Fast injection of stratospheric air to the lower troposphere – an ordinary feature of Northern Hemispheric midlatitudes?

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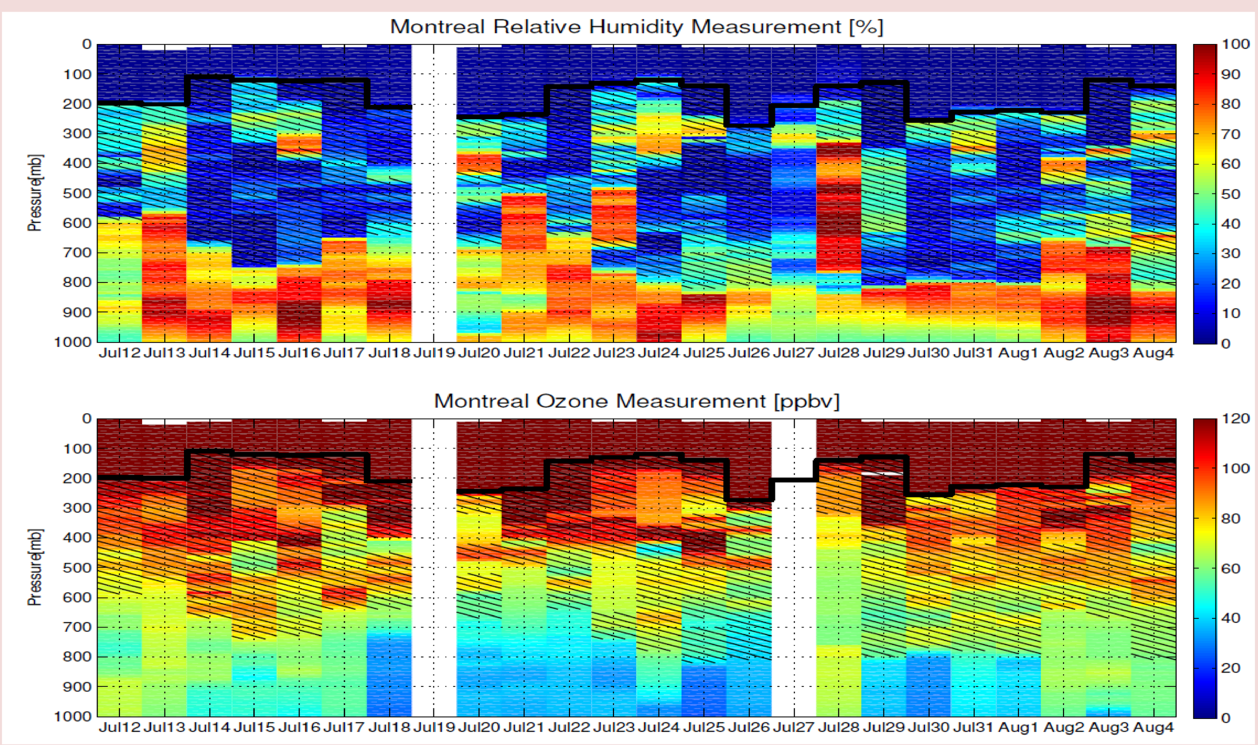
1. Introduction

Balloons measuring ozone, humidity and temperature were launched daily from three sites in South-Eastern Canada for a month in July 2010 (Montreal-QC, Egbert-ON and Walsingham-ON). These profiles showed consistently deep stratospheric intrusions penetrating below 700hPa almost every day of the campaign. These measurements are compared to predictions from a new, high-resolution global Lagrangian diagnosis system for Stratosphere-Troposphere Exchange (STE) which has been operational at Environment Canada (EC) since July 2010. The Lagrangian STE forecasts are found to have excellent predictive skills for stratospheric intrusions above 500hPa. Below this level, although the predictive skills vanish, the Lagrangian STE forecasts still keep unbiased statistical skills (Bourqui et al., 2011). The frequency of deep stratospheric intrusions found during this July 2010 campaign is consistent with that found during the IONS campaign in August 2006 (Bourqui and Trépanier, 2010), and is estimated to between 10 and 100 times larger than previous studies suggest (Sprenger and Wernli, 2003). This suggests that stratospheric intrusions reaching 700hPa may be much more frequent than previously thought.

This poster presents an analysis of the deep stratospheric intrusions measured during the July 2010 campaign and a validation of the high-resolution Lagrangian STE tool against these balloon sonde measurements. In addition, the first high-resolution Northern Hemispheric one-year climatology of deep stratospheric intrusions across the 700hPa level is presented as a result of the first year of operations of this diagnosis system. This one-year high-resolution climatology shows frequencies that are consistently larger by a factor 10 than those estimated by Sprenger and Wernli (2003), confirming that deep stratospheric intrusions are indeed more frequent than previously thought.

