

Satellite-derived gravity: Where we are and what's next

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Gravity anomalies can be derived from satellite radar altimeter data for virtually any marine area in the world. The accuracy and resolution of the anomalies have improved over the years, and these data are now of increasing value for modeling structures of interest in the oil industry as well as providing regional geological information.

The gravity field in marine areas is related to the equipotential shape of the sea surface — the geoid. Highs in the geoid correlate generally with gravity highs, with the shorter wavelengths enhanced in the gravity field. The shape of the sea surface itself can be measured by radar altimeters aboard satellites, but the observed sea surface differs from the geoid owing to the effects of tides, currents, and other oceanographic phenomena.

The coverage of available satellite altimeter data has increased vastly over recent years due to the acquisition and release of data from more satellite missions. Exact repeat missions, where the satellite passes a number of times over the same ground track, have been carried out by a number of satellites including Geosat, ERS-1 and Topex/Poseidon; these missions give intertrack spacing at this equator of about 160 km, 75 km and 300 km, respectively. In geodetic missions, satellite tracks are closely spaced but are not repeated. The geodetic mission of ERS-1 gives track spacing of 8 km; the geodetic mission of Geosat was previously classified but now gives track spacing of 5 km. Figure 1a shows the coverage of geodetic mission data from both satellites for a test area in the Gulf of Aden.

Processing. Sea-surface heights from satellite altimeter data have various inconsistencies between tracks even after adjustment using a standard ocean tide model (Figure 1b). These are mainly due to errors in orbit calculation (very long wavelength) and residual tidal and

oceanographic effects (shorter wavelength). These would produce even greater spurious features in

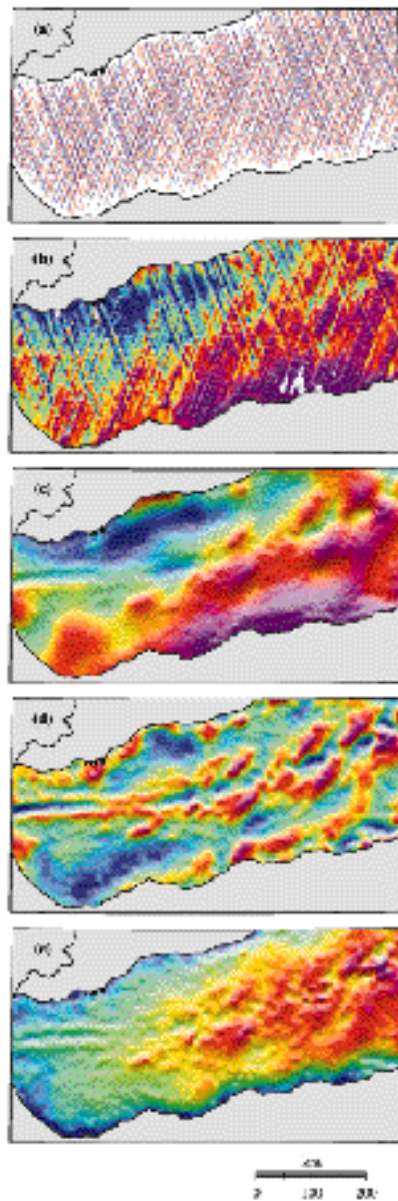


Figure 1. Satellite gravity processing sequence for a test area in the Gulf of Aden. (a) Track layout of geodetic mission data, ERS-1 = red, Geosat = blue; (b) raw geoid heights; (c) geoid heights after leveling and microleveling; (d) free-air anomaly; (e) Bouguer anomaly.

the gravity anomaly as the conversion process enhances the short wavelengths. Two main approaches have been used to avoid these spurious track-oriented gravity anomalies.

The first uses the gradient of the geoid surface, which is virtually unaffected by the orbit error and is relatively unaffected by the oceanographic phenomena. Geoid gradients in two orthogonal directions are calculated by a choice of techniques, and the gradients are subsequently converted directly to gravity, generally using Fourier transform techniques.

