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NONUNIFORMITY OF THE EARTH'S ROTATION AND MOTION OF THE POLES

N. S. Sidorenkov

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16. Abstract

A historical account of research on the Earth's rotation rate and motion of the poles. The reasons for changes in these parameters include: winds, solar action, atmosphere, glaciers, moon, oceans.

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NONUNIFORMITY OF THE EARTH'S ROTATION AND MOTION OF THE POLES

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The Earth's rotation around its axis has been used by man to measure time since time immemorial. It is an irreplaceable basis in astronomy and geodesy for introducing various coordinate systems. However, the Earth's rotation is not at all regular: its rotation rate changes and the geographic poles move. These irregularities in the Earth's rotation cause a lot of trouble for the astronomers and geodesists since they distort the coordinates of the celestial and terrestrial objects. Nonuniform rotation of the Earth and motion of the poles are caused by processes occurring on the Earth, and they depend on the structural features and physical properties of the Earth's depths. Being a reflection of the terrestrial processes, irregular rotation of the Earth contains valuable information about them and serves as

*Numbers in the right margin indicate pagination in original text.

a global characterization of these processes which can be presented by nature itself.

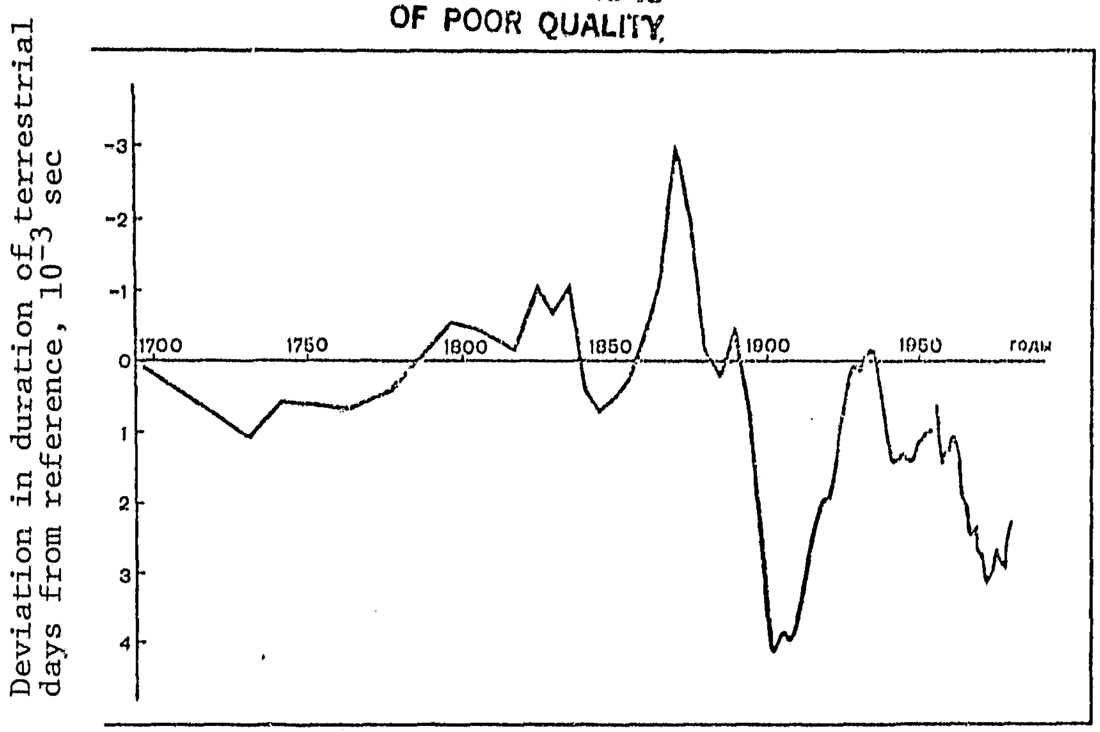
Study of the irregularities in the Earth's rotation and motion of the poles thus is of great practical and scientific importance. It permits correction of the distorted coordinates of celestial and terrestrial objects and promotes an expansion and deepening of our knowledge in different fields of earth sciences. How does the daily rotation of the Earth change in time? What causes the nonuniform rotation of the Earth and the polar motion?

Astronomical Data

Doubts as to the constant rotation rate of the Earth emerged after the discovery by Galileo in 1695 of the secular acceleration of lunar motion. E. Kant first advanced the idea about the secular slowing down of the Earth's rotation under the influence of tidal friction in 1755. Irregular fluctuations in the rotation rate of the Earth and motion of the poles began to be suspected in the second half of the last century. Since then, regular observations have been made of the nonuniformity in the Earth's rotation and polar motion.

The Earth's rotation rate can be characterized most simply as the deviation in the duration of the terrestrial days from the reference (the duration of the reference days is constant and equals 86,400 sec.). The shorter the terrestrial days, the faster the Earth rotates.

The Earth rotating around its axis is a type of clock. The celestial sphere is the face of this enormous clock, and any plane passed through the Earth's rotation axis and rigidly connected to the Earth's surface can serve as the hand. Astronomers, for example, use the meridional plane as the hand, i.e., the plane which conceivably passes through the plumb line of the observation site and the Earth's pole. The stars and heavenly bodies which are arranged in the celestial sphere are a type of face division. /83



Changes in the Earth's Rotation Rate in the Last 300 Years. Increase in the rotation rate of the Earth corresponds to decrease in the duration of the day. Complicated irregular changes in the Earth's rotation rate with periods of several dozen years are clearly visible.

