Proceedings of the 9th U.S. National and 10th Canadian Conference on Earthquake Engineering
Compte Rendu de la 9ième Conférence Nationale Américaine et
10ième Conférence Canadienne de Génie Parasismique
July 25-29, 2010, Vancouver, Canada ♦ Paper No. 1839

OFFSHORE TSUNAMETER DATA ANALYSIS AND APPLICATIONS: DE-TIDING, QUALITY CONTROL AND MODEL VALIDATION

N.A. Donoho[1], S.K. Gill, K. Glebushko

ABSTRACT

National Ocean Service's Center for Operational Oceanographic Products and Services performs harmonic analysis on Deep-ocean Assessment and Reporting of Tsunami (DART®) data and provides the resulting harmonic constants to the Tsunami Warning Centers, National Data Buoy Center and Pacific Marine Environmental Laboratory in order to develop research quality deep-ocean water level data and products. Generated predicted data sets are used as quality control to check for discontinuities, shifts, and/or invalid tsunameter data. Harmonic constants are evaluated using reduction of variance statistics from the least-squares harmonic analysis of the available time series. The resulting harmonic constants are essential to de-tiding the observations and analyzing the residuals for application to the tsunami forecast system. Some other application aspects are using the observational data for assessing the accuracies of the global tide models and improving previous comparisons with in-situ data using some bottom-pressure data based on long time series. The data also provides NOS with information on offshore tidal characteristics.

Key Words: tidal analysis, least squares harmonic analysis, tidal constituents, de-tiding, tsunami prediction

Introduction

Removal of the tidal component from offshore tsunameter observations is required for successful refinement of the seismic parameters that provide the basis for the real-time operational tsunami forecast system under development at the Pacific Marine Environmental Laboratory (PMEL). This forecast system is used by both of the National Oceanic and Atmospheric Administration's Tsunami Warning Centers. As the tsunami wave propagates across the ocean and successively reaches the tsunami buoy that employs the Deep-ocean Assessment and Reporting of Tsunami (DART®) technology, these systems report water level information measurements back to the Tsunami Warning Centers, where the information is processed to produce a new and more refined estimate of the tsunami source and estimates of the tsunami amplitudes. An increasingly accurate forecast of the tsunami will be used to issue warnings and watches for the at-risk communities following a potential tsunami-generating event.

---

[1]Oceanographer, National Oceanic and Atmospheric Administration, National Ocean Service,
Center for Operational Oceanographic Products and Services, USA, Natalia.Donoho@noaa.gov

Tidal harmonic constants provided by National Ocean Service's Center for Operational Oceanographic Products and Services (CO-OPS) for all DART® observation sites are used to generate predicted tides and subsequent residuals for model ingestion and in research towards the development of additional operational applications at PMEL. In addition, these NOS tidal harmonic constants are used to create tidal predictions that are subtracted from the observations to create de-tided residual time series. These residual time series are then used as a measure of DART® data quality at the National Data Buoy Center (NDBC).

Harmonic Constituents, Predictions and De-Tiding

To predict the tide at a particular location (for which there is an observed water level time series), harmonic analysis needs to be performed. There are several methods for removing tidal energy from a data time series (Parker 2007) such as de-tiding, tidal filtering (Foreman 1995), spectral analysis (Emery and Thomson 2001) and principal component or Empirical Orthogonal Function analysis (Tolkova 2009). Subtraction of the predicted from observed series produces a residual time series, and is usually referred to as de-tiding.

Observational data are analyzed using a least-squares harmonic analysis program to generate harmonic constants for a standard set of harmonic constituents for the location where each constituent represents the changes caused by a single astronomical effect and, when combined, will result in the tide prediction.

