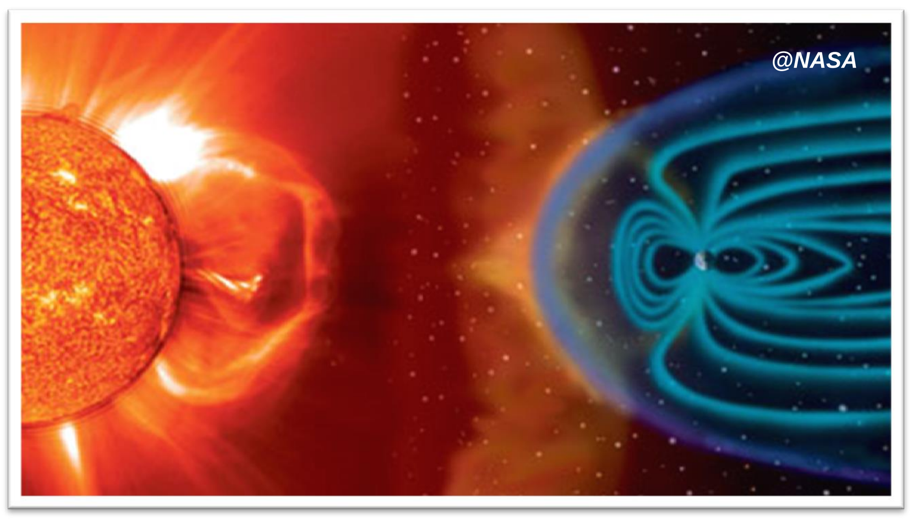



# Study of space weather impact on Antarctica ionosphere from GNSS data

N. Bergeot [1,2] , J.-M. Chevalier [1], C. Bruyninx [1], G. Denis [2], T. Camelbeeck[1], T. Van Dam[3], O. Francis[3]

(1) Royal Observatory of Belgium, Brussels, Belgium
(2) Université Catholique de Louvain, Louvain-la-Neuve, Belgium
(3) University of Luxembourg, Luxembourg

## 1. Space Weather and GNSS

The impact of solar activity on the ionosphere (*Figure 1*) at polar latitudes is not well known compared to low and mid-latitudes. This is especially the case over Antarctica due to a lack of experimental observations.

Consequently, one of the present challenges of the Space Weather community is to better characterize (1) the **climatological behavior of the Antarctica ionosphere** in response to variations in the solar activity and (2) the different responses of the ionosphere at high latitudes during **extreme solar events and geomagnetic storms.**

Toward these goals, the **combination of GNSS measurements** (e.g. GPS, GLONASS, Galileo …) on two separate frequencies allows us to determine the **ionospheric Total Electron Content (TEC, expressed in TEC units with 1TECu = $10^{16}$e$^{-}$.m$^{-2}$ ).**

It is thus possible to study the behavior of ionospheric TEC from the observations of a network of permanent GNSS stations.

