Improvents for the next Mean Sea Surface (MSS)

D. Sandwell , H. Harper, Y. Yu, B. Tozer	SIO
P. Schaeffer, M.I. Pujol, Y. Faugere.	CLS
G. Dibarboure, N. Picot	CNES

SWOT - Bordeaux

June 2019

Objective: Construct a MSS with spatial resolution of 6 km to evaluate the performance of SWOT early in the mission.

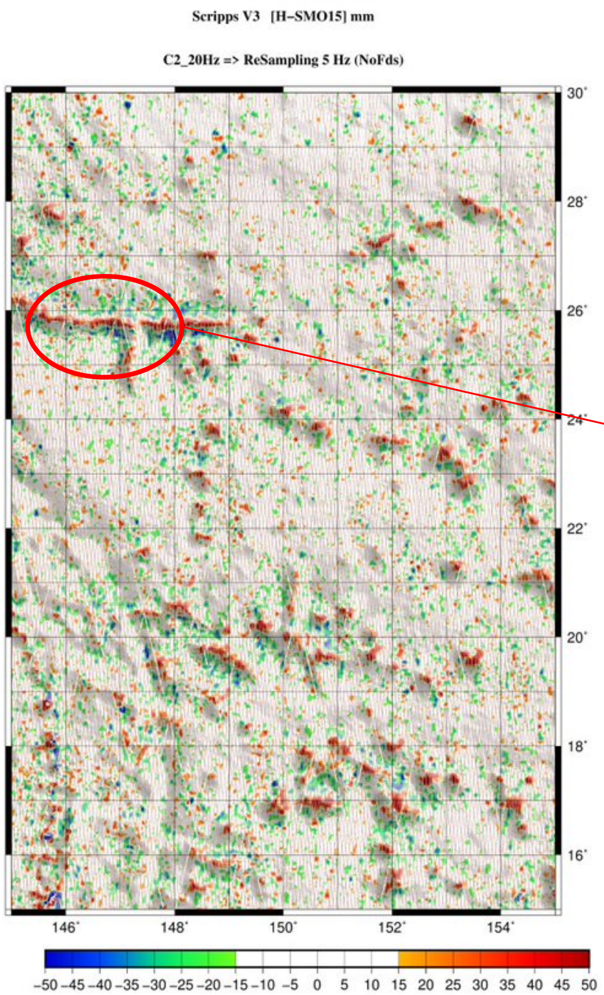
Tasks:

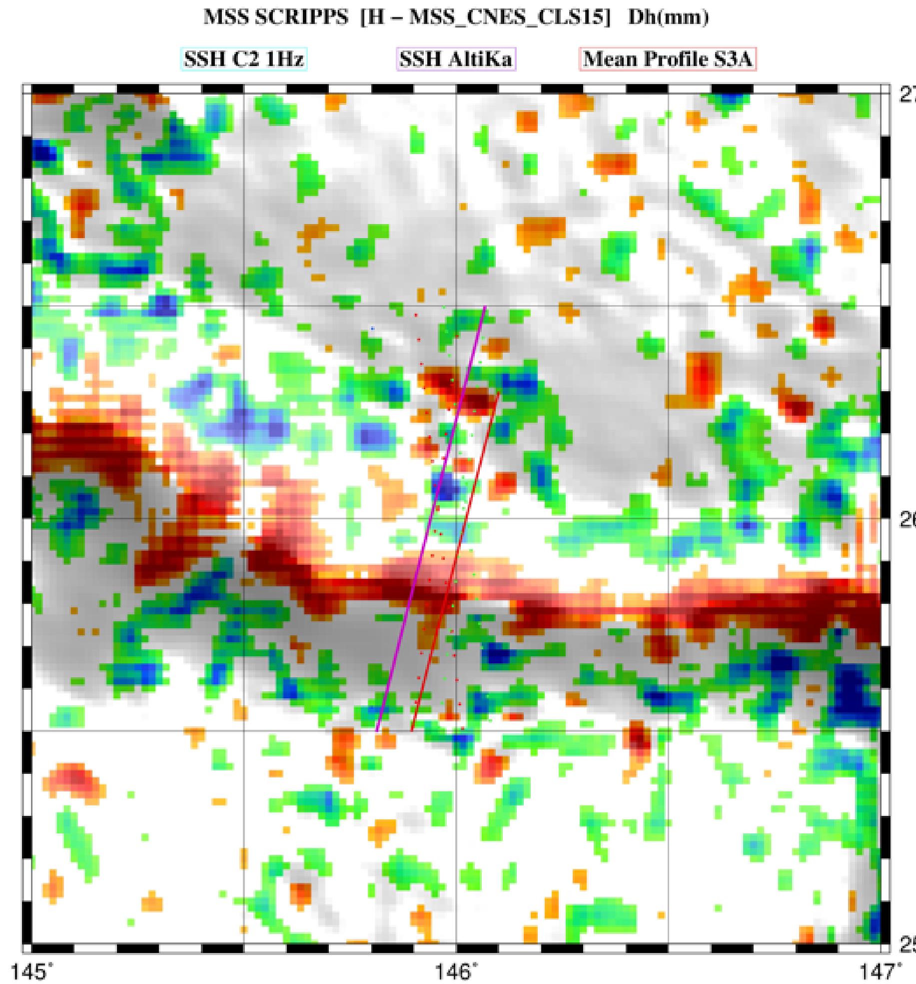
- Combine the MSS from repeat-track altimeter data developed at CLS/CNES with sea surface slope data developed at SIO.

- Need to apply geoid slope correction to all pulse-limited data.

- Need to retrack waveforms of all data to improve spatial resolution and reduce the sea state bias (SSB).

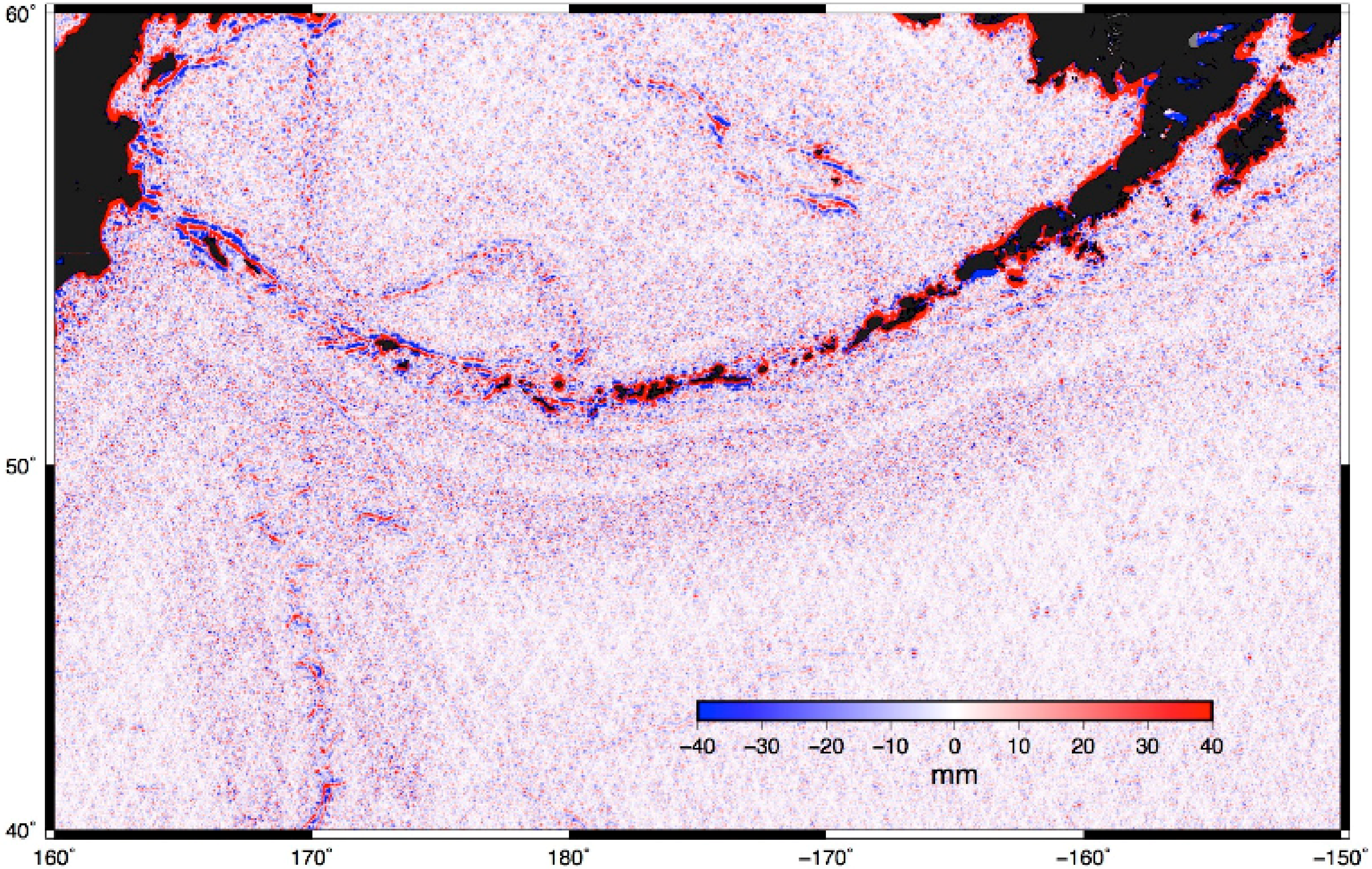
Example of resolution improvement from V3 of CLS-SIO combination





