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

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Motivation

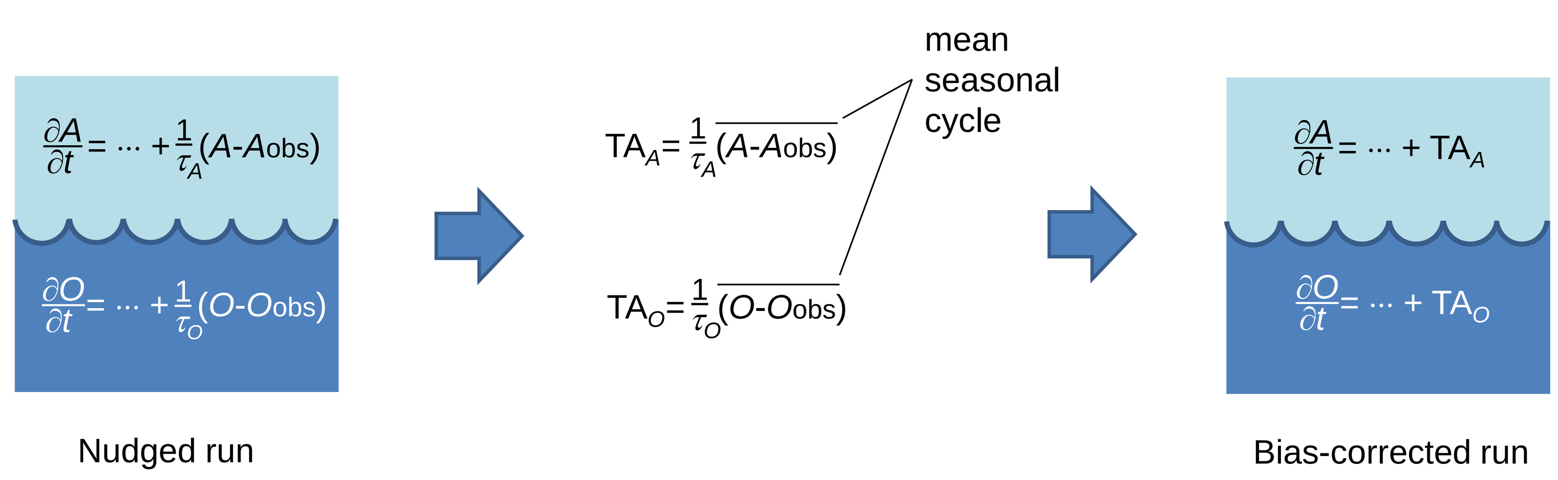
- Notable biases in CCCma's CMIP6 model CanESM5 [5] include
  - Too cold and too much sea ice in NW Atlantic/Labrador Sea
  - Too rapid warming during historical period
  - ENSO too weak with incorrect seasonality
- Possibly as a result, CanESM5 has lower skill for ENSO and decadal prediction than CCCma's current CanCM4i operational model
- Can atmosphere-ocean **tendency adjustments (TA)** reduce biases and improve skill in CanESM5?

Background

- Model biases and resulting drifts following observation-based initialization of climate prediction models [1] can potentially degrade forecast skill
- Although model improvements have led to their gradual reduction, significant biases are likely to remain for some time
- A pragmatic approach for reducing biases and potentially improving skill is to apply TA estimated from assimilation increments
- TA have previously been applied in
  - CCCma's atmospheric model (uncoupled) [2]
  - NASA's GEOS atmospheric model (uncoupled and coupled) [3]
  - GFDL's ocean model (coupled) [4]
- In these studies, TA is applied to one component of the coupled system (atmosphere or ocean) and leads to reduced biases and drift, plus modestly improved skill in some instances

