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# A COMPARISON OF DATUMS DERIVED FROM CO-OPS VERIFIED DATA PRODUCTS AND TIDAL ANALYSIS DATUM CALCULATOR

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U.S. DEPARTMENT OF COMMERCE
National Ocean Service
Center for Operational Oceanographic Products and Services

# Center for Operational Oceanographic Products and Services
National Ocean Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

The National Ocean Service (NOS) Center for Operational Oceanographic Products and Services (CO-OPS) provides the National infrastructure, science, and technical expertise to collect and distribute observations and predictions of water levels and currents to ensure safe, efficient and environmentally sound maritime commerce. The Center provides the set of water level and tidal current products required to support NOS' Strategic Plan mission requirements, and to assist in providing operational oceanographic data/products required by NOAA's other Strategic Plan themes. For example, CO-OPS provides data and products required by the National Weather Service to meet its flood and tsunami warning responsibilities. The Center manages the National Water Level Observation Network (NWLON), a national network of Physical Oceanographic Real-Time Systems (PORTS®) in major U. S. harbors, and the National Current Observation Program consisting of current surveys in near shore and coastal areas utilizing bottom mounted platforms, subsurface buoys, horizontal sensors and quick response real time buoys. The Center: establishes standards for the collection and processing of water level and current data; collects and documents user requirements, which serve as the foundation for all resulting program activities; designs new and/or improved oceanographic observing systems; designs software to improve CO-OPS' data processing capabilities; maintains and operates oceanographic observing systems; performs operational data analysis/quality control; and produces/disseminates oceanographic products.

# A Comparison of Datums Derived from CO-OPS Verified Data Products and Tidal Analysis Datum Calculator

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# NOTICE

# TABLE OF CONTENTS

# LIST OF FIGURES

# LIST OF TABLES

# EXECUTIVE SUMMARY

The NOAA National Ocean Service Center for Operational Oceanographic Products and Services (CO-OPS) has developed a publicly accessible tool to compute tidal datums from water level data with a variety of tidal signals. The Tidal Analysis and Datums Calculator (TAD) uses a Butterworth digital filter to remove high frequency (> 4 cycles/day) water level variability in order to identify tidal high and low waters from observed water level data. Present CO-OPS procedure uses a Curve Fit Manual Verification (CFMV) approach to identify tidal high and low waters.

A comparison of high and low water selections at eight long-term NOAA water level stations shows that the mean difference between selections made by TAD and CFMV have a mean bias of 0 at the 1 mm level, and the standard deviations of the differences are all within CO-OPS-accepted data processing error bounds. Instances of major differences (> 0.02 m) between individual high and low water selections are rare and have no significant influence on the resulting datums. The difference in errors associated with tidal datums computed by TAD and CFMV is less than 0.002 m when compared to the published tidal datums at the eight stations.

The results here demonstrate that TAD is able to efficiently determine accurate high and low water values without manual verification. Therefore, users of this new tool will be able to generate consistent and reproducible tidal datums that are useful for coastal planning and restoration.

# 1.0 INTRODUCTION

The Center for Operational Oceanographic Products and Services (CO-OPS) operates and maintains the National Water Level Observation Network (NWLON), a network of long-term, continuously operating water level stations throughout the U.S. and its territories. The NWLON provides the national standards for tidal datums and water levels used for hydrographic surveying, establishes boundaries and property ownership, illustrates changes in relative sea level and potential inundation, and establishes planting zones for restoration projects (Hicks, 2006; Gill and Schultz, 2001; CO-OPS, 2003). CO-OPS has developed a publicly accessible tool, Tidal Analysis and Datum Calculator (TAD), to support tidal datum computation from water level data with a variety of tidal signals that can benefit the work of coastal planners and practitioners.

A tidal datum is a mathematically standardized reference elevation defined by a certain phase of the tide from observed data (Table 1). The National Tidal Datum Epoch (NTDE) is the specific 19-year cycle adopted by the National Ocean Service (NOS) as the official time segment over which water level observations are taken and reduced to obtain mean values for tidal datums. A 19-year time segment is used to account for the influence of the regression of the moon's nodes, or the variation in interaction of the moon's orbital plane with the ecliptic (the plane of the Sun's orbit), which has a period of about 18.6 years (Hicks, 2006; Gill and Schultz, 2001; CO-OPS, 2003). The regression of the nodes introduces an important variation into the amplitude of the annual mean range of the tide. Adoption of the NTDE enables this complete cycle to be captured and also averages out long-term seasonal meteorological, hydrologic, and oceanographic fluctuations. The current NTDE is 1983-2001 (Hicks, 1980).

Due to various tide-producing forces and local hydrodynamics, tidal characteristics are complex along the coast of the United States. To compute tidal datums, standard computerized algorithms are used by CO-OPS to tabulate and quality-control high and low waters from 6-minute water level data. The 6-minute data, even with the mechanical filtering used by some instrumentation during data collection, contain high frequency changes in water level due to waves, meteorological effects, local hydrodynamics, or other local and regional factors (Parker, 2007; Hicks, 2006; Park et al., 2014). These high frequency effects can complicate selecting high and low waters manually. Thus, a numerical approach must be utilized to aid in accurately selecting the times and heights of high and low waters.

Present National Oceanic and Atmospheric Administration (NOAA) standard processing tools rely on a least-square polynomial curve fit to smooth tidal curves and determine the times and heights of the high and low waters. The tabulation routines contain error diagnostics for flat tides, curve fit failures, and other quality control parameters. The algorithms also use some quality control criteria to eliminate unwanted high and low water selections during periods of high frequency noise (e.g., not tabulating preliminary computer selections if a high water and its subsequent or preceding low water are not greater than 0.03 meters [m] apart in elevation or greater than 2 hours in duration; Hicks, 1980). To account for inconsistencies common with this approach, the initial computer-selected high and low waters are manually reviewed and modified if necessary by a trained analyst and verified by a senior oceanographer. This Curve Fit Manual Verification (CFMV) method tends to be labor intensive when examining tidal data in regions of high meteorological influence and is dependent on subjective judgments made by analysts.

