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USSR Report

SPACE

(FOUO 3/81)

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SPACE SUPPORT SHIPS

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/Text/ ANNOTATION

This book is concerned with the scientific research ships of the space service, which play an extremely important role in the study and conquest of space. In it the authors tell about the purpose of the ships and their scientific and technical equipment. They also present the necessary information on the theory of spaceflight and space radio engineering, as well as a brief description of the space command and measurement complex in which the ships of the scientific fleet function as floating measuring points.

In this book there is a discussion of questions that are common to both cosmonautics and shipbuilding. The explication is intended for a broad circle of non-specialist readers and does not require any prior knowledge in these areas of technology.

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CHAPTER 3. THE SPACE SUPPORT FLEET

3.1. Requirements for Space Service Ships

Ships participating in the investigation of space are a special class of oceangoing ships. Everything about them is unusual: architecture, the equipment in the internal compartments, the sailing conditions.

The architectural appearance of space service ships is determined primarily by the high-powered structures in their antenna systems. For example, such architectural elements as the 25-meter mirror on the "Cosmonaut Yuriy Gagarin" or the 18-meter, snow-white sphere of radio-transparent covers for the antennas on the "Cosmonaut Vladimir Komarov" attract attention to themselves right away and immediately create a prevailing impression of the ship. A more attentive look reveals dozens of other antennas of all different sizes and designs. There is no such abundance of antennas, of course, on any ship of any other class.

The antennas and radio engineering equipment with which the expedition laboratories are equipped impose their own conditions that are specific for ships of this class. The scientific assignments of expedition voyages dictate the requirements for the ships' seagoing qualities. Taken together, all of this also determines the requirements for space service ships.

Good seagoing qualities are needed by space service ships so that they can fulfill the scientific assignments they have been given while sailing in any area of the world ocean at any time of year and in any weather. At the same time, the sailing must be done safely. Expedition ships must go to those points in the ocean that are determined by ballistic calculations and there perform the work assigned to them without regard for the weather in that area. Sometimes they cannot even choose their course freely when working with an object in space, so as to make sailing easier with respect to the ocean's wave action: the course is determined by communication session assignments, the direction of the spaceflight trace, and the viewing angle of the ship's antennas.

The ships must be able to be controlled well, even at low speeds and while drifting, which are typical conditions for conducting communication sessions with space.

One of the main requirements for space service ships is that they be highly independent. Independence means a ship's ability to stay at sea for a long time, performing its work without putting into port to replenish its stocks of fuel, fresh water and provisions. A high degree of independence enables a ship not to interrupt communication sessions and not to waste time on trips from its working area to a port in order to replenish its stores. Given the great (as a rule) remoteness of these regions, the loss of time on trips would be significant and would possibly require an increase in the number of ships that support spaceflight while at sea.

Independent sailing is limited by the stocks of fresh water and provisions. For example, medium-displacement ships of the "Cosmonaut Vladislav Volkov" type can sail without replenishing its provisions for 90 days, while the fresh water supply for these ships is calculated for 30 days. The ships are equipped with large provision storerooms that have powerful refrigerating equipment. As far as the water supply is concerned, independence can be increased through the use of distilling units on the ships.

Space service ships conduct communication sessions at low speed and while drifting or at anchor. Therefore, the fuel for the engines is consumed mainly during passages. The fuel supply determines another important characteristic of a ship: its continuous cruising range. If it has a large cruising range, a ship is able not to interrupt its work with objects in space in order to put into port to take on fuel. This -- as is the case with increasing independence -- essentially increases the effectiveness of the utilization of the space service fleet. In order to form an opinion about the actual figures, let us say, for example, that the cruising range of the "Cosmonaut Yuriy Gagarin" is 20,000 miles. This distance is only less than an imaginary ocean voyage around the world at the equator.

The next characteristic is a ship's stability and, related to this, its rolling parameters. The radio engineering and electronic equipment that is the basis of the expedition equipment of space service ships has a weight distribution that is very disadvantageous for stability. The heaviest elements of this equipment -- the antennas with their foundations and powerful electric drives -- are located high above the decks and superstructure, while the internal compartments contain basically electronic units that are relatively light in weight. For example, the four main space antenna on the scientific research ship "Cosmonaut Yuriy Gagarin," together with their foundations, have a total weight of about 1,000 tons and are located on decks that are 15-25 meters above the water line, which displaces the ship's center of mass upward to a considerable degree.

Difficulties with stability also arise because of the great surface area of space antennas. For example, the four parabolic mirrors on the "Cosmonaut Yuriy Gagarin," which are 12 and 25 meters in diameter, have a total surface area of 1,200 square meters. When they are set "on edge" and turned toward the side of the ship (a typical position for beginning a communication session), they act as a sail that is trying to capsize the ship. Therefore, communication sessions are not held in high winds. It stands to reason that when an antenna is locked in the "travel" position and is pointed straight up, its sail effect is many times less and no longer poses a danger for sailing. In passing, let us mention here that achievement of the greatest space antenna viewing angles that are necessary to track a satellite in flight is a complicated problem in designing space service ships.

The rolling of a ship because of wave action creates considerable interference for communication sessions with space. In the first place, heavy rolling leads to an increase in the loads on a ship's antenna stabilization system and lowers the accuracy with which they are aimed. Secondly, rolling reduces the fitness for work of the scientific, technical and engineering personnel participating in a communication session. Therefore, reducing rolling is a very important goal when creating any scientific research ship. All available measures are taken to do this. Various kinds of stabilizers are usually installed on this type of ship.

The radio engineering systems on scientific research ships make increased demands on the strength and rigidity of a ship's hull. It is necessary to reinforce the hull at points where massive antenna and other pieces of equipment having considerable weight are installed. When several high-directional antennas are installed on a ship, increased hull rigidity is a condition for their joint operation. For sailing in subpolar latitudes, or in the middle latitudes during the winter, space service ships have reinforced hulls in order to deal with ice.

Extended expedition voyages force serious attention to be given to living conditions. The planners of space service ships try to create on them favorable conditions for both successful work and valuable rest for all expedition members. This is realized most fully on the space service's general-purpose ships. Even on the small ships, however, everything possible has been done to give the crew and expedition members comfortable quarters and so that they can take full advantage of their off-duty time.

3.2. The "Cosmonaut Yuriy Gagarin"

The "Cosmonaut Yuriy Gagarin" is the largest expedition ship and has the most powerful scientific equipment. As far as size, architectural appearance, equipment and investigative capabilities are concerned, it has no equal in worldwide shipbuilding practices (Figure 3.1).

The ship's main dimensions are: greatest length -- 231.6 m, greatest width -- 31.0 m, midship side height -- 15.4 m. Its displacement when fully loaded is 45,000 tons and its draft is 8.5 m. Its 19,000-hp steam turbine power plant gives it a speed of about 18 knots, and its continuous cruising range is 20,000 miles.

When sailing, the ship carries the following: boiler fuel (fuel oil) -- 9,000 tons, diesel fuel -- 1,850 tons; lubricating oil -- 115 tons, boiler water -- 80 tons, provisions -- 180 tons, drinking and washing water -- 2,100 tons. As far as its provisions and fuel and oil supplies are concerned, the ship can sail independently for 130 days. Replenishment of the fresh water supply is required after 60 days. With respect to the water supply, independence can be increased by using the two distilling units on the ship, which produce 40 tons of water per day. The drinking water is saturated with salts that, as far as composition and taste qualities are concerned, make it as good as Moscow's water supply.

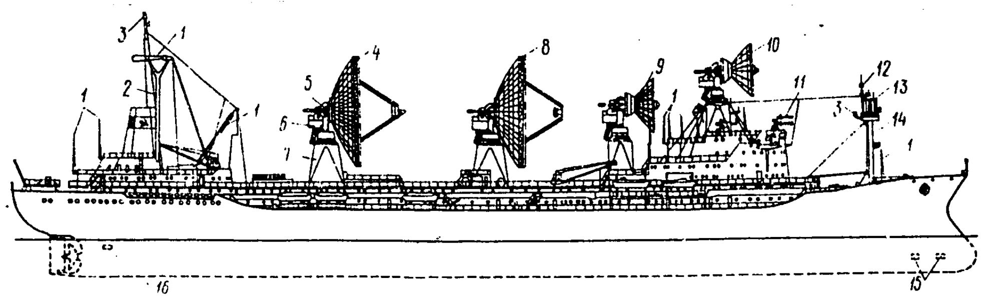

Figure 3.1. The "Cosmonaut Yuriy Gagarin": 1. antenna for long-range communication with marine and land radio stations; 2. mainmast; 3. antenna for short-range (ultrashort-wave) radio communication with marine and land radio stations; 4. A4 command and measurement system antenna; 5. booth behind mirror; 6. drive booth; 7. antenna barbette; 8. A3 command and measurement system antenna; 9. A2 command and measurement system antenna; 10. A1 satellite communication system antenna; 11. antenna for communication with cosmonauts; 12. navigational system (location determination system) antenna; 13. ship's radar antenna; 14. foremast; 15. bow secondary steering unit; 16. stern secondary steering unit.

The ship has a crew of 136 and can accommodate an expedition scientific, technical and engineering staff of 212. As on other space service ships, the number of participants can vary depending on the assignments for each expedition voyage. Here and henceforth the greatest possible number of participants, based on cabin space, is indicated.

The "Cosmonaut Yuriy Gagarin" has good seagoing qualities and can sail in any area of the world ocean under any sea conditions. It has a passive stabilizer to reduce rolling. In very high seas (force 7) the magnitude of the rolling is reduced from $\pm 10^{\circ}$ to $\pm 3^{\circ}$ with a period of about 16 seconds. Pitching at force 7 reaches $\pm 5^{\circ}$ with a period of 7 seconds.

This ship is equipped with secondary steering units. These are vertical-axis propellers, two in the bow and one in the stern, that are mounted inside the hull in open transverse ducts and driven by electric motors. The secondary steering units make it easier to control the ship at low speeds and when moored, and make it possible to keep it on course when the ship is drifting during communication sessions. They are turned on by remote control from the wheelhouse.

The ship's hull has a bulbous bow and is reinforced for sailing in ice.

Along its length, the ship is divided into eight compartments by watertight bulkheads, while from bottom to top it is divided into 11 levels (stages) formed by decks and platforms. The lowest of these is the inner bottom plating, above which are the lower, middle and upper platform decks. These four stages contain storerooms, boiler and diesel fuel tanks, fresh water tanks, ballast tanks and several laboratories. The second compartment (counting from the bow) of the second stage has been set aside as a gymnasium, and above it on the upper platform deck is a movie room. The seventh compartment contains the electric power station, while the engine and boiler room occupies the eighth compartment.

Two superstructure stages that are located even higher -- the first-stage and open decks -- extend the greater part of the ship's length from bow to stern. They are included in the overall hull strength system and, along with the three platform decks and the longitudinal and transverse bulkheads, increase its rigidity and reduce deformations caused by wave action and, consequently, make the work of the antenna stabilization system easier. On these two stages there are cabins, laboratories, the crew and expedition command staff wardroom and two recreation rooms. The first-stage deck has an open gallery along the entire perimeter of the ship. The barbettes of two parabolic antennas with mirror diameters of 25 meters are located on this deck, close to the stern. The antenna structures are mounted on the barbettes, with their purpose being to distribute the load of the antennas' weight uniformly on the hull's basic longitudinal and transverse bulkheads.

Above the open deck the superstructure is divided into two parts -- bow and stern. In the bow superstructure, the next higher stage is the lower bridge. In addition to cabins and laboratories, there is the barbette of one of the two 12-meter parabolic antennas. Farther, on the middle bridge, there is the radio room, and even higher, on the navigating bridge, are the wheelhouse and chart room and, finally, on the upper bridge area there are several antennas, including the second 12-meter parabolic antenna. The upper bridge is 25 meters above sea level.

All 11 stages are interconnected by ladders and passenger and freight elevators.

Space Systems. The basis of the scientific and technical equipment on the "Cosmonaut Yuriy Gagarin" is a multifunctional command and measurement system. It can operate simultaneously and independently with two objects in space, transmitting commands, making trajectory measurements, performing telemetric monitoring, carrying on bilateral telephone and telegraph communication with cosmonauts, and receiving scientific information and television images from space. Communication sessions can be conducted with space objects in near-Earth orbits, with lunar stations and with interplanetary stations flying to Mars and Venus. The achievement of such great radio communication ranges is contributed to by high-directional receiving and transmitting antennas, powerful transmitters and high-sensitivity receivers with input parametric amplifiers that are cooled by liquid nitrogen.

The three parabolic antennas that belong to the space command and measurement system -- the second (A2), third (A3) and fourth (A4) from the bow of the ship -- transmit and receive radio signals on the centimeter, decimeter and meter bands. The 25-meter stern antenna (A4) has a single mirror, while the other two (A2, A3) are double-mirror ones. Each of the A3 and A4 antennas weighs about 240 tons, while the A2 antenna weighs 180 tons.

Depending on the length of the operating wave, the width of the 25-meter antenna's radiation pattern ranges approximately from 10 angular minutes (centimeter waves) to 10° (meter waves). In the booths under the antennas there are receiver input units and high-frequency amplifiers. There is one other parabolic antenna, with a diameter of 2.5 meters. It is used to search for signals and is structurally combined with the A3 antenna.

Automatic tracking of space objects by the incoming radio signals and guidance according to a previously calculated program is provided for all the antennas. The antenna control system normally operates for wind speeds of up to 20 meters per second and seas up to force 7. The "Cosmonaut Yuriy Gagarin" is the only scientific research ship in the world with parabolic antennas of such a large diameter.

The "Cosmonaut Yuriy Gagarin" can control the flight of satellites and interplanetary stations independently, sending them commands and time programs. Another control mode is also possible: relaying of commands reaching the ship from the Flight Control Center. Trajectory monitoring data (range and radial velocity are measured) and the results of telemetric monitoring undergo preliminary machine processing on the ship and are then sent to the Center. In all of these instances, as well as for telephone and telegraph conversations between cosmonauts and the Flight Control Center, the transmissions pass through "Molniya" communication satellites.

Radio conversations with cosmonauts and telemetric spaceflight monitoring are also possible with the help of individual communication and telemetric stations; that is, in addition to the basic command and measurement system. In this case, special communication and telemetry antennas are used. In all, there are 75 antennas of different types and purposes on board the ship.

Control of the space radio engineering systems is automated and their operation is monitored from special panels. Information processing and control of the ship's systems during preparation for a communication session and during the session itself is performed by two general-purpose computers and several specialized computers that solve the separate problems of controlling the antennas and other equipment.

Supporting Systems. First we will describe the ship location determination system. It must correlate the points in the ocean at which communication sessions with space are held to geographic or rectangular geocentric coordinates and measure the ship's course and rolling, pitching and yawing angles. On the "Cosmonaut Yuriy Gagarin" this system is a branched, automated complex of variegated instruments and devices. The latter compute the current coordinates of the ship's location and plot the ship's path on a map. Radio-optical sextants that measure the height and azimuth of heavenly bodies by their light or radio-frequency emissions enable a computer to allow for astronomical observation data. Signals from navigation satellites are used for location determination. Gyroscopic instruments with an accuracy of up to several angular minutes give information on the ship's course and rolling, pitching and yawing, while hydroacoustical logs produce data on the ship's speed relative to the water and the sea bottom. An optical direction finder makes it possible to take into consideration the coordinates of shore reference points. The rolling rate due to wave action is also measured, since this is necessary in order to calculate correction factors during trajectory measurements of the radial velocity of satellites and interplanetary stations.

In addition to the devices listed above that are part of the location determination system, the ship has a complex of steering gear: gyroscopic and magnetic compasses, logs, fathometers, a driftmeter, an automatic position plotter, day and night sighting devices, a hydrometeorological station and equipment for receiving synoptical data. There are also various radio-navigation instruments on the ship, as well as a ship radar station for observing the surrounding situation and measuring bearings and distances. This equipment is also used on voyages, when the accuracy of the navigational correlation may be lower, and is located primarily in the wheelhouse and chart room.

The parabolic antennas are fitted with a triaxial stabilization and control system that allows for wave-induced rolling of the ship. The stabilization and control error is no more than several angular minutes. There is also opticoelectronic equipment to measure elastic deformations of the hull (the angles of curvature of the hull in the center-line plane and the waterline plane). Data on the angles are entered in the antenna stabilization system, as was described in an earlier section. The accuracy of the measurement of the values characterizing hull flexure is about 40 angular seconds.

The ship's basic communication with the Flight Control Center is over a multichannel radio link through "Molniya" relay satellites. This link is used to send command, trajectory, telemetric, telephone-telegraph and television information from space objects. The same link is used for radio exchanges related to the functioning of the ship and the scientific expedition (initial conditions for ballistic calculations, instructions on upcoming communication sessions, reports on sessions that have already been held and so on). The bow parabolic A1 antenna, with a mirror diameter of 12 meters, is used to transmit and receive signals to and from the "Molniya" satellites. As is the case with the A2-A4 antennas of the command and measurement system, it is equipped with a triaxial stabilization system that compensates for rolling and deformations of the ship's hull.

As is well known, satellite communications require that the space relay unit be simultaneously visible from the ocean and from the territory of our country, so that space communication with the Center is not possible from all regions. When a ship is sailing south of the equator, ship communication facilities operating in the short-, medium- and long-wave bands are used. They provide reliable radio communication between a ship and the Flight Control Center from any point in the ocean. The angled antennas of two power short-wave transmitters, with a characteristic design in the form of cones with converging acute vertices, are mounted on the left and right sides of the ship's mainmast at a height of 40 meters above sea level. The list of expedition communication equipment installed on the "Cosmonaut Yuriy Gagarin" (not counting satellite links) includes 7 transmitters, 28 receivers, 8 transceiving radio sets and 16 type-printing telegraph units. They are used to realize radio exchanges in all radio-wave bands in the telephone, acoustic telegraph and type-printing modes. It is also possible to exchange information with the Flight Control Center over ground wire or radio-relay communication links, through shore radio stations.

In addition to the radio communication facilities used by an expedition to solve the problems assigned to it, on scientific ships there is yet another communication complex that is at the captain's disposal and is used for navigation purposes.

Accurate time equipment has been installed on the "Cosmonaut Yuriy Gagarin." The standard oscillators' frequency instability does not exceed $3 \cdot 10^{-10}$ per day, while the temporal scale's drift in the course of a day is no more than several microseconds. The local scale is periodically correlated with common time by signals from special radio stations or signals reaching the ship through "Molniya" satellites. The accuracy of the correlation to common time on the ship is 2-3 microseconds.

The radio direction finders, lighting equipment and hoists on the ship are used to search for and retrieve sections of satellites and interplanetary stations that have fallen into the ocean.

The total number of laboratories on the "Cosmonaut Yuriy Gagarin" is 86. On scientific research ships, the name "laboratory" is given to an area in which the operating equipment for the solution of the expedition's problems is installed. It is not obligatory that any sort of scientific research, such as the analysis of telemetric information, be performed. A laboratory usually contains a complex of instruments and units for the solution of a common functional problem, such as the reception and transmission of radio signals, measurement of a satellite's range or radial velocity, control of the ship's antennas and so forth.

Most of the laboratories are densely packed with racks holding radio engineering and electronics equipment, consoles and information displays. The planners of scientific research ships usually try to save every possible meter of area. The designers and shipbuilders give serious attention to the convenient placement of equipment with easy access to it for maintenance and repair.

The entire shipboard complex of space and support systems is controlled centrally from a laboratory in which the measurement facilities control panel is located. During a communication system, operations at the central control panel are led by the expedition's leader or chief engineer.

Power Equipment and Ship Systems. This ship is equipped with a steam turbine power plant. The engine and boiler room are in the stern. In it there are two steam boilers and a steam turbine that turns the screw. The ship's main power plant has a high degree of automation.

Two power stations are in operation on the ship. Power Station No 1 is located in a separate compartment in the hold. It is used to power the expedition's scientific and technical equipment and consists of four 1,500-kW diesel generators. Power Station No 2, which is located in the engine and boiler room, produces current for all the other consumers on the ship. This power station's two 750-kW turbogenerators operate when the ship is moving, while the single 300-kW diesel generator takes over when it is not moving. There is also an emergency power station -- two 100-kW diesel generators. Thus, the total power of all the electricity sources on the ship is 8,000 kW. The main power plant and Power Station No 2 are controlled from a central post in the engine and boiler room, while Power Station No 1 is under remote control from a separate panel.

The ship's air conditioning system is highly developed. Regardless of the outside temperature, it maintains a temperature of 21-25° C in all the living, public and service quarters, with the possibility of individual temperature control in each area. A powerful refrigerating unit is the basis of the air conditioning, ventilation and radio equipment air-cooling system. There is yet another refrigerating unit on the ship that insures the maintenance of a given temperature regime in the provision storerooms. Liquid nitrogen for cooling the parametric amplifiers is obtained from atmospheric air by a cryogenic unit.

Habitability. Habitability means the working and leisure conditions for participants in expedition voyages. On the "Cosmonaut Yuriy Gagarin" the crew and expedition members are assigned comfortable one- and two-bed cabins (48 of the former and 145 of the latter). Each cabin has a shower (one shower for each two-bed cabin). The ship's command staff and the leader of the expedition's staff have suites that consist of a sitting room and a bedroom (17 suites), with the captain's and the expedition leader's suites also having conference rooms. Telephones and rebroadcasting facilities are installed in all the cabins. In all there are sleeping accommodations for 355 people in 210 cabins.

On the ship there are also two recreation rooms, a library with a reading room, a 250-seat movie theater, a gymnasium with a swimming pool (plus two open pools on deck), a 60-seat wardroom for the ship's officers and the expedition's main staff, and two 100-seat messes. Large provision storerooms, a galley, a bakery and pantries support the feeding of the sailors and the expedition members.

The medical unit on the ship consists of an operating room, a sick bay, a dispensary, an X-ray room and physical therapy and dental offices. They are manned by qualified physicians. The planners and shipbuilders gave special attention to the artistic decoration of all the ship's interior areas.

Construction. The ship was built in Leningrad in 1971. The design was based on the hull of a series-produced tanker that had proved itself in practice. Work began in the building berth in March 1969. The ship entered the water 7 months later, and on 14 July 1971 the USSR's flag was raised on the "Cosmonaut Yuriy Gagarin." The ship went to sea on 16 July 1971, sailing from Leningrad to Odessa, its port of registry.

From 1971 to 1980 the "Cosmonaut Yuriy Gagarin" completed 8 expedition voyages and participated in many prominent experiments in the Soviet program for investigating and conquering space.

3.3. General-Purpose Space Service Ships

This group of space service expedition ships includes those having scientific and technical equipment that enables them to carry out all the functions of stationary measuring points while at sea. In addition to the "Cosmonaut Yuriy Gagarin," which was described above, this group includes the "Cosmonaut Vladimir Komarov" and the "Academician Sergey Korolev."

The "Cosmonaut Vladimir Komarov"

The "Cosmonaut Vladimir Komarov" is the first general-purpose ship that was specially designed and built for the investigation of space. It began its expedition voyages in August 1967.

In order to shorten the planning and construction time, the ship was developed on the basis of the hull of a series-produced dry-cargo ship, while its radio engineering systems were based on the stations used at land measuring points. This required the solution of many pressing problems in insuring the stability of the finished hull when the heavy antenna installations were installed on it, as well as the creation of the proper conditions for the operation of the radio engineering and electronics equipment. The ship's greatest length is 155.7 meters, its greatest width is 23.3 meters, and the height of the side at midship is 14.8 meters. The main power plant is a 9,000-hp diesel engine.

The ship has two platforms, four decks and bow and stern superstructures (Figure 3.5). It has the seagoing qualities that are necessary for ships that can sail

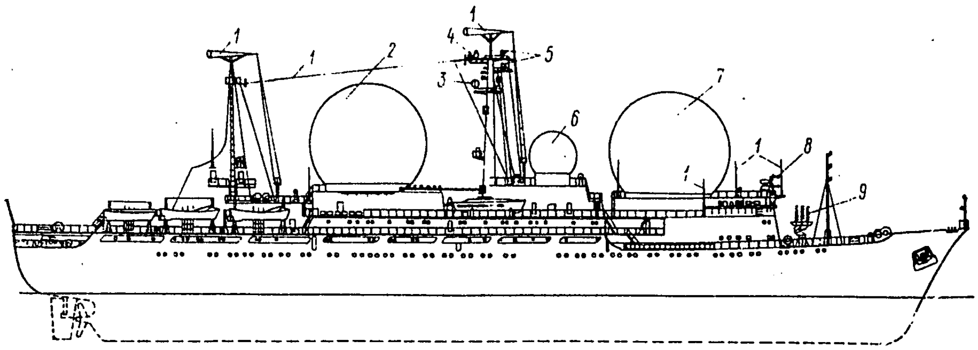

Figure 3.5. The "Cosmonaut Vladimir Komarov": 1. antenna for long-range communication with marine and land radio stations; 2. radio-transparent cover of A3 command and measurement system antenna; 3. navigation system (location determination system) antenna; 4. antenna for short-range (ultrashort-wave) communication with marine and shore radio stations; 5. ship's radar antenna; 6. radio-transparent cover of A2 command and measurement system antenna; 7. radio-transparent cover of A1 command and measurement system antenna; 8. radiotelemetry system antenna; 9. antenna for communication with cosmonauts.

anywhere. When fully loaded with 5,500 tons of fuel, 65 tons of lubricating oil, 85 tons of provisions and 320 tons of drinking and washing water, its displacement is 17,850 tons and it has a draft of 8.8 meters. Its speed is 15.8 knots and it has a cruising range of 18,000 miles. It carries a crew of 121 people and can accommodate 118 expedition members.

The power supply for general ship consumption comes from a 900-kW electric power station. The expedition's space and support systems are powered by a separate 2,400-kW station. The air conditioning and ventilation systems maintain a constant temperature of about 20° C in the laboratories and living and public quarters when the outside air temperature ranges from -30° C to +30° C.

Space and Support Systems. The multifunctional command and measurement system installed on the "Cosmonaut Vladimir Komarov" operates in the decimeter wave band. It measures the motion parameters (range and radial velocity) of satellites and interplanetary stations, receives telemetric and scientific information, transmits commands, and carries on two-way conversations with cosmonauts. All of the command and measurement system's elements are encompassed by a common monitoring and control system. The telemetric part of the system has separate antennas and receivers that make it possible to make telemetric measurements and receive scientific information without turning on all the other equipment.

Two high-directional antennas (receiving and transmitting) with parabolic mirrors 8 meters in diameter, parametric input amplifiers cooled by liquid nitrogen, and powerful transmitters make it possible to maintain radio communication with space objects at circumlunar distances (400,000 kilometers). Such communication with a floating measuring point was first realized in 1968, in operations with the "Zond-4" and "Zond-5" automatic interplanetary stations.

A third parabolic antenna that is 2.1 meters in diameter insures automatic tracking of space objects and generates signals for correcting the antenna guidance program. All three antennas are mounted on stabilized platforms. The 8-meter antennas, together with their stabilized platforms, weigh 28 tons each, while the weight of the direction-finding antenna with its platform is 18 tons.

Wind pressure on the surface area of each of the 8-meter antennas could create significant moments applied to the elements of the electric power drive and the structure of the antenna itself and would inevitably lower the accuracy of the stabilization and control process. For this reason the antennas have radio-transparent covers that are 18 meters in diameter. The direction-finding antenna's cover is 7.5 meters in diameter.

The design of all three radio-transparent housings is identical. The large covers weigh 20 tons apiece, the small one -- 2 tons. They consist of three-layer fiberglass panels that are glued together. The outer side of the radio-transparent covers is coated with a paint that has water-repellent properties. For antenna assembly and repair, there are releasable connections in the middle section of the spheres that make it possible to remove their upper halves when necessary. The electromagnetic energy losses during passage through the radio-transparent panels do not exceed 1 percent.

By eliminating wind pressure, the radio-transparent covers make it possible to conduct communication sessions when the wind is coming from any direction. Besides this, they protect the antennas from rain, snow, sea spray, solar radiation and dust, thereby making maintenance of the antenna installations considerably easier.

The command and measurement system antennas and the laboratories are situated such that the length of the cables and waveguides connecting the antennas to the receivers and transmitters is minimal. The A1 bow antenna is a receiving one, and the laboratories containing the command and measurement receiving units are located on the decks under it. The laboratory with the transmitting units is located under the A3 stern (transmitting) antenna. Three transmitters, the power of which is added together in the antenna, are installed in it.

The antenna and stabilized platform control laboratory is located in the middle part of the ship, on the boat deck. Here, also, is the central control console for all the ship's measuring facilities and the common time laboratory.

Determination of the ship's location during communication sessions is realized by a complex of instruments that utilize data from radio and optical sextants, the satellite navigation system and radio-navigation and direction-finding equipment. The coordinates are calculated by a computer. The magnitudes of the rolling, pitching and yawing angles, which are needed by the antenna stabilization and guidance system, are measured by gyroscopic instruments. There is also a unit that determines the antennas' linear rate of displacement due to wave action so that correction factors can be introduced when measuring the radial velocity of space objects.

The ship's information and computation facilities calculate target indications and antenna control programs, process information coming in from space in order to obtain preliminary evaluations, and condense information for transmission over the communication links to the Flight Control Center. On the ship there are also a general-purpose computer and several specialized ones.

For conversations with cosmonauts, on the ship there is an ultrashort-wave radio station that provides bilateral telephone and telegraph communication. This station's receiving antenna is of the spiral type and has a radiation pattern width of about 25°. The antenna features remote control and is located on the main deck in the bow section of the ship. A discone antenna on the mainmast is used for transmitting.

Satellite communication links provide for the transmission of trajectory and telemetric information to the Flight Control Center and also make it possible to send telephone and telegraph information to the Center during conversations with cosmonauts. When satellite communication is impossible, short- and medium-wave equipment is used for radio exchanges with the Center. Transmissions can also be made in the acoustical telegraph, type-printer or telephone modes.

The ship's space and support systems equipment is located in 43 laboratories. Radio signal reception and transmission is realized with 40 antennas of various types.

Radio Reception Interference. For the first time in the practice of building scientific ships, on the "Cosmonaut Vladimir Komarov" a large number of powerful transmitters and highly sensitive receivers, many of which must operate simultaneously, were concentrated in an area only 150 meters long and 20 meters wide. The complex and hard to solve problem of the electromagnetic compatibility of the radio engineering facilities was an urgent one.

In such conditions, the strongest radio reception interference is created by transmitters operating on nearby frequencies. Their nonbasic emissions -- on the harmonics, subharmonics, combined frequencies and so on -- also interfere. It was also necessary to take into consideration the spurious radiation of the heterodynes in the receivers.

The reradiation effect also carries substantial weight in the creation of interference. The role of reradiator is filled by masts, deckhouses, guard rails, neighboring antennas, spar and rigging elements and other equipment. Currents that are induced during the operation of transmitters also become a source of interference if they pass through couplings with poor contacts. The complexity of the electromagnetic situation is deepened even more by the fact that transmitting and receiving antennas that carry out directional tracking of satellites turn during communication sessions; that is, they change their position.

