RESPONSE TO REVIEWER #2, COMMENTS

Manuscript Title: Atmospheric Tidal Variability and Gravity Wave Forcing

During the January 19–21, 2026 Geomagnetic Storm

We sincerely thank the reviewer for their careful reading of our manuscript and for providing critical, constructive comments and suggestions. Below, we provide point-by-point responses outlining how each concern will be addressed in the revised manuscript.

1. SECTION 2.1 DATA & PARAMETER DESCRIPTIONS

Reviewer Comment:

"The information about all the links from where data can be obtained is already in 'Data Availability Statement' ... I suggest, to instead in 'Section

2.1 Data' very briefly describe what the parameters IMF Bz, Dst, Kp (ap) and AU indices represent ... Temperatures profiles are measured with the SABER instrument on the NASA TIMED satellite, altitude range, latitudinal, longitudinal and local time coverage and resolution etc."

Author Response:

We agree with the reviewer. In the revised manuscript, we will remove redundant raw URLs from Section 2.1 and keep them strictly within the Data Availability Statement. Section 2.1 will be rewritten to clearly describe the physical meaning of each space weather parameter (IMF Bz, Dst,

Kp, ap, AE/AU). Furthermore, we will add complete technical details for the SABER/TIMED observations, including:

- Instrument & Satellite: SABER (Sounding of the Atmosphere using Broadband Emission Radiometry) aboard NASA's TIMED satellite.
- Altitude & Latitudinal Coverage: Vertical profiles covering approximately 20–110 km with vertical resolution of ~2 km; latitudinal coverage spanning from 53°S to 83°N (or 83°S to 53°N depending on yaw maneuver cycles).
- Sampling & Resolution: Orbit inclination (~74.1°), local time coverage characteristics, and profile sampling intervals.

2. FIGURE 1 LAYOUT AND FORMATTING

Reviewer Comment:

"Figure 1 should have larger panels and letters/numbers by reducing the empty space between panels and sharing the time (x) axis. The (a), (b), .. Annotations could be moved into a corner inside the panels."

Author Response:

Thank you for this formatting recommendation. We will re-generate Figure 1 by stacking all subplots vertically with a shared x-axis (Time in UT), removing unnecessary whitespace between rows. Panel label annotations—(a), (b), etc.—will be moved inside the top-left corner of each corresponding panel and axis label font sizes will be increased for optimal visual presentation.

3. TERMINOLOGY: LINE 108 (FFT VS. DFT)

Reviewer Comment:

"Line 108: '.. Fourier Transform (FFT) ..' FFT is the acronym for 'FAST Fourier Transform'... Or was rather a discrete Fourier transform (DFT) used?"

Author Response:

We appreciate the clarification. A Discrete Fourier Transform (DFT) was implemented via the Fast Fourier Transform (FFT) algorithm. We will revise Line 108 to read: "The Discrete Fourier Transform (DFT) implemented via the Fast Fourier Transform (FFT) algorithm..." to ensure exact technical precision.

4. SEPARATION AND METHOD OF MIGRATING TIDES (EQ. 1, FIGURES 2 & 3)

Reviewer Comment:

"Equation (1), Figure 2 and text do not describe whether and if yes, how, migrating tidal variations were separated out... On what grounds is 'migrating' used in the Figure title and caption?"

Author Response:

We acknowledge that the methodological description of tidal decomposition in Section 2.2 needs to be expanded. To isolate migrating tides (DW1, SW2, TW3, QW4) from non-migrating components, a 2D spatial-temporal Fourier analysis (fitting in both longitude and local time / universal time) was applied to the SABER temperature data grid.

In the revised manuscript:

1. We will explicitly update Section 2.2 with the 2D harmonic analysis equation:

$$T\,(\boldsymbol{\lambda},\boldsymbol{t},\boldsymbol{z}) = \sum_{s}\sum_{n} \boldsymbol{A_{n,s}}(\boldsymbol{z})\,\boldsymbol{cos}(\boldsymbol{n\omega_0 t} + \boldsymbol{s\lambda} - \boldsymbol{\phi_{ns}}(\boldsymbol{z}))$$

   Where n represents the harmonic frequency (n = 1, 2, 3, 4 corresponding to 24h, 12h, 8h, 6h periods), s is the zonal wavenumber, λ is longitude, and t is Universal.
2. Migrating components correspond strictly to s = n (e.g., s = 1 for DW1, s = 2 for SW2, s = 3 for TW3, s = 4 for QW4).
3. The text and figure captions will be updated to explicitly state how these migrating wavenumbers (s = n) were extracted.

5. SECTION 3.6: ORIGIN OF GRAVITY WAVES POTENTIAL ENERGY (GWPE)

Reviewer Comment:

"From where does the GWPE come? Is it directly a parameter of the SABER data set?"

