Annals of the IQSY

5 Solar-Terrestrial Physics

TERRESTRIAL ASPECTS

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INTERNATIONAL YEARS OF THE QUIET SUN

VOLUME 5

Solar–Terrestrial Physics: Terrestrial Aspects (Proceedings of Joint IQSY/COSPAR Symposium, London 1967, Part II)

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December 31, 1965, brought to a close the International Years of the Quiet Sun (IQSY 1964–1965). The rich harvest of scientific results produced by this intensive study of the vast region between the sun and the earth will be published in a series of 7 volumes, of which this the fifth, under the general title of *Annals of the IQSY*. The series should be completed by 1969. The General Editorial Board for this project consists of 19 distinguished scientists gathered from 10 countries, with Professor W. J. G. Beynon as Chairman and Dr. A. C. Stickland as General Editor.

The IQSY was sponsored by the International Council of Scientific Unions. Its geophysical and solar observations were carried out by scientists in more than 70 countries. Since the dates of the IQSY were chosen to coincide with the period of minimum activity in the 11-year solar cycle, the results obtained form a complement and counterpart to those obtained in the International Geophysical Year (IGY 1957–1958), when the sun was in the most agitated state ever observed.

The proved success of efforts toward better international cooperation, at least in the sciences, was not the least of the triumphs of the IQSY. Indeed, without this cooperation, such a program would not have been physically feasible, since it demanded round-the-world, round-the-clock observations at widely scattered tracking stations, space radar and radio receivers, and observatories. The "patrols" undertook a constant optical and instrumental watch on the sun; they photographed its spots, coronal fluctuations, plages, and prominences; and they measured the entire spectrum of solar radiation: gamma and X-rays, visible and radio emissions. The effects of solar radiation and charged particles on the earth and its environment were an important aspect of these studies, especially since, in quiet years, solar outbursts are fewer in number, and hence the secondary effects do not seriously overlap and conflict with one another.

Some of the more dramatic experiments are the following:

–Satellites (including orbiting solar observatories) and space probes designed to measure the "solar wind" (streams of high-speed electrons and protons emitted by the sun), and the gamma rays and X-rays that cannot penetrate our atmosphere without undergoing changes.

–High-powered radar contact with the sun and its corona.

–A balloon-carried coronagraph (a telescope designed to block out the direct image of the sun) to photograph the corona from a point above most of the earth's distorting atmosphere.

–A mapping of the contours of the sun's radio image.

–A series of heliograms to map out the distribution of separate elements in the sun's atmosphere.

–Measurements of the effects of solar fluctuations on the earth's magnetic field and atmosphere: for example, the action of solar X-rays in reducing the ionosphere's ability to reflect short radio waves (a study of considerable practical interest, since the normal reflectivity of the ionosphere causes radio signals to be bounced around the world, and this work could lead to more reliable predictions of the blackout of radio communications).

–Studies of geomagnetically trapped radiation, and the study of galactic cosmic rays in relatively pure form, the sun's contribution to changes in the characteristics of these rays being at a minimum in quiet periods.

Other studies center on airglow, the aurora, the earth's heat budget, and high-altitude circulation in the atmosphere.

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II Sounding Rockets, Satellites and Space Probes in the IQSY Period
III Catalogue of IQSY Data available at World Data Centres
IV Tables of Contents of Annals of the IQSY Series

Foreword

The present volume of the *Annals of the IQSY* is the second of the two volumes containing the papers presented at the Joint IQSY/COSPAR Symposium held in London in July 1967.

As stated in the Foreword of Volume 4, it will be some years before a complete analysis and assessment of the observations on the many aspects of solar–terrestrial physics can be completed, but the Symposium gave a valuable opportunity for initial discussion.

The first volume of Symposium material covered the solar and interplanetary aspects, and the present volume contains papers on the terrestrial aspects: meteorology, the ionosphere, the earth's atmosphere, and geomagnetism.

These two volumes, together with the preceding Volume 3 on *The Proton Flare Project*, form a central group of three main scientific volumes in the *IQSY Annals* series. Volume 1 covered the basic measurement techniques, IQSY observation schedules, etc., and Volume 2 provided a day-by-day summary review (Calendar Record) of solar and geophysical activity in the years immediately before and during the period of the IQSY. The final two volumes will set out information on the IQSY Stations, a catalogue of the IQSY data available at World Data Centres, together with a survey for each discipline of the main features of these data, and a bibliography of IQSY publications.