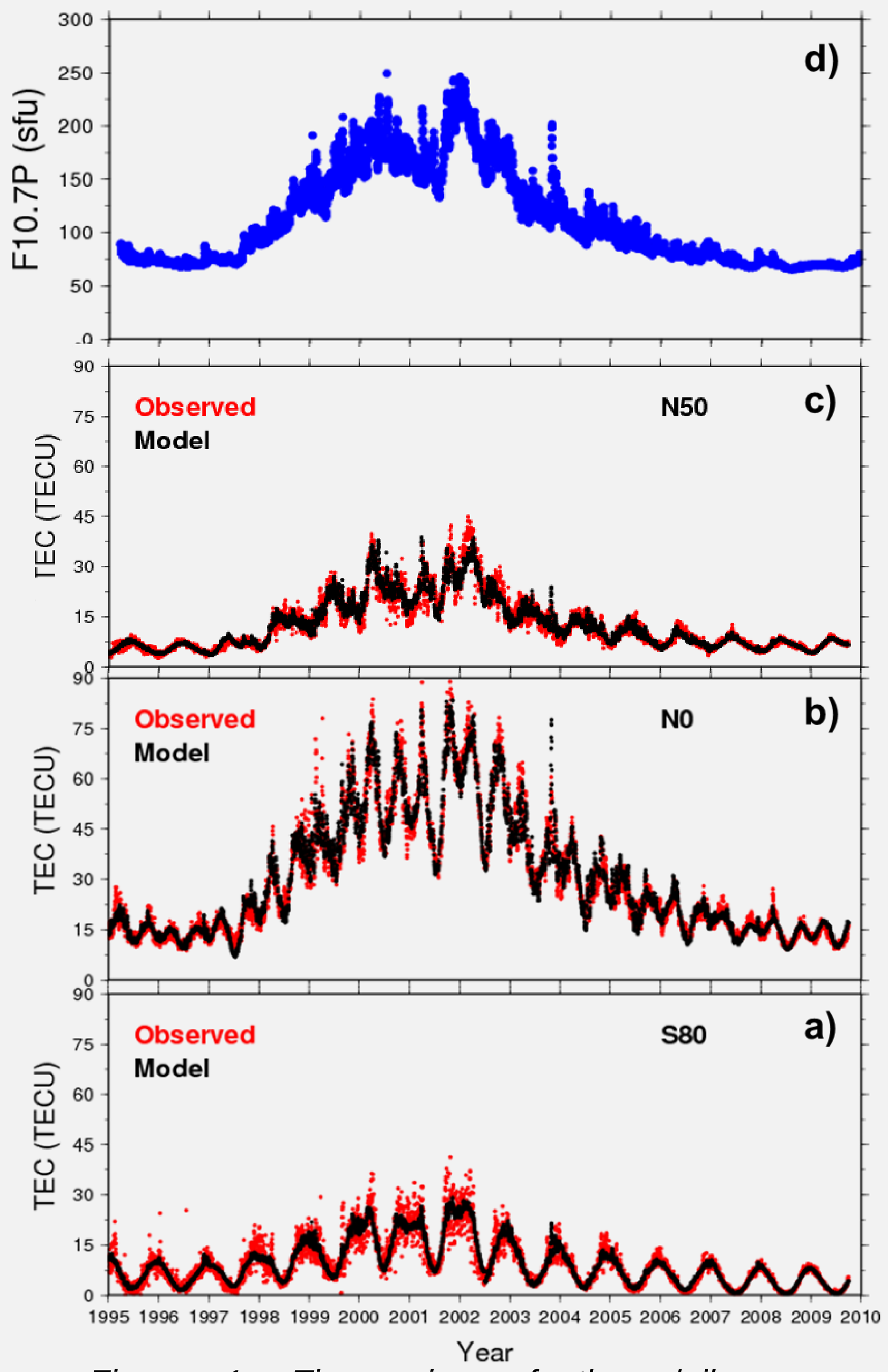



*Figure 1: Time-series of the daily mean ionospheric Total Electron Content (TEC) at different latitudes and F10.7P index reflecting the solar EUV emission (from Bergeot et al. 2013).*
*a), b) and c) modelled (in black) and observed (in red) of the ionospheric TEC for polar, equatorial and mid-latitudes regions respectively.*
*d) F10.7P index derived from the Penticton radio telescope observations*

