Accuracy analysis of global ionospheric maps in relation to their temporal resolution and solar activity level

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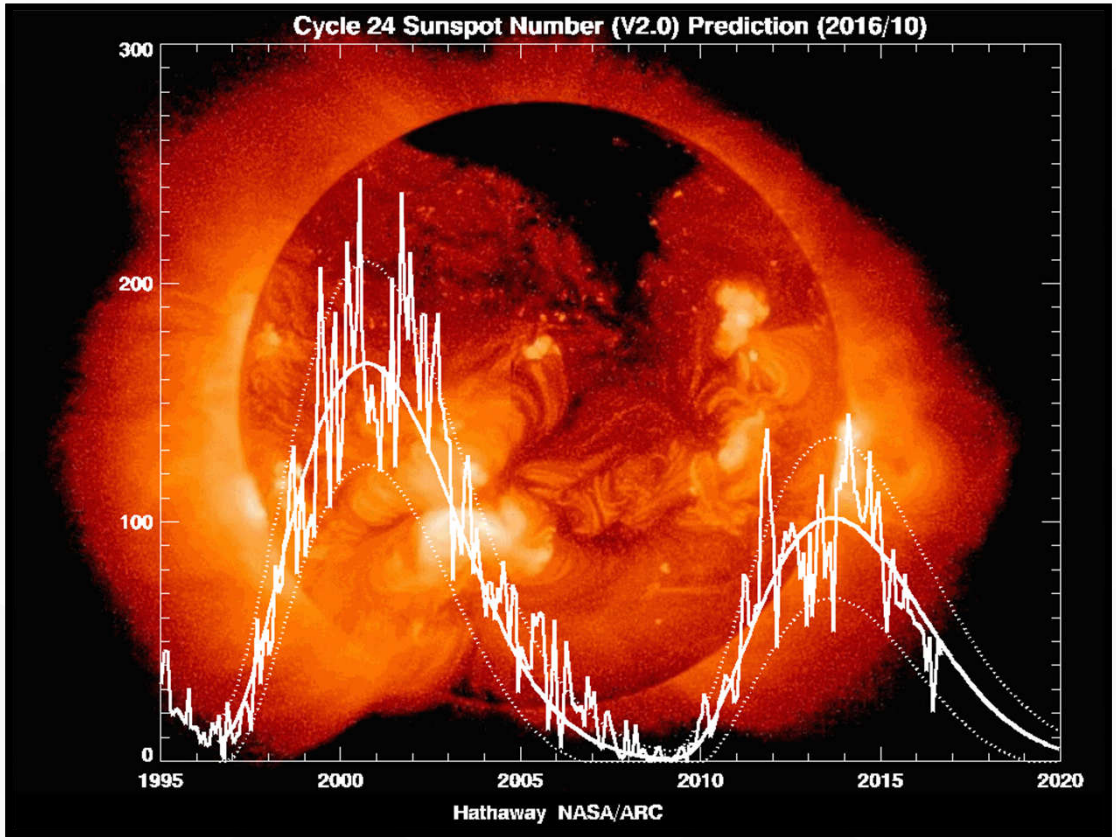
INTRODUCTION

- The ionosphere is still considered as the main source of errors in precise satellite positioning affecting surveying and geodetic applications.
- Currently, 7 IGS Ionosphere Associate Analysis Centers (IAACs) independently produce global ionosphere maps (GIMs) with different time interval and with the use of various methods.
- The official combined IGS GIMs are provided with 120-minute interval.
- Since 2015 some of the IAACs have started to provide their products with higher resolutions, up to 30 - 60 minutes.
- However, there are no comprehensive studies on the influence of the GIMs temporal resolution on their performance.
- Therefore, in this presentation we study GIMs accuracy in relation to their temporal resolution and solar activity level.

ANALYZED PERIODS

- High and low solar activity periods of 24th Solar Activity Cycle:
  - full year **2014**,
  - full year **2018**.
- Two geomagnetic storms:
  - **19 February 2014** (max Kp = 6+),
  - **17 March 2015** (max Kp = 8-),
    (St. Patrick's Day storm).



