Improving the geoid: Combining altimetry and mean dynamic topography in the California Current System

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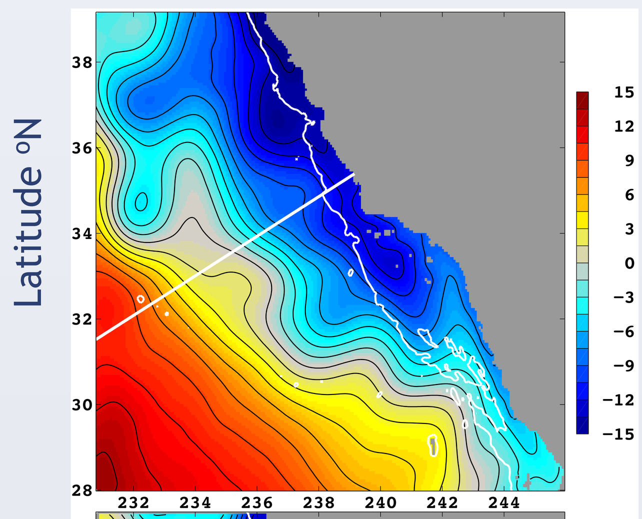
The Problem

- At horizontal resolutions less than 100 km the uncertainty in current estimates of the displacement of the Earth's gravitational field above a reference ellipsoid, i.e. the geoid, exceeds 10 cm (Bingham et al. 2014).
- Sea surface height (SSH) measurements from altimeters have an uncertainty of about 3 cm (Ponte et al. 2007).
- The ocean circulation can be inferred from the dynamic ocean topography, which is the difference between the SSH and the geoid: DOT = SSH − geoid.
- Individual DOT measurements, however, have an uncertainty that is primarily due to the geoid, and at greater than 10 cm have diminished value.

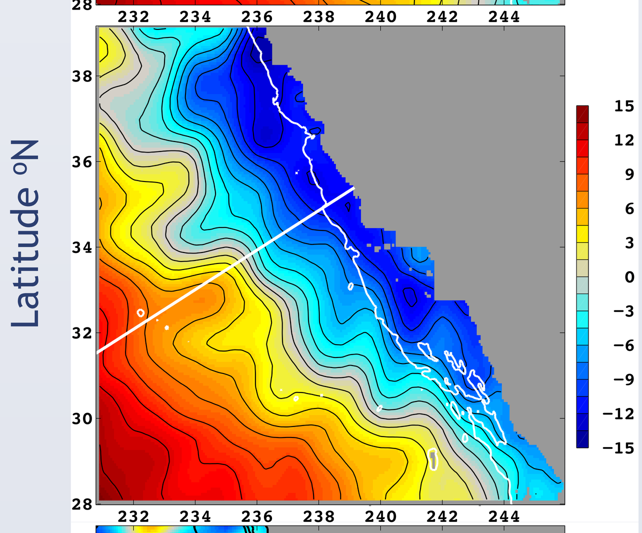
A Proposed Solution

Hypothesis: we can correct a geoid estimate over the ocean on scales below 200 km relying primarily on information from high-precision satellite altimeters and modern high resolution DOT products that utilize a priori knowledge of the ocean circulation. A proof of concept for the test-bed region of the California Current System is presented here.

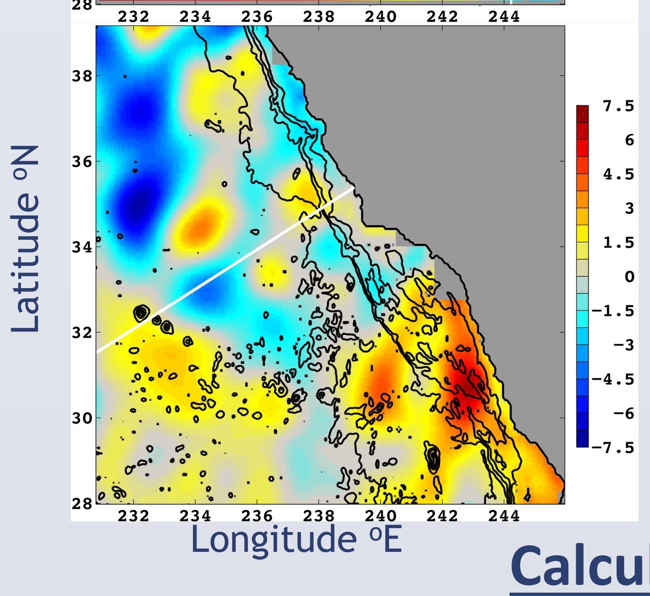
DOT products



Mean dynamic ocean topography in cm from a state estimate of the California Current System (http://sose.ucsd.edu/CASE). The contour interval is 1.5 cm. The bathymetry is contoured in black with a 1000m contour interval and the CalCOFI line 75 is shown in white.



