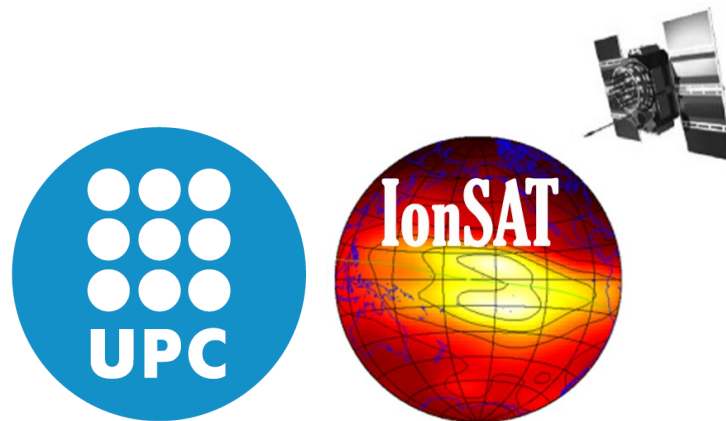




# Use Case 10: Access to UPC-IonSAT Global Ionospheric Maps registrations

*(AKA global VTEC maps every 15 minutes since end of 1996,  
i.e. ~1 million global VTEC maps &  $5 \times 10^9$  VTECs computed so far)*

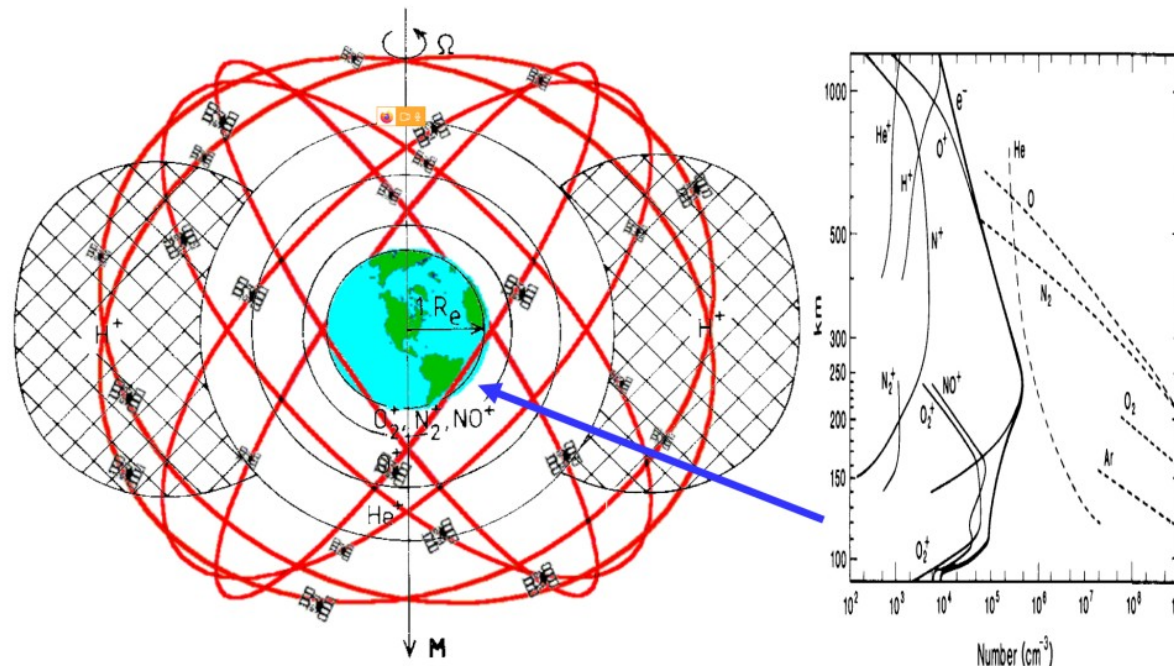
Manuel Hernández-Pajares, Victoria Graffigna, Alberto García-Rigo &  
Germán Olivares-Pulido on behalf of the UPC-IonSAT team



PITHIA-NRF TPW#5, Univ. Westminster, 12-13 September 2023

## GNSS Ionosphere

GNSS Ionosphere<sup>1</sup>: *Effects and computation of the distribution of free electrons, located at the partially ionized part of the atmosphere above 50 km height, from the **Global Navigation Satellite Systems** (GNSS) multi-frequency measurements crossing it; and its applications, such as Space Weather monitoring, precise real-time positioning and, among others.*



