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

M.Bourqui[1], A.Yamamoto[1], D.Tarasick[2], M.Moran[2], S.Argall[3], L-P.Beaudoin[4], I.Beres[2], J.Davies[2], A.Elford[2], C.Guertin[2], W.Hocking[3], M.Osman[3], and R.Wilkinson[4]

[1]Department of Atmospheric and Oceanic Sciences, McGill University [2]Air Quality Research Division, Environment Canada [3]University of Western Ontario [4]Canadian Space Agency

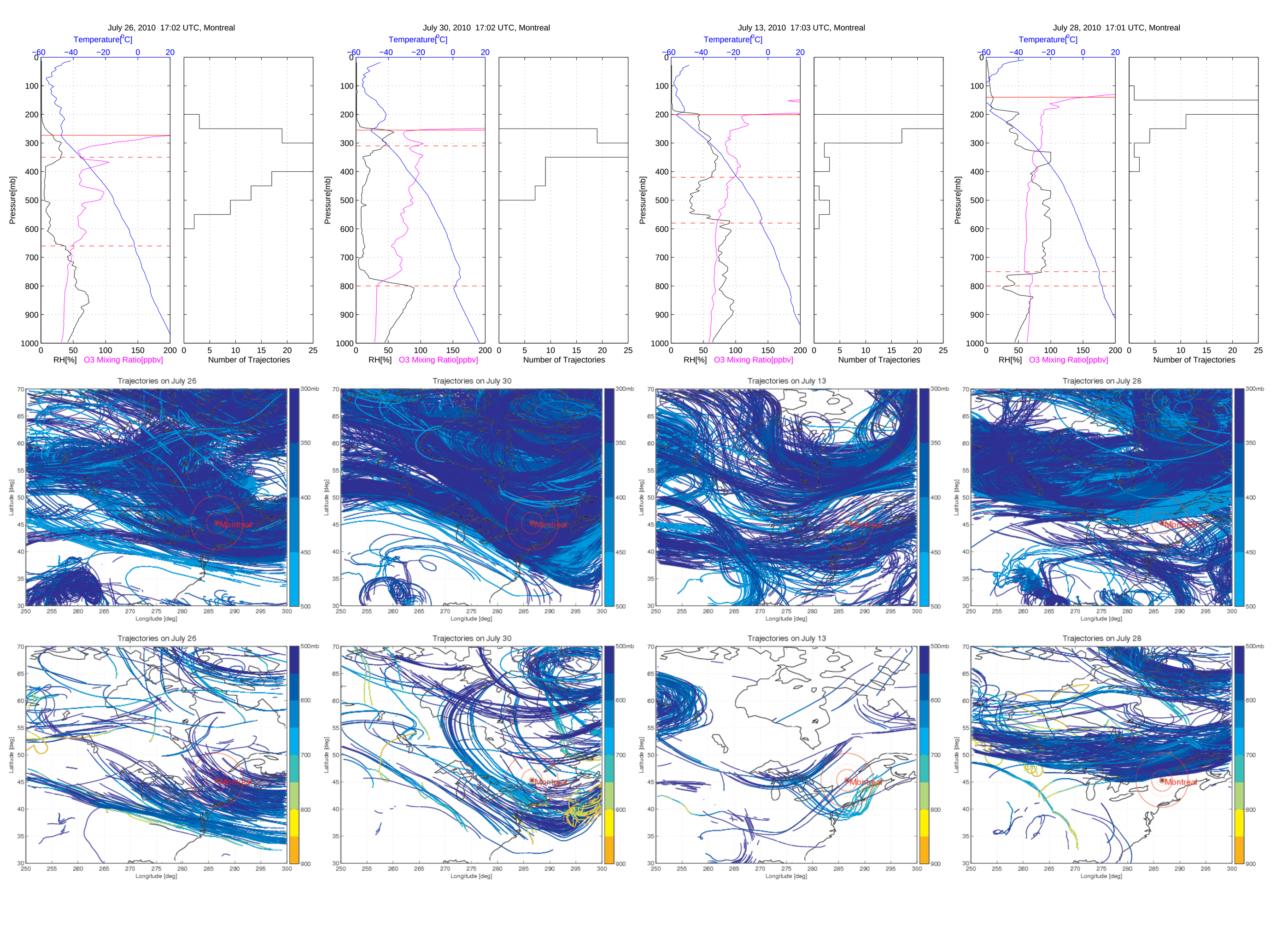
ayako.yamamoto@mail.mcgill.ca michel.bourqui@mcgill.ca

