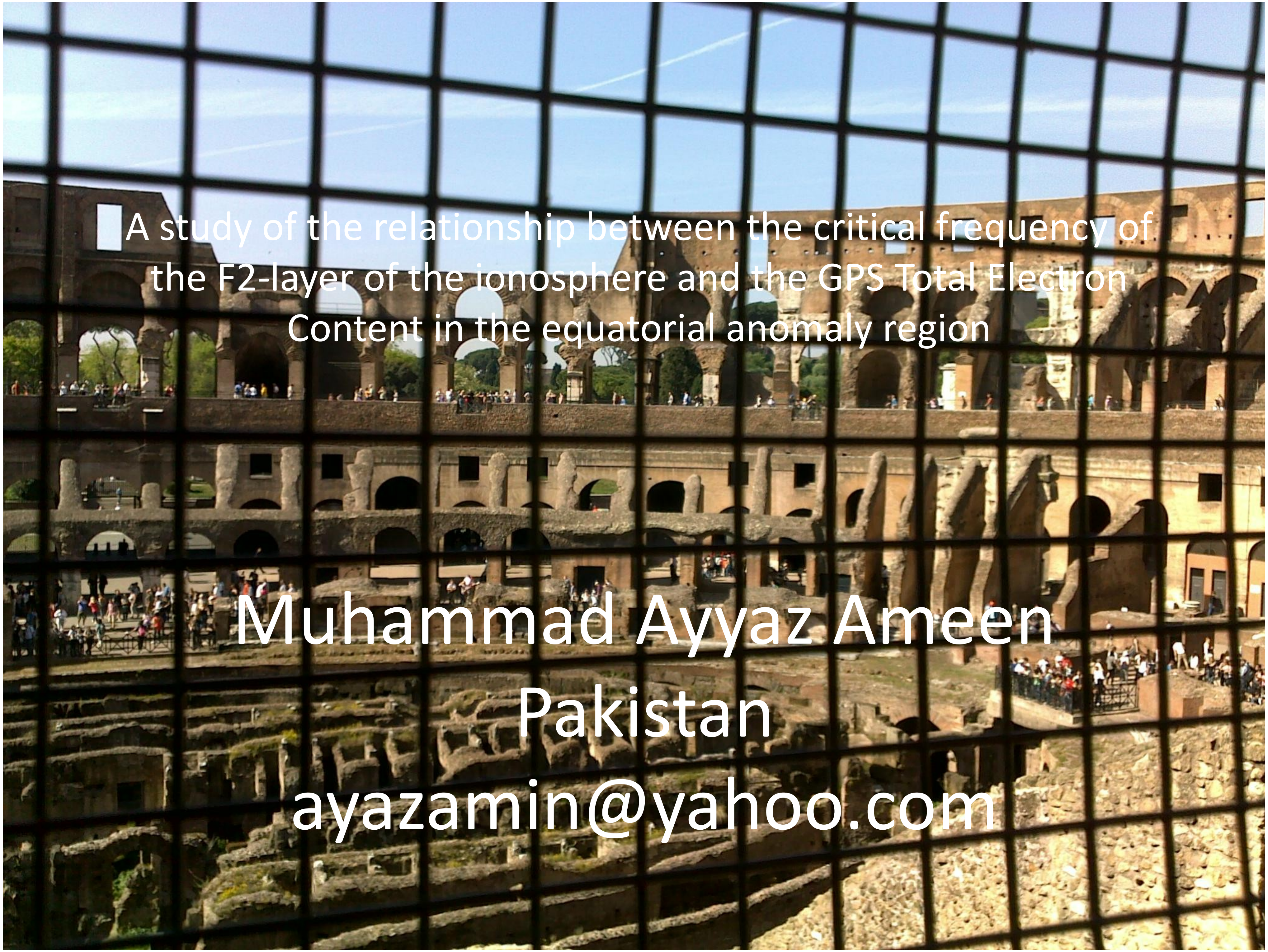

A study of the relationship between the critical frequency of the F2-layer of the ionosphere and the GPS Total Electron Content in the equatorial anomaly region

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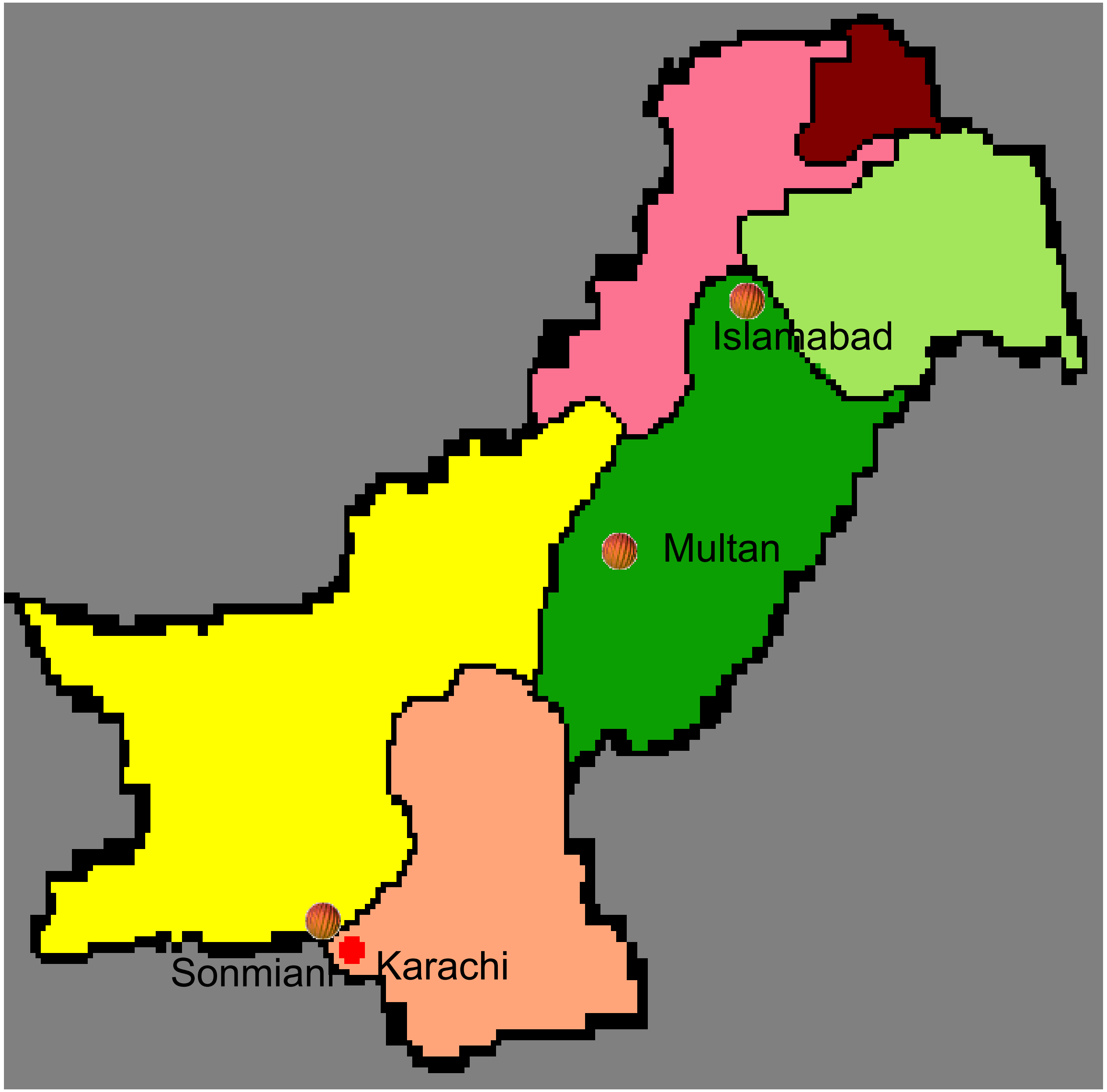
Outline

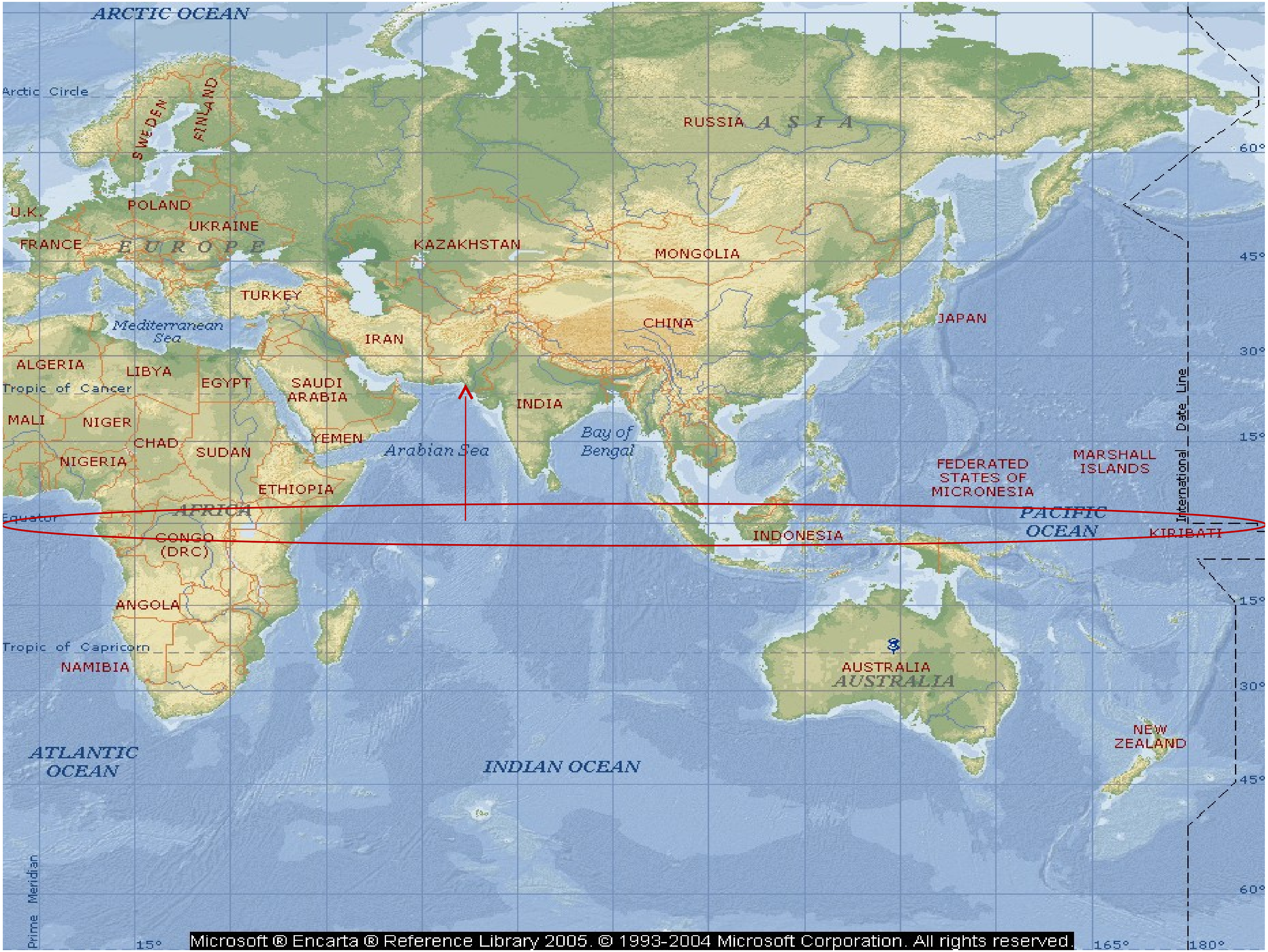
- Observatories/stations in Pakistan
- Introduction to the Thesis
- Ionosphere of the Earth
- Ionospheric Models
- Methods and their results
- Conclusion

Observatories/stations

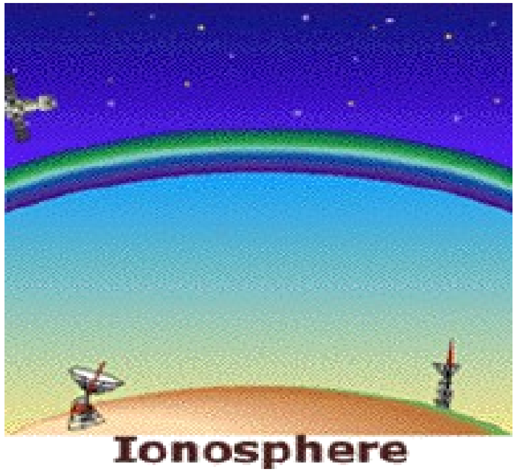


Introduction to the thesis

A study of the relationship between the critical frequency of the F2-layer of the ionosphere and the GPS Total Electron Content in the equatorial anomaly region


ARCTIC OCEAN
Arctic Circle
SWEDEN
FINLAND
RUSSIA
ASIA
U.K.
POLAND
UKRAINE
FRANCE
EUROPE
KAZAKHSTAN
MONGOLIA
TURKEY
Mediterranean Sea
IRAN
CHINA
JAPAN
ALGERIA
LIBYA
EGYPT
SAUDI ARABIA
Tropic of Cancer
INDIA
MALI
NIGER
CHAD
YEMEN
Arabian Sea
Bay of Bengal
NIGERIA
SUDAN
ETHIOPIA
FEDERATED STATES OF MICRONESIA
MARSHALL ISLANDS
International Date Line
Equator
AFRICA
CONGO (DRC)
INDONESIA
PACIFIC OCEAN
KIRIBATI
ANGOLA
Tropic of Capricorn
NAMIBIA
AUSTRALIA
AUSTRALIA
NEW ZEALAND
ATLANTIC OCEAN
INDIAN OCEAN
Prime Meridian
15°
165°
180°
60°
45°
30°
15°
15°
30°
45°
60°

