Using DORIS data in an OPerational Tool for Ionospheric MApping and Prediction

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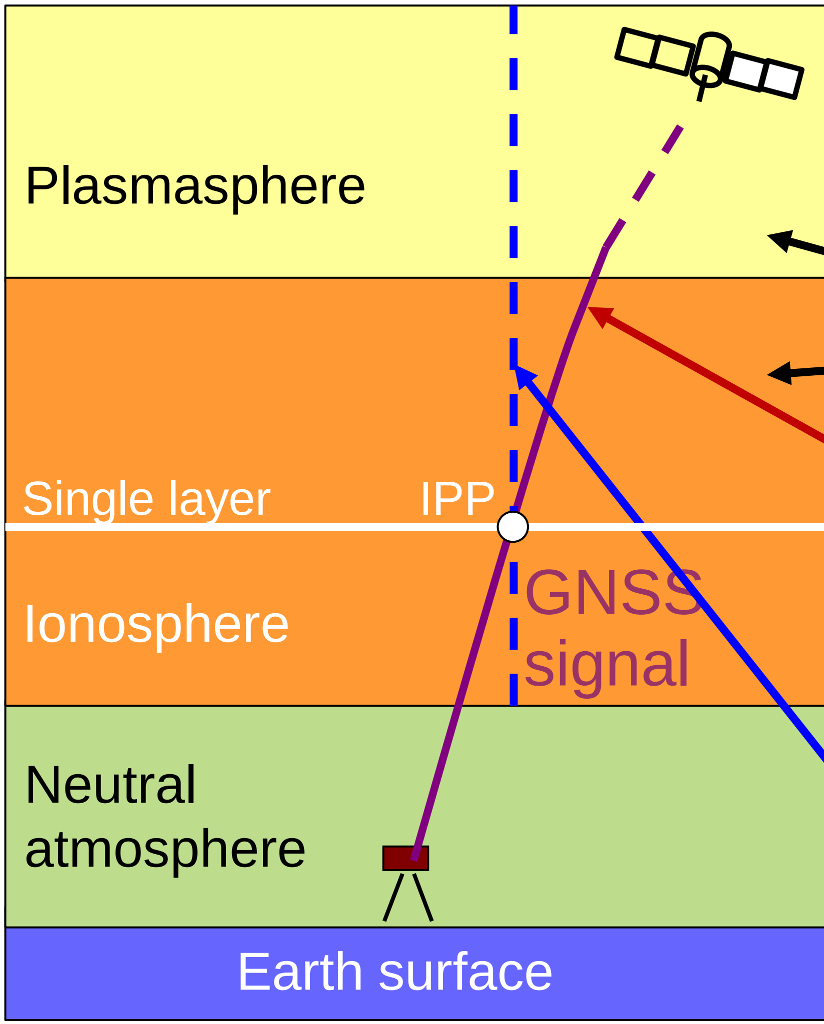
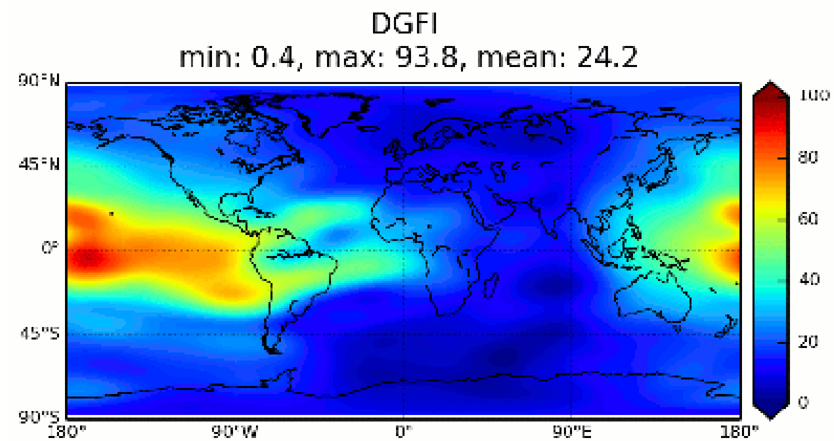
OPTIMAP
Operational Tool for Ionosphere Mapping and Prediction

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):

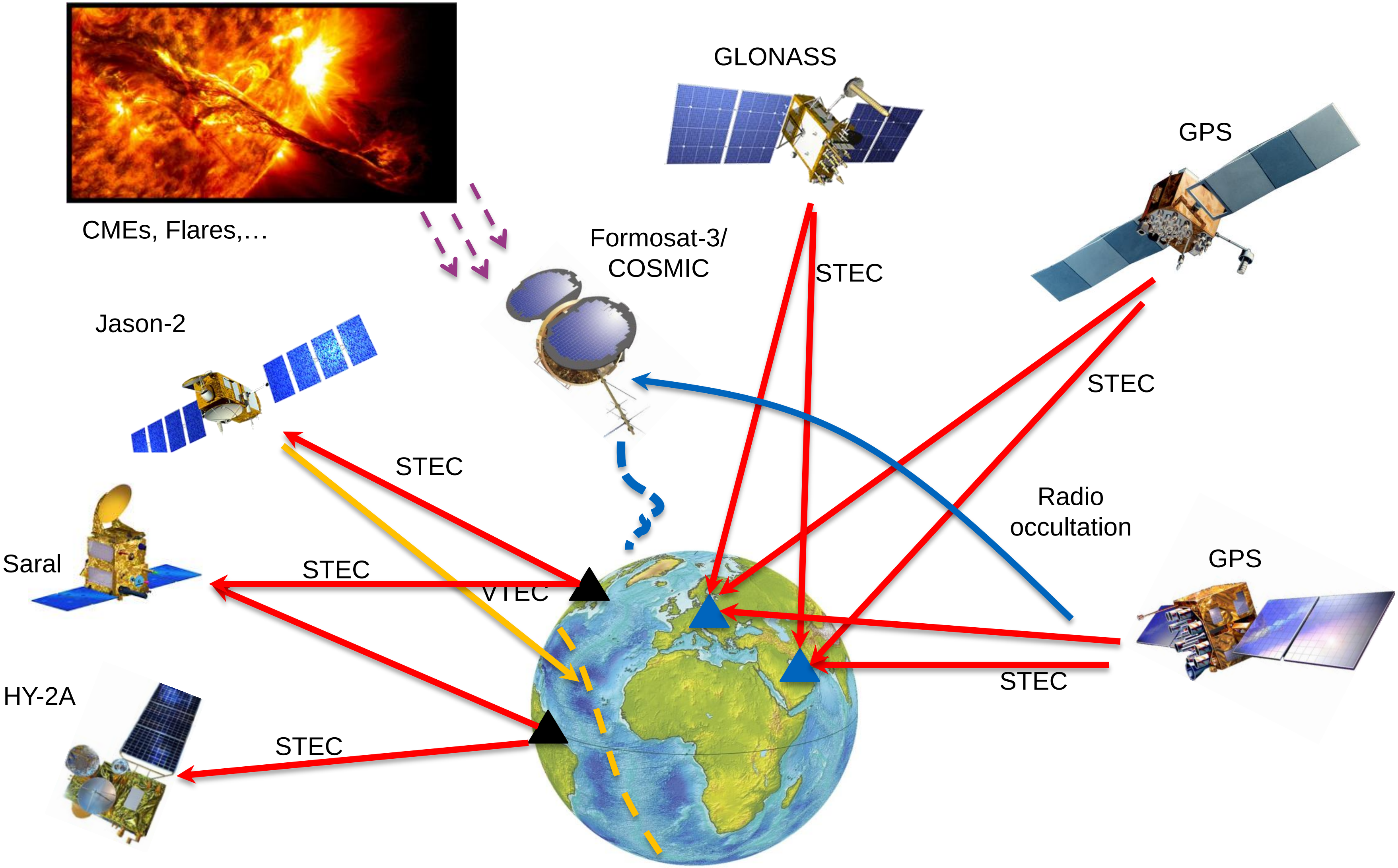
$$VTEC(IPP(t)) = \int_H N_e(\lambda, \varphi, h, t) dh$$

