Measuring Total Electron Content with GNSS: Investigation of Two Different Techniques

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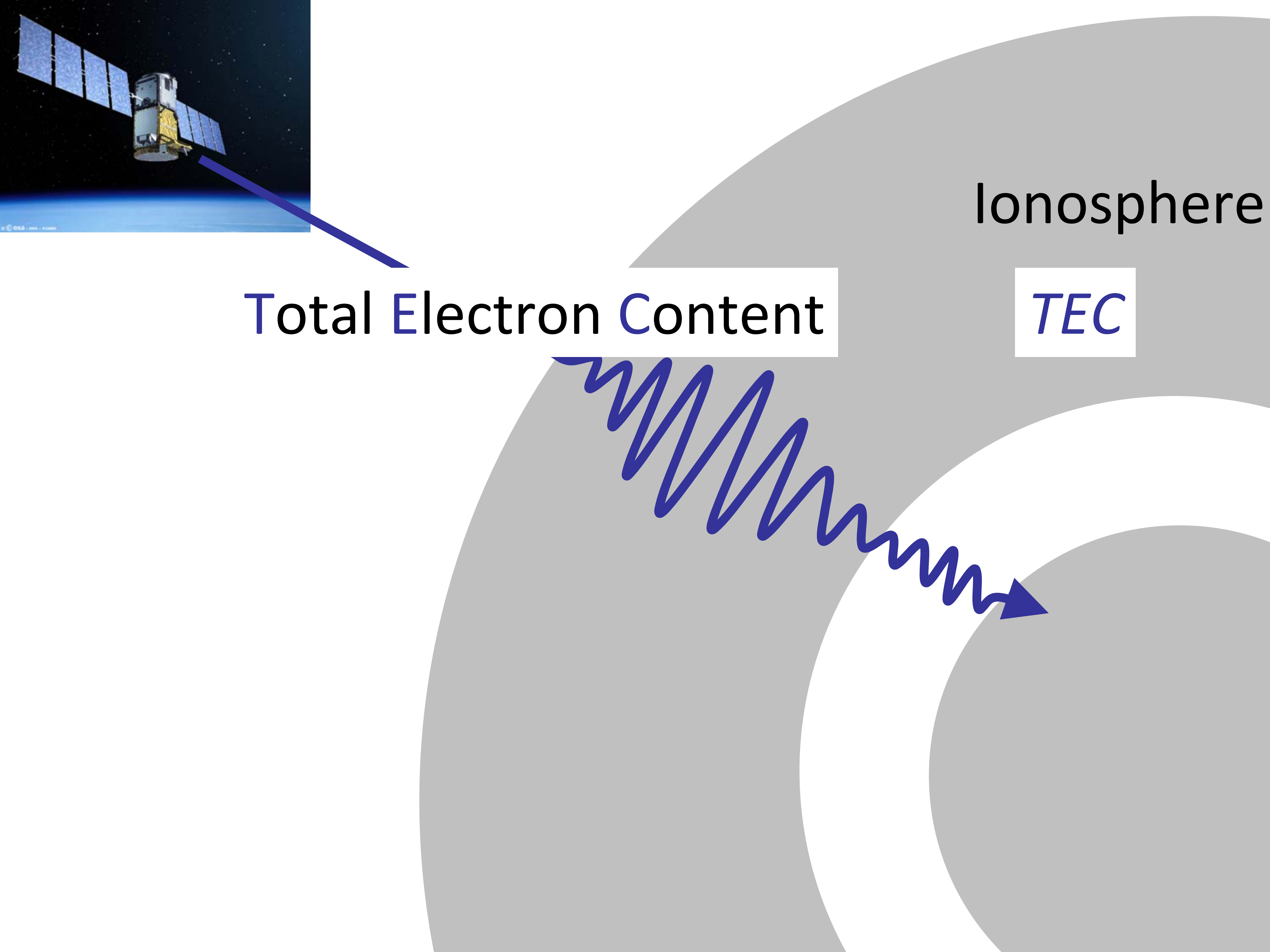
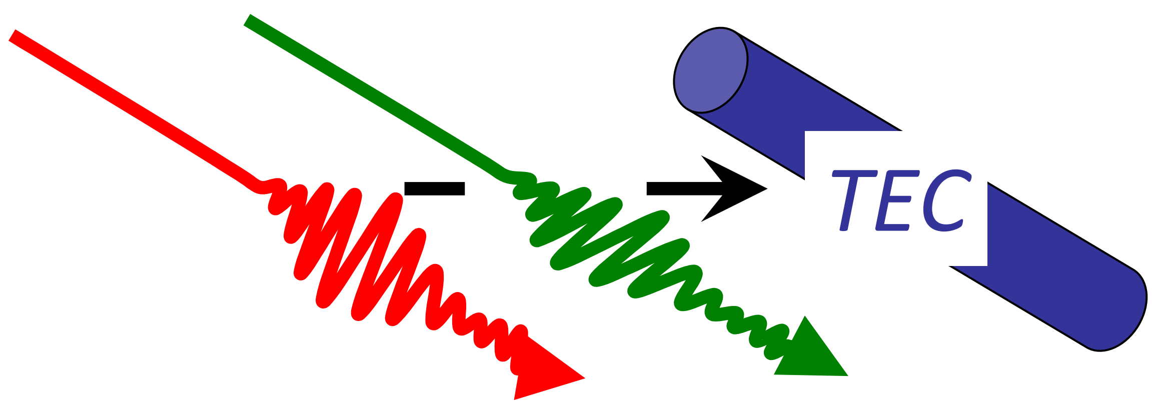

Ionosphere
Total Electron Content
TEC

TEC can be measured using GNSS.

- Dispersive ionosphere
- GNSS signals on several frequencies

→ Different ionospheric effect on each frequency

→ Different combinations removing all but ionospheric effect



We observe significant differences between two techniques.

1. Measuring TEC

Two methods for measuring TEC with GNSS

We observe significant differences between two techniques.

1. Measuring TEC

   Two methods for measuring TEC with GNSS

2. sTEC Comparison

   Global statistics and case studies

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1. Measuring TEC

   Two methods for measuring TEC with GNSS

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   Global statistics and case studies

3. vTEC Comparison

   Differences between GIMs

1. Measuring TEC

2. sTEC Comparison

3. vTEC Comparison

Phase combinations are preferred but need levelling.

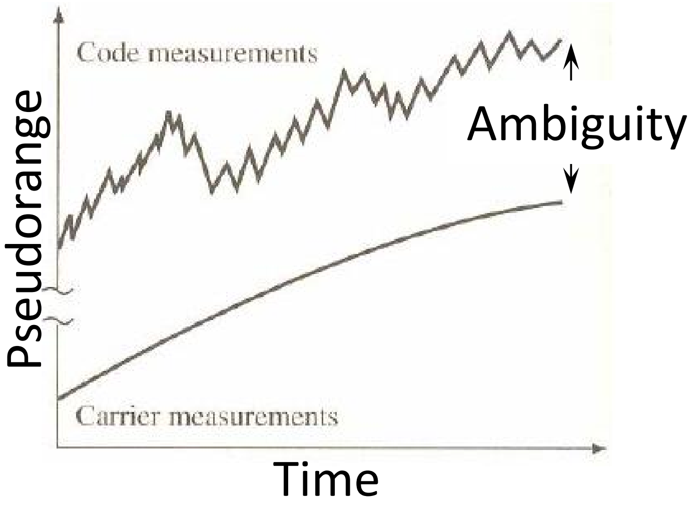
- GPS « geometric free » combinations → TEC

  Code: $\Psi_{GF} = \Psi_2 - \Psi_1$ Phase: $\Phi_{GF} = \Phi_1 - \Phi_2$

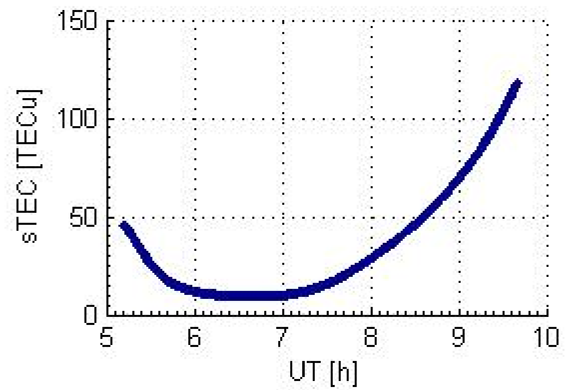
- Phase measurements less noisy but ambiguous

$$\Phi_{GF} \simeq A\ sTEC + N_{GF}$$

→ Ambiguity estimation = levelling



Levelling can be achieved using code measurements.

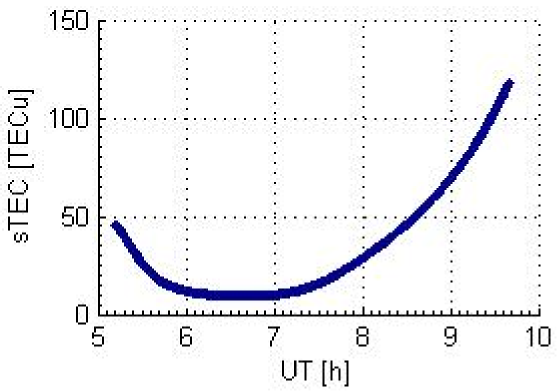


- Ambiguity = average on « arc » of difference between phase and sTEC
- sTEC ≈ code - hardware delays
- Hardware delays estimated on a long period using code and polynomial approximation of sTEC
- Remaining effects from code = multipath, residual hardware delays, noise

RMI

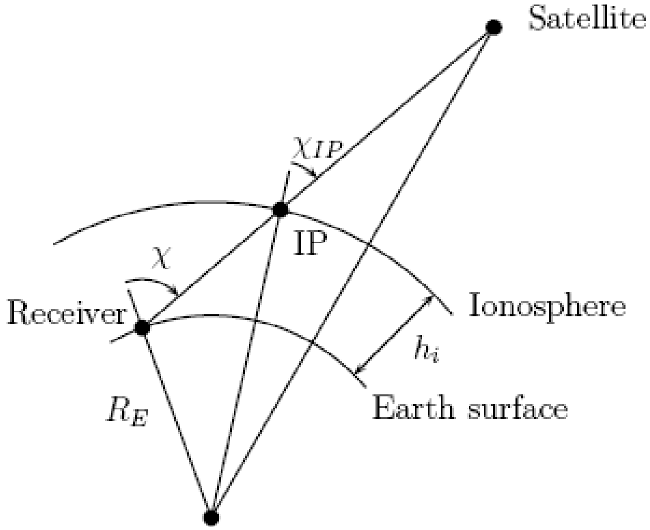
Levelling can be achieved using reference global TEC.

