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Near-Earth Space as an Object of Global Monitoring

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Abstract—Near-Earth space is analyzed as a specific object for global monitoring. The structure and specific features of near-Earth space are considered. It is shown that this zone includes almost all the terrestrial fields and the regions where space is actively explored by man.

Keywords: space exploration, space, near space, planetology

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INTRODUCTION

In the process of human development, new and unexplored areas are being discovered to become objects of research. Near-Earth space (NES) has become an object of research and a new habitat. Studies of NES become especially topical in terms of global monitoring (Men'shikov et al., 2010; Efanov et al., 2012). A new strategy for space exploration is required in the modern epoch of globalization. This strategy suggests that space needs to be explored in a more differentiated way. One of the first steps on this way implies the separation, investigation, and exploration of near-Earth space.

1. PRINCIPLES OF GLOBAL MONITORING

Modern global monitoring uses geoinformatics methods to a great extent (Maiorov, 2012) and is based on geoinformatic monitoring (Tsvetkov, 2005). Global monitoring related to the Earth includes external and internal monitoring. The internal monitoring is aimed at studying the Earth's surface and the external monitoring is directed toward the side opposite to Earth. The external monitoring deals with the following hierarchical structures: near-Earth, heliocentric, and deep space (Tsvetkov, 2012). The following key characteristics of modern monitoring can be singled out (Tsvetkov, 2012): view, object, target, field, system, methods, and techniques.

The field of monitoring is the range of possible objects and phenomena to which this type of monitoring can be applied. The monitoring field is defined by observational and processing methods and by a set of initial data. The wider the set of techniques and methods to use in the monitoring, the wider the monitoring field. The object of monitoring is a specific object of surveillance. How to monitor near-Earth space can be considered from different aspects.

2. ASPECTS OF CONSIDERING NES

From the geophysical perspective, NES includes several of Earth's protective envelopes. From the perspective of human development, NES is near space that is intensively explored by man. From the perspective of the geosphere, NES is a superstructure of the geosphere that becomes a part of it. From the perspective of constructing a unified Earth coordinate environment, NES is an extension of the Earth's coordinate system, which is especially important while coordinating especially dangerous space objects (Egorov and Tsvetkov, 2012). In terms of the global geosystem, NES is a superstructure of the global geosystem that also becomes a part of it. In terms of cognition, NES is a superstructure of the infosphere (Ivannikov et al., 2013) that widens the limits of human knowledge. In terms of space exploration, NES is a part of space that has been explored by man to the most extent in comparison with its other parts (Savinykh and Tsvetkov, 2012). In terms of space fields, NES is part of space where all the Earth's fields are located (electric, gravitational, and magnetic). In terms of the geoinforma-

Spatial zones of immediate influence on the terrestrial civilization

No.	Ambiance or space	Distant border
1	Atmosphere	~100 km from the Earth's surface
2	NES	~51000 km from the Earth's surface or 9 Re (Earth's radii) from the Earth's center
3	Sublunar space	Lunar orbit longer than 60 Re
4	Extralunar space	1AU, ~21481 Re

tional space (Lebedev, 2005), NES is the part of space that borders with the geoinformational space.

3. NES BORDERS

The determination of the near-Earth boundaries is necessary for monitoring tasks, coordinating this space with terrestrial space, navigation, etc. The terrestrial surface is surrounded with a gaseous envelope or atmosphere. NES borders the Earth's atmosphere. At present, there is no definite definition of the NES limits. Therefore, we propose our definition, which implies the inclusion of space adjacent to NES.

The table presents different zones of space relative to the Earth, in which we must take into account objects that may be encountered there.

According to an international agreement, the altitude of the atmosphere is tentatively defined as 100 km over the Earth's surface, although there are studies that indicate the presence of atmosphere at an altitude of 214 km. However, an altitude of 100 km is interpreted as a limit for airplane flights; space flights occur above this altitude. This distance can be considered a lower NES border with respect to the Earth's surface.

