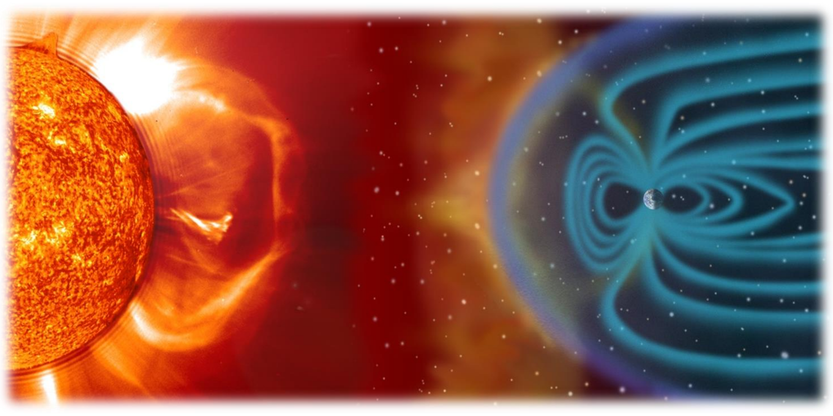

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Unusually strong NO descent in the Arctic middle atmosphere in early 2013 as observed by Odin/SMR

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Abstract

Measurements by the Odin/SMR limb emission sounder show that the middle atmosphere has been affected by an **exceptionally 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 powerful upper stratospheric vortex, associated with very efficient descent of air. Unprecedently large amounts of nitric oxide (NO) produced by **energetic particle precipitation** (EPP) could thus enter the polar stratosphere and lower mesosphere, where it could affect the ozone (O_3) balance. This outstanding situation is the result of the combination between a high geomagnetic activity and an unusually high dynamical activity. The results presented on this poster can contribute to a better understanding of the **EPP indirect effect**, which is an important solar-terrestrial coupling mechanism.

Keywords

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

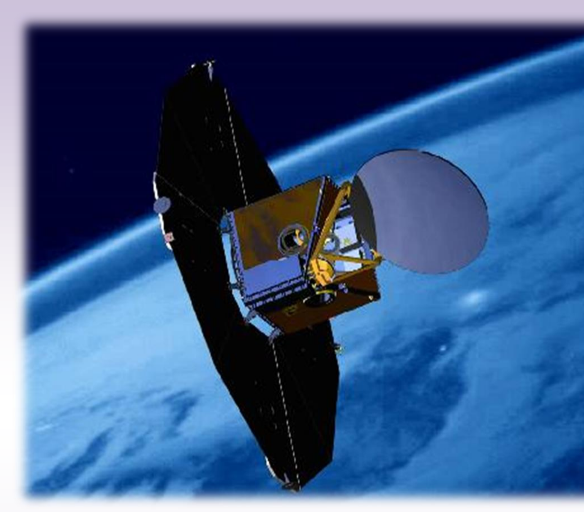
1. Background: Energetic Particle Precipitation (EPP)

EPP refers to the process by which energetic particles affect the Earth's atmosphere. Magnetospheric electrons can reach the **mesosphere and lower thermosphere** (MLT) during geomagnetic perturbations and generate large amounts of **nitric oxide** (NO) in the **polar regions**. In winter conditions, EPP-NO can be transported down to the stratosphere by the meridional circulation. This mechanism is called **EPP indirect effect** (EPP IE) [1].

EPP-IE is controlled by space weather and meteorology. It depends on:
- EPP-NO production, as inferred from the Ap index, which is linked to solar variability,
- Dynamical activity (transport).

EPP represents therefore an important **solar-terrestrial coupling mechanism**.
Exceptional dynamical conditions, such as the occurrence of a major **stratospheric sudden warming** (SSW) in the middle of the winter, can lead to surprisingly strong EPP IE.

2. Odin / SMR



Odin is a small **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.

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.

