GSSC Now and NAVISP (II)
GNSS Machine Learning Demonstrator (GMLD)

TOOLS TO INVESTIGATE AND DEMONSTRATE THE USE OF ML IN VARIOUS AREAS OF GNSS DOMAIN

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Objectives

- The main objective of the activity was to **assess the usability of machine learning (ML) techniques to improve availability and quality of GNSS navigation data**. The activity was performed during the *NAVISP-EL1-035.02* project funded by the *European Space Agency*.
  - The project was conducted in collaboration with Politecnico di Torino, Department of Electronics and Telecommunications (DET).

- The results of the activity provided
  - demonstration of usability of ML to improve data availability and/or quality in some segments of a GNSS system;
  - implementation of selected ML techniques into tools to simulate GNSS system segments capabilities and behavior;
  - implementation of a framework to conduct additional investigation on the usage of ML techniques in other use cases of the GNSS domain.

GMLD
GNSS MACHINE LEARNING DEMONSTRATOR
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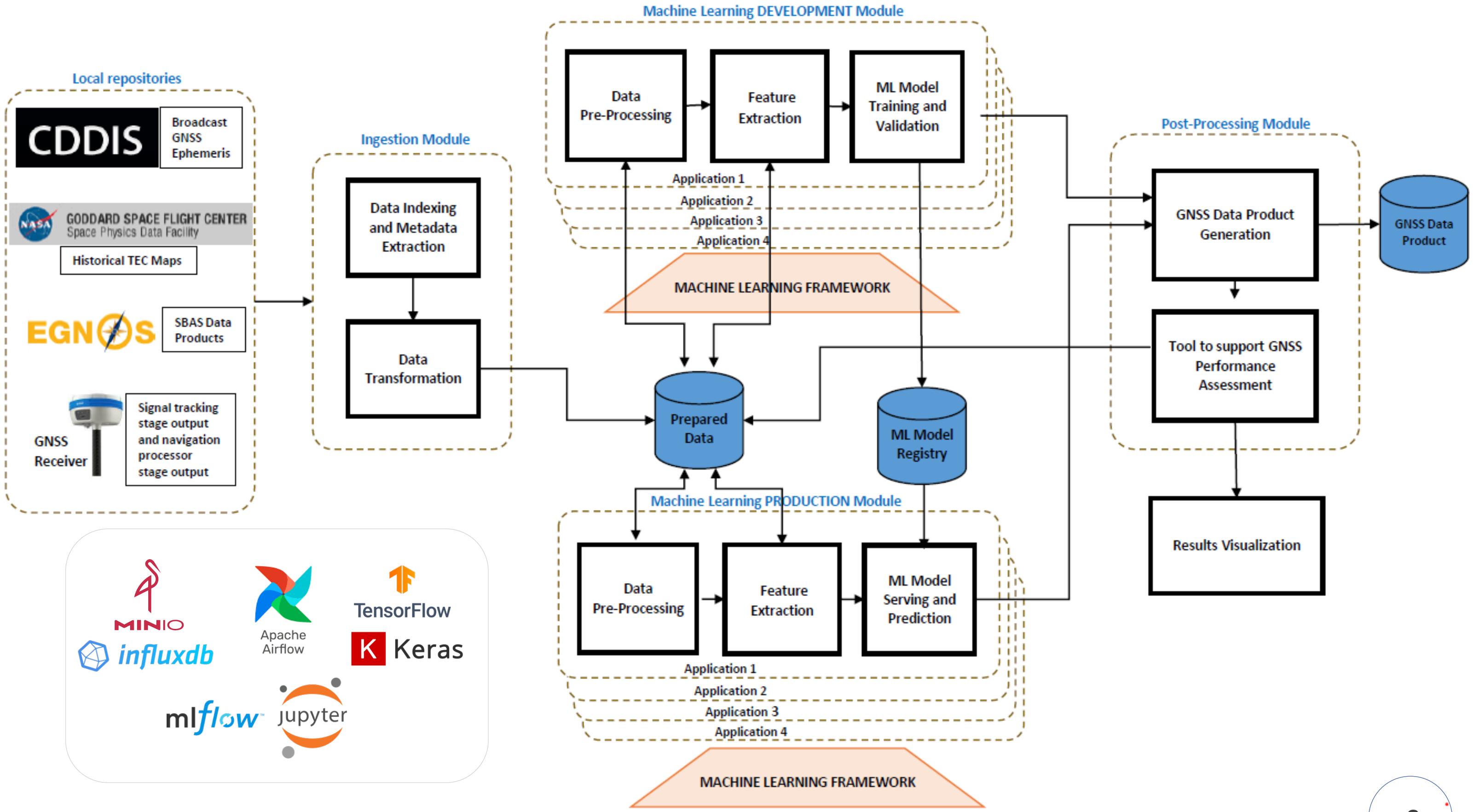
GMLD Overview

