Jet Propulsion
Laboratory
California Institute
of Technology

Retracked TOPEX Climate Data Record

OSTST October 2015

Phil Callahan, Joseph McMichael, Brent A. Williams
Jet Propulsion Laboratory, California Institute of Technology
Doug Vandemark, Hui Feng
University of New Hampshire, Institute for the Study of Earth, Oceans, Space

Copyright 2015 California Institute of Technology

Outline / Overview

- Completed work funded by NOAA Climate Data Records program task: “Generation of Altimeter Climate Data Records Using Retracking and Updated Corrections”
  - Also supported by TOPEX/Jason-1 Project
- TOPEX Retracking Overview, History
- Alt-A PTR Changes and Cal Data
- Retracking Results
  - Evaluated first version released in January 2015
  - Produced RGDR for cycles 1 - 480 for Skewness = 0.1 and Skew-solve; cycles 21-364 for Skewness = 0. Lists of missing input.
  - Final version generated in September. Data will soon be available on PODAAC
- Instrument (“WFF”) Range Calibration
- Sea State Bias Update
  - Doug Vandemark, Hui Feng used standard method to provide

TOPEX Climate Data Records

- TOPEX RGDR similar to Jason ver_D
  - NetCDF similar to Jason
  - Copy of original GDR
  - Retracking values for range, SWH, attitude
  - New GSFC orbits: std1410
  - New tide model GOT4.10C
  - Improved long period non-equilibrium tides
  - Updated MSS: CNES 2011
  - 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~~

- Recent issue – Loss of up to 10% of data relative to January 2015

- Future
  - NOAA CDR program to make “operational” – possible to update

TOPEX Data Conclusions

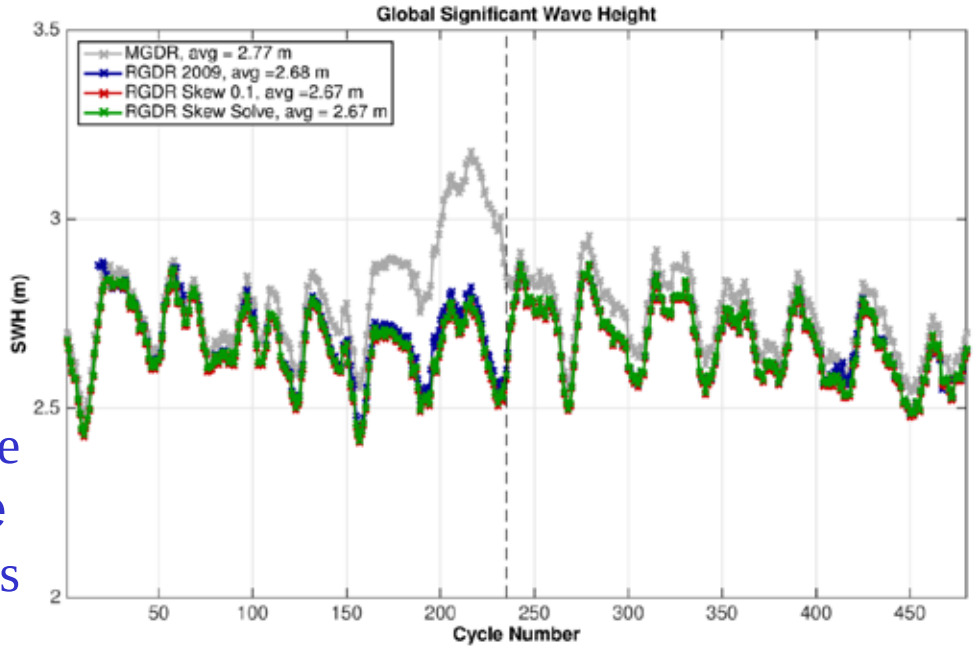
- Waveform leakages cannot be directly corrected. Could not determine from on-orbit data (low wave height, low range rate)
  - **Lesson:** Checkout the test data. WF "teeth" corrected by weights.
- Point Target Response (PTR) changes can be determined from Cal-1 data to correct Alt-A changes
  - All 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.

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

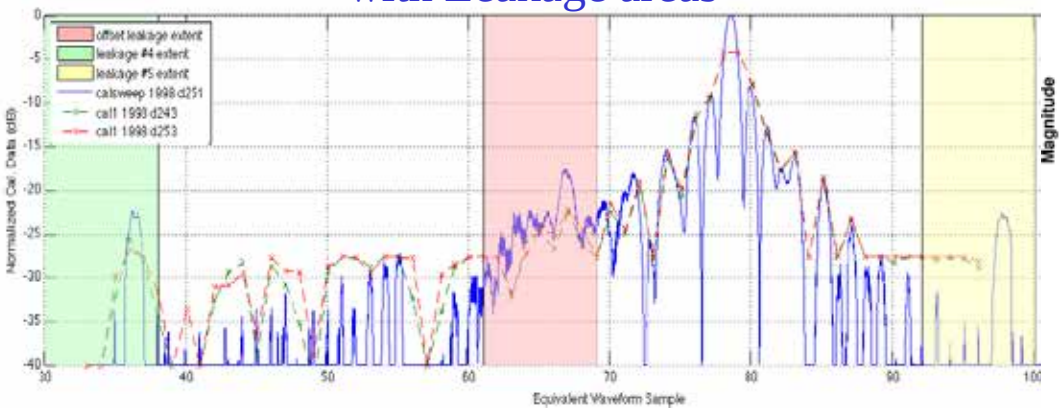
Correction of SWH change from Retracking è Similar in all versions

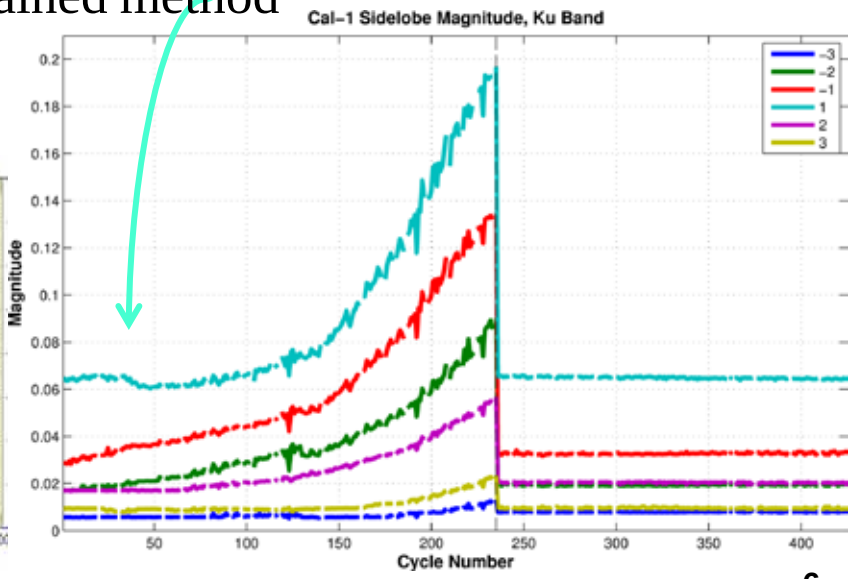


Cal-1 Data for PTR

- Reviewed Cal data based leakage transfer through signal path. (Note: Cal-1 data are just Nyquist sampled.)
  - Left: Data in colored areas are contaminated, not used in PTR – can only use lobes +/-6 from Cal-1 data
  - Right: Changes in sidelobes near cycle 50 (sidelobe +1 drop) seem to produce SSH change in early data
- Extended PTR to ~ +/-30 lobes needed for retracking consistent with PTR changes (increase in sidelobes, missing lobes with increasing phase imbalance)
  - Determined that method with fixed minima gave results not consistent with Cal Sweeps, so used non-constrained method

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

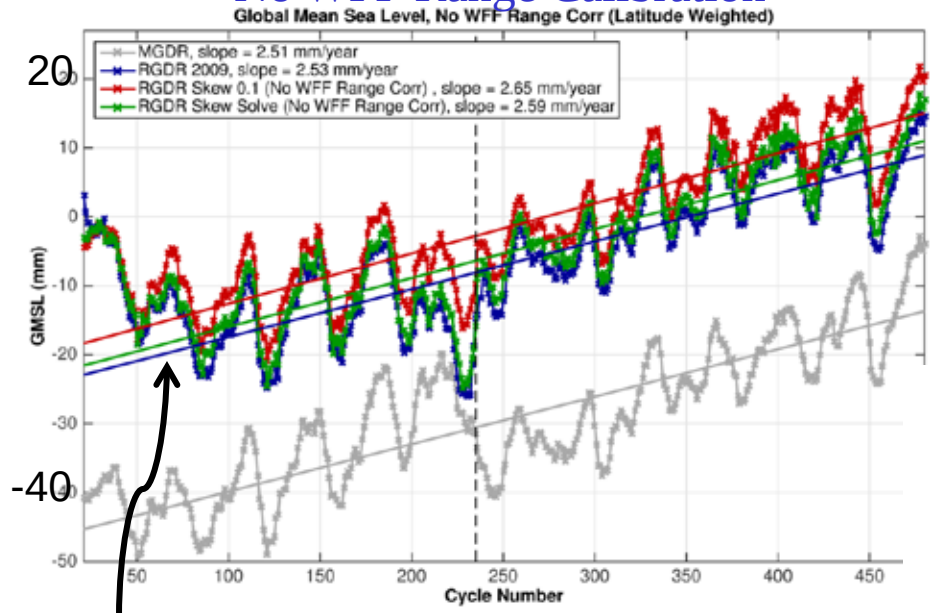




RGDR Analysis: Latitude-Weighted GMSL Trend

- Latest retracking corrects for GMSL depression near the end of Alt-A in 2009 release
  - Eliminates discontinuity between Alt-A and Alt-B

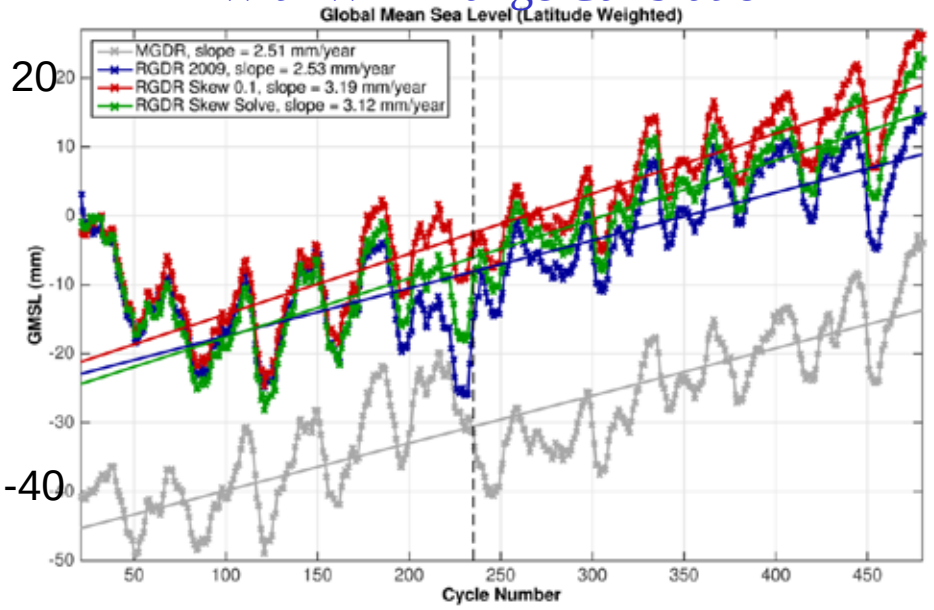
No WFF Range Calibration



From higher early sidelobe +1

- During analysis of the January version of the retracked data, we were reminded that MGDR-B contains the WFF Range Calibration. This calibration from the Cal-1 data produces a significant addition to the GMSL slope for Alt-A.