EVALUATED GLOBAL IONOSPHERE MAPS (GIMs)

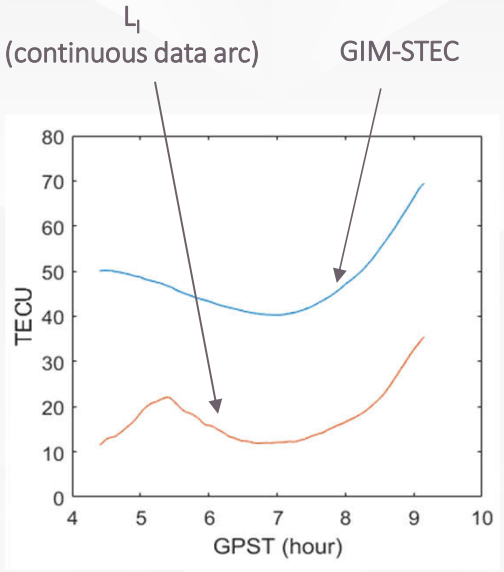
GIM ID	Method	Evaluated interval [minutes]		
		Year 2014 and storm on 19/02/2014	Storm on 17/03/2015	Year 2018
CASG	Spherical harmonics Plus generalized Trigonometric Series	120*	120*	30* / 60 / 120
CODG	Spherical harmonics	120*	60* / 120	60* / 120
EMRG	Spherical harmonics	-	-	60* / 120
UQRG**	Tomographic with kriging	15* / 60 / 120	15* / 60 / 120	15* / 60 / 120

