PREDICTION OF THE IONOSPHERIC IRREGULARITIES OVER EGYPT USING GNSS OBSERVATIONS AND DEEP LEARNING

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UNOOSA
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Content:

1- Introduction

The ionosphere, a dynamic layer within Earth's atmosphere, harbors intricate phenomena that exert a profound influence on our contemporary technological infrastructure.

- **Ubiquitous Impact:**
  GNSS, satellite communications, and radio transmissions rely on the ionosphere, and etc.

- **Dynamic Nature:**
  Ionospheric irregularities result mainly from complex interactions with solar and geomagnetic activity.

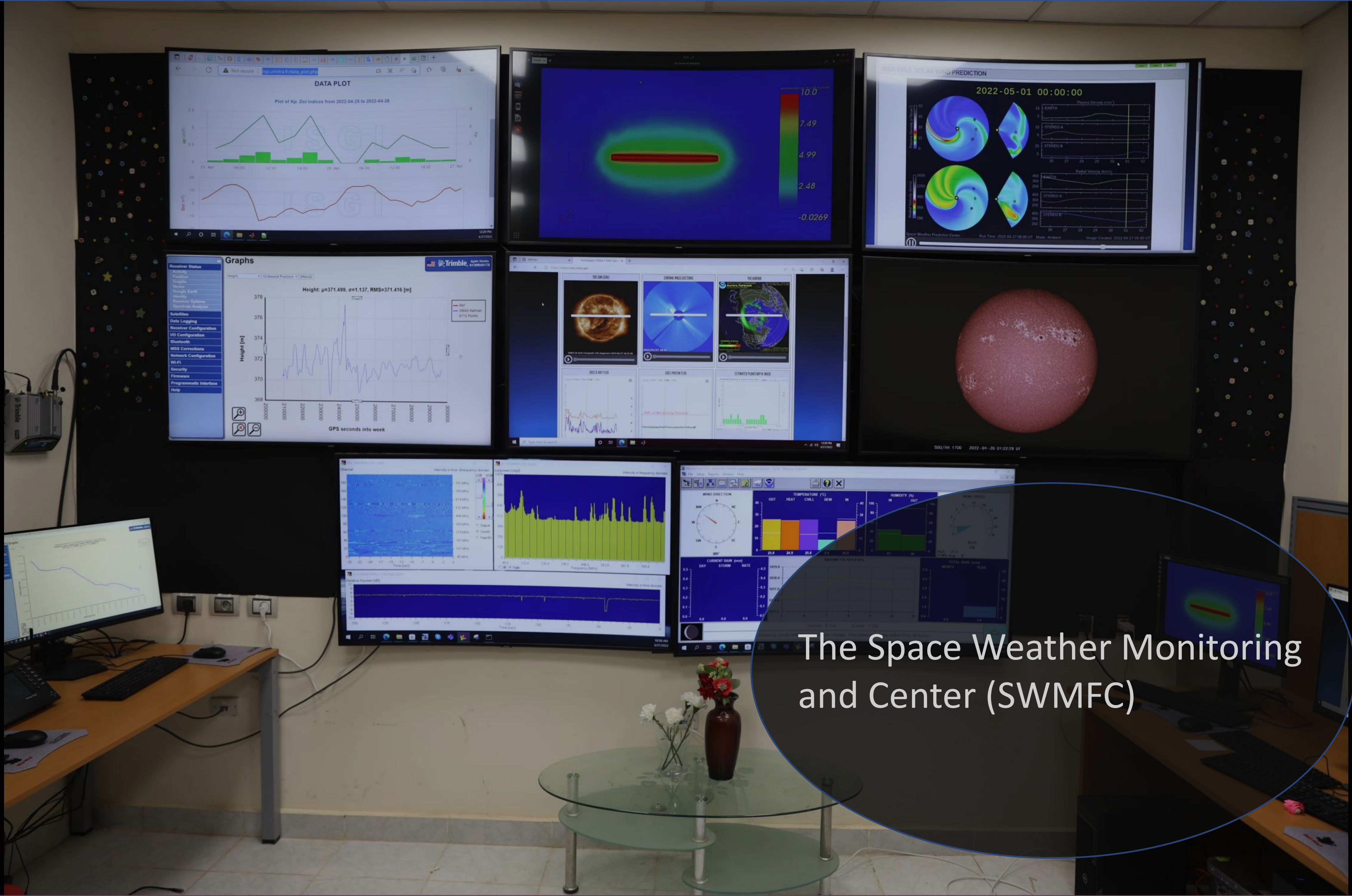
- **Unpredictable Consequences:**
  Irregularities can disrupt signal propagation, affect navigation accuracy, and endanger critical systems.

Understanding and predicting ionospheric irregularities is crucial for safeguarding our interconnected world.

The Impact of Ionospheric Irregularities on Satellites:

- Communication Disruptions
- Navigation Errors
- Payload Interference
- Satellite Health and Safety

Ionospheric irregularities pose significant challenges to satellite operations, communication, navigation, and scientific missions.
Understanding and mitigating the impact of these irregularities is crucial for enhancing the performance, reliability, and longevity of satellite systems and ensuring the continuity of services they provide.



The Space Weather Monitoring and Center (SWMFC)

