

# Assimilating DART Data into an Upgrade of VDatum for the US West Coast

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**Abstract**—The U.S. national VDatum program has an ongoing project to upgrade VDatum for the entire U.S. West Coast. In this study, we have tested a conceptually simple tides assimilation scheme based on linearized shallow water equations that will be used by the upgrade. It assimilates the data recorded by deep ocean bottom pressure recorders to optimize/improve the offshore boundary conditions for the ADCIRC tide model. The tests were done on a global scale as well as on a high resolution San Francisco Bay model. Good model accuracy were achieved for both test cases. The improvement in model accuracy can help to reduce the uncertainty in the tidal datum products for VDatum.

**Keywords**—VDatum, tides, data assimilation, linear shallow water equations

## I. INTRODUCTION

The U.S. national VDatum program has been providing datum products and software to vertically transform geospatial data between a variety of vertical datums, including tidal, orthometric, and ellipsoidal vertical datums. The tidal datums are the important references for broad coastal applications. The applications include but are not limited to flood forecasting, inundation modeling and mapping for tsunamis and storm surges, water control, flood incurrence rate map, navigation charting, topographic mapping, etc. To improve model accuracy and thus to further reduce the uncertainty in the VDatum products, the ongoing U.S. West Coast VDatum update project will employ a conceptually simple tides assimilation scheme based on linearized shallow water equations to optimize/improve offshore tidal boundary conditions for the ADCIRC tidal model.

Here we have developed a triangular, finite element global tide model to test the data assimilation scheme on a global scale as the first step. Deep-ocean Assessment and Reporting of Tsunamis/Bottom Pressure Recorder (DART/BPR) data are

essential for this application, since they not only provide observed offshore tidal harmonic constituents for data assimilation but also well represent the linearity of long wave dynamics in deep ocean (Fig. 1a). Data from the open coast tide stations along the US West Coast are used as an independent dataset for validation (Fig. 1b). In addition, we also tested the data assimilation scheme on a high resolution San Francisco SCHISM model grid.

## II. METHOD

The data assimilation scheme we used here is similar to [1]. We denote the dynamic and observations systems for tidal water level and velocity field  $u$  as Eqs. (1) and (2), respectively:

$$Su=f_o \quad (1)$$

$$d=Lu \quad (2)$$

Where  $S$  is the shallow water equation operator.  $f_o$  is forcing term.  $d$  is the observed state variable fields.  $L$  is the projection operator projecting the state variables into the observation location. The combination of Eqs. (1) and (2) is an over-deterministic system of equations.

To solve the problem, the cost function  $J(u)$  to compromise Eqs. (1) and (2) is defined as

$$J(u) = (Lu-d)^T R^{-1} (Lu-d) + (Su-f_o)^T B^{-1} (Su-f_o) \quad (3)$$

where  $R$  and  $B$  are the observation and model error covariance matrixes, respectively.

In deep ocean we assume the dynamic equation (1) is linear. Then the representor approach [1] can be used to minimize the cost function  $J(u)$ . The system are solved using finite element method.