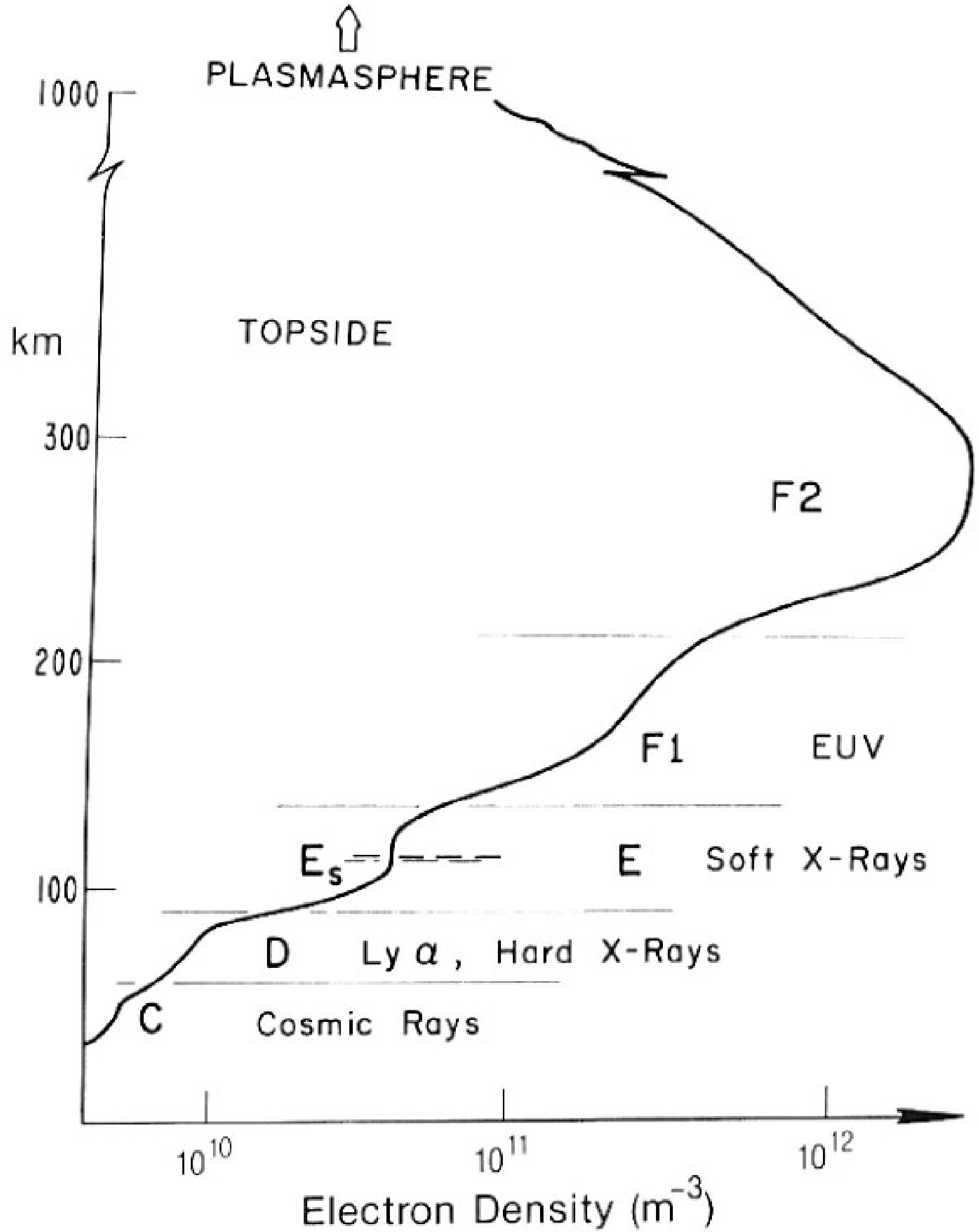
Ionosphere of the Earth



Upper ionized region of the atmosphere known as Ionosphere (from 60–800km approx.) acts as a mirror for High Frequency Radio Waves (3-30 MHz) so that Long Range Communication becomes possible.

c Features of Ionospheric Regions

S. #	Region	Cause of ionization
1	D	x-ray x-ray L_α
2	E	x-ray, L_β meteor shower
3	F	He II, UV Upward diffusion from the F_1 layer



From "Ionospheric Radio", K. Davies.

Critical Frequencies

The highest vertically propagated frequency that can be reflected by specific regions (or layers) of the ionosphere.

Reflected → fully refracted back to the Earth's surface

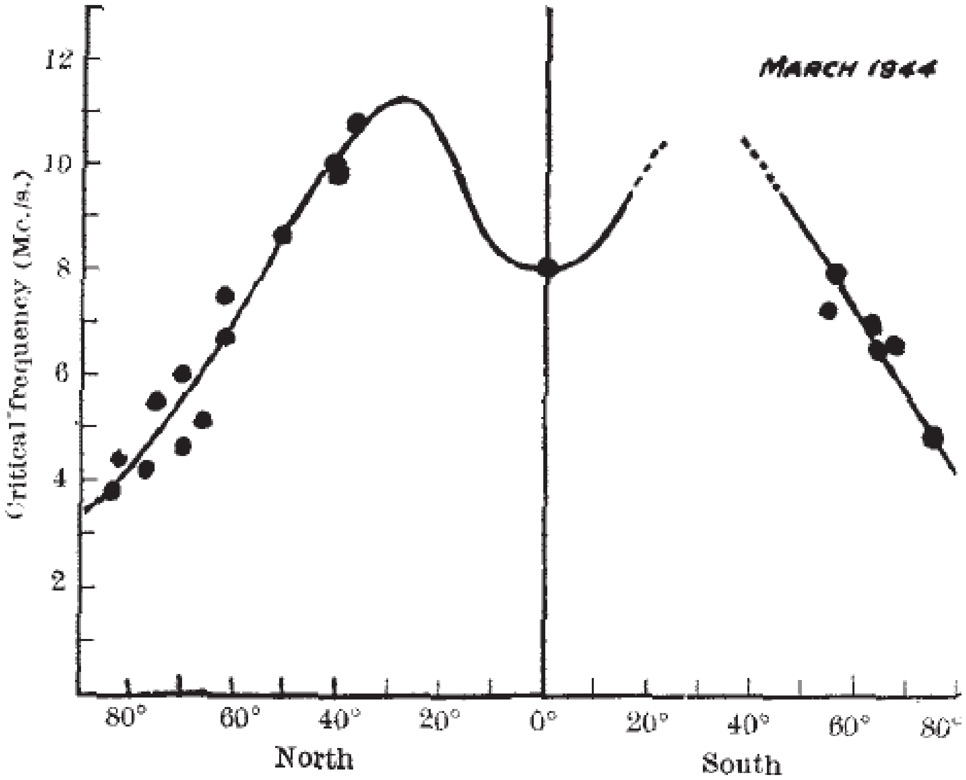
- foE
- foEs
- foF1
- foF2

Ionospheric Anomalies

- Unusual behaviour of an ionospheric layer which does not obey the Chapman’s Theory is called an ionospheric anomaly.
- The E and F1 layers generally show a regular solar controlled behaviour.
- The F2-layer shows unusual characteristics as compared to the E and F1 layers.
- Some important F2-region anomalies are:
  - Equatorial or Geomagnetic Anomaly

Equatorial Ionization Anomaly (EIA)

The peak electron density (number of electrons in F2 layer), shows a smooth variation with magnetic dip with a trough near the magnetic equator and crests near magnetic dips +30° and -30°



VARIATION OF CRITICAL FREQUENCY WITH MAGNETIC DIP

Sources of Error in GPS

- **Clock Error**

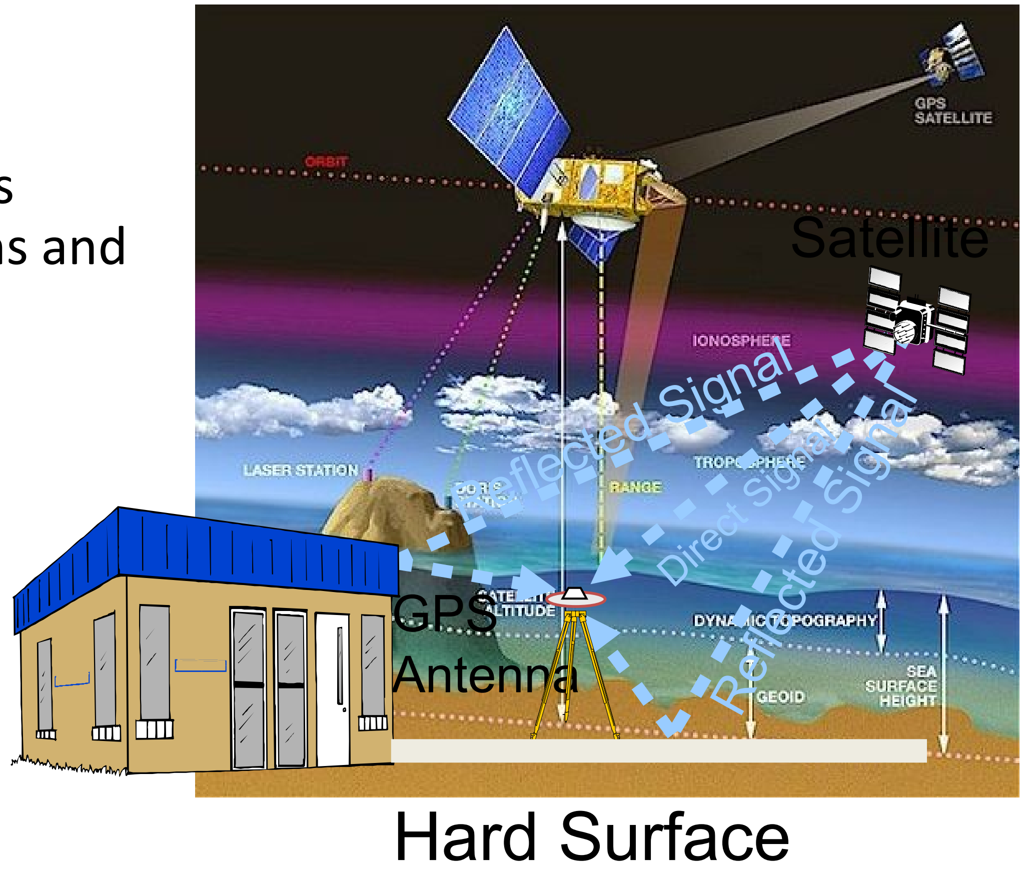
  Differences between satellite clock and receiver clock

- **Ionosphere Delays**

  Delay of GPS signals as they pass through the layer of charged ions and free electrons known as the ionosphere.

- **Multipath Error**

  Caused by local reflections of the GPS signal that mix with the desired signal



Total Electron Content

- Total number of electrons present between two points in a column of unit area.
- It is expressed in electron per square metre.
- 1 TECU is defined as the number of electrons in a 1m2 column, which is equal to 1016 electrons
- GPS TEC is evaluated due to the ionospheric delay in signal as mentioned in the previous slide

Relation between TEC and foF2

- Both TEC and foF2 exhibit significant variations in both space and time
- The perturbations in TEC are similar to foF2 variations
- TEC can be obtained (mathematically) as the product of thickness of the ionosphere multiplied by the maximum electron density (of F2-layer)

Research Objectives

- To study the relation between the total electron content (TEC) derived from a Global Positioning System (GPS) receiver and the critical frequency of the F2-layer of the ionosphere.
- To devise a method to use GPS TEC as a proxy of foF2 so that a simpler GPS receiver can replace an ionosonde at the location under study (Vanimo, Papua New Guinea). This ionosonde must soon be closed down.