## 2. Data and Method

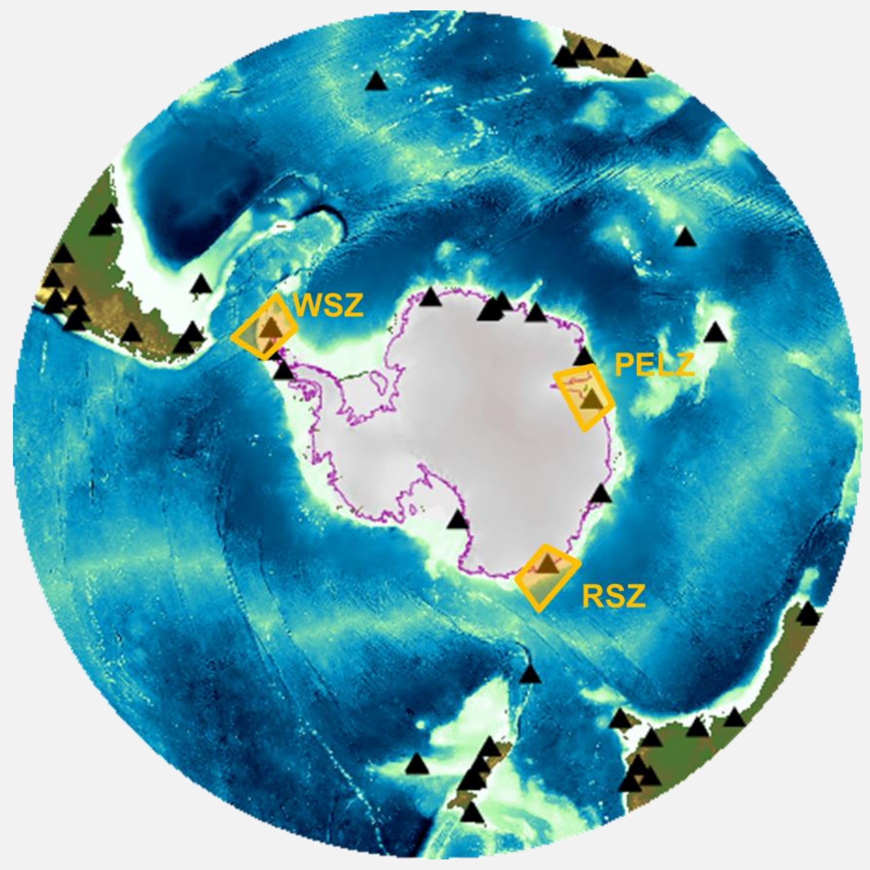



*Figure 2: GNSS network used in this study. The black triangles are the GNSS stations processed for the period of interest. In orange are represented the 3 zones presenting the different climatological patterns described in section 3.*

We used the data from **96 GNSS stations** (*Figure 2*) including **5 installed since 2009 around the Princess Elisabeth station** in the frame of the GIANT-LISSA and IceCon projects.

We used the ROB-IONO software (*Bergeot et al. 2014*) to reprocess **GPS and GLONASS data** from this GNSS Network for the period **2009-2016**.

This data set is then employed to constrain an **empirical model to predict the TEC every 15-min 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 eighth-order polynomial function with monthly coefficients between the TEC and F10.7P
- A discretization with respect to different zones of confidence where sufficient data are available.

Among all the tests, the optimal model to predict the TEC every 15 min. presents mean differences with observed values of 0.0 ± 4.5 TECu (2.9 ± 4.5 TECu for the absolute differences).

## 3. Climatological behavior of the Antarctica ionosphere

We identified 13 zones where sufficient TEC data are available to constrain the ionospheric climatological models. Then we analyzed 3 characteristic zones with relevant ionospheric behaviors (Figure 2): the Weddell Sea Zone (**WSZ**), the Ross Sea Zone (**RSZ**) and the Princess Elisabeth Land Zone (**PELZ**).

From the analysis of the model outputs (*Figure 3*), different sources impact the TEC behaviors:

- the Solar Cycle (**SC**) implying the ~11-years variation in the EUV emission with respect to solar activity levels,
- the Seasons (**Se**) due to the annual variations of the neutral atmosphere composition, especially the ratio [O]/[N2],
- the Local Time (**LT**) due to the solar zenith angle and induced photo-ionization processes predominant during the dayside compare to the night side of the ionosphere,
- the Magnetic Local Time (**MLT**) linked to E x B drift and induced particles precipitation.
- the Universal Coordinated Time (**UTC**) reflecting the neutral horizontal thermospheric winds active at 06:00 UTC.

The 3 zones followed the solar activity and seasonal variations. For the diurnal behaviors, WSZ and RSZ are dependent on UTC and LT mainly with seasonal dependencies. Concerning PELZ, the combination of UTC, LT and MLT could explain the maximum TEC values observed (*Table 1*).

| Zones | Long-term variations | | Diurnal variations | | | | | |
|---|---|---|---|---|---|---|---|---|
| | SC | Se | Summer | | | Winter | | |
| | | | UTC | LT | MLT | UTC | LT | MLT |
| WSZ | • | • | • | • | | | • | |
| RSZ | • | • | • | • | | • | • | |
| PELZ | • | • | (•) | (•) | (•) | (•) | (•) | (•) |

*Table 1: Effect of the different driving sources on the ionospheric TEC above the regions of interest.*

