Tropical Pacific boreal spring warming forced by strong Aleutian Low

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1. MOTIVATION:

Variability in the Aleutian Low is a known contributor to North Pacific sea surface temperature (SST) variability, but its role in forcing basin-scale Pacific SST anomalies, such as those that characterise Pacific Decadal Variability (PDV), is unclear owing to the difficulty of disentangling coupled atmosphere-ocean processes.

2. SUMMARY:

We perform a large ensemble experiment using a coupled atmosphere-ocean climate model (AOGCM), in which the winter-time Aleutian Low is nudged to an anomalously strong state during successive winters. This ensemble is compared to a free-running simulation to isolate the impacts of the anomalous Aleutian Low. The strong Aleutian Low experiment produces a basin-scale SST response with a similar pattern to the PDO in the free running simulation. Tropical Pacific SSTs are significantly warmer in the strong Aleutian Low experiment, demonstrating that North Pacific atmospheric forcing can impart a signature in tropical SSTs. The largest tropical Pacific warming occurs in the season following nudging (boreal spring), though anomalies persist year-round. A heat budget analysis shows the subtropical and tropical Pacific SST responses are predominantly driven by anomalous surface heat fluxes in boreal winter and meridional advection in boreal spring, respectively. The results show that Aleutian Low variability and trends can contribute to basin-scale PDO-like SST variability.

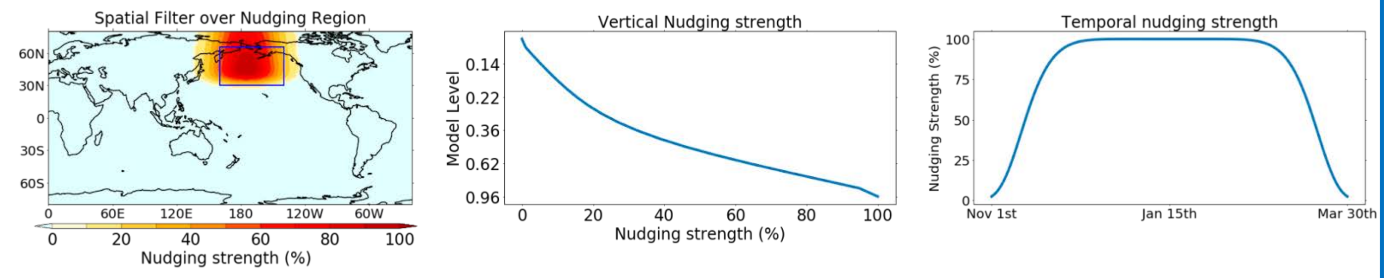
3. METHODOLOGY:

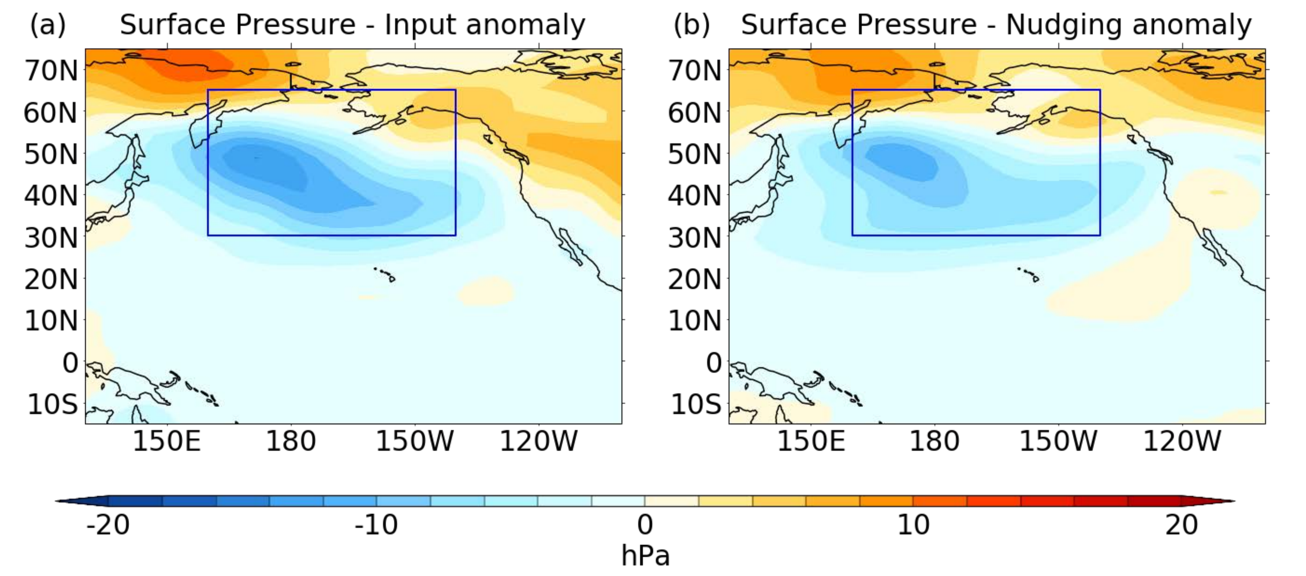
Grid-point nudging:

