Estimation of the vertical profile of SO_2 injection by a volcanic eruption

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Abstract

On September 30th the volcano Jebel al Tair (Red Sea) erupted. An SO_2 plume was released into the atmosphere and observed from different satellite platforms. With these observations, a transport model and an inversion method it was possible to successfully reconstruct the emission profile and the transport of the volcanic plume.

Method

For estimating an emission profile satellite-observed total SO_2 columns (OMI, SEVIRI and AIRS) and an atmospheric transport model (FLEXPART) were used. Because of the fact that winds change with altitude the position and shape of the volcanic plume bears information on its emission altitude. Our inversion method finds the vertical emission distribution which minimizes the total difference between simulated and observed SO_2 columns while also considering a priori information.

Transport of the volcanic SO_2 plume was simulated with the Lagrangian particle dispersion model FLEXPART (Stohl et al., 2005, see also *http://transport.nilu.no/flexpart)*. Driven by meteorological fields from the European Centre for Medium-Range Weather Forecast, it calculates the trajectories of tracer particles using the mean wind plus random motion representing turbulence.

Concentration maps resulting of atmospheric transport of a unit mass released for 160 height intervals of 150 m starting from the mountain top up to 25 km were calculated and paired with total column satellite observations and used for the inversion (Seibert et al., 2001).

Emission Profile

The result of the inversion using satellite data from the first 24 h after the eruption shows an emission maximum near 16 km above sea level, and secondary maxima near 5, 9, 12 and 14 km. 60% of the emission occurred above the tropopause (see Fig. 1). The inversion result is robust against various changes in both the a priori and the observations. Even when using only SEVIRI data from the first 15 h after the eruption, the emission profile was reasonably well estimated.

Based on this profile another FLEXPART model run was performed which was further compared with satellite data.

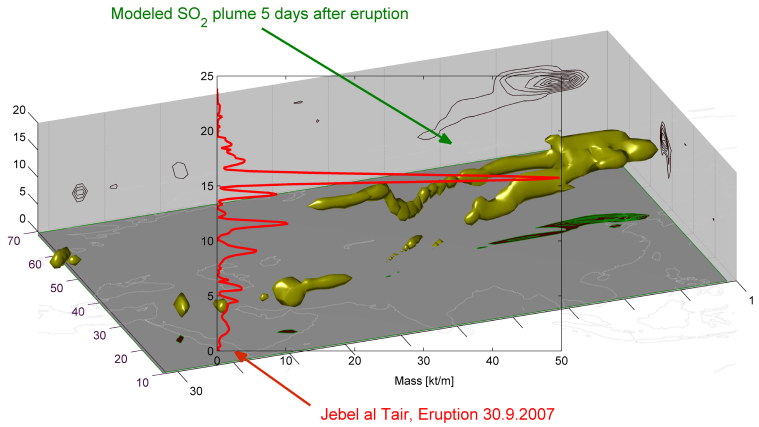

Fig 1: The red line shows the emission profile which was obtained by the inversion. The green plume is a 3dimensional depiction (snapshot from the 4th October) of the SO_2 plume as modeled by FLEXPART based on the emission profile.

Validation

The overall plume dispersion as observed by OMI (Fig 2), could be simulated well over the course of about a week. However, quantitatively the relative SO_2 distribution within the plume was not so well simulated.

Some cases were found, where CALIPSO data were available at the position of the modeled plume. These observations, which also capture the vertical information of the aerosol distribution showed thin veils of stratospheric aerosol that were well collocated with the FLEXPART plume (e.g. Fig 3), but the observed plume tended to be thinner than the simulated one.

An inversion experiment using OMI data until 4 days after the eruption shifted the emission maximum from 16 km to 18 km and brought the simulation in closer agreement with both the OMI and the CALIPSO observations. However, this may not actually be due to an emission at higher altitude but may instead compensate for errors in the simulated transport (probably due to radiative heating and self-lofting of the plume) en route.

The method is computationally very fast and it was possible to capture the development of the plume. It is therefore suitable for implementation within an operational environment, such as the Volcanic Ash Advisory Centers, to predict the threat posed by volcanic ash for air traffic.

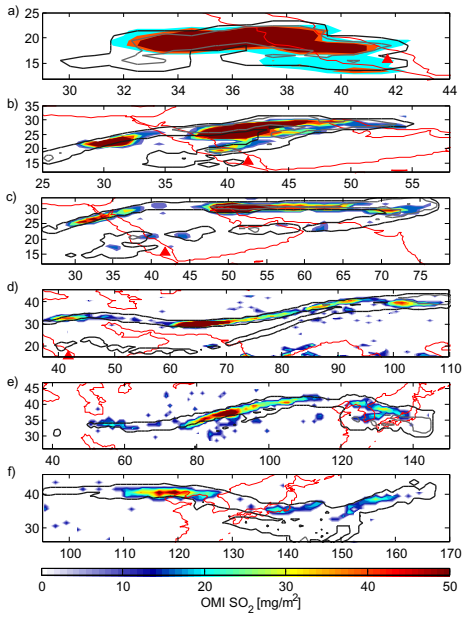

Fig. 2. Comparison of SO_2 columns measured by OMI and simulated by FLEXPART using the emission profile from our reference inversion for (a) 1 October, (b) 2 October (c) 3 October (d) 4 October (e) 5 October, (f) 6 October. The satellite data are shown by the color shading and the FLEXPART results are shown as isolines for 1 mg m^{-2} (thick black line) and 30 mg m^{-2} (thick grey line).

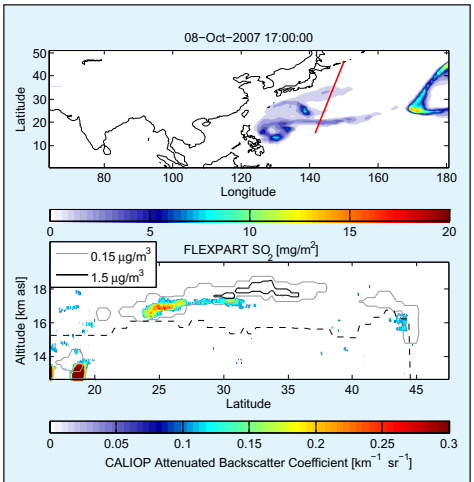

Fig. 3. Comparison of CALIPSO attenuated backscatter with SO_2 concentrations simulated by FLEXPART on 8 October at 17:00 UT. The map (upper panel) shows total columns of SO_2 simulated by FLEXPART. The red line indicates the location of the CALIPSO nadir track. In the lower panel, the CALIPSO data are shown by the color shading and the FLEXPART results are plotted as isolines for 50 µgm^{-3} (thick black line) and 5 µgm^{-3} (thick grey line). The tropopause altitude calculated from the ECMWF analyses is plotted as a thin dashed black line.

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Eckhardt S, Prata A.J., Seibert P., Stebel K. and Stohl A., *Estimation of the vertical profile of sulfur dioxide injection into the atmosphere by a volcanic eruption using satellite column measurements and inverse transport modelling*, Atmos. Chem. Phys. Discuss., 8, 3761-3805, 2008
At: www.atmos-chem-phys-discuss.net/8/3761/2008/

Acknowledgements

We thank I. Bey for supplying us with OH fields from GEOS-CHEM. CALIOP data were obtained from the NASA Langley Research Center Atmospheric Science Data Center. Support of this work through various grants of the Norwegian Research Council is gratefully acknowledged. P. Seibert acknowledges funding from the Fonds zur Foerderung der wissenschaftlichen Forschung (FWF grant 17924) and the Accent Network of Excellence.