Jet Propulsion
Laboratory
California Institute
of Technology

Progress in Retracking TOPEX Data for the Climate Data Record

OSTST October 2014

Phil Callahan, Joseph McMichael, Brent A. Williams
Jet Propulsion Laboratory,
California Institute of Technology

Outline / Overview

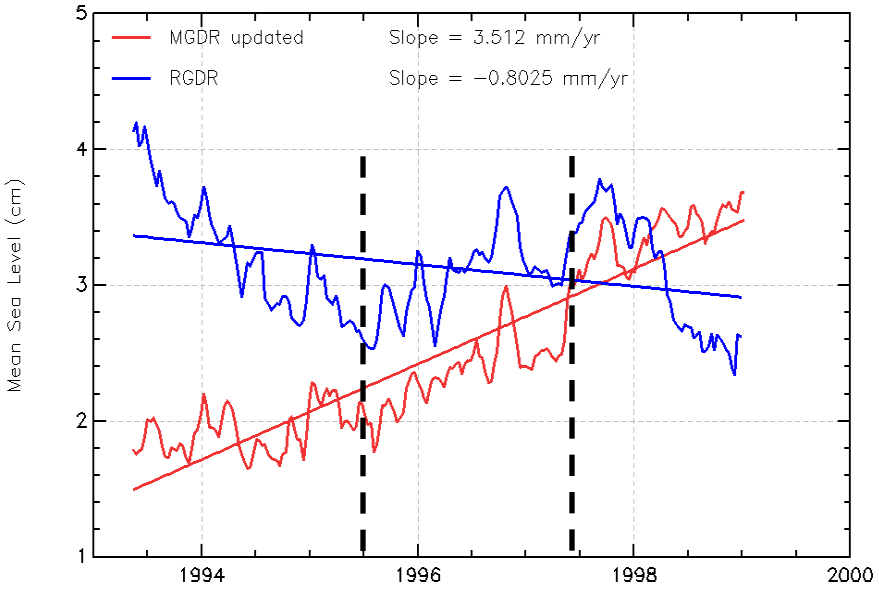
- Work funded by TOPEX/Jason-1 Project and NOAA Climate Data Records program task: “Generation of Altimeter Climate Data Records Using Retracking and Updated Corrections”
- TOPEX Retracking Overview, History
- New Results on Alt-A PTR Changes and Cal Data
- Recent Retracking Results
- GDR Update Plan

TOPEX Retracking Overview / History

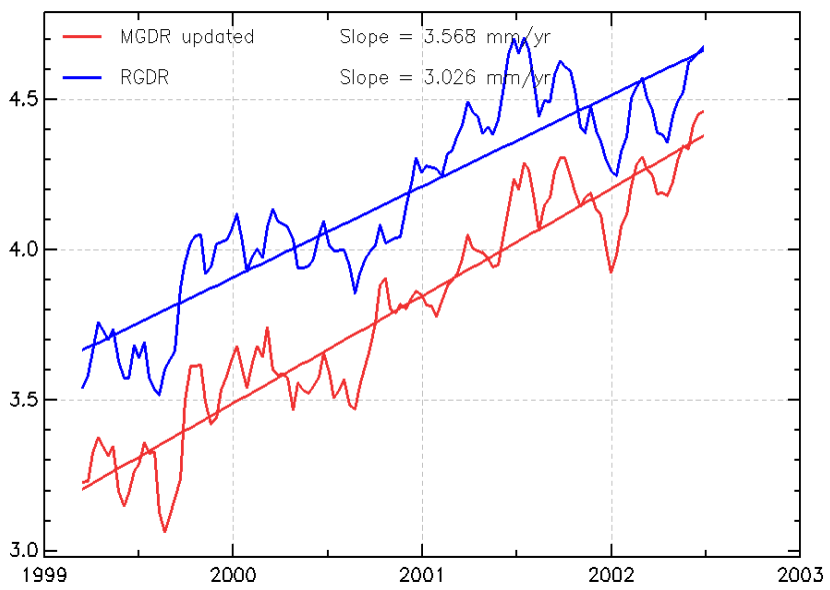
- TOPEX standard processing did not include retracking
  - Quantities were estimated onboard with "adaptive gate" (SWH dependent) tracker using sums of power in waveform gates
  - Ground processing corrections for pointing angle and SWH from simulations
- Alt-A had changes in Point Target Response (PTR) 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
- Previous versions of retracking in 2007, 2009
  - 2007 used original WFF waveform (WF) weights/gains, hand fit PTRs to some, especially late Alt-A, Cal-1 data
  - 2009 used refit WF weights, systematically fit PTRs to Cal-1 data to 10 lobes
  - Analysis by Labroue '09 (next page) showed that 2007 agree with MSL trend and improved agreement with Jason-1, while 2009 cased negative MSL trend and SSB was similar to original MGDR and rather different than that for Jason-1

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

Side A MSL



Side B MSL



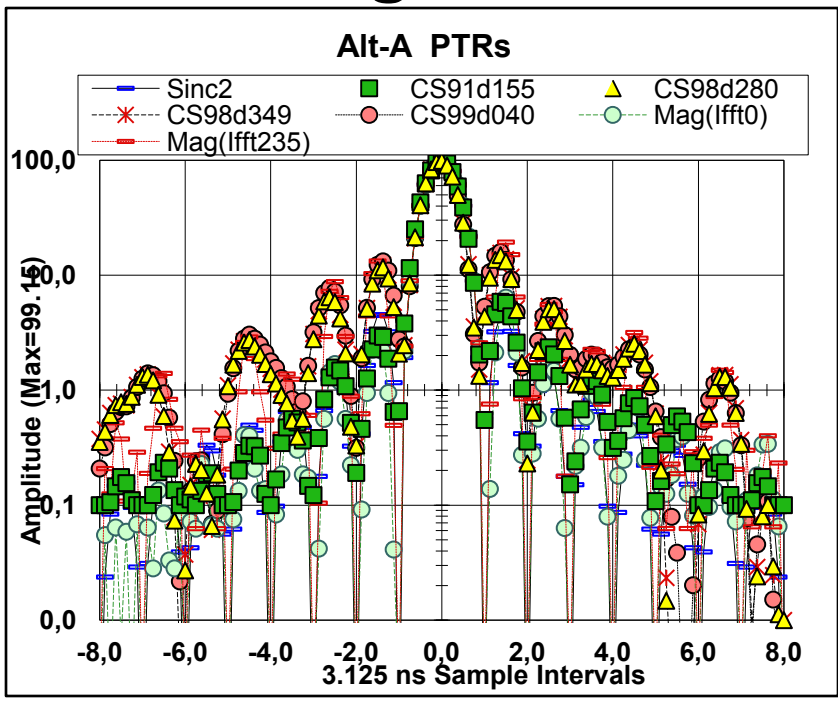
- Side A MSL with RDGR shows strong discrepancy with respect to MGDR MSL. RGDR exhibits a false curve and trend (-0.8 mm/year!!!!). The main differences appear at the beginning and the end of the time series.
- Side B MSL with RGDR data presents a trend lowered by 0.55 mm/year which is significant for MSL studies. We are more confident in MGDR MSL since side B is very stable (validated against in situ data and Jason-1 data)

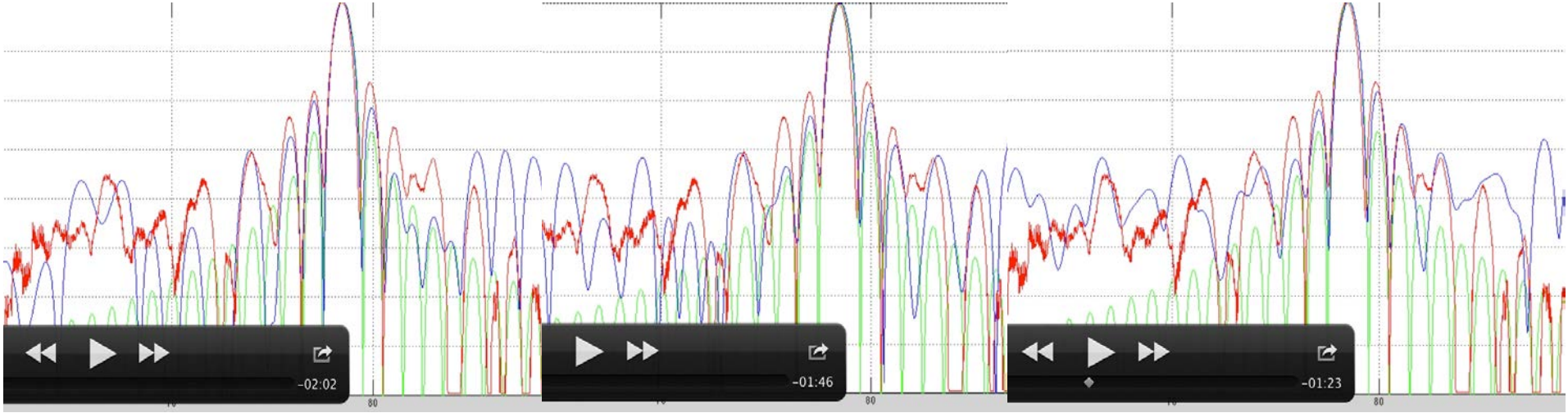
Careful assessment of the PTR correction needs to be performed on the SSH (including PTR corrections on range and SWH (through SSB)). A SSB has been estimated on RGDR products for each altimeter.

Jet Propulsion Laboratory
California Institute of Technology

TOPEX Alt-A PTR Changes

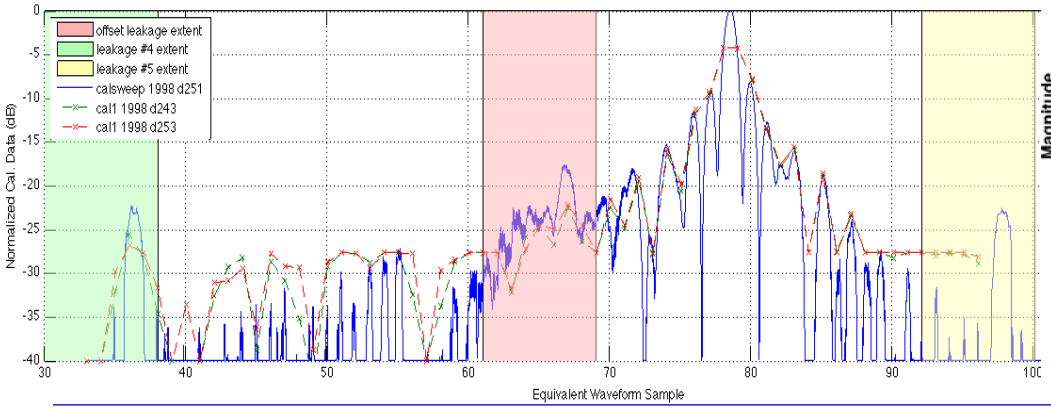
- TOPEX Alt-A PTR degradation – increase and distortion of sidelobes likely caused by I/Q phase difference
  - "Cal Sweeps" done only late in 1998
- Reproduced Jensen analysis
  - Reproduced Jensen analysis.
  - Effect depends on center location. Figures below shows I/Q phase diff 18 deg, 3 different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

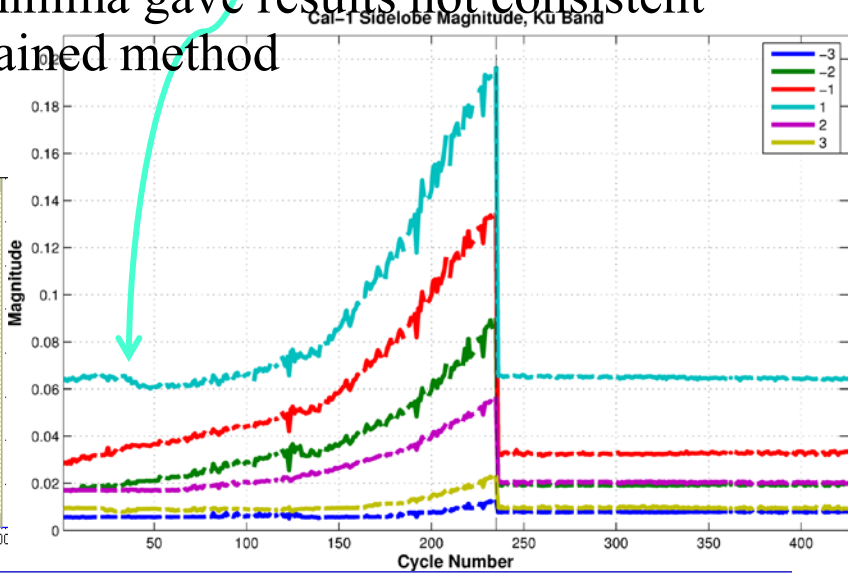




Usable Cal Data

- Revisited Cal data based on review of leakage transfer through signal path. Cal-1 data are just Nyquist sampled.
  - Data in colored areas are contaminated, should not be used in PTR – can only use lobes +/-6 from Cal-1 data
  - Changes in sidelobes near cycle 50: Side lobe +1 drop; 7-10 are below noise before (not shown)
- Developed 2 methods to extend PTR to ~ +/-30 lobes 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





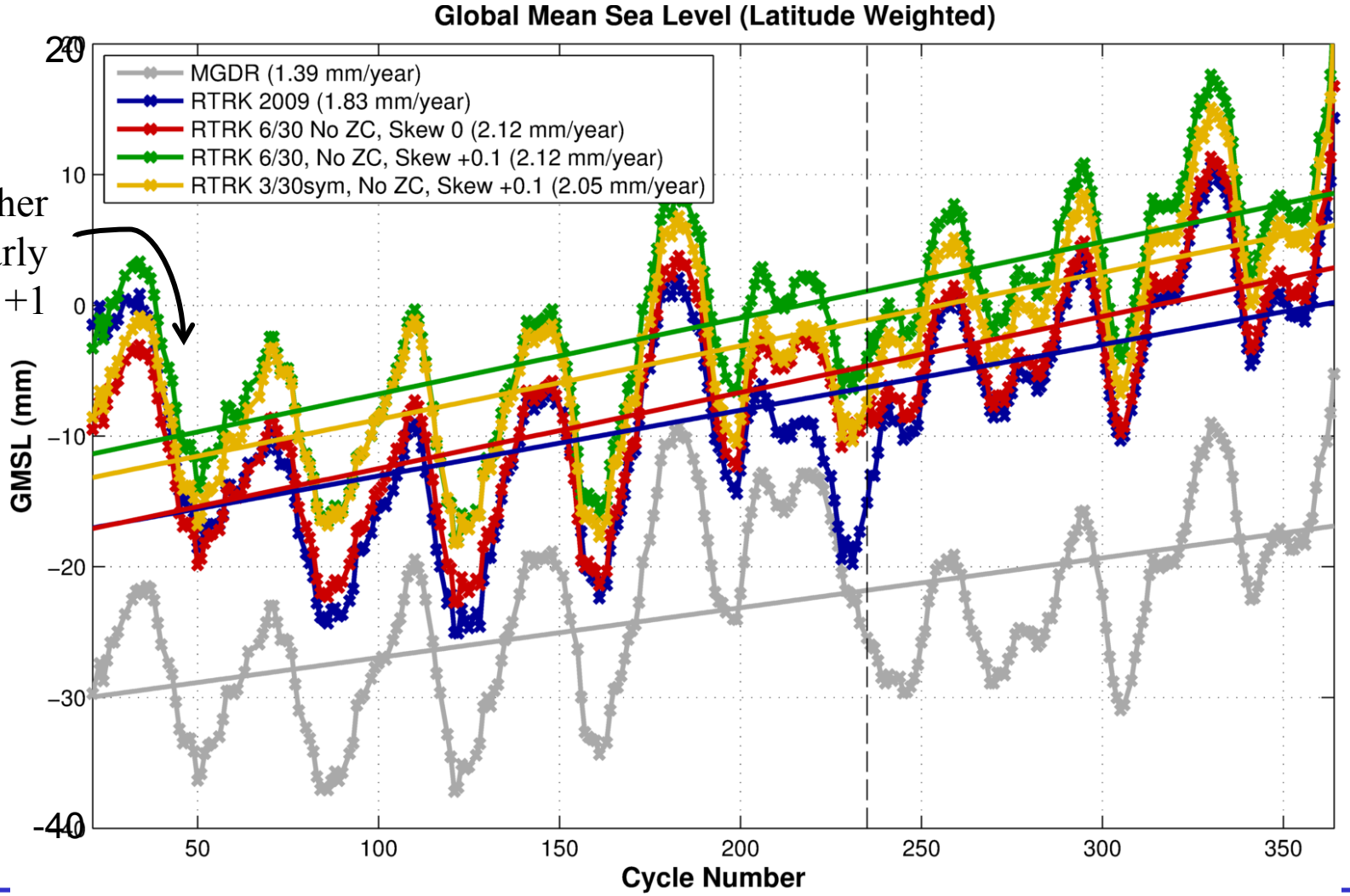
Retracking Processing

- Obtained computer that can process TOPEX cycles 20 – 364 in about 1 week
- Updated scripts so no passes are lost
- Updated code so can fix skewness
  - Decided from parameter correlation analysis that solving for skewness to absorb leakages was not the best approach
- Tested various PTR fitting methods and various skewness values
- Ran full data sets for PTRs from +/-6 Cal-1 lobes extended to +/-30 lobes
  - Fixed Skewness = 0, 0.1
  - Fitting Skewness (previous results)
- Did run with PTR from +/-3 Cal-1 lobes extended to +/-30 lobes
  - Very similar to 6/30 run, so not shown
- Have done initial comparisons to Jason-1 during overlap period (next pages)

