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Effect of ENSO and volcanic events on the Sun–cloud link

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Abstract

Results of correlation studies between solar proxies and clouds suggest that there is a solar effect on the occurrence of clouds. However, there is a possibility that terrestrial quasi-periodic and sporadic phenomena, such as ENSO and/or major volcanic eruptions, which have an effect on the cloud formation, may influence the results of statistical studies of the Sun–cloud relation. We show that removing ENSO and volcanic years from the full-set analysis does not alter the results. Moreover, the correlation between clouds of different type and two solar proxies, UV irradiance and cosmic ray induced ionisation, is partly improved. This supports the idea that the solar signal affects clouds directly. An interesting result relates to an area in the eastern Pacific where the full-set analysis showed that the relationship between clouds and cosmic ray induced ionization is opposite to the global one. When ENSO and volcanic years are removed this odd correlation disappears, suggesting that in this particular area, the ENSO effect prevails over solar effects.

Keywords: Solar-terrestrial relations; Solar effect on clouds; ENSO

1. Introduction

The link between the solar activity and global climate change is presently a highly debated issue. Several studies support the idea that low cloud amount (LCA) correlates (globally or in certain areas) with the flux of galactic cosmic rays (CR) impinging on the Earth (Marsh and Svensmark, 2000; Pallé Bago and Butler, 2000; Usoskin et al., 2004b; Pallé et al., 2004; Voiculescu et al., 2006). Besides the mechanisms that connect cloud occurrence with cosmic ray ionisation (Tinsley, 1996; Yu, 2002; Marsh and Svensmark, 2003a), there are also suggestions that solar irradiance may have an indirect effect on cloud cover (Haigh, 1996), supported by negative correlations between low clouds and total solar irradiance (TSI) (Kristjansson et al., 2004) or UV irradiance, UVI (Voiculescu et al., 2006).

To ascertain the existence of a Sun–cloud link, long-term studies are necessary. Satellite-based cloud data provided by the ISCCP project database (Rossow et al., 1996) are most appropriate, since they extend over more than two decades and also have a global cover with a fine spatial resolution. However, the validity of the correlation between CR and satellite defined cloud cover was questioned by Pallé (2005), who argued that low clouds can be obscured by upper clouds in the satellite view (Wang and Rossow, 1995; Doutriaux-Boucher and Séze, 1998; Norris, 2005; Rossow et al., 2005), leading to spurious correlation. High cloud cover data might also be affected by the existence of thick low clouds, especially over different backgrounds (Hahn et al., 2001; Rossow et al., 2005). Attempts to clarify this issue were made by Marsh and Svensmark (2003b), who found that most of the regions displaying a positive correlation between low cloud and CR are not affected by overlaying cloud. However, they used only data from 1983 to 1994, arguing that after 1994 ISSCP data had calibration problems. Using the entire ISSCP dataset, Pallé (2005) concluded that the strongly negative correlation between low and high + middle clouds, together with the fact that high clouds are

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anticorrelated with cosmic ray induced ionisation (CRII), could spuriously induce the positive correlation of low clouds with CRII. The possible intervening effect that one type of clouds may have on the relationships between solar proxy and other clouds was analysed in great detail by Usoskin et al. (2006), using partial correlations. They found that both correlations might be spurious in some limited, well defined, areas around 40–60°S and N above the Atlantic ocean; nevertheless, many large "clear" areas remain where correlation results are not affected by other clouds. This can be understood if one takes into account that the negative correlation between low and higher clouds might be not only of instrumental origin but can be caused also by a physical mechanism (Warren et al., 1985; Usoskin et al., 2006).

