A STATISTICAL STUDY ON THE EFFECTS OF FORBUSH DECREASE ON THE CLIMATE AT DIFFERENT LATITUDES

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ABSTRACT

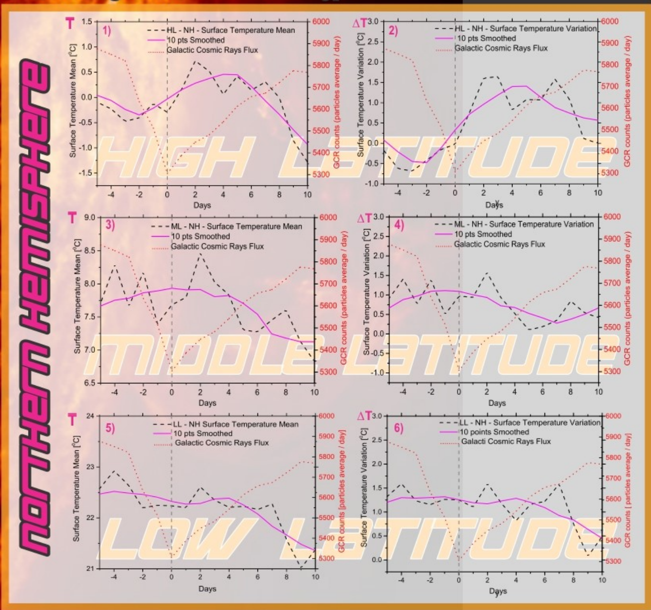
Considering the ground temperature like an essential parameter to characterize the Earth's climate, we present a statistical study about possible changes on the surface air temperature in different latitudes, during periods with decrease of atmospheric ionization induced by Galactic Cosmic Rays (GCR) on the Earth's troposphere. These GCR flux reductions are called Forbush Decreases (FD). They are mainly caused by Interplanetary Coronal Mass Ejections (ICMEs) deflection of GCR around Earth's orbit. This work was performed considering the possible influence of the cosmogenic atmospheric ionization on the water vapor condensation patterns (link GCR – cloud condensation nuclei) as the main hypothesis to be tested. For that, we have conducted a study to analyze the possible effects on the daily surface air temperature, using superposed epoch analysis around the ten strongest FD events occurred between 1987 and 2015. GCR data were collected from Oulu neutron monitor (cosmicrays.oulu.fi), and daily air surface temperature data were obtained from NOAA - National Oceanic Atmospheric Administration / GSOD - Global Surface Summary of the Day (https://data.noaa.gov/dataset/global-surface-summary-of-the-day-gsod) of ten meteorological stations of three latitudinal ranges of Northern and Southern hemispheres (20^0 - 30^0, 40^0 - 50^0 and 60^0 - 70^0). We investigated here the variation of the daily surface air temperature mean during FD for each one of the three latitudinal ranges (low, medium and high). The comparison between the daily surface air temperature averages during FD events periods and equivalent periods without FDs (during solar minima years of 1987, 1996 and 2008) was also performed.