If we associate NES with the Earth (more precisely, with terrestrial civilization), we must take into account the factor of human presence in this space. The analysis of this factor links the upper boundary with a geostationary satellite altitude of approximately 36000 km. The electric field also falls within this zone of 36000 km. High elliptical orbits extend to 47000 km. Therefore, we define the NES zone as an area lying from 100 km over the Earth's surface to a distance of 8 *Re* (Earth's radii) over the Earth's surface (approximately 51 000 km) or 9 *Re* from the center. Therefore, the farthest NES border (with respect to the Earth) is defined by a sphere with a center in the Earth's center and with a radius that is equal to nine Earth radii from the center or eight terrestrial radii from the surface.

In the United States, it is a common practice to divide space into the near-Earth, sublunar, and extralunar spaces. The sublunar space (SLS) extends to the Moon's orbit (384400 km or approximately 60 *Re*) and the extralunar space (ELS) is determined by one astronomical unit (23481 *Re*).

There exist also other estimates of the NES boundary. Novikov (2006) assumes that NES ends near the lunar orbit. In our opinion, this space is very nonuniform in terms of both its exploration by man and the presence of different fields. The estimates given in the table correspond to more uniform spaces with respect to their structure.

4. WHAT IS CONTAINED IN NES?

The NES region includes the zone of Earth's attraction. According to different estimates, the size of this area may be 930 km or 1500 km.

The overwhelming majority of space facilities are concentrated in NES, in the low-orbit region (approximately 60%). Low-orbit satellites (700–1500 km) have some advantages in their energy characteristics in comparison with other spacecraft, but at a disadvantage in communication-session duration and in general service life. The satellite orbits the Earth in 100 min on average; 30% of this time the satellite is in the shadow of the planet. On-board accumulators can sustain approximately 5000 charging/discharging cycles per year, suggesting that their lifetime does not exceed 5–8 years.

Mean-altitude orbits are located between the first and the second radiation belts, i.e., at an altitude of 5000–15 000 km. These spacecraft are less than geostationary, implying that an orbital group of 8–12 satellites is needed for the complete coverage of the Earth's surface (for example, *Spaceway NGSO*, *ICO*, or *Rostelesat*); each satellite of this group can only be for a short time in the radio visibility zone of a ground-based station, approximately 1.5–2 h.

Geostationary and high elliptical orbits (HEOs) are considered as high orbits. Spacecraft are most frequently located in geostationary (circular) orbits. These have significant advantages: uninterrupted round-the-clock communication is possible while the frequency shift is almost absent. Geostationary satellites are located at an altitude of approximately 36000 km above Earth's surface and rotate synchronously with the planet. They hover above a definite point, the so-called subsatellite point. However, the position of this satellite is not actually fixed. It undergoes a drift due to some factors, suggesting that the orbit changes in time. The HEO is a kind of an elliptical orbit for which the apogee altitude (up to 50000 km) is many times the perigee altitude (500 km).

The main physical properties and natural specific features of near-Earth space are as follows:

(1) the gravitational, magnetic, and electric fields of the Earth;

(2) the processes in the Earth's ionosphere;

(3) the deep space vacuum;

(4) heat radiation;

(5) cosmic rays and solar radiation;

(6) the Earth's radiation belts;

(7) space debris.

Let us consider how these factors affect the orbital parameters of spacecraft.

4.1. Effect of the Earth's Gravitational Field

The figure of the Earth is a sufficiently complicated surface called a geoid. So far, it has not been finalized and the task of its further improvement is a subject of the theory of gravimetry and the theory of the Earth's shape.

A perturbing acceleration due to the gravitational field of a nonspherical Earth is 1/656th of *g* (the Great Russian Encyclopedia, 2012). This factor plays a definite role for low and high elliptical orbits since spacecraft (SC) enter and exit the Earth's attraction zone (930 km) at regular intervals.

