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Effects of Vortices on Sound Propagation

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Our simulations indicate that the presence of a vortex in or near acoustic propagation paths can have profound effects on the distributions of sound energy and cause sound waves to originate from virtual source positions. For example, recent studies have shown that infrasonic energy arrives from the regions of hurricanes. The azimuths measured for a limited number of cases published to date do not seem to originate from the vortex cores; but rather from the periphery of the system. This raises the questions: Is the sound being affected by strong wind and temperature gradients with the measured azimuths indicating virtual source positions? -or- Is the sound generation mechanism located outside of the vortex core?

Acoustic ray tracing can provide valuable insights into the propagation environments of vortices. To address these questions we positioned a sound source at various stations in and near a hurricane-like vortex and examined the ray paths emitted by an isotropic source for a standard atmosphere with and without wind. This paper reviews the results of a series of ray trace simulations using a Rankine-combined vortex to define the tangential velocities..

There is a long history of investigation of the generation of infrasound -microbaroms- by ocean waves (e.g. Daniels (1953), Brekhovskikh (1966), Posmentier (1967), Donn and Naini (1972). One mechanism proposed for the infrasound generation mechanism is the interaction between systems of counter propagating waves. It has been a challenge to identify the source regions of the infrasound in part because of the masking effects of wind noise; but also because of propagation effects on acoustic bearing measurements.

Figure 1 shows an acoustic source (the black center of isotropic radiation) to the northwest of a hurricane-like Rankine-combined vortex core (transparent red circle). The ray paths are shown for 4 values of maximum tangential flow speed with the Mach numbers also indicated. As the vortex strength increases the effects on the ray paths get larger. At a maximum speed of 35 m/s there is region of strong focusing to the ESE. As the maximum wind speed increases further, quite large ray deviations can indicate virtual source locations or cause regions of de-focused weak energy. These results are similar to the results of Georges (1972) for planar acoustic wave fronts passing through a vortex.

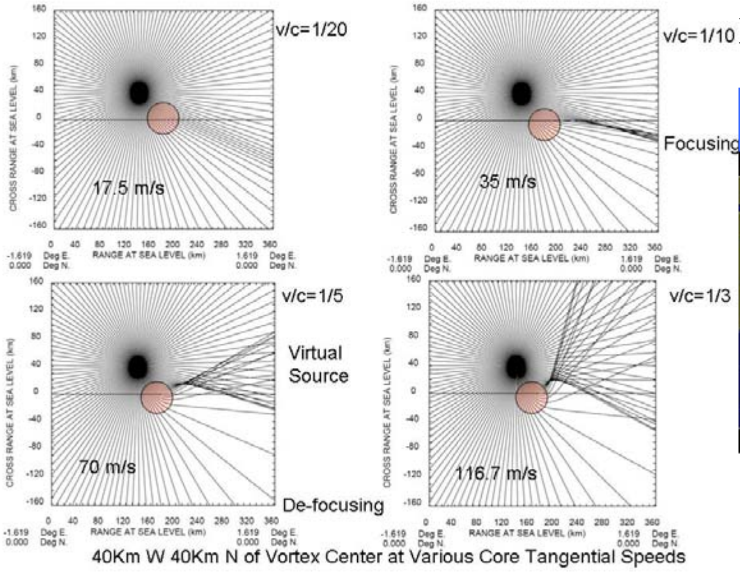


Figure 1. Ray paths from an isotropic acoustic source to the northwest of a hurricane-like vortex having maximum tangential winds of 17,5, 35, 70, and 116.7 meters per second.

Figure 2 shows the track of Typhoon Usagi (2007) as a function of time and also the relative positions of 2 infrasonic stations in the region. Winds of 120 knots were measured. The infrasound from this storm was studied by Hetzer et al. (2008) using infrasound station 139PW. They found that the acoustic energy did not originate from the direction of the Typhoon center, but from azimuths 10 to 30 degrees to the east. A wave hindcast model indicated that the origin could have been a region of counter propagating waves in the lee of the storm, which was moving to the northwest. Unfortunately high winds at station 130JP prevented the detection of infrasonic signals. We feel that their explanation of the bearing offsets is quite reasonable; but we use this case as an example of the large effects that the presence of a vortex can have on ray paths.