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

OPTIMAP: An OPerational Tool for Ionospheric MApping and Prediction

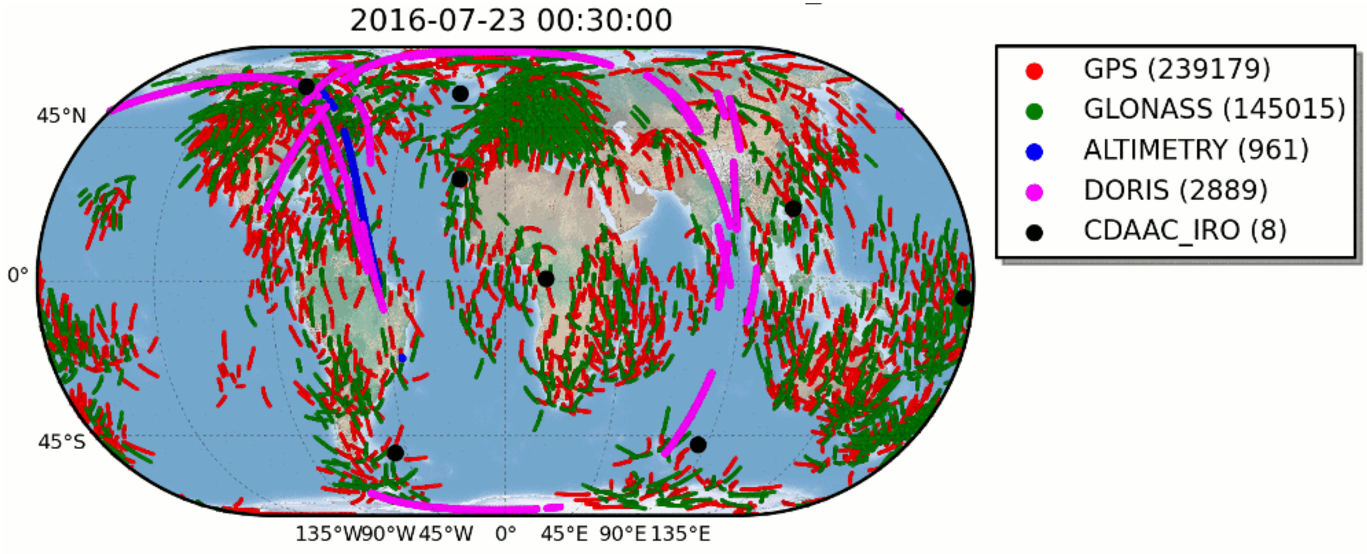
- Our approach aims on the development of a **global model** (including **regional densifications**) to generate
  - **low latency global VTEC** maps as well as
  - predictions **for several days into the future.**
- The model parameters will be computed from a **combination** of various **space geodetic (geoscientific) observation techniques**.
- The parametrization will be set up by B-spline functions **adapted** to the **distribution** of the input observations.
- The **sequential data processing** model is driven by a **Kalman filter** which allows for temporally high resolution outputs.
- To consider solar phenomena such as CMEs and flares **Sun observations** are incorporated.

Observation Techniques: Overview



Observation Techniques: Data Distribution

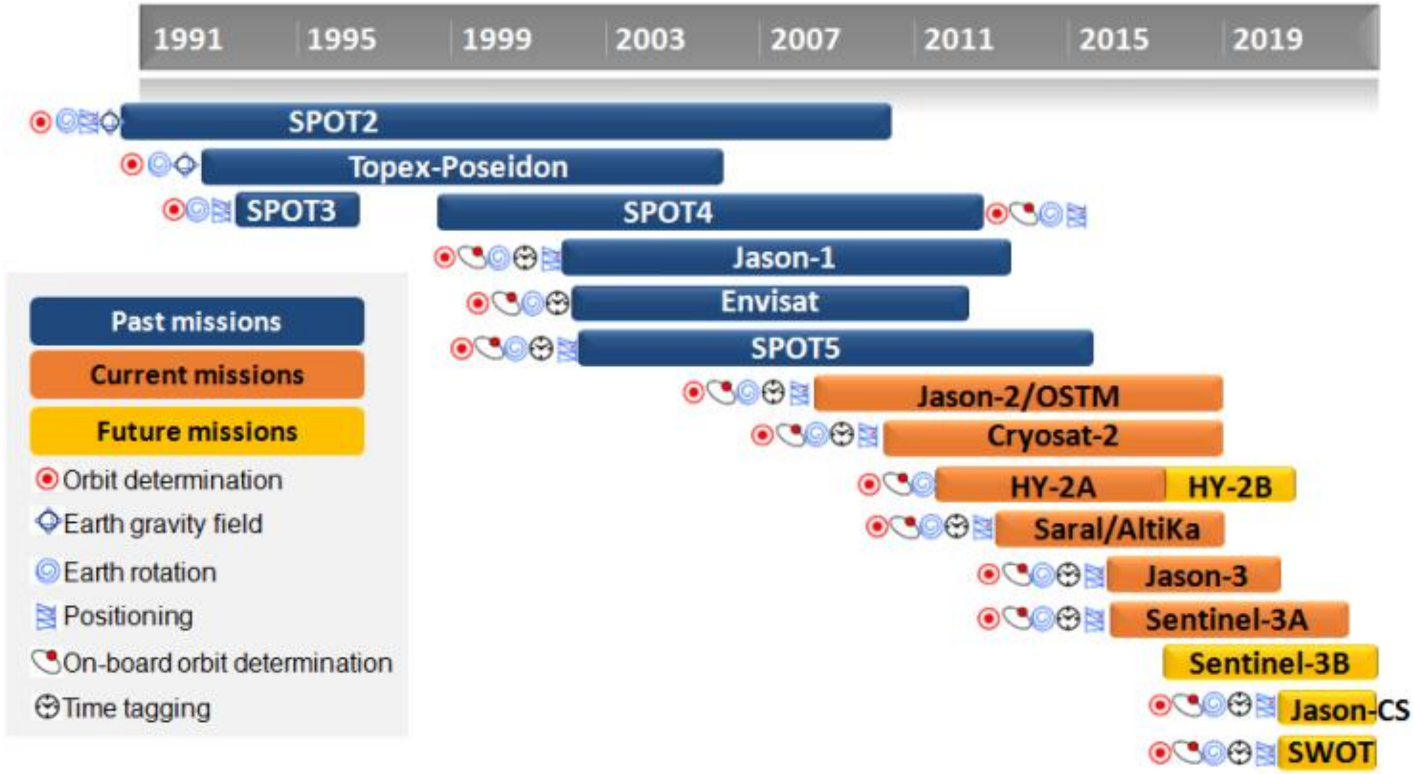
- Figure shows the overall **data distribution** from different space geodetic techniques on July 23, 2016.