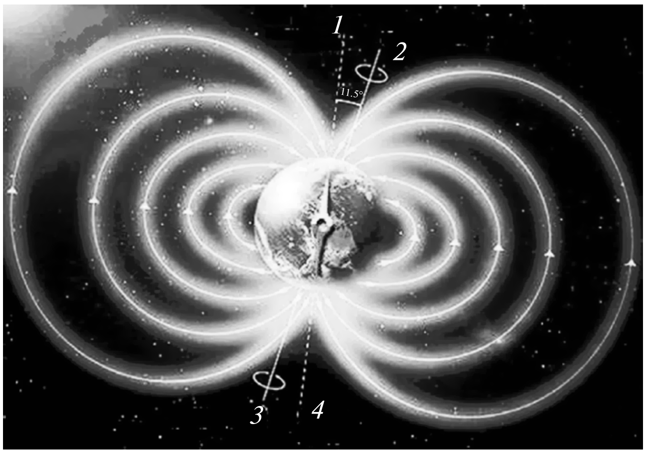
The analysis of the perturbation effect on the SC moving in an elliptical orbit indicates that the orbit does not change its size and shape on average, i.e., the semimajor axis, focal parameter, eccentricity, linear eccentricity, and apogee and perigee altitudes remain nearly unchanged. Along with that, the orbit gradually rotates in space around the axis that coincides with the rotation axis of the Earth, resulting in the rotation of the apsidal line (perigee–apogee), which appreciably affects the SC ballistic stability.

When forming orbital SC groups, it is necessary to choose orbital elements in such a way as to minimize the influence of the Earth's gravitational field on the SC motion. In the long run, this will provide a possibility to ensure the ballistic stability of the satellite group on a large time scale and to minimize the onboard propellant supplies required to correct the orbit.

4.2. Effect of the Earth's Magnetic Field

The magnetosphere of the Earth has a complicated form (see the figure). On the side that faces the Sun, the distance to its boundary varies depending on the solar wind intensity and is approximately 70000 km (10–12 Earth radii *Re*, where *Re* = 6371 km). The boundary of the magnetosphere, or the magnetopause, resembles a missile (on the side of the Sun) and is estimated to be approximately at a distance of 15 *Re*. On the night side, the Earth's magnetosphere is stretched into a long cylindrical tail (the magnetotail) with a radius of approximately 20–25 *Re*. The tail is stretched to an appreciable distance, much farther than 200 *Re*.; it is not known where the tail ends (the Great Russian Encyclopedia, 2012).

The sources of terrestrial magnetism are mainly in the three components of the planet: the core, crust, and upper atmosphere (Veselovskii and Kropotkin, 2010). The magnetic field undergoes definite changes and perturbations over time. Regular variations that occur according to a definite law are called unperturbed variations. These are annual lunar-daily and solar-daily unperturbed variations. Sporadic variations of the Earth's magnetic field are called magnetic perturbations.



1—South magnetic pole
2—geographic North pole
3—geographic South pole
4—North magnetic pole

Magnetosphere of the Earth.

Intense perturbations are called magnetic storms that may last from hours to days and are detected simultaneously throughout the Earth. The most intense storms are detected at high latitudes. Magnetic storms are caused by solar plasma flows from active regions on the Sun superimposed on the quiet solar wind. Magnetic storms are dangerous for crews of manned spacecraft and onboard facility functioning.

Magnetic storms can be forecast only three days ahead at best. In the meantime, some practical steps may be carried out to reduce (or exclude) the influence of the high-energy particle flux on the SC and crew. During the magnetic storms, the parameters of the ionospheric layers reflecting and absorbing radio waves change appreciably. As a result, appreciable radio frequency interference arises in the range of shortwave communication.