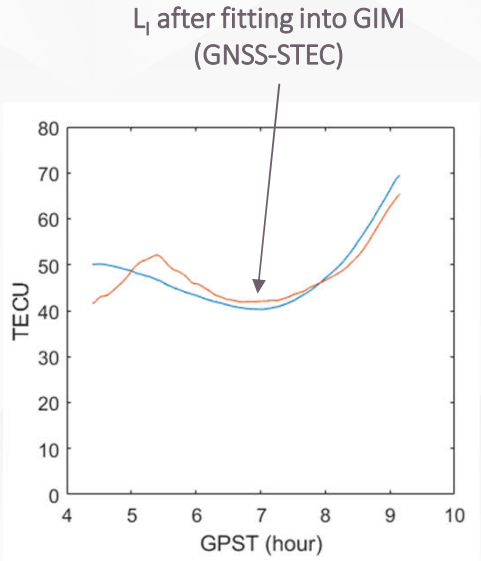
* nominal interval

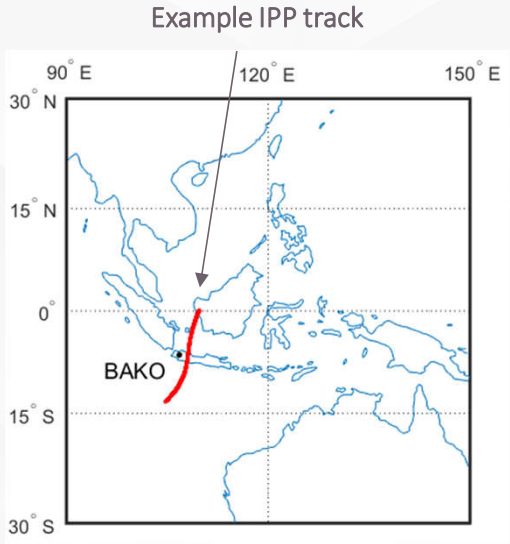
** not an official IGS product

METHODOLOGY – dSTEC ANALYSIS

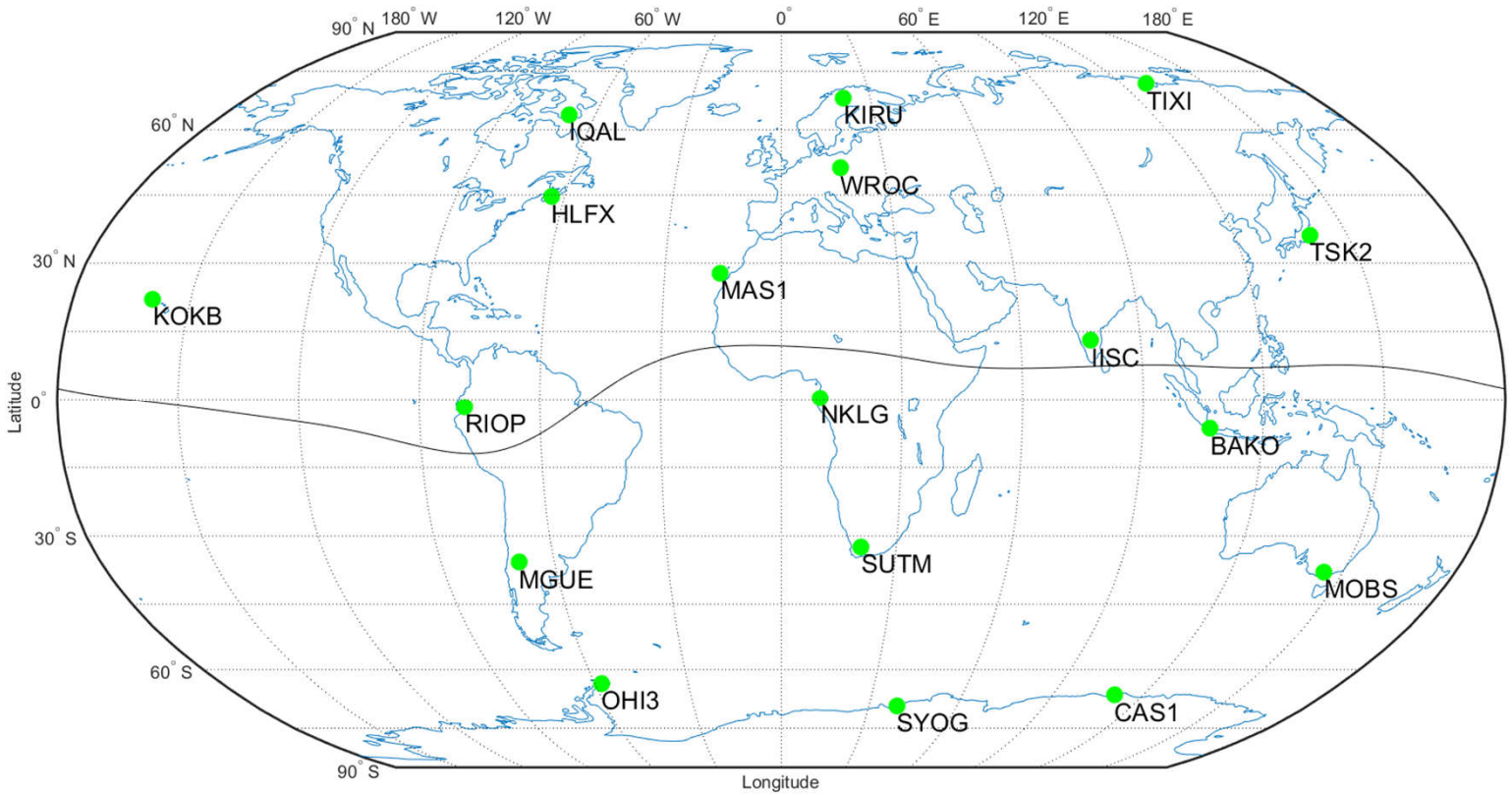
- Self Consistency Analysis (STEC):
    1. Calculation of geometry free combination of carrier phase observations (L_I) for continuous arc (elevation cut-off 20 deg.).
    2. Calculation of STEC for the same satellite arc, but from given GIMs (GIM-STEC).
    3. Fitting L_I into GIM-STEC (removing L_I bias, resulting in GNSS-STEC).
    4. Residual analysis (RMS).



