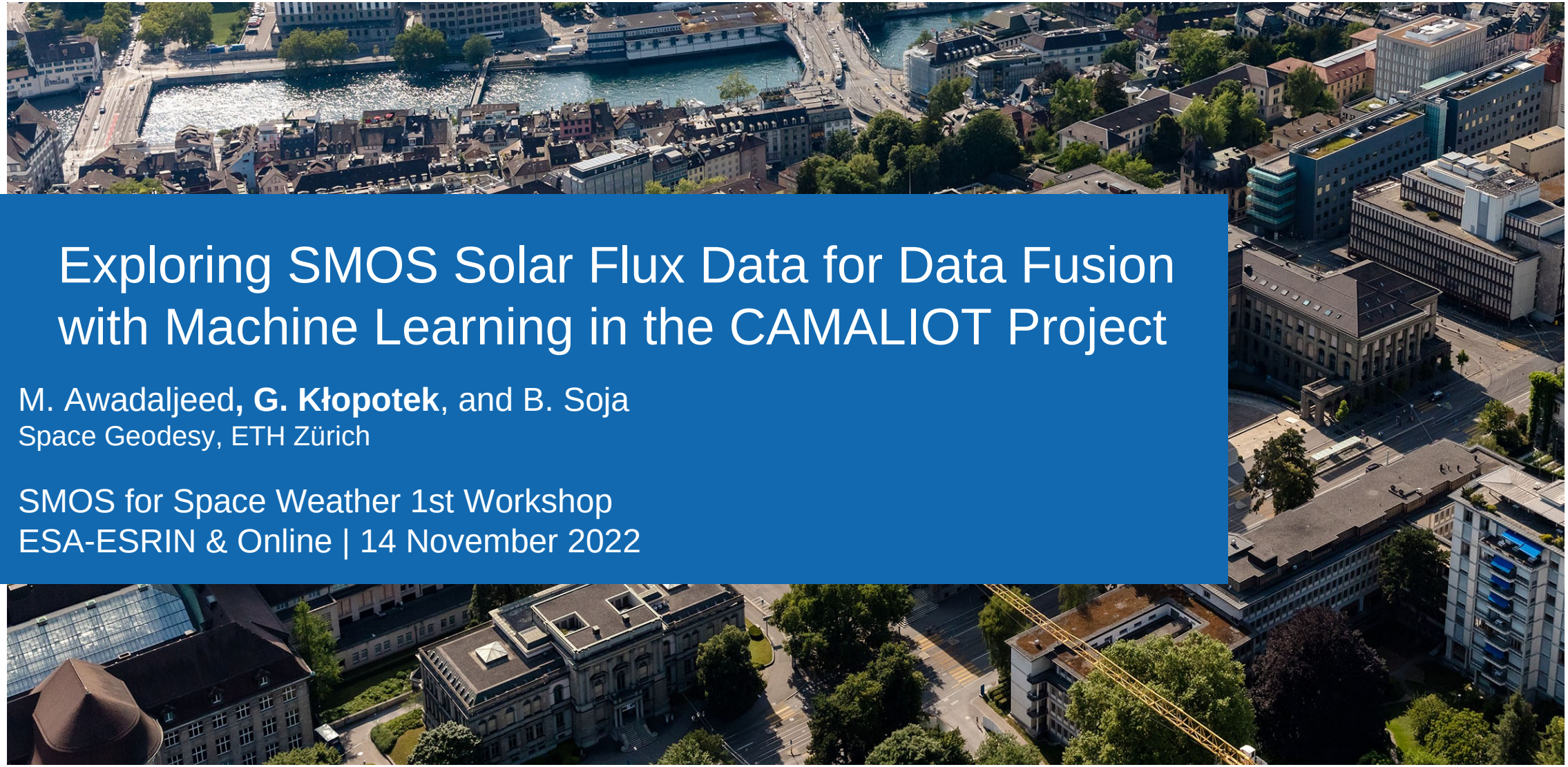

Exploring SMOS Solar Flux Data for Data Fusion with Machine Learning in the CAMALIOT Project