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 (STE) has been developed for Environment Canada (EC). The STE 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 1hour) 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 the 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 STE 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 STE was used extensively in a recent observational campaign focusing on STE 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/unclear 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).



1. Abrupt decrease in RH
2. Abrupt increase in ozone partial pressure
3. High anti-correlation value of RH and ozone partial pressure
4. Kink 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 counts.
- On July 30th (second column) there was a clear sign of intrusion yet the model did not capture the lower part of the event. Trajectories with pressure level of 700hPa appear very close to the station, however.
- On July 13th (third column) there was not a very clear sign of intrusion, yet the model did capture it correctly.
- On July 28th (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 [ºC] with intrusion levels (red dashed lines) and thermal tropopause (red solid line) overlayed, whereas the top right figure shows the forecasted number of trajectories that passed within a 0.5deg radius of the station within +/-6hr of the measurement time. The second and third row show the corresponding trajectory maps for 300-500mb 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 30th, the third from July 13th, and the fourth from July 28th. The circles represent 5deg, 3deg, 2deg, 1deg, 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.

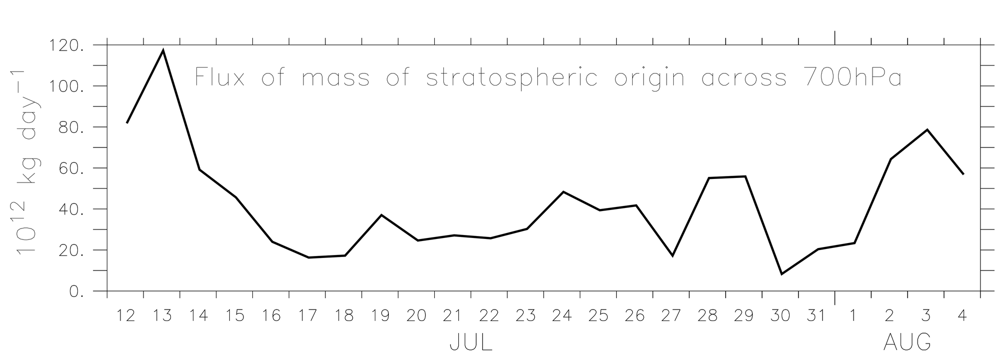
- All three locations show a high frequency of STT events, with a majority of measured profiles showing intrusions reaching at least 500hPa.
- In Montreal and Egbert, about a half of the measured profiles show intrusions reaching 700hPa.

Location	Measurement	Events(>500mb)	Events(>700mb)
Montreal	25	25	11
Egbert	20	19	11
Walsingham	17	15	4

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

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 Sprenger 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 Sprenger 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.

