Low frequency sea level variability on the Middle Atlantic Bight

by Dong-Ping Wang[1]

ABSTRACT

Low-frequency sea level fluctuations on the Mid-Atlantic Bight, from Cape Cod to Cape Hatteras, and their relations to wind forcing were examined over a one-year (1975) period. The dominant sea level fluctuations occurred at time scales of 4 days, and they were coherent over the entire Bight. On the other hand, sea levels were not coherent between the southern (south of Kiptopeake B.) and northern part at shorter time scales.

Local wind forcing was important from Cape Cod to Cape May; most of the sea level change was driven by the alongshore (northeast-southwest) wind. In addition, the east-west wind set up a large surface slope between Nantucket and Sandy Hook. The wind set-up may be due to the bent coastline around Sandy Hook; the frictional effect may also play a role.

South of Cape May, the local alongshore wind forcing was dominant at time scales shorter than 3.3 days (in winter). At longer time scales, contribution from free shelf waves was significant. A southward phase propagation of 600 km/day was found between Cape May and Cape Hatteras, which is consistent with the shelf wave model. The dominance of free waves apparently was due to the lack of coherent wind forcing south of Cape May.

1. Introduction

In their review of circulations on the Mid-Atlantic Bight, from Cape Cod to Cape Hatteras, Beardsley *et al.* (1976) indicated that most of the low-frequency sea level and nearshore currents are wind-driven. They further hypothesized, based on Beardsley and Butman (1974), that the winter "northeaster" whose wind stress tends to parallel the coasts, is the most effective wind forcing. Evidence for alongshore wind forcing was also obtained off Long Island (Scott and Csanady, 1976).

In addition to wind-driven currents which occur mainly at several day time scales, there is a mean, southwestward flow (Beardsley *et al.*, 1976; Boicourt and Hacker, 1976; Mayer *et al.*, 1979). Since mean flow apparently moves against mean wind, its obvious driving force is a mean southwestward pressure gradient (Stommel and Leetmaa, 1972). Scott and Csanady (1976) claimed some indirect observational evidence of mean alongshore slope which, however, appears to be tentative (Sturges, 1977; Beardsley *et al.*, 1977).

1. Chesapeake Bay Institute, The Johns Hopkins University, Baltimore, Maryland, 21218, U.S.A.

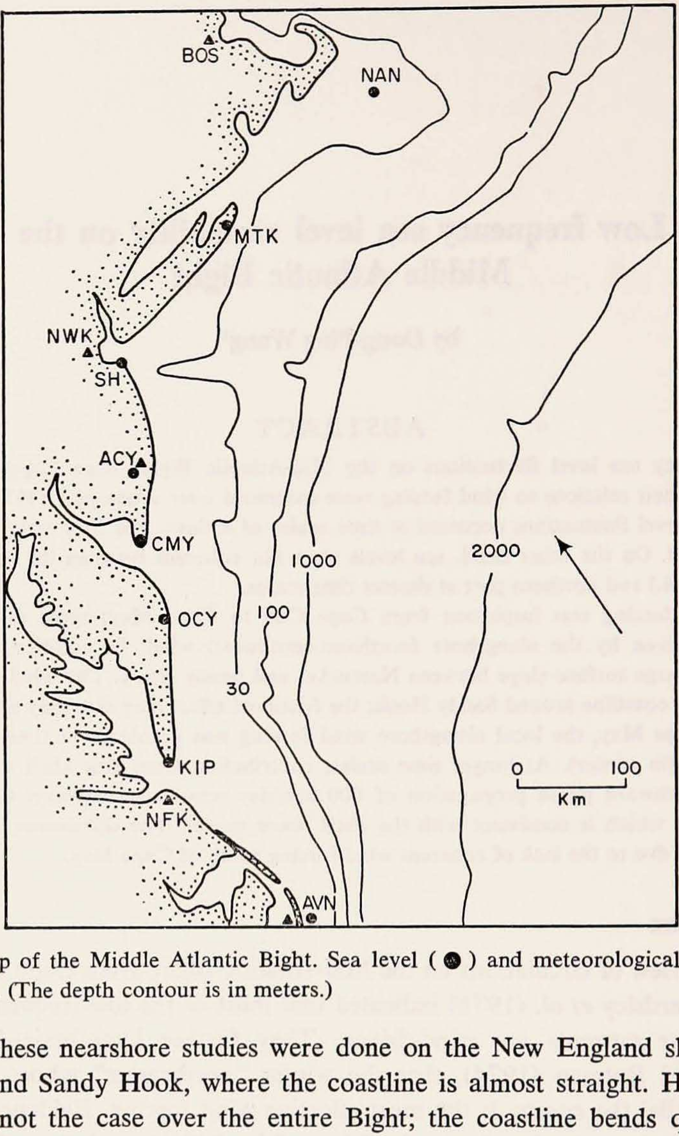

Figure 1. Map of the Middle Atlantic Bight. Sea level (●) and meteorological (▲) stations are marked. (The depth contour is in meters.)

