Ionospheric Activity in the South East Asian Region

J. Miguel JUAN†, Jaume SANZ†, Roberto PRIETO‡ and Stefan SCHLUETER§

†Research group of Astronomy and Geomatics (gAGE), Technical University of Catalonia (UPC)
C/. Jordi Girona, 1-3, Mòdl B4, Campus Nord UPC, 08034 Barcelona, Spain

‡ European Space Agency (ESA/ESTEC)
2200 AG Noordwijk, The Netherlands

§ European Space Agency, (ESA/EPO)
31402, Toulouse, France

E-mail:†miguel@fa.upc.es, jaume.sanz@upc.es,‡Roberto.Prieto.Cerdeira@esa.int, stefan.schlueter@esa.int

Abstract A SBAS Ionospheric Activity indicator, based in the RMS of Along Arc TEC Rate (AATR) computations has been defined by the gAGE/UPC authors in the context of previous studies on EGNOS Ionosphere. This indicator can be easily computed from GNSS data and, unlike other global indices which are related with the geomagnetic activity, it is sensible to the regional behaviour of the ionosphere.
After a deep assessment done over Europe and Africa during the last Solar Cycle, this AATR indicator has been chosen as the metric to characterise the ionospheric operational conditions in the frame of ESA EGNOS activities (EGNOS V3 Mission Requirements).
In this work we summarise the results of the application of the AATR indicator to the analysis of the ionospheric activity during an entire Solar Cycle in the South of Asia (SEA) Region. This region has special interest from the ionospheric point of view, because the larger Slant Total Electron Content (STEC) values and gradients experienced due to its proximity to the ionospheric equatorial anomaly.

Key words Ionosphere, TEC, AATR, Solar Cycle, ionospheric activity indicators.

1. Introduction

As it is known, the ionosphere plays an important role in satellite-based navigation. Indeed, either in precise navigation (when the user has a dual frequency receiver) or standard navigation (the receiver is a mass-market single-frequency receiver). In the first case, a good modelling of the user ionospheric delays can speed up the convergence to the precise positioning as it is shown in [1]. In the second case, in standard positioning the user has to correct its measurements with the predictions provided by a model (ionospheric model). Thence, the error of the ionospheric model is translated directly to the measurements and, consequently, to the positioning.

In general, one can build an ionospheric model by using the measurements gathered from a permanent dual frequency receiver network (such as in the SBAS networks). Once the STEC is computed for the reference receivers' measurements, it can be linearly interpolated to the user location. But under increased ionospheric activity the linearity in the STECs behaviour can be far from being fulfilled. In this sense, the performance of the ionospheric model (relaying on linear fits) is linked to the ionospheric activity, which can depend on many factors such as year, season, local time, location, geomagnetic activity…

Taking into account the previous considerations, it is mandatory to identify the ionospheric disturbed periods in order to prevent the users against large ionospheric errors.

2. The AATR indicator.

Several attempts have been done in order to characterize the ionospheric activity with a single parameter, for instance, in [2,3] the Disturbed Storm Time (DST) index is used for identifying such periods. In these works a correlation better than 0,5 is found between the DST and an indicator of the lack o linearity of the ionospheric model (adjusted with data gathered by North American receivers during geomagnetic storms).

But there are evidences that ionospheric activity depends on other factors which cannot be linked to a global index. In this sense, an index associated to the STECs measurements from a specific receiver was defined in [4,5], which allowed to take into account some local/regional characteristics of the ionospheric activity. In a similar way than in [4] and in the context of an ESA funded project [6], it is defined the so called Along Arc TEC Rate (AATR) as:

$$AASR_i = \frac{\Delta STEC}{\Delta t} \tag{1}$$

$$AATR_i = \frac{\Delta STEC}{(M(\varepsilon))^2 \Delta t} = \frac{AASR_i}{(M(\varepsilon))^2} \tag{2}$$

$$AATR = \sqrt{\frac{1}{N} \sum AATR_i{}^2} \tag{3}$$

where i corresponds to the time of the observation, $M(\varepsilon)$ corresponds to the mapping function or obliquity factor, $\Delta STEC$ is the difference of STECs between two consecutive observations in the same satellite-receiver arc, Δt is the elapsed time between these consecutive observations (typically 30 or 60 seconds) and, finally, N is the number of observations in 1 hour. In this sense AATR is the hourly RMS of the instantaneous values from any specific receiver. Indeed, the AATR can be easily computed from GNSS data.

As it is known AASR can be expressed as:

$$\frac{\Delta STEC}{\Delta t} = \frac{\partial STEC}{\partial t} + \nabla STEC \cdot v_{pp} \tag{4}$$

where v_{pp} is the velocity of the ionospheric pierce point and $\nabla STEC$ is the spatial gradient of the STEC.

Taking into account the previous considerations, the AATR is sensitive to spatial gradients, sudden temporal variation of STEC (for instance a Solar Flare) and, because it is a RMS, dispersive values of the STEC rates (as occurs under scintillation).

