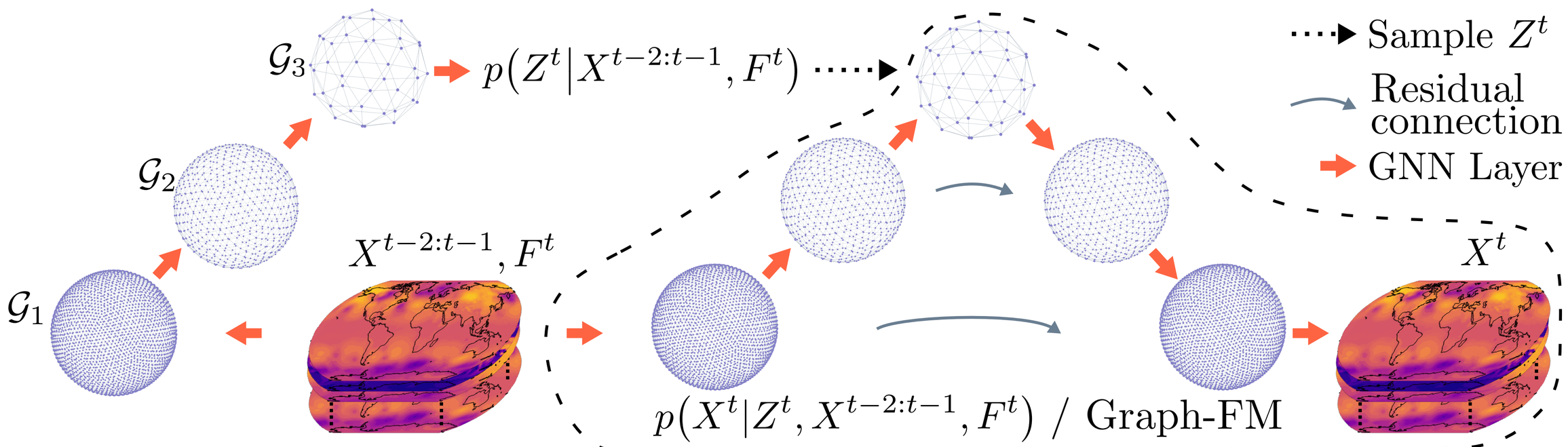
Probabilistic Weather Forecasting with Hierarchical Graph Neural Networks

Joel Oskarsson[1] Tomas Landelius[2] Marc Deisenroth[3] Fredrik Lindsten[1]

[1]Linköping University [2]SMHI [3]University College London



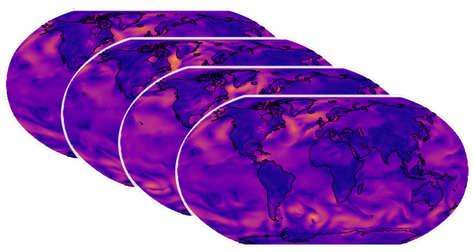
Probabilistic Weather Forecasting

Machine learning has proven useful for weather prediction, but current methods focus on deterministic forecasting.

- No estimate of forecast uncertainty

Our work: Probabilistic weather forecasting

- Model distribution $p(X^{1:T}|X^{-1:0}, F^{1:T})$
  - Future weather states $X^{1:T}$
  - Initial conditions $X^{-1:0}$
  - Forcing inputs $F^{1:T}$



- Sample to create *ensemble forecast*

Our Graph-EFM Model

Graph-based Ensemble Forecasting Model (Graph-EFM) is a deep latent variable model:

$$p(X^{1:T}|X^{-1:0}, F^{1:T}) = \prod_{t=1}^{T} \int p(X^t|Z^t, X^{t-2:t-1}, F^t) p(Z^t|X^{t-2:t-1}, F^t) dZ^t$$

- Conditional distributions implemented using hierarchical Graph Neural Networks (GNNs)

Latent Map $p(Z^t|X^{t-2:t-1}, F^t)$

- Defines distribution of latent random variable Z^t, describing uncertainty in single-step prediction

Predictor $p(X^t|Z^t, X^{t-2:t-1}, F^t)$

- Predicts next weather state given sample of Z^t
- No conditioning on Z^t: Deterministic Graph-FM model

Training Graph-EFM

- Maximizing variational objective (ELBO)
  - Variational approx. $q(Z^t|X^{t-2:t-1}, X^t, F^t)$ at each t
- Fine-tuning on rollouts + additional CRPS-based loss

Experiments: Global and Regional Forecasting

Dataset	Region	Years	Resolution	Fields
ERA5 Reanalysis	Global	61	1.5°, 6h	83
MEPS Forecasts	Nordics	2	10 km, 3h	17

