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Convolutional neural network-based approach for estimating ionospheric delay from GNSS observables

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The ionosphere and GNSS frequencies

- The Ionosphere is a highly variable error source
  - Few meters up to few tens of meters in extreme conditions
- Can be mitigated if the receiver has Multi-frequency capabilities
  - Ionosphere Free (IF) combination
- Can also use broadcast models to reduce the effect of ionosphere
  - Slow update frequency, thus slow to react to fast changes
- Or use global models
  - Might not suit local conditions
- Our aim is to train a Machine Learning model to estimate and later predict local ionospheric delay from GNSS observables

Ionospheric delay (ID) estimates

Input data: RINEX

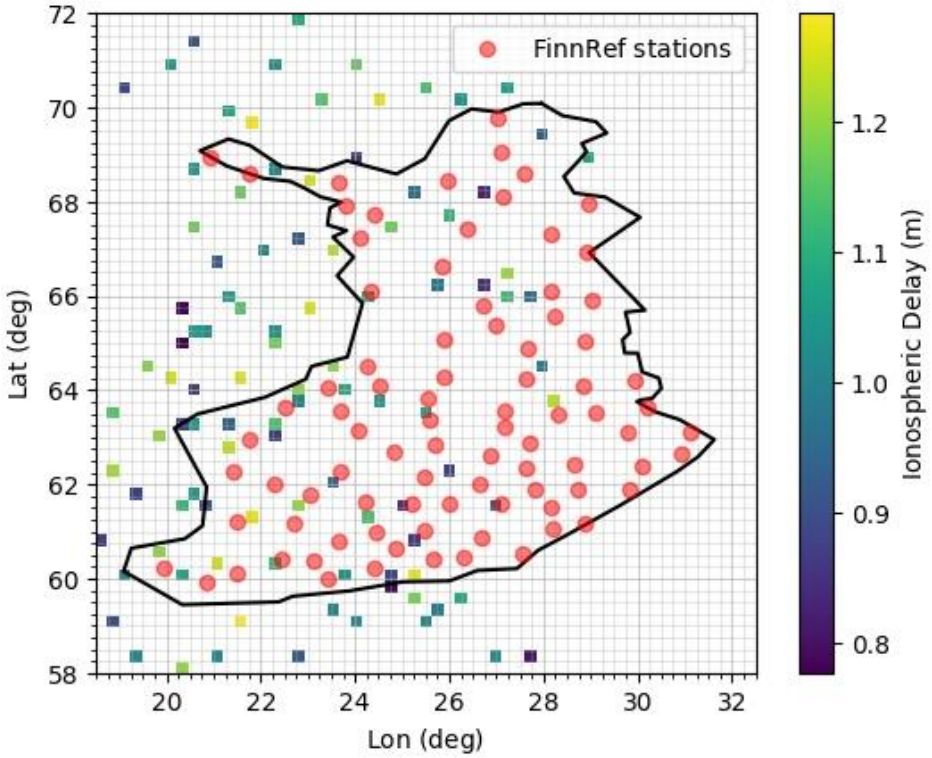
- Three months of data from FinnRef monitoring station network
  - 30 second time resolution
- Create a grid with cell size of 0.25 * 0.25 degrees (57x57 pixels)
- Two frequency Geometry Free (GF) combination with L1 and L2 signals
- Estimate the ionospheric pierce point (IPP) and compute the GF estimate if the IPP is within the grid

