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An Empirical Method for Estimating Surf Heights from Deepwater Significant Wave Heights and Peak Periods in Coastal Zones with Narrow Shelves, Steep Bottom Slopes, and High Refraction

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ABSTRACT

CALDWELL, P.C., and AUCAN, J.P., 2007. An empirical method for estimating surf heights from deepwater significant wave heights and peak periods in coastal zones with narrow shelves, steep bottom slopes, and high refraction. *Journal of Coastal Research,* 23(5), 1237–1244. West Palm Beach (Florida), ISSN 0749-0208.

Surf forecasts are vital for safety, property protection, and planning of coastal activities. In Hawaii, surf is frequently dangerous during the boreal fall through spring for northwest- through north-facing coastal areas, which are characterized by narrow shelves, steep bottom slopes, and zones of high refraction. Forecasts of deepwater wave characteristics have improved with the advancement of the Wave Watch III model. A waverider buoy located 5 km northwest of Waimea Bay, Oahu measures the deepwater wave field. Although the offshore wave field is well forecasted and observed, the transformation to surf heights has not been clearly defined and verified. This paper describes an empirical method for estimating breaker heights derived from a comparison of Waimea buoy measurements and north shore, Oahu daily surf observations, which nominally represent the $H_{1/10}$ for the locations with the highest reported surf and have been recorded in Hawaii scale. The first task of this study is to translate the visual surf observations from Hawaii scale to trough-to-crest heights. The results show that the trough-to-crest heights are twice the Hawaii scale values within the 10–20% margin of error for the full range of breaker sizes encountered in Hawaii. The empirical method is resolved by deriving a coefficient of refraction on the basis of comparisons of the trough-to-crest surf observations with the shoaling-only, estimated breaker heights, which are calculated from the Waimea buoy's significant wave heights and dominant periods. The resultant formula uses offshore wave height and period to estimate surf heights, which represent the $H_{1/10}$ for zones of high refraction, *i.e.,* nominally the areas of highest surf. The empirical formula should be applicable to other coastal zones of the world with similar geophysical traits and could serve as a scale reference for coastal wave models, such as the Simulating Waves Nearshore model.

ADDITIONAL INDEX WORDS: *Visual surf observations, buoy data, transformation.*

INTRODUCTION

Accurate and timely surf forecasts communicated in a clear, concise manner are essential in planning nearshore activities. In Hawaii, a large population of recreational enthusiasts comprising both residents and visitors uses surf forecasts on a daily basis. Forecasts are vital to commercial ventures, coastal engineers, ecosystem and geophysical researchers, and governmental coastal planners in making safe, strategic, and cost-effective decisions.

The National Oceanic and Atmospheric Administration (NOAA) Weather Service Forecast Office (WFO) in Honolulu, Hawaii issues surf forecasts as a range of trough-to-crest heights explicitly for the north-, east-, south-, and west-facing shores in pursuit of protection of life and property. Forecasts are validated by interpretation of offshore buoy measurements and visual surf observations. The complex transformation of wave characteristics from offshore to the surf zone leads to uncertainty in validating breaker heights with deepwater buoy data. Visual breaker observations are the best means of verifying a surf forecast.

Surf observations in Hawaii are routinely taken by various entities, primarily the Ocean Safety and Lifeguard Services Division of the City and County of Honolulu and the Surf

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News Network, Inc., and made publicly available via the media. Heights have traditionally been reported in Hawaii scale feet (HSF), which systematically underestimates breaker size by as much as one-half. Although exactly when and why this tendency originated is highly disputed, it became the primary means of communicating surf size by the late 1960s. The WFO historically issued forecasts in HSF until April 2001, when trough-to-crest heights were used. Since April 2001, surf observations have been made in both the HSF and trough-to-crest fashion. Confusion in the translation from HSF to trough-to-crest values has added uncertainty to the surf forecast validation.

Estimates of offshore wave characteristics have improved in recent years. The Wave Watch III (WWIII) model (TOLMAN, 2002) produces operational global wave field estimates for the oceans and major seas. The high quality of the model output has been verified through comparisons with buoy measurements (WINGEART *et al.,* 2001). At several fixed, nominal locations surrounding the Hawaiian Islands, the WWIII produces a time series of predicted deepwater significant heights, peak periods, and directions. This represents a valuable resource for surf forecasts.

A network of permanent NOAA buoys located roughly 300 to 400 km offshore of the Hawaiian Islands has been in place for two decades. Closer to shore near Oahu, the University of Hawaii has maintained directional waverider buoys for several years off Kailua on the windward side and Waimea Bay on the north shore. Data from these instruments are critical for fine-tuning the short-term surf forecasts.