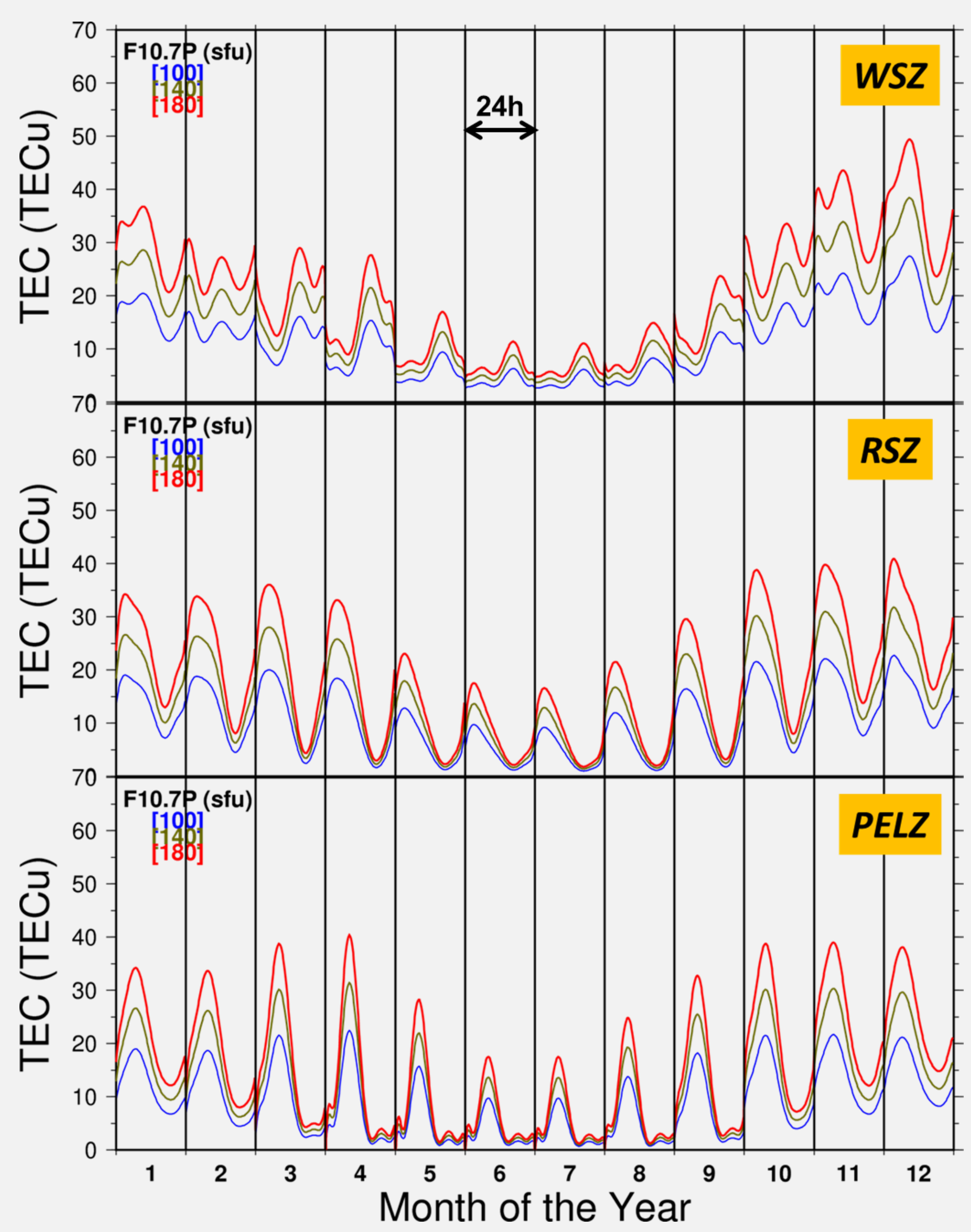
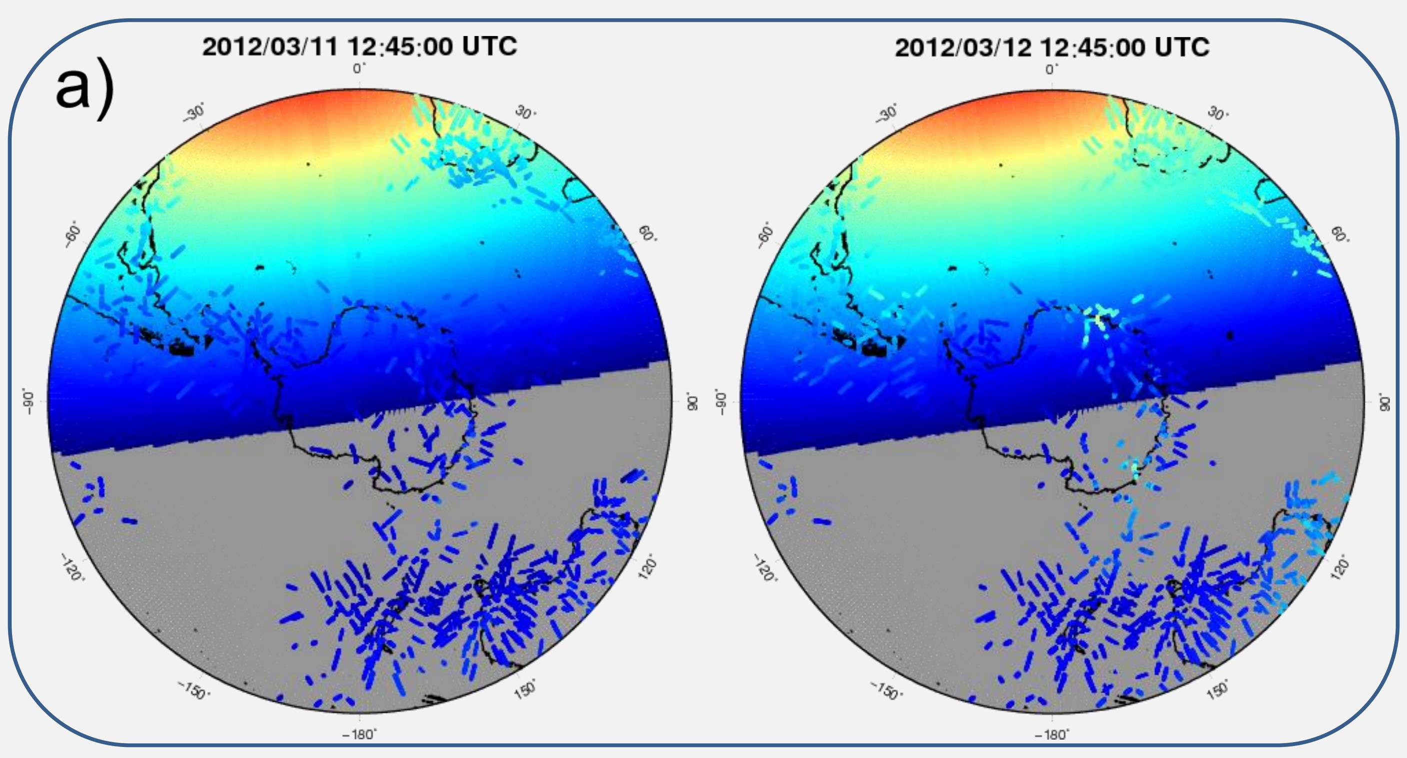
