Environment and Climate Change Canada / Environnement et Changement climatique Canada

Online atmosphere/ocean bias correction in CanESM5 and its impact on seasonal hindcast skill

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Canadian Centre for Climate Modelling and Analysis (CCCma)

WGSIP 25/WGNE 39

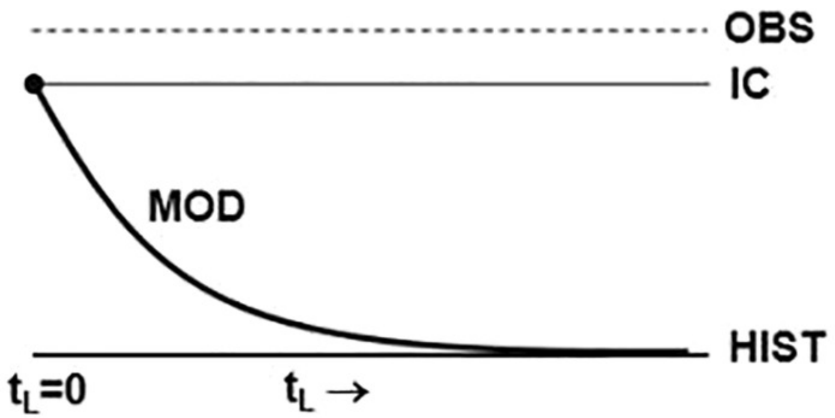
4-8 November 2024

Toulouse, France

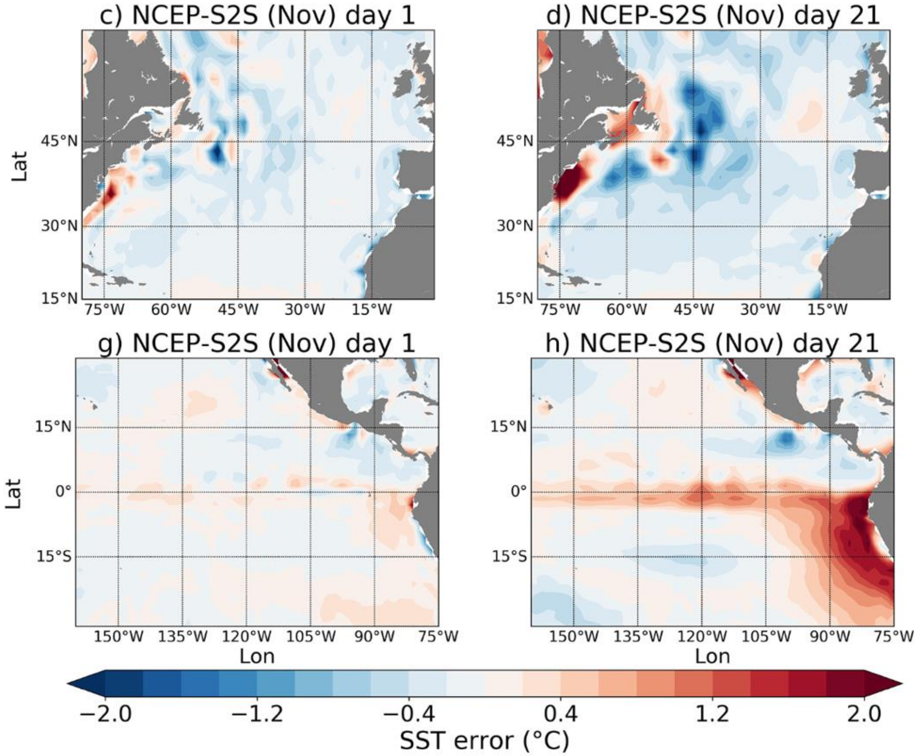
Canada

Motivation

- As long as model physics and numerics remain imperfect, prediction models initialized close to observations will *drift* toward **biased states** →



- A **pragmatic alternative**: compensate “missing” physical tendencies based on assimilation increments



Saurral et al. *JAMES* 2021
https://doi.org/10.1029/2021MS002570

The basic idea

- Consider atmospheric (or other) model component constrained by
  - nudging to gridded reanalysis time series, or

$$\frac{\partial X}{\partial t} = F(X) - \frac{1}{\tau}(X - X_R)$$

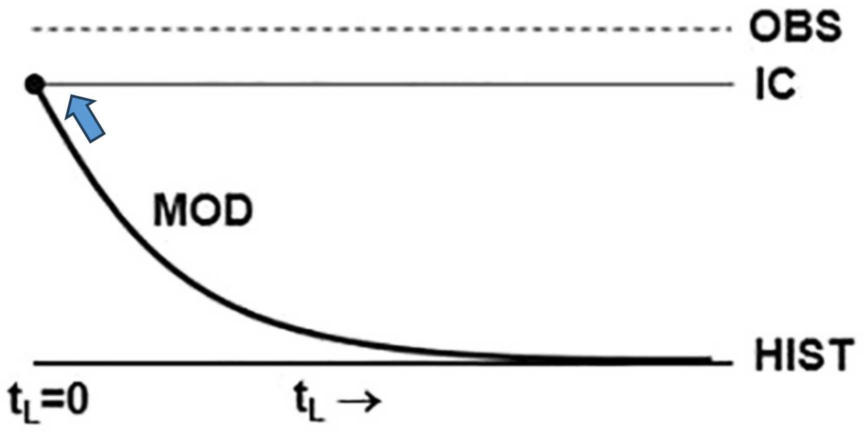
  - data assimilation

- Save time series of the nudging terms (or assimilation increments), compute mean annual cycle:

$$-\frac{1}{\tau}\overline{(X - X_R)}^{AC}$$

- Insert as a tendency correction in forecast runs:

$$\frac{\partial X}{\partial t} = F(X) - \frac{1}{\tau}\overline{(X - X_R)}^{AC}$$



