A Global Machine Learning-based Forecasting Model for Atmospheric Water Vapour sensed by Global Navigation Satellite Systems

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A Global Machine Learning-based Forecasting Model for Atmospheric Water Vapour sensed by Global Navigation Satellite Systems

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1. INTRODUCTION

Global Navigation Satellite System (GNSS) is mostly known for autonomous global positioning, navigation, and timing services. However, since GNSS signals pass the atmosphere while being transmitted from satellites in space to GNSS receivers on Earth, it is also a key tool for **atmospheric studies**.

The signals are delayed and bent when travelling through the atmosphere and this delay can be estimated. The so-called **zenith wet delay (ZWD)** is highly correlated to the atmospheric water vapour content which makes it an interesting parameter with applications in weather monitoring, forecasting and climate research.

In this study, a novel **global ZWD forecasting model** based on machine learning and meteorological data is presented that is able to accurately model and forecast ZWD anywhere on Earth.

2. DATA

Zenith Wet Delay

- **19.260** globally distributed GNSS stations (**Fig. 1**)
- 16.760 training + validation stations, 2.500 test stations
- Temporal resolution: down-sampled to **hourly** resolution

Specific Humidity

- Specific humidity on nine pressure levels: 1000 – 500 [hPa] from post-processed meteorological data (ERA5)
- Spatial resolution: **0.25 degrees**; Temporal resolution: **hourly**
- **Forecasts** of specific humidity from ECMWF's highest-resolution forecast model
- Four forecast runs per day (00/06/12/18 UTC) with **hourly steps** up to step 90 for each run

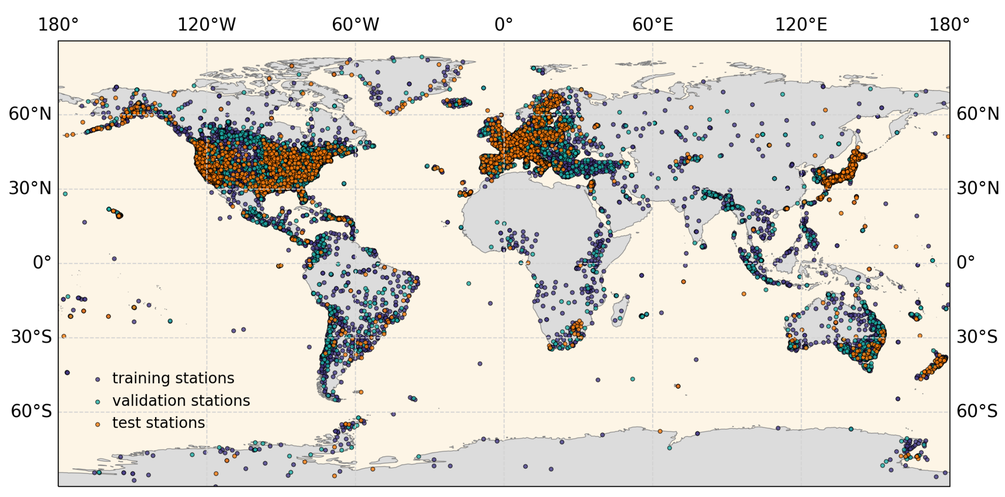

Fig. 1: Distribution of the 19.260 GNSS stations

3. METHOD

- Machine learning algorithm: **XGBoost**
- Target: **ZWD time series** of over 19.000 GNSS stations for the period 2010 to 2021 (training), and 2022 (testing)
- Input features: **GNSS station position, time information, specific humidity on nine pressure levels**
- **Performance metrics**: weighted root mean squared error (WRMSE) between GNSS ZWD and model output
- Evaluation using (1) **ERA5** data and (2) **forecast** data for **different forecasting horizons** from 0 to 48 hours

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4. RESULTS

ZWD predictions

Our model can make **ZWD predictions at any desired location** of the globe. In **Fig. 2** global ZWD predictions for July 1, 2022, at 00:00 UTC based on ERA5 data are displayed. Additionally, the differences between those ZWD predictions, and the ones resulting when using forecast data at a **forecasting horizon of 00, 24 and 48 hours** are depicted.