The meridional plane which rotates together with the Earth, indicating a certain heavenly body whose coordinates can be found in the astronomical annual, allows the terrestrial time to be "counted" from it.

In addition to the "Earth clock," man also uses mechanical clocks of the most diverse types, and in recent decades, quartz and atomic clocks. The accuracy of the atomic clocks is so high that the course of the "Earth clocks" can be checked with them. This "check" which has been conducted in the International Time Bureau since 1955 indicates that the "Earth clock" does not run in the best manner. Sometimes it is fast, but sometimes it is slow. The "Earth clock" runs poorly because of the inconstant rotation of the planet. Processing of observations indicates that before 1972 the Earth primarily slowed down its rotation. The rotation rate slightly increased only from 1958 to 1961. From 1973 to the present, accelerated rotation of the Earth has been noted.

Before the creation of atomic clocks, the running of the "Earth clock" was only monitored by comparing the observed and computed coordinates of the Moon, Sun and planets. An idea was thus obtained about the change in rotation rate of the Earth in the last three centuries (from the end of the 17th when the first instrument observations of the motion of the Moon, Sun and planets were made). It turns out that from the beginning of the 18th to the middle of the 19th centuries, the Earth's rotation rate changed little. From the second half of the 19th century to the present, considerable irregular fluctuations were observed in the angular velocity of the Earth's rotation with characteristic times on the order of 60 - 80 years. The Earth rotated most rapidly about 1870, when the duration of the terrestrial days was 0.003 sec. shorter than the reference, and the slowest--about 1903 (the terrestrial days were longer than the reference by 0.004 sec.). From 1903 to 1934, the Earth's rotation accelerated, and from the end of the 1930's to 1972, a slowing down was observed which was sometimes replaced by periods of slight acceleration. Unfortunately, from a comparison of the observed and computed coordinates of the Moon, Sun and planets, the nonuniformity of the Earth's rotation is determined /84 with very poor resolution. This is especially characteristic for the data of the 17th - 18th centuries, when the time intervals between the observations was sometimes 29 years.

The accuracy of determining the nonuniformity of the Earth's rotation radically improved starting in 1955, after atomic clocks began to be used. From this time it became possible to record all the fluctuations in the Earth's rotation rate with periods of more than one month. It was established with the use of atomic clocks that the Earth's rotation rate changes gradually, without any sudden jumps. The concepts regarding seasonal nonuniform rotation of the Earth changed particularly radically. It became clear that the seasonal nonuniformity in the Earth's rotation is not characterized by one minimum and one maximum of angular velocity during the year, but by two minimums and two maximums. The Earth's rotation rate diminishes in April and November, and the greatest, at the end of January and July. The January maximum is considerably smaller than the July. The difference between the minimum magnitude of deviation in the duration of the terrestrial days from the reference in July and the maximum in April or November is 0.001 sec.

The magnitude of the January maximum in the Earth's rotation rate undergoes considerable fluctuations from year to year. A quasi-two-year fluctuation cycle has been traced. Thus, in 1962, 1964, 1966, 1968, 1970, 1973, 1975, 1978 and 1980, the January maximums in velocity were lower than correspondingly in 1963, 1965, 1967, 1969, 1971 and 1972, 1974, 1976, 1977, 1979 a and 1981. Anomalously large January maximums in velocity were noted in 1963, 1971, 1972, 1974 and 1977. In addition to the quasi-two-year cyclicity, the magnitudes of January maximums experience irregular fluctuations with longer characteristic times. In particular, their rise from the 1950's to the present has been noticeable. The January maximums rose especially strongly in the early 1970's.

The magnitudes of the July velocity maximums are more stable. They show quasi-six-year cyclicity. The greatest magnitudes of July velocity maximums were noted in 1958, 1964, 1970, 1977, and the least in 1961, 1968, 1972 and 1979.

The seasonal fluctuations are usually described formally by the sum of the annual and the semiannual harmonics. The amplitudes and phases of these harmonics change from year to year, showing interesting laws. The annual harmonics amplitude changes with characteristic time about 6, and the semiannual--about 2 years. The average magnitude of the annual and semiannual harmonics amplitudes equals respectively 0.00035 and 0.00032 sec.

Not only the angular velocity of the Earth changes, but our planet also makes small fluctuations in relation to the rotation axis. Therefore the points at which the axis intersects the Earth's surface, momentary poles of the Earth, move. They move over the Earth's surface around the middle pole in the direction of the Earth's rotation, i.e., from west to east. The motion trajectory of the pole has the appearance of a spiral which periodically twists, then untwists. One of the pictures shows the motion trajectory of the pole for 1971 - 1978 as an example. The greatest distance of the momentary pole from the middle does not exceed 15 m. Twisting and untwisting of the trajectory of the pole is explained by the fact that the pole makes two periodic movements: free with period of about 14 months, and forced with annual period. The free polar motion is motion which develops if the Earth's rotation axis deviates in some way from the axis of its greatest inertia moment. Motion of the poles caused by the effect on the Earth of the periodic forces from the atmosphere and hydrosphere is called forced. The period of free motion depends not on the period of the exciting force as is characteristic for forced motion, but on the dynamic compression and elastic properties of the Earth. The summation of these two motions also provides the observed pattern of pulsations.[1]

Analysis of the polar coordinates in the last 90 years indicates that forced motion occurs on the ellipse from west to east. The magnitudes of the large ellipse semiaxes fluctuated in limits from 3.4 to 2.7 m, the small semiaxes, from 2.5 to 1.8 m, eccentricities from 0.15 to 0.46, and easterly longitudes of the large semiaxis had values from 205° to 145° e.l.