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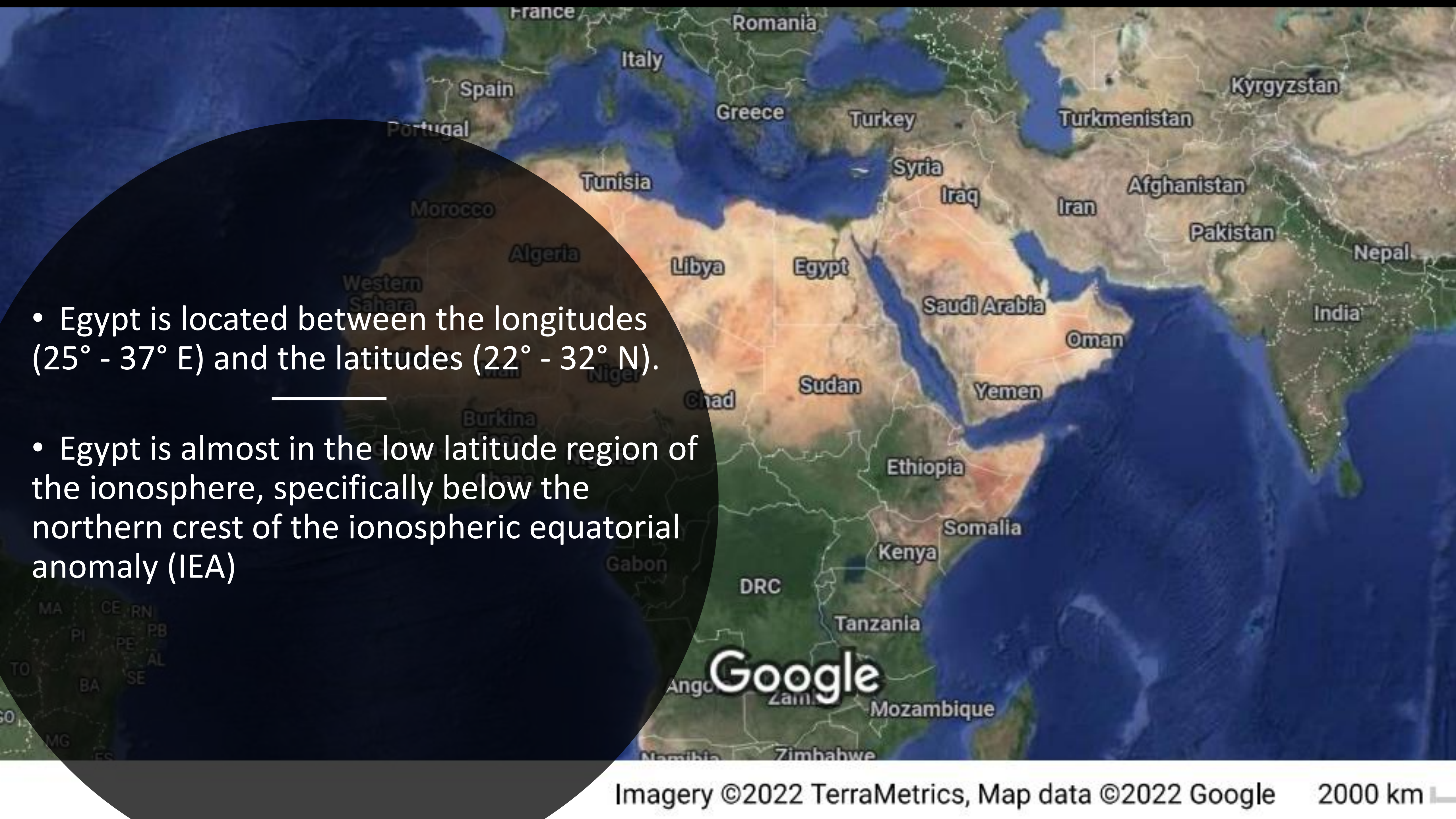
- Egypt is located between the longitudes (25° - 37° E) and the latitudes (22° - 32° N).

- Egypt is almost in the low latitude region of the ionosphere, specifically below the northern crest of the ionospheric equatorial anomaly (IEA)



- The Middle East suffers from a shortage of ionospheric observation data due to the lack of monitoring stations. This explains the scarcity of published research on the ionosphere over Egypt.

- Although the IGS network does not display any stations in Egypt, some previous studies relied on data from a few old stations in some Egyptian universities.

