THE "METEOR" EXPERIMENTAL SPACE METEOROLOGICAL SYSTEM

I. M. Andronov, N. N. Sheremet'yevskiy

Paper presented at United Nations Conference on the Exploration and Peaceful Uses of Outer Space, Vienna, August 14-27, 1968

Translated by Techtran Corp.
Glen Burnie, Md.
under Contract NAS 5-14826
Item No. 41

The "Meteor" Experimental Space Meteorological System
I. M. Andronov, N. N. Sheremet'yevskiy (USSR)
United Nations Conference on the Exploration
and Peaceful Uses of Outer Space, Vienna,
August 14-27, 1968

Introduction

In April, 1967, in Geneva, nearly 300 scholars from 129 countries discussed the plan, "World-Wide Weather Service", at the Congress of the World Meteorological Organization. On the basis of this plan, the problem of employing automatic meteorological artificial satellites in the World-Wide Weather Service was established as the subsequent development of the existing international collaboration of national meteorological services. Such artificial earth satellites, fitted out with appropriate equipment, will form the national meteorological space system.

The role and influence of satellite-acquired meteorological information is great, since it is practically impossible to organize systematical meteorological observations on the water areas of seas and oceans, in inaccessible regions, at high altitudes and in the polar regions of our planet.

In order for an artificial earth satellite to meet the requirements of space meteorological observatories, it must be fitted out with photographic equipment capable of capturing a sufficiently wide portion of the earth's surface, have a resolution capability of several square kilometers, and able to provide sufficient contrast. It is necessary to further determine the temperature of the underlying surface, the limits of the upper and lower boundaries of the clouds, humidity of the air, pressure, zones of heavy percipitation in order to obtain cloud characteristics.

Meteorological satellites can be divided into two basic classes, depending upon the meteorological instruments they are equipped with and the complexity of their data acquisition and transmission facility: the ISZ (artificial earth satellite), which is designed to fulfill a specific mission, for example -- only photography, and the space observatory class of satellites, designed to carry out a number of different missions.

Specialized satellites used for limited data acquisition are relatively simple as far as their onboard arrangement is concerned, but their ground stations for control, reception and processing of data are considerably more complex.

Satellite observatories, designed for a multifunction purpose, are more complex both in their composition of meteorological data acquisition instrumentation and in the intracacy of their onboard system designed to simplify the functions of the ground control complex.

In June, 1967, in the USSR, a TASS communique announced the creation of the Soviet experimental meteorological system, "Meteor." In the course of more than a year, the "Meteor" system, which is comprised of several satellites, has consistently and very successfully made possible the acquisition of information from the entire globe of the planet Earth. This meteorological information reflects cloud distribution, anticyclones, typhoons, temperature of the underlying surface, warm radiation from separate areas of the globe, and much other data characterizing the geophysical condition of near space.

A vast amount of scientific research and experimental engineering work in developing individual units of meteorological satellites, as well as in solving the technical problems facing a meteorological observatory, preceded the creation of the Soviet meteorological system, "Meteor."

The satellite, "Kosmos-14", placed into orbit on 13 April, 1963, with an apogee of approximately 500 kilometers from earth and at a 49° angle of orbital plane, and the satellite, "Kosmos-23", placed into orbit in the same year, on 15 December, with a 49° inclination of orbital plane and 600-kilometer apogee, were the first satellites on which experiments were conducted. Experimental research to develop systems of orientation and stabilization for the body of the satellite was conducted on these satellite laboratories, where the reliability of the design for exposing the antennas was checked, the packs of solar batteries were tested, the efficiency of the sun-earth reference sensors, temperature-measuring systems and the technical facilities for temperature control were also carefully examined. The efficiency of the servomechanisms, used with electric machines functioning in a weightless environment, as well as the influence of electromagnetic wave radiation on the various systems, was also checked on these satellites.

