

## Upper atmospheric variation inferred from the long-term trend in the geomagnetic solar quiet daily variation

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It has been well-known that the amplitude of geomagnetic solar quiet (Sq) daily variation depends on the intensity of global ionospheric currents flowing in the E-region from middle latitudes to the magnetic equator. These currents are generated by dynamo process via interaction between the neutral wind and ionospheric plasma in a region of the thermosphere and ionosphere (85-125 km). The motion of the neutral particles is driven by heat convection due to solar irradiance and by tidal force of the sun and moon. According to the Ohm's equation, the ionospheric currents strongly are related to ionospheric conductivity, polarization electric field and neutral wind. Then, to investigate the Sq amplitude using the long-term observation data of geomagnetic field is essential for understanding the long-term variations in the ionospheric conductivity and neutral wind of the thermosphere and ionosphere. Recently, Elias et al. [2010] found that the Sq amplitude tends to increase by 5.4-9.9 % in the middle latitudes (Apia, Fredericksburg and Hermanus) in a period of 1961-2001. They mentioned that the long-term variation of ionospheric conductivity associated with geomagnetic secular variation mainly determines the Sq trend, but that the rest component is ionospheric conductivity enhancement associated with cooling effect in the thermosphere due to increasing greenhouse gas. In this talk, we try to clarify the characteristics of the long-term variation in the Sq amplitude using the long-term observation data of geomagnetic field and neutral wind. These observation data have been provided from the IUGONET (Inter-university Upper atmosphere Global Observation NETWORK) project which stated in facial 2009. In the present analysis, we used the F10.7 solar flux as a good indicator of the variation in the solar irradiance in the EUV and UV range, geomagnetic field data with time resolution of 1 hour observed at 184 geomagnetic stations. The definition of the Sq amplitude is the difference of the H-component between the maximum and minimum every day when the Kp index is less than 4. As a result, the Sq amplitude at all the geomagnetic stations shows a close correlation with the solar F10.7 index, and tends to be more enhanced during the high solar activities (19- and 22- solar cycles) than during the relatively low activity (20-solar cycle). This result implies that the Sq amplitude strongly depends on the solar activity. Therefore, in order to minimize the solar activity dependence on the Sq amplitude, we calculated second orders of fitting curve between the F10.7 solar flux and Sq amplitude during 1950-2011, and examined the residual Sq field defined as the deviation from the fitting curve. The residual Sq amplitude at all the geomagnetic stations clearly showed increase and decrease trends with the periods of 20 years. The minimum and maximum of the residual Sq amplitude appear around 1970 and 1990. The residual Sq amplitude around 2010 is almost the same level as that around 1970. Moreover, the similar tendency can be seen in the diurnal variation of geomagnetic field in the auroral zone and polar cap (Sqp field) driven by the twin vortex of ionospheric currents associated with energy input of solar wind into the ionosphere. Then, it seems that the trends in the residual Sq and Sqp fields are related to the long-term variation in the ionospheric conductivities associated with the secular variation of the ambient magnetic field and the upper atmosphere (for example, plasma and neutral densities associated with increasing concentrations of greenhouse gases). In order to verify qualitatively the above signatures, we need to investigate the long-term variation in the ionospheric conductivities calculated using the IRI-2007 and MSIS-00 models.

Keywords: Solar activity, Sq variation, Ionospheric conductivity, Electron density, Geomagnetic secular variation, Global warming

## Reconstruction of summer insolation in the Yakushima island using stable carbon isotope in Yakusugi Cedar

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One of the most important climate feedback mechanisms is cloud cover effect. However, it is difficult to estimate the variability of the past cloud condition.

Tree ring  $\delta^{13}C$  reflects the balance between stomatal conductance to incoming  $CO_2$  and photosynthetic rate. In the case of moist area, dominant control of  $\delta^{13}C$  in tree ring is photosynthetic rate. The meteorological observations in the Yakushima island were conducted. As a result, Ishiduka region which is 900 m above sea level was extremely large amount of precipitation. Relative humidity was found to be almost 100% and to be very small changes. In this presentation, we will show the results of annual tree ring  $\delta^{13}C$  over the past millennium.

