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Machine Learning Model Development for Space Weather Forecast

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Space Weather (SW):

- Varying conditions between the Sun and Earth
- Impacts the technologies (satellites, navigation, communications, power grids)

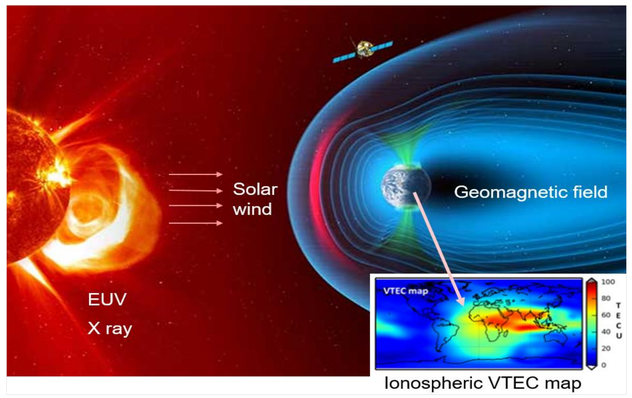

Fig. 1: SW processes. Image sources: ESA (background), DGFI-TUM (VTEC map).

Objectives:

- ML for the SW in the Earth's ionosphere
- Nonlinear functions of SW processes
- Corrections for navigation applications
- An early-warning system

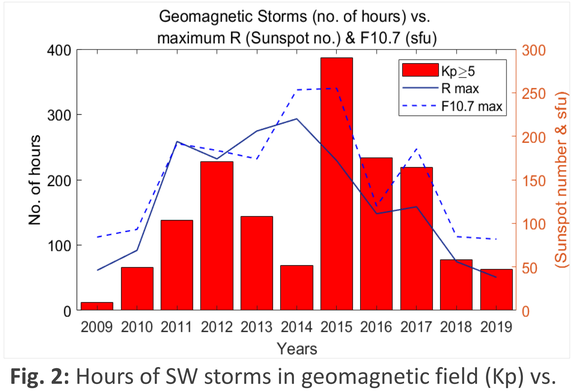

Fig. 2: Hours of SW storms in geomagnetic field (Kp) vs. maximum of solar activity (R and F10.7 indices).

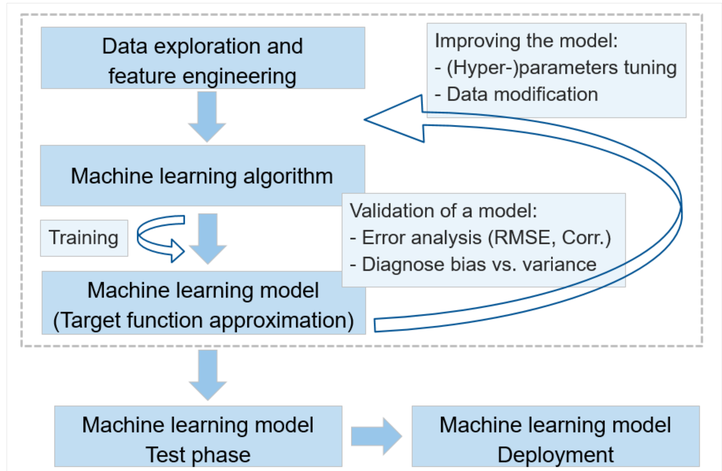

Fig. 3: Machine learning model development workflow

Data:

- ✓ **Inputs** (at time t): solar activity (**R**, **F10.7**), solar wind speed (**SW**), magnetic field (**Bz, AE, Kp, Dst**), time (**Hour** of day and day of year **DOY**), **VTEC** (GIM CODE)
- ✓ **Output** (t+24h): Vertical Total Electron Content (**VTEC**) in the ionosphere at high-, mid- and low- latitudes
- ✓ **Datasets (hourly)**: 1) original data, 2) 24h-differences (diff.) to reduce trends (except time info)
- ✓ **Time-series cross-validation:** 2015-2016, **Test:** 2017

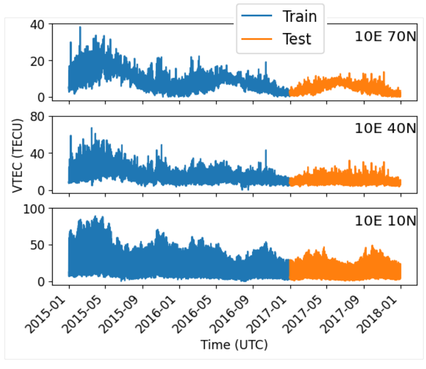

Fig. 4: VTEC for high (70N), mid (40N) and low (10N) latitudes, training and test datasets.

