Potential for improving marine gravity from CryoSat2 and Jason-1

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GRACE and GOCE are best for long wavelengths (> 200 km)

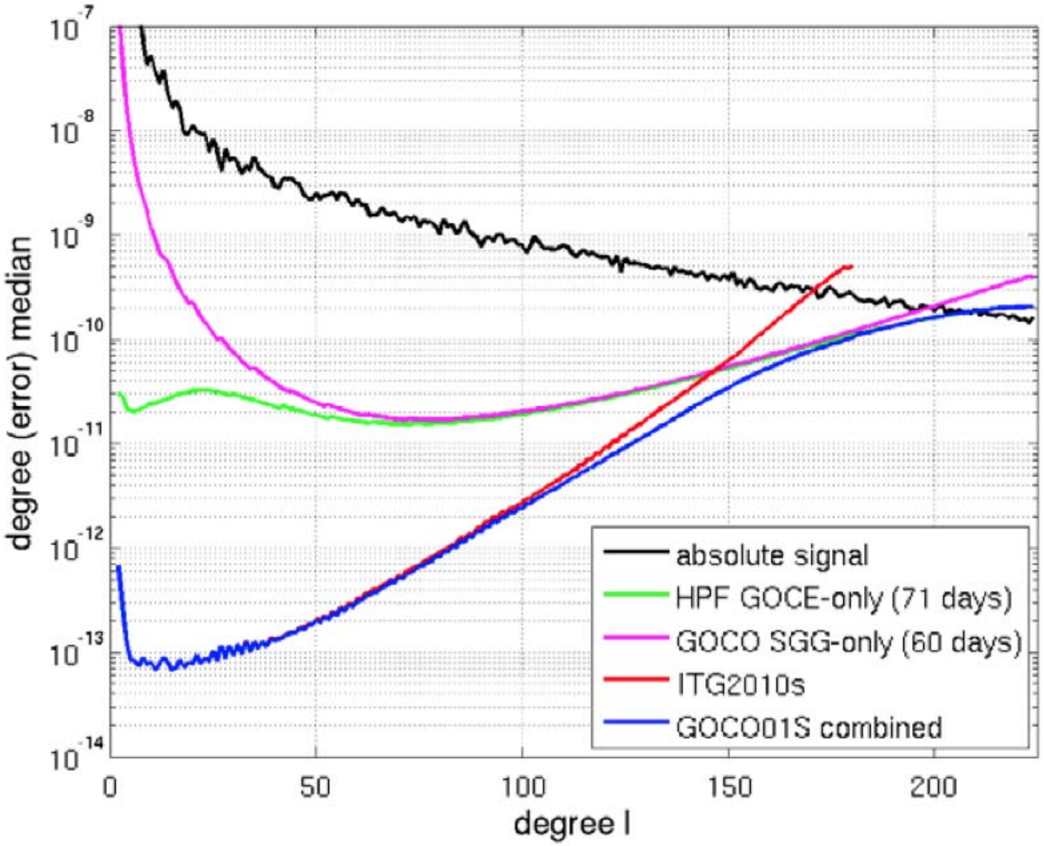


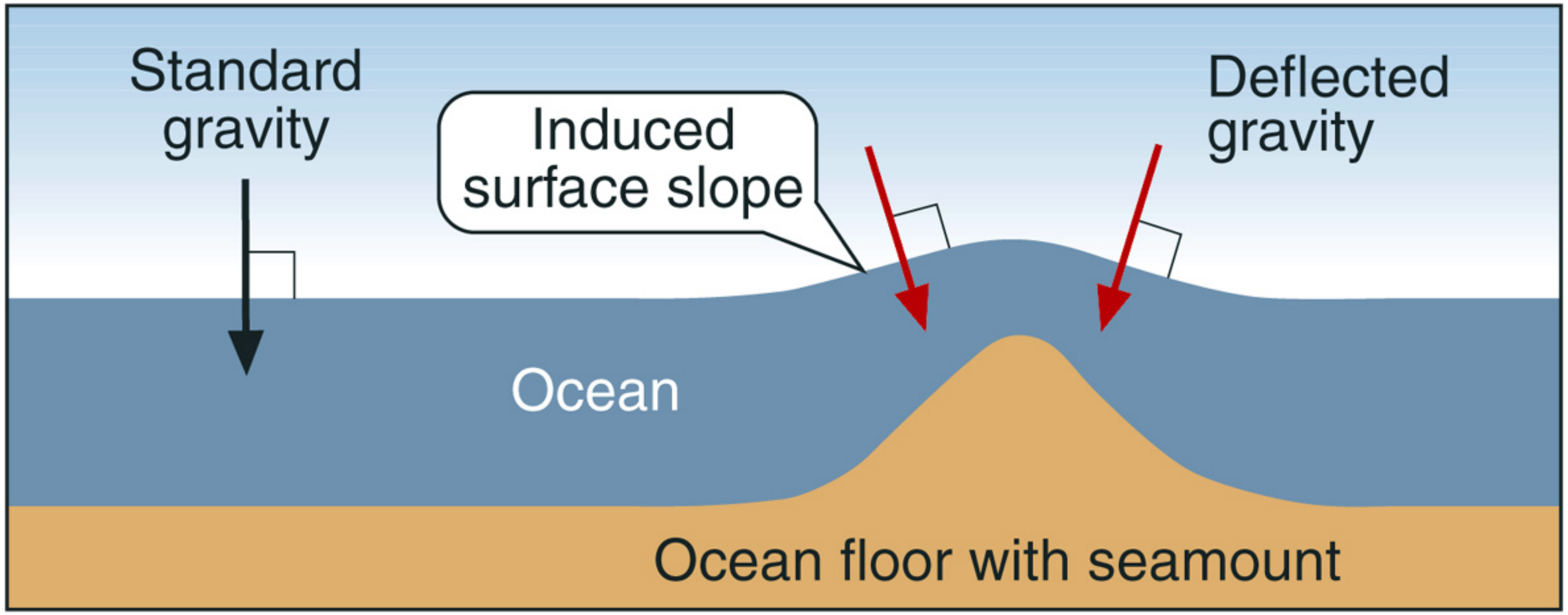
Figure from the GOCO1S combined GRACE-GOCE model document, R. Pail et al., 23-07-2010.