Most of these nearshore studies were done on the New England shelf between Cape Cod and Sandy Hook, where the coastline is almost straight. However, this is certainly not the case over the entire Bight; the coastline bends quite sharply around Sandy Hook and Norfolk. How does a bent coastline affect the nearshore water response? Is a "local" Ekman model valid? Is there any communication between different parts of the Bight? Some of these questions probably have already been answered or speculated upon. However, without a long-term, large-scale study, most of the hypotheses cannot be rigorously tested.

In this study, we examine sea level and wind data over a one-year period to study characteristics of coastal water response on the Mid-Atlantic Bight. Efforts are made also to compare our statistical analyses with previous results derived mainly from event studies.

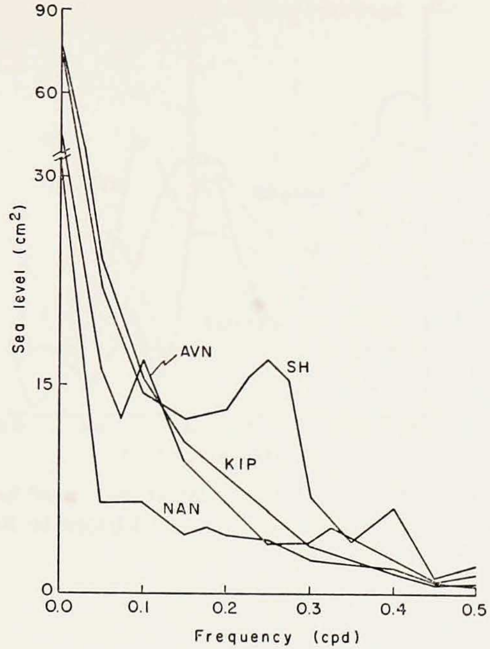

Figure 2. Power spectrum of sea level at Nantucket, Sandy Hook, Kiptopeake B. and Avon.

2. Low-frequency sea level variations

Tidal data were obtained for eight stations on the Mid-Atlantic Bight: Nantucket, Montauk, Sandy Hook, Atlantic City, Cape May, Ocean City, Kiptopeake B. and Avon (Fig. 1), over a one-year (1975) period. Original records were lowpass filtered to remove diurnal, semidiurnal and high-frequency fluctuations. (Filter response amplitude is 98% at 50 hr, 50% at 33 hr and nil at 24 hr.) Lowpass records were then decimated to a 6-hr interval.

Meteorological data (surface atmospheric pressure, wind speed and direction) were obtained for five stations: Boston, Newark, Atlantic City, Norfolk and Avon (Fig. 1), over the same period. Data were lowpass filtered and decimated to a 6-hr interval. Sea level was then adjusted for barometric effect; though the barometric contribution was small.

The spectrum of low-frequency sea level was computed for the total one-year period with a 80-hr lag window; corresponding frequency resolution is 0.025 cpd (cycle per day), and the number of degrees of freedom is 42.5. On the New York Bight, between Montauk and Cape May, the energy spectra were similar and they had distinct peaks at 4 and 2.5 days. (Only Sandy Hook is shown in Figure 2.) To the east and south, the energy level was much lower at time scales shorter than one week, and spectrum peaks were not present at Kiptopeake B. and Nantucket (Fig. 2).

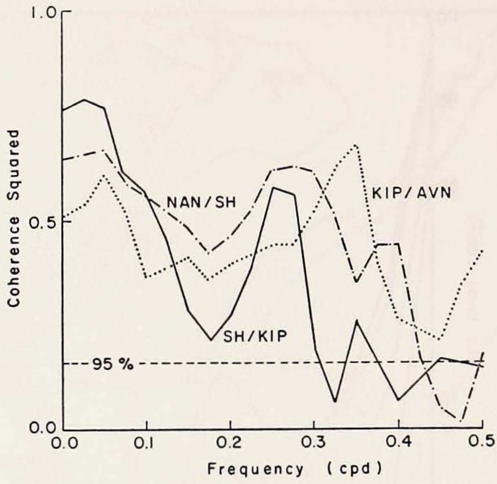

Figure 3. Coherence squared of sea level between: (a) Nantucket and Sandy Hook (- • - - • -), (b) Sandy Hook and Kiptopeake B. (———), and (c) Kiptopeake B. and Avon (• • • • • •). (The 95% significance level is marked.)