There are three basic ways of dealing with mutual interference. They are frequency, temporal and spatial separation of signals. In the frequency separation method, different sections of the frequency band are selected for the operation of the radio transmitting and receiving equipment. The correct choice is made more difficult by the fact that it is necessary to take into consideration not only the rated frequencies of the radio signals, but also the nonbasic emissions, the suppression of which is a difficult problem. Here we encounter various measures for combatting interference that are based on the use of the spectral characteristics of signals, such as the use of pseudorandom signals.

The temporal separation method consists of strict regulation of the order and time of use of all ship radio facilities. In particular, during communication sessions with space objects, the operation of all other emitting devices is sharply limited on board a ship.

The method of spatial signal separation requires that the transmitting and receiving antennas be as far apart as possible, which is realized at land measuring points solving the same problems without any special difficulty but runs into insurmountable complications on expedition ships. On these ships the antennas are maximally concentrated on the decks and masts. As a rule, receiving antennas are in the bow and transmitting antennas are in the stern.

The most essential measures for reducing mutual interference can be taken in the stage of the development of new radio engineering equipment. Primarily, this means the creation of highly selective receivers that have a low degree of sensitivity to any kind of incidental radiation, as well as a reduction in the incidental emissions of the transmitters themselves. The problem of mutual interference has continued to retain its urgency for space service ships built recently.

The creation of the "Cosmonaut Vladimir Komarov" saw the first solution for scientific research ships of the problem of shielding the personnel from the radio-frequency emissions of the space systems' powerful transmitters. Compartment screening was used on the ship. A signaling system was introduced that informs the personnel when it is prohibited to be on decks and in other places subject to radiation.

The scientific research ship "Cosmonaut Vladimir Komarov," built in Leningrad, has its home port in Odessa. The experience accumulated during its planning and construction has proven to be of valuable assistance in the building of subsequent space service ships.

The "Academician Sergey Korolev"

As is the case with the space service's other general-purpose ships, the "Academician Sergey Korolev" also performs at sea all the functions carried out by land measuring points. As far as the extent of its scientific and technical equipment, the level of automation of the measurements and information processing, the number of computers and control machines, and habitability conditions, this ship occupies an intermediate position between the "Cosmonaut Vladimir Komarov" and the "Cosmonaut Yuriy Gagarin."

The scientific research ship "Academician Sergey Korolev" was built in Nikolayev in 1970. It has the following specifications. Main dimensions: greatest length -- 180.8 meters, greatest width -- 25.0 meters, side height at midship -- 18.2 meters. Its displacement with a full complement of supplies is 21,250 tons and its draft is 7.7 meters. Supplies: fuel -- 5,720 tons, provisons -- 105 tons, fresh water (drinking and washing) -- 810 tons. The main power plant is a 12,000-hp diesel engine that provides a speed of 17.5 knots. Its cruising range is 22,500 miles. The ship has a crew of 119 and can accommodate 188 expedition members. A side view of this scientific research ship is shown in Figure 3.6.

The ship has secondary steering units: one propeller in the bow and two in the stern. The bow propeller is located in a transverse duct inside the hull, while the stern units are propeller steering columns with a changeable direction of operation. The propeller steering columns move the ship at up to 3 knots.

The ship's electric power station is equipped with six diesel generators that each produce 600 kW. The air conditioning and ventilation system insures constant air

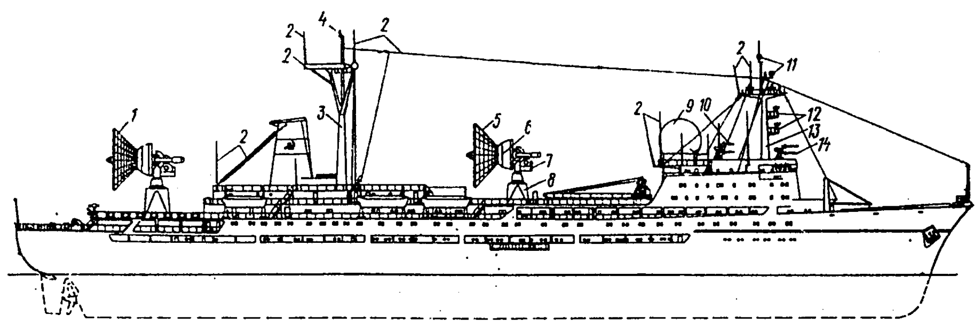

Figure 3.6. The "Academician Sergey Korolev": 1. A3 satellite communication system antenna; 2. antenna for long-range communication with ship and shore radio stations; 3. mainmast; 4. antenna for short-range (ultrashort-wave) communication with ship and shore radio stations; 5. A2 command and measurement system antenna; 6. booth behind mirror; 7. drive booth; 8. antenna barbette; 9. radio-transparent cover of A1 command and measurement system antenna; 10. radiotelemetric system antenna; 11. navigation system (location determination system) antenna; 12. ship's radar antenna; 13. foremast; 14. antenna for communication with cosmonauts.

parameters in all compartments and also cools the radio engineering and electronics equipment.

The command and measurement system, which is the basis of the ship's scientific and technical equipment, operates on decimeter waves. It transmits commands, performs telemetric and trajectory monitoring of a spaceflight (measures the values of r and $\dot{r}$), and makes it possible to carry on two-sided telephone and telegraph conversations with cosmonauts. Trajectory and telemetric information processing is performed by computers.

On the ship there are three parabolic antennas: A2 and A3 with mirror diameters of 12 meters and A1 with a mirror diameter of 2.1 meters. The A1 antenna has a radio-transparent cover. The A1 and A2 antennas are used in the space command and measurement system, while the stern A3 antenna is used for satellite communication with the Flight Control Center. Both 12-meter antennas have triaxial revolving support units with automatic stabilization relative to the rolling, pitching and yawing angles. The small antenna is mounted on a gyrostabilized platform.

The laboratories are located on the main, boat and superstructure decks. In contrast to the "Cosmonaut Vladimir Komarov," on this ship -- and on all subsequent ones -- the space and support system equipment that was installed was specially developed in marine versions for use on ships. On the ship there are two general-purpose computers and several specialized ones. The total number of laboratories is 79.

The location determination, communication and time service systems are basically the same as on other general-purpose space service ships. This ship is equipeed with short- and ultrashort-wave direction finders for searching for sections of spacecraft that have landed in the ocean.

The "Academician Sergey Korolev" departed on its first expedition voyage in March 1971. Its port of registry is Odessa.

3.4. Small Space Service Ships

This most numerous group of expedition ships for investigating space includes four ships of the "Cosmonaut Vladislav Volkov" type and four of the "Kegostrov" type. They all perform the same list of functions when working with space objects: telemetric monitoring and the reception of scientific information, as well as two-way telephone and telegraph radio communication with cosmonauts. However, as far as completeness of monitoring, the degree of automation, and perfection of the ship's space and support systems are concerned, the ships of the new "Cosmonaut Vladislav Volkov" series are considerably better than the other four ships, which began their expedition voyages as far back as the 1960's. The name "small ships" is somewhat conventional, since it refers not so much to their relatively small (in comparison with the general-purpose ships) displacement as to the narrower circle of problems that can be solved and, consequently, to the reduced amount of scientific and technical equipment.

The "Cosmonaut Vladislav Volkov"

Between the construction of the most powerful (in capability for scientific research) expediton ship, the "Cosmonaut Yuriy Gagarin," and the leading ship of the new series, the "Cosmonaut Vladislav Volkov," 6 years passed. During this time there appeared improved and more compact modifications of the basic space and support systems and methods for the machine processing of space information and automatic control of command and measurement systems were developed. Therefore, if we compare the investigative capabilities of the two ships -- the "Cosmonaut Yuriy Gagarin" and the "Cosmonaut Vladislav Volkov" -- it turns out that the fivefold difference in displacement in no way reflects the relationship of their scientific potentials. The new ship is packed with modern radiotelemetry, information and computer and machine data processing equipment, as well as the newest location determination and communication facilities and so on. While staying within the framework of the list of small space service ship assignments listed above, this new ship represents a significant step forward in the development of floating measuirng points.

The scientific research ship "Cosmonaut Vladislav Volkov" is characterized by the following data. Main dimensions: greatest length -- 121.9 meters, greatest width -- 16.7 meters, height of the side to the upper deck -- 10.8 meters. Its displacement with a full load of supplies is 8,950 tons and its draft is 6.6 meters. The main power plant is a 5,200-hp diesel engine that gives it a speed of 14.7 knots. The ship's supplies are: fuel -- 1,440 tons, lubricating oils -- 30 tons, drinking and washing water -- 600 tons. What is held in its fuel tanks gives it a cruising range of 16,000 miles. The ship's independence relative to provisions is 90 days, while for water it is 30 days. The crew numbers 66 and it has accommodations for 77 expedition members.

The ship's seagoing qualities correspond to the requirements for ships that can sail anywhere.

As far as its design is concerned, the "Cosmonaut Vladislav Volkov" (Figure 3.7) is a two-deck steamship with two platforms that extend the entire length of the hull

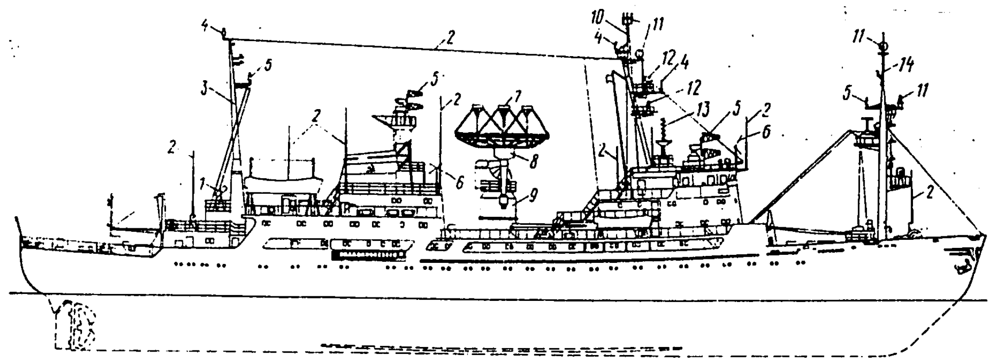

Figure 3.7. The "Cosmonaut Vladislav Volkov": 1. satellite communication system antenna; 2. antenna for long-range communication with ship and shore radio stations; 3. mizzenmast; 4. antenna for short-range (ultrashort-wave) communication with ship and shore radio stations; 5. antenna for system for communicating with cosmonauts; 6. antenna for receiving television broadcast programs; 7. antenna for general-purpose radiotelemetry system; 8. booth behind mirror; 9. antenna barbette; 10. mainmast; 11. navigation system (location determination system) antenna; 12. ship's radar antenna; 13. radiotelemetry system antenna; 14. foremast.

from bow to stern. Six watertight transverse bulkheads divide the ship into compartments. Above the first-stage superstructure deck there rise two "islands" -- the bow and stern superstructures -- and between them is the main four-mirror antenna for receiving signals from space.

The expedition's laboratories are located mainly on the first platform and the main and upper decks, as well as the second-stage superstructure deck, the navigating bridge and the second platform. The planners had to find that variant for placing the laboratories for which minimum length communications would be required, particularly insofar as the high-frequency switching between the laboratories and antennas was concerned, in order to avoid immoderate attenuation of the radio signals.

The common quarters (messes, recreation rooms) are located on the upper deck. On the upper and main decks there are a large number of cabins, with only the few cabins of the ship's command staff and the expedition leaders being located on the first- and second-stage superstructure decks. In the central part of the ship, the entire height of the fifth compartment is occupied by the engine and boiler room, while the electric power station is in the sixth compartment. Closer to the bow, the refrigerating machinery of the air conditioning system is in the fourth compartment and the gymnasium is in the third compartment.

In the bow superstructure (on the first- and second-stage decks) there are the medical unit and the radio room, while the wheelhouse and chart room are on the navigating bridge. The latter two are combined on this ship, but the navigation officer can create the conditions necessary for instrument operation by using movable wall panels. Such a wheelhouse layout is very convenient for navigation.

Space and Support Systems. The scientific research ship "Cosmonaut Vladislav Volkov" is equipped with a general-purpose telemetry system that acquires information from all the existing types of telemetric equipment on board the ship. This universality is manifested primarily in the broad range of frequencies for the incoming radio signals, from the shortest ones in the decimeter band to the longest meter waves, and also in the possible forms of modulation. This system also has a parabolic mirror antenna, receiving and direction-finding equipment and equipment for converting and recording telemetric and scientific information.

The main space antenna consists of four parabolic mirrors that are each 6 meters in diameter and are united in a common structure. By comparing the signals in the irradiators of neighboring mirrors, this antenna layout makes it possible to determine the direction from which radio waves arrive; that is, to find the direction of the space object. Until now we have been talking about direction finding carried out with four irradiators located close to the focus of a single parabolic mirror, but the principle of determining direction in both cases is obviously the same. The four mirrors' total radiation pattern has a width of from approximately 1° to 10° (depending on the radio signal's frequency).

A triaxial revolving support unit makes it possible to track the flight of a satellite within the limits of the entire upper hemisphere, including when the satellite passes through the zenith. The antenna stabilization system allows for the ship's rolling, pitching and yawing angles. The tracking drive for each of the three axes consists of an amplidyne and an actuating motor. The error signal that is needed for automatic tracking of satellites according to their radio-frequency emissions is received from the receiving and direction-finding equipment laboratory, while the antenna stabilization signals come from the location determination system's instruments.

The main space antenna's revolving support unit and the mirror and electric drive elements weigh 95 tons. Its base is mounted on a barbette. High-frequency parametric amplifiers are located in the booth behind the mirror. Other space and support system antennas are located in the forecastle, on the upper bridge and the superstructure decks, and on the foremasts, mainmasts and mizzenmasts. In all, there are 50 receiving and transmitting antennas that are used for different purposes.

Signals that have been received by the main space antenna and amplified and rectified in the receiving and direction-finding equipment are sent into the telemetric and scientific information conversion and recording laboratory. In this laboratory they are deciphered, distributed to the proper channels and recorded on magnetic tape. Machine processing of the information then follows.

Telemetric data processing is performed by a general-purpose computer, but first it is necessary to solve the problem of information coupling between the telemetric station and the computer, and after processing, of coupling between the computer and the satellite communication link into which the information is sent after computer processing. Thus, a continuous flow of telemetric data passes through the ship during communication sessions. The path it follows is: space object-scientific research ship-communication satellite-Flight Control Center.

Telemetric information can be evaluated not only by personnel at the Flight Control Center, but also by specialists on the ship itself who view the telemetric data they need on special cathode-ray tube screens that are similar to those in the

Flight Control Center's main room. We have already said that all space information is recorded on magnetic tape simultaneously with its transmission over the communication links, so after a communication session it can be played back repeatedly.

The ship can received telemetric and scientific information simultaneously from two space objects. Telephone and telegraph information follows the same path -- through the space communication link -- when the Center is conducting two-way conversations with cosmonauts.

In addition to the general-purpose computer that processes the space information and makes the necessary calculations for communication sessions, there are several specialized computers of the digital and analog types on the ship.

The elimination of trajectory measurements from the number of functions performed by the small scientific research ships sharply loosened the requirements for accuracy in determining their location in the ocean. Therefore, the location determination system on the "Cosmonaut Vladislav Volkov" is considerably simpler than the one on the space fleet's general-purpose ships. It is based on equipment that determines the ship's location with the help of signals from navigation satellites and gyroscopic instruments that measure the course and the rolling, pitching and yawing angles for antenna stabilization purposes. In addition, the ship has the normal full complement of navigating equipment.

Information exchange with the Flight Control Center is realized over satellite and the normal short- and medium-wave communication channels. The common time service's equipment insures correlation of the local time scale to the standard scale with an error of no more than several microseconds. Two direction finders operating in the ultrashort- and short-wave bands can determine the direction to spacecraft sections that have landed in the sea.

This is a short list of the space and support equipment installed on the "Cosmonaut Vladislav Volkov." It is located in 25 expedition laboratories: the receiving, recording and telemetric and scientific information analysis facilities occupy 5 laboratories; the location determination, direction-finding and antenna control equipment -- another 5; the facilities for communicating with space objects and the Flight Control Center, with its control point, and the common time service's receiving station -- 11; the information and computation center -- 3; the measuring equipment control point -- 1.

Power Equipment and Ship Systems. This scientific research ship's main power plant is located in an engine room in the middle part of the ship. Here there is also an electric power station that supplies electricity for general ship usage. It consists of three 200-kW diesel generators. Another electric power station that is used to power the expedition's scientific and technical equipment is located in the next compartment toward the stern, and consists of three 630-kW diesel generators. The emergency electric power station has one 100-kW diesel generator.

The air conditioning and radio engineering and electronics equipment cooling and ventilation systems have about the same characteristics as they do on other space service ships.

Habitability, The installation of a complicated complex of equipment on a ship with comparatively small dimensions resulted in a need for maximum economy of space in the planning of all areas. This could not help but affect the habitability conditions if they are compared with, for example, the conditions on the scientific research ship "Cosmonaut Yuriy Gagarin."

The crew and expedition has two recreation rooms available. A large gymnasium that occupies two stages between the inner-bottom plating and the first platform can be adapted for holding meetings and showing movies. The crew and expedition's mess is also used to show movies, and the movie-showing equipment is next to this area. The swimming pool is open and is located on the first-stage superstructure deck.

The crew and expedition members sleep in one- and two-man cabins. The cabins are well laid out, which compensates somewhat for their small size. The senior ship's officers and the expedition leaders have suites consisting of a sitting room and a bedroom. On the ship's decks there are several shower rooms. In the cabins, laboratories, shiphandling and public areas there are telephone equipment that is part of the ship's automatic telephone exchange and radio rebroadcasting facilities. The canteens, galley and bakery are located on the upper deck, toward the stern and immediately behind the crew's and expedition's messes.

Construction. The hull of a standard lumber carrier was used as the basis of the plan for all the scientific research ships of this series. They were designed and built in Leningrad and entered the service of the scientific research fleet in the years 1977-1979. In addition to the "Cosmonaut Vladislav Volkov," there are three more ships in this series: the "Cosmonaut Pavel Belyayev," the "Cosmonaut Georgiy Dobrovol'skiy" and the "Cosmonaut Viktor Patsayev."

All of the ships belong to the Baltic Oceangoing Steamship Line and are registered in Leningrad. The first ship sailed on its first scientific voyage in the Atlantic Ocean on 18 October 1977. It was followed by the "Cosmonaut Pavel Belyayev" (15 March 1978), the "Cosmonaut Georgiy Dobrovol'skiy" (14 October 1978) and the "Cosmonaut Viktor Patsayev" (19 June 1979). In the same way that the "Cosmonaut Yuriy Gagarin" is a significant achievement of Soviet science and technology in the creation of general-purpose ships for investigating space, these four ships, led by the "Cosmonaut Vladislav Volkov," are a substantial landmark in the creation of small scientific research ships for the space service.

The "Kegostrov"

The scientific research ship "Kegostrov" is from a series of monotypical ships constructed in 1967 (Figure 3.10). Its characteristics are as follows: total displacement -- 6,100 tons; length -- 121.9 meters; width -- 16.7 meters; draft -- 4.7 meters. It has a 5,200-hp diesel engine that gives it a speed of 15.6 knots and its cruising range is 16,000 miles. The crew numbers 53 and it can accommodate 36 expedition members. The "Morzhovets," "Borovichi" and "Nevel'" have the same characteristics.

As is the case for all small space service ships, the "Kegostrov" performs two basic functions at sea: the ship's space systems receive telemetric and scientific information from satellites and interplanetary stations and carry on two-way radio communication with cosmonauts. In order to accomplish this, the ship is equipped with various types of telemetry systems and a radio station for telephone and

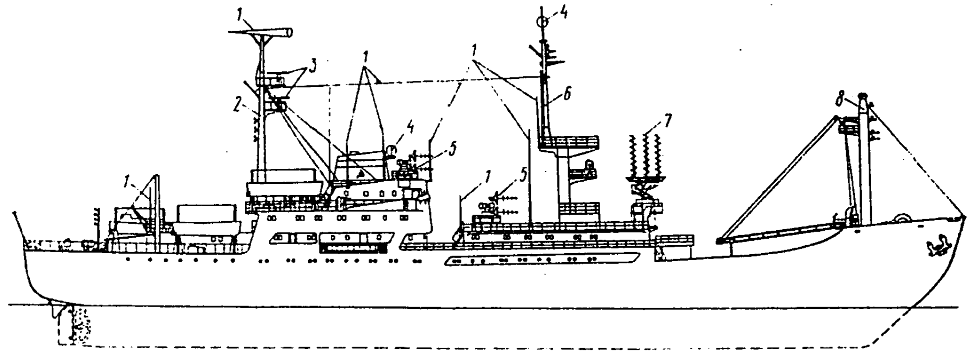

Figure 3.10. The "Kegostrov": 1. antenna for long-range communication with ship and shore radio stations; 2. mizzenmast; 3. ship's radar antenna; 4. navigation system (location determination system) antenna; 5. radictelemetry system antenna; 6. mainmast; 7. antenna for communication with cosmonauts; 8. foremast.

telegraph communication with the crews of spacecraft and orbital stations. Telemetric and scientific information are processed and analyzed on the ship by specialists on the expedition's staff. The analyzed data are sent to the Flight Control Center over radiotelegraph communication links.

The space and support system equipment is located in 10 laboratories on the "Kegostrov." It includes equipment for receiving, recording and processing telemetric and scientific information and conducting radio communication with cosmonauts and the Flight Control Center, as well as a common time service receiving station and a radio engineering equipment control point.

The laboratories, living quarters and service and public quarters have a stable microclimate created by an air conditioning system. The system for ventilating and cooling the scientific and technical equipment provides the temperature conditions needed for its normal operation when the ship is sailing in any climatic belts at at any time of the year.

All four ships were designed on the basis of the hull of a series-produced lumber carrier. In past years their scientific equipment has been repeatedly supplemented and improved. Outwardly, this is expressed primarily by changes in the number, types and locations of the radio antennas. Such work will also be done in the future, so the diagram of the side view of the "Kegostrov" (Figure 3.10), as is the case with the other general layout diagrams presented in this book, can differ in detail from the actual external appearance of these ships.

The ships' first expedition voyages took place in 1967. Their port of registry is Leningrad.

These steamships have come to be known as tireless laborers for science. From 1967 to 1980 they each completed 13-14 expedition voyages. Their work was important and necessary for many achievements of Soviet cosmonautics.

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SPACE ENGINEERING

UDC 621.313.12:538.4

MODEL OF THE HIGH-TEMPERATURE FAILURE OF HEAT SHIELDS DURING THE ENTRY OF SPACE-CRAFT INTO THE DENSE LAYERS OF THE ATMOSPHERE (RADIANT AND CONVECTIVE HEATING)

Kiev KOSMICHESKIYE ISSLEDOVANIYA NA UKRAINE in Russian No 14, 1980 (signed to press 4 Sep 80) pp 89-95

/Article by V.S. Dvernyakov, Kiev, manuscript received 16 Oct 79/

/Text/ Investigations of the rules governing the high-temperature interaction of materials in different mediums are related to the determination of heat and mass transfer in a gaseous medium and inside a material, as well as the experimental study of the properties of materials with different external flow-past parameters.

When creating materials with given properties for multilayer heat-shield systems, it is necessary that there be a substantiated interrelationship of the external parameters along the flight path with the nature of the separate components, their relationship, the structure of composite materials and their production process, the choice of the relationship of these components to the structure of the multilayered system as a whole, the moment of the realization of one reaction or another on the surface and inside the material, and so forth. Materials experts must have an opportunity to evaluate the kinetics of the high-temperature interaction process for the purpose of rapid implementation of correction of the composition, structure and manufacturing method of materials created with given properties. In connection with this, the experimental methods for determining the dynamic interrelationship among the parameters of the medium and materials and the rate of advance in the latter of the boundary of physicochemical transformations must be easily accessible, variegated with respect to the conditions created, and easily regulated.

In this article we offer an analytical relationship that reflects the qualitative picture of these interrelationships for the radiant and convective heating conditions in the SGU-3 installation at the Ukrainian SSR Academy of Sciences' Institute of Problems of Material Science.

This installation combines a solar furnace having a parabolic mirror 2 m in diameter with a special supersonic flow generator (a gas and air reaction engine).

The installation is described in /1/. The special feature of the combustion chamber's design (d_{kp} = 12 mm) is primarily that its transverse dimension has been reduced to the least possible width (the middle section's diameter is 55 mm) for a length of 600 mm. This made it possible to reduce the thermal stress on the chamber and avoid shading of the radiant energy from the parabolic mirror when the

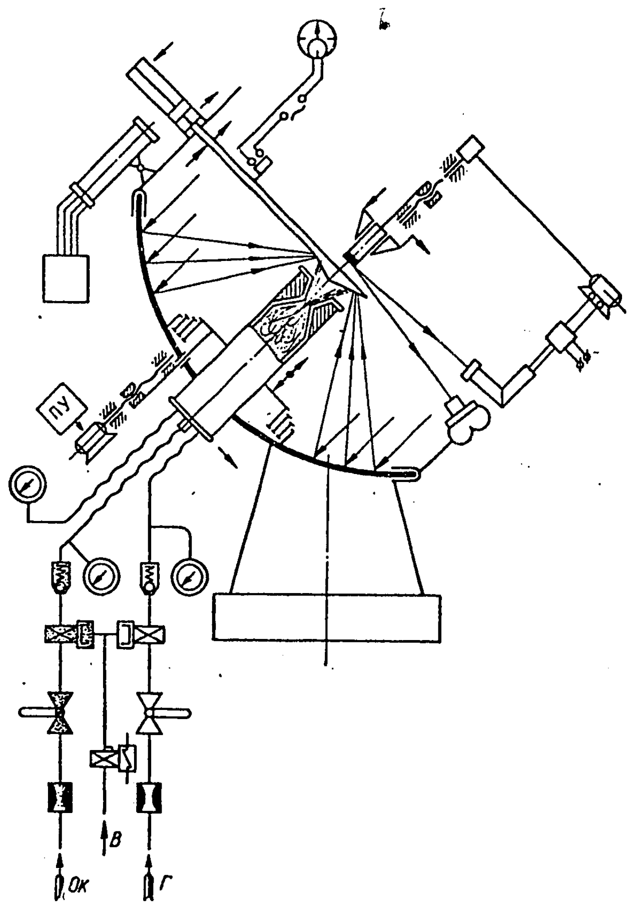

Figure 1. Schematic diagram of installation for investigating heat-shielding materials acted upon by the combined effect of radiant and convective heat flows.

distance from the nozzle's mouth to the focal plane is up to 130 mm. Since the radiant energy concentrator follows the Sun, the fuel and measuring lines are connected to the chamber by flexible hoses.

The radiant heat flows are controlled by a regulator placed at the apex of the paraboloid, movement of the elements of which screens the appropriate part of the radiation striking the test piece. The regulator consists of four telescoping cylinders with annular, dual action supports that realize reciprocal engagement of the cylinders. The regulator is connected to the programming unit of the system for the automatic reproduction of given heating curves.

The convective heat flows, as well as the velocity of the incoming gas jet, are regulated both by changing the consumption rates of the fuel components with the appropriate throttles and by changing the distance of the combustion chamber nozzle's mouth from the piece being tested.

A test piece of the material being investigated is placed in a conical, water-cooled holder and covered by a cooled shutter that actuates heating of the test piece when the installation is operating in transient modes. The parabolic mirror is placed in the operating position, the automatic Sun-tracking system is turned on, and the gas jet generator is started and brought into the working mode. When the protective shutter is removed, the programming unit and an electric timer, which records the test piece testing time, are turned on automatically.

For the purpose of preventing a change in the radiant flow and the parameters of the incoming medium on the surface being destroyed, the SGU-3 is equipped with an automatic test piece feed system that compensates for the wear on it.

The SGU-3 installation's basic parameters are as follows: D = 2,000 mm, d = 12 mm (diameter of the focal image), q_{rad} = 0-1,500 W/cm^2, q_{con} = 420 W/cm^2, $P_{kc} = 5 \cdot 10^5$ Pa, V_∞ = 1,300 m/s, T_a = 1,500 K.

If we consider only the radiant flow, in our case we can describe the transfer of radiant energy on the basis of a diffusion approximation. The condition for the applicability of the diffusion approximation is smallness of the radiation density gradient /2/, which must not change much at distances on the order of the radiation's path (ℓ_R). As a matter of fact, when materials are being irradiated with the Sun's radiant energy, it is possible to eliminate the mirror reflection from the concentrator and consider the entire layer of the atmosphere as an optically thick layer with a small density gradient at the Sun's effective temperature. In the general case, the energy parameters at each point of the focal spot of solar power engineering units depend on the point's distance from the Sun.

In an infinite medium with a constant temperature, in a steady state the radiation is in thermodynamic equilibrium. Its intensity does not depend on direction and is determined by Planck's formula. At the same time, the condition for the existence of local equilibrium -- smallness of the gradients in an extended, optical thick medium -- serves as justification of the diffusion approximation when discussing radiation transfer.

Starting from (Rosseland's) concept of the average value of the length of the radiation's path, the flow of radiant energy can be represented in the form /2-4/

$$q_r = -\lambda' \frac{\partial T}{\partial x}.$$

In this case the radiation transfer is of the thermal conduction type, or radiant thermal conduction. In connection with this, the coefficient of thermal conductivity (the expression before the temperature gradient $\lambda' = (c\ell_R/3)(d(\sigma T^4)/dT)$, or $\lambda' = 16\sigma\ell_R T^3/3$) depends on the temperature.

The diffusion approximation, which in some cases results in significant errors, nevertheless does not distort the qualitative picture of the radiation transfer phenomena, even when the angular distribution is strongly anisotropic. This also enables us to use it to solve the radiation transfer problem when it is essentially not in equilibrium. We are dealing with a radiation field and an abrupt jump in temperature on the test piece's surface, which is divided into strongly heated and cold sections.

In the high-temperature (T_c) area, the radiation density is high -- on the order of the equilibrium density $U_p = 4\sigma T_c^4/c$. In the low-temperature area quanta are not given off, for all practical purposes, and the radiation density in it is determined by the flow emanating from the heated area's surface and is much greater than the equilibrium density $U_{pw} = 4\sigma T_w^4/c$, since $T_c \gg T_w$ (the x-axis is directed along the beam of light).

Despite the fact that this case is far from local equilibrium, the diffusion approximation leads to a qualitatively correct result, which is that if the cold medium (the test piece) absorbs light, the radiation density and flow are reduced as the distance from the heated surface into the depths of the cold medium increases. In connection with this, the scale of the distance for a noticeable reduction in these values is the free run for the absorption of quanta in the cold medium. The diffusion equations in the cold medium give the solution for the radiation density and flow:

$$S_\nu = \frac{cU_\nu}{\sqrt{3}} \sim e^{-\sqrt{3}\tau_\nu}$$

(where $\tau_\nu = \int^x k_\nu dx$ is the optical thickness of the layer), which correctly reflects the reduction in these values [2].