Analysis: 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

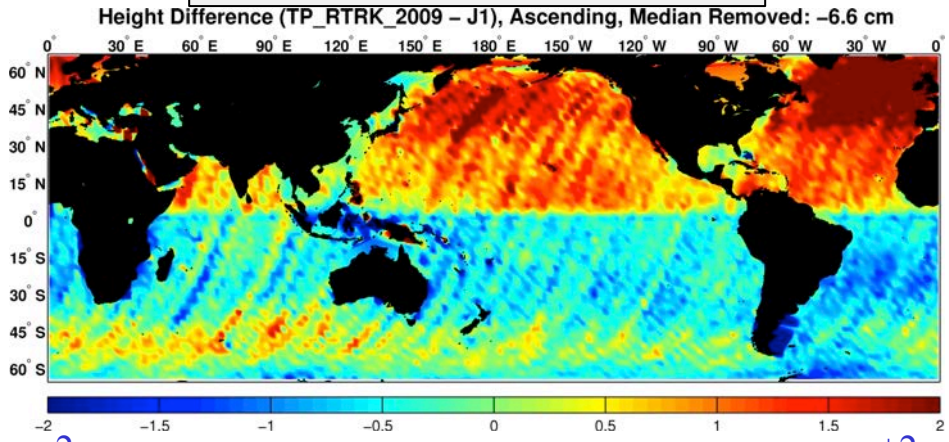
From higher early sidelobe +1



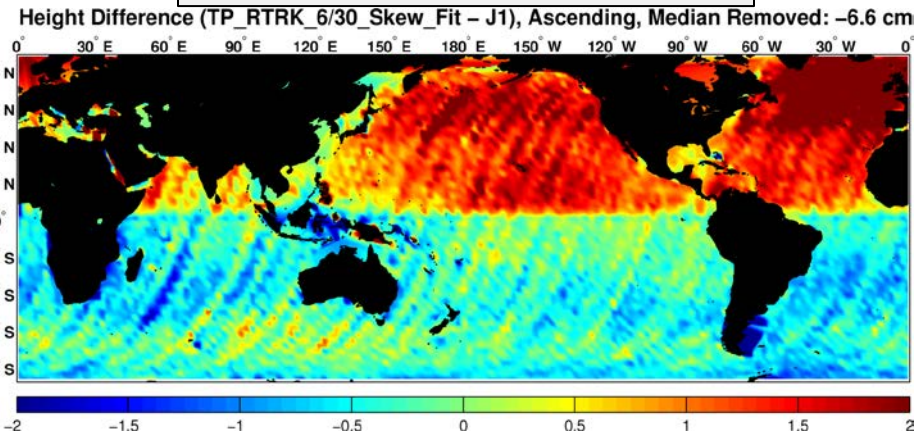
Jet Propulsion
Laboratory
California Institute
of Technology

TOPEX – Jason-1 SSH Comparison – Asc

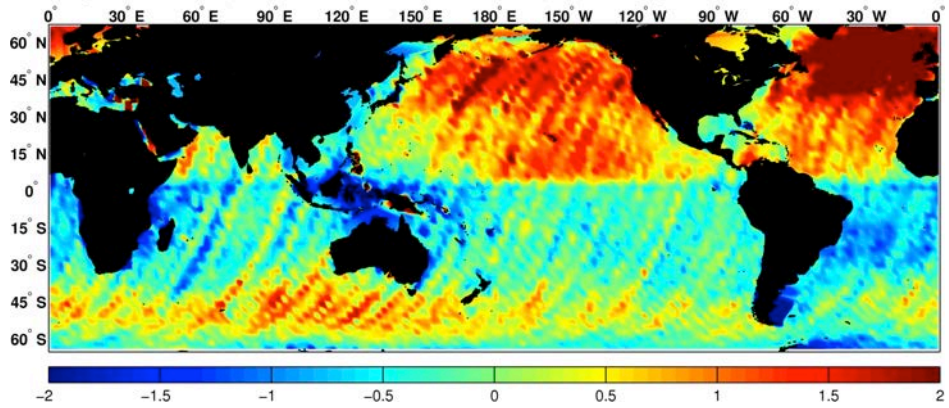
Retrk09 Skew Fit – J1



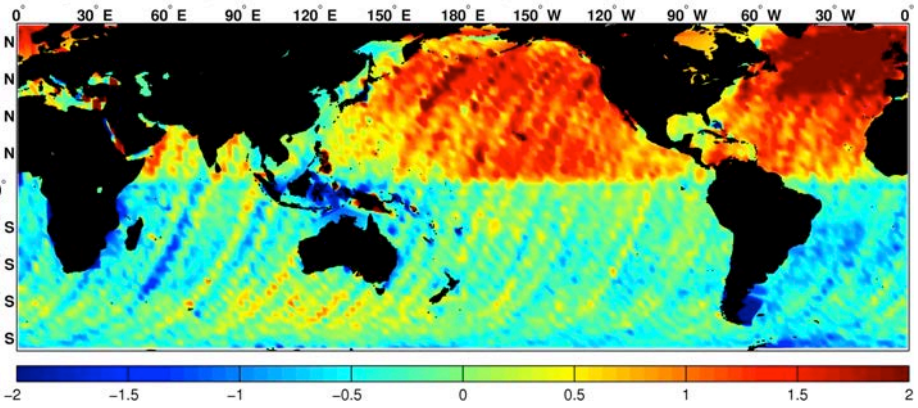
Retrk14 6/30 Skew Fit – J1



Retrk14 6/30 Skew = 0.1 – J1



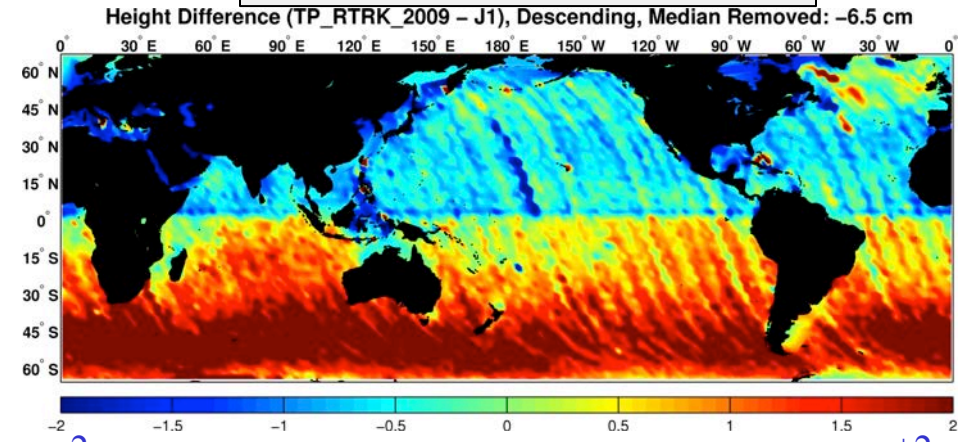
Retrk14 6/30 Skew = 0 – J1



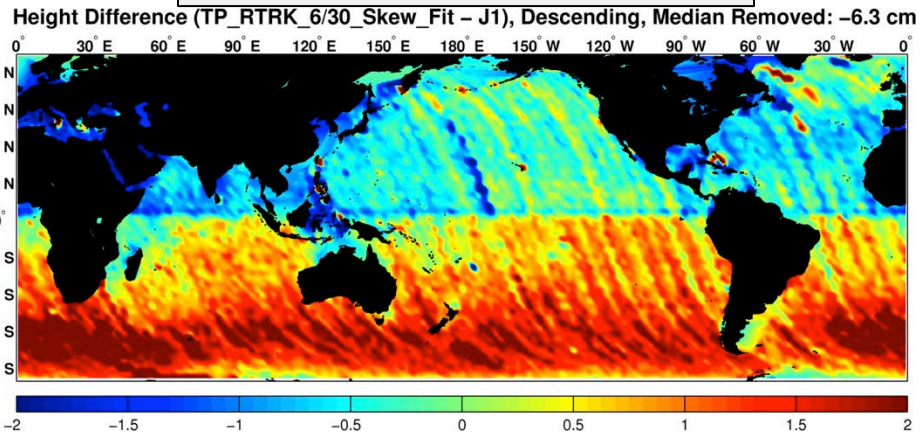
Jet Propulsion Laboratory
California Institute of Technology

TOPEX – Jason-1 SSH Comparison – Des

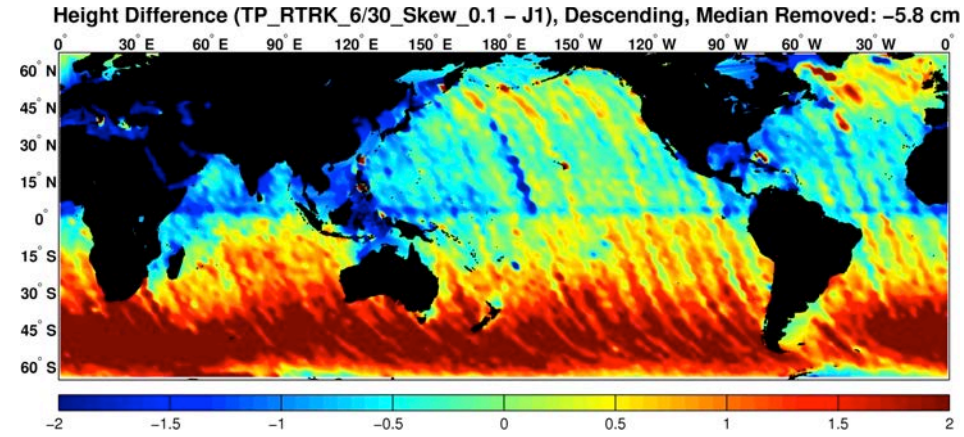
Retrk09 Skew Fit – J1



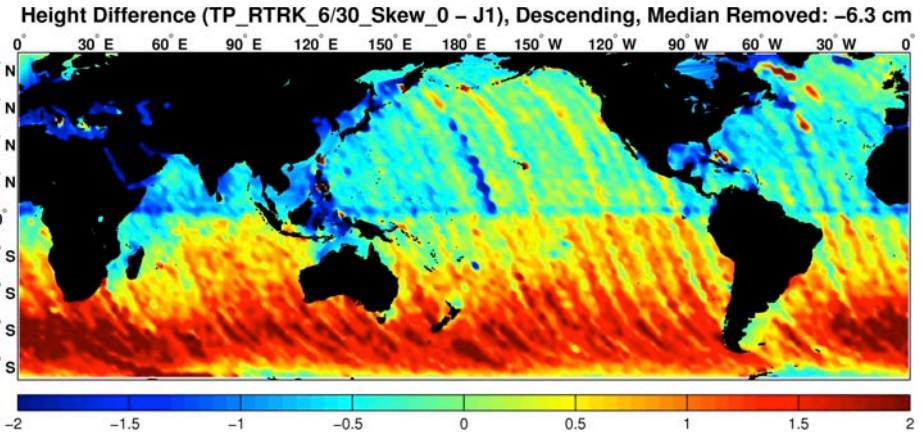
Retrk14 6/30 Skew Fit – J1



Retrk14 6/30 Skew = 0.1 – J1



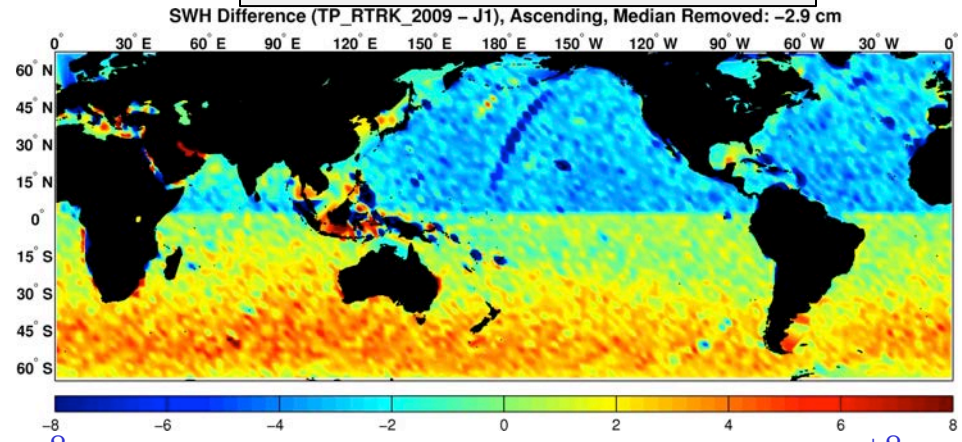
Retrk14 6/30 Skew = 0 – J1



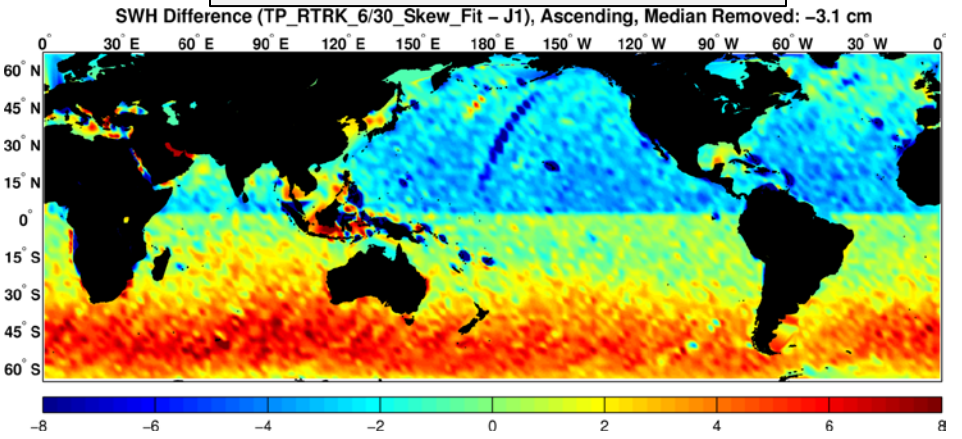
Jet Propulsion Laboratory
California Institute of Technology