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Space Geodesy, ETH Zürich

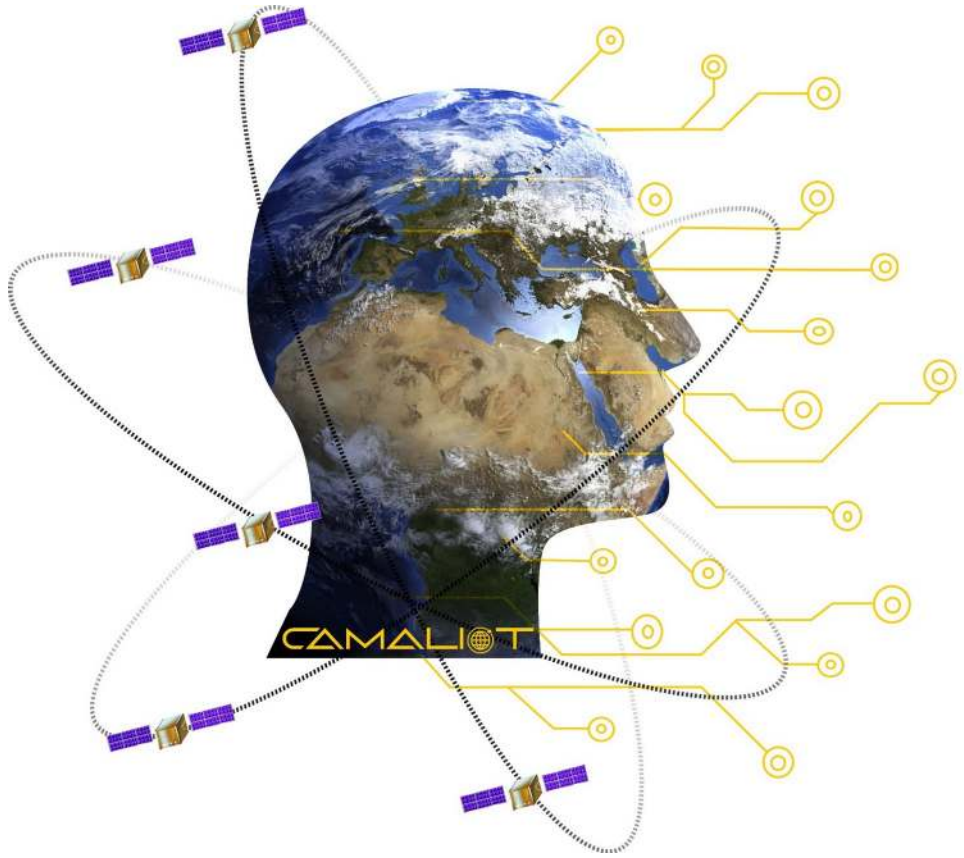
SMOS for Space Weather 1st Workshop
ESA-ESRIN & Online | 14 November 2022

CAMALIOT

Application of **ma**chine **l**earning technology for GNSS **IoT** data fusion

(NAVISP-EL1-038.2)

funded by ESA NAVISP Programme Element 1,
dedicated to innovation of the PNT technology



CAMALIOT - Goals

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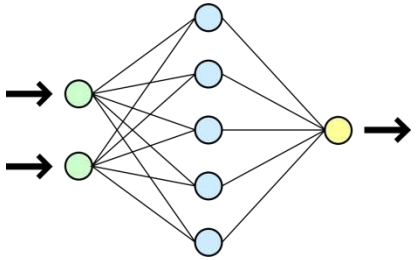
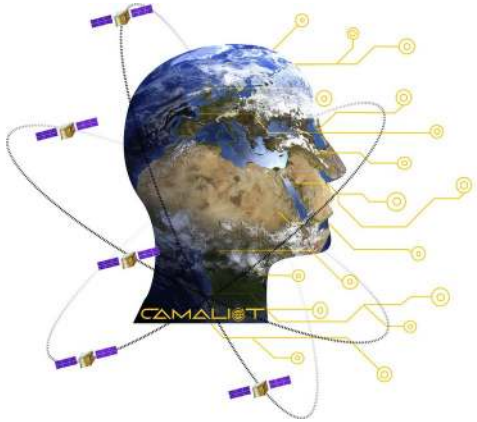
- GNSS IoT Data
  - Investigate alternative sources of GNSS observations
  - Collection of GNSS community data
- GNSS Big Data Processing
  - Framework for an automated, robust and scalable GNSS processing
  - Fusion of indices and models with huge and heterogeneous data sets of various quality



- **Science Use Cases**
  - Troposphere – Earth Weather
  - Ionosphere – Space Weather

