Infrasound radiation from sea waves: Sensitivity to climate changes

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It is interesting to estimate possible variations of infrasound activity (intensity of microbaroms and “voice of the sea”) associated with variations of temperature, wind and intensity of sea waves under climate changes. The source strength spectral density for infrasound radiation from sea waves to the atmosphere was obtained in [1] and can be presented in the following form

$$\mathrm{S}(f)=\frac{4\pi^4\rho_{air}{}^2 g^2 f^3}{c_{air}{}^2}\left[\frac{c_{air}{}^2}{c_w{}^2}+\frac{9g^2}{4\pi^2 c_{air}{}^2 f^2}\right]W(f) \qquad (1)$$

where $W(f)\equiv\int_0^{2\pi}F(f/2,\theta)F(f/2,\theta+\pi)\,\mathrm{d}\theta$ is the so-called Hasselmann term, which is an integral over all directions of the product of frequency-angular spectra of sea waves $F(f/2,\theta)$ taken in opposite directions [1], c_{air} is the sound speed in the atmosphere, ρ_{air} is the atmospheric density, c_w is the sound speed in the water, g is the gravity acceleration and f is the frequency. If infrasound sources are uniformly distributed within a certain area A of the ocean, then at a distance R that is much larger than the size of this area, the spectral density of infrasonic pressure pulsations $<\left|\hat{P}(R,f)\right|^2>$ is equal to the product $A\cdot S(f)\cdot Q(R,f)$, where $Q(R,f)$ is the transfer function of the atmosphere through which the infrasound propagates from the region of its radiation to the point of observation. The term $W(f)$ takes non-zero values only in case of existence of nonlinear interactions between counter propagating surface waves. Such conditions arise in case of occurrence of a strong atmospheric vortex over the ocean surface so that the wind vector turns and becomes opposite to the background wind field. At typical values of the sound speed in air and water and the maximum of the microbarom spectrum at $f\approx 0.2$ Hz , the ratio of the second term in the square brackets in (1) to the first one is about 0.08. The main contribution to infrasound radiation (1) into the atmosphere is caused by pressure fluctuations in the water generated by water-air interface motions:

$$S(f)=\left[\frac{4\pi^4\rho_{air}g^2f^3}{c_w{}^2}+\frac{4\pi^4\rho_{air}g^2f^3}{c_{air}{}^4}\left(\frac{9g^2}{4\pi^2f^2}\right)\right]W(f,u*)=\frac{4\pi^4\rho_{air}g^2f^3}{c_w{}^2}[1+\eta]W(f,u*) \qquad (2)$$

$$\eta=\frac{9g^2}{4\pi^2f^2}\frac{c_w{}^2}{c_{air}{}^4}<<1$$

It is taken into account in (2) that the sea wave spectrum depends on the dynamic friction velocity $u*$, the sound speed in water c_w and in air c_{air} . The relative changes in the infrasound source strength spectrum at a fixed frequency can be approximately presented as

$$\frac{dS}{S}=-\left(\frac{2dc_w}{c_w}+\frac{4\eta dc_{air}}{c_{air}}\right)+\frac{\partial W}{\partial u*}\frac{du*}{W} \qquad (3)$$

There are different models of the sea-wave spectrum [2]. For example, the models both by Kitaygorodsky and Zakharov lead to the following spectrum of the surface vertical displacements

h [2]: $F_h(f) = \alpha u^* g \omega^{-4}$, where α is a numerical constant. Since W is proportional to the product of the sea surface spectra and therefore to u^{*2}, the last term in (3) becomes $2du^*/u^*$. It characterizes the relative changes in the wind vertical shear within the atmospheric vortex over the ocean surface.

It can be shown that the relative changes in the speed of sound in water and air (the first two terms in (3)) arising because of the increase in air and water temperatures by 1 deg are two orders of magnitude less than the contribution to source strength spectrum (3) due to wind shear changes (the last term in (3)) as large as 1 m/s per 20 m. Thus, the problem of finding relative changes in source strength of infrasound radiation is associated with relative changes in the sea wave interaction integral *W*. In [3] the infrasound source strength during stratospheric warmings was predicted by using the 2D wave energy spectrum obtained from the ECMWF ocean wave model.

Microbarom observations at a network of infrasound stations around the globe do reveal an increase in the intensity of the microbarom radiation when the wind speed increases in tropical cyclones [1]. However, at large distances (hundreds and thousands of km) from the ocean area occupied by storm winds, the changes in the infrasound source strength are masked by the influence of the stratospheric stratification on the microbarom amplitudes. The sensitivity and contributions of various terms in (3) can be estimated from climate model simulations with different scenarios of natural and anthropogenic forcings [4].

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