Hemispheric distributions and inter-annual variability of NOy produced by Energetic Particle Precipitation in 2002-2012

B. Funke[1], M. López-Puertas[1], G.P. Stiller[2], T. von Clarmann[2], L. Holt[3], and C. Randall[3]

[1] Instituto de Astrofísica de Andalucía (CSIC), Granada, Spain, email: bernd@iaa.es, [2]Karlsruhe Institute of Technology (KIT), Institute for Meteorology and Climate Research, Germany, [3]University of Colorado, Boulder, CO, USA

The MIPAS Fourier transform spectrometer on board Envisat has measured limb emission spectra in the mid-IR for a 10-year period (2002-2012) which have been used to retrieve vertical profiles of the six principal reactive nitrogen (NOy) compounds (HNO_3, NO_2, NO, N_2O_5, $ClONO_2$, and HNO_4) with global coverage and independent of illumination conditions. From these data, the contribution of NOy produced by energetic particle precipitation (EPP) has been discriminated from the background NOy by using a tracer correlation method based on co-located MIPAS CH_4 and CO measurements. The obtained EPP-NOy distributions demonstrate a regular indirect EPP impact on the entire stratosphere (down to 22-25 km) by polar winter descent and show a clear solar cycle signal in consonance with the change in the geomagnetic activity. Furthermore, a pronounced hemispheric asymmetry is observed, with higher concentrations of EPP-NOy in the Southern Hemisphere (SH) and a larger variability in the Northern Hemisphere (NH). Here, possible drivers of the observed hemispheric asymmetry are discussed. We also show by multi-linear regression of the temporal evolution of EPP-NOy with the Ap index that 80-90% of the SH inter-annual variability (excluding direct contributions by Solar Proton Events) can be attributed to changes in the geomagnetic activity. This tight relationship holds throughout the winter season and at all vertical levels. In the NH, a similar well-correlated relationship is found until mid-winter. Afterwards, the Ap correlation breaks down above the 2 hPa level in years with elevated stratopause occurrence.