With WFF Range Calibration



- The WFF Range Calibration was not used in the original GDRs or previous versions of the RGDR

WFF Range Calibration

- During analysis of the January version of the retracked data, we were reminded that MGDR-B contains the WFF Range Calibration. This calibration from the Cal-1 data produces a significant addition to the GMSL slope for Alt-A from about cycle 80 to 235.

Alt-A Range Calibration

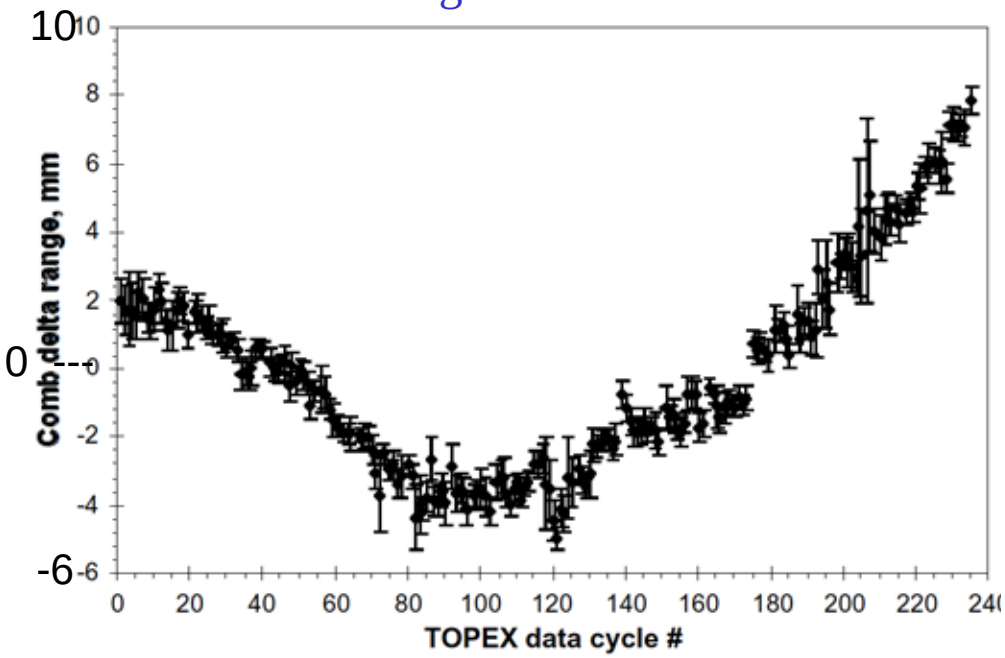


Figure 3-2 Combined (Ku & C) Delta Range vs. Cycle - With UCFM Temperature Correction

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.

Alt-B Range Calibration

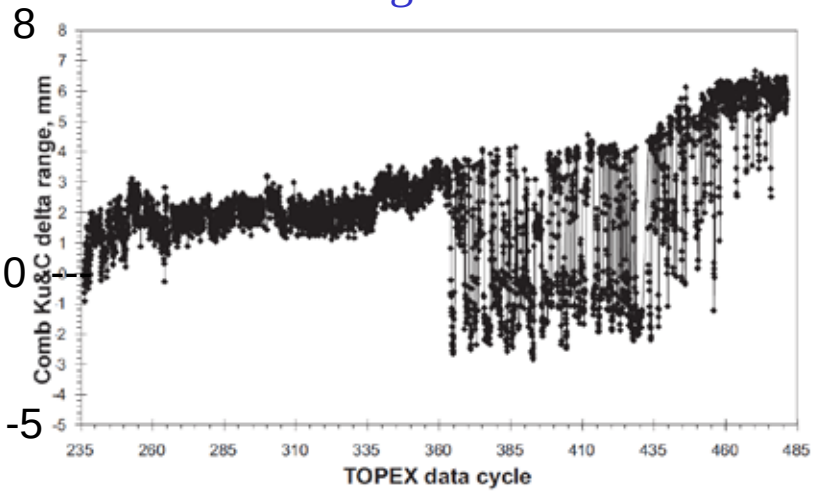
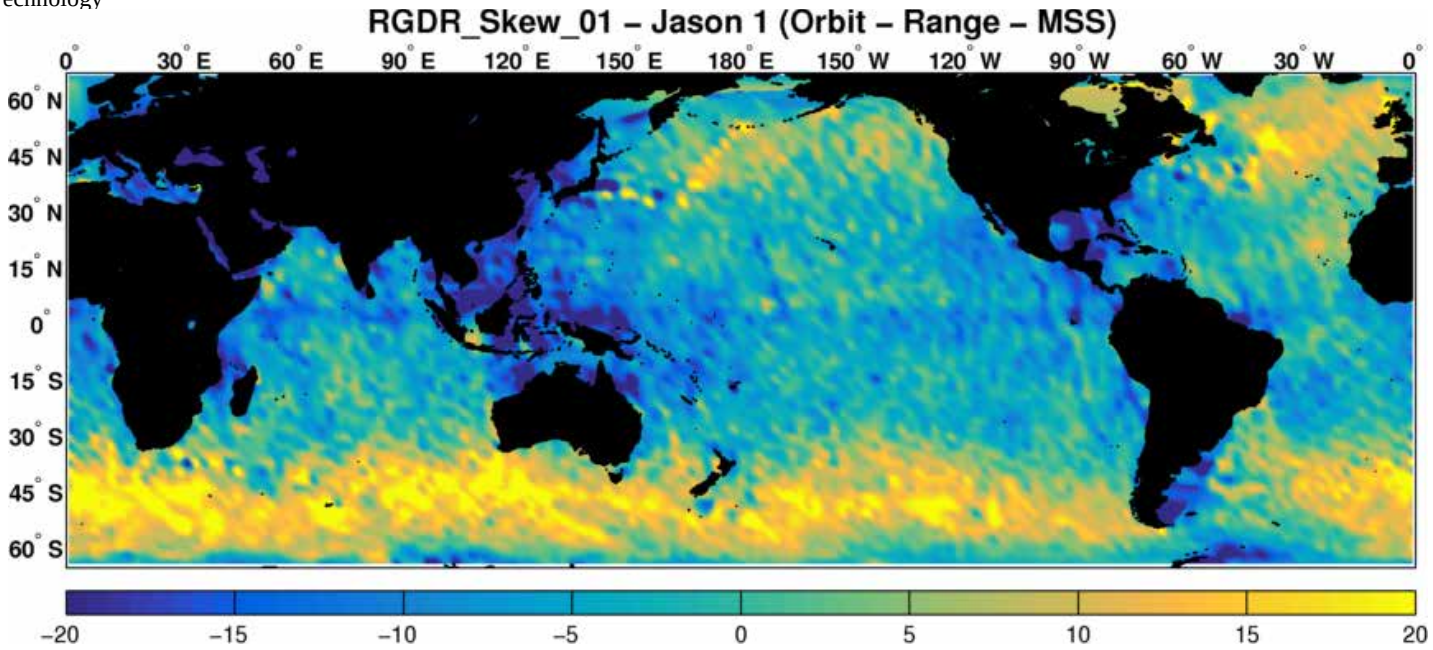


Figure 3-7 Side B CAL1 Step-5 Combined dRange vs. Cycle after Correction for Receiver AGC Temperature

