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TECHNICAL COMMUNICATION

Comparison of Visual Observations of Wave Height and Period to Measurements Made by an Offshore Slope Array

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ABSTRACT

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Records of littoral environment parameters such as wave height, period, and direction are essential to nearshore process studies. The most detailed studies require an elaborate and expensive array of current meters and wave gauges, which allow high resolution spectral analysis of wave and current variability. Studies concerned with low frequency variability or relatively large stretches of coastline may not be able to afford or even need high resolution spectral analyses. Incident wave parameters of study sites that lack offshore wave gauges can be characterized with data collected by human observers from the shoreline (SMITH and WAGNER, 1991). However, without documentation of observational accuracy, human observations provide only a relative comparison of daily littoral environment conditions. These observations become more useful to researchers when confidence limits can be assigned to the data, allowing their applicability to specific projects to be evaluated.

This study compares simultaneous observations made by two observers over a four month period. The study period comprised enough observations to determine confidence limits about estimates of wave heights ranging from 1 to 4 meters and periods ranging from 5 to 20 seconds. These statistics broaden the range of previous statistical comparisons. As in previous studies (SCHNEIDER and WEGGEL, 1980; PERLIN, 1984), observers tend to overestimate the period of short period waves, underestimate the period of long period waves, and underestimate wave height as incident wave height increases.

ADDITIONAL INDEX WORDS: *Visual observations, wave gauge, wave height, wave period.*

INTRODUCTION

The Littoral Environment Observation (LEO) program, established in 1968 by the Coastal Engineering Research Center (CERC) of the U.S. Army Corps of Engineers, provided an inexpensive method of recording nearshore wave, current, and morphologic variables important to coastal planning and engineering problems. Data from the LEO program has been used to predict longshore transport rates, test some beach response models, and document the wave and wind climate of individual observation sites (PERLIN, 1984; SMITH and WAGNER, 1991). Some measure of observation precision and accuracy is necessary, however, in order to develop confidence in the method. This study compares height and period observations to pressure gauge measurements over a wide range of incident wave heights and periods. Statistical analysis documents the observational accuracy and provides confidence limits.

This study, patterned after PERLIN'S (1984) study, contains a broader range of observed wave heights and periods, but uses fewer observers. PERLIN (1984) used six observers who made 26 observations in a 25 hour period at the CERC research facility in Duck, North Carolina, and concluded that the accuracy of breaking wave height and wave period estimates varied with both wave height and period. Visual estimates were compared to simultaneously collected wave gauge measurements. Wave periods reported during the study ranged from 8 to 11 seconds and wave heights ranged from 30 to 90 cm (heights were actually

