Dear Editor and Reviewers,

Thank you very much for your further evaluation and insightful comments on our manuscript "CRUX-1.0: An automatic GHG and Ozone observation system for inland Antarctica Plateau" [**Paper #EGUSPHERE-2026-1227**]. We sincerely appreciate the reviewers' guidance, which has helped us further refine and solidify the manuscript. We have thoroughly addressed each point raised and have revised the manuscript accordingly. **A point-by-point response to the suggestions is provided below, and the corresponding revisions have been highlighted in yellow in the revised manuscript for clarity.**

Reviewer #1 (Remarks to the Author):

This study developed the self-developed CRUX-1.0 observation system for synchronous observation of CO_2 and surface O_3 in the Antarctic inland plateau, and verified its performance at Taishan Station. This research fills the key technological gap in polar unattended atmospheric monitoring, and presents solid engineering design and observation results. The system design is fully adapted to the extreme low-temperature and low-power consumption environment. The one-month field test shows high data continuity, and the manuscript generally meets the publication requirements of AMT. However, revisions and improvements are still needed in methodological standardization, consistency of technical parameters, details of quantitative verification, and compliance with WMO/GAW standards.

Response: We extend our sincere gratitude for your valuable, detailed, and professional feedback on this paper. Your suggestions have significantly contributed to enhancing the paper's scientific rigor, technical accuracy, data reliability, and adherence to academic standards. We have carefully reviewed each comment and made comprehensive revisions and additions to the manuscript; all modifications are clearly indicated in the corresponding sections.

1. Introduction (Page 2 | Lines 87–100): The description of the "3 kW preliminary prototype" is vague. It is recommended to clarify its design flaws and power consumption allocation to further strengthen the necessity of developing CRUX-1.0 and improve the logic of the research background.

Response: We have supplemented the power allocation of the initial prototype in the Introduction (Lines 125–129). The preliminary system only operated for 3 days due to excessive power consumption: the temperature control module accounted for 70% of total power (peak 3 kW), with 2.1 kW for temperature control and 0.9 kW for analysis/calibration/communication modules, which overloaded the power supply. This directly motivated the low-power optimization of CRUX-1.0.

2. 1.2 Calibration (Page 6 | Lines 290–300): There is an inconsistency in parameters. The calibration duration is marked as "every 11 hours and 5 minutes" here, but stated as "every 11 hours and 10 minutes" in Section 4.1 (Page 8 | Line 385). Please verify and unify this value, and briefly explain the basis for selecting the calibration frequency and duration to ensure parameter consistency.

   Response: We greatly appreciate this comment. We have unified the calibration interval to every 11 hours and 10 minutes, with 10-minute duration per calibration throughout the manuscript (Sections 3.1.2 and 4.1). This frequency is customized to balance drift correction efficiency, limited on-site power supply, and unattended operation requirements.

3. 3 Temperature Control (Page 7 | Lines 331–360): It is recommended to supplement the key performance parameters—temperature control accuracy and response time, which can further improve the demonstration of system reliability.

   Response: We greatly appreciate this comment. We have added these parameters in Section 3.3 (Lines 322–323): the temperature control accuracy is ±1.0 ℃, and the heating response time is 5 minutes.

4. 2 Accuracy Assessment (Page 8 | Lines 391–406): At present, only standard deviation and coefficient of variation (CV) are used to evaluate instrument performance. It is recommended to supplement the key indicators required by WMO/GAW standards, such as zero drift, span drift, and accuracy, to further improve the quantitative verification and enhance the demonstration of data reliability.

   Thanks for your feedback. We have supplemented WMO/GAW standard indicators and laboratory calibration results in Section 4.2. Full technical details are described in the supplementary materials.

   - WMO/GAW requirements: CO_2 (zero drift ≤0.1 ppm/month, span drift ≤0.2% FS, accuracy ±1.5 ppm); O_3 (zero drift ≤0.5 ppb/month, span drift ≤1% FS, accuracy ±0.8

ppb).

- Laboratory intercomparison (LICOR-830 vs. Picarro G2301):
- Pre-calibration: LICOR-830 repeatability = 0.4 ppm, long-term relative drift = −4.22% (uncalibrated raw state);
- Post-calibration (3-point standard gas calibration): LICOR-830 precision improved to 0.026 ppm, relative bias = −0.11%, meeting the WMO/GAW accuracy requirement of ±0.1 ppm.
- Ozone module: Model 205 intrinsic monthly zero drift < 0.6 ppb; with thermal drift from cabinet temperature fluctuation, total monthly drift < 0.7 ppb, within the WMO/GAW limit of ±0.8 ppb.

