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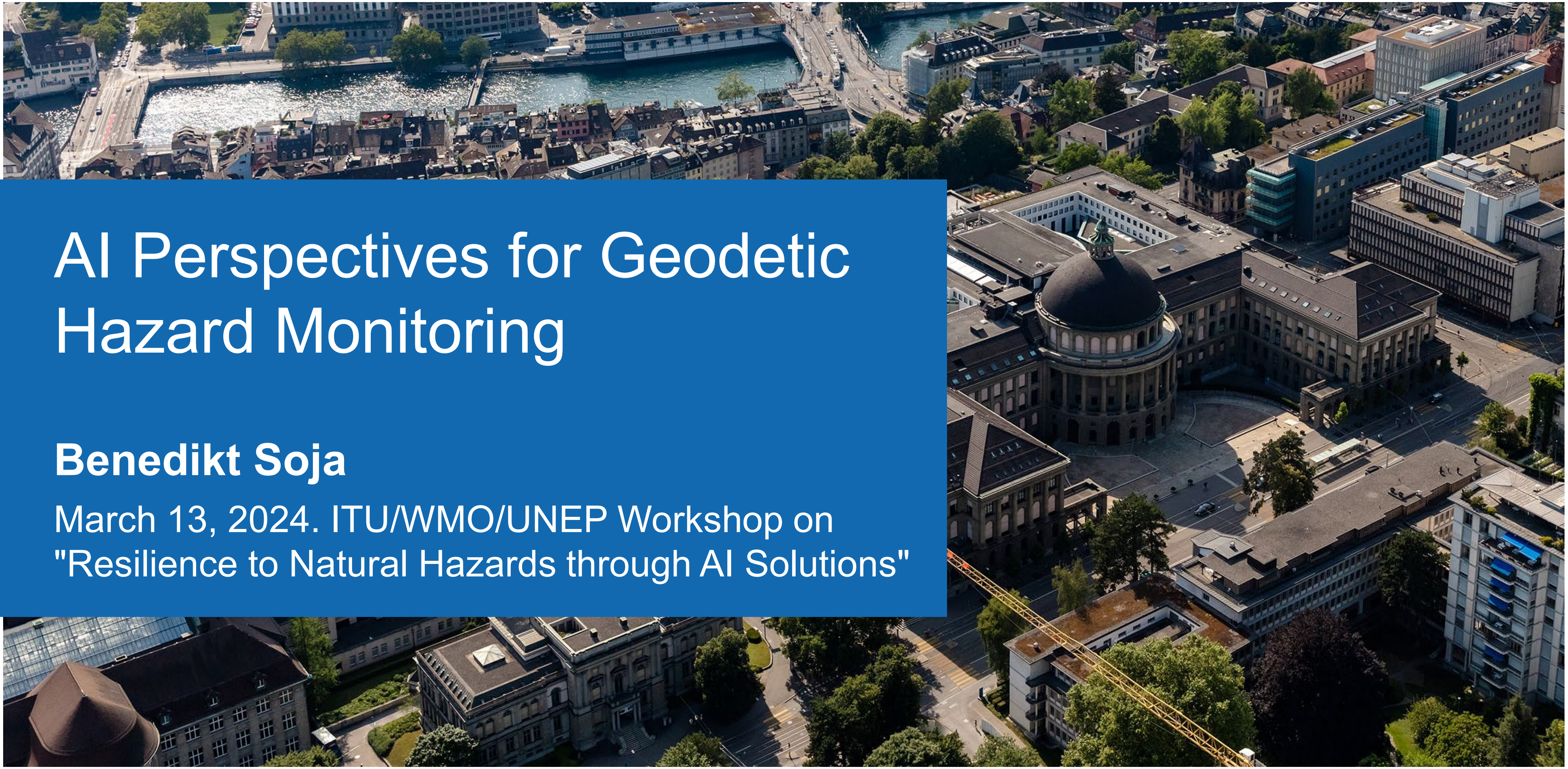
SPACE GEODESY



AI Perspectives for Geodetic Hazard Monitoring

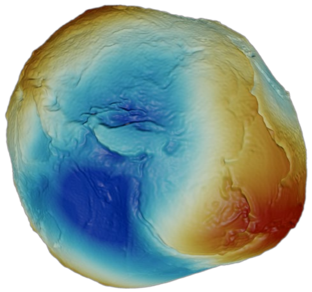
Benedikt Soja

March 13, 2024. ITU/WMO/UNEP Workshop on "Resilience to Natural Hazards through AI Solutions"

Geodesy: measuring the Earth

Geometry

Gravity Field



Orientation in Space

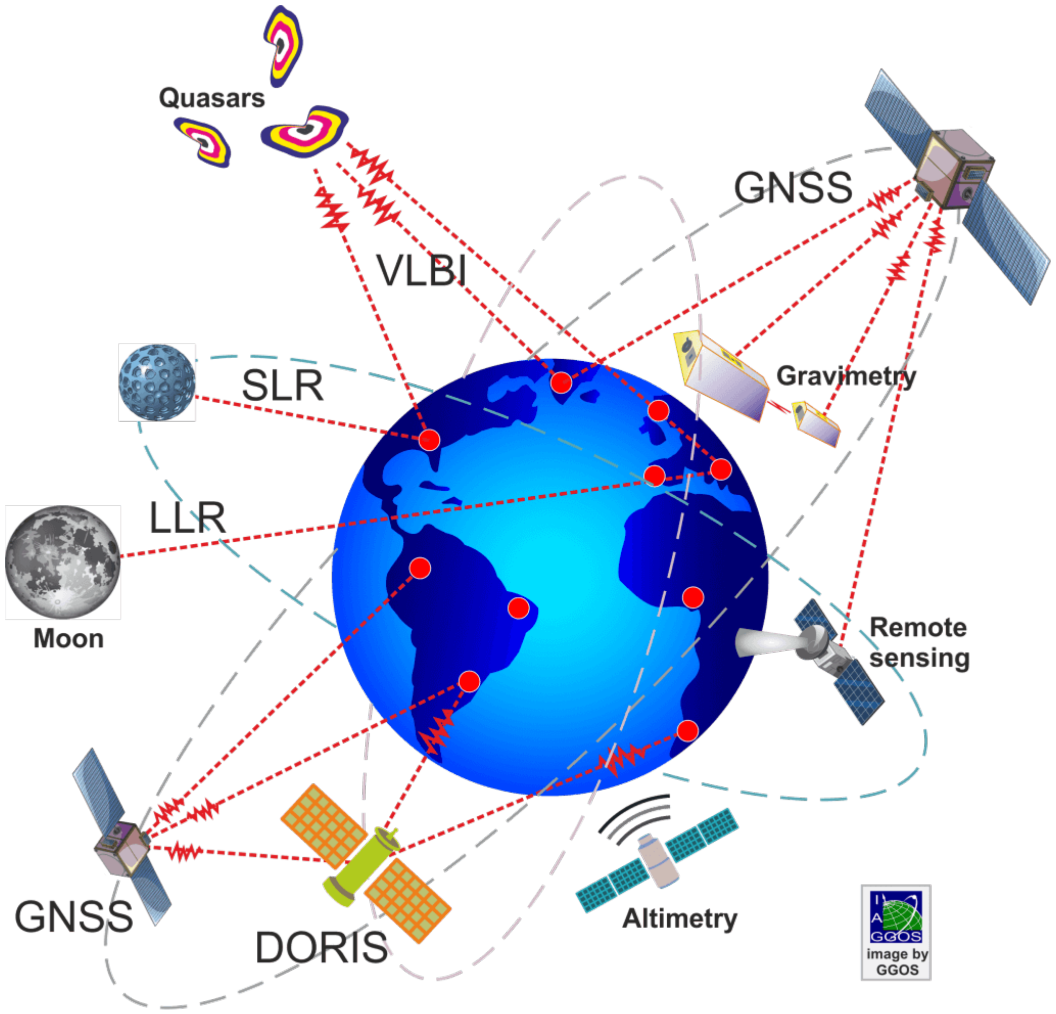
- International coordination of geodetic activities:
  - International Association of Geodesy (IAG)
  - Global Geodetic Observing System (GGOS)
  - Several other entities related to geodesy