Although the offshore wave characteristics are well predicted and observed around Hawaii by the WWIII model and buoys, respectively, the transformation of waves from deep water to the surf zone has not been understood well enough to adopt an operational method, which can utilize the offshore information in making explicit surf height estimates.

A thorough literature review concerning the transformation of waves both theoretically and empirically is provided by WALKER (1974). For oceanic island locations, various studies have been made. An investigation was undertaken by LUGO-FERNANDEZ, HERNANDEZ-AVILA, and ROBERTS (1994) at Margarita Reef in southwestern Puerto Rico to relate wave energy distribution to observed reef damage following a hurricane-generated swell. Shoaling effects were calculated from linear wave theory (KINSMAN, 1965; U.S. ARMY CORPS OF ENGINEERS, 1984) and refraction coefficients were derived from refraction diagrams (ARTHUR, MUNK, and ISAACS, 1952). Comparisons of the predictor with observations showed a one-to-one agreement with an 85% level of confidence. Wave refraction at Jaws, Maui, Hawaii has been quantified by FEARING and DALRYMPLE (2003) using a combined refraction/diffraction model (KIRBY and DALRYMPLE, 1983, 1994). It estimates the wave height amplification and depth of breaking point as a function of varying offshore heights and periods. The refractive amplification on the reef is greater than a factor of two relative to an offshore height of 10 ft and period of 15 s. WALKER (1974) estimated shoaling and refraction on an idealized three-dimensional Hawaiian Island reef using both Airy theory and a finite height method. A refraction coefficient greater than two was found to occur over the center of the reef. His results show that conventional refraction analysis is a function of finite height and wave breaking.

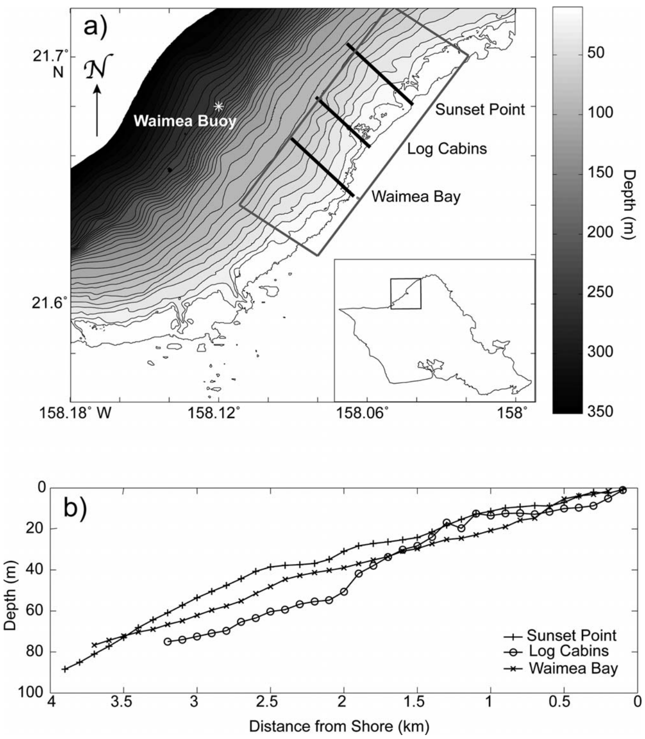

Figure 1. (a) Study area, depths (m). The box denotes the SWAN model domain as shown in Figure 2. (b) Coastal seafloor slopes for locations referenced by the solid lines in (a).

This paper presents an empirical method for estimating surf heights. It is based on a comparison of visual surf observations and estimated breaker heights, which were derived from significant wave heights and peak periods measured at a nearshore, deepwater buoy.

STUDY AREA AND DATA

The north shore of Oahu, Hawaii (Figure 1a) is recognized as one of the world's premier epicenters of surfing because of various physical and geophysical factors. With the proximity to the north Pacific storm track, abundant large surf occurs from October through April. The coastline faces the predominant northwesterly swells (CALDWELL, 2005) while the common trades blow against the waves, creating a desirable surfing form. The coastal bathymetry includes a narrow shelf, a steep slope (Figure 1b), and a pattern of underwater troughs and ridges near the surf zone associated with reef systems, submerged river and stream beds, and ancient lava flows. The narrow shelf means a minimal loss of energy due to bottom friction during wave transformation from deep to intermediate depths. The steep nearshore slope and sharp gradients in depth parallel to the shore result in substantial height amplification from shoaling and refraction as waves enter the surf zone.

With the growth of surfing in the 1960s on the north shore rose casual observations made by surfers, and later in the 1970s, more systematic reports by lifeguards and commercial surf report ventures. Observers ignore the smaller waves and the observations are reported as a height range. As a result, this range is roughly equivalent to the $H_{1/3}$ to the $H_{1/10}$, the average of the highest one-third and one-tenth waves, respectively. Observers sometimes note occasionally higher sets, which are nominally the $H_{1/100}$, or the average of the highest one-hundredth waves.