- Ambiguity = average on « arc » of difference between phase and sTEC



GIMI

- sTEC ≈ vTEC from Global Ionospheric Maps (GIM) mapped to slant
- Remaining effects from GIM = mismodelling, mapping function error



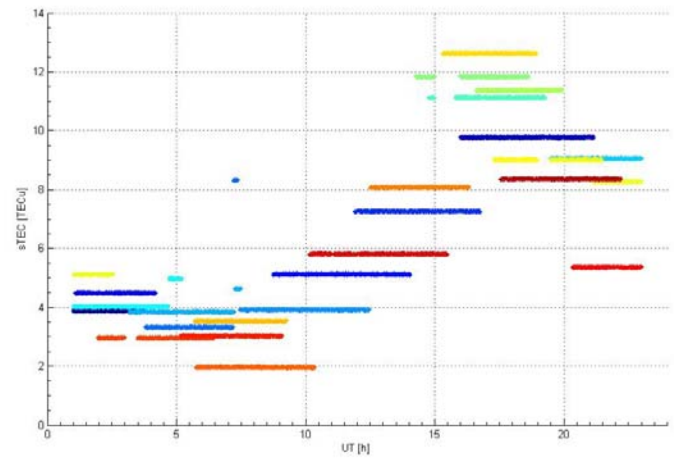
1. Measuring TEC

We observe expected constant sTEC differences by arc.

- Remaining effects constant by arc

  → Constant difference by arc

  → Statistics by arc



- Data set:

  - Brussels (mid-latitudes)

  - 2002 (high solar activity level)

  - UPC GIMs

1. Measuring TEC

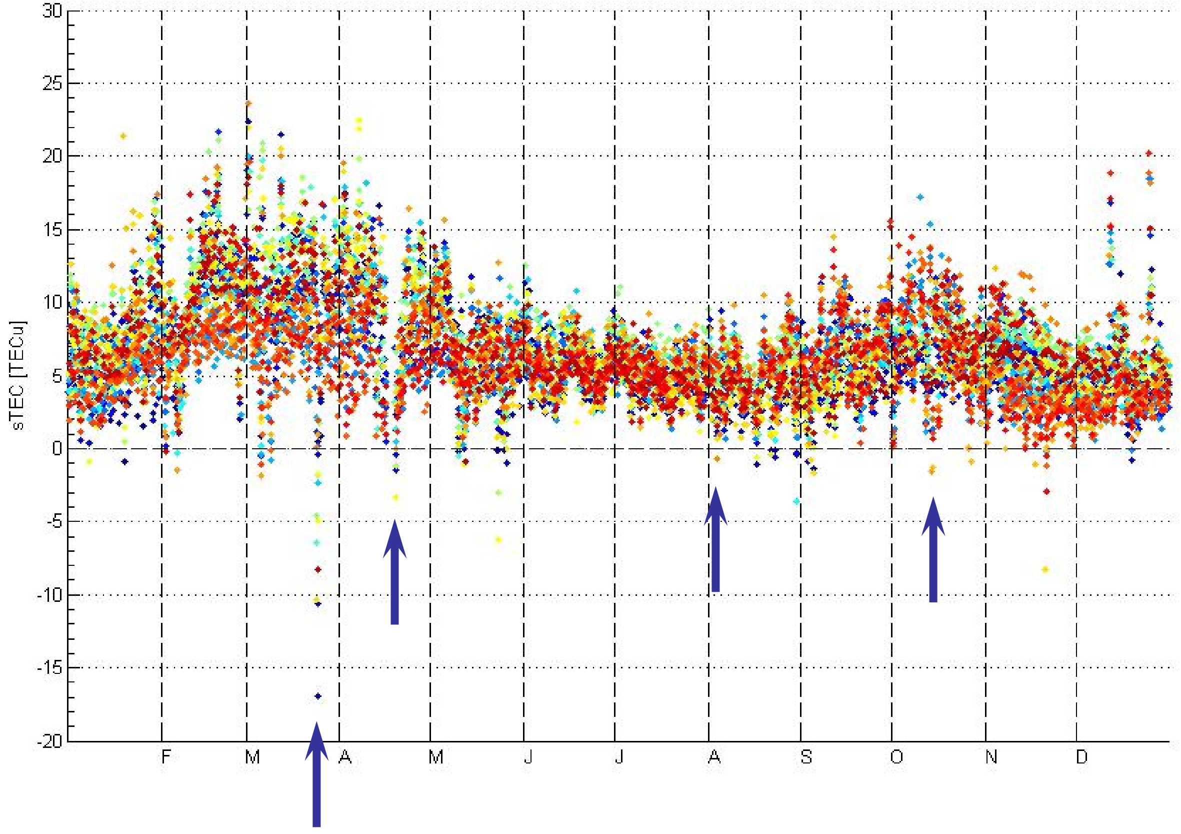
2. sTEC Comparison

3. vTEC Comparison

2. sTEC Comparison

We obtain fairly large sTEC differences by arc.

$sTEC_{GIMI}$ - $sTEC_{RMI}$ by arc



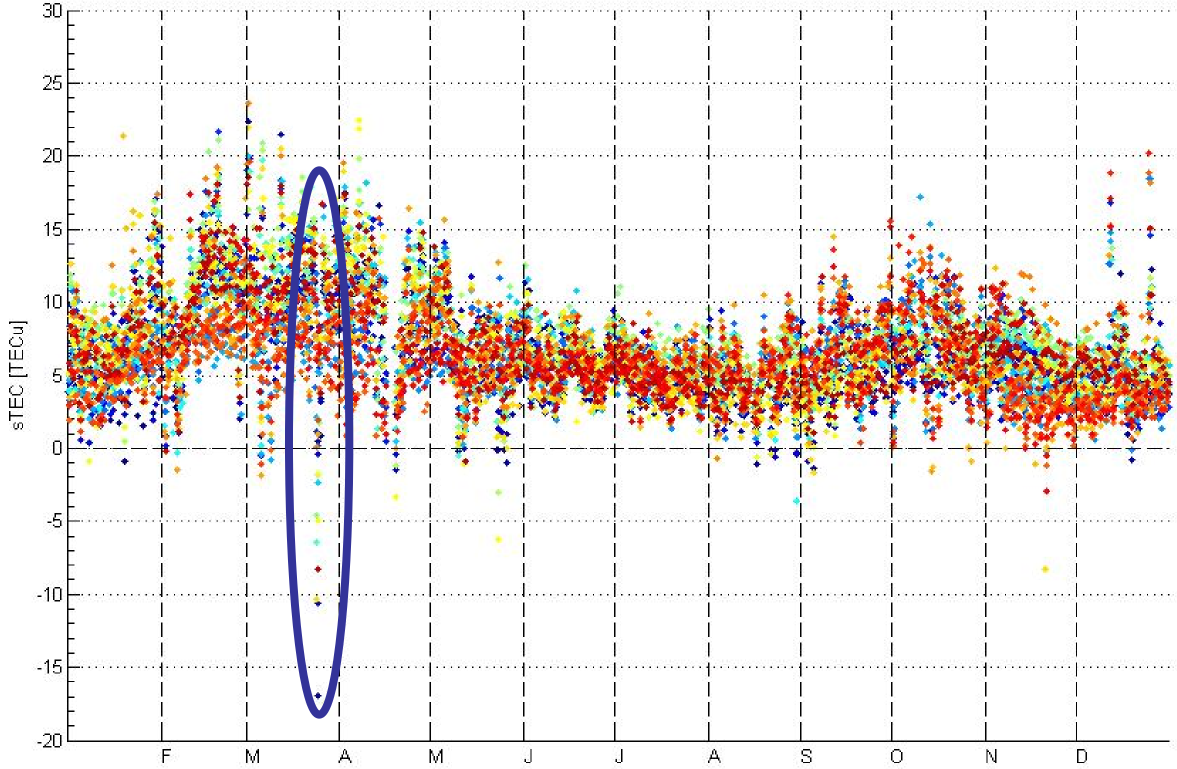
$1 TECu \rightarrow 16\ cm$ error for L_1

- Bias = 6.8 TECu
- Std = 3.5 TECu
- Correlation with ionospheric and geomagnetic activity
- Specific cases wrt adjacent days

2. sTEC Comparison

We obtain fairly large sTEC differences by arc.

$sTEC_{GIMI}$ - $sTEC_{RMI}$ by arc



- Large negative differences

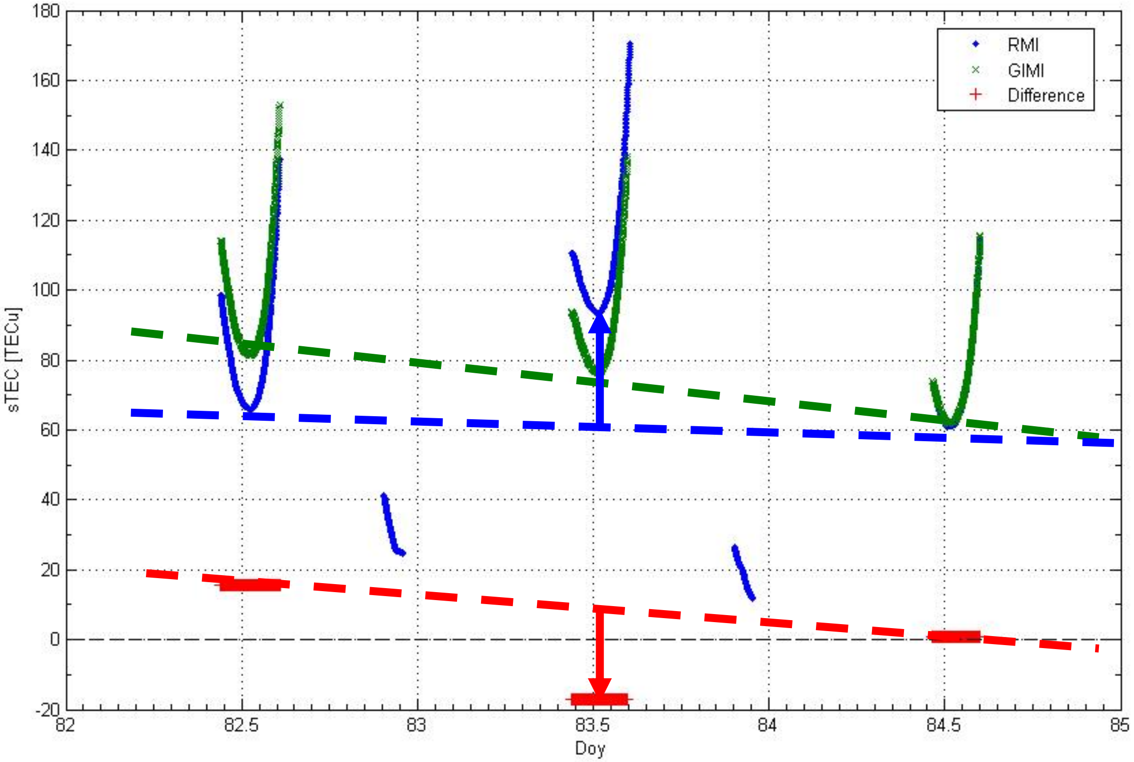
→ -17 TECu on March 24th

- Coinciding with geomagnetic storm

2. sTEC Comparison

GIMI sTEC seems to react less to geomagnetic storms.