Color scale is this on left +/- 50 mm

Example of resolution improvement from V3 of CLS-SIO combination



geoid slope correction for pulse-limited altimetry

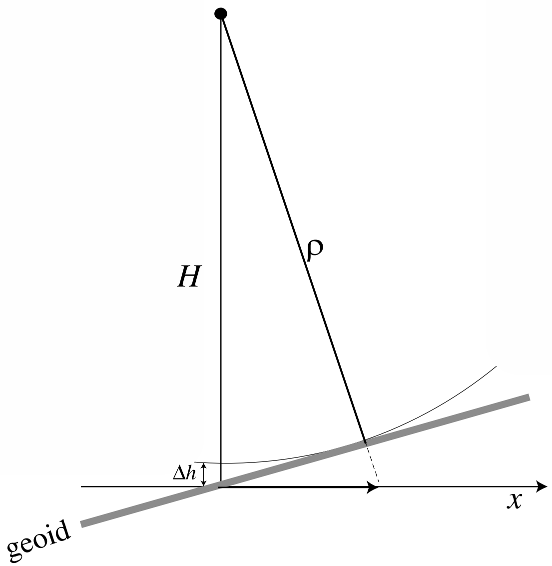
In areas of steep geoid slope, the reflection point of a pulse-limited the altimeter footprint is offset from Nadir resulting in a shorter range. A slope correction must be applied to achieve 10 mm height, 1 mGal, and 10 cm/s velocity accuracy.

$$\Delta h = \frac{s^2 H_e}{2} \qquad H_e = \frac{H}{(1 + H/R)}$$

s - slope

H - satellite altitude

R - radius of earth



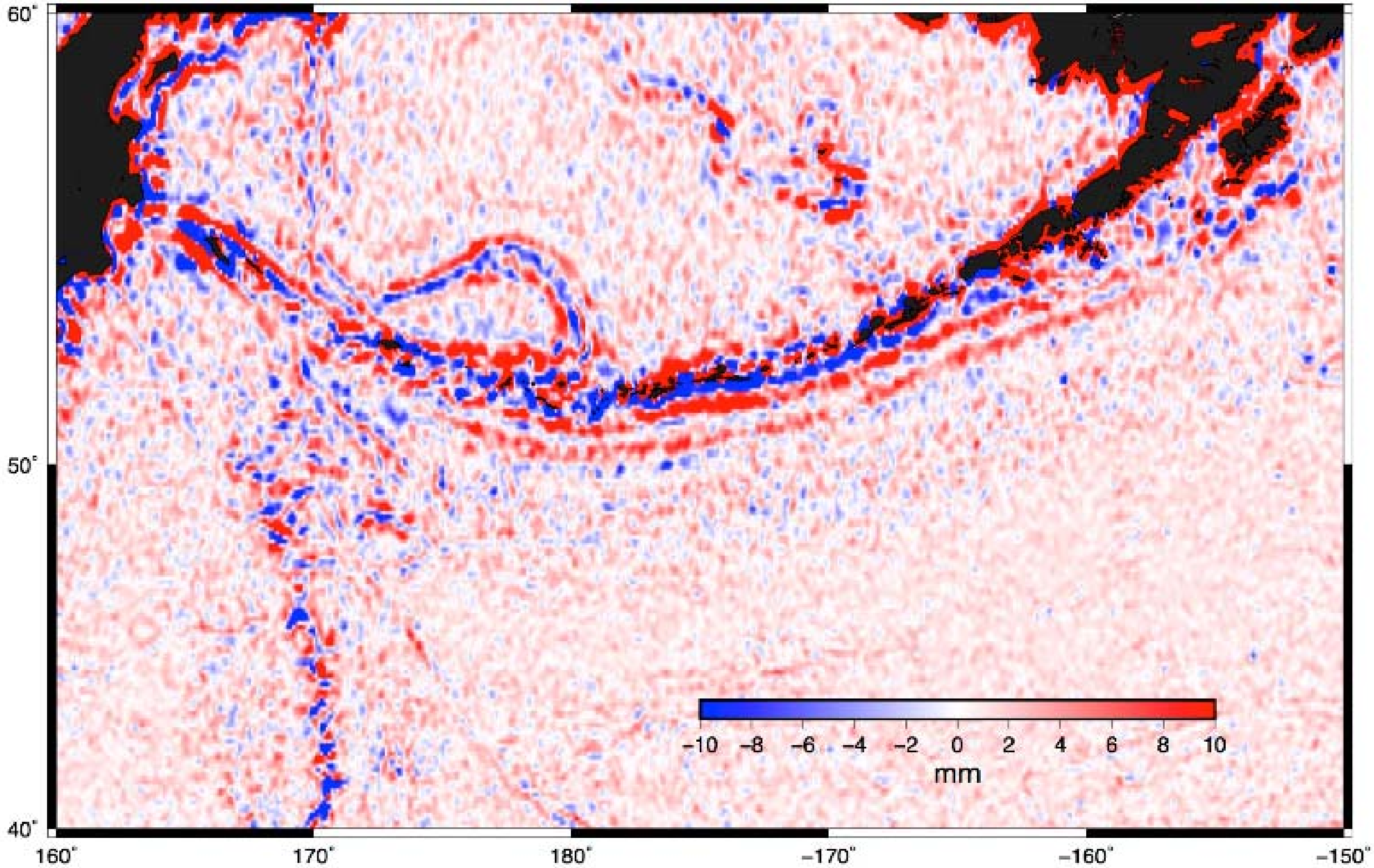
Ocean trenches have sea surface slopes of ~300 μrad.

H= 790 km	Δh = 32 mm	Δx = 210 m
H = 1330 km	Δh = 50 mm	Δx = 331 m

Correction depends on altitude. SWOT will not need a correction.

