Progress in Altimeter Calibration Using the Global Tide Gauge Network

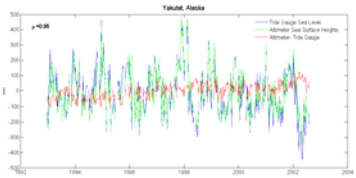
Kara Sedwick Doran and Gary T. Mitchum, College of Marine Science, University of South Florida, ksedwick@marine.usf.edu
Daniel Morken and R. Steven Nerem, Colorado Center for Astrodynamics Research, University of Colorado

Abstract

In the past decade, the use of tide gauges in calibrating satellite altimeters has become widely accepted. Because tide gauge sea levels are referenced to a datum on land, an estimation of land motion at each tide gauge must be made in order to compare tide gauge sea levels with altimeter heights. The errors due to land motion at the tide gauges are the largest remaining source of uncertainty in this method of altimeter calibration. Since the last calibration method was described (Mitchum, 2000) more GPS and DORIS stations have become available, many near to the tide gauges presently used for altimeter calibration. Through careful examination of tide gauge derived land motion estimates and land motion estimates from nearby GPS stations, we can make an estimate of land motion and its uncertainty at any tide gauge. By estimating land motion at each tide gauge, we reduce the error on the tide gauge-altimeter differences and improve the uncertainty of computing linear sea level trends from altimetry.

General Method of Altimeter Calibration Using Tide Gauges

The current method of tide gauge/altimeter calibration (Mitchum, 2000) is performed by taking the difference of a tide gauge sea level time series and nearby satellite altimetry sea surface height time series. By taking the difference, the ocean signals common to both series cancel out, leaving a series dominated by altimeter drift and any land motion at the tide gauge.



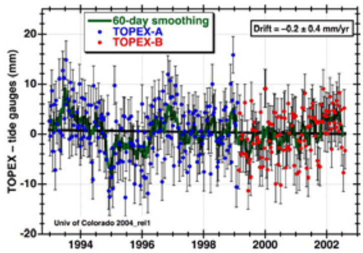
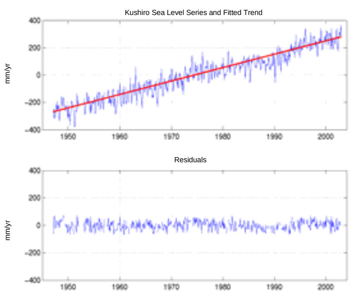


Figure courtesy of The University of Colorado. http://sealevel.colorado.edu

The above figure shows the tide gauge, altimeter, and difference series for Yakutat, Alaska. Even though the altimeter and tide gauge time series have large standard deviations (~150 mm), the difference series has a standard deviation of only 46 mm. The altimeter and tide gauge time series are also highly correlated (0.95), meaning most of the common signals will cancel out. From the difference series we can clearly see an upward trend. This can be interpreted as land motion at the tide gauge and altimeter drift. In this figure we have used only TOPEX altimeter heights which are considered to be free from drift, so the red line indicates a large land motion at the tide gauge. The right figure shows the most recent TOPEX calibration and the linear drift which is not statistically different from zero. However, since we must apply the calibration to JASON, which is not free from drift, we must make an estimate of land motion at every tide gauge in order to obtain the drift series.

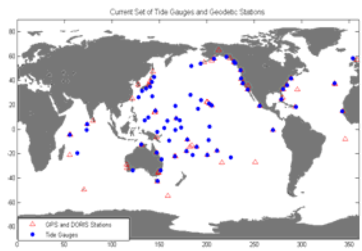
Estimating Land Motion

We have three ways of making the land motion estimate: a tide gauge derived estimate (internal), a GPS derived estimate (external) and an estimate from the difference series. The internal estimate is made by fitting a linear trend to the tide gauge sea level series as seen in the figure below. The red line indicates the trend, fitted to the blue tide gauge sea level. The lower panel shows the residuals of the fit after the trend, tidal harmonics, annual and semi-annual harmonics and ENSO signals have been removed.

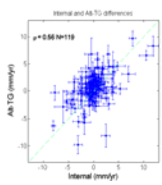


To extract land motion from this series, we must assume that some of the trend is due to global sea level rise. We assume a global rate of sea level rise of 1.8 mm/yr (Douglas, 1995). Of course, the true sea level rise may not be the same as the global rate, so we must add a bias error term of 0.4 mm/yr to the estimate. This bias error term dominates the error on the tide gauge/altimeter difference series and is especially troublesome for fitting a linear trend to the drift estimate.

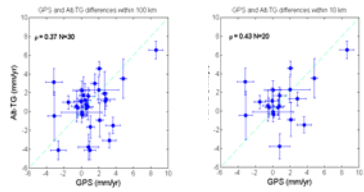
Our second land motion estimate is the external estimate from the vertical trend of a geodetic measurement time series such as GPS or DORIS. GPS vertical trends and their respective errors were computed by Dan Morken at the University of Colorado. Nearly half of the 64 tide gauges used in the present calibration have a GPS or DORIS within 100 km. Unfortunately, since there is not a GPS or DORIS at every station, we must come up with the best way to combine the three land motion estimates to make the best rate for each tide gauge.



