High Resolution Mean Sea Surface for SWOT

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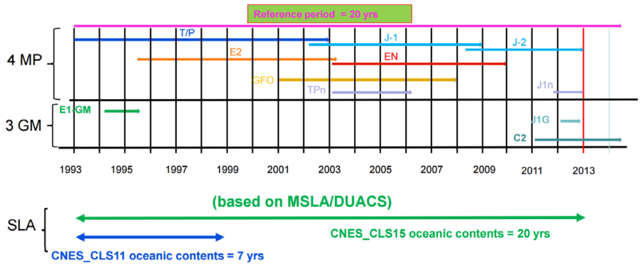
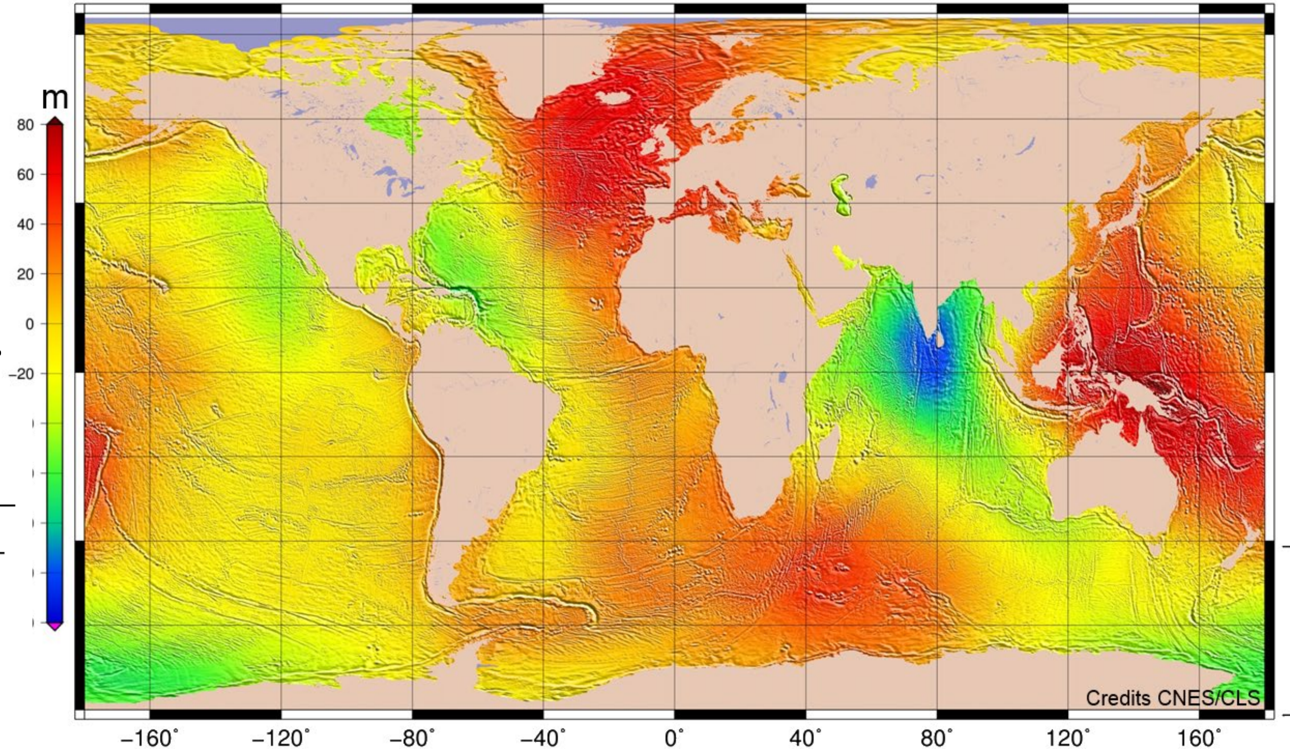
- Need high resolution MSS for CAL/VAL early in the mission.
- MSS should have long wavelength accuracy from multidecadal repeat-track altimetry and short wavelength precision from GM phases.
- Approach: Use CLS MSS model for to constrain large scales (> 30 km).
  Use SIO slope profiles to constrain small scales.
- Biharmonic splines in tension can combine height and slope data with appropriate uncertainties.

Attributes of CLS MSS Model

- Based on 20 years of altimetry data.
- All corrections applied to improve absolute height accuracy.
- 1 minute resolution.
- Matching uncertainty grid.





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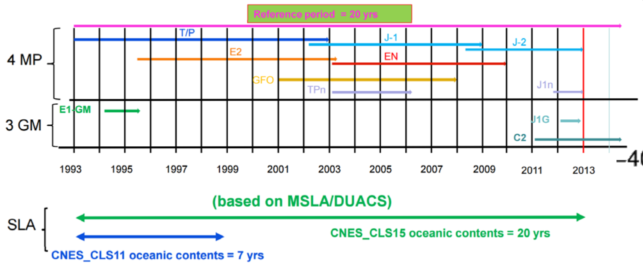
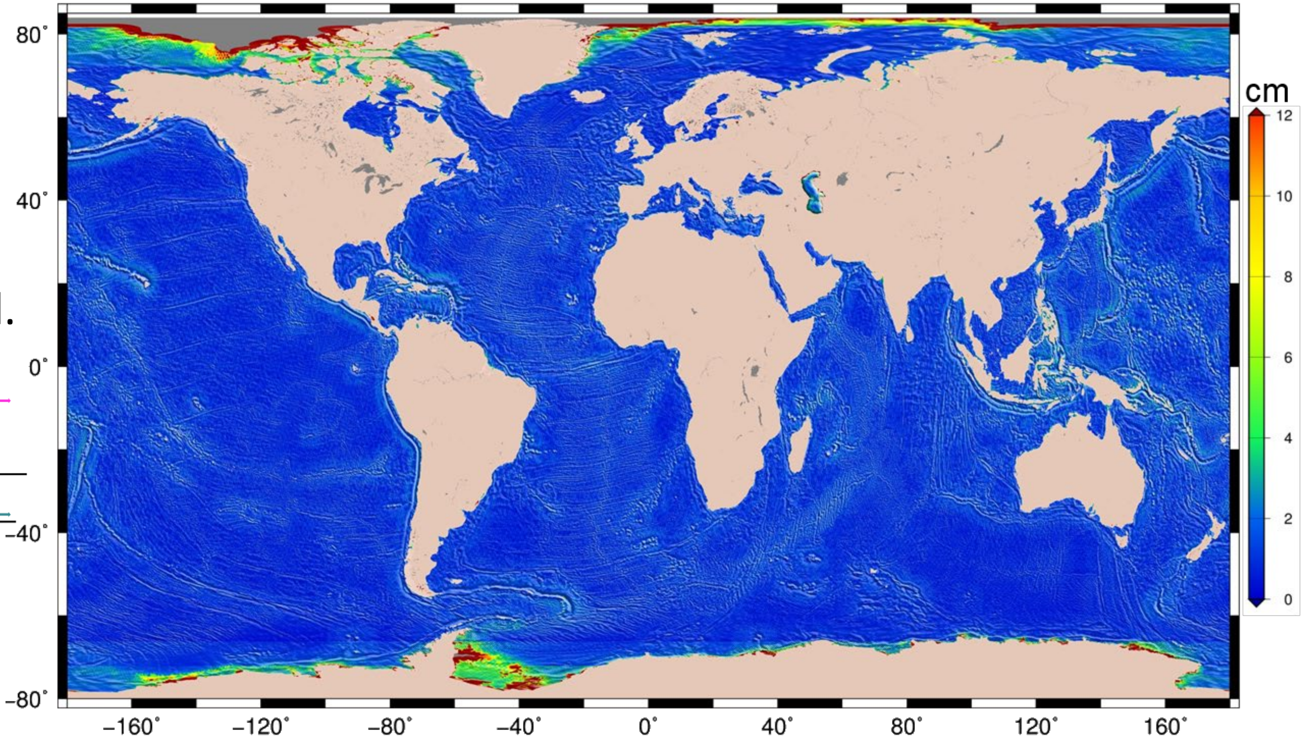
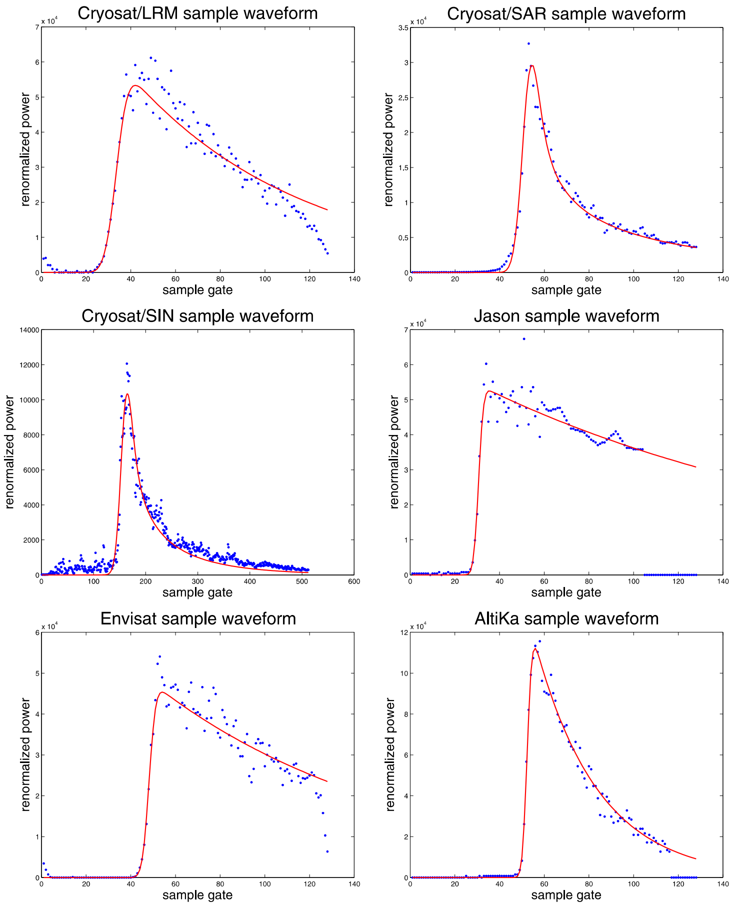