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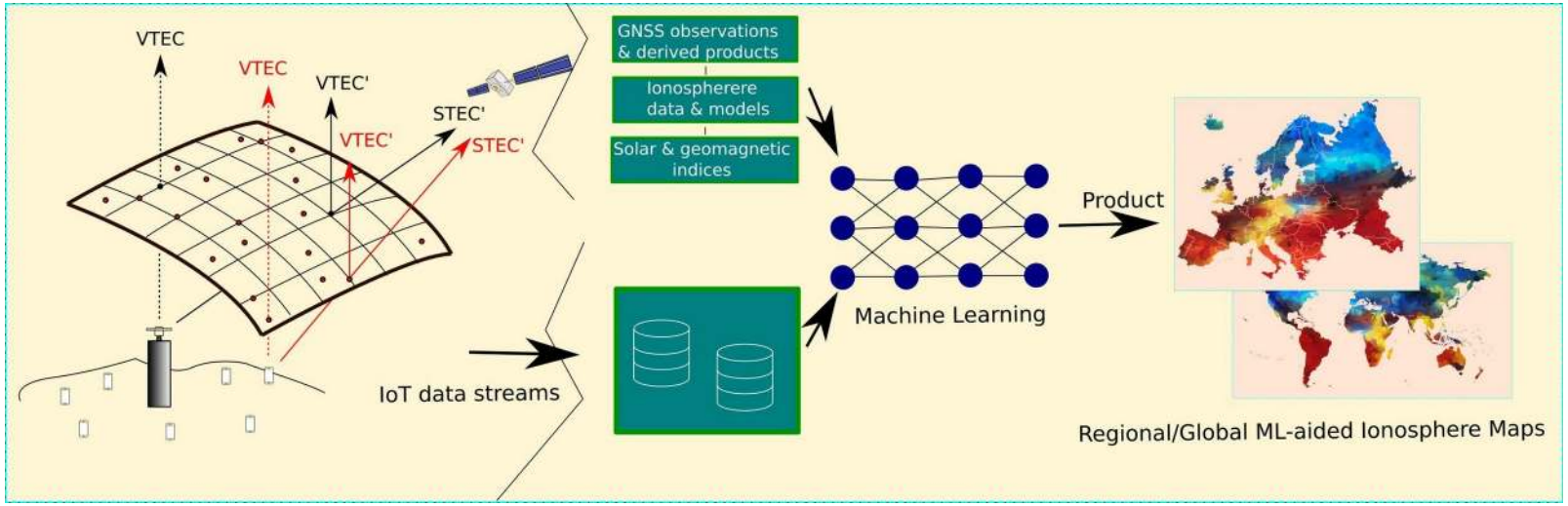
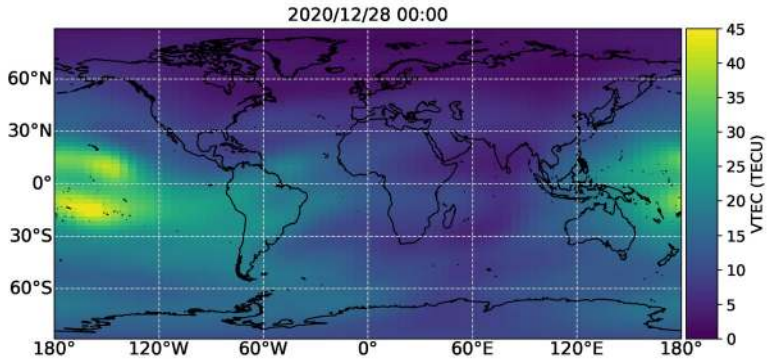
Data Fusion and Spatial Interpolation of TEC

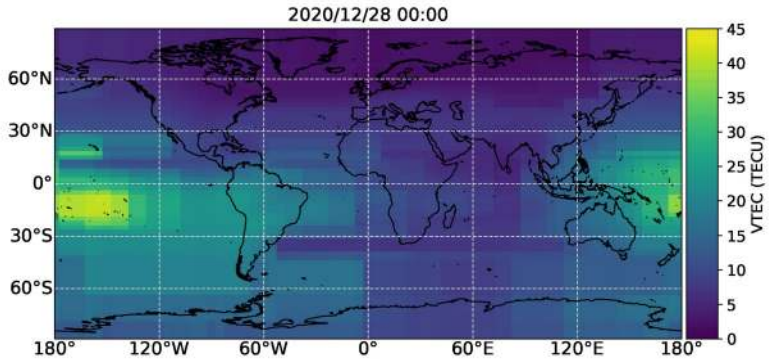


- Machine Learning / Deep Learning to combine different data relevant for ionosphere modeling
- Potentially an alternative to the operational Global Ionosphere Maps (GIM):
  - GNSS data: implementing multi-GNSS support (GPS, Galileo, Beidou, QZSS), revising method for the STEC extraction
  - Complementary data (satellite altimetry, low-cost GNSS receivers, ...): improving spatial resolution and spatio-temporal prediction capabilities of the model(s)

