# A Graph-Based Latent Variable Model for Probabilistic Weather Forecasting

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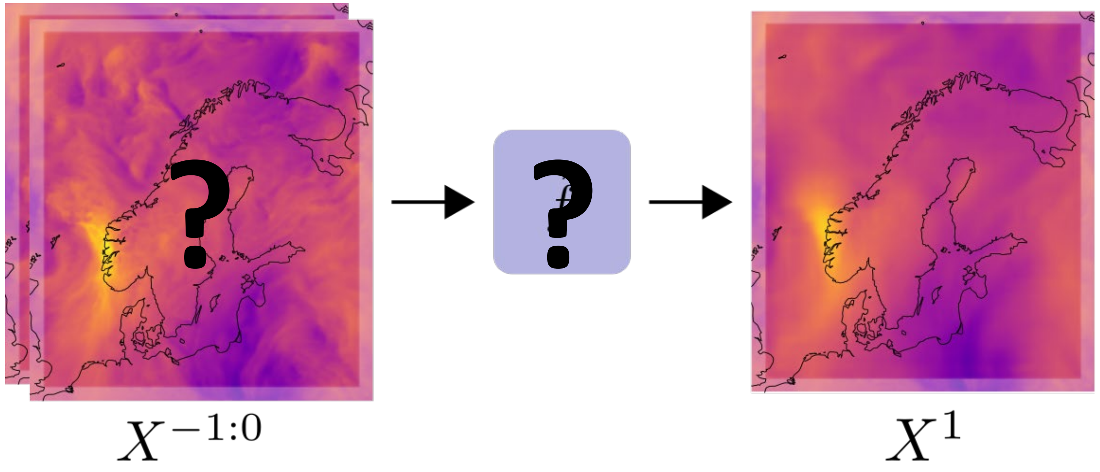
# Probabilistic weather forecasting




- Currently:
  - Deterministic models
  - MSE loss

$$p(X^t|X^{t-1:t-2}, F^t) = \mathcal{N}\left(X^t\middle|\hat{f}(X^{t-1:t-2}, F^t), \sigma^2 I\right)$$

- Want:
  - Capture full distribution
    $p\left(X^{1:T}|X^{-1:0}, F^{1:T}\right)$
  - Ensemble forecasting

# Latent variable formulation

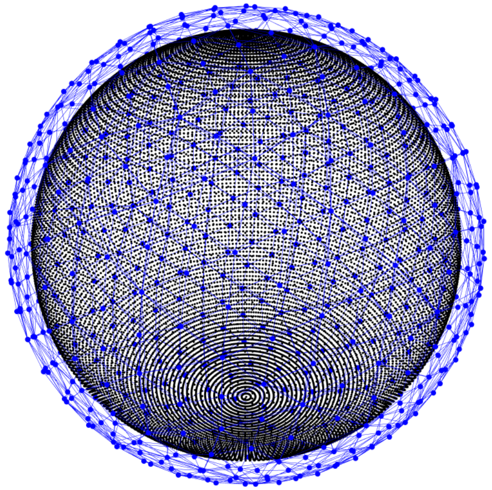
- Probabilistic + auto-regressive

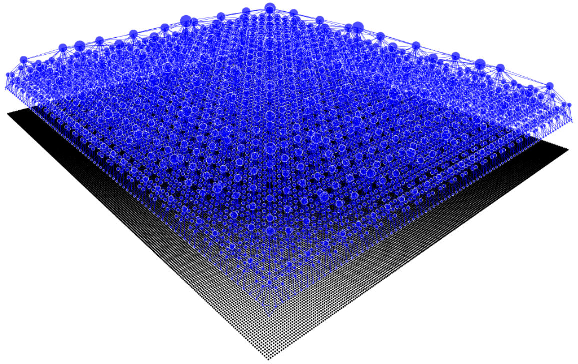
$$p(X^t|X^{t-2:t-1}, F^t) = \int \underbrace{p(X^t|Z^t, X^{t-2:t-1}, F^t)}_{\text{Predictor}} \underbrace{p(Z^t|X^{t-2:t-1}, F^t)}_{\text{Latent map}} dZ^t$$

