ConvCastNet: A Global Weather Forecasting model based on convolutional encoder-decoder architecture

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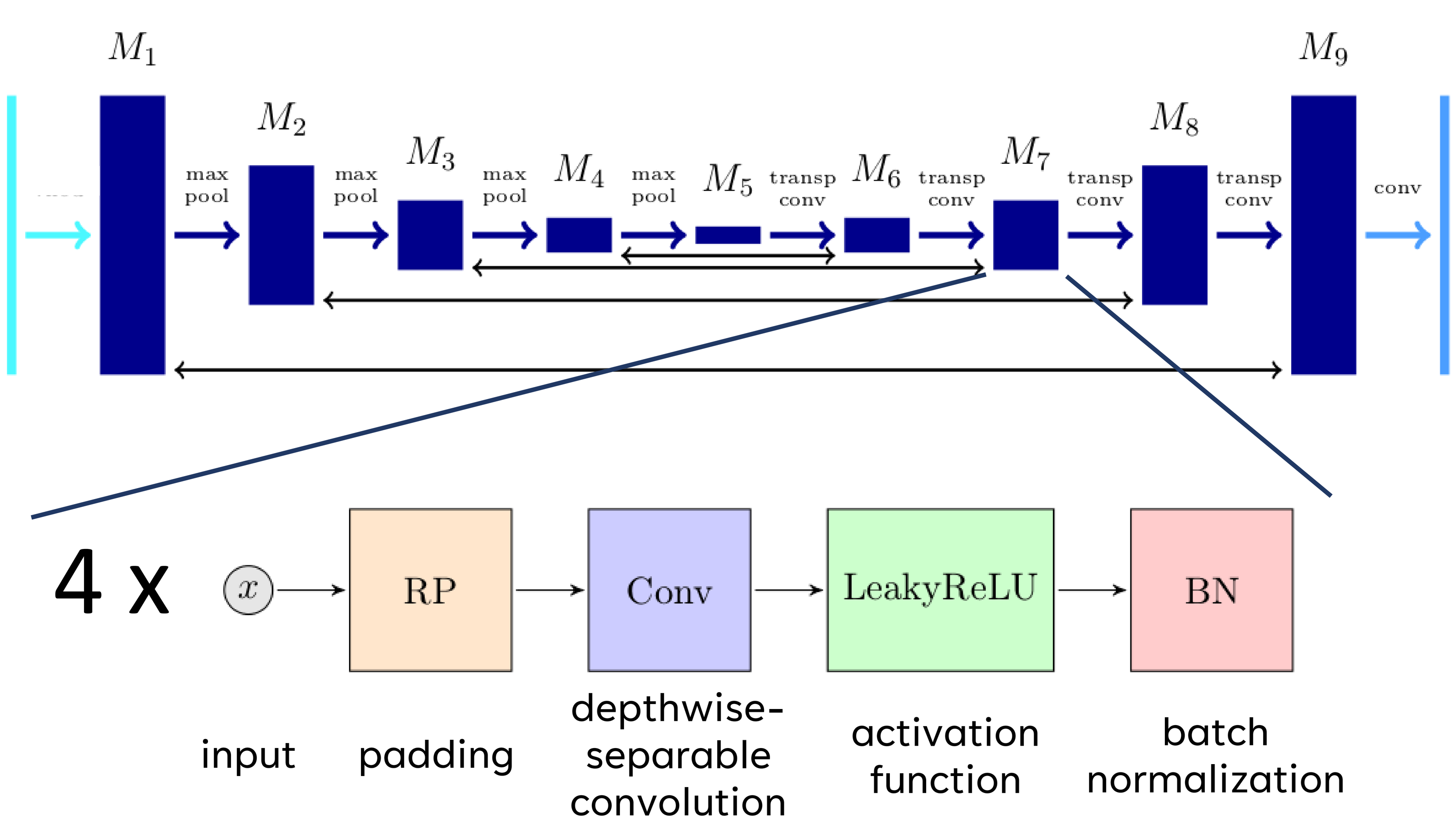
INTRODUCTION