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The Ground GNSS Network

Image Credits: NASA

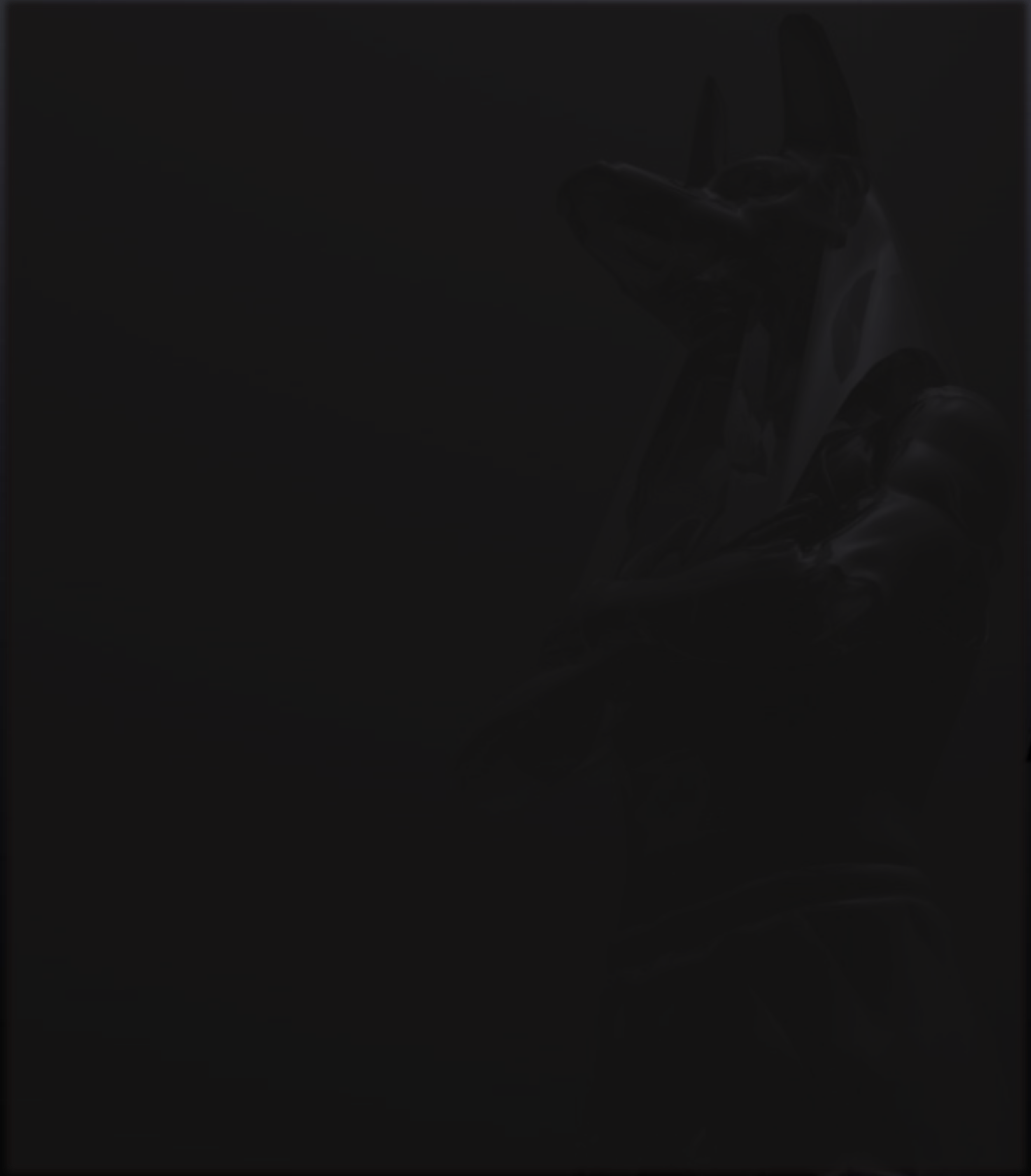
Available Reference Stations

ADFO
ADWH
ALEX
ALMN
ASHM
ASOF
AYAT
BADR
BLTM
BNHA
BORG
CARO
DBAA
DKRN
DMNH
DOMT
ETSA
FAYD
GHNM
HMOL
ISML
ISNA
KBER
KRKS
LXOR

Objective:

The primary aim of this research is to leverage deep learning techniques and artificial neural networks to construct a predictive model that captures and forecasts ionospheric irregularities over Egypt.

This model incorporates GNSS observations from both ground-based and space-based equipment (Vertical Total Electron Content VTEC), as well as geomagnetic parameters (Kp-index, VSW, Bz, Dst).



Methodology

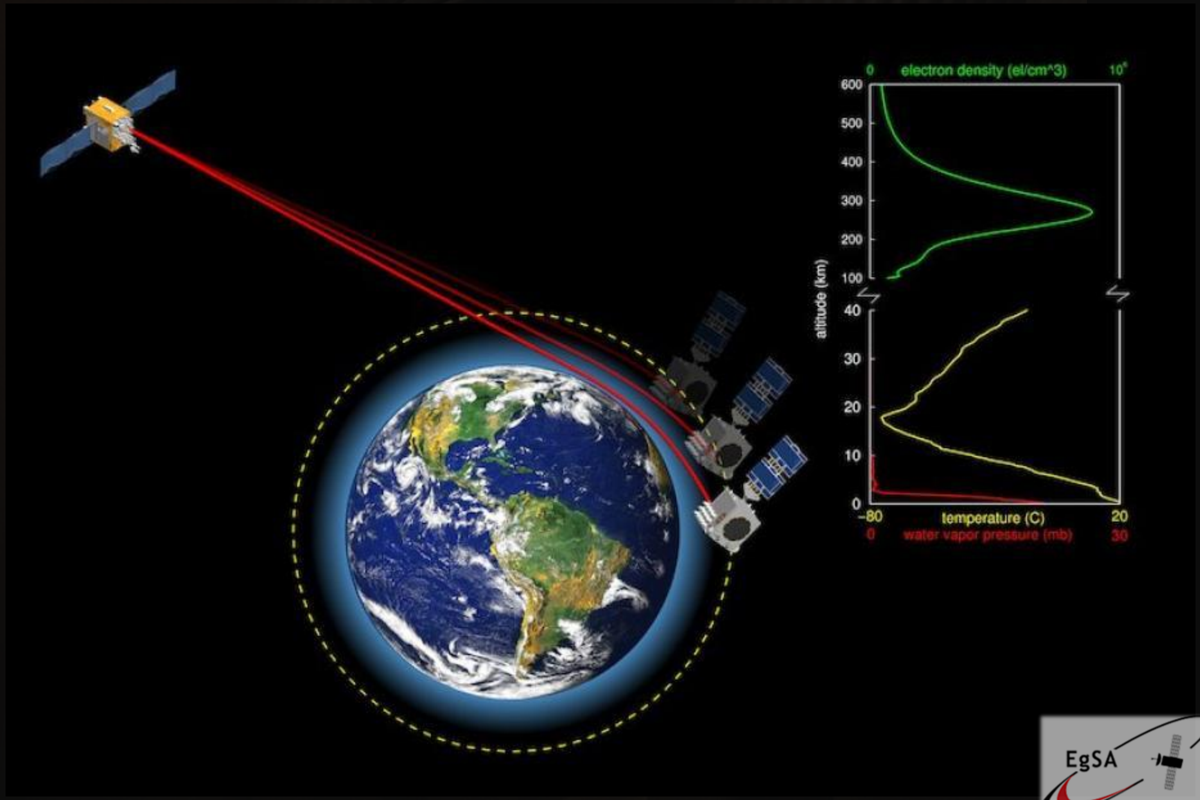
Data acquisition:

- In the first stage, we worked on data from Jan 2022 to May 2023.

- Gathered GNSS data from selected ground stations in Egypt, we selected 10 stations spread across Egypt.

- Incorporated satellite measurements from COSMIC2 in areas where ground data was unavailable.

- Download Geomagnetic indices and solar wind parameters data from the OMNIWEB data center.



Preprocessing:

- VTEC was driven from the Ground GNSS data using the GPS-TEC program (developed by Gopi Seemala).

- VTEC from the COSMIC2 was obtained by integrating the electron density profile.

- a calibration method needed because the COSMIC-VTEC and Ground VTEC are calculated using different algorithms so the absolute value of VTEC is different between them.

- using the Ground-VTEC and the calibrated COSMIC-VTEC with some geomagnetic indices to train the deep neural network.

