The impact of low-latency DORIS data on near real-time VTEC modeling

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2018 IDS Workshop
Ponta Delgada (Azores Archipelago), Portugal, 24-26 September 2018

Motivation

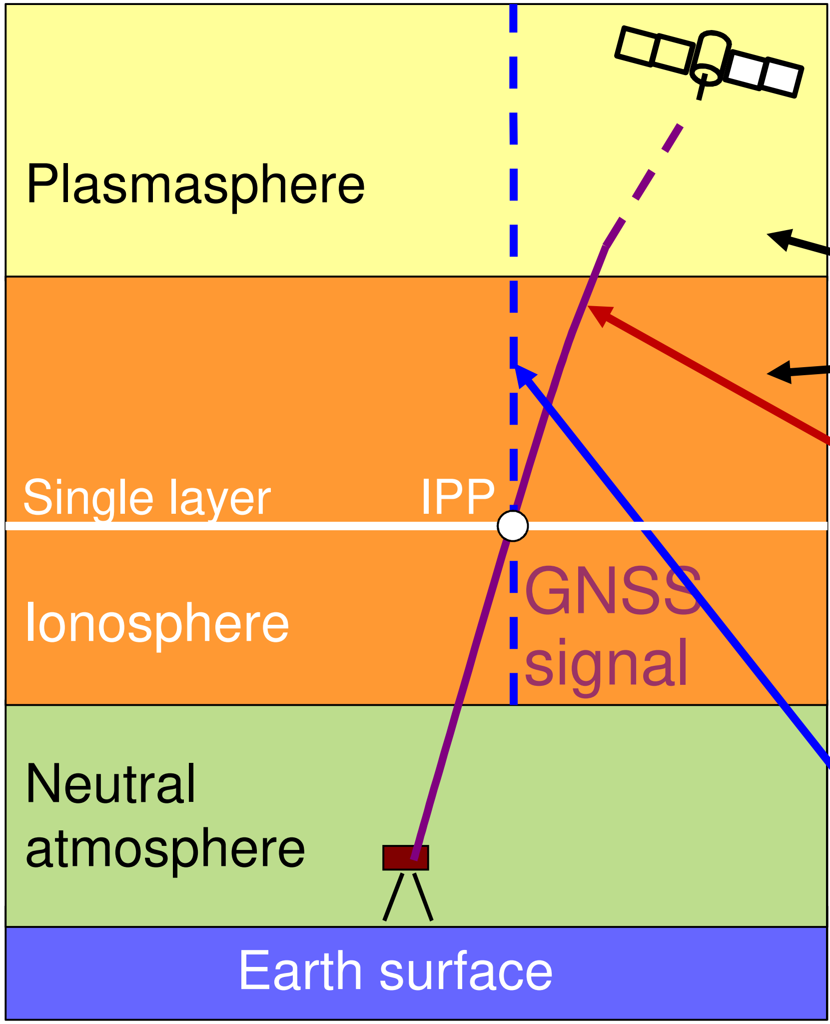
- Ionospheric modeling is important for various applications, e.g. correcting space-based microwave observations; space weather;
- Today, most models are computed based on GNSS measurements; e.g. IGS GIM
- Other space-based geodetic techniques also provides valuable data sets, e.g. DORIS.
- DORIS may help to improve the data coverage and to fill data gaps.

Problem: DORIS is only usable for post-processed products, since today, no NRT data sets are available (current latency = around 3 days).

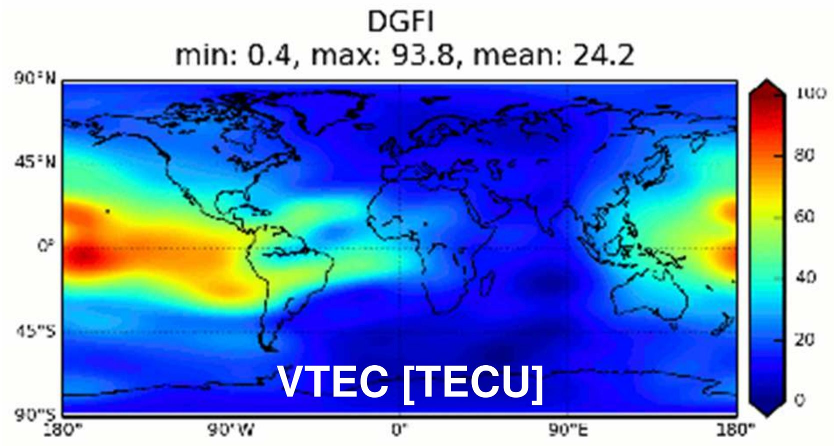
Aim of this presentation:

➢ investigate the impact of DORIS for NRT VTEC models by means of simulations

Introduction



IPP: Ionospheric pierce point



- Electron density:

$$N_e(\lambda, \varphi, h, t)$$

- Slant total electron content (STEC):

$$STEC(t) = \int_R^S N_e(\lambda, \varphi, h, t)\,ds$$

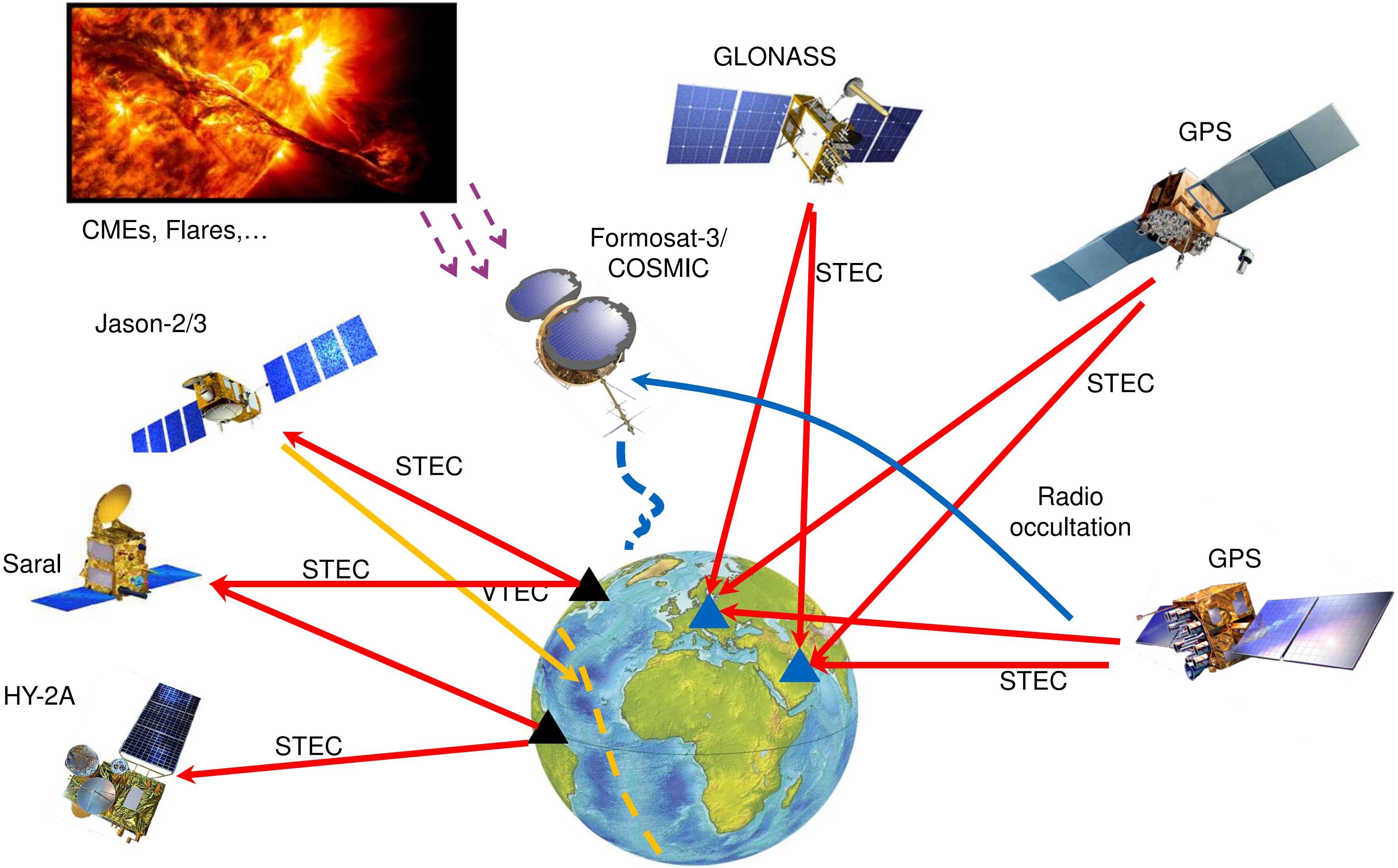
determinable by GNSS and DORIS geometry-free observations