We developed grid-point atmospheric nudging capability within the 20-level, IGCM4 [1] component of the AOGCM FORTE2.0 [2]. Relaxation was performed on the surface pressure (Fig. 2), zonal and meridional winds and temperature fields in the troposphere. The nudging was confined to the region which defines the Aleutian Low and the strength of the tropospheric nudging is set to its maximum value at the lowest pressure level (σ = 0.96) (Figure 1). The nudging ramps up and down within extended boreal winter (NDJFM) to a maxima on January 15th. A large ensemble of 50 members were run for 30 years each and compared against a long (650 year) control run.

Heat budget analysis:

We consider the heat budget for the uppermost layer in the regions shown in green and black boxes in Figure 1. Daily diagnostics of tendencies due to advection, vertical and horizontal diffusion and convection are output directly from the model. Vertical diffusion represents the contribution due to surface heat fluxes.



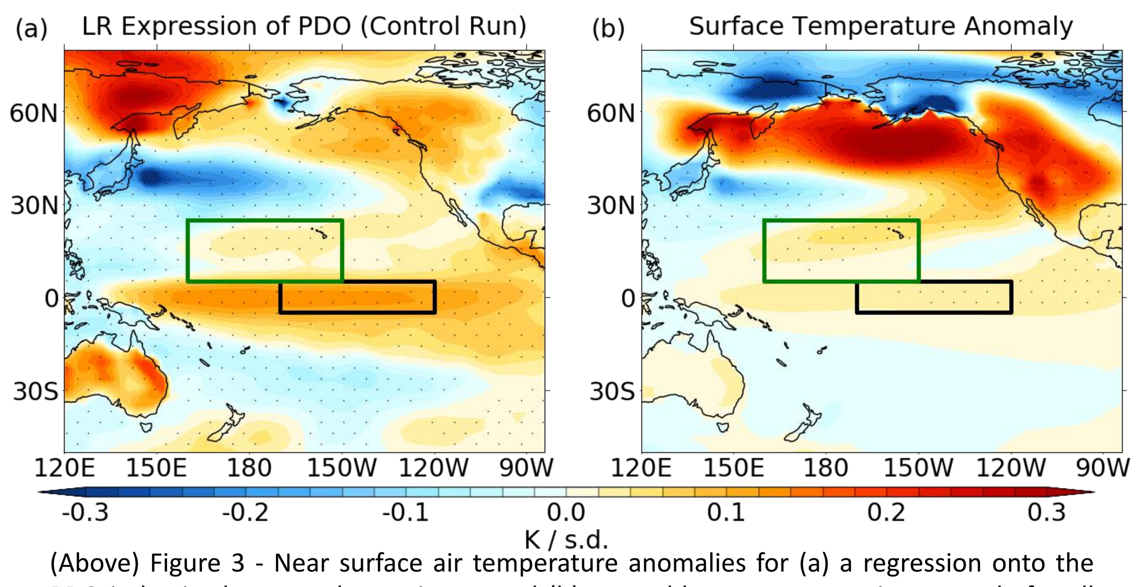


(Top) Figure 1 – Spatial, Vertical and Temporal Profiles of the nudging simulations