Because all solar drivers are correlated, it is difficult to evaluate their individual effect on the clouds from simple correlation studies. As shown in our previous work, Voiculescu et al. (2006), the cloud response to solar variations at global scale is not uniquely defined by a single solar proxy. Both CRII and UVI seem to act in a complementing way and the prevalence of one or another depends on the type of cloud and on climatic conditions. Low clouds show more significant (anti)correlation to the UVI irradiance over oceans and dry continental areas in equatorial, tropical and subtropical regions, while they correlate with CRII above oceans and moist continental areas at mid to high latitudes. High clouds are negatively correlated to CRII and seem to be almost unaffected by UVI, except for the Siberian area where the correlation with UVI is positive. For middle clouds the pattern is restricted to smaller correlation areas that give more credit to a possible UVI influence.

It is likely that climatic or terrestrial quasi-periodic and sporadic phenomena, such as ENSO and/or major volcanic eruptions, which do affect the cloud formation, may influence the results of statistical studies of the Sun–cloud relation. Although this topic has been discussed earlier (e.g., Luo et al., 2002; Marsh and Svensmark, 2003b), it is still unclear to what extent and in what geographical regions these effects can overcome or mimic the possible solar signal. Fig. 1 shows the annual time series of the globally averaged amount of high, middle and low clouds between 1984 and 2004, together with CRII and UVI variations. Some significant variations in the global cloud amount time series coincide with ENSO years, which might have an effect on the analysis of cloud–Sun correlation. This is visible especially in the high cloud amount variation, which peaks in 1987 and 1997 that are ENSO years.

In the following we will check the robustness of the cloud–Sun correlations with respect to ENSO and major volcanic eruption, by removing the years with strong ENSO events, as well as the year when the Pinatubo eruption took place, from the analysis. We use ISCCP cloud data for the period 1984–2004 and corresponding CRII and UVI data. Removing or including these years in correlation studies has various shortcomings that will also be discussed.

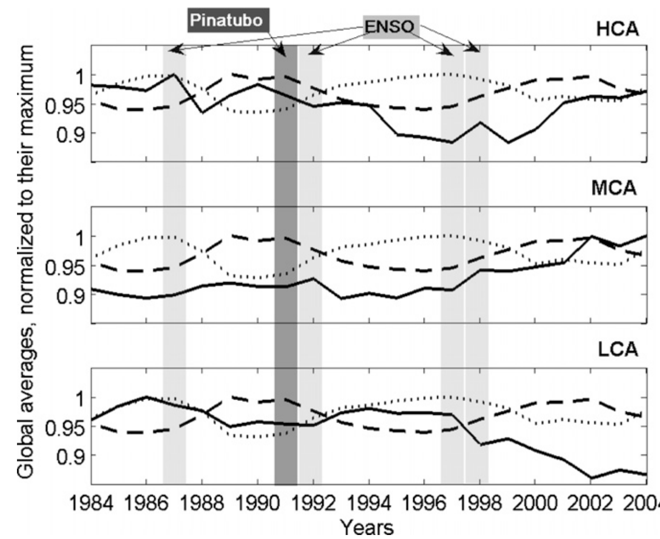

Fig. 1. Relative variation of annual global values (continuous line) between 1984 and 2004 for high (HCA), middle (MCA) and low (LCA) cloud amounts (top, middle and low panels, respectively), together with variations of CRII (dotted line) and UVI (dashed line). Grey columns correspond to ENSO years, while the light grey column stands for the Pinatubo volcanic eruption.

2. Data

The cloud data are annual means of the cloud amount (percentage of the area covered by clouds of a given type for both day and night) in geographical grid of $5^\circ \times 5^\circ$, observed in IR by satellites and collected during the period 1984–2004 in the ISCCP-D2 dataset (http://isccp.giss.nasa.gov). We have studied high, H ($P < 440$ mb), middle, M ($440 < P < 680$ mb) and low, L ($P > 680$ mb) clouds. The CRII data were computed using a physical model simulating the nucleonic-electromagnetic cascade produced by cosmic ray particles in the atmosphere (see full details in Usoskin et al., 2004a; Usoskin and Kovaltsov, 2006). Cosmic ray variability during the period under investigation was derived by Usoskin et al. (2005) from observations of the world neutron monitor network. CRII has been computed for three layers of barometric pressure 700, 500 and 300 g/cm^2, corresponding to the low, middle and high clouds, respectively. The UVI data were derived using the MgII core-to-wing index given by the NOAA Space Environment Center (http://www.sec.noaa.gov/Data).