Author Response:

GWPE is derived directly from SABER Level-2A kinetic temperature profiles (T0) and calculated using Equation (4).

$$E_p = \frac{g^2}{2N^2}\left(\frac{T'}{T_0}\right)^2$$

Where g is gravitational acceleration, N is the Brunt-Vaisala frequency $N^2 = \frac{g}{T_0}\left(\frac{dT_0}{dz} + \frac{g}{C_p}\right)$ and T' is the temperature fluctuation profile. T' is obtained by removing the background mean state and large scale tidal oscillations using a vertical band pass filter (sampling vertical wavelengths λz ~ 4–15 km). We will add this step-by-step derivation to

Section 3.6.

6. SECTION 3.7: RADIATIVE COOLING

Reviewer Comment:

"Shouldn't it be 'Radiative Cooling'? How are the values obtained from the data, is it a direct parameter of the SABER data set?"

Author Response:

- Terminology: We will correct the section title to "Radiative Cooling".
- Data Source: The NO 5.3 µm and CO2 15 µm cooling rates are direct data products available within the SABER Level-2A dataset (calculated using SABER-observed volume emission rates and non-LTE radiative transfer modeling). We will state this explicitly in the revised text.

7. SECTION 3.8: HEAT FLUX DETERMINATION

Reviewer Comment:

"How is this heat flux obtained?"

Author Response:

The heat flux values shown represent vertical eddy heat flux perturbations $\rho C_p \overline{W'}\,\overline{T'}$ derived from SABER temperature gradient perturbations $T' \cdot \frac{\partial T'}{\partial z}$ In the revised manuscript, we will include the explicit formula used to compute this parameter alongside its physical units (mW/m²or K·m/s).

8. SECTION 4: REVISION OF CONCLUSIONS & CLAIMS

A. Tidal Amplification & Color Scales

Reviewer Comment:

"Significant amplification of semidiurnal and terdiurnal tides: I think that this has not really been demonstrated. The panels in Figure 2 have all different color scales... Also I don't see any plausible physical explanation how a geomagnetic storm would amplify tides..."

Author Response:

- Color Scales: In the revised manuscript, we will unify the colorbar limits across quiet (Figure 2) and storm (Figure 3) panels for each individual tidal mode (DW1, SW2, TW3, QW4) to make direct visual comparisons unambiguous.
- Physical Mechanism: Geomagnetic storms inject energy via high-latitude Joule heating and particle precipitation. This produces strong, localized in-situ thermal expansion and modifies high-latitude wind systems. This secondary heating source can directly excite higher-harmonic tidal modes (e.g., SW2 and TW3). Additionally, storm-time thermospheric wind modifications alter the background refractive index, allowing enhanced upward propagation or constructive interference. We will add this detailed physical discussion to Section 3.2

B. Higher-Order Harmonics

Reviewer Comment:

"Only the 6 hour period is shown... and Figure 2 does not show any 'emergence' when comparing both periods."

Author Response:

We will refine our terminology. Rather than claiming "emergence of new modes," we will clarify that the quarterdiurnal (6h, QW4) tide undergoes amplitude intensification and spatial redistribution during storm conditions compared to quiet times.

C. Gravity Wave Intermittency

Reviewer Comment:

"What is meant by intermittency, that the wave activity seems to vary from day-to-day?"

Author Response:

By "intermittency," we refer to localized spatial patches and day-to-day temporal bursts in T' RMS amplitudes rather than continuous spatial coverage. We will rephrase this in Section 3.3 and Section 4 to clearly define "spatial and temporal localized enhancements".

D. Vertical Propagation & Coupling Statements

Reviewer Comment:

"Please explain how these statements can be concluded from the presented analysis?"

Author Response:

- Reduced Vertical Propagation / Dissipation: In Figure 7, elevated GWPE is observed in the lower thermosphere (80–100 km), but higher altitude penetration is constrained during storm days due to critical layer filtering by storm-driven background winds.
- Coupling: The simultaneous enhancements in temperature perturbations, GWPE, and NO radiative cooling demonstrate that magnetospheric energy deposition alters the thermal structure, which in turn influences wave propagation filtering. We will revise Section 4 to tie all conclusions directly to these specific observational lines of evidence.

9. SECTION 5: ACKNOWLEDGMENT & DATASET SCOPE

Reviewer Comment:

"Where and how were the IGS TEC and Swarm data used in this study?"

Author Response:

We thank the reviewer for pointing this out. In the initial draft, Swarm and

IGS TEC datasets were examined for context on ionospheric storm response, but the primary focus of this manuscript shifted strictly to middle/upper atmospheric neutral dynamics using SABER observations.

In the revised manuscript:

- We will either integrate a concise complementary figure showing GPS TEC / Swarm electron density perturbations during January 19–21, 2026 to show thermosphere-ionosphere response, OR We will remove references to Swarm and IGS TEC from the abstract, data section, and acknowledgments to keep the scope tightly focused on SABER atmospheric dynamics.