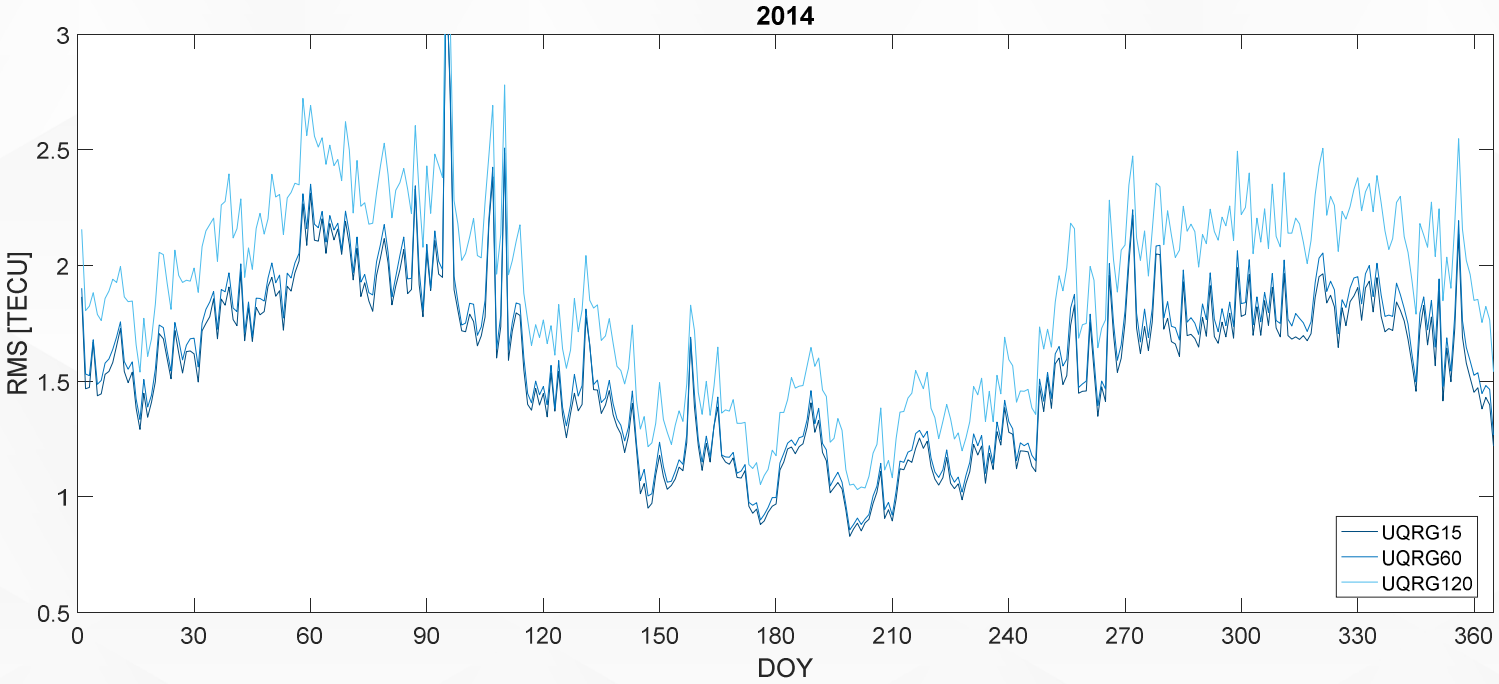




dSTEC ANALYSIS:
GPS TEST DATA - 18 GLOBALLY DISTRIBUTED IGS STATIONS



dSTEC ANALYSIS: HIGH SOLAR ACTIVITY RESULTS

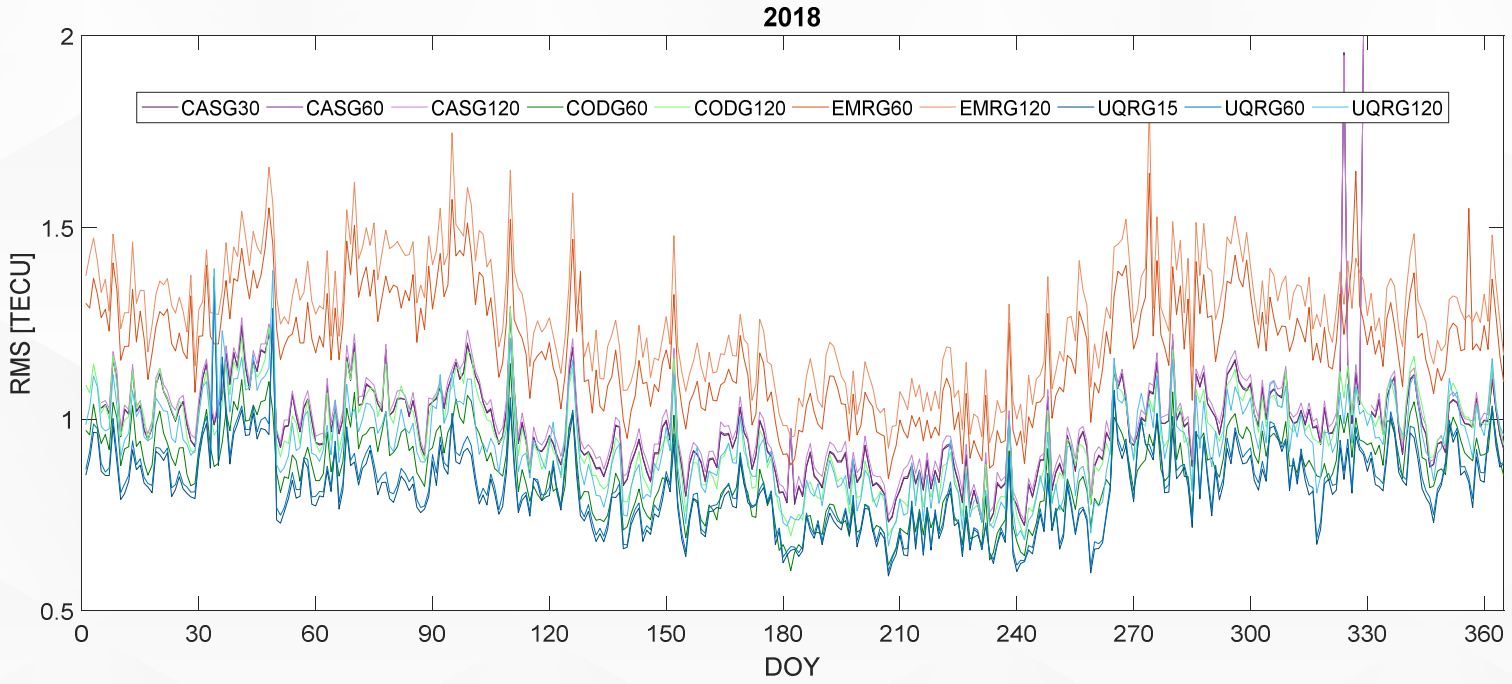


Daily RMS distribution for GIMs with different time resolution (2014).