- The **GNSS Machine Learning Demonstrator** (**GMLD**) is composed by **4 applications that implement ML models** able to predict missing information or the presence of possible error sources
  - The applications have been identified in order to cover **a variety of diverse error sources**, as well as different data structures.

- Shared modules used across the applications provide capabilities to read and write GNSS data and manage ML model definition, training, validation and run.

- The GMLD provides capabilities to implement the applications as composition of the following modules:
  - Data indexing and transformation
  - ML model (including pre-processing, feature extraction and machine learning model)
  - Data output transformation



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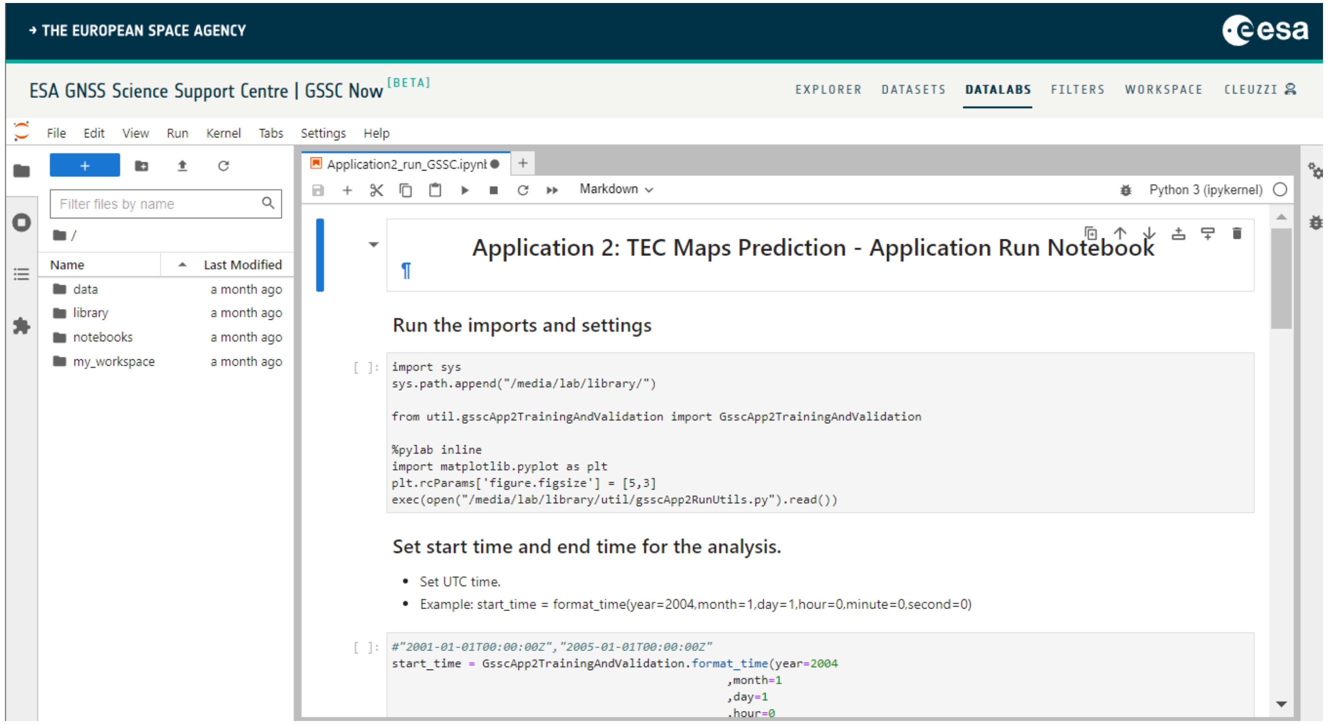
GMLD Deployed into GSSC Now

- **Each GMLD application corresponds to a GSSC DataLab**, which is a container encapsulating different tools
  - In our case, it is Jupyter Hub that exposes the applications in the form of notebooks.
- Each container provides a set of libraries needed by the processing, both custom and off-the-shelf modules.
- The DataLab contains source data made available for the application, any useful configuration/accessory file and one or more notebooks, which processing output is saved into the user persistent workspace.