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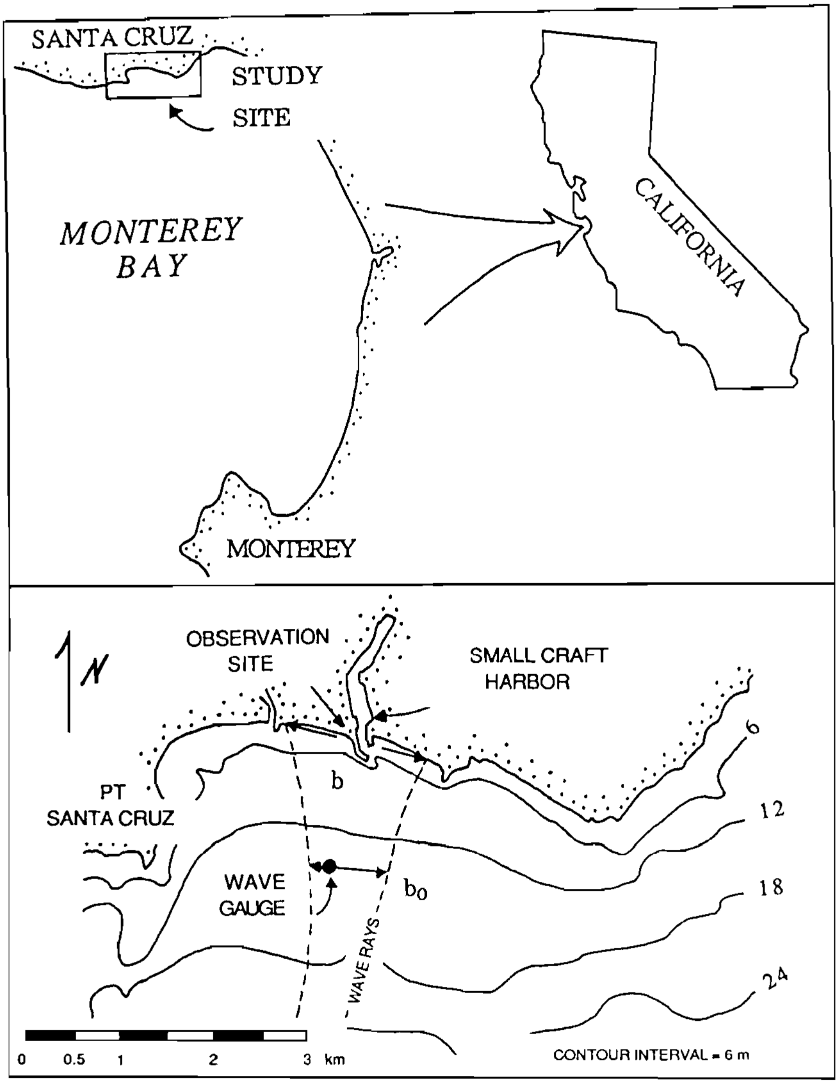

Figure 1. Seabright Beach, west of the small craft harbor, Santa Cruz, California. Ray paths show the refraction of waves passing the offshore slope array.

reported in feet). Perlin concluded that observers tended to overestimate the period of short period waves, underestimate the period of long period waves and underestimate the heights of most waves.

As part of ongoing evaluation of the LEO program, the Coastal Structures and Evaluation Branch of CERC funded a four month study in which two observers recorded estimates of wave height and dominant wave period at adjacent locations along the shoreline of northern Monterey Bay, California (Figure 1). The proximity of these observations to instrument measurements from an offshore slope array provided an excellent opportunity to evaluate the accuracy and usefulness of these low cost littoral environment observations over a wide range of wave heights and periods.

DATA COLLECTION

This study occurred between 19 November 1987 and 17 March 1988. The Santa Cruz Harbor slope array, located in 13 meters of water and 1 kilo-