Geodetic contributions to hazard monitoring

- Earthquakes
- Tsunamis
- Volcanic activity
- Landslides
- Flooding
- Severe weather events
- Cyclones
- …

Most important geodetic observations for hazard monitoring

- GNSS
  - GNSS remote sensing
  - GNSS reflectometry
- InSAR
- GRACE(-FO)
- …

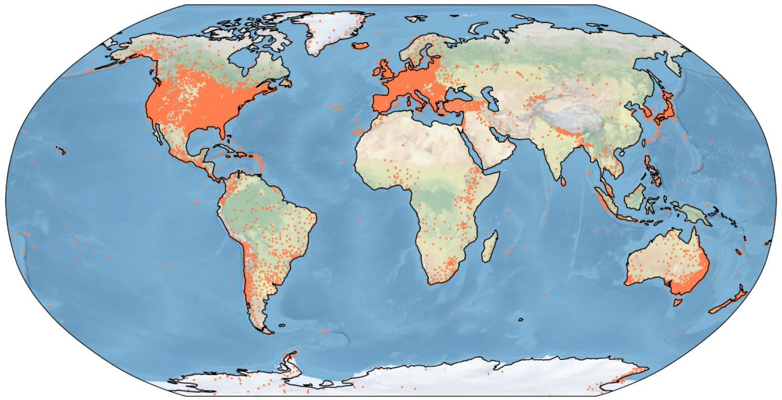


Opportunities for AI in Geodesy

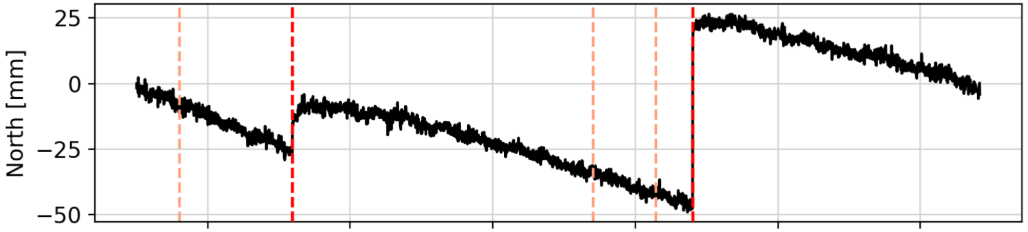
- Geodetic problems very suitable for the application of techniques from the field of AI
  - Detection of anomalies
  - Fusing different geodetic and auxiliary datasets
  - Modeling and prediction of spatio-temporal data

- Data-rich:
  - Huge increase in data volume from GNSS stations, InSAR, etc.
  - Auxiliary data: weather, climate, environmental models, etc.

- Label-rich: data analysis logs, labeled discontinuities



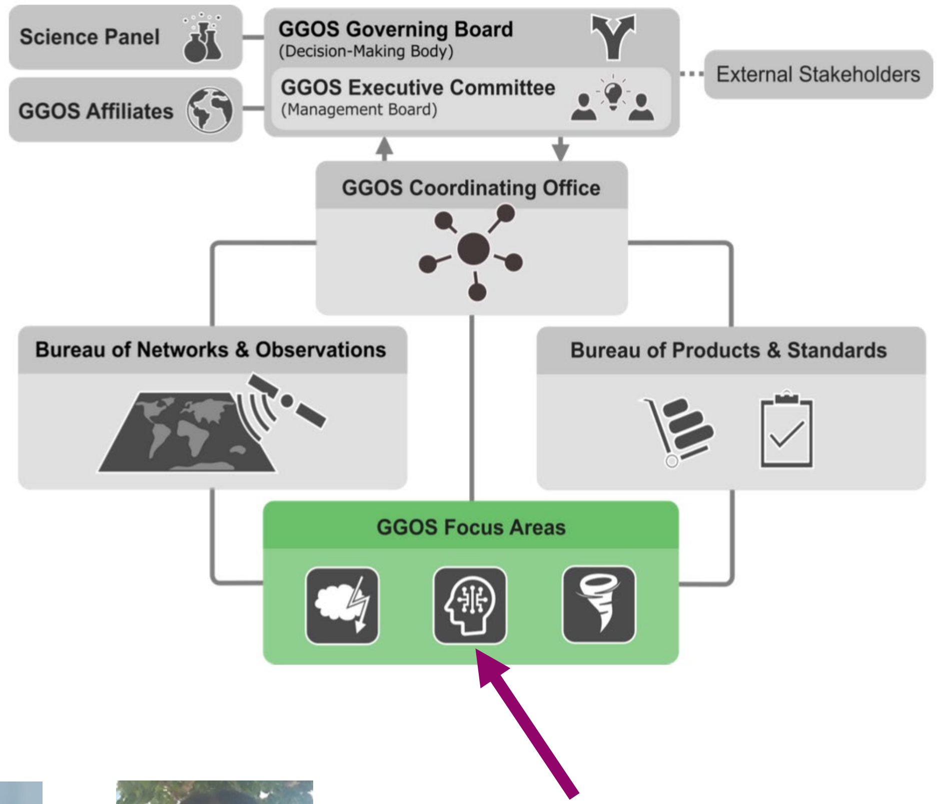
18’000 GNSS stations



IAG components related to the application of AI in geodesy

- GGOS Focus Area: AI for Geodesy (AI4G)
- ICCT JSG T29: Theoretical Foundations of Machine and Deep Learning in Geodesy
- Several other components with close connection to AI
  - GGOS Focus Area on Geodetic Space Weather Research
  - ...

