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Dredging Research Technical Notes

Tidal Constituent Database — West Coast of the United States and Eastern North Pacific Ocean

Purpose

This technical note describes a database of tidal elevation boundary condition information generated in support of the "Long-Term Fate of Dredged Material Disposed in Open Water" research of the Dredging Research Program (DRP), being conducted at the U.S. Army Engineer Waterways Experiment Station. The database, described in detail by Hench and others (1994), allows the user to manually generate time series of tidal elevations or to use a program to access the full database to generate time series of both tidal elevations and currents for any location along the west coast of the United States and eastern north Pacific Ocean, extending from Seal Cape on Unimak Island, Alaska, in the north to Punta Parada, Peru, in the south. The land boundary includes the Pacific shorelines of Alaska, Canada, mainland United States, Mexico, Guatemala, El Salvador, Nicaragua, Costa Rica, Panama, Columbia, and northern Peru. Although the capability to generate these time series was developed to provide input to the Long-Term Fate and Stability Model (LTFATE), the generated time series can be used for any application requiring tidal forcing data.

Background

The Long-Term Fate work unit has been concerned with developing techniques to predict the long-term fate of dredged material after it has been deposited in open water on the ocean floor, that is, to address the question of whether a dredged material disposal site, either existing or proposed, is dispersive or nondispersive (Scheffner 1992). If the site is dispersive, an additional capability of the model is to estimate the rate of erosion and fate of the material. Because sediment is eroded and transported primarily as a function of waves and currents, the approach taken was to construct databases of site-specific information that can be used as input to coupled hydrodynamic, sediment transport, and bathymetry change models for predicting the long-term behavior of disposal sites. In the DRP, attention was focused on developing the wave, tidal, and storm surge components.

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The wave component of the database provides a capability of generating time series of wave height, period, and direction for any location at which a Wave Information Study (Jensen, Hubertz, and Payne 1989) hindcast is available. The wave simulation capability is described in Borgman and Scheffner (1991) and in *Dredging Research Technical Notes* 1-12 (Scheffner 1994a). A database of storm surge elevations and currents corresponding to 134 historically based tropical storm events along the coastline of the eastern United States and Gulf of Mexico is reported by Scheffner and others (1994) and described in *Dredging Research Technical Notes* 1-17 (Scheffner 1994c). The companion database of extratropical storm surge elevation and current hydrographs is currently under development. The database of tidal constituents for the east coast, Gulf of Mexico, and Caribbean Sea is reported by Westerink, Luettich, and Scheffner (1992) and described in *Dredging Research Technical Notes* 1-13 (Scheffner 1994b). This technical note describes the tidal database for the U.S. west coast and the eastern north Pacific Ocean (Hench and others 1994).

Additional Information

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The Tidal Database

The west coast and eastern north Pacific Ocean tidal contribution to the overall DRP family of databases has been completed. The area of coverage extends from Seal Cape on Unimak Island, Alaska, in the north to Punta Parada, Peru, in the south. The database is both co-tidal chart-based for manual simulation of time series and personal computer (PC)-based. Both versions are briefly described in this technical note.

The tidal database consists of precomputed amplitudes and Greenwich epochs corresponding to five primary diurnal and semidiurnal astronomical constituents (K_1, O_1, M_2, S_2, and N_2). The constituents were based on a 62-day simulated tidal time series computed by the long-wave hydrodynamic finite element model ADCIRC (Luettich, Westerink, and Scheffner 1992). To ensure that the simulated time series used in the harmonic analysis were free from startup transients, the harmonic constituents were computed from the data for days 30-62.

Tidal constituents were computed by a harmonic analysis of model output elevation and current time series at each node of the 27,494-node computational grid shown in Figure 1. The open boundary was forced with a surface elevation time series reconstructed from the five astronomical constituents cited above. Boundary condition amplitude and epoch data for these constituents were obtained by interpolating results from a finite element global ocean model (Le Provost and others, in press).

