Data-aided model estimation of the morphology of equatorial zonal plasma drifts

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Abstract: Background electric fields and the resulting **ExB** plasma drifts in the Earth's ionosphere are the result of complex thermosphere-ionosphere (IT) interactions. Our ability to model low-latitude drifts is motivated by fundamental processes in the IT system and the impact of drifts in structuring of the ionosphere. Here, we combine climatological measurements and models of the IT system to evaluate our ability to model zonal plasma drifts.

We use long-term measurements made by the Jicamarca ISR to obtain the height versus local time climatology of equatorial zonal and vertical plasma drifts. In a data-model fusion approach, we combine vertical plasma drift measurements and modeling to predict the behavior of zonal plasma drifts. Focus, at this moment, is given to responses to different wind models.

Our results show that during low solar flux conditions, HWM14 outperforms the previous two versions across all seasons. However, during high solar flux conditions, HWM93 outperforms the other two models during equinox and winter months.

1. RELEVANCE AND MAIN OBJECTIVES

This study has been motivated by the need of a climatological description of the height variation of plasma drifts, and recent studies correlating the height variation of zonal plasma drifts to equatorial spread F.

- ❑ **Goal 1:** To determine, experimentally, the response of equatorial plasma drift height profiles to variations in solar flux and season.
- ❑ **Goal 2:** To assess the ability of readily available climatological models (IRI, MSIS, HWM, IGRF) and a 2D description of the low-latitude electrodynamics to reproduce the observed variability in zonal drifts. Focus is given to the impact of different wind models (HWM93, HWM07, and HMW14) in the variability of the modelled drifts.

2. METHODOLOGY

2.1 Experimental Analysis

- ❑ In order to determine the response of equatorial plasma drifts to geophysical conditions, we used long-term Jicamarca incoherent scatter radar measurements made between 1984 and 2017 available in the Madrigal Database.
- ❑ Geomagnetically quiet data is grouped into seasons for low ($F_{10.7} < 115$ SFU) and high ($F_{10.7} > 115$ SFU) solar flux conditions.
- ❑ Attempts to filter contaminated background drifts due to equatorial spread-F (ESF) events are done by SNR and error bar filters. Additionally, LT-vs-height bins with reduced number of points or unusually high variability are not included in our analysis. **Table 1** provides additional information.

Parameter	Value
Num High SFU Days	331
Num Low SFU Days	450
Local Time/Altitude Bins	15 min / 40 km
Max Kp	3
Max SNR+1	1 dB
Max Error Bar in Vertical Drifts	6 m/s
Max Error Bar in Zonal Drifts	25 m/s

Table 1: Values used in binning/filtering JRO drift measurements.

2.2 Modeling

- ❑ Following a 2D flux tube integrated description of ionospheric electrodynamics (Haerendel et al., 1992) one can write:

$$U_i = U_\phi^P + \frac{\Sigma_H}{\Sigma_P}(U_L^H - W_i) + \frac{g_0}{B\Sigma_P}\Sigma_{Pg} - \frac{J_L}{B\Sigma_p}$$

  Where, U_i and W_i are the zonal and vertical drifts, Σ_P and Σ_H are the Pedersen and Hall conductance, U_ϕ^P and $\mathrm{U}_\mathrm{R}^\mathrm{H}$ are the Pedersen weighted zonal winds and Hall weight meridional winds, Σ_{Pg} is a modified Pedersen conductance, $J_L$is the integrated vertical current, B is the magnetic field strength and g_0 is the acceleration due to gravity at the Earth's surface. The $J_L/(B\Sigma_P)$ term is neglected in the present analysis.

- ❑ W_i is obtained from Jicamarca drift measurements. Other terms are estimated from climatological models IRI-2016, NRLMSISE-00, IGRF-2012, HWM93, HWM07 and HWM14.