- Vertical total electron content (VTEC):

$$VTEC(IPP(t)) = \int_H N_e(\lambda, \varphi, h, t)\,dh$$

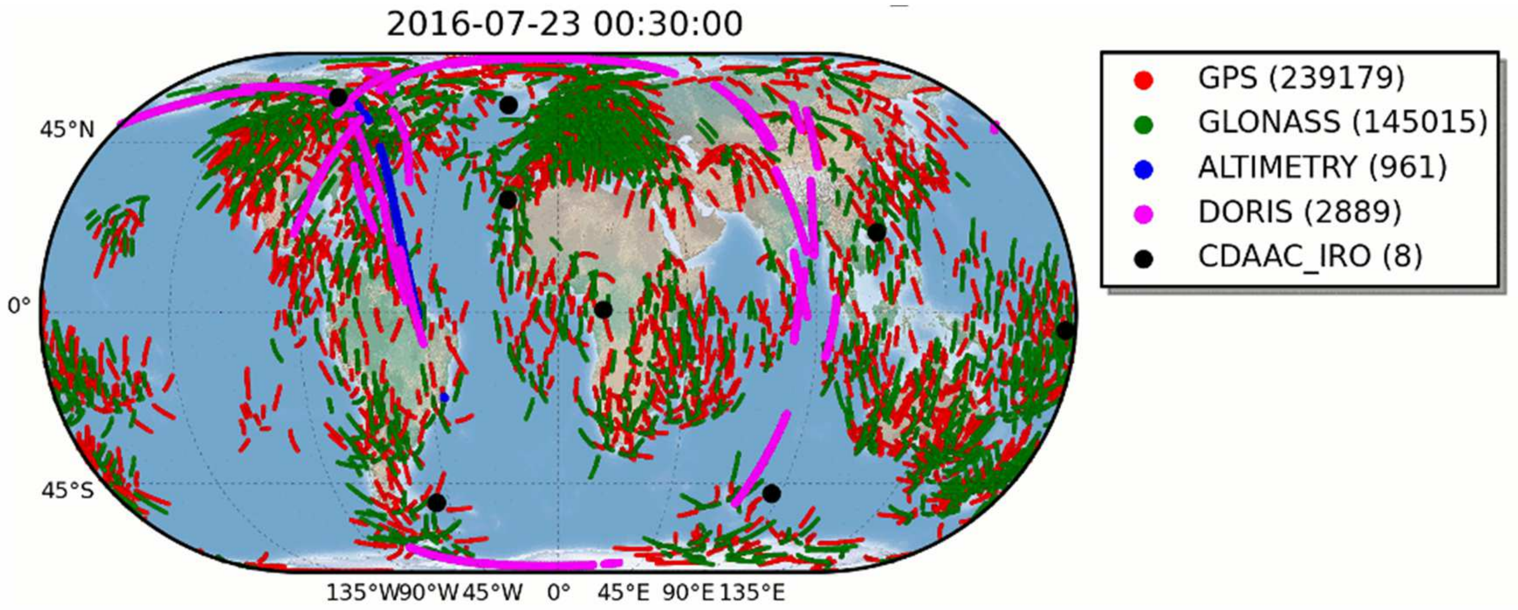
$$= MF(z)\ \ STEC(t)$$

Observation Techniques: Overview



Observation distribution

- The figure shows the **data distribution** of the different space geodetic observation techniques on July 23, 2016:

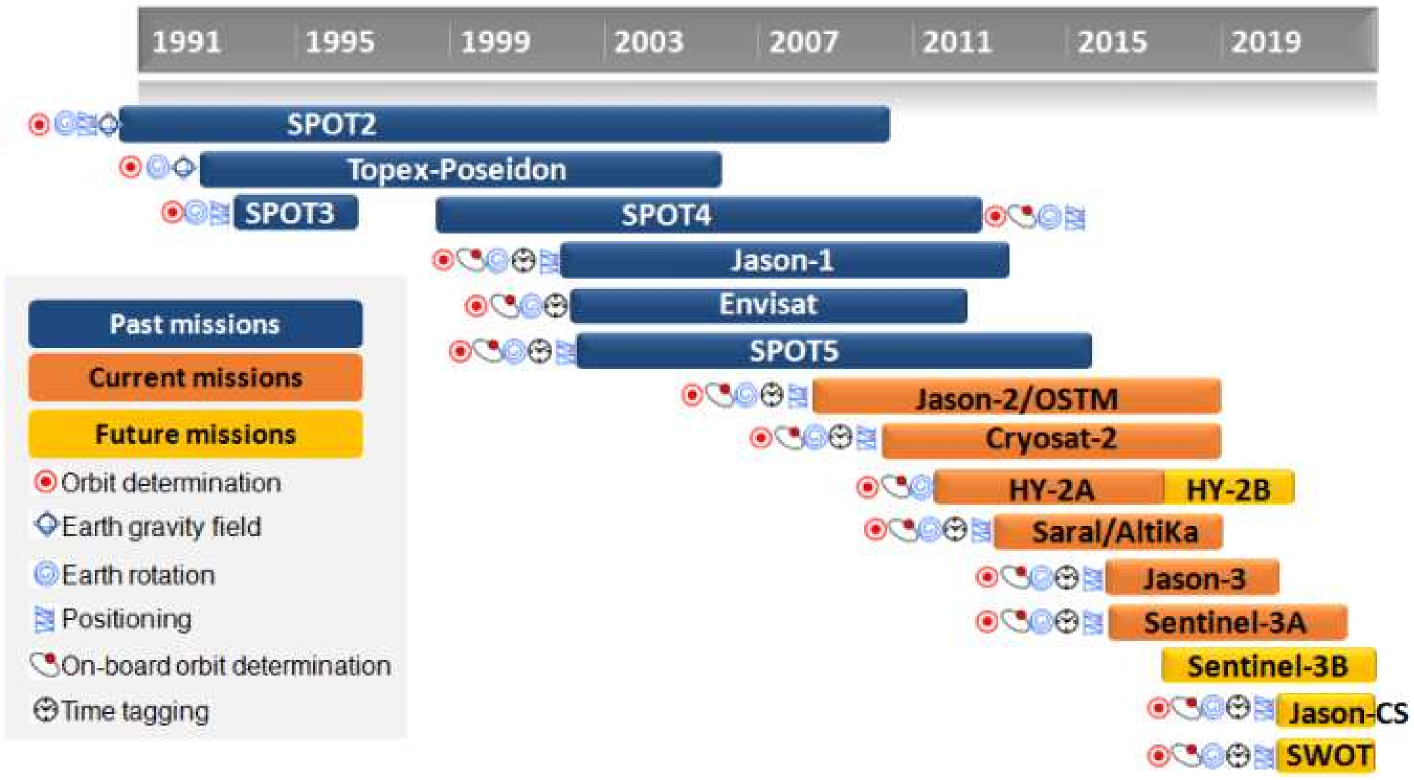


- Terrestrial **GPS and GLONASS** observations provide a **high-resolution coverage** of continental regions.

