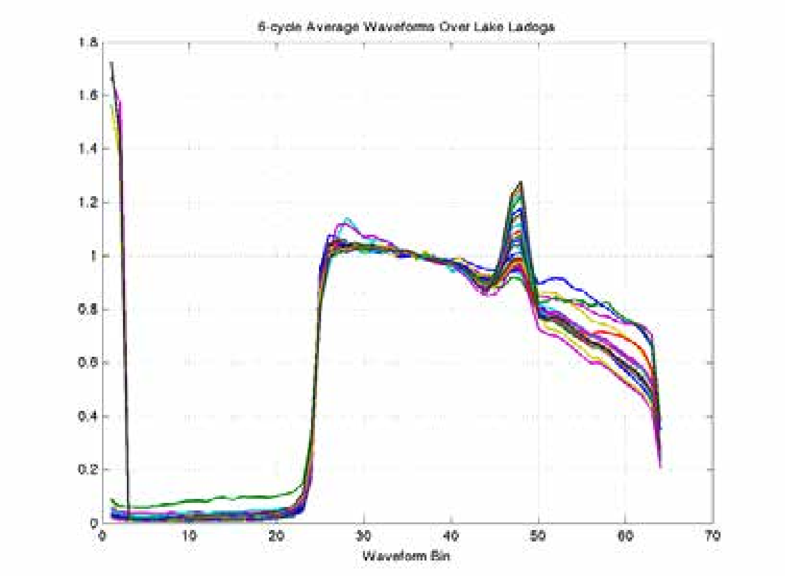
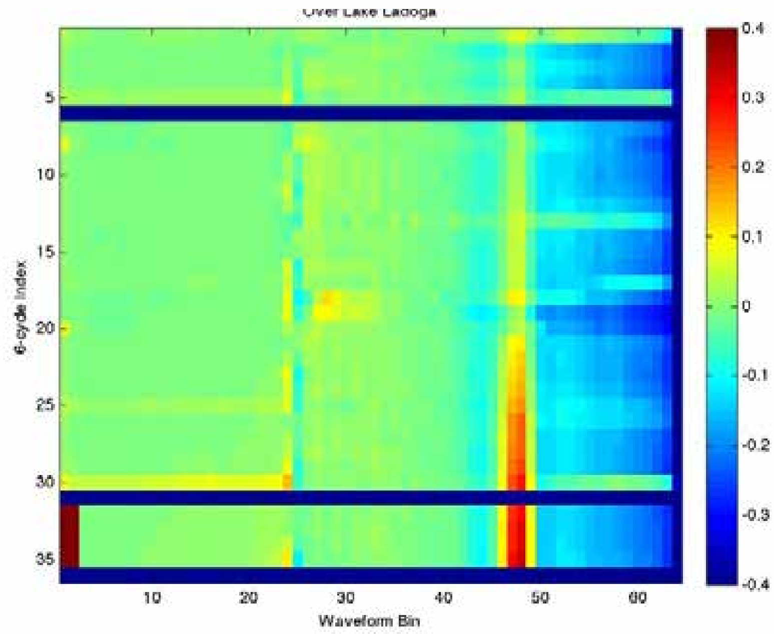
TOPEX Alt-A PTR Changes (2 of 2)

