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CLIMATOLOGY OF INTERNAL GRAVITY WAVES IN THE MARINE SURFACE LAYER IN A COASTAL ENVIRONMENT

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1. INTRODUCTION

Formation of stable atmospheric layers often leads to the generation and propagation of internal gravity waves. Instability of these waves causes breaking and enhanced turbulence. Wave-breaking in upper layers of the atmosphere leads to "clear air turbulence" (CAT), a phenomenon extensively investigated. Internal waves could also occur near the earth's surface within the atmospheric boundary layer when stable atmospheric conditions prevail (SethuRaman, 1977; Caughey and Readings, 1975; Metcalf, 1975, etc.) In such cases, internal waves coexist with turbulence caused by mechanical roughness for moderate stabilities. Enhancement of turbulence occurs when the waves break. Occurrence of the waves in the boundary layer significantly modifies the diffusion characteristics of the atmosphere since waves are known to transport rather than diffuse momentum and heat.

Restricting ourselves to the atmospheric surface layer, a layer within the first 100 m above the surface, waves occur over land mostly with nocturnal inversions. But, over coastal waters, stable atmospheric conditions conducive to the formation of internal waves can occur at any time of the day due to the thermal inertia of large bodies of water. The purpose of this paper is to discuss the climatological variations of the occurrence of internal gravity wave events at a coastal site as compared with an inland site, and possible reasons for the differences.

2. DATA

Mean wind speed and direction at a height of 24 m have been recorded continuously at Tiana Beach, Long Island, New York, since June 1975 as part of a coastal meteorological study (Raynor, et al., 1975). A directional vane with a propeller (aerovane) is used for the measurements. An Easterline-Angus recorder is used for recording the observations on a chart.

Data for this study were obtained from wind speed and direction charts. Internal waves were relatively easier to identify from wind direction than from wind speed charts due to better sensitivity in the chart records. Data were obtained as "gravity wave events", an event consisting of a number of internal gravity waves that occurred consecutively. From the number of waves and the beginning and ending times of an event, average apparent period of the waves can be estimated.

Observations at Tiana Beach over a three-year period, from 1976 to 1978, were used for the analysis. Similar data were obtained from wind speed and direction measurements made at a height of 106 m at Brookhaven National Laboratory, 15 km inland, to compare with the observations made at the coastal site.

3. DISCUSSION OF RESULTS

One of the objectives of this paper is to examine the directional, diurnal and seasonal dependence of the occurrence of internal waves at Tiana Beach and compare the results with those obtained at an inland site. The main differences between coastal and an inland site are the presence of a large body of water for onshore wind directions at the coastal site and greater aerodynamic roughness inland. (Figures 1 and 2).

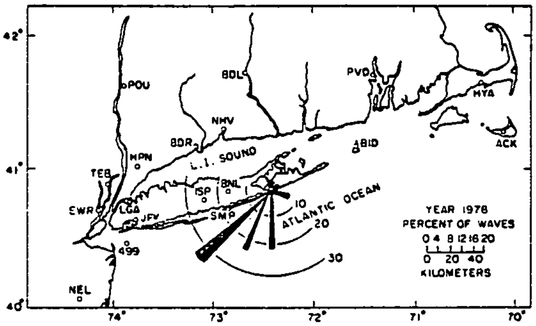

Figure 1. Occurrence of internal gravity wave events as a function of wind direction for the year 1976. Total number of events was 40.

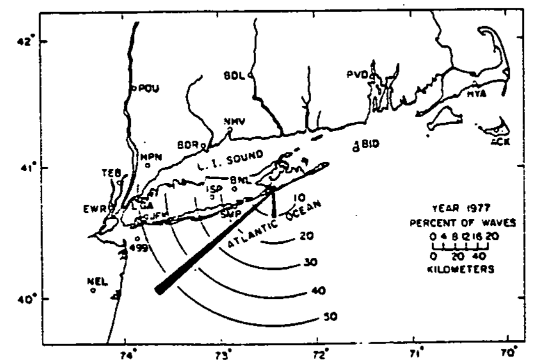

Figure 2. Occurrence of internal gravity wave events as a function of wind direction for the year 1977. Total number of events was 88.

DISCLAIMER

The number of gravity wave events that occurred at Tiana Beach during the years 1976 and 1977 are shown by sectors (of 22½ deg. each) in Figures 1 and 2 respectively. It can be seen that for both the years the maximum percentage of internal wave events occurred with southwesterly wind direction although the actual number of wave events varied significantly between the two years. The total number of internal wave events was 40 in 1976 and 88 in 1977. Data for three months, from August to October, was missing in 1976; but it is believed that this may not have altered the total number of events appreciably. Thus onshore flow with a southwesterly wind direction seems to account for most of the internal wave events that occur at the coastal site. This is probably due to warm continental air flowing over the cooler ocean causing surface-based inversions.

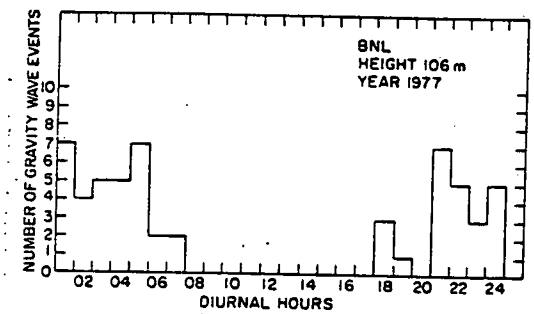

Figure 3. Diurnal variation of the internal wave events for 1977 at the inland site (BNL).