A digital database of north shore, Oahu surf observations, which is referred to as the Goddard and Caldwell (GC) set, dates back to 1968 and is recorded in HSF. Surf reports are typically made several times per day. The daily value in the GC set represents the upper end of the reported height range ($H_{1/10}$) for the observing time and location with the highest breakers. For the north shore, most observations are taken at Sunset Point, which is usually one of the areas of highest surf along the coast under the dominant northwest swell direction. For days of extreme surf with heights greater than 15 HSF, visual observations are reported from Waimea Bay, where breakers are closer to shore. Comparisons of the GC database to 1981–2002 data from NOAA buoy 51001, which is located roughly 400 km west-northwest of Oahu, show that the surf observations are temporally consistent with the shoaling-only, buoy-estimated breaker heights and have an uncertainty of 10% to 15% of the surf height (CALDWELL, 2005).

The University of Hawaii has maintained a datawell directional waverider buoy roughly 5 km northwest of Waimea Bay, Oahu (Figure 1) in roughly 200 m ocean depth since December 2001. For very long period swell of 17 s or greater, this location is at the starting zone of transformation, although wave height increase is negligible. The buoy is a 0.9-m metallic floating sphere with a combination of a bungee and chain anchoring system.

The directional waverider measures the horizontal and vertical components of acceleration of the buoy, which rides up and down with the waves as it floats on the surface. Data are recorded continuously at a sampling rate of 1.25 Hz. Directional wave spectra are computed on 30-min samples every 30 min. From these spectra, significant wave height, dominant wave period, and dominant wave direction are inferred.

A Simulating Waves Nearshore (SWAN) model (Figure 2) is helpful in understanding the surf height variability along the north shore of Oahu. SWAN is a third-generation wave model for use in coastal areas (BOOIJ, RIS, and HOLTHUIJSEN, 1999). It includes wave generation by winds, propagation, shoaling, refraction, bottom friction, and breaking. It uses a 50-m horizontal grid.

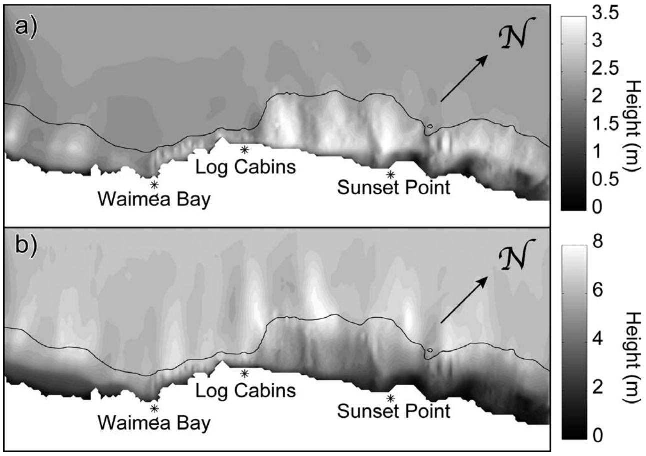

Figure 2. (a) SWAN model significant wave height estimates (m) for a typical winter deepwater swell of 2.5 m at 14 s from 315°. (b) Similar output under extreme offshore swell of 6.5 m at 18.6 s from 317°. The solid line denotes the 20-m depth contour.

ANALYSIS

Translation of HSF to Trough-to-Crest Heights

A translation of the surf observations from HSF to trough-to-crest heights is essential for comparisons with surf estimates derived from offshore wave characteristics, for validating WFO surf forecasts, and for better understanding the historical GC database and north shore, Oahu surf climatology (CALDWELL, 2005). The GC data set is the most requested regional data set from the NOAA Data Center Hawaii Liaison Office for a variety of engineering, research, commercial, and recreational objectives. A translation is presented in this paper on the basis of photographic evidence (CALDWELL and AUCAN, 2004), using surfers as benchmarks.

A breaker or surf is defined at the moment in time when some portion of the front face of a wave becomes vertical and unstable due to a decrease in water depth. The trough-to-crest surf height used in this paper is defined as the vertical distance between the crest and the preceding trough at the moment and location along the wave front of highest cresting, which has been shown in models and observations to be at the time and location of breaking (WALKER, 1974). For locations with high refraction, such as Sunset Point, where most of the visual observations are made, there is a very local alongshore increase in breaker height at the moment of initial cresting. The trough-to-crest height refers to the point along the breaking wave front with the highest height.

Photographs were obtained from Internet sites or directly from photographers. Location and date were a prerequisite. Photographs showing the highest waves of a given day were chosen from the available pool of pictures. Pictures were sorted by size in HSF matching the date to the GC database. Typically, 15 images for each size category were selected (Table 1).