W. J. G. Beynon
President,
Special Committee for the IQSY

Aberystwyth
February 1969

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World Meteorological Organization	*WMO Reports*

Contents

1

METEOROLOGY

I

A Discussion of the Structure and Energy Budget of the Upper Atmosphere

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Abstract

A brief history is given of investigations over the past 100 years of the structure of the free atmosphere. Recent (IGY/IQSY) observations of the temperature distribution and composition of the stratosphere and mesosphere together with experimental results and advances in spectroscopic theory have led to a number of studies of the thermal (primary radiative) energy sources and sinks of this part of the atmosphere. Such studies have been extended to include

1. Improved models for band absorption for each of the relevant absorption bands.
2. Mixed line profiles involving both Doppler and Lorentz (collision) broadening mechanisms.
3. Assumptions of non-local thermodynamic equilibrium (non-LTE) source functions where applicable.
4. Re-evaluation of the absorption of solar radiation by O_2, O_3, and CO_2 in the upper atmosphere.

The resulting pattern of the geographical and seasonal distribution of net radiative temperature changes in the region 30–100 km shows that

1. Radiative energy sources are found at high latitudes during the summer; energy sinks are found at high latitudes during the winter.
2. In general, maximum radiative heating rates occur at about 50 km (8 degK day^{-1}) and 80 km (15–20 degK day^{-1}).
3. Maximum radiative cooling is found at 55 km (8 degK day^{-1}) and 85–90 km (10 degK day^{-1}).

The upper atmosphere radiation budget could respond to solar cycle variations through variations of the distribution of atmospheric ozone since ozone might be sensitive to changes in solar radiation. Worldwide measurements made during the IGY/IQSY period fail to reveal any persistent changes in the distribution of total ozone. Computations of the effect of anomalous solar activity such as variable ultraviolet radiation and/or solar particle emission on the photochemistry of a pure oxygen atmosphere do not indicate the likelihood of any significant ozone variations in the mesosphere.

1 The Structure of the Atmosphere

It is now more than one hundred years since the British geophysicist James Glaisher pioneered a program of manned balloon observations to investigate conditions of man and his environment in the upper atmosphere. The start of planned aerological investigations was made by Glaisher and his colleague Coxwell in a two-hour balloon flight from Wolverhampton to Langham on 30 June 1862 (Glaisher *et al.* 1870). In this first flight Glaisher and Coxwell reached an altitude of close to 8 km in a balloon-borne gondola that was filled with scientific instruments. On a subsequent flight the two balloonists reached the amazing height of approximately 11 km, arriving at this level in a semiconscious condition. Fortunately, Coxwell was still able to release sufficient gas to cause the balloon to descend. Shown in Fig. 1 is a graph of the temperature observations of Glaisher and Coxwell on this historic flight. At the top of the ascent the indicated temperature was about −25°C which is somewhat warmer than the average temperature (−55°C) at this height, latitude, and season (Craig 1965). Since the instruments were exposed to the sun at various times during the flight period (the balloon was launched at about 1300 local time) it is quite likely that the temperature observations were subjected to considerable radiation error. Nevertheless, the apparent change in lapse rate at the top of the curve and the extreme height reached by the balloon (11 km) suggest that the manned instrumented gondola was probably the first such vehicle to penetrate the stratosphere. It is also interesting to note that the first (but unsuccessful) attempt to measure the presence of ozone in the free air was made during this balloon voyage. During the course of the observation program of about thirty balloon ascents in the period 1862–1868, Glaisher verified the fact (contrary to then current beliefs) that the average temperature lapse rate in the free atmosphere was somewhat less than the dry adiabatic lapse rate.

Realization of the need to develop balloon flights to levels higher than the limit for man's survival ability soon led in mid-1892 to experimentation with free floating balloons containing automatic registering instruments (Hermite 1892). L'Aerophile, a balloon equipped with two baro-thermographs was