The results of this experimental research served as the basis for creating "Kosmos-122", orbited on 25 June, 1966, 625 kilometers from the earth and with an orbital inclination of 65°. On "Kosmos-122", the complex layout of television, actinometrical, and infra-red apparatus for meteorological use had already been set up and tested and the first data pertaining to cloud distribution, snow and ice cover, together with the temperature of the earth's surface and upper boundaries of clouds, as well as thermal and energy parameters of the cloud cover and underlying surface was being received. The first global phenomena -- typhoons "Alice", "Cora" and "Grace" -- were recorded by this satellite, both by television in the visible portion of the spectrum, and by infra-red photography received from the earth's shadow side. The long period of time "Kosmos-122" was in existence, as well as its active life, made it possible to prepare and carry out the launchings of a number of satellites: "Kosmos-144" was launched on 28 February, "Kosmos-156" on 27 April, "Kosmos-184" on 28 October, 1967, and "Kosmos-

206" on 14 March, 1968, all of which made up the experimental space meteorological system, "Meteor." These meteorological satellites, the first in the USSR, were placed in a circular, near-polar orbit at 81.2° inclination and at an altitude of 625-630 kilometers. A near-polar orbit at this inclination made it possible to receive information concerning cloudiness from regions making up eight per cent and data on radiation flux from nearly 20 per cent of the earth's surface, from each satellite in only one orbit about the earth.

A circular orbit is very necessary for meteorological satellites, since the meteorological data registered is easily unified during this type of motion, thereby facilitating its processing.

Each satellite of the "Meteor" system is an automatic-adjusting earth satellite, the mission of which is to receive and transmit three types of meteorological data to earth: video pictures in visible and infra-red spectrums and multiband radiational measurements of cloud cover and the underlying surface. The meteorological data indicated can be acquired both during the course of the entire orbit and in cycles, making it possible to select certain areas for data acquisition.

Meteorological data acquired from any given area of the earth's surface and which is taken aboard the satellite is stored in special memory units. The meteorological processes should be traced in their dynamics; in order to do this, an exact geographical and time control tie for meteorological information is required.

Enumerated requirements imposed upon data received from the satellite determined the necessity of solving the following problems:

1) orientation of receiver and transmitter units of the meteorological apparatus located on earth and determination of their angular attitude at the moment meteorological data is

recorded;

2) insuring the required intake of electrical energy during the varying cycles of operation of the scientific and space-borne servicing apparatus, in orbits having varying inclination in relation to the solar rays;

3) support of the specified temperature condition during the different lengths of time the satellite remains in the earth's shadow and during those periods when there is a variation in the release of heat by the space-borne apparatus which works in cycles;

4) program control of the apparatus for recording and transmitting meteorological information to earth.

The functions listed for control of the satellite are worked out, accordingly, by an automated system which orients the hull of a space vehicle with the meteorological apparatus; by a space-borne power plant, consisting of solar batteries and storage cells; and by a temperature control system and onboard program-time device.

The System for Orienting the Body of the Space Vehicle

The meteorological satellite's orientation system insures the continuous and precise attitude of the vehichle relative to its orbit, in such a manner that the sensitive devices of the meteorological apparatus are always oriented toward the earth. This permits uninterrupted recording of weather conditions over the lane of orbit; adoption of simple apparatus working on the principle of continuous scanning of the earth's surface and reduction of the demand on the apparatus with photographic frame exposure. In addition to that, the pin-point precision with which the orientation must be accomplished facilitates the determination of angular attitude of the apparatus during the geographical control tie of the meteorological information.

The satellite's orientation system is a control system and does not require the intrusion of ground-located computer systems to monitor its operation. This makes the satellite's exploitation considerably easier.

The orientation system's logic specifies the automatic change of work schedules during damping, during the search for reference points and exit into the established mode of stabilization, which also makes easier the satellite's exploitation.

The orientation system is electromechanical in nature. Its executive elements are three electric motor flywheels. A direction finder with an infra-red horizon of the earth and course sensor is used as quick-response sensors for the angular attitude of the apparatus.

For initial damping and releasing of the kinetic movement stored up by the motor flywheels in the process of orbital motion, electrical magnets are used, which interact with the earth's magnetic pole.

In creating the system for orienting the satellite, a series of problems had to be solved, which had to do with the dynamics of motion of the apparatus relative to its center of mass. The satellite's dynamics are further complicated by the presence of large solar batteries, which, when they rotate, alter the inertia characteristics of the apparatus and cause moments of great external disturbance.

