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Effects of solar wind on Magnetic storm, Ozone hole, Westerlies, Trade winds, Typhoons, Lightning and Superrotation

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Abstract: Based on the data from space explorations, it became clear that the solar wind influences the upper atmosphere and various phenomena on weather. The solar wind has a rotating component due to the rotation of the Sun in addition to the components that radiate vertically from the Sun. The continuous collision of charged particles with the atmosphere causes westerlies and trade winds. The atmospheric pressure becomes low when cumulonimbus is rose up to the stratosphere, and the dry air which contains H^+ of the solar wind gathers. Those cold dry air is concerned with generating Typhoons and Lightning.

Keywords: Solar wind, Magnetic storm, Ozone hole, Westerlies, Trade winds, Cumulonimbus, Typhoon, Thunder, Superrotation

1. Introduction

Observations by space probes were accumulated and their findings were examined. As a result, it has been revealed that solar wind has a significant impact on earth's weather phenomena such as partial westerlies, trade winds, and typhoons

When an explosion occurs on the surface of the Sun, it is known that two types of radio propagation failures occur i.e. magnetic storms and Dellinger effect. The Dillinger effect is caused by the x-ray due to explosion in the Sun. That is, the ionization of molecules in the atmosphere by the X-ray generates an unusually high layer of electron density. The layer reflects the radio waves of the high frequency band in daytime.

On the other hand, the magnetic storm is caused by a shockwave of the solar wind. The wave changes the magnetosphere of the Earth, making it impossible for the HF band to communicate for hours or days. The charged particles of the solar wind (H^+) are positive ions, reducing the electron density of the ionosphere and not reflecting HF radio waves.

In the event of a magnetic storm, active activity of the Sun has been reported to reduce the electron density of the peak of the ionosphere [1].] That is, the total number of electrons in the ionosphere (TEC) and the maximum electron density in the F region (NmF2) is significantly reduced from the median, and the ionospheric negative storm is reported [2].

In addition, data on the measurement value of (N_2/O) in the magnetic storm by satellite IMAGE SI-13 shows that the high ratio region is spread from the polar region to the mid and low latitudes [3]. This is evidence that the charged particles (H^+) of the solar wind connects with free electrons and oxygen ions.

The high-speed charged particles (H^+) of solar wind are captured by the earth's geomagnetism via electrons. Those H^+ and electrons are separated by the magnetic field and those are continued to stay in the geomagnetic field.

Since H^+ captured in the earth's magnetosphere is driven by H^+ of solar wind additionally, the collisions deform the magnetosphere of the Earth.

The Sun is turning in the anticlockwise direction. So, the solar wind that pass through the side of the Earth drives wind of counterclockwise rotation due to the rotation of the Sun. The wind from west to east become weak at the polar region the distance of the circumference which orbits is short in the polar region.

On the other hand, the solar wind collides head-on near the equator of the earth facing the Sun. Since the direction of the rotation of the Sun is counterclockwise, and when the solar wind with the component of the rotational motion collides vertically, generating the trade wind that moves the atmosphere of the stratosphere near the equator from east to west by a mechanism of the gears,.

When the temperature of seawater or the land rises and the air containing water vapor rises, the water vapor turns to liquid particles and the atmospheric pressure becomes low. When the atmosphere containing H^+ of the solar-wind charged particles gathers at cumulonimbus, it increases the positive potential and the polarization of molecule of water is arranged in the cloud, resulting in a negatively charged at bottom of the cumulonimbus. That is the mechanism of thunder.

When a group of cum-turbulent clouds occurs near the equator, and dry cold air gathers in the counterclockwise in the sky, the eye of the typhoon can be formed in the center. The centrifugal force prevails at center of the eye. The cloud group facing at the sea surface also moves toward the eye of the typhoon. In the eye of the typhoon, both gas molecules collide and rotate in the same direction, causing the water vapor of the cloud to condense and rain. Typhoons are caused by a group of clouds at the sea surface and dry cold air rotational flow in the upper cloud.