- Terrestrial **GPS and GLONASS** observations provide a **high-resolution coverage** of continental regions.
- Additional techniques, namely DORIS, Altimetry and Radio occultation can not entirely eliminate the **data gap** problem**,** but can bridge the gaps considerably.

Observation Techniques: DORIS System

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



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

Extracting Ionosphere Data from DORIS Observations

Carrier-phase measurement

$$\lambda\Phi = \rho_t^r + c(\Delta t^r - \Delta t_t) + \Delta_{Tropo} - \Delta_{Iono} + CPB + D + \epsilon_\Phi$$

Geometric distance | Clock errors | Tropospheric delay | Ionospheric delay | Carrier phase bias | Phase Centre Offset

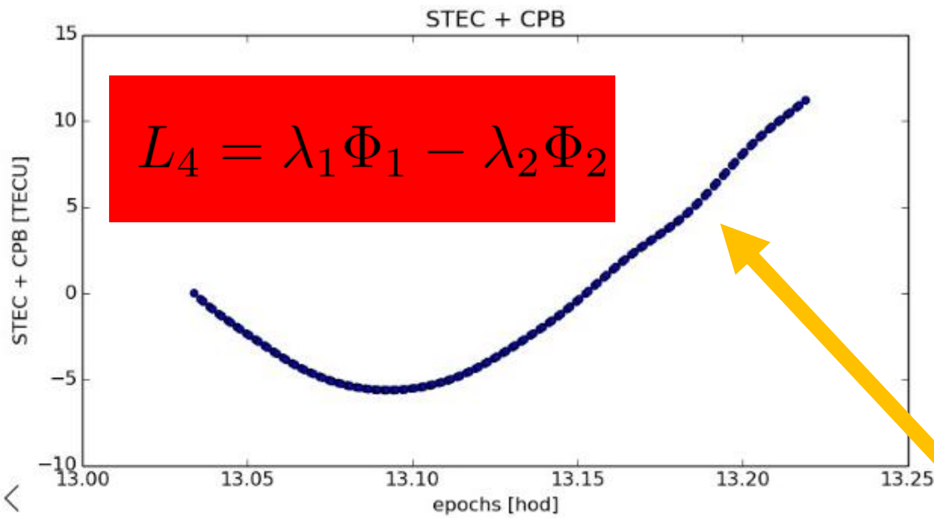
Linear combination of carrier-phase measurements for two different frequency

$$L_4 = \lambda_1\Phi_1 - \lambda_2\Phi_2 = \Delta_{Iono,L_4} + CPB_4 + \Delta D + \epsilon_\Phi$$

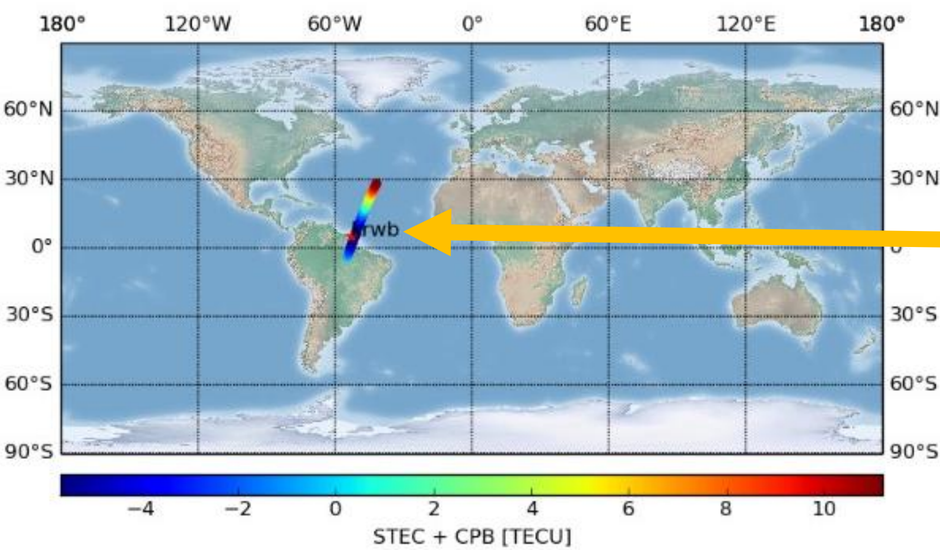
Ionosphere data | Carrier-Phase bias | Geometric Correction