Ionospheric Models

- Ionospheric models play a vital role in understanding ionospheric phenomena and forecasting the space weather. They fall in these categories:
  - Empirical models
  - Physical models
  - Semi-empirical models

Ionospheric Models used in the study

- International Reference Ionosphere – IRI

  "ISO/TS 16457:2009 Space systems -- Space environment (natural and artificial) -- The Earth's ionosphere model: international reference ionosphere (IRI) model and extensions to the plasmasphere"

- Electron density profiler – NeQuick
- Both models use coefficients produced by International Telecommunication Union Radio-communication – ITU-R

Methods and their results

- Direct correlation between the observed data sets
  - Ionosonde foF2
  - GPS TEC
- Comparison with model values
- Climatological model of thickness and reserve calculation

Stations under study

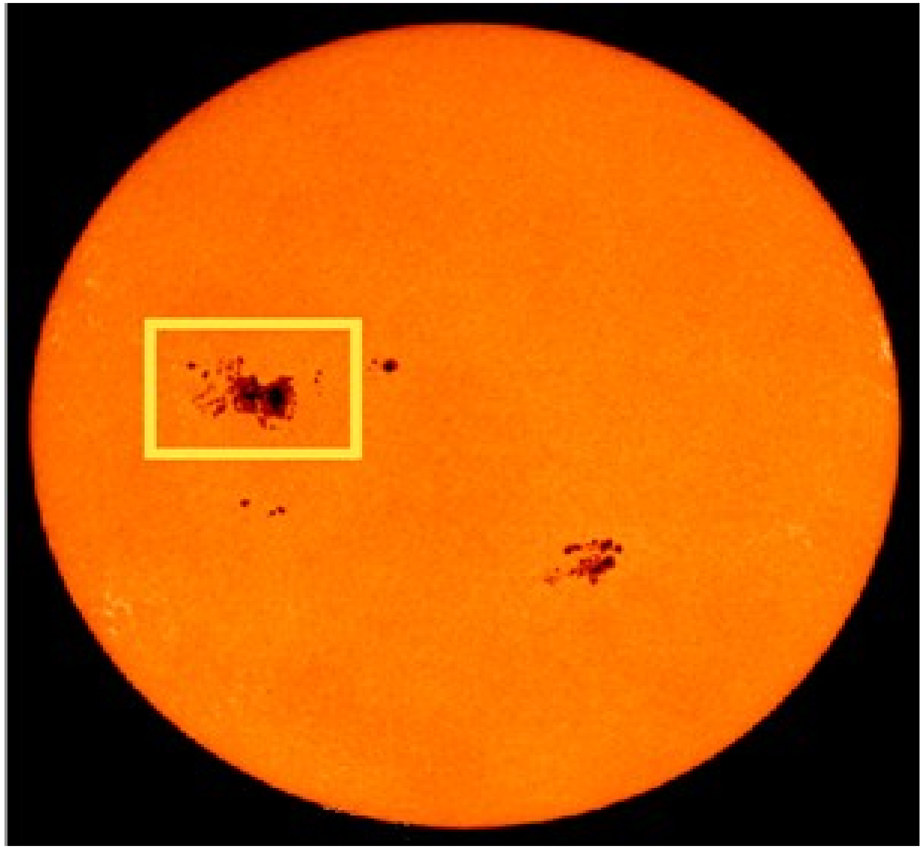
Station name	Geographical latitude (°)	Geographical longitude (°)	Geomagnetic latitude (°)	Dip (°)
Vanimo	-2.7	141.3	-12.6	-21.6
Canberra	-35.32	149	-44.0	-66.1
Darwin	-12.45	130.95	-23.2	-44.5
Okinawa	26.68	128.15	17.0	37.7

Geographical coordinates and geomagnetic latitudes and Dips of stations where data was acquired

Geographical coordinates, geomagnetic latitudes and Dips of stations where data were acquired

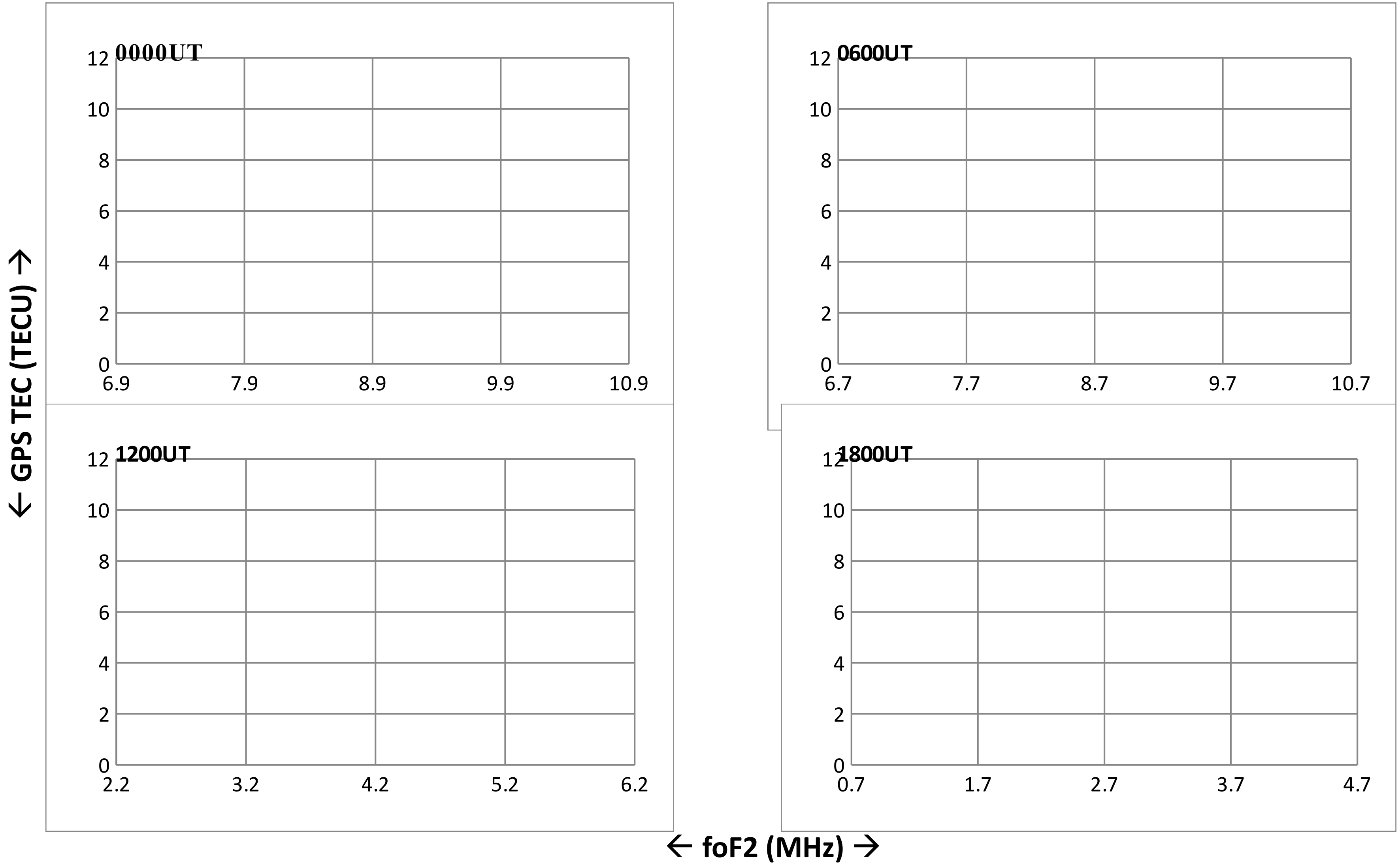
Sunspot Number and Kp index

Sunspot number (SSN) → model input

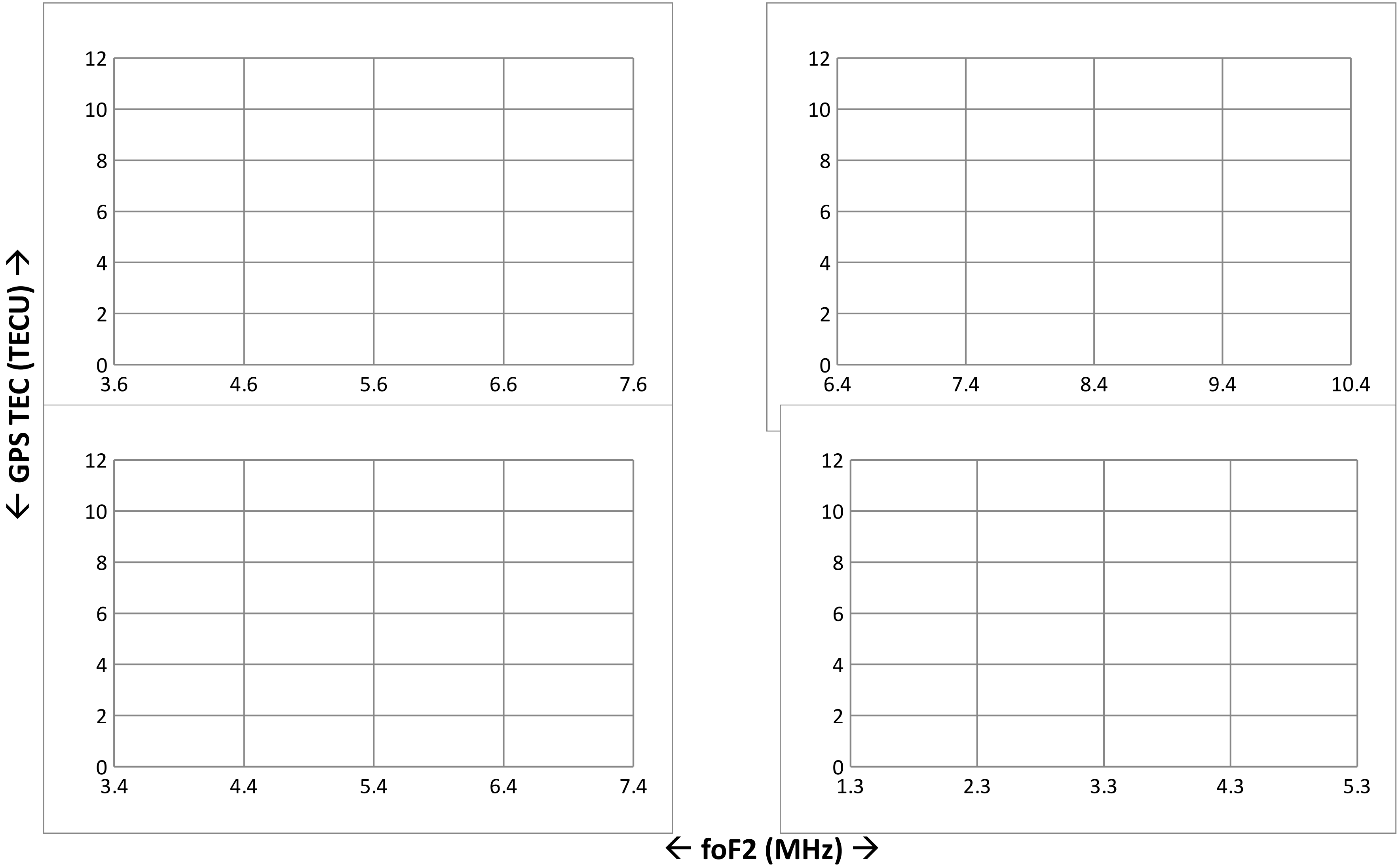


Days	SSN	Maximum Kp	Days	SSN	Maximum Kp
1	23	3	17	25	3
2	23	1	18	26	4
3	15	2	19	22	3
4	13	1	20	15	3
5	12	1	21	12	3
6	10	1	22	10	4
7	9	5	23	10	6
8	7	4	24	2	6
9	12	2	25	0	4
10	15	2	26	0	4
11	16	1	27	1	3
12	16	1	28	2	3
13	14	2	29	7	2
14	21	2	30	6	2
15	19	2	31	1	3
16	23	2			

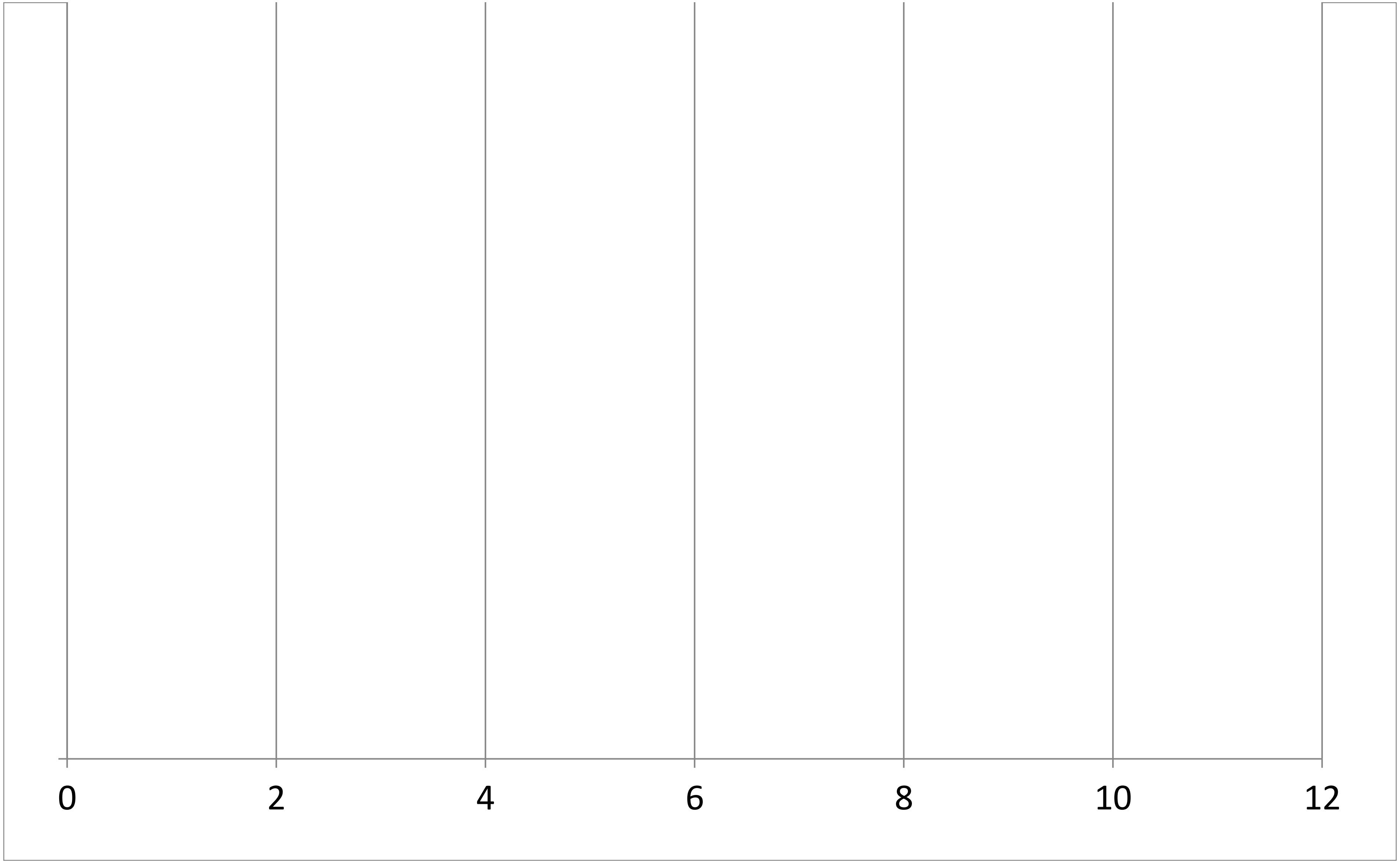
Direct correlation between observations for Vanimo



