Validation of a New Operational Package for the Lagrangian Diagnosis of Stratosphere-Troposphere Exchange at Environment Canada

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1. Introduction and Methodology

It has been acknowledged that stratospheric-to-tropospheric transport (STT) is responsible for 25 to 50% of the tropospheric ozone budget. Recent studies suggest that tropospheric ozone from stratosphere may increase in the future in relationship with climate change; however, there exists large quantitative uncertainties to this. A new operational diagnostic package for stratosphere-troposphere exchange (STTE) has been developed for Environment Canada (EC). The STTE calculations are made daily on the basis of 10-day global forecasts (0.3 x 0.3 degrees x 80 levels up to 0.1hPa x 1 hour) produced by the EC GEM model. Following a Lagrangian approach, 18 million trajectories are calculated for 48h from five different times (0, 24, 48, 72, 96 hours) along each global forecast, starting from a global grid spanning the atmosphere from 600hPa to 10hPa. The trajectories crossing a 2PVU dynamical tropopause or the 380K isentrope are then selected and extended for four days forward or backward. A number of diagnostics are calculated, including global maps of the mass flux across the 2PVU tropopause and the 380K isentrope, and clusters of cross-tropopause transport events reaching the lower troposphere (700hPa). The resulting data set is global and will shed new insights into STTE processes, their frequency of occurrence in different regions of the world, and their possible impacts on the chemical composition of the troposphere and the lower stratosphere, and on surface air quality. It will also be useful as a new reference for validating cross-tropopause fluxes in general circulation models or in chemistry transport models. This real-time forecasting of STTE was used extensively in a recent observational campaign focusing on STTE with balloon sondes launched daily from Montreal (QC, CA), Egbert and Walsingham (ON, CA) through the month of July 2010. This poster presents a validation of this diagnostic package against these balloon sonde measurements. The main focus here is placed on Montreal measurements.

2. Selected Measured Profiles and Corresponding STT Forecasts

Here, a selection of four measured profiles and corresponding STT forecasts are shown for cases with clear/nuclear intrusions in combination with good/poor forecasts. Intrusion levels on each measurement are determined subjectively based on the following criteria (in descending order of priority): abrupt decrease in RH; abrupt increase in ozone partial pressure; high anti-correlation value of RH and ozone partial pressure; Kelvin in temperature.

- On July 26th (first column) there was a clear sign of intrusion and it was correctly forecasted by the model, as can be seen on the profile of the trajectory charts.
- On July 30th (second column) there was a clear sign of intrusion yet the model did not capture the lower part of the event.
- On July 13th (third column) there was not a very clear sign of intrusion, yet the model did capture it correctly.
- On July 26th (fourth column) there was not a very clear sign of intrusion and the model did not capture the lowest intrusion. However, it did capture correctly the upper intrusion.

Figure 1. For each column, the top left figure shows the measured profiles of RH [%], ozone partial pressure [ppbv] and temperature [ °C] with intrusion levels (red dashed line) and thermal tropopause (red solid line) overlayed, whereas the top right figure shows the forecasted number of trajectories that passed within a 0.5deg latitude of the station within +/- 6hr of the measurement time. The second and third row show the corresponding trajectory maps for 200-500mb levels and for 500-900mb levels respectively, whose pressure levels are expressed in different colours. The first column shows an example from July 26th, the second from July 29th, the third from July 13th, and the fourth from July 29th. The circles represent 5deg, 10deg, 2deg, and 0.5deg radii of the station.

3. Overall Frequencies of Intrusions in Observations

Table 1 summarizes the overall frequencies of intrusions in measurement profiles for each location.

- All three locations show a high frequency of STT events, with a majority of measured profiles showing intrusions reaching at least 500hPa.
- In Montreal and Egbert, about a half of the measured profiles show intrusions reaching 700hPa.

Table 1. Number of intrusions found in measurement profiles for each location.

<table>
<thead>
<tr>
<th>Location</th>
<th>Measurement</th>
<th>Event&lt;500mb</th>
<th>Event&gt;700mb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Montreal</td>
<td>25</td>
<td>25</td>
<td>11</td>
</tr>
<tr>
<td>Egbert</td>
<td>10</td>
<td>15</td>
<td>4</td>
</tr>
<tr>
<td>Walsingham</td>
<td>17</td>
<td>15</td>
<td>4</td>
</tr>
</tbody>
</table>

4. Comparison of STT Forecast with Previous Modelling Studies

Figure 2 shows the mass flux across 700hPa which is of stratospheric origin, as calculated from the STT forecasts. It is to be compared to the values from Bourqui and Trepanier (2010) and Sprunger and Wernli (2003) in figure 3.

- The values shown on figure 2 are similar to those given by Bourqui and Trepanier (2010) shown on figure 3, confirming the much larger amount of deep STT events over North America during summer season compared to the result from Sprunger and Wernli (2003).
- Possible reasons for this unexpectedly large deep intrusion frequency include: Better modelling skills, summers in 2006 and 2010 being extremes and/or a long term increase due to climate change.

5. Comparison between Observations and STT Forecast

Since RH is the main criterion for the detection of intrusions for the observations, it is used to evaluate our forecast.

- On these plots, we expect low RH to be associated with one or more trajectories (intrusions), as well as high RH with zero trajectory (no intrusion).
- Low RH with zero trajectory could mean either missed events, or dry tropospheric air (eg, upper troposphere). The high zero trajectory counts in low RH region on the left figure of Figure 5 most likely mean dry tropospheric air.
- High RH with one or more trajectories could mean overforecast by the model, or it could be due to the mixing with moist air, which the trajectories do not take into account.
- There is some limited room for improving the comparison between the model and the observations by increasing the radius from 0.5deg to 1deg (not shown).

6. Towards the Validation of the Model Using RH

- Three main periods of deep intrusions are clearly observed from the RH and O3 figures (July 11-20, July 24-27, and July 29-Aug 1).
- Same pattern can be seen from the forecasted trajectory plot; however, it tends to underestimate the events below 700hPa.
- The forecast agrees reasonably well with the observations, given the following uncertainties: GEM model forecast, trajectories, lack of mixing and clouds in trajectories, and the ambiguities in detecting intrusions from the observed profiles.

7. Conclusion

Since RH is the main criterion for the detection of intrusions for the observations, it is used to evaluate our forecast.

- Overall, the STT forecast represents well the intrusions observed in balloon profiles. Some are missed, due to a spatial shift of the descent in the GEM forecast. In general, however, the STT forecast tends to underestimate lower tropospheric intrusions.
- Unexpectedly large amount of deep STT events were observed during this summer campaign, confirming the study of Bourqui and Trepanier (2010).
- The actual mass flux across 700hPa by deep STT during summer is likely to be larger than what we found in figure 2, which is already ten times larger than what Sprunger and Wernli (2003) estimated.

8. References