- Latent random variable $Z^t$
  - Captures uncertainty in single-step prediction

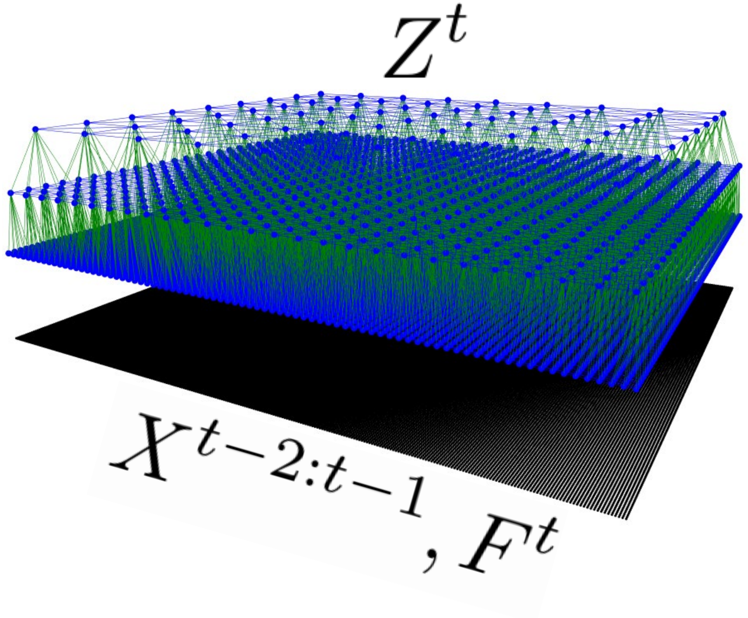
# Graph-based weather forecasting

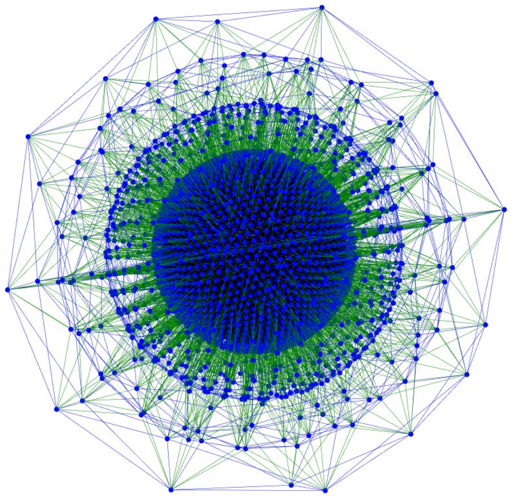
- Flexible framework for both global[1] and regional forecasting[2]