The second approach applies crossover-based line adjustments to remove the orbit errors and microleveling techniques to remove the residual oceanographic errors. This produces a smooth geoid surface (Figure 1c) which can be converted to free-air anomaly (Figure 1d) by Fourier transform techniques.

The Fourier transform techniques themselves can be modified to better account for the spherical Earth. By either technique the gravity anomalies calculated from geodetic mission data have better accuracy and resolution than those calculated from exact-repeat mission data — despite the fact that stacking collinear tracks of exact-repeat mission data gives better along-track consistency than single geodetic mission tracks.

Free-air anomaly can be converted to Bouguer anomaly (Figure 1e) and subsequently to isostatic anomaly to give further insights into structures near the top of the crust by removing the effects of bathymetry and crustal thickness variation.

Data quality. Satellite-derived gravity maps can be compared visually with shipborne marine gravity to assess the correlation of the two data types and hence the quality of the satellite-derived gravity data. A clearer assessment of data quality can be made by comparing a track of

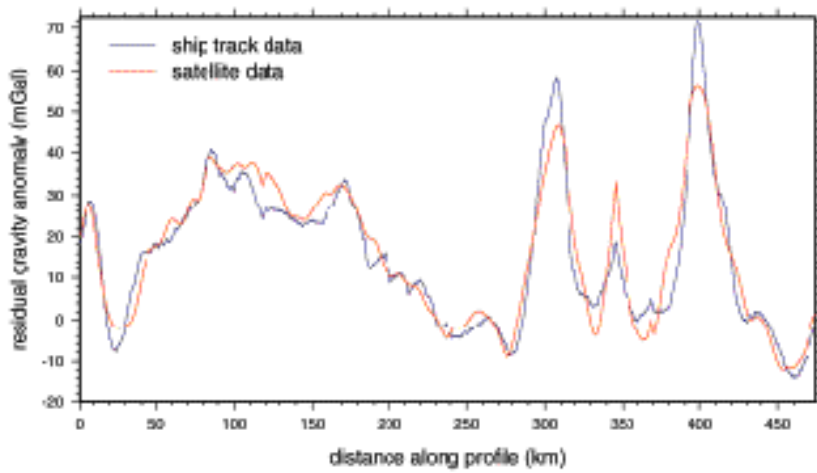


Figure 2. Comparison of satellite gravity grid and marine gravity track from the South China Sea. Note that some anomalies with amplitudes less than 5 mGal and wavelengths less than 10 km can be clearly correlated. Anomalies with wavelengths of 20 km and amplitudes of 10 mGal can be reliably correlated.

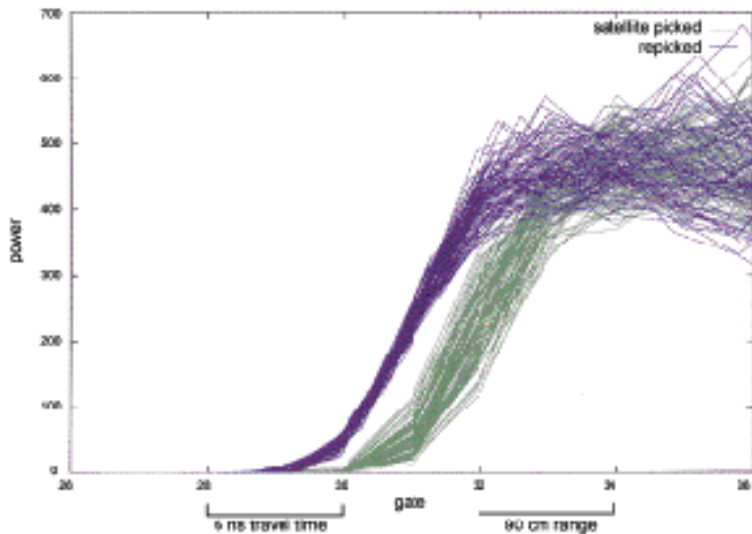


Figure 3. Satellite altimeter waveforms aligned based on satellite picked arrival times (green) and repicked waveforms (blue). The two sets of waveforms are offset for clarity.