Recently, many successful neural network implementations have shown promising results in predicting the time evolution of atmospheric dynamics. We introduce ConvCastNet, a convolutional encoder-decoder neural network-based weather prediction model with skillful forecast on a 3° latitude-longitude grid. It leverages convolutional kernels for modeling relationships between weather variables. We extensively optimize the model architecture and training algorithm, evaluate the model forecasts, and perform adjustment experiments. With 8.5 days of Z(500 hPa) ACC > 0.6 and physically meaningful response to perturbations, we show ConvCastNet can learn global atmospheric dynamics even at such sparse grids.

MODEL ARCHITECTURE

Architecture scheme

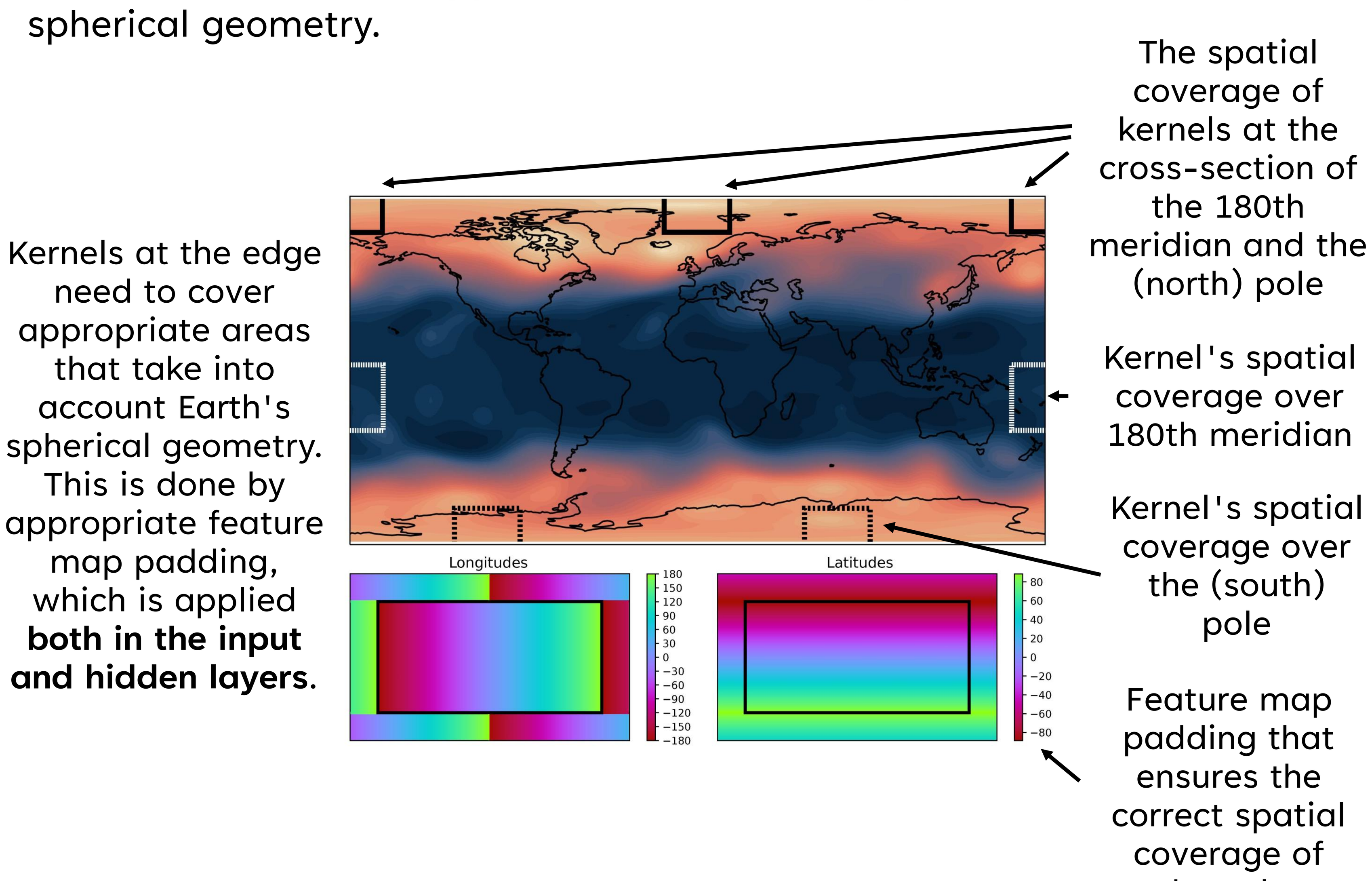


Key features:

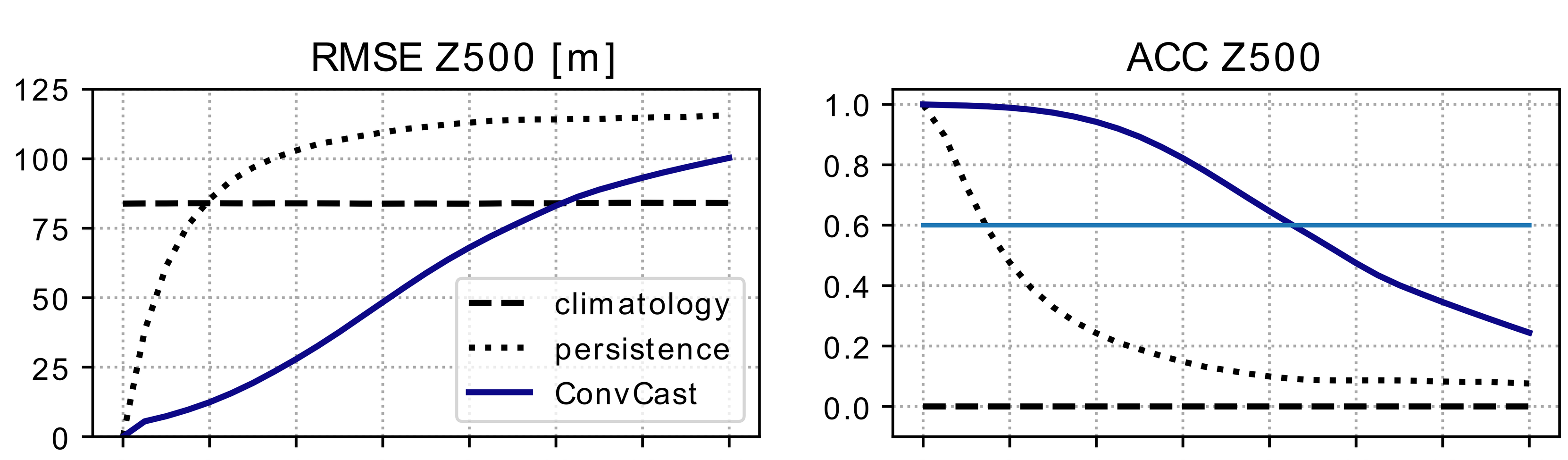
- Deep neural network
- **Feature map padding**
- **Depthwise-separable convolutions**
- Batch normalization
- LeakyReLU activation
- Skip connections

Feature map padding

We introduce a **novel approach to feature map padding** to account for the spherical geometry.



