# Annual maximum wave heights from Waverider Buoy data

*By*

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**ABSTRACT**

The difficulties associated with potentially spurious spikes from remote wave measurement buoys during retransmission from satellite have led to the predominant use of an arbitrary factor times the significant wave height to estimate the probable maximum wave height in the record. The inclusion of an onboard digital memory storage device in newer Waverider buoys has allowed an after-the-fact determination of maximum wave height over a time period upwards of a year which is free of spurious data. The Coastal Data Information Program's (CDIP) data set is expanded with stored data from buoys with the onboard recording capability. Crest-leading and crest-following definitions of a wave replace the "upcrossing" and "downcrossing" definitions. Stored buoy data was downloaded at roughly one year intervals as part of the refurbishment process. These data yielded a significant spread in the magnitude of the ratio of maximum observed height to the significant wave height (Hmax/$H_{s)}$, typically assumed to be close to 2.0, and referred to here as the intensity index. This paper establishes crest-leading and crest-following definitions of a wave, replacing the "upcrossing" and "downcrossing" definitions. Variation of the intensity index is illustrated for six buoys representative of open-ocean conditions on the North American coast during 2013. Tabulated annual wave height maximum data for 68 buoy installations with onboard storage are appended.

Multiple generations of physical oceanographers and ocean engineers have utilized some concept of significant wave height ($H_s$) to characterize the intensity of waves at a location and over an interval of time. $H_s$ is, in present usage, based on the standard deviation of a time series of wave height observations over an interval judged to provide a quasi-stationary local wave field. In the 1970s, when these records became available digitally, the time series typically was also converted into an energy spectrum using Fourier techniques. The spectrum, when coupled with some knowledge of the forcing wind fields, was used to provide insights into the origins and likely future condition of the observed wave field.

A wave climate characteristic of primary interest for a variety of applications is an estimate of the highest wave that might be encountered. The ratio of the estimate of the highest wave in the interval to $H_s$ is known as the intensity index and is usually assigned an estimated value of 2.0. Wave models or historical records typically provide values for $H_s$ which are sufficient to support decision making in many situations. But since the largest wave in the train can be more than twice as high as the $H_s$ value, there are applications where knowledge of, or guidance on, this maximum event are necessary.

*Manuscript submitted 13 July 2016, accepted 6 January 2017.*

Following the broadly accepted practice, a wave is defined by the association of two connected elements. Thus the wave train is a continuous series of alternating crests and troughs and any adjacent pair can be called a wave. There are arguments in the literature in favor of both upcrossing (i.e. crest followed by trough) and downcrossing (i.e. trough followed by crest) methods in defining the elements of a single wave. Typically, one or the other approach is arbitrarily assumed. Unfortunately, this approach obscures the fact that a given crest is associated with two troughs, one preceding and one following, and can therefore be considered as two different waves. Rather than excluding half of the possible wave descriptions, both types were included in the tabulations in this paper. Since the expressions "upcrossing" and "downcrossing" have no hydrodynamic significance, the authors chose to use "crest leading" and "crest following" throughout this work to provide a simple, easily visualized discrimination.

A comprehensive network of more than 60 continuously maintained Datawell buoys has been developed, as depicted in Figure 1. Access to both current and historical data is available through the CDIP web site (cdip.ucsd.edu) for all locations shown in Figure 1, as well as historical data for a number of temporary buoy locations which are no longer in service. Tabular wave height values are available for each 30 minute record.

An illustrative example occurred on 24 February 2008 at 21:18 hours (Figure 2a)

