CHAPTER 34

WIND/WAVE RELATION AND THE PRESSURE GRADIENT EFFECT

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Abstract

The S.M.B. prediction model is used worldwide to hindcast sea wave characteristics using wind data. Even though wave parameters showed that qualitative similarities are present between ocean and small basin waves, major weather factors such as the wind speed and barometer pressure gradients in relation with the topography should be considered as calibration factors.

Introduction

The Laboratory of Harbour Works, National Technical University of Athens (N.T.U.A.), is conducting a Wave Measurement Project aiming at developing a wave prediction model adjusted to Greek Seas, especially in the Aegean Sea, well-known for its particular wind and wave conditions. Nowadays, the L.H.W. has installed the Wave Measurement, Transmission and Analysis network (in Greek: KYMATA) in the Aegean Sea and Cyprus using five Waverider buoys.

The Heraklio Wave Measurement Program was conducted in the South Aegean Sea for one year, using a Waverider buoy. In the present paper, the wind/wave interrelations and the S.M.B. prediction model are examined, taking into account the topography and the pressure systems affecting the East Mediterranean region.

The wind velocity gradient and the pressure jump are major factors in waves' development. The S.M.B. prediction model seems not always to be adequate in fully describing the development of the waves, in the Aegean Sea. A special model should be applied, distinguishing at least the most critical differences (North from South winds and storm from squall events).

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Wave Measurements

The South Aegean Basin is about 130 km long from North to South and 300 km wide from West to East, while the whole Aegean basin, being a little narrower, is nearly 610 km long. Due to the orientation of the measurements' field and the dominant weather conditions in the Aegean Sea, the winds of interest are those blowing from the North during the winter season, when several storms occur. (See Fig. 1)

Fig. 1 Geomorphologic map of the Greek Archipelagos and the Aegean Sea region.

A Waverider buoy was moored about a mile off Heraklio shore North of Crete Island, at a water depth of about 22 m. Wave characteristics were recorded from of October 1, 1992 until September 22, 1993.

An accelerometer on board the buoy estimated the vertical acceleration. Water surface elevation time series of 20-min. duration was recorded every second hour or continuously in cases where the wave was higher than a threshold defined height (2.5 m). Considering the quality of raw data, the measurements conducted are highly accurate.

A total of 5014 records were processed, examining the relationship between the wave characteristic parameters, as well as the wave energy density spectrum characteristics. The wave parameters investigated showed that qualitative similarities exist between ocean and small basin waves, and also that quantitative differences do exist (Gouloumis and Moutzouris, 1995).

Wind/Wave Interrelation

Significant wave heights were related to the corresponding wind speed blowing from the North and recorded onshore, considering several storm events of developing sea. The data plotted in Fig. 2 refer to rather high wind speeds, being proportional to the wave heights as it is widely accepted and supported from both theory and field measurements (Bretschneider, 1958; Pierson and Moshowitz, 1964; Hogben N., 1988). Further on, the spectral peak periods Tp of the waves vs. the corresponding wind speed seem to be in some agreement with the JONSWAP result (Fig. 3)

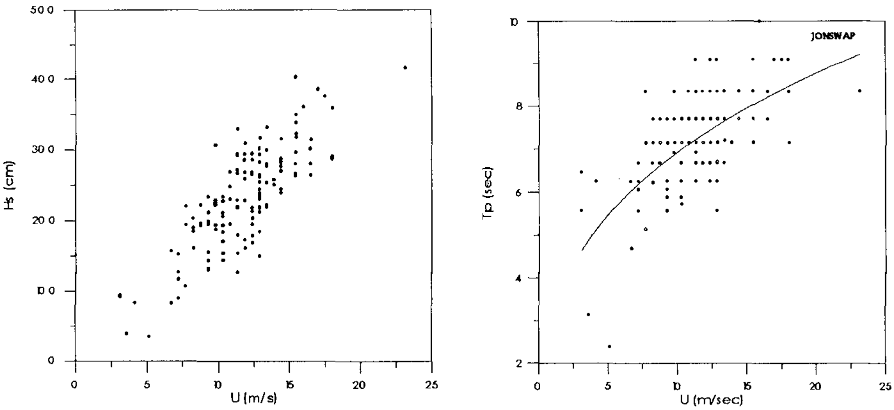

Fig. 2, 3 Significant wave heights and spectral peak periods vs. the wind speeds blowing three hours before the wave measurements

An interesting feature also is that the relation between the non-dimensional expressions of the characteristic wave heights Hs and the spectral peak periods Tp plotted in Fig. 4, is found to be almost identical to the result found if the deepwater fetch-limited equations for wave height and wave period in the Shore Protection Manual (SPM) (1984) are combined, and to the TMA equations for deep water (Hughes S., 1984), the only difference being a coefficient of 0.01096 instead of 0.0105 and 1.0112 respectively. Thus, it can be supported that waves have similar characteristic parameters both in the ocean and in the small Aegean basin examined.