To identify areas of "real" and spurious cloud–UVI or cloud–CRII correlation, we have used direct (called also bivariate or Pearson's) correlation, as well as partial correlations. By "real" we do not necessarily mean here a real physical Sun–cloud relation but rather a firm statistical correlation, which is not spuriously induced by other clouds. The standard bivariate (Pearson's) correlation of two variables, R, accounts for all possible links between them, including indirect relations via other (third) variables. The partial correlation gives the same result as the corresponding bivariate correlation if the third (intervening) variable is constant. If the direct correlation coefficient and the difference between partial and bivariate correlation coefficients have opposite signs, the correlation is spuriously induced by the third variable. If they have the same signs, the correlation is, at least mathematically, real. Details about the use of the direct and partial correlations to identify areas of spurious or real correlations are given in Usoskin et al. (2006) and Voiculescu et al. (2006).

3. Results

We have calculated coefficients of direct and partial correlation between clouds and solar proxies separately in each geographical grid cell, considering all years when cloud data was available (1984–2004). Global maps of correlation were produced for the relationships between each of the three types, H, M and L, of clouds and each of the two solar proxies, UVI and CRII. These are shown in the right-hand side of Figs. 2–4. In the same figures the left-hand side panels show the geographical distribution of correlations when Pinatubo and strong ENSO years were removed. These years are 1991, the year of the Pinatubo volcanic eruption, and 1987, 1992, 1997 and 1998 – corresponding to ENSO events. During 1992 clouds have, presumably, been influenced also by ash deposition descending from stratosphere (McCormick et al., 1995).

In the present analysis we are primarily interested in the significance of the partial correlation rather than in its correlation coefficient. In the right-hand side panels (where all 21 annual points are considered) we show only pixels where the correlation is significant at 90% confidence, i.e., correlation coefficients higher than 0.37 (absolute value). One consequence of removing the five years with ENSO and Pinatubo events from the analysis, i.e., of shortening the series from 21 to 16 points, is that the correlation coefficient corresponding to 90% confidence increases from 0.37 to 0.42. Correlation coefficients higher than 0.42 are denoted with big markers in the left-hand side panels. In these panels we show also areas where the correlation has absolute values between 0.37 and 0.42, using markers of smaller size (see Figure caption for details). These correspond to areas where the correlation becomes, after removing the "problematic" years, formally higher but less significant (due to the

