



Temporal stability of calibration functions in the traditional pure rotational Raman lidar technique: supplement

VLADISLAV V. GERASIMOV^{1,2,*}

¹*V.E. Zuev Institute of Atmospheric Optics SB RAS, Tomsk 634055, Russia*

²*Faculty of Physics, National Research Tomsk State University, Tomsk 634050, Russia*

**gvvsake@mail.ru*

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Temporal stability of calibration functions in the traditional pure rotational Raman lidar technique: supplemental document

VLADISLAV V. GERASIMOV^{1,2,*}

¹*V.E. Zuev Institute of Atmospheric Optics SB RAS, Tomsk 634055, Russia*

²*Faculty of Physics, National Research Tomsk State University, Tomsk 634050, Russia*

**gvvsake@mail.ru*

This document provides supplementary information to “Temporal stability of calibration functions in the traditional pure rotational Raman lidar technique,” <https://doi.org/10.1364/OSAC.xxxxxx>. The following materials are presented: temperature profiles from radiosondes launched in Novosibirsk and Kolpashevo, and reference points for the IMCES lidar calibration; raw and averaged signals detected by the IMCES lidar; temperature profiles retrieved from the signals using TRFs 3, 4, 7–9; weighting factors for calculating calibration coefficients; numerical characteristics and their averaged values for assessing the 1-week and 3-day TRF stability.

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1. Temperature Profiles from Radiosondes and Reference Data for the IMCES Lidar Calibration

Figures S1–S3 show temperature profiles (3–9 km) obtained by radiosondes that were launched at meteorological stations in Novosibirsk (55.02°N, 82.92°E) and Kolpashevo (58.32°N, 82.92°E) simultaneously with the IMCES lidar measurements in Tomsk (56.48°N, 85.05°E) at 06:00 LT (00:00 UTC) on 1, 6, and 8 April 2015. The reference points for the IMCES lidar calibration are also given.

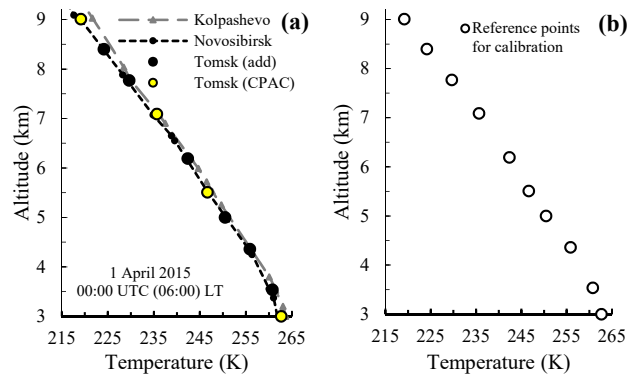


Fig. S1. (a) Temperature profiles (3–9 km) from radiosondes launched in Novosibirsk and Kolpashevo at 06:00 LT (00:00 UTC) on 1 April 2015, temperature points over Tomsk retrieved using CPACs, and additional points obtained by linear interpolation. (b) Reference points for the IMCES lidar calibration.

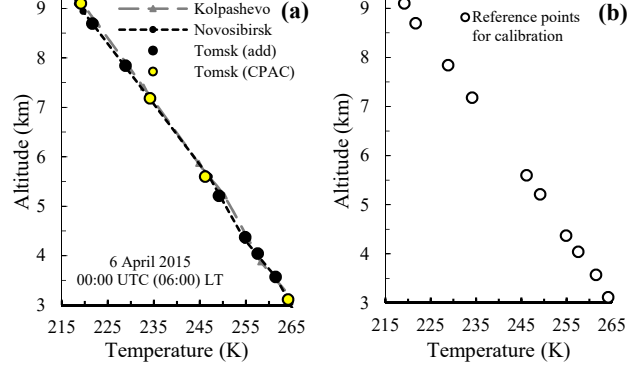


Fig. S2. (a) Temperature profiles (3–9 km) from radiosondes launched in Novosibirsk and Kolpashevo on 6 April 2015, temperature points over Tomsk (CPACs), and additional points obtained by linear interpolation. (b) Reference points for the IMCES lidar calibration.

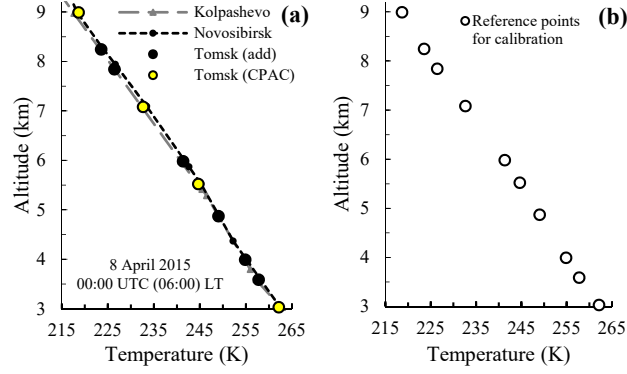


Fig. S3. (a) Temperature profiles (3–9 km) from radiosondes launched in Novosibirsk and Kolpashevo on 8 April 2015, temperature points over Tomsk (CPACs), and additional points obtained by linear interpolation. (b) Reference points for the IMCES lidar calibration.

2. Raw and Averaged IMCES Lidar Signals

Figures S4–S7 present raw signals N_L and N_H detected in two IMCES lidar channels on 1, 6, 7, and 8 April 2015, single-averaged signals $\bar{N}_L$ and $\bar{N}_H$, ratio of raw signals $Q_{\text{raw}} = N_L/N_H$, and additionally averaged ratio of single-averaged signals $\bar{Q} = \bar{N}_L/\bar{N}_H$. The description of the raw lidar-data-averaging procedure is given in [1].

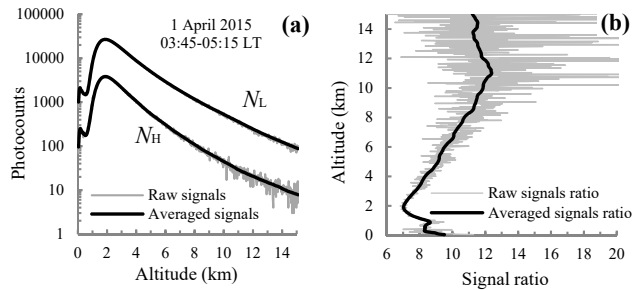


Fig. S4. (a) Raw photocounts N_L and N_H taken from 03:45 to 05:15 LT on 1 April 2015 along with single-averaged photocounts $\bar{N}_L$ and $\bar{N}_H$. (b) Raw photocount ratio $Q_{\text{raw}} = N_L/N_H$ and additionally averaged ratio of single-averaged signals $\bar{Q} = \bar{N}_L/\bar{N}_H$.

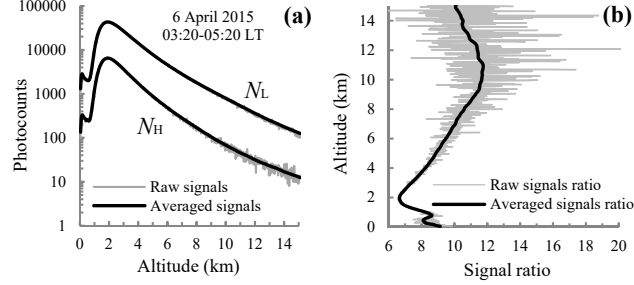


Fig. S5. (a) Raw photocounts N_L and N_H detected on 6 April 2015 along with single-averaged photocounts $\bar{N}_L$ and $\bar{N}_H$. (b) Raw photocount ratio Q_{raw} and additionally averaged ratio of single-averaged signals $\bar{Q}$.

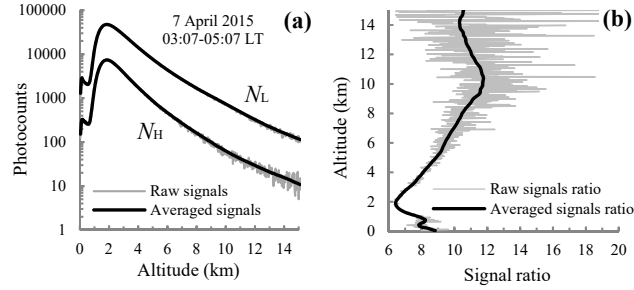


Fig. S6. (a) Raw photocounts N_L and N_H detected on 7 April 2015 along with single-averaged photocounts $\bar{N}_L$ and $\bar{N}_H$. (b) Raw photocount ratio Q_{raw} and additionally averaged ratio of single-averaged signals $\bar{Q}$.

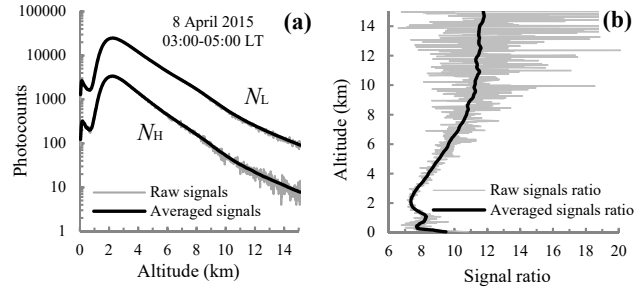


Fig. S7. (a) Raw photocounts N_L and N_H detected on 8 April 2015 along with single-averaged photocounts $\bar{N}_L$ and $\bar{N}_H$. (b) Raw photocount ratio Q_{raw} and additionally averaged ratio of single-averaged signals $\bar{Q}$.

3. Temperature Profiles Retrieved using TRFs 3, 4, 7–9

Figures S8–S11 show tropospheric temperature profiles (3–9 km) retrieved from the 1, 6, 7, and 8 April lidar data using TRF 3, 4, 7–9. For simplicity, the absolute ΔT and relative $(\Delta T/T)$ statistical uncertainties of temperature retrieval from the ratio $\bar{Q} = \bar{N}_L/\bar{N}_H$ are denoted by ΔT and $(\Delta T/T)$, respectively. The formulas for calculating both uncertainties for all used TRFs are given in Ref. [2]. The absolute differences $|T_{\text{ref}} - T|$ between the reference points T_{ref} and corresponding points T (in altitude) of the retrieved profile are also shown in Figs. S8–S11. The retrieved profiles are very close to each other, especially in Figs. S8–S10. However, it is possible to distinguish between the profiles via the difference $|T_{\text{ref}} - T|$.

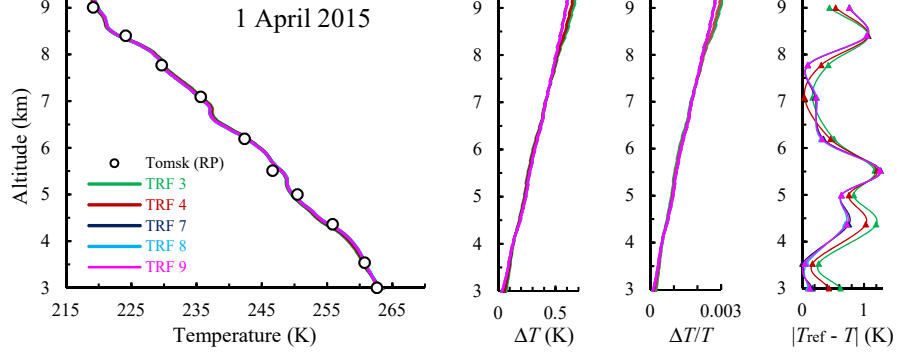


Fig. S8. Reference points (RP) T_{ref} over Tomsk and temperature profiles T retrieved from the 1 April lidar data (Fig. S4) using TRFs 3, 4, 7–9; absolute ΔT and relative ($\Delta T/T$) statistical uncertainties of temperature retrieval, and absolute difference $|T_{\text{ref}} - T|$.

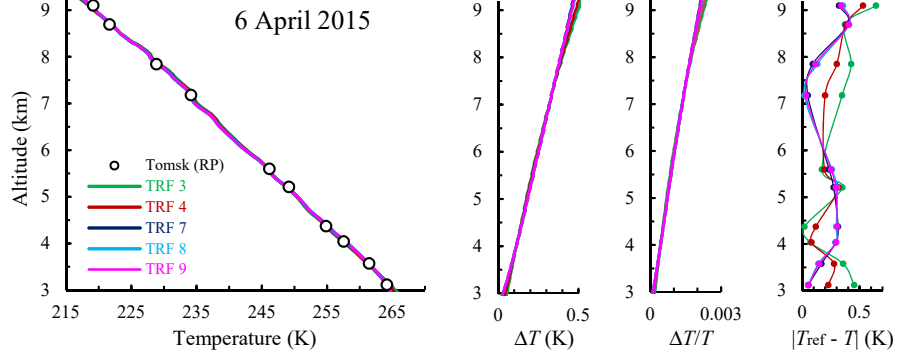


Fig. S9. Temperature profiles T retrieved from the 6 April lidar data (Fig. S5) using TRFs 3, 4, 7–9; absolute ΔT and relative ($\Delta T/T$) statistical uncertainties of temperature retrieval, and absolute difference $|T_{\text{ref}} - T|$.

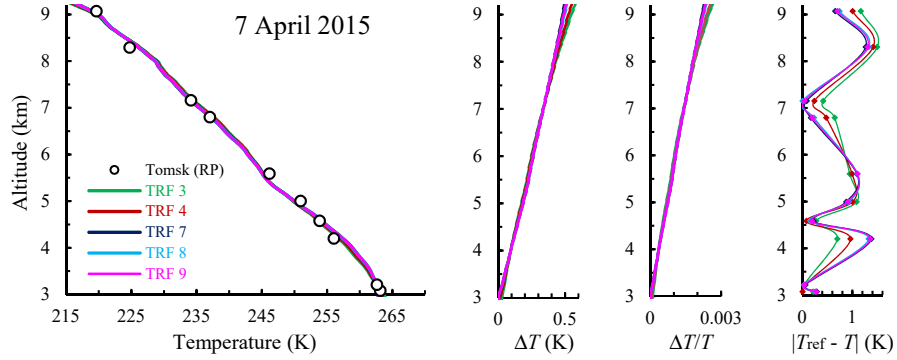


Fig. S10. Temperature profiles T retrieved from the 7 April lidar data (Fig. S6) using TRFs 3, 4, 7–9; absolute ΔT and relative ($\Delta T/T$) statistical uncertainties of temperature retrieval, and absolute difference $|T_{\text{ref}} - T|$.