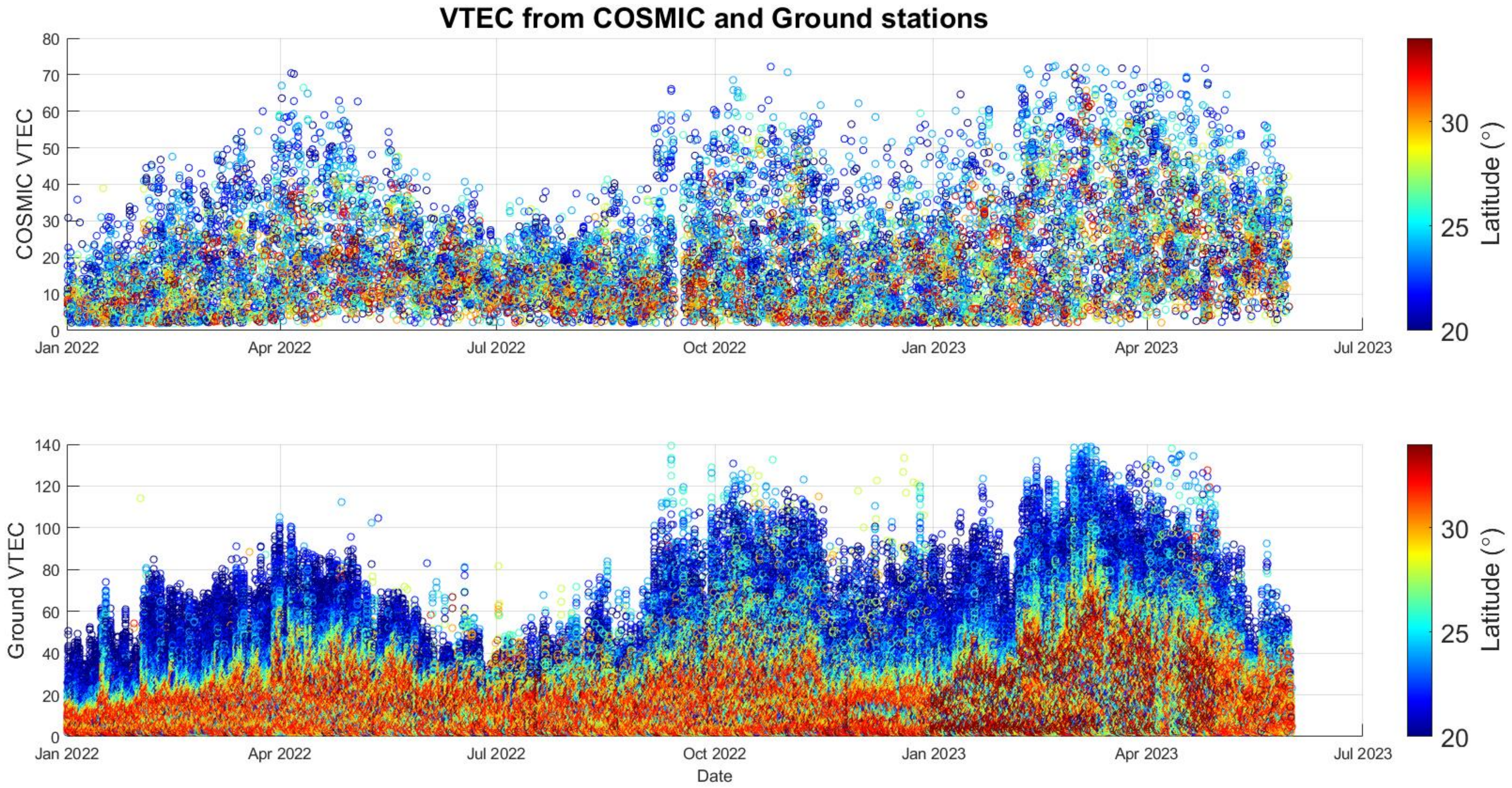
Calibrating COSMIC-VTEC:

- We followed a method similar to what (S. Shi et al, 2022) did, with some differences

- COSMIC-TEC was matched spatially and temporally with GNSS ground station data.

- The derived VTEC from COSMIC-2 and the GNSS ground stations were considered spatially co-located if the tangent point of the peak density for a COSMIC-2 RO profile was within 2 latitude and 2 longitude of the ground stations.

- The COSMIC-2 TEC and ground-based GPS-TEC were temporally co-located if their times were within 5 min.


VTEC from COSMIC and Ground stations
COSMIC VTEC
Ground VTEC
Date
Jan 2022
Apr 2022
Jul 2022
Oct 2022
Jan 2023
Apr 2023
Jul 2023
Latitude (°)
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The neural network in the provided code has the following details:

Training set ratio: 85% (trainRatio = 0.85)

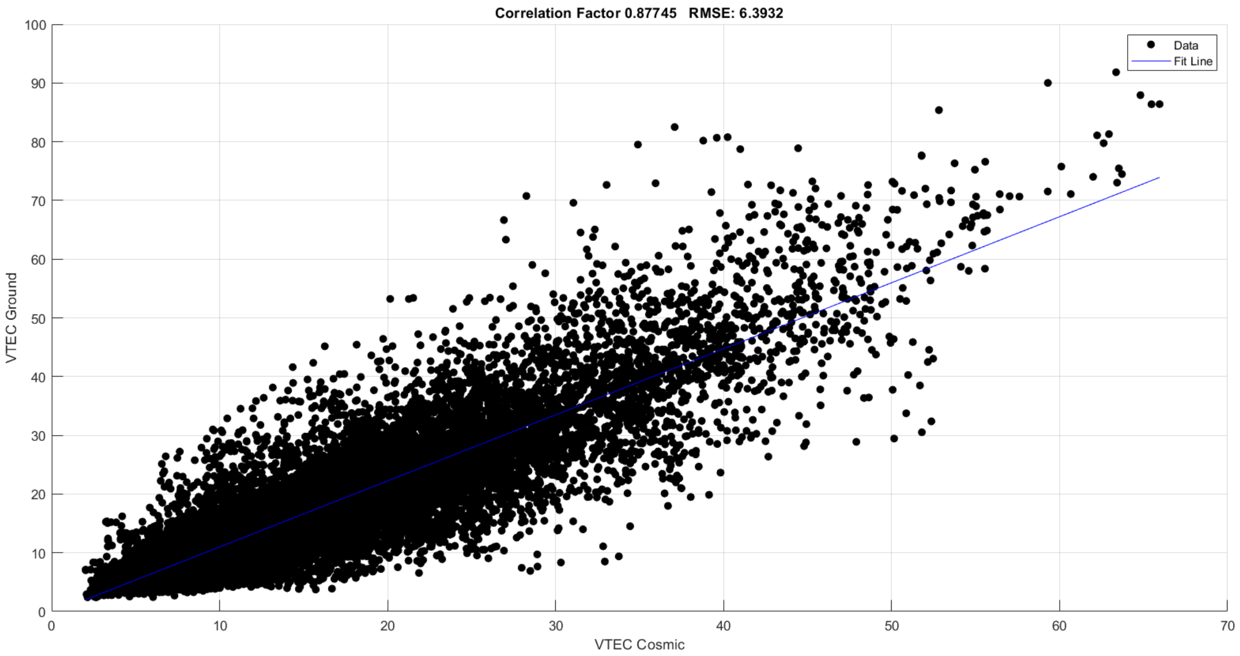
Testing set ratio: 15% (testRatio = 1 - trainRatio)