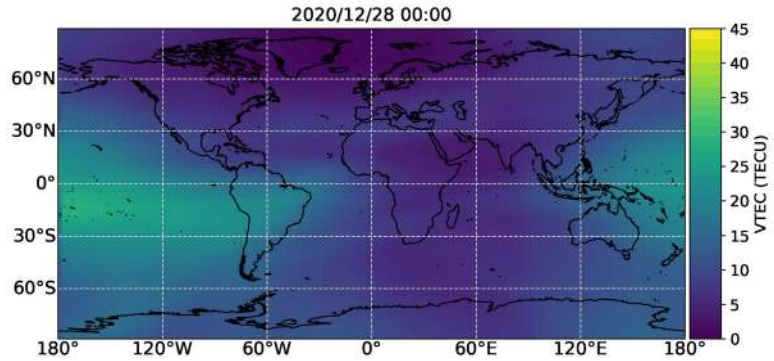
GIM - IGS



ML-based GIMs

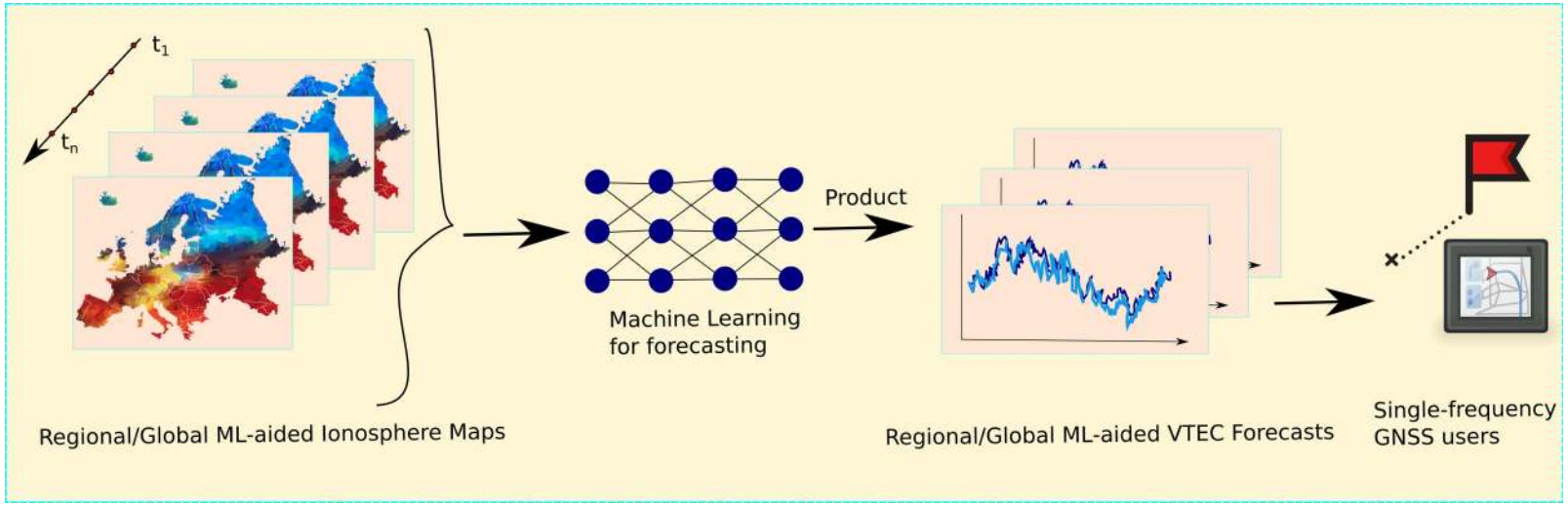


XGBoost



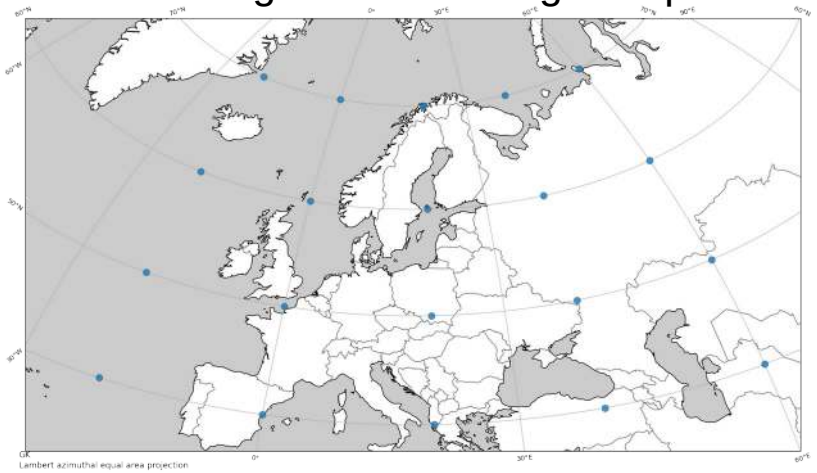
MLP

Data Fusion and Forecasting (Temporal Extrapolation) of TEC (I)

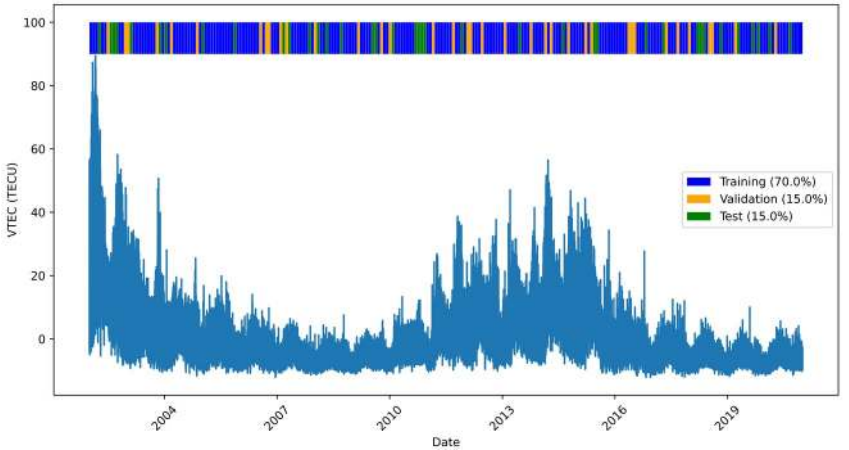


- VTEC forecasting:
  - Model working at a global scale with a satisfactory performance under quiet and disturbed geomagnetic conditions
  - Forecasting up to 24 hours
  - Ensemble models with a point-wise-based TEC forecasting approach (e.g. Cesaroni et al., 2020)