Three wind records have been used from the Heraklio and Thira Island weather stations, corresponding to winds that were blowing simultaneously and 3 hours before the wave measurements. Thira is located at the North of the basin we examine. The Heraklio weather station seems to give the most appropriate wind data.

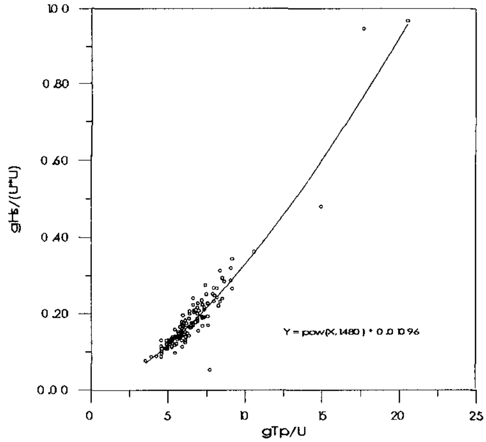

Fig. 4 The nondimensional expressions of the characteristic wave height Hs and the spectral peak period Tp.

An evaluation was carried out using the SMB method of predicting wave conditions from wind data, since "...the best equations to use in a simple wind/wave hindcast model are the SMB equations of SPM '77" (Parle P., Burrows R., 1989) and it is a widely used method in the design of most marine works. The SPM '77 simplified wave prediction equations using the SMB method are as follows:

$gHs/U^2 = 0.283 \tanh(0.0125 F\text{^}0.42)$

$gTz/U = 1.20\tanh(0.077(gF/U^2)\text{^}0.25)$, where $F=gX/U^2$ is the fetch coefficient

The data plotted refer only to the North wind records which is the dominant wind direction, in order that better correlation is achieved. In Fig. 5 the dimensionless wave height equation has been plotted vs. the fetch coefficient, where the effective fetch for the North direction is calculated to be 150.6 km.

The data plotted using the Thira wind records seem not to be suitable enough to describe weather conditions at Heraklio area, probably due to the location of the station (the island's airport on a plateau). Further more, it is not yet understood what is the effect of the numerous islands lying in the central Aegean Sea to the wind field and the wave generation conditions.

It should be noted that although a lot of data points are gathered near the values estimated by the SMB model, many other measurements are well out of the predicted values, scattered over a large area of Fig. 5.

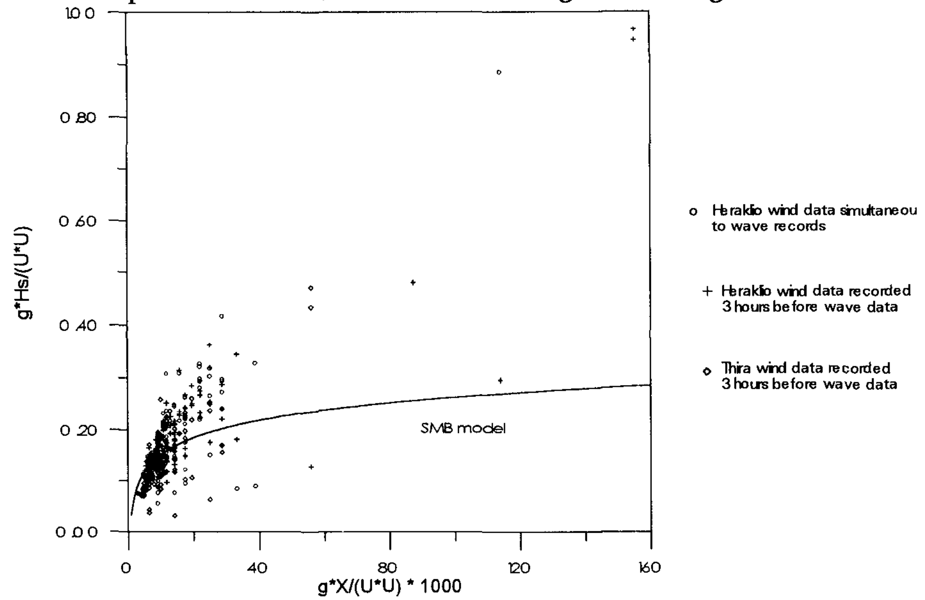

Fig. 5 The dimensionless significant wave heights vs. the fetch coefficient.