Even in such an extremely "nondiffusion" layer, where there is maximally expressed anisotropy of the quanta's angular distribution and all the quanta are moving in one direction in the cold medium (the test piece), it turns out that the flow is proportional to the density gradient $S_\nu = -\ell_e c(dU_\nu/dx)$ with a proportionality factor that is triple that of the usual diffusion factor. For the case of pure absorption of a parallel beam of light in a nonradiating medium, there is the exact solution $S_\nu = cU_\nu \sim e^{-\tau_\nu}$, which differs from the solution in the diffusion approximation only by the numerical factor $\sqrt{3}$ in the exponent's coefficient.

In our case, the radiating medium borders on a solid and the boundary condition is given in terms of the temperature at the wall ($T = T_w$). The heat flow through the boundary is considered to be the sum of the radiation flow and the molecular heat flow [3].

On the radiation flow we superimpose the molecular flow, which in our case is created by the gas jet generator (Figure 1). The gasoline combustion products in the air flow around the test piece, which is 10 mm in diameter and is situated in the solar installation's focal plane. Since the test piece is placed at a distance of 130 mm from the nozzle mouth in order to reduce shading, the flow's parameters are reduced considerably because of the injection of surrounding air. For calculating the compression zone above the surface, the Mach number is assumed to be M = 1.2.

The compressed layer's thickness can be evaluated with the help of the following formula [5]: $\delta/R = 0.66 / 1 - \varepsilon$, where $\varepsilon = (k - 1)/(k + 1) + 2/((k + 1)M^2)$ = the adiabatic curve's coefficient. For our case, this estimate gives a value for the layer's thickness on the order of δ = 20 mm.

According to the results of the calculation of the combustion product (CO_2, H_2O, CO, OH and other) absorption coefficient, with due consideration for the partial pressures and the gaseous products of decomposition of the material (C_3, CN, SiO

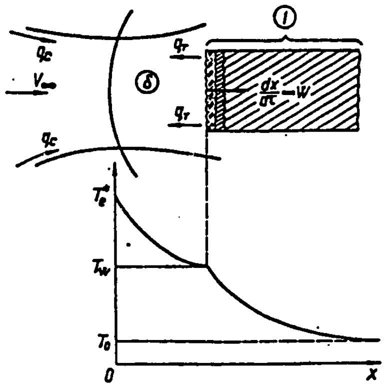

Figure 2. Model of interaction during radiant and convective heating of heat-shielding material, allowing for the moving transformation boundary.

vapor, Si and so on), an estimate of the length of the radiation's free run ℓ_R was made in accordance with /6,7/ for an effective Sun temperature T_C = 6,000 K. These estimates yield values on the order of $\ell_R \approx 0.1$ mm. In this case, the optical thickness of the layer, as evaluated by the formula $\tau_\nu = \int_0^\delta k_\nu dx$, is optically thick.

To this we should add that this optically thick compressed layer, together with the shock wave, is irradiated by an external radiation flow of solar radiation. As is well known, transillumination of a layer of gas increases that layer's effective optical thickness.

Considering that the shock wave is not very intense, the transfer of radiant energy inside the compressed layer because of the molecular flow's kinetic energy can be ignored.

It is fully obvious that, starting from the assumptions and calculations that have been presented, the radiant energy transfer can be represented by the expression

$$q_r = -\lambda' \left(\frac{\partial T}{\partial x}\right)_\delta .$$

The final model of the interaction, allowing for the moving physicochemical transformation boundary inside the material, has the form depicted in Figure 2.

In Figure 2, T_e^* = temperature at the outer boundary of the compressed layer (δ), which equals the Sun's effective tempera[illegible]; T_w = temperature on the material's surface; $T_{0,c}$ = temperature at an infinite distance into the material.

The indices δ and 1 correspond to the compressed layer and the material, respectively.

We assume a linear rate of motion of the surface being destroyed (the wear rate) that is equal to rate of motion of the physicochemical transformation (coking, melting and evaporation) boundary; that is,

$$\frac{dx}{d\tau} = w.$$

I. The initial conditions are:

$$\left.\begin{aligned} \tau = 0,\ x = 0,\ T_\delta = T_e^*, \\ \tau = 0,\ x = \infty,\ T_1 = T_0. \end{aligned}\right\} \quad (1)$$

II. The boundary conditions are:

$$\left.\begin{aligned} \tau > 0,\ x = \delta,\ T_\delta = T_1 = T_w, \\ \text{Stefan's condition:}\ q_w - q_1 = q_{\rho L} \end{aligned}\right\} \quad (2)$$

The flow of heat (q_w) to the surface being destroyed is the resultant of the convective flow from the incoming gas jet (q_δ), the radiation flow from the external radiation (q_c) and the radiation flow from the body's intrinsic radiation (q_t); that is, $q_w = q_\delta + q_c - q_t$.

The density of the flow of physicochemical transformations (q_{pt}) is a combination of the following endothermic processes: coking ($L_1\gamma_1$), melting and partial evaporation of the liquid film ($kL_1'\gamma_1'$); that is,

$$(\lambda_\delta' + \lambda_c' - \lambda_T')\left(\frac{\partial T}{\partial x}\right)_\delta - \lambda_1\left(\frac{\partial T}{\partial x}\right)_i - (kL_1'\gamma_1' + L_1\gamma_1)\frac{dx}{d\tau} = 0. \quad (4)$$

where L_1' and L_1 = latent heats of melting and coking, respectively; $k \geqslant 1$ = correction factor for evaporation of the melted surface. When k = 1, there is no evaporation.

This representation of the phase transitions' heats is the result of an effort to discover the essence of these processes. As is known, melting and evaporation take place on the surface of a material that has already undergone a transformation (coking), and its density (γ_1') and subsequent transformations (kL_1') differ substantially from the corresponding transformations for the material in its original state ($L_1\gamma_1$).

Since the thickness of the melted and coked zones in the process of the destruction of heat-shielding materials is, as a rule, insignificant, all the physicochemical transformations are removed to the corroding surface of the material.

Thus, at the gas-solid interface we have:

$$\underbrace{q_\delta + q_c - q_T}_{q_w} - q_1 = q_{pt} \quad (5)$$

where $q_\delta = -\lambda_\delta(\partial T/\partial x)_\delta$ = density of the molecular heat flow; $q_c = -\lambda_c'(\partial T/\ x)_\delta$ = density of the flow of radiation from the external source; $q_t = -\lambda_t'(\partial T/\partial x)_\delta$ = density of the radiation flow from the material's surface; $q_1 = -\lambda_1(\partial T/\partial x)_1$ = density of the flow absorbed by the material; $q_{pt} = (kL_1'\gamma_1' + L_1\gamma_1)(dx/d\tau)$ = specific flow of phase transformations. The balance equation can be written as

$$q_{pt} = (kL_1'\gamma_1' + L_1\gamma_1)\frac{dx}{d\tau}, \quad (6)$$

If we assume a partial solution of the Fourier equation in the form of a rectilinear dependence on the Gaussian error function -- that is, $T_i = C_i + D_i \cdot \mathrm{erf}(x/2\sqrt{a\tau})$ -- it is possible to write

$$\left.\begin{aligned} T_\delta &= C_\delta + D_\delta G(z), \\ T_1 &= C_1 + D_1 G(z), \end{aligned}\right\} \quad (7)$$

where C_i, D_i = arbitrary constants; $G(z) = \mathrm{erf}(x/2\sqrt{a\tau})$; $G(0) = 0$; $G(\infty) = 1$ = the Gaussian function. Let us determine the constants C_i and D_i from the initial and boundary conditions.

I. $\tau = 0,\ x = 0,\ T_\delta = C_\delta = T_e^*$,
$\tau = 0,\ x = \infty,\ T_1 = C_1 + D_1 = T_0$.

From which

$$C_\delta = T_e^*,\ C_1 = T_0 - D_1. \quad (8)$$

Substituting (8) into (7), we have

$$\left.\begin{array}{l} T_\delta = T_e^* + D_\delta G(z), \\ T_1 = T_0 - D_1[1 - G(z)]. \end{array}\right\} \quad (9)$$

II. $\tau > 0,\ x = \delta,\ T_\delta = T_1 = T_w,$

$$T_e^* + D_\delta G\left(\frac{\delta}{2\sqrt{a_\delta \tau}}\right) = T_0 - D_1\left[1 - G\left(\frac{\delta}{2\sqrt{a_1 \tau}}\right)\right] = T_w. \quad (10)$$

The last equation will be correct only on the condition that the numerator in the error function's argument is proportional to $\sqrt{\tau}$; that is,

$$\delta = m\sqrt{\tau}. \quad (11)$$

From (10) we then obtain

$$D_\delta = \frac{T_w - T_e^*}{G\left(\frac{m}{2\sqrt{a_\delta}}\right)},\ D_1 = \frac{T_0 - T_w}{1 - G\left(\frac{m}{2\sqrt{a_1}}\right)}. \quad (12)$$

Substituting the value of D_i, we obtain:

$$\left.\begin{array}{l} T_\delta = T_e^* - \dfrac{T_e^* - T_w}{G\left(\frac{m}{2\sqrt{a_\delta}}\right)} G\left(\dfrac{x}{2\sqrt{a_\delta \tau}}\right), \\ T_1 = T_0 + \dfrac{T_w - T_0}{1 - G\left(\frac{m}{2\sqrt{a_1}}\right)}\left[1 - G\left(\dfrac{x}{2\sqrt{a_1 \tau}}\right)\right]. \end{array}\right\} \quad (13)$$

Differentiating expression (11), we have

$$\frac{d\delta}{d\tau} = \frac{m}{2\sqrt{\tau}}. \quad (14)$$

On the basis of the assumptions that have been made, we assume conditionally that the rate of growth of the boundary layer's thickness equals the rate of movement of the physicochemical transformation boundary or the wear rate; that is,

$$\frac{dx}{d\tau} = \frac{d\delta}{d\tau} = w = \frac{m}{2\sqrt{\tau}}. \quad (15)$$

If we take the derivatives of the last expressions in (13), after making the appropriate transformations we obtain the equation in its final form:

$$(1 + \Delta K_r)\frac{\exp(-K_m^2)}{\operatorname{erf} K_m} - K_b K_d \frac{\exp(-K_m^2 K_a)}{\operatorname{erf} cK_m K_a^{1/2}} - \sqrt{\pi} K_f K_m = 0, \quad (16)$$

Where $\Delta K_r = K_c - K_t$, $K_c = \lambda_c'/\lambda_\delta$, $K_t = \lambda_t'/\lambda_\delta$ = radiation criteria = ratio of photon to molecular thermal conductivity; $K_d = (T_w - T_0)/(T_e^* - T_w)$ = temperature criterion = ratio of the heat differential in the body to the heat differential in the compressed layer of the medium; $K_b = \sqrt{(\lambda c\gamma)_1/(\lambda c\gamma)_\delta} = b_1/b_\delta$ = heat penetration criterion; $K_a = a_\delta/a_1$ = temperature conductivity criterion; $K_f = (kL_1\gamma_1 + L_1\gamma_1)/((c\gamma)_\delta(T_e^* - T_w))$ = phase transition criterion = ratio of heat absorbed during the physicochemical transformations of the material to the molecular heat flow through the boundary layer; $K_m = m/2\sqrt{a_\delta}$ = criterion for the rate of movement of the physicochemical transformation boundary or the wear rate.

The derived equation (16) reflects the qualitative picture of the interrelationship of the properties of the medium and the material and the physicochemical transformation boundary's rate of movement. Here the flexible, synthetic relationship between the theoretical and experimental data is expressed quite clearly. Its solution requires the use of data on the high-temperature properties of materials (available in the literature) and the results of experimental investigations of thermophysical properties, mass wear rates, solid failure temperature and mechanism, the optical properties of the surfaces of solids and so on.

In order to make a qualitative analysis of the interdependences of external conditions and the properties of materials in a broader range of temperatures and pressures that are not achievable under the conditions of the experiment described here, the parameters indicated above were used as input data for the solution of the equation. It was only from these positions that we investigated the picture of the interrelationships of the properties of the medium and the material for various limiting cases, which -- in the final account -- makes it possible to expose the formulative and technological aspects of a directed effect on the course of the process of the high-temperature destruction of heat-shielding materials.

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SPACE APPLICATIONS

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REDUCING THE ERROR IN REMOTE MEASUREMENTS OF THE OCEAN'S PHYSICAL FIELDS

Kiev KOSMICHESKIYE ISSLEDOVANIYA NA UKRAINE in Russian No 14, 1980 (signed to press 4 Sep 80) pp 80-89

/Article by S.V. Dotsenko and M.G. Poplavskaya, Sevastopol', manuscript received 2 Aug 79/

/Text/ One of the most promising and rapidly developing areas in the study of the ocean is the remote, noncontact measurement of its physical fields. The use of remote sounding equipment, which senses electromagnetic waves in the band from ultraviolet to microwave radiation, makes it possible to investigate the ocean from airplanes and directly from space /1-4/. This explains the huge interest in remote methods of studying the ocean and the great progress that has been made in recent years in the development of remote sounding equipment and methods of interpreting the data obtained with its help.

Despite the diversity of the engineering realization, all remote instruments contain a sensing section that consists of a sensor (an objective in the optical and infrared bands and an antenna in the microwave band) and a sensitive element that is connected to a signal amplification and processing unit. Real objectives and antennas have a radiation pattern of finite width. Therefore, the volume of the medium from which radiation is sensed by the instrument (the instrument's sensor's "resolving element") also has finite dimensions and gets larger as the instrument's sensor moves away from the volume. Although at close range (meters) the resolving element's value is comparable to that of traditional oceanographic equipment, when sounding from an airplane and (in particular) from space it takes on much greater values (up to tens of kilometers).

The instrument's output signal is the result of averaging of a measured field with respect to the resolving element and without regard for it with a weight assigned by the instrument's spread function, which in turn is a projection of the instrument's sensor's radiation pattern onto the sea's surface. Such averaging leads to suppression -- in comparison with the measured field -- in the instrument's output signal of the high-frequency components of the spectrum of the field's spatial irregularities and, consequently, to the appearance of an error in the measurement of the field's spatial structure /5/. This averaging is most tangible in passive microwave sounding of the ocean, where the width of the antenna's radiation pattern is quite large, while the methods for narrowing it that are realizable in active radar are not applicable here. Naturally, this error can be reduced by simply narrowing the width of the instrument's radiation pattern, but this requires a proportional increase in the antenna's dimensions, which cannot always be implemented technically. However, measurement error is determined not only by the size of the resolving element, but also by the form of the instrument's spread function both within the limits of this element and outside it. This was confirmed by calculations in /5-7/, where it was shown that for identical resolving element dimensions, a remote instrument's metrological characteristics depend on the form of its spread function. In connection with this there arises the problem of finding that form of an instrument's spread function for which the smallest measurement error is insured for a given value of its resolving element.

Below we give one of the possible methods for solving this problem and then demonstrate it on a particular example that is of considerable interest for practical purposes.

The mean square of the absolute error in measurement of a homogeneous, isotropic, "frozen" field by an instrument with a sensor having axial symmetry is determined by the expression /8/

$$\varepsilon^2 = 2\pi \int_0^\infty G_2(\alpha)\,[1 - \tilde{h}(\alpha)]^2\, \alpha d\alpha, \tag{1}$$

where α = wave number; $G_2(\alpha)$ = two-dimensional spatial energy spectrum of the field being measured; $\tilde{h}(\alpha)$ = spectrum of the instrument's spread function, which is related to the spread function h(r) itself by the (Gankel') transformation

$$h(r) = \frac{1}{2\pi} \int_0^\infty \tilde{h}(\alpha)\, J_0(\alpha r)\, \alpha d\alpha. \tag{2}$$

Here, $J_0(x)$ = Bessel's function. The spread function's characteristic radius

$$R_x = \int_0^\infty \frac{h(r)}{h(0)}\, dr,$$

which is the radius of the instrument's resolving element, can -- with due consideration for relationship (2) -- be defined as

$$R_x = \frac{\int_0^\infty \tilde{h}(\alpha)\, d\alpha}{\int_0^\infty \tilde{h}(\alpha)\, \alpha d\alpha}.$$

In order to solve the problem formulated above it is necessary to find the spread function that insures a minimum value for expression (1), providing that

$$R_x = \text{const}. \tag{3}$$

We will call this spread function optimal.

Finding this solution by the precise methods of calculus of variations is difficult. Therefore, let us show how to solve it directly with the help of the expansion of $\tilde{h}(\alpha)$ into a finite sum by the full (in an infinite interval) system of functions $\tilde{h}_n(\rho\alpha)$, which are the spectra of the partial spread functions:

$$\tilde{h}(\alpha) = \sum_{n=0}^{N} a_n \tilde{h}_n(\rho\alpha), \tag{4}$$

where ρ = some factor that is identical for all $\tilde{h}_n(\rho\alpha)$. Considering the fact that in this case $\tilde{h}(\alpha)$ is an even function of its own argument, as this system we will take the functions /9/

$$\tilde{h}_n(x) = \frac{1}{(2n)!!} e^{-\frac{x^2}{2}} x^{2n}. \tag{5}$$

In connection with this, the integrals for all the practically important forms of the spectrum of field $G_2(\alpha)$ and any numbers n of sum (4)'s components make sense.

The problem of finding the optimum function $\tilde{h}(\alpha)$ now reduces to determining that set of coefficients in expansion (4) that (keeping condition (3) in mind) insure a minimum error (1).

Let us find the relationship between the coefficients a_n that results from condition (3). Considering that /10/

$$\int_0^\infty e^{-\frac{x^2}{2}} x^{2n} dx = \sqrt{\frac{\pi}{2}} (2n-1)!!, \quad \int_0^\infty e^{-\frac{x^2}{2}} x^{2n+1} dx = (2n)!!,$$

and choosing $\rho = R_x$, we find that condition (3) reduces to the equation

$$\sum_{n=0}^{N} g_n a_n = 0, \tag{6}$$

where it is designated that

$$g_n = 1 - \sqrt{\frac{\pi}{2}} \frac{(2n-1)!!}{(2n)!!}.$$

Substituting sum (4) into formula (1), we find

$$\varepsilon_N^2 = \sigma^2 \left(1 - 2\sum_{n=0}^{N} a_n W_n + \sum_{m=0}^{N}\sum_{n=0}^{N} a_m a_n A_{mn}\right), \tag{7}$$

where σ^2 = dispersion of the field and it is designated that

$$A_{mn} = \frac{M_{m+n}(1)}{(2m)!!\,(2n)!!}, \quad W_n = \frac{2M_n(\sqrt{2})}{n!} \tag{8}$$

and, in turn,

$$M_k(t) = \frac{2\pi}{\sigma^2 R_x^2} \int_0^\infty G_2\left(t\frac{x}{R_x}\right) e^{-x^2} x^{2k+1} dx. \tag{9}$$

Index N in the variable ε_N means that we are looking for a finite, optimum set of N + 1 coefficients a_n. From formulas (2), (4) and (5) we find that the optimum spread function has the form

$$h(r) = \sum_{n=0}^{N} a_n h_n(r), \tag{10}$$

it being the case that part of this expression is the partial spread functions

$$h_n(r)=\frac{1}{2\pi R_x^2}\exp\left(-\frac{r^2}{2R_x^2}\right)L_n\left(\frac{r^2}{2R_x^2}\right),$$

where $L_n(z)$ are the Laguerre polynomials /10/

$$L_n(z)=\sum_{k=0}^{n}\frac{(-1)^k}{k!}\binom{n}{k}z^k.$$

Function $M_k(t)$ in formula (9) is presented in terms of the field's two-dimensional spectrum $G_2(\alpha)$. In some cases that are important for practical applications, it is desirable to express it in terms of the field's spatial autocorrelation function B(r). Let us consider the fact that in a homogeneous, isotropic field /11/,

$$G_2(\alpha)=\frac{1}{2\pi}\int_0^\infty B(r)J_0(\alpha r)\,r\,dr.$$

Substituting this relationship into formula (9), by changing the order of integration and using the integral value /12/

$$\int_0^\infty J_0\left(t\frac{r}{R_x}x\right)e^{-x^2}x^{2k+1}dx=\frac{k!}{2}\exp\left[-\frac{t^2}{4}\left(\frac{r}{R_x}\right)^2\right]L_k\left[\frac{t^2}{4}\left(\frac{r}{R_x}\right)^2\right],$$

we obtain the desired expression

$$M_k(t)=\frac{k!}{2\sigma^2R_x^2}\int_0^\infty B(r)\exp\left[-\frac{t^2}{4}\left(\frac{r}{R_x}\right)^2\right]L_k\left[\frac{t^2}{4}\left(\frac{r}{R_x}\right)^2\right]r\,dr. \quad (11)$$

The solution of the formulated problem reduces to determining the set of coefficients $a_0, a_1, \ldots, a_N$ that insures a minimum value of (7) providing that condition (6) is met. Let us write the latter in the form

$$a_N=-\frac{1}{g_N}\sum_{n=0}^{N-1}g_na_n. \quad (12)$$

Given condition (12), the minimum of the square of error (7) is achieved in the case when N equalities are satisfied:

$$\frac{\partial}{\partial a_k}\left(\frac{e_N}{\sigma}\right)^2=0 \text{ for } k=0,1,\ldots,N-1,$$

which, in developed form, have the form

$$\sum_{n=0}^{N-1}\left[\left(A_{nk}-\frac{g_k}{g_N}A_{nN}\right)-\left(A_{kN}-\frac{g_k}{g_N}A_{NN}\right)\frac{g_n}{g_N}\right]a_n=W_k-\frac{g_k}{g_N}W_N \quad (13)$$

$$\text{for } k=0,1,\ldots,N-1.$$

When differentiating expression (7) with respect to a_k, it was taken into consideration that, in accordance with equality (12), $\partial a_N/\partial a_k = -g_k/g_N$.

Let us simplify expression (7), which corresponds to a minimum measurement error. In order to do this, we multi[illegible] the k-th equation in system (13) by a_k and sum up the equalities thus found, with respect to k, from 0 to (N - 1). Combining the expression that is obtained with formula (7) yields

$$\left(\frac{\varepsilon_{N\,min}}{\sigma}\right)^2 = 1 - \sum_{n=0}^{N} W_n a_n, \tag{14}$$

where coefficients $a_0, \ldots, a_{N-1}$ are a solution of system (13), while a_N is determined by formula (12).

The coefficients a_k $(0 \leq k \leq N)$ obtained from system (13) solve the formulated problem for any finite number of partial spread functions. For $N \to \infty$, formula (10) can be used to find the limiting form of the instrument's optimum spread function (if it exists), while formula (14) yields the measurement error that corresponds to it. For large values of N, however, there is no need for this. As will be shown below, the value of N determines the number of lobes of the spread function. In practice, it is possible to create antenna radiation patterns (which means spread functions, also) with only a finite number of lobes. Therefore, finite values of N evoke the greatest interest.

Assuming that they are isotropic, the spatial correlation function of many physical fields of the ocean (in particular, fields of temperature, transparency and other irregularities) can frequently be approximated by the exponential curve /13,14,17/

$$B(r) = \sigma^2 e^{-\frac{r}{r_x}}, \tag{15}$$

where σ^2 = the field's dispersion, while r_x is its characteristic scale. The determination of the form of a remote instrument's optimum spread function during the measurement of such a field is a matter of great interest. Let us find the form of these spread functions for different numbers of lobes and evaluate the accuracy of the measurement of a field with instruments with sensors that are described by these functions.

Let us substitute correlation function (15) into formula (11). In connection with this, having made use of the value of the integral /12/

$$\int_0^\infty x^{\nu-1} e^{-\beta x^2 - \gamma x} dx = (2\beta)^{-\frac{\nu}{2}} \Gamma(\nu) \exp\left(\frac{\gamma^2}{8\beta}\right) D_{-\nu}\left(\frac{\gamma}{\sqrt{2\beta}}\right),$$

where $\Gamma(\nu)$ = a gamma-function and $D_p(z)$ = function of a parabolic cylinder, we can write

$$M_k(t) = \frac{k!}{t^2} \exp\left(\frac{z^2}{2t^2}\right) \sum_{m=0}^{k} (-1)^m (2m+1)!! \binom{k}{m} D_{-2(m+1)}\left(\frac{\sqrt{2}\,z}{t}\right). \tag{16}$$

Consequently, in the case under discussion, functions $M_k(t)$ are expressed in terms of parabolic cylinder functions with integral, even, negative indices. According to /12/ we have

$$D_0(z) = e^{-\frac{z^2}{4}}, \quad D_{-1}(z) = \sqrt{\frac{\pi}{2}}\, e^{\frac{z^2}{4}} \left[1 - \Phi\left(\frac{z}{\sqrt{2}}\right)\right], \tag{17}$$

where $\Phi(x)$ = the probability integral. The values of functions $D_{-2(m+1)}(z)$ with the necessary indices can be derived from (17) with the help of the recurrence formula /12/

$$D_{-(n+2)}(z) = \frac{1}{n+1}\,[D_{-n}(z) - zD_{-(n+1)}(z)].$$

Combining expression (16) and (8), we find that for the field under discussion, coefficients (8) have the form

$$A_{mn} = 2^{-(m+n)}\binom{m+n}{m}\exp\left(\frac{z^2}{2}\right)\sum_{k=0}^{m+n}(-1)^k(2k+1)!!\binom{m+n}{k}D_{-2(k+1)}(\sqrt{2}z) \quad (18)$$

and

$$W_n = \exp\left(-\frac{z^2}{4}\right)\sum_{k=0}^{n}(-1)^k(2k+1)!!\binom{n}{k}D_{-2(k+1)}(z). \quad (19)$$

As a standard for the comparison of optimum spread functions for different values of N, let us take a spread function with a bell-shaped form:

$$h(r) = \frac{a_0}{4R_x^2}\exp\left(-\frac{\pi r^2}{4R_x^2}\right), \quad (20)$$

the characteristic radius of the resolving elments of which is R_x. Let us mention here that questions on the remote measurement of physical fields with instruments having such spread functions are also of independent interest, since they approximate the radiation patterns of infrared and optical radiation receivers /15,16/. The spectrum of spread function (20) also has a bell-shaped form:

$$\tilde{h}(\alpha) = a_0\exp\left[-\frac{(R_x\alpha)^2}{\pi}\right]. \quad (21)$$

The mean square of the error in measurement of an isotropic field having a two-dimensional spectrum $G_2(\alpha)$ by a remote instrument with an arbitrary spread function h(r) is given by formula (1). The field's two-dimensional spectrum, corresponding to correlation function (15), has the form

$$G_2(\alpha) = \frac{\sigma^2 r_x^2}{2\pi}\,[1 + (\alpha r_x)^2]^{-3/2}. \quad (22)$$

Substituting expressions (22) and (21) into formula (1) and using the values of the tabular integrals /12/, we find that the value of the mean square of the error ε_0^2 that corresponds to the bell-shaped spread function can be determined with the formula

$$\left(\frac{\varepsilon_0}{\sigma}\right)^2 = 1 - 2a_0P_1 + a_0^2P_2, \quad (23)$$

where

$$P_1 = 1 - ze^{\frac{z^2}{\pi}}\left[1 - \Phi\left(\frac{z}{\sqrt{\pi}}\right)\right],$$

$$P_2 = 1 - \sqrt{2}\,ze^{\frac{2z^2}{\pi}}\left[1 - \Phi\left(\sqrt{\frac{2}{\pi}}\,z\right)\right];$$

while the variable $z = R_x/r_x$ is the ratio of characteristic radius of the instrument's spread function to the field's characteristic scale. Error (23) reaches its minimum value at

$$a_0 = P_1/P_2, \tag{24}$$

it being the case that

$$\left(\frac{\varepsilon_{0\,min}}{\sigma}\right)^2 = 1 - \frac{P_1^2}{P_2}. \tag{25}$$

For $z \ll 1$ it is not difficult to show that

$$P_1 = 1 - z,\ P_2 = 1 - \sqrt{2}z,\ a_0 = 1 + (\sqrt{2} - 1)z = 1 + 0{,}414z$$

and the relative error's mean square

$$\left(\frac{\varepsilon_{0\,min}}{\sigma}\right)^2 = (2 - \sqrt{2})z = 0{,}5858z \tag{26}$$

increases proportionally to the value of z.

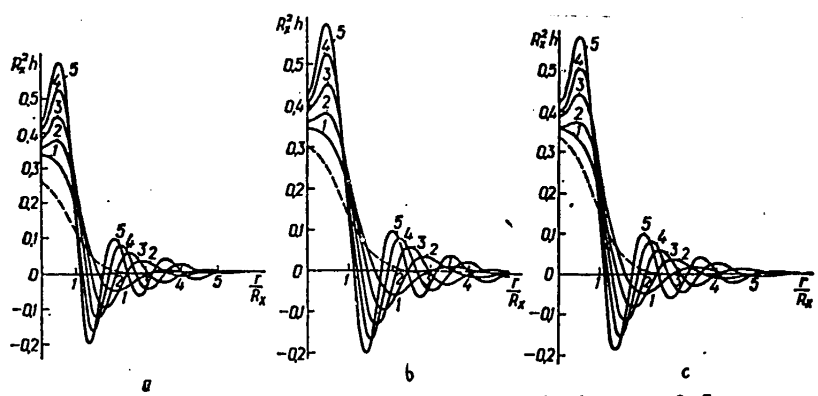

Figure 1. Optimum spread functions: a. z = 0.1; b. z = 0.5; c. z = 1.0; 1. N = 3; 2. N = 4; 3. N = 5; 4. N = 6; 5. N = 7; broken line = bell shaped spread function.

In Figure 1, the broken line represents spread functions (20) in which a_0 was determined by formula (24). The spectra corresponding to them are represented in Figure 2 (broken line). The dependence of coefficient a_0 on z, as found with formula 24, is represented in Figure 3a (broken line). The dependence of the value of $\varepsilon_{0min}^2/\sigma^2$ on z, as calculated by formula (25), is depicted by the broken line in Figure 4. It is close to linear for $z < 1$, which is confirmed by formula (26).

Let us obtain an analytical solution for the formulated problem for $z \ll 1$ and different values of N. Let us mention here that the case of a resolving element of small size in comparison with the field's characteristic scale is the one most often encountered in actual research.

Actually, for measurements from space the resolving element's radius -- even for equipment operating in the superhigh-frequency range, which has the lowest resolution -- does not exceed R_x = 30-50 km, while for the infrared band the value is smaller yet. The characteristic scales of the spatial irregularities of hydrological fields, which are of interest when studying synoptic phenomena in the ocean

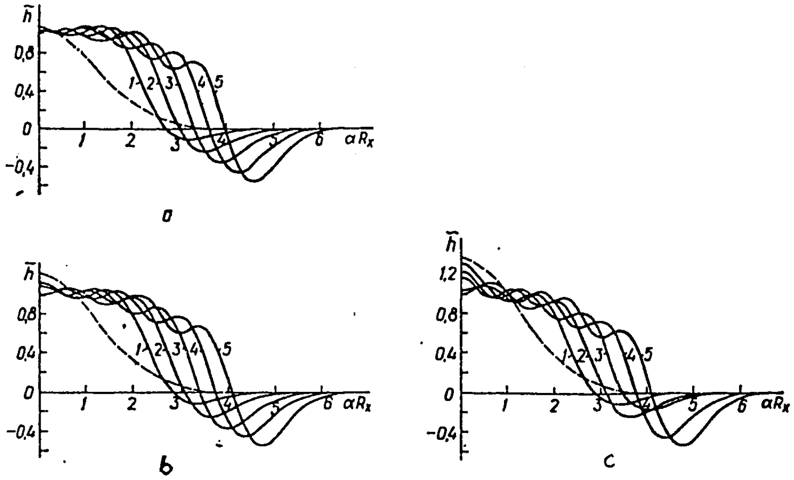

Figure 2. Spectra of optimum spread functions: a. z = 0; b. z = 0.5; c. z = 1.0; 1. N = 3; 2. N - 4; 3. N = 5; 4. N = 6; 5. N = 7; broken line = = spectrum of bell-shaped function.

