Ionosphere/plasmasphere system in polar region and mid-latitude

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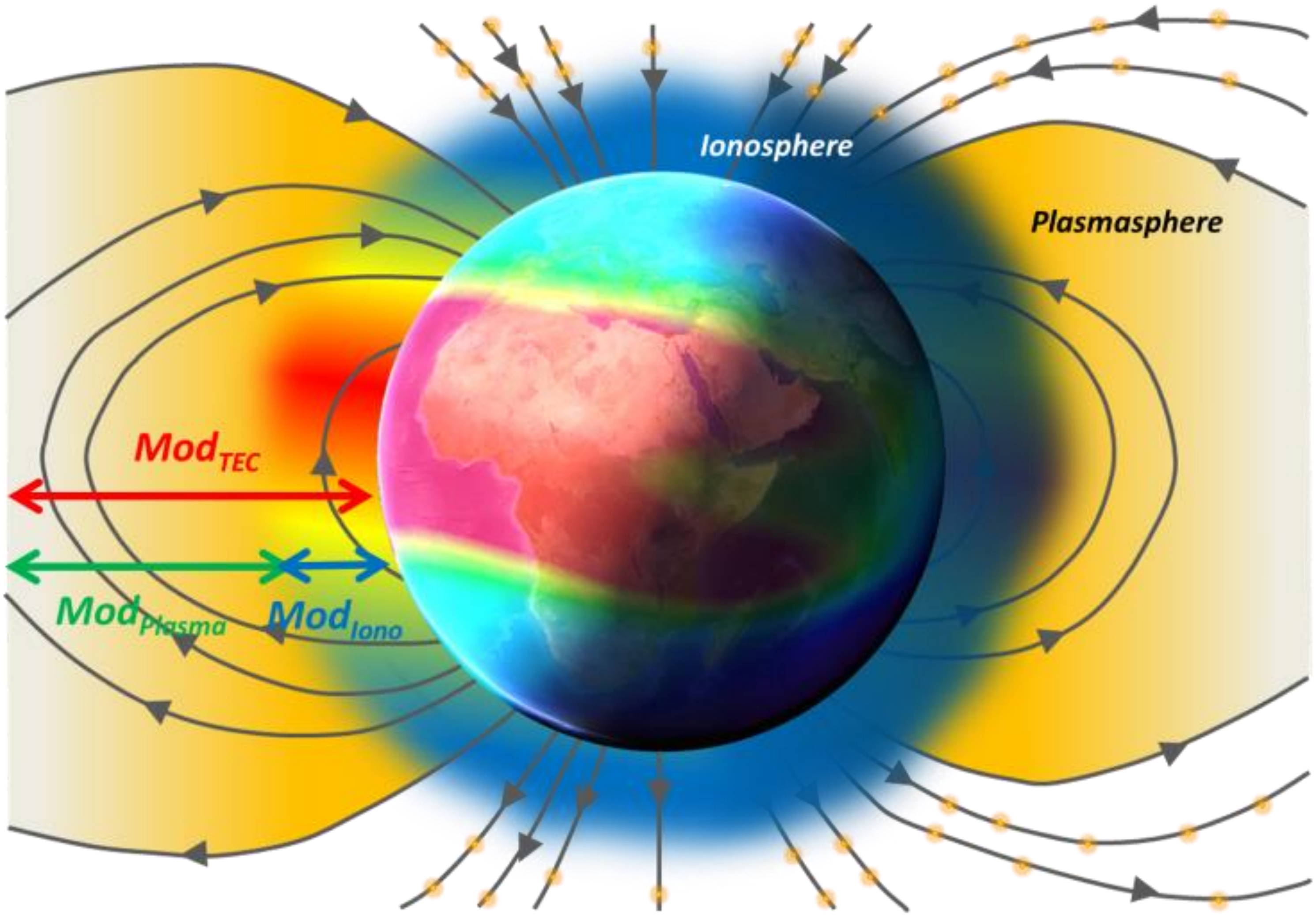
First Workshop under the Project "Interhemispheric Comparison of the Ionosphere-Plasmaphere System (2019-2021)"
SANSA Space Science, Hermanus, South Africa: 19-21 November 2019

What is the contribution of the plasmasphere to GNSS TEC data in at mid-latitudes (BEZA-COM) and Polar regions ?



BEZA-COM: Interhemispheric Comparison of the Ionosphere-Plasmasphere System. 2019-2021

“What are the differences in the inter-hemispheric conjugacy between the ionosphere and that in the lower, middle and upper atmospheres, and what causes those differences?”

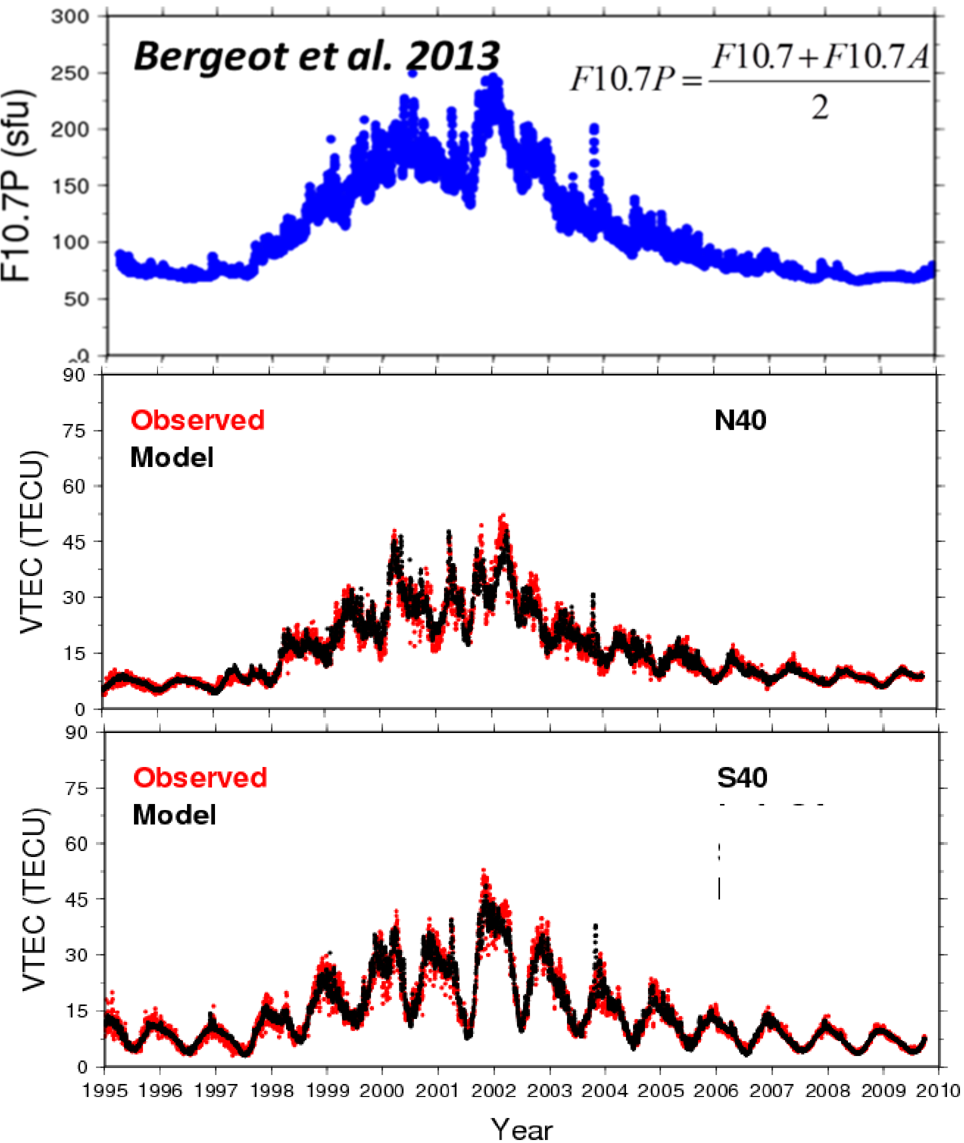
From : Kennicutt, et al., 2015 - A roadmap for Antarctic and Southern Ocean science for the next two decades and beyond*, International Steering Committee of the Scientific Committee on Antarctic Research (ISC-SCAR) *, Antarctica Science.

BEZA-COM: Interhemispheric Comparison of the Ionosphere-Plasmasphere System. 2019-2021

One of the goal of BEZA-COM is to provide inter-hemispheric comparison of the I/Ps implying:

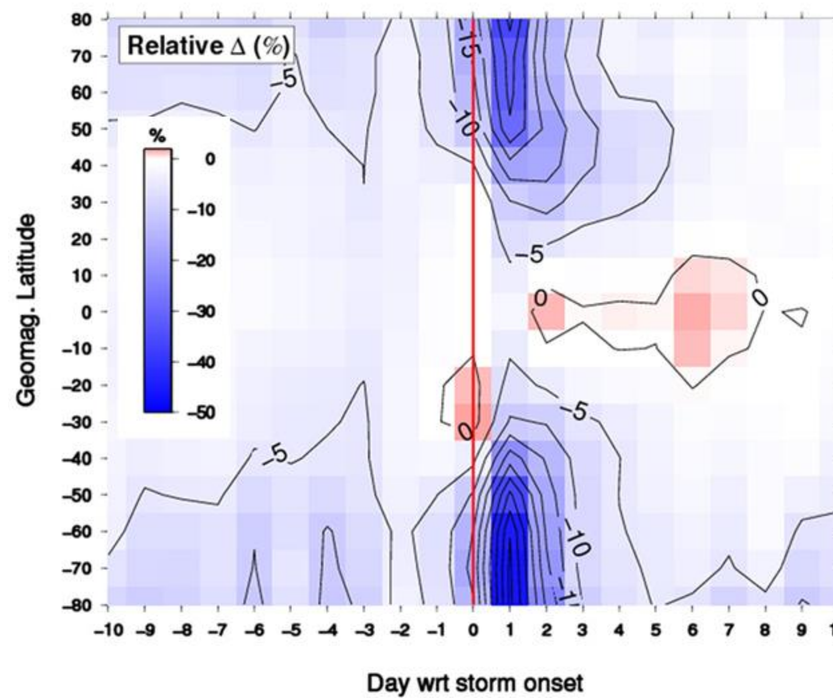
A characterisation of the climatological behaviour of the Total Electron Content (TEC) in the I/Ps, over European and South African regions.

Climatological behavior of the daily mean TEC (DMTEC) at high latitudes



Climatological behavior of the Daily mean Total Electron Content (DMTEC).

Impact of geomagnetic storms on the DMTEC (70 onsets detected from NASA ACE spacecraft for the period 1998 - 2005).



GNSS data processing

Bergeot N., et al. (2014) J. Space Weather Space Clim.

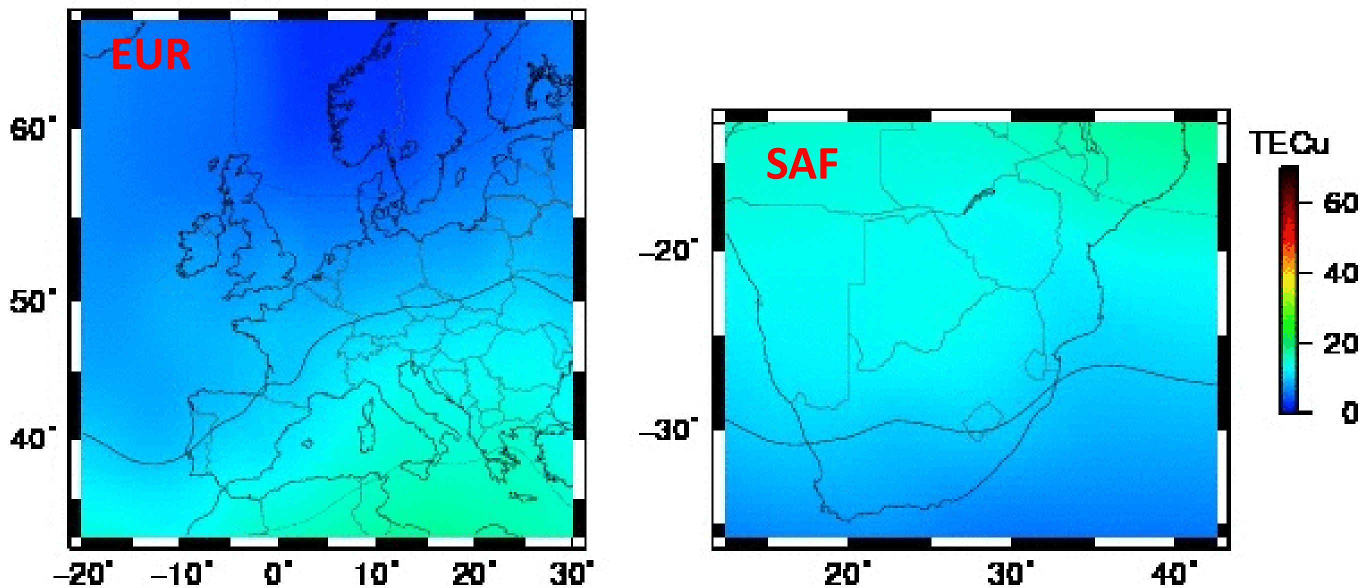
- Input data: ROB-IONO software. GPS + GLONASS data from the EUREF (~320 stations, Bruyninx et al. 2012) or TRIGNET and IGS (~80 stations, www.trignet.co.za and Dow et al. 2009) permanent networks since 1998.

- Outputs: TEC maps in IONEX format in TECu (1 TECu = $10^{16}e^{-}.m^{-2}$)

  Sampling rate : 15 min.

  Grid resolution : 0.5°x0.5°

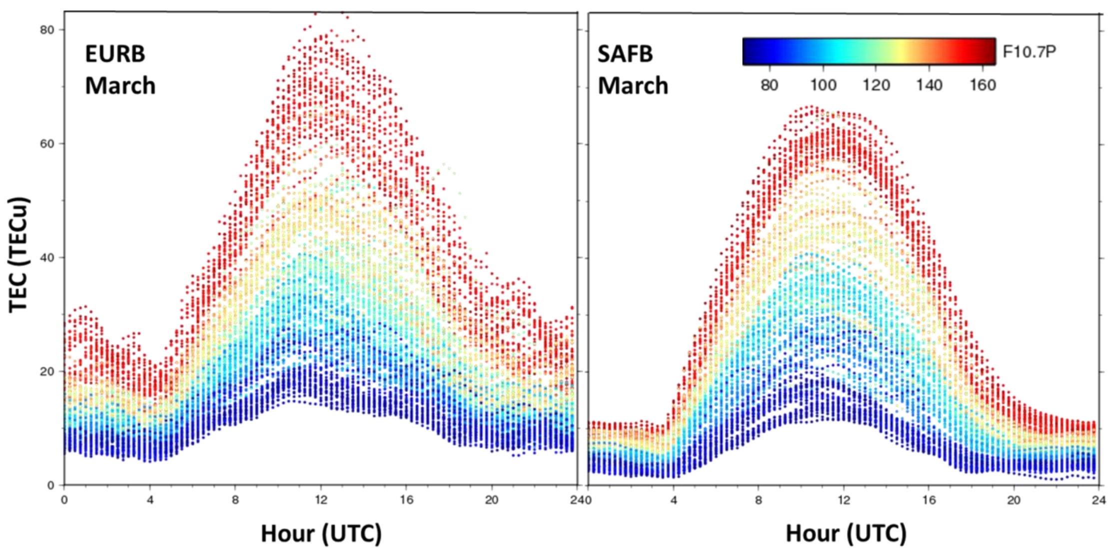
DoY 075 2015
00:00 UTC

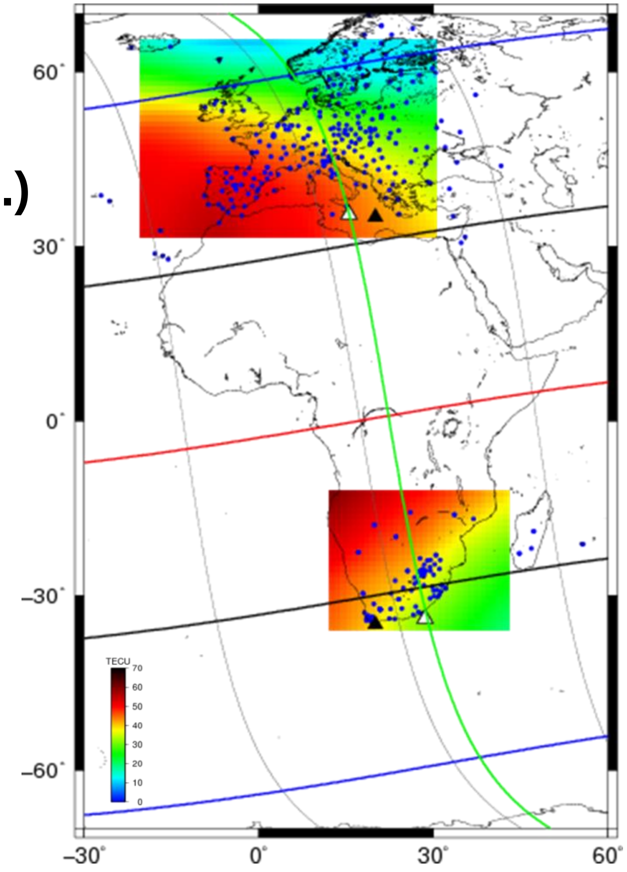


TEC time-series at conjugate locations

Region	Data processing		#Stations	Extracted coordinates	
	TEC at IPP	TEC maps		Geographic	Geomagnetic
EU (EPN)	1998-2017	1998-2017	57-320	E20 / N35 **EURG**	E95 / N35 **EURB**
SA (TRIGNET) + IGS	2000-2017	2003-2017	3-83	E20 / S35 **SAFG**	E95 / S35 **SAFB**

14 years of TEC maps for South Africa
19 years of TEC maps for Europe
Conjugate locations : E95° N-S 35° (Geomag. Coord.)

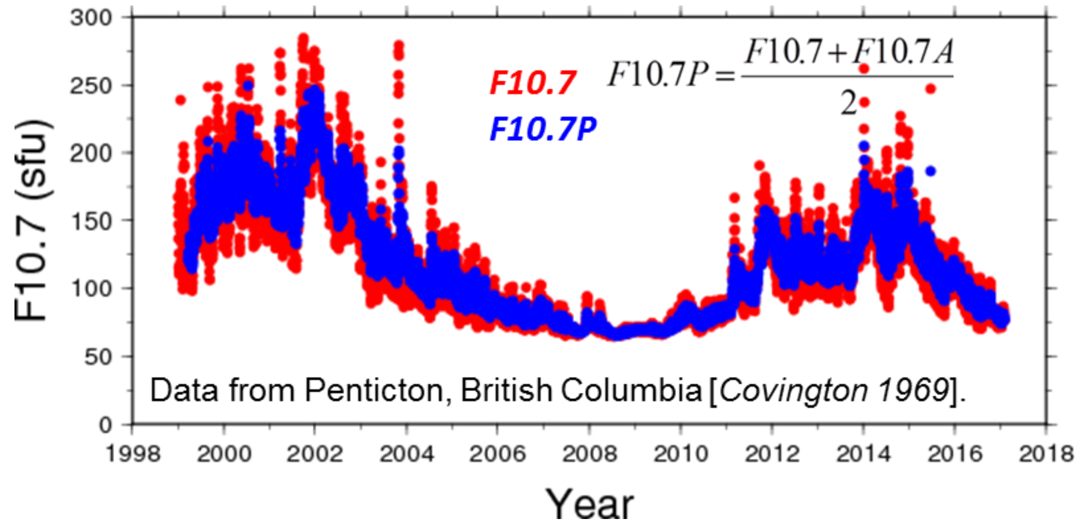




Empirical TEC-model

Empirical model based on F10.7P index (~ EUV emission from the Sun)

The data set is then employed to constrain an empirical model to predict the vTEC at a given time and location from F10.7P solar index in entrance using a least-square adjustment.



