Wind Product Inferred From CDIP Buoy Measured Wave Spectra

Kaley Mudd, Sophia Merrifield, Alli Ho, Jim Behrens, Andre Amador, John Lodise

Motivation

- Meteorological data is essential to understanding coastal marine weather conditions
- Offshore surface wind data improve weather forecasting, surface transport estimates, etc.
- In-situ wind sensors offshore are extremely sparse, relative to onshore, due to high cost and challenging environmental conditions
- Coastal Data Information Program (CDIP) wave monitoring buoy array stations can serve as proxy surface wind data sources where direct measurements are unavailable because of the precision, frequency band, persistence, and free availability of the data, both real-time and archived.

Observational Data

Wave Data
The wave buoy records surface displacement and acceleration and applies a Fourier transform over 30-minute intervals to produce wave spectra. Wave energy and wave direction measurements are resolved into 64 bands with a frequency range of 0.0250–0.5800 Hz at CDIP station 185 at Monterey Bay, integrated into the National Data Buoy Center (NDBC) as station 46114.

Wind Data
Wind data were collected every 10 minutes at NDBC station 46042. The raw wind speeds are converted to the standard height of 10 meters following $U_{10} = U_{z} \left( \frac{z}{10} \right)^{1.012}$ (Hsu et al. 1994) where $z_0$ is the anemometer height of 3.8 meters. The wind speed and direction values are averaged over 30-minute intervals to match the temporal resolution of the wave spectra data.

Method

Determining The Equilibrium Range

$E(f) f^4$ has a predicted slope of 0 in the equilibrium range. The frequency range is chosen by minimizing the RMSE between the predicted slope and the actual $E(f) f^4$ data for each possible frequency range.

Wave Spectra → Wind Friction Velocity

Wind friction velocity ($u_\tau$) at each time is calculated via equation (2) by using the average value of $E(f)$ across the fitted frequency range.

Wind Friction Velocity → $U_{10}$

$\tau \approx \rho u_\tau = \rho C_D U_{10}^2$ (3)

Where $\tau$ is the surface stress, $\rho$ is the density of air, and $C_D$ is a viscous drag coefficient. A value of $C_D = 0.00114$ suggested by Large & Pond 1981 is used.

Wind Direction

Wind direction is determined by averaging the wave direction values across the same frequency range used for determining wind speeds.

Results

Wave spectra over time, colored by measured wind speeds. Frequency band fitting method example indicating $E(f) f^4$ (blue), upper and lower limits of the fitted equilibrium range (vertical dotted lines), predicted $f^4$ equilibrium slope (dashed red), and the average $E(f)$ value over that range (solid red).

Figure 3. a) Measured wind speeds plotted against calculated wind speeds (colored by the low limit of the equilibrium frequency range) and the regression function (red). The overall RMSE value is 1.8 m/s. (b) Bias (black), standard deviation (blue), and RMSE (red) values over all wind speeds. (c) Measured direction values plotted against calculated wind direction values (colored by direct-measured wind speeds). The overall RMSE is 42.0° with a mean error of 24.9°. (d) Direction RMSE and mean error for all wind speeds.

Figure 4. Time series comparison of direct-measured (blue) and calculated (green) wind speeds (a) and wind direction (b).

Conclusions

- Wave measurements can be used to estimate wind speeds with less than 2 m/s error in magnitude and 42° error in direction for wind speeds of 5–15 m/s.
- The bias of the calculated wind speeds compared to measured wind speeds is near 0 for wind speeds of 5–15 m/s, and increases for higher or lower speeds.
- It may be useful to determine a minimum and maximum cutoff for wind speeds and directions to decrease overall RMSE values.
- This model can provide remote and short-term forecasts to be used by mariners, oil spill tracking information, and eventually be implemented into a publicly available CDIP online product.

Discussion

Biofouling

- Biofouling causes the high frequency tail of wave spectra to deviate from the $f^{-4}$ equilibrium slope (Thomson et al. 2015).
- Effects of minor biofouling are not expected to make significant impacts on the model as the fitting method should choose a portion of the spectra that is not impacted.
- If biofouling is significant enough that there is no 18-band frequency range that falls in equilibrium, there may be impacts.

Land Proximity

- Proximity to land may have an impact on the frequency range selection because nearshore buoys typically see diurnal wind and wave cycles.
- The fitting method could account for these cycles, but it has not been explored.

Form Factor

- Form factor may impact the model because of varied responsiveness to high frequency waves based on buoy size and shape.

References