Attributes of SIO Slope Data

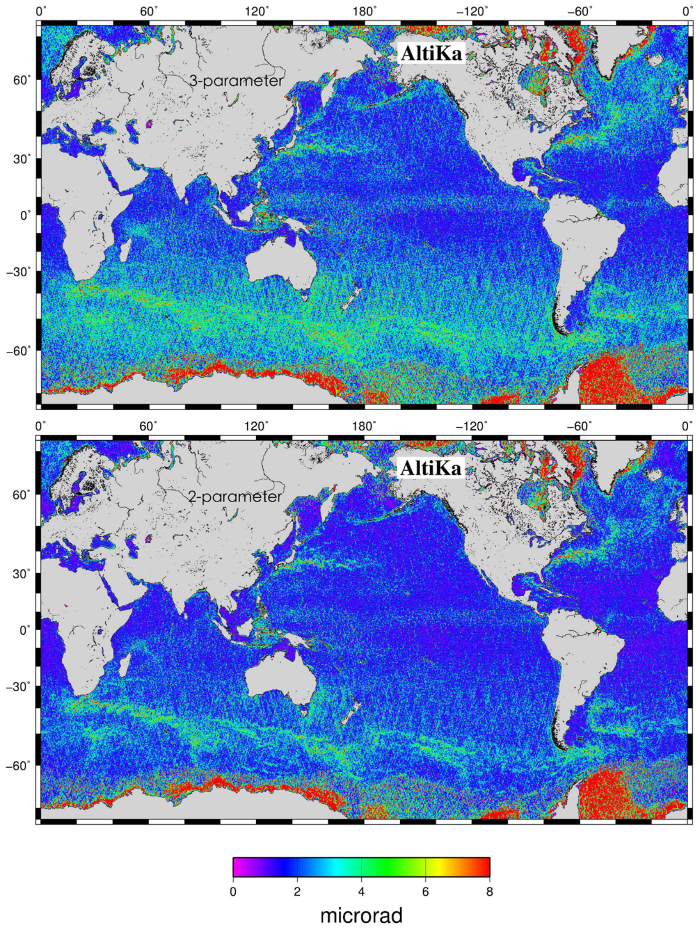
- Two-pass waveform retracking of Geosat-GM, ERS-1, Envisat, Jason-1, Cryosat-2, and AltiKa.
- Identical filters are applied to all data. (0.5 gain at 7 km wavelength and resample at 5 Hz.)
- No corrections except for ocean tide **high precision but low accuracy**.
- Slope correction is applied to all data.



[Zhang and Sandwell, 2016]

Altimeter Noise at 20 Hz (mm)

Altimeter	3-PAR @ 2 m	2-PAR @ 2 m
Geosat	88.0	57.0
ERS-1	93.6	61.8
Envisat	78.9	51.8
Jason-1	75.9	46.4
CryoSat-2 LRM	64.7	42.7
CryoSat-2 SAR	49.5	49.7
AltiKa	**34.3**	**20.5**

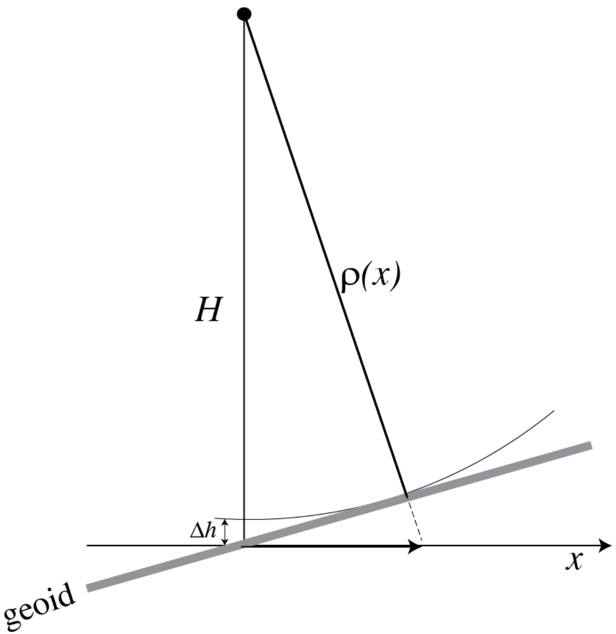


AltiKa 4.5 mm @ 1 Hz

[Zhang and Sandwell, 2016]

Slope Correction for Ocean Radar Altimetry

In areas of steep geoid slope, the reflection point of 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

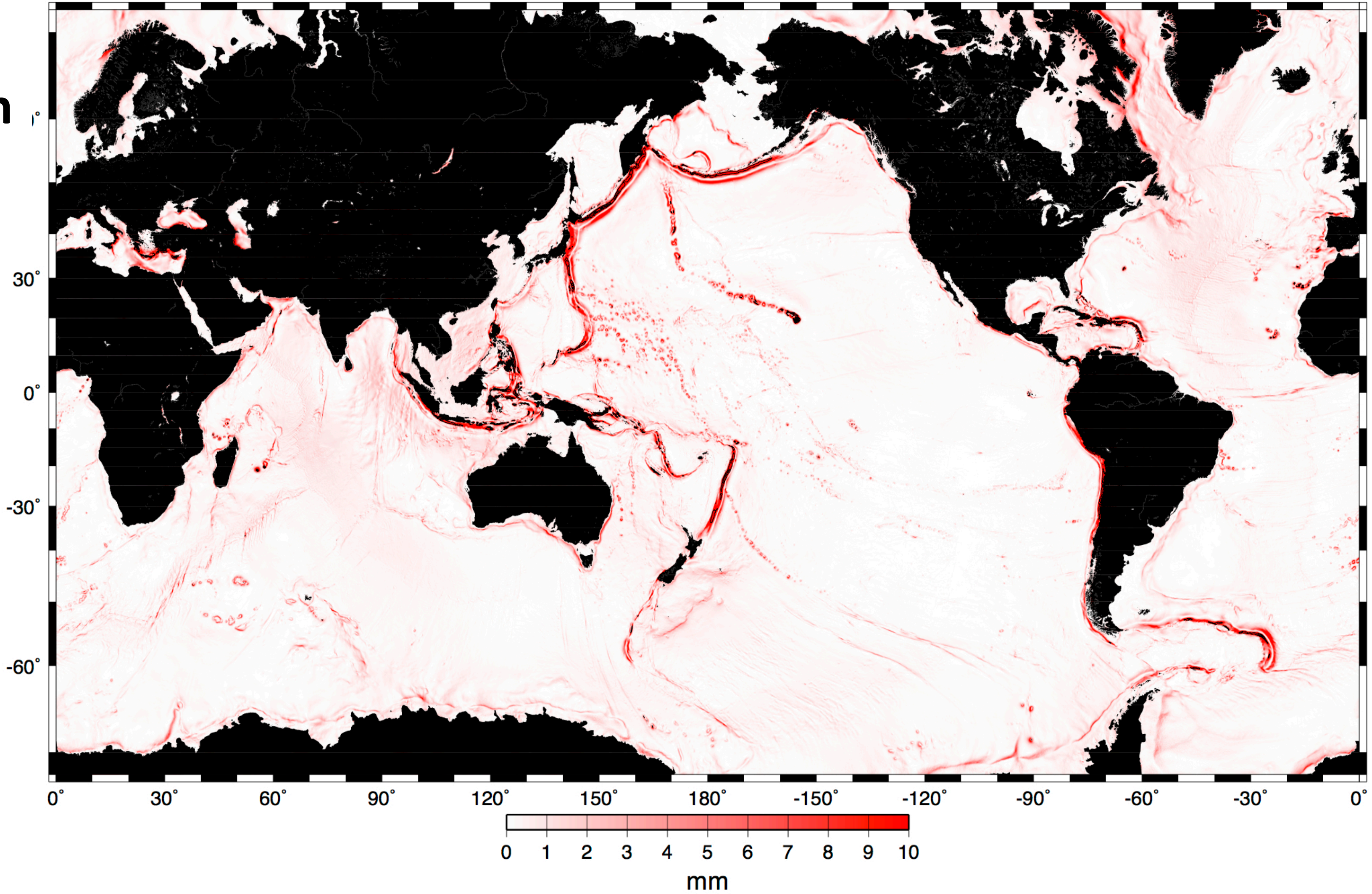
Ocean trenches produce sea surface slopes of ~300 μrad.

