Spatial structure of connection between the troposphere heat content and variations in solar and geomagnetic activities

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Accepted : 22 July 2015

Abstract We have carried out correlation analysis of connection between the heat content of different tropospheric layers and variations of solar (F10.7cm) and geomagnetic activity (AA index) in 1950-2007. The heat content response to effects of solar and geomagnetic activity has been found to have an explicit spatial structure. The heat content of the most of the troposphere correlates with solar and geomagnetic activity; however, we have observed significant anticorrelation in some regions.

The degree of connection between the tropospheric heat content change and variations of solar and geomagnetic activity have been shown to depend on the time scale (time averaging period). The time averaging period increasing from 5 to 7 years, the correlation coefficient grows in most regions (up to 0.6-0.7), but if the increase continues, only weaker growth is observed. This time-scale dependence can be explained by the fact that the majority of variations in tropospheric heat content on the time-scale of less than 5 years are affected by processes having no connection with solar or geomagnetic activity.

We have performed analysis of the influence of atmospheric circulation on connection between the tropospheric heat content change and variations of solar and geomagnetic activity. The heat content change in regions that are frequently occupied by the cyclones is shown to have practically no connection with variations of solar and geomagnetic activity.

Keywords: solar-terrestrial relationship, troposphere, solar and geomagnetic activity.

Introduction

Connection of solar and geomagnetic activity with different characteristics of the terrestrial troposphere was revealed long ago. The results of numerous studies concerning this connection are presented in many reviews and books, e.g., (Herman and Goldberg, 1978; Hoyt and Schatten, 1997; Avdyushin and Danilov, 2000). Though the correlation revealed between the parameters of solar and geomagnetic activity and characteristics of the troposphere are statistically significant in many works, their properties are rather unstable. This peculiarity is conditioned on the fact that the tropospheric response to heliogeophysical disturbances at this point depends on the state of the troposphere. Therefore, variations in the characteristics of the troposphere having high amplitude and no connection with solar or geomagnetic activity hamper the study of the role of solar and geomagnetic activity in the observed variations. According to the model proposed in Zherebtsov et al. (2005), Molodykh et al. (2009), the tropospheric response to heliogeophysical disturbances also depends on geographical position of the region under consideration.

In this paper, we consider the spatial structure of connection between solar and geomagnetic activity and heat content (heat content of dry air) of the some tropospheric layers. We also study dependence of this connection on the time scale and atmospheric circulation.

Data and method

Here we use the tropospheric temperature distribution for 1950-2007 (according to the NCEP/NCAR reanalysis project data Kalnay et al. (1995)), AA - index of geomagnetic activity, solar radio emission flux at F10.7cm (according to the OMNI project data (http://omniweb.gsfc.nasa.gov)), and extratropical storms trajectories (according to data by the Atlas of Extratropical Storm Tracks (http://data.giss.nasa.gov/stormtracks)).

The heat content of dry air was calculated on base of the tropospheric temperature distribution as:

$$Q_i = C_P l^2 6.25\cos(\theta)\sum_{j=n}^{j=m} T_{ij}(P_{j-1} - P_{j+1})/(2g) \qquad (1)$$

where Q_i.- heat content of air mass in grid cell between the pressure level P_n and P_m, T_{ij} – temperature, Cp –specific heat capacity, l - arc length of 1 degree of equator, θ - the latitude of grid cells center, g - gravitational acceleration.