2. Balloon sonde observations



Dry, ozone-rich air is present throughout the tropospheric column, reaching the lower troposphere down to 600-800hPa, almost every day of the campaign in the three stations (see Fig. 1 for Montreal) This suggests the presence of air of stratospheric origin in the troposphere through most of the campaign.

	Nr observed events (% w.r.t. Nr profiles)		
Station (Nr profiles)	$P > 300$ hPa	$P > 500$ hPa	$P > 700$ hPa
Montreal (22)	21 (95%)	20 (91%)	11 (50%)
Egbert (17)	15 (88%)	14 (82%)	6 (35%)
Walsingham (17)	14 (82%)	10 (59%)	4 (24%)
Total (56)	50 (89%)	44 (79%)	21 (38%)

Figure 1 (left). Balloon observations above Montreal. Black thick line: thermal tropopause. Black hatching: regions identified as stratospheric intrusions. Blank columns: missing profiles.

We developed a simple algorithm for detecting stratospheric intrusions from observed profiles based on the vertical gradients of ozone and relative humidity. The number of intrusions so detected is given in Table 1 for the three stations. The number of stratospheric intrusions detected during this campaign is markedly larger than expected (e.g. Sprenger and Wernli, 2003).

Table 1. Number of profiles where a stratospheric intrusion was found somewhere at pressures higher than 300, 500 and 700 hPa, for each site during the campaign. Numbers in brackets next to the station names: total number of successful launches. Percentages in brackets: percentage of successful profiles with a stratospheric intrusion detected.

3. Evaluation of Lagrangian STE forecast

In Fig. 2 we compare the stratospheric intrusions identified from observations (black hatched regions) with the stratospheric intrusions captured by the Lagrangian STE forecast (blue shading). Missing observational data are denoted as white hatching. The overall match is reasonably good, with a tendency for a degradation of the performance in the lower troposphere.

Table 2 presents the statistical evaluation of the skills of the Lagrangian STE forecast using contingency tables and categorical scores (see Table 3 and the definitions of categorical scores). We interpret these data as follows:

- The predictive skills, i.e. the skills for predicting observed events, are evaluated by the PC, HR and FAR scores. The predictive skills are very good above 500hPa and almost vanish below.
- The statistical skills, i.e. the skills for predicting the observed frequency of stratospheric intrusions are assessed by the FB. This score is very good everywhere except in the region 500 – 700hPa, where a low bias of 31% is found.

Pressure range	$P < 300$ hPa	$300 < P < 500$ hPa	$500 < P < 700$ hPa	$700 < P < 900$ hPa
Contingency table	129, 22 ‖ 151	138, 43 ‖ 181	68, 26 ‖ 94	7, 19 ‖ 26
	2, 4 ‖ 6	29, 14 ‖ 43	68, 62 ‖ 130	23, 175 ‖ 198
	131, 26 ‖ 157	167, 57 ‖ 224	136, 88 ‖ 224	30, 194 ‖ 224
PC	0.85^a (0.95, 0.84, 0.75)	0.68^a (0.73, 0.66, 0.63)	0.58^a (0.60, 0.49, 0.65)	0.81^a (0.77, 0.79, 0.88)
FB	1.15 (1.06, 1.20, 1.24)	1.08 (0.97, 1.28, 1.07)	0.69 (0.58, 0.67, 1.00)	0.87 (0.56, 1.57, 1.00)
HR	0.98 (1.00, 1.00, 0.95)	0.83 (0.83, 0.89, 0.76)	0.50 (0.52, 0.44, 0.56)	0.23 (0.22, 0.29, 0.20)
FAR	0.15 (0.05, 0.16, 0.24)	0.24 (0.15, 0.30, 0.29)	0.28 (0.11, 0.33, 0.44)	0.73 (0.60, 0.82, 0.80)

^{a}: Statistically significant at the 10% bilateral level.

Table 2. Contingency tables for the three stations together. Categorical skill scores for the three stations together, with individual stations given in bracket. An event is here defined as the presence of stratospheric air in a 50 hPa vertical bin.

Definition of categorical scores

PC (Proportion Correct) = (a+d)/n
1=all correct; 0.5=random

FB (Frequency Bias) = (a+b)/(a+c)
1= perfect; >1 overforecast; <1 underforecast

HR (Hit Rate) = a/(a+c)
1=all obs predicted; 0=all observed events missed

FAR (False Alarm Rate) = b/(a+b)
0=perfect; 1=all forecasts are false alarms

Number of events that are	Observed	Not observed	Total
Forecast	a	b	a+b
Not forecast	c	d	c+d
Total	a+c	b+d	a+b+c+d=n

Table 3. Definition of the contingency table and categorical scores.

