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# CLOUD COVER AND INTERPLANETARY MAGNETIC FIELD: POSSIBLE RELATIONSHIP

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**Abstract:** Solar energy is the main driver of the climate on Eart, thus the variation of solar activity may affect climate variability via changes in irradiation, energetic particles, cosmic ray flux or solar wind parameters. Solar wind is characterized by speed, magnetic and electric fields, flow pressure, particle flux, dynamic pressure, with various effects on atmospheric processes. One of these is the formation and evolution of clouds which play a crucial role in the terrestrial climate, since they induce cooling or warming effects, depending on their heights and composition. Possible relationship between solar activity and cloud cover variability are lately the subject of various studies, but no clear conclusion exists due to contradictory results obtained so far. This article studies the possible relationship between mean cloud cover and the interplanetary magnetic field at global scale, as well as geographical/regional characteristics for the 1984 – 2009 period, i. e. for solar cycles 22-23, when satellite observations are available at global scale and on a continuous basis. The study also shows the seasonal dependence and is made for different cloud height and composition, i. e. for low/middle/high and liquid/ice types of clouds.

**Keywords:** *cloud cover, cloud composition, solar wind, time series, correlations, seasons*

## I. INTRODUCTION

There are three main factors considered to influence the terrestrial climate, along with the intrinsic variability of the climate on different time scales, from seasons to millennia, namely: solar activity, interplanetary conditions (affecting fluxes of Galactic Cosmic Rays - GCRs) and the concentration of anthropogenic greenhouse gases, continuously increasing relative to the preindustrial era. Within the climate system, clouds intervene both as cause and as result of weather and climate at regional and global scale (Gray et al, 2010; Voiculescu et al, 2006;

Ramanathan et al, 1989). It has already been established that clouds cool the troposphere, by reflecting the short-wave radiation coming from space, while they heat the troposphere by back-scattering the long-wave radiation emitted by the Earth. The net effect of clouds on the terrestrial radiation budget depends on their composition, which, in turn, depends on the formation mechanism–and altitude. Water and ice content of clouds determines their short-wave forcing, i. e. their albedo (Ramanathan et al, 1989; Gray et al, 2010). Low clouds tend to cool the troposphere, while high clouds have a heating effect (Marsh and Svensmark, 2003). The droplets size influences cloud radiative properties: the smaller the drops, the higher the albedo of the cloud (Haigh, 2005).

Some recent studies of possible connections between terrestrial cloudiness and solar activity focus on solar wind variability (Tinsley, 2000). Solar wind is a flux of charged particles (protons and electrons) originating from the Sun, travelling with speeds between 300 and 800 km/s, which depends on the magnetic activity at different regions of the Sun (Bothmer, 1998; Kasper, 2012). Solar coronal magnetic field gets frozen into the solar wind plasma and dragged by the solar wind radially away of the Sun forming the interplanetary magnetic field (Kamide, Chian, 2007). The Coupling between solar wind, magnetosphere and ionosphere affect the global electrical circuit (GEC) by changes in the vertical atmospheric current which, in turn, might influence cloud formation, temperature and dynamics in the troposphere (Tinsley, 2000; Rycroft et al, 2012, Harrison and Ambaum, 2013). Long-term correlations between GCR and cloud cover were identified, which vary with altitude and geographical area (Harrison, 2008, Usoskin et al, 2010; Voiculescu et al, 2006; Voiculescu and Usoskin, 2012). Ionized particles seem to favor the nucleation and increase the number of cloud condensation nuclei (CCN) in particular conditions (Egenhoff et al, 2011, Yu et al, 2008, Kirkby et al., 2010). Electrically charged CCNs inhibit evaporation and influence particle and droplets sizes and collision rates (Tinsley, 2012, Rycroft et al, 2012).

The solar activity variation is accompanied by interplanetary magnetic field (IMF) and associated electrical field variations, which influence the GCR flux towards the Earth and ionization rates in the troposphere. This article presents the study of the possible connection on long time-scales between the interplanetary magnetic field variations and cloud cover on Earth. The studies are done seasonally and they are differentiated by clouds height and composition (i. e. for low, middle and high clouds, respectively and for liquid and ice clouds, as well). The time span is 1984-2009.