- The additional techniques, i.e. DORIS, satellite altimetry and radio occultation **cannot repair** the problem of **data gaps**, but **reduce it**.

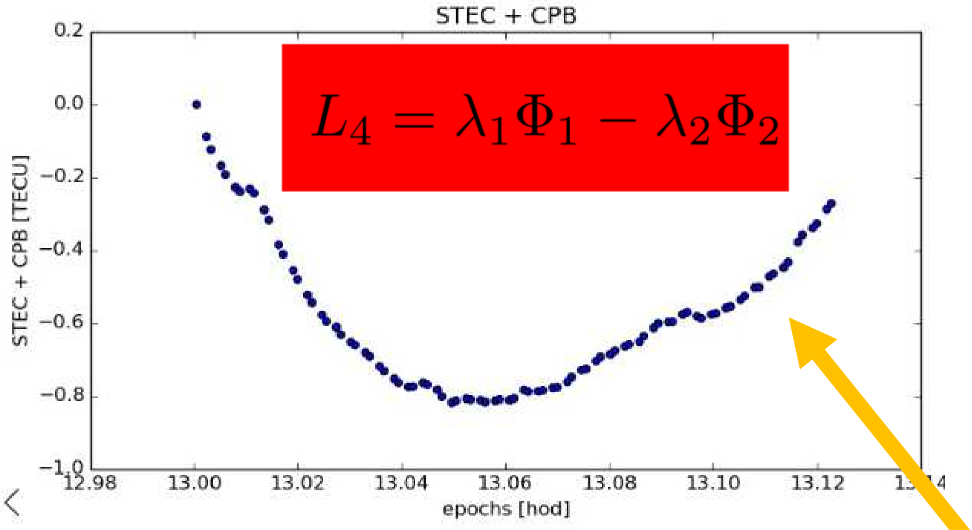
Observation Techniques: DORIS System

Satellites with the Doris system on-board (Credit CLS/Cnes)

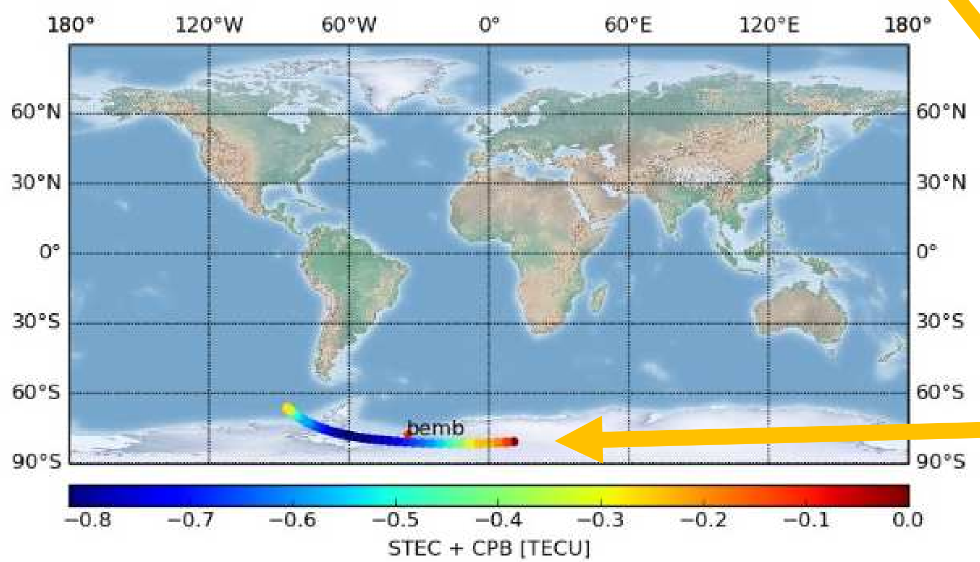


- Data extracted from **Jason-2, Jason-3, Saral, HY-2A** are used for ionosphere modelling.
- In near future, **Cryosat-2** and **Sentinel** missions are planned to be incorporated into the modelling approach.

DORIS Ionsopheric Observable: Example Saral



- DORIS **biased STEC** observations (shifted w.r.t. first observation) through a pass of the **Saral satellite** observed on August 23, 2016 between at 13:00:01 and 13:07:21



http://ids-doris.org/images/world_map_doris.jpg

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Extracting Ionosphere Data from DORIS Observations

Carrier-phase measurement

$$\lambda\Phi = \underbrace{\rho_t^r}_{\text{Geometric distance}} + \underbrace{c(\Delta t^r - \Delta t_t)}_{\text{Clock errors}} + \underbrace{\Delta_{Tropo}}_{\text{Tropospheric delay}} - \underbrace{\Delta_{Iono}}_{\text{Ionospheric delay}} + \underbrace{CPB}_{\text{Carrier phase bias}} + \underbrace{D}_{\text{Phase Centre Offset}} + \epsilon_\Phi$$

Linear combination of carrier-phase measurements for two different frequency

$$\boxed{L_4 = \lambda_1\Phi_1 - \lambda_2\Phi_2} = \underbrace{\Delta_{Iono,L_4}}_{\text{Ionosphere data}} + \underbrace{CPB_4}_{\text{Carrier-Phase bias}} + \underbrace{\Delta D}_{\text{Geometric Correction}} + \epsilon_\Phi$$

- Geometric corrections are determined in the data pre-processing step whereas carrier phase biases are estimated by a Kalman filter.

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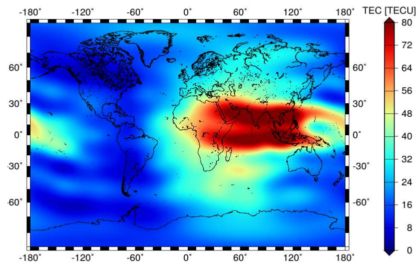
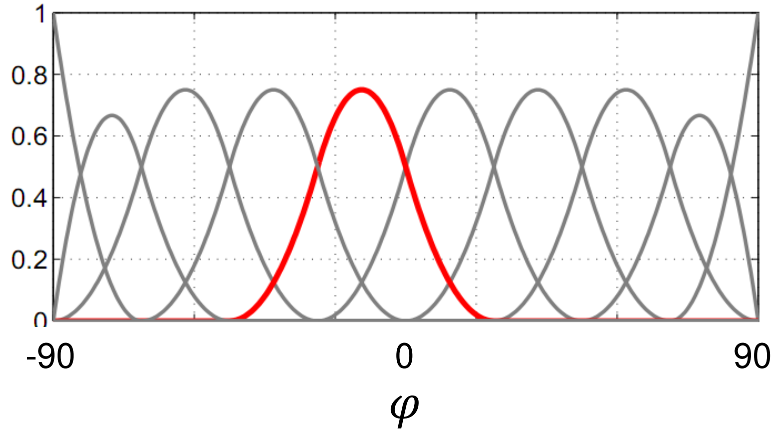
VTEC Representation: Uniform B-splines (UBS)

