gAGE/UPC
Research group of Astronomy & Geomatics
Technical University of Catalonia

Ionospheric Monitoring Experimentation Plan and Instrument Development

MONITOR TN2230-40-50 DRAFT

gAGE/UPC
Research group of Astronomy & Geomatics
Technical University of Catalonia

EXTERNAL UPC PRODUCTS:

"TOMION TEC MAP PROVISION", "GEODETIC PREPROCESSING AND IONOSPHERIC TRUTHS" AND "PRELIMINARY PERTURBATION ANALYSIS BASED ON IGS DATA"

FINNISH METEOROLOGICAL INSTITUTE

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Edited by	M. Hernández (gAGE/UPC)		30/09/2010
Approved by:	Y. Béniguel (IEEA)		

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Name	Company
Manuel Hernández-Pajares	gAGE/UPC

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1 INTRODUCTION

1.1 PURPOSE

The main purpose of this report is to summarize the results of the following MONITOR WPs: WP2230 “External Product - TOMION TEC map provision”, WP2240 “Geodetic preprocessing and Ionospheric Truths” and WP2250 “External Product - Preliminary Perturbation Analysis based on IGS data”, following the WPDs included in the MONITOR proposal, pages 13-32, 13-33 and 13-34, updated with the decision agreed in delta-PDR meeting.

1.2 DISTRIBUTION OF THE DOCUMENT

After a first section containing the main characteristics of the UPC external products in tabular format (content, messages, format, plots, sampling, latencies), a short practical description is given for each UPC external product, including the needed references and examples of plots to be provided to CAPF.

2 MAIN CHARACTERISTICS OF MONITOR UPC EXTERNAL IONOSPHERIC PRODUCTS

#	*Acronym*	*Ext.Product*	*Sampling*	*Latency*	*Message*	*References*
1	**VTEC-TOMION**	Global VTEC maps with the Tomographic Ionosphere Model,TOMION (possibility of <u>partial</u> maps in real-time)	5 deg x 2.5 deg x 15 min in Lon x Lat x UT	48 hours (less than 30 min. in real-time)	**IONEX file** UQRGDOY0.YYi.Z where DOY is the Day of Year YY	Hernández-Pajares et al. 1999, 2009, Schaer et al. 1998.
2	**TDCBs-TOMION**	Transmitters' Delay Code Biases, in ns of P2-P1, P1-C1 and P2-C2 (same units and definition than in IONEX file headers).	Daily, for each GPS satellite	48 hours	Header of **IONEX file** UQRGDOY0.YYi.Z where DOY is the Day of Year YY and **Message MUTD**	Hernández-Pajares et al. 2004, 2009, Schaer et al. 1998.
3	**RDCBs-TOMION**	Receivers' Delay Code Biases, in ns of P2-P1 and C1-P1 (same units and definition than in IONEX file headers).	Daily, for each frequently used GPS receiver	48 hours	Header of **IONEX file** UQRGDOY0.YYi.Z where DOY is the Day of Year YY and **Message MURD**	Hernández-Pajares et al. 2004, 2009, Schaer et al. 1998.
4	**STECs-TOMION**	Slant Total Electron Content values for a selected subset of receivers (TECU), to feed NeQuick-Galileo Ionospheric Model.	1200 sec, under GMV requirement	two weeks in principle	**Message MUST**	Aragón-Àngel et al. 2004

5	**GEC-TOMION**	Global Electron Content, total number of free electrons in the atmosphere, in GECUs	15 min in UT	48 hours	**Message MUGE**	Hernández-Pajares et al. 2009
6	**GSFLAD**	GNSS Solar Flare detector in real-time (looking for significant correlation of simultaneous VTEC variation in the daylight hemisphere).	30 sec, globally	30 sec	**Message MUSF**	An optimized implementation for real-time conditions, evolved regarding to García-Rigo et al. 2007
7	**SDTVAR**	Sidereal day-to-day Total Electron Content variability (TECU)	30 sec, per station	30 sec	**Message MUSD**	Hernández-Pajares et al. 1997
8	**SRMTID**	Single Receiver Medium Latitude / Medium Scale Travelling Ionospheric Disturbance index for mid-latitude stations, the mean root square of double diff. in time of STEC for each pair GNSS transmitter-receiver, each 5 minutes (TECU/900 sec^2)	30 sec over each station	~5 min 30 sec	**Message MUMT**	Hernández-Pajares et al. 2006a-b
9	**ROTI**	Rate of Total Electron Content Index (TECU)	30 sec	~180 sec	**Message MURO**	MONITOR TN-1200
10	**ITSVAR**	Ionospheric truth: Slant Total Electron Content variation	30 sec, under requireme	two weeks in	**Message MUIT**	Hernández-Pajares, 2004, Feltens et al.

		referred to a given observation, in a continuous arc of carrier phase GNSS data (TECU)	nt.	principle .		2010

Table 1: Main characteristics of the UPC external ionospheric products for project MONITOR.

Msg.	Main content	Fields	Format	Filename
IONEX	VTEC (in 0.1 TECUs, 1 TECU=10^{16} electrons/m^2), Std.Dev.VTEC, Transmitter and Receiver for P1-P2 DCBs (ns, referred to average of GPS satellites DCBs)	Non-column wise format (see reference at format column)	http://igscb.jpl.nasa.gov/components/formats.html http://igscb.jpl.nasa.gov/igscb/data/format/ionex1.pdf	XXXXDDD"0."YY"i.Z" where XXXX is the 4-digits IONEX files id, DDD is the day of year YY (two last digits, e.g. uqrt3240.10i.Z)
MUTD	GPS Transmitter DCBs and Std.Dev. est.	"MUTD00",tdjm,const,prn,dcb,sdcb,kind_of_dcb,ref_of_dcb,year,doy	printf "%s %12.6f %s %2d %9.3f %8.3f %s %s %4d %3d\n"	"tdcbs-"XXXX"."YYYY"."DDD" .mutd" where XXXX is the 4-digits IONEX files id for P1-P2, or "P1-C1", "P2-C2" for corresponding DCBs, DDD is the day of year YYYY (e.g. tdcbs-uqrg.2010.324.mutd)
MURD	GPS Receiver DCBs and	"MURD00",tdjm,const,re	printf "%s %12.6f %s %s %9.3f %8.3f %s %s %4d %3d\n"	"rdcbs-"XXXX"."YYYY"."DDD"

	Std.Dev. est.	c,dcb,sdcb,kind_of_dcb,ref_of_dcb,year,doy		.murd" where XXXX is the 4-digits IONEX files id for P1-P2, or "P1-C1", "P2-C2" for corresponding DCBs, DDD is the day of year YYYY (e.g. rdcbs-uqrg.2010.324.murd)
MUST	Slant Total Electron Content estimates	yy,doy,thours,rec,prn,elev,xrec,yrec,zrec,xtra,ytra,ztra,xli,stec,res,narch,stec_tecu,const," MUST00"	printf "%2d%4d%12.8f %4s%3d%7.2f%15.3f%15.3f%15.3f%15.3f%15.3f%15.3f%21.13e%10.4f%21.13e%7d %9.3f %s %s\n" [*] This record is actually generated in FORTRAN code.	"stecs-"XXXX"."YYYY"."DDD0"-"DDD1"."REC".window"WWW".must" where XXXX is the 4-digits IONEX file (or other ionospheric source) id, DDD0 and DDD1 represent the interval in days of year YYYY, in 24 hours windows, sliding each 6 hours for receiver REC, following GMV requirements (e.g. stecs-uqrg.2010.324-325.ebre.window002.must)
MUGE	Global Electron Content estimation (in GECUs, 1 GECU=10^{32} electrons)	"MUGE00",tdjm,gec_in_gecus,sgec_in_gecus,year,doy,tsec	printf "%s %12.6f %11.7f %10.7f %4d %3d %5d\n"	"gec-"XXXX"."YYYY"."DDD".muge" where XXXX is the 4-digits IONEX files id, DDD is the day of year YYYY (e.g. gec-uqrg.2010.324.muge)