MIPAS NOy and tracer climatologies / Extraction of EPP-NOy

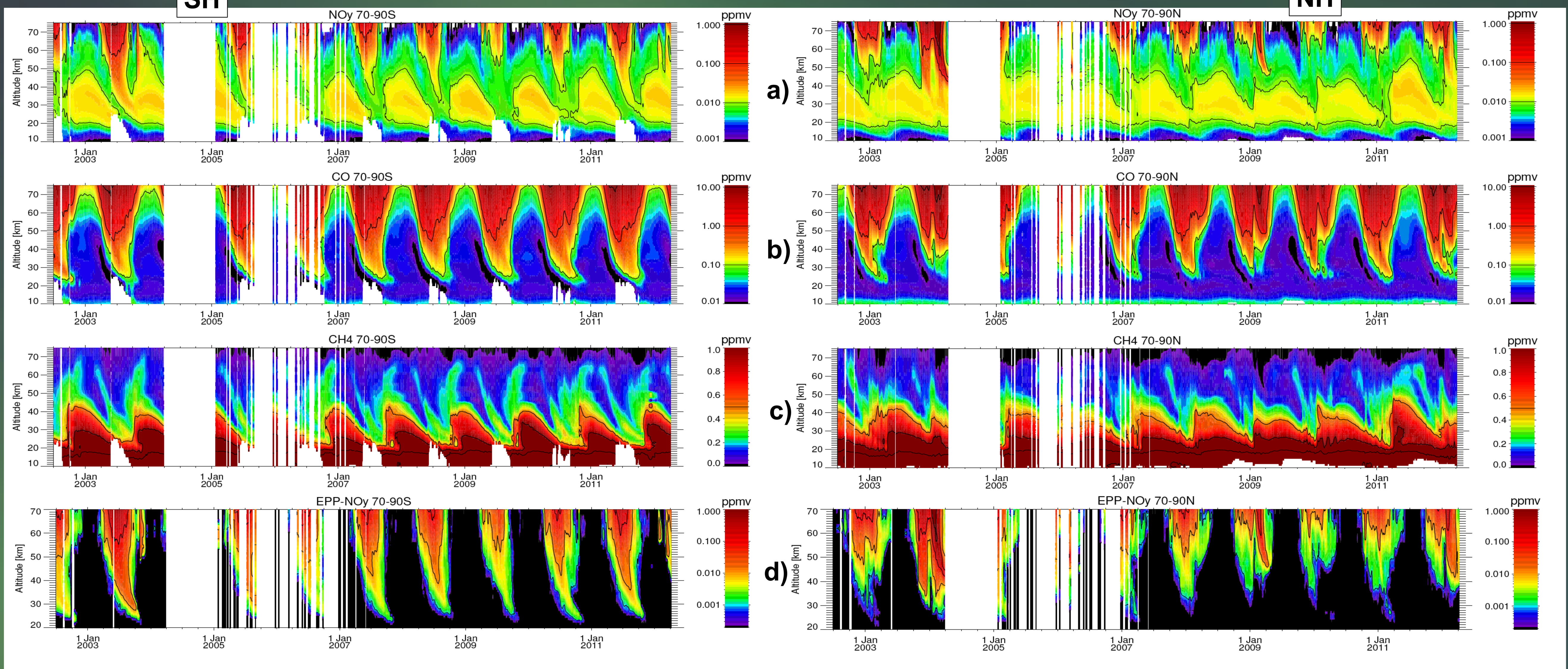
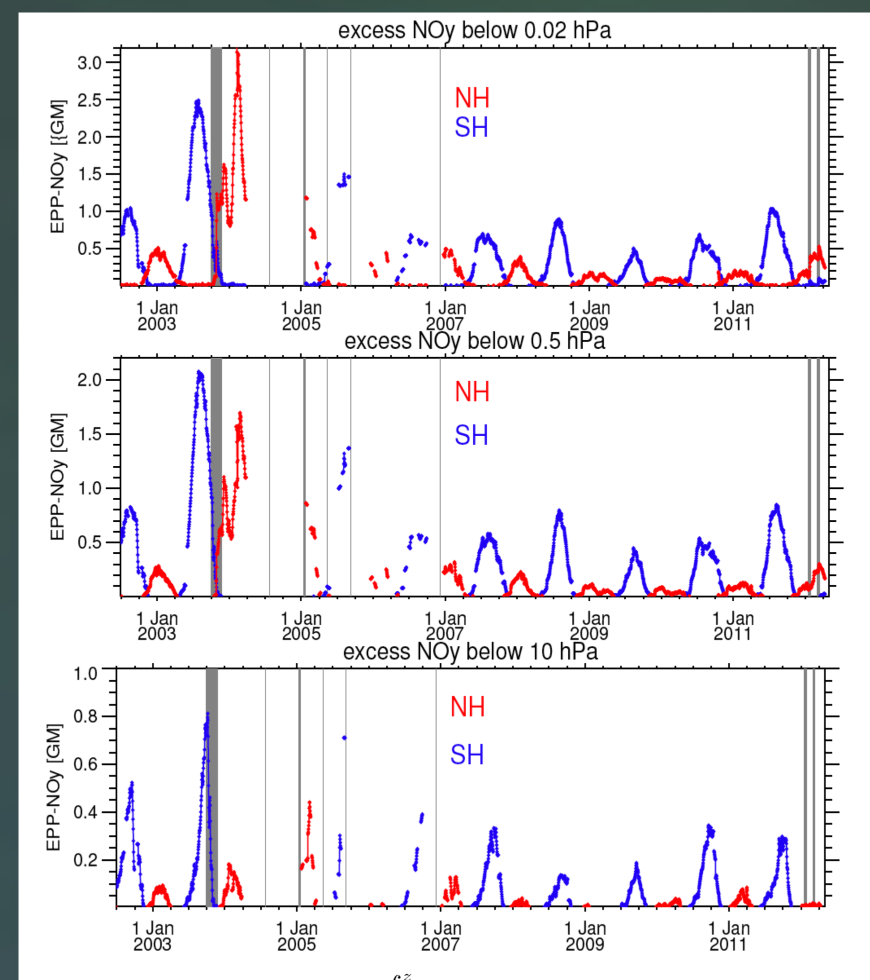