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

DORIS Ionsopheric Observable: Example Jason-2

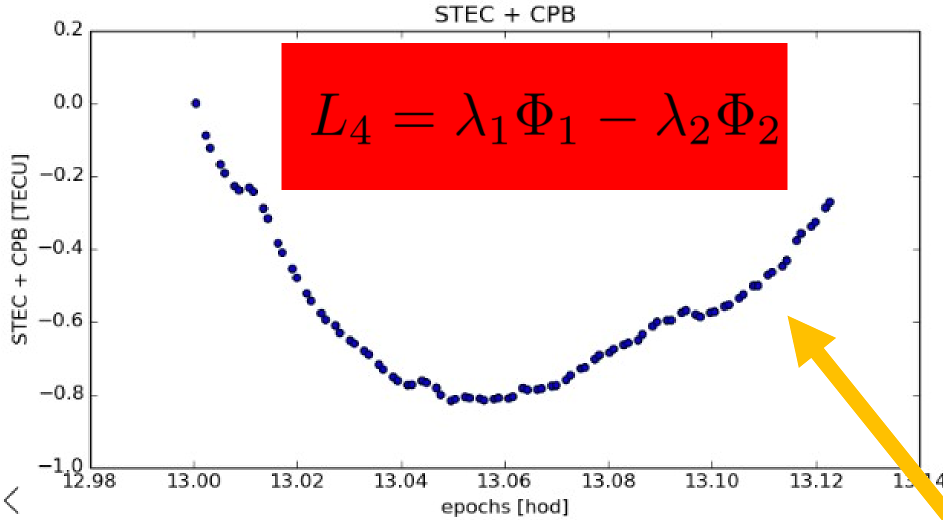


- DORIS **biased STEC** observations (shifted w.r.t. first observation) through a pass of the **Jason-2 satellite** observed on August 23, 2016 between at 13:02:01 and 13:13:08

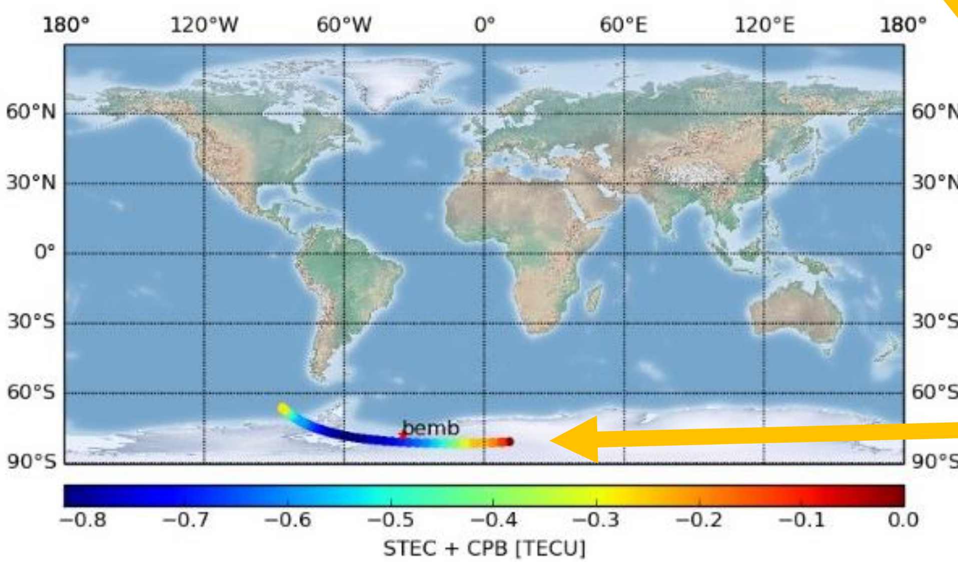


http://ids-doris.org/images/world_map_doris.jpg

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

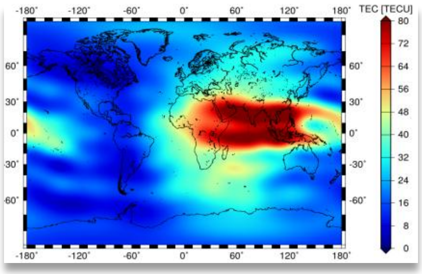


http://ids-doris.org/images/world_map_doris.jpg

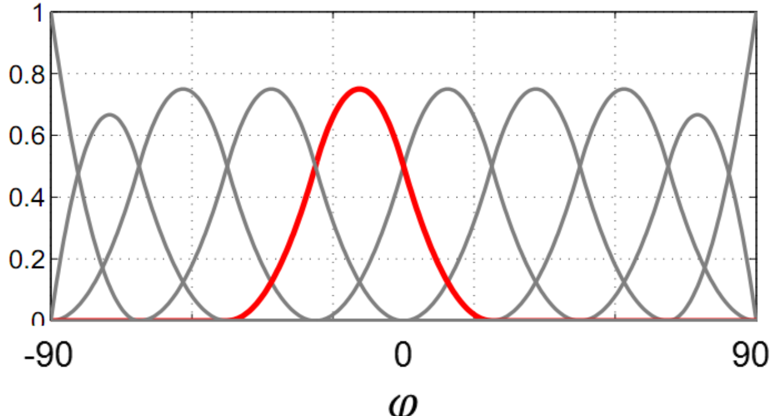
VTEC Representation: Uniform B-splines (UBS)