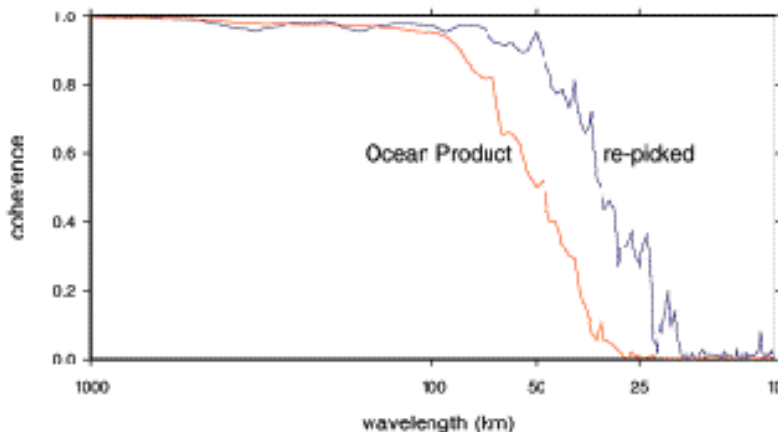


Figure 4. Coherence against wavelength for repeat tracks for standard Ocean Product and repicked data. Note that the median along-track wavelength is reduced from ~50 km to ~30 km by the repicking process.

shipborne gravity data with the satellite gravity data.

Figure 2 shows a modern high-quality ship gravity profile from the South China Sea together with gravity values extracted from the satellite gravity grid. Some anomalies of less than 10 km in width and 5 mGal in amplitude can be seen to correlate between the two data sets, but anomalies of 20 km in width can be much more consistently imaged in the satellite gravity data.

The future. Improvements in resolution and accuracy of satellite-derived gravity data in the last few years have been based on greatly enhanced track coverage. No such improvements in coverage can be expected within the next few years; hence, further developments must come from improving the process.

One intriguing possibility in this area is the use of improved tidal and oceanographic models. Tidal models based on satellite altimeter data are already proving valuable, but they still have low spatial resolution compared to some of the tidal effects observed in the satellite altimeter data. Satellite altimeter and other data can be used to study both the geoid and oceanographic phenomena. Joint solutions allow all the available data to be used with less of the signal described as “noise.” In general, improved oceanographic models will improve the reliability of the derived gravity field and will not necessarily impact the limiting accuracy or resolution.

Repicking of the radar altimeter traveltime shows great promise for improving the consistency of the sea-surface heights and hence of the gravity. The radar traveltime is normally picked independently for each radar signal by fitting a standard waveform shape based on five parameters, one of which is the traveltime. A new technique, devised last year by the authors, matches the leading edges of a series of radar waveforms to give maximum coherence. Hence the traveltime only is picked. Figure 3 shows a series of waveforms aligned by the standard picking algorithm and also the much improved alignment from the new algorithm. This improved picking can be further enhanced by applying statistical constraints to the relative times of a series of radar signals based on the known statistical properties of gravity fields.

The resolution of the enhanced waveform picking can be assessed from the coherence of the sea-surface heights along repeat tracks. Figure 4 shows the coherence against wavelength for ERS-1 data. The coherency of standard Ocean Product sea-surface heights and those derived from repicked waveforms show a marked difference, with limiting wavelength resolution of about 50 km and 30 km, respectively. This improved repeatability of the repicked waveforms gives great promise that the limiting resolution of the satellite gravity data themselves can also be dramatically reduced.

Conclusions. Satellite gravity solutions can currently reliably image anomalies as small as 5 mGal and 20 km in width. Smaller features can sometimes be imaged. There is scope for improving the reliability of the solutions by using improved oceanographic models. The limiting resolution and accuracy of the solutions can be addressed by repicking the radar traveltimes by waveform matching. \square

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