- VTEC is parametrized in tensor products of **trigonometric B-spline functions** $T^2_{J_2,k_2}$ for longitude λ and **polynomial B-spline functions** $N^2_{J_1,k_1}$ for latitude φ

$$VTEC(\lambda,\varphi) = \sum_{k_1=0}^{K_{J_1}-1} \sum_{k_2=0}^{K_{J_2}-1} d^{J_1,J_2}_{k_1,k_2}\, N^2_{J_1,k_1}(\varphi)\, \boxed{T^2_{J_2,k_2}(\lambda)}$$

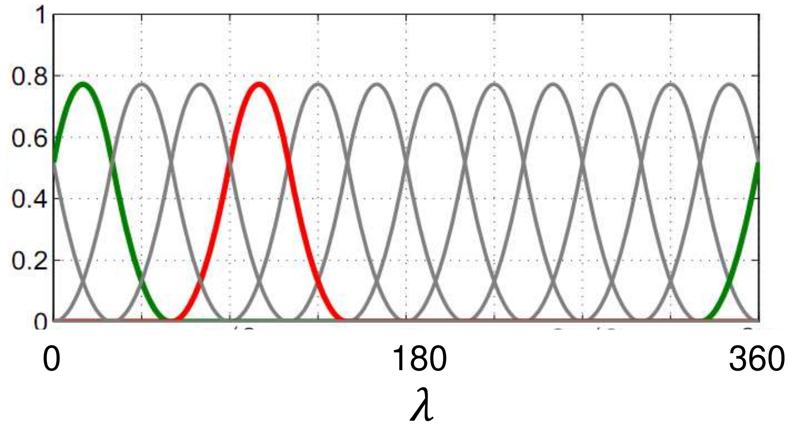


Polynomial B-spline functions N^2_{3,k_1}



$J_1 = 3, K_3 = 10,\ k_1 = 0,1,\ldots,9$

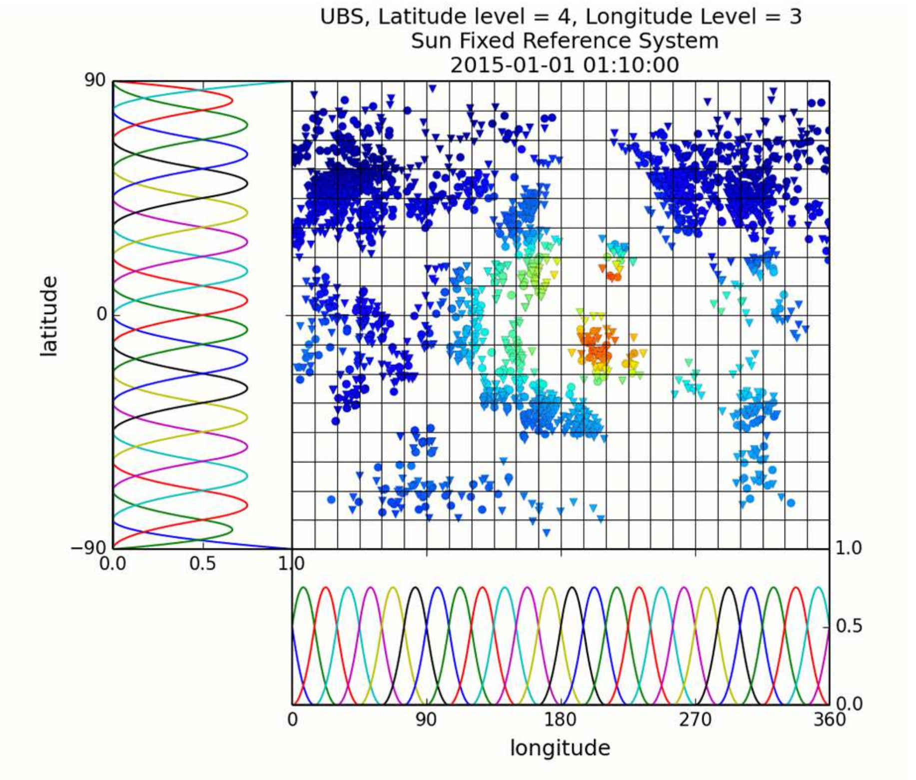
Trigonometric B-spline functions T^2_{2,k_2}



$J_2 = 2,\ K_2 = 14,\ k_2 = 0,1,\ldots,13$

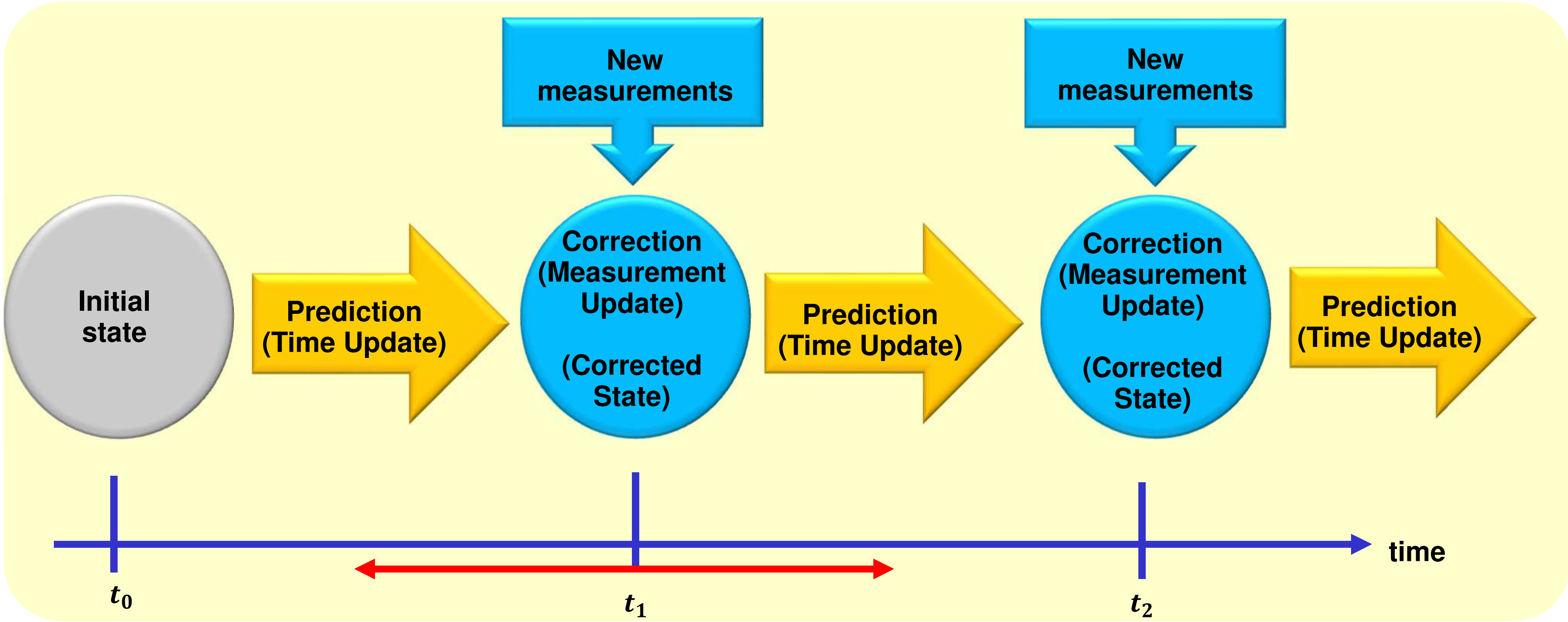
VTEC Representation: UBS Model

UBS; Sun-fixed coordinate system
- Level $J_1 = 3$ in longitude
- Level $J_2 = 4$ in latitude



- Base functions are only different from zero in a local environment (compact support).
- The compact support can allow:
  - modification of present data and
  - incorporation of new measurements **without causing global effect**
- Data gaps can be handled appropriately.
- The approach can be applied for global, regional and combined modelling,
- The approach can be used in an Earth- or Sun-fixed geographical or geomagnetic coordinate system.