Atmosphere-Ocean TA in CanESM5

- Initial conditions for CanESM5 predictions come from coupled runs in which atmospheric T/Q/U/V and ocean θ/S are nudged to reanalyses [6]
- Atmosphere & ocean TA terms are diagnosed from monthly climatologies of nudging increments over 1981-2020 in similar runs
- Influence of atmosphere-ocean TA is evaluated in
  - 30-year runs initialized in 1981
  - Seasonal hindcasts initialized each month in 1981-2020



TA versions considered

- **noBC** = no Bias Correction (TA not applied)
- **defBC**= default Bias Correction based on const τ_A =24h for all variables
- **optBC**= optimized " " with τ_A dependent on height and variable
- In each case τ_O = 30d in upper 800m, transitioning to 360d in deeper ocean (smaller τ_O led to crashes, larger τ_O to larger biases)

CanESM5 versions considered

- **CanESM5**: CCCma's primary CMIP6 model
- **CanESM5.1p1 ("p1")**: includes bug fixes and other improvements that have little impact on its climate
- **CanESM5.1p2 ("p2"):** several atmospheric physics parameters have been retuned to reduce global mean temperature bias and excessive historical warming, and increase ENSO amplitude

Results

- Mean SST/SSS biases are much reduced when atmosphere-ocean TA is applied, more so for optBC than defBC (Fig. 1)
- ENSO variability has improved seasonality in bias corrected runs although it is too rapid, and still too weak with optBC (Fig. 2)
- Improvement in ENSO seasonality may be connected with much more realistic mean seasonal cycle of equatorial Pacific SST (Fig. 3) [7]
- Despite better ENSO seasonality, ENSO skill is not improved (Fig.4)
- Skill for other variables is improved in p1 defBC and p1 optBC hindcasts (Table 1); p2-based hindcasts not yet carried out

Conclusions

- Novel simultaneous atmosphere-ocean TA-based bias correction <u>reduces mean biases</u> and <u>slightly improves temperature, precipitation and Z500 skill</u> in seasonal hindcasts
- <u>ENSO skill</u>, already lower than for older CanCM4i, <u>is not improved</u>
- p2-based seasonal and decadal hindcasts using TA remain to be done

Table 1: Global mean anomaly correlation skill for prediction of seasonal means in 1991-2020, averaged over all initial months and 0-9 month lead times. Bold font indicates the highest mean skill value for each variable.

Variable	Verification	CanCM4i	p1 noBC	p1 defBC	p1 optBC
Temperature	ERA5	0.418	0.434	0.446	**0.448**
Precipitation	GPCP2.3	0.139	0.128	**0.154**	0.152
Z500	ERA5	0.461	0.458	**0.470**	0.469
Nino3.4	OISSTv2	**0.794**	0.716	0.698	0.683

1. Saurral et al. *JAMES* 2021 https://doi.org/10.1029/2021MS002570
2. Kharin & Scinocca *GRL* 2012 https://doi.org/10.1029/2012GL052815
3. Chang et al. *J. Clim.* 2019 https://doi.org/10.1175/JCLI-D-18-0598.1
4. Lu et al. *JAMES* 2020 https://doi.org/10.1029/2020MS002149
5. Swart et al. *GMD* 2019 https://doi.org/10.5194/gmd-12-4823-2019
6. Sospedra-Alfonso et al. *GMD* 2021 https://doi.org/10.5194/gmd-14-6863-202
7. Liu at al. *Env. Res. Comm.* 2021 https://doi.org/10.1088/2515-7620/abf295