GGOS Focus Area: AI for Geodesy (AI4G)



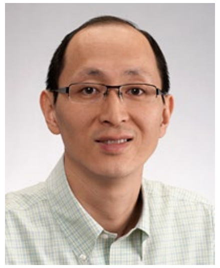
- Goals:
  - **Develop** improved geodetic products based on AI
  - **Evaluate** these products thoroughly → build trust

- Chair: Prof. Dr. Benedikt Soja (ETH Zurich, Switzerland)
- Vice-chair: Dr. Maria Kaselimi (NTUA, Greece)
- 4 Joint Study Groups
- 80+ members

Joint Study Groups of AI4G

- AI for GNSS Remote Sensing


- AI for Gravity Field and Mass Change



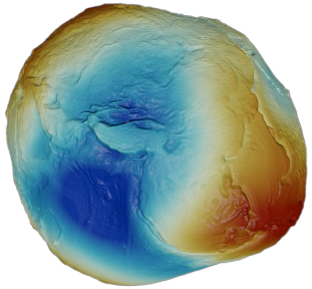

- AI for Earth Orientation Parameter Prediction



- AI for Geodetic Deformation Monitoring


Geometry

Gravity Field

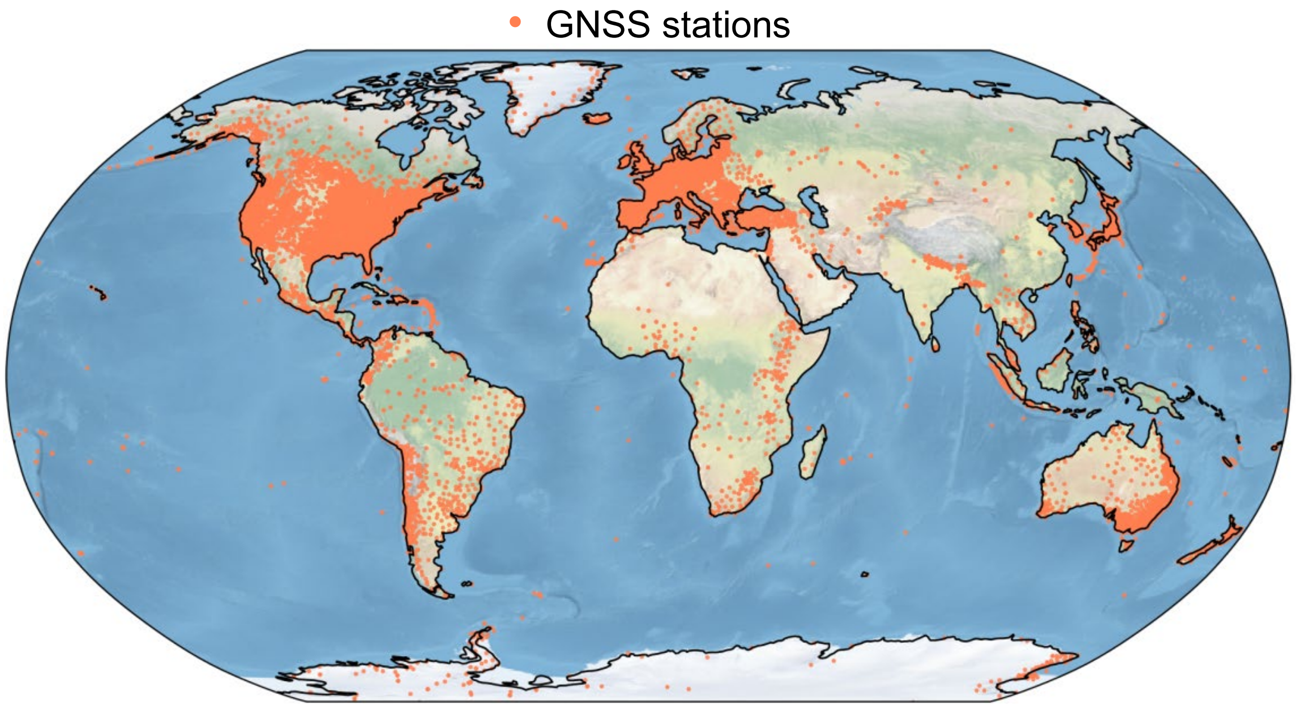


Orientation in Space

Examples of AI for geodetic hazard monitoring

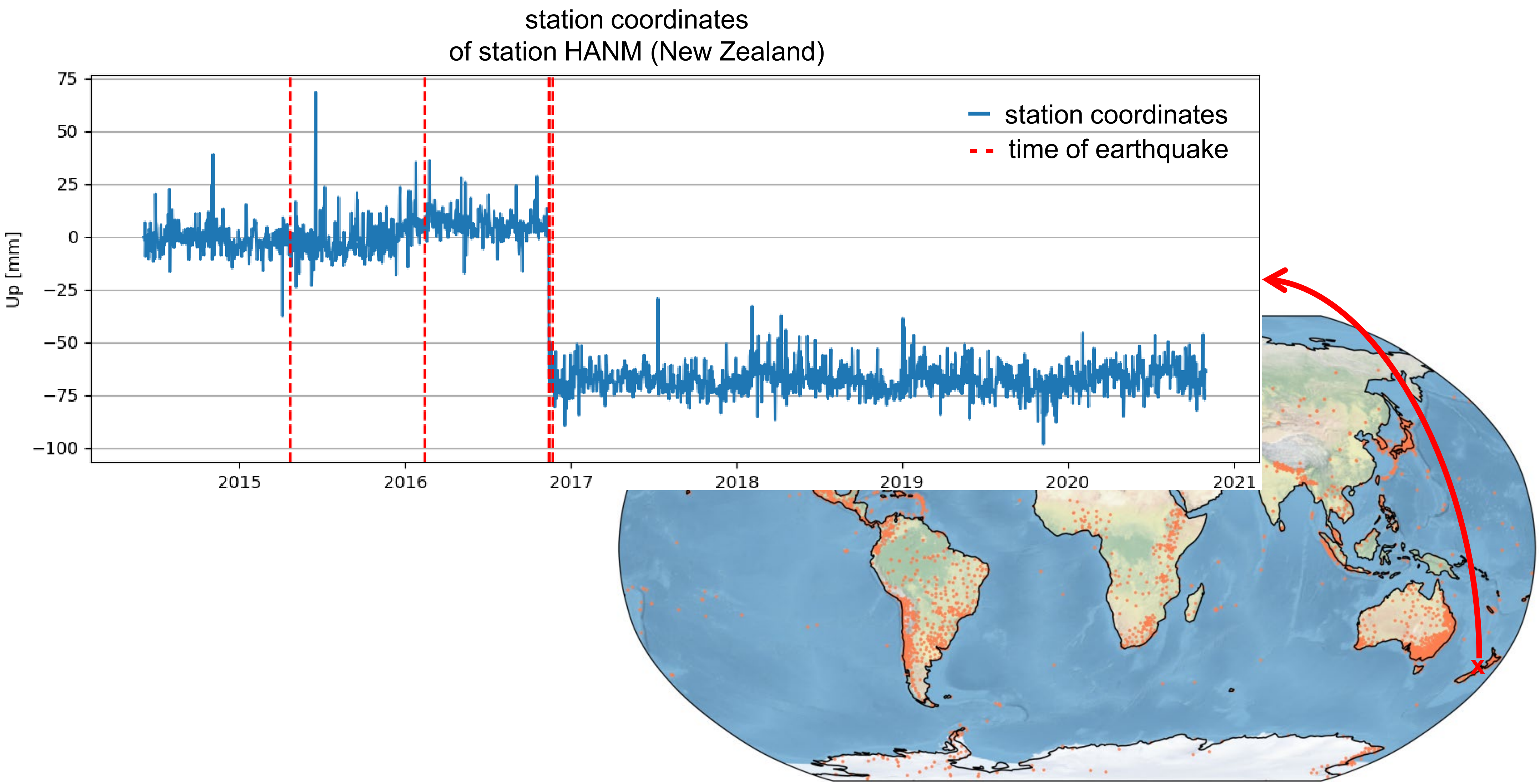
Detection of earthquakes in GNSS station position time series