The same data indicate that free polar motion has almost a circular trajectory. It is characterized by even greater

[1]Podobed, V. V.; and Nesterov, V. V. Obshchaya astrometriya ["General Astrometry"], Moscow, 1975.

variability in its parameters. The period of free motion was from 1.13 to 1.21 years (most likely 1.19 years). The radius of free polar motion in 1930 - 1940 did not exceed 2.5 m, and in 1950 - 1955 reached 9.5 m. It averaged 5.1 m in the last 90 years. /85

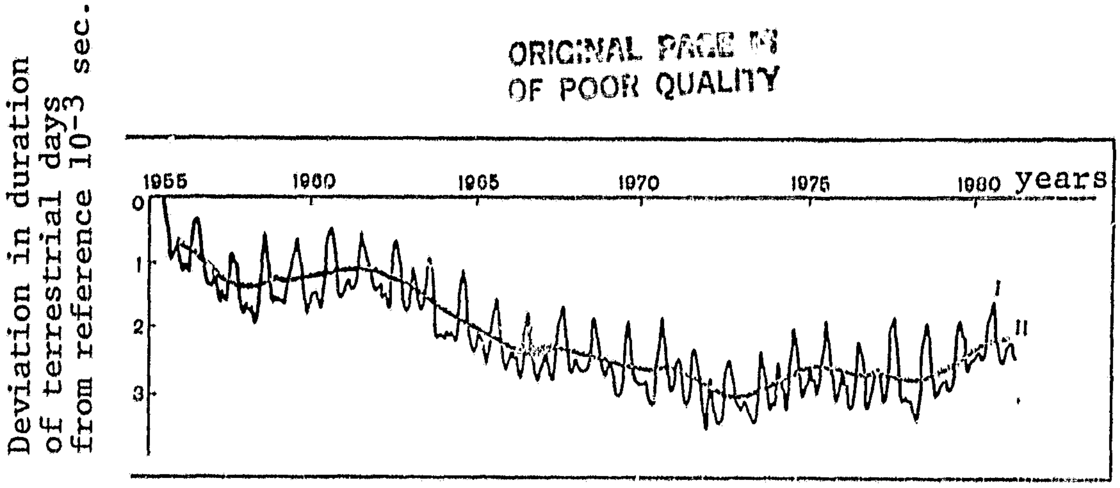
Examination of the motion trajectory of the pole in the observations available for 90 years shows that the spiral-shaped trajectory of the momentary pole gradually creeps in the direction of the 70° w.l. direction at a rate of about 0.13 m per year. In other words, the middle pole undergoes secular motion. Unfortunately, the accuracy of determining the secular polar motion is still so low that its reality is still questioned.

Nature of Periodic Fluctuations in the Earth's Rotation

What governs the nonuniformity in the Earth's rotation and polar motion? There are quite a number of processes which in principle could influence the Earth's rotation. For example, these are changes in the distribution of air masses in the atmosphere, snow and ice covers, precipitation and vegetation on the Earth's surface, variations in the World Ocean level, interaction of the Earth's core and mantle, volcanic eruptions, earthquakes, effects of external forces, etc. Careful evaluation of the contribution of these processes made it possible to reveal the most significant ones.

It was found that terrestrial tides play a noticeable role in the fluctuations in the Earth's rotation rate with periods of less than 1 month. The tidal-forming force stretches the Earth along a straight line that connects its center with the center of the perturbing body, the Moon or Sun. The inertia moment[1] of the "flattened" Earth is greater than the undeformed spherical planet. Since the pulse moment of the Earth (i.e., product of its inertia moment times angular velocity) should

[1]The inertia moment of a particle in relation to the Earth's rotation axis equals the product of its weight times the square of the distance to the axis. The Earth's inertia moment is the sum of the inertia moments of the particles comprising it.



Change in Earth's Rotation Velocity in the Last 30 Years

Average monthly magnitudes [I], sliding average annual magnitudes [II]. The marks on the x-axis designate the beginning of the year. On the background of long-period changes, seasonal fluctuations in the Earth's rotation rate are noticeable. The dips in curve I which are usually noted in November and April correspond to the minimum velocity, while the crests in July and January correspond to the maximum rotation rate of the Earth. It is apparent that the seasonal fluctuations change strongly from year to year. The tidal fluctuations with monthly and semimonthly periods are not found because of insufficient resolution.

remain constant, then the rotation rate of the "flattened" Earth is lower than the undeformed. During motion of the Moon and the Earth - Moon system, the distance from the Earth to the Moon and the Sun changes. Therefore the tidal-forming force fluctuates in time. In the final analysis, this causes non-uniformity in the Earth's rotation. Fluctuations with semi-monthly and monthly periods are the most significant of these tidal changes in the Earth's rotation rate.