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→ Reduced biases, modestly improved skill

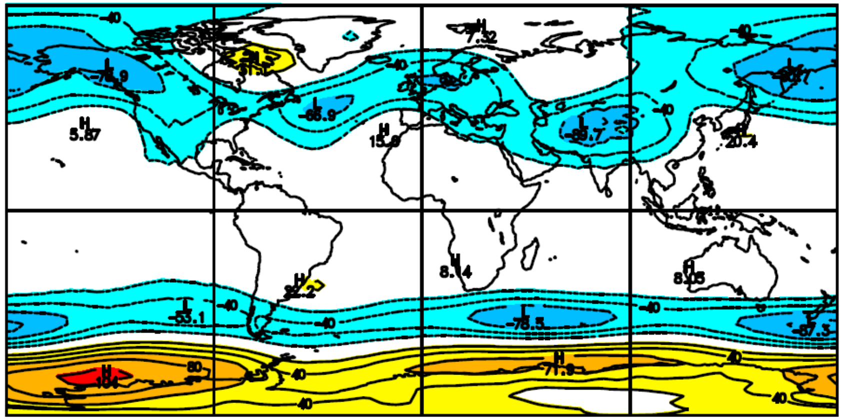
Geophysical Research Letters

The impact of model fidelity on seasonal predictive skill

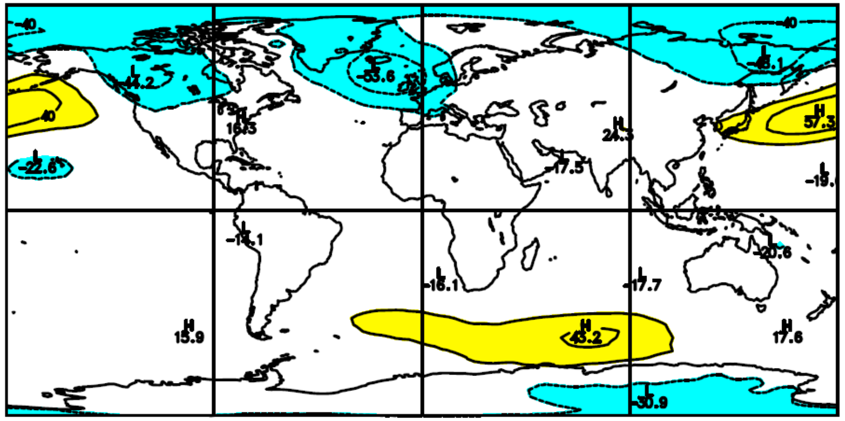
V. V. Kharin, J. F. Scinocca

First published: 22 September 2012 | https://doi.org/10.1029/2012GL052815 | Citations: 44

Z500 RMSE no bias correction



Z500 RMSE with bias correction



Related methods

NASA GEOS

- Estimate tendency corrections from **atmospheric** assimilation increments
- Apply long-term averaged increments (retaining diurnal and annual cycles) as forcing terms to atmospheric u, v, T, and p_s
- Atmospheric/surface biases reduced
- "Modest at best" improvements in S2S skill

Journal of Climate

Tendency Bias Correction in Coupled and Uncoupled Global Climate Models with a Focus on Impacts over North America

Y. Chang, S. D. Schubert, R. D. Koster, A. M. Molod, and H. Wang

Print Publication: 15 Jan 2019

DOI: https://doi.org/10.1175/JCLI-D-18-0598.1

GFDL SPEAR

- Estimate tendency adjustments from **ocean** T/S assimilation increments during 2007-2018
- Apply OTA from annual cycle of increments
- SST and subsurface biases greatly reduced
- Improved ENSO skill after first months

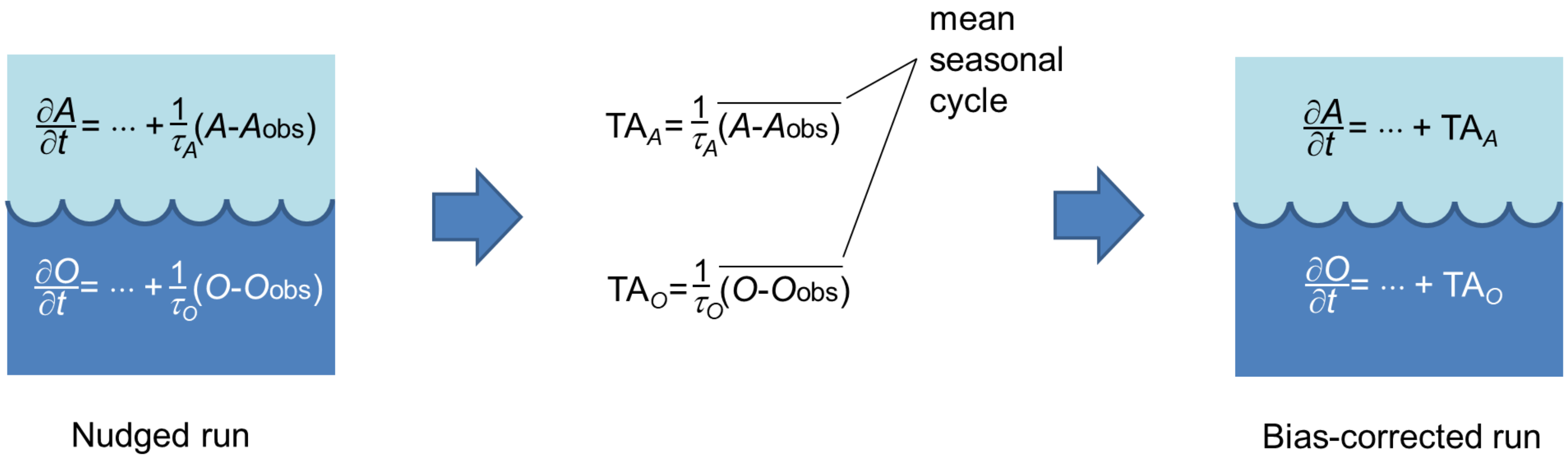
JAMES | Journal of Advances in Modeling Earth Systems

