RESPONSE OF THE ADRIATIC SEA-LEVEL SLOPE TO THE AIR-PRESSURE GRADIENT AND WIND FORCING AT SUBSYNOPTIC FREQUENCIES

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Abstract

Low-frequency variability (0.01 cpd < f < 0.1 cpd) of air pressure, wind and sea level is examined through long time series originating from three locations along the east Adriatic coast. Wind has substantial energy at subsynoptic frequencies, and could be related to the same atmospheric formations as air pressure. Response of sea-level slope to the atmospheric forcing is spatially variable. In the southern, deeper-sea region the sea-level slope is fully explained by isostatic adjustment to air-pressure gradient, whereas over the shelf it is considerably affected by the action of wind. Due to errors in determining wind stress a biased estimate of response to air pressure is obtained.

Key-words: Adriatic sea, air-sea interactions

Introduction

Subsynoptic oscillations (0.01 cpd < f < 0.1 cpd) of air pressure at sea surface are related to passage of planetary atmospheric waves. Empirical analyses carried out in the Adriatic (1, 2) and throughout the Mediterranean (3, 4, 5) show that at these time scales (i) sea level is highly coherent with the air pressure and (ii) adjustment of sea level by far surpasses the isostatic value of -1cm/mbar. It was concluded (5) that the overshoot cannot be accounted for by the direct action of wind. However, theoretical models (6, 7) predicted isostatic response to the air pressure alone. It is the aim of this paper to reexamine the action of wind which acts on sea level at planetary time scales, coherently with the air pressure.

Data

Seven and a half years (September, 1983 - April, 1991) of hourly sea-level data, recorded at three tide gauge stations along the east Adriatic coast (Bakar, Split and Dubrovnik), are used together with sea-surface air pressure and wind from nearest meteorological stations (Figure 1); meteorological data of somewhat shorter length are obtained at some of the stations.

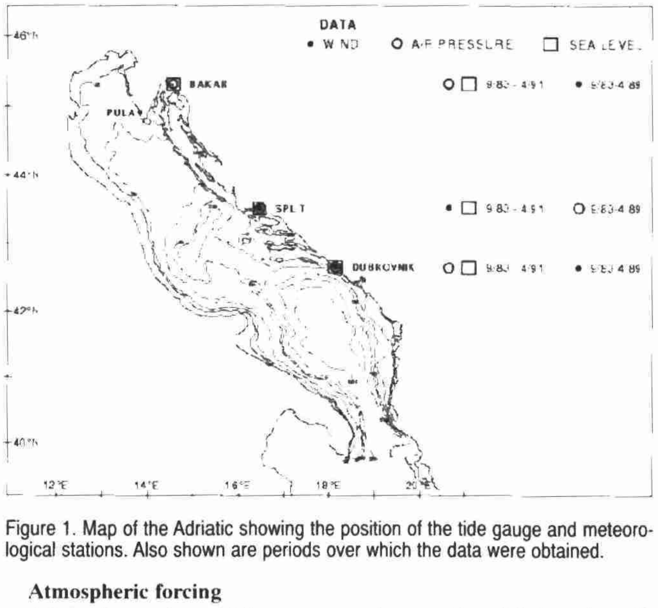

Figure 1. Map of the Adriatic showing the position of the tide gauge and meteorological stations. Also shown are periods over which the data were obtained.

Atmospheric forcing

All the time series exhibit a pronounced seasonal modulation of amplitudes. Seasonal energy spectra show that at all time scales energy is greater in winter than in summer. Furthermore, at subsynoptic frequencies there is a substantial amount of energy not only in air pressure and sea level but also in wind, the long-shore component being much more energetic than the cross-shore component. A very high coherence of the long-shore wind with difference of air pressure along the basin indicates that subsynoptic wind and air pressure could be related to the same atmospheric formations, namely to planetary atmospheric waves.

The seasonal variability of energy suggests that in the empirical analysis only the winter data be used; synoptic and higher frequency variability was smoothed out by low-pass filtering at ten days.

