Atmospheric Pressure and Temperature Changes During the 7 March 1970 Solar Eclipse

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ABSTRACT

Air pressure and temperature measurements were made during the 7 March 1970 solar eclipse. A Fourier analysis showed a primary wave with a period of 89 min and an amplitude of 250 μb. Smaller peaks were found with periods of 57, 51, 45, 38, 20.3, 18.2, 15.7 and 12.3 min. The primary wave agreed reasonably well in magnitude and phase with five earlier eclipse measurements dating back as far as 1887. The temperature decreased 3C with a minimum slightly after totality. This occurred under a thick cloud blanket.

1. Introduction

Measurements of the temperature and barometric pressure were made at a single station on the shadow centerline during the 7 March 1970 solar eclipse in Florida. The experiment was prompted by the suggestion of Chimonas and Hines (1970) that atmospheric gravity waves would be generated as a result of a solar eclipse and that these waves should be detectable at ground level.

Table 1 is a summary of measurements similar to ours, dating back to 1887, that attributed atmospheric pressure changes to a solar eclipse. There are several trends in these experiments which should be noted. The magnitude of the pressure change seems to be quite consistent. The average of the pressure amplitudes is 244 μb. Only Clayton's (1901) measurement differs from the mean by a factor greater than 2. All measured pressures reported from a single station show oscillations except Clayton's and, in addition, all but one of the authors reported two maxima and two minima beginning with a minimum after first contact. Klein and Robinson (1952) reported two maxima and three minima, the third minimum being a weak one after the first two major oscillations. In all cases, the waves seem to have a period about the same as the semi-duration of the eclipse. When waves were not reported, the data from several stations had been averaged. Further, when the results were averaged for many stations, up to 55, all but Schönrock (1887) found a decrease in the pressure.

The present work qualitatively agrees with much of the older observations and appears to reveal some fine structure that was not observable with the older instrumentation. In addition to the presentation of our data, a suggestion as to why the waves reported here were not seen by other observers is given.

TABLE 1. Summary of early eclipse pressure measurements.

Investigator	Eclipse date	Approximate pressure change (μb)	Number of maxima	Number of minima	Single station	Location
Hesehus (1886)	8/19/1887	260	0	1	No	Russia
Schönrock (1887)	8/19/1887	NA[b]	1	0	No	Russia
Upton and Rotch (1887)	8/19/1887	230[c]	2	2	Yes	Russia
Upton and Rotch (1893)	1/1/1889	280	2	2	Yes	California
Upton and Rotch (1893)[a]	4/16/1893	150[c]	2	2	Yes	Chile
Clayton (1901)	5/28/1900	100	0	1	Yes	Georgia
Kimball and Fergusson (1919)	6/18/1918	200	—	—	No	United States
Lindholm and Bergstein (1923)	4/8/1921	280	2	2	Yes	Sweden
Klein and Robinson (1952)	2/25/1952	450	2	3	Yes	Israel

[a] See Footnote 1.
[b] Not available.
[c] Peak-to-peak values.

2. Site conditions

The observations were made in an open field at Lee, Fla., 30°23.1′N, 83°18.8′W, very near the centerline of the total eclipse. It was felt that a site free from obstructions such as trees and buildings was essential to minimize any disturbances caused by wind gusts.

The morning of the eclipse was foggy with a light breeze from the east. The temperature was 13C. Fog remained until about 0930 (all times EST) after which the sun could be seen through a heavy haze. Easterly winds continued at about 5 kt. By 1300 the wind stopped and a dead calm prevailed throughout the remainder of the eclipse. This, of course, eliminated all wind noise from the pressure data. The cloud cover continued to thicken throughout the morning. At 1158, the time of first contact, the location of the sun could not be determined through the clouds. This condition continued past fourth contact (the end of the eclipse) which occurred at 1440. A light rain began at about 1730 with the clouds estimated to be at an altitude of 3500 ft. This was judged by observing a light aircraft flying under them at about 1300.

3. Experimental apparatus

The atmospheric pressure measurement was made using a commercially available (MKS Baratron Series 90) differential capacitance manometer. This transducer has eight ranges with full-scale sensitivities from 13.3 μb to 40 mb. The transducer is calibrated by the manufacturer using an air dead-weight tester. The accuracy, quoted by the manufacturer, was 4 μb on the range used for the eclipse measurement. To make the atmospheric pressure measurement using a differential transducer, a reference pressure was established by sealing one side of the transducer at atmospheric pressure. This had the advantage of not limiting the low- or high-frequency response of the instrument. However, it introduced an uncertainty in the pressure measurement because of possible temperature changes in the reference volume. When the temperature of the reference volume does change, the resulting expansion or compression produces a displacement of the diaphragm which is recorded as a change in pressure. At the same time the displacement of the diaphragm changes the reference volume which partially compensates for the temperature change.