The S.M.B. prediction model seems not always to be adequate in fully describing the development of the waves, in the Aegean Sea. A major reason could be that the wind field over the Aegean Sea is not uniform due to the topography forming a long, from North to South, rather narrow basin containing the Archipelagos Islands causing strong orographic effect.

The Pressure Jump Effect

In order to further investigate the situation, six representative storm events of developing sea were selected. The wind was always blowing from the 48 degrees north sector. In Fig. 6 the dimensionless wave heights have been plotted versus the fetch coefficient. The data clearly represent two different sea-states, one of which is characterized by sudden occurring high waves, corresponding to relatively low wind speeds.

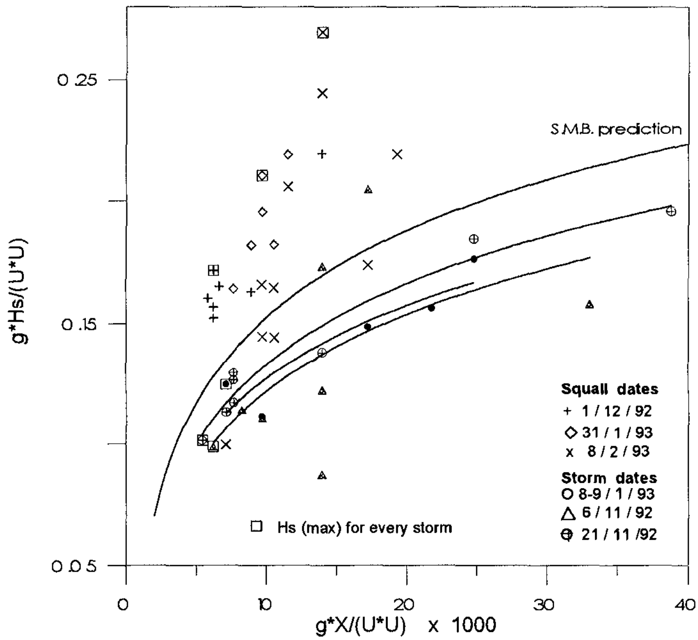

Fig. 6 The six storm events forming two groups with different characteristics (Heraklio wind data recorded 3 hours before wave measurements)

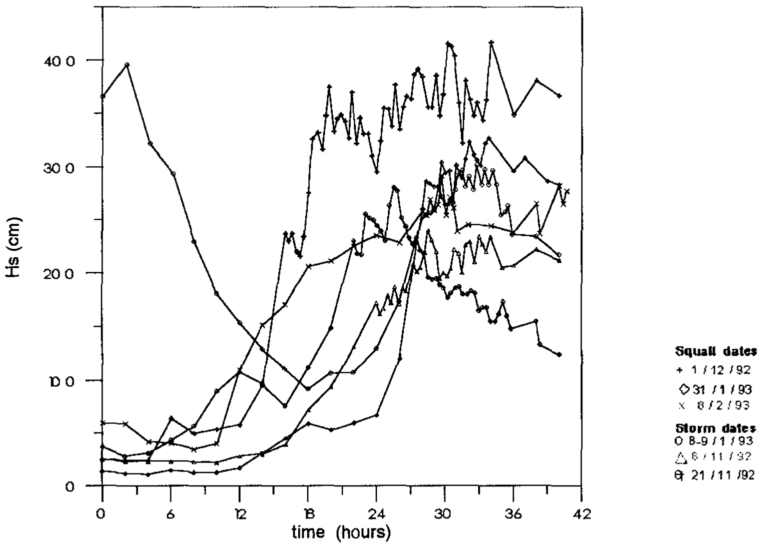

Fig. 7 Significant wave heights' time series of six storm events.

The time series of measured significant wave heights (Hs) plotted in Fig. 7 show that three of the curves corresponding to the storm events of December 1st, 1992, January 31st and February 8th, 1993, are characterized by rapidly growing waves, being fully developed in just 3 to 6 hours, indicating the occurrence of squall storms and fast arising sea.