The selection of the control principle, which insures a small a small power demand in the stabilization schedule, is an all-important problem in those systems using electromechanical control devices. In the meteorological satellite's orientation system, impulse control of the motors and flywheels was adopted, which made it possible to obtain a high degree of precision in orientation, with a very short period in which the motors and flywheels were switched on. Along with those measures adopted for reducing power demand for those instruments and devices which were continuously switched on, this made it possible to create an orientation system having a very high power characteristics (nearly ten per cent of the power of the onboard power plant).

The problem of high reliability during the long life of the apparatus is solved through the simplification of the system's logic and functional structure, the selection of a more efficient layout for the various instruments and devices, and by the adoption of a reserve for all the system's different elements and the use in the system of the methods of functional reserve, which insure the satellite's longevity.

The Space-Borne Power Plant

The space-borne power plant (BEU) provides the electric power for the satellite's scientific and service apparatus. The irregularity of the inflow of electric energy, specified by the change in the plane of orbit in relation to the sun's rays is a feature of the BEU's (power plant) function. In addition, the potential inflow of electric power changes in the course of one orbit to another, since the satellite's apparatus is exposed to the sun in part of its orbit and is shaded by the earth in the other part of its orbit. Moreover, the period of time the apparatus is located in the illuminated portion of the orbit determines the greatest opportunity for power intake per revolution of the satellite in orbit, which is changed through precession of the orbit and annual movement of the earth from maximun magnitude, at which time the satellite is under continuous illumination during its orbit, to the minimum magnitude, when the orbital plane is parallel to the sun's rays.

On the other hand, the space-borne power plant should insure constancy of voltage output of the onboard power supply net during the various programming operations; that is, during time variant requirements for electrical energy on the part of the onboard installations.

In other words, the task of the space-borne power plant (BEU) consists in supporting the onboard power supply net, within accepted limits, even when the most unfavorable combinations of intake and consumption of electric power exist. It is natural that the periodicity of solar energy requires power storage cells in the BEU complex. They should have enough minimum capacity to insure a power balance on board the satellite, even under the most unfavorable circumstances.

In order to get the most effective use out of solar energy, the solar batteries must be continuously oriented toward the sun. At the same time, however, the drive for the solar batteries, which causes the batteries to rotate in two planes, must be used in this instance. This complicates the kinematics and apparatus of the drive devices and, as a consequence, increases the weight of the power mechanism and reduces its reliability. A monoaxial system for homing the solar batteries on the sun was adopted on the satellite. The solar battery panels, which are made of silicon elements, are inclined at an angle to the vertical axis of the apparatus and revolve around this axis, being oriented to the sun. This arrangement for homing in the solar batteries insured minimum weight in the BEU, while retaining maximum effeciency in its operation and in the use of the solar energy converters.

The solar battery drive consists of a photoelectric solar sensor, an electronic logic device, and a drive mechanism for turning the solar batteries.

The regulator for the onboard power net, which is part of the BEU assembly, controls the current power state of the storage cells, monitors the programming of the scientific and servicing devices and, in conjunction with this, regulates the inflow of electric energy from the solar silicon elements for recharging the storage cells.

The Meteorological Apparatus

The artificial earth satellite's television apparatus (TV) makes frame exposures of cloudiness and underlying surface by means of two cameras. The TV cameras are designed in such a way that at an altitude of 600-700 kilometers the width of the belt captured on film is about 1000 kilometers, while the three-dimensional resolution of the pictures was equal to 1.25 x 1.25 kilometers.

Infra-red (IK) apparatus is sensitized to radiation currents, "in the window of transparency" of the atmosphere, of 8-12 microns and can function on both the bright and dark sides of the earth. This is a scanner-type apparatus, having a temperature sensitivity of 2-3° during absolute temperatures and 7-8° during negative temperatures. The three-dimensional resolution of the IK (infra-red) apparatus is 15 x 15 kilometers, while the area of the zone covered by the photography is on the order of 1000 kilometers.

The actinometrical apparatus (AK) includes two scanning narrow-sector instruments and two non-scanning wide-sector instruments, which have a field of vision that takes in the entire disk of the earth visible from the satellite's altitude.

One of the narrow-sector instruments measures the intensity of the discharge emissions in a spectral diapason of 0.3-3 microns; the second instrument measures in a spectral diapason of 3-30 microns, when scanning in the opposite direction.

In defining the parameters of the narrow-sector AK instruments, it was given the task of receiving measurements suitable for joint analysis with ground observations and to make a more precise definition of the analysis of TV and infra-red pictures.

