Estimating Uncertainties of the NOAA Regional Geoelectric Field Map with the ACCRUE Model

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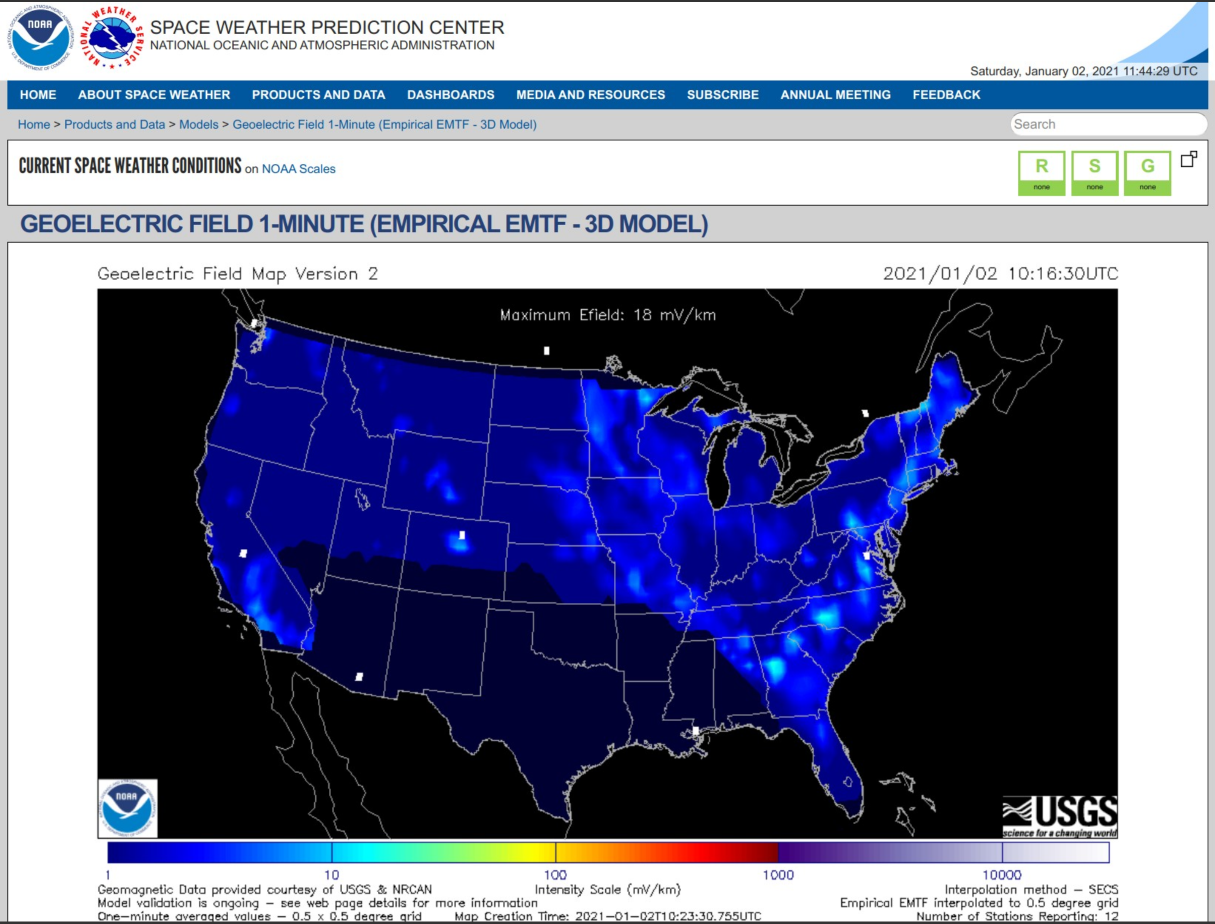
Operational NOAA Geoelectric Field Map



https://www.swpc.noaa.gov/products/geoelectric-field-1-minute-empirical-emtf-3d-model

1-minute resolution

3D Empirical Magnetotelluric Transfer Function, using up to 17 real-time magnetic stations

Details of the method in Kelbert et al. (2017) https://doi.org/10.1002/2017SW001594