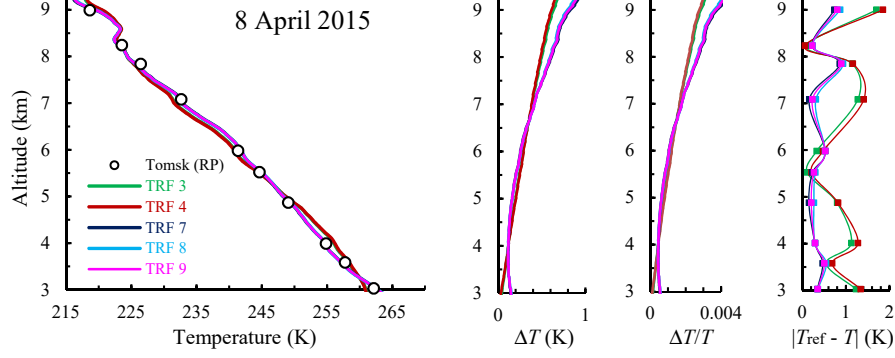


Fig. S11. Temperature profiles T retrieved from the 7 April lidar data (Fig. S7) using TRFs 3, 4, 7–9; absolute ΔT and relative ($\Delta T/T$) statistical uncertainties of temperature retrieval, and absolute difference $|T_{\text{ref}} - T|$.

Table S1 shows the average values of $|T_{\text{ref}} - T|$ (i.e., $\langle |T_{\text{ref}} - T| \rangle$) for each measurement date (Figs. S8–S11), sum Σ of these values, and averaged value $\Sigma/4$ when using TRFs 3, 4, 7–9. The averaging of $|T_{\text{ref}} - T|$ is performed over ten reference points. The smallest values of $\langle |T_{\text{ref}} - T| \rangle$, Σ , and $\Sigma/4$ in each column are highlighted in bold. It is clearly seen that the use of four-coefficient TRFs 7–9 leads to smaller temperature errors than the use of three-coefficient TRFs 3 and 4, and TRF 7 provides the most accurate temperature retrievals.

Table S1. Average values of the difference $|T_{\text{ref}} - T|$ (for 1, 6–8 April). The smallest value in each column is in bold

	1 April	6 April	7 April	8 April		
	$\langle T_{\text{ref}} - T \rangle$ (K)				Σ (K)	$\Sigma/4$ (K)
TRF 3	0.67	0.32	0.70	0.84	2.53	0.63
TRF 4	0.60	0.26	0.62	0.93	2.41	0.60
TRF 7	0.53	0.22	0.61	0.40	1.76	0.44
TRF 8	0.52	0.23	0.61	0.46	1.82	0.46
TRF 9	0.52	0.22	0.61	0.43	1.78	0.45

4. Calibration Coefficients of TRF 3, 7, 8, and 9

Figures S12–S15 present the calibration coefficients of TRFs 3, 7–9, calculated by applying the least square method to the lidar data and reference temperature points of 1, 6, 7, and 8 April 2015. The coefficients of TRF 4 are given in Fig. 2 in the main text.

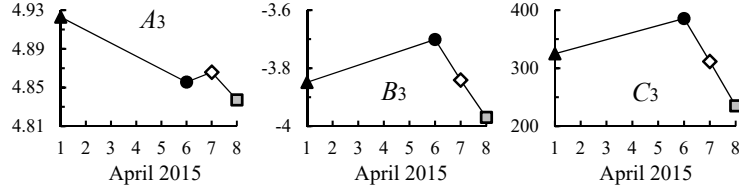


Fig. S12. Calibration coefficients A_3 , B_3 , and C_3 of TRF 3 calculated for 1, 6, 7, and 8 April 2015.

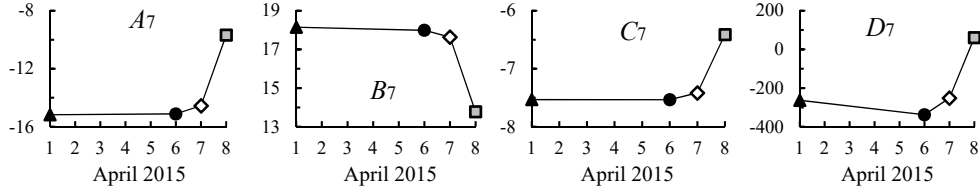


Fig. S13. Calibration coefficients A_7 , B_7 , C_7 , and D_7 of TRF 7 calculated for 1, 6, 7, and 8 April 2015.

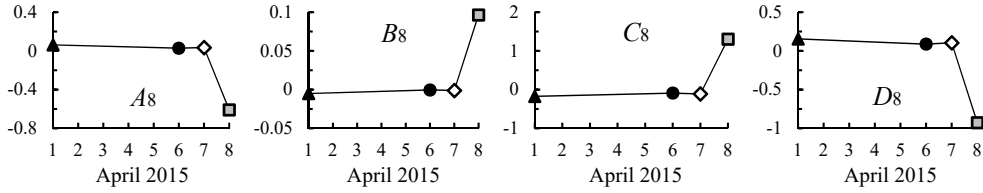


Fig. S14. Calibration coefficients A_8 , B_8 , C_8 , and D_8 of TRF 8 calculated for 1, 6, 7, and 8 April 2015.

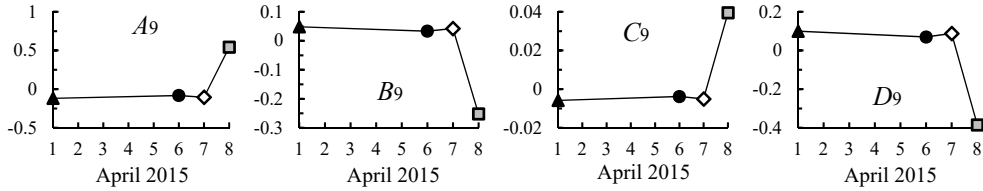


Fig. S15. Calibration coefficients A_9 , B_9 , C_9 , and D_9 of TRF 9 calculated for 1, 6, 7, and 8 April 2015.

5. Weighting Factors for Calculating Calibration Coefficients

In order to calculate the calibration coefficients of TRFs 3, 4, 7–9 on the day, on which the reference points are absent, we use both arithmetic and weighted average values of the coefficients determined in the remaining days of the measurement campaign. When using the arithmetic average, all the weights of calibration coefficients (and, therefore, their weighting factors) determined in different days are equal to each other. In contrast, when using the weighted average to calculate the calibration coefficients on day k , we assume that the weight of the coefficients on each subsequent ($k + 1$) and previous ($k - 1$) day is two times smaller than that on day k . For example, the weighted average value of each of A_i , B_i , C_i , (D_i) for 6 April is obtained as the sum of the coefficients for 1, 7, and 8 April with weighting factors of $1/25$, $16/25$, and $8/25$, respectively. All the weighting factors for calculating calibration coefficients are given in Table S2 and S3 for the 1-week (1, 6–8 April) and 3-day (6–8 April) periods, respectively.

Table S2. Weighting factors for calculating calibration coefficients (1-week period)

1 April								
Day	1 Apr	2 Apr	3 Apr	4 Apr	5 Apr	6 Apr	7 Apr	8 Apr
Weight (max = 1)	1	1/2	1/4	1/8	1/16	1/32	1/64	1/128
Weight (min = 1)	128	64	32	16	8	4	2	1
Weighting factor	(4 + 2 + 1 = 7) ⇒					4/7	2/7	1/7
6 April								
Day	1 Apr	2 Apr	3 Apr	4 Apr	5 Apr	6 Apr	7 Apr	8 Apr
Weight (max = 1)	1/32	1/16	1/8	1/4	1/2	1	1/2	1/4
Weight (min = 1)	1	2	4	8	16	32	16	8
Weighting factor	1/25	⇐ (1 + 16 + 8 = 25) ⇒					16/25	8/25
7 April								
Day	1 Apr	2 Apr	3 Apr	4 Apr	5 Apr	6 Apr	7 Apr	8 Apr
Weight (max = 1)	1/64	1/32	1/16	1/8	1/4	1/2	1	1/2
Weight (min = 1)	1	2	4	8	16	32	64	32
Weighting factor	1/65	⇐ (1 + 32 + 32 = 65) ⇒				32/65	32/65	
8 April								
Day	1 Apr	2 Apr	3 Apr	4 Apr	5 Apr	6 Apr	7 Apr	8 Apr
Weight (max = 1)	1/128	1/64	1/32	1/16	1/8	1/4	1/2	1
Weight (min = 1)	1	2	4	8	16	32	64	128
Weighting factor	1/97	⇐ (1 + 32 + 64 = 97) ⇒				32/97	64/97	

Table S3. Weighting factors for calculating calibration coefficients (3-day period)

6 April			
Day	6 Apr	7 Apr	8 Apr
Weight (max = 1)	1	1/2	1/4
Weight (min = 1)	4	2	1
Weighting factor		2/3	1/3
7 April			
Day	6 Apr	7 Apr	8 Apr
Weight (max = 1)	1/2	1	1/2
Weight (min = 1)	1	2	1
Weighting factor	1/2		1/2
8 April			
Day	6 Apr	7 Apr	8 Apr
Weight (max = 1)	1/4	1/2	1
Weight (min = 1)	1	2	4
Weighting factor	1/3	2/3	

6. 1-Week Stability Characteristics of TRFs 3, 7, 8, and 9

Figures S16–S25, S26–S35, S36–S45, and S46–S55 contain the same information for TRFs 3, 7, 8, and 9, respectively, as Figs. 3–12 do for TRF 4 in the main text. Two numerical characteristics for assessing the temporal stability of TRFs are taken into account, the description of which is given in detail in the main text (see Section 4.2).

6.1 TRF 3

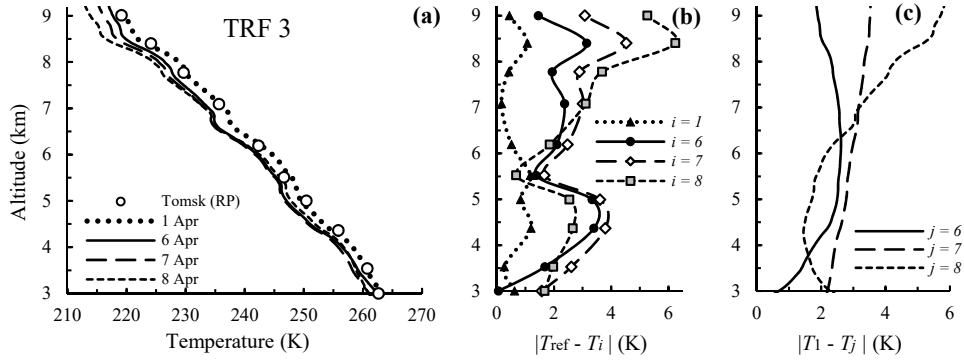


Fig. S16. (a) Temperature profiles retrieved by TRF 3 from the 1 April lidar data. Reference points (RP) are given for 1 April. The absolute differences: (b) $|T_{\text{ref}} - T_i|$ ($i = 1, 6, 7, 8$); (c) $|T_1 - T_j|$ ($j = 6, 7, 8$).

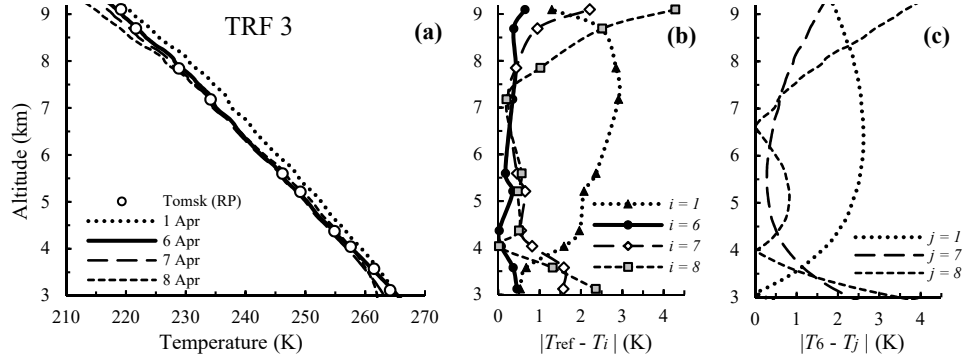


Fig. S17. (a) Temperature profiles retrieved by TRF 3 from the 6 April lidar data. Reference points (RP) are given for 6 April. The absolute differences: (b) $|T_{\text{ref}} - T_i|$; (c) $|T_6 - T_j|$ ($j = 1, 7, 8$).

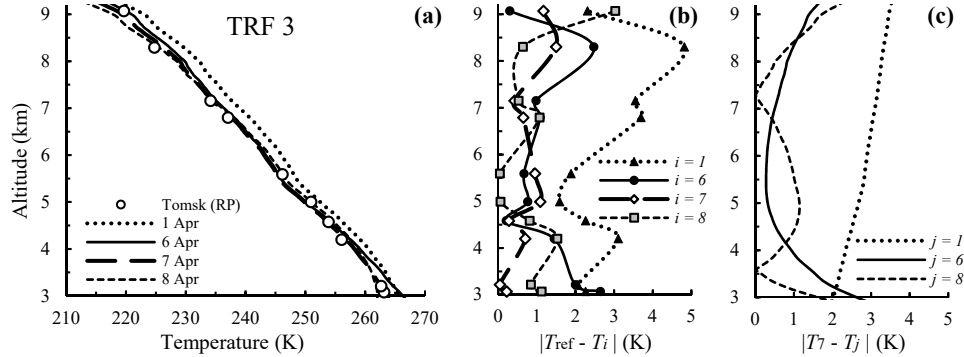


Fig. S18. (a) Temperature profiles retrieved by TRF 3 from the 7 April lidar data. Reference points (RP) are given for 7 April. The absolute differences: (b) $|T_{\text{ref}} - T_i|$; (c) $|T_7 - T_j|$ ($j = 1, 6, 8$).

