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Run-time bias correction of CanESM5 and its impact on seasonal forecast skill

Bill Merryfield*, *Slava Kharin, Woo-Sung Lee, John Scinocca and Reinel Sospedra-Alfonso

Canadian Centre for Climate Modelling and Analysis (CCCma)

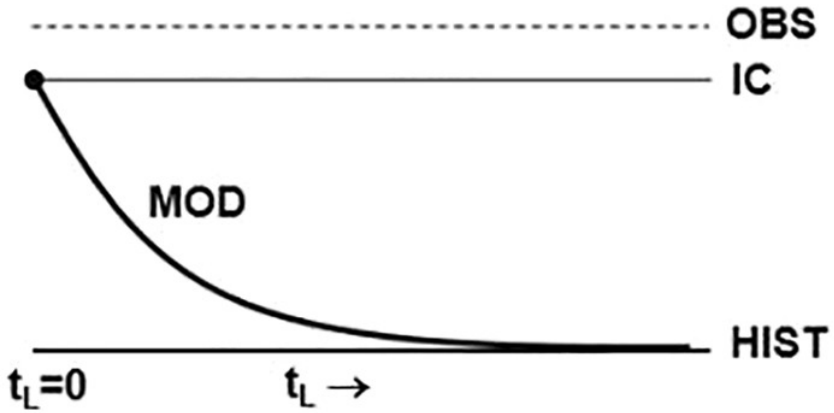
Canada

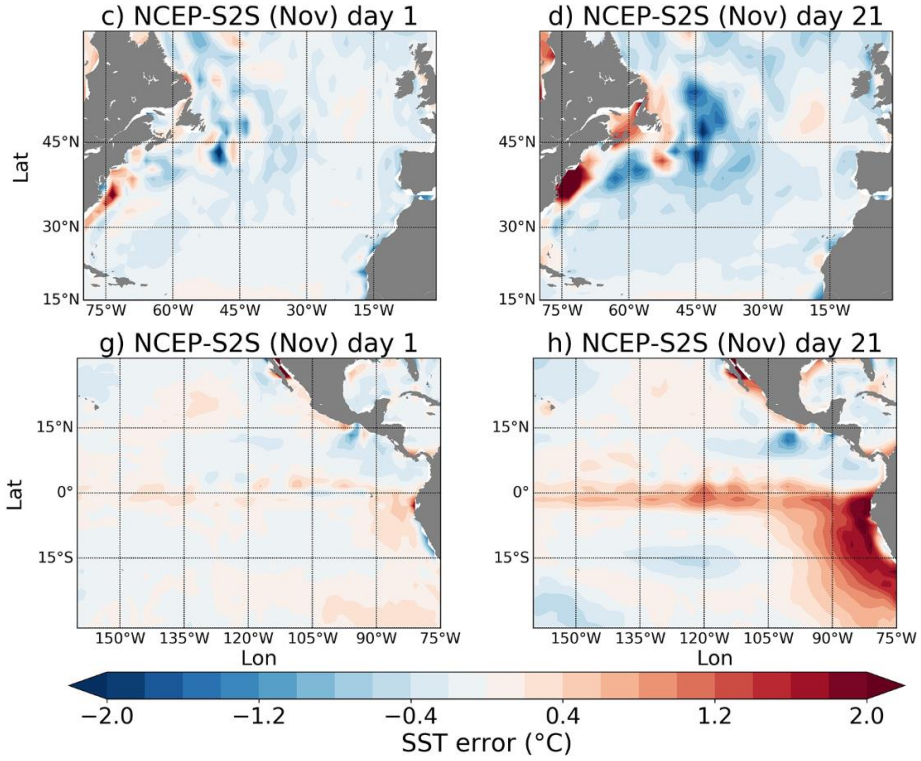
S2S Community Workshop
5-7 June 2024

Motivation

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

- A **pragmatic alternative**: estimate “missing” physical tendencies from 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

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

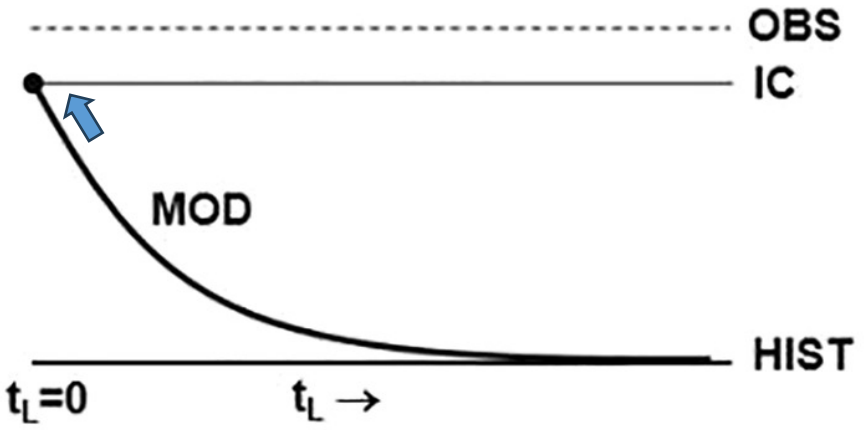
  - data assimilation

- 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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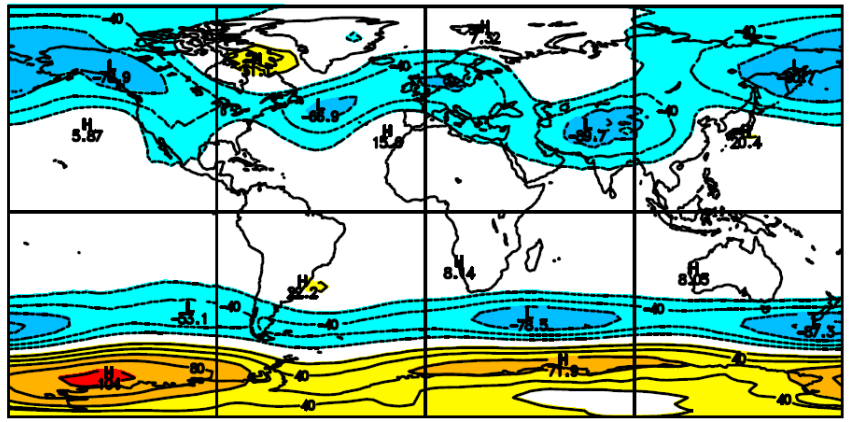
Geophysical Research Letters

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



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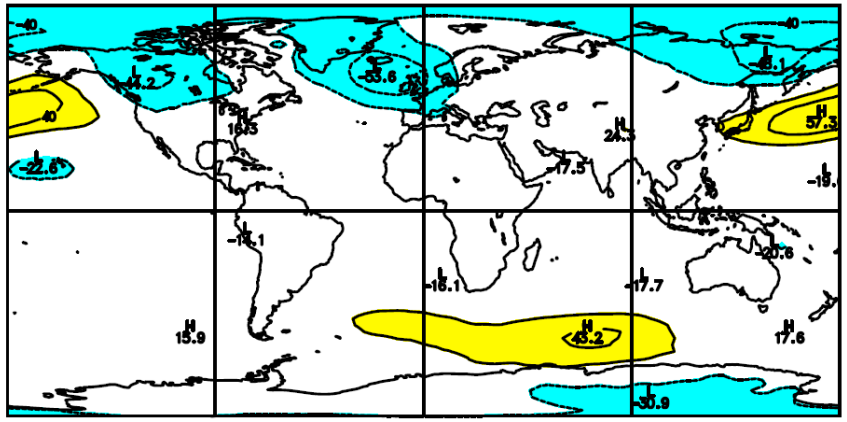