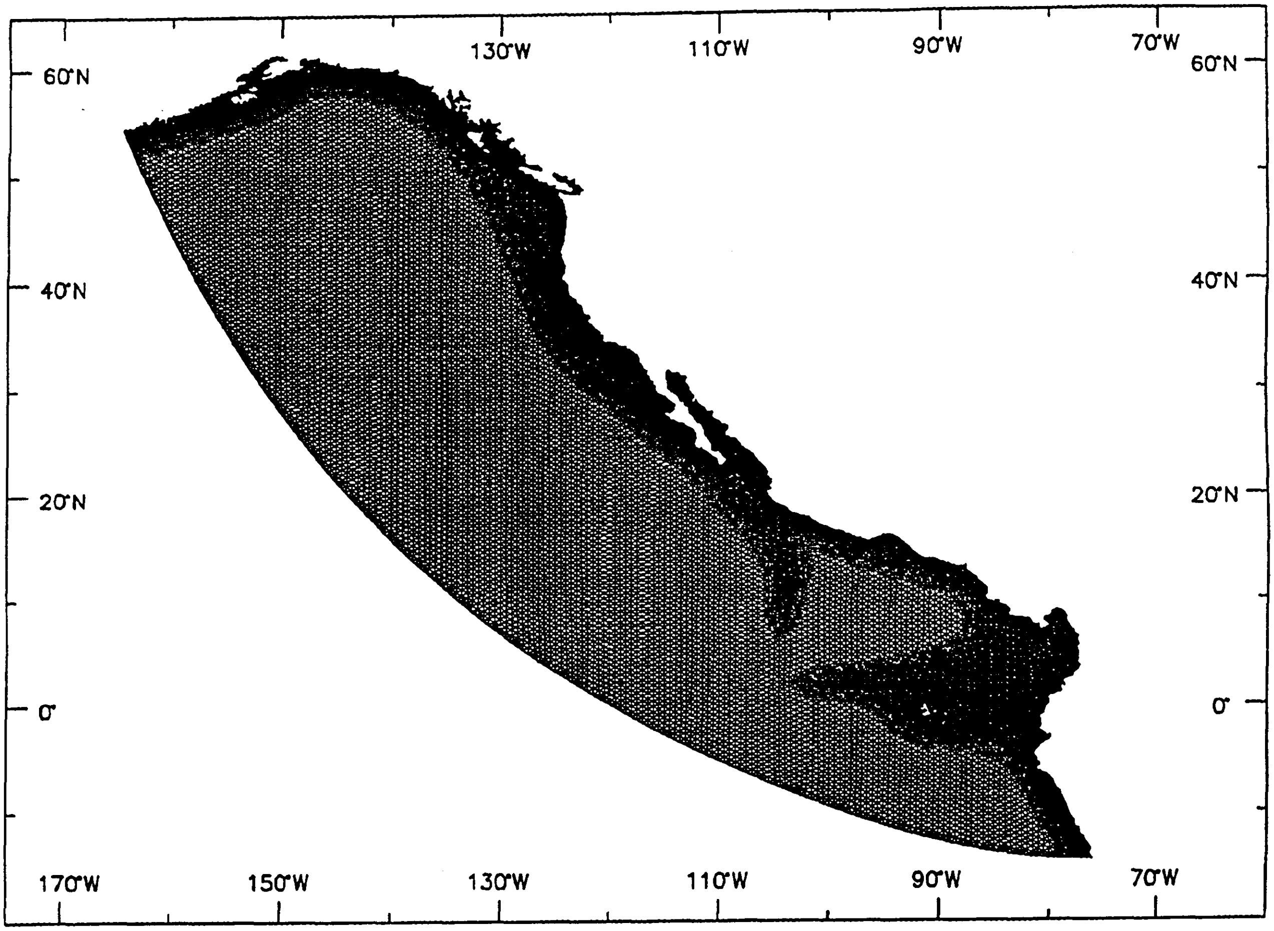

Figure 1. Eastern North Pacific computational domain

Use of the DRP tidal database allows the user to generate time series of tidal elevations and currents at any location within the computational domain for any time period—past, present, or future. Although the intent of the simulation capability is to provide time series input to LTFATE, the generated data can be used for any application requiring tidal forcing (that is, tidal circulation studies).