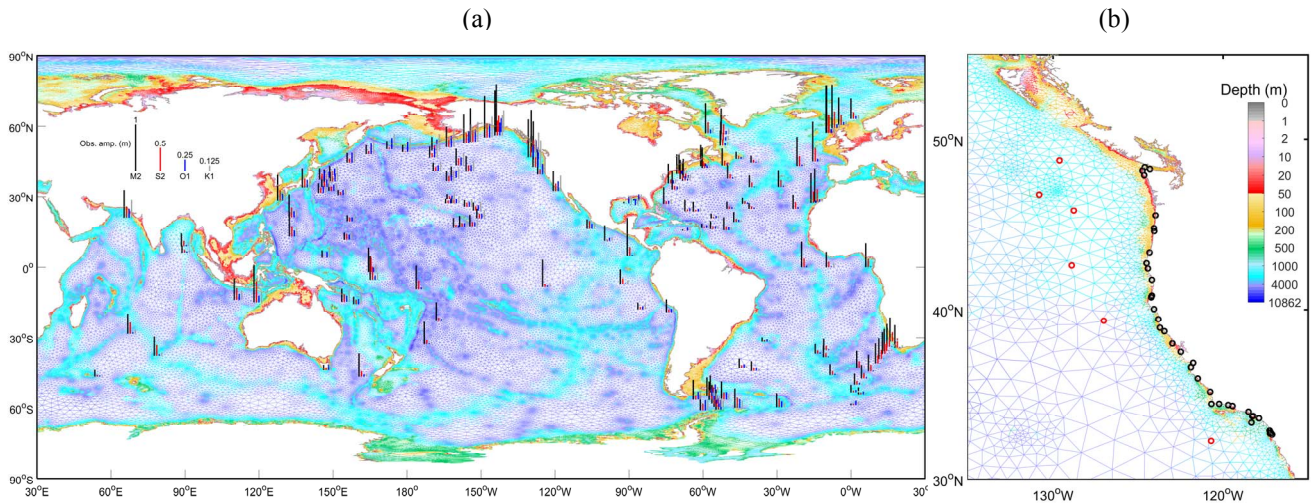


Fig. 1. (a) Global tide model grid and locations of 151 Bottom Pressure Recorder (BPR) stations. Height of the bars indicate the M2, S2, O1, and K1 amplitudes at the stations. BPR data are provide by [2]. (b) o, 38 tide open coast tide stations along US West Coast. +, six DART stations offshore.

The precise distanced-based OceanMesh2D toolbox [3,4] was used to develop the finite element triangular global grid (Fig. 1a). It takes into consideration of variety of geometric and bathymetric mesh size functions driven by features such as wavelength, distance, slopes, feature size, shoreline curvature etc. The latest version of the toolbox is capable using stereographic projection centered on the north pole to mesh the globe. In deep ocean, the grid resolution is primarily controlled by the wavelength/depth (30 nodes per M2 wavelength) to achieve efficiency. For the global coastal areas, the minimum

resolution is set to 2.5 km. Higher min resolution of 300m was applied to the continental U.S., Puerto Rico, the U.S. Virgin Islands, Alaska, Hawaii, and Guam. The total number of nodes in the global model grid is 883,514.

The shoreline boundaries were provided by the 2017 GSHHG database [5]. The bathymetry data were taken from two DEMs, SRTM 15-sec DEM [6] ( for the majority of the grid) and ETOPO1 (for depth around Antarctic only). The 151 deep ocean BPR stations data were used for data assimilation. In addition, we have chosen 38 CO-OPS tide stations at open coast