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→ Improved skill

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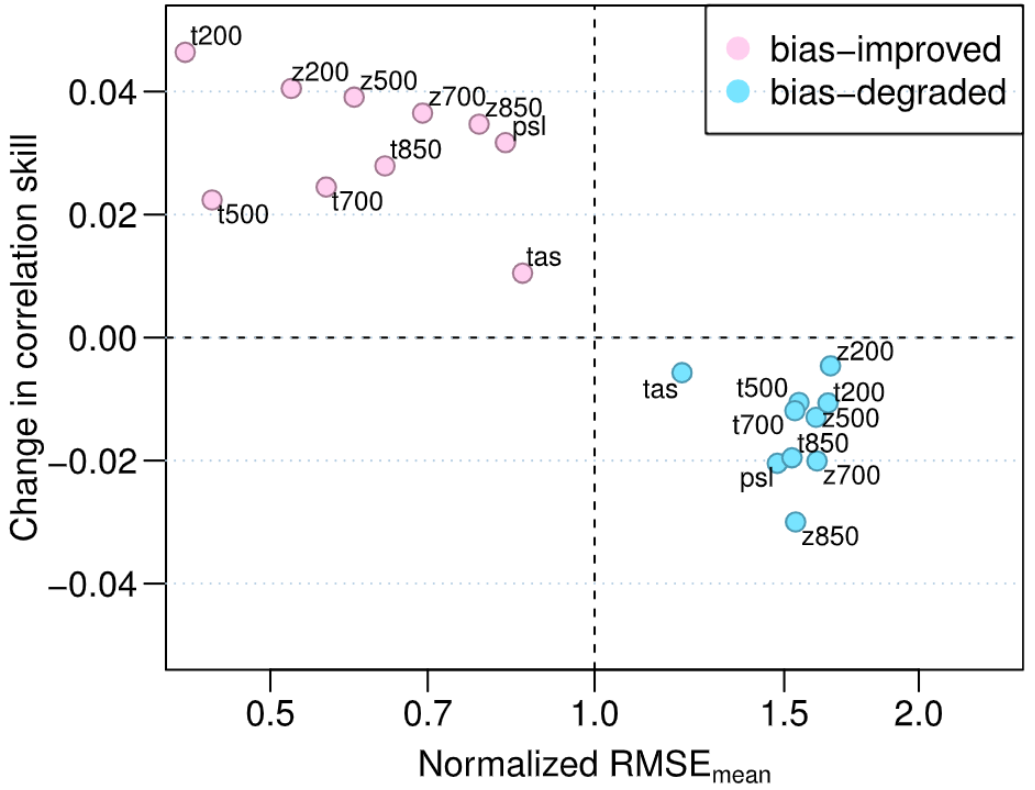


Related methods

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

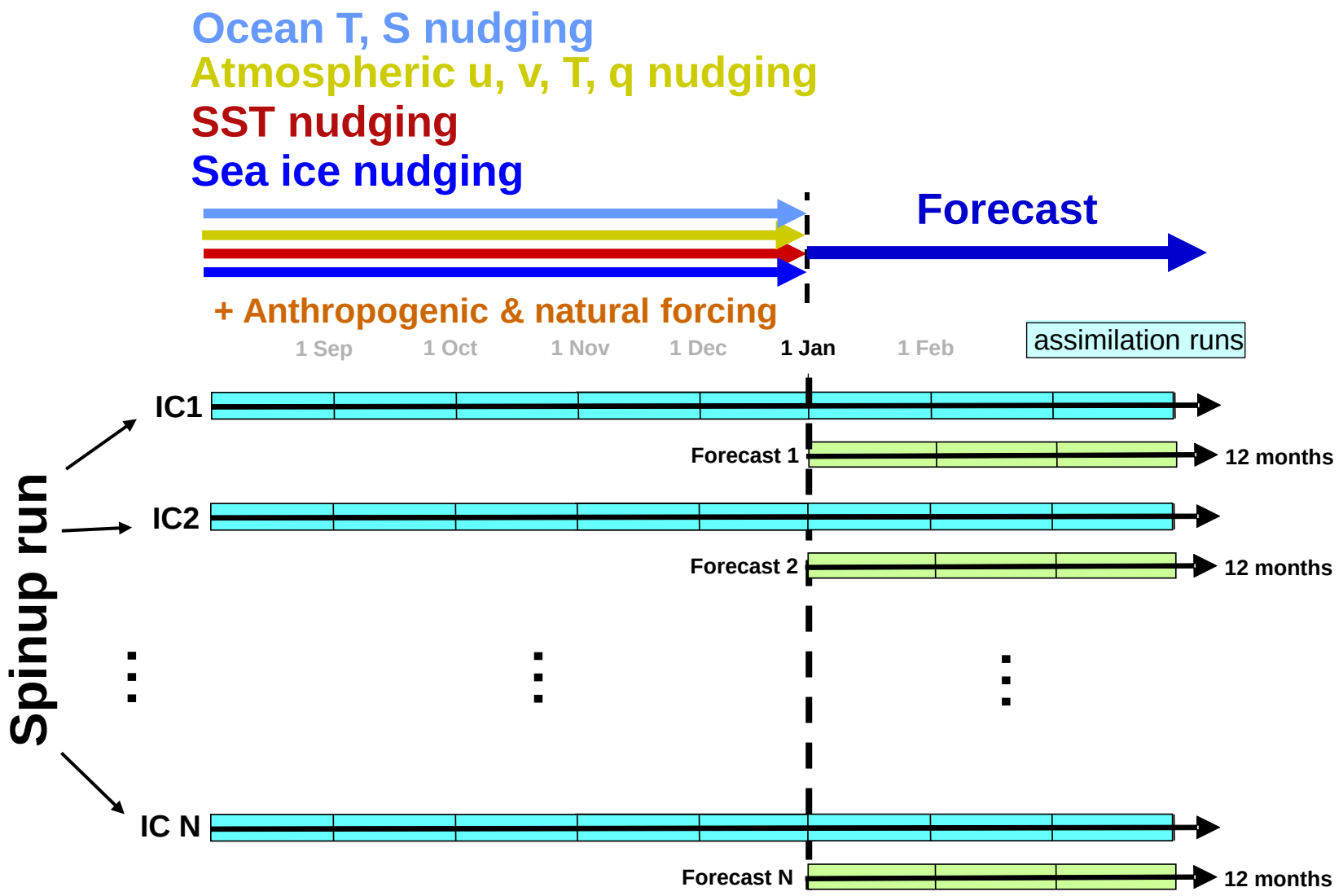
JAMES | Journal of Advances in Modeling Earth Systems