- 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

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

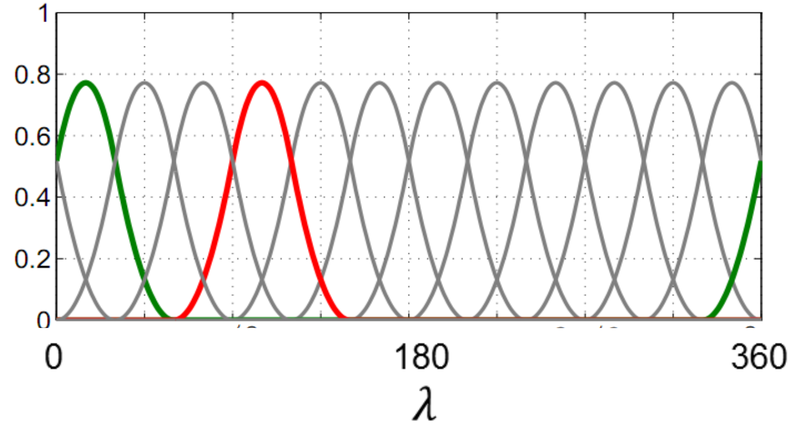


Polynomial B-spline functions N^2_{3,k_1}



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

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

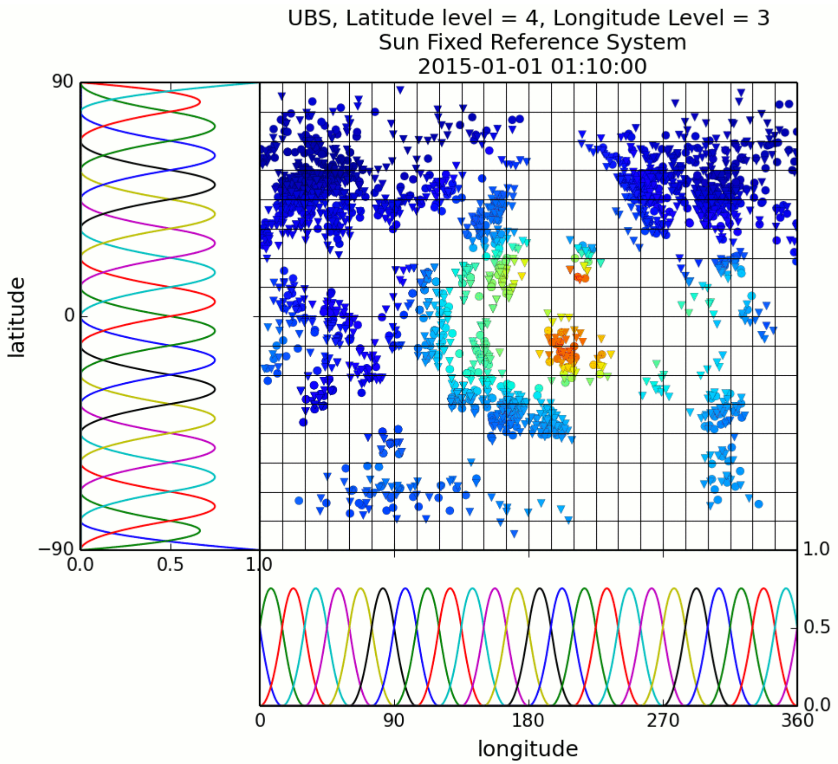


$J_2 = 2, K_2 = 14,\ k_2 = 0,1,\dots,13$

VTEC Representation: UBS Model

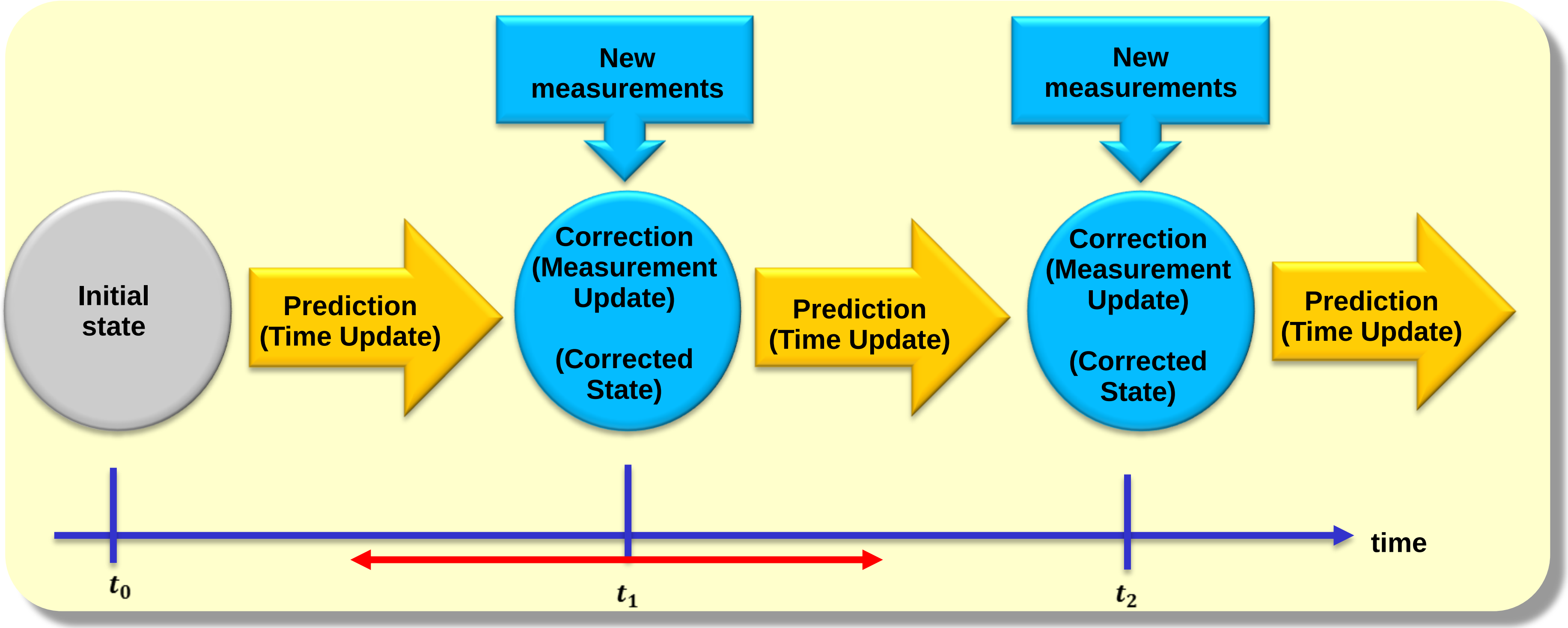
UBS; Sun-fixed coordinate system

- 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).

Case study: July 21, 2016

Post-processing data for simulation of a near real-time scenario

Data Set:

- **GNSS-only solution**: the data acquired from 285 GPS receivers and 214 GLONASS receivers

  (It has to be noted that there are additional receivers in the data set, since the data is downloaded in offline mode. The number of additional receivers (not able to provide data in near-real time) varies from day to day and can reach up to 25-30 satellites.)