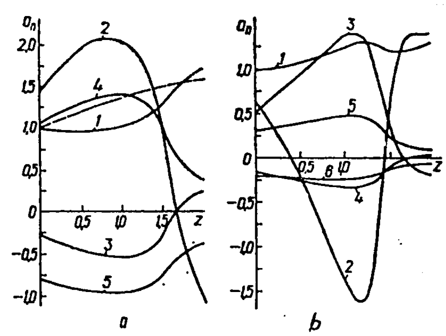

Figure 3. Coefficients for partial spread functions of an optimum spread function: a. N = 4; 1. a_0; 2. a_1; 3. $10^{-1}a_2$; 4. $10^{-1}a_3$; 5. $10^{-1}a_4$; broken line = a_0 for bell-shaped spread function; b. N = 5; 1. a_0; 2. a_1; 3. $10^{-1}a_2$; 4. $10^{-2}a_3$; 5. $10^{-2}a_4$; 6. $10^{-2}a_5$.

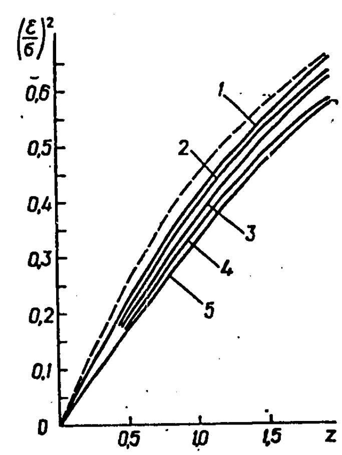

Figure 4. Mean square of field measurement error: 1. N = 3; 2. N = 4; 3. N = = 5; 4. N = 6; 5. N = 7; broken line = = bell-shaped spread function.

(and it is exactly these phenomena that it is most feasible to investigate from space), are hundreds of kilometers /13,17,18/. According to /13/, for instance, the characteristic scale r_x of the temperature field is 130 km, while for the most important hydrological fields in the Atlantic Ocean, such as the temperature and salinity fields, it is on the order of 2`f km /17,18/. Consequently, when studying the ocean from space, the most typical values are $z < 0.3$. Therefore, our further discussion will be confined to solutions for $z < 1$.

Let us first find the values of variables A_{mn} and W_n for small values of z. Ignoring the powers of z above one in the expansion of the parabolic functions into power series /12/, we obtain

$$D_{-2(k+1)}(z)=\frac{1}{(2k+1)!!}-\sqrt{\frac{\pi}{2}}\cdot\frac{z}{(2k)!!}.$$

Substituting these values into formula (18) and (19), we find that

$$A_{00}=1-\sqrt{\pi}\,z,\quad W_0=1-\sqrt{\frac{\pi}{2}}\,z,$$

$$A_{mn}=\sqrt{\pi}\,B_{mn}z\quad(m\neq 0 \text{ or } n\neq 0),$$

$$W_n=\sqrt{\frac{\pi}{2}}\,E_n z\quad(n\neq 0),$$

where it is designated that

$$E_n=-\sum_{k=0}^{n}(-1)^k\frac{(2k+1)!!}{(2k)!!}\binom{n}{k},$$

$$B_{mn}=2^{-(m+n)}\binom{m+n}{n}E_{m+n}.$$

Let us now turn to the approximate analytical determination of the optimum spread functions for different values of N.

1. For N = 1, system of equations (13) reduces to a single equation, the solution of which yields

$$a_0=1+0{,}2920z. \qquad (27)$$

Application of the expressions presented above shows that in the case under discussion the square of the relative error is determined by the formula $(\varepsilon_{1min}/\sigma)^2 = 0.5361z$ and it also increases proportionally to the value of z, although the proportionality factor is less than in formula (26).

Let us call the variable $\mu_N = \varepsilon_0^2/\varepsilon_N^2$ the gain in accuracy during the measurement of a field by an instrument with an optimum spread function for a given N is comparison with its measurement by an instrument with a bell-shaped spread function. In the case under discussion, where N = 1, this gain has the value μ_1 = 1.0927. It exceeds unity and does not depend on z. From this it follows that for small values of z, the transition from a bell-shaped spread function to an optimum one gives a gain in accuracy of 9.27 percent when N = 1.

In accordance with formulas (12) and (27), coefficient a_1 is given by the expression a_1 = 0.6785 + 0.1981z and has a value comparable to that of a_0.

2. For N = 1, system (13) consists of two equations. Its solution is

$$a_0=1-0{,}1093z,\quad a_1=1{,}5520+0{,}6966z.$$

In accordance with formula (12), a_2 = -(0.6153 + 0.5429z). Substituting the values we have found into formula (14), we obtain $(\varepsilon_{2min}/\sigma)^2$ = 0.4864z; that is, in this case the square of the relative measurement error also increases as z does. The gain in accuracy is μ_2 = 1.2043 or 11.2 percent, which exceeds the value of the gain for N = 1.

3. For N = 3, system (13) consists of three equations, the solution of which is

$$a_0=1+0{,}1004z,\quad a_1=0{,}6441-1{,}1148z,$$

$$a_2=3{,}4095+2{,}6045z,\quad a_3=-(2{,}9493+1{,}5431z).$$

Substitution of the obtained values into formula (12) yields $(\varepsilon_{3min}/\sigma)^2 = 0.4462z$; that is, the mean square of the error is also proportional to the value of z. The gain in accuracy here is $\mu_3 = 1.3129$, which is even greater than for N = 2.

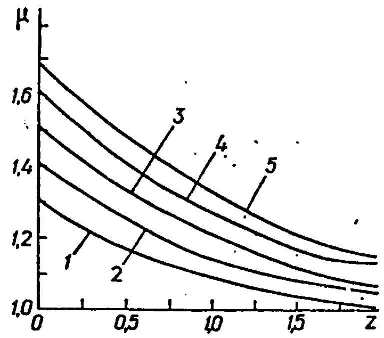

Figure 5. Gain in accuracy: 1. N = = 3; 2. N = 4; 3. N = 5; 4. N = 6; 5. N = 7.

In order to solve the formulated problem for any values of z, a program for computing the unknown values on a computer has been written. The results of the calculations are presented in Figures 1-5. From an analysis of them it follows that as N increases, the following changes ensue:

A. The spread functions, which on the whole decrease as the distance from the center increases, take on an oscillating nature. The number of their lobes is N. The main lobe acquires a dip at r = 0. The amplitude of the side lobes increases and they are constricted and shift toward the spread function's center. For $N \geqslant 7$, the first side lobe's level exceeds 30 percent of that of the main lobe.

B. The spectra of the optimum spread functions, having a single negative lobe, take on the ever more rectangular form of the main lobe.

C. The values of coefficients a_n depend essentially on N and z.

D. Measurement error decreases. Consequently, the presence of side lobes in the radiation patterns of instruments, which is typical of real antennas, is a factor that increases the accuracy of the measurement of two-dimensional physical fields. The suppression of these lobes, which is necessary for distinguishing point objects (such as in radioastronomy) and is a technically difficult problem, is undesirable when measuring distributed objects of investigation.

E. The gain in accuracy increases, particularly for small values of z. For an undifferentiated field with a correlation function of the type of (15), for $N \leqslant 7$ -- as is obvious from Figure 5 -- it does not exceed 1.7. However, calculations show that for smooth fields having high-order derivatives, it can be on the order of hundreds or thousands. Consequently, the smoother the field is, the farther from optimum an instrument's sensor's bell-shaped spread function is when it does not have side lobes.

In conclusion, let us give a physical explanation of the increase in the accuracy of measurement of a field by an instrument with a spread function that has side lobes. In performing spatial averaging, a remote instrument realizes low-frequency filtration of the field (its integration). Lobes with different polarities perform an operation that is close to spatial differentiation; that is, high-frequency filtration. For a given R_x, the optimum relationship between these two effects leads to the forms of equipment spread functions that we have found.

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ANALYSIS OF REMOTE MEASUREMENTS OF THE TEMPERATURE OF THE PACIFIC OCEAN'S SURFACE FROM SPACE

Moscow ISSLEDOVANIYE ZEMLI IZ KOSMOSA in Russian No 2, Mar-Apr 81 (manuscript received 13 Aug 80) pp 45-56

/Article by M.S. Malkevich, V.A. Malkova and Z.P. Startseva, Institute of Oceanography imeni P.P. Shirshov, USSR Academy of Sciences, Moscow/

/Text/ The remote determination of the sea surface's temperature on the basis of measurements of the Earth's intrinsic radiation or radiant temperature in the infrared band was carried out on most of the satellites used to investigate the Earth's surface and atmosphere from space (see, for example, /1-3/). This problem was formulated on the physical assumption that in the atmosphere's transparency "windows" the terrestrial surface's intrinsic radiation undergoes a minor and easily allowed for transformation as it passes through the atmosphere and into space. Actually, as numerous experiments have shown, the intensity of the intrinsic radiation I of the terrestrial surface-atmosphere system, which is related to the temperature T_0 of the surface, is a rather complex functional of a series of physical parameters of the Earth's surface and the atmosphere. In addition to the known temperature T_0, which is -- generally speaking -- a function of the spatial coordinates x and y and time t, functional I_ν or the radiant temperature $T_r = B_\nu^{-1}(I_\nu)$ is determined by the investigated surface's radiating capacity δ_ν; the atmosphere's vertical temperature profile $T(\zeta)$; the atmosphere's transmission function P_ν, which, in turn, depends on the moisture content, the aerosol and cloudiness; the angle θ of the line of sight with the direction to the nadir; the altitude ζ in relative units of pressure. The relationship is

$$I_\nu(x,y,t;\theta)=\delta_\nu(x,y,t;\theta)B_\nu[T_0(x,y,t)]P_\nu(x,y,1,t;\theta)-$$
$$-\int_0^1 B_\nu[T(x,y,\zeta;t)]\frac{\partial P_\nu(x,y,\zeta,t;\theta)}{\partial\zeta}d\zeta-2(1-\delta_\nu)P_\nu(x,y,1,t;\theta)\times \quad (1)$$
$$\times\int_0^1 B_\nu[T(x,y,\zeta;t)]\frac{\partial P_\nu}{\partial\zeta}d\zeta,$$

where $B_\nu(T)$ = a Planck function.

Unmonitorable variations in the parameters in relationship (1) can cause substantial errors in the determination of T_0. Therefore, considerable importance has been attached to evaluations of the accuracy of remote methods, for which a comparison of

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the surface temperature $T_{0,r}$ obtained with satellites with the results of measurements of temperature T_0 by contact methods in the same regions, using ships and airplanes (see, for example, /4-7/), has been used. As could have been expected, this comparison led to contradictory evaluations of the accuracy of the determination of T_0 (the errors $\Delta T_0 = T_{0,r} - T_0$ had different signs and varied in magnitude from fractions of a degree to several degrees). These contradictions had the following general causes: a) a difference in the oceanic and atmospheric conditions under which the sets of $T_{0,r}$ and T_0 data used for the evaluations were gathered; b) a difference in the methods for converting from the ocean-atmosphere system's temperature T_r, as measured directly by satellites, to the water surface's temperature $T_{0,r}$; c) a difference in the spatial areas of the ocean and the time intervals for which the compared values of $T_{0,r}$ and T_0 were averaged. The detailed investigation of the role of each of these causes requires the making of a complex of simultaneous measurements of the atmospheric parameters that are critical for the transformation of the ocean's radiation, as well as of the radiant temperature (from satellites) and the vertical and horizontal distributions of the thermodynamic temperature in the surface layers of the ocean (with ships and other floating facilities) that generate the radiation measured by satellites.

In order to formulate the specific requirements for this complex of measurements, it is necessary to analyze the most substantial errors in the remote methods that are now being used by satellites to obtain the mass information about the ocean's temperature fields that is utilized in operational practice. Let us mention that, starting with relationship (1), even in the earliest works /8-14/, the authors pointed out the factors of the terrestrial surface-atmosphere system that had to be taken into consideration in order to make a sufficiently accurate and reliable determination of the underlying surface's temperature or other parameter's in the system. However, obtaining substantiated evaluations of each of these factors was difficult, in view of the absence of a complex of simultaneous measurements of the needed parameters. Such evaluations were recently made in /6/ on the basis of an extremely careful analysis of sea surface temperature fields obtained by NOAA /National Oceanic and Atmospheric Administration/ satellites for the tropical zone of the Pacific Ocean. In view of the great methodical significance of the results in /6/, which confirm both previously derived (see, for example, /1,4/) evaluations of the accuracy and reliability of the remote determination of the ocean surface's temperature and the requirements for the information complex that should insure the solution of this problem in planned space experiments, it is advisable to give a brief formulation of the problem and the basic results reached in /6/. A comparison of these conclusions with the results of preceding works /1,4/, as well as with the results of the determination of $T_{0,r}$ from measurement materials obtained by a geostationary Japanese satellite (which are the basis of this article), will make it possible to clarify the physical causes of the differences in the evaluations of errors ΔT_0 that were mentioned above.

Basic Results of Work /6/. The authors of /6/ investigated the acceptability of space data on the temperature of the tropical region of the Pacific Ocean for climatological problems. For this purpose they used the daily maps of $T_{0,r}$ isotherms that are produced in the United States as part of the standard program for the global, operational calculation of the sea surface's temperature (GOSSTCOMP), which have a temperature interval of 1°C. These data, which were averaged for latitudinal intervals of 2° along two meridional profiles (150° and 158° W.Long.), were compared with the results of contact measurements of T_0 that were obtained with the help of

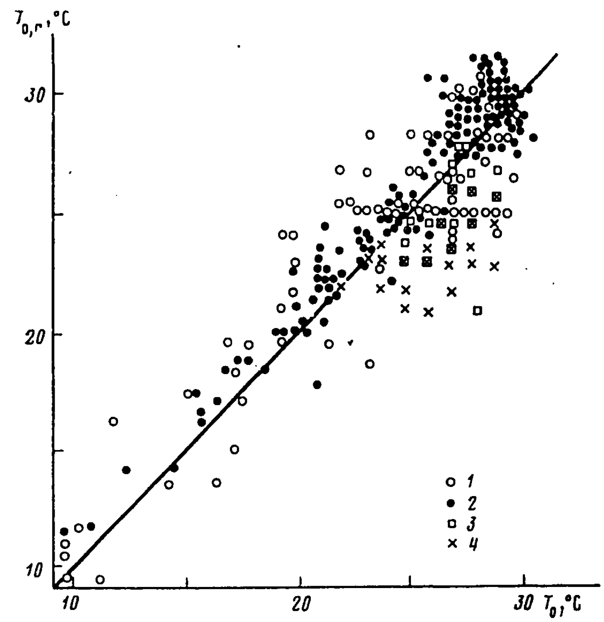

Figure 1. Regression between ocean temperature obtained by contact and remote methods, according to materials from: 1. /4/; 2. /15/; 3. /6/; 4. /7/.

an AXBT airborne, droppable bathythermograph along tracks 3,400 km long between 20° N.Lat. and 17° S.Lat., with a latitudinal spacing of 1° (except for the section between 14° N.Lat and 7° S.Lat., where the spacing was 0.5°). The error in the measurements of the values of T_0 corresponding to a depth of 20 cm was 0.2°C, while the error in the correlation to the horizontal coordinates was ±4 km. The AXBT data showed that the T_0 varies only slightly both temporally and spatially: for the averaging areas, the variations over the course of a week are 0.1°C, while the daily changes in T_0 in the surface layer of water (down to 5 m) are of the same order (0.1-0.3°C) but reach 0.4°C in rare instances. In other words, when compared with the AXBT's measurement error, the spatiotemporal variations in T_0 insure the reliability of the comparison of the local and practically instantaneous measurements of T_0 with the averaged values of $T_{0,r}$ and cannot be responsible for the differences between T_0 and $T_{0,r}$ that go beyond the limits of the indicated errors.

In /6/, measurements of T_0 were also compared with average monthly $T_{0,r}$ data obtained by the improved "Advanced" method for the same region of the Pacific Ocean (areal averaging was 1°). The regression between T_0 and $T_{0,r}$ presented in Figure 1 shows that the values of $T_{0,r}$ are systematically reduced in comparison with those of T_0; that is, T_0 is always negative and T_0 varies within limits of 1-4°C, reaching 7°C. Analogous results were obtained in /7/ for a comparison of ship measurements of T_0 and $T_{0,r}$ made in the tropical zone of the Atlantic Ocean (12-20° N.Lat, 0-60° W.Long.) on the basis of radiation measurements in the atmosphere's transparency windows close to 3.7 and 11 m from the "Nimbus-5" satellite for the periods 18-31 July and 23-30 August 1973. The average value of $|\Delta T_0|$ is ~3°C, with the maximum difference reaching 6°C (see Figure 1).

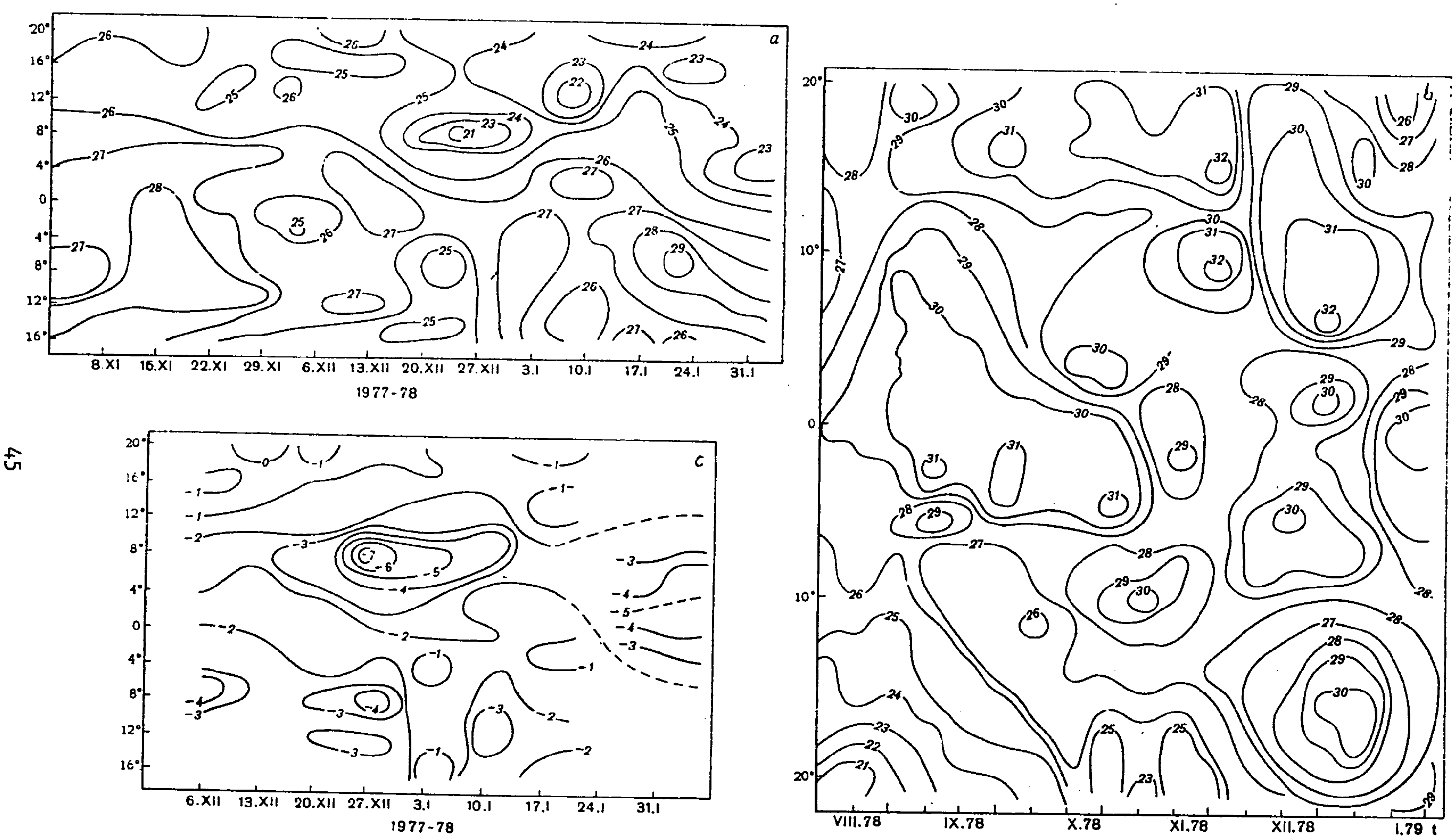

Figure 2. Spatiotemporal structure of T_0 fields, obtained: a. with NOAA satellite /6/; b. on the basis of materials gathered by Japanese geostationary satellite; c. spatiotemporal structure of ΔT_0 anomalies relative to average climatic values of T_0 /6/.

An analysis of the results of the comparison of T_0 and $T_{0,r}$ enabled the authors of /6/ to obtain a series of important conclusions about the relationship of the spatiotemporal structure of the T_0 and $T_{0,r}$ fields, as well as the connection between the difference $\Delta T_0 = T_{0,r} - T_0$ and atmospheric factors:

in contrast to the T_0 fields, which vary only slightly with respect to time and space, the $T_{0,r}$ and ΔT_0 fields have a substantially more complex spatiotemporal structure (Figure 2) that is related to the errors ΔT_0;

the systematic component $|\Delta T_0|$, averaged for the 3-month period of the airplane experiment, as well as the corresponding root-mean-square deviation, have a strict latitudinal relationship that reaches it maximums in the areas of 8° N.Lat. and 10° S.Lat (corresponding to the cloud cover and moisture content maximums) and a minimum in the area of the equator that is less cloudy;

a comparison of the latitudinal pattern of ΔT_0, moisture content w and degree of cloudiness n indicates a close relationship between errors in the remote determination of the sea surface's temperature and these parameters of the atmosphere, but the errors are not completely determined by them (the correlation coefficients of ΔT_0 with w and n are 0.63 and 0.53, respectively);

an increase in the averaging interval (1 month) does not change the latitudinal pattern and the value of the systematic component ΔT_0; that is, the number of observations taken into consideration in the averaging cannot explain the indicated difference between T_0 and $T_{0,r}$, although the root-mean-square variation of ΔT_0 is diminished by half.

On the basis of the analysis they performed, the authors of /6/ reached the conclusion that the methods they were discussing for the remote determination of T_0 from satellites are not very useful when studying the structure of the temperature field in the tropical region of the Pacific Ocean. Moreover, the authors of /6/ pointed out that the latitudinal and longitudinal pattern of variations in $T_{0,r}$ that was caused by atmospheric factors could be mistakenly interpreted as features of actual oceanic phenomena.

In order to obtain acceptable data on the ocean's temperature, it is necessary to have more refined methods of allowing for cloud cover and moisture content that make it possible to eliminate the systematic errors related to these factors. The random error, averaged for a month, can then be reduced to 0.5°C, which is fully suitable for climatic investigations. The authors of /6/ are completely correct in pointing out the necessity of using prior information on the atmospheric factors for this purpose, although they do not specify the form of this information and the technique used to allow for it.

In connection with the results published in /6/, let us mention that it was suggested long ago that prior information, in the form of the statistical characteristics of the vertical structure of the atmosphere's temperature and moisture content be used in the solution of the corresponding inverse problems of the remote sounding of a cloudless atmosphere by the method of statistical regularization, as well as for determining the underlying surface's temperature (see, for example, /1/). It is necessary to use similar information about the spatial structure of the cloud cover's characteristics and aerosol attenuation for the remote determination of the ocean's temperature, averaged for temporal intervals on the order of a week or a month. However, investigators have still not reached a consistent opinion on the need for such information, to say nothing of its composition. Below we will give the substantiation for and a description of that complex of initial information that will insure sufficiently high accuracy and reliability for the remote method of determining the ocean surface's temperature. The results of an analysis of the materials for determining $T_{0,r}$ that were obtained with the Japanese geostationary satellite serve as convincing proof of the necessity for a physical approach to the solution of this problem.

Analysis of Temperature Fields on the Basis of Materials From the Geostationary Satellite. The Japanese geostationary satellite provides for obtaining sea surface temperature fields on the basis of measurements of the ocean-atmosphere system's radiation in the 10.5-12.5 μm spectral band, with spatial resolution of 8 km, with the help of a VISSR scanning radiometer (the instrument also has a channel for measuring the Earth's brightness in the 0.55-0.75 μm spectral band, with spatial resolution of 1 km). The measurements are made in the Pacific Ocean area bounded by 50° N.Lat., 50° S.Lat., 90° E.Long and 170° W.Long. The surface temperatures $T_{0,r}$, as presented in the monthly reports from the Japanese Meteorological Satellite Center (see, for example, /15/), are obtained in the following fashion. For each area in the indicated region with dimensions of 1° of latitude and longitude, histograms of the radiant temperature T_r, as measured from the satellite in the 10.5-12.5 μm "window," were constructed for the complete cycle of measurements for a day (a single cycle of measurements of the radiant temperature field for the entire field of view is 20 min). The value of T_r on the part of the histogram corresponding to radiant temperature values exceeding the mode by the value of the root-mean-square deviation were taken as the sea surface's temperature $T_{0,r}$ for this area /15/. The values of $T_{0,r}$ that were obtained in this manner were subjected to a quality inspection and then averaged for 10 days and presented in the form of 10-day tables of the sea surface's temperature with an accuracy of up to 0.1°C and a spacing of 1° in both latitude and longitude. An example of the map of the field of $T_{0,r}$ values for the first 10 days of March 1979 is presented in Figure 3 (the dotted lines indicate a lack of data, since it was cloudy in the corresponding regions and the value of $T_{0,r}$ was not determined).

This method of converting from measurements of T_r to the sea surface's temperature $T_{0,r}$ primitively allows for the factors (radiating capacity of the ocean, attenuation of its radiation by the atmosphere and the latter's intrinsic radiation) that, in accordance with the physical regularities of the generation and transfer of radiation in the ocean-atmosphere system for typical thermal stratification of the atmosphere, must always lead to the relationship $T_r < T_{0,r}$. However, the degree of accuracy and reliability of this method remains undetermined, since such an allowance for the physical factors means that a random value that is realized on the histogram with an arbitrary (but known to be small) probability is used for $T_{0,r}$. Consequently, $T_{0,r}$ values obtained in this manner can reflect random processes that do not actually determine the temperature of the section of the sea's surface being investigated. For this approach, the question of the temporal and spatial comparability of T_0 and $T_{0,r}$ is also of fundamental importance, since the experimental values of T_r that are used for $T_{0,r}$ can characterize those same low-probability random variations in the radiation of limited sections of the surface film of water that is 20-30 μm thick. This film can be either severly overheated or, on the contrary, supercooled in comparison with the layer of water beneath it or adjacent sections of the sea surface, the temperature T_0 of which is used for comparison with $T_{0,r}$. For these reasons, $T_{0,r}$ cannot always be the representative temperature characteristic of the 1° areas of the ocean's surface and the 10-day temporal averagings that are under discussion.

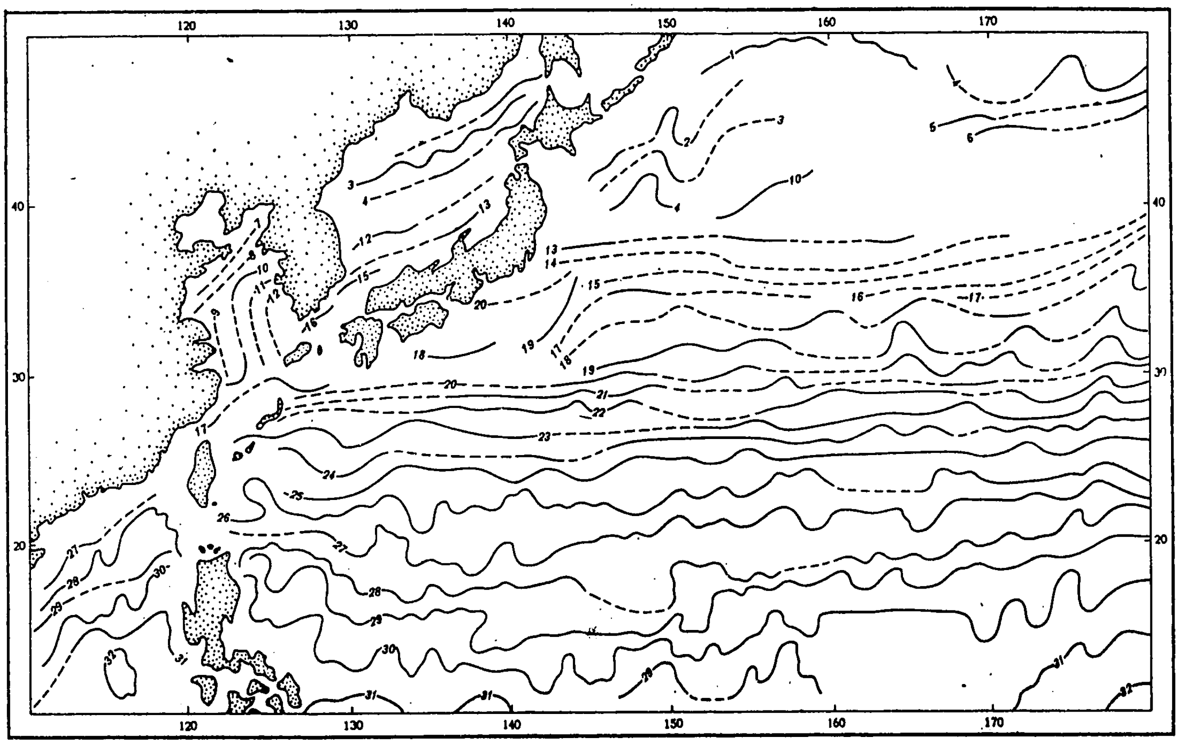

Figure 3. Example of map of $T_{0,r}$ temperature field for the first 10 days of March 1979, based on materials gathered by Japanese geostationary satellite /15/.