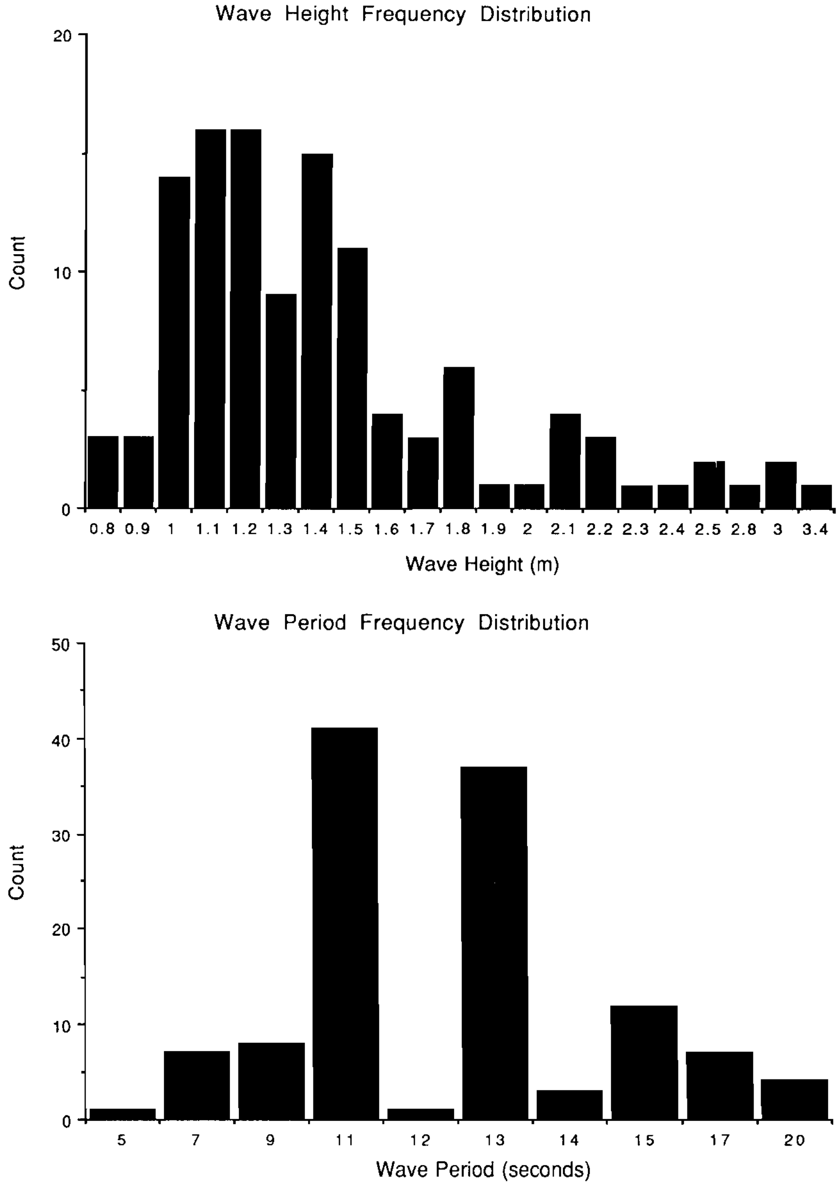

Figure 2. Frequency distribution of wave heights and periods recorded by the Santa Cruz harbor slope array between 19 November 1987 and 17 March 1988.

meter offshore from the study beach, recorded wave height and period continuously throughout the study. The Coastal Data Information Program (sponsored by the U.S. Army Corps of Engineers and the State of California Department of Boating and Waterways) provides monthly reports of wave period and height information that is recorded four times daily. Since most littoral environment observations in this study took place in the morning, we compared the significant wave height, and dominant period reported at 0830 hours by the slope array to the littoral observations. Wave heights during the study period ranged from 80 to 340 cm while periods ranged from 5 to 20 seconds (Figure 2).

Both observers had considerable prior experience estimating wave heights and periods. Out of the 136 days encompassed by the study period, one observer (A) collected information on 72 days while the other (B) collected data on 62 days. Each observer estimated the height of the breaking waves, and estimated the wave period by recording the time for 11 waves to break on the beach and dividing through by 10. There is not an offshore bar at the study site; the beach face is relatively steep, and the waves broke at nearly the same position, regardless of wave height.

DATA TRANSFORMATION

Since shoaling and refraction modify the wave heights between the offshore slope array and the study site, the significant heights reported by the offshore slope array must be corrected for shoaling and refraction. The amount that the wave heights are modified depends on both direction of wave approach and wave length. This analysis uses an equation developed by KOMAR (1976), which is an empirically derived shoaling equation based on linear wave theory, to transform the wave heights reported at the offshore array:

$$H_b = (0.563)H_o^{4/5}(b_o/b)^{1/2}L_o^{1/5} \qquad (1)$$

where:

H_b = the predicted wave height at breaking
H_o = the deep water wave height
$(b_o/b)^{1/2}$ = the refraction coefficient
L_o = the deep water wave length

The deep water wave length varies with wave period while the relationship of the deep water wave height to the height reported by the slope array varies with both period and water depth at the slope array. The appropriate values of H/H_o (where H is the wave height at the slope array) and L_o can be selected from tables in *Oceanographical Engineering* (WEIGEL, 1965) for each wave period. The wave heights at the slope array are transformed to the predicted height at breaking by period bands.

The refraction coefficient accounts for the dispersion of wave energy between the slope array and the breaking point and varies depending on the angle of incidence for the income waves. This study assumes that the amount of refraction is constant for all waves and the value b_o/b is 0.5 (Figure 1) (b_o/b actually varies between 0.33 to 1.0). These transformations ought to provide a more realistic time series of wave heights that would be observed from the beach. However, dissipation, wave-wave interactions, and changes in the angle of wave approach also affect wave heights at the beach but are not accounted for.

