Examining the impact of equatorial plasma bubbles on the retrieval of electron density profiles (EDPs) via RO with machine learning

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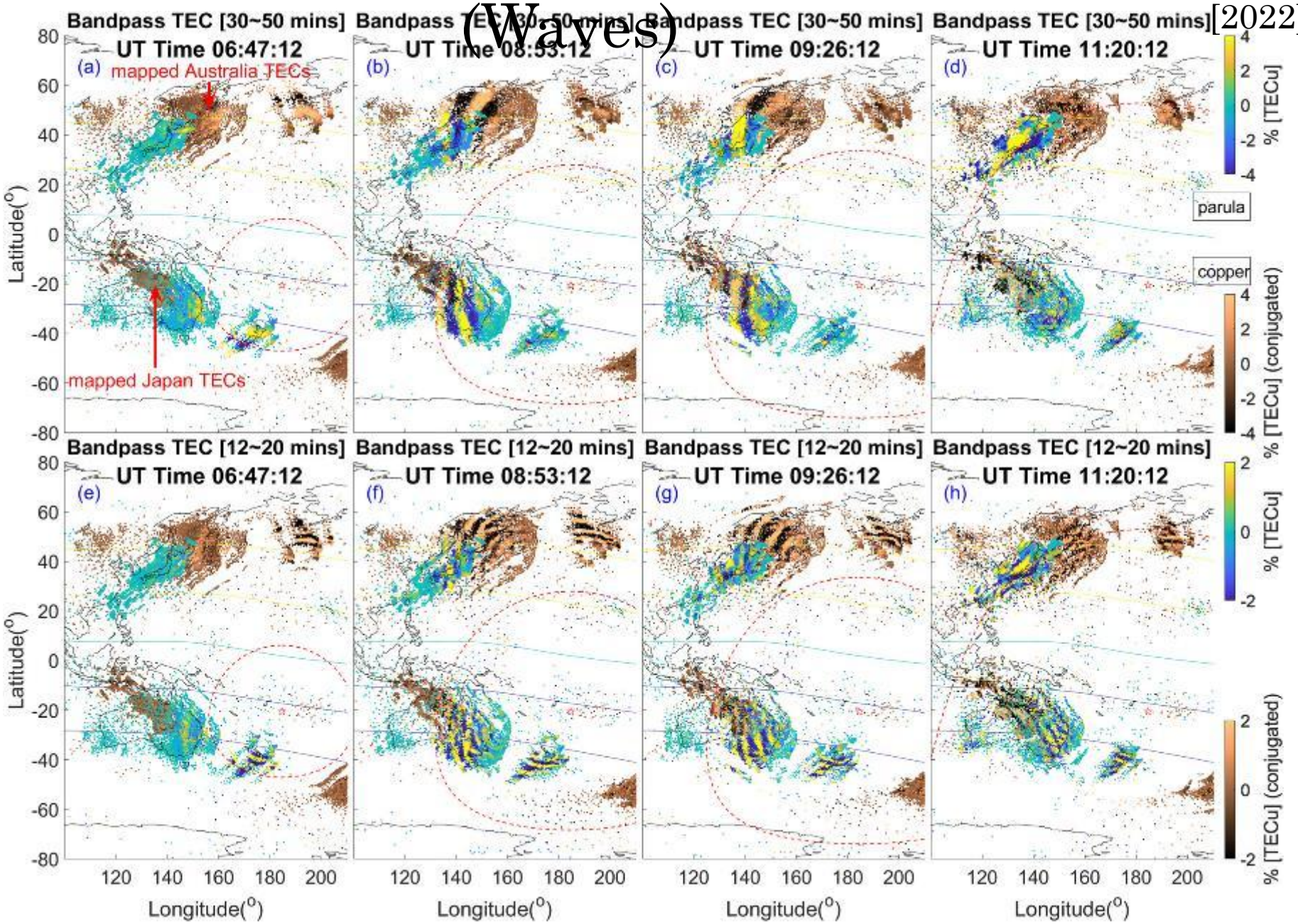
Curtesy: Tonga Geological Services

Mega Terrestrial Event

2022 Tonga volcanic eruptions

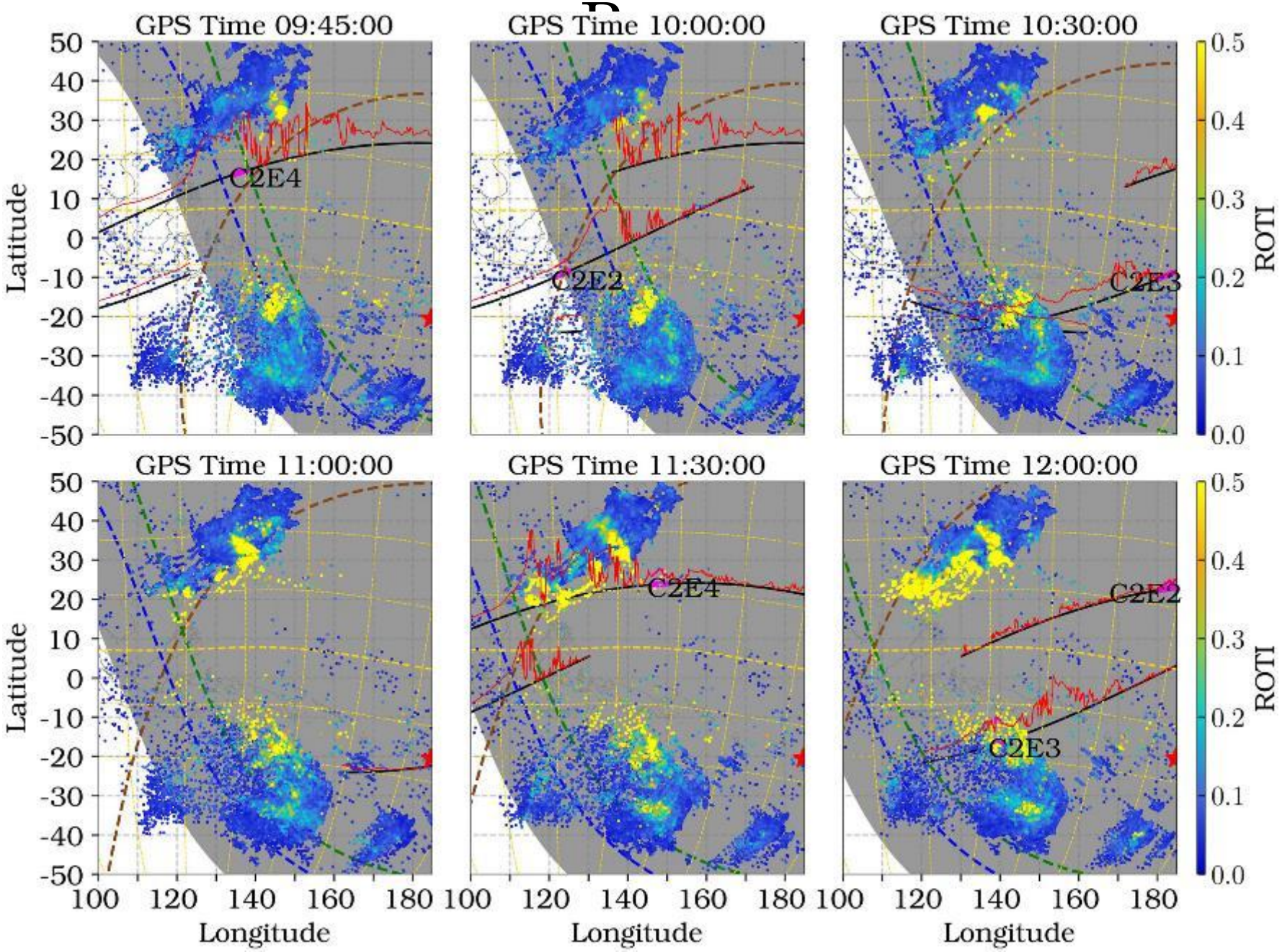
TIDs (Waves)

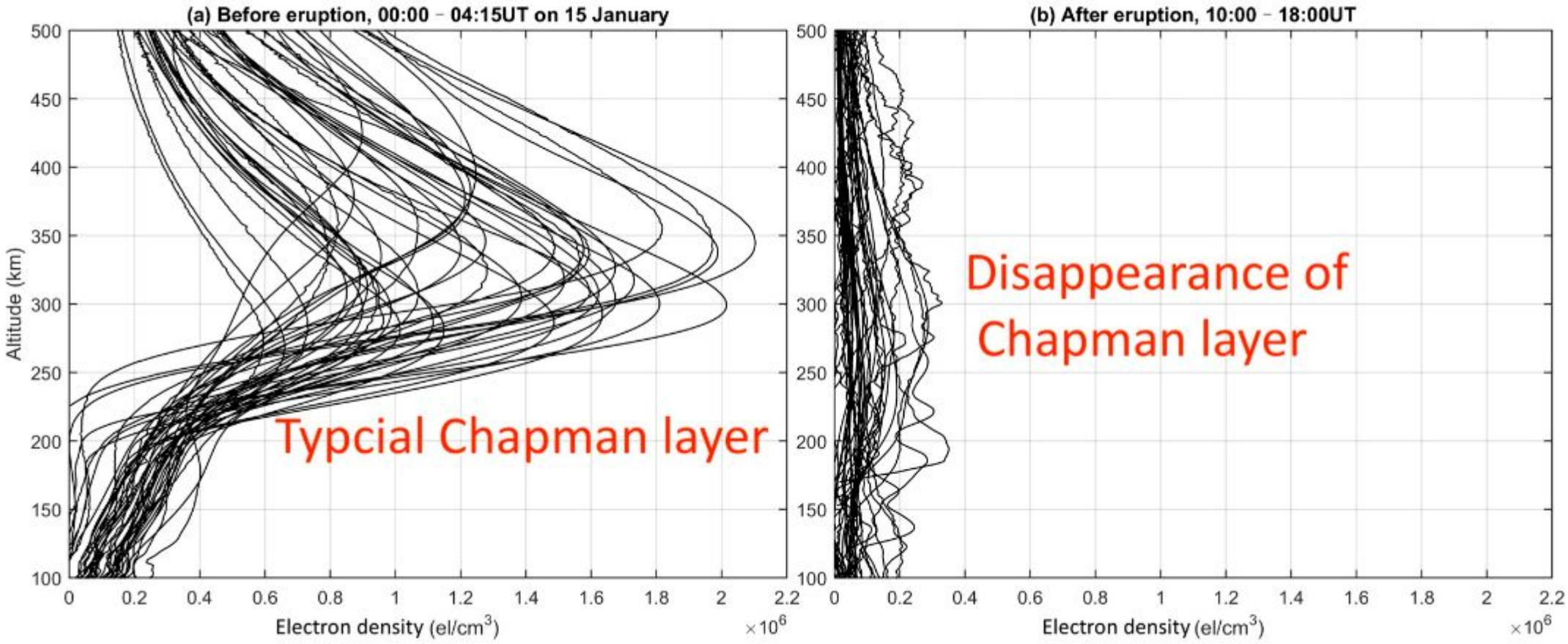
Lin et al. [2022]