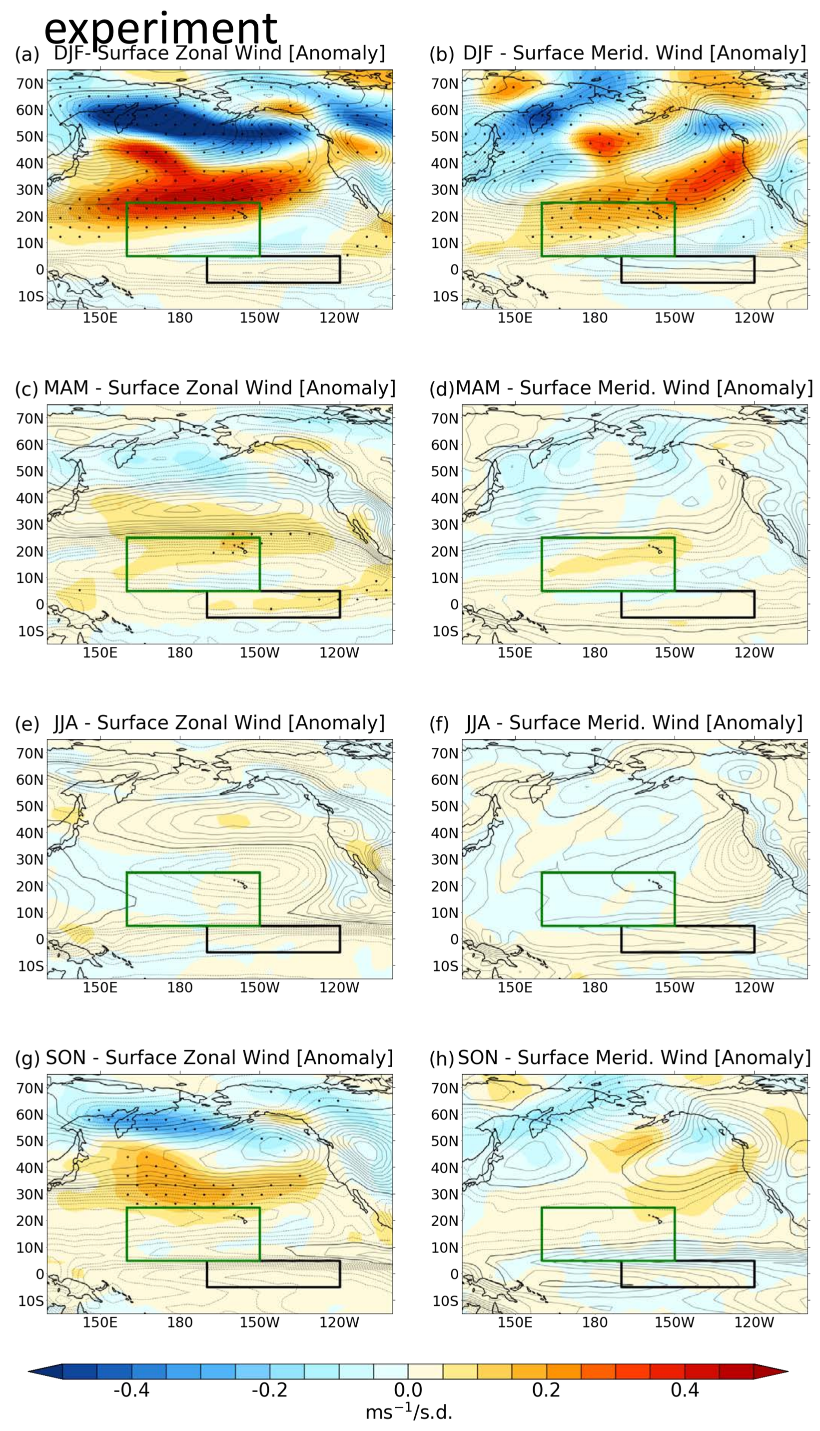
(Bottom) Figure 2 – (a) The input Aleutian Low anomaly derived from a free-running model and (b) the nudging simulation anomaly