sTEC + difference
(March 23rd to 25th – PRN 2)



- No visible effect on GIMI sTEC

→ Less reactions to storms

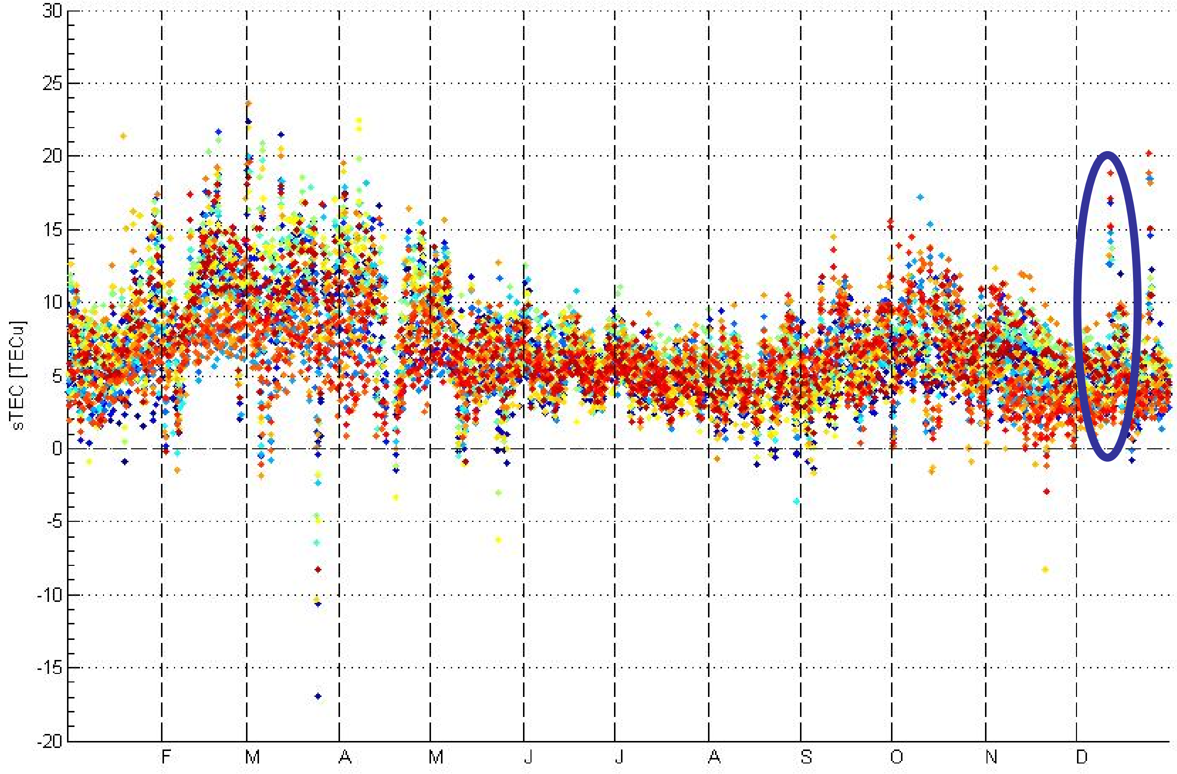
- Largest difference for lowest maximum elevation

→ influence of mapping function/code multipath effect

2. sTEC Comparison

We obtain fairly large sTEC differences by arc.

$sTEC_{GIMI}$ - $sTEC_{RMI}$ by arc



- Large positive differences

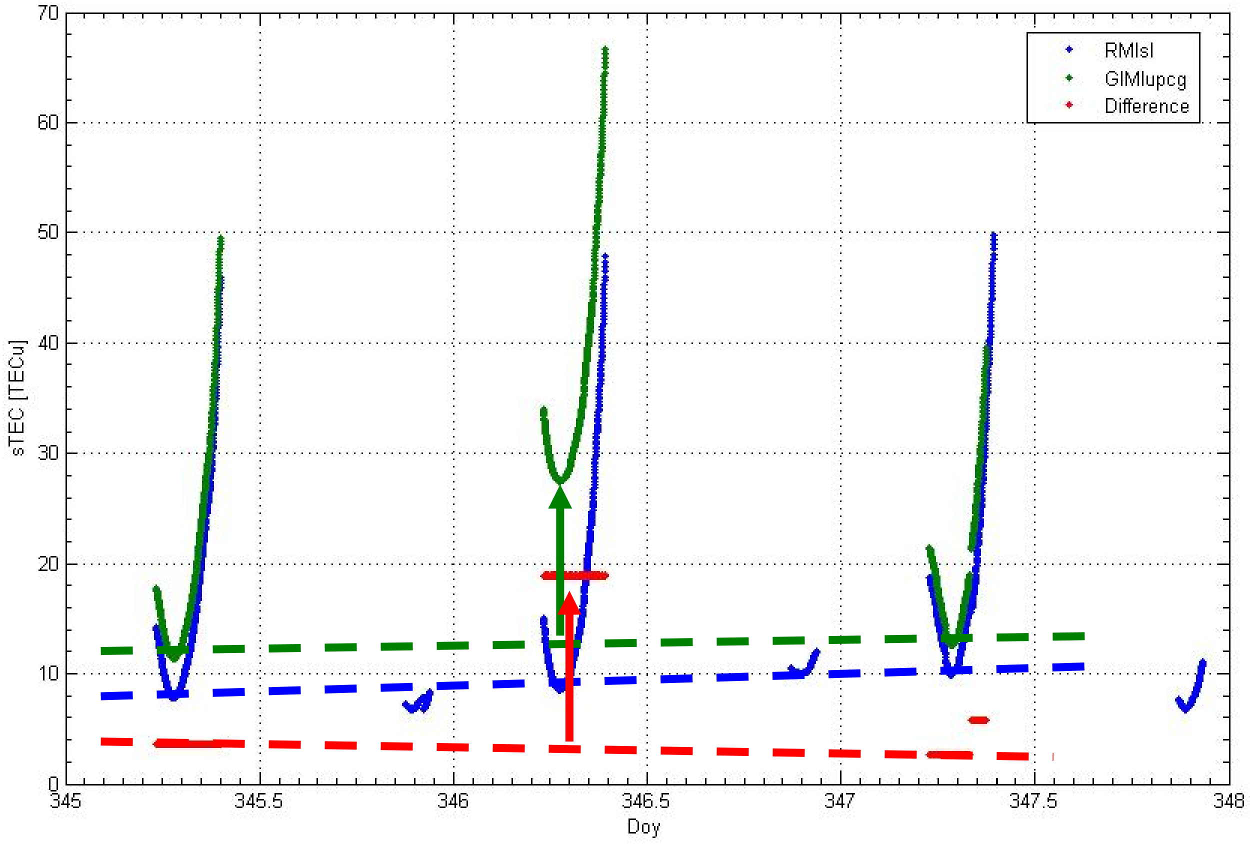
→ 19 TECu on December 12th

- Geomagnetically quiet

2. sTEC Comparison

We observe irregular sTEC values in GIMI data.

sTEC + difference
(December 11th to 13th, PRN 28)



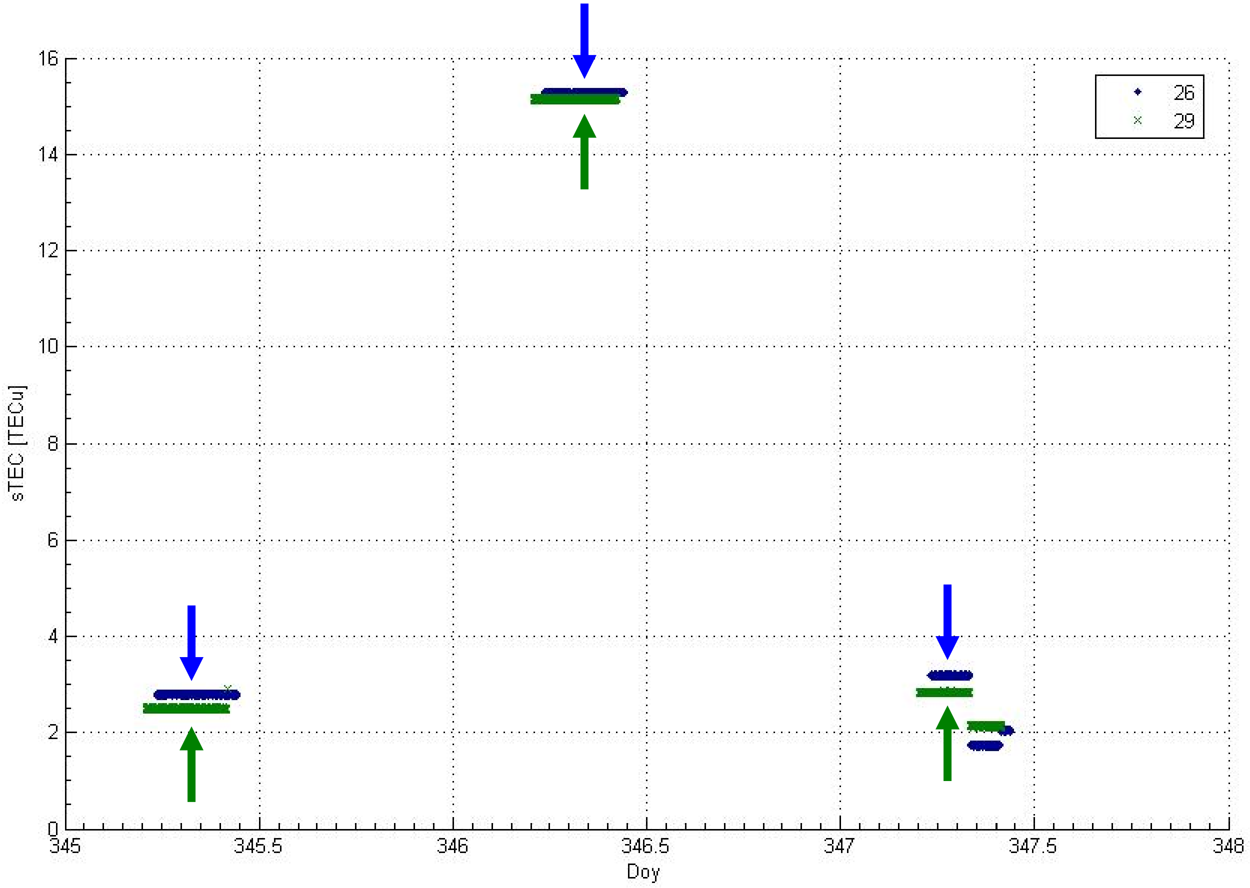
- Visible effect in GIMI sTEC

→ Influence of GIM residual errors

2. sTEC Comparison

Close satellites could help in highlighting geometry-dependent effects.