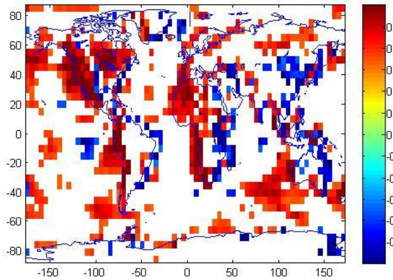
## II. DATA AND METHODS

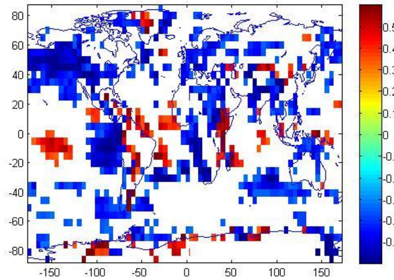
Monthly means of cloud cover data are provided by the ISCCP website (http://isccp.giss.nasa.gov/products/browsed2.html), for grids of 2.5x2.5 deg. The data are obtained from IR reflectance measurements taken from satellites. Cloud cover for low, middle and high clouds are computed, as well as for different composition: ice and water (liquid). In the following, various type of clouds are identified using acronyms: LCA – low cloud amount; MCA – middle cloud amount; HCA – high cloud amount; LLCA - liquid low cloud amount; ILCA - ice low cloud amount. The cloud differentiation by height is done according to their top pressure: clouds are considered low when $p > 680$ mb, middle for $440 \text{ mb} < p < 680$ mb and high for $p \leq 440$ mb, respectively (Rossow and Schiffer, 1999). Solar wind data were downloaded from NASA's OMNIweb site (http://omniweb.gsfc.nasa.gov/form/dx1.html) from where monthly averages of IMF magnitude (B) were used. Correlation coefficients between cloud cover in each grid and IMF variations were calculated, at annual and seasonal scales and correlation maps for each type of clouds were produced. The correlation was assessed for a significance threshold of 90 %.

## III. RESULTS AND DISCUSSION

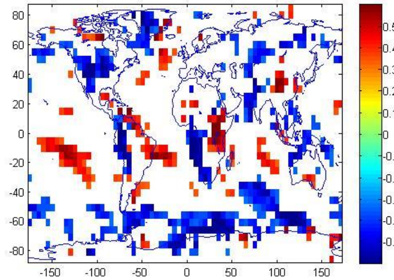
Fig. 1 presents the results of the correlation analysis between IMF and cloud cover, for the 1984-2009 period, for low, middle and high clouds. Fig. 1 shows that positive correlation exists between LCA and IMF, i. e. when IMF increases, LCA increases.

MCA-IMF correlations are negative, while HCA correlation with IMF varies, according to geographical areas. Also, HCA seem to respond less to IMF variations then lower clouds, which might be surprising since high clouds form in the upper troposphere, where IMF effects should be stronger. On the other hand, ionization at upper altitudes is larger, thus relative variations might be smaller at upper heights. Moreover, mechanisms might act differently on ice and liquid clouds (Tinsley, 2012) and meteorological conditions might prevail over extraterrestrial influences in specific areas (Voiculescu and Usoskin, 2012).




a). LCA-IMF b). MCA-IMF

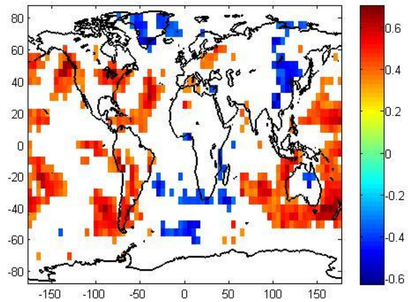



c). HCA-IMF

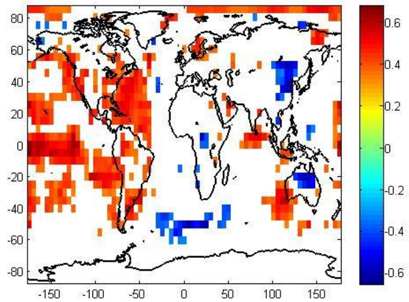
**Fig. 1** Correlation maps between low, middle and high cloud cover, and IMF at annual scale. Correlation coefficient is given in terms of color coding (see color bars) and white areas correspond to correlation with lower significance

Next, Figs. 2 and 3 show the seasonal variation of the LCA-IMF correlation for different cloud composition, i.e. for liquid low clouds (fig 2), and for ice low clouds (fig 3). Seasons are defined for the Northern Hemisphere: winter average is calculated using December, January, February data, spring corresponds to March, April, May, summer to June, July, August, and fall covers September, October, November.

