EQIT-1

Study of zonal wind effect on the equatorial return currents using ICON/MIGHTI and Swarm Observations

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Introduction

The ionospheric current density represented using Ohm's Law:

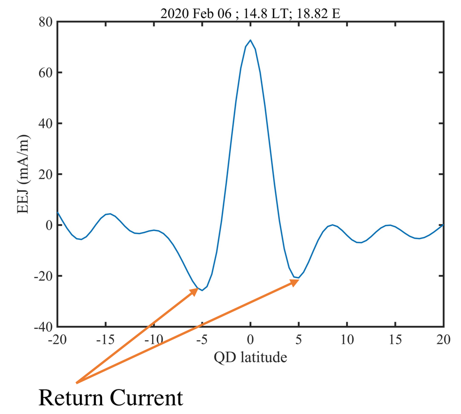
$$\vec{J} = \hat{\sigma}.(\vec{E} + \vec{U}\times\vec{B})$$

$\hat{\sigma}$:Ionospheric Conductivity Tensor

$\vec{E}$: Electric Field

$\vec{U}$: Neutral Wind

$\vec{B}$:Ambient Magnetic field



- The thermospheric neutral winds collide with the ionospheric plasma in the presence of Earth's magnetic field causing differential rotation of ions and electrons, which results in wind dynamo currents.
- The dynamo currents further generates polarization electric fields and currents to make a divergence-free current system.
- At dip equator, the horizontal geometry of magnetic fields along with anisotropic conductivity and the vertical limitation of conducting layer enhances conductivity (Cowling effect) and further generates an intense eastward current known as Equatorial Electrojet (EEJ) in the ionospheric E-region on the dayside .
- However, there are westward currents on either side of the dip equator, which are called EEJ Return currents.

Motivation

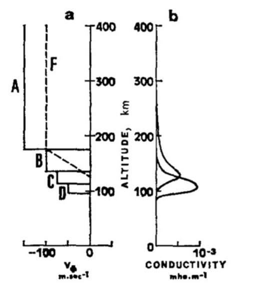
Eastward current density due to eastward neutral wind [Richmond (1973)],

$$J_\phi = \sigma_2 B U_\phi - \sigma_2 B\left[\int_{s_1}^{s_2}\sigma_1 U_\phi ds\right]\Big/\left[\int_{s_1}^{s_2}\sigma_1 ds\right]$$

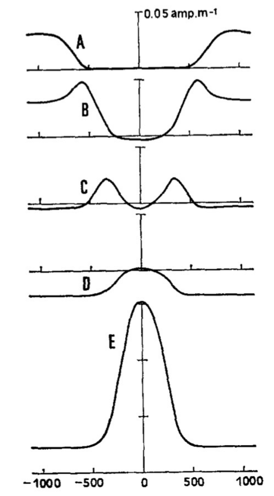
σ_1 - Pederson Conductivity

σ_2 - Hall Conductivity

U_ϕ - Eastward zonal winds

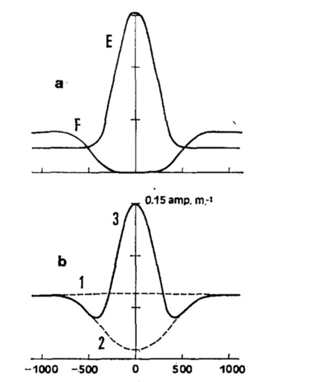


(a)Height profiles of westward winds (b) Height profiles of ionospheric conductivities



(A)-(D) Latitude profiles of height-integrated ionospheric currents calculated using wind profiles A- D and (E) And eastward electric field of 0.4 mAm⁻¹