[*Brenner et al.*, 1983; *Sandwell and Smith*, 2014]

Example of resolution improvement from V3 of CLS-SIO combination

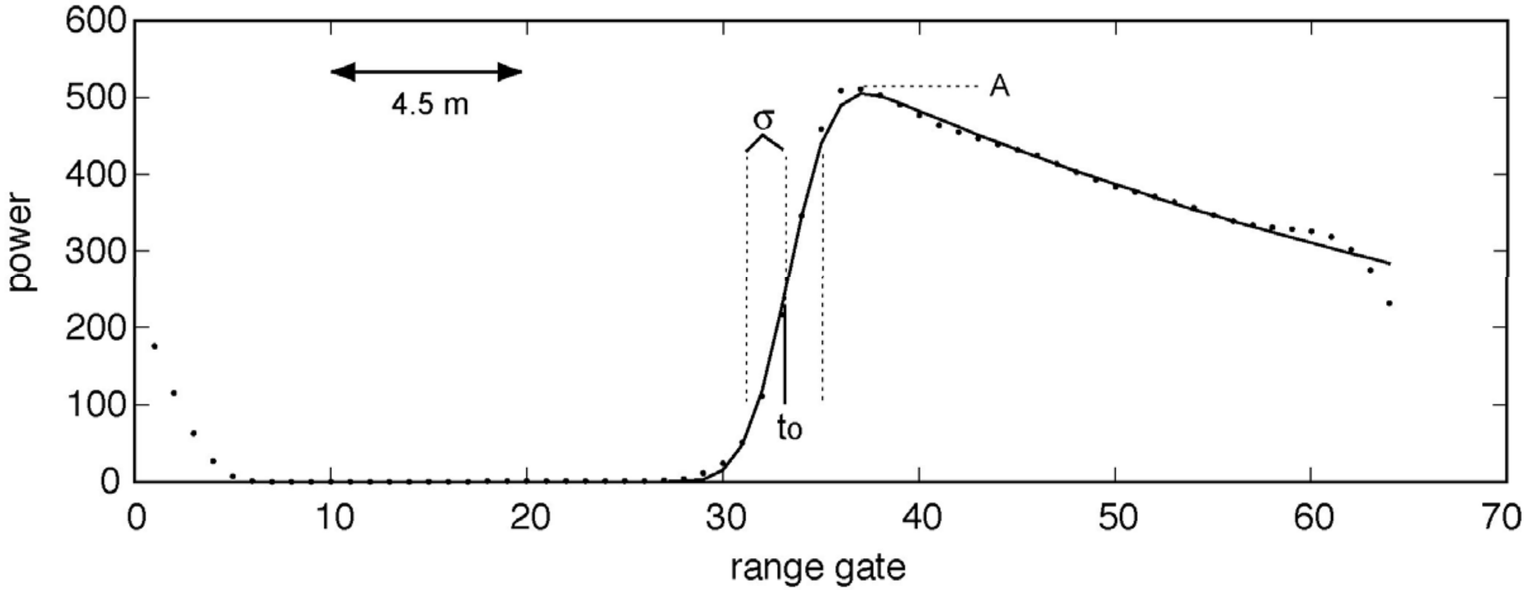


Objective: Construct a MSS with spatial resolution of 6 km to evaluate the performance of SWOT early in the mission.

Tasks:

- Combine the MSS from repeat-track altimeter data developed at CLS/CNES with sea surface slope data developed at SIO.
- Need to apply geoid slope correction to all pulse-limited data.
- **Need to retrack waveforms of all data to improve spatial resolution and reduce SSB.**

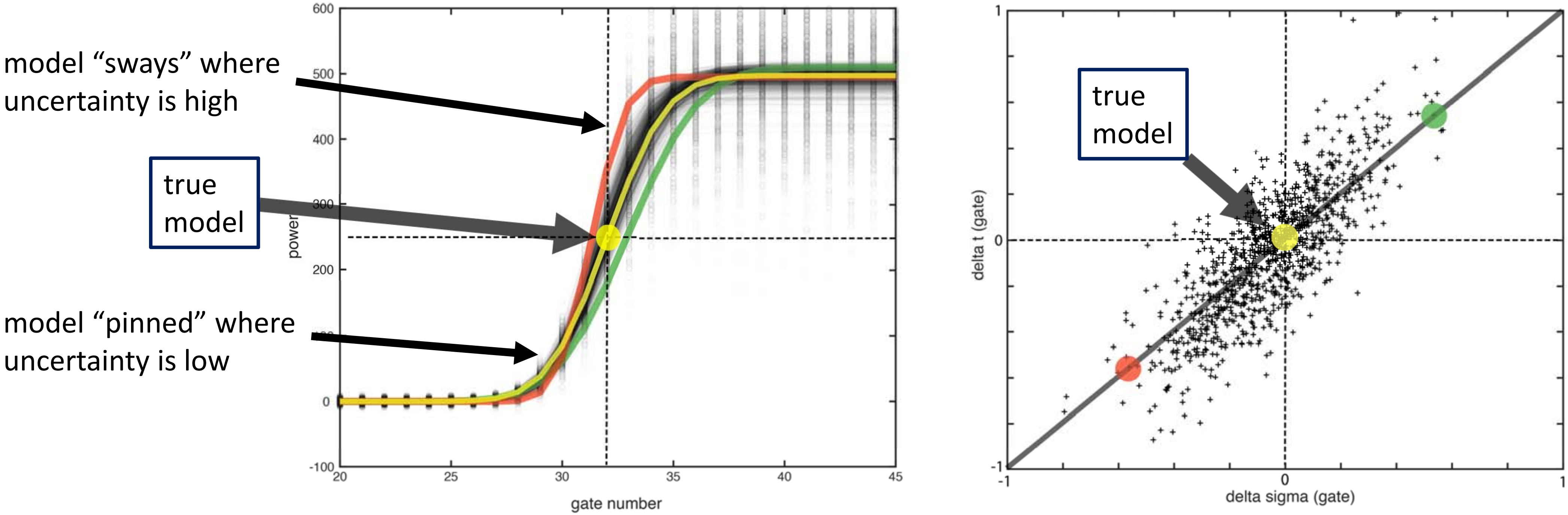
Brown model for pulse-limited waveform



Estimate 3 parameters: arrival time (t_o), rise time (σ), and power (A).

$$M(t) = \frac{A}{2}\left\{1 + erf(\eta)\right\}; \qquad \eta = \frac{t - t_o}{\sqrt{2}\sigma}$$

Brown model fits to 1000 simulations of waveform plus noise.



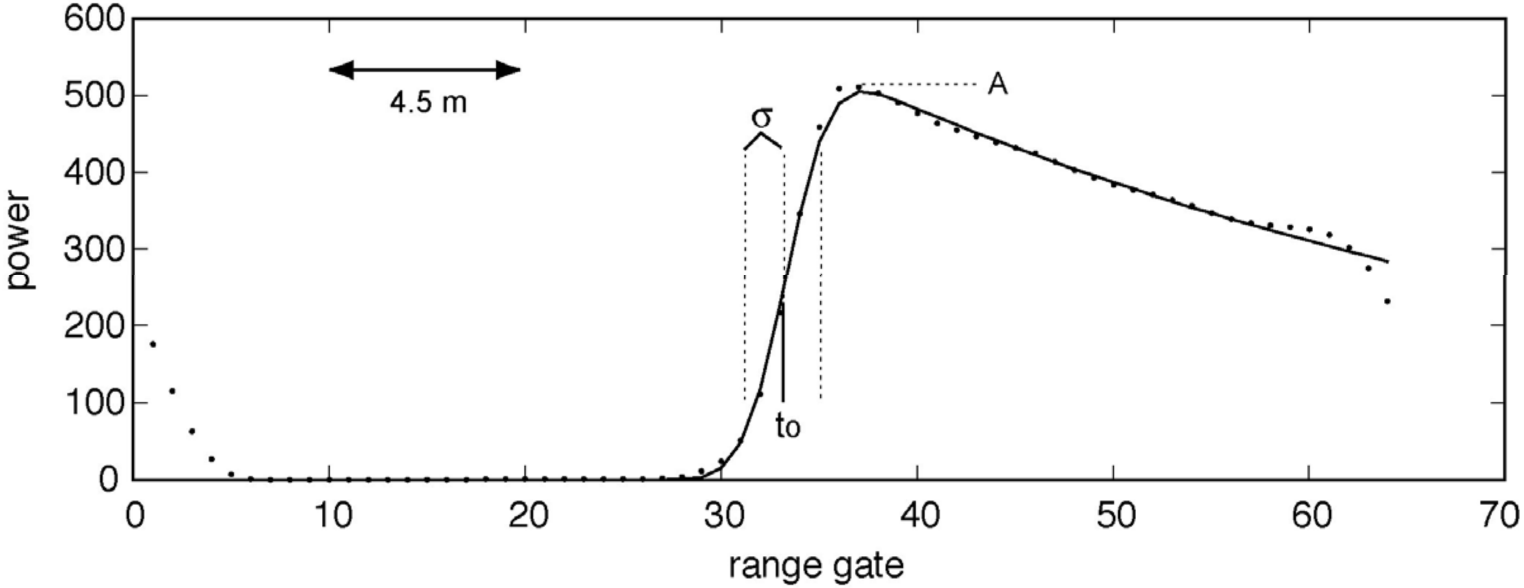
$$W_i = \frac{(P_i + P_o)}{\sqrt{K}}$$

Least-squares uncertainty W_i proportional to power P_i.