4. Nudging Simulation Findings:

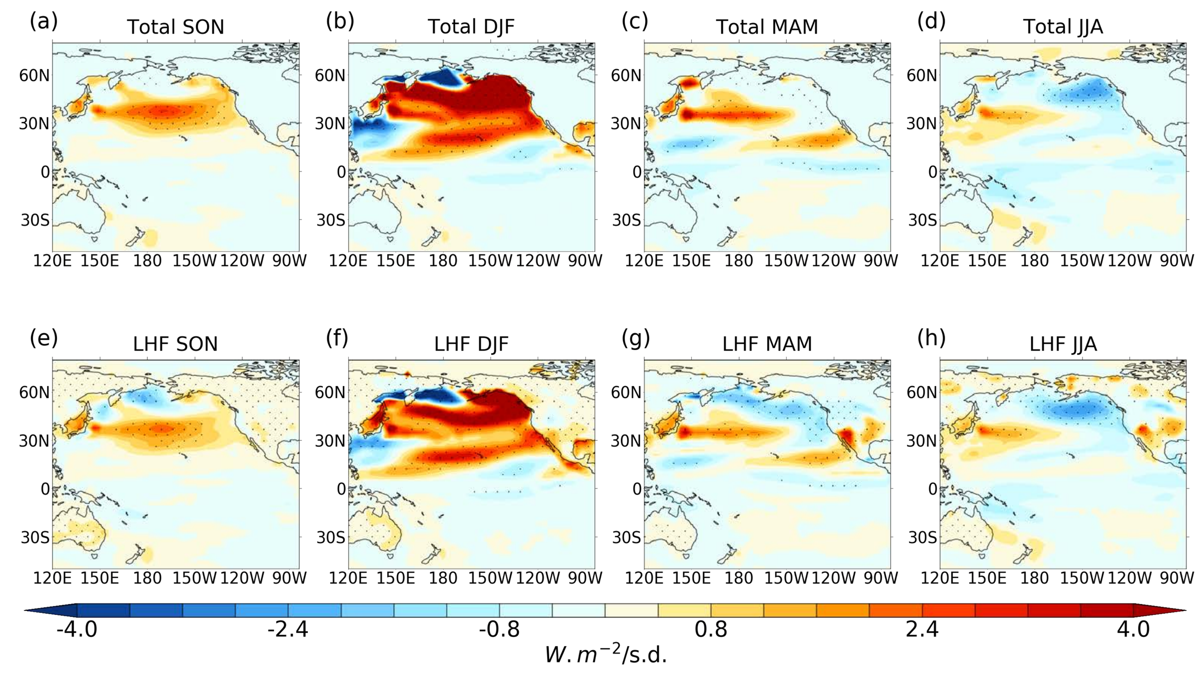
- Horse-shoe warming pattern (PDO-like) evident across North Pacific.
- Significant warming seen across tropical Pacific- with maxima in spring, with N.Pacific persistence year-round
- Generally, there is broad agreement between spatial patter of the mean anomaly and expression of PDO in control experiment



(Above) Figure 3 - Near surface air temperature anomalies for (a) a regression onto the PDO index in the control experiment and (b) ensemble mean composite anomaly for all years of the nudged strong Aleutian Low experiment. Stippling denotes anomalies that are statistically significant at the 95% confidence level



(Above) Figure 5 - Seasonal evolution of the ensemble mean wind field anomalies. Contours represent the seasonal climatology (dashed lines are negative, contour interval set to 1ms^{-1}).