GFDL's SPEAR Seasonal Prediction System: Initialization and Ocean Tendency Adjustment (OTA) for Coupled Model Predictions

Feiyu Lu, Matthew J. Harrison, Anthony Rosati, Thomas L. Delworth, Xiaosong Yang, William F. Cooke, Liwei Jia, Colleen McHugh, Nathaniel C. Johnson, Mitchell Bushuk, Yongfei Zhang, Alistair Adcroft

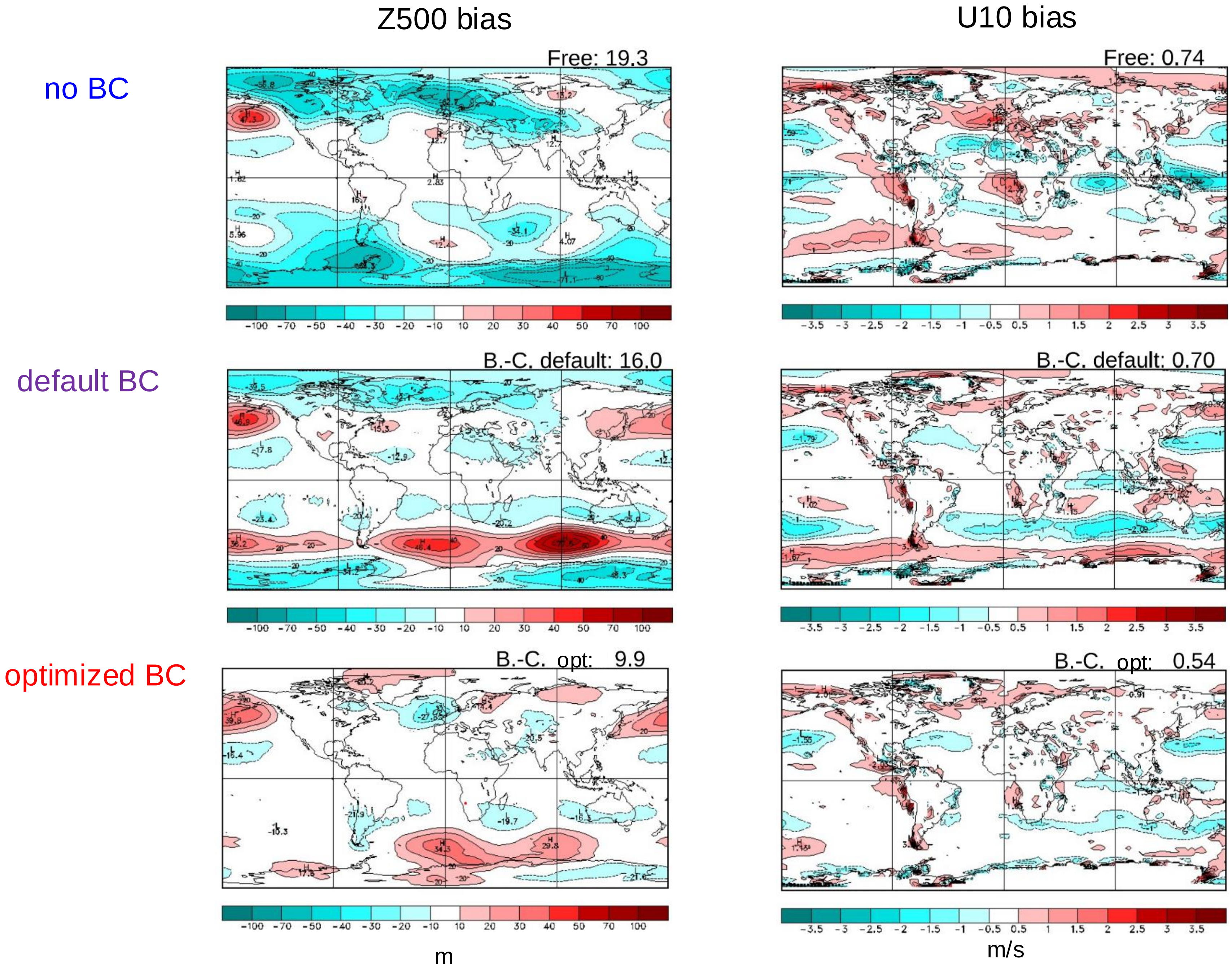
First published: 03 November 2020 | https://doi.org/10.1029/2020MS002149 | Citations: 31