Based on the density of the existing net of meteorological stations, the three-dimensional resolution of these instruments was made equal to 50 x 50 kilometers. The working angle of their scanning amounts to $\pm 60^{\circ}$, which insures a zone of coverage on the earth's surface equal to 2500 kilometers.

Information from meteorological apparatus is only valuable in those instances when it is simultaneously tied in by area and by time. The system just described provides great accuracy in the geographical control tie of information.

Analysis of material acquired from observations received from satellites making up the "Meteor" experimental meteorological system revealed that peculiarities crop up in the structure of cloud fields that would be impossible to observe from the ground network of meteorological stations. Regular meteorological data received from stably oriented satellites furnished synoptics with additional data on weather genesis in process over various portions of the earth's surface.

The Space-Borne Programming and Timer Device

The mission of the onboard programming and timer device (BPVU) consists of programming control of the cyclic nature of the operation of the self-recording onboard apparatus, for the purpose of acquiring more valuable meteorological data, and programming control of the drive apparatus for transmitting this information to ground-located devices, with a minimum expenditure of time in radio communications. The second task of the BPVU (onboard programming and timer device) is to synchronize the movement of all self-recording and memory-storage devices, located on board the satellite, which insure a time and, consequently, a geographical control tie of all meteorological information.

The BPVU lays out a set of programs insuring both maximum continuous and selective acquisition of weather data in conjunction with the missions of the weather service in forecasting the weather for the immediate period. The selection of the required set of programs is carried out on command from earth, after which these programs are automatically corrected by the BPVU, in conjunction with the power and heat status of the apparatus.

The synchronization of the movement of the self-recording and memory devices of the onboard apparatus is accomplished from a single power source of highly stable frequency. The necessary range of pulses for each aparatus is shaped in the computer of the BPVU and is altered to conform with the programming of the apparatus.

The "Meteor" System

In the absence of automatic space stations designed to fulfill a specific purpose and having a limited life period which allows for acquisition of only limited information from the satellite, the meteorological satellites of the "Meteor" system are effective automatic observatories, having an uninterrupted operation, while orbiting the earth, of all their functional and scientific-meteorological systems.

A "Meteor" system satellite is connected with a network of ground stations of the command and data acquisition complex. These stations are spread out at great distances from each other and connected together by a community of control, recording, processing and transmission of information. This command and data acquisition complex carries out continuous radio control of the orbit, transmits appropriate commands to the satellite, acquires, records and stores all television actinometrical and infra-red data, processes and transmits it to corresponding meteorological points which forecast the weather.

The "Meteor" weather system makes it possible to conduct a survey of the earth's surface, using meteorological apparatus for specified intervals of time. When two of "Meteor's" artificial earth satellites are in operation at the same time on near-polar orbits and in suitable difference of independent variables of longitudes of ascending nodes, meteorological data can be received from half the earth's surface in a 24-hour period.

When several satellites are in operation at the same time, that task of controlling them, as well as the system as a whole, is considerably complicated.

The complexity of the missions carried out by the system requires the use of electronic computers which make an operational analysis of telemetric information containing both meteorological data and information pertaining to the space-borne apparatus.

Some Results of Exploitation Of Artificial Earth Satellites Placed into Service in the "Meteor" System

The many months the "Meteor" system's satellites have been in use have proved their reliablity.

The reliable function of the solar battery drive, which has bearings that work under conditions of space, come in for special notice.

The operation of all the components making up the electromechanical system responsible for the pin-point orientation of vehicle itself -- an operation that lasted many months -- must also be noted.

The television apparatus, with which all of "Meteor's" satellites were equipped, and which made the frame exposures, possess sufficiently good resolution capability, permitting identification of cloud formations several kilometers in size. The sensitivity of the television cameras mounted on the satellites to contrasts of brightness between clouds and the underlying surface allows for clear-cut contours of cloudiness and individual clouds as well.

Imagery of cloud formations on the shadow side is acquired by means of infra-red apparatus. The receiver of this apparatus is sensitive to heat radiation in that region of the earth's infra-red radiation, which freely filters through the atmosphere, thereby making it possible to use infra-red apparatus to determine the temperature of the earth and its clouds.