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

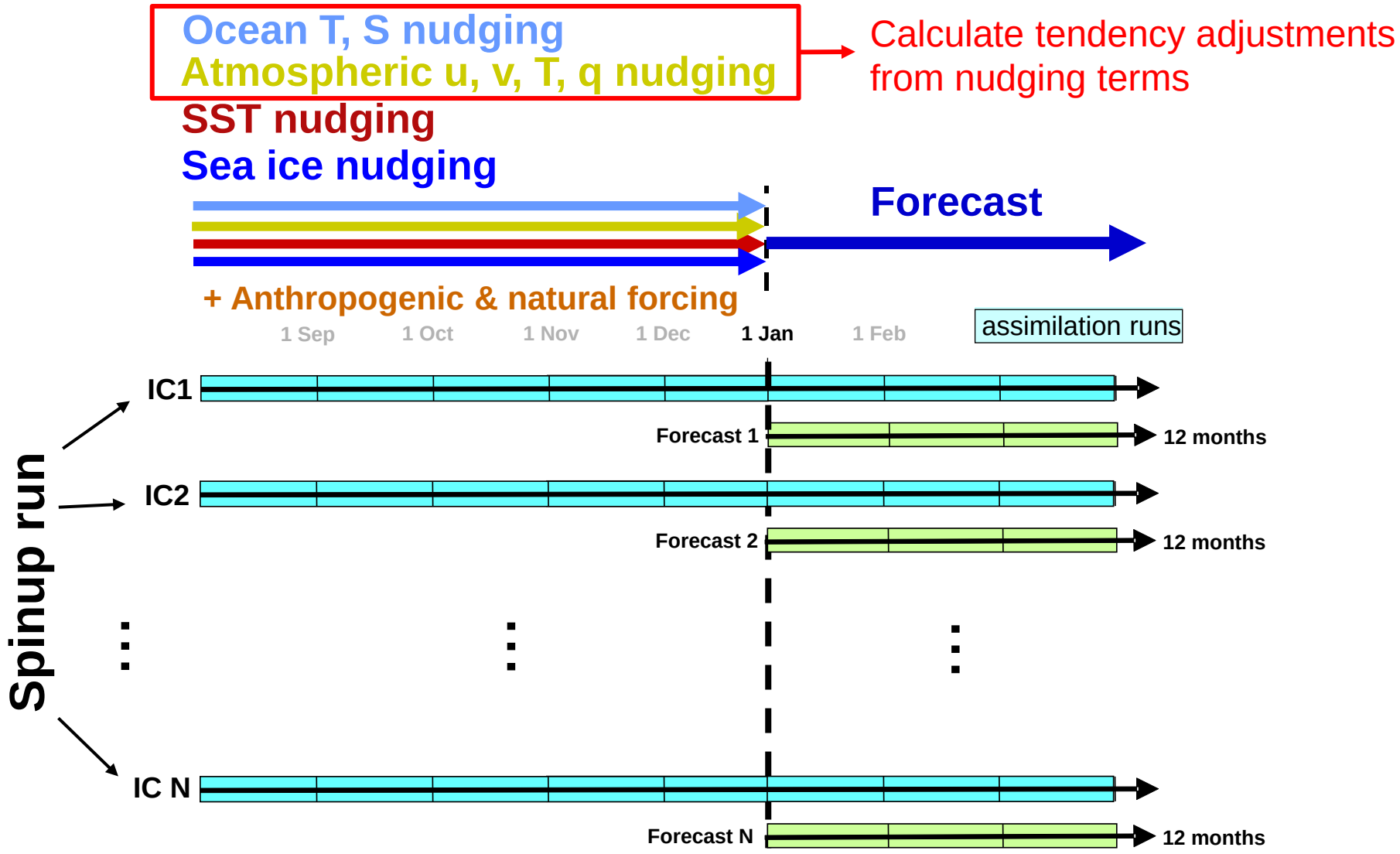
Feiyu Lu, Matthew J. Harrison, Anthony Rosati, Thomas L. Delworth, Xiaosong Yang, William F. Cooke, Liwei Jia, Colleen McHugh, Nathaniel C. Johnson, Mitchell Bushuk, Yongfei Zhang, Alistair Adcroft

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

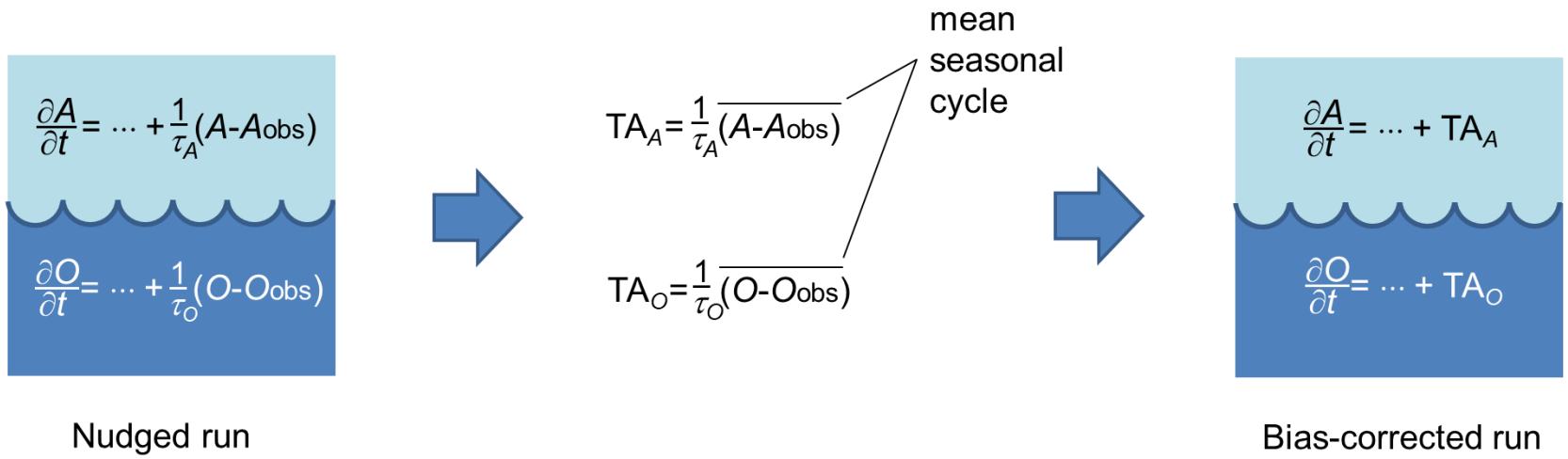
CanESM5 seasonal forecast initialization