As the tropospheric heat content is influenced by some natural phenomena (e.g., dust emissions caused by volcanic eruptions, and EL NINO phenomenon), we have made corrections to the heat content using a multi-variate regression procedure by technique similar to that in Gleisner and Thejll (2003). Each tropospheric observable heat content is described by

$$Q_i = k_0 + k_1 NINO3 + k_2 AOD + k_3 F_{lin} + k_4 F_{ext} \quad (2)$$

where *NINO3* is the mean sea-surface temperature in the equatorial Pacific (5_N–5_S, 150_W–90_W), *AOD* is the global stratospheric Aerosol Optical Depth Sato et al. (1993), F_{lin} is a linear trend, and F_{ext} is *AA* or *F10.7*. The coefficients k_n are obtained independently for each spatial location through multi-variate regression on monthly anomaly data. A time lag of 3 months is applied to *NINO3* (see section 16.3 of Peixoto and Oort (1992)). No delays are applied to *AOD*, *AA* or *F10.7*. By subtracting the terms $k_1 NINO3$, $k_2 AOD$ and $k_3 F_{lin}$ from the observed data, Q_i, we obtain the corrected data Q_i^*, which describe all tropospheric variations that are not explained by El Nino, stratospheric aerosols, or other forcing factors primarily expressed as trends in the climate data.

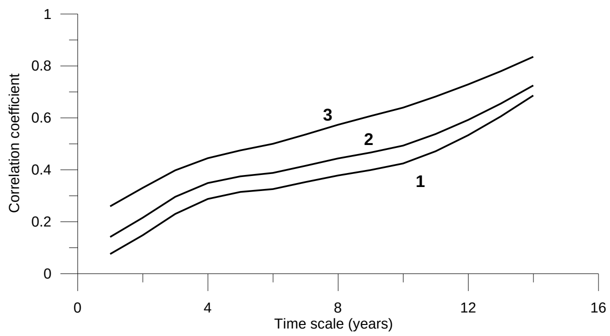

Figure 1a The correlation coefficients between global heat content of tropospheric layers (1000-950 GPa – 1, 800-400 GPa – 2, 300-150 GPa - 3) and solar activity for different smoothing intervals.

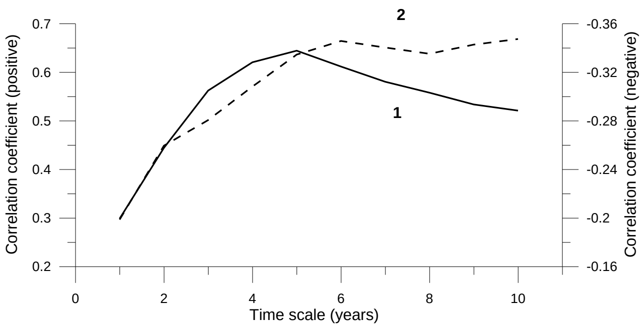

Figure 1b The correlation coefficients between heat content of tropospheric layer 800-400 GPa and solar activity for different smoothing intervals in the regions of positive (10-40E; 65-80N) and negative (30-45W; 50-60N) correlation (1 is positive; 2, negative.

The analysis of the calculation results with corrected and not corrected heat content exhibited that taking these corrections into consideration does not practically influence the obtained results, therefore in this paper we show the calculation results only for no corrected heat content.

Time scale dependence

The global surface temperature is known to correlate with solar activity on the time scale of some centuries, whereas this connection on the interannual time scale is unstable. We have used the moving average method with different smoothing intervals to study dependence of connection between the global heat content and geomagnetic activity (AA index) on the time scale. Fig. 1a presents dependence of the correlation coefficient between the AA index and global heat content on a smoothing interval value for 3 tropospheric layers. As smoothing interval increases, the correlation coefficient in all layers grows too, with the most considerable increase observed when the interval is less than 5 years. We emphasize that the value of the correlation coefficient decreases as the ground surface is approached. This can be explained by the fact that the main power of processes that affect the heat content and are not related to solar or geomagnetic activity coincides with the time periods of greater than 4-5 years. Dependence of connection degree (correlation coefficient) of the global heat content and solar radio emission flux at the wavelength of 10.7cm (F10.7) is of similar nature. Fig. 1b shows dependence of the correlation coefficient between the geomagnetic activity AA index and heat content on the time scale (smoothing interval) value for the tropospheric layer at 400-850 GPa in two regions, with maximum positive (10-40E; 65-80N) and negative (30-45W; 50-60N) correlation. As illustrated, dependence of connection degree on the smoothing interval value is similar to that in Fig. 1a, i.e., connection of geomagnetic activity with the heat content in separate regions and with the global content becomes most apparent when the characteristic time scale increases. Thus, we can suppose that with the increasing time scale internal variations become less significant as compared with geomagnetic activity; therefore, influence of variations of solar and geomagnetic activity on the tropospheric heat content appear clearer on these time scales.