**Table 1.**The tidal datums calculated by TAD and their definitions.

| | |
|---|---|
| Mean Higher High Water (MHHW) | The average of the higher high waters of each tidal day observed. |
| Mean High Water (MHW) | The average of all the high waters observed. |
| Diurnal Tide Level (DTL) | The arithmetic mean of mean higher high water and mean lower low water. |
| Mean Tide Level (MTL) | The arithmetic mean of mean high water and mean low water. |
| Mean Sea Level (MSL) | The arithmetic mean of hourly heights observed. |
| Mean Low Water (MLW) | The average of all the low water heights observed. |
| Mean Lower Low Water (MLLW) | The average of the lower low waters of each tidal day observed. |
| Great Diurnal Range (GT) | The difference in height between mean higher high water and mean lower low water. |
| Mean Range of Tide (MN) | The difference in height between mean high water and mean low water. |
| Mean Diurnal High Water Inequality (DHQ) | The difference in height of the two high waters of each tidal day for a mixed or semidiurnal tide. |
| Mean Diurnal Low Water Inequality (DLQ) | The difference in height of the two low waters of each tidal day for a mixed or semidiurnal tide. |

TAD explores a new, fully automated method that uses a digital filter to remove high frequency variability in water level data and then select the times and heights of the high and low waters from the filtered water level signal. Tidal filters have been available to the oceanographic community for nearly 100 years (Doodson and Warburg, 1941; Groves, 1955). The typical purpose of these filters, however, has been to remove tidal energy from a water level signal by creating band-stop or high-pass filters designed to preserve the meteorological or other influences on the water level (Parker, 2007). TAD uses a low-pass Butterworth filter to preserve the tidal energy and remove the meteorological effects of the water level.

This report demonstrates the performance of this new approach of selecting highs and lows from water level data with tidal signals. Water level observations from eight NOAA NWLON water level stations with varying tidal characteristics were analyzed by TAD, and the results compared to NOS-verified high and low tide selections. Instances of significant (> 0.02 m) differences between selections are presented. The resulting datums calculated by TAD are then compared with datums calculated from NOS-verified data in order to determine the accuracy and consistency of TAD.

# 2.0 METHODS

## 2.1 NOAA Standard Procedures of Selecting High and Low Tides

The CFMV method is the present operational approach utilized by CO-OPS for identifying high and low waters in a water level signal. This approach applies a 3rd order least-square polynomial curve fit to 6-minute water level data over a 6-hour period to identify the local minima and maxima of the fitted curve, thus making the curve fit dependent on the input water level signal. This approach can generate inaccurate and disjointed fits when the water level signal is heavily influenced by non-tidal effects like weather or local hydrodynamics. The local minima and maxima of the fitted curve are found by comparing the water level at time $t$, $h(t)$ to $h(t+1)$ and $h(t-1)$. If $h(t)$ is greater/less than $h(t+1)$ and $h(t-1)$, then $h(t)$ is the maxima/minima. The disjointed and often inaccurate curve fit generated by a 3rd order polynomial causes many false positive or false negative high and low tide selections, particularly in water level signals that are heavily influenced by meteorological or hydrodynamic effects.

The large number of false positive and false negative tide selections generated by the polynomial curve fit require trained analysts to review the high and low water selections and determine if the selections are physically reasonable and actually correspond to high or low tide. Analysts consider meteorological and hydrodynamic effects as well as their own experience to guide their judgment. This process is labor intensive and open to subjective judgments made by each analyst. This method is done on a monthly basis for long-term water level stations and can take several hours to complete in cases where high variability of the water level causes a large number of erroneous selections. In addition, non-specialists cannot take advantage of this method due to their lack of training in tidal analysis or lack of computational tools.

After the high and low waters from a given analysis period are tabulated, the data are ready for datum computations by one of three different methods: Monthly Mean Simultaneous Comparison (MMSC), Tide-by-Tide Analysis (TBYT), or First Reduction (FRED). The type of datum computation is based on the geographic location and/or record length of the water level. See CO-OPS (2003), Gill and Schultz (2001), and Hicks (2006) for a complete description of each approach.

## 2.2 TAD Procedures

TAD uses a different approach than CFMV to determine the high and low water selections in a water level signal. The input water level signal is digitally filtered by a 6th order low-pass Butterworth filter. The filter uses a cutoff frequency of 4 cycles per day (cpd) in order to preserve the low frequency tidal energy and remove as much of the high frequency variability as possible (Figure 1). Much of the high frequency variability above this cutoff frequency can be considered "noise" in the water level signal for the purpose of datum computation and can be attributed to short-term meteorological and oceanographic forcing mechanisms. An additional benefit to utilizing a 4-cpd cutoff frequency is that some of the higher order tidal harmonic frequencies (e.g., resulting from shallow water effects), which can complicate datum selection, are also removed while still preserving the principle diurnal and semidiurnal tidal frequencies (Parker, 2007). Emery and Thompson (2014) discuss Butterworth filters in more detail.