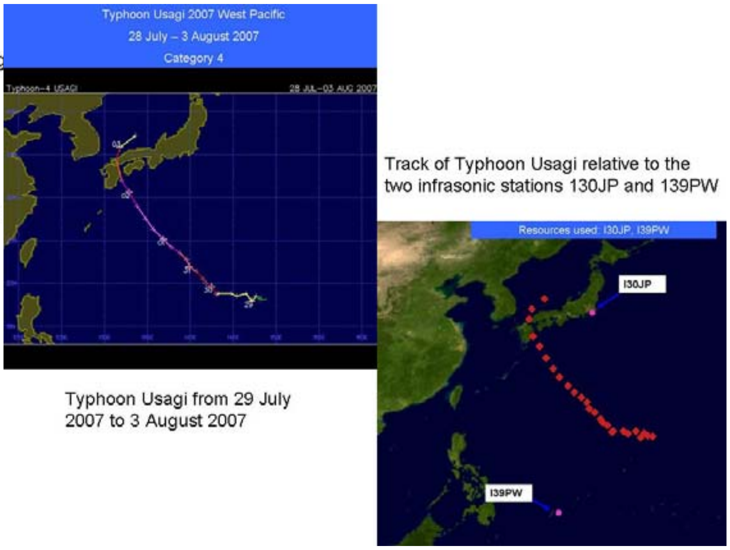
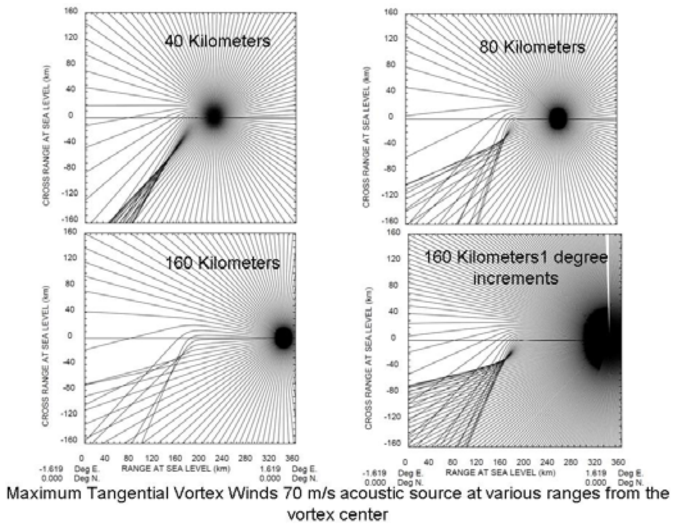


Figure 2. Views of the track of typhoon Usagi as a function of time relative to the locations of two infrasonic observatories.

Figure 3 shows the sound source at 3 ranges from a vortex center with 70 m/s maximum winds at the 20 Kilometer radius core. The ray paths for the 40 kilometer range show a region of strong focusing with many of the rays off azimuth from the origin of the sound. At a range of 80 kilometers there are greater azimuthal deviations of the ray paths, with the dominant ensemble of azimuths originating from a virtual source distant from the real source. Another feature of the ray distributions is that there is strong de-focusing for rays passing directly through the vortex. In this case infrasonic signals would probably not be detected by an observatory in the “shadow” of the vortex. The 160 kilometer range is similar to the 80 kilometer situation, with the virtual source also about 20 km south of the vortex center. But, because the propagation from the virtual source is toward the southwest, the sound appears to come from southeast of the center of the hurricane. That is, the azimuth of the sound arrivals would be somewhat greater than the azimuth of the hurricane center. This agrees with the measurements of infrasound from the region of a hurricane presented by Hetzer, et al. (2008). This follows the same pattern as with all the other cases we have modeled.

Thus, depending on the relative positions of the source, the vortex, and the location of the observatory great differences in azimuth and detectability can occur. These can range from very minor deviations in bearing from the true bearing to azimuths passing hundreds of kilometers from the infrasonic source.



. Figure 3. Views of the ray paths from an isotropic sound source at ranges of 40, 80, and 160 kilometers from the center of a vortex with 70 meter per second maximum tangential wind speeds.

Concluding Remarks

We have made a series of simulations of the effects of propagation of sound waves through vortices. These results have defined important impacts important for measurements of acoustic bearings and signal strengths.

The acoustic ray paths can:

- Be Focused
- Be De-focused
- Indicate virtual source positions, or
- Be unperturbed.

We also note that the interactions of the rays with an unsteady velocity vortex field can cause broadening of the sector from which signals are received.

A goal of our simulations is to alert investigators of the potential complications of identifying source positions in the presence of vortices. We note that, conversely, the strong interactions could be exploited to identify the presence of a vortex in a well defined propagation path. One possible application is to detect the presence of an aircraft wake vortex entering a continuous acoustic transmission/reception beam. In the future we hope to examine the role of hurricane temperature perturbation fields on the acoustic energy distributions.

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