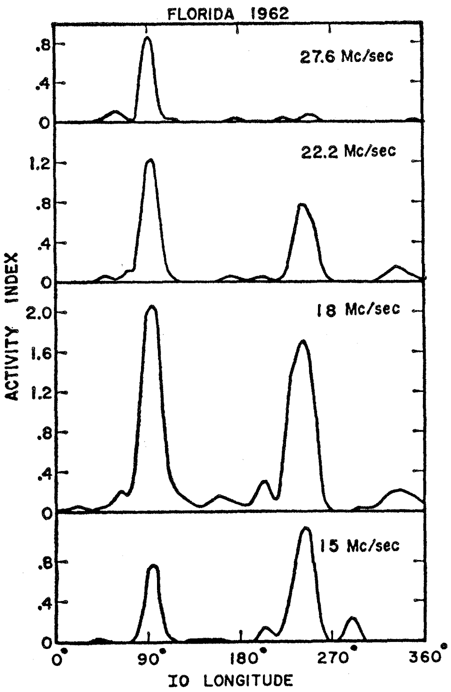

Fig. 3. Influence of Io on Jovian radiation of various frequencies during the apparition of 1962.

"sources" maintain fixed positions, although around 1960 their apparent rotation period changed from $9^h55^m29^s.35$ to $9^h55^m30^s.52$ (at 18 Mc/sec) (*3*). Bigg investigated the influence of the angular relationship between Io and the decametric sources through a contour plot such as is shown in Fig. 4. This figure is based on all of the data for 18 Mc/sec obtained during 1957–1963 at the University of Florida; the computations took account of the change in rotational period since 1960, and resulted in an appreciable sharpening of the

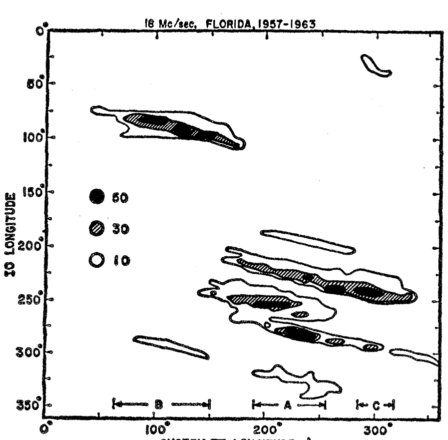

Fig. 4. Jovian decametric activity as a function of both Io longitude and system III longitude (λ_{III}). The contours represent the activity index for 18 Mc/sec emission during the apparitions of 1957–1963.

contours as compared with an earlier analysis in which this refinement was omitted.

In agreement with Bigg's work, it appears that the most active source, *A* (at $\lambda_{III} \cong 250°$), can be stimulated over a relatively wide range of Io longitudes. On the other hand, the secondary source, *B* (at $\lambda_{III} \cong 140°$), is observed only over a narrow span of Io longitudes. The tertiary source, *C* (at $\lambda_{III} \cong 320°$), is similarly more sensitive than *A* to the position of Io. It seems quite likely that the greater probability of receiving emission from *A* is related to the tolerance of that source for changes in the location of the satellite. The general slope of the contours in Fig. 4 is simply a time effect; that is, if one regards the horizontal axis as a time axis, making a giant clock of Jupiter, the slope of the contours indicates the rate at which Io longitude increases in this time system.

If the influence of Io is tidal in nature, one might anticipate similar, but smaller, effects from the other major satellites. The tide-raising forces of the second and third satellites, Europa and Ganymede, are respectively about 1/7 and 1/9 that of Io. Figure 5 shows a polar plot of activity index versus satellite longitude for Io, Europa, and Ganymede, the data for 18 Mc/sec from the apparition of 1962 again being used. There appear to be reasonably pronounced activity peaks for Europa and Ganymede longitudes between 270° and 360°, and for Ganymede between 80° and 180°. When the longitudes of Europa and Ganymede are either equal or differ by 180°, the joint tide-raising force is ¼ that of Io. Long ago, Laplace (*5*) showed that the mutual perturbations of the three satellites bring them exactly into line at intervals of about 7 days, with Io and Ganymede on one side of the planet and Europa on the other. Because of the near-harmonic relationship between the periods of the three satellites, an approximate realignment occurs 3½ days after syzygy, with Europa and Ganymede on the same side of Jupiter and Io on the opposite side. The line of syzygy precesses about Jupiter in the retrograde sense with a period of 437 days, and it is interesting to note that during the most productive portion of the 1962 apparition the longitude of the line changed from 180° to 80° (or from 360° to 280°), covering just that portion of the polar diagram in which the activity of Europa and Ganymede appears to peak. A study similar to that