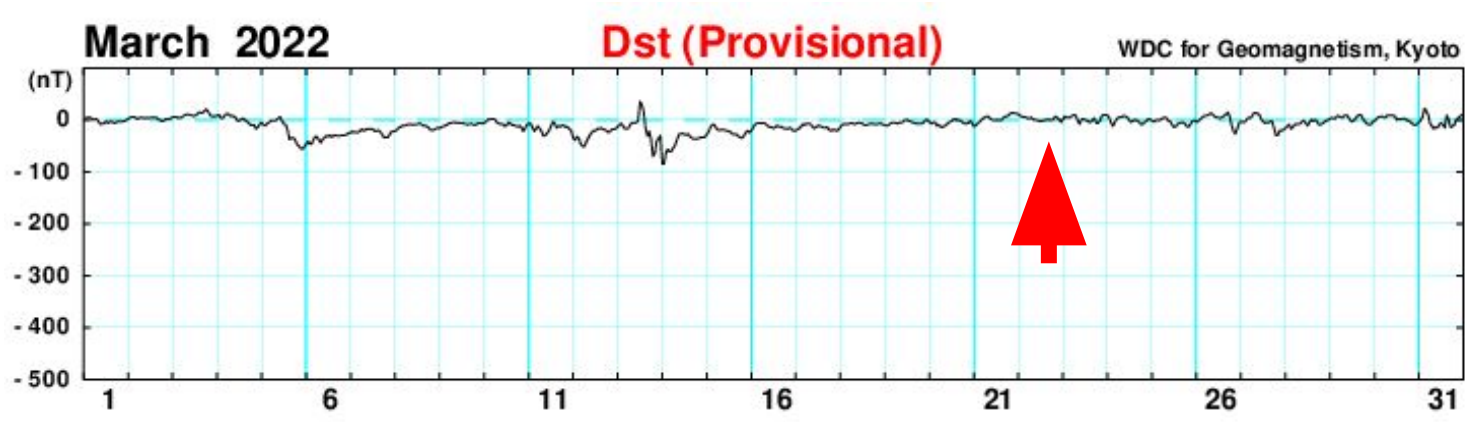
EP

Rajesh et al. [2022]

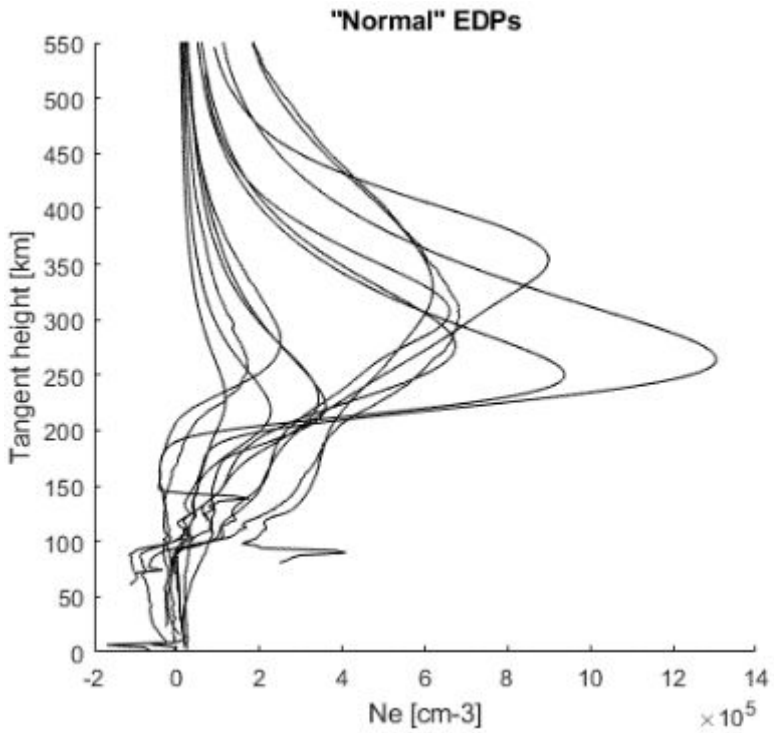


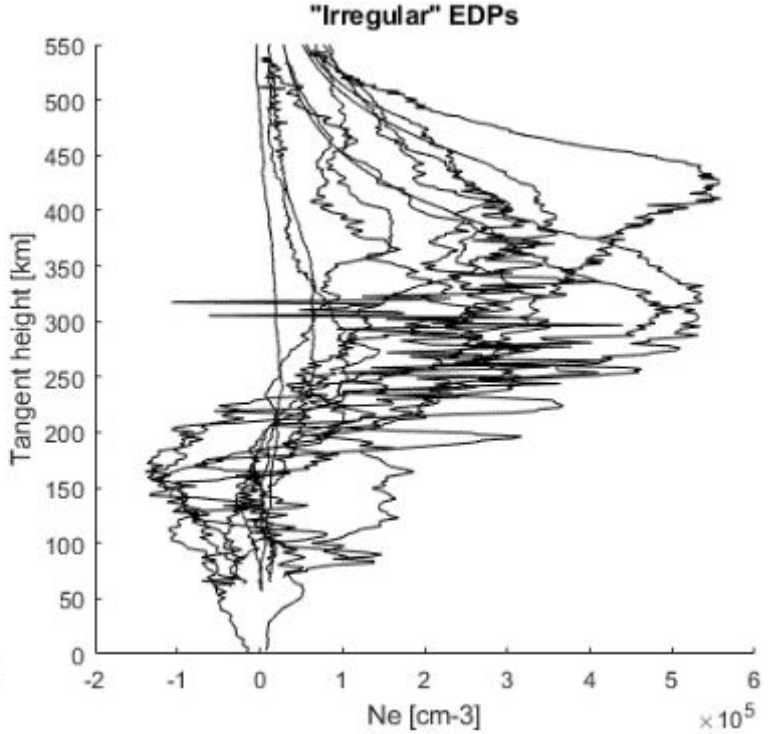


Sun et al. [2022]



DOY 081, 2022

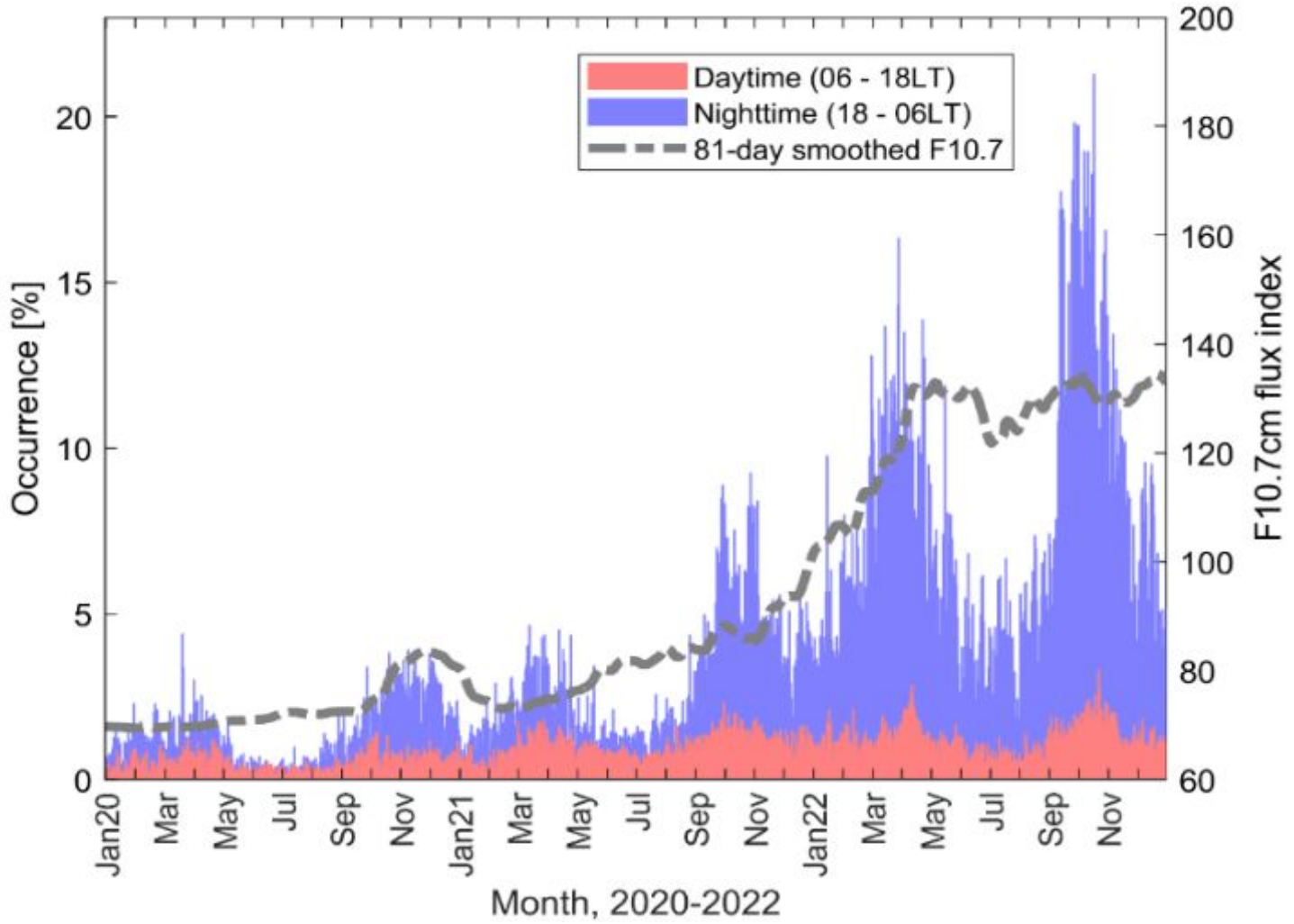




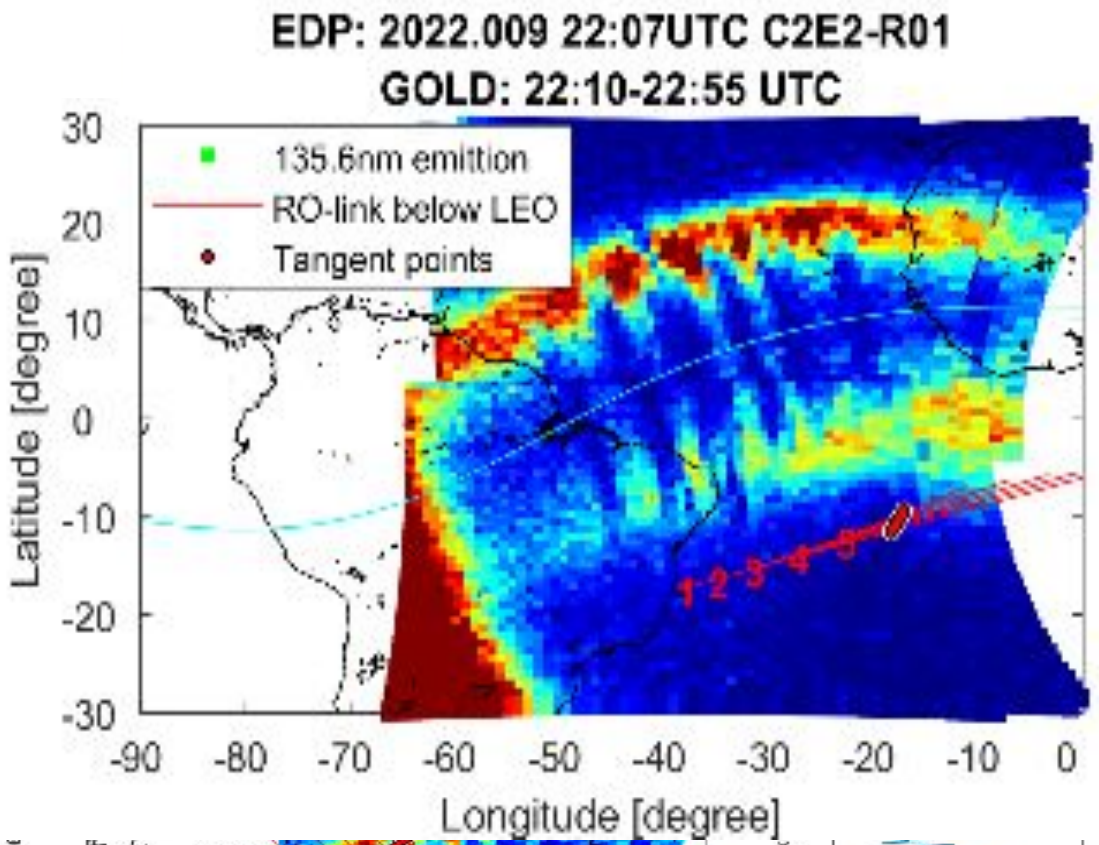
Define "Irregular"