- Earthquakes cause discontinuities in GNSS station position time series
  - Important to consider when modeling the time series (e.g., estimation of velocities)



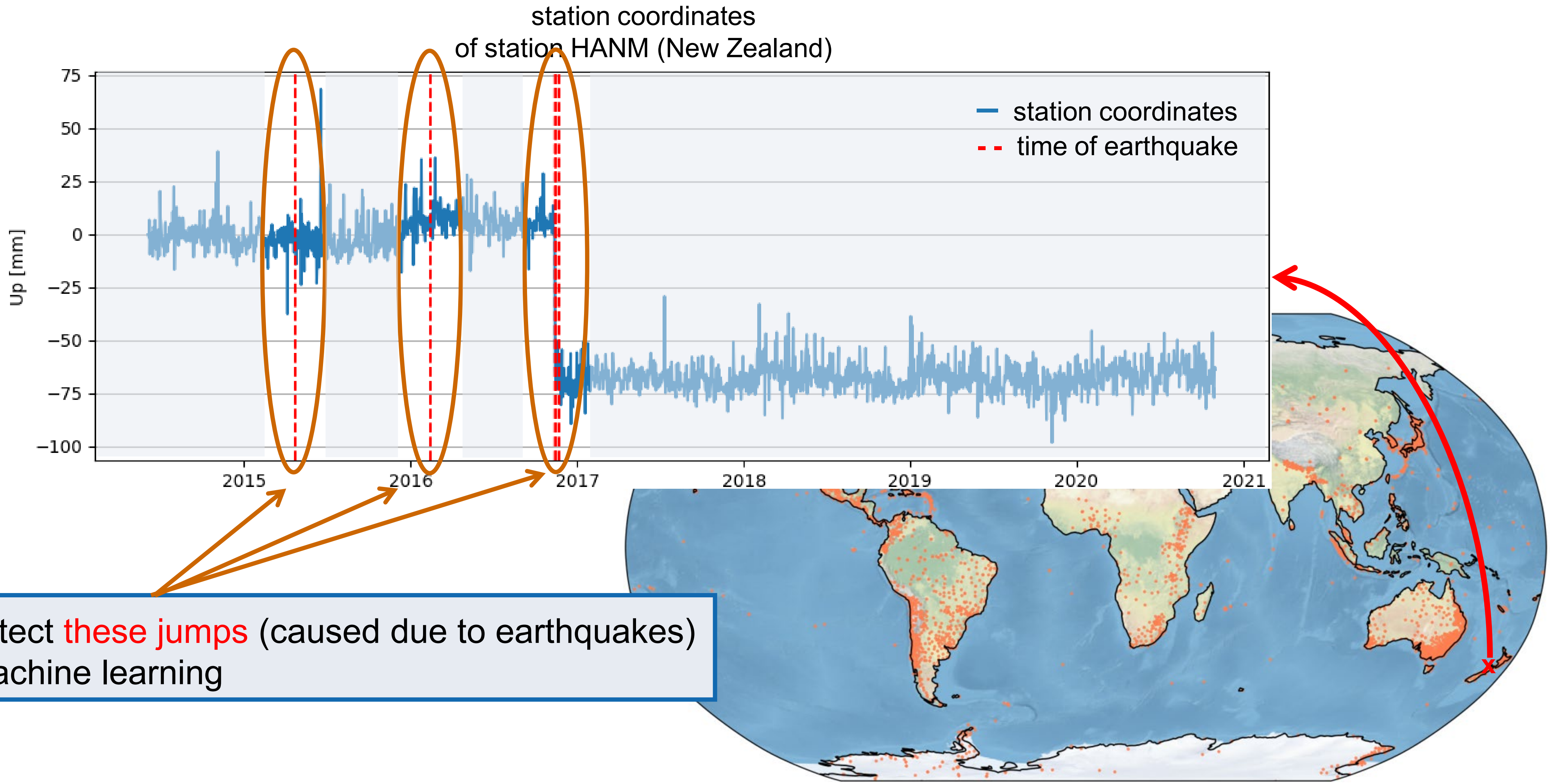
Data Products: Blewitt et al. 2018

Station coordinate time series



Data Products: Blewitt et al. 2018

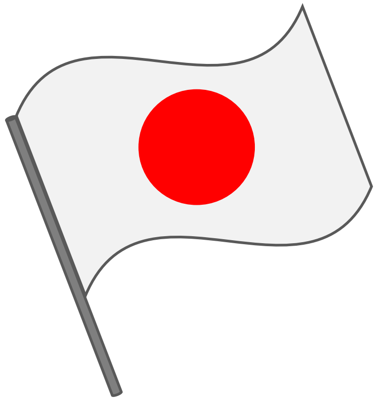
Station coordinate time series



Idea: detect these jumps (caused due to earthquakes) using machine learning

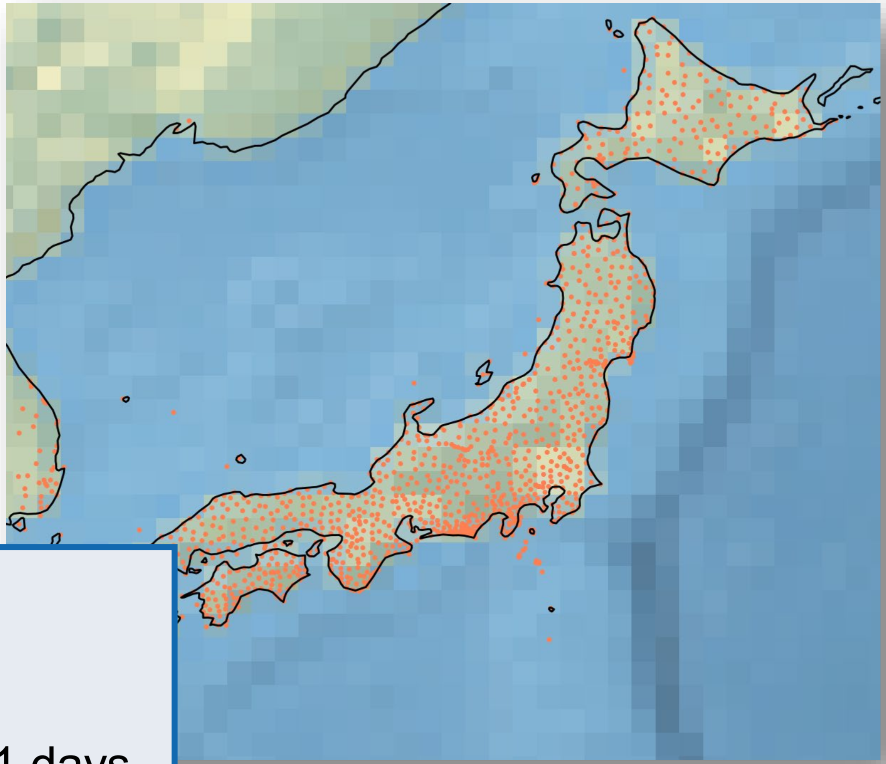
Data Products: Blewitt et al. 2018

Overview of study



Task: classify **EQ causing a jump > 10 mm** based on GNSS station coordinate time series

- Study region: Japan (664 stations)
- Data:
  - daily GNSS station coordinate time series
  - Earthquake (EQ) catalogue → time of EQ is known
- Testing various machine learning algorithms



Data Products: Blewitt et al. 2018

Classification

- Target: EQ causing a jump > 10mm
