Factor of 2 Improvement in Marine Gravity from CryoSat and Jason-1

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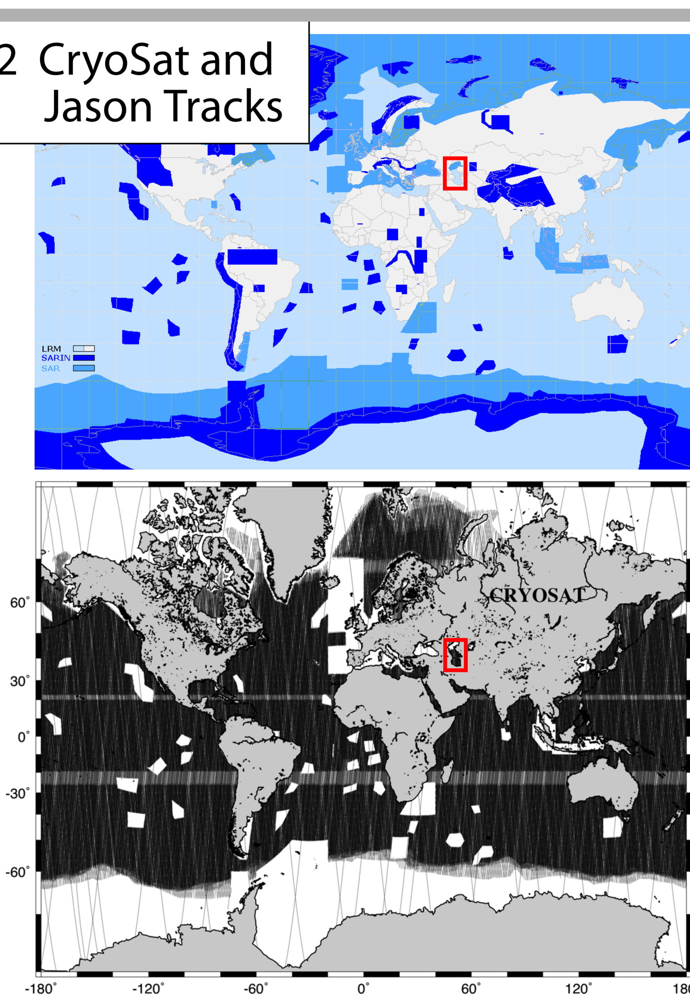
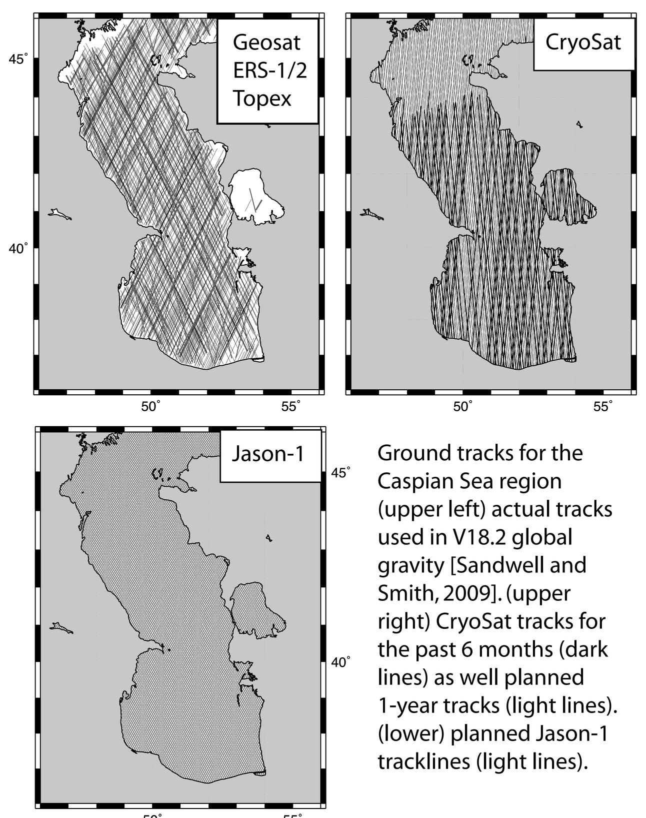
1 Abstract