In the stratosphere of Antarctica in winter, ozone (O_3) hole is formed. The H^+ of the solar wind does not react when it collides with H^{+}, but when a high-speed H^{+} collides with an ice crystal H^{+} reacts with an ice crystal. A hypothesis is proposed in this report as follows. The ozone hole is formed when a large amount of H^{+} collides with ozone (O_3), making H_2O and becoming an ice crystal, which becomes a polar stratospheric cloud that shines in the rainbow color.

This article reports on the meteorological phenomena involving charged particles of solar wind, and it points out that the effects of solar wind charged particles on the Earth have been under evaluated.

2. Effects of solar wind on radio propagation

2.1 The structure of the ionosphere

Atmospheric molecules above the Earth are ionized by-rays and ultraviolet rays emitted from the sun. Radio waves are absorbed or reflected in the ionosphere with a strong free electron density.

The response of the ionosphere on radio waves vary depending on the frequency band. By the way, high frequency radio waves above VHF and UHF will pass through the ionosphere. Shortwaves pass through the D layer and are reflected in the F layer.

The formation of ionosphere by X-rays and ultraviolet rays that reach directly from the Sun is diminished at night. So, the transmission of the electric wave also changes according to the time zone. An example of the structure of the ionosphere layer is shown in Fig.1.

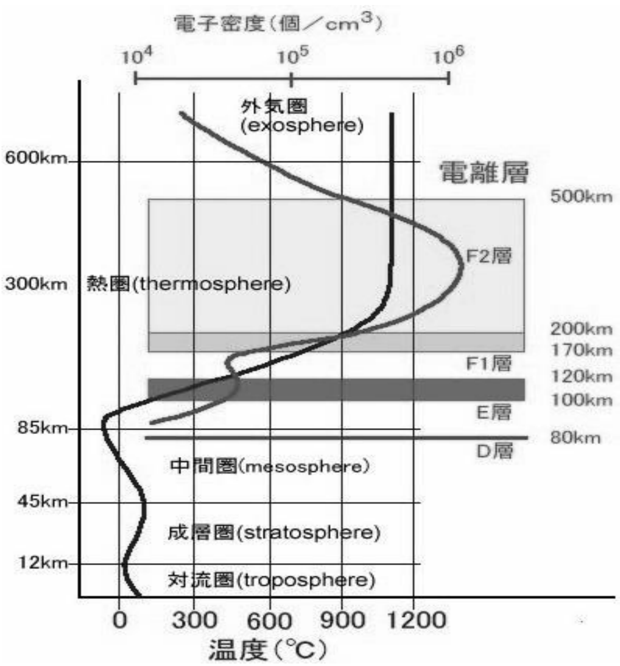

Fig. 1 A structure of ionosphere (source: website http://www.geocities.jp/hiroyuki0620785/intercomp/wireless/ionsphere.gif)

2.1. Failure of radio wave propagation by Dellinger Effect

The phenomenon known as the Dillinger effect causes a significant disturbance on a radio waves propagation of the high frequency band in low latitude areas during the daytime. It is considered that the effect is caused by the increase in free electrons in the D region of the innermost ionosphere (60km to 90km).

The mechanism is as follows. When an explosion occurs on the surface of the Sun, the electromagnetic waves reach Earth eight minutes after the explosion. N_2 and O_2 in the D layer are ionized by hard X-rays (wavelength < 1 nm). So, the radio waves in the high frequency band are reflected in the D layer of the abnormally high electron density suppresses the propagation radio wave suddenly.

2.2. Radio propagation disorder by the magnetic storm

After the explosion of the Sun, a strong solar wind reaches to the Earth. Normal solar wind speeds are about 450km/sec on す average, but when an explosion such as coronal mass emission (CME) occurs on the surface of the sun, a high-speed (~1000km/sec) solar wind occurs. The magnetic storm is the shock wave that compressed the slow solar wind went ahead. The magnetic storm causes HF radio wave propagation disorder in hours or days.

