Ionosphere Monitoring Using Dual Frequency Smartphones

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GNSS-Based Ionosphere Monitoring

- The Geometry-free combination of GNSS dual frequency measurements makes it possible to monitor the ionospheric activity.
  - Absolute Total Electron Content (2-3 TECU)
    - Mitigation of the ionospheric error on absolute positioning
    - Ionosphere modelling
  - Rate of Total Electron Content (TEC) change (<=0,1 TECU/min)
    - Small-scale structures in TEC (Travelling Ionospheric Disturbances, scintillation monitoring)
    - Mitigation of ionospheric error on relative/differential positioning.
    - Tsunami early detection
- Could Smartphone GNSS Measurements give a useful contribution to this type of study ?

Smartphones versus Geodetic receivers

- Since Android version 7, raw GNSS measurements (code, phase, doppler, ...) collected by compatible Android Smartphones are available for their users in addition to computed positions.
- Smartphone disadvantages
  - Code and phase observable are less precise
  - Very strong multipath on code observables
  - Frequent cycle slips and data gaps
- Smartphone advantages
  - Availability of a large number of Smartphones (much denser information)
  - Cheap devices

Methodology

- We identify the different steps of the data processing which could be affected by specific smartphone data characteristics.
  - Cycle slips detection
    - Many more cycle slips.
    - Might not be easy to detect with the "usual" detection procedures.
  - Geometry-free phase ambiguity computation (Absolute TEC)
    - Cycle slips ➔ additional ambiguities.
  - Detection of small-scale structures
    - Can be detected out of the observation noise in Rate of TEC ?
- For all the tests, elevation mask = 10°
- (Rate of) TEC from geodetic receiver taken as "truth"

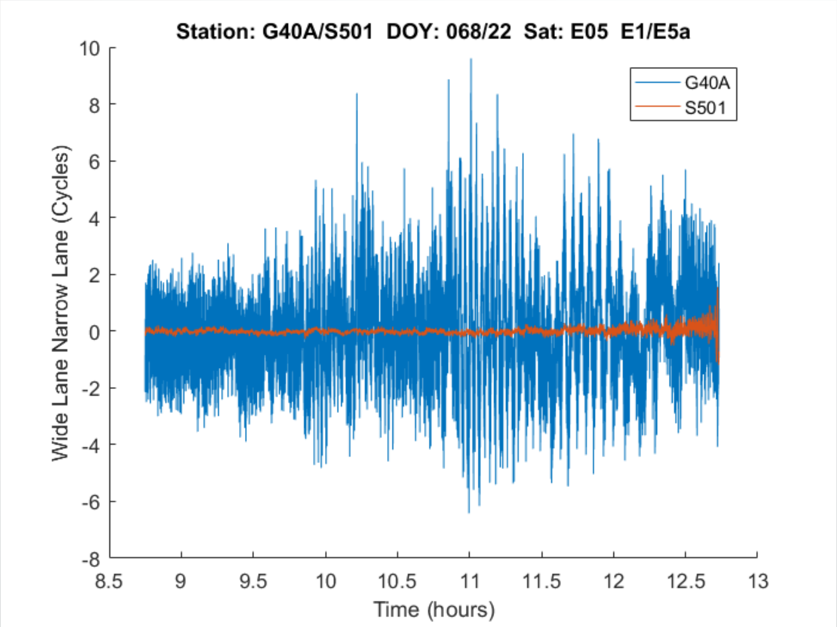
GNSS equipment

- S501: Septentrio PolaRx5 on ULG1
- G40A: Google Pixel 4 XL on ULGA
  - Qualcomm Snapdragon 855 chipset.
  - Dual frequency GPS (L1/L5), Galileo (E1/E5a).
- G60A: Google Pixel 6 on ULGA
  - Broadcom BC47756 chipset
  - Dual frequency GPS (L1/L5), Galileo (E1/E5a) and Beidou (B1-2/B2a)
- Rinex data acquisition (4 hour files)
  - GEO++ for smartphones (does not support 2F Beidou)