Marine gravity anomalies derived from radar altimeter measurements of ocean surface slope are the primary data for investigating global tectonics and seafloor bathymetry. The accuracy of the global marine gravity field is limited by the availability of non-repeat altimeter data. Current models, having accuracies of 3-5 milligals (e.g., S&S V18 and DNSC08), are based on the non-repeat data collected by Geosat (18 mo.) and ERS-1 (12 mo.) which use altimeter technology from the 70's and 80's, respectively. The next opportunities for significant improvements in marine gravity will come from CryoSat and perhaps Jason-1 if it is placed into a non-repeat orbit. In addition to complete ocean coverage, the three attributes needed for improved gravity are improved range precision, optimal satellite inclination, and long mission duration. Range precision is established through a coherence analysis of repeating profiles. We will use these standard methods to assess the range precisions of CryoSat and Jason-1 in relation to Geosat, ERS, Topex, and Envisat. We expect that the higher PRF's of the newer altimeters will provide a square root of 2 improvement in range precision. The low inclination of the Jason-1 orbit offers the best opportunity for improvement in the E-W variations in gravity, especially at low latitude. The hopefully, long mission duration of CryoSat provides the best opportunity for reducing the noise due to ocean surface roughness from swells. Data from these two missions may eventually result in a factor of two improvement in the accuracy of the marine gravity field and geoid at scales less than 100 km.

2 CryoSat and Jason Tracks

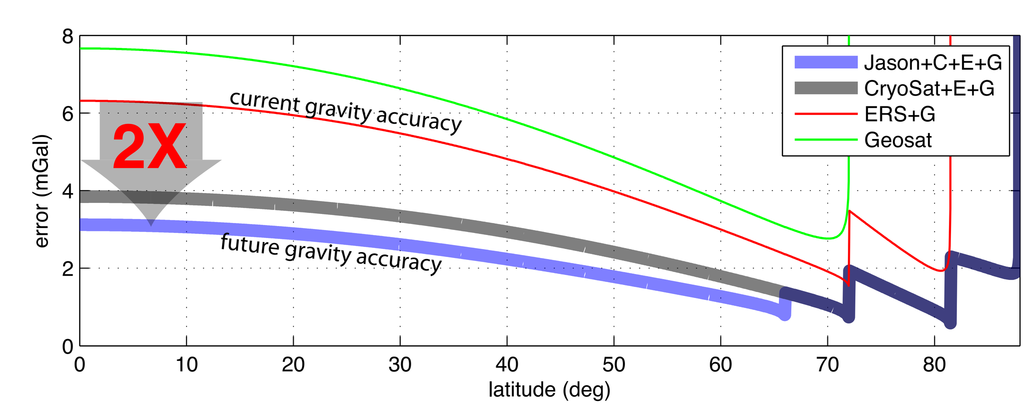


(upper) Planned radar operating modes for CryoSat; LRM – standard mode used by all previous altimeters; SAR – synthetic aperture radar mode may provide 2-4 times better range precision. SARIN – uses two receive antennas to also measure cross-track slope over ice. (lower)Actual CryoSat data collected in the LRM mode for the past 6 months basically follows the acquisition plan. Missing bands at +/- 21 latitude will be added in the second distribution of the data.