Each DART® system records continuous high frequency temperature and pressure parameters for the entire bottom pressure recorder (BPR) deployment period. Data are recorded in units of pressure (pounds per square inch in the sensor calibration equation) but are converted to meters of sea surface displacement (an assumption is made that 1 psi <=> 0.670 m) (Meinig 2005). These water level series are downloaded from the NOAA operated public website or using NDBC's Data Management Console, and a preliminary analysis on 3-months is conducted, followed by a final analysis after one-year of data are accumulated. Analysts use a standard harmonic analysis program in order to compute harmonic constants and generate predicted data sets for de-tiding and plotting as quality control of the observations and to check for discontinuities, datum shifts, and invalid data. Harmonic constituents are evaluated for applicability using the reduction of variance output statistics from the harmonic analysis program. This is done by creating a matrix of correlation coefficients between each individual constituent time series and the observed time series (Zervas 1999). We eliminate tidal constituents that are not completely and accurately resolved or necessarily stable because they are considered noise and would add noise back into the prediction in the future if used (Figure 1.).

Many of the higher frequency compound tides and overtides in the set of constituents are "shallow water" tides that become significant only when the tide reaches into bays, harbors, and rivers affected by shallow water and frictional effects and distort the tide wave. For DART® buoy locations, they show up with very low amplitudes (only a few millimeters), with unstable phases over time, and show virtually no contribution to the reduction of variance. They would only add noise to the analyses if left in. These low amplitude constituents vary slightly by location and analyses time period. Compared to coastal stations, relatively few constituents can be used to predict the "clean" open ocean tide signal.

