The response of low latitude ion drift variability to geomagnetic activity and solar flux in ICON observations

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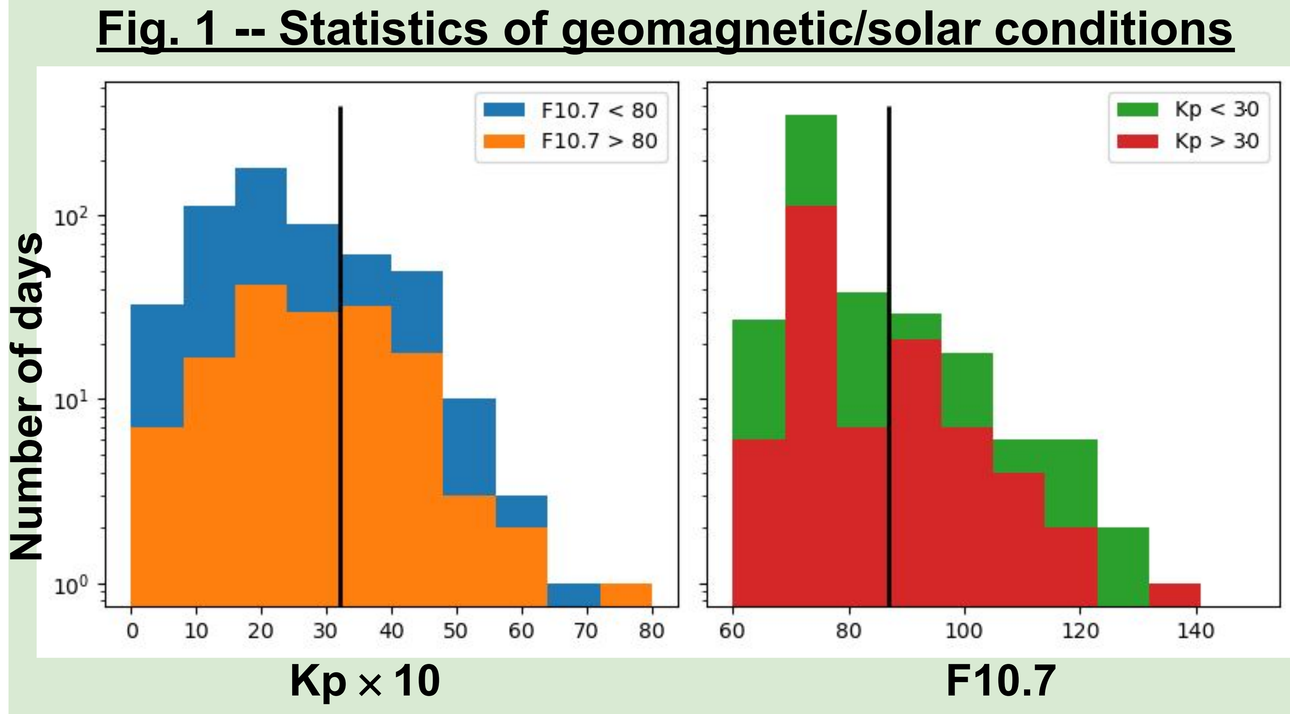
Introduction:

- Low latitude ion drifts respond to field-aligned E-region winds, with ~25% of ICON observed drift variance is attributed to "forcing from below" (Immel and Harding et al., 2021; Harding et al., 2024).
- We describe the influence of forcing from above on ICON zonal ion drift (UI) variance climatologically.
- We examine the dependence of ion drifts on solar flux and geomagnetic activity as functions of local time and longitude.
- We have used ~2.5 years of ICON IVM drift measurements to develop a preliminary empirical model of low latitude ion drifts.

Solar activity conditions and data selection

- ICON data: Dec. 2019 (solar minimum) - Feb. 2022
- Version 6 data of ICON IVM are binned according to:
  - Solar flux: low → f10.7 < 85 and "high" f10.7 > 85
  - Geomagnetic activity: quiet →Kp < 3.3 and active Kp > 3.3

Fig. 1 -- Statistics of geomagnetic/solar conditions



- Zonal ion drifts from IVM, version 6 with good data quality
- UI measurements are further binned into 1 hour local time by 10 degree longitude bins.
- Mean climatology (Fig. 2) calculated by averaging all measurements in a given LT x longitude bin
- Standard deviation of all measurements in a bin (after detrending) is used as a proxy for < 30 day variability
  - Detrending: subtract zonally averaged 30-day running mean

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References:

(1) Immel TJ, Harding BJ, Heelis RA et al (2021) Regulation of ionospheric plasma velocities by thermospheric winds. Nat Geosci 14:893–898.