3. Results

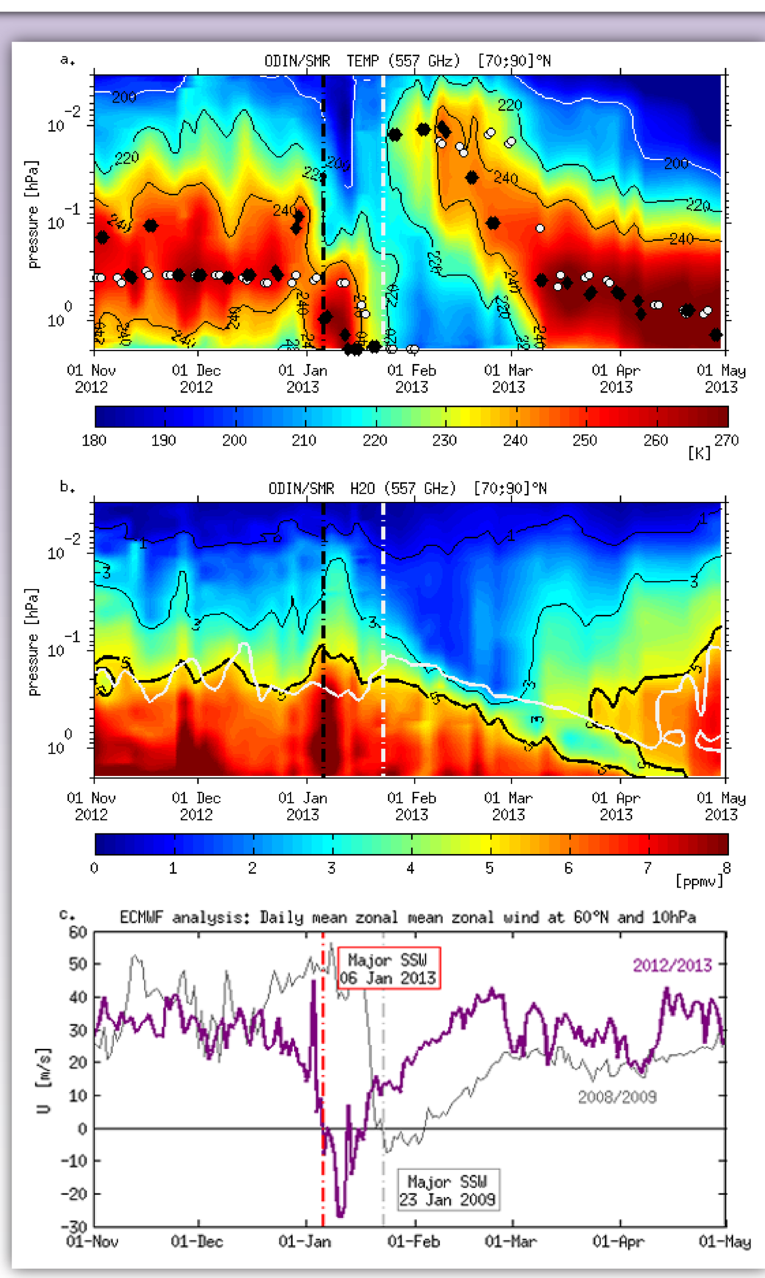


Fig. 1 a. Upper stratosphere / mesosphere pressure-time section of SMR zonal mean temperature in the 70-90° latitude band during the Arctic winter 2012/2013. Black diamonds: altitude of the stratopause. Black dashed line: central date of the warming. Overlaid white circles and white dashed line: same parameters for the 2009 event (for comparison).
b. Same as (a) but for SMR zonal mean H_2O volume mixing ratio (vmr). Thick black contour: vmr = 5 ppmv. Solid white line: vmr = 5 ppmv in 2008/2009 (for comparison).
c. Daily mean zonal mean zonal wind at 60°N and 10 hPa from ECMWF analyses in 2008/2009 (grey) and 2012/2013 (purple). Dashed lines: central dates of the SSWs.

What do the measurements performed during the **Arctic winter 2012/2013** show?

- A warming event occurred in early January 2013 (Fig. 1 a.), associated with a brief increase in water vapour (Fig. 1 b.), which is a feature of an upward motion.
- The criteria for a **major midwinter SSW** have been fulfilled on **January 6, 2013**, which is considered as the central date of the warming (according to the WMO definition: 10 hPa zonal mean winds (Fig. 1 c.) and temperature (not shown) gradient reversal poleward of 60°N).
- The **vortex** was **split** into two smaller vortices (Fig. 2)
- A distinct **elevated polar stratopause** formed around 80 km in the following weeks (Fig. 1 a.). The recovery period is associated with a **particularly strong descent of mesospheric dry air** (Fig. 1 b.).

➢ **Unusually high dynamical activity:**
The SSW event that has affected the middle atmosphere in early 2013 appears to disrupt the dynamical structure even more strongly than the one that occurred in January 2009 (Fig. 1 b), which was yet considered as a record-breaking event [2].

- **Average Ap index** (a measure of geomagnetic activity over the globe) [3]:
  - from Oct. 1, 2008 to Mar. 1, 2009 = 4.8
  - from Oct. 1, 2012 to Mar. 1, 2013 = 6.6

➢ **Relatively high geomagnetic activity:**
Energetic electrons trapped in the magnetosphere can thus precipitate in the polar MLT. It increases ionisation, which leads to a **high NO production level**.