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GMLD Deployed into GSSC Now

- The main **refactoring** of the application in order to be integrated into GSSC platform consists in **making the process independent from GMLD components in terms of databases, ML registry and ML Flow Engine**, that were missing in the context of a DataLab.

- For this reason, the main technical aspects of the GSSC tailored application are the following:

  - Source data are present as files and are read and parsed at the application execution time.

  - Final ML/DL model(s) for the application is provided as serialized Pickle file, together with a JSON file which contains all the parameters needed by feature preparation according to what is expected by the ML model.

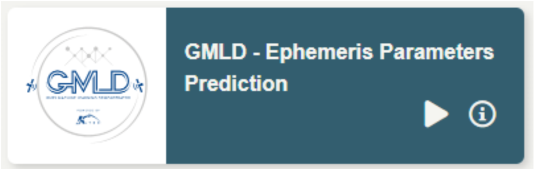
  - The Application pipeline has been refactored to be performed inside the notebook, removing its dependence from an orchestration engine and coding it as a sequence of custom library methods.

  - The output repository is not implemented as a dedicated storage system, but files are directly saved inside the Jupyter environment.

Identified GNSS Applications

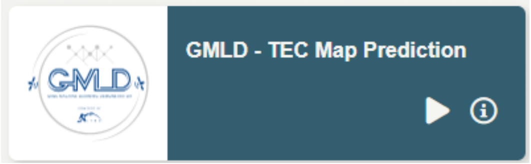
Four use-cases have been chosen in order to cover a variety of diverse applications, as well as different data structures.

Improving Orbit Prediction by means of Machine Learning Approaches



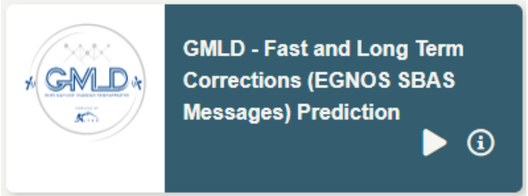
- In case of missed updated ephemeris, the aim of this application is
  - forecasting the ephemeris parameters relying on the historical data by means of ML algorithms
  - improving the computed satellite positions in a stand-alone receiver as a complement to the approximations generated by classical theory

Prediction of daily maps of the ionosphere



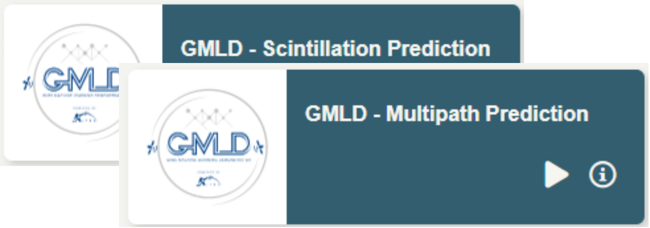
- Predict global TEC map sequences given the previous states of the ionosphere

Estimation of the SBAS correction parameters in the missed messages



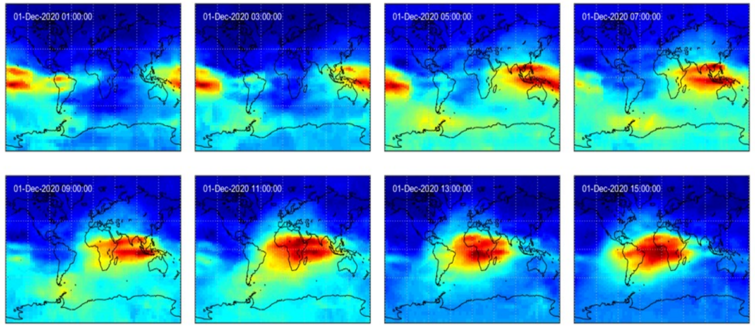
- Time to time, the user could miss some SBAS messages broadcasted. The use of the old data yields an increased error.
- Fast and long-term corrections and their impact on the pseudorange correction are of particular interest since they are specific of the SBAS messages content.