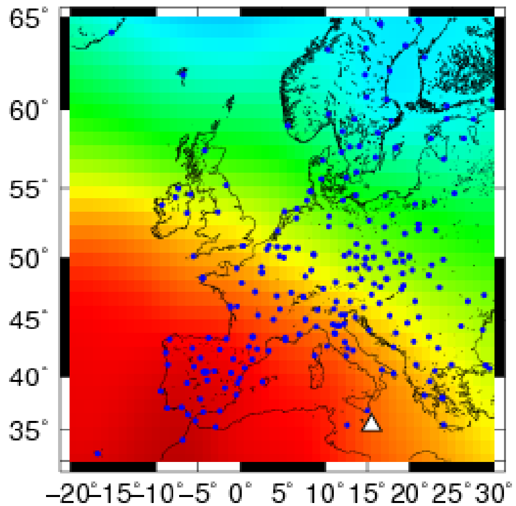
To minimize the differences between the modelled and observed TEC we considered:

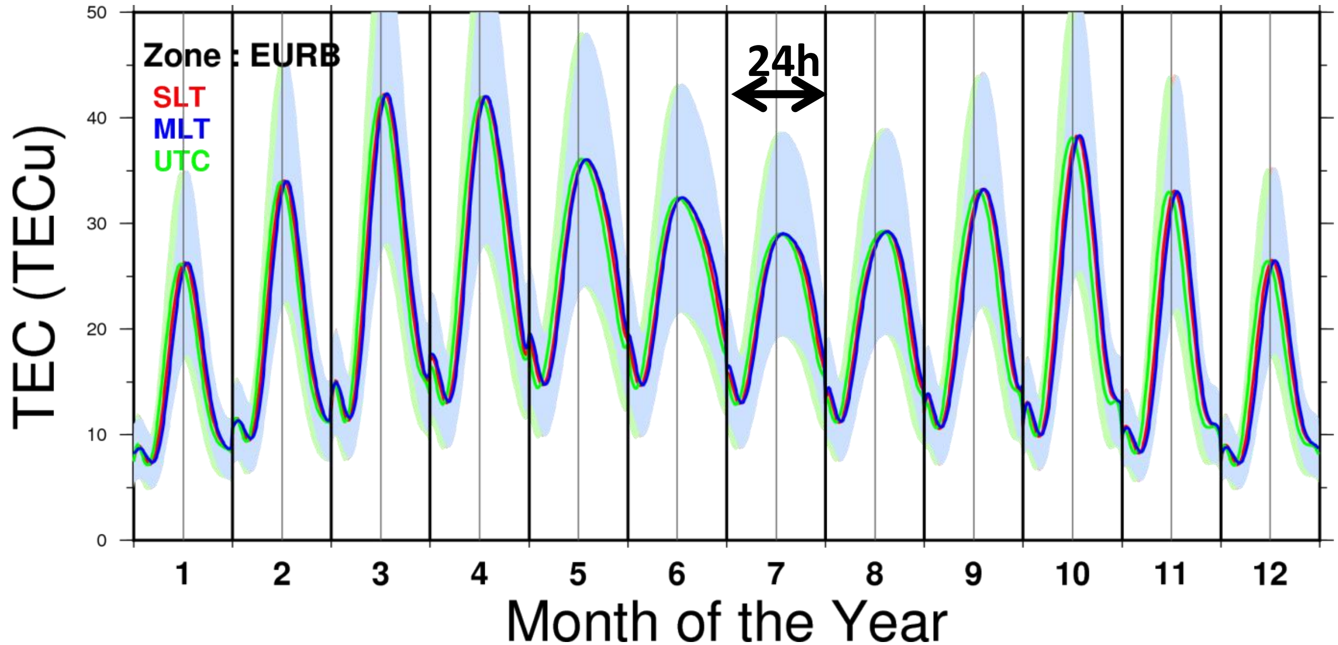
- An eight-order polynomial function between the TEC and F10.7P

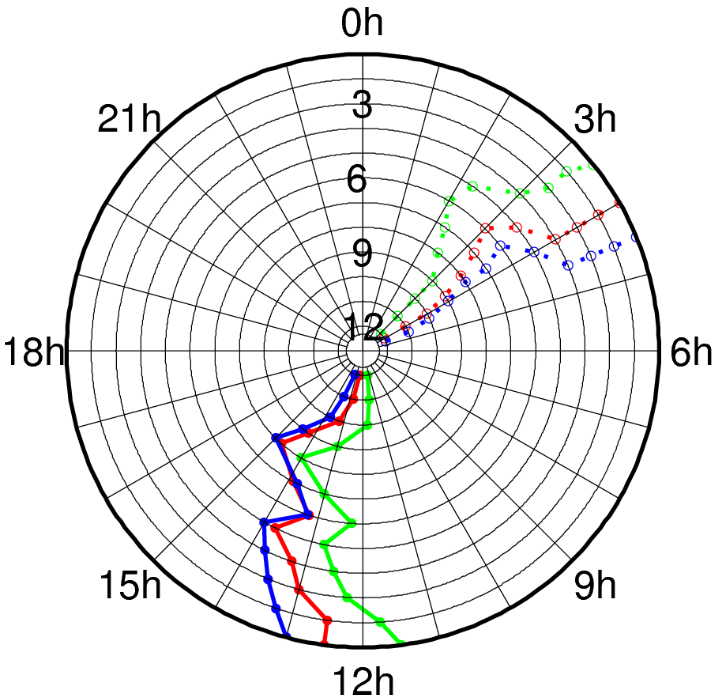
$$TEC = F10.7P \sum_{i=0}^{i=8} (\alpha_i t^i + \beta)$$

- A discretization with respect to the month of the year.

Daily-TEC climatological patterns - Europe





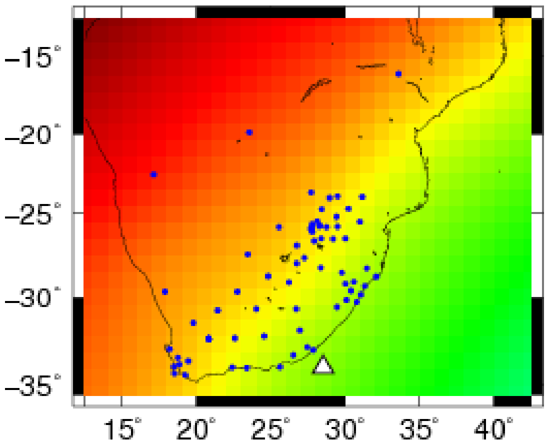


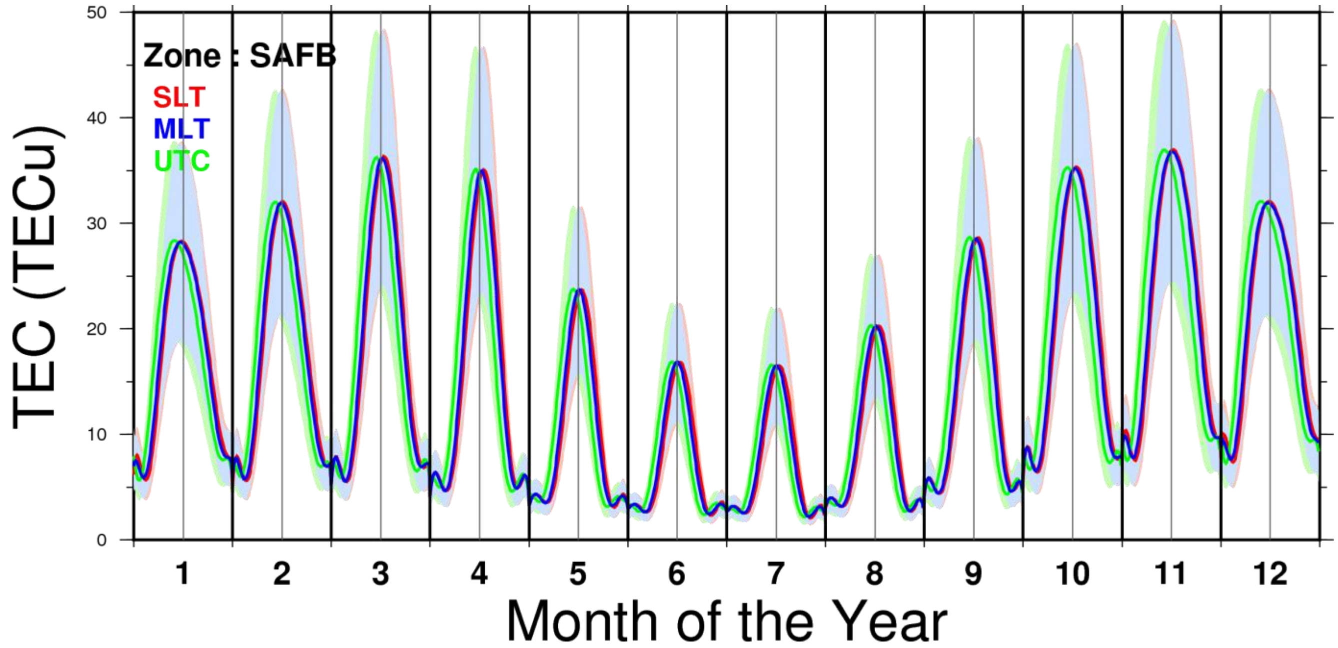
TEC presents mean differences with observed values of 0.5 ± 1.2 TECu for European region (~57000 data/month).

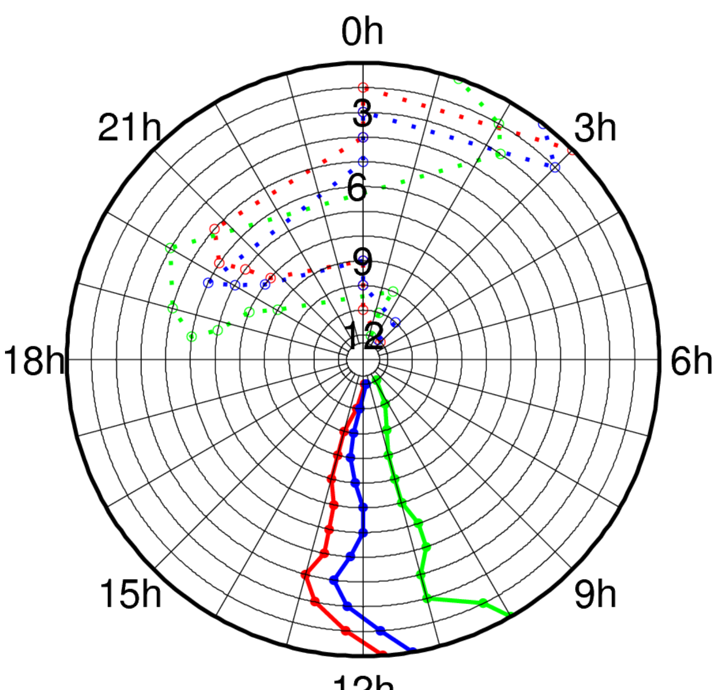
The maximum TEC occurs mainly around 13:00 for any of the time definitions (UTC, SLT and MLT) and are quite constant over the year.

F10.7P=120 sfu
Max. TEC = 42 TECu in March
Min. TEC = 7 TECu (F10.7P=120 sfu) in December

Daily-TEC climatological patterns - South Africa







TEC presents mean differences with observed values of 0.4 ± 0.6 TECu for South African region (~41 000 data/month).

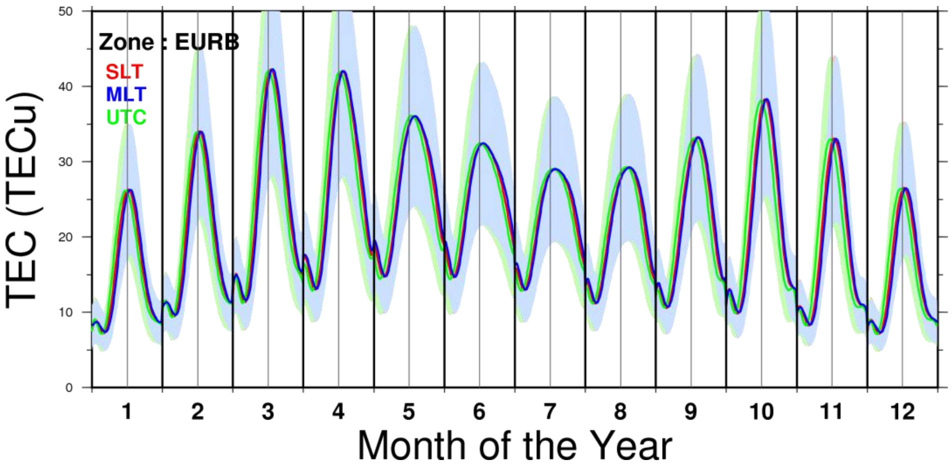
The maximum TEC occurs mainly around noon for any of the time definitions (UTC, SLT and MLT) and are quite constant over the year.

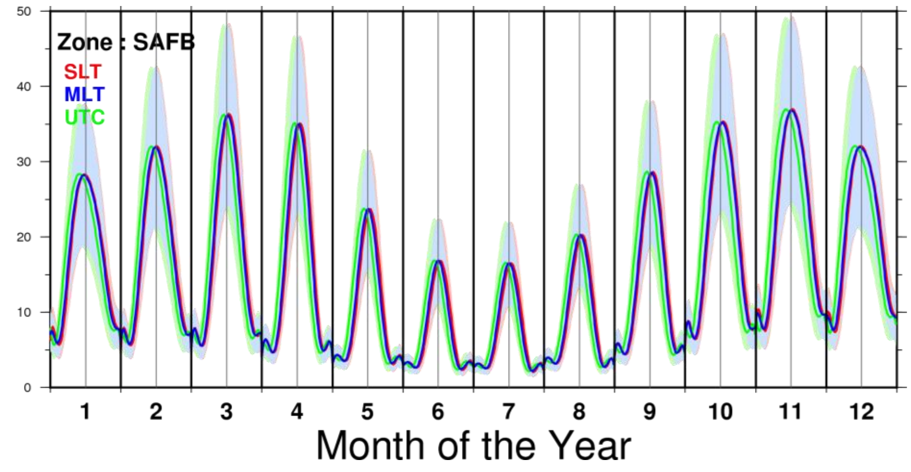
F10.7P=120 sfu

Max. TEC = 36 TECu in March

Min. TEC = 2 TECu in November

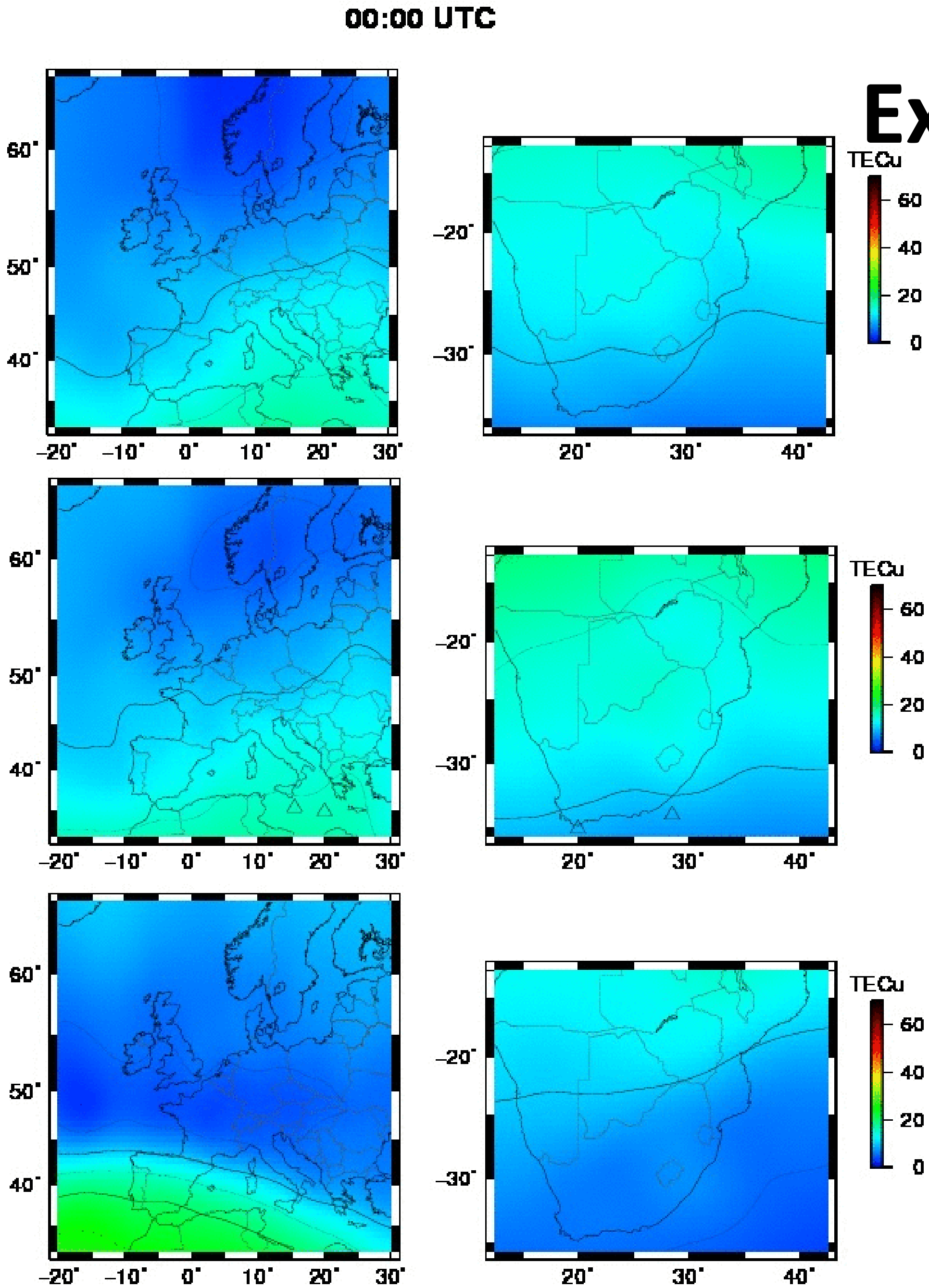
Inter-hemispheric comparison





- ✓ The maximum of the TEC is higher during the daylight (10 to 55% for hours between 10:00 and 15:00) in the Northern hemisphere compare to the Southern for February to September.
- ✓ The maximum of the TEC is higher (5 to 20% for hours between 10:00 and 15:00) in the Southern hemisphere from November to January.
- ✓ The minimum TEC (i.e. during low solar zenith angle between 22:00 and 6:00) is also higher in the Northern hemisphere for the period February-September (16 to 80%).
- ✓ The minimum TEC is higher in the Southern hemisphere (16 to 45%) during from November to January.
- ✓ The time of occurrence of the minimum TEC is generally constant over the year for the European region.