4.3. Effect of the Earth's Electric Field

The natural electric field is observed in the solid Earth's body, on the sea, in the atmosphere, and in the magnetosphere. Its origin is due to a complex of geophysical phenomena. The distribution of the field potential delivers specific information on Earth's composition and the processes in the lower atmospheric layers, in the ionosphere, the magnetosphere, near interplanetary space, and on the Sun.

The presence of an electric field in the Earth's atmosphere is mostly related to the processes of air ionization and the spatial separation of positive and negative electric charges arising in ionization. The air ionization occurs due to the influence of cosmic rays, solar UV radiation, radiation of radioactive substances on the Earth's surface and in the air, electric discharges in the atmosphere, and other factors (the Great Russian Encyclopedia, 2012). The Earth has a negative charge with respect to the atmosphere.

Electric fields in the ionosphere are due to the processes that occur in both upper atmospheric layers and the magnetosphere. Tidal motions of air masses, winds, turbulence are among the sources of electric field generation in the ionosphere. The electric field strength is a function of the point location, time of the day, general state of the magnetosphere and ionosphere, and solar activity. The current strength reaches hundreds and thousands of amperes (the Great Russian Encyclopedia, 2012).

Solar wind is one of direct sources of the electric field in the magnetosphere. In the period of magnetic storms and auroras, electric fields and currents in the magnetosphere and ionosphere vary appreciably. The effects of Earth's electric field on the SC operation are as follows: electrization of outer SC surfaces, malfunctions of onboard systems, and disturbances in communication.

4.4. Effect of the Earth's Ionosphere

The ionosphere extends from the mesosphere to altitudes of approximately a hundred kilometers. The ionosphere is a natural formation of a rarefied, weakly ionized plasma that is located in the Earth's magnetic field. A high electroconductivity of the ionosphere results in its specific properties that determine the character of radio wave propagation and different perturbations. As radio waves propagate in the ionosphere, they are reflected, undergo double refraction and scattering, and are subject to nonlinear effects.

Depending on the density of charged particles, three layers can be singled out in the ionosphere: *D* (60–90 km), *E* (90–120 km), and *F* (higher than 130–140 km) (the Great Russian Encyclopedia, 2012). A wave arriving at the ionosphere (an anisotropic medium) undergoes double refraction, i.e., it bifurcates to produce two waves that differ in velocity, direction of propagation, absorption, and polarization. As the two waves propagate in the medium, a phase shift between them accumulates, suggesting that the polarization of a resulting wave remains unchanged under definite conditions, although the polarization plane rotates during the propagation. Generally, the polarization of both waves is elliptical.

Along with a regular dependence of electron concentration on altitude (the regular ionosphere), there are occasional concentration variations in the ionosphere. The ionospheric layer contains a great number of differently sized sporadic formations that are in continuous motion and change, dispersing and arising again. In signal transmission, this leads to chaotic changes of the received signal. The presence of nonuniform formations brings about the scattering of radio waves at frequencies that appreciably exceed the maximum frequencies of reflection from the regular ionosphere. Nonuniform formations also arise in the ionosphere when meteorites pass through it.

Radio waves propagate in the ionosphere in different ways depending on the frequency range. In particular, their lower frequency is limited by absorption. Therefore, communication is carried out in the shortwave band and—at night—in the mid-wave band. Long and superlong waves hardly ever propagate into the ionosphere, being reflected from its lower boundary.

Audio-frequency radio waves can percolate through the ionosphere along Earth's magnetic field lines. As it propagates, the wave moves away to a distance of several Earth radii and after that returns to a conjugate point located in the other hemisphere. For infrasonic radio waves with frequencies shorter than the ion frequency, the ionosphere behaves as a neutral liquid whose motion is described by hydrodynamic equations. Therefore, the influence of the ionosphere is manifest through impacts on communication lines in the form of radio frequency interference and signal variations.

4.5. Deep-Space Vacuum

Deep-space vacuum brings about the following processes: the evaporation of the SC surface layers in the process of sublimation; the change of optical characteristics of thermoregulating materials and onboard 3
facilities; the change of conditions for the SC heat exchange with the external medium; and the change of surface and bulk properties of materials.