Examining the weather systems experienced at the time of the wave measurements, we can distinguish a certain combination of pressure systems over East Europe, similar for all three cases of fast arising sea not complying with the S.M.B. prediction model (Fig. 8 of the Appendix). Waves rise much faster during squall storms where intense winds, suddenly blowing, sweep over the Aegean Sea. Winds are triggered by the intense barometric gradient in South East Europe, caused by the combination of an East Europe High pressure field and the Low pressure systems passing over East Mediterranean, in the region of the island of Cyprus.

Medium velocity winds blowing over the Black Sea are canalized into the Aegean Sea through the mountain ranges of mainland Greece on the west and Asia Minor on the east, becoming very intense because of the Bernoulli phenomenon. Furthermore, simultaneously to the maximum wind gust, a major barometric pressure jump is noticed at all three episodes where wave development does not follow the S.M.B. prediction model, as it can be clearly seen in Fig. 9 of the Appendix.

In all other cases examined, where the measured wave heights were close to the predicted ones rarely exceeding them, the High pressure system lies at the west over central Europe and the pressure gradient is mild causing winds of normally arising speed (Fig. 10)

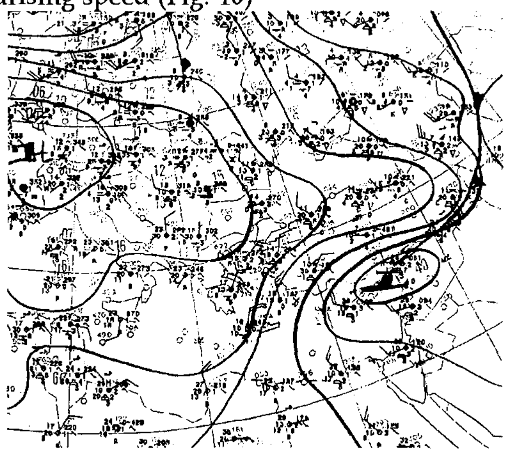

Fig. 10 Weather map dated on November 6th 1992, at 12:00 UTC. When the High pressure system lies at the west the pressure gradient is mild.

While the frontal systems pass over the measurements' region, the pressure jumps up to 9 milibars in total and on the order of 1 Mb per hour. In all three cases, the wave still rises following the pressure jump, even though the wind speed decreases. The relative isobar maps in Fig. 11 show clearly that a pressure front moves from north to south over the Aegean Sea, causing a forced wave which seems to reinforce the wind generated wave while interaction between them should be present, as well. Examining the barometric pressure records as well as the isobar maps of the events, we can estimate the speed of the pressure front propagation to be in the order of U=51 km per hour as the 610 km long Aegean basin was swept from north to south in about 12 hours. A resonant wave is therefore possible to be produced, since the face velocity at the specific depth of 22 m at the buoy location is $C=\sqrt{gh}$ = 52.2 km/hour ≈ U, indicating the possible presence of a squall line surge (Thieke R., Dean R., GARCIA A., 1994).

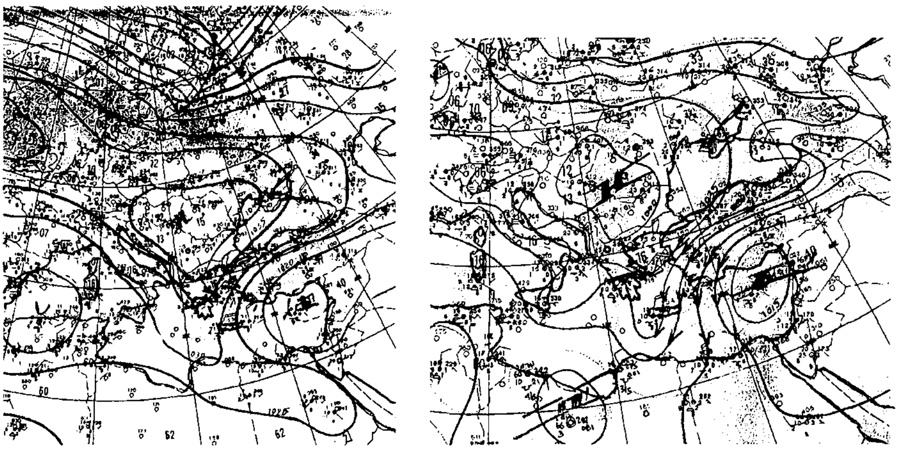

Fig. 11 Weather map dated on February 8th 1993, at 06:00 and 12:00 UTC. The High pressures propagate from north to south over the Aegean Sea.