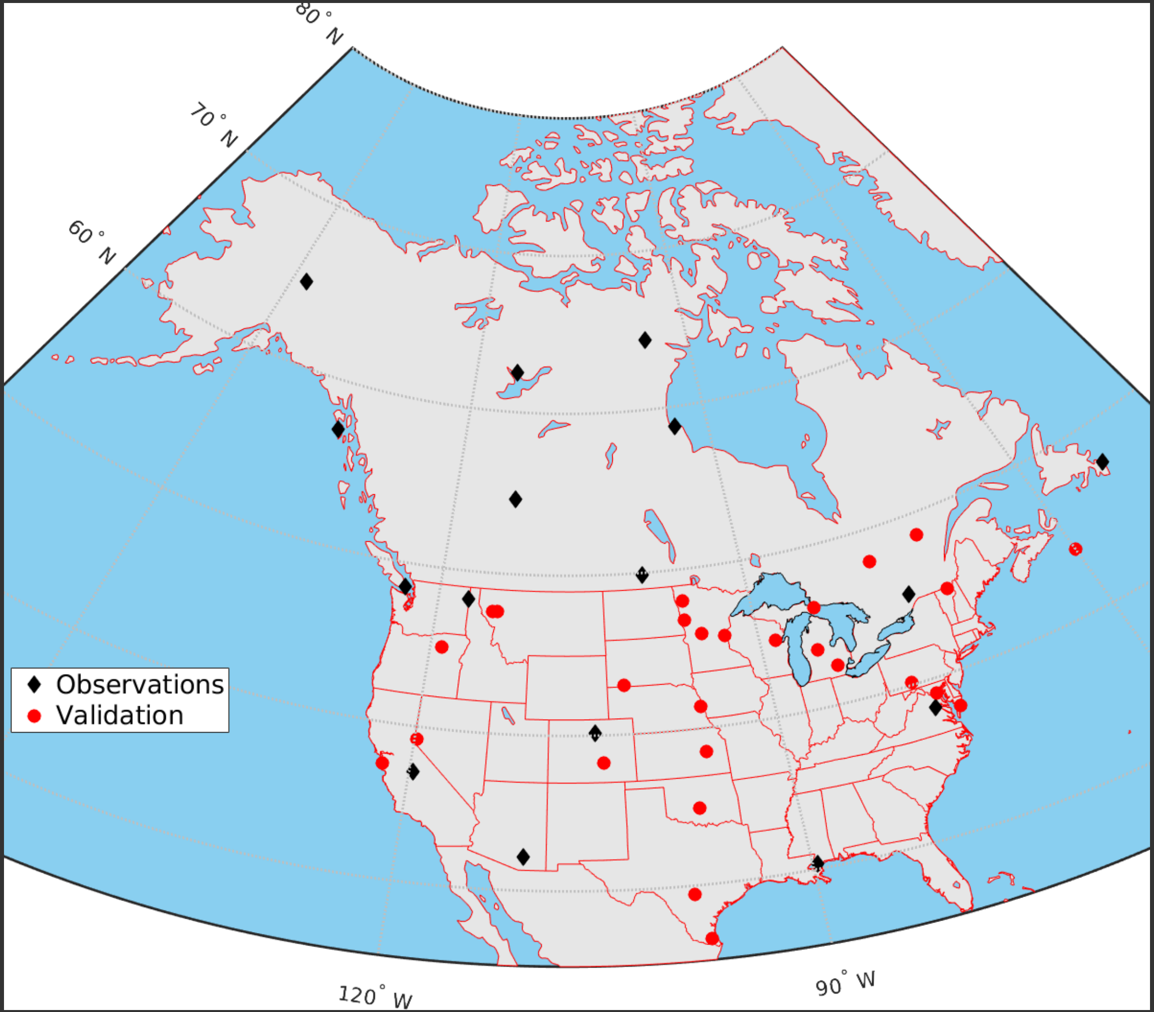
Context and Objective

- NASA SWQU (Space Weather with Quantified Uncertainty)
  - Ensemble Learning for Accurate and Reliable Uncertainty quantification
- ACCRUE (Accurate and Reliable Uncertainty Estimate) is a core component of the project
  - In short, it is a methodology to estimate uncertainties associated with deterministic predictions
  - E. Camporeale & A. Care' (2021) ACCRUE: Accurate and Reliable Uncertainty Estimate in Deterministic models, *International J. Uncertainty Quantification,* in press
  - E. Camporeale et al. (2019) On the generation of probabilistic forecasts from deterministic models, *Space Weather,* 17(3)

