Reply to Referee 1 Comments - Supplement

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Sensitivity of polar stratospheric cloud formation to changes in water vapour and temperature

The sensitivity study performed on single back trajectories as presented in our paper for the Arctic winter 2010/2011 is repeated here applying trajectories from other Arctic winters, namely the Arctic winters 2009/2010, 2008/2009, 2007/2008 and 2004/2005. From our previous Arctic studies (Blum et al., 2005; Khosrawi et al., 2011 and Achtert et al., 2011) we have calculated trajectories with the HYSPLIT and the CLaMS (Chemical Lagrangian Model of the Stratosphere) model, respectively. The trajectories were calculated based on PSC measurements from the IRF lidar and the Esrange lidar, both located in Kiruna, Northern Sweden as well as the Alomar lidar located at Andøya Rocket Range in Northern Norway.

It does not matter for which Arctic winter the trajectories were calculated. They all show the same behaviour. A temperature decrease or water vapour increase will prolong the time periods where the temperature is below the threshold temperatures for T_{NAT} and T_{ice}.

The same holds if we take into account potential uncertainties of the trajectory temperatures. We perform our sensitivity study on single trajectories and assess the impact a potential temperature bias would have on our results.The temperatures along the trajectories were thus increased by 2 K (corresponding to a cold bias) and decreased by 2 K (corresponding to a warm bias), respectively. The total time the temperatures along the trajectory are below T_{NAT} and T_{ice}, respectively, is changing accordingly, but the increase in time is comparable to the times we derive without assuming a temperature bias.

1. Other Arctic winters

1.1 Arctic winter 2009/2010:

The Arctic vortex formed in December 2009. A Canadian warming in mid-December caused a vortex split. Nevertheless, the polar vortex recovered and gained strength again. Although the Arctic winter 2009/2010 was rather warm in the climatological sense, the 2009/2010 winter was distinguished by a cold phase extending over four weeks. Between mid-December and mid-January the vortex cooled down to temperatures below T_{ice} (both by orographic waves and synoptic cooling) leading to extensive PSC formation during this time period (Khosrawi et al., 2011 and references therein).

17 January 2010
On 17 January a PSC was measured by both the IRF and the Esrange lidar. The PSC was observed between 19 and 26 km and was mainly composed of STS. The trajectory considered here was calculated 6-days backward based on the PSC measured by the IRF lidar on 17 January and was started on 17 January 01 UTC at 22 km.

Along the trajectories temperatures drop below T_{NAT} twice (at t=−135 to t=−110, temperature range T_1, and at t=−10 to t=0, temperature range T_2). With increasing H_2O

mixing ratios (Case A), the time the temperatures drops below T_{NAT} is increasing by a few hours for both temperature ranges (Figure 1). If additionally the temperature is decreased by 1 K (Case B), the time where the temperatures drop below T_{NAT} is further prolonged and still slightly increasing when the H_2O mixing ratio is increased (Table 1).

Table 1: Time periods when T_1 and T_2 are below the NAT and ice threshold temperature along the trajectory. T_{NAT} and T_{ice} were derived for H_2O mixing ratios of 5, 5.5. and 6 ppmv for the back trajectory started on 17 January 2010 at 01:00 UTC. Water vapour increases (Case A) as well as an additional temperature cooling by 1 K (Case B) are considered.

	Case A				Case B			
H_2O (ppmv)	$T_1 < T_{\mathrm{NAT}}$ (h)	$T_1 < T_{\mathrm{ice}}$ (h)	$T_2 < T_{\mathrm{NAT}}$ (h)	$T_2 < T_{\mathrm{ice}}$ (h)	$T_1 < T_{\mathrm{NAT}}$ (h)	$T_1 < T_{\mathrm{ice}}$ (h)	$T_2 < T_{\mathrm{NAT}}$ (h)	$T_2 < T_{\mathrm{ice}}$ (h)
5	24	–	10	–	27	–	12	–
5.5	26	–	11	–	28	–	13	–
6	27	–	11	–	28	–	14	–

23 January 2010

On 23 January 2010 a PSC was observed by both the IRF and the Esrange lidar. The PSC was observed between 18 and 26 km and was composed of STS and NAT particles. The trajectory considered here was calculated 6-days backward based on the PSC observed by the Esrange lidar on 23 January and was started on 23 January at 19 UTC at 22 km.

Temperatures drop below T_{NAT} twice along the trajectory (at t=−140 to t=−95, temperature range T_1, and at t=−30 to t=0, temperature range T_2) and once below T_{ice} within the temperature range T_2 (at t=−140 to t=−125). With increasing H_2O mixing ratios (Case A), the time the temperatures drop below T_{NAT} and T_{ice}, respectively, is increasing (Figure 2). The temperature where the temperature is below T_{NAT} and T_{ice}, respectively, is prolonged by several hours. If additionally the temperature is decreased by 1 K (Case B), the time where the temperatures are below T_{NAT} is further prolonged and increasing when the H_2O mixing ratio is increased. For 5.5 ppmv and 6 ppmv also during the temperature T_2 temperatures drop below T_{ice} significantly (Table 2).

Table 2: Time periods when T_1 and T_2 are below the NAT and ice threshold temperature along the trajectory. T_{NAT} and T_{ice} were derived for H_2O mixing ratios of 5, 5.5 and 6 ppmv for the back trajectory started on 23 January 2010 at 19:00 UTC. Water vapour increases (Case A) as well as an additional temperature cooling by 1 K (Case B) are considered.

	Case A				Case B			
H_2O (ppmv)	$T_1 < T_{\mathrm{NAT}}$ (h)	$T_1 < T_{\mathrm{ice}}$ (h)	$T_2 < T_{\mathrm{NAT}}$ (h)	$T_2 < T_{\mathrm{ice}}$ (h)	$T_1 < T_{\mathrm{NAT}}$ (h)	$T_1 < T_{\mathrm{ice}}$ (h)	$T_2 < T_{\mathrm{NAT}}$ (h)	$T_2 < T_{\mathrm{ice}}$ (h)
5	48	18	29	–	49	26	31	–
5.5	48	21	30	–	50	27	32	6
6	49	26	33	–	51	29	32	14

1.2 Arctic winter 2008/2009:

Until 8 January the circulation in the stratosphere was undisturbed with a strong cyclonic vortex and very weak planetary wave activity. The vortex was very cold during that time period, with a minimum of −93°C at 10 hPa over Iceland. A major Warming occurred on 24 January 2009 and ended the Arctic winter abruptly. This major warming was the strongest and most prolonged warming on record (Manney et al., 2009, Labitzke and Kunze, 2009).

8 January 2009

A PSC was observed on 8 January 2009 with the Esrange lidar at 22-28 km. The PSC was composed of STS with NAT layers inbetween. The trajectory considered here was calculated 6-days backward based on the PSC observed by the Esrange lidar on 8 January and was started on 8 January at 22 UTC at 23 km.

Along the trajectory temperatures drop below T_{NAT} once (at t=−18 to t=−0, temperature range T_2) (Figure 3). With increasing H_2O mixing ratios (Case A), the time the temperatures drop below T_{NAT} is increasing by a few hours (from 16 to 20 h for an increase in H_2O mixing ratios of 1 ppmv). Temperatures also start to drop then below T_{NAT} for the temperature range T_1, though only for 1 h, which in this case can be neglected. However, this temperature drop becomes more important when additionally the temperature is decreased. If additionally the temperature is decreased by 1 K (Case B), the time where the temperatures drop below T_{NAT} is further prolonged and still slightly increasing when the H_2O mixing ratio is increased. For the temperature range T_1 the increase is quite significant from 2 h for a H_2O mixing ratio of 5 ppmv to 9 h for a H_2O mixing ratio of 6 ppmv (Table).

Table 3: Time periods when T_1 and T_2 are below the NAT and ice threshold temperature along the trajectory. T_{NAT} and T_{ice} were derived for H_2O mixing ratios of 5, 5.5 and 6 ppmv for the back trajectory started on 8 January 2009 at 22:00 UTC. Water vapour increases (Case A) as well as an additional temperature cooling by 1 K (Case B) are considered.

	Case A				Case B			
H_2O (ppmv)	$T_1 < T_{\mathrm{NAT}}$ (h)	$T_1 < T_{\mathrm{ice}}$ (h)	$T_2 < T_{\mathrm{NAT}}$ (h)	$T_2 < T_{\mathrm{ice}}$ (h)	$T_1 < T_{\mathrm{NAT}}$ (h)	$T_1 < T_{\mathrm{ice}}$ (h)	$T_2 < T_{\mathrm{NAT}}$ (h)	$T_2 < T_{\mathrm{ice}}$ (h)
5	–	–	16	–	2	–	21	–
5.5	1	–	19	–	6	–	22	–
6	1	–	20	–	9	–	23	–

9 January 2009

A PSC was observed on 9 January 2009 with the Esrange lidar at 22-25 km. The PSC was composed of STS with NAT layers inbetween. The trajectory considered here was calculated 6-days backward based on the PSC observed by the Esrange lidar on 9 January and was started on 9 January at 01 UTC at 22 km.