JRO Drifts - High Solar Flux

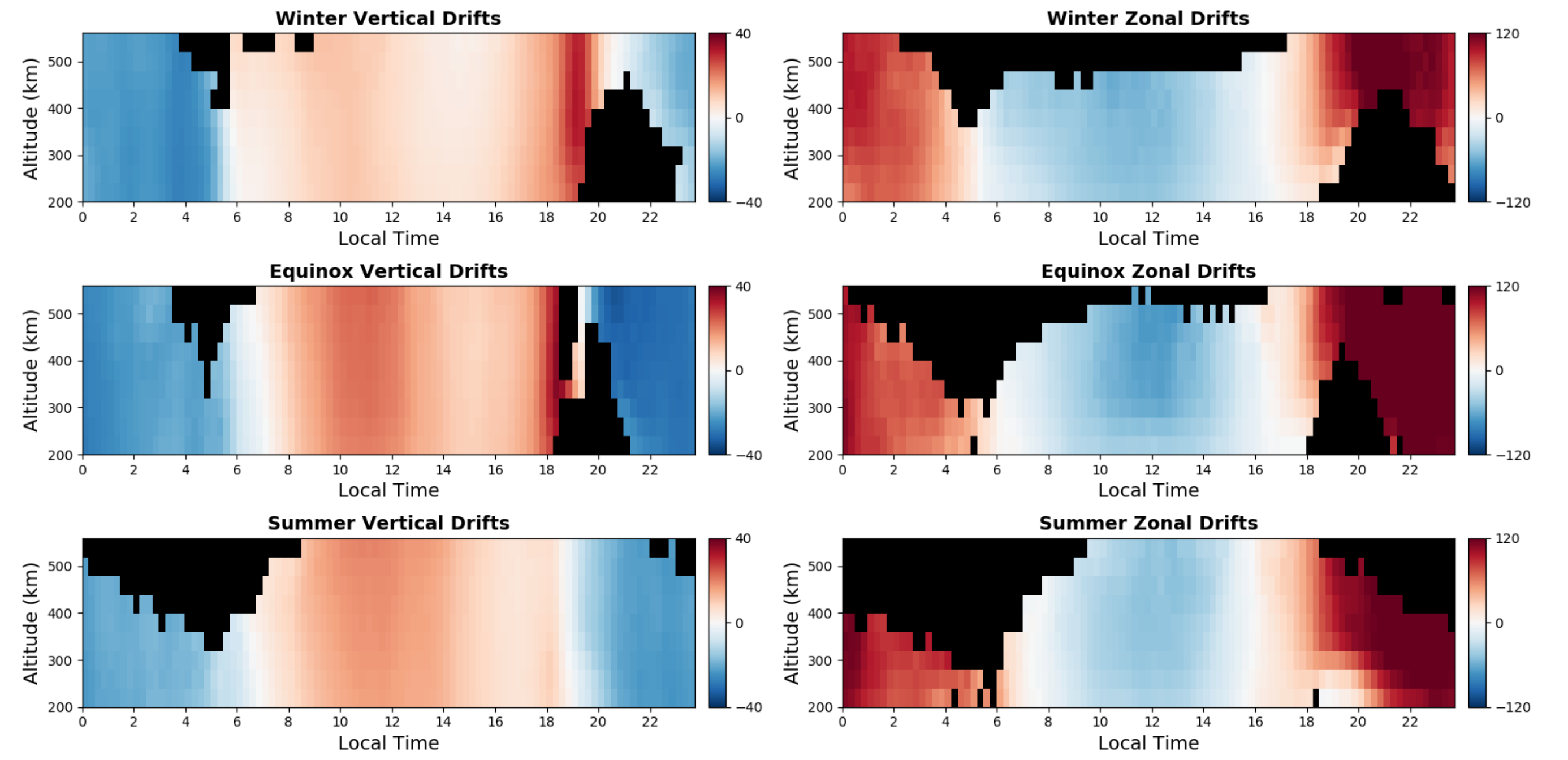

Figure 1: Vertical (left column) and zonal (right column) drifts at JRO for winter, equinox, and summer conditions during high solar flux ($F_{10.7} > 115$ SFU). Data in black are bins that are not included in our analysis due to limited observations or high uncertainties.