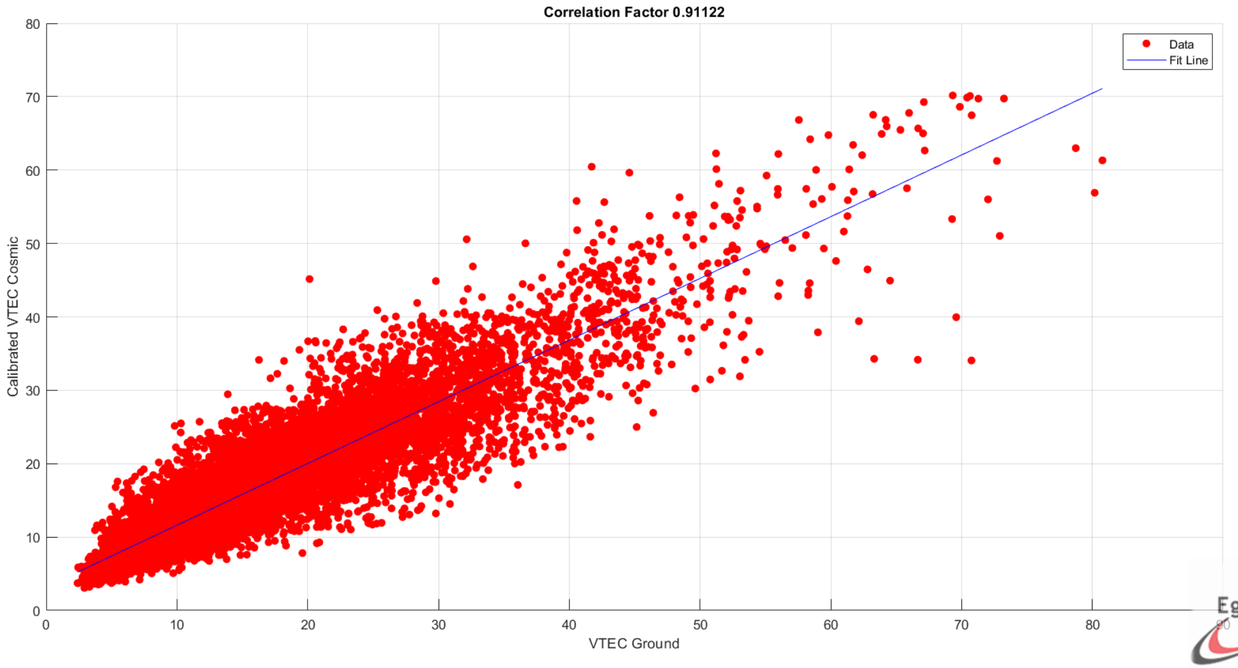
Training options: The network is trained using the Adam optimizer

Neural network architecture:

- Accepts sequences of length 4 (sequenceInputLayer(4)).
- Fully connected layer:
- ReLU layer: Applies rectified linear unit activation function (reluLayer()).
- Regression layer

The correlation coefficient between COSMIC-TEC and Ground-TEC is 0.87 before and 0.91 after calibration.