Satellite gravity missions yield excellent resolution of large-scale anomalies (spherical harmonic degree < 200, or wavelength > 200 km).

However, because they measure the field at satellite orbital altitude, they are limited by ‘upward continuation’, due to a physical law. They cannot resolve the field at scales much shorter than their orbital altitude.

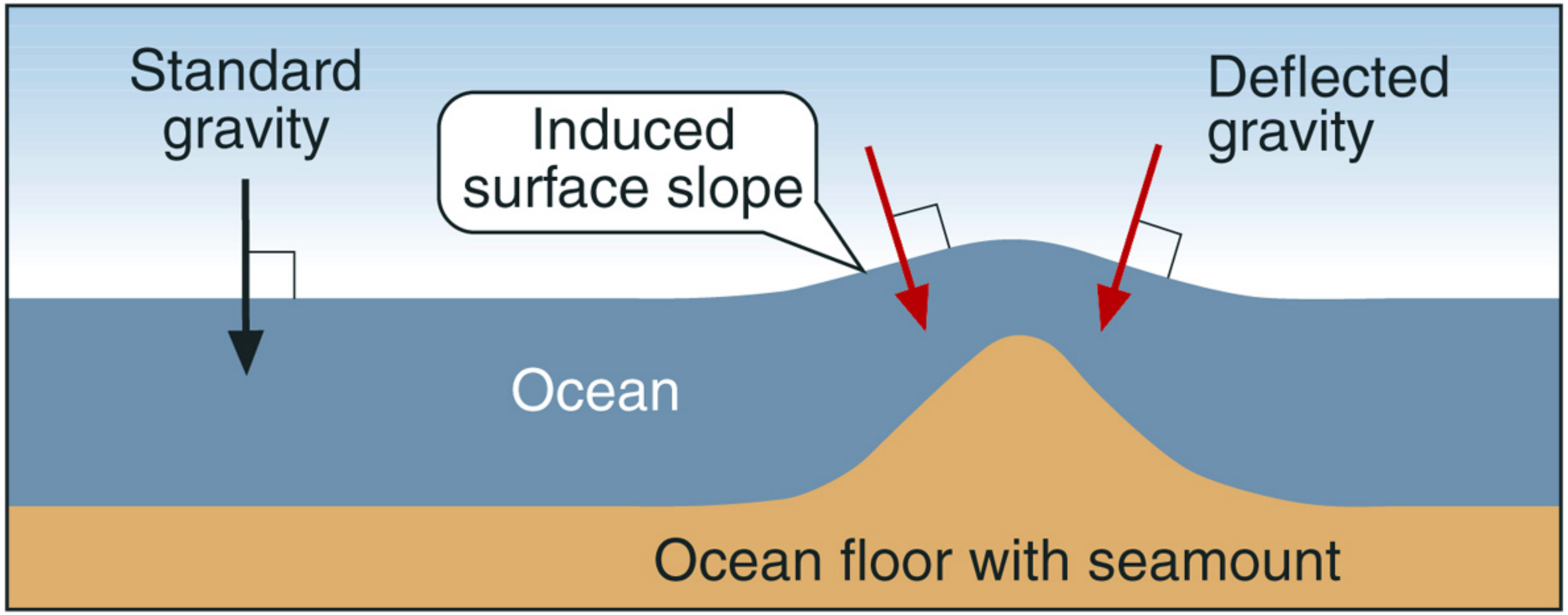
Satellite altimeters measure the effect of the gravity field on sea level, so they resolve shorter scales.

Altimetry is best for short wavelengths



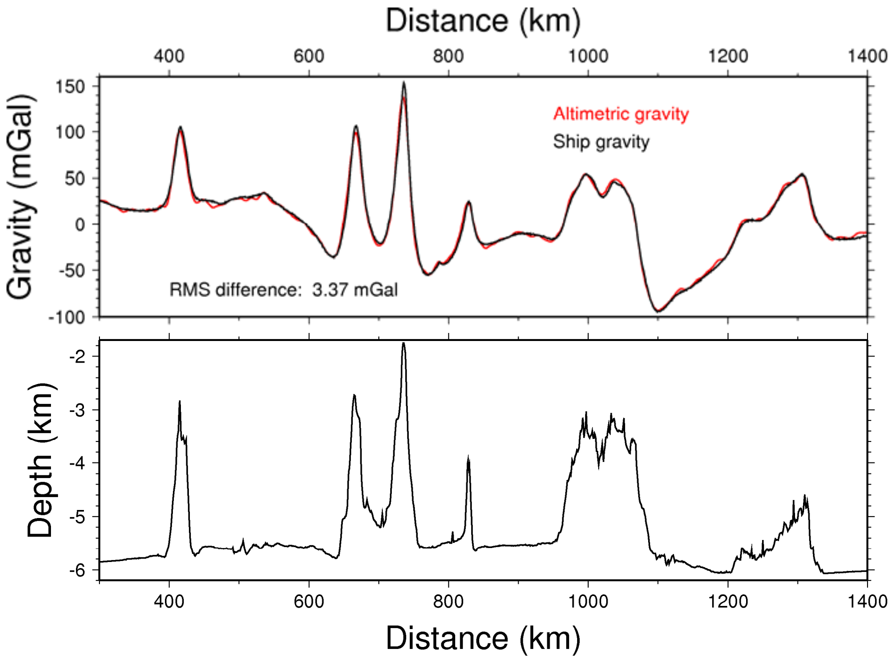
The altimeter sees the effect of the gravity field on sea level, where there is zero upward continuation (no gravity signal loss).

