

Detail of case selection for analysis

In this material, we explain how to select cases for analysis in detail, using the highest altitude among all trajectories (\hat{z}_1) and the top-1% average of the highest reached altitude of each trajectory (\hat{z}_a). As to their more detailed definitions, see subsection 3.2.

5 Some results of backward trajectory analysis are shown in Fig. 1, which shows the time variations of \hat{z}_1 and \hat{z}_a . When the averaging time (sampling interval) is one day, backward trajectories are calculated five times (00:00, 06:00, 12:00, 18:00, and 24:00 UTC), and the objects for analysis are the time when \hat{z}_a is the maximum and $\hat{z}_1 \geq 8000$ m among the five times. Thus, in the example that a high-concentration day is isolated (Fig. 1a), the time (18:00 UTC) when \hat{z}_a is the maximum and \hat{z}_1 is
10 greater than 8000 m is selected. This time is enclosed by a red square in Fig 1a to distinguish from the other times. High-concentration days sometimes continue consecutively. This example is shown in Fig. 1b. Even in this case, the selection rule is the same as that in isolated high-concentration days. In this case, therefore, 06:00 UTC 1 and 00:00 UTC 2 June are selected as objects for analysis. Although 00:00 UTC 2 June is common between 1 and 2 June, we can regard that 06:00 UTC 1
15 (00:00 UTC 2) June is selected for the first (second) day. Even when the averaging time is longer than one day, the selection rule is basically the same; all times when \hat{z}_a is a local maximum and $\hat{z}_1 \geq 8000$ m between sampling intervals are chosen. However, when the two maxima of \hat{z}_a are separated for only 12 h, that is, only one calculation is “slipped” in between, only one time (obviously that with larger \hat{z}_a) is selected. Thus, in the example of Fig. 1c, 12:00 UTC 3, 18:00 UTC 4, and
20 00:00 UTC 6 May are selected. Although \hat{z}_a attains its local maximum at 00:00 UTC 3 May, this time is not selected, because this time is separated for only 12 h from 12:00 UTC. A comparison of these results reveals that the case at 12:00 UTC 2 June 2009 shows a local maximum for \hat{z}_1 in Fig. 1b, whereas \hat{z}_a attains the maximum at 00:00 UTC 2 June, showing a monotonic decrease around 12:00 UTC 2. Therefore, using both \hat{z}_1 and \hat{z}_a is preferable.

25 Thus, 33 times (cases) are finally selected. The details of these cases are shown in Table 1. The numerals prior to the time are expressed as the case numbers; for example, the case of 00:00 UTC 18 March 2009 is referred to as case 1. The maxima of the potential vorticity (PV) of parcels on trajectories are also shown. Since PV is given at isentropic surfaces in the JRA-55 data, PV at arbitrary points is obtained by interpolation. The values are all more than 2 PVU ($10^{-6} \text{ m}^2 \text{ s}^{-1} \text{ K kg}^{-1}$); the
30 minimum is 2.35 PVU for case 24, and 30 cases exceed 3 PVU.

Finally, we explain case 1, which is taken as a typical high-latitude route in subsection 4.2.1. Because case 1 (starting time of 00:00 UTC 18 March 2009) listed in Table 1 has the highest \hat{z}_a among high-latitude routes, it may be the best case for analysis. However, in this case, several trajectories among the top-1 % backward trajectories are from the mid-latitudes, which are markedly different from the other high-latitude routes. That is, routes are roughly divided into the two kinds (not shown). Thus, this case cannot be considered typical. We then substitute the case starting at 18:00 UTC 17 March 2009, i.e., 6 h before case 1. In this case, all of the top-1 % backward trajectories are from high latitudes. \hat{z}_1 , \hat{z}_a , and the maximum PV are 9722, 9157 m, and 8.63 PVU, respectively. The former two are nearly the same as those in case 1 (Table 1). The PV is much larger than that in case 1 and is the largest among the 33 cases. In terms of PV, we can say that the trajectories start from the stratosphere. Therefore, as a representative of the high-latitude route, this case gives clearer results than case 1, being simply referred to as case 1 in subsection 4.2.1.

Table 1. Objects for analysis of fast descent routes in which $\hat{z}_1 \geq 8000$ m and the maxima of \hat{z}_a are satisfied. The numerals before the time indicate the case numbers, which are ordered in time. Numerals below the time indicate \hat{z}_1 (m), \hat{z}_a (m), and maximum of potential vorticity (PVU) in order.