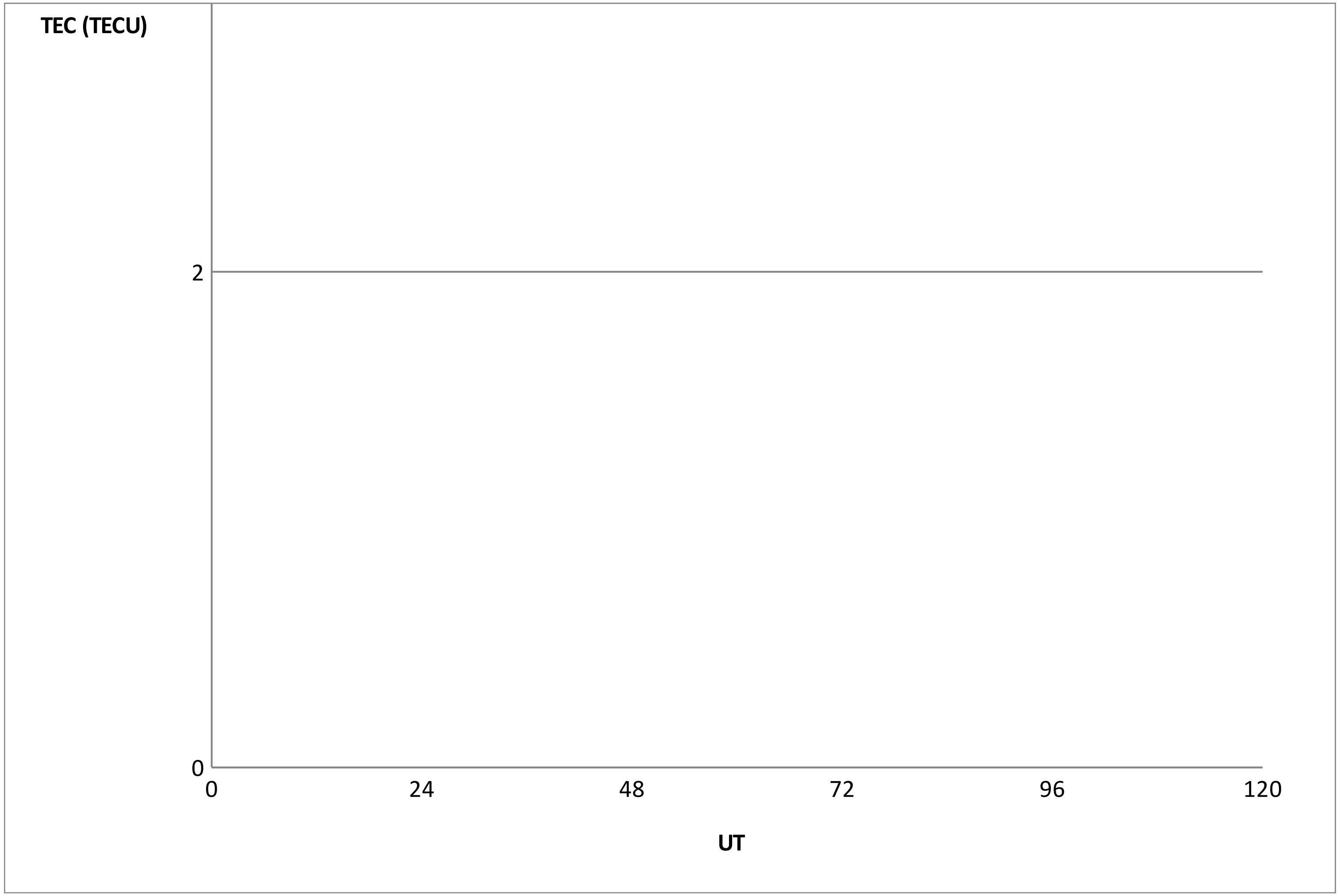
Direct correlation between observations for Okinawa



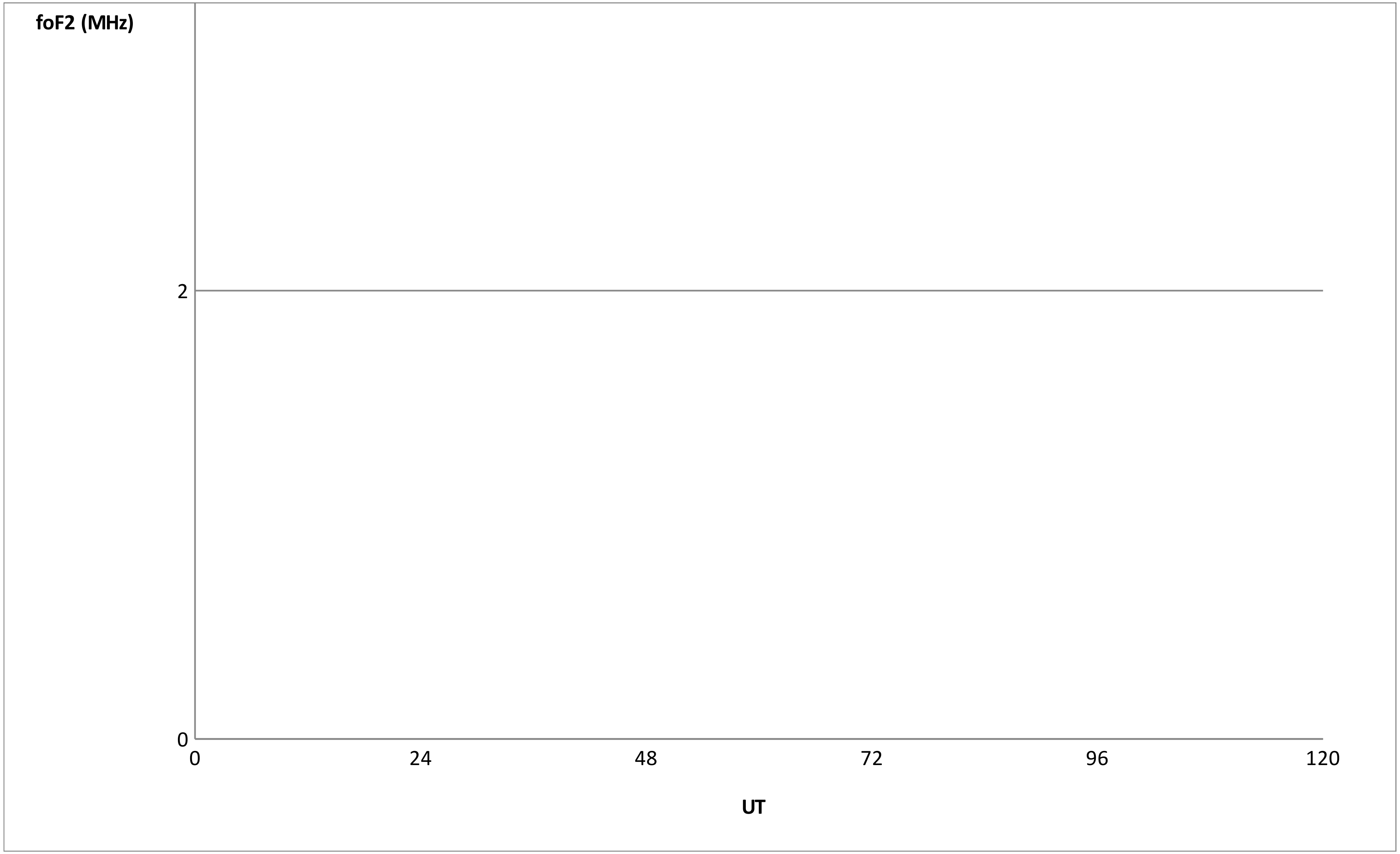
Direct Correlation Between TEC & foF2



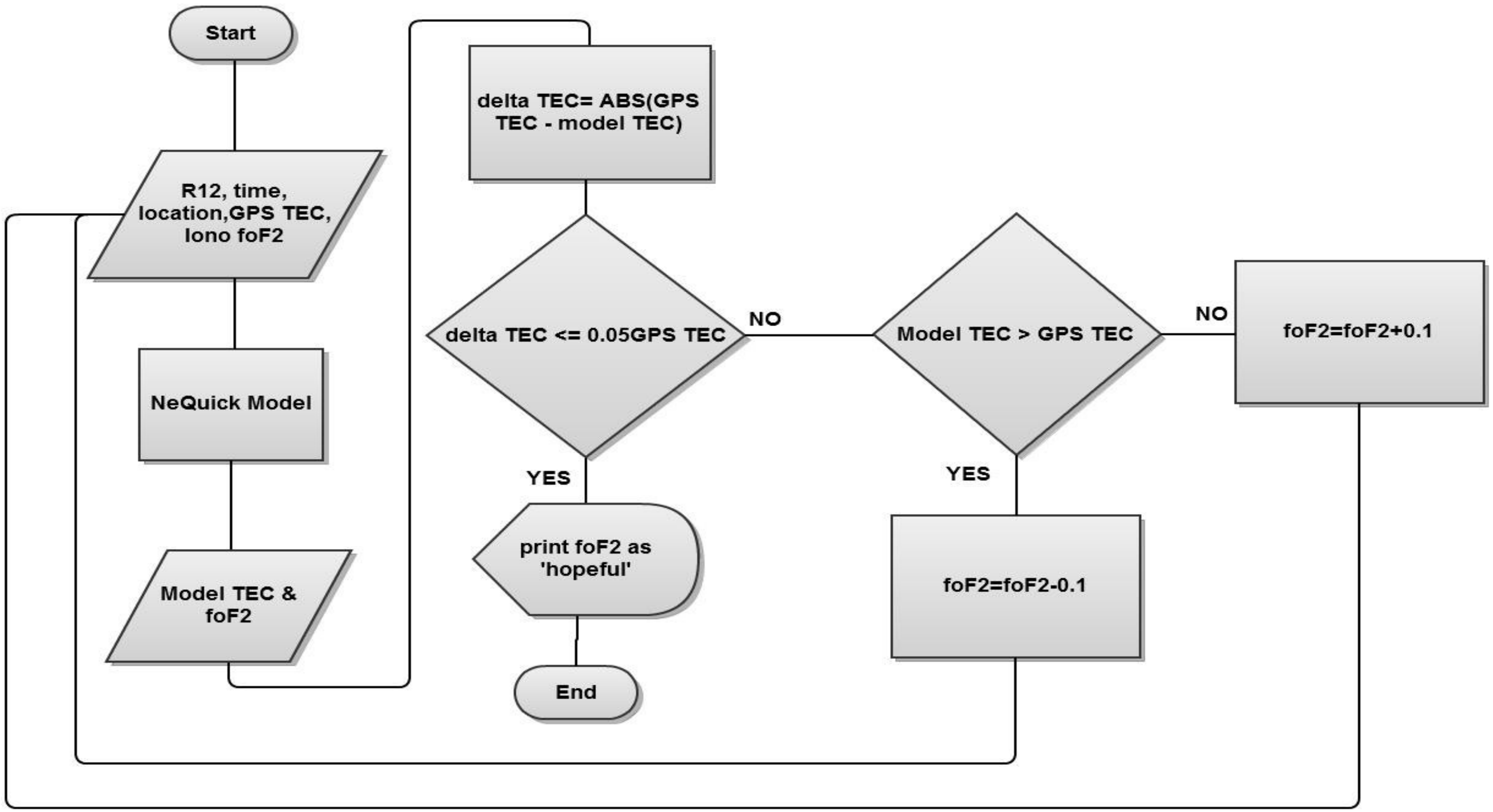
Comparison of GPS and model TEC over Vanimo (1–5 May 2007)