sTEC difference (December 11th to 13th)



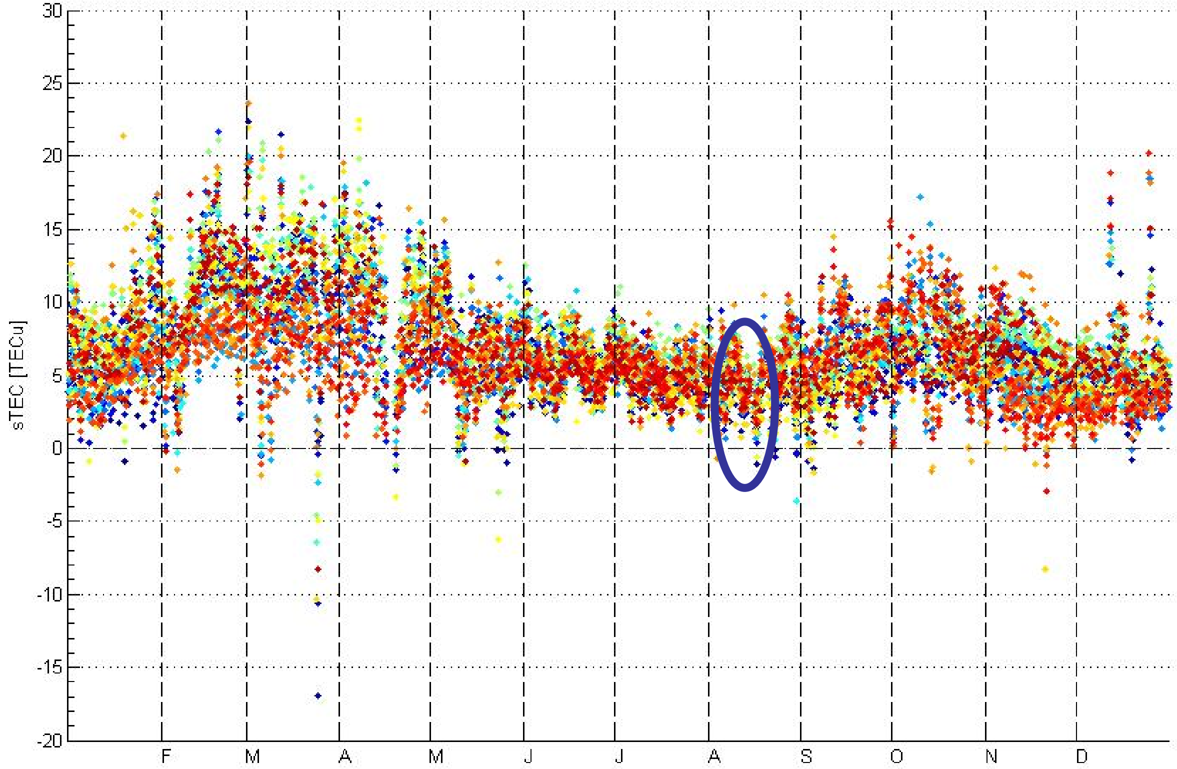
- Continuously close differences
- Close satellites

→ Geometry-dependent effects (not code delays)

2. sTEC Comparison

We obtain fairly large sTEC differences by arc.

$sTEC_{GIMI}$ - $sTEC_{RMI}$ by arc



- Small differences

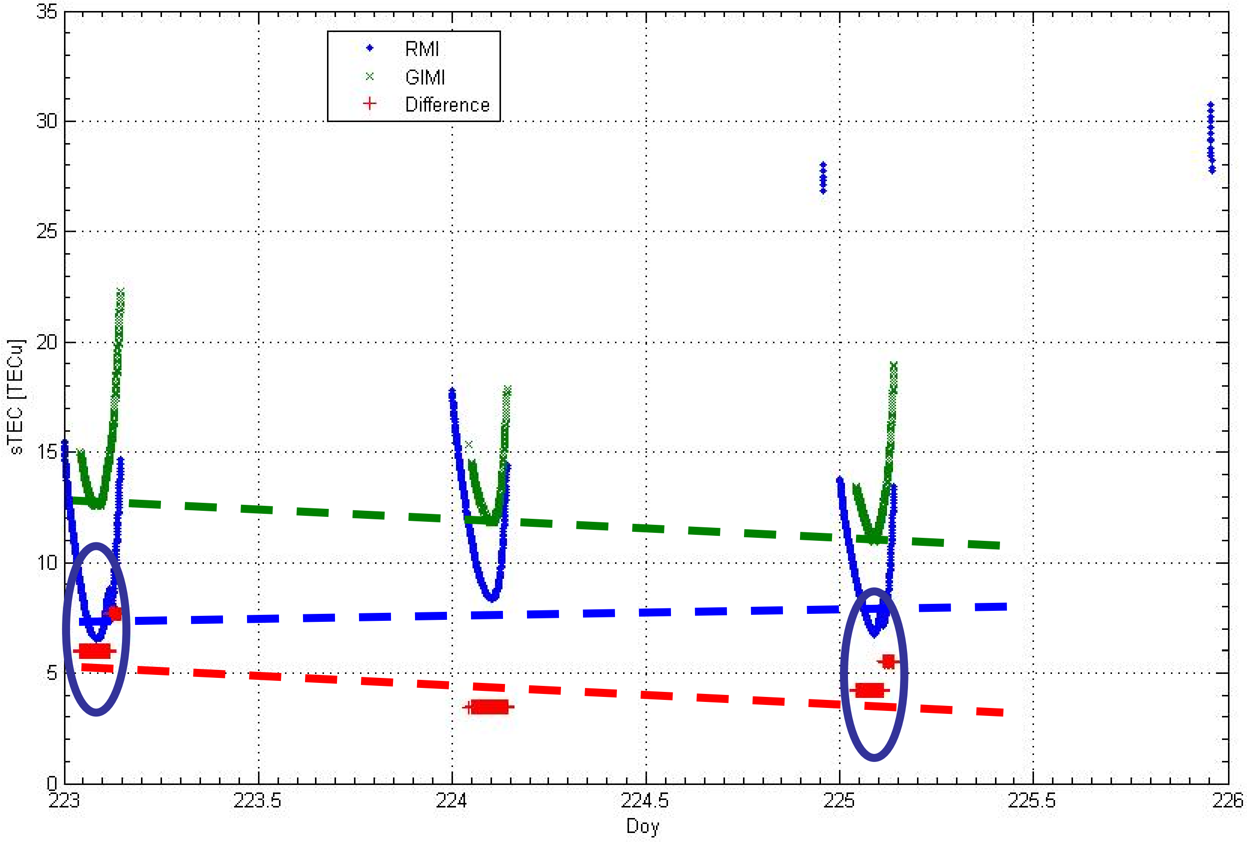
→ Range of 3.1 TECu on August 12th

- Geomagnetically quiet

2. sTEC Comparison

We observe many arc discontinuities.

sTEC + difference
(August 11th to 13th – PRN 17)

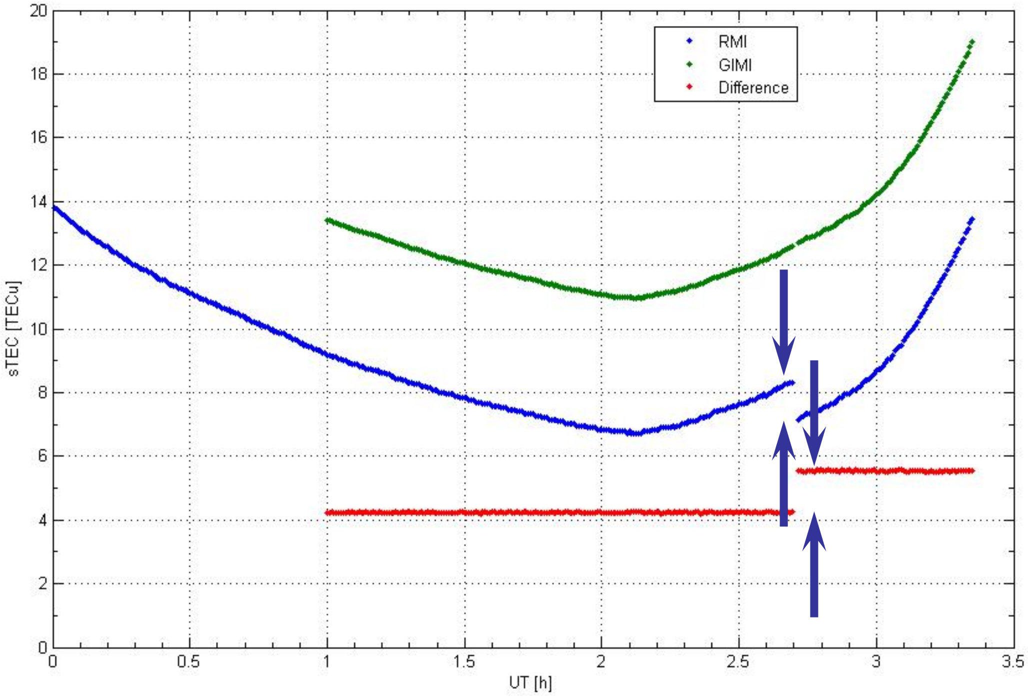


- Stable situation
- Recurrent discontinuities (cycle slips?)
- 12% of arcs involved in discontinuities larger than 1 TECu

2. sTEC Comparison

Discontinuities reveal differences in averaged remaining effects.

sTEC + difference (August 13th – PRN 17)



- Several arcs for one satellite

→ Different ambiguities

→ Different averages for remaining effects

→ Eg multipath for RMI

1. Measuring TEC

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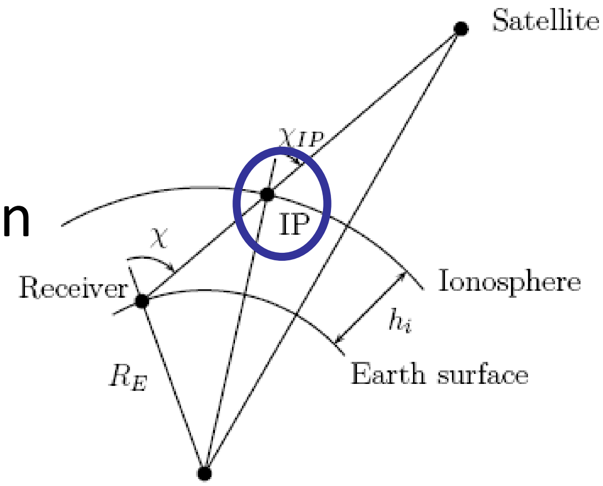
3. vTEC Comparison

vTEC is a different-level product for both data type.