March		April		May		Others	
1.	00:00 UTC 18, 2009 9851, 9240, 6.27	8.	00:00 UTC 6, 2010 9231, 8755, 4.53	2.	00:00 UTC 2, 2009 8895, 8394, 4.97	5.	06:00 UTC 1 Jun 2009 9987, 9199, 4.32
15.	18:00 UTC 19, 2011 8752, 8379, 3.90	9.	00:00 UTC 9, 2010 8410, 8275, 3.56	3.	06:00 UTC 3, 2009 9291, 8574, 3.82	6.	00:00 UTC 2 Jun 2009 10 498 9157 5.31
16.	18:00 UTC 31, 2011 8450, 7903, 4.97	10.	12:00 UTC 27, 2010 9228, 7104, 5.77	4.	12:00 UTC 5, 2009 9937, 9240, 4.56	7.	18:00 UTC 25 Dec 2009 10 585, 10 025, 5.27
22.	00:00 UTC 11, 2012 8297, 7376, 4.17	17.	18:00 UTC 14, 2011 10 475, 9355, 4.21	11.	12:00 UTC 3, 2010 8374, 8108, 5.77	14.	18:00 UTC 27 Nov 2010 8410, 7668, 3.84
25.	12:00 UTC 9, 2013 9379, 8762, 2.77	18.	12:00 UTC 17, 2011 8407, 8135, 5.42	12.	18:00 UTC 4, 2010 8363, 8028, 4.38	21.	00:00 UTC 5 Dec 2011 8127, 7203, 3.40
26.	06:00 UTC 10, 2013 8979, 8792, 2.42	23.	18:00 UTC 7, 2012 8150, 7844, 4.69	13.	00:00 UTC 6, 2010 8714, 8326, 6.16	24.	00:00 UTC 7 Jan 2013 8211, 8116, 2.35
27.	18:00 UTC 12, 2013 10 084, 8898, 6.52	30.	18:00 UTC 15, 2013 9328, 8756, 5.17	19.	12:00 UTC 16, 2011 8439, 8229, 5.87	32.	12:00 UTC 25 Oct 2013 9217, 8321, 7.61
28.	12:00 UTC 22, 2013 8115, 7787, 5.36	31.	12:00 UTC 30, 2013 8887, 8208, 3.42	20.	00:00 UTC 20, 2011 10 683, 9938, 6.64		
29.	00:00 UTC 23, 2013 8266, 7724, 5.30			33.	00:00 UTC 18, 2014 8988, 8664, 5.28		

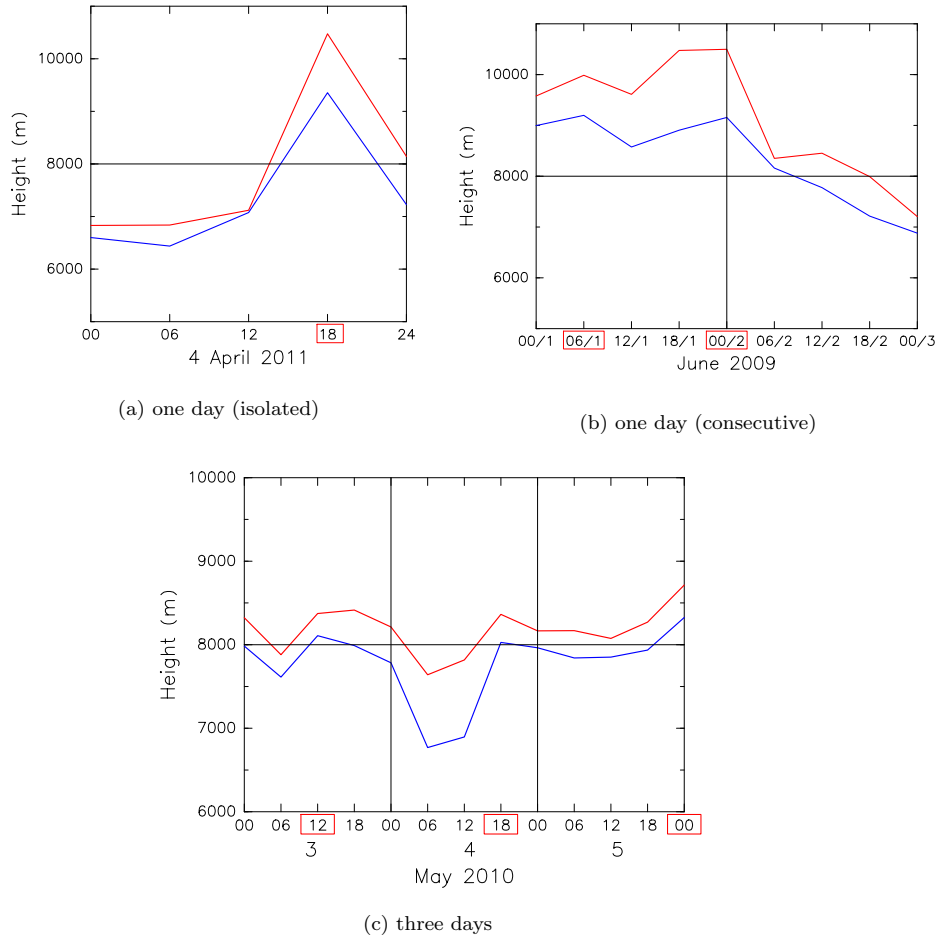


Figure 1. Figure for explaining the case (time) selection for analysis. Examples that (a) a high-concentration day is isolated, (b) high-concentration days are consecutive, and (c) the averaging time (sampling interval) is three days are illustrated. Time variations of \hat{z}_1 (red line) and \hat{z}_a (blue line) of backward trajectory analysis from (a) 4 April 2011, (b) 1 and 2 June 2009, and (c) 3 to 5 May 2010 are shown. The abscissa indicates time, and the ordinate expresses height (unit: m). The selected times are enclosed by red squares.