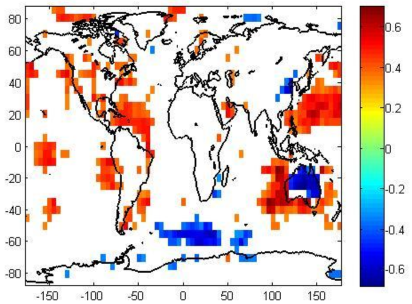
A seasonal variation of the correlation is observed in Fig. 2, but, generally, there is a positive correlation between liquid low clouds and IMF. The correlation varies across the Earth with changing season over some regions, but exists during the entire year in other areas from the Pacific Ocean, some equatorial oceanic regions around Central America or parts of the Indian Ocean.



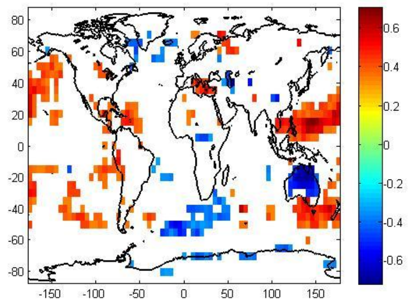

a). LLCA-IMF during spring (MAM)




b). LLCA-IMF during summer (JJA)




c). LLCA-IMF during autumn (SON)

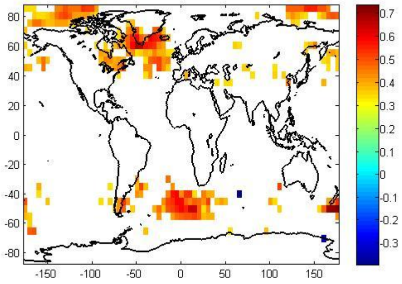



d). LLCA-IMF during winter (DJF)

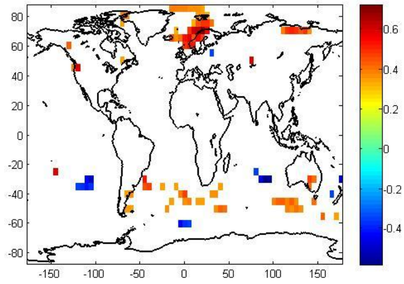
**Fig. 2** Seasonal correlation maps between of liquid low cloud cover and IMF; seasons are defined for the Northern Hemisphere

In spring (in the Northern Hemisphere), positive correlations are seen over oceanic areas around Australia and on the Western part of the Pacific Ocean. During summer, most of the areas with positive LLCA-IMF significant correlations are on the western part of Atlantic Ocean, above the American continents and continue on the Eastern Pacific Ocean.

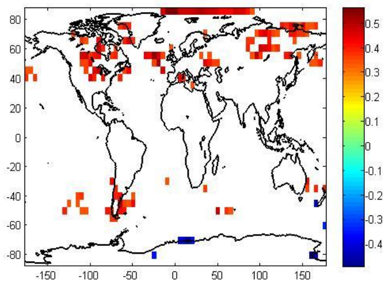
Low clouds made of water do not correlate almost at all with IMF above Antarctica, most likely because that they simply do not exist above the Southern Pole, since temperatures are too low there. On the other hand, some correlation is seen at high latitudes in the Northern Hemisphere. Negative correlation is seen during spring and summer above Eastern Asia. In the southern hemisphere, the negative correlation between LLCA and IMF is strengthened during fall and winter (i.e. local spring and summer) above Australia, but also above the Southern Atlantic Ocean.