- RMI:
  - sTEC mapped to vertical
  - IP filter: within 200km around the station
  - Average over 15 minutes

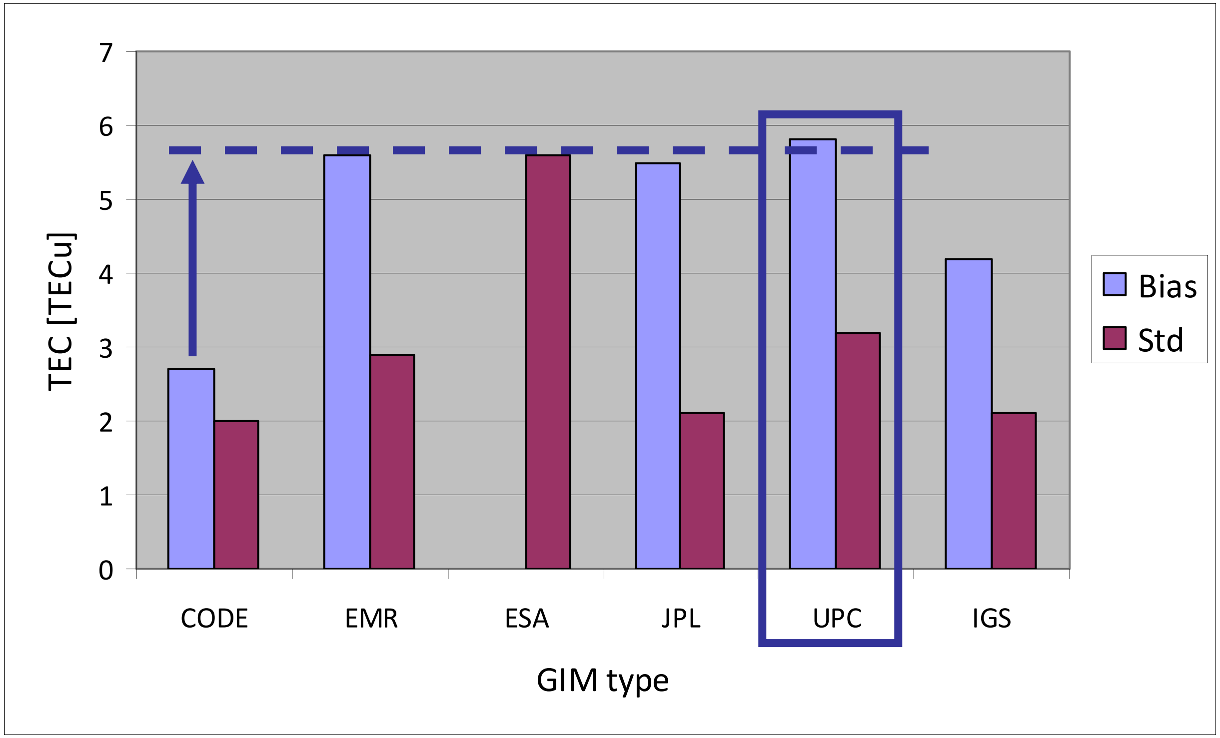


- GIM:
  - Resolution: 2.5° in latitude, 5° in longitude, 2h
  - Linear time interpolation between consecutive rotated maps
  - Bi-linear space interpolation
  - Several centres (5) + combination (IGS)

3. vTEC Comparison

We obtain consistent results for most of the GIMs.

Difference between RMI and GIM vTEC (Brussels - 2002)



- Consistent with sTEC comparison
- Underestimation from RMI vTEC
- Potential overestimation from GIM vTEC

We observe significant differences between two techniques.

- Levelling using
  - code measurements → residual hardware delays, multipath and noise
  - global reference TEC (GIM) → mismodelling and mapping function error
- Investigation for mid-latitudes and high solar activity

We observe significant differences between two techniques.

- sTEC difference constant by arc
  - 6.8 TECu on average
  - Large differences concommitant or not with geomagnetic disturbances
  - Day-to-day variability or recurrence → GIMs or multipath main influence
- vTEC underestimation from RMI but potential overestimation from GIM

TEC can be measured using GNSS.

- Further investigations
  - Arc-to-arc (discontinuities)
  - Inter-satellite
  - Inter-station
- Comparison with new TEC monitoring techniques (triple frequency)

TEC modelling eg for Galileo needs reliable measurements…

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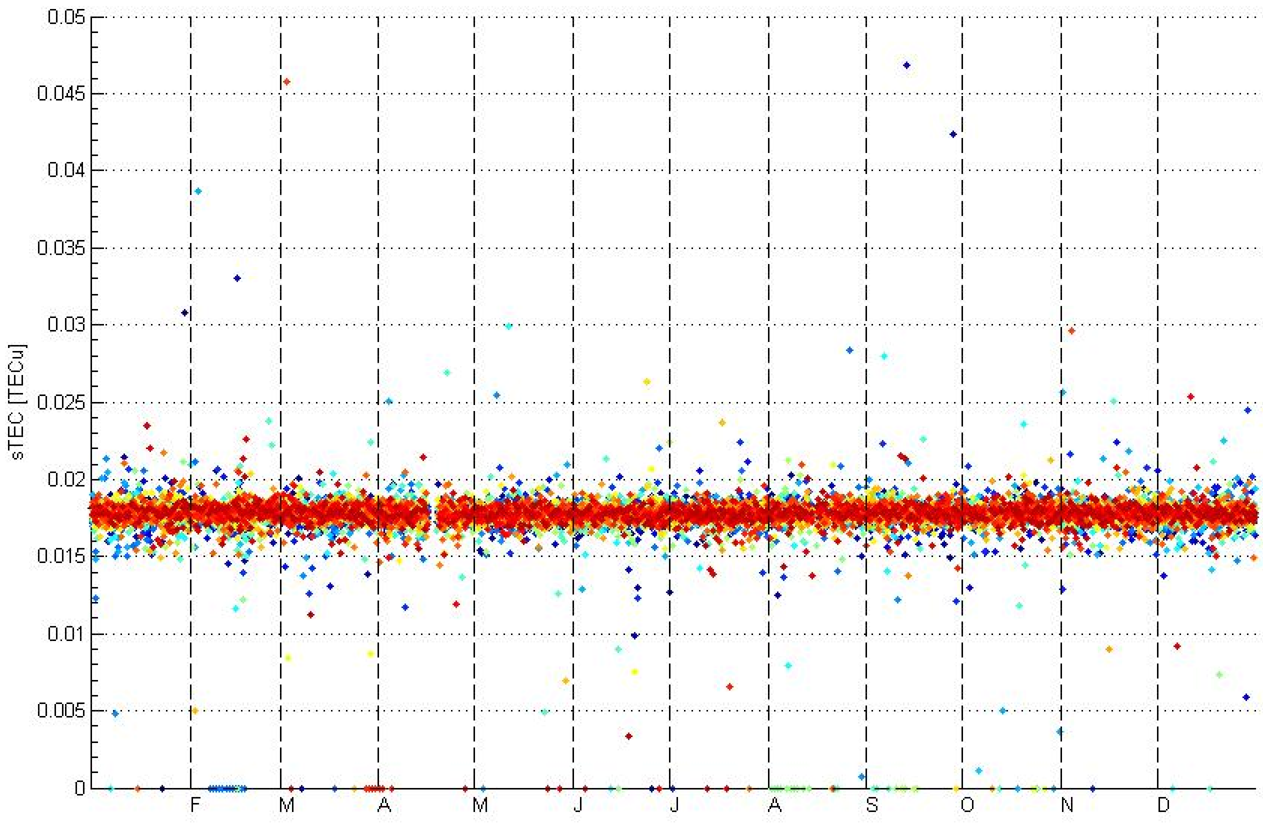
2. sTEC Comparison

We observe expected constant sTEC differences by arc.

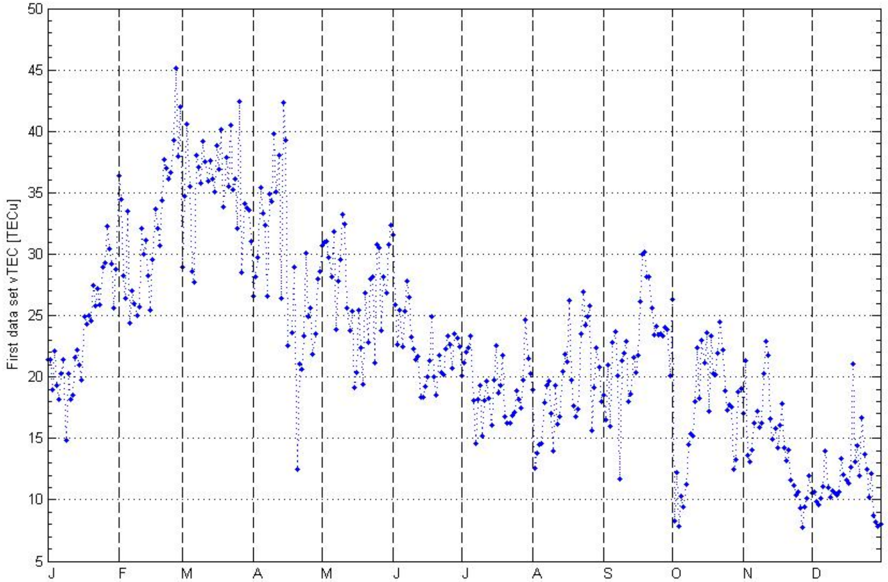
Standard deviation of sTEC difference by arc (Brussels - 2002)