Sea surface slope is our signal



Sea surface height departs significantly from the geoid, but the sea surface slope is usually within 1 micro-radian (1 mm per 1 km) of the geoid slope. Where dynamic slope is larger, we filter it out.

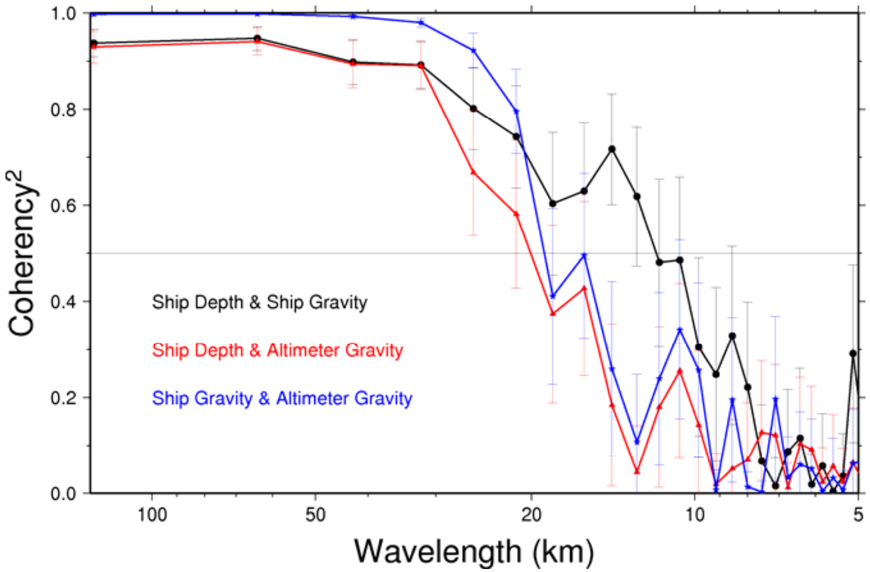
Altimetric gravity quality so far, 1



The Geosat Geodetic Mission (1985-86, 18 months) and the ERS-1 Geodetic Phases E and F (1994-95, 11 months) furnished a spatially dense network of ground tracks (~5 km for Geosat, ~8 km for ERS-1, at the Equator). Spatial resolution of the marine gravity field is determined by these data sets.

Let's compare gravity anomalies derived from altimetry [Sandwell & Smith, *JGR*, 2009] to gravity measurements made by a ship [*JAMSTEC*, 2010; the analysis here follows Marks et al., *Mar. Geophys. Res*., in press]. Note that the altimetry resolves anomalies associated with narrow (~20 km wide) seamounts, and recall that GRACE and GOCE cannot resolve these anomalies. The RMS difference in the two gravity flavors is around 3 mGal. But is this error in the altimeter data or the ship data?