ULG0

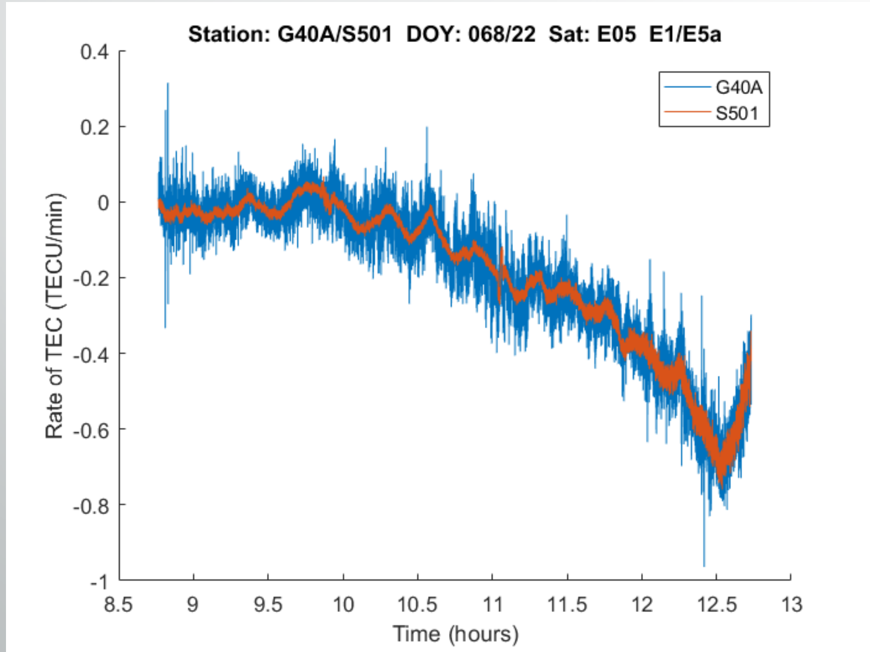
Cycle Slip detection

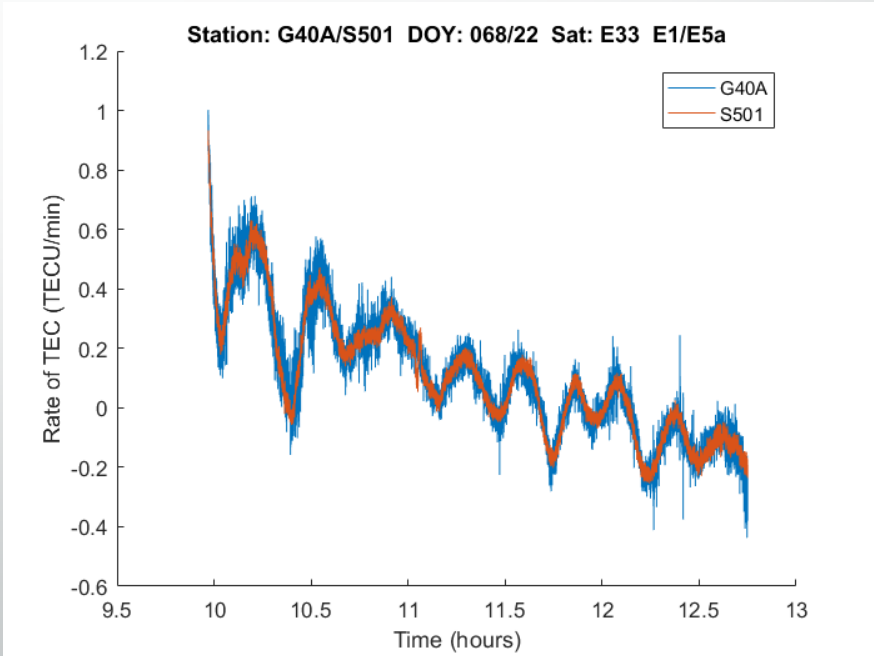
- Detection usually based on Widelane-Narrowlane combination.
  - Ionosphere-free and geometry-free based on dual frequency code and phase
  - CS up to 6 Cycles (Pixel 6) or 8 cycles (Pixel 4) might remain undetected.