At longer time scales, the energy level was about the same from Sandy Hook to Kiptopeake B., but it dropped considerably towards Nantucket. Sea level spectrum at Avon had peaks at 10 and 3 days (Fig. 2), which was somewhat different from the others.

Coherence of sea level was high ($\gamma^2 > 0.9$) on the New York Bight at all time scales (Figure not shown). It remained significant east to Cape Cod with the exception of periods shorter than 2.5 days (Fig. 3). To the south, coherence between Sandy Hook and Kiptopeake B. was significant at time scales longer than 10 days and at a 4 day time scale. These results were consistent with Beardsley *et al.* (1977) and Boicourt and Hacker (1976) who suggested that during a wind event, sea levels were coherent over the entire Bight.

At time scales shorter than 3.3 days coherence between Sandy Hook and Kiptopeake B. was only marginally significant (at 95% level) (Fig. 3). On the other hand, coherence between Kiptopeake B. and Avon was high, particularly at time scales of 3 days. In other words, while the short period sea levels were coherent on the southern Mid-Atlantic Bight, they were not coupled to the northern part. Coherent short period motion was also found south in the North Carolina coast (Brooks, 1978).

On the New York Bight, there was no significant phase change of coherent fluctuations. In other words, sea levels between Montauk and Cape May were simple oscillations; in fact, a single empirical mode (from empirical orthogonal function analysis) accounted for 94% of the total variance. Modal amplitude was 10.2, 15.4

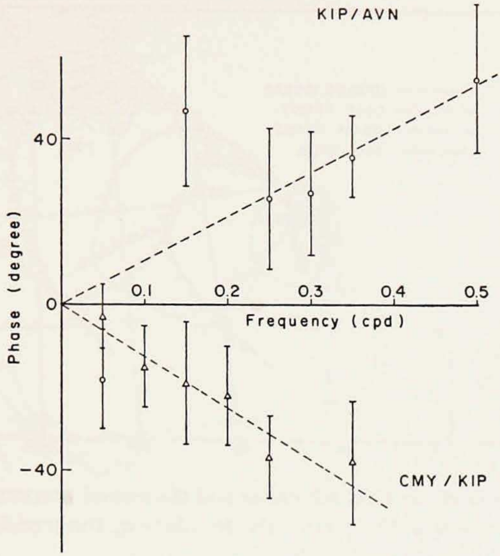

Figure 4. Phase difference between: (a) Cape May and Kiptopeake B. and (b) Kiptopeake B. and Avon. (The error bar is based on 95% confidence interval, and the dashed line corresponds to a southward phase speed of 600 km/day.)

and 14.0 cm, and the variance explained was 89, 97 and 94% at Montauk, Sandy Hook and Cape May, respectively.

Between Nantucket and Montauk, there was in general a westward phase propagation. However, the phase changes were small ($< 10°$), and hence, the corresponding phase speed was irregular, averaging about 2000 km/day. On the other hand, consistent southward phase propagation was found from Cape May to Cape Hatteras (Fig. 4). Between Cape May and Kiptopeake B., the southward propagation at about 600 km/day was evident at all time scales for coherence squared > 0.5. Between Kiptopeake B. and Avon, similar phase speed was found also at time scales shorter than 4 days. However, the longer period motion did not have the same characteristics.

In essence, the most distinct sea level fluctuations on the Mid-Atlantic Bight occurred at the 4 day time scale, whose amplitude was large between Sandy Hook and Cape May. The 4 day motion was coherent over the entire Bight, with a time lag of about 20 hr between Cape May and Cape Hatteras. In contrast, there was only a small time lag (~ 3 hrs) from Cape Cod to Cape May. In the light of simple coastal water response model (e.g., Gill and Schumann, 1974), these results seem to suggest primary wind forcing on the New York Bight, and downstream wave influence on the southern Bight. Relations of sea level to wind forcing are examined in the next section.

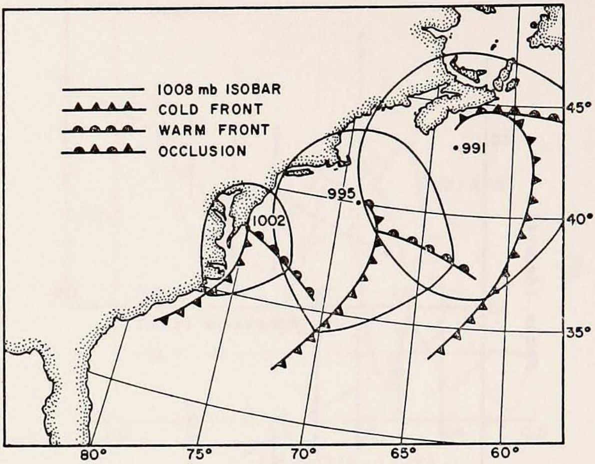

Figure 5. Time evolution of the 1008 mb isobar and the central pressure (in mb) for the model cyclone, over two successive 12 hr intervals. In addition, front positions are shown in the figure. (Adapted from Mooers *et al.*, 1976.)