- 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







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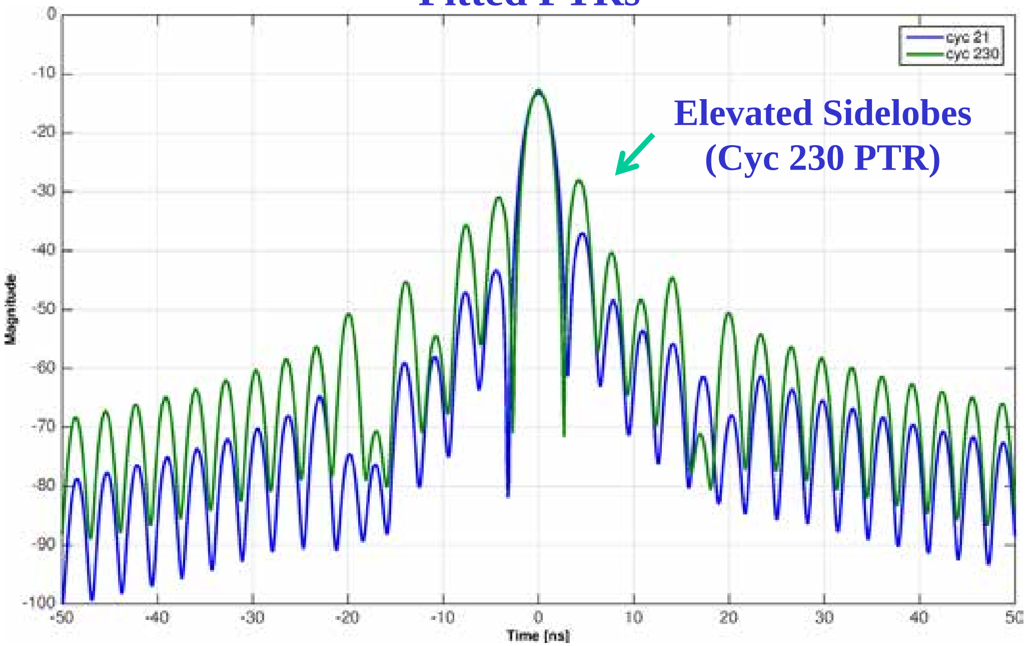
Simulated Waveform Return from Broadened PTR

