Coordinate-Invariant Contribution Function for Thermospheric Emission Analysis: Application to Data-Model Comparisons During April 2023 Storm

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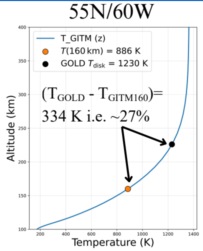
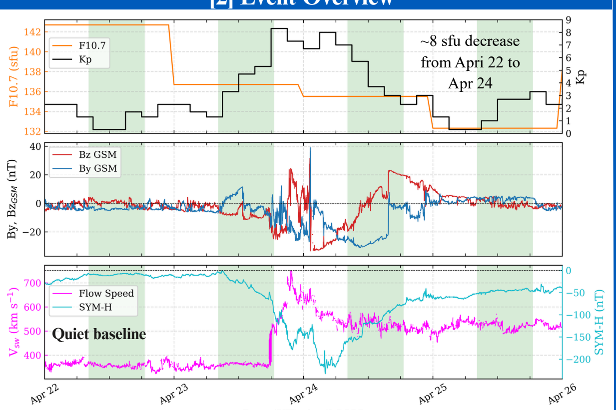
[1] Introduction and Motivation

55N/60W

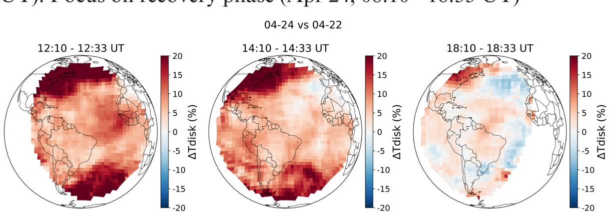


- **Why?** How much of Data-Model temperature discrepancy is a vertical-sampling artifact- and can physics-based weighting reduce it, especially during geomagnetic storms?
- Neutral temperatures in 120–200 km are remotely sensed from the rotational structure of N_2 LBH dayglow emission peaking at ~150-250 km for ~0° - 90° SZA.
- **Goal:** Build a pressure-vertical coordinate Contribution Function framework to make model neutral temperature retrieval-consistent with observed neutral temperature.
- **Data:** Global Observation of Limb and Disk (**GOLD**) Level 2 TDISK
- **Model:** Global Ionosphere-Thermosphere Model (**GITM**)

[2] Event Overview



Apr 22-25, **G4 Storm**: Kp 8+, **SYM/H min -233 nT** (Apr 24, 04 UT). Focus on recovery phase (Apr 24, 08:10 - 18:33 UT)



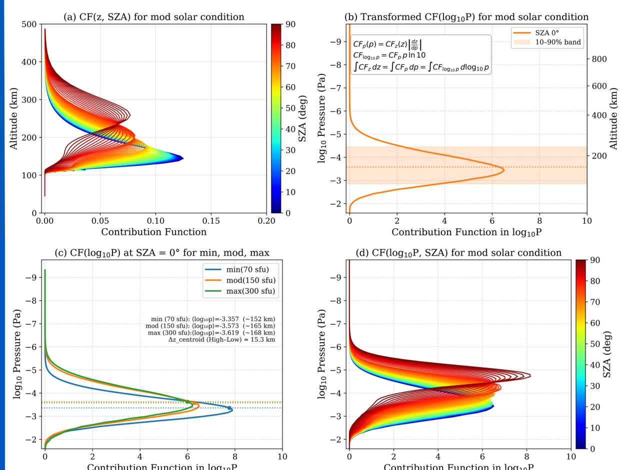
GOLD disk neutral temperature (Tdisk) on Apr 24 relative to Apr 22 shows strong, spatially varying neutral temperature perturbations - upto 15 - 20 % at high latitudes and 5-10 % at mid-to-low latitudes, migrating westward through the day showing early cooling starting 18:10 UT.

[3]Method: Contribution Function Weighting

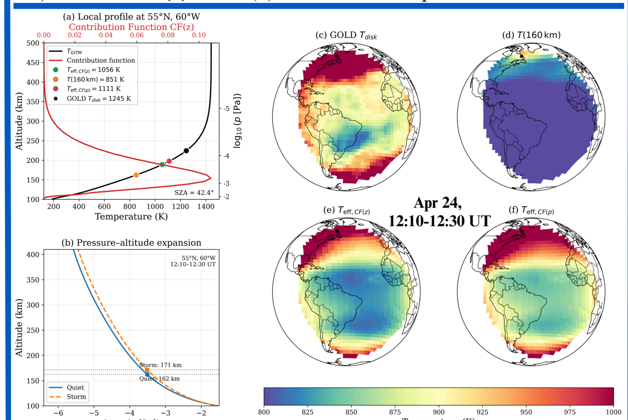
$$CF(z,SZA)=\frac{j(z,SZA)\,e^{-\tau(z,EMA)}}{\int_{z_0}^{z'} j(z,SZA)\,e^{-\tau(z,EMA)}\,dz},\quad T_n^{eff}(SZA)=\frac{\int_{z_0}^{z'} j(z,SZA)\,e^{-\tau(z,EMA)}\,T_n(z)\,dz}{\int_{z_0}^{z'} j(z,SZA)\,e^{-\tau(z,EMA)}\,dz}\ \text{(K)}$$

- Weigh GITM Tn by a **Forward Operator** called N_2 LBH **Contribution Function** to get an effective temperature.