TOPEX – Jason-1 SWH Comparison – Asc

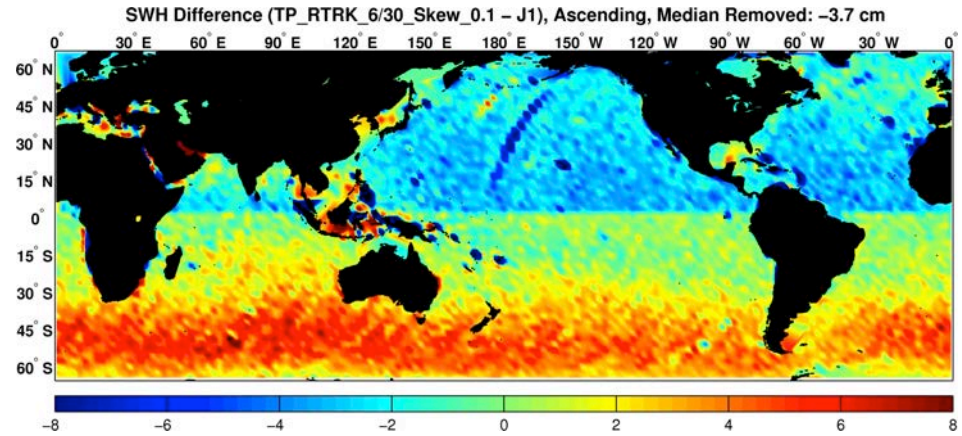
Retrk09 Skew Fit – J1



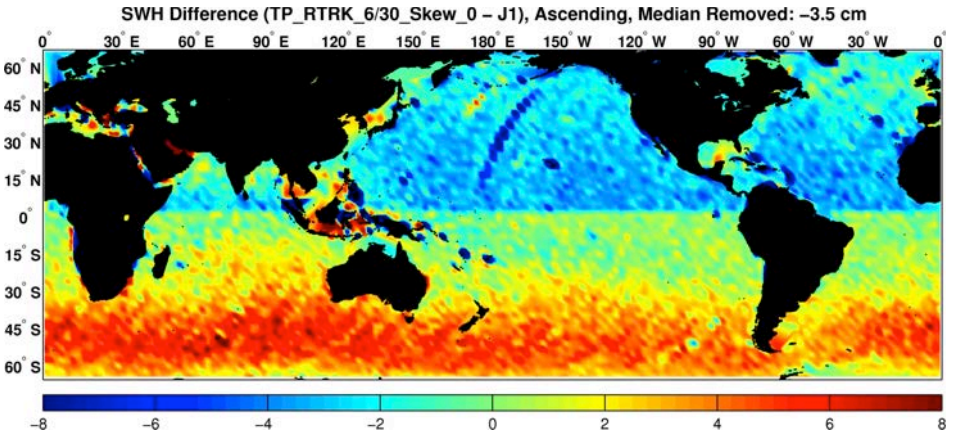
Retrk14 6/30 Skew Fit – J1



Retrk14 6/30 Skew = 0.1 – J1



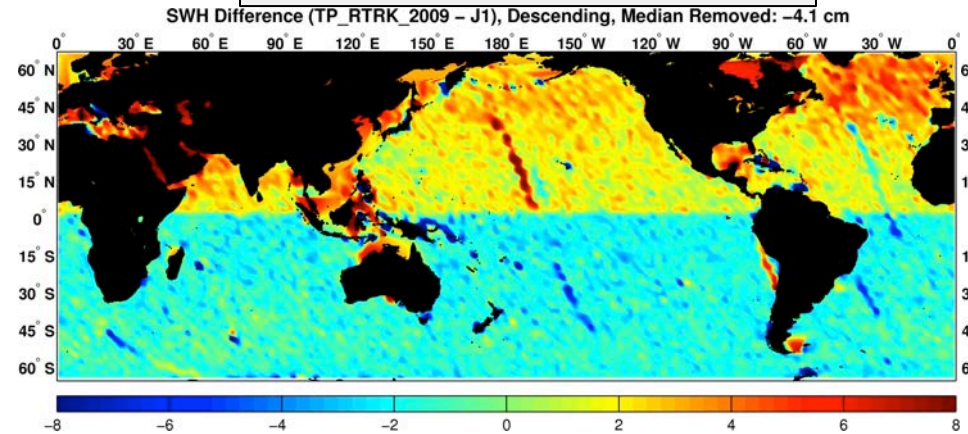
Retrk14 6/30 Skew = 0 – J1



Jet Propulsion Laboratory
California Institute of Technology

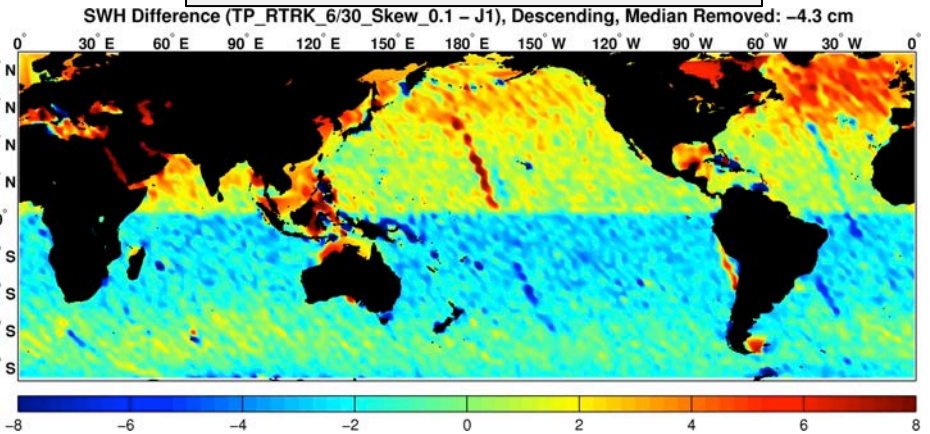
TOPEX – Jason-1 SWH Comparison – Des

Retrk09 Skew Fit – J1



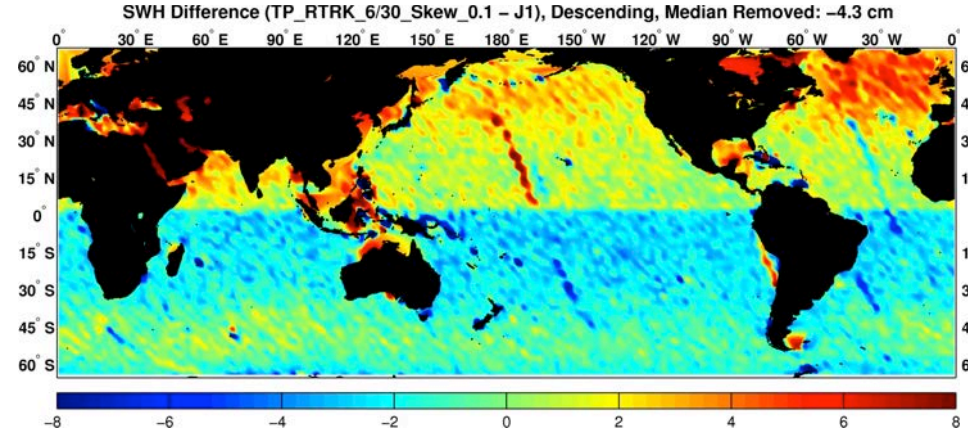
-8 cm

Retrk14 6/30 Skew Fit – J1

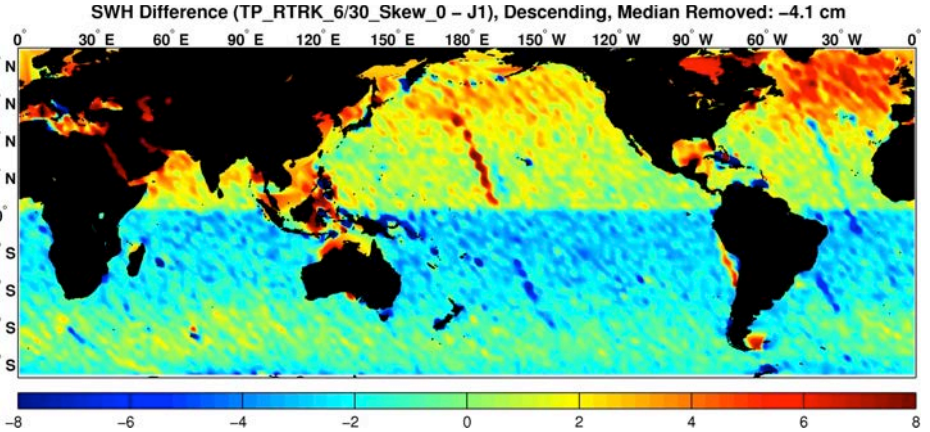


+8 cm

Retrk14 6/30 Skew = 0.1 – J1



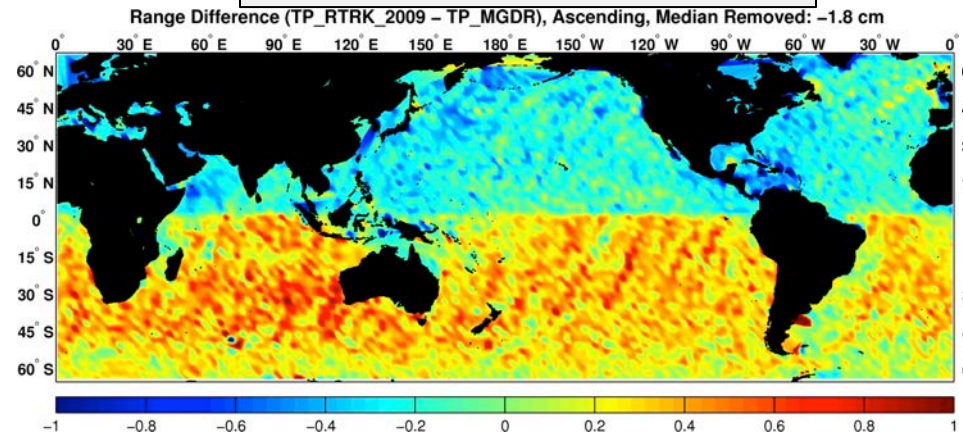
Retrk14 6/30 Skew = 0 – J1



Jet Propulsion
Laboratory
California Institute
of Technology

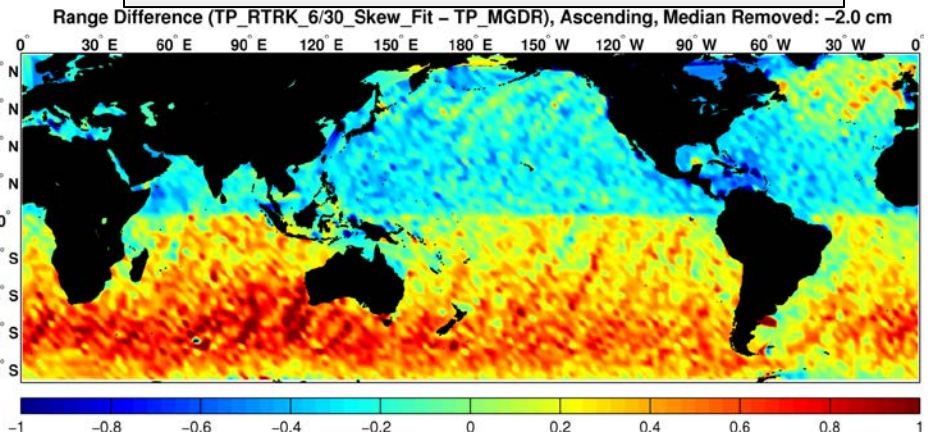
TOPEX – MGDR SSH Comparison – Asc

Retrk09 SkewFit – MGDR



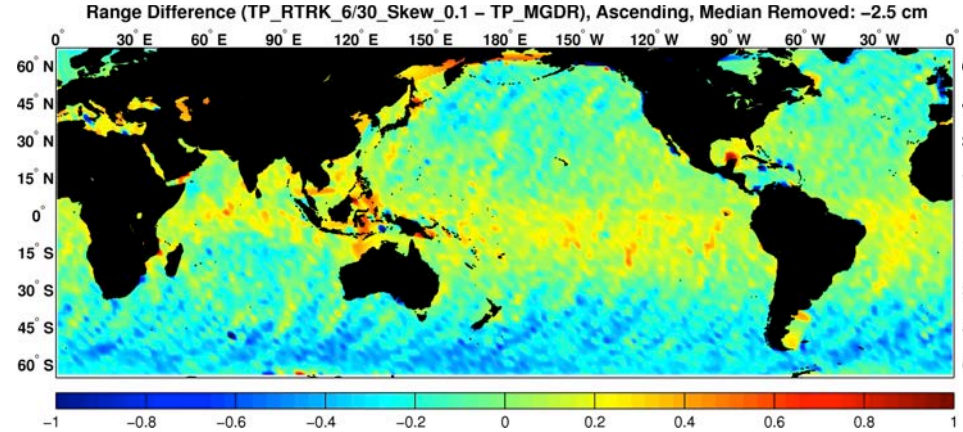
-1 cm

Retrk14 6/30 Skew Fit – MGDR

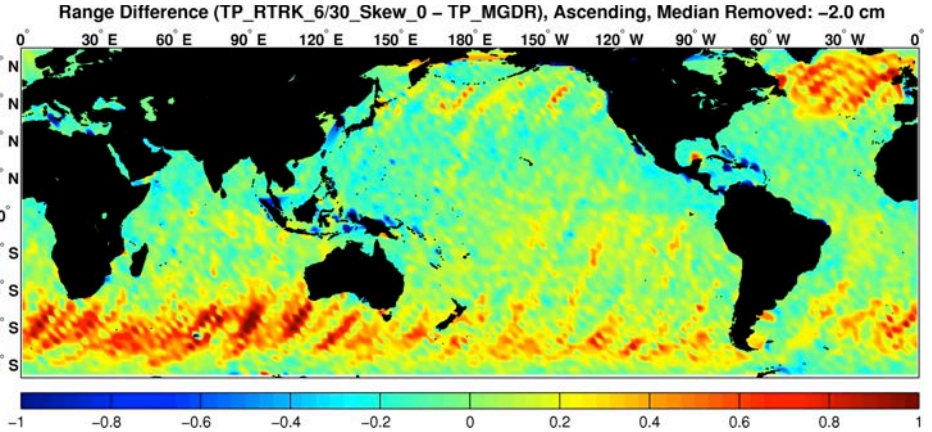


+1 cm

Retrk14 6/30 Skew = 0.1 – MGDR



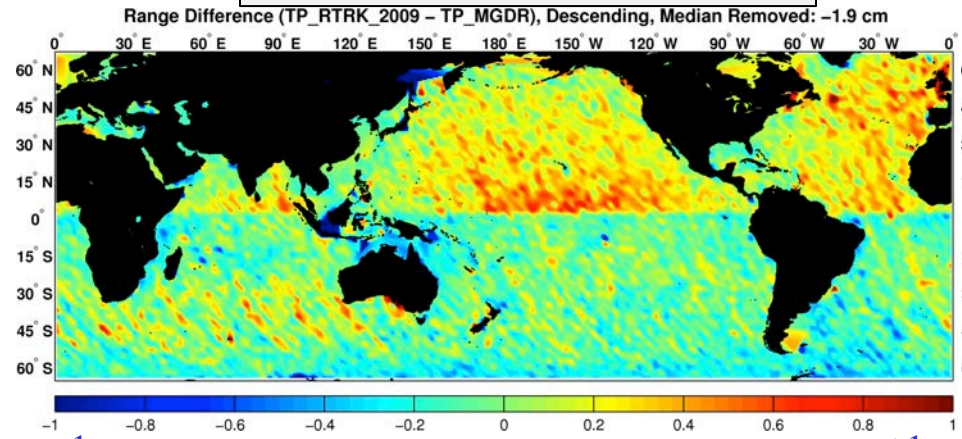
Retrk14 6/30 Skew = 0 – MGDR



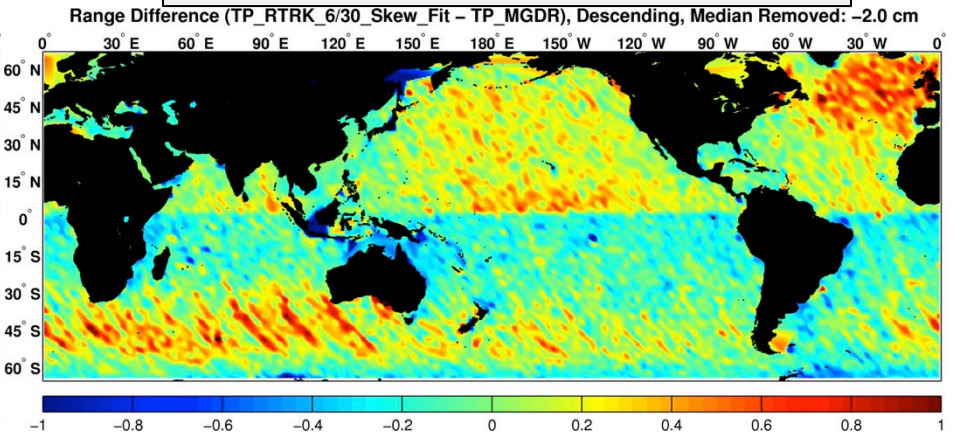
Jet Propulsion Laboratory
California Institute of Technology