The tidal projections are constantly shifted over the Earth's surface after the Moon and the Sun from east to west, i.e., in a direction which is the opposite to the Earth's diurnal rotation. It is natural that with this movement, friction forces develop in the oceans and in the Earth which slow down the Earth's rotation. Secular slowing down of the Earth's rotation should also occur for this reason. Assessments indicate that this should cause the days to become longer by 0.003 sec in 100 years. Thus, nonuniformities in the Earth's rotation which are presented in our pictures are almost not related to the influence of the tides, but are caused by other reasons.

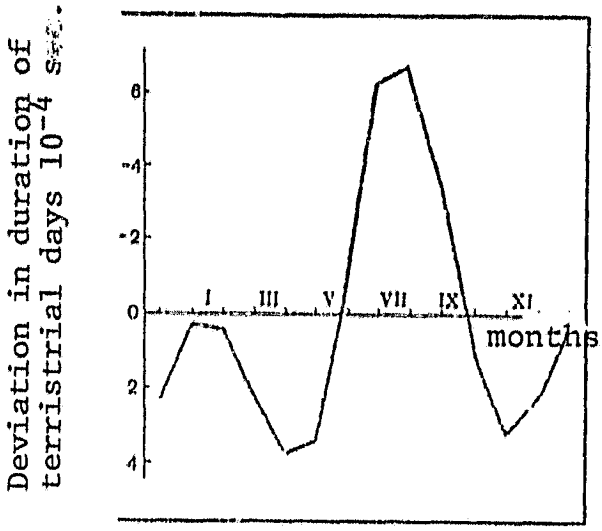
During the year, masses of air and moisture (water, snow and ice) are redistributed between the continents and the oceans, as well as between the Northern and Southern Hemispheres. Thus, the air mass above the Eurasian continent in January is 6×10^{15} kg greater than in July. From January to July, 4×10^{15} kg of air is transferred from the Northern Hemisphere into the Southern. Throughout the winter, snow is accumulated in the northern regions of Eurasia and North America. The snow melts in spring and the moisture is returned to the World Ocean. All of this alters the inertia moment of the Earth, and to a certain degree, influences its rotation. The estimates show that seasonal redistribution of the air and water masses have little effect on the seasonal nonuniformity of the Earth's rotation, but are almost completely responsible for the forced motion of the poles. /86

Free polar motion develops, as we have already stated, when the Earth's rotation axis deviates from the axis of the Earth's greatest inertia moment. However, it should attenuate in time, since the free motion energy of the poles is convered into heat in the Earth.

The absence of attenuation in free polar motion indicates that there are some processes which continually maintain it. These processes include earthquakes, electromagnetic interation of the Earth's core and mantle, lunar-solar precession, and so forth. It is most likely that free polar motion is maintained by the constantly occurring hydrometeorological processes.[1]

Studies in the last quarter of a century have demonstrated that the main reason for seasonal nonuniformity in the Earth's

[1] Mank, U.; and Makdonal'd, G. Vrashcheniye Zemli ["Rotation of the Earth"], Moscow, 1964.



Average Seasonal Fluctuation in the Earth's Rotation Velocity

The Earth rotates the slowest in April and November, and the fastest in July-August and January.

rotation is atmospheric circulation. It is common knowledge that the atmosphere moves in relation to the Earth's surface in the lower latitudes on the average from east to west (easterly winds blow), and in the temperate and higher latitudes--from west to east (westerly winds dominate). The pusle moment of the easterly winds is negative, and the westerly is positive. One could think that these moments compensate for each other, and that the pulse moment of the winds in the entire atmosphere always equals zero. However, the calculations indicate that the pulse moment of the easterly winds is several times lower than the pulse moment of the westerly winds.[1] Therefore the pulse moment of the winds in the entire atmosphere does not equal zero, but averages $+13 \times 10^{25}$ kg x m^2 x sec^{-1} for the year. Its magnitude changes during the year from $+14.5 \times 10^{25}$ kg x m^2 x sec^{-1} in April and November, to $+9 \times 10^{25}$ kg x m^2 x sec^{-1} in August.

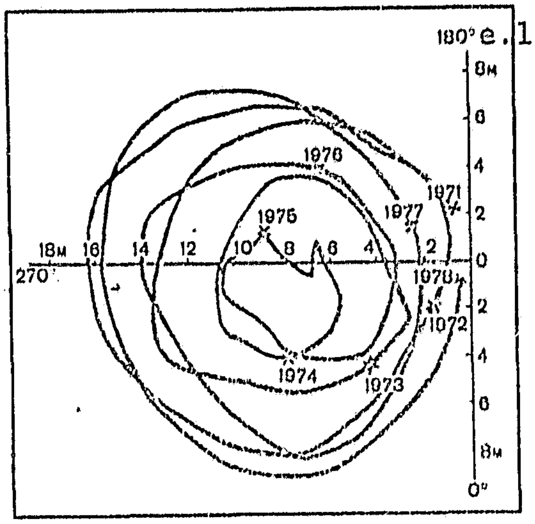
The pulse moment is that physical quantity which cannot

[1] Sidorenkov, N. S. Izvestiya AN SSSR. Ser. Fizika atmosfery i okeana, Vol. 12, No. 6, 1976, p. 579.

emerge or be destroyed. It is only capable of being redistributed. In the examined case, redistribution occurs between the atmosphere and the Earth. When the pulse moment of the atmosphere increases, i.e., the westerly winds intensify or the easterly diminish, the Earth's pulse moment diminishes, i.e., its rotation slows down. When the pulse moment of the atmosphere diminishes (the westerly winds diminish or the easterly intensify), the Earth's rotation accelerates. The summary pulse moment of the Earth and the atmosphere always remain unchanged. This result can serve as a good illustration that the law of preservation of the pulse moment is correct not only in physical laboratory experiments, but also on global scales in nature.

