PROCEEDINGS OF THE FIRST INTERNATIONAL SYMPOSIUM ON THE USE OF ARTIFICIAL SATELLITES FOR GEODESY

WASHINGTON, D.C., 1962

PROCEEDINGS
OF THE
FIRST INTERNATIONAL SYMPOSIUM ON ROCKET AND SATELLITE METEOROLOGY

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PREFACE*

Historically, meteorological observing stations have spread outward from centers of population, mostly along trade routes on land, the oceans, and finally in the air. Vertically, the atmosphere has been successively sounded by aid of mountain observatories, manned balloons, instrument balloons, kites, and airplanes. Occasionally as in the first and second International Polar Years, there have been planned expansions of observing networks to remote, uninhabited regions such as the Arctic. In the International Geophysical Year, this expansion spread to the Antarctic and did more than that. Simultaneous with pushing balloons to their maximum practical operating ceiling of close to 30 kilometers at many of the world's radiosonde stations, two significant developments occurred in the IGY: first, the vertical sounding probes were pushed to their ultimate limit by systematic use of sounding rockets to heights considerably above balloon ceilings. Although this development started during and shortly after World War II, its widespread application occurred during the IGY. Second, the horizontal scanning of the atmosphere reached its ultimate with the introduction of the earth-orbiting satellite.

Now with these aids, for the first time meteorologists can cope with the problems of the atmosphere on somewhat more equal terms. Recognizing the importance of these new developments, three international organizations involved in atmospheric research and applications joined in initiating and organizing this Symposium: the International Union of Geodesy and Geophysics (IUGG); the Committee on Space Research (COSPAR); and the World Meteorological Organization (WMO). The first two organizations are affiliated with the International Council of Scientific Unions and the third is a specialized agency of the United Nations – a fine example of the joining together of non-governmental and governmental bodies towards the achievement of a common goal. Dr. W. L. Godson of the Meteorological Office, Canada and Secretary of the International Association of Meteorology and Atmosphere Physics of the IUGG was designated as that organization's

* This Preface was written by Dr. H. Wexler shortly before his death.

representative to the Board of Chairmen of the Symposium, Dr. R. Frith of the Meteorological Office, United Kingdom was similarly designated by COSPAR, and the undersigned by the World Meteorological Organization.

During the three days of the Symposium, thirty-five speakers from ten countries discussed the results of these new observing tools in the form of rockets and satellites and their implications for the solution of many important problems of the atmosphere. Four speakers from three countries presented five additional papers on these or related subjects during Session I of the Third International Space Science Symposium which was held the week after the ISRSM in conjunction with the Fifth Plenary meeting of COSPAR. Thirty-eight of the papers or abstracts from the two symposia are published in this volume with the hope that they will contribute to better understanding of atmospheric phenomena and to wider employment of the powerful new tools made possible by the new Age of Space.

H. WEXLER
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Washington, D. C.

A Dedication

HARRY WEXLER AND THE ISRSM

Throughout his mature life, which ended so suddenly on August 11, 1962, Dr. Harry Wexler was always in the forefront of meteorological research. He clearly foresaw the value of rockets and satellites in meteorological research and operations; as early as 1954 he had already published on meteorological satellites. And his interest in research with rockets dates from the earliest rocket measurements.

He viewed rockets and satellites as important new tools – the rocket, to pin-point meteorological parameters in the vertical above balloon altitudes at selected locations – the satellite, to give the broad, world-wide distribution with coarser vertical detail.

For this reason, and because he was Correspondent for Meteorology in COSPAR, he felt strongly the need to present results already achieved before the COSPAR meeting scheduled for Washington in April 1962. With characteristic drive and enthusiasm and in spite of his overburdened schedule, he set the wheels in motion to organize the International Symposium on Rocket and Satellite Meteorology in Washington, and followed it personally through all the stages – inviting speakers, arranging the program, participating as chairman of a session, urging participants to submit their results for publication, and finally arranging for the actual publication of the proceedings – in all these phases of the ISRSM he was the driving force, infusing his associates with his own enthusiasm and insight.

This volume of the Proceedings of the ISRSM is only one small example of the results from the energy and leadership which the scientific world knew so well in Dr. Harry Wexler.

S. Fritz
Washington, D. C.
September 21, 1962

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REPORT ON
SYMPOSIUM ON METEOROLOGICAL ROCKETS

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1. Introduction

To paraphrase the remarks of Dr. Harry Wexler (USA) as he opened this COSPAR Symposium, meteorologists have always endeavored to push higher into the atmosphere with their instruments. During the IGY a dramatic leap upward was made by the extensive use of a new tool, the rocket. Our function during the first day of this Symposium was to see how far meteorologists have come in the use of rockets—to see what we have learned, how we do it, and what new opportunities are now open to us for exploring the upper atmosphere.