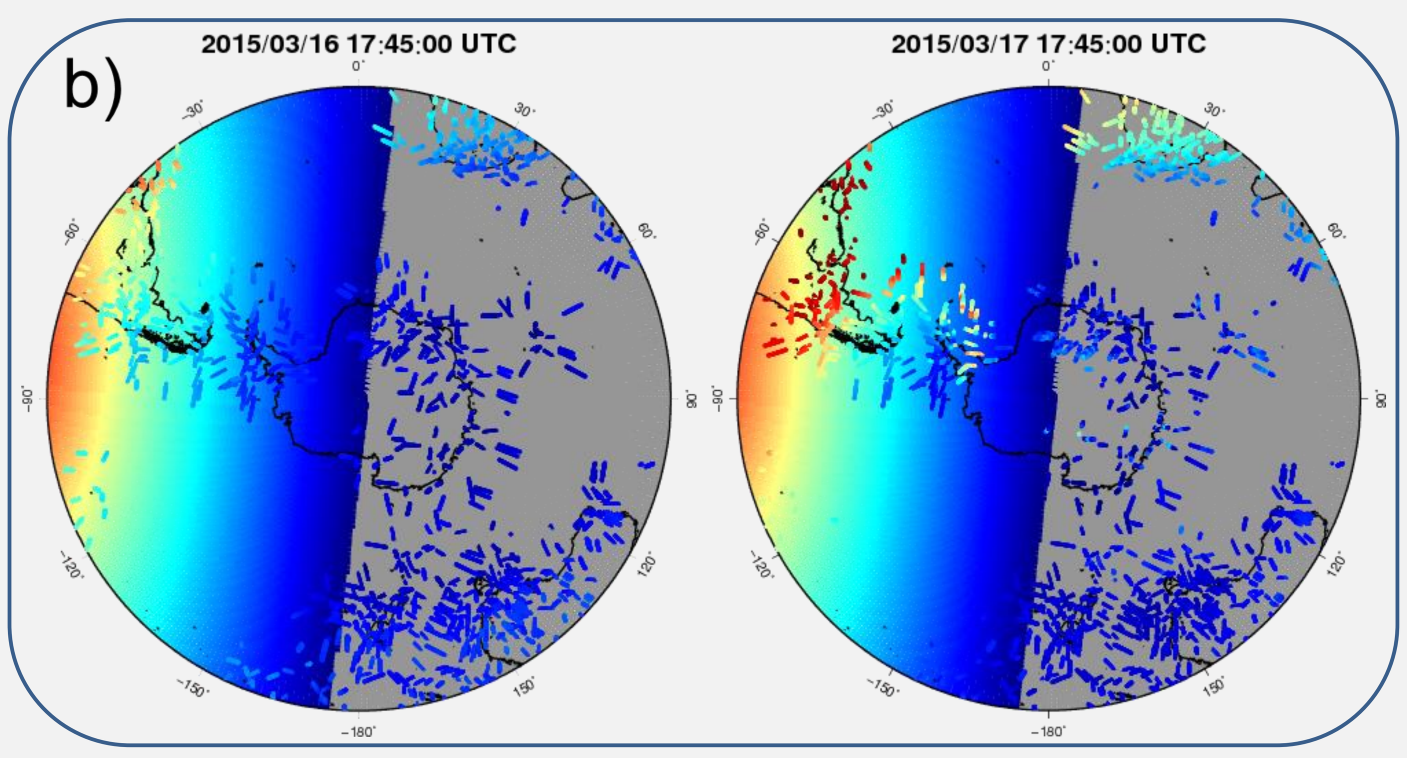