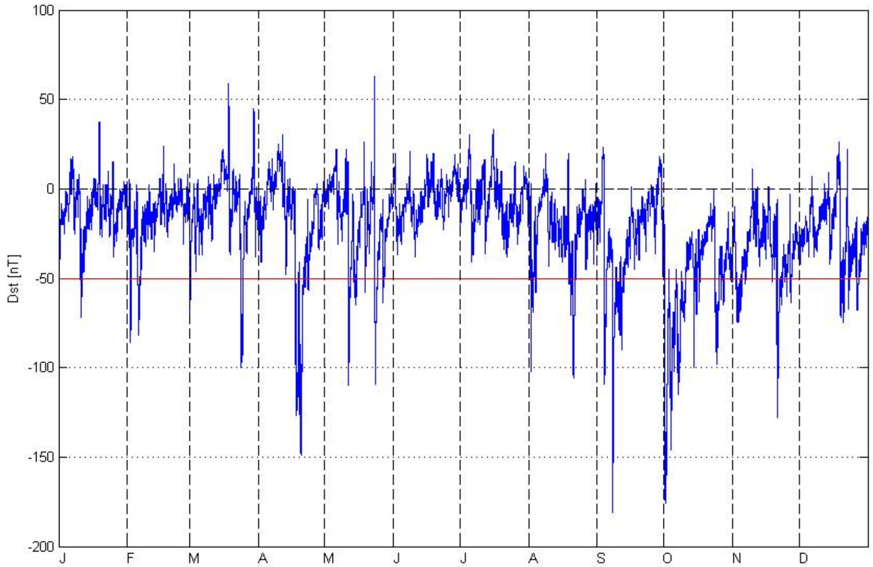
2. sTEC Comparison

We observe some correlation with ionospheric/geomagnetic activity.

Daily vTEC (Brussels - 2002)



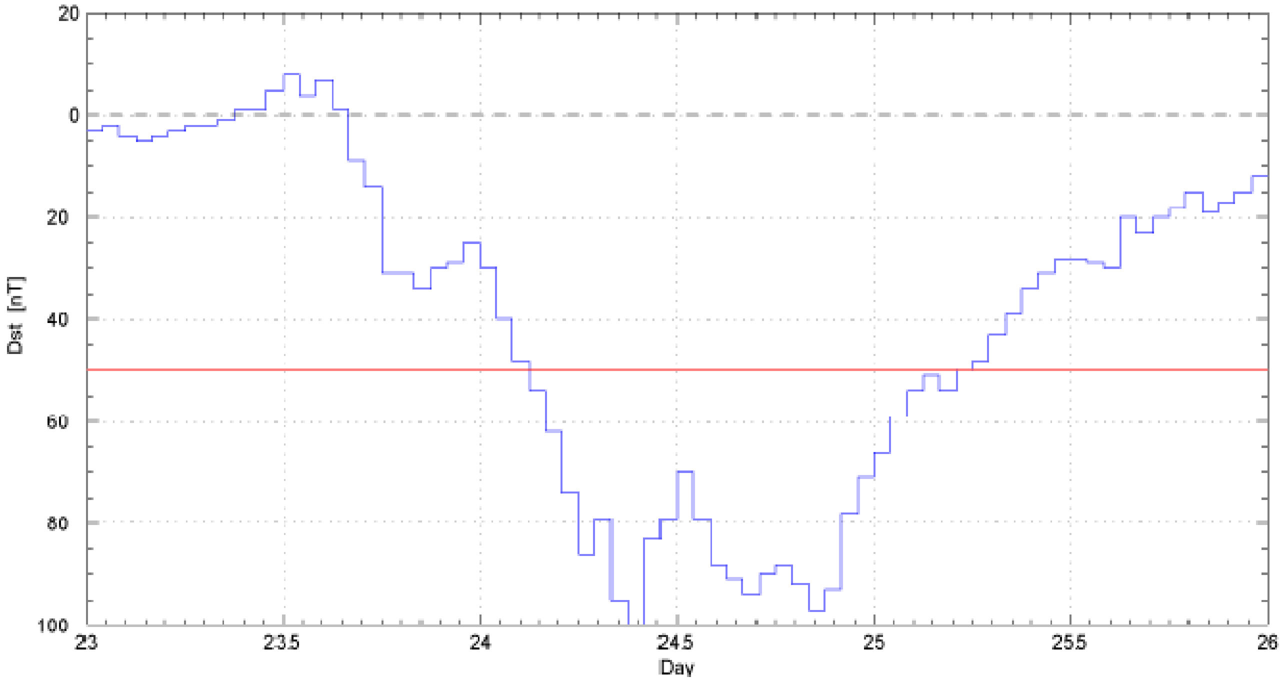
Dst index (2002)



2. sTEC Comparison

GIMl sTEC seems to react less to geomagnetic storms.

Dst (March 23rd to 25th)



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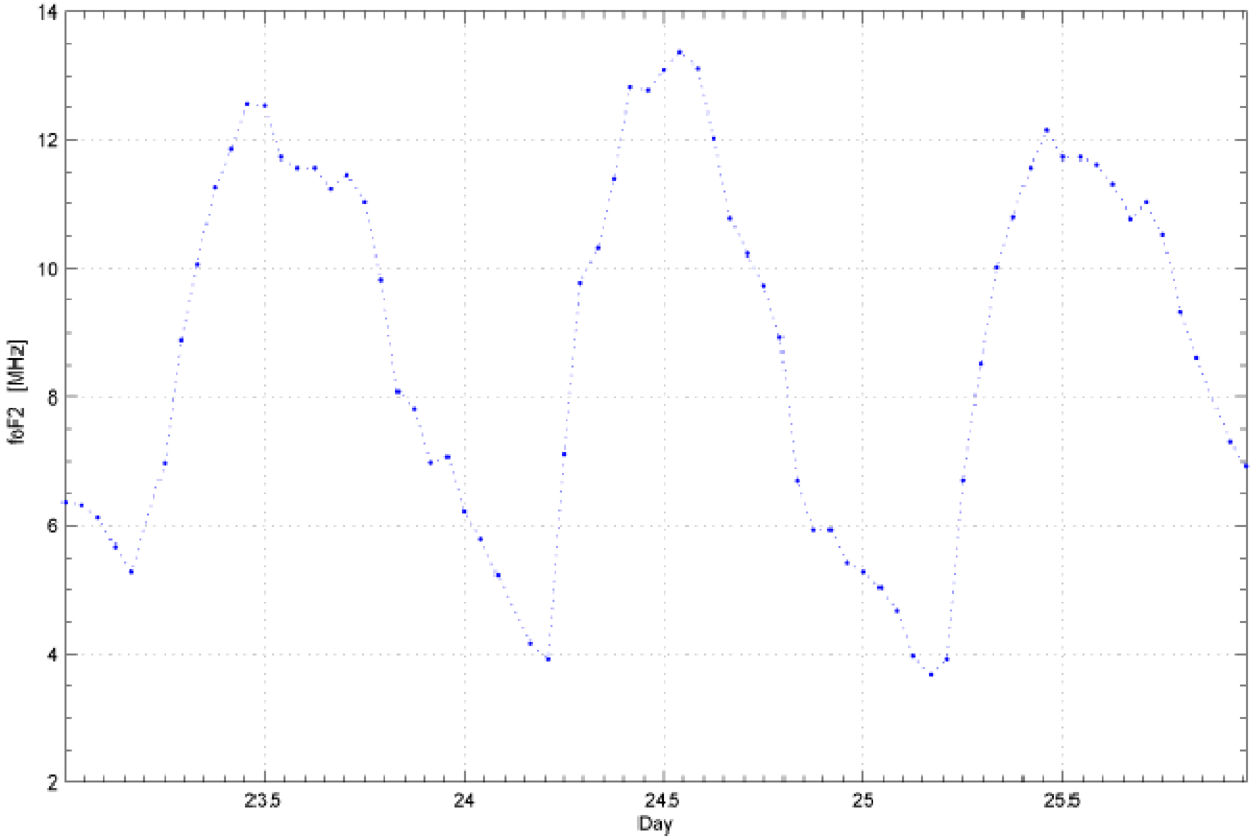
foF2 (Dourbes, March 23rd to 25th)



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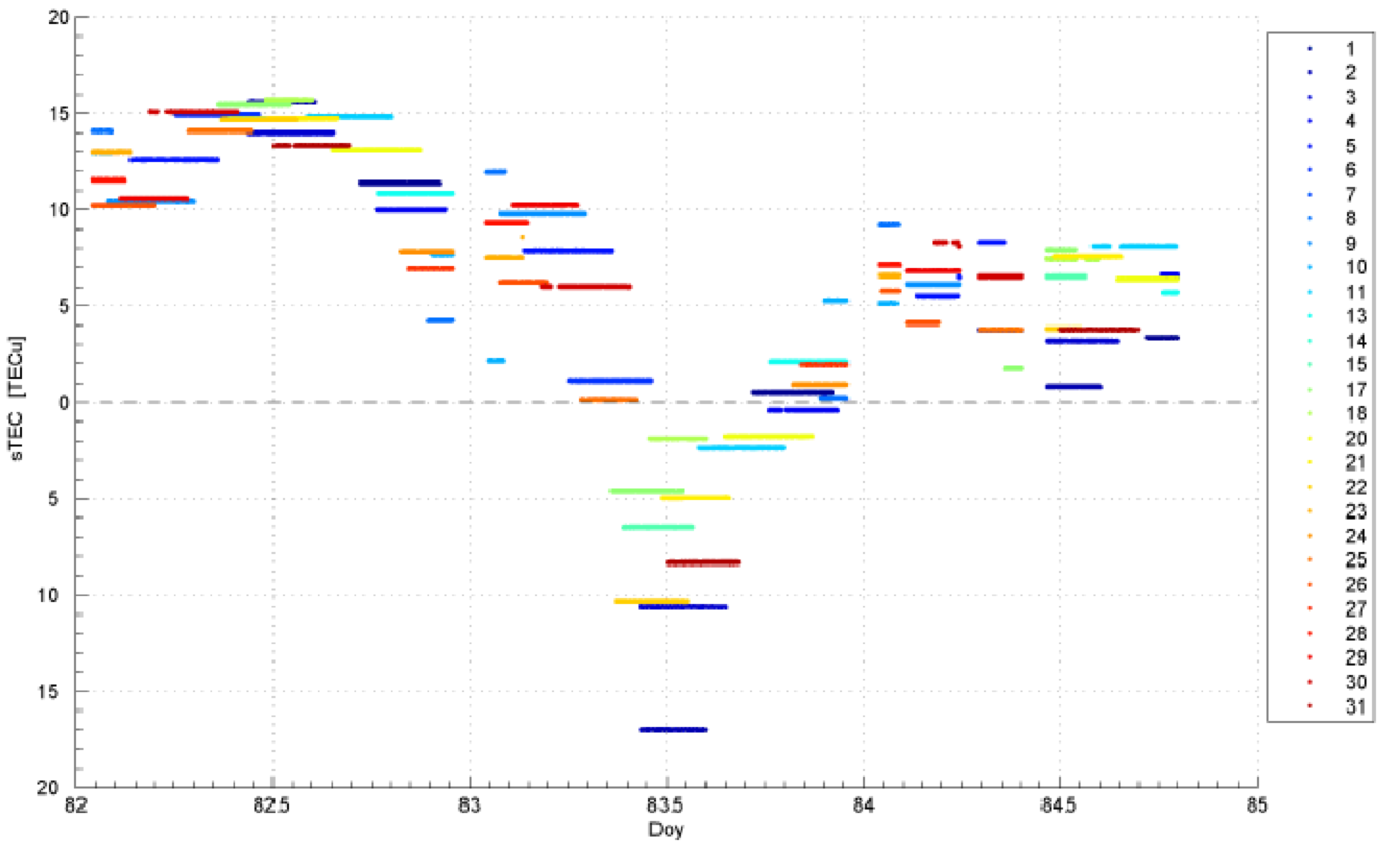
sTEC difference (March 23rd to 25th)