Experiments have shown that measured heat radiation is not distorted by solar radiation and therefore can be used for detecting cloudiness and measuring the temperature of the underlying surface, not only at night, but also during the day.

In the "Meteor" meteorological system, solar radiation, the heat emission from the earth and atmosphere are measured by several radiometers, which makes it possible to compute the temperature of continents, seas, oceans and cloud cover.

First and foremost is the problem of further development of meteorological apparatus which will make it possible to measure the vertical temperature profile of the atmosphere.

The computer mounted in the "Meteor" system's satellites for processing and analyzing data, so the vast amount of information that would normally be transmitted to earth can be reduced, commands special interest.

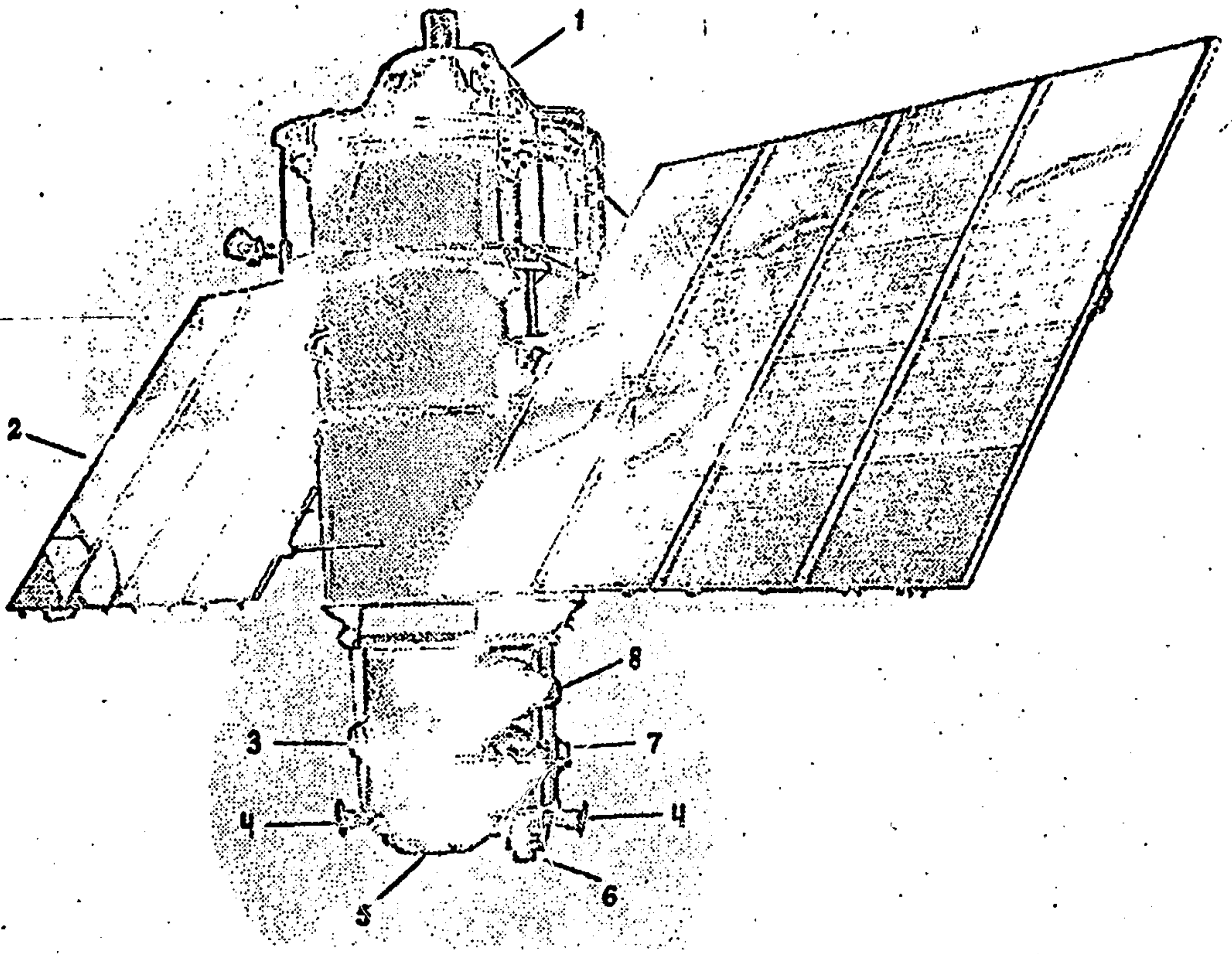
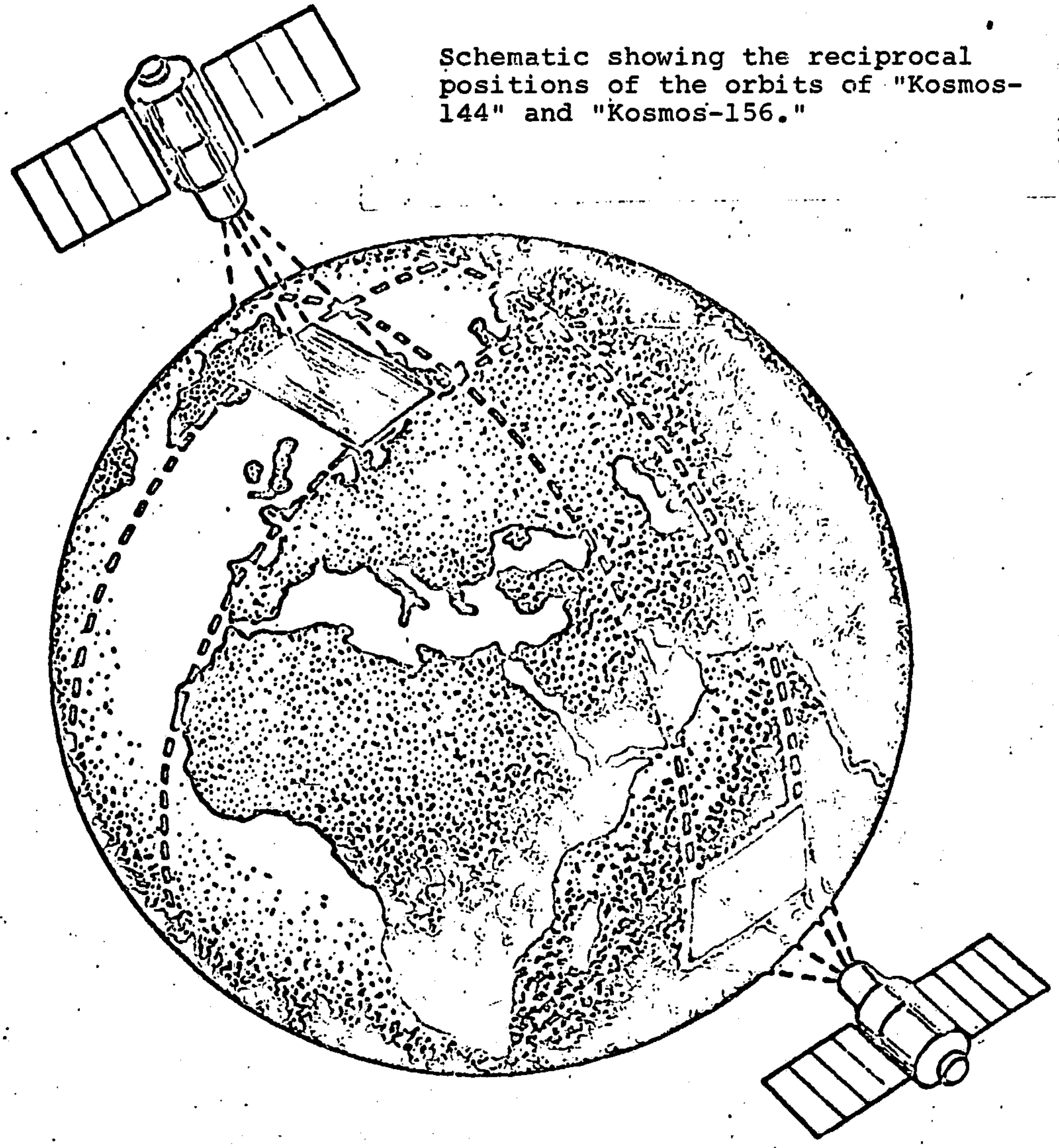