Spatial structure

We have mapped correlation coefficients between the heat content of different tropospheric layers and solar and geomagnetic activity. Using these maps, we have analyzed the spatial structure of connection of these characteristics on the time scale of more than 5 years (smoothing period is 60 months). The choice of this smoothing period was determined by the fact that the correlation coefficient weakly varies with greater smoothing periods (Fig. 1b).

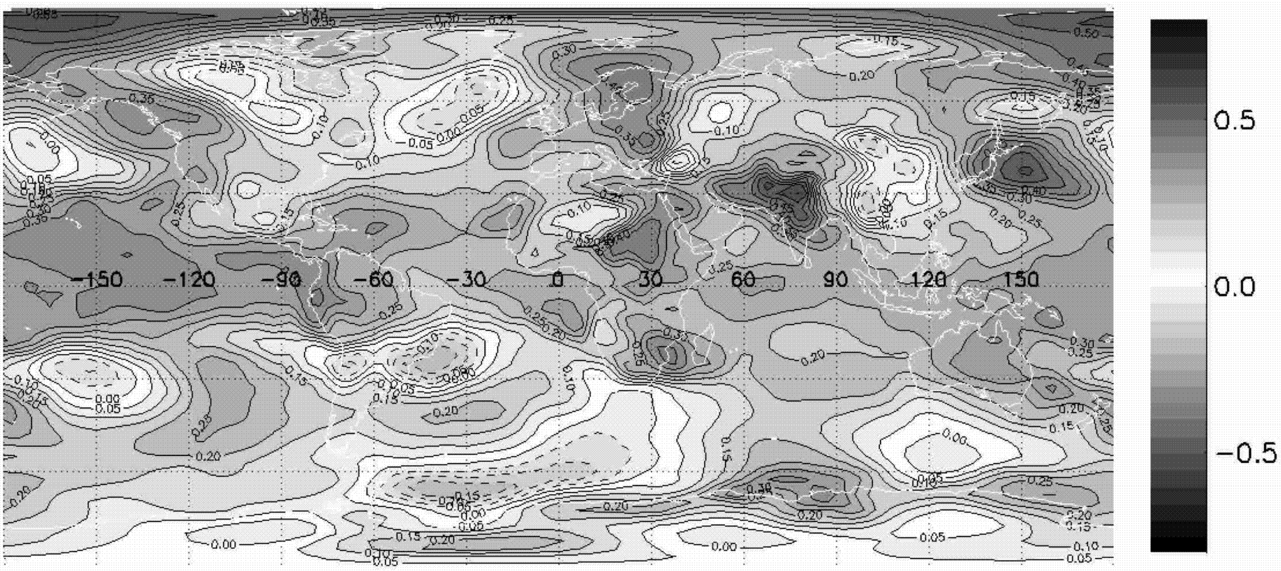

Figure 2a The spatial structure of the correlation coefficient between the heat content in the lower troposphere at 400-850 GPa and solar radio emission flux (solid line – positive correlation; dashed-line – negative; the linear trends are not eliminated).

