SOLAR INDUCED PERTURBATIONS IN THE MIDDLE ATMOSPHERE: IS IT JUST A MATTER OF MAGNITUDE?

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CAL Coupling of Atmospheric Layers

Abstract As a first order approximation, the response of the middle atmosphere to perturbations that are likely to occur, is characterized by changes in the O_3 distribution. In fact, because of the peak in the O_3 heating profile at about 50 Km, strong variations in the O_3 concentration cause a corresponding change in the heating of the atmosphere. As a consequence, temperature and wind fields are changed. But what does "strong" mean? A large drop of ozone concentration in a very stable atmospheric region can have a weaker response than one in an unstable region. Thus, "strong" should be considered not on the base of the perturbation itself, but on the base of the response to that perturbation.

This study attempts to investigate the characteristics of perturbations that may affect the atmosphere, showing preliminary results of analyses of the response of a middle atmospheric model. In this poster, rather than constructing a complete set of test perturbations, we focus on a few case studies and will later test our hypothesis on more complete models (such as the ARPEGE - see DMI Peter Berg, poster X441 this session). Even though not directly involving solar variability, the different scales we study may as well be considered different scales of (indirect) solar induced perturbations.

1. OBSERVATIONS

In order to obtain observational evidence of the atmospheric response to perturbations, we have started an analysis of natural events exploiting the capabilities of the MIPAS instrument onboard the ENVISAT satellite.

Here we present the first results for the large Solar Proton Event (SPE) of October 2003, day 26 to 31. Daily zonal mean mixing ratios and temperature were obtained from level 1b MIPAS data. We used the GeoFit reduction package, based on a 2-dimensional geo-located multi-target retrieval, to increase the sensitivity to small variations (Carlotti et al. 2001, Dinelli et al. 2004).

Figure 1a shows the time sequence of the event for O_3, NO_2, HNO_3 VMRs and temperature field. The top panels are absolute values for day 26th (reference prior to the major event), panels below show variation from reference day. As expected (e.g. Jackman et al 2001), large changes are detected in O_3 and NO_2, and even in HNO_3. Unfortunately, we are not (yet?) able to isolate a clear signal of temperature changes to the SPE, signal that would be extremely useful for model comparison. Background temperature variability is, in fact, much larger than any signal we observe (compare temperatures in Fig. 1a and Fig1b, the latter showing no SPE conditions).

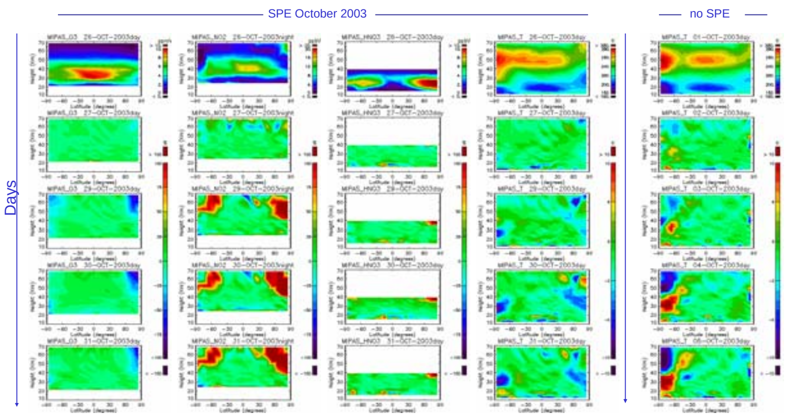

Figure 1a. MIPAS observations for the large SPE - October 2003. Left to right: the VMR for O_3, NO_2 and HNO_3, and the temperature are shown. Top to bottom: absolute values for day 26th (top panel – prior to major event) and changes for days 27th, 29th, 30th and 31st compared to the 26th.

Figure 1b. MIPAS temperature for 1st- 5th Oct 2003 (compare with Figure1a). Background T variability is much larger than possible T changes due to SPE.

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2. MODELING

Middle scale perturbations

As a first order approximation, the response of the middle atmosphere to perturbations that are likely to occur, is characterized by changes in the O_3 distribution. In fact, because of the peak in the O_3 heating profile at about 50 Km, variations in the O_3 concentration cause a corresponding change in the heating (and cooling) of the atmosphere. As a consequence, temperature and wind fields are changed somehow affecting the global circulation.

A series of idealized experiments have been developed on a mechanistic middle atmospheric model (see e.g. Arnold and Robinson 2003), to test the hypothesis that geo-location and time characteristics of a perturbation may increase its efficiency in altering equilibrium conditions as much as a higher magnitude. In previous experiments, we tested the influence of large scale phenomena such as changes in the solar input (e.g. changes in the solar surface temperature, changes due to the 11-year solar cycle). These large scale perturbations have been shown to have an impact on the middle atmosphere temperature of a few K (see e.g. Hoyt and Schatten 1997, Labitzke and van Loon 1993).