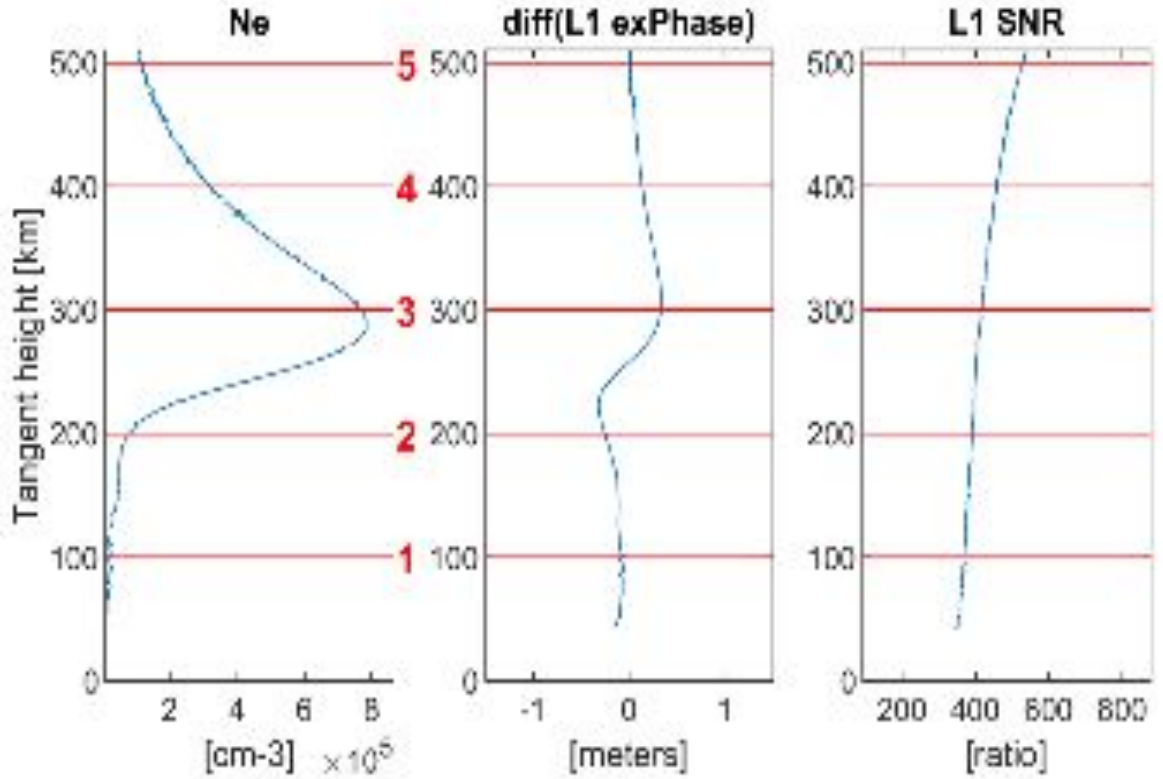
Source: TACC (Taiwan Analysis Center for COSMIC)

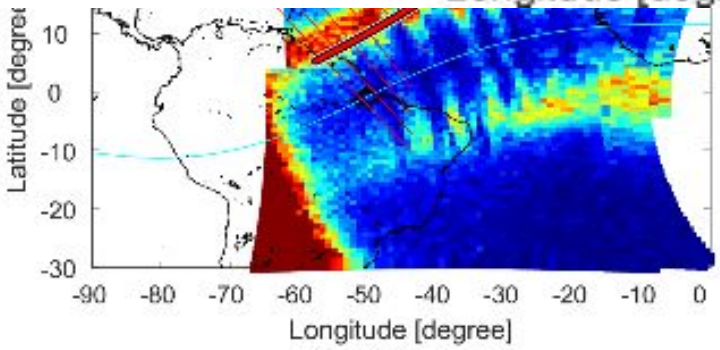
Criteria:
F-region (200 - 450 km)
10km Max(Abs(ΔNe)) > 10^5 cm^{-3}

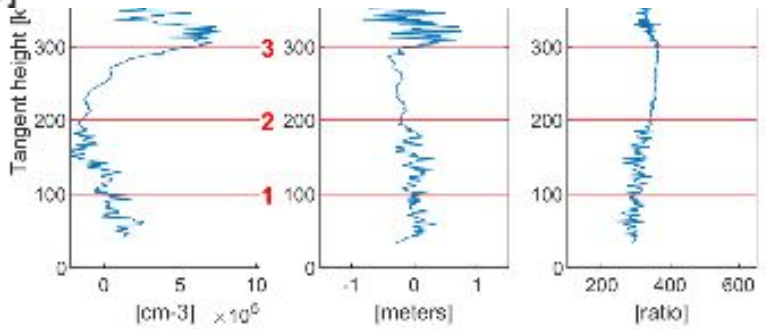


Constant criteria tells



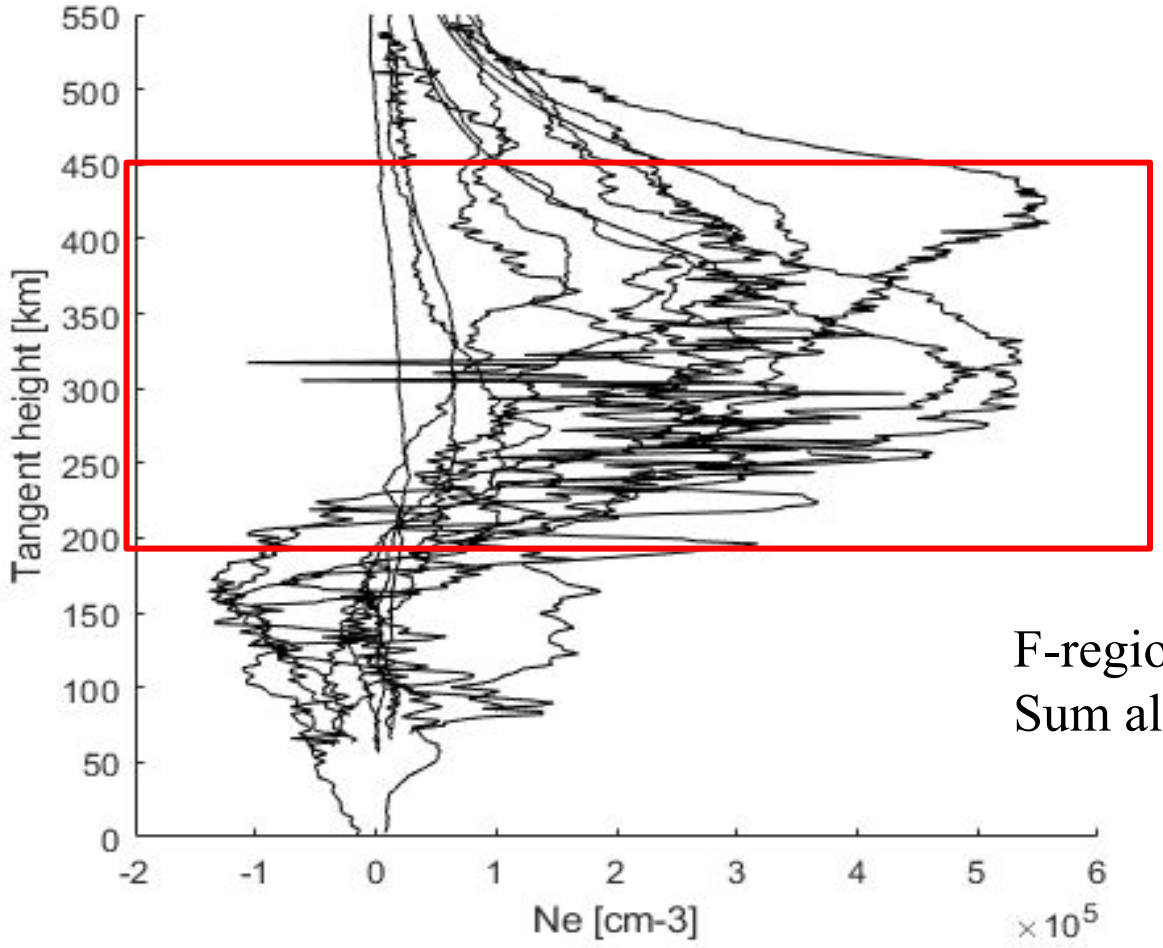




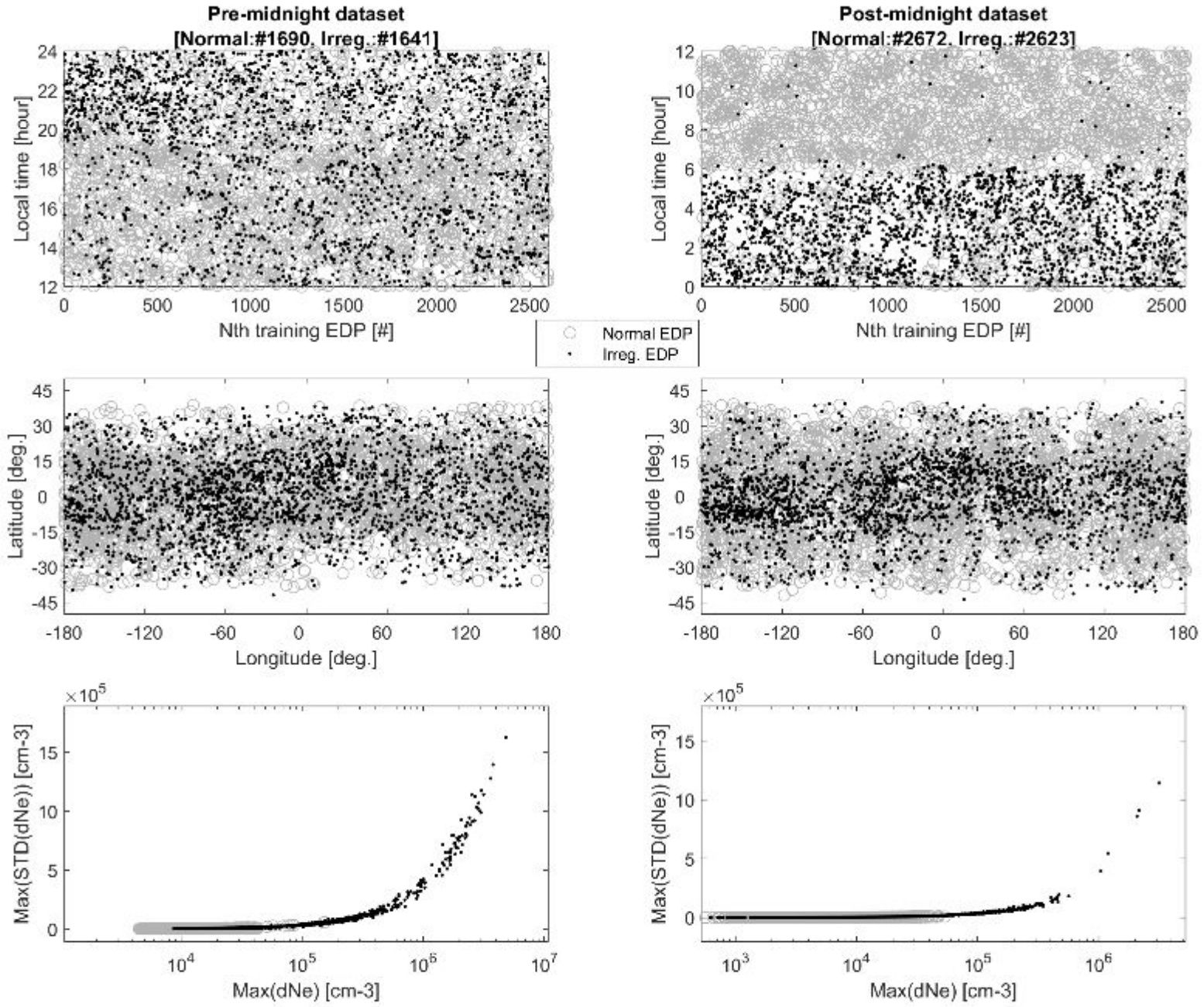


Is constant criteria sufficient to detect irregular EDPs?

