AERONOMICAL BALLOON EXPERIMENTS

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Abstract. Aeronomical balloon observations can be divided into two categories: in situ measurements of atmospheric constituents and other physical parameters, and measurements of the atmospheric transmission characteristics of the layers above the balloon. The optical experiments, in the infrared, the visible, the ultraviolet and the X-ray parts of the electromagnetic spectrum are discussed in detail whereas a brief review is given of in situ measurements of atmospheric composition, of the electric field and of cosmic dust.

1. Introduction

Quite rapidly after the balloon had been invented scientists tried to use this vehicle to study the atmosphere. At the end of the 18th Century, Gay Lussac sampled the high altitude air to study possible changes in composition with height. It is however much later that molecular physics and chemistry of atmospheres, more simply called aeronomy, have gained appreciable information from balloon borne instruments. The development of plastic films having simultaneously strength and small specific weight have on one hand led to the possibility of carrying relatively heavy payloads in the middle and upper parts of the stratosphere for appreciable times. On the other hand the availability, due to the technical development which has taken place for the last two decades, of miniaturized automatic devices has allowed the use of a great variety of balloon borne instrumentations combined with modern data transmission and handling systems. The description of these is out of the scope of this paper where experiments pertinent to aeronomy will only be dealt with. This field is already so large that the list of references will not be exhaustive but only examples of the various types of information available from balloon borne experiments will be given.

At stratospheric float altitude the balloon offers possibilities of investigation which can be devided in two categories. The air can be sampled up to 30 or 40 km for long periods of time. This leads to in situ measurements of minor atmospheric constituents of major importance for the understanding of the upper atmosphere. At the 1 to 10 mb levels the transparency and other optical properties of the atmosphere are quite different from what they are at ground level. Radiation generated in the atmosphere or coming from exterior sources and possibly interfering with it can be studied at many more wavelengths than from ground level. This leads to balloon borne optical studies.

2. Optical Experiments

Investigations have been performed in a wide wavelength range going from the X rays to the far infrared. Various types of information have been obtained relating to minor

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atmospheric constituents absorbing the infrared solar radiation or reponsible for night sky emissions, to visible light scattered by dust layers in the atmosphere and to the production of X rays in correlation wich auroral and magnetospheric phenomena. In addition to studies of astrophysical interest of the solar ultraviolet radiation, absolute measurements in this region have appeared to be important for the mesospheric photochemistry.

The infrared absorption method has proved to be the most successfull to make new indentifications of minor stratospheric constituents and to determine concentrations of such species at high altitudes. Even if the technique is not always easy to handle as it realy is for any balloon borne experiment it is in principle quite simple and involves a pointing control system maintaining the solar radiation on the entrance slit of a spectrometer. At present this one uses always a grating associated with a predispersing prism or with a wide bandpass filter used for the selection of the order of the spectrum. Usually a cooled detector is used in conjunction with a synchronous detection system coupled with telemetry and sometimes on board tape recording. Due to the controversy that existed a decade ago concerning the amount of water vapor that exists in the stratosphere, this constituent has been the subject of many investigations. In 1962, Murcray *et al.* (1962) found a minimum mixing ratio of 7.5×10^{-6} in the lower stratosphere and an increase by a factor of then above 29 km. This result was in agreement with data obtained previously by other methods. The increase of mixing ratio was however experimentally shown by Zander and Bottema (1967) to be due to contamination carried aloft by the instrumentation and by the balloon itself. Application of suitable corrections could bring the data in agreement with those indicating a dry stratosphere (Houghton and Sealy, 1960). New measurements by Murcray *et al.* (1969a) have confirmed this conclusion. A method to check the absence of contamination consists in observing absorption spectra for a wide range of zenith distances. In this case the appearance of absorption features in the spectrum can be more surely attributed to atmospheric species. In addition observations at the horizon have the advantage of large optical depth allowing identification of constituents presenting very low mixing ratios or weak bands. Fourty times the vertical optical thickness can be obtained by this method and even more when solar zenith distances are larges than 90° (Swider, 1964). For instance, Ackerman and Frimout (1969) have in such conditions identified NO_2 in the stratosphere at a zenith distance of 94°. This observation has been confirmed by spectra recently observed, one of which being shown in Figure 1. Murcray *et al.* (1969b) have scanned the solar spectrum in a wide wavelength interval leading to the firm identification of HNO_3 (Murcray *et al.*, 1968) and a confirmation for NO_2 (Goldman *et al.*, 1970). Measurements concerning CH_4, N_2O, CO_2 for instance have also been obtained. Quantitative interpretations of the data are unfortunately not always possible due to the lack of laboratory data. This is however a type of work in which the progress is very rapid.