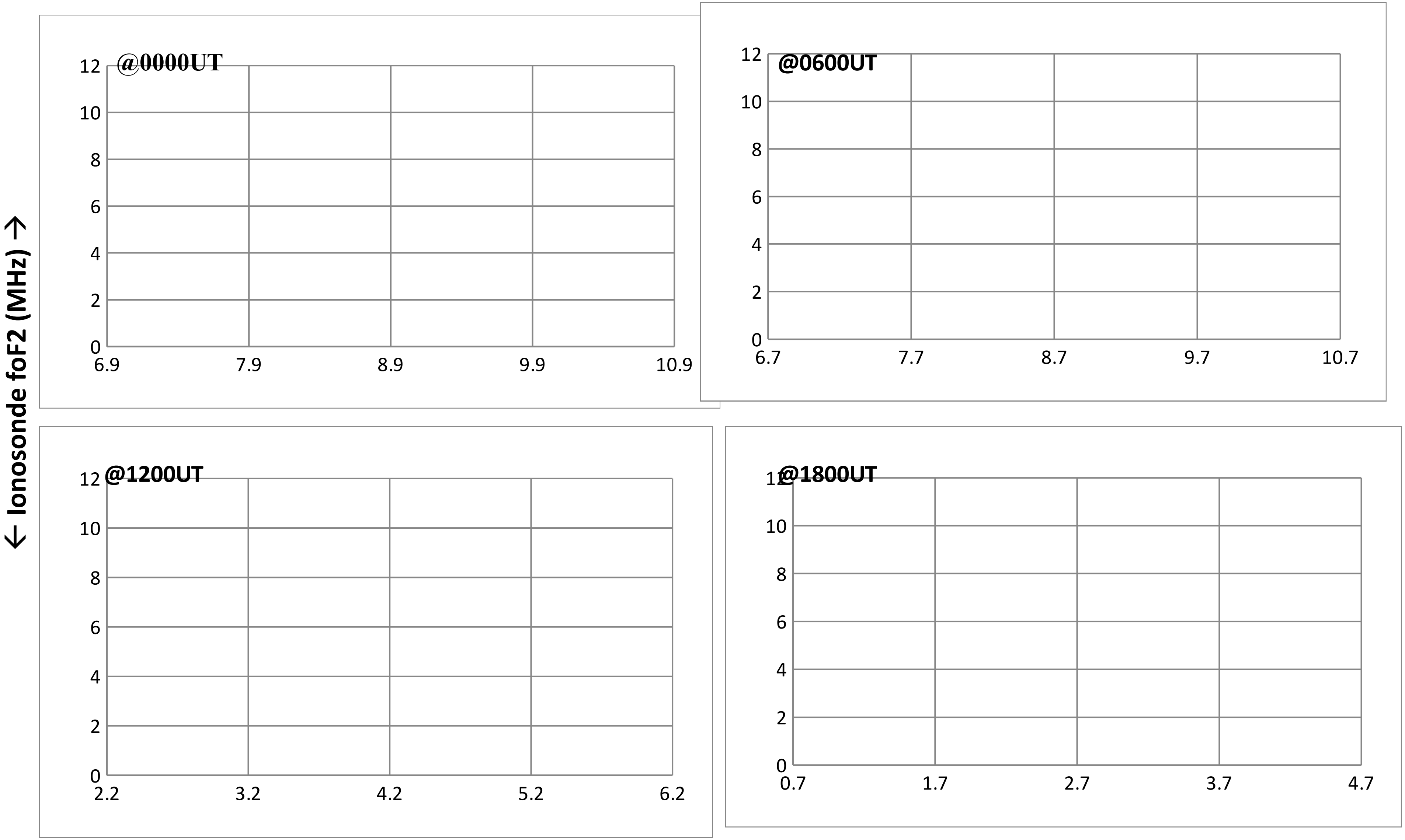
Comparison of ionosonde and model foF2 over Vanimo (1–5 May



NeQuick Iteration Process



Correlation between ionosonde foF2 and model driven ‘hopeful foF2’ for Vanimo



Direct Correlation and Iteration

Vanimo

Good points decreased to 57%

Climatological Thickness Model

The relation between TEC and foF2 is mathematically given as

τ = TEC/ NmF2

NmF2 (in elec-m-3) = 1.24×1010×(foF2)2

foF2 (the critical frequency of F2 layer) is in MHz

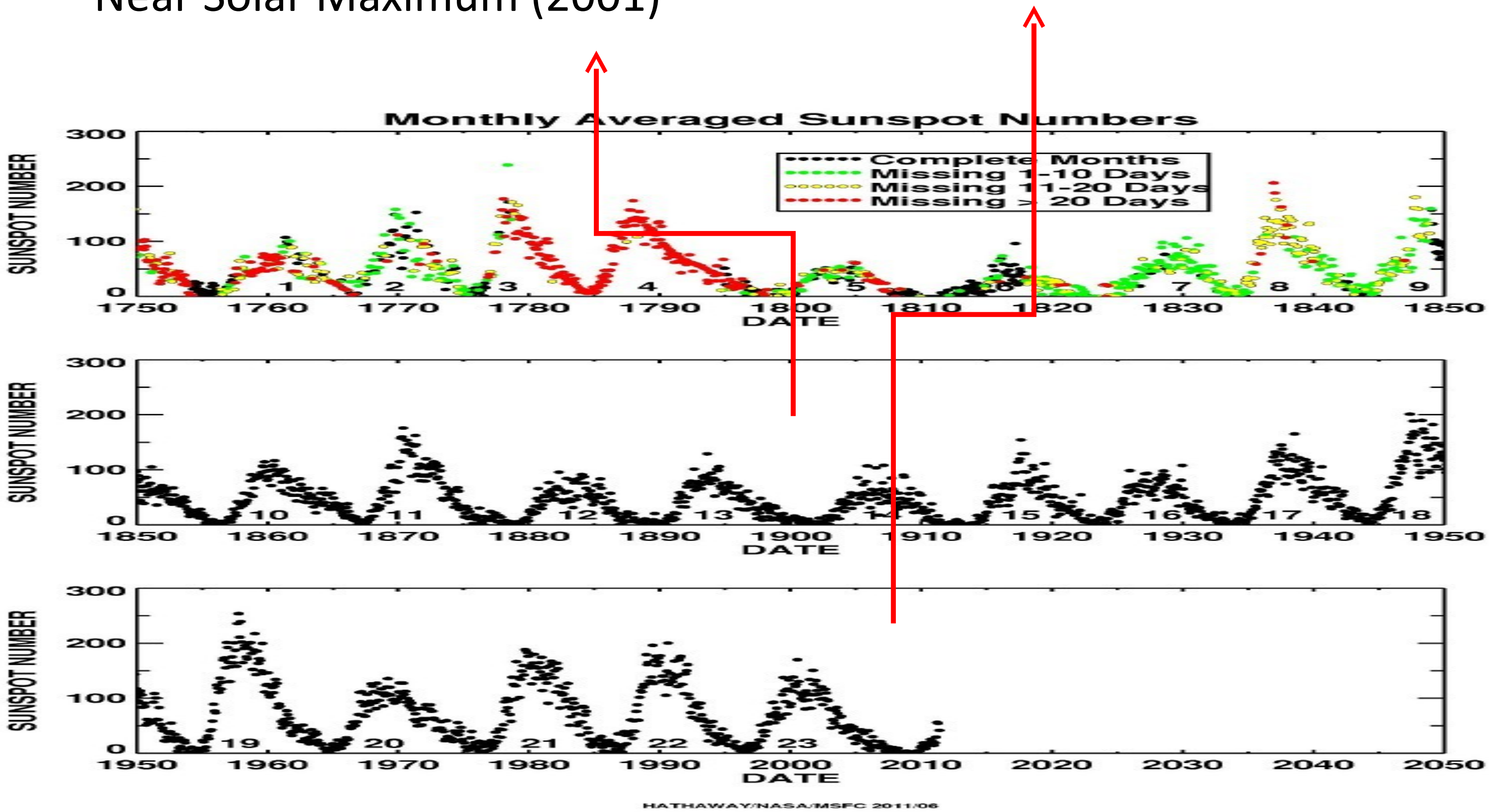
TEC is in elec-m-2

With all above we get τ in meter

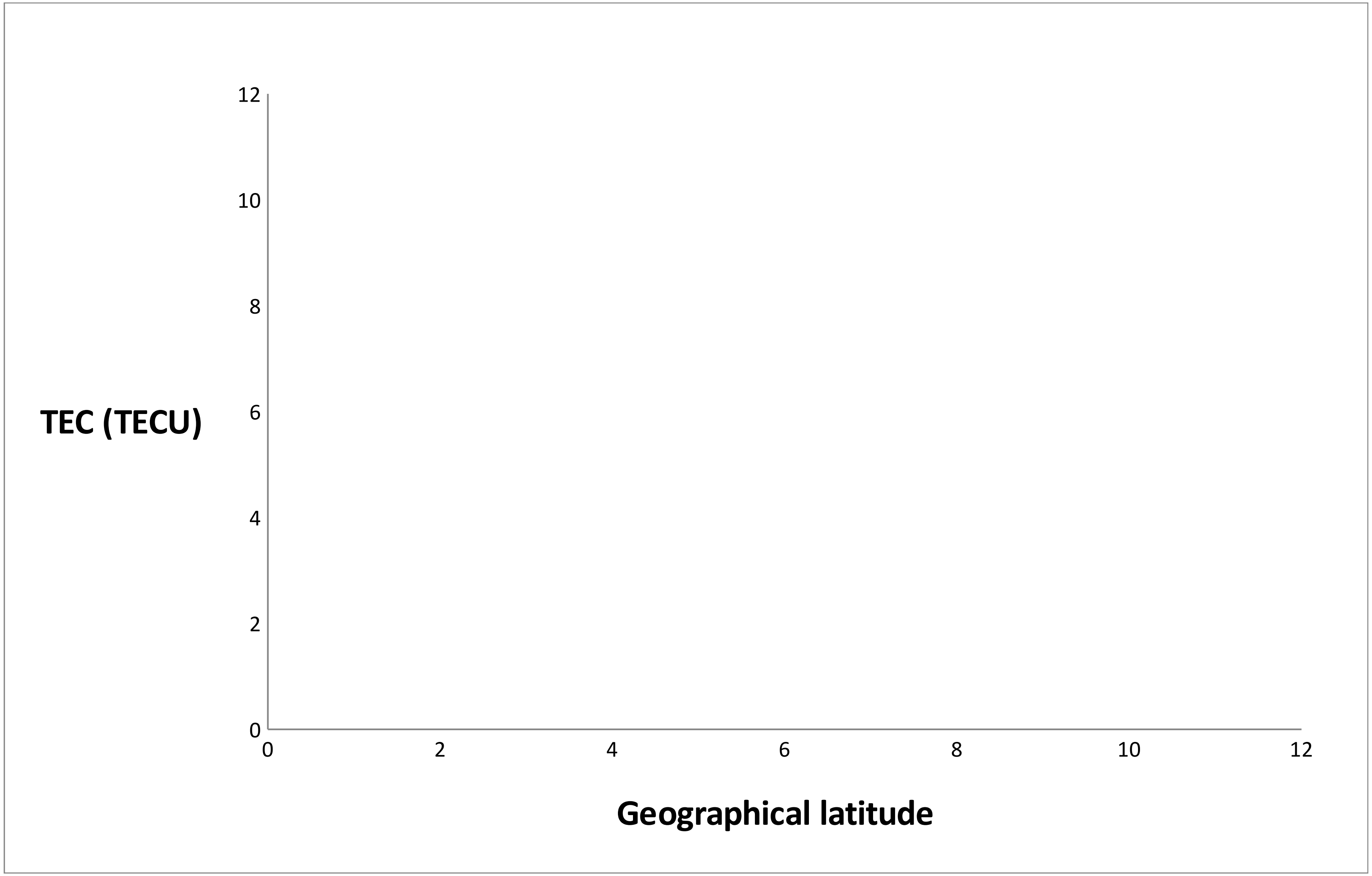
Data Analysis

Near Solar Maximum (2001)

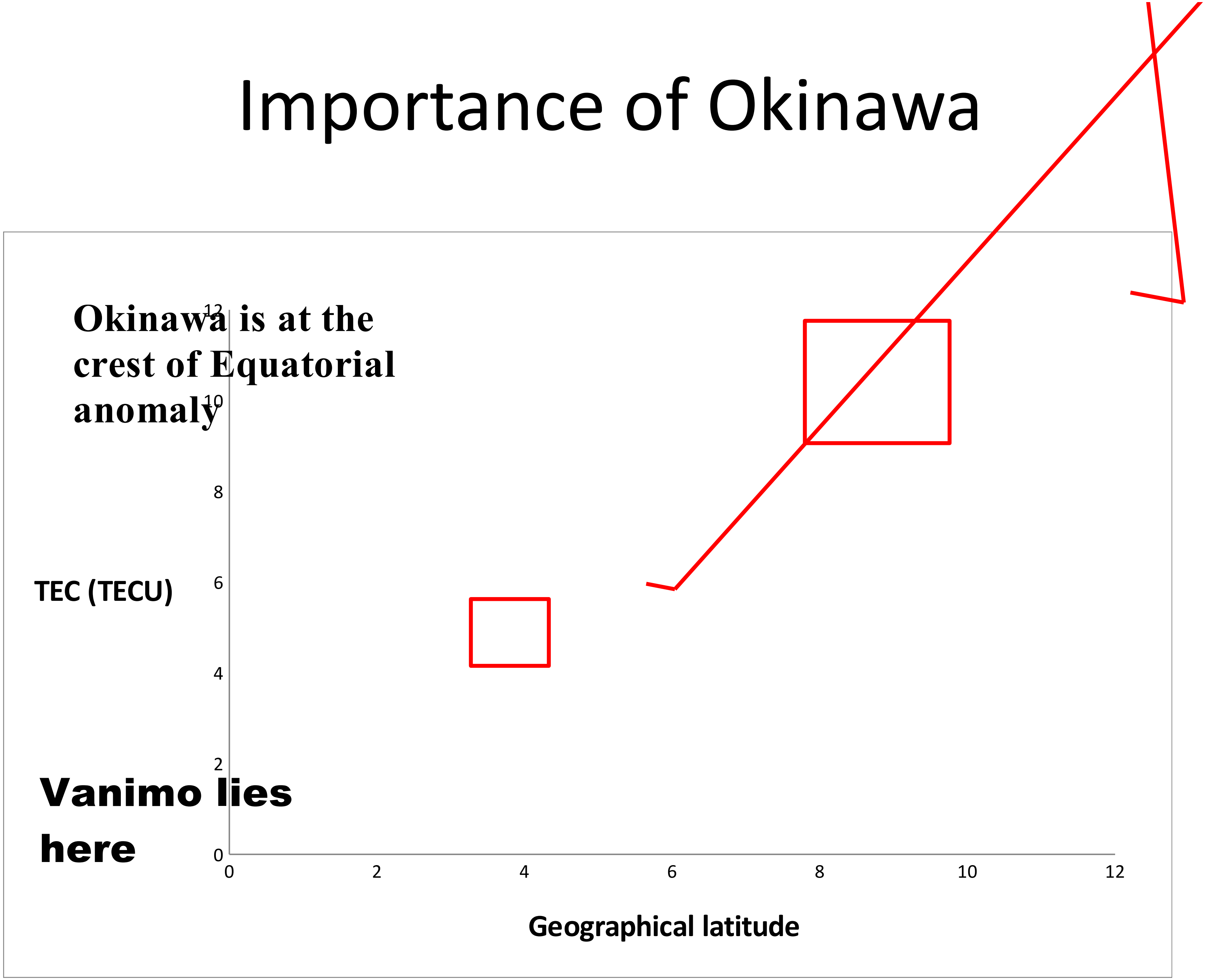
Solar Minimum (2008)