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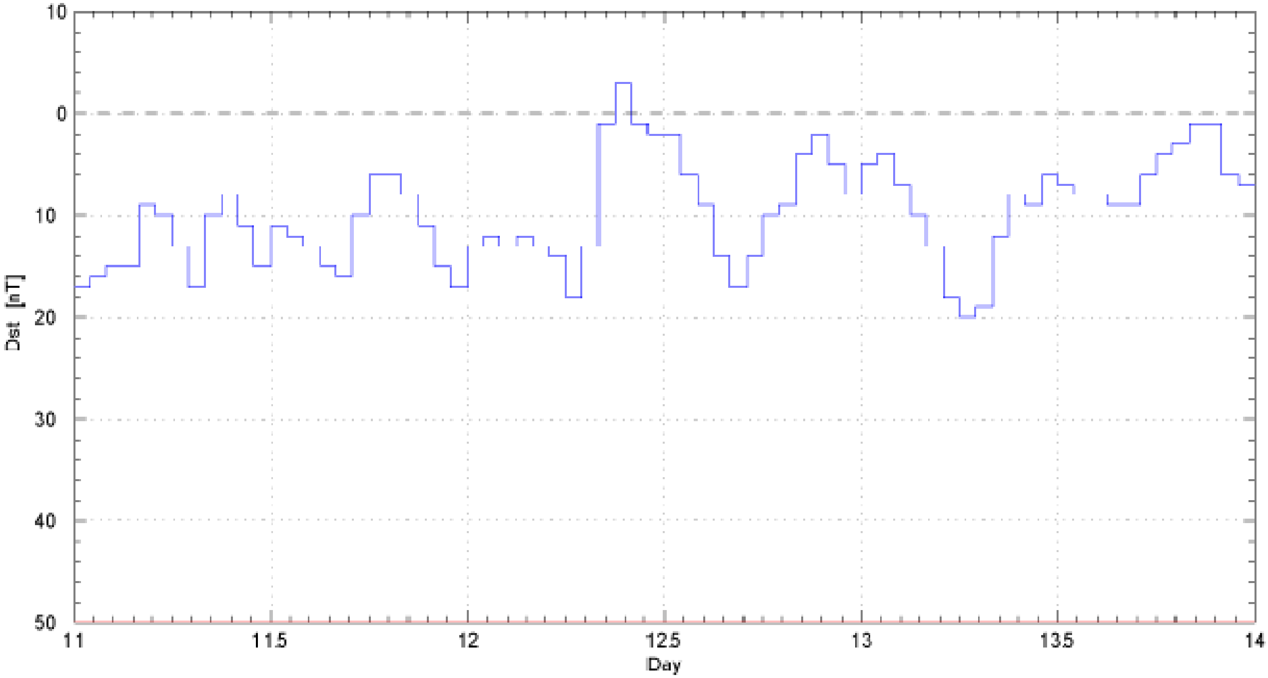

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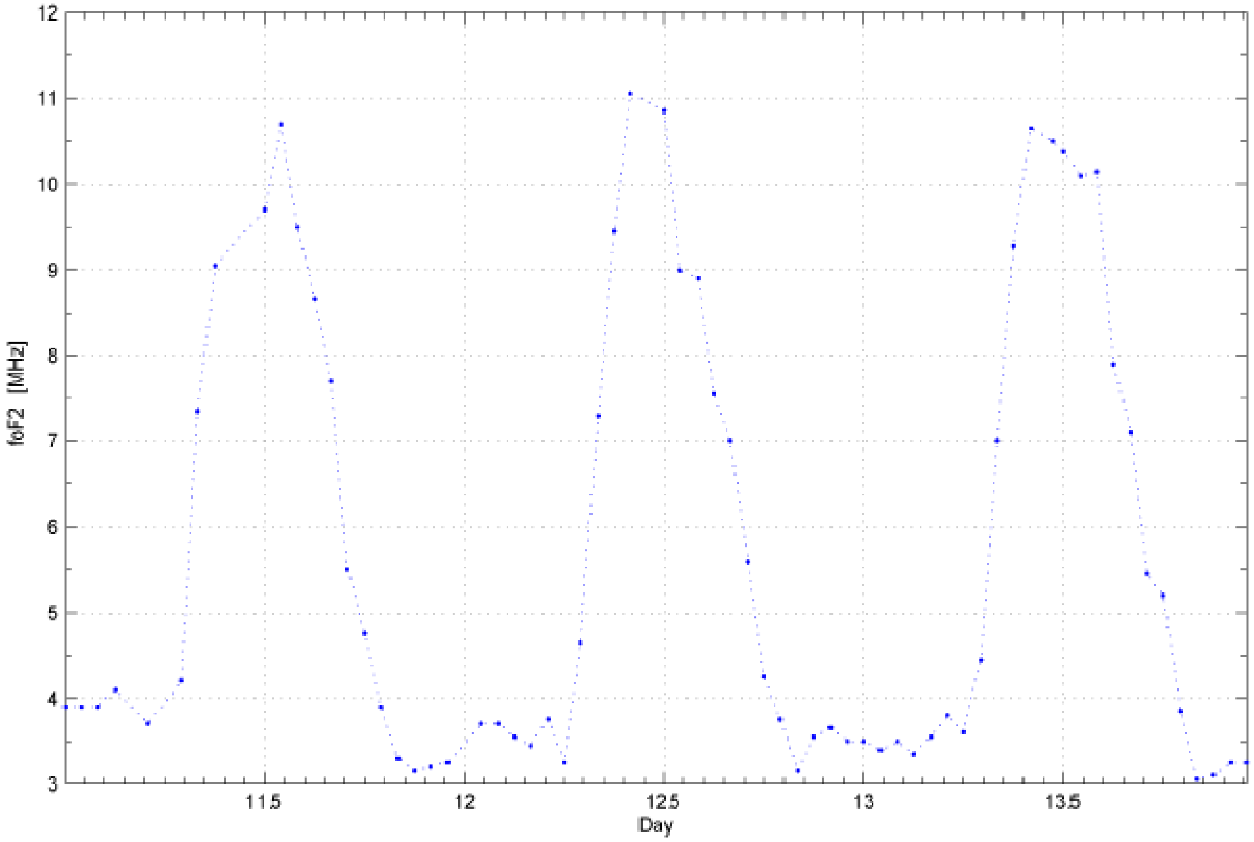