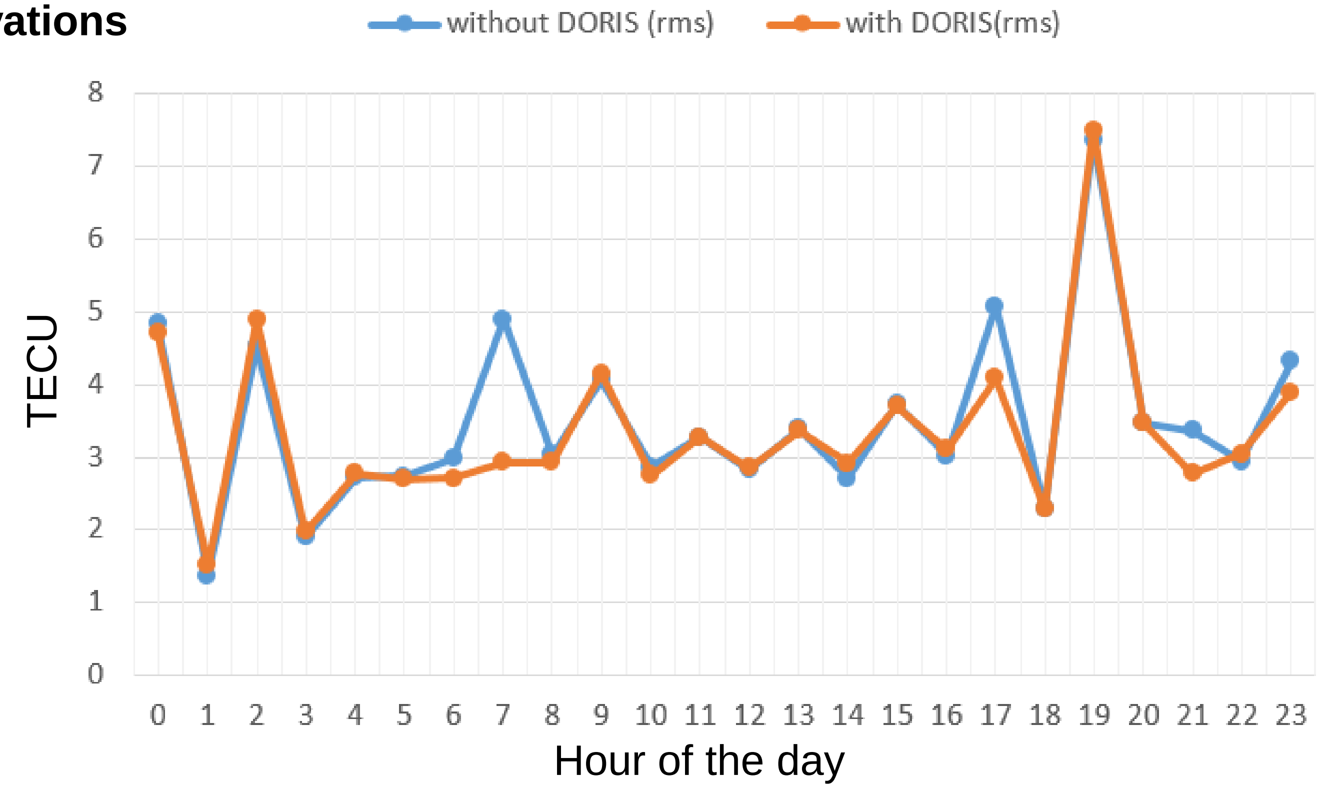
- **GNSS and DORIS solution**: In addition to the GNSS data, the estimation model exploits data acquired from DORIS system on-board of **Jason-2, Saral,** and **HY-2A** satellites.

Comparison:

- **Altimetry Jason-2:** VTEC obtained from Jason-2 is compared with the estimated VTEC maps
- **Self-consistency check (GPS STEC**): differenced STECs (dSTECs) observations on a continuous arc are compared with those of the dSTECs computed from estimated VTEC maps.

A case Study: July 21, 2016
Comparisons to Jason-2 Altimetry data

Hourly RMS values for the entire day of the estimated VTEC models with/without DORIS observations



Average RMS:

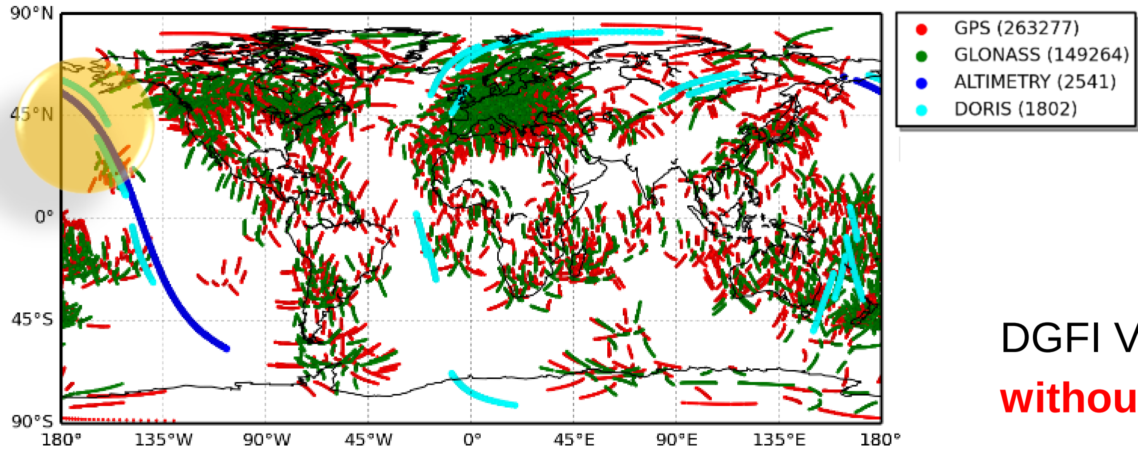
Without DORIS: 3.5 TECU

With DORIS : 3.3 TECU

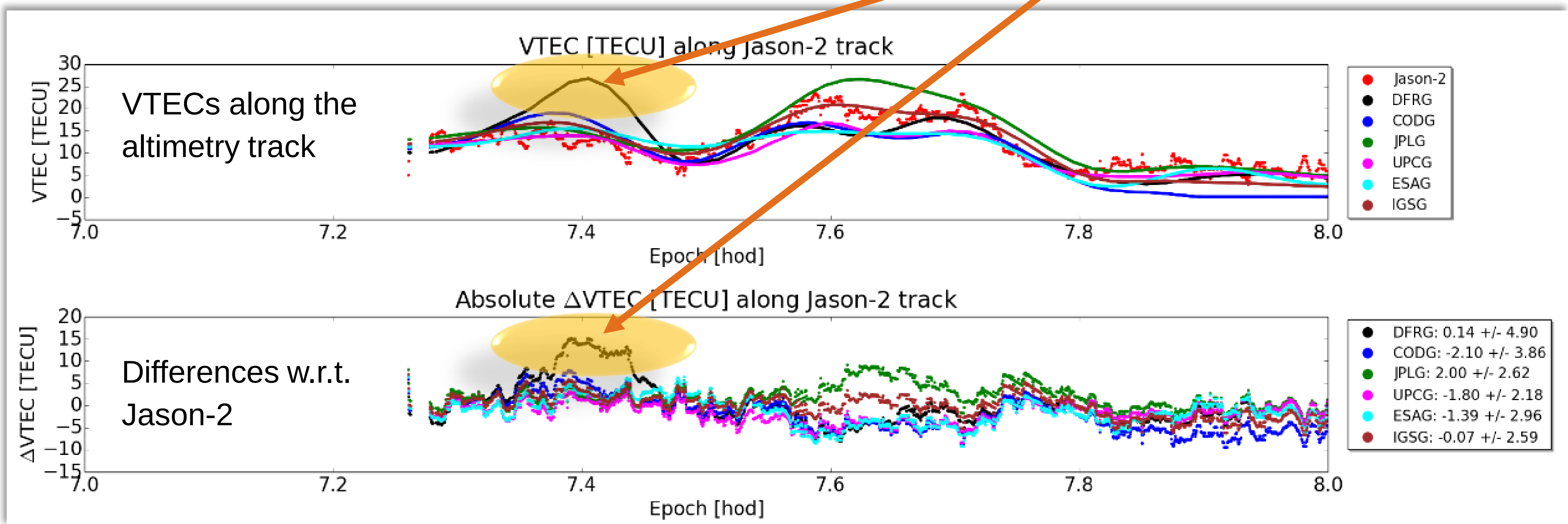
Inclusion of DORIS measurements into the ionosphere modelling results in slightly better RMS for the day

