

1 **Comprehensive validation of MODIS atmospheric temperature**
2 **profile data across mainland China using sounding observations**

3 Wenjie Zhang^{1,2}, Mengxi Qu¹, Ranhao Sun², Jiarui Zhao¹, Guicai Ning³, Aziz Inamov⁴, Zokhid
4 Mamatkulov⁴, Di Zhou⁵, Bakhtiyor Pulatov⁶, Yuanjian Yang^{1,3*}

5 1 State Key Laboratory of Climate System Prediction and Risk Management, Nanjing University of Information Science and
6 Technology, Nanjing 210044, China.

7 2 State Key Laboratory of Regional and Urban Ecology, [Research Center for Eco-Environmental Sciences, Chinese Academy](#)
8 [of Sciences, Beijing 100085, China.](#)

9 3 School of Atmospheric Physics, Nanjing University of Information Science and Technology, Nanjing 21004, China.

10 4 Tashkent Institute of Irrigation and Agricultural Mechanization Engineers, Tashkent 100043, Uzbekistan.

11 5 State Key Laboratory of Integrated Service Networks, Xidian University, Xi'an 710071, China.

12 6 Central Asian University of Environmental and Climate Change Studies, Tashkent, Uzbekistan.

13 * Correspondence to: Yang Yuanjian (yyj1985@nuist.edu.cn)

14 **Abstract.** The vertical profile of atmospheric temperature is crucial for understanding energy transfer within the climate
15 system. The Moderate Resolution Imaging Spectroradiometer (MODIS) atmospheric profile product (MOD07_L2) provides
16 vertical temperature profiles at 5 km spatial resolution. However, comprehensive validation of its absolute accuracy—
17 particularly for lower tropospheric stability (LTS) and temperature inversion layer (TIL) detection—remains limited.
18 Therefore, this study conducted systematic evaluations using sounding data from 74 stations across mainland China spanning
19 2003–2020, encompassing both daytime and nighttime periods. Results indicated that [MOD07_L2 temperature-profile](#)
20 [retrievals were generally more accurate at nighttime than during daytime and performed better in the upper layers \(400–620](#)
21 [hPa\) than in lower layers \(850–1000 hPa\). In particular, pronounced negative biases were observed at 850 and 920 hPa,](#)
22 [especially during daytime.](#) In contrast, MODIS-derived LTS was more accurate during daytime ($r = 0.74$, $B = -0.33$ K, RMSE
23 $= 4.52$ K) than at nighttime ($r = 0.57$, $B = -3.59$ K, RMSE $= 6.78$ K). For TIL, MOD07_L2 displayed limited detection
24 capability, achieving an overall detection rate of 6.6% during daytime and 13.1% at nighttime. This study provides essential
25 data support for atmospheric science, hydrology, and ecology fields that rely on high-resolution vertical temperature profiles.

26 **Keywords:** MODIS, Vertical atmospheric temperature profiles, Absolute accuracy, Lower tropospheric stability, Temperature
27 inversion layers

28 **1 Introduction**

29 The vertical distribution of atmospheric temperature constitutes a fundamental component of Earth's climate system,
30 profoundly influencing weather patterns, atmospheric circulation, and surface environmental processes. In recent years,

Deleted: .

Formatted: Font: (Asian) +Body Asian (等线), (Asian) Chinese (Simplified, Mainland China)

Formatted: Font: (Asian) +Body Asian (等线), (Asian) Chinese (Simplified, Mainland China)

Deleted: absolute retrieval accuracy was generally superior at nighttime compared to daytime, with MOD07_L2 demonstrating better performance in upper layers

Deleted: Nonetheless, retrieval errors at the 700 hPa level exhibited a more pronounced bias (B) relative to other pressure levels. In contrast,

Deleted: LTS accuracy was higher

Deleted: 0.04°C

Deleted: °C

Deleted: 0.3°C

Deleted: °C

Formatted: Font: Not Bold

43 intensified global climate change has induced substantial alterations in this distribution. Notably, the pronounced tropospheric
44 warming juxtaposed against stratospheric cooling highlights the intricate energy exchanges and dynamic interactions among
45 atmospheric layers (Dessler & Davis, 2010; Seidel et al., 2016). These anomalous variations in temperature profiles have
46 consequently reconfigured global circulation patterns and heightened the frequency of extreme weather events (Seeley &
47 Wordsworth, 2021; Galfi & Lucarini., 2021).

48 In recent years, rapid advancements in remote sensing technology and numerical simulations have greatly advanced the
49 observation and analysis of vertical temperature distributions from the surface to the stratosphere (Santer et al., 2018; Thorne
50 et al., 2016). The acquisition of vertical temperature data drawn from diverse sources, yet notable disparities existed among
51 datasets in spatial and temporal resolution, parameter coverage, and applicability. Reanalysis datasets, such as the National
52 Centers for Environmental Prediction (NCEP), European Centre for Medium-Range Weather Forecasts Reanalysis 5 (ERA5),
53 and Climatic Research Unit (CRU), offered global coverage and long-term consistency but fell short in meeting the demands
54 of fields requiring high-resolution data (Hersbach et al., 2020; Gelaro et al., 2017; Saha et al., 2010). For instance, despite
55 optimizations in NCEP's boundary layer parameterization, its coarse spatial resolution (2.5°) remained inadequate for resolving
56 local-scale temperature details (Saha et al., 2010; Grimmond et al., 2010). Similarly, while the CRU dataset provided long-
57 term records, its 0.5° resolution constrained its utility in local-scale studies (Harris et al., 2020). Furthermore, although ERA5
58 excelled in global climate trend analysis, its 0.25° resolution still imposed limitations on regional-scale investigations (Zhao
59 et al., 2014). In contrast, the Moderate Resolution Imaging Spectroradiometer (MODIS) atmospheric profile product
60 (MOD07_L2) emerged as an optimal choice for regional studies, owing to its high spatial resolution of 5 km (Schwarz et al.,

61 2011; Chen et al., 2019). However, existing research has primarily focused on the retrieval accuracy of [surface or near-surface](#)
62 [temperatures](#). For example, Ouyang et al. (2015) evaluated the effects of atmospheric water vapor and land-surface emissivity
63 on land surface temperature retrieval in the Heihe River Basin, while Zhu et al. (2017) used MOD07_L2-derived near-surface
64 air temperature for regional daytime air-temperature estimation in the eastern Qaidam Basin. Systematic evaluations of vertical
65 temperature profiles, particularly in the mid-to-upper atmosphere, remain limited (Zhang et al., 2021; Yuan et al., 2023).

66 Additionally, some studies have employed MOD07_L2 vertical temperature profiles to examine atmospheric structures and
67 thermal stratification, albeit relying on limited station data (F. Huang et al., 2020; Barlow et al., 2015). To date, no nationwide
68 assessment of these profiles has been undertaken across complex terrains and diverse climatic zones.

69 Lower tropospheric stability (LTS) served as a pivotal factor influencing atmospheric vertical distributions and weather
70 patterns, governing air vertical mixing and convective activity intensity. Variations in LTS exhibited strong correlations with
71 atmospheric temperature profiles, particularly in modulating extreme weather events such as severe pollution episodes, air
72 humidity fluctuations, and precipitation extremes (Ning et al., 2018; Guo et al., 2016a; Guo et al., 2016b). Additionally, Li et

Formatted: Font: Not Bold

Formatted: Font: Not Bold

Deleted: near-surface (2 m) air temperatures, with
systematic evaluations of vertical profiles in mid-to-upper
atmospheric layers largely absent

al. (2014) confirmed that in low-latitude oceanic regions, enhanced LTS is typically significantly associated with subsidence at 700 hPa and increased low-level cloud cover, indicating that LTS serves as a crucial link connecting large-scale dynamical processes with the vertical structure of clouds. As a high-resolution atmospheric vertical profile product, MOD07_L2 held substantial potential for national-scale LTS analysis, yet its efficacy in this domain remained unvalidated. In addition, temperature inversion layers (TIL) represented a key feature of atmospheric vertical temperature distributions, suppressing vertical air mixing and thereby altering local climate conditions (Barlow et al., 2015; Li et al., 2019). Recent research further revealed a close coupling between the inversion layer and the atmospheric boundary layer, jointly influencing the vertical distribution and capture efficiency of aerosols (Liu et al., 2022). The MOD07_L2 dataset furnished temperature data across 20 vertical pressure levels, laying a robust foundation for inversion layer detection and analysis (Coll et al., 2012; Leng et al., 2019). Existing validations have predominantly relied on radiosonde or lidar data, leaving the performance of MOD07_L2 in inversion detection unevaluated on a systematic basis.

Therefore, this study makes several novel contributions to the field. First, it provides the first long-term (2003–2020) and nationwide validation of MOD07_L2 vertical temperature profiles across China's diverse climatic and topographic regions beyond previous site-specific assessments. Second, it represents the first systematic evaluation of the MOD07_L2 product's capability to retrieve LTS and detect TIL, thereby extending validation beyond single-level temperatures to derived parameters critical for boundary layer and climate studies. Third, the diagnostic analysis of retrieval errors—particularly the attribution of [the pronounced negative biases at 850 and 920 hPa to surface and atmospheric conditions and the limited vertical sensitivity of infrared retrievals](#)—provides actionable insights for both users of the MODIS archive and developers of future satellite missions.

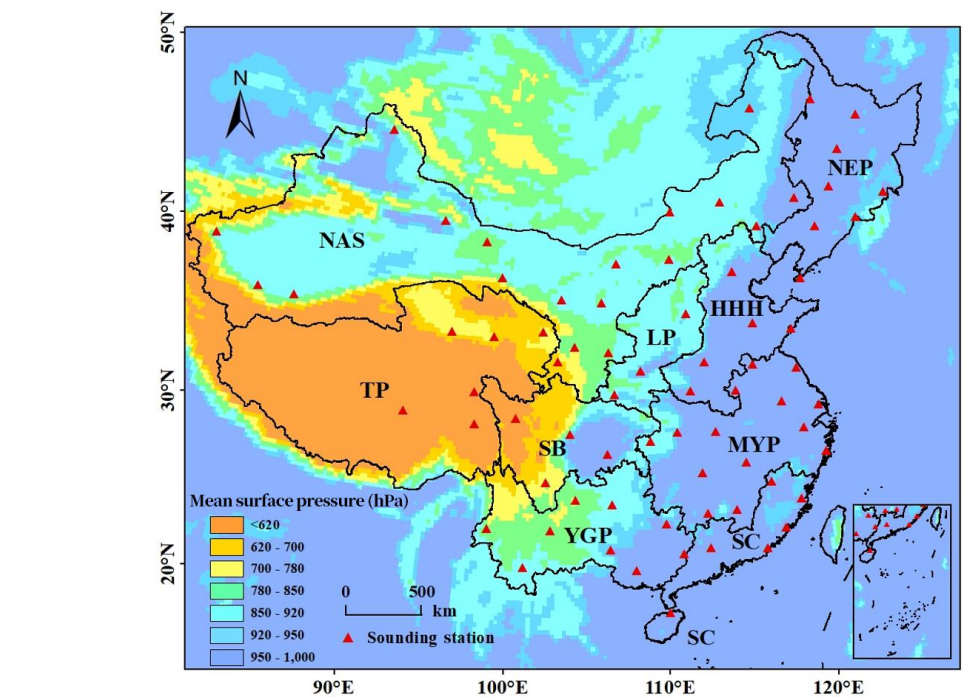
Deleted: the 700 hPa bias to a combination of atmospheric dynamics, topographic effects, and sensor characteristics

2 Materials and methodology

2.1 Study area

This study covered the entirety of China, characterized by complex and diverse geographical and climatic conditions. China's topography ascended progressively from east to west, featuring low-lying plains and hills in the east and towering mountains and plateaus in the west—most notably the Tibetan Plateau, with an average elevation surpassing 4,000 m. This configuration established a pronounced topographical gradient. China encompassed a broad spectrum of climate types, spanning tropical zones in the south to cold temperate regions in the north, complemented by alpine climates in the west, thereby engendering substantial climatic diversity. Eastern coastal areas are predominantly humid, whereas western regions are largely arid or semi-arid. These geographical and climatic characteristics amplified variations in surface temperature distributions and atmospheric

106 boundary layer features across regions. To delineate these regional distinctions more precisely, this study adopted China's
 107 agricultural zoning framework (Fig. 1), comprising the Northeast China Plain (NEP), the Northern Arid and Semi-Arid Region
 108 (NAS), the Huang-Huai-Hai Plain (HHH), the Loess Plateau (LP), the Qinghai-Tibet Plateau (TP), the Middle-Lower Yangtze
 109 Plain (MYP), the Sichuan Basin and Surrounding Areas (SB), the Yunnan-Guizhou Plateau (YGP), and Southern China (SC).
 110 This zoning scheme is accessible via the following link: [https://gitcode.com/open-source-](https://gitcode.com/open-source-toolkit/6b76d/commit/aab463c56bfcb7b0de5024ef53da43a634529ac?ref=main)
 111 [toolkit/6b76d/commit/aab463c56bfcb7b0de5024ef53da43a634529ac?ref=main](https://gitcode.com/open-source-toolkit/6b76d/commit/aab463c56bfcb7b0de5024ef53da43a634529ac?ref=main).



112
 113 Figure 1. Annual mean surface pressure and [distribution of sounding stations](#) in China from 2003 to 2020. [The nine agricultural](#)
 114 [zones \(NEP, NAS, HHH, LP, TP, MYP, SB, YGP, and SC\) are labeled in the figure](#).