According to a report examining the behavior of the total electrons (TEC) and F-region maximum electron density (NmF2) during magnetic storms, both data are decreased significantly from the median, resulting in negative storms in the ionosphere.

In addition, data on the ratio of measurements (N_2/O) in magnetic storms by the camera in satellite IMAGE SI-13 revealed that the high ratio region spread from the polar region to the mid and low latitudes[3]. In magnetic storms, it is thought that the chemical reaction of the H^{+} of the solar wind and the ion of the ionosphere neutralizes the free electron, and it does not reflect HF radio waves.

3. Atmospheric phenomena caused by H^{+} in solar wind

3.1 Internal structure of the Earth's atmosphere

Molecular density of the Earth's atmosphere decreases as it goes up in the sky, but there are two areas where the temperature of the Earth's atmosphere decreases between the stratosphere and the troposphere (10km to 20km) and the intermediate area (80km to 90km).

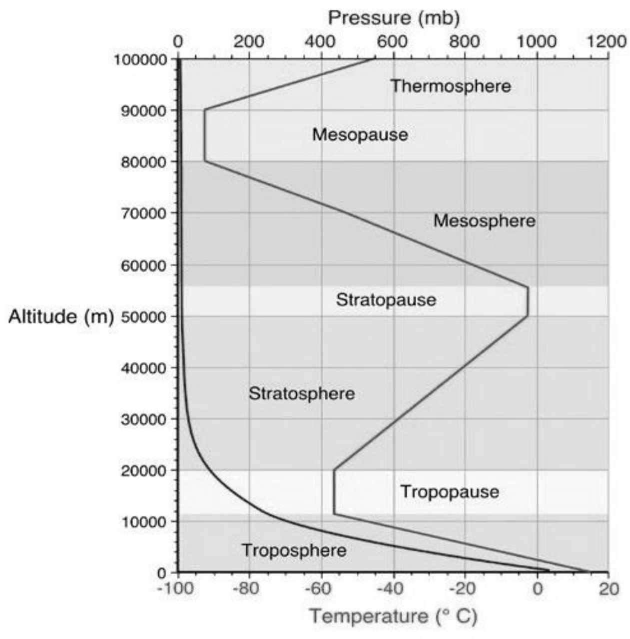

Fig. 2 A stratospheric structure (source website http://www.coolgeography.co.uk/A-level/AQA/Year%2013/Weather%20and%20climate/Structure/atmslayers.gif)

As shown in Fig.2, the temperature increases lowering the altitude in the mesosphere, the temperature peaks at once, and further down the altitude reduces the temperature decreases to about -60 °C. In the troposphere, the vapor water becomes a cloud, and it rains.

Here, we calculate the amount of H^+ reaching the earth from the sun, ignoring the effects of magnetic fields. The typical amount of H^+ ions emitted from today's sun is $N=10^9$kg/sec.

The amount of H^+ reaching to the Earth is estimated by the ratio of the sphere area (S_{sphere}) (of which radius is $1.5x10^8$ km the distance from the Sun) and the Earth's cross section (S_{Earth}).

$$N \cdot (S_{Earth} / S_{sphere}) = (10^{12})x(6.02x10^{23})/\{4\pi(1.5x10^{13})^2\}$$
$$= 6.02x10^{35}/(2.83x10^{27})=2.1x10^8 \text{ [pieces/(cm}^2 \cdot \text{sec)]}$$

This is equivalent to approximately 2.1 pieces by 1μm². The amount of H+ to reach the Earth is 39,000 kg/day.

3.2 Formation of ozone holes by solar wind

The total distribution of ozone (O_3) measured by Earth probe and Aurora probe is low in concentration near the equator and in the Arctic and Antarctic regions [4] p.985-986. It became clear that an ozone hole appears over Antarctica. So, fluorocarbons were discussed as a destructive material in the O_3 layer of [5]. Chemicals that produce polar stratospheric clouds were also studied [6].