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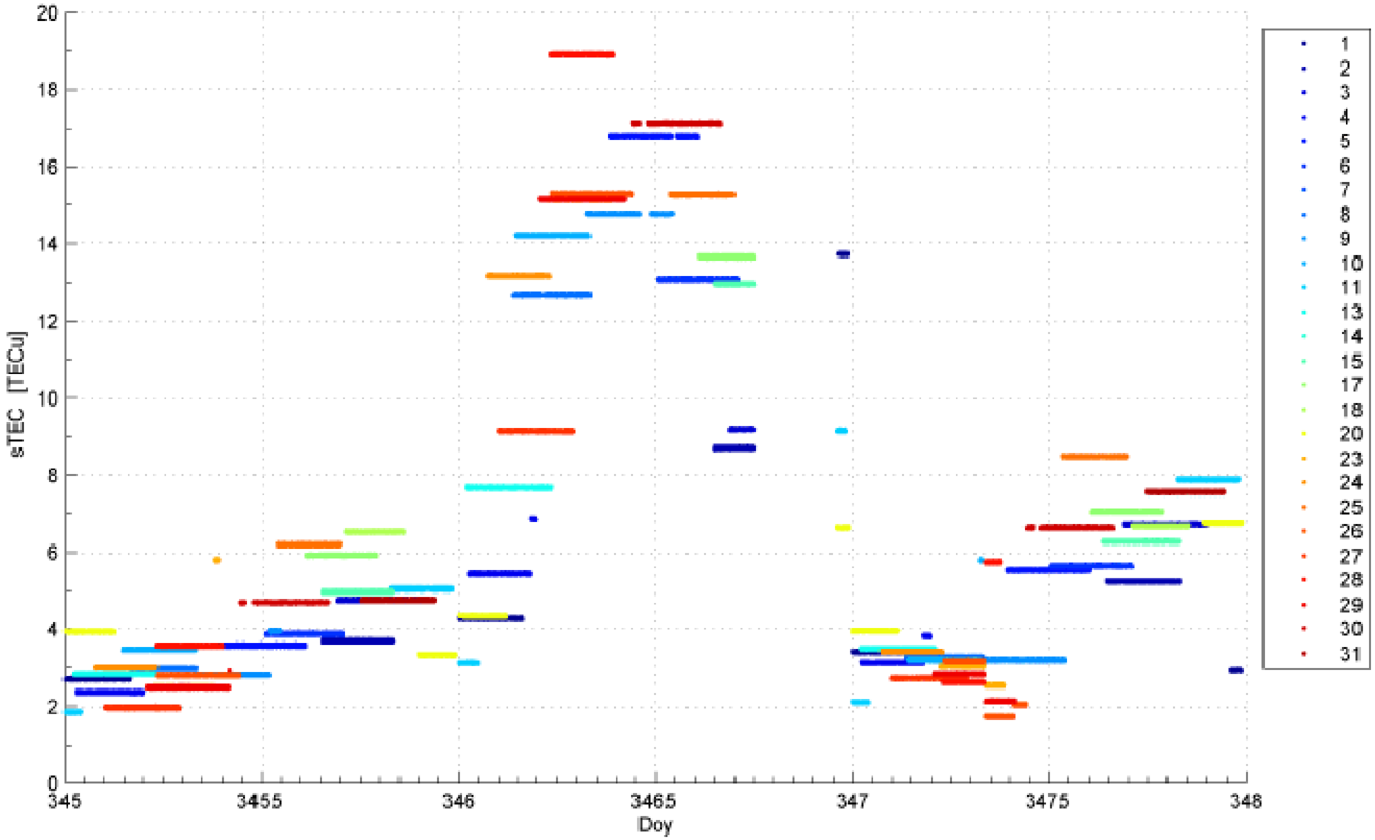
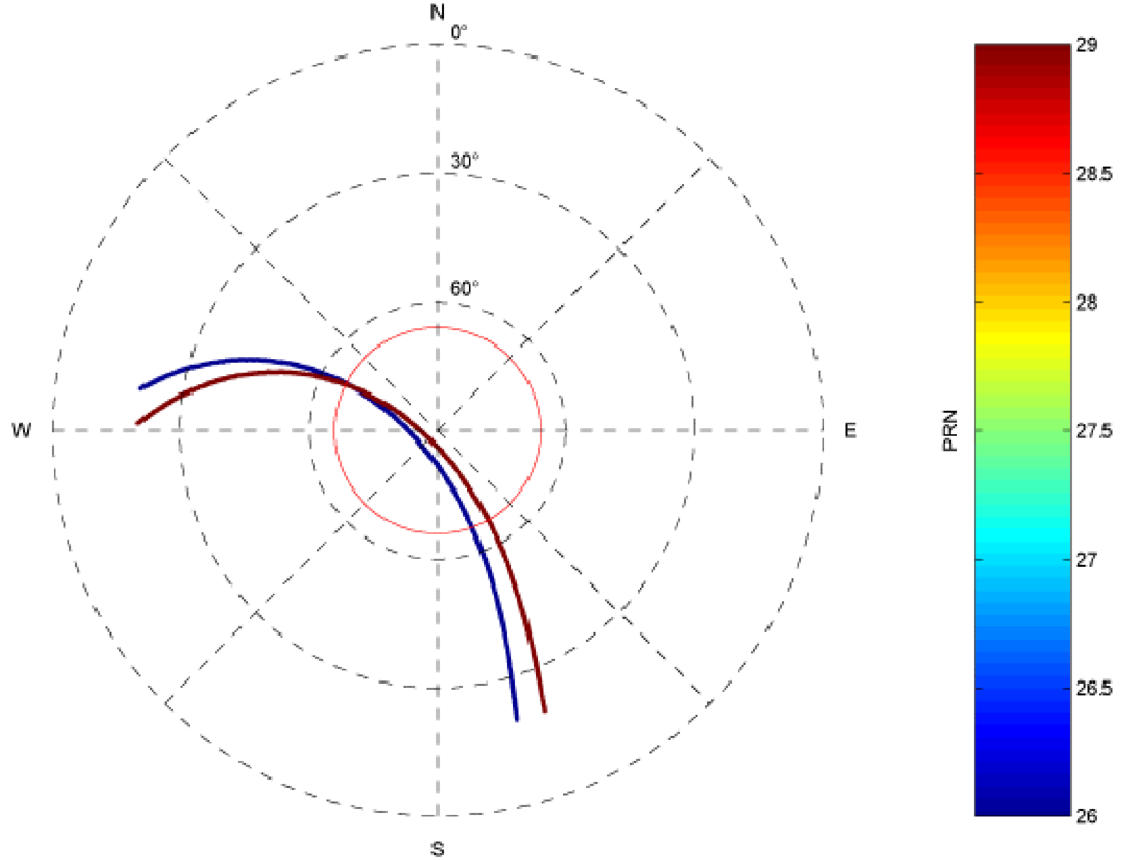


2. sTEC Comparison

Close satellites could help in highlighting geometry-dependent effects.

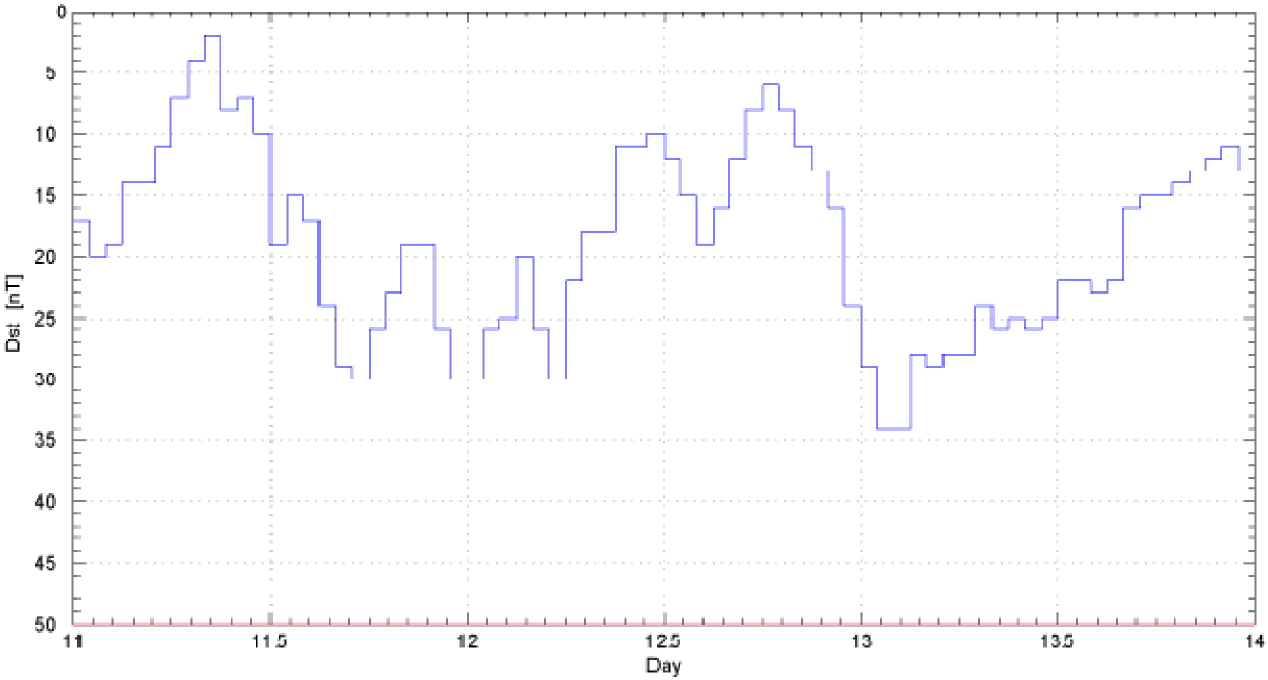
Sky plot (December 12th, PRN 26 and 29)



2. sTEC Comparison

We observe many arc discontinuities.

Dst (August 11th to 13th)



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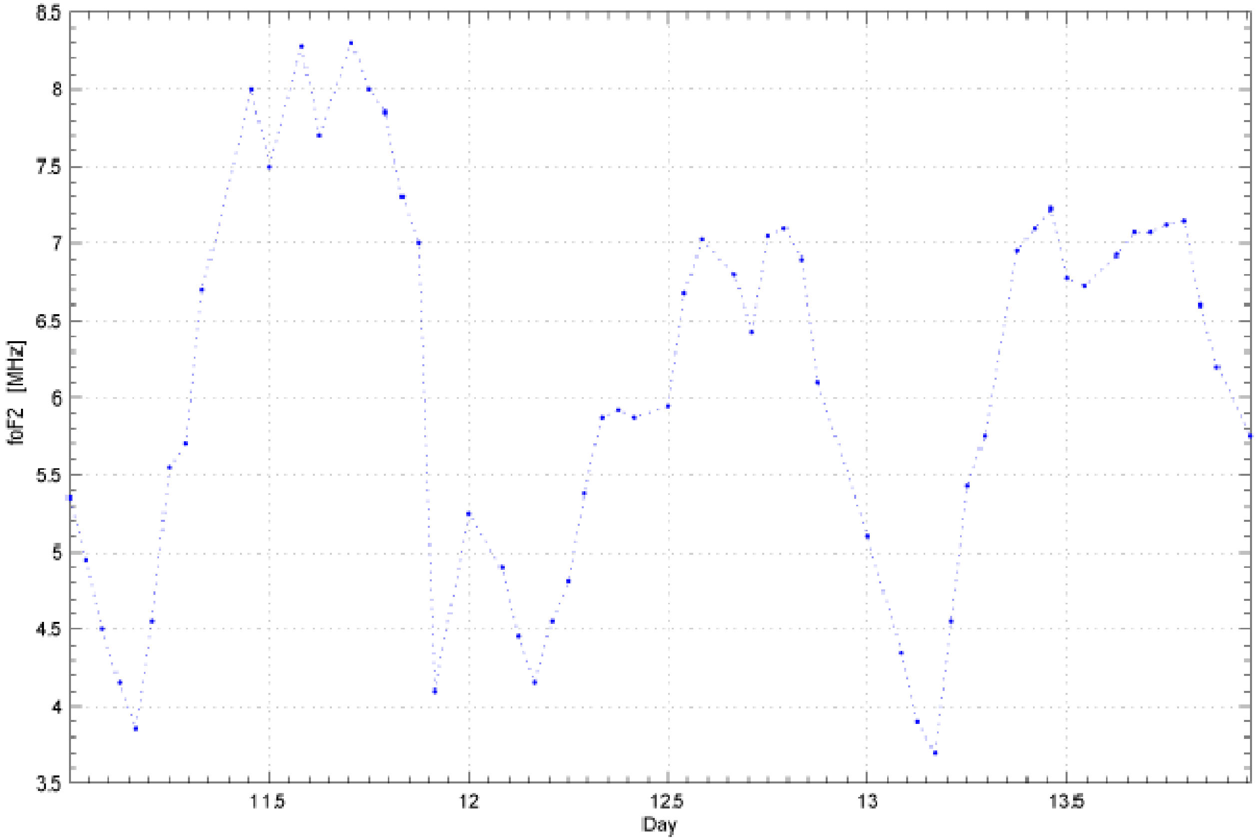

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