Focusing on Fig. 6, it can be noted that during the three storm events where the wind is increasing in a normal way and there is no severe change in the barometric pressure, the wave development is generally over-estimated by the S.M.B. model. The dimensionless maximum wave heights appear close to the predicted values and they are all gathered together showing the maximum possible wave developed at this area under normal weather conditions.

On the other hand, considering the cases not complying with the SMB model, the dimensionless maximum wave height expressions show a tendency that unusually high significant waves can appear corresponding to relatively low wind speeds the fetch being constant, depend obviously on the pressure gradient propagation experienced. The corresponding characteristic wave periods of these cases are higher than the periods corresponding to the "normal" conditions, indicating long wave existence mentioned before (Fig. 12). Attention should also be paid to the characteristic periods of the maximum significant waves measured during the abnormal storms, being linear proportional to the wind speed.

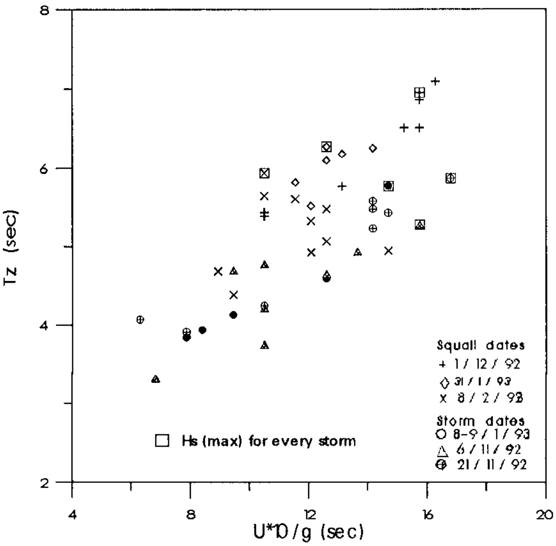

Fig. 12 Characteristic wave periods versus wind speed transformed to period

The theory analyzed above in order to explain high waves measured corresponding to relatively low wind speeds at fetch limited conditions, is further supported by the storm episode of November 21, 1992. Even though it has the characteristics of the "abnormal" cases, it is well described by the S.M.B. model. Besides the fact that the wind speed rises very quickly and the pressure jump is intense (Fig. 13), the measured wave heights follow the S.M.B. model supporting even further the previous conclusion since the pressure front propagates from west to east as it seen in Fig. 14, not reinforcing the north wind generated waves as the buoy's location is sheltered from the west.

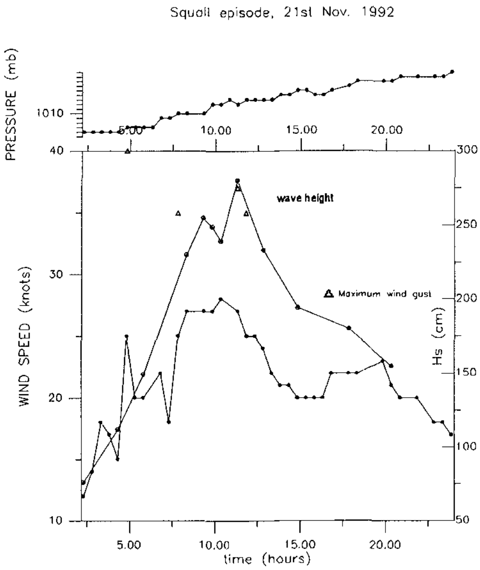

Fig. Wind speed, significant wave height and barometric time series of the storm episode dated November 21, 1992.