GIM	UQRG		
Interval [minutes]	15*	60	120
Annual RMS [TECU]	1.56	1.60	1.89
Accuracy [%]	100.0	102.9	121.3

* nominal interval

dSTEC ANALYSIS: LOW SOLAR ACTIVITY RESULTS

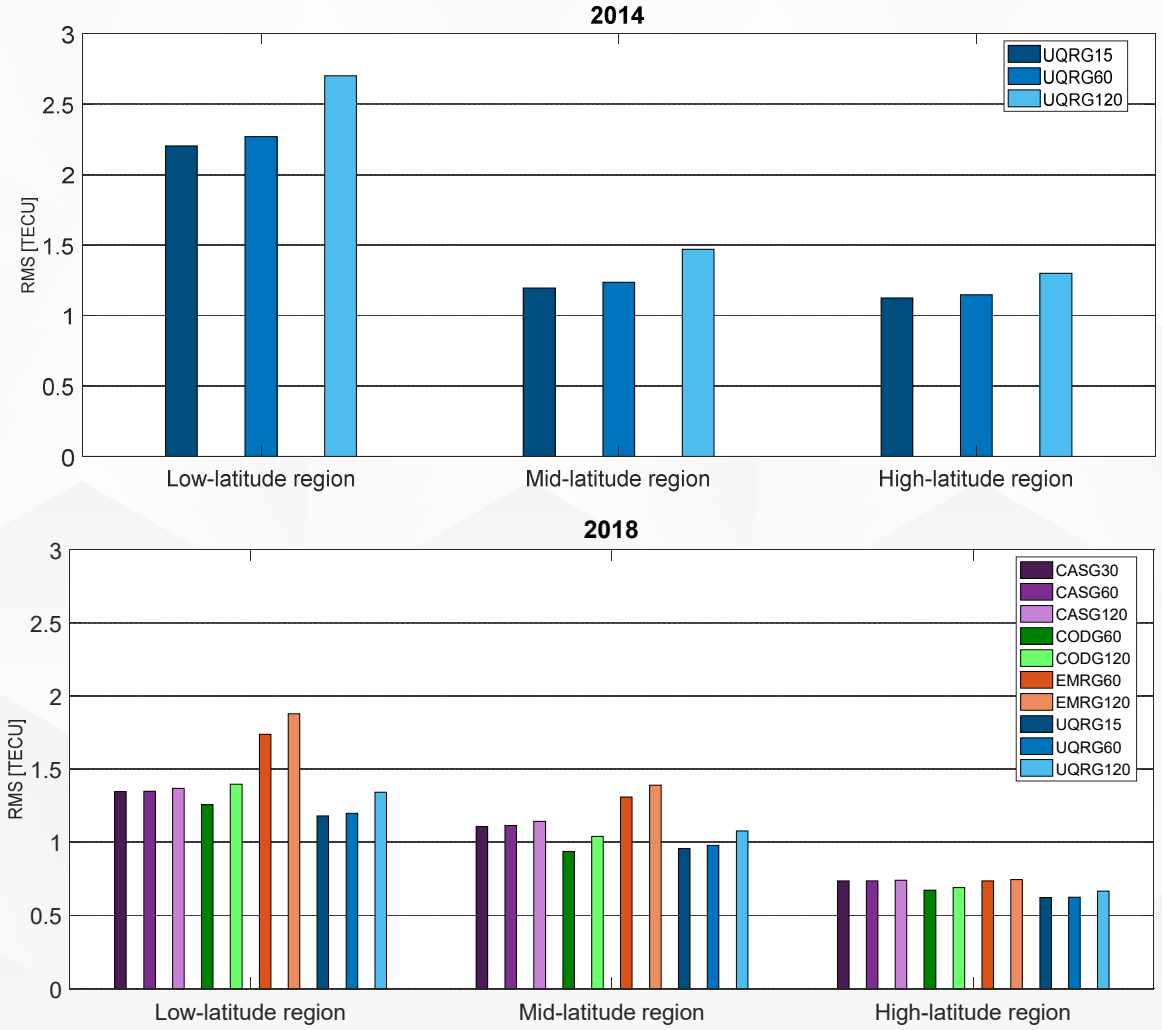


Daily RMS distribution for GIMs with different time resolution (2018).

