Tide Gauge Estimates of Altimeter Stability: Improved Methods and Updated Results

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Background

At the very beginning of the TOPEX/Poseidon mission, actually before, we developed a method for using the global tide gauge network to estimate any possible (globally uniform) drift rate in the altimetric heights. These calculations did not, however, receive a great deal of attention prior to the discovery of the so-called "algorithm error", which the tide gauge analysis successfully predicted. Subsequently, in collaboration with Steve Nerem, this method was further developed during the T/P and Jason-1 missions. More recently, support from the NOAA Laboratory for Satellite Altimetry (Miller and Leuliette) and from NASA as part of the Measures project (Ray and Beckley) has allowed for significant improvement and generalization of the method. Describing the upgraded method and system is the main point of this poster.

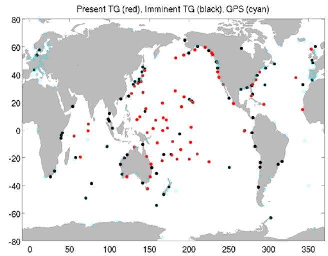
Since the time our abstract was submitted, we learned that other groups will be reporting on the most recent results of the tide gauge drift estimates for the Jason-1 and Jason-2/OSTM missions. We will therefore focus on the improvements to the method and will not show the most recent Jason-1/2 results. We will use the well-studied TOPEX time series for all of our examples, but please note that these results apply to any past, present and future altimeter missions.

There are two main sections to this poster. In the original method, the matching of the tide gauge time series and the nearby altimetric time series was rather simple (nearest point), and no consideration of known errors (seasonal at the tide gauges and at the tidal aliases for the altimeters) was made. The first section deals with improvements on this front. The second, rather brief, section, describes technical improvements that allow us to deal with multiple altimetric datasets from multiple originations, and multiple dataset versions from each originator with a reasonably rapid turnaround of each individual altimetric dataset.

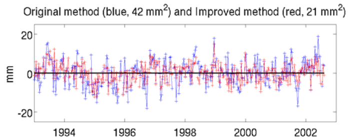
Ocean Signal Cancellation

A major improvement over the past 10 years has been the greatly increased number of tide gauges that are available in near-real time (within 1-2 months for tide gauge data!) and have time series that span most of the altimeter time period, defined to be 1993 to present. This is thanks to the efforts of the University of Hawaii Sea Level Center operated by Mark Merrifield.

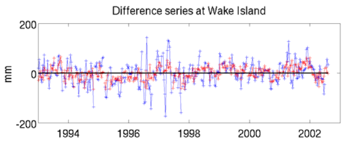
The figure to the right shows the gauges used in the altimeter drift estimation over the past few years (red), along with the additional gauges that are now candidates for inclusion in this set (black). In cyan we also show the location of continuous GPS stations that are used to determine land motion rates at the tide gauges. The results that follow use the gauges shown in red, primarily because an issue involving the land motion correction has arisen in the past month or so. Please talk to Gary or see the talk in the "Error Budgets" splinter to hear more about this. Once this issue is resolved, the expanded set of tide gauges will be used, and the error bars should decrease substantially, meaning on the order of 50%.



As mentioned above, the original method used a rather crude method to match up the tide gauge and altimeter time series in the vicinity of each gauge, and also did not take into account known errors in the tide gauges (mainly seasonal variations due to local density changes) and the altimetric series (primarily due to tide model errors). The improved method deals with both of these deficiencies.



The figures to the right show the drift series (top) from the original method (blue) and from the improved method (red). The key point is that the variance (i.e., random error) has decreased by a factor of roughly two. The lower panel shows an example from one of the tide gauges. Close examination of this series reveals apparent outliers and quasi-periodic differences. It turns out, however, that most of the difference is due to propagating signals that are not captured by the simplistic matching of the series in the original method.

