

# **Galileo Precise Point Positioning**

**55<sup>th</sup> Meeting of the  
Civil GPS Service Interface Committee**

**ION GNSS+ 2015**

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- ***Galileo MGEX product analysis***
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  - ***TUM*** – *Technische Universität München*
  - ***CNES*** – *Centre National d'Études Spatiales*
- ***Galileo E1/E5b & E1/E5 processing solutions***
- ***Combined GPS L1/L5 & Galileo E1/E5a processing analysis***
- ***GAPS v5.9.1 & v6.0.0 overview***

# GENERAL PROCESSING STRATEGY

- **Preliminary analysis of the functionality of the Galileo GNSS**
  - *Limited number of observable satellites*
    - PRNs 11, 12, 14, 18, 19, 22, & 26
    - Two more successfully launched on Sept. 11<sup>th</sup>
    - PRN 20 E1 transmission only
  - *Limited periods of simultaneous observability*
    - 4-5 satellites for up to 5 hours
  - *IGS MGEX orbit and clock products still experimental*
- **UNB's GPS Analysis and Positioning Software (GAPS) PPP engine**
  - <http://gaps.gge.unb.ca>
  - *Modified to utilize Galileo observables*
  - *Galileo-only & Galileo + GPS combined processing options*
  - *Use of IGS MGEX products to align reference frames and time systems*
  - *Estimation of Inter-System Biases to account for residual Galileo biases*

# GENERAL PROCESSING STRATEGY

- **Stations**

- *IGS MGEX stations BRST (France), UNB3 (Canada), & USN8 (USA)*

- **Observation periods**

- *DOY 190 & 200 of 2015*
- *4-5 hours of GPS & Galileo simultaneous observability*

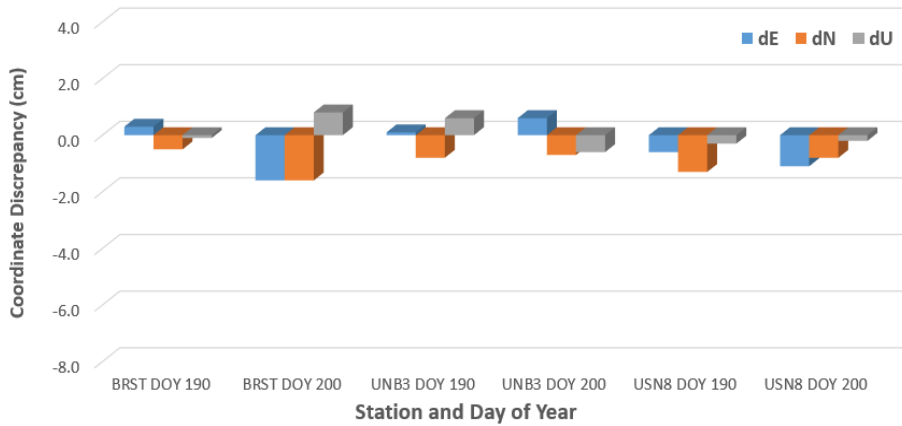
- **Observables**

- *Galileo E1/E5a, E1/E5b, & E1/E5*
- *GPS L1/L2 & L1/L5*
- *Carrier-phase & pseudorange iono-free combinations*

- **Processing Parameters**

- *Static mode processing*
- *Elevation angle cutoff: 3°*
- *VMF1 (ECMWF) a priori NAD prediction model and Vienna mapping functions*
- *Tropospheric gradients NOT estimated*
- *IGS ANTEX antenna calibrations*

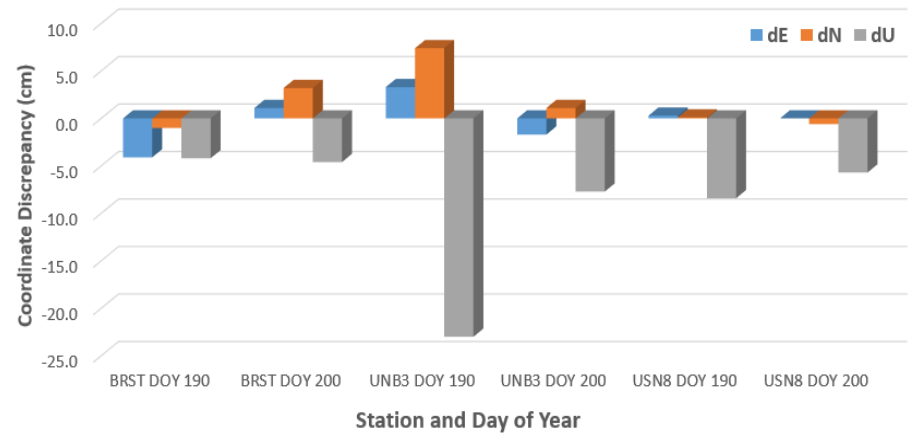
GPS-Only Discrepancy from IGS Weekly Combined Solutions