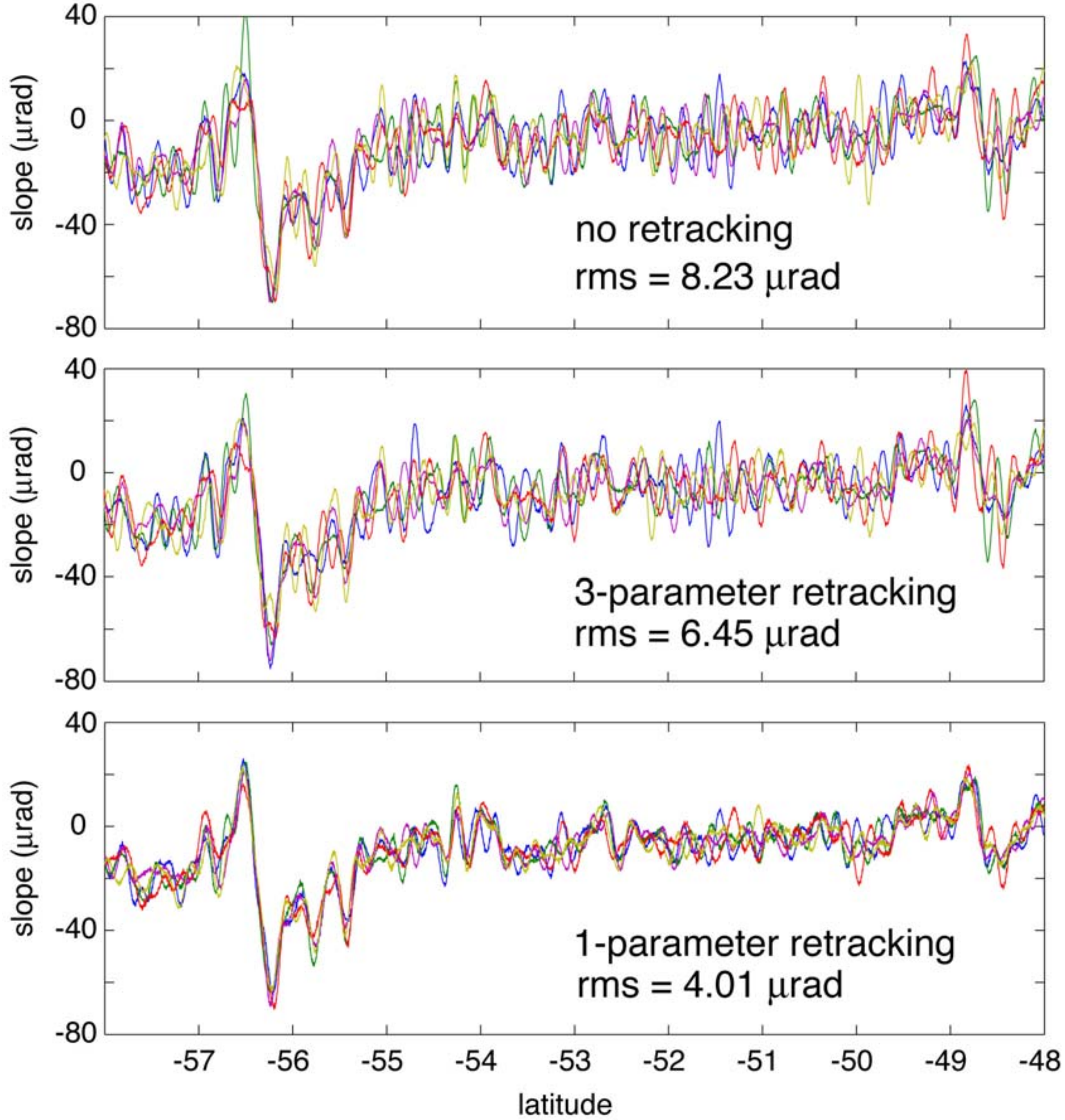
Altimetric gravity quality so far, 2



The cross-spectral coherency between depth and ship gravity, depth and altimetric gravity, and ship gravity and altimetric gravity is high where the two are well-correlated (signal dominates) and low where the two are poorly correlated (noise dominates).

Although ship gravity is coherent with depth at wavelengths longer than 10 km, altimetric gravity is coherent with ship gravity only at wavelengths longer than 20 km. We conclude that: (1) **there is signal in the marine gravity field at very short wavelengths**; (2) **Geosat & ERS-1 have not resolved it**; (3) **present gravity resolution is limited to about 20-30 km wavelength**. If we assume that all the 3 mGal RMS gravity difference is due to error in the altimetric gravity, then *geoids & mean sea surfaces built from these altimetric gravity data (such as EGM2008, DNSC08, DTU10) should have slope errors around 3 mm/km, mostly at wavelengths less than 20-30 km*.

Resolving shorter wavelengths



We have a two-pass retracking process to optimize slope resolution. The 20 km limit is due to the speckle noise level in the Geosat & ERS-1 waveforms. An altimeter with more independent looks (Jason, AltiKa, or CryoSat2 in SAR mode) should give lower noise and thus better slope and gravity resolution.

Lowering the noise level

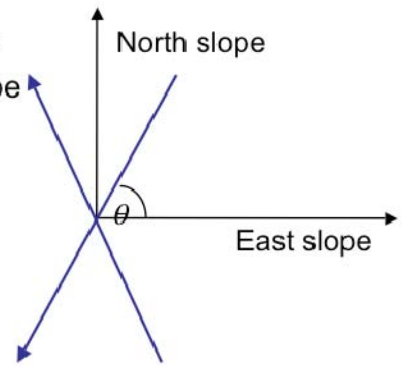
- SAR mode (Delay-Doppler) altimetry in Ku band should cut noise level by ~2x. But CryoSat2 will not operate in SAR mode over all the ocean.
- Ka altimetry should also cut noise by ~2x. But AltiKa on SARAL will stay on a 35-day repeat orbit, not a geodetic orbit.
- Jason-1, with PRF ~2x Geosat or ERS-1, could cut noise level by ~1.4x or more, depending on geodetic mission duration.

Another consideration: inclination

Gravity calculation requires north and east components of sea surface slope. The accuracy with which these can be obtained from an altimeter depends on the track crossing angle, which is a function of latitude and the orbital inclination of the satellite.

Track angles set North vs. East VD error

- Error propagation
  - θ - local inclination of track
  - σ - error in along-track slope
  - σ_x - error in east slope
  - σ_y - error in north slope



$$\sigma_x = \frac{\sigma}{\sqrt{2}\cos\theta}$$

$$\sigma_y = \frac{\sigma}{\sqrt{2}\sin\theta}$$

Orthogonal tracks are optimal

Because CryoSat2, AltiKa/SARAL & Hy-2 have polar orbits, they cannot contribute much new information about the east-west component of sea surface slope. Because Jason-1 is in a lower inclination, its track crossing angles are similar to those of Geosat.

Jason-1 can give us more information about the gravity field than CryoSat2.