- Features: station coordinates → chunks of 21 days

High-level overview

GNSS STATION COORDINATES

Pre-processing of data
(outliers, discontinuities, seasonal signal, trend …)

CLASSIFICATION OF EQ CAUSING A JUMP > 10 mm

Target: EQ occurrence (>10mm)
Features: station coordinates (chunks of 21 days)

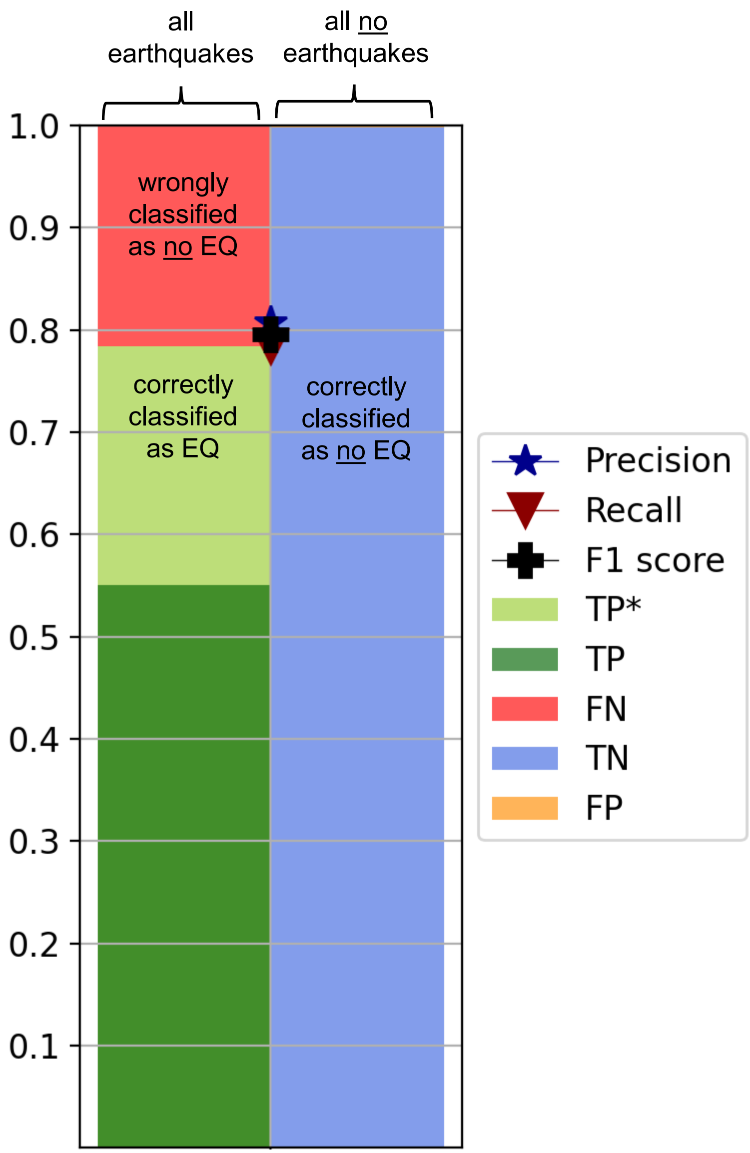
Split data into training and testing stations → Fit machine learning model → Calculate predictions → Validate the model

Results of Random Forest

★ **Precision** → among all detected EQ, **~81%** are truly EQ
▼ **Recall** → among all 'true' EQ, **~78%** are detected correctly
✚ **F1 score** → weighted average of precision and recall (**~80%**)

True Positives ☺ → EQ correctly classified as EQ (**~78%**)
False Negatives ☹ → EQ wrongly classified as no EQ (**~22%**)

True Negatives ☺ → no EQ correctly classified as no EQ (**~100%**)
False Positives ☹ → no EQ wrongly classified as EQ (~0%)