Ref: Fambitakoye et al., 1976

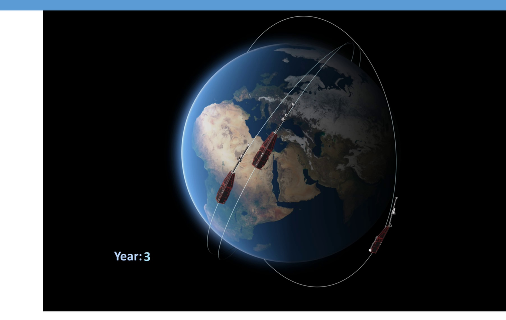


(a)Latitude profiles of height-integrated ionospheric currents using E = 0.4 mAm⁻¹(profile E) and wind profile F (b) Combination of current profiles E and F

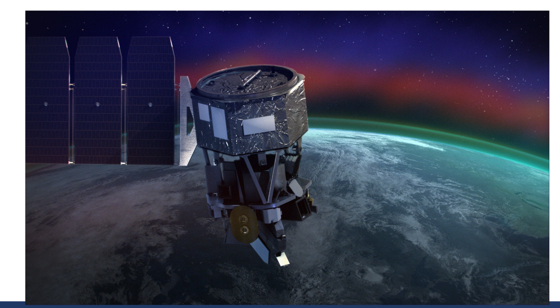
- Using Richmond's (1973) physical model of the electrojet, Fambitakoye et al. (1976) demonstrated that the increasingly westward neutral wind with altitude at low latitude in the E- and lower F-region are related to the strength of the currents at the flanks of EEJ, which are visible as dips.
- There was no wind data available in the lower ionospheric altitudes above E region dynamo till now to check the prediction from Richmond's 1973 EEJ model.
- After 50 years, there is a unique opportunity to inspect the effect of zonal winds on EEJ return currents using the wind measurements from ICON and EEJ estimated from Swarm satellites.
- Does the vertical shear of zonal winds affect the westward currents at low-latitudes?

Data

ICON Satellite



- Altitude : ~580 km.
- Inclination : 27° (Equatorial)
- MIGHTI –MIGHTI A & B measures the wind along its line of sight. Combining data from MIGHTI A & B separated by 90˚ between their views allows the wind vector (horizontal wind speed and direction) to be determined.
- Level 2.1 Neutral wind vector data