Tendency adjustment methodology for CanESM5

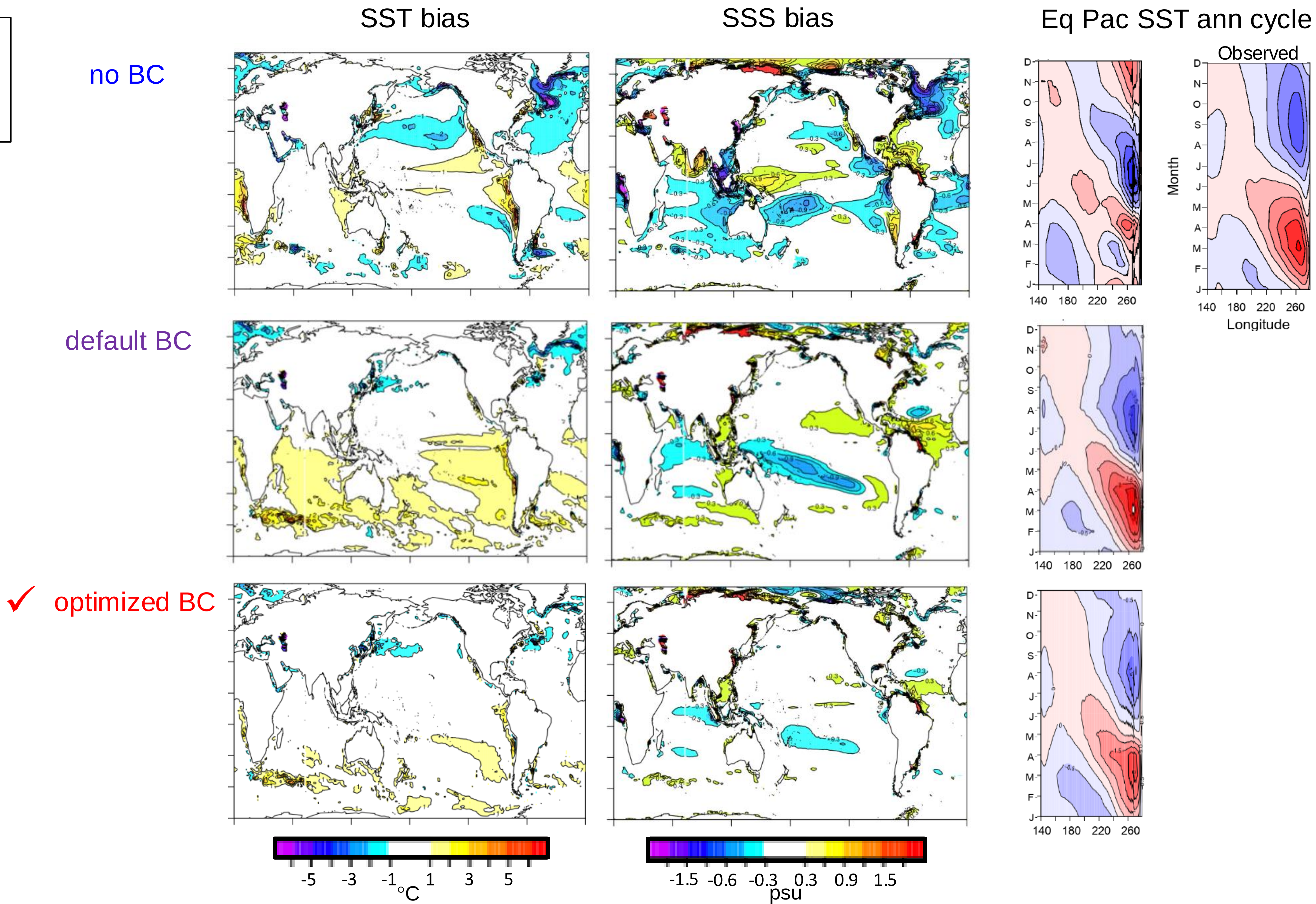


- Atmosphere
  - **default** settings: τ_A=24h, apply on scales ≳1000km
  - **optimized** settings: $\tau_A(z)$, spectral truncation per variable
- Ocean
  - τ_O=30 days for T/S in upper 800m, 360 days below
  - no nudging within ±2° of Equator
- Evaluate CanESM5 free runs and hindcasts using
  - no bias correction
  - **default** bias correction settings
  - **optimized** atm bias correction settings

