Development of a Coupled Atmosphere-Ocean Model for Subseasonal-to-Seasonal Forecasting

Linlin Cui[1*] (linlin.cui@noaa.gov), Jun Wang[2], Jacob Carley[2]
[1]Lynker at NOAA/NWS/NCEP/EMC; [2]NOAA/NWS/NCEP/EMC

Motivation

Subseasonal-to-seasonal (S2S) forecasting is a complex challenge in Earth system science due to the intricate, nonlinear interactions between the atmosphere and ocean across various scales. This work is motivated by the potential of machine learning weather prediction models, specifically a Spherical Fourier Neural Operator (SFNO) architecture, to offer a data-driven alternative for modeling these dynamical systems and improving S2S forecasts. The aim is to develop a coupled atmosphere-ocean model that exhibits stable long-range simulations, preserves annual climatological cycles, and demonstrates skill in predicting prognostic variables and phenomena like ENSO, ultimately providing new insights into Earth system dynamics and predictability.

Data Sources

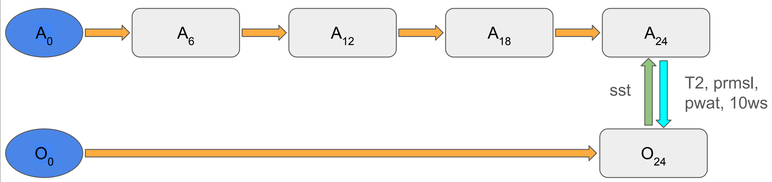
- UFS-replay dataset
- 1994-2016 as training dataset, 2017-2018 as validation dataset, 2019-2021 as test dataset
- Atmospheric fields include five 2D variables and six 3D variables at 13 pressure levels:
  - 2-m temperature, 10-m, u and v components of wind, pressure at mean sea level, precipitable water
  - Temperature, u and v components of wind, vertical velocity, geopotential height, specific humidity
  - Vertical pressure levels: 50, 100, 150, 200, 250, 300, 400, 500, 600, 700, 850, 925, and 1000 hPa
- Ocean fields include ssh, sst, and potential temperature at [0.5, 9.8, 47.3, 97.2, 200.3, 301.7] m
- Timestep: 6-h for the atmospheric model and 24-h for the ocean model
- Gaussian grid (1.5 degree)

Model Training

- Atmospheric and oceanic model were trained separately
- Hyperparameters:

Embed_dim: 192 (atmos), 128 (ocean)	Operator llayers: 8 (atmos), 4 (ocean)
Filter type: linear	Normalization layer: instance_norm
Activation function: Gaussian Error Linear Unit (GELU)	Optimizer: Adam