Intense I/P activity
Ex. St Patrick Storm 2015



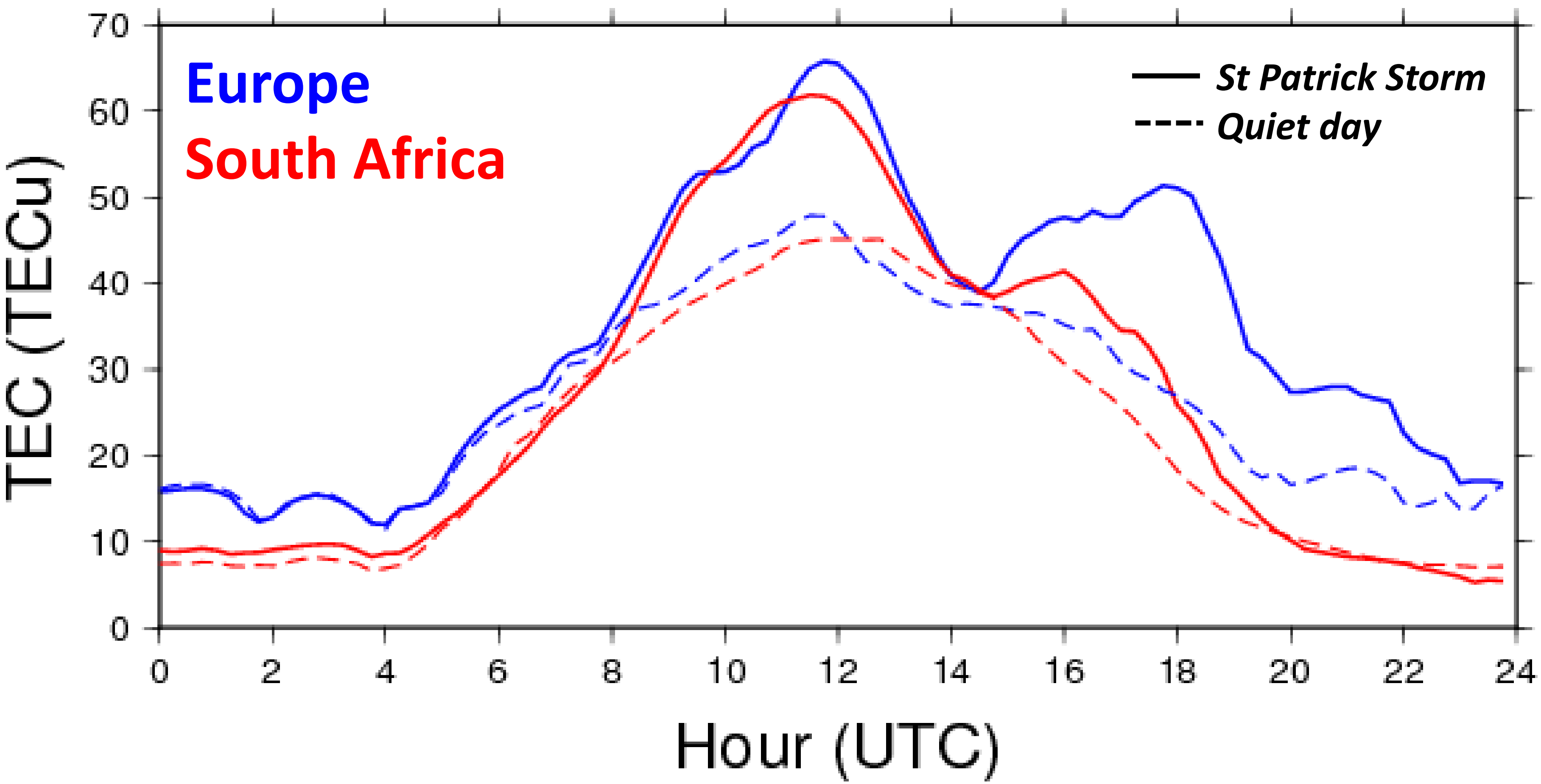
16th March 2015

17th March 2015

18th March 2015

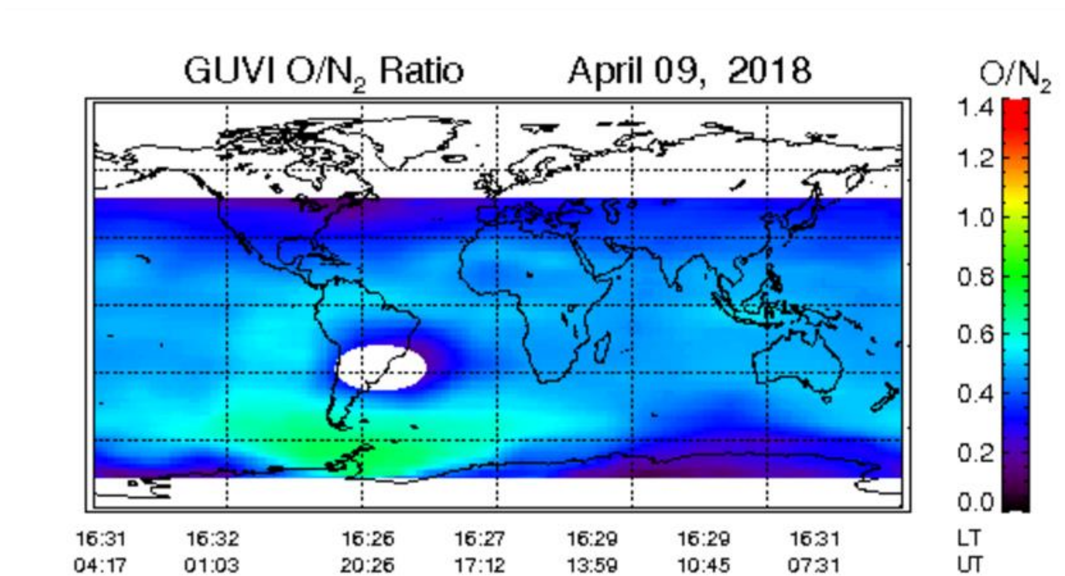
March 17, 2015 - Onset 03:30 UTC
Dst = -223 nT – Geom. Storm (Kp=7)

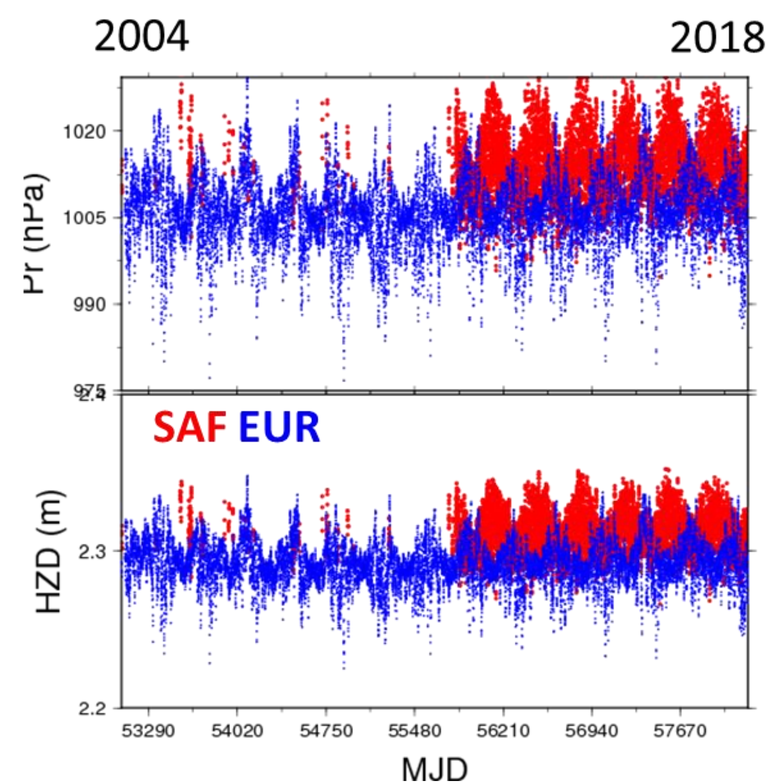
Intense I/P activity
Ex. St Patrick Storm 2015



Next Steps

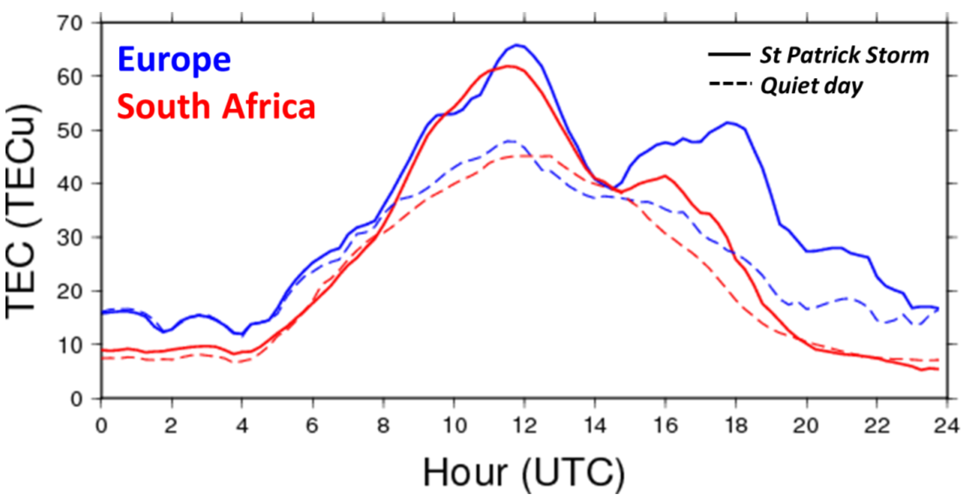
- An identification of the mechanisms that regulate inter-hemispheric differences, asymmetries and commonalities in the I/Ps from low to high-latitudes.





Next Steps

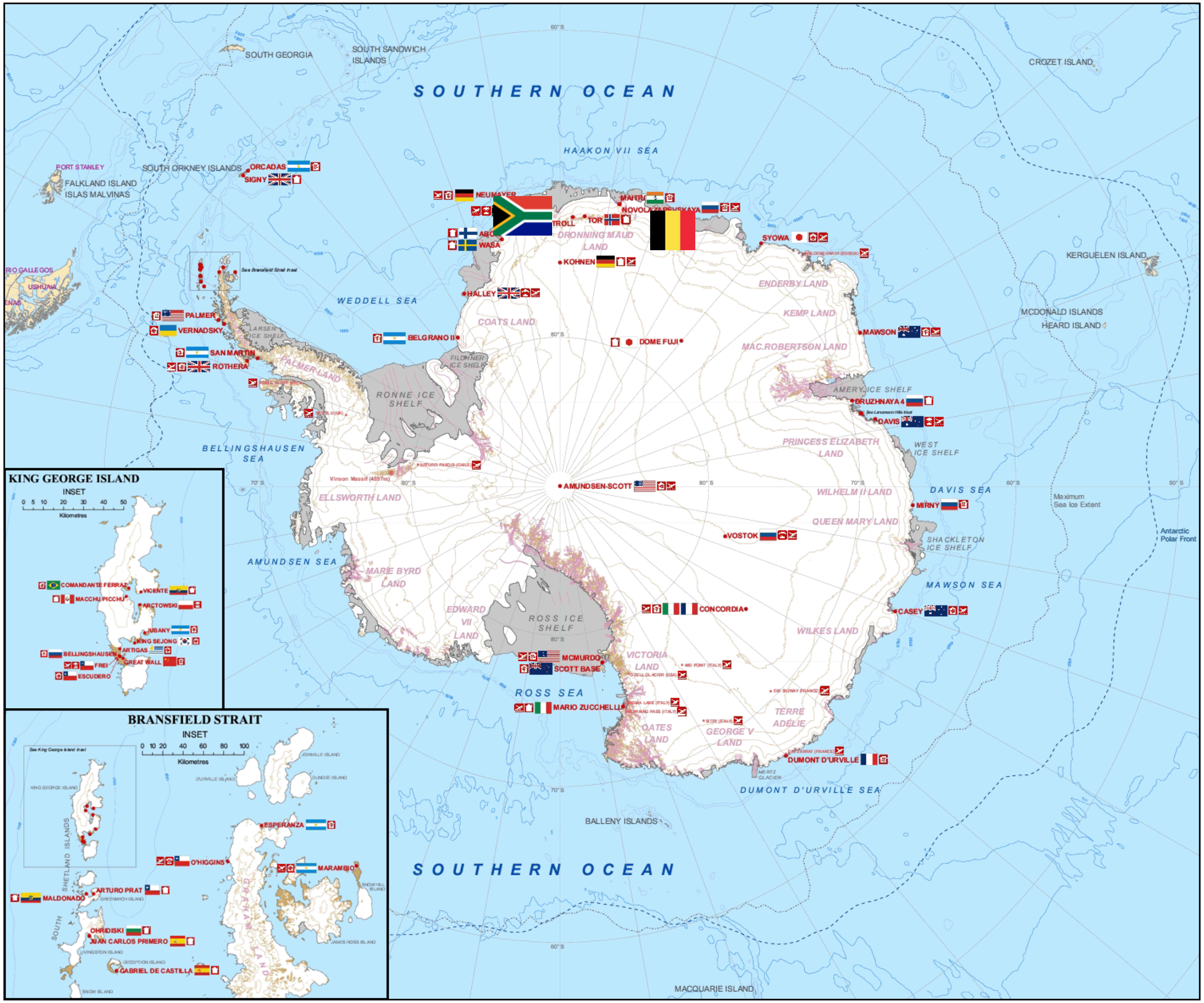
- A study of the different responses of the I/Ps during extreme solar events and induced geomagnetic storms in the two hemispheres.



Moderate	**#163**
Intense	**#35**
Super-storm	**#3**

#174 storms since 2003

What is the contribution of the plasmasphere in Polar regions ? Here Antarctica.



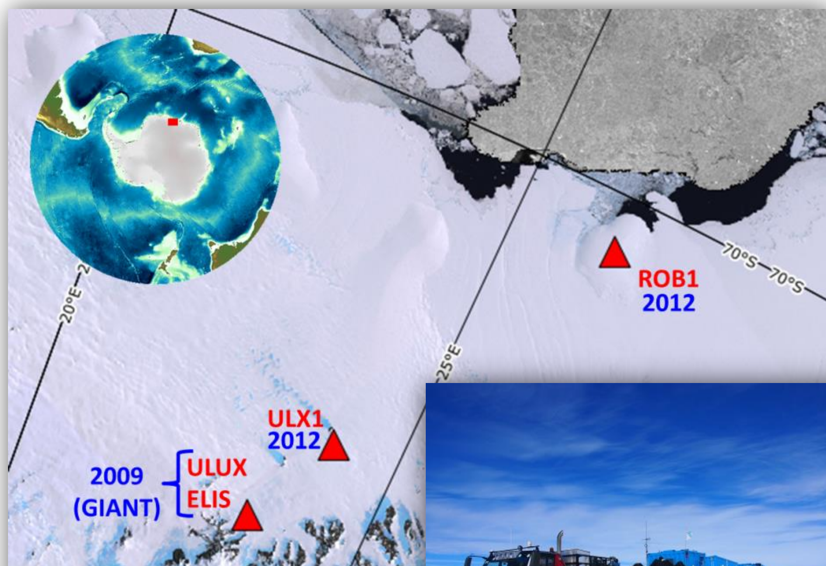
Princess Elisabeth station
Utsteinen

Geographic Coordinates
71.93S 23.33E
Ellipsoid Height : 1389.8 m

Magnetic Coordinates
70.54S 68.52E

Operational since February 2009

Instrumentation dedicated to Geospace environment monitoring at PEA monitoring



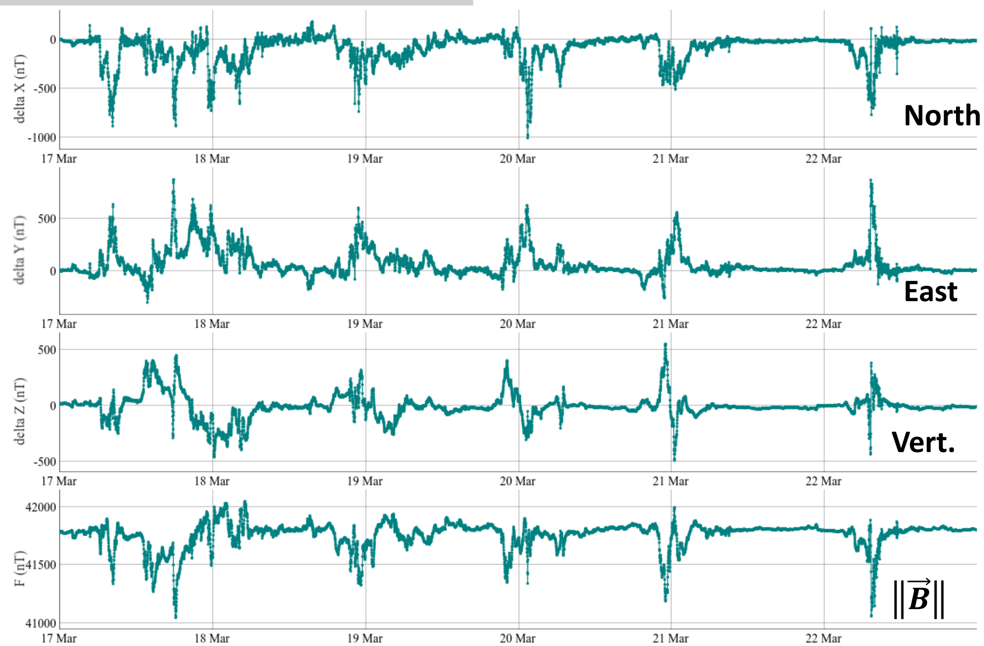
Instrumentation dedicated to Geospace environment monitoring at PEA monitoring

GEOMAG project (since 2015)

A proton magnetometer

A triaxial variometer

Data : 1 Hz to 10 Hz data send in NRT at RMI.

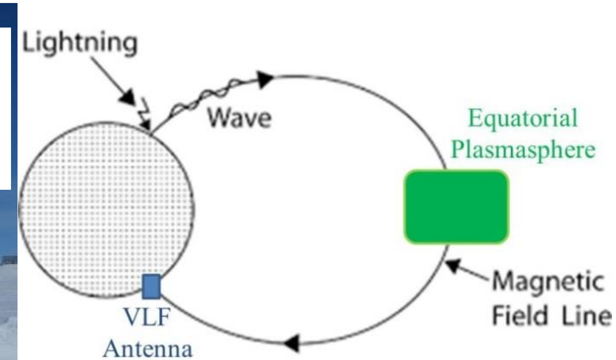


Absolute measurement of magnetic induction and sampling of the magnetic field

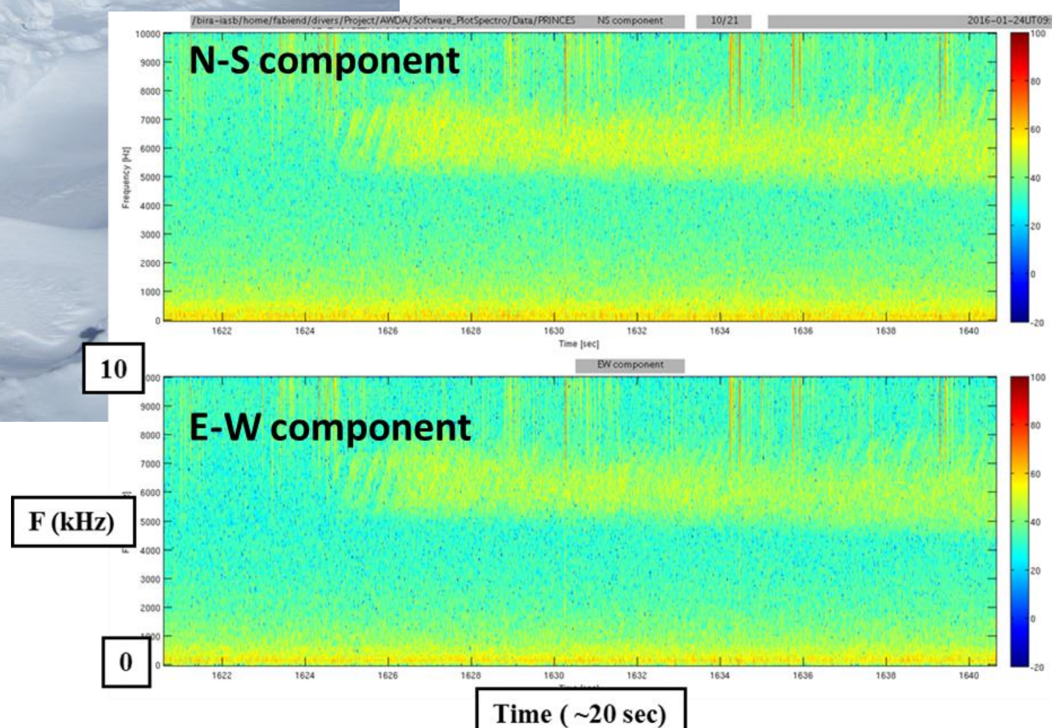
Instrumentation dedicated to Geospace environment monitoring at PEA monitoring

AWDA project (since 2016)

