Energetic Particle Precipitation Indirect Effect During the Arctic Winter 2012/2013: WACCM-SD vs. Odin/SMR

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1. Background: Energetic Particle Precipitation Indirect Effect:

EPP refers to the process by which energetic protons and electrons affect the Earth’s atmosphere. It is an important source of ionization in the mesosphere and lower thermosphere (MLT), linked to solar activity. It leads to the formation of nitric oxide (NO) in the polar regions. In winter conditions, EPP-generated NO can be transported downward into the lower mesosphere and the stratosphere by the meridional circulation, where it can affect the ozone (O3) balance. The EPP indirect effect is an important solar-terrestrial coupling mechanism.

This is observed every winter, but exceptional dynamical conditions, such as the occurrence of a major stratospheric sudden warming (SSW), can lead to particularly strong EPP IE. In early January 2013 for example, wave activity 2) a) in the Northern Hemisphere led to the reversal of the mean zonal wind in the stratosphere (Fig. 1). This complete disruption of the polar vortex was associated with strong perturbations in the temperature structure (stratospheric warming and mesospheric cooling, as seen in Fig. 2 a, b). This event was followed by the reformation of the stratopause at mesospheric altitudes, associated with an efficient downward motion of air (Fig. 2 c, d), which led to the transport of NO formed by EPP in the MLT down to the stratosphere (Fig. 2 e, f).

2. Whole Atmosphere Community Climate Model (WACCM)

WACCM is a comprehensive 3D chemistry climate model developed at NCAR (National Center for Atmospheric Research, USA). It includes stratospheric chemistry, gravity wave parametrisation, and basic processes in the mesosphere and lower thermosphere.

For this project, it has been used in its Specified Dynamics version (WACCM-SD), which means that it has been nudged with NASA MERRA reanalysis (wind and temperature) up to 3 hPa. It is free running above this level. The output interval of the simulation used is 3 hours.

3. Odin / SMR

Odin is a Swedish-led research satellite, in cooperation with Canada, France and Finland, launched in 2001. It was initially dedicated to aeronomy and astronomy, but is entirely dedicated to aeronomy since 2007. It is part of the ESA third party mission programme 3).

The Sub-Millimetre Radiometer (SMR) is one of the main instruments aboard Odin. It is a limb emission sounder measuring globally a variety of trace gases, as well as temperature in the whole middle atmosphere. This work is based on water vapour (H2O) and temperature retrieved from a strong line at 557 GHz, as well as nitrous oxide (N2O) measured at 501.8 GHz and NO at 551.7 GHz.

4. Results

Energetic particle precipitation indirect effect in WACCM:

- NO formation in the middle atmosphere is forced with observed solar flux variations, daily mean proton fluxes and electron precipitation in the auroral region (upper mesosphere and lower thermosphere) driven by daily Kp index.
- The ionization by medium energy and relativistic electrons, which can result in local NO production in the lower mesosphere and upper stratosphere, is not taken into account.
- The NO is transported downward both by diffusion (molecular and turbulent) and by the residual circulation.

Comparison WACCM / SMR:

- Temperature (Fig. 2 a, b): Stratopause in WACCM slightly higher than the stratopause observed by SMR. WACCM temperature higher than SMR temperature: not a deficiency of the model, SMR mesospheric temperature is known to have a low bias compared to other instruments 4).
- WACCM does not reproduce the elevated stratopause as high as was observed.
- Water vapour (Fig. 2 c, d): H2O good tracer for the dynamical processes in the middle atmosphere. Brief increase of VMR values during the SWW: upward motion of H2O-rich air and mixing of mid-latitude air into the polar regions. Descent of mesospheric air following the SWW event: recovery of a strong upper stratospheric vortex. The descent event reproduced by WACCM is not strong enough.
- Nitric oxide (Fig. 2 e, f): The amount of NO transported down to the lower mesosphere and to the stratosphere is too low in the model, despite the fact that the amount of NO produced by EPP in the MLT seems to be correct (Fig. 3a). A second experiment has been done with a higher Kz coefficient (Fig. 3b). The comparison is slightly better, because turbulent diffusion is the conduct by which thermospheric NO can be transported through the mesopause so it can be transported downward by the mean meridional circulation. But Fig. 3b shows that there is still an important deficit of NO in WACCM following the SWW event.

5. Summary & Discussion

WACCM-SD fail to reproduce the unusually strong NO descent observed by Odin/SMR following the SWW event in early 2013. It has been shown also in the framework of the HEPPA (High Energy Particle Precipitation in the Atmosphere) working group that this is a common deficiency of high-top models. In order to get a better understanding of the EPP impact on the atmosphere, the models should be improved to be able to reproduce correctly the changes in stratospheric composition associated with the EPP IE. The thing follows should be investigated:
- The impact of medium energy electrons, which can result in local NO production at mesospheric altitudes.
- The representation of the dynamics (mainly role of planetary wave versus gravity wave forcing of mesospheric descent).

References