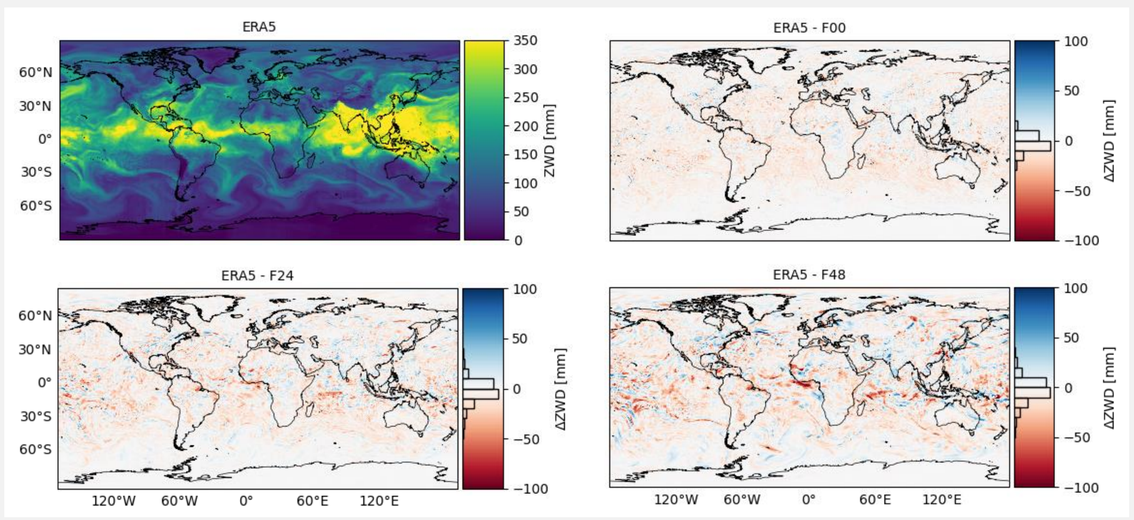

Fig. 2: Global ZWD predictions for July 1, 2022, 00:00 UTC using ERA5 (top left) and its differences when using different forecasting horizons of the forecast data (F00, F24, F48). The histograms in the colorbars represent the distribution of the ZWD differences.

Performance of model

Fig. 3 shows the performance of the test stations for the year 2022 in terms of RMSE for (1) **ERA5** data and (2) **forecast** data.

(1) Applying the model to ERA5 data leads to a **WRMSE of 10.8 mm** for the test data.

(2) Applying the model to forecast data leads to WRMSEs that differs depending on the forecasting horizon (**WRMSE of 10.1 mm** for forecasting horizon of 0 hours and **16.2 mm** for forecasting horizon of 48 hours).

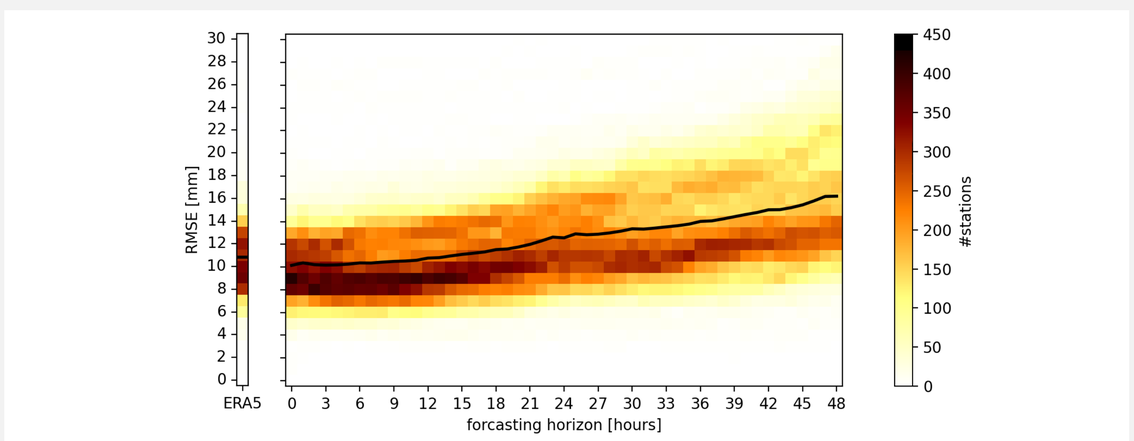

Fig. 3: RMSE [mm] over the test stations for the year 2022, using ERA5 (left) and using forecast data (right). The colors represent the number of stations and the black line represents the WRMSE.

5. SUMMARY

- Global machine learning-based ZWD model was developed that provides ZWD predictions at any desired location on Earth
- **Accurate ZWD predictions** are
  - interesting for meteorological studies
  - required to improve real-time navigation applications
- The model as well as a gridded hourly product is available at the Geodetic Prediction Center of ETH Zurich

Reference:
Crocetti, L., Schartner, M., Zus, F., Zhang, W., Moeller, G., Navarro, V., See, L., Schindler, K., & Soja, B. (2024). Global, spatially explicit modelling of zenith wet delay with XGBoost. In Journal of Geodesy (Vol. 98, Issue 4). https://doi.org/10.1007/s00190-024-01829-2