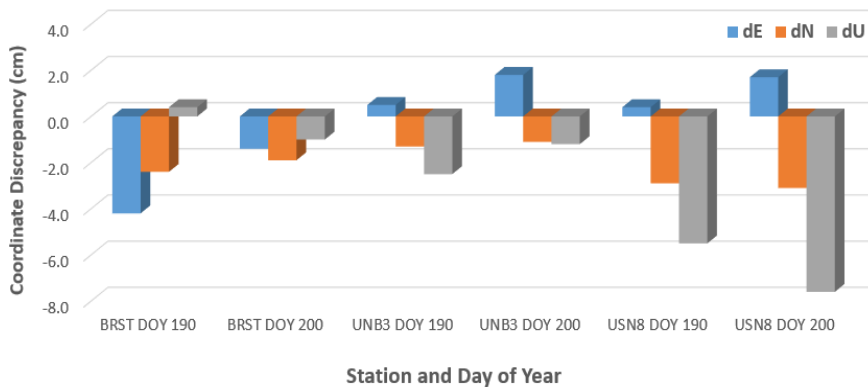
- 4 GPS satellites
- GPS C1C/C2W & L1C/L2W
- Within 1.3 cm (on average)

- 4 Galileo satellites
- Galileo C1X/C5X & L1X/L5X (BRST & UNB3)
  - C1C/C5Q & L1C/L5Q (USN8)
- MGEX CODE orbits and clocks
- Within 9.7 cm (on average)