*Figure 3: Monthly climatological behavior of the TEC over Antarctica over PELZ, RSZ and WSZ (see figure 2) for different level of solar activity: high (red), transition (green) and low (blue) solar activity level.*

## 4. Effect of extreme solar events on polar ionosphere

**Ionospheric storms** induced by extreme solar events such as **Coronal Mass Ejections (CME)** impacting the magnetosphere imply rapid variations of the ionospheric TEC. The GNSS-based ionospheric data sets permit to highlight such variations at the ionospheric pierce points (IPPs) over Antarctica (*Figure 4*). In the future the maintenance of existing GNSS stations (GPS+GLONASS+Galileo+Beidou) and the installation of new ones will allow to better characterize the **TEC increase and decrease phases** during these extreme events and their interaction with geomagnetic field (e.g. aurora oval).



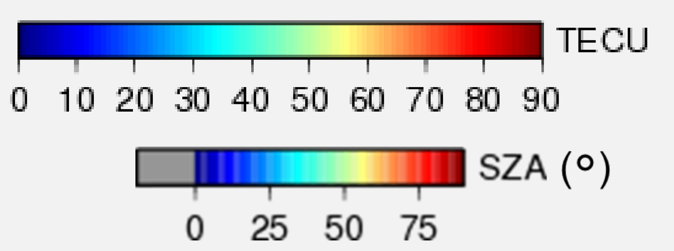




*Figure 4: Impact of two CMEs on ionospheric Total Electron Content over Antarctica. The grids are the solar zenith angle for the days and hours of interest. The dots are the TEC values at IPPs estimated from the GNSS network described in section 2.*
*a) Event on March 12, 2012. Geomagnetic indices Kp = 6; Ap = 94*
*b) Event on March 17, 2015. Geomagnetic indices Kp = 8; Ap = 179*
*Also shown the quiet ionospheric conditions during the day before the storm.*