TOPEX – MGDR SSH Comparison – Des

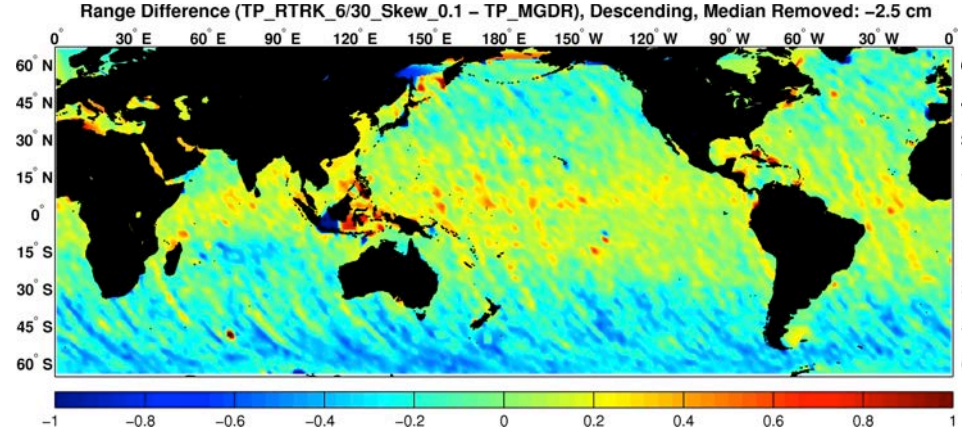
Retrk09 Skew Fit – MGDR



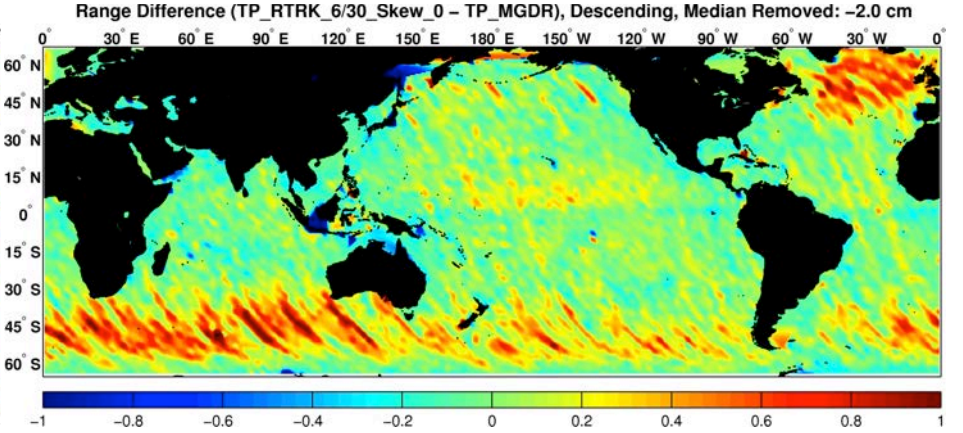
Retrk14 6/30 Skew Fit – MGDR



Retrk14 6/30 Skew = 0.1 – MGDR



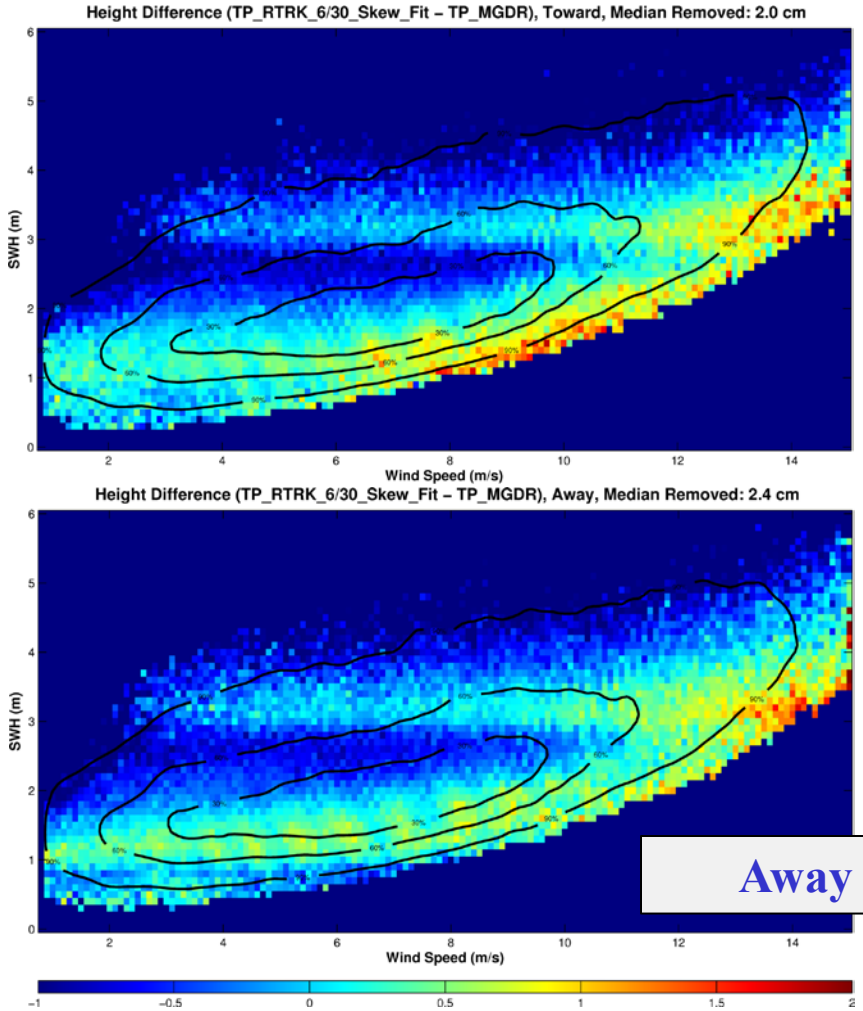
Retrk14 6/30 Skew = 0 – MGDR

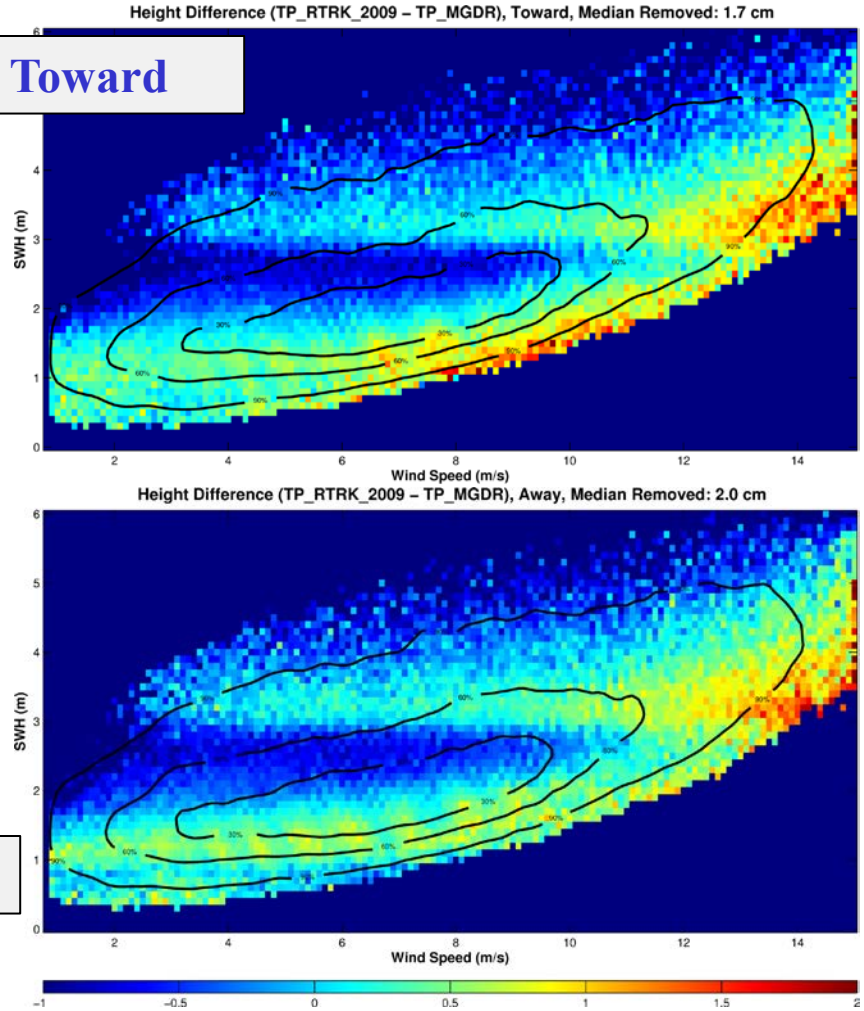


Jet Propulsion Laboratory
California Institute of Technology

TOPEX Retrack – MGDR SSH Comparison

TOPEX Wind Speed





Toward

Away

-1 cm +2 cm

TP_RTRK_2014 6/30 Skew Fit – TP_MGDR

-1 cm +2 cm

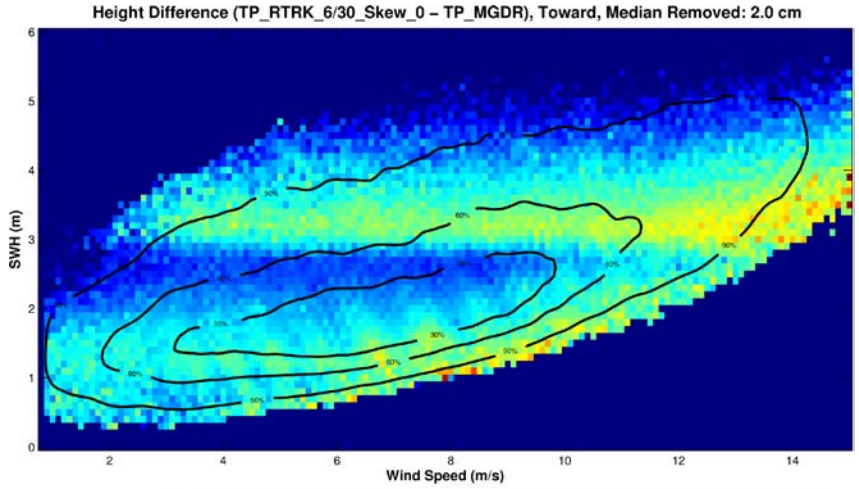
TP_RTRK_2009 – TP_MGDR

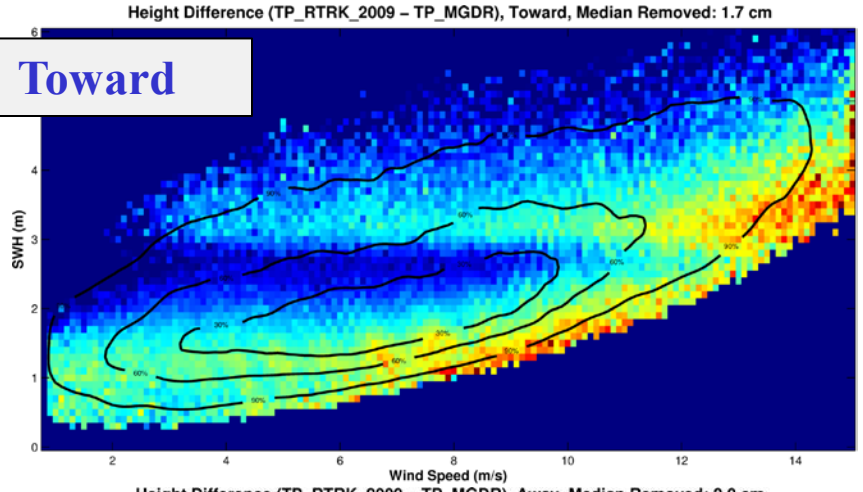
MSS: CLS 2011, Orbits: GSFC 2013 (TP) / GDR-C (J1)

Jet Propulsion Laboratory California Institute of Technology

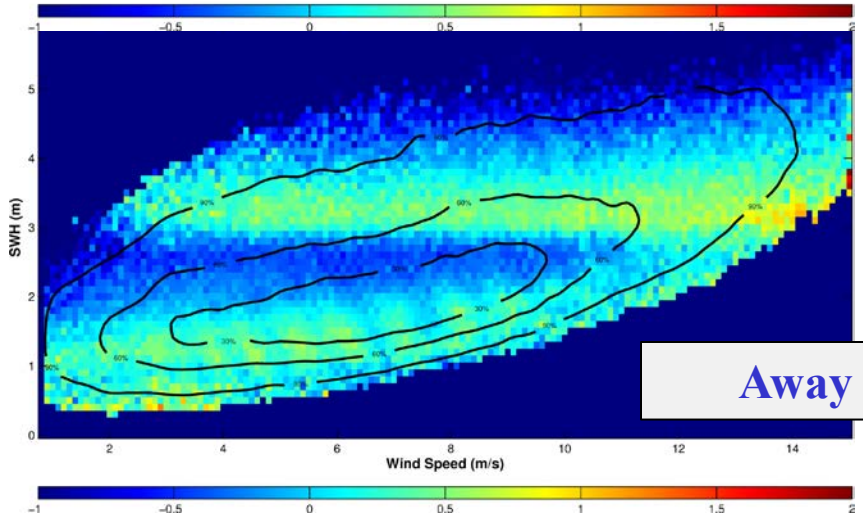
TOPEX Retrack – MGDR SSH Comparison

TOPEX Wind Speed

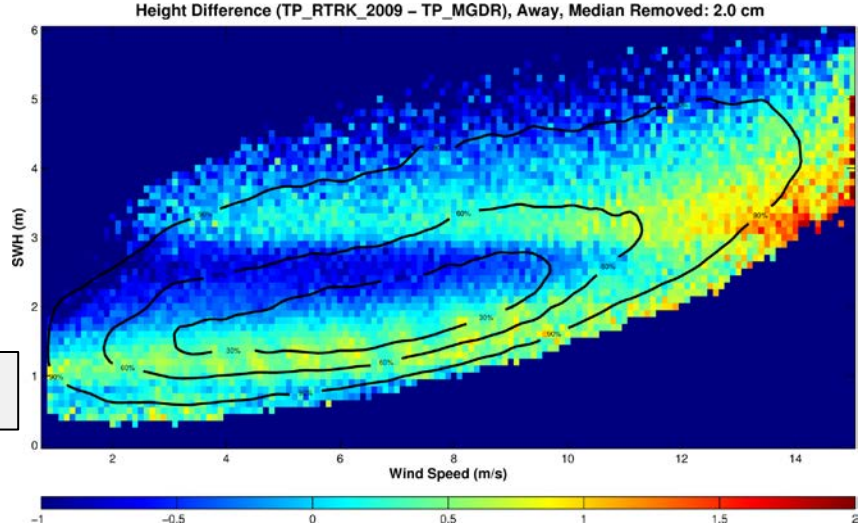




Toward



Away



-1 cm +2 cm

TP_RTRK_2014 6/30 Skew 0 – TP_MGDR

-1 cm +2 cm

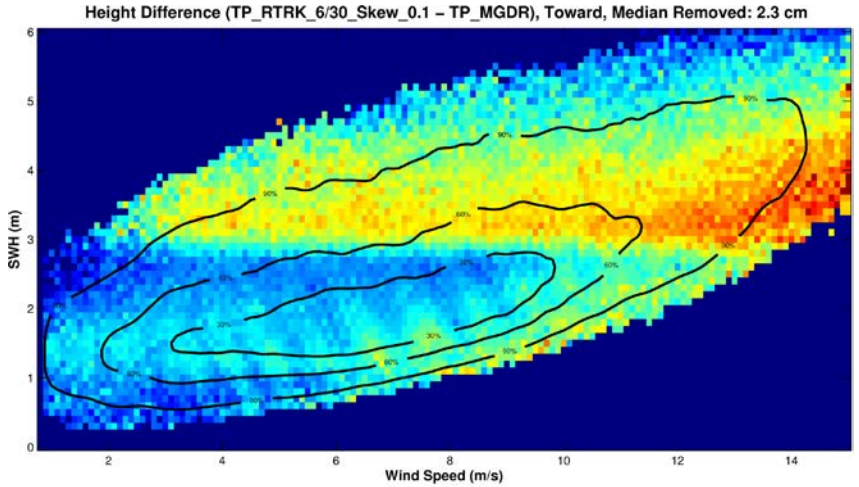
TP_RTRK_2009 – TP_MGDR

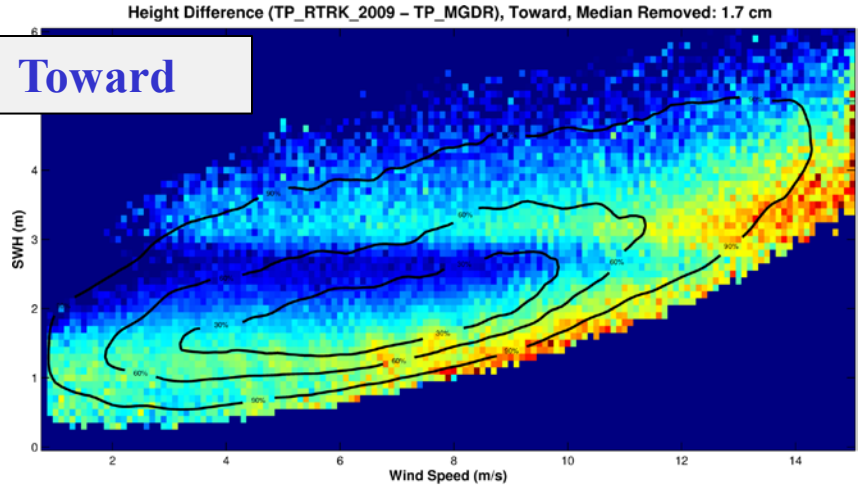
MSS: CLS 2011, Orbits: GSFC 2013 (TP) / GDR-C (J1)