Galileo-Only Discrepancy from IGS Weekly Combined Solutions

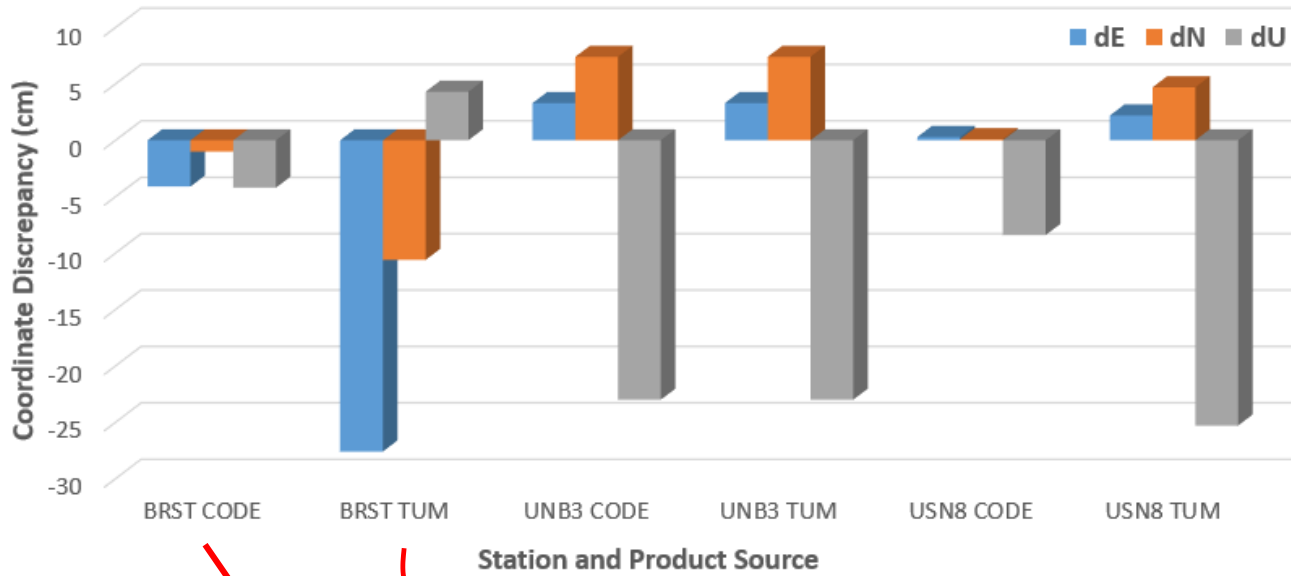


GPS+Galileo Discrepancy from IGS Weekly Combined Solutions



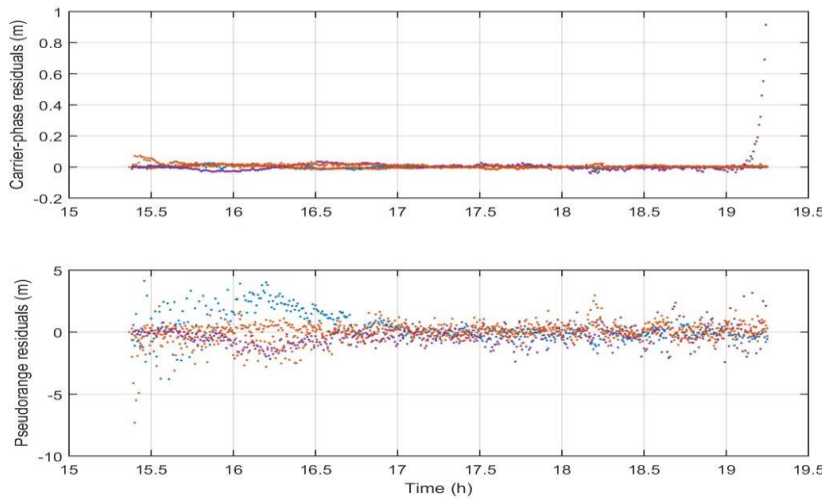
- 4 Galileo & 4 GPS satellites
- GPS C1C/C2W & L1C/L2W
- Galileo C1X/C5X & L1X/L5X (BRST & UNB3)
  - C1C/C5Q & L1C/L5Q (USN8)
- MGEX CODE orbits and clocks
- Within 4.6 cm (on average)

# Galileo-Only Product Discrepancy from IGS Combined Weekly Solutions

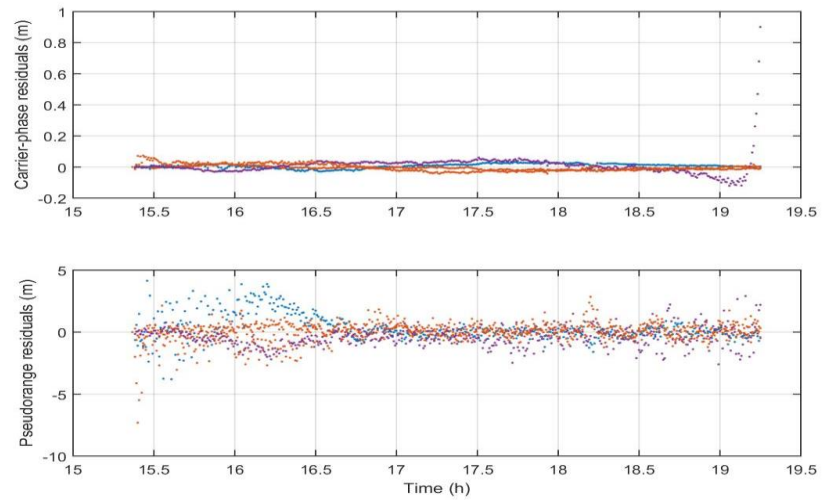


- 4 Galileo satellites
- Galileo C1X/C5X & L1X/L5X (BRST & UNB3)
- C1C/C5Q & L1C/L5Q (USN8)