115 2.2 Data

116 2.2.1 Sounding data

117 The [radiosonde observations used](#) in this study were provided by the China Meteorological Administration
 118 (<http://weather.uwyo.edu/upperair/sounding.html>). [Hereafter, these observations are referred to as sounding data](#). This

Deleted: sounding stations distribution

Formatted: Font: (Default) Times New Roman, (Asian) Times New Roman

Formatted: Font: (Asian) Times New Roman, 9 pt, Bold, Ligatures: None

Formatted: Font: (Default) Times New Roman, (Asian) Times New Roman

Formatted: Font: (Asian) Times New Roman, 9 pt, Bold, Ligatures: None

Deleted: sounding data utilized

121 investigation employed vertical temperature profile data from 74 stations recorded from 2003 to 2020 across China. These
122 data were collected using meteorological balloons that measure atmospheric temperature, pressure, and other parameters at
123 various altitudes, ranging from the surface to the upper atmosphere. Sounding observations were conducted daily at 00:00 and
124 12:00 across more than 100 pressure levels, thereby enabling a detailed characterization of the vertical temperature distribution.
125 The sounding data used in this study adhere to the World Meteorological Organization (WMO) Global Climate Observing
126 System (GCOS) Upper-Air Network (GUAN) standards and underwent rigorous quality control procedures. During the study
127 period, the data completeness rate across all selected stations exceeded 90%, providing a reliable foundation for statistical
128 analysis.

129 **2.2.2 MOD07_L2 data**

130 This study utilizes the MOD07_L2 Collection 6.1 atmospheric profile product generated by NASA's Moderate Resolution
131 Imaging Spectroradiometer (MODIS) sensor. This version incorporates significant improvements in retrieval algorithms and
132 cloud detection, (<https://ladsweb.modaps.eosdis.nasa.gov/search/>). This product provided vertical atmospheric temperature
133 profiles at 20 pressure levels (5, 10, 20, 30, 50, 70, 100, 150, 200, 250, 300, 400, 500, 620, 700, 780, 850, 920, 950, and 1000
134 hPa) with a spatial resolution of 5 km. For this study, temperature data were selected at the 400, 500, 620, 700, 780, 850, 920,
135 950, and 1000 hPa levels, which ~~can represent key features of the vertical temperature distribution relevant to LTS calculation~~
136 ~~and TIL detection.~~ For clear expression, the nine pressure levels were categorized into lower layers (850, 920, 950, and 1000
137 hPa), middle layers (700 and 780 hPa), and upper layers (400, 500, and 620 hPa). This classification aligned with standard
138 isobaric surfaces in meteorological studies and reflected the characteristic atmospheric processes at varying altitudes.
139 Additionally, surface pressure ~~was obtained directly from the MOD07_L2 Surface Pressure data set (hPa) at 5 km resolution~~
140 ~~and was used to calculate near-surface potential temperature for LST. Fill values and invalid surface-pressure records were~~
141 ~~excluded, and no external surface-pressure data or additional surface-pressure-specific correction was applied. Cloud screening~~
142 ~~followed the standard clear-sky screening inherent in the MOD07_L2 product.~~

143 **2.3 Methodology**

144 **2.3.1 Vertical interpolation of vertical temperature profiles**

145 To ensure comparability between ~~the MOD07_L2 temperature retrievals~~ and sounding observations, vertical interpolation ~~was~~
146 ~~performed~~ in this study. A linear interpolation method was employed to interpolate the sounding temperature data onto the
147 corresponding pressure levels of MOD07_L2. If a pressure level P_{modis} in MOD07_L2 exactly matched a pressure level in
148 the sounding data, the corresponding sounding temperature T_{sod} was directly used without interpolation. For pressure levels

Formatted: Font: Not Bold

Deleted: can represented key temperature distribution characteristics, such as LTS and TIL.

Deleted: data were extracted from the MOD07_L2 product. This dataset shares the same 5 km spatial resolution as the temperature profiles and will be used

Deleted: the assessment of lower tropospheric stability.

Deleted: the

Deleted: retrieved temperature profiles

Deleted: data

Deleted: of pressure levels was carried out

Formatted: Font: Not Bold

in MOD07_L2 (P_{modis}) that did not match any sounding pressure levels, the two adjacent pressure levels in the sounding data (P_{lower} and P_{upper}) and the corresponding temperatures (T_{lower} and T_{upper}) were searched to satisfy the following relationship:

$$P_{\text{lower}} < P_{\text{modis}} < P_{\text{upper}} \quad (1)$$

Then, the vertical temperature lapse rate γ was calculated as follows:

$$\gamma = \frac{T_{\text{upper}} - T_{\text{lower}}}{P_{\text{upper}} - P_{\text{lower}}} \quad (2)$$

where γ is the temperature lapse rate with respect to pressure ($^{\circ}\text{C} \cdot \text{hPa}^{-1}$). P_{lower} and P_{upper} are the two adjacent sounding pressure levels below and above P_{modis} , respectively, and T_{lower} and T_{upper} are their corresponding sounding temperatures ($^{\circ}\text{C}$). This value indicated the amount of temperature change corresponding to a unit change in pressure between adjacent sounding layers. By applying the calculated lapse rate γ , the temperature at the MOD07_L2 pressure level (P_{modis}) was interpolated to obtain its equivalent sounding temperature value as below:

$$T_{\text{modis}} = T_{\text{lower}} + \frac{T_{\text{upper}} - T_{\text{lower}}}{P_{\text{upper}} - P_{\text{lower}}} \times (P_{\text{modis}} - P_{\text{lower}}) \quad (3)$$

where T_{modis} represents the equivalent sounding temperature ($^{\circ}\text{C}$) interpolated to the MOD07_L2 pressure level P_{modis} .

When P_{modis} fell outside the maximum or minimum pressure levels of the sounding data, the following approach was used to handle boundary cases: If the pressure value corresponding to the MOD07_L2 pressure level (P_{modis}) was greater than the maximum pressure value (P_{max} corresponding to the lowest altitude) in the sounding data, interpolation was performed using the two sounding pressure levels with the highest pressure values, $P_{\text{max}-1}$ and P_{max} . Similarly, if the pressure value of MOD07_L2 (P_{modis}) was less than the minimum pressure value (P_{min} corresponding to the highest altitude) in the sounding data, P_{min} and $P_{\text{min}+1}$ were used.

2.3.2 Accuracy evaluation metrics

The retrieval accuracy of MOD07_L2 was evaluated using the Pearson correlation coefficient (r), bias (B), and root mean square error (RMSE), which were calculated as follows:

$$r = \frac{\sum_{i=1}^n (M_i - \bar{M})(S_i - \bar{S})}{\sqrt{\sum_{i=1}^n (M_i - \bar{M})^2 \sum_{i=1}^n (S_i - \bar{S})^2}} \quad (4)$$

$$B = \frac{1}{n} \sum_{i=1}^n (M_i - S_i) \quad (5)$$

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (M_i - S_i)^2} \quad (6)$$

where M_i and S_i represent the MOD07_L2 retrieval and the corresponding sounding observation, respectively. $\bar{M}$ and $\bar{S}$

are their mean values, and n is the number of matched samples. Bias (B) was calculated as the mean difference between the MOD07_L2 retrievals and sounding observations. The correlation coefficient is dimensionless, whereas B and RMSE are expressed in $^{\circ}\text{C}$. A negative B indicates an underestimation by MOD07_L2, while a positive B indicates an overestimation. The same metrics were also applied to the evaluation of MOD07_L2-derived LTS by replacing temperature with the corresponding LTS values. For LTS, B and RMSE are expressed in K.

2.3.3 Sensitivity analysis of temporal matching window

Sounding data are typically observed at 00:00 and 12:00 Beijing Time. However, due to the sun-synchronous orbit of the Terra satellite carrying MODIS, the overpass times of MOD07_L2 data exhibit spatial variations within China, with earlier overpass times in the eastern regions compared to the western regions. To ensure the comparability between satellite retrievals and sounding observations, and to assess the impact of time deviations on retrieval accuracy, this study conducted a time-matching sensitivity experiment. The time deviation ($|\Delta t|$) was divided into four intervals: 0–0.5 hours, 0.5–1 hour, 1–1.5 hours, and 1.5–2 hours. Statistical metrics between MOD07_L2 temperature retrieval values and sounding data were calculated within each interval to determine the optimal matching window. Detailed sensitivity analysis results are presented in the Results section of this article.

2.3.4 Lower Tropospheric Stability Calculation

Lower tropospheric stability (LTS) was defined as the difference between the potential temperature at 700 hPa level and that near the surface (Guo et al., 2016a; Ning et al., 2018). To accurately obtain the near-surface temperature from MOD07_L2 data, a linear interpolation method was employed. Based on the two pressure levels closest to the surface and their corresponding temperature values, the temperature corresponding to the surface pressure was calculated. In the sounding data, the near-surface layer was defined as the lowest-altitude, highest-pressure valid level and its corresponding temperature in the raw data. Subsequently, the temperatures at 700 hPa level and near the surface were converted to potential temperatures using the standard formula. The calculation formula for potential temperature (θ) is as follows:

$$\theta = T \left(\frac{p_0}{p} \right)^k, k = \frac{R}{c_p} = \frac{287.05}{1004} \approx 0.286 \quad (7)$$

In this formula, T is the temperature (K), p is the pressure, p_0 is the reference pressure (usually taken as 1000 hPa), R is the gas constant for dry air (R usually taken as $287.05 \text{ J} \cdot \text{kg}^{-1} \cdot \text{K}^{-1}$), and c_p is the specific heat at constant pressure for dry air (c_p usually taken as $1004 \text{ J} \cdot \text{kg}^{-1} \cdot \text{K}^{-1}$). After obtaining the potential temperatures at the 700 hPa level and near the surface, LTS was calculated as their difference:

$$\text{LTS} = \theta_{700\text{hPa}} - \theta_{\text{surface}} \quad (8)$$

Deleted: 2

Deleted: 3

Deleted: lowest pressure

Deleted: Rc_p

Deleted: 4

Deleted: 5

219 LTS represents atmospheric stability, higher values indicate greater stability. [LTS is expressed in K.](#)

220 **2.3 [Temperature inversion layer detection](#)**

221 The identification of TIL was based on analyzing the vertical temperature differences between neighboring pressure levels.
222 Under standard adiabatic conditions, temperature should decrease as pressure decreases. If adverse, temperature inversion was
223 defined. To evaluate the detection accuracy of temperature inversions in the MOD07_L2 data, its results were compared against
224 sounding observations. [In this study, an inversion was regarded as co-detected when both the MOD07_L2 profile and its](#)
225 [corresponding sounding profile contained at least one inversion. \$N_{\text{both}}\$ represents the number of matched profiles in which](#)
226 [both MOD07_L2 and sounding data detected at least one inversion.](#) The ratio of this number to [the total number of sounding](#)
227 [profiles containing at least one inversion](#), (N_{SD}) defines the inversion detection accuracy for that dataset:

228
$$A = \frac{N_{\text{both}}}{N_{\text{SD}}}$$

229

Deleted: 4

Deleted: The number of inversion layers co-detected with the sounding data (N_{both}) was calculated.

Formatted: Font: Not Bold

Deleted: the total number of inversions independently detected by the soundings

Deleted: 6

(9)

236 **3 Results**

237 **3.1 Sensitivity analysis of time-matching window**

238 To determine the optimal time-matching window, we analyzed the variations in accuracy between MOD07_L2 temperature
239 retrievals and sounding observations [across different time-difference intervals](#) ($|\Delta t|$) (Fig. 2). The results indicated that when
240 $|\Delta t| < 1$ hour, no effective matches were found in the NEP, and the sample size in the HHH was also limited, making it insufficient
241 to support a national-scale evaluation. When the window was expanded to 1–1.5 hours and 1.5–2 hours, the sample size
242 increased significantly. [During daytime, the B values for the SB and LP reached -3.81 and -3.30 °C, respectively, under the 1–](#)
243 [1.5-hour window \(Fig. 2c\), with corresponding RMSE values of 4.33 and 4.60 °C. Under the 1.5–2-hour window, the daytime](#)
244 [B in the HHH was -1.91 °C, with a corresponding RMSE of 3.78 °C. These results suggest that greater time differences may](#)
245 [contribute to larger discrepancies between MOD07_L2 retrievals and sounding observations in some regions. By contrast,](#)
246 [nighttime B and RMSE varied relatively little across the four time windows. At the national scale, extending the matching](#)
247 [window from \$|\Delta t| < 1\$ h to \$|\Delta t| < 2\$ h increased the number of matched records from 554,128 to 894,061 during daytime and from](#)
248 [299,578 to 711,344 at nighttime. Averaged across the nine pressure levels, daytime r, B, and RMSE changed from 0.961,](#)
249 [-1.00 °C, and 3.22 °C to 0.963, -0.91 °C, and 3.18 °C, respectively; the corresponding nighttime values changed from 0.958,](#)
250 [-0.46 °C, and 2.76 °C to 0.968, -0.37 °C, and 2.73 °C. Thus, although errors increased in a few regions, the 2 h window](#)
251 [substantially increased sample coverage without reducing national-scale accuracy and was retained for the subsequent analyses.](#)

Deleted: under different time deviations

Deleted: < 1

Deleted: , but the B in some regions became larger: during daytime, the bias in HHH reached -1.77°C under the 1–1.5 hour window (Fig. 2C); at night, under the 1.5–2 hour window, the bias in the NEP reached 2.24°C, and in the NAS increased to -0.78°C (Fig. 2D). Nevertheless, the r at most sites remained above 0.9, and the increase in RMSE was within an acceptable range. Balancing sample coverage and retrieval accuracy, this study selected $|\Delta t| < 2$ hours as the final matching threshold. This threshold ensures sufficient sample size across the national scale while cont

Deleted: rolling the uncertainty introduced by temporal mismatch at a reasonable level, laying the foundation for subsequent validation of temperature profiles and derived parameters....