MUSF	Solar Flare indicator (in TECUs)	"MUSF00",tdjm,SFcoeff,sSFcoeff,potentialSF_warning,positive_d2V,kone_d,kone_n,year,doy,tsec,hh,mm,ss	[*] printf "%s %12.6f %13.5e %13.5e I1 I1 %5d %5d %4d %3d %5d %2d %2d %2d\n" [*] This record is actually generated in FORTRAN code (RT UPC external product).	"gsflad." YYYY"."DDD".musf" where DDD is the day of year YYYY (e.g. gsflad.2010.324.musf)
MUSD	Sidereal Day-to-day TEC variation (in TECUs)	"MUSD00",tdjm,rec,const,prn,ele,dvtec,sdvtec,dele,rion,lonion,lation,ltion,year,doy,tsec,hh,mm,ss	[*] printf "%s %12.6f %s %s %2d %8.3f%10.3f%8.1f%9.3f%8.1f%9.3f%8.3f%9.4f %4d %3d %5d %2d %2d %2d\n" [*] This record is actually generated in FORTRAN code (RT UPC external product).	"sdtvar." YYYY"."DDD".musd" where DDD is the day of year YYYY (e.g. sdtvar-uqrg.2010.324.musd)
MUMT	Single Receiver Mid-Lat Medium Scale Travelling Ionospheric Disturbance index (SRMTID, in TECUs)	"MUMT00",tdjm,rec,srmtid,kone_srmtid, year,doy,tsec,hh,mm,ss	[*] printf "%s %12.6f %s %13.5e %4d %4d %3d %5d %2d %2d %2d\n" [*] This record is actually generated in FORTRAN code (RT UPC external product).	"srmtid." YYYY"."DDD".mumt" where DDD is the day of year YYYY (e.g. srmtid.2010.324.mumt)
MURO	Rate of TEC Index (ROTI, in TECUs)	"MURO00",tdjm,rec,const,prn,ele,roti_stec,roti_vtec,konm, rion,lonion,lation,ltion,year,doy,tsec	[*] printf "%s %12.6f %s %s %2d %8.3f%11.4ff%11.4f%3d%8.1f%9.3f%8.3f%9.4f %4d %3d %5d %2d %2d %2d\n" [*] This record is actually generated in FORTRAN code (RT UPC external product).	"roti." YYYY"."DDD".muro" where DDD is the day of year YYYY (e.g. roti.2010.324.muro)

		,hh,mm,ss		
MUIT	Ionospheric truth: observed STEC referred to STEC measured at highest elevation line-of-sight for the same phase continuous transmitter-receiver arc (in TECUs)	year,doy,tsec,rec,prn,ele,xrec,yrec,zrec,xtra,ytra,ztra,year_elemax,doy_elemax,tsec_elemax,elemax,xtra_elemax,ytra_elemax,ztra_elemax,dSTEC_obs,iaac,dSTEC_iaac,const," MUIT00"	printf "%4d %3d %5d %4s %2d %8.3f %13.3f %13.3f %13.3f %13.3f %13.3f %13.3f %4d %3d %5d %8.3f %13.3f %13.3f %13.3f %10.3f %4s %10.3f\n"	"itsvar-"XXXX"."YYYY"."DDD".muit" where XXXX is the 4-digits IONEX files id, DDD is the day of year YYYY (e.g. itsvar-uqrg.2010.324.muit)

Table 2: Messages and details, corresponding to UPC external ionospheric products.

Field	Description
tdjm	Mean Julian Day
const	GNSS Constellation ("G" for GPS, "R" for Glonass, "E" for Galileo)
rec	Receiver Id. (typically 4 digits, IGS coding)
dcb	Delay Code Bias (DCB), in ns
sdcb	Standard Deviation estimation of DCB, in ns
kind_of_dcb	Kind of DCB (in this project "P1-P2", "P1-C1" or "P2-C2")
ref_of_dcb	DCB to which all the DCBs are referred to ("AAT" = Average for All Transmitters, "Txyy" = Transmitter # yy of constellation x (e.g. TG02), "Rxyyyy" = Receiver yyyy of constellation x (e.g. RGebre)

year	Year (e.g. 2010)
doy	Day of Year (e.g. 324)
thours	GPS time of the day, in hours
xrec,yrec,zrec	Coordinates of GNSS receiver (ITRF-05), in meters.
Xtra,ytra,ztra	Coordinates of GNSS transmitter (ITRF-05), in meters.
Xli	Ionospheric combination of measured carrier phases in both GPS frequencies, L1-L2, in meters
stec	Computed Slant Total Electron content, in meters of L1-L2
res	Residual
narch	Integer id of transmitter-receiver carrier phase arch
stec_tecu	Computed Slant Total Electron content, in TECUs
gec_in_gecus	Global Electron Content, in GECUs
sgec_in_gecus	Std. Dev. Estimate of GEC, in GECUs
tsec	GPS time of the day, in seconds
SFcoeff	Daylight correlation Solar Flare coefficient (TECUs)
sSFcoeff	Std. Dev. Of the Daylight correlation Solar Flare coefficient (TECUs)
potentialSF_warning	Logical flag indicating Potential Solar Flare Warning (F=False, T=True)
positive_d2V	Logical flag indicating positive Vertical TEC drift rate (F=False, T=True)
kone_d	Number of selected observations falling in daylight hemisphere
kone_n	Number of selected observations falling in night hemisphere
hh	GPS Time: Hour (00 to 24)
mm	GPS Time: Minute (00 to 60)

ss	GPS Time: Second (00 to 60)
ele	Elevation on the horizon (degrees)
dvtec	Sidereal day-to-day VTEC variation (TECUs)
sdvtec	Std.Dev. of the Sidereal day-to-day VTEC variation (TECUs)
dele	Sidereal day-to-day Elevation variation (degrees)
rion	Geocentric distance of the assumed 2D ionospheric layer for quick slant-to-vertical conversions in the detectors (km).
Lonion	Idem for Longitude (degrees)
lation	Idem for Latitude (degrees)
ltion	Idem for Local Time (hours)
srmtid	Single Receiver Mid-Latitude/Medium Scale TID index (single value per receiver and epoch, quickly deduced from the TEC drift rate at 5 minutes)
kone_srmtid	Counter of single observations involved in the computation of srmtid
roti_stec	More frequent definition of Rate of TEC Index (ROTI), derived from STEC (in TECU)
roti_vtec	Alternative definition of Rate of TEC Index, derived from VTEC (in TECU)
konm	Number of data involved in the computation of ROTI (“10” indicates full availability of data).
year_elemax	Year of dSTEC reference observation (at higher elevation in the continuous arc of phase data).
doy_elemax	Similarly for day of year.
tsec_elemax	Idem for GPS time of day, in seconds
elemax	Elevation of reference (higher elevation...) ray, in degrees
xtra_elemax, ytra_elemax, ztra_elemax	Coordinates of GNSS transmitter (ITRF-05) corresponding to the ref. Ray, in meters.
dSTEC_obs	Ionospheric truth: observed STEC, referred (minus) to the

	STEC observed in the reference ray / TECUs
iaac	IGS Ionospheric Associate Analysis Center id
dSTEC_iaac	Modelled value for dSTEC_obs, given by Ionospheric center 'iaac'

Table 3: Fields and explanation, all of them included in the messages corresponding to UPC external products.