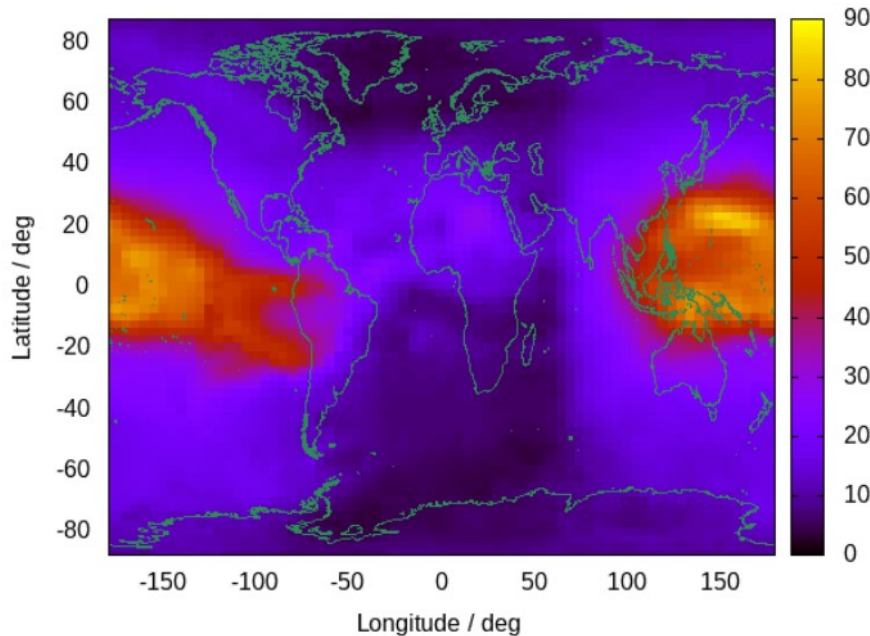
<sup>1</sup>Manuel Hernández-Pajares. "GNSS Ionosphere". In: *Encyclopedia of Geodesy* (2022). Ed. by Michael G. Sideris, pp. 1–7.



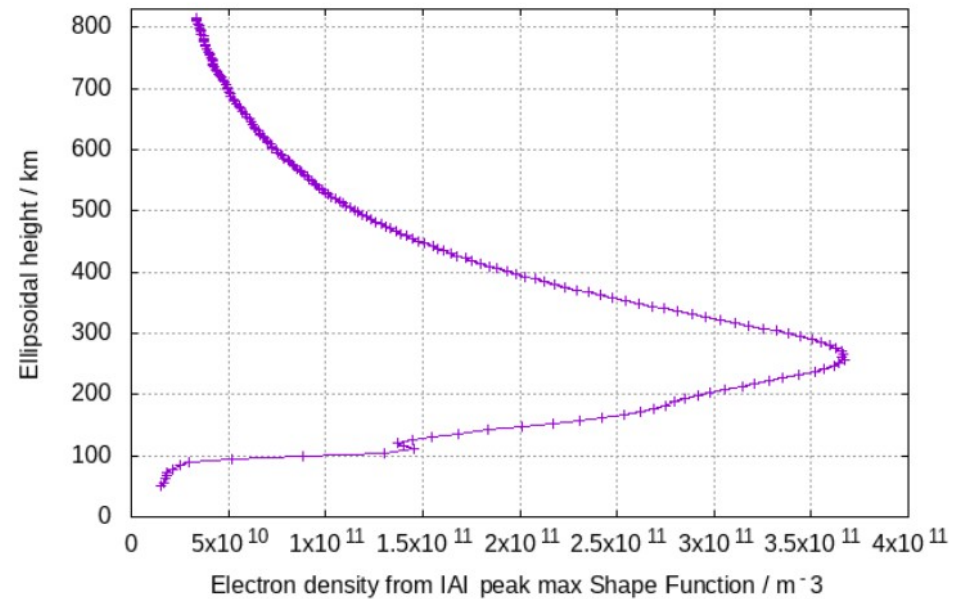
# The ionosphere in brief seen by GNSS

- The **ionosphere** is typically distributed from around 50 km to 1000 km height, where some predominant air molecules, such as O<sub>2</sub> and NO at the very bottom and mostly O above, are partially ionized respectively by the x-ray and specially Extreme Ultraviolet (EUV) solar flux (see for instance<sup>2</sup>).