Madrigal TEC on a quiet day in solar minimum year at local noon



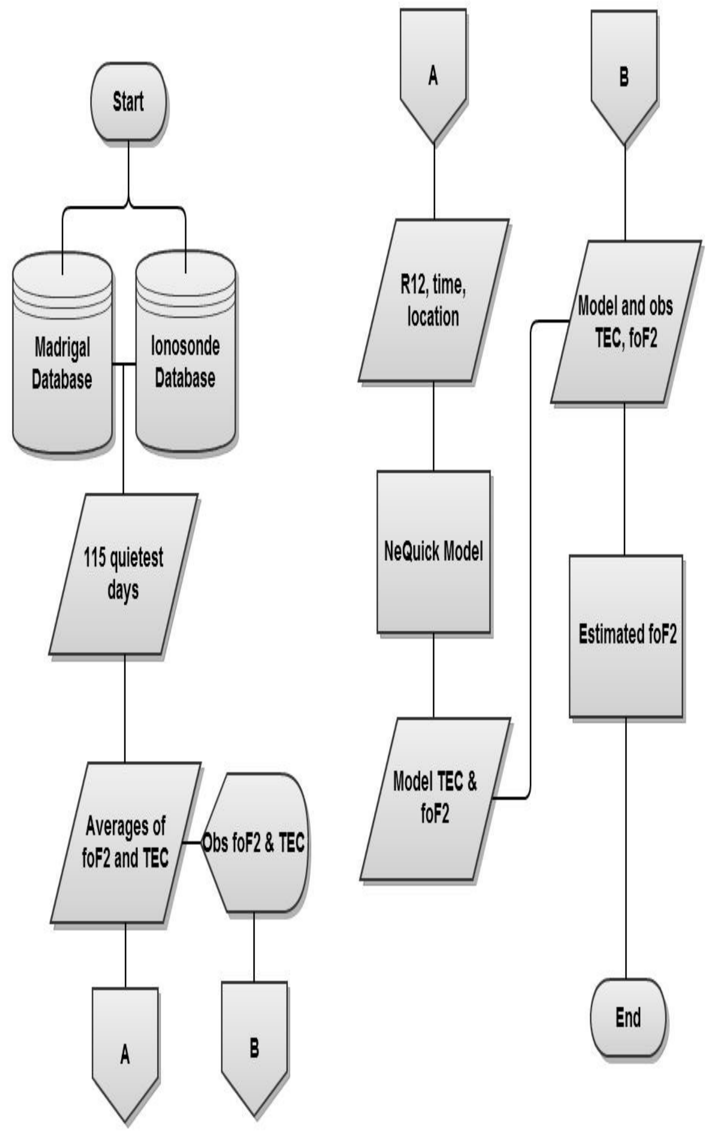
Importance of Okinawa



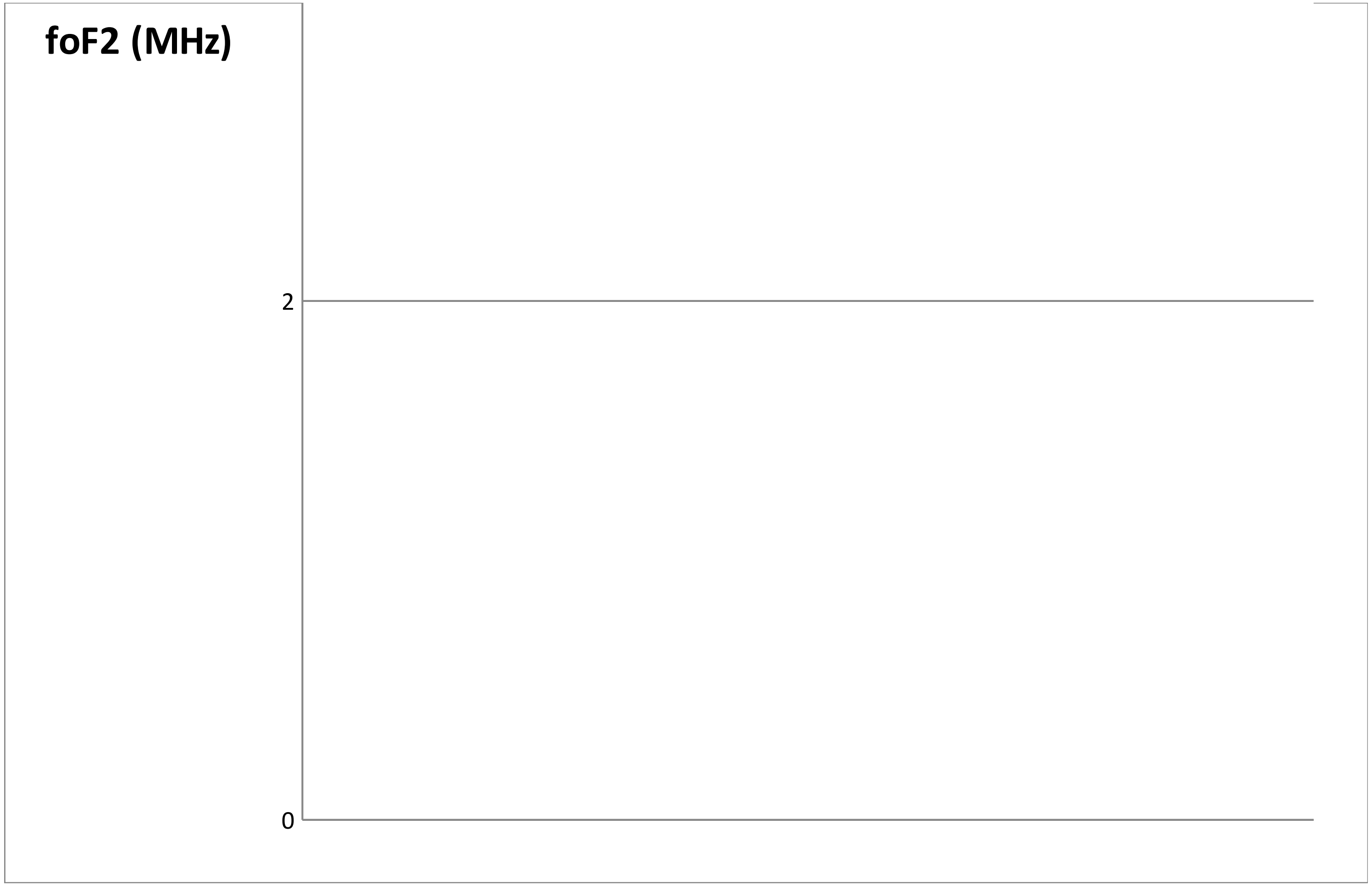
Method

- For every month 5 quiet days (QD) were selected (approx), with 115 QD in all.
- Hourly values of foF2 were obtained
- Madrigal TEC was averaged over a latitude range of 24° to 28° with a longitude range from 95° to 105° to focus Okinawa at the centre latitude
- Both foF2 and TEC were averaged for each month to get monthly values at local midnight and noon.

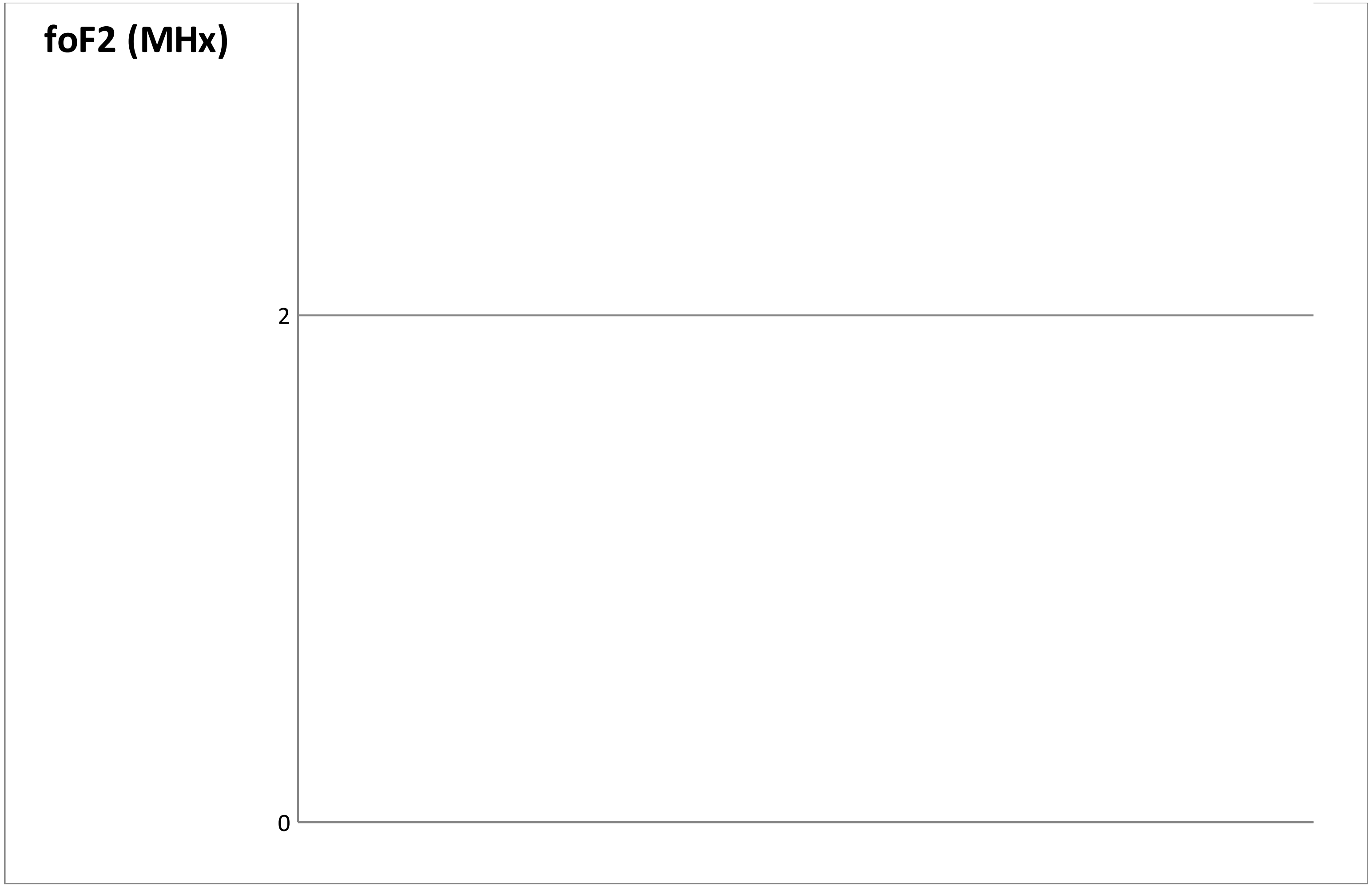
Flow diagram (1/2)