Context and Objective

- The objective of this work is to quantify uncertainties associated with the geoelectric field map
- As a first step, we focus here on the uncertainty generated by the interpolation algorithm of the magnetic field observations
  - Ground magnetic field is observed in real-time at 17 stations and interpolated on a grid covering the continental US

Stations used for interpolation and validation



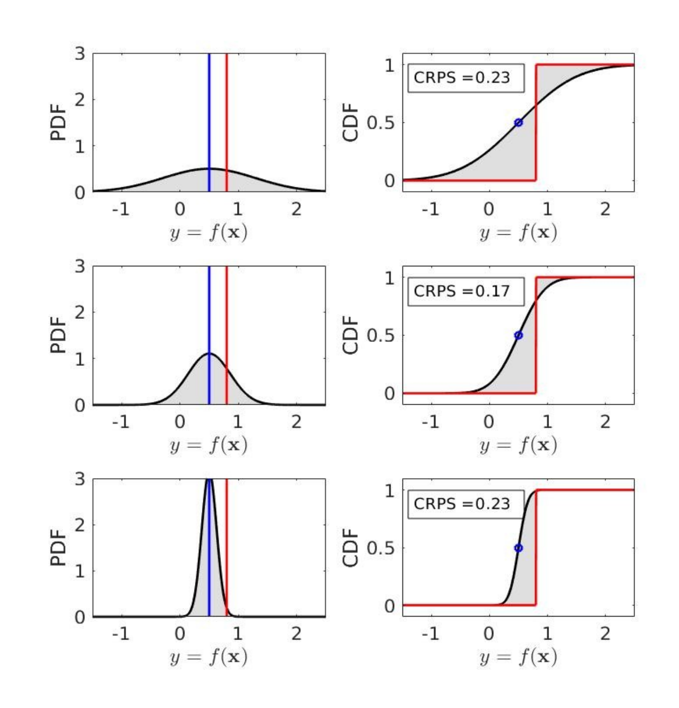
B interpolation

- Operationally SWPC uses an interpolation method called Spherical Elementary Current System (SECS)
  - Pulkkinen, A., Amm, O., & Viljanen, A. (2003). Ionospheric equivalent current distributions determined with the method of spherical elementary current systems. Journal of Geophysical Research: Space Physics, 108(A2).
- SECS enforces that the derived magnetic field is consistent with a system of “elementary currents” (ie is physical)
- Here we test a simpler interpolation scheme, based on linear Radial Basis Functions (RBF)

ACCRUE method - preliminaries

Two qualities of a probabilistic forecast:

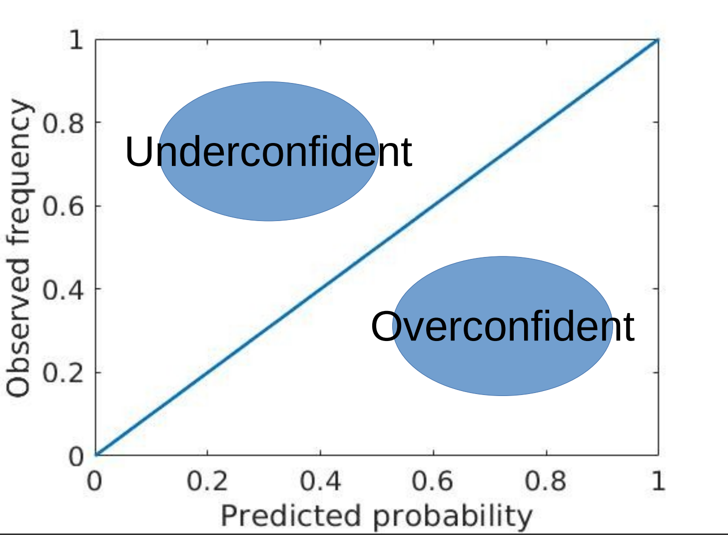
- Accuracy (sharpness)
  - Measures how close the probability density is to the observed value
  - Measured by a “score” such as CRPS (Continuous Rank Probability Score)
    - CRPS = 0 for perfect forecast
    - It measures the “distance” between cumulative distribution functions
    - CRPS= $\int (C(y) - H(\hat{y}))^2 dy$