Along the trajectory temperatures drop below T_{NAT} once (at t=−16 to t=−0, temperature range T_2) (Figure). The time period where the temperatures drop below T_{NAT} is increasing by a few hours if the H_2O mixing ratios are increasing (Case A), e.g. from 16

to 20 h for an increase in H_2O mixing ratio by 1 ppmv. If additionally the temperature is decreased by 1 K (Case B), the time where the temperatures drop below T_{NAT} is further prolonged and still slightly increasing when the H_2O mixing ratio is increased. If a cooling of 1 K and an increase of H_2O mixing ratio of 0.5-1 ppmv is considered, temperatures also drop below T_{ice} for a few hours during temperature range T_1 (Table).

Table 4: Time periods when T_1 and T_2 are below the NAT and ice threshold temperature along the trajectory. T_{NAT} and T_{ice} were derived for H_2O mixing ratios of 5, 5.5 and 6 ppmv for the back trajectory started on 9 January 2009 at 01:00 UTC. Water vapour increases (Case A) as well as an additional temperature cooling by 1 K (Case B) are considered.

	Case A				Case B			
H_2O (ppmv)	$T_1 < T_{\mathrm{NAT}}$ (h)	$T_1 < T_{\mathrm{ice}}$ (h)	$T_2 < T_{\mathrm{NAT}}$ (h)	$T_2 < T_{\mathrm{ice}}$ (h)	$T_1 < T_{\mathrm{NAT}}$ (h)	$T_1 < T_{\mathrm{ice}}$ (h)	$T_2 < T_{\mathrm{NAT}}$ (h)	$T_2 < T_{\mathrm{ice}}$ (h)
5	–	–	16	–	–	–	20	–
5.5	–	–	19	–	2	–	21	–
6	–	–	20	–	3	–	22	–

1.3 Arctic winter 2007/2008:

The Arctic polar stratosphere cooled down as usual in November/December 2007 as the polar vortex grew in strength. Temperatures necessary for the formation of polar stratospheric clouds were reached by mid-December. The temperatures remained cold enough for PSC formation until late February 2008. Since mid January several minor warmings disturbed the polar stratosphere and a major warming in late February ended the conditions favourable for PSC formation (from: http://www.ozone-sec.ch.cam.ac.uk/EORCU/arctic_reports.html). In January 2008 the polar vortex was located over the Norwegian Sea and Barents Sea. In mid-January, the vortex moved slightly toward Scandinavia. Between 15 and 35 hPa (20-25 km) the temperatures above Esrange decreased below the existence temperature of STS and even reached below T_{ice} in mid January (Achtert et al., 2011).

22 January 2008

A PSC was observed on 22 January 2008 with the Esrange lidar at 19-26 km. The PSC was composed of STS with NAT layers inbetween. The trajectory considered here was calculated 6-days backward with HYSPLIT. The trajectory was started on 22 January at 22 UTC at 24 km.

Temperatures drop below T_{NAT} twice along the trajectory (at t=−141 to t=−82, temperature range T_1, and at t=−29 to t=0, temperature range T_2). With increasing H_2O mixing ratios (Case A), the time the temperatures drop below T_{NAT} is increasing (Figure 5). The time period where the temperature is below T_{NAT} is prolonged by 3-4 hours for an increase in H_2O mixing ratio of 1 ppmv. If additionally the temperature is decreased by 1 K (Case B), the time where the temperatures are below T_{NAT} is further prolonged and increasing when the H_2O mixing ratio is increased (Table 5).

Table 5: Time periods when T_1 and T_2 are below the NAT and ice threshold temperature along the trajectory. T_{NAT} and T_{ice} were derived for H_2O mixing ratios of 5, 5.5 and 6 ppmv for the back trajectory started on 22 January 2008 at 22:00 UTC. Water vapour increases (Case A) as well as an additional temperature cooling by 1 K (Case B) are considered.

	Case A				Case B			
H_2O (ppmv)	$T_1 < T_{\mathrm{NAT}}$ (h)	$T_1 < T_{\mathrm{ice}}$ (h)	$T_2 < T_{\mathrm{NAT}}$ (h)	$T_2 < T_{\mathrm{ice}}$ (h)	$T_1 < T_{\mathrm{NAT}}$ (h)	$T_1 < T_{\mathrm{ice}}$ (h)	$T_2 < T_{\mathrm{NAT}}$ (h)	$T_2 < T_{\mathrm{ice}}$ (h)
5	54	–	29	–	58	–	35	–
5.5	56	–	30	–	60	–	36	–
6	57	–	34	–	62	–	38	–

23 January 2008

A PSC was observed on 23 January 2008 with the Esrange lidar at 19-26 km. The PSC was composed of STS with NAT layers inbetween. The trajectory considered here was calculated 6-days backward with HYSPLIT. The trajectory was started on 23 January at 01 UTC at 24 km.

Temperatures drop below T_{NAT} twice along the trajectory (at t=−127 to t=−85, temperature range T_1, and at t=−21 to t=0, temperature range T_2). With increasing H_2O mixing ratios (Case A), the time the temperatures drop below T_{NAT} is increasing (Figure 6) for both T_1 and T_2 by 6 h. If additionally the temperature is decreased by 1 K (Case B), the time where the temperatures are below T_{NAT} is further prolonged and increasing by 4-5 h when the H_2O mixing ratio is increased (Table 6).

Table 6: Time periods when T_1 and T_2 are below the NAT and ice threshold temperature along the trajectory. T_{NAT} and T_{ice} were derived for H_2O mixing ratios of 5, 5.5 and 6 ppmv for the back trajectory started on 23 January 2008 at 01:00 UTC. Water vapour increases (Case A) as well as an additional temperature cooling by 1 K (Case B) are considered.

	Case A				Case B			
H_2O (ppmv)	$T_1 < T_{\mathrm{NAT}}$ (h)	$T_1 < T_{\mathrm{ice}}$ (h)	$T_2 < T_{\mathrm{NAT}}$ (h)	$T_2 < T_{\mathrm{ice}}$ (h)	$T_1 < T_{\mathrm{NAT}}$ (h)	$T_1 < T_{\mathrm{ice}}$ (h)	$T_2 < T_{\mathrm{NAT}}$ (h)	$T_2 < T_{\mathrm{ice}}$ (h)
5	42	–	21	–	50	–	28	–
5.5	47	–	23	–	53	–	29	–
6	48	–	27	–	54	–	33	–

1.4 Arctic winter 2004/2005:

A stable polar vortex was formed by mid-November. From early December on temperatures were low enough to allow PSC formation. The polar vortex remained cold until begin of March. In the beginning of January the vortex was centred above Greenland and northern Scandinavia, reaching temperatures below 190 K between the 15 and 25 km

altitude. A minor warming occurred at the end of January, but temperatures still remained cold until 24 February where a major warming caused a vortex split. The vortex parts reunited by 1 March and by 11 March the vortex split a second time. The vortex finally broke up around 22 March (Blum et al., 2006; Rösevall et al., 2008)

5 January 2005

On 5 January 2005 a PSC was observed between 19 and 22 km simultaneously on the east and west sides of the Scandinavian mountains by ground-based lidars (Esrange and Alomar lidar). This cloud was composed of liquid particles with a mixture of solid particles in the upper part of the cloud. The trajectory considered here was calculated 5-days backward with CLaMS using UKMO meteorological analysis.

Temperatures drop below T_{NAT} twice along the trajectory (at t=−111 to t=−51, temperature range T_1, and at t=−30 to t=0, temperature range T_2). With increasing H_2O mixing ratios (Case A), the time where the temperatures drop below T_{NAT} is increasing (Figure 7) for both T_1 and T_2 by 4 h. If additionally the temperature is decreased by 1 K (Case B), the time where the temperatures are below T_{NAT} is further prolonged and increasing by 5 h when the H_2O mixing ratio is increased. For an increase in H_2O mixing ratio and an additional cooling of 1 K even temperatures even drop below T_{ice} for 5 h (Table 7).

Table 7: Time periods when T_1 and T_2 are below the NAT and ice threshold temperature along the trajectory. T_{NAT} and T_{ice} were derived for H_2O mixing ratios of 5, 5.5 and 6 ppmv for the back trajectory started on 5 January 2005 at 20:00 UTC. Water vapour increases (Case A) as well as an additional temperature cooling by 1 K (Case B) are considered.