2. 1. AATR performance assessment

This indicator has been intensively assessed over different European receivers and/or sub-networks along the last Solar Cycle, period that includes the Halloween Storm (2003 from Day of Year (DoY) 302 to 304). During these days we have built a very precise ionospheric model (with accuracies better than 1 TECU in nominal conditions). As it was expected, the modelling of the GPS ionospheric delays during the disturbed days was clearly worse than during the quiet days. In this sense, the post-fit residuals (i.e. actual minus modelled GPS delays) provided a measure of the ionospheric activity. Then, the assessment of the AATR indicator was done by comparing the hourly RMS of the iono-model post-fit residuals with the AATR.

Examples of such comparisons are depicted in Figure 1, for a sub-network in the North of Europe (POTS, upper plot) and a sub-network in the South of Europe (LLIV, bottom plot). It is shown the good correlation between the RMS of the ionospheric model post-fit residuals and the RMS of the AATR. This good correlation occurs not only during disturbed periods but also during the daily variation of the RMSs (larger at noon). Furthermore, one shall notice the different figures of RMS values found in the North and in the South of Europe (see, in particular, the DoY 304). They confirm the need of using regional indicators instead of global indicators as the Solar Flux or DST.

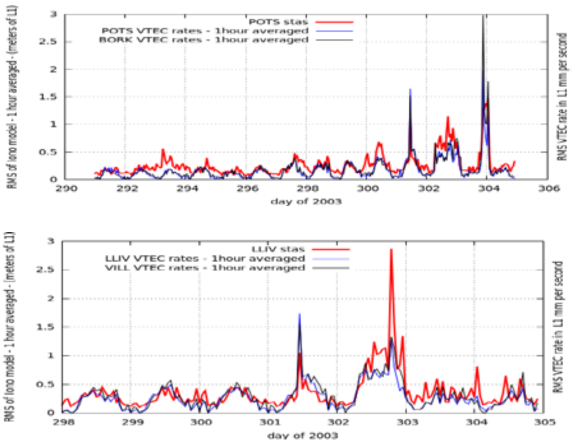

Figure 1: Comparison of the post-fit residuals RMS of an ionospheric model (red) and the RMS of AATR (blue and black) for two selected receivers. Left plot is for POTS sub-network (receivers POTS and BORK with 445km of baseline). Right plot is for LLIV sub-network (receivers LLIV and VILL with 544km of baseline).

2. 2. Main results of AATR over Europe and Africa

The evolution of the AATR indicator has been analyzed along the last Solar Cycle (i.e. 2001-2012) over European and African stations in the context of previous studies on EGNOS Ionosphere [7]. The main results are:

The main events occur before 2006. For the Northern receivers (up to 60 deg of Latitude) these events are related with geomagnetic superstorms (large values of Ap or DST). However, for South European receivers, the influence of the geomagnetic activity in the ionosphere decrease with the latitude, being the main factor correlated to the Solar Flux at 10.7 cm.

Finally, for low latitude receivers in Africa, the most important source of ionospheric activity, in nominal conditions, is correlated with Solar Flux. Besides such dependency, the largest values of AATR occur after the Solar Terminator. As it is known, during such hours (lasting 1/3 of the day) events such as bubbles, depletions... are experienced in these regions, often related with ionospheric scintillation. Outside this period, observed values are comparable to those of the European region.

3. Ionospheric activity in the SEA region

In the context of the Growing-NAVIS (FP7) project from the European Union, an analysis of the AATR values has been done for an entire Solar Cycle over 3 receivers located in the South of Asia (SEA) Region (see the Table 1).

Table 1. Selected receivers (geographical coordinates).

Receiver ID	Latitude [o]	Longitude[o]
NTUS	1.3	103.7
CUSV	13.6	100.5
KUNM	24.9	102.8

From the ionospheric point of view the SEA region is interesting because it is close to the ionospheric equatorial anomaly, so comparing with other regions, one expect to have larger STEC values and gradients, and consequently, larger values of AATR.

From this study, some of the conclusions that have arisen are as follows:

1) Like in other regions, there is a significant relationship between the ionospheric activity and the Solar Flux. In this sense, the largest values of AATR are experienced in the years around the Solar Cycle Maximum and close to Equinoxes.

2) The main driving factor for ionospheric activity is the equatorial scintillation after Solar Terminator. Indeed, the largest values of AATR occur during some hours after the sunset, specifically during the Equinoxes. Excluding these hours, the AATR values are quite moderated and comparable to the European ones.

3) This activity, occurring after the sunset, decrease with the latitude. For instance, in spite the receiver KUNM presents also ionospheric activity episodes after the sunset, the frequency of such events are clearly lower than the receiver CUSV.

4) Unlike mid latitude regions, the influence of the geomagnetic storms is quite moderate in this low latitude region.

Figure 2 shows an example of large AATR values corresponding to the day 2002 051 where the AATR achieve one of the largest values (0.19 cm/s of L1-L2 delay).