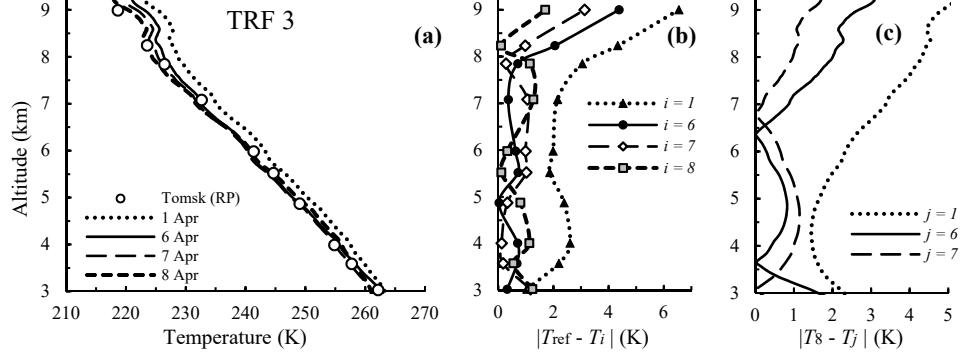


Fig. S19. (a) Temperature profiles retrieved by TRF 3 from the 8 April lidar data. Reference points (RP) are given for 8 April. The absolute differences: (b) $|T_{\text{ref}} - T_i|$; (c) $|T_8 - T_j|$ ($j = 1, 6, 7$).

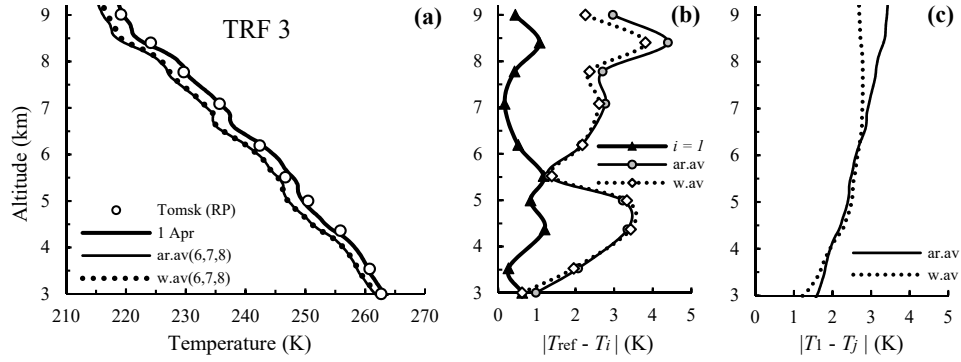


Fig. S20. (a) Temperature profiles retrieved by TRF 3 from the 1 April lidar data. Arithmetic and weighted average values of TRF 3 coefficients were used to obtain profiles "ar.av(6,7,8)" and "w.av(6,7,8)". The absolute differences: (b) $|T_{\text{ref}} - T_i|$ ($i = 1$, "ar.av", "w.av"); (c) $|T_1 - T_j|$ ($j =$ "ar.av", "w.av").

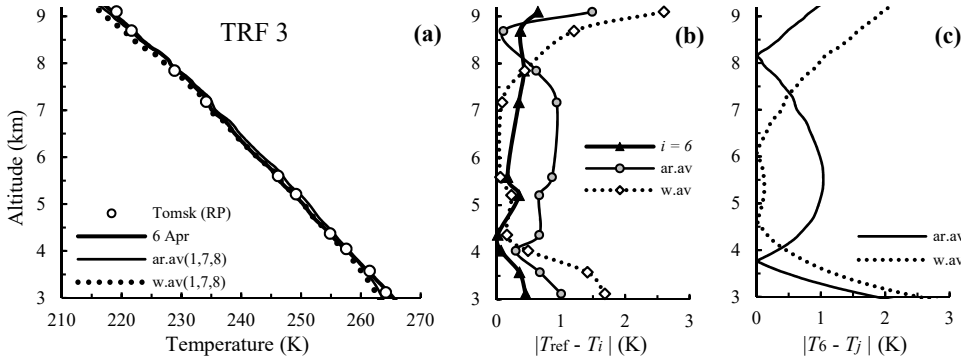


Fig. S21. (a) Temperature profiles retrieved by TRF 3 from the 6 April lidar data. Arithmetic and weighted average values of TRF 3 coefficients were used to obtain profiles "ar.av(1,7,8)" and "w.av(1,7,8)". The absolute differences: (b) $|T_{\text{ref}} - T_i|$ ($i = 6$, "ar.av", "w.av"); (c) $|T_6 - T_j|$.

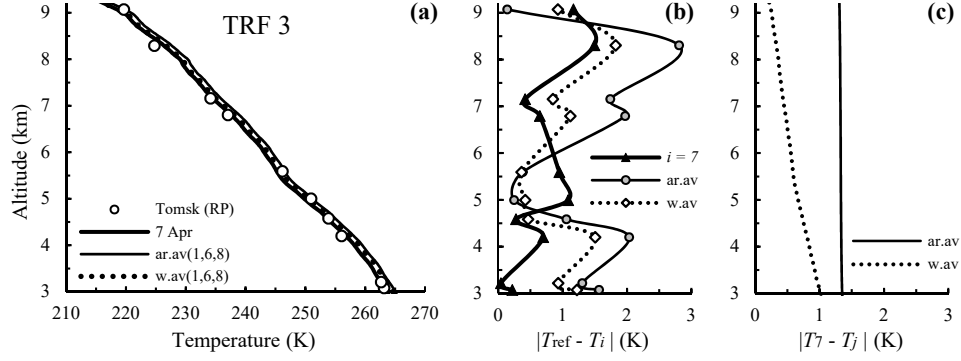


Fig. S22. (a) Temperature profiles retrieved by TRF 3 from the 7 April lidar data. Arithmetic and weighted average values of TRF 3 coefficients were used to obtain profiles “ar.av(1,6,8)” and “w.av(1,6,8)”, respectively. The absolute differences: (b) $|T_{\text{ref}} - T_i|$ ($i = 7$, “ar.av”, “w.av”); (c) $|T_7 - T_j|$.

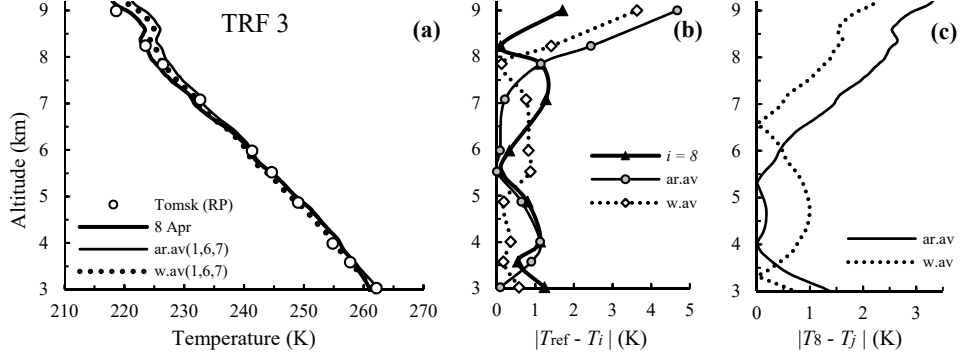


Fig. S23. (a) Temperature profiles retrieved by TRF 3 from the 8 April lidar data. Arithmetic and weighted average values of TRF 3 coefficients were used to obtain profiles “ar.av(1,6,7)” and “w.av(1,6,7)”, respectively. The absolute differences: (b) $|T_{\text{ref}} - T_i|$ ($i = 8$, “ar.av”, “w.av”); (c) $|T_8 - T_j|$.

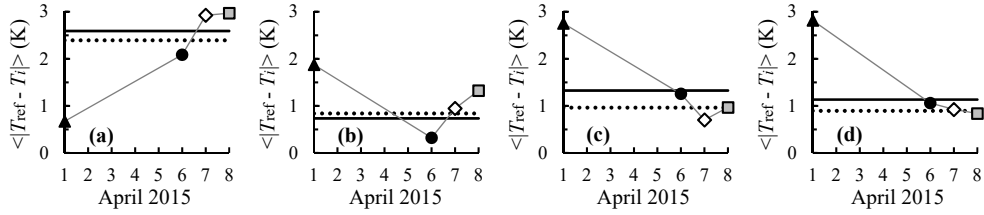


Fig. S24. (TRF 3) Average differences $\langle |T_{\text{ref}} - T_i| \rangle$ ($i = 1, 6, 7, 8$, “ar.av”, and “w.av”) obtained using the lidar measurement data of: (a) 1 April, (b) 6 April, (c) 7 April, and (d) 8 April. The solid and dotted horizontal lines correspond to $i = \text{“ar.av”}$ and $i = \text{“w.av”}$, respectively.

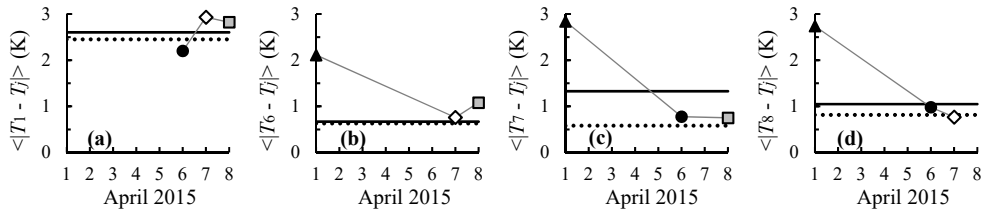


Fig. S25. (TRF 3) Average differences: (a) $\langle |T_1 - T_j| \rangle$ ($j = 6, 7, 8$, “ar.av”, and “w.av”), (b) $\langle |T_6 - T_j| \rangle$ ($j = 1, 7, 8$, “ar.av”, and “w.av”), (c) $\langle |T_7 - T_j| \rangle$ ($j = 1, 6, 8$, “ar.av”, and “w.av”), and (d) $\langle |T_8 - T_j| \rangle$ ($j = 1, 6, 7$, “ar.av”, and “w.av”). The solid and dotted horizontal lines correspond to $j = \text{“ar.av”}$ and $j = \text{“w.av”}$, respectively.

6.2 TRF 7

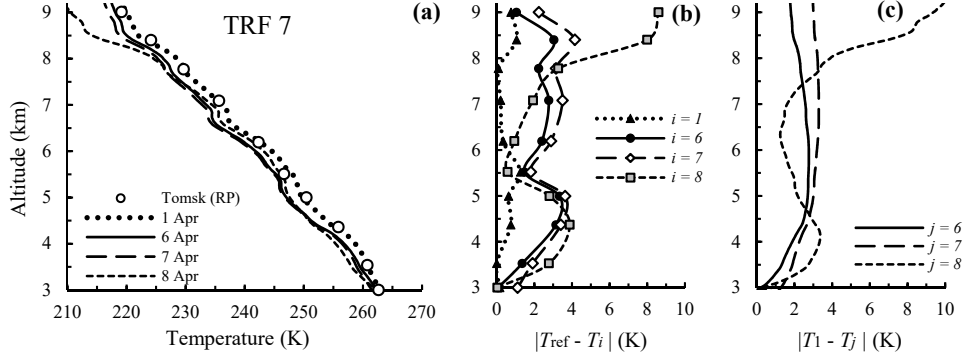


Fig. S26. (a) Temperature profiles retrieved by TRF 7 from the 1 April lidar data. Reference points (RP) are given for 1 April. The absolute differences: (b) $|T_{\text{ref}} - T_i|$ ($i = 1, 6, 7, 8$); (c) $|T_1 - T_j|$ ($j = 6, 7, 8$).

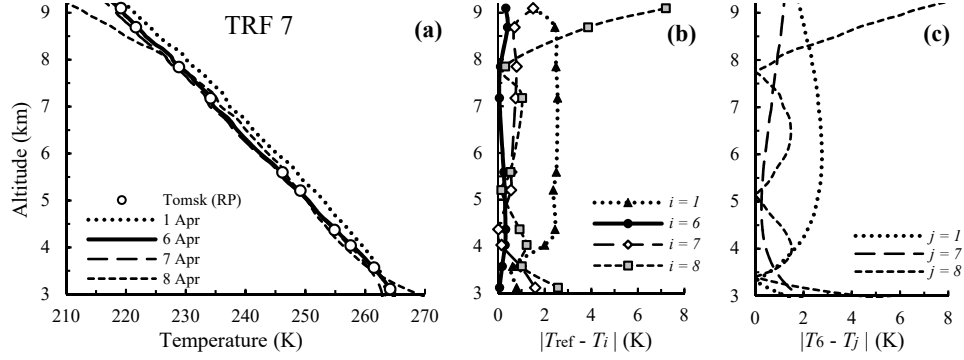


Fig. S27. (a) Temperature profiles retrieved by TRF 7 from the 6 April lidar data. Reference points (RP) are given for 6 April. The absolute differences: (b) $|T_{\text{ref}} - T_i|$; (c) $|T_6 - T_j|$ ($j = 1, 7, 8$).

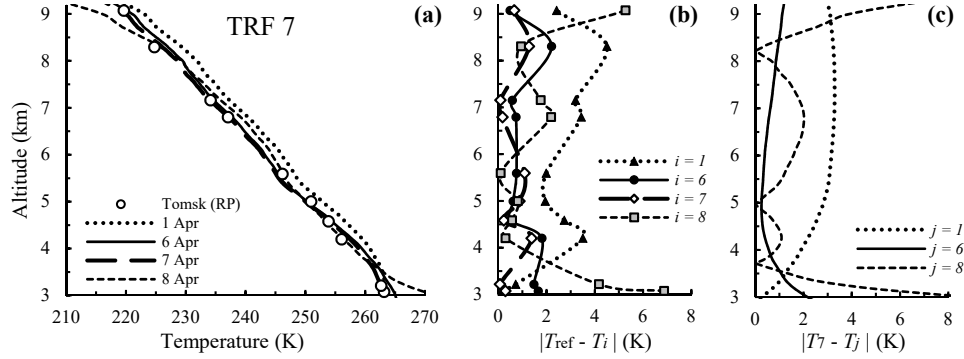


Fig. S28. (a) Temperature profiles retrieved by TRF 7 from the 7 April lidar data. Reference points (RP) are given for 7 April. The absolute differences: (b) $|T_{\text{ref}} - T_i|$; (c) $|T_7 - T_j|$ ($j = 1, 6, 8$).