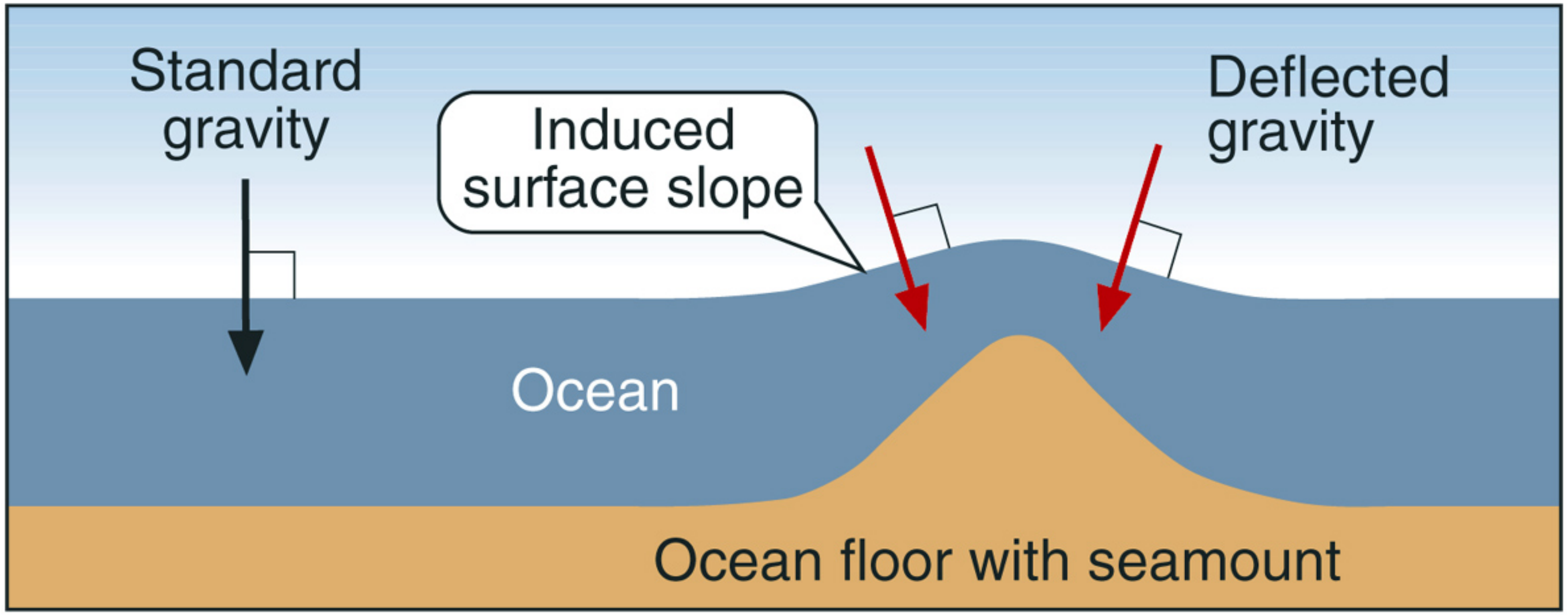
No alternative to Jason-1

- Envisat's new orbit is not geodetic, and it is polar (poor east-west resolution).
- Same goes for SARAL/AltiKa.
- Hy-2 is polar, we don't know much about it, and data sharing agreements are in doubt.
- CryoSat2 is in a geodetic orbit, but very polar, and not in SAR mode over all the ocean.
- ***Jason-1 is the best hope for geodesy.***

What orbit would Jason-1 need to be geodetically useful?

- To resolve to 20 km or better, we need tracks to be 10 km or closer; implying that the orbit should not repeat for at least 4000 revolutions (roughly 312 days).
- During that time, it could have "near repeats", that is, sub-cycles that would repeat "closely enough" (within an eddy correlation scale?) to allow simultaneous observation of mesoscale oceanography.
- Gerald Dibarboure has studied many orbit options and sent interesting results to the J-1 EoL discussion. His suggestion of a 12+341/419 orbit seems a good one.

