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 Raw GNSS Measurements give a useful contribution to this type of study ?

Smartphones versus Geodetic receivers

- Smartphone disadvantages
  - Code and phase observable are less precise
  - Very strong multipath on code observables
  - Frequent cycle slips
- Smartphone advantages
  - Availability of a large number of Smartphones (much denser information)
  - Cheap devices

Methodology

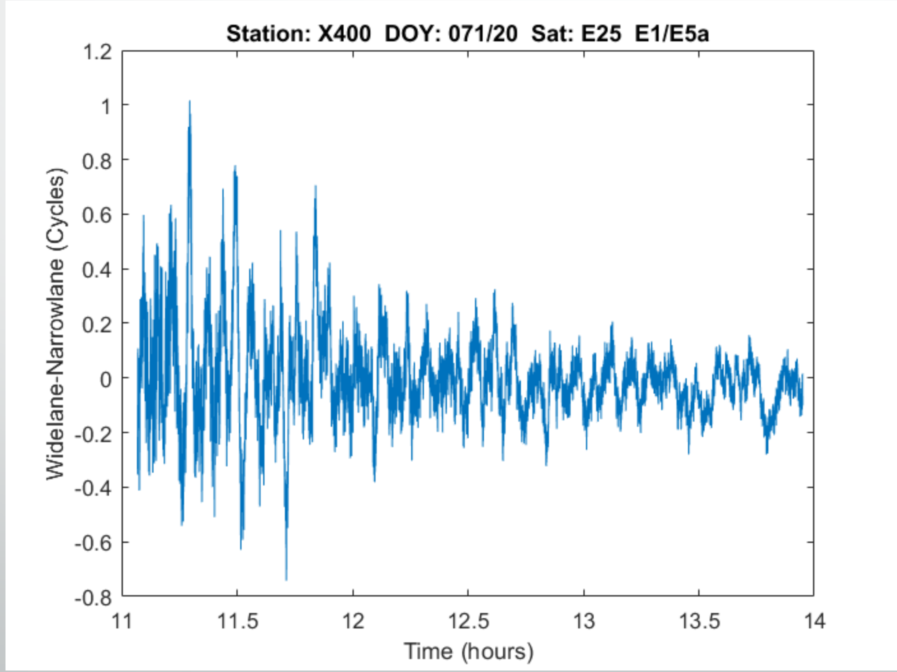
- TEC from geodetic receivers as reference.
- We identify the different steps of the data processing which could be affected by specific smartphone data characteristics.
  - Cycle slips
    - Many more cycle slips.
    - Not easy to detect with combined code/phase combinations (Widelane-narrowlane)
  - Geometry-free phase ambiguity computation (Absolute TEC)
    - Cycle slips ➔ additional ambiguities.
    - Comparison Smartphone Absolute TEC accuracy/precision wrt Geodetic Absolute TEC
  - Detection of small-scale structures
    - Can be detected out of the observation noise in Rate of TEC ?
- For all the tests, elevation mask = 10°

GNSS equipment

- X400: Septentrio PolaRx4 (ULG0)
- BCM: Broadcom BCM47765 Evk
  - Dual frequency GPS (L1/L5), Galileo (E1/E5a) and Beidou 3 (B1-2/B2a).
  - Directly connected to a geodetic antenna (ULG1).
- PIX4: Google Pixel 4 XL
  - Qualcomm Snapdragon 855 chipset.
  - Dual frequency GPS (L1/L5), Galileo (E1/E5a).
  - Connected to a geodetic antenna through a shielded box (ULG1).