VTEC / TECUs 01h30m,18Sep2011 (source: UQRG GIMs from UPC-IonSAT)



RO GPS PRN17 from COSMIC1-06 LEO (150E,50°S) on 01h30m,18Sep2011

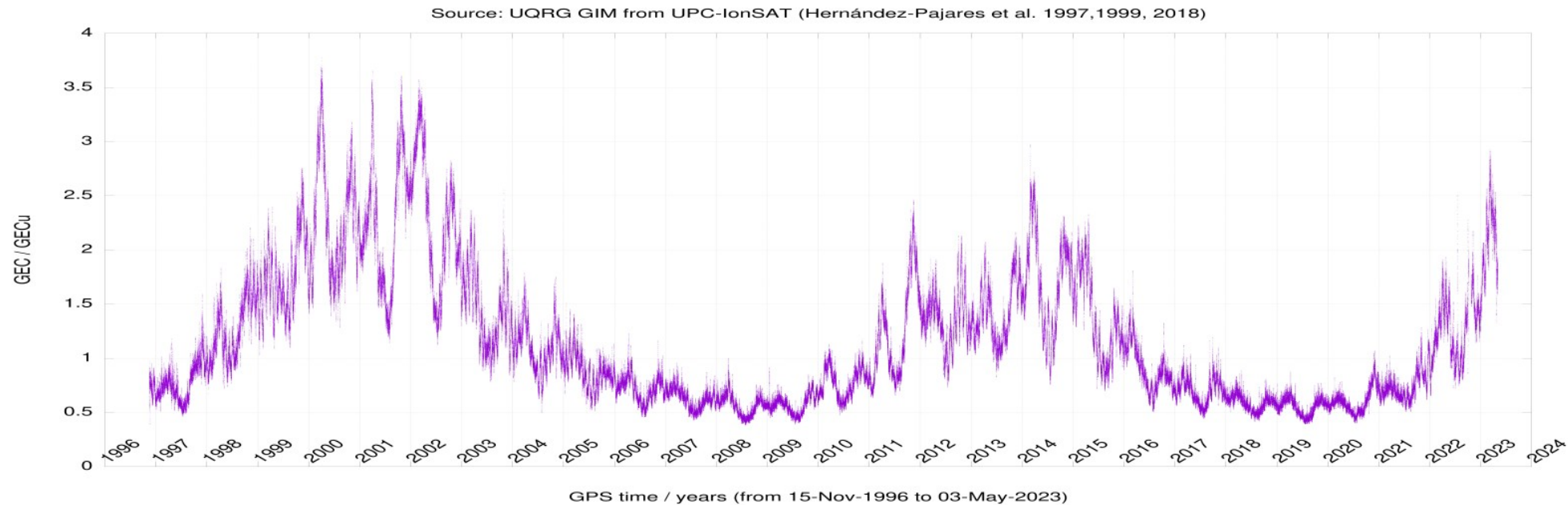


<sup>2</sup>Peter Teunissen and Oliver Montenbruck. *Springer handbook of global navigation satellite systems*. Springer, 2017, 1327, DOI: 10.1007/978-3-319-42928-1.



## Global Electron Content (GEC)

As consequence of its main origin, the total number of ionosphere free electrons (GEC) follows closely the solar activity, specially in normal (undisturbed) conditions: see the GEC time series obtained from the UQRG GIMs, computed every 15 minutes since end of 1996. The origin of features, like the semiannual and annual anomalies, are still under discussion <sup>(3)</sup>.