3. Wind forcing

Mooers *et al.* (1976) have conducted an extensive study of meteorological forcing fields of the Mid-Atlantic Bight. Dominant synoptic scale disturbance was the winter cyclone which passed through the area about every 8 days (based on 1970 data). Pressure disturbance was coherent over the entire Mid-Atlantic Bight, and it propagated to the northeast at a speed of about 15 m/s. Mooers *et al.* (1976) also constructed a model cyclone based on a total of 34 extratropical cyclones affecting the Bight area in the 1972-1973 and 1974-1975 winter seasons. A cyclone passes across the east coast between Cape May and Kiptopeake B. (Fig. 5). As it travels over water, its central pressure drops and the size increases. Its maximum wind, however, only changes slightly during the course of cyclone development.

Our surface atmospheric data (from land stations only) indicated a similar, large-scale feature; the dominant time scale, however, was 6 days (0.175 cpd) (Fig. 6a). In other words, cyclones passed more frequently through the Mid-Atlantic Bight in 1975 than in 1970. There were also secondary energy peaks at 0.25, 0.325 and 0.4 cpd, whose origins were not clear. (It is interesting to note that the frequency difference was 0.075 cpd between two adjacent peaks.)

Windstress spectrum had the same 6 day peak (Fig. 6a). However, unlike the surface atmospheric pressure, coastal winds were poorly organized. Wind fluctuations were mainly in the SE-NW (cross-shore) direction over the New York Bight, but in the NE-SW (alongshore) direction over the southern Bight. Figure 6b shows the spectrum of alongshore wind at Newark and Cape Hatteras. In the southern Bight, the alongshore wind contained most of the kinetic energy, with a distinct

Figure 6. (a) Power spectrum of surface atmospheric pressure (ATP), the r.m.s. kinetic energy of windstress at Newark and Cape Hatteras;
(b) Power spectrum of alongshore windstress at Newark and Cape Hatteras.

6-day peak. In contrast, the alongshore wind was a minor component of the total wind fluctuation in the New York Bight. The results were consistent with the fact that the "model" cyclone affects the southern Bight during its earlier stage, and the New York Bight when it develops (Fig. 5). Consequently, wind over the southern Bight was not coherent with wind further north, despite both being dominated by cyclones.

Relations between local wind and sea level were examined from cross-spectrum analysis; wind direction was allowed to rotate over a complete circle. On the New York Bight, sea levels at Montauk, Sandy Hook and Cape May can best be analyzed through the empirical mode (Section 2). Sea level (empirical mode) was highly coherent with the 30°/210° wind (Fig. 7a), which suggests local forcing. Dominant sea level fluctuation occurred at the 4 day time scale (Fig. 2), corresponding to the peak of alongshore wind (Fig. 6b). The phase difference between sea level and alongshore wind was almost a linear function of frequency (Fig. 8), implying a constant time lag (adjustment time) of about 9 hrs. The modulus of the transfer function was also quite uniform: the sea level change at Sandy Hook was about 20 cm per unit dyne/cm^2 windstress (based on Newark wind and a drag coefficient of 2.0 $\times 10^{-3}$).

At Nantucket, coherence was high between 60°/240° wind (rotating counterclockwise from the east) and sea level (Fig. 7b). As the local coastline is along the same

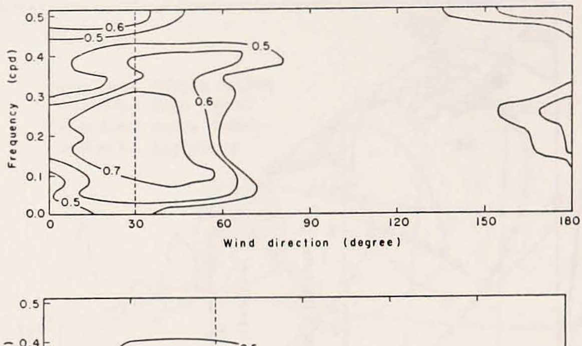

Figure 7. Coherence squared as a function of the wind direction. (The 90° direction is along the N-S axis, and the optimum wind direction is marked by a dashed line.):
(a) Sandy Hook sea level and Newark windstress;
(b) Nantucket sea level and Boston windstress;
(c) Avon sea level and Cape Hatteras windstress.

direction, Nantucket sea level also appeared to be driven by alongshore wind. The phase differences were more scattered, with an estimated time lag of 10 hrs.