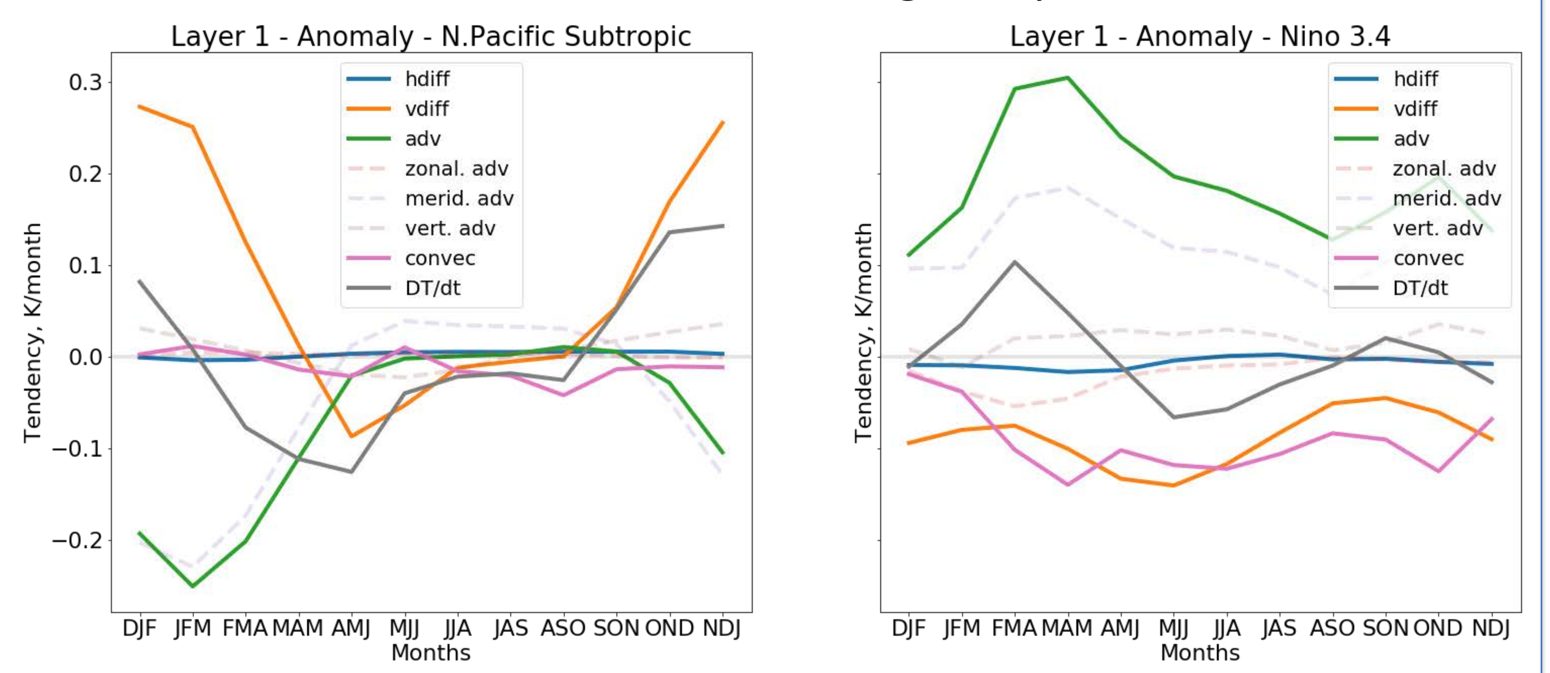


(Above) Figure 4 - Top Row: Mean seasonal downward heat flux anomaly into the ocean. Bottom Row: Mean seasonal latent heat flux anomaly. Stippling denotes anomalies that are statistically significant at the 95% confidence level.