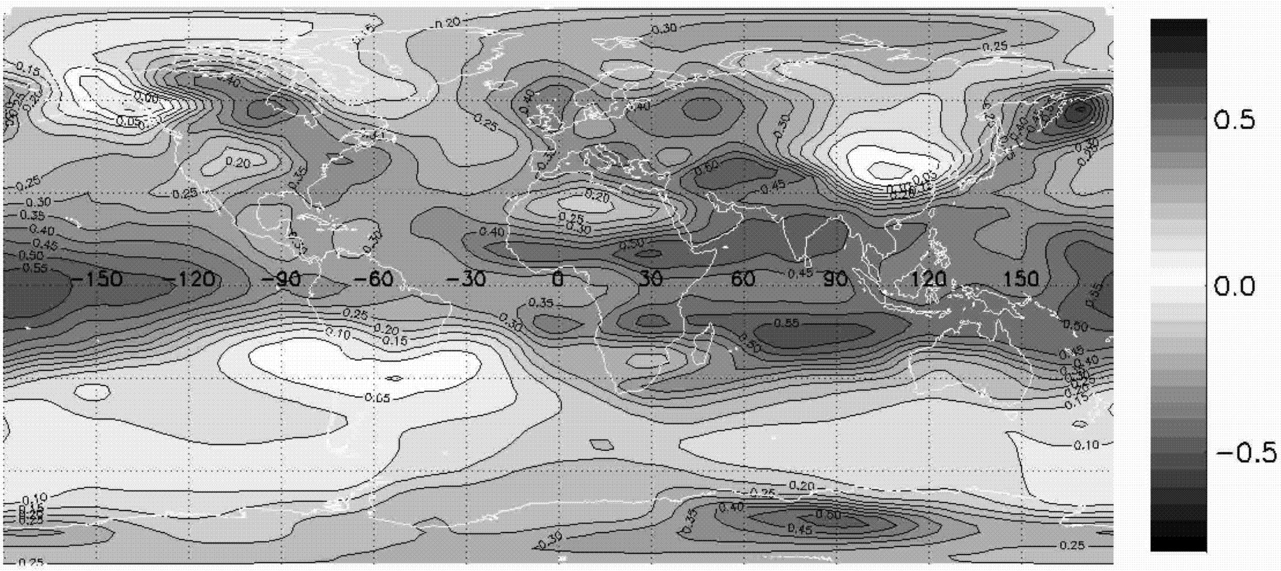

Figure 2b The spatial structure of the correlation coefficient between the heat content of the upper troposphere at 150-300 GPa and solar radio emission flux (solid line is positive correlation, dashed-line - negative; the linear trends are not eliminated).

Fig. 2a presents the spatial structure of the correlation coefficient between the heat content of the lower troposphere at 400-850 GPa and solar radio emission flux at the wavelength of 10.7 cm; Fig. 2b, at 150-300 GPa and 10.7 cm.

Connection between F10.7 and the heat content is not spatially uniform: there are regions of positive correlation, along with those of negative one. The exclusion of the linear trend from the heat content of the tropospheric layer and solar radio emission flux provokes a total increase in the correlation coefficient and to its considerable increase at a longitude of 60-180ºE in the tropical region. The spatial distribution of the correlation coefficient for the upper layer is more homogeneous. The exclusion of the linear trend from the heat content of the tropospheric layer and solar radio emission flux when studying connection between F10.7 and the heat content yields an increase in the correlation coefficient at a longitude of 30-150ºE of the tropical region and a slight total increase in the correlation coefficient in both lower and upper layers.

Connection between the AA index and heat content in the lower layer (Fig. 3a) is similar to the F.10 connection; however, the correlation is somewhat higher, and the exclusion of the linear trend from the heat content of the layer troposphere and from the AA index does not provide a noticeable increase. This is caused by the fact that the geomagnetic activity index along with the heat content has a long-term trend. With an increasing height, area of regions with the positive correlation expands and that with anticorrelation reduces in size. Moreover, a relative increase in the correlation coefficient can be observed in low-latitude regions. Connection between the AA index and heat content in the upper layer (Fig. 3b) is more homogeneous. Note that positive connection is more considerable in low-latitude regions; negative correlation, weak in mid- and high-latitudes of the northern hemisphere (90-130^{0}E, between 30 and 60^{0}S). The regions with positive correlation correspond to those where some heliogeophysical disturbances entail an increase in temperature and thus in the heat content. Some heliogeophysical disturbances studied by Rubtsova, Kovalenko and Molodykh (2008, 2009), Rubtsova et al. (2009), have shown a slighter decrease in temperature in some regions along with temperature increase in adjacent areas. This produces regions with negative correlation (regions with most frequent decreases in temperature during heliogeophysical disturbances).