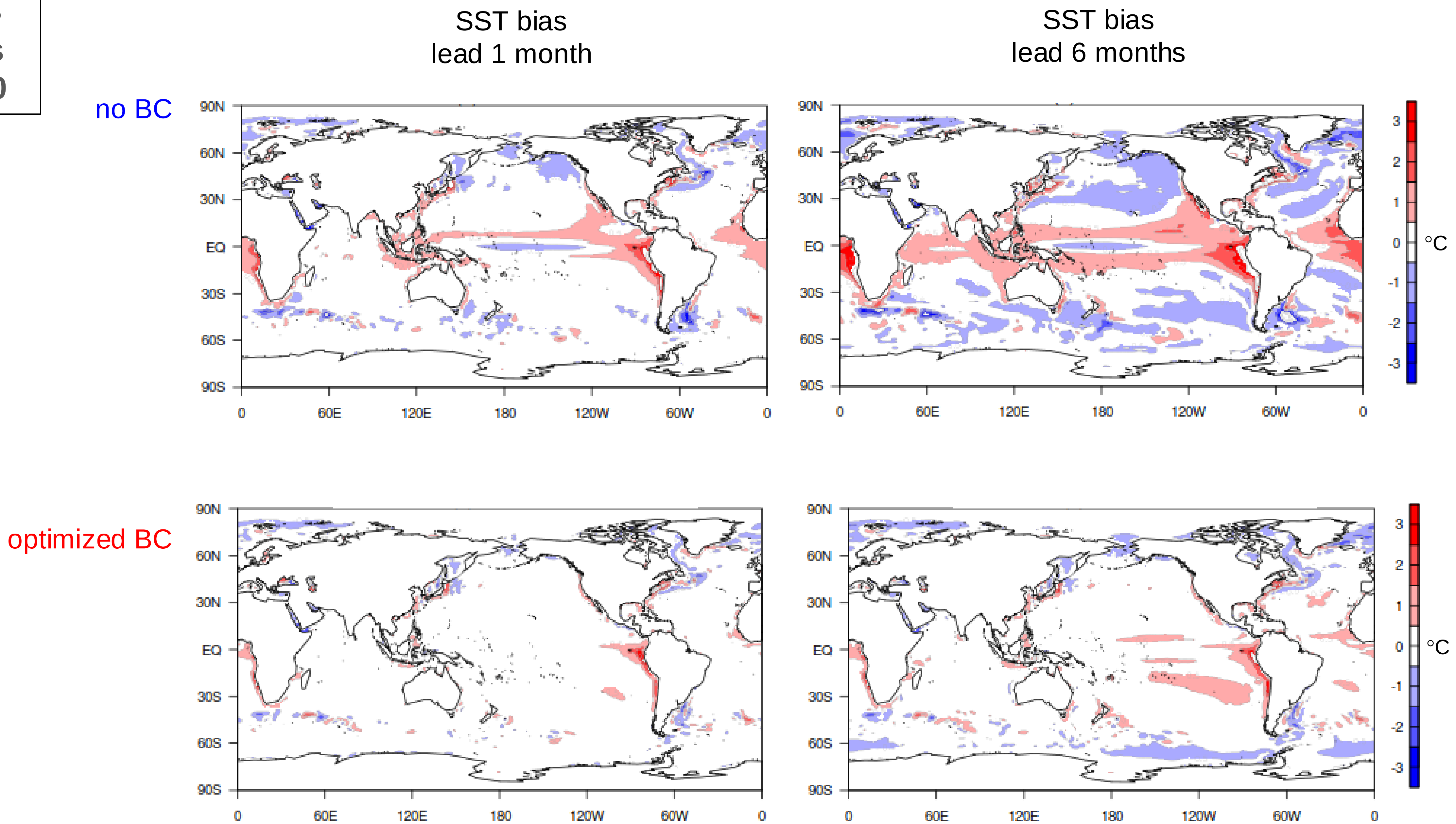
CanESM5 AMIP runs 2004-2008



CanESM5 free coupled runs 1981-2020

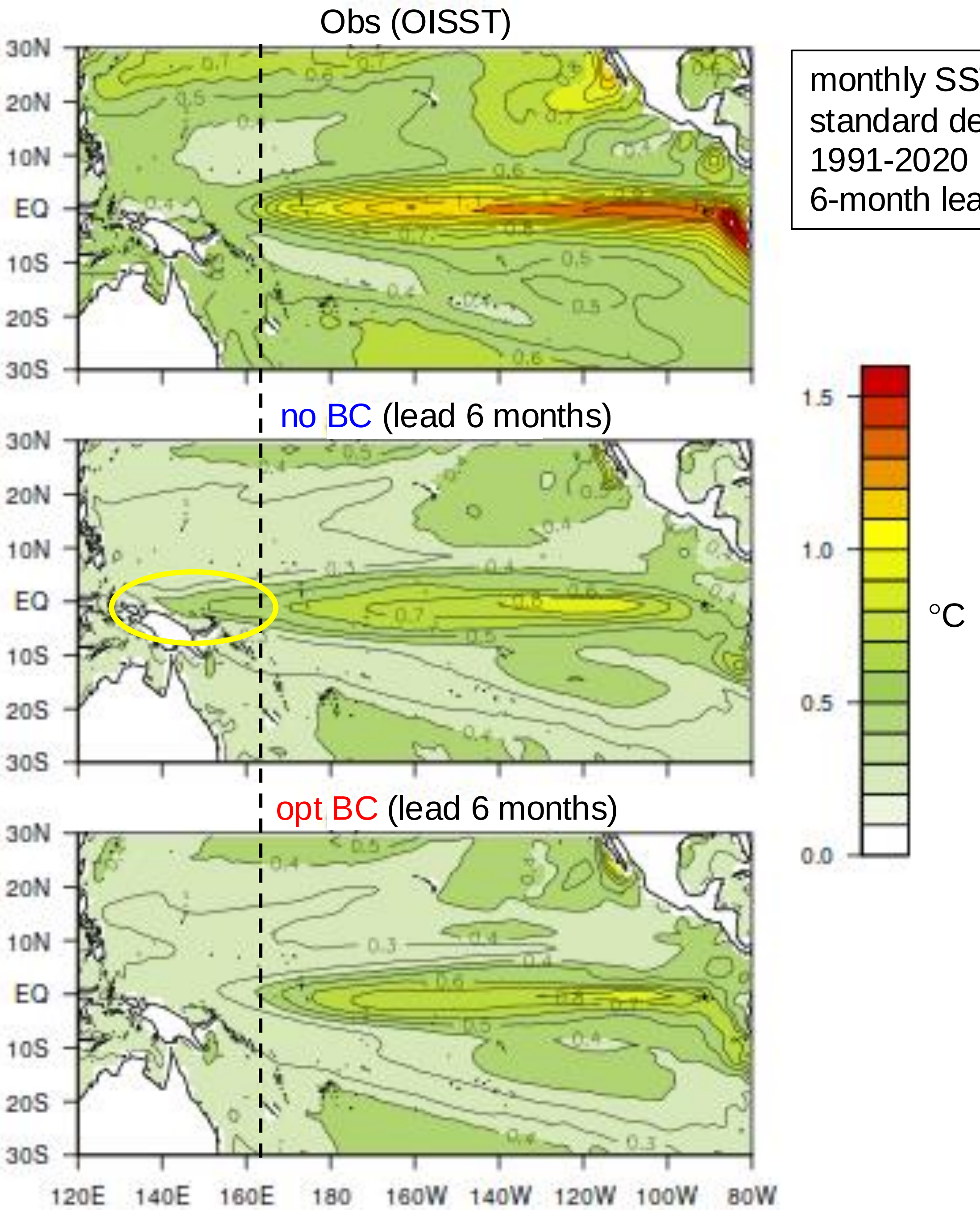


CanESM5 hindcasts 1991-2020



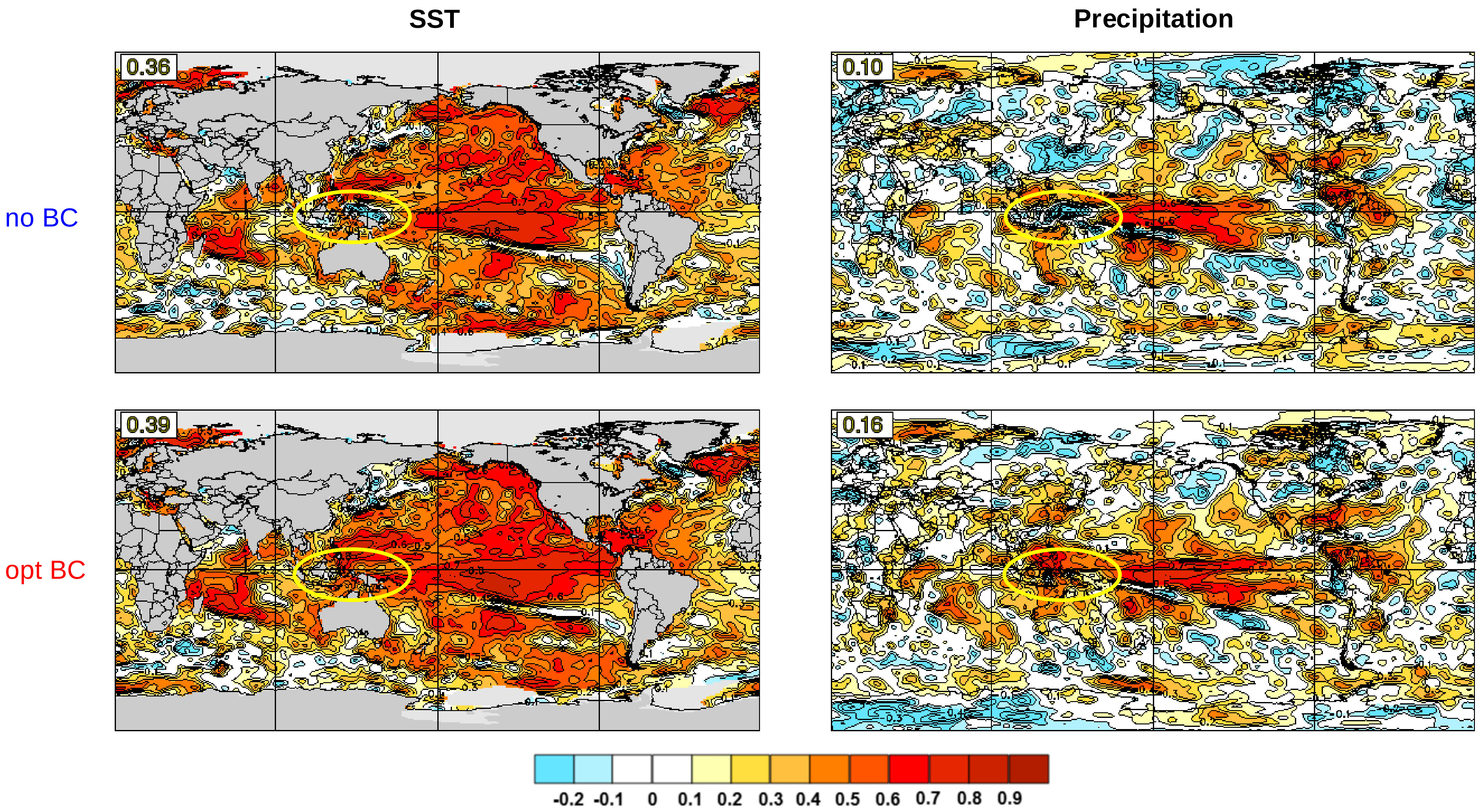
ENSO variability in hindcasts

- ENSO in hindcasts is weaker than observed
- Bias correction doesn't help
- However, bias correction **reduces the unrealistic westward extension** of El Niño/La Niña SST anomalies (a common error in climate models)
- This impacts skill in the affected region, and possibly teleconnected regions as well



monthly SSTA
standard deviation
1991-2020
6-month lead

DJF anomaly correlation from June (lead 6 months)