Arrival time and rise time are correlated with a slope of ~1.

[*Sandwell and Smith*, 2005]

2-pass waveform retracking improves range precision



1) retrack waveforms with standard 3-parameter model

2) smooth rise time over 45-km wavelength

3) retrack waveforms with 2-parameter model

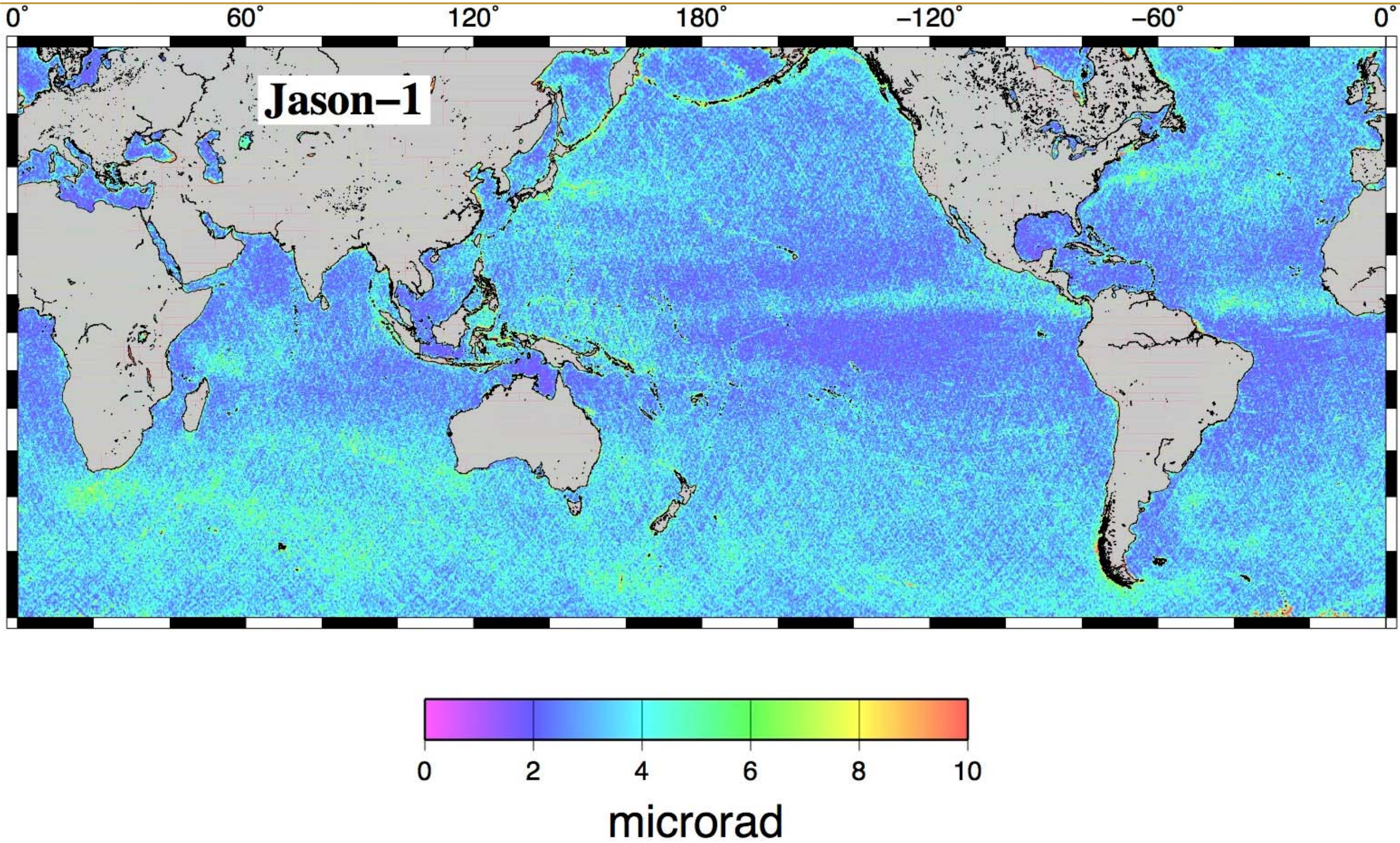
Note: this assumes wave height varies smoothly along track.

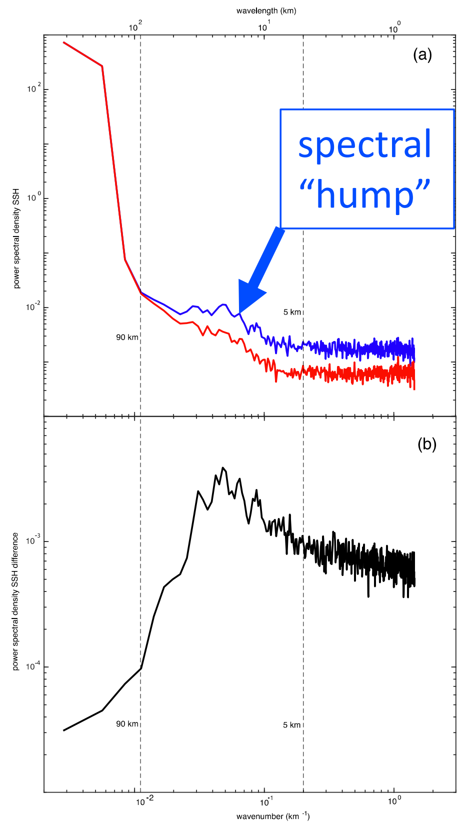
Estimate 2 parameters: arrival time (t_o), and power (A).

$$M(t) = \frac{A}{2}\left\{1 + erf(\eta)\right\}; \qquad \eta = \frac{t - t_o}{\sqrt{2}\sigma}$$

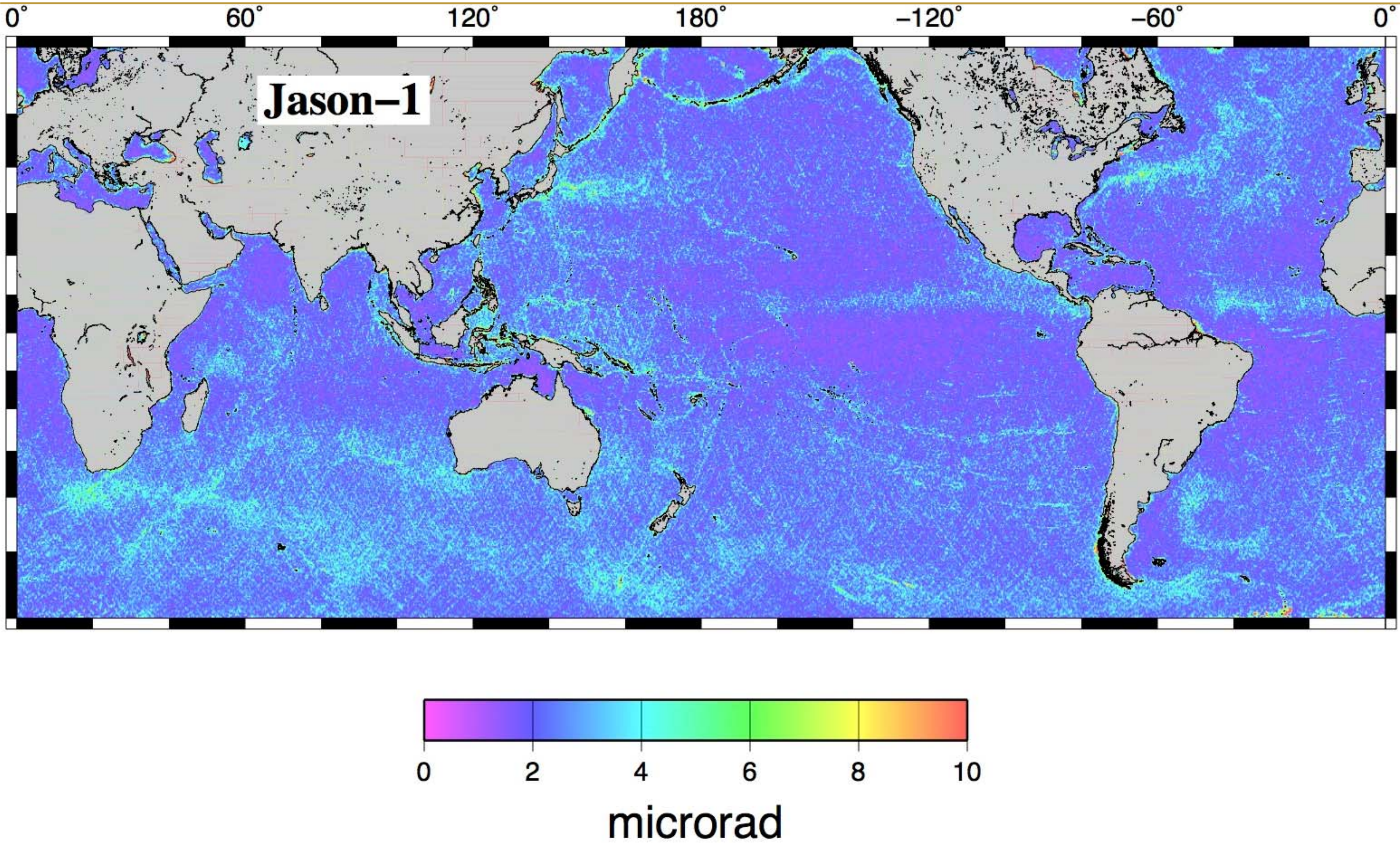
[*Sandwell and Smith*, 2005]