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

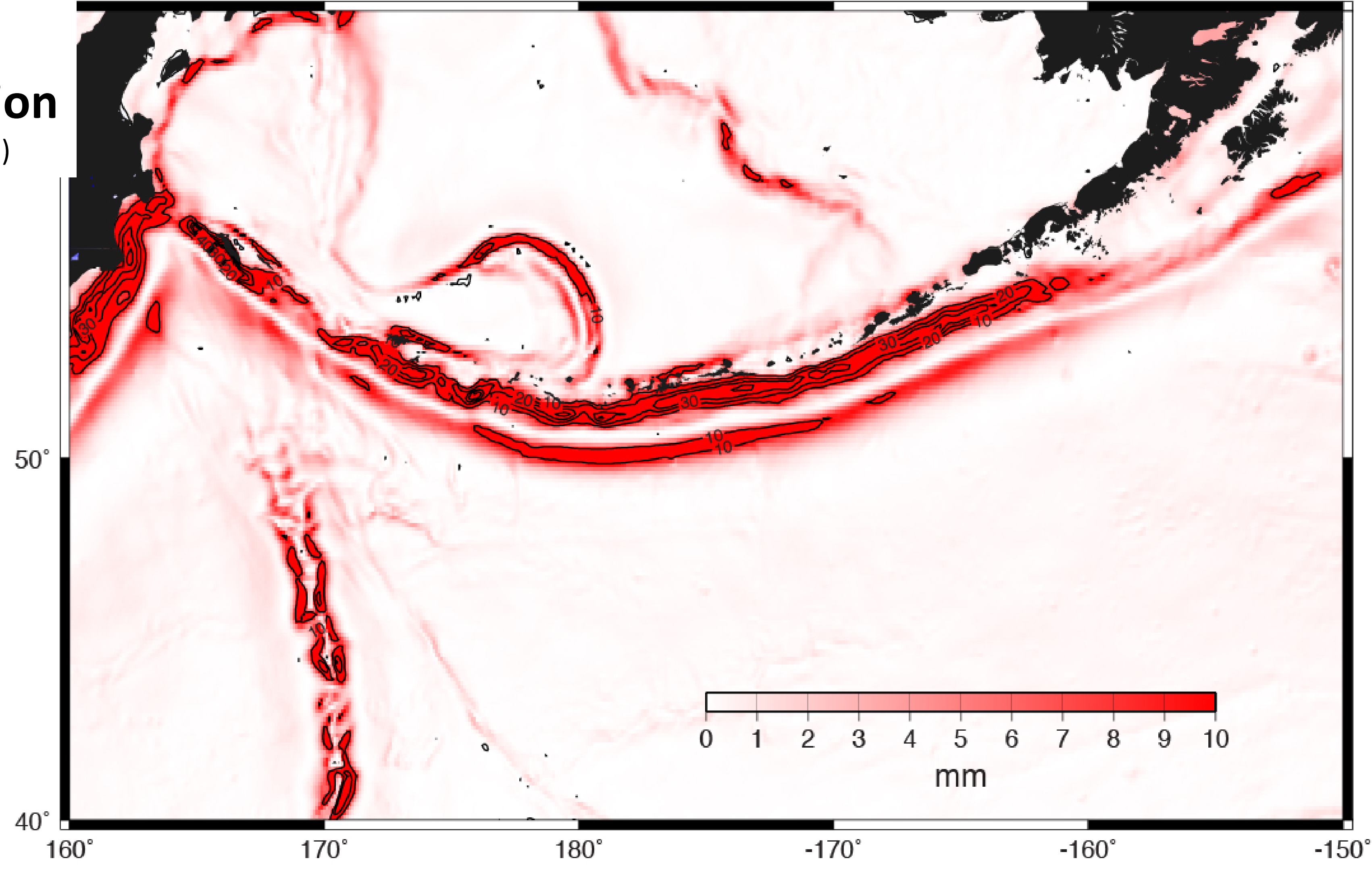
Correction depends on altitude.

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

height correction
(H = 1000 km)

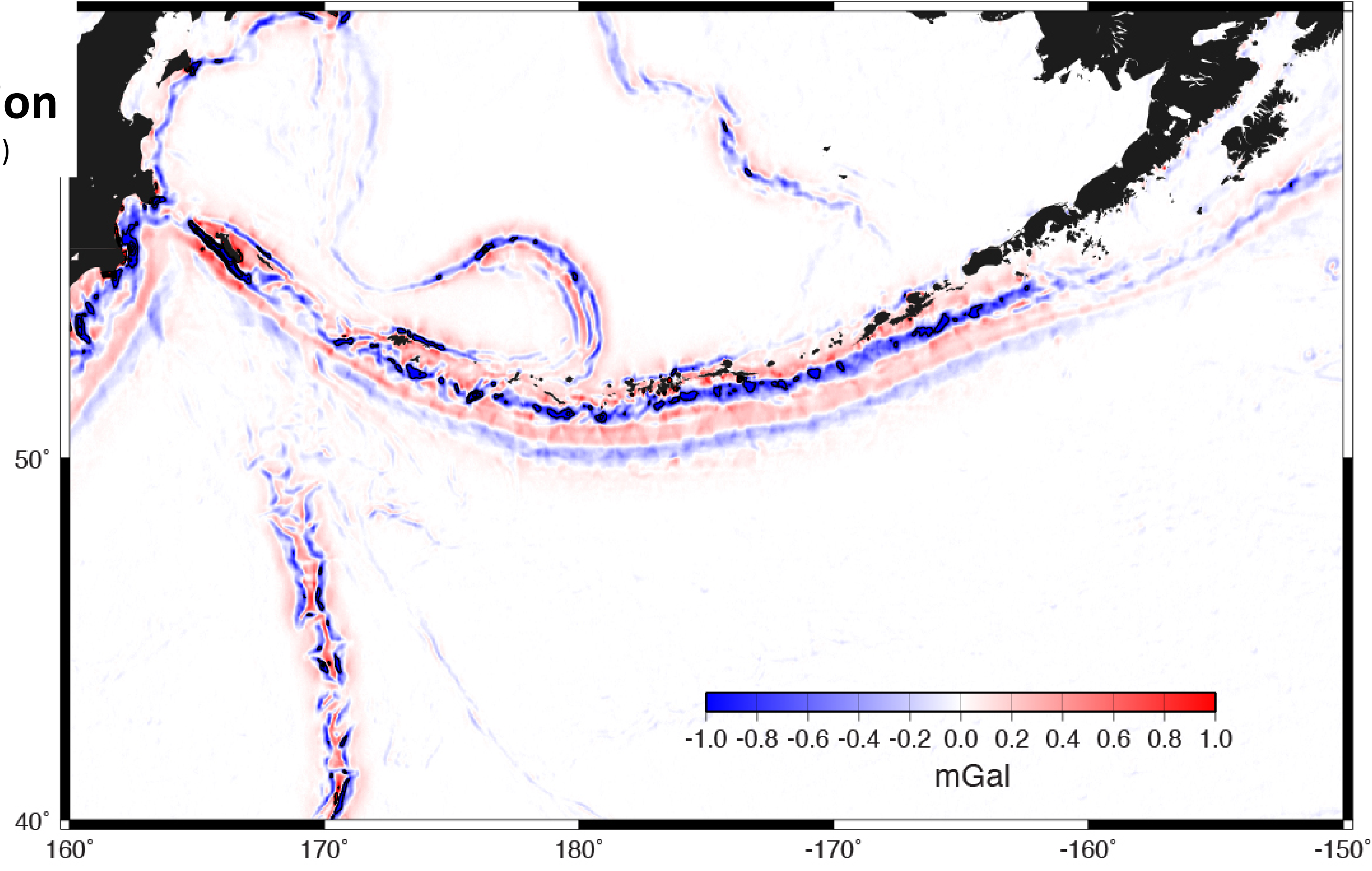


height correction
(H = 1000 km)