	Case A				Case B			
H_2O (ppmv)	$T_1 < T_{\mathrm{NAT}}$ (h)	$T_1 < T_{\mathrm{ice}}$ (h)	$T_2 < T_{\mathrm{NAT}}$ (h)	$T_2 < T_{\mathrm{ice}}$ (h)	$T_1 < T_{\mathrm{NAT}}$ (h)	$T_1 < T_{\mathrm{ice}}$ (h)	$T_2 < T_{\mathrm{NAT}}$ (h)	$T_2 < T_{\mathrm{ice}}$ (h)
5	60	–	30	–	66	–	35	–
5.5	62	–	32	–	69	–	38	–
6	64	–	34	–	71	–	40	5

2. Sensitivity to temperature uncertainties:

Comparisons of different meteorological analyses (e. g. Manney et al., 2003) show that distributions of "potential PSC lifetime" and total time spent below a PSC formation threshold (T_{NAT} or T_{ice}) may vary significantly between the analyses. The data sets may have warm or cold biases which are not the same for every year or month considered. One specific data set may have in one month a positive bias, but in the other month a negative bias. The biases have usually the magnitude of a few degrees.

Although we found a good agreement between the temperatures at the start point of the trajectory (which coincides with the CALIPSO measurement) and the specific PSC type observed by CALIPSO at that time and altitude where the trajectory was started, we investigate the impact potential temperature uncertainties of the meteorological data set used for the trajectory calculation would have on our sensitivity study. We repeat our

sensitivity study for one trajectory for the Arctic winter 2009/2010 and for one for the Arctic winter 2008/2009 assuming a potential warm and cold bias, respectively, of 2 K.

23 January 2010 - Assuming a warm bias

To investigate a potential warm bias, the temperature along the trajectory was decreased by 2 K. Since temperatures along the trajectory were already quite low, the total times where the temperature is below T_{NAT} and T_{ice} are even longer. Additionally, the ice threshold temperature is reached during the time period T_2. However, the increase in time due to increases in water vapour are comparable to the increases in time shown above (section 1).

Table 8: Time periods when T_1 and T_2 are below the NAT and ice threshold temperature along the trajectory when the temperature along the trajectory is decreased by 2 K. T_{NAT} and T_{ice} were derived for H_2O mixing ratios of 5, 5.5 and 6 ppmv for the back trajectory started on 23 January 2010 at 19:00 UTC.

H_2O (ppmv)	$T_1 < T_{\mathrm{NAT}}$ (h)	$T_1 < T_{\mathrm{ice}}$ (h)	$T_2 < T_{\mathrm{NAT}}$ (h)	$T_2 < T_{\mathrm{ice}}$ (h)
5	52	30	33	13
5.5	53	33	34	16
6	55	34	35	17

23 January 2010 - Assuming a cold bias

To investigate a potential cold bias, the temperature along the trajectory was increased by 2 K. Since temperatures along the trajectory were already quite low, the temperature still drops below T_{NAT} for T_1 and T_2. However, temperatures below T_{ice} are only reached when the water vapour mixing ratio is increased by 1 ppmv. Nevertheless, the increase in time where the temperature is below T_{NAT} due to a increase in the water vapour mixing ratio is comparable to the increases in time shown above when no bias in temperature is assumed (section 1).

Table 9: Time periods when T_1 and T_2 are below the NAT and ice threshold temperature along the trajectory when the temperature along the trajectory is increased by 2 K. T_{NAT} and T_{ice} were derived for H_2O mixing ratios of 5, 5.5 and 6 ppmv for the back trajectory started on 23 January 2010 at 19:00 UTC.

H_2O (ppmv)	$T_1 < T_{\mathrm{NAT}}$ (h)	$T_1 < T_{\mathrm{ice}}$ (h)	$T_2 < T_{\mathrm{NAT}}$ (h)	$T_2 < T_{\mathrm{ice}}$ (h)
5	40	–	25	–
5.5	42	–	25	–
6	43	2	26	–

9 January 2009 - Assuming a warm bias

The same sensitivity test as described above is performed for the trajectory started on 9 January. This trajectory was one of the warmest we considered here. Temperatures dropped only below T_{NAT} during T_2. If we assume a warm bias of 2 K in temperature,

temperatures would get cold enough so that not only during T_2 temperatures drop below T_{NAT}, but also during the T_1. The increase in time due to an increase in water vapour is again comparable to the case considered in section 2.

Table 10: Time periods when T_1 and T_2 are below the NAT and ice threshold temperature along the trajectory when the temperature along the trajectory is decreased by 2 K. T_{NAT} and T_{ice} were derived for H_2O mixing ratios of 5, 5.5 and 6 ppmv for the back trajectory started on 09 January 2009 at 01:00 UTC.

H_2O (ppmv)	$T_1 < T_{\mathrm{NAT}}$ (h)	$T_1 < T_{\mathrm{ice}}$ (h)	$T_2 < T_{\mathrm{NAT}}$ (h)	$T_2 < T_{\mathrm{ice}}$ (h)
5	6	–	24	–
5.5	8	–	33	–
6	12	–	35	–

9 January 2009 - Assuming a cold bias

The temperature along the trajectory was increased by 2 K to investigate a potential cold bias. Temperatures drop below T_{NAT} once, for the time range T_2 as it was the case for this trajectory without considering any temperature biases (section 2). The total time temperatures drop below T_{NAT} is shorter when a cold bias in the trajectory temperatures is assumed, but the increase in time due to increases in H_2O mixing ratio is comparable.

Table 11: Time periods when T_1 and T_2 are below the NAT and ice threshold temperature along the trajectory when the temperature along the trajectory is increased by 2 K. T_{NAT} and T_{ice} were derived for H_2O mixing ratios of 5, 5.5 and 6 ppmv for the back trajectory started on 9 January 2009 at 01:00 UTC.

H_2O (ppmv)	$T_1 < T_{\mathrm{NAT}}$ (h)	$T_1 < T_{\mathrm{ice}}$ (h)	$T_2 < T_{\mathrm{NAT}}$ (h)	$T_2 < T_{\mathrm{ice}}$ (h)
5	–	–	7	–
5.5	–	–	8	–
6	–	–	11	–

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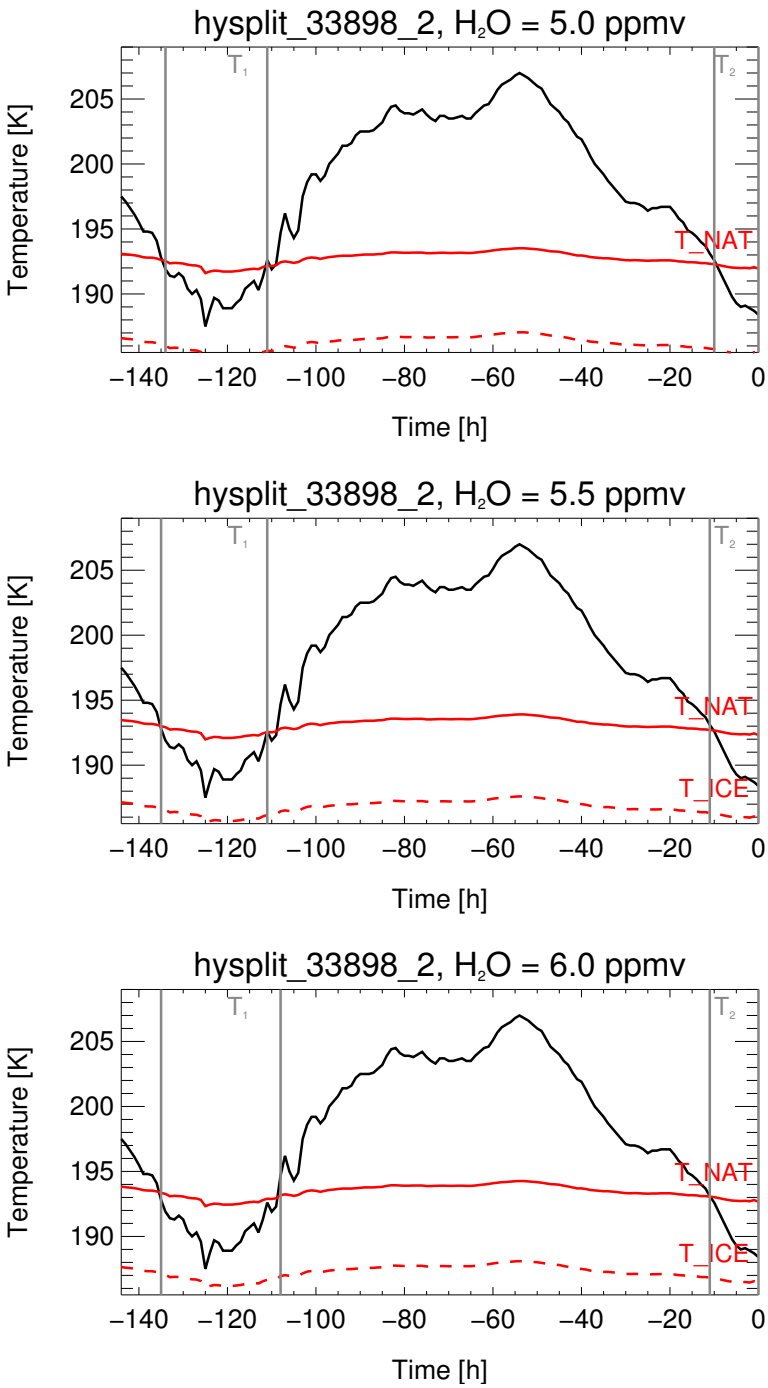