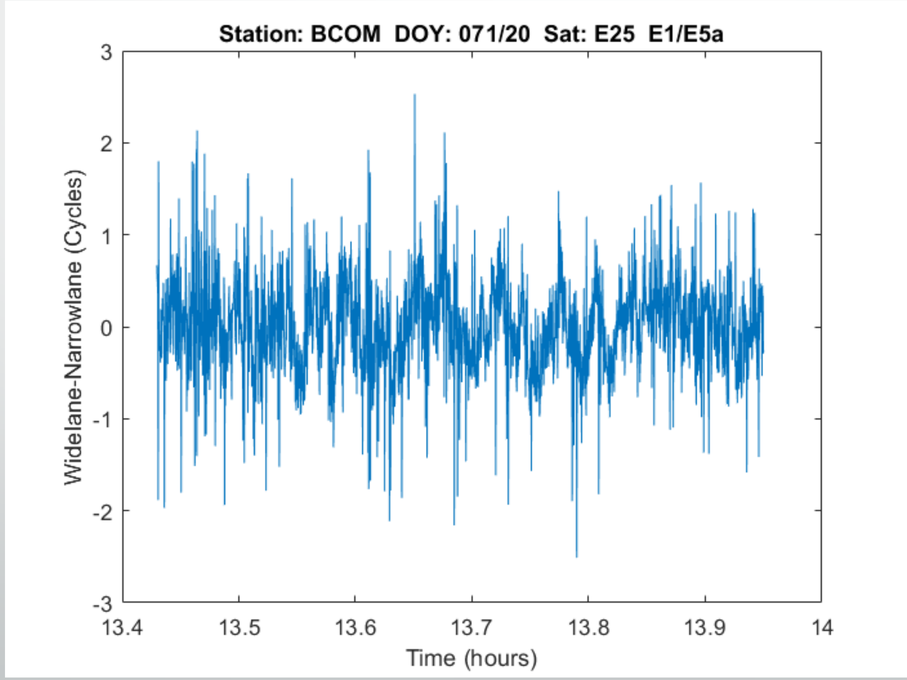
Cycle Slips : X400

- Detection based on Widelane-Narrowlane combination (uses codes !)
- X400 (Geodetic) :
  - CS >= 1-2 cycles can be easily detected but they are very rare (<1/day).



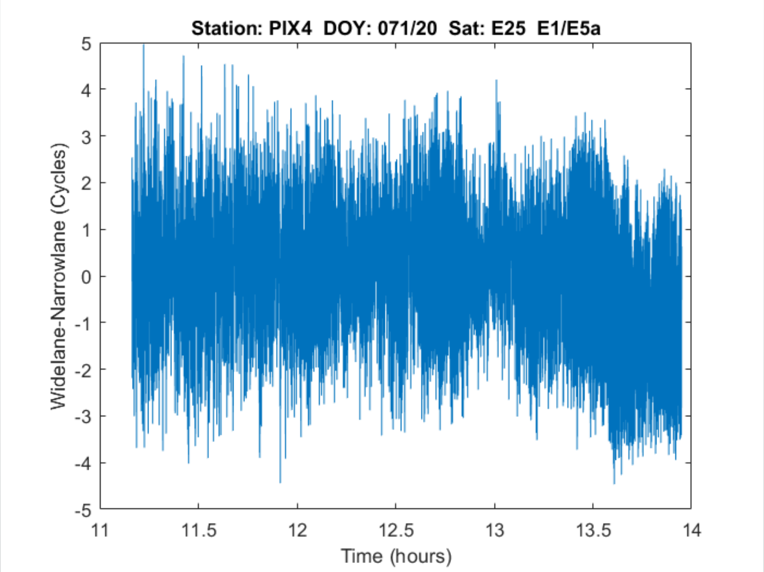
Cycle Slips : BCOM

- BCOM :
  - CS >=1-5 cycles (GPS) or >=2-7 cycles (Galileo) can be detected
  - There many (large) cycle slips which can usually be detected by WLNL.