Jet Propulsion
Laboratory
California Institute
of Technology

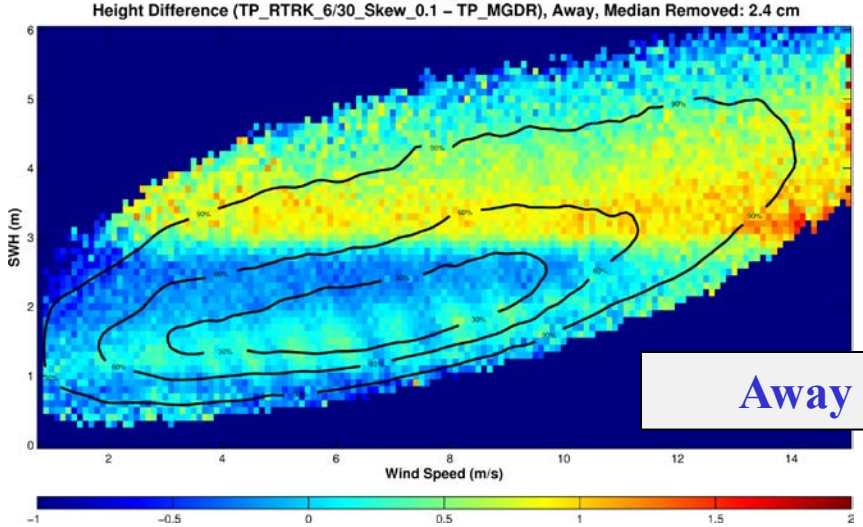
TOPEX Retrack – MGDR SSH Comparison

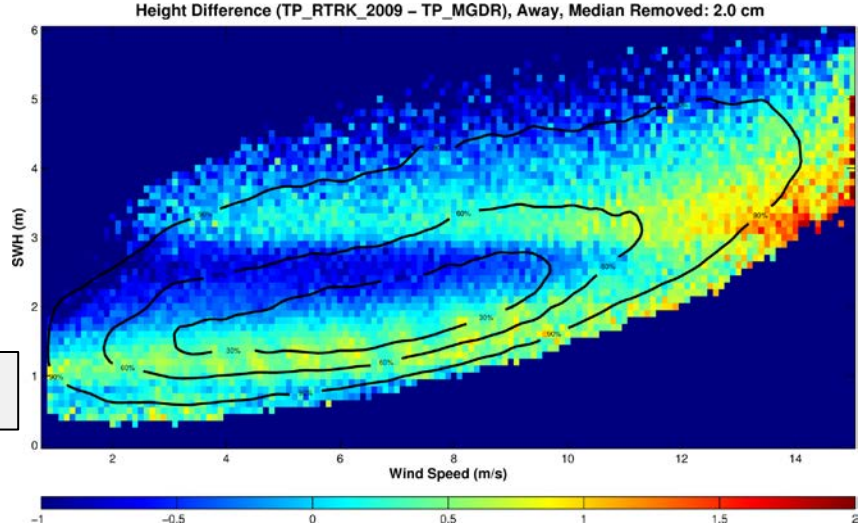
TOPEX Wind Speed





Toward





Away

-1 cm +2 cm

TP_RTRK_2014 6/30 Skew 0.1 – TP_MGDR

-1 cm +2 cm

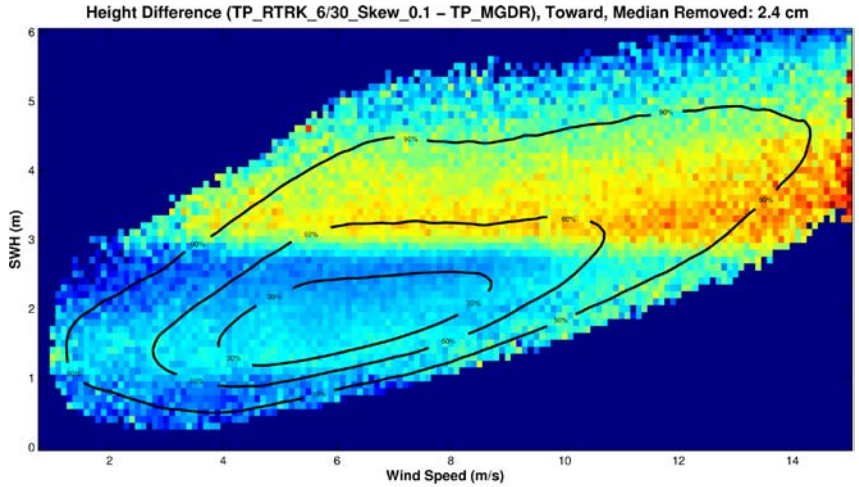
TP_RTRK_2009 – TP_MGDR

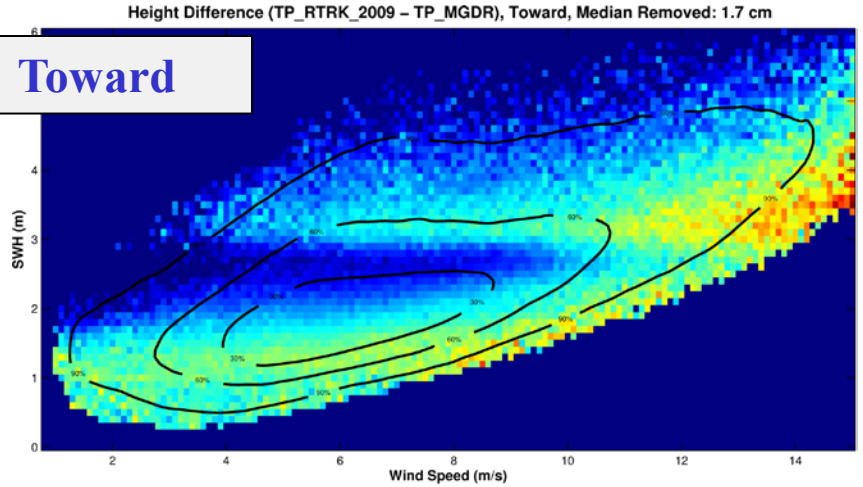
MSS: CLS 2011, Orbits: GSFC 2013 (TP) / GDR-C (J1)

Jet Propulsion
Laboratory
California Institute
of Technology

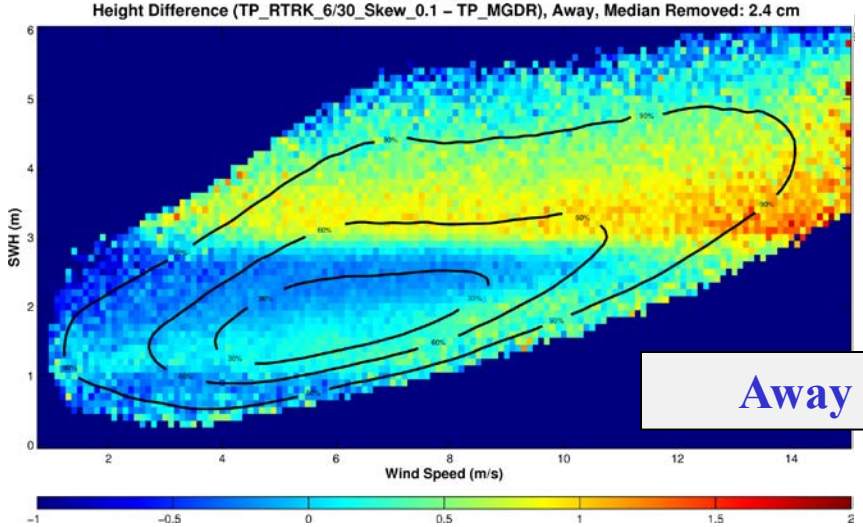
TOPEX Retrack – MGDR SSH Comparison

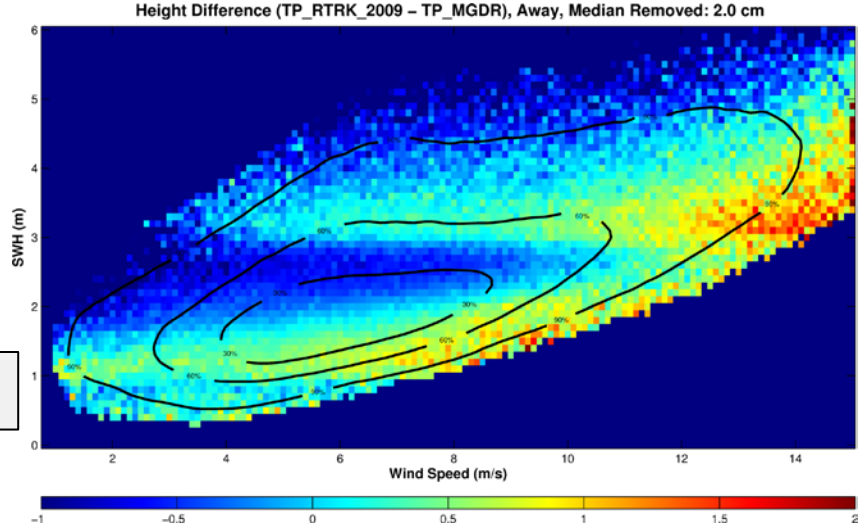
Jason Wind Speed





Toward





Away

-1 cm +2 cm

TP_RTRK_2014 6/30 Skew 0.1 – TP_MGDR

-1 cm +2 cm

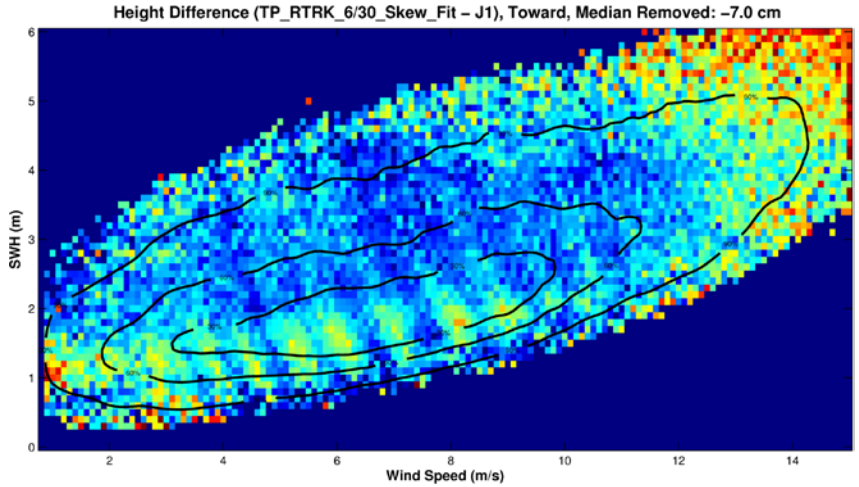
TP_RTRK_2009 – TP_MGDR

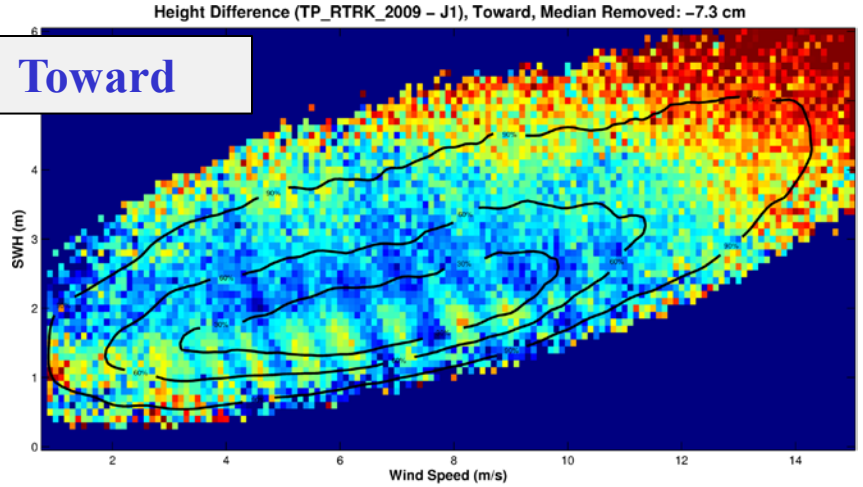
MSS: CLS 2011, Orbits: GSFC 2013 (TP) / GDR-C (J1)

Jet Propulsion Laboratory
California Institute of Technology

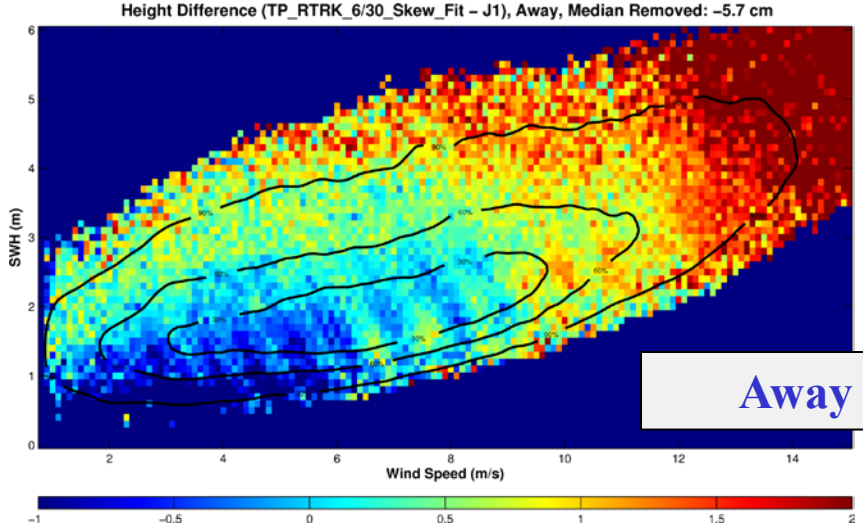
TOPEX Retrack – Jason-1 SSH Comparison

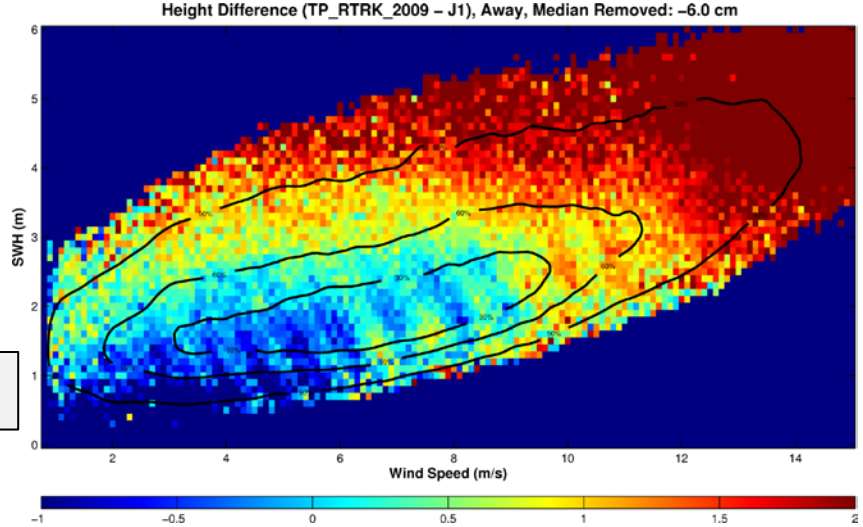
TOPEX Wind Speed





Toward





Away

-1 cm +2 cm

TP_RTRK_2014 6/30 Skew Fit – J1

-1 cm +2 cm

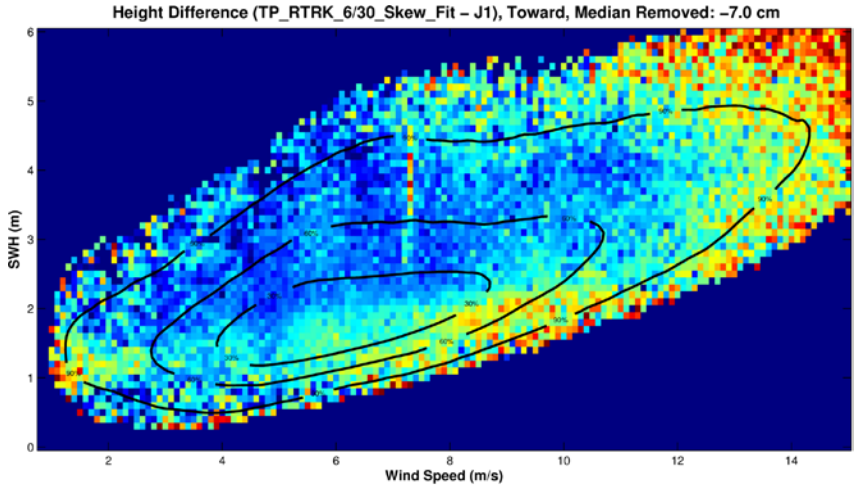
TP_RTRK_2009 – J1

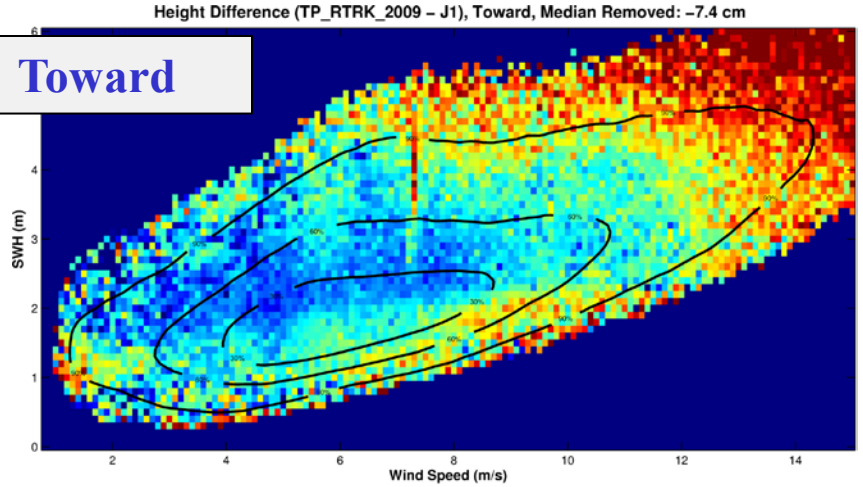
MSS: CLS 2011, Orbits: GSFC 2013 (TP) / GDR-C (J1)