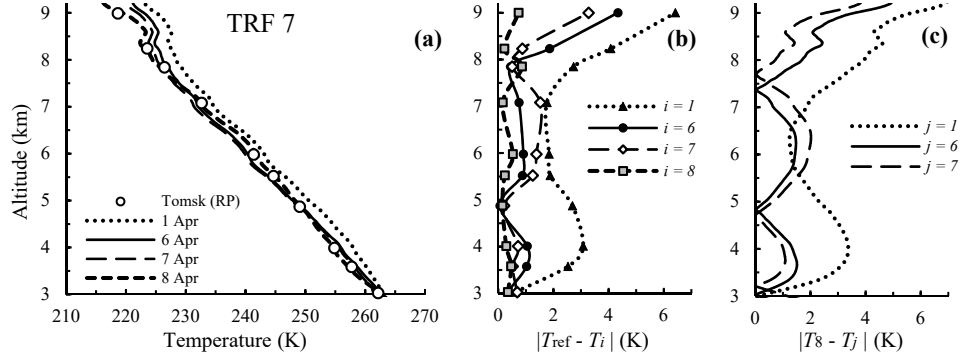


Fig. S29. (a) Temperature profiles retrieved by TRF 7 from the 8 April lidar data. Reference points (RP) are given for 8 April. The absolute differences: (b) $|T_{\text{ref}} - T_i|$; (c) $|T_8 - T_j|$ ($j = 1, 6, 7$).

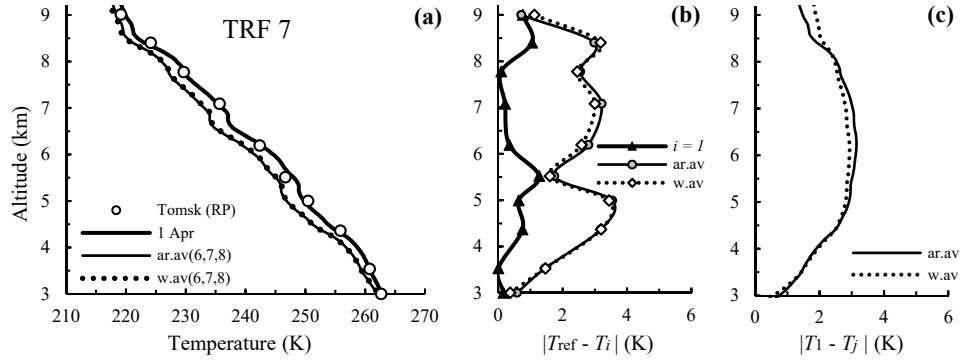


Fig. S30. (a) Temperature profiles retrieved by TRF 7 from the 1 April lidar data. Arithmetic and weighted average values of TRF 7 coefficients were used to obtain profiles "ar.av(6,7,8)" and "w.av(6,7,8)". The absolute differences: (b) $|T_{\text{ref}} - T_i|$ ($i = 1$, "ar.av", "w.av"); (c) $|T_1 - T_j|$ ($j =$ "ar.av", "w.av").

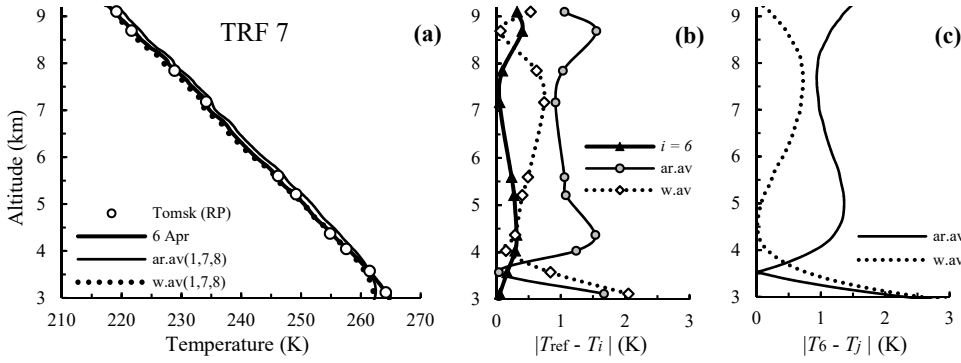


Fig. S31. (a) Temperature profiles retrieved by TRF 7 from the 6 April lidar data. Arithmetic and weighted average values of TRF 7 coefficients were used to obtain profiles "ar.av(1,7,8)" and "w.av(1,7,8)". The absolute differences: (b) $|T_{\text{ref}} - T_i|$ ($i = 6$, "ar.av", "w.av"); (c) $|T_6 - T_j|$.

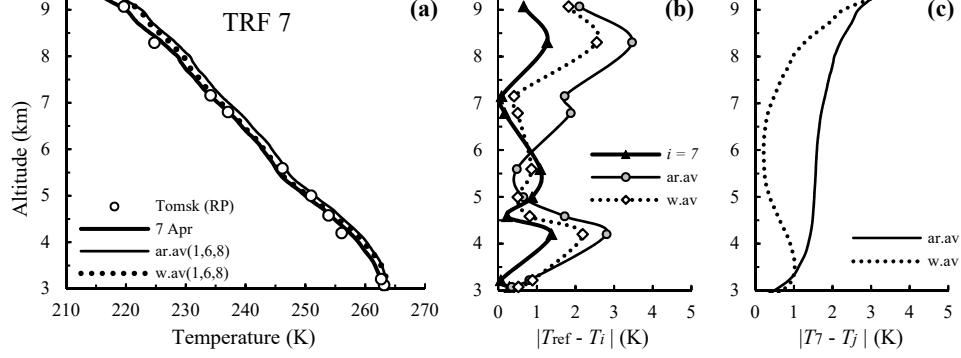


Fig. S32. (a) Temperature profiles retrieved by TRF 7 from the 7 April lidar data. Arithmetic and weighted average values of TRF 7 coefficients were used to obtain profiles “ar.av(1,6,8)” and “w.av(1,6,8)”, respectively. The absolute differences: (b) $|T_{\text{ref}} - T_i|$ ($i=7$, “ar.av”, “w.av”); (c) $|T_7 - T_j|$.

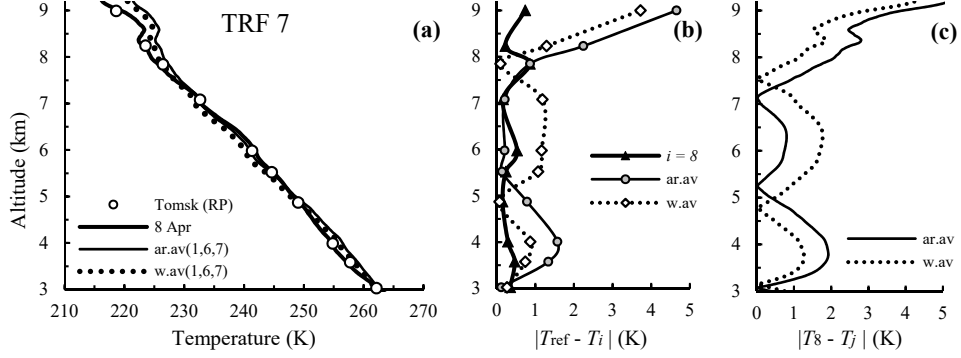


Fig. S33. (a) Temperature profiles retrieved by TRF 7 from the 8 April lidar data. Arithmetic and weighted average values of TRF 7 coefficients were used to obtain profiles “ar.av(1,6,7)” and “w.av(1,6,7)”, respectively. The absolute differences: (b) $|T_{\text{ref}} - T_i|$ ($i=8$, “ar.av”, “w.av”); (c) $|T_8 - T_j|$.

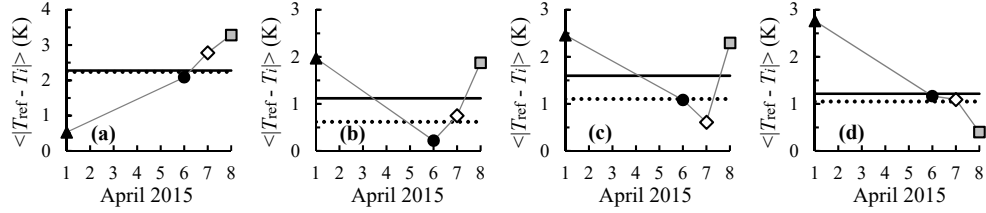


Fig. S34. (TRF 7) Average differences $\langle |T_{\text{ref}} - T_i| \rangle$ ($i=1, 6, 7, 8$, “ar.av”, and “w.av”) obtained using the lidar measurement data of: (a) 1 April, (b) 6 April, (c) 7 April, and (d) 8 April. The solid and dotted horizontal lines correspond to $i=$ “ar.av” and $i=$ “w.av”, respectively.

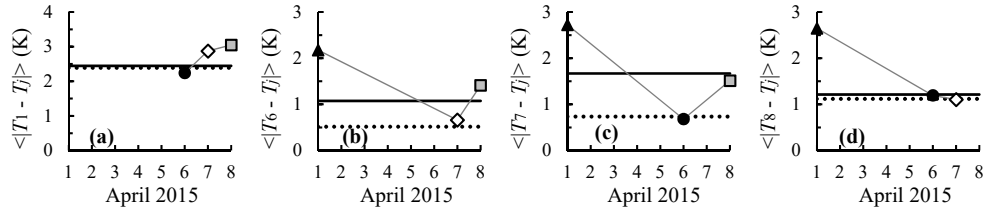


Fig. S35. (TRF 7) Average differences: (a) $\langle |T_1 - T_j| \rangle$ ($j=6, 7, 8$, “ar.av”, and “w.av”), (b) $\langle |T_6 - T_j| \rangle$ ($j=1, 7, 8$, “ar.av”, and “w.av”), (c) $\langle |T_7 - T_j| \rangle$ ($j=1, 6, 8$, “ar.av”, and “w.av”), and (d) $\langle |T_8 - T_j| \rangle$ ($j=1, 6, 7$, “ar.av”, and “w.av”). The solid and dotted horizontal lines correspond to $j=$ “ar.av” and $j=$ “w.av”, respectively.

6.3 TRF 8

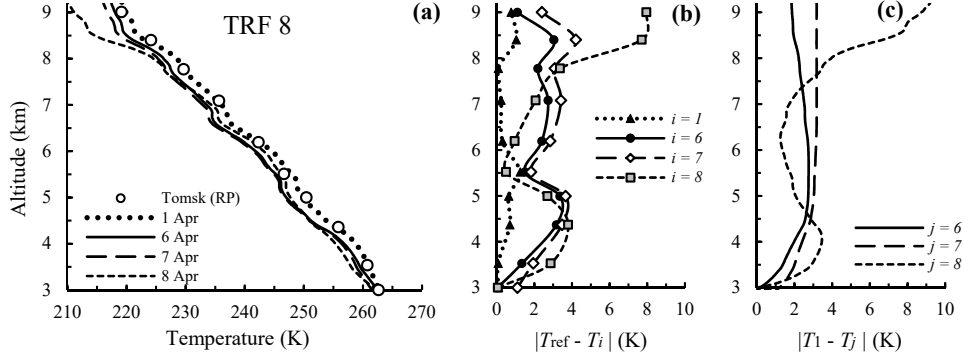


Fig. S36. (a) Temperature profiles retrieved by TRF 8 from the 1 April lidar data. Reference points (RP) are given for 1 April. The absolute differences: (b) $|T_{\text{ref}} - T_i|$ ($i = 1, 6, 7, 8$); (c) $|T_1 - T_j|$ ($j = 6, 7, 8$).

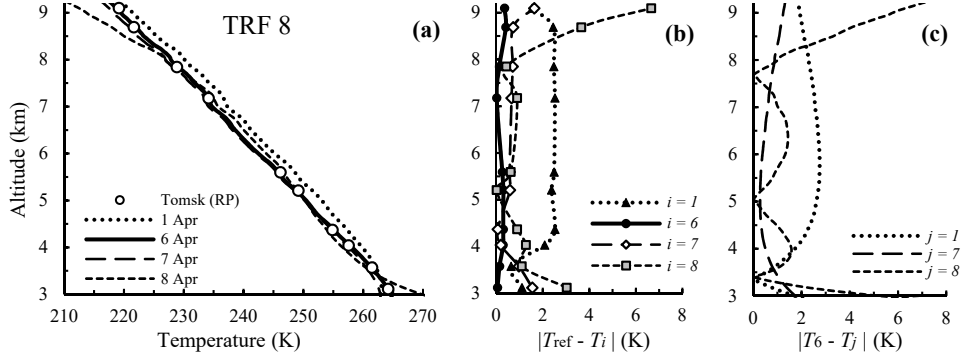


Fig. S37. (a) Temperature profiles retrieved by TRF 8 from the 6 April lidar data. Reference points (RP) are given for 6 April. The absolute differences: (b) $|T_{\text{ref}} - T_i|$; (c) $|T_6 - T_j|$ ($j = 1, 7, 8$).

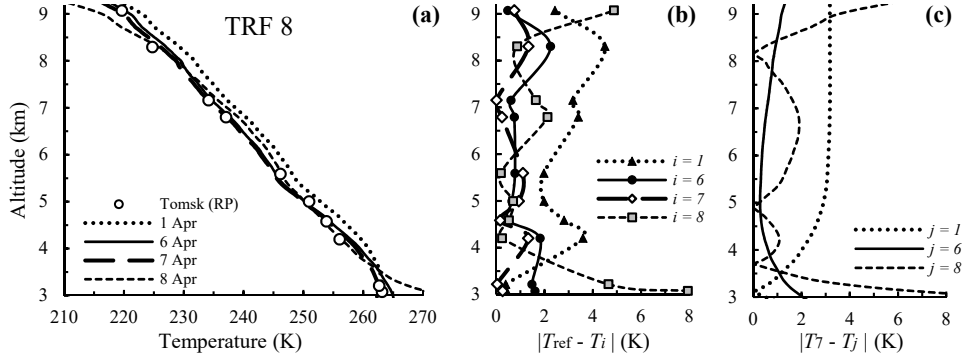


Fig. S38. (a) Temperature profiles retrieved by TRF 8 from the 7 April lidar data. Reference points (RP) are given for 7 April. The absolute differences: (b) $|T_{\text{ref}} - T_i|$; (c) $|T_7 - T_j|$ ($j = 1, 6, 8$).