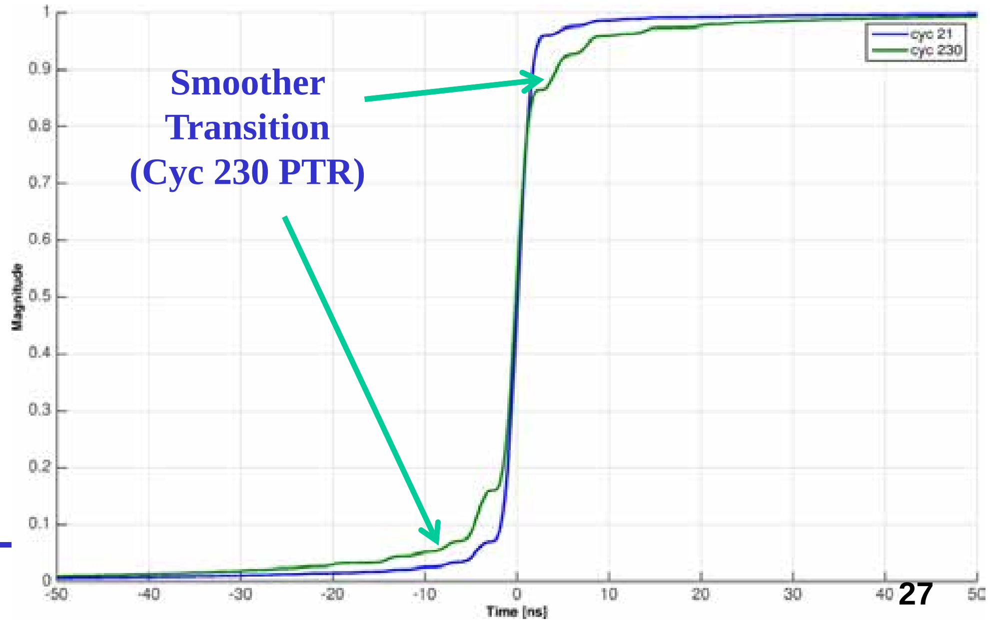
Joe McMichael, JPL

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

Simulated Ocean Backscatter Return



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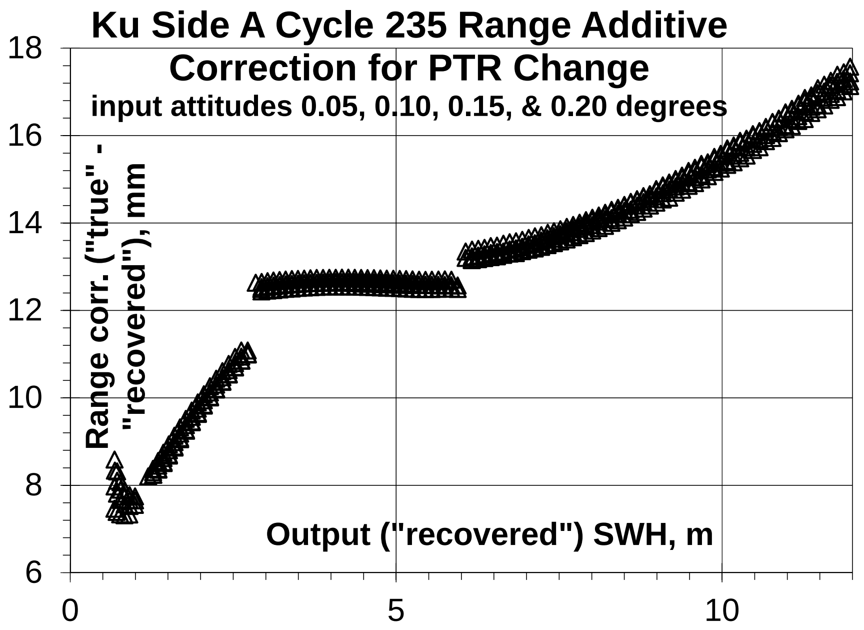
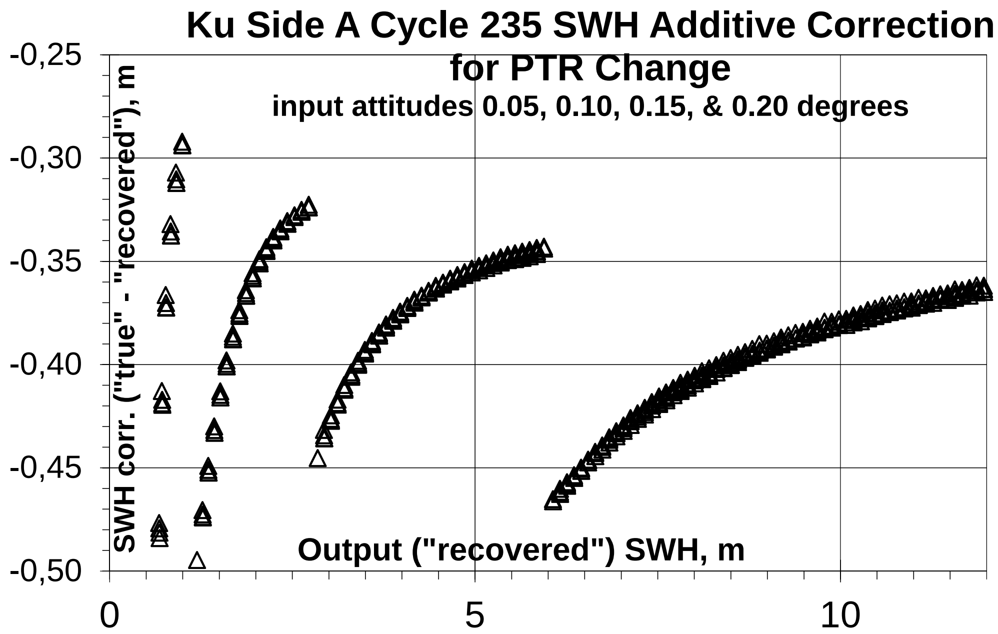
WFF Alt-A PTR Change Simulation

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.





