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Supplement of

A novel method for detecting tropopause structures based on the bi-Gaussian function

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Supplement

The supplement lists the definitions of the two methods (Bi-Gaussian and lapse rate tropopause (LRT)) and a wide variety of scenarios that may be encountered in the process of identifying the tropopause structure in details, in order to demonstrate the differences of two different methods.

S1 Thermal tropopause definitions

The lapse rate tropopause (LRT) definition is as follows (WMO, 1957):

(i) the first tropopause is defined as the lowest level at which the lapse rate decreases to 2 °C/km or less, provided also the average lapse rate between this level and all higher levels within 2 km does not exceed 2 °C/km.

(ii) If above the first tropopause, the average lapse rate between any level and all higher levels within 1 km exceeds 3 °C/km, then a second tropopause is defined by the same criterion as under (i). This tropopause may be either within or above the 1 km layer.

This definition requires calculating the gradients between the tropopause level and every level above a 2 km altitude range. Details can be seen in the APPENDIX of Maddox and Mullendore (2018).

The new Bi-Gaussian method described in Sec.2.3 in the main text.

S2 Cases for explaining the discrepancies between two methods

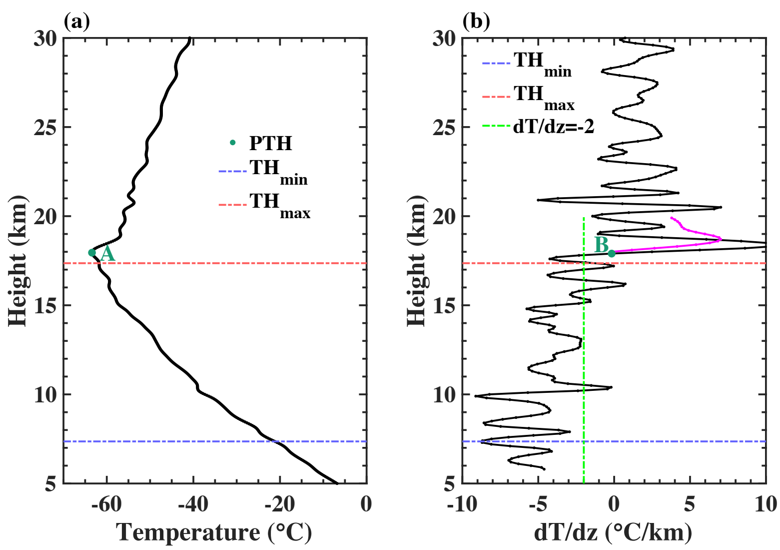

Figure S1: An example of identification results by bi-Gaussian and LRT beyond the search range. The temperature profile was sourced from the observation site (121.22 °E, 46.6 °N) on 04 Aug 2014.

As shown in Fig. S1, A and B are higher than the upper search range of tropopause height. Limiting the search range can lead to missed detection (Li et al., 2017). However, if the search range is expanded, both methods can get effective identification results.

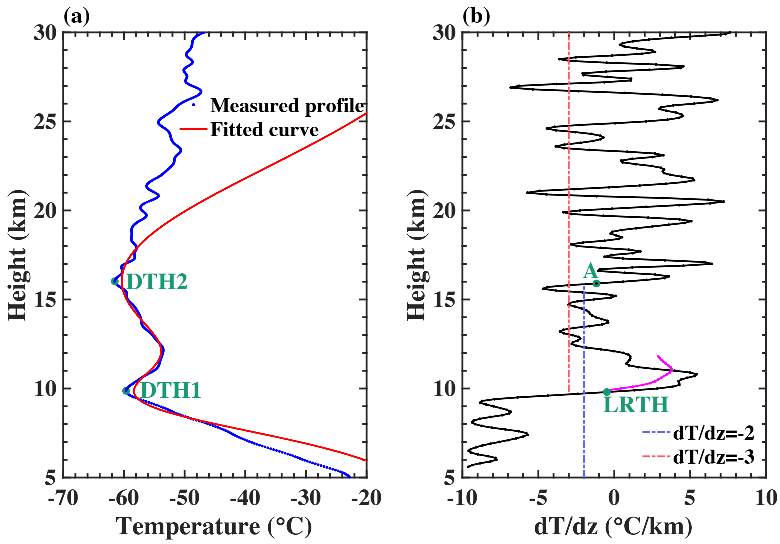

Figure S2: An example defined as DT by the bi-Gaussian method but only ST by LRT. The temperature profile was sourced from the observation site (103.08 °E, 38.63 °N) on 14 Feb 2014. (a) temperature profile and the new bi-Gaussian method, (b) temperature lapse rate and LRT. The magenta dotted line indicates "the average lapse rate between this level and all higher levels within 2 km".