Slope measurement is simple

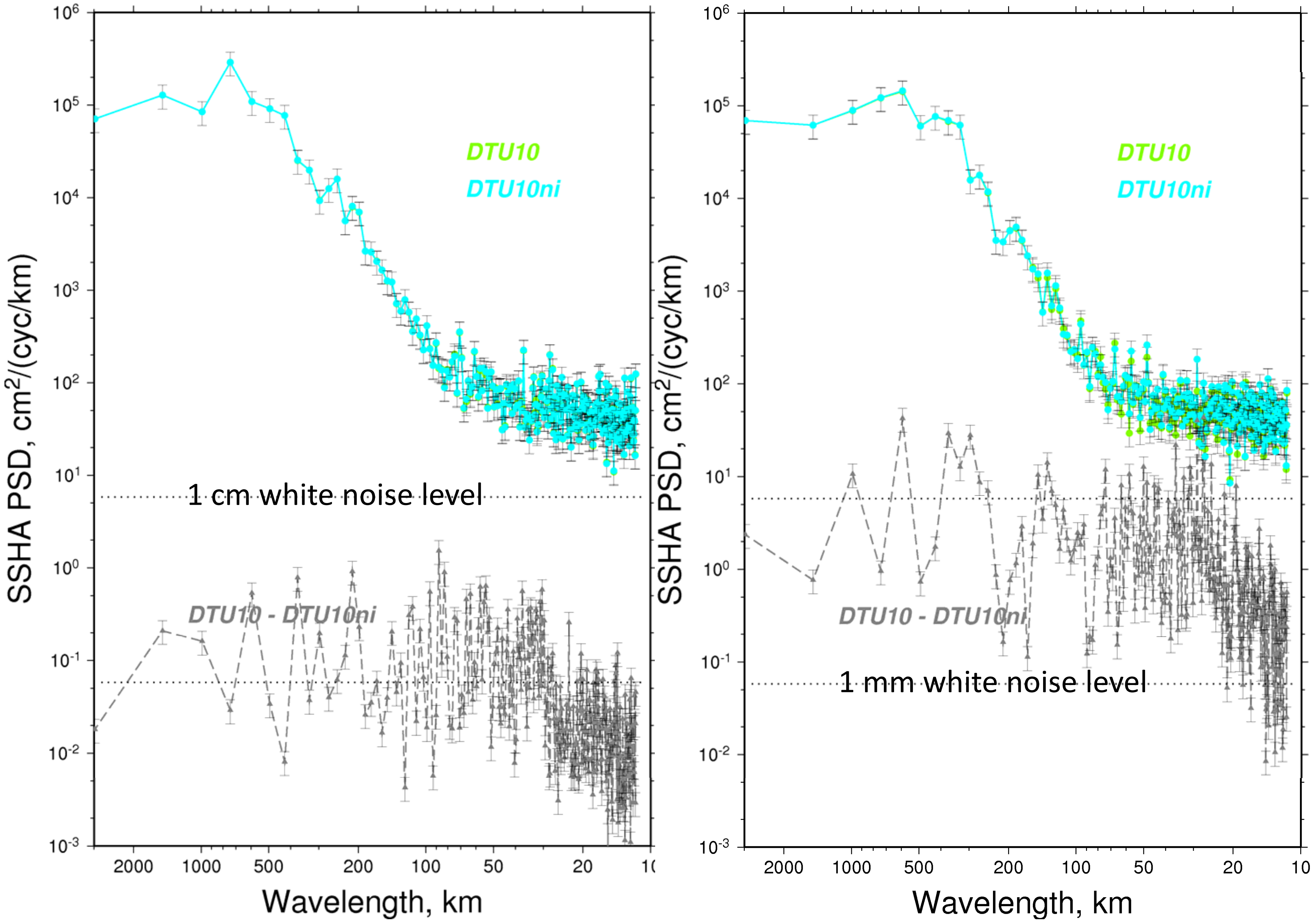


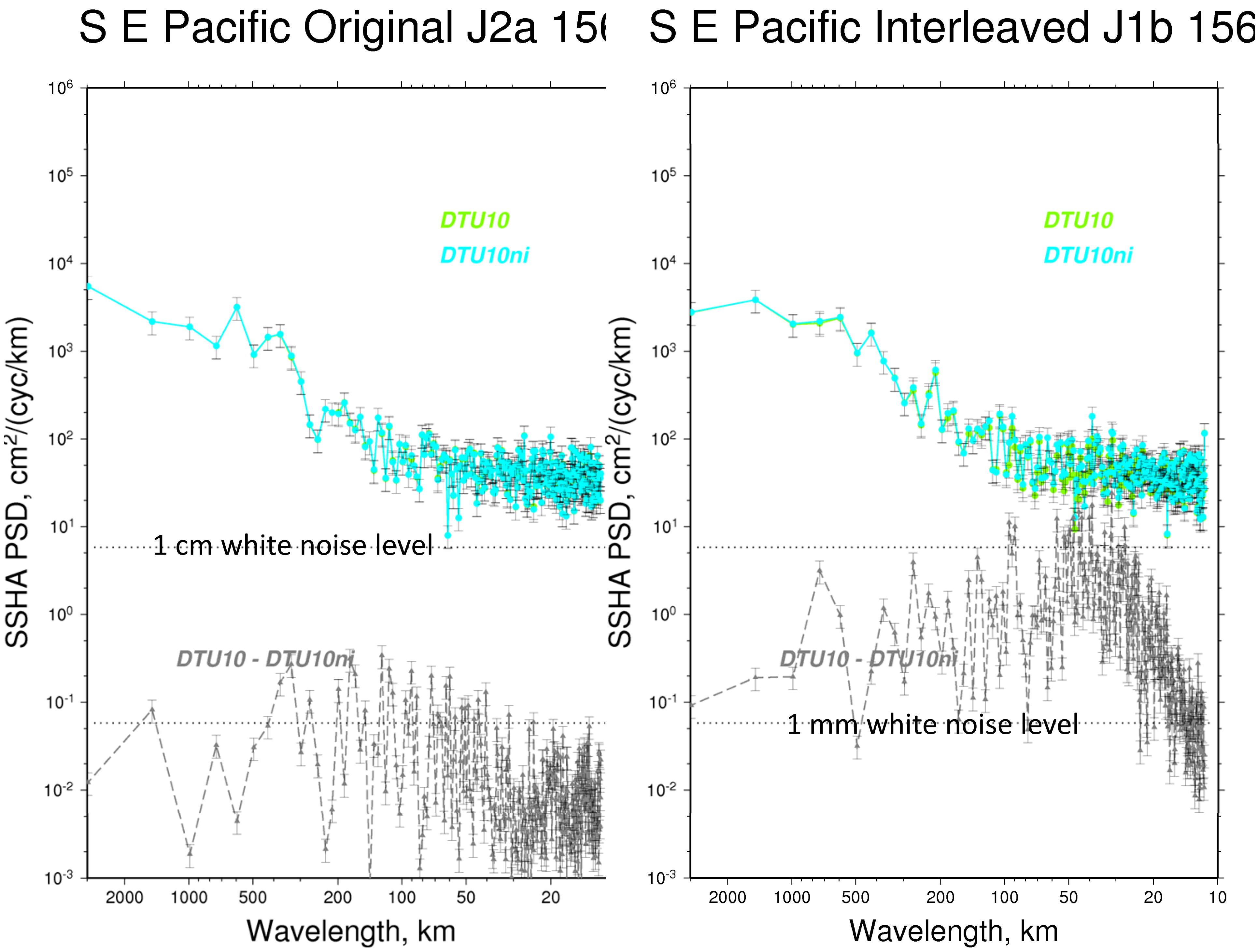
The ionosphere, troposphere and sea-state bias corrections have correlation scales longer than 20-30 km. Therefore they do not affect short-scale slope resolution. ***(A geodesy mission can be done by J-1 even if the C-band or MWR fails.)***

Simultaneous mesoscale?

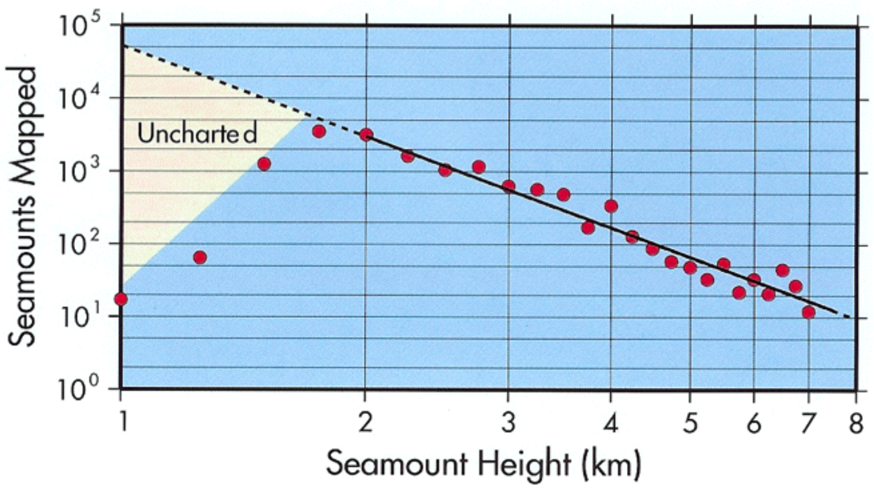
- We believe an altimeter in a geodetic orbit, or previously unflown orbit, can observe SSHA.
- We think (some) MSS models are good enough. For example, DTU10.
- *This question is relevant not only to a Jason-1 End-of-Life orbit change, but also to a Jason-CS orbit change.*

Kuroshio Original J2a 136 Kuroshio Interleaved J1b 136




S E Pacific Original J2a 15
S E Pacific Interleaved J1b 156
SSHA PSD, cm²/(cyc/km)
DTU10
DTU10ni
DTU10 - DTU10ni
1 cm white noise level
1 mm white noise level
Wavelength, km
2000
1000
500
200
100
50
20
10

Why do we want to measure the small-scale marine gravity field?



