CONCERNING THE PROGRAM FOR PLANETARY ATMOSPHERIC RESEARCH

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Concerning the Program for Planetary
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During 1967 several sessions were held by international commissions and working groups which were devoted to the discussion of the Program of Planetary Atmospheric Research. I refer, in particular, to the sessions held in late February and early March at Geneva by the Sixth Working Grou[p] of the Committee of Space Research, the Committee on the Atmospheric Sciences of the International Council of Scientific Unions, and the International Geodetic and Geophysical Year; and also by the Consultative Committee of the World Meteorological Organization. The Sixth Working Group of the Committee of Space Research continued its discussions up until the conference of the Committee in London in July 1967. What follows is a brief survey of the results of these discussions.

The following three aspects of the Program were the primary object of discussion:

1) numerical experiments in studying planetary atmospheric circulation;

2) the possibilities of obtaining meteorological information with the use of artificial earth satellites; and

3) the prospects of the combined use of sounding balloons and satellites.

Let us proceed, now, to a brief examination of the essentials of each of these three aspects.

Observations of Global Weather and Prognostic Experiments

The report presented by E. Mintz (Los Angeles campus of the University of California) was devoted to the problem of initial data in the study of numerical methods in the prognosis of planetary weather--data based on the "primitive" system of the equations of thermohydrodynamics. This system comprises the following;

The equation of statics:

$$\frac{\partial p}{\partial z} - \rho g = 0. \quad (1)$$

The equation of horizontal motion:

$$\frac{\partial V}{\partial t} = - V_0 \nabla V - \omega \frac{\partial V}{\partial p} - 2 \Omega_z \times V - g \Delta z + F(V, T), \quad (2)$$

The energy equation:

$$\frac{\partial T}{\partial t} = - V_0 \nabla T - \omega \left(\frac{\partial T}{\partial p} - \frac{RT}{c_p p} \right) + \frac{\dot{h}(I)}{c_p}, \quad (3)$$

The continuity equation:

$$\nabla V + \frac{\partial \omega}{\partial p} = 0, \quad (4)$$

and the equation of state:

$$\rho - \frac{p}{RT} = 0, \tag{5}$$

Here,

p is the pressure,

ρ is the density,

V is the horizontal velocity vector,

T is the temperature,

$\omega \equiv (dp/dt)$,

Ω_z is the vertical component of the vector of terrestrial angular rotation,

R is the gas constant of the atmosphere,

c_p is the thermal capacity of the atmosphere,

g is the gravity acceleration,

∇ is the operator of the horizontal gradient along the constant-pressure surface,

z is the altitude,

t is the time,

F(V,T) is the horizontal component of the force of eddy viscosity,

$\dot{h}(I)$ is the heat inflow, computed per unit of mass.

The system of equations (1) - (5) can be supplemented by a boundary system at the level of the upper boundary of the atmosphere (p = 0), expressing the assumption that this level is the free surface

$$\omega = \frac{\partial p}{\partial t} = 0 \quad for \quad p = 0$$

At the ground level, where the vertical velocity component is zero, we have the following (allowing for the continuity equation):

$$\frac{\partial p_s}{\partial t} = -\int_0^{p_s} \nabla \mathbf{V} dp - \mathbf{V}_s \nabla p_s, \tag{6}$$

where p_s and V_s are the pressure and the horizontal velocity at ground level.

The reliability of results obtained with use of the system of equations cited here, and the assumption of boundary conditions, largely depends upon the accuracy of the initial meteorological information, which determines the initial conditions of the problem. But two other factors are also important: 1) the adequacy of the physical model of the atmosphere (that is, the degree to which physical factors affecting variability in the field of the meteorological elements are represented), and 2) the computed errors.

Let us consider first the effect of the initial conditions in the case of the adiabatic approximation (h(I) = 0). Here, the solution of the system (1) - (6) requires initial data on the horizontal wind velocity V, the temperature T, and the pressure at ground level p_s. If all these are known, then ω can be obtained by integrating (4) with respect to p (from

$p = 0$). Then, integrating (1) with respect to p(from $p = p_s$) with allowance for (5), we can obtain z. Following this, the right-hand members of prognostic equations (2), (3) and (6) make it possible to determine the local derivatives of V, T and p_s with respect to time at the initial moment t_o. By extrapolating these derivatives for brief time intervals Δt, we obtain values for V, T and p_s for subsequent moment $t_o + \Delta t$. By N repetitions of this cycle, we arrive at a prognosis for the moment $t_o + N \Delta t$.