The fact that the pulse moment of the winds is always positive indicates that the atmosphere as a whole rotates around the axis faster than the Earth. By comparing the motion of the atmosphere as a whole to rotation of a solid body, one can state that the rotation period of the atmosphere around the axis in April and November is 23 h 36 min., and in August 23 h 43 min. /87
On the average during the year, the days for the atmosphere last 23 h 38 min., and not 23 h 56 min. as for the Earth.

It is sometimes thought that since the atmosphere overtakes the Earth in its diurnal rotation, then it must continually accelerate the Earth's rotation. However, only changes in the pulse moment of the winds affects the nonuniformity of the Earth's rotation. The constant magnitude of the pulse moment of the winds was borrowed by the atmosphere from the Earth at the moment that atmospheric circulation was formed. Then the Earth's rotation rate was slightly slowed down (the duration of the days rose by 0.002 sec) and has remained so into the present. If the source maintaining the winds in the atmosphere, the Sun, dries up, then atmospheric circulation will cease, the pulse moment of the winds will "drain off" towards the Earth, and the duration of the days will adopt its original value (be reduced by 0.002 sec.).



Motion Trajectory of Momentary North Pole of the Earth

On the axes which are directed along the Greenwich meridians, 270° e.l. and 180° e.l., the distance to the Earth's surface is plotted in meters. The stars indicate the beginning of the year. Polar motion occurs from west to east on a spiral curve which first twists (1971 - 1974) , then untwists (1975 - 1978).

The atmosphere which is nonuniformly heated over the horizontal by solar beams, can be viewed as a thermal machine. It converts the solar heat into kinetic energy of the winds. The warmest parts of the atmosphere in this case fulfill the role of the heater, while the coldest are the cooler. The air itself serves as the working fluid. There are several known thermal machines in modern atmospheric physics. The most important of them are thermal machines generated by the temperature contrast between the equator and the poles. The famous Soviet geophysicist V. V. Shuleykin called them thermal machines of the first type.[1] One of them operates in the Northern Hemisphere, and the other in the Southern. The observed easterly winds are maintained in

[1] Shuleykin, V. V. "Interaction of Links in the System 'Ocean-Atmosphere - Continents'," Priroda, No. 10, 1971, p. 12.

the lower latitudes because of these machines, and the westerly are maintained in the temperate and high. The greater the temperature contrast equator - pole, the more intensive the atmospheric circulation in the given hemisphere, and the greater the magnitude of the pulse moment of the winds.

Temperature contrast in each hemisphere fluctuates with an annual period. It is the greatest in winter, and the least in summer. Therefore the pulse moment of the winds in the Northern Hemisphere which can be confined by the thermal machine of the first type makes harmonic fluctuations with period of one year from the maximum value in January to the minimum in July. In the Southern Hemisphere, the annual fluctuation has the opposite phase: the pulse moment is the maximum in July, and the minimum in January. Therefore the annual fluctuations of winds in the Northern and Southern Hemispheres compensate for each other, and the pulse moment of the winds in the entire atmosphere should remain almost constant. Thus, the thermal machines of the first type govern the appearance in the atmosphere of a positive pulse moment of the winds, but have almost no effect on its observed seasonal fluctuations.

It was not clear for a long time why the pulse moment of the winds in the entire atmosphere undergoes the observed seasonal fluctuations. It was found in 1975[1] that in the upper atmospheric layers, the warmest region is not the equator and not the parallel at which the Sun is at its zenith at noon, but the polar "cap" of the summer hemisphere (in July the Northern, and in January the southern). It was found that the average air temperature diminishes continually from the pole of the summer Hemisphere to the pole of the winter (in July from the North Pole to the South , and in January, from the South Pole to the North). /88
It became clear that the atmosphere has a thermal machine whose