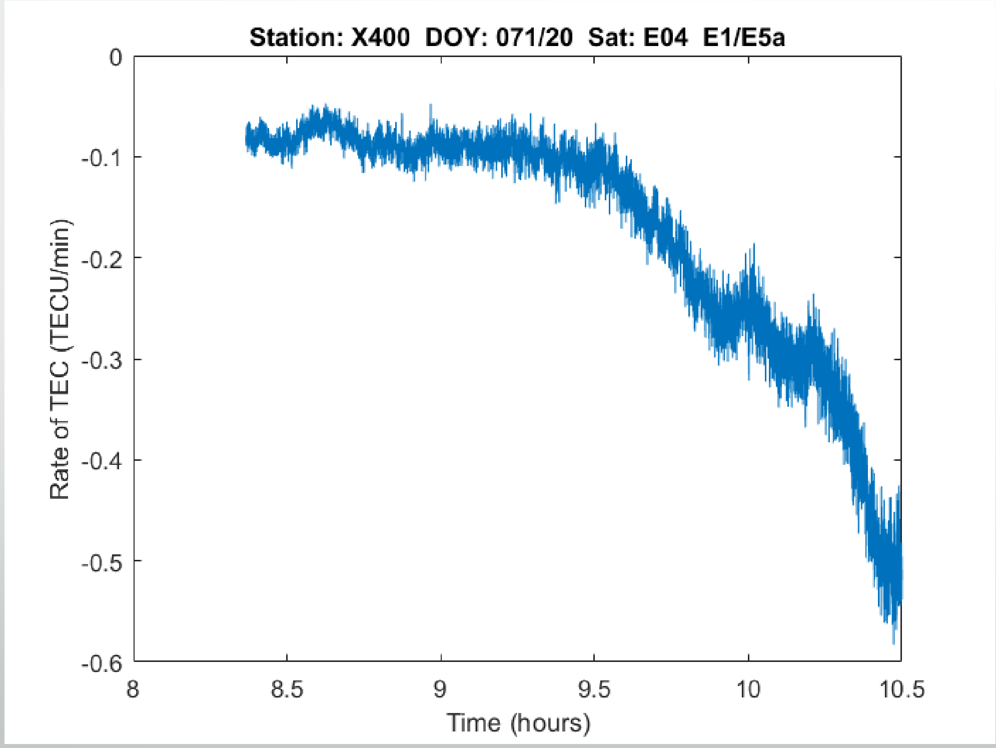
Cycle Slips : PIX4

- PIX4
  - CS >=5-9 cycles (GPS) or >=3-9 cycles (Galileo) can be detected.
  - Not as many CS observed but they are small and difficult to detect using WLNL
  - Can be detected using the Geometry-free combination in a second step