Initial Investigations covering Europe

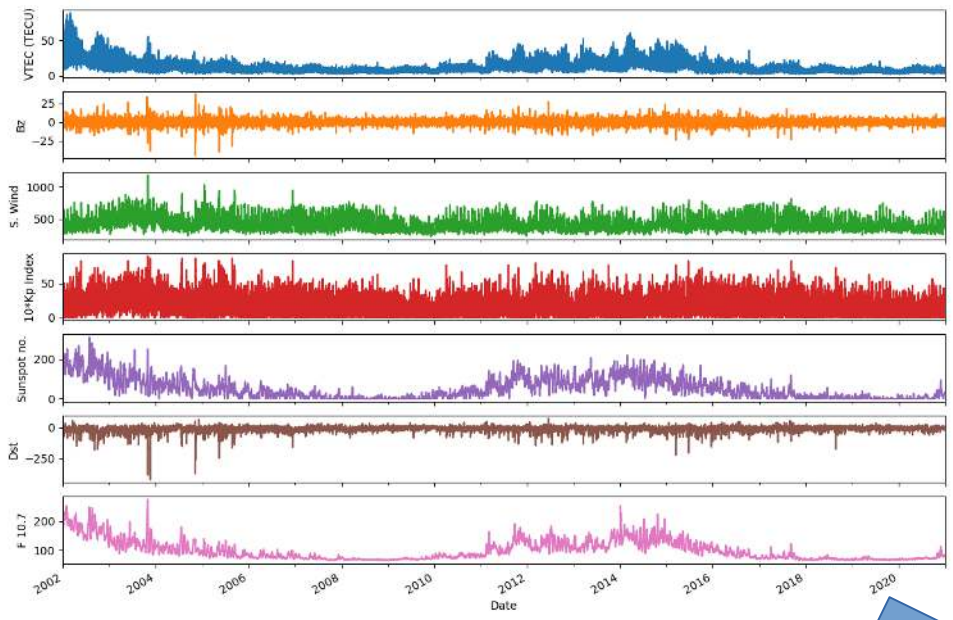


GIM-based point-wise VTEC Time series



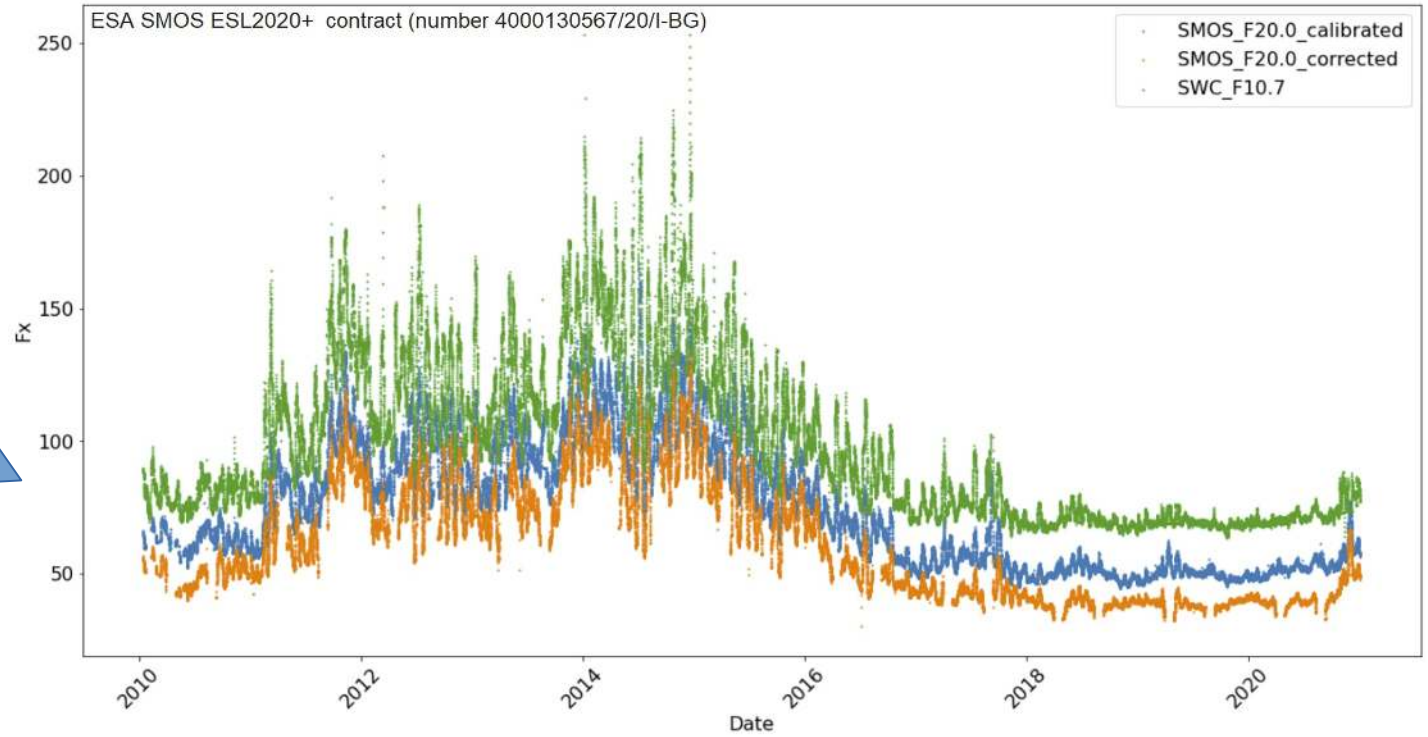
VTEC time series extracted from GIMS for lat. 50 N and lon. 20 E.

Data Fusion and Forecasting (Temporal Extrapolation) of TEC (II)



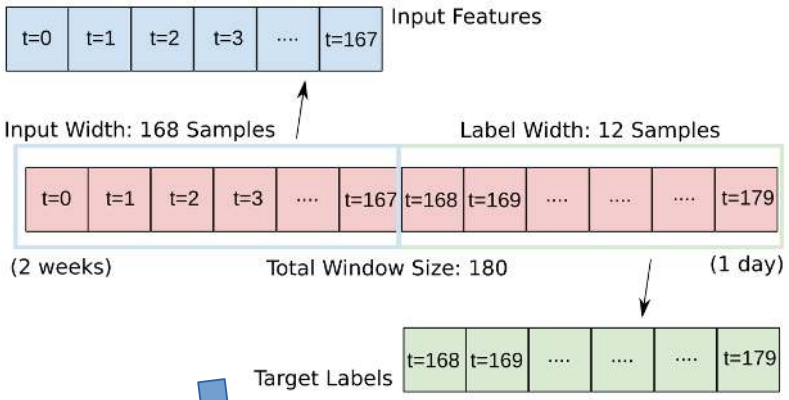
An example time series of the investigated input features.