ACCRUE method - preliminaries

Two qualities of a probabilistic forecast:

- Accuracy (sharpness)
- Reliability (calibration)
  - Measures how consistent the probabilities are w.r.t. observed frequencies

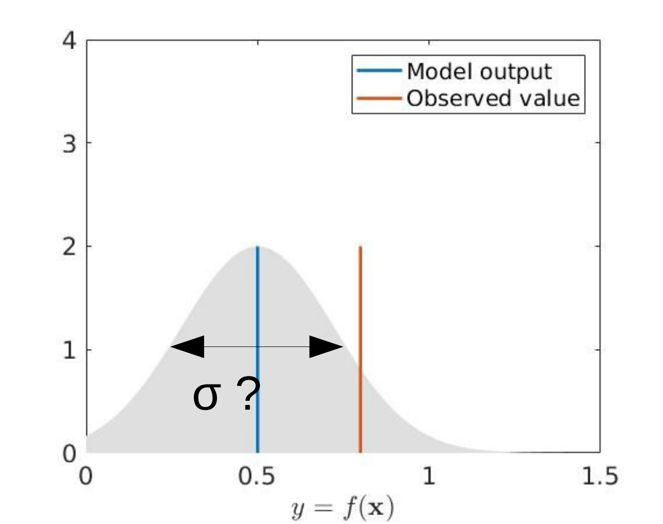


Reliability diagram

What is a reliable model?
It rained 20% of all the times in which I have predicted “20% chance of rain”

ACCRUE method

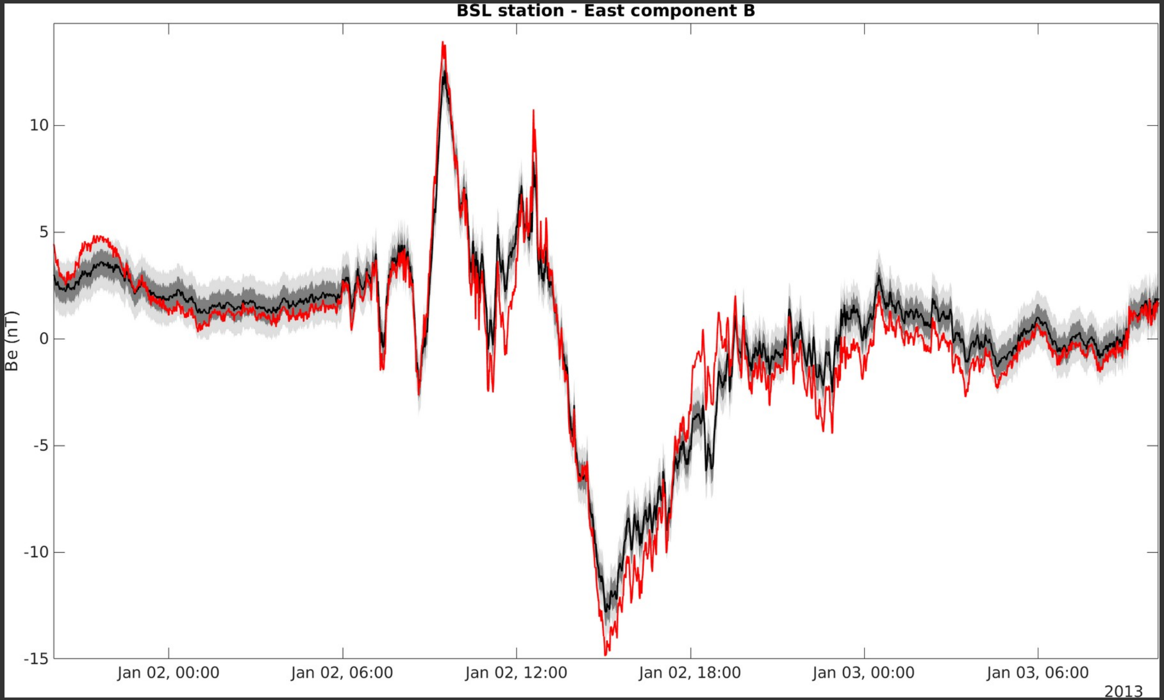
- This method takes a deterministic model that outputs a continuous scalar output (real number) and estimates what is the Gaussian uncertainty associated with that
- It solves a ‘self-supervised’ learning problem where the cost function ensures a trade-off between accuracy and reliability
- The problem is solved with a deep neural network that outputs the variance of a Gaussian distribution associated with each prediction

