The Radiation of Microbaroms from Isolated Hurricanes over Deep Water

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Abstract. Cyclonic storms over water radiate a infrasound at about 0.2 Hz. The atmospheric component of this radiation is called the microbarom peak. The seismic component is called the microseism peak. It is believed that the source of the radiation is the non-linear interaction of colliding waves on the ocean surface. Results from our ongoing studies of the radiation mechanism will be reported. These include conjectures about the influence of the finite depth of the ocean on the microbarom/microseism spectrum and about the origin of the colliding waves produced by isolated storms.

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INTRODUCTION

Studies of the equations of fluid mechanics have shown that colliding ocean surface waves of nearly equal periods and nearly opposite propagation direction radiate sound into the ocean and atmosphere.[1, 2, 3, 4] The radiation mechanism is non-linear and the radiation may be considered to be a harmonic of the ocean surface wave field. It is generally believed that the sources of the microbarom/microseism signal are such ocean surface wave collisions. Paradoxically, it is known that significant microbarom/ microseism radiation is produced in the vicinity of hurricanes even when the hurricane is isolated and far from any land mass.[5, 6, 7, 8] Under such conditions it is not clear what can produce counter propagating ocean surface waves. In this note a recently discovered mechanism is suggested through which counter propagating ocean surface waves are produced by the interaction of the wave field produced by the hurricane with the ambient wave field.[9] In addition, an improved formula for the effect of the ocean floor on the microbarom spectrum is presented.

A PROPOSED SOURCE MECHANISM

We propose that the microbarom/microseism radiation from an isolated hurricane is produced by the collision of the ocean waves produced by the hurricane with the ambient wave field over the ocean. The ambient waves are produced far from the hurricane by the prevailing winds over the ocean. The hurricane itself produces a rotational wave field. There is a region, a stagnation zone, in which the the ocean waves produced by the hurricane and those produced by the prevailing winds directly oppose each other and

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have similar periods. We propose that this stagnation zone is the source of the infrasound.

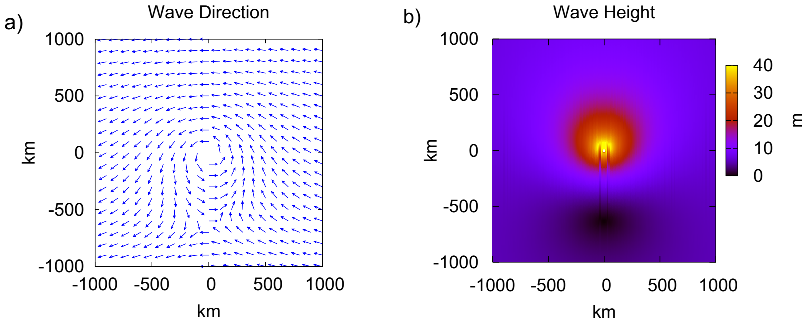

FIGURE 1. A depiction of an ocean surface wave field in the vicinity of a hurricane. (a) shows the predominant propagation direction and (b) shows the wave height averaged over all directions.

The situation is depicted schematically in Fig. 1. A wave field of the sort produced by a hurricane is superimposed on a unidirectional ambient wave field. In Fig. 1(a) the predominant wave directions are shown and in Fig. 1(b) the direction averaged wave heights are shown. One sees a region, about 600 km below the eye of the storm in this depiction, a stagnation zone, in which the rotational wave field produced by the hurricane winds and the ambient wave field produced by large scale winds over the ocean oppose each other.

There is experimental evidence that the source of the radiation from an isolated storm is typically from a region hundreds of kilometers from the eye.[7, 8, 9] In Ref. [9] evidence is presented that the microbarom/microseism signal indeed originates in the stagnation zone. It has been reported[7] that the amplitude of the microbarom/microseism signal decreases if the motion of the hurricane slows. For the motion of the hurricane to slow the prevailing winds must decrease. If the prevailing winds die down the stagnation zone will vanish and, if the mechanism proposed here is correct, the microbarom/microseism signal should die down as well.

THE INFLUENCE OF THE SEA FLOOR

At 0.2 Hz the acoustic wavelength in sea water is about 7.5 km. It follows that the infrasonic radiation from ocean surface waves into the water interacts strongly with the sea floor. A simple model for the microbarom source strength was presented in [10]. It was stated that the microbarom radiation excites resonances in the water column which manifest themselves as structure (visible peaks) in the received microbarom power spectrum. More recently signal processing techniques designed to enhance coherent parts of a signal have been applied to the microbarom signal received from hurricane Katrina in 2006.[11] Most of the microbarom signal was lost in the processing. This is not surprising since the source of the signal, colliding ocean waves produced by winds over the sea surface, are expected to be incoherent. What remained was a series of evenly space peaks. We conjecture that these peaks are vertical resonances in the water column and in the Earth's crust excited by the microbarom radiation.