RMSE and ACC ANALYSIS



- ConvCastNet > Persistence
- ConvCastNet > Climatology for 10 days
- Z(500 hPa) ACC > 0.6 for **8.5 days**

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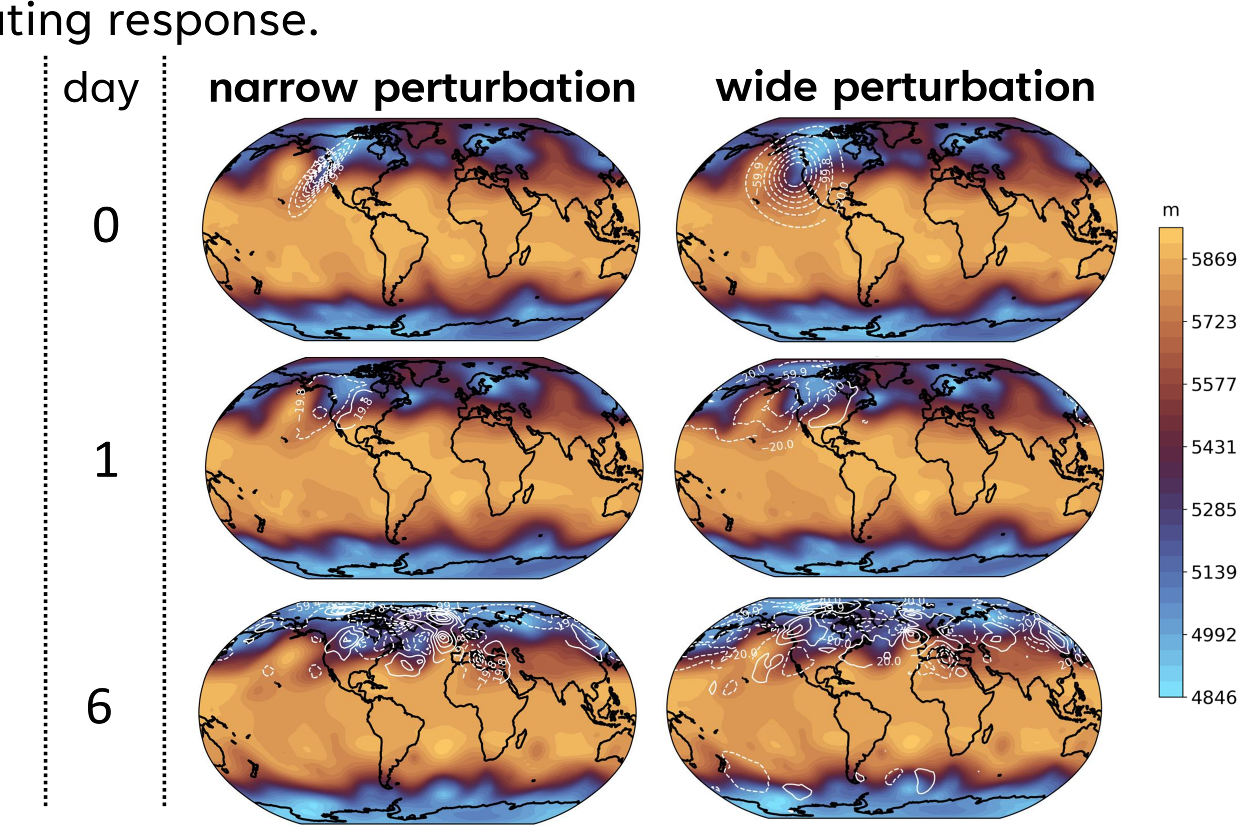
ADJUSTMENT EXPERIMENTS