Figure 1: Temperature history of the back trajectory calculated with HYSPLIT based on the PSC measured with the IRF lidar in Kiruna, Sweden on **17 January 2010** (back trajectory started at 22 km at 01:00 UTC). Top: for a typical H_2O mixing ratio of 5 ppmv in the polar lower stratosphere, middle: for an H_2O enhancement of 0.5 ppmv (5.5 ppmv), bottom: for an H_2O enhancement of 1 ppmv (6 ppmv). The NAT existence temperature T_{NAT} and ice formation temperature T_{ice} are given as solid and dashed lines, respectively. The temperature ranges during the time periods where the temperature drops below T_{NAT} and T_{ice}, respectively, are denoted by T_1 and T_2, respectively (grey solid lines).

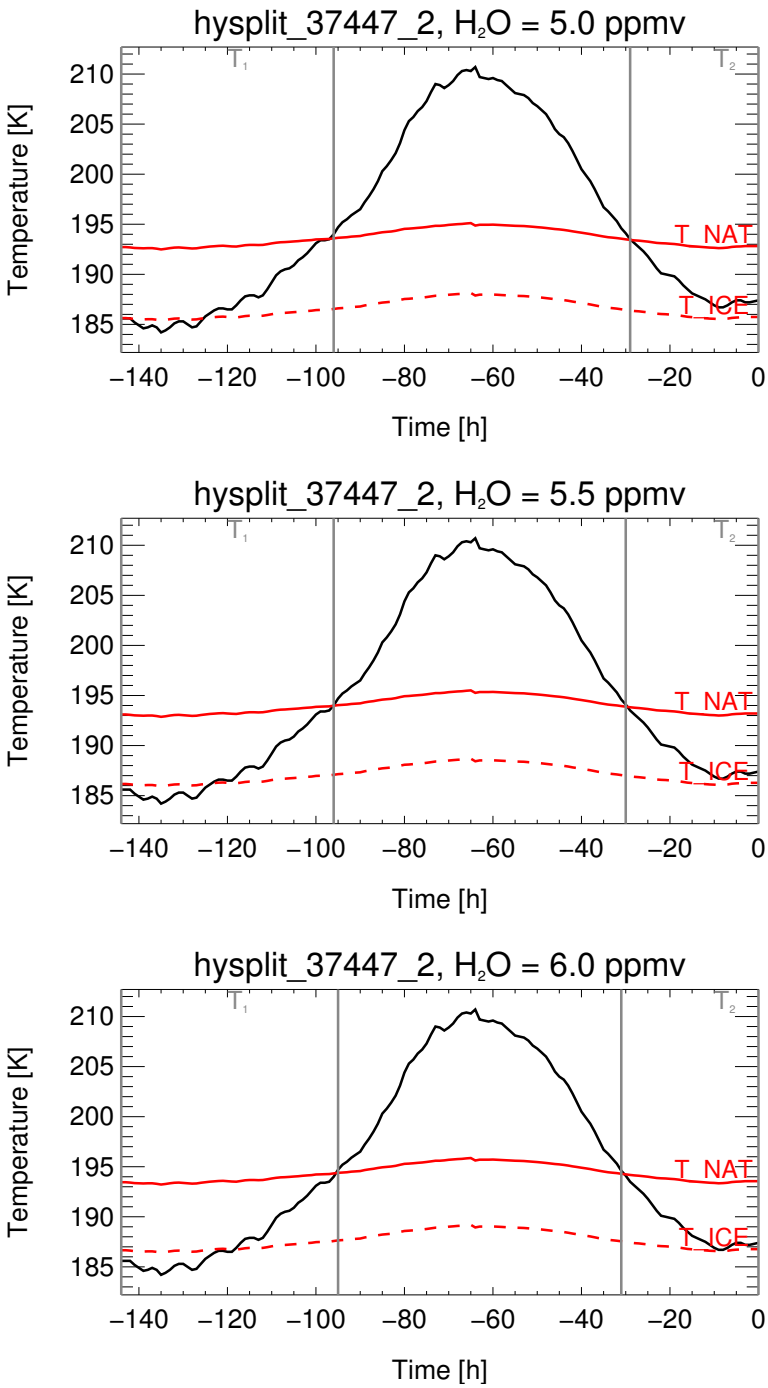

Figure 2: Temperature history of the back trajectory calculated with HYSPLIT based on the PSC observed with the Esrange lidar in Kiruna, Sweden on **23 January 2010** (back trajectory started at 22 km at 19:00 UTC). Top: for a typical H_2O mixing ratio of 5 ppmv in the polar lower stratosphere, middle: for an H_2O enhancement of 0.5 ppmv (5.5 ppmv), bottom: for an H_2O enhancement of 1 ppmv (6 ppmv). The NAT existence temperature T_{NAT} and ice formation temperature T_{ice} are given as solid and dashed lines, respectively. The temperature ranges during the time periods where the temperature drops below T_{NAT} and T_{ice}, respectively, are denoted by T_1 and T_2, respectively (grey solid lines).

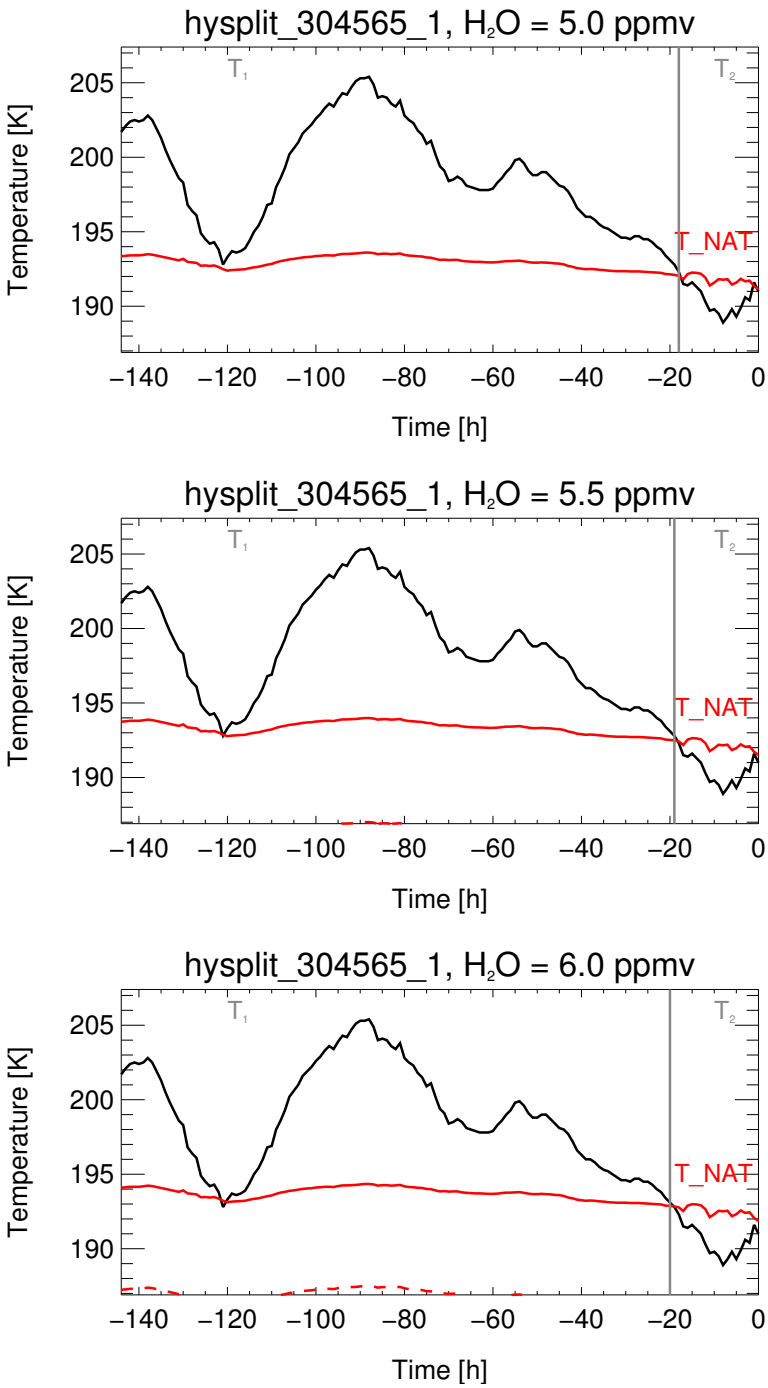

Figure 3: Temperature history of the back trajectory calculated with HYSPLIT based on the PSC observed with the Esrange lidar in Kiruna, Sweden on **8 January 2009** (back trajectory started at 23 km at 22:00 UTC). Top: for a typical H_2O mixing ratio of 5 ppmv in the polar lower stratosphere, middle: for an H_2O enhancement of 0.5 ppmv (5.5 ppmv), bottom: for an H_2O enhancement of 1 ppmv (6 ppmv). The NAT existence temperature T_{NAT} and ice formation temperature T_{ice} are given as solid and dashed lines, respectively. The temperature ranges during the time periods where the temperature drops below T_{NAT} and T_{ice}, respectively, are denoted by T_1 and T_2, respectively (grey solid lines).