The twilight studies performed from the ground have since a long time contributed to the knowledge of the upper atmosphere. Even in the visible the light scattering is difficult to interpret when observed from the ground since multiple diffusion and low

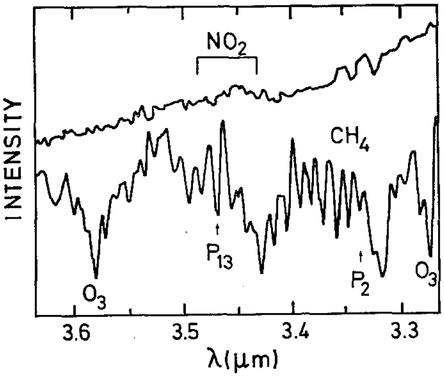

Fig. 1. Solar infrared radiation absorbed by atmospheric constituents. This spectrum has been obtained in conditions similar to those described by Ackerman and Frimout (1969).

level polution add a component wich is hard to take into account. At balloon altitudes. these effects are considerably reduced (Link *et al.*, 1967) and experiments can be undertaken at any time whithout practically no meteorological or cloud coverage constraints. For instance, it has recently been possible to launch a series of 6 twilight photometers at preditermined moments during the Orionides meteoritic showers. This experiment has brought evidence (Frimout *et al.*, 1971) for a correlation, between the sky brightness at solar depression angles between 8° and 13° and the amount of meteoritic precipitation which can for instance be monitored by radar.

Daylight scattering by dust has also been analysed by Newkirk and Eddy (1963) using a balloon borne coronograph to measure the intensity and distribution of sunlight scattered in the stratosphere. Instruments carried aloft permitted the continuous observation of the angular and spectral distribution of sky radiance as it varied with altitude. Observations were made within 1°67 of the Sun to make use of the preferential foward scattering properties of aerosols. Such observations are suitable to find information on the particulate content of the atmosphere which is of interest as nucleating and catalytic agent.

Night and twilight glow observations can be performed on very favorable conditions at balloon heights for the two following main reasons: low altitude absorbing species have their concentration considerably reduced so that the wavelength range which can be investigated is considerably enlarged and the observation at the horizon becomes possible. In this last case it has to be recalled that an emitting layer located at an altitude of 100 km is viewed from a gondola at 30 km under an angle of 8° at a distance of 1000 km. The optical thickness is then 7 times larger than for a vertical observation and geographic distributions can be studied over extended areas. The OH emissions have been observed during the twilight period by Moreels *et al.* (1970) to gain information on the evolution at sunset. A similar study has been reported recently by Pick *et al.* (1971). These authors have also observed the evolution at the end of the day of the $O_2\ {}^1\Delta g$ emissions to measure the decay of this species at sunset and later in the night. Dayglow measurements will also certainly be soon performed. The measurements of the intensity distribution of the OH rotational lines yield temperature determinations and help to clarify the fundamental excitation and deexcitation processes.

Compared with ground based observations balloon borne measurements benefit also from the extended transparency of the atmosphere towards shorter wavelengths namely in the ultraviolet and X regions. Solar radiation has been measured through the optical window of 2000 Å by Ackerman *et al.* (1971) by means of a balloon borne grating spectrometer. This type of data is of fundamental interest for the photochemistry of the stratosphere and of the mesosphere. The determination of the atmospheric optical thickness at these wavelengths is also available from such experiments and present a considerable interest especially if highly resolving instruments are used.

Informations on X rays in the energy range above 20 keV can be obtained from balloons. Their measurements have started about a decade ago. The Earth albedo of the 40 to 190 keV X rays has for instance been studied by Brini *et al.* (1965). X-rays have been measured in correlation with auroral glow for instance by Anderson and De Witt (1963) and by Barcus (1965). Such investigations have given informations on the energy spectrum of the auroral electrons. One of the main advantages of the balloon in this type of investigations is the possibility of long periods of observations in relatively small areas sometimes coupled simultaneoresly with other balloon measurements taken at different locations. Bewersdorff *et al.* (1968) have had for instance up to 9 balloons in flight simultaneously gathering X-ray data over large areas of the order of 10^5 km^2, in correlation of absorption events, for several hours. These investigations undertaken at stratospheric heights reach aeronomical Earth data up to magnetospheric levels.

3. In Situ Measurements

Much less in situ measurements have been reported. The sampling of air particles at balloon heights is however the only way of determining some stratospheric properties also suitable to deduce fundamental informations in relation with the whole amosphere.

Electric field measurements have been very profitable in this respect as the work of Mozer and Manka (1971) shows. From the analyses of nearly 400 h of electric field measurements these authors have been able to describe magnetospheric phenomena in detail.

Collection of dust has been performed in the stratosphere in the 1 to 100 μ size. This has allowed to set some limits on the total amount of solid material precipitating as such daily on the Earth (Nahrenda Bhandari *et al.*, 1968). The publication by Ponzi *et al.* (1970) of the description of a gas chromatograph designed for operation aboard stratospheric gondolas indicates that an effort is made in this direction.

Ion mass spectrometry at balloon altitudes may also appear very profitable.

4. Concluding Remarks

Balloon experiments performed in aeronomy are of course not suitable to answer all the questions. However, they fill the gap between airplane and rocket altitudes with advantages resulting from the long time of observation available when compared with rocket possibilities, associated with relatively small geographic displacement compared with satellite possibilities. In addition to the relatively low cost of operation this gives to balloon experiments their unique meaning and to the data obtained by means of them their full scientific significance. Eventually this vehicle leaves to its user a large independence.

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DISCUSSION

C. de Jager: The interesting observations of the sky-brightness around the Orionid meteor shower lead to the question whether such observations could not also be made during and after a very short-lived shower such as the Quandrantids. The injection would in that case be quasi-momentaneous, facilitating the theoretical interpretation.

M. Ackerman: Unfortunately, one is limited by the fact that the observations should be made near sunrise and sunset.

C. de Jager: The mentioned difficulty could be overcome by a cooperative campaign in which balloons were launched at many longitudes spread around the Earth.