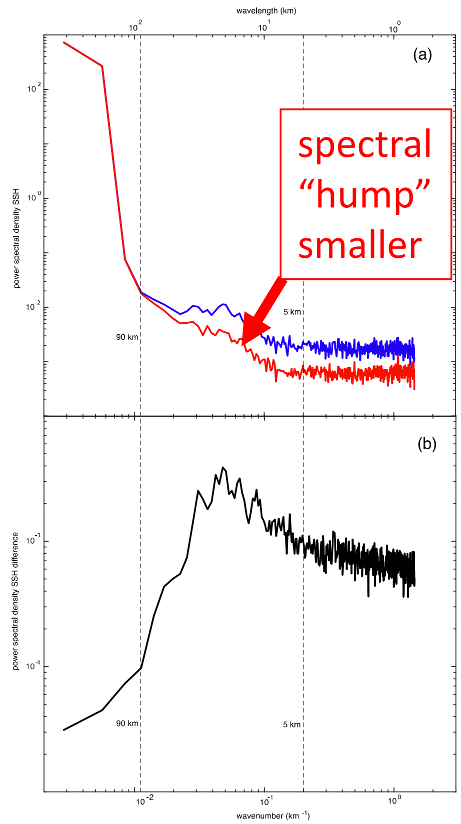
jason w.r.t. - 3par





jason w.r.t. - 2par





improved range precision for all pulse-limited altimeters

Altimeter	3-PAR @ 2 m (mm)	2-PAR @ 2 m (mm)
Geosat	88.0	57.0
ERS-1	93.6	61.8
Envisat	78.9	51.8
Jason-1	75.9	46.4
CryoSat-2	64.7	42.7
Jason-2	71.5	42.9
AltiKa	**34.3**	**20.5**

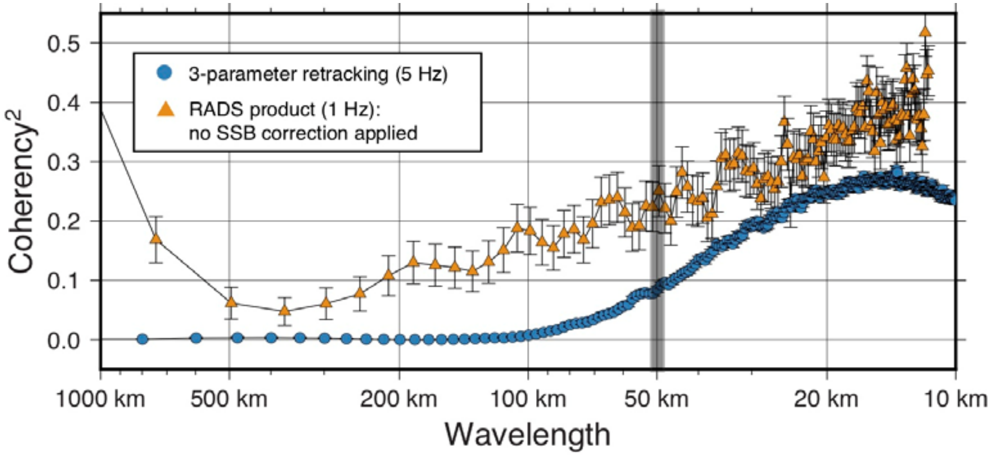
Smith [2015] showed standard GDR of AltiKa is 2 X more precise than Envisat

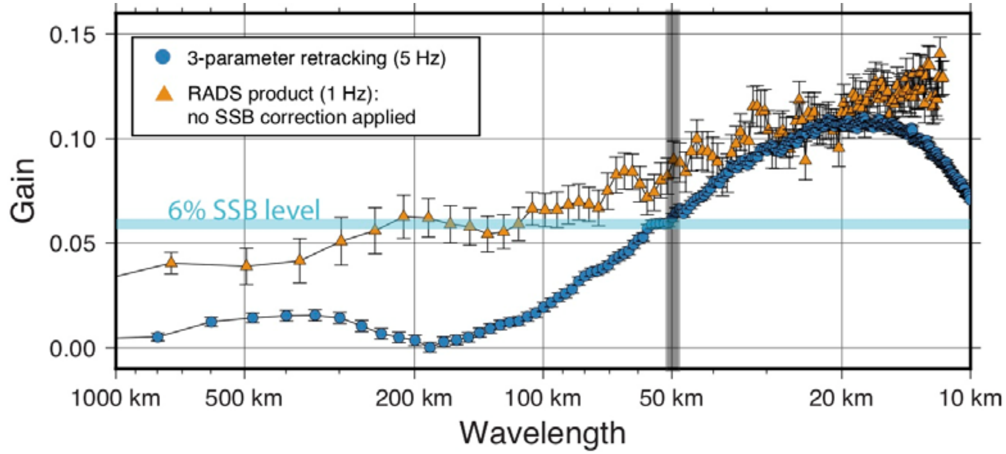
Zhang and Sandwell [2016] showed that AltiKa also benefits from 2-pass retracking.

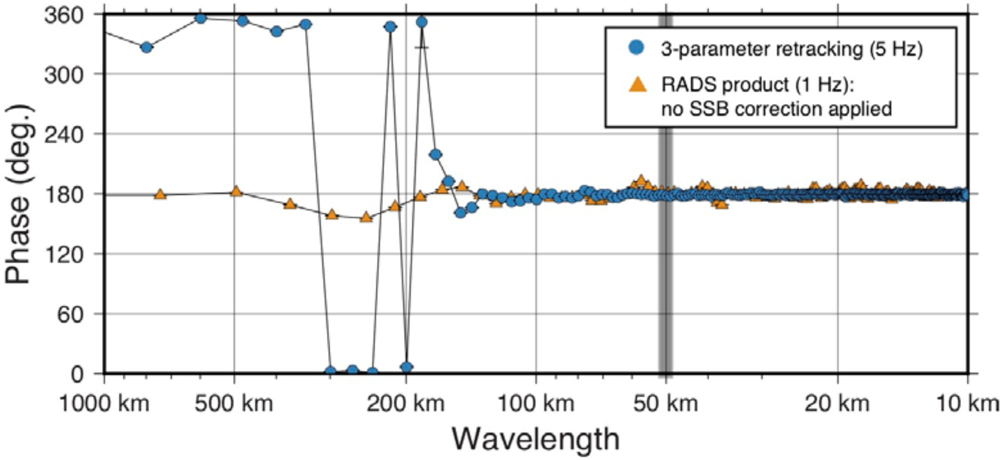
In July 2016 AltiKa began geodetic mapping. Could achieve 1 mGal global marine gravity.