Jet Propulsion Laboratory
California Institute of Technology

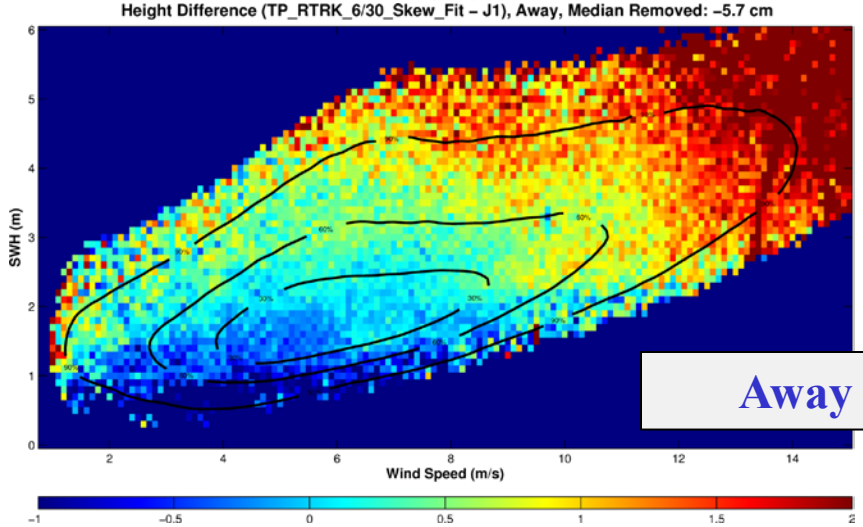
TOPEX Retrack – Jason-1 SSH Comparison

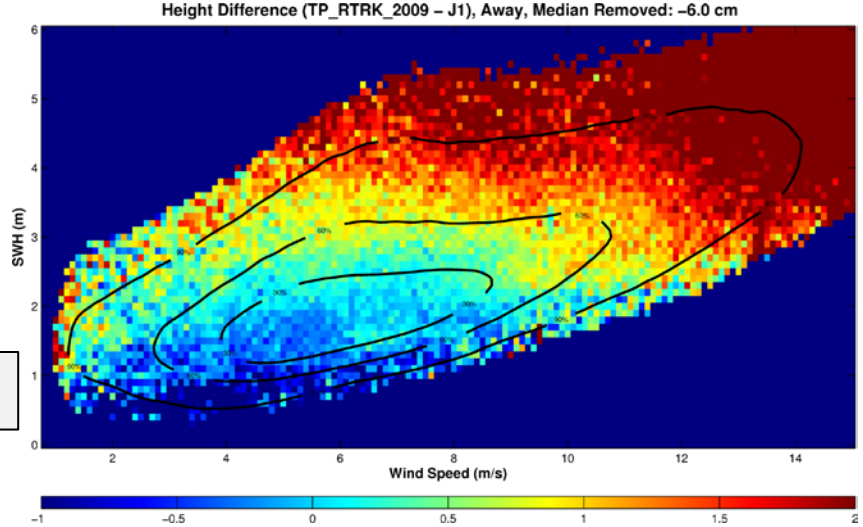
Jason Wind Speed





Toward





Away

-1 cm +2 cm

TP_RTRK_2014 6/30 Skew Fit – J1

-1 cm +2 cm

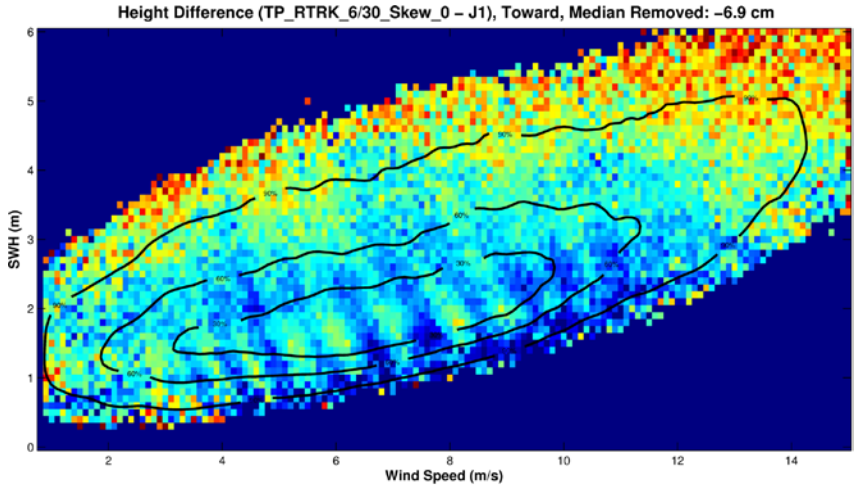
TP_RTRK_2009 – J1

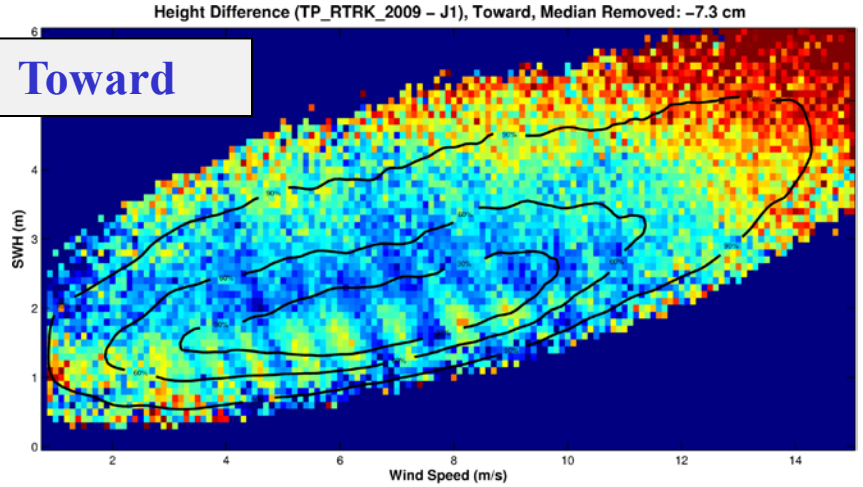
MSS: CLS 2011, Orbits: GSFC 2013 (TP) / GDR-C (J1)

Jet Propulsion
Laboratory
California Institute
of Technology

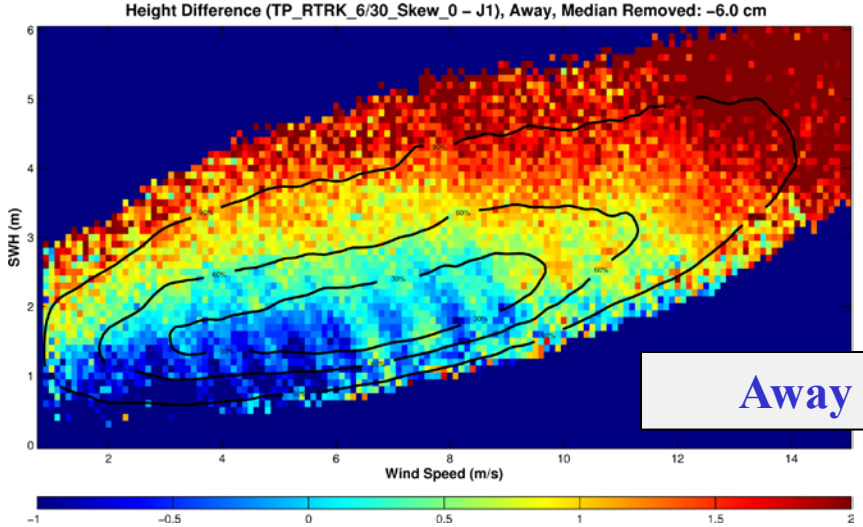
TOPEX Retrack – Jason-1 SSH Comparison

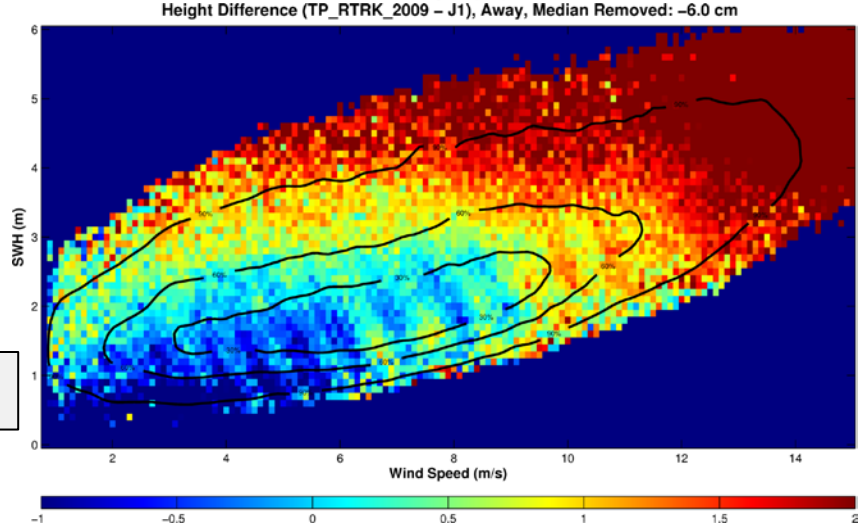
TOPEX Wind Speed





Toward





Away

-1 cm +2 cm

TP_RTRK_2014 6/30 Skew 0 – J1

-1 cm +2 cm

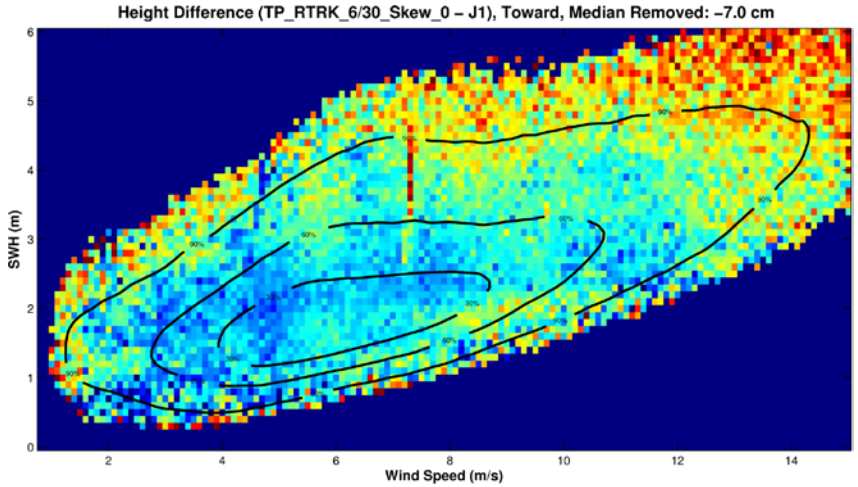
TP_RTRK_2009 – J1

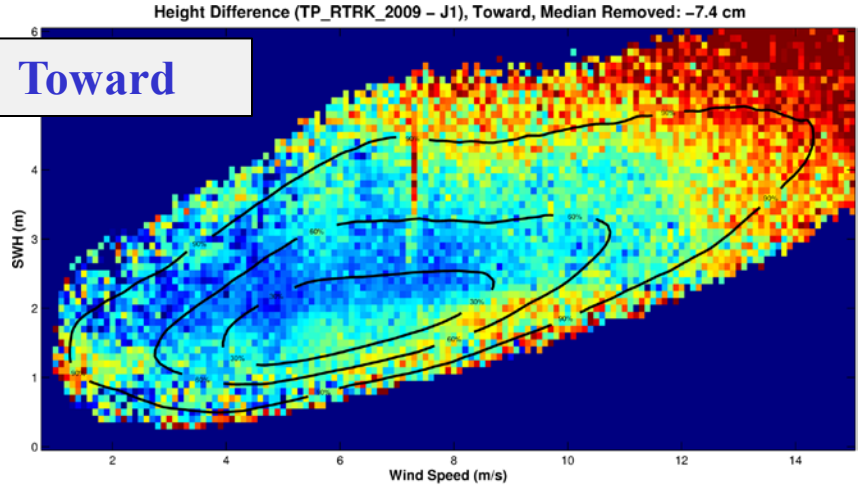
MSS: CLS 2011, Orbits: GSFC 2013 (TP) / GDR-C (J1)

Jet Propulsion
Laboratory
California Institute
of Technology

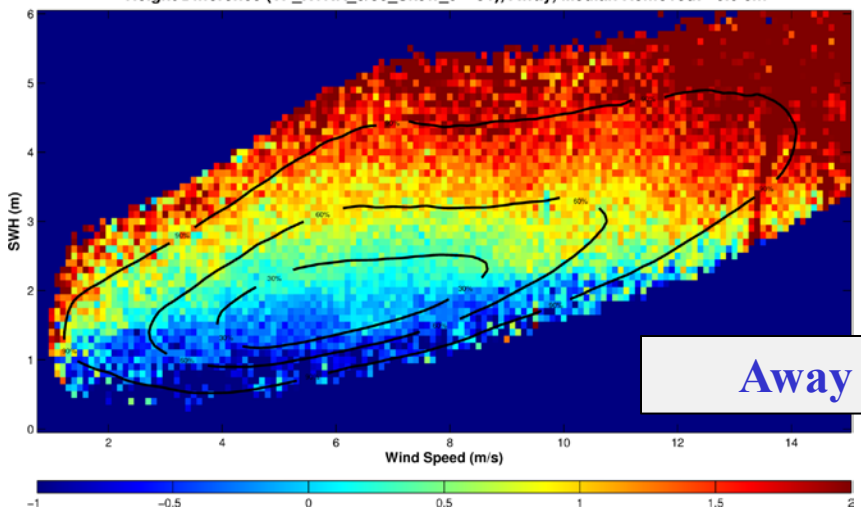
TOPEX Retrack – Jason-1 SSH Comparison

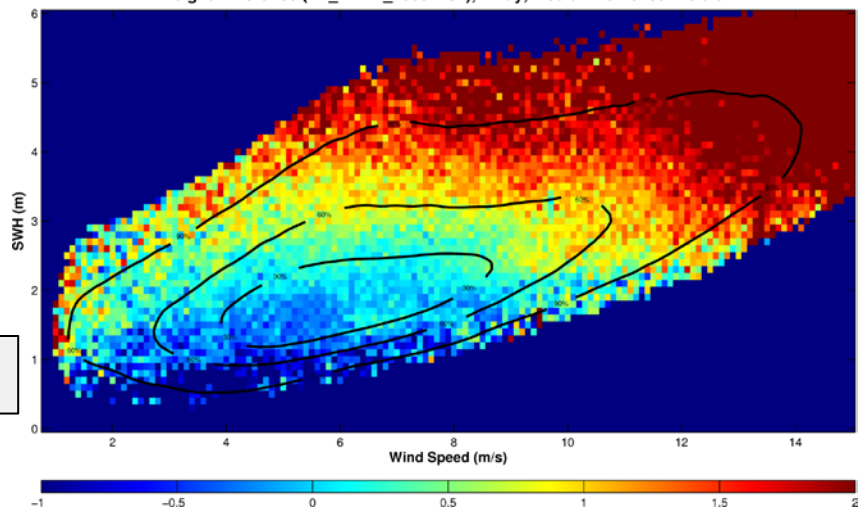
Jason Wind Speed





Toward





Away

-1 cm +2 cm

TP_RTRK_2014 6/30 Skew 0 – J1

-1 cm +2 cm

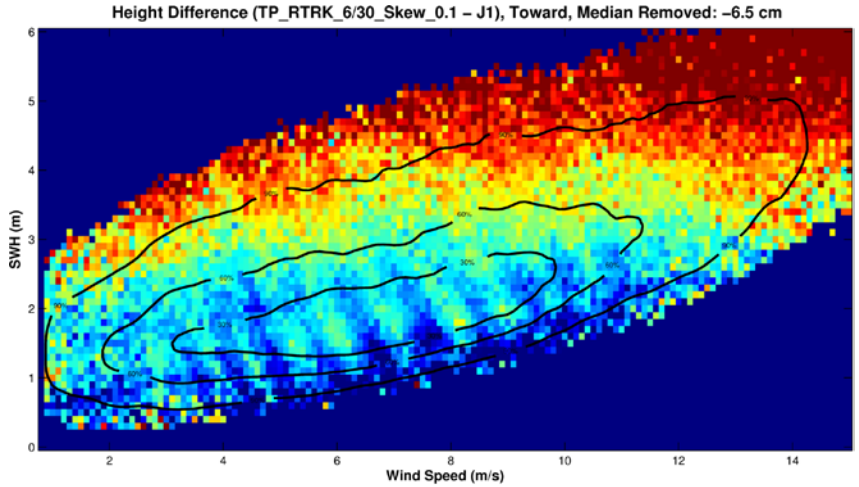
TP_RTRK_2009 – J1

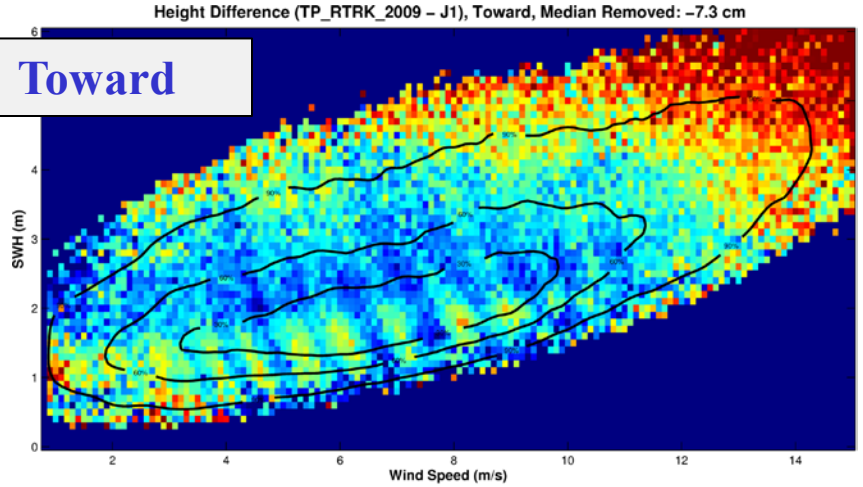
MSS: CLS 2011, Orbits: GSFC 2013 (TP) / GDR-C (J1)