However, O_3 is generally higher in the southern hemisphere than in the northern hemisphere. O_3 layers can be at the top of the interface between the troposphere and the stratosphere and it is a low temperature region, as shown in the temperature change in Fig.2. The fine particles of water are ice crystals at temperatures below -40°C. It converts into an ice crystal a -78°C [7].

H^+ of solar wind are captured at the polar region by the geomagnetic filed. Temperatures drop and dry in the low stratosphere in the winter in antarctica especially. If H^+ strikes O_3, H_2O is produced. The H_2O will immediately become ice crystal, creating a rainbow-colored polar stratospheric cloud, and the O_3 layer disappears.

The author proposes the theory that the ozone hole is involved in the H^+ of the solar wind in this way.

3.3 Formation of auroras in the ionosphere

Auroras can be seen in the high latitude regions around north and south poles. The altitude at which it occurs is in the ionosphere of 100km to 500km, where atoms will be ionized by H^+ of solar wind. The generated electrons via ionization are captured by the geomagnetic field and generate auroras in polar regions.

4. Effects of solar wind on Earth's magnetosphere

4. 1. Deformation of the Earth's magnetosphere

The velocity of the solar wind emitted from the Sun is on average 450km/sec, the Earth's magnetosphere is deformed by the solar wind of H^+, as shown in Fig.3. The magnetosphere on the side facing the Sun is compressed and expanded to the behind side. When the magnetosphere rotates together with Earth's rotation, the expanded magnetosphere is more affected by the solar wind than the compressed side.

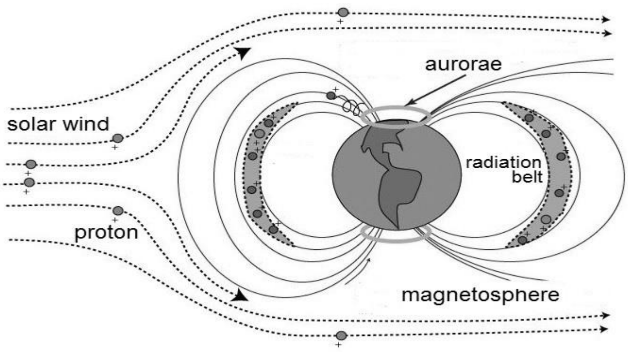

Fig. 3 Magnetosphere of the Erath(reproduced from http://www.astronomynotes.com/solarsys/radiationbelts.png)

4. 2. Circulation of atmosphere of the Earth by the solar wind

On the Earth, the east wind of the trade wind and the west wind of westerlies at middle latitude are always blowing. This continuous wind orbiting the earth will not be maintained without force from the outside of the Earth.

The magnetosphere on the daytime hemisphere side facing is compressed, and the nighttime hemisphere side extends. The Earth's magnetosphere rotates in the direction of counterclockwise direction as seen from the North Star. The ground velocity of Earth's rotation is 463m/sec. The other hand, the radiation direction speed of the solar wind **is** an average of 45**0**km/sec.

The passing solar wind is accelerated on the east side of the earth, creating a new tail of the magnetosphere, and acting to push back the tail of the magnetosphere in the west side. Due to the east-west difference in the collision action of this solar wind, the H^+ captured by the geomagnetic field and the upper atmosphere of the earth move from the west to the east, causing the westerlies.

On the other hand, the Sun and the Earth are rotating in the direction of counterclockwise. The Sun emits protons from near the equator of the Sun's surface with a maximum rotational speed of 2km/sec due to 25.4 days rotation.

The solar wind which contains the rotational motion collides to the atmosphere of the daytime hemisphere. So, the atmospheric molecules rotate via a mechanism of the gears, circulates around the Earth's from east to west.