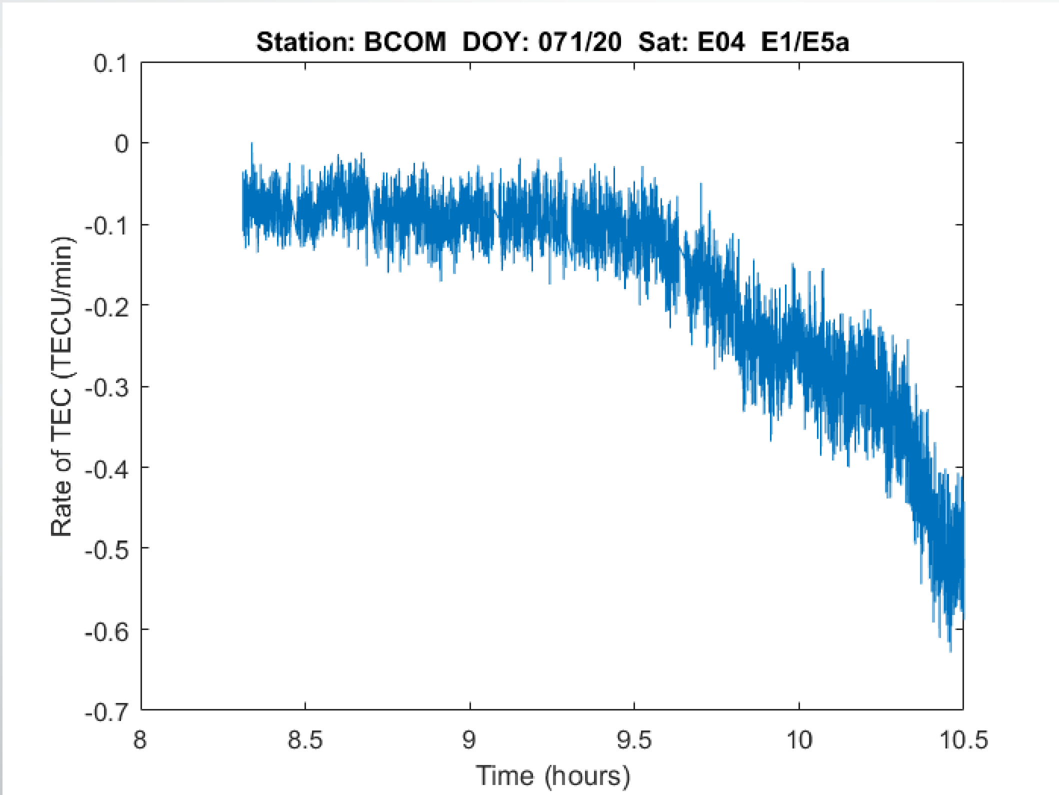
TEC rate of change : X400

- Small-scale structures can be detected based on Rate of TEC Change.
- TEC rate of change precision <= 0,1 TECU/min