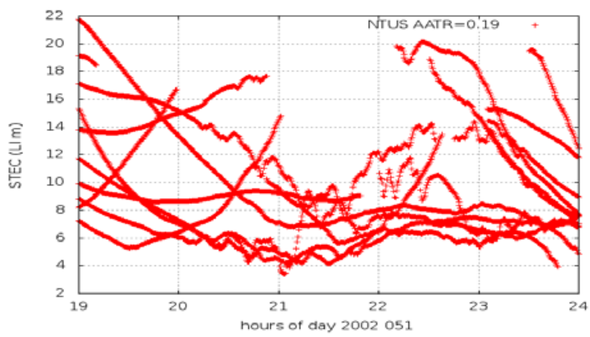

Figure 2. STEC for NTUS station.

Figures 3 and 4 show the AATR values over the last 2.5 years for the receivers KUMN and CUSV, where the values associated to the hours before de sunset (local time < 18:00) are represented in green and the values gathered under geomagnetic activity (Ap>97) are depicted in blue.

Similar plots are shown in Figures 5 and 6 for the receivers CAGL and NKLG for comparison, as these receivers are located at similar latitudes than KUMN and CUSV.

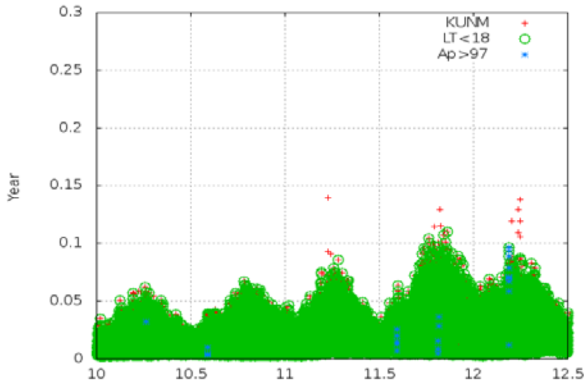

Figure 3: AATR for KUMN station (ϕ=24º9, λ=102º8).

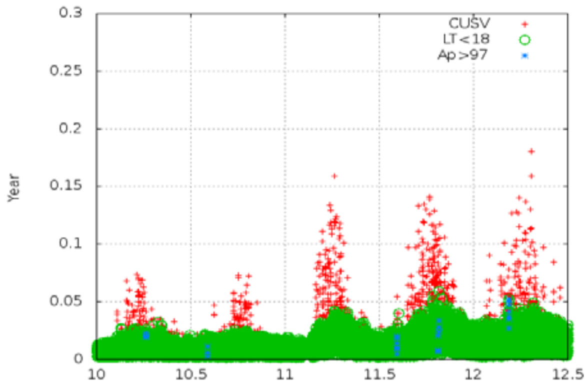

Figure 4: AATR for CUSV station (ϕ=13º6, λ=100º5).

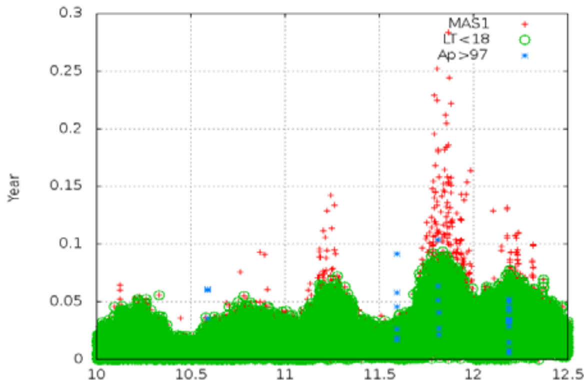

Figure 5: AATR for MAS1 station (ϕ=27º6, λ=-15º6).

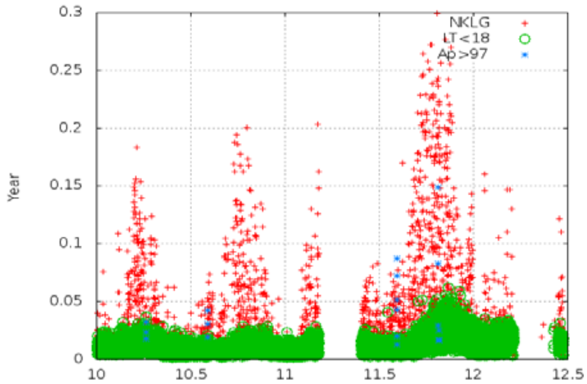

Figure 6: AATR for NKLG station (ϕ=0º4, λ=9º7).

3. Conclusions

The Ionospheric activity in the South East Asian region has been analysed using the AATR indicator. This indicator can be easily computed from GPS data and, unlike other global indicators which are related with the geomagnetic activity, it is sensitive to the regional behaviour of the ionospheric activity.

Results confirm that the range of ionospheric activity in the SEA region is quite similar to the activity observed in previous studies on similar geomagnetic latitudes where large values of AATR are experienced linked to the Solar Terminator events, during high values of Solar Flux. Thence, the largest values appear during equinoxes and close to the solar maximum, lasting for several hours after the Sunset.

4. References

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