Jet Propulsion Laboratory
California Institute of Technology

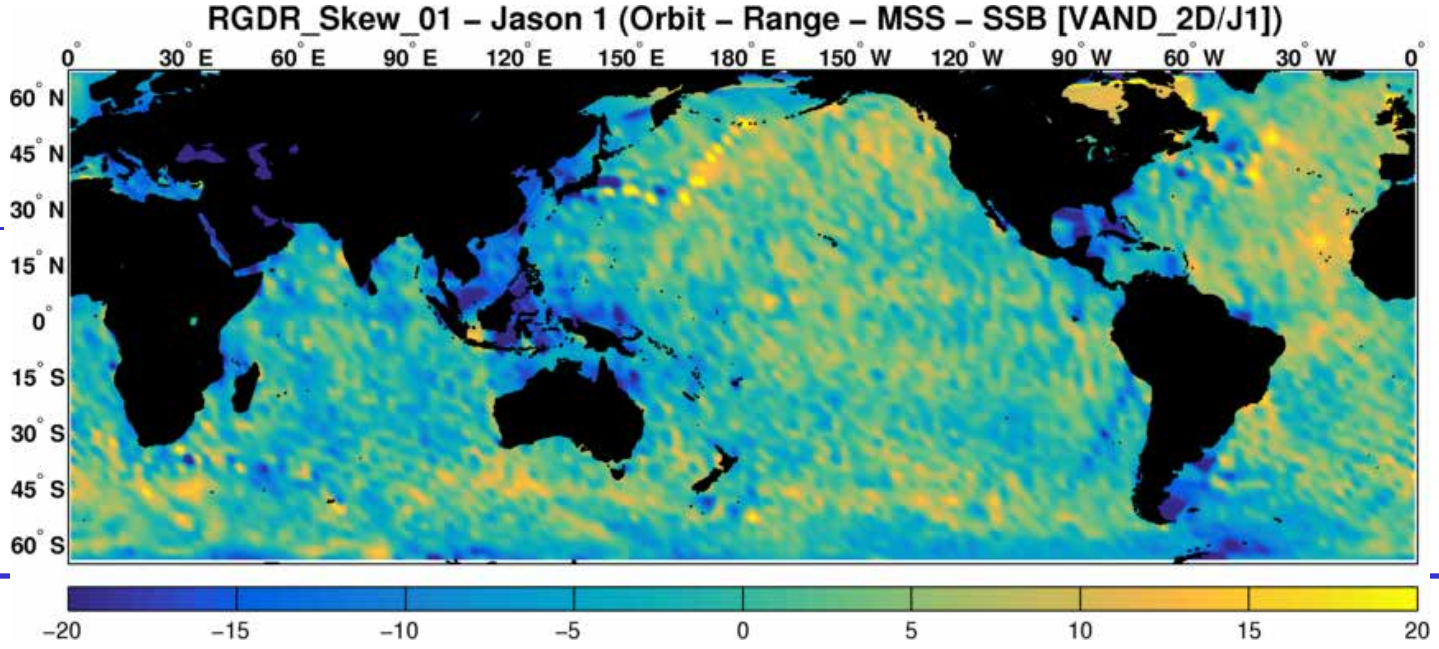
TOPEX RGDR, Skew 0.1 - Jason 1

Orbit – Range – MSS



Bias removed: -56 mm

Orbit – Range – MSS – SSB

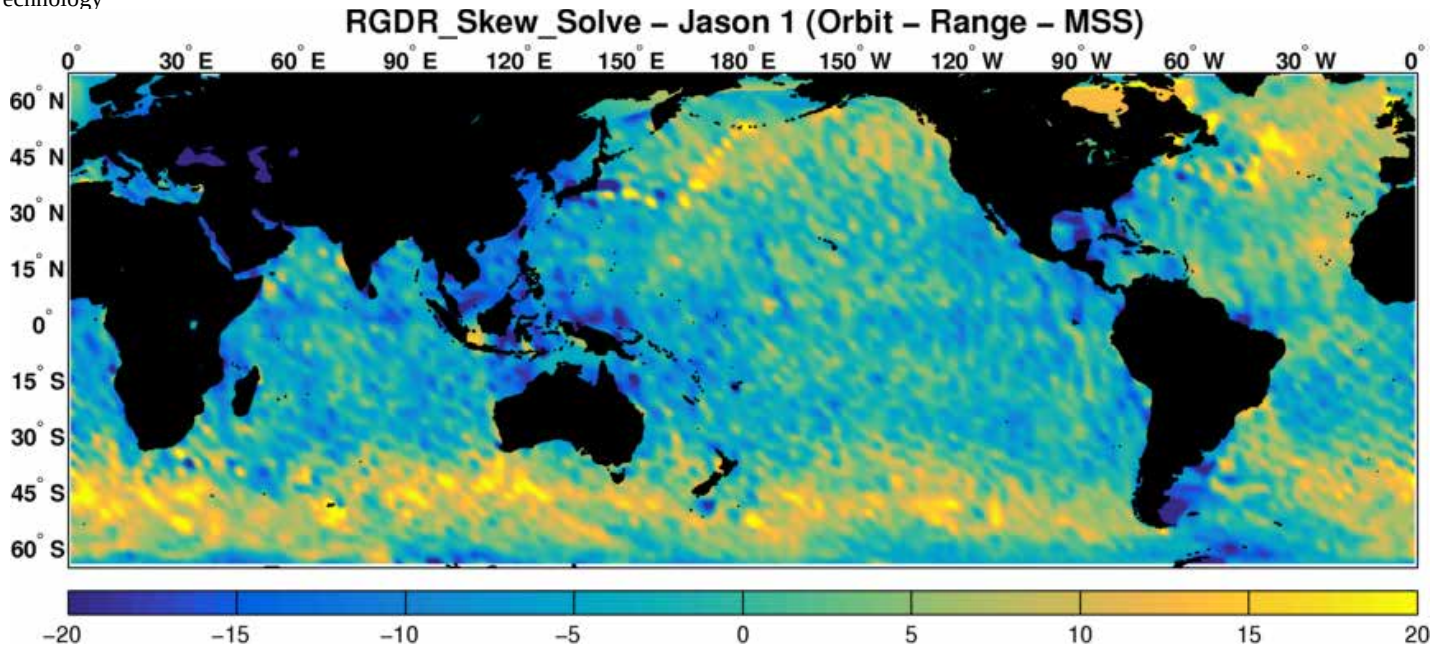


Bias removed: -82 mm

Jet Propulsion Laboratory
California Institute of Technology

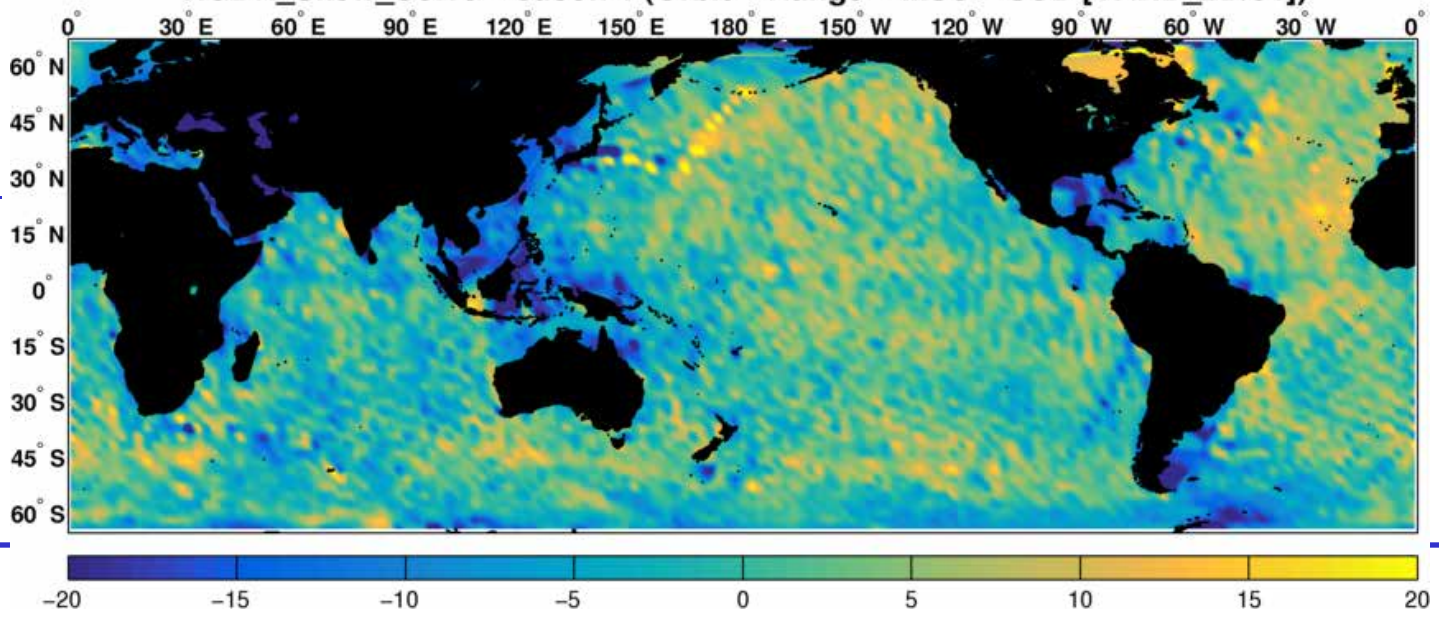
TOPEX RGDR, Skew Solve - Jason 1

Orbit – Range – MSS



Bias removed: -62 mm

Orbit – Range – MSS – SSB



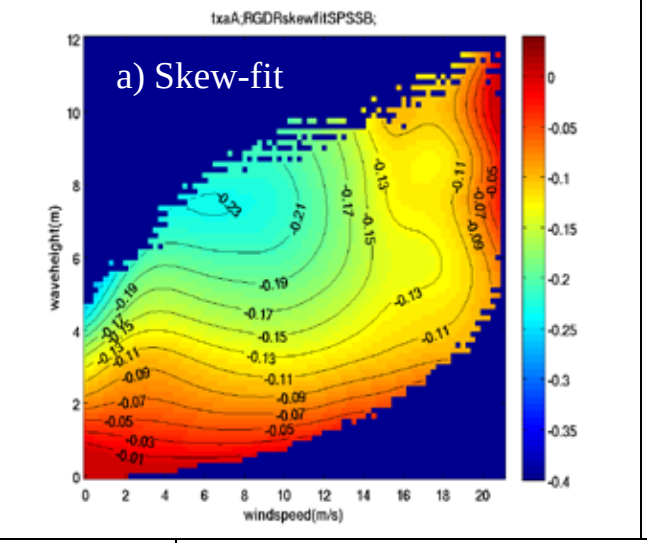
Bias removed: -85 mm

Jet Propulsion Laboratory
California Institute of Technology

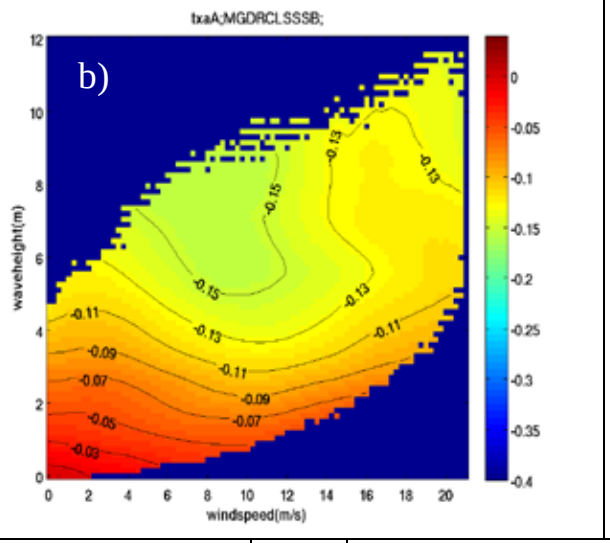
TOPEX Side A: RGDR SPSSB vs. MGDR CLSSSB2d

D. Vandemark, H. Feng analysis

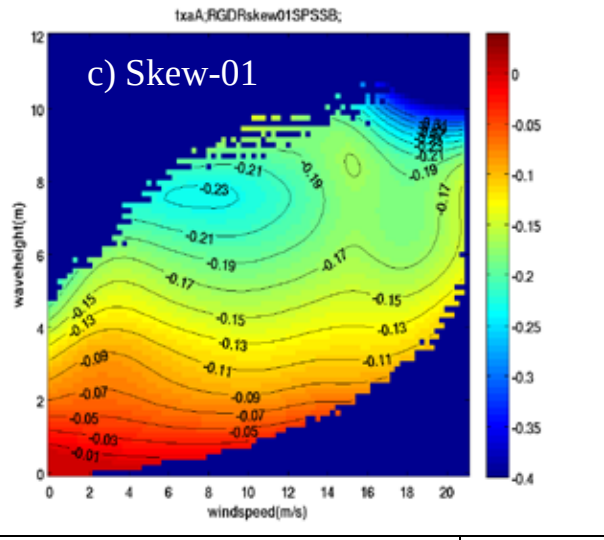
RGDR (skewfit) SPSSB2d



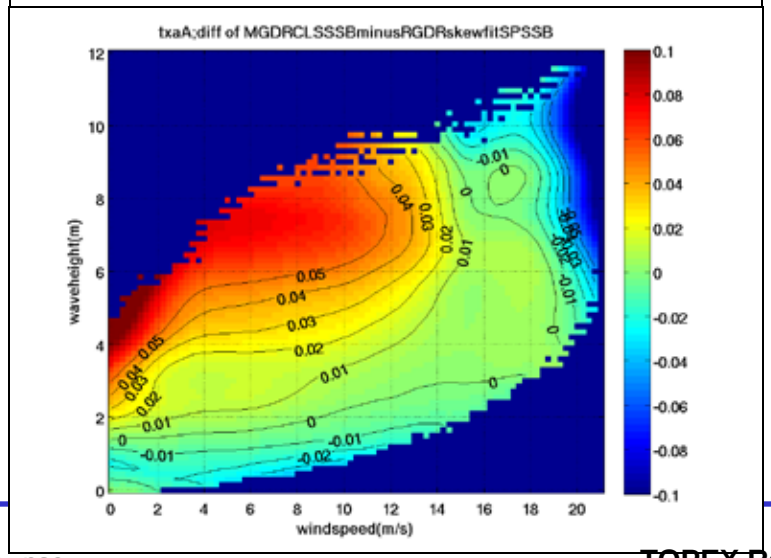
MGDR CLS SSB2d



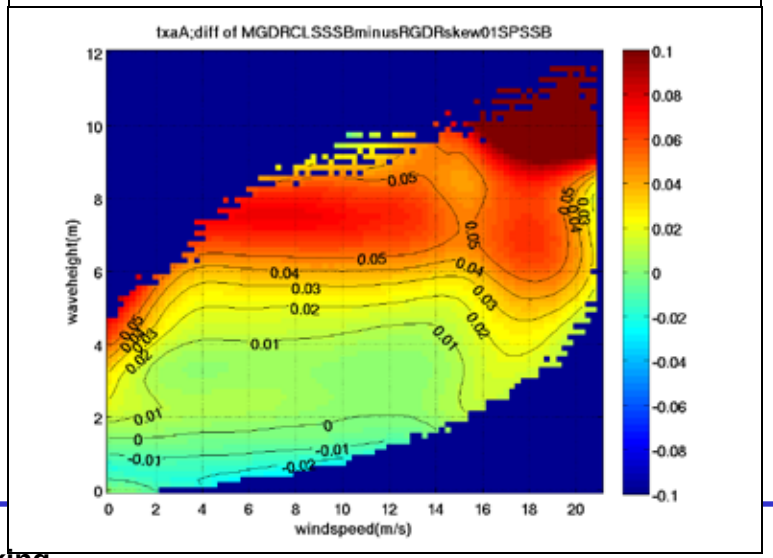
RGDR (skew01) SPSSB2d



SSB difference between b) and a)



SSB difference between b) and c)

