Acta Adriat., 23 (1/2): 21—27 (1982) YU ISSN: 0001—5113
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THE INFLUENCE OF AIR PRESSURE ON SEA LEVEL IN THE NORTH ADRIATIC — A FREQUENCY-DOMAIN APPROACH

PRIKAZ DJELOVANJA TLAKA ZRAKA NA VODOSTAJ SJEVERNOG JADRANA, U FREKVENCIJSKOJ DOMENI

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Yearly time series of air-pressure and sea-level data, taken at the Rovinj station in the North Adriatic, were used for gaining an insight in the influence of air pressure on sea level in that part of the Adriatic.

Through application of spectral analysis and systems analysis it was shown that the influence of air pressure on the sea-level changes is of a far greater significance in the long-period range (periods of two days and more) than in the short-period range. Furthermore, a linear proportionality with proportionality factor negative and near to the theoretical value was shown to exist.

The described analysis was utilised to examplify and comment the applicability of spectral and systems analysis in investigation of the dynamics of physical phenomena in the sea.

INTRODUCTION

The propose of sampling and analysis of oceanographic data (on sea-level changes, currents, waves etc.) is to investigate either the kinematics or the dynamics of the measured phenomenon.

Investigation of kinematics leads to a phenomenological description of phenomena, and for its successful implementation classical descriptive and statistical methods (calculation of mean values, nomograms, statistical distributions . . .) are usually a sufficient tool.

On the other hand, the investigation of dynamics, where finding a cause for the established kinematics of the phenomenon is the capital goal, is a more difficult task, because physical phenomena in the sea are influenced by several factors at the same time, and these factors are to be separated when accounting for and explaining their relative influence and importance. Therefore in this kind of investigations more sophisticated statistical, analytic and numerical techniques must be used.

Once it is known which factors, in what ways and to what extent influence sea-level changes, currents or some other phenomenon in the investigated area, its is possible to predict its future behaviour via appropriate models.

In this paper we shall give an example of application of elaborate statistical methods in investigate of dynamics of physical phenomena in the sea. I. e. the influence of air pressure on sea-level changes in the North Adriatic will be investigated by application of spectral analysis and systems analysis to data sampled at the Rovinj station, in 1978.

DATA PREPARATION AND ESTIMATION OF SPECTRA

The sea-level data were obtained from original tables of hourly values (H I J R M, 1978) and the air-pressure data (three-hourly values) were taken from synoptic charts (S R H M Z, 1978). When comparing the two data sets in order to examine how the air pressure influences the sea level, its is essential that the data were completely simultaneous. Therefore, the sea-level time series was shifted in time for one hour backwards (sea-level sampling time is measured in EMT, whereas air-pressure sampling time is measured in GMT) and every third value was sampled out to obtain three-hourly values.

In order to prevent aliasing, the original hourly time series had to be filtered before sampling. An LP numerical filter was used, rejecting all frequency components at periods of 6 hours and less (which, according to the sampling theorem, must not be present in the sampled data) and passing without distortion all components that are relevant for the analysis. The effect of filtering can be seen on the sea-level power spectra as a steep descent of power level in the rightmost end of the short-period range.

From each of thus-obtained simulataneous time series a linear trend was eliminated, and the cosin-taper data window (Tukey window) was applied. Power spectra, coherence squared spectra, phase difference spectra and barometric factor spectra were computed via the FFT method for two seasons: winter and summer (Figs. 1—4). Seasonal spectra were chosen in accordance with the results of an earlier analysis (O r l i ć and K a r a b e g, 1980) which proved the existence of significant differences between seasonal sea-level spectra, leading to a conclusion that stationarity can not be assumed on a greaterthan-seasonal scale. As long-period components were of major importance for interpretation, logarithmic scale was chosen for presentation on both axis. All computations were performed on a laboratory mini computer PDP 11/20 interactively, by the use of interactive programs for oceanographic time — series data analysis (K a r a b e g, 1980).

SEA-LEVEL AND AIR-PRESSURE POWER SPECTRA

The dominant feature of the sea-level power spectra (Figs. 1 and 2) are the peaks on diurnal and semidiurnal periods. As it is well known, these peaks primarily reflect tidal oscilations caused by gravitational attraction of Sun and Moon. The peaks corresponding to diurnal periods are slightly lower than the ones on semidiurnal periods, which is in accordance with results of harmonic analysis for the North Adriatic. A smaller portion of power on diurnal and semidiurnal periods should be attributed to free oscillations of the Adriatic. Sea.

Peaks in power spectra reveal the existence of periodicities in the analysed phenomenon. As the diurnal and semidiurnal peaks in sea-level spectra are very well developed (they are »absolute« maxima in a spectrum) it follows that sea-level changes are to a great extent a periodic phenomenon, a well--known fact, used in the harmonic method of sea-level prediction.