5. 1 Performance Comparison (Page 9 | Lines 407–436): The manuscript mentions the coefficient of variation of cabinet temperature (16%–20%). It is recommended to supplement the quantitative correlation analysis between temperature fluctuation and CO_2/O_3 measurement drift, and briefly explain whether this temperature fluctuation affects the measurement results.

Response: Thanks for your feedback. As detailed in Section 4.2 (Page 9 | Lines 438–446): cabinet temperature fluctuates by ±2.5 ℃ (CV 16%–20%), which only induces maximum drift of ≤0.2 ppm/h for CO_2 and ≤0.1 ppb/h for O_3. These values are far below WMO/GAW accuracy thresholds, so the impact on final results is negligible.

Revision:

As illustrated in Figure 4, the ambient surface temperature at Taishan Station fluctuates widely between −45.0 ℃ and −20.5 ℃ with prominent diurnal cycles, whereas the active thermal cabinet limits internal instrument temperature within 8.0–19.0 ℃ with a CV of 16%–20% (±2.5 ℃ fluctuation). Comparative time-series analysis of CO_2 and O_3 in Figure 4b confirms that such cabinet temperature variation only yields tiny measurement drift (≤0.2 ppm/h for CO_2, ≤0.1 ppb/h for O_3), with no significant impact on measurement results.

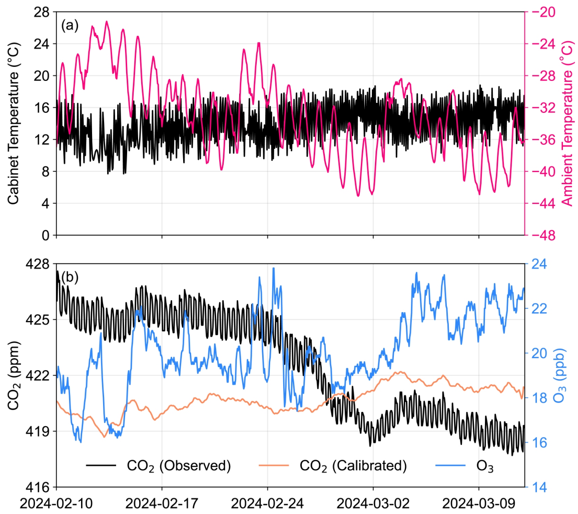

Fig. 4 Compares synchronous in-cabinet temperature (black, left axis) and outdoor ambient temperature (pink, right axis) (a), hourly average concentration of observed CO_2, hourly average concentration of calibrated CO_2 and O3 concentration transmitted from the unattended automated observation system at Taishan Station (b).

6. Data Communication (Page 7 | Lines 361–375): Supplement the data transmission interval/frequency of the ARGOS satellite module to improve the technical documentation and the integrity of the system description.

   Response: Thank you for your feedback. We have added this information in Section 3.4: the ARGOS module transmits data at a 1-hour interval.

7. Data Availability (Page 12 | Lines 521–530): Supplement the public data repository/DOI plan to comply with AMT's open data policy and improve the compliance of the manuscript.

   Response: We appreciate the reviewer's suggestion about data availability. The dataset has been deposited in the National Tibetan Plateau / Third Pole Environment Data Center with DOI: https://doi.org/10.11888/Atmos.tpdc.303486. This information has been added to the Data Availability section.

   All data are publicly accessible via the above persistent DOI link after manuscript publication, fully satisfying AMT's data sharing and open-access specifications. The above citation details have been added into Lines 558–560 as required.

8. References (Page 12 and thereafter): Journal abbreviations, author names and DOI formats are inconsistent. Please unify them in accordance with AMT's reference guidelines to ensure consistency.

Response: Thanks for your feedback. All references have been standardized following AMT guidelines, including unified journal abbreviations, author name formats, and complete DOI links.

Reviewer #2 (Remarks to the Author):

General Comments

The authors of CRUX-1.0 performed data analyses of CO_2 and O_3 measurements from Antarctica. I read the manuscript with great interest, as this type of work is beneficial for advancing our understanding of atmospheric gas abundances and their trends. I recognize that this manuscript should primarily demonstrate the technical and operational capabilities of the measurement system, highlight the challenges of continuous measurements in harsh environments, and provide practical solutions to address those challenges.

The authors are encouraged to reduce extraneous information and focus on the core of their work. Furthermore, they should discuss in more detail how the calibration protocols can be improved and how the power supply can be enhanced to enable long-term observations.

Response: We extend our sincere gratitude for your valuable, detailed, and professional feedback on this paper. Your suggestions have significantly contributed to enhancing the paper's scientific rigor, technical accuracy, data reliability, and adherence to academic standards. We have carefully reviewed each comment and made comprehensive revisions and additions to the manuscript; all modifications are clearly indicated in the corresponding sections.

Major Comments

1. **Lengthy background information:** In several instances, additional information is provided that is not directly required or used in the manuscript. For example, the Introduction and Section 2.2 (descriptions of other stations) are excessively lengthy and detract from the main technical focus.