Disturbances classifications – Outlier Detection

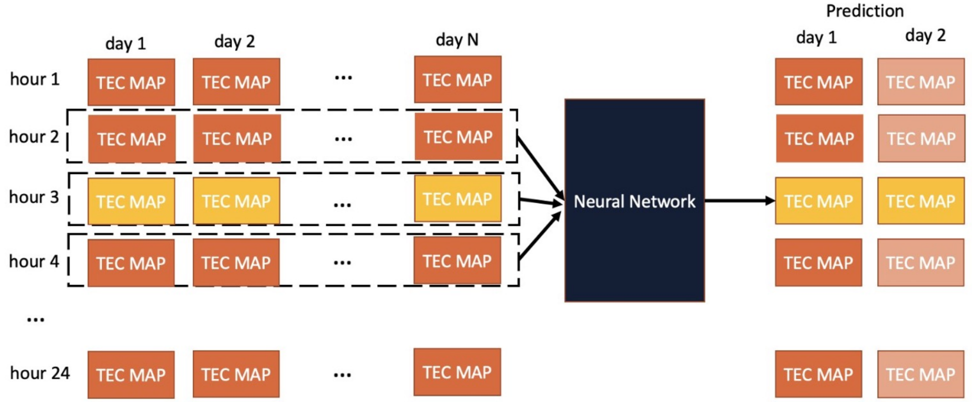


- Detect the existence of outliers due to scintillation and multipath events at the early stages, by processing the post correlation outputs and observables/measurements of a GNSS receiver.

Prediction of daily maps of the ionosphere



- When looking at the temporal evolution of TEC maps, they represent a time series of **image frames**, and the current status maps can be inferred from the previous ionosphere states.
- The **performance assessment** was performed using **historical time series of TEC maps** to assess the quality of the prediction with respect to measured data maps.
- **Model 1** concatenates TEC maps from the **same hour-of-the-day as time T from the last K days**, because:
  - Due to Earth's rotation, the highest temporal correlation between TEC maps can be found between maps that are 24 hours apart.
  - The model considers K maps each 24 hours apart to capture long-term trends in the evolution of TEC

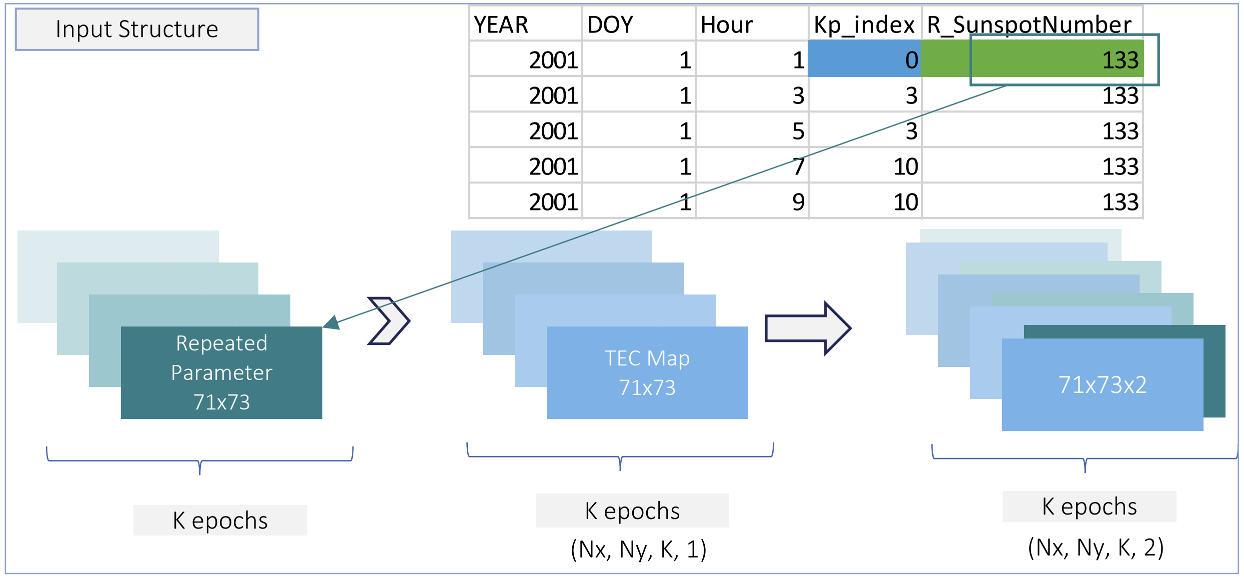


- **Model 2** concatenates **all the past TEC maps from T to T-K hours**:
  - maps at hours-of-the-day that are different from the target one are exploited
  - it allows better exploitation of short-term spatial and temporal correlation patterns thanks to the smooth evolution of TEC over temporally subsequent maps.