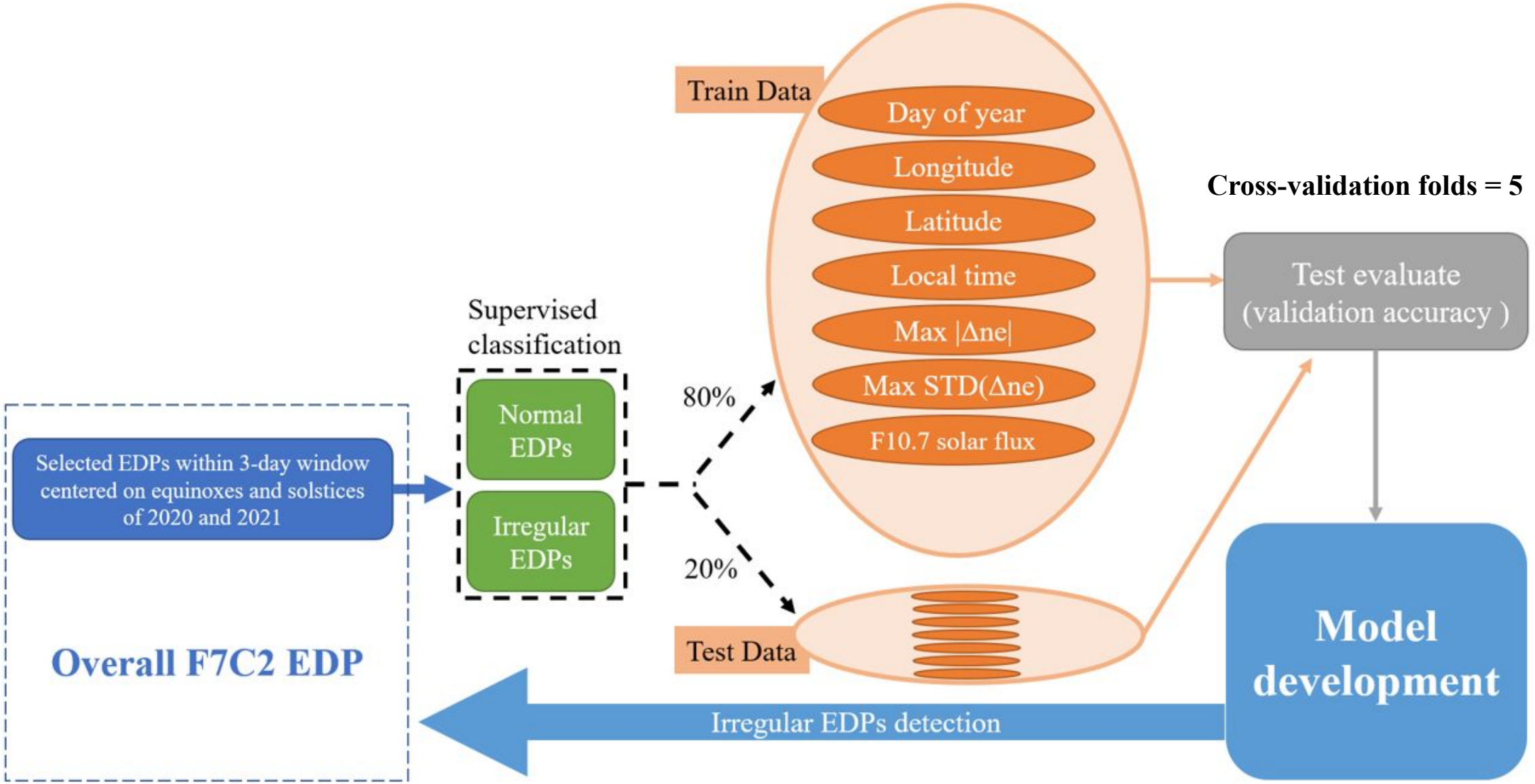
Adapted criteria: Machine learning

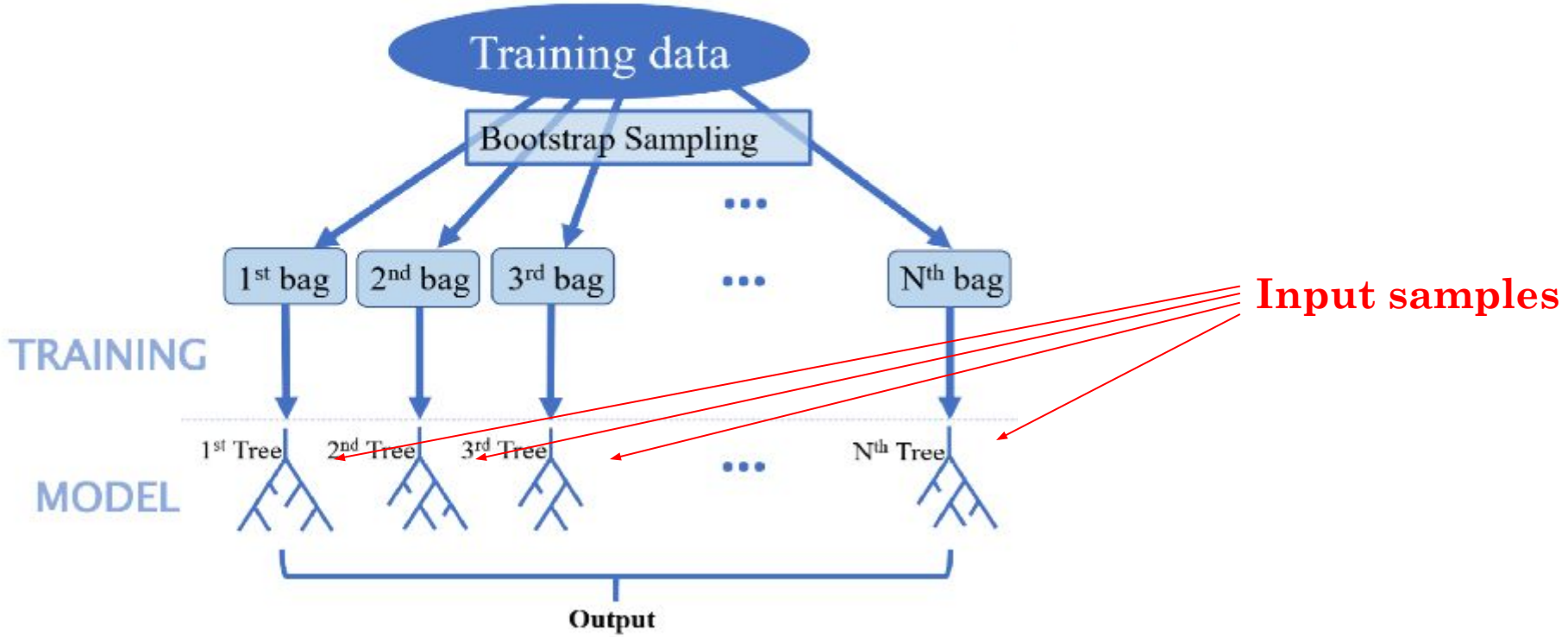


F-region (200 - 450 km)
Sum altitudes of fluctuating > 50km



Distribution of training data


Train Data
Day of year
Longitude
Latitude
Local time
Max |Δne|
Max STD(Δne)
F10.7 solar flux
Cross-validation folds = 5
Test evaluate
(validation accuracy)
Supervised
classification
Normal
EDPs
Irregular
EDPs
80%
20%
Selected EDPs within 3-day window
centered on equinoxes and solstices
of 2020 and 2021
Overall F7C2 EDP
Test Data
Model
development
Irregular EDPs detection



Pre-midnight

True Class \ Predicted Class	Norm.	Irreg.
Norm.	1528	162
Irreg.	74	1567

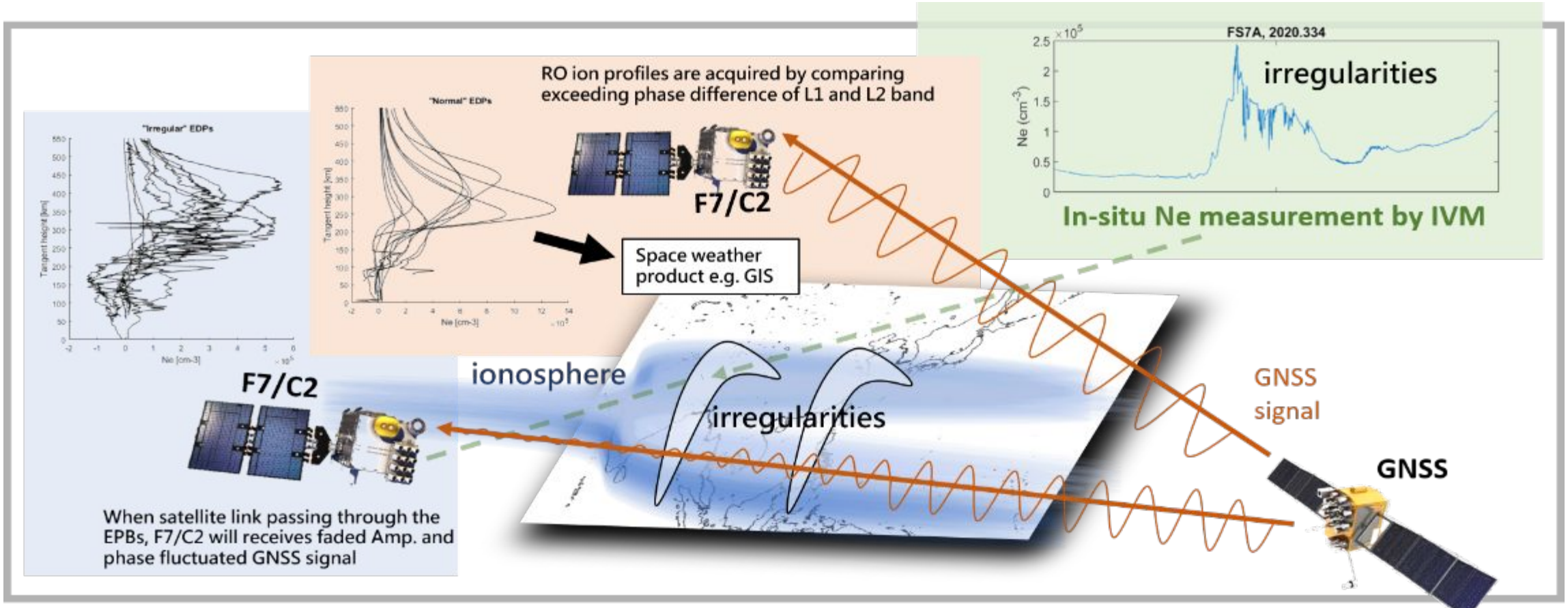
F-score = 0.928
Preci. = 0.954
Recall = 0.904
κ value = 0.858