The following section provides a brief background of the harmonic reconstruction of tides. This section is followed by an example application of the procedure with the DRP-generated database to either manually compute equilibrium tidal elevation time series or use a computer-based program to generate simulated forecast or hindcast time series of surface elevations and currents.

Harmonic Reconstruction of Tides

The tidal elevation and current time series at any location can be written as a function of known harmonic constituents according to the following general relationship:

$$h = H_0 + \sum_{n=1}^{N} f_n H_n \cos [a_n t + (V_0 + u)_n - \kappa_n] \quad (1)$$

where

h = height of the tide at any time t

H_0 = mean water level above some defined datum such as mean sea level

N = total number of tidal constituents in the series reconstruction

f_n = node factor for reducing mean amplitude

H_n = mean amplitude of tidal constituent n

a_n = speed of constituent n, degrees/unit time

t = time measured from some initial epoch

$(V_0 + u)$ = value of the equilibrium argument for constituent n at some location when $t = 0$

κ_n = local epoch of constituent n

In the above formula, the tide is represented as the sum of a coefficient multiplied by the cosine of its respective arguments. A finite number of constituents are used in the reconstruction of a tidal signal. The values for the arguments are generally computed through least squares analysis of prototype data (Dronkers 1964). The National Oceanic and Atmospheric Administration's National Ocean Survey generally uses 37 constituents in its published harmonic analyses. These results are usually based on an analysis of a minimum of 1 year of prototype data. A listing of 16 tidal constituent amplitudes and modified local epochs (g) obtained from the Canadian Hydrographic Service (International Hydrographic Organization 1990) for a tide station located at Cape Whitshed, Orca Inlet, Alaska, is shown in Table 1. A thorough description of each constituent is provided in Dronkers (1964) and Schureman (1958).

The astronomical constituents in Table 1 are associated with a subscript that indicates the approximate number of cycles per solar day (24 hr). The constituents with subscripts of 2 are classified as semidiurnal constituents and produce a tidal contribution that occurs approximately twice a day. Diurnal constituents occur approximately once a day and have a subscript of 1.

Table 1. IHO Tidal Constituents for Cape Whitshed, Alaska					
Symbol	Amplitude H, m	Epoch g, deg	Symbol	Amplitude H, m	Epoch g, deg
K_1	0.461	125.5	K_2	0.129	35.0
O_1	0.323	124.5	ν_2	0.048	353.7
P_1	0.153	126.3	μ_2	0.032	345.2
Q_1	0.062	123.9	L_2	0.036	29.5
M_1	0.028	125.0	T_2	0.028	36.2
M_2	1.348	10.0	$2N_2$	0.033	331.9
S_2	0.475	35.8	M_4	0.111	235.0
N_2	0.245	351.4	M_6	0.044	17.0

The majority of constituents shown above can be seen to be negligible with respect to the major contributing constituents. For example, in the analysis shown in Table 1, 97.4 percent of the tidal energy is represented by the K_1, O_1, M_2, S_2, and N_2 constituents used to develop this database. For this reason, the above five constituents were used to define the tidal contribution for the eastern north Pacific Ocean computational domain.

Two categories of tidal constituents are computed: those that represent the elevation of the water surface and those that specify time. For example, the value for the H_n in Equation 1 is the constituent amplitude and is a function of both location and variations arising from changes in the latitude of the moon's node. The moon's nodal effect is reflected by the introduction of the node factor f_n, which modifies each constituent amplitude to correspond to a specific time period. Midyear values are usually specified for a given time series reconstruction because node factors vary slowly in time. Midyear values for each constituent of Table 1 are published for the years 1850 to 1999 (Schureman 1958).

The second category of arguments specify the timing of the individual constituent high-water mark with respect to both local time and global time. These arguments are based on the fact that phases of the constituents of the observed tide do not coincide with the phases of the corresponding constituents of the equilibrium tide. For example, a high tide does not occur directly beneath the moon; there is a lag between the high-water phase of the argument (that is, location of the moon) and the observed time of high water. This lag is referred to as the epoch of the constituent and is denoted by κ in Equation 1.