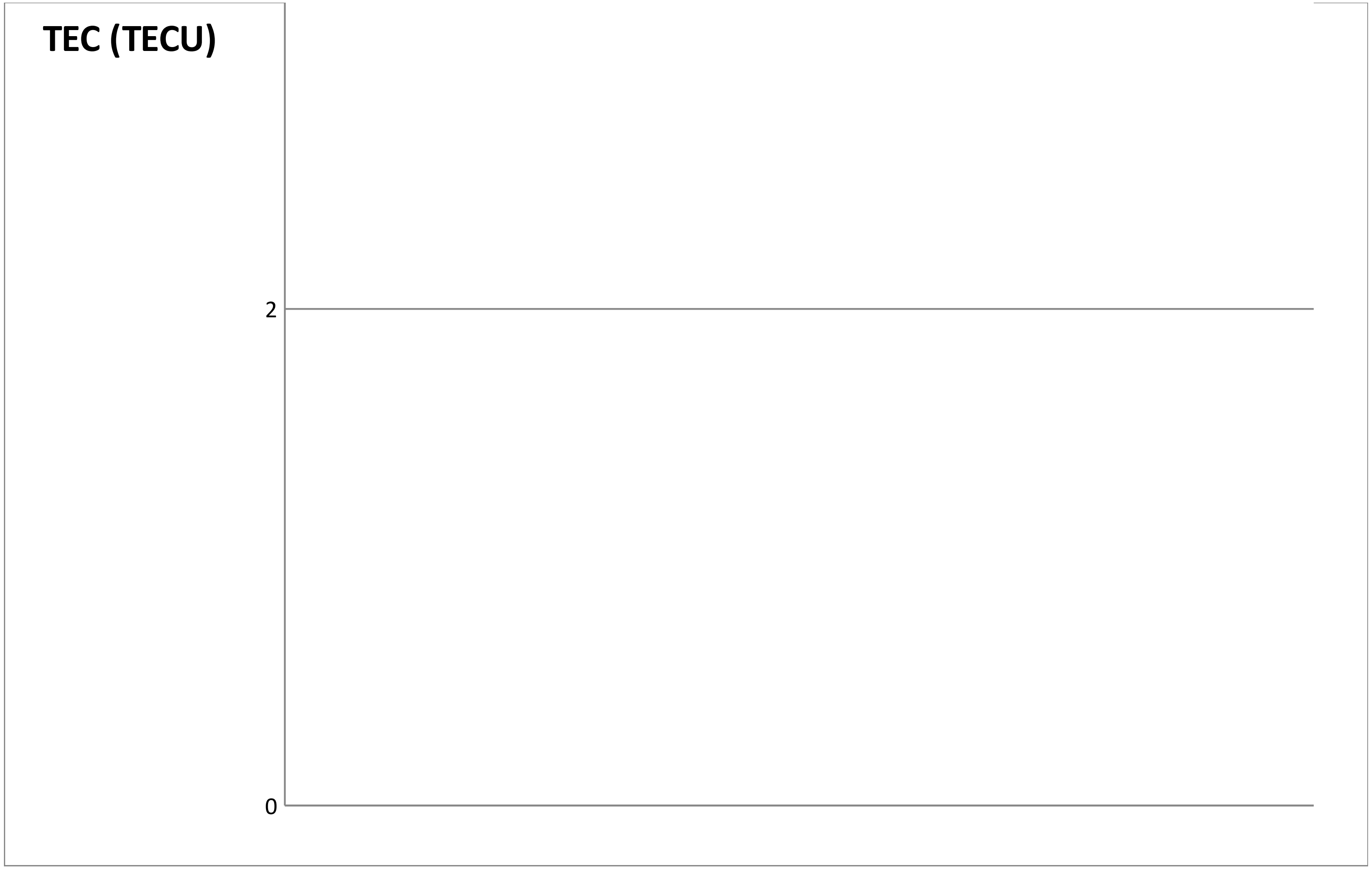
Noon foF2 at Okinawa



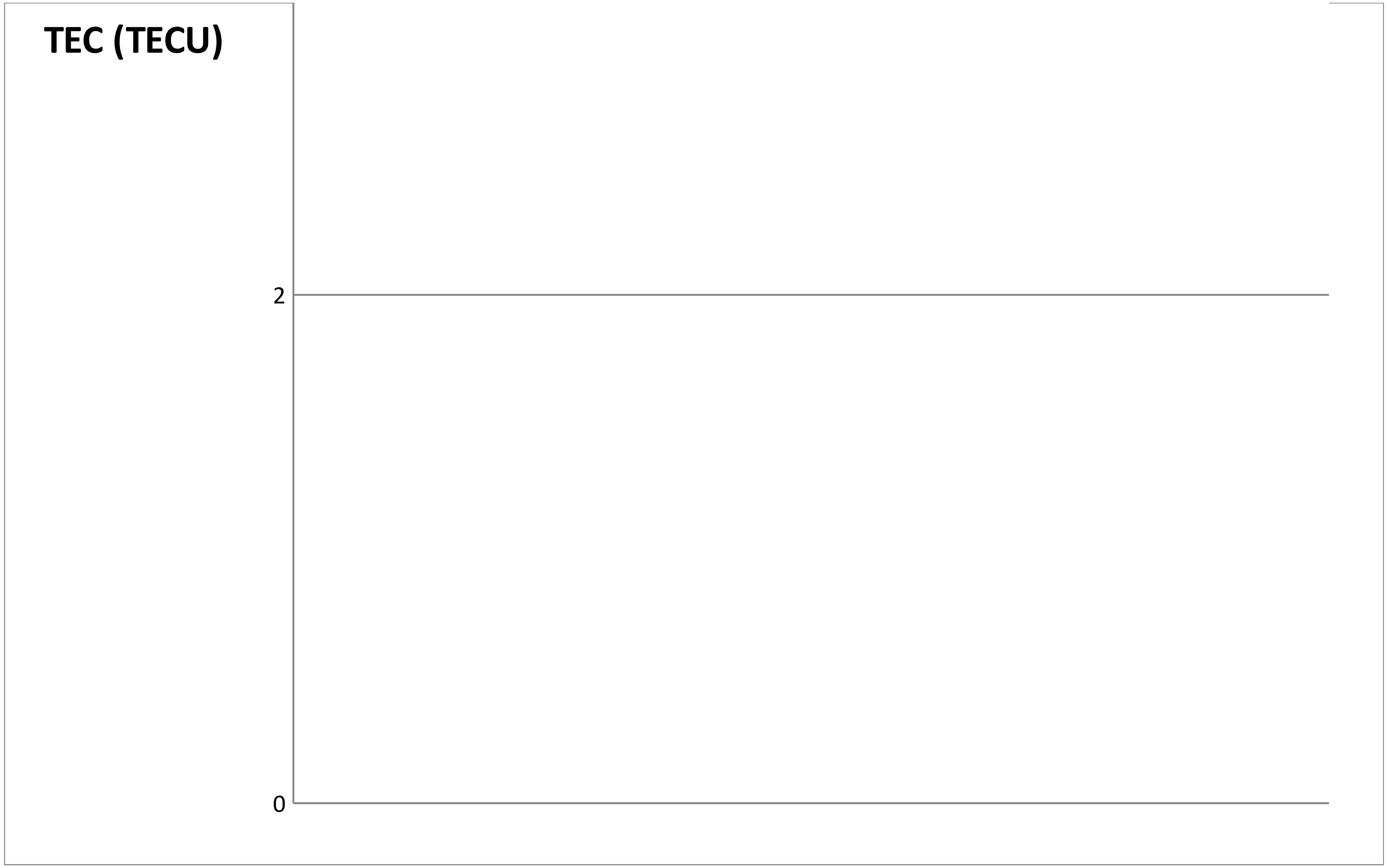
Midnight foF2 at Okinawa



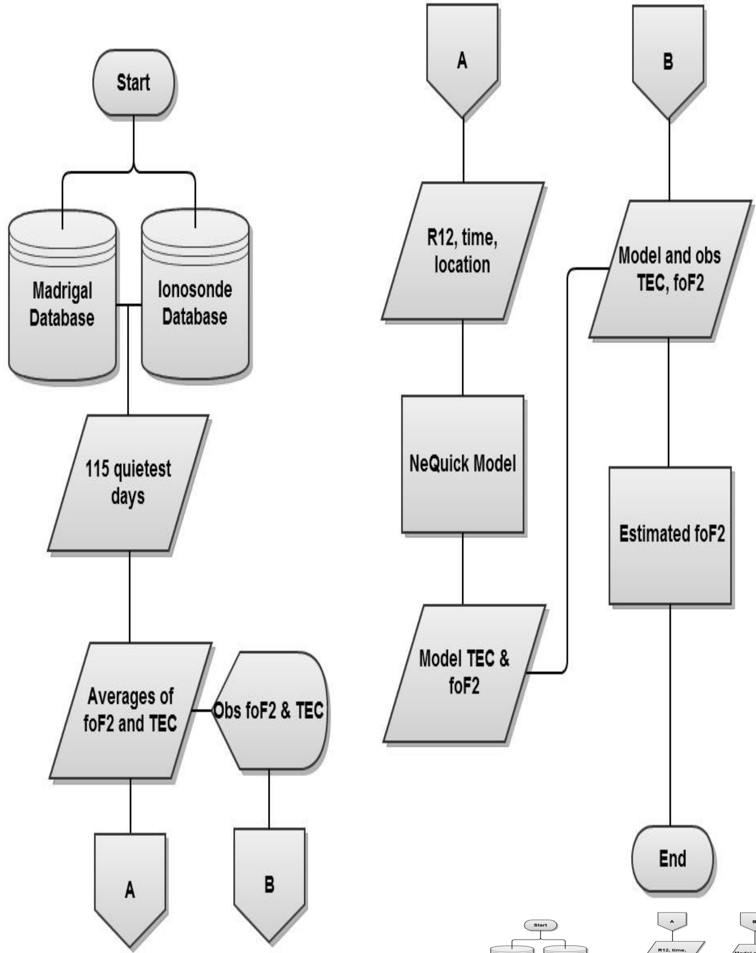
Noon TEC over Okinawa

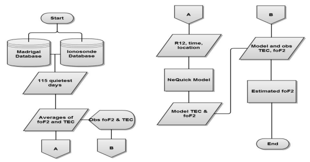


Midnight TEC over Okinawa



Flow diagram (2/2)





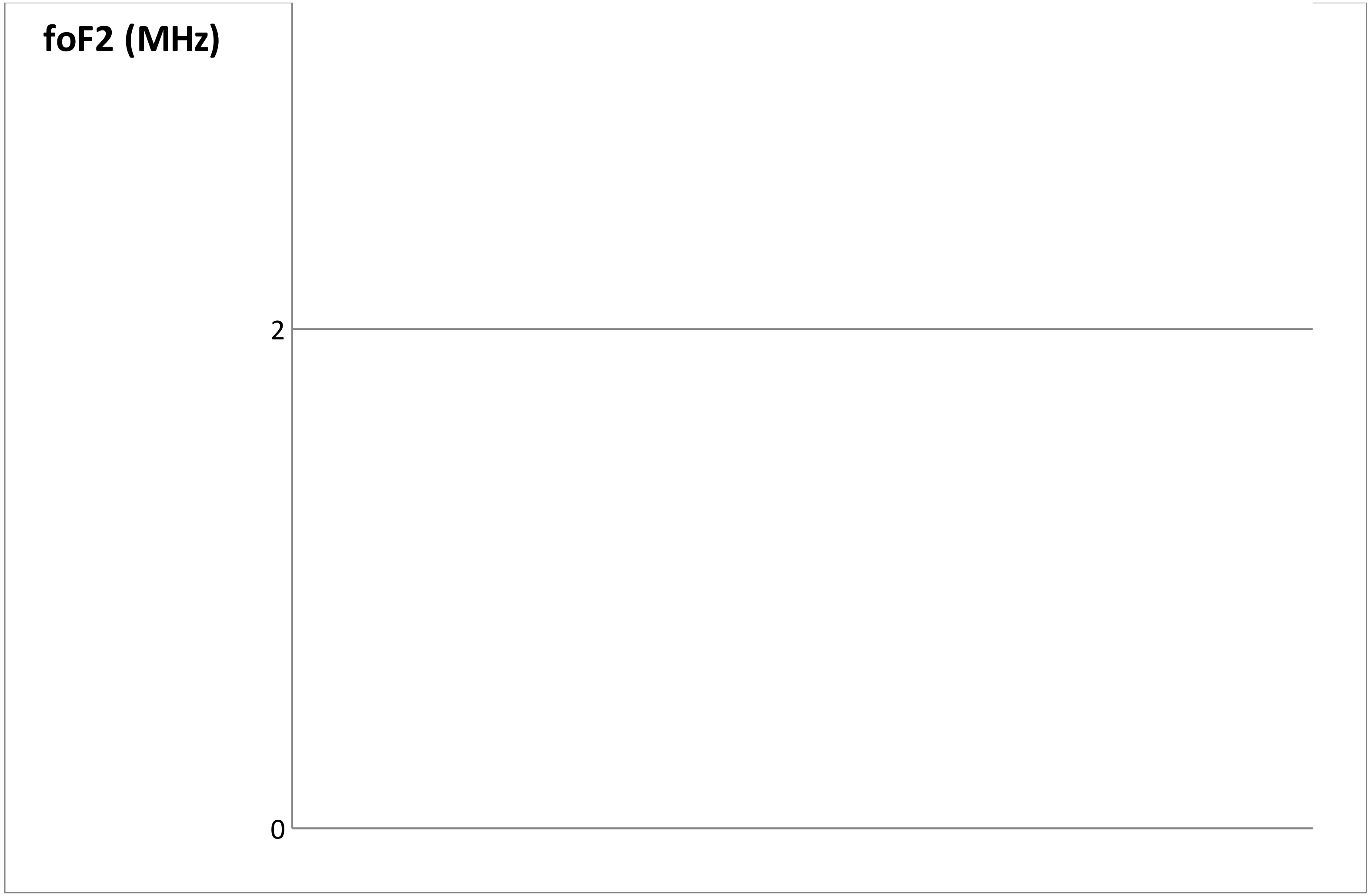
Bringing NeQuick in the picture

- NeQuick was used to derive model TEC by substituting the sunspot numbers, time and location of Okiwana
- It also gives the foF2 for every corresponding TEC value
- foF2 was estimated using the relation τ = TEC/ NmF2 such that