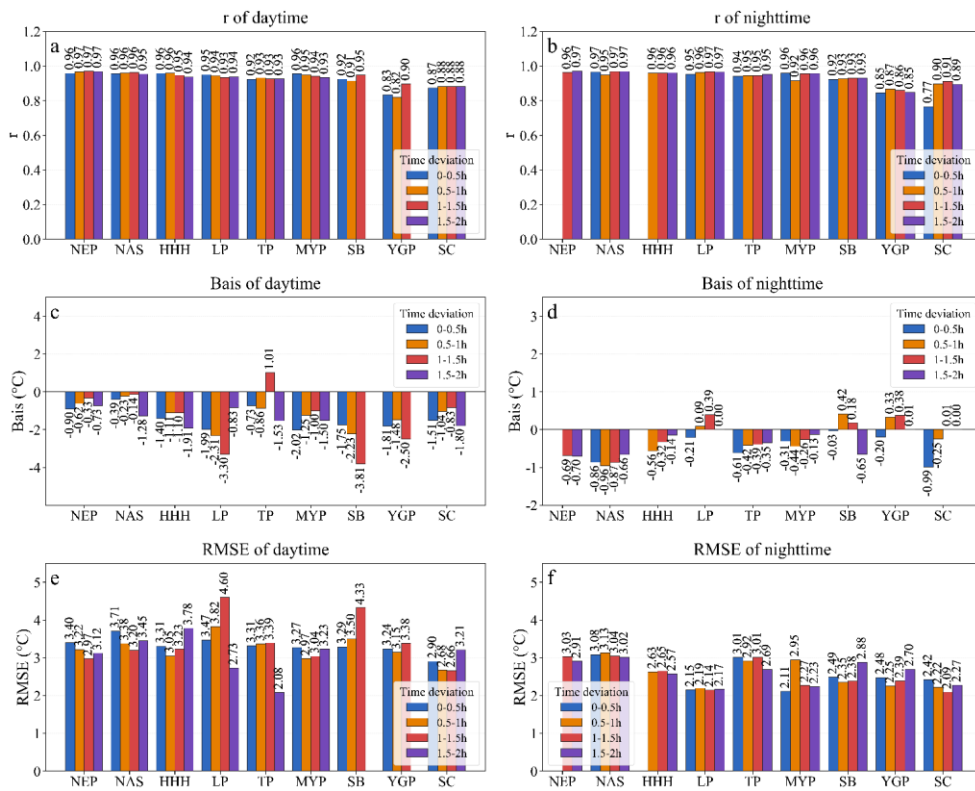


Figure 2. Sensitivity analysis of temperature retrieval accuracy to different temporal matching windows. (a), (c), and (e) show daytime correlation coefficient (r), bias (B), and root mean square error (RMSE), respectively; (b), (d), and (f) show the corresponding nighttime statistics.

3.2 The overall absolute retrieval accuracy during daytime and nighttime

Figure 3 illustrates the density scatterplots comparing MOD07_L2 instantaneous retrievals with sounding temperatures at different pressure levels during daytime. MOD07_L2 agreed closely with the sounding observations in the upper layers (400–620 hPa), with r values of at least 0.95 and RMSE values ranging from 2.53 to 2.86 °C. Retrieval errors increased toward the lower layers, particularly at 850 and 920 hPa, where the B values were -2.03 and -2.14 °C, respectively, with corresponding RMSE values of 3.74 and 4.11 °C. Thus, the daytime retrievals showed pronounced negative biases and greater uncertainty at these two lower pressure levels.

Deleted: illustrated

Deleted: scatter distributions between

Deleted: and

Deleted: Results indicated that the retrieval accuracy of MOD07_L2 data was high in the upper layers (400, 500, and 620 hPa). Specifically, at 400 hPa, the r was 0.95, the B was near 0°C, and the RMSE was around 2.8°C. Similar trends were observed at the 500 and 620 hPa levels, where the r remained above 0.95, the B approached 0°C, and the RMSE ranged from 2.5°C to 2.7°C. These results demonstrated the good consistency between the retrievals and the observations in the upper layers. However, the error increased in the lower layers (850, 920, 950 hPa and 1000 hPa). Particularly

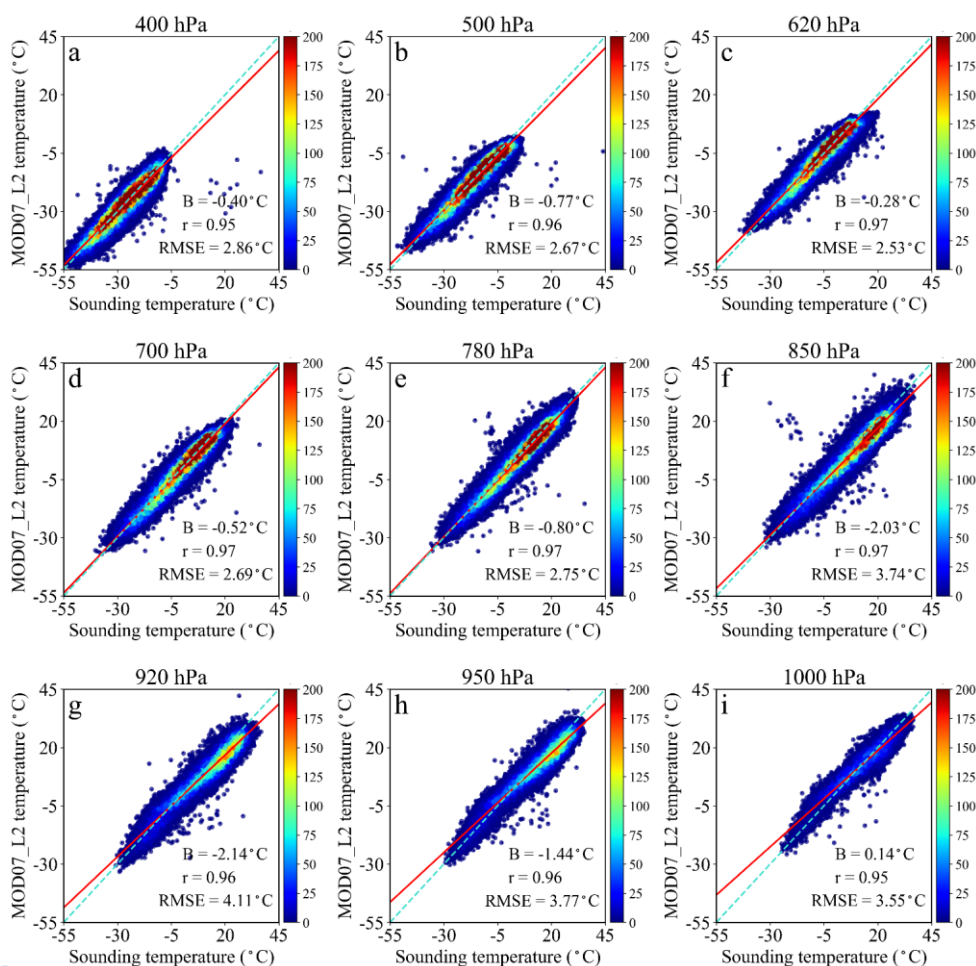


Figure 3. Overall accuracy of MOD07_L2 temperature retrievals evaluated against sounding observations during daytime from 2003 to 2020.

Figure 4 illustrates the density scatterplots comparing MOD07_L2 instantaneous retrievals with sounding observations at different pressure levels during nighttime. In general, the overall retrieval performance during nighttime was better than that during daytime. In the upper layers, r was above 0.96, the RMSE ranged from 2.21°C to 2.63°C, indicating strong correlations and relatively small errors. RMSE values were lower at nighttime than during daytime at all examined pressure levels. At 850 and 920 hPa, the B values were -1.62 and -1.37 °C, respectively, with corresponding RMSE values of 3.42 and 3.18 °C. Although these negative biases and RMSE values were lower than during daytime, they remained relatively large compared

Deleted: at the 920 hPa, the r was 0.96, the B was near 0.2°C, and the RMSE reached approximately 4.1°C. This indicated that the retrieval results of MOD07_L2 were unstable in the lower layers. In addition, the 700 hPa presented the high r of 0.97 and the RMSE of 2.69°C, but the B was 0.49°C, which was higher than that at other layers. Overall, MOD07_L2 exhibited better retrieval accuracy in the upper layers during daytime conditions, but retrieval errors were larger than those in the lower layers, especially near the surface. ¶

Deleted: retrieved temperatures compared with sounding observed temperatures

Deleted: illustrated

Deleted: scatter distributions between

Deleted: retrieved

Deleted: and observed atmospheric temperatures

Deleted: the

Deleted: the B approached 0°C, and

Deleted: was

Deleted: 2

Deleted: 7

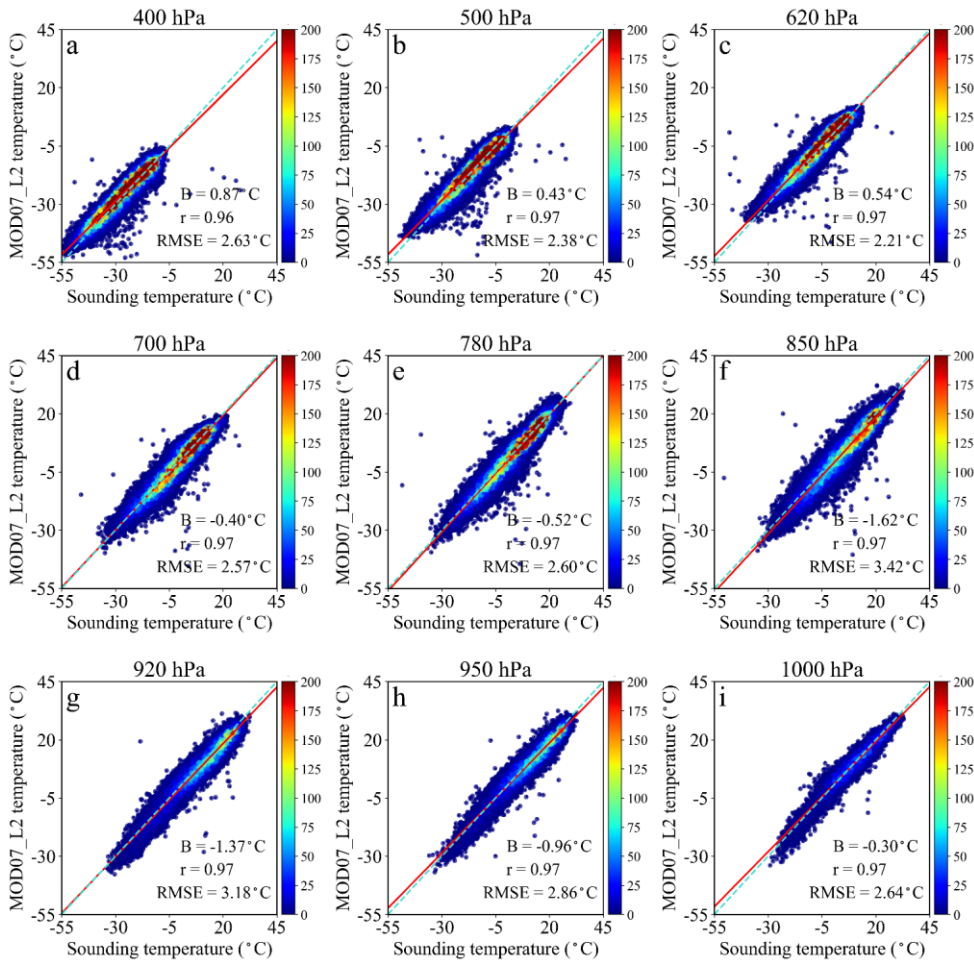
Deleted: . However, at the 700 hPa, the nighttime retrieval B reached 0.56°C, which was higher than other levels. In the lower layers, the RMSE remained lower than during the daytime.

Formatted: Font: Not Bold

Formatted: Font: Not Bold

Formatted: Font: Not Bold

326 with those at the other pressure levels.



327

328 **Figure 4. Overall accuracy of MOD07_L2 temperature retrievals evaluated against sounding observations during nighttime from**
329 **2003 to 2020**

330 Table 1 summarizes the national-scale validation statistics (r, B, and RMSE) for all nine pressure levels.

331 [Table 1. National-scale validation statistics for MOD07_L2 temperature retrievals at nine pressure levels during daytime and](#)

Deleted: For example, at the 1000 hPa, the r increased from 0.95 during daytime to 0.97, the B remained near 0°C, and the RMSE improved to approximately 2.6°C.

Deleted: retrieved temperatures compared with sounding observed temperatures

337

nighttime from 2003 to 2020.

Pressure (hPa)	Daytime			Nighttime		
	r	B (°C)	RMSE (°C)	r	B (°C)	RMSE (°C)
400	0.95	-0.40	2.86	0.96	0.87	2.63
500	0.96	-0.77	2.67	0.97	0.43	2.38
620	0.97	-0.28	2.53	0.97	0.54	2.21
700	0.97	-0.52	2.69	0.97	-0.40	2.57
780	0.97	-0.80	2.75	0.97	-0.52	2.60
850	0.97	-2.03	3.74	0.97	-1.62	3.42
920	0.96	-2.14	4.11	0.97	-1.37	3.18
950	0.96	-1.44	3.77	0.97	-0.96	2.86
1000	0.95	0.14	3.55	0.97	-0.30	2.64

338

339 3.3 The Spatial Distribution of the Absolute Retrieval Accuracy.