Here, we present results that show how impulsive O_3 perturbations can cause changes in temperature twice as large as a constant perturbation having the same overall magnitude, and same spatial geo-location. We focused on SPE like experiment (“middle scale” because they affect large parts of the atmosphere), dropping the ozone in the polar regions and studying the radiative-driven response in a model with no active-chemistry.

We have dropped the ozone by 10% constantly (Figure 2a) and by 90% every 9 days (Figure 2b). On average, the ozone has been dropped by the same amount in the two runs (figures show a 9-days average).
The difference in temperature between the -10% (Figure 2a) case and the control run shows patterns with peak temperature differences of about -1.5K.
The case of -90% every 9 days has much stronger deeps (about -5K), with pulsing drops of temperature that propagate also towards mid latitudes and are even visible in the equatorial regions. Moreover, in the latter case, there is a stronger coupling of the lower part of the atmosphere that seems to respond to the changes of ozone only after the upper zone has reacted by a certain magnitude. These details disappear taking a 9-days average (Figure 2b), showing only the longer term variations comparable with the constant perturbation (Figure 2a).
However, the response remains very different: the impulsive perturbation shows regions of about 1.5-2K cooler, both in the NH and in the SH. This test shows that the pulsed perturbation can be twice more efficient than the constant one. Similar experiments with different magnitude and time-dependence have been performed supporting these findings

For both experiments, winds are stronger than the control run, by as much as +3.5m/s in summer SH and summer NH for the constant perturbation and with peaks reaching +15m/sfor the impulsive perturbation. If we take a 9 days average of the latter, the increase reduces to +5m/s, thus about 1.5m/s more than in the constant ozone drop, about 40% increase. Figure 2c shows the difference in the zonal wind field for the two cases.

3. WORK in PROGRESS

These experiments show how smaller local perturbations may rise their impact on the atmosphere by repeated impulsive occurrence. The magnitude of a single event may be small as long as a series of event can build up a strong response of the atmosphere. What is important to underline is that if the atmosphere has not enough time to release back to equilibrium conditions, a second perturbation will build up on a previously altered system. This is what both the model experiment (section 2) and the observations (section 1) seem to show. A statistical analysis of these results will allow the definition of thresholds needed to have significance changes.

The parallel development of model experiments and the seek for observational signatures is the base for understanding whether repeated small scale perturbations of the middle atmosphere such small SPE or transient luminous events (TLEs) may have an impact on the atmosphere.

Particular attention will be addressed to perturbations to the NO_x and ozone distributions (phenomena like sprites may be a NO_x source in the upper atmosphere). In synergy with the CAL network, dedicated experiments and observations of VMRs will focus on events identified by the growing sprite-community.

Acknowledgments

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The modelling is developed at the University of Leicester, U.K.

The MIPAS data reduction is developed in collaboration with the ISAC institute in Bologna, Italy.

Figure 2. MODEL 150-days sequences (starting Dec 20th) for SPE-like perturbations. 9days averages are shown in order to compare the overall effect of impulsive and constant perturbations.
In each figure, top 6 panels are mean values in regions 90N-60N, 60N-30N, …, 60S-90S. Bottom panel is the global mean.

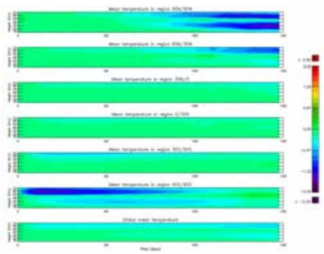

Figure 2a O_3 drop by 10% at polar regions, constant in time. Temperature difference to control run (solar max conditions).

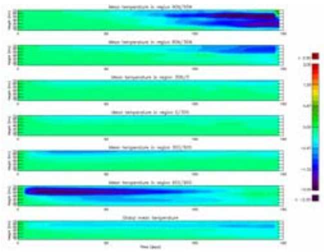

Figure 2b O_3 drop by 90% at polar regions, every 9 days. Temperature difference to control run (solar max conditions). The total O_3 decrease we impose is equal to the perturbation of the previous figure.

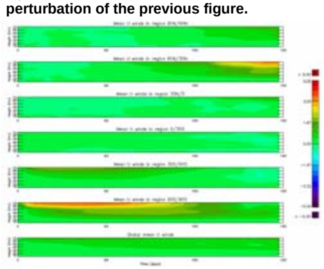

Figure 2c. Mean zonal wind fields. Difference of the two runs are showed in the figures above. The impulsive perturbation is about 40% more efficient in altering the wind field.