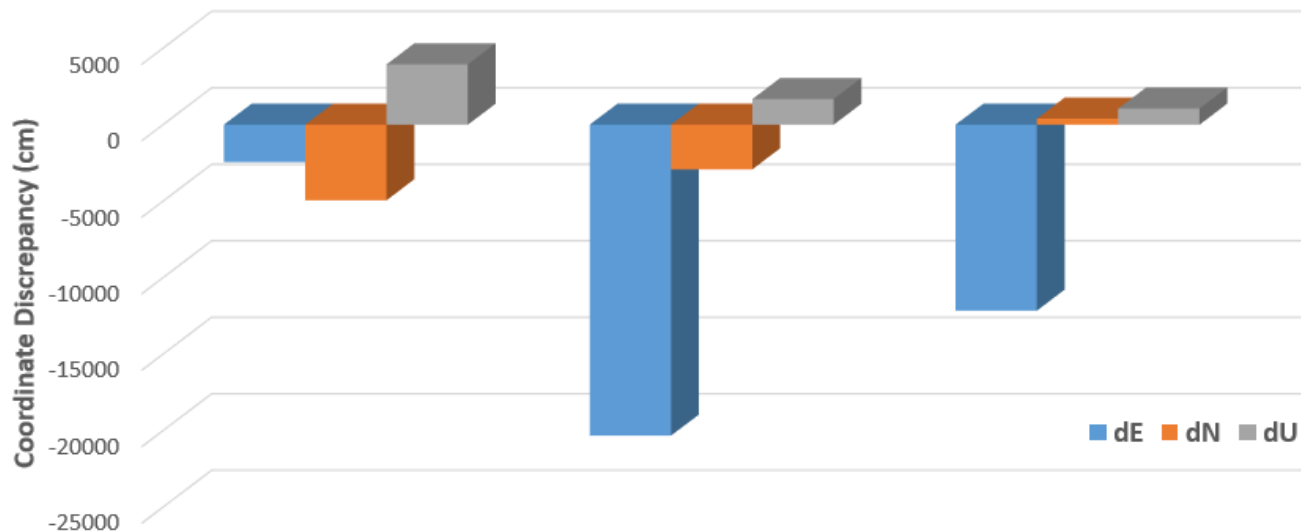
**BRST CODE Residuals**



**BRST TUM Residuals**



# CNES Galileo-Only Product Discrepancy from IGS Weekly Combined Solutions



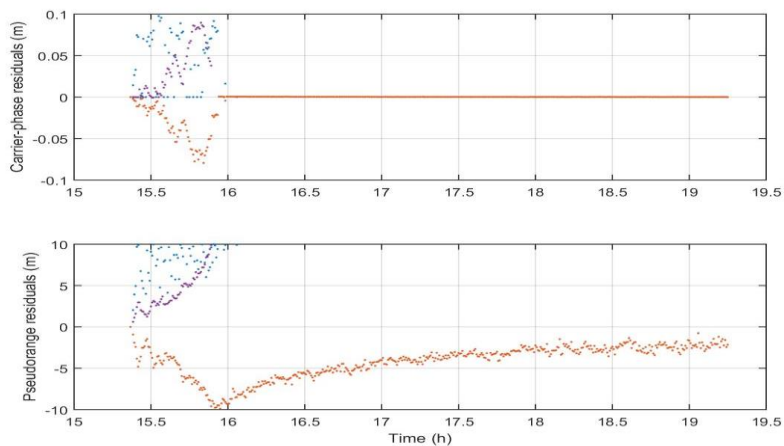
- 4 Galileo satellites
- Galileo C1X/C5X & L1X/L5X (BRST & UNB3)
- C1C/C5Q & L1C/L5Q (USN8)