340 Figure 5 presents the spatial distribution of MOD07_L2 retrieval accuracy metrics across various pressure levels during
341 daytime. The first two columns display the effective matching sample size for each station and the pressure difference (hereafter
342 ΔP) between the local near-surface pressure and the target pressure level, respectively. The pressure difference was calculated
343 as $\Delta P = P_{\text{near-surface}} - P_{\text{target}}$, where $P_{\text{near-surface}}$ is the pressure of the local near-surface layer and P_{target} is the target
344 pressure level. A smaller ΔP indicates that the target pressure level is closer to the local surface. The sample size generally
345 exhibits a decreasing trend from northwest to southeast across China. In the upper layers, retrieval performance was generally
346 better over the NEP, NAS, and HHH, which are characterized by relatively flat terrain and sufficient sample sizes. The r
347 exceeded 0.95, the B was within ± 2 °C, and the RMSE was around 2.5 °C. However, relatively large negative B values were
348 observed over the MYP, whereas relatively large positive B values occurred over the TP. In the middle levels, B was generally
349 small across most regions. In the lower layers, relatively large negative B values were observed in the western part of the NAS
350 at 850 hPa. At 920 and 950 hPa, pronounced negative B values mainly occurred over southern regions, including the SC, YGP,
351 SB, and MYP where RMSE exceeded 3.5 °C at some stations. At 1000 hPa, relatively large positive B values were observed
352 in parts of the NEP. Overall, daytime retrieval errors became larger and more spatially variable in the lower layers, particularly
353 over southern China and regions with complex terrain.

13

Formatted: Font: Not Bold

Deleted: the pressure difference (ΔP) between the given level and the near-surface layer,

Formatted: Font: Not Bold

Formatted: Font: Not Bold

Formatted: Font: Not Bold

Formatted: Font: Not Bold

Formatted: Font: Not Bold

Deleted: The spatial pattern of the ΔP reflects the influence of topography, where a smaller value indicates that the selected standard isobaric surface is closer to the local ground surface in those regions. The retrieval accuracy of MOD07_L2 varies across different regions and atmospheric pressure levels.

Formatted: Font: Not Bold

Deleted: optimal in regions characterized by flat terrain, ample sample sizes, and a large ΔP from the surface, such as the NEP, NAS, and HHH.

Deleted: 0.5

Formatted: Font: Not Bold

Deleted: Nevertheless, at some stations over the TP and the MYP, the RMSE at these pressure levels increased to approximately 3.0 °C.

Deleted: the retrieval accuracy improved over the MYP and SB compared with the upper layers

Formatted: Font: Not Bold

Deleted: Conversely, i

Deleted: the retrieval errors increased.

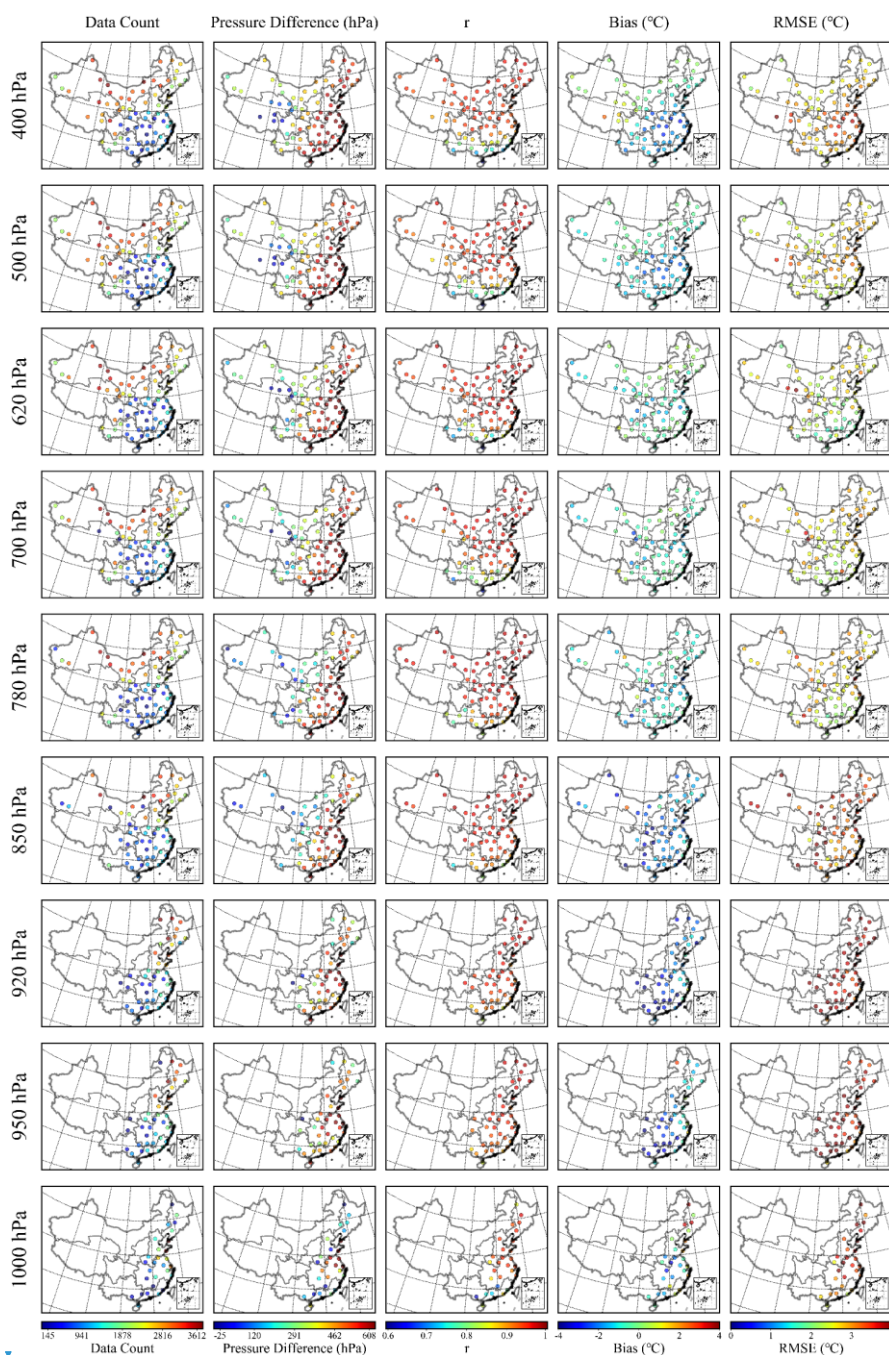
Formatted: Font: Not Bold

Formatted: Font: Not Bold

Formatted: Font: Not Bold

Formatted: Font: Not Bold

Formatted: Font: Not Bold

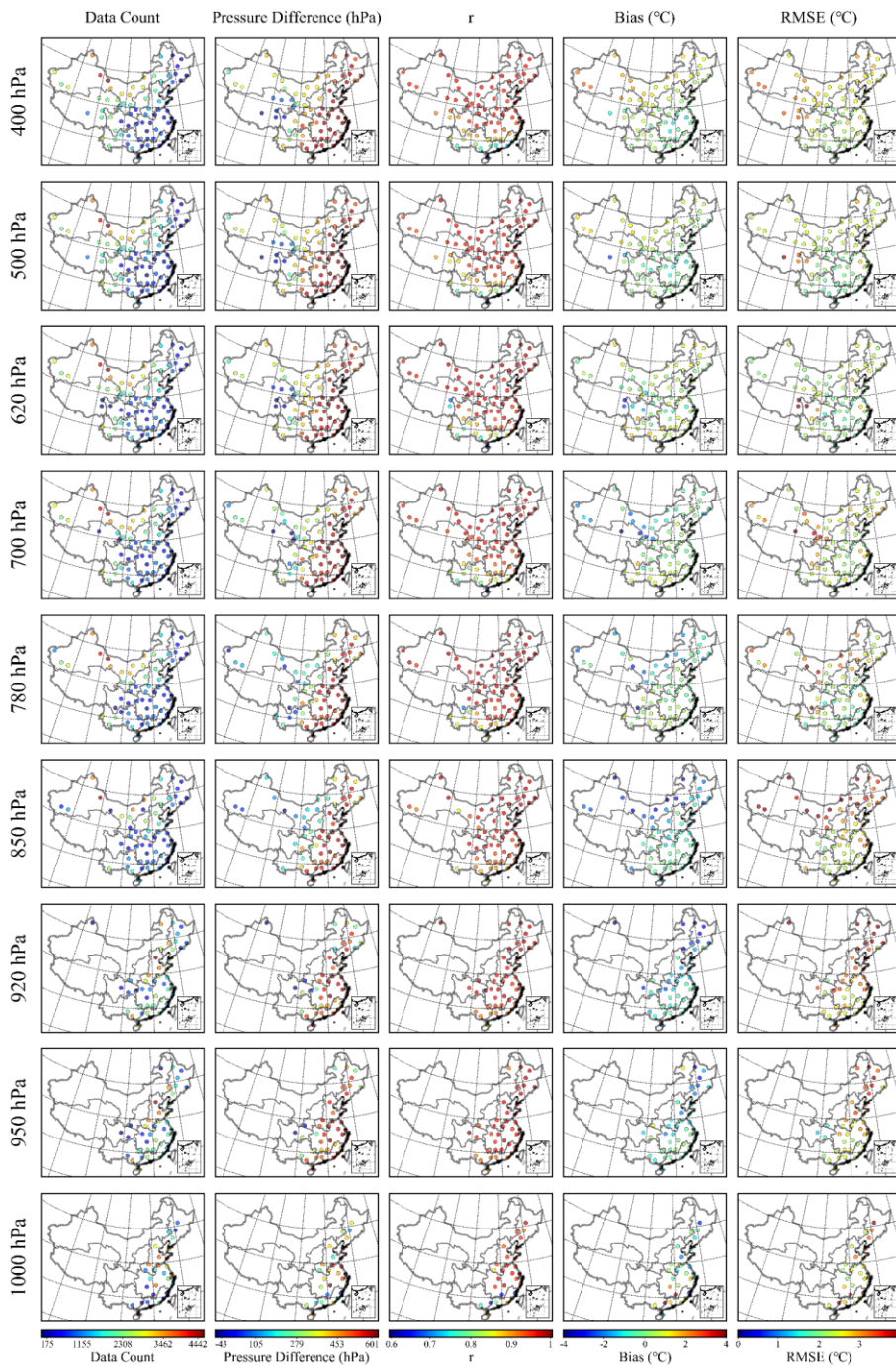


Deleted: Particularly over the SC, MYP, and YGP, where sample sizes are relatively small, despite favorable r and minimal B , the RMSE was above 3.5 °C. In contrast, retrievals over the NEP and the HHH at the lower layers indicated better accuracy, with r greater than 0.9, the B near 0, and the RMSE stabilized near 3.0 °C. Overall, under daytime conditions, MOD07_L2 exhibited superior retrieval accuracy at upper-air pressure levels, particularly over flat terrain. In contrast, larger retrieval errors were observed in the lower pressure layers, over complex terrain, and across southern regions with limited data availability¶

385 Figure 5. Spatial distribution of statistical indicators at each station for MOD07_L2 temperature retrievals evaluated against
386 sounding observations at nine pressure levels during daytime from 2003 to 2020.

387 Figure 6 illustrates the comparison between MOD07_L2 retrieved temperatures and sounding observations at different pressure
388 levels during nighttime. The first two columns present the effective matched sample size for each station and the corresponding
389 pressure difference (ΔP), calculated as described above, respectively. Spatially, the nighttime sample size exhibited a
390 decreasing gradient from northeast to southwest in the upper and middle layers, while lower counts were observed in the lower
391 layers over the NEP, SC, and the southeastern part of the YGP. In the upper layers, the retrieval accuracy was slightly higher
392 than that during daytime over flat regions such as the NEP, HHH, and NAS. r exceeded 0.95, RMSE ranged from 2.0 to 2.5 °C
393 at most stations, and slight positive biases were generally observed. Negative biases persisted over the MYP, but their absolute
394 values were generally less than 2 °C. In the middle layers, nighttime retrieval errors were generally lower than those during
395 daytime. In the lower layers, the retrieval accuracy at nighttime improved over most regions, especially over the HHH and
396 MYP. In these regions, r approached 0.9, B remained close to 0 °C, and RMSE decreased to approximately 2.0 °C. By
397 contrast, negative biases over the NAS and NEP became more pronounced, approaching -4 °C at some stations. In the NEP,
398 where the sample size was relatively small, RMSE ranging from 3.0 to 4.0 °C. Overall, nighttime retrieval performance
399 improved across most regions, although relatively large negative biases and RMSE values persisted over the NAS and NEP in
400 the middle and lower layers.