As is obvious from Figure 1, in which the regression between (in particular) $T_{0,r}$ according to /15/ and the standard contact measurements of T_0 is plotted, in contrast to the data in work /6/, the data from the Japanese geostationary satellite are systematically too high in comparison with T_0, it being the case that T_0 reaches a value of 5°C with a mean deviation from the bisector $\overline{\Delta T_0}$ = 1.5°C and a root-mean-square value of $[\overline{\Delta T_0^2}]^{1/2} \approx 1.5$°C. Considering the already mentioned spatiotemporal randomness of its realization, such errors in the determination of $T_{0,r}$ place in doubt the possibility of using the temperature fields that are obtained. For example, an analysis of these fields does not make it possible to detect known currents in the investigated region of the Pacific Ocean. As in the case of the American satellite measurements /6,7/, the $T_{0,r}$ fields that are obtained have a complex spatiotemporal structure in comparison with the T_0 fields (Figure 2) that does not reflect the ocean's real thermal structure. It is completely clear that these data are of as little use for oceanographic problems requiring higher ocean temperature determination accuracy and reliability as those discussed in /6,7/ on the basis of the materials gathered by the "Nimbus-5" and NOAA satellites. The basic cause of the large errors and the doubtfulness of the described materials is the lack of substantiation for the methods for converting from T_r to $T_{0,r}$, which do not allow for the rules for the generation and transfer of radiation under the real conditions of the multiparametric ocean-atmosphere system. For example, the method used in /7/ is based on the following assumptions: 1) for cloudless conditions, the radiant

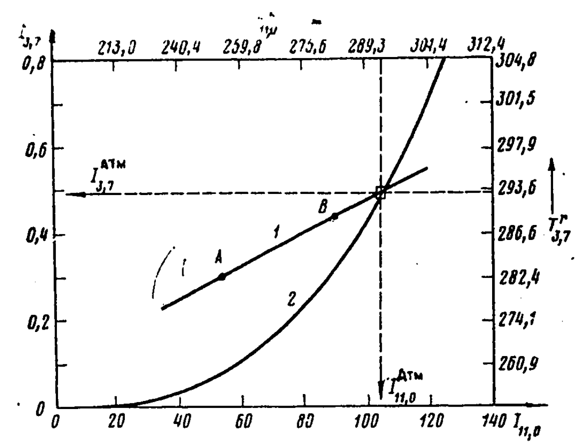

Figure 4. Illustration of conversion from T_r to $T_{0,r}$ by measuring radiation in two adjacent scanning elements with a different amount of clouds A and B in the 3.7 and 11 μm "windows": 1. observed values; 2. Planck function. The point of their intersection gives the radiation that would have been observed in the absence of clouds; temperature T_r, corresponding to this radiation, is the surface's temperature (in this case, 293.5 K).

temperature of the ocean-atmosphere system in the 3.7 μm transparency window is taken to be the temperature of the ocean's surface; 2) in the case of cloudiness, different percentages of which fall into the instrument's field of view, there exists the linear relationship

$$\overline{I_{3.7}^{clo} = c_1 I_{11}^{clo}} \qquad (2)$$

between the I^{clo} radiation values near 3.7 and 11 μm. Hypothesis (2) is based on the substantially different temperature relationship of the radiation in thermally homogeneous mediums in these "windows" ($I_{3.7} \sim T^{15}$; $I_{11} \sim T^5$). However, if the radiating medium is thermally heterogeneous (when the instrument's field of view is partially blocked by clouds, for example), then the measured radiant temperature in the 3.7 μm "window" is determined primarily by the emission's of the ocean's warm surface, while in the 11 μm "window" there is also a component contributed by the commensurate radiation from the clouds. This leads to some equalization of the radiation values in both "windows" and, possibly, to linear relationship (2) instead of the cubic parabola

$$\overline{I_{3.7} = c_2 I_{11}^{3}} \qquad (3)$$

in the case of thermally homogeneous objects. According to /7/, the contribution of cloudiness to the measured values of I^{clo} is eliminated by linear extrapolation of the measurements in two adjacent sections that are characterized by different amount of clouds, using relationship (2) until it intersects with curve (3). The radiant temperature corresponding to the point of intersection of curve (2) and curve (3) is taken to be the temperature of the ocean's surface (Figure 4).

This method of converting from T_r to $T_{0,r}$ does not guarantee a reliable determination of T_0. Actually, the $I_{3.7}^{clo}$ values and, consequently, the slope of curve (2) will vary arbitrarily, depending on the relationship of the intrinsic radiation of the cloudless section of the ocean and the cloud cover, as well as the contribution of the solar radiation scattered by the clouds. In connection with this, the values of $I_{3.7}^{clo}$ at the points on line 1 (Figure 4) that correspond to a greater percentage of clouds in the instrument's field of view and are burdened with more scattered radiation will, as a rule, be too high in comparison with the value of the instrinic radiation of the section under discussion by itself. For this reason, and despite the random variations of the $I_{3.7}^{clo}$ values, the points of intersection of line 1 and curve 2 will be systematically too low. However, even if this random error is eliminated during averaging for sufficiently large areas and time periods, as in /6,7/, there still remains the systematic error $\Delta T_0 < 0$, which is related to the fact that T_r is taken to be $T_{0,r}$ at the point of intersection of line 1 and curve 2, without allowing for the attenauting effect of the atmosphere in the 3.7 μm "window." The enumerated causes also probably lead to the fact that $\Delta T_0 < 0$ in /6,7/.

Errors with opposite signs have different causes: $\Delta T_0 > 0$ (for approximately the same absolute error values), as obtained from data gathered by the Japanese geostationary satellite /15/. For instance, the use of the section of maximum values of T_r as $T_{0,r}$ in /15/ means that when temperature maps are compiled by the proposed method, the factors taken into consideration objectively are only those measurements of T_r that pertain either to the conditions of a severely overheated surface film and an extremely transparent atmosphere or to conditions of complete compensation or supercompensation for the factors attenuating the ocean surface's radiation that corresponds to temperature T_0, such as when there exist large temperature inversions in the atmosphere. We have also not yet eliminated the possibility that the exaggeration of $T_{0,r}$ is related to the appearance of patches of sunlight in the radiometer's field of view, which entails an increase in the probability of high T_r values used in the histograms. Since such conditions can occur only in a cloudless atmosphere, the choice of those T_r values is deliberately eliminated from the analysis of a T_r measurement under conditions when there is any cloudiness. Actually, the absence of a large amount of data in the tables in /15/ is related to the presence of cloudiness in the corresponding regions. Nevertheless, the determination of the ocean's temperature under cloudy conditions is probably of more importance for the solution of fundamental problems as that of long-term weather forecasting or the problem of a change in the Earth's climate, since the most substantial deviations in the ocean surface's thermal regime and the related processes of ocean and atmosphere interaction are caused by spatiotemporal variations in the cloud cover. For this reason, the use of the described method for determining $T_{0,r}$, which allows the loss of so much important information, is not justified. As was correctly noted in /6/, it is necessary to have improved and more reliable methods that will provide for the determination of the ocean surface's temperature under variegated oceanic and atmospheric conditions.

Integrated Method for Determining the Ocean's Temperature. Improving the reliability of ocean temperature determinations is an extremely important problem for the remote method. The fact of the matter is that this method can, in principle, not always provide high accuracy in determining the ocean's parameters. However, considering the well known merits of space investigations of the world ocean on a global scale, it is necessary to have a method that makes it possible to obtain reliable estimates of the errors in determining these parameters in any specific instance of measurement. Such an approach makes it possible to perform the necessary spatiotemporal averagings more intelligently by eliminating or allowing for individual values that are known to be unreliable. Let us discuss ways of improving the reliability of the remote method, as it applies to the problem of determining the ocean's temperature.

An obvious shortcoming of the methods of determining the ocean's temperature that were discussed above is that they do not use the physical regularities governing the generation of radiation by the ocean-atmosphere system under specific experimental conditions. When I_ν measurements in only a single spectral band of the atmosphere's transparency window are used, naturally it is impossible to construct a physically substantiated and reliable (in the sense stated above) method of determining $T_{0,r}$ because of the absence of the necessary complex of initial information. It might be possible to use the optimal method of determining atmospheric and cloud parameters that was proposed in /1/ and is based on prior information in the form of statistical characteristics of the vertical structure of the temperature, moisture, and cloudiness fields in regions being investigated. In order to test the effectiveness of this technique for allowing for atmospheric factors in the materials from the American or Japanese satellites that were discussed above, it is necessary to have initial data on the radiation intensity I_ν and the radiant temperature T_r that are obtained directly by these satellites. However, in view of the large number of unknown factors on which the measured radiation I_ν in the "windows" depends, for a radical improvement in accuracy and reliability it is necessary to have additional measurements of I_ν in other parts of the spectrum that carry information about these parameters. In other words, it is necessary to have an integrated formulation of the problem of determining T_0 and the auxiliary parameters of the atmosphere and the ocean.

The formulation of this problem and the requirements for prior information follow from the theory of radiation transfer in the ocean-atmosphere system and experimental data on the optical properties of the ocean and the atmosphere in the infrared band of the spectrum.

Under cloudless conditions, I_ν is related to T_0 by relationship (1), in which the transmission function $P_\nu(\zeta,\theta)$ in the infrared band "windows" for a horizontally homogeneous atmosphere can be represented in the form of the product

$$P_\nu(\zeta,\theta)=P_\nu^{H_2O}(\zeta,\theta)P_\nu^{a}(\zeta,\theta), \quad (4)$$

where

$$P_\nu^{H_2O}(\zeta,\theta)=\exp[-k_\nu w(\zeta)\sec\theta], \quad (5)$$

$$P_\nu^{a}(\zeta,\theta)=\exp[-\tau_\nu(\zeta)\sec\theta] \quad (6)$$

are the transmission functions caused by the water vapor continuum and aerosol attenuation; k_ν, $w(\zeta)$ = absorption factors and the mass of the water vapor, respectively; $\tau_\nu(\zeta)$ = optical thickness of the aerosol.

Consequently, in order to allow for the atmospheric factors it is necessary to have additional initial information that makes it possible to determine the vertical temperature $T(\zeta)$, moisture content $w(\zeta)$ and $\tau_\nu(\zeta)$ profiles. These parameters can be obtained by I_ν measurements in the CO_2 (4.3 and 15 μm) and water vapor (6.3 and 20-25 μm) absorption bands using prior information in the form of the statistical characteristics of the vertical temperature and moisture structure, the optical characteristics of water vapor and the aerosol in different continual attenuation sections, and the basic properties of the aerosol transmission function (limitedness and monotonicity).

The first successful attempts to solve this complex of problems were described in /16/; experimental data on the optical characteristics of water vapor and the aerosol have been published in /17/.

In addition to the atmospheric factors, noticeable errors in the determination of T_0 can be caused by variations in the ocean's radiating capacity δ_ν that are the result of surface phenomena (wave action, foam, foreign bodies). As was shown in /18/, variations in δ_ν in the 10-12 μm transparency window for the tropical region of the Atlantic Ocean cause variations in the temperature being determined that average 0.5°C with a spread of 1-1.5°C. Under calm conditions, overheating of the ocean's surface reaching 1.5°C have been observed. In the case of pollution of the surface (by oil films, for example), this overheating can reach even greater values.

In order to allow for variations in δ_ν when determining T_0 it is necessary to investigate their relationship with the characteristics of the ocean's surface, which can be determined from measurements of the reflected or intrinsic radiation in the microwave band of the spectrum. Actually, measurements of the reflected radiation in the superhigh frequency band make it possible to identify foreign bodies on the sea's surface and the characteristics of the wave action /19/. Measurements of the intrinsic radiation in the superhigh frequency "windows" make it possible to determine the ocean surface's temperature for any state of the atmosphere /2/, it being the case that under cloudless conditions the atmospheric factors are comparatively small, but allowing for large variations in δ_ν then becomes of substantial importance. Allowing for these variations is made more complicated by the fact that they are comparable with the variations in I_ν caused by cloudiness.

On the other hand, it is a well known fact that broken or semitransparent clouds contribute substantial interference when determining T_0 using the infrared band, while solid cloud cover eliminates completely the possibility of using that band for this purpose. At the same time, however, measurements of I_ν in the infrared band "windows" make it possible to determine the temperature and altitude of the cloud cover's upper boundary. From this, naturally, there arises a need for formulating the integrated problem of determining the ocean's temperature and the parameters of the atmosphere, the cloud cover and the ocean's surface (wind velocity, foam, wave action) on the basis of the use of radiation measurements in the infrared and superhigh frequency bands. Such an integrated approach will make it possible to increase the effectiveness of the remote method of sounding the atmosphere and the sea's surface substantially.

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INVESTIGATION OF THE ORBITS OF ARTIFICIAL EARTH SATELLITES USED FOR OCEANOGRAPHIC PURPOSES

Moscow ISSLEDOVANIYE ZEMLI IZ KOSMOSA in Russian No 2, Mar-Apr 81 (manuscript received 14 Oct 80) pp 111-115

/Article by A.A. Astashkin, V.K. Saul'skiy and G.R. Uspenskiy/

/Text/ The spatiotemporal characteristics of the objects and phenomena encountered in oceans make specific demands on the coverage and frequency of coverage of the surface of the seas, oceans and coastal zones. These demands can be reduced to the following: 1) it is necessary to insure full coverage of the Earth's surface from 85° S.Lat. to 85° N.Lat.; 2) the renewal period for the global information that is obtained must range from several hours to several days.

Considering the fact that when oceanographic observations are made the basic information is obtained by a complex of radiophysics equipment for which the condition of solar illumination is not a limitation, below we discuss a rational plan for covering the Earth's surface with "diurnal" and "nocturnal" tracks for the purpose of insuring the minimum time for full coverage of the surface.

The plan has been formulated so that one half of any interorbit distance on the equator is covered successively by only "diurnal" scanning strips, while the other half is covered by "nocturnal" ones. Basically, this type of coverage can also be retained for the remaining parallels. The plan can be realized if an approximately even number of ISZ /artificial Earth satellite/ orbiting periods is set up for the mean solar day. In this case, 12 hours after the beginning of coverage of the first half of any interorbit distance on the equator by "diurnal" revolutions, in precisely the same manner its second half will begin to be covered by "nocturnal" revolutions, since the displacement between the "diurnal" and "nocturnal" revolutions is at least half the interorbit distance (more precisely, it will equal the sum of half the interorbit distance and half the daily displacement between the "diurnal" revolutions). For the case of an approximately odd number of orbiting periods during a mean solar day, this coverage plan cannot be realized, since here the displacement between the "diurnal" and "nocturnal" revolutions covering the same interorbit distance on the equator equals half the displacement between the "diurnal" revolutions, so that the "diurnal" and "nocturnal" scanning strips will always alternate. Complete coverage of the equator by such alternating strips is not retained in any other latitudes because of the different inclination of the "diurnal" and "nocturnal" strips, as a result of which beyond the equator they will either be superimposed on each other or diverge and form gaps in the coverage of the Earth.

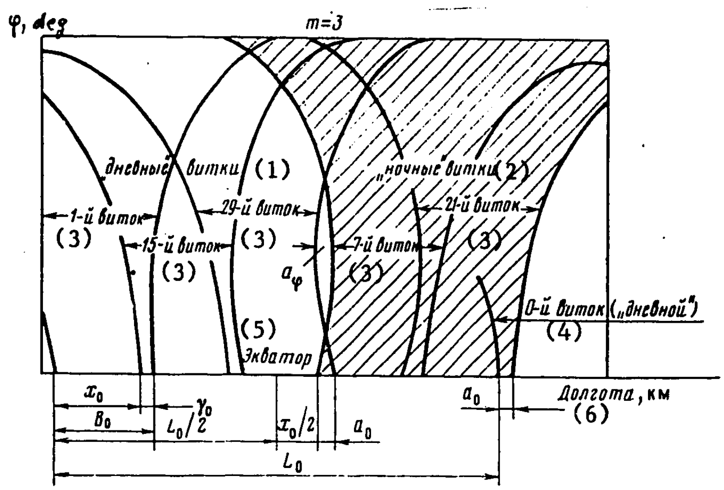

Diagram of coverage of the Earth by "diurnal" and "nocturnal" ISZ scanning strips at different latitudes.

Key:

1. "Diurnal" revolutions
2. "Noctural" revolutions
3. Revolution # ..
4. Revolution # 0 ("diurnal")
5. Equator
6. Length, km

Considering what has been said, the possible range of orbits under discussion for oceanographic ISZ's must be reduced to $700 \leqslant H \leqslant 1{,}100$ km; that is, to the neighborhood of the altitude $H \approx 900$ km with a circular orbit, the period of revolution of which is set at an even number of times (14) per mean solar day.

In the figure above we present an example illustrating the coverage plan under discussion. Here the interorbit distance L_0 on the equator is covered on the 1st, 15th and 29th "diurnal" revolutions and the 7th and 21st "nocturnal" ones. From the figure it is obvious that the overlap γ_0 on the equator between the "diurnal" scanning strips is determined by the daily displacement x_0 on the equator, while the overlap a_0 between the "diurnal" and "nocturnal" scanning strips satisfies the relationship

$$a_0=mB_0-(m-1)(B_0-x_0)-L_0/2-x_0/2, \qquad (1)$$

where B_0 = section where the equator is crossed by the satellite's scanning strip; m = number of "diurnal" revolutions.

The figure depicts a quite general case, where m = 3. Keeping in mind the latitudinal changes in the lengths of the interorbit distance and the section of intersection of the latitude with the scanning strip, as well as the change in the relative position of the "diurnal" and "nocturnal" revolutions (as a result of orbital inclination and the Earth's rotation) relative to the equator, overlap a between the "diurnal" and "nocturnal" scanning strips at an arbitrary latitude is determined by the expression

$$a_\varphi=\cos\varphi[a_0+B/\sqrt{\sin^2 i-\sin^2\varphi}-B/\sin i- -|2R\arcsin(\mathrm{tg}\,\varphi/\mathrm{tg}\,i)-L_0\arcsin(\sin\varphi/\sin i)/\pi|], \qquad (2)$$

where B = width of the satellite equipment's scanning strip, in kilometers; i =

= orbital inclination; R = 6,371 km = average radius of the Earth. It is then the case that

$$B=B_0 \sin i. \qquad (3)$$

Relationship (2) shows that the overlap between adjacent "diurnal" and "nocturnal" scanning strips is of such a nature that in the low and medium latitudes, these strips try to div-rge (overlap a_φ decreases), while in the higher latitudes overlap a_φ increases again because of the increase in the width of the scanning strip. In order to analyze this point and allow for it when selecting a_0, it is convenient to represent relationship (2) in the form

$$a_\varphi=\cos\varphi\,(a_0-\xi L_0), \qquad (4)$$

where

$$\xi=(1/\sin i-1/\sqrt{\sin^2 i-\sin^2\varphi})B/L_0+|2R\arcsin(\mathrm{tg}\,\varphi/\mathrm{tg}\,i)/L_0- -\arcsin(\sin\varphi/\sin i)/\pi|. \qquad (5)$$

In order to insure gapfree scanning it is necessary that the following condition is fulfilled at all latitudes:

$$a_\varphi\geqslant 0,$$

or, allowing for (4),

$$a_0\geqslant \xi L_0.$$

We will carry out a further analysis for the condition of a given orbital inclination. Let us find the maximum value ξ_m of ξ, which is reached at some latitude φ_m. In order to do this, let us first determine φ_m from the following equation:

$$\frac{d\xi}{d\varphi}=\pm\left(\frac{2R}{L_0\sqrt{\mathrm{tg}^2 i-\mathrm{tg}^2\varphi}\cos^2\varphi}-\frac{\cos\varphi}{\pi\sqrt{\sin^2 i-\sin^2\varphi}}\right)-\frac{B\sin\varphi\cos\varphi}{L_0\sqrt{(\sin^2 i-\sin^2\varphi)^3}}=0, \qquad (6)$$

where the sign "+" is used in front of the parentheses if

$$2R\arcsin(\mathrm{tg}\,\varphi/\mathrm{tg}\,i)/L_0-\arcsin(\sin\varphi/\sin i)/\pi\geqslant 0,$$

while the sign "-" is used in the opposite case.

Substituting the value obtained for φ_m with this equation into (5), let us determine the value of ξ_m and then check the fulfillment of the complete coverage condition, which takes the form

$$a_0\geqslant \xi_m L_0. \qquad (7)$$

Equation (6) can have more than one root (for $86^\circ < i < 90^\circ$). In this case we take as ξ_m the greatest of the corresponding values of ξ, as computed with formula (5).

From equation (1) we determine the minimum width of the equator's section of intersection with a scanning strip for which gapfree coverage of the globe is insured, provided that the following conditions are fulfilled: $a_0 = \xi_m L_0$, $x_0 = B_0$. It is

$$B_0=(L_0+2L_0\xi_m)/(2m-1).$$

Considering (3), let us derive the following expression for the minimum scanning strip width that insures complete coverage of the globe:

$$B=\sin i L_0(1+2\xi_m)/(2m-1). \qquad (8)$$

From the condition of daily displacement of the ISZ's trace on the equator by a shift of magnitude x_0, the following relationship ensues:

$$NL_0=2\pi R\pm x_0, \tag{9}$$

where the sign "+" corresponds to a westerly displacement of the ISZ's trace, while "-" corresponds to its displacement in an easterly direction; N = a whole number that is approximately equal to the number of ISZ revolutions per day.

Since for the value of B_0 that is minimally allowable for gapfree scanning it is necessary that $x_0 = B_0$ or $x_0 = B/\sin i$, in this case formula (9) takes on the form

$$NL_0=2\pi R\pm B/\sin i. \tag{10}$$

For given values of the orbital inclination i, the direction of the ISZ trace's daily shift and parameter m, it is possible to determine the scanning strip's minimum necessary width B and the interorbit distance on the equator L_0 by the joint solution of system of equations (5), (6), (8) and (10).

It should be mentioned that parameter m determines the scanning periodicity τ that is insured in connection with this; when expressed in days, it is approximately

$$\tau=m-0{,}5. \tag{11}$$

Knowing L_0 and i, it is possible to find the corresponding orbital altitude H. In order to do this we made use of the following relationship, in which the Earth's rotation and orbital precession are allowed for during a single ISZ revolution period:

$$L_0=(T_d\omega-\delta\Omega)R, \tag{12}$$

where T_d = draconic period of revolution; ω = angular velocity of revolution of the Earth, which is $7.29211\cdot10^{-5}$ rad/s; $\delta\Omega$ = precession of the orbit's ascending node during one revolution in the eastern direction, in radians; R = average radius of the Earth, which is 6,371 km. Formulas for T_d and $\delta\Omega$ are presented in (for example) [1]. Using them for substitution into equation (12), we obtain

$$L_0=\{[2\pi\sqrt{(R+H)^3}/\sqrt{\mu}+2\pi\varepsilon(1-4\cos^2 i)/\sqrt{\mu^3(R+H)}]\omega+ +2\pi\varepsilon\cos i/\mu(R+H)^2\}R, \tag{13}$$

where $\mu = 3.98602\cdot10^5$ km^3/s^2; $\varepsilon = 2.634\cdot10^{10}$ km^5/s^2.

Thus, if L_0 is known it is possible to determine orbital altitude H from equation (13).

The procedure presented above for computing the minimum strip width B, for gapfree scanning, from system of equations (5), (6), (8) and (10) also makes it possible to determine the most rational orbital inclination i. In order to do this it is sufficient that, having assigned different values to i, we compare among themselves the minimum values of B that are obtained, selecting in the end that inclination that gives the smallest value among all the scanning strip widths that are obtained.

The results of the calculations illustrating this technique for selecting orbital parameters are presented in the table on the next page.

In all cases N = 14 and the ISZ's trace is displaced to the east. In the first three examples the scanning period provided is 1.5 days, while in the last it is 2.5

Results of Calculation of Minimum Strip Width B for Gapfree Scanning and Orbital Altitude H

m	i, deg	L_0	B	H
		KM		
2	81	2750	1550	690
2	85	2790	950	760
2	90	2780	1100	750
3	85	2810	700	790

days. From the examples in the table it is obvious that the use of inclination i = = 85° yields the greatest gain, since the scanning strip's width is at a minimum in this case.

For the case where complete coverage condition (7) is not fulfilled, there can arise the necessity of determining the area of total gaps ΔS during a scanning cycle.

The value of ΔS can be determined in the following manner:

$$\Delta S=4\pi R^2\sum_j\int_{\varphi_{jH}}^{\varphi_{jK}}(\xi-a_0/L_0)\cos\varphi d\varphi, \tag{14}$$

where φ_{jH}, φ_{jK} designate the latitudes of the beginning and ending of the gaps and are found from the equation $a_\varphi = 0$, which -- allowing for (2) -- has the form

$$a_0=-B/\sqrt{\sin^2 i-\sin^2\varphi}+B/\sin i+|2R\arcsin(\mathrm{tg}\,\varphi/\mathrm{tg}\,i)-L_0\arcsin(\sin\varphi/\sin i)/\pi|. \tag{15}$$

The values of φ_{jH} and φ_{jK} can change within the following limits: $0\leqslant\varphi_{1H}\leqslant\varphi_{1K}\leqslant\leqslant\varphi_{2H}\leqslant\ldots\leqslant i$. By substituting the value of ξ from formula (5) into (14) and integrating, we obtain the final expression for calculating the absolute area of the gaps:

$$\Delta S=4\pi R^2\sum_j[f(\varphi_{jK})-f(\varphi_{jH})], \tag{16}$$

where

$$f(\varphi)=-B\arcsin(\sin\varphi/\sin i)/L_0+B\sin\varphi/L_0\sin i+|2R\sin\varphi\arcsin(\mathrm{tg}\,\varphi/\mathrm{tg}\,i)/L_0+2R\,\mathrm{arctg}\sqrt{\mathrm{tg}^2 i-(1+\mathrm{tg}^2 i)\sin^2\varphi}/L_0-\sin\varphi\arcsin(\sin\varphi/\sin i)/\pi-\sqrt{\sin^2 i-\sin^2\varphi}/\pi|-a_0\sin\varphi/L_0.$$

It is necessary to mention that formulas (14) and (16) are correct for $a_0\geqslant 0$. The case where $a_0<0$ can reduce to a more cumbersome expression for calculating ΔS, the form of which depends on the specific combination of values for a_0, L_0, B and i.

An expression for calculating the relative losses when scanning the entire surface of the Earth can be derived from (16) if we relate ΔS to the maximally possible scanning area S for a given inclination i, which can be calculated with a degree of accuracy that is sufficient for practical purposes by the following approximative formula:

$$S=4\pi R^2\sin i. \tag{17}$$

Using (17) and (16), we find that

$$\Delta S/S=\left\{\sum_j [f(\varphi_{jк})-f(\varphi_{jн})]\right\}/\sin i.$$

Thus, the method and relationships that have been presented make it possible to accomplish the following: 1) analysis of the completeness of the coverage of the Earth's surface by scanning strips; 2) finding of rational values for orbital altitude and the minimum scanning strip width to fulfill the complete coverage condition; 3) calculation of the losses appearing in the coverage because of gaps.

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MAIN DIRECTIONS OF EARTH RESEARCH FROM SPACE IN LIGHT OF THE DECISIONS OF THE 26TH CPSU CONGRESS

Moscow ISSLEDOVANIYE ZEMLI IZ KOSMOSA in Russian No 2, Mar-Apr 81 pp 5-8

/Article by Aleksandr Vasil'yevich Sidorenko, vice president, USSR Academy of Sciences/

/Text/ "There is a great need in this country that the forces of 'major science,' in addition to working on theoretical problems, be concentrated to a greater degree on the solution of key national economic problems..."
(From Comrade L.I. Brezhnev's Summary Report to the 26th CPSU Congress)

The decisions of the 26th CPSU Congress outlined the paths for the comprehensive economic and social development of our country. In particular, they stipulate the further development of research into the use of space facilities in different branches of the national economy for the study of the Earth's natural resources and the protection of the environment, in addition to aiming at the solution of this extremely important scientific and technical problem by the integrated, dialectic development of the Earth, physicotechnical and mathematical sciences.

The extensive program of Earth research from space that is being realized in the Soviet Union provided us with the possibility of a synthesizing approach to the discussion of natural objects and processes relative to their interrelationships, intercausality and organic unity. This approach determines, in turn, the formation of a new fundamental scientific field: space Earth science. At the present time, Soviet scientists are faced with the fullblown problem of carrying out planned, integrated investigations for the development of space Earth science, both relative to the use of information obtained from space for the benefit of different sciences and branches of the national economy, and relative to the development of new and the improvement of existing methods and facilities for surveying the Earth from space, as well as the transmission, processing and automated interpretation of video information that is obtained from space.

The fundamental scientific research that is being planned for the 11th Five-Year Plan by the USSR Academy of Sciences and is based on an analysis and synthesis of the current level of knowledge in the field of space Earth science has been called upon to insure the implementation of the 26th CPSU Congress's decisions as part of the development of space Earth science, the introduction into practice of new methods and facilities for investigating the Earth from space and, as a consequence, the acceleration of technical progress in a number of the most important branches of the national economy. At the present time the plans for this research are being discussed extensively by the scientific community at seminars and scientific councils.

There are two basic directions in space Earth science. The first of them encompasses space investigations of the lithosphere, biosphere, hydrosphere and atmosphere of our planet; that is, the solution of problems in space geology, space biology, space hydrology, oceanography and space meteorology.

In the field of space geology we should develop methods for interpreting video information that is obtained, in order to study the deep structure of the Earth's crust, determine and analyze the interrelationships of different structural elements, and investigate the dynamics of contemporary processes and the effect of anthropogenic factors on the lithosphere. Improvements in the methods used for the structural analysis of space video information about the Earth should insure the discovery of new ore-controlling faults and ring and other structures, and -- in the final account -- increase the effectiveness of metallogenic predictions and exploratory geological prospecting work. This methods will be used extensively for the analysis of contemporary geodynamic conditions, the physical properties of the lithosphere, contemporary geological processes and the prediction of earthquakes. We are also faced with the development of theoretical principles and techniques for geophysical and geochemical investigations by remote sounding methods that will provide an increase in the effectiveness of prospecting for useful minerals and the accuracy of predictions of seismic and volcanic danger.

In the field of space meteorology and oceanography, we are planning to investigate the relationships between the world ocean's natural resources and phenomena and processes in the aqueous medium and the atmosphere and to study the effect of synoptic variability in hydrophysical fields and their contribution to the ocean's energy balance. This will make it possible to develop recommendations for determining zones of increased biological productivity, including fish, as well as scientific principles for the regional utilization of the ocean's biological and energy resources. It is advisable to continue working to improve methods for the operational monitoring and prediction of variability in weather conditions and the ice situation, primarily in the Arctic and Antarctic, where this is necessary in order to support year-round navigation and marine industries. Right now, one matter that is acquiring special importance is remote methods of studying thermal anomalies in the oceans, frontal zones, vortex formations and ocean-atmosphere interaction processes that affect changes in climate and weather, which methods will also make it possible to monitor air and water pollution.

In the field of space geography and predicting the state of the environment, it is important to provide for the further development of remote methods of geosystem monitoring, determining the parameters of geosystems and ecological systems, the snow and ice cover and so on, and to look for ways of improving thematic mapping methods that will assist in inventorying natural resources (agricultural lands, forests, glaciers and so forth) and monitoring changes in them caused by natural and anthropogenic factors. Increasing the effectiveness of water resource control requires the development of methods of using space information to observe changes in the dynamic, hydrological, physicochemical and biological characteristics of inland water, large reservoirs and chains of reservoirs, the mouths of large rivers, melt water runoff conditions and the dynamics, reserves and quality of underground water in the different natural climatic regions of the USSR. Space methods should give us much better capabilities in the study of the biological productivity of land on the continental and regional levels, which capabilities will be the basis for the solution of the problem of accounting for and producing an economic evaluation of land resources, compiling a cadaster and improving agricultural land utilization.

