Assessing the Impact of Air-Sea Interactions on Subseasonal Predictability of Atmospheric Rivers

2025 AMS Annual Meeting @ New Orleans

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Courtesy of Hai Lin and Gregory Smith (ECCC)



Center for Western Weather and Water Extremes



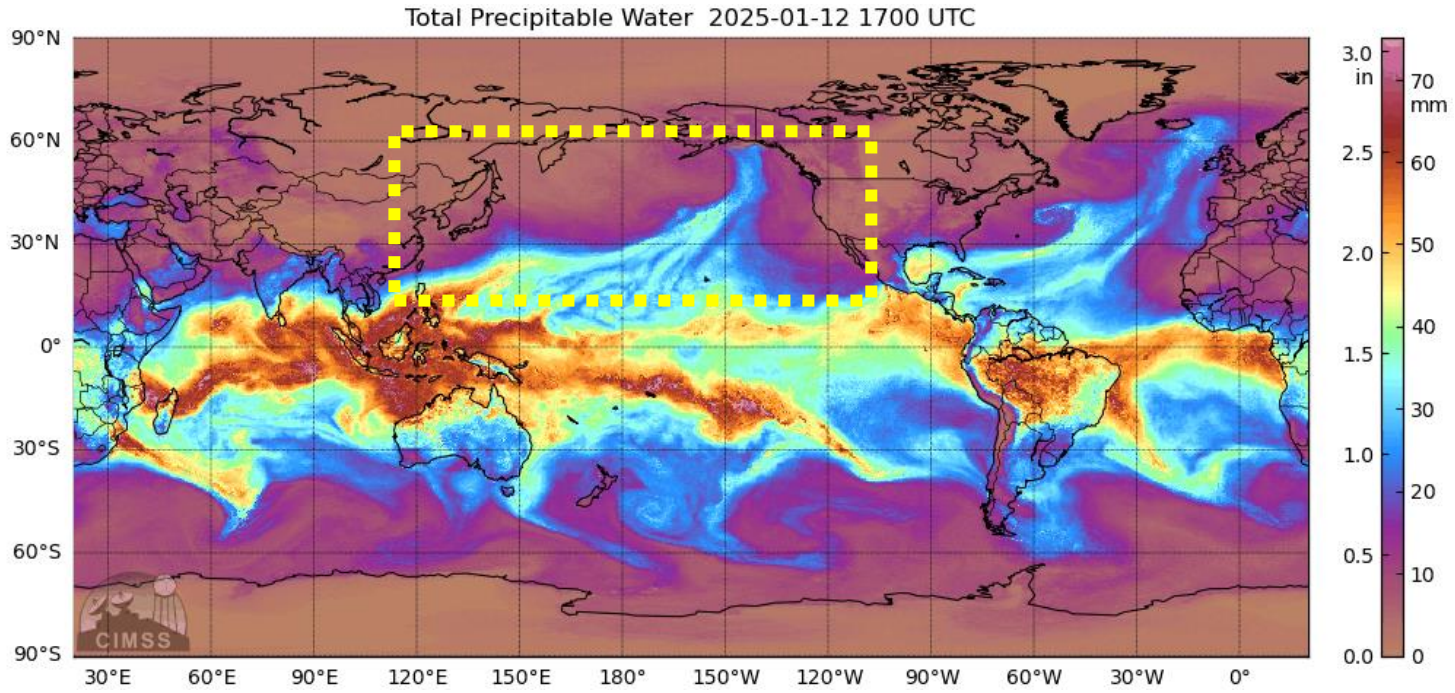
SCRIPPS INSTITUTION OF OCEANOGRAPHY



Environment and Climate Change Canada

Motivation

- Atmospheric rivers (ARs) are characterized by tropical moisture filaments.
- ARs contribute more than 50% of California annual rainfall (Gimeno et al. 2014), and cause1 billion USD annually in Western United States (Prince et al. 2021).

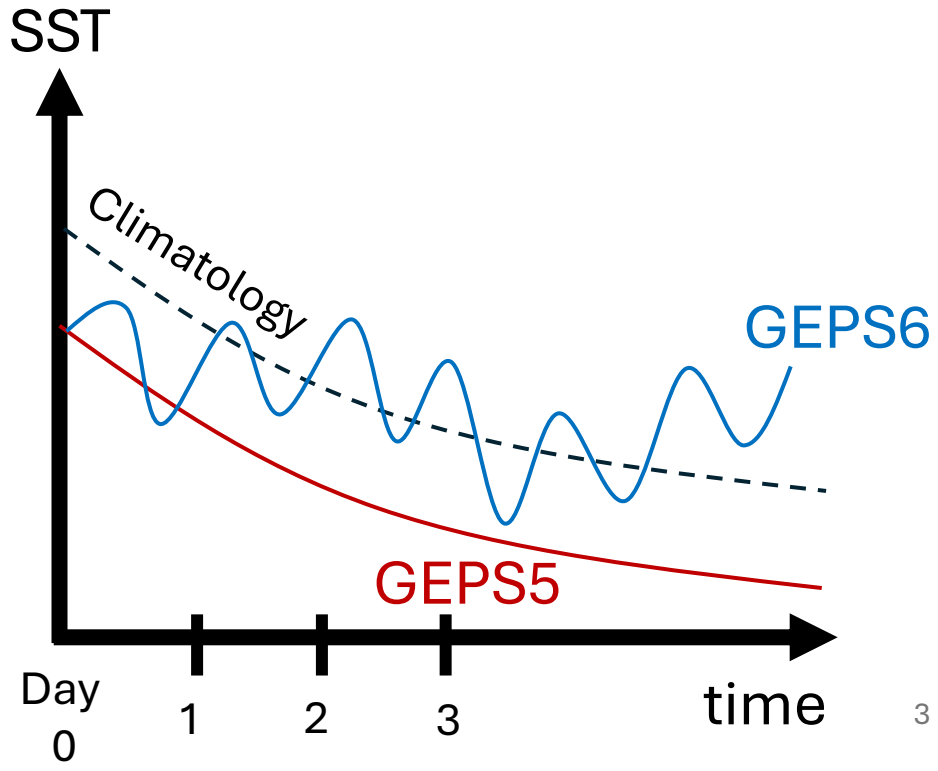


- AR prediction skill is about 3 weeks (DeFlorio et al. 2019)
- What are impacts of air-sea interactions on S2S prediction of ARs?