Each photograph requires a surfer or some other identifiable object to use as a benchmark in estimating wave height. Dashed lines were superimposed on each photograph to indicate the approximate trough and crest. An arrow was overlaid next to each benchmark to denote a 5-ft unit. The benchmark arrow was duplicated and subsequent arrows were stacked from trough to crest to gauge the wave size (Figure 3).

Photographs capture a two-dimensional image of a three-dimensional world and distortions of shapes and sizes are

Table 1. *Translation from Hawaii scale feet to trough-to-crest heights (feet). Non-Waimea refers to locations between Log Cabins and Sunset Point.*

	Hawaii Scale Feet	Trough to Crest Height (feet)		Number of Photos	Translation Factor
		Mean	St. Dev.		
Non-Waimea observing locations	2	5.07	0.5	15	2.54
	3	7.44	0.63	15	2.48
	4	9.5	0.79	15	2.38
	6	12.9	0.99	15	2.15
	8	16.6	0.78	15	2.08
	10	20.28	1.64	15	2.03
	12	23.54	1.08	18	1.96
	15	28.4	4.16	8	1.89
Waimea Bay	15	25.73	1.27	8	1.72
	18	28.93	2.79	13	1.61
	20	31.69	2.59	16	1.58
	25	34.07	1.18	14	1.36
	27.5	38.5	1.14	11	1.4
	30	47.6	0.85	3	1.58
	35	51	0	1	1.46
Peahi (Jaws), Maui	18	35	2.78	5	1.94
	30	59.46	6.13	7	1.98
Oahu outer reefs	20	41.3	1.80	4	2.07
	27.5	50.1	1.24	4	1.82
	35	65.9	5	7	1.88

