Exploration of the Upper Atmosphere by means of Sound Waves.

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THE maximum height which balloons carrying self-registering instruments have reached is about 35 km. A limit to the attainable height is set by the properties of the fabrics out of which balloons can be made. With improved fabrics it is possible that this height may be exceeded, but this is a problem for the future. An altogether different method for studying the physical conditions in the layers of the atmosphere which lie immediately above the reach of balloons is by the use of sound-waves. Beginning from 1904, when Van d. Borne discussed the propagation of sound-waves proceeding from an explosion of dynamite in Westphalia, the subject has developed considerably. During the second Polar Year, August 1932 to August 1933, a special series of explosions were arranged in Holland and also in the Polar regions. The results of this and other previous work are collected together in a special number of the *Zeitschrift für Geophysik* published last year. A lucid resumé of the present position of the subject and an account of the work done in England in the last decade is contained in the Symons Memorial Lecture delivered in March 1935 before the Royal Meteorological Society of London by Dr. F. J. W. Whipple, the Director of the Kew Observatory, and the foremost worker on the subject in Britain.

Some of the principal features of the propagation of sound from a loud explosion which can be inferred from aural observations can be summarised as below. Surrounding the source of sound, there is a region of 50–60 km. radius in which the intensity of the sound falls off gradually with distance; beyond 50–60 km. the sound is not audible. Going farther from the source, the sound again revives, often sharply, at a distance which may vary from 100 to 200 km. This second "zone" of audibility is often about 100 km. wide. If we calculate the velocity of the sound heard in this region from the distance from the source and the time between the explosion and the time of hearing the report, the computed velocity is found to be much smaller than the velocity corresponding to the temperature prevailing in the lower atmosphere. An explanation of these peculiarities was offered by Van d. Borne himself. In the immediate neighbourhood of the source the sound travels in the lower atmosphere, but that received in the second zone comes not directly, but by a longer path after reflection from the upper atmosphere. Timing the reception of the sound at known distances enables the determination of the delay in making the detour and the results of observations show that the sound gets reflected at heights ranging from 35 to 45 km. in the atmosphere.

Curr. Sci. 4, 140–142, 1935–36.

Occasionally, the second zone of audibility is followed by yet a third one with a second zone of silence between. The sound received in this zone is due to waves reflected twice from the upper atmosphere and once from the ground.

The hearing of gun-fire at great distances from the battle-front during the European War in 1914–18 provided much interesting new information. It was found that during summer in Europe sounds travelled to great distances to the west, while during winter, they could be heard much farther in the east. The audibility at the same distance in different directions was not also the same. Further progress in the subject came with the organisation of pre-arranged explosions and the development of the technique for the reception of the sound. In the Continent of Europe, special explosions were made by the destruction of surplus munitions and in England advantage was taken of the firing of artillery guns. The receiving instruments used in Germany are based on the principle of magnifying optically the movements of a light piston or stretched membrane at the mouth of a resonator; in England, Tucker's hot-wire microphone is used. The arrival of waves is recorded at a number of places at distances going up to 300 or 400 km. from the source and advantage is taken of the broadcasting organisation to send wireless waves every second for time-marking purposes. An important quantity that is determined in recent work is the angle which the arriving wave makes with the horizontal; this gives the velocity of sound at the topmost part of the trajectory, being equal to $v \sec i$, where v is the velocity of sound near the ground and i the angle which the trajectory makes with the ground. The angle generally lies between 10° and 35°. Knowing the velocity of propagation at the topmost part of the trajectory and the distribution of temperature in the first 30 km., it is possible with certain simple assumptions to complete the trajectories of the sound in the upper atmosphere. The assumptions usually made are that up to a certain height, the velocity of sound in the stratosphere is constant and that above this it increases rapidly. In recent calculations, the influence of wind in the accessible layers of the atmosphere is also taken into account. The calculations show that the downward movement of sound begins at 35–45 km. The increased velocity in the upper atmosphere implies either an increase of temperature or a decrease of molecular weight. For various reasons, the former alternative is believed to be true in the layers under consideration.

The average distribution of temperature in the upper atmosphere over Europe in summer deduced from the collected results of these experiments is shown in Fig. 1.

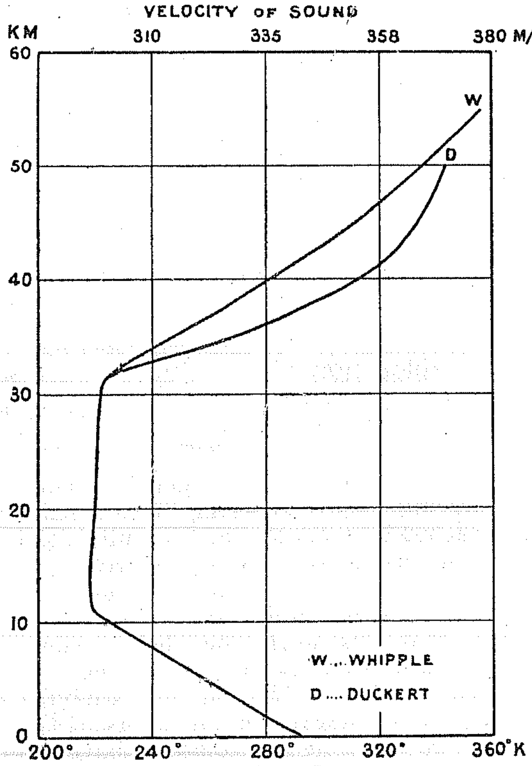

Fig. 1.

The marked difference between summer and winter as regards audibility at stations east and west of the source has already been mentioned. The records of self-registering instruments also show differences of times of travel of sound in different directions which can only be explained by large velocities of the order of 20–40 metres per second in the stratosphere, easterly in summer and westerly in winter. Many other facts such as the movement of persistent meteor trails and luminous night clouds support the same conclusion.

A reason for the strong westerly and easterly winds in winter and summer respectively in European latitudes has been put forward by Whipple. The results of sounding balloon ascents made at Abisko in Lapland during the years 1921 and 1929 showed a remarkable annual variation of temperature in the stratosphere, the mean temperature at 18 km. changing from 235° A. in June and July to about 210° A. in November to February. This very large change of temperature causes a seasonal change of pressure gradient between the temperate and polar regions causing easterly winds in the stratosphere in summer and westerly winds in winter.

The rise of temperature above 35 km. in the temperate latitudes is generally attributed to the absorption of ultra-violet solar radiation by ozone in the region 2,900–2,200 A.U. Taking the distribution of ozone in the vertical as worked out by Dobson, Götz, and Meetham, and assuming that the main radiating substance in the stratosphere below 50 km. is water-vapour (in such quantities as we may reasonably expect to be present) and carbon dioxide, it is easy to explain the course of temperatures over Europe deduced from experiments on the propagation of sound from explosions. But the fact that even in Polar regions in winter where the atmosphere has not received solar radiation for weeks, the phenomenon of anomalous propagation of sound is observed shows that the above explanation is insufficient.

Observations of the anomalous propagation of sound in the tropical atmosphere are practically absent, the only known instance in low latitudes being those of an explosion of a train-load of gelignite in South Africa in July 1932, when the sound was heard at a distance of 500 km.

It is obvious that the detailed investigation of the propagation of sound to great distances in low latitudes cannot fail to yield results of fundamental importance to the Physics of the Atmosphere. If the sympathetic co-operation of the Indian Military Department can be secured, the problem does not appear to present serious difficulties. Side by side with this, the problem of the vertical distribution of ozone in our latitudes would also have to be investigated.