The displacement of the diaphragm is assumed to be proportional to the pressure difference, i.e.,

$$\Delta x = k\Delta p,$$

and the change in reference volume is given by

$$\Delta V = \alpha A \Delta x,$$

where A is the diaphragm area and α a geometric factor depending on the shape of the displaced diaphragm. The fractional change in indicated pressure it related to the fractional change in temperature by

$$\frac{\Delta p}{p} = -\left(\frac{1}{1+k\alpha AP/V}\right)\frac{\Delta T}{T}.$$

If it is further assumed that the displaced diaphragm is spherical, α is approximately $\frac{1}{2}$.

Using information supplied by the manufacturer for the 30 torr transducer, the fractional change in indicated pressure is given by

$$\frac{\Delta p}{p} = -0.242\frac{\Delta T}{T}. \tag{1}$$

The Baratron transducer was enclosed in a thermal jacket whose temperature was controlled to ±0.05C by a proportional controller. This uncertainty in temperature results in an uncertainty in the indicated pressure of ±40 μb.

The entire assembly was enclosed in a 30-cm styrofoam cube which was wrapped with aluminum foil and sealed with tape. The measuring port was attached to a copper tube connected to a pitot-static probe mounted 3.3 m above ground level on a weather vane so that the static pressure ports were maintained in a perpendicular orientation to the local wind direction. An initial zero offset, required by variation in the local barometric pressure, was established using the digital dials provided on the readout unit. This procedure allowed the pressure measurement to be made on the higher sensitivity ranges of the instrument. The pressure measurement was recorded on a 10-inch strip chart recorder from the dc output provided on the readout unit.

The local air temperature was measured during the eclipse at a height of 30 cm above the ground. A cromel-alumel thermocouple was mounted in an aluminum duct 10 cm in diameter, to shield it from solar radiation. Air was drawn across the thermocouple, at 50 cm sec^{-1}, by a small fan mounted in the duct to insure that its temperature was determined by convective rather than radiative heat transfer. The thermocouple was calibrated *in situ* by means of an ice bath and boiling water. The output of the thermocouple was recorded on a separate 10-inch strip chart recorder. All measurements were correlated in time by using the time signal broadcast from station WWV which was monitored by means of a shortwave receiver.

Electrical power was provided by a portable gasoline powered generator. To provide a stable constant frequency voltage source for the Baratron, it was powered by an inverter operating from a 12 V storage battery which was maintained at full charge by a battery charger powered from the portable generator. The input voltage was continuously monitored and kept constant by means of a variable autotransformer.

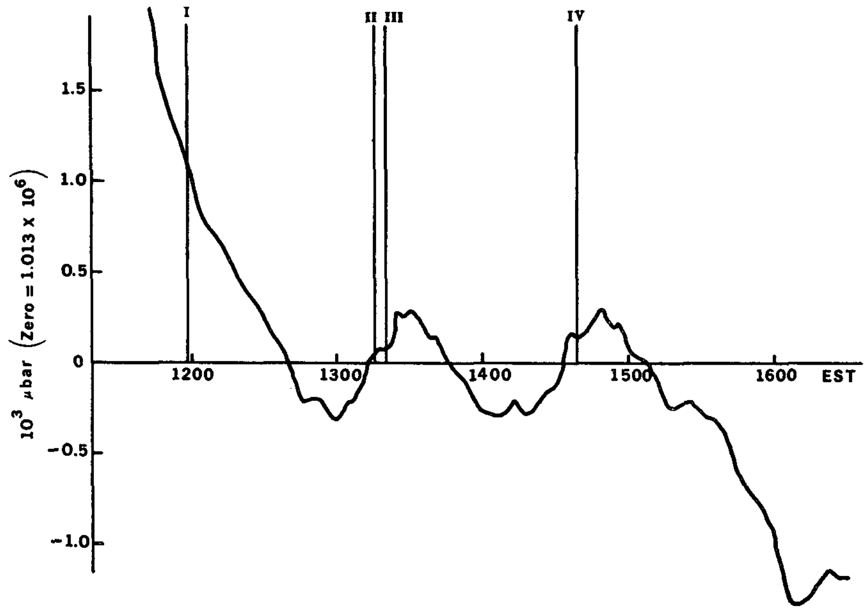

FIG. 1. Barometric pressure at Lee, Fla., during the 7 March 1970 eclipse.

4. Results

Atmospheric pressure measurements, recorded during the period 1140 through 1620 on 7 March 1970, are shown in Fig. 1. The roman numerals I through IV indicate the time of first, second, third and fourth contacts, respectively. No attempt was made to filter the signals prior to recording. The plan was to record all the information and then to apply filtering in the data analysis.