JRO Drifts – Low Solar Flux

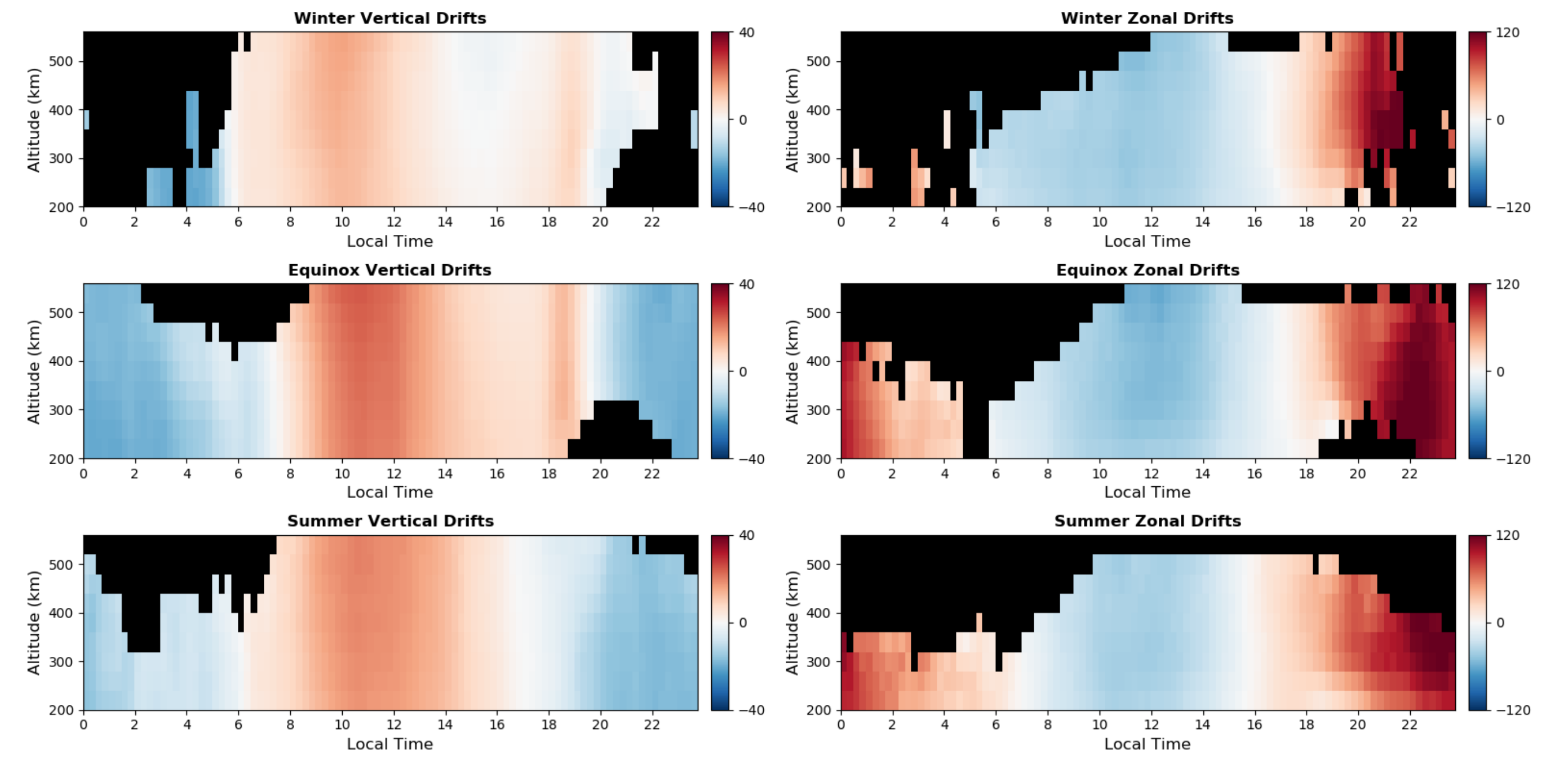

Figure 2: Vertical (left column) and zonal (right column) drifts at JRO for winter, equinox, and summer conditions during lower solar flux ($F_{10.7} < 115$ SFU). Data in black are bins that are not included in our analysis due to limited observations or high uncertainties.