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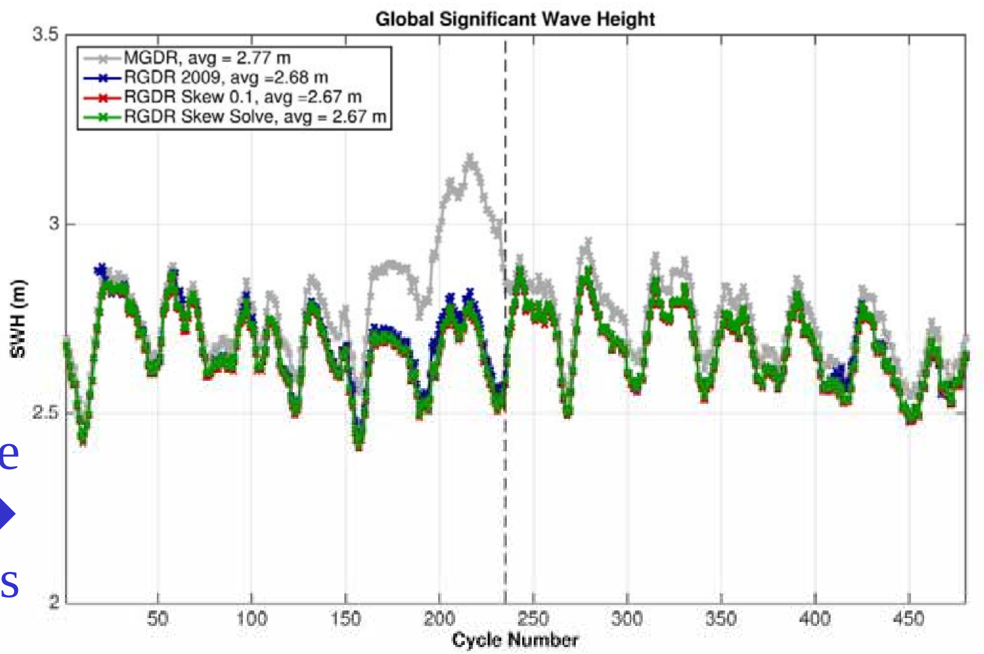
TOPEX Retracking Overview / History

- 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

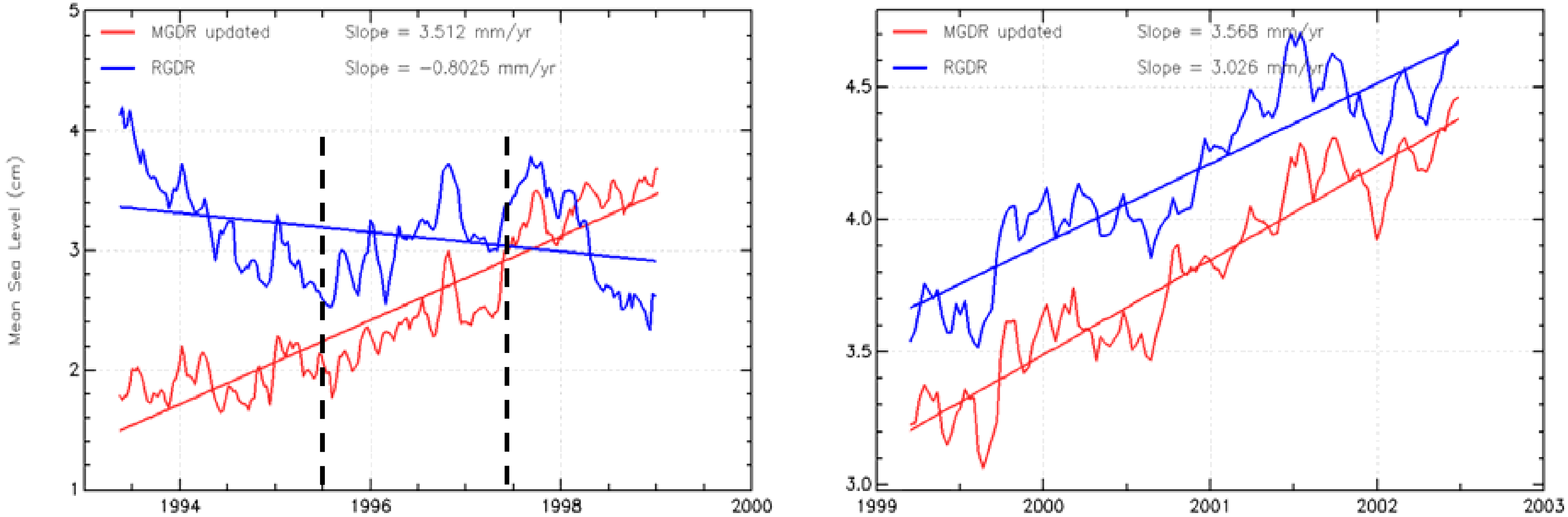


TOPEX Data Conclusions

- 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.

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.