Figure I

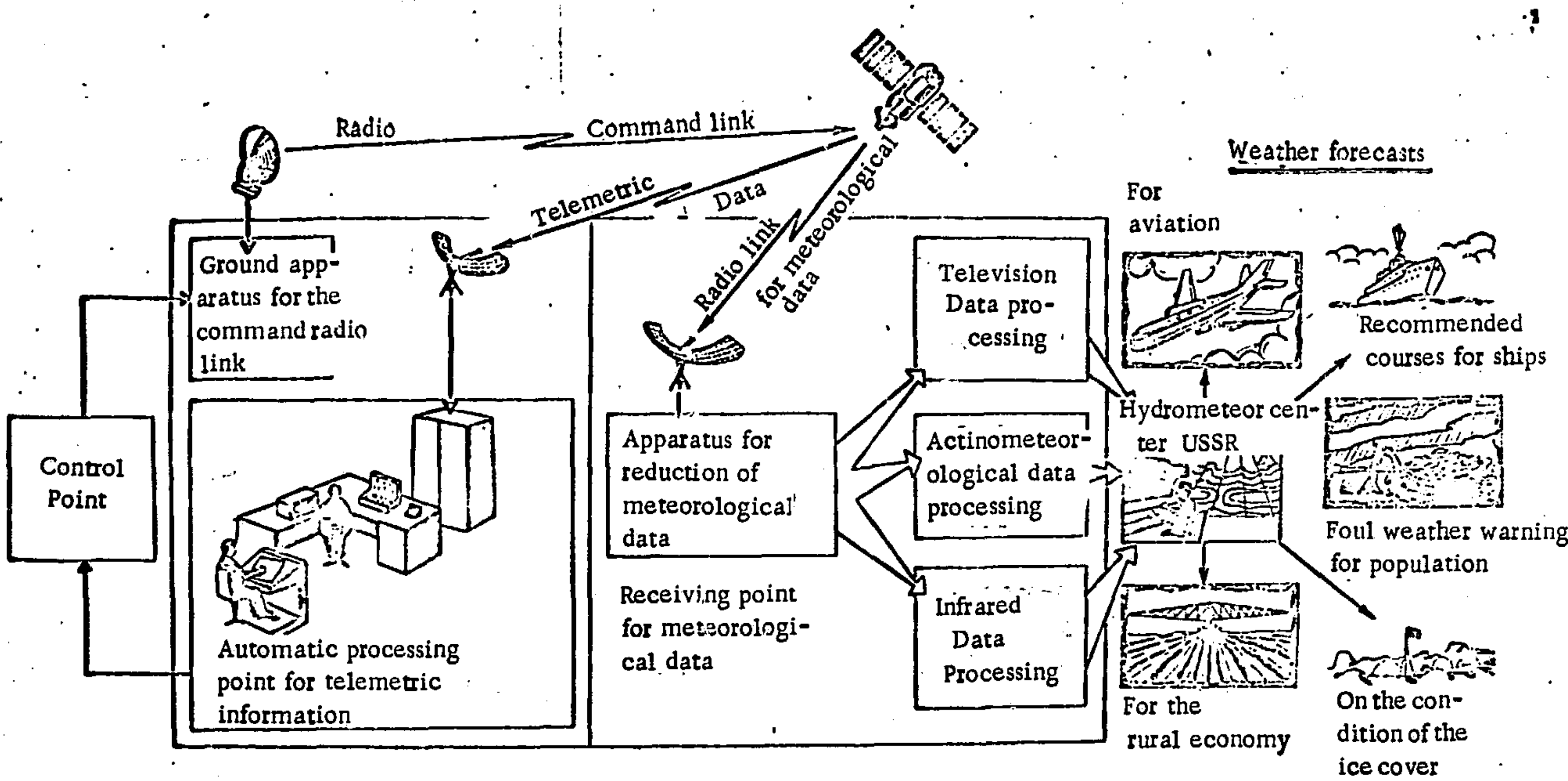
General view of the satellite, "Kosmos-144", of the "Meteor" system:

1-drive mechanism for orienting the solar batteries; 2-solar battery panels; 3-orbital control apparatus; 4-antennas; 5-television camera; 6-magnetic sensor; 7-receiver for actinometrical apparatus; 8-receiver for infra-red apparatus.



Schematic showing the reciprocal positions of the orbits of "Kosmos-144" and "Kosmos-156."

Figure II



Schematic of the "Meteor"System

Figure III Schematic of the "Meteor" system.