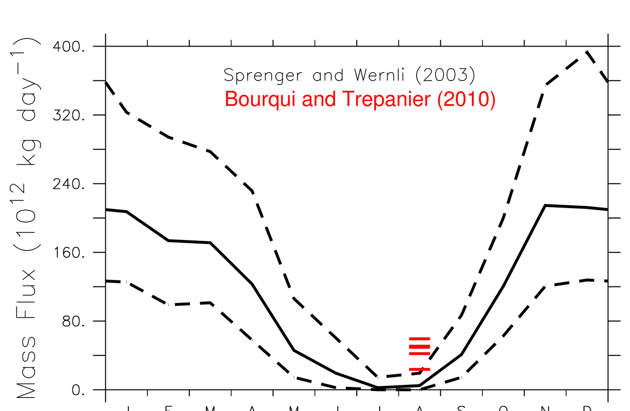
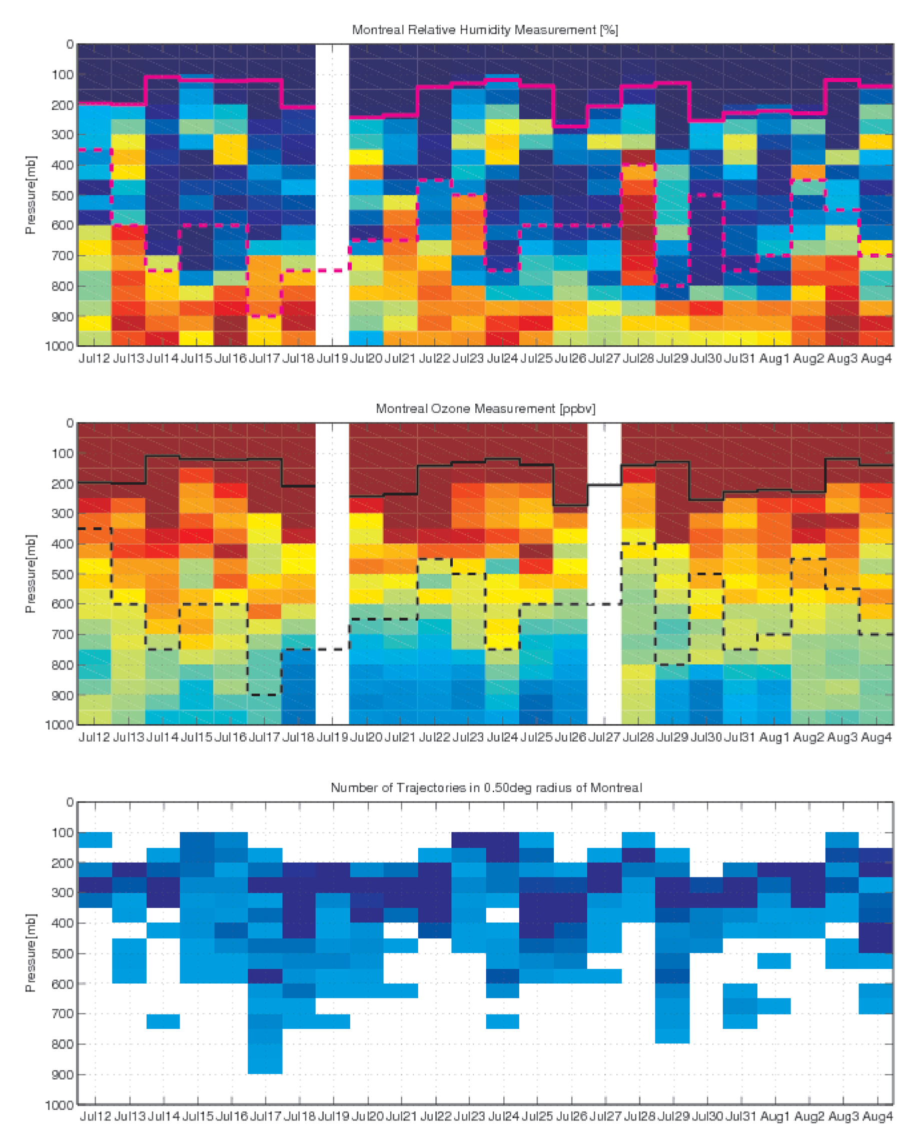


Figure 2 (Above). The stratospheric-origined mass flux across 700hPa for the period of the campaign for the domain of 137W-23W x 33N-67 in North America.