Plot description	Plot filename	Gen. period	Latency	Source (ext. prod. message & file)
Image representing the snapshot of the global VTEC map	XXXXYYDDD"."HHMM".tec0.global.gif" where XXXX is the 4-digits IONEX files id, DDD is the day of year YYYY, and HH and MM represent the hour and minute (e.g. uqrg10325.0715.tec0.global.gif)	15 min	48 hours	IONEX file XXXXDDD"0."YY"i.Z"
Image representing the snapshot of the global VTEC RMS map	XXXXYYDDD"."HHMM".rms0.global.gif" where XXXX is the 4-digits IONEX files id, DDD is the day of year YYYY, and HH and MM represent the hour and minute (e.g. uqrg10325.0715.rms0.global.gif)	15 min	48 hours	IONEX file XXXXDDD"0."YY"i.Z"
Values and Std. Dev. Of GPS transmitter DCBs	"tdcbs-"XXXX"."YYYY"."DDD".mutd.gps.snapshot.gif" where XXXX is the 4-digits IONEX files id, DDD is the day of year YYYY (e.g. tdcbs-uqrg.2010.324.mutd.gps.snapshot.gif)	Daily	48 hours	TDCBs-TOMION, MUTD, "tdcbs-"XXXX"."YYYY"."DDD".mutd"
Values and Std. Dev. Of GPS receiver	"rdcbs-"XXXX"."YYYY"."DDD".murd.gps.snapshot.gif" where XXXX is the 4-digits IONEX files id, DDD is the day of year YYYY (e.g.	Daily	48 hours	RDCBs-TOMION, MURD, "rdcbs-"XXXX"."YYYY"."DDD".murd"

DCBs	rdcbs-uqrg.2010.324.murd.gps.snapshot.gif)			
STEC in terms of GPS time (days of year, in 24 hours windows, sliding 6 hours)	"stecs-"XXXX"."YYYY"."DDD0"-"DDD1"."REC".window"WWW".must.gif" where XXXX is the 4-digits IONEX file (or other ionospheric source) id, DDD0 and DDD1 represent the interval in days of year YYYY, in 24 hours windows, sliding each 6 hours for receiver REC, following GMV requirements (e.g. stecs-uqrg.2010.324-325.ebre.window002.must.gif)	Under requirement	two weeks in principle	STECs-TOMION, MUST, "stecs-"XXXX"."YYYY"."DDD0"-"DDD1"."REC".window"WWW".must"
GEC in terms of GPS time (hours of day)	"gec-"XXXX"."YYYY"."DDD".muge.gif" where XXXX is the 4-digits IONEX files id, DDD is the day of year YYYY (e.g. gec-uqrg.2010.324.muge.gif)	15 min	48 hours	GEC-TOMION, MUGE, "gec-"XXXX"."YYYY"."DDD".muge"
Solar Flare indicator in terms of GPS time (hours of day)	"gsflad."YYYY"."DDD".musf.gif" where XXXX is the 4-digits IONEX files id, DDD is the day of year YYYY (e.g. gsflad.2010.324.musf.gif)	30 sec	30 sec	GSFLAD, MUSF, "gsflad."YYYY"."DDD".musf"
Sidereal day-to-day VTEC variation in terms of GPS time (hours of day)	"sdtvar."YYYY"."DDD".musd.REC.gif" where DDD is the day of year YYYY for receiver REC (e.g. sdtvar.2010.324.musd.ebre.gif)	30 sec	30 sec	SDTVAR, MUSD, "sdtvar." YYYY"."DDD".musd"
SRMTID index in terms of	"srmtid."YYYY"."DDD".mumt. REC.gif" where DDD is the day of year YYYY, given for the receiver REC (e.g	30 sec	5 min 30 sec	SRMTID, MUMT, "srmtid." YYYY"."DDD".mum

GPS time (hours of day)	srmtid.2003.344.mumt.ebre.gif)			t”
ROTI in terms of GPS time (hours of day)	“roti.”YYYY”.”DDD”.muro.REC.gif” where DDD is the day of year YYYY, given for the receiver REC (e.g roti.2003.344.muro.ebre.gif)	30 sec	180 sec	ROTI, MURO, “roti.” YYYY”.”DDD”.muro ”
dSTEC in terms of GPS time (hours of day)	“itsvar.”YYYY”.”DDD”. REC.muit.gif” where DDD is the day of year YYYY, given for the receiver REC (e.g itsvar.2003.344.ebre.muit.gif)	Under requirement	two weeks in principle	ITSVAR, MUIT, “itsvar-“XXXX”.”YYYY”.”DDD”.muit”

Table 4: Table containing the plots to be provided as companion of the UPC external ionospheric products.

3 Global VTEC maps with the Tomographic Ionosphere Model, TOMION (VTEC-TOMION, UPC)

The development of the tomography approach used in the TOMographic IONosphere model (TOMION) was started at UPC in the second half of the 1990s [Hernández-Pajares et al., 1997, 1999; Juan et al., 1997]. At that time, the main focus was to assess the feasibility of computing better TEC maps with a coarse tomography algorithm. TOMION has since been developed to provide several versions which are able to process ground based GNSS ionospheric data, GNSS LEO radio occultation data [Hernández-Pajares et al., 1998, 2000a], GNSS geodetic data [Hernández-Pajares et al., 2000b], and ionosonde data [García-Fernandez et al., 2003]. In real-time processing it is also possible to provide corrections for precise user positioning (Wide Area RTK, see Hernández-Pajares et al. [2002, 2010]. Since 1998, TOMION has been used in the UPC Ionospheric Analysis Centre for the IGS [Hernández-Pajares et al., 2009].

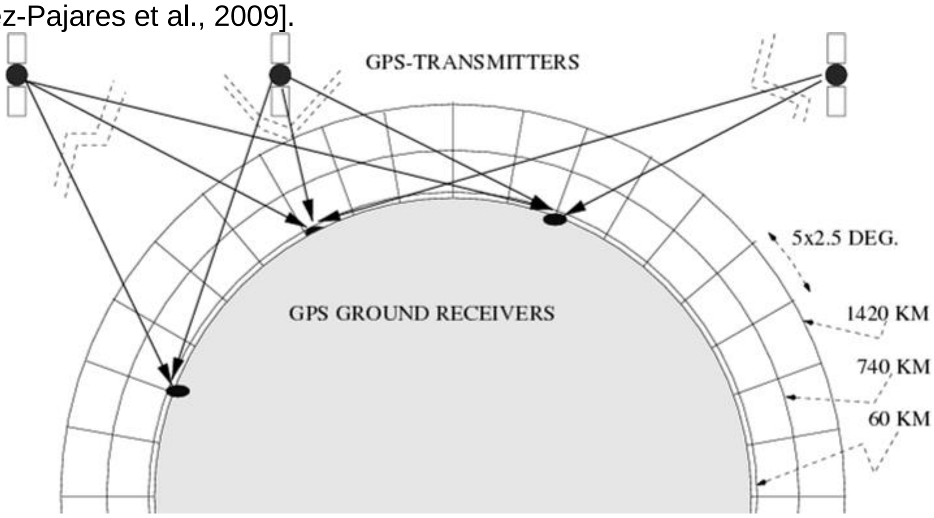

Figure 1: *2-layer voxel model typically used in TOMION with ground-based GNSS data.*

The version of TOMION used in this study (v1.5) generates Global Ionospheric Maps (GIMs) of vertical TEC (vTEC) and includes an interpolation module using Kriging interpolation [Orús et al., 2005]. The ionosphere is represented by two or more layers of voxels (see Figure 1). In each voxel the electron density is assumed to be constant. No background model is used and the overall accuracy is better than 80% in the worst case (Solar Maximum and over the oceans with few and isolated receivers, see Figure 14d in Hernández-Pajares et al. 2009). The assimilation of data proceeds in three steps: 1) an initial fit is made to the ground based

TEC data; 2) data gaps are filled using a modified Kriging interpolation technique to generate GIMs, taking into account the correlation lengths of the vTEC errors in the interpolation process, specially important in ocean and southern hemisphere regions with sparse ground-based GPS data available. And 3) an enhanced Abel Transform retrieval can be addititonally used to produce high accuracy and high resolution electron density fields in the vicinity of radio occultation measurements, by taking the previous vTEC as proxy of the horizontal gradients in the occultation region. Presently new optimized versions of TOMION, for real-time and predicted VTEC maps, are continuously running in the context of IGS real-time and ionospheric working groups, respectively.