Coherence between Norfolk wind and Kiptopeake B. sea level was low ($\gamma^2 < 0.5$) (Figure not shown), suggesting nonlocal wind forcing. Our earlier results have indicated southward phase propagation from Cape May to Kiptopeake B. (Fig. 4). Thus, a significant portion of Kiptopeake B. sea level might have originated from the New York Bight area. At Avon, coherence was high between 70°/250° (alongshore) wind and sea level, particularly at time scales shorter than 3.3 days (Fig. 7c). High coherence was an indication of local wind forcing. We have also shown separation of coherent motion between northern and southern Bight at short periods (Fig. 3). Thus, local wind forcing was dominant on the southern Bight at time scales shorter than 3.3 days.

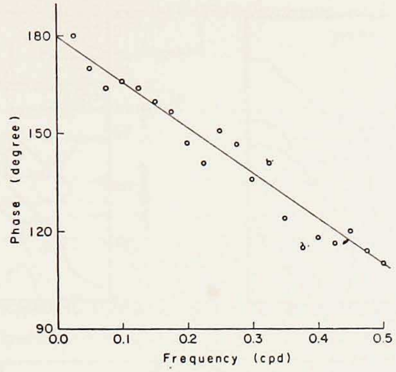

Figure 8. Phase difference between the alongshore windstress and sea level at Sandy Hook. (Solid line corresponds to a 9 hr time lag.)

Along the New England Shelf, relation between wind and surface slope (between Sandy Hook and Nantucket) was also examined. Coherence was high for the 0°/180° (E-W) wind (Fig. 9), and the time lag was small (~5 hrs). The modulus of the transfer function was rather uniform: surface slope of 5.4×10^{-7} can be induced by 1 dyne/cm² windstress (Newark wind). It is noted that the NE-SW wind which was the most effective forcing of the New York Bight/New England shelf, was much less coherent with the slope (between Sandy Hook and Nantucket). The lack of high coherence was due to the fact that both Sandy Hook and Nantucket sea levels responded to the NE-SW wind forcing (Figs. 7a and 7b), and thus their relative difference was small. On the other hand, only the Sandy Hook sea level responded to the E-W wind forcing. Consequently, alongshore sea level slope was more effectively set up by the E-W wind.

Beardsley and Butman (1974) found that an eastward wind only set up a large slope, but a southwestward wind drove a large sea level rise and a strong alongshore flow. They speculated that the apparent asymmetry of coastal water response was caused by a different windstress pattern. Our results support the notion that coastal

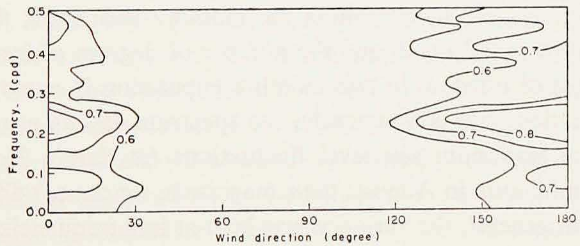

Figure 9. Coherence squared as a function of wind direction (the 90° direction is along the N-S axis), between surface slope (sea level difference between Nantucket and Sandy Hook) and Newark windstress.