But instead of the initial distributions V, T and p_s, we may have given the fields of V and ρ. If the vertical density distribution is measured "from top to bottom" (satellites of "eclipsing" type), then integration of (1) with respect to altitude allows us to determine the pressure. Having a measured value for $\rho(z)$ and a computed value for p(z), we can then find T from (5).

Of great importance here is the accuracy of the initial data. Numerical experiments have shown, for example, that a random error of about 1^o in the initial temperature field means that, in the course of 15 - 20 days, the discrepancy between the predicated fields will become as great as the mean discrepancy between any two random states of any one of those fields--in other words, the prognosis will be incredible.

Adiabatic approximate, generally speaking, offers only limited possibilities for periods in excess of 1 - 2 days, just because of the great role of heat inflow. We should consider that this factor is of the very greatest importance as regards the adequacy of our physical model of the atmosphere.

In the study of nonadiabatic factors, a substantial role is played by heat exchange between the underlying layer (primarily, the surface of the ocean) and the atmosphere, on the one hand, and by the phase transformations of atmospheric water, as well as by radiant heat exchange.

To allow for heat exchange between the ocean and the atmosphere naturally requires knowledge of the surface temperature of the former as an initial item of data. In view of the fact, however, that the mechanism of this heat exchange is not perfectly understood, so that significant errors may arise in consequence, we shall limit ourselves here to the use of seasonal climatic temperature means for the surface of the ocean.

As regards the heat of condensation, it is sufficient, at the present stage of research, to limit ourselves to climatological vertical distributions of humidity, or else to determine those distributions diagnostically with respect to wind and temperature fields. The same can be said for radiant heat inflow: to allow for the time-variations of this quantity --although this will be necessary in the future--would at the present moment involve very serious complications of the system of basic equations, as well as increase in the volume of calculations. It is therefore evident that in the study of radiant heat inflow, it is more important to determine the initial field of water-vapor concentration than the factor of cloudiness. Determining the longwave component of radiant heat inflow requires that we assign or search for the temperature of the underlying surface.

E. Mintz believes that the question of the effect of solar activity should not, at this point, enter into our attempts to improve weather prognostication.

We should make a clear distinction between "hydrostatic" and "non-hydrostatic" scales of motion, and assign parameters to represent the effect of the latter on the former. The study of hydrostatic motions can be made at a certain stage of the computing network--about 200 kilometers on the horizontal, and, on the vertical (within the limits of the troposphere), on the order of 100 millibars, with several additional limits within the stratosphere to be considered. The three-dimensional "resolving power" of the network of observations at the present time can be even finer: 400 - 600 kilometers along the horizontal, and 300 millibars along the vertical. Here it is important to emphasize the necessity of achieving harmony (unity) among observational methods, objective analysis, and prognosis.

Prospects for the Development of Satellite Meteorology

Table 1, below, represents a summary of the discussions on the results and prospects of satellite meteorology.

As regards the possibility (and the necessity) of obtaining meteorological information by 1972, we can describe the situation as follows:

Further development of satellite meteorology will place at our disposal both local and global data on cloudiness and on the vertical temperature profile (the radiometric method).

We have already instituted a planetary system of sounding balloons, interrogated and tracked by satellites, which drift, at the very least, at the 200-, 100- and 30-millibar levels in the Southern Hemisphere.

It is possible (in the case of a successful probe) to determine density on the basis of refraction measurements.

Collecting Data from Atmospheric and Ground Platforms through Satellites

The basic idea underlying such projects as the American GHOST and the French EOL is to create a global system of sounding balloons drifting along fixed levels of constant pressure, in combination with ground and oceanic (buoy) automatic meteorological stations. The collection and transmission of meteorological information at ground stations, and the reception and processing of that information, can be carried out only with the use of special communications satellites. The most important data which can be obtained in this fashion are wind direction and velocity (determined by tracking the sounding balloons), and temperature (through direct measurement).

Three methods of interrogation and search of sounding balloons with use of satellites have been proposed; these employ two principles for searching the coordinates of balloons. The first principle is based on measurement of the angle between the direction of the satellite-balloon line and some second known direction, such as the perpendicular or the tangent to the satellite orbit. Here the satellite-balloon distance can be determined either from the time of transmitting a radio signal from satellite to balloon and back (IOLS method proposed by NASA collaborators), or by using a sun-altitude sensor set up on the balloon (GHOST). The angle can be determined from measurements of the Doppler displacement of the radio frequency signal from the satellite to the balloon and back. In any case, of course, two such measurements must be made.