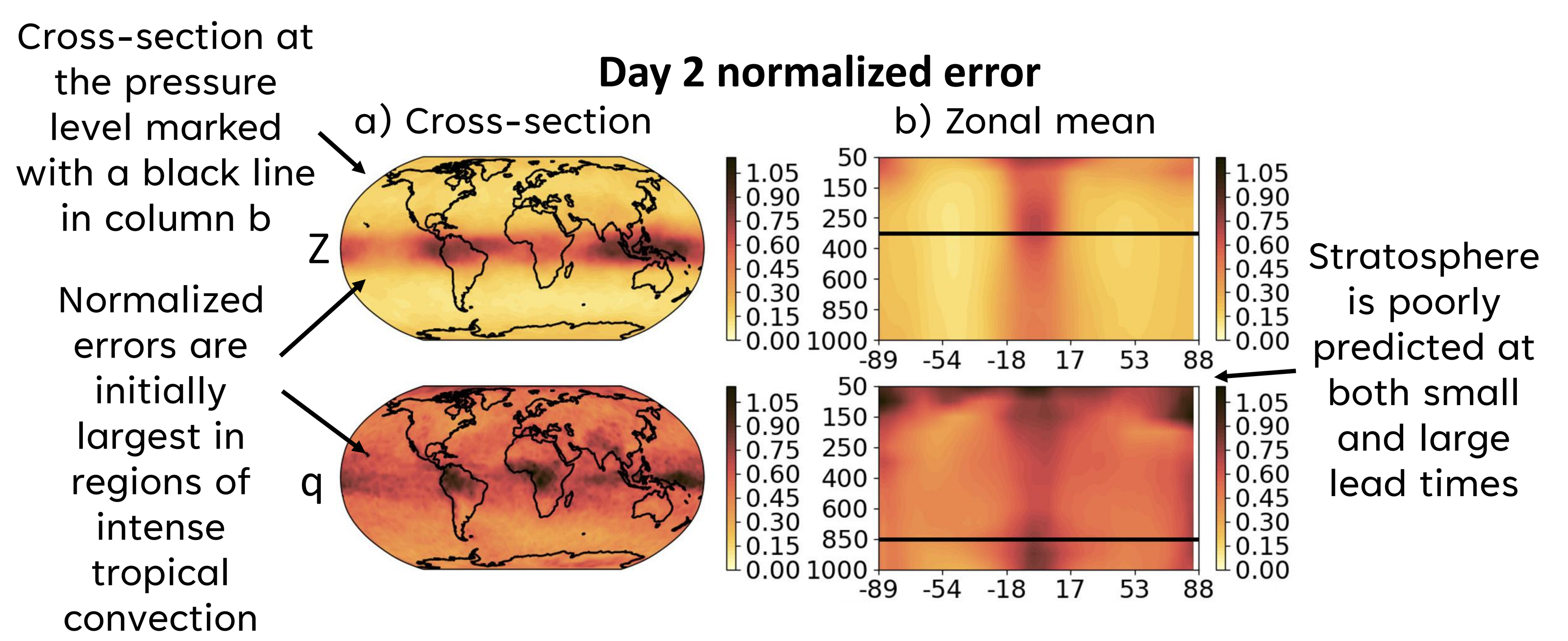
ML models have not yet been thoroughly tested in terms of response to perturbations in initial conditions. Here, we present an example where a wide zonal perturbation in the 500 hPa geopotential produces a westward response, while a narrow zonal perturbation results in an eastward propagating response.



Observations:

- Eastward response propagates with a speed higher than Rossby wave phase speed.
- Wide perturbation initially propagates in a westward direction, which is consistent with the analytically expected westward movement of wide Rossby waves.
- After 6 days, we observe only relatively small changes in overall weather evolution.