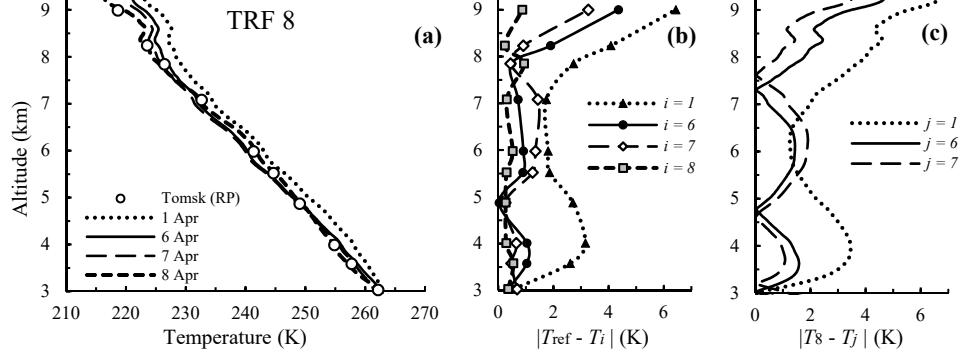


Fig. S39. (a) Temperature profiles retrieved by TRF 8 from the 8 April lidar data. Reference points (RP) are given for 8 April. The absolute differences: (b) $|T_{\text{ref}} - T_i|$; (c) $|T_8 - T_j|$ ($j = 1, 6, 7$).

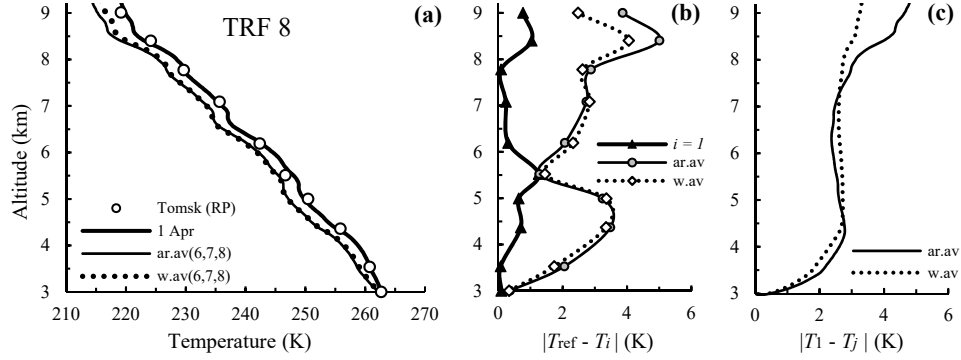


Fig. S40. (a) Temperature profiles retrieved by TRF 8 from the 1 April lidar data. Arithmetic and weighted average values of TRF 8 coefficients were used to obtain profiles "ar.av(6,7,8)" and "w.av(6,7,8)". The absolute differences: (b) $|T_{\text{ref}} - T_i|$ ($i = 1$, "ar.av", "w.av"); (c) $|T_1 - T_j|$ ($j =$ "ar.av", "w.av").

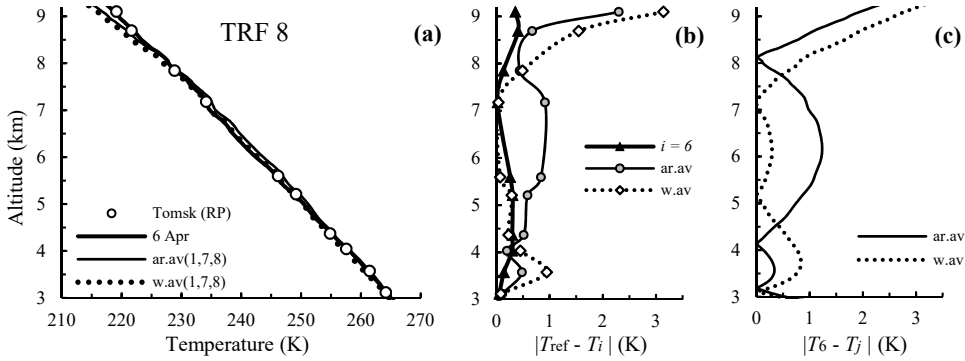


Fig. S41. (a) Temperature profiles retrieved by TRF 8 from the 6 April lidar data. Arithmetic and weighted average values of TRF 8 coefficients were used to obtain profiles "ar.av(1,7,8)" and "w.av(1,7,8)". The absolute differences: (b) $|T_{\text{ref}} - T_i|$ ($i = 6$, "ar.av", "w.av"); (c) $|T_6 - T_j|$.

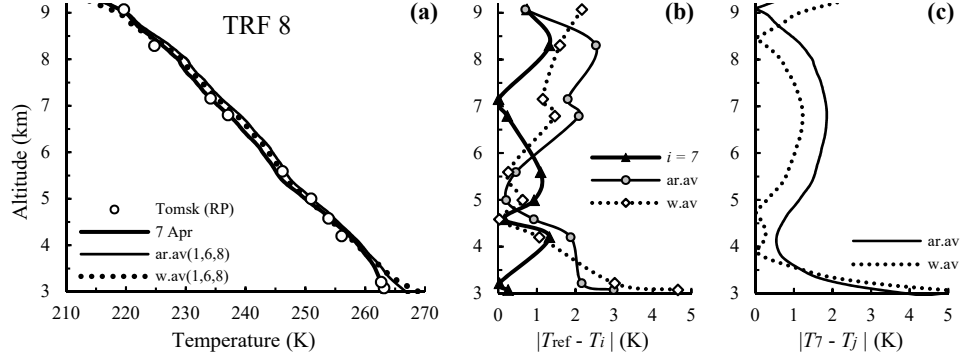


Fig. S42. (a) Temperature profiles retrieved by TRF 8 from the 7 April lidar data. Arithmetic and weighted average values of TRF 8 coefficients were used to obtain profiles “ar.av(1,6,8)” and “w.av(1,6,8)”, respectively. The absolute differences: (b) $|T_{\text{ref}} - T_i|$ ($i = 7$, “ar.av”, “w.av”); (c) $|T_7 - T_j|$.

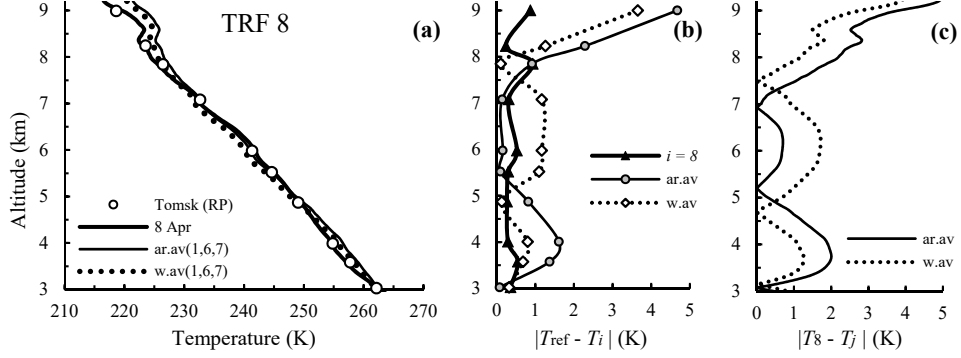


Fig. S43. (a) Temperature profiles retrieved by TRF 8 from the 8 April lidar data. Arithmetic and weighted average values of TRF 8 coefficients were used to obtain profiles “ar.av(1,6,7)” and “w.av(1,6,7)”, respectively. The absolute differences: (b) $|T_{\text{ref}} - T_i|$ ($i = 8$, “ar.av”, “w.av”); (c) $|T_8 - T_j|$.

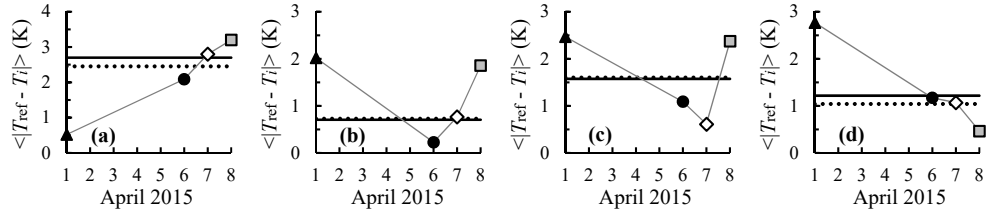


Fig. S44. (TRF 8) Average differences $\langle |T_{\text{ref}} - T_i| \rangle$ ($i = 1, 6, 7, 8$, “ar.av”, and “w.av”) obtained using the lidar measurement data of: (a) 1 April, (b) 6 April, (c) 7 April, and (d) 8 April. The solid and dotted horizontal lines correspond to $i = \text{“ar.av”}$ and $i = \text{“w.av”}$, respectively.

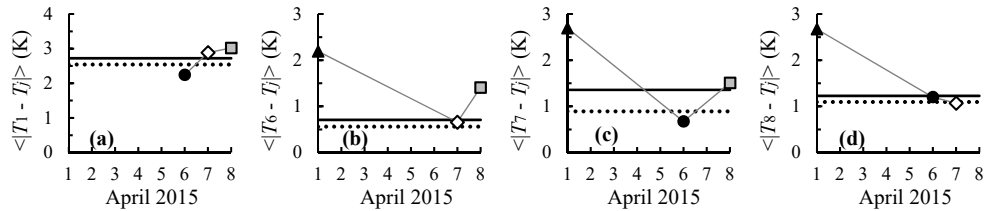


Fig. S45. (TRF 8) Average differences: (a) $\langle |T_1 - T_j| \rangle$ ($j = 6, 7, 8$, “ar.av”, and “w.av”), (b) $\langle |T_6 - T_j| \rangle$ ($j = 1, 7, 8$, “ar.av”, and “w.av”), (c) $\langle |T_7 - T_j| \rangle$ ($j = 1, 6, 8$, “ar.av”, and “w.av”), and (d) $\langle |T_8 - T_j| \rangle$ ($j = 1, 6, 7$, “ar.av”, and “w.av”). The solid and dotted horizontal lines correspond to $j = \text{“ar.av”}$ and $j = \text{“w.av”}$, respectively.

6.4 TRF 9

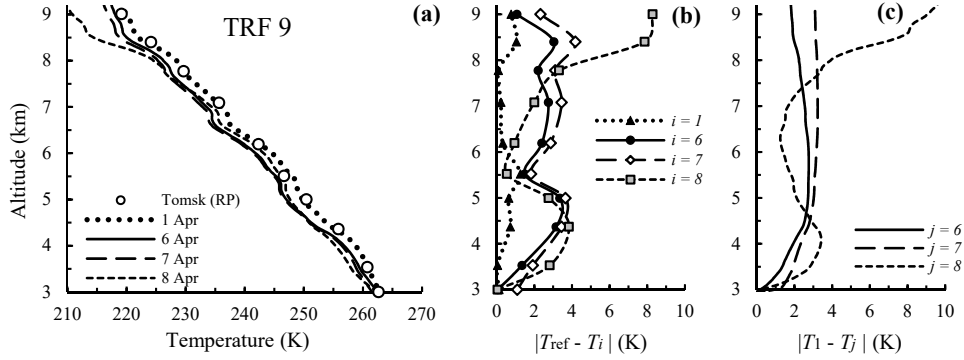


Fig. S46. (a) Temperature profiles retrieved by TRF 9 from the 1 April lidar data. Reference points (RP) are given for 1 April. The absolute differences: (b) $|T_{\text{ref}} - T_i|$ ($i = 1, 6, 7, 8$); (c) $|T_1 - T_j|$ ($j = 6, 7, 8$).

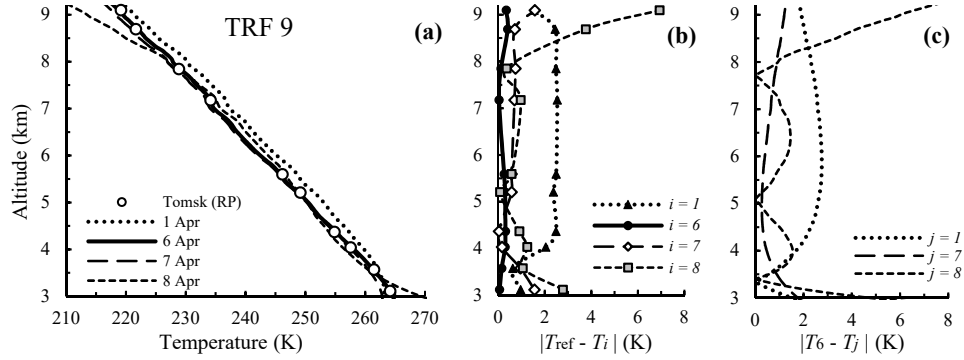


Fig. S47. (a) Temperature profiles retrieved by TRF 9 from the 6 April lidar data. Reference points (RP) are given for 6 April. The absolute differences: (b) $|T_{\text{ref}} - T_i|$; (c) $|T_6 - T_j|$ ($j = 1, 7, 8$).