BRST CNES

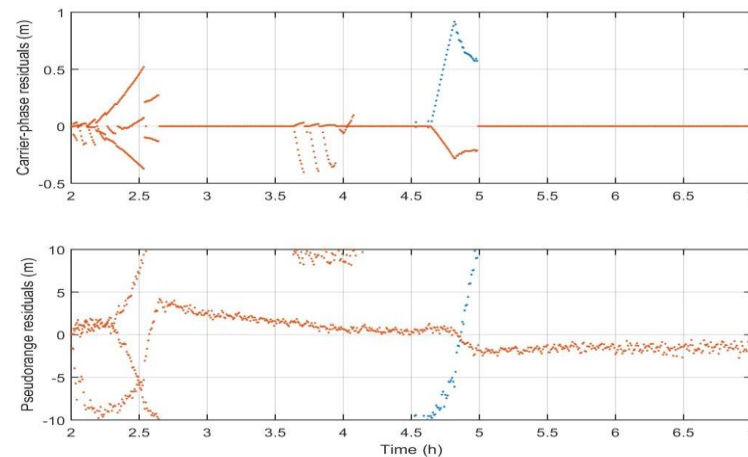
UNB3 CNES  
Station and Product Source

USN8 CNES

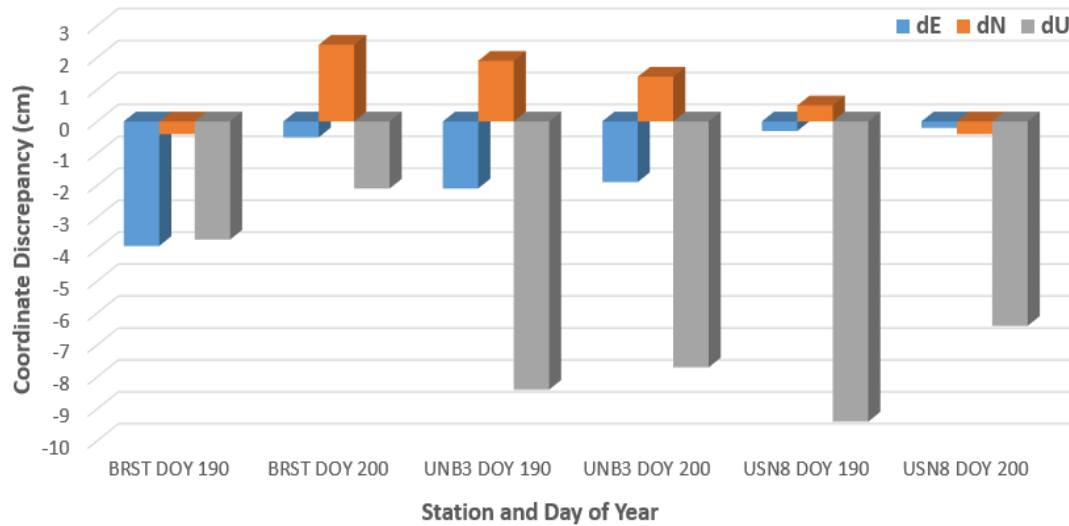
**BRST CNES Residuals**



**USN8 CNES Residuals**

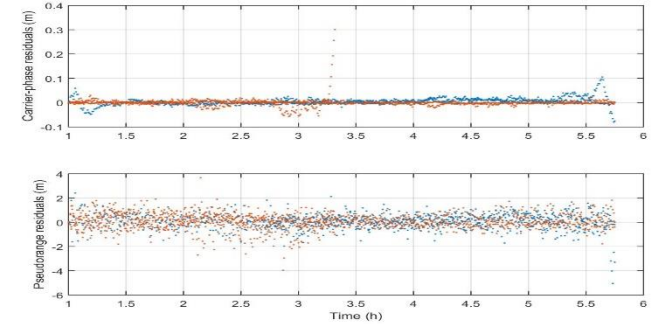


Galileo E1/E5b Discrepancy from IGS Weekly Combined Solutions

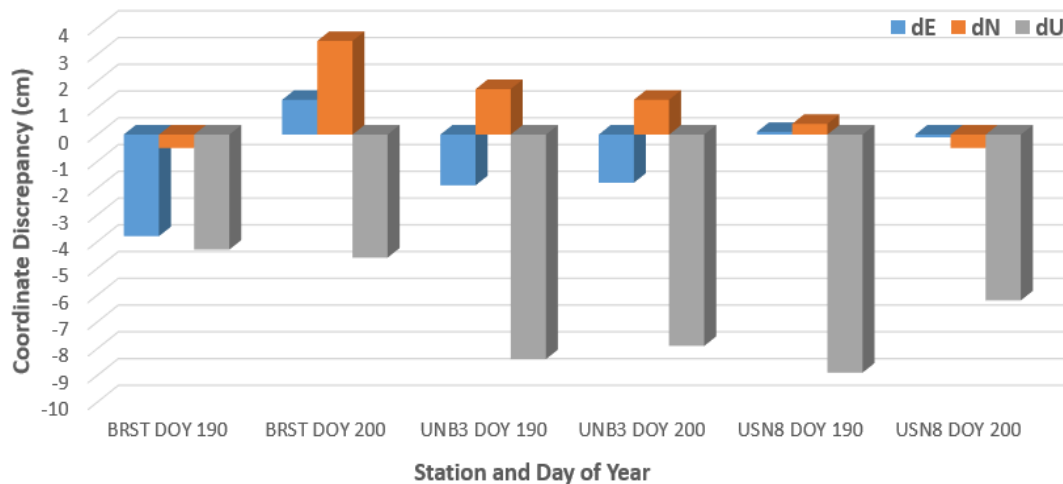


- 4 Galileo satellites
- Galileo C1X/C7X & L1X/L7X (BRST & UNB3)
  - C1C/C7Q & L1C/L7Q (USN8)
- MGEX CODE orbits and clocks
- Within 6.9 cm (on average)