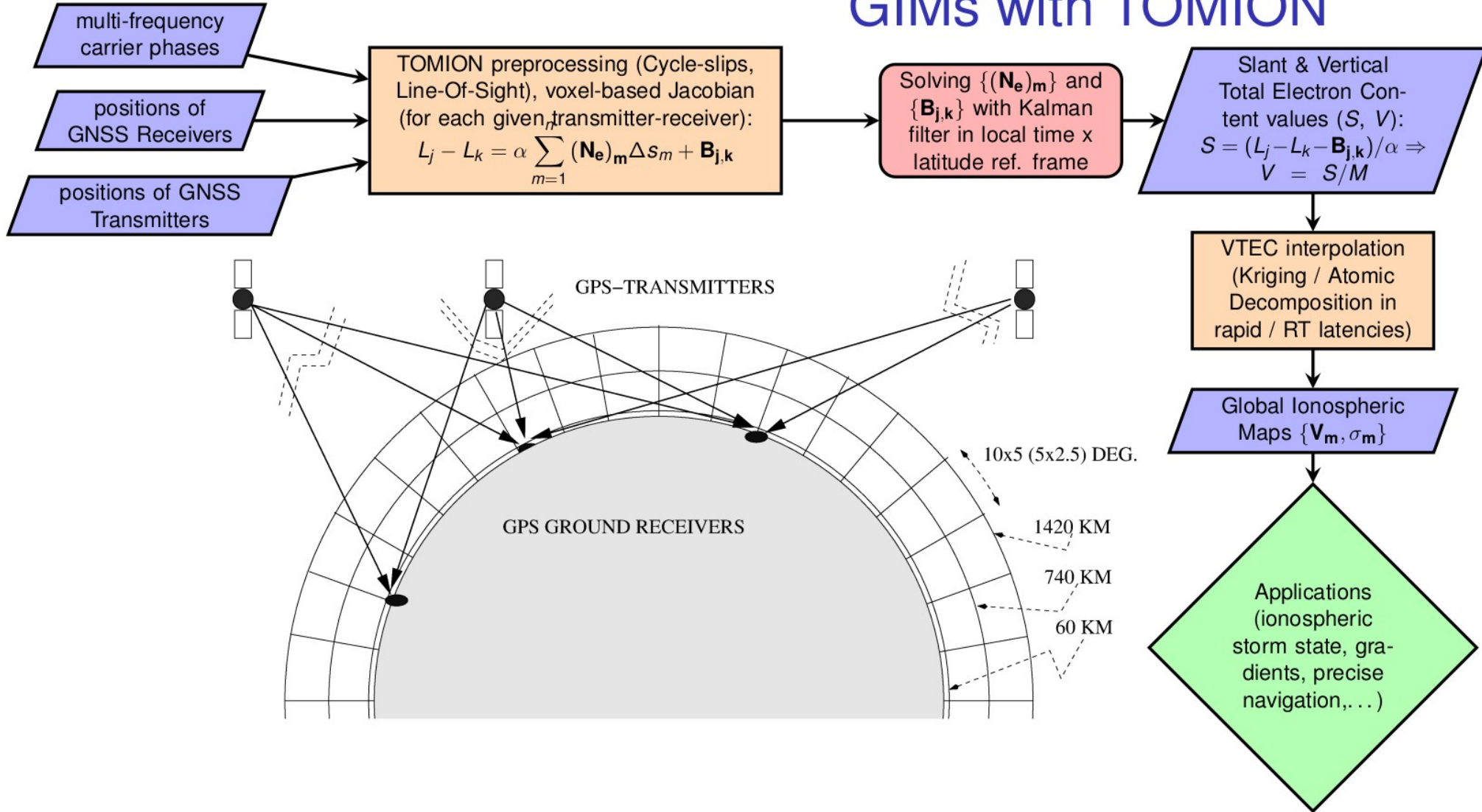


<sup>3</sup>Francisco Azpilicueta and Claudio Brunini. "A new concept regarding the cause of ionosphere semiannual and annual anomalies". In: *Journal of Geophysical Research: Space Physics* 116.A1 (2011).