VLF AWDA magnetic antenna

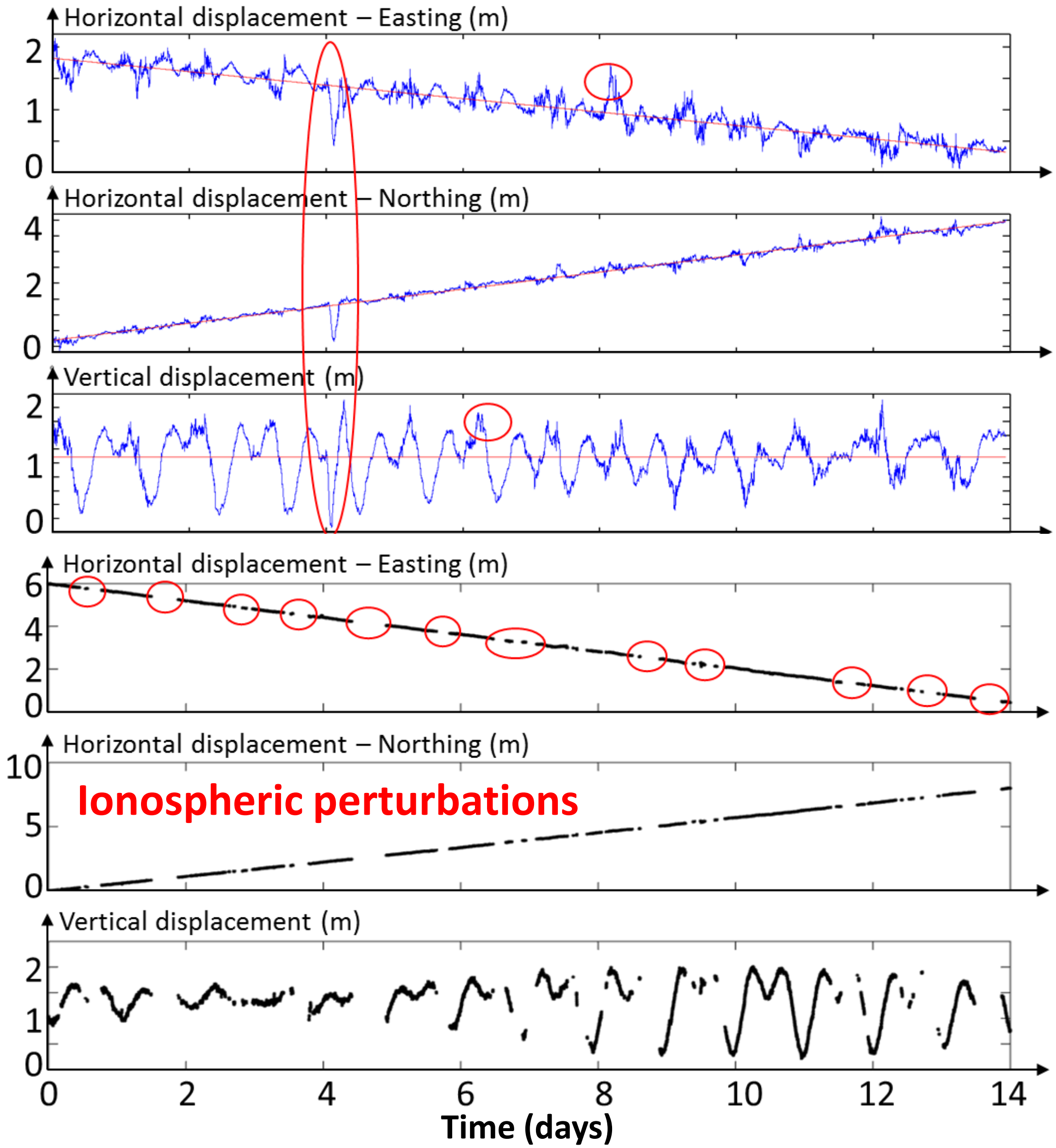


Detector of whistler waves.

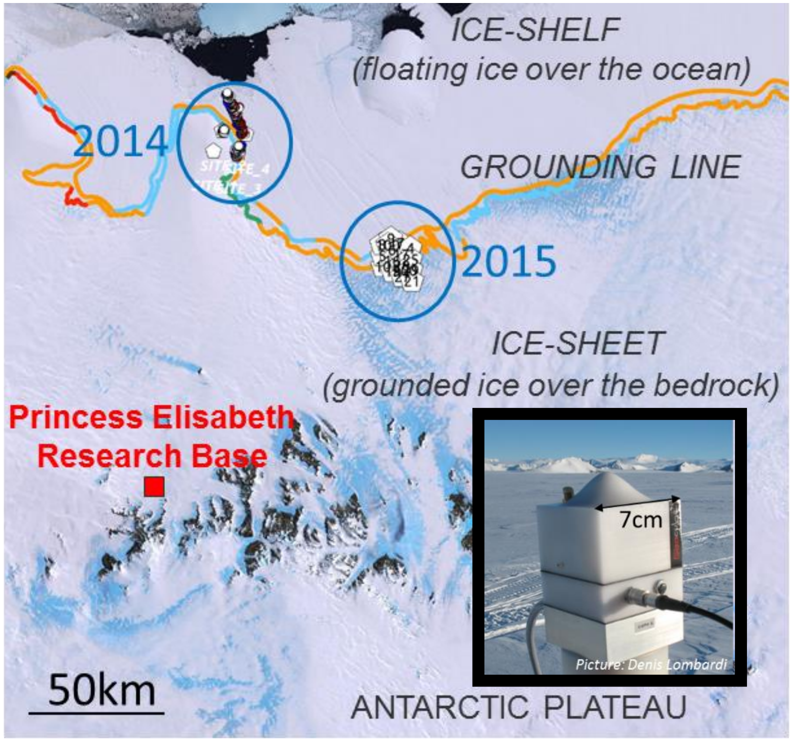


The goal is to infer information about the state of the plasmasphere (Lichtenberger, 2009)

Dense networks of single-frequency GPS receivers in North-East Antarctica ?

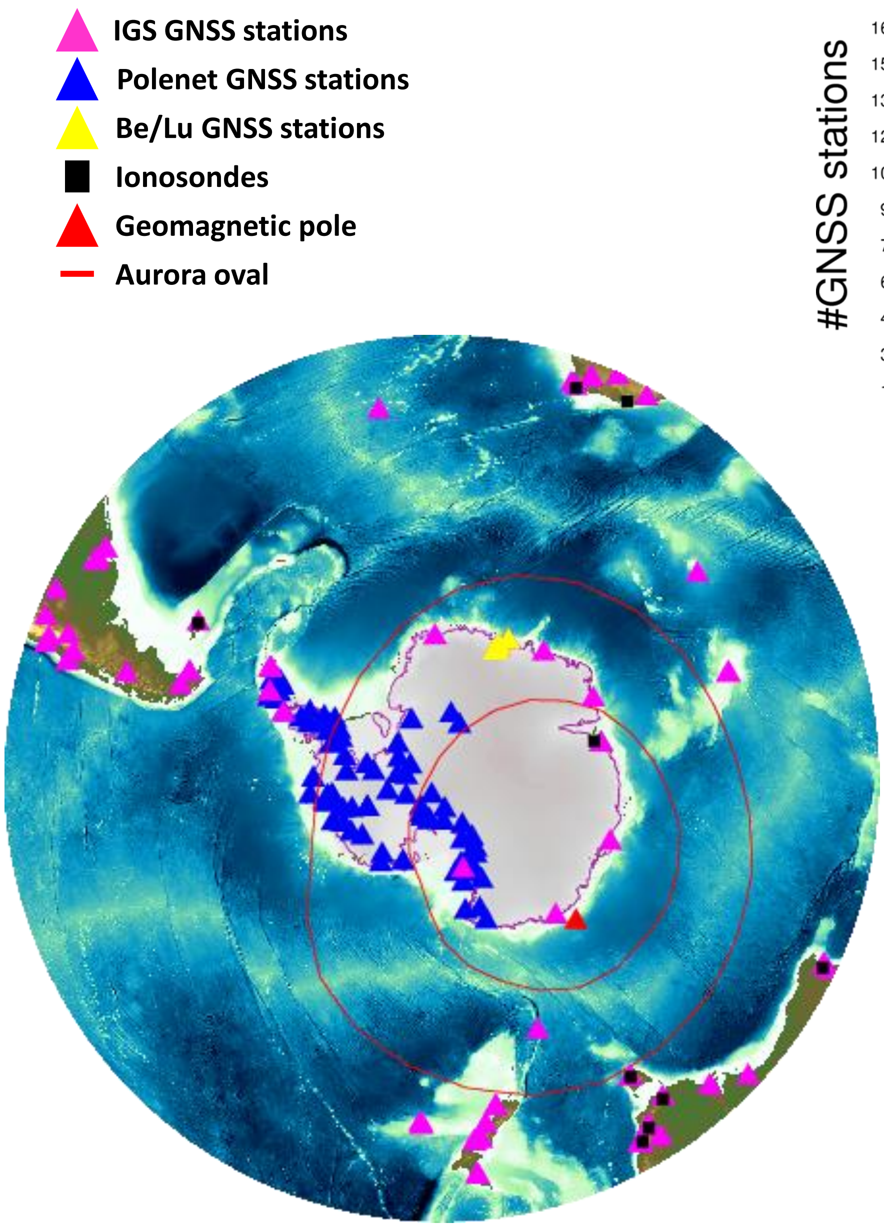


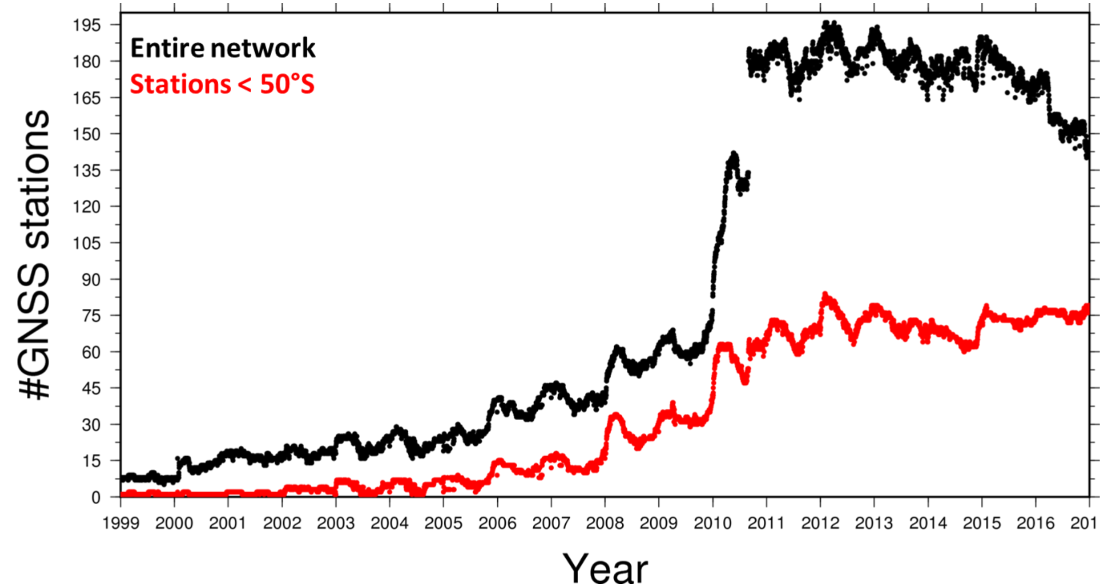
Courtesy: L. Benoit, D. Lombardi, C. Thom (IGN-ROB) – Lombardi et al. 2016



Ionospheric un-modelled electron content is the main obstacle to extend single-frequency GPS positioning from <1km to 1-10km baselines.

IGS + POLENET + BE/LUX (PEA) GNSS stations





IGS (Dow et al. 2009) http://www.igs.org/

POLENET http://polenet.org/

http://www.unavco.org/

BE-LUX Stations

Important for the densification in North-East Antarctica region.

GNSS data reprocessing

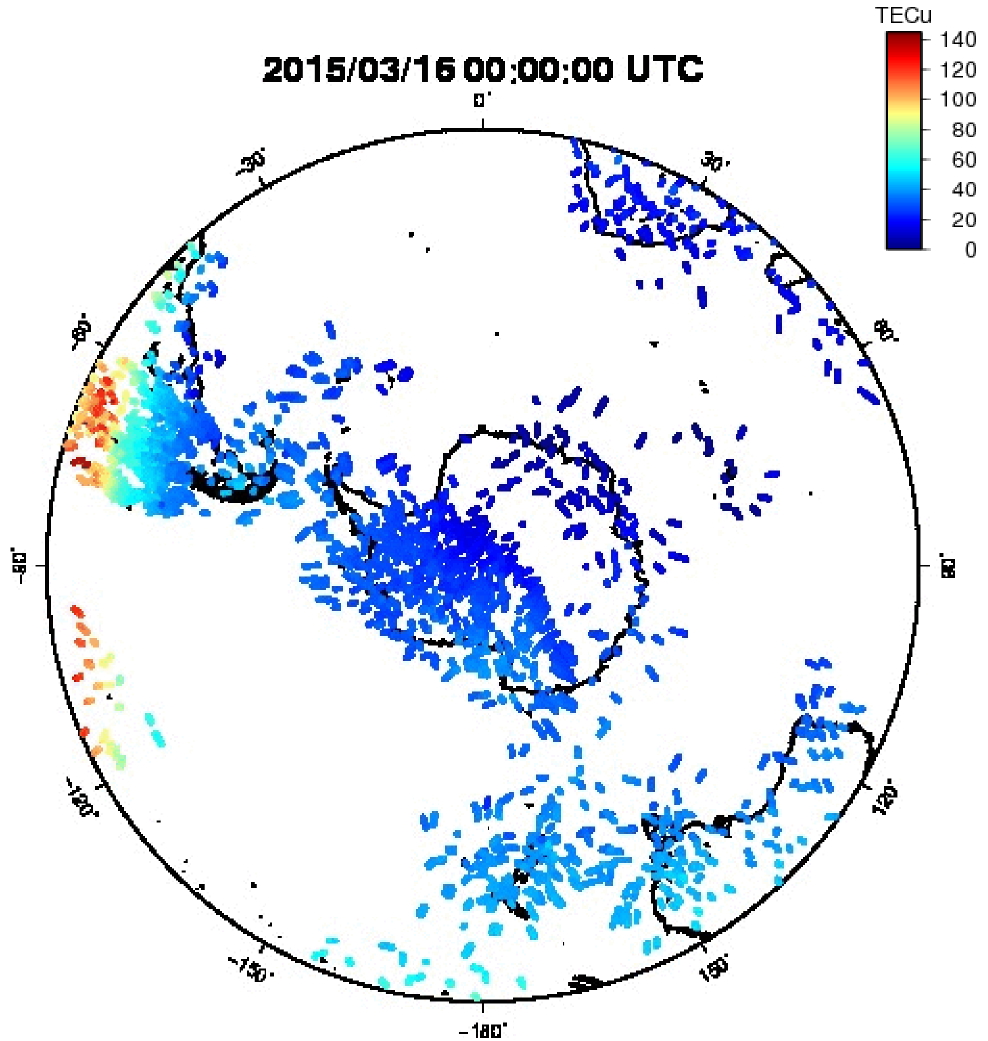
Reprocessing of the entire network using GPS + GLONASS data for the period 1998-2018

ROB-IONO software (Bergeot et al 2014):

- ➢ Phase-smoothed code observables
- ➢ A two phases processing approach (DCB then sTEC_2_vTEC)

Output : vTEC at IPPs for every 30s

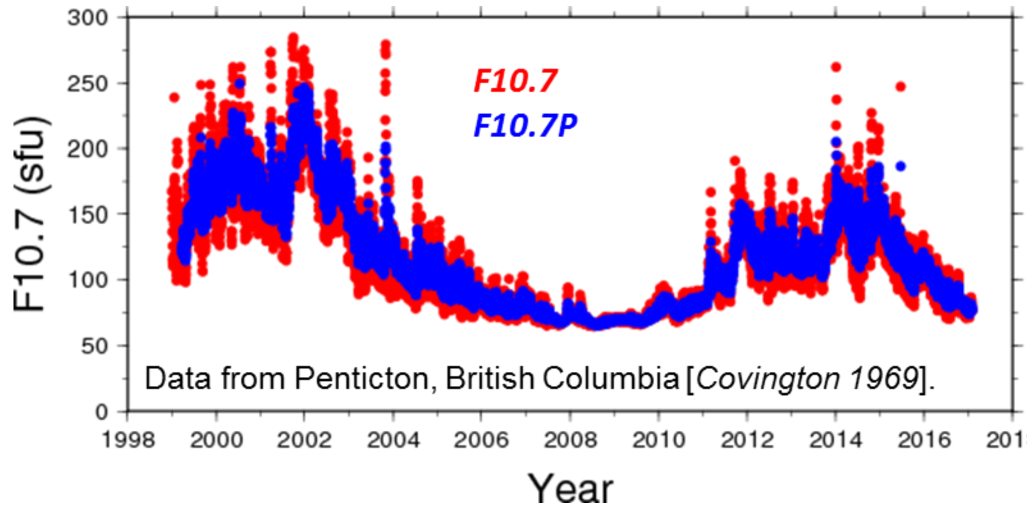
Cut –off angle : 40°



Multi-Stations empirical TEC-model

Empirical model based on F10.7P index (~ EUV emission from the Sun)

The data set is then employed to constrain an empirical model to predict the vTEC at a given time and location from F10.7P solar index in entrance using a least-square adjustment.



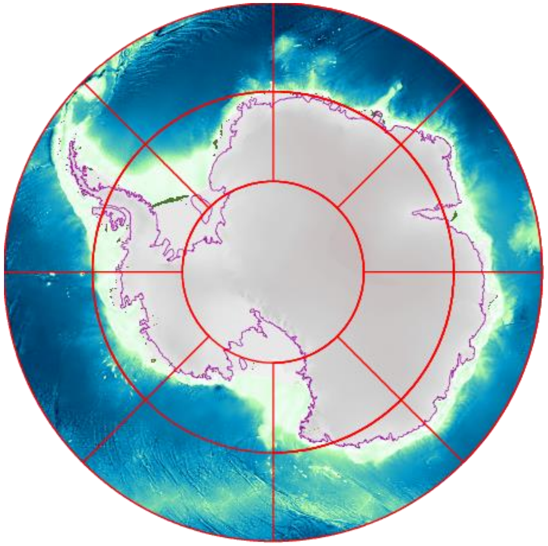
To minimize the differences between the modelled and observed vTEC we considered:

- An eight-order polynomial function with monthly coefficients between the TEC and F10.7P

$$TEC = F10.7P \sum_{i=0}^{i=8} \left(\alpha_i t^i + \beta \right)$$

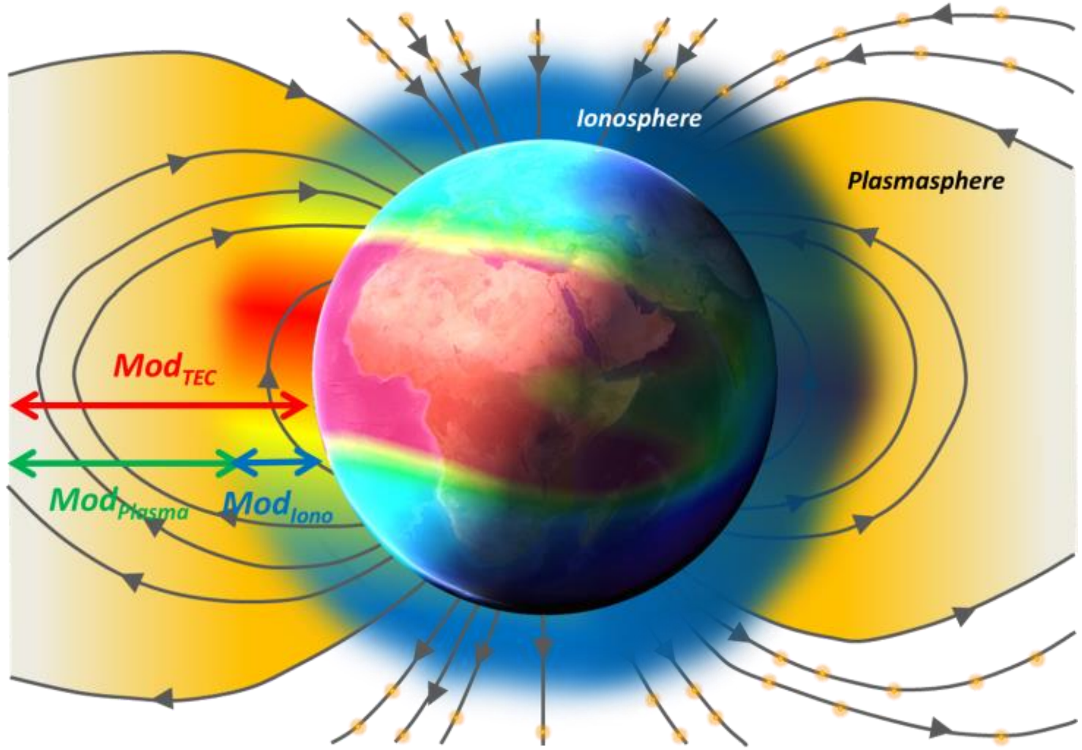
- A discretization with respect to different zones over Antarctica region to highlight different climatological patterns.