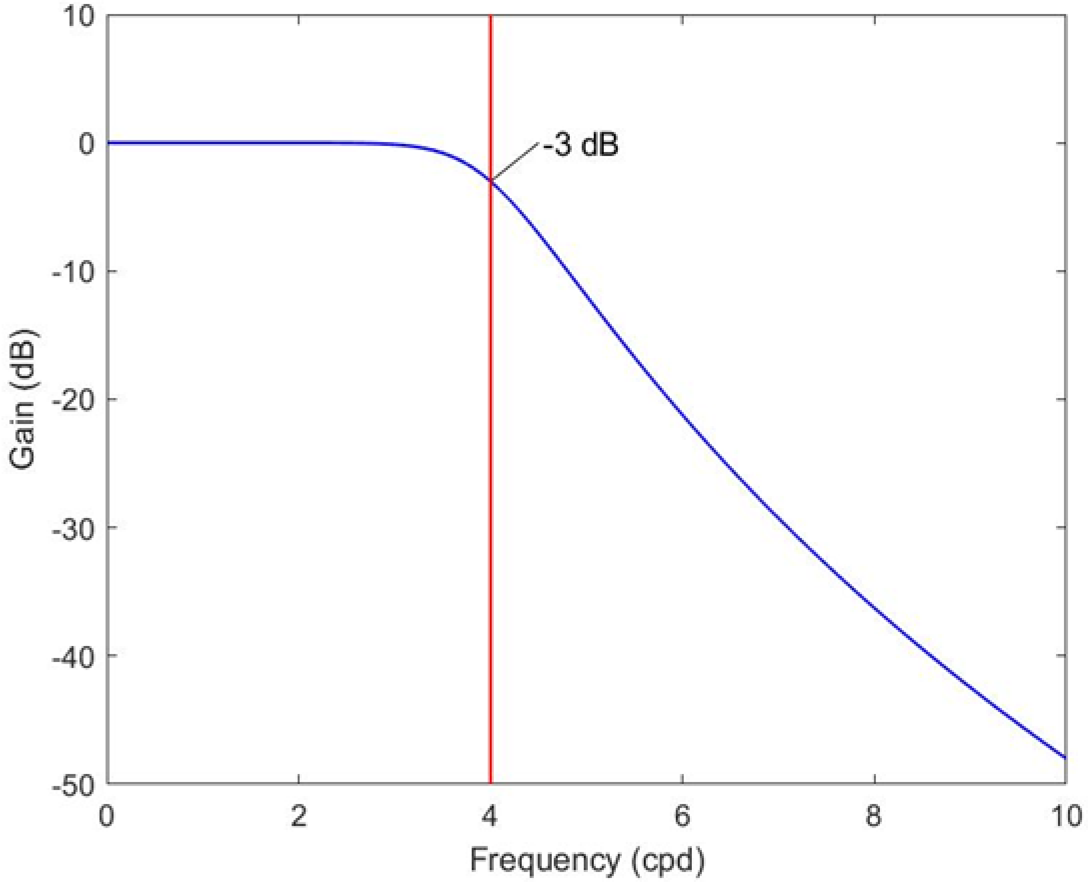

**Figure 1.** The frequency response (blue) of a 6th order Butterworth filter with a cutoff frequency (red). Frequencies higher than the cutoff frequency are subject to signal gains that are less than -3 dB.

TAD uses the digitally filtered water level signal to find locations of high and low tides. The local minima and maxima of the filtered signal are identified in the same manner as CFMV, but the filtered signal eliminates the high frequency variability that causes the false positives and false negatives in CFMV. When the high and low tide locations are identified, TAD applies NOAA standard tide definition criteria as outlined in Hicks (1980) to eliminate high and low selections that are less than 0.03 m different in height or 2 hours apart from the subsequent or preceding selections. Finally, the unfiltered water level signal is used to find the observed data point that is closest to the selection made using the filtered water level signal. This closest point is then recorded as the time and height of high or low tide.

The digitally filtered signal has several advantages over a least-square polynomial fit. The low pass filter is constructed independently of the input water level signal and is thus not influenced by the presence of any meteorological or hydrodynamic effects other than those effects that occur at frequencies equal to or lower than those of the principal diurnal or semidiurnal tides (< 4 cpd). The input water level signal is also filtered as a continuous time series instead of being separated into discontinuous segments as with the polynomial fit. Finally, identifying the local minima and maxima from the filtered signal results in minima and maxima at or near the times and heights of high or low tides without creating a large number of false positives that need to be analyzed by experts (Figure 2).

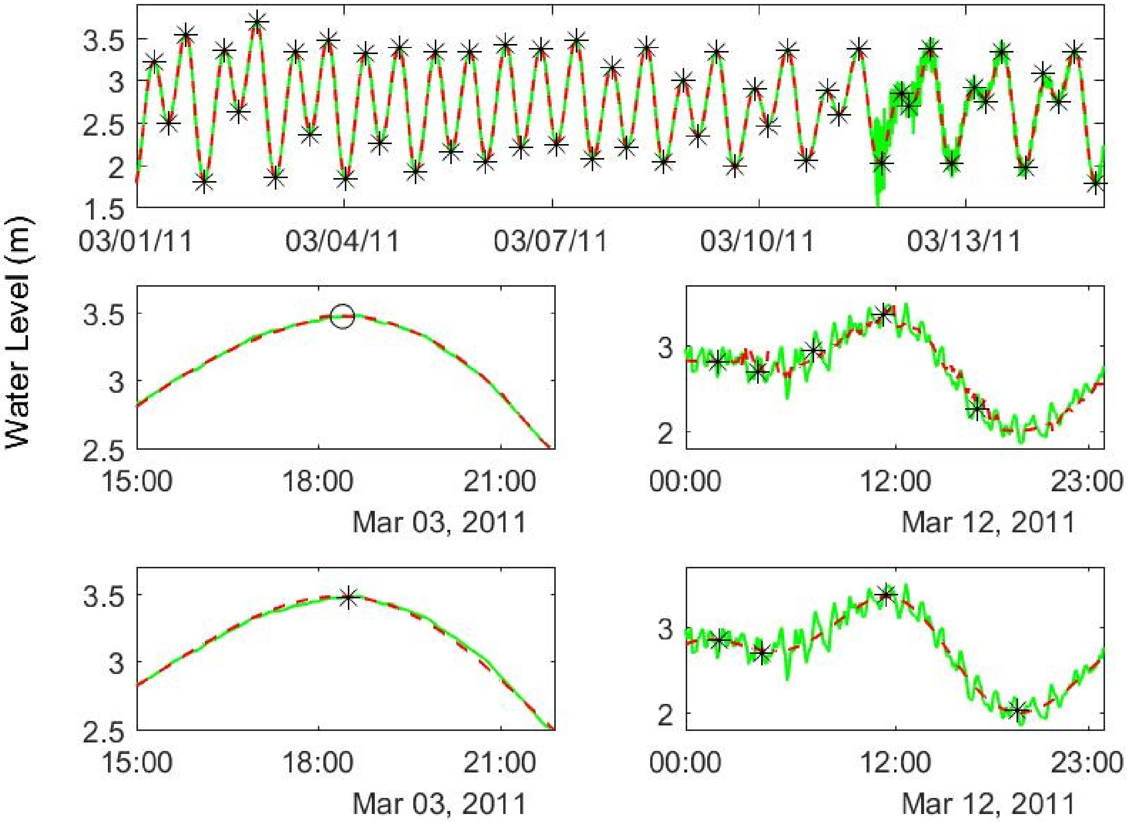

**Figure 2.** Water level data from 9414290 San Francisco (green), digitally filtered water level (red), and tide selections (black) for two weeks in March 2011. On March 3 (middle, left) a high tide occurred and was identified by the polynomial fit to the water level. This same tide was also identified by TAD's filtered water level (bottom, left). Strong meteorological influence on March 12 caused several false positives (middle, right) that were later removed by analysts; TAD was also able to correctly identify the high and low waters (bottom, right).