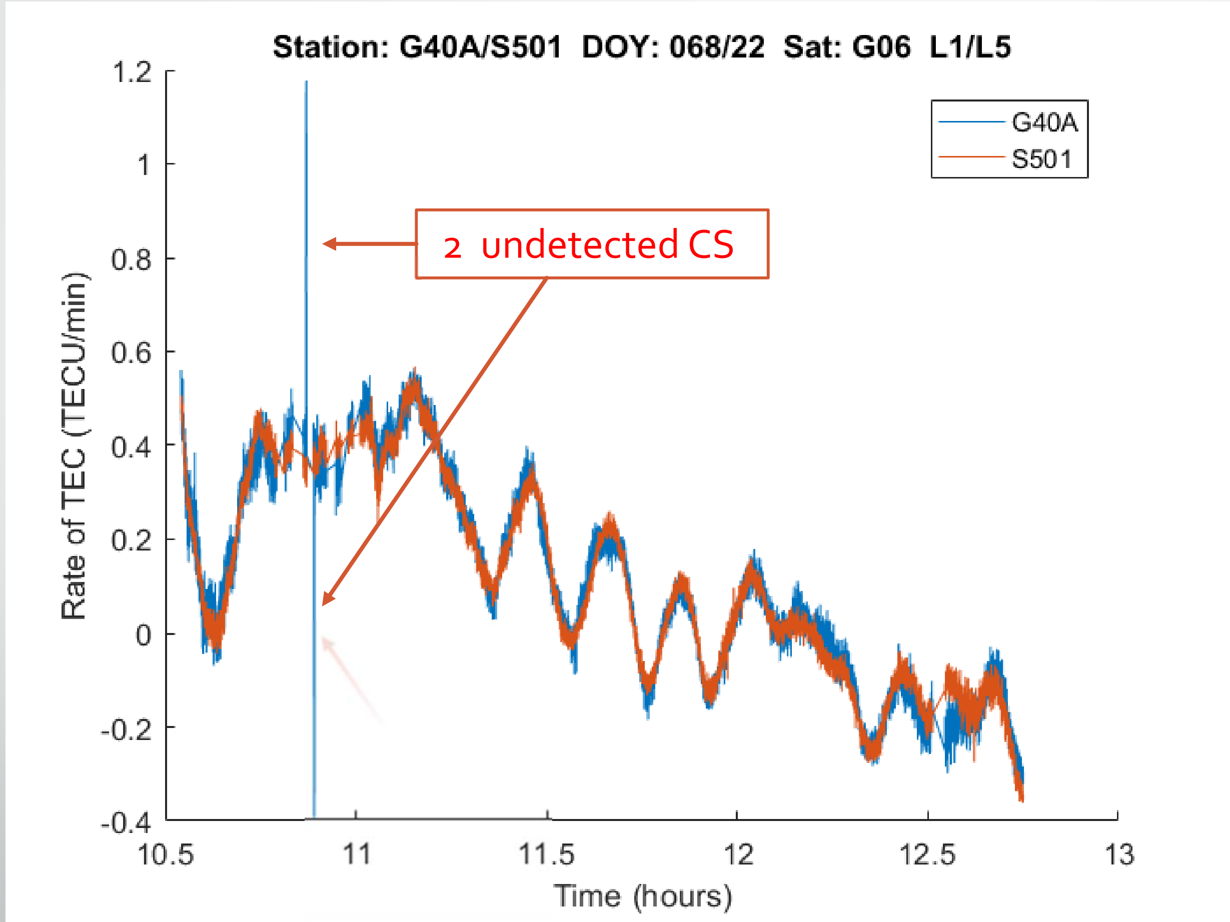
TEC rate of change

- Small-scale structures can be monitored based on TEC rate of change :
  - <=0,1 TEC/min for geodetic receivers
  - 0,2-0,3 TECU/min for Smartphones