Multi-Stations empirical TEC-model

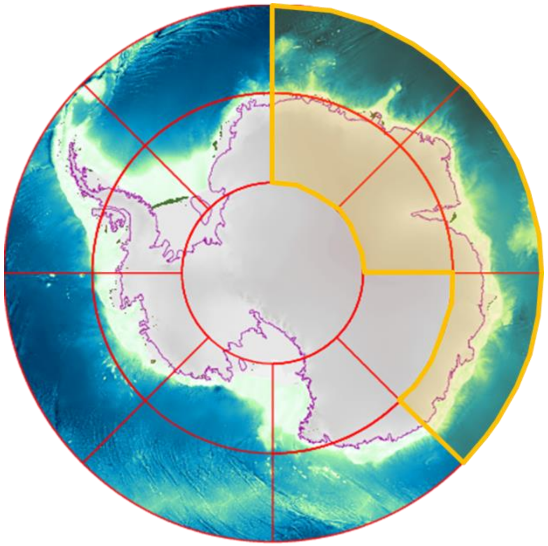


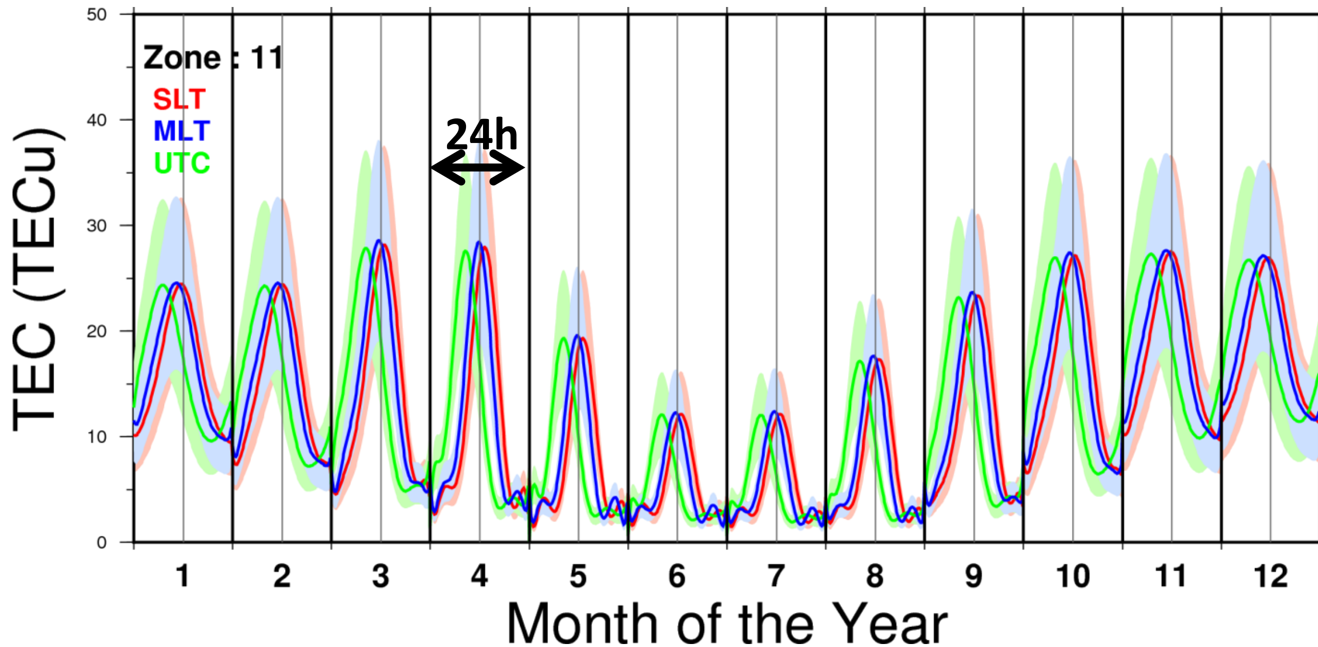
Antarctica divided in 17 zones.

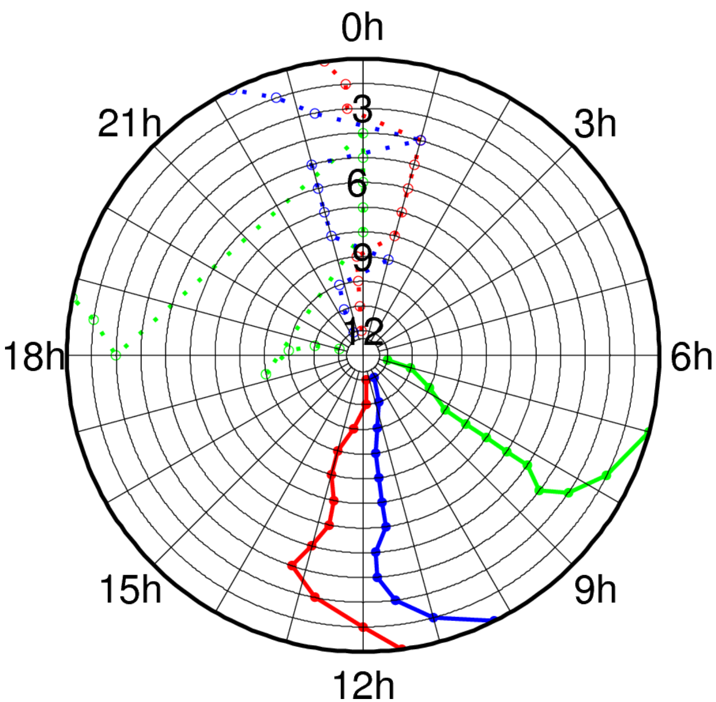
- **~5 000 000 of TEC at IPPs per zone/per month**
- **Mean differences : 0.1 ± 4.3 TECu**



Daily-TEC climatological patterns

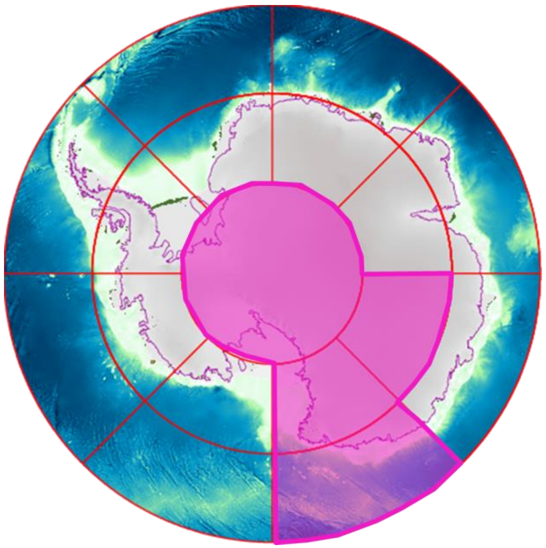


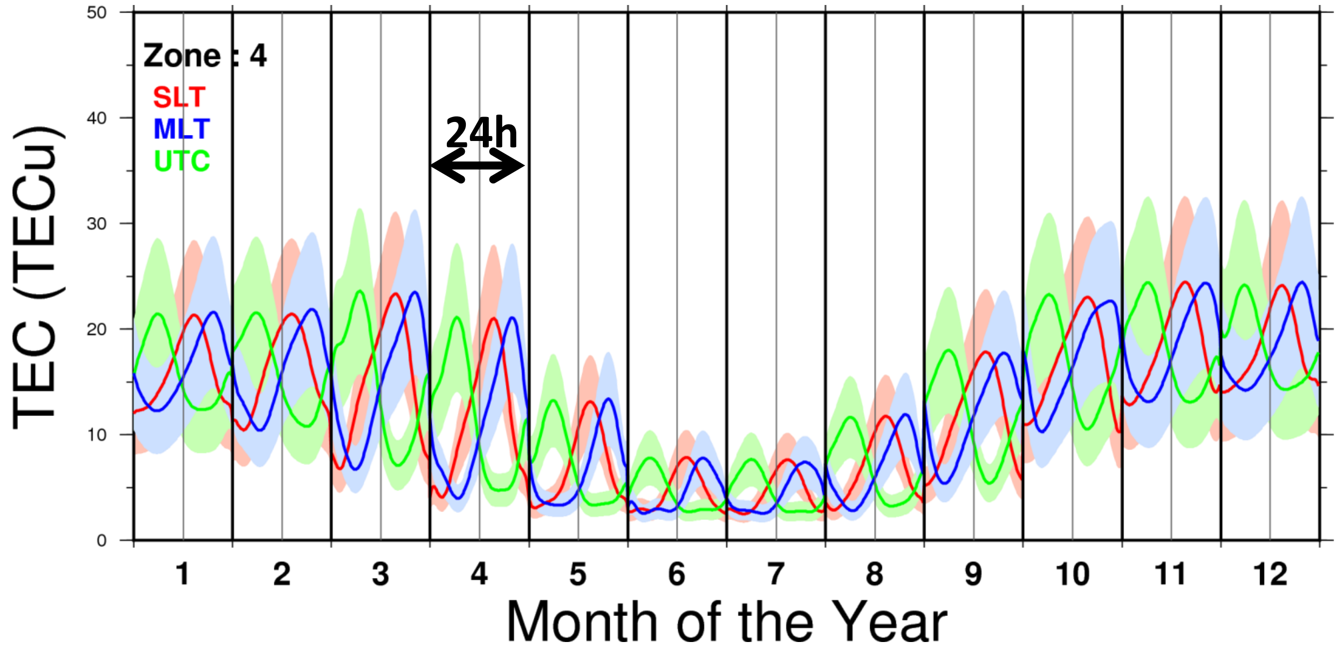


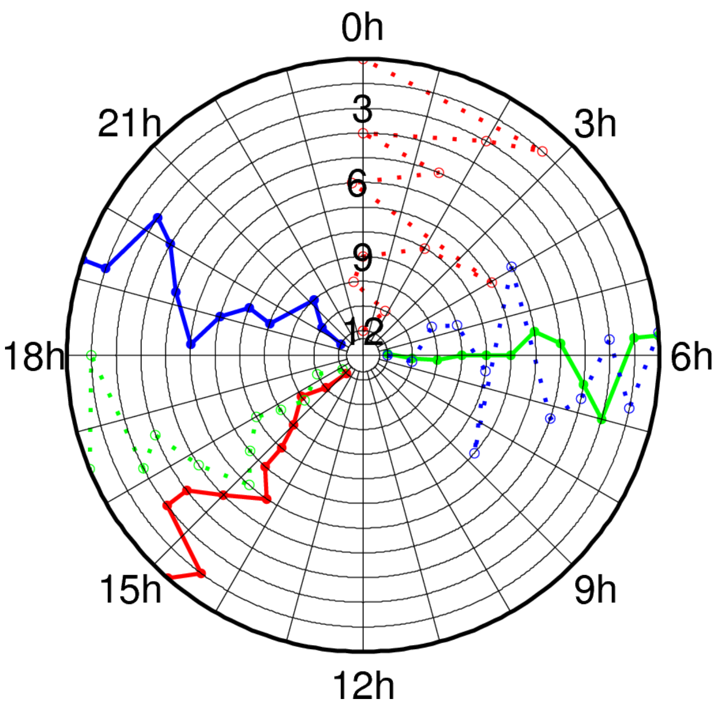


The maximum TEC occurs around 12:00 SLT, 11:00 MLT and 08:00 UTC with no significant variation w.r.t the month of the year.

Daily-TEC climatological patterns

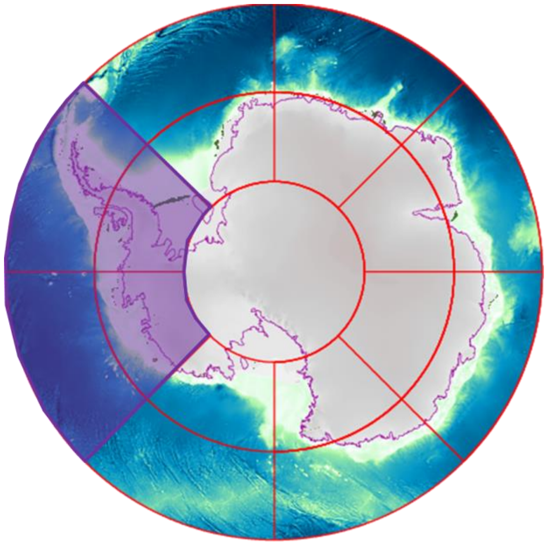


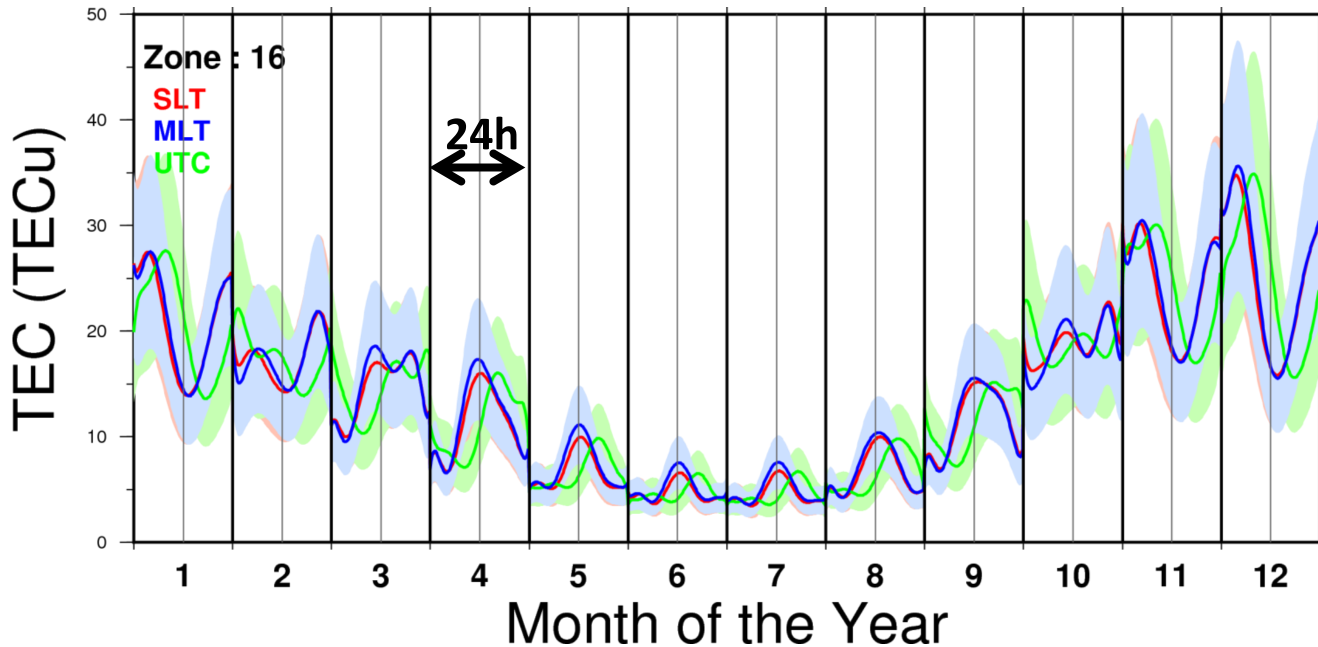


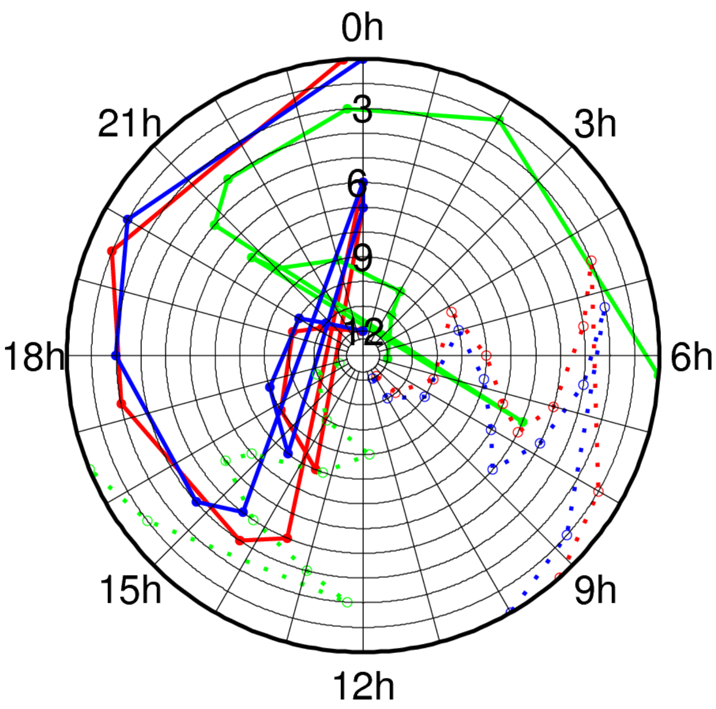


The maximum TEC is constant over the year and at 19:00 MLT. Maximum TEC is around 06:00 UTC and 15:00 SLT with no significant change the entire year.