The relationships between the constituent argument and the corresponding high tide are shown in the schematic diagram of Figure 2 (Schureman 1958). In this figure, time is increasing to the right, and κ represents the phase lag or time required for the water surface to reach high water following the

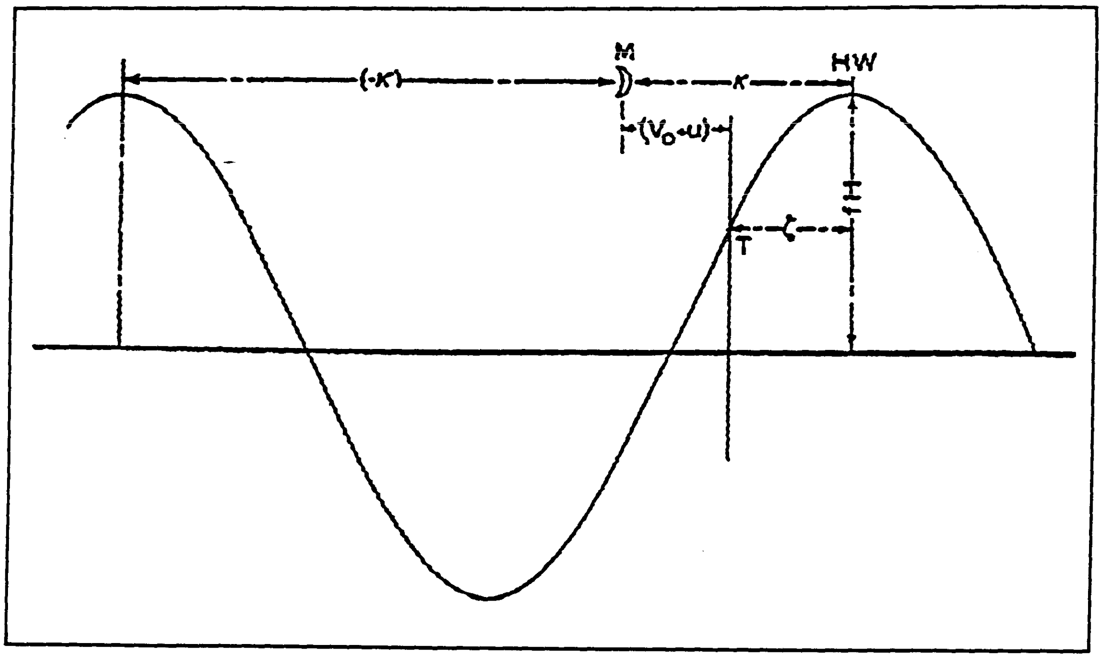

Figure 2. Tidal phase relationships (Schureman 1958)

crossing of the moon. Because the water does not respond exactly according to theory, the value of κ is computed as the sum of the theoretical argument $(V_0 + u)$ and the actual observed phase angle ζ at some time T.

Because constituents can be considered harmonic (can be expressed as a cosine function whose argument increases linearly with time), the value of κ is relatively constant at every location. That is, the value of κ represents the actual lag between the tidal potential and the following high tide as a function of observational data adjusted to reflect time to equilibrium theory. The value of κ can therefore be computed from the value of ζ derived from prototype data measured at any time and the corresponding adjustment according to $(V_0 + u)$ for that location at that time. Values of the equilibrium argument for the constituents of Table 1 relative to the passing of the tidal potential at the Greenwich meridian are published for each calendar year from 1850 through 2000 (Schureman 1958).