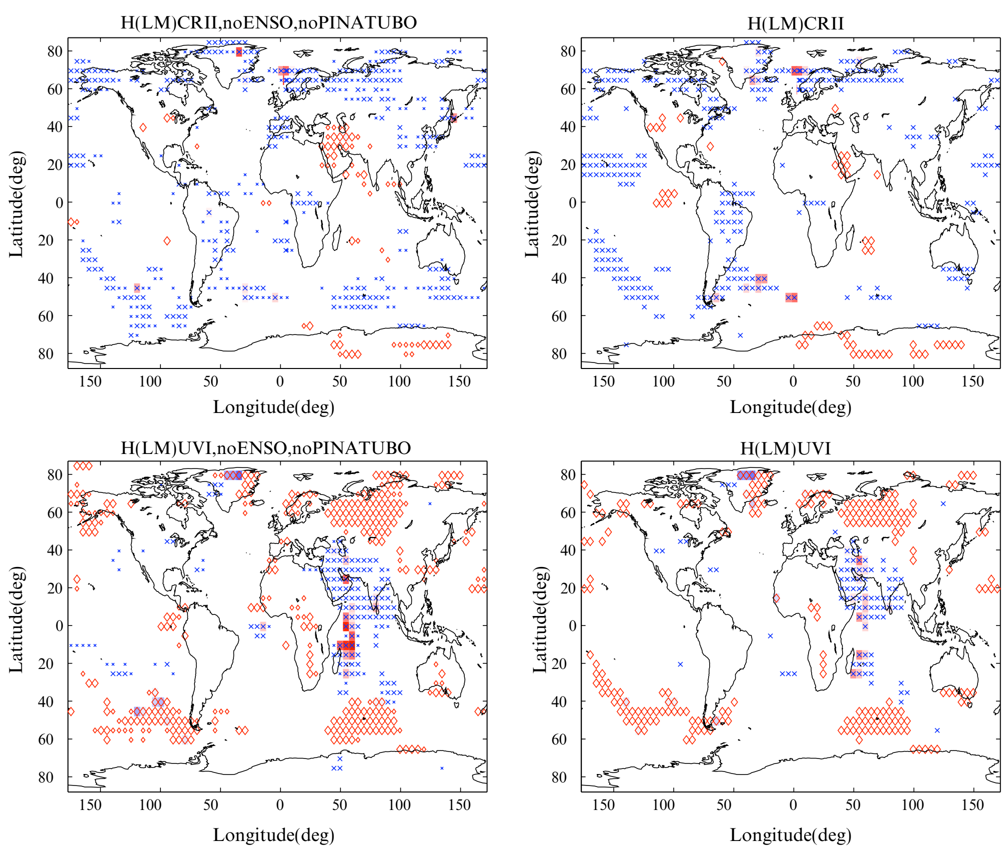

Fig. 2. (Right-hand panels) Geographical distribution of the correlation between high clouds (*H*) and solar proxies (*UVI*-upper panels, *CRII*-lower panels) when all years are included in the analysis; (Left-hand panels) The same as for the right hand panels but after removing the five ENSO and Pinatubo years. Shading denote areas of spurious correlation, possibly induced by the other cloud types (*LM*). Correlation significant at 90% confidence level is shown with big markers. Small markers in the left-hand panels show correlation coefficients between 0.37 and 0.42 (see text). In all plots blue crosses correspond to negative correlation and red diamonds to positive correlation. Notations on the top of each panel define the studied relation. For example H–(LM)–CRII stands for the partial correlation between high clouds and CRII with low + middle clouds being fixed. Colour plots are given in the on-line version. (For interpretation of color mentioned in this figure the reader is referred to the web version of the article.)

