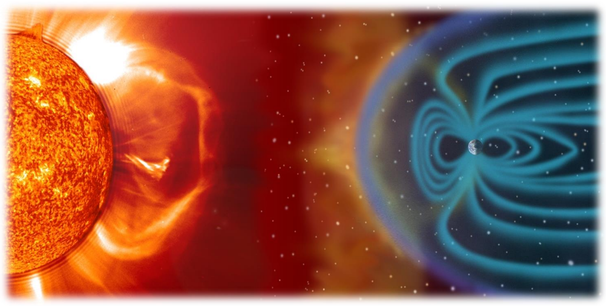

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Energetic Particle Precipitation Indirect Effect During the Arctic Winter 2012/2013: WACCM-SD vs. Odin/SMR

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Abstract

Measurements by the Odin/SMR limb emission sounder show that the middle atmosphere has been affected by a particularly **strong midwinter stratospheric sudden warming** (SSW) during the Arctic winter 2012/2013. This event led to a breakdown of the polar vortex, and was followed by the reformation of a strong upper stratospheric vortex, associated with very efficient descent of air. Unusually large amounts of nitric oxide (NO) produced by **energetic particle precipitation** (EPP) could thus enter the polar stratosphere and lower mesosphere [1]. This mechanism is generally called the **EPP indirect effect** (EPP IE).

Its large variability, related to dynamical modulations, makes the representation of this mechanism in atmospheric models particularly challenging. Here we are investigating the deficiencies of the model WACCM. Our study is based on the comparison of its representation of the 2012/2013 event with Odin/SMR observations.

Keywords

- ✓ Energetic Particle Precipitation
- ✓ Polar middle atmosphere
- ✓ Stratospheric Sudden Warming
- ✓ EPP indirect effect
- ✓ Solar-terrestrial coupling
- ✓ Nitric oxide (NO)

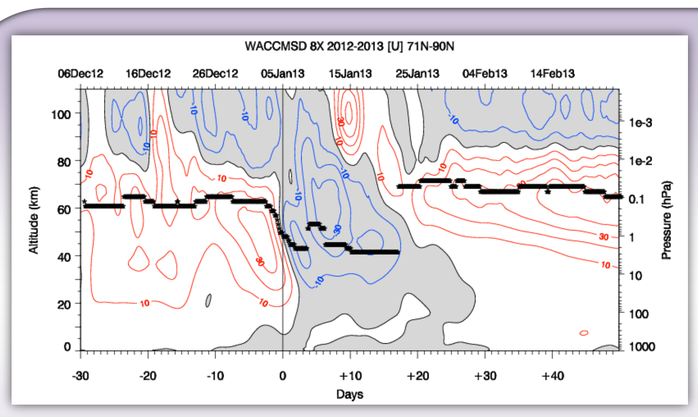


Fig. 1 WACCM mean zonal wind during the Arctic winter 2012/2013. Time expressed in number of days relative to January 5, 2013 (SSW central date). Red: positive values, blue: negative values. Thick black line: location of the stratopause.

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 could affect the ozone (O_3) balance. The EPP indirect effect is an important **solar-terrestrial coupling mechanism**.

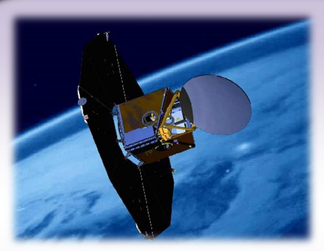
This is observed every winter, but exceptional dynamical conditions, such as the occurrence of a major **stratospheric sudden warming** (SSW), can lead to **particularly strong EPP IE**. In early January 2013 for example, wave activity [2] in the Northern Hemisphere led to the reversal of the mean zonal wind in the stratosphere (Fig. 1). This complete disruption of the polar vortex was associated with strong **perturbations of 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 1 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 (H_2O) and temperature retrieved from a strong line at 557 GHz, as well as nitrous oxide (N_2O) 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.