CanESM5 seasonal forecast initialization



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

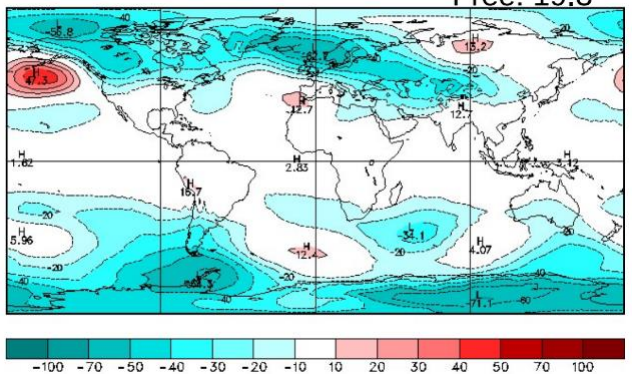
CanESM5 AMIP runs 2004-2008

Z500 bias

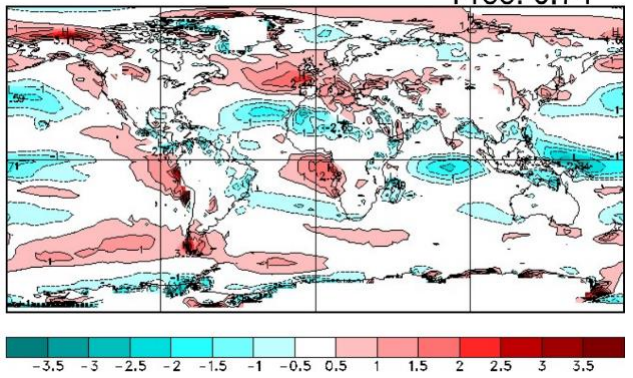
U10 bias

no BC

Free: 19.3

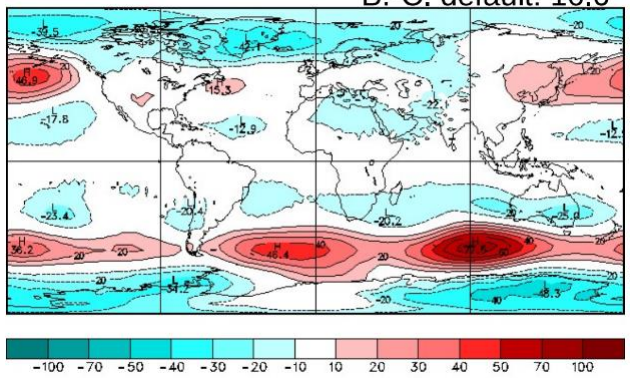


Free: 0.74

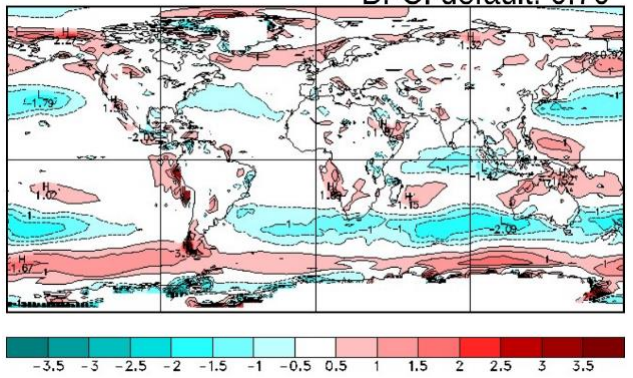


default BC

B.-C. default: 16.0

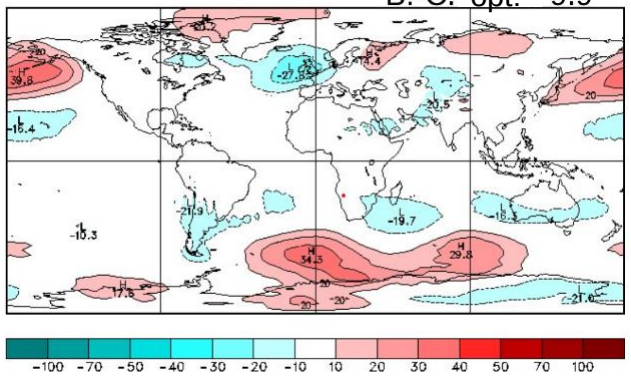


B.-C. default: 0.70



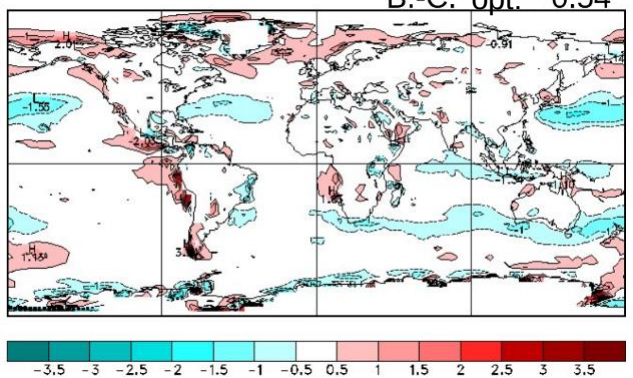
optimized BC

B.-C. opt: 9.9



m

B.-C. opt: 0.54



m/s

CanESM5 free coupled runs 1981-2020

SST bias