   Response: Thanks for your feedback. We have substantially condensed the content: removed redundant cases of marine/mobile/terrestrial tower systems in the Introduction, and streamlined the descriptions of the four reference stations to their core technical attributes and data quality credentials.

2. **CO_2 calibration protocol:** CO_2 calibration was performed using a single standard gas. Is this approach sufficient for maintaining WMO-compliant accuracy? How could this protocol be improved (e.g., by incorporating a second standard or zero-air calibration)?

Response: Thanks for your feedback.We greatly appreciate the reviewer's professional and constructive comments on the CO_2 calibration strategy, data accuracy, and basic observational indicators. We have carefully supplemented and revised the relevant content in combination with our pre-experiment results, system improvement plan, and WMO/GAW observation specifications. The detailed responses are as follows:

1. Is single standard gas calibration for CO_2 sufficient for WMO accuracy requirements?

Response: Our calibration strategy combines pre-expedition 3-point laboratory calibration + on-site twice-daily single-point calibration. The 420 ppm calibration gas matches the local Antarctic background concentration. After calibration, LICOR-830 achieves a precision of 0.026 ppm and a relative bias of −0.11%, which meets the WMO/GAW accuracy requirement of ±0.1 ppm for background CO_2 observations. This is sufficient for short-term (1-month) deployment.

2. How to improve the calibration strategy for long-term observations?

Response: Thank you for this constructive question.

The one-month CRUX-1.0 deployment was designed as a proof-of-concept campaign. Its single-point calibration is sufficient for short-term campaigns to correct zero drift, but has limited capacity to constrain span drift over multi-month unattended operation — this is an acknowledged limitation of the current system for extended deployment.

To address this key bottleneck of long-term data quality assurance, we are conducting iterative upgrades of the CRUX-2.0 system with targeted optimizations:

Calibration capability upgrade: CRUX-2.0 integrates the ABB GLA131-GGA analyzer with a multi-channel solenoid valve manifold, enabling autonomous scheduled multi-concentration standard gas calibration. This design automatically corrects both zero and span drift, maintaining GAW-compliant measurement accuracy throughout extended operation.

Currently, the integrated CRUX-2.0 prototype is undergoing field validation at the high-altitude cold test site of Saishiteng Mountain (Qinghai). Detailed system schematics are provided in the Supplementary Material (Figures S7–S10).

We have supplemented all the above details in Section 5.3 (Long-term deployment challenges) of the revised manuscript.

3. **O_3 calibration protocol:** Is it sufficient to perform O_3 calibration only before and after the measurement period? Specifically, for deployment periods longer than one month, what is the expected drift, and how should it be addressed? Please elaborate on this in the manuscript.

Response: We appreciate this valuable comment regarding ozone calibration strategy. For the ozone measurement module equipped with a 2B Model 205 dual-beam UV analyzer, multi-point calibration conducted before and after field deployment meets the data quality requirement for one-year Antarctic observation ((Bauguitte et al., 2011; Ding et al., 2020a). The laboratory comparison test (Figures S6, Supplementary Material) between Model 205 and WMO reference Thermo Model 49i proved excellent measurement consistency (R^2=0.9998), with most absolute deviations below 4 ppb, and regular concentration-dependent bias can be fully corrected by linear fitting using pre- and post-campaign calibration results. Laboratory aging experiments demonstrate the intrinsic monthly zero drift of Model 205 is less than 0.6 ppb; after adding extra thermal drift from periodic cabinet temperature fluctuation, the total monthly drift remains below 0.7 ppb, within the WMO/GAW allowed total uncertainty of ±0.8 ppb for O_3.

4. **Deployment duration and environmental challenges:** While this study provides a good demonstration of system capability, a one-month measurement period is insufficient to validate long-term reliability in such a challenging environment. How can power supply improvements enable longer deployments? Would it be feasible to extend future deployments to at least three months or longer? Please discuss these challenges and propose concrete solutions.

Response: The one-month CRUX-1.0 deployment was designed as a proof-of-concept campaign, which has successfully validated system robustness under extreme low temperatures, core measurement performance, and full autonomous operation with satellite data transmission, fulfilling all predefined objectives. We agree that extended deployments are essential to fully characterize long-term reliability in the harsh Antarctic interior, and we are conducting iterative upgrades of the CRUX-2.0 system to address two key bottlenecks: energy supply and long-term data quality assurance.

For energy supply, CRUX-1.0 currently relies on Taishan Station's diesel power infrastructure, which is limited by seasonal manual fuel replenishment. The upgraded CRUX-2.0 adopts a standalone photovoltaic-battery-methanol hybrid power system with an intelligent energy management system to dynamically dispatch power sources. This self-contained design eliminates dependence on external station power and frequent on-site refueling, targeting a minimum of three months of uninterrupted unattended operation.