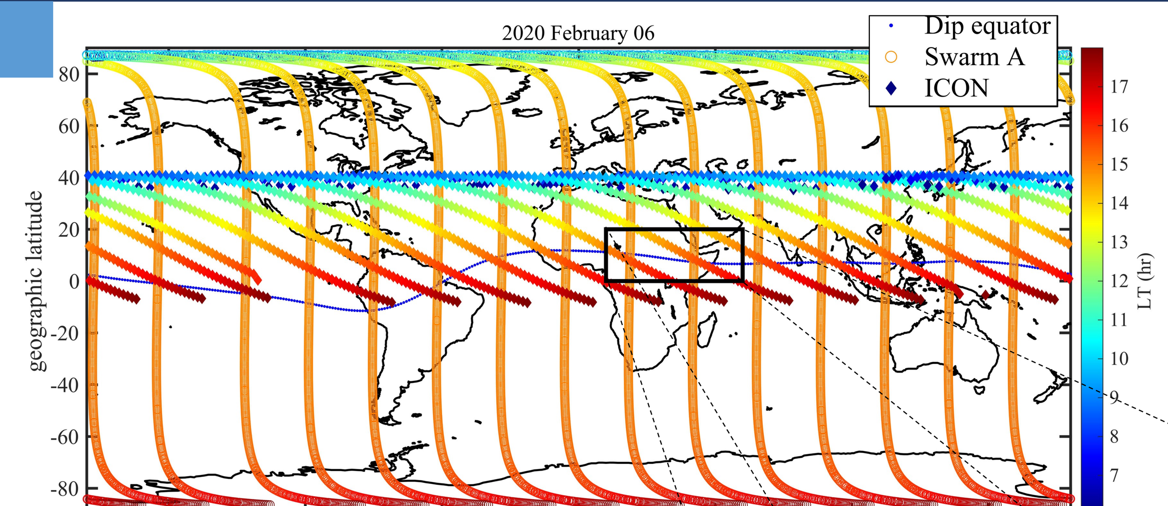


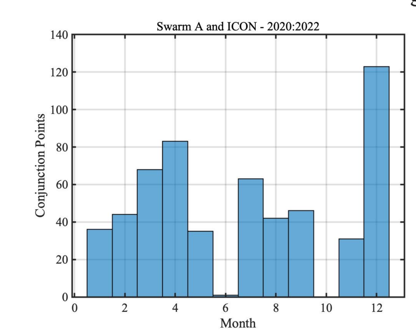
Swarm multi-Satellite mission

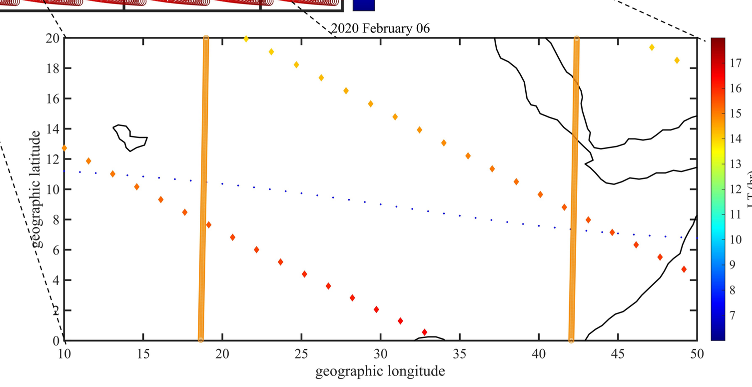
- Satellite : Swarm A,B, C
- Swarm A and C are flying side-by-side at an altitude of 460 km; Swarm B is flying at 510 km.
- Inclination: 87°-88° (polar)
- Level 2 EEJ data – Magnetic data measured by Absolute Scalar Magnetometer is inverted to height-integrated eastward currents at the equatorial to low-latitudes using the least square inversion method.

Criteria for Data Selection

- Days Selected : 2020 January – 2022 February
- Geomagnetic Quiet days (Kp<=3+)
- conjunction dt = +-0.5 hr
- LT : 9-15 hr.
- Δglon = +-10 deg
- Wind data selection: -5 <= mlat <= 5
- Wind data Quality > 0.5
- EEJ(mlat =0) >= 25 mA/m
- Return current Intensity (RC) Criteria:
  - Criteria 1: RC < = -30 mA/m (HIGH)
  - Criteria 2: -30 < RC <= -5 (MEDIUM)
  - Criteria 3: RC > -5 (LOW)
- Total Conjunction points between Swarm A and ICON in 26 months of data considered : 572