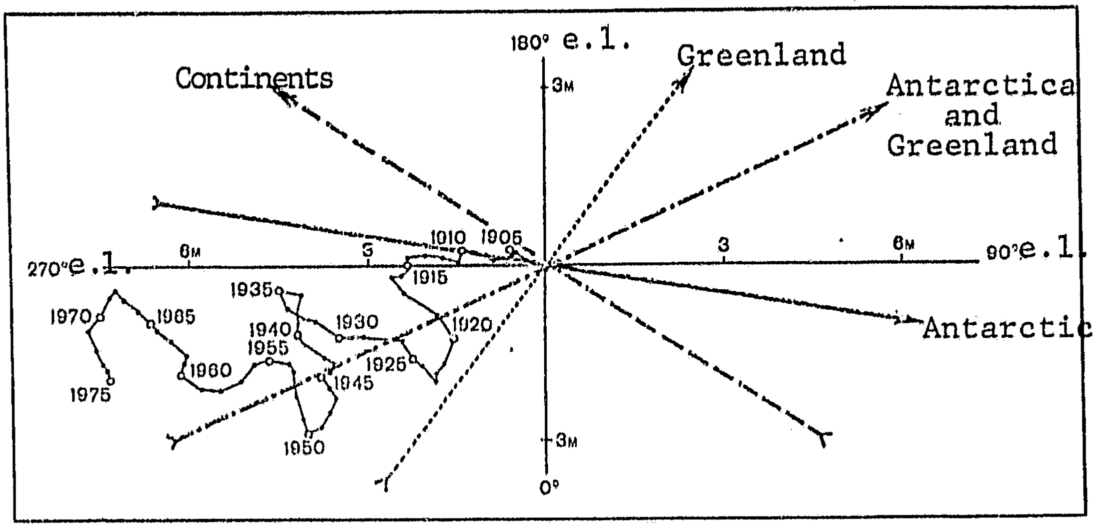
[1] Sidorenkov, N. S. Doklady AN SSSR, Vol. 221, No. 4, 1975, p. 835.

heater is the atmosphere of the summer hemisphere, and the cooler is the atmosphere of the winter hemisphere. This interhemispheric thermal machine prevents operation of the thermal machines of the first type. It reduces the magnitude of the wind pulse moment which can be restrained in the atmosphere by the thermal machines of the first type. The greater the temperature contrast between the hemispheres, the more significant this effect. In January and July, when the operation of the interhemispheric thermal machine is the most intensive, the wind pulse moment is reduced to the minimum values, and the Earth's rotation rate reaches the maximum values. In April and November, the temperature differences between the atmosphere of the Northern and Southern Hemispheres are equalized. The interhemispheric thermal machine ceases its operation, therefore the maximum magnitude of the wind pulse moment is retained in the atmosphere, and the Earth's rotation rate becomes the minimum.

The difference in the magnitudes of the July and January maximums in the Earth's rotation rate is associated with the fact that the atmosphere of the Northern Hemisphere on the average is warmer during the year than the atmosphere of the Southern Hemisphere. Therefore the temperature contrast between the poles is considerably greater in July than in January. If the underlying surfaces in the Northern and Southern Hemispheres were the same, then the magnitudes of the January and July maximums of the Earth's rotation velocity would not differ. The intensity of work of the interhemispheric thermal machine changes from year to year. Correspondingly, the parameters of seasonal fluctuations in the Earth's rotation velocity also change.

Nature of Long-Period Changes in the Earth's Rotation Velocity

Long-period changes in the Earth's rotation velocity are too great to be explained in the same way as seaonal fluctuations by the redistribution of the pulse moment between the atmosphere and the Earth. Thus, for example, slowing down of the rotation



Trajectory of Shifting in the middle North Pole in the Period 1900 - 1975 from Data of International Latitude Service.

Coordinate axes are directed along 0° - 180° and 90° - 270° e.l. The distance is plotted on them in meters. The pole is shifted on the average on the meridian 300° e.l. The arrows indicate the directions of pole shifting in the case of ice accumulation in individual glacial regions (Antarctic , Greenland, Antarctica and Greenland) and on all the continents. When ice melts in the indicated regions, the direction of shift changes to the opposite. The observed shift in the North Pole corresponds to melting of ice in Antarctica and Greenland.

velocity from 1961 to 1972 was such that the pulse moment of the Earth was diminished by 14×10^{25} kg x m^2 x sec^{-1}. If this slowing down occurred because of redistribution of the pulse moment between the Earth and the atmosphere, then the pulse moment of the winds in 1972 would have been 14×10^{25} kg x m^2 x sec^{-1} greater than in 1961. In other words, the wind velocity in the atmosphere by 1972 should have almost doubled. However there are no such large long-period fluctuations in the atmospheric circulation. The same simple estimates of the changes in the Earth's inertia moment which may be required to explain the long-period nonuniformity of the Earth's rotation yield unnaturally large magnitudes. Therefore until recently it was believed that long-period nonuniformity in the Earth's rotation could not be caused by geophysical processes occurring on the Earth's surface. It was usually tied to such internal terrestrial processes as the interaction of the Earth's core and mantle, recrystallization of certain rocks forming the Earth. However, there are currently no observation data which would confirm the existence of these processes within the Earth.

A number of empirical facts have been obtained in recent years which force us to re-examine these viewpoints on the nature of the interannual nonuniform rotation of the Earth. We will discuss them in order.