Keywords: tree ring, stable carbon isotope, summer insolation

## Meteorological influence of the solar wind ? Correlation of the surface temperature and the aa index, and participation

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We have shown the correlation between the surface temperature and the aa index [1], and are examining possible mechanisms now. The followings are examples of observations obtained so far. 1) Correlation between the winter aa index and the spring temperature was positive and high ( $r = \text{ca. } 0.7$ ) at Northern Europe for the period of 1960-2001. 2) Correlation between the Arctic Oscillation and the surface temperature was strong for the winter-winter pair, and the correlation maps resembled those for the correlation between the temperature and the aa index. 3) The OMNI2 solar wind data gave high correlations between Pa (rate of energy flow from the solar wind into the magnetosphere, which highly correlates with the aa index) and the surface temperature. 4) The correlation between Pa and the Arctic Oscillation was high, for instance, for the January-January pair. 5) The correlation was high when the QBO was at easterly phase in January.

Thus, we can conclude that there should be certain connection between the solar wind and the meteorology. In this presentation, we extend our current approach by using the aa index because it has been shown that the aa index is a good measure of the effect of the solar wind.

The months employed in the stratification based on QBO phase was found to largely affect the correlation coefficient values. For the combination of the winter aa index and spring surface temperature, the  $r$  values were 0.78 for January as the stratifying month, 0.82 for February, 0.91 for March, 0.9 for April and 0.92 for May. The other months gave smaller values.

Northern Europe and North Atlantic regions gave high positive correlation at QBO easterly phase, and central part of the North Pacific regions gave high negative correlation at QBO westerly phase.

While the QBO is spatially limited to the equatorial stratosphere, its wind direction can affect, for instance, the propagation of planetary waves from the troposphere to the upper atmosphere.

Thus, the fact that the QBO takes part in the correlation between the aa index and the surface temperature shows that large-scale atmospheric circulations participate in the meteorological influence of the solar wind.

The high correlation between Pa and the aa index, together with the physical meaning of Pa, suggests that the correlation between these factors and the surface temperature may relate to the auroral electrojet current. Hence, there should be a link between the magnetosphere and the middle atmosphere, which can explain the meteorological influence of the solar wind.

[1] Kiminori Itoh, JpGU, 2008, 2009, 2010, 2011.

Keywords: Solar wind, Temperature, QBO, aa index, Arctic oscillation

## Influence of solar wind on the temperatures of the troposphere and lower stratosphere

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Influence of solar wind on the temperatures of the troposphere and lower stratosphere

The correlation between surface temperature and solar magnetic activity is evident though the cause is not clear. In this presentation, we analyze the vertical structure of the global atmosphere to examine the cause on the basis of the previous observations [1].

The OMINI2 solar wind data as well as the aa index data were used to detect the influence of the solar wind on the vertical temperature distribution. The period examined was 1980-2010, and the region examined was Sodankyla, Finland. The aerological data was obtained from Wyoming University HP.

In the analysis, the following factors were taken into account: 1) near UV is mainly absorbed by the atmosphere in the vicinity of 50 km altitude, and hence, the temperature there changes 1-2 degC during the 11 year solar cycle: 2) in the ionosphere, the height of the D layer will change with solar flares.

We analyzed the phases of the OMINI2 solar wind data and the aerological data to examine whether and how the effect of the solar wind propagates from the D layer to the lower stratosphere and troposphere. Meteorological rocket data will also be effective for the analysis in future.

### References

K. Itoh, JpGU 2008-2011.

Keywords: solar wind, troposphere, lower stratosphere, geomagnetic activity index, temperature, correlation

## Maximum Entropy Production (MEP) in Global Heat Transfer (GHT) model

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According to the Maximum Entropy Production (MEP) principle by Kleidon et al., dissipative systems in the state far from equilibrium are stabilized when entropy production is maximized. It is supposed that heat transportation on the Earth from the equatorial to the polar area occurs in such systems where the MEP principle is applicable. So far, the KL model by Kleidon and Lorenz [1] and the RB model by Reis and Bejan [2] are known as representative heat transfer models to testify such optimal theories. However, both are two-partitioned models that divide the Earth surface into only two parts, i.e., the heat absorption and the heat rejection regions, so we cannot help saying that these are too simple. In this exhibition, we provide the original multi-partitioned Global Heat Transfer (GHT) model to testify the MEP principle. The constructal theory by Bejan et al. [2] is another optimal theory similar to the MEP theory. The difference between two is that the former insists the maximization of heat transfer itself, while the latter does that of entropy production. Finiteness of the Earth surface is required as a necessary condition for the invocation of the constructal law, which restricts the choice of the model parameter. Meanwhile, the MEP theory does not necessitate such restriction, which guarantees a broader application to various kinds of climatic models.

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[4] Bejan, A. (2010). Design in nature, thermodynamics, and the constructal law. Comment on Life, hierarchy, and the thermodynamic machinery of planet Earth by Kleidon. *Physics of Life Reviews* 7:467-470.