The nighttime hemisphere on the other side of the Earth does not have the rotational force due to the direct collisions. Therefore, trade winds blow from east to west continuously at near the equator.

4. 3. Mechanism of typhoon and hurricane

Water vapor is condensed at the top of cumulonimbus group, where the pressure of dry and cold atmosphere becomes lower which will trigger a typhoon. That is,

The atmosphere flows by trade winds and westerlies. The direction of this flow is counterclockwise in the northern hemisphere. Angular momentum is maintained and moves to the center of rotation. The velocity of rotation becomes faster by approaching to the center.

If the centrifugal force of the rotation is stronger than the force due to the pressure, the eye of the typhoon can be made. There is a dry, cold atmosphere in the upper sky.

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On the other hand, the cumulonimbus that occur above sea surface move toward the center of the low pressure. The wet air rises in the cumulonimbus.

The rising air flow which contains a lot of water vapor of the cold and the falling of cold dried air flow are mixed at the boundary area of the eye of the typhoon. So, the water vapor at the boundary area of the eye of the typhoon becomes rain.

When the molecules in the atmosphere mix together, the rising cumulonimbus clouds rotate counterclockwise because they gain rotational force in the direction of falling cold dry air.

The entire course of these cumulonimbus clouds moves to northern area greatly in the clockwise direction by the outside air flow of the trade wind and the westerlies.

In this way, the typhoon develop in the mid-latitude region can be explained by an effect of solar wind. Moreover, the recent trends of the rapid development of the typhoon, and the movement of generation of the typhoon to northward of latitude can be explained by the reaction of the Sun becomes active.

In addition, the atmospheric pressure at the top of a cumulonimbus is lowered, and a dry atmosphere including H^+ of the charged particles gathers at the top of a cumulonimbus, resulting in a positive high voltage. So, lightning is generated when the electrical dipoles of water molecules are arranged in the cloud and the bottom of the cloud is negatively charged.

5. Circulation of the atmosphere on the Earth

5. 1 Mechanism of jet stream

As shown in Fig.4, there is Hadley circulation over the Northern Pacific Ocean. The hot air near the equator rises, heads to the high latitude area in the upper sky, is changed to west wind due to westerlies, moves eastward, and then travels in the direction of the clockwise by trade winds.

The Hadley circulation includes atmospheric flows up and down altitude. The flow up and down altitude is driven by cumulonimbus.

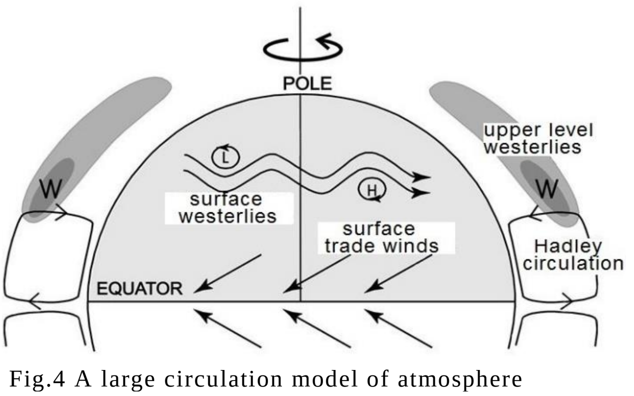

Fig.4 A large circulation model of atmosphere (Reproduced from http://paoc.mit.edu/labguide_old/gen_circ/theory/fig._8.2.jpg)

On the other hand, the speed of the westerlies is decreased in the north pole. In winter, the temperature on North Pole becomes low. So, the atmosphere above the Asian continent rotates counterclockwise while receiving westerlies. The continent's atmospheric circulates collides with Hadley circulation near Japan. The flows between north and south cancel each other, and the flows from west to east accelerates each other. This is the mechanism of a jet stream.