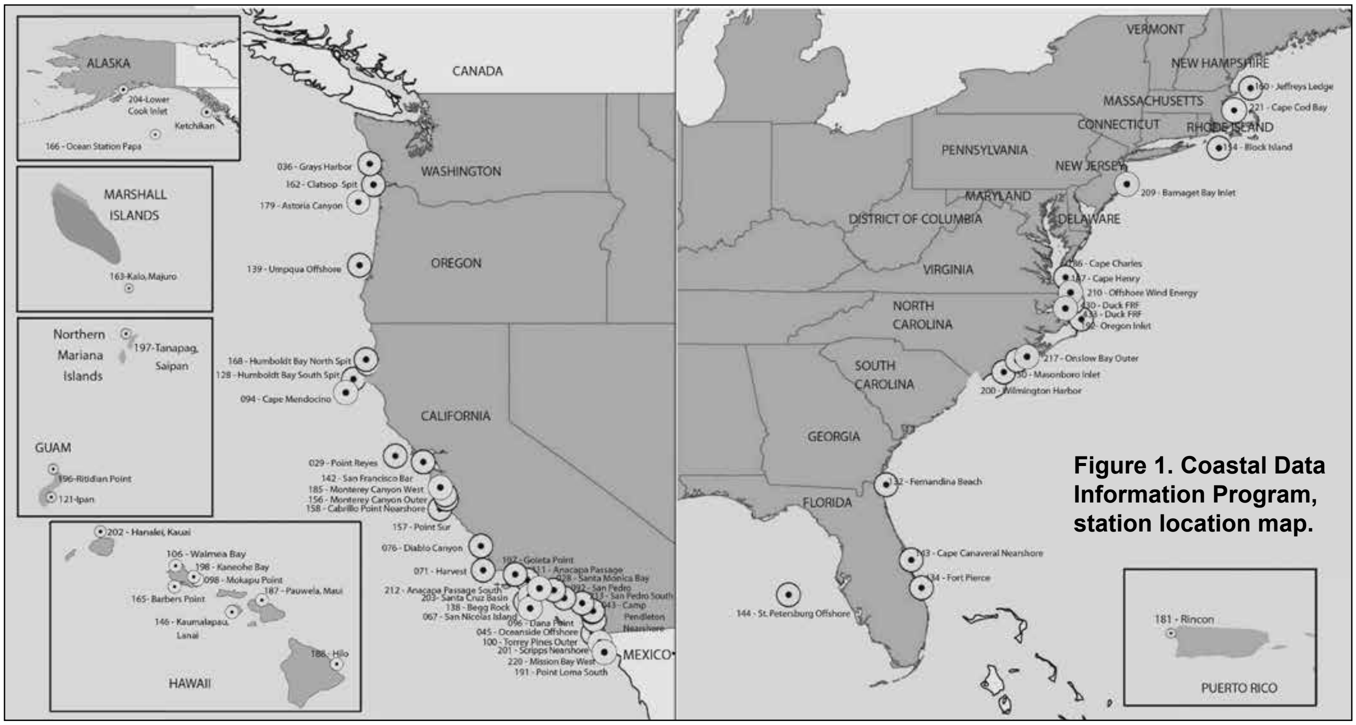



**Figure 1. Coastal Data Information Program, station location map.**

at the Harvest CA station when a crest-leading elevation measuring 10.29 m was followed by a trough measuring 10.16 m resulting in a wave 20.45 m high (Figure 2b). The 30 min parent record yields an Hs of 7.61 m. The large crest-leading wave was followed by a trough-leading wave with an $H_{max}$ of 18.95 m. Automated inspection identified the two large events as spikes and, even though they passed most other tests, the record was rejected. Subsequent manual inspection however revealed that these two waves appeared normal in all other respects, therefore they were incorporated into the main database.

## DATA ANALYSIS METHODOLOGY

The modern Datawell buoys record the complete data stream in onboard storage. This affords access to records that are free of any transmission noise when the buoy is taken out for service, but after-the-fact on the order of a year.

As explained above, two wave heights were determined for each crest, corresponding to the position of the trough relative to the crest. These wave heights and periods, identified with their date and time of observation, were added to the new system record. It was clear that the principal new knowledge involved those waves which were larger than twice $H_s$, however, the number of these waves was still substantial. Finally, we decided that the most valuable datum that could be extracted was the largest wave of either type measured by each buoy in a year. These results are presented as supplemental data.

In order to assess the significance of differences between crest-leading and crest-following definitions of very large waves, a brief comparison was made using maximum values from six west coast buoys in 2013, as shown in Tables 1, 2, and 3. Table 1 contains maxima of wave heights, Table 2 shows annual maxima of crest height and trough depth, and Table