[5] Kleidon, A. (2010). Life as the major driver of planetary geochemical disequilibrium. Reply to comments on Life, hierarchy, and the thermodynamic machinery of planet Earth. *Physics of Life Reviews* 7:473-476.

Keywords: Global Heat Transfer (GHT) model, Principle of Maximum Entropy Production (MEP), Constructal theory, Dissipative structure, Far from equilibrium

## Spatial distribution of climate response to the solar cycles during the Maunder Minimum

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The Maunder Minimum (A.D. 1645-1715) is a useful period to investigate possible sun-climate linkages as sunspots became exceedingly rare and the characteristics of solar cycles were different from those of today. We have previously reported that climate (the rainy-season humidity in central Japan, the winter temperature in Greenland, and the mean annual temperature in the Northern Hemisphere) responded significantly to the characteristic solar magnetic cycles during the Maunder Minimum (Miyahara et al. 2008 EPSL; Yamaguchi et al. 2010 PNAS). At the solar cycle minima of negative polarity, we observed wet climate in Japan, and cold climate in Greenland and in the Northern Hemisphere. Here, we further examine climate responses to the solar cycles for wider areas including the Southern Hemisphere using the records of paleoclimate obtained from previous studies. We will discuss the spatial distribution of responses and its possible mechanism.

Keywords: Solar activity, Little Ice Age, Paleoclimate reconstruction, Tree rings, Maunder Minimum

## Causal Link between Solar Magnetic Variability and Japanese Climate Anomalies during the Maunder Minimum

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Causal link between solar variations and climate has been actively discussed for a various time scales. There is one major problem on this issue. It is difficult to distinguish each of the effects of solar parameters (total solar irradiance (TSI), solar ultraviolet (UV) radiation, and galactic cosmic rays (GCRs)) on climate changes as their variations are more or less synchronized. The characteristics of GCR variations associated with solar magnetic activity, however, are slightly different from other solar related parameters, such as TSI and UV. Especially, previous study has suggested that the cosmic ray variation was unique during the Maunder Minimum (A. D. 1645-1715), a period of prolonged sunspot absence. Comparison of annually measured tree-ring D14C and ice-core 10Be records revealed that GCRs had significant amplification associated with the magnetic polarity reversals of the Sun during the Maunder Minimum. This phenomenon enables us to estimate the GCR effect on climate.

In this study, we utilize tree rings that contain both climate and cosmic ray proxies (d18O, D14C) that can directly compare these reconstructions without any dating error. Our tree-ring d18O records from both high and middle latitude Japan show distinct negative spikes indicating cold and wet climate at every other 28 years at which anomalous GCR flux was detected in 10Be record.

Keywords: Solar Magnetic Activity, Galactic Cosmic Ray, The Maunder Minimum, Tree-ring isotope

## Laboratory experiment for verification of cloud condensation nucleation by cosmic rays

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Ion-induced nucleation of condensed particles has been suggested as one of mechanisms for correlation between the solar activity and the global climate change. The idea is that ions, which are produced by atmospheric ionization of cosmic-ray particles, promote growing-up of aerosol particles, then create cloud condensation nuclei and provide the increase of cloud amount. Recently some experiments have been planned or on progress in order to verify this scenario. We are also trying to verify independently of the other experiments. In a talk, we will explain our experimental method, report the progress and discuss the future prospect.

The galactic cosmic-ray flux reaching the earth is modulated by change in interplanetary magnetic field due to the solar activity. It was the start of the controversy that change in cosmic-ray intensity measured by neutron monitors on ground correlated well to the change in low cloud amount in the earth's atmosphere. Although there are many subjects to be examined such as method of cloud measurement, interpretation of cosmic-ray data and bias for the correlation, it would be valuable to investigate the relation between the ionizing radiation and cloud nucleation in laboratories under controlled conditions. We have introduced the air with some constituents simulating the real clean atmosphere into the chamber, which can be sealed or evacuated in order to reproduce the reactions in the atmosphere, and created a near-natural situation by irradiating with Sr-90 beta-rays and exposed to UV light, and measured ions and aerosol particles in the chamber. Assuming sulfuric-acid aerosols are the most effective to develop the size of aerosol particles, we have tried to create sulfuric-acid molecules based on sulfuric dioxides in air. Then water molecules condensate on the sulfuric-acid molecules and develop their size and, if exceeding the critical size, they can grow up to cloud condensation nuclei.