Meteorological rockets can, of course, do a number of things. In particular, they make it possible to extend the region available to meteorologists above the present level of their balloon network, which is about 30 km. In doing this, they can reach for the first time into an essentially unexplored region of the atmosphere. This region is the one lying between the realm with which meteorologists are familiar and the realm of the ionospheric physicists, or aeronomists. If meteorologists are indeed to understand the entire atmosphere, and the effects of solar activity on it, it will be essential for them to understand this connecting region between the lower atmosphere and the ionosphere. The story of how meteorologists are exploring this region is the story of this COSPAR Symposium.

In order to summarize the material presented, it will be necessary to reorder the presentations, and I have chosen to divide this summary into three parts. First, there will be a brief review of the vehicles and the rocket programs of the various countries. Then it will be appropriate to discuss the observing techniques used in conjunction with these rockets in some detail. Finally, some of the results reported and the new puzzles presented will be

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briefly reviewed. In this latter connection, the exploration of the upper stratosphere and mesosphere is a good example of a common experience in geophysics, in which a region becomes more complex as we find more out about it.

2. The rocket

While presentations on rockets themselves were not encouraged in this symposium, it is probably interesting and certainly pertinent briefly to summarize some of the trends in rockets used for upper atmosphere soundings.

In the U.S. (aufm Kampe, USA), there was an emphasis originally on the larger rockets to probe the ionosphere. Starting in 1945 and 1946, V-2 rockets, Aerobees, and Viking rockets fired from White Sands, New Mexico, were used to explore the upper atmosphere, and these usually went considerably higher than 100 km. Except for a few special pioneering flights by such organizations in the U.S. as the Applied Physics Laboratory (under Navy sponsorship) and the University of Michigan (under Air Force and Army sponsorship), there was very little US rocket activity outside of New Mexico until the IGY. During the IGY the joint U.S.-Canadian program at Ft. Churchill, and the U.S. program at Guam, greatly extended the latitude covered by rockets, and gave us an idea of upper atmosphere conditions in the Arctic and the tropics. Moreover, during the IGY the smaller rockets began to make more extensive observations in the atmosphere *below* 100 km.

A somewhat similar development took place in the Soviet Union (Kvostikov *et al.* USSR), beginning in 1951 with a program of upper atmosphere rocket soundings. This program was gradually extended to include firings in the Arctic and at mid-latitudes in the Soviet Union, and from shipboard at many latitudes down to the Antarctic. More recently, during the IGY and subsequently, the USSR has had an extensive program involving the smaller meteorological rockets.

In Great Britain, there was a rocket program already going by the time of the IGY, with firings in Australia of experiments under the direction of the University College of London (Groves, UK), and Imperial College, London (Sheppard, UK). There was also an Australian rocket program begun during the IGY.

In France, the Véronique rocket, while developed prior to the IGY, was not used for meteorological soundings until the post-IGY period (Israel, Blamont, and Vassy, France). Since the IGY this French rocket has been used extensively for upper atmosphere soundings, mostly operating from the Sahara desert near Colomb Beshar.

In Japan the Kappa series of rockets came into use during the IGY (Maeda, Japan). Since the IGY the original Kappa-VI has been used extensively, and there is now a Kappa-VIII with improved performance which came into operation last summer (1961).

Returning to the U.S., one of the more significant developments in meteorological rocketry was the initiation of the U.S. Meteorological Rocket Network in 1959, in which four stations fired small rockets into the stratosphere on a regular synoptic basis (aufm Kampe, USA). Since this first modest start with a synoptic rocket network, the US network has expanded to about 8 stations, and the network continues to operate on a regular basis, probing the atmosphere to about 60 km.

Since the IGY several more countries have begun their own rocket sounding programs, and we heard from one of these countries, Italy (Broglio, Italy), which has one of the more active new rocket programs, begun in 1961. The Italian program involves Nike-Cajun and Nike-Asp rockets fired from the east coast of Sardinia.

It is notable that we can now hold an important symposium on meteorological rockets under COSPAR auspices and have so many countries represented. It would not have been possible without the development of good small rockets, most of which (though perhaps not all) were designed for the express purpose of sounding the upper atmosphere with a minimum of cost and a maximum of reliability. Nevertheless, it is still a very expensive business.