## 2.3 Datum Calculations

Following the tabulation of high and low waters, a datum computation is performed. If the input water level series spans at least one calendar month, then a series of monthly means are computed. Monthly means are the average value of a tidal datum parameter (high waters, low waters, range, etc.) over one month (Gill and Schultz, 2001; CO-OPS, 2003; Parker, 2007). If monthly means are available, then an MMSC datum computation will be performed. If the input water level series does not span at least one calendar month, then a TBYT datum computation will be performed. If the data series is sufficiently long (18.6 years) or a suitable control station does not exist, a FRED datum is performed.

By performing MMSC and TBYT datum computations, tidal datums at a non-permanent water level station can be tied to a 19-year NTDE. For example, a "corrected" MTL at a location B (a location with fewer than 19 years of data) is computed via MTL at a "datum control" location A (a location with an accepted 19-year datum) such that:

$$MTL_{CORRECTED\ FOR\ B} = MTL_{ACCEPTED\ FOR\ A} + \left(\frac{1}{N}\right)\sum_{i=1}^{N}(MTL_B(i) - MTL_A(i)) \tag{1}$$

Where $MTL_A$ and $MTL_B$ are the monthly MTL values over the period of comparison for which there are $N$ months of water level observations. Mean Sea Level (MSL) and Mean Range (MN) are determined by the same algorithm. Once you have MTL, MN, and MSL values, other datums such as MHHW, MHW, MLLW, MLW, DHQ, etc., are computed by different mathematical equations, depending on the regions where the stations are located. The method generally used for the West Coast and Pacific Island stations is called standard method, and for the East Coast, Gulf Coast, and Caribbean Island Stations, it is called modified-range ratio method. For additional information on datum computation, see Gill and Schultz (2001), CO-OPS (2003), Hicks (2006), and Parker (2007).

## 2.4 Validation of Results

To validate the results of TAD, data series at eight water level stations from different tidal regimes were retrieved and processed via TAD. NOS-verified high and low water picks were also retrieved from the CO-OPS website (*https://www.tidesandcurrents.noaa.gov*). Figure 3 shows the locations and tide ranges of each of the eight water level stations used for the analysis. The stations vary in types of tide, tidal ranges and meteorological influences. The longest continuous segment of data available at each station was processed with TAD. Table 2 shows the details of the water level data used.

**Table 2**. The data used for analysis of TAD. CO-OPS verified 6-minute data and high and low picks were used.

| Station ID | Station Name | Data Series |
|---|---|---|
| 9450460 | Ketchikan, AK | 01/01/1997-12/31/2015 |
| 9447130 | Seattle, WA | 01/01/1997-12/31/2015 |
| 9414290 | San Francisco, CA | 01/01/1997-07/31/2012 |
| 8729840 | Pensacola, FL | 08/01/2008-02/29/2012 |
| 8774770 | Rockport, TX | 01/01/1997-10/31/2015 |
| 8652587 | Oregon Inlet Marina, NC | 01/01/1997-12/31/2011 |
| 8638863 | Chesapeake Bay Bridge Tunnel, VA | 01/01/1995-12/31/2013 |
| 8418150 | Portland, ME | 01/01/1996- 06/30/2007 |

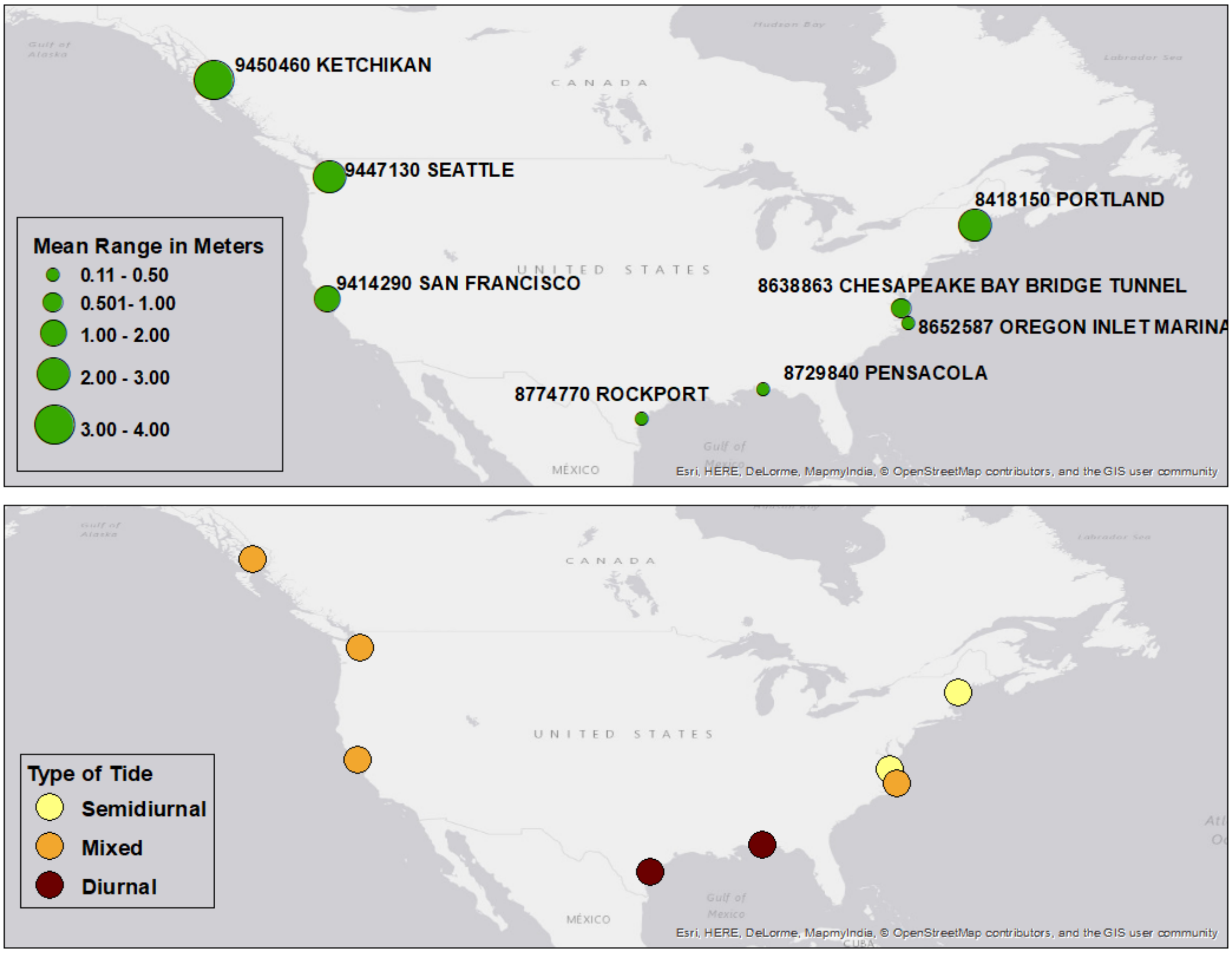

**Figure 3.** The locations and ranges (top) as well as the tide types (bottom) of the data series used to validate the output of TAD.

