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CFI - A COASTAL FLOOD INDEX TO ASSESS FLOODING POTENTIAL AND MAGNITUDE ON OCEANIC COASTS

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Introduction

Ocean front coastal flooding is defined by the National Weather Service (NWS) as "the inundation of land areas along the oceanic coast caused by sea waters over and above normal tidal action" (National Weather Service, 1993). To date, no universal tools have been developed for the operational meteorologist to quickly appraise the coastal flood threat posed by an extratropical storm.

A combination of events can contribute to the occurrence of coastal flooding. These can include the effects of storm surge, wind and wave action, tides, and local terrain characteristics such as bathymetry and topography. The Coastal Flood Index (CFI) was developed to account for the primary contributing factors to coastal flooding. The CFI is the sum of four variable parameters:

CFI Variable Parameters
Wave Runup (ft)
Wave Setup (ft)
Predicted Tide (ft)
Anomaly From Predicted Tide (ft)

Although the CFI is given in terms of a unit of length (in terms of feet here, but easily could be converted to, and used in meters), it is probably best to treat it as being unitless. This lends the CFI to being thought of more as a comparative index, rather than as an absolute measure of the vertical rise of the seawater up the beach. It would be invalid to think of the CFI in absolute terms, as beach characteristics will be treated as a constant, while in reality this will almost never be the case.

In its development, an emphasis was made to utilize only information readily available to the operational forecaster. The use of an index value not only simplifies the coastal flood warning decision-making process, but also allows for making comparative assessments between the magnitude of various events occurring in the same locale.

Contributing Factors as Handled by the CFI

A. Beach Characteristics

A number of the physical characteristics of a beach can influence wave energy dissipation within the surf zone and, in turn, the potential for, and magnitude of, coastal flooding. These include bottom surface friction and permeability (Massel, 1996), as well as slope and geometry characteristics (Sorenson, 1993).

Beach slope and composition can vary considerably along any stretch of coastline. Constant slope and composition are assumed here for the purpose of simplifying the computation of CFI for both operational purposes and for determination of critical CFI. Since the CFI will be used primarily for comparative purposes between events and not as an absolute measure of the vertical reach of water up a beach, the choice of constant beach characteristics becomes less critical. For purposes in this paper, the beach is assumed to consist of sand with a constant slope of 0.02.

B. Wave Runup

Part of the oscillatory motion of an incident wave is converted into forward motion up the beach in the wave-breaking process. The maximum vertical reach of this water on the beach above still water is defined as “wave runup” (Sorenson, 1993).

Simple monochromatic wave runup for a smooth impermeable surface has been observed by Hunt (1959) to be a function of beach slope, wave height and wave length in deep water:

$$R' = \frac{mH}{(H/L_o)^{1/2}}$$

where “R” is wave runup, “H” is wave height, “*m*” is the beach slope (or tan of the slope angle), and “L_o” is the wave length in deep water. Assuming a constant beach slope and making adjustments to the runup for assumed beach surface conditions (Sorenson, 1993), the runup becomes a function of wave height and period.

C. Wave Setup

Wave setup is the increase in mean water level shoreward of the breaker line due to a net decrease in radiation stress. Only the shore normal component of momentum applies to wave setup (Sorenson, 1993). As applied to the CFI, wave setup refers to the setup value at the still water line (i.e., on the beach).

Longuet-Higgins and Stewart (1964) derived equations for setup. The following from their work, wave setup (d') can be approximated by:

$$d' = \frac{-H^2}{16d_b} + \frac{d_b}{1 + (8d_b^2 / 3H_b^2)}$$

where "H" is wave height, "d_b" is depth at wave breakers, and "H_b" is wave breaker height. Wave breaker height and wave breaker depth are both functions of bottom slope, wave period and deep water wave height (U.S. Army Coastal Engineering Research Center, 1984). When beach slope is assumed, it follows that wave setup ultimately is a function of the variables deep water wave height and wave period.