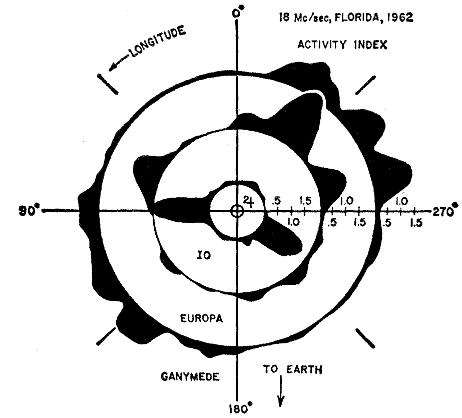

Fig. 5. Jovian 18 Mc/sec activity indices versus the longitudes of Io, Europa, and Ganymede during the apparition of 1962.

shown in Fig. 5 and based on the data for 18 Mc/sec from 1957 through 1963 failed to show localized peaks for the second and third satellites, perhaps because of the "smearing" caused by precession of the line of syzygy during the 7-year period.

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16 April 1965

Microseisms from Hurricane "Hilda"

Abstract. *As hurricane "Hilda" crossed the Gulf of Mexico the dominant period of the microseisms shifted from about 8 to 5 seconds as the eye reached water about 150 to 200 meters deep. The conversion of wind energy to microseismic energy is most efficient in water depths from 20 to 200 meters. There is no evidence that two periods, one twice the other, are present.*

The vicinity of the Gulf of Mexico is particularly well suited for the study of microseisms: the Gulf is a restricted body of water through which accurately mapped hurricanes move fairly frequently. The recent hurricane

"Hilda" (1964) was chosen for a first approach to the problem.

The term microseisms designates the constant ground motion due to natural sources. This motion is particularly large for periods ranging from about 4 to about 10 seconds. The exact mechanism by which the energy in this range of periods enters the ground is in doubt; it is known, though, that the largest part of the energy is transferred from the air to the sea, and from the sea to the ground, where it propagates with very little attenuation. This report is concerned with attempts to increase our understanding of this mechanism by examining the microseisms in Houston as "Hilda" crossed the Gulf.

The Rice seismographic station in Houston is equipped with three long-period instruments and one microbarograph. All record (*1*) digitally on magnetic tape in a computer-compatible format. The system is designed in such a way that it is possible to start and stop the reading of the original tape anywhere and to do this repeatedly without having to rewind the tape before each reading (*2*) The system also records on semiconventional pen-and-ink recorders for monitoring purposes. The records of the horizontal seismographs were used in this analysis.

The standard way of analyzing waves which exhibit large statistical fluctuations is to compute their power spectra (*3*). In essence the results of this method are of the same nature as those of Fourier analysis, but they are statistically significant.

The method may be very briefly outlined as follows. One first computes the autocorrelation function; as its name implies, this function shows how much the curve repeats itself after a variable time interval δt, generally referred to as time-lag. The autocorrelation is then tapered so as to avoid sharp discontinuities at its ends. Finally a Fourier analysis (in this case a cosine transformation) is performed on the tapered autocorrelation, yielding the power spectrum. It can be shown that the power spectrum is the square of an average amplitude spectrum; moreover, the power spectrum becomes increasingly stable as the maximum time-lag used in the autocorrelation becomes smaller compared to the length of the record. In most cases a lag of 10 percent of the record length is adequate, and this was used here.

I computed the power spectra of the ground displacement for each horizontal instrument after correction for instrumental response. I then plotted the sum of these spectra on a logarithmic scale. Practical considerations limited the analysis to a 4-minute stretch of record at a time. After some experimenting I decided to compute one spectrum every 4 hours.

In addition I computed a number (S) proportional to the seismic energy (for periods between 3.3 and 20 seconds) by integrating the sum of the power spectra of the horizontal ground velocities; this was multiplied by the distance to take the effect of geometrical spreading into account. The energy (H) of the hurricane was estimated, to a constant factor, from the square of the wind velocity near the eye of the hurricane; the area of gale-force winds give a similar result. Nevertheless, this figure is only tentative.

The ratio, S/H, gives a measure of the efficiency of the energy transfer from the air to the ground, and it was also computed.

Figure 1 shows the track of the eye of the hurricane in the western Gulf of Mexico. The times are those at which the spectra were computed. Figures 2 and 3 show the water depth (D) in fathoms (1 fathom = 1.83 m), the hurricane energy (H), the seismic energy (S), the ratio S/H, and the spectra with the dominant period.