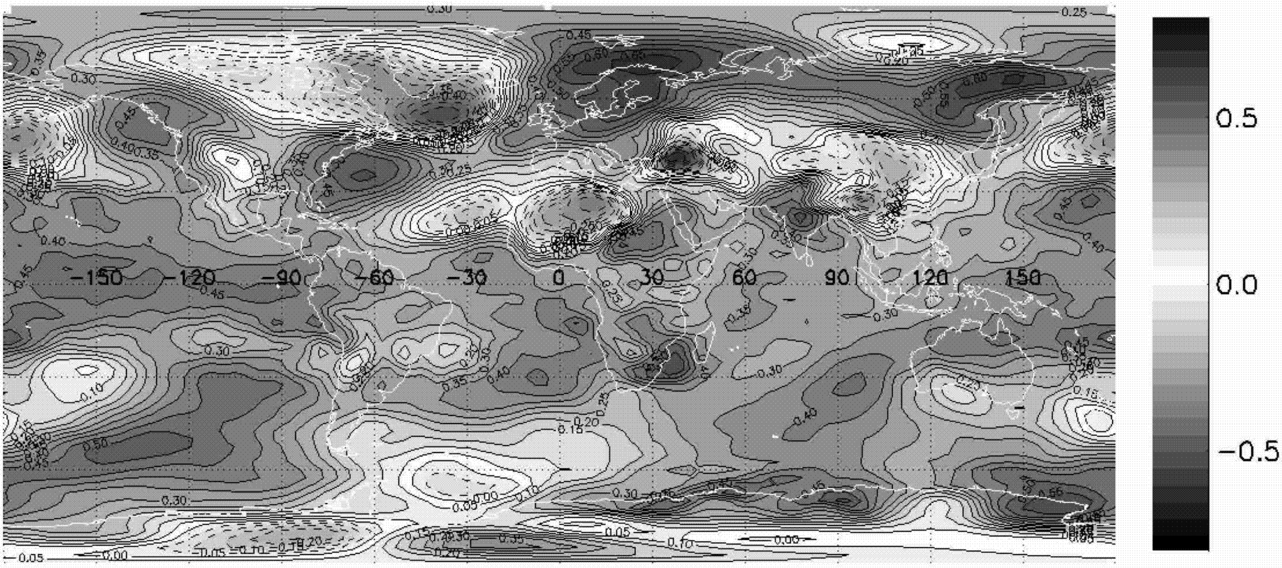

Figure 3a The spatial structure of the correlation coefficient between the heat content of the lower troposphere at 400-850 GPa and geomagnetic activity (solid line is positive correlation, dashed-line - negative; the linear trends are not eliminated).