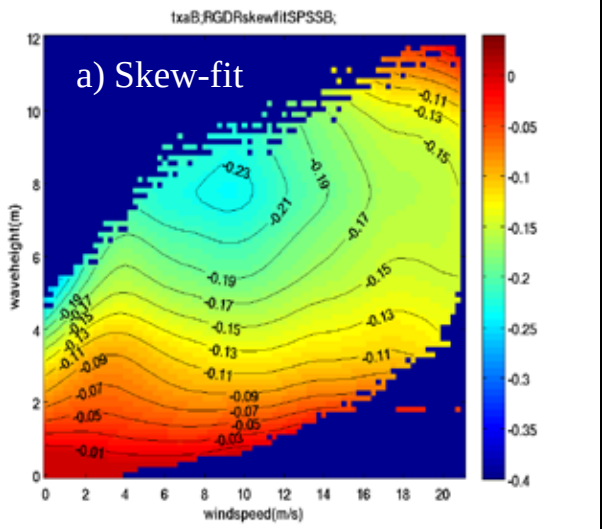


Jet Propulsion Laboratory
California Institute of Technology

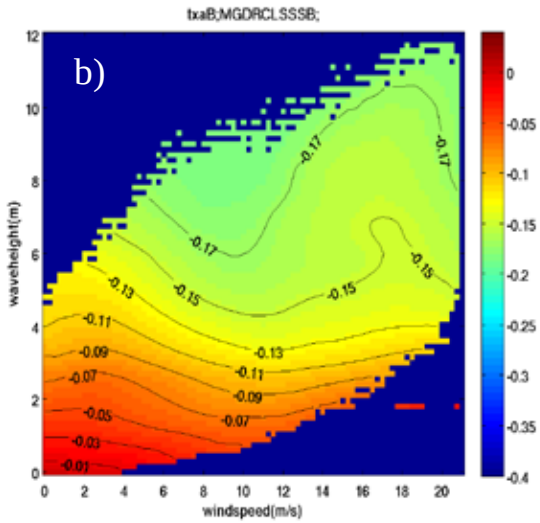
TOPEX Side B: RGDR SPSSB vs. MGDR CLSSSB2d

D. Vandemark, H. Feng analysis

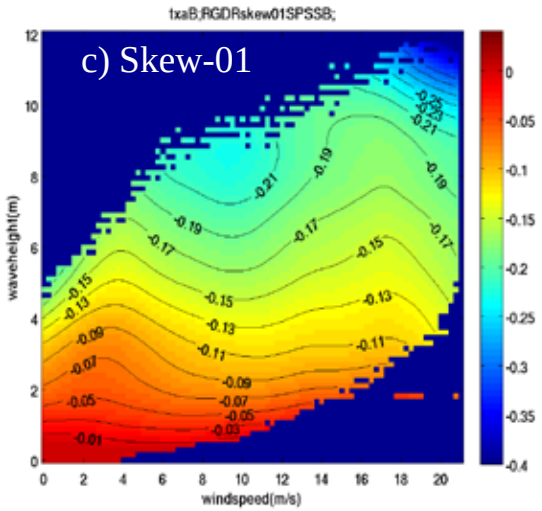
RGDR (skewfit) SPSSB2d



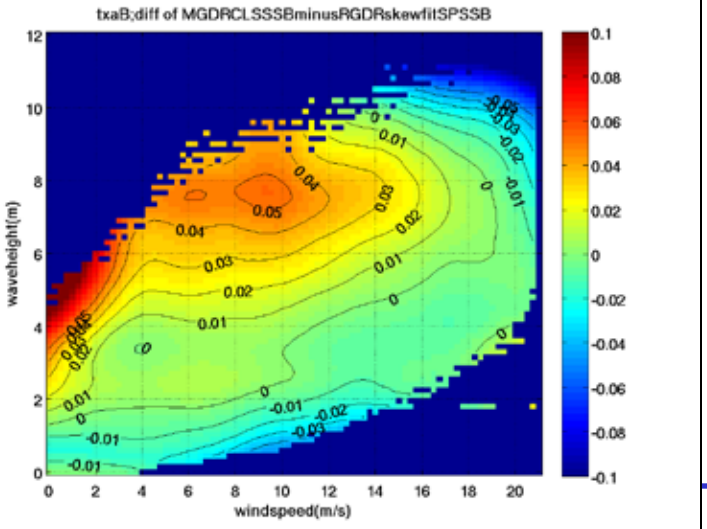
MGDR CLS SSB2d



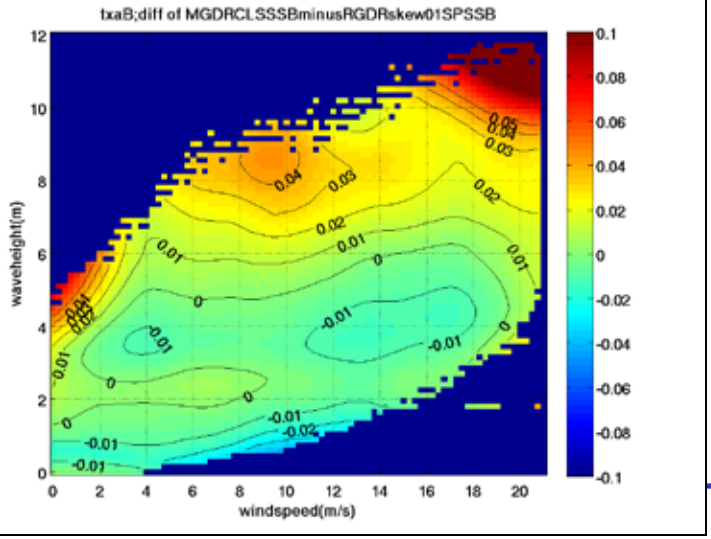
RGDR (skew01) SPSSB2d



SSB difference between b) and a)



SSB difference between b) and c)

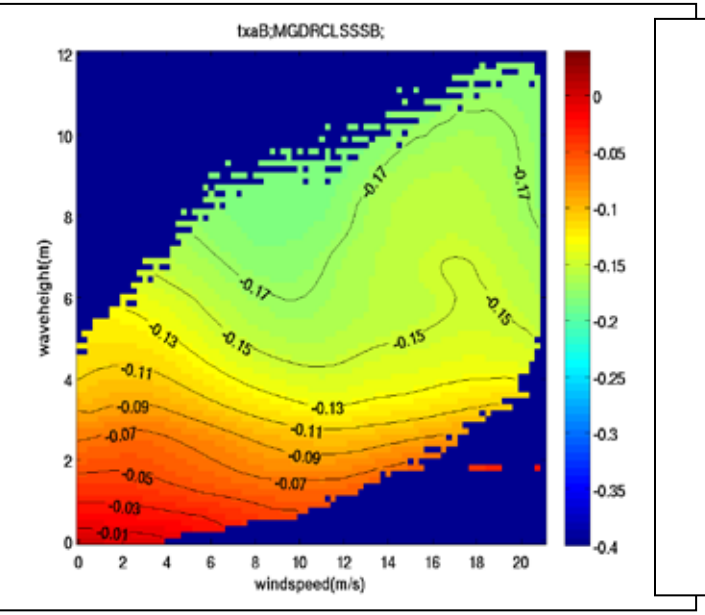


Jet Propulsion
Laboratory
California Institute
of Technology

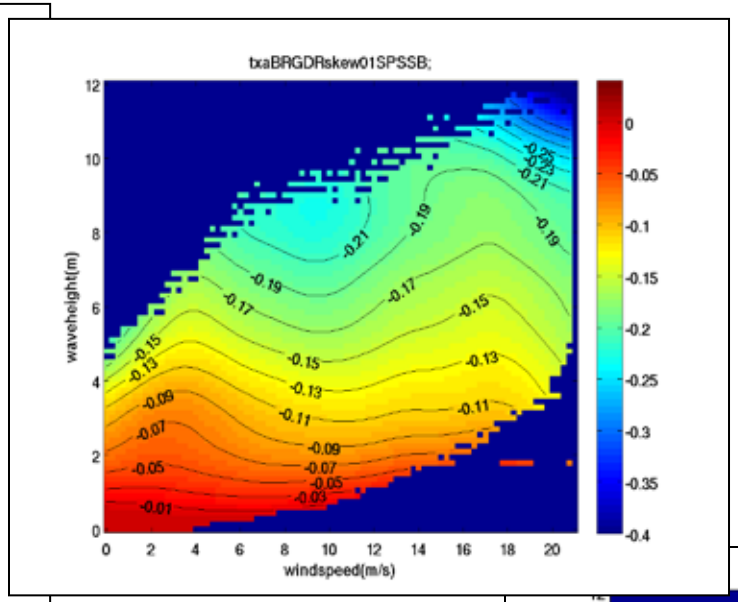
2D SSB models: TPX Side B and J1

RGDR model appears bit closer to J1 in terms of SWH sensitivity

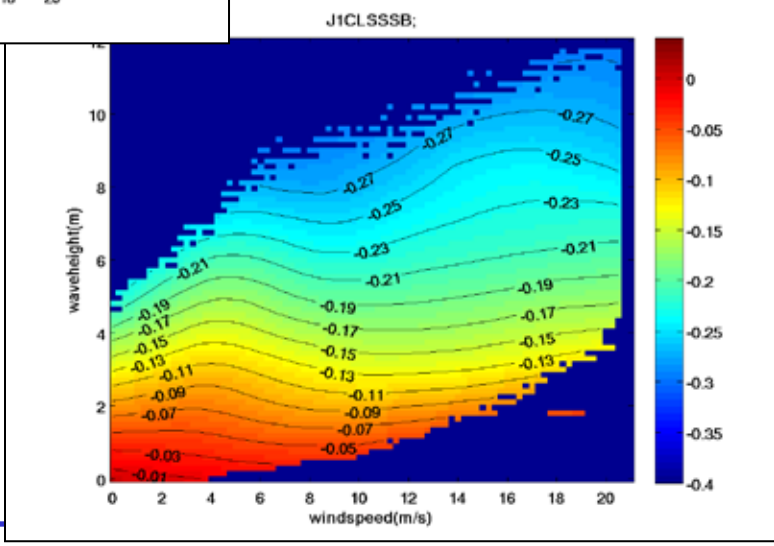
MGDR CLS SSB2d



TxB RGDR (skew01) SPSSB2d



(b) J1 GDR CLS SSB2d



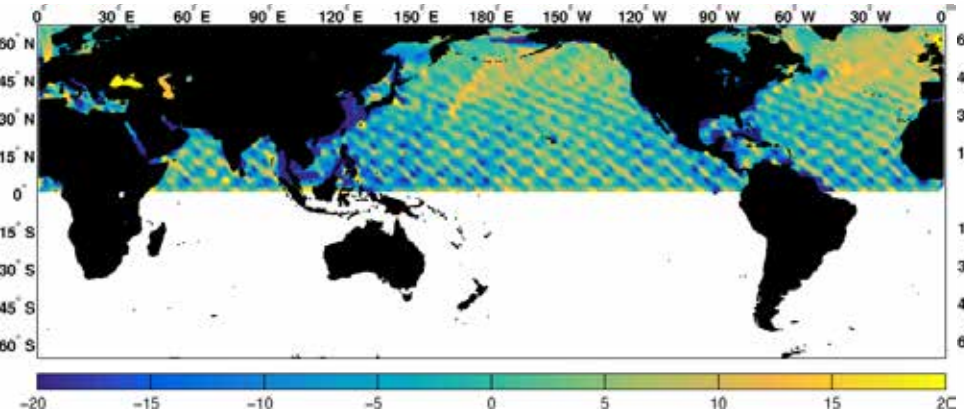
D. Vandemark, H. Feng analysis

Backup Material

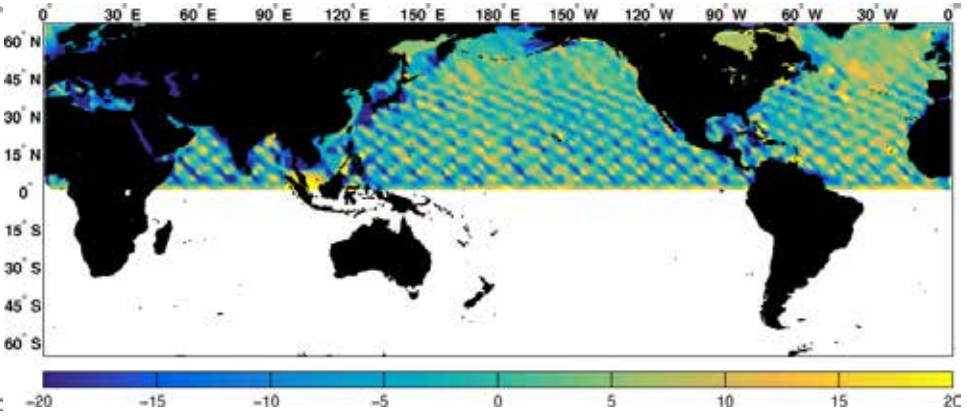
Jet Propulsion Laboratory
California Institute of Technology