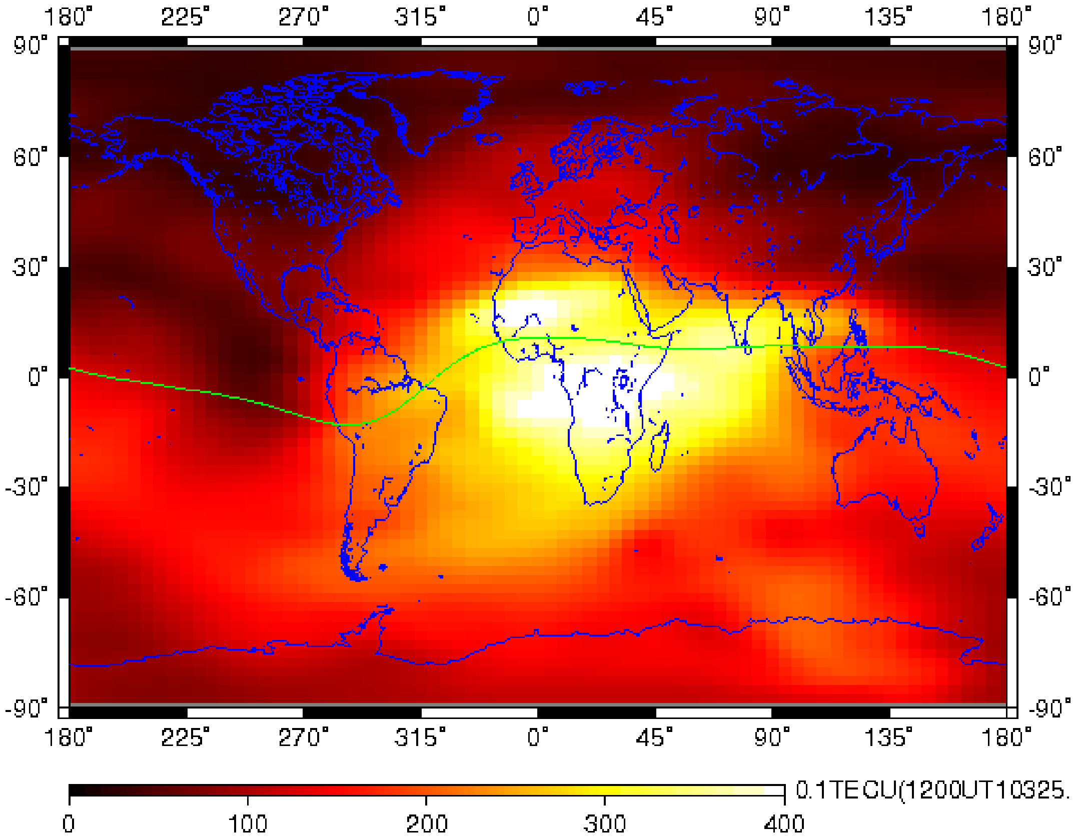

***Figure 2:** Example of VTEC map plot associated to VTEC-TOMION UPC external products for day 325 of 2010, 1200h GPS time (file uqrg10325.1200.tec0.global.gif, see **Table 4** for details).*

4 DELAY CODE BIASES OF GPS TRANSMITTERS (TDCBS-TOMION, UPC)

The Satellite Delay Code Biases of P1-P2 are being computed as well by TOMION, as a derived product from the VTEC global maps. Indeed, the ionospheric carrier phase is aligned with the pseudorange, estimating the corresponding ambiguity by averaging with the ionospheric pseudorange for every phase continuous arc of data. The resulting values can be considered directly Slant TEC (STEC) excepting for the receiver and transmitters DCB values, which are then estimated by averaging the “post-fit residual” after substracting the STEC prediction given by the global VTEC model, previously calculated. The DCBs for the GPS satellites or transmitters are obtained, after substracting the average of the DCBs between them (which constitutes the receiver DCB, see next section). The values of the transmitters are quite stable, typically at the level of few tenths of ns (see for instance Hernández-Pajares et al. 2009), as it can be seen in particular for recent datasets in Figure 3 and Figure 4.

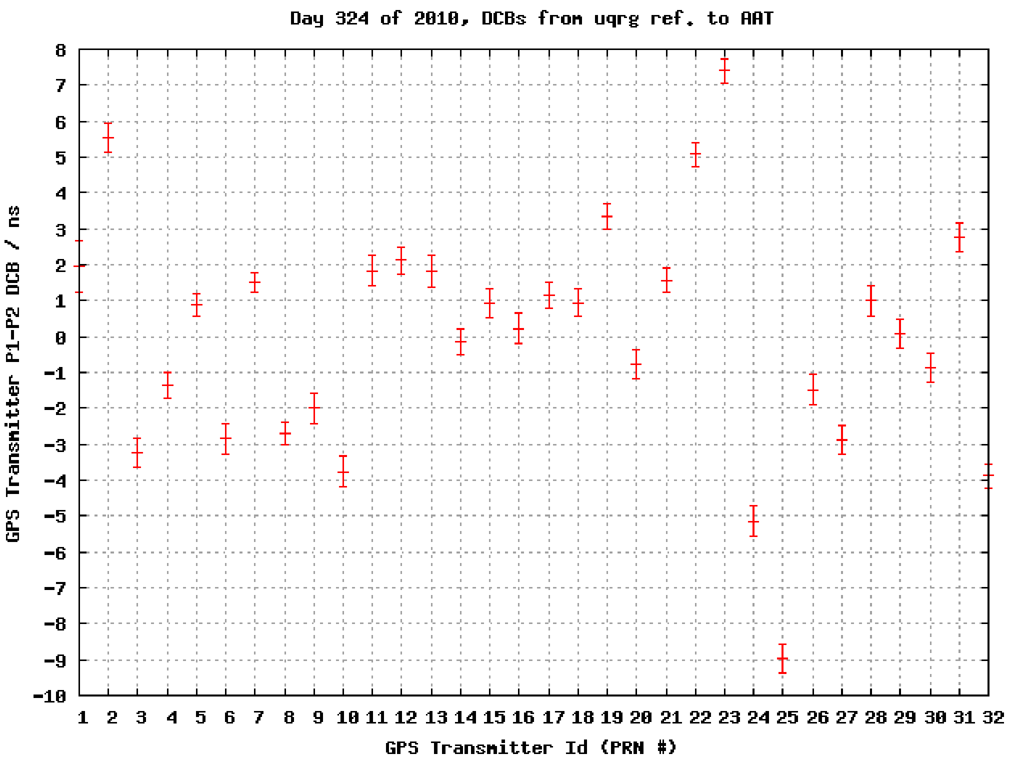

Figure 3: *Example of GPS transmitter DCB values associated to TDCBs-TOMION UPC external products for day 324 of 2010 (file tdcbs-uqrg.2010.324.mutd.gps.snapshot.gif, see **Table 4** for details).*

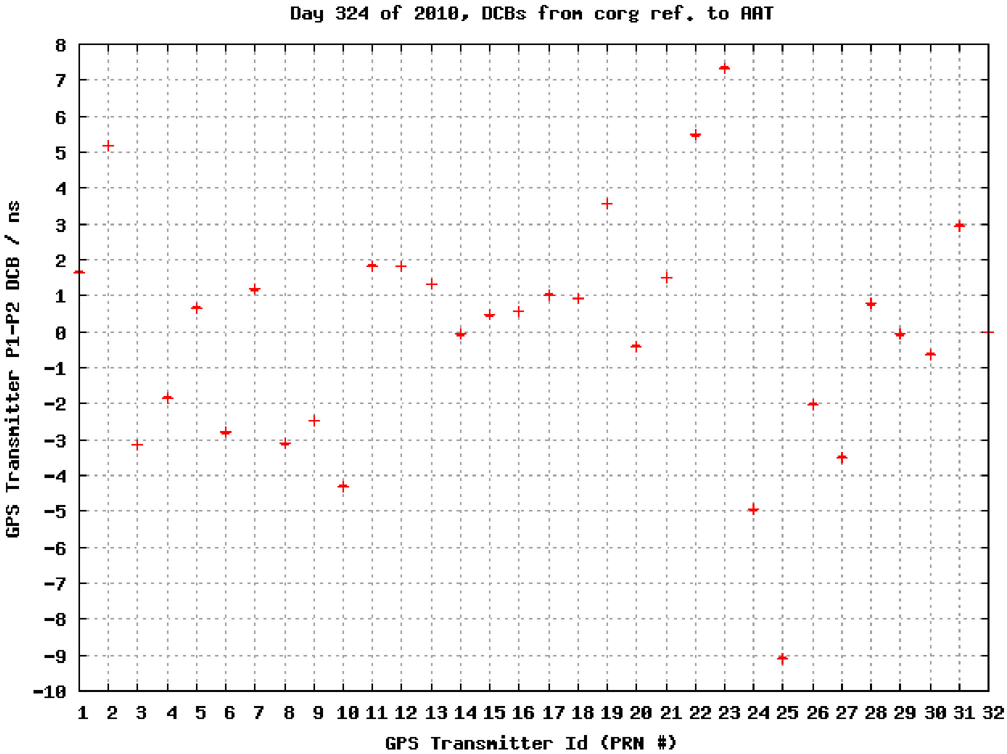

Figure 4: *Same plot than previous one, but based on the GPS transmitter DCB estimation provided by a different IGS ionospheric analysis center (CODE, day 324 of year 2010).*

5 DELAY CODE BIASES OF GPS RECEIVERS (RDCBS-TOMION, UPC)

The Receiver Delay Code Biases of P1-P2 are similarly computed to the transmitter ones, described in previous section, as the between-transmitter-average DCBs affecting the given receiver. The values of the receiver DCBs are stable typically at the level of up to few ns (see for instance Hernández-Pajares et al. 2009). You can see recent estimates for some IGS receivers in Figure 3.