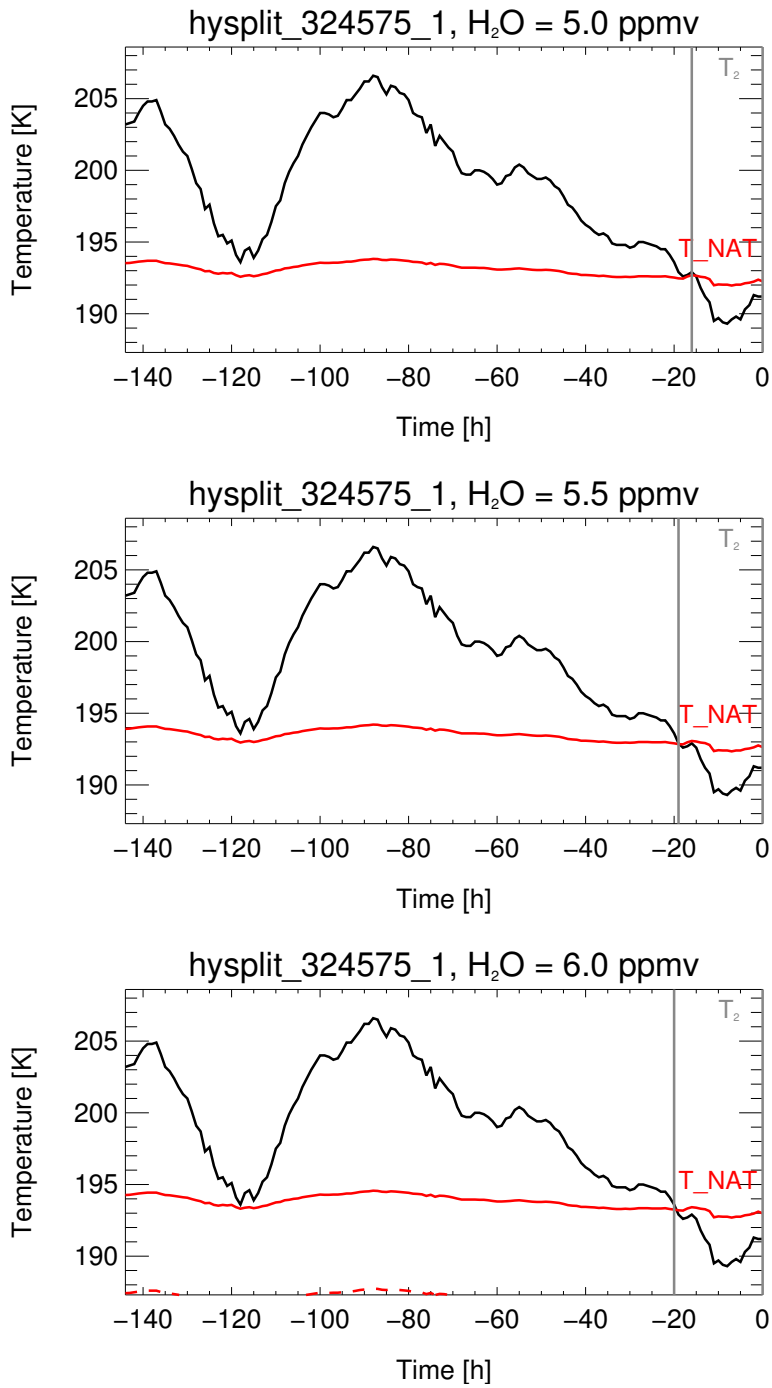

Figure 4: Temperature history of the back trajectory calculated with HYSPLIT based on the PSC observed with the Esrange lidar in Kiruna, Sweden on **9 January 2009** (back trajectory started at 22 km at 01:00 UTC). Top: for a typical H_2O mixing ratio of 5 ppmv in the polar lower stratosphere, middle: for an H_2O enhancement of 0.5 ppmv (5.5 ppmv), bottom: for an H_2O enhancement of 1 ppmv (6 ppmv). The NAT existence temperature T_{NAT} and ice formation temperature T_{ice} are given as solid and dashed lines, respectively. The temperature ranges during the time periods where the temperature drops below T_{NAT} and T_{ice}, respectively, are denoted by T_1 and T_2, respectively (grey solid lines).

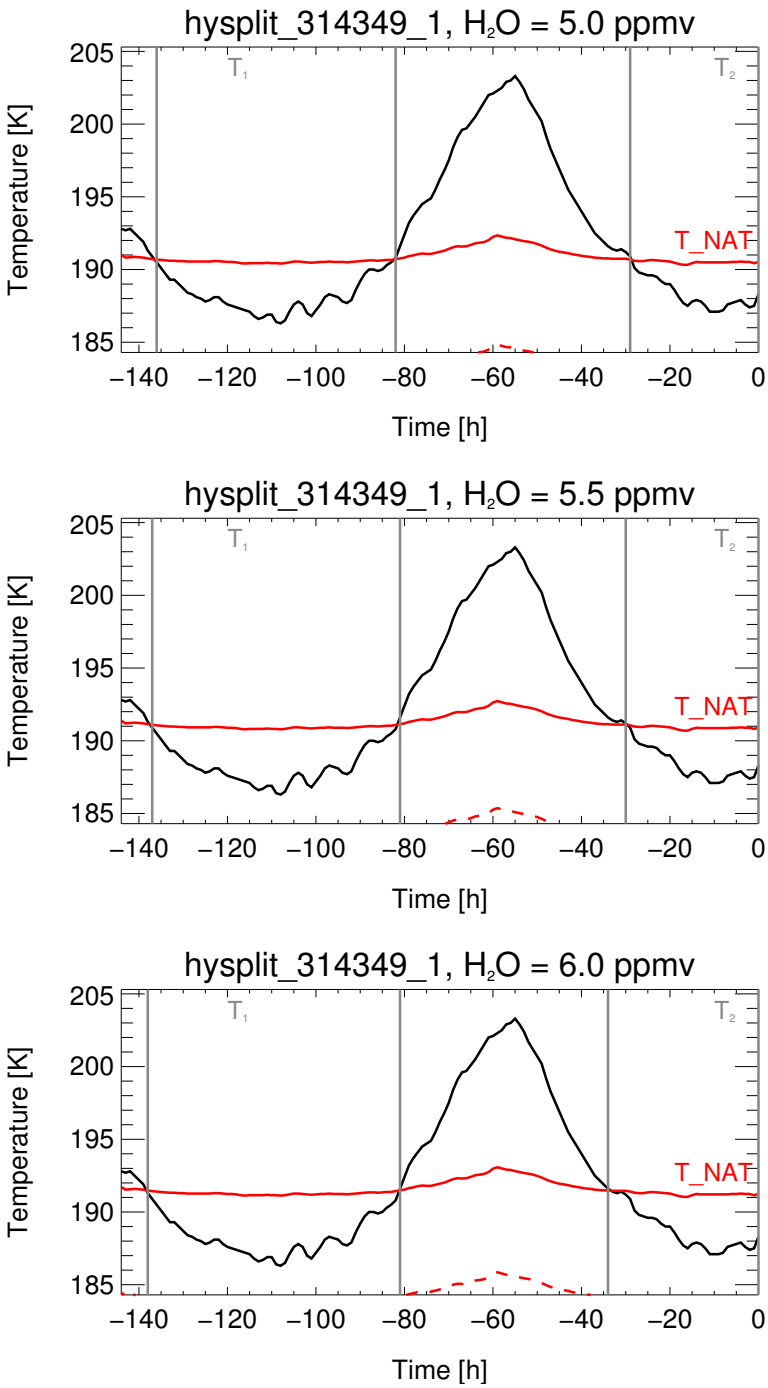

Figure 5: Temperature history of the back trajectory calculated with HYSPLIT based on the PSC observed with the Esrange lidar in Kiruna, Sweden on **22 January 2008** (back trajectory started at 24 km at 22:00 UTC). Top: for a typical H_2O mixing ratio of 5 ppmv in the polar lower stratosphere, middle: for an H_2O enhancement of 0.5 ppmv (5.5 ppmv), bottom: for an H_2O enhancement of 1 ppmv (6 ppmv). The NAT existence temperature T_{NAT} and ice formation temperature T_{ice} are given as solid and dashed lines, respectively. The temperature ranges during the time periods where the temperature drops below T_{NAT} and T_{ice}, respectively, are denoted by T_1 and T_2, respectively (grey solid lines).