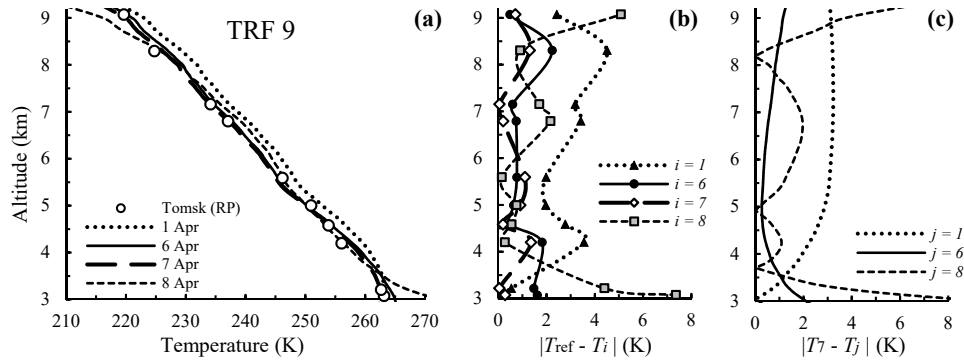


Fig. S48. (a) Temperature profiles retrieved by TRF 9 from the 7 April lidar data. Reference points (RP) are given for 7 April. The absolute differences: (b) $|T_{\text{ref}} - T_i|$; (c) $|T_7 - T_j|$ ($j = 1, 6, 8$).

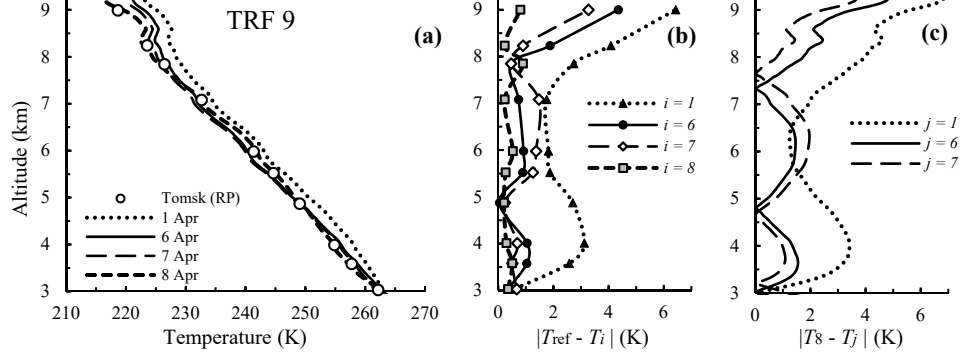


Fig. S49. (a) Temperature profiles retrieved by TRF 9 from the 8 April lidar data. Reference points (RP) are given for 8 April. The absolute differences: (b) $|T_{\text{ref}} - T_i|$; (c) $|T_8 - T_j|$ ($j = 1, 6, 7$).

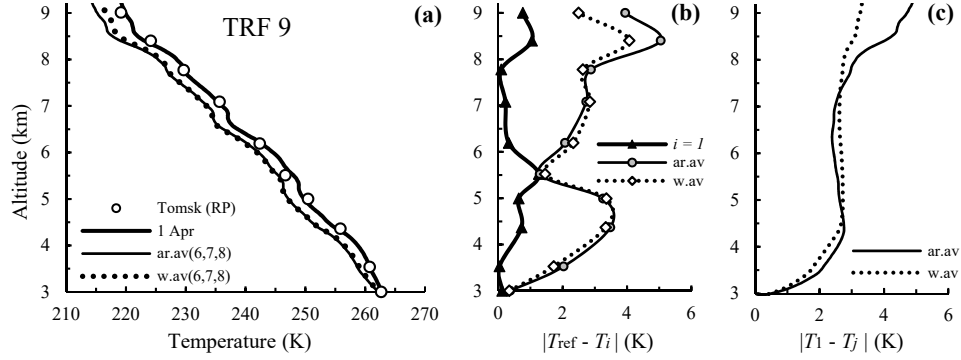


Fig. S50. (a) Temperature profiles retrieved by TRF 9 from the 1 April lidar data. Arithmetic and weighted average values of TRF 9 coefficients were used to obtain profiles "ar.av(6,7,8)" and "w.av(6,7,8)". The absolute differences: (b) $|T_{\text{ref}} - T_i|$ ($i = 1$, "ar.av", "w.av"); (c) $|T_1 - T_j|$ ($j =$ "ar.av", "w.av").

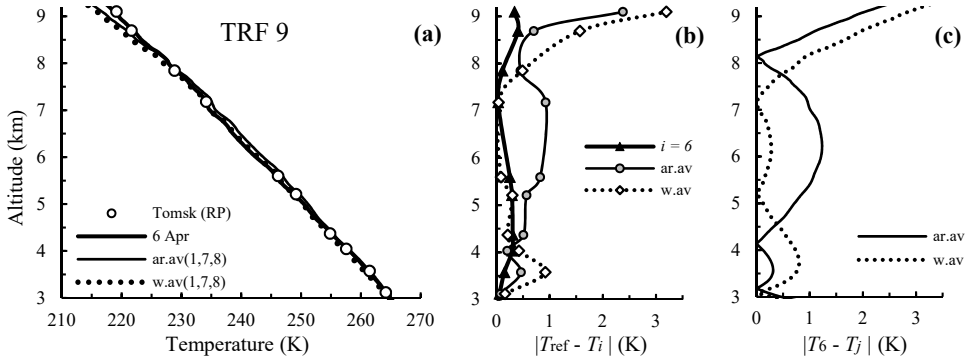


Fig. S51. (a) Temperature profiles retrieved by TRF 9 from the 6 April lidar data. Arithmetic and weighted average values of TRF 9 coefficients were used to obtain profiles "ar.av(1,7,8)" and "w.av(1,7,8)". The absolute differences: (b) $|T_{\text{ref}} - T_i|$ ($i = 6$, "ar.av", "w.av"); (c) $|T_6 - T_j|$.

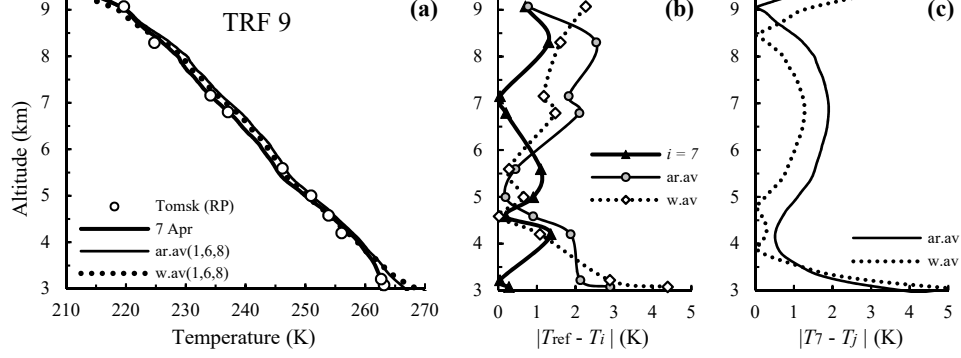


Fig. S52. (a) Temperature profiles retrieved by TRF 9 from the 7 April lidar data. Arithmetic and weighted average values of TRF 9 coefficients were used to obtain profiles “ar.av(1,6,8)” and “w.av(1,6,8)”, respectively. The absolute differences: (b) $|T_{\text{ref}} - T_i|$ ($i = 7$, “ar.av”, “w.av”); (c) $|T_7 - T_j|$.

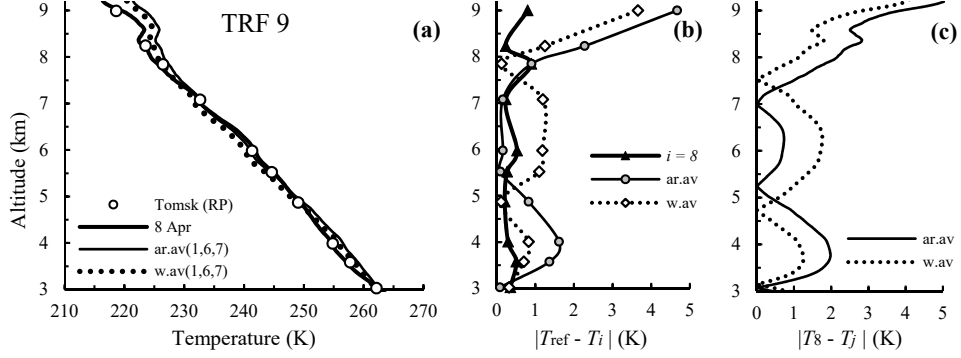


Fig. S53. (a) Temperature profiles retrieved by TRF 9 from the 8 April lidar data. Arithmetic and weighted average values of TRF 9 coefficients were used to obtain profiles “ar.av(1,6,7)” and “w.av(1,6,7)”, respectively. The absolute differences: (b) $|T_{\text{ref}} - T_i|$ ($i = 8$, “ar.av”, “w.av”); (c) $|T_8 - T_j|$.

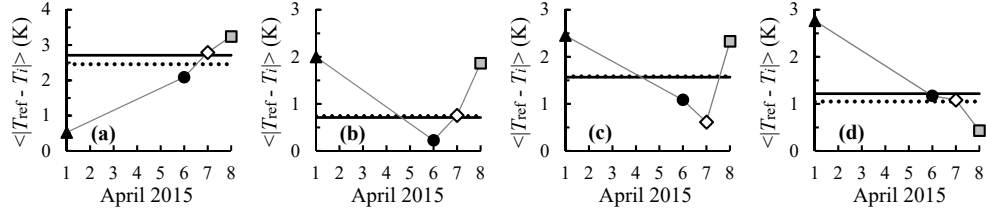


Fig. S54. (TRF 9) Average differences $\langle |T_{\text{ref}} - T_i| \rangle$ ($i = 1, 6, 7, 8$, “ar.av”, and “w.av”) obtained using the lidar measurement data of: (a) 1 April, (b) 6 April, (c) 7 April, and (d) 8 April. The solid and dotted horizontal lines correspond to $i = \text{“ar.av”}$ and $i = \text{“w.av”}$, respectively.

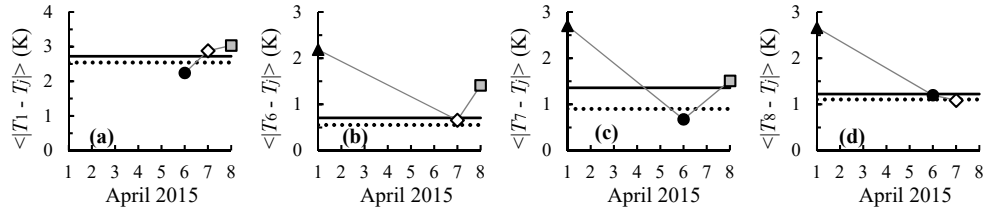


Fig. S55. (TRF 9) Average differences: (a) $\langle |T_1 - T_j| \rangle$ ($j = 6, 7, 8$, “ar.av”, and “w.av”), (b) $\langle |T_6 - T_j| \rangle$ ($j = 1, 7, 8$, “ar.av”, and “w.av”), (c) $\langle |T_7 - T_j| \rangle$ ($j = 1, 6, 8$, “ar.av”, and “w.av”), and (d) $\langle |T_8 - T_j| \rangle$ ($j = 1, 6, 7$, “ar.av”, and “w.av”). The solid and dotted horizontal lines correspond to $j = \text{“ar.av”}$ and $j = \text{“w.av”}$, respectively.

7. 3-Day Stability Characteristics of TRFs 3, 4, 7–9

Figures S56–S60, S61–S63, S64–S68, S69–S73, and S74–S78 present temperature profiles retrieved from the 6–8 April lidar measurement data using TRFs 3, 4, 7, 8, and 9, respectively, along with both characteristics for assessing the TRF temporal stability and their averaged values.

7.1 TRF 3

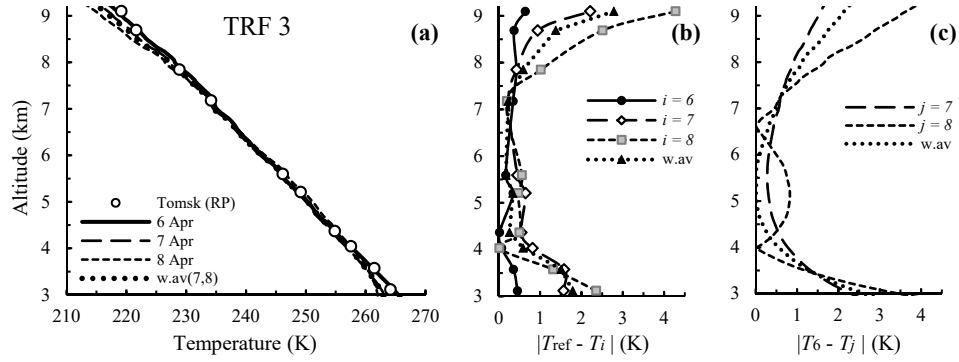


Fig. S56. (a) Temperature profiles “6 Apr”, 7 Apr”, and 8 Apr” retrieved from the 6 April lidar data using TRF 3 with calibration coefficients determined for 6, 7, and 8 April, respectively. The weighted average values of TRF 3 coefficients were used to obtain profile “w.av(7,8)”. Reference points (RP) are shown for 6 April. The absolute differences: (b) $|T_{\text{ref}} - T_i|$ ($i = 6, 7, 8$, “w.av”); (c) $|T_6 - T_j|$ ($j = 7, 8$, “w.av”).

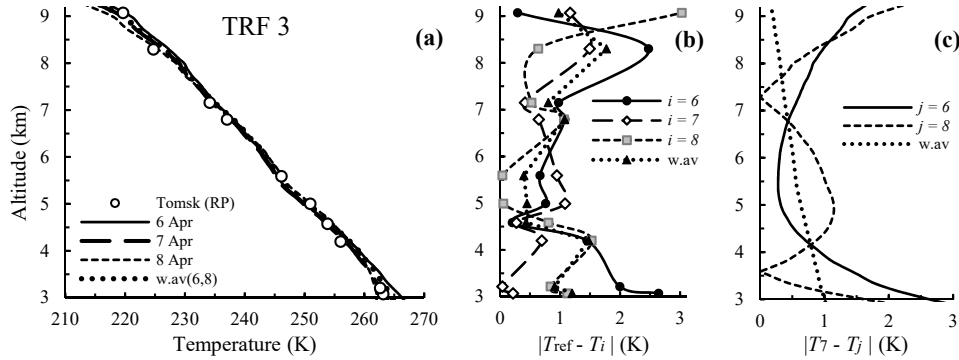


Fig. S57. (a) Profiles “6 Apr”, 7 Apr”, 8 Apr”, and “w.av(6,8)” retrieved from the 7 April lidar data using TRF 3. Reference points (RP) are shown for 7 April. The absolute differences: (b) $|T_{\text{ref}} - T_i|$; (c) $|T_7 - T_j|$.