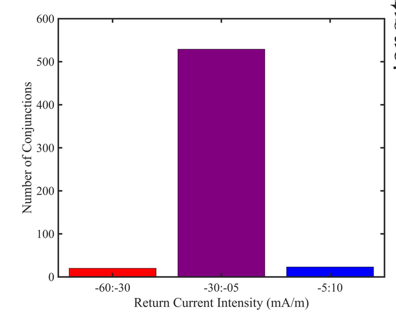


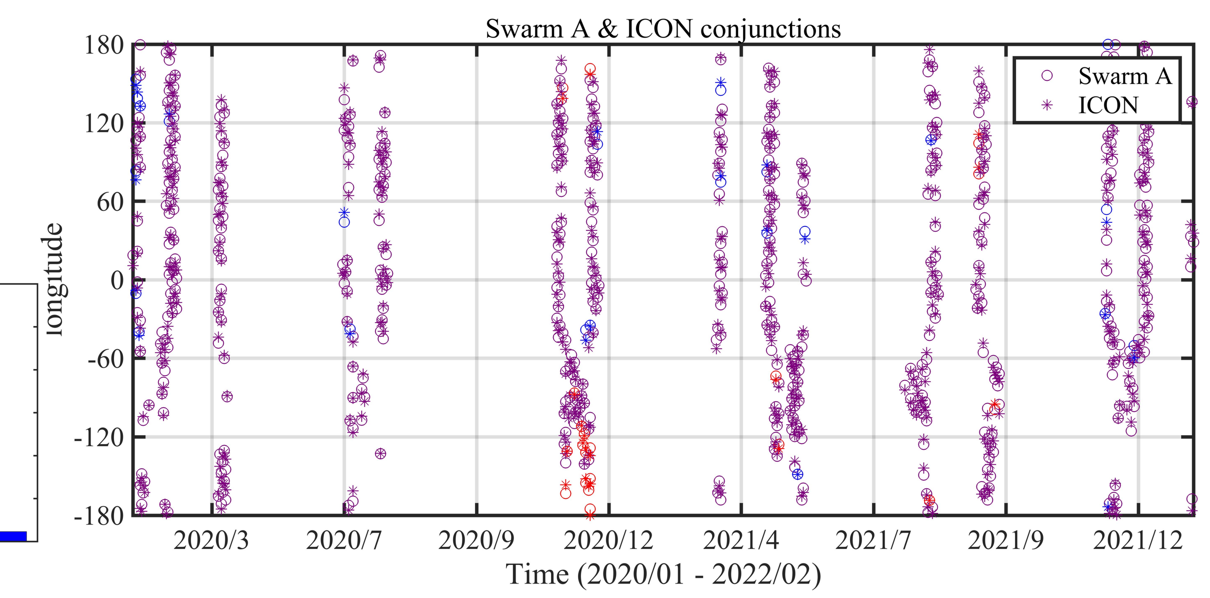


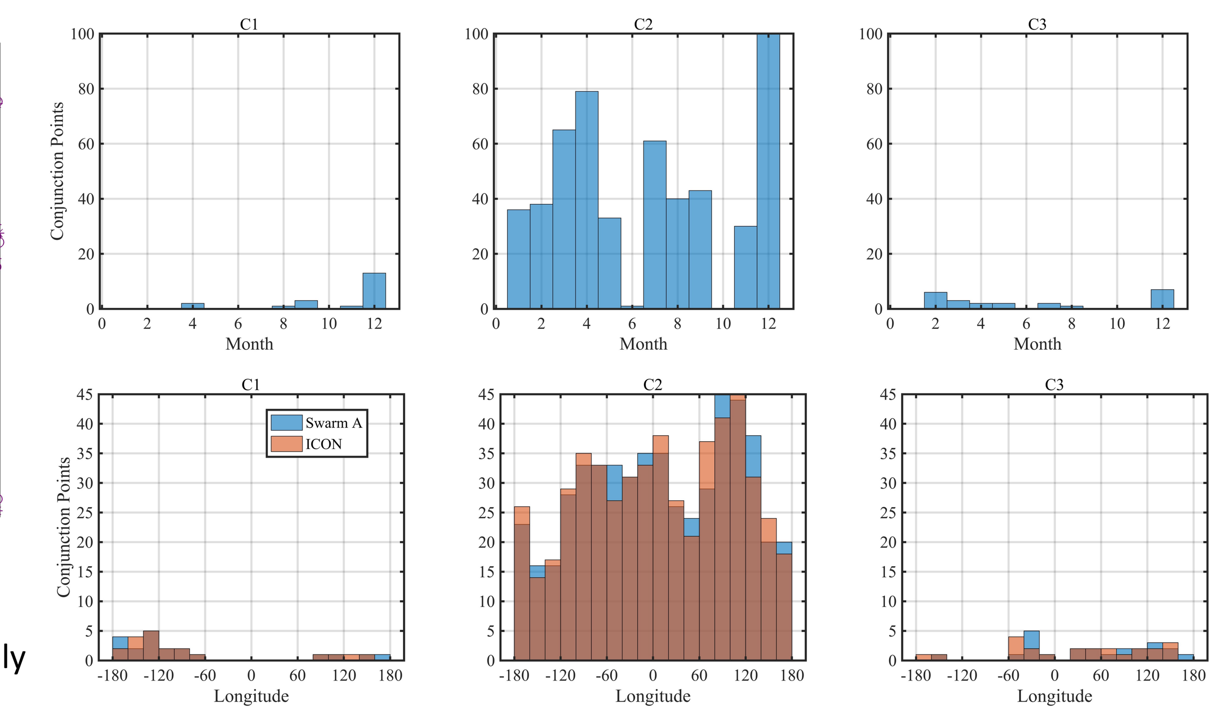


Seasonal and longitudinal variation of Swarm and ICON Conjunction Points

With two years of Swarm and ICON conjunctions, the number of conjunctions points is less for higher magnitude return currents (criteria-1) and no return currents (criteria-3) as compared to the medium magnitude currents.