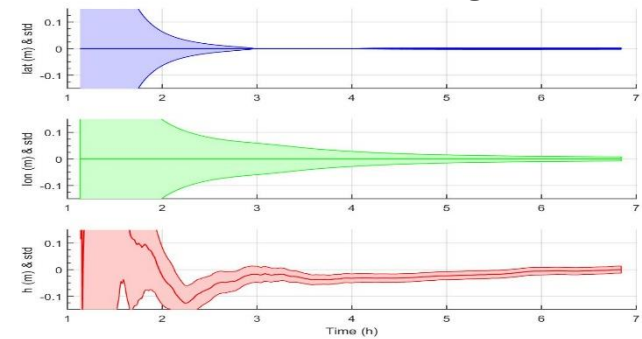
UNB3 200 E1/E5b Residuals



Galileo E1/E5 Discrepancy from IGS Weekly Combined Solutions



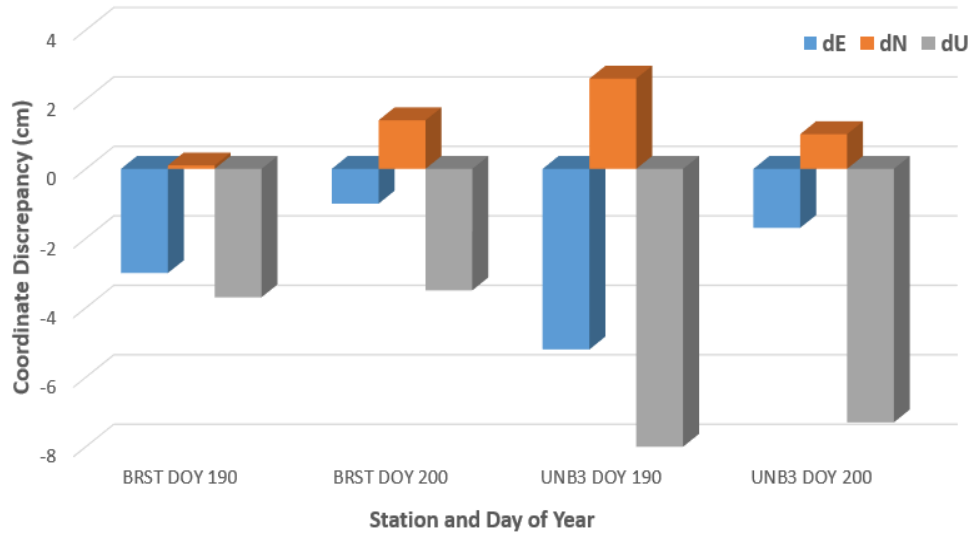
USN8 200 E1/E5 Convergence



- 4 Galileo satellites
- Galileo C1X/C8X & L1X/L8X (BRST & UNB3)
  - C1C/C8Q & L1C/L8Q (USN8)
- MGEX CODE orbits and clocks
- Within 7.3 cm (on average)



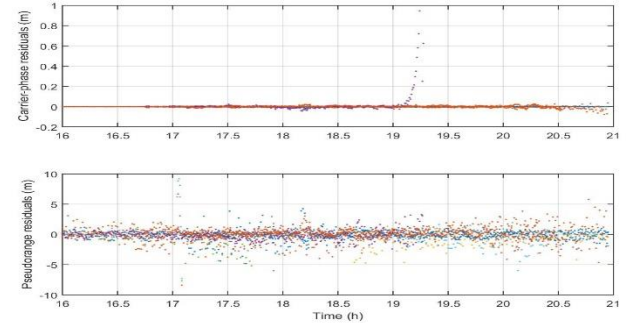
L1/L5 & E1/E5a Discrepancy from IGS Weekly Combined Solutions



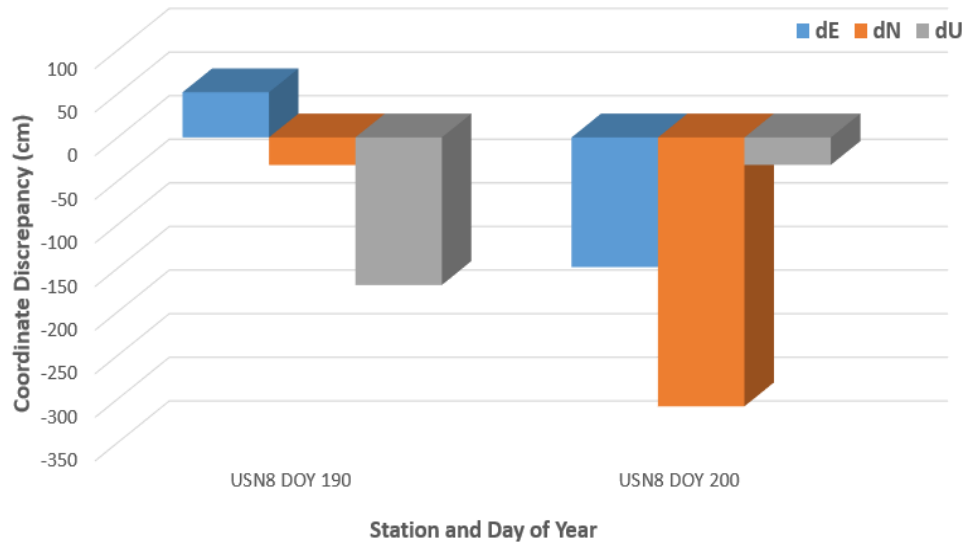
- 4 GPS & 4 Galileo satellites
- GPS C1C/C2W & L1C/L5X
- Galileo C1X/C5X & L1X/L5X
- MGEX CODE orbits and clocks
- Within 6.5 cm (on average)