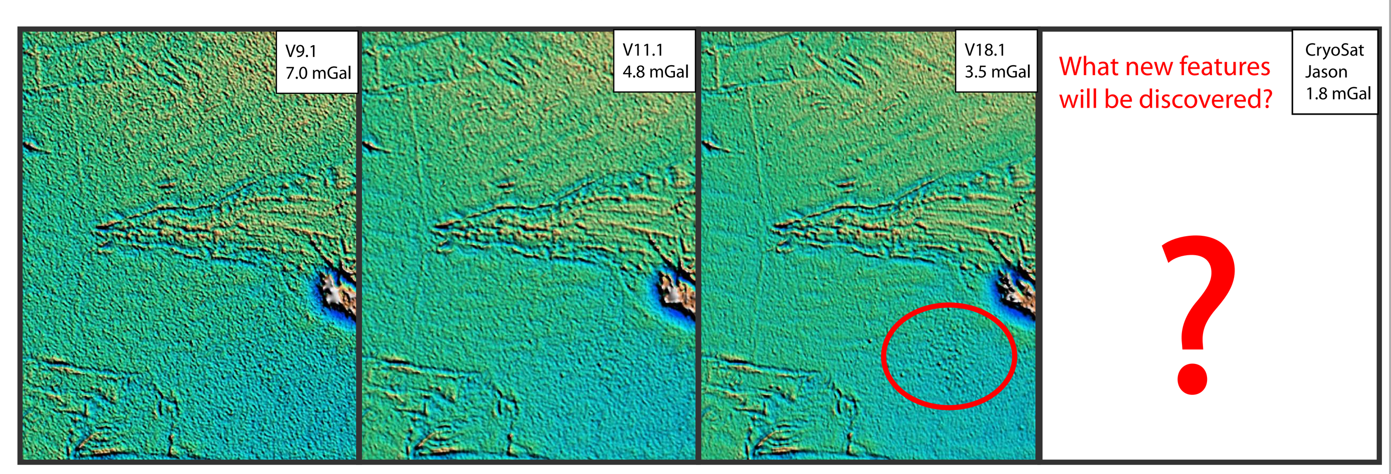


Ground tracks for the Caspian Sea region (upper left) actual tracks used in V18.2 global gravity [Sandwell and Smith, 2009]. (upper right) CryoSat tracks for the past 6 months (dark lines) as well planned 1-year tracks (light lines). (lower) planned Jason-1 tracklines (light lines).

3 Gravity Improvement

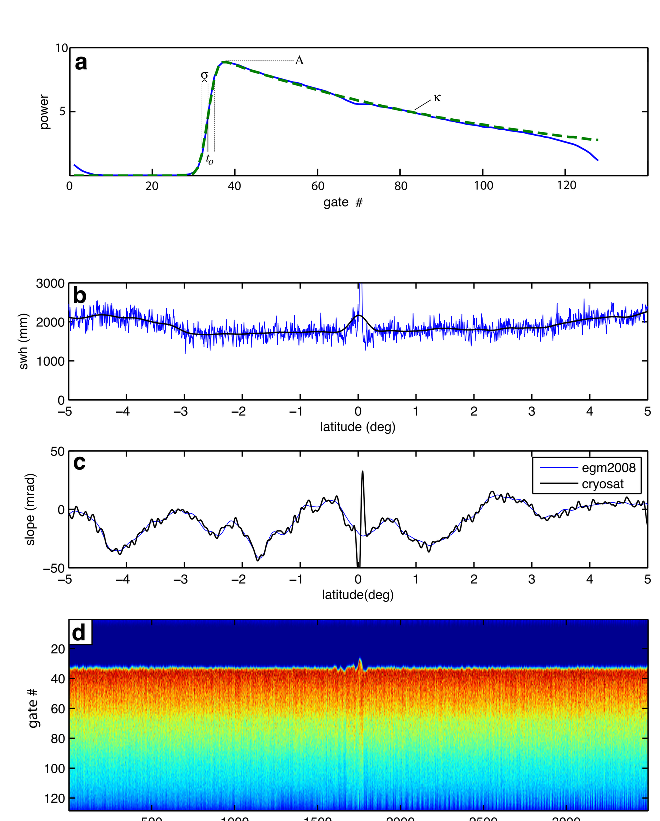


Theoretical gravity field accuracy versus latitude showing relative improvements as new altimeter data become available. Green curve shows gravity field accuracy based on retracked Geosat only which has a maximum latitude of 72˚. Accuracy improves with latitude to 72˚ as tracks become more orthogonal and track density increases. Red curve shows the present-day gravity accuracy from V18.1 [Sandwell and Smith, 2009], which also includes retracked ERS-1 data which has a maximum latitude of 81.5˚. The thick black and blue curves show improvements by adding CryoSat (3 years retracked) and Jason (1.15 year retracked).



Shaded gravity anomaly for a large region in the Central Pacific Ocean centered at the Galapagos Triple Junction (latitude 11˚ to –8˚, longitude 255˚ to 270˚). Colors saturate at +/- 60 mGal. The visual noise level decreases as one moves from V9.1 (left) to V11.1 (center) to V18.1 (right). The axis of the East Pacific Rise is well defined in V18.1 but more difficult to trace in V9.1 because of the higher noise level. The red oval outlines a patch of small uncharted seamounts not apparent in V9.1. The evolution from V9.1 to V18.1 corresponds to a factor of 2 improvement in gravity field accuracy. Our proposed investigation will improve the accuracy by another factor of 2. This will reveal significant unknown details in seafloor morphology.