(2) Harding, B. J., Immel, T. J., Mende, S. B., Wu, Y.-J. J., Maute, A., England, S. L., et al. (2024). Day-to-day variability of the neutral wind dynamo observed by ICON: First results from conjugate observations. Geophysical Research Letters, 51, e2023GL107110.

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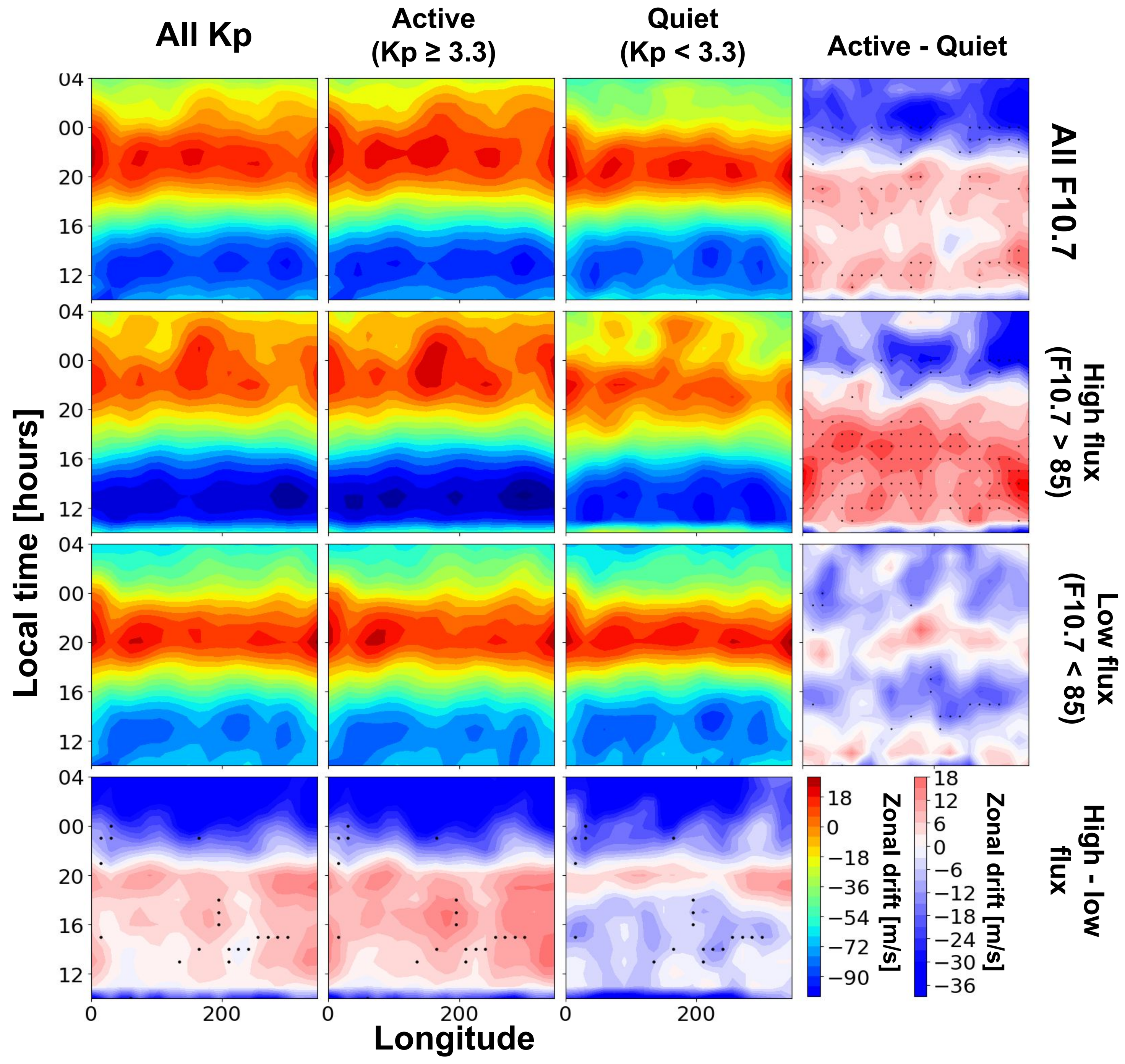
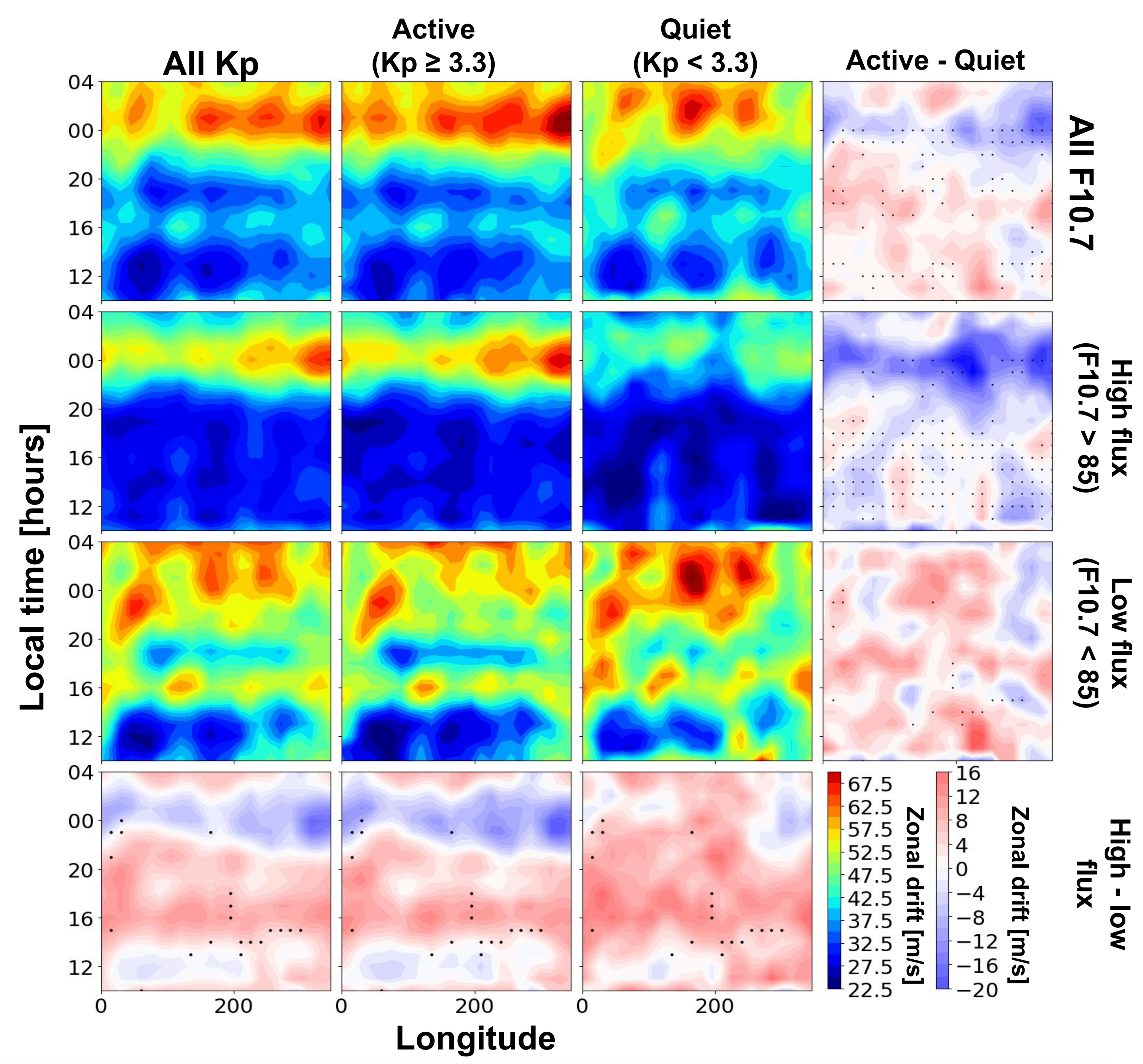
Fig. 2 -- UI Climatology (Mean)



Mean climatology:

- Longitudinal wave 3/4 patterns visible in daytime westward drifts and nighttime eastward drifts
- Geomagnetic activity drives (relatively) westward drifts at night (negative difference after 20 LT) and eastward drifts during the day
- Enhanced solar flux strongly reduces nighttime eastward drifts
- Possible impact of pre-reversal enhancement apparent in quiet time solar flux difference

Fig. 3 -- UI Variability (std.)