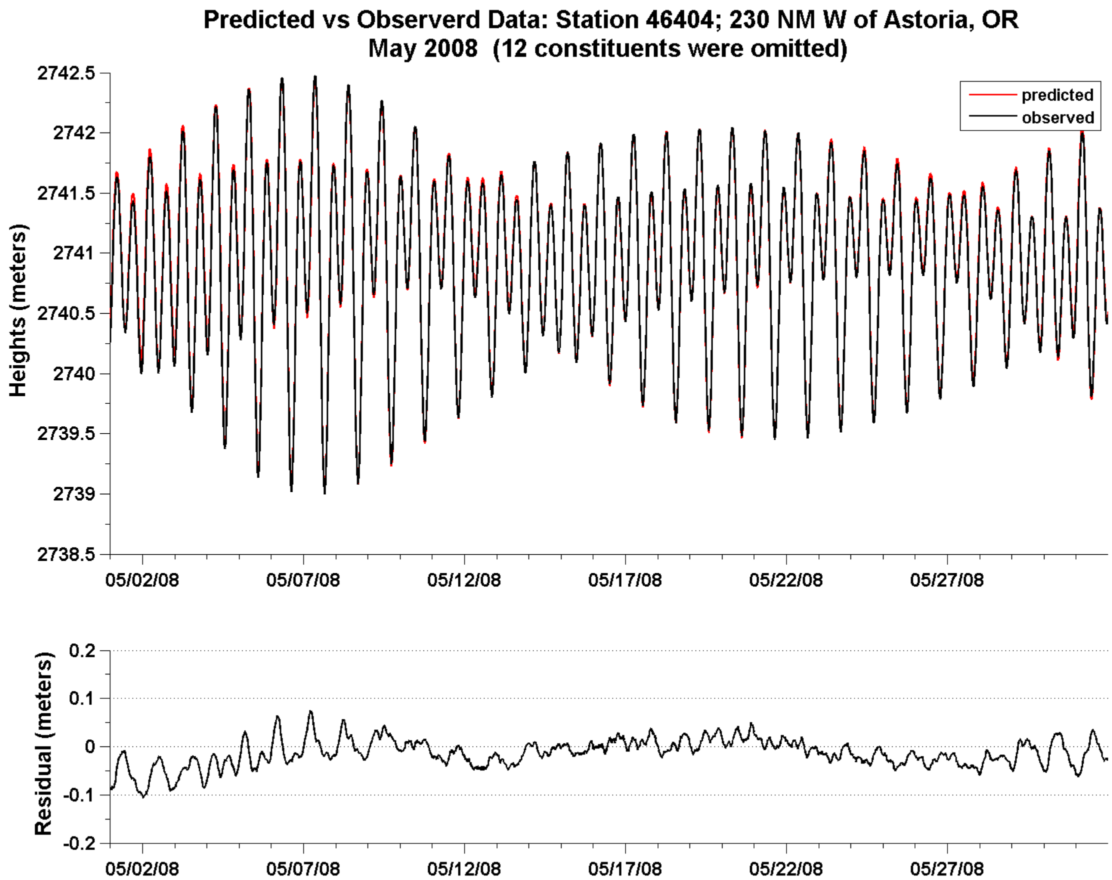

Figure 1. Observed, predicted and de-tided water level series in meters from DART® station 46404 (230 nm West of Astoria, OR)

Almost all of the analyses omitted the long period (semi-monthly to yearly periods) constituents Sa, Ssa, Mf, Msf, and MM, because they cannot be accurately determined with less than one-year of data. The observational deployment time series were all less than one-year in length. Values for these constituents will be determined as longer data sets are analyzed. For coastal stations, these long-term tidal constituents are reflective of local variations in wind stress and barometric pressure as weather frontal passages come thru and are not reflective of theoretical tidal forcing. There also may be changes at these frequencies due to oceanic sea surface topography changes caused by temperature and salinity variations and ocean circulation changes.

For the Sa and Ssa constituents which have periods of one year and one-half year, they can only be resolved after looking at a couple of years of continuous data, even though they might show up as a significant contributor to the reduction of variance and have significant amplitudes for any given analysis. In a self-prediction mode in which the constituents are used to predict the same time period that the analysis is run for, their use would minimize the residual. However, because they are not necessarily stable from year to year, they would add unwanted biases for future predictions. Similarly for the monthly and semimonthly constituents for Mf, Msf, and MM; they are typically unstable (have varying amplitudes and phases from one time period to the next), even though they also may have significant amplitudes and contribution to the reduction of variance. So even though using them in a self-prediction mode would reduce the residual, they cannot be counted on to provide better predictions in the future. Using longer period constituents for operational forecasts is not recommended until they can be resolved using longer time periods of observations. This should be possible soon, as we are starting to accrue some long period records now for analysis at many stations.

Applications

In recent years, post-event tsunameter data were directly used in many applications, including identification of drift and trend problems in the DART® systems (Figure 2.), global tide and inundation modeling, tidal corrections to hydrographic data, comparisons of bottom pressure tides with altimeter tides, and in research towards the development of additional operational products.

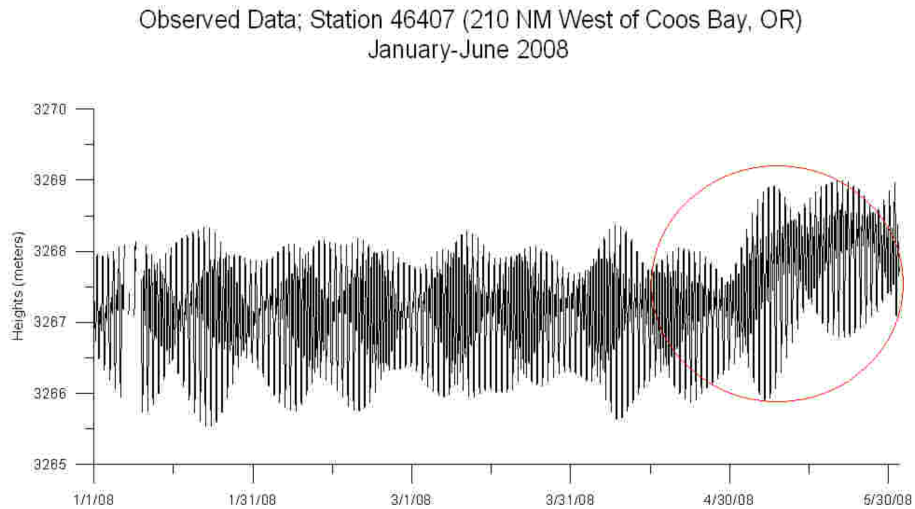

Figure 2.   A drift discovered at DART® station 46407 (210 nm West of Coos Bay, OR) while quality controlling the analysis results.