The high and low water selections from TAD were compared to the CO-OPS-verified high and low water selections. Statistical analysis of the differences in times and heights of high and low waters were conducted. Specific instances of the greatest differences in times and heights between each approach were examined to identify the reason(s) for the discrepancy. The difference in the resulting datums from TAD and from CO-OPS standard procedures based on data lengths of 1 month, 3 months, 6 months, 1 year, and 5 years were analyzed. The derived datums based on the data lengths of 1 month, 3 months, 6 months, 1 year, and 5 years from both methods were compared to the CO-OPS-published datum values to compute the uncertainty associated with FRED datums based on different data lengths.

The datum computation and comparison were conducted via the following process. Highs and lows tabulated by TAD were averaged to monthly means, and CO-OPS-verified monthly means were retrieved (*https://www.tidesandcurrents.noaa.gov*). The monthly means from TAD and CO-OPS-verified data were then binned into overlapping time series of 1, 3, 6, 12, and 60 months. For example, the data series used for 8638863 Chesapeake Bay Bridge Tunnel, Virginia spans 19 years of data from 01/01/1995 through 12/31/2013. Thus, 228 months (samples) of data were available for use in comparisons of a 1-month datum, 226 samples for a 3-month datum, 223 samples for a 6-month datum, 217 samples for a 1-year datum, and 169 samples for a 5-year datum. The 1-, 3-, 6-, 12-, and 60-month FRED tidal datums were computed by averaging each of these monthly mean bins. The standard deviation of the difference in tidal datums computed from TAD and CO-OPS standard procedures (CFMV) was calculated. Then, the standard deviation relative to the accepted datums at each of the eight stations was calculated (Equation 2). Finally, the standard deviations of the individual bins for all stations were averaged to create a cumulative uncertainty value, which represents the FRED datum computation error associated with each binned group for each data length.

The standard deviation ($S_{ij}$) for MTL for each station and for each data length of 1, 3, 6, 12, and 60 months relative to the published datums at each station was calculated as:

$$S_{ij} = \frac{\sum_{K=1}^{N_{ij}} (X_{ijk} - A_i)^2}{N_{ij} - 1} \tag{2}$$

Where i = station identification number (i = 1, 2, 3, 4, 5, 6, 7, 8),
j = length of running mean used (j = 1, 3, 6, 12, 60 months),
$N_{ij}$ = number of j month running means for station i,
k = index number for running mean observations,
$X_{ijk}$ = running mean observations with index k
$A_i$ = accepted datums at station i

An average standard deviation ($S_j$) was then computed for all eight stations.

# 3.0 RESULTS

## 3.1 Comparison of High and Low Water Selections

The TAD high and low water selections are compared to the CO-OPS CFMV high and low waters by examining each tide selection made by TAD and identifying the corresponding CO-OPS-verified selection and then calculating the height difference (CFMV - TAD) and time difference (|CFMV - TAD|). Distributions of the height differences are closely centered about 0 and are normally distributed (Figure 4, Table 3). For each station, the mean difference indicates sub-millimeter-level bias, if any. The standard deviations of the differences are similar for all stations and are less than 0.013 m. The variability in the standard deviation values, visualized by the spread in the distributions, aligns closely with meteorological influence relative to tidal range. Standard deviations are small (~ 0.001 m) at stations with strong tidal forcing and large range of tide (Seattle, Ketchikan, and Portland). The standard deviation is highest at Rockport and Pensacola, where water levels are meteorologically dominated with small tidal range.

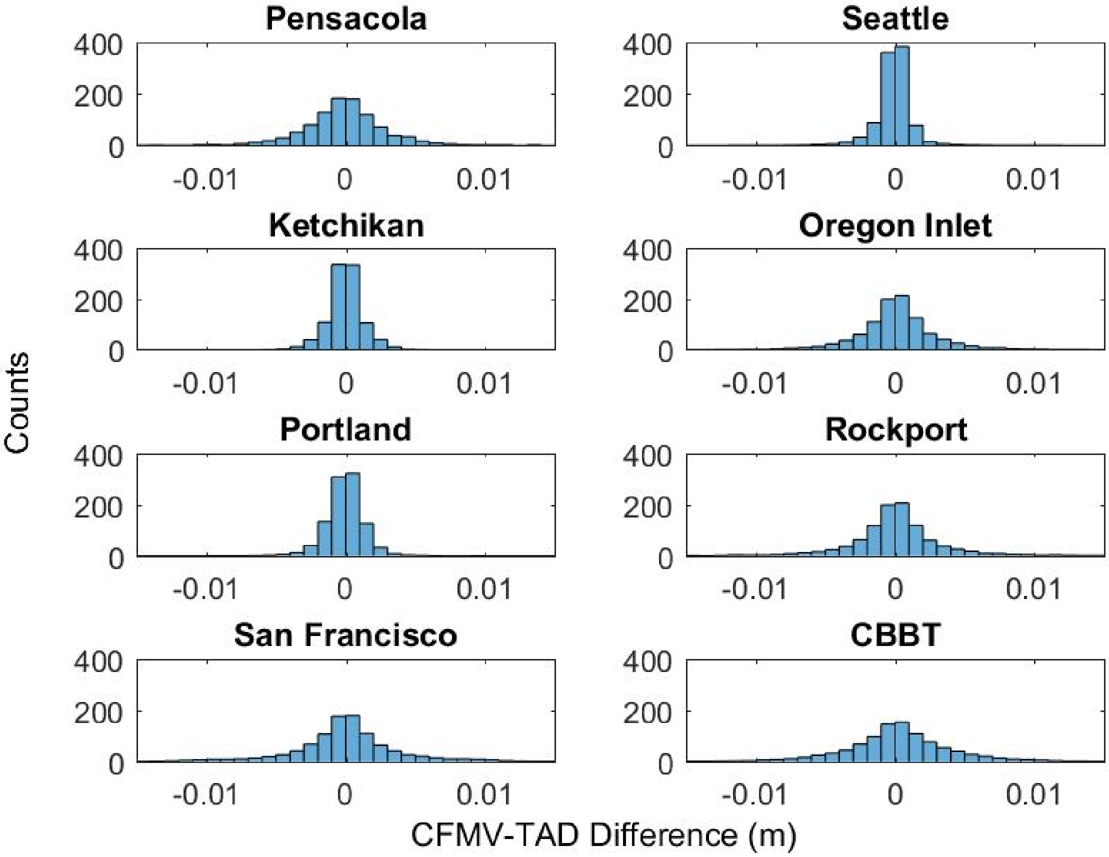

**Figure 4.** Distribution of differences in height from high and low tide picks from TAD and CFMV.

**Table 3.** Details of the distribution of the differences between the verified and TAD-picked high and low waters and height and time difference corresponding to the greatest difference in high or low water selections.