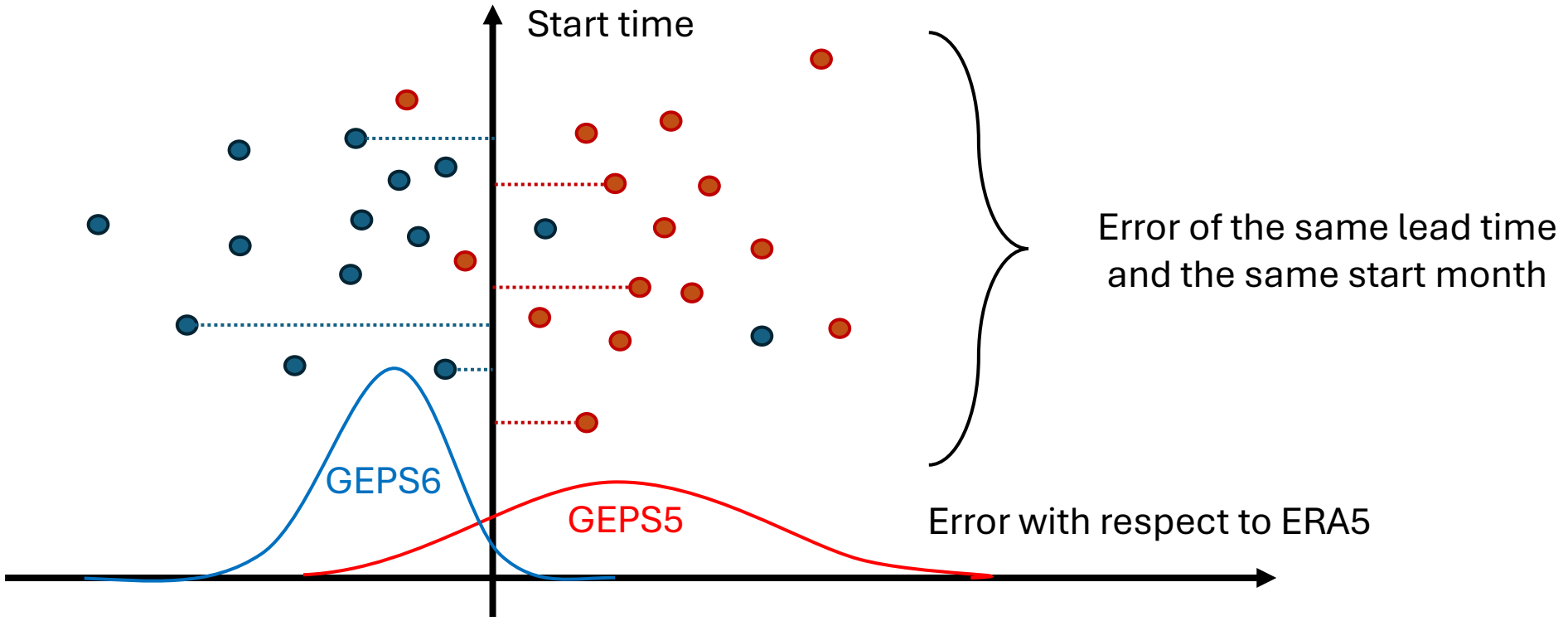
Dataset

- We use the S2S database of Environment and Climate Change Canada (ECCC) Global Ensemble Prediction Systems 5 and 6 (GEPS5 and GEPS6).
- Reforecast time range: weekly 1998 – 2017 (20 years Dec-Mar), 4 ensemble members
- Domain of interest: Northeast Pacific
- Data is verified with respect to ECMWF Reanalysis Version 5 (ERA5)

Model / Detail	GEPS5 (AGCM)	GEPS6 (AOGCM)
Sea surface temperature (SST)	Persistent anomaly. No diurnal cycle, foundation SST is used	Active ocean model. Has diurnal cycle. Init. with ORAP5 ocean reanalysis
Atmosphere Resolution	0.35 degree	
Ocean Resolution	N/A	0.25 degree



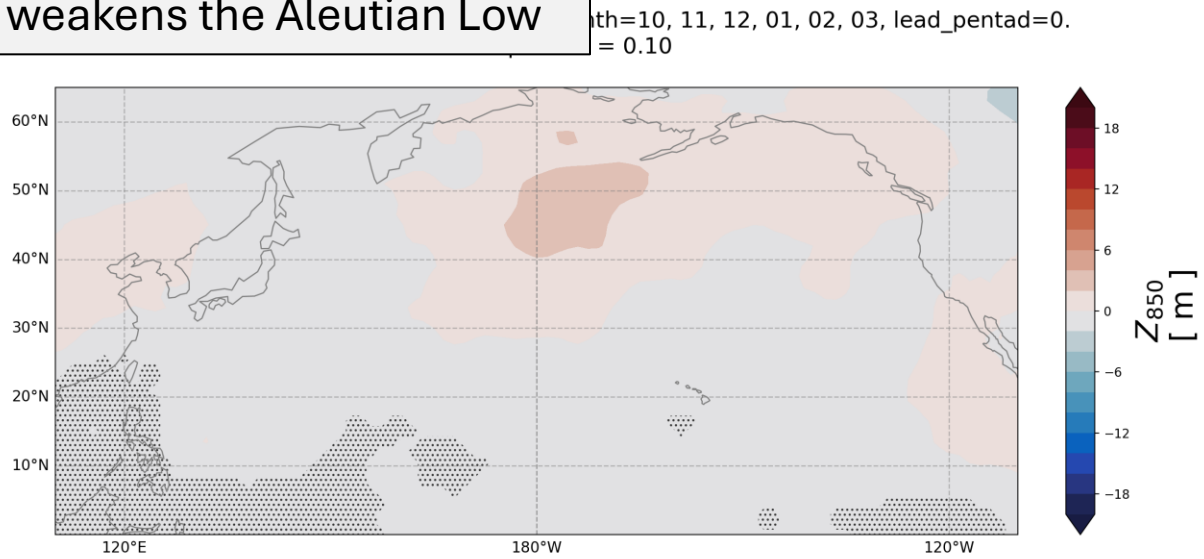
GEPS5 and GEPS6 do not share the same start time
➔ Group start time into the same start months Oct-Mar



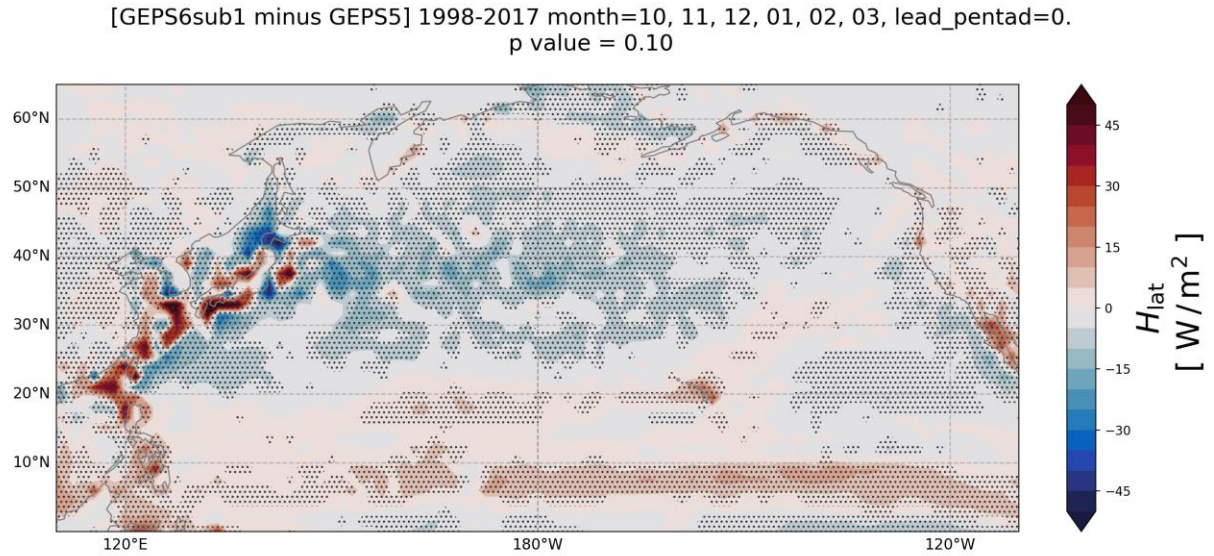
Therefore, a T-test is possible to compare between groups