Prediction of daily maps of the ionosphere – The model

Source data

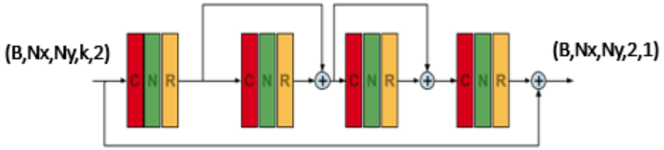
- **TEC (Total Electron Content) maps**, data rate of 2 hours
  - 2001-2004 (maximum of the solar cycle 23)
  - 2009-2010 (low solar activity)
- Additional parameters were tested: **Sunspot number**, **Kp index**
- The data (IONEX files of TEC maps and TXT files of add params) provided to GSSC team through a SFTP server, and then mounted to the DataLab file system.



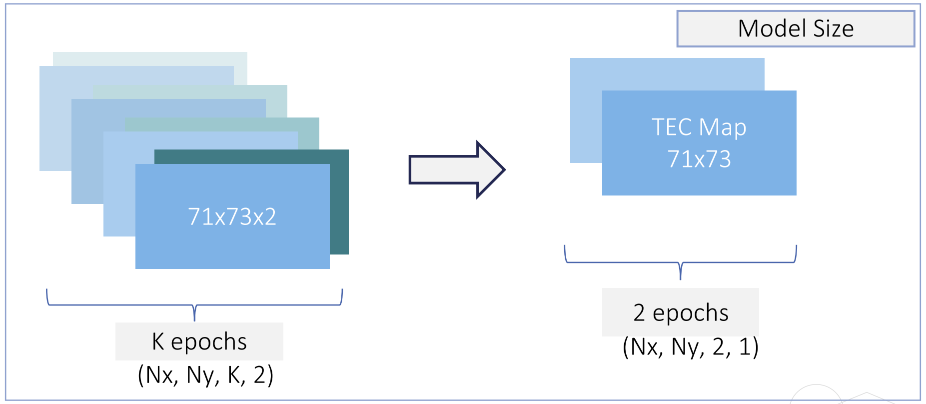
YEAR	DOY	Hour	Kp_index	R_SunspotNumber
2001	1	1	0	133
2001	1	3	3	133
2001	1	5	3	133
2001	1	7	10	133
2001	1	9	10	133

Application Design

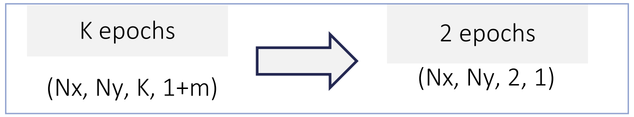
- **ResNet based model** with partial and global skip connection
- **3D convolution *(Nx, Ny, K)***, K number of previous time step in the time series



- Number of features/channel depending on input dataset
  - *(Nx, Ny, K, 1)* when using only TEC maps
  - *(Nx, Ny, K, 2+)* when using TEC maps and one or more additional parameter



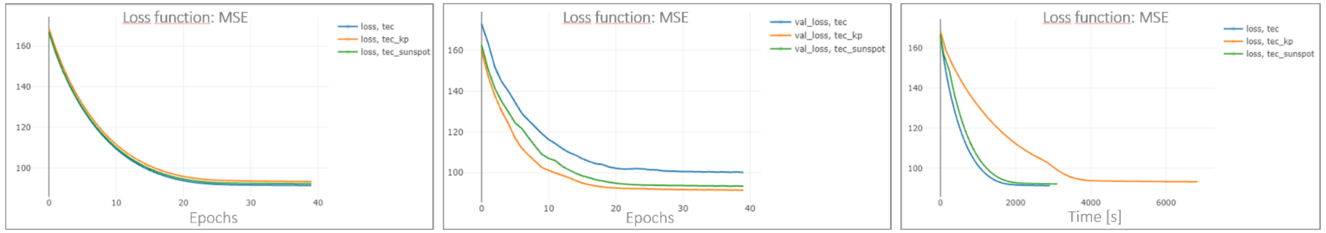
→ Easy to Scale the Input Size, when considering more parameters