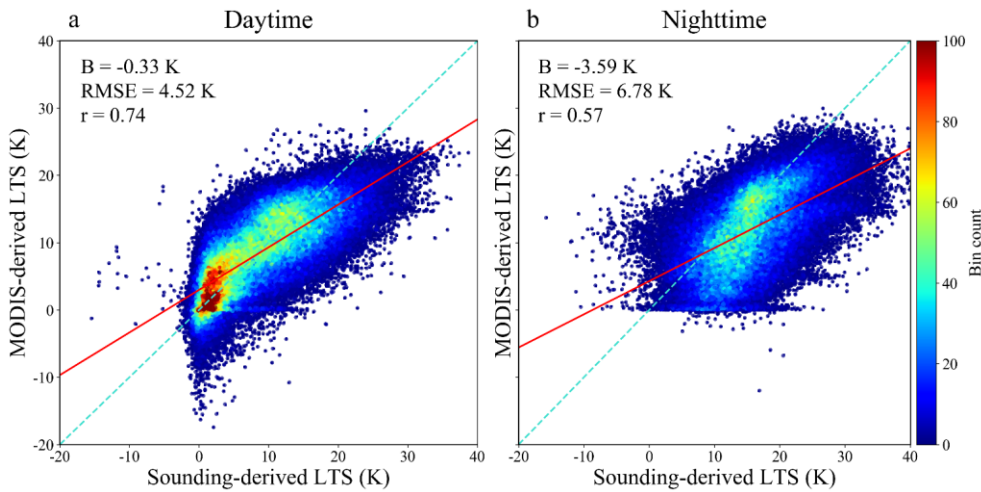
- Deleted: retrieved versus sounding temperatures
- Deleted: illustrated
- Formatted: Font: Not Bold
- Deleted: the ΔP between the given atmospheric level and the near-surface layer,
- Deleted: exhibits
- Deleted: are
- Deleted: Overall, the retrieval accuracy was higher during nighttime than during daytime.
- Formatted: No underline
- Deleted: accuracy
- Deleted: The r was above 0.95, the B was close to 0°C, and the RMSE at most stations fell between 2.0°C and 2.5°C. In particular, the RMSE decreased by about 0.5°C compared to daytime over the TP and MYP regions.
- Deleted: the
- Deleted: Overall, the r remained above 0.95, and the B was close to 0°C. Regionally, the RMSE was about 2.5°C over the NEP and HHH, and about 3.0°C over the NAS. All of these were lower than their daytime counterparts. In
- Deleted: showed improvement,
- Deleted: in
- Deleted: The
- Formatted: Font: Not Bold
- Deleted: and the B remained near 0°C at these regions and the RMSE decreased to around 2.0°C. However, i
- Deleted: region
- Formatted: Font: Not Bold
- Deleted: considerable retrieval errors persisted in the lower atmospheric layers, where r decreased to around 0.9,
- Formatted: Font: Not Bold
- Deleted: the B exceeded $\pm 0.5^\circ\text{C}$, and the RMSE ranged between 3.0°C and 4.0°C. In general, nighttime retrieval accuracy of MOD07_L2 was higher than that during daytime in the upper layers, especially over flat regions. In contrast, the retrieval errors exhibited only a slight increase in lower atmospheric levels, especially in regions characterized by both complex topography and data scarcity.¶



435 Figure 6. Spatial distribution of statistical indicators at each station for MOD07_L2 temperature retrievals evaluated against
436 sounding observations at nine pressure levels during nighttime from 2003 to 2020.

437 3.4 The accuracy of lower tropospheric stability

438 Figure 7 illustrated the ability of the MOD07_L2 product to capture lower tropospheric stability (LTS) during both daytime
439 and nighttime. During daytime, the r , B , and RMSE were 0.74, -0.33°C , and 4.52°C , respectively. At night, r decreased to
440 0.57, B became more negative at -3.59°C , and RMSE increased to 6.78°C . Furthermore, the red regression line deviated more
441 markedly from the cyan 1:1 line at night, indicating a stronger negative bias and greater dispersion in the MOD07_L2-derived
442 LTS. Overall, MOD07_L2 captured daytime LTS more accurately than nighttime LTS.



443
444 Figure 7. Heat map of sounding-derived and MOD07_L2-derived lower tropospheric stability during daytime and nighttime from
445 2003 to 2020.

446 In terms of spatial distribution, the retrieval accuracy of LTS exhibited pronounced regional variability during both daytime
447 and nighttime. During daytime, r values were lower in humid and topographically complex regions such as the SB, MYP, LP,
448 and HHH, with most values falling below 0.5. By contrast, higher r values were observed over the NAS and Northeast China
449 Plain, with regional means of approximately 0.58. These results indicated that retrieval performances were superior in arid and
450 flat terrains. The mean RMSE during daytime was approximately 4.38°C nationwide and was relatively low over the TP, SC,
451 and SB, whereas higher values occurred over the HHH and Northeast China Plain. The mean bias was close to zero nationwide,
452 although negative biases occurred over the TP and Northeast China Plain, whereas positive biases were evident over the YGP.

Deleted: MOD07_L2 retrieved versus sounding temperatures

Deleted: 0.04

Deleted: In contrast, during nighttime, r decreased to 0.57, the B increased to 0.30°C and the RMSE rose to 6.78°C . Furthermore, during nighttime, the red regression line diverged more substantially from the cyan diagonal in the density scatter plot, indicating a pronounced systematic error.

Deleted: lower tropospheric stability derived from sounding and MOD07_L2 observations

Formatted: Font: Not Bold

Formatted: Font: Not Bold, Not Italic

Formatted: Font: Not Bold

Deleted: the r values were higher in northern and southern regions, particularly over the NAS where the mean approached 0.6.

Deleted: about 4°C

Formatted: Font: Not Bold

467 SB, and LP. During nighttime, the spatial distribution of r exhibited a distinct pattern. Lower r values were observed over the
468 TP, SB, LP, NAS, and YGP, whereas higher values occurred over the SC, MYP, Northeast China Plain, and HHH, suggesting
469 that retrieval performance in humid zones improved at nighttime compared with daytime. Nighttime RMSE values were lower
470 over the YGP, SC, MYP, and HHH, mostly ranging from 3°C to 4°C, reflecting greater retrieval stability. Higher RMSE values
471 occurred over the TP, NAS, LP, Northeast China Plain, and SB, with regional means generally exceeding 5°C, thereby
472 indicating greater uncertainty. In terms of bias, relatively small deviations occurred over the HHH, SC, and YGP, whereas
473 pronounced negative biases persisted over the TP, LP, NAS, and SB. Overall, the retrieval performance was better over arid
474 and flat regions during daytime but improved over humid regions at nighttime, while larger nighttime uncertainties remained
475 in arid, high-elevation, and topographically complex regions.

Deleted: , but that was lower along the margins of the TP. Additionally, the large mean biases were evident at the margins of the TP, indicating a systematic error in this area. In contrast, most other regions exhibited modest biases, with errors displaying patchy spatial variability.

Formatted: Font: Not Bold

Formatted: Font: Not Bold, Not Italic

Formatted: Font: Not Bold

Deleted: On the NAS and along the margins of the TP, the r fell below 0.6. In contrast, the higher r values were observed over southeastern and northeastern China,

Formatted: Font: Not Bold

Deleted: The RMSE values were elevated over eastern and southern China, as well as along the TP margins, generally exceeding 5°C and thereby indicating greater uncertainty.

Formatted: Font: Not Bold

Formatted: Font: Not Bold

Deleted: eastern and southern China exhibited small deviations, whereas systematic biases persisted on arid and high-elevation regions.

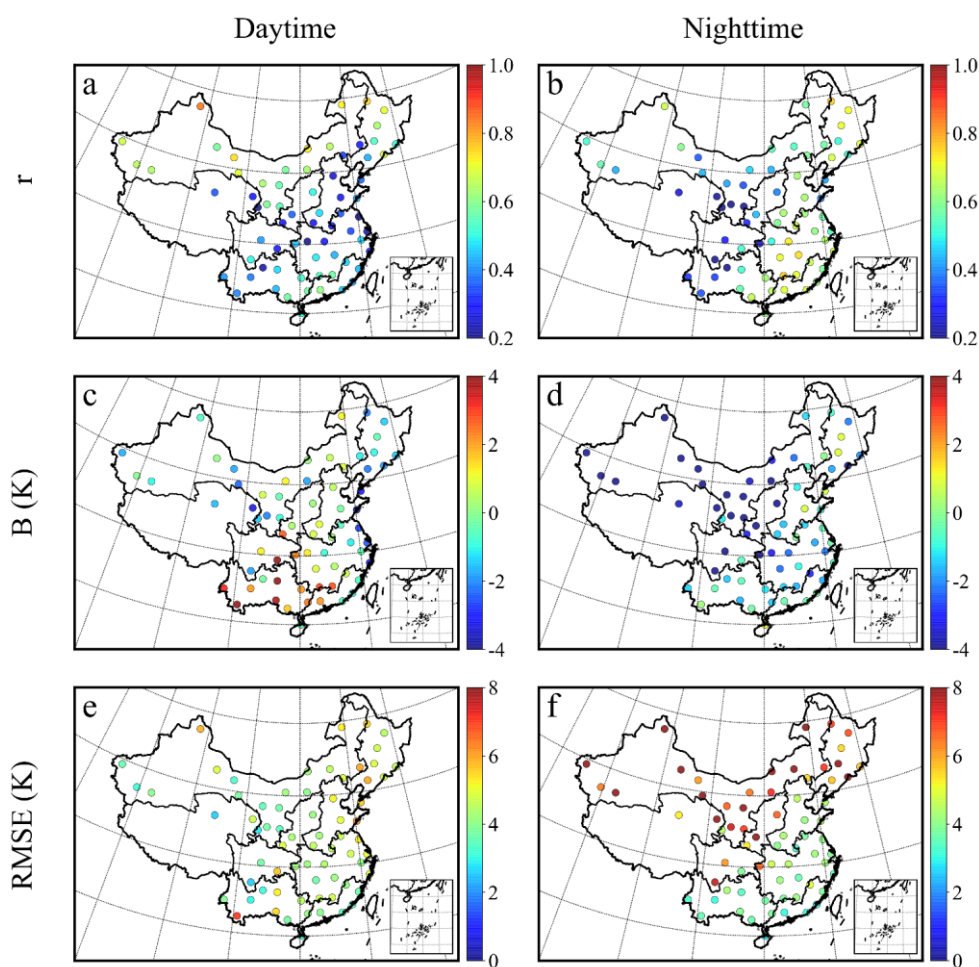


Figure 8. Spatial distribution of MOD07_L2 lower tropospheric stability retrieval accuracy for daytime and nighttime from 2003 to 2020. (a), (c), and (e) show daytime r , B , and $RMSE$, respectively; (b), (d), and (f) show the corresponding nighttime metrics.

3.5 The identification of temperature inversion layers

Figure 9 illustrated the detection results of TILs by MOD07_L2 over China and its nine agricultural zones during daytime and nighttime. Overall, the proportion of TILs detected by MOD07_L2 was low, with 6.6% during daytime and 13.1% during nighttime. Generally, regions with higher detection rates during the daytime also exhibited higher rates during the nighttime, except for the SB. During daytime, the detection rate of inversion layers by MOD07_L2 was below 6% in most regions, and

Deleted: the

Deleted:

Formatted: Font: Not Bold

inversion layers were not detected over the TP or in the SB. Only NAS and NEP showed respective 10.6% and 8.4% detection rates during daytime. During nighttime, the detection rate remained below 10% in most regions, with only NEP and NAS at 29.9% and 20.0%, respectively. During nighttime, inversion layers were not detected over the TP. In general, the detection rates were higher during nighttime than during daytime across most regions.

Deleted: even no inversion layers were detected on the TP and in the SB.

Deleted: No inversion layers were detected on the TP during nighttime.

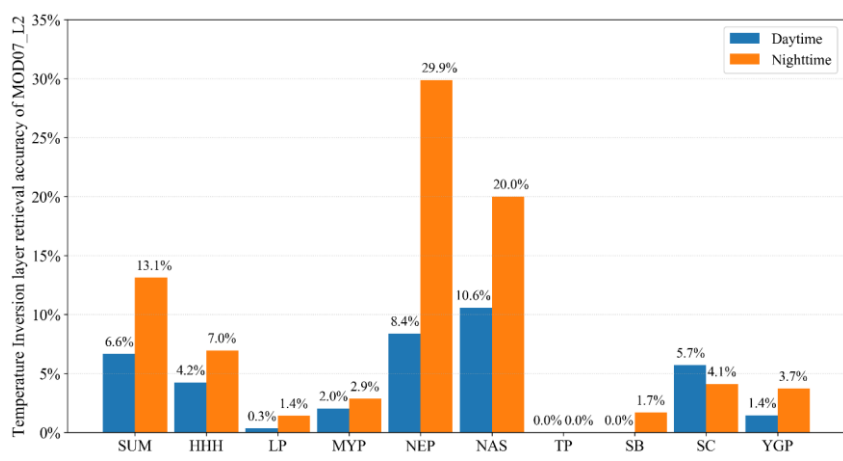


Figure 9. The overall detection accuracy of MOD07_L2 for temperature inversion layers, as well as over nine agricultural regions during daytime and nighttime.