(Note these statistics are done at 20 Hz or 350 m along-track resolution.)

2-pass waveform retracking reduces SSB







SSH and SSB are highly correlated for wavelengths less than 50 km and poorly correlated at longer wavelengths.

The ratio of SSH to SWH is at least 12% at short wavelengths and < 6% at long wavelengths.

[Garcia et al., OSTST Poster 2013]

can correct 1 Hz GDR [Zaron and deCarvalho, 2016]

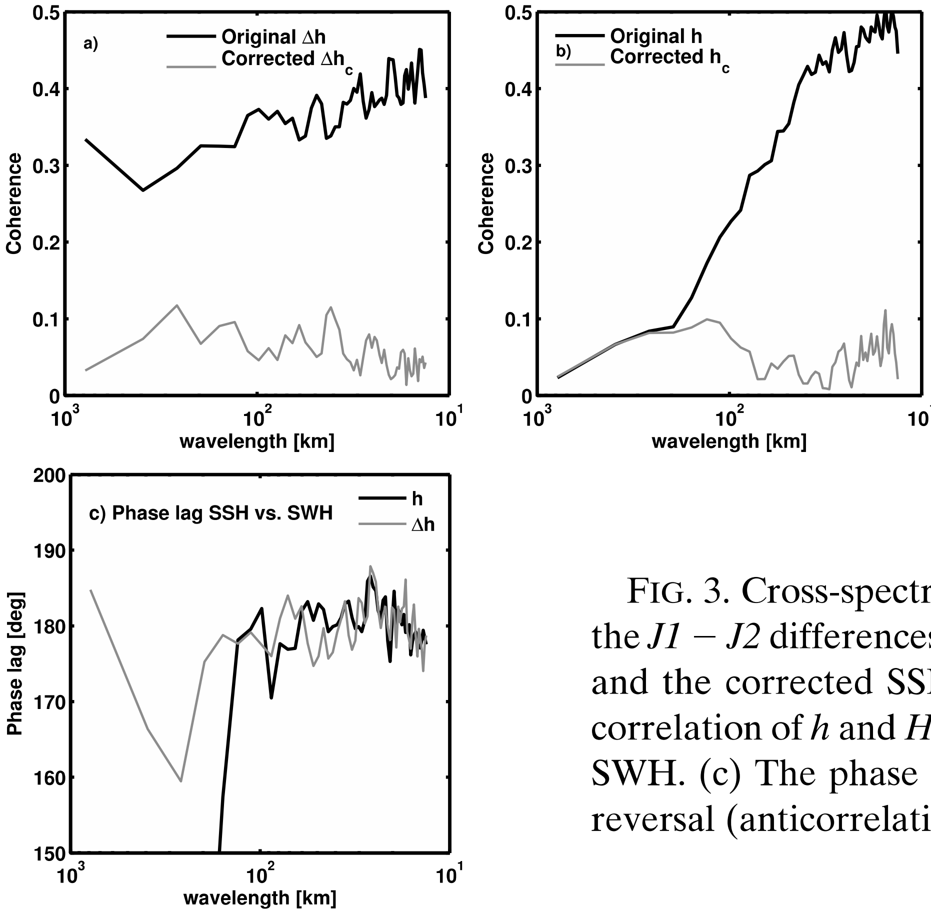
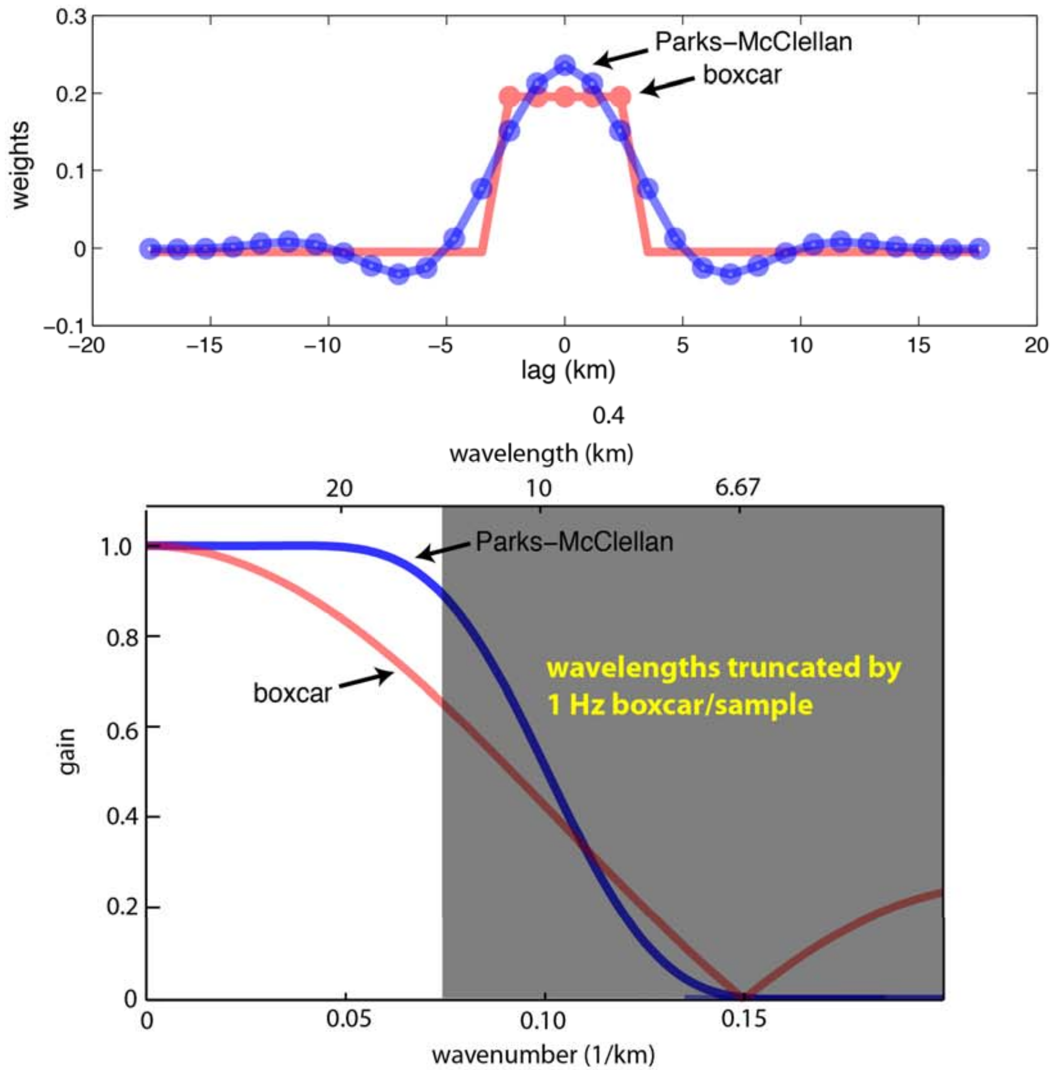


FIG. 3. Cross-spectral statistics. (a) The coherence spectrum of SSH and SWH is shown for the $J1 - J2$ differences from the calibration/validation orbit phase for both the original SSH Δh and the corrected SSH Δh_c. (b) The coherence spectrum of SSH and SWH data shows the correlation of h and H_s for scales shorter than 100 km; the h_c is not significantly correlated with SWH. (c) The phase lag computed from the cross spectrum indicates the unambiguous sign reversal (anticorrelation) between the correlated components of SSH and SWH.