- A **tongue of increased NO volume mixing ratios** is clearly visible both in 2009 and 2013: EPP-generated NO reached the stratosphere during the months following the warming events (Fig. 3).
- The onset of the enhancements coincides exactly with the formation of the elevated stratopause (Fig. 4).

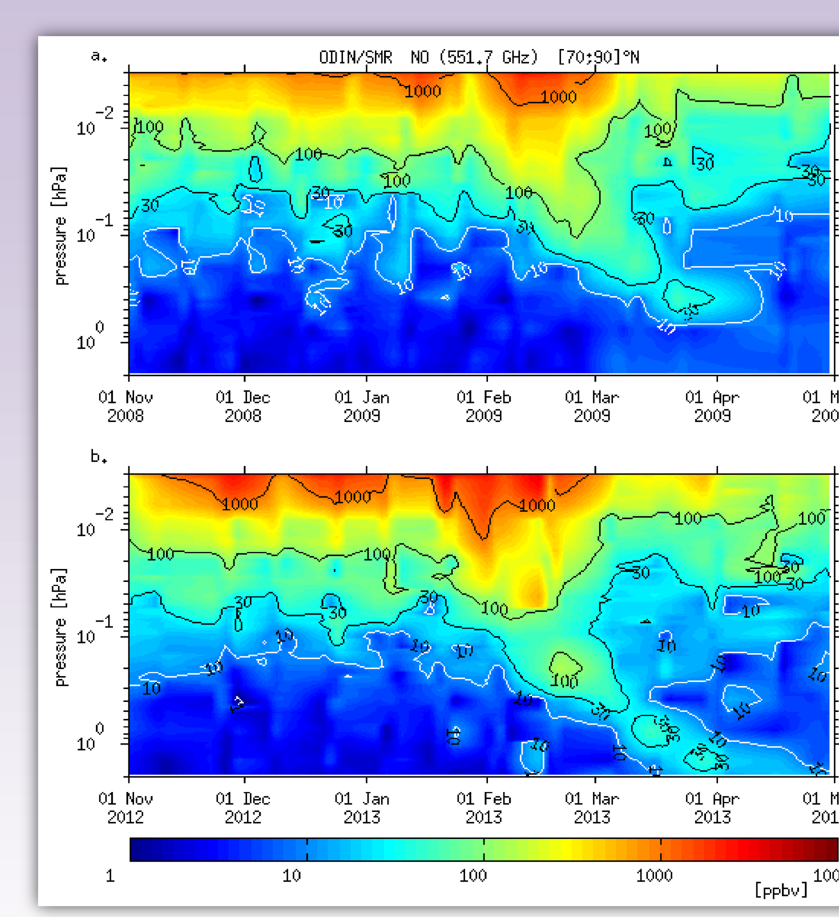


Fig. 3 Upper stratosphere / mesosphere pressure-time sections of SMR zonal mean NO vmr in the NH high latitudes (poleward of 70°N) for the Arctic winter seasons 2008/2009 (a) and 2012/2013 (b).

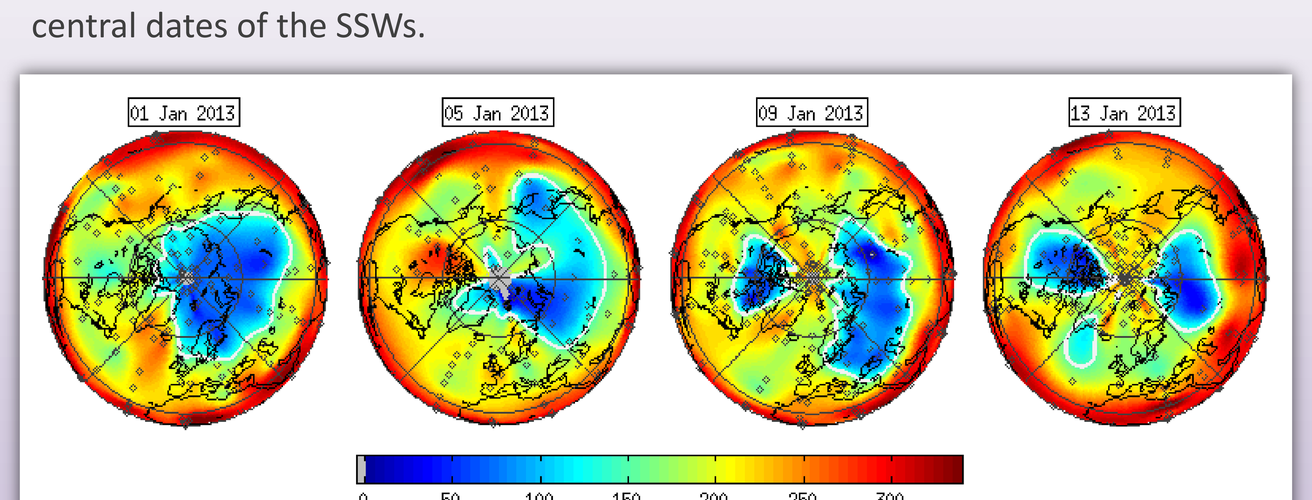


Fig. 2 Polar maps of N_2O vmr measured by SMR in the stratosphere on four selected observation days during the warming event. White overlays: 150 ppbv contours (help to visualise the vortex edge). Grey diamonds: positions of the measurements.