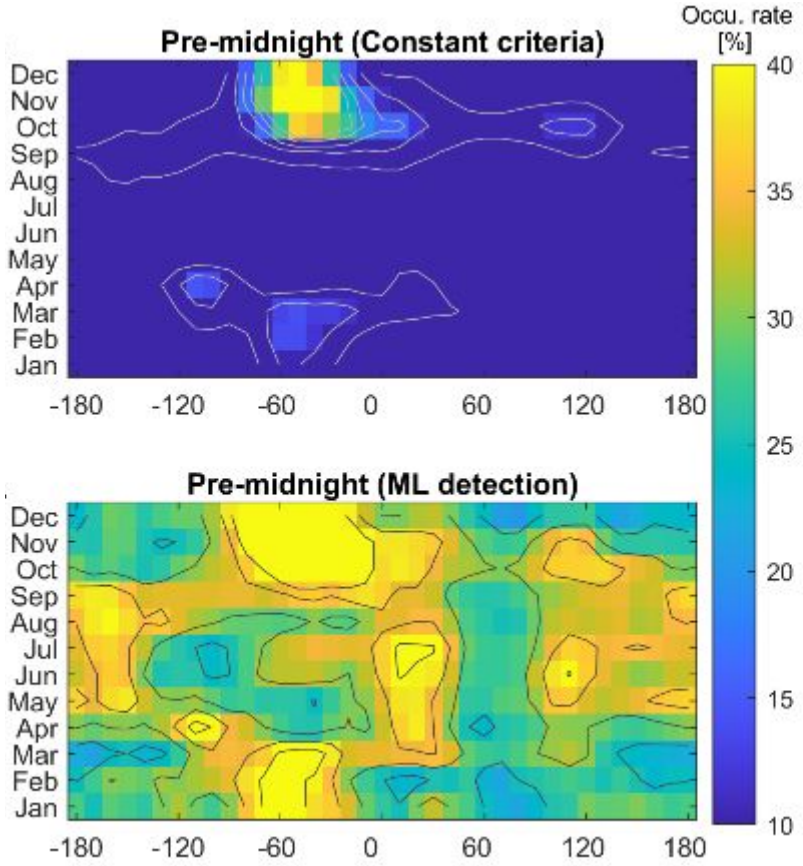
Post-midnight

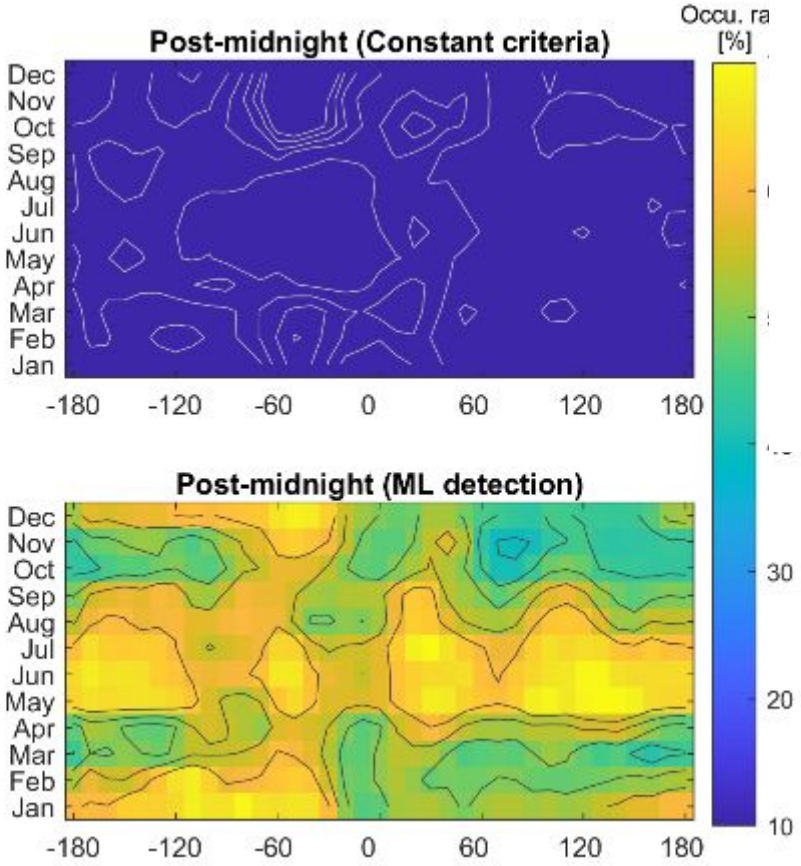
True Class \ Predicted Class	Norm.	Irreg.
Norm.	2460	212
Irreg.	121	2502

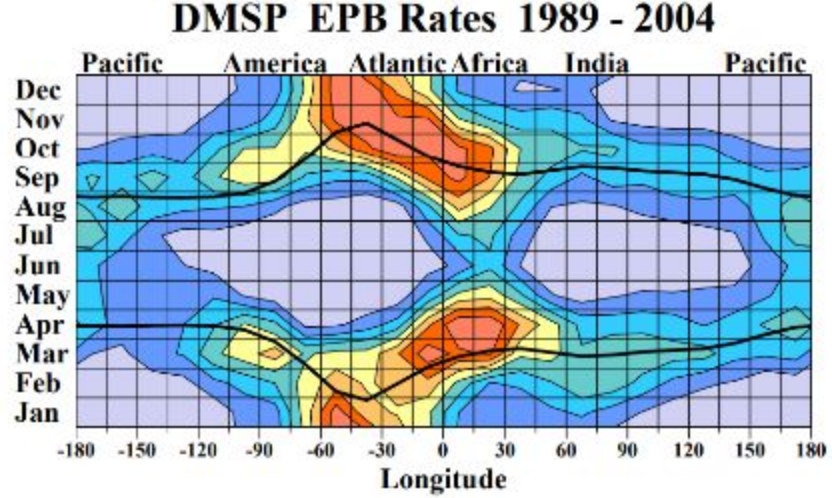
F-score = 0.934
Preci. = 0.953
Recall = 0.921
κ value = 0.874

Climatology results

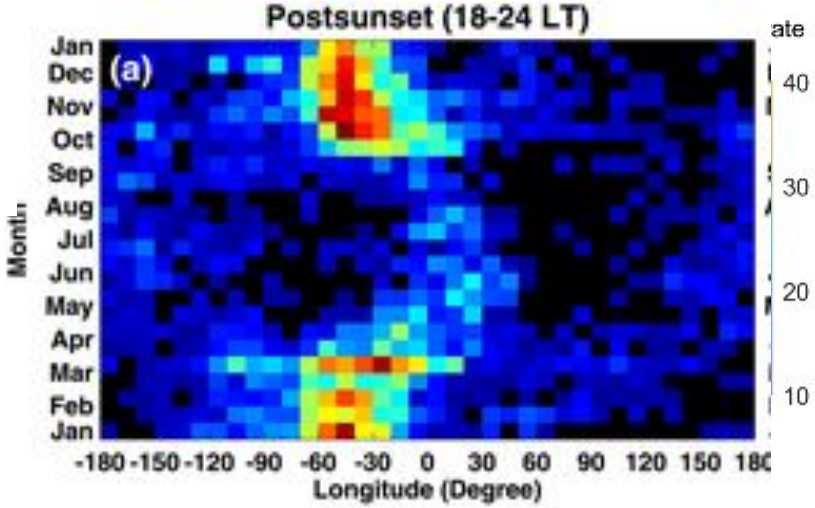


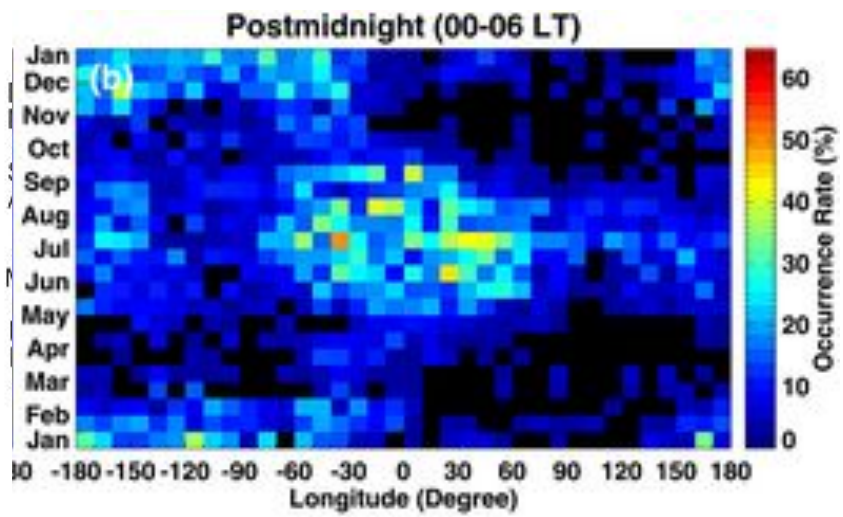






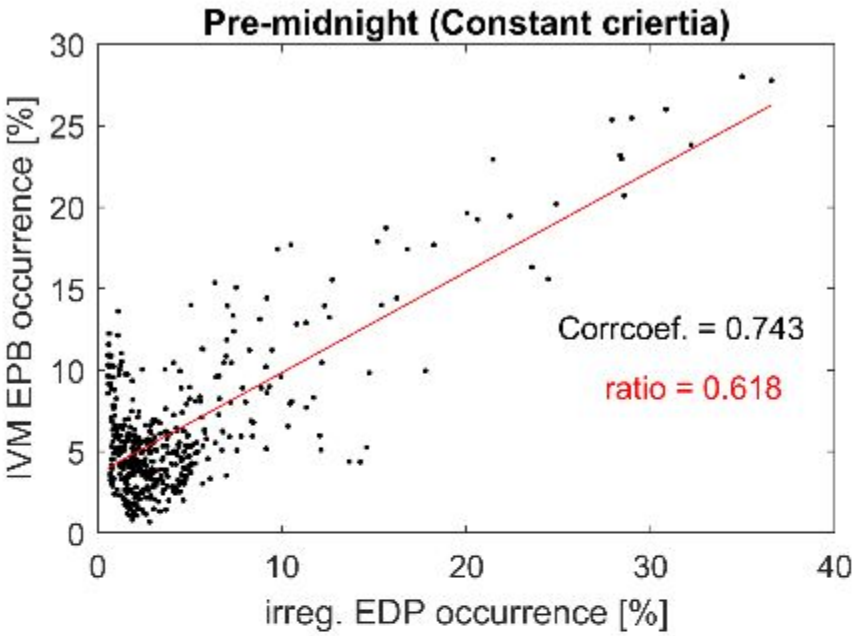
Gentile et al. [2006]