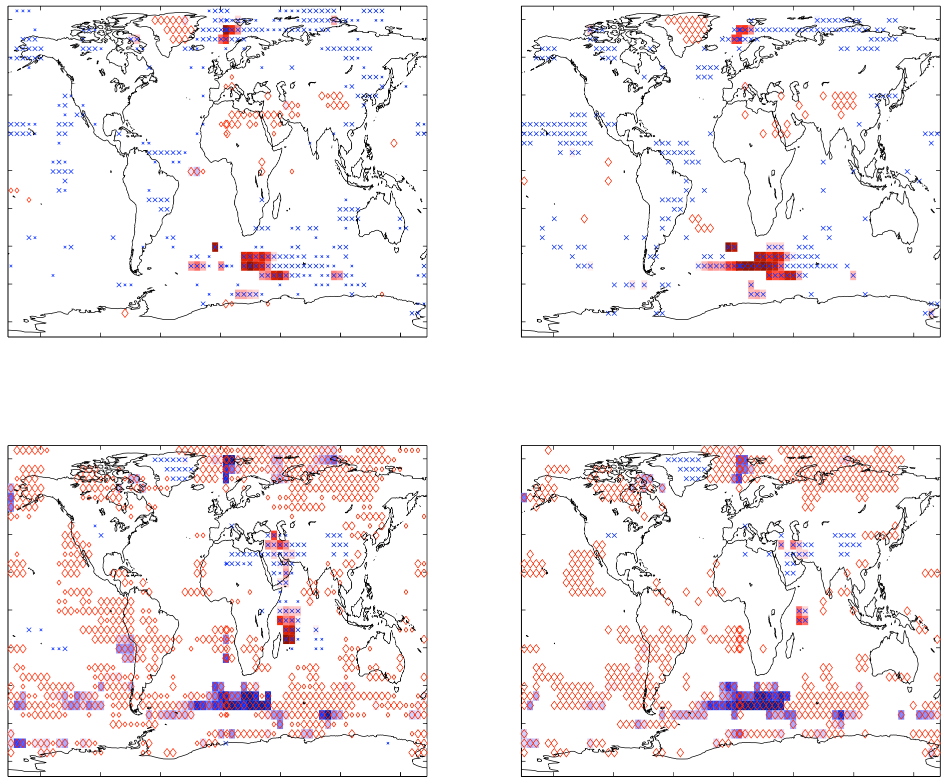

Fig. 3. As for Fig. 2 but for middle clouds. (For interpretation of color mentioned in this figure the reader is referred to the web version of the article.)

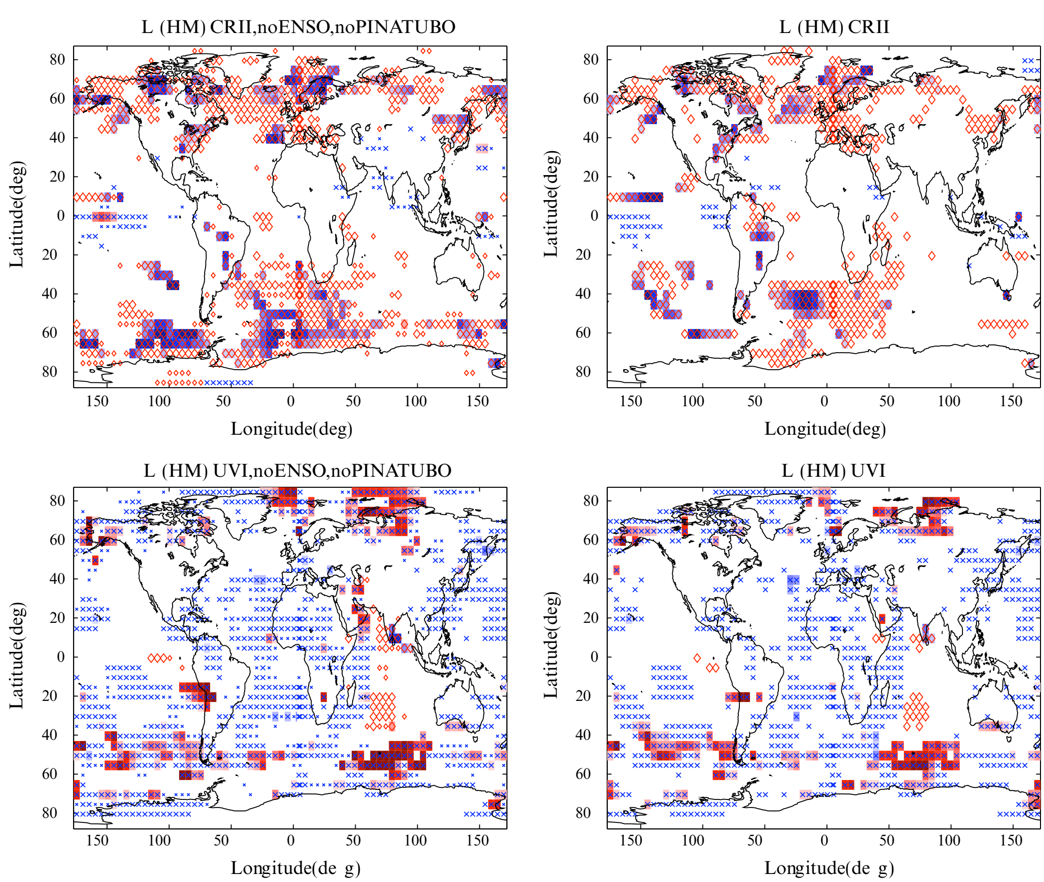

Fig. 4. As for Fig. 2 but for low clouds. (For interpretation of color mentioned in this figure the reader is referred to the web version of the article.)

decreasing number of degrees of freedom). Areas with possible intervening effect of other clouds in the correlation with solar proxy are shaded.