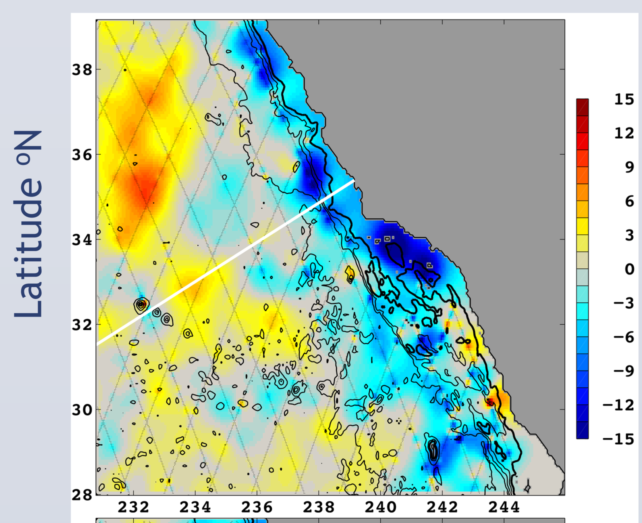
Mean dynamic ocean topography in cm from AVISO for 2007-2010, produced by Ssalto/Duacs and distributed by AVISO, with support from CNES (http://www.aviso.oceanobs.com/duacs/). The contour interval is 1.5 cm. The bathymetry is contoured in black with a 1000m contour interval and the CalCOFI line 75 is shown in white



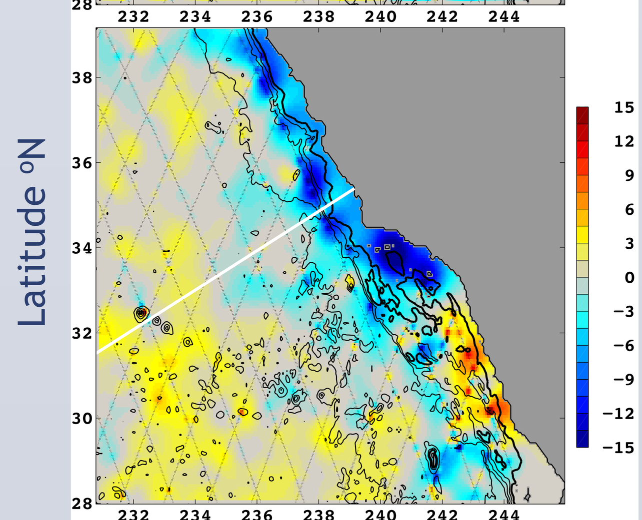
The state estimate mean DOT minus the AVISO mean DOT. Bathymetry is contoured in black with a 1000 m interval. This difference field, which has a maximum of 7.1 cm and a Root-Mean-Square (RMS) of 2.1 cm, is an indicator of the uncertainty in the estimated mean dynamic ocean topography.

Calculating a geoid correction

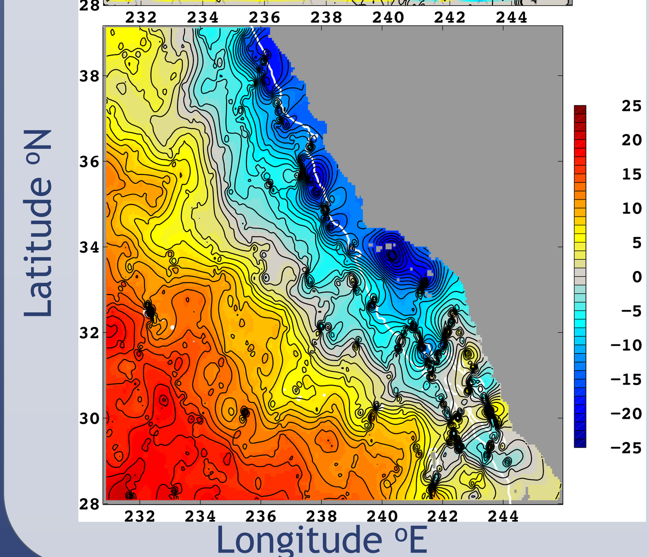
We calculate the residuals between the SSH, DOT, and geoid. For SSH we use the Jason altimeters which have a 10 day repeat period. For geoid we use EGM2008 (Pavlis et al. 2012). The calculation is carried out twice, once using the state estimate DOT and once using the AVISO DOT. For both calculations, the residuals are time-averaged and mapped to a 1/32° grid. The correction is then mapped from this grid (Mazloff et al., submitted).