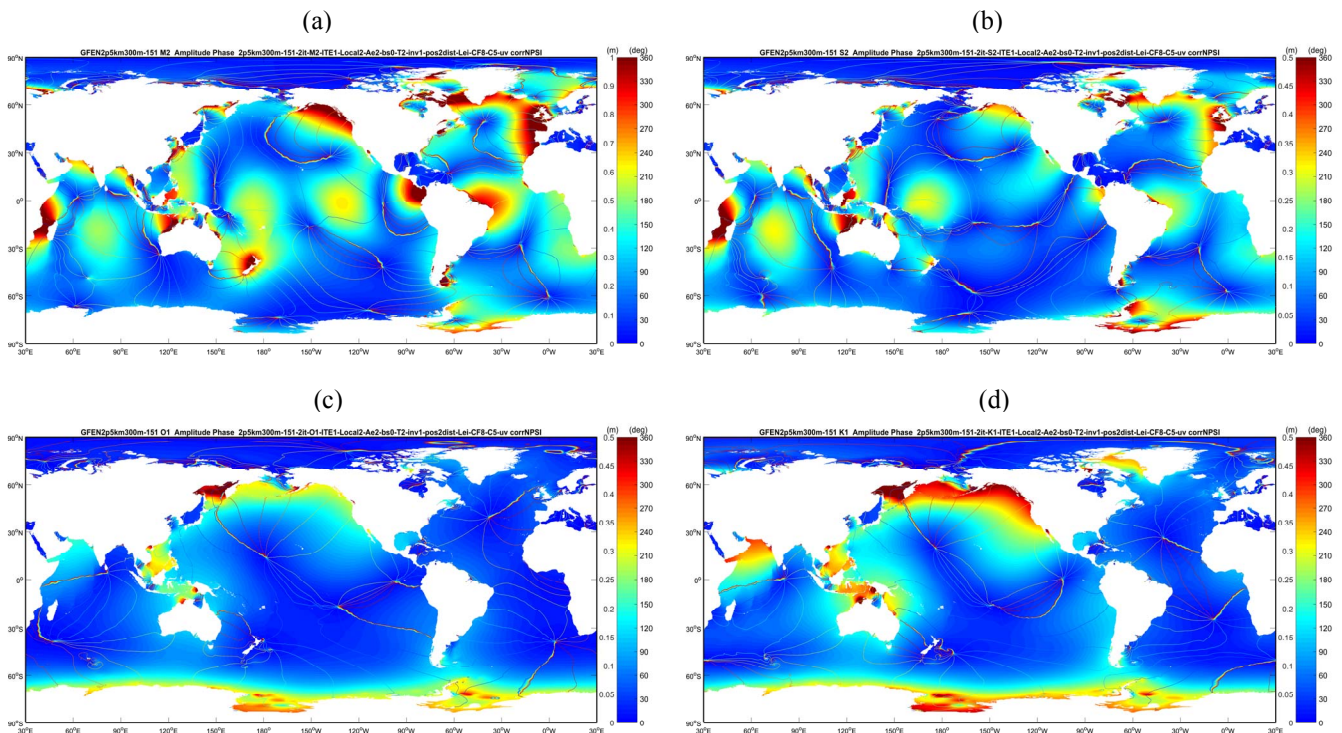


Fig. 2. Global models of amplitude and phase for for principal tidal constituents. (a) M2, (b) S2, (c) O1, and (d) K1.

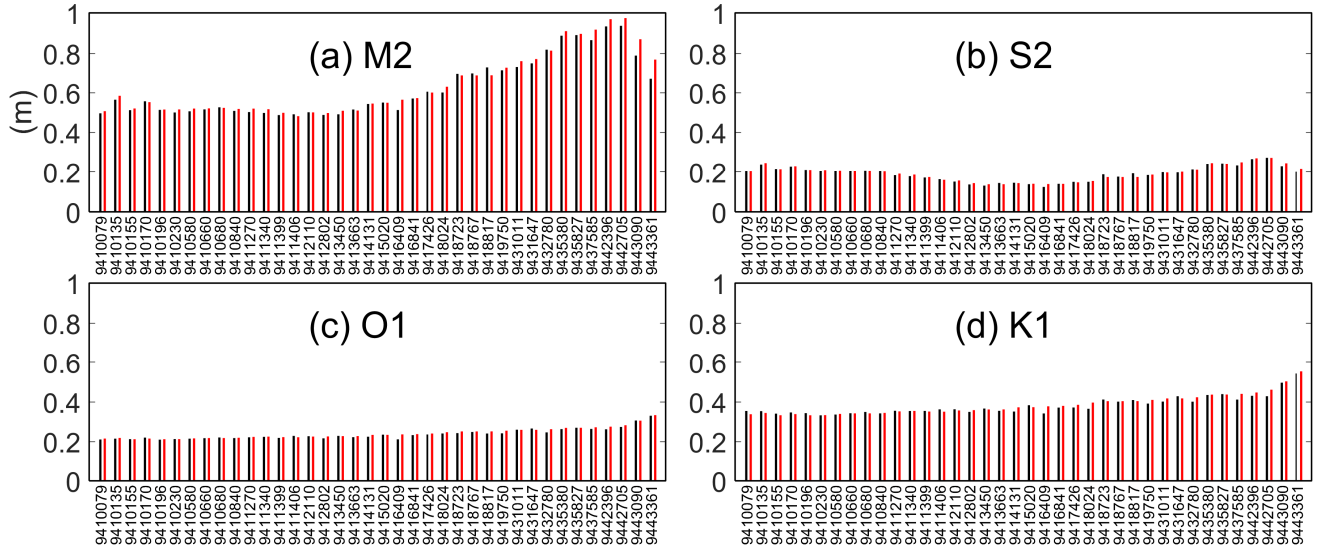


Fig. 3. Observed (black) and modeled (red) amplitudes at 38 open coast tide stations along US West Coast.

along US West Coast for validation even though data are available for 147 tide stations. The reason is that the current version of the global grid is unable to resolve the narrow entrances to the bays/ivers stations or breakwaters well.

To resolve the above issue, we conducted the second test on a high resolution San Francisco Bay SCHISM grid ([http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/bay\\_delta\\_schism/](http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/bay_delta_schism/)). The original SCHISM grid has 164,016 nodes with the finest resolution of 4 meter covering the small streams in the Bay delta area. We embedded it with a preliminary West Coast base grid to extend the coverage to deep ocean, to utilize the data from the six DART stations offshore. The node number was then increased to 222,404 for the merged grid. For this test, data from the 6 DART stations were used for assimilation while 36 tide stations with data in the San Francisco Bay were used for validation.

### III. RESULTS AND DISCUSSION

The data assimilation scheme described in previous section was applied to the 151 BPR data for the global scale test. Four principal tidal constituents (M2, S2, O1, and K1) were modeled. Computational time for each is about 45 min on a PC using Matlab. Fig. 2 a-d show the global solutions for amplitude and

phase for the four tidal constituents. Model results at 38 open-coast tide stations at the US West Coast were plotted along with the observations as in Fig. 3. Table 1 summarizes the model error in the amplitudes for both datasets.