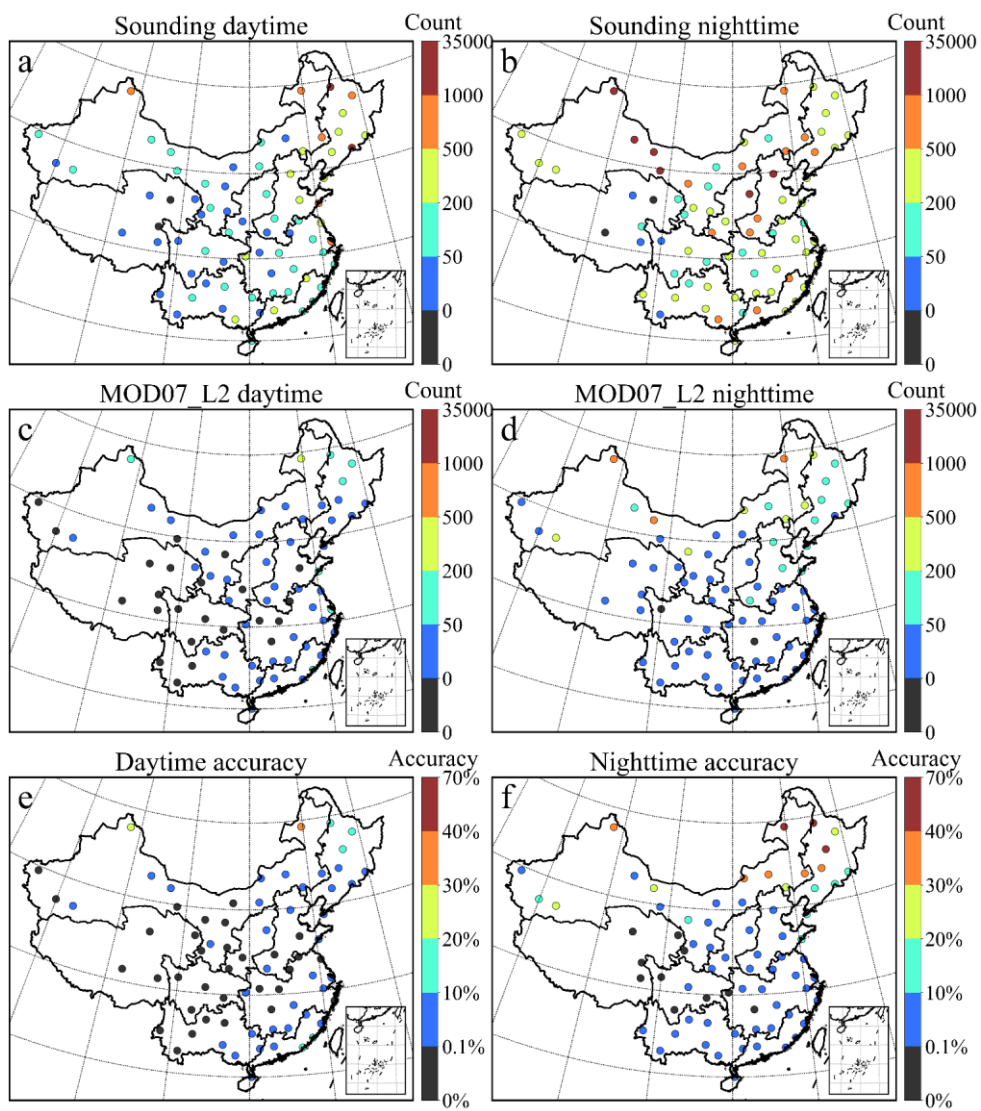
As illustrated in Fig. 10, the spatial distributions and detection accuracies of temperature inversions derived from sounding data and MOD07_L2 exhibited marked discrepancies between daytime and nighttime. During daytime, sounding data recorded the highest inversion counts in the NEP, with two stations surpassing 1000 events. Most stations in the NEP and HHH region ranged from 200 to 500 counts, while those in other areas were predominantly below 200. Notably, two stations on the TP detected no inversions. In contrast, MOD07_L2 identified inversion counts between 50 and 500 solely in the northern portions of the NEP and in the NAS. The majority of stations elsewhere fell below 50 counts, and no inversions were detected in the SB. Only one northeastern station on the TP detected a minimal number. Furthermore, stations in the western portions of the YGP and on the MYP also failed to detect any inversions. Detection precision exceeded 10% at only a few isolated sites in the northern NAS and NEP. During nighttime, sounding data revealed that inversion events were more prevalent and frequent. Stations with inversion counts exceeding 1000 were primarily distributed in western NAS, northern LP, and northern HHH. Specifically, inversion counts in western NAS, NEP, HHH, and LP were relatively high, all surpassing 200. In contrast, the TP exhibited the fewest inversions, with two stations detecting none. The detection performance of MOD07_L2 improved at night,

Deleted: detections

Deleted: in the northern

Deleted: regions

526 identifying 500–1000 inversions at three stations in northern NAS and exceeding 50 counts in NEP, northern NAS, and
 527 northern HHH. However, inversion counts at stations in other regions remained below 50. Detection precision reached 10%
 528 only in northern NAS and northern NEP. Notably, MOD07_L2 failed to detect any inversions at stations on the TP, as well as
 529 in parts of the SB and MYP.



530

Figure 10. Spatial distribution and precision of temperature inversion detection based on MOD07_L2 and sounding data during daytime and nighttime from 2003 to 2020. (a) and (b) show the daytime and nighttime distributions derived from sounding data, (c) and (d) show the corresponding distributions from MOD07_L2, (e) and (f) show the detection precision at each station for daytime and nighttime.

4 Discussion

4.1 Uncertainty of the absolute temperature retrieval

This study reveals that the retrieval accuracy of MOD07_L2 satellite temperature profiles significantly decreases as pressure levels approach the Earth's surface. This phenomenon primarily arises from stronger interference by surface longwave radiation in the lower atmosphere, greater variability in surface thermal inertia, and more intense local circulation and temperature fluctuations induced by complex terrain near the surface (Xue et al., 2023; Cheng et al., 2025; Song et al., 2024). Additionally, overall retrieval accuracy is higher at night than during the daytime, mainly because nighttime surface radiative cooling reduces diurnal variations in thermal infrared signals (He et al., 2023).

Spatially, the retrieval errors exhibit pronounced regional heterogeneity. In the TP, errors in the middle and lower layers are high, primarily attributable to high elevation and complex terrain causing standard pressure levels to be closer to the surface, as well as extreme diurnal temperature variations that amplify fluctuations in thermal infrared signals (Zhao et al., 2020; Ma et al., 2023). Additionally, the MOD07_L2 product integrates multi-channel infrared brightness temperatures with global reanalysis and sounding data through statistical regression and physical retrieval algorithms (Sobrino et al., 2014; Zhang et al., 2025). The SB and MYP exhibited relatively large lower-layer errors during daytime due to humid climate, frequent stratiform cloud cover, and topographic enclosure (Zhang & Zhang, 2019; Feng et al., 2020). In addition, the time-matching sensitivity analysis indicated that larger temporal differences also contributed to increased daytime retrieval errors over the SB and LP (Fig. 2). At nighttime, retrieval errors decreased markedly over the HHH and MYP, possibly because weaker surface heating reduced short-term thermal heterogeneity. In the NAS, sparse vegetation cover weakens near-surface energy exchange, thereby increasing retrieval errors in the lower layers (Meier et al., 2022). Dust storms and aerosols with high optical thickness further interfere with atmospheric transmittance (G. Huang et al., 2020). Moreover, the pronounced nighttime negative biases over the NAS and NEP may be associated with strong stable stratification and sharp low-level temperature gradients, which are difficult for infrared profile retrievals with limited vertical resolution to resolve accurately (Guo et al., 2020; Gopikrishnan et al., 2023). It is particularly noteworthy that MOD07_L2 exhibits pronounced negative biases at 850 and 920 hPa, especially during daytime. Because these levels are close to the surface over most regions, uncertainties in surface temperature and

Deleted: Retrieval accuracy is higher in the upper layers, whereas errors increase in the lower layers, with the largest errors occurring in levels close to the surface.

Deleted: In high-elevation regions, the limited number of meteorological stations and sounding observations increases errors in numerical simulations (Zhang et al., 2023).

Deleted: , experience significantly larger lower-layer errors

Formatted: Font: Not Bold

Deleted: ¶
It is particularly noteworthy that MOD07_L2 exhibits substantial systematic biases at the 700 hPa level. The causes of this bias are complex. First, the 700 hPa level serves as a key interface in the mid-troposphere, commonly used to characterize mid-level humidity, vertical motion, and weather system structures such as fronts and shear lines. Its temperature field displays strong spatial heterogeneity, making retrieval or assimilation challenging (Hersbach et al., 2020; Li et al., 2021). Second, in high-elevation regions of China, the 700 hPa standard pressure level lies closer to the surface, rendering this layer susceptible to contamination by surface influences during retrieval (Ma et al., 2023; Zhao et al., 2020). Additionally, the weighting functions of MODIS infrared channels typically peak near the 700 hPa level in the mid-troposphere. This makes them sensitive to temperature but highly susceptible to interference from clouds, water vapor, and aerosols, resulting in cloud contamination or weakened signals in absorption bands (Menzel et al., 2019; Platnick et al., 2003). ¶

spectral emissivity can propagate into the retrieved lower-tropospheric temperatures (Xie et al., 2023; Gopikrishnan et al., 2023). Moreover, the broad vertical weighting functions and limited vertical sampling of MOD07_L2 may smooth strong temperature gradients and warm anomalies in the lower atmosphere, thereby contributing to temperature underestimation (King et al., 2003; Sobrino et al., 2014). Water vapor absorption and residual thin-cloud contamination may further reduce the sensitivity of infrared radiances to these levels, particularly in humid regions (Platnick et al., 2003). These combined effects likely explain the more pronounced daytime negative biases at 850 and 920 hPa.

4.2 Uncertainty of lower tropospheric stability and temperature inversion layer

This study revealed that the accuracy of LTS retrieved by MOD07_L2 was higher during the daytime than at nighttime, which appears inconsistent with the superior absolute retrieval accuracy of atmospheric temperature observed at night. This discrepancy arose from the nature of LTS as a derived parameter, whose accuracy hinges not only on the absolute retrieval precision of individual layer temperatures but also on the fidelity of vertical temperature gradient retrieval. At night, although atmospheric temperature retrieval accuracy may be enhanced, the frequent occurrence of strong near-surface inversion layers heightened vertical structural complexity (Kaushal et al., 2022; Tan et al., 2021). A ground-based study at the Southern Great Plains site showed that during cloudy nights, clouds absorb surface longwave radiation and re-radiate it downward, reducing surface radiative cooling rates and thereby enhancing atmospheric instability and turbulence intensity (Li et al., 2025). This leads to more complex vertical temperature gradients at night, increasing the difficulty of LTS retrieval using MOD07_L2.

The limited vertical resolution of MOD07_L2 thus struggled to resolve sharp temperature gradients within thin inversion layers, and may smooth shallow nocturnal inversions. Because near-surface potential temperature was estimated by linear interpolation from discrete pressure levels, failure to resolve the colder air near the inversion base may lead to an overestimation of near-surface potential temperature and consequently an underestimation of LTS (Zhang et al., 2023).

Moreover, nighttime thermal infrared remote sensing exhibited diminished sensitivity to subtle thermal variations in the boundary layer (He et al., 2023). Prevalent cloud cover and elevated water vapor may partly explain the relatively low daytime accuracy over the SB and MYP and the persistently large nighttime errors over the SB (Zhang & Zhang, 2019). However, the improved nighttime performance over the MYP, SC, and HHH indicates that atmospheric moisture alone does not determine regional retrieval accuracy, which is also influenced by terrain and nighttime thermal structure. Additionally, pronounced nighttime negative biases persisted over the TP, LP, NAS, and SB. In these arid, high-elevation, or topographically complex regions, strong nighttime radiative cooling and terrain effects can enhance low-level temperature gradients, increasing the difficulty of accurately retrieving LTS (Feng et al., 2020; Guo et al., 2020; Chen et al., 2022). In addition, MOD07_L2 identified only a limited number of TILs, possibly due to its 5 km spatial resolution, which may average out thin inversion structures (Borbas et al., 2011). Furthermore, the limited vertical sampling of only 20 standard pressure levels in MOD07_L2 hindered

Deleted: Furthermore, clouds further complicate nighttime boundary layer structure.

Formatted: Font: Not Bold

Deleted: leading to underestimation of near-surface potential temperature via linear interpolation.

Deleted: In humid regions such as SB and MYP, prevalent cloud cover and elevated water vapor further attenuate infrared signal sensitivity to the lower atmosphere (Zhang et al., 2019), thereby degrading LTS retrieval accuracy.

Deleted: in areas like the TP edges and NAS, intense nighttime radiative cooling induced rapid temperature gradient shifts, exacerbating LTS retrieval errors (Tian et al., 2023; Chen et al., 2022). ¶

Deleted: Seemann et al., 2006

the resolution of shallow near-surface inversions. MOD07_L2 data indicated that nighttime inversions were more frequent than those during the daytime, attributable to nighttime surface longwave cooling that readily initiates and sustains near-surface inversions. This mechanism aligned with findings from multi-site radiosonde observations (Zhang et al., 2022; Zeng et al., 2022). The present study further demonstrates that MOD07_L2 exhibited a higher detection rate and accuracy for nighttime inversions compared to daytime ones, primarily owing to the enhanced boundary layer stability and reduced atmospheric turbulence, which improve the reliability of satellite-based inversion detection (Tan et al., 2021). On a regional scale, the frequency of temperature inversion detection over the Tibetan Plateau is relatively low. This finding aligns with recent evaluations of reanalysis products over the TP, which have also revealed substantial challenges in capturing low-level temperature inversions due to complex terrain and surface-atmosphere interactions (Luo et al., 2025). Furthermore, MOD07_L2 provided fewer effective pressure levels at high-altitude regions, thereby reducing its inversion detection capabilities (Che & Zhao, 2021; Chen et al., 2016). At the SB, the humid and enclosed terrain promoted inversion formation. However, the multi-layered structure and moist air impeded thermal infrared profile retrieval, resulting in lower accuracy (Feng et al., 2020; Feng et al., 2023). At high latitude areas, despite the greater temporal mismatch between the datasets at northern NEP and NAS, MOD07_L2 demonstrated superior accuracy in inversion layer detection in these regions. This finding aligned with long-term radiosonde climatology, underscoring that colder, higher-latitude areas were prone to forming thicker and stronger near-surface inversions (Guo et al., 2020). In humid southern regions such as MYP and YGP, abundant moisture and thin inversion layers impeded effective detection by MOD07_L2. Furthermore, Huang et al. (2021) reported that humid southern China predominantly featured thin, weak elevated inversions, which posed significant challenges for reliable infrared profile retrievals.