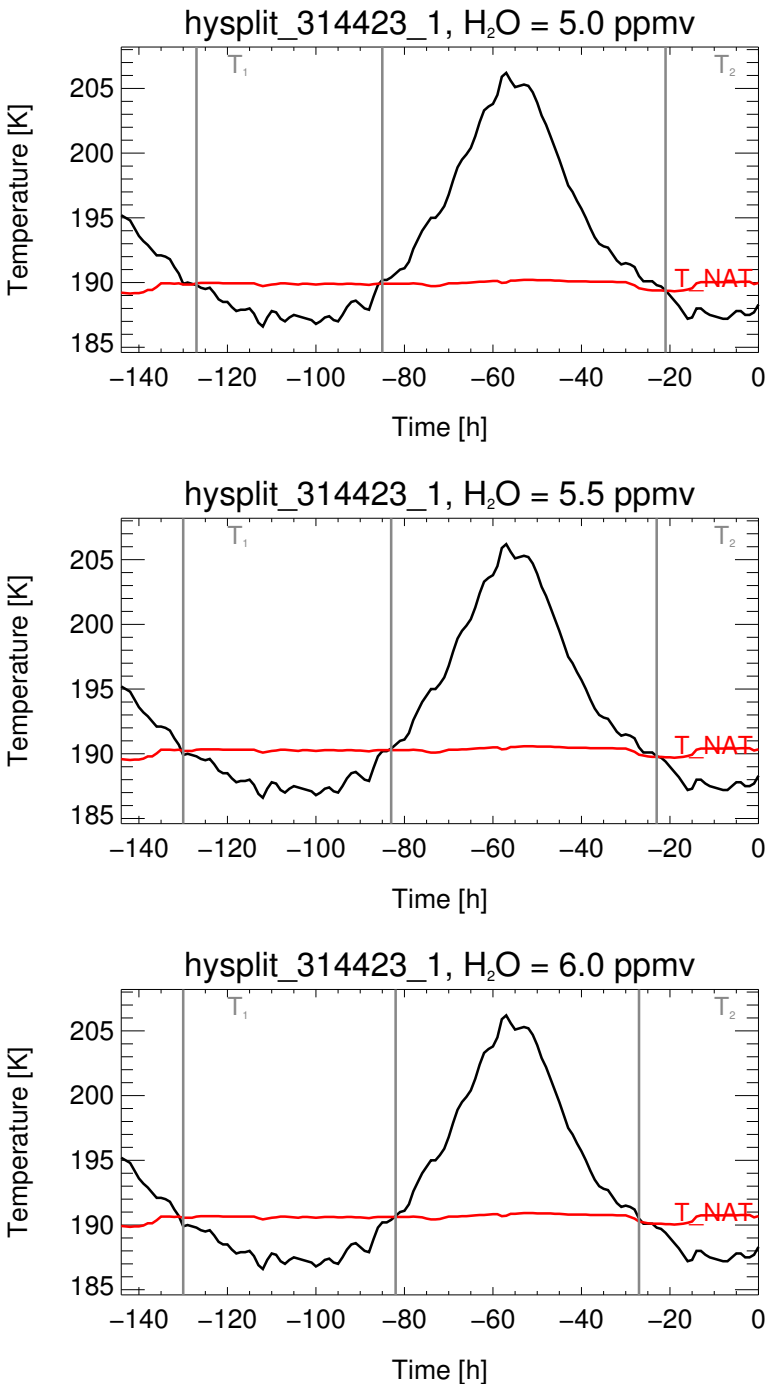

Figure 6: Temperature history of the back trajectory calculated with HYSPLIT based on the PSC observed with the Esrange lidar in Kiruna, Sweden on **23 January 2008** (back trajectory started at 24 km at 01:00 UTC). Top: for a typical H_2O mixing ratio of 5 ppmv in the polar lower stratosphere, middle: for an H_2O enhancement of 0.5 ppmv (5.5 ppmv), bottom: for an H_2O enhancement of 1 ppmv (6 ppmv). The NAT existence temperature $T_{textrmNAT}$ and ice formation temperature T_{ice} are given as solid and dashed lines, respectively. The temperature ranges during the time periods where the temperature drops below T_{NAT} and T_{ice}, respectively, are denoted by T_1 and T_2, respectively (grey solid lines).

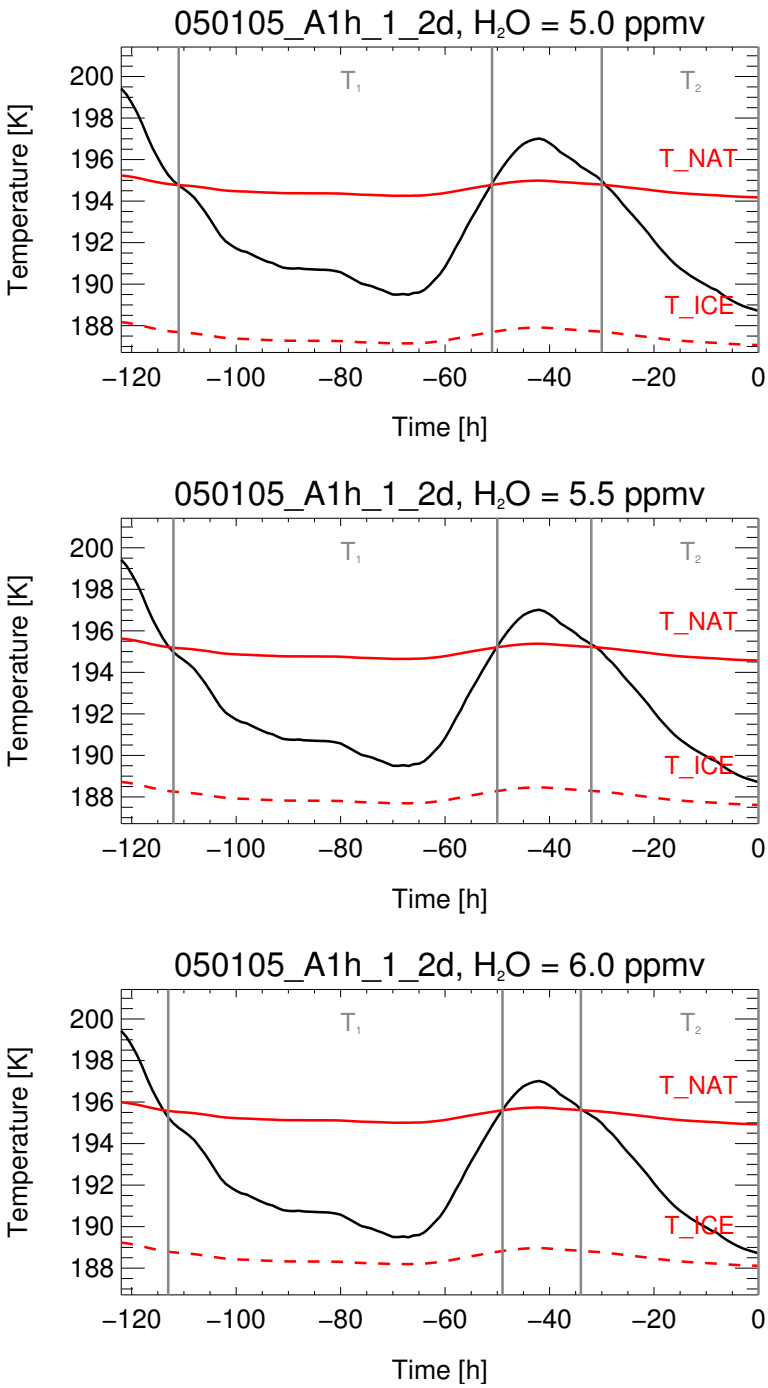

Figure 7: Temperature history of the back trajectory calculated with the CLaMS trajectory tool based on the PSC observed with the Alomar lidar in Norway on **5 January 2005** (back trajectory started at 18 km at 20:00 UTC). Top: for a typical H_2O mixing ratio of 5 ppmv in the polar lower stratosphere, middle: for an H_2O enhancement of 0.5 ppmv (5.5 ppmv), bottom: for an H_2O enhancement of 1 ppmv (6 ppmv). The NAT existence temperature T_{NAT} and ice formation temperature T_{ice} are given as solid and dashed lines, respectively. The temperature ranges during the time periods where the temperature drops below T_{NAT} and T_{ice}, respectively, are denoted by T_1 and T_2, respectively (grey solid lines).