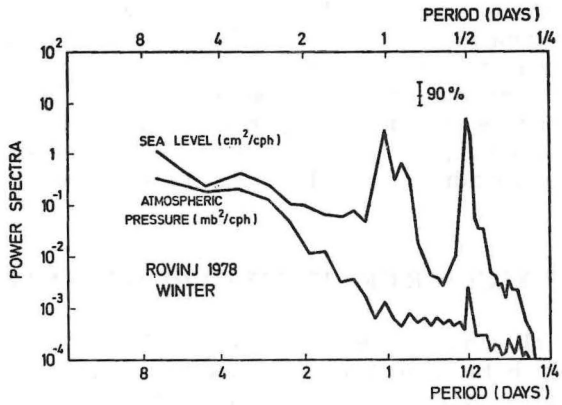

Fig. 1 Sea-level and air-pressure power spectra, Rovinj station, winter 1978.

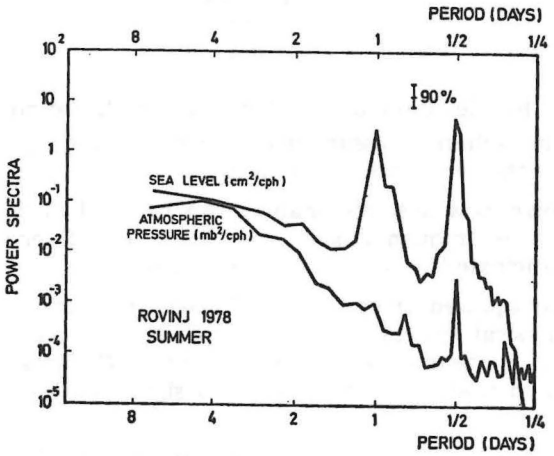

Fig. 2 Sea-level and air-pressure power spectra. Rovinj station, summer 1978.

The air-pressure spectra (Figs. 1 and 2) exibit well developed peaks on semidiurnal periods. These peaks are connected with atmospheric tides, which are known and analysed in the time domain since the 17th century. Several explanations to this phenomenon have been proposed. According to an accepted theory atmospheric tides are effected by the heating of the Sun, while purely gravitational influences are relatively insignificant.

The semidiurnal pekas in atmospheric-pressure spectra are only local and not absolute maxima, which means that atmospheric pressure changes may not be approximated by a periodic function.

Concerning the influence of air pressure on sea level, another characteristic of the atmospheric-pressure power spectra should be noticed, that is, that the greatest portion of power in the spectra appears in the long-period range (periods of two days and longer). It follows that air pressure is a band-limited phenomenon, and, consequently, its stronger influence on sea level should be expected in the long-period range than in the short-period range .A further confirmation of this can be obtained by direct comparison of sea-level an air-pressure spectra — while the power levels are comparable in the long-period range, the power level in the air-pressure spectra is for about two decades (hundred times) lower in the short-period range.

THE INFLUENCE OF AIR PRESSURE ON SEA LEVEL

Disregarding all other influences on sea level, and including some other constraints, of which the most important one its the elimination of local and advective acceleration terms, it can be proved that the sea elevation is proportional to air pressure according to equilibrium theory:

$$\xi = -\frac{p_a - \overline{p_a}}{\varrho g}$$

where ξ denotes the elevation of sea level, p_a is the atmospheric pressure, $\overline{p_a}$ is the mean atmospheric pressure over the sea surface, ϱ is the density of sea water, and g is the acceleration of gravity.

It will be shown how systems analysis can be used to determine to what extent and in which frequency span air pressure influences the sea-level changes as it is anticipated by the equilibrium theory.

The coherence squared spectra (Figs. 3 and 4) clearly show that in the long range the physical system connecting the air pressure and the sea level is to a great extent a linear system with constant coefficients, as the coherence squared measured in that frequency span has significantly high values (0.6——0.8).

High coherence is also obtained on semidiurnal periods. But it would be unjust to conclude that this proves the existence of a cause-effect relation The maxima of coherence on towelve-hour periods are due to the fact that in both data series well developed semidiurnal periodicities coincide.

The phase difference spectra neatly point out the existence of linear proportionality with a negative proportionality coefficient: in the long-period range the measured phase shift is persistently about 180° for both seasons (Figs. 3 and 4). The phase shift on semidiurnal periods significantly differs from 180° on both spectra, confirming that there does not exist a cause-effect relation as defined by the equilibrium theory.