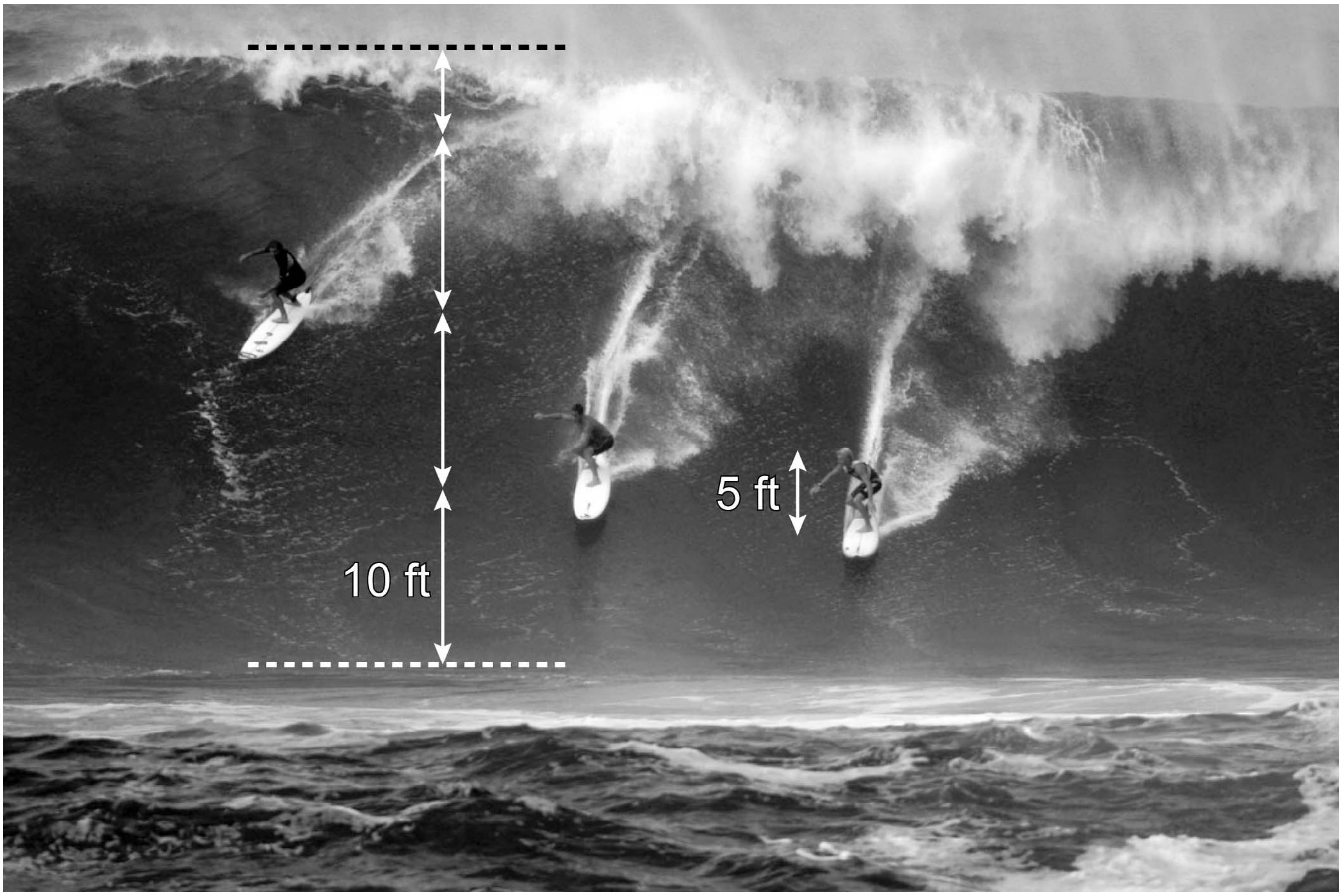

Figure 3. Scaled surf photograph, Waimea Bay, Oahu, January 25, 2003. The arrow next to the surfer is an estimation of a 5-ft unit, from which the 10-ft arrow is derived. The surf observation recorded in the GC dataset was 25 HSF. The trough-to-crest height is estimated at 35 ft. Photographer: Jamie Ballenger.

inherent. Shots taken from a high vantage point, such as a cliff or helicopter, make detection of the wave trough difficult. Wave size is distorted in pictures taken by a swimming photographer near the surfer. Priority in selecting shots was given to images taken by a photographer standing close to mean sea level either on shore or on a floating craft. Distortion of perception decreases as the distance between the camera and the surfer/wave increases.

There are various sources for errors in this exercise. The error associated with trough identification was arbitrarily estimated by the authors as 10% of the wave height. The surfer's height is not known in most images. It is assumed that the average surfer height is 5 ft 9 inches and a typical surfer stance is roughly 5 ft with a 6-inch uncertainty, which leads to an error of 10% in the surf height estimate. For both cases, the errors average out as the number of photographs increases. Since the photographs were selected from still images, it is not certain that any given picture represents the highest height reached by that wave during breaking, or if these few select waves represent $H_{1/10}$, which is assumed in the GC database. With the small number of available pictures per day, the translation based on these pictures likely underestimates the heights in the GC database.

Each scaled photograph was examined to estimate the height to the nearest 10th of a foot for heights below 20 ft and to a quarter of a foot otherwise. For each size category, a mean and standard deviation of the estimated trough-to-crest heights were computed (Table 1). Using two standard deviations as a proxy for uncertainty, the margin of error is within 10–20% of a given size for categories with at least 15 photographs, disregarding the lowest and highest percentage values. For days with surf heights of 15 HSF or less, most photographs are taken at spots from Log Cabins to Sunset Beach, which typically has the highest surf on the north shore (Figure 2a). For days with surf heights greater than or equal to 15 HSF, photographs were further sorted by location: Waimea Bay, Oahu outer reefs, and Jaws (Peahi), Maui. Under northwest swell with 17–20-s wave periods, the travel time from Oahu to Maui is roughly 3 h, which makes comparisons of daily data appropriate. Fewer photographs were available for the Oahu outer reefs than for Waimea Bay. The paired HSF and trough-to-crest heights are plotted in a scatter diagram (Figure 4).

For surf heights from two to eight HSF, the translation shows that the trough-to-crest heights are more than double the HSF observations (Table 1, last column). From eight to 12 HSF, the translation is close to double. An inadequate supply of photographs was available of Sunset Point for heights in the 13–15 HSF range, when the offshore-most breaking point is roughly 1 km from shore and strong currents impede water photography. The available images suggest that the translation of 15 HSF to trough-to-crest heights is slightly less than double. For the entire range from two to 15 HSF, the translation can simply be defined as double within the margin of error.

For surf above 15 HSF, the wave energy at Sunset Point becomes overwhelming and the resultant breakers occur unpredictably over a wide area both parallel and perpendicular to shore. Cresting begins beyond 1 km from shore, reducing the accuracy of observations. The surf breaks uniformly and closer to shore at Waimea Bay, where surf observations are taken.

