Auroral Driven Gravity Waves in the Thermosphere During Geomagnetically Quiet Conditions- Implications for GOLD Observations

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Abstract

We use TIEGCM simulations to investigate thermospheric gravity waves generated by aurora under low geomagnetic conditions. We perform two TIEGCM simulations with identical SuperDARN SHF potential forcing but different auroral inputs: an empirical GUVI-based aurora under Kp = 0 conditions and a DMSP-constrained data-assimilated aurora with realistic Kp. The difference between the two simulations isolates the auroral contribution to TIEGCM outputs. Gravity waves are then identified from the neutral vertical wind (WN) field using 2D-FFT filtering. We detected thirty-four gravity waves (GWs) during 10–15 July 2021, mostly propagating in meridional direction, with periods of 2–4 h, wavelengths of 2000–4000 km, and phase speeds of 200–300 m/s. Their amplitudes correlate positively with auroral number flux and characteristic energy, and the characteristics are largely consistent with previous studies based on GOLD observations, highlighting the role of aurora in generating thermospheric GWs.

Science Question: How do aurora generate and modulate thermospheric GWs during low geomagnetic condition?

Geomagnetic Conditions July 10-15, 2021

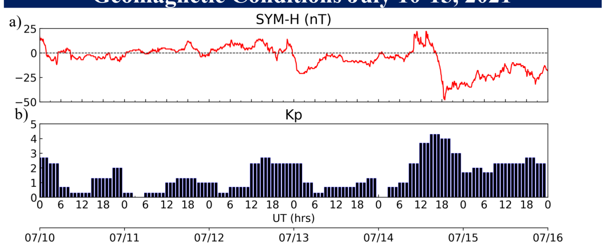
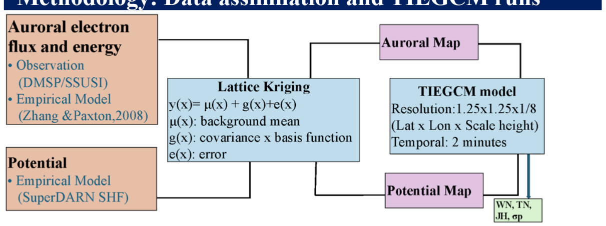


Figure 1: a) Dst and b) Kp index from July 10 to July 15, 2021

- Mostly quiet to moderately disturbed geomagnetic conditions.
- Brief increase in geomagnetic activity on 14–15 July (Kp ≈ 4, SYM-H ≈ −50 nT)

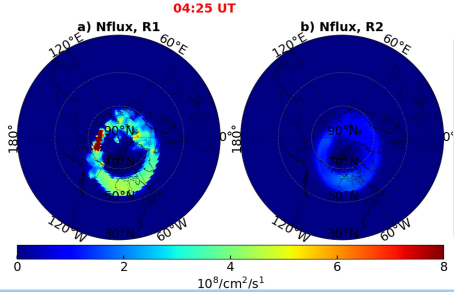
Methodology: Data assimilation and TIEGCM runs



TIEGCM runs:

Assimilation Run (R1): Data assimilated Aurora with realistic Kp+ Empirical Potential

Background Run (R2): Empirical Aurora with Kp=0 + Empirical Potential



- Data assimilation enhances fine-scale auroral structure and captures localized precipitation enhancements.

Figure 2: a) Data assimilated and b) Background aurora number flux at 04:25 UT of July 15,2021 over the Northern Hemisphere.

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Methodology: Isolating the wave field due to Aurora

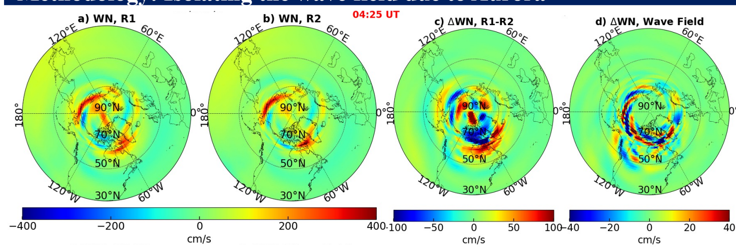
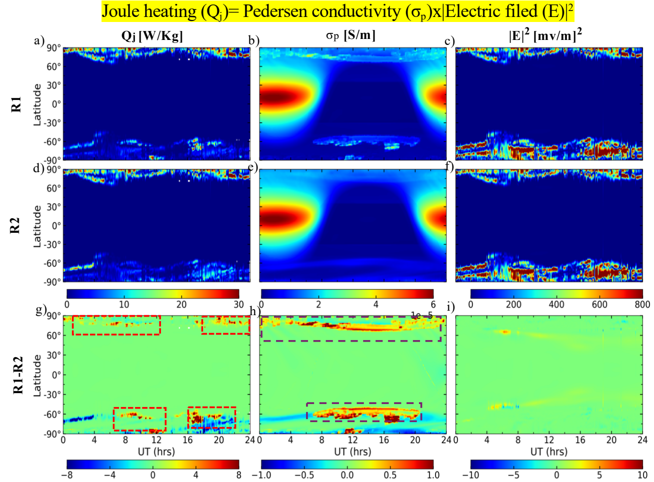


Figure 3: TIEGCM simulated neutral vertical wind (WN) speed from a) Assimilation run, b) Background run c) their differences (a-b), and the extracted wave field at 04:25 UT of July 15, 2021

- The wave field is obtained by applying a 2D FFT filter to the difference field (c), retaining only components with wave number > 4 and periods < 8 hours.

