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Interactive Comment

Interactive comment on "Atmospheric changes caused by galactic cosmic rays over the period 1960–2010" *by* C. H. Jackman et al.

Anonymous Referee #1

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The paper studies, in the framework of the set of models involved, the effect of GCR variability on the Earth's atmosphere. The topic is important, and the authors make a strong effort in assessing the effect. The paper would be worth publishing in ACP, but this reviewer has some specific comments on the models used.

The authors use the NAIRAS model for GCR modulation, based on the Badhwar-O'Neill approach, which computes the GCR spectrum on the top of the atmosphere. This spectrum is further applied for computations of the ion-production rate (IPR) in the atmosphere, using the NZETRN code, which is based on a solution of Boltzman equations to simulate transport of the nucleonic component of the cosmic-ray induced atmosoheric cascade in the atmosphere. It is noteworthy that the NZETRN code was primarily designed for computations of the radiation dose, which is mostly defined by

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the nucleonic component of the cascade, reasonably described by the Botlzman equation approach. However, this approach neglects muon and electromagnetic branches of the cosmic ray induced cascade, which contribute essentially to ionization, especially in the lower atmosphere: for example, the electromanetic component dominates atmospheric ionization in the range between 10 and 25 km (see Fig. 11 of Bazilevskaya et al., SSR, 2008; Mishev & Velinov, JASTP, 2010, Fig. 2). This shortcoming is well realised at NASA (see, e.g., Heinbockel et al., NASA/TP-2009-215560 report, 2009): "It should also be emphasized that HZETRN does not transport certain particles such as pions, muons, positrons, electrons, and photons. These particles are used in calculating dose and dose equivalent by HETC-HEDS and FLUKA, but not HZETRN. The contribution of these particles to dose and dose equivalent values can be significant." Accordingly, this approach may lead to significant distortion of the ionization pattern as discussed below. A modern way to calculate GCR-related ionization is based on a full Monte-Carlo simulation of the atmospheric cascade (e.g., PLANETOCOSMICS, Desorgher et al., 2005; CRAC:CRII, Usoskin et al., 2006; or similar models – Atri et al., 2010; Mishev and Velinov, 2014).

The authors are requested either to use an appropriate model or to explain specific questions raised below about the validity of the used model:

1) As one can see in Fig.1, the ionization maximum is modeled to occur at the height of ∼5 km at the equator and ∼10 km in polar regions. This is unrealistically low. The ionization maximum (related to the Pfotzer maximum) is typically at 10 (equator) to 15-18 (polar) km heights, according to both measurements and models, see, e.g., Fig.2. of Bazilevskaya et al. (2008) or Fig.2 in Calogovic et al. (2010), or Fig.4 of Mishev and Velinov (2014). Interestingly, the results shown by Mertenes et al. (2013, Fig. 12) for the dose rate computed by NAIRAS/HZETRN are reasonable, suggesting that it is only IPR, which is not correct, probably because of neglecting muon and electromagnetic components.

2) Another concern is about the North-South asymmetry. Figure 2 shows ionization at

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South and North poles. One can see that ionization at the S-pole is 15 % higher (at least at the height of 10 km) than at the N-pole. The same feature of N-S-asymmetry is observed also in Fig.1. This feature is not intuitively expected and is not shown by other models (e.g., Planetocosmics – see Calogovic et al., 2010). Moreover, dose rate profiles shown by Mertens et al. (2013) are perfectly symmetric as expected. Can the authors explain why GCR-related ionization is systematically higher in the S-hemisphere than in the N-hemisphere? Is it related to systematically different density profiles of the atmosphere?

3) As one can see in Fig.8d, the maximum of ionization during the year 1976-77 was the highest for the entire interval (equal to that of 2009). This disagrees with observations of GCR intensities, where the 1976-77 maximum was the lowest (or equal to those in 1987 and 1997, but significantly lower than 1965 and 2009). To illustrate it, Figure A (of this report) shows the variability of the count rates of the four NMs used as an input for NAIRAS model (Mertens et al., 2013). It is unclear how the profile, shown in Fig.8d, can be obtained from this input. The authors need to explain this.