| Station ID | Station Name | Mean of Differences (m) | Standard Deviation of Differences (m) | Max Height Difference (m) | Max Time Difference (h) |
|---|---|---|---|---|---|
| 9450460 | Ketchikan, AK | 0 | 0.001 | -0.037 | 0.5 |
| 9447130 | Seattle, WA | 0 | 0.001 | -0.022 | -0.1 |
| 9414290 | San Francisco, CA | 0 | 0.005 | -0.016 | 0 |
| 8774770 | Rockport, TX | 0 | 0.013 | 0.014 | 0.4 |
| 8729840 | Pensacola, FL | 0 | 0.011 | -0.06 | 3.3 |
| 8652587 | Oregon Inlet, NC | 0 | 0.006 | 0.09 | 0.7 |
| 8638863 | Chesapeake Bay Bridge Tunnel, VA | 0 | 0.005 | -0.013 | -0.3 |
| 8418150 | Portland, ME | 0 | 0.001 | 0.011 | 0.1 |

Figures 5 and 6 show the specific instances of the largest difference in each data series. Some differences are due to different points in the data being selected, and others are due to a high or low being selected by one method, while not being picked by the other. These instances are discussed in detail in Section 4.

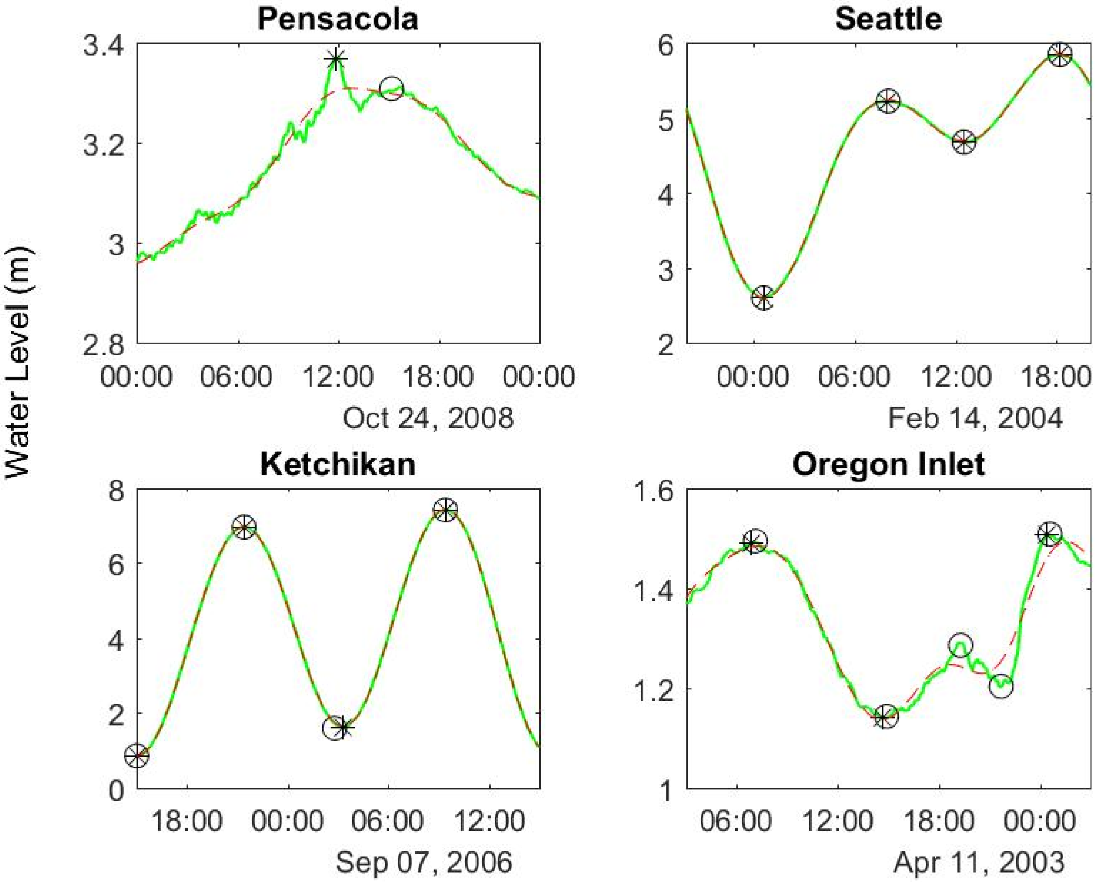

**Figure 5.** The high and low selections from TAD (asterisk) and CFMV (circle), observed water levels (green), and the filtered water level signal (red) used by TAD to find high and low selections. Note the high and low selections at Oregon Inlet (bottom right panel) that were not picked by TAD because the difference in height of the selections did not meet the minimum separation criteria of 0.03 m.