Short term variability:

- Wave 3/4 patterns are visible in both day and nighttime variability
  - Wave pattern in variability is maximized at a later LT (~00) than it is in the mean (~20)
- Nighttime zonal drift variability is enhanced during geomagnetically active times
- Daytime ion drift variability is strongly dependent on solar flux (variability increases with solar flux)

The apparent relationship between ICON UI variability with Kp and F10.7 motivates the creation of an empirical model based on this relationship.

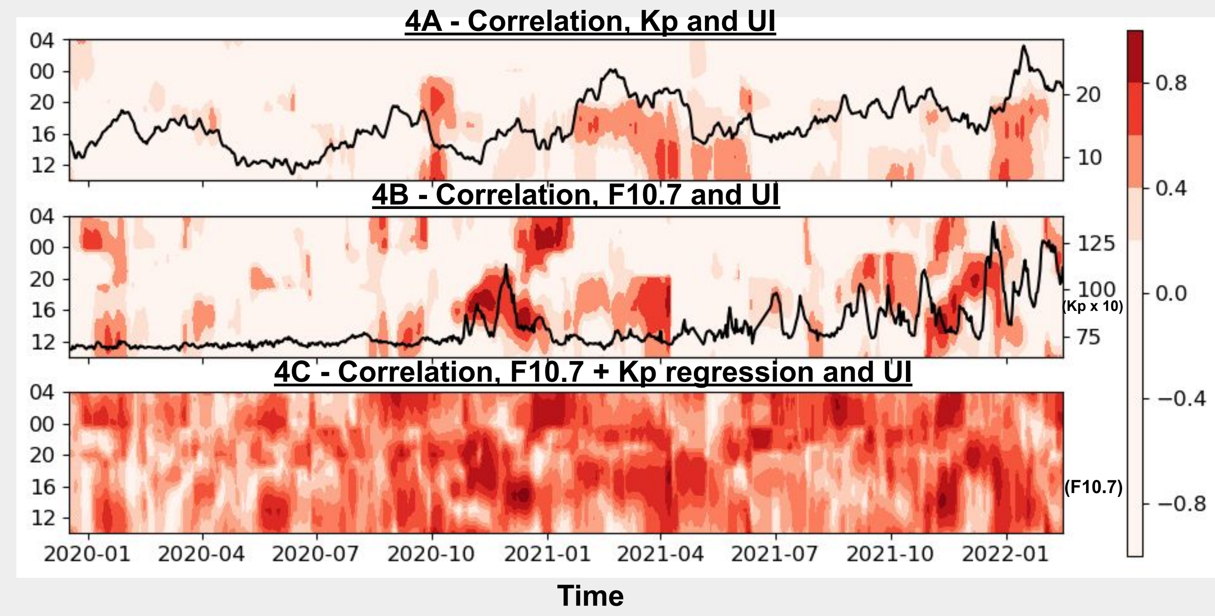
Measuring Kp + F10.7 impacts

- To further examine the impact on UI by Kp and F10.7 fluctuations:
  - For a given local time, calculate a 30-day sliding window correlation between Kp (Fig. 4A) and F10.7 (detrended, 4B) with UI (detrended)
  - Fit a function:

$$Y = (C_1 \cdot Kp) + (C_1 \cdot F10.7) + C_3$$

    to zonally averaged UI and correlate the fitted regression model with the observations (4C.)

Fig. 4 -- Correlations of "forcing from above" with UI



- High correlations between the regression model and observations indicate that UI variability is well captured by F10.7 and Kp fluctuations.
- Correlations are generally strongest when F10.7/Kp is enhanced, suggesting the model may perform well during more active stages of the solar cycle.