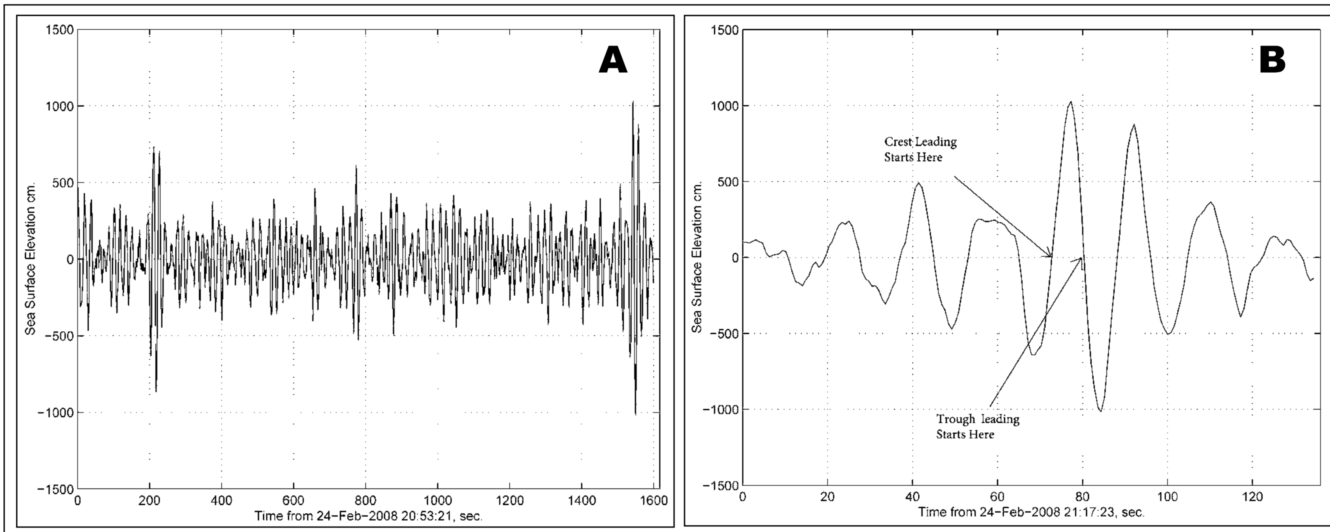



**Figure 2 (a). Sea surface elevation — Harvest CA: Time from 24 February 2008, 20:53:21, to 24 February 2008, 21:20:01; (b) Sea surface elevation — Harvest CA: Time from 24 February 2008, 21:17:23, to 24 February 2008, 21:20:01.**

3 contains the Intensity Index, the ratio of the annual maximum wave height to the corresponding Hs in the record containing that wave. This ratio, when it equals or exceeds 2.0, is often used to define a "rogue" or "extreme" wave.

The sample selected suggests that the differences between crest-leading and crest-following wave attributes are usually very small. However, if a single wave configuration is to be selected, the crest-leading choice would produce the larger maximum wave height in this limited data set 50.9% of the time.

## YEARLY MAXIMUM WAVE HEIGHTS AND ASSOCIATED INTENSITY INDICES

The annual maxima of wave heights for selected buoys for the years 2005 through 2013 with sufficient data availability are shown in a supplemental data file. Two wave heights are presented, selected from the appropriate populations of crest-leading and crest-following waves, for each year and each buoy. Figure 3 is a plot of intensity indices for each of the wave types. A histogram of the distribution of intensity values is shown in Figure 4.

Two methods are available for estimating the significant wave height from the data. The time domain method was used in this paper.

## SIGNIFICANT FINDINGS

In an earlier paper (Seymour and Castel 1998), we considered the effects of a software filter in all Waverider buoys that removes low frequency components from the data. The filter is a 3-pole Butterworth type with a cutoff frequency of 0.03247 Hz. This work was addressed to the effects of the filter on crest elevation measurements, but the findings can be readily extended to wave heights. The crest elevations were examined from the highest 15% of almost 2,000 hours of wave measurements at Grays Harbor, Washington, under winter wave climate conditions. The crest elevations were reverse filtered and the difference between these values and the forward filtered elevations was calculated. The errors were found to be closely clustered around zero with outliers grading to ±15%. This is supported by an extensive comparison of measured buoy energy with an array of pressure sensors (O'Reilly *et al.* 1996) which found a correlation of 0.98. Thus, although a rare error in wave height at great as 15% is possible, using the filtered

