Towards RT assessment of ionospheric monitoring within IAG's RTIM-WG

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IAG's RTIM-WG - Introduction

The **Real Time Ionosphere Monitoring** is a Working Group (RTIM-WG) within the **International Association of Geodesy (IAG) Sub-Commission 4.3 "Atmosphere Remote Sensing"**.

The WG will cover the **period 2016 – 2019**, and includes experts in the field from multiple countries world-wide.

The **complementary expertise** of the participating research groups allows to analyse the ionospheric behaviour from a broad perspective, taking benefit of comparing **multiple independent RT and NRT ionospheric approaches**.

The models are mainly based on GNSS and ionosonde data (as in the case of IGS Iono-WG Global Ionospheric Maps, GIMs, or the International Reference Ionosphere, IRI, respectively).

IAG's RTIM-WG - Introduction

Main objectives of the WG:

- Assessment of the **current status** of RT Ionosphere Monitoring
- **Comparison of existing** RT Ionosphere Monitoring **approaches** from different perspectives for a specific period.
- A procedure to **automatically compare/validate** on a daily basis real time ionosphere products providing the results in a common compatible IONEX-like format.
- The improvement in the **real-time dissemination and format** of GIMs.
- Assess the **performance in the positioning domain**.
- Open **discussion towards new concepts** on RT Ionosphere Monitoring. Drawing recommendations and arranging training and dissemination activities for the community.

Questionnaire on RT/NRT Data Products

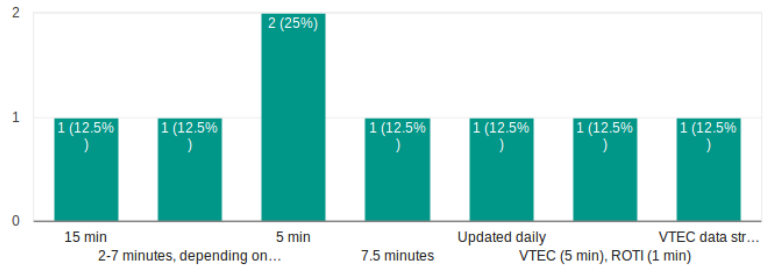
Which are the RT (or NRT) data products you are distributing or aiming to distribute? (ex. VTEC data streams in real time, foF2 global maps in real time, STEC regional data in near real time, etc.)

10 responses

TEC at 288 IGS stations W-index from TEC ar 288 IGS stations GIM-TEC global maps GIM-foF2 global maps GIM-hmF2 global maps GIM-W_index global maps
VTEC global and regional in near real time
regional hmF2 prediction for quiet and disturbed periods
Digisonde records in near real time
Global 2D maps of foF2, hmF2, B0, and B1 in near real time produced by IRTAM model using GIRO data
Standard URSI ionogram-derived characteristics in near real-time from GIRO ionosondes (~60 locations)
foF2 regional maps. In the near future aiming to distibute VTEC maps over eastern Mediterranean
regional/global VTEC data streams in real time and regional ionospheric coefficients based on ASH model in real time
VTEC/ROTI global and regional NRT data

What is the current latency of your product(s)? (optional)

8 responses



What is the format(s) you use for each data product to encapsulate your RT/NRT products? (RTCM SSR message 1264, IIWG SAO 4.3 format, Net-CDF, own format, etc.)

10 responses

TEC at 288 IGS stations and W_index from TEC at 288 IGS stations: Daily-hourly UT tables for current and preceding month IONEX format (GIM-TEC, GIM-foF2, GIM-hmF2, GIM- W-index maps)
IONEX, own SH and SCH format
web format
sao 4.3
IRTAM coefficients in text form, supported by IRI-2017 model
SAO 4.3 and simple tabulated format
Just images
VTEC data streams in RTCM SSR message and regional ionospheric coefficients in internal format
HDF5, JSON, GeoJSON, CSV, own formats
IONEX, HDF, internal ASCII formats

Available RT/NRT Data Products

Global and regional maps of different parameters, available with latencies ranging from 15 minutes down to 2 minutes.

- Vertical Total Electron Content (VTEC)
- F2 layer critical frequency (foF2)
- F2 layer maximum height (hmF2)
- W index
- F2 layer bottomside thickness (B0) and shape (B2)
- Rate of TEC Index (ROTI)

(Most usual, but they may be others we are not currently aware)

RT/NRT Data Products Distribution

Main specific formats for ionosphere data:

- IONEX
- RTCM SSR
- SAO 4.3

Other general purpose formats:

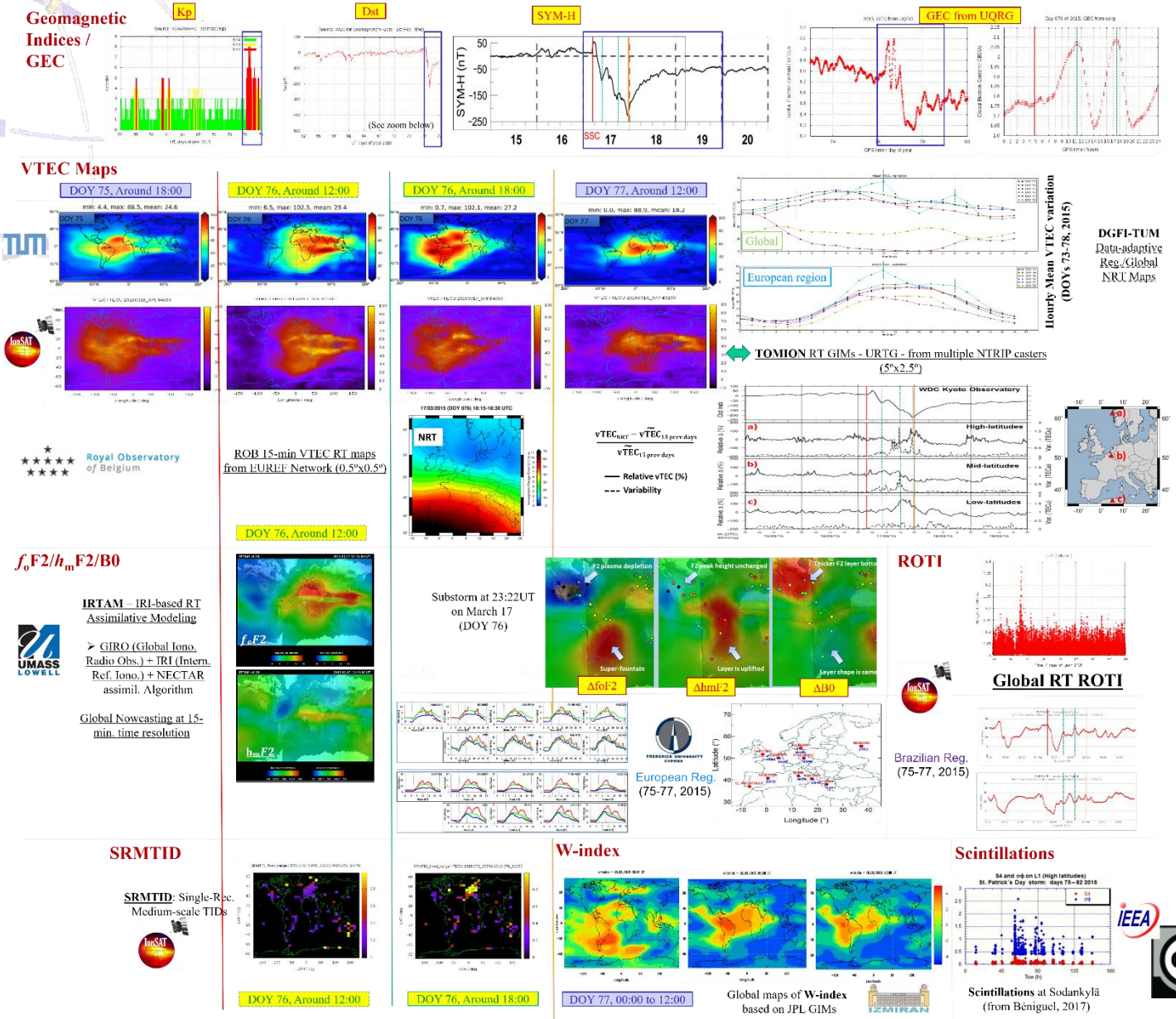
- HDF5
- Web page
- Image
- General Purpose text format: HDF5, CSV, JSON
- ASCII Text data with internal formats