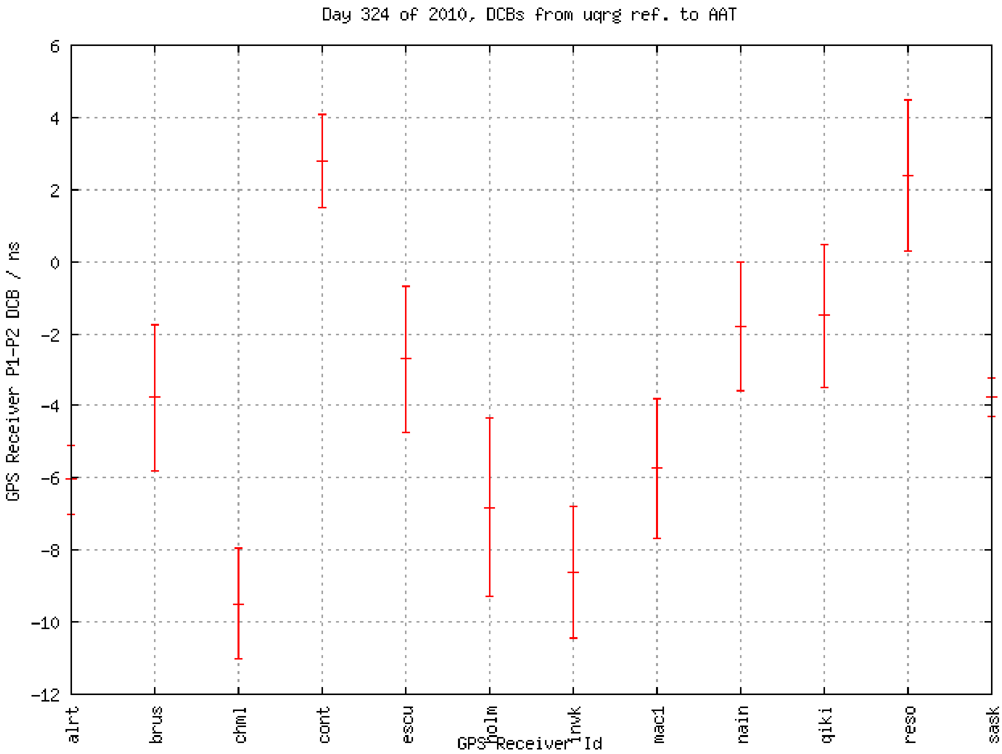

Figure 5: *Example of GPS receiver DCB values associated to RDCBs-TOMION UPC external products for day 324 of 2010 (file rdcbs-uqrg.2010.324.murd.gps.snapshot.gif, see* ***Table 4*** *for details).*

6 SLANT TOTAL ELECTRON CONTENT VALUES (STECS-TOMION, UPC)

The Slant Total Electron Content along the GPS transmitter-receiver line-of-sights (LOS) is another derived product from the VTEC-TOMION maps. Indeed, the STEC values directly given by TOMION for the LOS are used as reference to estimate the ionospheric phase ambiguities from the receiver measurements. Then they can be affected by errors of few TECU in well covered mid latitude regions (such as Europe) up to less than 20 TECU in isolated low latitude regions in Solar Maximum conditions when the data of the used receiver have not taken part in the computation of the global VTEC map. You can see a recent example in Figure 6.

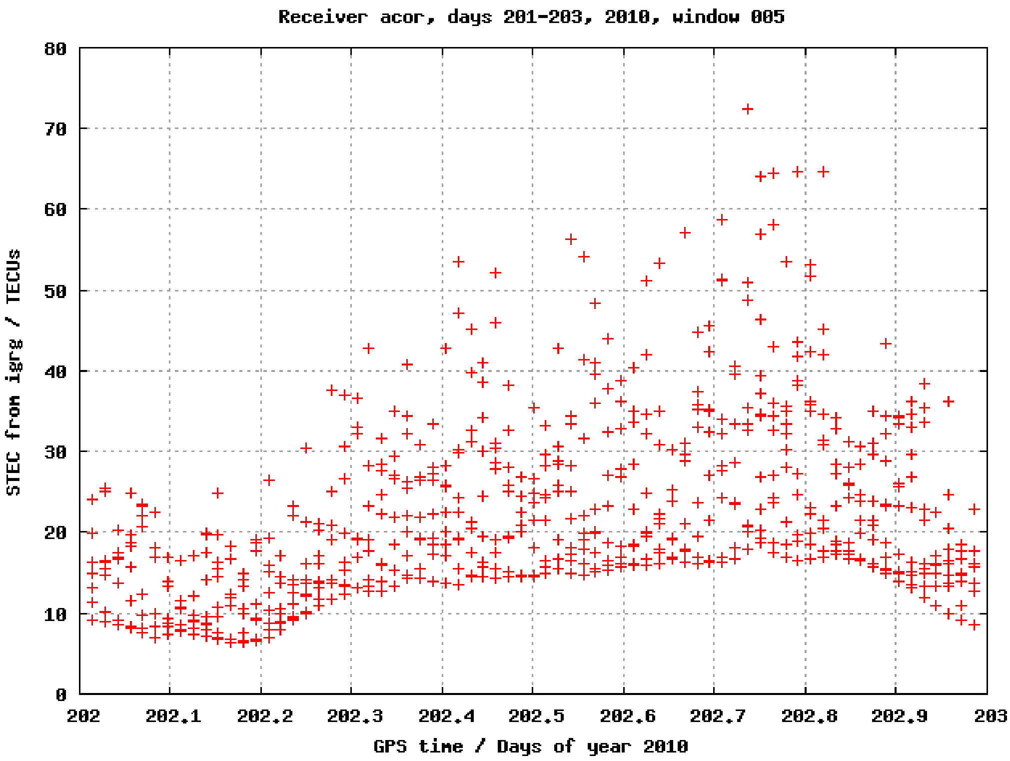

Figure 6: *Example of STEC values associated to STECs-TOMION UPC external product for a 24 hours window corresponding to day 202 of 2010 (file stecs-igrg.2010.201-203.acor.window005.must.gif, see **Table 4** for details).*

7 GLOBAL ELECTRON CONTENT (GEC-TOMION, UPC)

The Global Electron Content, GEC is a single global ionospheric index proposed by Astafyeva et al. 2006. It is computed from the integration of each given VTEC map on the overall Ionosphere surface (in which the free electrons distribution is approximated). The associated unit is called Global Electron Content Unit, or GECU, defined as 10^{32} electron/m^2.