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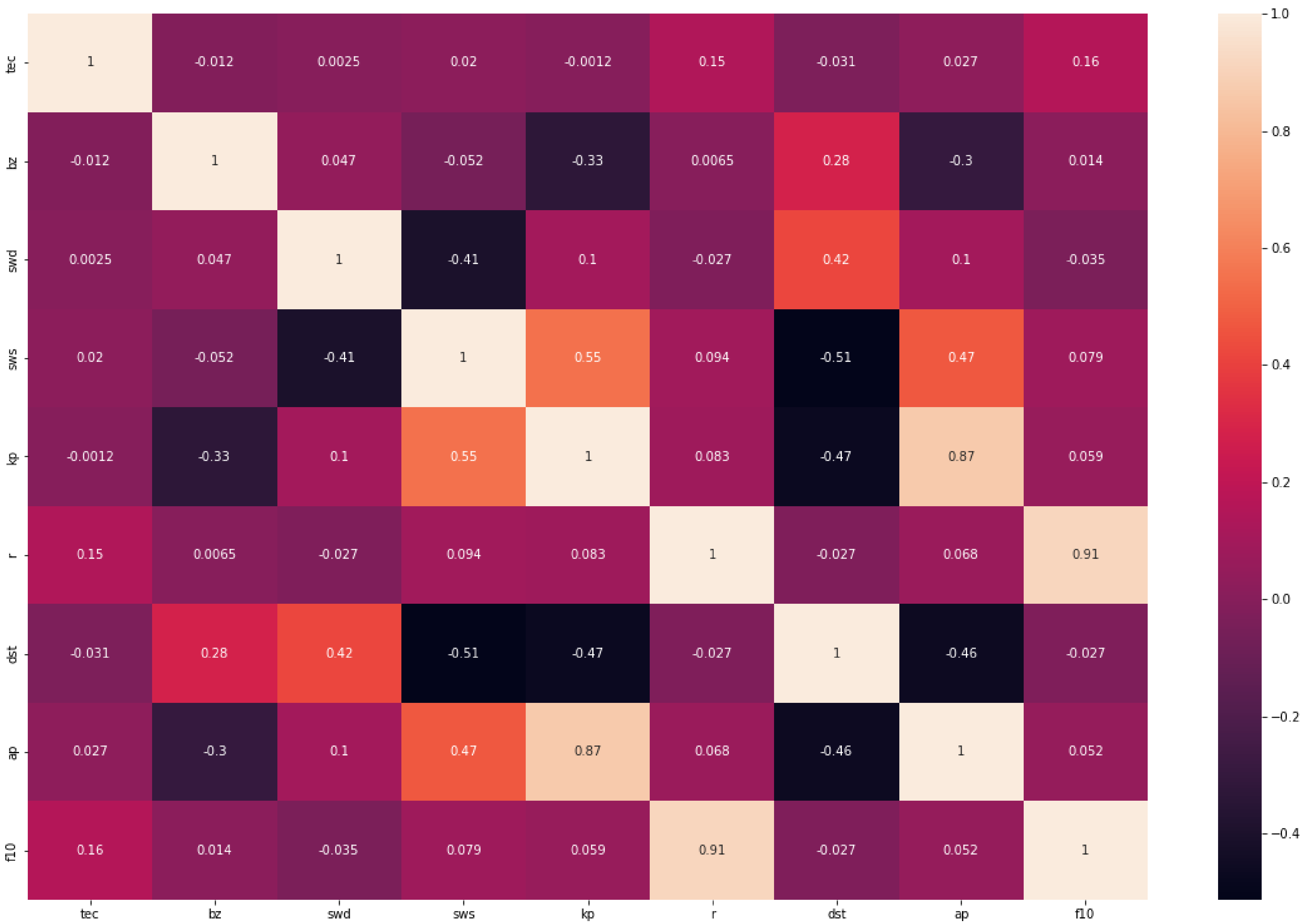