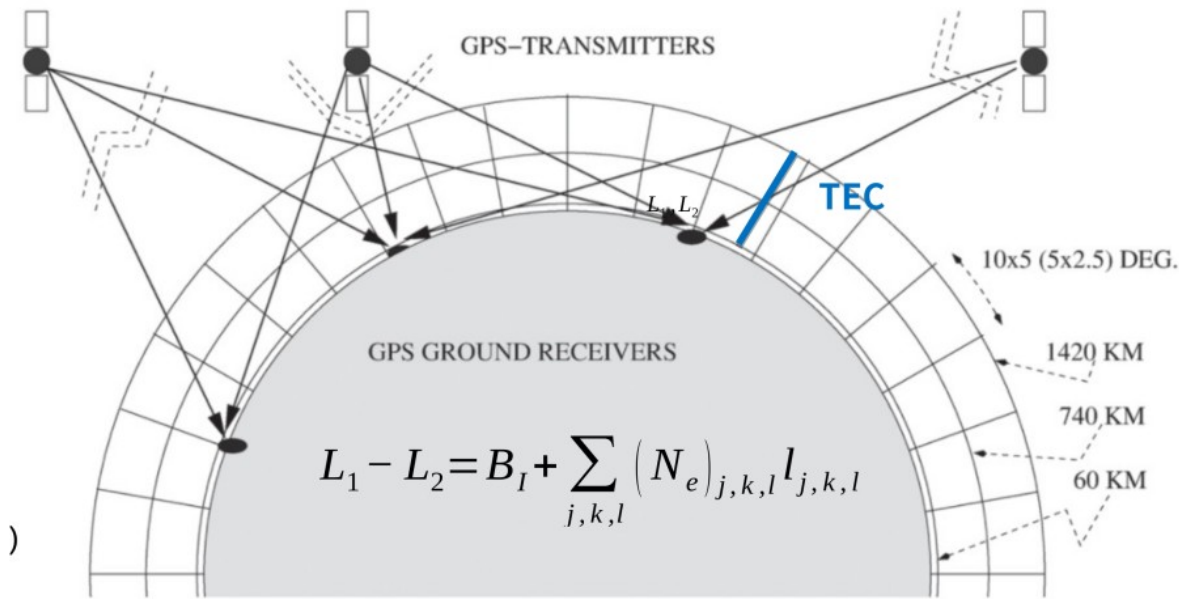




# GIMs with TOMION



# Introduction to TOMION model (2 of 3)



- It incorporates a **Kalman filter** and a **kriging-based interpolation** for the vertically integrated electron density (the vertical total electron content, VTEC, see<sup>6,7,8</sup>).

**UPC Quarter-of-an-hour time resolution Rapid GIM (UQRG)**

<sup>6</sup>M Hernandez-Pajares, JM Juan, and J Sanz. "Neural network modeling of the ionospheric electron content at global scale using GPS data". In: *Radio Science* 32.3 (1997), pp. 1081–1089.

<sup>7</sup>M Hernández-Pajares, JM Juan, and J Sanz. "New approaches in global ionospheric determination using ground GPS data". In: *Journal of Atmospheric and Solar-Terrestrial Physics* 61.16 (1999), pp. 1237–1247.

<sup>8</sup>R Orús et al. "Improvement of global ionospheric VTEC maps by using kriging interpolation technique". In: *Journal of Atmospheric and Solar-Terrestrial Physics* 67.16 (2005), pp. 1598–1609.





## Introduction to TOMION model (3 of 3)

- TOMION is the software used in the generation of UPC-IonSAT GIMs of VTEC for the International GNSS Service (IGS), such as the UQRG one, one of the best behaving GIMs in IGS (<sup>9, 10, 11</sup>).
- The tomography performed by TOMION is able to combine different data and geometries (<sup>12</sup>), in agreement with independent measurements and models (<sup>13, 14</sup>), also in the polar regions (<sup>15</sup>).

<sup>9</sup> M Hernández-Pajares et al. “The IGS VTEC maps: a reliable source of ionospheric information since 1998”. In: *Journal of Geodesy* 83.3-4 (2009), pp. 263–275.

<sup>10</sup> Manuel Hernández-Pajares et al. “Methodology and consistency of slant and vertical assessments for ionospheric electron content models”. In: *Journal of Geodesy* 91. doi:10.1007/s00190-017-1032-z (2017), pp. 1405–1414.

<sup>11</sup> David Roma-Dollase et al. “Consistency of seven different GNSS global ionospheric mapping techniques during one solar cycle”. In: *Journal of Geodesy* 92.6 (2018), pp. 691–706.

<sup>12</sup> Manuel Hernández-Pajares et al. “A new way of improving global ionospheric maps by ionospheric tomography: consistent combination of multi-GNSS and multi-space geodetic dual-frequency measurements gathered from vessel-, LEO-and ground-based receivers”. In: *Journal of Geodesy* 94.8 (2020), pp. 1–16.