The effect of the atmosphere on the Earth's rotation can be evaluated not only by computing the change in the inertia moment and the pulse moment of the atmosphere, but also by calculating the moments of the forces acting on the Earth on the part of the atmosphere. They include, as is known, the moments of the wind friction force on the underlying surface and the moments of the pressure force on the mountain ridges, which like sails, stand in the path of the winds. In order to define these moments of the forces, data are needed on the fields of the wind or atmospheric pressure in the near-earth layer over the entire Earth. By knowing the summary moment of the forces, it is easy to compute the acceleration and nonuniformity in the Earth's rotation. The author employed this method of the force moment and computed the Earth's nonuniform rotation for 1956 - 1977 from data of the average-monthly atmospheric pressure field at sea level over the entire globe for the indicated period.[1]

The calculations indicated that not only the seasonal, but also the long-period nonuniformity in the Earth's rotation was caused in 1956 - 1977 by the mechanical effect of the atmosphere on the Earth. This result indicates the existence of transfer

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[1]Sidorenkov, N. S. Astron. zh., Vol. 56, No. 1, 1979, p. 187.

of "portions" of sometimes positive, and sometimes negative pulse moment through the near-earth atmospheric layer. This results in long-period nonuniformity in the Earth's rotation. The corresponding changes in the wind pulse moment needed for fulfillment of the balance are not observed. Therefore there must be some "supplier" of the pulse moment to the atmosphere. It was natural to hypothesize that the atmosphere obtains the pulse moment either from the near-earth outer space, or from the Earth, in the process of long-period redistribution of moisture between the ocean and the land. The estimates indicated that the stream of the pulse moment from space is negligible, and further efforts were aimed at researching the role of moisture redistribution.

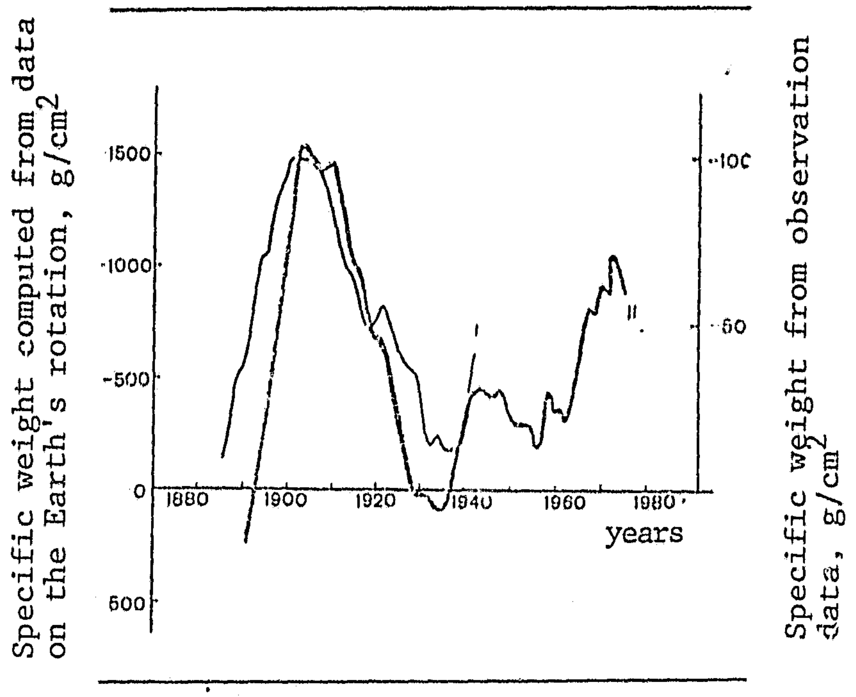
It is common knowledge that about 2% of all the water on the Earth is in the frozen state (mainly in the form of ice). The total weight of ice in the modern epoch is about equal to 28.4×10^{18} kg. Ninety percent of this is the glacial sheet of Antarctica, 9% is the glacier of Greenland, and less than 1% is the mass of ice on all the other mountain glaciers. The areas of the glacial sheets are: in Antarctica 13.9×10^{12} m^2, in Greenland 1.8×10^{12} m^2, and mountain glaciers 0.5×10^{12} m^2.

The weight of the glaciers changes considerably in time. For example, 12,000 years ago, an enormous glacial sheet melted, covering almost all the Russian plain and considerable spaces of West Europe and North America in the Quaternary period. During the small climate optimum which took place about a thousand years ago, the glacial sheet of Greenland weighed considerably less than it does today. This redistribution of moisture between the World Ocean and the glacial sheets was inevitably accompanied by a change in the Earth's inertia moment, and should have resulted in some nonuniformity in the Earth's rotation and polar motion.

The theory results in a system of algebraic equations which link the magnitude of the Earth's rotation rate and the polar coordinates with the ice masses in Antarctica, Greenland and the water in the World Ocean. These equations make it possible to solve two tasks. If the ice weights in Antarctica, Greenland and the World Ocean are known, then one can compute the characteristics of the Earth's rotation, the polar coordinates and the rotation velocity of the Earth. If these weights are not known, but the rotation characteristics of the Earth are available, then one can solve the inverse task: using the polar coordinates and the Earth's rotation velocity, compute the weights of the ice in Antarctica, Greenland and waters in the World Ocean. Using data on the Earth's rotation in the last 90 years, we solved the inverse task.[1] Unfortunately, we were not able to compare the /90 series of computed ice weights in Greenland and water in the World Ocean with the observation data because we did not have the latter. We were only able to compare the computed curve for changes in the ice weight with the observed for Antartica. Qualitative agreement of the curves was so good that a link between long-period nonuniformity in the Earth's rotation with fluctuations of global water exchange is possible. However, the computed fluctuations in global water exchange are almost 29-fold greater than the observed.