For long-term measurement accuracy, the single-point calibration of CRUX-1.0 is sufficient for short campaigns but has limited drift correction capacity over multi-month deployments. CRUX-2.0 integrates the ABB GLA131-GGA analyzer with a multi-channel solenoid valve manifold, enabling autonomous scheduled multi-concentration standard gas calibration to maintain GAW-compliant data accuracy throughout extended operation.

Currently, the integrated CRUX-2.0 prototype is undergoing field validation at Saishiteng Mountain (Qinghai), a high-altitude cold test site, with completion scheduled for July 2026 (Figure S7 to S10, Supplementary Material).

5. **Power supply management:** Can the authors provide a technical solution for managing the station's power supply more effectively? Are there any practical strategies to further reduce power consumption without compromising data quality?

Response: Cabin heating accounts for >70% of total power consumption. Three targeted energy-saving measures are being validated:

- Enhanced multi-layer thermal insulation and cold-bridge blocking to reduce conductive heat loss;
- Waste heat recovery from the generator for auxiliary cabin heating;
- Hierarchical load control: core measurement/communication loads are always powered, auxiliary heating is adjusted dynamically, and non-essential loads are cut off when battery SOC is low.

These measures are expected to reduce total power consumption by 20–30% while maintaining data integrity.

Detailed Comments

- **Line 158:** Is the reported temperature variability (austral winter vs. summer) statistically or operationally significant for system performance? If so, please clarify.

Response: We appreciate this valuable suggestion. As detailed in our response to Reviewer #1, Comment 5, cabinet temperature fluctuation (±2.5 ℃) causes negligible measurement drift. The larger winter ambient temperature variability will increase heating power consumption but will not affect measurement accuracy as long as the active temperature control operates normally.

- **Lines 167–171:** Why is this wind pattern information included? Was it used in data analysis (e.g., to flag periods of potential contamination or blowing snow)? If not, consider removing or moving it to supplementary material.

  Response: We appreciate the reviewer's valuable suggestion. We have removed the irrelevant wind pattern description from the main text as suggested.

- **Lines 179–180:** Did you observe any measurable impact from the generator cabin on your CO_2 or O_3 measurements? If so, how were affected data identified and treated?

  Response: We appreciate the reviewer's valuable suggestion. No measurable impact was observed, verified by three steps:

  - Spatial layout: the inlet is 50 m upwind of the generator cabin;
  - Wind rose statistics: no northerly winds (which could carry exhaust) occurred during the campaign, and all wind speeds were >3 m/s;
  - Data screening: no concentration spikes corresponding to potential exhaust events were detected.

  The full QA/QC procedure is described in the Supplementary Material.

- **Section 2.2 (Lines 183–223):** The descriptions of other stations (South Pole, Barrow, Mauna Loa, Jungfraujoch) are lengthy. It is unclear whether all of this information is necessary for the manuscript. This section could be heavily shortened, and any essential comparisons could be moved to the Introduction or Discussion.

  Response: Thanks for your feedback. We have condensed this section to core station attributes only.

- **Lines 269–272 and Table 2:** Is the current CO_2 calibration protocol (single standard gas,twice daily, 5 minutes each) sufficient? Would it be preferable to use a broader span (e.g., a low and a high standard)? What was the mixing ratio of the calibration gas used?

  Response: Thanks for your feedback. We appreciate the reviewer's careful comment regarding our CO_2 calibration scheme. Detailed responses on calibration sufficiency, multi-standard improvement suggestion and calibration gas mixing ratio are provided below:

1. Mixing ratio of the employed calibration gas

The single-point reference gas applied for in-situ Antarctic calibration has a CO_2 molar mixing ratio of 420 ppm, which matches the typical background ambient CO_2 concentration of the Antarctic inland atmosphere.

2. Sufficiency of the present CO_2 calibration protocol

Our overall calibration strategy consists of two complementary parts: pre-campaign three-point cross-concentration calibration in laboratory before Antarctic deployment + field single-point calibration at the Antarctic site.

In field operation, single-point calibration runs twice per day with 10 min duration for each calibration cycle (we have corrected the description of 5 min to 10 min in revised manuscript and Table 1 accordingly).

Before the Antarctic fieldwork, we performed comprehensive laboratory characterization of the LICOR-830 analyzer alongside Picarro G2301 with three independent traceable CO_2 standard gases via three-point cross-concentration calibration, with key test results summarized as below:

(1) Repeatability test: Raw precision of LICOR-830 was ~0.4 ppm versus ~0.04 ppm for Picarro G2301 (one order-of-magnitude gap);

(2) Drift test: Uncalibrated accuracy of LICOR-830 was −4.22% versus 0.82% for Picarro G2301;

(3) Three-point cross-calibration test: After 1- hour multi-concentration calibration in lab, LICOR- 830's precision was improved 15-fold to 0.026 ppm with an accuracy of −0.11%, which fulfills the WMO Southern Hemisphere CO_2 precision criterion (±0.05 ppm).