- SMOS Solar Flux data:
  - Treated as one of the input features for VTEC forecasting

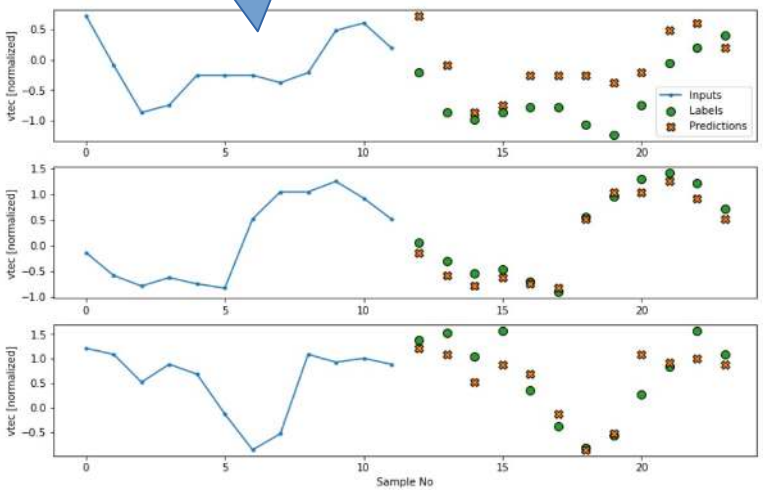


SMOS Solar Flux data in relation to the commonly used F 10.7 indices.

Data Fusion and Forecasting (Temporal Extrapolation) of TEC (III)

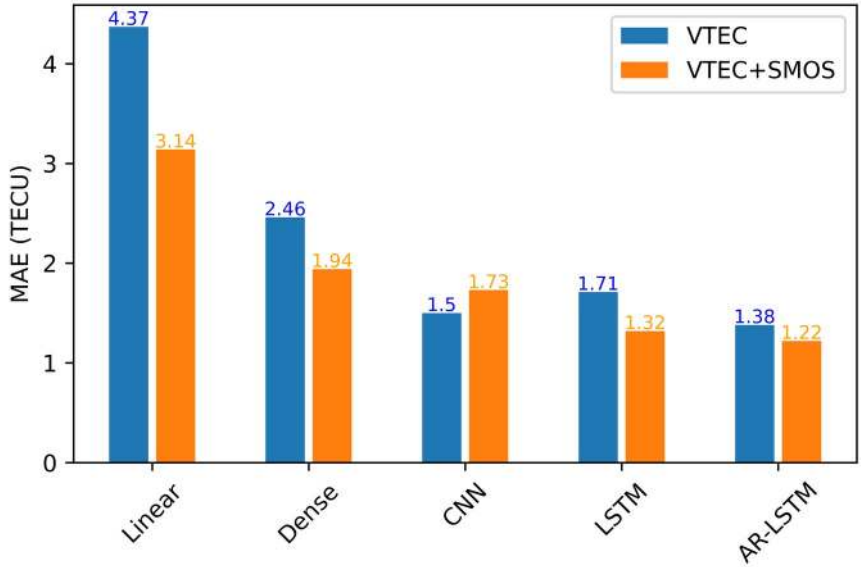


Data windowing for TEC forecasting.