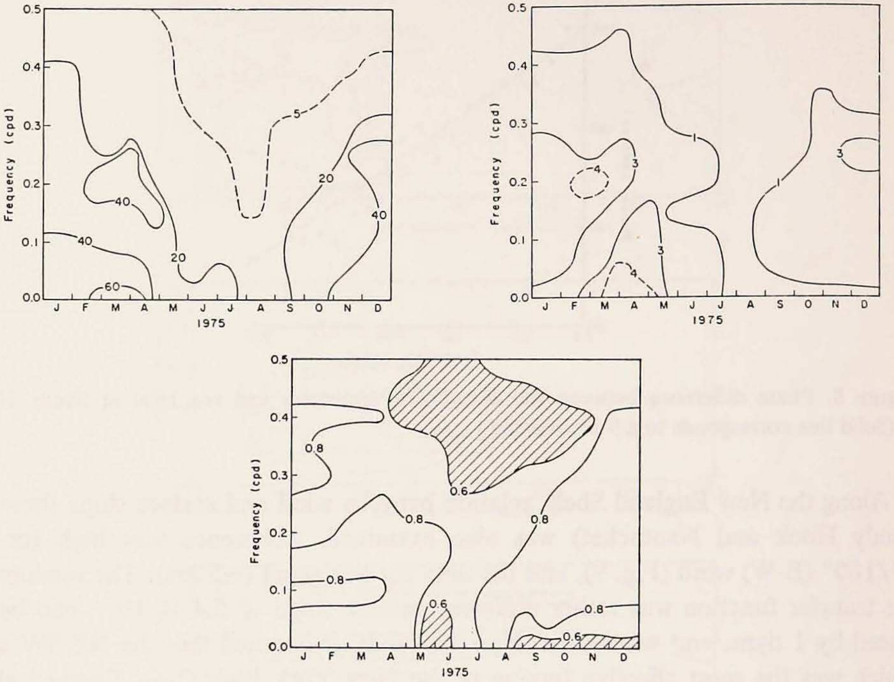

Figure 10. Seasonal variations of:

(a) Spectrum of sea level at Sandy Hook (unit: cm^2);

(b) Spectrum of alongshore windstress at Newark (unit: $(0.1\ dyne/cm^2)^2$);

(c) Coherence squared between sea level and alongshore windstress (shaded areas: $\gamma^2 < 0.6$).

water response is sensitive to the direction of wind forcing. A NE-SW wind will produce large sea level change over the entire New England shelf, while an E-W wind tends to produce only a large surface slope.

4. Seasonal variations

Sea level fluctuations had large seasonal variations. The spectrum is computed over each 60-day segment to determine the monthly variations; the corresponding frequency resolution is 0.05 cpd, and the number of degrees of freedom is 15. (The number of degrees of freedom in two-month computation is much smaller than the one-year computation, and consequently, the spectrum results are subject to larger uncertainty.) The maximum sea level fluctuations (at Sandy Hook) occurred in March, and the minimum in August; their magnitude (variance) differed by a factor of 5 (Fig. 10a). In general, the variance was high at low frequencies; however, there was a secondary maximum at around 4-5 days, during February-March and December. This secondary energy maximum corresponds to the 4-day energy peak in the one-year analysis (Fig. 2).

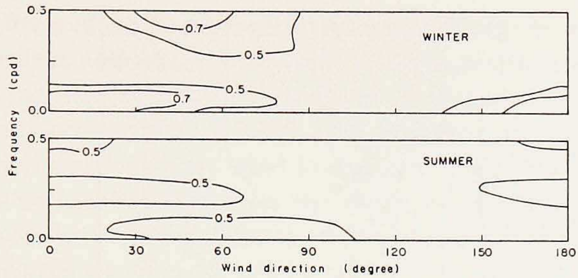

Figure 11. Coherence squared as a function of the wind direction (the 90° direction is along the N-S axis), between Kiptopeake B. sea level and Norfolk windstress in (a) winter and (b) summer.

Large seasonal variations were also found in the alongshore (30°/210°) wind (at Newark) (Fig. 10b). The maximum variance occurred in March, and the minimum in August, with a factor of 5 difference. The secondary maximum at around 4-5 days was also clear. On the other hand, the alongshore wind and sea level variation had some obvious differences. In particular, there were large, long-period (> 10 days) sea level fluctuations from September to December with no apparent counterpart in coastal wind.

Fig. 10c shows the seasonal variation in coherence between alongshore wind and sea level. A striking feature is the rather constant coherence throughout the year, despite large changes of wind and sea level variance. In other words, the relation between wind and sea level found earlier based on the whole year record, was valid most of the months, particularly at the storm time scales of 3-10 days (Fig. 7a). One exception was the response in the 2-3 day period in summer months when the sea level was too small (< 2 cm). Perhaps the most noticeable exception was the long-period fluctuation from September to December. Chase (1979) has shown the long-term (monthly averaged) sea level change in the New York Bight is strongly affected by the Gulf Stream position; the effect presumably is stronger in autumn (Montgomery, 1938).

Coherence between wind and sea level also remained rather constant at Nantucket and Avon, which was reflected by high coherence over the total one-year record. On the other hand, over a year, coherence was low at Kiptopeake B. Low coherence could be caused by nonstationary forcing, and therefore, the Kiptopeake B. sea level was examined for seasonal variation.