GIM	CASG			CODG		EMRG		UQRG		
Interval [minutes]	30*	60	120	60*	120	60*	120	15*	60	120
Annual RMS [TECU]	0.98	0.98	1.00	0.86	0.96	1.19	1.27	0.82	0.83	0.93
Accuracy [%]	100.0	100.2	102.1	100.0	110.8	100.0	107.1	100.0	101.8	114.3

* nominal interval

dSTEC ANALYSIS: DIFFERENT GEOMAGNETIC REGIONS



Annual RMS in low-, mid- and high-latitude regions for all analyzed GIMs.

Geomagnetic regions:

- low-latitude - from 30°S to 30°N,
- mid-latitude - from 30° to 60° in both hemispheres,
- high-latitude - from 60° to 90° in both hemispheres.

dSTEC ANALYSIS: RESULTS – GEOMAGNETIC STORMS

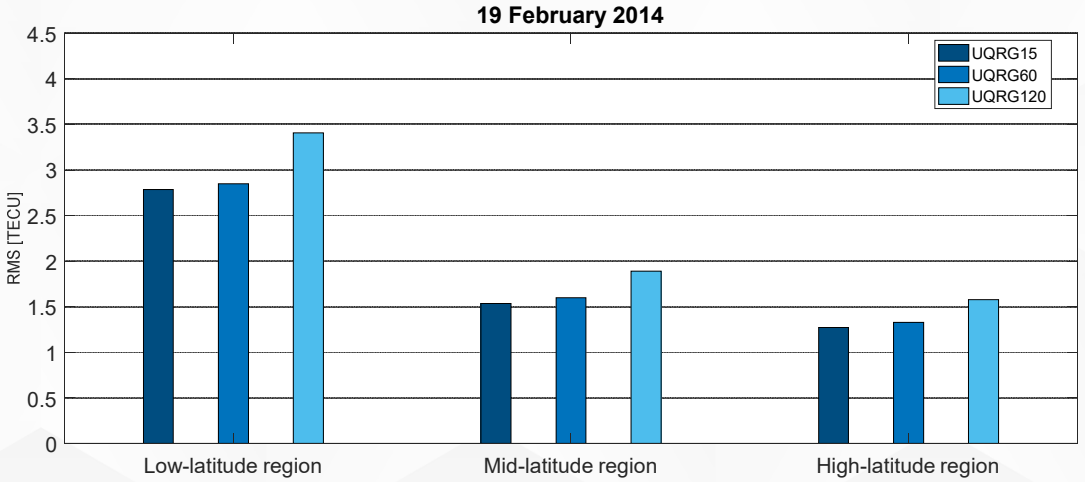
- 19 February 2014 (max Kp = 6+)

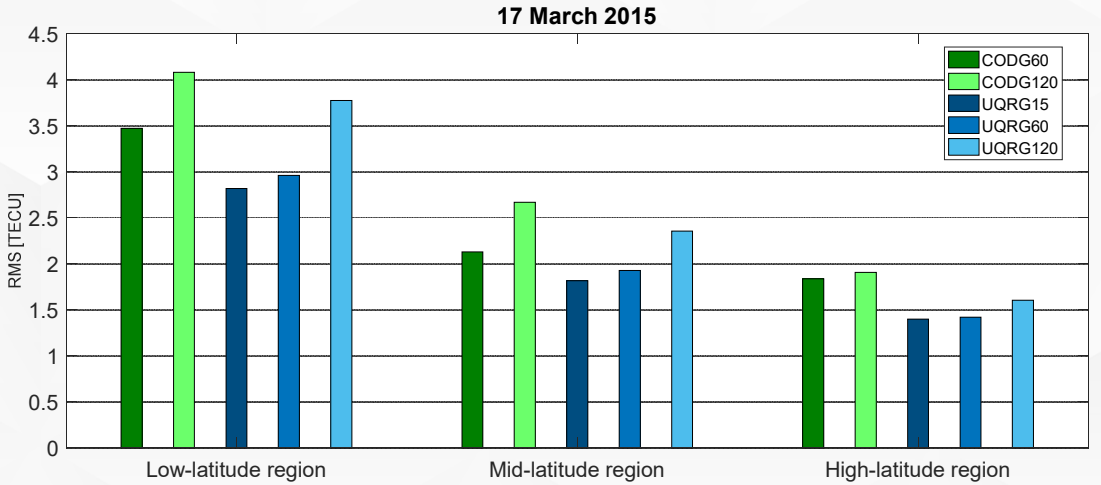
GIM	UQRG		
Interval [minutes]	15*	60	120
RMS [TECU]	1.95	2.01	2.39
Accuracy [%]	100.0	103.2	122.8