4 Waveform Model



(a) Average of 27,000 CryoSat radar waveforms (solid) and a simplified model with four adjustable parameters: A-amplitude, t_o – arrival time, σ – rise time, and κ – trailing edge decay. The spacing of the gates is 3.12 nsec or 468 mm.

$$P(t,t_o,\sigma,A)=\frac{A}{2}\left\{1+erf\left[\frac{(t-t_o)}{\sqrt{2}\sigma}\right]\right\}\begin{cases}1 & t<t_o\\ \exp[-\kappa(t-t_o)] & t\ge t_o\end{cases}$$

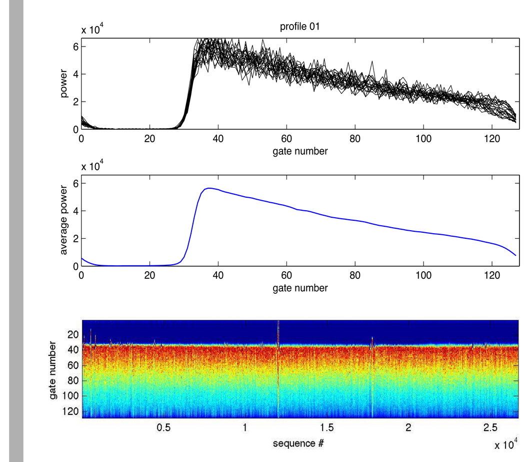
(b) Significant wave height (swh) derived from 4-parameter retracking model (blue curve) has unrealistic short wavelength jitter. Smoothed swh (black curve) was provided to a 2-parameter retracker to constrain the shape of the leading edge of the waveform so the arrival time is more accurately estimated.

(c) Arrival time converted to along-track slope (black curve) compared with slope from the EGM2008 model (blue curve, essentially V18.1 gravity). Both were low-pass filtered at 18 km wavelength for direct comparison with a previous analyses of Geosat and ERS-1 data. The slope differences have a median absolute deviation of 2.46 microradian – part of this difference is gravity signal and part is altimeter noise.

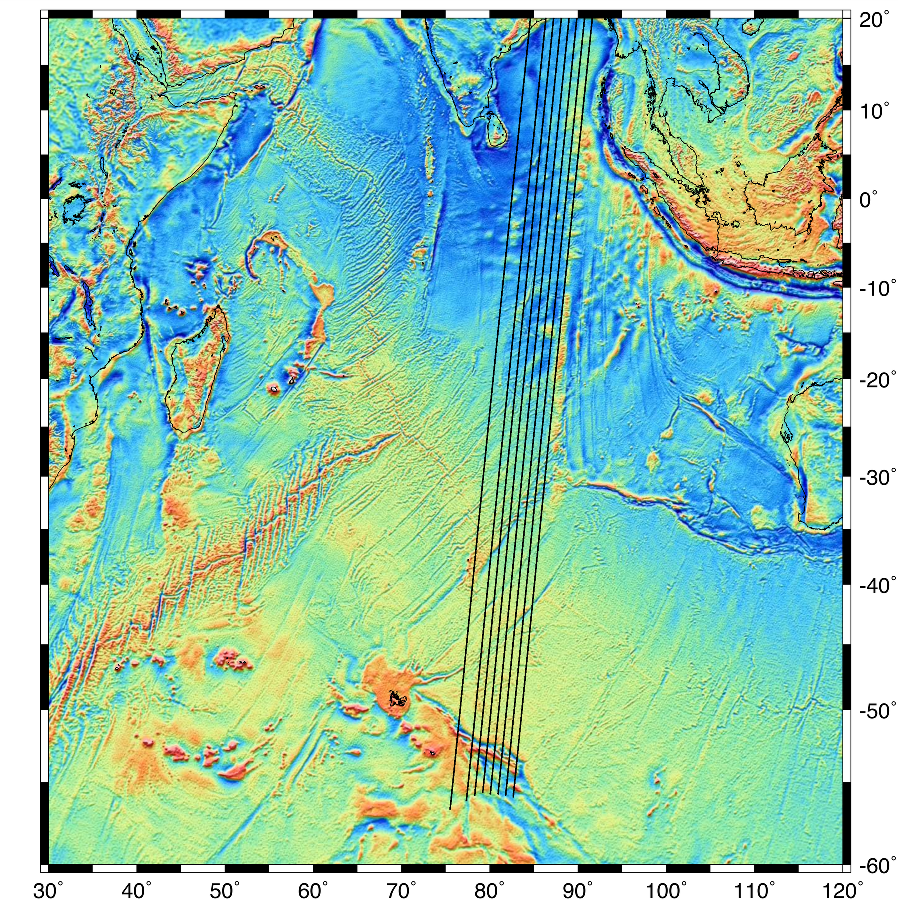
(d) CryoSat waveforms used for the analysis. The anomaly at the equator is perhaps due to a rain cell. Further algorithm development is needed to identify and remove these bad data.