Jet Propulsion Laboratory
California Institute of Technology

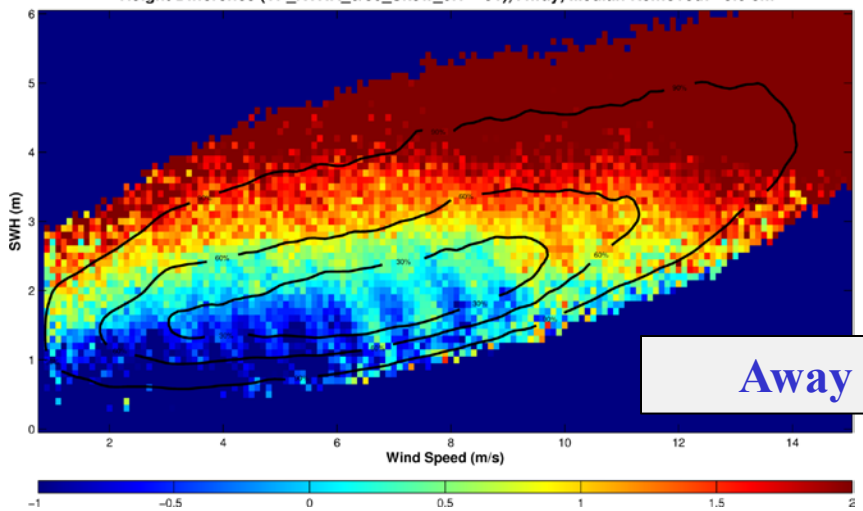
TOPEX Retrack – Jason-1 SSH Comparison

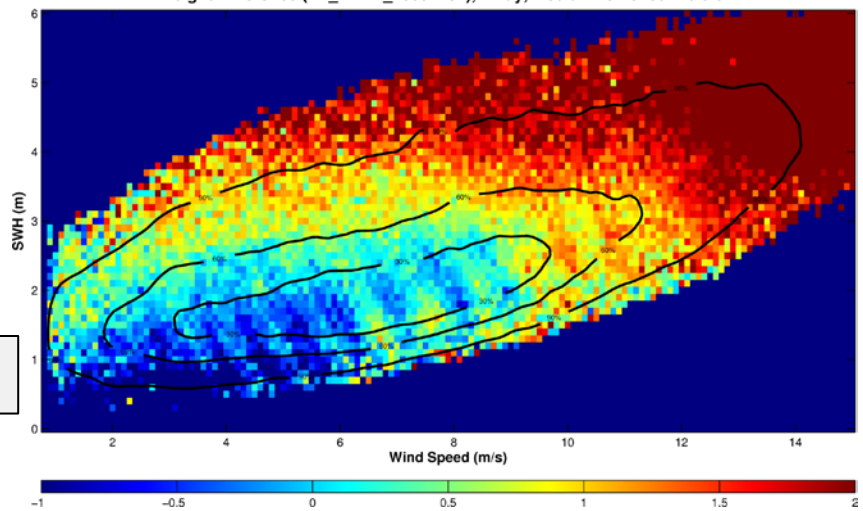
TOPEX Wind Speed





Toward





Away

-1 cm +2 cm

TP_RTRK_2014 6/30 Skew 0.1 – J1

-1 cm +2 cm

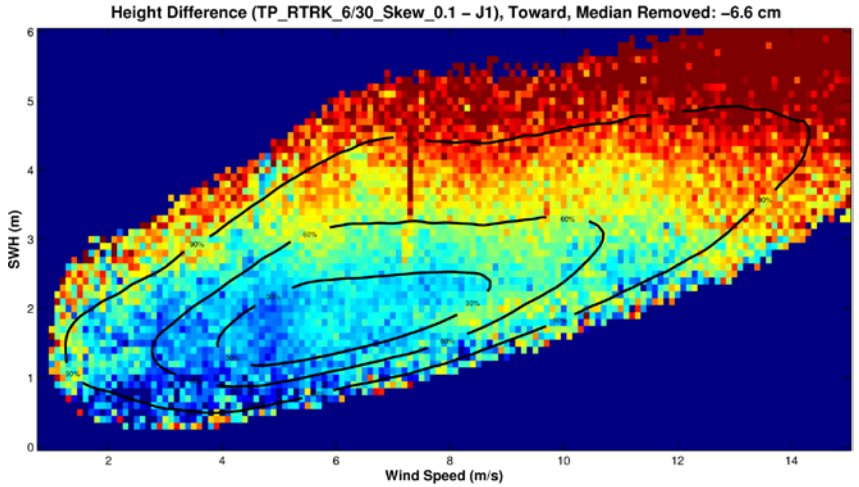
TP_RTRK_2009 – J1

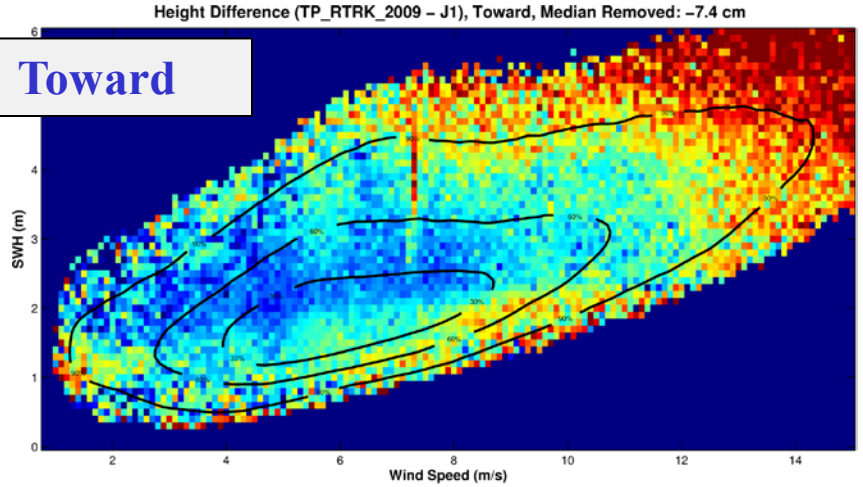
MSS: CLS 2011, Orbits: GSFC 2013 (TP) / GDR-C (J1)

Jet Propulsion
Laboratory
California Institute
of Technology

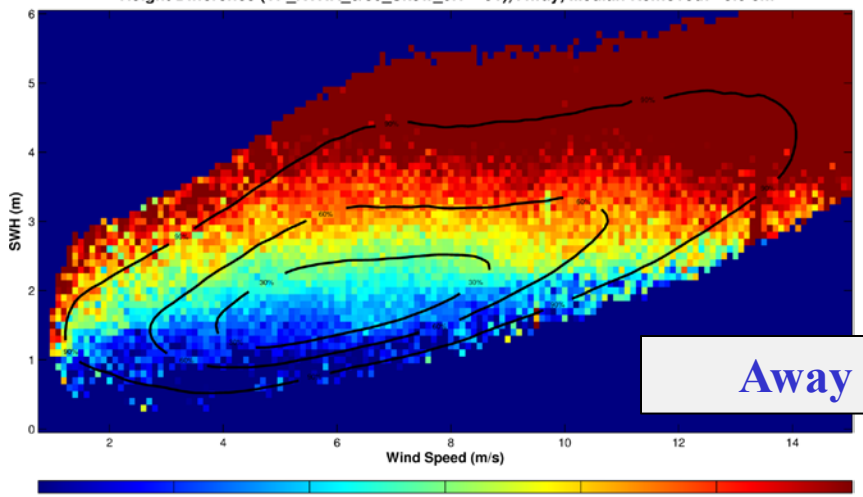
TOPEX Retrack – Jason-1 SSH Comparison

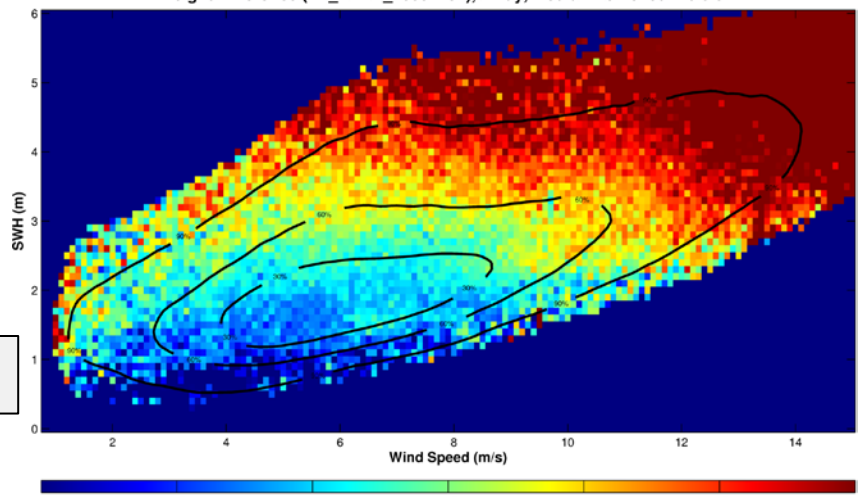
Jason Wind Speed



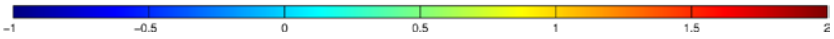


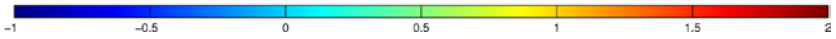
Toward





Away





-1 cm +2 cm

TP_RTRK_2014 6/30 Skew 0.1 – J1

-1 cm +2 cm

TP_RTRK_2009 – J1

MSS: CLS 2011, Orbits: GSFC 2013 (TP) / GDR-C (J1)

TOPEX Climate Data Records Plan

- Make new TOPEX RGDR consistent with Jason ver_D (or newer?)
  - Transform format into netCDF similar to Jason. (2009 RGDR available on PODAAC as netCDF)
  - Copy of original GDR
  - Retracking values for range, SWH, attitude (skewness likely to be removed from fits; did not have ocean information)
  - New GSFC orbits
  - New tide models GOT4.? And FES201?
  - Improved long period non-equilibrium tides
  - New dry tropo correction and associated MOG2D values
  - Reprocessed TMR data (Shannon Brown: improved calibration, coastal resolution)
  - Updated geophysical fields (MSS, Geoid, etc.)
  - SSB fitted on Retracked Data (with quadrant corrections) – ***Note that this requires making a full RGDR so that SSB does not pick up any orbit, tide, etc. errors***

- Schedule
  - ~~Oct – Dec '13~~ Aug – Oct '14: Develop systematic PTR generation. Produce sets of test cycles.
  - January 2015[~~4~~] begin bulk Retracking. Collect other data sets.
  - Spring 2015[~~4~~]: Begin SSB fits - Use Vandemark et als. OSTST set standard for product.
  - ~~Early~~ Mid 2015 products available

Jet Propulsion
Laboratory
California Institute
of Technology

Backup Material

Details

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

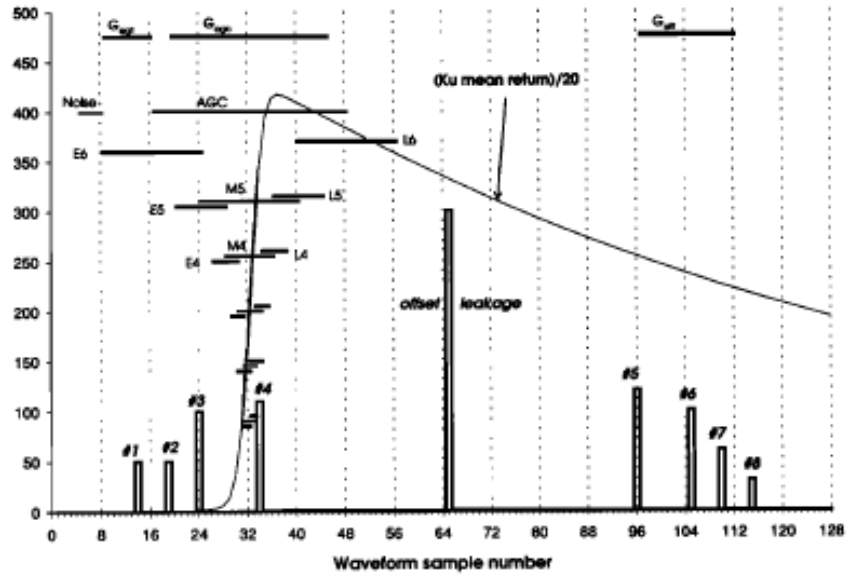
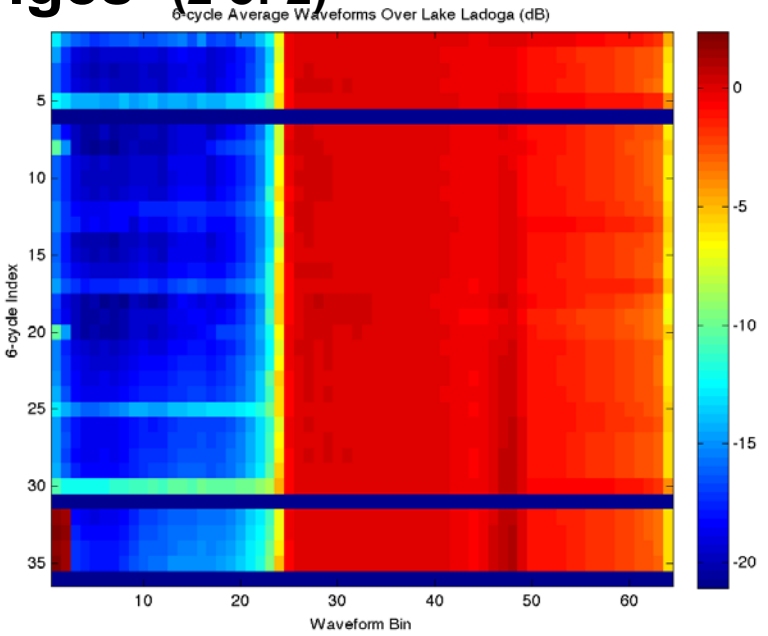


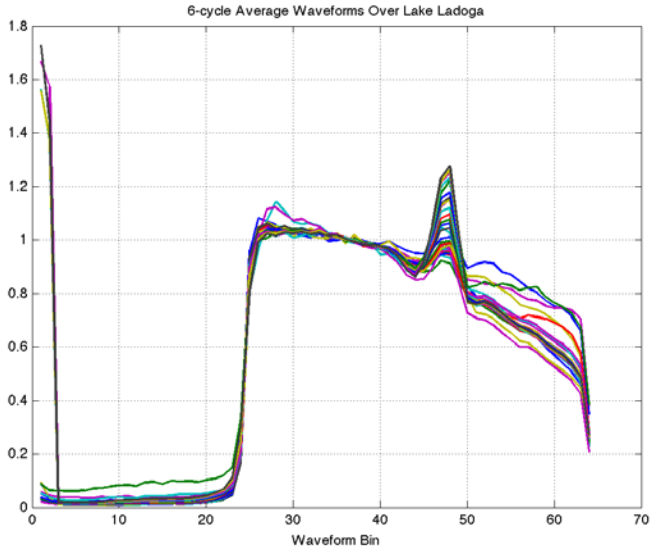
Figure 6. TOPEX Ku altimeter gates, mean return, and center locations of waveform leakage spikes.