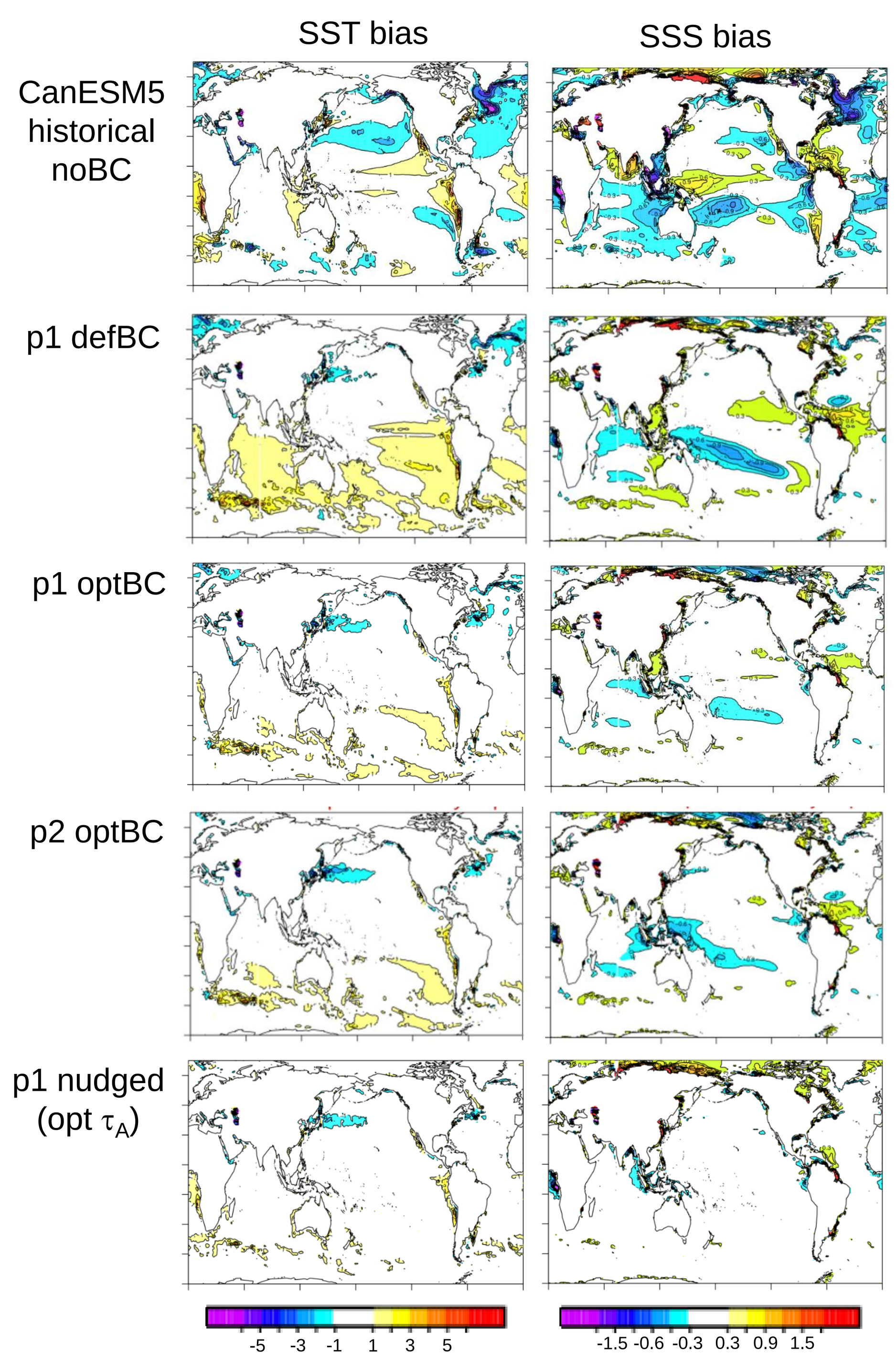


Fig. 1: Biases in annual mean SST (**left**) and SSS (**right**) for 1981-2010, verified against ORAS5. From top to bottom:
- CanESM5 historical run
- p1 with default τ_A bias correction
- p1 with optimized τ_A bias correction
- p2 with optimized τ_A bias correction
- p1 nudged using optimized τ_A