4 Example LRM L1 Data

(right) Eight tracks of CryoSat LRM L1 waveform data used to refine the 2-pass retracking algorithm originally developed for ERS-1. The V18.1 gravity model is based on Geosat/GM and ERS-1/GM altimetry. The addition of CryoSat and Jason-1 should improve the gravity accuracy by a factor of 2. The 2X better model will reveal small-acale features on the seafloor such as 20,000 seamounts and abyssal hill spreading fabric.

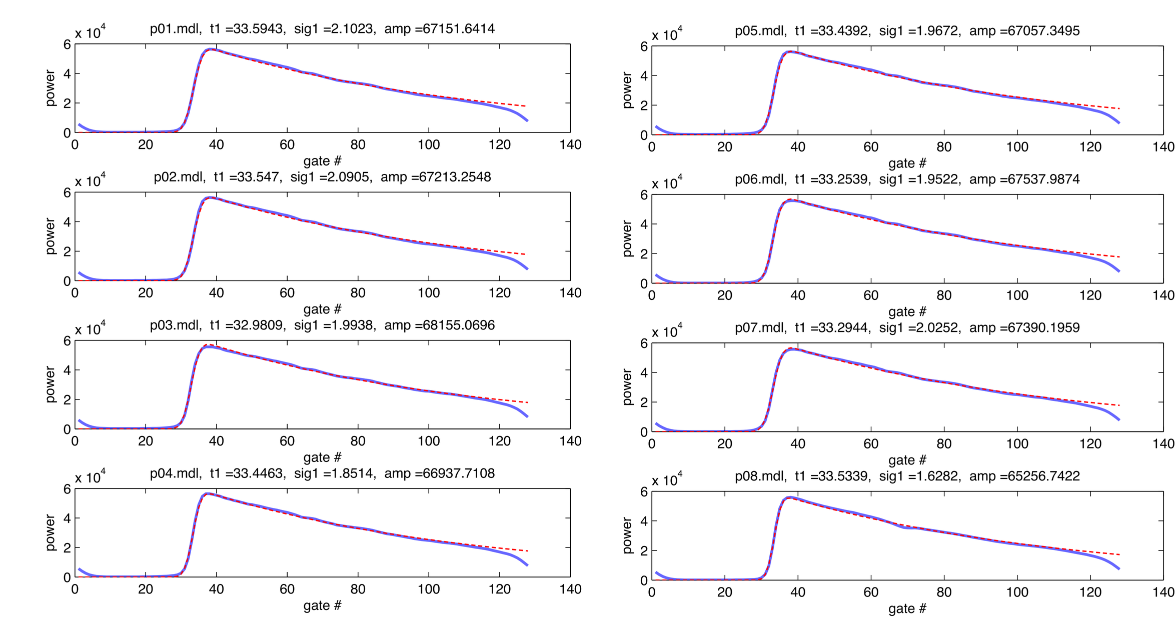


(upper) Example waveforms (20) from profile 1 show the increase in noise with increasing power.
(center) Average of 27,000 waveforms shows the characteristic leading edge shape of an error function with a trailing edge decay.
(lower) Image of all 27,000 waveforms reveals several anomalies.