Distribution itself is done through:

- HTTP or web service
- FTP

And only one method exclusive for GNSS/ionosphere data: Network Transport of RTCM over Internet Protocol (NTRIP)

St. Patrick's Day 2015 geomagnetic storm analysis



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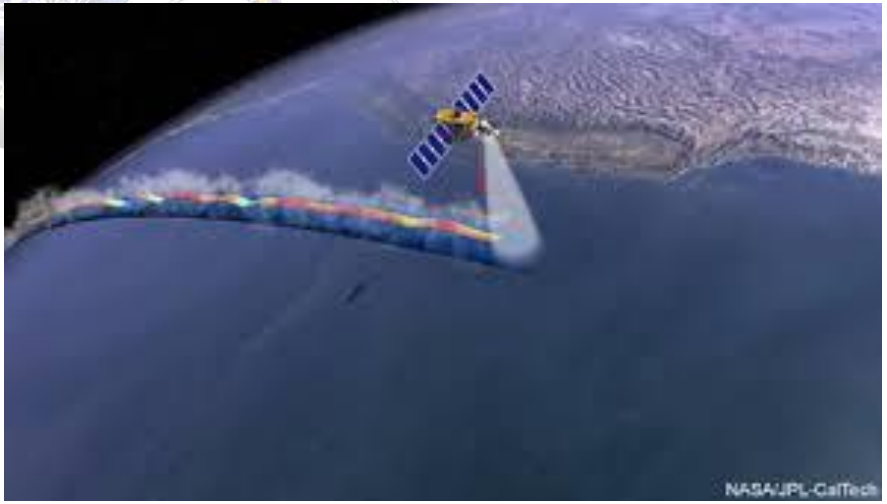
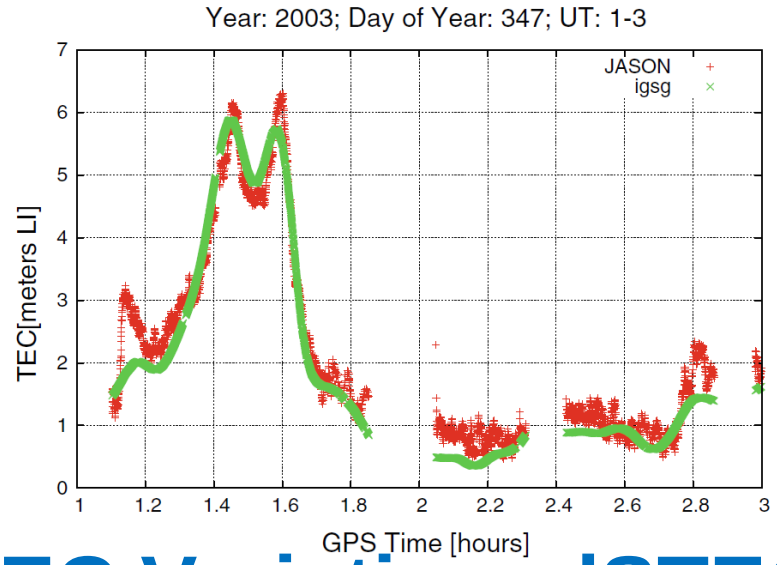
RT/NRT VTEC assessment

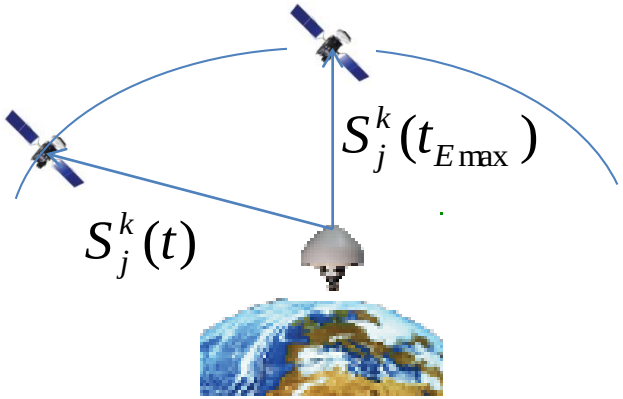
- **RT/NRT Vertical TEC IONEX** files were solicited on the period **45 to 59, 2016** to make a first comparison of Vertical TEC products in IONEX format from entities within RTIM-WG.
- The **consistency and accuracy** of the products **can be analysed against external assessment techniques** (as it is done within **IGS Iono-WG**): for both vertical geometries over the oceans/seas (vs **altimeter-VTEC**) and for slant variation (**GPS-dSTEC**) over independent GPS receivers.
- It is important that the accuracy should be assessed from independent ionospheric measurements not taking part in the generation of any of the products.

VTEC directly observed from dual-frequency altimeters: a GNSS-independent ionospheric truth