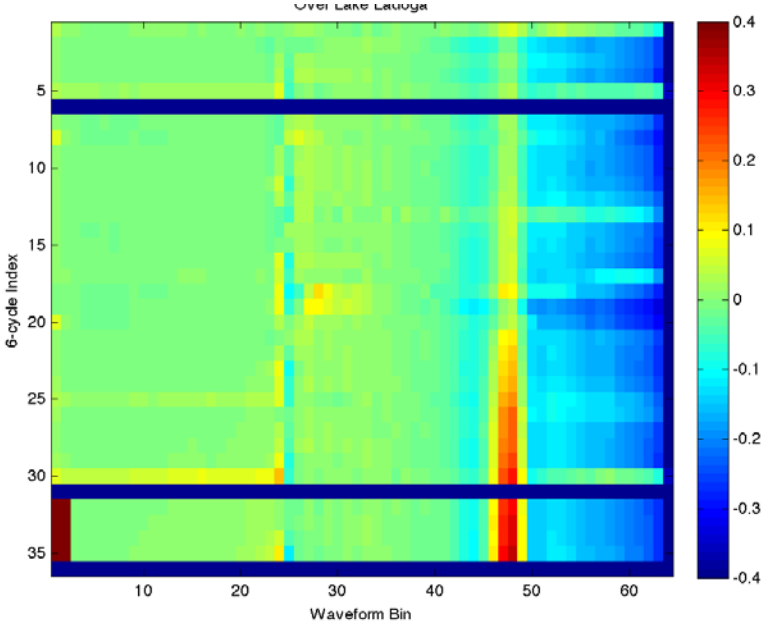
- Leakages (x20) in the TOPEX Alt-A waveform from Hayne et al., 1994, JGR, ***99***, 24,941.
  - Need correction in processing via masking or "weights" on WF gates
  - Move with range rate giving North/South Ascending/Descending ("toward" / "away" Eq) differences
  - Onboard gates used to estimate the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

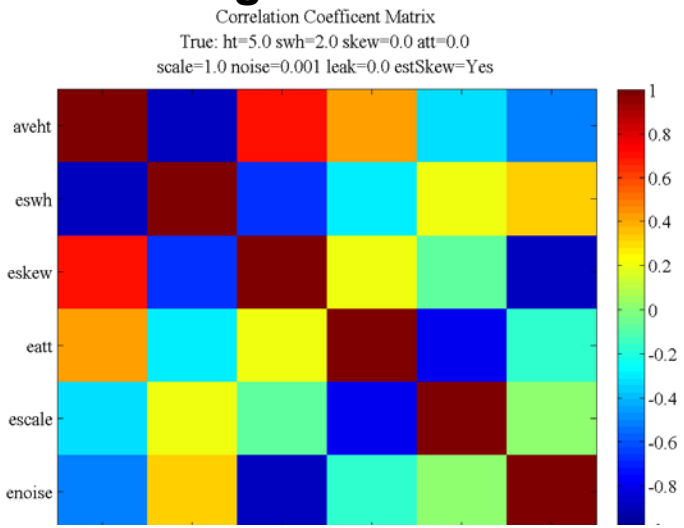


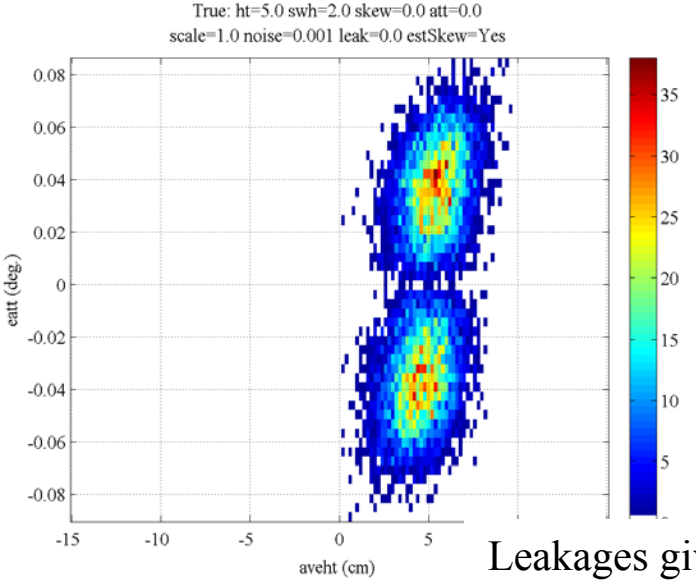




Simulation Results

Parameter Correlation Solving for Skewness





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

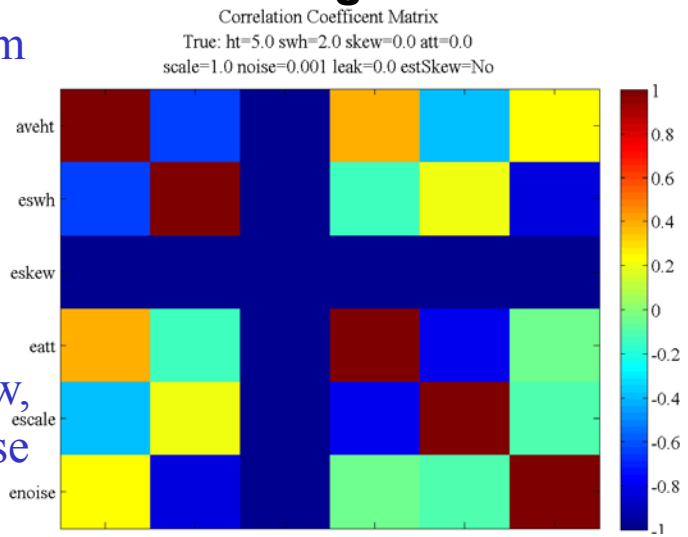
Parameters:
dH, SWH, Skew,
Att, Scale, Noise

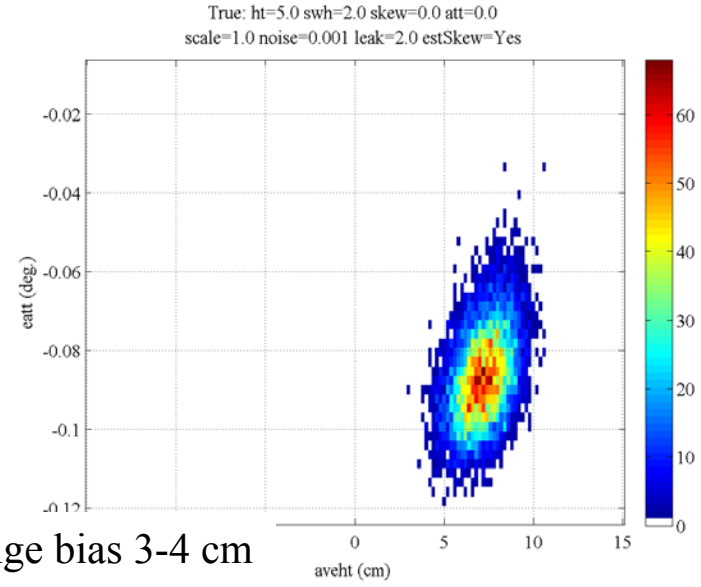
← Leakage = 0

Leakage = 2X →

2D Histogram:
Att / dH

Parameter Correlation Not Solving for Skewness





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

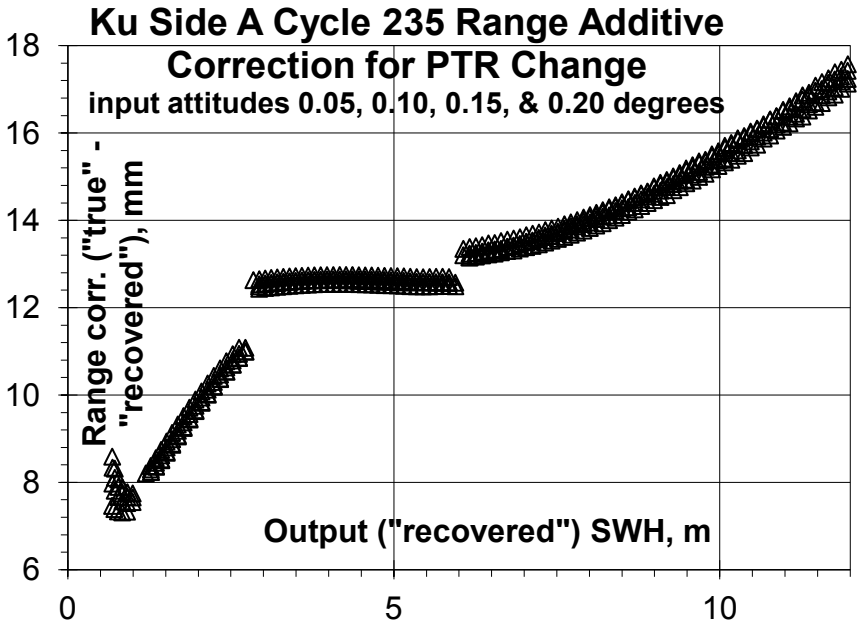
Alt-A PTR Change Simulation

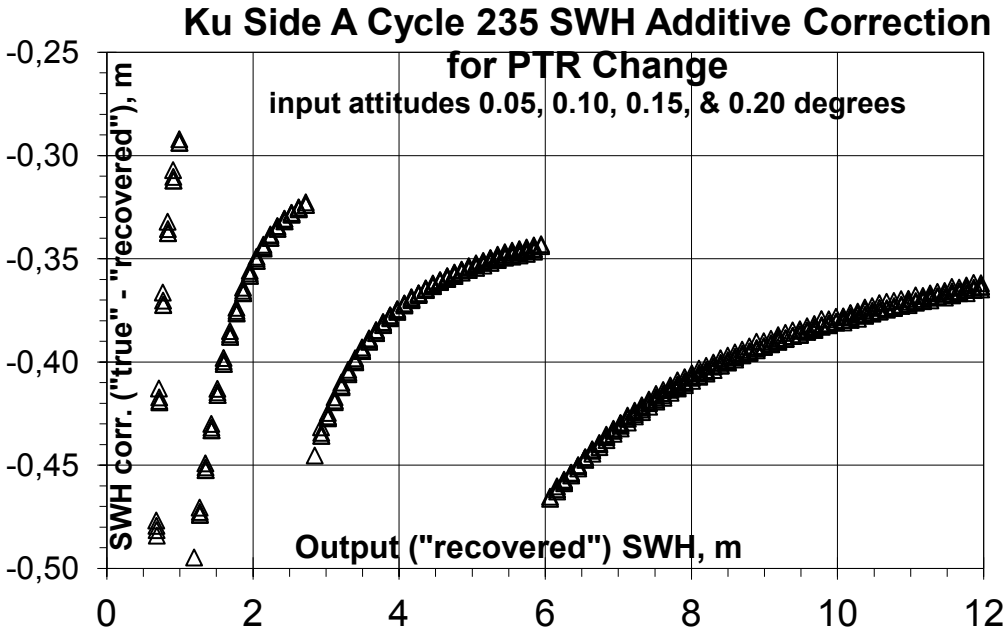
Simulation by G. Hayne (WFF) of change in Range and SWH as a function of SWH for PTR of Cycle 235 (discontinuities reflect internal altimeter function – change in adaptive gate widths).

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

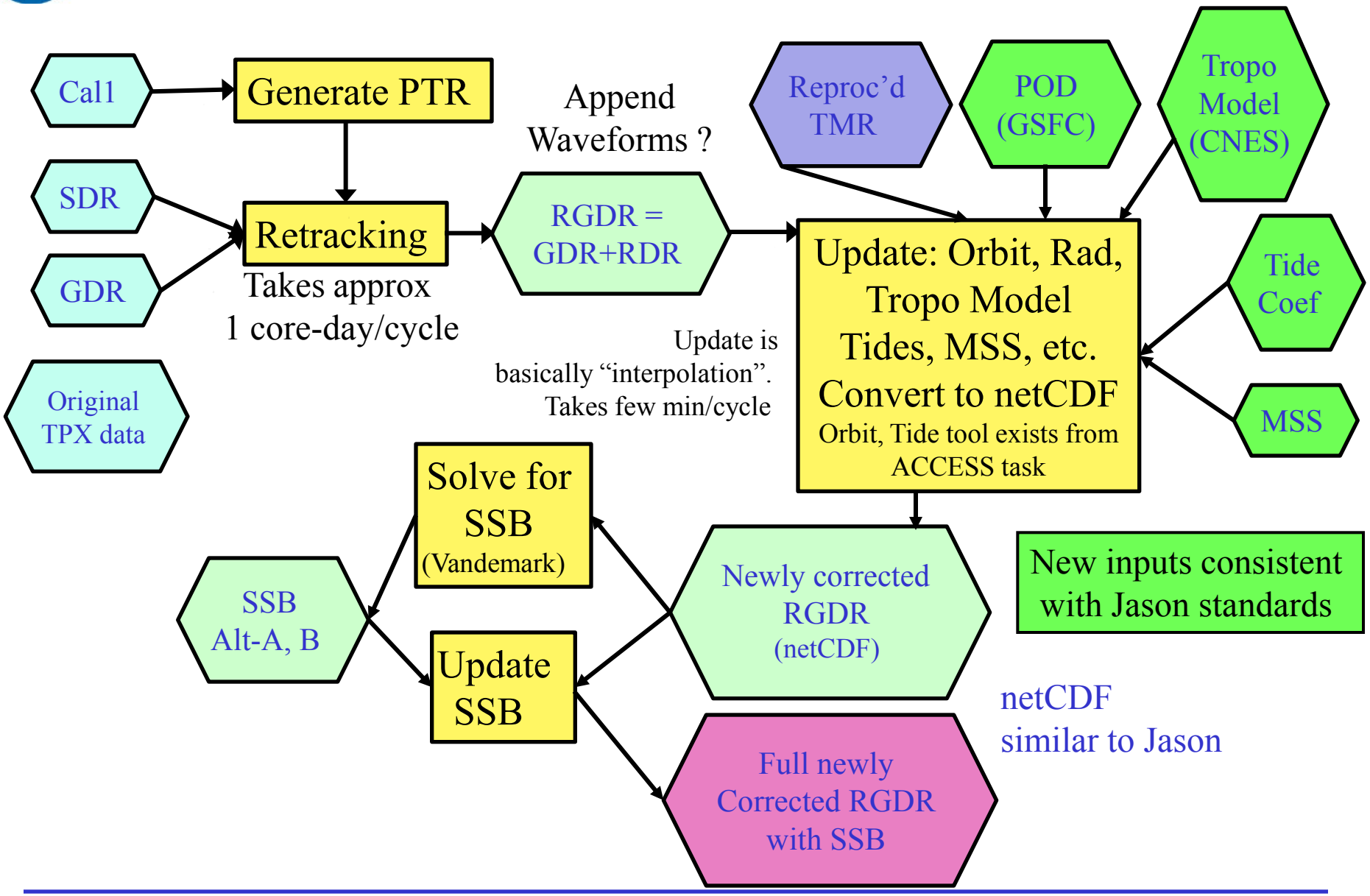
Right: SWH error of ~ 0.4 m as observed (slide 4).

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

  ☙ ➔ 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

Retracking Algorithms

Maximum Likelihood Estimator (MLE) Minimizes:

$$-\log(p(x \mid a)) \propto \sum_{i=1}^{Ndata} \frac{(x_i - M(a))^2}{\sigma_i^2}$$

Maximum a Posteriori (MAP) Minimizes:

$$-\log(p(x \mid a)p(a)) \propto \sum_{i=1}^{Ndata} \frac{(x_i - M(a))^2}{\sigma_i^2} + \sum_{n=1}^{Nparams} \frac{(a_n - A_n)^2}{\Sigma_n^2}$$

Where x is the data, a are the parameters to be estimated, A are the parameter a priori values, σ_i are the measurement errors and Σ_n measures the prior confidence level.

Setting the priors and their confidence levels is the trick!

Prior Values: smooth LSE SWH and attitude data over an extent < 80 km relative to center.

Prior Uncertainties: Root Squares Sum residual values in smoothing window with conservative estimate of minimum uncertainty of SWH and attitude variance. Use 1.5 as uncertainty on the skewness, and infinite variances (no priors) on the other parameters, including height.