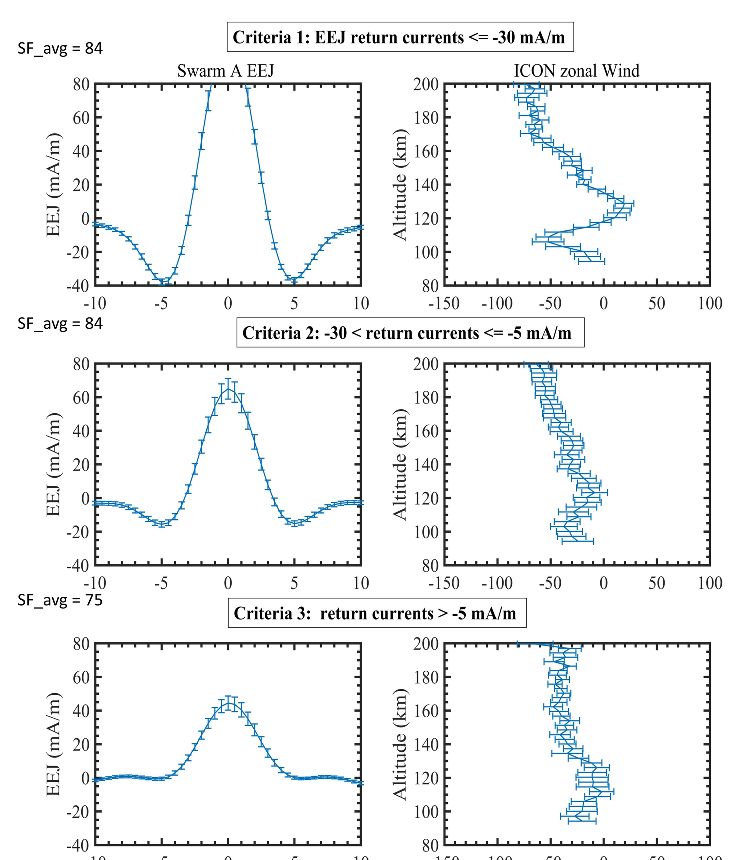


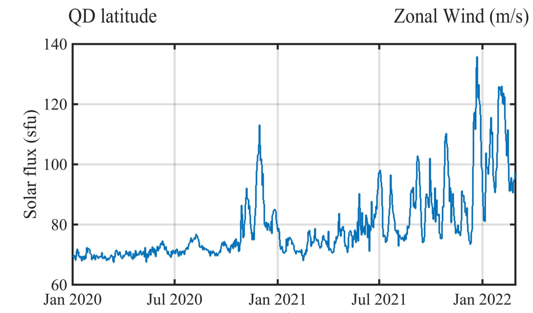
Seasonal and longitudinal distribution of conjunction points in each criteria is not enough to separately analyze them. So, a mix of seasons and longitudes is considered.