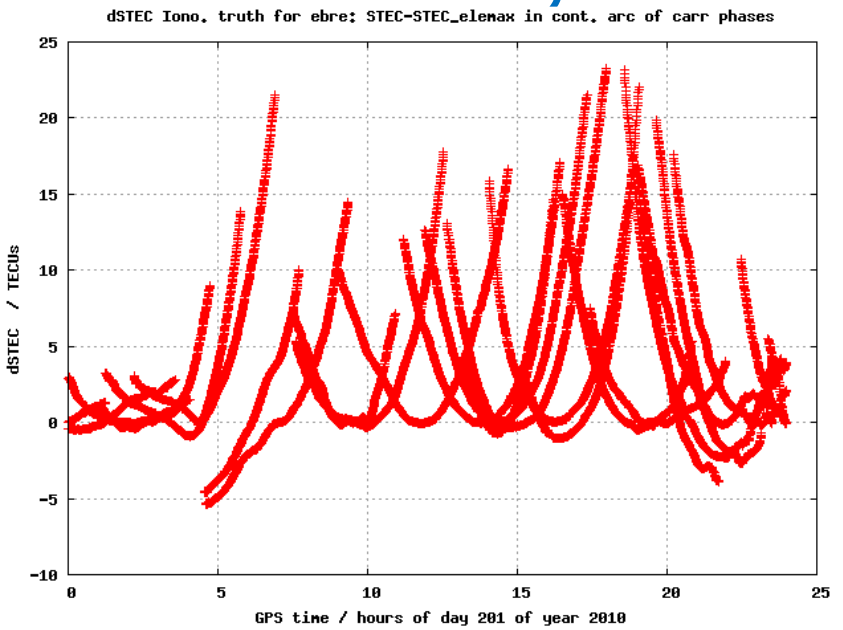


Ionospheric Truth: STEC Variation, dSTEC



$$\Delta S_O \equiv S_j^k(t) - S_j^k(t_{E\max}) =$$

$$= [(L_I)_j^k(t) - (L_I)_j^k(t_{E\max})] / \alpha \equiv \Delta L_I / \alpha$$

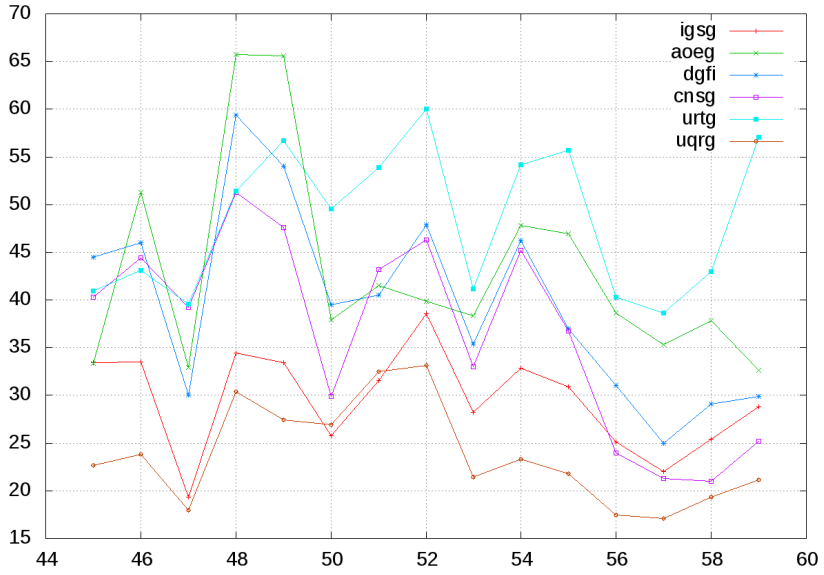


VTEC IONEXs: CAS/DGFI/URTG first comp.

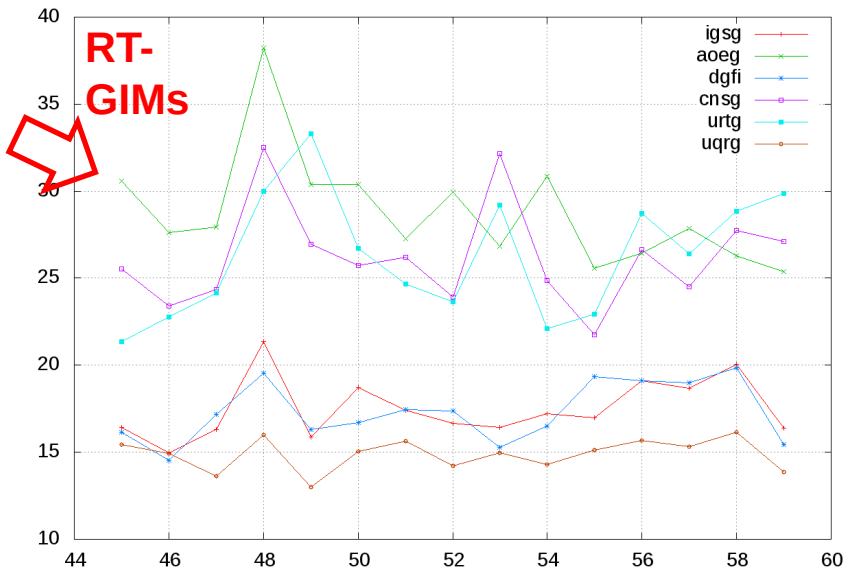
- **Comparison of six different VTEC products**: three RT from CAS (aoeg), CNES (cnsg) and UPC (urtg); one NRT from TUM (dgfi) and two traditional GIMs for reference, from UPC (uqrg) and IGS (igs).

JASON altimeter assessment

Europe



Global



Relative RMS error (%) for days of year 2016 from 45 to 59

External validation vs dSTEC-GPS @ independent receivers

RT-GIMs

GIM	RMS [TECU]	RMS max [TECU]	RMS min [TECU]	BIAS [TECU]
AOEG	11.8	22.6	4.8	-1.43
CNSG	9.2	18.8	3.0	0.21
URTG	8.2	14.9	3.4	0.30
DGFI	5.6	10.8	1.8	-0.57
IGSG	6.2	11.6	1.9	-1.01
UQRG	4.6	9.1	1.1	-0.61

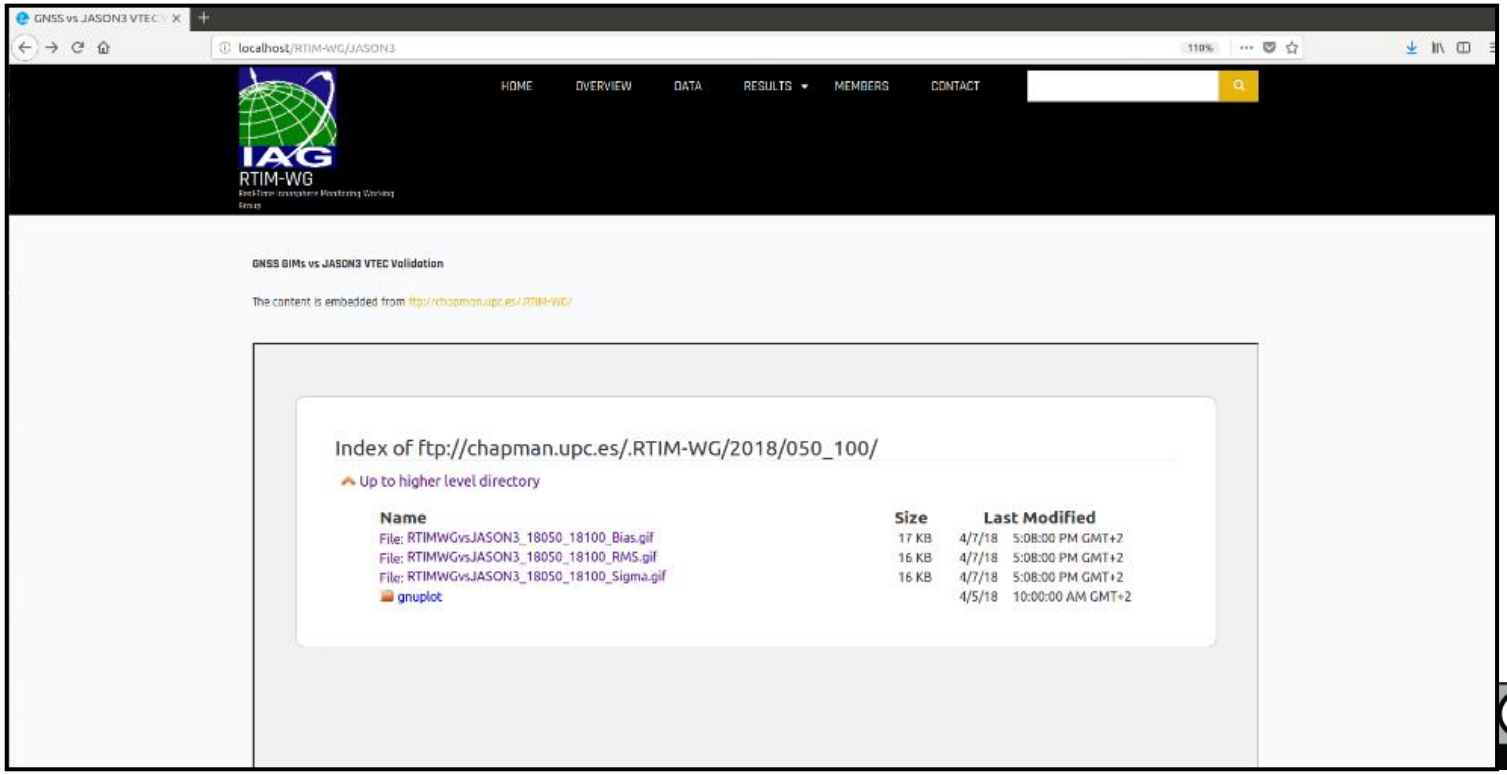
From left to right: GIM, square root of the arithmetic mean of the RMS for all stations and days; maximum and minimum RMS for all 35 stations; bias for all stations and days.

