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SEASONAL CHANGES ON SATURN'S MOON TITAN

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Abstract. *During its rotation around the Sun due to the inclination of the equator to the plane of the orbit at 26.73° Saturn has significant differences in the flow of solar energy to the opposite hemispheres. Due to the orbital eccentricit, the southern hemisphere receives 25% more energy from the Sun than the northern one. This affected the seasonal changes in the physical characteristics of visible clouds. Saturn's largest satellite Titan with a diameter of 5152 km rotates synchronously at a distance of 1221870 km from the planet in 15.945 Earth days. The plane of its orbit coincides with the plane of rings. Therefore, it is illuminated by the Sun like Saturn. During 29.46 Earth years, Titan also alternately leans toward the Sun by the N- and S- Poles. This leads to periodic changes in the inflow of solar energy to opposite hemispheres. Hadley's giant cell circulates from S Pole to N Pole and vice versa. It is the main method of heat transfer in Titan's atmosphere. Radar observations of the polar regions revealed significant differences between the opposite polar regions of Titan. In the winter polar region, few lakes and a large number of dry round depressions resembling northern lakes have been found. These "dry" southern regions have shown similarities with the northern regions, which have many fluid-filled lakes. This similarity of such elements around the poles suggests that the polar regions of Titan are under the influence of weather conditions, which change dramatically from time to time. This indicates that they are links in a chain similar to the Earth's water cycle. The main reason for the contrast in the landscapes around the opposite poles of Titan may be the differences in natural conditions between the winter and summer seasons in these regions. All this opens up new opportunities for comparative studies of the seasonal dynamics of changes in the atmospheres of Titan and Earth.*

Key words: *Saturn's moons, Titan, seasons variations, atmosphere, clouds*

The planets of the Solar System with a significant inclination of the plane of the equator to the plane of their orbits (Earth, Mars, Saturn, Uranus, Neptune), during the time of rotation around the Sun, there are significant differences in the arrival of solar energy to different latitudinal zones. For example, the inclination of Saturn's equator to the plane of its orbit is B≈26°44' with a period of rotation around the central luminary of 29.46 years. Therefore, this planet was the object on which we began to study seasonal changes in its atmosphere in 1977. Our calculations [9] showed that Saturn passes the perihelion of its orbit almost in the epoch of summer for the southern hemisphere; in aphelion - planet has summer at the northern hemisphere. And due to the eccentricity of the orbit e≈0.056, the southern hemisphere of Saturn receives 25% more energy from the Sun than the northern one. The rings additionally block the access of sunlight to Saturn's clouds, enhancing seasonal contrasts [10]. Similar changes in atmospheric irradiation affect the physical characteristics of clouds, fog above them, and the vertical structure of the entire troposphere, where they are formed [8, 12]. Therefore, they are associated with seasonal changes [1] inflow of solar energy.

The largest moon of Saturn, Titan, has a diameter of 5152 km. It is the second largest in the Solar System [11] after Jupiter's moon Ganymede. Titan rotates in

15,945 Earth days at an average distance of 1,221,870 km from the planet. The period of its rotation around the axis is synchronized with the rotation around the planet. The plane of the satellite's orbit almost coincides with the plane of Saturn's rings. Therefore, it is illuminated by the Sun in the same way as Saturn itself [9]. And this means that in 29.46 Earth years, Titan alternately leans towards the Sun by the northern and southern polar regions. This leads to periodic changes in the inflow of solar energy to its northern and southern hemispheres.