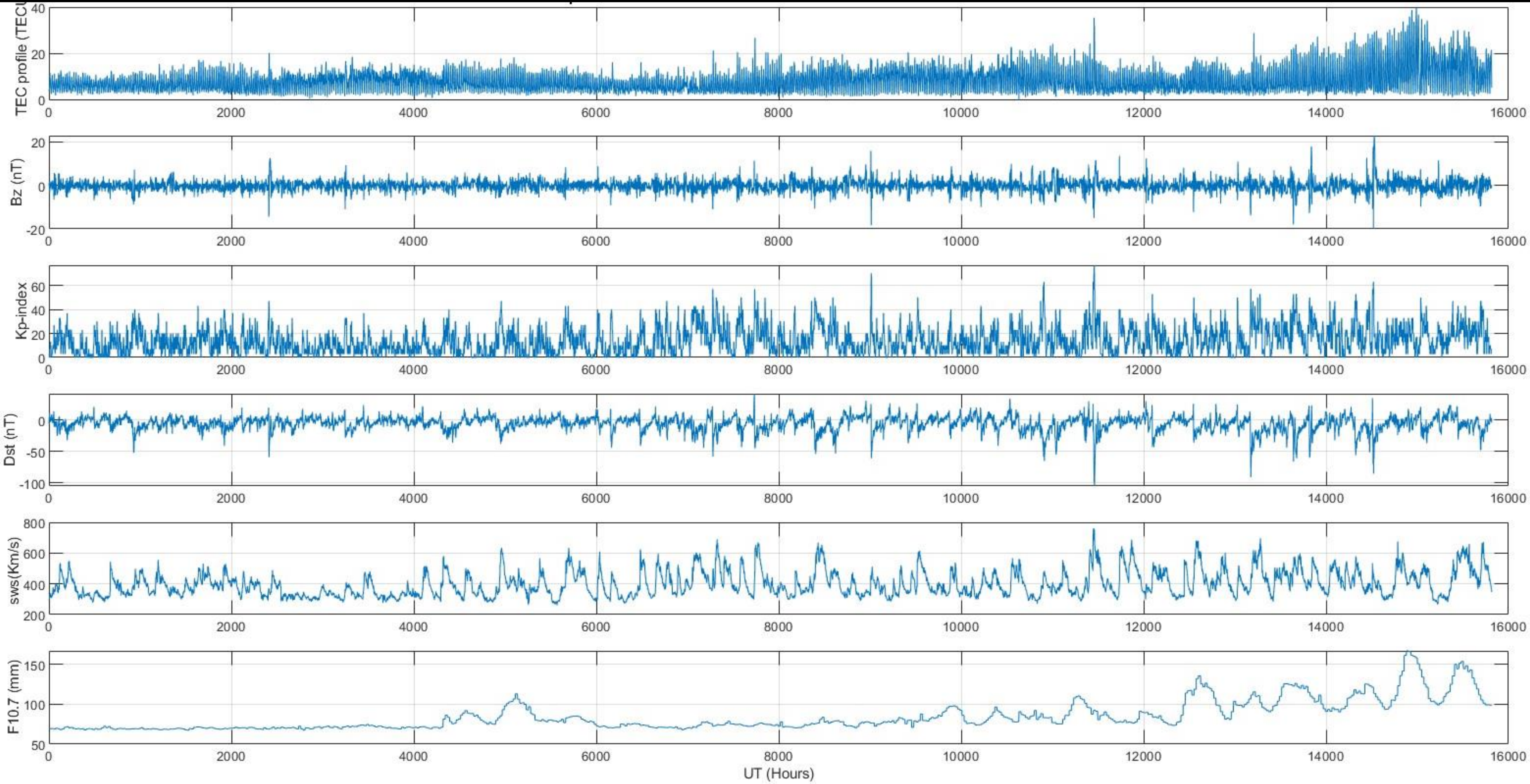
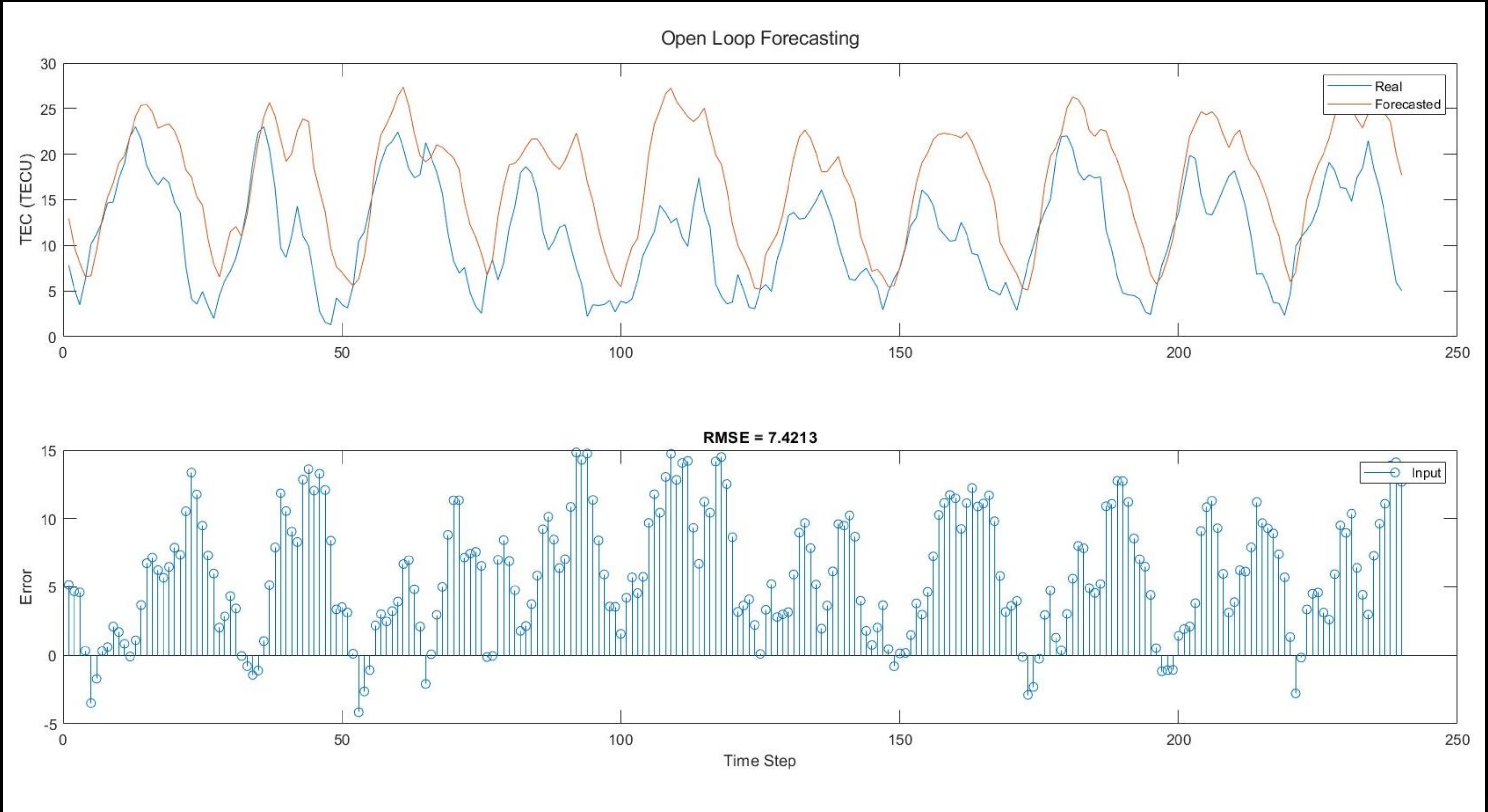
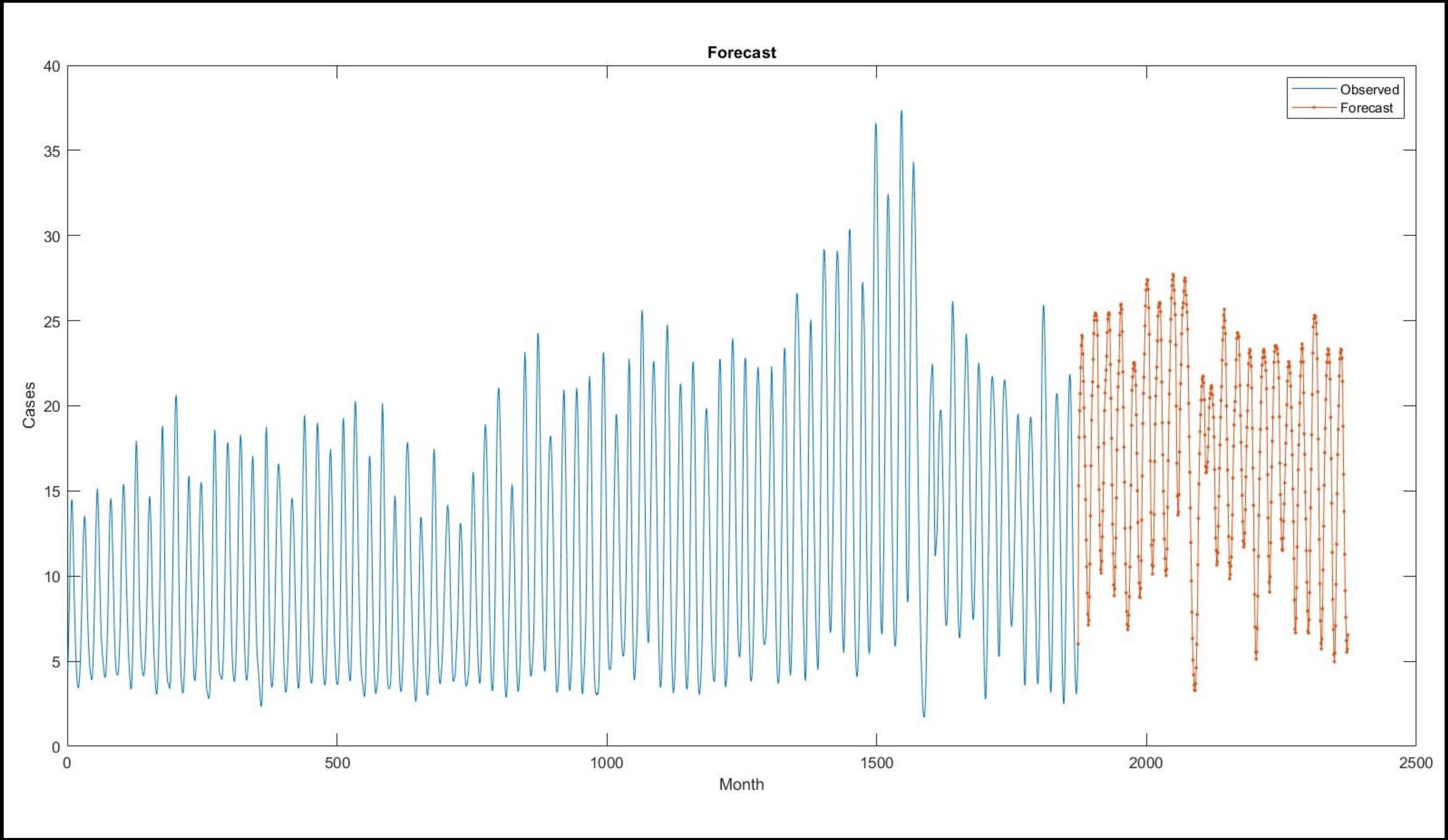