New IAG's RTIM-WG website

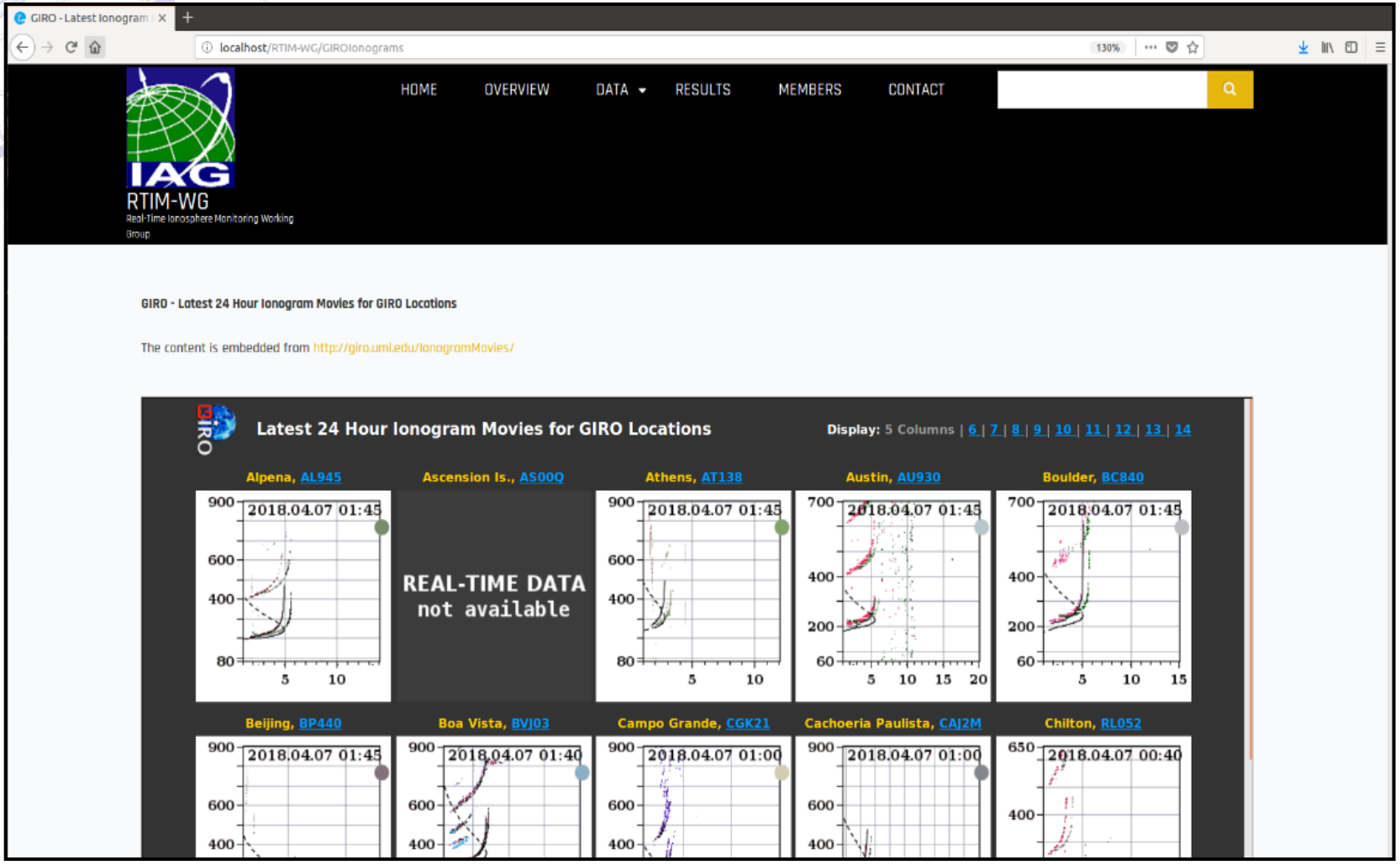
New website of IAG's RTIM-WG under test and to be launched in the near future

It contains **links to RT/NRT data sources** as well as **results on validation strategies** carried out within RTIM-WG

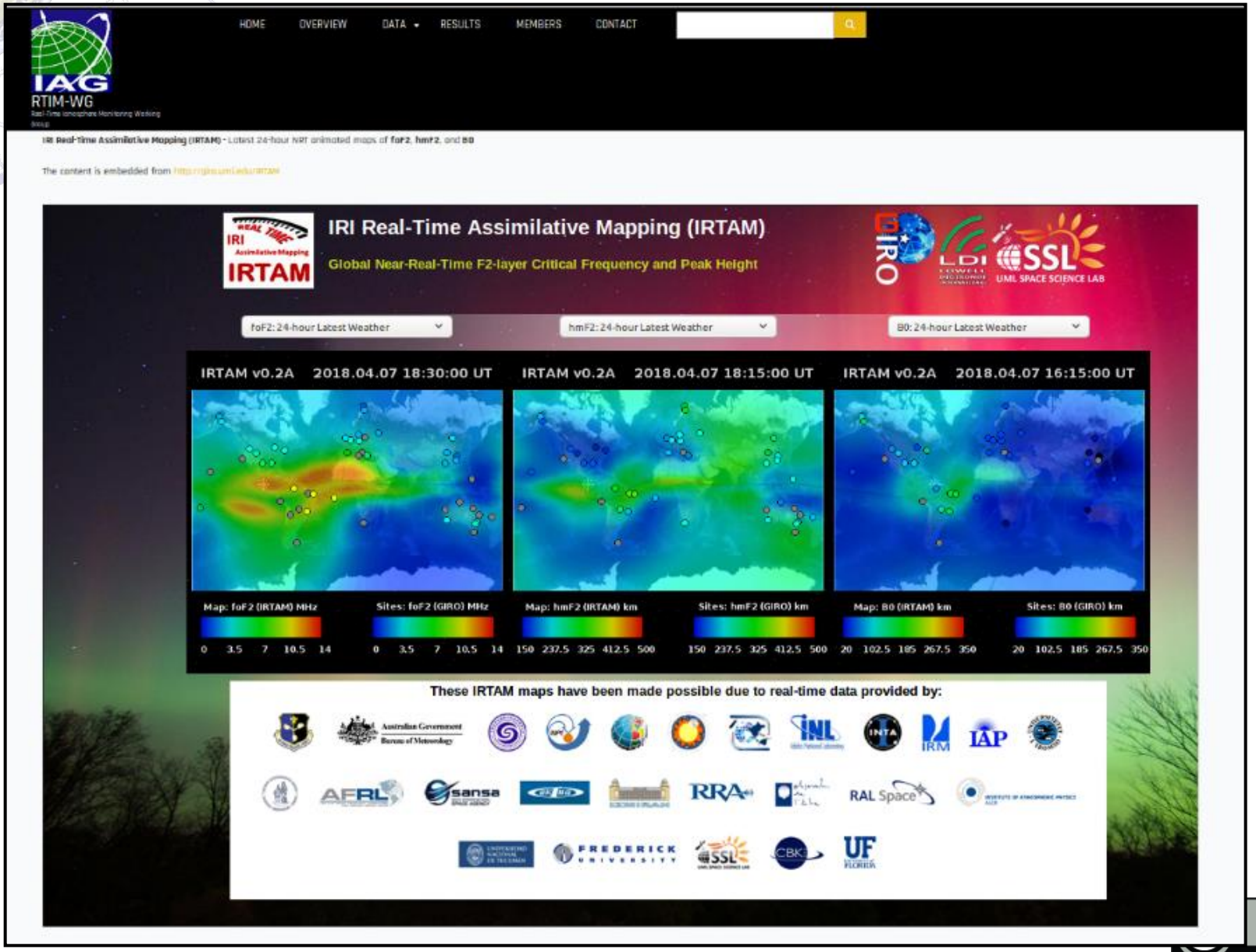
We are **open to discuss new features** that could be useful to the Ionospheric/Space Weather community.