These contradictory results possibly indicate that the observed features in rotation are not nonuniformity of rotation and motion of the poles of the entire Earth, but only changes in the drift rate of the lithosphere through the asthenosphere. In fact the moments of forces of one sign which develop during long-period global water exchange act in the space of decades. It is possible that the substances of the asthenosphere which lies under the lithosphere during such prolonged effects does not act as a solid body, but flows like a viscous liquid. Then the long-period global water-exchange can cause sliding of the lithosphere through the asthenosphere without having a noticeable effect on the deeper layers of the Earth. In the astronomical observations, the changes in drift velocity of the lithosphere will be recorded as "nonuniform rotation of the Earth"

[1] Sidorenkov, N. S. Meteorol. i gidrol., No. 1, 1980, p. 52.



Change with Time in Ice Weight in Antarctica

From data of empirical observations, from V. N. Petrov (I) and computed from data on Earth's rotation (II). At the end of the last century and from 1935 to 1972, the weight of ice of Antarctica diminished, and from 1903 to 1935 it increased.

and "polar motion." But 29-fold less moisture redistribution is required for the creation of these apparent "nonuniformities in the Earth's rotation" and "polar motion" than for the actual nonuniformities in rotation and polar motion of the entire Earth. The repeatedly noted correlation between seismic activity and nonuniform rotation of the Earth supports this hypothesis.

Fluctuations in global water exchange depend on the changes in the Earth's climate. The link between long-period nonuniformity in the Earth's rotation and changes in different climate indices becomes clear from these viewpoints. For example, the moments of the most drastic disorders in the Earth's rotation mode in the last 300 years which took place in 1870 and 1935 coincide with the epochs for the end of the "minor glacial period" and warming up of the Arctic. The later considerable change in the Earth's rotation mode which was observed in 1972 is memorable for the exceptionally hot and arid summer on the European territory of the USSR. It has been noted that each rotation mode of the Earth has its corresponding dominant form of atmospheric circulation, and consequently, its own weather pattern in different regions of the globe. /91

Climate fluctuations have characteristic times which are equal not only to decades, but considerably longer periods. Irregular changes in the Earth's rotation velocity probably can also have characteristic times on the order of centuries and milleniums. Estimates of the rate of secular slowing down of the Earth's rotation which are usually done for an interval of less than 2000 years can therefore hardly be linked merely to tidal slowing down. They can include irregular changes which distort the unknown rate of the tidal slowing down. Thus, for example, the trend which could be traced in the last two centuries towards slowing down in the Earth's rotation rate can be explained by melting of the glacial sheets of Greenland and Antarctica. The average direction of secular motion of the poles corresponds to this.

Use of Data on the Earth's Rotation in Hydrometeorology

Study of nonuniform rotation of the Earth and polar motion is promising for solving inverse tasks. The fact is that it is more complicated to determine the fluctuations in global characteristics of the atmosphere or hydrosphere than the fluctuations in the Earth's rotation velocity and polar motion which reflect them. Thus in order to compute the wind pulse moment once it is necessary to assemble data regarding wind distribution with height if possible from all the aerological stations of the world, to make an objective analysis of them (i.e., interpolation and extrapolation), and to numerically compute the integral for the volume occupied by the atmosphere. Since we are interested in the changes in the wind pulse moment in time, then these cumbersome and labor-intensive computations should be made regularly from day to day, or at least from month to month. It is not surprising that this work has not been done anywhere. Data on nonuniform rotation of the Earth make it possible to easily determine fluctuations in the wind pulse moment almost with the same accuracy. This only requires consideration for certain known corrections.

It was found by this manner that the wind pulse moment fluctuates during the year, having two maximums (in November and April) and two minimums (in August and January). It has been established that the magnitudes of the minimums change, revealing almost two-year and six-year cyclicity.

Seasonal nonuniform rotation of the Earth reflects the work of the interhemispheric thermal machine and can be used as indicators for the difference in temperatures, intensity of air circulation, and exchange of moisture between the Northern and Southern Hemispheres. This approach indicates that the August values of the listed characteristics change with six-year, and the January, with almost two-year periods.

Important results were obtained in analyzing overheating of the Northern Hemisphere as compared to the Southern, i.e., the difference in the average annual temperatures in the Northern and Southern Hemispheres. It was found that before 1962, overheating of the Northern Hemisphere as compared to the Southern was considerable. In 1963 it diminished drastically, but apparently was associated with atmospheric pollution resulting from eruption of the Agung volcano (March 1963). After 1963, overheating increased, but did not reach the magnitude of the preceding 1962. In 1971 - 1972, it decreased drastically and remained low up to 1977. After 1977, overheating drastically rose. These conclusions which were obtained from data on seasonal nonuniformity inthe Earth's rotation agree well with the empirical data. According to them, overheating of the northern polar region as compared to the southern was higher than the normal by 0.7° in the beginning of the 1960's, and lower by 0.6° in the early 1970's.

Long-period nonuniformity in the Earth's rotation and secular motion of the pole (with its accurate determination) can apparently be utilized to compute changes in the weight of the ice in Antarctica, Greenland and water in the World Ocean. Long-period nonuniformity in the Earth's rotation has great importance for tracking, and to a certain degree, for forecasting climate fluctuations. Thus, for example, its analysis indicates that the climate mode which was established in 1972 probably will be in existence for about two dozen more years. This means that in some regions of the globe, probably before the beginning of the next century it will be warmer and drier, and in others--cooler and moister.