Air—sea interactions weakens the Aleutian Low

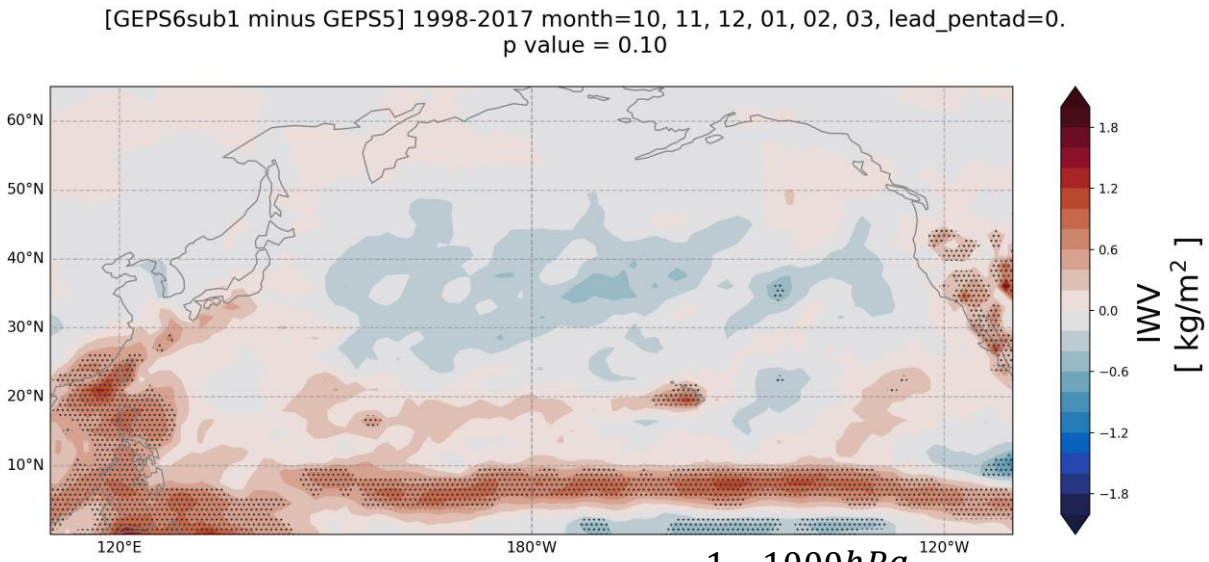
Lead Days 1-5 Δ = Coupled - Uncoupled



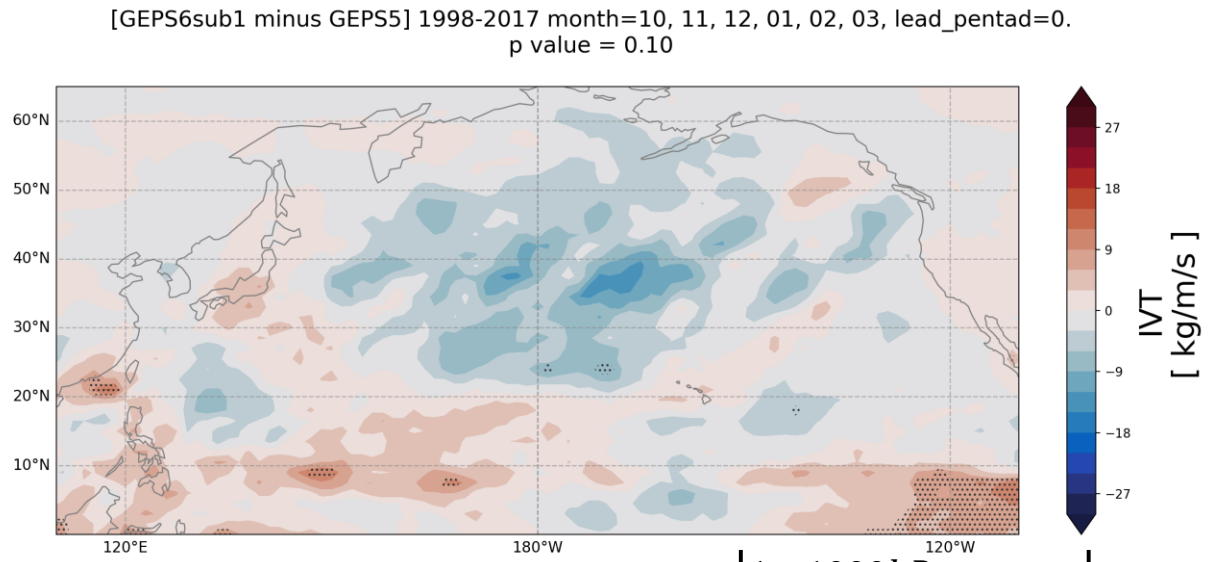
Z_{850}



Upward latent heat flux H_{lat}



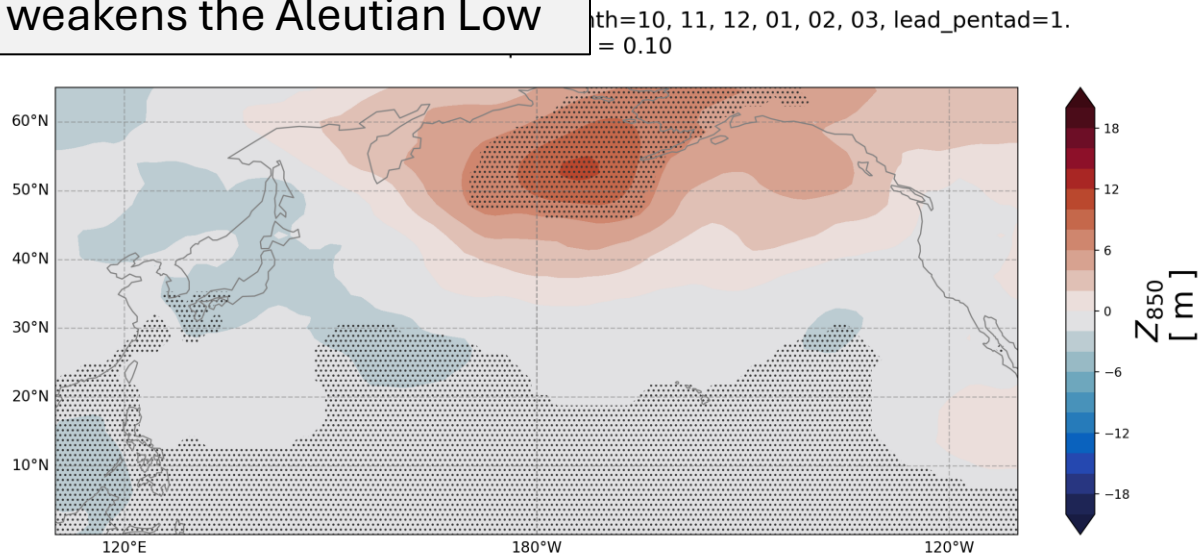
Integrated water vapor (IWV) = $\frac{1}{\mathrm{g}}\int_{200hPa}^{1000hPa} q\ \mathrm{d}p$



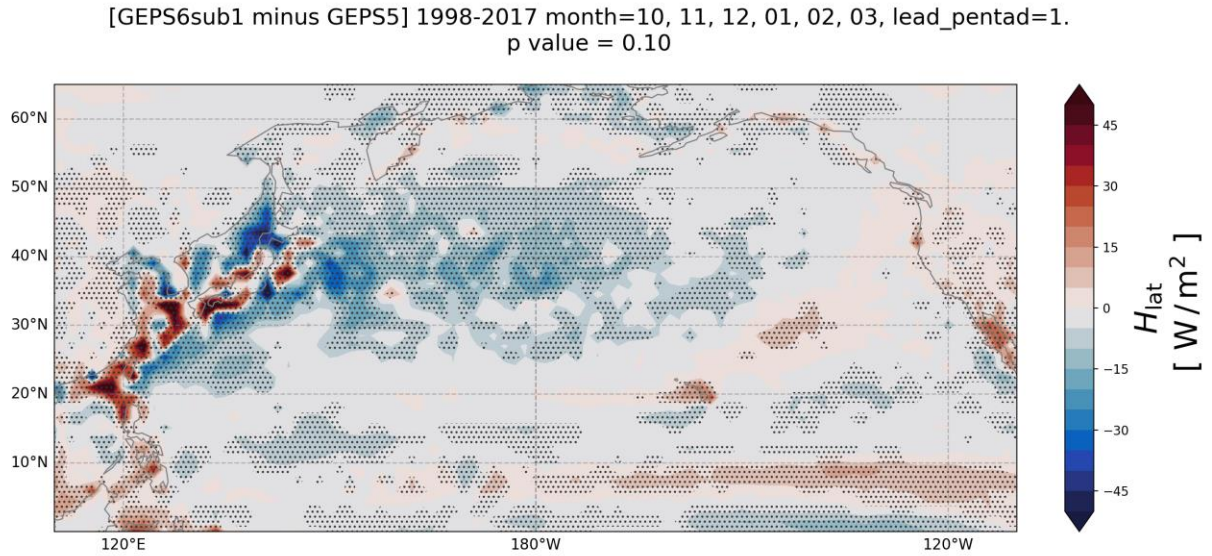
Integrated vapor transport (IVT) = $\left|\frac{1}{\mathrm{g}}\int_{200hPa}^{1000hPa} q\vec{v}\ \mathrm{d}p\right|$