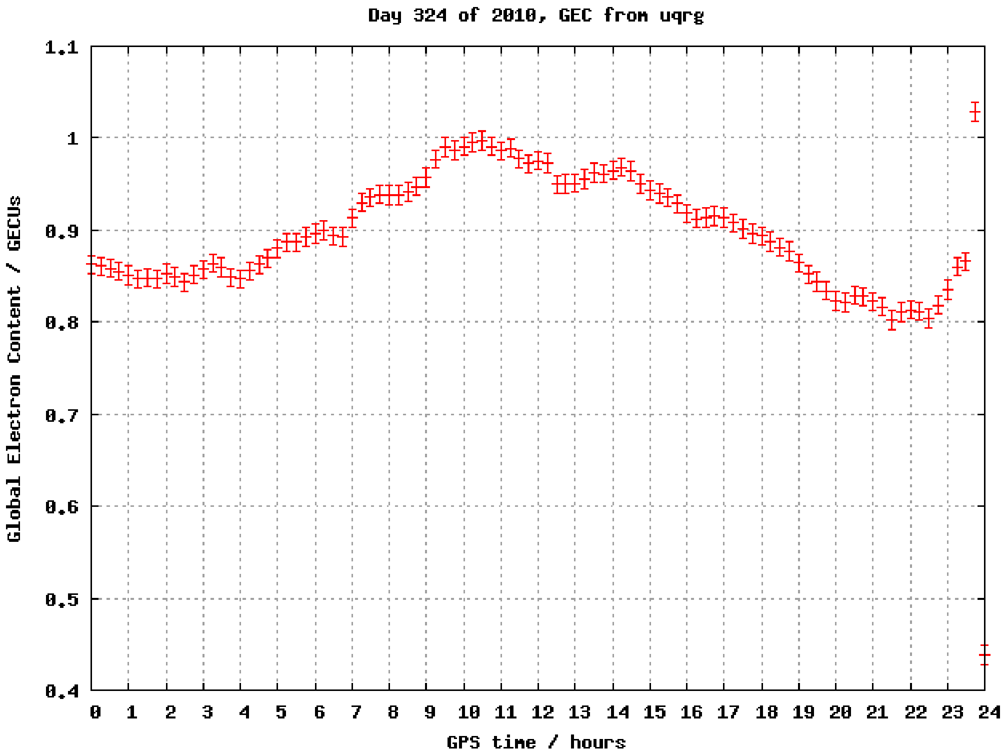

Figure 7: *Example of daily GEC evolution, given in the GEC-TOMION UPC external product for day 324 of 2010 (file gec-uqrg.2010.324.muge.gif, see* ***Table 4*** *for details).*

8 GNSS SOLAR FLARE DETECTOR IN REAL-TIME (GSFLAD, UPC)

The availability of a global network of GNSS receivers monitoring simultaneously the daylight and night hemispheres, makes feasible the detection of the main Solar Flares through the rapid overionization of the Ionosphere by means of a single GNSS Solar Flare Detector (GSFLAD, see in particular García-Rigo et al. 2007, and its monitoring previous to the Halloween storm in Figure 8).

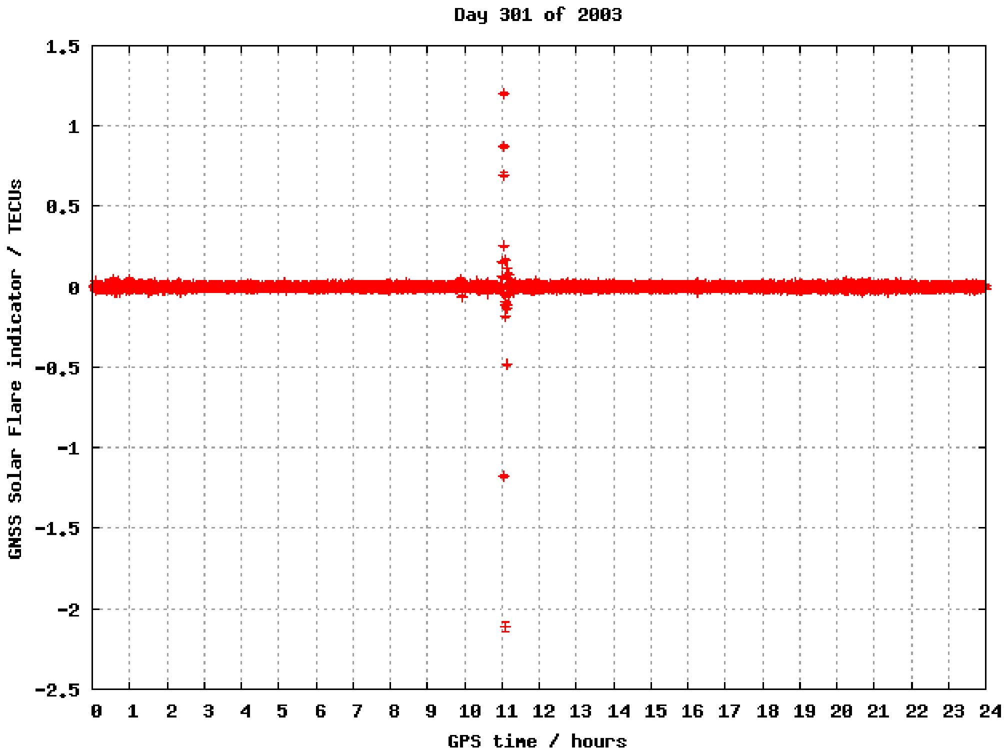

Figure 8: *Evolution of GSFLAD index, to be provided by UPC as external MONITOR product, for the big flare triggering the Halloween ionospheric storm, during the day 301 of 2003 (file gsflad.2003.301.musf.gif, see* ***Table 4*** *for details).*

9 SIDEREAL DAY-TO-DAY TOTAL ELECTRON CONTENT VARIABILITY (SDTVAR, UPC)

The direct computation of sidereal day-today total electron content variability (SDTVAR) from ground-based GPS data, was proposed in [Hernández-Pajares et al. 1997] as a simple way of increasing the accuracy in the computation of electron content variation. Indeed thanks to the repeatability of the transmitter-receiver geometry after every sidereal day, an efficient implicit filtering of pseudorange multipath and DCB intradaily variability is got after taking sidereal-day-to-day differences. This allows for instance to monitor ionospheric storm effects on electron content (see above mentioned reference) or increasing the detectability of Solar Flare events (Liu et al. 2004). A recent example can be found in

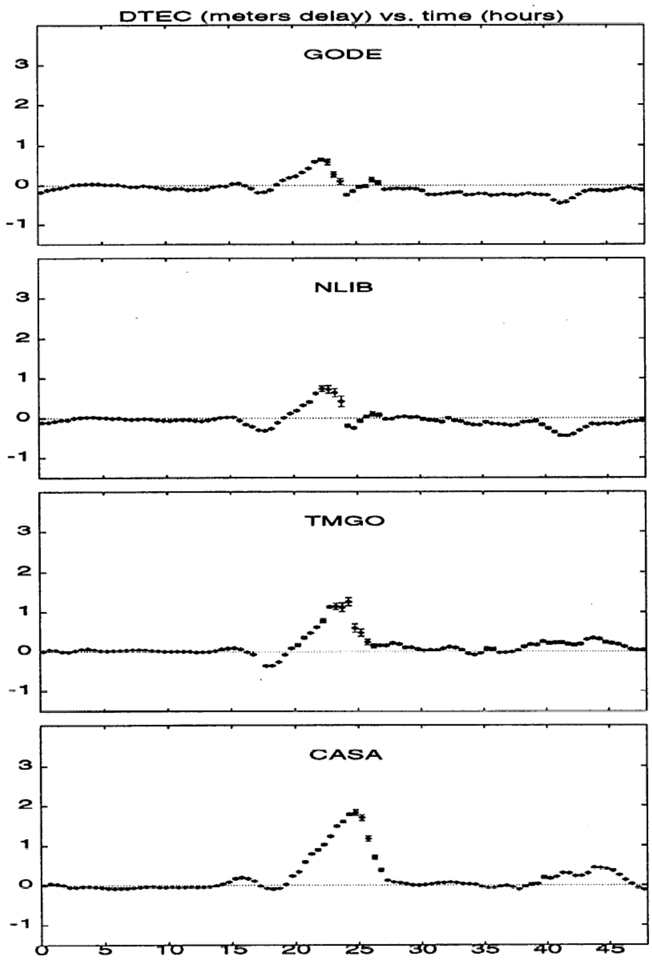

Figure 9: *SDTVAR based detection of one ionospheric perturbantion seen from four permanent GPS stations in NorthAmerica (ordered from West to East), during days 18 and 19 October 1995, referred*

to day 17 October (y-axis: VTEC variation in approx. tens of TECU, x-axis time in hours, referred to 18 October 0000 GPS time –source: [Hernández-Pajares et al. 1997]-).