Phases of a given tidal constituent in different parts of the world are not directly comparable with respect to the local epoch κ because κ is a function of the longitude of the specific location. However, an adjusted epoch can be computed which is independent of both longitude and the time meridian. This epoch has been designated as the Greenwich epoch G and is related to the local epoch κ of Equation 1 according to the following:

$$Greenwich\ epoch\ (G) = \kappa + p\,L \qquad (2)$$

where

p = coefficient indicating the number of cycles per day (1 for diurnal; 2 for semidiurnal)

L = longitude of the station

The epochs of the DRP database are Greenwich epochs because the time series generated by the ADCIRC model are computed with boundary conditions referenced to the Greenwich epoch.

Certain harmonic analyses, such as the analysis shown in Table 1, are referenced to the modified local epoch g. The relationship between the modified epoch g and the Greenwich epoch G in the database is shown below.

$$Greenwich\ epoch\ (G) = g + \frac{a\,S}{15} \quad (3)$$

where S is the longitude of the time meridian, positive for west and negative for east (Schureman 1958).

The following section demonstrates use of the DRP database to manually generate an equilibrium surface elevation time series of data at any location of the computational domain shown in Figure 1. This application provides the user a rapid capability of estimating tidal elevation data at any location without use of computer support.

Tidal Surface Elevation Time Series—Manual Reconstruction

One application of the database is to provide a means of specifying a realistic tidal elevation at some specific location but not to provide a tide prediction that is accurate in both magnitude and time of high and low tide. Because the precise time of arrival of the tide is not important in a long-term disposal site stability application, only the Greenwich epochs are used. Therefore, the following example demonstrates the generation of an equilibrium tide in which the nodal factor f is 1.0, the equilibrium argument $(V_0 + u)$ is 0.0, and the local epoch κ is replaced by the Greenwich epoch G. However, if a tidal hindcast or prediction is desired and computer resources are not available, guidelines for computing the node factor and equilibrium arguments are given in Schureman (1958), and the values of κ can be computed from the values of G according to Equation 2. If computer resources are available, guidelines for generating time series of tidal elevations and currents are provided in the next section.

To reconstruct the tide for any location, the values of the amplitudes and Greenwich epochs for a particular location have to be extracted from the database. For the manual reconstruction approach, detailed co-tidal charts are provided in Hench and others (1994). An example of the M_2 charts for the eastern north Pacific are shown in Figure 3 for amplitude and Figure 4 for Greenwich epoch. The two steps described below are performed to generate, or resynthesize, a tidal signal.

Step 1

Interpolate amplitudes and phases for the five astronomical constituents from the co-tidal charts. For the Cape Whitshed example (located at 145°55′ W and 60°28′ N), the amplitudes and Greenwich epochs shown in Table 2 were extracted from Hench and others (1994). The constituent speeds shown in the table are readily available from sources such as Schureman (1958) or Dronkers (1964).