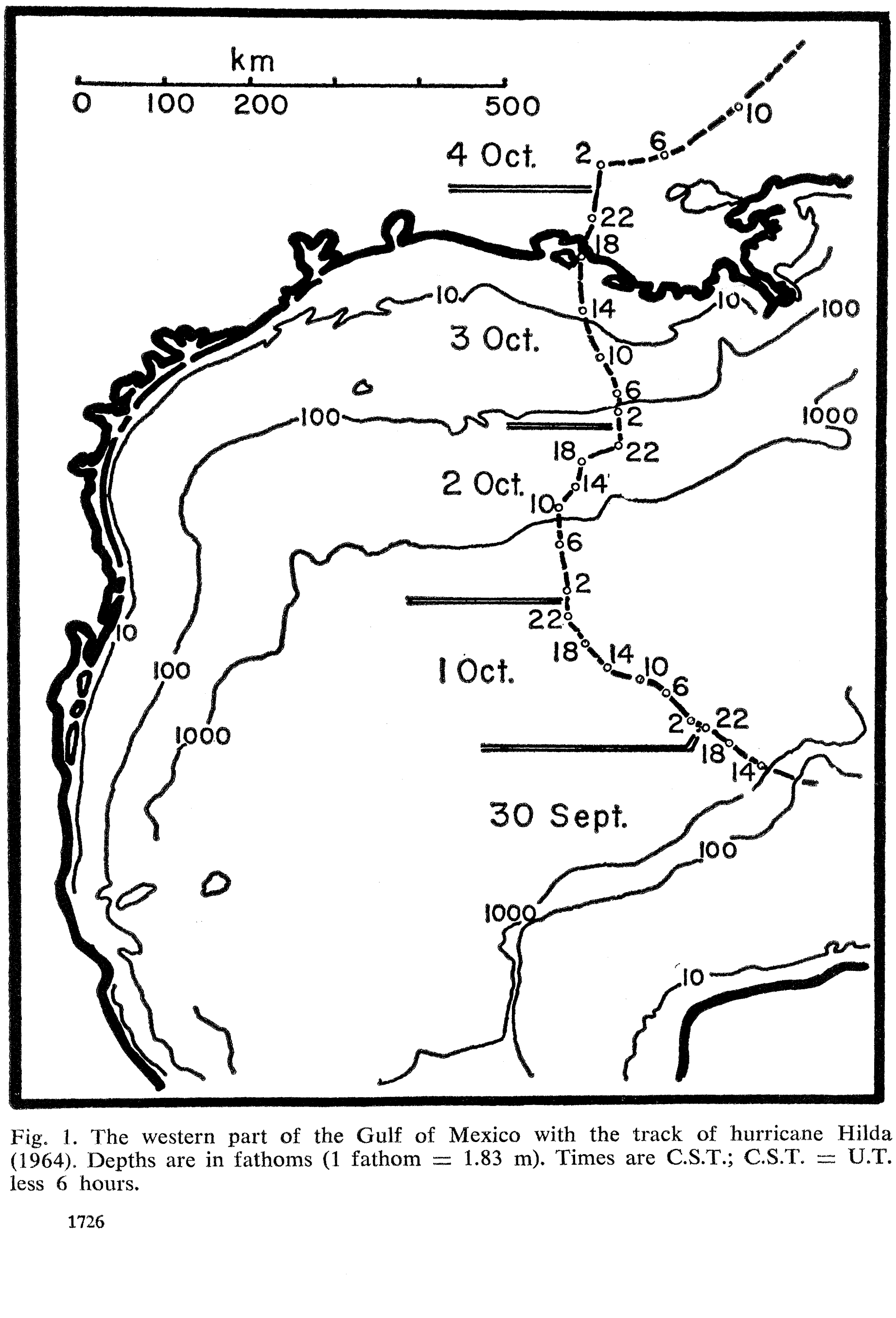
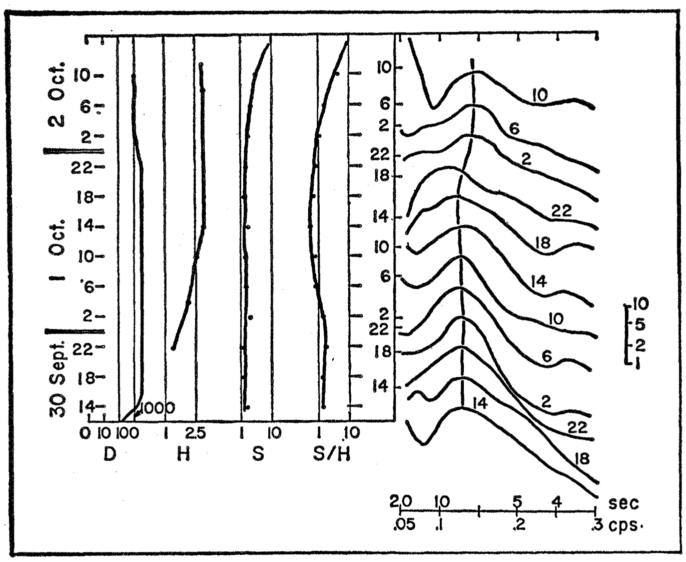


Fig. 1. The western part of the Gulf of Mexico with the track of hurricane Hilda (1964). Depths are in fathoms (1 fathom = 1.83 m). Times are C.S.T.; C.S.T. = U.T. less 6 hours.