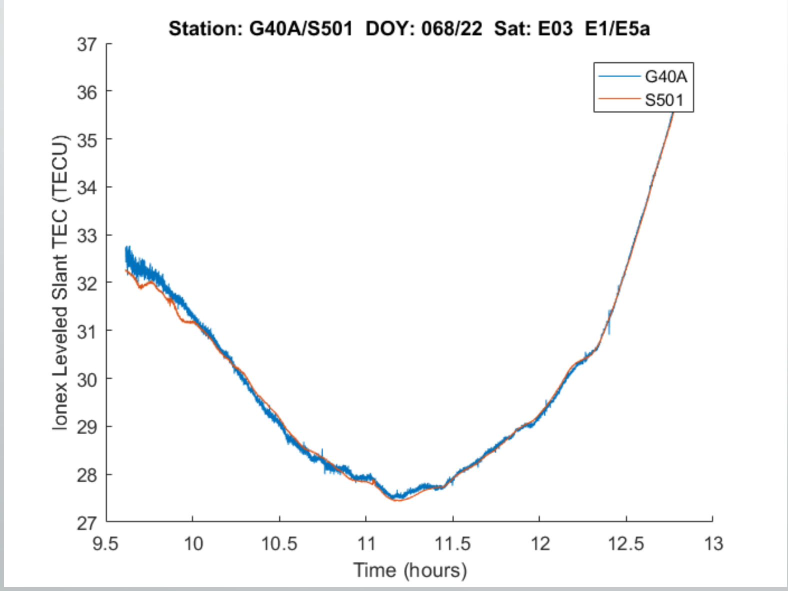


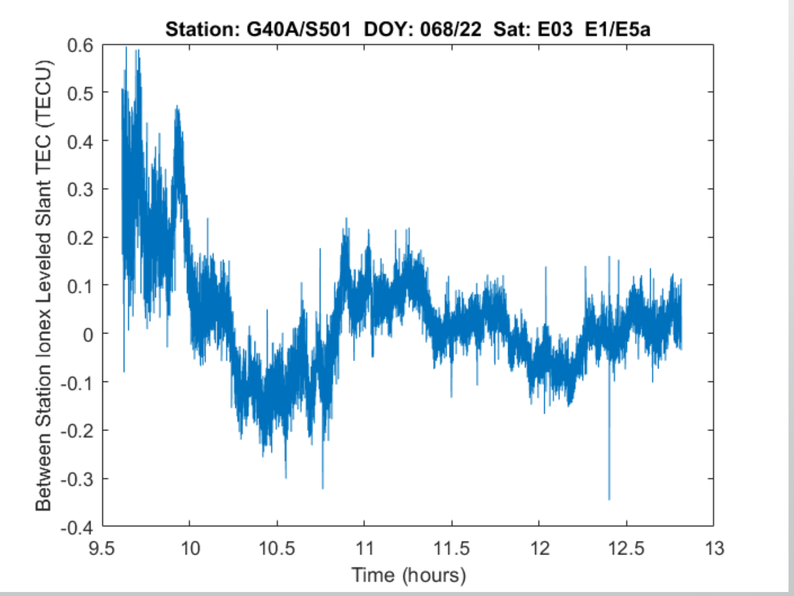
TEC rate of change



Absolute TEC

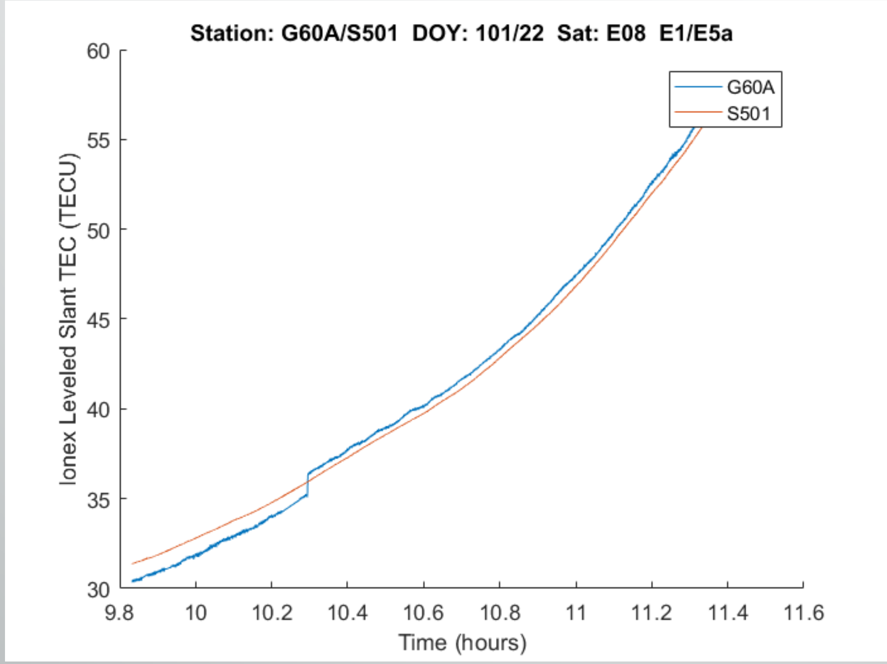
- Ambiguity computed using IONEX TEC maps from IGS
- Difference Geodetic – Smartphone :
  - Usually < 1 TECU
  - Maximum : 3 TECU for Pixel 4 and 1,5 TECU for Pixel 6