Constructing an empirical model (brief summary):

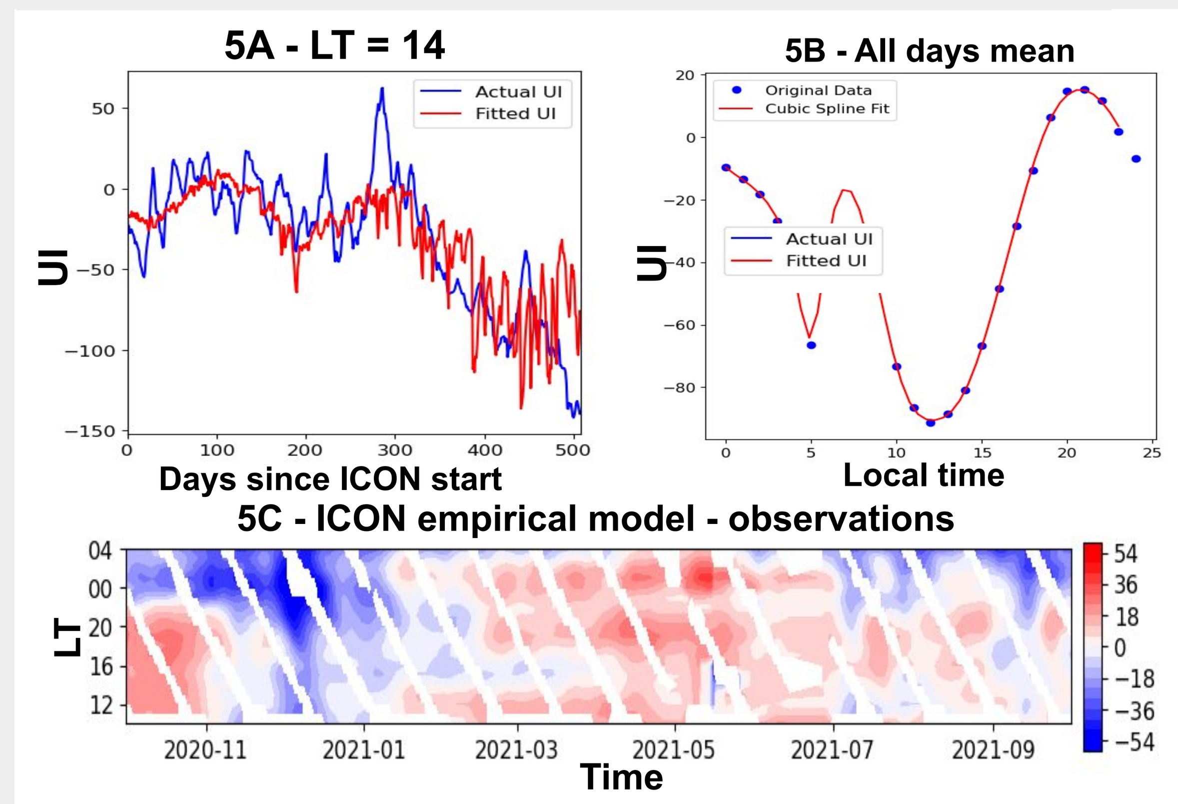
(1) Seasonal, solar cycle, and some short term variability is captured with linear regression of Kp, F10.7, and annual harmonics. (Fig. 5A)

(2) For each Kp and F10.7 bin (see Fig. 2 and 3) Cubic splines are fit to zonal means UI in order to capture local time variations. (Fig. 5B)

(3) Values are (weighted) averaged with mean values for a given Kp/F10.7 bin, with weights depending on day of year.

Fig. 5C shows the difference between one year of output from the regression model and one year of ICON observations.

Fig. 5 -- Correlations of "forcing from above" with UI



- Long term variations reasonably **well captured** for certain local times and seasons (e.g., 2021-01 to 2021-09, 14 LT)
- Short term/day-to-day variability **not** well captured
- Nighttime variations are highly variable and **not** well captured

Conclusions and next steps

- Nighttime mean zonal ion drift variations appear to be related to geomagnetic activity
- Daytime zonal ion drifts are strongly modulated by fluctuations in solar flux
- Zonal ion drift variations are well captured by variations F10.7 and Kp. → Empirical model is promising.
- Next steps: incorporating variability measurements to the empirical model
  - Validating the model against ground based and other satellite observations
  - Extending the model in longitude and latitude and incorporating additional parameters (e.g., vertical drifts, ion densities) observed by ICON