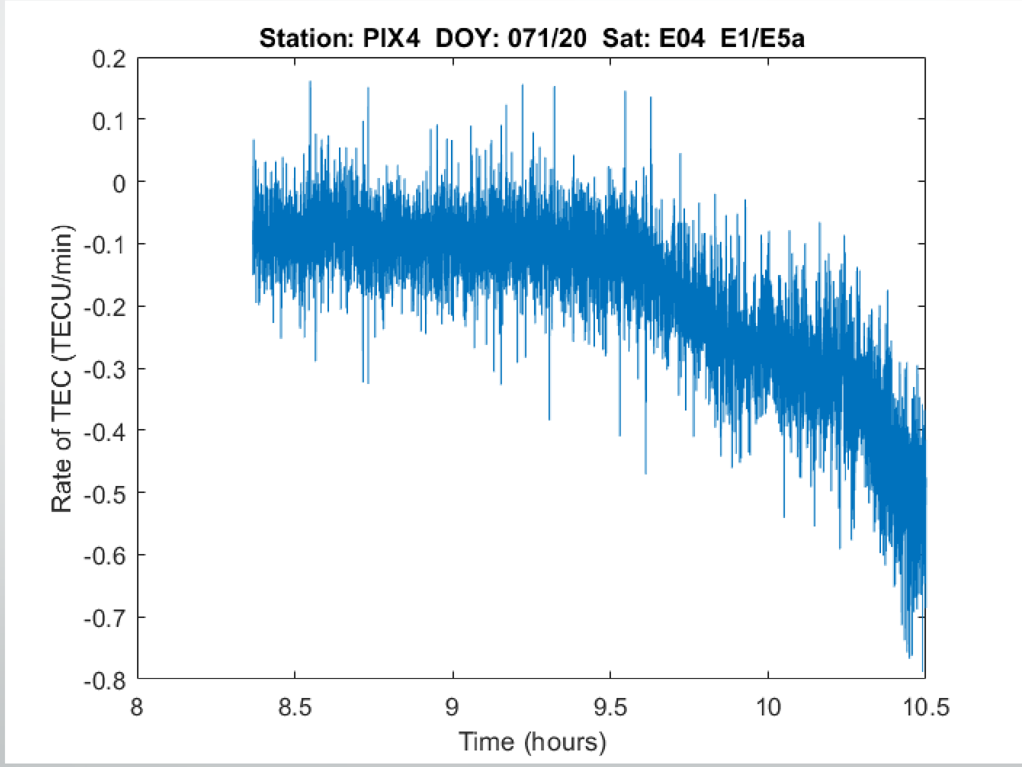
TEC rate of change: BCOM

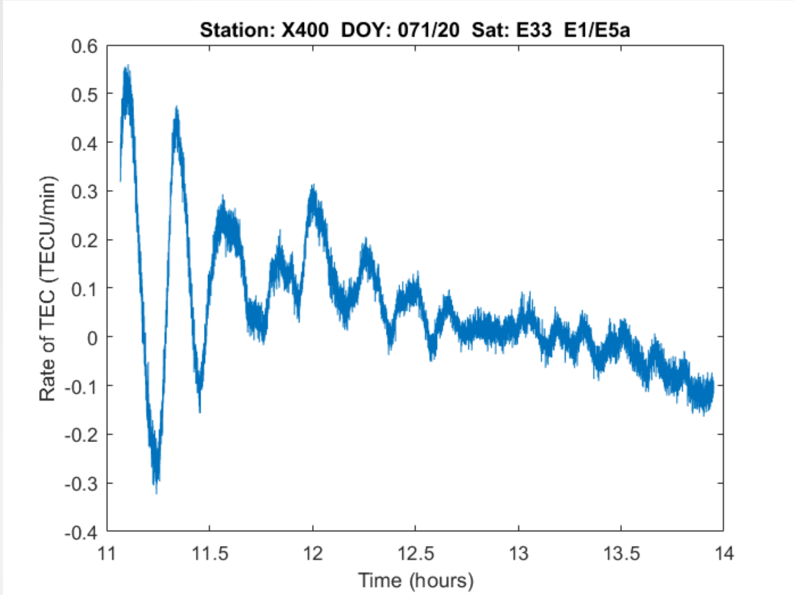
- TEC rate of change precision: 0,1-0,2 TECU/min