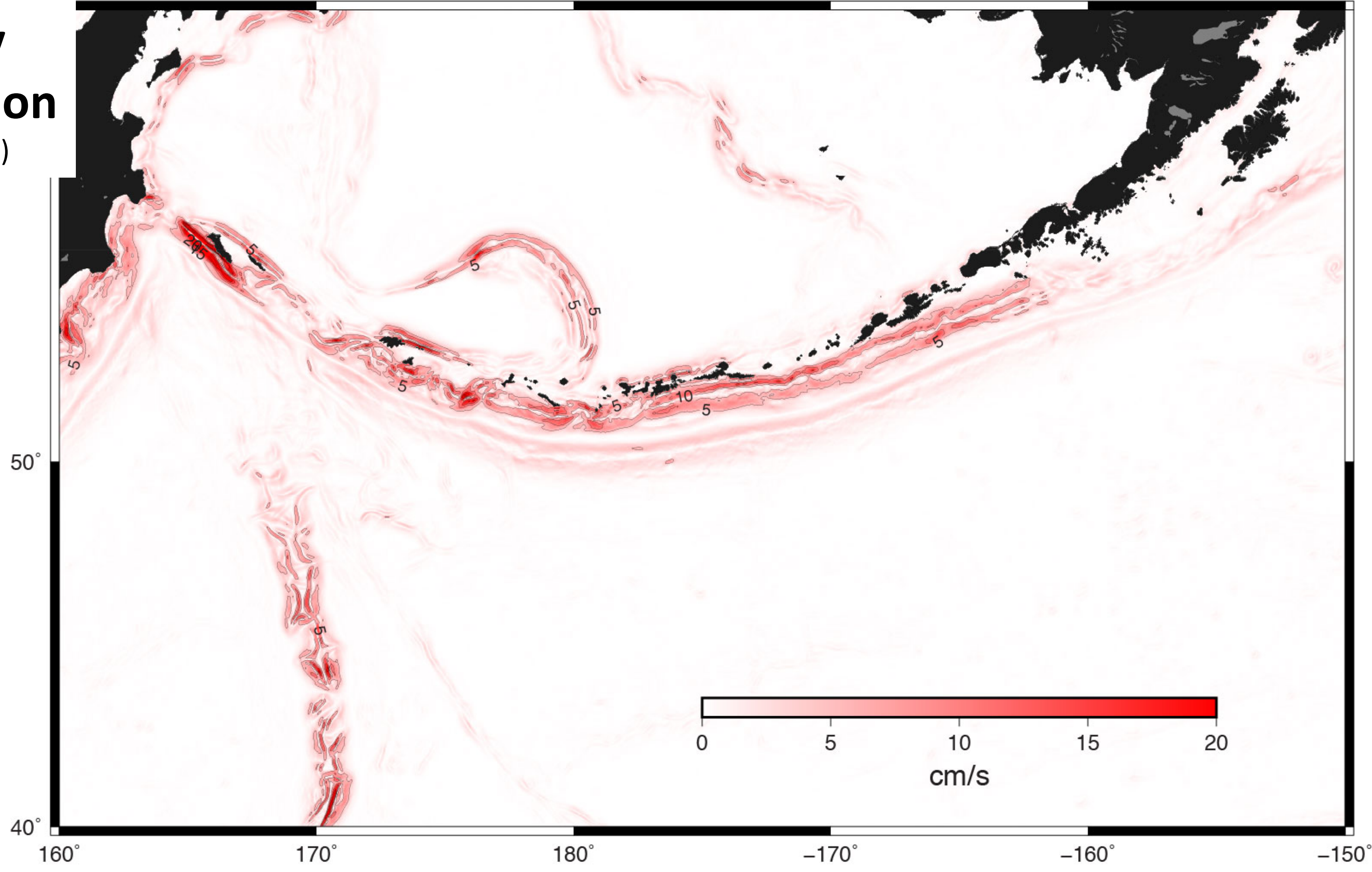
gravity correction

(H = 1000 km)



velocity correction

(H = 1000 km)



Slope Correction is Needed for SWOT MSS

- SWOT has a beam-limited footprint so will not have slope-induced range error.
- MSS from standard altimetry must be slope corrected for comparison with SWOT.
- Also MSS must be slope-corrected prior to subtracting the geoid to isolate dynamic topography.
- The slope correction **depends on satellite altitude** so the correction must be applied to the altimeter data prior to MSS construction.

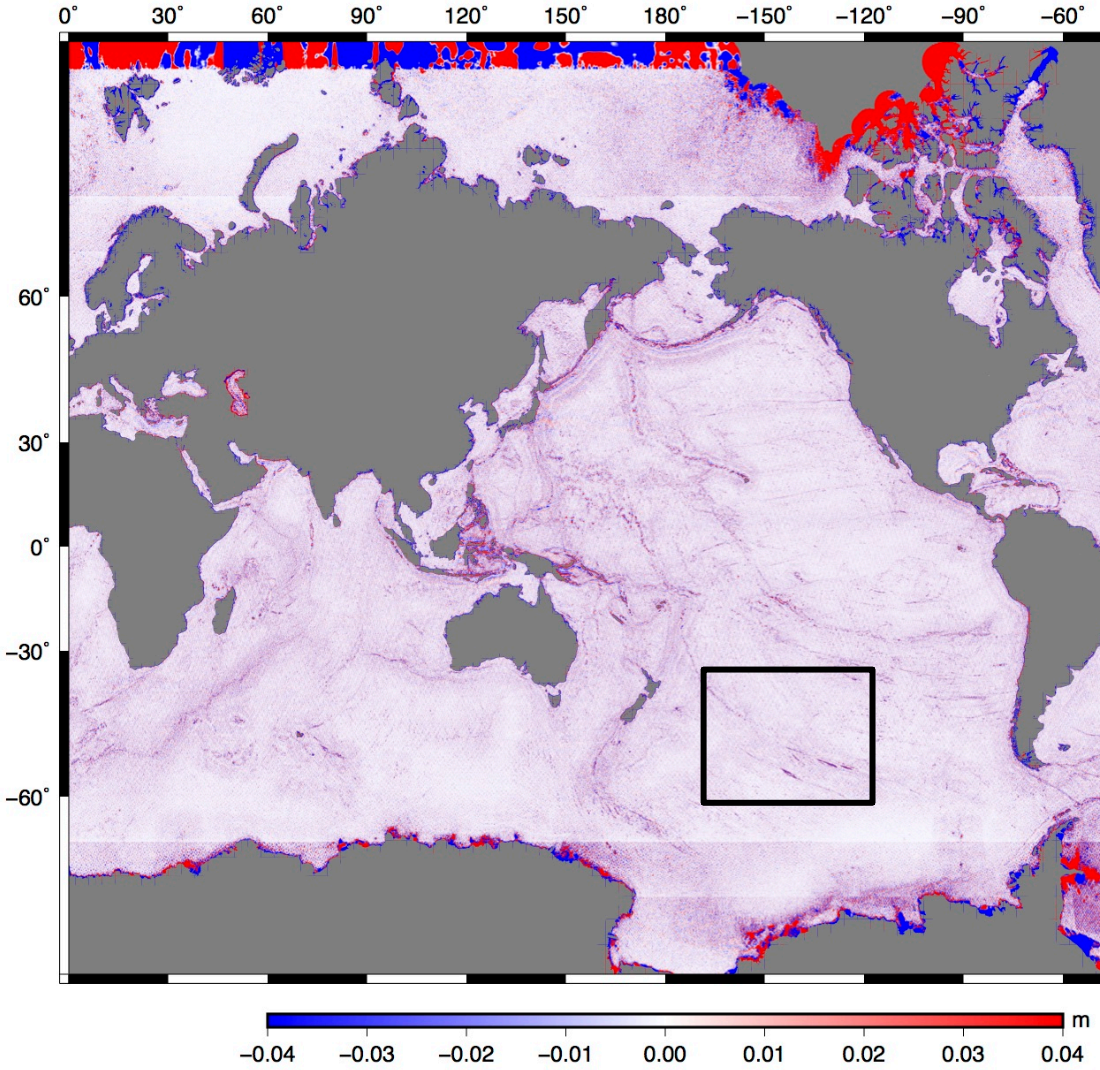
MSS from CLS height data and SIO slope data