Fig. 1: Temporal evolution of MIPAS NOy, CO, and CH_4 vmrs (a-c) at 70-90° in the SH (left) and the NH (right) during 2002-2012. The bottom panels (d) show the EPP-NOy vmr extracted by means of the NOy-tracer correlation method based on the coincident CO and CH_4 observations as described in Funke et al. (2014).

- Regular indirect EPP impact (polar winter descent of EPP-NOy) in the entire stratosphere (down to 23-27 km) observed in both hemispheres.
- SPE impacts (direct EPP effects) visible during the 2003, 2005 and 2012 events.
- Higher EPP-NOy abundances in the SH stratosphere.
- More pronounced variability of EPP-NOy in the NH.
- Interannual variation shows a clear solar cycle signal in consonance with geomagnetic activity variations.

Hemispheric EPP-NOy amounts



$$N(z,t) = \sum_{\lambda} \int_{z_{tp}}^{z} [\text{EPP-NOy}](z,\lambda,t)\,dz\,A(\lambda)$$

Fig. 2: Temporal evolution of hemispheric (SH: blue, NH: red) EPP-NOy amounts below 0.02 hPa (70 km, top), 0.5 hPa (50 km, middle), and 10 hPa (30 km, bottom). Grey lines indicate major SPE events with >10MeV proton fluxes greater than 10^3 pfu as measured by the GOES-11 satellite. The thickness of the lines reflect the strength of the events.

- Seasonal max. EPP-NOy amounts up to 3 GM.
- SPE contributions up to 0.8 GM (in 2003).
- NH amounts typically 2-5 times smaller than in the SH (except ES events) with increasing differences towards lower altitudes.

Photochemical losses

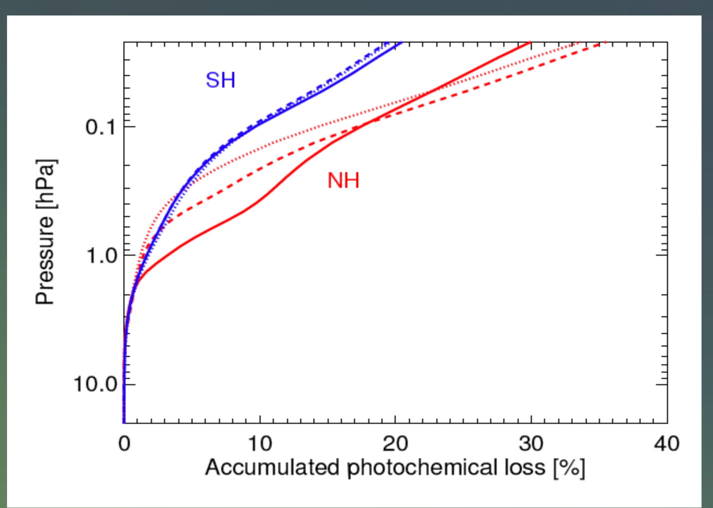


Fig. 3: 2002-2012 averages of the photochemically lost EPP-NOy relative to the amount of EPP-NOy deposited below the indicated pressure level in the NH (red) and SH (blue) winter seasons. Averages shown by solid lines include all available years whereas those shown by dashed lines exclude winters affected by SPE events. Dotted lines refer to averages excluding additionally winters with SSW events. Photochemical losses L(z,t) have been calculated with a photochemical box model under consideration of observed temperature and trace gas fields.

Hemispheric differences in photo-chemical losses explain only 25% of the encountered hemispheric asymmetry.