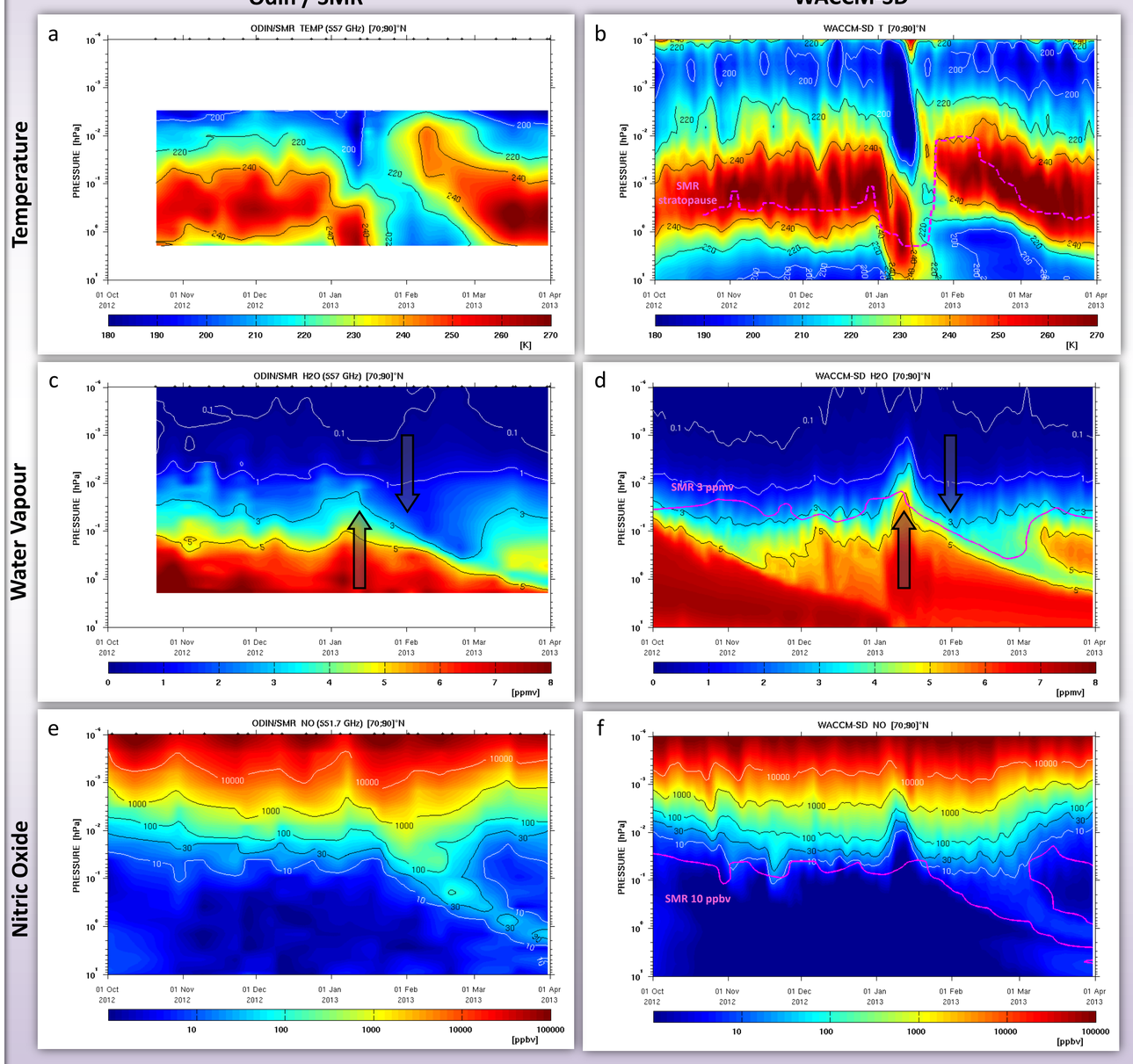


Fig. 2 Pressure-time section of Odin/SMR (*left*) and WACCM-SD (*right*) zonal mean temperature (*a, b*), water vapour volume mixing ratios (*c, d*) and nitric oxide volume mixing ratios (*e, f*) in the 70-90° latitude band, during the Arctic winter 2012/2013.

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]. However, **WACCM does not reproduce the elevated stratopause as high as what was observed**.

- Water vapour (Fig. 2: c, d):

H_2O: good tracer for the dynamical processes in the middle atmosphere. Brief increase of VMR values during the SSW: upward motion of H_2O-rich air and mixing of mid-latitude air into the polar regions. Descent of mesospheric dry air following the SSW 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 Kzz coefficient (Fig. 3b). The comparison is slightly better, because turbulent diffusion is the conduit by which thermospheric NO can be transported through the mesopause so that 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 SSW event.

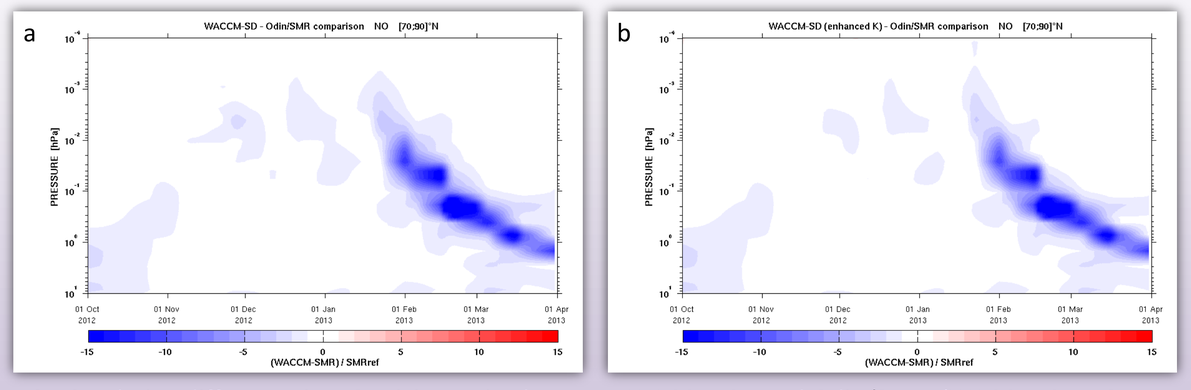


Fig. 3 Relative difference in NO mixing ratios between WACCM-SD and Odin/SMR: (WACCM-SD NO vmr – SMR NO vmr) / SMRref (with SMRref: average NO profile corresponding to SMR observations in October and November 2012). Only WACCM points in collocation with SMR measurements (time, latitude, longitude) have been considered for the comparison. *a*: standard version of WACCM. *b*: experiment with enhanced turbulent diffusion (Kzz coefficient).

References

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5. Summary & Discussion

WACCM-SD fail to reproduce the unusually strong NO descent observed by Odin/SMR following the SSW 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 following things 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).

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