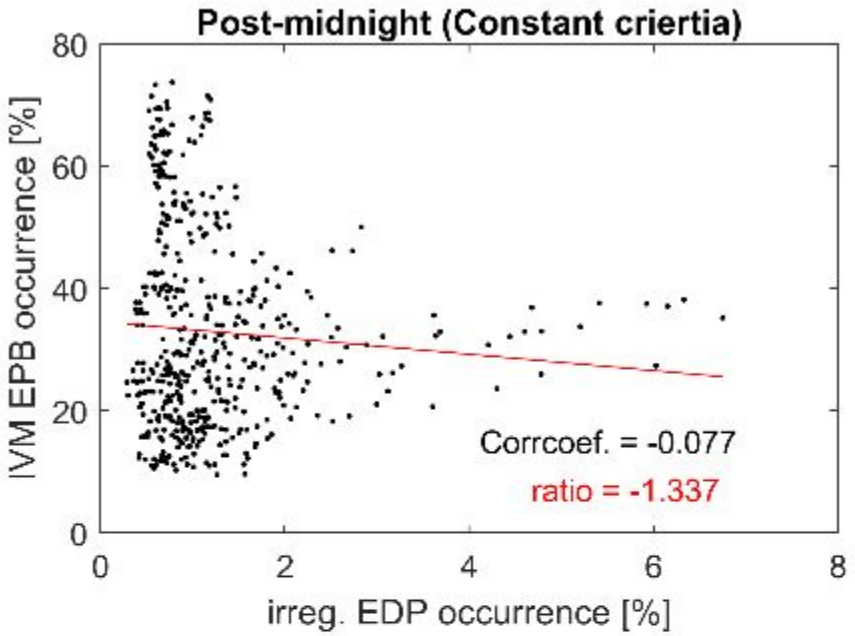


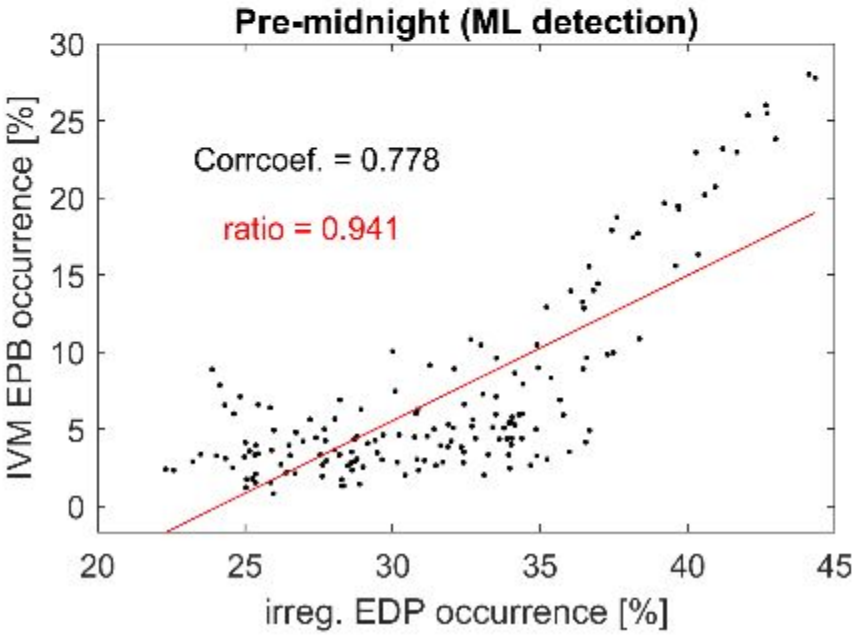


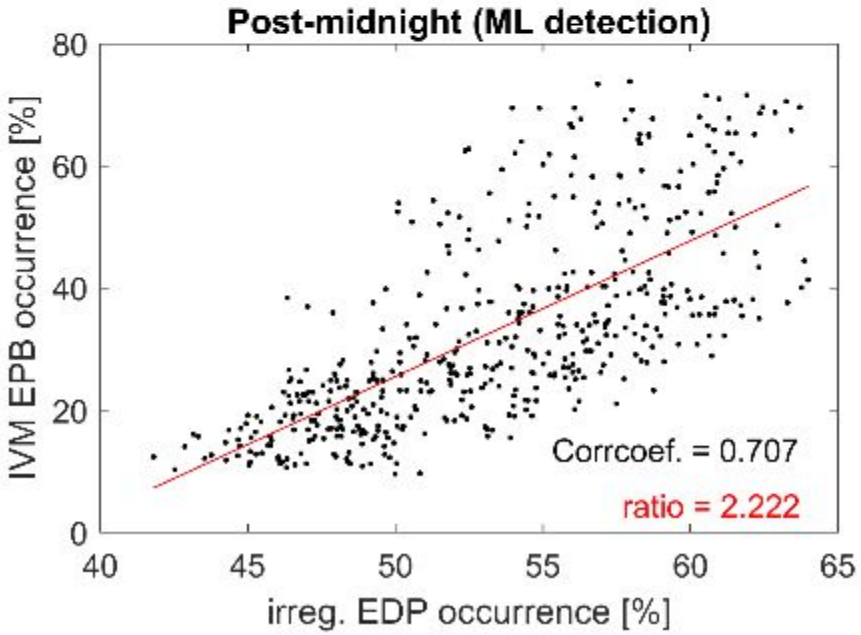
Swarm
2013-2019

Aa et al., [2020]


Pre-midnight (Constant criertia)
IVM EPB occurrence [%]
irreg. EDP occurrence [%]
Corrcoef. = 0.743
ratio = 0.618

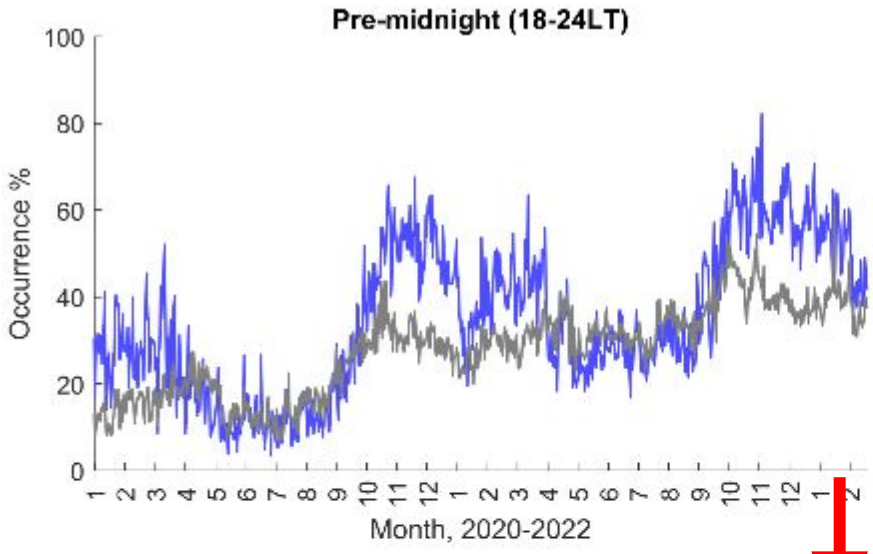

Post-midnight (Constant criertia)
IVM EPB occurrence [%]
irreg. EDP occurrence [%]
Corrcoef. = -0.077
ratio = -1.337

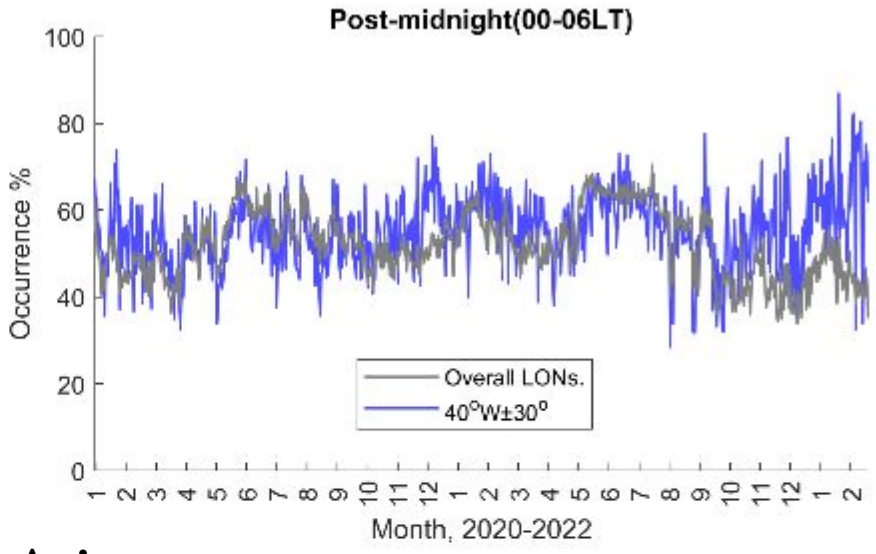

Pre-midnight (ML detection)
IVM EPB occurrence [%]
irreg. EDP occurrence [%]
Corrcoef. = 0.778
ratio = 0.941


Post-midnight (ML detection)
IVM EPB occurrence [%]
irreg. EDP occurrence [%]
Corrcoef. = 0.707
ratio = 2.222