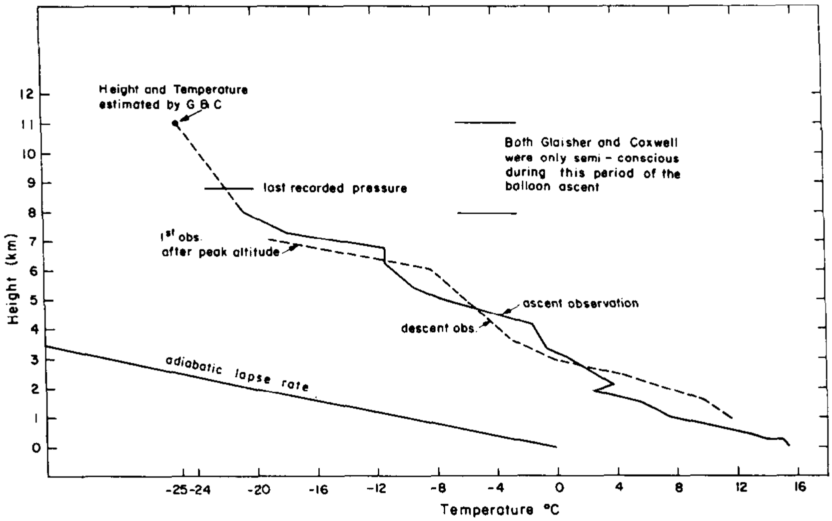

Fig. 1 Temperature observations taken by Glaisher and Coxwell on the balloon flight of 5 September 1862 (Glaisher *et al.* 1870).

launched by Gustave Hermite and his collaborator Besançon near Paris in 1893 and reached a height of 16 km. The temperature trace on the balloonsonde (Fig. 2) was the first clear record to show the existence of the stratosphere (although Hermite (1893) attributed the recorded relatively high temperature completely to the effect of solar radiation on the instrument). Near the top of the flight the temperature was recorded at −51°C just before the ink in the instruments congealed. Thus, the full temperature record from 14 to 16 km was not available. However, the probable radiation error contained in the observations is shown in Fig. 2 by the difference between the ascent and descent curves below about 10 km, since, as noted, that part of the descent took place after sunset.

A number of similar experiments were conducted during this period by Richard Assmann and his colleagues in Germany who verified the existence of a warm layer in the atmosphere somewhere above 10 km (Assmann 1902). For an interesting discussion of the early history of free air balloon observations see Van Mieghem (1958).

After his first balloon observations with improved remote recording instruments (Teisserenc de Bort 1898), the French meteorologist Léon Teisserenc de Bort carefully designed a balloonsonde program at the Trappes Observatory to determine the structure of the upper troposphere (and the "isothermal" layer above). By 1902 he was able to report on the results of 236 balloonsonde observations, 74 of which went higher than 14 km (Teisserenc de Bort 1902). Many of the basic features of the tropopause, particularly the latitudinal, seasonal, and meteorological variations were described by him at this time.

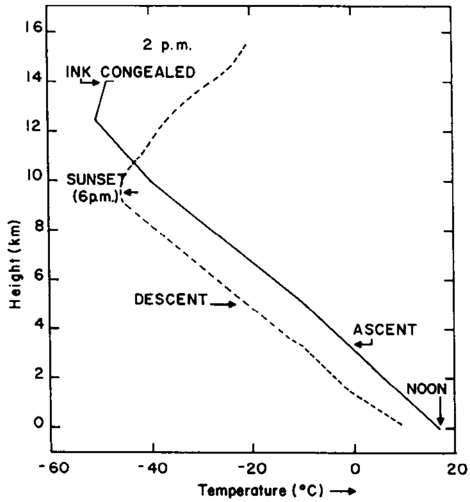

Fig. 2 Sounding taken on L'Aerophile, 21 March 1893 (Hermite 1893).

Both research and routine balloonsondes during the first quarter of the twentieth century provided many details of the latitudinal and seasonal temperature variation of the upper troposphere and the stratosphere up to about 25 km. From these observations Ramanathan (1929) constructed a vertical cross section for the summer and winter seasons of the Northern Hemisphere. Ramanathan showed that the lower stratosphere is not universally isothermal, but that "above a certain level there is a tendency for the temperature to increase with height". His analysis also indicated that there exists a cold equatorial ring of air (approximately 185°K) at a height of about 17 km. It was thought then that this was the lowest air temperature to be found over the earth. Direct observations of considerably lower temperatures at the summer polar mesopause did not come until about 25 years later (see, for instance, Stroud *et al.* 1960).

By the mid 1920's many scientists and engineers had suggested that balloonsondes be equipped to transmit radio signals. In 1926 the French geophysicist Pierre Idrac working with Robert Bureau designed a low-powered radio transmitter and the first successful radiosonde was flown from the Trappes Observatory on 3 March 1927. On the flight of 8 March 1927 the balloon reached an altitude of about 14 km and, for the first time, radio signals were emitted from the stratosphere and received at the ground (see Idrac and Bureau 1927). Although these experiments were designed by Idrac to study radio propagation as a function of altitude and atmospheric structure, the importance of this new method of remote transmission of observations of the free atmosphere was quickly realized by the meteorologist Bureau. The radiosonde represented an important new method of transmitting information