TOPEX RGDR, Skew 0.1 - Jason 1 (Orbit – Range – MSS)

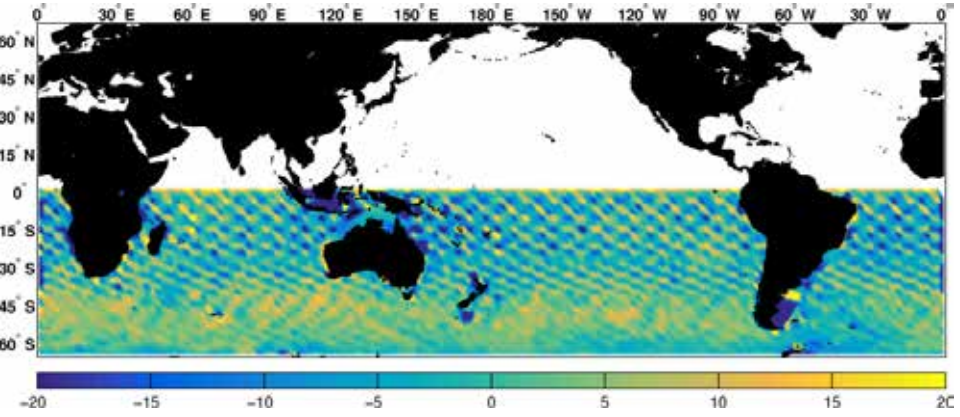
North, Ascending



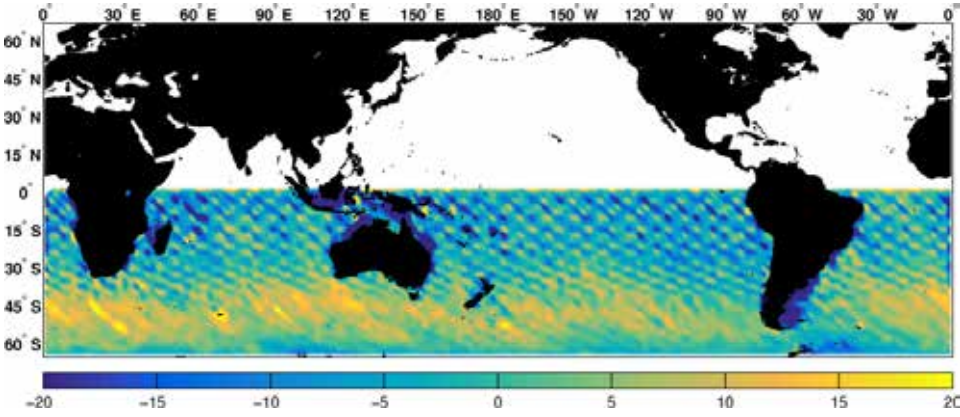
North, Descending



South, Ascending



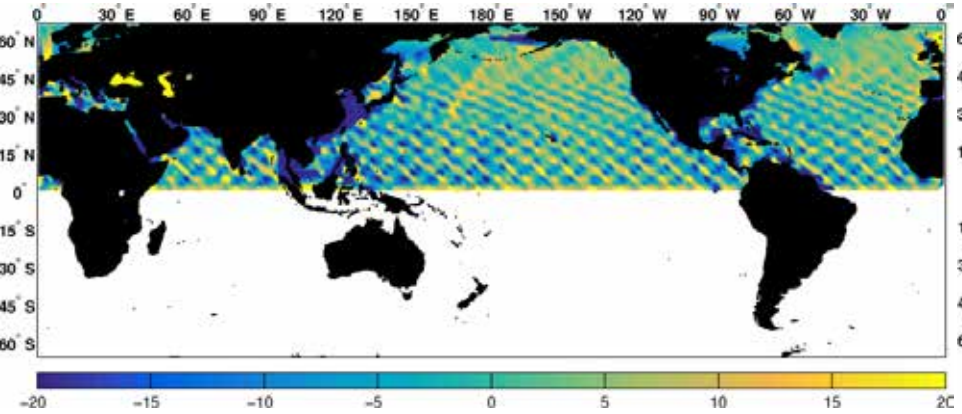
South, Descending



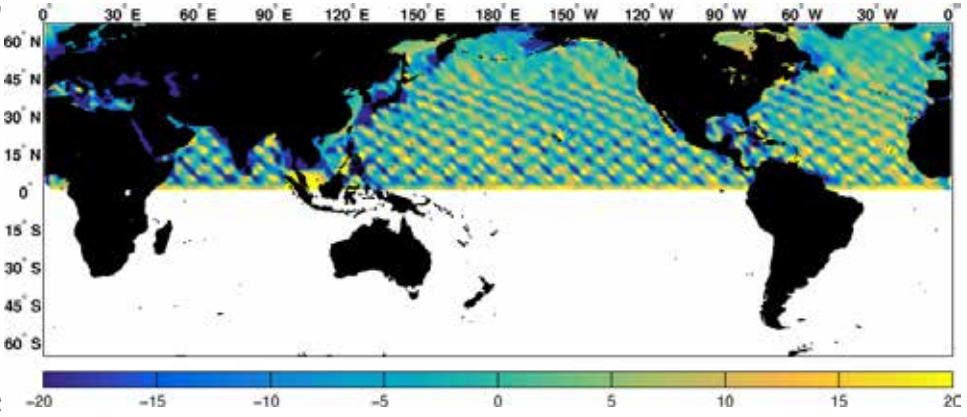
Jet Propulsion
Laboratory
California Institute
of Technology

TOPEX RGDR, Skew 0.1 - Jason 1 (Orbit – Range – MSS – SSB_VAND_2D)

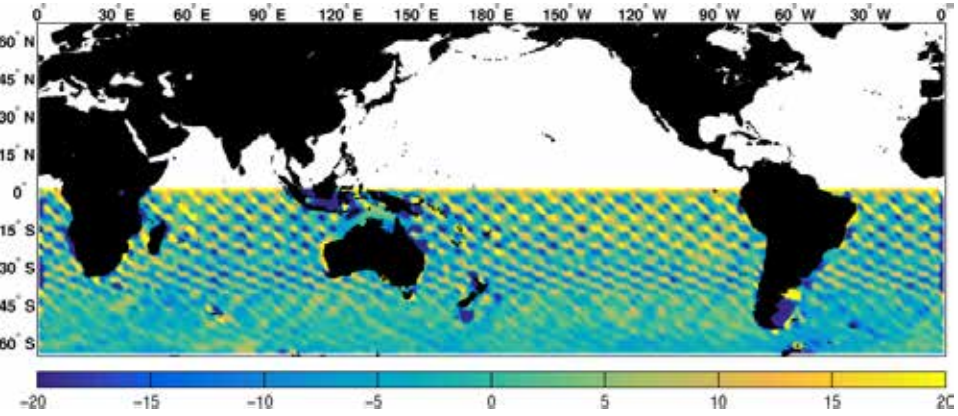
North, Ascending



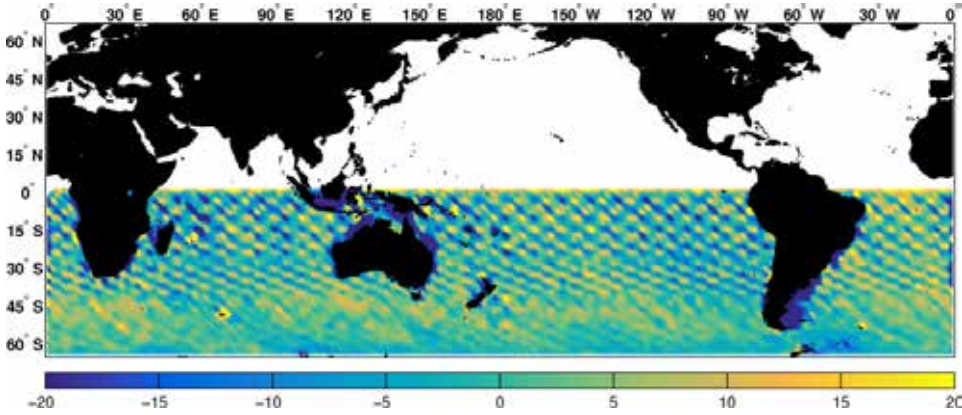
North, Descending



South, Ascending



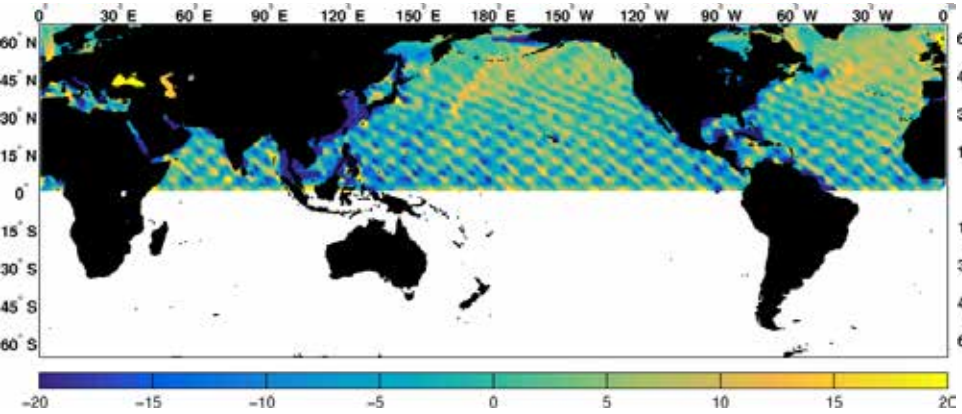
South, Descending



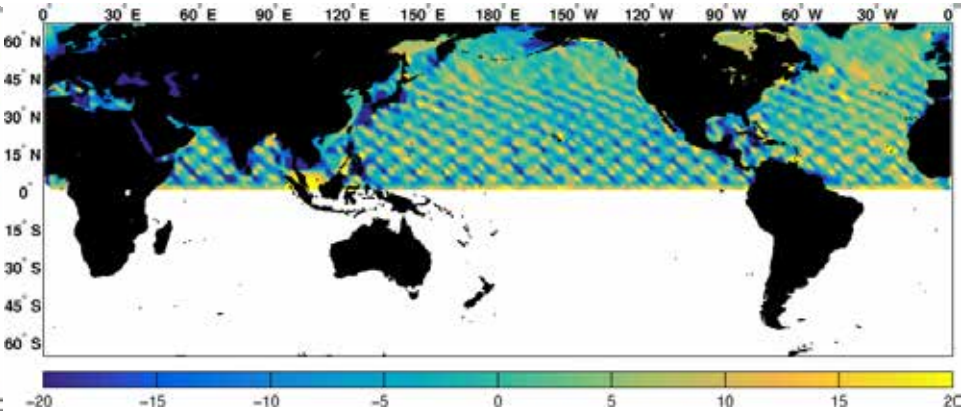
Jet Propulsion Laboratory
California Institute of Technology

TOPEX RGDR, Skew Solve - Jason 1 (Orbit – Range – MSS)