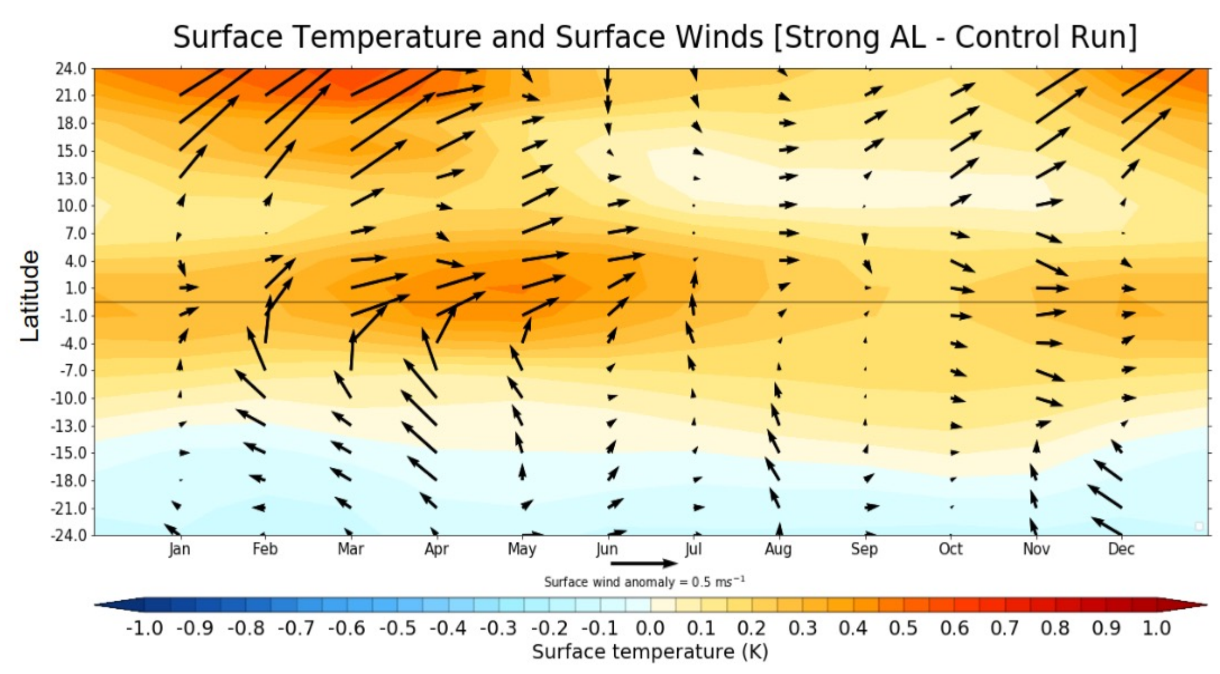
- Strengthening the Aleutian Low associated with increase in downward heat flux into the ocean – driven mainly by anomalous latent heat fluxes.
- Anomalous latent heat fluxes associated with southerly shift in the subtropical zonal wind anomalies – preventing heat loss from surface due to reduced evaporation (analogous to Seasonal Footprint Mechanism (SFM)
- Reduction in equatorial surface winds evident in season after nudging (Figure 7) - appear to be associated with cross-equatorial winds south of the equator. Occur alongside an increase in equatorial downwelling and increase in SST across the equatorial Pacific. Representative of the Wind-Evaporation-SST (WES) feedback

5. Heat Budget Analysis Findings:

- Temperature tendency increase in the northern subtropic coincides to its maxima within the nudging period (boreal winter)
- Subtropical region - vertical diffusion term offset by advection in driving the temperature tendency.
- Advection term dominated by the meridional component.
- Nino 3.4 region - advection term drives the warming over the region year-round, maxima in MAM. Warming offset by the vertical diffusion and convection terms, which remain negative year-round.



(Above) Figure 6 – Rolling seasonality of the temperature tendency and its constituent terms – vdiff (vertical diffusion), hdiff (horizontal diffusion), adv (advection), convec (convection) in the Northern Pacific subtropical region (left) and region defining Nino 3.4 (right)



(Above) Figure 7 - Latitude-time sections of monthly mean response of SST anomaly (°C; shading) and surface wind anomaly (ms^{-1}; vectors) averaged in the central-eastern tropical Pacific (205°-80°W).

6. Conclusions

- Relaxing a GCM towards a strong anomalous Aleutian Low produces warming across the tropical equatorial Pacific in the season after relaxation with North Pacific warming persisting annually.
- Changes to surface heat fluxes (subtropics) during boreal winter and meridional advection (equatorial) during boreal spring in the upper ocean drive the warming.
- Results provide evidence to suggest extra-tropical Pacific variability may directly drive variability into the tropical Pacific through excitation of the SFM and WES mechanisms.

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1. Joshi, M., Stringer, M., Van Der Wiel, K., O'Callaghan, A., & Fueglistaler, S. (2015). IGCM4: A fast, parallel and flexible intermediate climate model. *Geoscientific Model Development*, *8*(4), 1157–1167. https://doi.org/10.5194/gmd-8-1157-2015

2. Blaker, A., Joshi, M., Sinha, B., Stevens, D., Smith, R., & Hirschi, J. (2020). FORTE 2.0: a fast, parallel and flexible coupled climate model. Geoscientific Model Development Discussions, 1–22. https://doi.org/10.5194/gmd-2020-43

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