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Modeling theoretical radiative–dynamic response of tropospheric clouds to cosmic ray changes associated with Forbush Decrease events

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Abstract

Forbush Decrease (FD) effects on cloud composition and structure are under study and the results are still controversial. Time-scales are of paramount importance for supporting either a 'microphysical hypothesis', which hypothesizes a relation between FD and cloud microphysical parameters variability, or a different one. A most controversial question is related to the time delay between FD and cloud structure modification. The timescales of a radiative–dynamical mechanism, investigated through a simple model, are compatible with the observed variability with respect to cloud structure. Thus the delayed modification on cloud structure has to be put in relation with solar radiation variability, being coherent with the observed statistically significant Total Solar Irradiance (TSI), temperature and baric field variations, while not supporting the 'microphysical hypothesis'.

Keywords: Earth; Cosmic rays; Radiative–dynamical effect; Total Solar Irradiance; Temperature

1. Introduction

Transport of cosmic rays (CRs) in the heliosphere is one of the topics of major interest in space physics and presents several unsolved questions. This phenomenon is modulated by different physical mechanisms, which can be divided into large scale processes (related to the large scale heliospheric magnetic field) and transient phenomena, such as those produced by transient solar ejecta or inter-planetary shocks (Dasso et al. 2012).

Forbush Decreases (FDs), after the name of the American physicist Scott E. Forbush, who first noticed this effect in 1937, are significant depressions observed in CR flux at Earth, which are generally observed in association with the arrival to the Earth's environment of interplanetary shocks driven by huge transient magnetic structures of solar origin, the so called Interplanetary Coronal Mass Ejections (ICMEs) (e.g., Richardson and Cane, 2011). FDs can be also produced by ICMEs without shocks, and the structure of the time profile of CR intensity is significantly different in cases with the presence of a shock, when compared to cases of ICMEs without a driven shock wave (e.g., Kumar, 2014). Despite several properties of the structure of a FD being relatively well understood, their recovery times are difficult to define, because of imposing and merging of different effects (e.g., Usoskin et al., 2005). In particular, FDs variability depends both on the diversity of solar sources and their combinations and on the variety of interplanetary situations arising before and during the event (Belov, 2009).

FDs effects on atmospheric processes are still under investigation and the results are controversial. For sake of simplicity, we can say that, while some works state the presence of an effect on cloud composition and structure, which we will call 'microphysical hypothesis' (Svensmark

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and Friis-Christensen, 1997; Marsh and Svensmark, 2000; Kniveton, 2004; Todd and Kniveton, 2004; Harrison and Stephenson, 2006), others reach an opposite conclusion (Kristjánsson and Kristiansen, 2000; Sloan and Wolfendale, 2008; Kristjánsson et al., 2008; Benestad, 2013). The 'microphysical hypothesis' supports the idea that cosmic rays affect aerosols via the ion-mediated nucleation mechanism, implying they also influence cloud properties.

The disagreement between the different studies is actually of key importance to this field, as ideally there should be no distinction between the aims of the two groups. Nonetheless the strong disagreements still remain in the conclusions. The interest for this subject is not recent, since a work, discussing the influence of solar variability on the lower atmosphere, already appeared forty years ago (Dickinson, 1975). Possible effects of GCRs on aerosol nucleation (e.g., Arnold, 2006; Svensmark et al., 2007; Arnold, 2008; Pierce and Adams, 2009; Snow-Kropla et al., 2011; Dunne et al., 2012; Rawal et al., 2013; Yu and Luo, 2014) and on cloud characteristics (e.g., Yu, 2002; Svensmark et al., 2009, 2012; Calogovic et al., 2010; Laken et al., 2012), have been discussed. The general effect of particle ionization and electrical forces in CCN formation and aerosol nucleation is known and it is not under discussion here. Instead, the critiques moved against the 'microphysical hypothesis' are related to several factors.