Inference Coupling Mechanism



Preliminary results

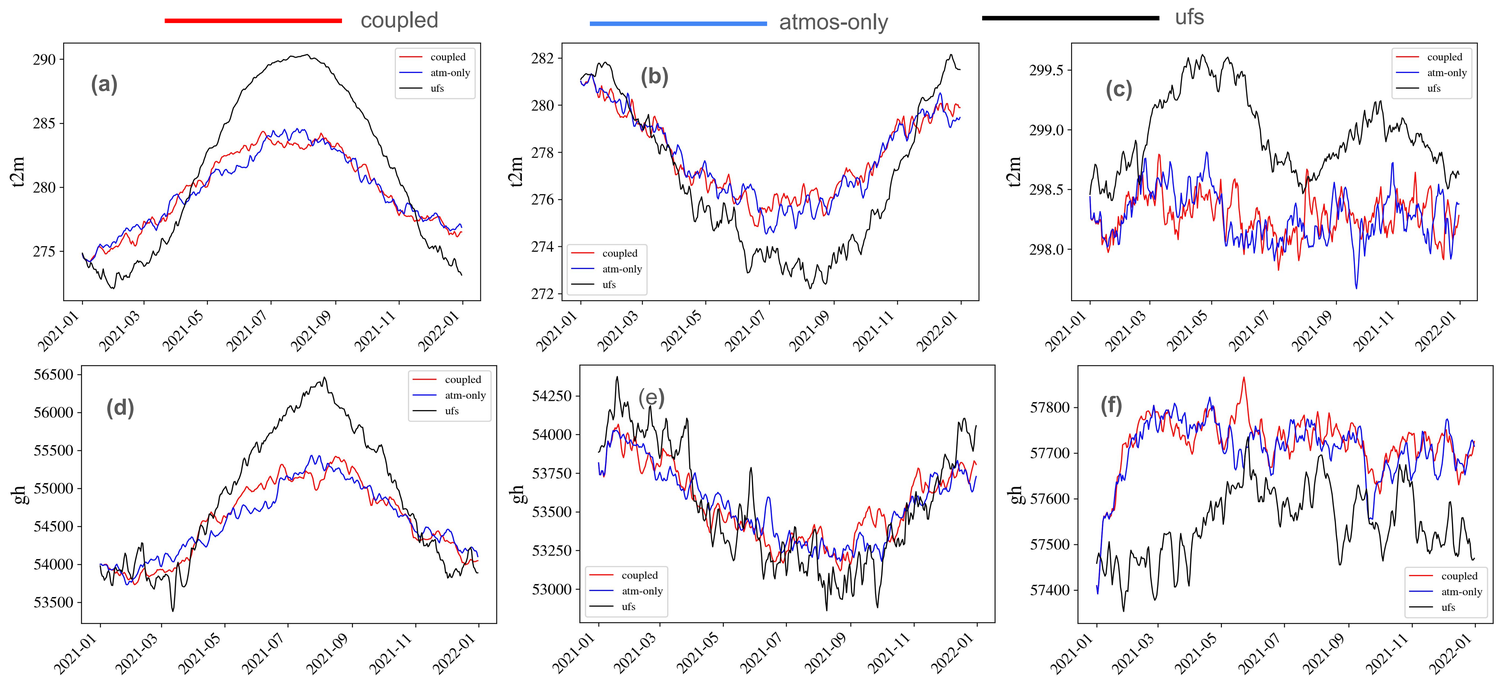


Figure 1: Daily-averaged mean 2-m temperature over (a) northern hemisphere (NH), (b) southern hemisphere (SH), and (c) tropics; (d)-(f) daily-averaged mean geopotential height at 500 hPa over NH, SH, and tropic, respectively.

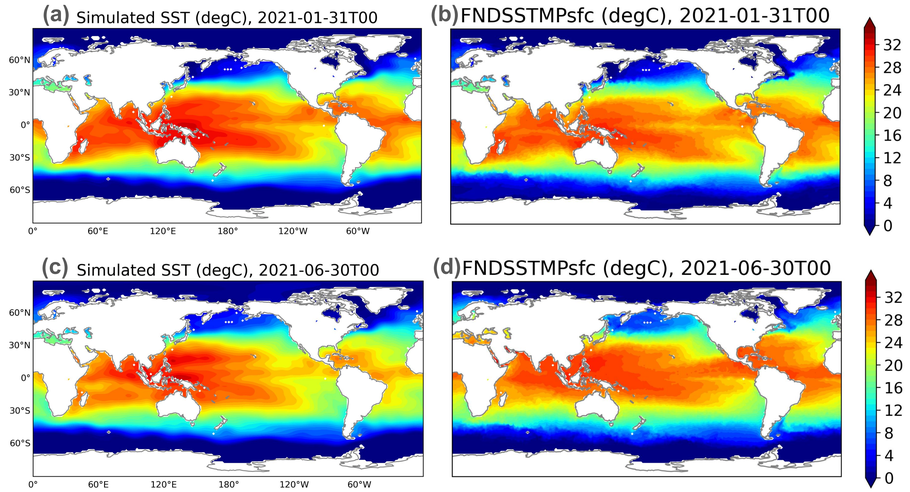


Figure 2: Reforecasts by the coupled model initialized on 2021/01/01. (a) and (b) show the SST at one month lead time, while (c) and (d) show SST at 6 months lead time.

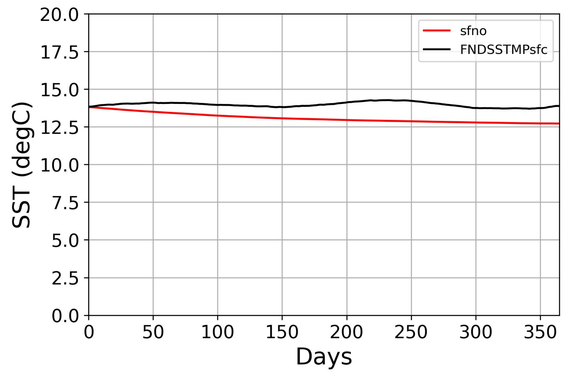


Figure 3: Global mean sea surface temperature over 1-year forecast period.

Summary

- A coupled atmosphere-ocean model was developed for S2S forecasting.
- The model utilizes a Spherical Fourier Neural Operator (SFNO) architecture.
- The atmospheric model and ocean model were trained separately with the UFS-replay dataset, then coupled in the inference.
- Preliminary results show that the coupled model can produce realistic atmospheric states in a one-year rollout and preserve the annual variations; however, the predictability of SST is only up to 6 months, then substantial drifts occur.
- The model can be accessed at: https://github.com/NOAA-EMC/aisfs

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