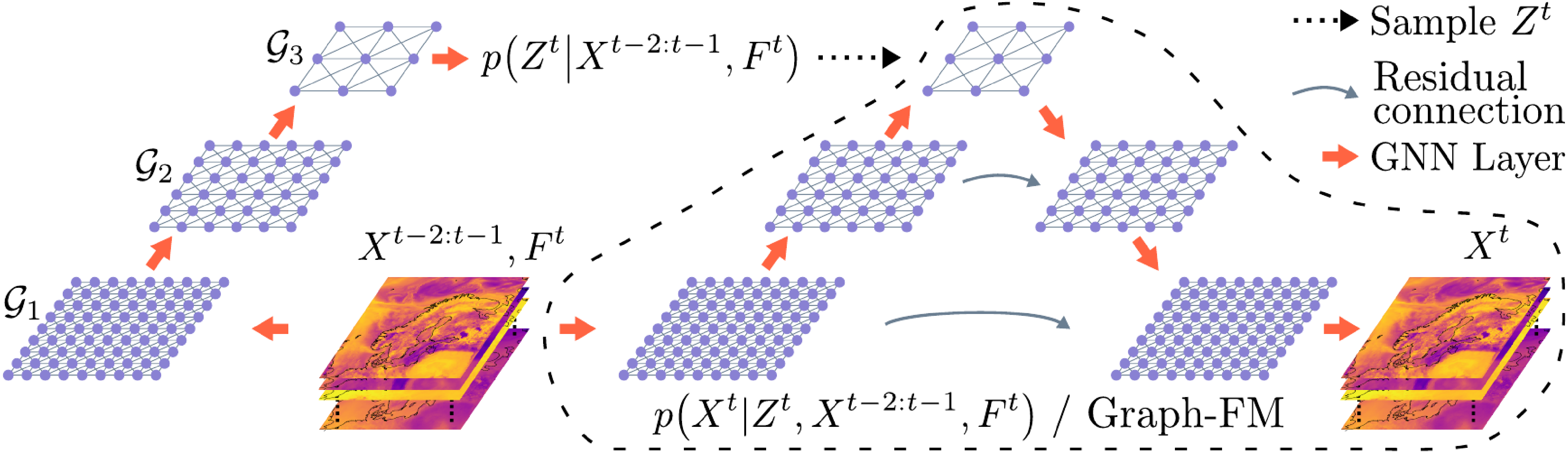
- Hierarchical graph construction



[1] Keisler, R. (2022). Forecasting global weather with graph neural networks. arXiv preprint. , Lam, R., et al. (2023). Learning skillful medium-range global weather forecasting. *Science*.
[2] Oskarsson et al. (2023). Graph-based Neural Weather Prediction for Limited Area Modeling. *NeurIPS 2023 Workshop on Tackling Climate Change with Machine Learning.*

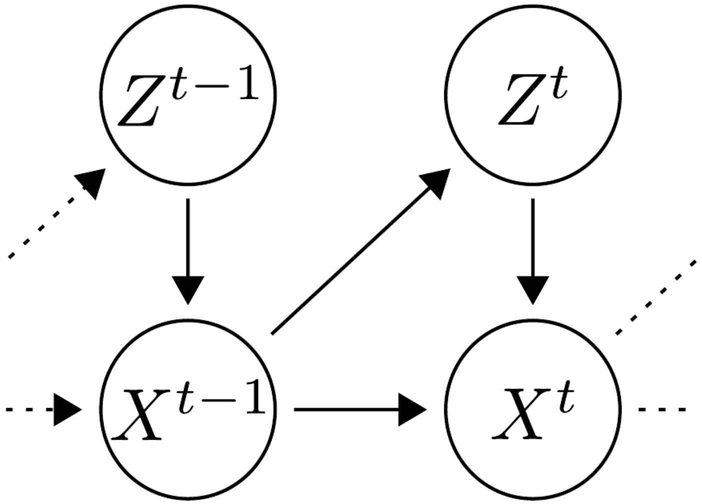
# Graph-EFM: Graph-based Ensemble Forecasting Model




- Graph-FM: Deterministic model using hierarchical graph

# Training and sampling

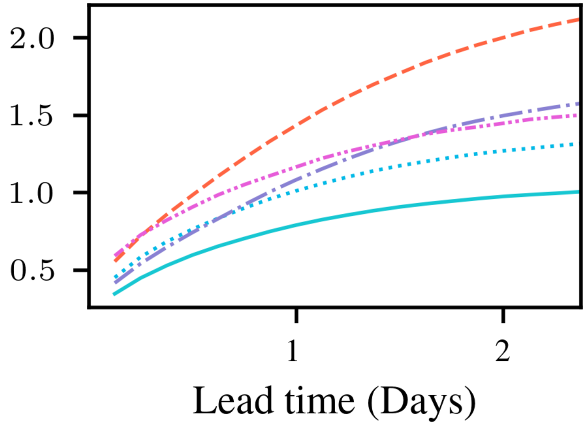
- Training
  - Maximize variational bound (ELBO)
  - First on single-step prediction
  - Finetuning on rollouts + using CRPS-based loss
- Sampling $X^t$
  - Requires single forward-pass
  - Contrast: Diffusion models



