Submillimetre wavelength atmospheric studies at Jungfraujoch

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The existence of observatories housing both telescopes and other scientific and meteorological equipment high in mountainous regions will be well known to many Alpinists. The reasons for choosing such high, remote situations are mainly meteorological, and may be basically summarised as enabling scientists to get above the lower atmosphere and the weather associated with this region. The scientific objectives associated with such observatories are principally of an astronomical nature, and the choice of site is generally based on the frequency of good, clear conditions to observe the stellar sources of interest. A second type of scientific investigation concerns measuring the properties of the atmosphere above the observatory, and it is this that will be considered here. This work most commonly concerns the transmission of radiation from the sun by the atmosphere, and can extend throughout the electro-magnetic spectrum from very short wavelengths ($\lambda \sim \frac{1}{10000}$ mm) in the far ultra-violet to the microwave region ($\lambda \sim 10$ mm). The principal reason for choosing the highest site is to get above as much as possible of the water vapour in the atmosphere. This is because water vapour, and the clouds associated with it, are concentrated in the lowest part of the atmosphere, unlike most of the other constituents which are in constant ratio to the pressure. This means that the undesirable effects associated with water vapour are combated most easily by increasing the altitude of the observatory. Also, at many wavelengths—especially in the infra-red region—water vapour strongly absorbs, so that unless high-altitude sites are used, it would be impossible to observe any transmitted energy.

In this article we will be considering atmospheric studies carried out at Jungfraujoch (3580 m) observing the transmission of solar submillimetre radiation. The submillimetre wavelength range ($\lambda \sim 1-\frac{1}{10}$ mm) may be considered as either long infra-red or short microwave radiation. This work is part of the programme of submillimetre studies carried out by the Division of Electrical Science of the National Physical Laboratory, Teddington, Middlesex. The observatory at Jungfraujoch has a high-quality, 76 cm-diameter telescope; and this, combined with the high altitude and northerly latitude which give very dry conditions during the winter months, makes it an excellent position for the work discussed here. On the deficit side the region is very stormy, being situated at the top of the steep, north-facing slope of the Jungfrau-Mönch massif, and so the number of good observing days is low. However, in the submillimetre wavelength region the absorption due to water vapour is so strong that only at the highest and driest sites is any measurable submillimetre energy transmitted by the atmosphere. To the present date, similar work has been carried out at Pic du Midi (Pyrenees),

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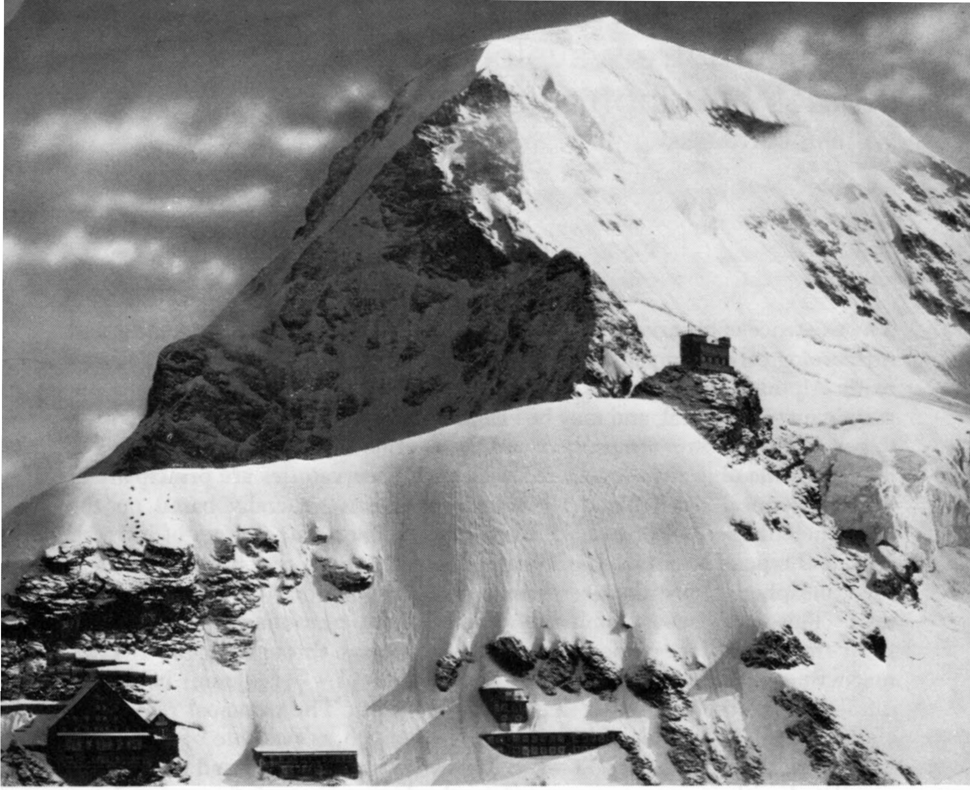

44 *Jungfraujoch*. Photo: Swiss National Tourist Office

45 *Pic du Midi*. Photo: French Government Tourist Office

Gornergrat (Zermatt), Chacaltaya (Bolivia) and Muona Kua (Hawaii), but it is probable that none of these can match Jungfraujoch at its driest. However, to restate an earlier point, during five weeks at this site in the first three months of 1970 we had only two days that were clear and dry.