<sup>13</sup> DV Kotov et al. “Coincident observations by the Kharkiv IS radar and ionosonde, DMSP and Arase (ERG) satellites, and FLIP model simulations: Implications for the NRLMSISE-00 hydrogen density, plasmasphere, and ionosphere”. In: *Geophysical Research Letters* 45.16 (2018), pp. 8062–8071.

<sup>14</sup> DV Kotov et al. “Weak magnetic storms can modulate ionosphere-plasmasphere interaction significantly: Mechanisms and manifestations at mid-latitudes”. In: *Journal of Geophysical Research: Space Physics* 124.11 (2019), pp. 9665–9675.

<sup>15</sup> Manuel Hernández-Pajares et al. “Polar Electron Content From GPS Data-Based Global Ionospheric Maps: Assessment, Case Studies, and Climatology”. In: *Journal of Geophysical Research: Space Physics* 125.6 (2020), e2019JA027677.







Home


## PITHIA-NRF e-Science Centre

### Search & Browse Metadata

Four buttons for metadata navigation:

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### Space Physics Ontology

 Space Physics Ontology

### Data Registration







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<a href="#">EIS Ionospheric Alerts</a>
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<a href="#">EPB_detectionTool</a>
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<a href="#">eSWua: Scintillation Indices and Total Electron Content (TEC) database</a>
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<a href="#">TechTIDE LSTID activity index</a>



## GIM: Global Ionosphere Maps

Global Vertical Total Electron Content 2D map computed using UPC Rapid Network of GPS receivers

### Interact

Interaction Method	Description	Data Format	Link
Direct Link to Data Collection	The GIM landing page has the list of data the 15-minutes maps.	<a href="#">text/html</a> (click the link to show information on this ontology term)	<a href="#">Open GIM Landing Page in new tab</a> ↗


### Identifier Properties

<b>Local ID</b>	DataCollection_UPC-RapidNetwork_GIM
<b>Namespace</b>	pithia
<b>Version</b>	1
<b>Created</b>	Tuesday 20th Dec. 2022, 09:30:00
<b>Last Modified</b>	Tuesday 20th Dec. 2022, 09:30:00

### Properties

Property	Value
<b>Type (1/2)</b>	<a href="#">Receiver of GNSS signals</a> (click the link to show information on this ontology term)
<b>Type (2/2)</b>	<a href="#">Assimilative Model</a> (click the link to show information on this ontology term)
<b>Project</b>	<a href="#">GIM: Global Ionospheric Maps</a> (click the link to show information on this metadata registration)
<b>Data Level</b>	<a href="#">Level 3</a> (click the link to show information on this ontology term)
<b>Result</b>	<i>Not used</i>
<b>Permission</b>	<a href="#">Creative Commons Attribution-NonCommercial-ShareAlike</a> (click the link to show information on this ontology term)



<b>Role</b> (from Related Party (1/2) > Responsible Party Info)	<a href="#">Point of contact</a> (click the link to show information on this ontology term)
<b>Party</b> (from Related Party (1/2) > Responsible Party Info)	<a href="#">Manuel Hernandez-Pajares</a> (click the link to show information on this metadata registration)
<b>Role</b> (from Related Party (2/2) > Responsible Party Info)	<a href="#">Data Provider</a> (click the link to show information on this ontology term)
<b>Party</b> (from Related Party (2/2) > Responsible Party Info)	<a href="#">UPC-IonSAT</a> (click the link to show information on this metadata registration)
<b>Result Time</b>	Not used
<b>Name</b> (from Collection Results > Source > Online Resource)	GIM Landing Page
<b>URL</b> (from Collection Results > Source > Online Resource > Linkage)	<a href="http://cabrera.upc.es/upc_ionex_GPSONly-RINEXv3">http://cabrera.upc.es/upc_ionex_GPSONly-RINEXv3</a> 
<b>Protocol</b> (from Collection Results > Source > Online Resource)	HTTP
<b>Data Format</b> (from Collection Results > Source > Online Resource)	<a href="#">text/html</a> (click the link to show information on this ontology term)
<b>Description</b> (from Collection Results > Source > Online Resource)	The GIM landing page has the list of the 15-minutes ionex files.





