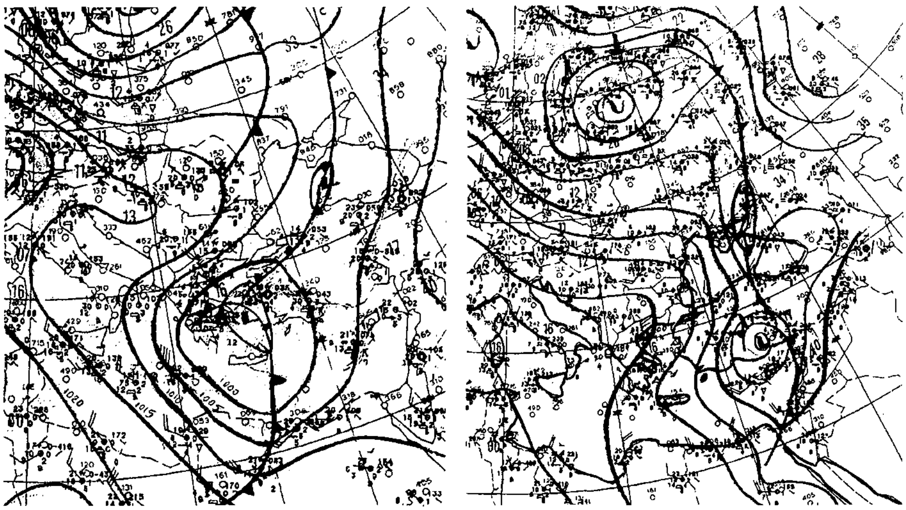

Fig. Weather maps of November 20th and 21st 1992, at 12:00 UTC. The Low pressure system travels from west to east **not** reinforcing the north wind generated waves.

Conclusions

Even though waves seem to have similar characteristic parameters both in the ocean and in the small Aegean basin examined, the S.M.B. prediction model is proved to be insufficient to fully predict wave climate in the Aegean Sea, where strong orographic effects and peculiar weather conditions are present.

It is necessary to consider all the meteorological factors involved to successfully predict wave heights under different weather conditions.

The wind velocity gradient and the pressure jump, when propagates to the same direction of the wind blowing, are major factors in describing the development of the waves. The possible effect of the Cyclades islands lying in the middle of the Aegean basin on the wave development and propagation has also to be assessed.

Large amount of measurements expected to derive from the Wave Measurement KYMATA network will hopefully give insight into the situation, now that a new perspective is applied.

The S.M.B. prediction model seems not always to be adequate in fully describing the development of the waves, in the Aegean Sea. A special model should be applied, distinguishing at least the most critical differences (North from South winds and storm from squall events).

Acknowledgments

Wind data and weather maps were obtained from the Greek National Meteorological Service. The contribution of the meteorologists Mrs. Petrou and Mr. Ziakopoulos to interpret the weather systems is highly appreciated.

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APPENDIX

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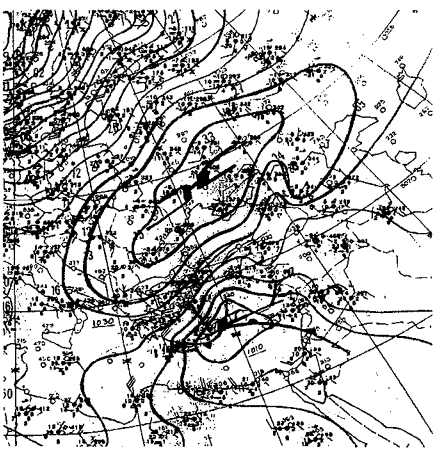
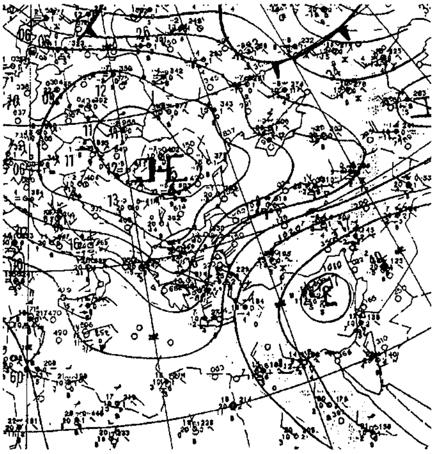
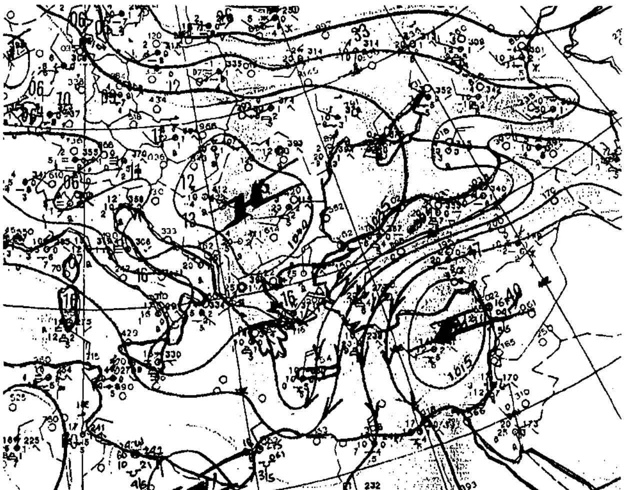