Sublimation can affect the operation of onboard radio electronic devices if different contacting materials have different temperatures. Most lubricators used under terrestrial conditions cannot be used under deep space vacuum conditions since these lubricators have high rates of evaporation.

One of negative phenomena that arise under conditions of space vacuum is the adhesion ("sticking" the surface layers of two unlike liquid or solid substances together as they touch). At this, microscopic flaws and corrosion arise, the coefficient of friction increases, and the cold welding of materials may happen.

Other negative effects of space vacuum can include the gas and vapor escape through both construction looseness and SC walls. As a result, the "own outer atmosphere" of the SC arises.

4.6 Earth's Radiation Belts

Earth's radiation belts are regions of space filled with charged particles retained by the Earth's magnetic field (the Great Russian Encyclopedia, 2012). Charged particle fluxes in Earth's radiation belts exceed cosmic ray fluxes by several orders of magnitude. Spacecraft operating in high elliptical and stationary orbits pass through two of Earth's radiation belts. These influence the functioning of radio-electronic facilities and affect the condition of a crew.

Along with natural radiation belts, artificial radiation belts can form as a result of high-altitude nuclear explosions and evaporation of radioactive substances in space.

Legal considerations related to the use of NES should be mentioned. Neither natural nor artificial borders could be used to demarcate NES.

At present, there is no unambiguous definition in international law as to which are the lower boundaries of near-Earth space. Outer space and air space are separated by a diffusion layer with a thickness of approximately 35 km in which orbital flight is not yet possible and aerodynamic manned flight is not yet possible.

4.7. Space Debris

In wide sense, the "space debris" is understood as
1 "anthropogenic waste" and natural space objects or their fragments that have fallen into the Earth's attraction sphere and located in near-Earth space (Mikisha et al., 2001). Space debris components are a dangerous factor for the functioning SC, especially manned SC.

In some cases, large space-debris objects and objects containing dangerous materials on board (nuclear, toxic, etc.) can be of direct danger to Earth if these reenter from orbits in an uncontrolled way and do not burn off completely when passing through dense layers of Earth's atmosphere, leading to precipitation of debris on settlements, industrial objects, transport communications, etc. Space debris is detected using chemical analysis, radio location, and optical methods.

At present, there are two condensation belts (two rings) of space debris: one at altitudes of 850–1600 km above the Earth's surface and the other at a geostationary orbit at an altitude of approximately 38 500 km.

CONCLUSIONS

The following special features of near-Earth space can be singled out:

(1) NES is a natural environment that is gradually
2 forming as a geotechnical system.

(2) The most important aspect of the space equipment used in NES is that it should operate in three domains: on Earth, in air, and in space.

(3) In the process of SC operation in space, the surface layers of SC housing materials evaporate and are continuously worn away, optical characteristics of
3 thermoregulating coatings and optical materials change, lubricators transform into abrasive materials, electrical discharges occur on the surface, and the thin-walled main-body cover is punctured. These circumstances lead to the deterioration in reliability of different technical systems and their shorter service life in orbit. This allows us to state that special facilities adapted to effective operation in space should be utilized in this environment.

(4) NES cannot be divided based on sovereignty; it is extraterritorial. The extraterritoriality of space provides a possibility to influence any events that occur at any point of the globe.

As a whole, near-Earth space is relatively "filled and active" space. It requires further exploration and is going to become an area of eager human activity in the foreseeable future.

Lyndon Johnson, the former president of the United Sates, gave an integrated estimate of the importance of the space exploration for achieving global aims when saying in 1964 that the British had had command of the sea and ruled the world, the Americans dominated the air and were leaders of the free world since they had established that empire, and those who were going to take command of outer space would occupy that position thenceforth.

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SPELL: 1. anthropogenic, 2. geotechnical, 3. thermoregulating