4.3 Future effort

Based on the systematic validation of the high-resolution MOD07_L2 satellite product conducted in this study, the performance characteristics and regional applicability of this dataset in terms of vertical temperature profile absolute accuracy, lower tropospheric stability (LTS), and temperature inversion layer (TIL) detection have been clarified. Future work can be deepened in the following directions. First, optimize the spatiotemporal matching scheme by developing more refined interpolation methods or incorporating atmospheric model corrections to reduce boundary layer evolution errors potentially introduced by the $|\Delta t| < 2$ -hour window. Second, deepen error attribution analysis by integrating auxiliary data such as cloud cover, aerosol optical depth, water vapor, and terrain, combined with radiative transfer simulations or machine learning methods, to quantitatively diagnose the mechanisms underlying the systematic negative biases at 850 and 920 hPa and their regional differences. Finally, further improve the retrieval algorithm performance of the MOD07_L2 product and explore feasible

Formatted: Font: Not Bold

Deleted: the formation mechanisms of systematic biases at 700 hPa and regional differences.

pathways for integrating multi-source observational data, with the aim of generating higher-accuracy temperature profile products, thereby significantly enhancing their application value in regional high-impact weather mechanism analysis, local climate monitoring, and environmental assessment.

5 Conclusion

While the MOD07_L2 atmospheric temperature profile product provides important information at high spatial resolution, there is still a lack of comprehensive evaluation in terms of its absolute retrieval accuracy and its capability to assess boundary layer stability and detect temperature inversions. Therefore, we conducted a comprehensive assessment by comparing it with 74 geographically dispersed sounding stations from 2003 to 2020 across China. The absolute retrieval accuracy of MOD07_L2 showed clear differences across pressure layers during both daytime and nighttime, with nighttime accuracy generally better than that during daytime. Meanwhile, the upper layers (400–620 hPa) demonstrated higher accuracy, whereas the lower layers (850–1000 hPa) exhibited larger errors in humid and topographically complex regions. In particular, pronounced negative biases were observed at 850 and 920 hPa, especially during daytime. In contrast, MOD07_L2-derived LTS was more accurate during daytime than nighttime. Moreover, there were limitations in detecting temperature inversion layers during both daytime and nighttime. The findings of this study enhance the utility of MODIS's long-term data archive for climate applications and provide a valuable reference for the development and validation of similar products from current and future satellite missions, such as the VIIRS instrument.

CRedit authorship contribution statement

Zhang Wenjie: Conceptualization, Methodology, Supervision, Funding acquisition, Resources, Writing – review & editing. Qu Mengxi: Methodology, Supervision, Data curation, Formal analysis, Writing - Original Draft. Sun Ranhao and Zhao Jiarui: Validation, Supervision. Ning Guicai: Conceptualization, Investigation, Writing – review & editing. Aziz Inamov, Zokhid Mamatkulov and Zhou Di: Validation, Methodology. Bakhtiyor Pulatov: Methodology. Yang Yuanjian: Conceptualization, Methodology, Supervision, Resources, Writing – review & editing.

Acknowledgments

This study is financially supported by the National Key Research and Development Program of China (2023YFE0208100), the National Natural Science Foundation of China (Grant 42201053 and 42222503) and the open fund project of the State Key Laboratory of Regional and Urban Ecology (Grant SKLURE2023-2-4).

Data availability

Deleted: However, the retrieval errors at the 700 hPa level showed a more significant bias than those in other pressure levels.

Deleted: the retrievals of lower tropospheric stability were more reliable

692 The shapefile data of agricultural zones is accessible from [https://gitcode.com/open-source-](https://gitcode.com/open-source-toolkit/6b76d/commit/aab463c56bfbc7b0de5024ef53da43a634529ac?ref=main)
693 [toolkit/6b76d/commit/aab463c56bfbc7b0de5024ef53da43a634529ac?ref=main](https://gitcode.com/open-source-toolkit/6b76d/commit/aab463c56bfbc7b0de5024ef53da43a634529ac?ref=main). The MOD07_L2 data are available
694 from <https://doi.org/10.5067/MODIS/MOD07L2.061>. The sounding data are available
695 from <http://weather.uwyo.edu/upperair/sounding.html>. These data are openly accessible, and no permissions are required to
696 download them. The corresponding data citations have been included in the reference list of this manuscript.

697 **Declaration of competing interest**

698 Some authors are members of the editorial board of *Atmospheric Measurement Techniques*.

699 **References**

700 Barlow, J. F., Halios, C. H., Lane, S. E., and Wood, C. R.: Observations of urban boundary layer structure during a strong
701 urban heat island event, *Environ. Fluid Mech.*, 15, 373–398, <https://doi.org/10.1007/s10652-014-9335-6>, 2015.

702 [Borbas, E. E., Seemann, S. W., Kern, A., Moy, L., Li, J., Gumley, L. E., and Menzel, W. P.: MODIS Atmospheric Profile](#)
703 [Retrieval Algorithm Theoretical Basis Document, Collection 6, Version 7, University of Wisconsin–Madison, Madison, WI,](#)
704 https://modis-images.gsfc.nasa.gov/docs/MOD07_atbd_v7_April2011.pdf (last access: 10 September 2026), 2011.

705 Che, J. and Zhao, P.: Characteristics of the summer atmospheric boundary layer height over the Tibetan Plateau and influential
706 factors, *Atmos. Chem. Phys.*, 21, 5253–5268, <https://doi.org/10.5194/acp-21-5253-2021>, 2021.

707 Chen, G., Zhang, X., and Fu, Y.: Diurnal variation in clouds and radiative budgets over the Tibetan Plateau during summer
708 using CERES data, *J. Geophys. Res. Atmos.*, 127, e2021JD036329, <https://doi.org/10.1029/2021JD036329>, 2022.

709 Chen, S., Hu, D., Wong, M. S., Ren, H., Cao, S., Yu, C., and Ho, H. C.: Characterizing spatiotemporal dynamics of
710 anthropogenic heat fluxes: A 20-year case study in Beijing–Tianjin–Hebei region in China, *Environ. Pollut.*, 249, 923–931,
711 <https://doi.org/10.1016/j.envpol.2019.03.113>, 2019.

712 Chen, X., Škerlak, B., Rotach, M. W., Añel, J. A., Su, Z., Ma, Y., and Li, M.: Reasons for the extremely high-ranging planetary
713 boundary layer over the western Tibetan Plateau in winter, *J. Atmos. Sci.*, 73, 2021–2038, [https://doi.org/10.1175/JAS-D-15-](https://doi.org/10.1175/JAS-D-15-0148.1)
714 0148.1, 2016.

715 Cheng, J., Zeng, Q., Sun, H., Guo, Y., Yang, F., Guo, M., and Wu, C.: A global 1 km resolution daily surface longwave radiation
716 product from MODIS satellite data from 2000–2023, *Sci. Data*, 12, 736, <https://doi.org/10.1038/s41597-025-05076-8>, 2025.

717 Coll, C., Caselles, V., Valor, E., and Niclòs, R.: Comparison between different sources of atmospheric profiles for land surface
718 temperature retrieval from single channel thermal infrared data, *Remote Sens. Environ.*, 117, 199–210,
719 <https://doi.org/10.1016/j.rse.2011.09.018>, 2012.

720 Dessler, A. E. and Davis, S. M.: Trends in tropospheric humidity from reanalysis systems, *J. Geophys. Res. Atmos.*, 115,
721 D19127, <https://doi.org/10.1029/2010JD014192>, 2010.

722 Feng, X., Wei, S., and Wang, S.: Temperature inversions in the atmospheric boundary layer and lower troposphere over the
723 Sichuan Basin, China: Climatology and impacts on air pollution, *Sci. Total Environ.*, 726, 138579,
724 <https://doi.org/10.1016/j.scitotenv.2020.138579>, 2020.

725 Feng, X., Zhang, Z., Guo, J., and Wang, S.: Multilayer inversion formation and evolution during persistent heavy air pollution
726 events in the Sichuan Basin, China, *Atmos. Res.*, 286, 106691, <https://doi.org/10.1016/j.atmosres.2023.106691>, 2023.

727 Galfi, V. M. and Lucarini, V.: Fingerprinting heatwaves and cold spells and assessing their response to climate change using

large deviation theory, *Phys. Rev. Lett.*, 127, 058701, <https://doi.org/10.1103/PhysRevLett.127.058701>, 2021.

Gelaro, R., McCarty, W., Suárez, M. J., Todling, R., Molod, A., Takacs, L., Randles, C. A., Darmenov, A., Bosilovich, M. G., Reichle, R., Wargan, K., Coy, L., Cullather, R., Draper, C., Akella, S., Buchard, V., Conaty, A., da Silva, A. M., Gu, W., Kim, G.-K., Koster, R., Lucchesi, R., Merkova, D., Nielsen, J. E., Partyka, G., Pawson, S., Putman, W., Rienecker, M., Schubert, S. D., Sienkiewicz, M., and Zhao, B.: The Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2), *J. Climate*, 30, 5419–5454, <https://doi.org/10.1175/JCLI-D-16-0758.1>, 2017.

Gopikrishnan, G. S., Kuttippurath, J., Thapliyal, P. K., and Shukla, M. V.: Validation of INSAT-3D and INSAT-3DR temperature profile retrievals using ground-based, satellite, and reanalysis data, *J. Geophys. Res. Atmos.*, 128, e2023JD038912, <https://doi.org/10.1029/2023JD038912>, 2023.

Grimmond, C. S. B., Roth, M., Oke, T. R., Au, Y. C., Best, M., Betts, R., Carmichael, G., Cleugh, H., Dabberdt, W., Emmanuel, R., Freitas, E., Fortuniak, K., Hanna, S., Klein, P., Kalkstein, L. S., Liu, C. H., Nickson, A., Pearlmutter, D., Sailor, D., and Voogt, J.: Climate and more sustainable cities: Climate information for improved planning and management of cities (producers/capabilities perspective), *Procedia Environ. Sci.*, 1, 247–274, <https://doi.org/10.1016/j.proenv.2010.09.016>, 2010.

Guo, J., Miao, Y., Zhang, Y., Liu, H., Li, Z., Zhang, W., He, J., Lou, M., Yan, Y., Bian, L., and Zhai, P.: The climatology of planetary boundary layer height in China derived from radiosonde and reanalysis data, *Atmos. Chem. Phys.*, 16, 13309–13319, <https://doi.org/10.5194/acp-16-13309-2016>, 2016.

Guo, J., Su, T., Li, Z., Miao, Y., Li, J., Liu, H., Xu, H., Cribb, M., and Zhai, P.: Declining frequency of summertime local-scale precipitation over eastern China from 1970 to 2010 and its potential link to aerosols, *Geophys. Res. Lett.*, 44, 5700–5708, <https://doi.org/10.1002/2017GL073533>, 2017.

Guo, J., Chen, X., Su, T., Liu, L., Zheng, Y., Chen, D., Li, J., Xu, H., Lv, Y., He, B., Li, Y., Hu, X.-M., Ding, A., and Zhai, P.: The climatology of lower tropospheric temperature inversions in China from radiosonde measurements: Roles of black carbon, local meteorology, and large-scale subsidence, *J. Climate*, 33, 9327–9350, <https://doi.org/10.1175/JCLI-D-19-0278.1>, 2020.

Harris, I., Osborn, T. J., Jones, P., and Lister, D.: Version 4 of the CRU TS monthly high-resolution gridded multivariate climate dataset, *Sci. Data*, 7, 109, <https://doi.org/10.1038/s41597-020-0453-3>, 2020.

He, G., He, C., Wang, H., Lu, X., Pei, C., Qiu, X., Liu, C., Wang, Y., Liu, N., Zhang, J., Lei, L., Liu, Y., Wang, H., Deng, T., Fan, Q., and Fan, S.: Nighttime ozone in the lower boundary layer: Insights from 3-year tower-based measurements in South China and regional air quality modeling, *Atmos. Chem. Phys.*, 23, 13107–13124, <https://doi.org/10.5194/acp-23-13107-2023>, 2023.