5. 2 Reaction of H^+ of solar wind with atmosphere in the early Earth's

Isolated atoms are in a high energy state, so chemical reactions proceed in a state where H^+ of solar wind collisions continuously. Molecule of CO_2 is decomposed by the highspeed H^+. The O^{2-} ion in the atmosphere binds with H^+ and produces H_2O. H^+ and nitrogen (N) ions are combined to generate NH_3. C^{4+} ions are combined with H^+ and generate hydrocarbons such as CH_4

The CO_2 in the cryogenic space exists is a solid state. The fine particles adhere to each other at low temperatures. According to the Virial theorem, half of the potential energy is kinetic energy and half of the potential releases to the outside. Since the gravitational energy increases as the planet grows, the center becomes hot. It degasses CO_2 from the crust during growth and the atmosphere of CO_2 was formed.

On the other hand, the activity of the Sun at Hayashi phase varied intensely. It can be considered that planets have grown to some extent in the solar system until T-Tauri star period of the Sun, and that the inner layer of the rocky planet was formed during the period of intense change. At that time, CO_2 also degassed into the Earth's atmosphere, and O_2 was hardly included.

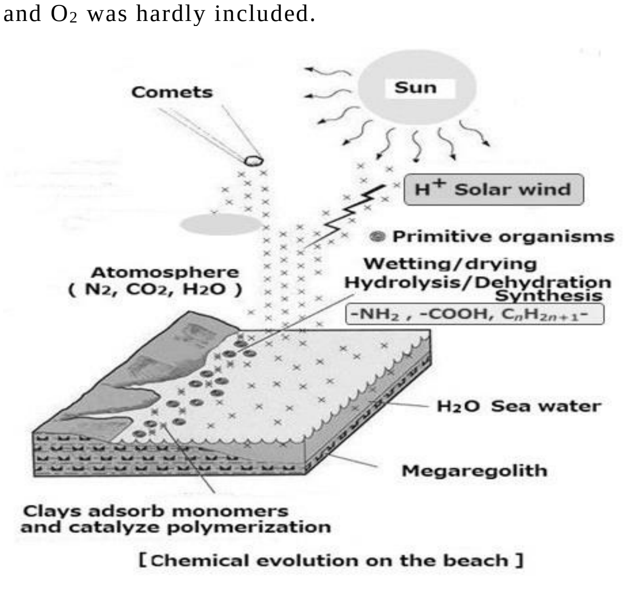

Fig.5 Generation of hydrocarbons by reaction of CO_2 in primitive atmosphere and H + of solar wind [9]

As shown in Fig.5, the CO_2 in the degassing atmosphere collides with the H^+ of the solar wind to produce H_2O and CH_4. When the temperature of the surface of the early Earth cool down, molecules of H_2O drop to the ground and the sea was formed.

as rain liquid state. The sea was able to be when the of H_2O in the was done though it condenses, and it Gases such as CO_2 and NH^3 do not blend into hot water. The water temperature became low, and CO_2 in the atmosphere melted into the sea, and it was chemically bonded with calcium (Ca) to become limestone ($CaCO_3$) and fixed to the rock sphere.

5. 3 Generation of organic molecules by H^+ of solar wind and CO_2

Hydrocarbon molecules such as CH_4 are synthesized from H^+ and atmospheric CO_2. The liquid of CH_4 exists in cold surface of Titan as we know.

Synthesized small molecules such as CH_4 remain in the atmosphere in the early Earth, and large molecule of hydrocarbons are synthesized by the energy from the Sun.

Hydrocarbons generally float on the surface of the water without the specific gravity being lighter than water and not dissolving in water. Long molecules of hydrocarbon in liquid states have strong hydrophobic bond. Such floating molecules were accumulated on the surface of the water.

The cell membrane of an organism consists of molecules of $C_{16}H_{34}$ (melting point 18 °C boiling point 287°) or $C_{18}H_{38}$ (melting point 28 to 30 °C boiling point 317° [10]. Those organic molecules, which are liquid states in primitive seas, formed cell membranes of the primitive cell [11].

