Energetic Particle Precipitation

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(SSW) during the Arctic winter 2012/2013. This event led to a breakdown of the polar vortex, and was followed by the reformulation of a powerful upper stratospheric vortex, associated with very efficient descent of air. Unprecedented 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 (O₃) 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.

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 reformulation of a powerful upper stratospheric vortex, associated with very efficient descent of air. Unprecedented 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 (O₃) 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 downward through 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 astrophysics, 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 (H₂O) and temperature retrieved from a strong line at 557 GHz, as well as nitrous oxide (N₂O) measured at 503.8 GHz and NO at 551.7 GHz.

3. Results

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 stratosphere 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

Relatively high geomagnetic activity:
Energetic electrons trapped in the magnetosphere can thus precipitate in the polar MCT. 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 stratosphere (Fig. 4).

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).

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].

References
[1] Forse et al. (2005): JGR 110, D24S08

Fig. 1 a. Upper stratosphere / mesosphere pressure-time section of SSMR 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 SMMR zonal mean H₂O volume mixing ratio [ppmv]. Thick black contour: 50 ppmv. Solid white line: 0 ppmv. 50 ppmv in 2008/2009 for comparison.

c. Daily mean zonal mean zonal wind (in °W) and 10 hPa from ECMWF analyses in 2008/2009 (grey) and 2012/2013 (purple). Dashed lines: central dates of the SSWs.

Fig. 2 Upper stratosphere / mesosphere pressure-time section of SSMR zonal mean NO volume mixing of NO vrr measured by SMR in the stratosphere on four selected observation days during the warming event. White overlaps: 150 ppmv counts of nitric oxide (the white edge). Grey diamonds: particle images of measurements.

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

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: SSMR central dates. Red and blue diameters: altitude of the stratosphere as measured by SMR.