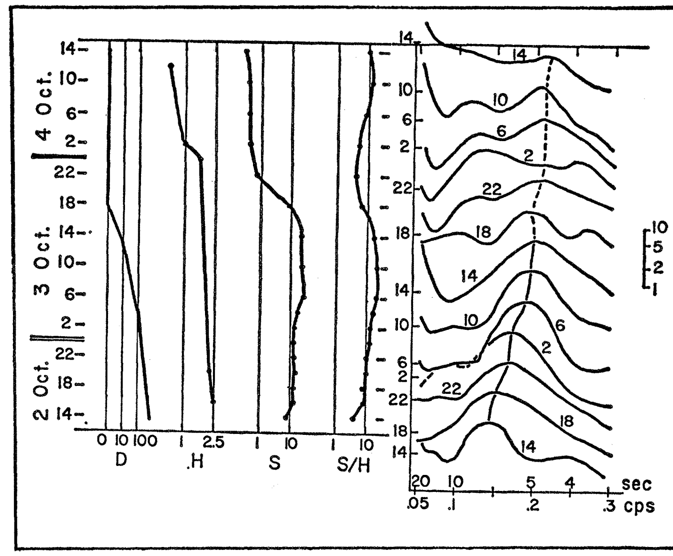


Fig. 2 (left) and Fig. 3 (right). Related measurements along the hurricane track. Times are C.S.T. *D*: water depth in fathoms (1 fathom = 1.83 m); *H*: number proportional to the energy of the hurricane; *S*: number proportional to the seismic energy. The spectra of the microseisms are on the right.

Each spectrum is identified by the time at which it was computed. Each is of course plotted from a different vertical origin, but the origin of each is indicated by the corresponding time on the left. All spectra are at the vertical scale shown on the right.

These figures show that from 30 September at 14:00 hours until 1 October at 22:00 hours the dominant period of the microseisms remained essentially constant ($\approx$ 7.8 sec), despite the change in the distance of the hurricane. As a matter of fact, this period changed only from 8.0 to 7.0 seconds until 2 October at 14:00 hours, while the seismic energy increased by a factor of approximately 10 between 06:00 and 14:00 hours. Up to 10:00 hours the water depth near the eye was greater than 1000 fathoms (1830 m).

Starting at 14:00 hours on 2 October the dominant period became rapidly shorter, while the seismic energy remained roughly constant. Correspondingly the water depth changed from 1000 to 100 fathoms (1830 to 183 m). Between 02:00 and 06:00 hours on 3 October the seismic energy doubled. The peak-to-peak ground motion was approximately 10 μ. At this time the water depth was between 10 and 100 fathoms; the dominant period continued to decrease in this interval.

The high level of seismic energy persisted until 14:00 hours, after which time an extremely rapid decrease took place: this corresponds to the eye of the hurricane arriving in depths less than 10 fathoms and then coming ashore. Simultaneously the spectra, which had shown a clear maximum, flattened markedly.

The efficiency of the energy transfer from the air to the ground is about ten times greater when the water depth is between 100 and 1000 fathoms than when it exceeds 1000 fathoms. It further increases by a factor of two for depths between 10 and 100 fathoms, but decreases sharply at shallower depths (and over land). An alternative explanation (*4, 5*) is that the increase in efficiency is due to the rapid change in crustal thickness. The crustal section through the Gulf of Mexico given by Dehlinger and Jones (*7*) suggests that water depth is probably the controlling factor; this section is very close to the hurricane track. On the other hand, the increase in *S/H* during 4 October is not clearly understood.

The relation between dominant frequency and water depth is remarkable: as can be seen between 18:00 hours on 1 October and 14:00 hours on 3 October, the dominant frequency tends to be proportional to minus the logarithm of the water depth. This result is not easily explained by present theories. One might suggest (*6*) that the periods of the waves at sea changed correspondingly; considering that the state of the sea near the center of the hurricane is mostly determined by the winds, one must tentatively reject this idea in the present case.

There is no evidence that spectral maxima occur at two frequencies, one double the other (*8*). This suggests that Hasselman's explanation (*9*) of the doubling effect as the interaction of incoming and reflected swell is correct: in a basin as small as the Gulf of Mexico such an interaction would not result in any consistent pattern.

The simplicity achieved by operating directly from the original magnetic tapes must be emphasized, but it is indispensable to plot the records from the tapes before carrying out the computations if serious errors are to be avoided.

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Both the track of the hurricane and wind velocities were obtained from the advisories of the Weather Bureau. Free computer time was made available by the Rice Computer Project under AEC contracts AT(40-1)-1825 and AT(40-1)-2572. G. A. Sitton helped in this work.

21 May 1965