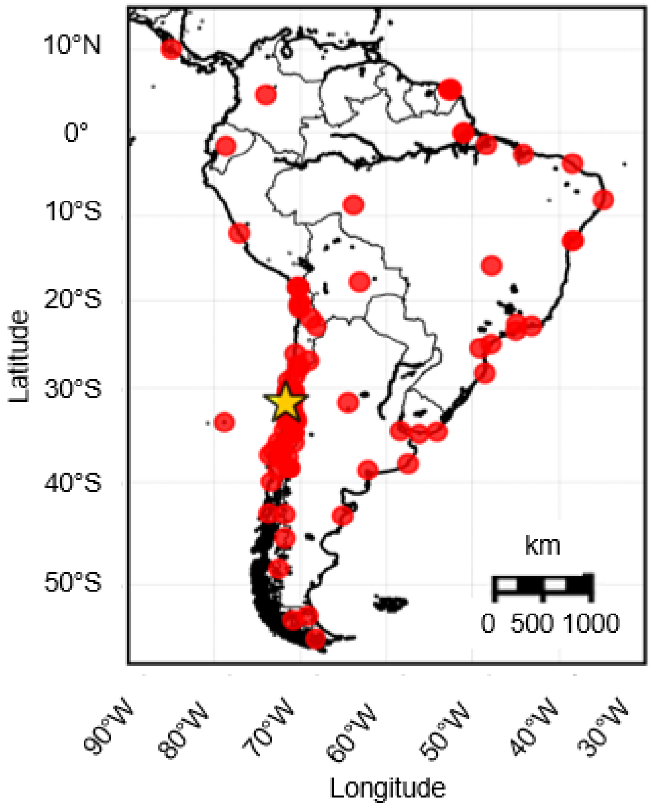


Crocetti et al., 2021

Detection of earthquakes and tsunamis via the ionosphere

- Strong earthquakes and tsunamis can cause traveling ionospheric disturbances (TIDs)
- Potential of TIDs in early warning systems highlighted by NASA-JPL GUARDIAN system

- Case study: Illapel earthquake (2015)
- Machine learning approach to detect TIDs
- GNSS data processing with VARION
- ML model trained with data from 25 station-satellite links



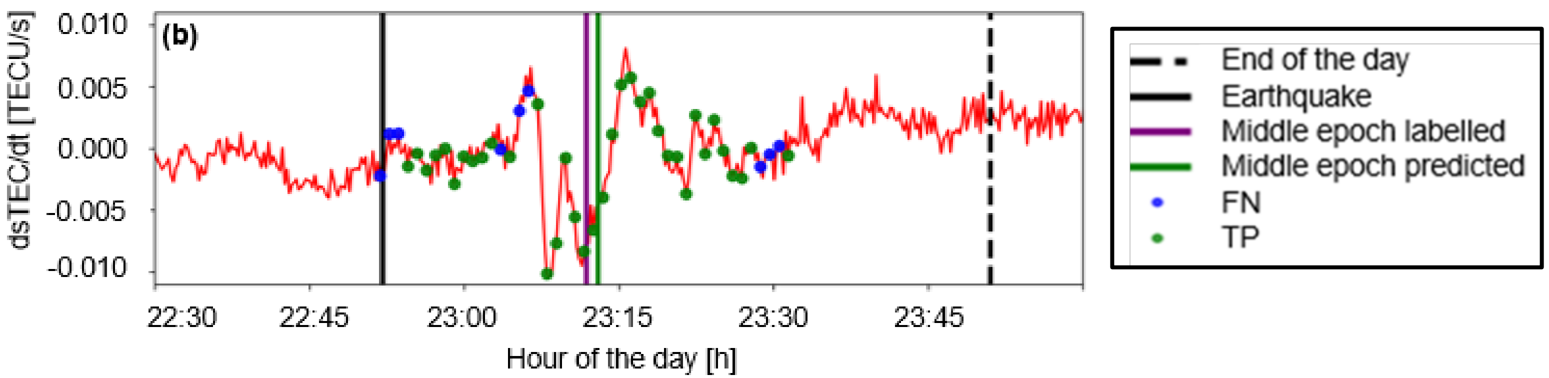
Classification performance

- ML model tested on 6 station-satellite links with TIDs and 18 links without TIDs
- Best performing model: XGBoost
- Approach could be applied in real-time with minor modifications