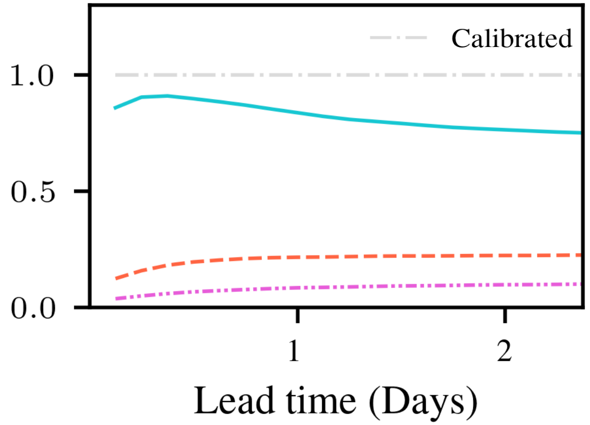
# Results: Limited area modeling

- Surrogate model for forecasting Nordic region
  - Trained on dataset of 6000 forecasts
  - 57 h forecasts with 3 h time steps
  - 17 variables
- Boundary forcing

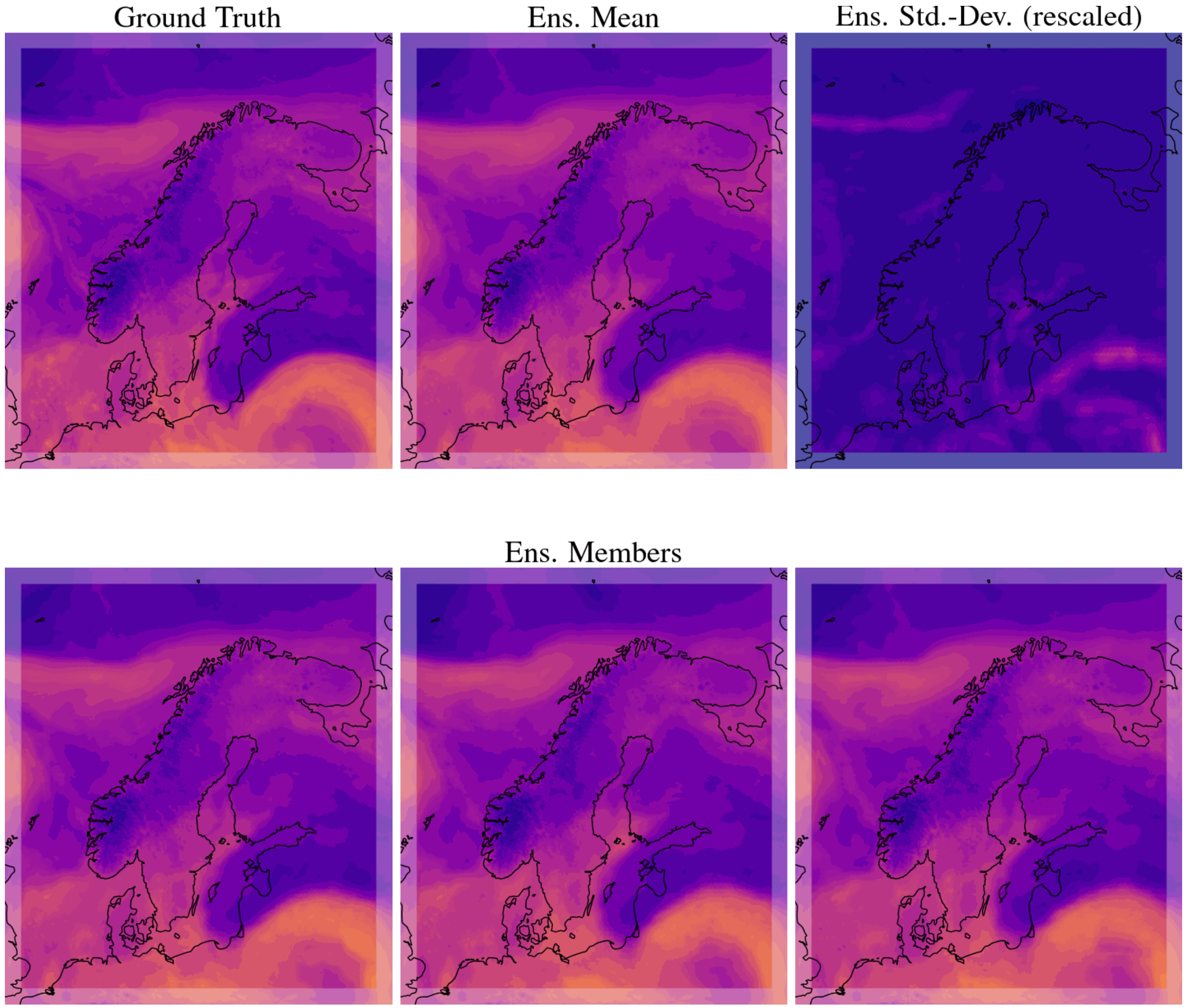
CRPS




Spread/Skill