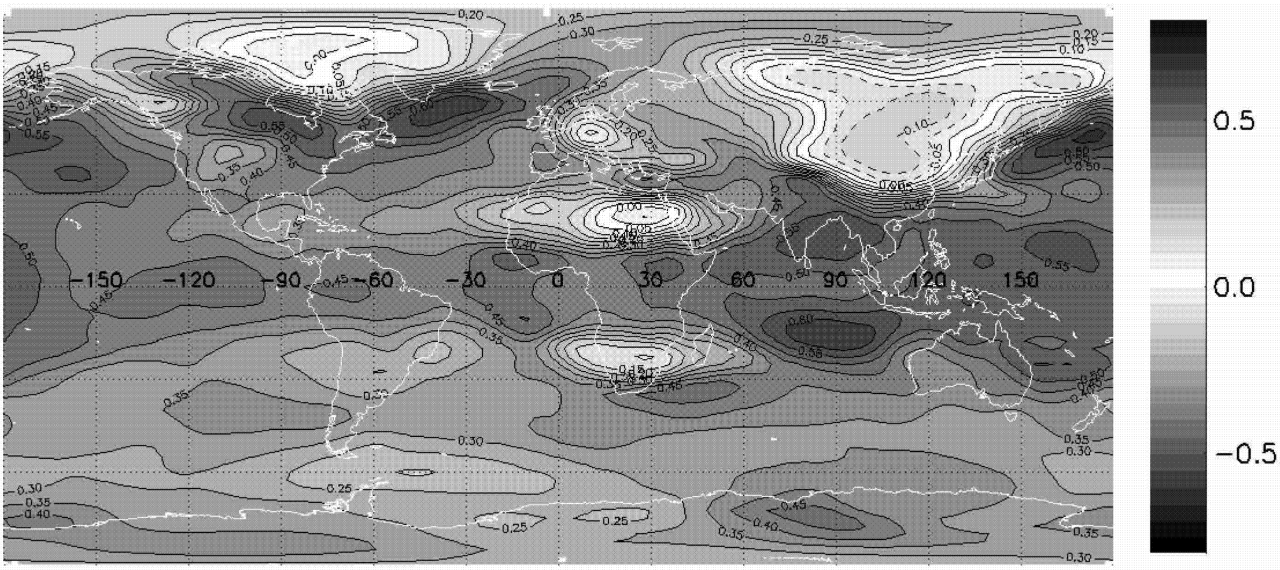

Figure 3b The spatial structure of the correlation coefficient between the heat content of the upper troposphere at 150-300 GPa and geomagnetic activity (solid line is positive correlation, dashed-line - negative; the linear trends are not eliminated).