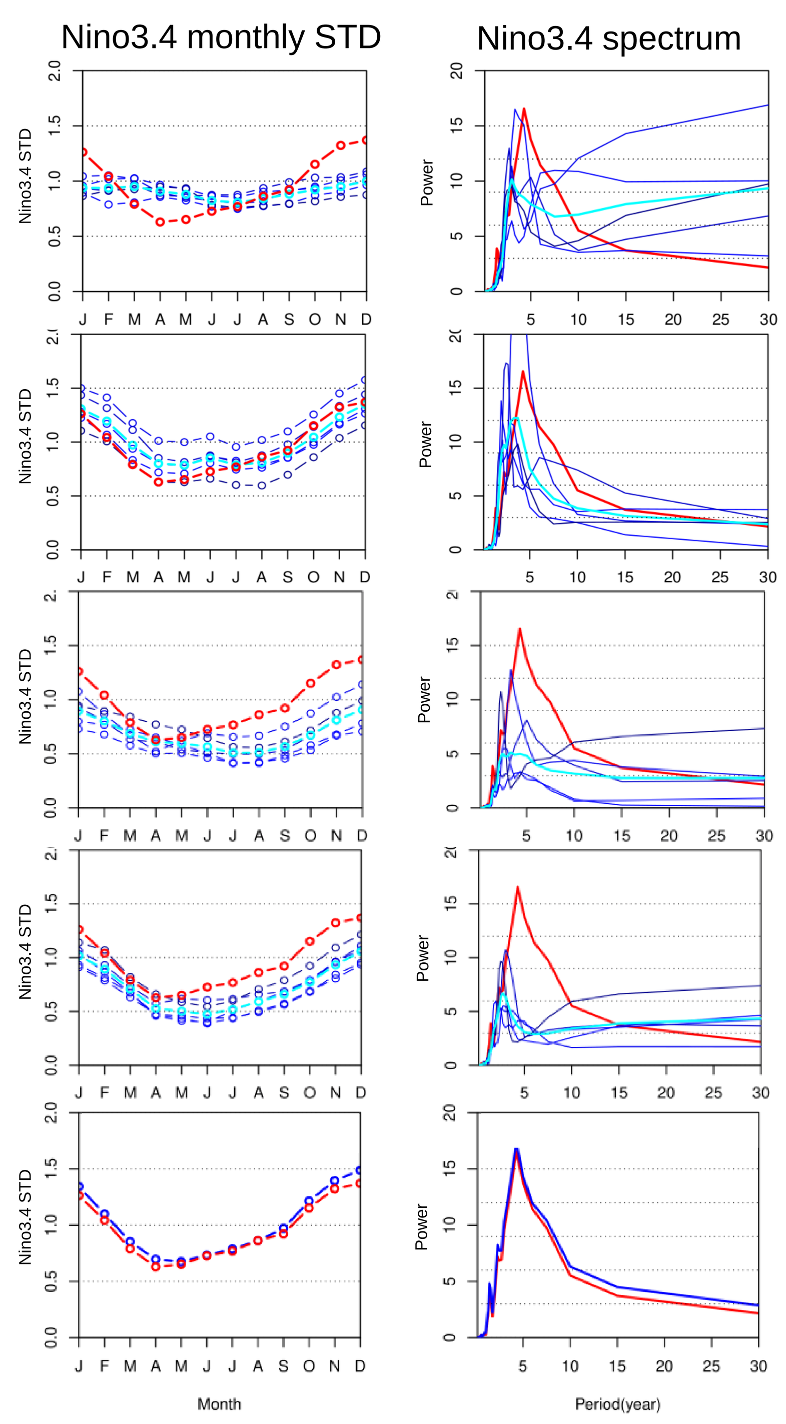


Fig. 2: **Left**: standard deviation of Nino3.4 index vs calendar month during 1981-2010. **Right**: power spectra of Nino3.4 index during same period. Red: observations (ORAS5). Blue: individual ensemble members. Cyan: ensemble mean. Vertical ordering is the same as in Fig. 1.