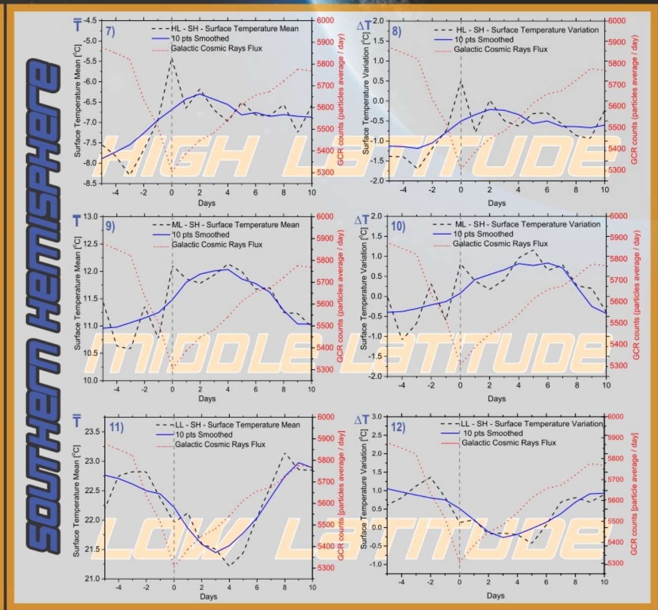
METHODOLOGY

We compiled time series of surface temperature daily means data from ten meteorological stations located at high (60^0 - 70^0), middle (40^0 - 50^0) and low (20^0 - 30^0) latitudes of Northern and Southern Hemispheres. We selected a period of fifteen days around the ten strongest FD occurred from 1987 to 2015: five days before and ten days after the day 0, characterized by the day with the lowest flux of GCR, measured by a neutron monitor station. We constructed also time series of the surface temperature variation, obtained by taking the difference between the surface air temperature daily averages during FD events periods and the surface air temperature daily averages from equivalent periods without FDs (during solar minima years of 1987, 1996 and 2008). A superposed epoch analysis was performed considering the surface temperature daily mean and the temperature variation of ten meteorological stations of each latitude region of each hemisphere. The possible climatic effects of GCR decreases were considered using linear and cross correlation methods. The temperature variation significance during FDs was assessed using the t-Student method hypothesis test.

FD	DAY "0" AND PERIOD ANALISED	INTENSITY (%)	SOLAR CYCLE AND SOLAR POLARITY
1	October 31, 2003 (10/26 to 11/10)	~33.76	Cycle #23 A>0
2	March 24,1991 (03/19 to 04/03)	~22.00	Cycle #22 A<0
3	October 29,1991 (10/24 to 11/08)	~20.20	Cycle #22 A<0
4	March 13,1989 (03/08 to 03/23)	~17.44	Cycle #22 A<0
5	March 9, 2012 (03/04 to 03/19)	~15.60	Cycle #24 A<0
6	July 27, 2004 (07/22 to 08/06)	~15.27	Cycle #23 A>0
7	November 30,1989 (11/25 to 12/10)	~14.73	Cycle #22 A<0
8	September 13, 2005 (09/08 to 09/23)	~14.35	Cycle #23 A>0
9	November 10, 2004 (11/05 to 11/20)	~13.00	Cycle #23 A>0
10	June 25, 2015 (06/20 to 07/05)	~11.00	Cycle #24 A<0

Table with the strongest FD events since 1987 to 2015, the 0 day, the periods analised, FD intensity considering Oulu Neutron Monitor data, solar cycle and the solar polarity of the periods investigated. These FD investigated are only events not related to the occurrence of Ground Level Enhancement events (GLEs).





Superposed epoch analysis of surface temperature daily mean during ten FD events (table) of ten meteorological stations of diferent regions, being: 1) High latitude of Northern Hemisphere; 3) Middle latitude of Northern Hemisphere; 5) Low latitude of Northern Hemisphere; 7) High latitude of Southern Hemisphere; 9) Middle latitude of Southern Hemisphere and 11) Low latitude of Southern Hemisphere (black line), and Superposed epoch analysis of surface temperature variation between the FD and quiet day periods (1987, 1996 and 2008 minimum solar years), being: 2) High latitude of Northern Hemisphere; 4) Middle latitude of Northern Hemisphere; 6) Low latitude of Northern Hemisphere; 8) High latitude of Southern Hemisphere; 10) Middle latitude of Southern Hemisphere and 12) Low latitude of Southern Hemisphere (black line). The colour lines (pink and blue) are representing the surface temperature data smoothed by 10 points. The red dashed lines are representing the superposed epochs of Galactic Cosmic Rays Flux from Oulu Neutron Monitor data and the grey vertical dashed line indicate the 0 day of FD. HL: High Latitude; ML: Middle Latitude; LL: Low Latitude; NH: North Hemisphere; SH: South Hemisphere.