- 17 March 2015 (max Kp = 8-)

GIM	CODG		UQRG		
Interval [minutes]	60*	120	15*	60	120
RMS [TECU]	2.57	3.01	2.09	2.19	2.70
Accuracy [%]	100.0	117.0	100.0	104.8	129.1

* nominal interval

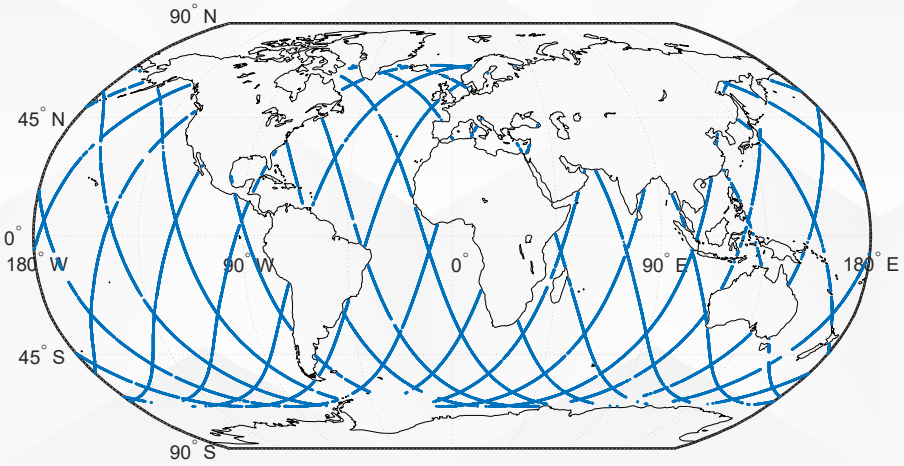




Annual RMS in low-, mid- and high-latitude regions for all analyzed GIMs.

METHODOLOGY – VTEC ANALYSIS VS. ALTIMETER DATA

- Altimetry satellites (Jason-2) are equipped with dual-frequency radar altimeters that enables determination of ionospheric signal delay below the satellite orbit (< 1300 km).
- Altimetry-derived VTEC (accuracy ~1 TECU) is an important source of validation for GNSS TEC models over the oceans.
- Remaining plasmospheric VTEC above the Jason-2 orbit (up to 4 TECU) is calculated from the NeQuick-2 empirical model.
- Standard deviation of differences between GIM and altimetry-derived VTEC is analyzed.



Daily ground track of Jason-2 on 01/01/2014.

VTEC ANALYSIS VS. ALTIMETER DATA – 2014 & 2018

- High solar activity – year 2014:

GIM	UQRG		
Interval [minutes]	15*	60	120
Annual STD [TECU]	3.61	3.61	3.81
Accuracy [%]	100.0	100.0	105.5

- Low solar activity – year 2018:

GIM	CASG			CODG		EMRG		UQRG		
Interval [minutes]	30*	60	120	60*	120	60*	120	15*	60	120
Annual STD [TECU]	2.26	2.26	2.25	2.22	2.23	2.42	2.40	1.92	1.92	1.95
Accuracy [%]	100.0	99.9	99.7	100.0	100.6	100.0	99.2	100.0	99.6	101.3