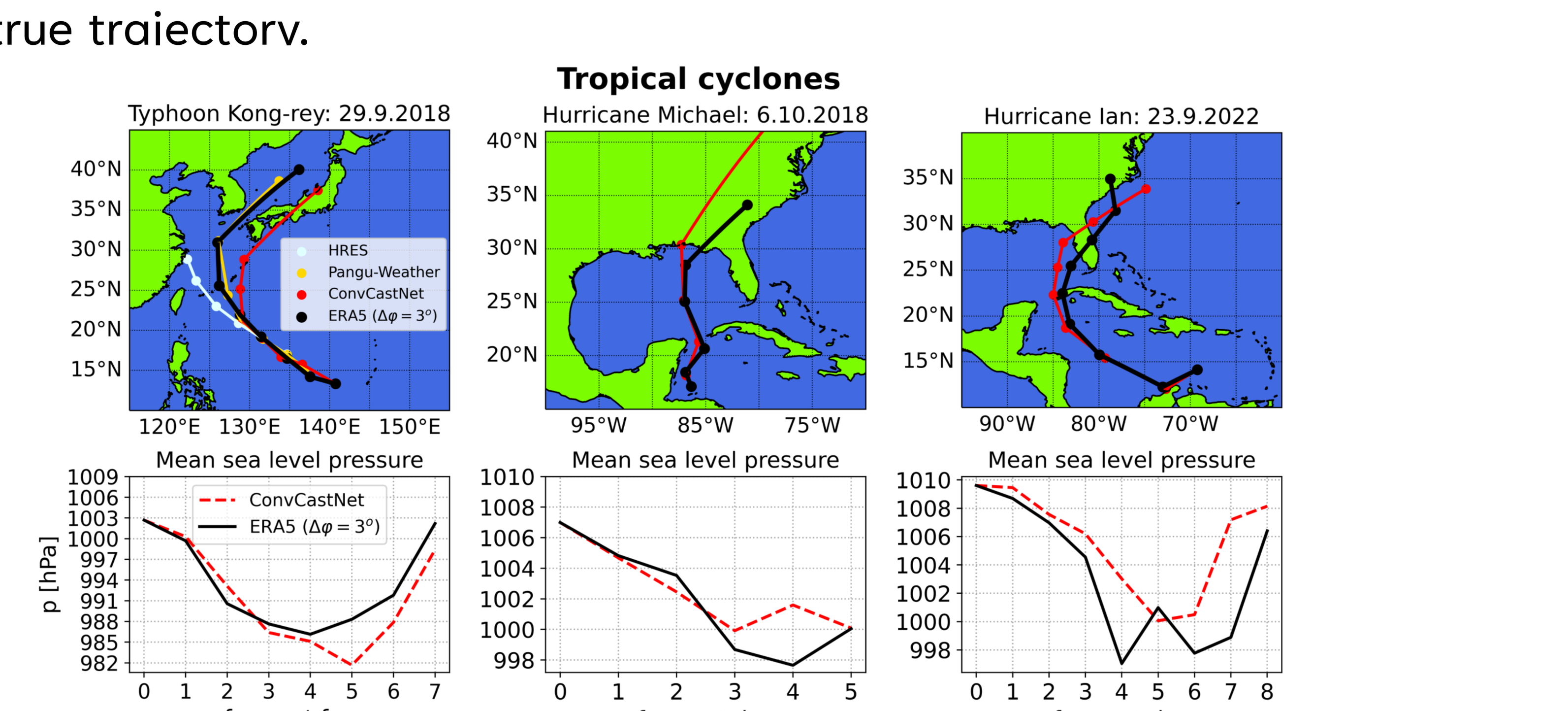
ERROR SPATIAL DISTRIBUTION



Normalized errors describe absolute errors divided by the climatological natural weather variability. Initially, the largest normalized errors occur in the tropical atmosphere and stratosphere. At later lead times, the largest errors occur at high latitudes, especially in the stratosphere. Different variables have different error magnitudes and distributions.

TROPICAL CYCLONE FORECASTS

Forecasted tropical cyclone tracks match the correct path several days in advance. The predicted mslp minimum is overestimated due to coarse resolution and daily averaging of the predicted fields, which was used for this case study. However, when the central pressure is compared to the daily averaged ERA5 reanalysis at a 3-degree resolution, it closely follows the true trajectory.



CONCLUSIONS

- ConvCastNet is an encoder-decoder convolutional neural network-based weather forecasting model that performs skillful weather prediction with Z(500 hPa) ACC > 0.6 for approximately 8.5 days on a 3° longitude-latitude grid.
- Adjustment experiments show physically meaningful responses with wide zonal wavelength perturbation components propagating toward the west and narrow components towards the east. Eastward propagation speed is larger than the phase speed of Rossby waves.
- The largest magnitude of normalized forecast error initially occurs in the tropics and stratosphere. Later, it spreads to high latitudes and becomes the largest in the stratosphere.
- The model accurately predicts tropical cyclone tracks for several days in advance.