Air—sea interactions weakens the Aleutian Low

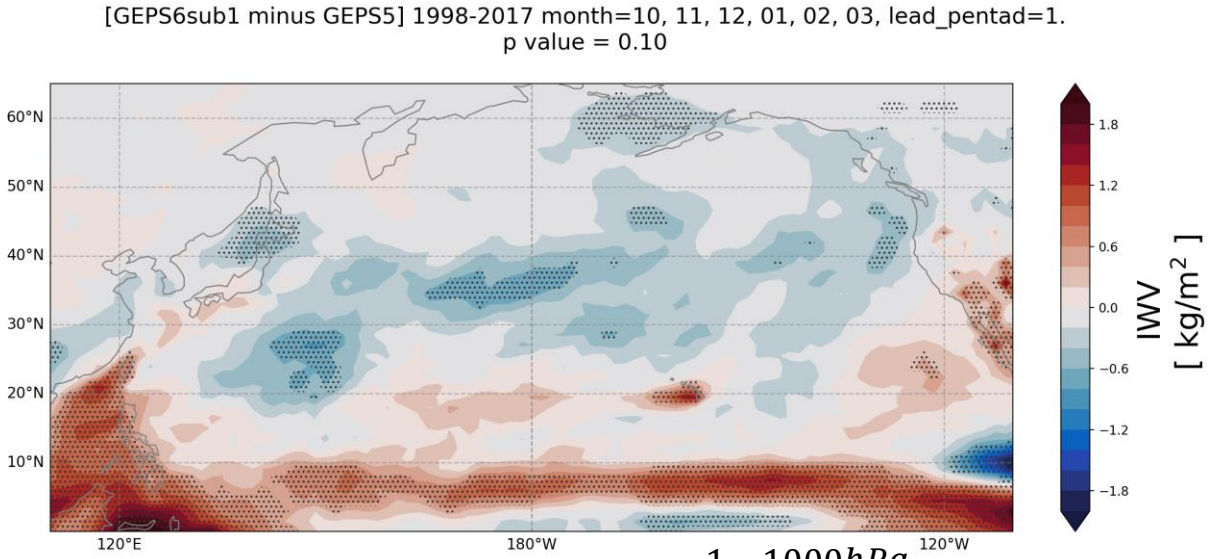
Lead Days 6-10 Δ = Coupled - Uncoupled



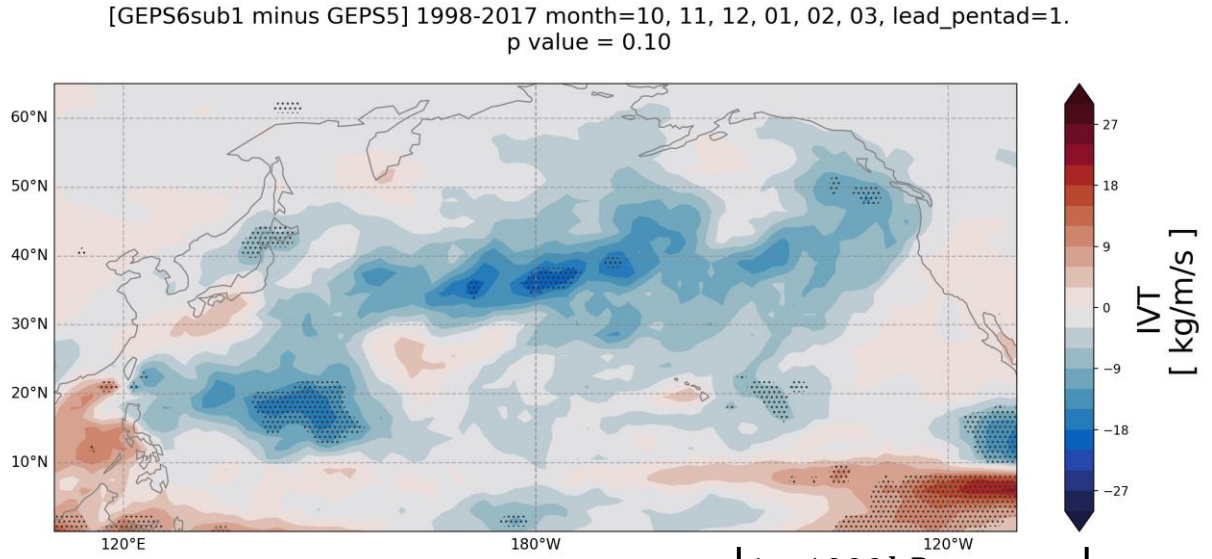
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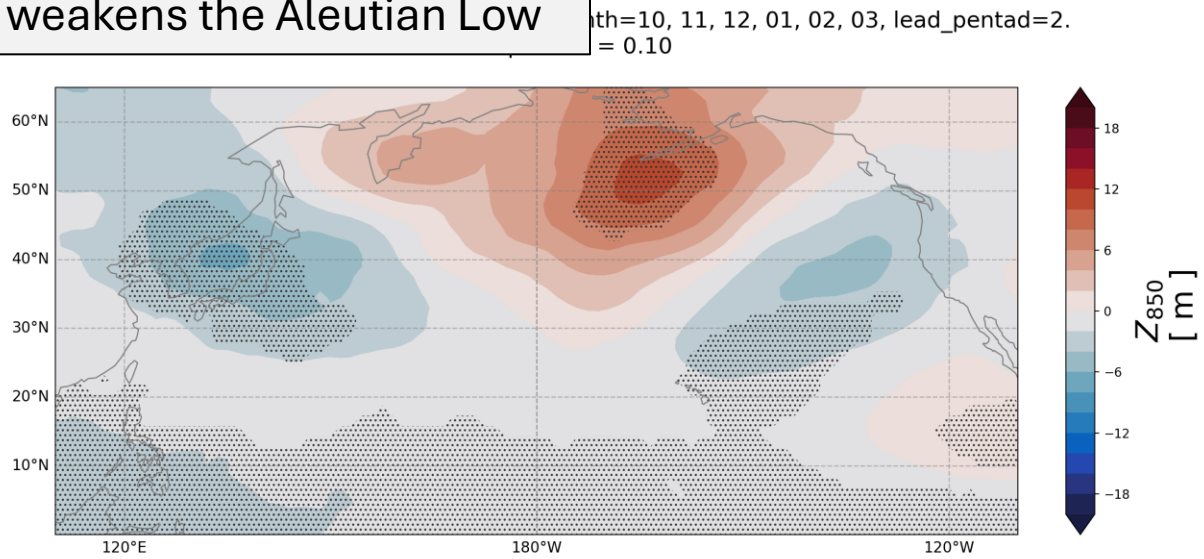
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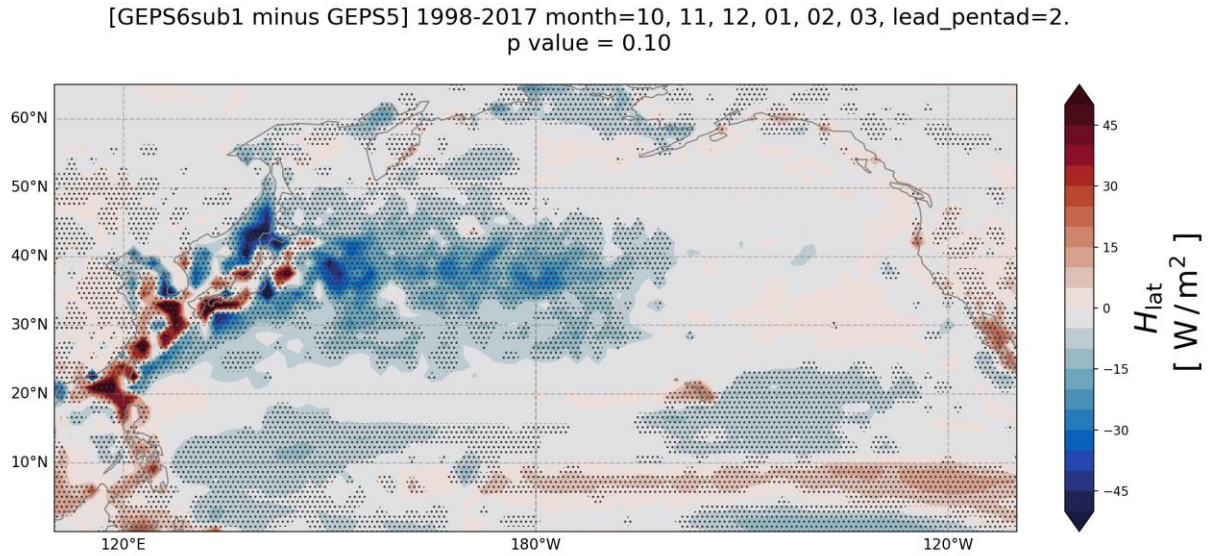
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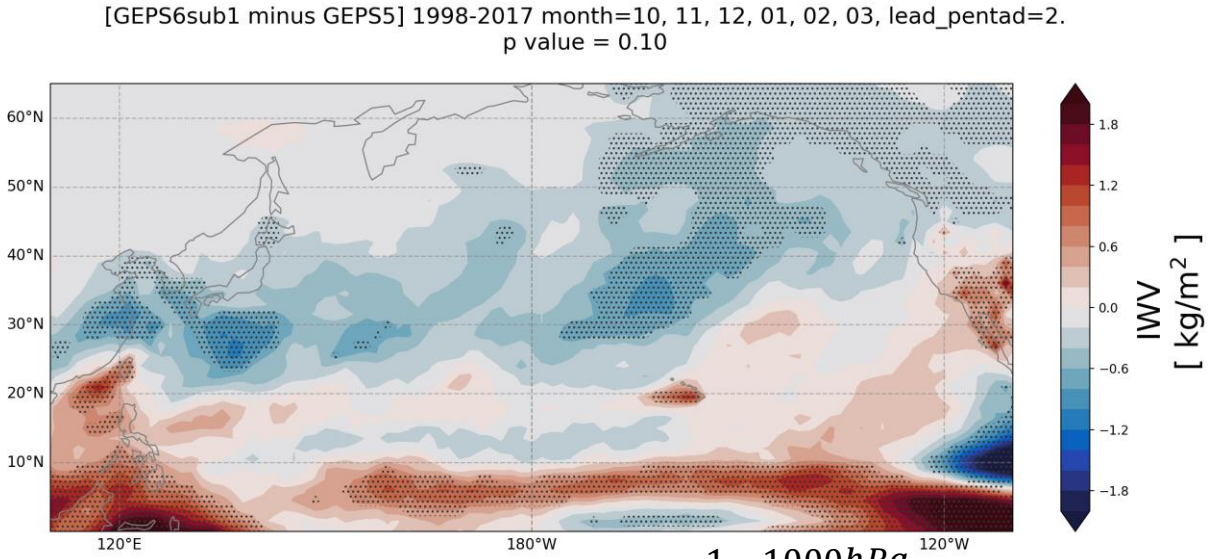
Lead Days 11-15 Δ = Coupled - Uncoupled