In 1944, J. Kuiper discovered Titan's powerful atmosphere. It consists of 95% nitrogen with admixtures of methane and small amounts of other gases. The thickness of its atmosphere at the height of the visible upper levels of the clouds is from 200 to 500 km. This creates a pressure near the surface of almost 1.5 bar [15]. The temperature on the surface of the satellite is about 94 K, which is the condensation temperature of nitrogen. Due to thick clouds, the surface of Titan remained invisible for a long time. And only the first radar studies from space vehicles and observations in the infrared (IR) part of the spectrum with the Hubble telescope, Keck telescopes and with the Very Large Telescope (VLT) indicated the possibility of the existence on the surface of Titan of seas and lakes of liquid nitrogen, islands of frozen water and methane, and from silicates on the "dry" surface. At the same time, methane rains were also recorded. These facts made it possible to put forward proposals for comparing the water cycle on the planet Earth with the processes on Titan. We drew attention to the possibility of the existence of so-called seasonal changes in Titan's powerful atmosphere [14]. These changes should cause periodic restructuring and variations of physical characteristics alternately in the northern and southern hemispheres of the satellite, similar to the existing seasonal changes in the atmosphere of Saturn [6], Jupiter [2, 7], Mars or Earth [4, 5]. Observations have shown that the vast majority of changes in visible clouds on Titan have formed over a long period of time, which may well be related to the changing seasons. Short-term observations of the vertical structure of the satellite's atmosphere were carried out simultaneously during the descent of the “Huygens” module and with the “Cassini” instrument. They allowed to register the existence of thick clouds at altitudes of 26-30 and 19-23 km from methane, and liquid smog at altitudes of 18-19 km in the atmosphere of the satellite. The structure of denser clouds turned out to be very similar to terrestrial cumulus formations [3]. Only the sizes of methane droplets on Titan and terrestrial water droplets differed. Their dimensions on the satellite were almost two orders of magnitude larger. Therefore, with the same level of humidity, the droplets in the clouds on Titan are located at a much greater distance from each other. Such clouds have a much lower density.

The obtained data indicated the presence of constant circulation in Titan's atmosphere at the time of the observations. It was recorded that huge masses of warmer gases at an altitude of about 7 km moved from the southern hemisphere to the northern polar region, descended there and returned back. The results of a computer simulation of global atmospheric circulation and measurements in the infrared range showed that the integrated temperature gradually decreased when moving from south to north. At the time of the probe's landing, it was winter there [15]. Due to the differences in the seasonal heating conditions of the opposite hemispheres of Titan, significant differences in the pressure values between the hemispheres were also recorded. We will remind that it was the southern hemisphere at the time of these observations that was tilted towards the Sun.

The "Huygens" probe noted that the wind changed its direction twice at an altitude of 6 km and then at an altitude of 0.7 km above the surface. It is believed that these two height values in Titan's atmosphere [14] indicate a circulation process known as the Hadley cell. This giant cell circulated during the years of observation from the south to the north pole and back. And it was the main way of heat transfer in the atmosphere. Therefore, it was 10 K warmer in the south of Titan than even at the equator. Such a southern summer continued there until 2010. After that, Saturn began to tilt in its orbit so that already its northern hemisphere began to be increasingly heated by the Sun. Such a huge Hadley cell can only exist on very slowly rotating objects. We will remind you that a day on Titan lasts up to 16 Earth days. Therefore, despite the fact that these cells are controlled by the same mechanisms, the system of air flows on Titan is significantly different from what is recorded on Earth [4]. This fact is important from the point of view of comparative planetology. After all, it allows studying a climatological system significantly different from Earth in a comparative aspect.

Direct measurements from the "Huygens" module showed that the temperature minimum in the tropopause of Titan's atmosphere is located at an altitude of about 45 km above the surface at a temperature of about 70 K and a pressure of 0.12 bar. Below this level, the temperature rises and near the surface reaches 94 K. Above the tropopause level is the stratosphere, where the temperature rises again with height. According to data obtained by the "Huygens" probe, methane clouds in Titan's troposphere turned out to be very dynamic. Analysis of observational data showed that they usually occur literally within half an hour when air masses rise from the middle troposphere to the tropopause level. After rain fell on the surface of the satellite, the clouds dissipated within the next hour.

Sometimes clouds of ethane snow were also observed in Titan's atmosphere. For example, in the winter northern hemisphere of the satellite, a similar cloud was observed with the "Cassini" instrument at all possible longitudes at latitudes $(50\div70)^\circ$. It is believed that it is the condensation of ethane snow around the polar regions of Titan during polar winter that can explain the practical absence of liquid reservoirs of ethane up to tropical latitudes. Riverbeds near the Huygens landing site, even in Titan's equatorial zone, were also not filled with liquid. Special studies showed that they could be seasonal channels that are filled only during the period of the year when precipitation falls. Whereas at the time of the probe landing, there was a dry season [15].