Comparison of the Arctic winter seasons 2008/2009 and 2012/2013, both characterized by two of the strongest major SSW events on record (see [4] for the case of 2009):

- The **2013 SSW** event led to significantly larger NO enhancements than the 2009 SSW event (**up to 20 times more NO in the stratosphere than the normal background**. In 2009, this ratio did not exceed 8) (Fig. 4).
- The tongue of EPP-NO in 2013 extends **much lower in altitude** (~30 km) than in 2009 (~50 km) (Fig. 4).

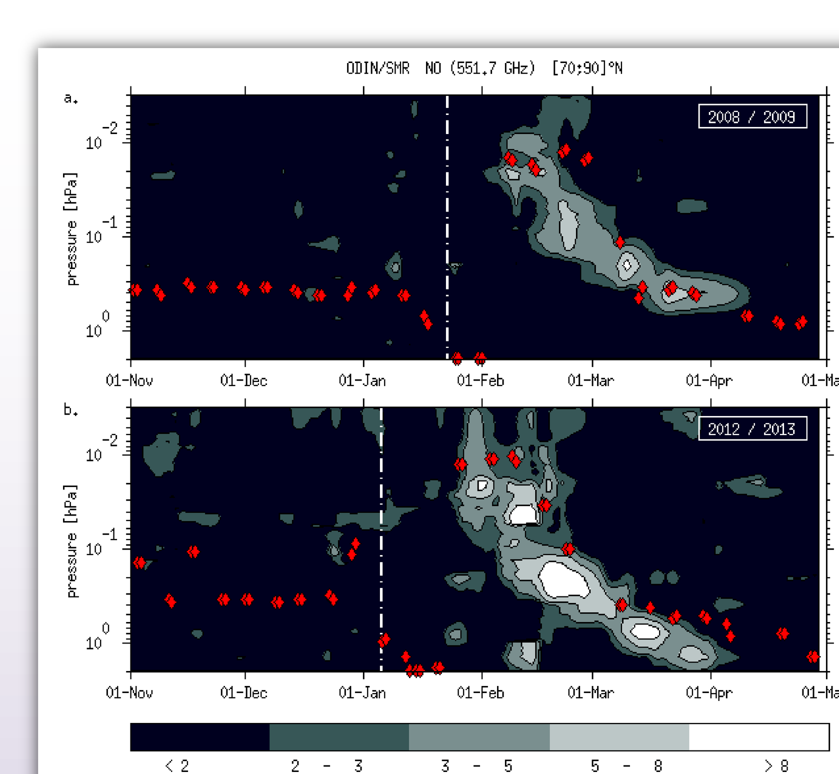


Fig. 4 Relative NO enhancements: NO ratio in 2008/2009 and 2012/2013 to the average NO observed in 2007/2008, 2009/2010 and 2010/2011 (Arctic winters characterized by standard dynamical conditions: no particular mixing between mesospheric and stratospheric air). White dashed lines: SSW central dates. Red diamonds: altitude of the stratopause as measured by SMR.

References

[1] Funke et al. (2005): JGR 110, D24308
[2] Manney et al. (2009): GRL 36, L12815
[3] ftp://ftp.ngdc.noaa.gov/STP/GEOMAGNETIC_DATA/INDICES/KP_AP
[4] Randall et al. (2009): GRL 36, L18811
[5] Seppälä et al. (2009): JGR 114, A10
[6] Semeniuk et al. (2011): ACP 11, 5045-5077

4. Summary & Discussion

The Arctic winter 2012/2013 was characterized by an unprecedented strong EPP indirect effect: very large amounts of NO could enter the polar upper stratosphere. This event has therefore a high potential to influence the middle atmospheric composition. That makes it a very interesting case to study the impact of EPP on climate, through stratospheric chemical and dynamical processes, which is still barely understood. This influence is likely to extend beyond the polar middle atmosphere. Recent publications showed that EPP could also affect the variability in the polar troposphere and tropical stratosphere ([5], [6]).

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