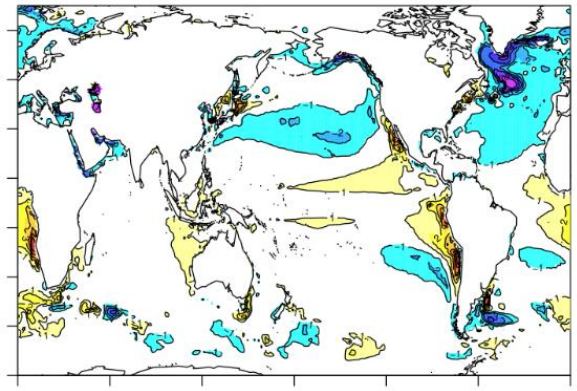
SSS bias

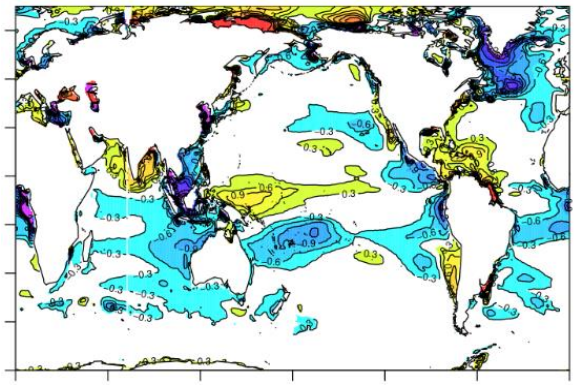
Eq Pac SST ann cycle

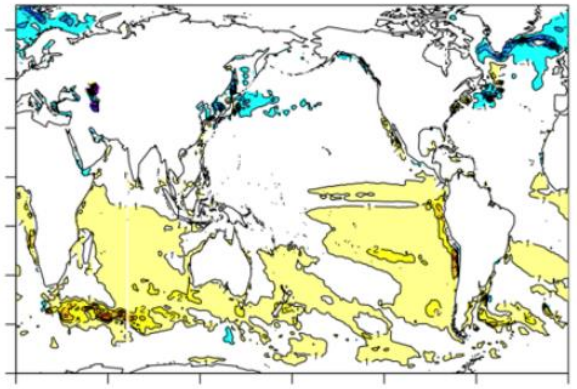
no BC

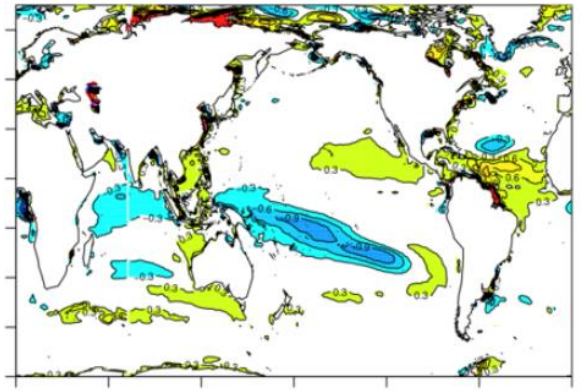
default BC

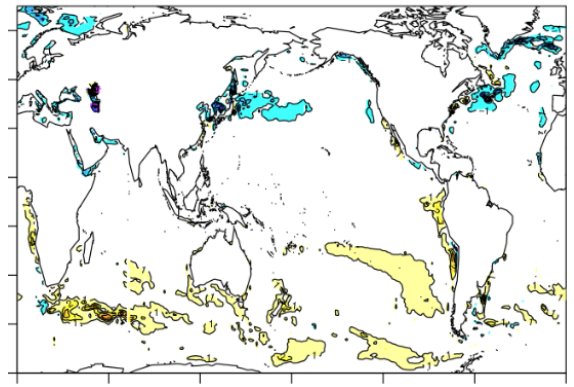
✓ optimized BC

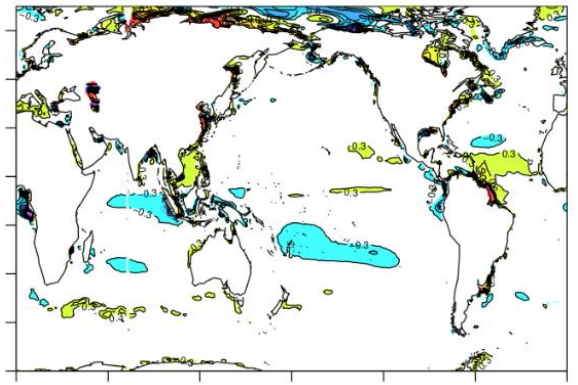


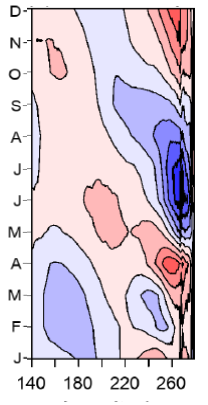


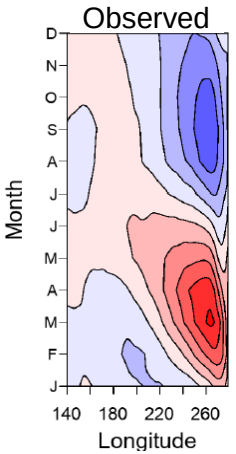


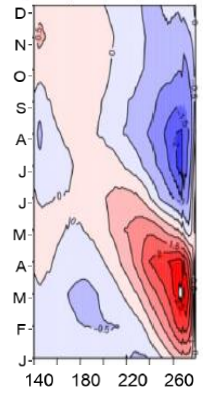


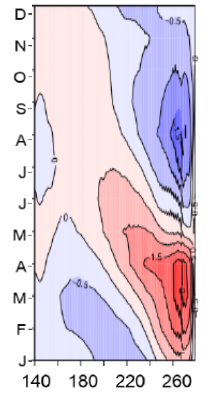










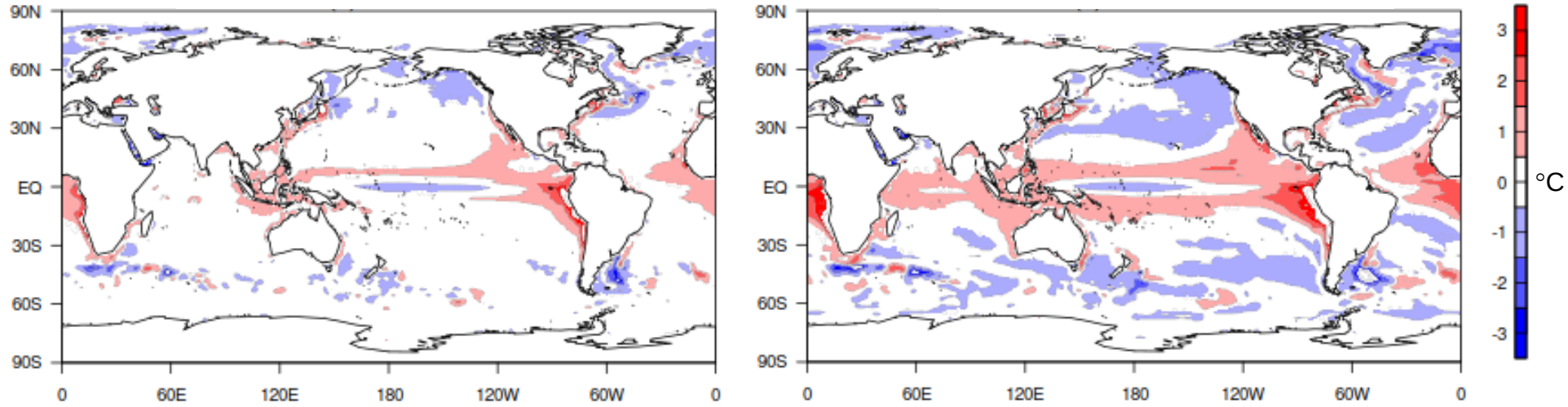


CanESM5 hindcasts 1991-2020

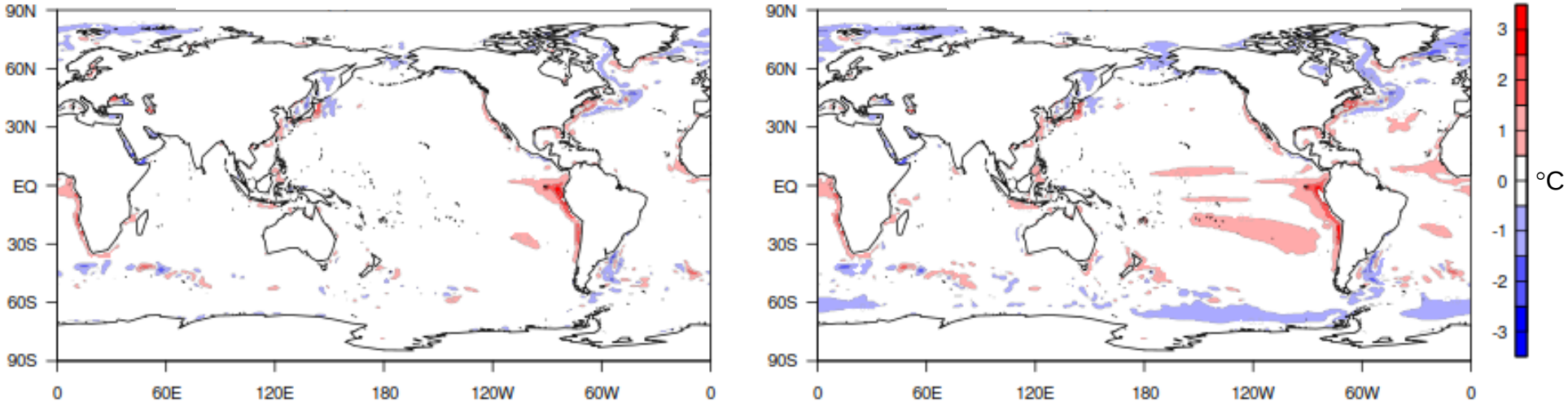