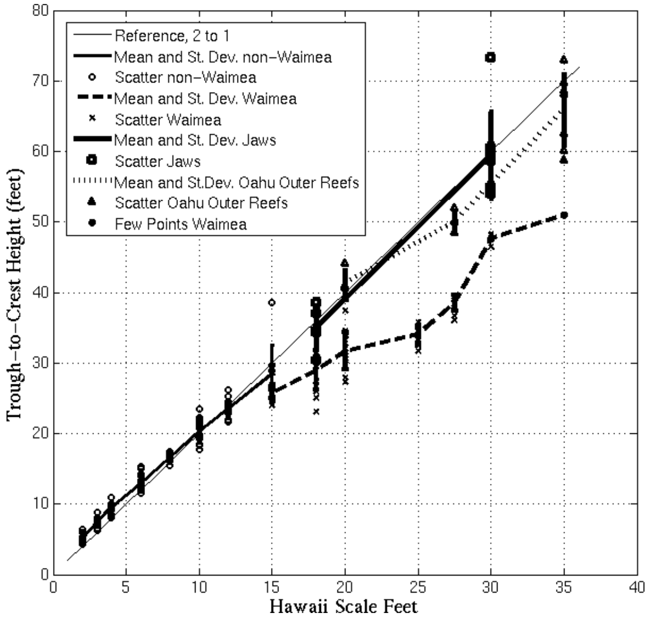

Figure 4. HSF to trough-to-crest height translation. Circles denote individual photographs. Non-Waimea refers to locations from Log Cabins to Sunset Point.

Numerous photographs are available for Waimea Bay during surf in the 12–30 HSF range. The surfers enter the wave about 50–100 m outside the point on the northeast side of the bay and ride at an angle toward the safety of the deep waters in the center of the bay. The wave-entry point shifts northwest of the northeast point of the bay with increasing wave size. At approximately 30 HSF, the entire wave front cascades nearly simultaneously across the breadth of the bay, ending a surfer's chance for a safe ride.

The photographs at Waimea Bay suggest that the trough-to-crest heights are roughly 1.5 times HSF during days with observations in the 15–30 HSF range. Within the collection of photographs, there are several occasions when images were available for the same day from both Waimea Bay and outer reefs of Oahu and Maui. Over the submerged ridges of the offshore reefs to either side of Waimea Bay, the SWAN output (Figure 2b) shows increased heights due to convergence of wave rays, *i.e.,* refraction. Photographs of surfers on outer reefs validate the larger heights relative to Waimea Bay.

In summary, the translation of HSF to trough-to-crest heights is a factor of two within the 10–20% margin of error for the full range of breaker sizes encountered in Hawaii. This assumes the height is defined as the highest height reached in the vertical from trough to crest at any point along the wave front during breaking and zones of high refraction (outer reefs) are included for extreme days when Waimea Bay was the reporting location. The HSF, or simply dividing trough-to-crest height by two, has been adopted by other big wave enthusiasts around the globe as seen in pictures and dialogue from extreme surf contests in California, Peru, and South Africa. It is important for scientists and the general public to understand this relationship for utilizing surf observations reported in HSF.

Empirical Method for Estimating Surf Heights

The GC database in HSF was converted to trough-to-crest heights as defined by the translation factors shown in Table 1. A factor between 2.1 and 2.5 was used for heights less than 7 HSF, whereas a factor of 1.84 was used for heights greater than 21 HSF. For heights of 7 to 21 HSF, the translation was exactly 2.0. The resultant trough-to-crest heights were compared with corresponding data from the Waimea buoy to derive an empirical relation.

Since the surf observations are made during daylight hours, buoy data from only 0700 to 1700 Hawaii Standard Time were considered. For each 30-min buoy reading, a shoaling-only breaker height was calculated following the method of KOMAR and GAUGHAN (1973):

$$H_b = H_o^{4/5}[(1/\sqrt{g})(gP/4\pi)]^{2/5} \tag{1}$$

where H_b = shoaling-only estimated breaker height, H_o = deep water significant wave height, P = dominant wave period, and g = gravity.

Equation (1) assumes wave energy flux is conserved from deep water to the time of breaking, and wave breaking occurs in water depth approximately equal to wave height. Refractive focusing and diffraction are not considered. It also ignores other relevant physics such as bottom friction, currents, wave–wave interactions, and wind. The 30-min buoy reading during the daylight hours with the maximum shoaling-only breaker height estimate was chosen for comparison with the daily surf observation.

Days of strong trade winds or moderate to strong onshore winds relative to Sunset Point were removed from the paired data sets. Under strong trades from 35° to 120°, the Waimea buoy registers wave energy while most reefs from Waimea to Sunset Point are sheltered. During onshore winds, wave observations are less accurate since surfers are usually not in the water and the breaking pattern is irregular. Additional filtering was performed for buoy wave directions greater than 10° and less than 270°, since the observing locations face roughly 315°. Thus, the incident wave directions were confined to within approximately ±55° of a line perpendicular to the coast. The focus of this study is for remote northwest and north-central Pacific swell sources typical of the high surf season. The result was a sample size of 404 pairs.