David T. Sandwell and Walter H. F. Smith, Marine Gravity Anomaly from Satellite Altimetry, Version 18.1

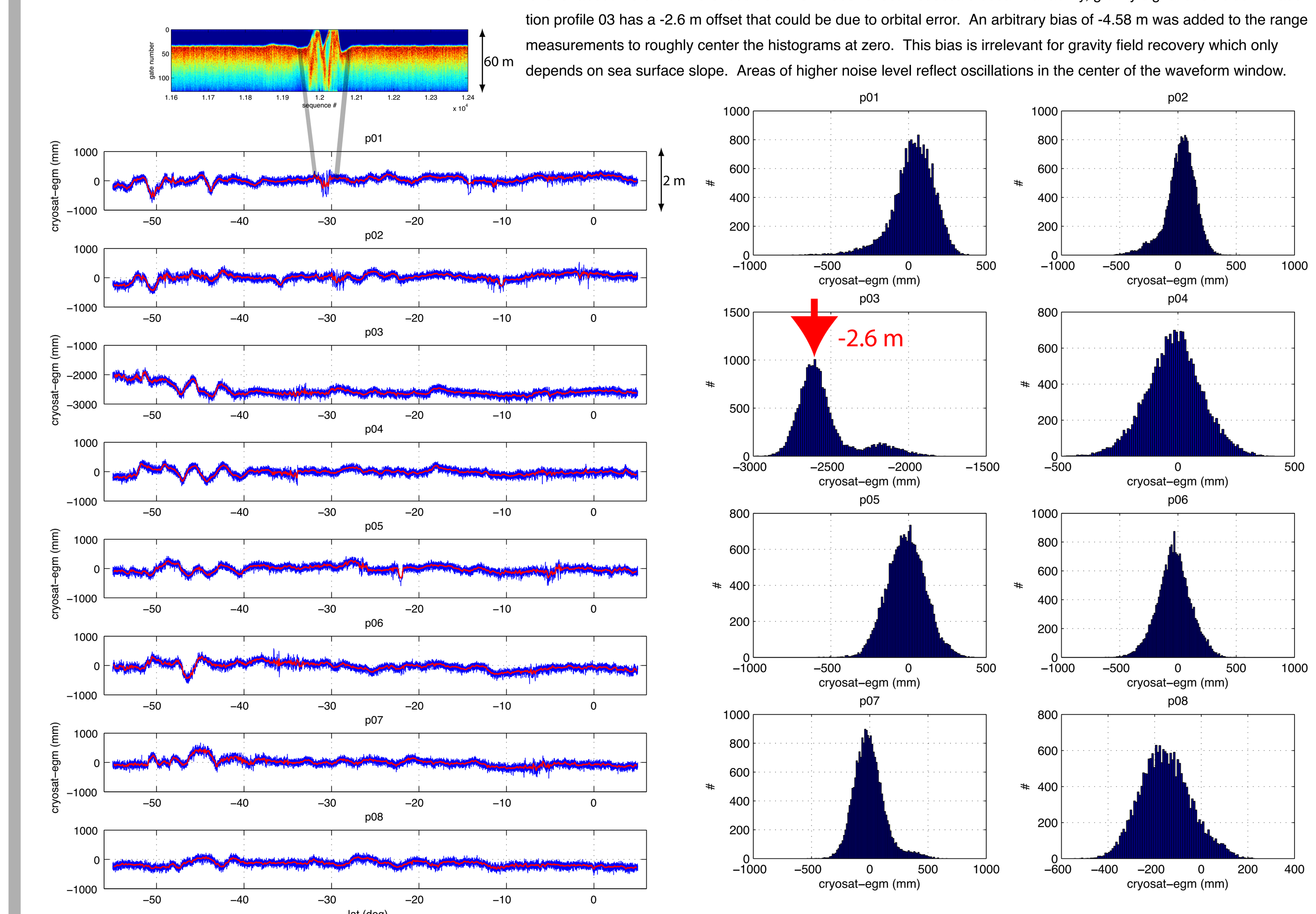
5 Average Waveforms



These averaged waveforms were used to decide on the fixed parameters for the retracking. The trailing edge decay rate is quite stable so the parameter was set to 0.013 gate^-1. Gates outside the range 10 to 110 were not used in the least squares adjustment. The uncertainty for each point in the waveform was (power + 10000)/8.48. This assumes a leading edge error of 10000 and 72 linearly undependent were averaged to make each 20 Hz waveform.