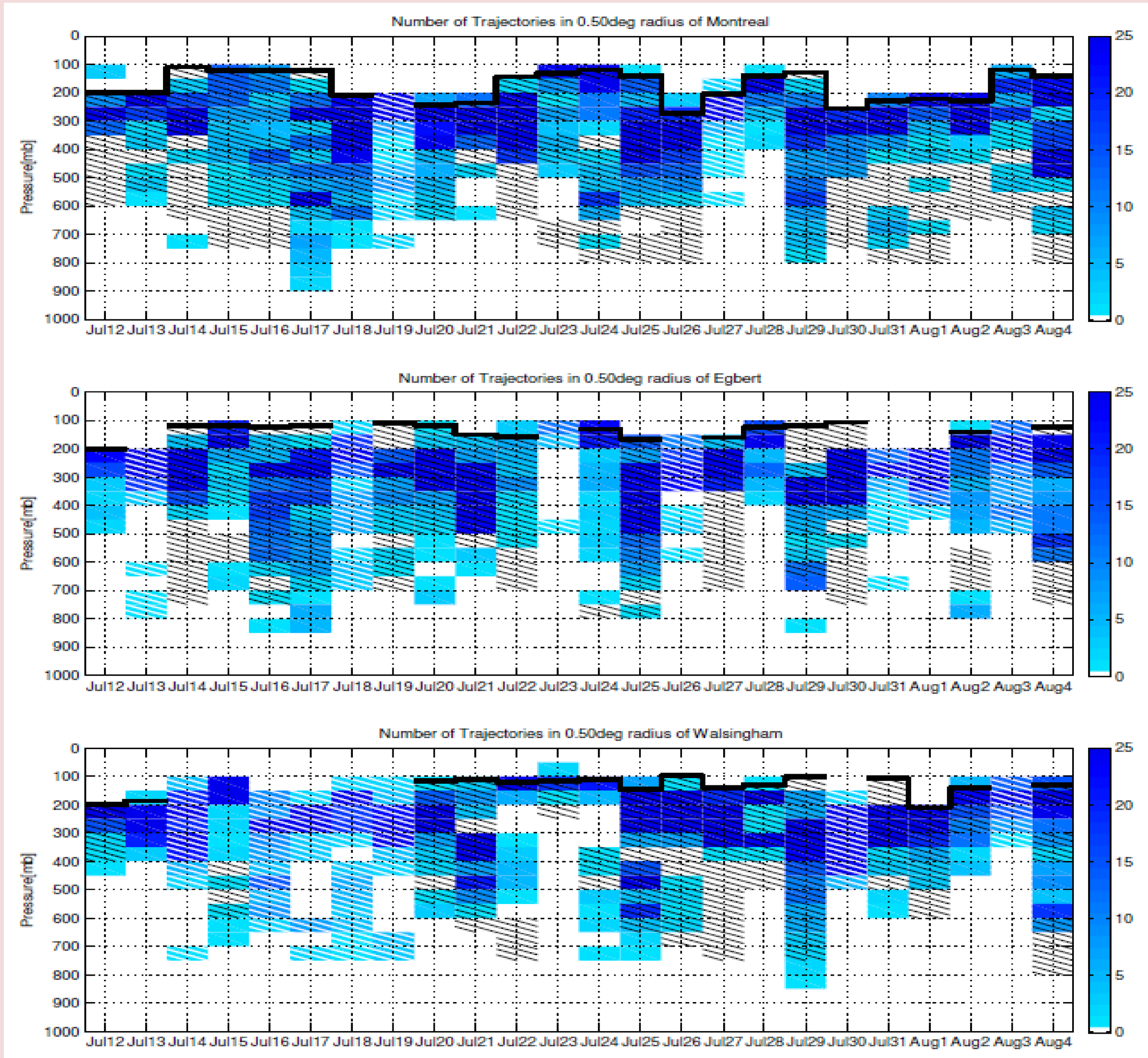


Figure 2 (right). Number of trajectories of stratospheric origin detected within 55 km of Montreal (top), Egbert (middle), and Walsingham (bottom) within ± 6 h from observation time (coloured shading). Black thick line: thermal tropopause. Black hatching: identified as stratospheric intrusions in the observed profiles. White hatching: missing observations.