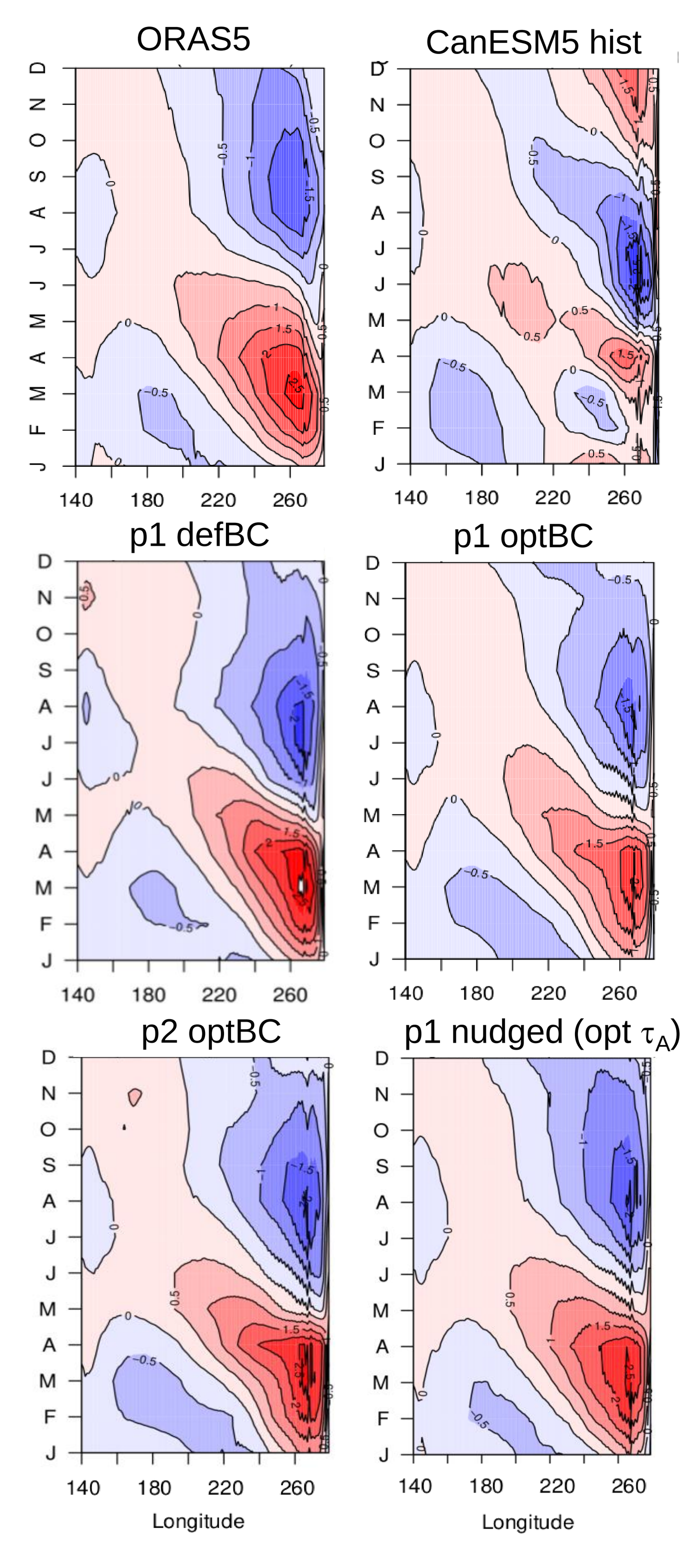


Fig. 3: Mean seasonal cycle of equatorial Pacific SST during 1981-2010 from ORAS5 (top left), CanESM5 historical run (top right), and bias corrected and nudged runs as indicated. Contour interval is 0.5°C.