Global Weather Forecasting

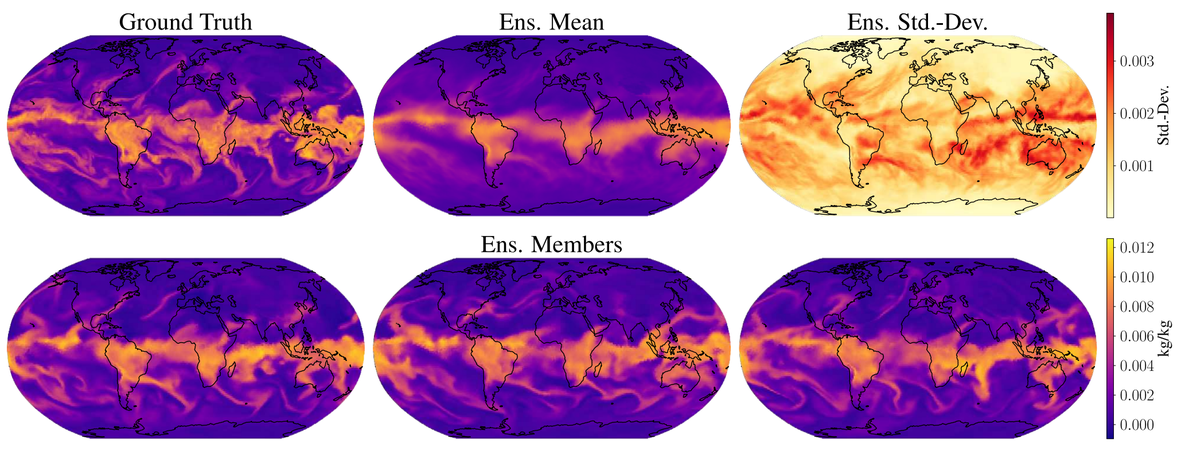


Figure: Ensemble forecast of humidity (q700), lead time 10 days

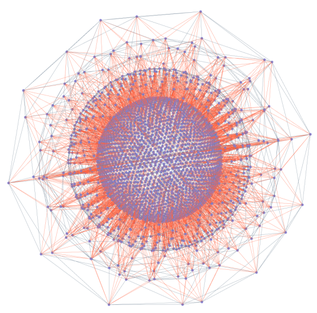


Figure: Global hierarchical graph

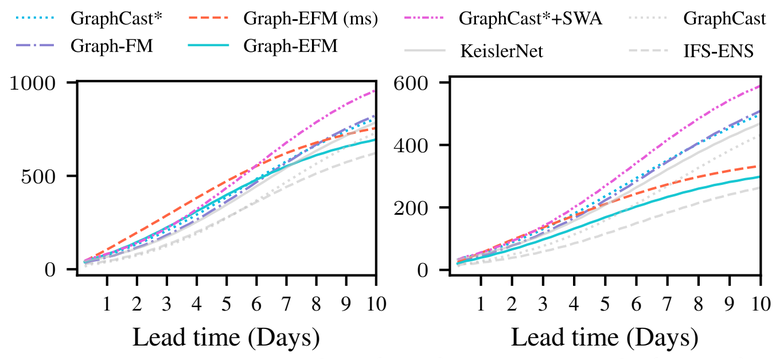


Figure: z500 RMSE (left) and CRPS (right)

Surrogate modeling of MEPS forecasting system

- Limited Area Model (LAM) with boundary forcing

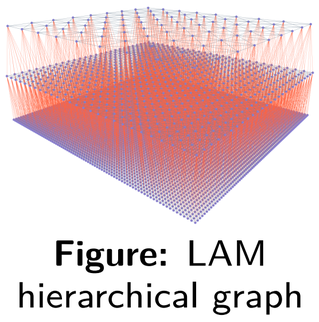


Figure: LAM hierarchical graph

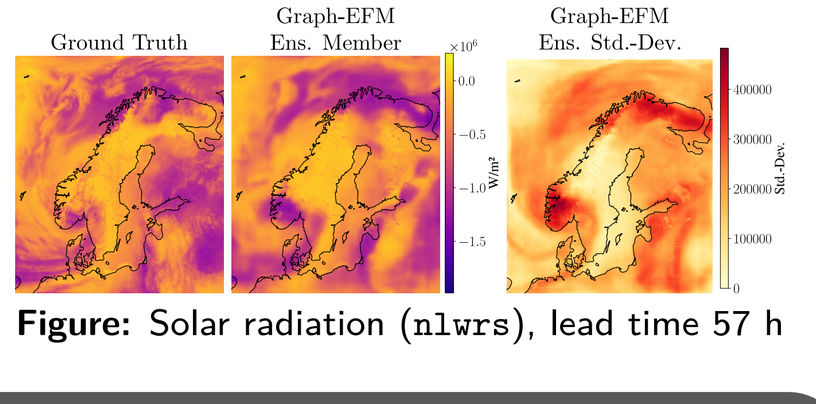


Figure: Solar radiation (`nlwrs`), lead time 57 h

Contact and Links

Paper [1]

Code

[1] J. Oskarsson, T. Landelius, M. P. Deisenroth, and F. Lindsten. Probabilistic weather forecasting with hierarchical graph neural networks. In *NeurIPS*, 2024.

Contact: `joel.oskarsson@liu.se`.

LINKÖPING UNIVERSITY

WASP WALLENBERG AI, AUTONOMOUS SYSTEMS AND SOFTWARE PROGRAM