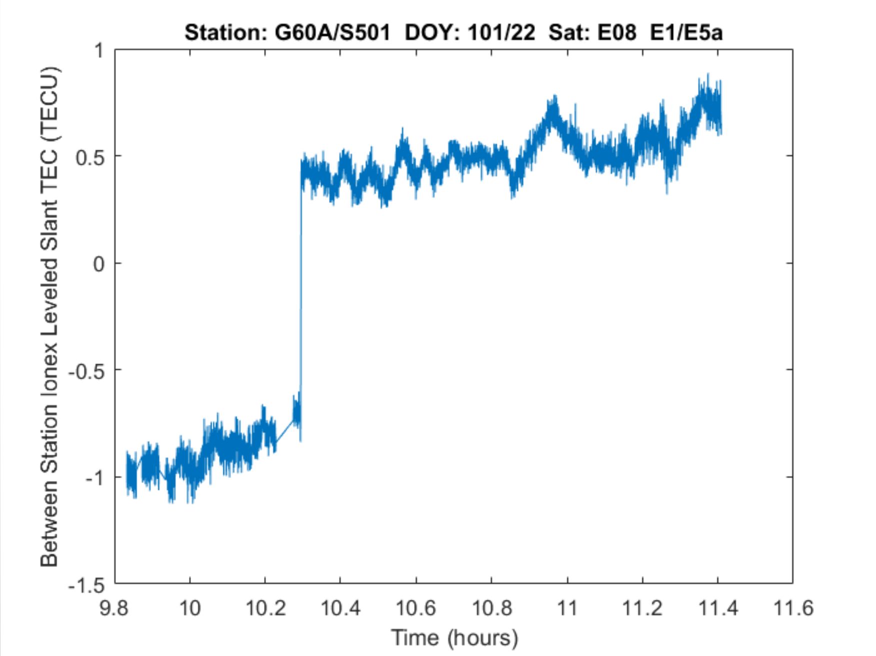




Absolute TEC

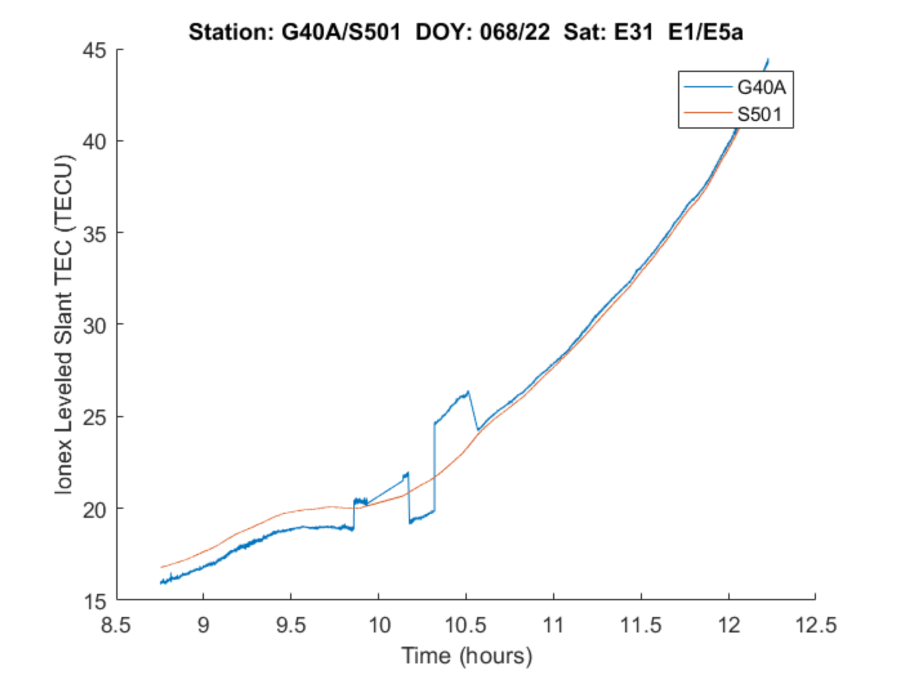
- Small jumps due to new ambiguity when cycle slips/gaps are detected.