# Index of /upc\_ionex\_GPSONly-RINEXv3



<u>Name</u>	<u>Last modified</u>	<u>Size</u>	<u>Description</u>
 <a href="#">Parent Directory</a>		-	
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 <a href="#">2000/</a>	2020-04-08 10:56	-	
 <a href="#">2001/</a>	2020-04-08 10:56	-	
 <a href="#">2002/</a>	2022-10-09 16:23	-	
 <a href="#">2003/</a>	2020-04-08 10:56	-	
 <a href="#">2004/</a>	2020-04-08 10:56	-	
 <a href="#">2005/</a>	2020-04-08 10:56	-	
 <a href="#">2006/</a>	2022-10-09 16:22	-	
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 <a href="#">2014/</a>	2020-04-08 10:56	-	
 <a href="#">2015/</a>	2020-04-08 10:56	-	
 <a href="#">2016/</a>	2020-04-08 10:56	-	



# Index of /upc\_ionex\_GPSonly-RINEXv3/2010





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<a href="#">003_100103.15min/</a>	2020-04-08 10:56	-	
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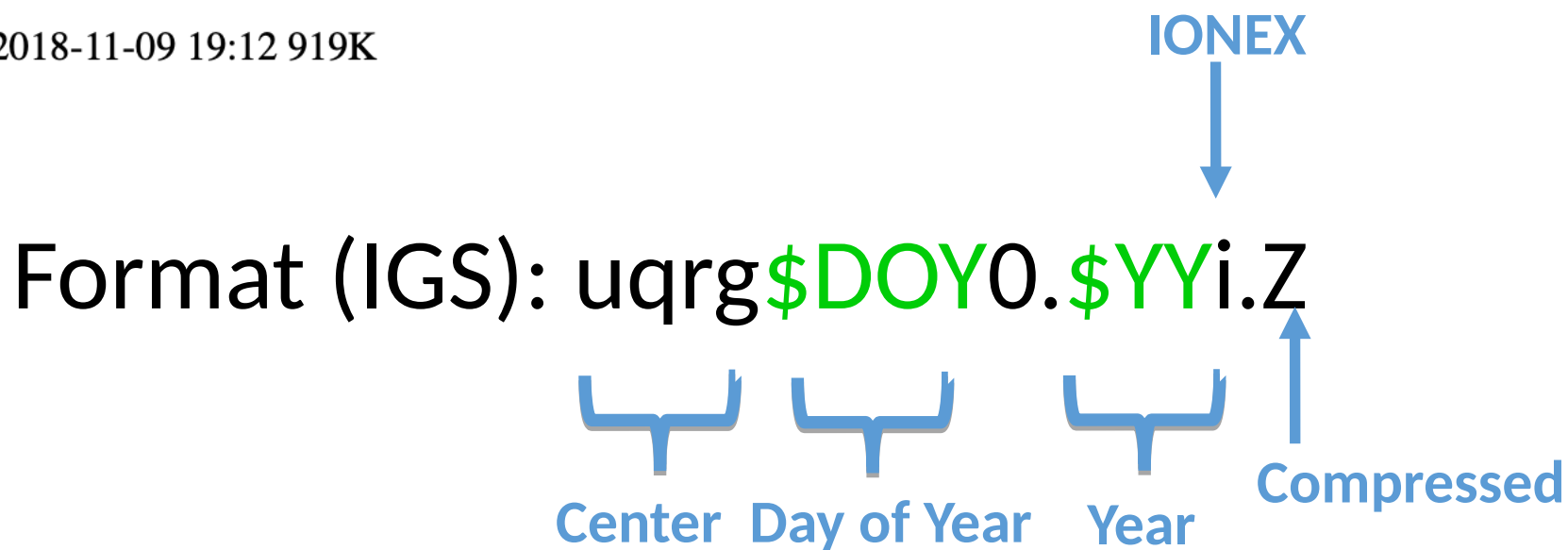
Format: **\$DOY\_****\$YY****\$MM****\$DD**.15min

Day of Year    Year    Month    Day    Resolution



# Index of /upc\_ionex\_GPSonly-RINEXv3/2010/015\_100115.15min

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## Index of /upc\_ionex\_GPSonly-RINEXv3/2010/015\_100115.15min

<a href="#">Name</a>	<a href="#">Last modified</a>	<a href="#">Size</a>	<a href="#">Description</a>
 <a href="#">Parent Directory</a>	-		
 <a href="#">uqrg0150.10i.Z</a>	2018-11-09 19:12	919K	

Apache/2.4.29 (Ubuntu) Server at cabrera.upc.es Port 80

Do you want to allow downloads on "cabrera.upc.es"?