Table S1: Identification results of the three methods in Fig. S2.

Method	Bi-Gaussian	LRT
Tropopause structure	double	single
Tropopause height/km	DTH1: 9.9 DTH2: 16.0	LRTH: 9.8

Both methods accurately identified the first tropopause as expected, but only single tropopause height defined by the LRT. The temperature lapse rate (in Fig. S2(b)) between LRTH and A did not satisfy "the average lapse rate between any level and all higher levels within 1 km exceeds 3°C/km" in criterion (ii) of the LRT. Therefore, LRT fails to detect the second tropopause height.

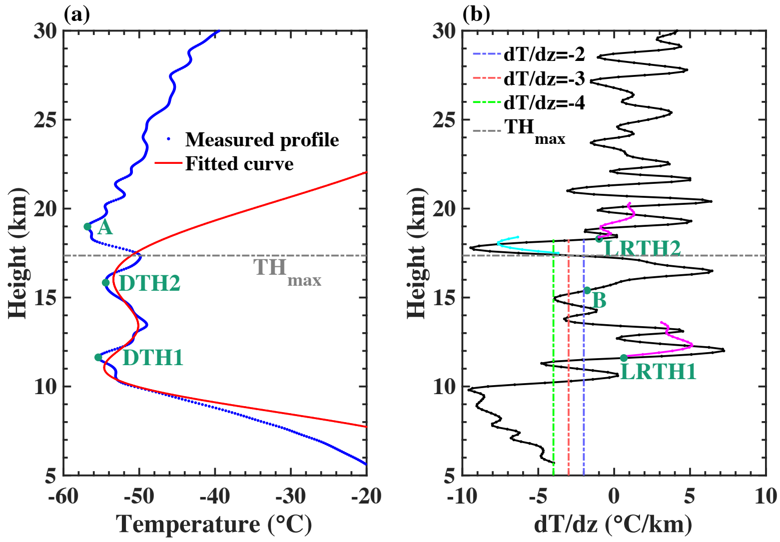

Figure S3: An example defined as DT by the bi-Gaussian method but only ST by LRT. This is also a typical profile representing triple tropopauses. The temperature profile was sourced from the observation site (83 °E, 46.73 °N) on 1 Jun 2014. The search range for the algorithm is limited to between 7.35 km and 17.35 km. (a) temperature profile and the new bi-Gaussian method, (b) temperature lapse rate and LRT. The magenta dotted line indicates "the average lapse rate between this level and all higher levels within 2 km", and the cyan dotted line indicates "the average lapse rate between any level and all higher levels within 1 km".

Table S2: Identification results of the three methods in Fig. S3.

Method	Bi-Gaussian	LRT
Tropopause structure	double	double
Tropopause height/km	DTH1: 11.6	LRTH1: 11.6
	DTH2: 15.8	LRTH2: 18.3

Both methods accurately identified the first tropopause as expected, but the second tropopause height as defined by the LRT was outside the search range. The temperature lapse rate (in Fig. S3(b)) between LRTH1 and B did not satisfy "the average lapse rate between any level and all higher levels within 1 km exceeds 3°C/km" in criterion (ii) of the LRT. From the temperature profile (in Fig. S3(a)), it is reasonable to consider A as the third tropopause height, since LRTH2 also is more than the threshold of –4 °C/km.

The temperature profile in Fig. S3(a) is a very typical profile for a triple tropopause structure, i.e., LRTH2 is roughly the third tropopause heights, corresponding to point A. It may be possible that the presence of the third tropopause weakens the temperature lapse rate between DTH1 and DTH2, resulting in failing to satisfy the criterion (ii) of LRT.