First: Some experimental evidence has been hypothesized that cosmic rays facilitate the formation of ultrafine 10–30 nm sulphuric acid aerosols within a few hours (Svensmark et al., 2013). Nevertheless, laboratory experimental measures during CLOUD experiment neither gives strong evidences of a possible generalization to other chemical species nor that there is a strong GGRs influence on aerosol nucleation (Erlykin et al., 2013). Furthermore results of laboratory tests suggest that the observed correlation between short-term decreases in cosmic ray ionization and cloud and aerosol properties cannot be explained by associated changes in the large-scale nucleation rate (Dunne et al., 2012). Moreover, the predicted aerosol sensitivity to week-long FDs of cosmic rays and, in particular, the maximum change in aerosol properties for these cases are similar to steady-state aerosol differences between the solar maximum and solar minimum. These results provide evidence that the effect of cosmic rays on CCN and clouds through the ion-aerosol clear-sky mechanism is limited by dampening from aerosol processes (Snow-Kropla et al., 2011).

Second; An evidence of change of cloud microphysical structure is claimed with respect to FDs (e.g., Svensmark et al., 2009; Svensmark et al., 2012). There have been harsh critiques and replies, immediately following the second paper, with respect to the way of handling the data. In support of the latter position, changes in CCN from changes in CRs during a solar cycle are two orders of magnitude too small to account for the observed changes in cloud properties, so that the hypothesized effect is too small to play also a significant role in current climate change (Pierce and Adams, 2009).

Third: It is known that changes in the GCR flux are linked to the solar wind and associated disturbances (such as Coronal Mass Ejections – i.e. CMEs) and that irradiance associated changes are experienced on Earth almost instantaneously following a solar event (Laken and Čalogović, 2011). A statistically significant decrease in the Total Solar Irradiance (TSI) has been evidenced during FDs (e.g., Laken et al., 2011; Svensmark et al., 2012). Nonetheless, the effect of this decrease on cloud formation and structure has not been further investigated, with respect to this short-timescale specific case. There is also an evidence of a response in cloud parameters after 6–9 days, consistent with several cloud data sets (Svensmark et al., 2012), which is in contrast to the hypothesis of a microphysical-based influence on cloud structure. In fact the typical time scale of microphysical processes is much smaller that the one observed here (Harrison and Carslaw, 2003). Furthermore, cloud condensation nuclei (CCN) concentration must drop within 1–2 days and recover during about a week (Calogovic et al., 2010).

Being these caveats fundamental, we still need to better define this cosmo-geophysical problem, since it might have (or not) many consequences on climate studies. In particular, understanding the impact of solar variations associated to GCR flux variations either on particle and cloud condensation nuclei (CCN) formation or in the thermodynamical conditions related to cloud formation is a critical step for describing one of the possible solar indirect climate forcing pathways. In order to establish whether or not such a relationship exists, measurements of short-timescale solar events, individual cosmic ray events, and spatially correlated cloud parameters could be of great significance. In the meanwhile, a simple model would help to support this search of data. This is why this work will be focused on such time-scales.

In particular, the aim of this paper is to explain, through a simple model, how the observed delay (Laken and Čalogović, 2011; Svensmark et al., 2012) can be found. It is possible to demonstrate that measurements are compatible to the time-scales of a radiative–dynamical process, which might be directly related to TSI variability, which depends upon solar disturbances (Laken and Čalogović, 2011). It will be demonstrated that the observed time-scales are compatible, as a first approximation, with a re-equilibrium process, which propagates along the atmospheric layers and which can occur in the atmosphere after any radiative imbalance. This argumentation, obviously, would further weaken the 'microphysical hypothesis', while possibly attributing the cause of the observed phenomenon directly to the measured solar parameters variations. This fact would also reduce the possibility of a causal relationship between FDs and the evolution of extratropical baric systems, while not necessarily reducing the possibility of a general atmospheric pressure increase, which has been