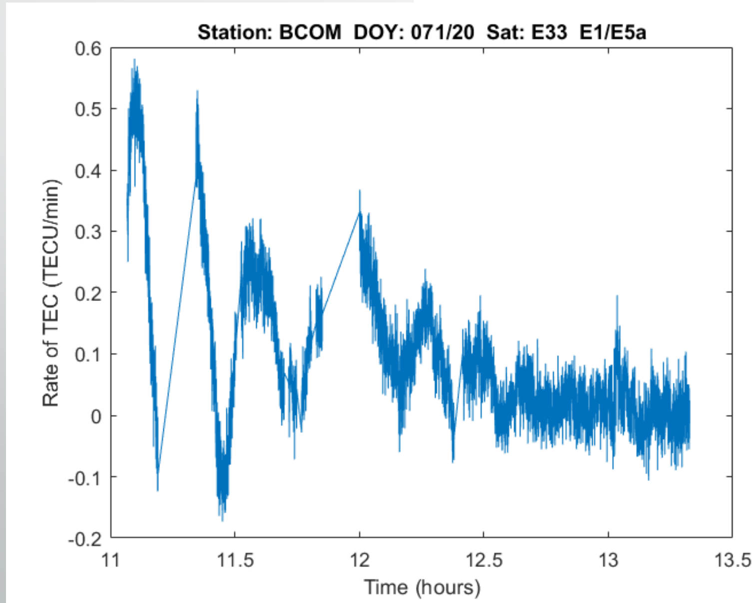


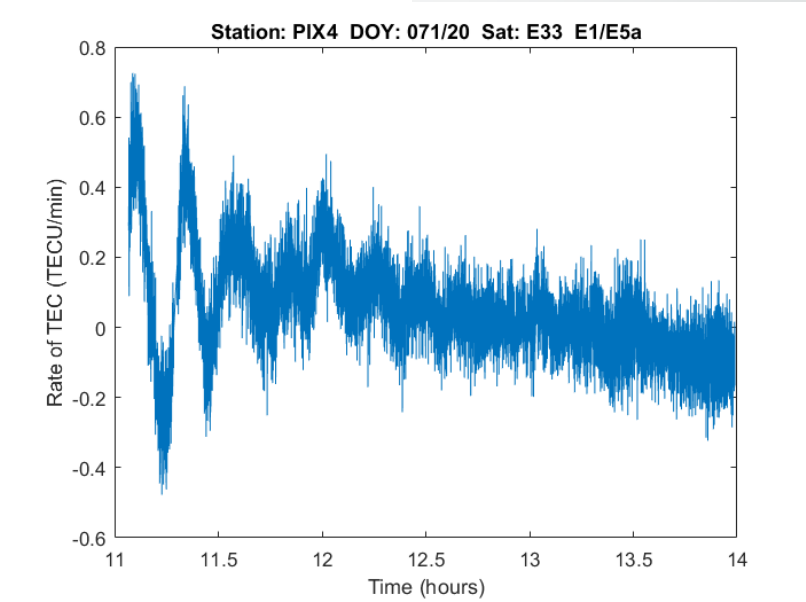
TEC rate of change: PIX4

- TEC rate of change precision: 0,2-0,4 TECU/min

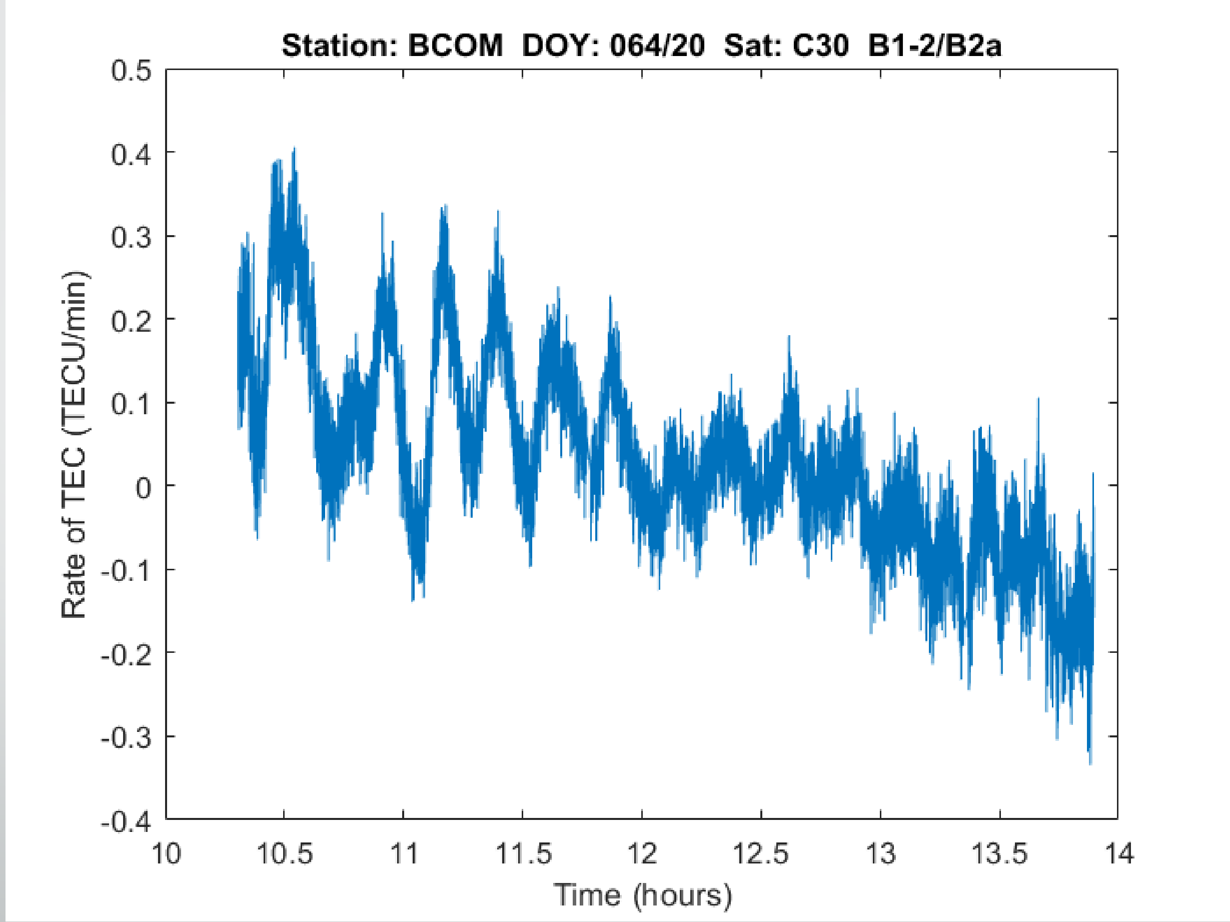



Station: X400 DOY: 071/20 Sat: E33 E1/E5a
Rate of TEC (TECU/min)
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
11
11.5
12
12.5
13
13.5
14
Time (hours)