So much for the vehicles. We will now turn to the techniques for observing the atmosphere with rockets.

3. Rocket probe techniques

There are at least four basic approaches for observing the atmosphere with rockets. These are: (A) direct measurement by instruments in the rockets. These are: (A) direct measurement by instruments in the rockets, with telemetry to the ground; (B) direct measurements with instruments separated from the rockets and allowed to fall with a parachute, with telemetry to the ground; (C) ejection of a tracer which can be observed from the ground and followed; (D) sending an impulse between the rocket and the ground and observing how the impulse propagates through the successive layers of the atmosphere.

There are variations on these four themes, of course, and there is still another important technique not mentioned at this symposium—the technique of letting a sphere fall freely to determine density by measuring the air drag. This method has proven highly successful in the U.S., but it did not happen to be discussed at the Symposium.

I will now amplify a bit on how each of these four techniques are used in practice, and indicate some of the new developments reported at this Symposium.

3.1. INSTRUMENTS IN THE ROCKET

The major problem in measuring ambient conditions in the atmosphere from a moving rocket is the speed with which the rocket travels and the difficulty in correcting for the air motion and the attitude of the rocket. Pressure and temperature measurements have been successfully made from rockets on many occasions, but there are usually complications involved.

A new attempt to measure pressure was reported from France (Israel, France) in which a novel "manomètre thermique" or "conductivity manometer" was used in a Véronique rocket. This pressure-measuring device sampled the air from the base of the nose cone in the single flight reported, and the recorded pressure depended on the aspect of the rocket. The aspect had to be known, therefore, so magnetometers were included in the rocket to measure aspect. W. Nordberg (USA) asked whether it would not be easier and better to install the pressure opening in the tip of the nose, and Israel replied that this change was already planned for the next firing. If this development works out and fulfills its initial promise, it will permit pressure to be measured by one compact instrument from below 30 km to over 80 km, and from a moving rocket. Furthermore, the effect of wind and wind shear was also sensed as a change in pressure (due to the change in the direction of air flow), and such an effect has actually been used in the U.S. to measure wind from a stable rocket using a set of pressure devices. This is a development that will be followed with great interest.

Although the Soviet report (Kvostikov *et al.* USSR) did not dwell on the techniques used by the Soviet scientists on their meteorological rockets, it was mentioned that temperature was measured by resistance thermometers and that pressure was also measured from the rocket. The top altitude attained by these meteorological rockets was said to be 70 or 80 km, though data were only presented to about 50 km. The Soviet package is lowered on a parachute and tracked on the way down, so the Soviet system also provides wind as well as temperature and pressure observations from the rocket.

In the U.S. measurements of ambient pressures have been made a number of times from rockets, but the trend in small rocket instrumentation has been away from this approach, and no new US developments along this line were reported at the Symposium.

3.2. ROCKET SONDES

The alternative method of measuring temperature and pressure with instruments, that of making the measurements entirely on the way down from a small package on a parachute, was described by aufm Kampe (USA). In the U.S. there are several successful packages of this sort, such as the well tested Arcasonde ("gamma" version) and the new DMQ-6, that can be used with the GMD-2 ground tracking and receiving system. The ceiling of these rocket sondes for effective temperature measurements is about 50 or 60 km. Winds can also be obtained by tracking the sonde as it descends.

Speaking of parachutes, one of the difficulties encountered in rocket sondes is that of finding a light weight parachute that will open at altitudes above 50 or 60 km and provide a slow enough descent. Facy (France) reported on a French development of an open net parachute—a sort of fine fishnet, as he explained it—that would reduce turbulence and permit a reasonable rate of descent by a small package at as high as 80 km. We understand that this still has to be flight tested.

3.3. EJECTION OF A TRACER

The ejection of a tracer from a rocket has proven to be the most effective way, if not the only way from a rocket, to observe winds above 90 or 100 km. There are two kinds of tracers in current use, radar chaff and chemicals.

3.3.1. *Radar chaff*

Radar chaff falls too fast at very high levels, but in the U.S. (aufm Kampe, USA) chaff ejected by Loki rockets and tracked by radar has routinely given good winds below about 60 km. It was also reported that a special chaff has been successfully used by L. B. Smith of the Sandia Corporation to about 80 km (Teweles, USA). Shephard (UK) reported that the British had also used ordinary chaff below 60 km successfully, and had used aluminum strips to as high as 80 km for obtaining winds. One of the troubles generally reported with this technique is that a cloud of chaff or aluminum strips grows larger as it falls, until the radar can no longer distinguish where the middle of the cloud is. Furthermore, in falling from, say, 60 to 30 km the rate of fall decreases by more than a factor of 5, so the sampling rate is extremely variable.