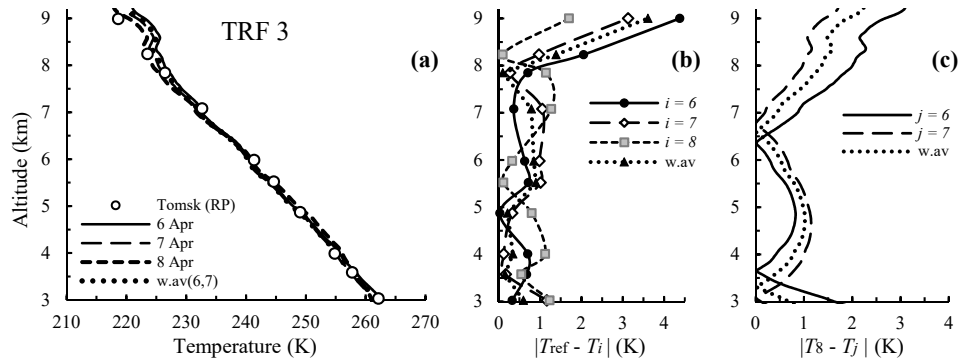


Fig. S58. (a) Profiles “6 Apr”, 7 Apr”, 8 Apr”, and “w.av(6,7)” retrieved from the 8 April lidar data using TRF 3. Reference points (RP) are shown for 8 April. The absolute differences: (b) $|T_{\text{ref}} - T_i|$; (c) $|T_8 - T_j|$.

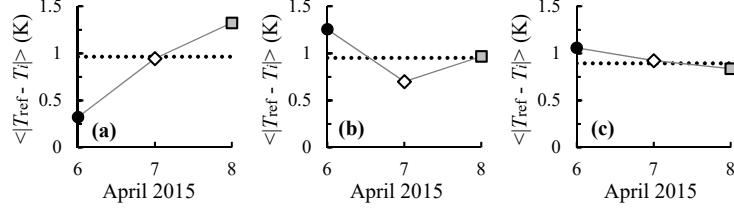


Fig. S59. (TRF 3) Average differences $\langle |T_{\text{ref}} - T_i| \rangle$ ($i = 6, 7, 8$, and “w.av”) obtained using the lidar data of: (a) 6 April, (b) 7 April, and (c) 8 April. The dotted horizontal line corresponds to $i = \text{“w.av”}$.

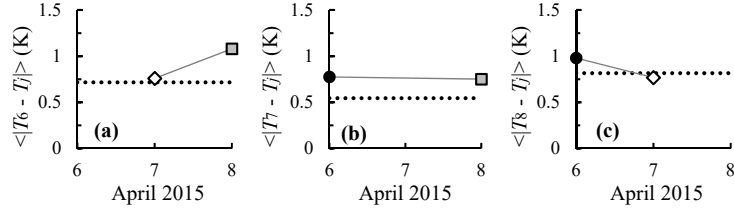


Fig. S60. (TRF 3) Average differences: (a) $\langle |T_6 - T_j| \rangle$ ($j = 7, 8$, and “w.av”), (b) $\langle |T_7 - T_j| \rangle$ ($j = 6, 8$, and “w.av”), and (c) $\langle |T_8 - T_j| \rangle$ ($j = 6, 7$, and “w.av”). The dotted horizontal line corresponds to $j = \text{“w.av”}$.

7.2 TRF 4

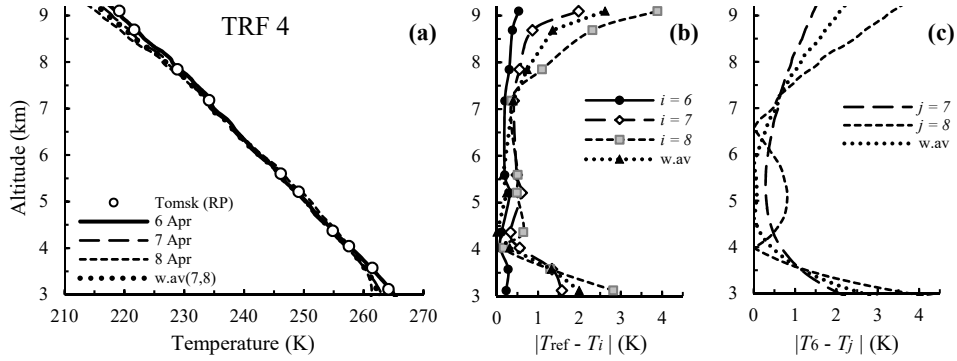


Fig. S61. (a) Temperature profiles “6 Apr”, “7 Apr”, and “8 Apr” retrieved from the 6 April lidar data using TRF 4 with calibration coefficients determined for 6, 7, and 8 April, respectively. The weighted average values of TRF 4 coefficients were used to obtain profile “w.av(7,8)”. Reference points (RP) are shown for 6 April. The absolute differences: (b) $|T_{\text{ref}} - T_i|$ ($i = 6, 7, 8$, “w.av”); (c) $|T_6 - T_j|$ ($j = 7, 8$, “w.av”).

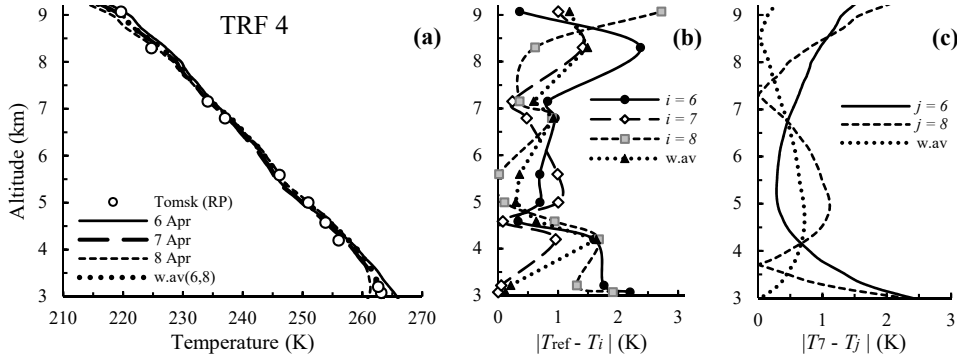


Fig. S62. (a) Profiles “6 Apr”, “7 Apr”, “8 Apr”, and “w.av(6,8)” retrieved from the 7 April lidar data using TRF 4. Reference points (RP) are shown for 7 April. The absolute differences: (b) $|T_{\text{ref}} - T_i|$; (c) $|T_7 - T_j|$.

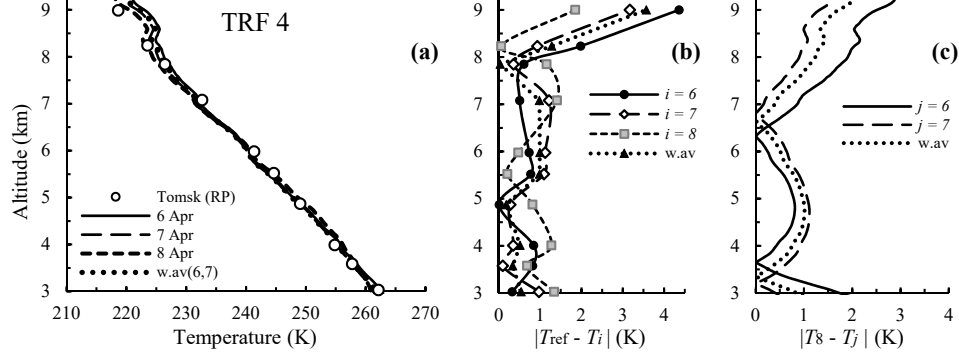


Fig. S63. (a) Profiles “6 Apr”, 7 Apr”, 8 Apr”, and “w.av(6,7)” retrieved from the 8 April lidar data using TRF 4. Reference points (RP) are shown for 8 April. The absolute differences: (b) $|T_{\text{ref}} - T_i|$; (c) $|T_8 - T_j|$.

For the case of TRF 4 the corresponding average differences $\langle |T_{\text{ref}} - T_i| \rangle$ ($i = 6, 7, 8$, and “w.av”), $\langle |T_6 - T_j| \rangle$ ($j = 7, 8$, and “w.av”), $\langle |T_7 - T_j| \rangle$ ($j = 6, 8$, “w.av”), and $\langle |T_8 - T_j| \rangle$ ($j = 6, 7$, and “w.av”) are presented in Figs. 13 and 14 in the main text.

7.3 TRF 7

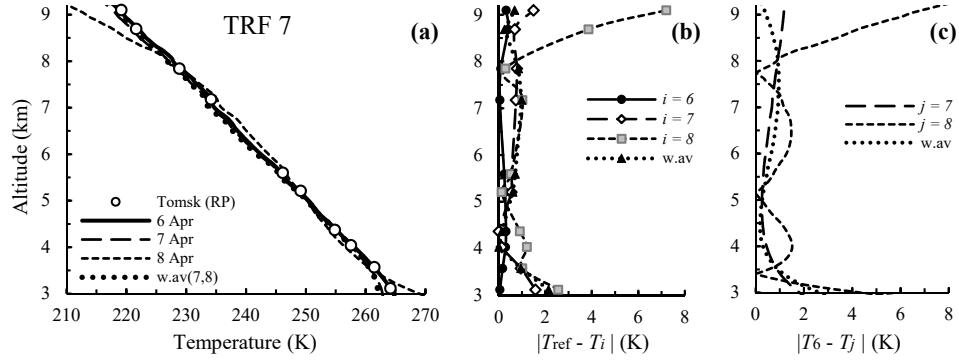


Fig. S64. (a) Temperature profiles “6 Apr”, 7 Apr”, and 8 Apr” retrieved from the 6 April lidar data using TRF 7 with calibration coefficients determined for 6, 7, and 8 April, respectively. The weighted average values of TRF 7 coefficients were used to obtain profile “w.av(7,8)”. Reference points (RP) are shown for 6 April. The absolute differences: (b) $|T_{\text{ref}} - T_i|$ ($i = 6, 7, 8$, “w.av”); (c) $|T_1 - T_j|$ ($j = 7, 8$, “w.av”).

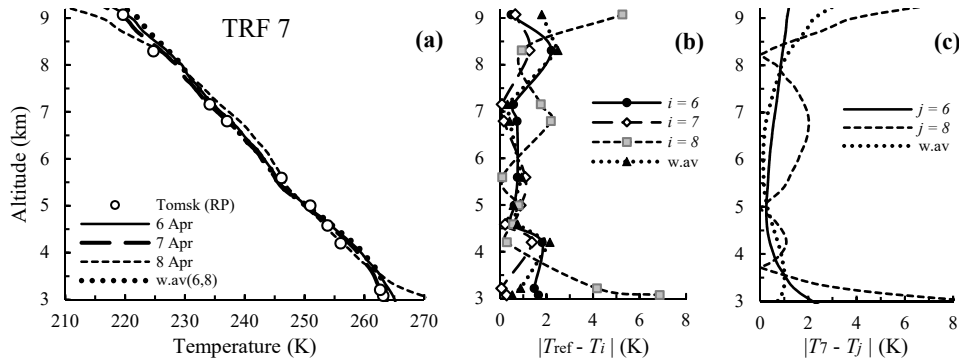


Fig. S65. (a) Profiles “6 Apr”, 7 Apr”, 8 Apr”, and “w.av(6,8)” retrieved from the 7 April lidar data using TRF 7. Reference points (RP) are shown for 7 April. The absolute differences: (b) $|T_{\text{ref}} - T_i|$; (c) $|T_7 - T_j|$.

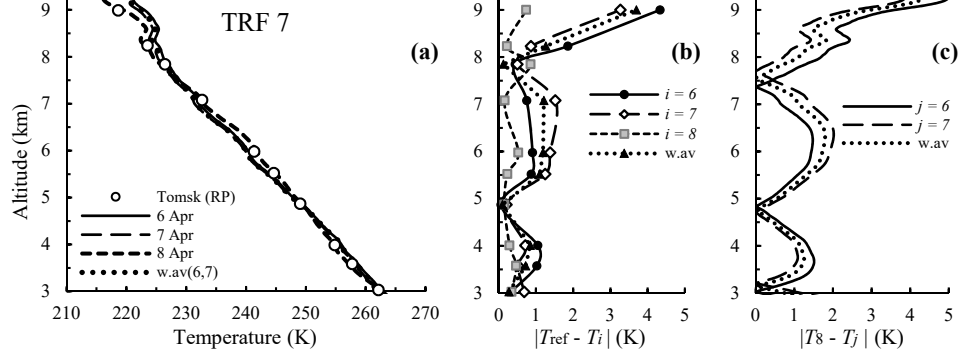


Fig. S66. (a) Profiles “6 Apr”, 7 Apr”, 8 Apr”, and “w.av(6,7)” retrieved from the 8 April lidar data using TRF 7. Reference points (RP) are shown for 8 April. The absolute differences: (b) $|T_{\text{ref}} - T_i|$; (c) $|T_8 - T_j|$.

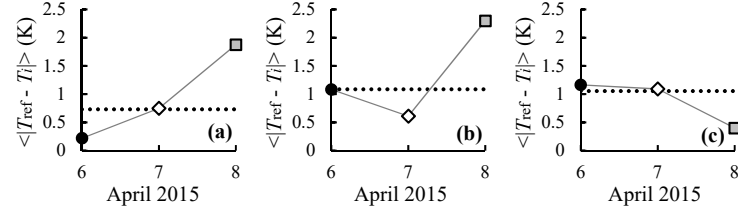


Fig. S67. (TRF 7) Average differences $\langle |T_{\text{ref}} - T_i| \rangle$ ($i = 6, 7, 8$, and “w.av”) obtained using the lidar data of: (a) 6 April, (b) 7 April, and (c) 8 April. The dotted horizontal line corresponds to $i = \text{“w.av”}$.