The physical reason for measuring the transmission of the atmosphere in the submillimetre region is to identify the absorption of various constituents such as water vapour, oxygen and ozone and the possible consequence of their absorption on the general properties of the atmosphere. The technique of analysis of the transmitted solar radiation is known as Fourier transform spectroscopy, and enables the variation of absorption of the atmosphere with wavelength to be measured. The technique is particularly suited to making the most efficient use of the minute quantity of submillimetre radiation available. In our experiments the total energy reaching the detector is of the order of a billionth of a watt, and in order to analyse this we must effectively divide it up into approximately one hundred wavelength components. The individual gaseous constituents of the atmosphere absorb at characteristic wavelengths defined by certain molecular parameters (the dimensions, shape and mass of the molecule), and thus their features can be identified by a combination of theoretical calculation and laboratory studies of the various gases.

Despite the high altitude of the observatory, only a narrow wavelength range (from 2 to $\frac{1}{3}$ mm) is accessible to analysis, as at shorter wavelengths the atmosphere is completely opaque until the transparent regions of the infra-red, which are beyond our experimental range. The first solar observations in the submillimetre region were made by Dr H. A. Gebbie (A.C.) in 1957, but the present programme has been carried out since 1967 when the new telescope was installed. In the spectroscopic results obtained we have been able to identify features due to water vapour, oxygen and ozone, plus discovering anomalous absorption due to dimers of the water vapour molecule. The last observation is of considerable importance, as it is the first time this molecular species has been experimentally seen in the atmosphere, despite numerous theoretical predictions of its existence. The dimer of the water molecule simply consists of two water molecules bound together to form a single molecule, and should, on the basis of thermodynamics, exist in low concentration ($\sim 0{\cdot}1\%$ of water vapour at typical sea-level conditions) in equilibrium with normal water vapour. By experimentally confirming the prediction that this species could explain anomalous absorption in both the microwave, submillimetre and infra-red regions, it is now possible to predict more definitely the possible consequences of this atmospheric constituent.

The applications of this work are principally in the field of meteorology and, to a lesser extent, communications. The meteorological value of our work derives from the ability of the observations to measure quantitatively the absorption of a number of atmospheric constituents. In particular, the extreme sensitivity of the observations to water vapour has allowed us to extend the measurements to higher altitudes, and find the concentration of this constituent at altitudes above 9000 m in the stratosphere. This work uses the same spectroscopic methods to observe the atmosphere from a high-flying aircraft. The experimental technique is to compare quantitatively features due to water vapour and oxygen and to measure accurately the concentration of the former. This is possible because the distribution of oxygen in the atmosphere is well defined, whilst the amount of water vapour (only a few parts per million in the stratosphere) is very difficult to measure by other methods. Without the Jungfraujoch observations—which first identified the oxygen lines—and subsequent laboratory measurements, it would not have been possible to develop this technique.

The concentration and distribution of water vapour in the stratosphere is of meteorological importance; the concentration exerts a major influence on the temperature of this region, whilst the distribution is a measure of the global circulation at these altitudes (9000–45,000 m). At present, data concerning water vapour at these altitudes is largely of academic interest. However, with the recent advent of global atmospheric measurements from satellites and the consequent potential development of long-range weather forecasting, a most complete knowledge of the atmosphere will be essential to the theoretical models required for this work.

A less academic interest in stratospheric water vapour concerns the controversy centred on the commercial flying of supersonic transports at altitudes around 18,000 m. It has been suggested that these aircraft could significantly pollute this region with water vapour from the exhaust gases of the engines. Such a change in water content might modify the world's climate, though certain theoretical work indicates that the magnitude of the effect would be negligible. However, if it is remotely possible, the ability to monitor accurately the properties of the stratosphere will be of major importance.

The interest in dimers of the water molecule centres on a different part of the atmosphere; namely, the most humid regions of the tropics. As yet, the influence of this molecule in such regions has not been fully calculated or accurately measured, but it appears to be of direct consequence in the stability of the lower tropical atmosphere. Also, the presence of this molecule in the tropics will affect existing satellite temperature measurements, and hence—without the necessary corrections—may influence the results obtained from these systems. It should also be noted that the presence of the dimer in the atmosphere attenuates the microwave radiation now being used for communications purposes. The increasing demand for more and more communications channels leads to a search for shorter wavelengths which may be transmitted by the atmosphere, so that the presence of this, previously unidentified, atmospheric constituent will influence the future choice of suitable wavelengths.

It can be seen that mountain observatories provide a valuable base for experimental studies of the upper atmosphere, enabling large, and sometimes complex, systems to be set up whilst similar installations in aircraft, balloons or satellites would be impossible. This means that for much atmospheric work these observatories are used to make preliminary observations with relatively crude apparatus and provide a convenient basis for improving both techniques and equipment. Only when this has been done is it feasible to make a more sophisticated system which can be flown to greater altitudes. Thus, not only does the mountain-top observatory provide the simplest method of getting above the lowest atmosphere, it also may provide an essential proving ground for developing methods for upper-atmosphere studies.