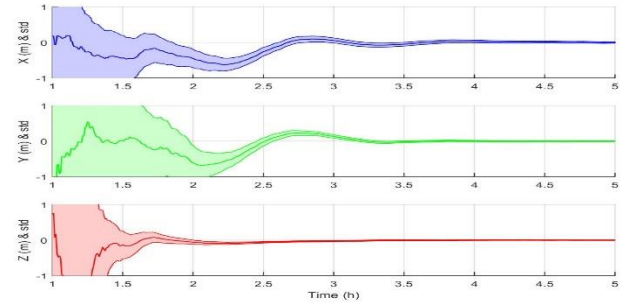
BRST 190 Residuals



L1/L5 & E1/E5a Discrepancy from IGS Weekly Combined Solutions



UNB3 200 Convergence



- 4 GPS & 4 Galileo satellites
- GPS C1C/C2W & L1C/L5X
- Galileo C1C/C5Q & L1C/L5Q
- MGEX CODE orbits and clocks
- Within 270.0 cm (on average)



# CONCLUSIONS

- **Galileo + GPS processing**
  - *Interoperability and interchangeability of system observables validated*
  - *Slight degradation of positional solution*
    - Perhaps attributed to use of MGEX products
- **Galileo-only processing**
  - *Achievable at decimetre-level accuracy (static)*
- **IGS MGEX product validation**
  - *CODE and TUM products far superior to CNES*
- **Galileo E5b and E5**
  - *Results suggest minor improvement in positional solution*
  - *Further investigation of C8X/C8Q multipath improvement needed*
- **Room for improvement**
  - *More observable satellites, better positioning*
    - Improved satellite geometry
    - Increased redundancy
  - *Improved product generation*
    - Currently the largest error contributor

# GAPS v5.9.1 Overview



## GAPS "Advanced" user submission page

### GAPS Advanced User Submission

#### Select Input File

Select Input Observation File:  No file chosen

#### Select Orbit and Clock Products

- GPS Orbit Product
- IGS Final
  - IGS Rapid
  - IGS Ultra-Rapid
  - NRCan Final
  - NRCan Rapid
- GPS Clock Product
- IGS Final
  - IGS Rapid
  - IGS Ultra-Rapid
  - NRCan Final
  - NRCan Rapid

#### Select Observables

- GPS Frequency 1 Phase
- L1W
  - L1C
  - L1X
- GPS Frequency 1 Pseudorange
- C1W
  - C1C
- GPS Frequency 2 Phase
- L2W
  - L5X
  - L2P
  - L5X or L2W
- GPS Frequency 2 Pseudorange
- C2W
  - C2C
  - C2P
  - C2C or C2W

Option to estimate/not estimate NAD →

User-selection of NAD prediction model and mapping functions →

← User-selection of orbit and clock products to be used

Option to estimate/not estimate tropospheric gradients →

← User-selection of RINEX v3.x observables to be used

Option to use GPS L5

Option to use GPS L2C

Option to use custom user antenna calibration files →

### Neutral Atmosphere Delay

Estimate NAD

- On  Off

A-Priori NAD Prediction Model

- UNB-VMF1 (NCEP)  UNB-VMF1 (CMC)  
 VMF1 (ECMWF)  UNB3m  
 GPT2 (1x1 deg.)  ESA 2.5  
 None

Mapping Functions

- Vienna  Niell

A-Priori NAD Standard Deviation (m)

NAD Process Noise (mm/√hr)

Tropospheric Gradient Estimation

- On  Off

A-priori Gradients (m)

A-priori Gradients Standard Deviation (m)

Gradients Process Noise (mm/√hr)

Select Input Meteorological File:

No file chosen

### User Receiver Antenna Calibration

User Antenna Calibration File

No file chosen

File must conform to GAPS ANTEX format. An example of the GAPS ANTEX antenna calibration format can be found [here](#).