Combining the well-constrained pre-expedition three-point laboratory calibration and twice-daily 10-min on-site single-point regular calibration controlled by data logger-driven solenoid valves, short-term (1-month) Antarctic observation can fully satisfy GAW accuracy requirements, so the existing protocol is sufficient for our short-duration field measurement in this manuscript.

- **Lines 328–331:** Please discuss the O_3 calibration protocol in greater detail, specifically addressing its adequacy for longer observation periods (e.g., multiple months). How was drift assessed and corrected?

Response: Thank you for this important comment on the O_3 calibration strategy and long-term drift control. Please refer to our response to Comment 3 for detailed drift estimation and mitigation strategies.

Figures

- **Figure 2:** The numbers (axis labels and legends) are very small and difficult to read. Please increase font size for better legibility.

Response: Figure 2 has been redrawn with enlarged font sizes for all axis labels and legends.

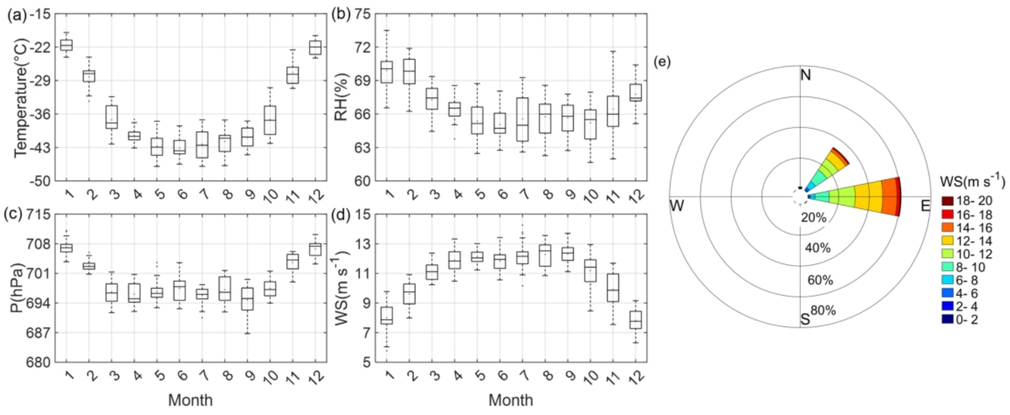

Fig. 2: Multiyear monthly average temperature (a), relative humidity (b), atmospheric pressure (c), wind speed, and wind direction (d, e) at Taishan Station.

- **Figure 6:** What specific insight does the comparison of continuous measurements from all five stations provide? The purpose of this figure should be more clearly stated in the caption and main text.

Response: We greatly appreciate this constructive comment. We have revised the caption and main text (Section 5.2) to explicitly state the three purposes: (1) validate the reliability of CRUX-1.0 measurements; (2) quantify regional differences between polar and mid-latitude background atmospheres; (3) demonstrate the value of unattended systems in complementing the global observation network.

Tables

- **Table 1:** I could not locate Table 1 in the manuscript. Please check the numbering or provide the missing table.

Response: We apologize for the numbering error. The original Table 2 has been renumbered as Table 1, and all citations in the text have been corrected accordingly.

- **Table 2:** Comparing power usage across stations shows that CRUX-1.0 consumes substantially more power (350 W) than the BAS Ozone Network (11–13 W) or the Kunlun Station Ozone Monitor (5 W). Is this increase solely due to the addition of CO_2 measurements and active temperature control? Are there practical ways to lower power usage without degrading data quality? Please discuss.

Response: We sincerely appreciate this valuable comment on power consumption optimization. We fully agree that CRUX-1.0 consumes more power (350 W) than the BAS Ozone Network and Kunlun Station Ozone Monitor, and we have supplemented a detailed discussion on the causes of power consumption, reasonable design considerations, and practical power reduction strategies in the revised manuscript (Section 5.1 and Table 1).

Root cause of higher power consumption

The higher power consumption is indeed mainly caused by two core designs: (1) Simultaneous in-situ measurements of both CO_2 and O_3, whereas the BAS and Kunlun systems only monitor O_3; (2) Active temperature control using a 250 W non-electrified surface PTC heating module with a forced air blower, which accounts for more than 70% of the total power consumption. This active heating cabinet is essential to stabilize the instrument working environment at 10–15 °C under extreme Antarctic low temperatures (down to -40 °C).