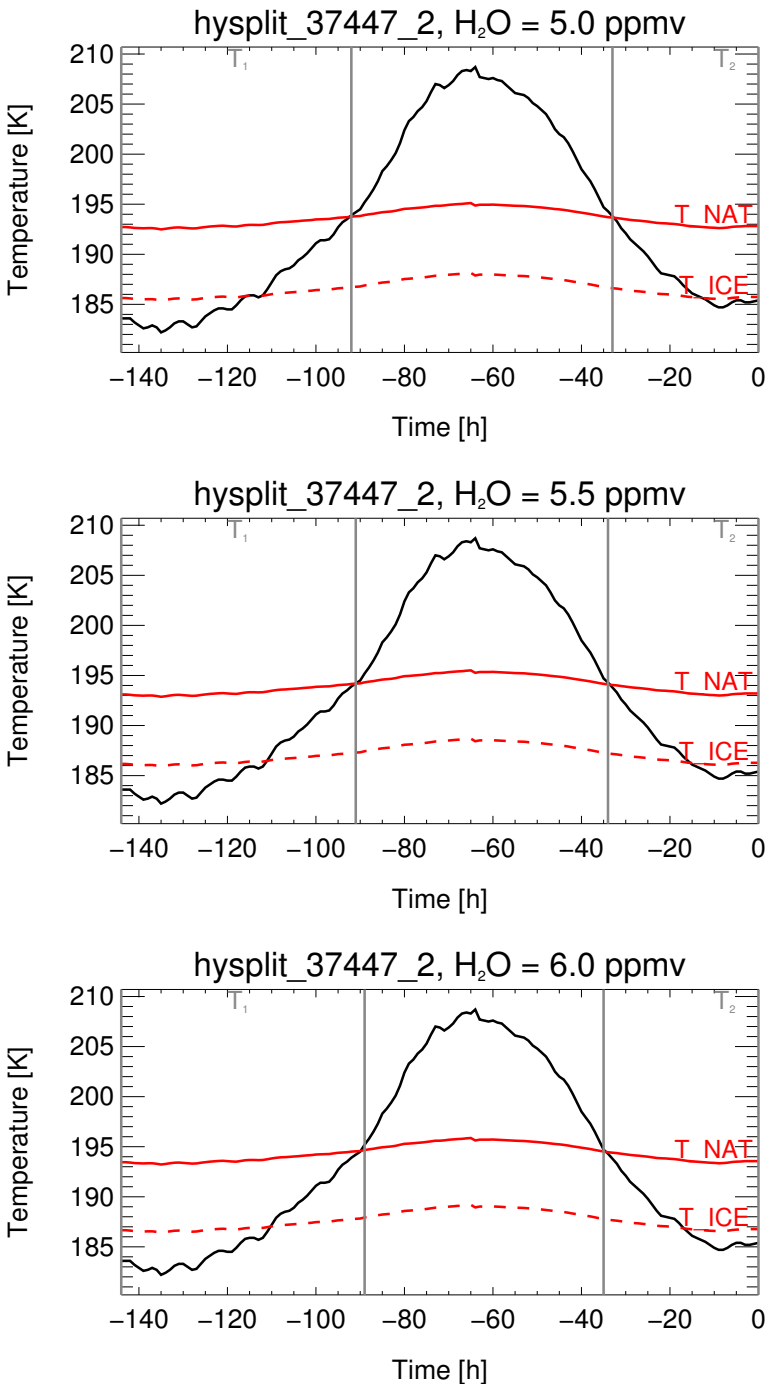

Figure 8: Temperature history of the back trajectory calculated with HYSPLIT based on the PSC observed with the Esrange lidar in Sweden on **23 January 2010** (back trajectory started at 22 km at 19:00 UTC). The temperature along the trajectory has been decreased by 2 K **(T−2 K)**. Top: for a typical H_2O mixing ratio of 5 ppmv in the polar lower stratosphere, middle: for an H_2O enhancement of 0.5 ppmv (5.5 ppmv), bottom: for an H_2O enhancement of 1 ppmv (6 ppmv). The NAT existence temperature T_{NAT} and ice formation temperature T_{ice} are given as solid and dashed lines, respectively. The temperature ranges during the time periods where the temperature drops below T_{NAT} and T_{ice}, respectively, are denoted by T_1 and T_2, respectively (grey solid lines).

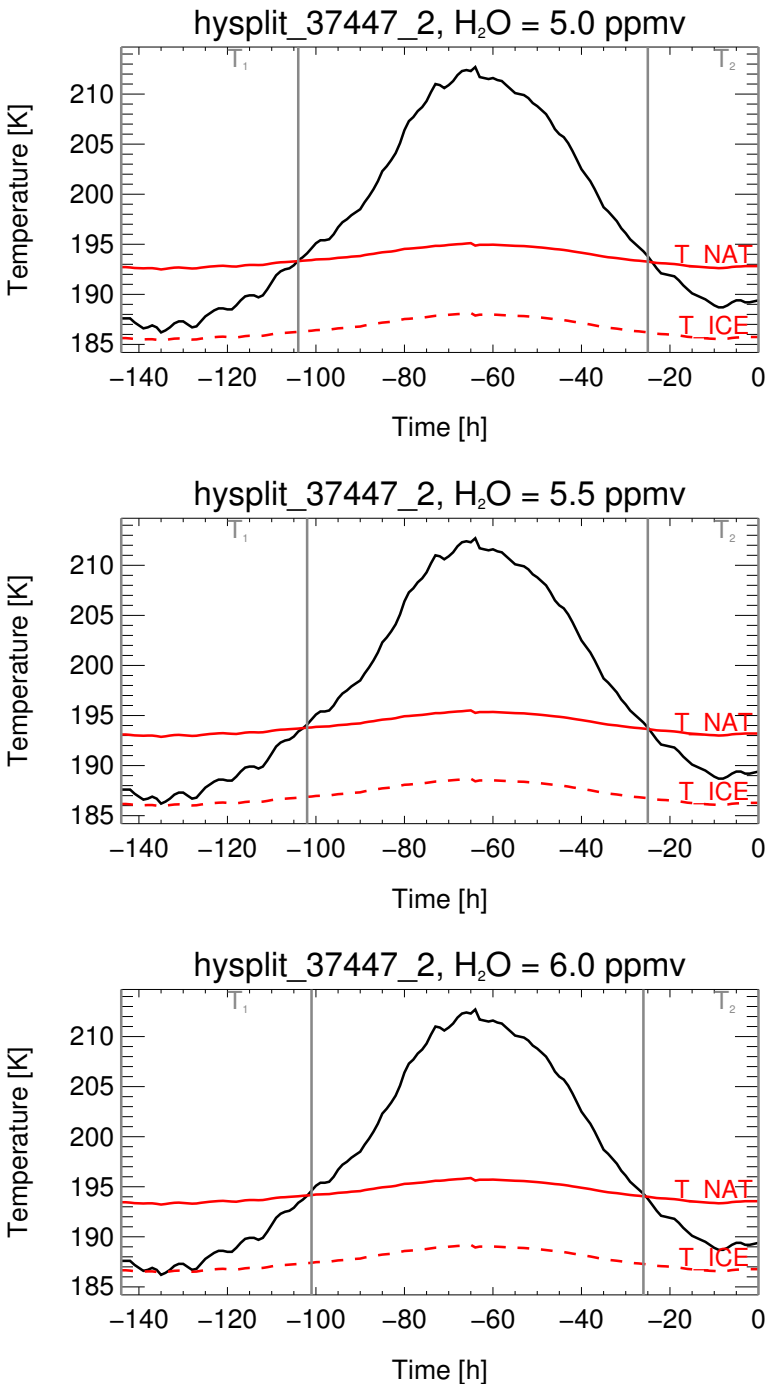

Figure 9: Temperature history of the back trajectory calculated with HYSPLIT based on the PSC observed with the Esrange lidar in Sweden on **23 January 2010** (back trajectory started at 22 km at 19:00 UTC). The temperature along the trajectory has been increased by 2 K **(T+2 K)**. Top: for a typical H_2O mixing ratio of 5 ppmv in the polar lower stratosphere, middle: for an H_2O enhancement of 0.5 ppmv (5.5 ppmv), bottom: for an H_2O enhancement of 1 ppmv (6 ppmv). The NAT existence temperature T_{NAT} and ice formation temperature T_{ice} are given as solid and dashed lines, respectively. The temperature ranges during the time periods where the temperature drops below T_{NAT} and T_{ice}, respectively, are denoted by T_1 and T_2, respectively (grey solid lines).