# GAPS v5.9.1 Overview

## GAPS Basic User Submission

Select Input Observation File: \*  No file chosen

X (m) / Latitude (dd.mmsssss)

Y (m) / Longitude (dd.mmsssss)

Z (m) / Height (m)

Positioning  Static  Kinematic

Elevation Cutoff Angle (deg)

E-mail \*

*Canada's CASSIOPE satellite*



## *GAPS "Basic" user submission page*

- *Allows for quick and easy submission of observation files*
- *For users who frequently use GAPS' default processing options:*
  - *IGS Final products*
  - *GPS C1W/C2W & L1W/L2W observables*
  - *NAD estimation*
  - *NO tropospheric gradient estimation*
  - *UNB3m NAD prediction model & Vienna mapping functions*
  - *IGS ANTEX antenna calibrations*

# GAPS v6.0.0 Preview

## Select System

- GPS     Galileo     GPS+Galileo

← **User-selection of system(s) to be used**

## Select Orbit and Clock Products

- |                              |   |                                       |
|------------------------------|---|---------------------------------------|
| <b>GPS Orbit Product</b>     | <input checked="" type="radio"/> IGS Final  | <input type="radio"/> NRCAN Final     |
|                              | <input type="radio"/> IGS Rapid             | <input type="radio"/> NRCAN Rapid     |
|                              | <input type="radio"/> IGS Ultra-Rapid       | <input type="radio"/> Navigation File |
| <b>Galileo Orbit Product</b> | <input checked="" type="radio"/> CODE Final | <input type="radio"/> TUM Final       |
|                              | <input type="radio"/> CNES Final            |                                       |
| <b>GPS Clock Product</b>     | <input checked="" type="radio"/> IGS Final  | <input type="radio"/> NRCAN Final     |
|                              | <input type="radio"/> IGS Rapid             | <input type="radio"/> NRCAN Rapid     |
|                              | <input type="radio"/> IGS Ultra-Rapid       | <input type="radio"/> Navigation File |
| <b>Galileo Clock Product</b> | <input checked="" type="radio"/> CODE Final | <input type="radio"/> TUM Final       |
|                              | <input type="radio"/> CNES Final            |                                       |

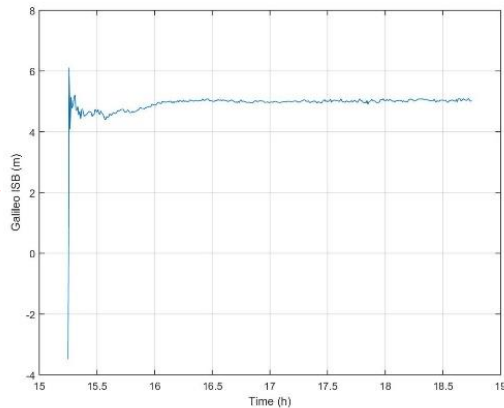
↙ **User-selection of Galileo Phase observables, including E5a, E5b, or E5**

↘ **User-selection of Galileo orbit and clock products to be used**

## Select Observables

- |                                    |  |                                  |
|------------------------------------|--|----------------------------------|
| <b>GPS Frequency 1 Phase</b>       | <input type="radio"/> L1W                  | <input type="radio"/> L1X        |
|                                    | <input type="radio"/> L1C                  |                                  |
| <b>GPS Frequency 1 Pseudorange</b> | <input checked="" type="radio"/> C1W       | <input type="radio"/> C1C        |
| <b>GPS Frequency 2 Phase</b>       | <input type="radio"/> L2W                  | <input type="radio"/> L2P        |
|                                    | <input type="radio"/> L5X                  | <input type="radio"/> L5X or L2W |
| <b>GPS Frequency 2 Pseudorange</b> | <input checked="" type="radio"/> C2W       | <input type="radio"/> C2P        |
|                                    | <input type="radio"/> C2C                  | <input type="radio"/> C2C or C2W |
| <b>Galileo Frequency 1 Phase</b>   | <input checked="" type="radio"/> L1X       | <input type="radio"/> L1C        |
| <b>Galileo Frequency 2 Phase</b>   | <input checked="" type="radio"/> L5X (E5a) | <input type="radio"/> L5Q (E5a)  |
|                                    | <input type="radio"/> L7X (E5b)            | <input type="radio"/> L7Q (E5b)  |
|                                    | <input type="radio"/> L8X (E5)             | <input type="radio"/> L8Q (E5)   |

**Galileo ISB**



**Galileo PRNs used in solution**