In [10] the theoretical treatment of Ref. [4] was generalized to take account of the finite depth of the ocean. It was assumed that the water is deep enough that the surface waves themselves don't interact with the ocean floor so that the linear solutions of the equations of fluid mechanics are as in the infinitely deep case.[12] In [10] the sea floor was assumed to be an infinite elastic solid with constant density and elastic moduli. Here the effect of the sea floor on the signal in the water column will be modeled by specifying a sea floor impedance.

As in Refs. [2, 4] the motion of the interface is described statistically by the frequency angle spectrum $F(f,\theta)$. The frequency angle spectrum can be thought of as the density of ocean surface wave power of frequency f propagating in the direction θ.[13, 14] The calculation of the microbarom/microseism source spectra then reduces to finding the vertically propagating, frequency doubled component of the second order velocity potential.[1, 2, 4] This component is produced during the collision of two counter propagating surface waves of equal frequency and opposite direction.

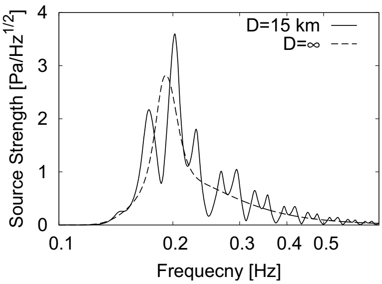

FIGURE 2. The microbarom source spectrum for the infinitely deep ocean and for an ocean of depth $D = 6$ km and sea floor impedance for seawater over a layer of bedrock with compressional wave speed $c_B = 2$ km/s terminating rigidly at depth $D_B = 18$ km: $Z = \frac{5}{2}\rho_{\mathrm{w}} c_{\mathrm{w}} \cot(\omega(D_B - D)/c_B)$.

Let ϕ be the relevant component of the second order velocity potential and ξ be the related component of the second order correction to the surface displacement. Assume that for the surface waves the deep water dispersion relation $\omega = \sqrt{g|\mathbf{k}|}$ is valid so that $\mathbf{k} = (4\pi^2 f^2/g)(\cos\theta, \sin\theta)$. As in Ref. [4] introduce $\phi(z,t) = \hat{\phi}(z)\, e^{-i2\omega t}$ and $\xi(t) = \hat{\xi}\, e^{-i2\omega t}$. Then for some constants C_σ

$$\hat{\phi}(z) = \begin{cases} C_{\mathrm{a}}\, e^{i\frac{2\omega}{c_{\mathrm{a}}} z} & \text{if } 0 < z \\ C_{\mathrm{w}}\Big(\cos(\frac{2\omega}{c_{\mathrm{w}}}(z+D)) + 2i\frac{\rho_{\mathrm{w}} c_{\mathrm{w}}}{Z(2\omega)} \sin(\frac{2\omega}{c_{\mathrm{w}}}(z+D))\Big) & \text{if } -D < z < 0 \end{cases}$$

with the impedance Z at the sea floor. The C_σ are determined by the air/sea interface conditions

$$\big(-2i\omega\hat{\phi} + \rho_\sigma g\hat{\xi}\big)\Big|_{z=-0^+}^{0^+} = 2\rho_{\mathrm{w}}\omega^2$$

$$\frac{\partial\hat{\phi}}{\partial z}\Big|_{z=-0^+}^{0^+} = 3i\frac{\omega^3}{|\mathbf{k}|c_{\mathrm{a}}^2}$$

and

$$-2i\omega\hat{\xi} = \left(\frac{\partial\hat{\phi}}{\partial z} - 3i\frac{\omega^3}{|\mathbf{k}|c_\mathrm{a}}\right)\Big|_{z=\pm 0^+}.$$

The source strength power spectrum is given by[2, 4]

$$\mathscr{D}(2f) = \frac{g^2}{f}H(f)\begin{cases}\rho_\mathrm{a}^2\left|\frac{d\hat{\phi}}{dz}\Big|_{z=0^+}\right|^2 & \text{into the air}\\ \rho_\mathrm{w}^2\left|\frac{d\hat{\phi}}{dz}\Big|_{z=-0^+}\right|^2 & \text{into the sea}\end{cases}$$

where

$$H(f) = \int F(f,\theta)F(f,\theta+\pi)\,d\theta$$

measures the density of counter propagating waves of frequency f on the sea surface.[2]

In Fig. 2 a model microbarom source spectrum for an ocean of finite depth over a finite layer of bedrock is compared to that for an ocean of infinite depth. Peaks due to vertical resonances in the water and bedrock are visible.

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