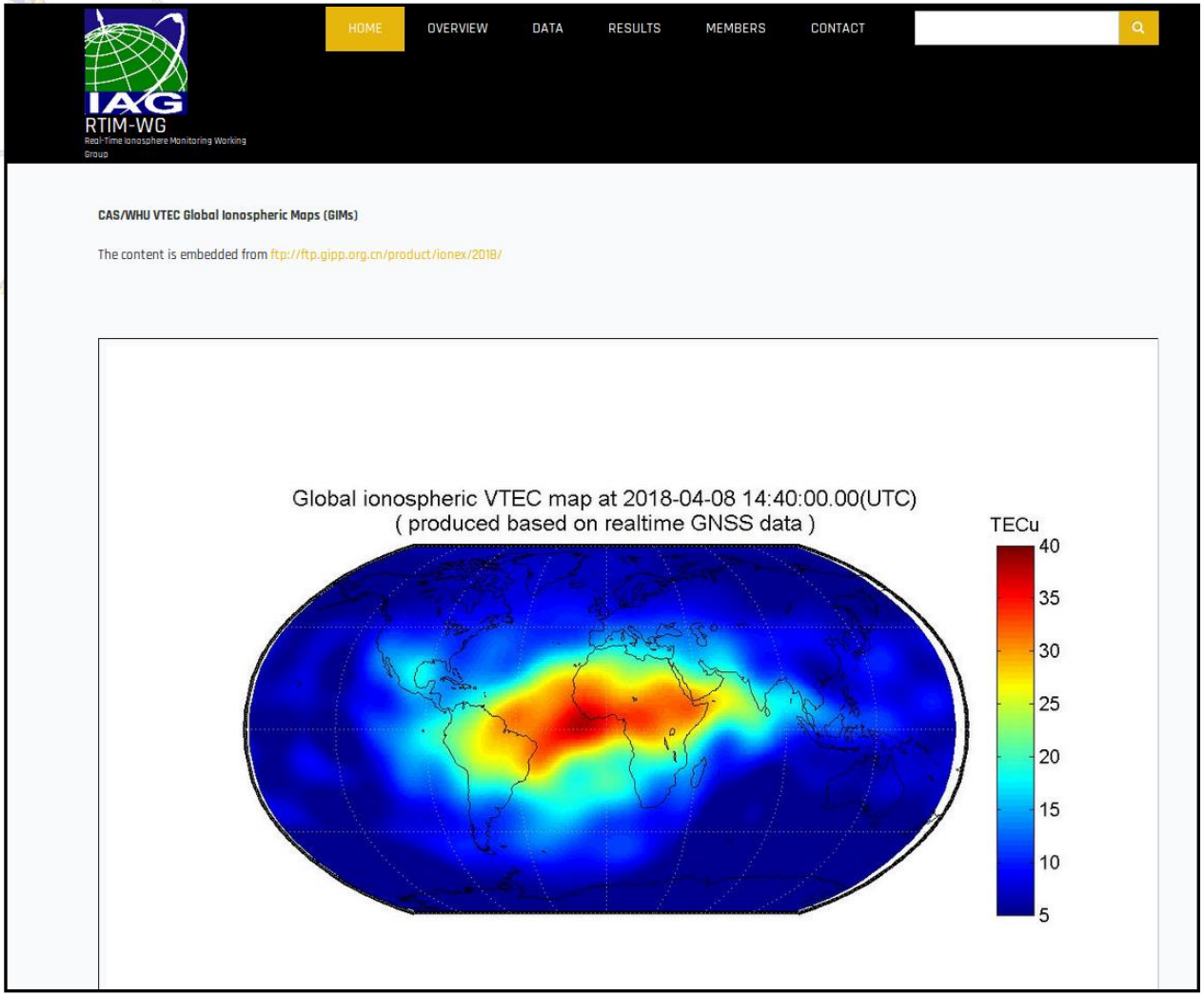
New IAG's RTIM-WG website



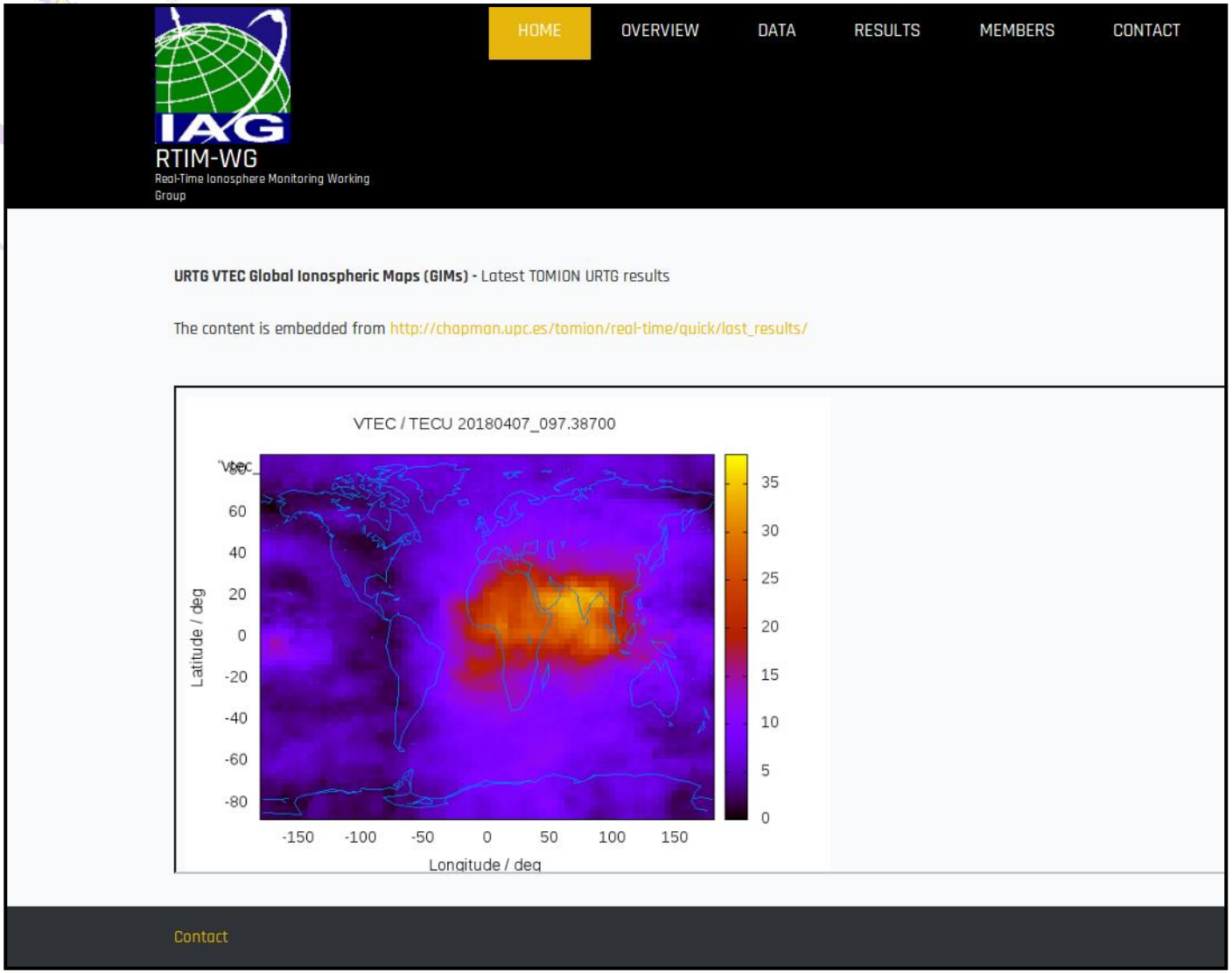
New IAG's RTIM-WG website



New IAG's RTIM-WG website



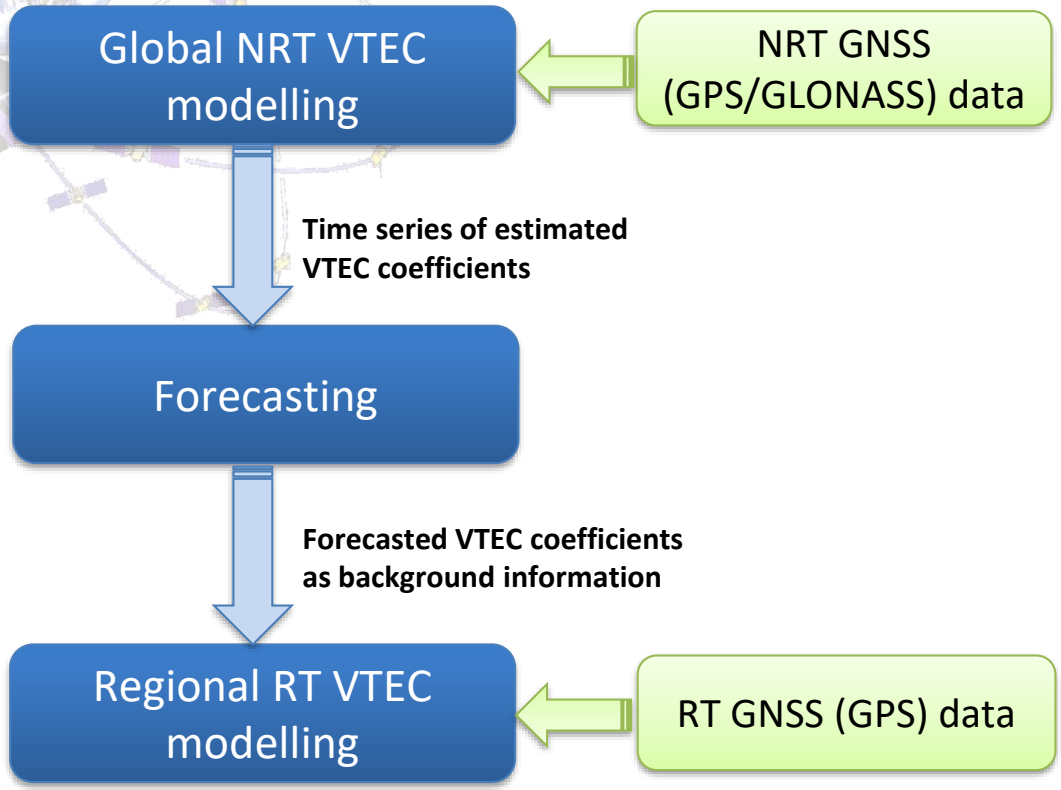
New IAG's RTIM-WG website

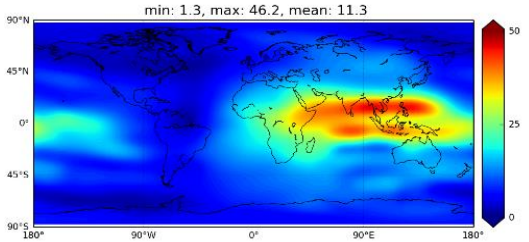


RT-VTEC GIMs assessment

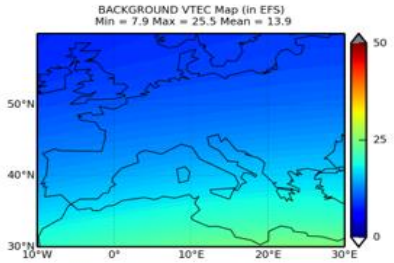
- Possibility to **assess RT VTEC GIMs continuously**. Useful to analyse performance and identify issues affecting real-time ionospheric products.
- Considering RT-VTEC GIMs **potential combination in actual real-time.**
- Experimental real-time assessment to be started with several centers providing RT GIMs either in RTCM format or in IONEX format (collaboration between IAG's RTIM-WG and IGS RT-WG).
- Necessary to identify a small set of receivers worldwide distributed and not used by any center to perform the external assessment.

DGFI-TUM's Concept for Global NRT and Regional RT Modelling

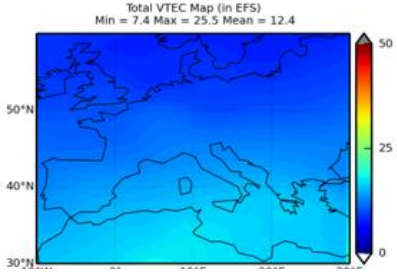




NRT modelling at 9:00 UTC on March 3rd, 2017.