The geoid correction field in cm using the state estimate DOT. The bathymetry is contoured in black with a 1000m contour interval, and the CalCOFI line 75 is shown in white.



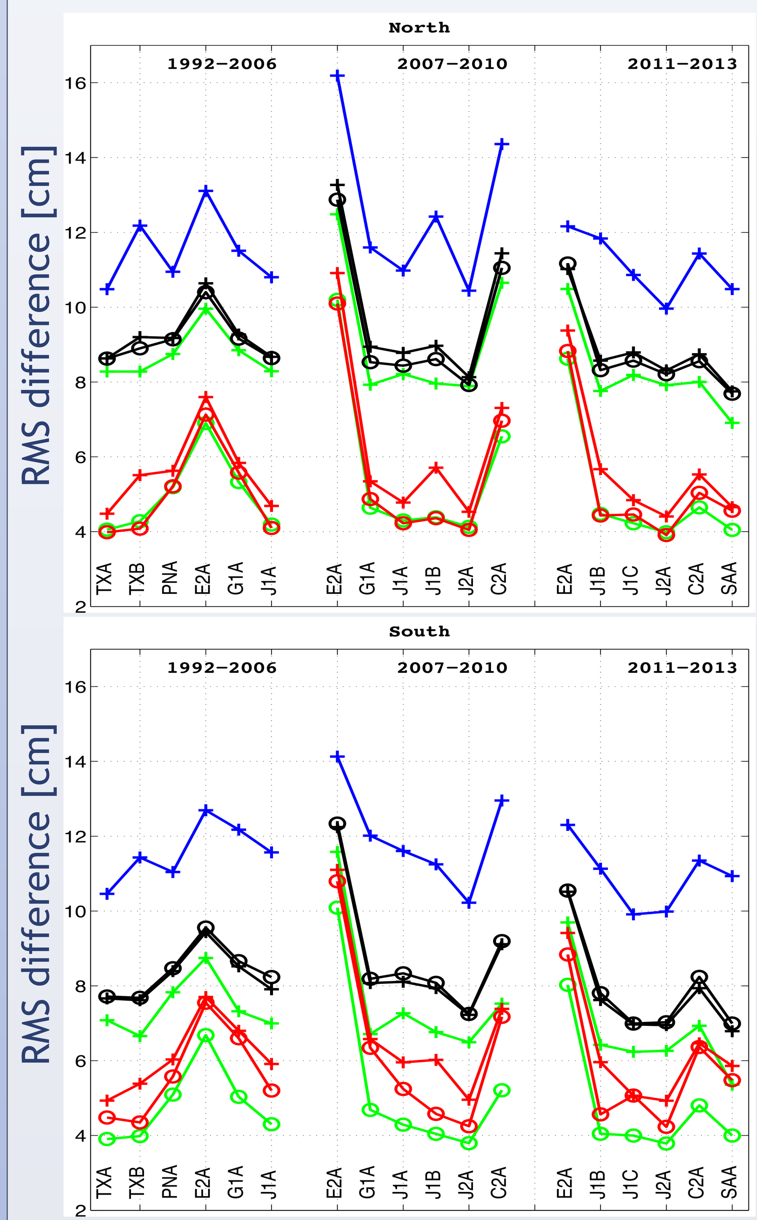
The geoid correction field in cm using the AVISO DOT for 2007-2010, produced by Ssalto/Duacs and distributed by AVISO, with support from CNES (http://www.aviso.oceanobs.com/duacs/). The bathymetry is contoured in black with a 1000m contour interval, and the CalCOFI line 75 is shown in white.



The state estimate mean dynamic topography plus the geoid correction field. The contour interval is 1.5 cm. The 2000m bathymetric contour is shown in white. This field implies a circulation that is far stronger than observed. Our method does not distinguish geoid errors from mean DOT errors, but physical arguments imply that the correction can be primarily attributed to uncertainty in the geoid.