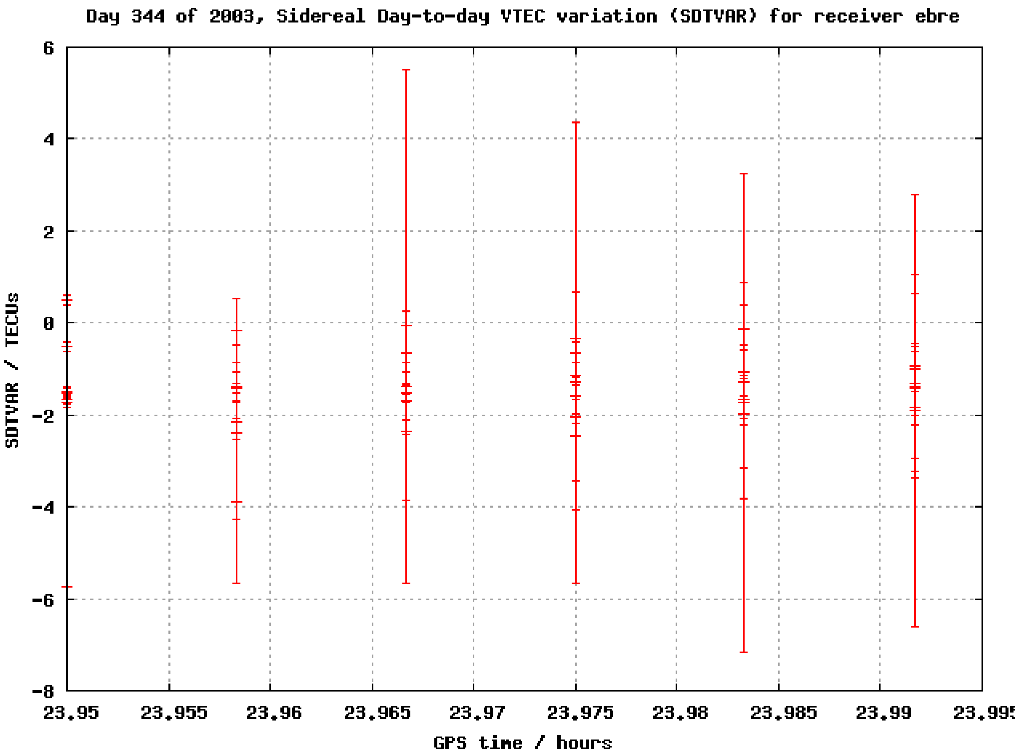

***Figure 10:** Example of VTEC variation corresponding to the SDTVAR UPC external products for day 344 of 2010 (file rdcbs-uqrg.2010.324.murd.gps.snapshot.gif, see **Table 4** for details).*

10 SINGLE RECEIVER MEDIUM SCALE TRAVELLING IONOSPHERIC DISTURBANCE INDEX FOR MID LATITUDES (SRMTID, UPC)

The Single Receiver Mid-Latitude Medium Scale Travelling Ionospheric Disturbance (SRMTID) was initially introduced in [Hernández-Pajares et al. 2006a] (Figure 15), in order to easily indicate in real-time the Medium Scale TID (MSTID) activity for mid latitude stations, in real-time and without the need of a local network (as it is needed for determining the MSTID propagation parameters, see [Hernández-Pajares et al. 2006b]). The SRMTID index is defined as the RMS of the STEC rate drift, very precisely deduced from the ionospheric phase for all the satellites in view for a given epoch. It is actually computed as double difference in time, each 300 seconds, to filter out larger periods much larger than those of MSTID (around 1000 seconds).

In detail the algorithm can be summarized in the following way, for each given pair of GNSS satellite-receiver independently:

1) The ionospheric combination, Li, is computed from the L1 and L2 GNSS carrier phases in length units:

Li=L1-L2

2) The cycle-slips are hopefully detected and marked, for instance looking for values of double consecutive difference in time of Li, $|d^2Li| = |Li(t+dt)-2Li(t)+Li(t-dt)| > d2Li\_threshold$ (for instance d2Li_threshold= 0.10 meters +0.002 meters/sec*(dt/sec))

3) For every time t with measurements, with no cycle slip regarding to the previous and later observations, separated each consecutive pair by dt=30 seconds, d2Li is computed.

4) The RMS of 10 consecutive d2Li values at 30 seconds, i.e. each 300 seconds, is computed, given the SRMTID index:

$$SRMTID\ [t] = \sqrt{\sum_{j=0}^{9} (d\,2Li[t - j * 30\ \mathrm{sec}])^2}$$

An example can be seen in Figure 11, showing the typical mid-latitude MSTID activity around local winter and noon (see [Hernández-Pajares et al. 2006b] for a full study). SRMTID can contain, especially at high or low latitude, part of the power due to shorter periods, as scintillation activity.

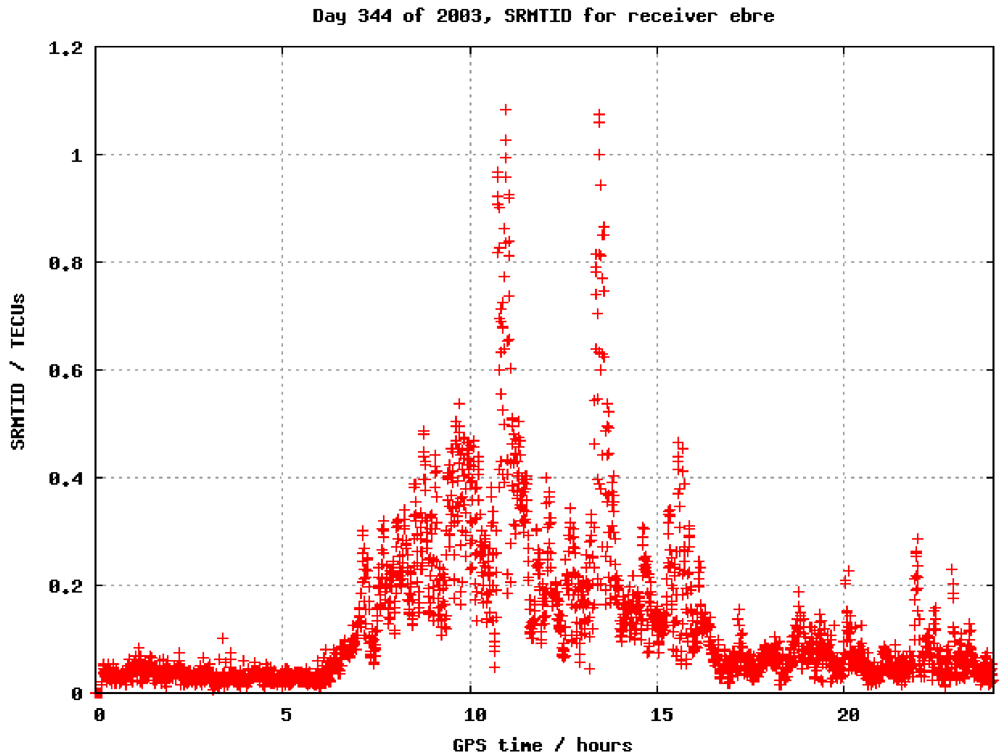

Figure 11: *Example of SRMTID index (other external MONITOR product provided by UPC) corresponding to receiver EBRE during day 344 of 2003 (file srmtid.2003.344.mumt.ebre.gif, see* ***Table 4*** *for details).*

11 RATE OF TOTAL ELECTRON CONTENT INDEX (ROTI, UPC)

The standard deviation of the TEC-rate (Rate-Of-TEC-Index, ROTI) is commonly calculated over a 5 minutes interval. For this task 30s-GNSS-receiver data is sufficient. As it was indicated in the output of MONITOR WP1200, different authors have compared it with direct amplitude measurements, suggesting that ROTI measurements can be a low-cost substitute for high-rate measurements allowing monitoring large areas. However it must be taken into account that it can be contaminated by variability components with periods of several seconds, likely due in some scenarios to phase multipath or interference. An example of ROTI evolution during a whole day can be seen in Figure 12).