You can change which websites can download files in Websites Preferences.

Cancel

Allow





```

1.0 IONOSPHERE MAPS GPS IONEX VERSION / TYPE
tecrms2ionex_4.awk UPC-IonSAT 11/09/18 1711UT PGM / RUN BY / DATE
Global ionosphere maps for day 15, 2010 (15- 1-2010) DESCRIPTION
Contact address: Manuel Hernandez-Pajares DESCRIPTION
IonSAT research group DESCRIPTION
Technical Univ. of Catalonia (UPC-IonSAT) DESCRIPTION
Mod. C3 Campus Nord UPC DESCRIPTION
E08034-Barcelona, SPAIN DESCRIPTION
e-mail: manuel@ma4.upc.edu DESCRIPTION

```

```

P1-P2 DCBs(UPC3-BRDC) 15 2010: Bias= 0.000 RMS= 0.855 [ns]DESCRIPTION
DESCRIPTION
2010 1 15 0 0 0 EPOCH OF FIRST MAP
2010 1 15 23 59 24 EPOCH OF LAST MAP
900 INTERVAL
97 # OF MAPS IN FILE
COSZ MAPPING FUNCTION
0.0 ELEVATION CUTOFF
300 # OF STATIONS
32 # OF SATELLITES
6371.0 BASE RADIUS
2 MAP DIMENSION
450.0 450.0 0.0 HGT1 / HGT2 / DHGT
87.5 -87.5 -2.5 LAT1 / LAT2 / DLAT
-180.0 180.0 5.0 LON1 / LON2 / DLON
-1 EXPONENT

```

```

TEC values in 0.1 TECUs; 9999 if no value available COMMENT
IGS GPS stations used in the computations: COMMENT
019b ab02 ab07 ab08 ab11 ab14 ab25 ab27 ab37 ab39 ab41 ab43 COMMENT
ab44 abmf abpo ac03 ac12 ac60 ac61 acor acso acu5 ade1 adks COMMENT
agmt ahid aira ajac alac alam albh algo alic allg alon alrt COMMENT
amc2 ankr antc areq arli artu asky aspa auck autf baie bake COMMENT
bako bamo ban2 barh bcyi bdos bell bjfs bla1 blmm bluf boav COMMENT
bogt bomj brft brib brip brmu brst brus bshm bsmk bucu bue1 COMMENT
buri bysp cabl cagl call cand cant cas1 casc ccj2 cedu cefe COMMENT
cfag chan chat chiz chme chum chur cjtr ckis clrk cmb1 cnmr COMMENT
coco cont copo cosa coyq crao crar cuib cusv daej dane darw COMMENT
dav1 devi dgar dgjg dksg drao dres dum1 dupt ecsd edoc eur2 COMMENT
faa1 falk fall flin flrs func g101 g107 g117 g124 g201 g202 COMMENT
ganp gisb glps glsv gmas gamma guat harb hdil helg her2 hil1 COMMENT
hilb hlfx hmbg hnlc hob2 hobu hofn holm howe hrst hueg hugo COMMENT
hvlk hvwy hyde ifr1 impz ineg invk iqal iqqe irkj isba ispa COMMENT
ista jct1 joen karr kerg khaj khar kir0 kiri kit3 kouc kour COMMENT
ksnb kuaq kunm kuuq kvtx lafe lamt laut lhaz lpal lthw mac1 COMMENT

```





 <a href="#">2014/</a>	2020-04-08 10:56	-
 <a href="#">2015/</a>	2020-04-08 10:56	-
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 <a href="#">2017/</a>	2020-04-08 10:56	-
 <a href="#">2018/</a>	2023-09-04 16:57	-
 <a href="#">2019/</a>	2023-09-04 16:59	-
 <a href="#">2020/</a>	2023-09-04 17:05	-
 <a href="#">2021/</a>	2023-09-04 17:08	-
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 <a href="#">uqrg.latest.rms.gif</a>	2023-09-05 07:45	4.5M
 <a href="#">uqrg.latest.tec.gif</a>	2023-09-05 07:45	4.8M



# THANK YOU!