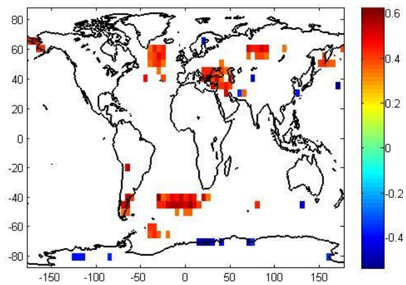
a). ILCA-IMF during spring



b). ILCA-IMF during summer



c). ILCA-IMF during autumn



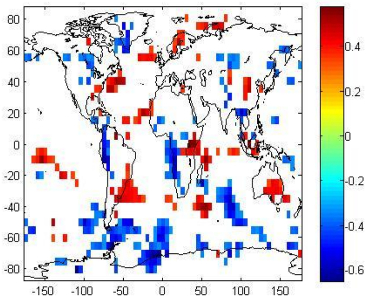
d). ILCA-IMF during winter

**Fig. 3** Seasonal correlation maps between mean values of ice low cloud cover and IMF, covered period: 1984-2009

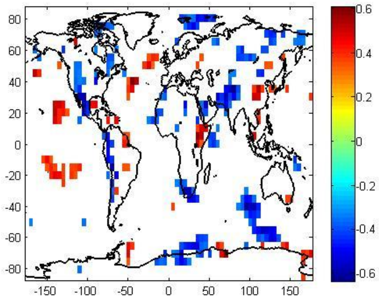
Low clouds have little ice content (less than 10%), compared to their water content, reaching tens of percentage. Correlation maps between ice low clouds and IMF for the four seasons are shown in Fig. 3.

The correlation is positive, but sporadic during the entire year except for spring, when clear well-defined regions where correlation exists are seen in the Northern and Southern Atlantic Ocean, at mid-high latitudes.

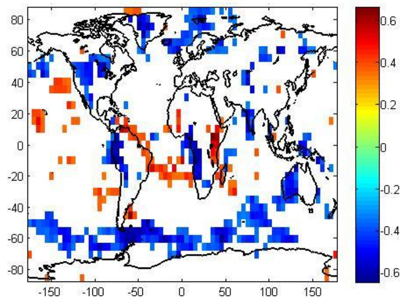
Finally, fig. 4 presents the HCA-IMF correlation for each season. The correlation is mainly negative, patchy and varies with season. The strongest correlation is seen during autumn, when a zonal band of negative correlation is observed at high latitudes, in the Southern Hemisphere. Spring and summer are characterized by varying correlation, from negative to positive, over different areas. Areas of positive correlation are larger during winter and appear over the Southern Pacific Ocean and on the Western Coast of Australia and partially over coastal regions of Eastern Africa, eastern South America and Central America.



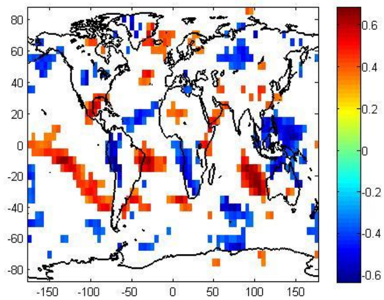

a). HCA-IMF during spring




b). HCA-IMF during summer




c). HCA-IMF during autumn




d). HCA-IMF during winter

**Fig. 4** Seasonal correlation maps between mean values of high clouds cover and IMF, covered period: 1984-2009

Since high clouds are made of ice, it is reasonable to compare correlations between IMF on low clouds made of ice with those between IMF and high clouds (figs. 3 and 4). There are many areas across the Earth exhibiting opposite behavior, i.e. where ILCA positively correlates with IMF, while HCA is anti-correlated with IMF and vice versa. For example, in the Eastern part of North America, ILC positively correlate with IMF during spring, while HCA anti-correlates with IMF. This is also the case during summer, in the South-Western corner of Australia and in the North-Eastern corner of Asia. During autumn, USA and Southern Canada exhibit positive correlation between ILC and IMF, while HCA and IMF anti-correlate. This is also the case, in the same season, for a small part of Central Asia. As for winter, a somehow larger area from Central Asia shows positive correlation for ILC-IMF and negative correlation for HCA-IMF. This may indicate either that the mechanism is efficient only at some particular heights, or that liquid or ice content may not be correctly retrieved in satellite data, especially for low clouds.

