Strategies for Stratosphere-Troposphere Separation of Nitrogen Dioxide Columns from the TEMPO Geostationary Instrument

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The Problem

Observations of \( \text{NO}_2 \) from satellite-based instruments have provided unprecedented global insight into tropospheric \( \text{NO}_2 \) concentrations. Stratosphere-troposphere separation (STS) is a crucial step in the application of these observations. The tropospheric vertical column density (\( \text{VCD}_{\text{trop}} \)) is calculated by:

\[
\text{VCD}_{\text{trop}} = \frac{\text{SCD}}{\text{AMF}_{\text{trop}}}
\]

where \( \text{SCD} \) is the slant column density (obtained by spectral fitting of solar backscattered radiation), \( \text{VCD}_{\text{trop}} \) is an estimate of the stratospheric vertical column density, and \( \text{AMF}_{\text{trop}} \) are the stratospheric and tropospheric air mass factors. Observations from low-earth orbit (LEO) provide a daily global view, with coverage over pristine areas where the \( \text{NO}_2 \) column is dominated by the stratosphere. This can be used to interpolate the stratospheric column elsewhere.

Spatial Filtering Approach

We use OMI observations clipped to the anticipated TEMPO field of regard to test strategies for STS. We start with a spatial filtering approach based on the current operational algorithm \cite{Zoogman et al. (2016)}. After removing a prior estimate of the troposphere (from an observation climatology), we mask regions that are likely to have strong signal coming from the troposphere. The threshold allows for polluted pixels to remain if the lower tropospheric signal is suppressed by clouds (and conversely exclude pixels that are not necessarily polluted but have high surface reflectivity):

\[
\frac{\text{VCD}_{\text{trop}}}{\text{AMF}_{\text{trop}}} > 0.3 \times 10^{15} \text{cm}^{-2}
\]

Context from Low-Earth Orbit

Where the averaging windows overlap with the field edges, the observations may be disproportionately influenced by continental signal instead of the pristine ocean regions outside of the boundaries. Suppose we have LEO observations from the same observation day, corrected for OMI overpass time based on their monthly mean ratio. We propose to use these observations as context near the TEMPO edges during the smoothing step.

Performance

Here we compare our TEMPO algorithm with the global algorithm.

Cloudy Pixels

Cloudy scenes (CF>0.9) where lower tropospheric signal is suppressed may be useful for STS. Mid-level clouds (600-400 hPa) will be least likely to contain \( \text{NO}_x \) associated with higher clouds. We find that around 60% of pixels that meet these criteria are already retained by our original masking algorithm (due to the threshold's dependence on radiative transfer). Incorporating the other cloudy pixels in the masked data increases data coverage only by about 4% in July (and even less in January). The value of cloudy pixels will be explored further in future work.

Near-Real-Time Retrieval Considerations

Incorporating independent observations from a low-earth orbit instrument may not always be feasible for near-real-time data products (i.e. within an hour of the observation). Moreover, observations from the west coast will not be available in the early morning over eastern North America (and vice versa in the late afternoon over western North America). An alternative for real-time retrieval may be the “reference sector” approach. A first-order stratospheric estimate could be derived as a function of latitude from all the available unfiltered observations in the current hour.

Summary & Recommendations

- A spatial filtering approach to STS works well for geostationary observations of \( \text{NO}_2 \) over North America from the TEMPO instrument field of regard
- Incorporating independent observations from low-earth orbit helps remove STS bias in the TEMPO domain near field-of-regard boundaries
- At high \( \text{AMF}_{\text{trop}}/\text{AMF}_{\text{strat}} \) ratios, uncertainty in stratospheric column can be magnified by more than an order of magnitude in the troposphere, suggesting screening based on AMFs should be good practice
- Cloudy pixels may offer supporting information, but mid-level clouds don’t add substantial coverage to our current spatial filtering algorithm
- Estimated stratospheric columns from a reference sector or from previous days at the same hour could be used for initial near-real-time data products

\cite{Bucsela et al. (2013)} Atmos. Meas. Tech., 6, 2607-2626.