Sequential Processing: Kalman Filter



- A **Kalman filter** is used to estimate the unknown parameters **sequentially**.
- The **state vector** of the unknown parameters is **updated at every 10 minutes** with the new observations.
- Currently, a **random walk** model is used to model time variations of the filter (prediction or time update).

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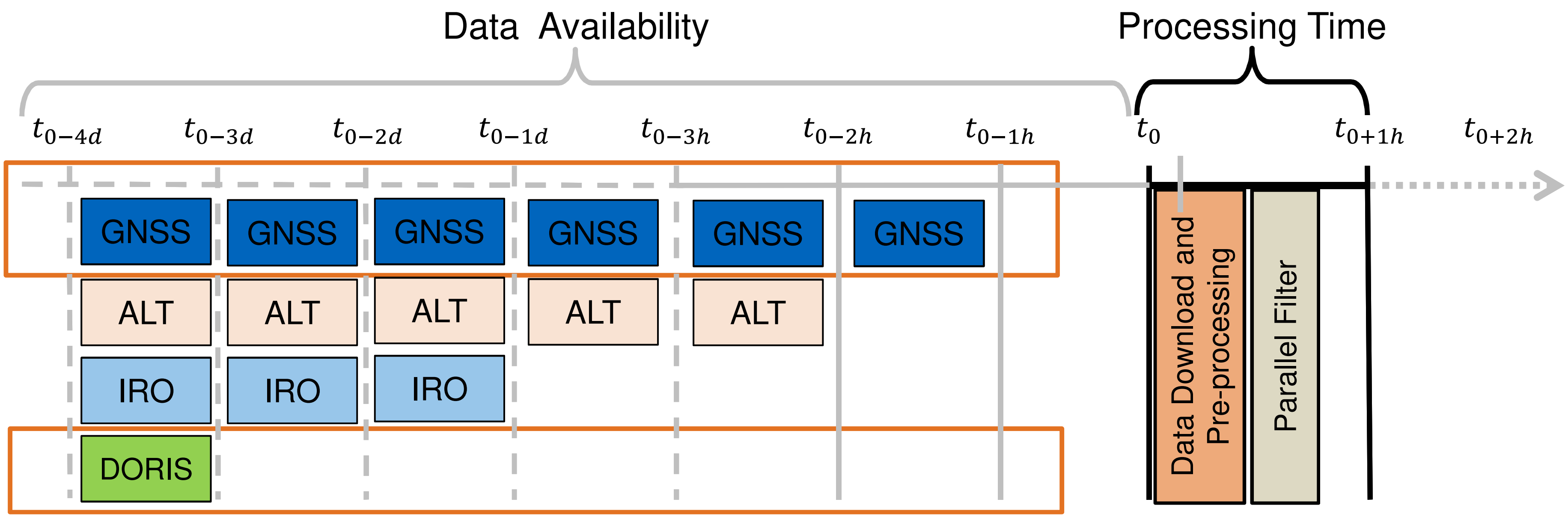
Multi-Filter approach



- … to combine space geodetic data acquired with different latencies without re-processing of all data set
- … to propagate model improvements obtained from latent data set to the (near)real-time
- … to use data as soon as possible

✓ **In this study, only GNSS and DORIS are considered.**
✓ **GNSS and altimetry combined VTEC solutions are just used for validation**

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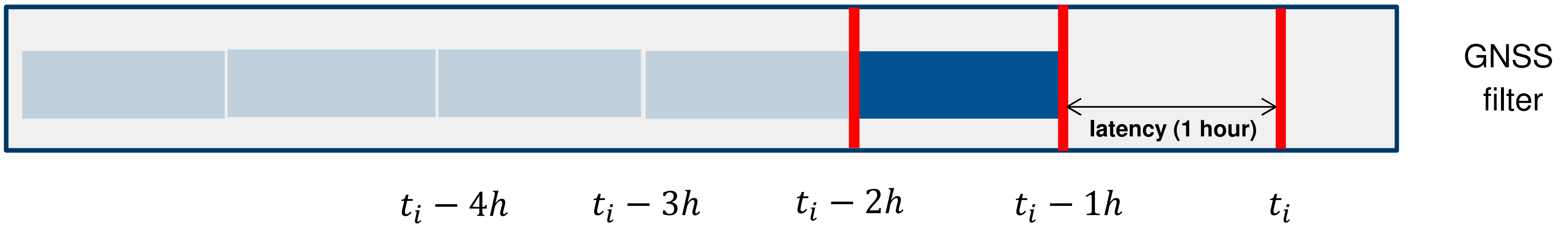
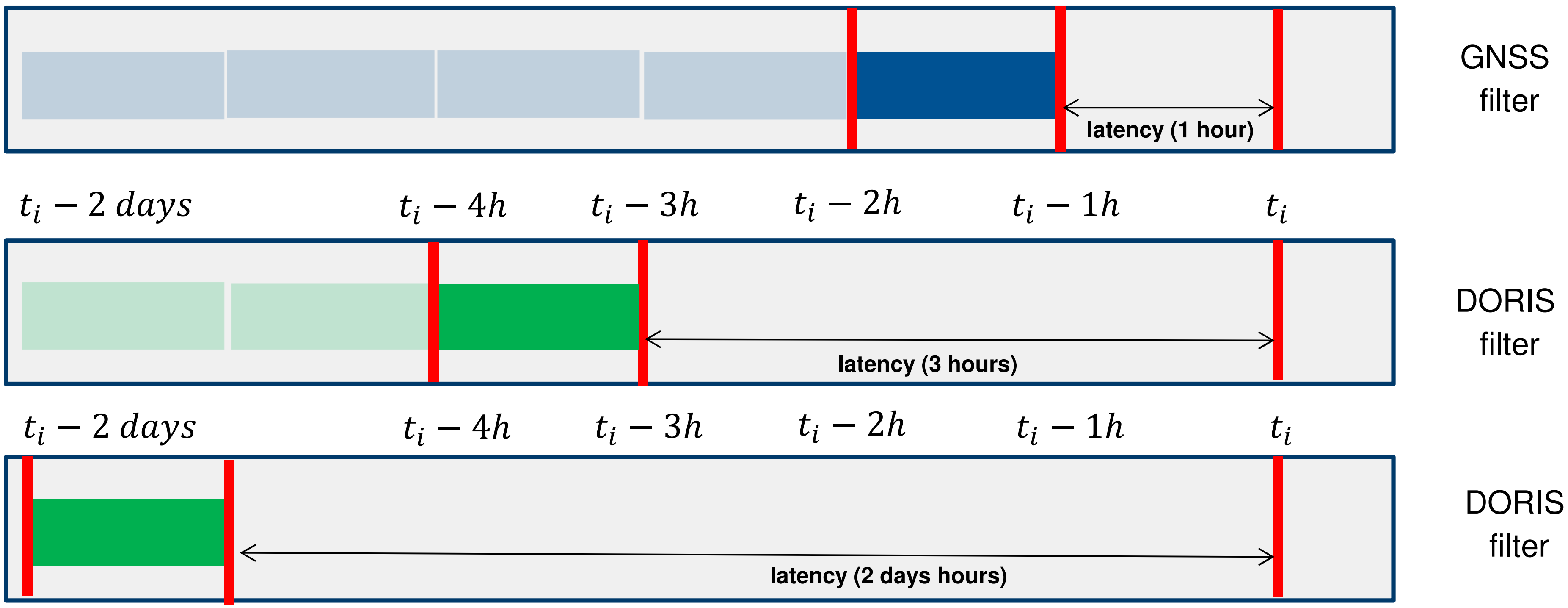
Multi-filter approach:

GNSS only filter



GNSS + DORIS filter with simulated latency of 3 hour (similar to altimetry) and 2 days



Case study: September 2017, during high and low solar activity

Data Set:

- **GNSS-only solution**: the data acquired from GPS and GLONASS receivers
- **GNSS and DORIS solution**: In addition to the GNSS data, the estimation model exploits data acquired from DORIS system on-board of **Jason-2, Saral, Jason-3** and **HY-2A** satellites.

Comparison:

- **Altimetry Jason-2/3:** VTEC maps obtained by combining GNSS and Jason-2/3 data are used for validation of VTEC maps derived from GNSS+DORIS .

Source https://www.spaceweatherlive.com/en/archive/2017/09/08/aurora

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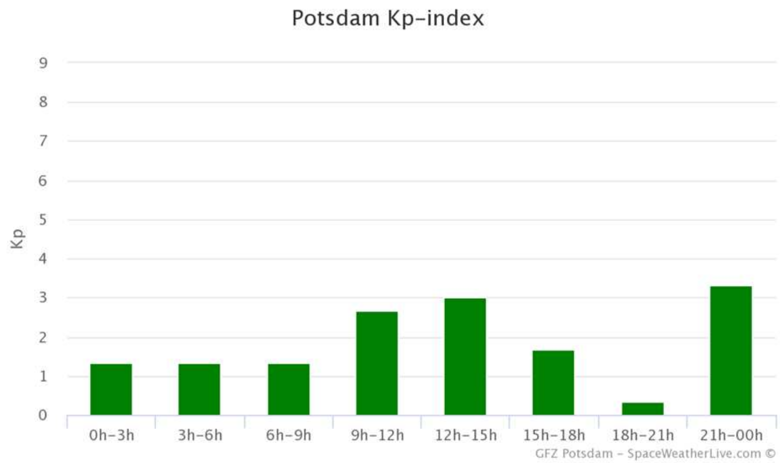
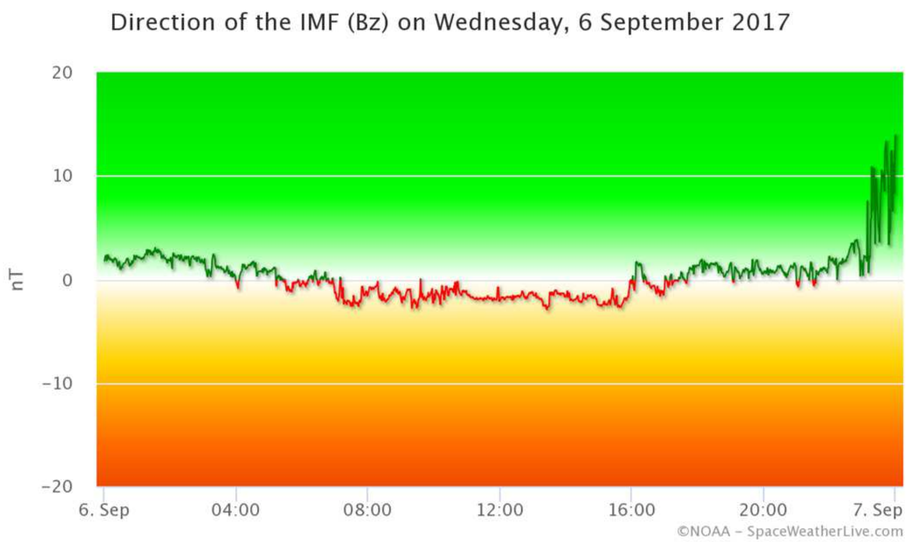
Case study: September 2017