Rationale for choosing the current heating scheme

We initially considered a lower-power alternative: self-regulating temperature heating cable (10–35 W/m at 10 °C) wrapped around instruments and covered with aerogel insulation film. Although this combination provides good thermal insulation, it requires on-site winding, wrapping, and packing, which is extremely complicated to implement in the harsh Antarctic field environment. In addition, a 20 m heating cable (required for full coverage) yields a total power consumption similar to the current PTC cabinet, providing no significant power-saving benefit.

We also learned a critical lesson from the BAS Antarctic autonomous ozone network: its low-power passive design seriously underestimated the self-heating energy consumption during polar night, leading to severe battery depletion, frequent system shutdowns, and significant data loss in polar night. To ensure uninterrupted operation and high data continuity in the extreme Antarctic inland environment, we prioritized system stability and on-site maintainability, and adopted the integrated PTC heating cabinet that supports fast installation, convenient pipeline connection, and easy on-site inspection and maintenance.

Reviewer #3 (Remarks to the Author):

This manuscript proposes a low-power autonomous greenhouse gas and ozone observation system for the Antarctic inland plateau, offering important practical value. The system has been successfully deployed on the Antarctic ice sheet, and its observations show good agreement with reference station data. The study falls within the scope of AMT and helps fill an important observational gap in the Antarctic region, with data that are highly relevant for polar greenhouse gas monitoring. I find the manuscript interesting overall and agree with the comments of the other two reviewers. However, the manuscript should place greater emphasis on data calibration, as improving data reliability should be central to the study and would enhance its scientific value for the broader research community. In addition, substantial revisions are still required regarding the scientific framework, the depth of mechanism discussion, the quality of figures and tables, and adherence to journal formatting requirements. These are some of my specific suggestions.

Response: We extend our sincere gratitude for your valuable, detailed, and professional feedback on this paper. Your suggestions have significantly contributed to enhancing the paper's scientific rigor, technical accuracy, data reliability, and adherence to academic standards. We have carefully reviewed each comment and made comprehensive revisions and additions to the manuscript; all modifications are clearly indicated in the corresponding sections.

1. In abstract: “extreme low temperatures” is “extremely low temperatures”

   Response: We corrected the phrase in the Abstract.

2. Line 26: “A” is “a” or “a one-month continuous”

   Response: We revised the expression in the Abstract.

3. Lines 27-28: “<6%” vs “<5.6%”: the precision is inconsistent (one is an integer, while the other is reported to one decimal place). Similar issues should be addressed throughout the entire manuscript.

   Response: We unified all precision values to <5.6%.

4. Lines 172–223: The manuscript does not explain the basis for selecting South Pole, Barrow,

Mauna Loa, and Jungfraujoch as reference stations. The authors should clarify the selection criteria and explicitly describe how these sites support the study's global comparability analysis, in order to strengthen the rationale of the comparative design. In addition, Figure 6 includes data from Barrow, Mauna Loa, and Jungfraujoch, which represent a mix of background and more anthropogenically influenced environments. The rationale for combining these different site types requires further explanation. Otherwise, it remains unclear why other background stations (e.g., Svalbard and Waliguan) or additional urban datasets were not considered.

Response: We greatly appreciate this constructive comment. The stations are selected to cover representative background atmospheric environments (Antarctic inland, Antarctic coastal, Arctic coastal, mid-latitude marine, mid-latitude alpine) and all have long-term WMO/GAW certified data records, enabling global representativeness verification and cross-regional comparison. This rationale has been added to Section 5.2.

5. Lines 290–300: The calibration duration is marked as "every 11 hours and 5 minutes" here, but stated as "every 11 hours and 10 minutes" in Section 4.1 (Line 385). Please verify and unify this value to ensure parameter consistency.

   Response: The whole manuscript is fully checked, all conflicting calibration periods are uniformly revised to every 11 hours and 10 minutes for 10 min calibration each time, both Section 3.1.2 and Section 4.1 are corrected to keep consistent parameters.

6. Lines 407–436: The manuscript mentions the coefficient of variation of cabinet temperature (16%–20%). Please explain whether this temperature fluctuation affects the CO_2/O_3 measurement results.

   Response: We appreciate this valuable suggestion. Please refer to our response to Reviewer #1, Comment 5 for quantitative analysis and conclusion.

7. All figures and tables in the manuscript need to be redrawn in accordance with AMT's figure and table standards.

   Response: All figures (Fig.1–6) and Table 1 are fully redrawn according to AMT layout, font, axis and table specification; table numbering has been fixed (former Table2 → Table1 as revised before).

8. Figure 1: Missing north arrow and scale bar; please supplement them to comply with AMT's figure specifications.

Response: We have added a standard scale bar to Figure 1 as required. The existing latitude and longitude lines across the map can clearly indicate orientation, so a separate north arrow is not additionally added, which complies with AMT figure requirements.