The solution of all the problems in the study of natural resources listed above is unthinkable without improvements in the fundamental physicotechnical and mathmatical principles of remote sounding of the Earth from space and the automated processing and interpretation of the video information that is obtained. The further development of space Earth science -- this extremely important direction for spplied cosmonautics -- is possible only on the basis of a close alignment of the natural and technical sciences, the improvement of the physical principles of remote sounding, and the development of equipment and systems for obtaining and processing space video information on the environment. Here it is first necessary to provide for the continuation of the study of the physical dependences of the characteristics of radiation and scattering on the parameters of natural systems: the atmosphere, the ocean, plants, soils, rocks. The establishement of the connections between the phenomena and processes taking place on the interfaces of natural systems in the inner layers will give us the opportunity to develop methods of studying mediums on the basis of remote sounding data and determine the characteristics of terrestrial formations allowing for variations in radiation and scattering. In the complex of problems involved in the reliable determination of the characteristics of the formation, by natural surfaces, of intrinsic and reflected solar radiation that contains information about natural resources, an important role is assigned to allowing for interference-forming factors. In order to do this, it is necessary to continue research and development in the field of techniques for the operational evaluation, allowance for and minimization of the atmosphere's effect on the measured spectral brightnesses and contrasts of natural formations during satellite observations.

On the basis of the theoretical and experimental research that has been mentioned, we must work out the scientific principles for operational information systems; create data banks and dynamic catalogs of the spectral-structural characteristics of research objects, with special emphasis on different types of soil and plant communities in different phenological stages that are capable of insuring the obtaining of reliable predictions for agricultural crop yields, pasture productivity, moisture reserves in the soil and so on; create the prerequisites for the automated solution of the problems of processing and interpreting thematically space video information about the Earth that is obtained.

The effectiveness of the utilization of the materials from space surveys depends to a considerable degree on the methods and facilities used to process them. In this area it is necessary to continue the development of theoretical principles, mathematical methods and systems for the automated processing of aerospace information and the control of space systems. The problem of the practical assimilation of the continuously growing flow of information needs fundamentally new solutions. One of these is the development of hierarchical recognition systems and a methodology for automated interpretation on the basis of statistical analysis and the algorithmic methods of an artificial intelligence.

The physicotechnical and mathematical research that has been mentioned will determine the success of the solution of the so-called inverse problem of the remote determination of the characteristics of natural formations with the help of measurements of their intrinsic and reflected radiation from space.

The development of space methods makes it possible to formulate the problem of studying the radiation characteristics of large regions (including the planet as a whole), using data on the parameters and anomalies of the Earth's gravitational and magnetic fields. When talking about the planetary level of study of geological-geographical and natural climatic processes, the first thing we should mention is geostationary artificial Earth satellites.

Fundamental scientific research also provides for the development of the principles of the construction and modeling of new facilities for the remote scunding of Earth from space and the digital and optical processing of space surveying materials. In connection with the working out of the complete technological cycle involved in the reception, operational processing and interpretation of multizonal space video information, the assignment given to the USSR Academy of Sciences' Siberian Department for the development and construction of a specialized experimental center based on the use of the newest achievements in the field of image processing with the help of computer technology is worthy of attention. All of this research is aimed at improving the technical facilities of the industrial space system for studying the Earth's natural resources and monitoring the state of the environment, as well as increasing the effectiveness of investigations of the Earth from space. It should also be mentioned that the program of scientific work for the 11th Five-Year Plan must include the realization of integrated technical-economic and social research for a comprehensive evaluation of the effectiveness of the utilization of space technology facilities in the solution of the most important national economic and scientific problems.

Many institutes and design offices of the USSR Academy of Sciences, the union republics' Academies of Sciences and branch and industrial ministries and departments are participating in the fundamental scientific research into the problem of space Earth sciences, which is being coordinated by the USSR Academy of Sciences' Commission on the Investigation of the Earth's Natural Resources With Space Facilities. Within the framework of the collaboration in the "Interkosmos" program, scientific collectives from the other socialists countries are being enlisted in this research.

In solving a number of fundamental problems, space Earth science is turning our knowledge of natural phenomena and processes and their interrelationships and intercausality in a new scientific direction. The formation of this method for scientific knowledge of the world and its practical introduction into the national economy will facilitate the realization of the decisions of the 26th CPSU Congress.

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NEW EXPERIMENT IN EARTH RESEARCH FROM SPACE

Moscow ISSLEDOVANIYE ZEMLI IZ KOSMOSA in Russian No 1, Jan-Feb 81 pp 5-6

/Editorial: title as above/

/Text/ "A 'Meteor' artificial Earth satellite was launched in the Soviet Union on 18 June 1980. It was inserted into an orbit with the following parameters:
maximum distance from the Earth's surface at apogee -- 678 km;
minimum distance from the Earth's surface at perigee -- 589 km;
inclination of orbit -- 98^{o};
initial orbital period -- 97.3 minutes."[1]

On board the satellite there are three basic equipment complexes that provide for observation of the Earth's surface in the interests of investigating its natural resources and meteorology:

1. A BIK-E experimental on-board information complex, which consists of: an MSU-SK medium-resolution multizonal scanning unit with a tapered opticomechanical image scanner; an MSU-E high-resolution multizonal scanning unit with electronic scanning that is based on instruments with charge coupling; a digital radio system.

2. An experimental, high-resolution "Fragment" multizonal system consisting of: an opticomechanical scanning unit; an information encoding and processing system; a digital radio system.

3. An RTVK operational radio and television complex, which consists of: a duplicated complex of multizonal opticomechanical scanning units with low (MSU-M) and medium (MSU-S) resolution; memory units; two radio systems operating in the meter and decimeter bands that are standard equipment on satellites of the "Meteor" series.

The basic parameters of these complexes are given in the table on the next page. Information from the BIK-E complex passes over a digital radio line to Goskomgidromet's receiving point in Obninsk. Primary data processing is performed at the State Scientific Research Center for the Study of Natural Resources (GosNITsIPR). Information from the "Fragment" complex is transmitted over a digital radio line to a receiving point at the Moscow Institute of Power Engineering's OKB /Special or

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[1] From a TASS report, PRAVDA, 19 June 1980.

Parameters	Name of Complex or Instrument				
	BIK-E		"Fragment"	RTVK	
	MSU-E	MSU-SK		MSU-S	MSU-M
Field of view (kilometers) for flight altitude of 650 km	30	600	85	1,400	2,000
Size of projection of field diaphragm (of an element of the structure) on the Earth's surface at the nadir (meters)	30	170	80	240	1,000
Spectral bands (microns)	0.5-0.7 0.7-0.8 0.8-1.0	0.5-0.6 0.6-0.7 0.7-0.8 0.8-1.0	0.4-0.8 0.5-0.6 0.6-0.7 0.7-0.8 0.7-1.1 1.2-1.3 1.5-1.8 2.1-2.4	0.5-0.7 0.7-1.0	0.5-0.6 0.6-0.7 0.7-0.8 0.8-1.0

Experimental Design Office/, where it is recorded magnetically. Further processing of the data and visualization of the images are carried out with the help of specialized computer facilities at the USSR Academy of Sciences' Institute of Space Research and GosNITsIPR. Information from the RTVK complex enters Goskomgidromet's network of receiving points.

The creation of the "Fragment" complex was assisted by specialists from the "Karl Zeiss-Jena" People's Enterprise in the German Democratic Republic, who developed and manufactured a reflecting telescope with a focal length of 1,000 mm and a diameter of 240 mm.

The basic goals of the experiment being conducted are:

1. Development and optimization of a method for an operational study of the Earth's surface on the basis of multizonal information.

2. Development of new equipment for obtaining multizonal video information in the visible and near-infrared bands of the spectrum.

3. Development of systems and methods for the digital transmission of multizonal video information.

4. Investigation and optimization of methods for the machine and visual-instrumental processing of multizonal video information.

5. Experimental production utilization of multizonal video information in the solution of practical problems of Earth research from space.

6. Development of recommendations for the construction of on-board and terrestrial equipment, the organization of surveying, and data collection and processing technology in the prospective system for studying the Earth from space on an operational basis.

Considering the great interest on the part of a broad circle of specialists in projects in the field of operational investigation of the Earth's surface and the uniqueness of the experiment being performed, the Editorial Board of this magazine proposes to devote a separate issue to it in 1981.

The scientists, designers, engineers, technicians and workers participating in the realization of this experiment have devoted it to the 26th CPSU Congress.

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TELEVISION METHODS OF COLOR FILTRATION IN AEROSPACE INVESTIGATIONS OF THE EARTH

Moscow ISSLEDOVANIYE ZEMLI IZ KOSMOSA in Russian No 2, Mar-Apr 81 (manuscript received 7 Apr 80) pp 76-81

/Article by R.Ye. Bykov, N.V. Ignat'yeva and Yu.M. Titov, Leningrad Electrotechnical Institute imeni V.I. Ul'yanov (Lenin)/

/Text/ The investigation of the Earth's surface with multizonal photographic and television systems is being used ever more extensively in the study of natural resources /1/. The quantitative analysis of color pictures has found a use in oceanographic research /2/ and a biological experiment /3/. The connection between the parameters of the images that are formed and the physical characteristics of the medium being investigated are caused by the processes of light absorption, scattering and reflection, which in the spectral band are -- as a rule -- of a selective nature.

Multizonal recording methods are based on works devoted to the quantitative description of color perceptions. In these works, the authors have developed ideas that formulate the concept of color as a type of mathematical abstraction and extend this concept beyond the framework of color perceptions caused by the action of luminous radiation on an optical analyzer. These ideas have proven to be extremely fruitful and have served as the starting point for much research, including that that culminated in the creation of multizonal television systems (MTVS).

In the process of analyzing an MTVS picture, quantification of the acting radiation is performed on the basis of elements of space $X\{x_1,x_2,\ldots x_\ell\}$, $Y\{y_1,y_2,\ldots y_z\}$, time $T\{t_1,t_2,\ldots t_n\}$ and the spectrum $\Lambda\{\lambda_1,\lambda_2,\ldots \lambda_\Lambda\}$. The multizonal image formed in this manner can be represented by a matrix of multidimensional vectors.

When visual methods of analysis are used, quasicolor images are synthesized from zonal images; these images make it possible, by color contrasting, to detect certain groups of objects on the surface being investigated.

We should regard as more promising those methods based on the quantitative analysis of multizonal pictures that, in turn, are based on color filtration with subsequent formation of binary images and the measurement of their metric, topological and dynamic characteristics /4,5/.

When radiation with a complex spectral composition is broken down into Λ zones, the output signal of the i-th spectral television detector at a fixed moment of time and for a fixed element of the image; that is, the element lying in the hyperplane

$J\{x_j, y_k, t_\psi\}$, can be represented in the form

$$U_i = \int_0^\infty \sigma_i(\lambda) W_J(\lambda)\, d\lambda, \qquad (1)$$

where $\sigma_i(\lambda)$ = spectral sensitivity function of the detector of the i-th spectral zone; $W_J(\lambda)$ = spectral density function of the radiation's power and the input of the detector in the hyperplane under discussion.

The choice of functions $\sigma_i(\lambda)$ gives us a basis for classifying the acting spectra in Λ-dimensional space $R^\Lambda\{U_1, U_2, \ldots U_\Lambda\}$ or, after normalization according to the value of the input energy, in the space $R^{\Lambda-1}$, the coordinates of which carry information on the portion of the energy registered in the i-th spectral interval relative to the entire amount of energy registered:

$$\bar{U}_i = \frac{\int_0^\infty \sigma_i(\lambda) W_J(\lambda)\, d\lambda}{\sum_{i=1}^{\Lambda} \int_0^\infty \sigma_i(\lambda) W_J(\lambda)\, d\lambda}, \qquad (2)$$

where $\sum_{i=1}^{\Lambda} \int_0^\infty \sigma_i(\lambda) W_J(\lambda)\, d\lambda = U_1 + U_2 + \ldots + U_\Lambda$. Consequently, $\bar{U}_1 + \bar{U}_2 + \ldots + \bar{U}_\Lambda = 1$.

The basis of space R^Λ can be a system of any linearly independent vectors $\{\bar{R}_1, \bar{R}_2, \ldots \bar{R}_\Lambda\}$. The choice of the basis makes it possible to realize the mapping f_1: $R^\infty \rightarrow R^\Lambda$ or, when normalization is introduced, f_2: $R^\infty \rightarrow R^{\Lambda-1}$, it being the case that since the number of spectral elements $\Lambda \rightarrow \infty$, the complete prototype of each element of $R^{\Lambda-1}$ is the set of all spectral characteristics resulting in equal coordinates $\bar{U}_i$. Thus, having united in a single class all those elements of R^∞, the images of which coincide in $R^{\Lambda-1}$, it is possible to realize some division into classes of spectral characteristics of the acting radiation.

The relationship between the parameters of the multidimensional space in which the evaluation is made and the properties of the registered radiation are determined by the MTVS's spectral characteristics $\sigma_i(\lambda)$.

Depending on the purpose of the MTVS, it is possible to solve typical problems in multidimensional statistical analysis: discrimination, classification or division according to the parameters of elements of the image being investigated, and formation of a system of binary images for the purpose of subsequent quantitative analysis.

Let us discuss the procedure for analyzing a multizonal picture, using as an example the most widely used system, with $\Lambda = 3$. The problems of selecting the image picture elements that belong to the standard set, classifying the picture elements or a set of elements by groups, and the actual division into groups, can be solved technically by the use of color filters (FTs) /4/. An FTs divides a multidimensional space into two subspaces $H \subset M$ and $\bar{H}/\bar{M}$. The basic characteristics of such a filter are its coordinates and the shape and size of the "window." Let us assume that in trizonal registration, the image f(x,y) is given in the system of coordinates x,y, while the evaluation of the color of its elements is made in coordinates $\bar{U}_1, \bar{U}_2$. In these coordinates let us formulate a rectangular "window" of the type

$$Y_j(\bar{U}_1,\bar{U}_2)=\bigwedge_{i=1}^{4}[a_{1j}{}^iU_1(\bar{U}_1,\bar{U}_2)+a_{2j}{}^iU_2(\bar{U}_1,\bar{U}_2)+ +a_{3j}{}^iU_\Sigma(\bar{U}_1,\bar{U}_2)>0]=1, \qquad (3)$$

where $\left[Pr_j^i\right]$ designates the image that places some function $Y_j(\bar{U}_1,\bar{U}_2) = 1$ in conformity with the true predicates Pr_j^i, while the function $Y_j(\bar{U}_1,\bar{U}_2) = 0$ corresponds to the false predicates; a_{1j}^i, a_{2j}^i, a_{3j}^i = coefficients defining the coordinates and size of the "window" H_j; $U_1(\bar{U}_1,\bar{U}_2)$, $U_2(\bar{U}_1,\bar{U}_2)$, $U_\Sigma(\bar{U}_1,\bar{U}_2)$ = signals of the television sensors for the first and second spectral zones and the summary signal, which correspond to an element of an image with color $\bar{U}_1,\bar{U}_2$.

This procedure is realized with the help of an FTs, at the output of which the binary signal $Y_j(t)$ is formed during the scanning process, it being the case that $Y_j(t) = 1$ at the moments of time when the picture section being scanned has the color belonging to the H_j "window," and $Y_j(t) = 0$ in all other cases. With the help of such a signal, in the coordinate area it is possible for the following binary image to be formed:

$$Y_j(x,y)=\begin{cases}1, f(x,y)\in H_j\\ 0, f(x,y)\notin H_j.\end{cases} \qquad (4)$$

Analogously, binary images corresponding to other "windows" in the color plane can be formed; that is, with the help of a set of FTs's 1,2,...N, a multizonal or color image can be represented in the form of a series of binary, achromatic images

$$f(x,y)\to\{Y_1(x,y),\ Y_2(x,y),\ldots,Y_N(x,y)\}. \qquad (5)$$

In those cases where the investigator has at his disposal prior data on the statistics of the distribution of color in a picture, the choice of the number of windows N, the nature of their arrangement on the color plane, and their shape can be made with due consideration for the specifics of the problems being solved. For example, in the process of the formation of a binary image, it is possible to use a "window" of as complex as shape as desired by approximating it with the sum of k rectangular windows:

$$Y(\bar{U}_1,\bar{U}_2)=\bigvee_{j=1}^{k}\{\bigwedge_{i=1}^{k}[a_{1j}{}^iU_1(\bar{U}_1,\bar{U}_2)+a_{2j}{}^iU_2(\bar{U}_1,\bar{U}_2)+ +a_{3j}{}^iU_\Sigma(\bar{U}_1,\bar{U}_2)>0]\}=1. \qquad (6)$$

The formation by the methods indicated above of one or a system of binary images from a color or multizonal multigradation picture makes it possible to reduce the further analytical procedure to known algorithms for investigating geometric characteristics -- distributions of two-gradation objects by dimensions $W(\ell)$, areas W(S), perimeters W(L) and others -- topological characteristics -- distribution of two-gradation fragments by the order of the nodal points W(K), by compendency $W(\rho)$, ranking and others -- and the dynamic characteristics of the set of two-gradation objects -- distributions by speed of motion W(v), direction of motion W(φ) and others.

$$f(x,y) \rightarrow \begin{Bmatrix} Y_1(x,y) \\ Y_2(x,y) \\ \cdots \\ Y_N(x,y) \end{Bmatrix} \rightarrow \begin{Bmatrix} W(l) \\ W(S) \\ \overline{W(L)} \\ \overline{W(K)} \\ W(\rho) \\ \overline{P} \\ \overline{W(v)} \\ W(\varphi) \end{Bmatrix}. \tag{7}$$

The sequence of operations that has been presented shows that after the spectral brightness functions are converted into binary code with the help of FTs's, further measurement procedures are performed only with those elements of a color or multizonal picture that have the given color operator. These elements are combined into a two-gradation image that forms a geometric image that is subject to further analysis by selected parameters. The choice of the number of two-gradation images is determined by the degree of complexity of the applied problems being solved and can range from 1 to N.

In the process of the integrated analysis of a color picture, the investigation can be supplemented by a study of the statistical characteristics of the picture itself, such as the distributions of the elements of the television grating f(x,y) by brightness W(B), color $W(\overline{U}_1,\overline{U}_2)$ and others.

In the Department of Television at the Leningrad Electrotechnical Institute imeni V.I. Ul'yanov (Lenin), we have developed and introduced into experimental operation the TATsI-4 measuring television complex [6], which is used for the automatic quantitative analysis of color or multizonal pictures. The investigated images that are formed by the optical system are separated by a light-splitting unit, with the help of a prism, into four spectrozonal components that are the sources of the primary information for the television sensor. The form of the spectral sensitivity characteristics of each of the channels is determined by the investigative problems and is realized by transmitting television tubes and correcting light filters. In the case of the analysis of zonal photographs, it is necessary to project the image of each achromatic channel directly onto the target of the appropriate transmitting tube. The parameters of the video signals formed by the television sensor are measured and registered in an analyzing system, the basic element of which is a triangular matrix of discrete FTs's. Each of the color space fragments that corresponds to a single discrete element of the matrix is realized in accordance with rule (3), which makes it possible -- as follows from (7) -- to carry out the analysis of the color image.

The TATsI-4 equipment complex includes units for putting out data on perforation (PL-150) and digital printing (MPU16-2) devices, a programmed illuminated indicator board for the formation of a standard color area with a complex form, and a unit for scaling the color histograms. Visual inspection of the color image being investigated, the results of its processing, and the measurement data is done with the help of color (VK-173) and black-and-white (VK-151M) television monitoring units, as well as with digital displays.

The basic specifications of the TATsI-4 are presented in [6].

An electronic discrete color field generator (with 528 color gradations) is used for purposes of calibration, evaluation of color distortions and operational monitoring of the operation of the entire measuring complex. An image that has been synthesized by this generator and taken from the screen of a VK-173 color television monitor is shown in Figure 1 /not shown/.

The procedure for isolating fragments of a given color (that is established manually by the operator on the basis of prior information about the class of objects being investigated) is illustrated in Figures 2 and 3 /not shown/. Figure 2 is a television image (VK-173) of a reproduction of a color photograph of the Lake Balkhash region taken from the "Salyut-5" orbital station. Fragments of the image, the color of which corresponds to $\{\bar{U}_1,\bar{U}_2\} = \{0.32;0.61\}$ and $\{\bar{U}_1,\bar{U}_2\} = \{0.28;0.24\}$ are shown in the form of binary images in Figures 3a and b, respectively. In the second case, sections of the water surface with the given color are isolated.

In a number of investigations, interest is exhibited not so much in the absolute values of the color of image sections as in the changes in it from element to element (differential color characteristics). The example of the binary image reflecting the structure of the color conversions $\{\bar{U}_{1i},\bar{U}_{2j}\} \rightarrow \{\bar{U}_{1(i+1)},\bar{U}_{2j}\}$ in the photograph in Figure 2 is shown in Figure 3c. Such images prove to be informative during the solution of classification problems based on a study of textural characteristics and shape characteristics of objects, since it is on the boundaries of objects that noticeable color gradients appear (objects of a single color against a background of another color and so on). The illumination conditions have a substantial effect on the structure of the pattern of color transitions.

The examples that have been presented are of an illustrative nature. The solution of such problems as the identification of agricultural crops, the analysis of forest masses, investigation of the continental shelf and others requires a preliminary study of these objects' characteristics in the given natural illumination modes. The subsequent algorithmic support for the analytical procedures is reduced (in the simplest case) to selecting the parameters of the color windows (6), and when textural characteristics are used, to selecting the more complex analysis algorithms that are discussed (for example) in /7/.

In the automatic analysis process it is possible to use measurement modes to determine the relative or absolute content of elements of a given color in the image field (such as the areas illuminated in Figures 3a and b), measurement of the color coordinates of any image elements with subsequent conversion of the results into the standard MKOXYZ colorimetric system, measurement and registration of the two-dimensional color distributions $p(\bar{U}_1,\bar{U}_2)$ (color histograms) and color transition distributions $p(\delta\bar{U}_1,\delta\bar{U}_2)$, and detection and identification of objects (or their separate components) according to a set of color features and the calculation of their total number and relative content in the image.

For the solution of such specialized analytical problems as detecting objects of a given color and measuring their areas or color coordinates on a real time scale, it is possible to use the portable TVFTs-2 analyzer, a picture of which is shown in Figure 4 /not shown/.

The basic specifications of the TVFTs-2 are as follows: dynamic brightness range of investigated images -- at least 25 dB; number of distinguishable color gradations for a signal-to-noise ratio of 40 dB -- at least $5 \cdot 10^3$; absolute error in color coordinate measurement -- 0.01 relative units; error in measuring color areas greater than 2 percent of the grating's area -- no more than 3 percent; power consumption -- 20 W; color and area coordinate measurement time -- 20 ms; dimensions -- 370 x x 230 x 140 mm; weight -- 7 kg.

The color filtration methods that have been discussed are suitable not only for realization in the standard systems used in ground centers, but also make it possible to design equipment for the rapid analysis of multizonal information under actual flight conditions, with visualization on television screens of some of the basic parameters of images that characterize their color structure.

The use of these methods for the quantitative analysis of multizonal pictures in investigations of the Earth's natural resources can facilitate to a considerable degree the successful solution of national economic problems such as prospecting for oil, gas, gravel and sand on the continental shelf and studying the food potential of separate regions.

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COMPARATIVE ANALYSIS OF RADIOTHERMAL AND INFRARED IMAGES OBTAINED WITH AN ARTIFICIAL EARTH SATELLITE

Moscow ISSLEDOVANIYE ZEMLI IZ KOSMOSA in Russian No 1, Jan-Feb 81, manuscript received 22 May 80, pp 43-47

[Article by A.A. Vlasov, S.T. Yegorov and V.A. Plyushchev]

[Text] The simultaneous measurement of the distributions of natural thermal radiation in the infrared and superhigh-frequency bands of the electromagnetic spectrum is of great interest for the remote investigation of natural resources and the environment. Actually, the relatively great radiative capacities (~1) and irregularities of many forms of natural cover in the infrared band results in a low polarization dependence of the intensity of infrared radiation, while its sensitivity to changes in the thermodynamic temperature is quite high [1]. In the superhigh-frequency band the range covered by the change in radiative capacity is considerably wider (from 0.4 to 1). Therefore, although an infrared image describes the distribution of an investigated surface's thermodynamic temperatures to a high degree, a radiothermal image basically depicts the distribution of electrophysical parameters related to the material properties of the surface and the environment. These features of the infrared and superhigh-frequency bands result in a situation where the same sections of the surface and the environment appear to be different on infrared and radiothermal images produced simultaneously by an artificial Earth satellite [2-4].

The radiothermal and infrared images of the Earth's surface that are discussed in this article were taken by a "Meteor" satellite equipped with a scanning superhigh-frequency radiometer and an infrared receiver operating in the 8 mm and the 8-12 μm bands, respectively. The superhigh-frequency radiometer's surface coverage field was 700 km, with the dimensions of an element of resolution on the Earth's surface being 15 x 20 = 300 km^2. Separate black and white elements (or groups of them) in the images appeared as the result of malfunctions during the transmission of telemetric information from the satellite to the ground measuring points. A combination of lines gives a full description of the nature of each system's scanning process: a beam from the superhigh-frequency radiometer's antenna makes a conical sweep (arc-shaped lines), while a beam from the infrared scanner sweeps in a plane perpendicular to the plane of the orbit (straight lines). The radiothermal images are formed as the result of digital machine processing of the superhigh-frequency radiometric information, which includes signal calibration and synchronization, geometric and brightness correction, and plotting on a grid of geographic coordinates.

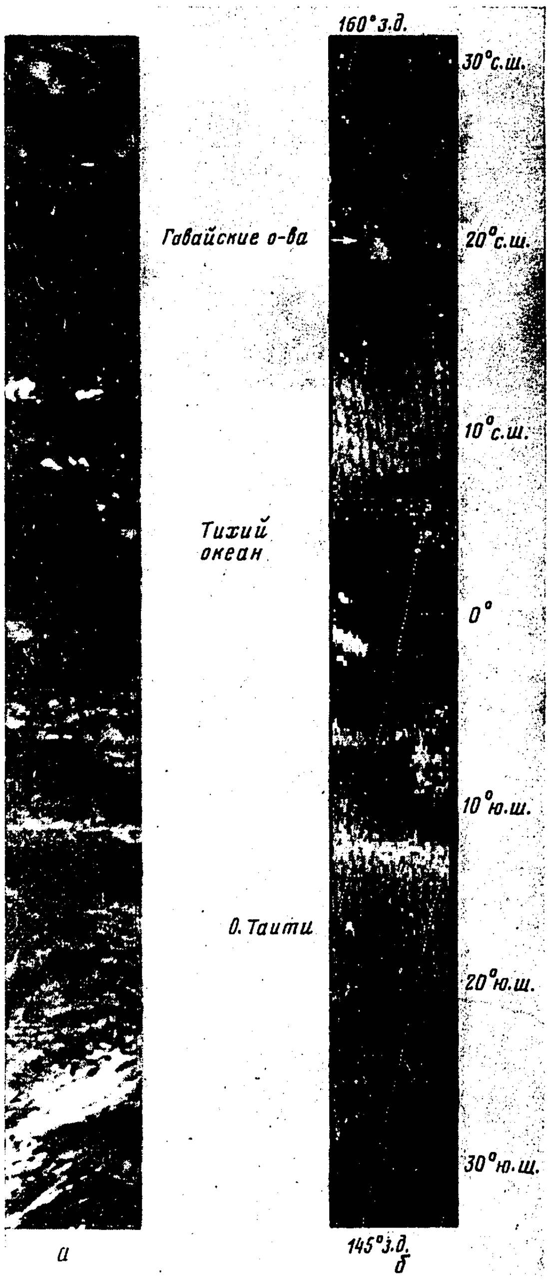

Figure 1. Synchronous infrared (a) and radiothermal (b) images of the Pacific Ocean's water area from 30° N.Lat. to 30° S.Lat in the 8-12 μm and 8 mm bands, respectively, as taken by the "Meteor" satellite.

Key:

1. Hawaiian Islands
2. Pacific Ocean
3. Tahiti

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Figure 1 contains synchronous infrared (a) and radiothermal (b) images of the Pacific Ocean from 30° N.Lat. to 30° S.Lat. In both images, the Hawaiian Islands are quite visible in the area of 20° N.Lat (as dark shading in the infrared image and light shading in the radiothermal image), with the largest island (Hawaii, with an area of 10,000 km²) is most clearly distinguishable. The island of Tahiti (1,000 km²) in the area of 20° S.Lat is distinguishable only on the radiothermal image, whereas in the infrared image it is covered by clouds.

The cloud formations are the matter of greatest interest in these images. The following factors were taken into consideration during their analysis. After digital processing, radiothermal images have eight gradations of brightness (the range of measurable radiobrightness temperatures is 140-300K, with the minimum reliable registerable contrast being 20K). However, allowing for distortions of the black-white scale during reproduction of such photographs, for a qualitative evaluation it is sufficient to operate with several halftones: dark, dark gray, light gray, light. In accordance with this sequence of halftones, on a radiothermal image the intensity of the clouds' radiothermal radiation increases as their content of water in liquid drop form does. For a quantitative determination of moisture content according to the radiobrightness temperature values corresponding to each gradation of brightness, it is necessary to use regression equations that describe the dependences of the radiobrightness temperature on the atmosphere's liquid drop water content [3] and on the intensity of falling rain [4]. An evaluation of the physical temperature at the upper edge of the cloud cover on the basis of infrared measurements makes it possible to form an opinion about its altitude. The scale of brightness gradations in infrared images has been chosen in such a fashion that lower-level cloud cover (up to 2 km) is depicted by a dark gray tone, middle-level cloud cover (2-6 km) by a light gray tone, and high-level cloud cover (above 6 km) by a light tone.

In the infrared and radiothermal images in Figure 1, in the area from the equator to Tahiti we see a cloud cover pattern with similar general features: the three light bands in the radiothermal image obviously correspond to heavy shower zones, while their gray tone in the infrared image enables us to assume that this is medium-level cloud cover. There is a sharp difference in the cloud cover pattern in the infrared and radiothermal images in the area from the equator to the Hawaiian Islands (in the radiothermal image, the solid, light cloud cover corresponds to a zone with moderate precipitation) and in the section to the south of Tahiti (in the infrared image, the light band most probably depicts a zone of cirrus clouds, whereas in the radiothermal image no traces of clouds are visible in this area).