RESULTS

SUPERPOSED EPOCH ANALYSIS: Figures 1, 3, 5, 7 and 9 suggest that there was an increase of the surface temperature during the occurence of FD events, reaching its maximum value some days after the 0 day. This might indicates that there is a connection between the GCR decrease and some changes on the atmosphere parameters, such as: ionization rate, aerossol nucleation, humidity, cloud cover etc. The surface temperature variations on the same regions between FD and normal day periods, represented by 1987, 1996 and 2008 years (minimum solar cycle periods) are presented in Figures 2, 4, 6, 8, 10 and 12. In Figures 2, 4, 6, 8 and 10 the temperature variation around the 0 day was positive, suggesting that the surface temperature during FD periods analyzed was higher than during normal days periods. These Figures also suggest that the surface temperature variation is more evident on the high latitude region of Northen Hemisphere ($\Delta T \cong 1{,}9\ ^0C$). A possible mechanism can be explained by effects of lower ionization on the chemical-physical atmospheric conditions due to lower GCR flux, that could lead to less cloud cover and consequently to the increase of amount of energy deposited in the atmosphere by solar radiation.

LINEAR AND CROSS CORRELATION: The results of the linear and cross correlation for the Northern Hemisphere (NH) have showed a latitudinal dependence of the induced ionization by GCR on the atmospheric parameters. It was possible to note the anti correlation between the surface temperature mean and the GCR flux, increasing from low to high latitudes. However, for the Southern Hemisphere (SH), the anti correlation between these data was only found for the high and medium latitudes, also with a poleward increase. But, it is possible to see that the cross correlation between data on the SH with Lag = 2 days, from polar region to equator, increase instead of decrease like the cross correlation with Lag = 0.

T STUDENT DISTRBUTION ANALYSIS ON THE TEMPERATURE VARIATION (ΔT): It is possible to verify the positive variation on the temperature of the NH between the period of FD events and the normal days for 11 and 16 days of analysis. On the SH this positive variation occurs only on the low latitude for 16 days of analysis and on medium latitude for 11 days of analysis.

From these results it seems that the FD effect on climate is more prominent in the Northern Hemisphere, increasing with latitude, and that its effect on the Southern Hemisphere does not show the same behavior (pattern). However, the influence of these natural oscillations on the air surface temperature can be dependent of some conditions, such as, land - ocean contrast, latitude and other regional effects that influence on the local climate.

SURFACE TEMPERATURE X GCR

LINEAR CORRELATION

LATITUDES	R_{NH}	R_{SH}
HIGH (60^0 - 70^0)	- 0.46	- 0.74
MEDIUM (30^0 - 40^0)	- 0.25	- 0.66
LOW (20^0 - 30^0)	- 0.10	0.59

CROSS CORRELATION

LATITUDE	Northern Hemisphere		Southern Hemisphere	
	L = 0 day	L = 2 days	L = 0 day	L = 2 days
	R	R	R	R
HIGH (60^0 - 70^0)	-0.46	-0.67	-0.74	-0.50
MEDIUM (40^0 - 50^0)	-0.25	-0.31	- 0.66	-0.69
LOW (20^0 - 30^0)	-0.10	-0.16	0.60	0.73

Correlation coefficient of the Northern Hemisphere(R_{NH}); Correlation coefficient of the Southern Hemisphere (R_{SH}); Cross correlation coefficient (R) and Lag (L).

TEMPERATURE VARIATION

t STUDENT (16 days)

Region	t	H_0 (m1=m2) $t \le 2{,}60$	H_1 (m1>m2) $t > 2{,}60$
NH - HL	3.29	Rejected	Accepted
NH - ML	7.10	Rejected	Accepted
NH - LL	10.936	Rejected	Accepted
HS - HL	- 4.82	Accepted	Rejected
HS - ML	1.33	Accepted	Rejected
HS - LL	3.42	Rejected	Accepted

t STUDENT (11 days)

Region	t	H_0 (m1=m2) $t \le 2{,}76$	H_1 (m1>m2) $t > 2{,}76$
NH - HL	5.18	Rejected	Accepted
NH - ML	5.17	Rejected	Accepted
NH - LL	7.43	Rejected	Accepted
HS - HL	- 3.27	Accepted	Rejected
HS - ML	3.71	Rejected	Accepted
HS - LL	1.66	Accepted	Rejected

H_0: Hypothesis 0; H_1: Hypothesis 1; t: t Student; NH: Northern Hemisphere; SH: Southern Hemisphere; HL: High Latitude; ML: Medium Latitude; LL: Low Latitude.

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