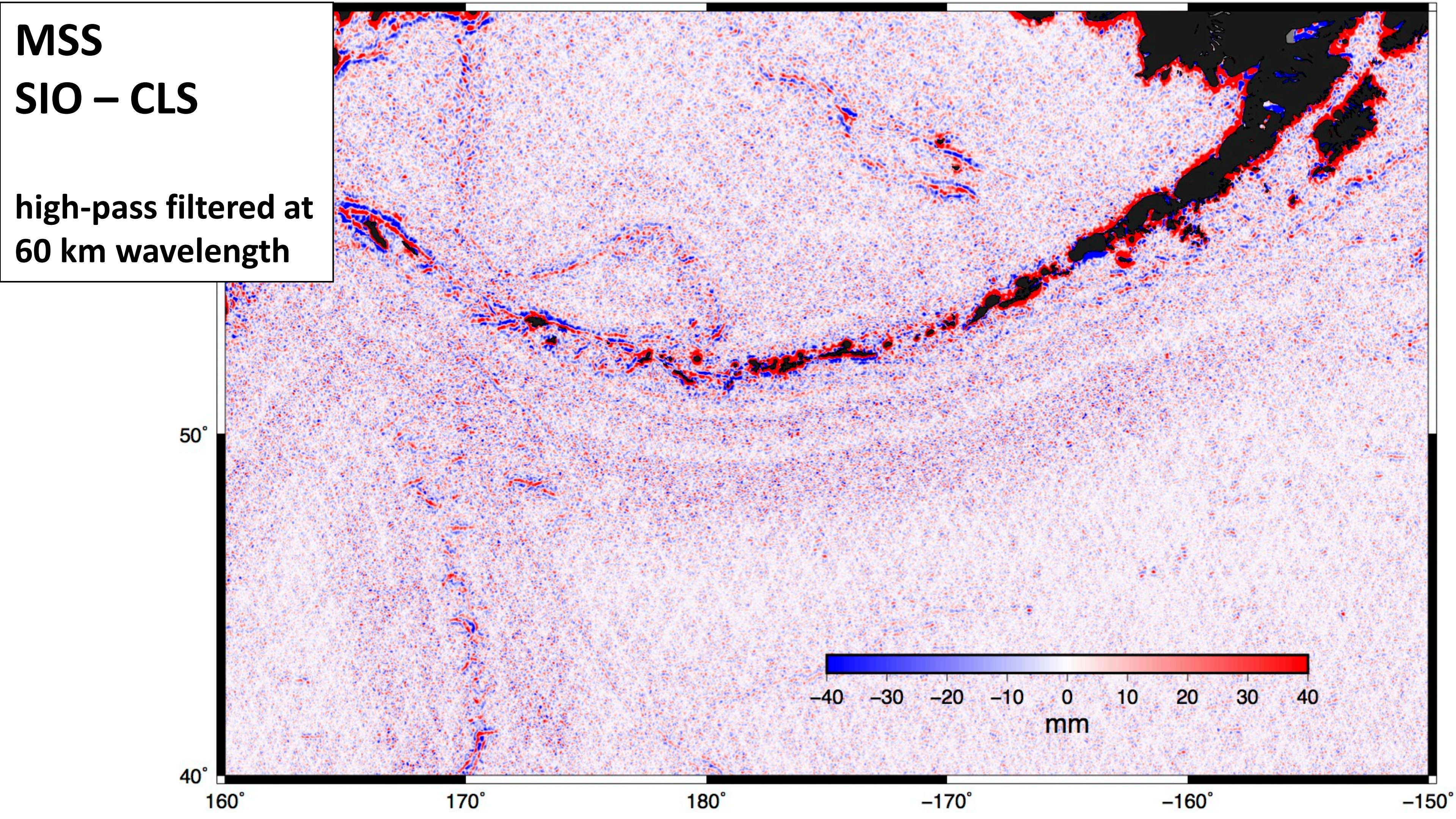
- Extract MSS heights from CLS 2015 model where standard deviation < 80 mm.
- Use all along-track slope data from Geosat, ERS-1, Envisat, Jason-1, CryoSAT-2 and Altika.
- EGM2008 is used in the remove/restore because it has complete global coverage and thus minimizes coastline edge effects.
- Use the standard SIO gridding code for biharmonic splines in tension [*Wessel and Bercovici,* 1998]

MSS
SIO - CLS

Statistics for
South Pacific Box

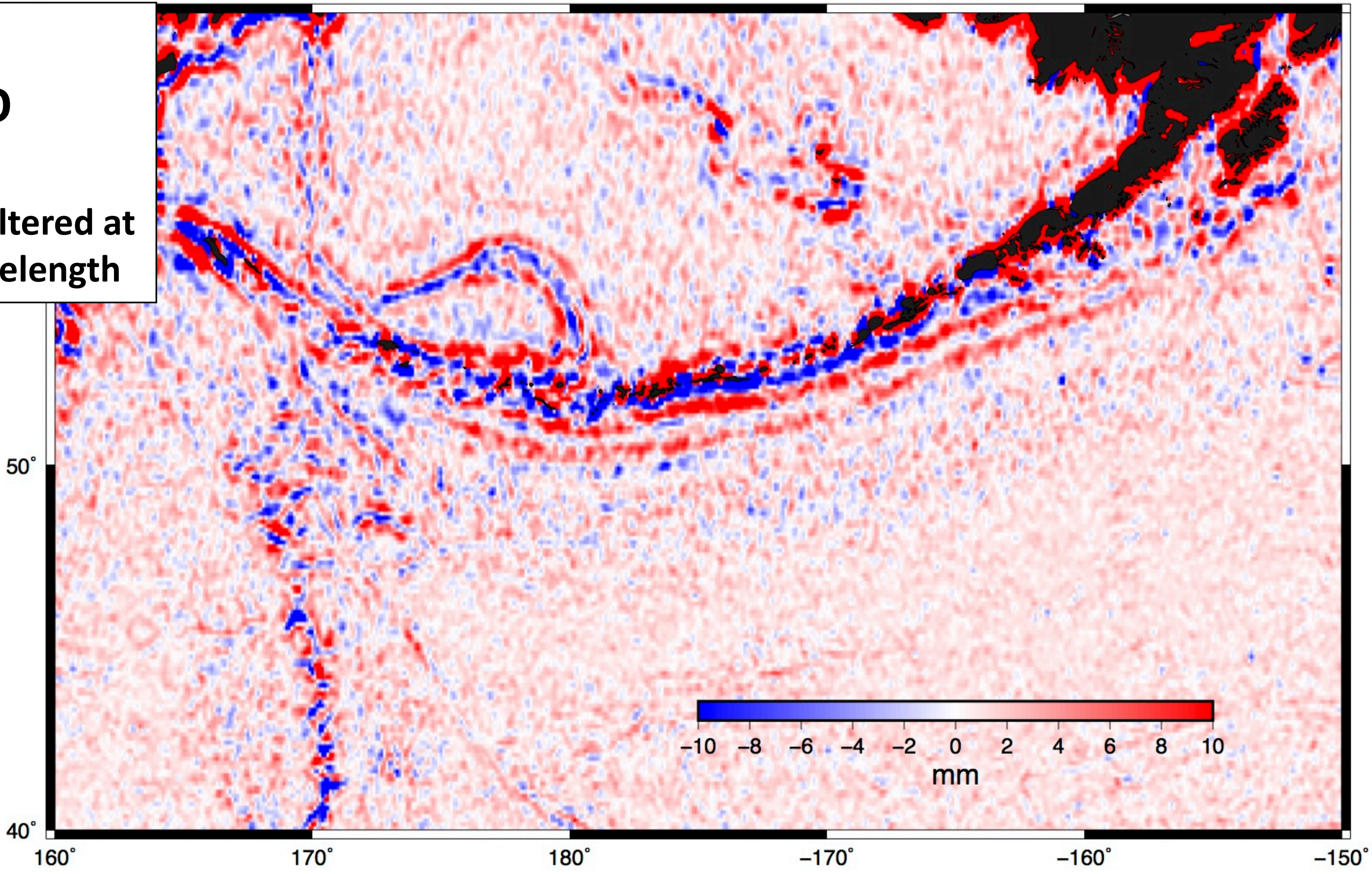
mean -2.01 mm
std 8.90 mm




MSS
SIO – CLS
high-pass filtered at
60 km wavelength
50°
40°
160°
170°
180°
–170°
–160°
–150°
–40
–30
–20
–10
0
10
20
30
40
mm