Figure 2 contains infrared and radiothermal images of a diametrically opposite section of the Earth's surface from the equator to 50° S.Lat., which pictures were taken synchronously by the "Meteor" satellite on the same orbit. In both images, the coast of Africa is clearly visible from Somali on the equator to Mozambique in the south, but in the infrared image the land sections are represented by a gray tone, whereas in the infrared image in Figure 1 they appear to be dark. This is all explained by the fact that the satellite had moved out of the zone where the Earth was illuminated by sunlight (land is warmer than the water surrounding it) and was moving over the Earth's dark side (land is colder than water). In the radiothermal images in Figures 1 and 2, land is represented by a single tone -- light -- since radiothermal images basically depict the distribution of the

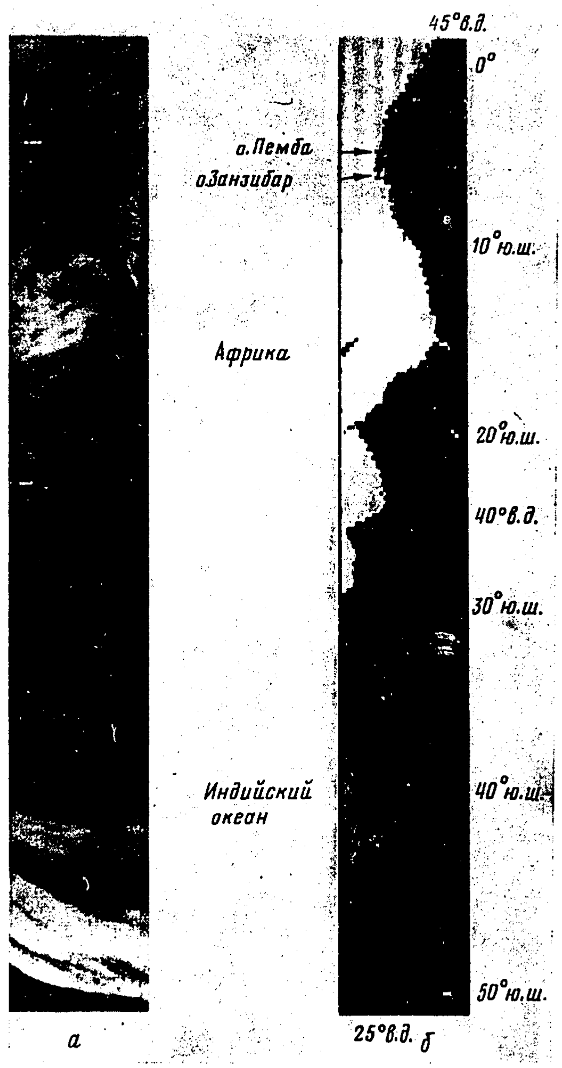

Figure 2. Synchronous infrared (a) and radiothermal (b) images of the east coast of Africa from the equator to 50° S.Lat. in the 8-12 μm and 8 mm bands, respectively, as taken by the "Meteor" satellite.

Key:

1. Pemba Island
2. Zanzibar
3. Africa
4. Indian Ocean

the surface's electrophysical properties and daily changes in the thermodynamic temperature are less than the minimally measurable contrast in radiobrightness temperature (20K). Relatively small sections of dry land, such as Pemba Island (1,000 km^2) and Zanzibar (1,600 km^2) near the African coast in the region of 5° S.Lat., 40° E.Long., can be detected positively in the radiothermal image, but in the infrared image they are masked by clouds.

In this case the cloud cover pattern in the radiothermal image differs substantially from what is seen in the infrared image. In the first place, in the infrared image almost all the water area of the Mozambique Channel is covered with different types of clouds (for example, upper-level clouds with a low water content in the area of 10° S.Lat. that are noticeable even against the land background, since their temperature is considerably lower than that of the land surface). In the radiothermal image we can see clearly only the part of this cloud cover to the east of the African coast that has a higher content of liquid-drop water. In the second place, in the radiothermal image the cloudy zone over the Indian Ocean in the area from 30° S.Lat. to 50° S.Lat. is expressed only by longitudinal light (intense precipitation) and oblique gray (moderate precipitation) bands, whereas different types of cloud cover are seen in this area in the infrared image. In all probability, the two light bands in the lower part of the infrared image represent cirrus clouds through which the contours of the medium- and low-level cloud cover shows quite clearly.

As a result of the comparison of infrared and radiothermal images obtained with the "Meteor" satellite, the following conclusions can be drawn:

1. In many cases, dry land sections can be distinguished much better in radiothermal images than in synchronous infrared images. This applies, in particular, to the discrimination of small sections of land amounting to only several resolvable elements (islands from 600 to 2,000 km^2 in size). Although land sections are represented by a certain tone in a radiothermal image, in an infrared image they can be represented by different tones on the same orbit, depending on whether the satellite is over a sunlit section of the Earth's surface or on its shaded side.

2. Analysis of a radiothermal image makes it possible to determine the location of zones of precipitation and to make an approximate evaluation of the cloud cover's water content, while analysis of a synchronous infrared image makes it possible to establish the altitude of its upper boundary. A comparison of infrared and radiothermal images makes it possible to distinguish clouds with a very low moisture content in an entire cloud cover field.

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RADIOPHYSICAL METHODS FOR SOUNDING THE ATMOSPHERE AND THE OCEAN'S SURFACE FROM SPACE

Moscow ISSLEDOVANIYE ZEMLI IZ KOSMOSA in Russian No 1, Jan-Feb 81 (manuscript received 21 May 80) pp 63-70

/Article by A.S. Gurvich, S.T. Yegorov and B.G. Kutuza, Institute of Physics of the Atmosphere and Institute of Radio Engineering and Electronics, USSR Academy of Sciences, Moscow/

/Text/ Radiophysical investigations of the atmosphere and the underlying land and sea surface were begun in 1968 by an experiment utilizing the "Kosmos-243" artificial Earth satellite. Since then there has been a series of satellite experiments conducted by both the Soviet Union and the United States that have proven the effectiveness of radiophysical methods in investigations of our surrounding natural environment.

In comparison with waves in the optical band, radio waves make it possible to obtain new information about the state of the atmosphere and the underlying surface. In satellite measurements, the radiophysical methods used normally involve both active and passive sounding: superhigh-frequency radiometry and radar. In comparison with the traditional optical methods, radiophysical methods have an advantage that is related to the ability of radio waves to penetrate clouds, precipitation and soil covers. The dependence of the atmosphere's optical thickness on meteorological conditions creates the prerequisites for determining the parameters of atmospheric formations affecting absorption, scattering, reflection and emission characteristics.

At the same time, where observations in the optical band are concerned, because of the strong scattering and absorption it is essentially impossible to obtain any information about the parameters of the atmosphere and natural objects either in clouds or beneath them.

Satellite radiophysical investigations of the atmosphere and the underlying surface utilize radio waves in the millimeter, centimeter and decimeter bands. The circle of problems solvable in these experiments depends primarily on the spectral bands that are used, spatial resolution, the field of view and the absolute accuracy of the measurement of the incoming signal's intensity.

The superhigh-frequency radiometry method for studying natural objects is based on the reception of the intrinsic thermal radiation of the objects and utilizes relationships that connect the characteristics of radio-frequency emissions with the medium's parameters. The intensity of the radiothermal radiation of the atmosphere and the underlying surface is measured by superhigh-frequency radiometers. The flow of the Earth's radio-frequency emission that is received by these devices consists of three components: 1) a flow of radiation from the layer of atmosphere lying between the spacecraft and the Earth's surface; 2) a flow of radiation from the underlying surface that has been attenuated by absorption in the atmosphere; 3) a flow of atmospheric radiation that has been reflected from the Earth's surface.

The extent of the effect of individual geophysical parameters on the Earth's radiobrightness temperature changes substantially with respect to the wavelength band. The radio-frequency emissions from the system "atmosphere-underlying surface" depends on the observation angle and is polarized to some degree. Multiwave and polarization measurements make it possible to separate the components indicated above and to determine geophysical parameters by solution of the inverse problem.

The Earth's radiothermal emissions were first measured from space by the "Kosmos-243" satellite in 1968 /1/ and the program was continued by the "Kosmos-384" in 1970. Analogous research began in the United State in 1972, when the "Nimbus-5" satellite was launched, and continued with other units: "Skylab" (1973), "Nimbus-6" (1975), "Geos-3" (1976) and "Seasat-A" (1978) /2-6/. Superhigh-frequency radiometric investigations of the Earth's surface and atmosphere were carried out with Soviet satellites of the "Meteor" series in 1974, 1976 and 1977, as well as the "Kosmos-669, -1076 and -1151" and "Interkosmos-20" satellites. In particular, in the space experiments listed above the following characteristics of the atmosphere and ocean were obtained:
the atmosphere's water vapor content and its distribution above the oceans;
the water content of drop-type clouds and its latitudinal distribution above the oceans;
data on the altitudinal temperature profile and its latitudinal variability;
estimates of the intensity of precipitation;
data on the distribution of temperature on the surface of the world ocean;
the state of the ocean's surface (determination of regions with storms and floating ice, wave action, wind velocity);
the state, solidity and boundary of ice fields.

Let us examine in more detail some of the results obtained with Soviet satellites. Superhigh-frequency radiometric equipment installed in the "Kosmos-243" and "Kosmos-384" satellites made it possible to receive emissions from the "atmosphere-underlying surface" system on wavelengths of 0.8, 1.35, 3.4 and 8.5 cm. The fluctuational sensitivity of the radiometers on the first two channels was 1 K for a time constant of 1 s. The radiometers' antennas were aimed at the nadir. The linear size of the section of surface that fell into the antenna's field of view on 8.5 cm was ~50 km, while for the other wavelengths it was ~20 km. The radiometers' temperature scales were calibrated with the help of a noise generator that was periodically connected to the input channel instead of the antenna. As a reference signal the modulation radiometers used the emissions of the cosmic background, which were picked up by small horns.

Joint processing of data on the radiobrightness temperature on four wavelengths made it possible to determine the values of the ocean surface's temperature, the total mass of water vapor, and the integral water content (water reserve) of the

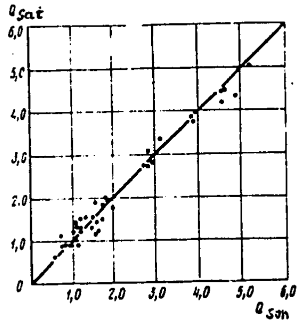

Figure 1. Comparison of results of water vapor content in the atmosphere on the basis of satellite (Q_{sat}) and radiosonde (Q_{son}) measurements.

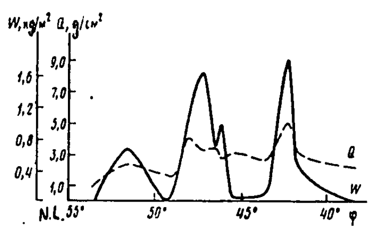

Figure 2. Water vapor (Q) and condensed moisture (W) content in the atmosphere along the satellite's trajectory above the Atlantic Ocean.

clouds along the projection of the satellite's orbit. In this first experiment, the accuracy of the measurement of the ocean surface's temperature was 1-3 K. The equipment's technical capabilities retain a considerable reserve for improving the temperature determination accuracy, and the goal of the oceanographers and radiophysicists is to realize these possibilities on the basis of special oceanological satellites, with due consideration for the actual conditions of wave propagation in the atmosphere and the variability and spectral features of the ocean surface's emissions.

The root-mean-square error in the determination of the total mass of water vapor over the oceans was 0.2 g/cm^2. An idea of the accuracy of the measurements can be gained by looking at Figure 1, which is a comparison of remote (from the "Kosmos-243" satellite) and terrestrial (radiosonde) measurements of the total amount of water vapor at a point under the satellite. It should be emphasized that these data were obtained both in the absence and presence of cloud cover. The relative accuracy of the measurement of the clouds' water reserve proved to be 30-50 percent. Such accuracy made it possible to differentiate 10-15 gradations in meteorological fields. The crossing of atmospheric fronts is registered particularly well. Figure 2 contains data on the total mass of water vapor and the water reserve of clouds in the North Atlantic, as derived from measurements made by the "Kosmos-243." It was possible to register reliably a change in the condensed moisture content during the crossing of three frontal interfaces, the positions of which match with satellite images of the cloud cover in the infrared and visible bands.

Radiometric measurements of the qualitative characteristics of the atmosphere and the underlying surface agree quite well with television and infrared images. The results of the daily measurements made by the "Kosmos-243" were used to compile maps of isolines of the total water vapor mass and the latitudinal pattern of the water reserve of clouds over oceans /7,8/.

Information on the characteristics of the ocean's surface has been obtained primarily on the basis of the results of measurements of radio-frequency emissions on wavelengths of 3.4 and 8.5 cm. Joint correlational analysis of superhigh-frequency radiometric data made it possible to detect storm regions and floating ice zones distinctly through cloud cover. Radiometric data gathered by the "Kosmos-243" were used to determine the contours of floating ice zone boundaries and the solidity of these zones. A low value was discovered for the radiative capacity of ice

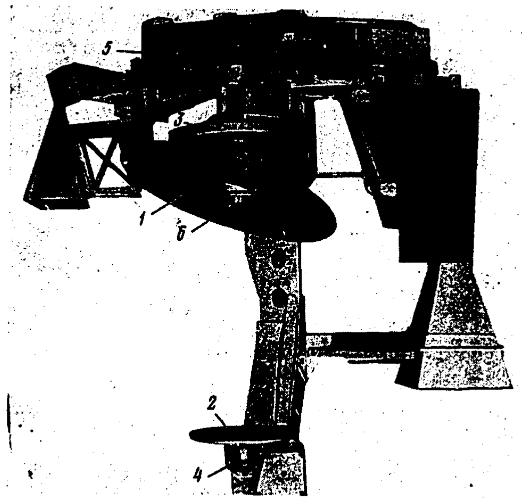

Figure 3. Overall view of radiometric equipment used on the "Meteor" satellites: 1. parabolic mirror; 2. small, flat mirror; 3. parabolic mirror gearhead; 4. electric motor for small mirror's drive; 5. high-frequency part of 8-mm channel; 6. receiving horn of 8-mm channel.

formations on the continental part of Antarctica. A quantitative description of this effect, based on an allowance for scattering by irregularities in the firn, was given in /9,10/. It is necessary to consider effects related to scattering when analyzing data from observations of floating ice, when a significant snow cap can form on them at low temperatures.

In "Meteor" series satellites, the superhigh-frequency radiometric equipment also operated on wavelengths of 0.8, 1.35 and 8.5 cm. However, in contrast to the equipment in the "Kosmos" series of satellites, the 0.8-cm channel was intended for obtaining two-dimensional maps depicting the distribution of radiothermal radiation in the "atmosphere-underlying surface" system /11/.

Figure 3 is a photograph of the superhigh-frequency radiometric equipment used on satellites in the "Meteor" series. The scanning antenna for the 8-mm band is constructed according to a two-mirror plan. Parabolic mirror 1 forms a beam about 1° wide at an angle of 40° to the nadir. Rocking of this mirror around a vertical axis results in movement of the beam along a cone within limits of ±40° in projection onto the horizontal plane and forms on it arc-shaped lines that are each 4 s in duration. Small flat mirror 2 completes the scanning on a doubled frequency, within limits of ±1°, in order to correct distortions in the array formed by the arc-shaped lines. The parabolic mirror is moved by an electric motor, through reduction gear 3. The small flat mirror is moved by independent electric motor 4. The two electric drive motors are synchronized with each other by a special electronic circuit. The 8-mm channel's high-frequency part 5 is located near the large antenna and connected to receiving horn 6.

A single element of resolution on the Earth's surface measures 20 x 30 km. The number of elements of resolution along the scanning arc is 53. With a receiver sensitivity that is 0.5 K when reduced to a time constant of 1 s, the scanning channel's dynamic sensitivity for these conditions is 20 K. In connection with this, up to 8-10 gradations can be realized on a radiothermal image.

The other details on the photograph belong to the nonscanning channels on wavelengths of 1.35 and 8.5 cm.

Figure 4 is a fragment of a radiothermal map obtained with a "Meteor" satellite on 28 September 1976, and depicts a strip of the Earth's surface that is about 1,000 km wide along the projection of the satellite's trajectory from the Taymyr Peninsula in the upper part, through the Bering Strait in the central section, to 35° N.Lat. in the Pacific Ocean at the bottom of the strip.

The radiothermal image is easy to tie in with geographic coordinates because of the very visible shores of the continents and islands, surrounded by open water. In this image, we can use as orientation points the islands of Anzhu, Chukotka and Alaska, with the Bering Straits between them, as well as the characteristic features of the Aleutian Islands.

The image shows quite clearly the visible boundaries of the autumn Arctic ice fields in the Laptev, East Siberian and Chukotskiy Seas, as well as up to five gradations of radiobrightness that correspond to different degrees of solidity of the ice fields.

Atmospheric formations are clearly visible: cloud cover to the north and south of the Bering Straits, a cyclonic vortex to the south of the Aleutian Islands, and cloud cover with precipitation on the bottom edge of the map. Such important details of atmospheric formations correspond to thick cloud cover with rain, but they are covered with a higher layer of clouds and so cannot be seen in images obtained in the visible and infrared bands by this satellite.

The first measurements of the atmosphere's radiation in the submillimeter band were made by the "Kosmos-669" satellite /12/. This experiment made it possible to distinguish the structure of the spatial distribution of water vapor in the upper part of the troposphere and the stratosphere and to note its special features in connection with the most powerful meteorological processes.

The American "Nimbus-5" and "Nimbus-6" satellites were put into orbit in December 1972 and June 1975, respectively. In addition to other equipment, they carried two instruments for passive sounding in the superhigh-frequency band: a 5-channel trace-type radiospectrometer (with frequencies of 22.235, 31.4, 53.65, 54.9 and 58.8 GHz) and a scanning radiometer on wavelengths of 1.55 ("Nimbus-5") and 0.8 ("Nimbus-6") cm. The radiospectrometer's sensitivity was 0.5-0.8 K for a time constant of 1 s. The accuracy of the measurement of the surface temperature, the clouds' water reserve and the total mass of water vapor proved to be about the same as in the experiments with satellites in the "Kosmos" series /13/, while the spatial resolution was worse by approximately an order of magnitude, because of the high altitude of the orbit.

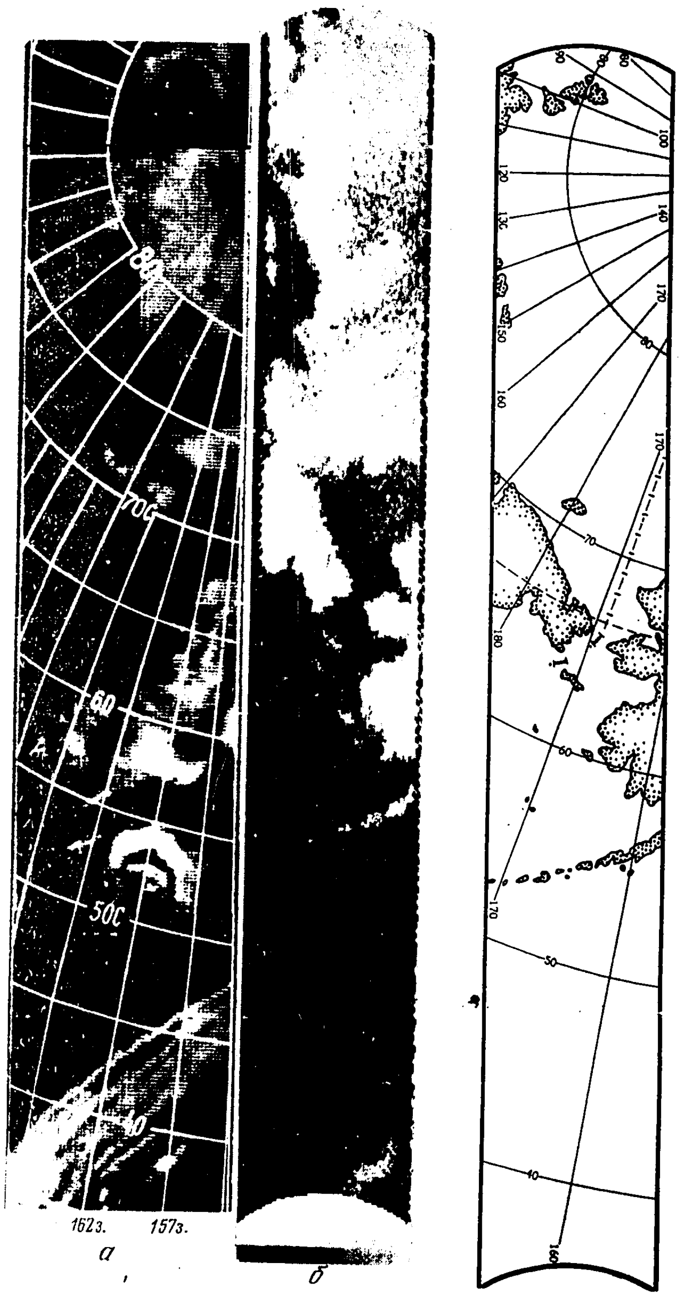

Figure 4. Infrared (a) and radiothermal (b) images of a section of the Earth's surface, taken synchronously by a "Meteor" satellite, and a geographic map section corresponding to them (c); the dotted line on the map marks the scaning band.

The radar method is based on the analysis of signals reflected from natural objects and uses relationships connecting the characteristics of back scattering to the physical parameters of objects.

The radar method was used in experiments with the "Skylab" station and the "Geos" and "Seasat-A" satellites. Two radar instruments were installed in "Skylab": a scatterometer (for measuring the back scattering value) and a precision radio-altimeter operating on a frequency of 13.9 GHz. The antenna unit made it possible to carry out mechanical beam scanning in two orthogonal directions in a sector of $\pm 50^{\circ}$. The width of the antenna's main lobe was 1.5°. The relative accuracy of the measurement of the surface's profile by the altimeter was $\sim$1 m.

As a result of the measurements made by "Skylab," it was shown that it is possible to determine the wind velocity above the surface of water areas within limits of 0-20 m on the basis of the amount of back scattering from the agitated surface of the sea. The accuracy of the wind speed evaluation on the basis of back scattering measurements is $\sim$10 percent. For example, the altimeter was used successfully to record the Puerto Rican depression, the gravitational anomaly of which is manifested in a lowering of the average sea level by about 10 m. A comparison of the heights determined by the altimeter with topographic heights of areal contours, which was carried out over different sections of the United States, showed that there is a good match between data gathered by remote and direct measurements.

The "Seasat-A" satellite was launched on 26 June 1978 into an orbit with an altitude of 800 km. Three instruments for active sounding of the sea surface were installed in it: a radar set with a synthesized aperture (SAR), a scatterometer (SASS) and a precision altimeter. Besides this, there were also instruments for obtaining images of the Earth in the optical and infrared bands and a five-channel scanning superhigh-frequency radiometer.

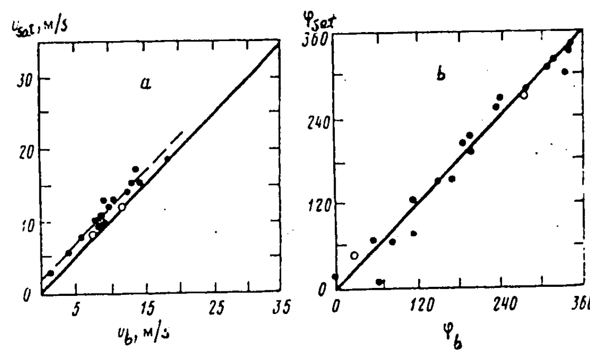

Figure 5. Comparison of measurements with a satellite (v_{sat}, φ_{sat}) and with the help of buoys (v_b, φ_b): a = wind speed, b = wind direction φ.

The SAR instrument operates on a wavelength of 23.5 cm. The field of view of the surface equals 100 km, while the spatial resolution is 25 m. This instrument has been used to investigate currents (primarily the Gulf Stream), subsurface and ocean waves, and sea ice. The scatterometer's operating frequency is 14.6 GHz and its spatial resolution is 50 km. This instrument's basic purpose is to determine the wind speed at the surface of the sea. Figure 5 contains data that make it possible to compare the results of measurements of wind direction and velocity from a satellite and with the help of buoys at a point under the satellite /14/. It is easy to see the good match between the data on the remote and direct measurements. The altimeter makes measurements on a frequency of 13.6 GHz and has a transceiving antenna 1 m in diameter. This instrument makes it possible to measure the height of ocean waves with an accuracy of 0.3 m. The radar with the synthesized aperture was used to obtain images of a number of areas in the North Atlantic, the Gulf Stream and Canada on which current outlines, ocean waves, ice and other features were clearly delineated.

Radiation measurements made by the five-channel radiometer made it possible to determine the distribution of surface temperatures with about 1.5° accuracy in the absence of storms and intense precipitation.

The investigations of the Earth's atmosphere and surface that have been conducted in the last 12 years with the help of superhigh-frequency radiometers and radar sets installed in satellites have demonstrated the considerable capabilities of radiophysical methods in studying our surrounding environment. Radiophysical methods of studying the Earth from space are far from being exhausted, and in the near future we should expect new and interesting results to be obtained in this field. In studies of thermal radiation, progress is connected to the creation of scanning antenna systems and the possibility of measuring the emissions from a section of the surface simultaneously on four or more wavelengths and in two polarizations. It is necessary to improve the fluctuational sensitivity of superhigh-frequency radiometers to 0.1 K for a time constant of 1 s and with a spatial resolution capability of up to 2-5 km. This will make it possible to distinguish, for example, individual ice and cloud formations and the details of rain foci, in addition to tracking the dynamics of wave action and atmospheric processes in meteorologically dangerous areas. There is a great deal of interest in synchronous, multiwave measurements of thermal radiation not only in the superhigh-frequency band, but also in the submillimeter and infrared bands.

The development of active radiophysical methods for the remote sounding of the Earth's natural resources from artificial Earth satellites requires a reduction in the size and weight characteristics of the equipment, a lowering of its energy requirements, and the improvement of data processing and interpretation techniques.

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EXPERIMENTAL MULTIZONAL AEROSPACE SURVEYS FOR THE STUDY OF NATURAL RESOURCES IN CUBA

Moscow ISSLEDOVANIYA ZEMLI IZ KOSMOSA in Russian No 1, Jan-Feb 81 pp 118-120

/Article by L. Fernandez/

/Text/ In the Republic of Cuba, problems related to conserving and improving the environment and making rational use of natural resources have acquired more and more urgency in recent years. In the directives promulgated by the 1st Congress of the CP of Cuba for the 5-year plan of development of the national economy for 1976-1980, a great deal of importance was attached to these nationwide problems. Special attention was given to the study of soil erosion and salinization, the pollution of subterranean, surface and sea water, and degradation of flora and fauna.

The "Theses and Resolutions" adopted by the congress provide for the implementation of investigations of natural resources using the newest scientific and technical equipment, among which aerospace surveys occupy an important place as being the most progressive method for investigating natural resources. In accordance with this, within the framework of the "Interkosmos" program a working group was set up in Cuba to study natural resources with the help of aerospace facilities and a special "Remote Sensing" subprogram was approved within the framework of CEMA. The members of the working group include specialists from the Cuban Academy of Sciences, the Ministry of the Mining Industry and Geology and the Cuban Institute of Geodesy and Cartography.

The most important goal that was formulated is an evaluation of the capabilities of remote sensing for studying natural resources under the subtropical conditions present in Cuba, with special emphasis on the development of techniques for obtaining and processing multizonal photographs, determining the zones of the spectrum with the greatest information content and so on. In connection with this, the group defined more precisely those problems for the solution of which it is feasible to use aerospace surveys and worked out a program for their realization that stipulates, during the first stage, the conduct of multizonal aerial surveys in order to develop the technology for obtaining, processing and using aerospace information. In accordance with this program, the first scientific experiment -- "Tropik-1" -- with multizonal aerial photographic surveying in the visible and near infrared bands was performed in 1977.

Among the basic problems solved in the course of the experiment, we will mention the following:

interpreting sugar cane fields and determining their state at different stages of development;
determining possible foci of agricultural crop diseases;
determining soil types and their basic characteristics (moisture content, temperature, salinity);
establishing the relationships between plant formations and the main elements of the landscape;
studying marine currents and sedimentary processes in the platform zone;
studying river beds that are developing under conditions of karst and differentiated relief.

Different organizations and departments involved in the national economy of Cuba took part in the preparations for the experiment, as well as the USSR Academy of Sciences' Institute of Space Research.

The experiment involved the use of a synchronously operating system of AFA-39 cameras, which have a focal length of 100 mm and a frame size of 70 x 80 mm. The survey was conducted on a scale of 1:45,000. Type 17 isopanchromatic film was used for surveying in the visible band of the spectrum. Different light filters ($\lambda_1 = 480$ nm; $\lambda_2 = 550$ nm; $\lambda_3 = 660$ nm; $\lambda_4 = 710$ nm) were used in connection with this; I-480 film was used for surveying in the near infrared band. In addition to the AFA-39 unit, there were also cameras with focal lengths of 50 and 100 mm that had a photograph format of 18 x 18 cm. These surveys, which are being used for the planned correlation of the multizonal photographs, were made with spectrozonal and panchromatic film. The multizonal surveying was conducted on key sections within test ranges; in order to investigate changes in the reflective capability of objects, the routes were set up in different directions and with different Sun positions.

The studies were carred out on four test ranges located in the physicogeographical regions that are most characteristic of Cuba, including part of the water area adjacent to the island.

The first range is located in northwestern Cuba, in Pinar del Rio Province. This range encompasses part of the Los Organos Mountains, where there are large masses of pine growth and interesting geological structures that extend right out to the shelf zone.

The second range is located along the northern coast from Havana to Varadero in Matanzas Province; on the south it includes a large variety of agricultural crops, a wide band of shore plant growth and the shelf zone.

The third range is in the central part of Cuba, in Los Villas Province. This range includes a large number of types of vegetation and interesting geomorphological objects.

The fourth range lies in northeastern Cuba, in Oriente Province, where there are nickel and iron deposits.

Multifaceted ground investigations were carried out in the key (standard) sections of each range. The dimensions of these sections were determined so that they could be easily recognized on the space photographs. Within the key sections, the objects of the survey were geological formations, soils, vegetation, agricultural crops, shore zones, water areas and other natural and anthropogenic objects.

A number of research and practical projects were realized on the basis of the materials that were obtained. The most informative bands of the spectrum for the interpretation of a large group of objects were determined. For example, on photographs in the 500-600 nm band, banks, shoals and underwater beds, channels and canyons were clearly visible in shallow-water sections in the northwestern part of Pinar del Rio Province. Large accumulations of seaweed and marine vegetation were also easy to recognize in the photographs of this zone. The distribution of river burden near river deltas shows up quite clearly. Photographs taken in the 600-700 nm band are notable for their high spatial resolution and have proven to be the most suitable ones for determining fine contours. Planted areas, forest masses and mangrove-type shore vegetation can be identified quite well in them. The shoreline of rivers, lakes, reservoirs and the sea can be seen quite clearly in infrared photographs (the 700-800 nm band).

Multizonal aerial photographs have been used to decipher basic types of soils and their boundaries. These results were used to refine a fragment of the soil map for the Havana area.

The first space photographs of Cuba, which were presented to us by the Soviets, were used for practical purposes. Using these materials and standard photogrammetric equipment, photomaps with a scale of 1:250,000 were produced. These maps made it possible to renovate the topographic foundation for the compilation of a series of thematic maps in the least possible time. Besides this, space photographs enlarged to scales of 1:100,000 and 1:50,000 were compared with topographic maps on the same scales. The results of the comparison of the photographic and cartographic materials showed that because of the high resolution and significant territorial coverage, space photographs can be used successfully to renovate the scale series of topographic and thematic maps of Cuba.