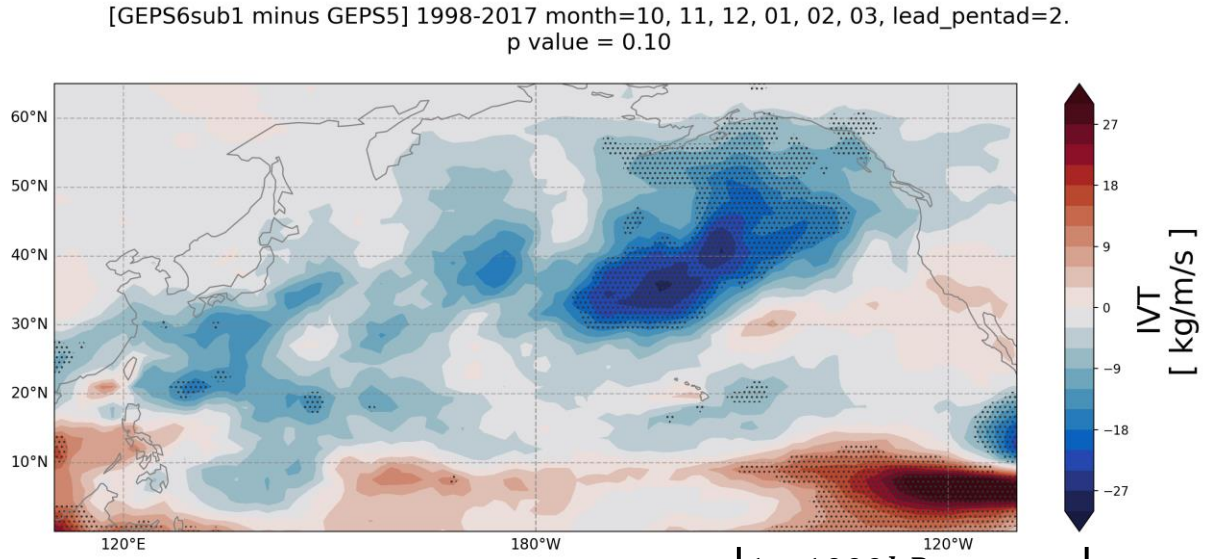
Z_{850}



Upward latent heat flux H_{lat}



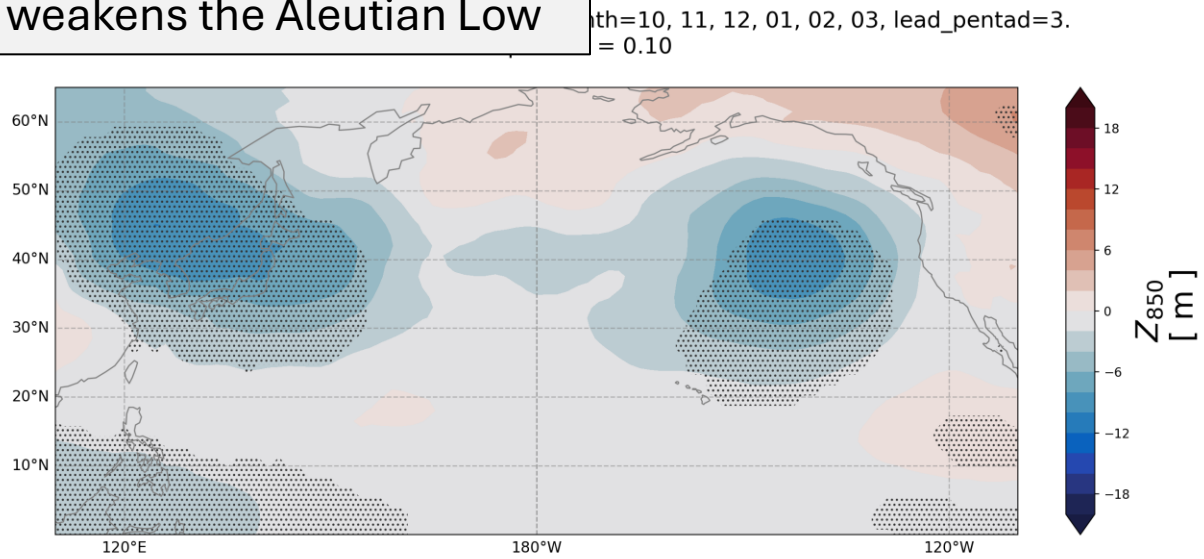
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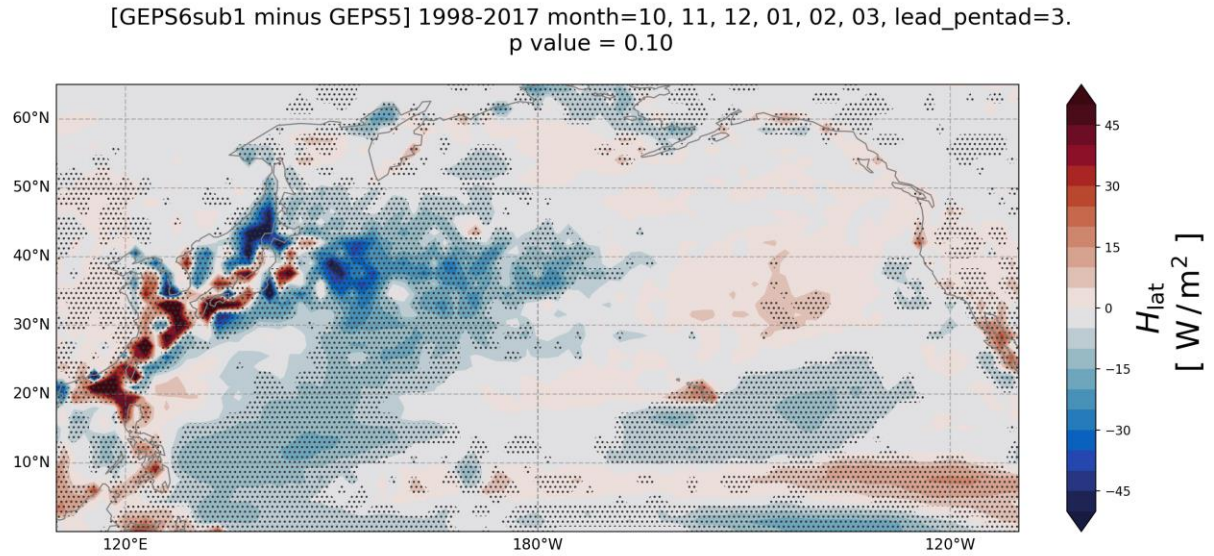
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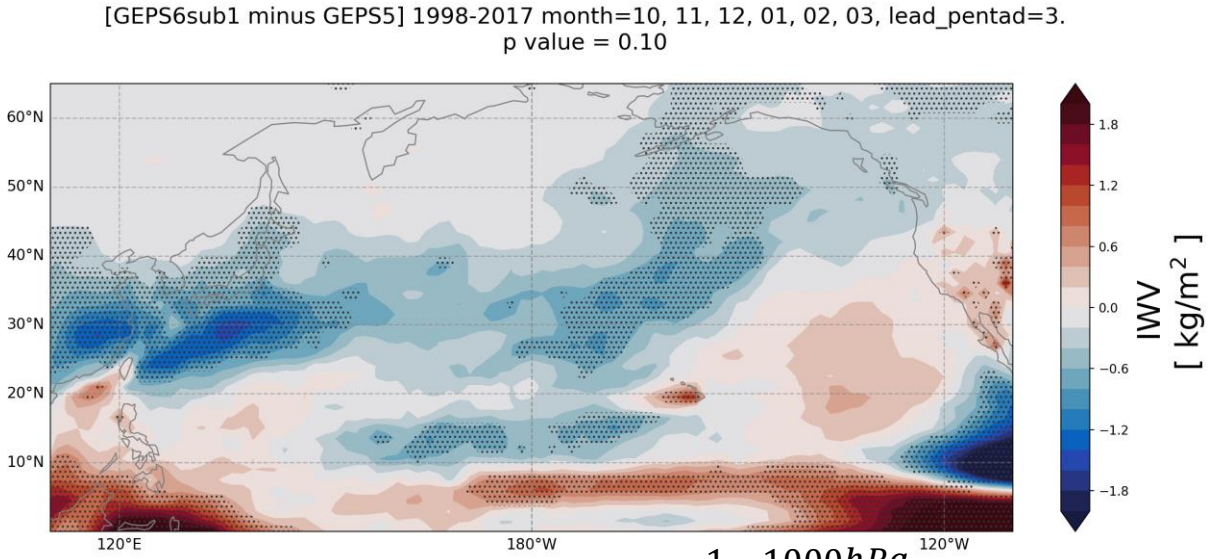
Lead Days 16-20 Δ = Coupled - Uncoupled