Hydrogen atom at the end of hydrocarbon molecule floating in the water are replaced with hydroxyl groups (OH^-) or carboxyl groups (-COOH) due to collisions with H+ in the solar wind. Then, amino acids are produced by binding the acidic carboxyl group end to the basic NH_3 in seawater. Its amino acids make peptide bonds that produce proteins. Peptide bonds are stronger than hydrophobic couplings between hydrocarbon molecules. It is the first step for the birth of creature

6. Super rotation of the thick atmosphere

6.1 Superrotation of atmosphere on Titan

Titan's atmospheric pressure is about 1.5 times that of Earth. In 2005, Huygens probe (European Space Agency), landed on Saturn's moon Titan [12]. In doing so, Huygens drifted from west to east. At an altitude of more than 45 km, the wind was faster than Titan's equatorial rotational speed of 12 m/s. The peak speed of its super rotation is 120 m/s at an altitude of about 120km. The wind decreased as it approached the ground.

Titan's orbital radius is 1.2 million km and most of orbit passes through the Saturn's magnetosphere. Saturn's rotation period is 10.7 hours, and Titan's rotation cycle is 15.9 days. Saturn's magnetosphere captures many H+ and sweeps the surface of Titan at a faster rate than Saturn's rotation.

It can be considered that Titan's superrotation takes place when the H^+ captured by Saturn's magnetosphere collides with Titan by Saturn's counterclockwise rotation.

That is, the Saturn's magnetic field moves together with charged particles of H^+. The speed of Saturn's magnetic flux far away from Saturn rotates faster than the magnetic flux closer to Saturn. So, the flow of H^+ back side of Saturn is faster compared with facing side of Saturn. Since the density of particle is very thin, both flows will mix with and the drift velocity becomes an average value. So, the counterclockwise rotation of Saturn's magnetosphere rotates titan's atmosphere counterclockwise.

The difference between the rotational speed on the Saturn side and the back side is calculated to be $\delta v_{max} = 2\pi\{(L_{Saturn\text{-}Titan} + r_{Titan}) - (L_{Saturn\text{-}Titan} - r_{Titan})\}$/Saturn's rotation period = 843 m/sec. This kind of difference does not exist at the polar region of Titan.

Although the amount of H^+ that reaches Titan directly is small in the state outside of magnetosphere of Saturn, the magnetosphere captures H^+ in a wide range of spatial areas.

The amount of H^+ is estimate by a ratio between the area S_{Sphere} (2.568×10^{25} m^2) of the sphere using the distance to Saturn's position around the Sun, and the titan cross section S_{Titan} (2.084×10^{12} m^2) as a part of the surface of the sphere. The typical amount of H^+ emitted from today's sun is 10^9 kg/sec. As the result of calculation, the quantity of H^+ is 0.81 g/sec, 70 kg/day, and 2.6 x 10^4 kg/year.

6.4 Superrotation of Venus by the solar wind

The superrotation of Venus's atmosphere is a strong wind orbiting planets from east to west, in the same direction as Venus's rotation direction [13].

It is a wind speed of 100 m/sec at 60km altitude, but lowering the altitude slows down to reach to Venus's rotation. The speed of the ground by its rotation at the equator of Venus is 1.8 m/sec of which period of one rotation is 243 days. The rotation cycle of the Sun is 25.4 days and the rotation speed of the Sun's surface is 2km/sec. The rotation of the Sun is the opposite direction of super rotation of the Venus.

H^+ of the solar wind in the vicinity of Venus reached by speed of 450km/sec, the solar wind possesses with a rotational speed of 0.44% for the speed of the radiation.

Only the thick atmospheric molecules of Venus facing the Sun are hit directly the solar wind. So, the atmosphere of Venus rotates in the opposite direction of the sun's rotation by the solar wind [14]$_{P,3\text{-}3}$.

It is explained that Venus's rotation has been changed in the opposite direction to the rotation of the Sun due to the superrotation of Venus that has been blowing over billion years.