3.3.2. *Chemical vapor*

The most common chemical tracer in current use for very high altitude observations is sodium or potassium vapor. To be seen, such trails of alkali vapor must be fired at twilight and during clear weather so observers on the ground can follow it photographically. This restriction (plus the considerable labor of reducing the wind from the pictures of the luminous trail) immediately suggests one reason why it is not used more universally. Otherwise, it is clearly an ideal way to measure winds at almost any altitude up to at least 200 km. Reports on its use were made by aufm Kampe and Nordberg (USA), Blamont (France), and Broglio (Italy). Maeda (Japan) said that in Japan they were planning to begin sodium trail experiments in October with the Kappa-VIII.

An additional item of great interest that can be determined from pictures of such trails is the character of the turbulence, and the remarkably abrupt transition from turbulent to molecular diffusion at 105 km. Furthermore, since molecular diffusion depends on both temperature and density of the air, observations of the rate of expansion of this trail above about 200 km can be used to determine density, assuming a temperature distribution (or vice versa). Although Kvostikov *et al.* (USSR) did not say so in their paper, Soviet scientists were the first to take advantage of this fact as a measuring tool.

A new twist to the vapor trail technique has recently been introduced by Blamont (France) and his colleagues, namely the measurement of vapor temperature from the Doppler broadening of the resonantly scattered light. He has previously described the technique for doing this, involving the filtering of the radiation from the trail by alkali vapor at a known temperature in the detector system. The accuracy of this temperature determination is currently about 50° C, but so far it is the only known rocket technique for directly measuring temperatures above 200 km. Below 200 km it is better to use potassium, according to Blamont, since natural sodium in the atmosphere makes it difficult to interpret the temperature from a sodium trail in the 100 to 200 km region (though he has done so on one occasion).

Another variation on the chemical tracer was reported by Groves (UK). It turned out that the puffs of smoke produced by grenades above 90 or 100 km persisted long enough to be followed at twilight. It was even possible to follow them at night from their persistent glow, apparently due to a chemi-luminescent reaction between the combustion products and atomic oxygen. By following the motion of these puffs photographically it is possible to obtain not only winds, but also a hint of the vertical motions in this part of the atmosphere between 100 and 200 km.

3.4. PROPAGATION FROM THE ROCKETS

There are two kinds of propagation possible from a rocket, radio waves and acoustic waves. Only the latter were discussed. From a measurement of radio propagation electron densities can be derived, and electron densities are still not considered as a prime meteorological parameter. (They may be some day, however.)

The use of grenades as a source of sound has been successful for a number of years, first having been tried in the U.S. prior to the IGY. The idea is to fire a succession of grenades, and the incremental travel time between successive explosions is a measure of the mean temperature in the intervening layer. Also, by using an array of microphones on the ground the direction of arrival can be observed, and from this the wind in each layer can be determined.

Papers reporting on the use of this technique were presented by Nordberg (US) (one of the pioneers in developing the technique), Groves (UK), and Maeda (Japan).

4. Meteorological rocket results

Having discussed the various techniques used with meteorological rockets, it is now time to turn to a general review of the results. After all, it is actually the results that we meteorologists are most interested in—and it is the results that were generally emphasized at this Symposium.

In an attempt to make as coherent picture as possible it will be necessary to take each region of the atmosphere in turn. One ought to talk about the whole atmosphere at once, presumably, but is is simply too big and complex a subject to take at one bite. So, we will begin with the stratosphere.

4.1. STRATOSPHERE

To start with, "the stratosphere" is now defined as the region from the tropopause to the stratopause, and the stratopause is the level where temperature reaches a maximum in the vicinity of 50 or 60 km.

Meteorologists have now been able to draw synoptic charts of the Northern Hemisphere from balloon observations to about 30 km, or 10 mb (Teweles, USA). At the Symposium, Teweles presented various meteorological charts for the 45 and 60 km levels, covering the North American continent and based on synoptic meteorological rocket observations. These charts were drawn by Teweles himself (US Weather Bureau), Thomas Keegan (Air Force Geophysics Research Directorate) and R. Scherhag (Free University, Berlin). We noted that these upper atmosphere analyses were based on rather few stations, usually only 3 or 4 at most, but they are the first of their kind and have already given us hints as to what to expect in the future.

Our picture now of the upper stratosphere can be described briefly as follows: In both winter and summer there is generally zonal flow, west winds