Daily-TEC climatological patterns

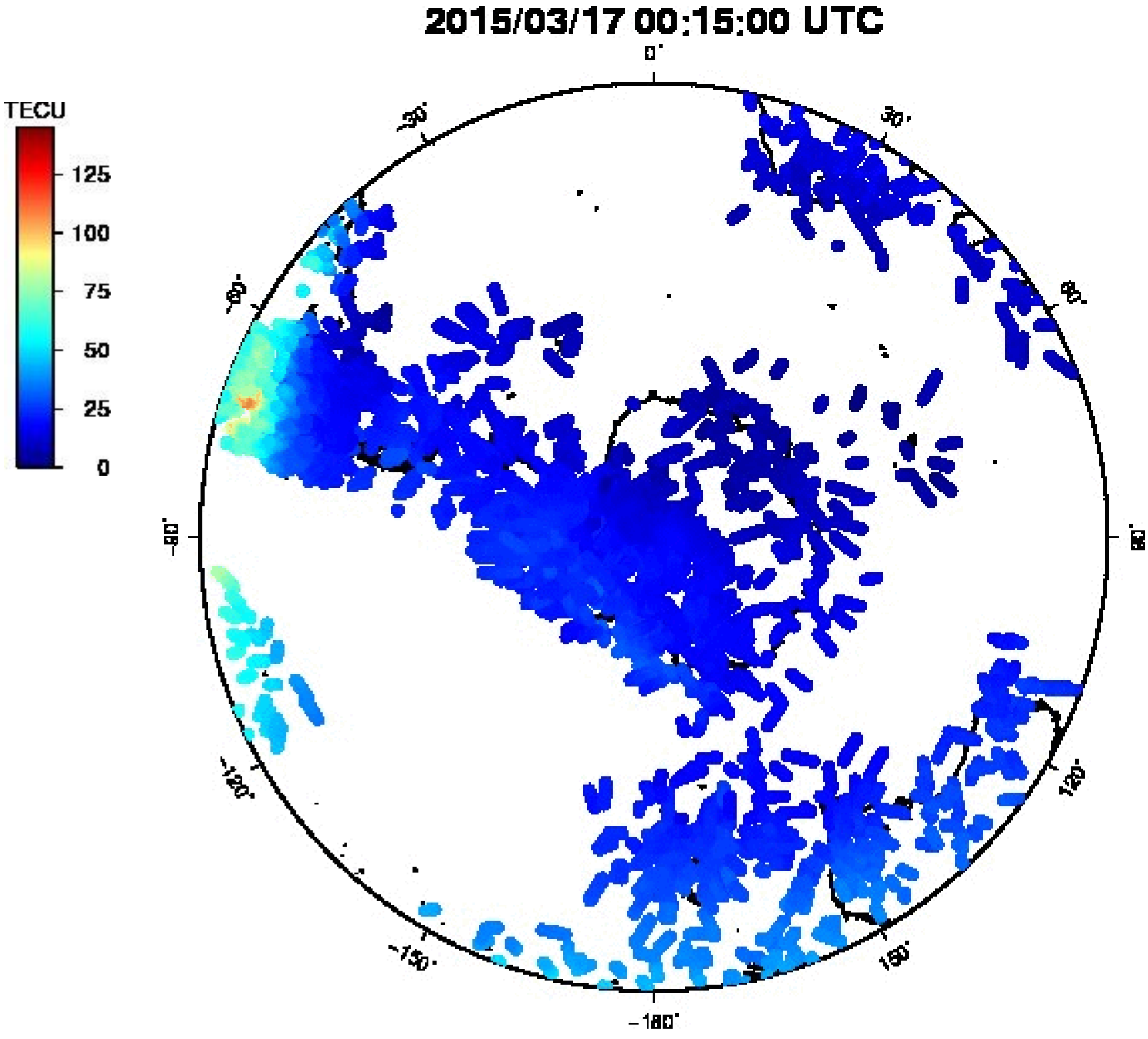






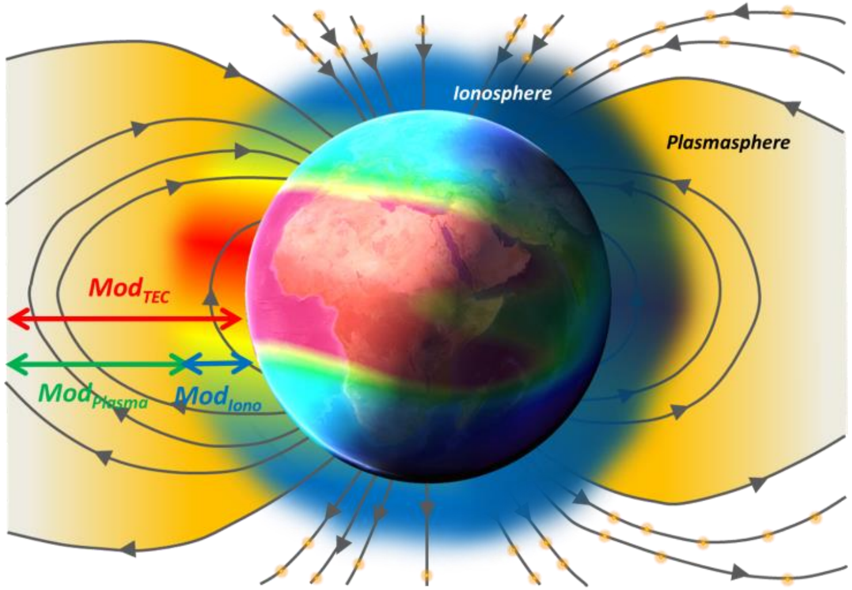
The maximum TEC is observed during the afternoon and evening for the three time definitions. This is due to the Weddell Sea Anomaly.

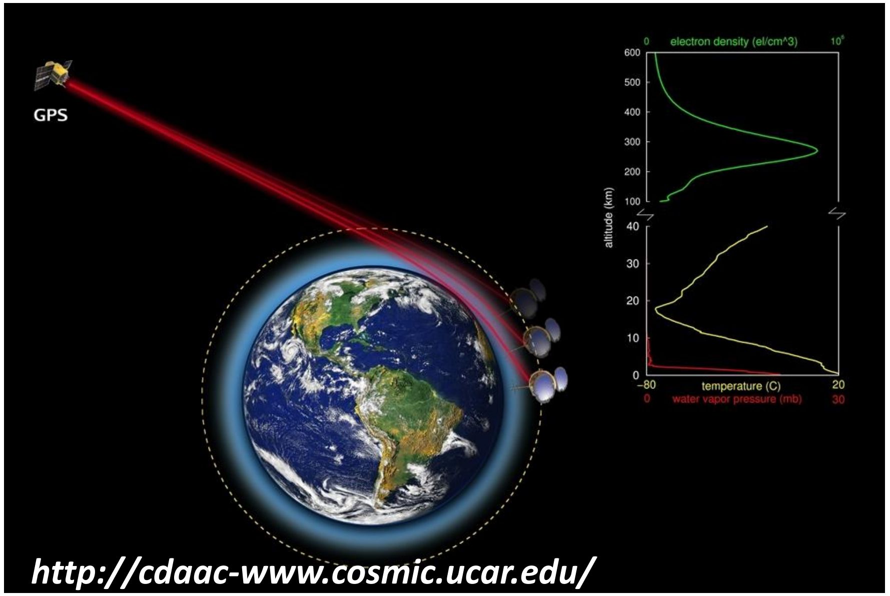
During the winter season SLT noon TEC maximum is present.

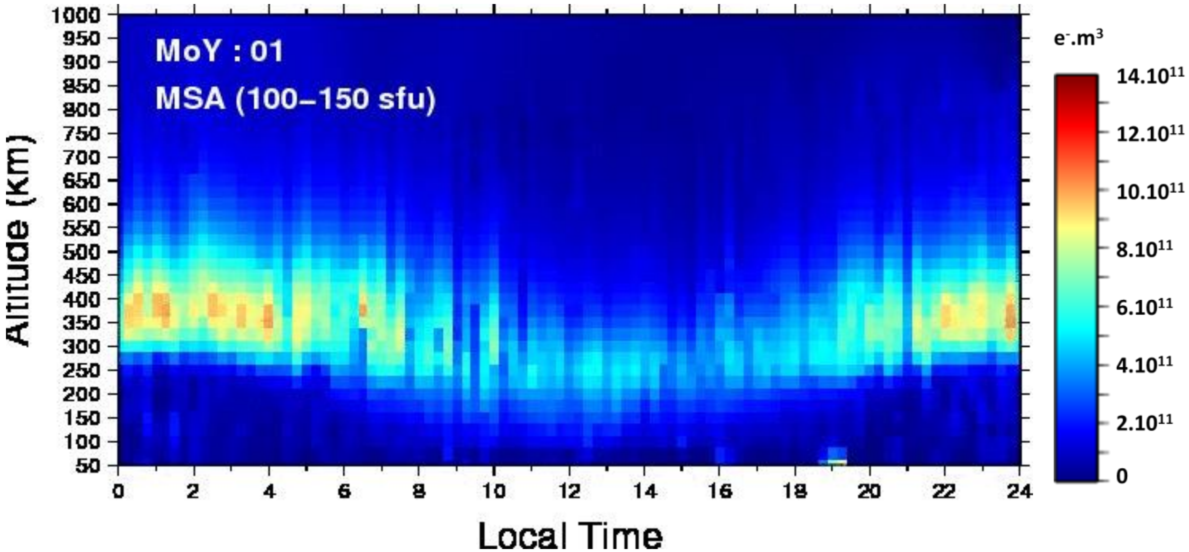

2015/03/17 00:15:00 UTC
TECU
125
100
75
50
25
0
0°
30°
-30°
60°
-60°
90°
-90°
120°
-120°
150°
-150°
-180°

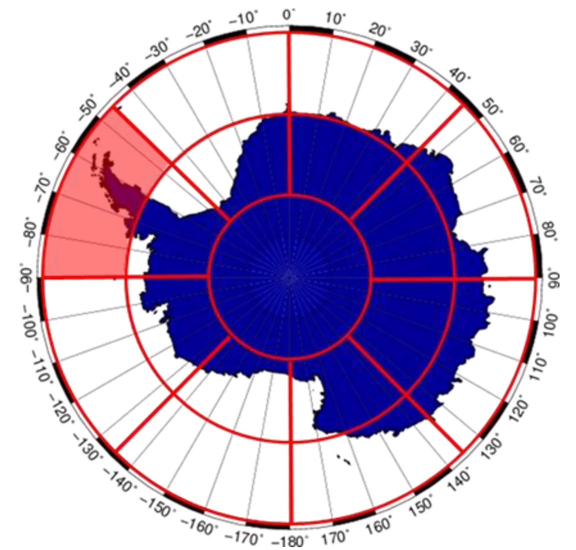
Ionospheric/Plasmaspheric contribution to TEC

Anthes, R.,et al. (2008)

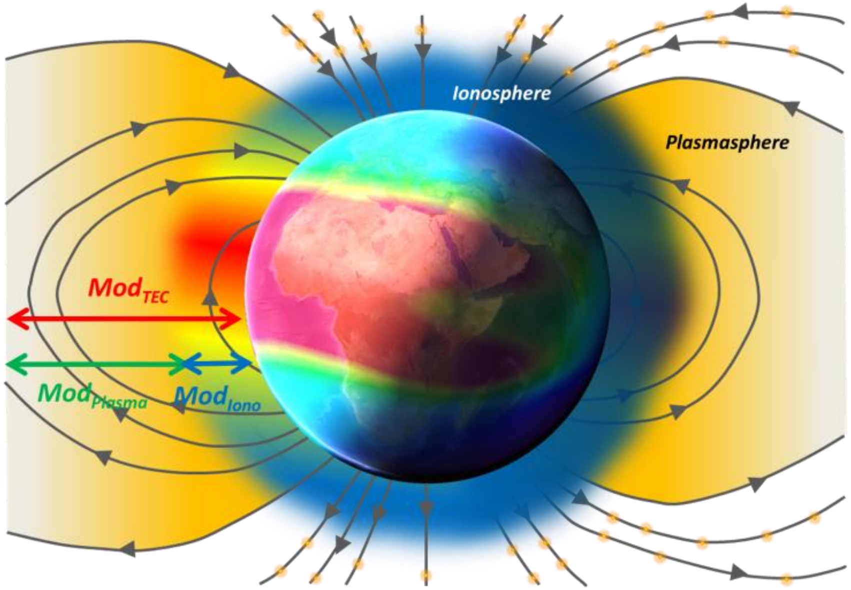




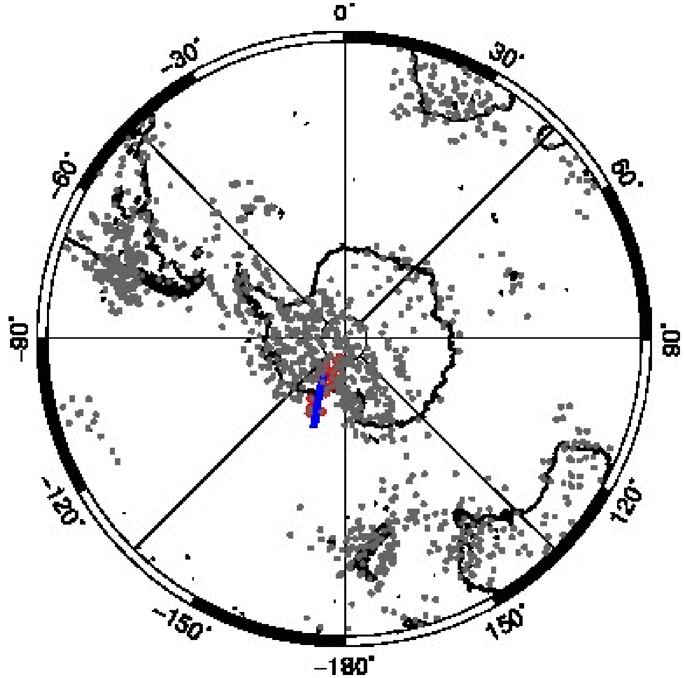




Plasmaspheric Empirical Model



2016-001



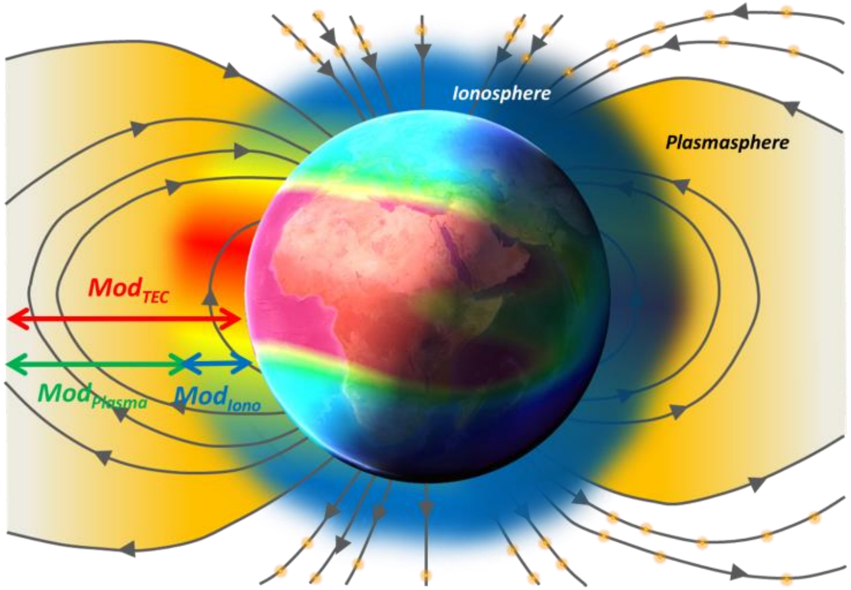
Final products of COSMIC density profiles for the 2006-2017

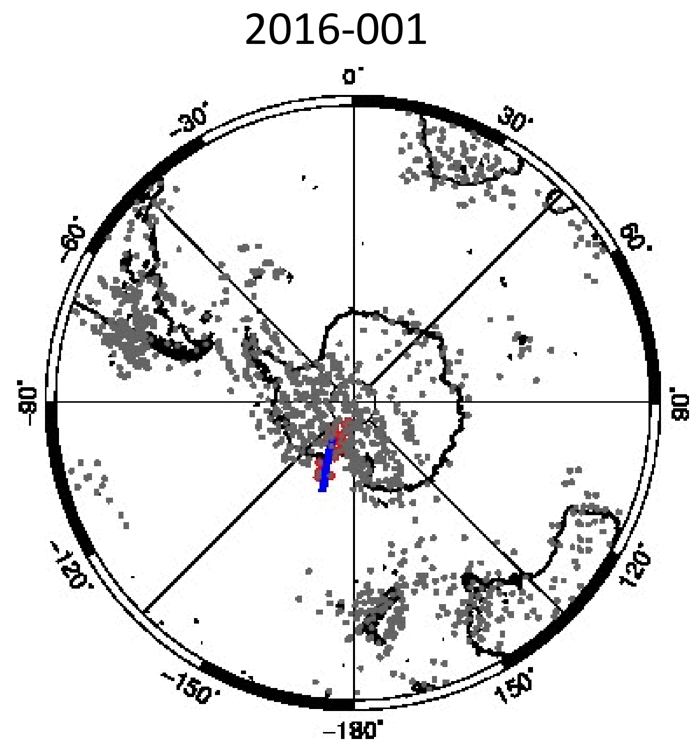
Estimation of ITEC from Ne(km)

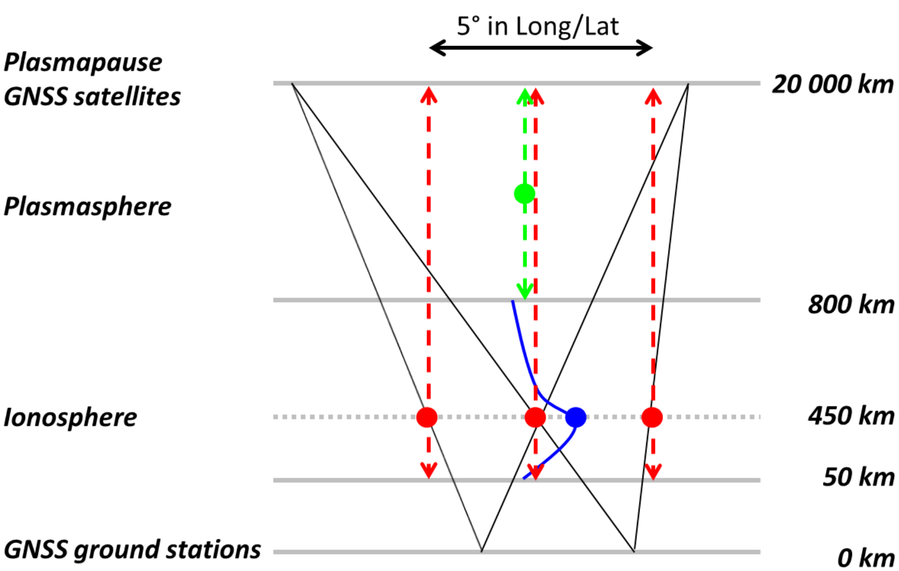
Collocated ITEC and TEC : ~500 000

PTEC = TEC - ITEC

Plasmaspheric Empirical Model

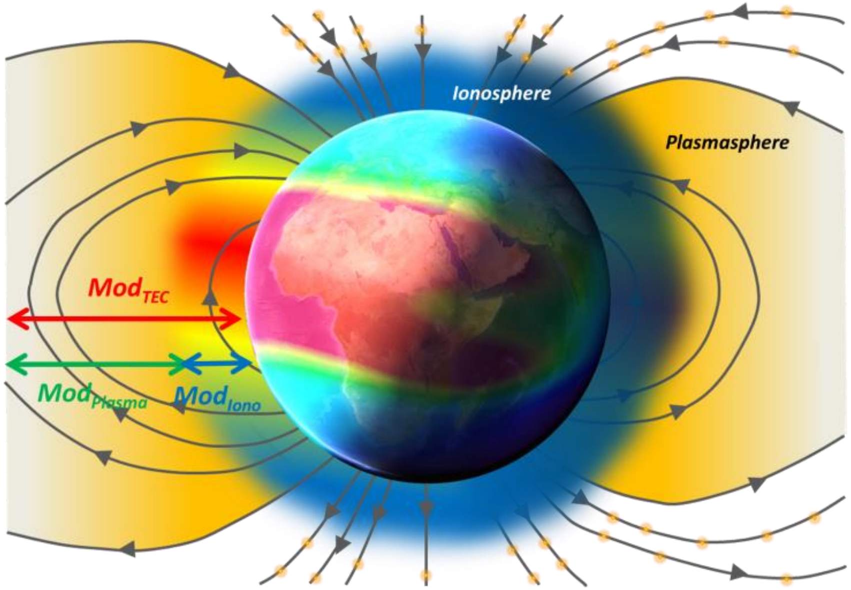


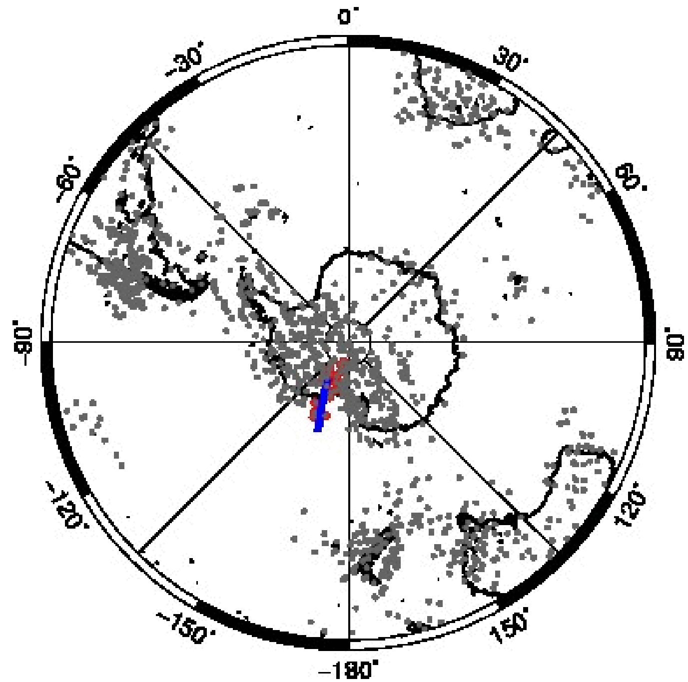




PTEC = TEC - ITEC

Plasmaspheric Empirical Model





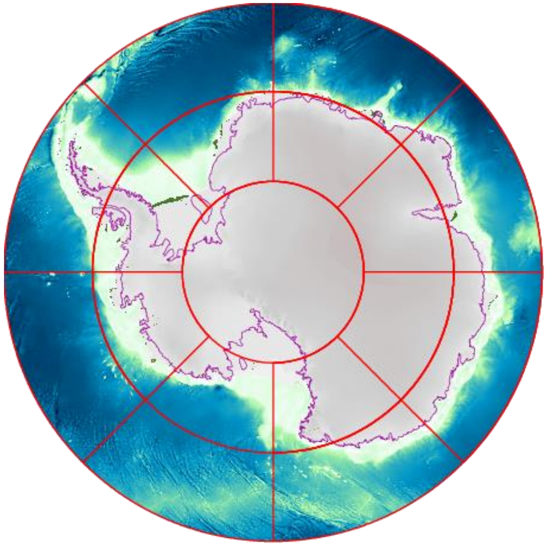
To minimize the differences between the modelled and observed PTEC we considered:

- An fourth-order polynomial function with monthly coefficients between the PTEC and F10.7P

$$PTEC = F10.7P \sum_{i=0}^{i=4} \left(\gamma_i t^i + \delta\right)$$

- A discretization with respect to different zones over Antarctica region to highlight different climatological patterns.