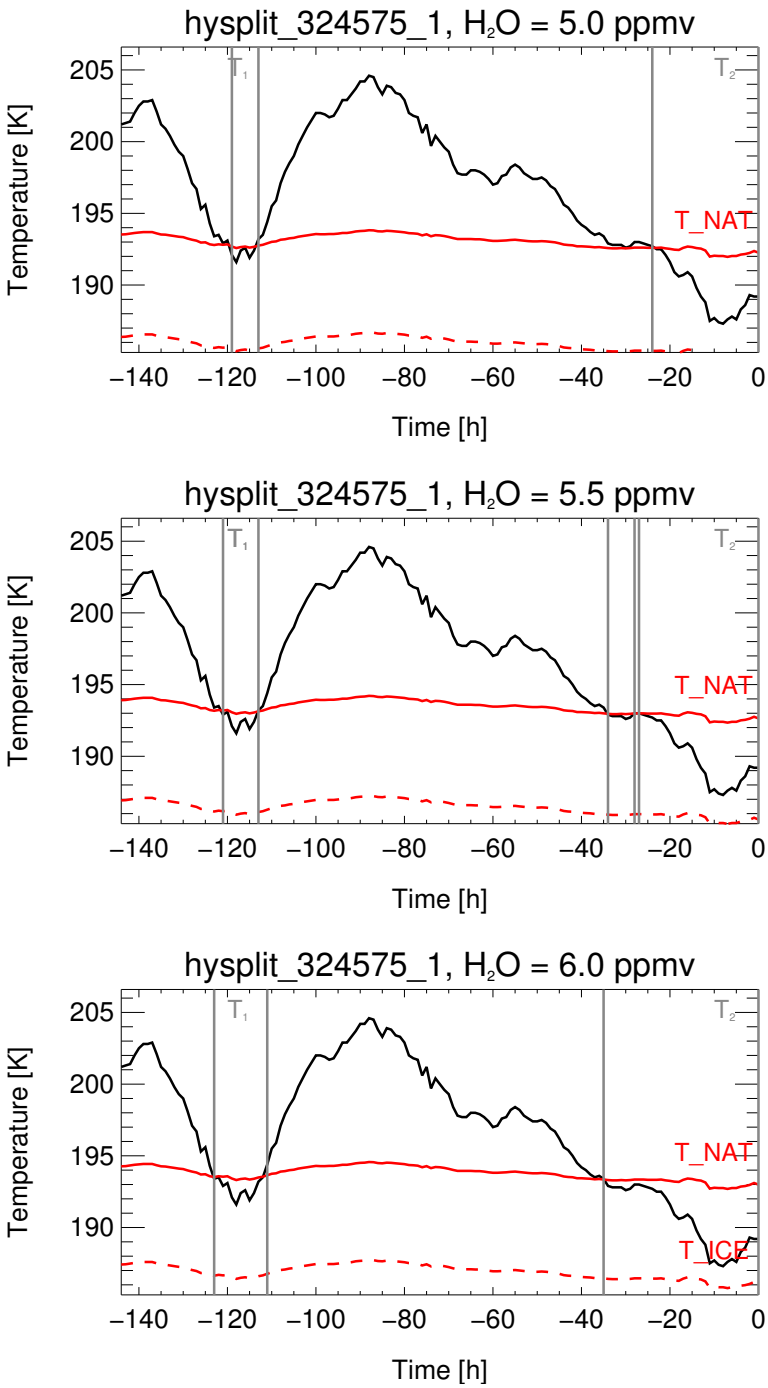

Figure 10: Temperature history of the back trajectory calculated with HYSPLIT based on the PSC observed with the Esrange lidar in Sweden on **09 January 2009** (back trajectory started at 22 km at 01:00 UTC). The temperature along the trajectory has been decreased by 2 K **(T−2 K)**. Top: for a typical H_2O mixing ratio of 5 ppmv in the polar lower stratosphere, middle: for an H_2O enhancement of 0.5 ppmv (5.5 ppmv), bottom: for an H_2O enhancement of 1 ppmv (6 ppmv). The NAT existence temperature T_{NAT} and ice formation temperature T_{ice} are given as solid and dashed lines, respectively. The temperature ranges during the time periods where the temperature drops below T_{NAT} and T_{ice}, respectively, are denoted by T_1 and T_2, respectively (grey solid lines).

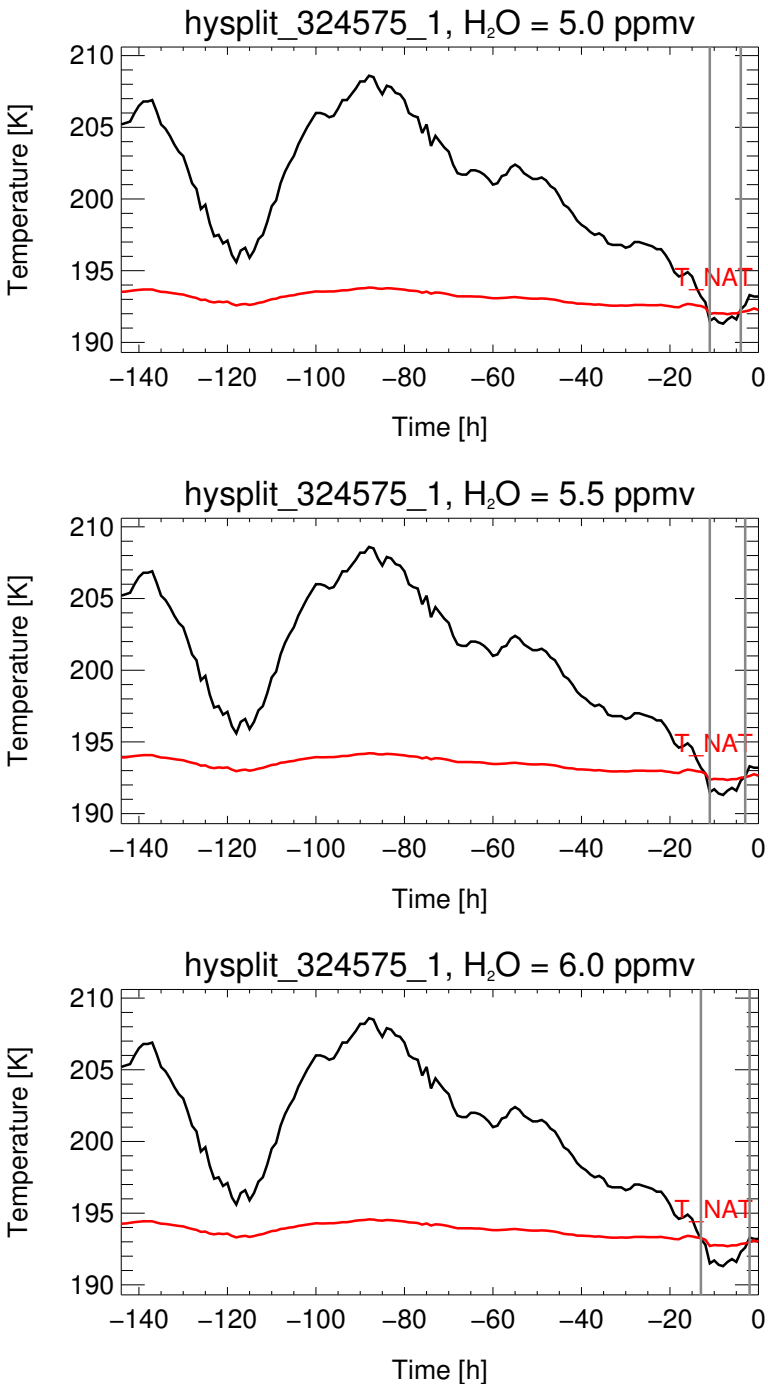

Figure 11: Temperature history of the back trajectory calculated with HYSPLIT based on the PSC observed with the Esrange lidar in Sweden on **9 January 2009** (back trajectory started at 22 km at 01:00 UTC). The temperature along the trajectory has been increased by 2 K **(T+2 K)**. Top: for a typical H_2O mixing ratio of 5 ppmv in the polar lower stratosphere, middle: for an H_2O enhancement of 0.5 ppmv (5.5 ppmv), bottom: for an H_2O enhancement of 1 ppmv (6 ppmv). The NAT existence temperature T_{NAT} and ice formation temperature T_{ice} are given as solid and dashed lines, respectively. The temperature ranges during the time periods where the temperature drops below T_{NAT} and T_{ice}, respectively, are denoted by T_1 and T_2, respectively (grey solid lines).