[Zaron and deCarvalho, 2016]

however, 1 Hz GDR has inadequate spatial resolution

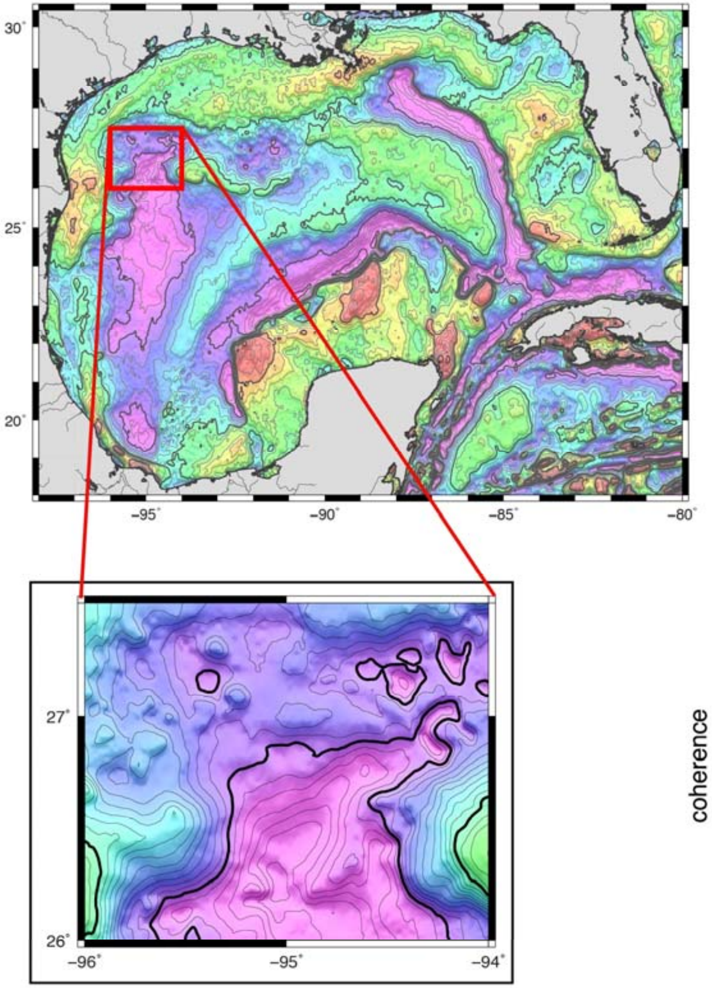


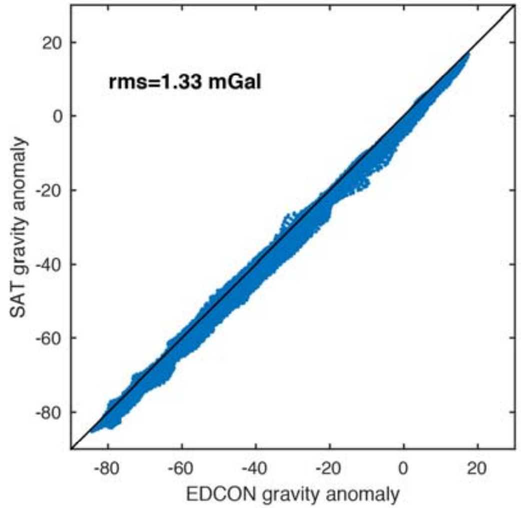
Nyquist wavelength of 1 Hz product is 13 km.

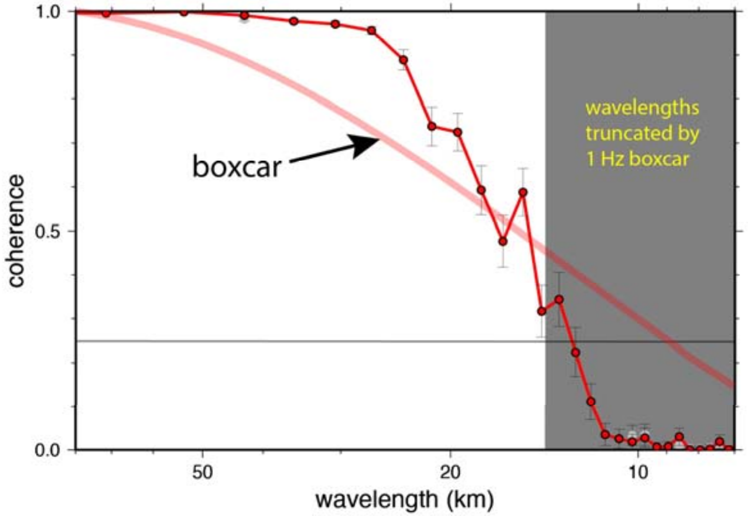
Our goal is to achieve 0.5 gain at 13 km wavelength.

Note that boxcar filtering followed by decimation at 6.7 km causes the shorter wavelength noise to be aliased into longer wavelengths.

accuracy and resolution of altimeter-derived gravity







Comparison of altimeter-derived gravity anomaly with more accurate shipboard gravity.

- rms difference is 1.33 mGal

- shortest resolvable wavelength is 12 km

Conclusions

- SWOT will require a MSS having both high accuracy and high spatial resolution.
- Our approach uses CLS MSS repeat profiles to constrain large scales (> 50 km) and the SIO non-repeat slope profiles to constrain small scales.
- Pulse-limited altimetry will need to be corrected for sea surface slope when compared with SWOT.
- The standard SSH and SWH are highly correlated for wavelengths < 50 km. This is due to the least-squares fitting.
- 2-pass retracking of all pulse-limited altimetry at 20 Hz will:
  fix the 1-Hz sampling problem;
  improve range precision by 1.5 times;
  reduce the SSB.
- What is a "safe" wavelength for SWH smoothing?

geoid slope correction for pulse-limited altimetry

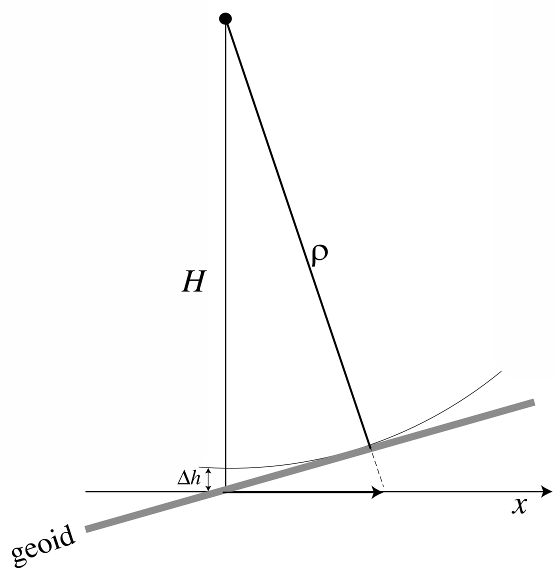
In areas of steep geoid slope, the reflection point of a pulse-limited the altimeter footprint is offset from Nadir resulting in a shorter range. A slope correction must be applied to achieve 10 mm height, 1 mGal, and 10 cm/s velocity accuracy.