It is proposed that in late 1967 or early 1968 the first tests of the IRLS method will be made on the satellite Nimbus B. Later on it is intended to continue the tests into 1969, using the Nimbus D satellite (the apparatus of the Nimbus D is suitable for interrogating 300 stations; it has a memory of approximately 100,000 bits).

The Franco-American EOL project calls for the use of the FR-2 satellite, launched into orbit from an American carrier, which is capable of interrogating 500 sounding balloons. The first experiment is planned for 1969.

The results of the first tests with sounding balloons, conducted in the Southern Hemisphere in 1966 in the GHOST project, were quite successful. In particular, it was found that sounding balloons will drift with very little deviation from their assigned constant-density surface. Actually, the maximal deviation at the 500-millibar surface amounts to only 22 meters (1.5 millibars), while the maximal drift is 19 days (a serious complicating factor is the icing of the balloons). At the 200-millibar level, the drift of sounding balloons along a closed quasi-zonal trajectory was found to continue from a few days to more than 200 days. The first tests run under the

EOL project were also found to be successful.

It is planned to implement the Program for Planetary Atmospheric Research during 1975.. Before this it will be necessary to develop the Program with wide-scale participation of the scientists of various countries. In order to develop the Program and carry out all operations for its implementation, it has been decided to set up an organizational committee, which will consist of some 12 specialists, to be chosen late in 1967 or early in 1968. During the preparation and execution of the Program, it is planned to conduct various sorts of local research, in combination with a large number of developments of individual character.

Table 1

Present and Long-Range Possibilities of Satellite Meteorology

Meteorological Element	Method of Determination	Stage of Development	Stage of Implementation	Resolving Power and Accuracy	Area of Application
1	2	3	4	5	6
Wind	a) by the characteristic distribution of clouds and moisture	numerous developments exist	already operative	low	only at altitudes where clouds exist
	b) by the condition of the ocean surface	has not been used	proposals have been formulated	very low	close to the surface of the ocean
Pressure, density	a) refraction of visible star light	theoretical estimates of possibilities	"	vertical profile ± 1%	above the clouds and aerosol layers; only at night
	b) artificial eclipsing of light from certain satellites with respect to others	"	"	"	"
Temperature, humidity	infraction spectometry	aerostatic tests	satellite experiment planned for 1969	vert. profile ± 20%; ± 10% rel. humidity, space resolution 100 - 200 km	above dense clouds

Table 1 (continued)

Present and Long-Range Possibilities of Satellite Meteorology

Meteorological Element	Method of Determination	Stage of Development	Stage of Implementation	Resolving Power and Accuracy	Area of Application
1	2	3	4	5	6
Cloudiness	TV and infrared images	realized	operative	space resolution 1 x 1 km in daylight, 10 x 10 km at night	--
Temperature	infrared scanning radiometer	realized	nearly operative	$\pm 1^\circ$, 10 x 10 km	underlying surface and upper boundary of dense cloudiness
Precipitation	scanning microwave radiometer	aircraft tests	possibities being studied	50 x 50 km	strong dependence on properties of the underlying surface; recommended only over the ocean
Radiation balance	radiometry	realized	nearly operative	5 x 5 km or smaller	only outgoing radiation
Ozone	a) ultraviolet spectrometry of solar rad.	partially realized	first tests with satelite	$\pm$ 20% above 15 km, very poor resolution with respect to altitude	only during sunrise or sunset

Table 1 (continued)

Present and Long-Range Possibilities of Satellite Meteorology

Meteorological Element	Method of Determination	Stage of Development	Stage of Implementation	Resolving Power and Accuracy	Area of Application
1	2	3	4	5	6
Ozone	b) scattered ultraviolet radiation	theoredical estimates of possibilities	first tests with satellites	vert. profile above 15 km; 5%	limited by dependence on albedo of underlying surface and by effect of stratospheric aerosols
	c) infrared spectometry	has not been used	proposals have been made	very poor resolution with respect to altitude; 200 x 200 km (all methods)	above clouds and smoke
Atmospherics	a) radio waves	theoretical estimates of possibilities	satellite experiments planned	observation of storm clouds with very poor resolution as regards direction	
	b) observation of storm clouds by lightning flashes	"	"	more reliable determination of direction than with radiometer	

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