Vertical descent rates

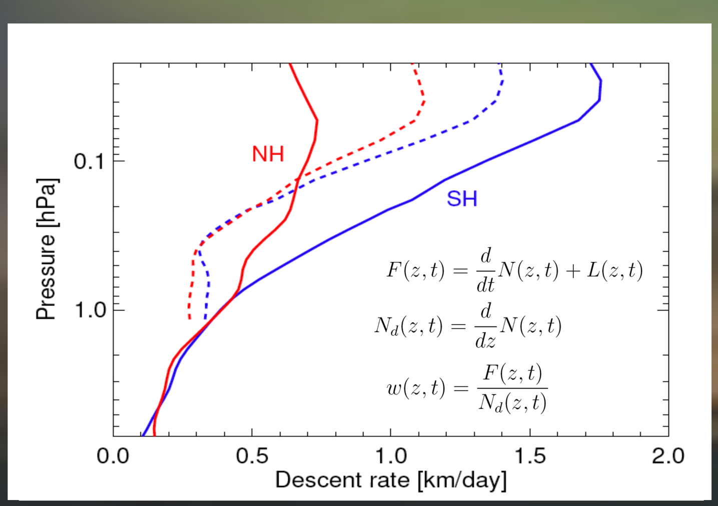


Fig. 4: Hemispherically averaged EPP-NOy descent rates for October – November (red dashed) and December - January (red solid) in the NH, and April - May (blue dashed) and June - July (blue solid) in the SH as observed during 2002-2012 (excluding SPEs and SSW/ES events). Descent rates have been derived from the ratio of EPP-NOy fluxes F(z,t) and differential amounts $N_d(z,t)$.

- Similar descent rates in early winter.
- Two times higher SH descent rates in mid-winter are the primary cause of the hemispheric asymmetry of EPP-NOy.