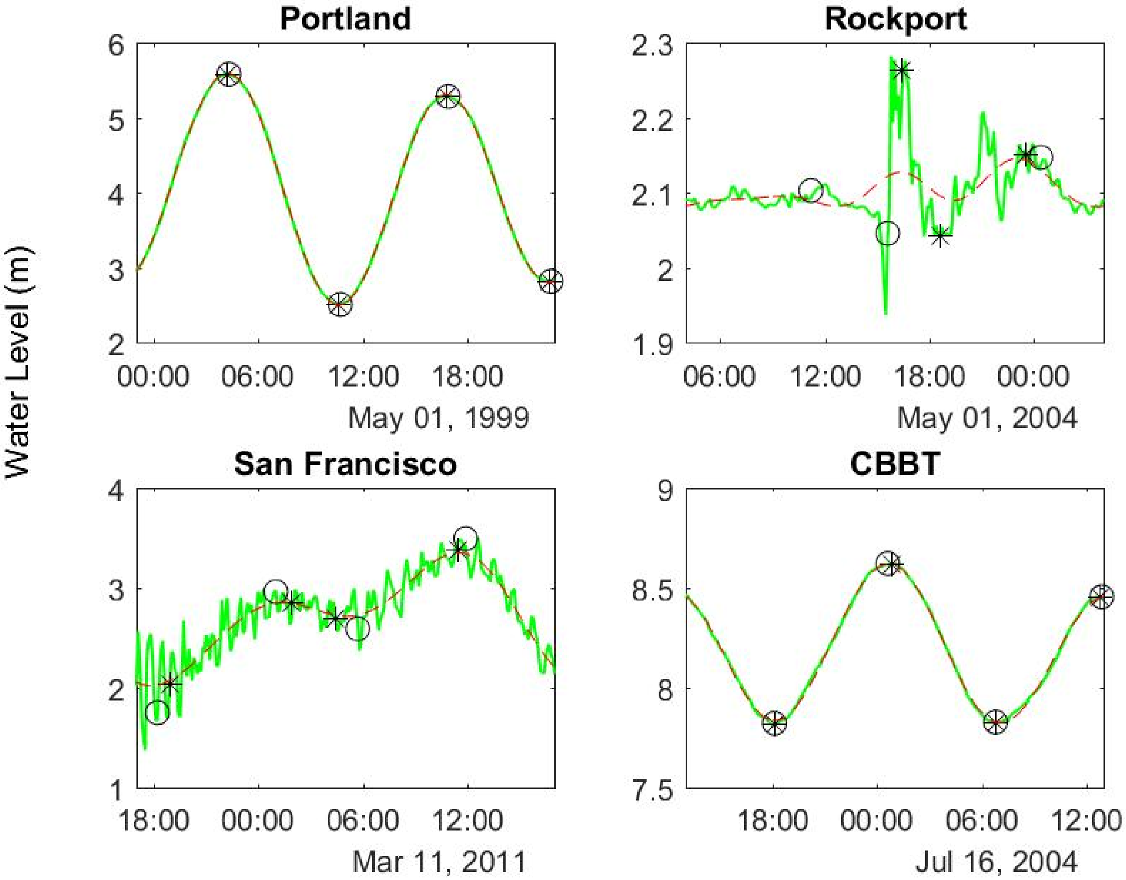

**Figure 6.** The high and low selections from TAD (asterisk) and CFMV (circle), observed water levels (green), and the filtered water level signal (red) used by TAD to find high and low selections. Note the high and low selections at Rockport (top right panel) that were not picked by TAD because the difference in height of the selections did not meet the minimum separation criteria of 0.03 m.

## 3.2 Comparison of Datum Calculation Results

The average of the datum errors from TAD and CFMV as compared to the NOS-published 19-year equivalent datum is shown in Figure 7. The standard deviation of the differences between the datums computed from TAD and CFMV is also shown in Figure 7. The variability in the datums derived from TAD and CFMV is small compared to the overall datum error. Other tidal datums show similar results.

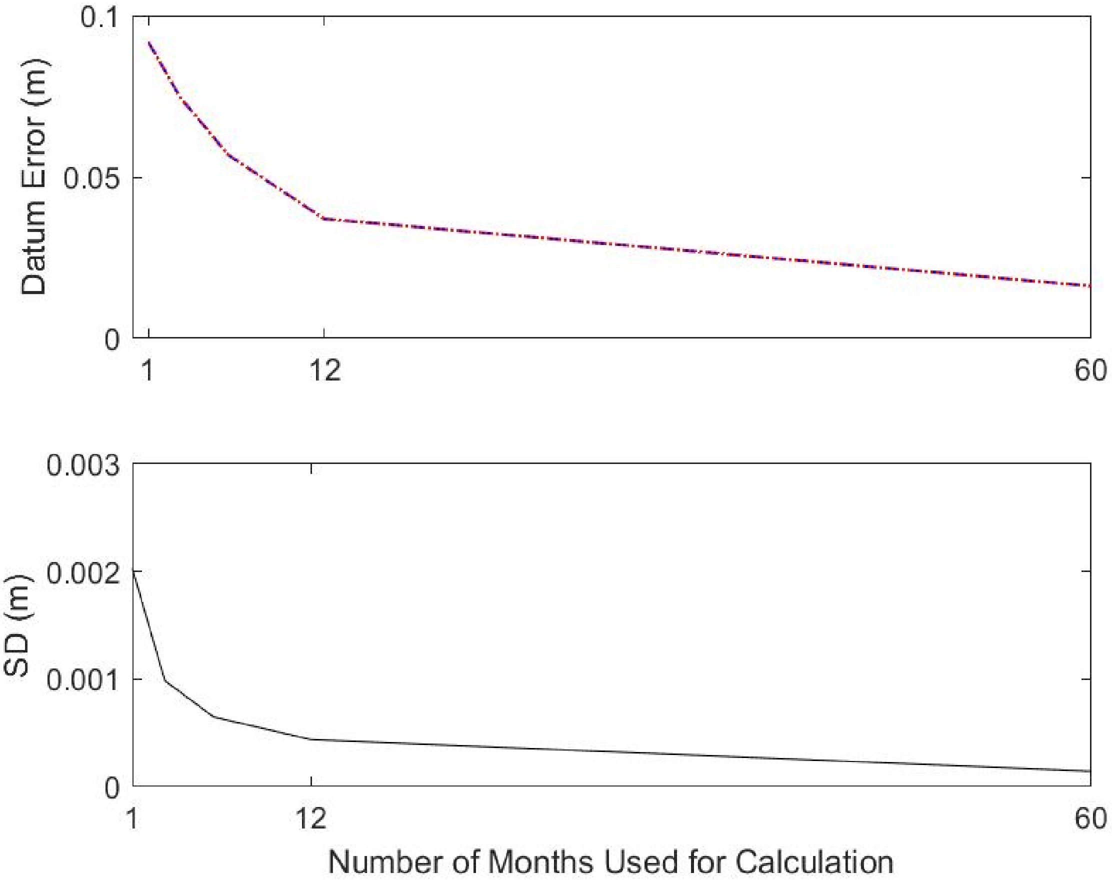

**Figure 7.** Datum error for MTL from TAD (blue) and from NOS-verified products (red) as compared to the NOS published datum (top panel). Note the different scales and that the standard deviation of the difference between CFMV and TAD derived datums (bottom panel) is small compared to the overall datum error.

