Improving U.S. Seasonal Climate Forecasts with CWRF Downscaling and Lateral Bias Correction

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Background

The regional Climate-Weather Research and Forecasting model (CWRF) has demonstrated exceptional downscaling capabilities across the contiguous United States (CONUS). By leveraging CWRF's strengths, including an ensemble of physics parameterization schemes and higher spatial resolutions, we perform dynamic downscaling of seasonal climate forecasts from the NCEP Coupled Forecast System model version 2 (CFSv2). We found that systematic biases in the lateral boundary forcing, due to CFSv2 circulation errors, hinder CWRF's optimal downscaling performance.

Objectives

In this study, we correct the forcing biases by eliminating CFSv2's long-term mean departures from the ECMWF 5th generation reanalysis (ERA5) for the period 2012-2023. By doing so, we enhance CWRF's ability to simulate a more faithful mean circulation state. This, in turn, enables more accurate generation of regional climate responses to significant large-scale anomalies introduced through lateral boundary forcing.

Methods

- Overall information for the test cases
  - The CWRF downscaling begins from 03/01/2021 at 06Z to predict the following JJA season.
  - The biases of Wind at 200hPa & 850hPa and GPH at 500hPa are evaluated for different bias correction configurations for the lateral boundary condition (see right upper column).
- Experiment 1: Bias correction with various variables combination
  - The selected variables are bias corrected with the following equation:

$$F^{new} = F - \bar{F} + \bar{O}$$

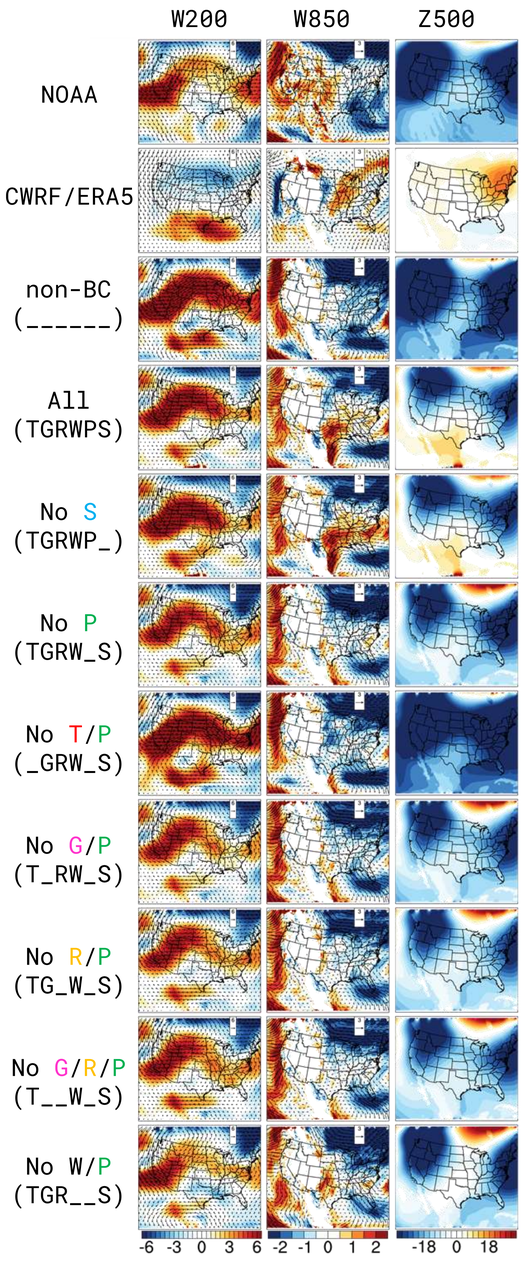
  where, F is raw CFSv2, F^{new} is bias corrected CFSv2, and $\bar{F}$ and $\bar{O}$ are multi-year climatological means for CFSv2 and observation, respectively. The climatological means are smoothed using 31-day moving average.
- Experiment 2: NOAA CFSv2's sensitivity for initial condition
  - Since the 00Z and 06Z cases tend to perform better than the 12Z and 18Z cases, we have selected the following four different starting times: [1] 03/01/2021 at 00Z, [2] 03/01/2021 at 06Z, [3] 03/02/2021 at 00Z, and [4] 03/02/2021 at 06Z.

Methods (continued)

- Here, we name the experiments as below.
  - NOAA: CFSv2 raw data (03/01/2023 06Z)
  - CWRF/ERA5: ERA5-driven CWRF
  - CWRF/CFSv2: CFSv2-driven CWRF; We set up various combinations of variables in bias correction; Omitted variables are denoted with an underscore symbol ('_').

<List of variables for bias correction>
T: Temperature
G : Geopotential height
R: Relative Humidity
W: Winds
P: PSFC (Surface Pressure)
S: SST (Sea Surface Temperature)

Result 1 – Bias Correction (BC)



NOAA's raw CFSv2 forecasts contain large-scale biases, which are not shown in CWRF/ERA5. Those biases of CFSv2 dominate the bias patterns of CWRF downscaling.

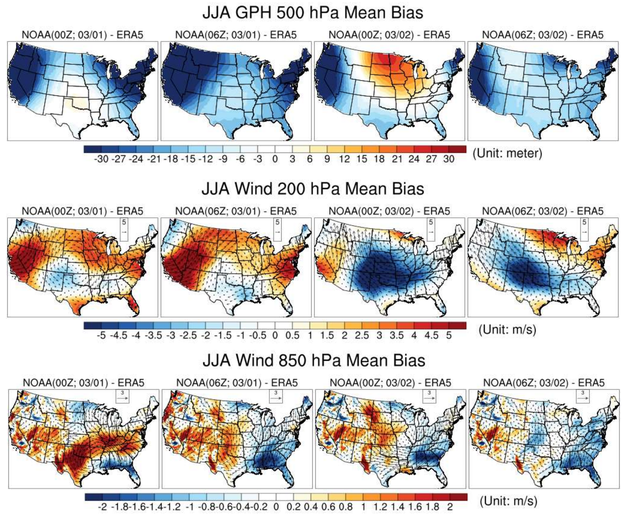
When BC is applied for all variables, the biases are improved; however, sporadic performance deterioration demonstrates a need for further investigation on the BC method.

Consistent performance improvements are found when **T**/**S** are included, and **P** is omitted. Considering this finding, the following results are selected and presented to investigate **G**/**R**/**W**.

Adding or omitting **G**/**R** shows mixed performance improvements. We may refine the BC method by calculating **G** based on the bias corrected **T** and **R**, instead of using independently bias corrected **G**.

When we omit **W**, some aspects of biases are improved. It demonstrates a need for investigating sensitivity of the vector interpolation.

Result 2 – Sensitivity Analysis



It is found that the current method that uses a single member may not fully represent the bias structure of CFSv2 for a given year. By using more ensemble members (i.e., additionally using the data of adjacent dates), we will be able to increase reliability in representing the characteristics of CFSv2's bias pattern.

Summary and Conclusion

The bias correction of lateral boundary condition is found to be promising in improving seasonal forecasting performance. Including temperature (T) and SST (S) yields consistently improved results. Meanwhile, the inclusion of surface pressure (P) did not contribute to the improvement, likely due to the duplicated application of model standard atmosphere (MSA) that addresses with topography effects.

In the subsequent research, we will further refine the bias correction method by calculating geopotential height (G) based on the bias corrected temperature (T) and relative humidity (R). We will also assess the sensitivity of vector interpolation methods between different projections in regional dynamic downscaling. To increase reliability of the seasonal forecast, a greater number of initial conditions will be utilized.

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