Multi-linear regression of hemispheric EPP-NOy to Ap

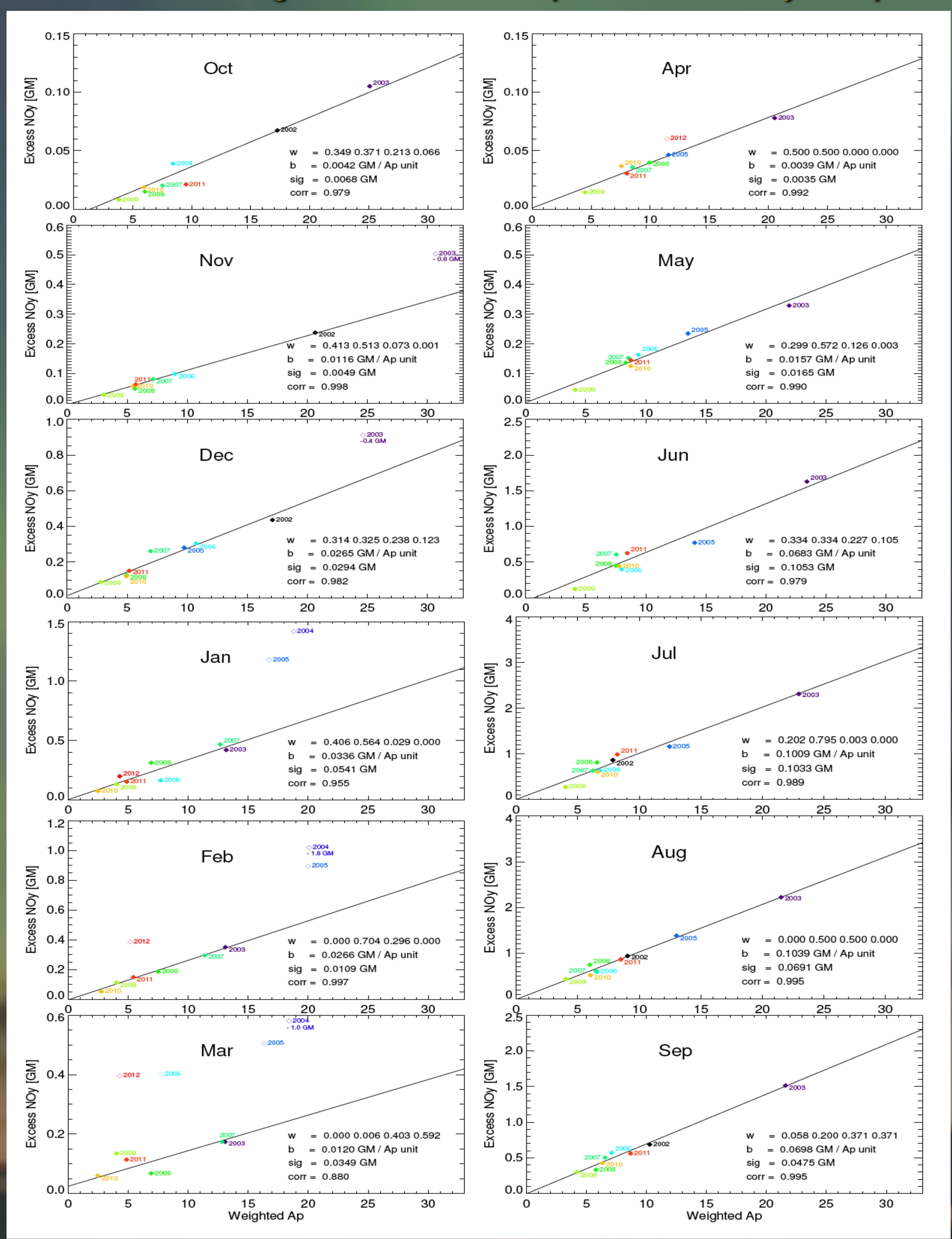


Fig. 5: Monthly averaged EPP-NOy amounts below 0.02 hPa (70 km) in the winters 2002-2012 as function of the weighted Ap index in October-March in the NH (left) and April-September in the SH (right). Note that for some years the symbols (open) are shifted along the y-axis by the indicated amount. A multi-linear regression fit to the EPP-NOy amounts (solid line) has been performed, considering only the months not affected by SPEs or ES events (shown by filled diamonds). The fitted Ap weights for the current and the preceding 3 months (w), the slope of the regression curve (b), the standard deviation (sig), and the correlation coefficient (corr) are also shown.