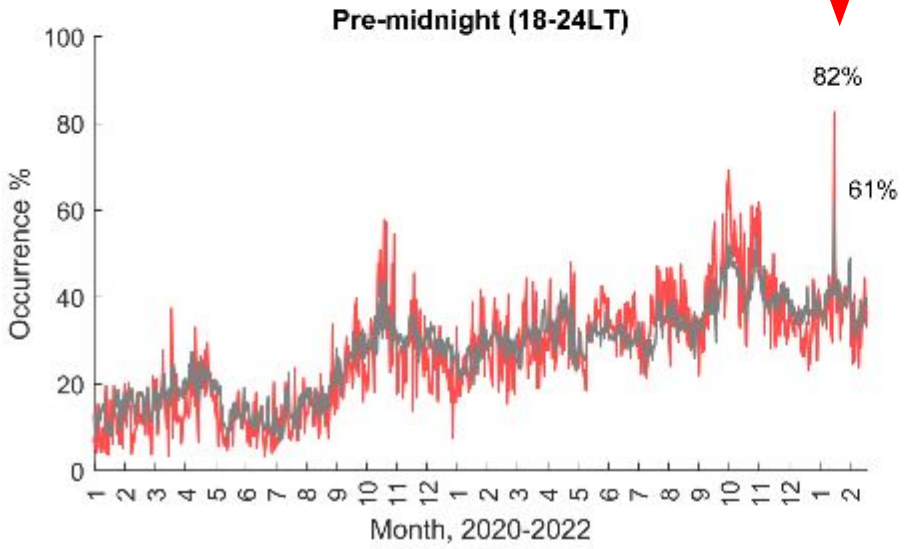
Climatology-2

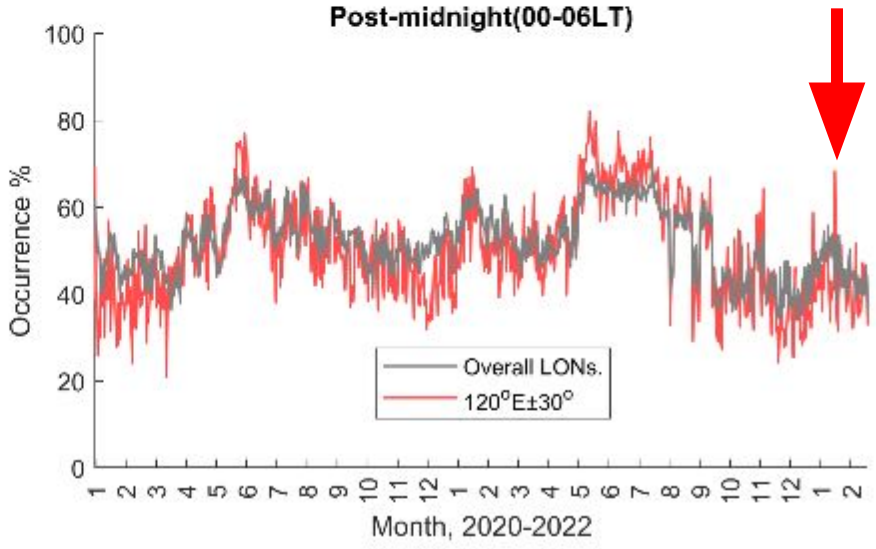
Atlantic





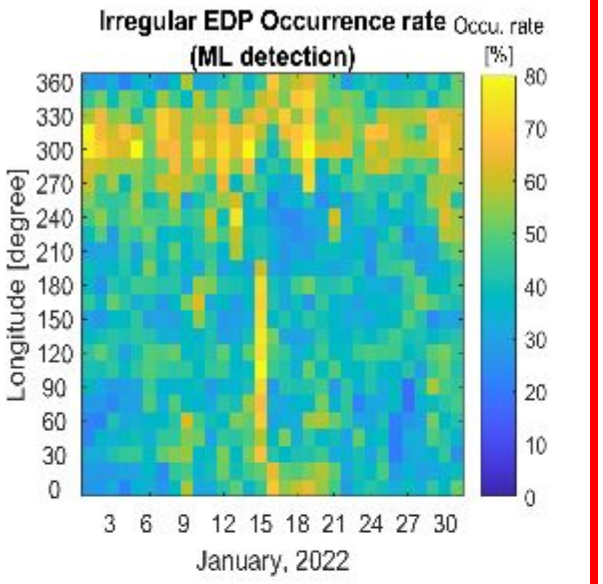
East Asia

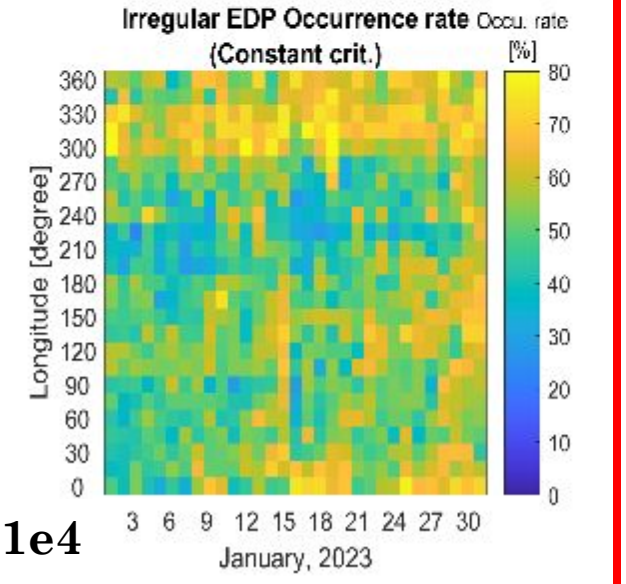




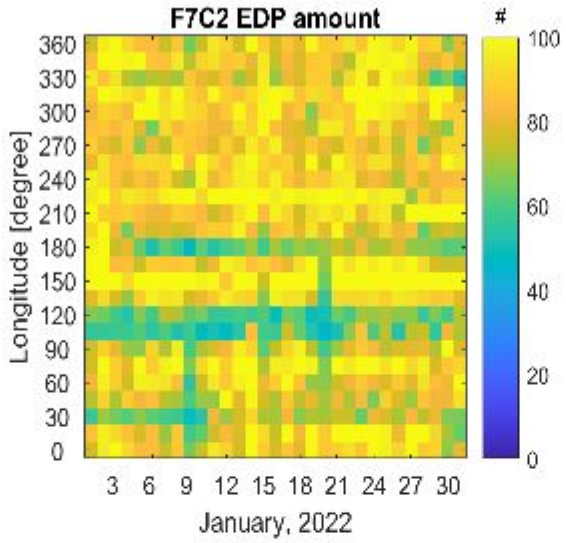
Curtesy: Tonga Geological Services

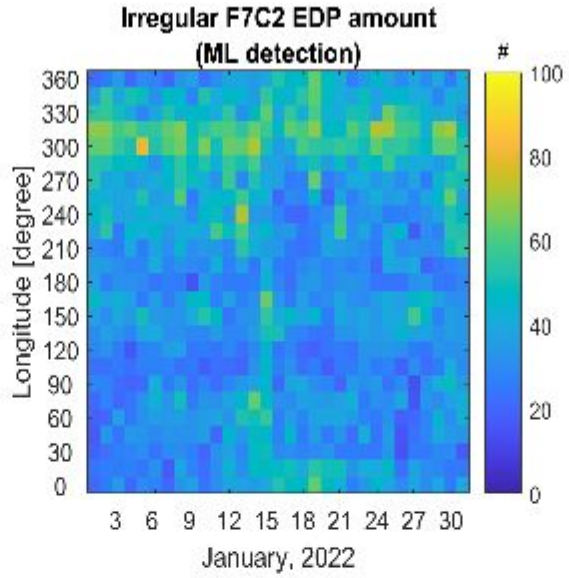
Japan Meteorological Agency

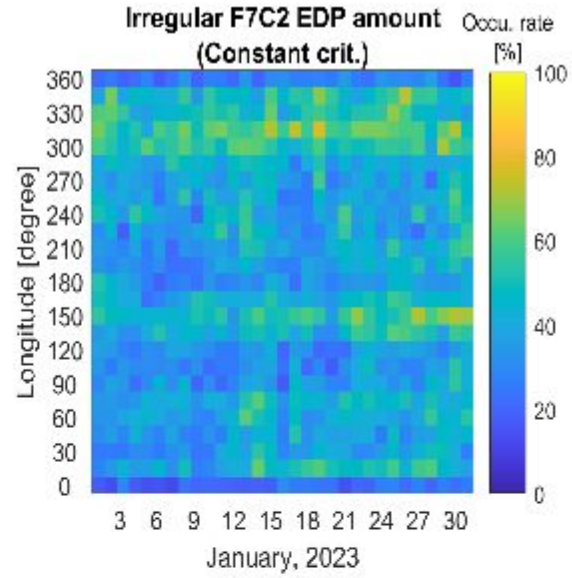


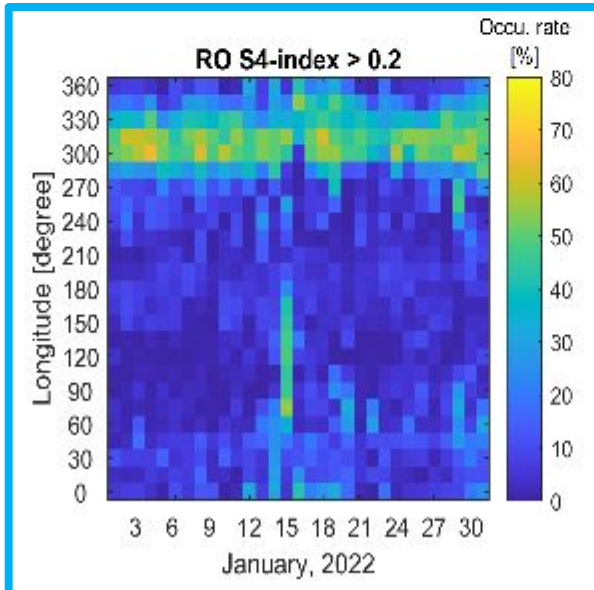


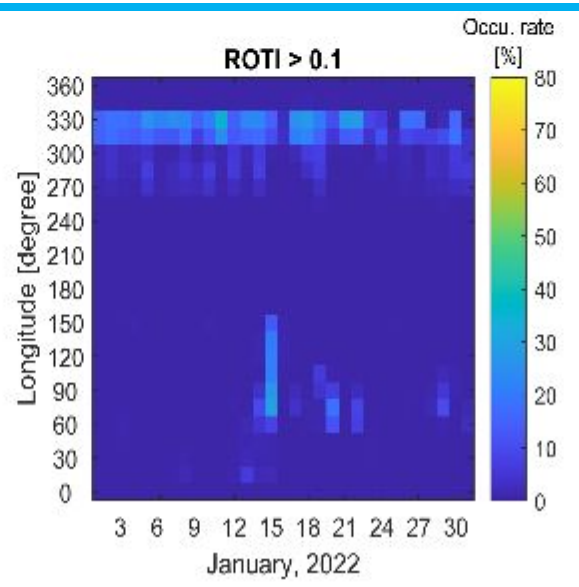
1e4

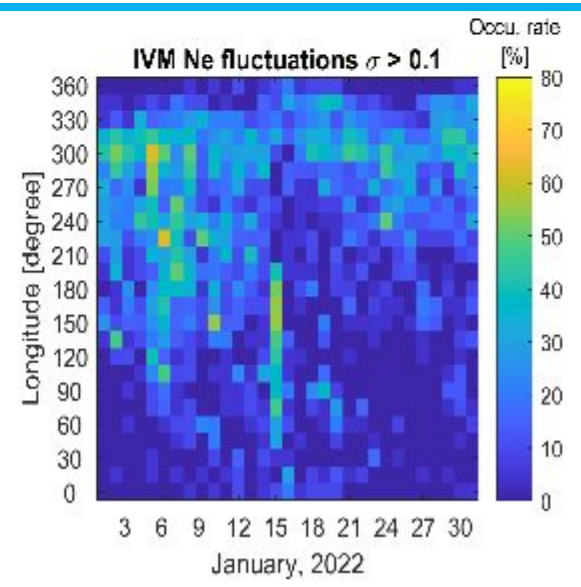






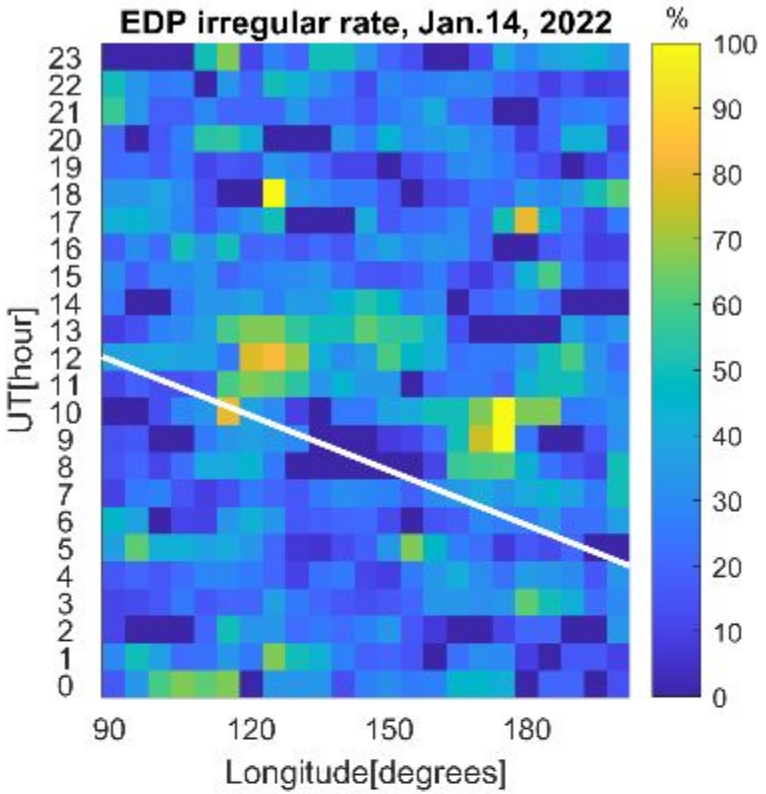


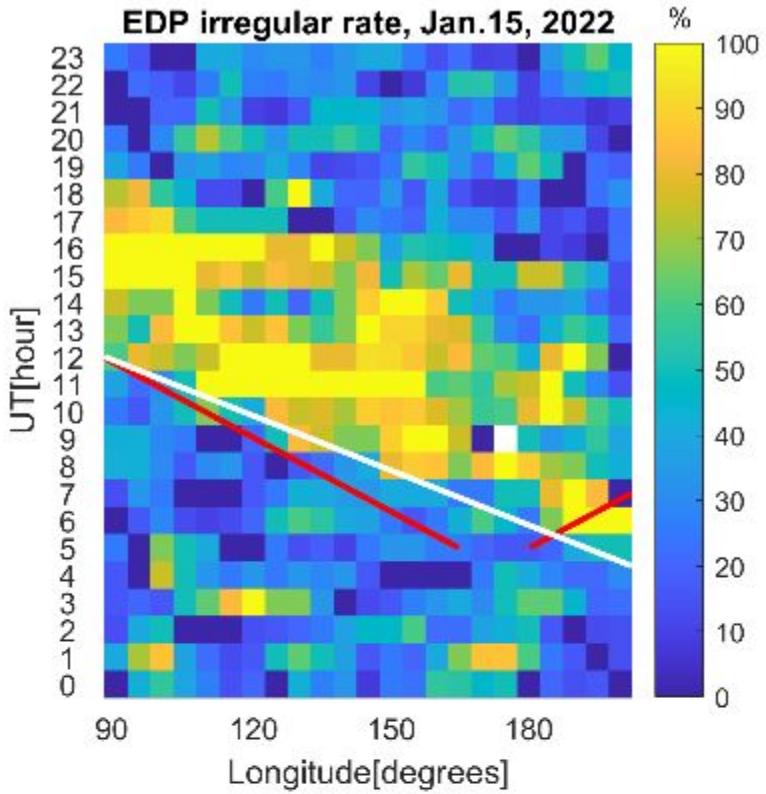


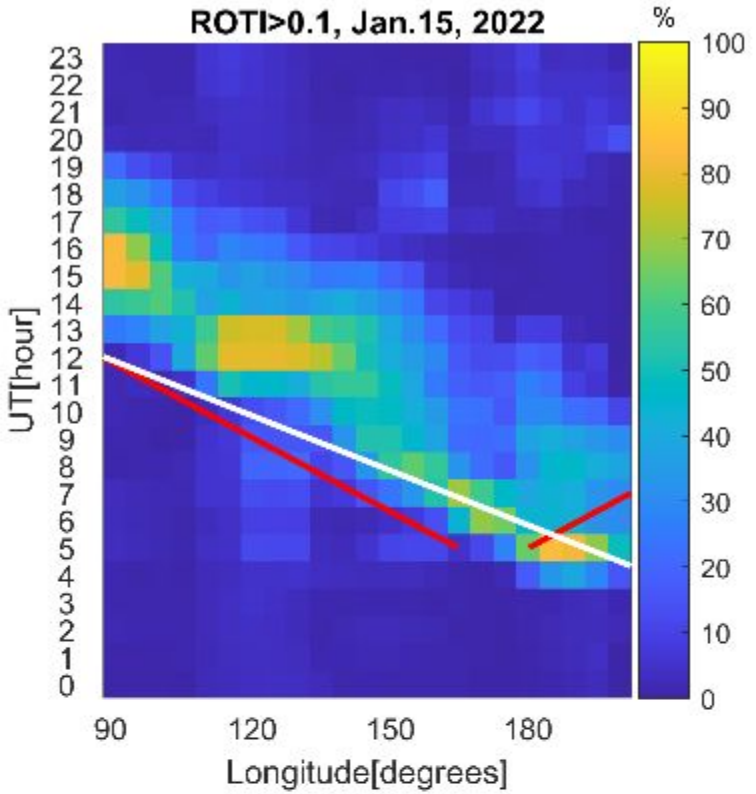


Tonga: 175E

The irregular EDPs occur after sunset terminator and lamb waves





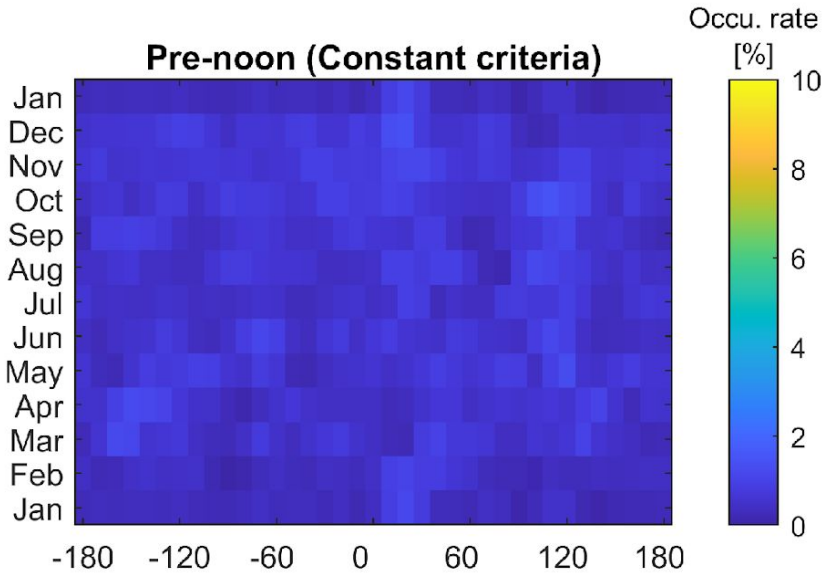


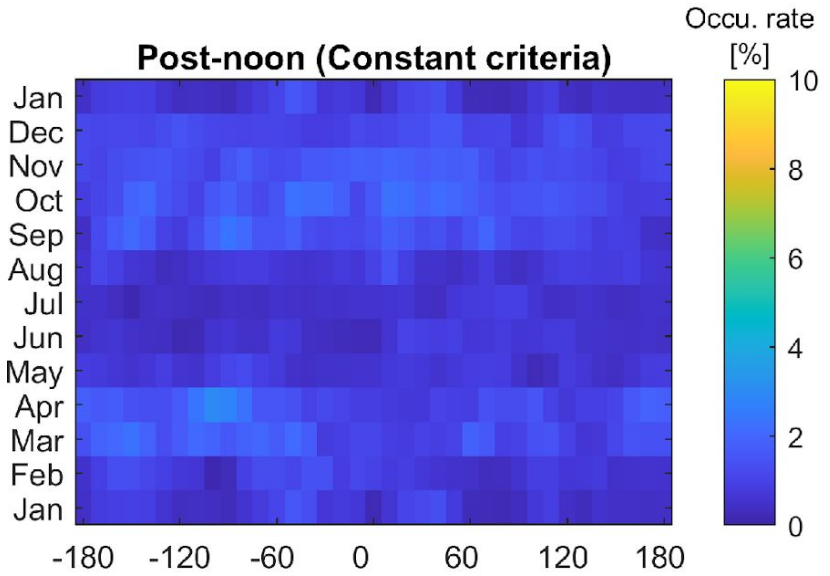
Tonga: 175E

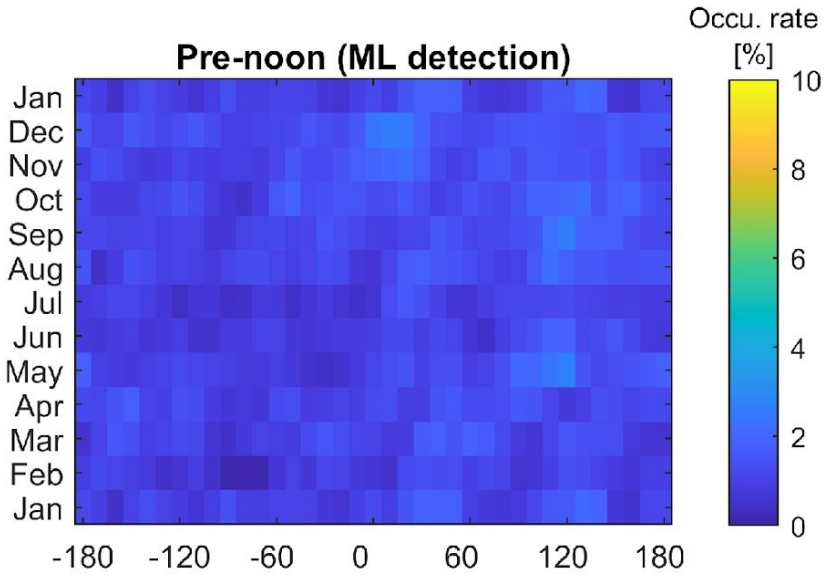
Conclusions

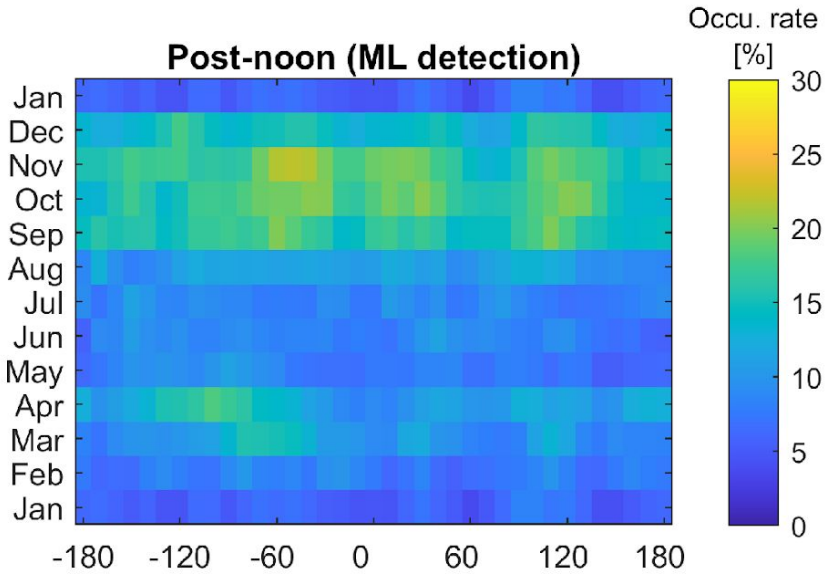
- The occurrence of irregular EDPs is unexpectedly high, indicating RO is highly sensitive to the plasma irregularities.
- The volcanic activity of Hunga Tonga-Hunga Ha'apai resulted in a significant occurrence of irregular EDPs. The intense surface events significantly disrupt the ionosphere and subsequently impacting RO observations.
- The chronological experiment observed the arrival time of eruption induced Lamb waves, sunset terminator, and the EDP irregular rate indicates that the major contribution of the irregular EDPs is the EPBs rather than the TIDs.
- The highly varying ionospheric conditions exhibit variability on diurnal, longitudinal, seasonal, solar activity, and day-to-day scales. The developed adaptive ML model can be utilized in operational settings to automatically identify poor-quality EDPs.