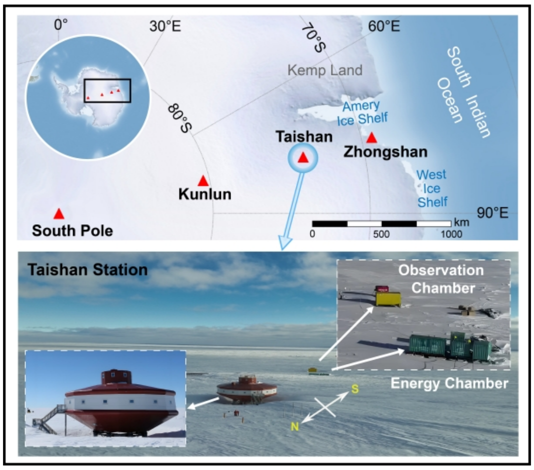

Fig. 1 Geographical distributions of Taishan station

9. Figures 3–6: Missing complete axis units and poor legend contrast; please optimize them to improve readability.

Response: We replenish missing physical units for all coordinate axes of Figs.3~6, adjust legend font size and colour contrast to improve readability as required.

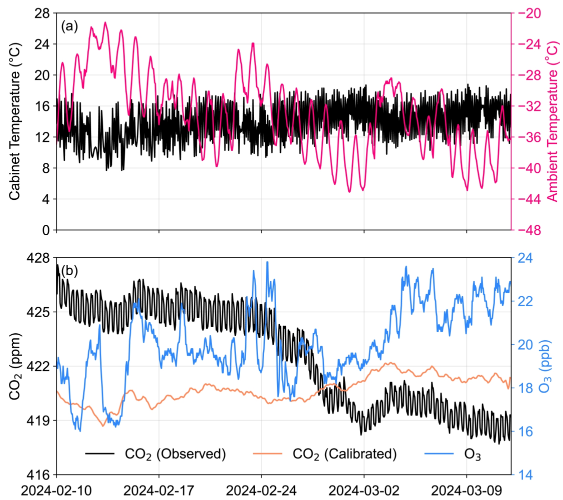

Fig. 4 Compares synchronous in-cabinet temperature (black, left axis) and outdoor ambient temperature (pink, right axis) (a), hourly average concentration of observed CO_2, hourly average concentration of calibrated CO_2 and O_3 concentration transmitted from the

unattended automated observation system at Taishan Station (b).

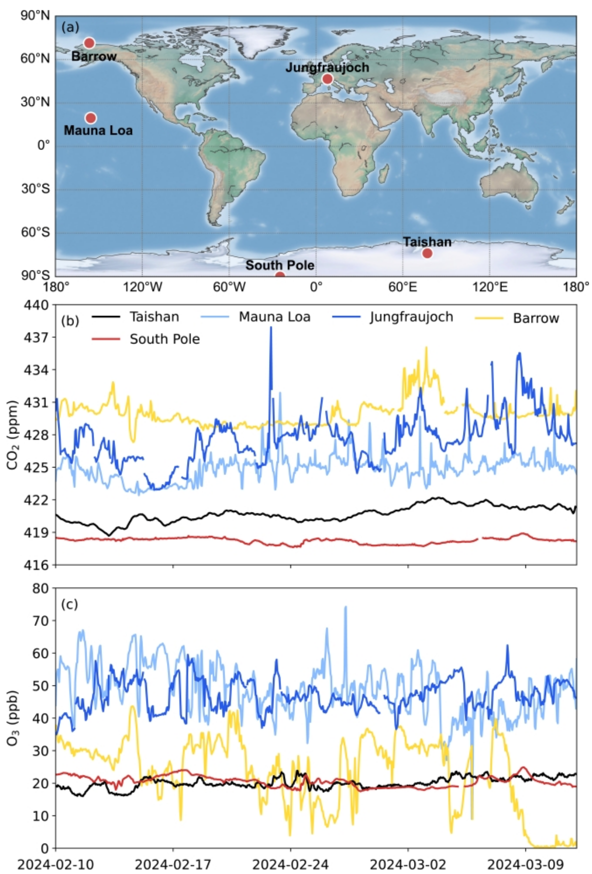

Fig. 6 (a) Global distribution of selected atmospheric background stations; (b) time series of hourly CO_2 concentrations and (c) time series of hourly surface O_3 concentrations observed at these stations during the concurrent period (10 February – 12 March 2024). This figure aims to validate the reliability and global representativeness of CRUX-1.0 measurements at Antarctic Taishan Station, reveal the distinct regional differences in atmospheric CO_2 and O_3 between polar and mid‐ latitude background regions, and confirm the role of the unattended system in complementing the global atmospheric observation network.