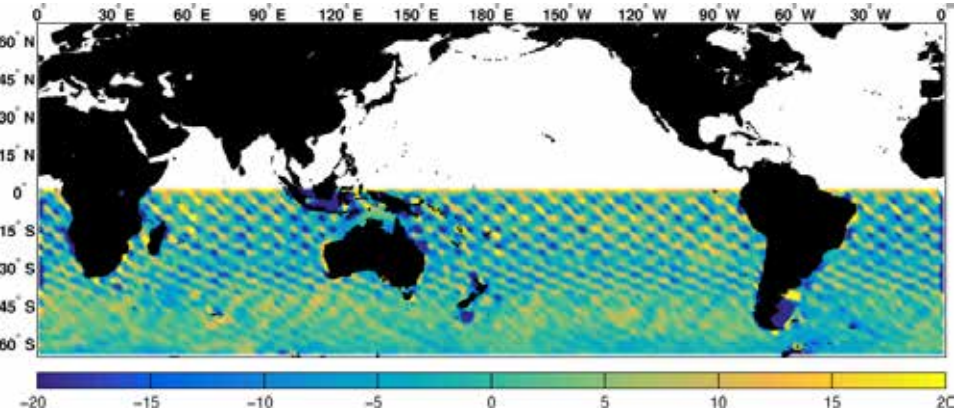
North, Ascending



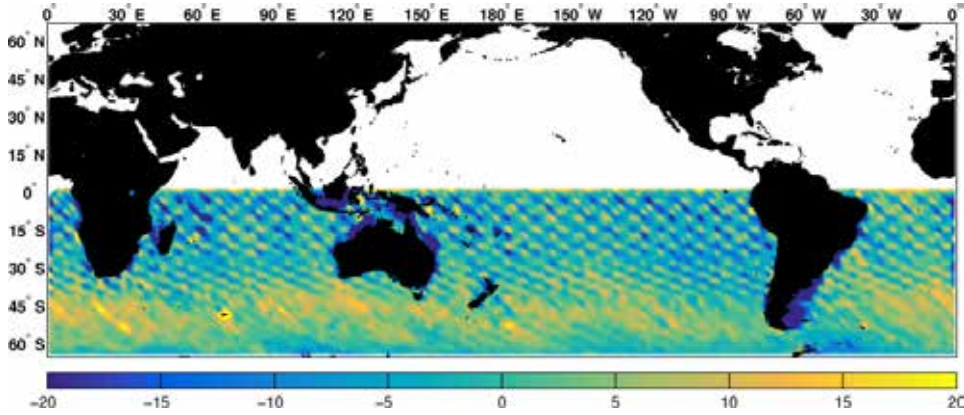
North, Descending



South, Ascending



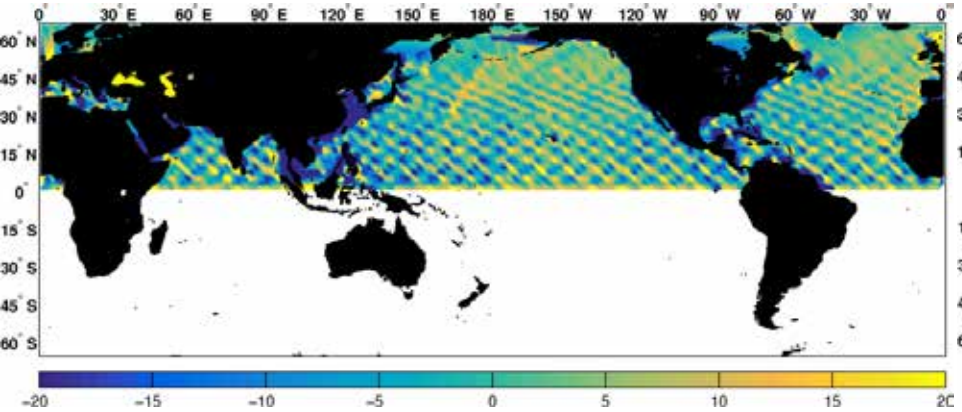
South, Descending



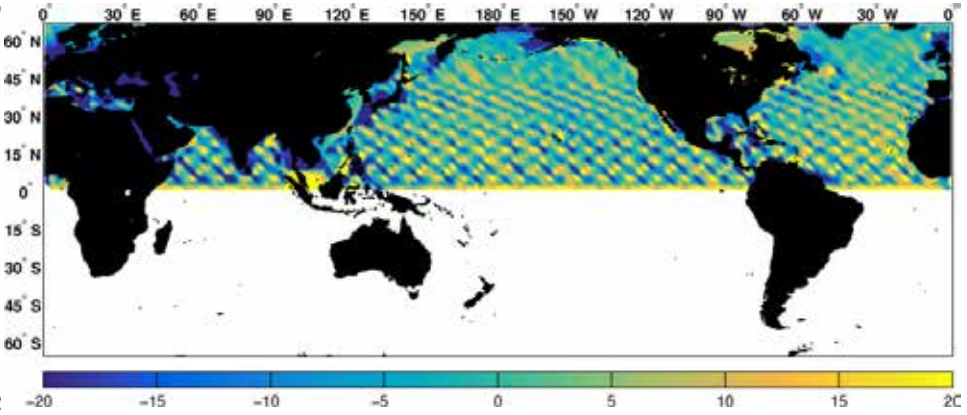
Jet Propulsion
Laboratory
California Institute
of Technology

TOPEX RGDR, Skew Solve - Jason 1 (Orbit – Range – MSS – SSB_VAND_2D)

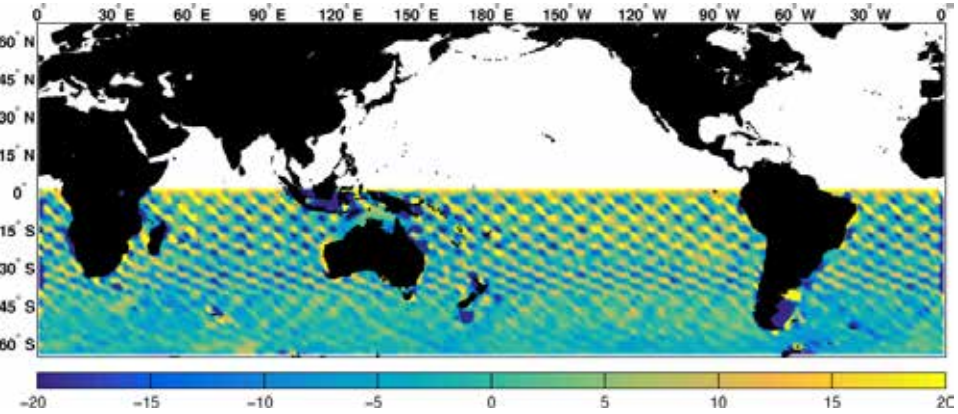
North, Ascending



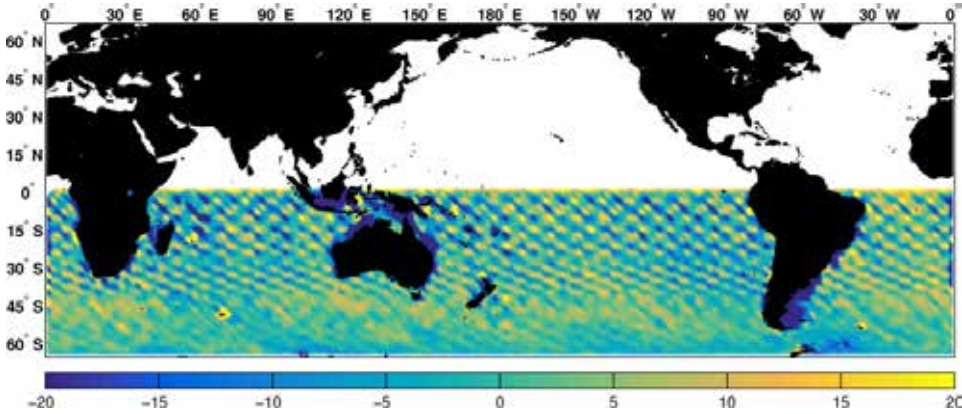
North, Descending



South, Ascending



South, Descending



TOPEX Overview / History

- TOPEX standard processing did not include retracking
  - Quantities were estimated onboard with "adaptive gate" (SWH dependent) tracker using sums of power in waveform gates
  - Ground processing corrections for pointing angle and SWH from simulations
- 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

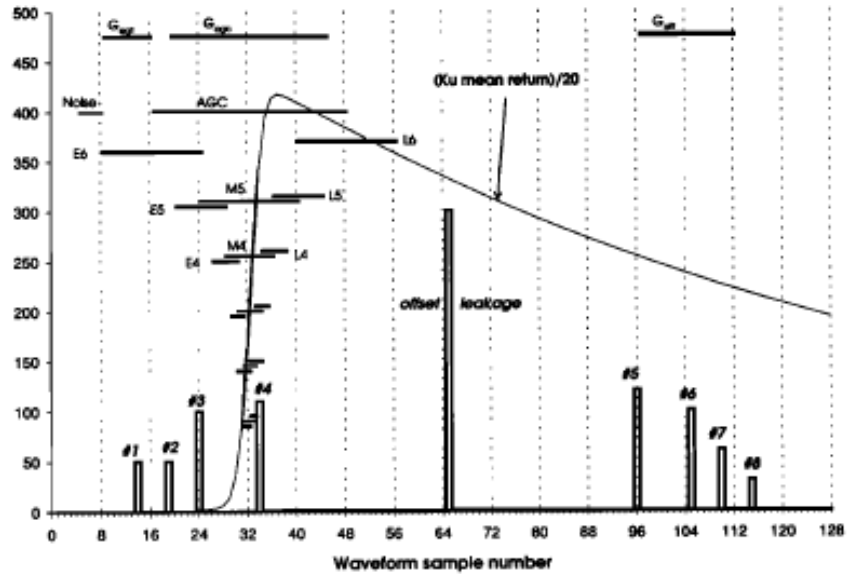
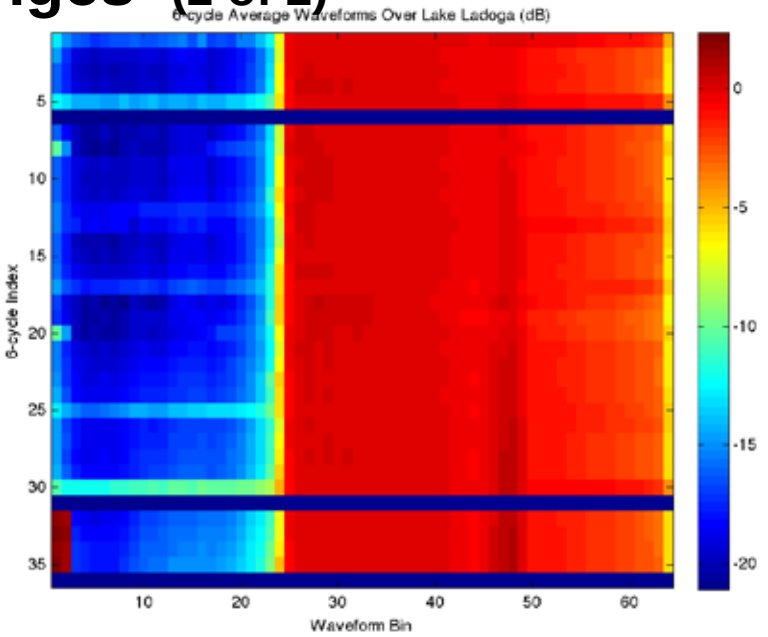


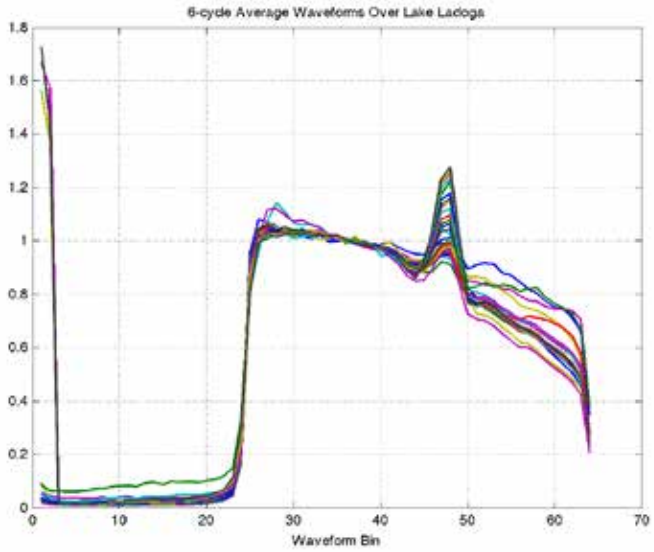
Figure 6. TOPEX Ku altimeter gates, mean return, and center locations of waveform leakage spikes.