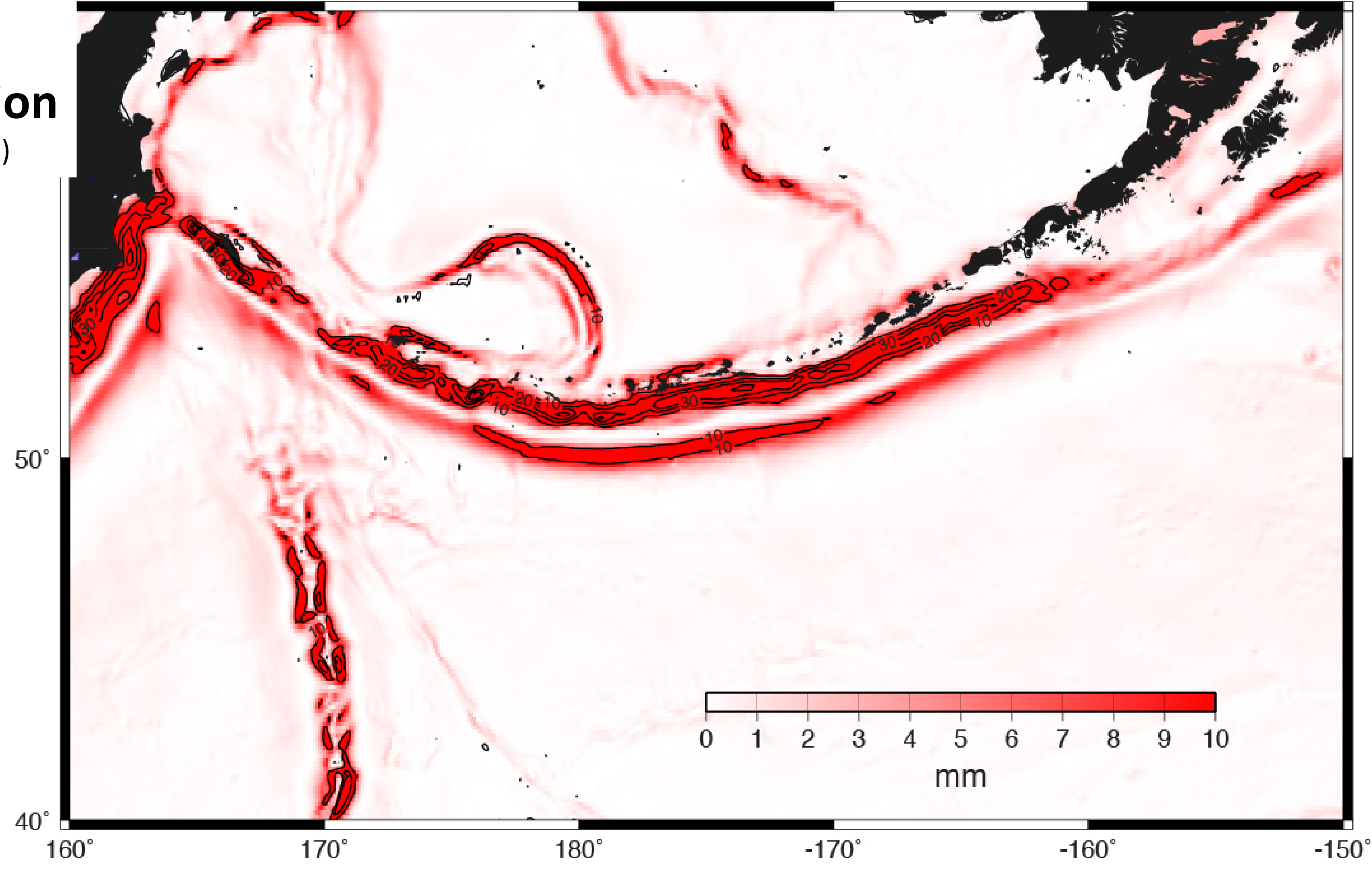
MSS
CLS - SIO

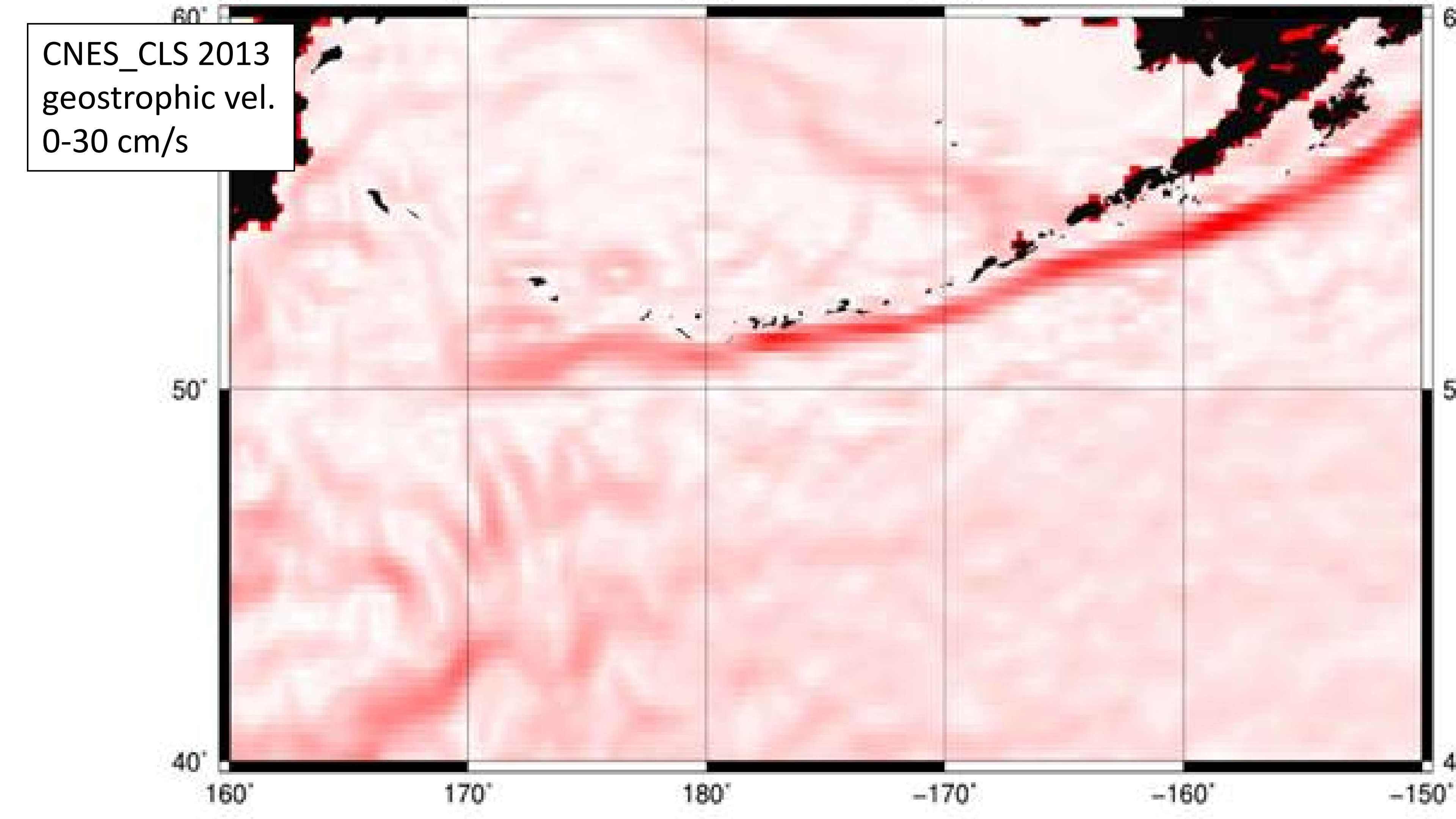
low-pass filtered at 60 km wavelength



height correction

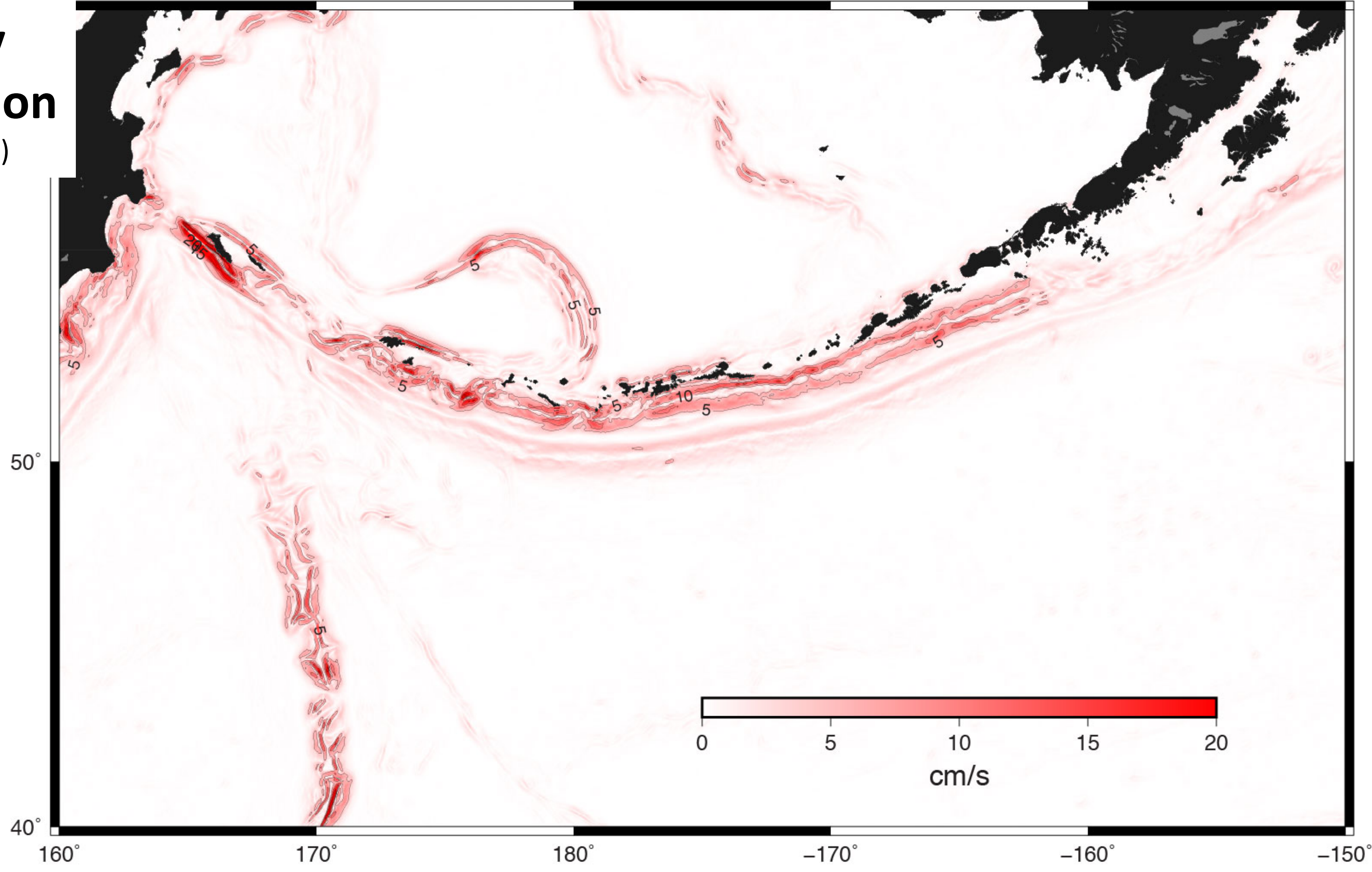
(H = 1000 km)




CNES_CLS 2013
geostrophic vel.
0-30 cm/s
60˚
50˚
40˚
160˚
170˚
180˚
−170˚
−160˚
−150˚

velocity correction

(H = 1000 km)



When do we need to make this correction?

Not needed for standard pulse-limited altimetry in exact repeat mission.

Needed to construct MSS using standard pulse-limited altimetry having very different altitude (e.g., 760 km Envisat and 1300 Jason).

Needed for MDT = MSS - geoid

Only cross-track component will be needed for SAR altimetry (e.g., CryoSat-2 SAR)