Average metrics over test set

	XGBoost
Precision	0.80
Recall	0.74
F1 score	0.77
Time diff.	75 seconds

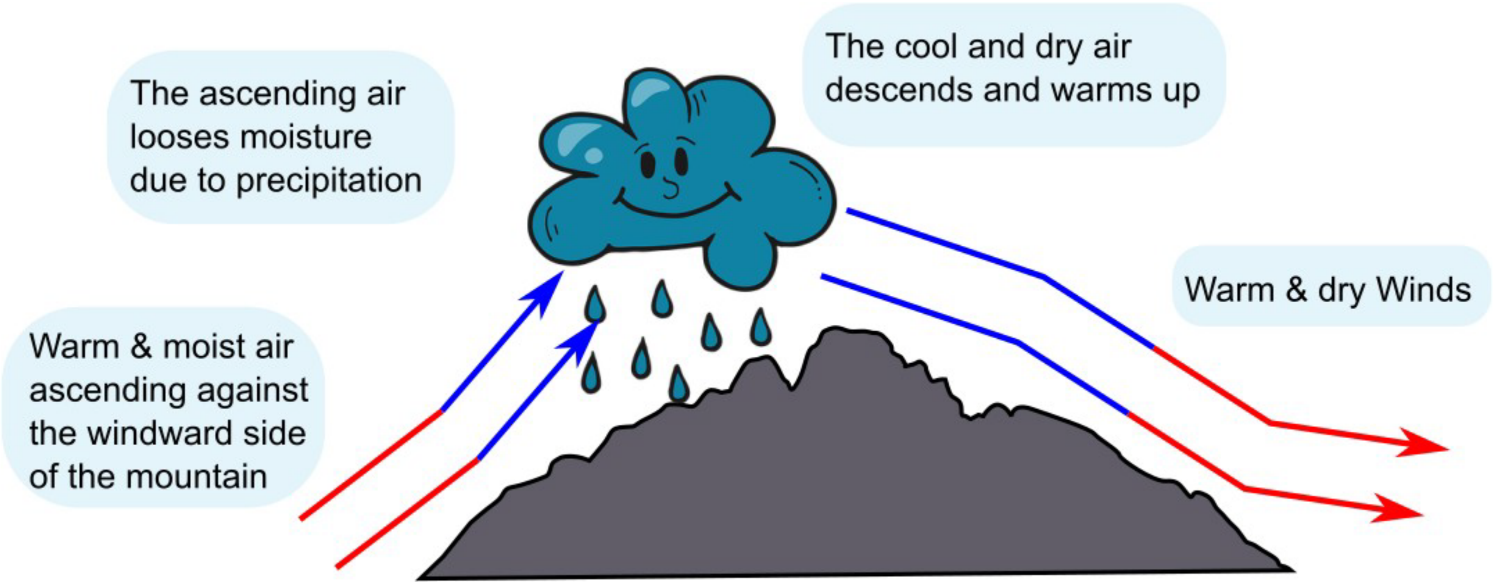
Test station UDAT



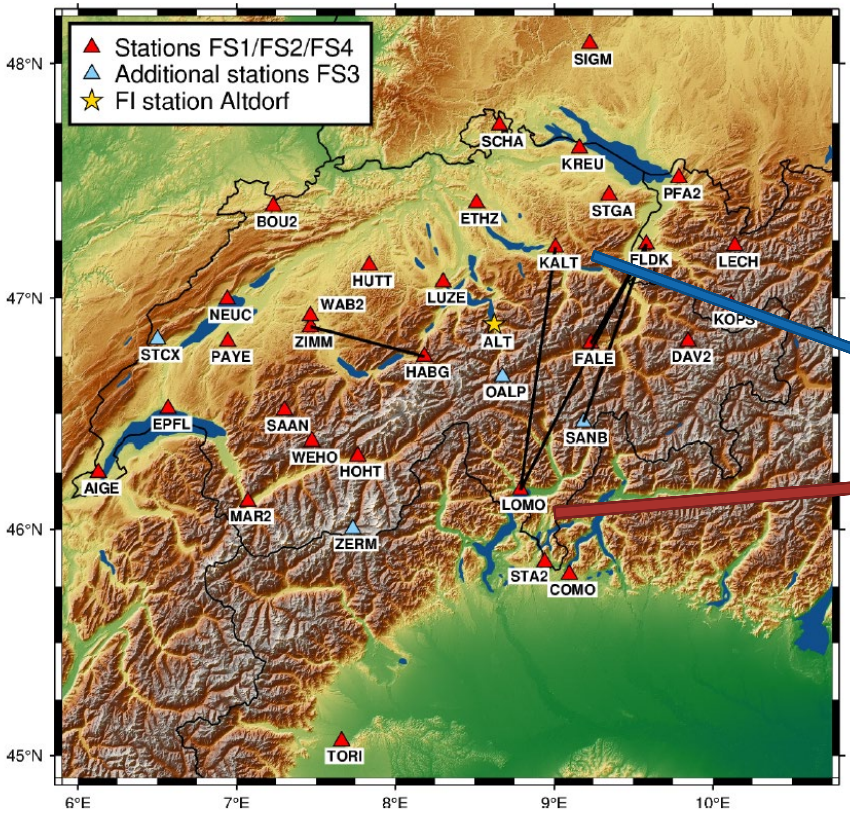
Fuso et al., GPS Solut., minor rev.

Detection of strong wind events with GNSS

- Alpine foehn: weather phenomena characterized by strong and warm winds
- Typical in mountainous regions
- Foehn events visible in meteorological data → Foehn index (FI)

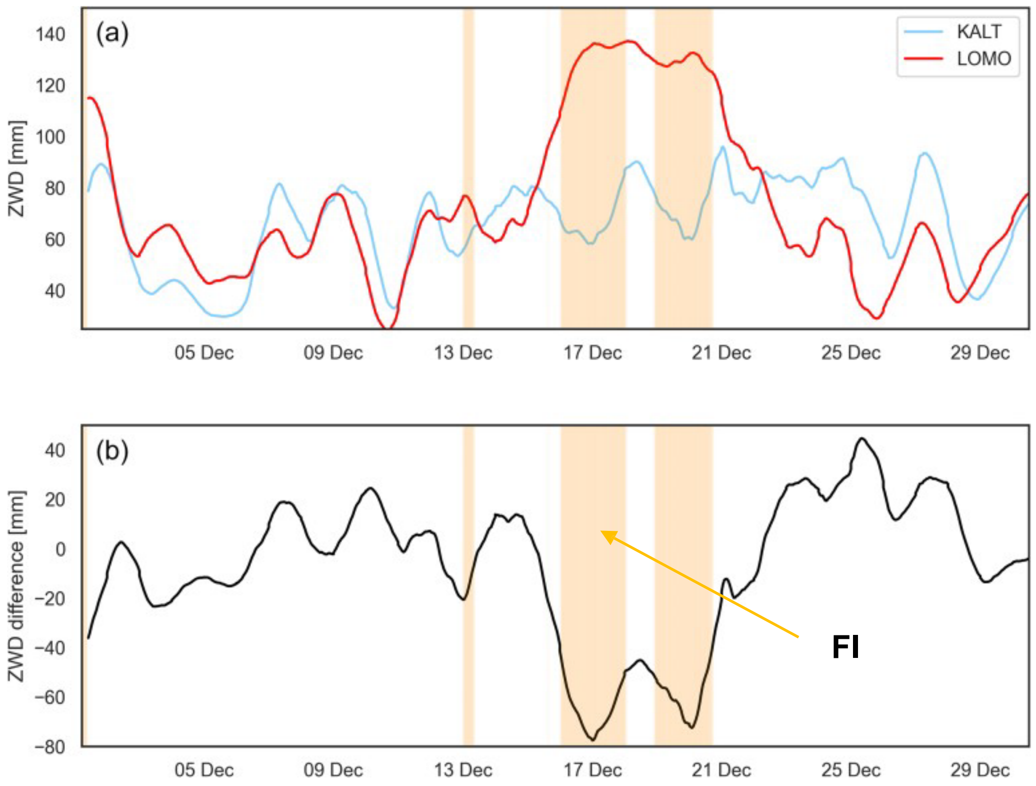


Alpine foehn visible in GNSS data?



Challenge: GNSS not sensitive to wind

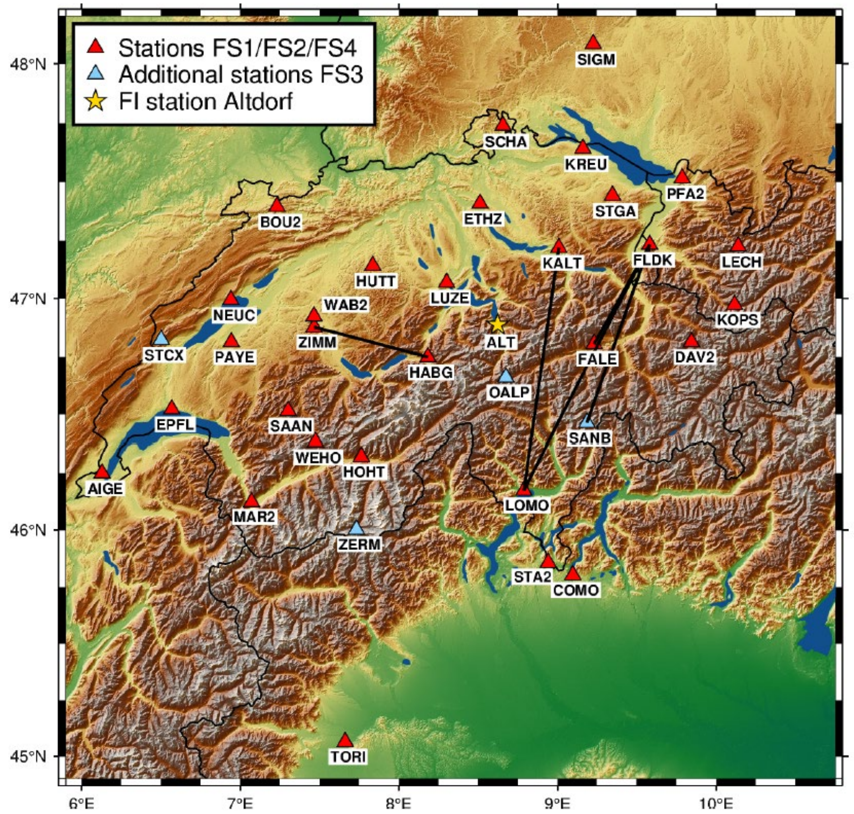
Goal: machine learning for foehn detection