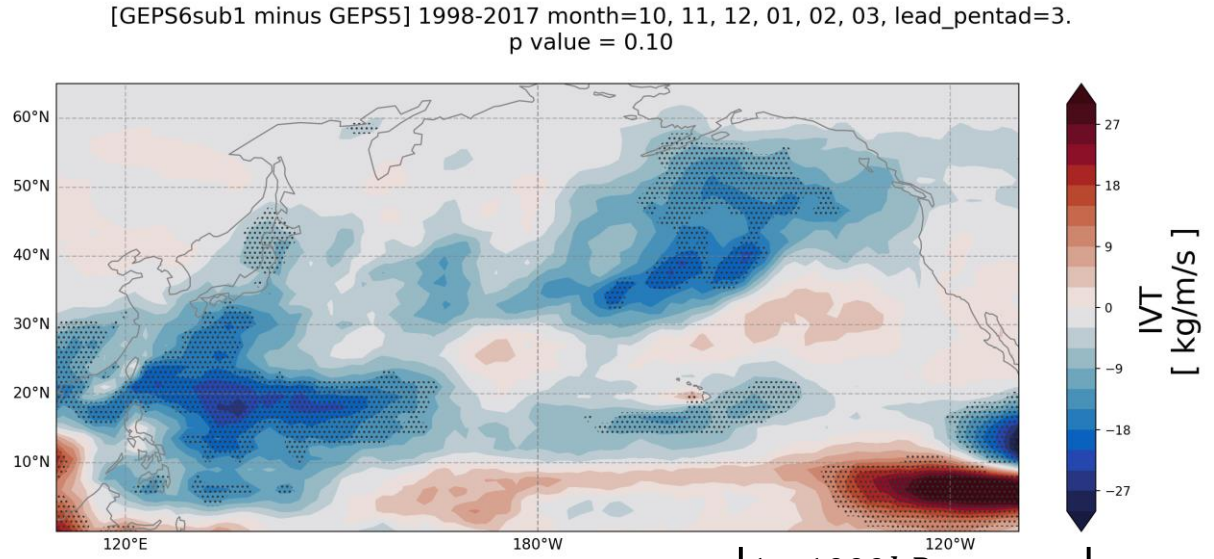
Z_{850}



Upward latent heat flux H_{lat}



Integrated water vapor (IWV) = $\frac{1}{\mathrm{g}}\int_{200hPa}^{1000hPa} q\ \mathrm{d}p$

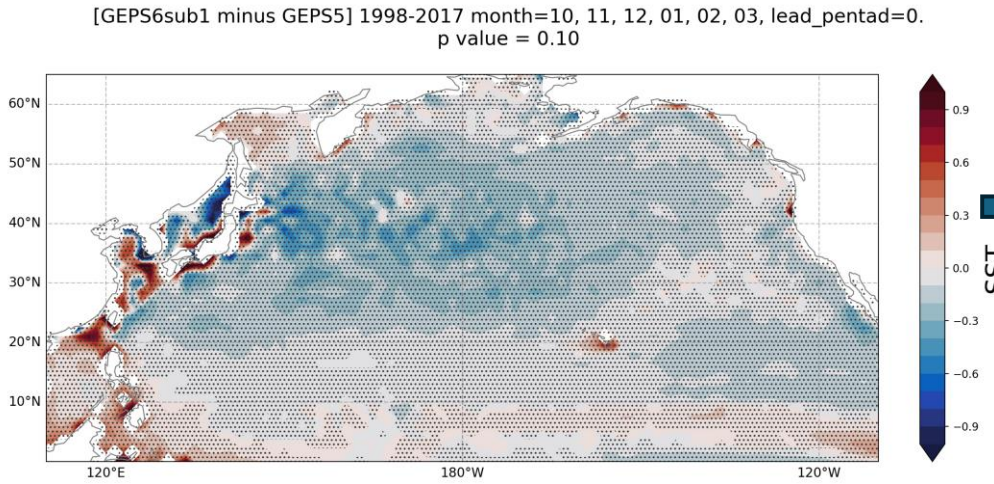


Integrated vapor transport (IVT) = $\left|\frac{1}{\mathrm{g}}\int_{200hPa}^{1000hPa} q\vec{v}\ \mathrm{d}p\right|$

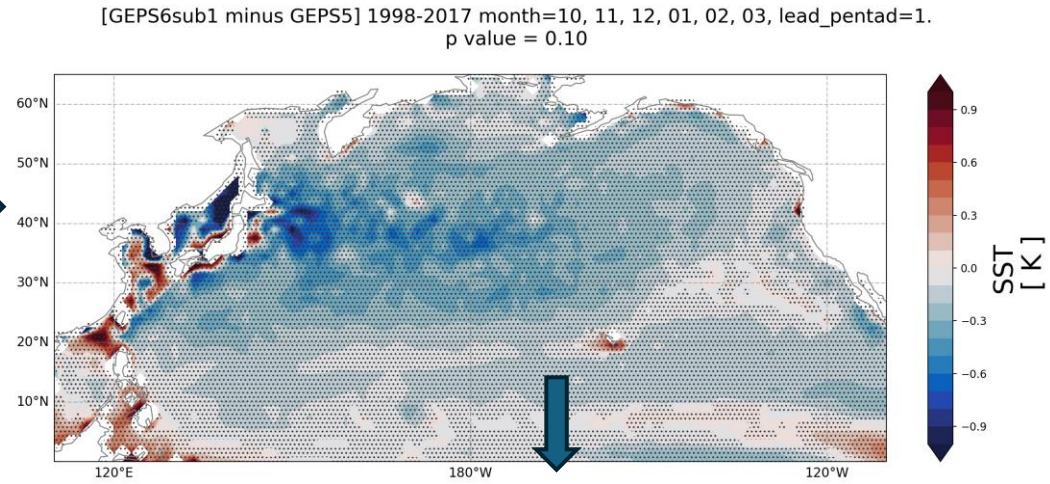
Air—sea interaction in Northwestern Pacific cools the SST significantly