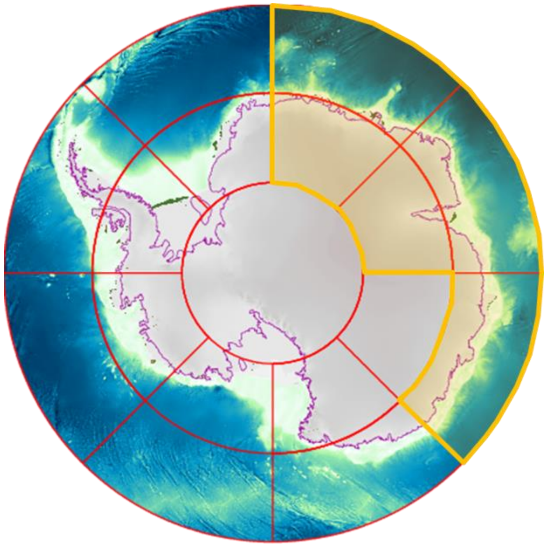
Plasmaspheric Empirical Model

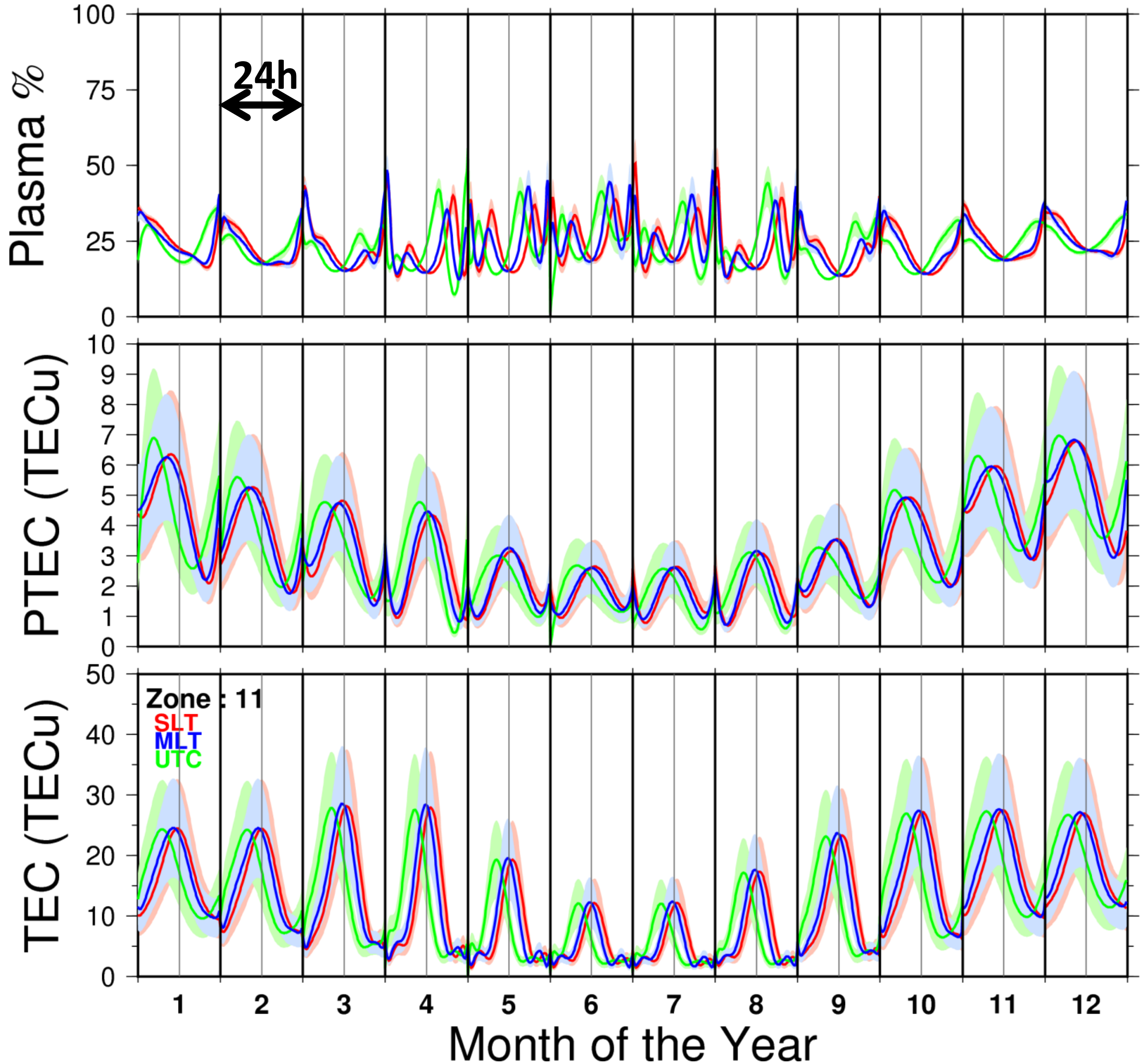


Antarctica divided in 17 zones.

- **~4 000 to 100s of PTEC at IPPs per zone/per month**
- **Mean differences : 0.2 ± 1.9 TECu**

Daily-PTEC climatological patterns





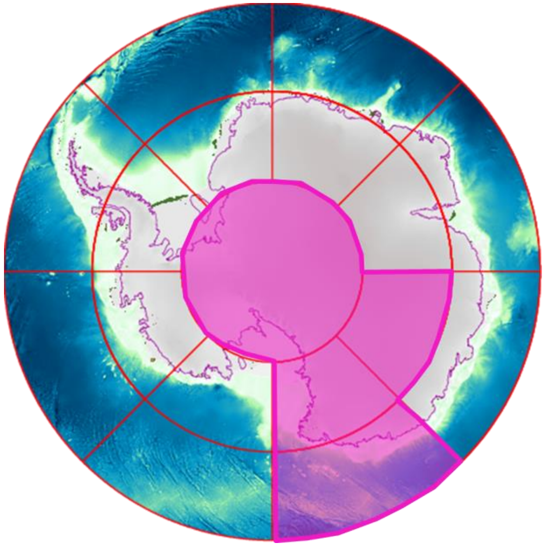
No clear variation w.r.t year in the contribution of the PTEC to TEC.

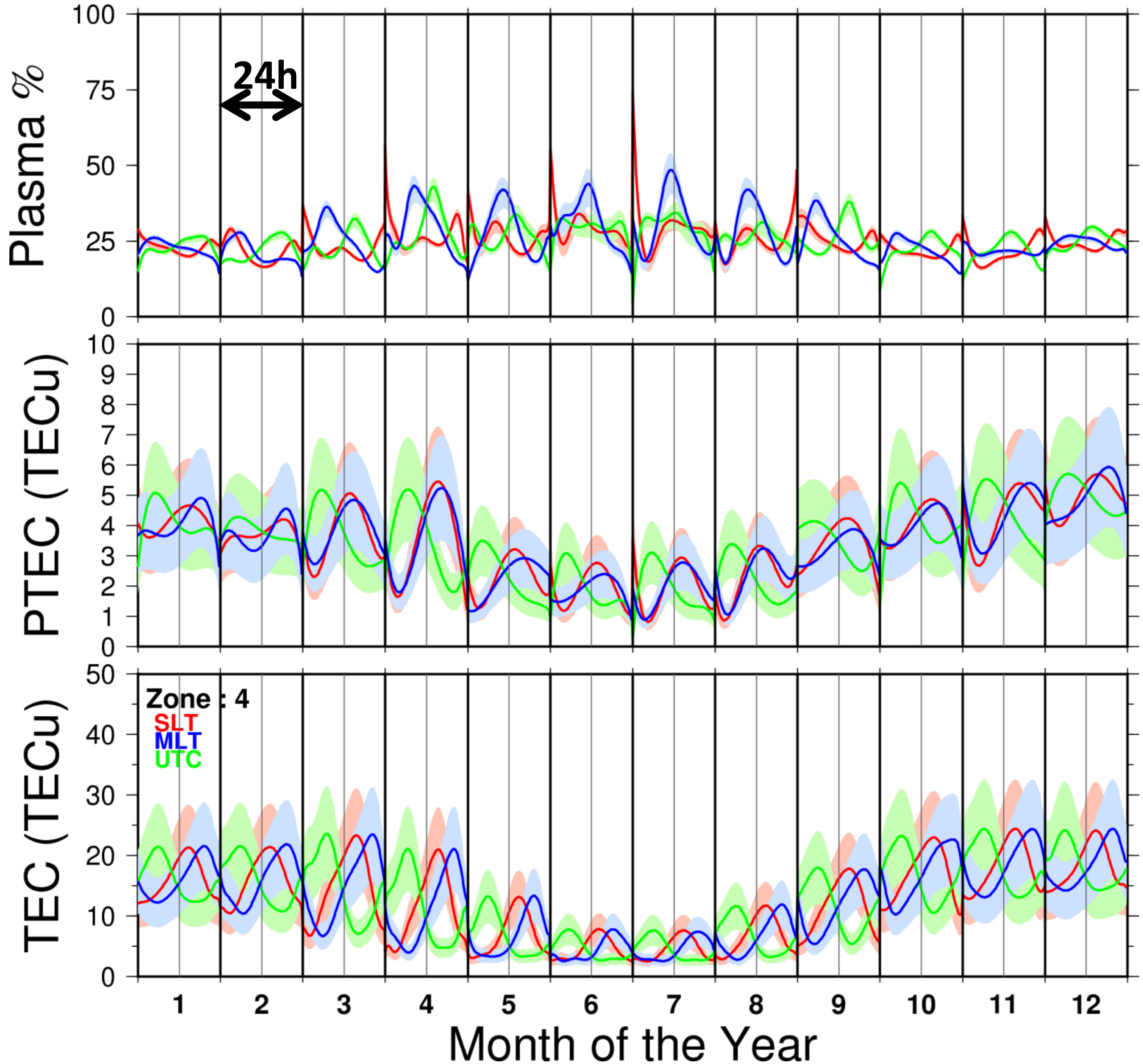
PTEC values

1-6 TECu

20-50% of the TEC

Daily-PTEC climatological patterns





No clear variation w.r.t year in the contribution of the PTEC to TEC.

MLT decorrelation = ITEC

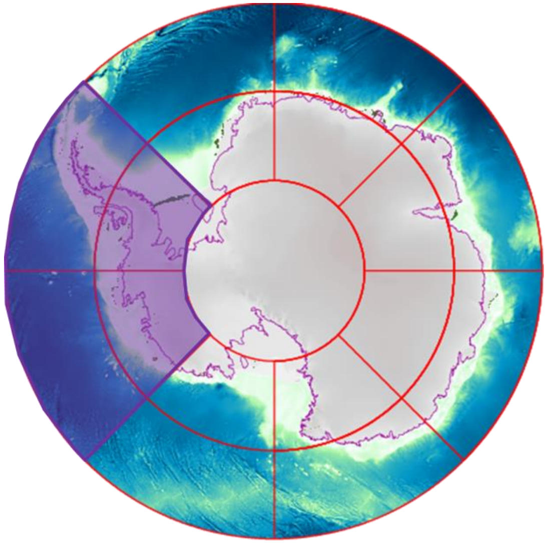
PTEC values

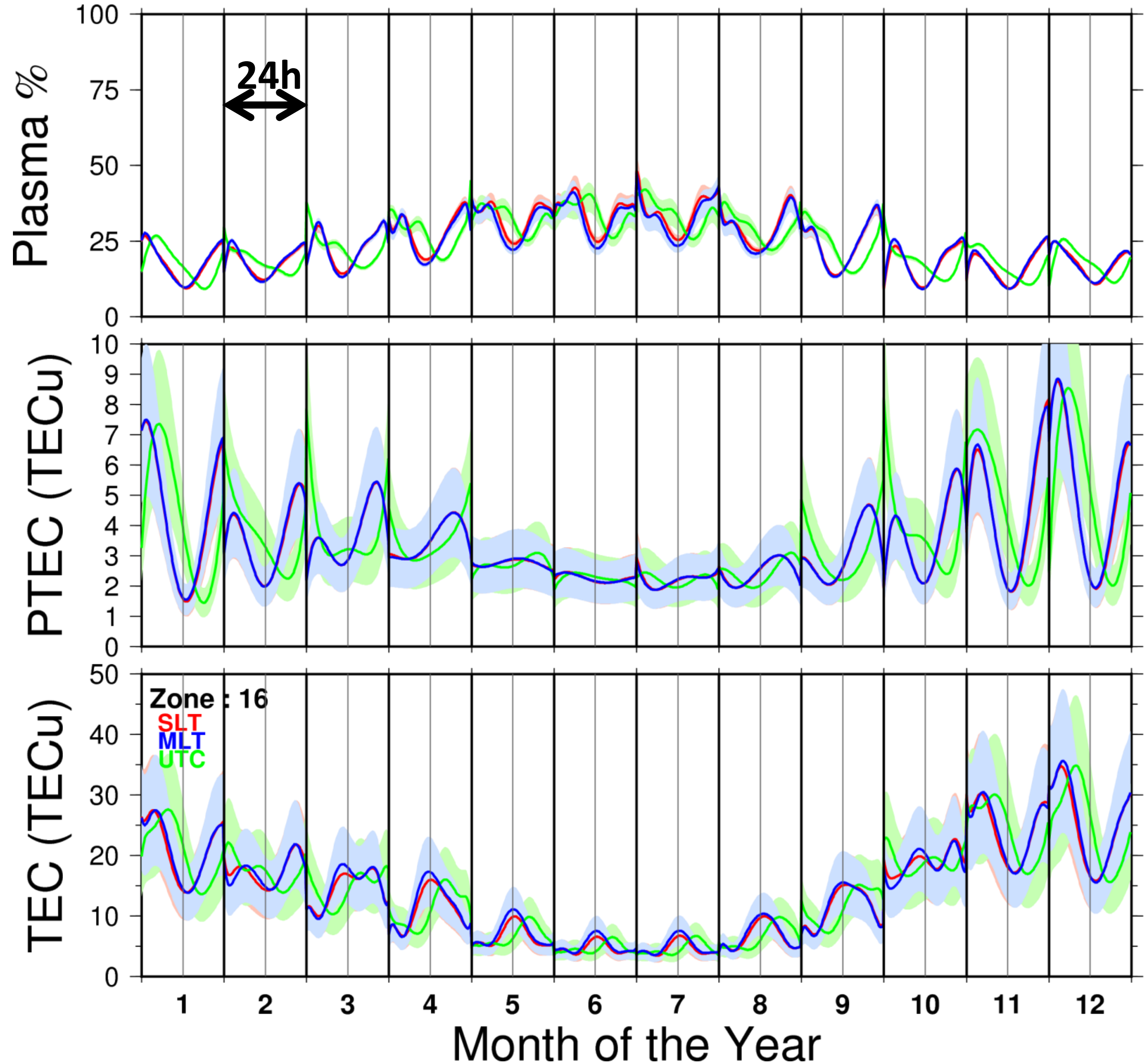
1-5 TECu

~25% in Summer

>25% in Winter

Daily-PTEC climatological patterns





Variation w.r.t year in the contribution of the PTEC to TEC.

PTEC values

2-9 TECu

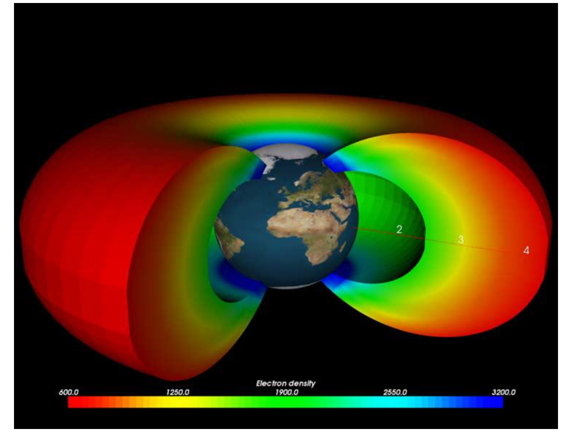
<25% in Summer

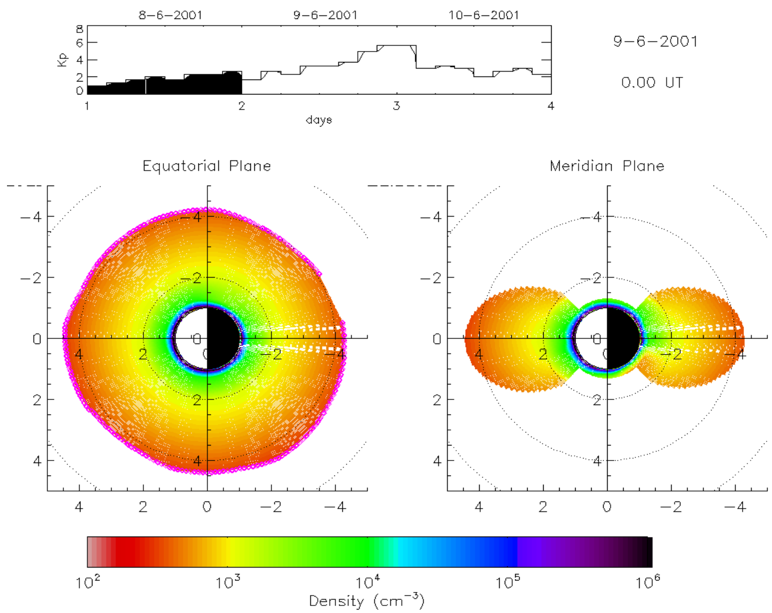
>25% in Winter

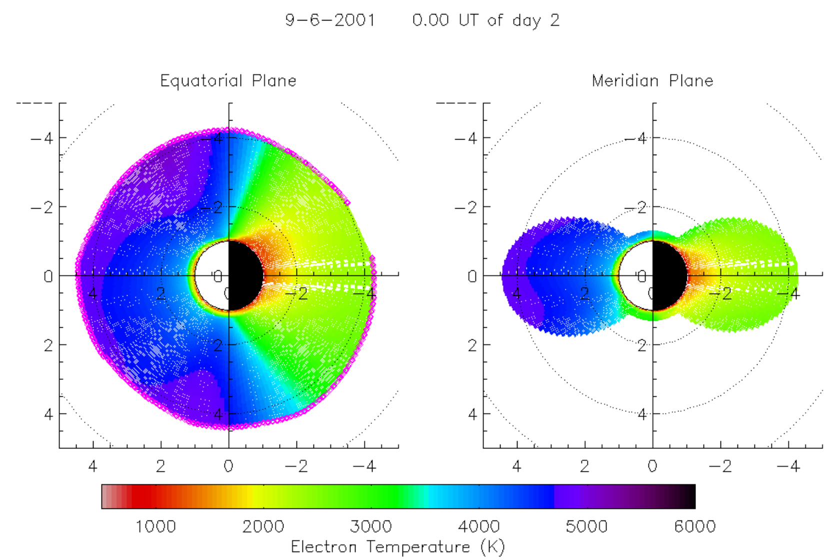
3D plasmasphere physical model

http://swe.ssa.esa.int/space-radiation

Pierrard and Stegen, JGR: Space Physics, 2008
Pierrard and Voiculescu, GRL, 2011







Number density (e, p) and temperatures provided inside and outside plasmasphere (coupling with ionosphere IRI)