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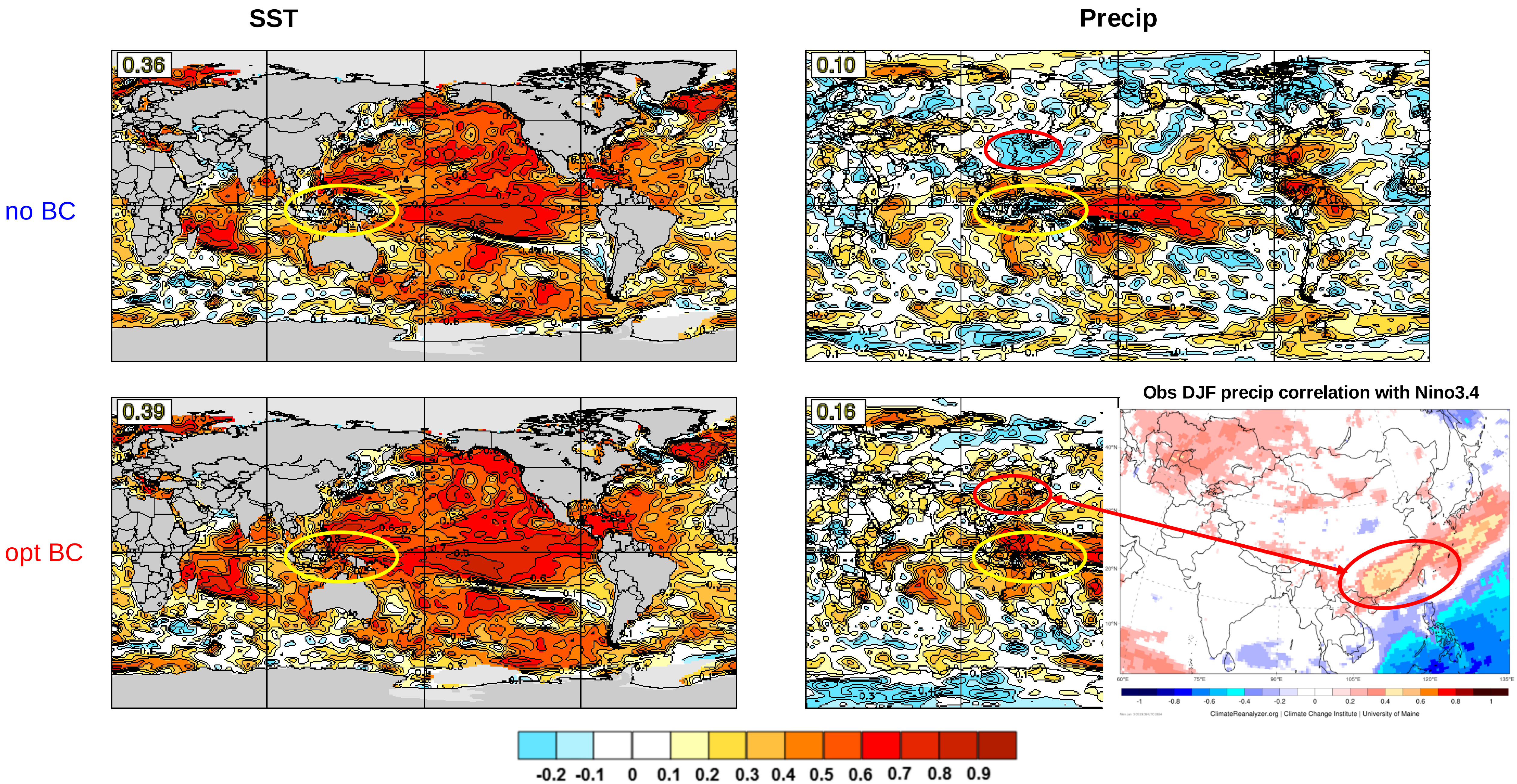
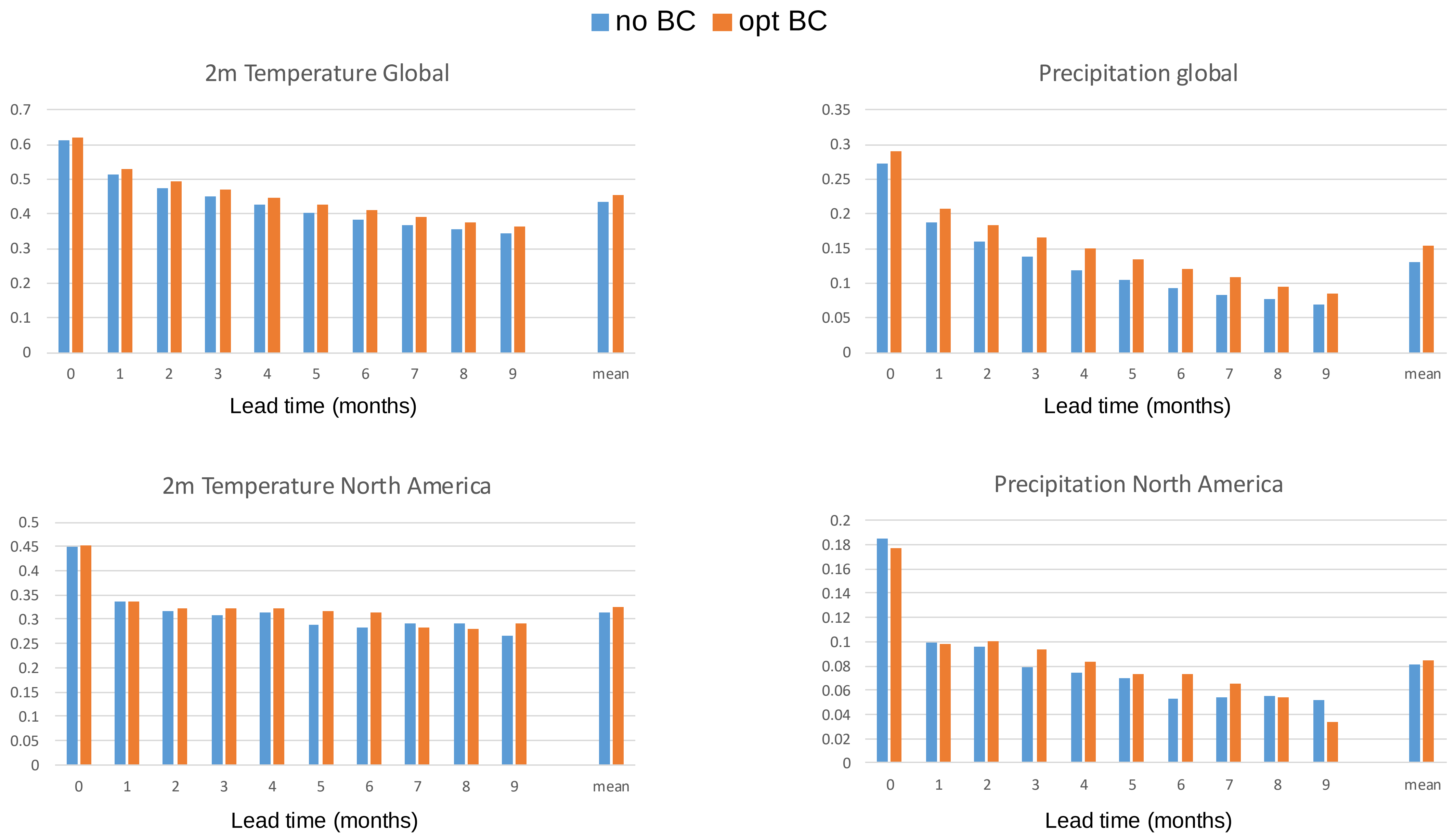