D. Tides

Tides are the daily rise and fall of the earth's oceans as caused by the gravitational pull of the moon and sun. Worldwide, tides at varying locations can range from as little as one foot to over 30 feet (National Ocean Service, 2000). Published tidal data computed by the National Ocean Service is widely available through independent publications and over the internet.[1]

In many cases, due to the comparative magnitude of tides with respect to the other variables used in the CFI, tides play a dominant role in the CFI. Therefore, it is important to consider not only the times of greatest wave heights and period as they affect the coast, but also conditions near the time of high tides. As a general rule, tides will have risen or fallen a total of these fractions of its range after these successive hours (National Ocean Service, 2000).

1/12	after the 1st hour
1/4	after the 2nd hour
1/2	after the 3rd hour
3/4	after the 4th hour
11/12	after the 5th hour
12/12	after the 6th hour

[1]As of this writing, the National Ocean Service maintains a website at *www.co-ops.nos.noaa.gov*, offering predicted and observed tidal data, including station historical data.

E. Tidal Anomalies

Differences in observed tides from predicted tides can be attributed to a number of causes. These causes can include such meteorological parameters as very high or low atmospheric pressure and strong winds piling up water in coastal areas, as well as topographic and bathymetric considerations which can play an important role in semi-enclosed areas (Britton, 1981). The magnitude of tidal anomalies may vary considerably by location and meteorological situation.

The forecasting of anomalies will depend largely upon the forecasters ability to identify the meteorological situations when such anomalies are likely, and assess the magnitude through some knowledge of the local climatology.

The Process of Determining Critical Values of CFI

In order to determine critical values of CFI in a specific locale as an aid to forecasting coastal flood events, a history of CFI values during both flood and non-flood events needs to be compiled. However, a complete hourly or daily history of CFI is not necessary. A manual examination of key parameters, such as significant wave height and dominant wave period, can identify periods of concern (i.e., periods of relatively large CFI) which, when coupled with computations of CFI during known flood events, should yield a sufficiently detailed history of CFI within the critical range of values.

As stated previously, predicted and observed tides can be obtained readily from internet sources. Computation of runup and setup require significant wave height and dominant wave direction data (or if preferred, peak period and corresponding direction), also readily available from the internet.[2] A computer program such as *Surf* (Elson, 2001) can simplify the necessary computations of runup, setup and CFI. Otherwise, tables and equations collected by Sorenson (1993) allow for the computation of runup and setup.

An example of determining a value of CFI might go as follows. A near shore deepwater buoy report indicates combined seas of 23 ft (7.0 m), with a dominant period of 15 s. Assuming a sand beach with a slope of 0.02 yields wave runup of about 3 ft (0.9 m) and wave setup of 6 ft (1.8 m). A nearby tidal gauge reports a tide of about 10 ft (3.0 m) above Mean Lower Low Water (MLLW). As this is an actual observed tide height, it would be the equivalent of a predicted tide plus tidal anomaly. Using the units in feet, adding runup, setup and tide height above MLLW yields a CFI of 19.

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[2]As of this writing, the National Data Buoy Center maintains a website at *www.ndbc.noaa.gov*, offering complete historical data, as well as current data for buoys maintained by the National Data Buoy Center in the United States.

For each coastal flood event or non-event, the CFI assigned to that event is the peak CFI observed. If for the case above where the CFI was 19, and no flooding was observed, then the critical value for flooding must then be some value greater than 19. Along the North Oregon and South Washington Coast, to date is has been found that coastal flooding has been observed with a CFI as low as 24. Several cases have been observed where the CFI reached 21 with no reported flooding, and in one case the CFI peaked at 22 with no flooding. This infers that the critical value for CFI must be between 22 and 24. To err on the side of safety, local policy is to issue a watch or warning if CFI is expected to reach 22 or greater.

Conclusions

The CFI was developed as an operational tool to aid in the forecasting of, and as a gauge to quantify the magnitude of coastal flood events. The CFI fills a void, by providing an operationally oriented tool to aid in the forecasting of coastal floods generated by extratropical storm systems.

By utilizing the readily available forecast variables of wave height and wave period, and assuming constant physical beach characteristics, wave runup and setup can be approximated. The wave runup and setup are summed with tidal data to generate the CFI.

Acknowledgments

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