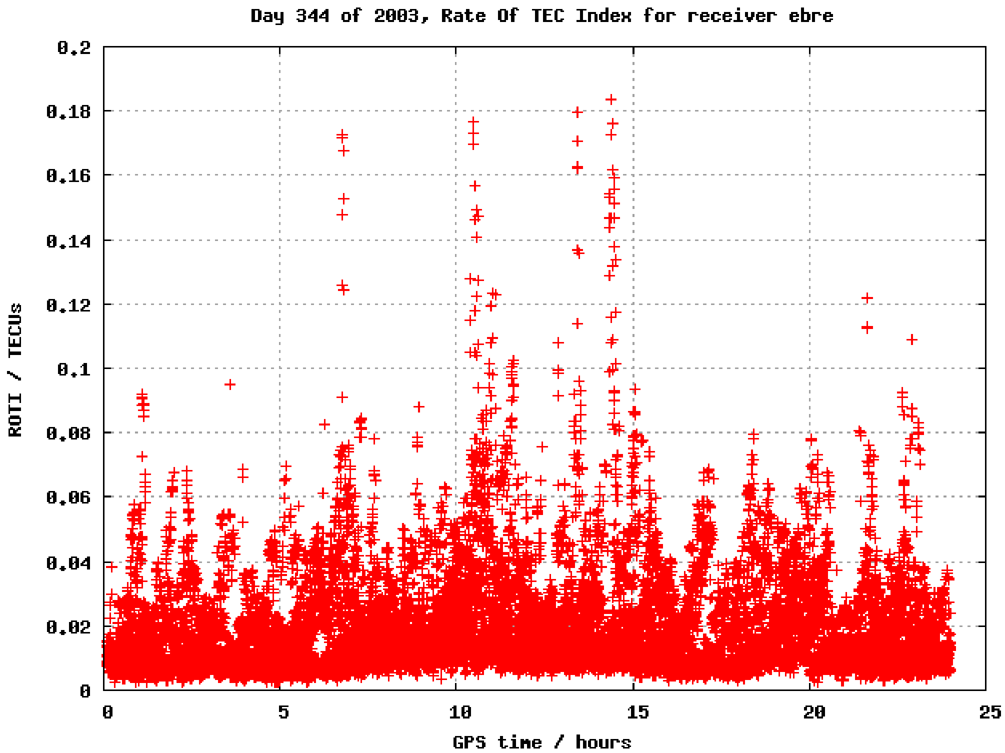

***Figure 12:** Example of ROTI evolution (additional external UPC product for MONITOR), for IGS receiver EBRE during the day 344 of 2003 (file roti.2003.344.muro.ebre.gif, see **Table 4** for details).*

12 IONOSPHERIC TRUTH: SLANT TOTAL ELECTRON VARIATION ALONG A CONTINUOUS ARC OF GNSS CARRIER PHASE (ITSVAR, UPC)

The GPS ionospheric carrier phase difference, for a given LOS, regarding to the value corresponding to the higher elevation ray in the phase continuous arc of data, provides a very precise ionospheric truth of the STEC variation, in space an time (typically much accurate than 0.1 TECU). This Ionospheric Truth of Slant Total Electron Variation can be used to compare the performance of ionospheric models. An example of ITSVAR can be seen in Figure 13)

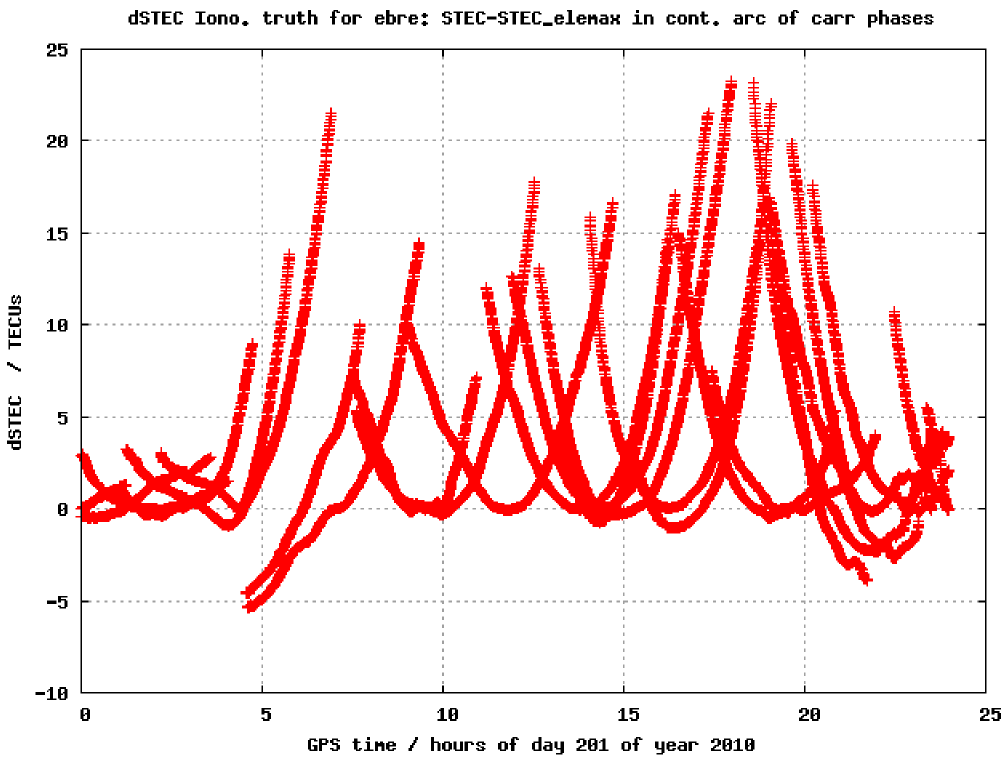

Figure 13: *Example of STEC variation Ionospheric Truth daily evolution (ITSVAR external UPC product) for IGS receiver EBRE, during day 201 of 2010 (file itsvar.2010.201.ebre.muit.gif, see* ***Table 4*** *for details).*

13 CONCLUSIONS

A summary of the external products, in which gAGE/UPC is contributing to MONITOR, is provided.

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14.1 APPLICABLE DOCUMENTS

Ref.	Document title	Document reference	Issue	Date
AD 1	MONITOR Contract		-	
AD 2	MONITOR Proposal	PR_318_19/10/2009		19/10/2009

Table 5: Applicable Documents

14.2 REFERENCE DOCUMENTS

Ref.	Document title	Document reference	Issue	Date

Table 6: Reference Documents

Annex 1
List of Acronyms

A1.1 Acronyms

A	
AR	Acceptance Review
C	
CAPF	Central Archiving and Processing Facility
CLS	Collecte Localisation Satellites SA
CDR	Critical Design Review
CFI	Customer Furnished Items
D	
DAMRR	Data Analysis, Modelling and Results Report
DFD	Data Formats Document
DJVP	Design, Justification and Verification Plan
DLR	Deutsches Zentrum für Luft und Raumfahrt
E	
ECP	Experimental Campaign Plan
EGNOS	European Geostationary Navigation Overlay Service
ESA	European Space Agency
F	
FMI	Finish Meteorological Institute
FR	Final Review
G	
GISMO	Galileo Ionospheric Sensor and Monitor
GMV	GMV Aerospace and Defence SA
GNSS	Global Navigation Satellite Service
GPS	Global Positioning System
I	
ICTP	International Centre for Theoretical Physics
IEEA	IEEA SARL
IEN	Ionospheric Experimentation Network
IES	Ionospheric Experimentation Station
ICD	Interface Control Document
IOM	Installation, Operation and Maintenance Manual

ITU-R	International Telecommunication Union: Radiocommunication sector
J	
JOP	Jena - OPtronik
K	
KO	Kick Off
P	
PDD	Preliminary Definition Document
PRR	Preliminary Requirements Review
PDR	Preliminary Design Review
Q	
QQ	Qinetiq
QR	Qualification Review
QOR	Quarterly Operations Review
QORR	QOR Report
R	
RD	Requirements Document
RX	Receiver
S	
SOC	Statement of Compliance (and Requirements Traceability)
SOW	Statement Of Work
SRD	System Requirements
T	
TAS	Thales Alania Space
TB	Télécom Bretagne
TEC	Total Electron Content
TN	Technical Note
TVR	Test and Verification Report
U	
UPC	University of Catalonia
W	
WBS	Work Breakdown Structure
WG	Working Group
WP	Work Package
WS	WorkShop

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