4) The authors state (page 33935, lines 12-16) that the approach was verified against data by Neher (1967) and the PLANETOCOSMICS model (Calogovic et al. (2010) and Gronoff et al. (2015)), but this statement is confusing. First, this reviewer cannot understand how the present result was compared with the data of direct measurements by Neher (1967), since the latter depict the maximum ionization at the height of 10/15 km for equator/poles, which disagrees with Fig.1 of this work. It is unclear how the present model can be in agreement with Calogovic et al. (2010) since the present Fig.1 disagrees with Fig. 2 of Calogovic et al., which shows the maximum of ionization at ∼15 km and ∼10 km in polar regions and equator, respectively (see item 1 above). Comparison with Gronoff et al. cannot be applied here since that paper deals with the thin Martian atmosphere where the atmospheric cascade is not fully developed and the difference between NZETRN and appropriate models is unimportant.

Accordingly, the validity of the GCR-induced cascade modelling in the

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NAIRAS/NZETRN model is not verified against full Montre-Carlo models and rises several questions. Unless the authors can prove that the computations of ionization are correct, the result cannot be trusted.

Other minor comments:

1) A brief summary is needed in the end of the abstract – are these changes important or not?

2) page 33935, line 6: Please give some detail how the cutoff rigidity was calculated from the IGRF model and please add a reference to IGRF.

2) page, line 3: "primarily protons" is not exactly correct. While protons form 90% in the particle number, heavier species constitute ∼30% in the nucleon number and may contribute up to 50% in the ionization rate.

Interactive comment on Atmos. Chem. Phys. Discuss., 15, 33931, 2015.

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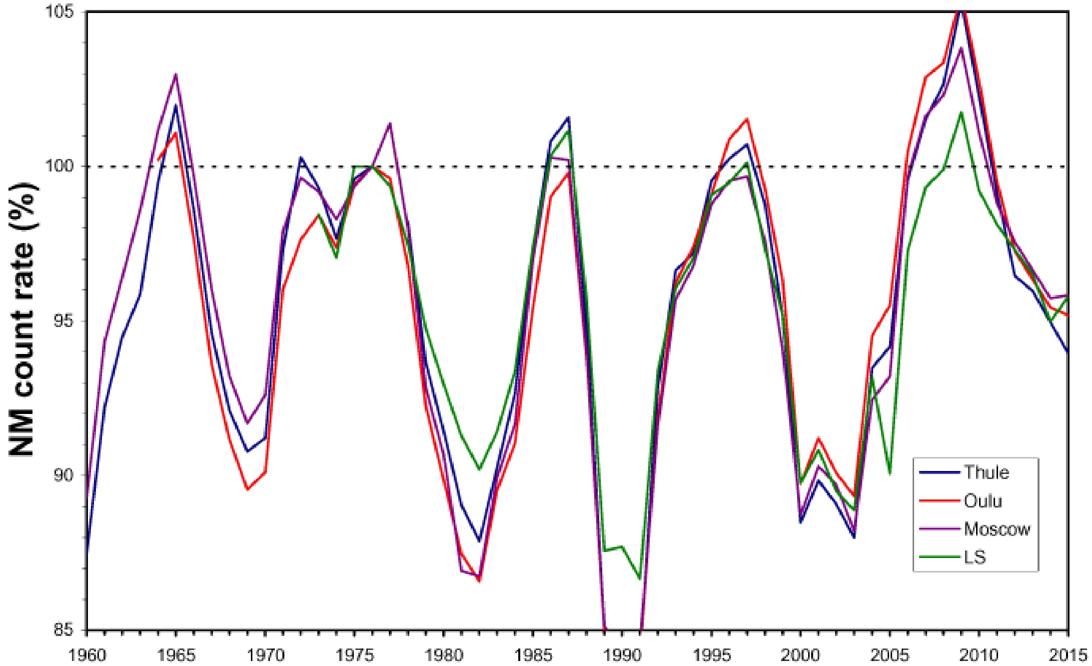

Fig. 1. Figure A. Variability of count rates of neutron monitors used in NAIRAS program, normalized to 100% for 1976.