Coherence between Norfolk wind and Kiptopeake B. sea level was computed for two 100-day subsets, corresponding to the winter (January to March) and summer (June to August) season, respectively (Figs. 11a and 11b). In winter, coherence with 20°/200° wind was high at time scales longer than 10 days, which was partly due to the southward propagation of sea levels generated on the New York Bight. On the other hand, local alongshore wind forcing was dominant at time scales shorter

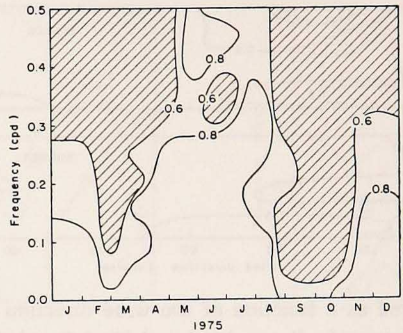

Figure 12. Seasonal variations of coherence squared between Kiptopeake B. and Cape May sea level (shaded areas: $\gamma^2 < 0.6$).

than 3.3 days, as evidenced by high coherence with the 60°/240° wind. In contrast, the coherence between wind and sea level was only marginally significant in summer. In particular, there was no indication of short-period local alongshore wind forcing.

Strong contrast between winter and summer response was also reflected in the change of sea level coherence between Cape May and Kiptopeake B. (Fig. 12). Over a year, coherence was high only at time scales longer than 10 days, and around 4 days (Fig. 3). However, when computed over 60-day segments, high coherence was found in summer at short time scales. High spatial coherence of sea level was coincidental with the period of low local wind coherence (Fig. 11b). Thus at Kiptopeake B., while local forcing was dominant at short time scales during most of the year, the summer season was marked by nonlocal influence. In fact, a southward phase propagation of sea level at 600 km/day was found in summer.

5. Discussion

On the Mid-Atlantic Bight, coastal sea level response to wind forcing had considerable variations. Between Nantucket and Cape May where cyclone forcing was more or less coherent (Fig. 5), the local wind was dominant. South of Cape May, the meteorological condition was different. Local wind forcing was dominant at time scales shorter than 3.3 days. However, at longer time scales, nonlocal contribution was important as evidenced by the lack of local wind coherence and the southward phase propagation of sea levels from Cape May to Kiptopeake B.

The local wind forcing was mainly due to the alongshore wind, which agrees with a local Ekman model. However, between Montauk and Cape May (New York Bight), optimum wind was in the 30°/210° direction (rotating counterclockwise from the east), which does not parallel either the Long Island (10°/190°) or New Jersey (60°/240°) coastline.

Deviation from local alongshore wind forcing in the New York Bight is mainly due to blocking effects of the bent coastline. A sudden change in coastline direction would tend to restrict alongshore wind forcing. As a simple approximation, the situation may be modeled as shelf water response to alongshore wind forcing of a finite extent (from Nantucket to Cape May). With a frictional model, Csanady (1978) has shown over the range of direct wind forcing, an alongshore pressure gradient (surface slope) is set up, which opposes the windstress. Further downstream, the pressure gradient changes direction, and in effect, it replaces windstress as the driving force. Although the model is not strictly valid for a bent coastline, it appears to give a rather realistic description of shelf water response from Cape Cod to Cape May. A large eastward surface slope was set up by a westward wind along the New England shelf, together with the general rise of sea level. The highest elevation occurred at Sandy Hook where the coastline bends sharply (about 120°) to the south. Surface elevation then gradually decreased toward Cape May. A reversed response was induced by an eastward wind; the lowest elevation occurred at Sandy Hook. Since the coastline does not turn 90° at Sandy Hook (a condition for a finite extent of alongshore windstress), we found a 30° difference in optimum wind direction between surface slope and sea level.

The frictional model can not account for the observed phase propagation south of Cape May. Instead, a nonfrictional response consisting of shelf waves (Gill and Schumann, 1974), seems more appropriate. Shelf wavemode was computed for a section off Ocean City, with a continuously stratified model (Wang and Mooers, 1976). (Because the water is shallow, the density effect is small for long waves.) Phase speed of the first mode is about 550 km/day, which agrees with the observation. The ratio between sea level and maximum alongshore current is about 1.6 s^{-1}, i.e., 1 cm sea level rise corresponds to 1.6 cm s^{-1} southward flow. (The ratio is basically a measure of the offshore length scale.) This result was compared to the nearshore current measurement off Ocean City in summer 1977 (Carter and Regier, 1978); a similar ratio was obtained during strong events.

Good agreement between simple wave model and observations suggests a nondissipative response south of Cape May. On the other hand, friction seems essential for the observed large surface slope between Nantucket and Sandy Hook; the length scale for long waves is too large (a few thousand kilometers) to have any significant slope. The apparent discrepancy suggests a large difference in dissipation between the two areas. Noble and Butman (1979) suggested doubling of bottom friction in the Georges Bank compared to the New York Bight, due to a large difference in tidal velocity; however, there seems no appreciable variation of tidal velocity throughout the Mid-Atlantic Bight. Alternatively, application of the Csanady (1978) model to transient wind forcing is probably a fortuitous coincidence. The effect of the bent coastline, which has not been included in the shelf wave model, may cause a large alongshore slope without recourse to friction.