Station: BCOM DOY: 071/20 Sat: E33 E1/E5a
Rate of TEC (TECU/min)
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
11
11.5
12
12.5
13
13.5
Time (hours)

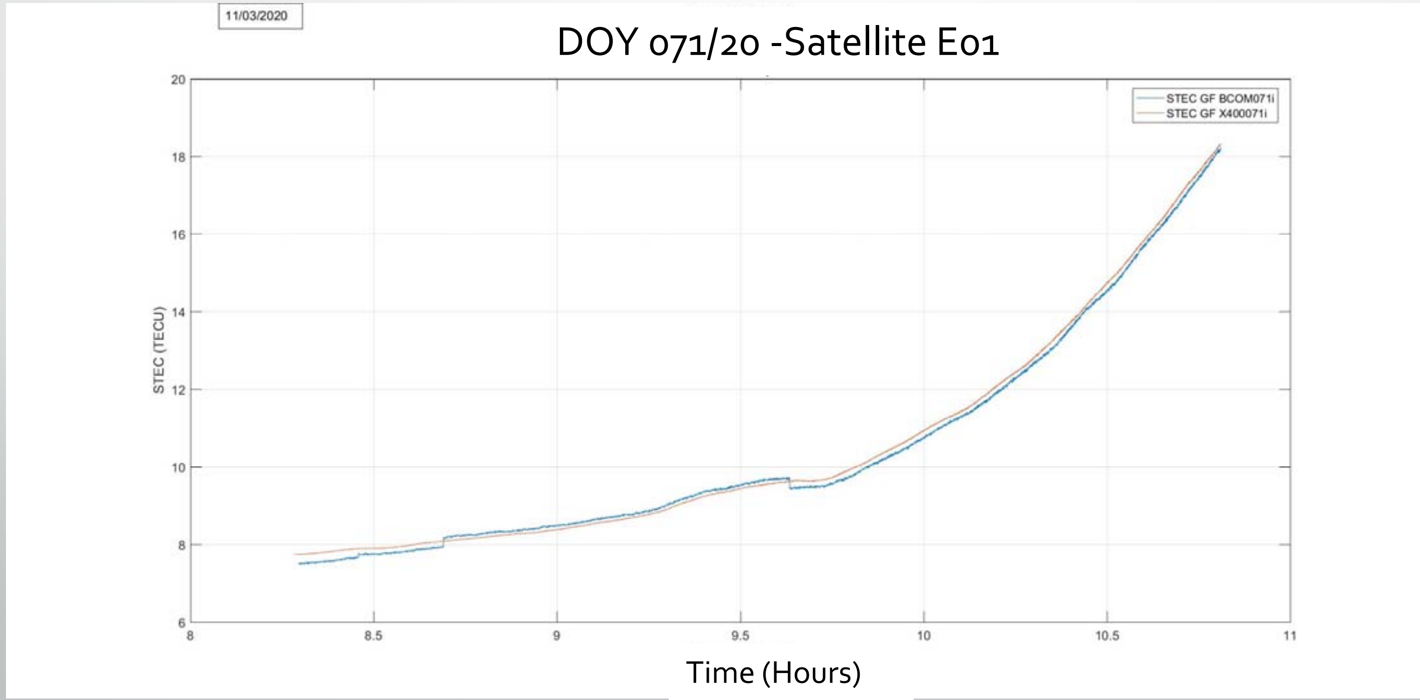

Station: PIX4 DOY: 071/20 Sat: E33 E1/E5a
Rate of TEC (TECU/min)
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
11
11.5
12
12.5
13
13.5
14
Time (hours)

TEC Rate of Change (Beidou 3)