SST bias
lead 1 month

SST bias
lead 6 months

no BC

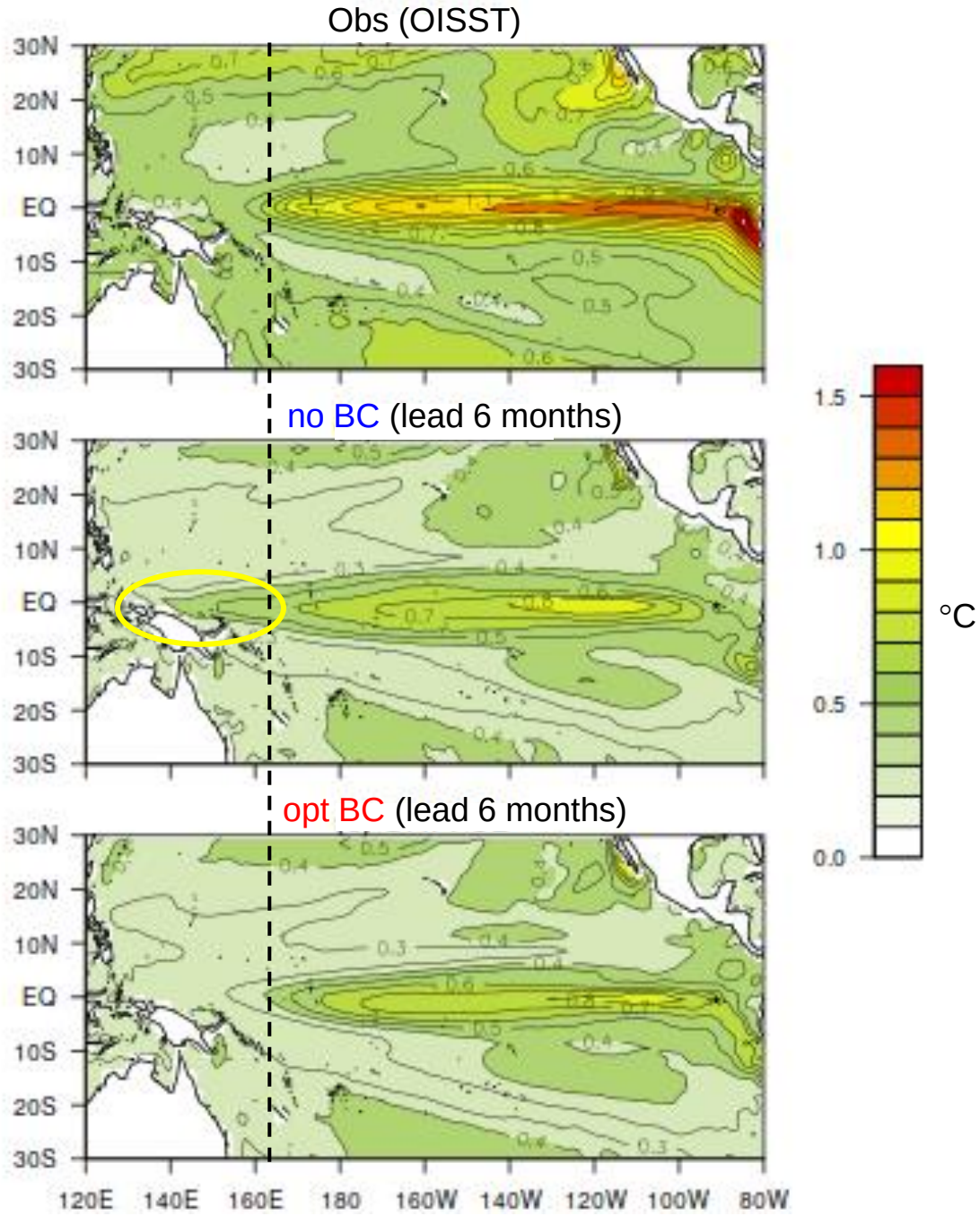


optimized BC



SSTA standard deviations 1991-2020

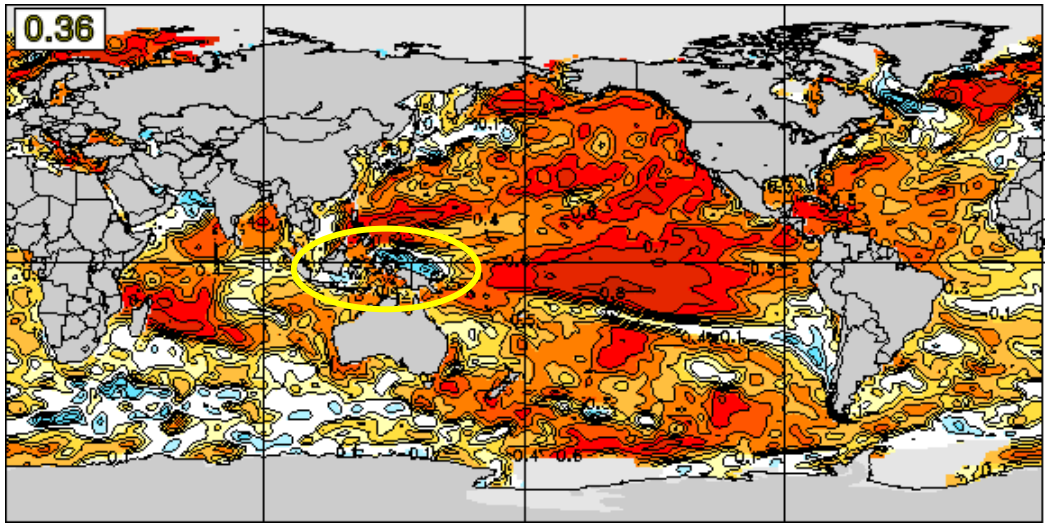
- ENSO in hindcasts is weaker than observed
- Bias correction doesn't help
- However, bias correction **reduces the unrealistic westward extension** of El Niño/La Niña SST anomalies (a common error in climate models)
- This impacts skill in the affected region, and possibly teleconnected regions as well

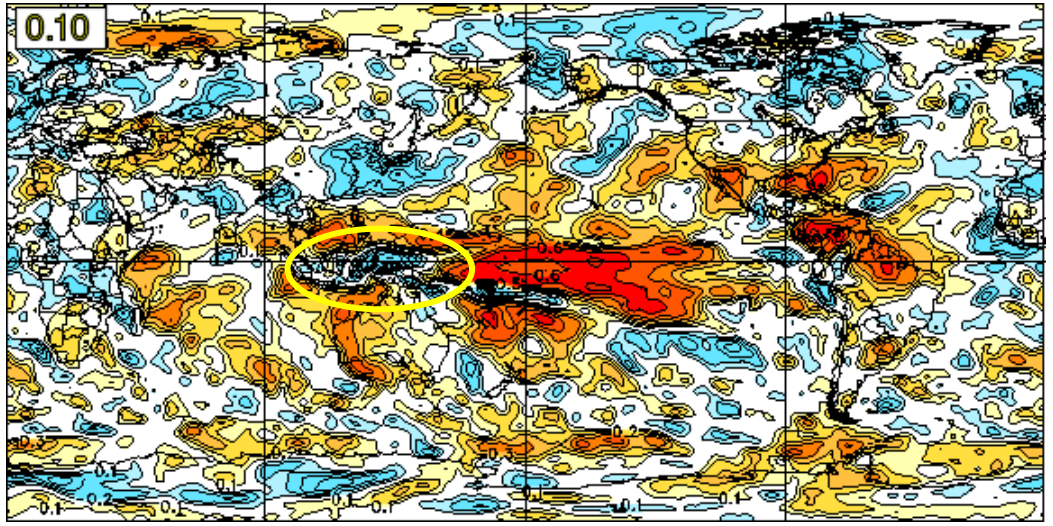


DJF anomaly correlation from June (lead 6 months)