Algorithms: Decision Tree (DT), Random Forest (RF), AdaBoost (AB), XGBoost (XGB), Voting regressor (VR): RF, AB & XGB

Results: 24-hour forecast (test)

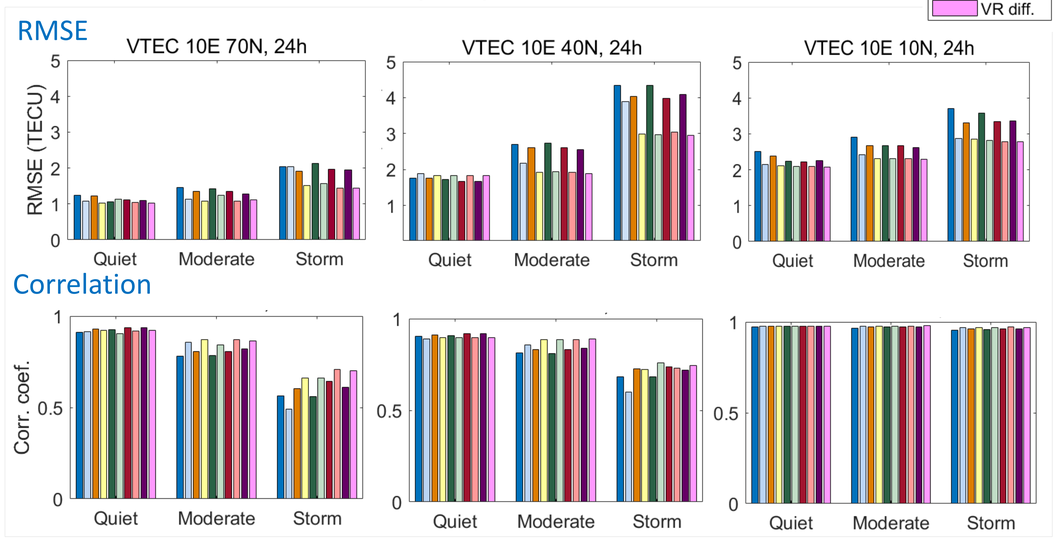

Fig. 5: RMSE (up) and correlation coefficients (bottom) between gound-truth and predicted VTEC for quiet (Kp<3), moderate (3≤Kp<5) and storm (Kp≥5) conditions. Models trained on differences (diff.) provide lower RMSE and higher correlation coefficients during SW storms.

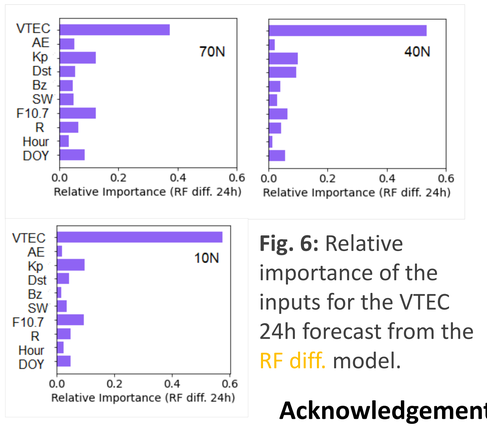

Fig. 6: Relative importance of the inputs for the VTEC 24h forecast from the RF diff. model.

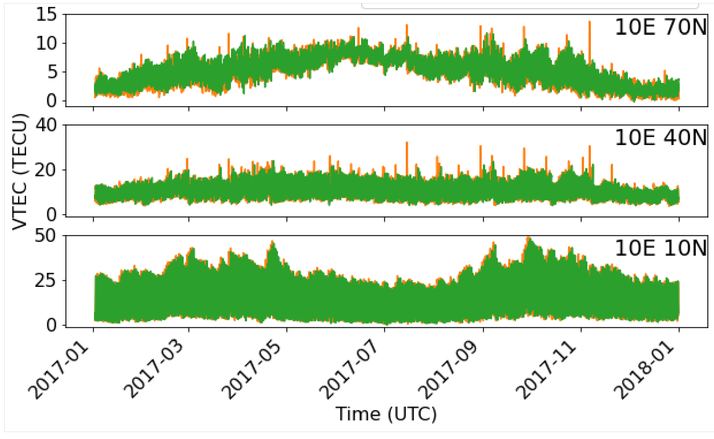

Fig. 7: Predicted VTEC (24h) vs. ground-truth VTEC for 2017 (VR diff.)

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