We want to resolve more of the unmapped sea floor topography to reveal more habitat, geology, and obstacles to flow.

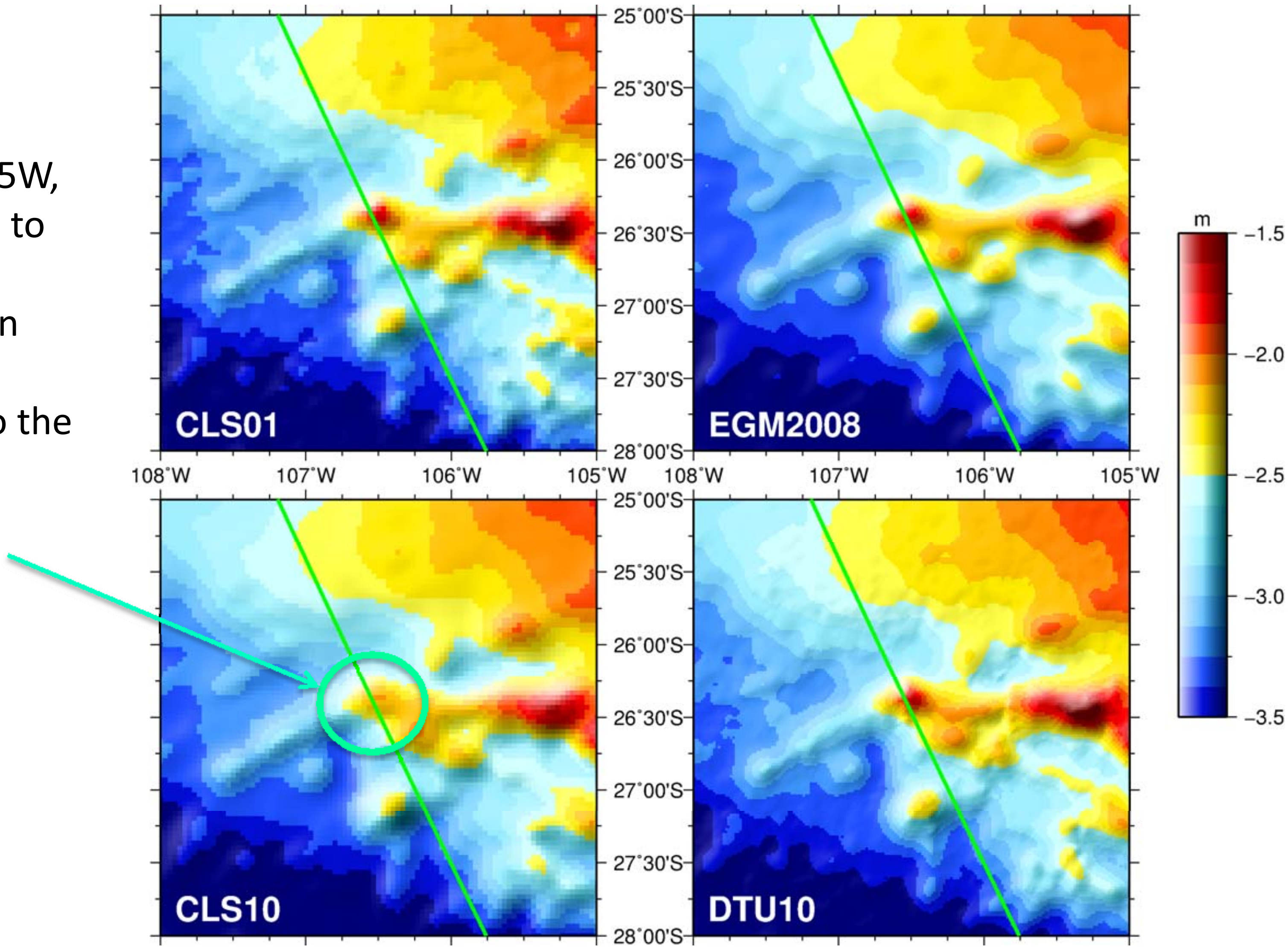
The present resolution of altimetric bathymetry maps yields seafloor slopes that are too smooth and fails to identify areas that may excite mixing and baroclinic tides [Becker & Sandwell, JGR, 2008].

As an example, studies of the size-frequency distribution of seamounts suggest that if we can improve seamount anomaly resolution by a factor of two, we will reveal between 50 thousand and 100 thousand seamounts that are currently invisible in the existing geodetic altimeter maps. Present maps resolve only a few thousand seamounts.