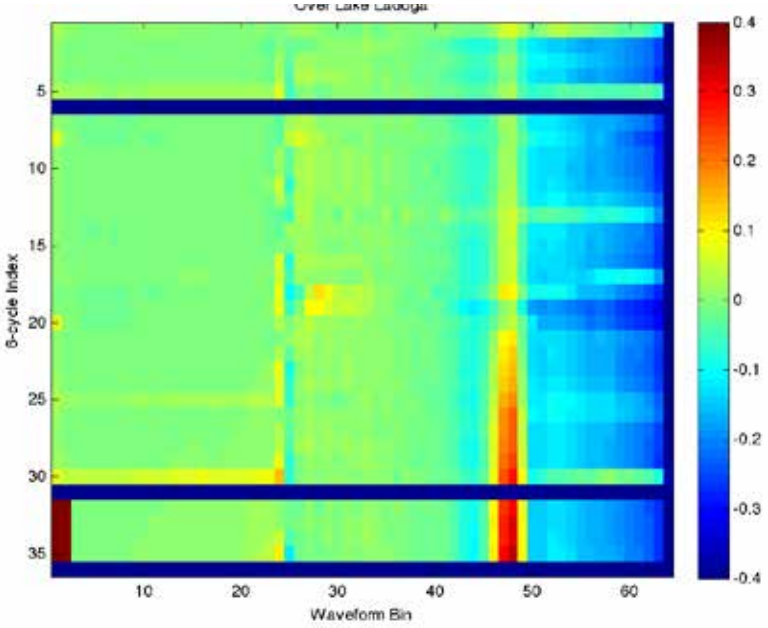
- Leakages (x20) in the TOPEX Alt-A waveform from Hayne et al., 1994, JGR, ***99***, 24,941.
  - Need correction in processing via masking or "weights" on WF gates
  - Move with range rate giving North/South Ascending/Descending ("toward" / "away" Eq) differences
  - Onboard gates used to estimate the same parameters obtained from retracking shown as bars

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



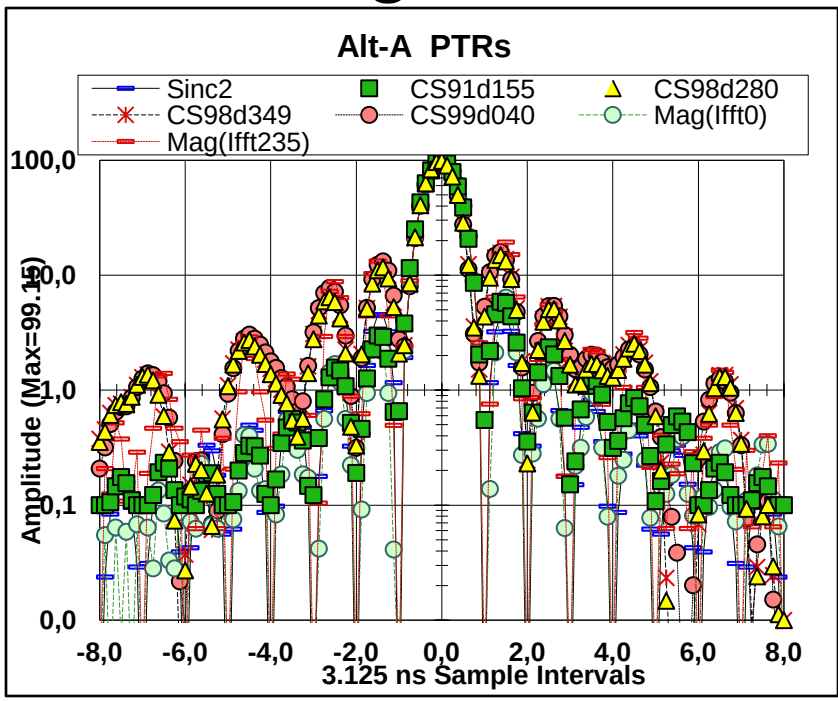


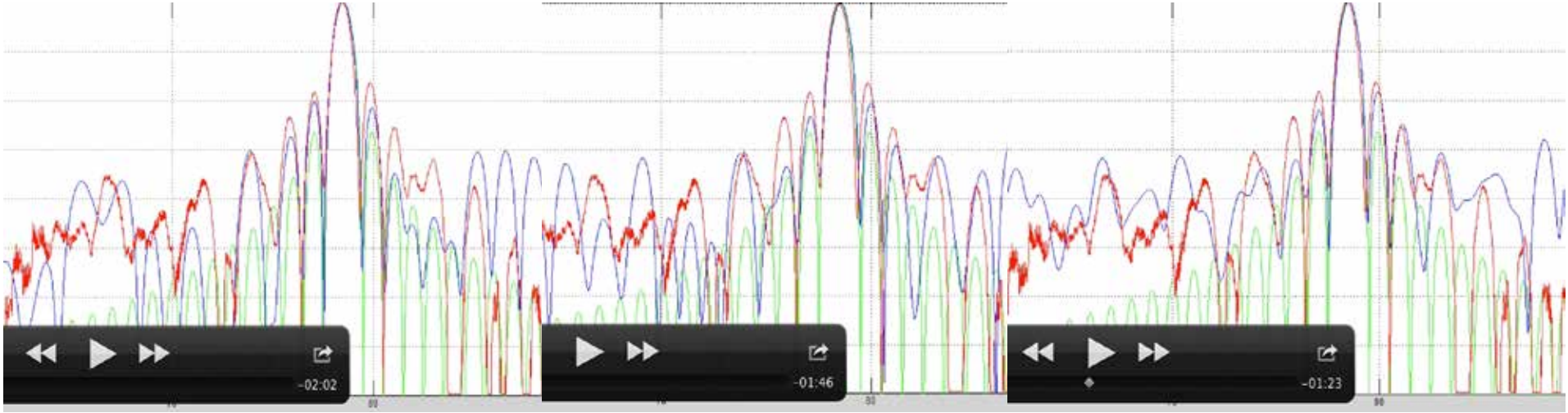


Jet Propulsion Laboratory
California Institute of Technology

TOPEX Alt-A PTR Changes

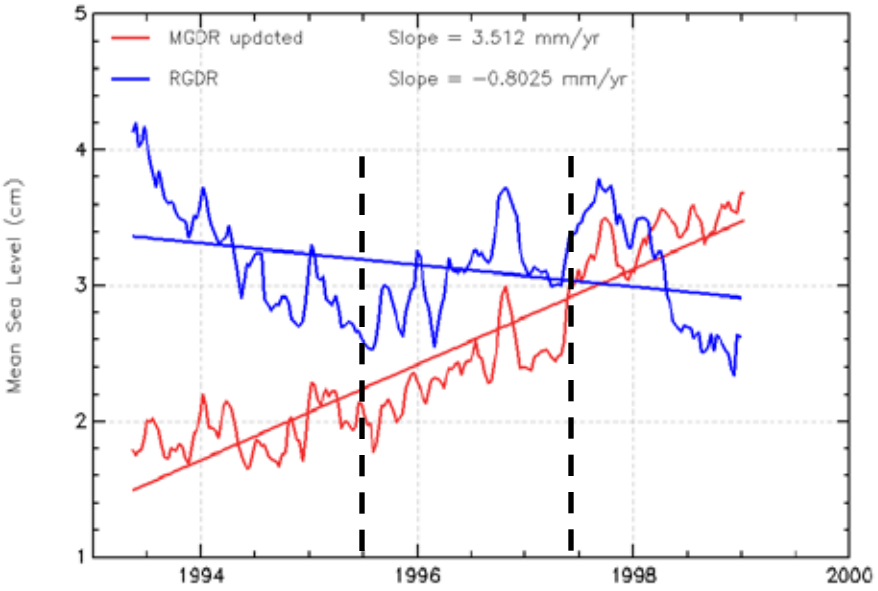
- TOPEX Alt-A PTR degradation – increase and distortion of sidelobes likely caused by I/Q phase difference (Jensen analysis)
  - "Cal Sweeps" done only late in 1998
- Reproduced Jensen analysis
  - Effect depends on center location. Figures below shows I/Q phase diff 18 deg, 3 different center locations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



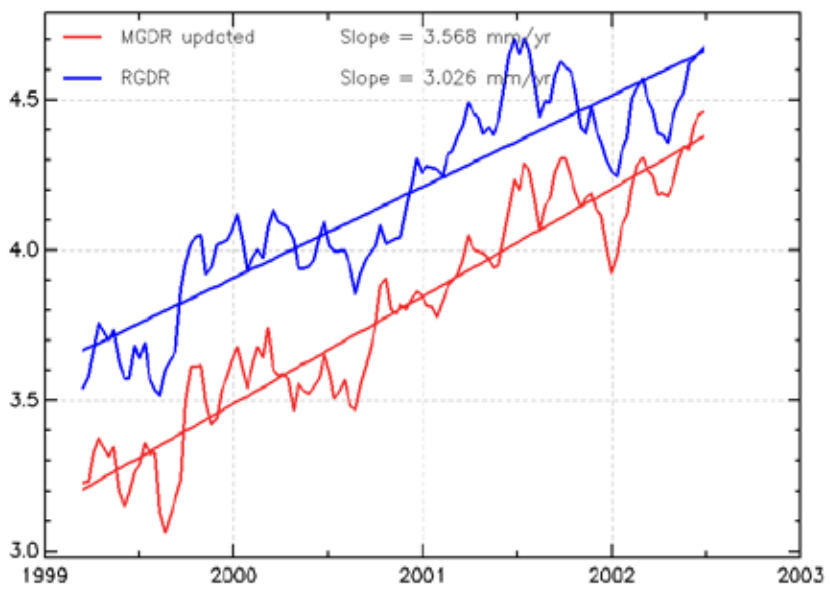


Mean Sea Level Analysis by S. Labroue (CNES) '09 OSTST

Side A MSL



Side B MSL

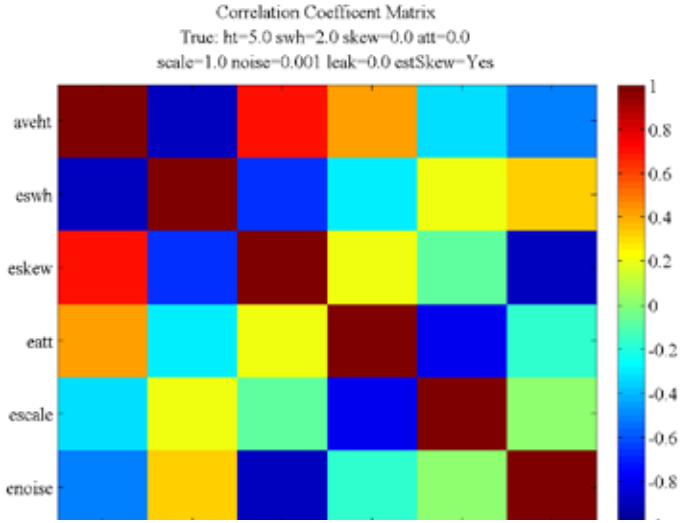


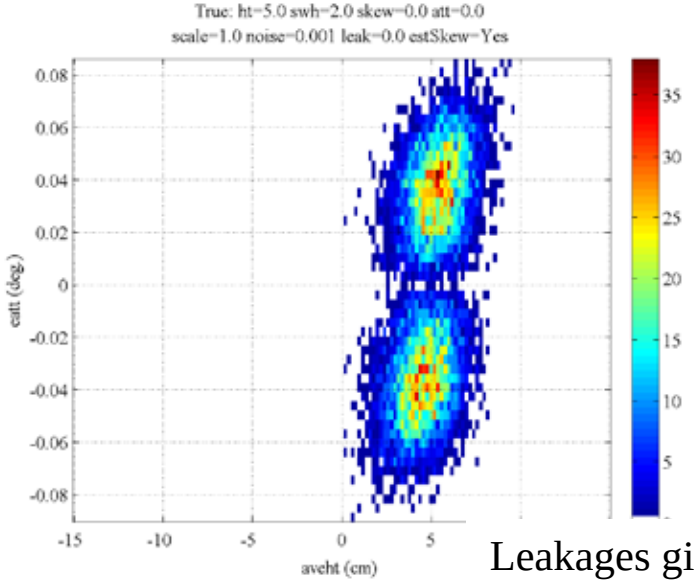
- Side A MSL with RDGR shows strong discrepancy with respect to MGDR MSL. RGDR exhibits a false curve and trend (-0.8 mm/year!!!!). The main differences appear at the beginning and the end of the time series.
- Side B MSL with RGDR data presents a trend lowered by 0.55 mm/year which is significant for 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.