4. Analysis of errors

In order to analyse the low bias found between 500 and 700hPa, we clusterised the trajectories that reach 700hPa within a radius of 1,111km from Montreal into clusters of at least 10 trajectories with time-average distances between pairs of trajectories of maximum 222km (following Bourqui and Trépanier, 2010). For each missed observed event, we screened through the clusters to identify candidates for the missed events. We found that 70% of the missed events match with clusters flying above Montreal within the expected time interval, but where trajectories are too dispersed to be detected within the 55km radius around Montreal. All other missed events, except one, could be explained by slight spatial shifts in clusters (max 555km). Two examples are given in Fig. 3.

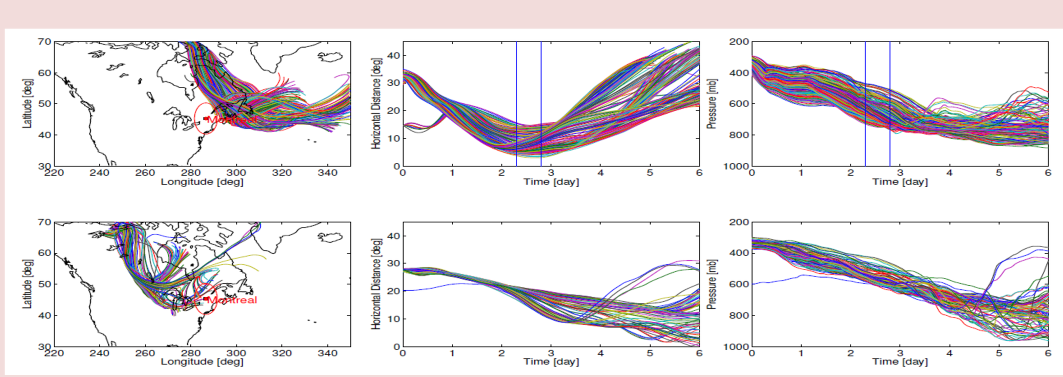


Figure 3 (left). Examples of typical clusters of trajectories that could be candidates for missed observed events in Montreal. Left column: location of the cluster's trajectories. Middle column: Horizontal distance with respect to Montreal station (units of distance equivalent degrees latitude). Right column: Pressure of cluster's trajectories (hPa) as a function of time elapsed after starting time. The black vertical lines in the middle and right columns show the window ±6 h around measurement time. In the second row, this time interval starts on day 6 of the cluster.

5. The first global one-year climatology of deep stratospheric intrusions

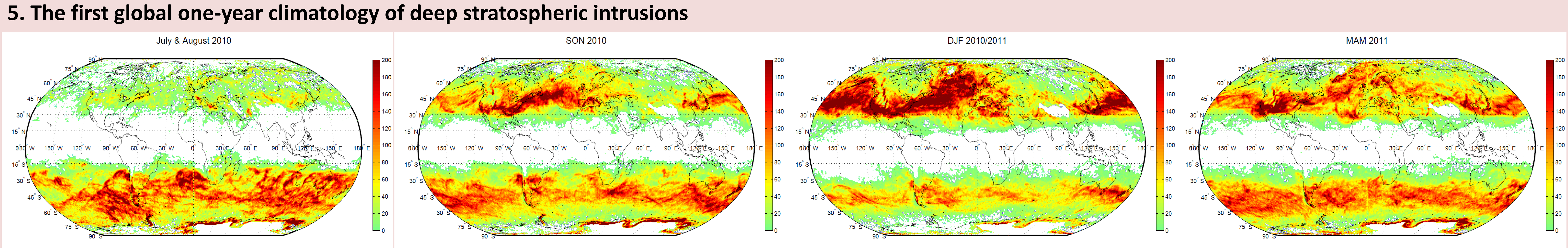


Figure 4 (above). Mass flux of stratospheric air at 700hPa estimated from the new Lagrangian STE diagnosis system at Environment Canada. Units: kg / s / km^2 .

6. Conclusions

We conclude that the Lagrangian STE forecasting system implemented at Environment Canada, within the limits of this study, has very good predictive skills for stratospheric intrusions above 500hPa. Below this level, although the predictive skills vanish, the analysis suggests that the Lagrangian STE system keeps very good statistical skills. Further evaluation is required in different seasons and locations before generalising these results.

We have derived the first global one-year climatology of deep stratospheric intrusions from this Lagrangian STE diagnosis system. It shows overall frequencies ten times larger than the Northern Hemisphere climatology of Sprenger and Wernli (2003). Clear seasonal cycles are found, with a minimum in the summer and a maximum in the winter. The southern hemisphere shows as much activity as the northern hemisphere, but with a slightly lower amplitude seasonal cycle.

6. References

Bourqui et al., ACPD (just submitted), 2011
Bourqui and Trépanier, JGR, vol. 115, 2010
Sprenger and Wernli, JGR, vol. 108, 2003.