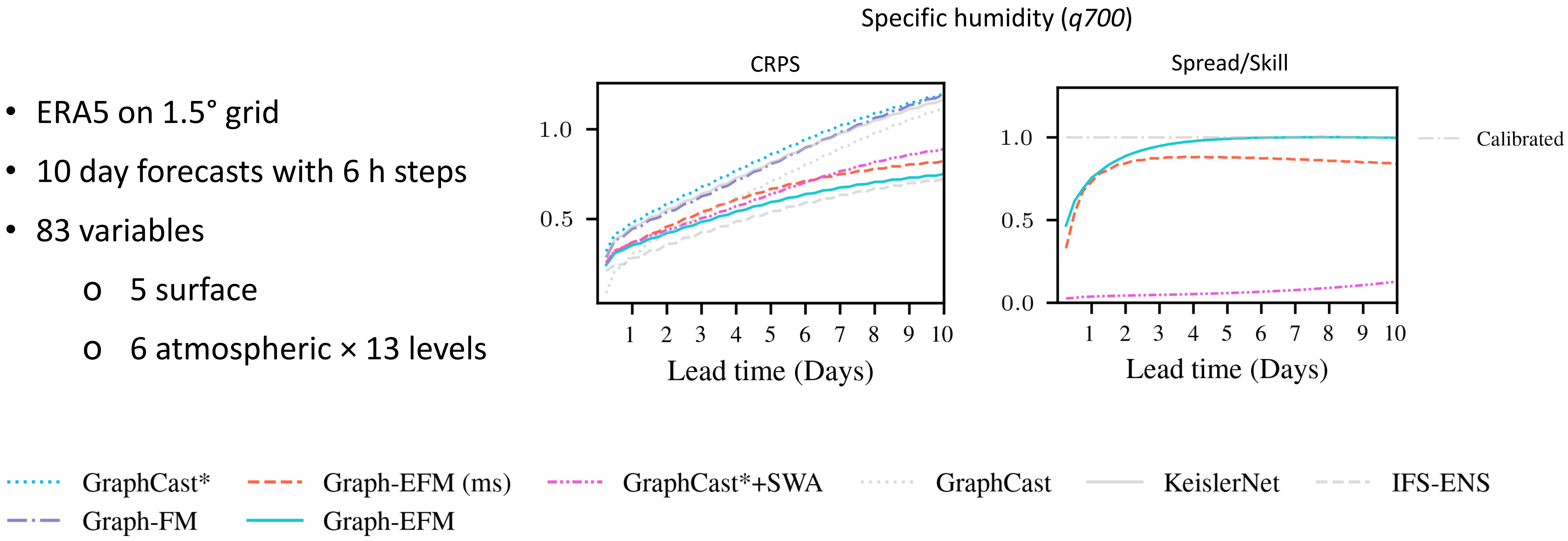

GraphCast* Graph-FM Graph-EFM (ms) Graph-EFM GraphCast*+SWA



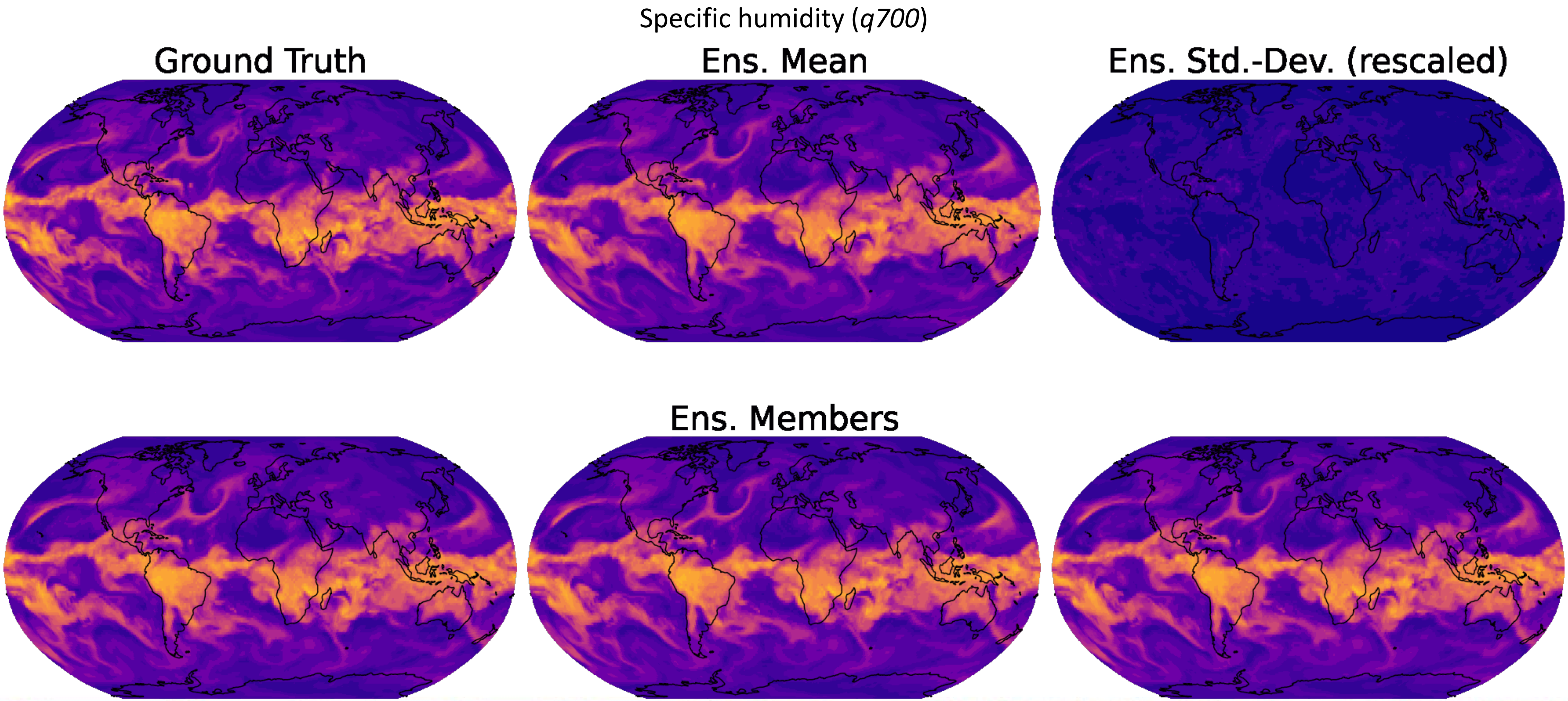

Water vapor (*wvint*)