Empirical vs Physical models

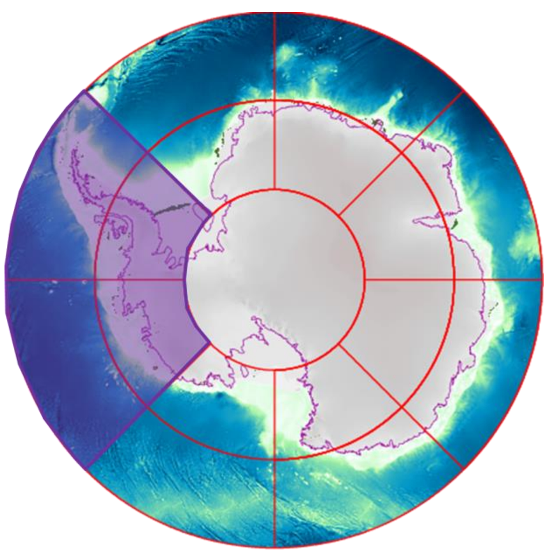
Date : Jan. to Dec. at UTC : 12:00

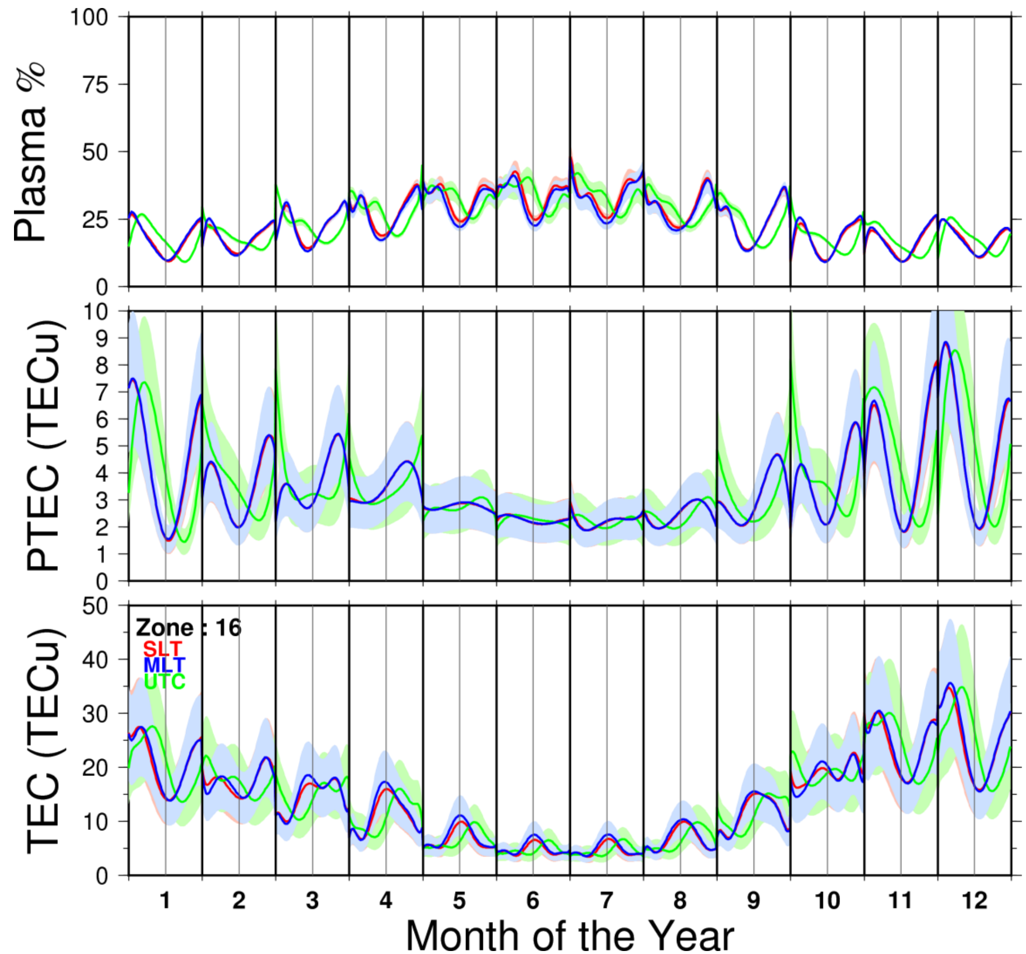
IRI for boundary condition (H^+,He^+)

Rz12 = 70 for the Solar activity

Kp = 2 for the plasmapause

	Longitude	Latitude
Geographic	70.00S	292.50E
Geomagnetic	60.22S	3.55E





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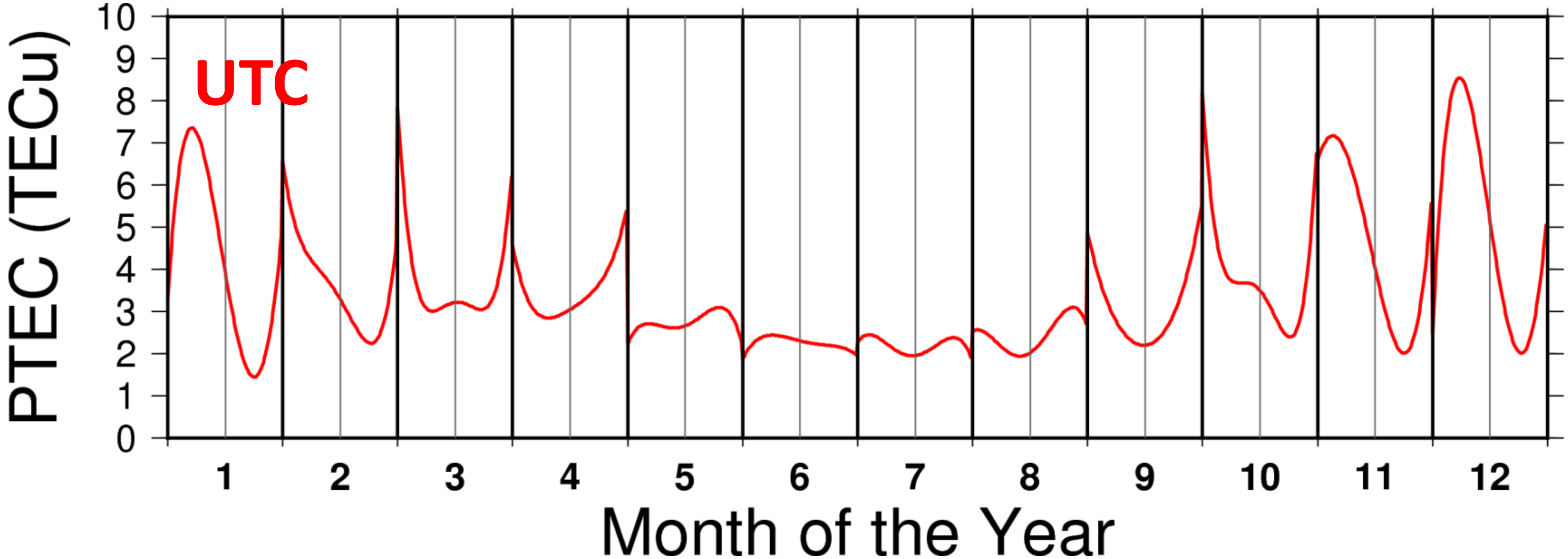

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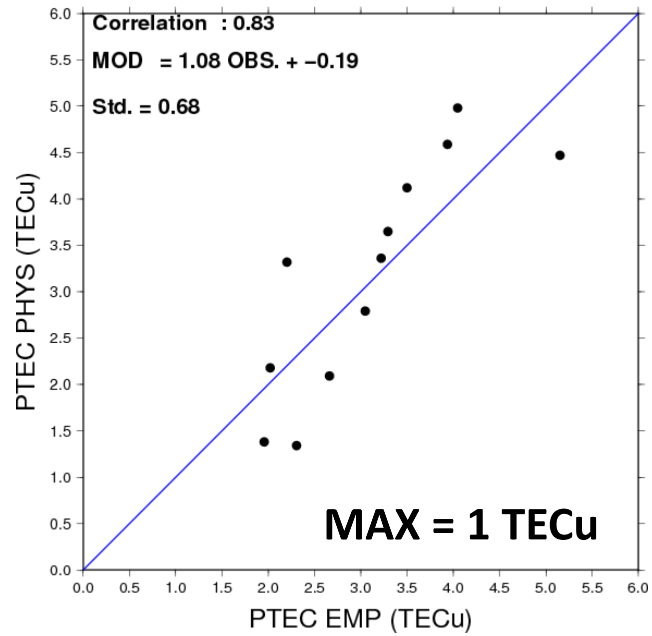
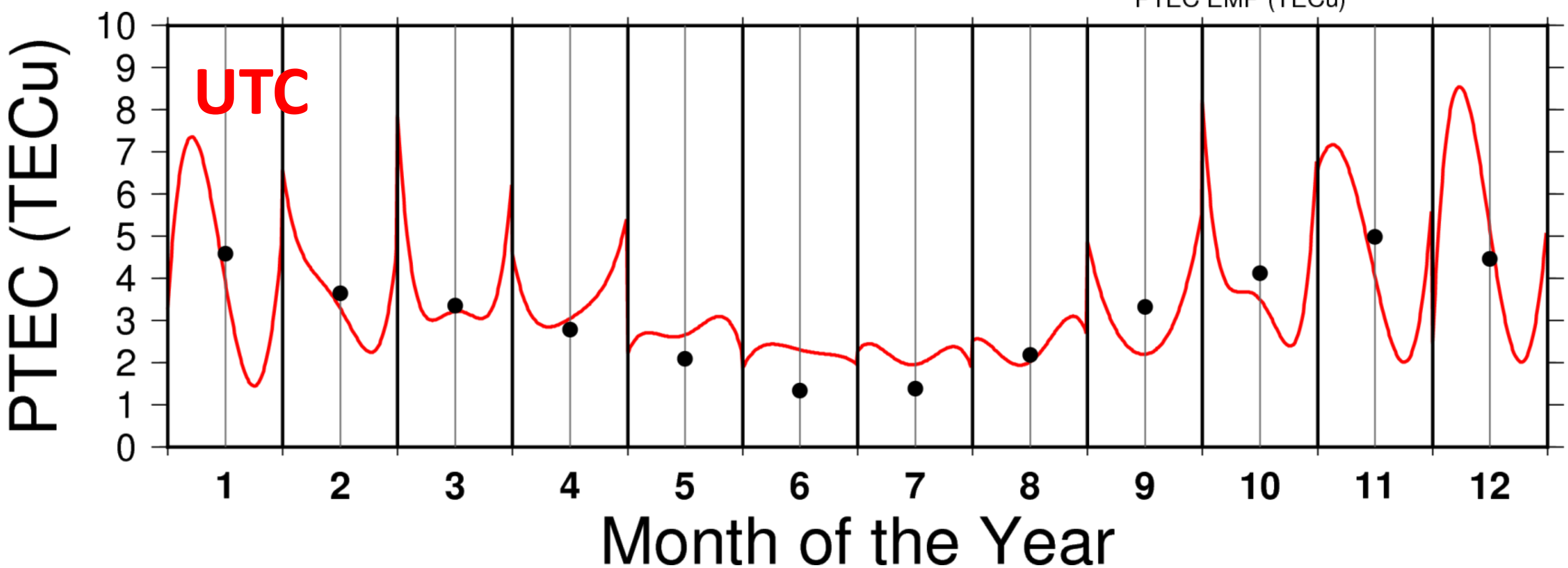




Empirical vs Physical models

Date : Jan. to Dec. at UTC : 12:00

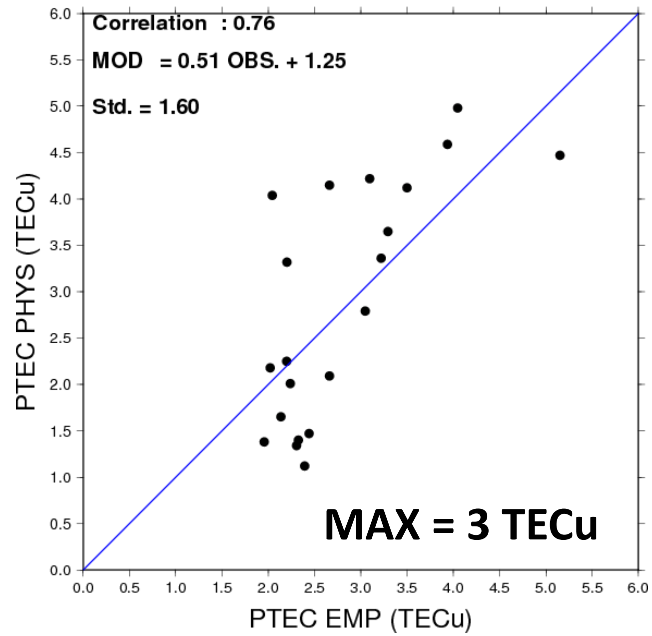
Date : Jun. & Dec. at ≠ UTC

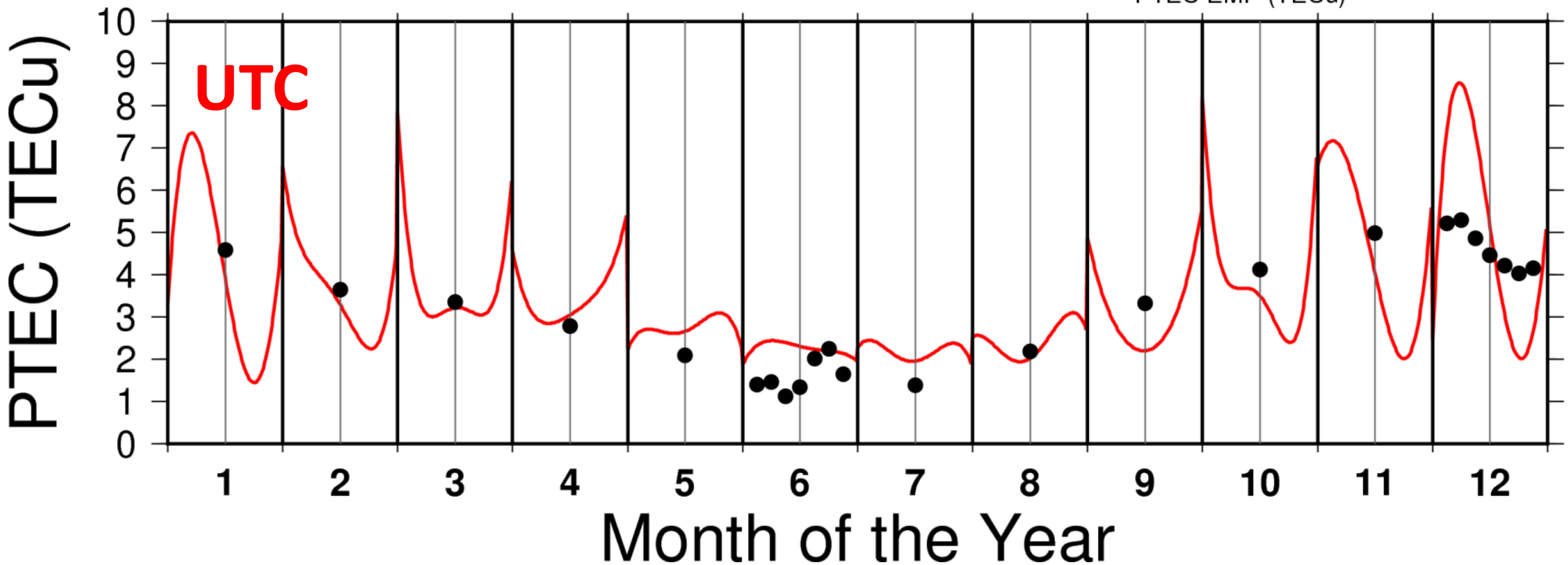
IRI for boundary condition (H^+,He^+)

Rz12 = 70 for the Solar activity

Kp = 2 for the plasmapause

	Longitude	Latitude
Geographic	70.00S	292.50E
Geomagnetic	60.22S	3.55E





Empirical vs Physical models

Possible explanations of differences outside 12:00 UTC:

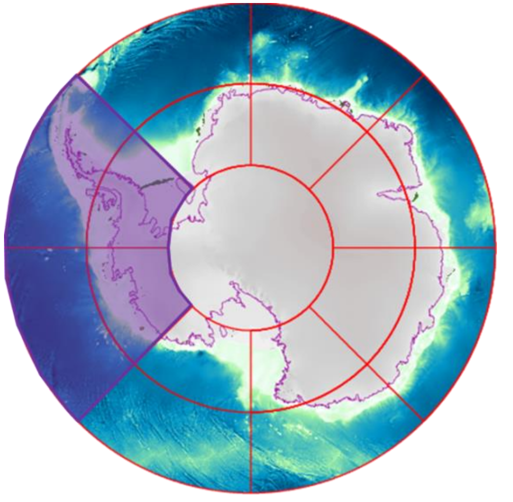
Empirical vs Physical models

Possible explanations of differences outside 12:00 UTC:

Empirical model side

- TEC model based on GNSS

> 8 M #data per month



Empirical vs Physical models

Possible explanations of differences outside 12:00 UTC:

Empirical model side

- TEC model based on GNSS

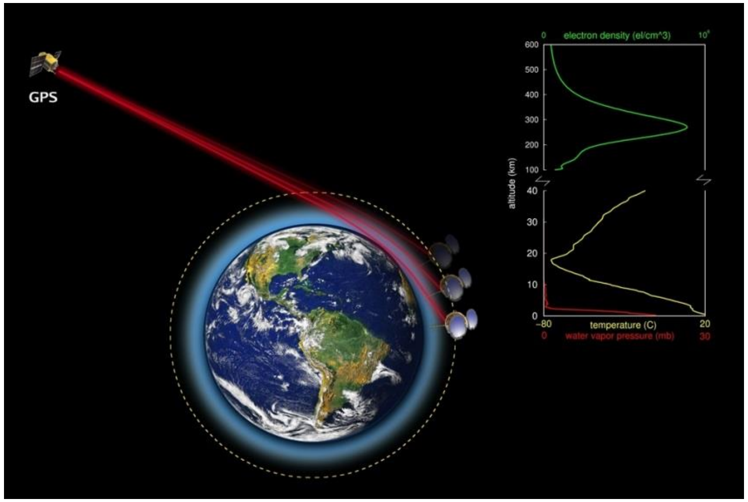
  > 8 M #data per month

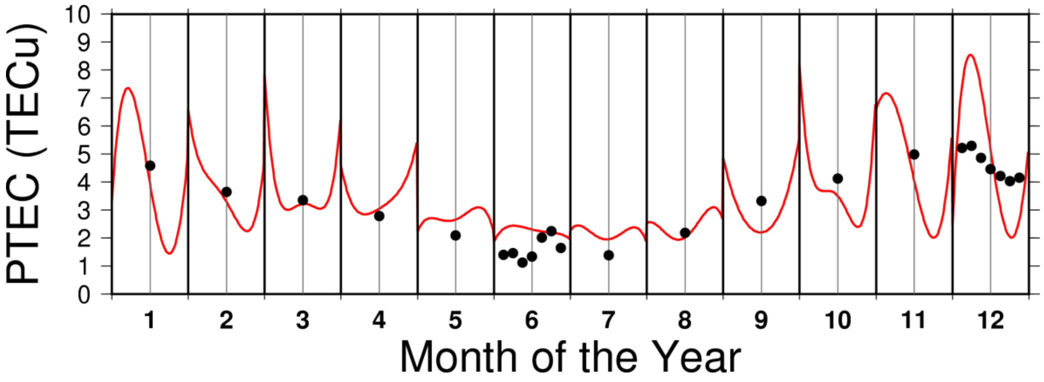
- ITEC model and then PTEC model from RO

  1100-1900 #data per month

PTEC = TEC – (ITEC+RO$_{PTEC}$) ?

Empirical model < Physical model





RESOURCE
Radio Sciences Research on AntarctiC AtmospherE

Scientific Committee of Antarctic Research (SCAR) Expert Group GRAPE (GNSS Research and Application for Polar Environment, http://www.grape.scar.org/)

Resource is a new scientific research programme: RESOURCE (Radio Sciences Research on AntarctiC AtmospherE).

RESOURCE wish to represent:

- the need of the scientists that **investigate the atmosphere** by means of radio observation,
- the requirement of the scientists that want **to remove or to mitigate the atmospheric noise** from their radio measurements.

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