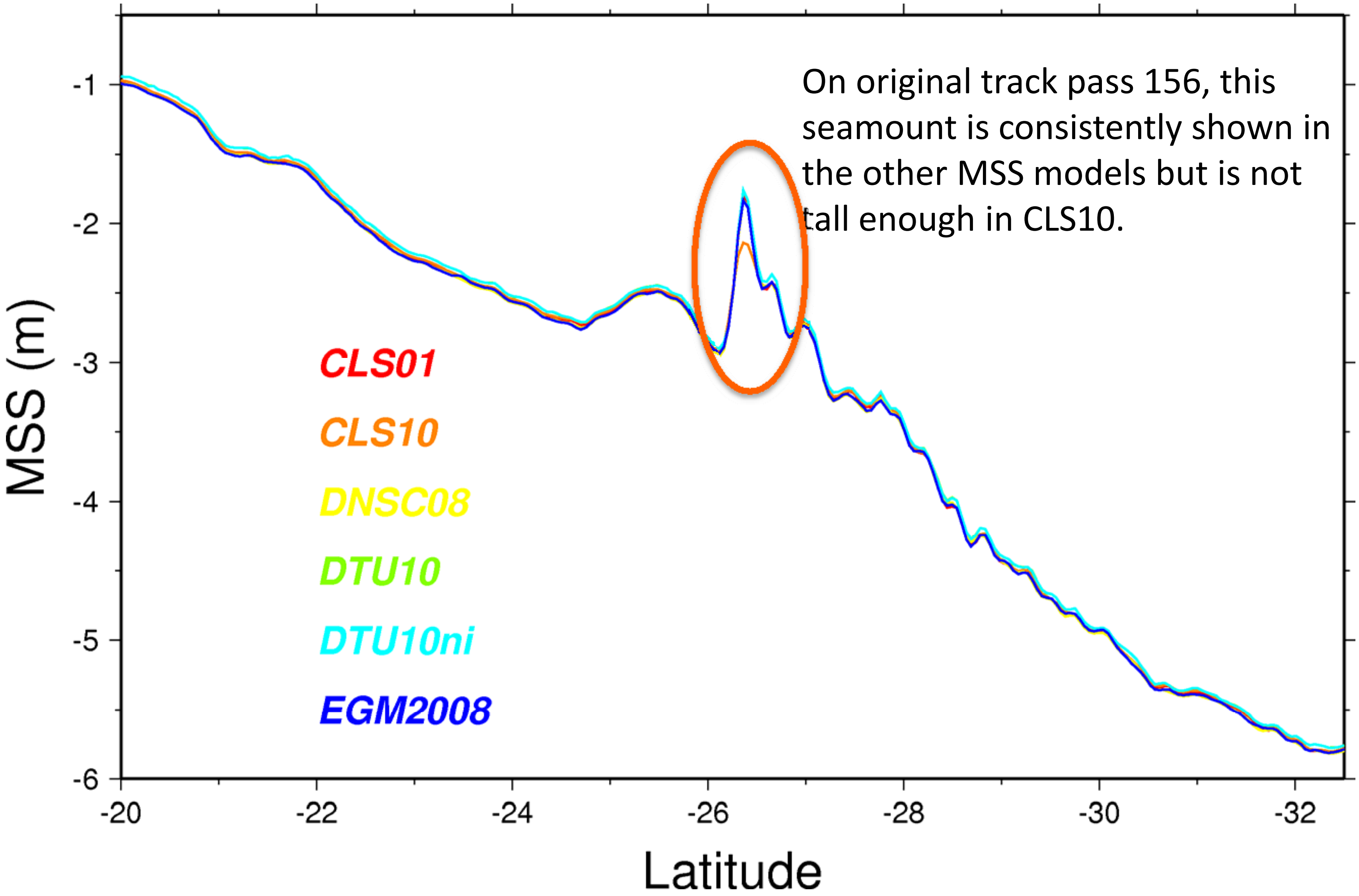
ADDITIONAL SLIDES FOLLOW

Not all MSS are good for this

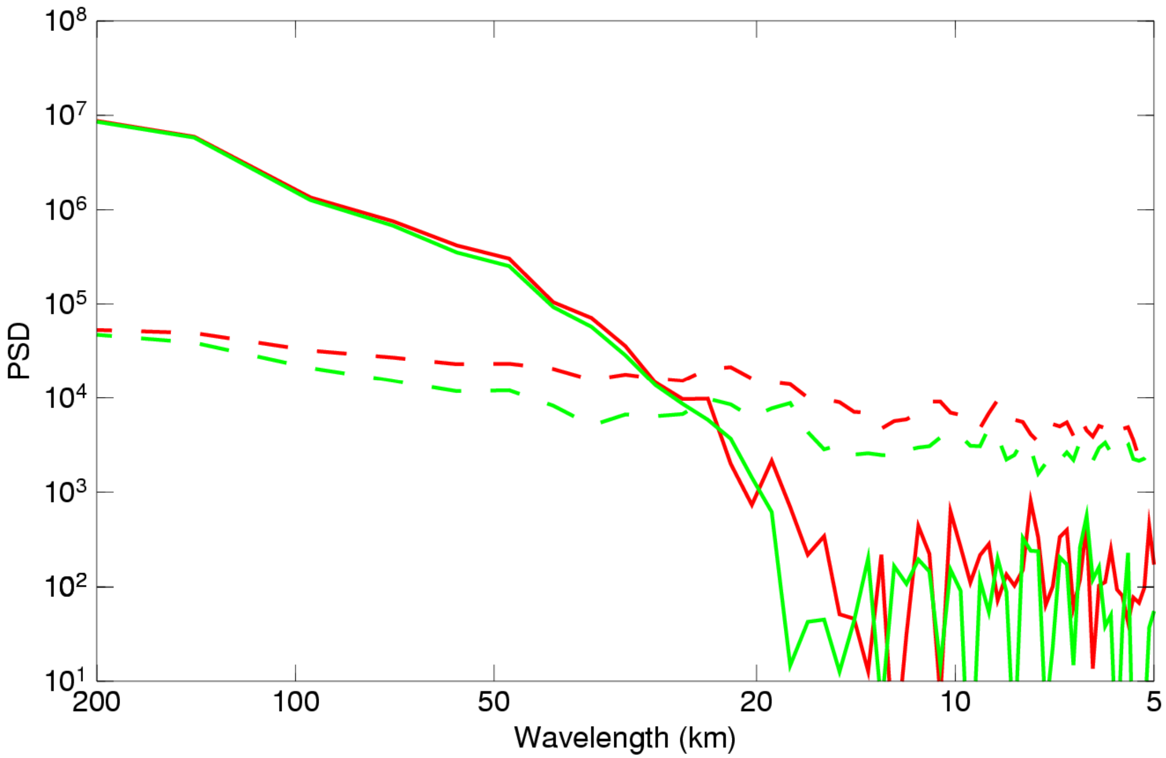
A seamount around 106.5W, 20.4S seems to be strongly attenuated in CLS10, as compared to the other MSS models.



MSS profiles on pass J2a 156



Gravity signal-to-noise



The two-pass retracking shows improved signal (solid) to noise (dashed) compared to the original range data.