tec
bz
swd
sws
kp
r
dst
ap
f10
1 -0.012 0.0025 0.02 -0.0012 0.15 -0.031 0.027 0.16
-0.012 1 0.047 -0.052 -0.33 0.0065 0.28 -0.3 0.014
0.0025 0.047 1 -0.41 0.1 -0.027 0.42 0.1 -0.035
0.02 -0.052 -0.41 1 0.55 0.094 -0.51 0.47 0.079
-0.0012 -0.33 0.1 0.55 1 0.083 -0.47 0.87 0.059
0.15 0.0065 -0.027 0.094 0.083 1 -0.027 0.068 0.91
-0.031 0.28 0.42 -0.51 -0.47 -0.027 1 -0.46 -0.027
0.027 -0.3 0.1 0.47 0.87 0.068 -0.46 1 0.052
0.16 0.014 -0.035 0.079 0.059 0.91 -0.027 0.052 1
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4

f10	ap	dst	r	kp	sws	swd	bz	tec	long	lat
69.5	4	-3	12	10	456	3.9	1.8	3.484512	33.5458	29.8675
69.5	4	-5	12	10	460	3.9	-0.8	2.782071	34.54197	31.52601
69.5	4	-4	12	10	459	4	2	2.462509	35.29519	30.21448
69.5	5	-2	12	13	453	4.5	2.7	2.635067	33.85051	29.85668
69.5	5	1	12	13	446	5.2	0.1	3.300737	32.68341	30.79458
69.5	5	-3	12	13	438	4.6	-3.2	5.414262	34.03853	30.23862
69.5	12	-6	12	27	433	4.3	-3.2	7.505308	34.44379	30.95994
69.5	12	-12	12	27	430	4.3	-3.1	9.464362	33.01697	29.84205
69.5	12	-17	12	27	423	4.7	-3.5	11.09596	33.03872	30.08751

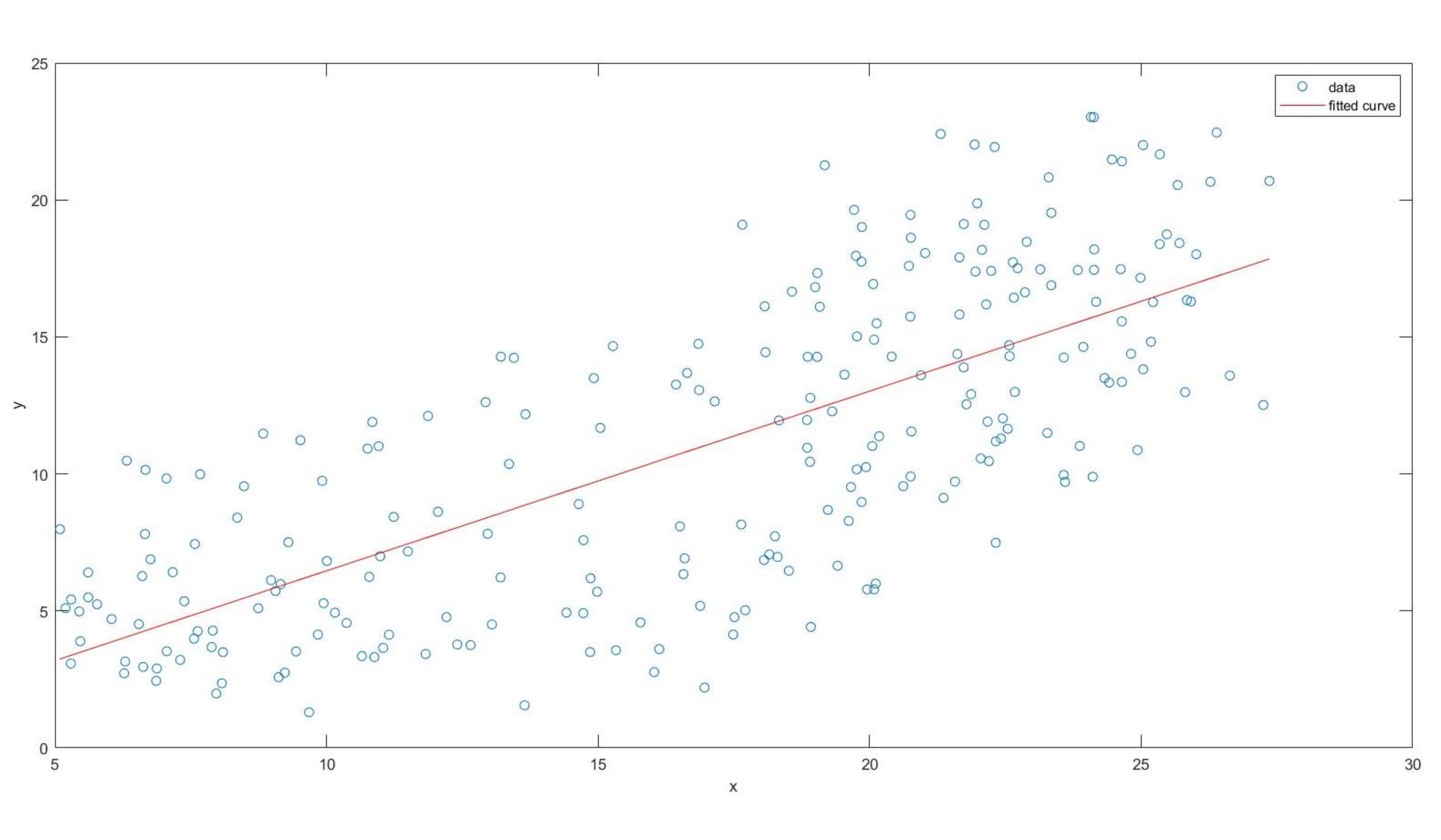

TEC profile (TECU)
0
20
40
Bz (nT)
-20
0
20
Kp-index
0
20
40
60
Dst (nT)
-100
-50
0
sws(Km/s)
200
400
600
800
F10.7 (mm)
50
100
150
0
2000
4000
6000
8000
10000
12000
14000
16000
UT (Hours)



Open Loop Forecasting
TEC (TECU)
Real
Forecasted
RMSE = 7.4213
Error
Input
Time Step



Forecast
Observed
Forecast
Cases
Month
0
5
10
15
20
25
30
35
40
0
500
1000
1500
2000
2500



data
fitted curve
y
x

6- Conclusion

- In conclusion, our study utilized ground stations distributed across various regions in Egypt, providing comprehensive coverage for data collection.
- Additionally, cosmic data was incorporated, although it accounted for only 12% of the total data used in our analysis.
- It is worth noting that further improvements are required in calibrating the cosmic data to enhance its accuracy and reliability. This could involve expanding the data collection to longer periods and larger geographic areas.
- As for future work, we aim to incorporate an extended dataset spanning a duration of three years. By incorporating more data.
- As Neural Networks are time consuming, we anticipate building a more robust and reliable prediction model based on more accurate techniques.
- Overall, our study highlights the significance of ground stations in providing valuable data for ionospheric analysis in Egypt.

- We acknowledge UCAR data center for COSMIC2 data, Gopi Seemala for using his GPS-TEC, and OMNIweb data center for the Geomagnetic indices program.

Thank You

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