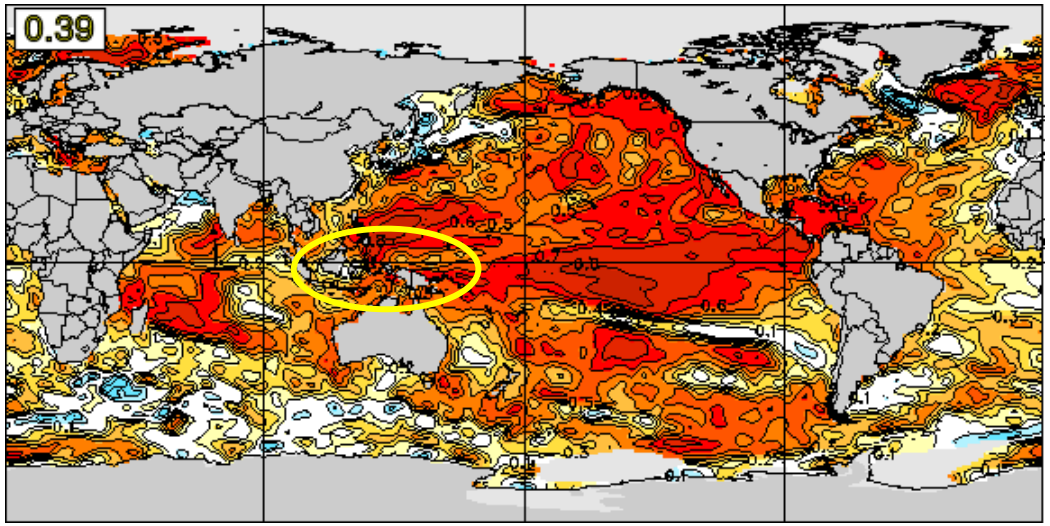
SST | **Precipitation**

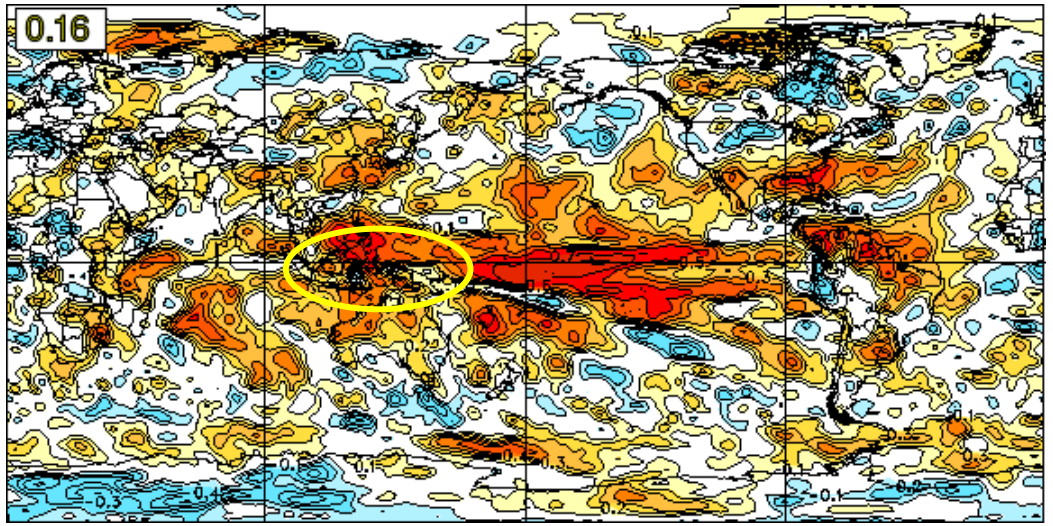
no BC





opt BC





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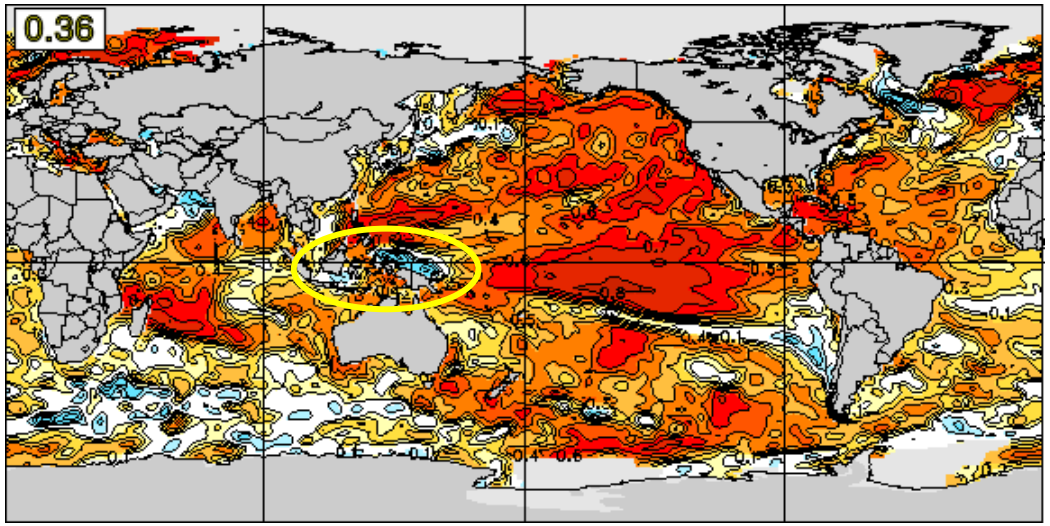
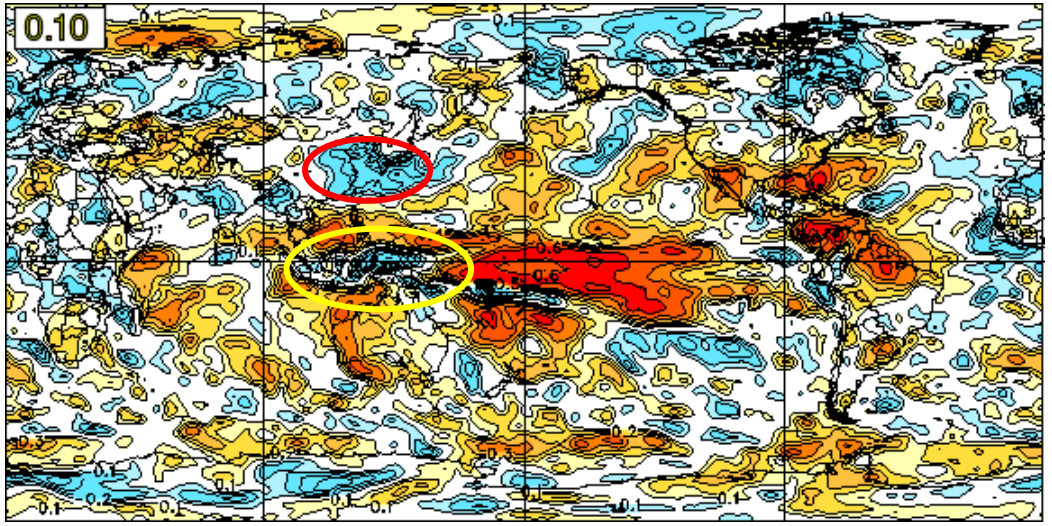
SST