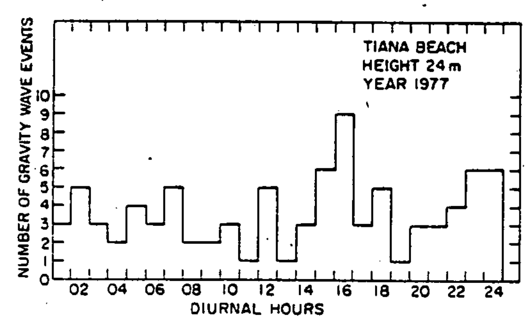

Figure 4. Diurnal variation of the internal wave events for 1977 at the coastal site (Tiana Beach).

For a typical inland location, stable atmospheric conditions occur at night due to radiational cooling of the surface. This was found to be the case for the observations at the Laboratory, as indicated by the frequency diagram in Figure 3. On the other hand, data at the coastal site (Figure 4) showed the occurrence of internal waves during both day and nighttime hours. This is believed to be again due to the formation of surface-based inversion caused by the cool ocean surface.

Numbers of internal wave events at the coastal site as a function of month are plotted in Figure 5 for 1976 and 1977 and show seasonal effects. For both the years mentioned, the maximum number of wave events occurred in spring and summer. The difference in magnitude and distribution of the internal wave events between the two years could be due to a relatively more severe winter in 1977 as compared with 1976. The

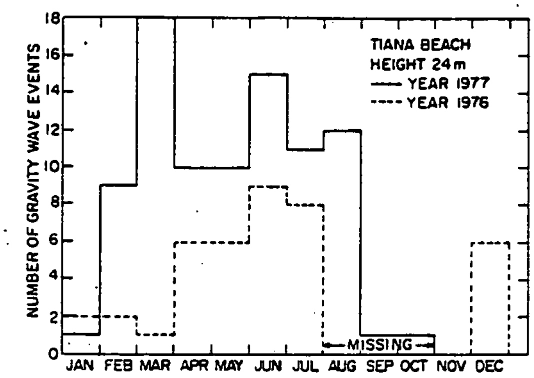

Figure 5. Internal wave event as a function of the month for 1976 and 1977 at Tiana Beach.

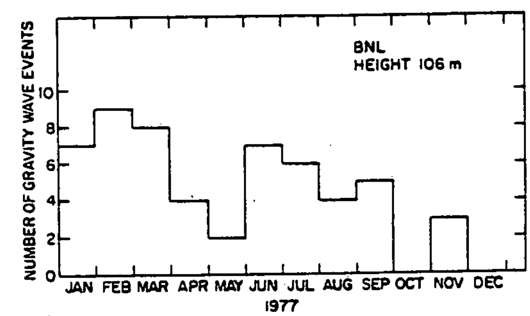

Figure 6. Internal wave events as a function of the month for 1977 at BNL.

severity of the winter in 1977 could be inferred from radiometric sea temperature measurements made by the U. S. Coast Guard and from monthly mean air temperatures measured at BNL. No significant variations in the occurrence of internal waves between different seasons are noticeable for the inland site at BNL (Figure 6).

In order to investigate the existence of any critical range of mean wind speed for the occurrence of internal wave events, variation with wind speed was investigated. For the coastal site, a range of wind speeds, from 3 to 8 m sec^{-1}, was found to be present when most of the internal waves occurred. For the inland site, the range was 2 to 7 m sec^{-1}. The maximum number of wave events occurred for the wind speeds between 4 and 5 m sec^{-1} at the beach and between 3 and 4 m sec^{-1} inland. For wind speeds higher than about 8 m sec^{-1}, mechanical turbulence probably becomes important and prevents the formation of temperature inversions.

Mean horizontal amplitudes of the internal waves were computed for each month in 1977 from wind direction charts. The mean horizontal amplitudes at the beach varied between 10 and 15 degrees for the month of May when they reached a value of about 25 degrees. Corresponding values inland showed the mean to be between 10 and 15 degrees for all months with a maximum of about 25 degrees for June. Time period for the wave was computed from a knowledge of the total period of the event and the number of waves in the event. Number of waves in one event varied from 2 to 10 with a mean of about 5. Mean monthly time periods of the internal waves varied from 6 to 9 minutes for Tiana Beach. Variability from month to month was greater for BNL with values between 4 and 10 minutes. An estimate of wave lengths is difficult to obtain without a knowledge of stabilities and vertical velocity variations. But previous studies at Tiana Beach have indicated wave lengths of the order of 100 to 500 m at the height of measurements (SethuRaman, 1977, 1979) for similar time periods.

4. CONCLUSIONS

Stable atmospheric conditions that are conducive for the formation of internal gravity waves occur at all hours at a coastal site. At inland sites, stable conditions occur only during nights due to daytime surface heating by solar radiation. Thermal inertia of large bodies of water, on the other hand, prevents the formation of a diurnal cycle of heating and radiational cooling. During spring and early summer, cooler ocean water causes the formation of stable atmospheric layers near the surface when warmer air masses move in from land. Internal gravity waves tend to get generated and break in these layers and affect the transport and diffusive characteristics of the atmosphere. Meandering of plumes of materials released in the atmosphere during stable conditions is one affect. The internal waves seem to form in air masses with moderate wind speed in the range of 3 to 8 m sec^{-1} and have significant amplitudes. Mean periods of the waves were around 6 to 9 minutes.

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