Also, another problem can exist due to existing trends in cloud cover. Evan et al (2007) showed that part of the trend observed in global cloud cover may be due to artifacts originating in the changing view angle of satellites.

A plot of the annual variation of global mean of LCA, LLCA and ILCA, together with the variation of annual means if the magnitude of IMF (Fig. 5) shows that a descending trend exists in all datasets. The most important one is noticed in LCA, which might explain the important positive correlation seen over large areas of the globe.

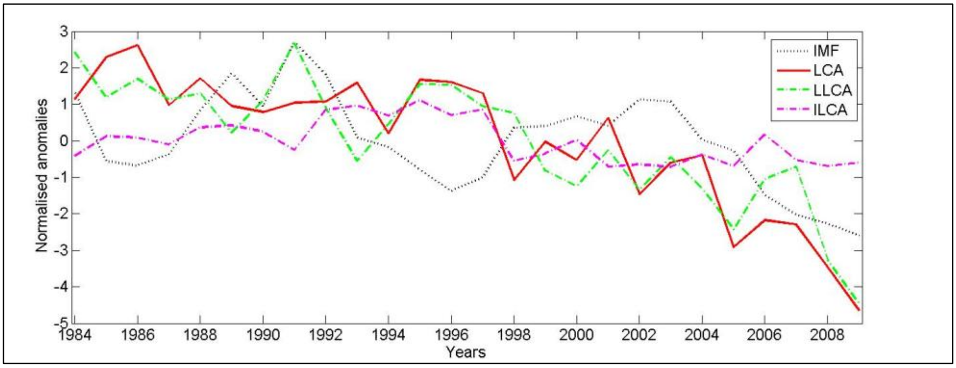



**Fig. 5** Annual variation of IMF (black dotted line), global mean of LCA (red solid line), LLCA (green dash line), ILCA (magenta dash-dotted line)

Taking into account the observed positive correlation between low clouds and cosmic ray flux (Marsh and Svensmark, 2003, Voiculescu et al, 2006) and the anticorrelation between IMF and CR flux (since a large interplanetary magnetic field will reduce the flux of galactic cosmic rays reaching the terrestrial atmosphere), one expects that low cloud amount would increase with descending IMF. Our results show the opposite, which is certainly due to the important trend observed in both datasets. In such cases, the trend dominates over variations at shorter time scale. Indeed, variations in cloud cover at smaller scale in fig. 5 seem to be anti-correlated with IMF. Thus, one step further will be to investigate if correlations change after removing the trend.

## IV. CONCLUSIONS

A possible connection between the interplanetary magnetic field – as solar wind proxy – and cloud cover on Earth was investigated. Clouds were differentiated by height and composition, since water and ice content are influenced differently by the atmospheric environment and by the ionization processes up in the air. We focused on correlations at annual scale, as well as seasonal variation for both ice and water clouds, for low and high clouds, as middle clouds might be sometimes misinterpreted as low/high clouds.

Low cloud cover positively correlates with IMF, while middle clouds anti-correlate with IMF on most part of the Earth. High clouds exhibit either positive or negative correlation, depending on the region. Liquid low clouds correlate positively in most regions, especially during spring and summer time, while during summer and winter, strong anti-correlation between LLCA and IMF is seen at high latitudes in the Southern Hemisphere. Ice low clouds positively correlate with IMF only in small regions, in small patches, while high clouds, which are only made on ice, are anti-correlated with IMF, mainly during autumn.

Several regions were identified where clouds made of ice respond differently to IMF variations at low, respectively high, altitudes: when one is positively correlated with IMF, the other one is anti-correlated and the other way round.

These changes in the sign and values of the correlations and their distribution on Earth depend not only on clouds height and on their composition, but also on the local geographical conditions, through ocean-atmosphere coupling and other local influences, that will need further investigations. Our results indicate that some coincident variations exists, but further study is required in order to correctly identify the nature of this relationship and the atmospheric conditions when such a relationship might have a physical basis. Correlation studies only can indicate the possibility that cloud might be affected by extraterrestrial processes, but the mechanisms themselves or the magnitude of the effects are not straightforward.

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