Precip

no BC





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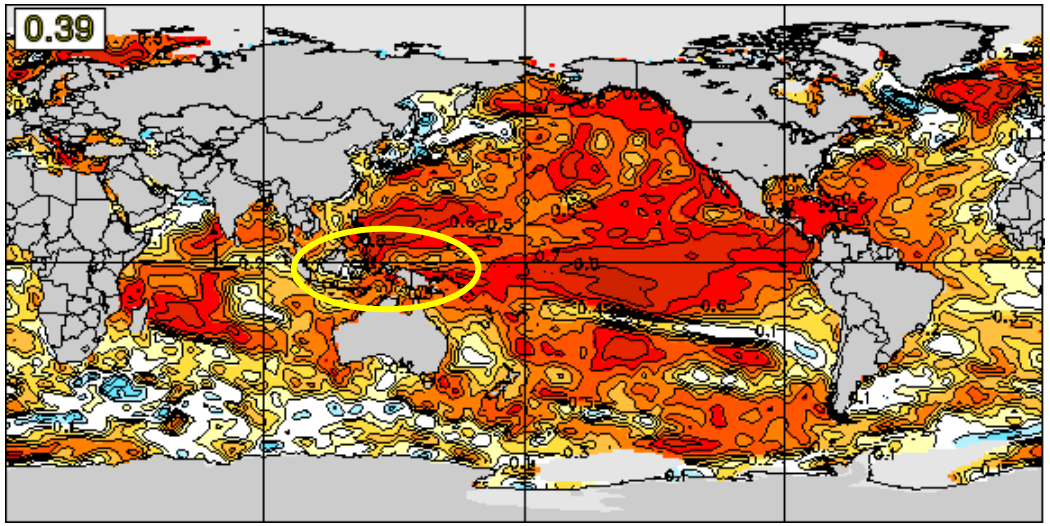
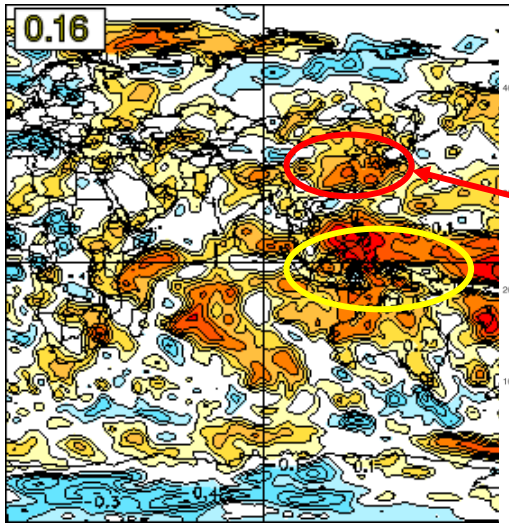
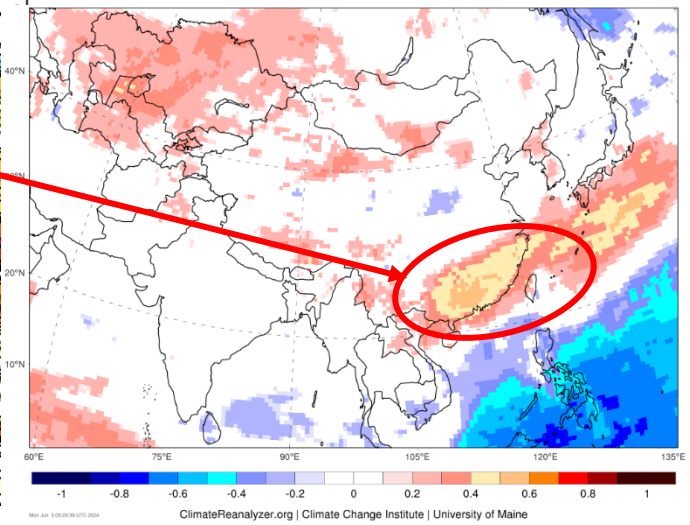
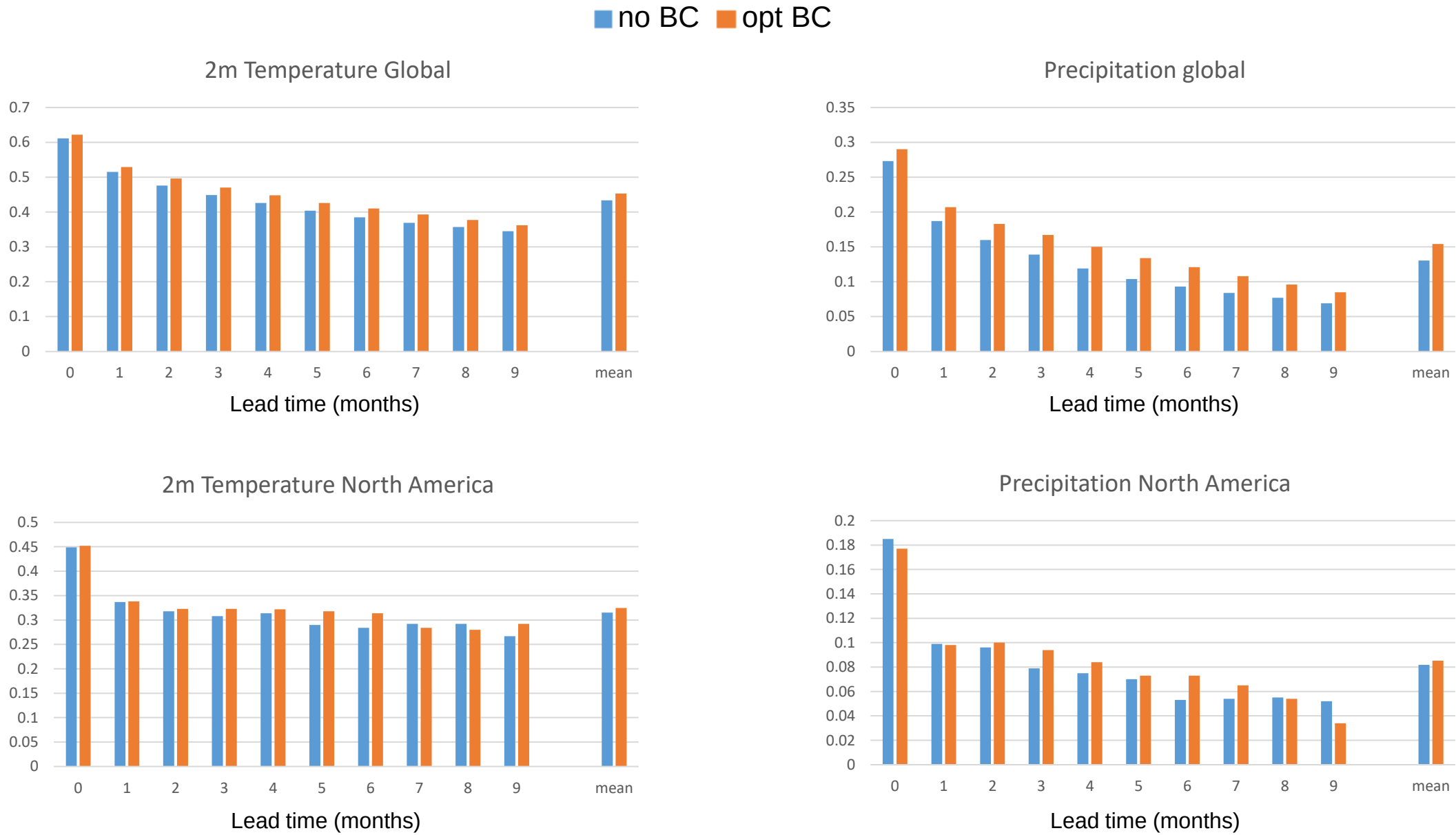




Obs DJF precip correlation with Nino3.4



Anomaly correlation vs lead time (all initial months)



Summary

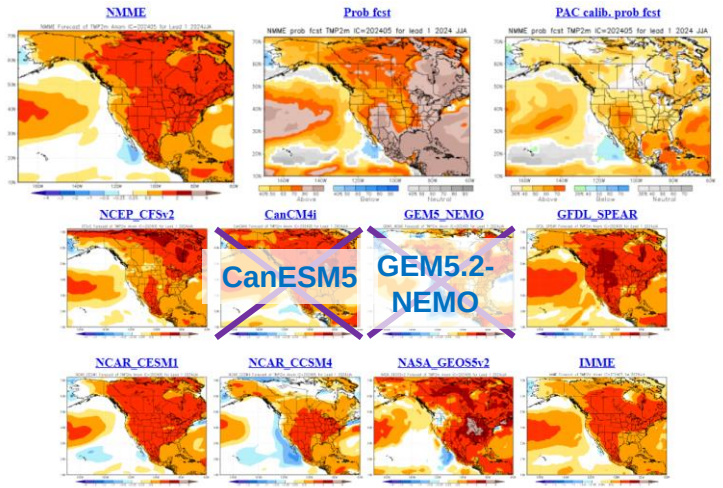
- Simple tendency adjustment/bias correction derived from nudging terms has been applied in **atmosphere and ocean** components of CanESM5

- Atmosphere and ocean state **biases are substantially reduced**, both in free runs and hindcasts

- Temperature and precipitation **hindcast skill improved** globally

- Skill improvements partly attributable to **improved ENSO SSTA pattern** (CanESM5 Nino3.4 skill mediocre, not improved by BC)

- CanESM5 opt BC begins contributing to NMME **July 1**, along with GEM5.2-NEMO



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**

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