The averaged model error at the 38 open coast tide stations are quite small, ranging from 0.5 – 1.9 cm (2.3% to 2.9%) (Table 1). The two tide stations from the right for M2 in Fig. 3a have the largest model error. These two stations are near the entrance of Strait of Juan De Fuca. Preliminary test shows that by using

TABLE I. ERROR IN AMPLITUDE FOR THE GLOBAL TEST

Tidal Constituents	Average error from the global tide model		
	Station	Error in (cm)	Error in (%)
M2	151 BPRs	0.6	2.5
	38 Tide Stations	1.9	2.9
S2	151 BPRs	0.3	3.9
	38 Tide Stations	0.5	2.9
O1	151 BPRs	0.2	2.4
	38 Tide Stations	0.5	2.3
K1	151 BPRs	0.3	2.8
	38 Tide Stations	1.1	2.9

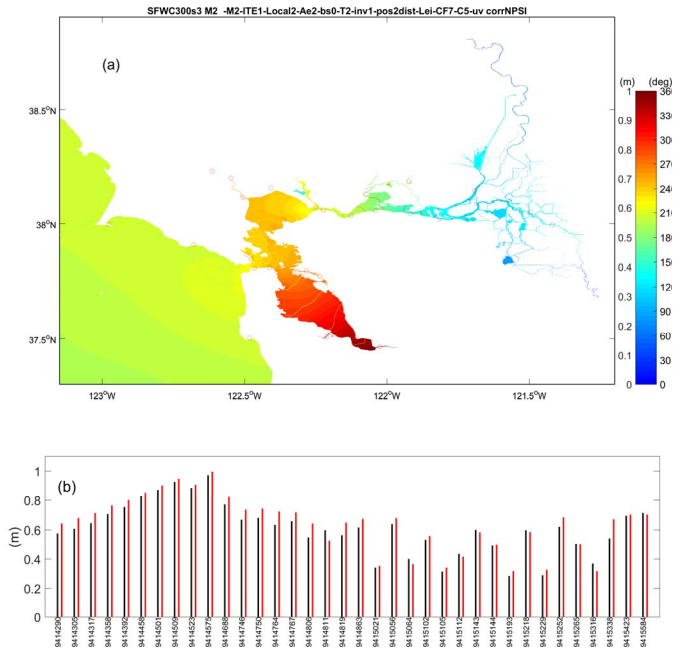


Fig. 4. (a) Modeled M2 amplitude and phase in San Francisco grid. (b) Observed (black) and modeled (red) M2 amplitudes at 36 tide stations (red circles) in the Bay.

NOS bathymetry survey data in the area and Puget Sound, the model error can be reduced at the two stations.

For the San Francisco test case, the average error of the M2 amplitude for the 36 tide stations is 4.4 cm or 7.8%. The largest error is 12.8 cm at station 9415338. This tide station is a river station which is not covered by current grid. The final West Coast tide model grid will be extended to cover all CO-OPS tide stations.

The average model error for M2 at the San Francisco Bay stations is more than double the average error at the open coast tide stations. The tests also show Bay stations are more sensitive to the friction coefficient than the open coast stations. The reason is the US West Coast has a steep offshore slope to deep ocean. Therefore, it has much less continental effect on the open coast stations.

#### IV. CONCLUSION AND FUTURE WORK

We have presented and applied the data assimilation scheme to assimilate deep ocean BPR data for global ocean tides as well as tides in San Francisco Bay. The good model-data comparisons at 38 open coast tide stations and 36 Bay stations validate the approach. This scheme will then be applied to an upgrade of US West Coast VDatum.

We are in the process of compiling high resolution CUSP shoreline data and collecting the latest NOS bathymetry survey data for US West Coast. These data will be used to develop a high resolution regional VDatum tide model, which can well resolve major bays, rivers, intra-coastal waterways, breakwaters, etc. This regional model will be used to further improve the current version of global tide model

#### ACKNOWLEDGMENT

We thank William J. Pringle and Keith J. Roberts at University of Notre Dame for their support and discussion on generating the global model grid; Richard Ray for providing the BPR data; Y. Joseph Zhang and Eli Ateljevich for providing San Francisco SCHISM grid; Hurt Hess and Alexander Kurapov at CSDL for discussion, CSDL's IT group for their assistance. L. Tang thanks Chang Zhao and Karen Ferebee at ERT, Julia Powell and Neeraj Saraf at CSDL for their administrative support; and Pacific Hydrographic Branch and Olivia Hauser for providing office accommodation and support to the project.

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