Target data: IONEX

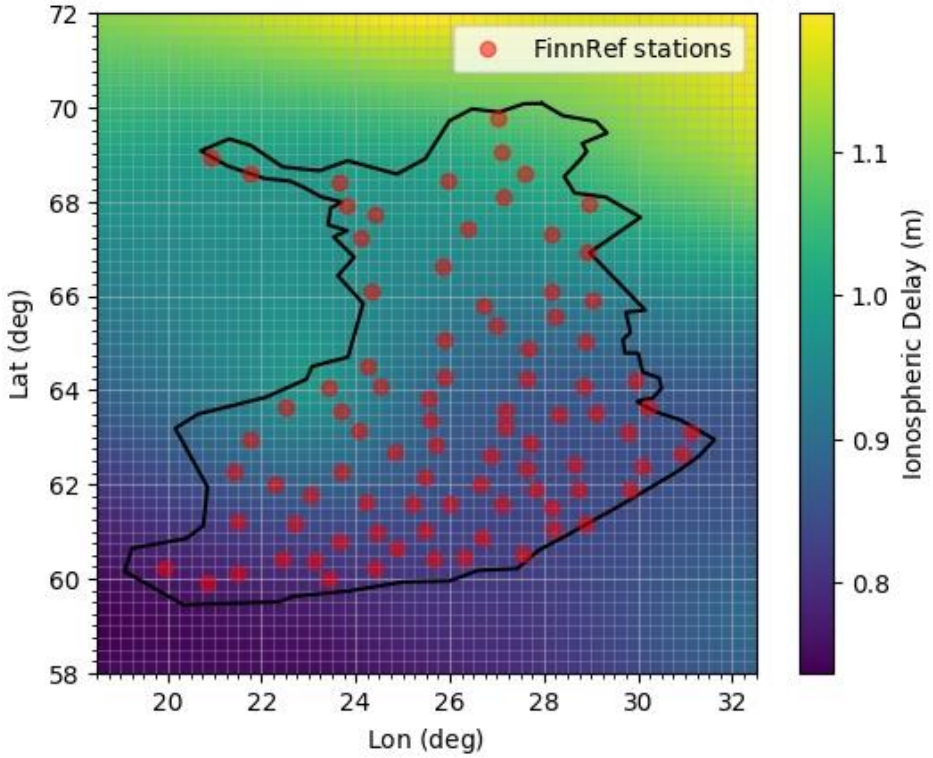
- IONEX maps computed by CODE covering three months
- Native cell size of 5 * 2.5 degrees and time resolution of 1 hour
- The maps are interpolated to a grid of 0.25 * 0.25 degrees with a time resolution of 30 seconds
- Rotate the maps to consider the correlation between the Sun's position and ionosphere