Needed for both cross-track and along-track SWOT comparisons with MSS.

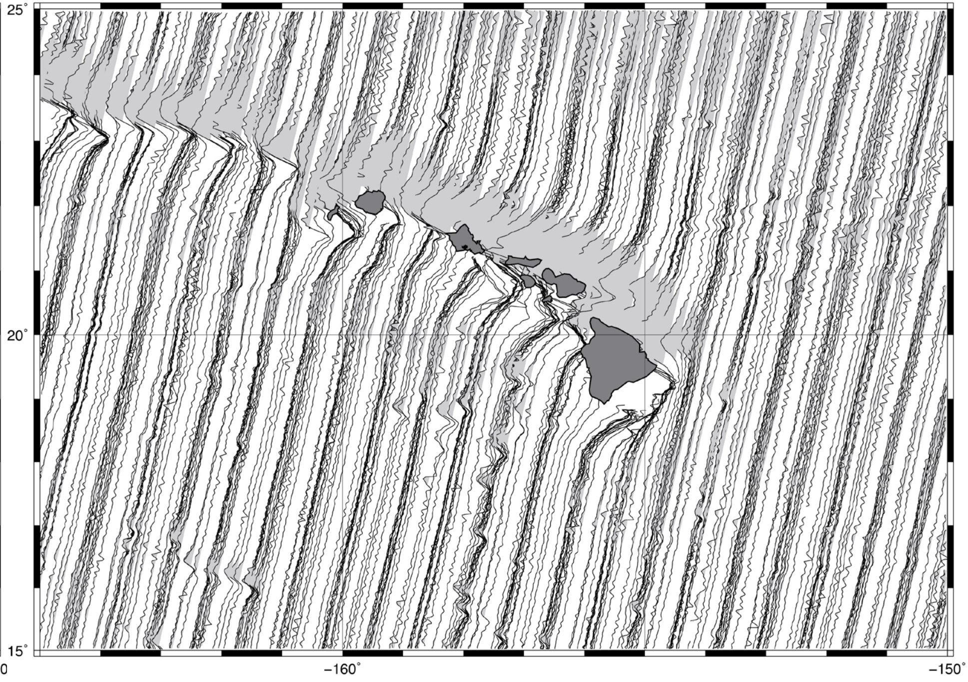
Conclusions

- SWOT will require a MSS having both high accuracy and high spatial resolution.
- Our approach uses CLS MSS model to constrain large scales (> 30 km) and the SIO slope profiles to constrain small scales.
- CryoSAT-2, AltiKa **and now Jason-2** may enable a spatially uniform MSS accuracy for oceanography and geodesy.
- The slope correction is needed for SWOT and also for estimating dynamic topography using the new GOCE geoid models.

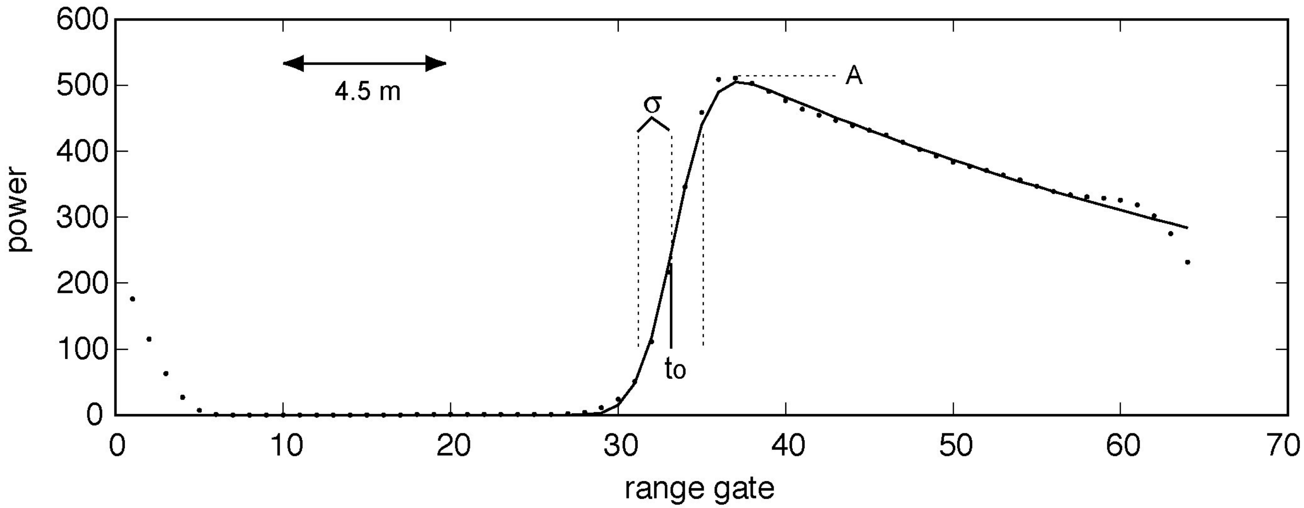
along-track sea surface slope over Hawaii

CryoSat-2 (66 mo.)