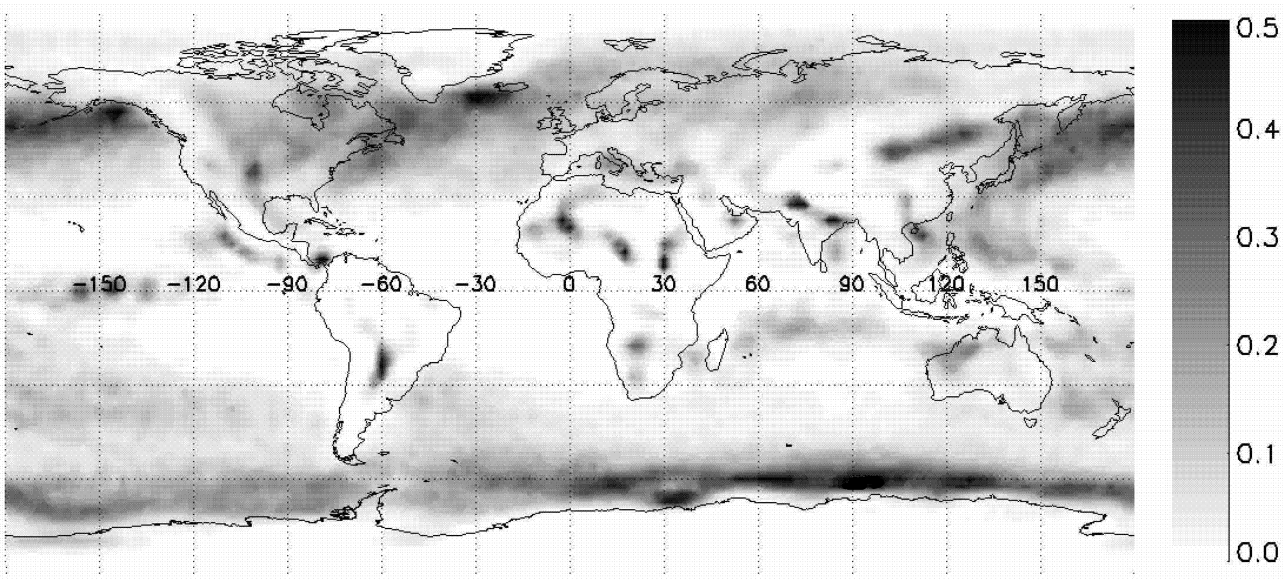

Figure 4 The map of extratropical storm frequency.

Role of atmospheric circulation

Fig. 4 presents map showing frequency of extratropical storms. Comparison of Fig. 4 with Fig. 2 and 3 allows us to notice that regions with frequent storms correspond to those with the minimum correlation coefficient. Thus, it is rather difficult to find a response to the effect of solar and geomagnetic activity in tropospheric regions with high internal variability (natural internal variations in climate system). This can be explained by the fact that the response value in these regions is considerably lower than the level of internal variations.

Conclusion

The performed analysis of connection between the tropospheric heat content and solar and geomagnetic activity has proved that the influence of variations in solar and geomagnetic activity on the heat content strongly depends on the time scale. These variations on small time scales are weakly pronounced in the background of strong internal variations. With the increasing time scale internal variations become less significant; therefore, variations of solar and geomagnetic activity influence the tropospheric heat content on these time scales.

Manifestation of solar and geomagnetic activity variations in the heat content depends on the region. Manifestation of solar and geomagnetic activity in the regions with large internal variations (with frequent storms) is faint. The heat content of most regions together with its the global value correlates with both solar and geomagnetic activity. However, anticorrelation is observed in some areas of the lower troposphere (over Baffin Bay, the Sahara, and Tibet).

Acknowledgement

This work was done under the Fundamental Research Program of the RAS Presidium No. 4, Program of the RAS Earth Science Department No. 12.1.

References

Avdiushin S.I., Danilov A.D.: 2000, Geomagnetism and aeronomy. 40, 3. (in Russian).

Gleisner H., and Thejll P.: 2003, Geophys. Res. Letters. 30, doi: 10.1029/2003GL017129.

Herman J.R., and Goldberg R.A.: 1978, Sun, Weather, and Climate. *Scientific and Technical Information Branch*, NASA, Washington, D.C. (NASA SP-426).

Hoyt D.V., and Schatten K.H.: 1997, *The role of the sun in Climate change*. Oxford University Press, New York.

http://omniweb.gsfc.nasa.gov/ . Accessed on April 20, 2009.

http://data.giss.nasa.gov/stormtracks. Accessed on April 20, 2009.

Kalnay E., et al.: 1996, *Bull.Am. Met. Soc.* 77, 437.

Molodykh S.I., Zherebtsov G.A., Kovalenko V.A.: 2009, *SUN and GEOSPHERE*. 4, 25.

Peixoto, J. P., and Oort A.H.: 1992, *Physics of Climate*, Springer Verlag, New York.

Rubtsova O.A., Kovalenko V.A., Molodykh S.I.: 2008, *Atmosphere and ocean optics*. 21, 532. (in Russian).

Rubtsova O.A., Kovalenko V.A., Molodykh S.I.: 2009, *Geomagnetism and Aeronomy*. 49, 1288.

Rubtsova O.A., Zherebtsov G.A., Kovalenko V.A., Molodykh S.I.: 2009, *SUN and GEOSPHERE*. 4, 22.

Sato, M., Hansen J.E., McCormick M.P., and Pollack J.B.: 1993, *J. Geophys. Res.*, 98, 22987.

Zherebtsov G. A, Kovalenko V. A, Molodykh S.I., Rubtsova O. A.: 2005, *Atmosphere and ocean optics*. 18, 1042. (in Russian).