Vertical structure and Ap dependence

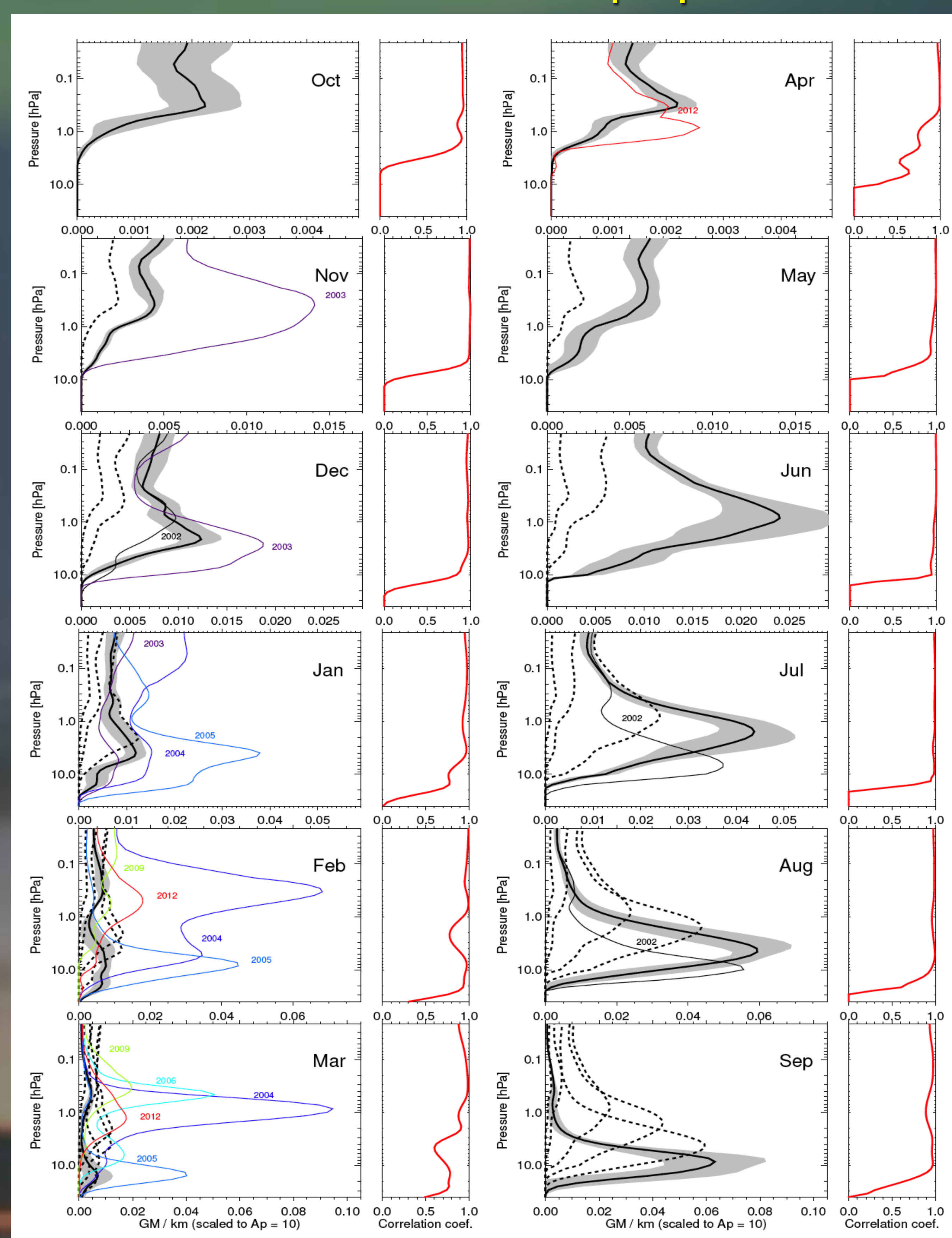


Fig. 6: Vertical distributions of hemispheric EPP-NOy differential amounts N_d in GM/km (solid black lines) for Ap = 10 (2002-2012 average geomagnetic activity) as predicted from multi-linear regression for the months October - March in the NH (left) and April - September in the SH (right) along with their estimated standard deviation (shaded area). The Ap-scaled distributions for some months affected either by SPEs and/or SSW/ES events (and which have been excluded from the regression) are shown by colored lines. Vertical distributions of the preceding months are indicated by dashed black lines. The right panels show the correlation coefficient of the Ap regression.

- Excluding SPEs, 80 - 90% of the interannual variability in the SH throughout the winter season at all vertical levels can be linked to geomagnetic activity on long- (solar cycle) and short-term scales.
- A similar well-correlated relationship is found in the NH until mid-winter. Afterwards, the Ap correlation breaks down above 2 hPa in years with ES occurrence. In the middle and lower stratosphere, the NH interannual variability for January - March is still ruled by geomagnetic activity variations.
- As an exception, the NH 2004/2005 winter showed characteristics more typical for the SH (due to unusually stable dynamical conditions with record low temperatures), resulting in much higher stratospheric EPP-NOy depostions than in other years with similar geomagnetic activity level.

Funke, B., M. López-Puertas, G. P. Stiller, and T. von Clarmann (2014), Mesospheric and stratospheric NOy produced by energetic particle precipitation during 2002–2012, *J. Geophys. Res. Atmos.*, *119*, doi:10.1002/2013JD021404.