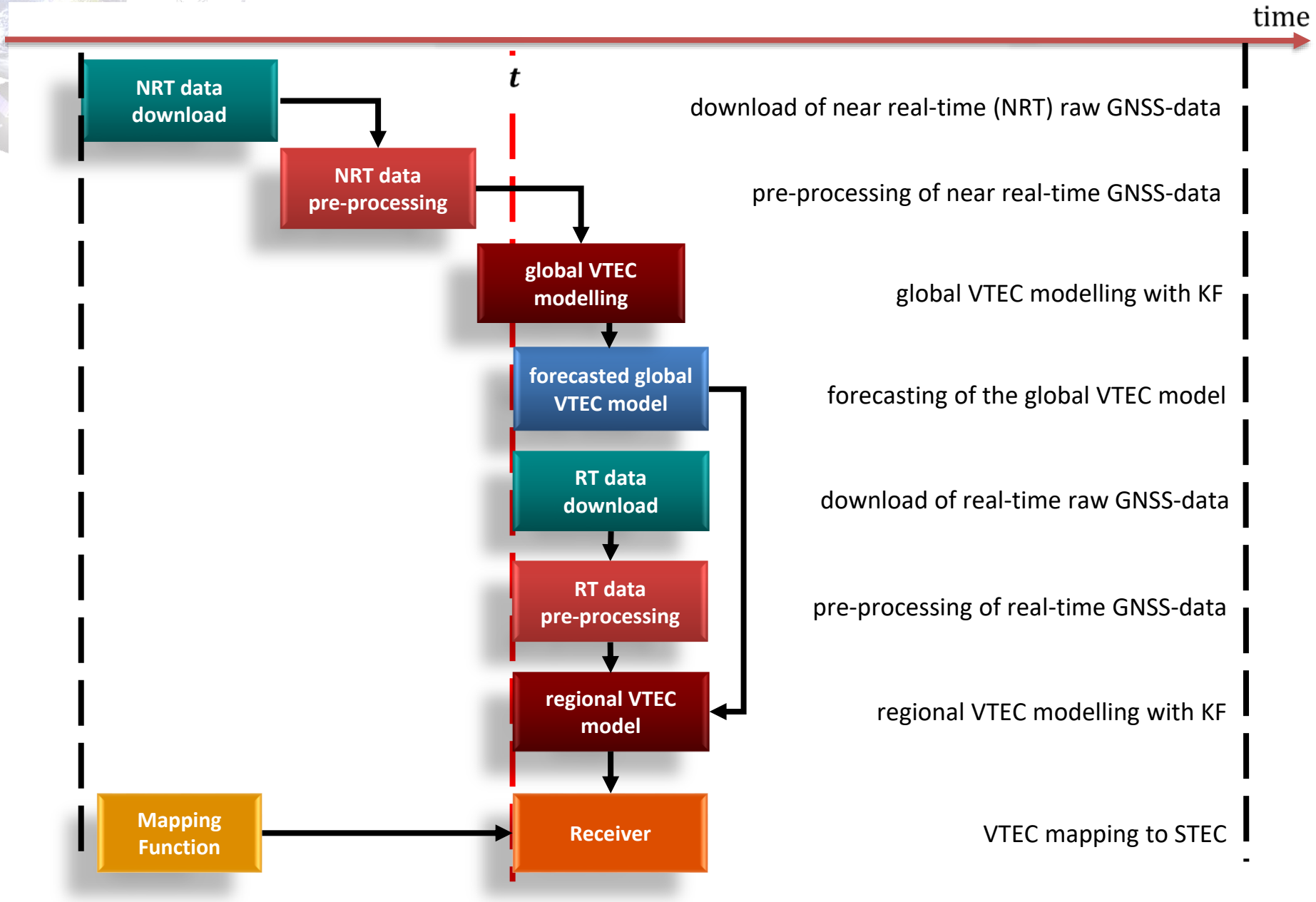
Forecasting to: 12:00 UTC on March 3rd, 2017.



RT Modelling at 12:00 UTC on March 3rd, 2017.

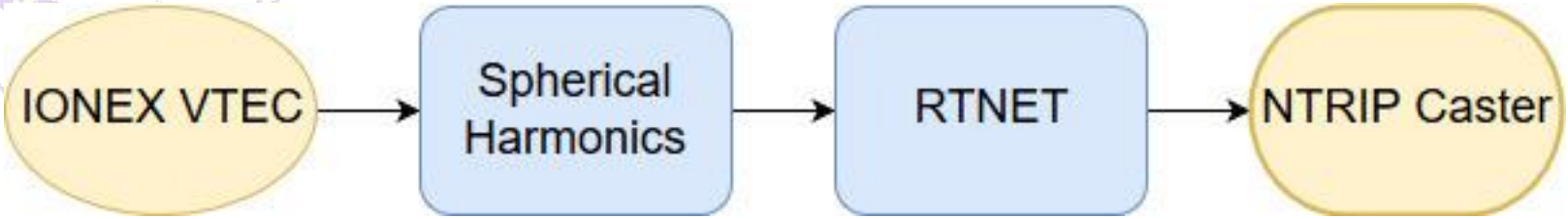
- Globally distributed GNSS data sequentially processed in hourly batches using **Kalman filtering** utilizing a **series expansion in terms of B-spline functions** for VTEC representation. The VTEC maps derived from the estimated B-spline coefficients (BS) are computed in **near-real time** with a latency of at most two and half hours.
- The **forecast model** is based on a **Fourier series** and an **ARMA model** representation for the estimated BS coefficients and is responsible for generating forecasted VTEC products to real-time.
- The **real-time modelling** approach attempts to generate VTEC products with a latency of around thirty seconds by updating the forecasted products (considered as background information) with GPS data collected in real-time (using **RTCM data streams**) over European region.

DGFI-TUM Concept for Global NRT and Regional RT Modelling (Detailed)



UPC-IonSAT VTEC dissemination

✓ **VTEC dissemination via RTCM 1264 implementation**



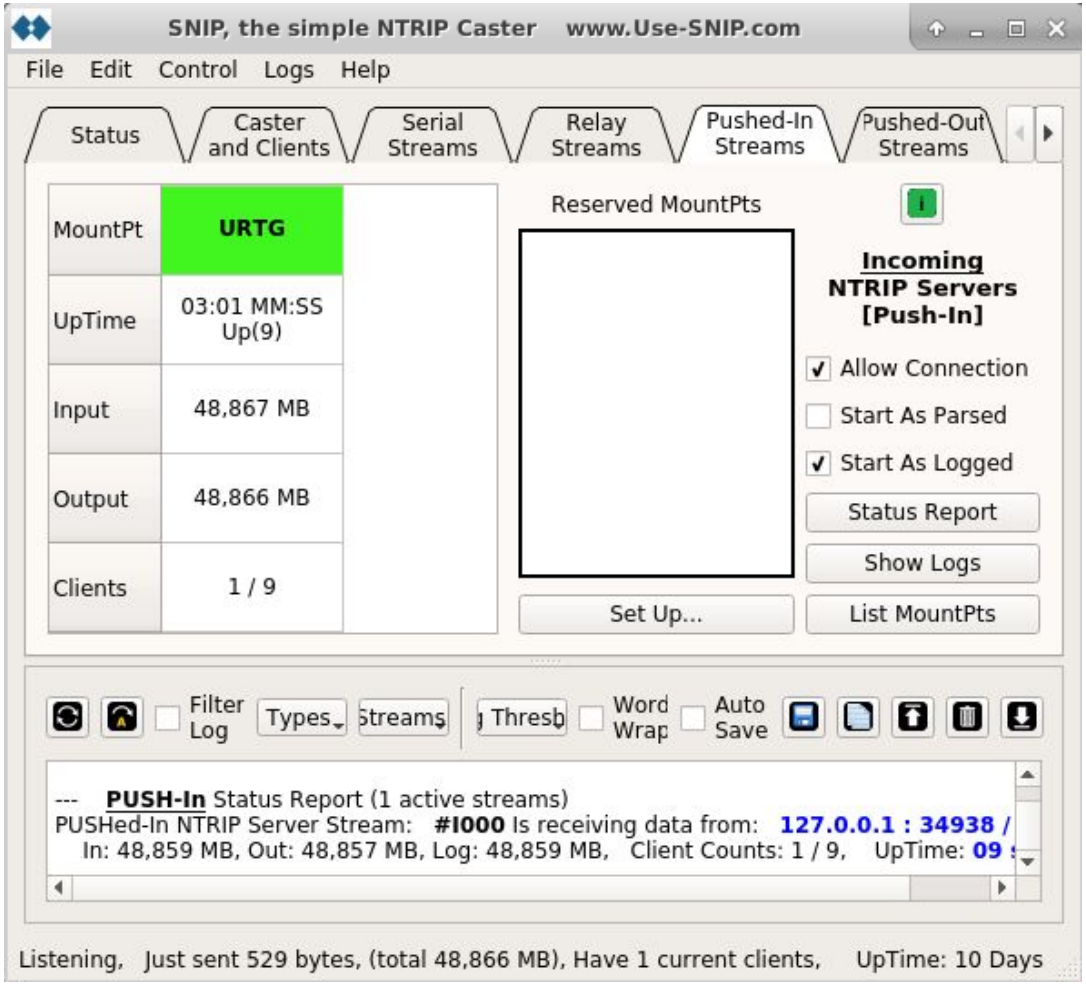
VTEC dissemination flow chart

- The process uses as input a RT VTEC map in IONEX format.
- Each map is then transformed in spherical harmonics to be compatible with the RTCM standard 1264 message.
- Afterwards, these data are transformed to a RTNET message. In this way, the BNC (BKG NTRIP Client) software is able to encode and send RTCM 1264 messages to a NTRIP caster.
- The VTEC data are then sent continuously at a 10 seconds update rate