# Results: Global forecasting

- ERA5 on 1.5° grid
- 10 day forecasts with 6 h steps
- 83 variables
  - 5 surface
  - 6 atmospheric × 13 levels



# Results: Global forecasting



# Graph-EFM: A Graph-Based Latent Variable Model for Probabilistic Weather Forecasting[1]

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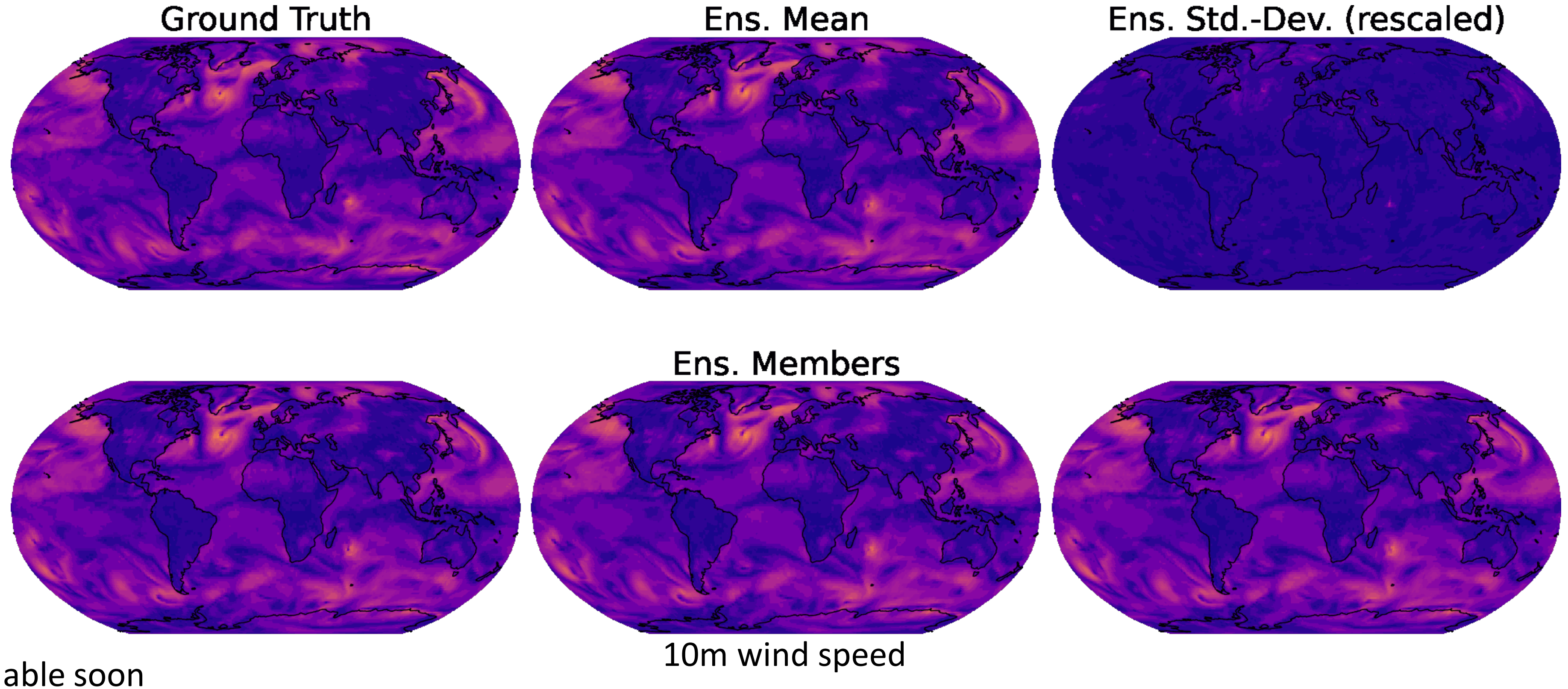


[1] Preprint available soon