A case Study: July 21, 2016, between 07:00 and 08:00

Comparisons to Jason-2 Altimetry data

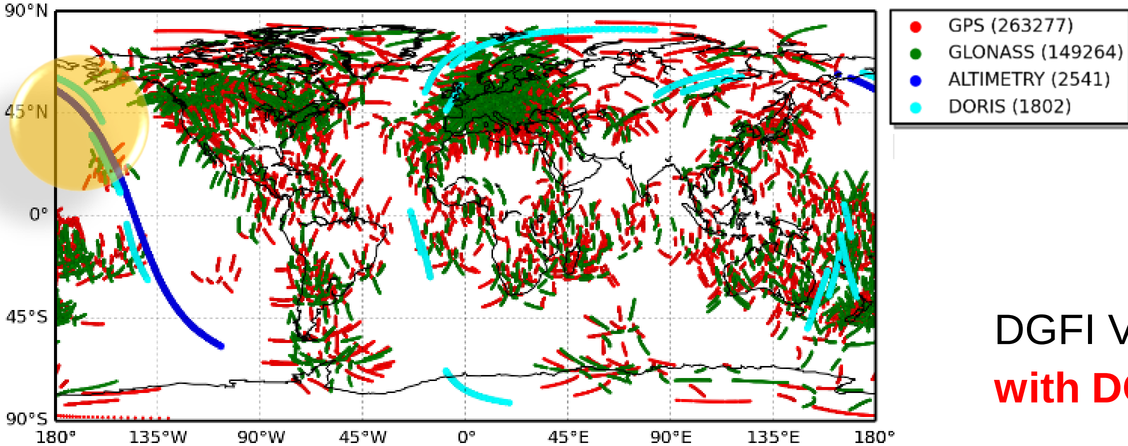


DGFI VTEC values generated **without DORIS observations**



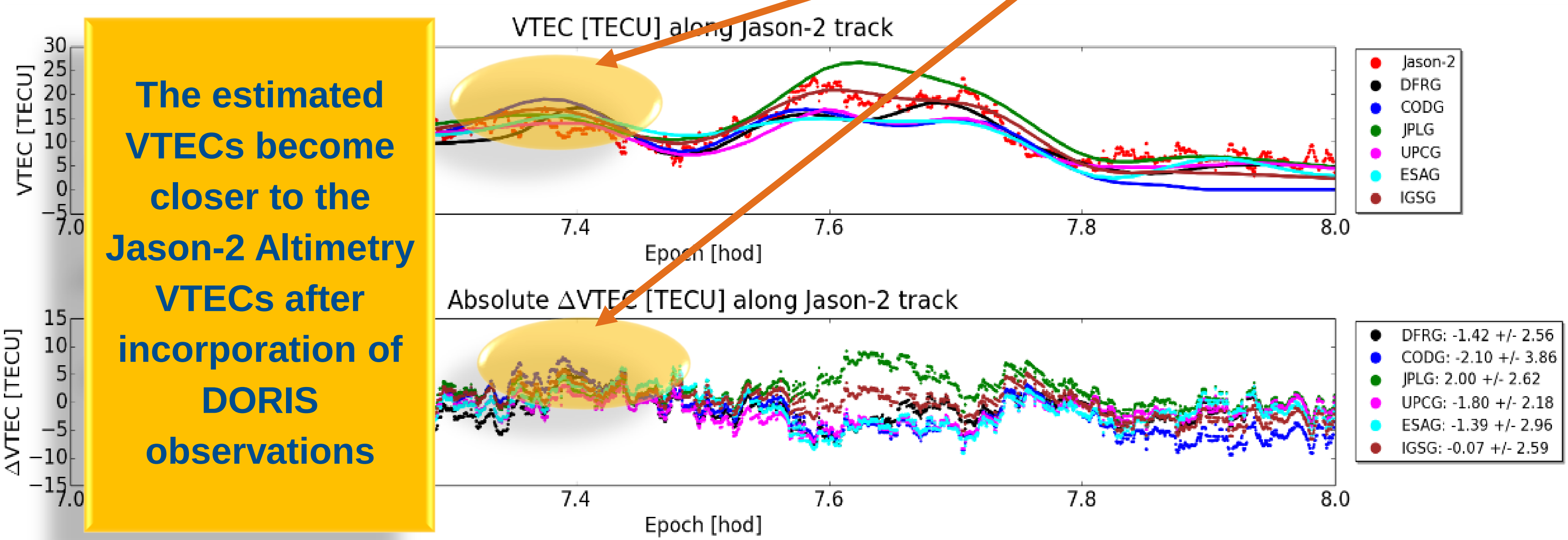
A case Study: July 21, 2016, between 07:00 and 08:00