Low solar activity
September 6, 2017

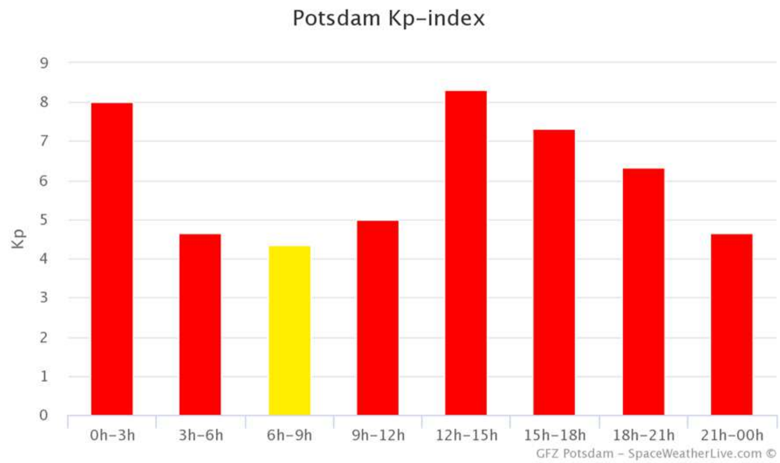


Source https://www.spaceweatherlive.com/en/archive/2017/09/06/kp

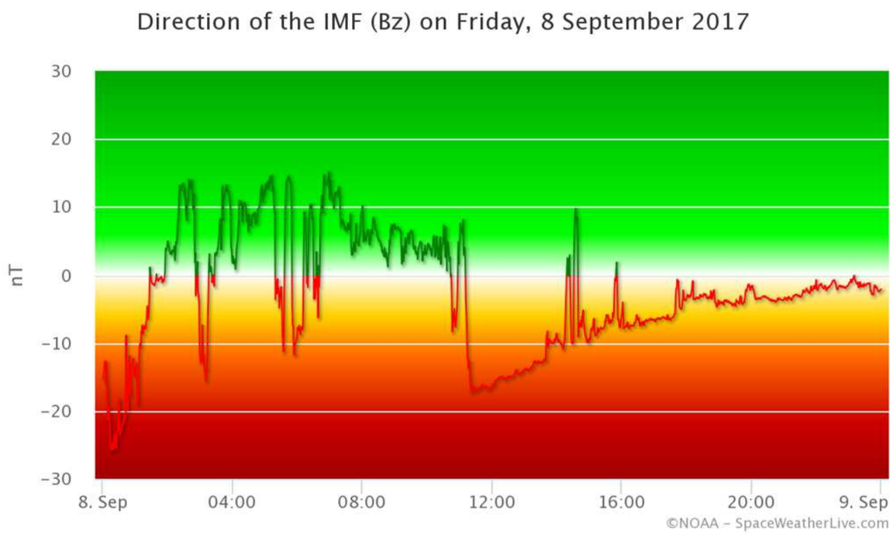


Source https://www.spaceweatherlive.com/en/archive/2017/09/06/aurora

High solar activity
September 8, 2017



Source https://www.spaceweatherlive.com/en/archive/2017/09/08/kp



Source https://www.spaceweatherlive.com/en/archive/2017/09/08/aurora

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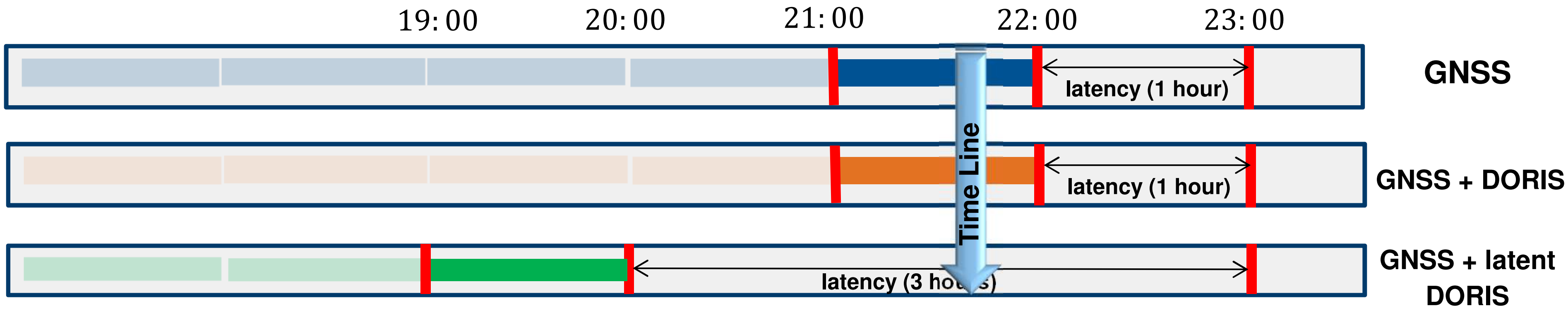
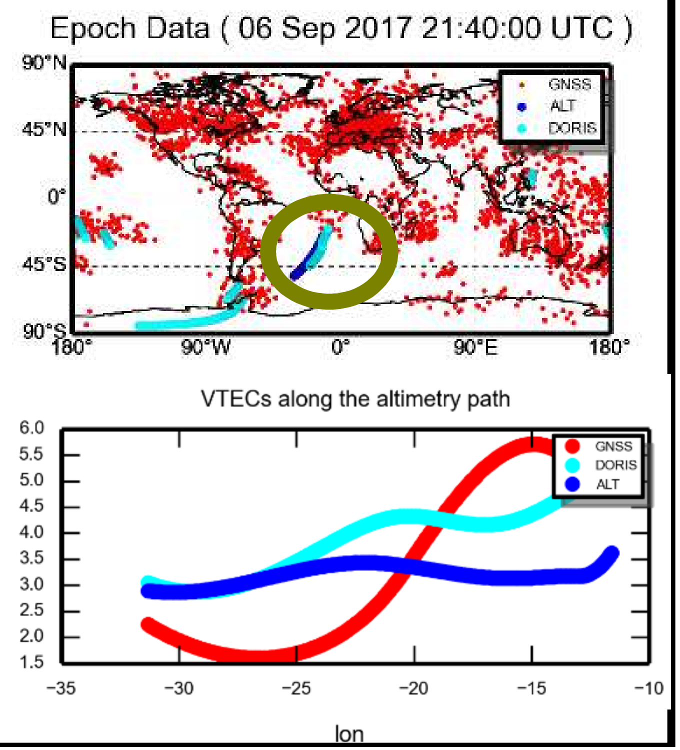
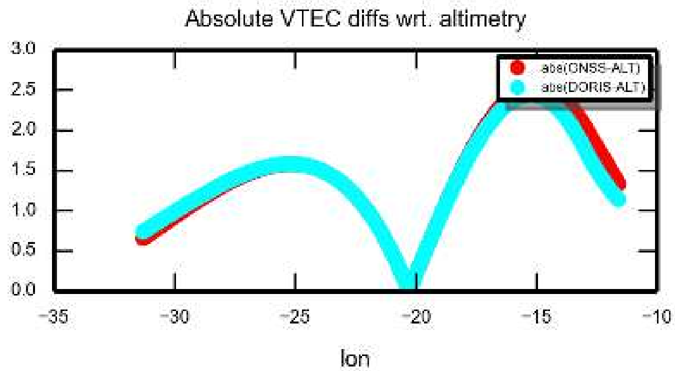
Case Study: Example, September 6



GNSS + DORIS solution :
DORIS has the same latency with GNSS



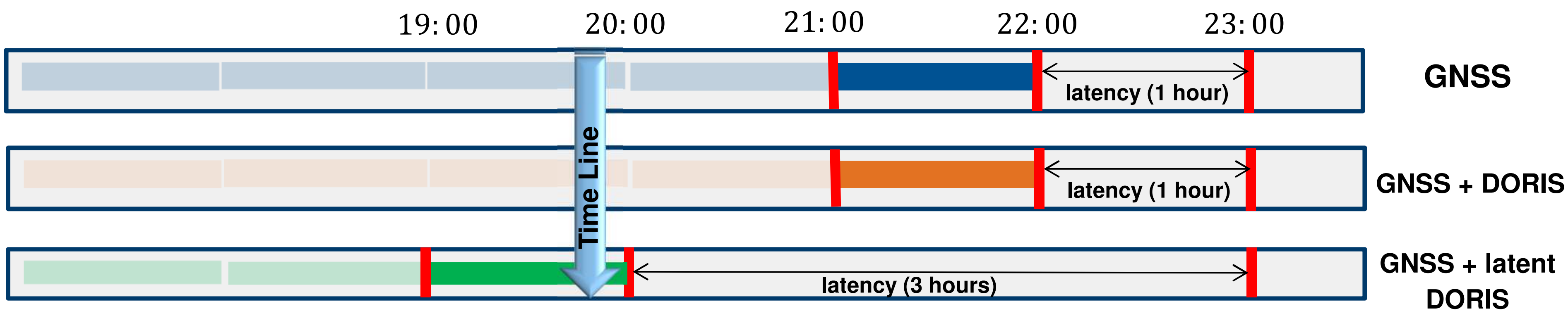
GNSS + latent DORIS solution:
DORIS has different latency



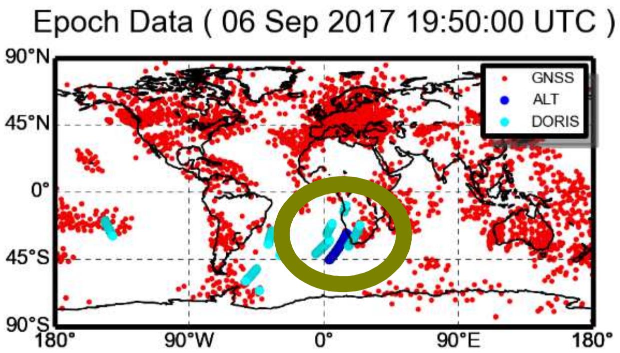
Differences with respect to GNSS+Altimetry solution