AltiKa/GM (7 mo.)



2-pass waveform retracking improves range precision



1) retrack waveforms with standard 3-parameter model
2) smooth rise time over 45-km
3) retrack waveforms with 2-parameter model

Note: this assumes wave height varies smoothly along track.

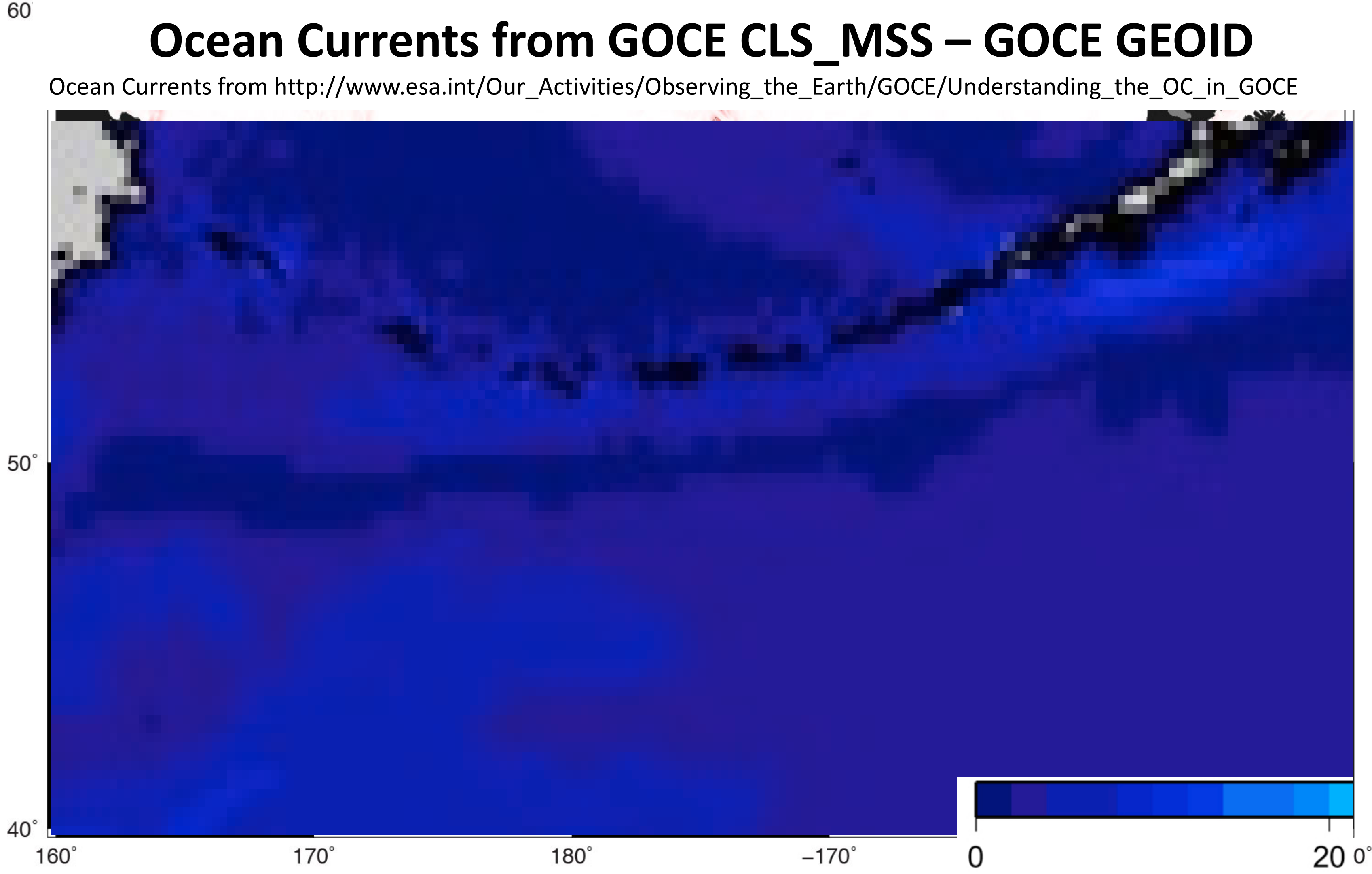
Estimate 3 parameters: arrival time (t_o), rise time (σ), and power (A).

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

[*Sandwell and Smith*, 2005]

Ocean Currents from GOCE CLS_MSS – GOCE GEOID

Ocean Currents from http://www.esa.int/Our_Activities/Observing_the_Earth/GOCE/Understanding_the_OC_in_GOCE

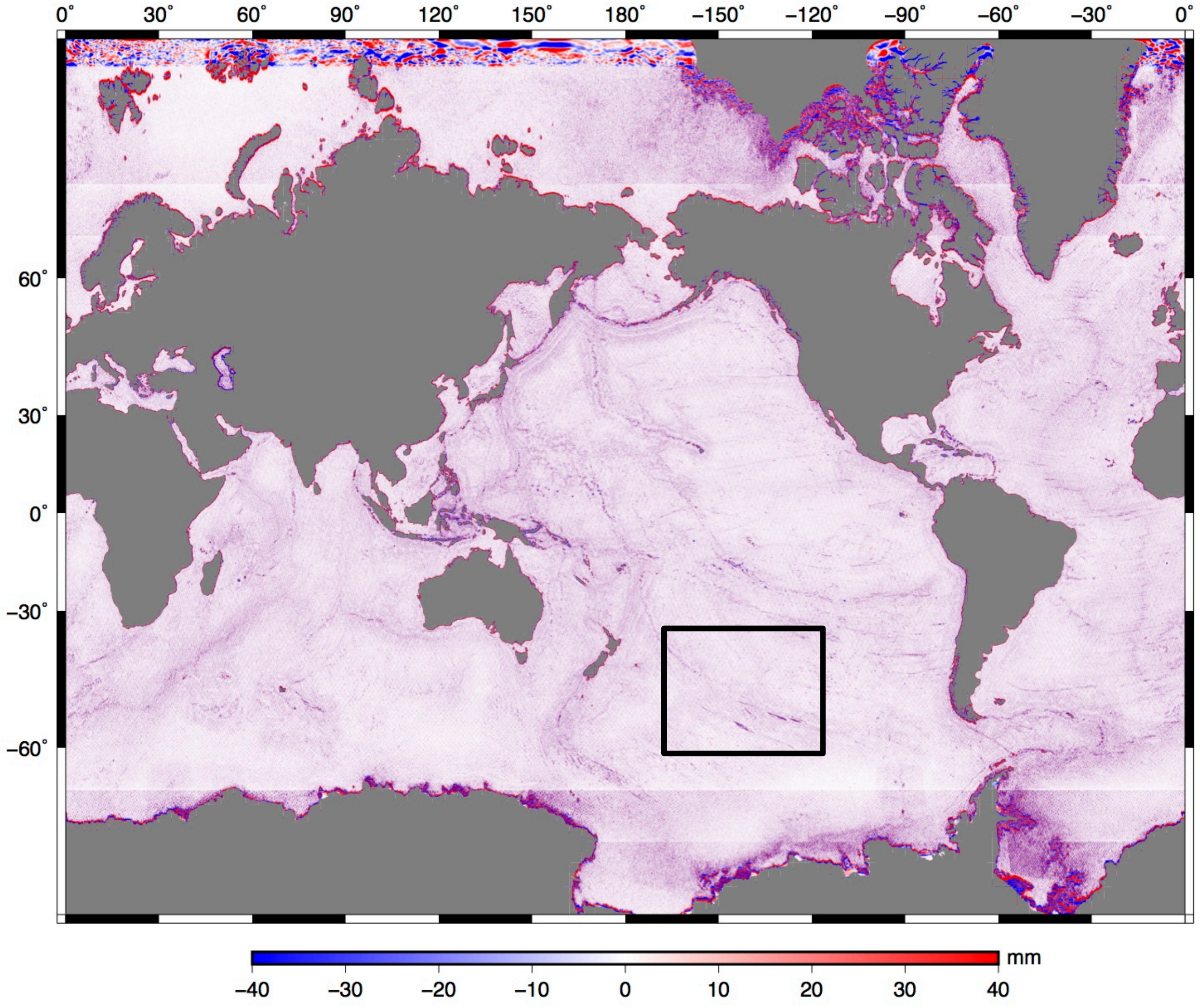


MSS
SIO – CLS

high-pass filtered at 60 km wavelength

Statistics for
South Pacific Box

mean 0.003 mm
std 8.3 mm



MSS
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low-pass filtered at 60 km wavelength

Statistics for
South Pacific Box

mean -2.01 mm
std 1.78 mm