Prediction of daily maps of the ionosphere - Results

1. Functional Validation of the Models

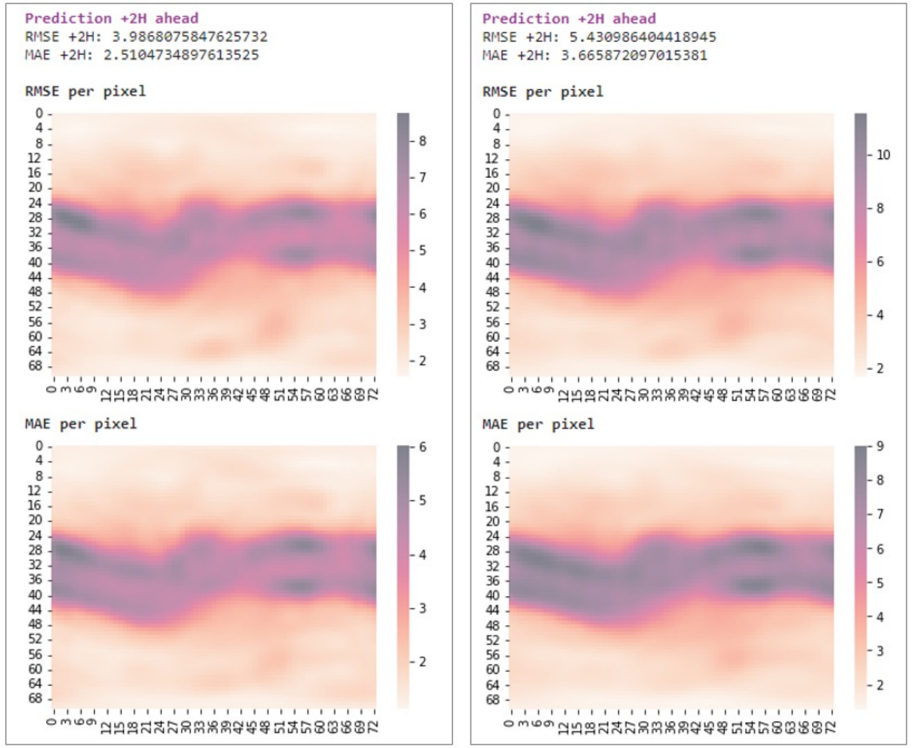
The analysis of the overall TEC prediction performance was carried out w.r.t. the ground truth TEC maps in the test set.

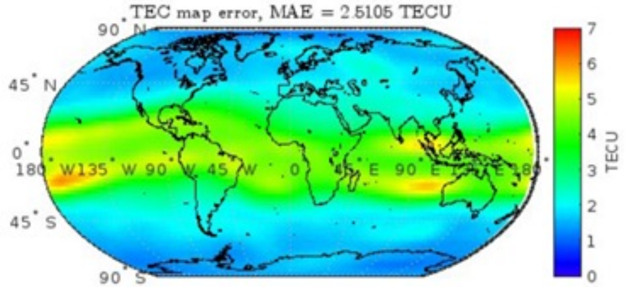


Training and Validation Loss functions.

2. GNSS Performance Evaluation

- Comparison with Benchmark Methods
  - **Last Available Map** uses the map at time T as prediction of next maps.
  - **Previous Day Map** uses the map at 24H before as prediction of next maps.
- The estimated maps provided by the ML model were used to compute the average vertical ionospheric bias error (**AVIBE**) affecting the pseudorange.
  - The resulting AVIBE was drawn onto an *Eckert map projection*. The whole error map was aggregated into a MAE of 2.5105 TECU → 40.8cm of vertical ionospheric bias.
  - Results show the capability to forecast at different time steps ahead, thus making this method applicable in a potential GNSS service, or in a receiver unable to get updated information neither from a SBAS satellite nor from a third party service.





Average vertical ionospheric bias error, T+2H, performed over consecutive snapshots.

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Thank You

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