The pressure curve was first fitted to the expression

$$p = A + Bt + C\cos\left(\frac{2\pi t}{\theta}\right) + D\sin\left(\frac{2\pi t}{\theta}\right), \qquad (2)$$

where A, B, C, D and θ are free parameters and t is the time. The constant, linear and trigonometric terms were intended to represent the average pressure, instrument zero drift, and the thermal tide, respectively. Since the wind was dead calm during the experiment, leading to a high signal-to-noise ratio, filtering of high-frequency wind noise was not necessary. A minimum residual was obtained when $\theta = 12^h\ 30^m$, a value quite compatible with the thermal tide considering that the curve was fitted over only a quarter cycle and was assumed to be a simple harmonic wave. Eq. (2) was then subtracted from the empirical curve to get the result shown by the solid curve in Fig. 2.

The curve of Fig. 2 was further treated by discrete autocorrelation and fast Fourier transform to obtain the spectral power density. A sharp peak occurs at a period of 89±4 min, with essentially no evidence for any longer period despite the simplicity of the filtering described above. Other weaker peaks in the power density curves occurred with periods of 57, 51, 45, 38, 20.3, 18.2, 15.7 and 12.3 min. Their amplitudes were less than one-fourth of the primary 89-min, 250-μb component.

The results of the atmospheric temperature measurement which was described in an earlier section are shown in Fig. 3. A maximum change of 3C was observed just after totality. It should be noted that the atmospheric conditions were quite favorable for measuring the eclipse-induced temperature change in that the ambient temperature returned to within ½C of its value before the eclipse.

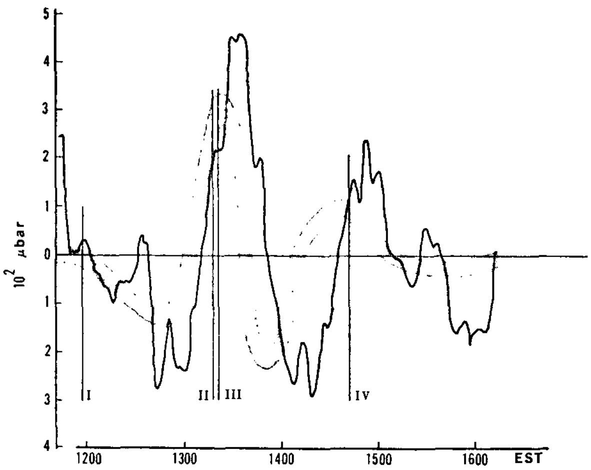

FIG. 2. Barometric pressure fluctuations recorded during the eclipses of 7 March 1970 (solid line) and 25 February 1952 (shaded line).

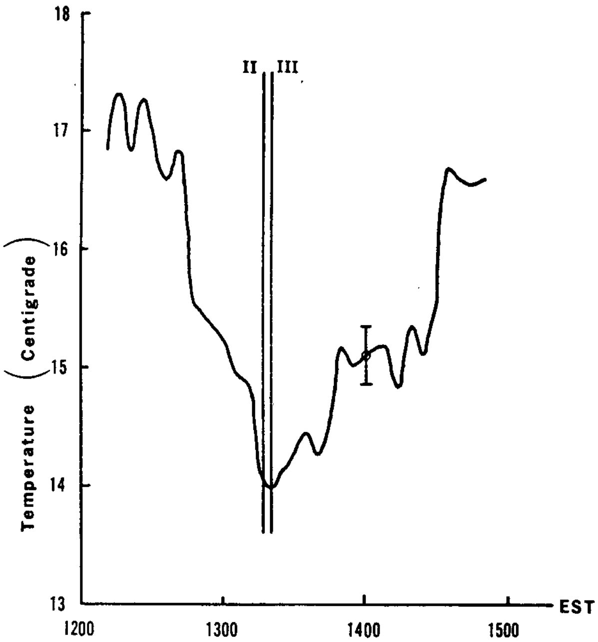

FIG. 3. Temperature changes recorded during the 7 March 1970 eclipse.

5. Discussion

The prime question concerning the pressure fluctuations shown in Fig. 2 is whether the changes are eclipse associated or are due to either noise in the instrumentation or to an atmospheric event not caused by the eclipse.

The Baratron pressure gage had been used in various laboratory experiments for a period of two years preceding the eclipse experiment. During this time no instrument fluctuations were observed which even approached the magnitude of the eclipse associated signal. The local atmospheric pressure was observed for a period of three days during the week preceding the eclipse. Pressure changes associated with local weather conditions and the thermal tide were observed, but no fluctuations were observed with a period similar to the eclipse-associated signal. Gradual drifts in the instrument null do occur over rather long periods. A check of the null before and after the eclipse showed a 50-μb change. This is presumably removed from the data by the linear term in Eq. (2).