ID Samples

Input data: RINEX

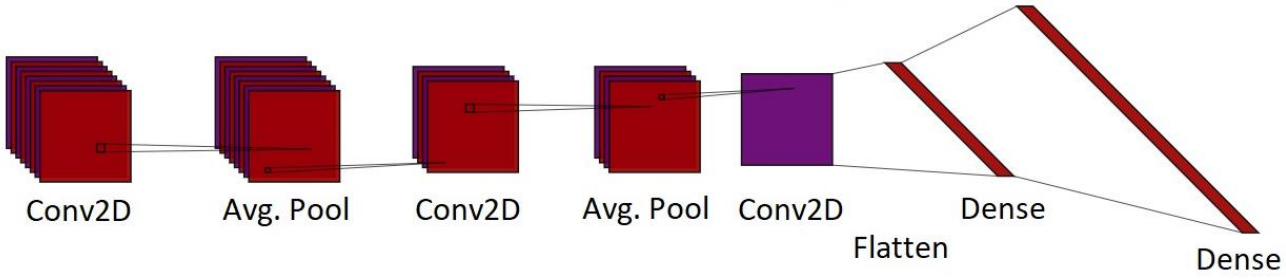


Target data: IONEX



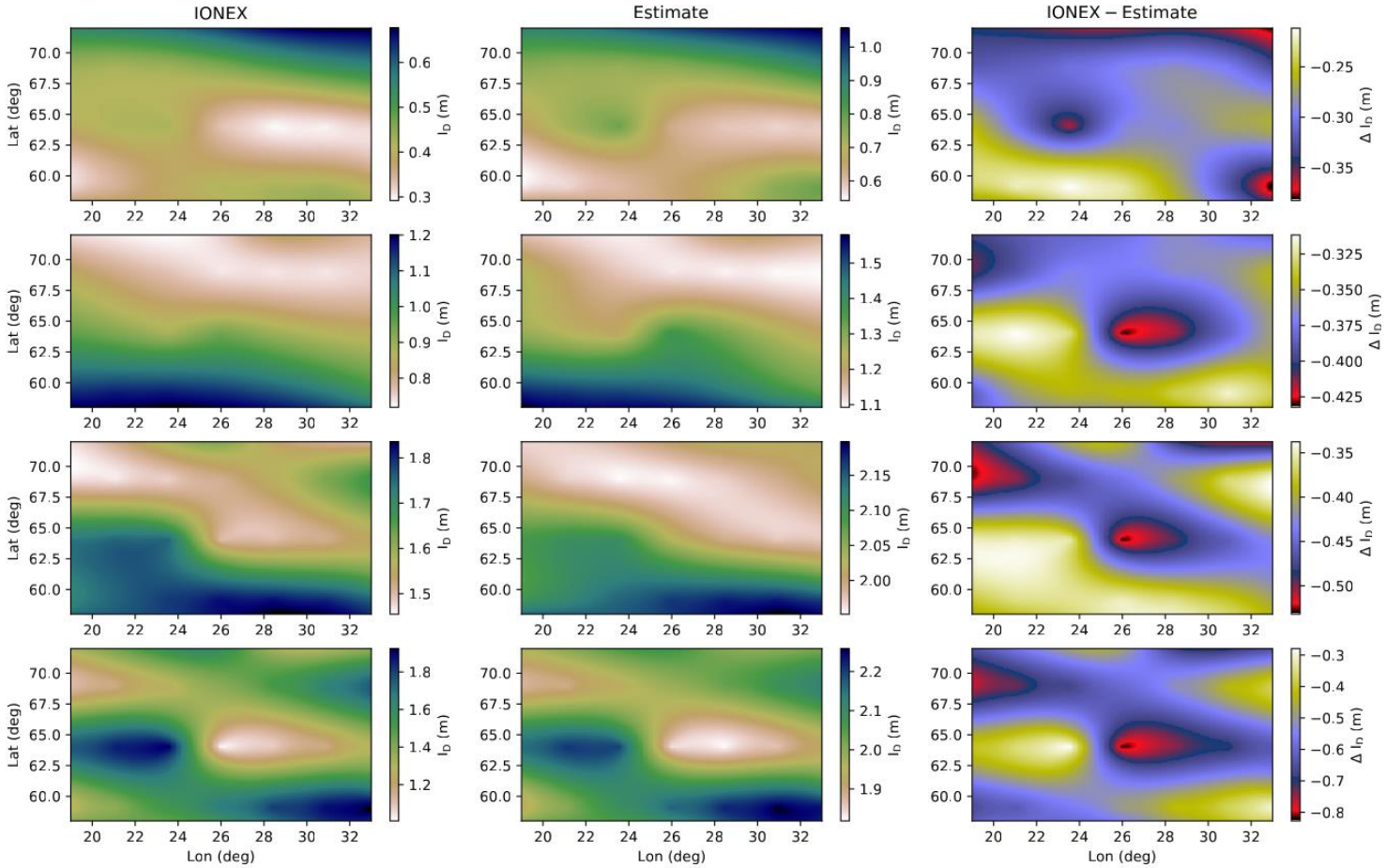
CNN-model

- Written in Python, using keras and Tensorflow libraries
- Model consists of three Conv2D layers with average pooling layers and two fully connected dense layers, with 100 and 3249 units, respectively
- Optimizer: ADAM
- Activation function: ReLU
- Before training: both input and target data scaled to a range [0,1], with any missing values set to -1