Hersbach, H., Bell, B., Berrisford, P., Hirahara, S., Horányi, A., Muñoz-Sabater, J., Nicolas, J., Peubey, C., Radu, R., Schepers, D., Simmons, A., Soci, C., Abdalla, S., Abellan, X., Balsamo, G., Bechtold, P., Biavati, G., Bidlot, J., Bonavita, M., De Chiara,

758 G., Dahlgren, P., Dee, D., Diamantakis, M., Dragani, R., Flemming, J., Forbes, R., Fuentes, M., Geer, A., Haimberger, L.,
 759 Healy, S., Hogan, R. J., Hólm, E., Janisková, M., Keeley, S., Laloyaux, P., Lopez, P., Lupu, C., Radnoti, G., de Rosnay, P.,
 760 Rozum, I., Vamborg, F., Villaume, S., and Thépaut, J.-N.: The ERA5 global reanalysis, *Q. J. R. Meteorol. Soc.*, 146, 1999–
 761 2049, <https://doi.org/10.1002/qj.3803>, 2020.
 762 Huang, F., Zhan, W., Wang, Z.-H., Voogt, J., Hu, L., Quan, J., Liu, C., Zhang, N., and Lai, J.: Satellite identification of
 763 atmospheric-surface-subsurface urban heat islands under clear sky, *Remote Sens. Environ.*, 250, 112039,
 764 <https://doi.org/10.1016/j.rse.2020.112039>, 2020.
 765 Huang, G., Chen, Y., Li, Z., Liu, Q., Wang, Y., He, Q., Liu, T., Liu, X., Zhang, Y., Gao, J., and Yao, Y.: Validation and accuracy
 766 analysis of the Collection 6.1 MODIS aerosol optical depth over the westernmost city in China based on Sun–Sky Radiometer
 767 observations from SONET, *Earth Space Sci.*, 7, e2019EA001041, <https://doi.org/10.1029/2019EA001041>, 2020.
 768 Huang, Q., Chu, Y., and Li, Q.: Climatology of low-level temperature inversions over China based on high-resolution
 769 radiosonde measurements, *Theor. Appl. Climatol.*, 144, 415–429, <https://doi.org/10.1007/s00704-021-03536-w>, 2021.
 770 Kaushal, S., Singh, D. K., and Sreenivas, K. R.: Penetrative convection in nocturnal atmospheric boundary layer and radiation
 771 fog, *arXiv [preprint]*, <https://doi.org/10.48550/arXiv.2209.13185>, 27 September 2022.
 772 King, M. D., Menzel, W. P., Kaufman, Y. J., Tanré, D., Gao, B. C., Platnick, S., Ackerman, S. A., Remer, L. A., Pincus, R., and
 773 Hubanks, P. A.: Cloud and aerosol properties, precipitable water, and profiles of temperature and water vapor from MODIS,
 774 *IEEE Trans. Geosci. Remote Sens.*, 41, 442–458, <https://doi.org/10.1109/TGRS.2002.808226>, 2003.
 775 Leng, P., Liao, Q.-Y., Gao, M.-F., Duan, S.-B., Li, Z.-L., Zhang, X., and Shang, G.-F.: A full satellite-driven method for the
 776 retrieval of clear-sky evapotranspiration, *Earth Space Sci.*, 6, 2251–2262, <https://doi.org/10.1029/2019EA000869>, 2019.
 777 Li, H., Liu, B., Gong, W., Ma, Y., Jin, S., Wang, W., Fan, R., and Jiang, S.: Influence of clouds on planetary boundary layer
 778 height: A comparative study and factors analysis, *Atmos. Res.*, 314, 107784, <https://doi.org/10.1016/j.atmosres.2024.107784>,
 779 2025.
 780 Li, J., Chen, H., Li, Z., Wang, P., Fan, X., He, W., and Zhang, J.: Analysis of low-level temperature inversions and their effects
 781 on aerosols in the lower atmosphere, *Adv. Atmos. Sci.*, 36, 1235–1250, <https://doi.org/10.1007/s00376-019-9018-9>, 2019.
 782 Li, Y., Thompson, D. W. J., Stephens, G. L., and Bony, S.: A global survey of the instantaneous linkages between cloud vertical
 783 structure and large-scale climate, *J. Geophys. Res. Atmos.*, 119, 3770–3792, <https://doi.org/10.1002/2013JD020669>, 2014.
 784 Liu, B., Ma, X., Ma, Y., Li, H., Jin, S., Fan, R., and Gong, W.: The relationship between atmospheric boundary layer and
 785 temperature inversion layer and their aerosol capture capabilities, *Atmos. Res.*, 271, 106121,
 786 <https://doi.org/10.1016/j.atmosres.2022.106121>, 2022.
 787 Luo, Y., Wang, S., Zhang, L., Tian, B., Jia, J., Sun, W., Wu, X., Ding, M., and Zuo, Z.: Comparative evaluation of reanalysis-

788 derived temperature profiles and low-level temperature inversion on the Tibetan Plateau, *Res. Cold Arid Reg.*,
789 <https://doi.org/10.1016/j.rcar.2025.08.004>, 2025.

790 Ma, Y., Huang, X.-D., Yang, X.-L., Li, Y.-X., Wang, Y.-L., and Liang, T.-G.: Mapping snow depth distribution from 1980 to
791 2020 on the Tibetan Plateau using multi-source remote sensing data and downscaling techniques, *ISPRS J. Photogramm.*
792 *Remote Sens.*, 205, 246–262, <https://doi.org/10.1016/j.isprsjprs.2023.10.012>, 2023.

793 Meier, R., Davin, E. L., Bonan, G. B., Lawrence, D. M., Hu, X., Duveiller, G., Prigent, C., and Seneviratne, S. I.: Impacts of
794 a revised surface roughness parameterization in the Community Land Model 5.1, *Geosci. Model Dev.*, 15, 2365–2393,
795 <https://doi.org/10.5194/gmd-15-2365-2022>, 2022.

796 Ning, G., Wang, S., Yim, S. H. L., Li, J., Hu, Y., Shang, Z., Wang, J., and Wang, J.: Impact of low-pressure systems on winter
797 heavy air pollution in the northwest Sichuan Basin, China, *Atmos. Chem. Phys.*, 18, 13601–13615, [https://doi.org/10.5194/acp-](https://doi.org/10.5194/acp-18-13601-2018)
798 18-13601-2018, 2018.

799 [Ouyang, X., Jia, L., Pan, Y., and Hu, G.: Retrieval of land surface temperature over the Heihe River Basin using HJ-1B thermal](#)
800 [infrared data, *Remote Sens.*, 7, 300–318, <https://doi.org/10.3390/rs70100300>, 2015.](#)

801 Platnick, S., King, M. D., Ackerman, S. A., Menzel, W. P., Baum, B. A., Riedi, J. C., and Frey, R. A.: The MODIS cloud
802 products: Algorithms and examples from Terra, *IEEE Trans. Geosci. Remote Sens.*, 41, 459–473,
803 <https://doi.org/10.1109/TGRS.2002.808301>, 2003.

804 Saha, S., Moorthi, S., Pan, H.-L., Wu, X., Wang, J., Nadiga, S., Tripp, P., Kistler, R., Woollen, J., Behringer, D., Liu, H., Stokes,
805 D., Grumbine, R., Gayno, G., Wang, J., Hou, Y.-T., Chuang, H.-Y., Juang, H.-M. H., Sela, J., Iredell, M., Treadon, R., Kleist,
806 D., Van Delst, P., Keyser, D., Derber, J., Ek, M., Meng, J., Wei, H., Yang, R., Lord, S., van den Dool, H., Kumar, A., Wang,
807 W., Long, C., Chelliah, M., Xue, Y., Huang, B., Schemm, J.-K., Ebisuzaki, W., Lin, R., Xie, P., Chen, M., Zhou, S., Higgins,
808 W., Zou, C.-Z., Liu, Q., Chen, Y., Han, Y., Cucurull, L., Reynolds, R. W., Rutledge, G., and Goldberg, M.: The NCEP Climate
809 Forecast System Reanalysis, *Bull. Am. Meteorol. Soc.*, 91, 1015–1058, <https://doi.org/10.1175/2010BAMS3001.1>, 2010.

810 Santer, B. D., Po-Chedley, S., Zelinka, M. D., Cvijanovic, I., Bonfils, C., Durack, P. J., Fu, Q., Kiehl, J., Mears, C., Painter, J.,
811 Pallotta, G., Solomon, S., Wentz, F. J., and Zou, C.-Z.: Human influence on the seasonal cycle of tropospheric temperature,
812 *Science*, 361, eaas8806, <https://doi.org/10.1126/science.aas8806>, 2018.

813 Schwarz, N., Lautenbach, S., and Seppelt, R.: Exploring indicators for quantifying surface urban heat islands of European
814 cities with MODIS land surface temperatures, *Remote Sens. Environ.*, 115, 3175–3186,
815 <https://doi.org/10.1016/j.rse.2011.07.003>, 2011.

816 Seeley, J. T. and Wordsworth, R. D.: Episodic deluges in simulated hothouse climates, *Nature*, 599, 74–79,
817 <https://doi.org/10.1038/s41586-021-03919-z>, 2021.

Deleted: Seemann, S., Borbas, E., Li, J., Menzel, W., & Gumley, L., 2006. MODIS Atmospheric Profile Retrieval Algorithm Theoretical Basis Document (Version 6). Cooperative Institute for Meteorological Satellite Studies, University of Wisconsin–Madison, Madison, WI, https://modis-images.gsfc.nasa.gov/_docs/MOD07_atbd_v7_April2011.pdf

Seidel, D. J., Li, J., Mears, C., Moradi, I., Nash, J., Randel, W. J., Saunders, R., Thompson, D. W. J., and Zou, C.-Z.: Stratospheric temperature changes during the satellite era, *J. Geophys. Res. Atmos.*, 121, 664–681, <https://doi.org/10.1002/2015JD024039>, 2016.

Sobrino, J. A., Jiménez-Muñoz, J. C., Mattar, C., and Soria, G.: Evaluation of Terra/MODIS atmospheric profiles product (MOD07) over the Iberian Peninsula: A comparison with radiosonde stations, *Int. J. Digit. Earth*, 8, 771–783, <https://doi.org/10.1080/17538947.2014.936973>, 2015.

Song, Z., Bai, W., Zhang, Y., Wang, Y., Xu, X., and Xin, J.: Evaluation of satellite-derived atmospheric temperature and humidity profiles and their application as precursors to severe convective precipitation, *Remote Sens.*, 16, 4638, <https://doi.org/10.3390/rs16244638>, 2024.

Tan, J., Che, T., Wang, J., Liang, J., Zhang, Y., and Ren, Z.: Reconstruction of the daily MODIS land surface temperature product using the two-step improved similar pixels method, *Remote Sens.*, 13, 1671, <https://doi.org/10.3390/rs13091671>, 2021.

Thorne, P. W., Lanzante, J. R., Peterson, T. C., Seidel, D. J., and Shine, K. P.: Tropospheric temperature trends: History of an ongoing controversy, *WIREs Clim. Change*, 2, 66–88, <https://doi.org/10.1002/wcc.80>, 2011.

Xie, Y., Huang, X., Chen, X., L'Ecuyer, T. S., and Drouin, B. J.: Joint use of far-infrared and mid-infrared observation for sounding retrievals: Learning from the past for upcoming far-infrared missions, *Earth Space Sci.*, 10, e2022EA002684, <https://doi.org/10.1029/2022EA002684>, 2023.

Xue, Y., Zhu, X., Wu, Z., and Duan, S.-B.: Retrieval of land surface temperature over mountainous areas using Fengyun-3D MERSI-II data, *Remote Sens.*, 15, 5465, <https://doi.org/10.3390/rs15235465>, 2023.

Yuan, B., Li, X., Zhou, L., Bai, T., Hu, T., Huang, J., Liu, D., Li, Y., and Guo, J.: Global distinct variations of surface urban heat islands in inter- and intra-cities revealed by local climate zones and seamless daily land surface temperature data, *ISPRS J. Photogramm. Remote Sens.*, 204, 1–14, <https://doi.org/10.1016/j.isprsjprs.2023.08.012>, 2023.

Zeng, H., Tian, P., Zhang, M., Cao, X., Liang, J., and Zhang, L.: Rapid change in surface-based temperature inversions across the world during the last three decades, *J. Appl. Meteorol. Climatol.*, 61, 175–184, <https://doi.org/10.1175/JAMC-D-21-0093.1>, 2022.

Zhang, A. and Zhang, X.: Landsat-8-based land surface temperature inversion and comparative analysis with MODIS temperature product, *J. Beijing For. Univ.*, 41, 1–13, <https://doi.org/10.13332/j.1000-1522.20180234>, 2019.

Zhang, L., Ding, M., Zheng, X., Chen, J., Guo, J., and Bian, L.: Assessment of AIRS Version 7 temperature profiles and low-level inversions with GRUAN radiosonde observations in the Arctic, *Remote Sens.*, 15, 1270, <https://doi.org/10.3390/rs15051270>, 2023.

Zhang, W., Zhang, B., Zhu, W., Tang, X., Li, F., Liu, X., and Yu, Q.: Comprehensive assessment of MODIS-derived near-

Deleted: Zhang, K., Zhao, L., Yang, K., Qin, J., Song, L., Ni, X., Fan, L., & Han, X., 2023. Spatiotemporal scales of precipitation in the Central Tibetan Plateau identified by in-situ soil moisture observations. *Journal of Hydrology*. 626, 130319,

860 surface air temperature using wide elevation-spanned measurements in China, *Sci. Total Environ.*, 800, 149535,
861 <https://doi.org/10.1016/j.scitotenv.2021.149535>, 2021.

862 Zhang, W., Zhao, J., Zhu, W., Kong, Y., Wan, B., and Liao, Y.: Comprehensive validation of MODIS-derived instantaneous air
863 temperature and daily minimum temperature at nighttime, *Remote Sens.*, 17, 1732, <https://doi.org/10.3390/rs17101732>, 2025.

864 Zhang, Y., Zhang, B., and Yang, N.: Characteristics of temperature and humidity inversions based on high-resolution
865 radiosonde observations at three Arctic stations, *J. Appl. Meteorol. Climatol.*, 61, 415–428, [https://doi.org/10.1175/JAMC-D-](https://doi.org/10.1175/JAMC-D-21-0054.1)
866 [21-0054.1](https://doi.org/10.1175/JAMC-D-21-0054.1), 2022.

867 Zhao, L., Lee, X., Smith, R. B., and Oleson, K.: Strong contributions of local background climate to urban heat islands, *Nature*,
868 511, 216–219, <https://doi.org/10.1038/nature13462>, 2014.

869 Zhao, X., Liu, C., Yang, N., and Li, Y.: Diurnal and seasonal variations of surface energy and CO₂ fluxes over a site in the
870 western Tibetan Plateau, *Atmosphere*, 11, 260, <https://doi.org/10.3390/atmos11030260>, 2020.

871 [Zhu, W., Lü, A., Jia, S., Yan, J., and Mahmood, R.: Retrievals of all-weather daytime air temperature from MODIS products,](#)
872 [Remote Sens. Environ., 189, 152–163, <https://doi.org/10.1016/j.rse.2016.11.011>, 2017.](#)