4. RESULTS

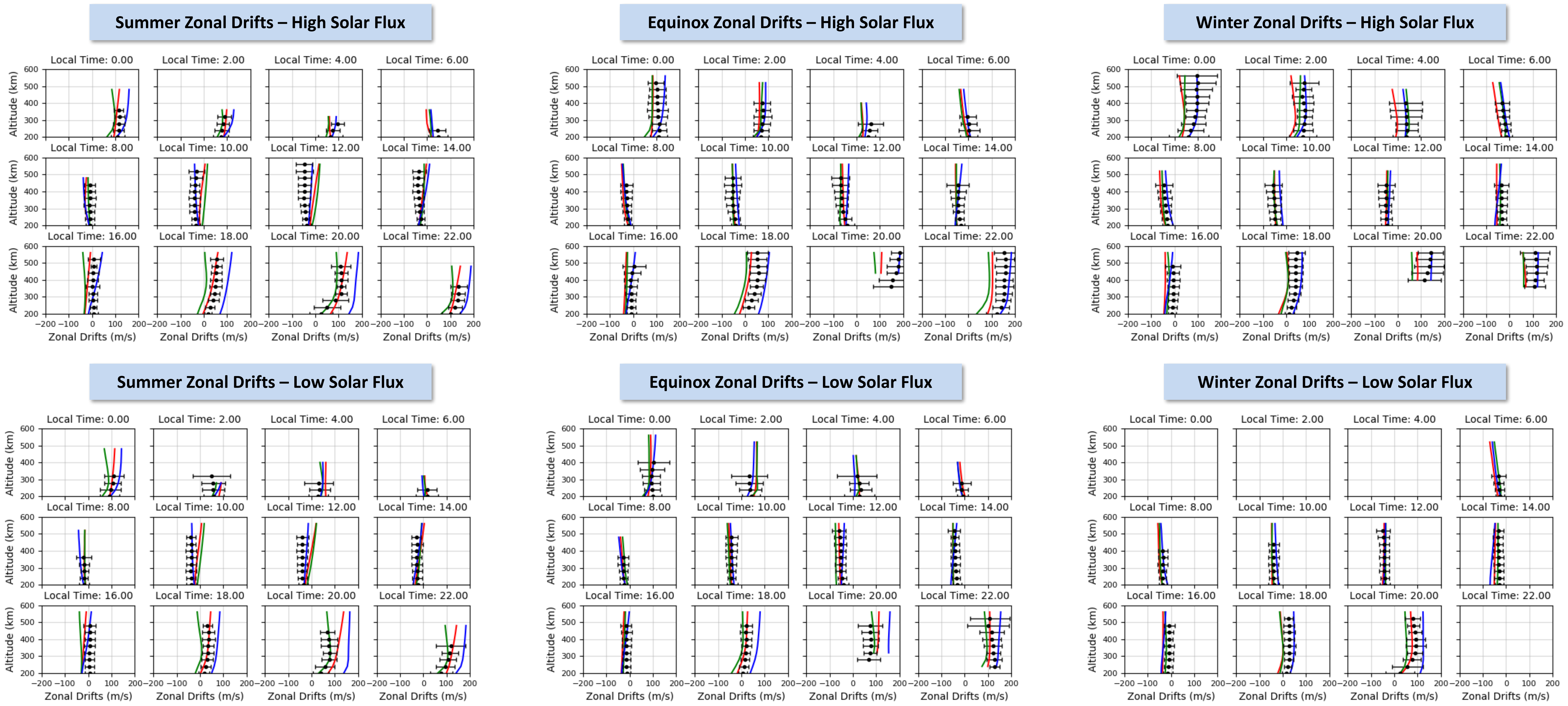
Summer Zonal Drifts – High Solar Flux
Equinox Zonal Drifts – High Solar Flux
Winter Zonal Drifts – High Solar Flux
Summer Zonal Drifts – Low Solar Flux
Equinox Zonal Drifts – Low Solar Flux
Winter Zonal Drifts – Low Solar Flux

Figure 3: Altitude profiles of the average zonal drifts from JRO (Black) with the modeled zonal drifts using **HWM14 (Red)**, **HWM07 (Green)** and **HWM93(Blue)**. The error bars represent the standard deviation of the measurements for each bin.

Table 3: Following Drob et al. (2015), we provide values of model bias, $\mu_i = \frac{1}{N}\sum_{j=1}^{N}(d_j^{avg} - d_j^i)$ and root-mean-square error (RMSE), $\sigma_i^{RMS} = \sqrt{\frac{\sum_{j=1}^{N}\left(d_j^{avg} - d_j^i\right)^2}{N}}$, for HWM version $i = \{93, 07, 14\}$. Where d^{avg} is the unweighted average of JRO zonal drifts and d^i are model values for HWM version i. The best performing RMSE for each season/SFU is highlighted in bold.

Season / SFU	μ_{14}	μ_{07}	μ_{93}	σ_{14}	σ_{07}	σ_{93}
Summer High SFU	-3.07	3.08	-24.00	**24.04**	34.42	37.06
Equinox High SFU	21.18	26.99	-9.97	28.50	37.56	**20.47**
Winter High SFU	30.57	20.19	-5.99	36.71	31.14	**19.59**
Summer Low SFU	-11.29	-1.21	-19.26	**24.59**	26.68	38.37
Equinox Low SFU	1.17	7.49	-12.71	**15.66**	17.85	32.60
Winter Low SFU	15.62	10.82	-2.43	**19.07**	19.92	25.25

5. MAIN FINDINGS

- ❑ Despite limitations in data availability, we were able to create climatological profiles of vertical and zonal drifts for low and high solar flux conditions.
- ❑ The climatology shows typical features such as the diurnal variation of the drifts, the PRE, but also the vertical shear in zonal plasma drifts in some cases.
- ❑ All three models results converge to similar drift values during daytime but tend to diverge at nighttime, particularly in the evening sector.
- ❑ The zonal drifts resulting from HWM93 overestimate climatological drifts across all seasons and solar fluxes, particularly during night time.
- ❑ HWM14 outperforms both HWM07 and HWM93 during low solar flux conditions across all seasons.
- ❑ HWM93 outperforms HWM14 and HWM07 in equinox and winter seasons during high solar flux conditions.

REFERENCES

Drob et al. [2015] *Earth and Sp. Sci.*, 2, 301-319
Haerendel et al. [1992] *J. Geophys. Res.*, 97, 1181-1197

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