Figure 3 (Left). Black solid line: Annual cycle of monthly medians of the stratospheric mass flux crossing 700hPa calculated for the period 1983-1993 from the trajectory dataset of Sprenger and Wernli (2003) in the same domain in North America as figure 2. Black dashed lines: First and third quartiles. Red segments: Stratospheric mass crossing the 700hPa on four different days in the study of Bourqui and Trepanier (2010).

5. Comparison between Observations and STT Forecast



- Three main periods of deep intrusions are clearly observed from the RH and O3 figures (Jul14-20, Jul24-27, and Jul29-Aug1).
- Same pattern can be seen from the forecasted trajectory plot; however, it tends to underesitmate 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.

Figure 4. The first figure: The relative humidity data [%] from measurement for each day during the campaign at Montreal station. The data was averaged for every 50hPa. The magenta line shows the thermal tropopause. The second figure: The same as the first figure, but with ozone partial pressure [ppbv]. The black line marks the thermal tropopause. Blank columns are when data was missed. The last figure: The corresponding model forecast on each measurent day. Note that the denser the colour, the more trajectories were found within the 0.5 radius of Montreal within +/-6hr of observation time. The forecasted lowest intrusion level for each day was overlayed on top of the relative humidity plot and ozone partial pressure plot using dashed lines.

6. Towards the Validation of the Model Using RH

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).

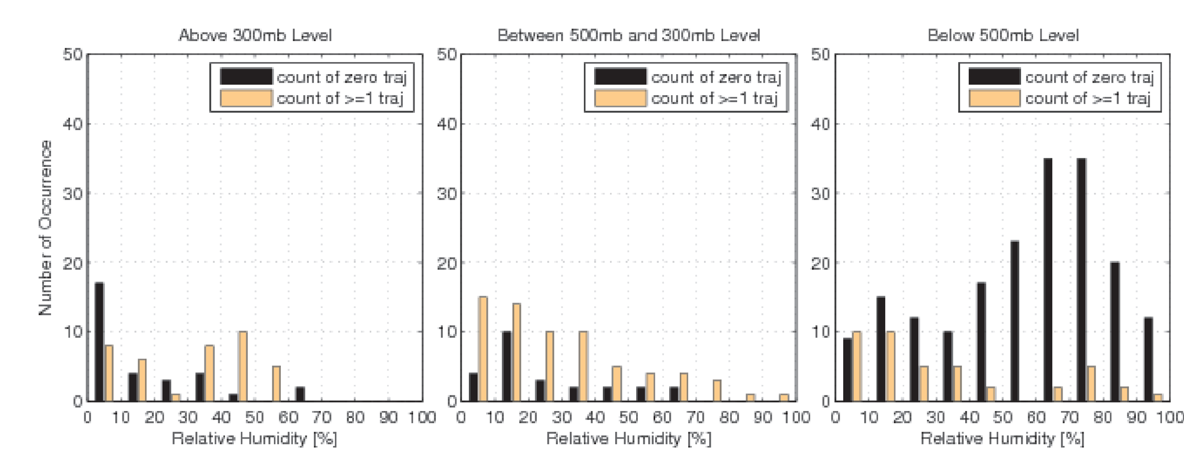


Figure 5. The sum of the counts of either zero or one (or more) trajectory forecasted by the model for each 50hPa bin as a function of observed RH. They are divided into three pressure levels: above 300mb level, between 300 and 500mb levels, and below 500mb level.

7. Conclusion

- 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 Sprenger and Wernli (2003) estimated.

8. References

[1] Bourqui M.S., and P.-Y. Trepanier., 2010. Descent of Deep Stratospheric Intrusions during the IONS August 2006 Campaign, J. Geophys. Res., 115, D18301, doi:10.1029/2009JD013183.

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[3] Sprenger M. and Wernli H., 2003. A northern hemispheric climatology of cross-tropopause exchange for the ERA15 time period (1979-1993). J. Geophys. Res., 108(D12), 8521, doi:10.1029/2002JD002636.