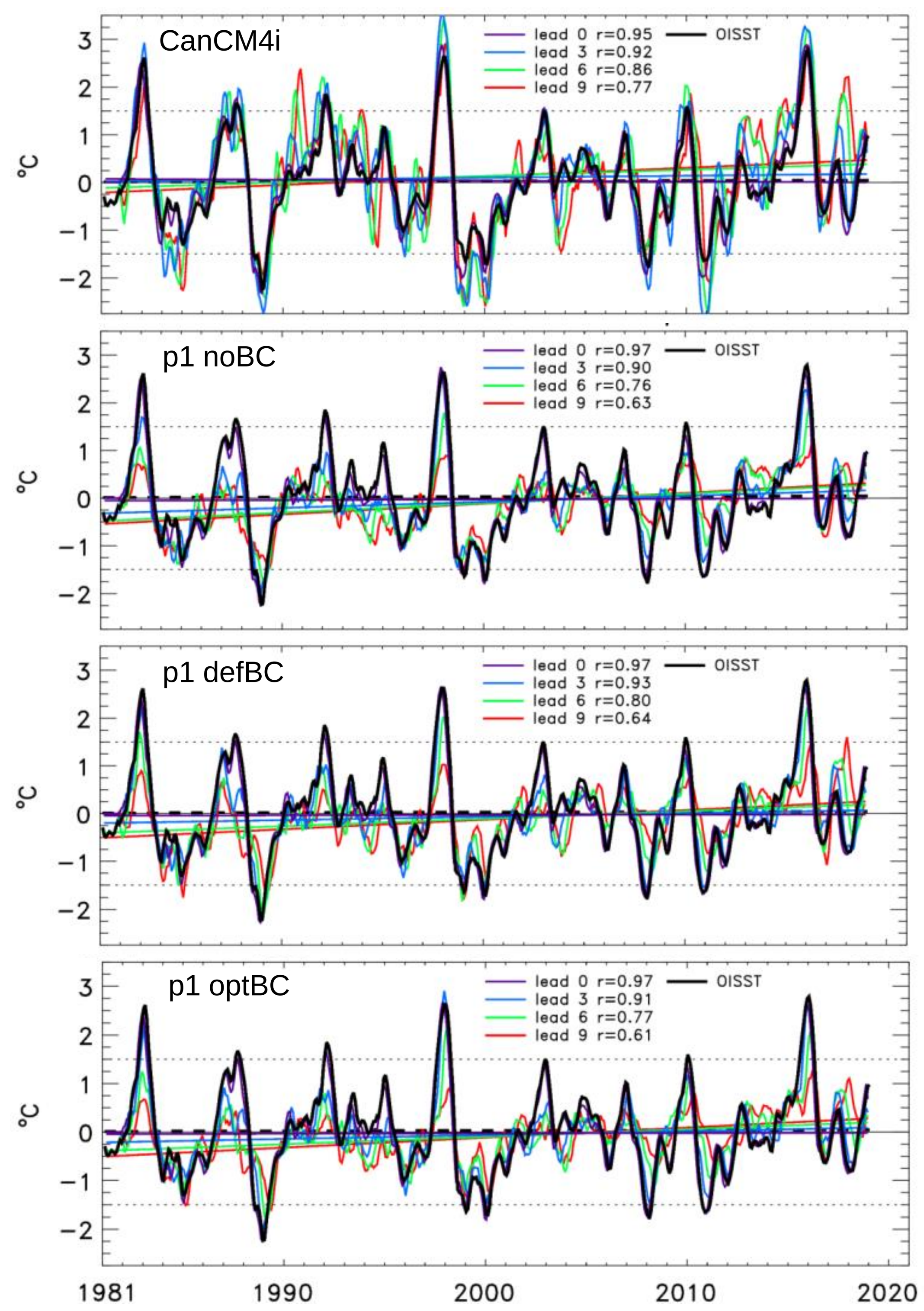


Fig. 4: Predicted seasonal mean Nino3.4 index from seasonal predictions having 10 ensemble members initialized each month during 1981-2020. Black indicates observed values from OISSTv2, and colours lead time in months, with anomaly correlation values and linear trend lines indicated.