The largest uncertainty in the instrumentation is in the temperature control of the pressure reference volume as stated earlier. The calculations indicated a maximum pressure change of $\pm 40\,\mu$b based on the temperature controller specifications for the maximum and minimum temperature excursions. The fact that a proportional controller is used reduces the possibility that maximum excursions would occur in a time as short as 90 min. The manufacturer states that changes over periods of several hours would be expected. Based on this, $\pm 40\,\mu$b is thought to be a rather conservative value for the uncertainty.

Hence, with the estimated errors limited to less than $\pm 40\,\mu$b, we conclude that the major, 89-min observed oscillations and probably at least some of the shorter period waves were real.

Unfortunately, there is no way to tell with any certainty from a single sensor measurement if the pressure changes were the result of the eclipse. The best that can be offered is a comparison with earlier work. The shaded curve in Fig. 2 shows the most recent measurement made by Klein and Robinson (1952) during the 25 February 1952 eclipse. Fig. 4, taken directly from Clayton (1901), shows the results of measurements taken at four earlier eclipses. There is reasonable agreement with measurements made by Upton and Rotch in 1887 and 1893.[1] A pattern that seems to be followed is that there are two cycles for the pressure waves and that these have a period approximately equal to the semi-duration of the eclipse. Additional observations to this effect were reported by

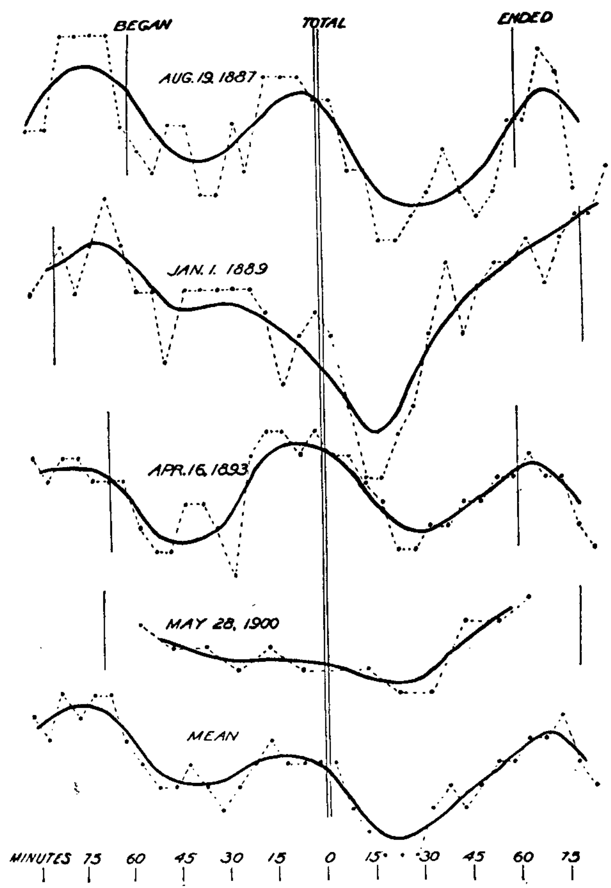

FIG. 4. Barometric pressure fluctuations recorded at earlier eclipses [taken from Clayton (1901)]. The verticle pressure scale can be judged from the approximate 150 μb peak-to-peak amplitude of the 1893 curve.

[1] Private communication. See Clayton (1901) for details.

Lindholm and Bergstein (1923) and Klein and Robinson (1952).

The work of Chimonas and Hines (1970) theoretically predicted the presence of eclipse-generated gravity waves. However, the magnitude as predicted by Chimonas (1970) was the order of 2 μb at the centerline with the value increasing with distance from the center path. The expected periods for the waves are 15–150 min.

A complete summary of the stations that attempted to measure these waves during the 7 March eclipse, along with brief descriptions of the apparatus, is given in the Solar Eclipse 1970 Bulletin F prepared by the National Science Foundation. All the experimental results were negative except the one reported here. It is felt that the prime reason that the waves were not detected by other observers was that most of the instrumentation was filtered for periods $<$16.7 min. Therefore, the 89-min period, largest amplitude waves that we recorded could not be observed by the other experimenters. We have concluded from this that Chimonas and Hines' theory has neither been disproven nor proven. Of course our measurements do show a large disparity between predicted and measured wave amplitudes. This would be especially interesting if it could be proven that 250-μb waves at the surface were associated with the eclipse. The most likely explanation of the larger pressure changes would be that low-altitude infrared heating, due to water vapor absorption, was important in the process. Chimonas was forced to neglect this contribution to the heating function in his calculations because of a lack of information.

In summary, we feel that the question of eclipse-induced pressure waves is still very much open. It is reasonable to suspect that the waves seen in this experiment were eclipse associated in view of the fact that waves, similar in amplitude and phase, have been reported for at least five previous eclipses. Future experiments should be designed to observe these waves and to establish if they are eclipse associated.

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