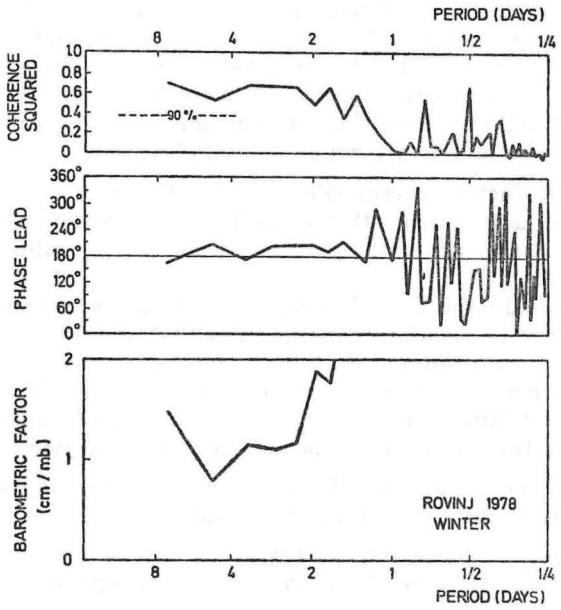

Fig. 3 Coherence squared, phase difference and barometric factor spectra. Rovinj station winter 1978.

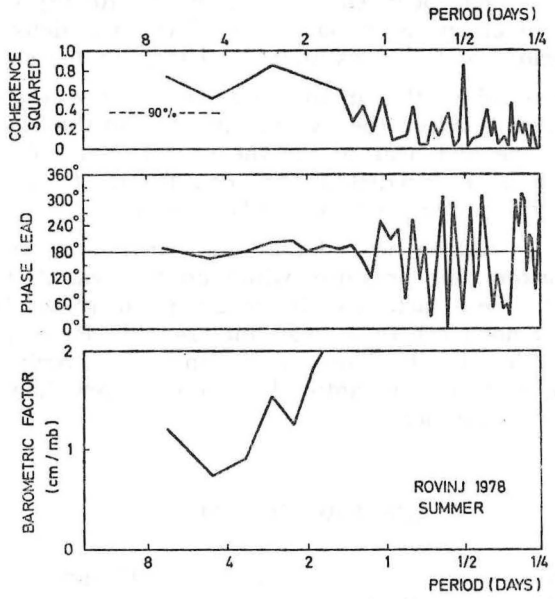

Fig. 4 Coherence squared, phase difference and barometric factor spectra. Rovinj station, summer 1978.

So far the existence of linear relation with negative proportionality coefficient has been proved to exist between air-pressure and sea-level changes in the long-period range. But this still doesn't prove the existence of that very relation that is anticipated by the equilibrium theory. Namely, a supplementary condition follows from the equilibrium theory, stating that a 1 mb change of air pressure effects a 1 cm change of elevation.

The barometric factor spectra (Figs. 3 and 4) can well be used for checking whether the data satisfy this condition. In the long-period range the barometric factor varies arround 1 cm/mb, what is the value anticipated by the equilibrium theory.

If we wish explain the fact that given air-pressure changes effect elevations that are bigger or smaller than the ones that should be expected according to the equilibrium theory, it should be taken into account that the Rovinj station (which is where our data originate from) is situated on the coast of the shallow North Adriatic. Therefore it may happen that some of the assumptions of the equilibrium theory are there no more valid:

— if acceleration is accounted for, the computed elevations may be greater or smaller, under certain circumstances;

— the influence of wind can be significant in this area, and it can have the same or the opposite sense from the atmospheric-pressure effects.

CONCLUSION

In this paper it has been shown that at the Rovinj station in 1978 a greater influence of air pressure on the sea level was detected in the long-period range (periods of two days and more) than in the short-period range.

It was also determined that in the long-period range a well-distinct linear proportionality exists between the two quantities, and that the proportionality coefficient is negative and near to the theoretical value. That is not exactly the relation which is anticipated by the equilibrium theory, and that may be explained by wind effects, or some other deviation from the theory.

In the end it should be noticed that this paper deals with the influence of *atmospheric factors* (air pressure, wind) on the sea. A separate problem would be to relate these factors with the belonging *atmospheric formations*. That problem — among others — was analysed by Penzar et al. (1980), and they showed that in the long-period range the dominant influence on the Adriatic have cyclones and anticyclones on the one hand, and planetary atmospheric waves on another.

ACKNOWLEDGEMENT

This work was sponsored by Selfmanaging Community of Interest in Scientific Research of the S. R. Croatia.

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PRIKAZ DJELOVANJA TLAKA ZRAKA NA VODOSTAJ JADRANSKOG MORA, U FREKVENCIJSKOJ DOMENI

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KRATAK SADRŽAJ

Godišnji nizovi podataka o tlaku zraka i kolebanju razine mora, izmjereni na postaji Rovinj u Sjevernom Jadranu, upotrebljeni su da se ispita utjecaj tlaka zraka na kolebanje razine mora u tom dijelu Jadrana.

Primjenom spektralne analize i analize sistema pokazano je da je utjecaj tlaka zraka na kolebanje razine mora u području dugih perioda (dva dana i više) od znatno veće važnosti nego li u području kratkih perioda. Nadalje, upozoreno je da u području dugih perioda postoji jasno izražena linearna veza, te da je koeficijent proporcionalnosti negativan i blizak teorijskim putem dobivenoj vrijednost.

Opisani primjer je iskorišten za kritički osvrt na primjenljivost spektralne analize u istraživanju dinamike fizičko-oceanografskih pojava.