- **Coordinate Transformation: Altitude → Pressure**



(a) N_2 LBH emitting layer ≠ single altitude: as SZA rises, CF peak climbs 144 to 259 km, broadens, and weakens. **(b)** Altitude (z) → Pressure (p) transformation conserves kernel area through Jacobian (shown for 0° SZA). **(c)** Across solar flux (70, 150, 300 sfu) for 0° SZA. **(d)** Panel (a) transformed to pressure coordinate.



(a) CF weighting for a local temperature profile at 55°N, 60°W. GOLD Tdisk = 1245 K, but **GITM T(160 km) = 851 K (31.6%)**, Teff, CF(z) = 1056 K (15.2 %), **Teff, CF(p) = 1111 K (10.8 %).**
(b) Thermosphere expands during geomagnetic activity: the same pressure level sits at 162 km (quiet) vs 171 km (storm). **N_2 LBH emitting layer shifts upward**, so **CF weighing in pressure coordinate is essential** to account for this.
(c,d,e,f) shows **pressure coordinate produces temperature values consistent with observed GOLD Tdisk** in terms of both magnitude and spatial pattern.

[7] Acknowledgements

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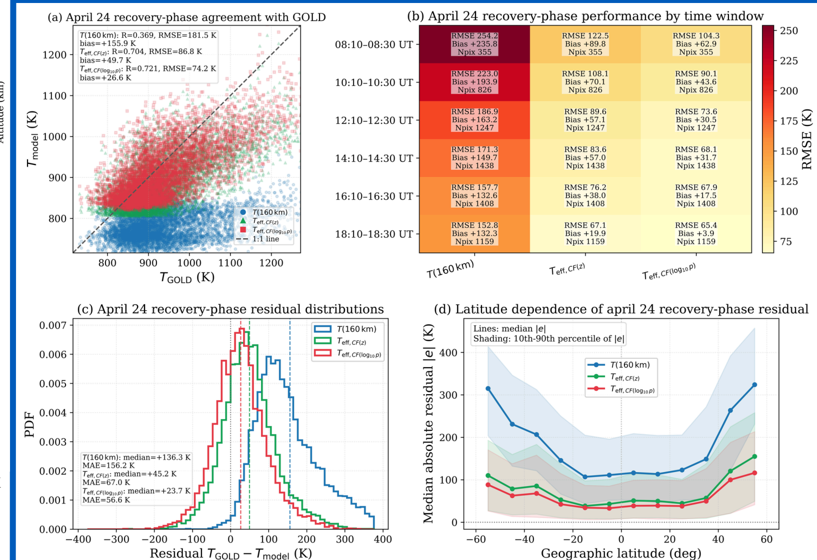
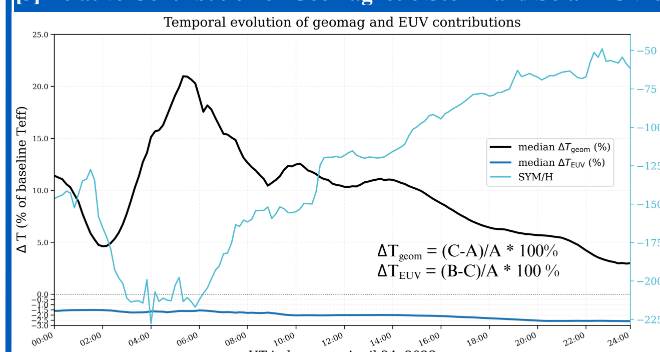
[4] Temperature Diagnostics Against GOLD Tdisk



Diagnostic	Pearson R	RMSE (K)	Bias (K)
GITM(160 km)	0.37	182	+156
Teff,CF(z)	0.70	87	+50
Teff,CF(p) ← best	0.72 94.6% improvement	74 59.3% improvement	+27 82.7% improvement

(d) By latitude: Teff, CF(p) reduces the mean absolute residual |e| at high latitudes significantly compared to GITM T(160 km). Accounts for higher thermosphere expansion in high latitudes during geomagnetic activity.

[5] Relative Contribution of Geomagnetic Storm and Solar EUV on Temperature



GITM
Run A: Apr 22 EUV + Apr 22 geom forcing,
Run B: Apr 24 EUV + Apr 24 geom forcing,
Run C: Apr 22 EUV + Apr 24 geom forcing

Modest ~ 8 sfu decrease in solar EUV has a negligible impact on thermospheric temperature perturbations (**<1% relative to quiet day**)
Whereas storm forcing drove large high-latitude enhancements (**20-30% of quiet day**).

[6] Summary & Future Work

1. GOLD Tdisk must be compared to model temperature as a CF weighted effective temperature, not a single altitude temperature. **2.** Using CF(pressure) improved R, RMSE, & Bias by 94.6%, 59.6%, & 82.7 % respectively **3.** On April 24, (~8 sfu) solar EUV change produced <1 % temperature change, whereas storm forcing drove large high-latitude heating (20-30% of quiet baseline). **Future Work 1:** Test the CF framework on multiple minor, moderate, super storms and quantify how much pressure coordinate CF accounts for thermosphere expansion. **Future Work 2:** Use PCA, PCR, and Optimal Estimation to predict temperature and composition profiles.

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