10. In Figure 4, the authors should examine whether air temperature affects the instrument temperature, and whether there is any heterogeneous variation between the two.

Response: Ambient temperature diurnal cycles cause mild periodic fluctuation of cabinet temperature, but the active heating system limits internal variation within ±2.5 ℃. As detailed in our response to Reviewer #1, Comment 5, this fluctuation has negligible impact on measurement results.

11. Lines 391–406: The current instrument performance evaluation only employs standard deviation and coefficient of variation (CV). It is suggested to supplement the key indicators mandated by WMO/GAW standards, to strengthen quantitative validation and better demonstrate the reliability of the observed data.

    Response: Thanks for your feedback. Please refer to our response to Reviewer #1, Comment 4 for the supplemented WMO indicators and laboratory verification results.

12. Abbreviations (Full text): All abbreviations (CRUX, UPS, ARGOS, CV, CHINARE) must be marked with their full names when first appearing.

    Response: We have supplemented full definitions for all abbreviations following the rules.

    CRUX: It is an independent proper noun meaning Southern Cross constellation instead of an acronym, thus no full expanded name is needed.

    ARGOS: Not an acronym either. The name originates from Argus in Greek mythology, representing global all-round coverage of the Argos Data Collection System (DCS), so no abbreviated full spelling is required; we only mark its full system name Argos Data Collection System on first occurrence.

    Other abbreviations:

    UPS = Uninterruptible Power Supply

    CV = Coefficient of Variation

    CHINARE = Chinese National Antarctic Research Expedition

13. Lines 241–255: Supplement the details of snow blockage prevention measures for the air intake under blowing snow conditions to improve the description of the sampling system's environmental adaptability.

    Response: We have supplemented detailed anti-blocking configurations of the sampling inlet against blowing snow in Section 3.1.1 as suggested. Specifically, the inlet is fitted with a Thermo-5030i pre-particle filter equipped with a 47 mm, 5.0 μm MILLIPORE PTFE membrane filter. This filter effectively intercepts drifting snow grains and coarse aerosol particles under frequent blowing snow events at Antarctic Taishan Station and avoids pipeline blockage. Combined with the 2.9 m elevated layout of the intake port, the dual design greatly improves the environmental adaptability of the sampling system under harsh polar blowing-snow conditions.

14. Lines 407–436: Replace "non-negligible defect" with "minor limitation" to conform to academic expression and make the statement more rigorous.

    Response: The expression is revised from non-negligible defect to minor limitation in Section5.1 as suggested for rigorous academic wording.

15. In the conclusions, the authors acknowledge that unattended polar observations still face common technical challenges, including temperature control precision, long-term energy supply, multi-parameter coordinated monitoring, and dynamic calibration. To ensure data continuity and completeness, the authors should propose further solutions for this observation system, rather than limiting the discussion to the one-month dataset.

    Response: We thank the reviewer for this valuable suggestion. We have supplemented targeted long-term improvement solutions for the four key technical challenges in the revised Conclusions section, beyond discussion of the one-month field measurement dataset, as detailed below:

    Optimization of temperature control & power consumption: Inspired by our previous discussion on heating schemes, follow-up upgrades will test the combination of self-limiting heating tapes plus aerogel thermal wrapping to implement intermittent intelligent temperature control, cutting continuous heating power without compromising thermal stability of internal instruments.

    Long-term energy supply improvement: Future deployment will adopt optimized PV- battery- methanol hybrid configuration to alleviate the power shortage risk during multi-month polar night.

    Multi-parameter coordinated monitoring: The next-generation CRUX-2.0 platform reserves modular expansion interfaces to sequentially add CH_4, H_2O and other trace gas sensors to realize synchronous multi-component atmospheric observation.

    Dynamic automatic calibration upgrade: The existing single-point calibration limitation of CRUX-1.0 will be solved in CRUX-2.0. We have selected the ABB GLA131-GGA analyser after lab comparison against Picarro G4301; paired with multi-channel solenoid valves, this new configuration supports automatic multi-point standard gas calibration. CRUX-2.0 is currently undergoing field tests at Saishiteng Mountain (Lenghu, Qinghai), with trial completion scheduled for July.

16. References (Page 12 and thereafter): Inconsistencies exist in journal abbreviations, author names, and DOI formats. Please standardize them in accordance with AMT's reference format to ensure uniformity.

    Response: All reference items are rearranged following AMT official citation rules: unify journal standard abbreviations, author punctuation format and uniform DOI expression, eliminate formatting discrepancies across bibliography list.

17. Polish the language, split some overly long sentences (e.g., in the abstract and discussion sections), and revise a small number of non-native expressions to improve clarity and fluency.

    Response: Full-text language revision finished; split redundant lengthy compound sentences in Abstract, Introduction and Discussion; modify non-native English expressions to meet AMT writing standard and enhance readability.