Δ = Coupled - Uncoupled

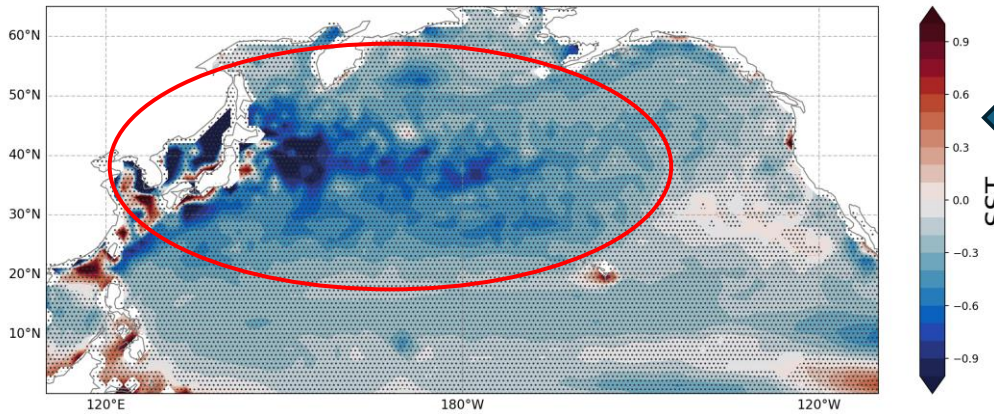
Lead Days 1-5



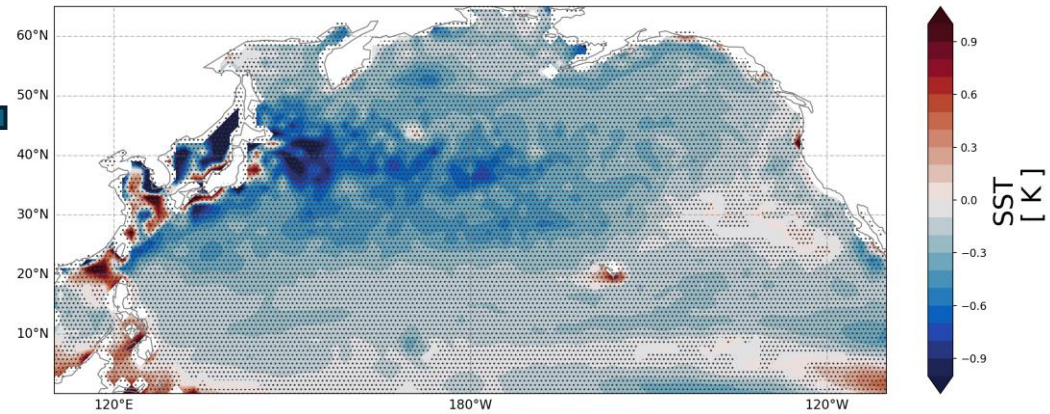
Lead Days 6-10



Lead Days 16-20



Lead Days 11-15

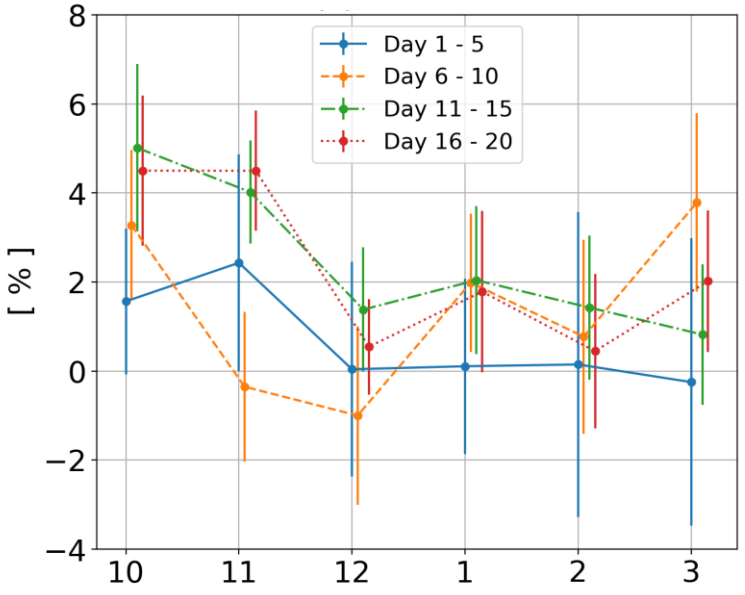


Improvement of IVT prediction comes from IWV

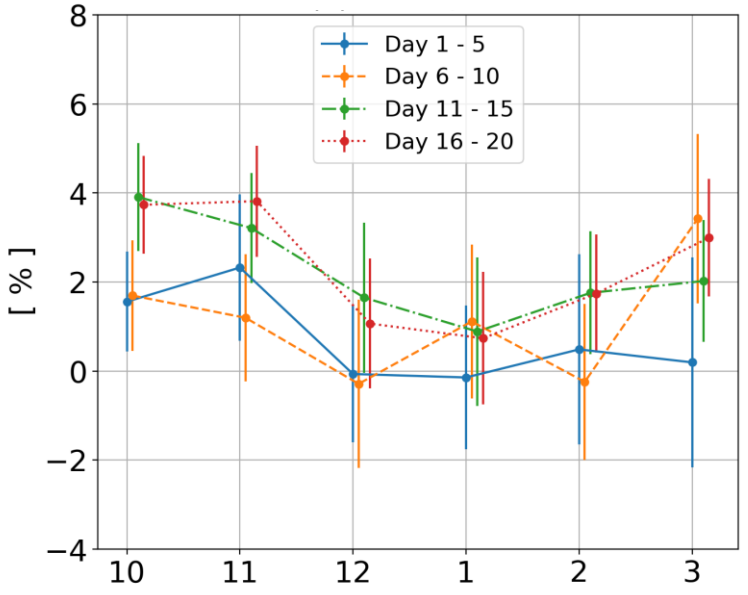
$$\left(1 - \frac{RMSE_{GEPS6}}{RMSE_{GEPS5}}\right) \times 100\% .$$

Positive means better prediction.

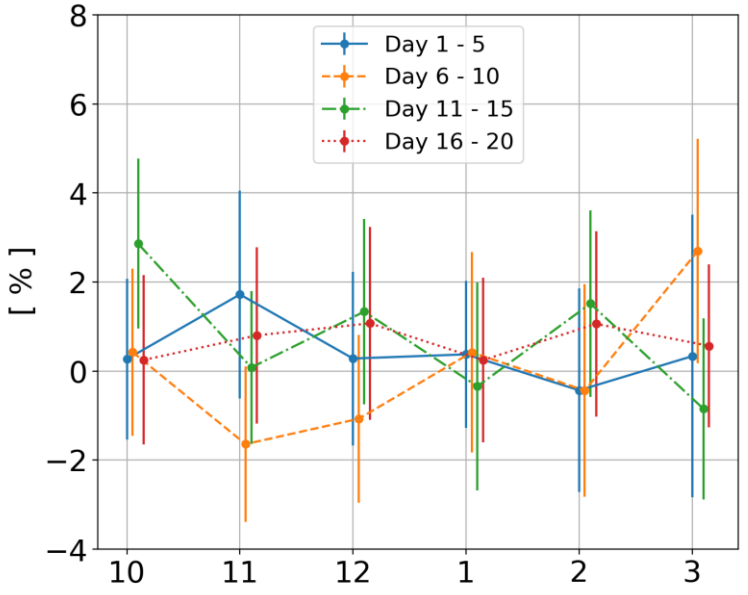
(a) IVT



(b) IWV



(c) Z_{850}



$$\text{IVT} = \left|\frac{1}{g}\int_{200hPa}^{1000hPa} q\vec{v}\, dp\right|$$

$$\text{IWV} = \frac{1}{g}\int_{200hPa}^{1000hPa} q\, dp$$

Take home message

1. The air-sea coupling results in less upward latent heat fluxes over Northwest Pacific that weakens the Aleutian Low within 10 days. This results in improvement of less northward moisture transport towards Gulf of Alaska.
2. While air-sea interactions affect both wind and water vapor, the improvement of IVT in coupled simulation comes from better water vapor prediction.
3. Improvement happens during late fall—early winter. Northwest Pacific is important.

⬇ Strong SST cooling by atmospheric river during Oct-Nov

Hsu, T. Y., Mazloff, M. R., Gille, S. T., Freilich, M. A., Sun, R., & Cornuelle, B. D. (2024). Response of sea surface temperature to atmospheric rivers. *Nature Communications*, *15*(1), 5018.