Another interesting aspect of shelf water response on the New England shelf is an inferred mean southwestward pressure gradient. Scott and Csanady (1976) deduced a mean slope of 1.4×10^{-7} from a frictional balance model. However, the assumption of no wind set-up is unjustified, and therefore, their result is inconclusive. In fact, our results indicated a definite set-up relation between E-W wind and surface slope (Fig. 9). Generalizing the spectrum result to zero frequency, we found an annual mean westward slope of 1.3×10^{-7}, responding to the mean southeastward wind. In other words, the wind set-up can produce large long-term variations of "mean" southwestward slope along the New England shelf. Similar results were found in Chase (1979).

Acknowledgments. We thank Dr. C. N. K. Mooers for making the edited meteorological data available to us. We also wish to thank Mr. H. H. Carter for the use of unpublished current meter and sea level data. Comments by Dr. G. T. Csanady and an anonymous reviewer are also greatly appreciated. This study was sponsored by the National Science Foundation, under Grant OCE 76-82151.

REFERENCES

Beardsley, R. C. and B. Butman. 1974. Circulation on the New England continental shelf: Response to strong winter storms. Geophys. Res. Lett., *1,* 181–184.

Beardsley, R. C., W. C. Boicourt and D. V. Hansen. 1976. Physical oceanography of the Middle Atlantic Bight. Special Symposia, *2,* 20–34, Amer. Soc. Limn. Oceanogr.

Beardsley, R. C., H. Mofjeld, M. Wimbush, C. N. Flagg and J. A. Vermersch Jr. 1977. Ocean tides and weather-induced bottom pressure fluctuations in the Middle Atlantic Bight. J. Geophys. Res., *82,* 3175–3182.

Boicourt, W. C. and P. W. Hacker. 1976. Circulation on the Atlantic continental shelf of the United States, Cape May to Cape Hatteras. Mem. Soc. R. Sci. Liege Ser., *10,* 187–200.

Brooks, D. A. 1978. Subtidal sea level fluctuations and their relation to atmospheric forcing along the North Carolina coast. J. Phys. Oceanogr., *8,* 481–493.

Carter, H. H. and R. J. Regier. 1978. A physical assessment of the Maryland coastal waters to receive wastewaters. Chesapeake Bay Institute, Baltimore, Md., Spec. Rept. 62, 92 pp.

Chase, R. R. P. 1979. The coastal longshore pressure gradient: temporal variations and driving mechanisms. J. Geophys. Res., *84,* 4898–4904.

Csanady, G. T. 1978. The arrested topographic wave. J. Phys. Oceanogr., *8,* 47–62.

Gill, A. E. and E. H. Schumann. 1974. The generation of long shelf waves by the wind. J. Phys. Oceanogr., *4,* 83–90.

Mayer, D. A., D. V. Hansen and D. Ortman. 1979. Long-term current and temperature observations on the Middle Atlantic Bight. J. Geophys. Res., *84,* 1776–1792.

Mooers, C. N. K., J. Fernandez-Partagas, and J. F. Price. 1976. Meteorological forcing fields of the New York Bight (first year). University of Miami (RSMAS) Tech. Rept. TR76-8, 151 pp.

Montgomery, R. B. 1938. Fluctuations in monthly sea level on eastern U.S. coast as related to dynamics of western North Atlantic Ocean. J. Mar. Res., *1,* 165–185.

Noble, M. and B. Butman. 1979. Low frequency wind-induced sea level oscillations along the east coast of North America. J. Geophys. Res., *84,* 3227–3236.

Scott, J. T. and G. T. Csanady. 1976. Nearshore currents off Long Island. J. Geophys. Res., *81,* 5401–5409.

Stommel, H. and A. Leetmaa. 1972. The circulation on the continental shelf. Proc. U.S. Nat. Acad. Sci., *69,* 3380–3384.

Sturges, W. 1977. Comments on "Nearshore currents off Long Island" by J. T. Scott and G. T. Csanady. J. Geophys. Res., *82,* 1451–1452.

Wang, D-P. and C. N. K. Mooers. 1976. Coastal-trapped waves in a continuously stratified ocean. J. Phys. Oceanogr., *6,* 853–863.

Received: *14 August, 1978;* revised: *15 August, 1979.*