We did not transform the wave period, although comparisons made when bi-modal spectra occurred may benefit from a simple transformation. The Coastal Data Information Program reports period data as energy per period band. The dominant period selected and that used to calculate the shoaling transformation was the central period of the band with the highest energy density. Occasionally two peaks indicated that at least two periods were prevalent and the average of these two was selected for the reference period. However, a bi-modal spectra reduces the observed wave period; an average of the two periods will not be observed. Note that when the wave frequency spectra is bi-modal with peaks at P_1 and P_2, the number of waves passing a point in time t is:

$$\#\text{waves} = (t/P_1) + (t/P_2) \qquad (2)$$

where P_1 and P_2 are the periods of the two incoming waves. Thus, the observed wave period is:

$$P_{obs} = t/\#\text{waves} = P_1P_2/(P_1 + P_2) \qquad (3)$$

For example, if two wave groups approach the shore, with 10 and 12 second periods, the observed wave period would be about 5.5 seconds.

Also, the energy density spectra can change rapidly and discrepancies between the reported spectra and those which apply at the time of shore observations may increase the difference between observed and reported values.

STATISTICAL METHODS

Comparisons of shore observations of wave height and period to data obtained from the offshore slope array (Figure 3) employed the paired t-test (ZAR, 1974), which tests the significance of the difference between two means and also provides confidence limits about this difference. The paired t-test is used when the measurements in the two samples are related (in this case, measurements taken on the same day are paired). The calculated t-value is compared to the critical two-tailed t-value ($t_{a(2),v}$) at (1 − a) confidence and v degrees of freedom:

$$t = D/S_d \qquad (4)$$

where:

$$D = (1/n)[(A_1 - B_1) + (A_2 - B_2) + \ldots + (A_n - B_n)] = (1/n)[d_1 + d_2 + \ldots d_n] \quad (5)$$

is the mean of the differences between the two samples and

$$S_d = (1/n)^{1/2}[(d_1 - D)^2 + (d_2 - D)^2 + \ldots + (d_n - D)^2]^{1/2} \quad (6)$$

is the standard error of the difference between the two samples. The means are significantly different if the calculated t-value is less than the critical value.

Confidence limits are calculated using the critical t-value and the standard error:

$$D \pm (t_{a(2),v})(S_d) \quad (7)$$

where:

v = the degrees of freedom from both samples (# sample pairs − 1)

Significance and confidence limits are reported at the 95% confidence level (a(2) = 0.05).

This analysis attempts to characterize how well field observations compare with instrument records and it attempts to find relationships between wave parameters and the fit of field observations to the instrument record. In order to observe the effects of period and wave height variation on observational accuracy, the data were first divided into two sets. One data set compares all of observer A data to corresponding slope array data; the other data set compares all of observer B data to the corresponding slope array data. These comparisons utilize the most data and resolve the relationship of observational error to both wave period and wave height.

Each of these data sets is divided into two more data sets, one sorted into wave height categories and the other sorted into period categories. The wave heights (corrected for shoaling and refraction) and periods reported at the offshore slope array are used to define the categories. Within each category, the mean of observer data is compared to the mean of the slope array data.

RESULTS

The statistical results reveal that the accuracy of wave height observations can depend strongly on both incident wave height and period (Figures 4 and 5). Accuracy of wave period observations show strong dependence on wave period but little dependence on wave height (Figures 4 and 5).

