Cosmic Ray Induced Ionization in the Atmosphere: Galactic and Solar Cosmic Rays

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Abstract

Using a physical model based on Monte-Carlo simulation of the cosmic ray induced cascade, we calculate cosmic ray induced ionization in the atmosphere. The results for long-term changes in the ionization due to galactic cosmic rays are presented. The ionization effect of strong solar energetic particle events is also discussed.

1. INTRODUCTION

Cosmic rays form the main source of the atmospheric ionization in the troposphere and lower stratosphere, contributing significantly also into the ionization of higher atmospheric layers. When entering the Earth's atmosphere, very energetic cosmic rays initiate a nucleonic-electromagnetic-muon cascade in the atmosphere. All thus forming secondary particles/radiation ionizes the ambient air, leading to essential physical and chemical changes in the atmosphere.

Two main components are important for cosmic ray induced ionization of the lower atmosphere: (1) high energy galactic cosmic rays that are always present in the vicinity of the Earth and are subject of the solar modulation and (2) sporadic solar cosmic rays of lower energy but very high momentary flux. The effect of both components is quantitatively studied here.

2. NUMERICAL MODEL

A full physical model has been recently developed to calculate cosmic ray induced ionization in the atmosphere, taking into account all the related processes (Usoskin et al., 2004; Usoskin and Kovaltsov, 2006). The model is based on the Monte-Carlo CORSIKA tool, which simulates full development of an electromagnetic-muon-nucleonic cascade in the atmosphere, with the FLUKA package used for low energy interactions. The direct ionization by primary cosmic rays is explicitly taken into account. The model is applicable to the entire atmosphere, from the ground up to the stratosphere. A comparison to fragmentary direct measurements of the ionization in the atmosphere confirms the validity of the model in the whole range of geographical latitudes and altitudes. We provide a detailed tabulated ionization yield function, which, together with a detailed recipe, allows one to compute easily the cosmic ray induced

ionization for given location, altitude and the spectrum of cosmic rays. This provides a new tool for a quantitative study of the space weather influence upon the Earth's environment.

3. GALACTIC COSMIC RAYS

The ionization due to galactic cosmic rays is always present in the atmosphere. However, due to the solar modulation, it changes with the 11-year solar cycle. Using the model results and a reconstruction of the past solar modulation we calculate the temporal variability of the cosmic ray induced ionization for the last 50 years and, with lower resolution, for the last four centuries.

4. SOLAR COSMIC RAYS

Solar cosmic rays, i.e. energetic particles accelerated in the solar corona and interplanetary medium, appear during sporadic solar energetic particle events associated with solar flares and/or coronal mass ejections. During such events, the flux of charged particles of lower energy may increase by orders of magnitude. There are some studies showing a statistical relation between such events and atmospheric properties, although a quantitative modeling of such a relation was still missing. Here we present quantitative results to compute the possible effect of solar cosmic rays in the ionization of the troposphere-stratosphere for several solar energetic particle events, ranging from severe to moderate. It is shown that a severe event may indeed enhance the cosmic ray induced ionization in middle and high latitudes down to the troposphere, but moderate events produce no additional ionization in the troposphere, even in polar regions. The global effect of moderate-to-strong solar energetic particle events in the ionization is tiny.

5. CONSCLUSIONS

The atmospheric ionization due to cosmic rays is quantitatively studied. It is shown that the effect of solar proton events is significant only for high-latitude regions and can be neglected in middle and low latitudes. Cosmic ray induced ionization due to galactic cosmic rays is the main factor of ionization and it varies with the 11-year solar activity cycle. In addition, the long-term trend in the ionization is evaluated in the past.

REFERENCES

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