Comparisons to Jason-2 Altimetry data

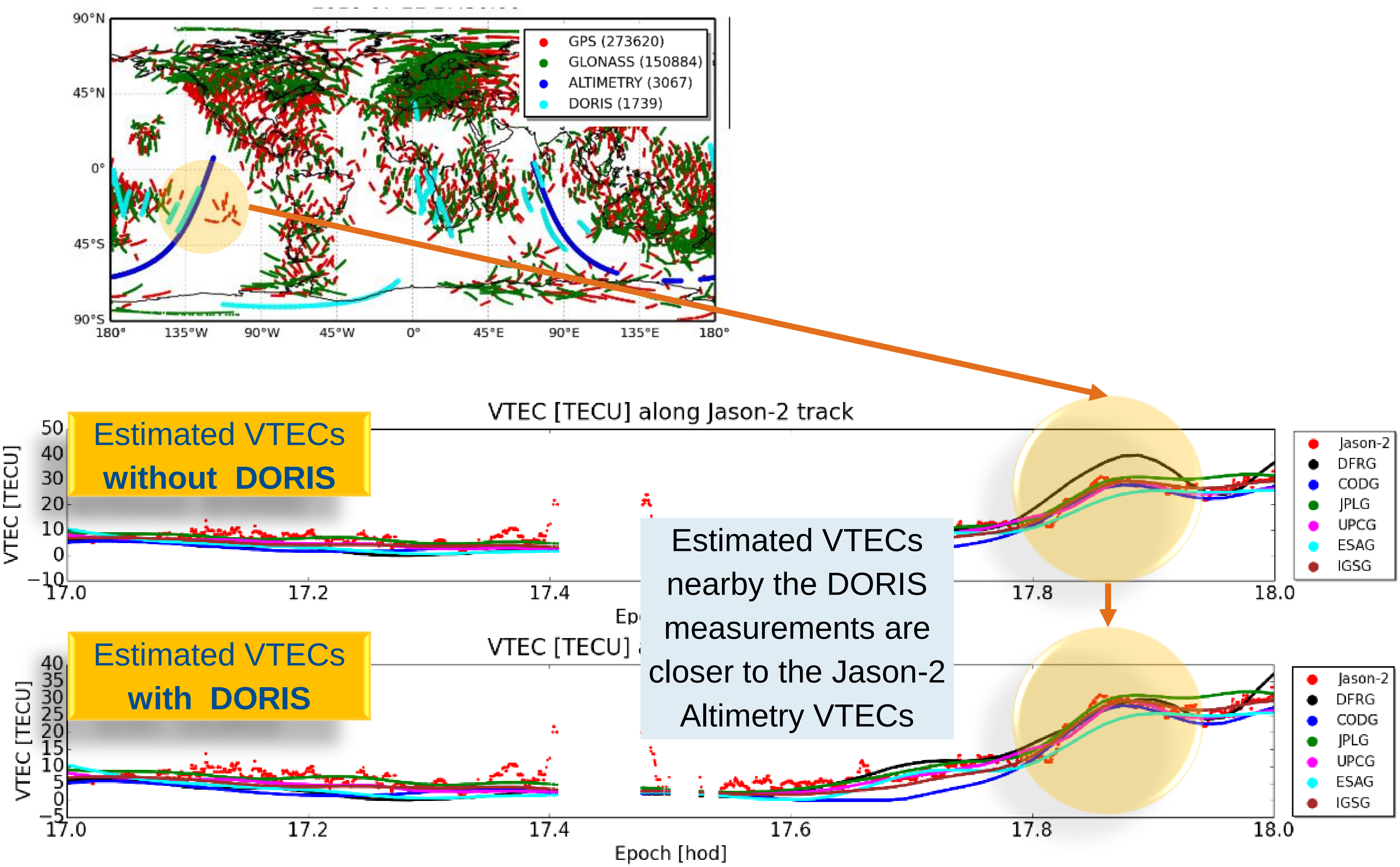


DGFI VTECs generated
with DORIS observations

The estimated VTECs become closer to the Jason-2 Altimetry VTECs after incorporation of DORIS observations

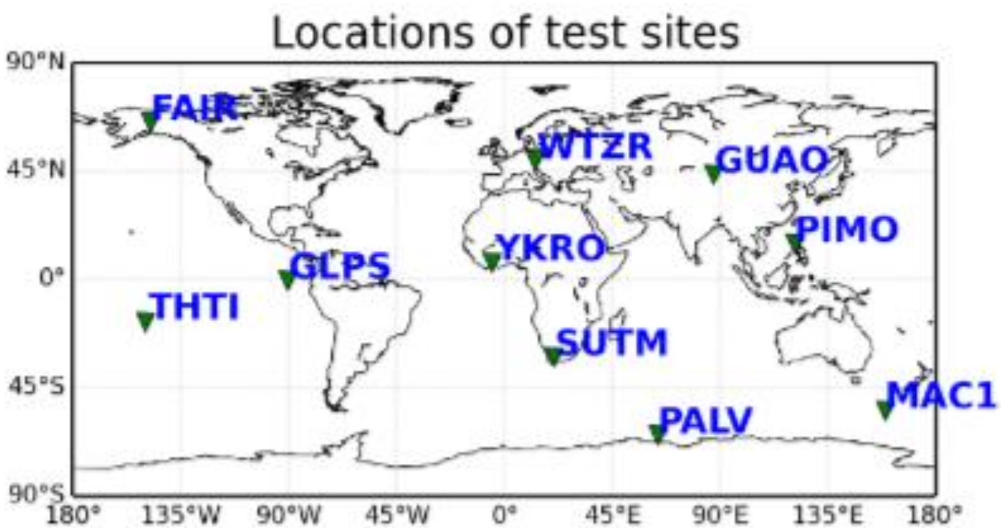


A case Study: July 21, 2016, between 17:00 and 18:00
Comparisons to Jason-2 Altimetry data



Self Consistency Analysis
A case Study: Mean RMS Values for the Entire Day July 21, 2016

- Self consistency analysis is based on a comparison of STEC values computed from GPS **geometry free phase measurements** L_c along a continuous arc and **STEC values computed from VTEC products (maps)**



Station ID	With DORIS	Without DORIS
FAIR	0.60	0.58
GLPS	1.64	1.64
MAC1	1.29	1.28
PALV	0.58	0.57
PIMO	1.78	1.78
SUTM	0.88	0.86
THTI	1.43	1.44
YKRO	1.49	1.47

- The precision of self consistency test is about 0.1 TECU.
- Results of both estimated solutions, with and without DORIS observations, are almost identical in the areas supported by GNSS data.

Summary

- One of the key points of our approach is to compute global VTEC maps with
  - **low latency** and **high accuracy**.
- **GNSS observations** are available as hourly files and as real-time data streams. They allow for **near-real time products** as an alternative to traditional VTEC products.
- Data gaps may lead to locally poor quality VTEC estimations,
- Additional techniques, such as DORIS, **can bridge the data gaps** and **improve VTEC solutions locally** on the regions that are not supported by GNSS data.

- **DORIS** provides significant input for VTEC modelling with increased temporal resolution.
- Data latency of DORIS RINEX is currently 1 day (AVISO) or 3 days (IDS). This hinders the use of DORIS for near real-time processing.

Outlook

- Concept to combine data sets of different latencies (GNSS and DORIS/Altimetry)
- Different Kalman Filters running in parallel (will be implemented in 2017)