Results and Discussions

Results from Swarm and ICON conjunctions

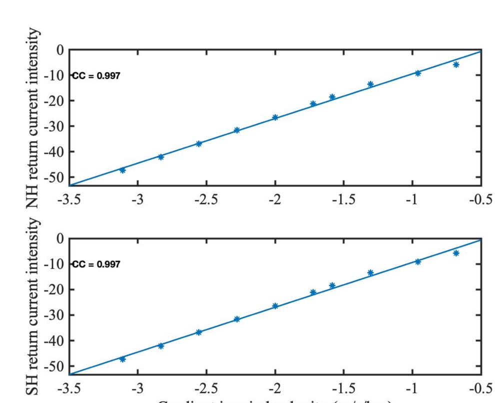
- The EEJ and zonal wind data obtained for three different criteria of Swarm and ICON conjunctions is averaged.
- The mean solar flux (SF_avg) for each criteria is mentioned on the top left of each subplot.
- The amplitude of maximum return current in both hemispheres is compared with the gradient of zonal winds.
- The amplitude of return current intensity increases with increase in gradient in zonal wind velocity at altitudes between 130 and 200 km.
- The results obtained from Swarm A is consistent with Swarm B and C.
- Some limitations of the study:
  - The number of conjunction points obtained for different criteria is not the same.
  - The longitudinal and seasonal variation is not considered.
  - The LT variation of EEJ is not taken into account.
  - The solar flux during 2020 to 2022 is low and so the effect of high solar flux is neglected.

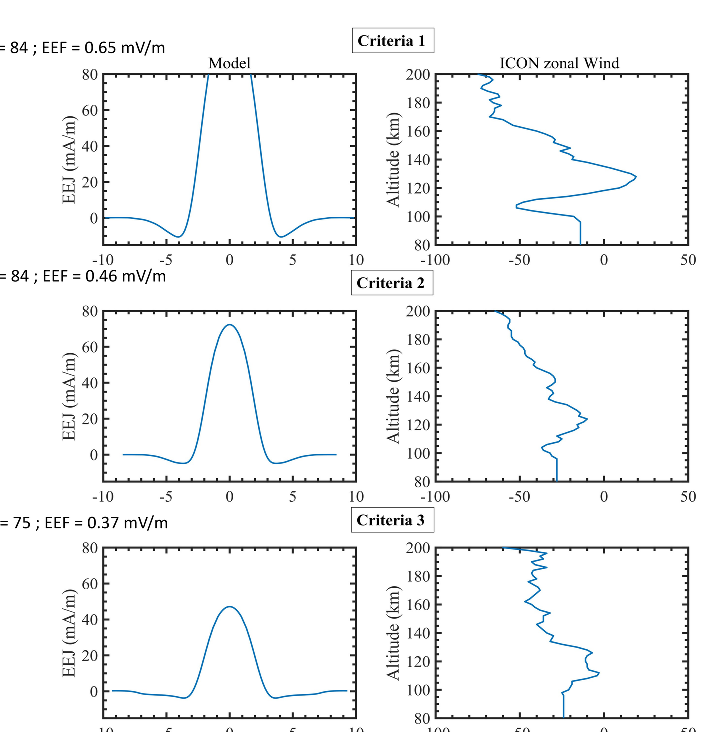


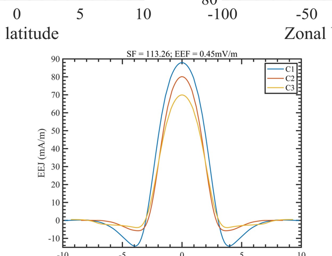


Using ICON wind data in Richmond's 1973 Model of EEJ

- The ICON wind measurements were fed into Richmond's 1973 model of EEJ to compare with the observational results.
- The solar flux and equatorial electric fields (EEF) used in the model are mentioned on the top left corner of each subplot.



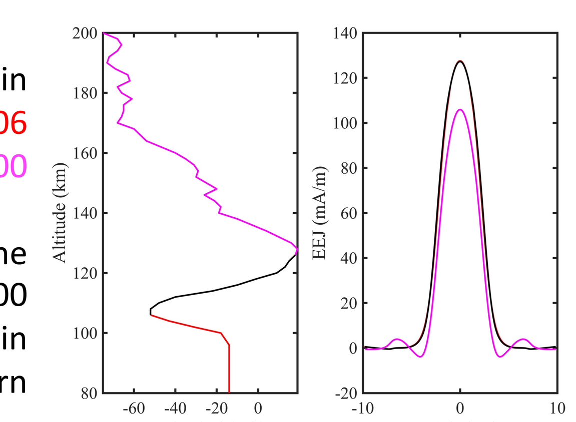




- The EEJ model also shows an agreement with the satellite observations even though with a weaker magnitude.
- For a given solar flux and EEF, electrojet return currents increases with the increase in gradient in zonal wind.