# 4.0 DISCUSSION

The differences in the high and low water selections between TAD and CFMV shown in Figure 4 are all within the accepted data processing error range of 0.02 m as described in Swanson (1974) and Bodnar (2014). The largest differences are during times of strong meteorological influence, questionable high and low selections made by analysts, tides picked by analysts or TAD that are not selected by the other method, or are selected at a slightly different time (Figures 5, 6; Table 3). These situations can occur at any given location depending on local events but are extremely rare over a long data record. The mean bias in Table 3 indicates that mean differences in heights of highs and lows are not statistically significant and are within accepted data processing error (Swanson, 1974; Bodnar, 2014).

The meteorological influences shown in Figures 5 and 6 caused an increase in recorded water levels just prior to high tide at Pensacola and Rockport. As a result, TAD picked that increase of water level as the high-water level for that tidal cycle, while an analyst chose the time and water level corresponding to the predicted tide level. The high-water level that was not exactly at the time of predicted or filtered water level still fell within the search window used by TAD to find high and low waters.

The uncertainties associated with datums computed by TAD are nearly identical to the uncertainties associated with datums computed from CFMV when compared to the full 19-year datum. The uncertainty associated with TAD and NOS published datums is greatest when comparing 1-month datums, and the uncertainty decreases as the datum computation period increases as shown in Figure 7. The 12-month record length shows a dramatic turning point of the slope of the uncertainty, where the decreasing slope of datum uncertainty is much more gradual. This result indicates that users should attempt to collect at least one year of data so that seasonal variations can be accounted in the datum computation, greatly reducing error.

The differences between datums computed from TAD with those computed from CFMV are very small regardless of time scale or location (Figure 7; Table 4). Even with only 1 month of data, standard deviations of the differences average across all stations to be about 0.002 m. This is nearly two orders of magnitude smaller than the datum error established by relating the 1-month datum to the full 19-year datum (~ 9 cm). This difference, which is roughly two orders of magnitude, is retained regardless of time series duration (Figure 7; Table 4). This result is extremely important and demonstrates that any datum differences resulting from choosing either the CFMV or TAD method are statistically insignificant compared to datum error resulting from utilizing a time series of less than 19 years. Thus, users can have confidence that datums calculated with the automated TAD method will be statistically equivalent to those calculated with the more time and expertise intensive CFMV approach.

**Table 4.** The average difference between TAD-computed FRED datums and CFMV-computed datums at the eight locations used for each time period of analysis.

| Station ID | Station Name | 1 Month | 3 Month | 6 Month | 12 Month | 60 Month |
|---|---|---|---|---|---|---|
| 9450460 | Ketchikan, AK | 0.001 | 0 | 0 | 0 | 0 |
| 9447130 | Seattle, WA | 0.002 | 0.001 | 0.001 | 0 | 0 |
| 9414290 | San Francisco, CA | 0.001 | 0.001 | 0 | 0 | 0 |
| 8774770 | Rockport, TX | 0.006 | 0.003 | 0.002 | 0.001 | 0 |
| 8729840 | Pensacola, FL | 0.002 | 0.001 | 0.001 | 0 | N/A |
| 8652587 | Oregon Inlet, NC | 0.002 | 0.001 | 0.001 | 0 | 0 |
| 8638863 | Chesapeake Bay Bridge Tunnel, VA | 0.001 | 0 | 0 | 0 | 0 |
| 8418150 | Portland, ME | 0.001 | 0 | 0 | 0 | 0 |

# 5.0 CONCLUSION

TAD can compute tidal datums that are comparable to the datums computed using CO-OPS standard procedures with the standard deviations of differences between them within 0.002 m (Figure 7, lower panel). The standard deviations of the difference in highs and lows selected by TAD and by CFMV are within 0.02 m (Figure 4, Table 3). TAD is able to determine accurate high and low water values and times without the need for a trained analyst or additional input. Use of this fully automated tool will decrease the amount of time required to calculate a datum from an input water level signal and will also eliminate the potential uncertainties due to the subjective judgments of selecting highs and lows by different analysts.

The tool is able to generate consistent and reproducible results. This is important for short period datums, as the inconsistency in selecting highs and lows by different analysts can result in a varying range of datums, particularly in the region of meteorologically dominated water levels with small tidal range. Progressively longer input time series result in more accurate output datums (Figure 7). Datum error is most significantly reduced once seasonal cycles are resolved with at least 1 year of data; thus, it is strongly recommended that at least 1 year of data be collected to compute tidal datums.

It is important to note that all of the above analyses are based on CO-OPS-verified 6-minute data. Depending on the data quality and time intervals, the uncertainty associated with tidal datums computed can be much higher than Figure 7. Users are responsible for quality controlling their data to ensure high quality data are uploaded into the tool to generate high quality tidal datums. CO-OPS standard procedures require quality controlling the metadata, including sensor stability, sensor calibration, etc. before using the data for datum computation. Since user data may or may not have gone through CO-OPS quality assurance procedures, the datums computed from TAD may not meet the requirements of CO-OPS published tidal datums. TAD datums should be used strictly as a planning reference and are not appropriate for navigation, establishing land boundaries, permitting or other regulatory purposes.

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# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| CFMV | Curve Fit Manual Verification |
| CO-OPS | Center for Operational Oceanographic Products and Services |
| cpd | Cycles Per Day |
| dB | Decibels |
| DHQ | Diurnal High Water Inequality |
| DLQ | Diurnal Low Water Inequality |
| DTL | Diurnal Tide Level |
| FRED | First Reduction |
| GT | Great Diurnal Range |
| m | Meters |
| MHHW | Mean Higher High Water |
| MHW | Mean High Water |
| MLLW | Mean Lower Low Water |
| MLW | Mean Low Water |
| MMSC | Monthly Mean Simultaneous Comparison |
| MN | Mean Range |
| MSL | Mean Sea Level |
| MTL | Mean Tide Level |
| NOAA | National Oceanic and Atmospheric Administration |
| NOS | National Ocean Service |
| NTDE | National Tidal Datum Epoch |
| NWLON | National Water Level Observation Network |
| TAD | Tidal Analysis and Datums Calculator |
| TBYT | Tide-by-Tide |