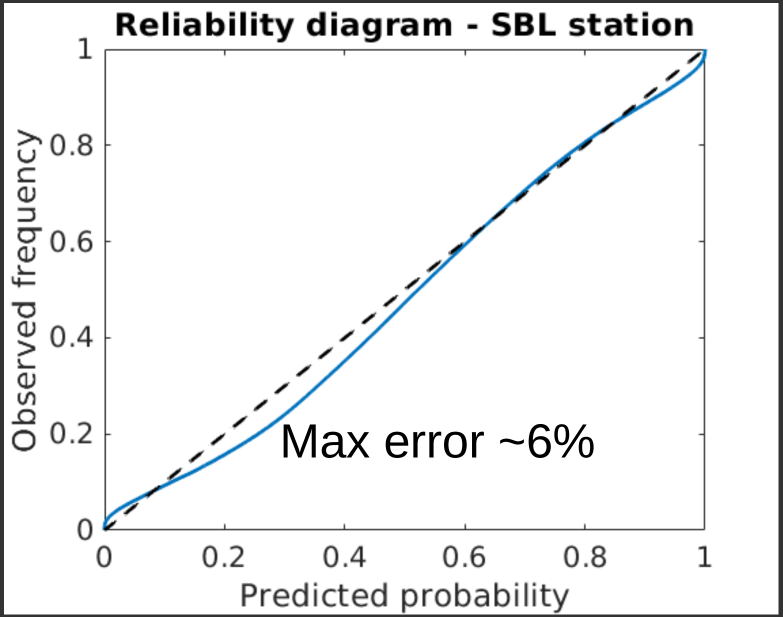


Data

- We use SuperMAG data (2010-2019) for 45 stations: interpolate from 17 (train-stations) to the remaining 28 (val-stations) .
- We treat the North and East component of the magnetic field independently
- The inputs of the neural network are the values observed at the stations used for interpolation + a flag that indicates which stations are not available
- An ACCRUE model is trained independently for each validation station
- 50% of available times are used for training. Results are tested on remaining 50%

Results – SBL station





Results – SBL station

2013

Sable Island (Nova Scotia, Canada)

Work in progress...

- Extend the estimated uncertainties (calculated on 28 validation stations) to a gridded output
- Propagate the uncertainty from B (magnetic field) to E (electric field) through the magnetotelluric transfer functions

Conclusions

- We are applying the ACCRUE (Accurate & Reliable Uncertainty Estimate) method to the NOAA operational Geoelectric map.
  - Uncertainty associated with the B interpolation → E field
- ACCRUE is “model agnostic”
  - It can be applied to any model for which we have a sufficiently general database of (inputs, errors)
  - E. Camporeale & A. Care’ (2021) ACCRUE: Accurate and Reliable Uncertainty Estimate in Deterministic models, *International J. Uncertainty Quantification,* in press (an older version here: https://arxiv.org/abs/2003.05103)
  - E. Camporeale et al. (2019) On the generation of probabilistic forecasts from deterministic models, *Space Weather,* 17(3) https://doi.org/10.1029/2018SW002026

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