Response of sea level

Response of the Adriatic to forcing by slowly varying air pressure and the related winds is analysed through a one-dimensional model:

$$\Delta\zeta = A\cdot\Delta p_a + B\cdot\int_1^2 \frac{\tau_{sx}}{H}\,dx + Residual.$$

which relates difference of sea level between two tide-gauge stations $\Delta\zeta$ to air pressure difference Δp_a and to integral between the two stations of long-shore wind stress τ_{sx} over depth of water column H. Thus one requires knowledge of wind stress along the whole distance; because of large-scale nature of subsynoptic processes in evaluating the integral it has been assumed that spatially homogeneous wind is acting over the open sea of flat bottom.

The response parameters A and B are determined in time domain through multivariate linear regression. The corresponding model in frequency domain is approached through two-input spectral analysis.

Analysis in time domain

Prior to examining the combined effect of air pressure and wind forcing, the response to air pressure alone is examined. Table 1 summarizes results of uni- and bivariate multiple regression, obtained for different pairs of stations. The analysis between the far points, namely between Bakar and Dubrovnik, yields a much stronger-than-isostatic response of sea level to forcing by air pressure alone. When the action of wind is considered (wind stress at Split taken as representative for the region), the overshoot is considerably reduced but still not fully accounted for. Since greater part of the Adriatic between Bakar and Split is occupied by shelf in contrast to the much deeper southerly part between Split and Dubrovnik, spatial variability of response is examined. The analysis over the shelf gives similar results, yet if the 95% confidence limits are taken into account, with the inclusion of wind stress (mean of Pula and Split) the response is brought near the isostatic value. Results obtained for the deeper sea region are quite different. Here the response to forcing by air pressure alone is isostatic. However when wind stress (mean of Split and Dubrovnik) is introduced into the analysis, the stress being highly coherent with air- pressure gradient, response to air pressure is reduced to a very low, physically unacceptable value. As for the response of sea-level slope to wind stress integral, analysis for the shelf gives estimate B that is surprisingly close to the theoretical value of $1\cdot10^{-4}$ m/(Nm^{-2}).

Analysis in frequency domain

Results of spectral analysis are very similar. Over the shelf (Figure 2), the single input analysis gives high coherence, phase equal to π and

Table 1. Results of one- and two-input linear regression, obtained for different pairs of stations. Here R is correlation coefficient, A and B are linear regression parameters, R_{12} and R_{mult} are correlation coefficient between the two inputs and multiple correlation coefficient. The 95% confidence limits, obtained by the Monte Carlo Method, are given in brackets. In $f(\tau)$, τ_{hom} is spatially homogeneous wind stress. Asterisk denotes results obtained from six 128-day winter intervals; otherwise eight intervals are used.

	single input		two inputs			
FORCING / PAIR	$\Delta p_a = p_{a_2} - p_{a_1}$		$\Delta p_a = p_{a_2} - p_{a_1}$		$f(\tau) = \tau_{hom} \cdot \frac{L}{H}$	
	R	A (cm/mbar)	R_{12}	R_{mult}	A (cm/mbar)	B cm/(10^{2}Nm^{-2}))
BAKAR-DUBROVNIK	-0.91 (-0.94, -0.87)	-1.70 (-1.81, -1.58)	-0.81 (-0.86, -0.76)	0.92 (0.89, 0.95)	-1.32 (-1.52, -1.12)	0.61 (0.37 0.87)
*BAKAR-SPLIT	-0.75 (-0.85, -0.65)	-1.71 (-1.98, -1.42)	-0.57 (-0.67, -0.47)	0.79 (0.70, 0.88)	-1.33 (-1.65, -1.01)	1.17 (0.73, 1.62)
*SPLIT-DUBROVNIK	-0.66 (-0.78, -0.53)	-0.91 (-1.09, -0.73)	-0.80 (-0.85, -0.72)	0.74 (0.66, 0.83)	-0.31 (-0.65, 0.04)	3.39 (1.94, 4.86)