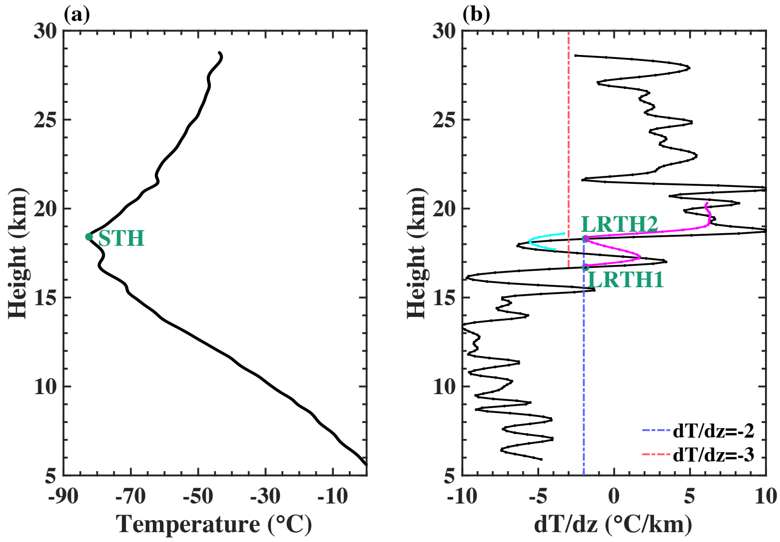

Figure S4: An example defined as DT by LRT, but only ST by bi-Gaussian. The temperature profile was sourced from the observation site (109.13 °E, 21.45 °N) on 08 Jun 2014. (a) temperature profile and STH, (b) temperature lapse rate and LRT. The magenta dotted line indicates "the average lapse rate between this level and all higher levels within 2 km", and the cyan dotted line indicates "the average lapse rate between any level and all higher levels within 1 km".

Table S3: Identification results of the three methods in Fig. S4.

Method	Bi-Gaussian	LRT
Tropopause structure	single	double
Tropopause height/km	STH: 18.4	LRTH1: 16.7 LRTH2: 18.3

There is only one possible tropopause height in Fig. S4(a), which is defined as STH. However, LRT identifies double tropopause heights, and LRTH1 corresponds to STH. However, the height difference between LRTH1 and LRTH2 is relatively small. This may be due to temperature fluctuations caused by atmospheric fluctuations, causing an erroneous judgement.

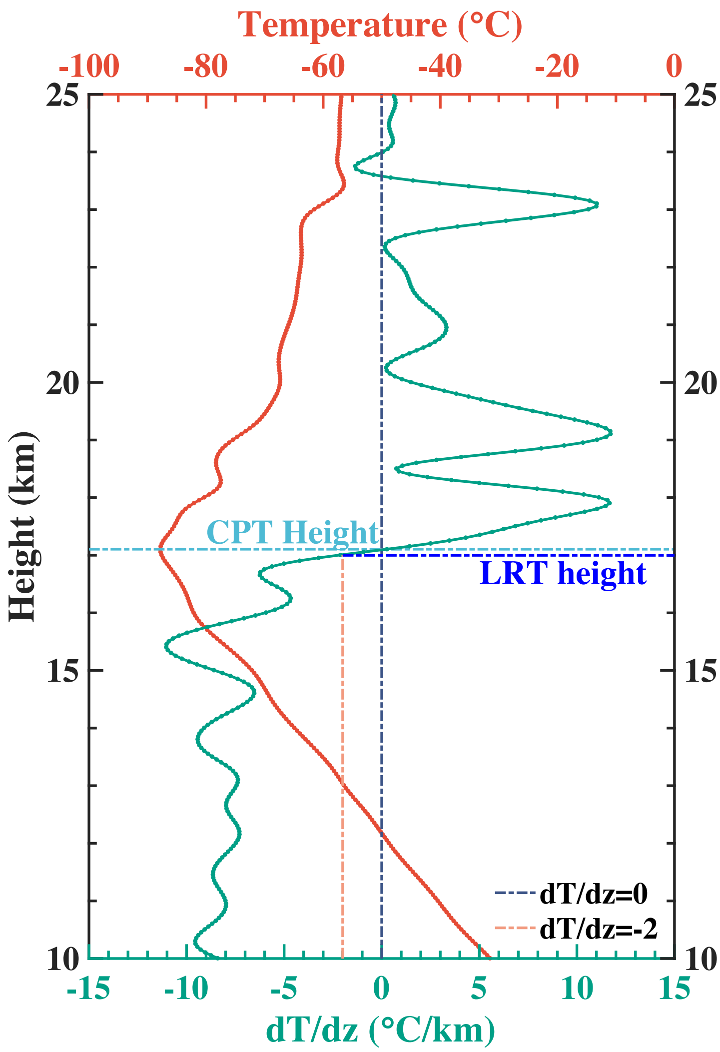

Figure S5: An example to explain the inherent bias of CPT height over LRT height. Because CPT is the transition point at which the temperature lapse rate changes from negative to positive. The temperature profile was sourced from the observation site (112.3333 °E, 16.8333 °N) on 27 Dec 2014. A 9-point running mean was adopted for the temperature lapse rate profile.

Abbreviations

LRT: lapse rate tropopause

ST: single tropopause

DT: double tropopauses

STH: single tropopause height by bi-Gaussian

DTH1: first tropopause height for double tropopauses by bi-Gaussian

DTH2: second tropopause height for double tropopauses by bi-Gaussian

LRTH: LRT height for single tropopause

LRTH1: first LRT height for double tropopauses

LRTH2: second LRT height for double tropopauses

CPT: Coldest Point Tropopause

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