Retrieval and analysis of vertical columns of sulfur dioxide over South America and Central Chile

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Abstract

Satellite borne instruments are providing a vast worldwide amount of data regarding gas-phase, aerosols and clouds (e.g., Fishman et al., 2008). These data must nevertheless be carefully validated against in situ measurements, and retrieval algorithms have to be continuously corrected and improved. First we show a filtering exercise of sulfur dioxide retrievals from the Ozone Monitoring Instrument (OMI) e.g., Krotkov et al, 2006) over South America, where the OMI signal shows significant perturbations due to solar particles. Secondly, we evaluate the signal over the central region of Chile where very significant emissions of SO2 occur in connection with copper smelting. There are several sources of sulfur dioxide (SO2), such as copper smelters, that oxidize to sulphate which affects regional air quality and global climate. Satellite observations provide valuable information on these emission sources however care is needed to fully account for atmospheric scattering in the heterogeneous environment. In particular, we address the question of improving the estimate of the atmospheric mass factor (AMF), taking into consideration a high spatial resolution (4km horizontal) regional chemical transport model (Polyphemus) to represent the vertical profile of the SO2. We also use a radiative transfer model LIDORT (Spurr et al., 2002) to compute scattering weights. These observations will provide constraints on emissions of sulphur dioxide through inverse modelling.

Filtering OMI Satellite data

Between 20º-45º South OMI retrievals are hampered by the South Atlantic Anomaly (SAA), which is an area where a dip in the Van Allen radiation belt increase the flux of the energetic particles to satellite. Over South America, OMI is exposed to high energy radiation due to the SAA (Heitzler 2002). This implies that over our region of study the signal that is received is noisier than in other parts of the world. In this case applying a multi-step filtering using several stepsopan a grid of 0.1º x 0.1º over the South America region:

- Cloud Fraction < 0.2, 10°<CTP<50°(Nadir viewing), SZA<50°
- 98% of the sample for each grid point in time
- Fourier Filter
- Residual filter

The Fourier filter eliminates certain frequencies on the signal, which is a priori would be considerd a noise. In this case we eliminate all the normalized frequencies higher than 0.7 which in terms of real time is one year and a half. Once eliminated the noise we reestimate the values for the time series using the inverse Fourier transform.

The residual filter considers the residual spectral fitting for each measurement. The residuals correspond to the ratio between the Earth radiation (λ) and the Solar radiation (F) in N-values (-100log(F/λ)) as described in Krotkov et al. 2006). This provides us a way to identify when the measurements of vertical column are incorrect. The filter rejects the measurements of SO2 for which the residual are not in the 98% of the sample (eliminate the outliers).

The plots of the result are below: Figure 1 shows the aerosal emmissions in South America using the VOCA emmissions inventory (Spak et al., 2010). Figure 2 shows the data for period 2005 without any filtering. Figure 3 corresponds to the standard deviation, clearly showing the SAA region. Notice that over this region there are several SO2 sources (fig 1) in which it is possible to see high variability of the measurements over that region. Figure 4 and 5 correspond to the plot of the data after the filter, in which we apply step by step in the same order of what we enumerate here, showing the filtered data and the corresponding standard deviation. It’s possible to conclude that by using this filters the noise is reduced with respect to the original, but there are high values that persist on it. The effects of the SAA persist. Hence, further filtering and analysis is required.

The AMF Calculation

The air mass factor (AMF) is required for the conversion from slant columns (line-of-sight path) to vertical columns like the figure 6. The Planetary Boundary Layer vertical column of SO2 product from OMI, assumes for simplicity a globally constant value for the calculation (AMF=0.36). Given the complex topography and atmospheric circulation we propose to develop a local AMF. We extend the approach of Lee et al., 2009, but considering a meso-scale model i.e., the Polyphemus system (Mallet et al., 2007).

The calculation is made using the formula:

$$ \text{AMF} = AMF_0 \int_0^\infty \omega(z) S(z) dz $$

where \( \omega(z) \) corresponds to the Shape factor, which is a normalized profile of SO2: that comes from the model. Either the other function that appears correspond to the scattering weights that are calculated with a Radiative transfer model LIDORT (Spurr et al., 2002). The parameters to calculate these scattering weights include an OMI ozone column, surface reflectivity and clouds. For this purpose we define the cloud radiance fraction c as:

$$ RCF = \frac{f - R_{cloud}}{f - R_{cloud} + (1 - f) \cdot R_{clear}} $$

where f corresponds to the effective cloud fraction and R is the top of the atmosphere reflectances for cloudy scene (\( R_{cloud} \)) and for clear scene (\( R_{clear} \)), obtained from the Radiative transfer model. Finally we estimate the AMF by:

$$ \text{AMF} = (1 - RCF) \cdot AMF_{clear} + RCF \cdot AMF_{cloud} $$

As this is an early stage of the research, we can not show the result of the AMF. In this case we show the plot for the SO2 burden by the Model and OMI, figures 7 and 8 respectively. The SO2 burden correspond to the sum of SO2 contained in a column, i.e.:

$$ \text{SO2 burden} = \int_0^{\infty} \text{SO2} \cdot \omega(z)dz $$

OMI retrievals of SO2 burden for period 2005 are shown in the figure 7. The corresponding SO2 burden calculated for the model for January 2005 is shown in the figure 8 where we made the average for OMI equator crossing time at local time 13-15 hrs. The model simulation was made using Polyphemus fed with meteorological fields calculated with the MMS model at 4 km horizontal resolution as described by Castillo et al., 2010.

Future work

- We will explore the use of other filtering techniques to address the SAA perturbations on the OMI SO2 signal over South America. We may also use a regional model to estimate the AMF.
- For estimating AMF we intend to use several models and periods to capture climatologically representative SO2 profiles for the main sources over South America.
- Calculations of the AMF, it’s corresponding error, and sensitivity analysis of the calculations.

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