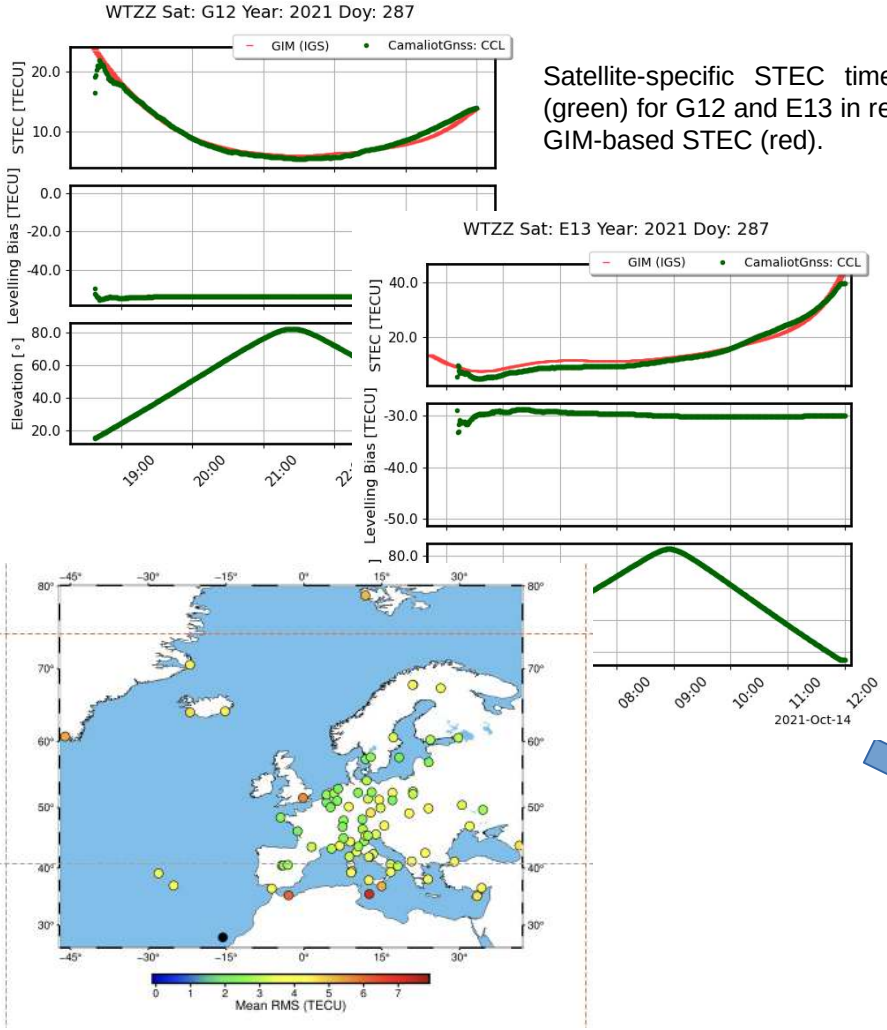
Example of the forecasted VTEC (12 points) based on 168 previous samples (2 weeks).

- Model Training:
  - Utilization of models (LSTM, CNN, …) suitable for forecasting tasks
- Validation:
  - Baseline: ARIMA and repeating the VTEC values from the previous day
- Impact of SMOS flux data on VTEC forecasting (preliminary):



The impact of the SMOS solar flux data on the single-point VTEC forecasting (24 hour window), for a mid-latitude point, expressed as mean absolute error (MAE) when using in conjunction with the VTEC time series as an input feature (orange). In blue, model training, where only VTEC time series are used as input features.

Current Work & Outlook

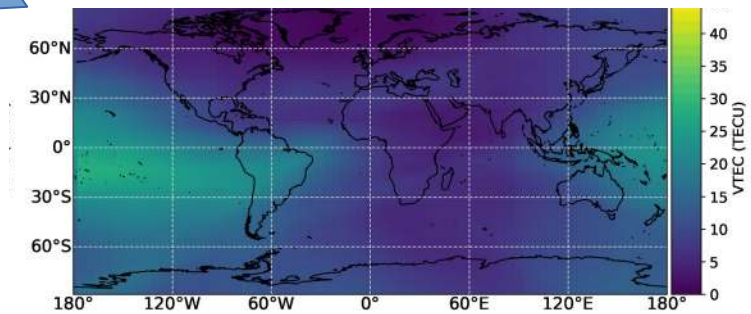


Satellite-specific STEC time series (green) for G12 and E13 in relation to GIM-based STEC (red).

Assessment of the generated satellite-specific VTEC time series. Validation against GIMs. Image credits: S. Mao (Space Geodesy, ETHZ)

- Current work:
  - Refinement and validation of the STEC extraction algorithm and inclusion of multi-GNSS observations (GPS, Galileo, Beidou, QZSS)
  - Currently exploiting Carrier-to-code levelling (CCL), which is not optimal, but implementing approaches utilizing Precise Point Positioning (PPP) for STEC extraction
- **SMOS-based ionosphere products**:
  - An **interesting alternative** to the commonly used indices, which are limited by latency and a temporal resolution
  - Space Geodesy @ ETHZ open for **collaboration** and further **testing**

ML/DL



THANK YOU FOR YOUR ATTENTION!

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