7. Conclusion

In conventional studies, X-rays and ultraviolet rays from the activity of the Sun have been over-evaluated, and the effects of H^+ of solar wind on the atmosphere of planets were underrated

In this report, we described phenomena such as magnetic storms, westerlies, trade wind, typhoon, lightning, and ozone hole as mechanisms involving high speed H^+ of charged particles of solar wind.

We were able to understand the phenomena of the wide area of weather by effects of the behavior of proton from the solar wind in a unified manner. The principal mysteries of planet's atmospheric phenomena such as superrotation of the Venus and Titan are also explained in a unified manner.

The author hopes that more research will be done using satellites and other means.

References

[1] R. A. Duncan, F-region seasonal and magnetic storm behavior, *J. Atmos. Terr. Phys.*, **31**, 59-70, 1969

[2] Jin, H. Maruyama T, "Temporary decrease in daytime F-region peak electron density due to eastward electric field penetration during magnetic storm" J. Geophys. Res., Vol.113, A05305, 2008

Jin, H., Maruyama, “Total electron scan observed during a large magnetic storm and different behavior of NmF2”, National Institute of Information and Communications Technology, Vol.55 Nos.1-4 pp.335-341, 2009

[3] Y. Zhang, L. J. Paxton, D. Morrison, B. Wolven, H. Kil, C. I. Meng, S. B. Mende, T.J. Immel, O/N_2, changes during 14 October 2002 storms: IMAGE SI-13 and TIMED/GUVI observations, J. Geophys. Res., 109, Oct. 2004

[4] National Astronomical Observatory of Japan, Chronological scientific Tables 2018, p.77, p.985, Maruzen Pub. Co. Japan, 2017

[5] J.W. Barrett, P. M. Solomon, R. L. de Zafra, M. Jaramillo, L. Emmons, Formation of the Antarctic ozone hole by the ClO dimer mechanism, Nature (ISSN 0028-0836), vol. 336, p. 455-458 Dec. 1988

[6] H. Nakane, Current Status of Ozone Layer and Ozone Layer Research, Science and Technology Trends p.21-31, October 2004.

[7] Kobayashi, T., Crystal of Snow, blue backs b-163, Koudansya, 148-149,1970.

[8] T. Kusaka, T. Nakano, C. Hayashi, Growth of Solid Particles in the Primordial Solar Nebula, Prog. Theor. Phys., 44, 1580-1595, 1970

[9] S. Karasawa," Collisions of the early Earth's atmospheric molecules (H_2O, CO_2, N_2) and solar-wind (H^+) ", Viva Origino Vol.46, Supplement, pp.49, Saitama Univ., March 2018.

[10] B. Alberts, D. Bray, J. Lewis, M. Raff, K. Roberts, J. D. Watson, Molecular biology of the cell, Third Ed., p.479, 1994

[11] Karasawa, S. The birth of life on the Earth, Web site (video) ,2018, https://www.youtube.com/watch?v=p-PfUaZ1s7A

[12] Science highlights from Huygens, #2. Superrotating winds, Jan. 2017. http://sci.esa.int/cassini-huygens/55223-science-highlights-from-huygens-2-superrotating-winds/

[13] Schubert, G., C. Covey, A. Del Genio, L.S. Elson, G. Keating, A. Seiff, R.E. Young, J. Apt, C.C. Counselman, III, A.J. Kliore, S.S. Limaye, H.E. Revercomb, L.A. Sromovsky, V.E. Suomi, F. Taylor, R. Woo, and U. von Zahn, Structure and circulation of the Venus atmosphere. *J. Geophys. Res.*, **85**, 8007-8025, 1980 doi:10.1029/JA085iA13p08007.

[14] S. Karasawa, Comparative planetology based on material physics - How planets were formed -, Web site: http://www7b.biglobe.ne.jp/~shinji-k/Eg%20planetology%20index.htm 2018.