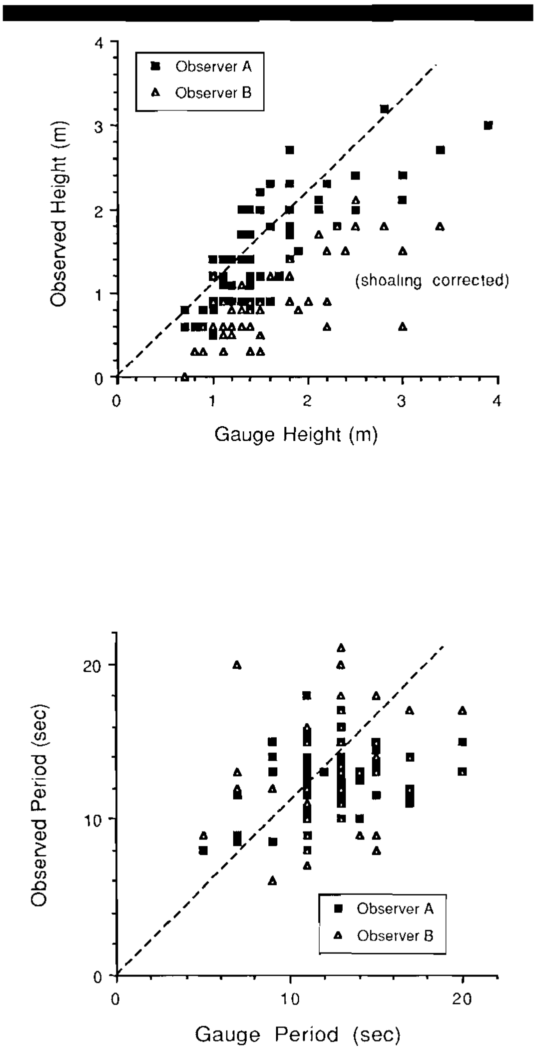

Figure 3. Relationship of observed to gauge measured data.

A. Comparison of Observer A data to Offshore Array

Observer A height observations did not differ significantly from slope array data over most height categories, while height observations were significantly different in some period categories. Period estimates differed significantly from the slope array data for both long and short period waves (Figures 3 and 4).

(1) Heights of high waves (greater than 2.0 meters) tend to be underestimated by 33 ± 28 cm.

(2) The height of short period (7–9 seconds) waves tended to be overestimated (not significantly).

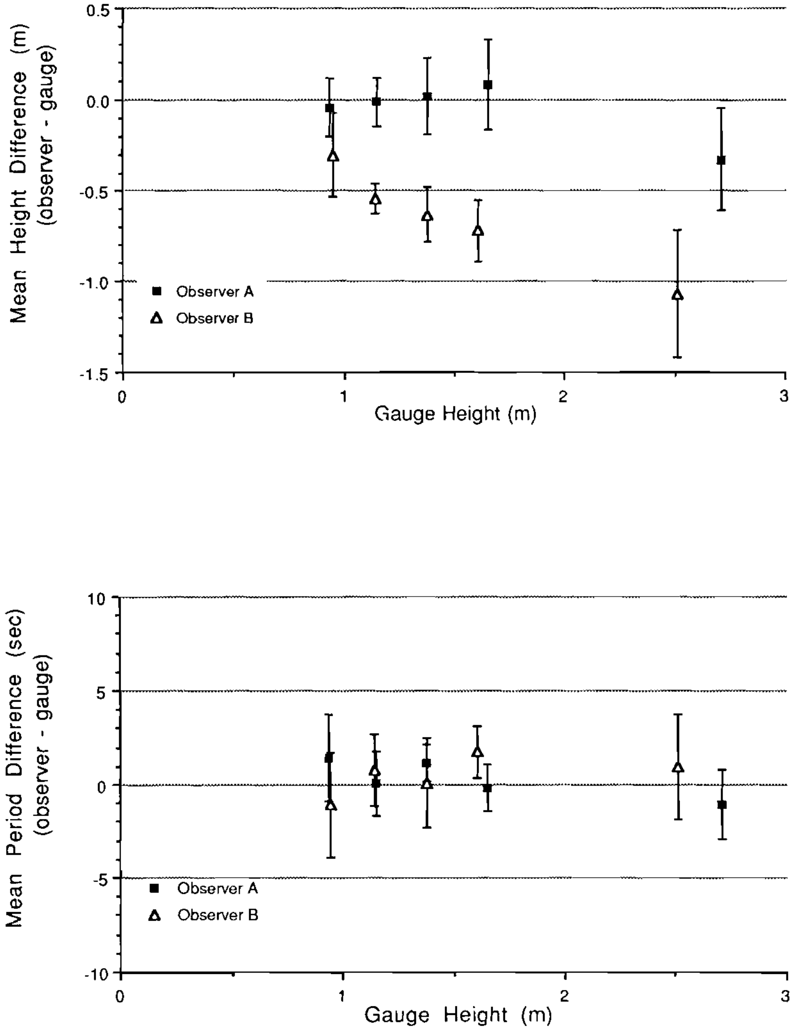

Figure 4. Accuracy of height and period estimates categorized by wave height. Error bars represent 95% confidence limits.