**Table 1.**
**Maximum wave heights at six deepwater buoys on the northwest Pacific Coast in 2013.**

| | TROUGH FOLLOWING | | | | TROUGH LEADING | | | |
|---|---|---|---|---|---|---|---|---|
| Buoy name | Date max wave | Time (UTC) | Max wave ht (m) | Ts (sec) | Date max wave | Time (UTC) | Max wave ht (m) | Ts (sec) |
| Grays Harbor | Sept. 30 | 07:11 | 12.29 | 12.1 | Sept. 30 | 07:11 | 13.51 | 12.0 |
| Astoria Canyon | Nov. 2 | 19:27 | 13.64 | 11.1 | Nov. 7 | 22:53 | 13.03 | 12.4 |
| Umpqua Offshore | March 20 | 09:15 | 11.37 | 9.4 | Sept. 30 | 8:52 | 10.97 | 11.9 |
| Cape Mendocino | Feb. 24 | 01:04 | 11.07 | 13.7 | Feb. 24 | 1:04 | 11.50 | 13.4 |
| Point Reyes | April 8 | 13.51 | 9.89 | 9.5 | April 8 | 11.09 | 10.21 | 9.6 |
| Harvest | April 8 | 21:43 | 11.31 | 10.5 | April 9 | 01:43 | 11.56 | 10.8 |

**Table 2.**
**Maximum crest heights and trough depths at six deepwater buoys in 2013.**

| | CREST HEIGHT | | CREST LEADING | TROUGH DEPTH | | |
|---|---|---|---|---|---|---|
| Buoy name | Date max wave | Time (UTC) | Max crest height (m) | Date max wave | Time (UTC) | Max trough depth (m) |
| Grays Harbor | Sept. 30 | 07:30 | 7.09 | Sept. 30 | 07:11 | 6.64 |
| Astoria Canyon | Nov. 7 | 22:53 | 7.38 | Nov. 2 | 19:27 | 6.98 |
| Umpqua Offshore | Sept. 30 | 00:33 | 6.18 | Sept. 30 | 1:27 | 6.12 |
| Cape Mendocino | Feb. 24 | 1:04 | 5.88 | Feb. 24 | 02:00 | 5.94 |
| Point Reyes | April 8 | 11:09 | 5.38 | Sept. 30 | 14:49 | 5.37 |
| Harvest | April 9 | 03:33 | 6.03 | April 9 | 01:43 | 6.12 |

**Table 3.**
**Intensity index: Ratio of maximum wave height to Hs at six deepwater buoys in 2013.**

| | TROUGH FOLLOWING | | | | TROUGH LEADING | | | |
|---|---|---|---|---|---|---|---|---|
| Buoy Name | Date max wave | Time (UTC) | Max ht (m) | Intensity index | Date max wave | Time (UTC) | Max ht (m) | Intensity index |
| Grays Harbor | Sept. 30 | 07:11 | 12.29 | 1.81 | Sept. 30 | 07:11 | 13.51 | 1.97 |
| Atoria Canyon | Nov. 2 | 19:27 | 13.64 | 2.06 | Nov. 7 | 22:53 | 13.03 | 1.70 |
| Umpqua Offshore | March 20 | 09:15 | 11.37 | 1.99 | Sept. 30 | 08:52 | 10.97 | 1.76 |
| Cape Mendocino | Feb. 24 | 01:04 | 11.07 | 1.93 | Feb. 24 | 01:04 | 11.50 | 1.98 |
| Point Reyes | April 8 | 13:51 | 9.89 | 2.04 | April 8 | 11:09 | 10.21 | 1.97 |
| Harvest | April 9 | 03:33 | 11.45 | 1.80 | April 9 | 01:43 | 11.56 | 1.82 |