Anomaly correlation vs lead time (10 ensemble members, all initial months)



Outlook

- Tendency adjustments thus far in ECCC/GFDL/NASA models have been **state-independent**

- Current research on multiple fronts is exploring **state-dependent** tendency adjustment facilitated by **machine learning**

Quarterly Journal of the Royal Meteorological Society RMetS

RESEARCH ARTICLE | Open Access

Using machine learning to correct model error in data assimilation and forecast applications

Alban Farchi, Patrick Laloyaux, Massimo Bonavita, Marc Bocquet

First published: 02 July 2021 | https://doi.org/10.1002/qj.4116 | Citations: 39

JAMES | Journal of Advances in Modeling Earth Systems

Research Article | Open Access

Correcting Systematic and State-Dependent Errors in the NOAA FV3-GFS Using Neural Networks

Tse-Chun Chen, Stephen G. Penny, Jeffrey S. Whitaker, Sergey Frolov, Robert Pincus, Stefan Tulich

First published: 18 October 2022 | https://doi.org/10.1029/2022MS003309 | Citations: 10

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Deep Learning to Estimate Model Biases in an Operational NWP Assimilation System

Patrick Laloyaux, Thorsten Kurth, Peter Dominik Dueben, David Hall

First published: 16 May 2022 | https://doi.org/10.1029/2022MS003016 | Citations: 7

Geophysical Research Letters

Research Letter | Open Access

Correcting Weather and Climate Models by Machine Learning Nudged Historical Simulations

Oliver Watt-Meyer, Noah D. Brenowitz, Spencer K. Clark, Brian Henn, Anna Kwa, Jeremy McGibbon, W. Andre Perkins, Christopher S. Bretherton

First published: 15 July 2021 | https://doi.org/10.1029/2021GL092555 | Citations: 38

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Christopher S. Bretherton, Brian Henn, Anna Kwa, Noah D. Brenowitz, Oliver Watt-Meyer, Jeremy McGibbon, W. Andre Perkins, Spencer K. Clark, Lucas Harris

First published: 21 January 2022 | https://doi.org/10.1029/2021MS002794 | Citations: 24

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William Gregory, Mitchell Bushuk, Alistair Adcroft, Yongfei Zhang, Laure Zanna

First published: 27 September 2023 | https://doi.org/10.1029/2023MS003757 | Citations: 4