(3) The height of long period (greater than 14 seconds) waves tended to be underestimated by as much as 40 ± 24 cm.

(4) The period of short period (less than 11 seconds) waves was overestimated by as much as 3 ± 1 seconds.

(5) The period of long period (greater than 14 seconds) waves was underestimated by 5 ± 1 seconds.

B. Comparison of Observer B data to Offshore Array

Observer B underestimated the height of all waves, underestimating large waves the most and small waves the least. The differences between the observed and predicted wave heights did not vary significantly over all period categories. However, the period estimates were significantly different over most period categories and behaved similarly to observer A (Figures 3 and 4).

(1) Heights of high waves (greater than 2.0 m) tend to be underestimated by 1.01 ± 35 cm.

(2) Heights of waves less than 1.0 m were underestimated by 31 ± 23 cm.

(3) Wave heights within all period categories were underestimated by 47 ± 20 cm to 80 ± 21 cm. None of these estimates were significantly different from each other.

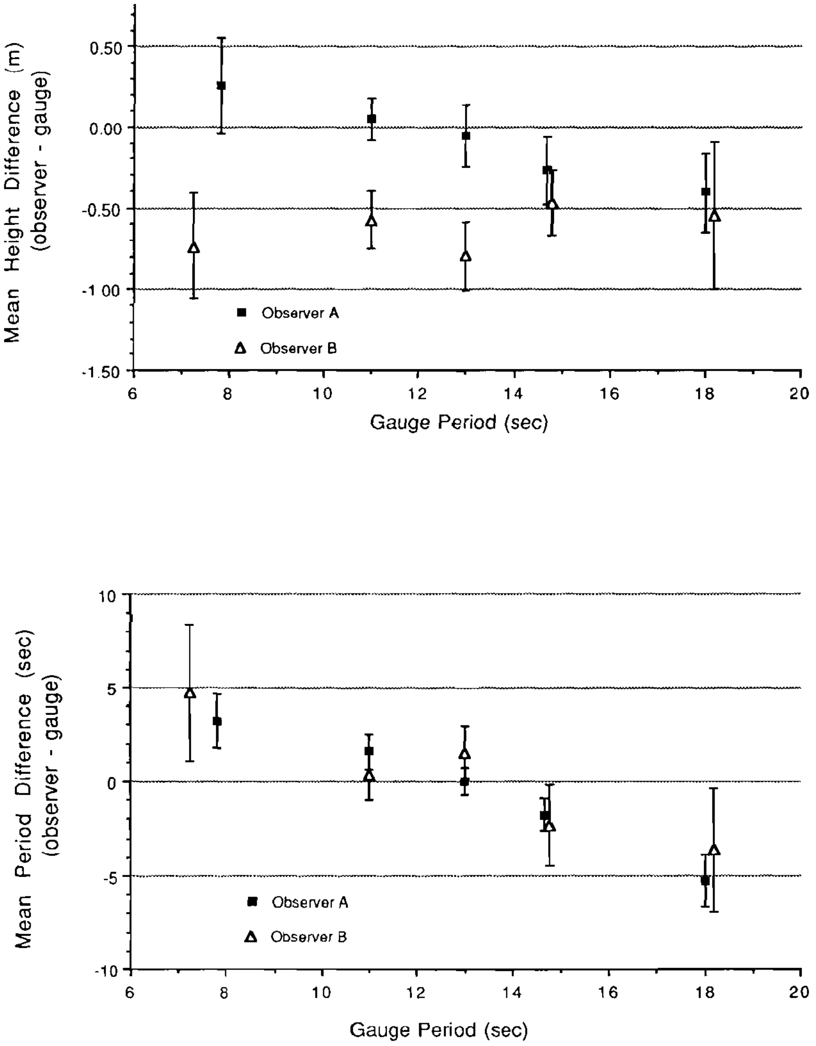

Figure 5. Accuracy of height and period estimates categorized by wave period. Error bars represent 95% confidence limits.