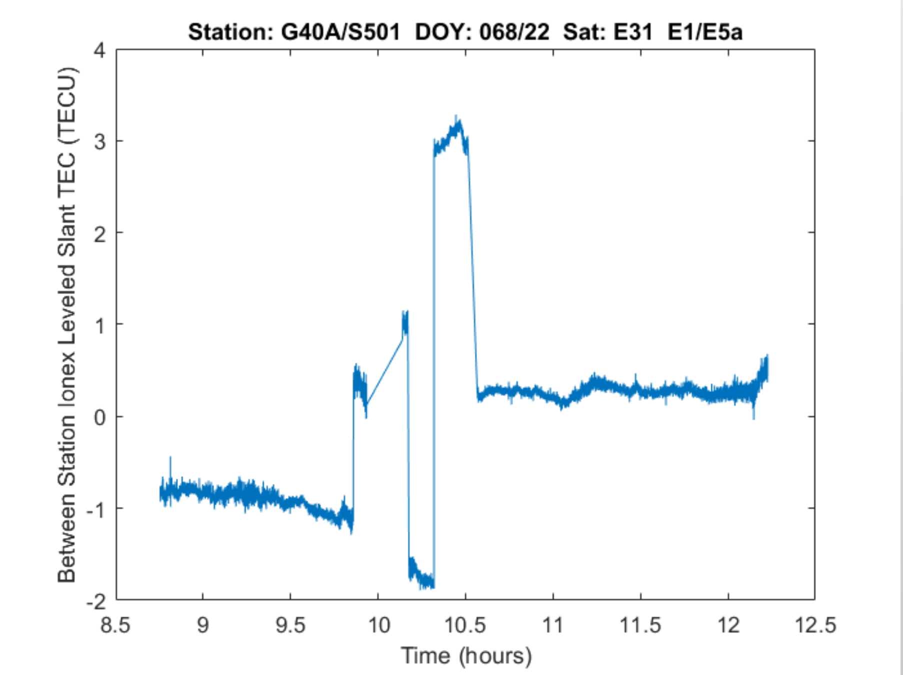




Absolute TEC:

- Difference Geodetic – Smartphone : Worse case 3 TECU





Discussion : Cycle slips and gaps

- The main weakness is related to gaps and cycle slips
- Cycle slip detection should be more “customized” to Smartphone data :
  - Detect small cycle slips and avoid false positive
  - Geometry-free combination but it is not ionosphere-free
  - Phase minus Doppler range-rate
- Gaps :
  - Does missing code and/or phase automatically mean cycle slip ?
  - Missing data in Rinex file might be “repaired” by data acquisition software.

Conclusions

- Smartphone dual frequency GNSS chips are valuable tools to monitor the ionospheric activity.
- Absolute STEC reconstruction (IONEX):
  - Accuracy: 0,1 TEC to 3 TECU taking geodetic receivers as reference.
  - Precision: No significant difference wrt geodetic receivers.
- Rate of TEC change makes it possible to detect small-scale structures in the ionosphere (Travelling Ionospheric Disturbances) if their amplitude is not smaller than 0,1-0,2 TECU/min
- Cycle Slip detection and gap "management" should be improved.