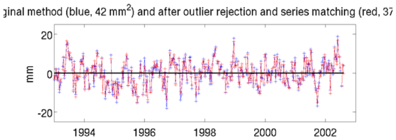


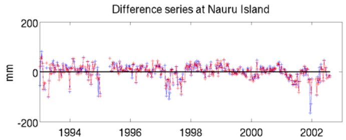
Ocean Signal Cancellation (continued)

The first improvement to the method is to do a simple outlier rejection in the difference series at each tide gauge that are eventually averaged to form the final drift series. The difference series at Nauru (lower right) shows an example of this.

Nauru Island is subject to harbor set up during westerly wind events that are more common during ENSO events; these outliers are seen in 1997-98 and 2001-02, for example. More importantly, though, is the improved series matching that allows for spatial and temporal lags, as discussed earlier using Wake Island as an example.

The outlier rejection does not reduce the drift series (top right panel) variance very much, but can be significant at individual sites such as Nauru. Taken together, though, we see that the combination of the outlier rejection and the improved series matching reduces the variance of the drift series by about 10%.

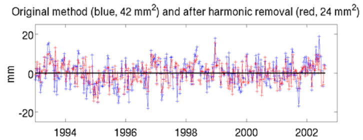


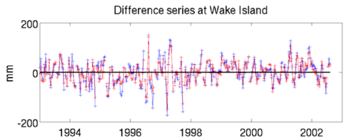


The major improvement is from accounting for seasonal errors at the tide gauges, and from tide model errors in the altimetric heights. These are removed by fitting and subtracting energy at specific frequencies (annual, semiannual, and the aliases of the M_2, S_2, N_2, O_1, K_1, Mf and Mm tidal frequencies).

This adjustment reduces the variance of the drift series (upper panel) substantially. Wake Island, which we noted previously was mainly improved by the allowance for propagating signals, is hardly changed by this adjustment. This is a good thing, as it shows that we are not over-fitting and incorrectly removing other errors.

This adjustment cannot be done on short time series. In implementing this correction we exclude periods shorter than one third the record length, and use the Rayleigh criterion to avoid including redundant frequencies.





Data Management Improvements

Aside from the algorithmic improvements that we've discussed above, there has been a substantial effort spent on data management issues. The improvements to the algorithms has mostly been enabled by the NASA support via the altimetry missions (Nerem) and the recent Measures project (Ray and Beckley), while the data management improvements are thanks to NOAA (Miller and Leuliette) support. The purpose of this final section is to briefly describe these efforts.

First, prior to these improvements, separate codes existed for each group that wanted to have altimeter drift estimates made for their datasets. Also, separate codes existed for each altimeter, with the implementation of the algorithms unfortunately depending on when the codes were written. This was a natural consequence of how the system developed.

With the NOAA support, a single processing system has been developed that uses consistent algorithms for any data originator, any altimeter, and all versions of any altimeter dataset. Only two originator-specific codes need to be written, and this only happens the first time that a group sends a dataset. The first code is a pre-processor unit that converts the originators' format for any altimeter dataset into the format used at the USF for input to the drift estimation. The second is a post-processor unit that outputs the results into the format requested by the data originator. This system allows an arbitrary user to access the system in a relatively simple fashion, meaning that once we agree on their input and output formats, they can send multiple sets for multiple versions of multiple altimeters with no further adjustments necessary.

As presently implemented, the USF codes ask for an originator id, an altimeter id, and a version number. Everything from that point forward is handled internally. One of the advantages of this system is that the turnaround time for creating the drift estimate time series for any altimeter dataset is basically limited to the time taken to download the altimeter dataset from the originator. Note that even this download is now automated, as is the upload of the drift estimate output file.

The result of these improvements is that a data originator can send a message giving an altimeter id and a version number, and receive within a few hours the altimeter drift estimate series for their dataset. And iterations are unlimited, meaning that they can look at the output, modify their input series, send another message, and start the process over again.