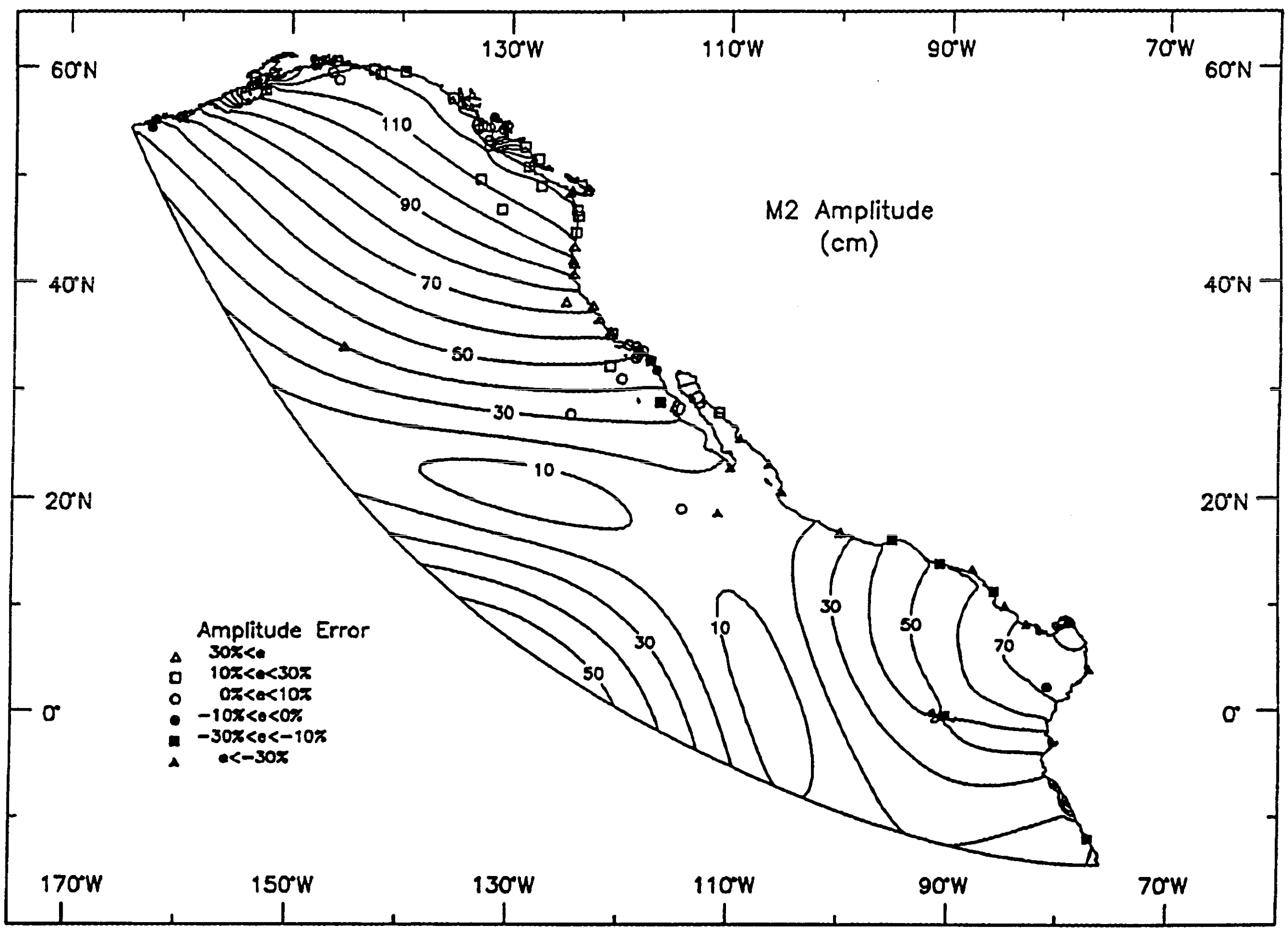

Figure 3. Computed contours for the M_2 amplitude (meters)