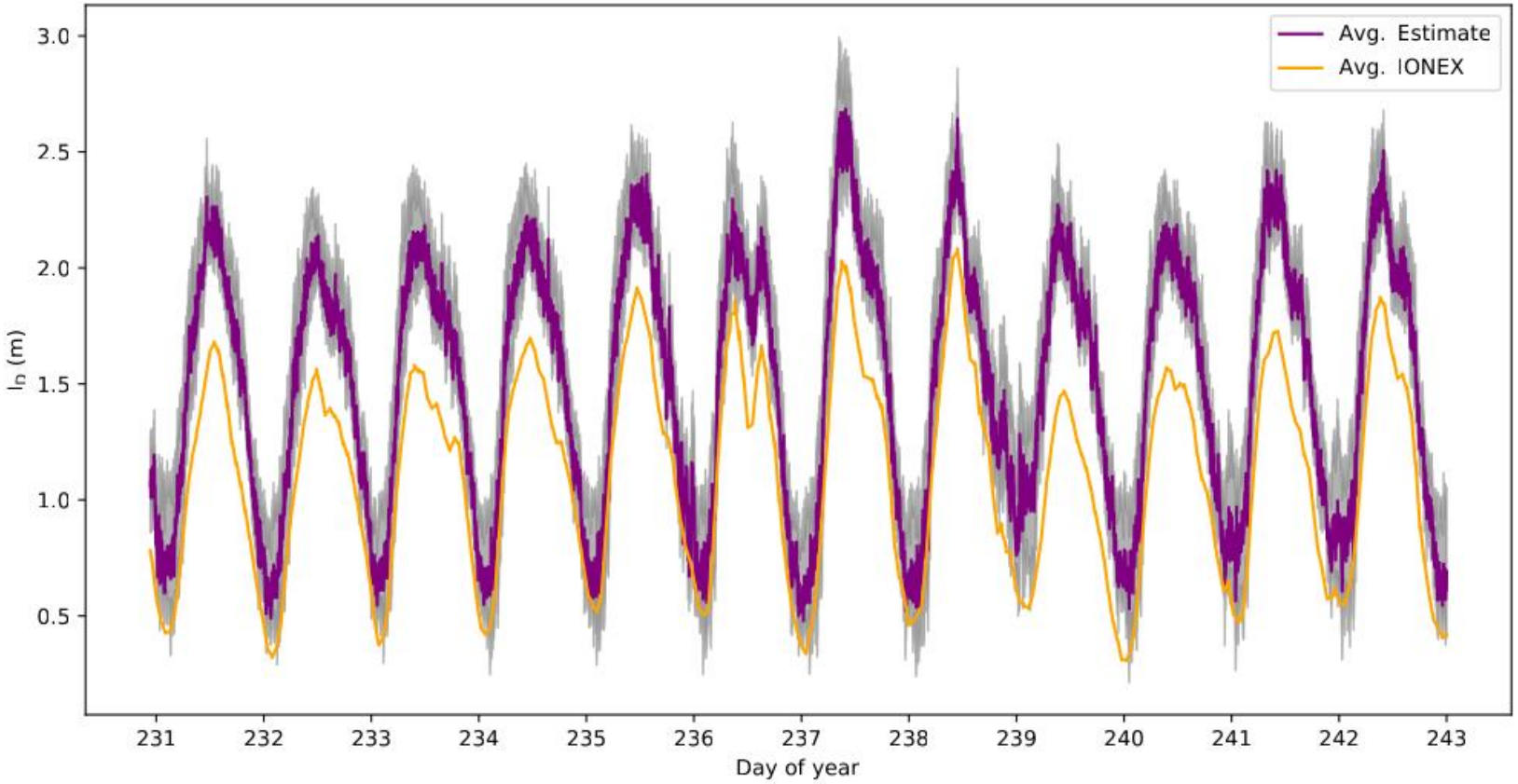
ML-model performance against IONEX

- The shape of the estimated ionosphere and the IONEX are similar
- The estimated maps show a higher ionospheric delay
  - Expected as IONEX maps are smoothed
- The estimated maps have point like structures
  - Possible artefacts caused by numerical effects



ML-model performance against IONEX

- Data shown is from the validation data-set
- Nighttime / daytime variation is well captured
- ‘Fast’ daytime variations can be somewhat traced
- Model estimates are clearly overestimated compared to the IONEX
- Variance of the estimated ionospheric delay large, especially during nighttime



Future Work:

- The current model is just a simple CNN: The temporal dependency of the data is not taken into account during training
  - Update the model to use Time-Delay Neural Networks (TDNN) or Recurrent Neural Networks (RNN)
- The model was trained with only three months of data, recorded during summer months: expand the training data
  - Unclear how well strong ionospheric events can be traced with the current model and solar activity expected to increase
- Test if the model estimates help with positioning
  - Differences between northern and southern Finland?
- Predict the Ionospheric delay?

Conclusions:

1. CNN-model for estimating ionospheric delay
2. Use IONEX maps as ground truth and RINEX data as input
3. Shape of the estimated ionospheric delay and the IONEX are similar
4. The estimated maps show a higher ionospheric delay
5. Update the model to take into account the temporal dependency of the data

Advancing together

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