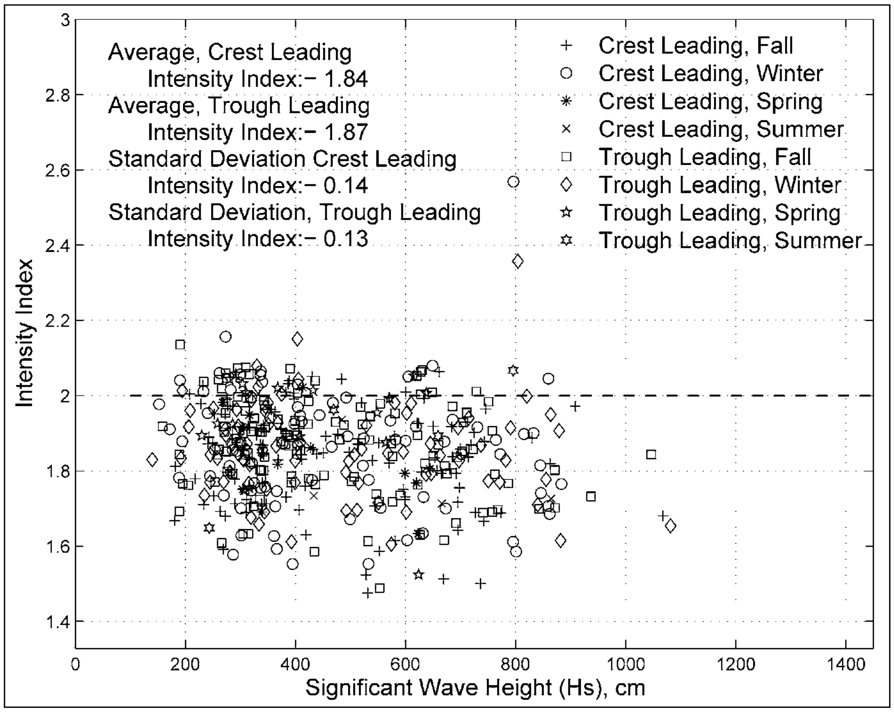
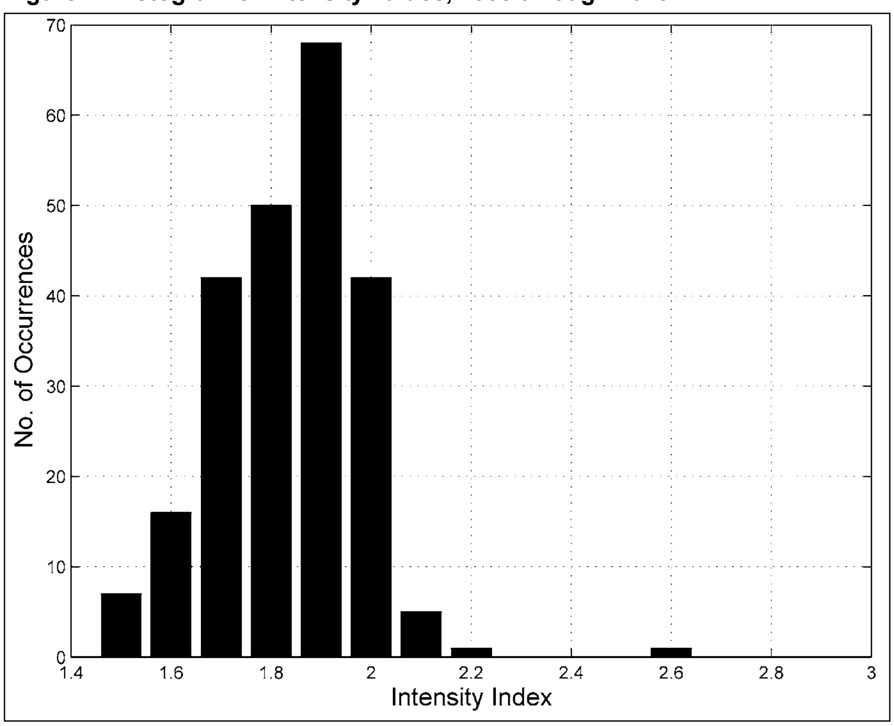



**Figure 3. Intensity index at maximum wave height, 2005 through 2013.**

**Figure 4. Histogram of intensity values, 2005 through 2013.**




output directly appears to yield useful values in most instances.

This paper has presented filtered data on maximum annual wave height assuming that the available approximate data are of interest and value.

## ACKNOWLEDGMENTS

The CDIP wave buoy network is supported jointly by the U.S. Army Corps of Engineers and the California Department of Parks and Recreation, Division of Boating and Waterways. Their support is greatly appreciated.

## SUPPLEMENTAL DATA

Supplemental Data for the 68 buoys investigated lists the Annual Maximum Wave Heights from 2005 through 2013 for both crest leading and trough leading methods. Included in the table are the Station Name, Date of the Maximum Wave, Intensity Index and Peak Period for the reporting record. These data are available at: http://asbpa.org/seymour-castel-annual-maximum-wave-heights-2005-thru-2013/

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