It took up to two years after the landing of "Huygens", before from radar studies from "Cassini" – the seasonal hypothesis received direct confirmation for the moments of the end of winter in the northern polar region of Titan. We will remind you that the main chemical component of the atmosphere on Titan and Earth – is the same: it is nitrogen. However, the chemical composition of the rest of the elements is significantly different from their earthly counterparts. After all, the role of rocky rocks on Titan is assigned to water ice [15], and the role of Earth's water is performed by liquid methane with additives. Brighter spots in dark seas and lakes are islands of various sizes. Therefore, the lakes found in the spring in the northern hemisphere became a serious proof of the existence of a liquid circulation cycle on Titan. After all, with such a cycle, the very beginning of heavy methane precipitation in the spring and the subsequent filling of lakes, which was accompanied by the rise of soil fluids, is a confirmation of seasonal changes.

The 29.46-year period of Saturn's rotation around the Sun, and the change of seasons caused by this fact, well explains why during the operation of "Cassini" in 2008-2017, there were heavy rains in the northern hemisphere. Therefore, a large number of lakes were registered there. Whereas in the southern hemisphere, almost all reservoirs gradually dried up in those days. Many of the bodies of water in northern latitudes were much larger than even some seas on Earth. For example, the "Cassini" radar recorded the largest such dark spot on the surface near the north pole of the satellite (Fig. 1). Such large dark areas extended further than 1000 km from the pole. In 2008, "Cassini" radars scanned up to 60% of the northern polar region above 60° latitude. It turned out that one-sixth of this area was covered by hydrocarbon lakes with sizes ranging from units to hundreds of kilometers [18]. After that, radar observations of the previously little-studied region around the South Pole began. This made it possible to reveal significant differences between the northern and southern polar regions of Titan. It was possible to find only one large lake with a size of up to 230 km, three small lakes and several small spots near -70° beyond the winter southern polar circle. A large number of dry rounded depressions were also found there, which were similar in shape to craters [13,18] and northern lakes. Also, a large-scale structure with a depression was found, which can be interpreted as a basin from under a dry sea with a system of rivers and canals that seasonally filled it. The length of a season on Titan is almost 7.5 years, which is 1/4 of a Saturnian year of ~29.46 Earth years.

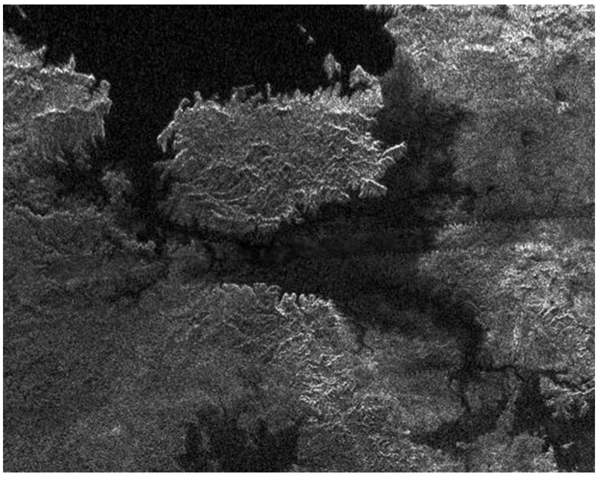

Figure 1 – Surface images from the "Cassini" spacecraft in the infrared range showed the presence of fragmentary seas around Titan's north pole (http://nssdc.gsfc.nasa.gov/photo_gallery).

After careful studies of these seasonal changes [16, 17], several mechanisms were proposed that can form hydrocarbon reservoirs of the above types on the satellite. The lakes found on Titan have a huge interval of filling. This indicates their long evolution, as well as the fact that they are links in a chain similar to the Earth's water cycle. Therefore, Titan is a unique body among those that are at great distances in the Solar System.

Thus, the main reason for the sharp contrast in the landscapes around the opposite poles of Titan is most likely the differences in natural conditions between the winter and summer seasons [4] in these regions. It can be predicted that at the equinox in 2023, Titan's southern hemisphere will experience the end of winter, and the northern hemisphere will experience the end of summer. And it is at these moments that the existing contours of lakes and seas undergo radically opposite changes. Therefore, it would be very appropriate in 2024-2026 to conduct appropriate observations in the IR range with Keck telescopes, space telescopes and the Very Large Telescope in order to test this hypothesis regarding seasonal changes on Titan. Taken together, all this opens up new opportunities for comparative studies of the seasonal dynamics of changes in the sufficiently powerful atmospheres of Titan and our planet Earth.

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