Our system consists of a gas mixing apparatus, a reaction chamber with ionizing radiation and UV radiation, and measuring instruments. The gas mixing apparatus mixes pure dry air, wet air involving water vapor, oxygen-based ozone and nitrogen-based sulfuric dioxide. The concentrations of these gases were controlled by changing the flow rates of the components. Typical total flow rate was 5 L/min. The reaction chamber is a cylinder of 40 cm in diameter and 60 cm in length and the volume is about 75 L. With a flow of 5 L/min, all gases in the chamber should be exchanged in 15 min. assuming the gas flow is uniform in the chamber. In the reaction chamber, the mixed gas is irradiated by beta rays and exposed to UV radiation. One can change the amount of irradiation by putting thin (0.1 mm thick) SUS plates between the chamber window of 0.2 mm thick and the radiation source. The UV window is made of quartz and a mercury lamp with light of 254 nm can be set at the window. No control of light yield was done. Considering the creation of sulfuric acid molecules, we first exposed the air with sulfuric dioxide, water vapor and ozone to the UV light. Then we irradiate the gas with beta rays and measure the change of products, that is, concentrations of ozone and sulfuric dioxide, densities of ions and condensed particles with a size larger than 2.5 nm, and temperature and relative humidity. We will report the results of measurements under several conditions.

Keywords: cosmic rays, solar activity, global climate, atmospheric ionization, aerosol, cloud formation



## Prosperity of Oshu Fujiwara clan and climatic change

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Last year, Hiraizumi in Iwate Prefecture was recognized as a UNESCO World Cultural Heritage site, where the ancient Oshu Fujiwara clan was flourished. Here, we regard as a prosperous era of the Oshu Fujiwara clan the period from 1087 A.D. when Gosannen no Eki ended and Kiyohira built up a firm foundation for the rule of Oshu as an only survivor of the Kiyohara clan to 1189 A.D. when the Fujiwara clan perished by the invasion of Minamoto no Yoritomo. This period of about 100 years spanning from the end of the Heian to the beginning of the Kamakura period is included within the Medieval Warm Period (900-1300), when temperatures on the Earth were elevated globally [1]. The view is broadly accepted that the prosperity of the Oshu Fujiwara clan was due to mass production of gold. However, it is also known that northern special products, as well as gold, such as tail feathers of sea-eagles and seal skins were presented to the court in Kyoto, which were highly appreciated among Heian aristocrats for the use of arrow feathers and harness. Furthermore, according to Azumakagami, the historical book of the Kamakura period, Kiyohira said proudly that people living in Karafuto and Siberia were obedient to me, which suggests the existence of the close relation with these areas [2]. In fact, the same iron arrowheads, which has the Z-shaped section, as excavated in the Nadedinskoe ruins in the Amur River basin was also found in the Atsuma town in Hokkaido. Thus, the possibility of the cultural interaction between Hokkaido and Siberia in those days is strongly suggested. Meanwhile, Japanese visitors to the Siberia continent in the Edo period, for example, Daikokuya Kodayu (1751-1828) and Mamiya Rinzou (1780-1844), told that the climate in these areas was very cold [3],[4],[5]. It should be noticed that this period overlaps the global cold period called Little Ice Age (1450-1850) including the Maunder Minimum (1645-1715) and the Dalton Minimum (the beginning of the 19th century). In the older times, other evidences for the inflow of the Siberian cultures can be found in the Sannai-maruyama ruins in the Jyomon period, when the climate are thought to have been comparatively mild. On the basis of these considerations, we could propose a following hypothesis, which connects the Japanese cultural history with climatic change on the Earth. That is, the exchange route was formed intermittently from Siberia to northern Japan via the Karafuto island in global warm periods, and that the inflow of continental cultures has been repeated.

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Keywords: Little Ice Age in Edo period, Oshu Fujiwara clan, Inflow of Siberian culture, Daikokuya Kodayu, Medieval Warm Period, Mamiya Rinzou

## Solar-Terrestrial Environment Project in Liberal Arts Education

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We had a class "Introduction to Project Management on Space" as liberal arts education in Wakayama University. Aim of this class is to make students get project management skills. A characteristic point of this class is to focus on achieving a goal through collaboration work with team members.

In this class, we prepared a course "Solar-Terrestrial Environment Project" which was focused on a relationship between global warming and solar activity, and a goal of this course is to make a brochure about the relationship for elementary school students.

Tasks of students are (1) election a leader and sharing roles in the project, (2) completing a preprint in several months, (3) making a presentation in front of elementary school students and having a questionnaire for them, (4) being reviewed by experts, (5) completing a brochure after repeating revisions of the preprint.

The students of the course achieved above all tasks. Especially, the presentation and the questionnaire were useful for polishing up the brochure. It was educational both for university students and elementary school students. We have a plan to improve the class.

Keywords: sun, climate change, education