Machine learning to detect Alpine foehn in GNSS data

- Methods:
  - Gradient boosting (GB)
  - Support vector classifier (SVC)
- Input data:
  - ZWD and ZHD (and their differences)
  - Tropospheric gradients
- Target data:
  - Foehn index at station Altdorf, CH

- Training: 2010-2018
- Test: 2019-2020

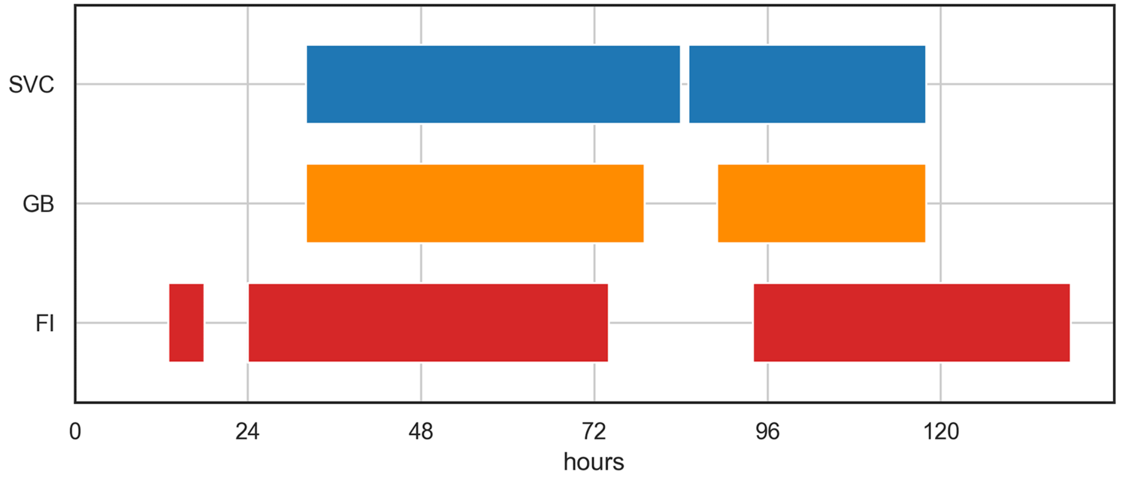


Machine learning to detect Alpine foehn in GNSS data

Method	Probability of detection	Correct alarm ratio	Average
GB	0.753	0.764	0.758
SVC	0.804	0.663	0.733

- Main result: GNSS-based alternative to FI
- Possible in near real-time with slightly worse performance

Example:

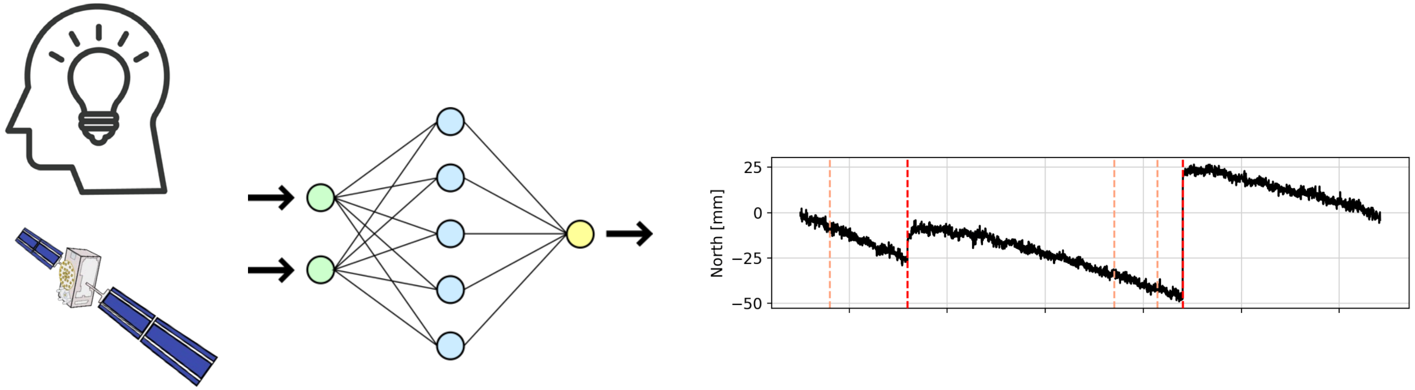


Aichinger-Rosenberger et al., Atmos. Meas. Tech., 2022

AI perspectives for geodetic hazard monitoring

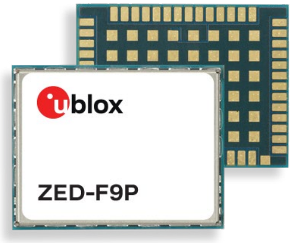
AI perspectives for geodetic hazard monitoring

- AI offers a powerful new way to detect patterns and anomalies in geodetic data
  - …including those related to hazards!
- AI has significant potential to issue early warnings or at least offer an indication
  - Final decision could still be made by humans
- Domain knowledge will always be essential



AI perspectives for geodetic hazard monitoring

- Increasingly difficult to properly exploit the available geodetic data
  - Efficiency of deep learning algorithms could become a necessity
  - Accelerated by low-cost sensors and smallsats




- Trust & interpretability will be essential in the acceptance of AI results
  - Explainable learning
  - Uncertainty quantification
  - Feature importance
  - Physics-based learning

Conclusions

- Geodesy contributes significantly to hazard monitoring
- AI with great potential to improve upon current approaches to hazard monitoring
  - Successful applications of AI in anomaly detection problems
- Further opportunities with the growing amount of data
- Importance of trust and interpretability of AI

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Thanks for your attention!