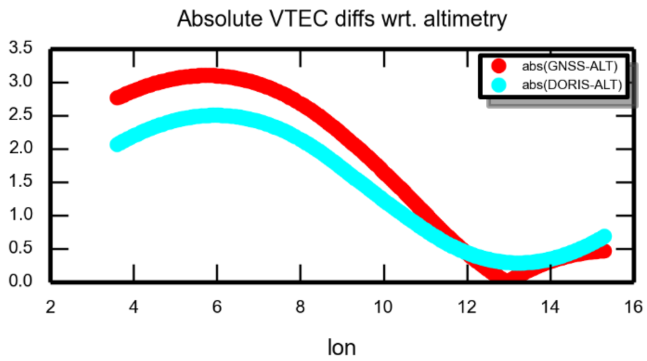
- **DORIS data collected between 19:00-20:00 was assimilated.**
- **After 20:00 the model coefficients were propagated to 21:40.**
- **GNSS + latent DORIS solution is slightly better than the GNSS solution, but can not exceed the performance of GNSS + DORIS solution**

Case Study: Example, September 6

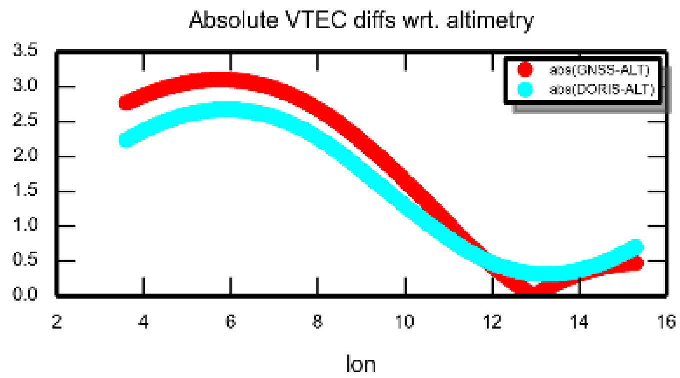


GNSS + DORIS solution :
DORIS has the same latency with GNSS





GNSS + latent DORIS solution:
DORIS has different latency



Differences with respect to GNSS+Altimetry solution

- **DORIS data collected between 19:00-20:00 was assimilated.**

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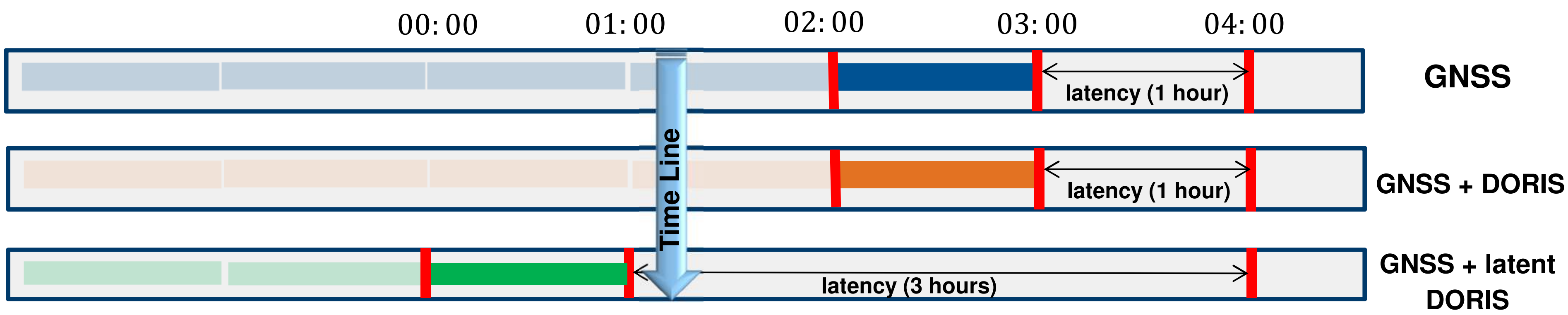
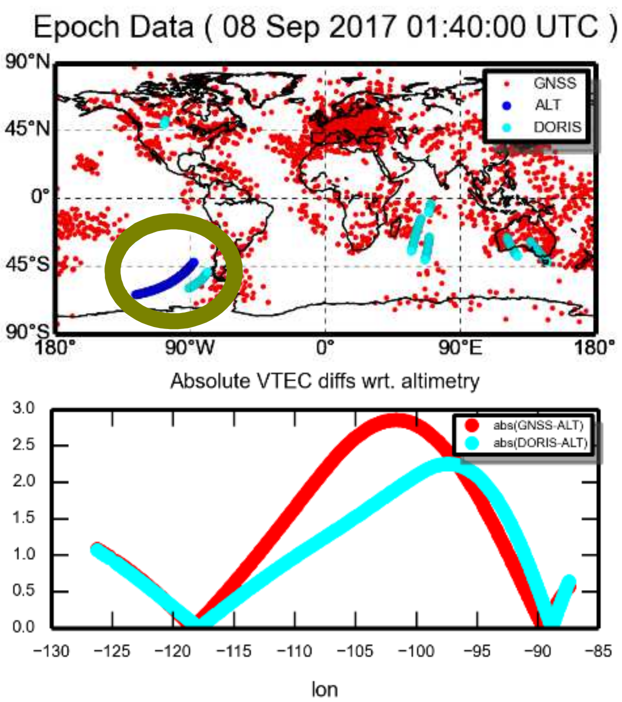
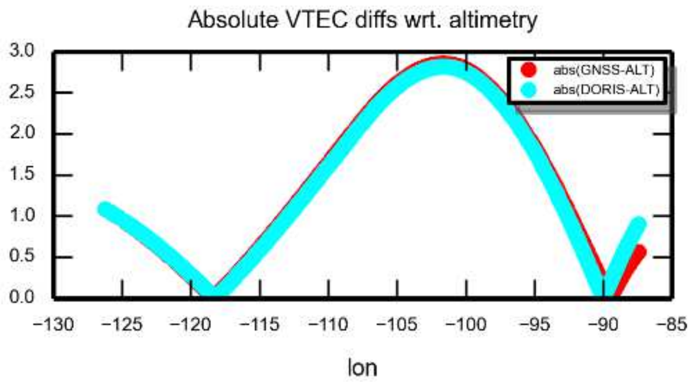
Case Study: Example, September 8



GNSS + DORIS solution :
DORIS has the same latency with GNSS



GNSS + latent DORIS solution:
DORIS has different latency



Differences with respect to GNSS+Altimetry solution

- **DORIS data collected between 00:00-01:00 was assimilated.**
- **After 01:00 the model coefficients were propagated to 01:40**
- **GNSS + latent DORIS solution is slightly better than the GNSS solution, but far away from the performance of GNSS + DORIS solution**

Summary and outlook

- A **multi-filter approach** based on **Kalman filtering** was presented.
- To consider the **individual latencies** of the applied observation techniques we setup our approach by one **main filter** based on **GNSS** data and additional **filters** for satellite DORIS data with simulated latencies.
- In the first study case, the latency of DORIS data is set to **1 hour**, i.e. identical to the near real-time GNSS data latency. Results show that DORIS significantly improves the VTEC maps, at least in regions that are less or not supported by GNSS data.
- In the second case, the latency is set to **3 hours**. Improvements of GNSS-only solutions are less pronounced but still visible. The impact depends on the dissemination time of DORIS data (with respect to the modeling epoch).
- **Extensive validation** studies covering more and longer data sets will be performed next and shown in near future. These validations will also cover latencies between 1 and 3 hours.