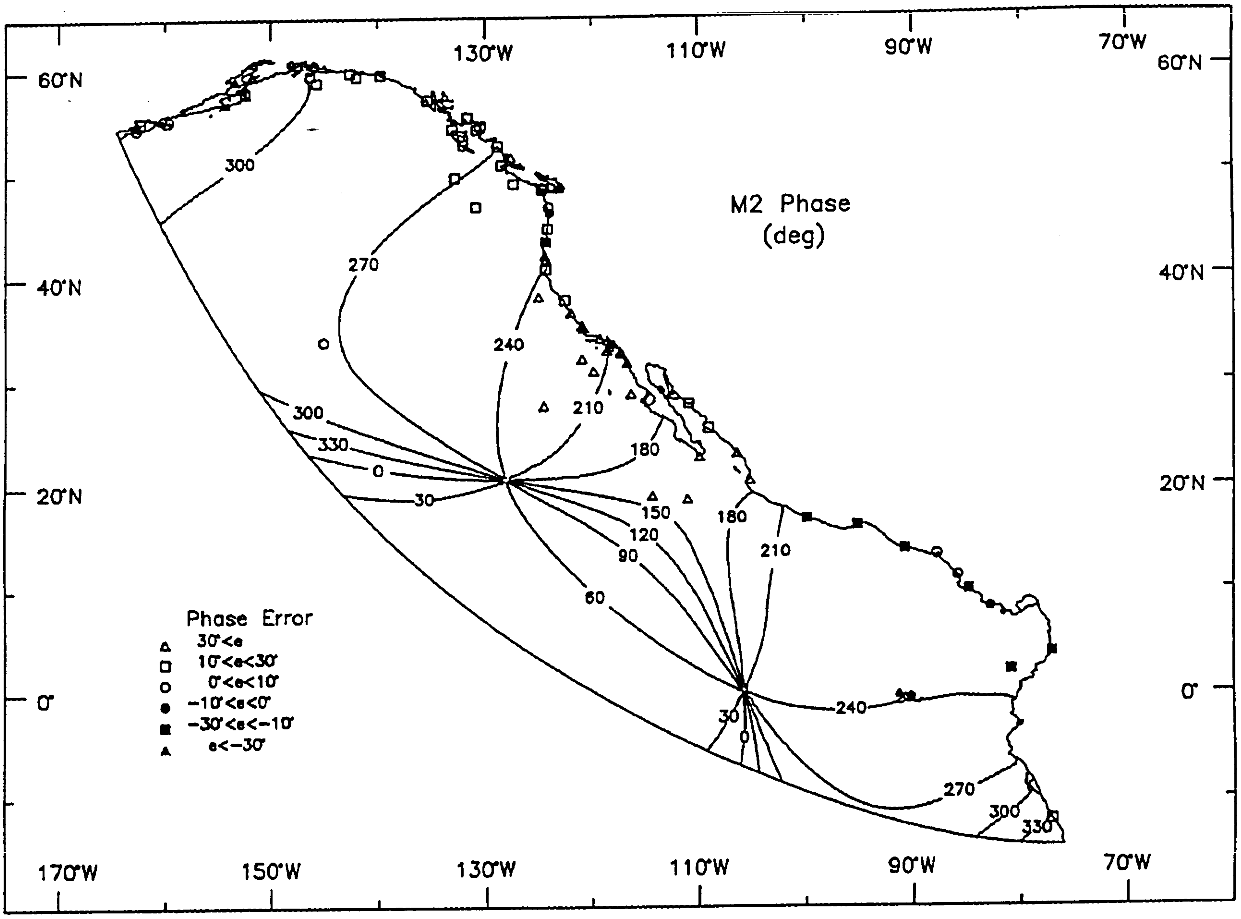

Figure 4. Computed contours for the M2 Greenwich epoch G (degrees)

Table 2. Harmonic Arguments for Cape Whitshed, Alaska

Constituent	Amplitude H, m	Epoch G, deg	Modified Epoch g	Speed ω, deg/hr
K_1	0.504	273	123	15.0410686
O_1	0.323	256	117	13.9430356
M_2	1.360	307	7	29.9841042
S_2	0.619	352	52	30.0000000
N_2	0.14	354	70	28.4397296

Step 2

Compute the tide signal according to Equation 1. Note that the speeds in Table 2 must be converted to radians. The resynthesized tidal elevation signal for the data between days 30 and 40 is shown in Figure 5.