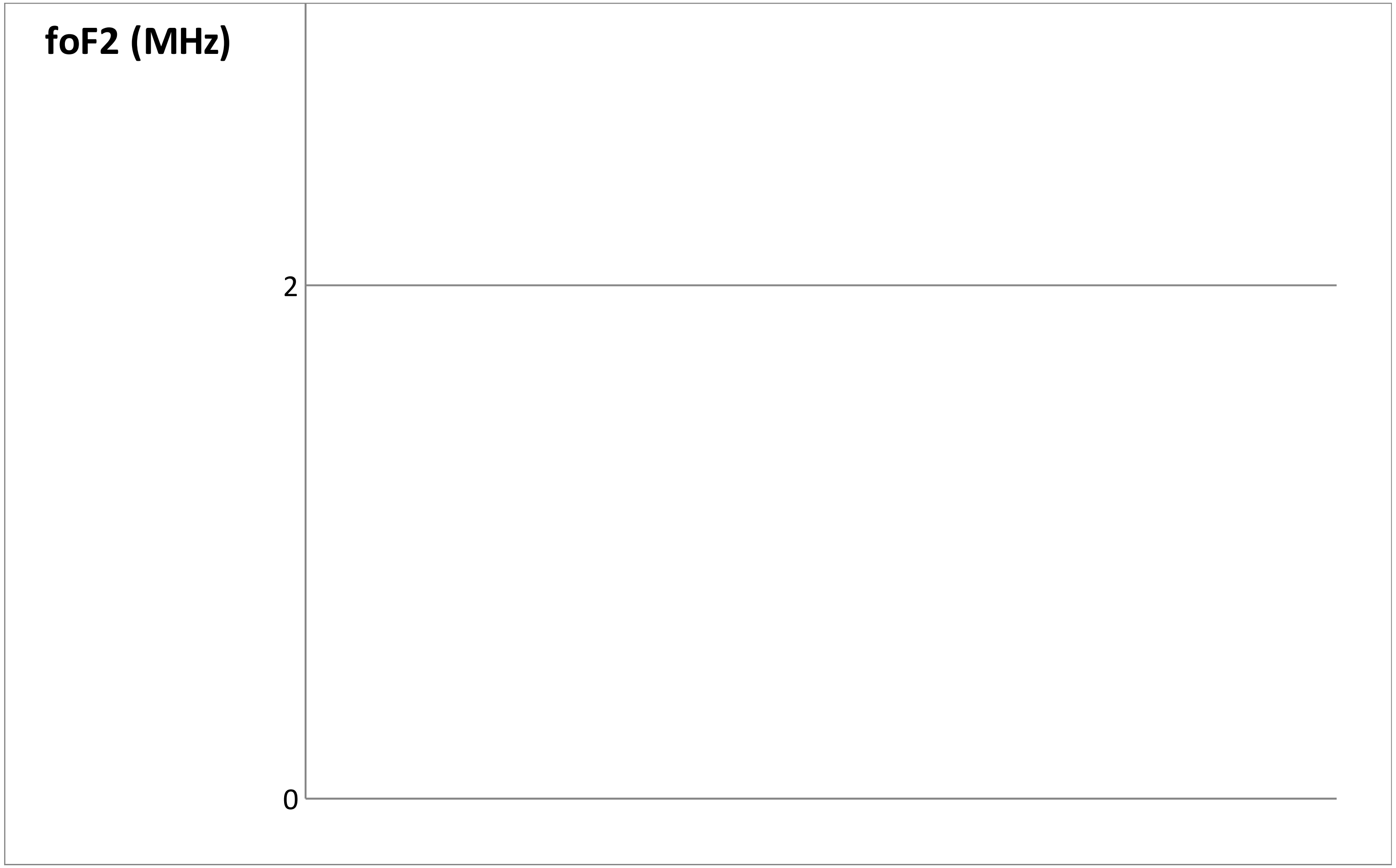
TEC(obs)/TEC(NeQuick)=foF2(est)/foF2(mod)

foF2(est) = (TEC(obs)/TEC(NeQuick) * foF2(mod)

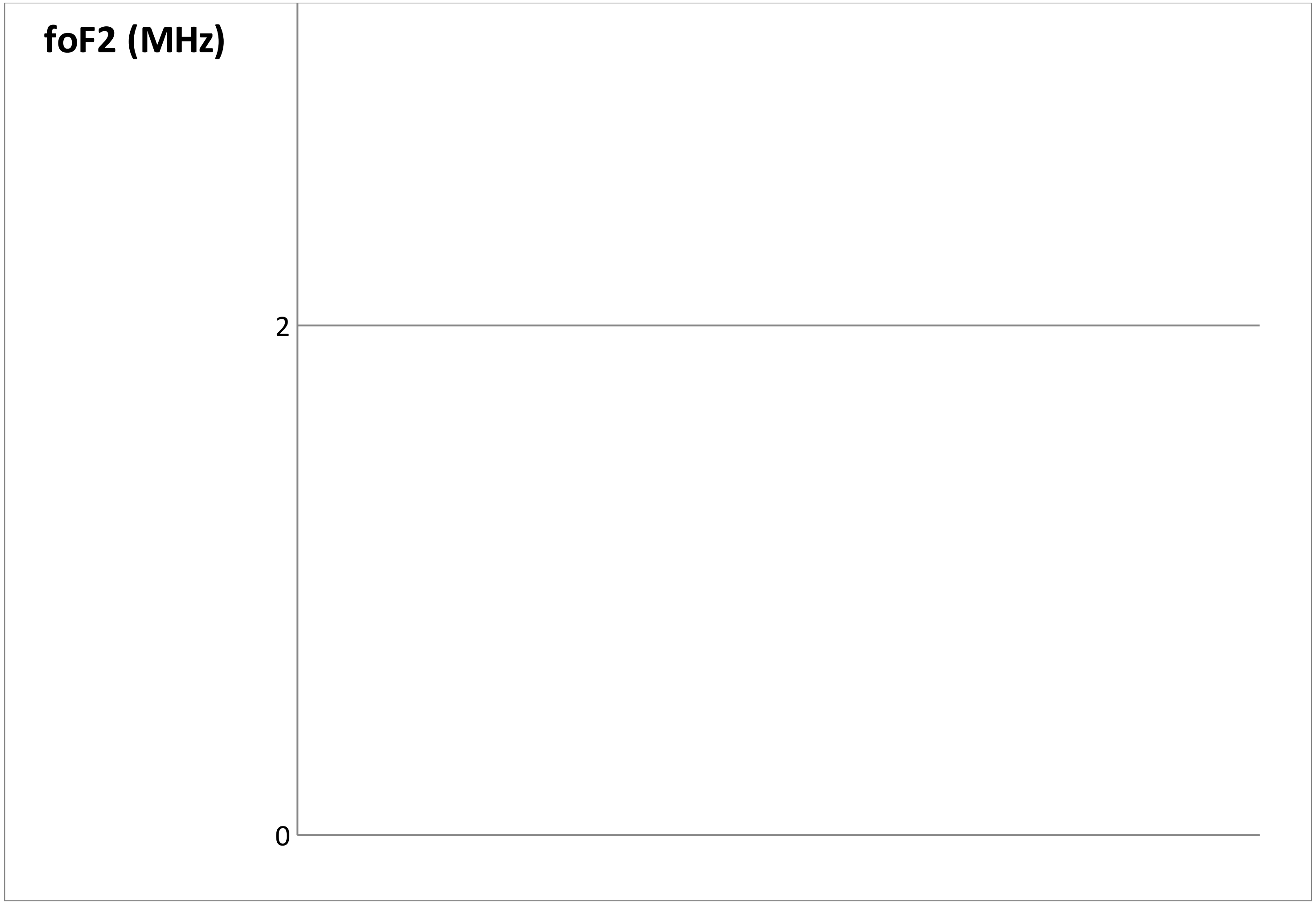
Ionosonde & estimated foF2 at Okinawa & Vanimo during 2001 at



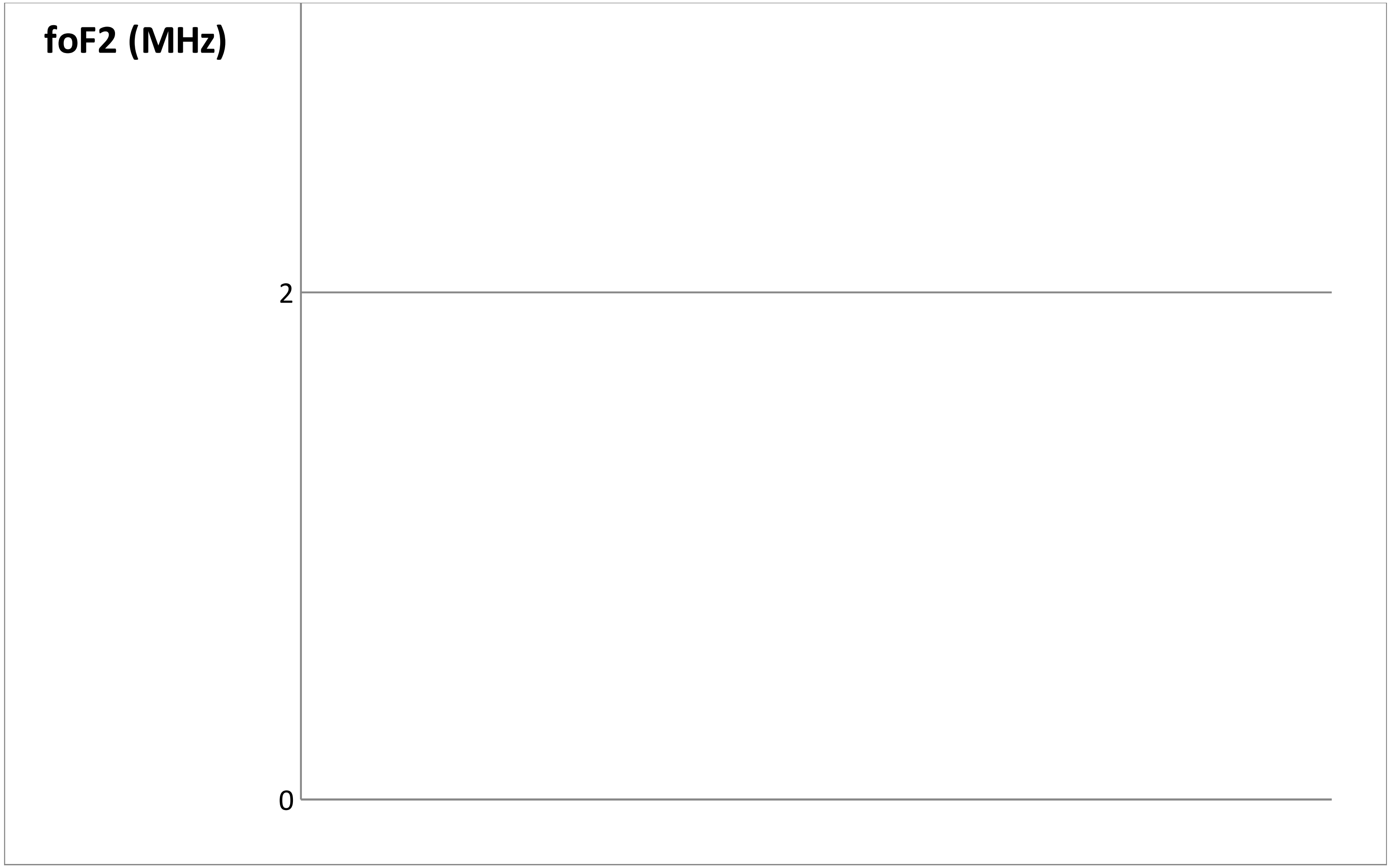
Ionosonde & estimated foF2 at Okinawa & Vanimo during 2001 at



Ionosonde & estimated foF2 at Okinawa & Vanimo during 2008 at



Ionosonde & estimated foF2 at Okinawa & Vanimo during 2008 at midnight



Result (Thickness Model) (1/2)

- Seasonal variations in daytime foF2 and TEC show the semi-annual periodicity, with maxima at equinox, and minima at summer. This is related to change in temperature and composition of ions.
- Midnight seasonal variations are not periodic, especially for TEC.
- The charts exhibit the winter and equatorial anomaly for both foF2 and TEC.

Result (Thickness Model) (2/2)

- The Madrigal dataset for some months is underestimated by the model which resulted in large discrepancy between estimated and observed foF2 values
- More efforts are needed to concentrate on the data collection exactly at the location of station under study.

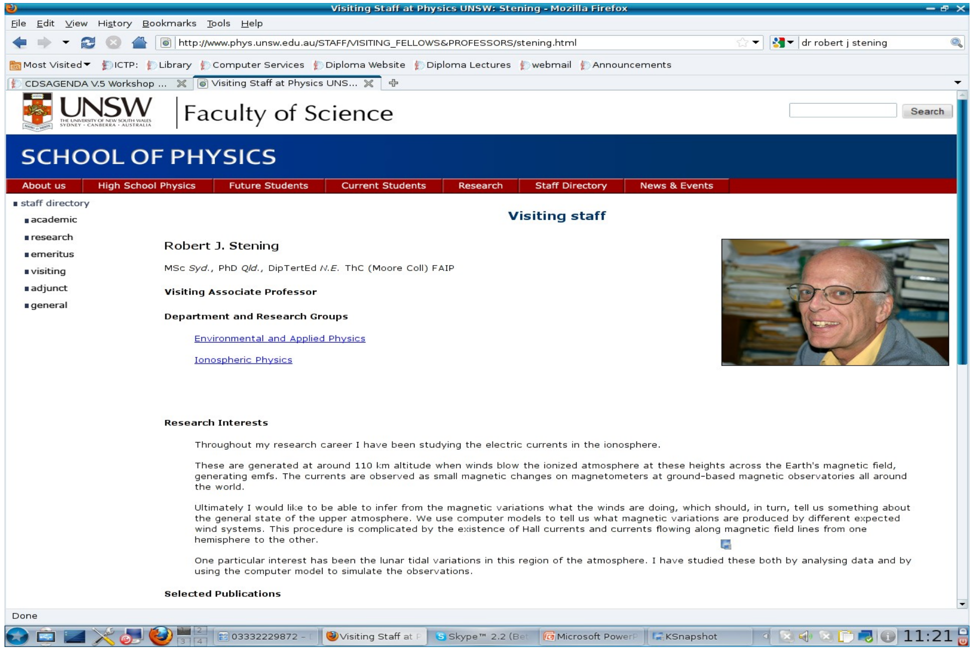
Conclusion

- The idea of using GPS TEC as a proxy of foF2 worked for more than half of the available dataset only.
- NeQuick was given preference over IRI due to its coverage.
- The ionospheric stations under study did not show major deviations from the model due to usual or routine behaviour of ionosphere, but the equatorial anomaly station Vanimo showed higher values of foF2 .

Recommendation

- On the basis of outcome of the current study it is suggested that a large dataset of GPS TEC received over the equatorial anomaly station shall be used to verify and construct a suitable model as desired.
- Improvements in the thickness model are also recommended.

My supervisor and co-supervisor




Thank you