UPC-IonSAT VTEC dissemination

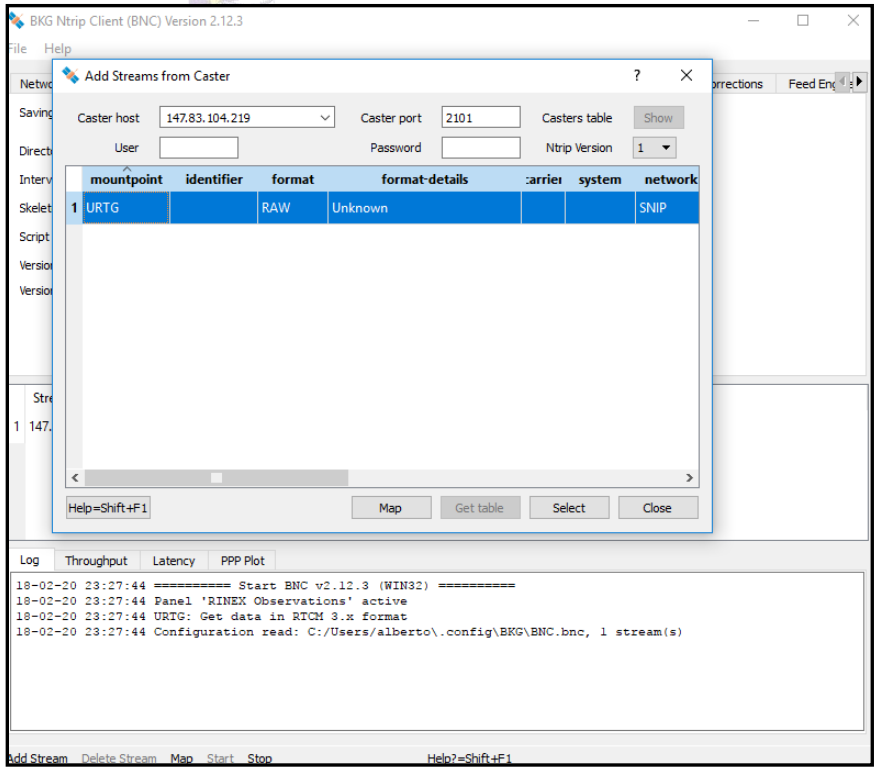
- ✓ **VTEC dissemination via RTCM 1264 implementation**

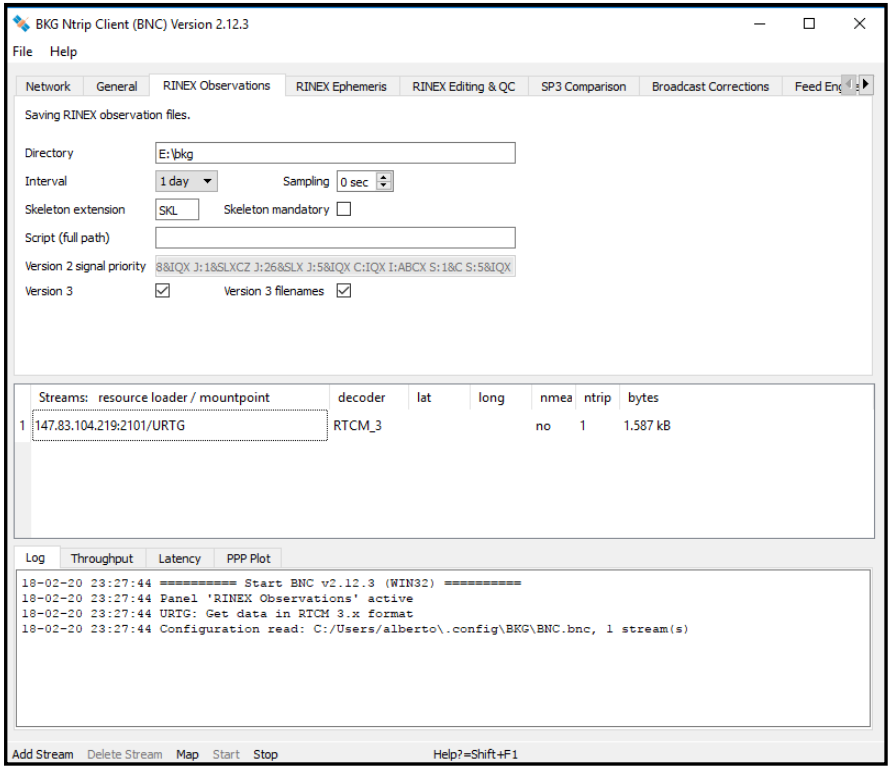
SNIP Caster used for testing the VTEC dissemination **distributing URTG GIMs**



UPC-IonSAT VTEC dissemination

- UPC's RT-GIM experimental product through the following NTRIP caster under test: 147.83.104.219:2101
- Stream to be distributed through the Real-Time IGS NTRIP caster.
- Possibility to retrieve the stream by means of BKG NTRIP Client (BNC)





Thoughts on potential RT ionospheric combination strategies: *i) weighting*

RT Weighting scheme	PROS	CONS
[A] "Self-consistency" (reference: L1-L2 at the same elevation in the same phase continuous arc...)	The same which is being already applied for final and rapid combination with common mapping	We have to wait to the second (elevation-decreasing) half of each arc, i.e. half number of performance estimations...
[B] "dSTEC" (reference: L1-L2 at max. elev. ....)	Well characterized (e.g. recent paper); it only demands to store the reference LI, which is less affected by mapping errors	Same than [A] "Self-consistency"
[C] "RT-dSTEC" (The first L1-L2 measurement in the arc is taken as reference)	Full data availability, only one data stored per arc	The low elev. Ref. STEC is typically the (or one of the) very bad estimated ones, affecting all the time series.
[D] = [C] (during the ascending arc part) + [A] (during the descending part)	Full data availability, only one memory record per arc (updated at max. elevation).	Potential "overweight" of the first low-elevation reference ray (potentially mitigated with elev. mask).

Conclusions

- Recent steps taken within the RTIM-WG are presented towards the identified objectives.
- A new website shall be launched soon.
- St. Patrick storm analysis based on RT/NRT data was conducted taking benefit of the complementary products.
- Assessment of several RT and NRT VTEC models has been done. JASON3 assessment has already been automatized and made available through the website.
- Discussion of potential RT combination strategies has already started.

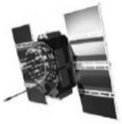
Natural Resources Canada

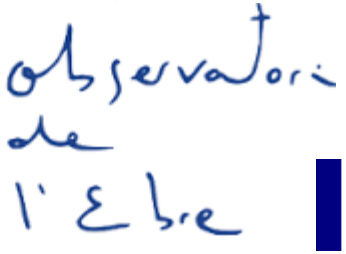
Royal Observatory of Belgium

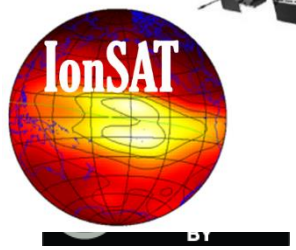
Thank you very much

Jet Propulsion Laboratory
California Institute of Technology

UNIVERSITAT DE BARCELONA







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