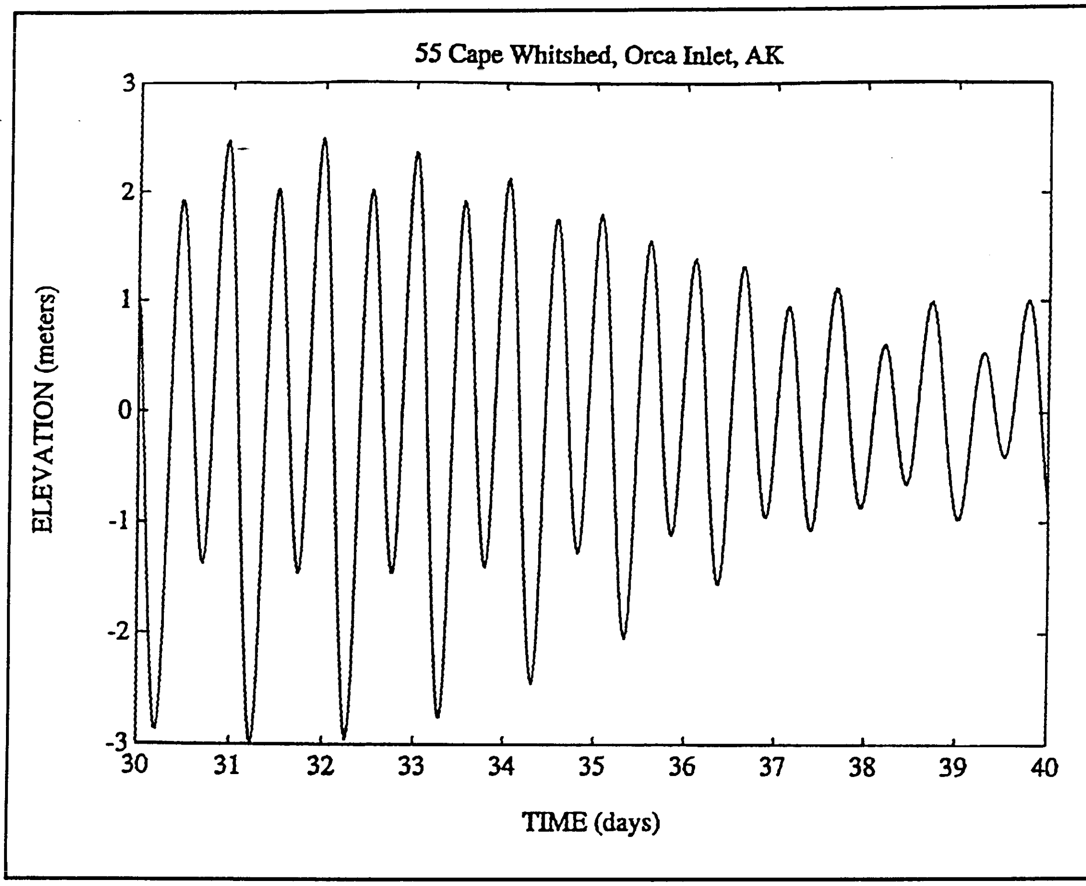

Figure 5. Manually computed equilibrium tidal elevation time series for Cape Whitshed, Alaska

Tidal Surface Elevation and Current Time Series—Computer Generation

Tidal time series based on the surface elevation and current (*u* and *v* components) amplitude and Greenwich epoch database is available for mainframe or PC applications. The computer program that accesses these data has the capability of computing equilibrium arguments (Equation 1) so that hindcast or forecast time series can be generated. Therefore, either equilibrium time series or time-referenced time series can be generated. Input to the program is

- Equilibrium or hindcast/forecast option,
- Length of desired time series and time increment between data points,
- Location latitude and longitude,

and if a hindcast/prediction is desired

- Starting time in hour, day, month, and year.

The program for the eight-constituent east coast and five-constituent west coast is presently being reformatted to include mean flow values (tidal circulation-induced average values). Therefore, an example of the computerized time series-generation program for the eastern north Pacific domain is not included in this technical note. However, the procedures will be identical to those reported in Scheffner (1994b) for the east coast domain with the exception that mean values will be output for both databases.

Conclusions

A database of tidal elevation and current astronomical arguments has been completed for the eastern north Pacific Ocean. Co-tidal charts of surface elevation amplitudes and Greenwich epochs for the entire domain are provided in Hench and others (1994). This database provides the capability of simulating equilibrium tidal elevation time series for any location included in the charts and does not require the use of a computer. The full database of surface elevation and current amplitudes and epochs as well as the capability of computing equilibrium arguments for tidal hindcasts or predictions is available to users with mainframe or PC capabilities.

The intended purpose of the database is to generate realistic tidal data for a specific location for use as boundary conditions for LTFATE (the Long-Term Fate and Stability Model). However, tidal elevation and current hindcast or prediction capabilities are available as an alternative to published tide tables which only give high and low tide predictions. The DRP database therefore represents an improvement to the tide tables because it provides a capability of generating a continuous tidal signal for any time period at any location in the computational domain shown in Figure 1.

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