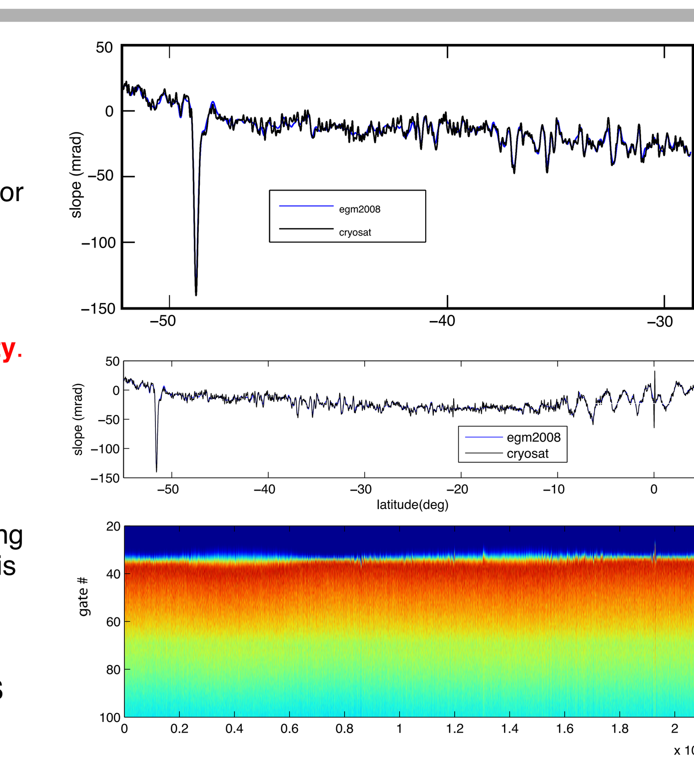
6 Retracked Data

Retracked sea surface height minus the sea surface height from the EGM2008 model reveals signal and noise: The 20Hz estimates (blue curves) have a typical noise level of 11 cm. Along track filtered estimates (red curves) have a lower noise level of about 2.5 cm. Differences from EGM2008 reflect mesoscale ocean variability, gravity signal and noise. In addition profile 03 has a -2.6 m offset that could be due to orbital error. An arbitrary bias of -4.58 m was added to the range measurements to roughly center the histograms at zero. This bias is irrelevant for gravity field recovery which only depends on sea surface slope. Areas of higher noise level reflect oscillations in the center of the waveform window.



7 Results and Conclusions

- The noise level of CryoSat is about 1.4 times lower than Geosat and ERS-1. This is consistent with a factor of 2 higher PRF.
- Three years of CryoSat LRM data combined with 1 year of Jason-1 data will provide a **factor of 2 improvement in the accuracy of global marine gravity**. This will reveal small-scale features on the seafloor such as 20,000 seamounts and abyssal spreading fabric.
- The next step is to estimate the noise level of the SAR-mode data over the ocean and to refine retracking methods. Another factor of 2 improvement in gravity is possible.
- Current issues with CryoSat LRM data:
  - there are significant bands of missing data at 21 N/S
  - one of the eight profiles has a -2.6 m bias



			3-parameter retrack		2-parameter retrack	
profile	# good	# bad	median (μrad)	mad (μrad)	median (μrad)	mad (μrad)
1	20722	327	0.0757	3.0352	0.0120	2.4649
2	20743	305	0.0208	3.3795	-0.0041	2.6484
3	20960	88	-0.1472	2.7753	-0.1556	2.1928
4	20963	83	-0.0240	2.7438	0.0172	2.2733
5	20737	307	-0.0763	3.1039	-0.0687	2.4448
6	20851	191	-0.0131	3.3554	0.0531	2.5796
7	20928	111	-0.0417	3.4093	-0.0313	2.6628
8	21002	29	0.0699	2.6920	0.0141	2.1061
tot	166906	1144		3.0618		**2.4216**
ERS-1				3.5633		3.3133
Geosat				4.576		3.4270

Notes:

2-parameter retrack provides 21% improvement with respect to 3-parameter retrack

ratio of ERS to Cryosat 1.3682
ratio of Geosat to Cryosat 1.4152