Results

RMS residuals for the (top) north of CalCOFI line 75 and (bottom) south of of CalCOFI line 75 in cm. The analysis has been separated into the period before the assimilation (1992-2006), during the assimilation (2007-2010), and after the assimilation (2011-2013). The geoid correction is determined only using data during the assimilation period.



Excluding the Dynamic Ocean Topography

SSH minus geoid

Excluding Ocean Variability

SSH minus the DTU10 mean sea surface product (Anderson 2010)

SSH minus geoid minus mean DOT from the state estimate

SSH minus geoid minus mean DOT from AVISO

Accounting for Ocean Variability

SSH minus the DTU10 mean sea surface product (Anderson 2010) and using the AVISO DOT anomaly

SSH minus geoid minus AVISO DOT

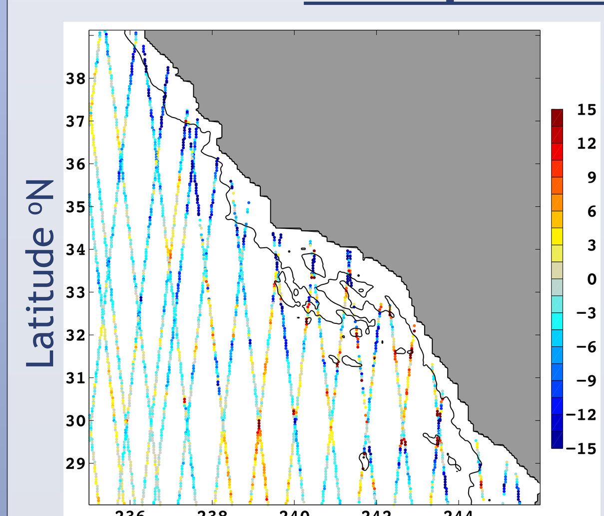
Using the geoid correction

SSH minus corrected geoid minus AVISO DOT

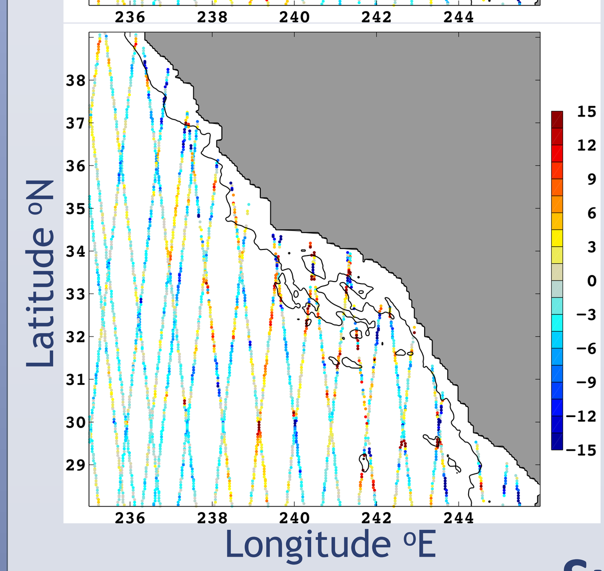
The x-axis denotes the altimeter used with nomenclature consistent with the RADS database where the data were obtained (http://rads.tudelft.nl/). The third character denotes mission phase (e.g., J1B denotes the Jason-1 altimeter phase B). All the altimeters have relatively short orbit repeat periods except J1C, C2A, and SAA.

Example: Residuals for CryoSat-2 in July 2012

Mapping a geoid correction propagates information provided by short repeat altimeters, allowing better use of non-repeat altimeters. The result is that prescribed uncertainty on non-repeat altimeter constraints can be reduced in ocean assimilations.



The residuals between the AVISO DOT, EGM2008, and CryoSat-2 for July 2012 in cm. The 1000m bathymetry contour is shown in black.



The residuals after applying the correction to EGM2008. The residuals are now less structured, especially off the coast of northern California, and the RMS has been reduced from 6.3 cm to 5.5 cm over the domain shown.

Summary and Conclusions

- We solved for a geoid correction for the region of the California Current System using two dynamic ocean topography estimates that have uncertainties less than 10 cm.
- This geoid correction improved the overall consistency with along-track altimetric observations in the region by about 1 cm (see red lines above).
- This correction is as large as the dynamic ocean topography itself, with a magnitude of approximately 15 cm and a RMS of 3 cm. The correction has significant structure, especially near the coast.
- Modern high-resolution dynamic ocean topography products, which are inferred by combining known physics with observations, can inform geoid models and allow better use of altimeters with long repeat periods.

References

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