- The good agreement of the climatology comparison with independent assessments of EPB distribution in this study, which would consist various F7/C2 RO geometries, and its sensitiveness during the Mega Terrestrial Event, shows that geometry dependent effects do not impact the performance of the model. If future opportunities allow for the integration of observations from high inclination orbit satellites into the developed model, it can be applied to more complex missions.

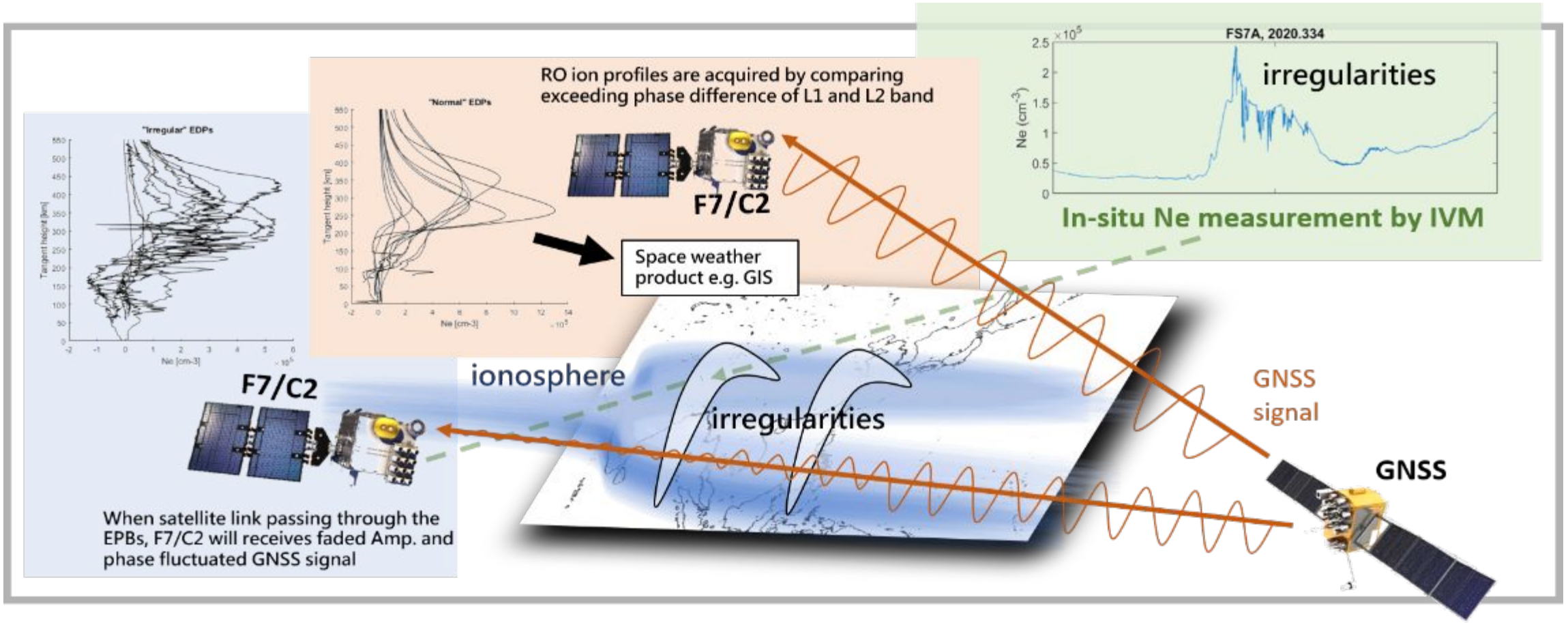
Credit:


Pre-noon (Constant criteria)
Occu. rate
[%]
Jan
Dec
Nov
Oct
Sep
Aug
Jul
Jun
May
Apr
Mar
Feb
Jan
-180 -120 -60 0 60 120 180
0 2 4 6 8 10


Post-noon (Constant criteria)
Occu. rate
[%]
Jan
Dec
Nov
Oct
Sep
Aug
Jul
Jun
May
Apr
Mar
Feb
Jan
-180 -120 -60 0 60 120 180
0 2 4 6 8 10


Pre-noon (ML detection)
Occu. rate
[%]
Jan
Dec
Nov
Oct
Sep
Aug
Jul
Jun
May
Apr
Mar
Feb
Jan
-180 -120 -60 0 60 120 180
0 2 4 6 8 10


Post-noon (ML detection)
Occu. rate
[%]
Jan
Dec
Nov
Oct
Sep
Aug
Jul
Jun
May
Apr
Mar
Feb
Jan
-180 -120 -60 0 60 120 180
0 5 10 15 20 25 30


"Irregular" EDPs
"Normal" EDPs
RO ion profiles are acquired by comparing exceeding phase difference of L1 and L2 band
F7/C2
Space weather product e.g. GIS
FS7A, 2020.334
irregularities
In-situ Ne measurement by IVM
ionosphere
irregularities
GNSS signal
GNSS
F7/C2
When satellite link passing through the EPBs, F7/C2 will receives faded Amp. and phase fluctuated GNSS signal

The irregular EDPs occur after sunset and lamb wave