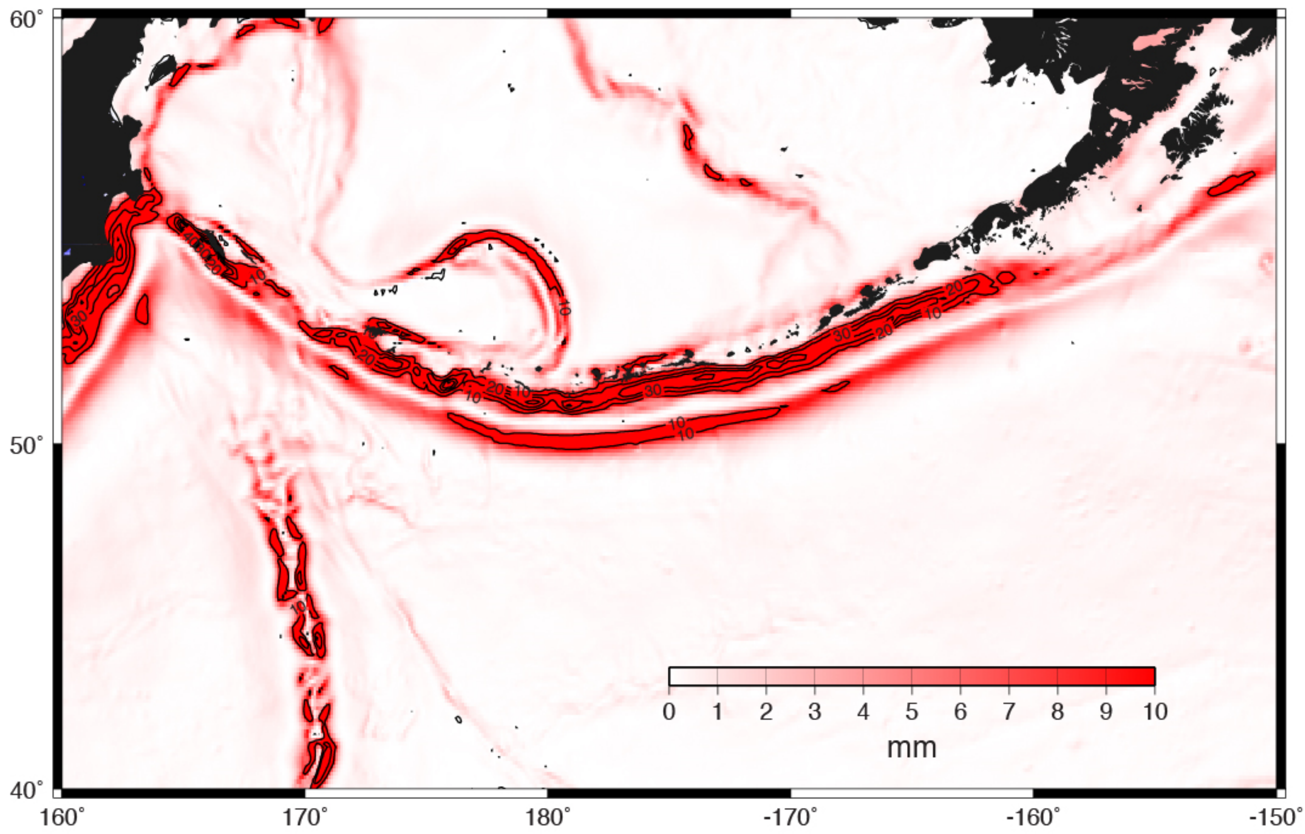
$$\Delta h = \frac{s^2 H_e}{2} \qquad H_e = \frac{H}{(1 + H/R)}$$

s - slope

H - satellite altitude

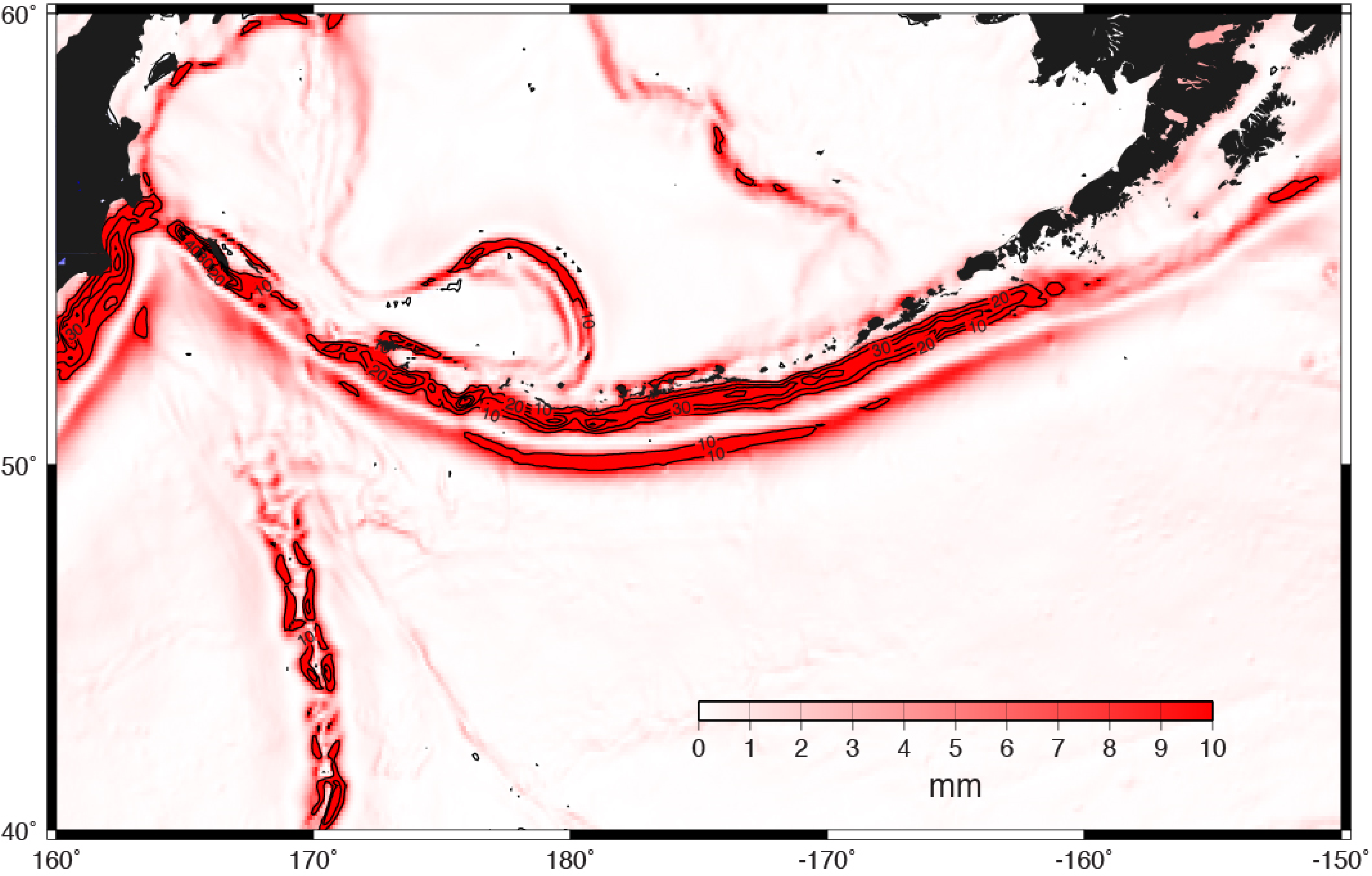
R - radius of earth





[*Brenner et al.*, 1983; *Sandwell and Smith*, 2014]

geoid slope correction for pulse-limited altimetry

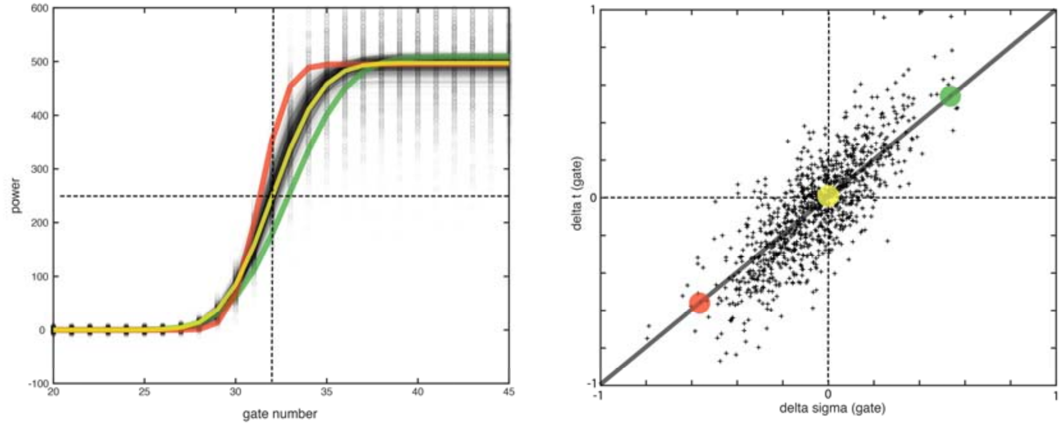


In areas of steep geoid slope, the reflection point of a pulse-limited the altimeter footprint is offset from Nadir resulting in a shorter range. A slope correction
must be applied to achieve 10 mm height, 1 mGal, and 10 cm/s velocity accuracy.

least squares correlation of arrival time and rise time

- SSH and SWH are correlated with a "sea state bias" of ~25%.
  (Note SWH = 4 X rise time.)

- Could improve the estimate of the SSH by 1.5 times if the value of SWH was known.



Arrival time and rise time are correlated with a slope of ~1.

[*Sandwell and Smith*, 2005]