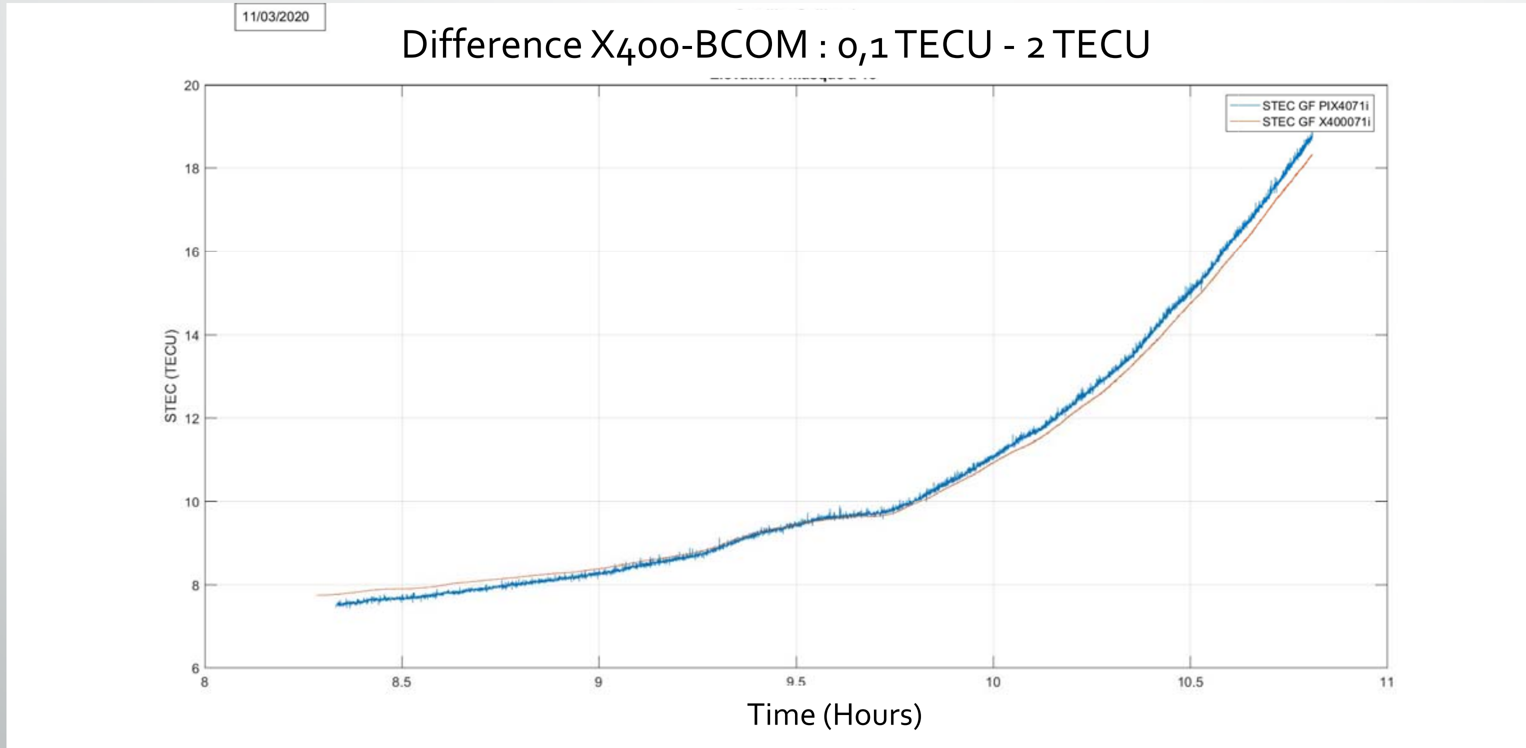
Absolute TEC: BCOM vs X400

- Ambiguity computed using IONEX TEC maps from IGS
- Difference X400-BCOM : 0,1 TECU - 2 TECU (due to CS).
- Small jumps due to new ambiguity when cycle slips are detected



Absolute TEC: PIX4 vs X400

- Difference X400-PIX4 : 0,1 TECU - 2 TECU



Conclusions

- Smartphone dual frequency GNSS chips are valuable tools to monitor the ionospheric activity.
- Absolute STEC reconstruction (IONEX):
  - Accuracy: 0,1 TEC to 2 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)
- Results to be confirmed
  - When smartphone antenna is used
  - On more data, in particular, during more active ionospheric conditions.