* nominal interval

VTEC ANALYSIS VS. ALTIMETER DATA – GEOMAGNETIC STORMS

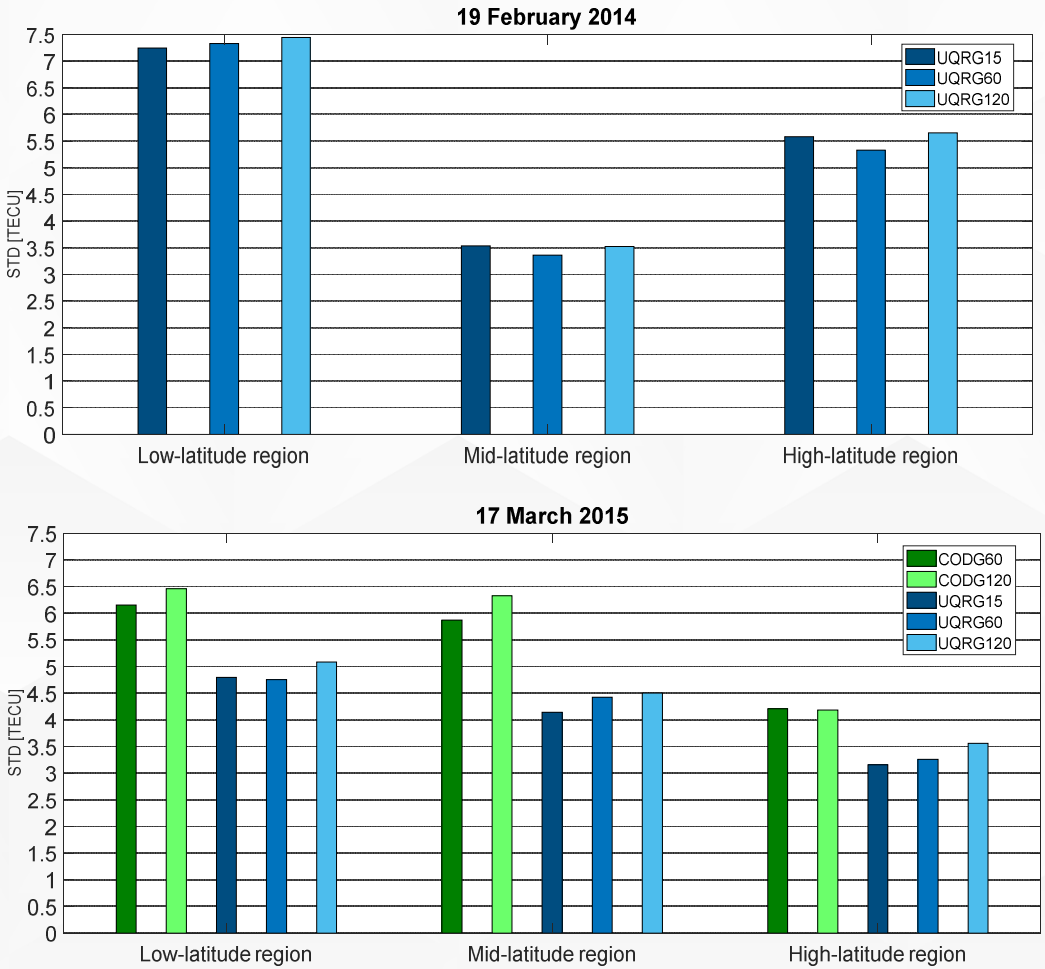
- 19 February 2014 (max Kp = 6+)

GIM	UQRG		
Interval [minutes]	15*	60	120
STD [TECU]	5.70	5.66	5.81
Accuracy [%]	100.0	99.4	102.0

- 17 March 2015 (max Kp = 8-)

GIM	CODG		UQRG		
Interval [minutes]	60*	120	15*	60	120
STD [TECU]	6.10	6.47	4.32	4.45	4.69
Accuracy [%]	100.0	106.1	100.0	103.0	108.7

* nominal interval



The annual STD in low-, mid- and high-latitude regions for all analyzed GIMs.

CONCLUSIONS

- dSTEC analysis:
  - during high solar activity period, when increasing GIM interval from 15 minutes to 60 and 120 minutes, STEC accuracy decreases by 3% and 21%, respectively,
  - during low solar activity period 60-minute interval presents a good accuracy, and when increasing map interval to 120 minutes, the accuracy degrades by ~2% to 13%,
  - under disturbed conditions, GIMs with 60-min. interval are less accurate by ~3-5%, and 120-min. maps are less accurate by even~30% (comparing to 15-minute interval),
  - in case of CASG GIM there is a little influence of map interval on STEC accuracy, this may suggest that intrinsic interval of the underlaying model is longer than 30 minutes.

- VTEC analysis:
  - contrary to dSTEC results, the degradation of VTEC accuracy is less pronounced, amounting to 6% in 2014 and only 1% in 2018, when decreasing GIM interval from 60 to 120 minutes, and almost no accuracy change for intervals shorter than 60 minutes,
  - during St. Patrick's storm, the accuracy decreases by 3% when increasing interval from 15 to 60 minutes, and by additional 6% when increasing interval from 60 to 120 minutes.

- In summary:
  - the best overall results were obtained for 15-minute UQRG maps,
  - however, 60-minute GIM interval seems like a good compromise.