(4) The period of short period (less than 11 seconds) waves was overestimated by 5 ± 4 seconds.

(5) The period of long period (greater than 14 seconds) waves was underestimated by 4 ± 3 seconds.

CONCLUSIONS

The wave height and period measurements within several height and period categories suggest several statistically significant relationships between observation accuracy and wave parameters. In general, both observers underestimate the height of large waves, overestimate the period of short period waves, and underestimate the period of long period waves. These systematic differences between observations and gauge records can be used to isolate causes of the discrepancies and indicate the confidence levels of these records, which makes the LEO data more useful to scientists, engineers and planners.

The causes of the error trends reported above may result from the variable behavior of waves in shallow water, variable observation difficulty, and basic discrepancies in how the slope array data is reported compared to how an observer on the beach reports data. Short period waves tend to be lower, less distinct, and more interactive with other waves. Thus some of these waves will be missed by observers as it becomes difficult to distinguish individual waves. Long period waves, which tend to be higher, groupy, and have more energy will be reported as the dominant period by the slope array. Shorter period waves, however, may not be distinguished from the dominant swell by observers. Also, the groupiness of longer period waves allows shorter period waves to dominate in the surf zone during wave-group height minima.

The height of long period and high waves, which were underestimated by both observers, may be reduced by dissipation between the slope array and the beach. Also, larger waves will break farther offshore; an observer may not be able to compensate for the added distance between himself and the breaking wave. Dissipation effects are usually negligible unless the waves travel over a wide shelf (WRIGHT *et al.*, 1987). However, there is no clear definition of how wide the shelf must be to make dissipation effects significant.

PERLIN (1984) suggests that improvements to the observation techniques used in the LEO program should not raise the cost nor increase the amount of time required to make the observations. He suggests that some sort of graduated staff could be installed if observation sites were near structures. Further improvements can be made to the observation technique. Rather than recording a mentally averaged estimate of wave height, observers might record their estimates of the height of ten or more consecutive waves, and then average these values. This will provide a range of heights as well as an average height value.

Although the accuracy of wave height and period often varied significantly from the gauge data, systematic behavior of this accuracy ought to allow coastal researchers to use this data within the bounds of the confidence limits for each type of observation. The precision of the LEO observations may be adequate for some research needs and such observations can provide a reasonable estimate of the general wave climate at sites lacking wave gages.

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□ RÉSUME □

Les enregistrements de période, hauteur, direction de la houle sont fondamentaux pour l'étude des processus d'actions littorales. Les études plus détaillées nécessitent courantomètres et marégraphes qui permettent une analyse spectrale de la variation des houles et des courants à haute résolution. Pour les sites où la variabilité de la fréquence est faible, ou bien pour de larges portions de littoral, une analyse spectrale à haute résolution n'est pas permise ou n'est pas nécessaire. Les paramètres de la houle incidente des sites où les marégraphes manquent peuvent être caractérisés par les données d'observations visuelles depuis la côte (Smith et Wagner, 1991). Pourtant on ne peut attendre de ces observations qu'une comparaison relative des conditions journalières de l'environnement littoral. Elles deviennent beaucoup plus utiles lorsque l'intervalle de confiance peut être attribué aux données, ce qui permet de les appliquer pour évaluer des projets spécifiques. Cette étude compare simultanément des observations faites par deux personnes sur une période de quatre mois. Cette période est trop courte pour déterminer un intervalle de confiance pour l'estimation de la hauteur de la houle (variant de 1 à 4 m) et de la période (variant de 5 à 20 secondes). Ces statistiques élargissent l'ordre de grandeur des observations dans les comparaisons statistiques antérieures. Dans ces études (Schneider et Weggel, 1980; Herlin 1984), les observateurs ont tendance à surestimer la période des houles courtes, et à sous estimer la période des houles longues, et la hauteur de la houle lorsque augmente la hauteur de la houle incidente.—*Catherine Bousquet-Bressolier, Géomorphologie E.P.H.E., Montrouge, France.*