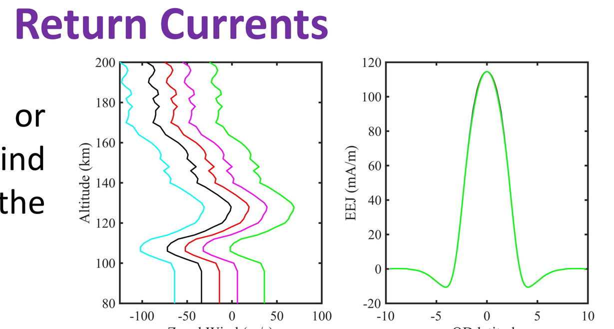
Effect of Winds at Different Altitudes

- The effect of winds in different regions : 80-106 km, 106-128 km, 128 – 200 km on EEJ return currents.
- Only westward winds in the Pederson region (128 – 200 km) play a role in generating the EEJ return currents.



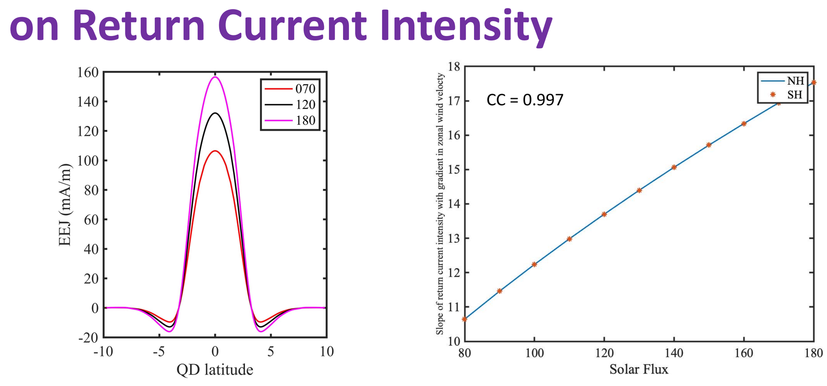
Influence of magnitude of zonal winds on EEJ Return Currents

- The amplitude or value of zonal wind does not affect the EEJ amplitudes.



Effect of Solar Flux on Return Current Intensity

- A change in solar flux by ~100 sfu changes the return current intensity by ~6 mA/m
- For a given wind velocity gradient, return current increases if solar flux increases.



Conclusions and Future works

- The predictions from Richmond's 1973 model of EEJ are examined and found to be in agreement using the data conjunctions of Swarm and ICON satellite observations.
- Westward winds in the Pederson region (upper E region to low F region) play a role in generating the EEJ return currents.
- As the gradient in zonal wind velocity increases, amplitude of maximum return current increases.
- The EEJ model using observational wind data agrees well with the satellite results even though with a weaker magnitude.
- Only the gradient in zonal wind affects the return current intensity and not the magnitude of zonal wind velocity.
- Increase in solar flux increases return current intensity for a given zonal wind gradient.
- The reason for EEJ model to show low magnitude is being examined.
- Understanding the effect of zonal winds on EEJ return currents using Swarm and ICON satellites with a well distributed seasonal, longitudinal, solar flux and LT conjunctions can provide an improved statistical study in the future for a better understanding of the EEJ return currents.

References

1. Fambitakoye, O., Mayaud, P. N., & Richmond, A. D. (1976). Equatorial electrojet and regular daily variation SR—III. Comparison of observations with a physical model. Journal of Atmospheric and Terrestrial Physics, 38(2), 113–121. https://doi.org/10.1016/ 0021-9169(76)90118-5
2. Richmond, A. D. (1973). Equatorial electrojet—I. Development of a model including winds and instabilities. Journal of Atmospheric and Terrestrial Physics, 35, 1083.

Acknowledgements

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