A scatter diagram (Figure 5) shows the ratio, surf observations to H_b, as a function of H_b. The mean and standard deviation of the ratio for HSF observation sizes was calculated and overlaid. A three-degree polynomial was fit to the mean ratios. This relation represents an empirical estimation of the refraction coefficient, K_r, as a function of the shoaling-only, buoy-estimated breaker height, H_b, or

$$K_r(H_b) = -0.003 \times H_b^3 + 0.0099 \times H_b^2 - 0.025 \times H_b + 1.0747. \tag{2}$$

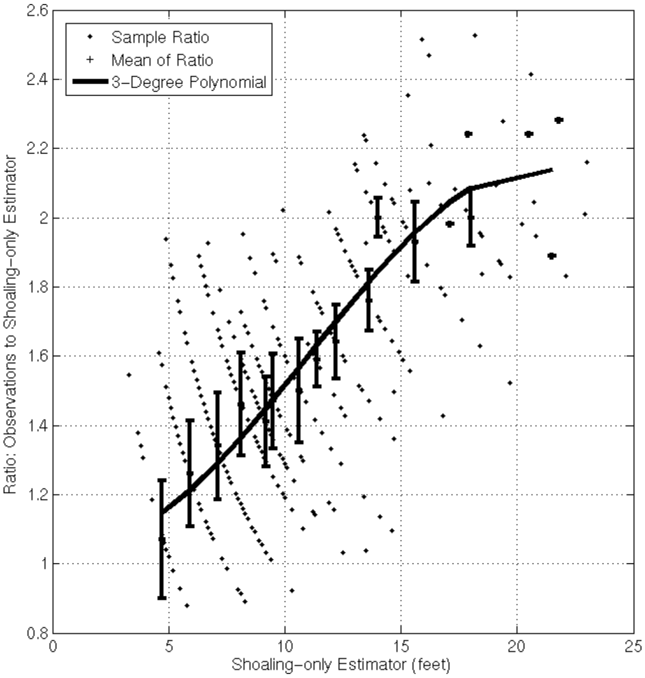

Figure 5. The solid line represents the refraction coefficient as a function of the buoy-derived shoaling-only estimated height. Observations are trough-to-crest heights. A three-degree polynomial was fit to the mean ratios. The bars over the mean ratios denote ±1 standard deviation. No bar denotes sample size less than 5.

For H_b greater than 21 ft, the polynomial becomes unstable and K_r is fixed at 2.145. Thus, the estimated surf height, H_{surf}, based on offshore wave height and period, including shoaling and refraction, is given by

$$H_{surf} = H_b \times K_r(H_b) \tag{3}$$

To test the validity of H_{surf}, Equation (3) was applied to the Waimea buoy data, with filtering on the basis of wind conditions and swell directions as defined previously. A scatter diagram of H_{surf} *vs.* the trough-to-crest surf observations is shown in Figure 6. The correlation coefficient among the pairs is 0.94. A two-sample sign test and Wilcoxon rank sum test with 0.05 significance level and a Kolmogorov-Smirnov test at 0.01 significance level all supported the goodness-of-fit hypothesis that the samples were derived from the same population.

A linear least-squares fit of these pairs shows a nearly one-to-one relation. Since the observations are based on the $H_{1/10}$, it is assumed that the regression line in Figure 6 represents the $H_{1/10.}$ Estimated surf heights over a range of incident offshore heights and periods are depicted in Figure 7. Assuming a Raleigh distribution, additional statistical parameters can be defined:

$$H_{1/3} = 0.79 \times H_{1/10} \tag{4}$$

$$H_{1/100} = 1.32 \times H_{1/10}. \tag{5}$$

The $H_{1/3}$ and $H_{1/100}$ are overlaid in Figure 6. The $H_{1/100}$ and

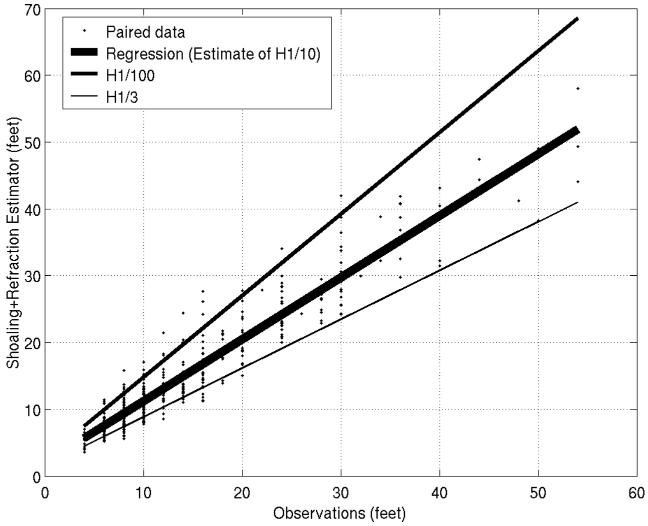

Figure 6. Waimea buoy data are input into Equation (3) to acquire H_{surf}, the estimated surf heights, which are plotted against the trough-to-crest surf observations.