□ RESUMEN □

Para estudiar los procesos costeros, los parámetros ambientales tales como la altura, el período y la dirección de las olas son de suma importancia. Los estudios detallados requieren a su vez un elaborado y costoso conjunto de correntógrafos y olígrafos, de modo tal que permitan realizar con los datos de olas y corrientes un análisis espectral de alta resolución para el oleaje y conocer la variabilidad de la corriente. Los estudios relativos a la variabilidad de las bajas frecuencias o sobre extensiones de costas relativamente grandes, pueden no ser adecuados para realizar análisis espectrales de alta resolución. Ante la carencia de olígrafos, en aguas profundas, que permitan conocer los parámetros de las olas incidentes en el sitio de estudio, éstos pueden ser caracterizados por medio de los datos que son capaces de efectuar observadores situados en la playa (Smith y Wagner, 1991). Sin embargo, si no existen antecedentes sobre la precisión de las observaciones, los observadores sólo proveen una comparación relativa de las condiciones diarias del ambiente litoral. Estas observaciones se tornan muy útiles para los investigadores cuando es posible asignar a los datos límites de confianza, permitiendo así su aplicabilidad a proyectos específicos.

En este estudio se comparan observaciones simultáneas realizadas por dos observadores durante un período de 4 meses. El período de estudio consideró suficientes observaciones como para determinar los límites de confianza en las estimaciones de alturas de olas comprendidas entre 1 a 4 m y períodos de 5 a 20 s. Tal como fue establecido en estudios previos (Schneider y Weggel, 1980; Perlin, 1984), los observadores tienden a sobreestimar el período de las olas de corto período, a subestimar el período de las olas de largos períodos, y a sobreestimar las alturas de las olas incidentes cuando las altura de las olas aumentan.—*Néstor W. Lanfredi, CIC-UNLP, La Plata, Argentina.*

□ ZUSAMMENFASSUNG □

Für die Feststellung küstennaher Prozesse ist die Registrierung der beeinflussender Faktoren wie Wellenhöhe, periode und richtung sehr wichtig. Sehr detaillierte Studien erfordern ausgesuchte und teure Ausrüstungen für Strömungsmesser und Wellenpegel, die eine Spektralanalyse der Wellenveränderung und der Strömungsvariabilität mit großer Aufloösung erlauben. Untersuchungen mit einer geringen Spannbreite der Variabilität oder solche entlang langer Küstenstrecken sind für solche Studien dagegen weniger geeignet. Eher zufällige Beobachtungen über Wellenparameter ohne Benutzung von Wellenpegeln im freien Wasser sind etwa so zuverlässig wie reine Beobachtungen an der Küstenlinie. Ohne Beschreibung der Genauigkeit der Beobachtungen haben solche optischen Registrierungen für Vergleichszwecke jedoch nur einen geringen Wert. Für andere Forscher sind solche Beobachtungen schon eher nützlich, wenn über die Mitteilung der Zuverlässigkeit der erhobenen Daten ihre Verwertung für bestimmte Projekte eingeschätzt werden kann Diese Studie vergleicht gleichzeitig angestellte Beobachtungen von zwei Beobachtern über einen Zeitraum von 4 Monaten. Dabei wurden genügend Einzelfälle registriert, um die Zuverlässigkeit der Abschätzungen bei Wellenhöhen zwischen 1-4 Metern und Wellenperioden von 5 20 Sekunden beurteilen zu können. Diese Statistiken erweitern bereits früher gewonnenes Material. Wie bereits früher mitgeteilt (Schneider und Weggel, 1980; Perlin, 1984) überschätzen die Beobachter die Periode kurzer Wellen und unterschätzen sowohl langperiodische Wellen sowie auch die Wellenhöhe, wenn diese im Verlauf der Beobachtung zunimmt.—*Dieter Kelletat, Essen, Germany.*