Generally, the geographical pattern of anticorrelation between high clouds and CRII is maintained and the correlation is slightly improved after ENSO and Pinatubo years are removed (Fig. 2). There is only one small area, located in a relatively narrow longitudinal sector in the eastern Pacific (120–140°W), around 20°N, where the anticorrelation disappears. On the other hand, new areas of negative correlation extend from mid to high latitudes of the southern Atlantic, and new areas of negative correlation appear over the waters south and west of Australia, the equatorial Pacific as well as over the continental mid-latitudinal eastern Asia. The odd positive correlation west of Peru, which appears in the full-set analysis, is not present after the removal of the "problematic" years. The second row of Fig. 2 shows that the isolated areas of positive and negative high cloud–UVI correlation are practically unmodified. The abrupt change of high cloud–UVI correlation from positive to negative over the middle Asia and from negative to positive over the waters of the Indian Ocean is seen in both plots and remains unexplained. These results indicate that the correlations between high clouds and the solar proxies is not spuriously induced by ENSO events and volcanic eruptions. This supports Yu (2002), who suggested that these internal climatic sources might mask the solar signal in the high cloud cover.

The patterns of the relationship between middle clouds and both solar proxies, shown in Fig. 3, also undergo little modification. According to Voiculescu et al. (2006), middle clouds correlate better with UVI than with CRII, but the correlation is partly induced by other clouds. The relationship with CRII is not clear and is observed only in relatively small areas. When the five years are removed, the negative correlation with CRII becomes clearer in the equatorial belt of the Indian and the Atlantic Oceans, and in the most western Pacific. The positive correlation with UVI is also improved but the pattern remains essentially the same. We note that the negative correlation with UVI seen over Greenland and tropical Asia remains unchanged.

The situation is the same for the positive correlation between low clouds and CRII (Fig. 4). The two patterns are almost identical, except for a few individual pixels. The areas of correlation remain unchanged. The odd negative correlation seen over the equatorial and tropical Pacific shrinks, so that it is no longer present over the coastal waters of Peru. The anticorrelation between low clouds and UVI, which is practically the clearest relationship between any type of clouds and solar proxy, clearly improves after removing the possible effects of ENSO and Pinatubo eruption; it is more consistent and the areas are wider, extending in regions where no correlation was found in the full-set analysis, such as the equatorial and tropical northern Atlantic and the continental central America.

4. Discussions and conclusions

One main conclusion of the present study is that removing ENSO and major volcanic years not only keeps the pattern of the cloud-solar proxies correlation unaltered, but even improves it, especially with UVI. This indicates that the strong disturbances in the atmospheric properties, such as ENSO and major volcanic eruptions, do not mimic the Sun–cloud relation, at least for the past two solar cycles. Moreover, there are indications that the global effect of Pinatubo on the cloud cover might have not been very strong (e.g. Luo et al., 2002) This supports the idea that the solar signal affects clouds directly. On the other hand, due to removing points from data analysis, the statistics gets worse and the overall significance of results is not improved. We conclude that such correlation studies are not greatly affected by the "problematic" years.

However, there is a specific area, over the coastal waters west of Peru, which deserves more attention. When all years are included, the relationship of clouds to CRII over this area is positive for high clouds and negative for low clouds, i.e., opposite to the dominant global relation that is negative for high and middle clouds, and positive for low clouds. When ENSO and Pinatubo years are removed from the analysis this odd correlation disappears for high clouds and is greatly reduced for low clouds. The fact that clouds seem to respond to the solar input differently in that area compared to elsewhere suggests that ENSO effects prevail over CRII effects there. We conclude that, although removing years of strong ENSO and volcanic eruptions has no important effect on global correlation patterns, caution must be paid when interpreting the results of correlation studies in some areas, prone to be affected by extreme internal climate processes. A more detailed analysis of the localised effects of internal sources on the cloud-solar activity relationship is presently under way.

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