For planning purposes and software development, PMEL also generated harmonic constants for all the stations in the full, expanded DART® Network using the state-of-the-art global tide model TXPO 6.2 developed at Oregon State University. The modeled harmonic constants from this model have compared well with ones from least squares harmonic analysis of the observed series. There is also some work in progress to assess the accuracies of new state-of-the-art global tide models. One aspect of this would be to improve previous comparisons with in-situ data. The DART® stations would be a very useful addition in this regard, because previous comparison studies (e.g., Shum 1997) used some bottom-pressure data based on rather short time series.

Conclusions

Standard NOAA harmonic analysis programs have been successfully applied to produce a residual de-tided time series for each DART deployment. The residuals are used to detect drifts, datum shifts, and other periods of invalid observations. The residuals also provide higher resolution of the actual tsunami waves as they pass over the tsunameters. Secondarily, the harmonic analyses provide valuable observational information on deepwater harmonic constants than can be used to evaluate global tide models and used as offshore forcing functions to coastal shelf models. It is intended that a more detailed study of model validation and comparison with satellite altimetry data discussed in this paper will be presented in subsequent publications.

Eventually the NOAA National Geophysical Data Center will be archiving all tidal harmonic constants along with metadata and thus they will be available for download for retrospective analyses of bottom pressure recorder data.

Acknowledgements

We wish to thank NDBC's Richard Bouchard, Bill Burnett and Ray Locatto for assistance with Data Management Console and providing DART® data; Marie Eble, and Mick Spillane (PMEL) for their assistance with the model results and tsunami forecast system overview; Kelly Stroker (NGDC) for helpful discussions; Thomas Huppmann (CO-OPS) for the creation of the analysis program and Chris Zervas (CO-OPS) for his enhancements to and assistance with the harmonic analysis and prediction programs; Peter Stone, Allison Allen and other office reviewers for their constructive comments and suggestions.

References

Emery, W.J., Thompson, R.E., 2001. *Data Analysis Methods in Physical Oceanography*. Elsevier, Amsterdam

Foreman, M.G.G., Crawford, W.R. and Maesden, R.F., 1995. De-Tiding: Theory and Practice. Lynch, D.R., Davies, A.M. (Eds.), *Quantitative Skill Assessment for Coastal Ocean Models*. Coastal and Estuarine Studies, 47. American Geophysical Union, Washington DC, pp. 203-239

Meinig, C., S.E. Stalin, A.I. Nakamura, H.B. Milburn (2005), *Real-Time Deep-Ocean Tsunami Measuring, Monitoring, and Reporting System: The NOAA DART II Description and Disclosure.* [Available online at http://www.ndbc.noaa.gov/dart.shtml.]

Parker, B. B., 2007. *Tidal analysis and prediction*. NOAA Special Publication NOS CO-OPS 3, U.S. Department of Commerce, 378 pp. [Available online at http://tidesandcurrents.noaa.gov.]

Shum, C. K., and Coauthors, 1997. Accuracy assessment of recent ocean tide models. *J. Geophys. Res.,* 102**,** 25 173–25 194

Tolkova, E., 2009. Principal component analysis of tsunami buoy record: Tide Prediction and removal. *Dynamics of Atmospheres and Oceans* 46 (2009), 62-82

Zervas, C., 1999. Tidal current analysis procedures and associated computer programs. *NOAA Technical Report NOS CO-OPS 021*, U.S. Department of Commerce. [Available online at http://tidesandcurrents.noaa.gov.]