Simulation Results

Parameter Correlation Solving for Skewness





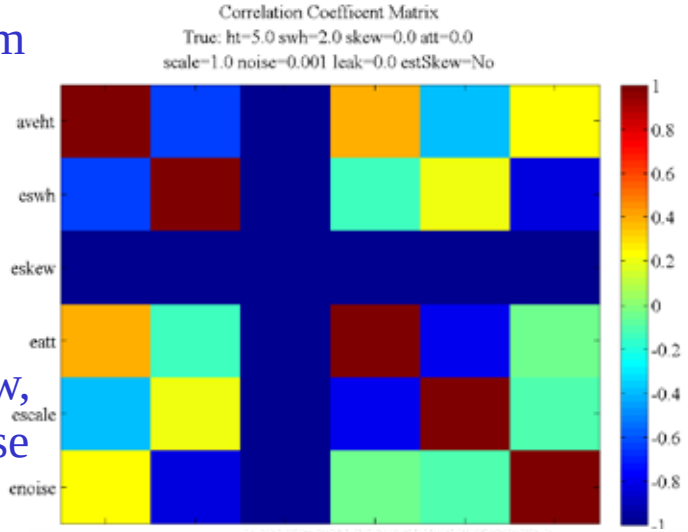
All: SWH = 2 m
Att = 0
Skew = 0
dH = 5 cm

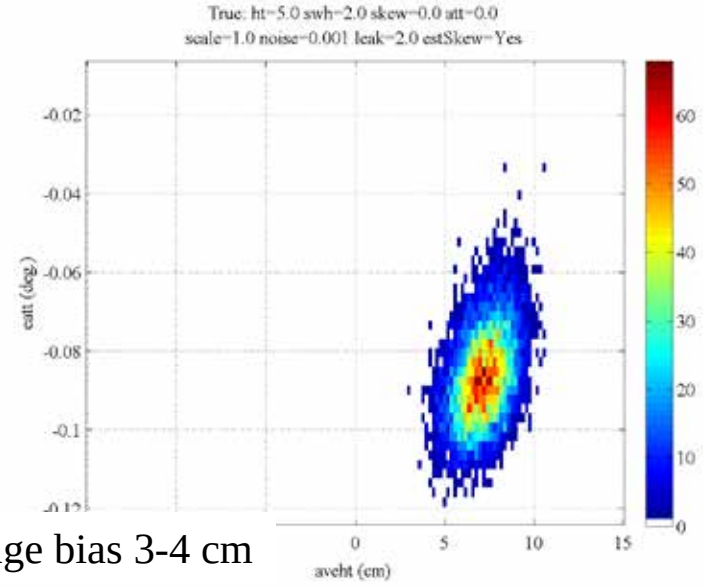
Parameters:
dH, SWH, Skew,
Att, Scale, Noise

ç Leakage = 0

Leakage = 2X
è
2D Histogram:
Att / dH

Parameter Correlation Not Solving for Skewness





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

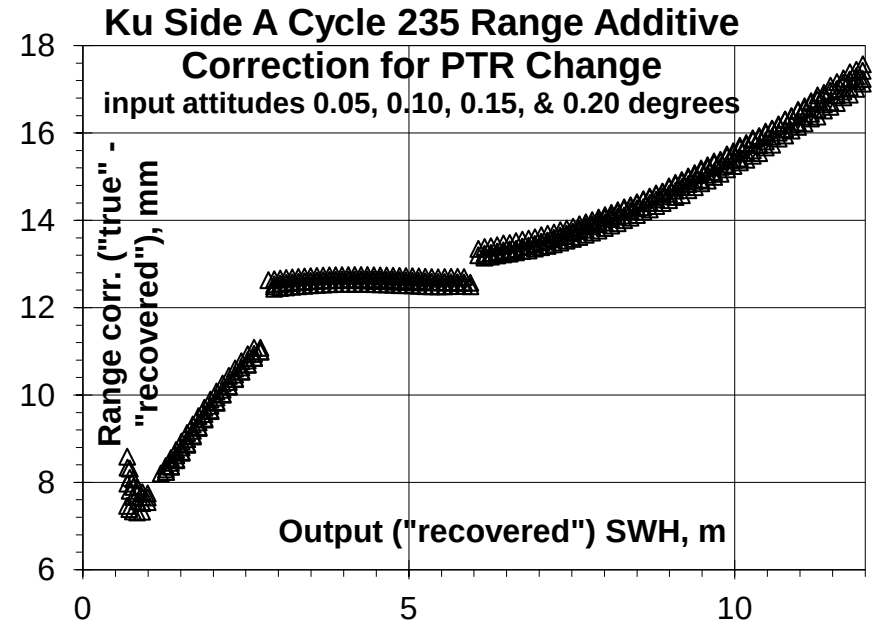
Alt-A PTR Change Simulation

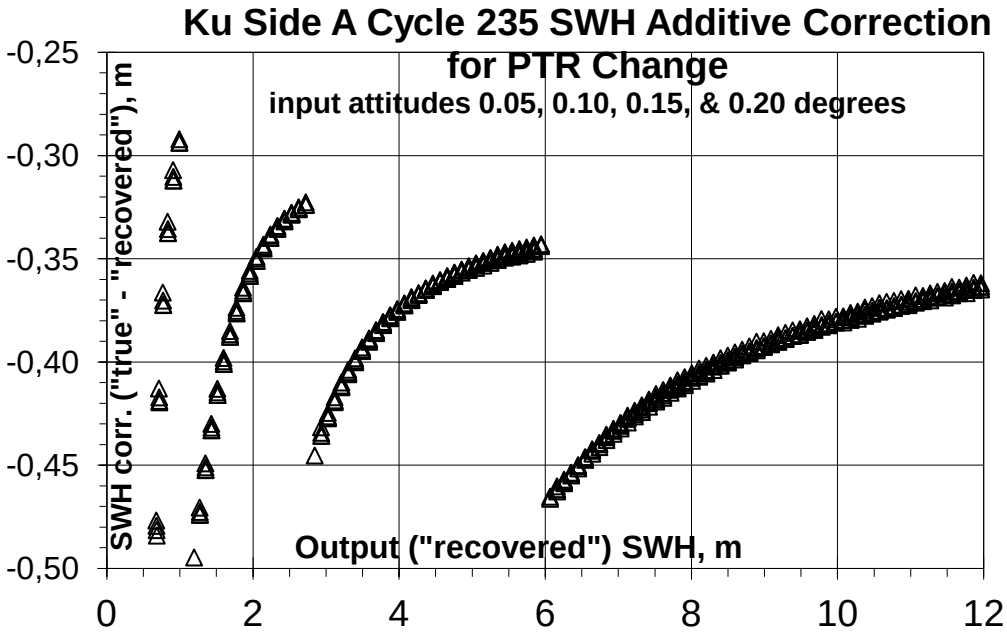
Simulation by G. Hayne (WFF) of change in Range and SWH as a function of SWH for PTR of Cycle 235 (discontinuities reflect internal altimeter function – change in adaptive gate widths).

Left: Range error of ~ 8-13 mm for typical SWH of 1.5 – 6 m.

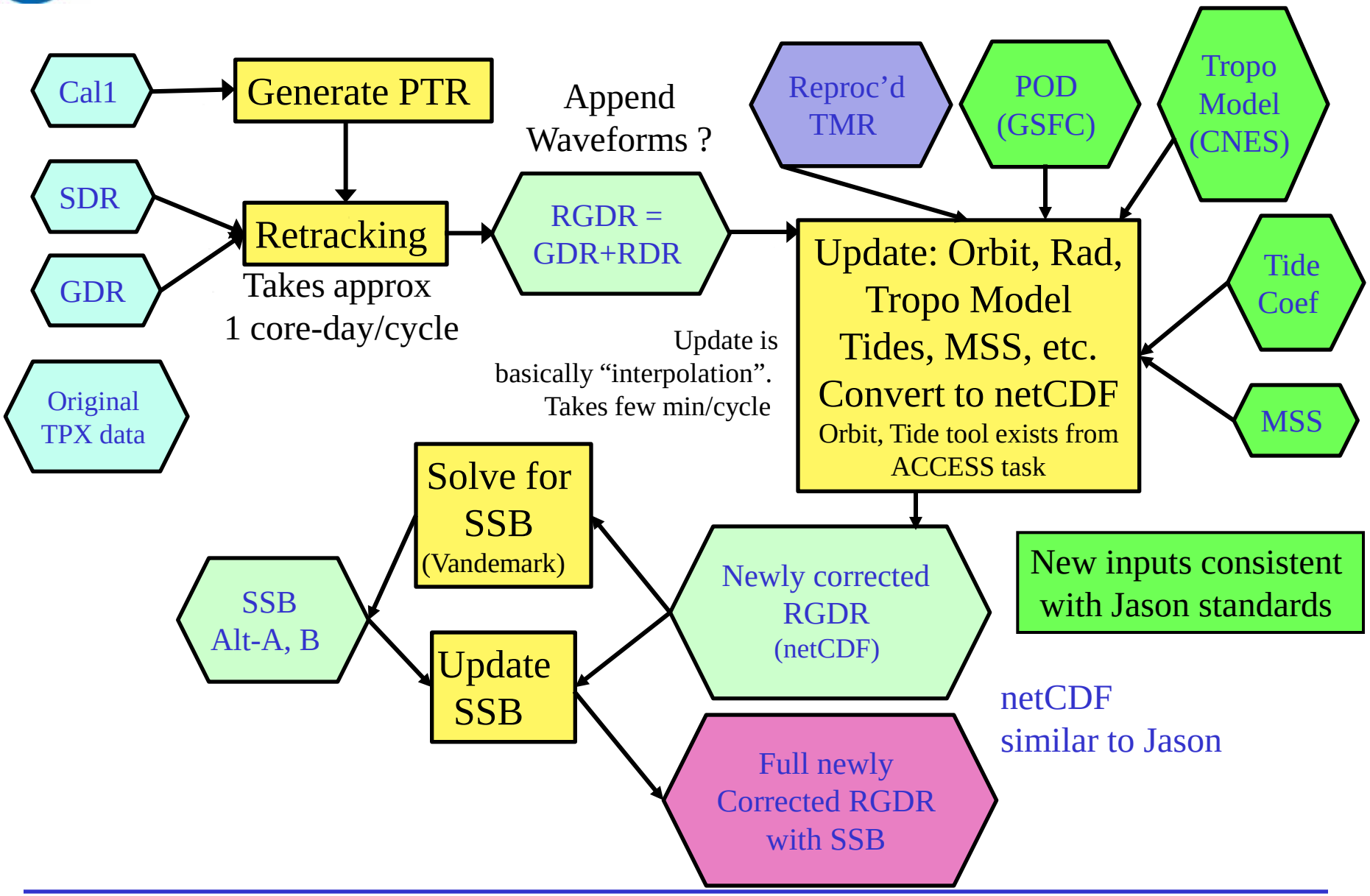
Right: SWH error of ~ 0.4 m as observed (slide 4).

The change in apparent altimeter SWH will also change the calculated Sea State Bias correction.





TOPEX 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
  - è 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