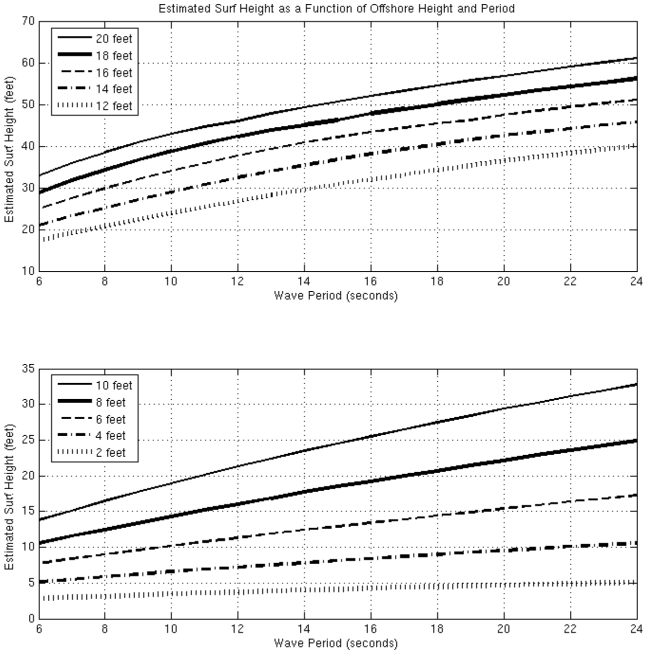

Figure 7. The empirical $H_{1/10}$ (H_{surf}) for varying offshore conditions.

$H_{1/3}$ brackets most of the occasions when the $H_{1/10}$ under- or over-estimated the surf heights.

CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

An empirical technique is described for estimating surf heights in coastal zones with narrow shelves, steep bottom slopes, and high refraction. The method is based on comparisons between visual surf observations from the north shore, Oahu, Hawaii, and nearby deepwater buoy-measured significant wave heights and peak periods from directions within approximately ±55° of a line perpendicular to the coast. The technique provides surf estimates of the $H_{1/3}$, $H_{1/10}$, and $H_{1/100}$, which represent the lower and upper ranges of commonly arriving heights, and the occasional extreme height, respectively. Such information is vital for safety, engineering, environmental research, and coastal planning.

Using this approach, one can also derive an estimate of the maximum expected daily wave height. Since waves break in roughly a depth equal to the breaker height, the resulting surf estimates can be used along with high-resolution bathymetry to give warning to boaters of the offshore boundary of the expected surf zone.

The database of surf observations was recorded in HSF. A translation from HSF to trough-to-crest heights was performed on the basis of photographic evidence. The translation is a simple factor of two within a 10–20% margin of error for the full range of breaker sizes encountered in Hawaii. This translation makes two important assumptions: (1) the trough-to-crest surf height is defined as the vertical distance between the crest and the preceding trough for the moment and location along the wave front of highest cresting, and (2) zones of high refraction (outer reefs) are included for extreme days when Waimea Bay was the reporting location.

Offshore models of the deepwater wave field have improved in recent years and offshore buoys give short-term warnings with a lead time that depends on the buoy's distance from shore. The simple empirical formula for estimating surf heights described in this paper opens the door for more accurate surf forecasts utilizing the offshore swell characteristics. Assuming a directional band of incident swell relative to the coast similar to this study, the method should also be applicable in other coastal zones of the world with similar sea floor topography, which includes most of Hawaii. For future work, testing the use of this method in other areas will be undertaken.

There are opportunities to improve the empirical relation presented in this paper. Future work will target the short-period (<11 s) domain, during which surf heights are overestimated by the empirical formula. This study focused on a sample set representing remote source swell with wave periods primarily in the 10–20-s range. A similar empirical technique could be applied to surf observations from the windward side of Oahu and the nearby deepwater buoy off Kailua for days dominated by short-period swell generated by the prevailing trade winds.

Utilizing high-resolution bathymetry, one can derive refraction coefficients under a range of offshore wave conditions for the study locations used in this paper—Sunset Point, Waimea Bay, and Outside Log Cabins. Both the traditional refraction diagram technique and the contemporary REF/DIF model can be used. The results could help qualify the empirical method as described above.

The empirical relation presented in this paper could be used to calibrate the height scale of estimated breakers as output by coastal wave models, such as SWAN. All coasts of

Hawaii have regions with nonuniform seafloor topography. This results in high refraction at select locations of almost every stretch of coast. One could associate the zones of highest heights in the model output to the surf heights derived from the empirical formula. This relation could be used to adjust the scale of heights in the model output, thus allowing more precise estimates for all surf zones in the model domain. In turn, it would help define the upper limit of expected breakers and increase the accuracy of surf forecasts for all shorelines of Hawaii as well as other areas of the world with similar geophysical coastal features.

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