December 1st 1992 at 12:00 UTC



January 31st 1993 at 12:00 UTC



February 8th 1993 at 12:00 UTC

Fig. 8 Weather maps over the East Mediterranean Sea and Europe

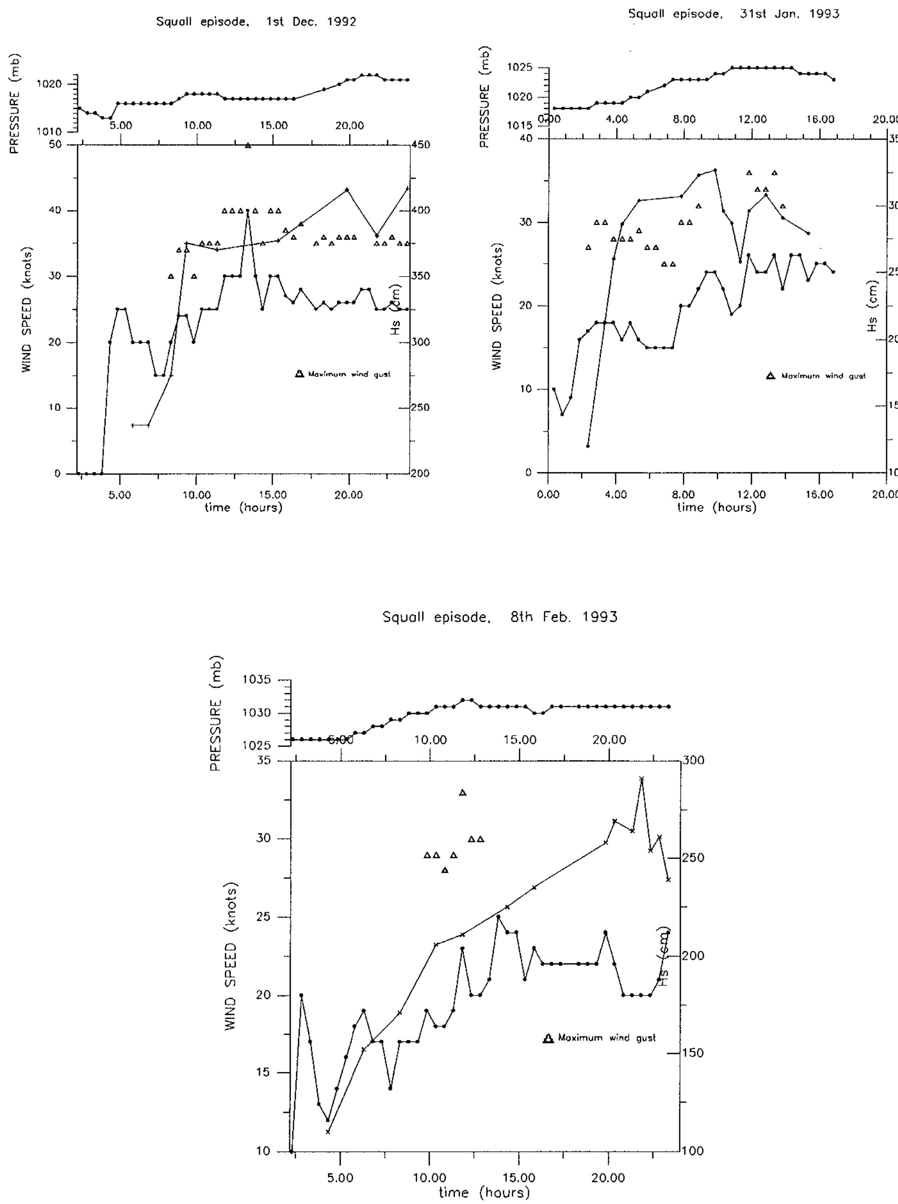


Fig. 9 Wind speed, significant wave height and barometric pressure time series of the storm episodes not complying with the SMB model.