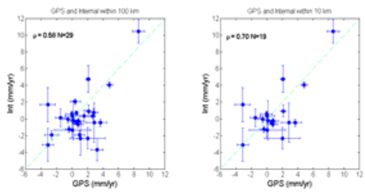
The third way to compute a land motion estimate is to fit a trend to the altimeter-tide gauge difference (Nerem and Mitchum, 2002). This method assumes that the altimeter is free from drift, so that the difference series represents only land motion. This approach is illustrated in the Yakutat figure above.



The three approaches are compared to the right. Each approach compares similarly with the others. At this time, there is no reason to suspect that any of the three ways of estimating the land motion are better than the others.



GPS rates and altimeter-tide gauge rates do not agree as well as the GPS and internal rates. The reason for this is not entirely clear, given the agreement seen between internal and altimeter-tide gauge rates in the plot to the left.

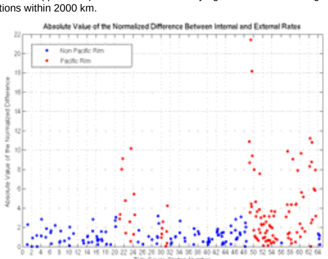


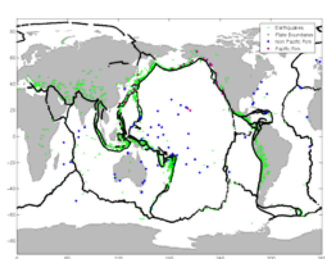
GPS rates and Internal rates agree reasonably well, especially when constrained to be within 10 km of each other. The reasonable agreement indicates that assuming the sea level rise rate of 1.8 mm/yr is not that far off from the true rate.

New Approach to Land Motion

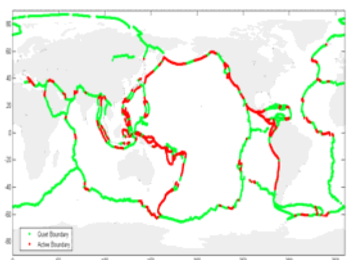
In the previous calibration (Mitchum, 2000), land motion estimates were computed at each tide gauge by combining nearby GPS in a weighted average. In the case where no GPS were within 1000 km , the internal land motion estimate was used. Because the internal land motion estimate adds a bias error to the calibration, we prefer to make an external estimate at each tide gauge if possible.

Through our examination of tide gauge and GPS pairs, we discovered that in areas of quiescent tectonic activity, internal and external rates were consistent if the stations were on the same tectonic plate. Even stations separated by more than 2000 km showed reasonable agreement. We devised a classification of tide gauges and geodetic measurements into Pacific Rim (active) and Non Pacific Rim (quiescent) based on how well they agreed with surrounding stations within 2000 km.





We then tried various methods of classifying stations according to tectonic activity (frequency, magnitude, energy). We decided to classify the boundaries into active or quiet categories according to earthquake average and total energy within 200 km of that boundary.

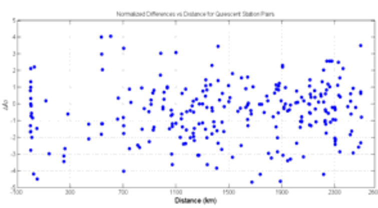


We then examined various criteria to exclude stations with large internal and external differences. The criteria for rejection were

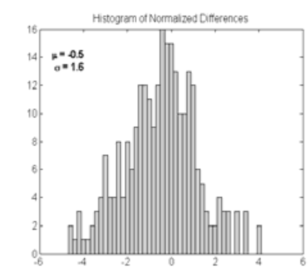
- Stations separated by a distance greater than 2500 km
- Stations not on the same or adjacent tectonic plate
- Stations less than 250 km from an active boundary or 100 km from a quiet boundary

We also rejected Hilo, Hawaii tide gauge and GPS because of volcanic activity.

Plotted below are differences from all pairs (tide gauge/tide gauge, GPS/GPS, and tide gauge/GPS) normalized by their combined errors, that are left after the above stations are rejected. Notice there is no discernable trend with distance.



In principal, all of the normalized differences should fit a normal distribution with unit standard deviation if the only error in land motion estimates is random. Of course, this is not the case, as you can see by the histogram below. We have investigated many potential error sources, but have not come to a conclusion yet. Finding out how to inflate the error on these estimates is a topic of ongoing research.



Using this classification approach, one could add any tide gauge to the calibration set and make an estimate of land motion and it's error. Since we can use GPS far away, we may also eliminate the need for the internal estimate and thereby eliminate the bias error, which is the largest source of error for fitting linear sea level trends from TOPEX and JASON altimetry.

Future Work

We are now working on how to use the altimeter-tide gauge differences in lieu of the internal estimate. Further work is needed to explain why the internal estimates should agree better with external estimates than the altimeter –tide gauge differences.

Further investigation is needed into how to inflate the error of the quiescent set of station pairs.

We must decided what to do with the active tectonic stations. Our current thinking is that the distance to the nearest GPS must be much smaller (10's of kilometers) because of localized tectonics.

Selected References

Douglas, B.C., 1995: Global sea level change: Determination and interpretation. *Rev. Geophys.* **33**. 1425-1432.
Mitchum, G.T., 2000: An improved calibration of satellite altimetric heights using tide gauge sea levels with adjustment for land motion. *Marine Geod.* **23**. 145-166.
Nerem, R.S and G.T. Mitchum, 2002: Estimates of vertical crustal motion derived from differences of TOPEX/POSEIDON and tide gauge sea level measurements. *Geophys. Res. Lett.* **29**(19). 1934-1937.