The amount of information accumulated during the first multizonal experiment proved to be much greater than our capabilities for processing it. Therefore, the second experiment (in 1978) covered a limited area. The routed multizonal surveys were conducted in the western part of Cuba, in the most thoroughly studied key sections. Multizonal surveys made at different times over a 1-year interval made it possible to investigate the dynamics of several natural and socioeconomic objects.

Our experience in processing experimental materials indicates that there are great prospects for using multizonal aerospace surveying to study Cuba's natural resources.

The scale of the implementation of the assignment for the integrated study of Cuba's natural resources requires the close cooperation of the scientific and production organizations of a number of ministries and departments. The Academy of Sciences of the Republic of Cuba and the Cuban Institute of Geodesy and Cartography have divided between themselves the sphere of activity in the field of using remote methods to study natural resources and the surrounding environment. The Academy of Sciences is directing its efforts to the solution of scientific and theoretical problems; that is, to the development of fundamentally new methods and facilities for obtaining, processing and utilizing aerospace information. The Institute of

Geodesy and Cartography is concentrating its efforts on applied research and the introduction of the results obtained into the practices of the national economy. The Institute will carry out the primary processing of the photographic information and, in collaboration with other departmental organizations, will realize the integrated mapping of natural resources by creating a series of interrelated thematic maps.

A unified interbranch program for the integrated utilization of space information is being set up to carry out and coordinate this work in Cuba.

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AEROSPACE RESEARCH IN THE POLISH PEOPLE'S REPUBLIC: THE 'ZEMLYA' EXPERIMENT

Moscow ISSLEDOVANIYE ZEMLI IZ KOSMOSA in Russian No 1, Jan-Feb 81 pp 121-123

/Article by M. Germashevskiy and R. Kachin'ski/

/Text/ During the flight of an international crew, consisting of Soviet and Polish cosmonauts, on board the "Salyut-6" orbital station, in July 1978 an experiment was performed as part of the "Remote Sounding of the Earth From Space" program. This experiment, which was entitled "Zemlya," was prepared by Polish scientists and specialists with help from specialists from the USSR and consisted of two parts: "Telefoto-78" and "Okean."

The basic goal of the "Zemlya" experiment was to photograph certain sections of the Earth's surface and the ocean with the MKF-6M multizonal space camera and to make visual observations of processes taking place on the Earth's land and water surfaces.

Let us turn our attention to the basic results and conclusions obtained as the result of the processing of materials from the "Telefoto-78" experiment.

The main purpose of the "Telefoto-78" experiment was to determine the possibility of using multizonal aerospace photographs taken at different altitudes by different surveying systems for the benefit of agriculture, conservation, geology, forestry and for cartographic purposes, as well as for the benefit of other branches of the national economy and the Earth sciences.

The objects investigated were test sections, scientific test ranges and separate regions in the PNR /Polish People's Republic/.

The performance of the "Telefoto-78" experiment was preceded by a large amount of preparatory work that consisted of selecting the regions to be investigated, analyzing the available cartographic materials and physicogeographic and other descriptions, compiling thematic maps (on a scale of 1:25,000) of geological, geomorphological and soil complexes, hydrographic features and agricultural crops, and selecting and analyzing other thematic materials and documents. Space photographs of the PNR's territory obtained with the "Landsat" satellite were also used.

During the experiment the following operations were performed: a) from the "Salyut-6" in orbit -- multizonal photographic surveying with an MKF-6 camera; b) from an altitude of 10,000 m -- black-and-white aerial photographic surveying; c) from an altitude of 6,500 m -- multizonal aerial photographic surveying with MKF-6 and MB-470 NAC cameras, telephotometric surveying with an S-500M multispectral scanning system, and topographic black-and-white aerial photographic surveying; d) from an altitude of 4,500 m -- topographic black-and-white aerial photographic surveying; e) from an altitude of 2,500 m -- multizonal aerial photographic surveying with the MKF-6 and MB-470 NAC cameras and topographic black-and-white aerial photographic surveying.

The surveys from the altitudes of 2,500-6,500 m were conducted with an AN-30 laboratory airplane belonging to the USSR Academy of Sciences' Institute of Space Research.

While the aerospace surveys were being conducted, there were simultaneous ground meteorological and soil moisture measurements, a description of the types and state of agricultural crops, and a determination of their spectral reflection coefficients using ground-based spectrometers.

The conduct of such an extensive experiment in remote sounding in Poland for the first time became possible because of the "Interkosmos" program and the active participation of scientists and specialists from the USSR Academy of Sciences" Institute of Space Research, the Bulgarian Academy of Sciences' Central Laboratory for Space Research, the GDR Academy of Sciences' Central Institute of Physics of the Earth and Institute of Electronics, the Azerbaijan SSR Academy of Sciences' Institute of Space Investigation of Natural Resources, the Polish Academy of Sciences' Center for Space Research, the Universities of Warsaw, Vrotslav and Poznan', and the Polish Institute of Geodesy and Cartography (IGiK).

Some Results of the Processing and Interpretion of the Space Photographs. At the IGiK there was an investigation of the possibility of using the space photographs obtained with the MKF-6M camera for cartographic purposes. The initial material used was photographs of the southern part of Poland on a scale of 1:2,652,000. As a result of the comparison of the coordinates of control points identified in the photographs and on a 1:200,000 topographic map, it was found that the accuracy was on the order of $m_x \cong m_y \cong \pm 50$ m; $m_z \cong \pm 60$ m.

There was also a study of the possibility of creating a topographic map on a scale of 1:200,000 by the stereophotogrammetric method, using as the original material negatives that had been obtained with the MKF-6M and enlarged to a scale of 1:1,000,000.

On the basis of the interpretation of the synthesized images produced on an MSP-4 and an AC-90 NAC, as well as an MCDS 4200 EPNAC electronic analog system, the following results were obtained:

a map of the forests of Silesia and the Krakovsko-Chenstokhovskaya upland was created (images from channels 3, 4 and 6 were used) on a scale of 1:200,000, with division into coniferous and deciduous forests, it being the case that within the coniferous forests sections heavily damaged by industrial effects were distinguished;

the nature of the utilization of the lands in the "Shroda-Shlenska" test range was evaluated.

As a result of the interpretation of the synthesized images, it was possible to distinguish the following classes: gardens and forests, grain crops, cultivated fields, cultivated crops and meadows, populated points. A land use map has been compiled, on which the following features are distinguished: mixed, coniferous and deciduous forests, meadows, scattered rural economies, large-scale rural economies with a predominance of cultivated crops, large-scale economies with a predominance of grain crops, cities, rivers, lakes, communication lines and, in the Vrotslov region, its center with the continuous built-up area and suburban regions with intermittent buildings.

Some Results of the Processing and Interpretation of Photographs Taken From the Airplane. On the basis of the interpretation of the multizonal aerial photographic surveys carried out with the MKF-6M and MB-470 NAC cameras, the following problems were solved: the possibility of identifying different types of cultivated crops was evaluated; the crop structure and state of utilization of the land in the "Shroda-Shlenskaya" test range were determined; the possibility of using multizonal aerial photographs for identifying types of cultivated plants was analyzed; varieties of standing timber were defined; a method for creating a topographic map on a scale of 1:25,000 by the stereophotogrammetric method, using photographs taken on different channels, was developed.

There was also processing of scanner images recorded on magnetic tape, and their cartometric value was determined; the possibility of distinguishing objects with different reflection coefficients on the basis of the interpretation of multizonal photographs obtained under laboratory conditions was analyzed.

Conclusions. All of the surveying and measurement materials obtained during the "Zemlya" experiment were used successfully for scientific purposes and for the benefit of different branches of the national economy, although the period during which the experiment was conducted was not optimum for the solution of many problems.

The extensive surveying material on several test sections and ranges that was obtained from different altitudes with different equipment made it possible to do a study on the utilization of optimum equipment for obtaining data on the Earth's surface for the solution of different scientific and economic problems.

The multizonal space photographs obtained with the MKF-6M proved to be effective during interpretations for geological and hydrological purposes and the definition of forest complexes and less effective during interpretation for agricultural purposes, particularly in areas with intermittent economies, of which there are a significant number in the PNR.

A multizonal aerial photograph scale of 1:50,000 is sufficient for the solution of most problems concerning Poland's national economy. The use of equipment available at the IGiK made it possible, during the processing, to classify these pictures according to the spectral features of winter barley, sugar beets and rye with an accuracy on the order of 90 percent.

The multizonal aerial photographs obtained with the MKF-6M camera made it possible to differentiate six classes of land use: built-up areas, forests and green space, water areas, unproductive land, agricultural territories with intermittent economies, agricultural territories with large-scale economies.

A comparison of the interpretation opportunities afforded by photographs taken with the MKF-6M and MB-470 NAC cameras shows that multizonal photographs in the narrowest bands of the spectrum (MKF-6M) are more suitable for analyzing the structure of cultivated agricultural crops than photographs with broad spectral bands (MB-470 NAC).

The S-500 m multispectral scanning system, which was installed in the airplane and features magnetic tape recording of data within narrow spectral bands makes it possible to obtain extensive information on phenomena taking place in the area being photographed. Such information can be processed on analog and digital units utilizing computers, which reduces the processing and interpretation time substantially. However, in order to make complete use of the information reserve contained in a scanner image, it is necessary to carry out further investigations involving the determination of the spectral characteristics of different objects. The geometrical accuracy of scanner images makes it possible to use them as original material for the compilation of thematic maps.

The use of aerial and space multizonal photographs for the interpretation of phenomena occurring on Earth makes it possible to achieve a significant reduction in time and expense in comparison with direct observations of an area, as well as to obtain qualitatively new information on the state of investigated objects and phenomena that it is impossible to obtain using traditional methods and equipment.

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SPACE SHUTTLE PROGRAM: POLITICAL AND LEGAL PROBLEMS

Moscow SOVETSKOYE GOSUDARSTVO I PRAVO in Russian No 4, Apr 81 pp 86-94

[Article by A. I. Rudev, candidate of juridical sciences]

[Text] The creation of reusable transport systems is one of the areas of development of space engineering. The basic element of these systems providing for the insertion of payloads into orbit, the assembly and servicing of space objects in orbit, and, if necessary, return of them to earth for repair and reuse is coming to be the reusable transport spacecraft (MTKK) capable also of functioning as a small orbital station. Having the capability of maneuvering in orbit, gliding descent and broad lateral maneuvering in the atmosphere, the MTKK will increase the role of man in space operations, reduce the material expenditures on inserting a payload in space and permit elimination of the presently used nonrecoverable booster rocket.

Space Shuttle Program. The United States is manifesting special attention in the creation of transport systems. The National Aeronautics and Space Administration (NASA) sees the space shuttle transport system based on MTKK[1] as a universal means capable of providing for both implementation of all prospective space plans and holding a leading position in the space field [1].

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[1]This system is built as a two-stage system. The reusable modules of the solid-propellant rocket engines serve as the first stage. The second stage is the MTKK -- a flight vehicle which combines the characteristics of the spacecraft and an aircraft, equipped with an engine which operates on liquid fuel and also an expendable fuel tank which is jettisoned before the MTKK goes into orbit. Orbital modules which are inseparable from the MTKK and also tow ships designed for moving payloads from low earth orbits to high orbits, including geostationary orbits and also for servicing orbital entities can be included in the system. The calculated operating time of the MTKK in orbit is 7 days; it can be increased to 30 days in the future. The MTKK which will be reusable (up to 100 flights) provide for launching payloads of up to 29.5 tons into low orbits and returning up to 14.5 tons to earth.

When advertising the space shuttle program, NASA places the accent on the significance of the expected scientific-technical, economic and political gains. Actually, the participation of foreign countries has given the United States the possibility of using their scientific-technical and economic potential[1], and a favorable climate in Congress has been created for NASA in order to achieve the needed appropriations for the program. In addition, the cooperation with Western European countries developing the Spacelab orbital module permitted the United States to keep these countries from creating their own booster rockets capable of competing with the American rockets. At the same time, the hopes of these countries that cooperation with the United States would lend significant momentum to the overall development of European engineering and production control and also the hopes of acquiring experience in the solution of a number of scientific and technical problems [3] have not for the most part been justified.[2]

Until recently the space shuttle program had a number of unanswered questions with respect to the number of MTKK to be used, the beginning of the experimental vertical flights and introduction of them into operation, and the total number of planned flights, and so on.[3] Nevertheless, analysis of the program permits the conclusion to be drawn that in a number of cases the functioning of this system will involve the interests of other countries, in connection with which the study of the international legal regulation of the use of the space objects making it up, above all, the MTKK, is acquiring important significance.

Space Shuttle System and International Law. When considering this problem one should keep in mind that the basic principles of international law extend their force to activities using the space shuttle system. These principles, including the UN Charter, apply regardless of the sphere and type of activity, technical means utilized, or other factors.

Being designed for the direct study and exploitation of outer space or the support of such activities, the MTKK, just as other components of the system, undonditionally are in the category of space objects. The conclusion of the applicability of the principles and standards of international space law to their use, which is a component part of the space activity of governments, follows, accordingly.

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[1]The contribution of Western European countries to the space shuttle program has amounted to $700 million (according to other sources, $839 million), and Canada contributed about $80 million [2].

[2]In striving to free themselves from American dependence, the Western European countries are studying the possibilities of creating their own MTKK which would be launched using the "Ariane" booster rocket developed by the member countries of the European Space Agency (ESA) [4].

[3]Initially provision was made for putting five MTKK into operation. Later, for economic reasons they were reduced to four. The first MTKK flights were planned as follows: experimental no sooner than March 1981, operational in September 1982. The number of MTKK flights planned before 1991 has been reduced from 775 to 487 [5, 6].

These principles and norms were confirmed in the agreement on the principles of government activity with respect to the study and use of outer space, including the moon and other celestial bodies of 1967 which were further developed and specifically defined in other agreements on international space law (the agreements on the rescue of cosmonauts, the return of the cosmonauts and objects launched into outer space of 1968; the convention on international responsibility for damage caused by space objects, 1972; and the convention on registration of objects launched into space, 1975).

The individual standards contained in the bilateral and multilateral agreements regulating specific forms of activity of governments (in the agreement to prohibit the testing of nuclear weapons in the atmosphere, in outer space and under water of 1963; the Soviet-American agreements on strategic arms limitations of 1972; the convention to prevent military or any other hostile use of means affecting the environment of 1977; and the SALT-2 agreement of 1979 (after its ratification) and certain others) can be used to regulate the use of the space shuttle system.

Inasmuch as in the existing international agreements the most general problems of the legal status of space objects are solved, it is natural that the peculiarities of the functioning of the objects making up the space shuttle system were not fully taken into account. However, it would be incorrect to talk about a "legal vacuum" in this area, for the basic principles of international law, including the United Nations Charter and the special principles of international space law are applicable to relations developing between governments due to the use of the space shuttle system. At the same time, this does not exclude the possibility or appropriateness of further development and specific definition of the basic principles of international space law as applied to the specific nature of the operation of this type of object.

The most urgent problems of international legal control following from the specific nature of the operation of the space shuttle system, in our opinion, are the problems pertaining to the movements of the MTKK and other components of the system in space, prevention of harmful environmental effects from them, prohibiting the use of MTKK for military purposes and the establishment of lower altitude limits for MTKK flights and objects connected with them over the territories of foreign countries.

Movement in Orbit. The United States plans to make broad use of the maneuvering capabilities of the objects making up the space shuttle system not only to service its own orbital vehicles, but also to inspect the objects of other governments.[1] The possibility of damaging these objects, destroying them or removing them from orbit is not excluded.

Statements with respect to the existence of a "right of access" or "visitation rights" as applied to space objects of other governments of registry are encountered in western literature on international space law. Whereas before signing

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[1]Tow ships, remote manipulators and other devices capable of supporting access to orbital objects can be included in the space shuttle system.

the Space Agreement of 1967, for example, English lawyer W. Jenks took the position, stating that a space object abandoned by its crew ceases to be under the jurisdiction of the government that launched it [7], even after this agreement went into effect, A. A. Cocca (Argentina) stated the opinion that the right to visit stations, installations, equipment and spacecraft on the moon and other celestial bodies provided for by Article XII of the Agreement under the condition of advance notification of the planned visit also applies to space stations in near-earth orbits [8].

There are no grounds for such statements. Article VIII of the Space Agreement confirmed the unambiguous position in accordance with which launched objects are under the jurisdiction and control of the government of registry for the entire period that they are in space, independently of whether there is a crew on board, they are functioning or they have already served their purpose. Article XII of the Space Agreement pertains exclusively to the right to visit stations, installations, equipment and spaceships on the moon and other celestial bodies which is realized on the basis of reciprocity and under the condition of advance notification of the forthcoming visit. The granting of this right to the governments participating in the agreement is determined by the specific nature of the legal status of the moon and other planets, and it is aimed at supporting the functions of monitoring the observance of Article IV providing for the study and use of the moon and other celestial bodies exclusively for peaceful purposes. Accordingly, the visitation right granted by Article XII of the Agreement cannot be interpreted expansively and acknowledged with respect to stations or other space objects in near-earth orbits [9]. A number of western legal experts support this position [10, 11, 12].

In our opinion, only special permission from the government of registry of orbital objects and bilateral or multilateral agreements on this question can constitute legal grounds for access to foreign orbital objects and visitation of them. However, even in such cases advance notification of the government of registry of the objects is required, and the possibility of access or visitation obviously will depend on the reasons for it, the technical condition of the objects, the health of the crew, and so on.

The uncontrolled maneuvering of MTKK and other objects near orbital objects of other governments can lead to collision of them or the creation of mutual radio interference and also promote contamination of the optical surfaces of the windows and instruments of these objects (as a result of evaporation of materials, the ejection and leakage of gases and fuel, the effects from the jets of operating rocket engines, waste disposed of in space, and so on), which would significantly reduce the effectiveness, and in some cases, exclude the possibility of performing a number of studies. Accordingly, the problem arises of the development of the corresponding space traffic rules, inasmuch as such lack of regulation can, in our opinion, complicate the normal operation of orbital objects, especially the near-earth manned space stations. One way to solve the problem of the safety and operation of such stations could be international agreement on the creation of safety zones within the limits of which the government of registry of the station could assume jurisdiction and control of MTKK and other vehicles moving near it. The definition of the spatial limits of these zones and also the formation of the corresponding international legal standards can soon become a subject of discussion for specialists in the field of engineering and international law.

Environmental Impact. In proceeding with the development of the space shuttle system, NASA stated that its use will not generate ecologic problems, and the possible insignificant impact on the environment poses no threat [13]. However, it was soon discovered that the operation of the system will cause sonic boom phenomena[1] on entering space and returning to earth, and it will have a negative influence on atmospheric conditions. When the system is launched the sonic boom will be felt at a distance of several hundreds of kilometers from the launching site. The return of the MTKK along initially planned trajectories would also lead to an increase in sonic boom within a corridor 185 km wide and result in damage within the territory of a number of American states. The indicated facts have forced NASA to change the launch and return formats, which has made it possible to reduce the sonic boom over the territory of the United States somewhat [14, 15].

However, considering that for the entire return time of the MTKK to the earth, amounting to 31 minutes of which 27 minutes are at supersonic velocity (for 14 minutes from an altitude of 120 km to 70 km the speed of the MTKK will be from M[2]=24.7 to M=20 and between the altitudes of 35 to 25 km, from M=5 to M=2), and the distance from reentry into the atmosphere to the landing point is about 8000 km [17], the possibility of the occurrence of problems connected with the consequences of sonic boom within the territories of other countries and also in the open sea should not be excluded.

The operation of the space shuttle system can lead to serious consequences in connection with the harmful effect of the combustion products of solid-propellant rocket engines of the first stage on atmospheric ozone.[3] The research performed in 1976 demonstrated that at a constant level of flights (85 per year) a growing disastrous depletion of the ozone layer can occur. Hard ultraviolet radiation, which is dangerous to the life and health of people, animals and plants, can also penetrate through the "windows" (breaches) formed in the ozone layer in the launch area [18].

The possibility of such harmful consequences has found official confirmation in the report by a special committee appointed by the American Congress to analyze various aspects of the space shuttle program [19]. This forced NASA to begin

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[1]Sonic boom is the excess pressure wave arising during supersonic flights of vehicles in the atmosphere, and it can have negative impact on the environment.

[2]M is the Mach number, that is, the ratio of the speed of a flight vehicle to the speed of sound in the environment [16].

[3]The free chlorine contained in these combustion products acts as a catalyst for chemical processes in the atmosphere and accelerates the breakdown of ozone, the main part of which is concentrated in the stratosphere. As is known, by absorbing the hard ultraviolet radiation coming from space, which is dangerous to all life on earth, ozone, of which there are insignificant reserves, plays a primary role in protecting life on earth.

studies of the possibilities of replacing the first-stage solid-propellant rocket engines by liquid or solid-propellant engines with different fuel composition. However, none of the more than 250 fuel formulas investigated suited NASA even from the point of view of providing the necessary power characteristics of the rocket engines or from the point of view of material expenditures (it would require about $1500 million to develop the new engines). The problem of using such engines will be considered only as applied to improved models of the space shuttle system.

As is known, Article IX of the Space Agreement of 1967 strengthened the obligation of the participating governments to conduct their activities in space with due consideration of the legal rights and interests of all other governments participating in the agreement, to prevent potentially harmful consequences of experiments in space and for this purpose, to take the corresponding measures in necessary cases. It also contains an item pertaining to the holding of international consultations between governments performing or planning experiments in space and governments which have reason to assume that such experiments will involve harmful consequences. In spite of certain deficiencies (optional nature, the absence of exact instructions regarding the time for holding consultations and their participants, the procedure for holding consultations and specific international legal consequences of them), these rules have great significance for the prevention of potentially harmful consequences of space experiments when using the space shuttle system.

The United States is a participant in the above-mentioned international agreements, and in the operation of the new transport system it is, of course, obligated to consider the legal rights and interests of other governments and the requirements of the principles contained in them. Nevertheless, in our opinion, the expediency of the possibility of further development and specific definition of the mentioned principles considering the specific nature of the operation of the space shuttle system should be evaluated.

Problem of Demilitarization of Space and the MTKK. The government of J. Carter has given special attention to the military aspects of the space shuttle program, demanding the broadest use on this level of the new transport system which is intended to be the only means of providing for the insertion of all prospective payloads for military purposes, the assembly of the corresponding objects in orbit and also the solution to the inspection and reconnaissance problems. In recent years work has taken shape with respect to the creation of such weapons as laser and beam weapons[1]; the possibilities of using the MTKK for placement of such weapons in near-earth orbits in the near future are being discussed [20, 21].

In the future the United States plans to build a fleet of two-man military MTKK capable of being launched from ordinary airports and returning to base after

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[1]A beam-weapon is based on using elementary particles (electrons, protons and neutrons) propagated at speeds close to light speed, and, from the point of view of American military specialists, it has a number of advantages over other modern weapons (instantaneous reaching and destruction of the target, all-weather capability, invulnerability, absence of the necessity for maneuvering, and so on).

performing their missions in space [22, 23]. It is expected that after the brigades for servicing and repair of orbital satellites, space command post personnel will be delivered into orbit. They will replace the modern air command posts for the control of nuclear weapons under extraordinary circumstances. This is confirmed by long-standing Pentagon plans to create a new type of armed forces -- the aerospace forces, the formation of which on the basis of MTKK type objects, it is assumed, will permit the United States to "hold the initiative in all forms of international situations, including peace, 'cold war,' local wars of various types and all-out war" [24].

In the light of what has been discussed it becomes obvious that the civilian projects of NASA using the space shuttle system on a national or international level have secondary significance, and they are recognized as serving as a cover for the aggressive efforts of the military-industrial complex of the United States in space. Accordingly, the problem arises of the legality of this activity from the point of view of the basic principles and standards of international space law.

The basic principles pertaining to the legal status of outer space and its study and use for peaceful purposes are contained in the 1967 Space Agreement. According to Article IV of this Agreement the moon and other celestial bodies are to be used exclusively for peaceful purposes, the creation of military bases, structures and fortifications as well as the testing of any types of weapons or holding of maneuvers are forbidden on them. At the same time, outer space itself has been demilitarized only partially inasmuch as the Agreement has forbidden the insertion into earth orbit or placement in space of any type of object with nuclear weapons or any other form of weapon of mass destruction.[1] Outer space was removed from the sphere of nuclear weapons testing still earlier by the agreement in 1963 to forbid nuclear testing in three environments. For the solution of the problem of complete demilitarization of space it is necessary to agree to forbid the launching of space objects for military purposes, use of space for holding military maneuvers, testing various types of weapons, and so on.

Implementing the program of peace adopted by the 24th CPSU Congress, supplemented and developed by the 25th and 26th CPSU Congresses, the USSR together with the socialist countries and other peace-loving powers has succeeded in bringing about the conclusion of a number of important international agreements which narrow the possibilities for military use of space. These include the Soviet-American agreement on strategic arms limitation: the agreement to limit antimissile defense systems and the provisional agreement of 26 May 1972 on some measures in the area of limiting strategic offensive weapons. In particular, the agreement to limit antimissile defense systems has obligated the participants not to build,

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[1]In spite of this, certain circles in the United States, taking a course of undermining detente and aggravating the international situation, are nurturing plans to place 250 modified "Minuteman-2" intercontinental ballistic missiles with nuclear warheads in near-earth orbit, and they are also studying the possibilities for launching a large unmanned installation for the "Minuteman-3" ICBM [25].

test or deploy antimissile defense systems or components for sea, air, space or mobile-ground basing (Article III, V).[1] The convention of 1977 on prohibition of military or any other hostile use of means having impact on the environment was an important agreement aimed at preventing the use of the achievements of science and engineering, including space technology, for creating new forms of weapons and new methods of waging war. New possibilities for further demilitarization of space were opened up by the agreement between the USSR and the United States to limit strategic offinsive weapons in 1979. Article IX of this agreement provides, in particular, for the obligation of each of the countries not to create, test or deploy means of inserting nuclear weapons or any other type of weapon of mass destruction, including fractional orbit missiles, into near-earth orbit.[2]

The analysis of the principles of Article IV of the Space Agreement indicates that they do not prohibit the flight of intercontinental ballistic missiles and other suborbital objects with nuclear weapons or other forms of weapons of mass destruction through space, inasmuch as such objects are not encompassed by the concept of objects inserted into orbit or placed in outer space, and they are not designed for long-term operation in space. Considering the undisguised agressive aims of the efforts of certain circles in the United States on the part of the military use of the space shuttle system, it appears expedient to achieve a special international accord with respect to forbidding the placement of weapons of mass destruction on space objects of the MTKK type independently of the nature of the flights made by them, and, in the final analysis, an agreement with respect to the use of such objects exclusively for peaceful purposes.

Accordingly, the initiative of the USSR in 1976 contained in the Soviet memorandum on the problems of curtailment of the arms race and disarmament has important significance. In this memorandum it is proposed that the creation of new forms of weapons of mass destruction be forbidden, that systems of such weapons or weapons based on scientific principles by which new elements of combat and support means could be given still more dangerous properties than those which they have individually, not be built. An aeroscace system with nuclear weapons or other forms of weapons of mass destruction based on the MTKK would be an example of such use of space rocket technology.

MTKK and the Sove eignty of Air Space. The published data indicate that on each segment of the flight of the space shuttle system the possibility of intrusion of the objects of this system, above all, the MTKK, into the air space of other

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[1]The treaty (Article XII) and provisional agreement (Article V) also provided for the right of each of the sides to use national technical means equipment available to them in accordance with generally accepted principles of international law to insure the observance of the principles of the concluded agreements, thus permitting the use of space means along with other technical means.

[2]Soviet-American talks on the problem of antisatellite systems began in February 1979 [26].

countries is not excluded.[1] Autonomous flights at low altitude over the territories of other countries can be made by small reuseable military vehicles by utilizing the lift of the airframe during flight in the atmosphere. They will be inserted into orbit and returned to the earth by the MTKK. By 1983 the United States expects to build special satellites which will be inserted into orbit from the MTKK on a cable up to 100 km long [30, 31]. The plans by the United States to make flights in the air space of other countries are indicated also by the plans to equip landing strips for the MTKK within the territories of other countries.[2]

Thus, under the conditions of absence of an agreement on the definition of the boundary between the air space of countries in which the countries have complete and exclusive sovereignty over their territories and outer space in which the generally accepted principle of freedom of the study and use of space applies, the problem of the necessity of insuring the legal rights and interests of the countries below, above all, their safety from possible encroachments on their sovereignty by means of both the MTKK themselves and other vehicles directly connected with them, unavoidably arises. To a certain degree these rights and interests could be insured by establishing the boundary between air space and outer space which would introduce clarity into the question of the altitude limit of the sovereignty of countries over their territory. In the literature on the problem of the altitude limit of sovereignty of countries, proposals can be found to confirm by agreement the practice of free flight of space objects through the air space of other countries for insertion of them into outer space and return to earth.

We are unable to consider this complex, multifaceted international legal problem in detail here [33], but, at the same time, we emphasize that the privileged legal status in this regard cannot be extended to the MTKK type spacecraft. Considering the specific nature of their possible operation and potential threat to the safety of the underlying countries, it is difficult to imagine that the governments will agree to free flights of such vehicles in the air space over their territories. It is more logical to expect that in the case of establishing a low-altitude limit, the question will unavoidably arise of insuring the safety of the underlying

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[1] After launching the space shuttle system, the spent modules of the solid-propellant rocket engines are dropped in the ocean on parachutes at a distance of about 310 km from the launch site. Unburnable elements of the fuel tank can be expected to fall within a corridor 1100 km long and 185 km wide. The MTKK, which after completion of the flight program reenters the atmosphere at an altitude of 120 km, gradually switches to control by the use of aerodynamic surfaces, as a result of which the proposed distance from the point of reentry into the atmosphere to the landing point will be 8000 km. Gliding in the atmosphere, without using its engines the MTKK can maneuver laterally within a strip 1760 km wide [27, 28, 29].

[2] In addition to its own territory, the United States proposes to equip landing strips for the MTKK at American military bases in Spain (Rota base), in Turkey (Injirlik), in Japan (the base on Okinawa), and so on [32].

countries and establishment of a lower limit of descent of MTKK type spacecraft in the space over the territories of other countries for these purposes. In our opinion, it should also not be excluded that this limit may be established at an altitude exceeding the level of the possible boundary between air space and outer space.

The flights of the MTKK and objects connected with them at low altitude in the air space over the territories of other countries must be considered as a violation of the sovereignty of these countries. They also cannot be justified by possible references to the Soviet-American SALT-1 and SALT-2 agreements inasmuch as the parties agreed to use the national technical means at their disposal in accordance with the generally accepted principles of international law. As is known, one of the basic generally accepted principles of modern international law, which is of a mandatory nature, is the principle of exclusive and complete sovereignty of governments in the air space over their territories.

Of course, the investigated problems do not exhaust the problem arising in connection with using reuseable transport space systems of the space shuttle type. However, in our opinion, these problems are the most urgent ones and require immediate solution. Beginning with the special characteristics of the launching and return of MTKK, their operation in near-earth orbits and considering the possible areas of the use of such objects, it is possible to conclude that special resolution of various aspects of their international legal status is necessary, especially on the level of guaranteeing the legal rights and interests of other countries. In our opinion the most satisfactory form of solution of this problem could be the development of a special international agreement.

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