Wave source and Aurora

Joule heating (Q_j)= Pedersen conductivity (σ_p)x|Electric filed (E)|²



- Enhanced Joule heating in R1 is due to the contribution of Pederson conductivity.
- Electric-field differences are negligible ($\Delta E^2 \approx 0$) because both simulations use the same SuperDARN SHF forcing.

Figure 4: Latitude-time distributions of TIEGCM simulated a) Q_j, b) σ_p and c) E^2 from R1 at longitude=150° E for July 15, 2021. Panels (d–f) show the corresponding results for R2, while panels (g–i) present the difference fields (R1 − R2).

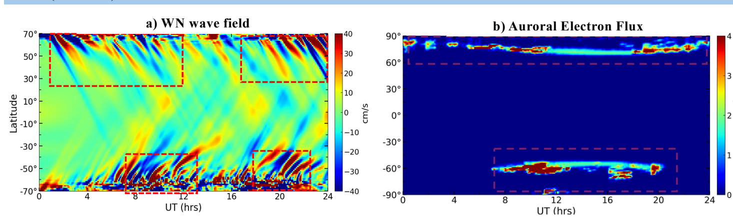


Figure 5: Latitude–time cross-sections at 150°E from the TIEGCM simulation on July 15, 2021. a) Wave perturbation field, with red boxes highlighting pronounced wave activity corresponding to enhanced Joule heating (Figure 4 (g)). b) Auroral energy flux, with the purple boxes indicating regions of auroral precipitation that align with enhanced conductivity (Figure. 4 (h)).

- Aurora precipitation increases ionospheric conductivity.
- Conductivity enhancements due to aurora increase Joule heating.
- The enhanced Joule heating provides a source of gravity-wave activity.

Enhanced aurora increases ionospheric conductivity and generate waves in the Ionosphere-Thermosphere region through Joule-heating forcing.

Results : Wave Characteristics and Analysis

Wave fitting equations and parameters

Cosine fitting equation

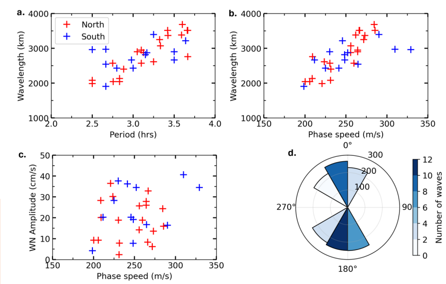
$$WN'(t,y) = A_y cos\left(\frac{2\pi t}{\tau} - \frac{2\pi y}{\lambda_y} + \emptyset_y\right)\text{- meridional direction}$$

$$WN'(t,x) = A_x cos\left(\frac{2\pi t}{\tau} - \frac{2\pi x}{\lambda_x} + \emptyset_x\right)\text{ -zonal direction}$$

Wave Amplitude $(A) = \sqrt{A_x^2 + A_y^2}$; Horizontal wavelength , $\lambda_h = \sqrt{\frac{1}{\lambda_x^2} + \frac{1}{\lambda_y^2}}$

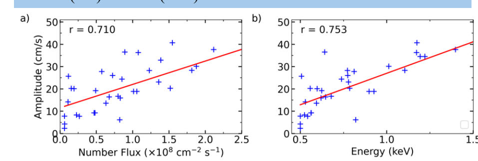
Propagation direction, $\theta = tan^{-1}2(\frac{\lambda_x}{\tau}, \frac{\lambda_y}{\tau})$

τ =period; $\emptyset_x$ and $\emptyset_y$ are phases and λ_x and λ_y are wavelengths in zonal and meridional direction respectively.



- Horizontal Wavelength : 2000-4000 Km
- Periods: 2 hours-4 hours
- Phase speed : 200-300 m/s
- Waves with larger wavelength propagate faster
- Waves propagation towards the meridional directions

Figure 6: Characteristics of GWs derived from the neutral wind (WN) perturbation field for July 10-15, 2021. Relationships between wavelength, period, phase speed, and amplitude are shown for NH (red) and SH (blue) wave events.



- Stronger auroral forcing produces larger-amplitude GWs

Figure 7: Correlation of wave amplitude with (a) electron number flux (r=0.710) and (b) auroral characteristic energy (r=0.753).

Comparison with GOLD (England et al. , 2026)

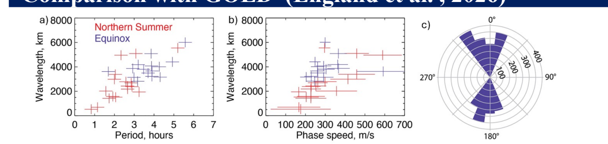


Figure 8: GWs characteristics observed during the GOLD Gravity Wave Campaign (2019–2022) (England et el. , 2026).

- Most of the GOLD observed GWs have periods of 2–4 hrs, wavelengths of 2000–4000 km, and phase speeds of 200–400 m/s, propagating meridionally.
- These characteristics closely match with GWs from simulations, supporting auroral Joule heating as a plausible source for GOLD observed GWs.

Summary

- Auroral enhancement increases Pedersen conductivity and intensifies Joule heating, which drives gravity wave activity even under relatively quiet geomagnetic conditions.
- TIEGCM simulated wave characteristics are mostly consistent with large-scale gravity waves observed by GOLD.
- The stronger auroral precipitation is associated with larger gravity wave amplitudes.

References: England, S. L., Zhang, S. R., Evans, S., & Eastes, R. W. (2026). A survey of atmospheric gravity waves observed by GOLD during quiet to moderate solar and geomagnetic activity. *Journal of Geophysical Research: Space Physics*, *131*(1), e2025JA034068.