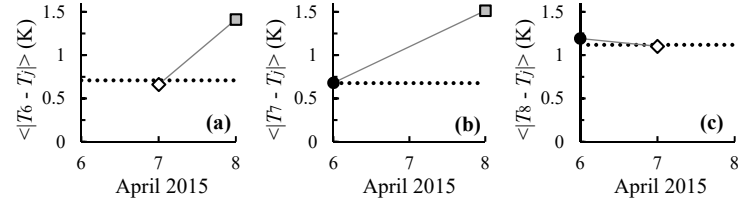


Fig. S68. (TRF 7) Average differences: (a) $\langle |T_6 - T_j| \rangle$ ($j = 7, 8$, and “w.av”), (b) $\langle |T_7 - T_j| \rangle$ ($j = 6, 8$, and “w.av”), and (c) $\langle |T_8 - T_j| \rangle$ ($j = 6, 7$, and “w.av”). The dotted horizontal line corresponds to $j = \text{“w.av”}$.

7.4 TRF 8

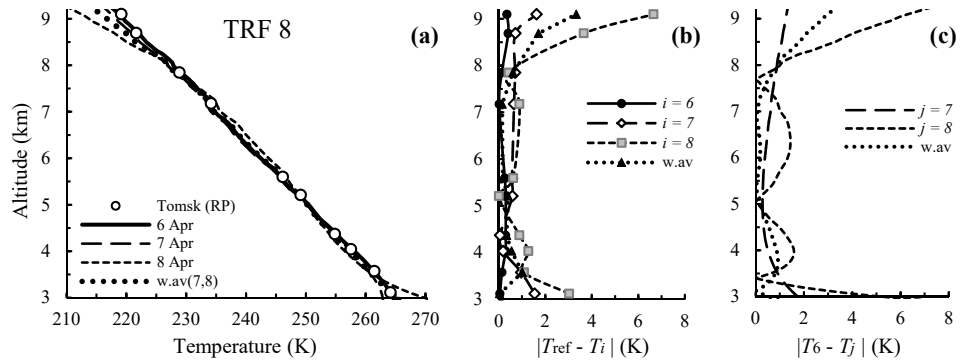


Fig. S69. (a) Temperature profiles “6 Apr”, 7 Apr”, and 8 Apr” retrieved from the 6 April lidar data using TRF 8 with calibration coefficients determined for 6, 7, and 8 April, respectively. The weighted average values of TRF 8 coefficients were used to obtain profile “w.av(7,8)”. Reference points (RP) are shown for 6 April. The absolute differences: (b) $|T_{\text{ref}} - T_i|$ ($i = 6, 7, 8$, “w.av”); (c) $|T_1 - T_j|$ ($j = 7, 8$, “w.av”).

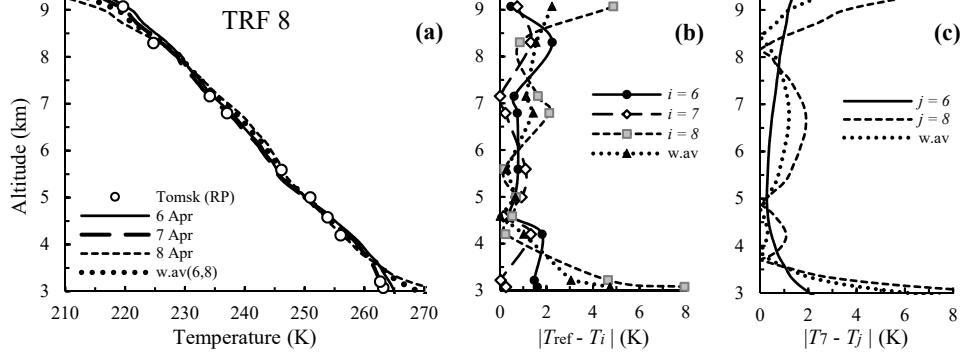


Fig. S70. (a) Profiles “6 Apr”, 7 Apr”, 8 Apr”, and “w.av(6,8)” retrieved from the 7 April lidar data using TRF 8. Reference points (RP) are shown for 7 April. The absolute differences: (b) $|T_{\text{ref}} - T_i|$; (c) $|T_7 - T_j|$.

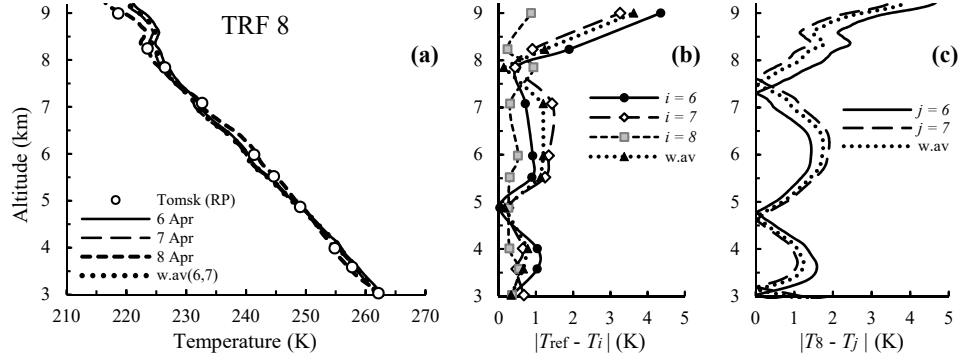


Fig. S71. (a) Profiles “6 Apr”, 7 Apr”, 8 Apr”, and “w.av(6,7)” retrieved from the 8 April lidar data using TRF 8. Reference points (RP) are shown for 8 April. The absolute differences: (b) $|T_{\text{ref}} - T_i|$; (c) $|T_8 - T_j|$.

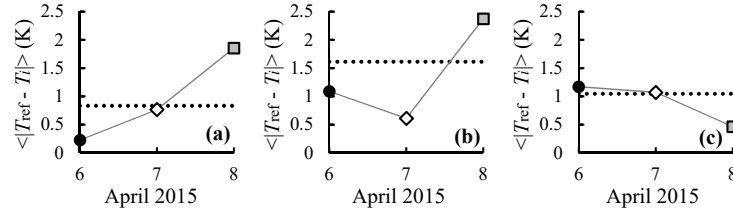


Fig. S72. (TRF 8) Average differences $\langle |T_{\text{ref}} - T_i| \rangle$ ($i = 6, 7, 8$, and “w.av”) obtained using the lidar data of: (a) 6 April, (b) 7 April, and (c) 8 April. The dotted horizontal line corresponds to $i = \text{“w.av”}$.

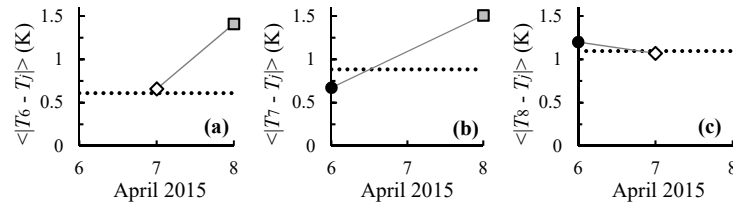


Fig. S73. (TRF 8) Average differences: (a) $\langle |T_6 - T_j| \rangle$ ($j = 7, 8$, and “w.av”), (b) $\langle |T_7 - T_j| \rangle$ ($j = 6, 8$, and “w.av”), and (c) $\langle |T_8 - T_j| \rangle$ ($j = 6, 7$, and “w.av”). The dotted horizontal line corresponds to $j = \text{“w.av”}$.

7.5 TRF 9

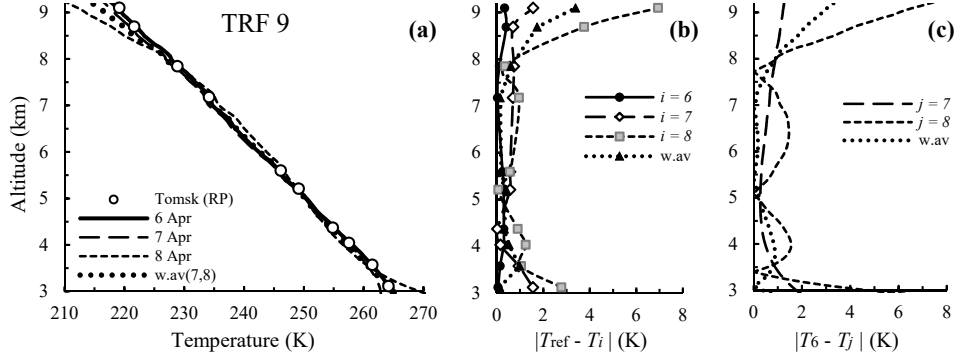


Fig. S74. (a) Temperature profiles “6 Apr”, “7 Apr”, and “8 Apr” retrieved from the 6 April lidar data using TRF 9 with calibration coefficients determined for 6, 7, and 8 April, respectively. The weighted average values of TRF 9 coefficients were used to obtain profile “w.av(7,8)”. Reference points (RP) are shown for 6 April. The absolute differences: (b) $|T_{\text{ref}} - T_i|$ ($i = 6, 7, 8$, “w.av”); (c) $|T_1 - T_j|$ ($j = 7, 8$, “w.av”).

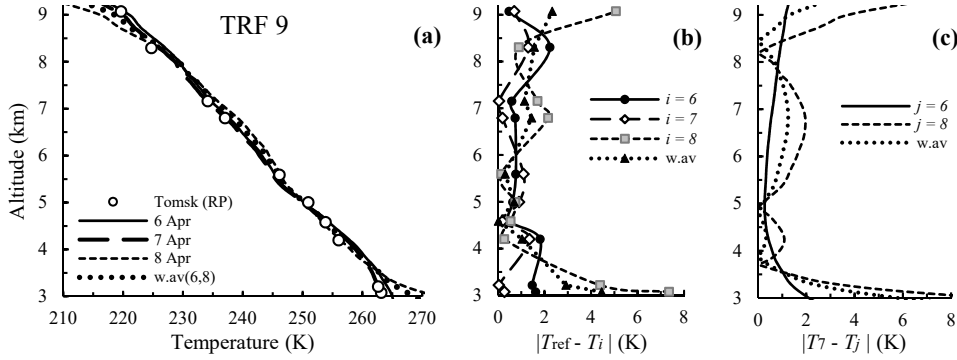


Fig. S75. (a) Profiles “6 Apr”, “7 Apr”, “8 Apr”, and “w.av(6,8)” retrieved from the 7 April lidar data using TRF 9. Reference points (RP) are shown for 7 April. The absolute differences: (b) $|T_{\text{ref}} - T_i|$; (c) $|T_7 - T_j|$.

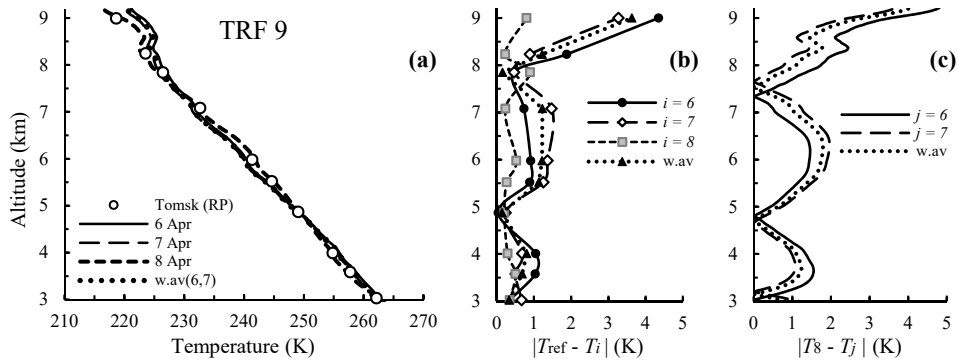


Fig. S76. (a) Profiles “6 Apr”, “7 Apr”, “8 Apr”, and “w.av(6,7)” retrieved from the 8 April lidar data using TRF 9. Reference points (RP) are shown for 8 April. The absolute differences: (b) $|T_{\text{ref}} - T_i|$; (c) $|T_8 - T_j|$.

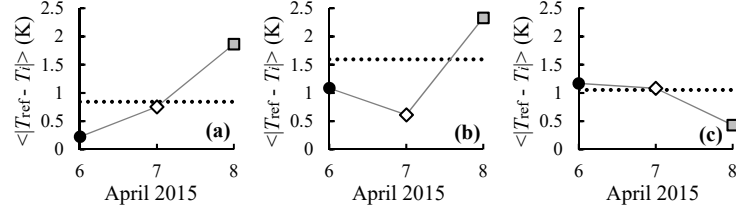


Fig. S77. (TRF 9) Average differences $\langle |T_{\text{ref}} - T_i| \rangle$ ($i = 6, 7, 8$, and “w.av”) obtained using the lidar data of: (a) 6 April, (b) 7 April, and (c) 8 April. The dotted horizontal line corresponds to $i = \text{“w.av”}$.

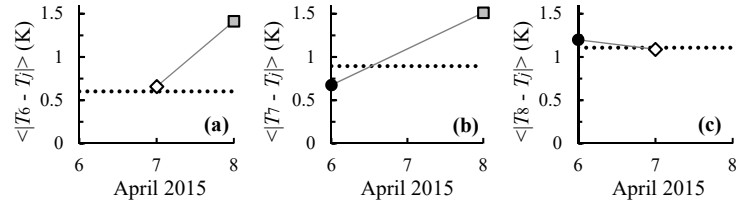


Fig. S78. (TRF 9) Average differences: (a) $\langle |T_6 - T_j| \rangle$ ($j = 7, 8$, and “w.av”), (b) $\langle |T_7 - T_j| \rangle$ ($j = 6, 8$, and “w.av”), and (c) $\langle |T_8 - T_j| \rangle$ ($j = 6, 7$, and “w.av”). The dotted horizontal line corresponds to $j = \text{“w.av”}$.

References

1. V. V. Zuev, V. V. Gerasimov, V. L. Pravdin, A. V. Pavlinskiy, and D. P. Nakhtigalova, “Tropospheric temperature measurements with the pure rotational Raman lidar technique using nonlinear calibration functions” *Atmos. Meas. Tech.* **10**, 315–332 (2017).
2. V. V. Gerasimov, “Comparative analysis of calibration functions in the pure rotational Raman lidar technique,” *Appl. Phys. B* **124**, 134 (2018).