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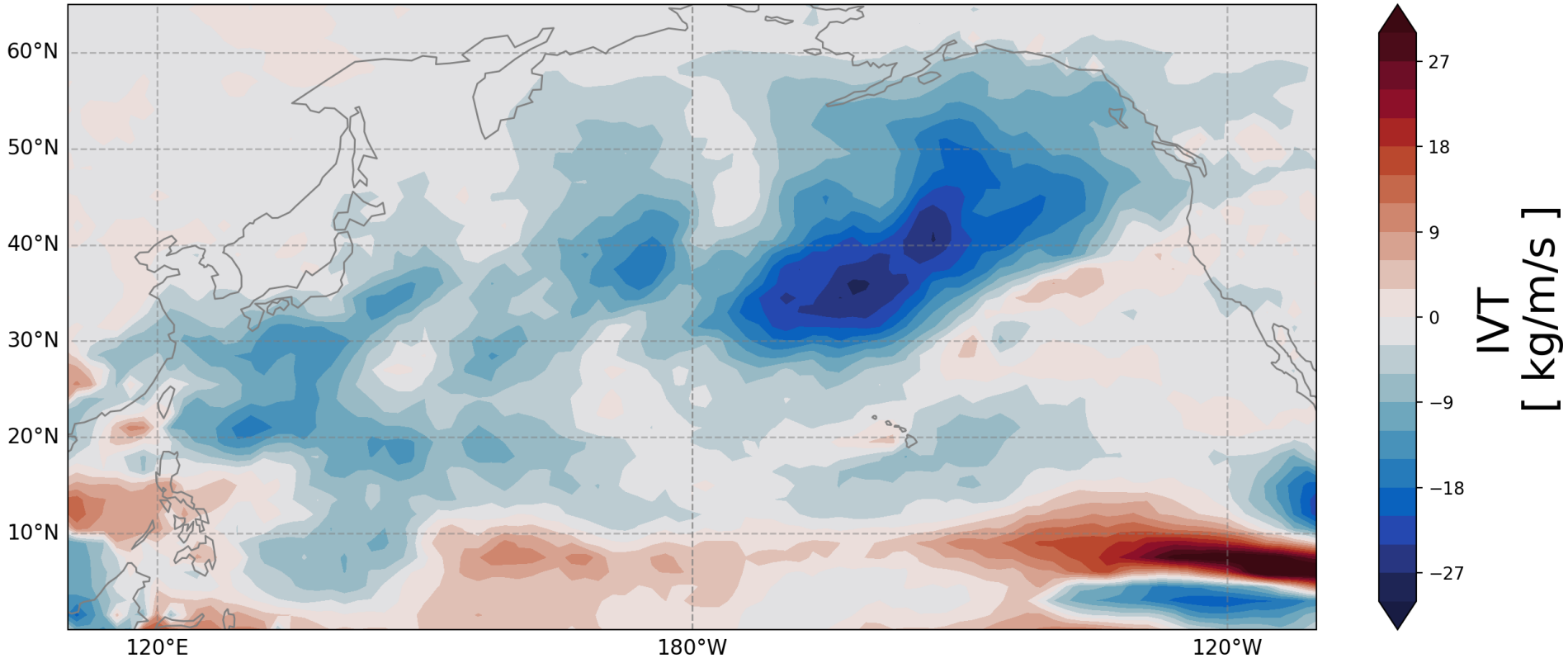
Reference

- Gimeno, L., Nieto, R., Vázquez, M., & Lavers, D. A. (2014). Atmospheric rivers: A mini-review. *Frontiers in Earth Science*, *2*, 2.
- DeFlorio, M. J., Waliser, D. E., Guan, B., Ralph, F. M., & Vitart, F. (2019). Global evaluation of atmospheric river subseasonal prediction skill. *Climate Dynamics*, *52*, 3039-3060.
- Prince, H. D., Gibson, P. B., DeFlorio, M. J., Corringham, T. W., Cobb, A., Guan, B., ... & Waliser, D. E. (2021). Genesis locations of the costliest atmospheric rivers impacting the Western United States. *Geophysical Research Letters*, *48*(20), e2021GL093947.
- Hsu, T. Y., Mazloff, M. R., Gille, S. T., Freilich, M. A., Sun, R., & Cornuelle, B. D. (2024). Response of sea surface temperature to atmospheric rivers. *Nature Communications*, *15*(1), 5018.

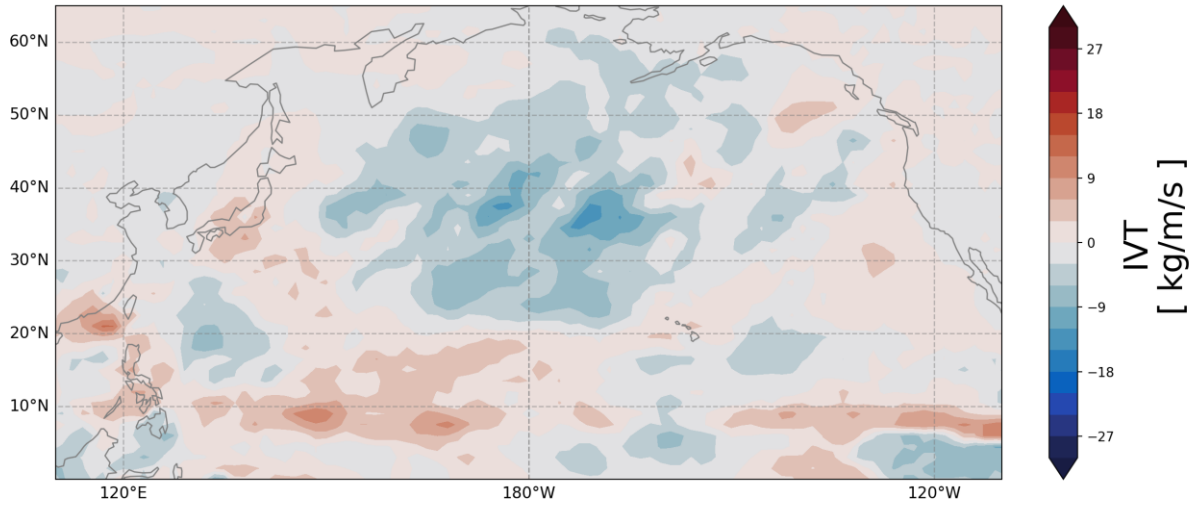
Extra slides after

$RMSE_{GEPS6} - RMSE_{GEPS5}$

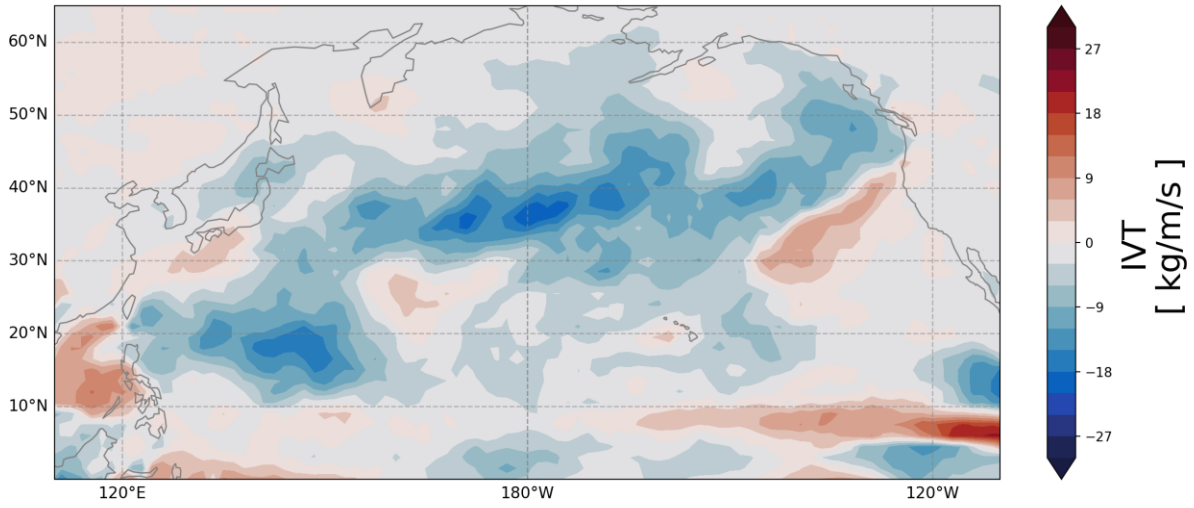
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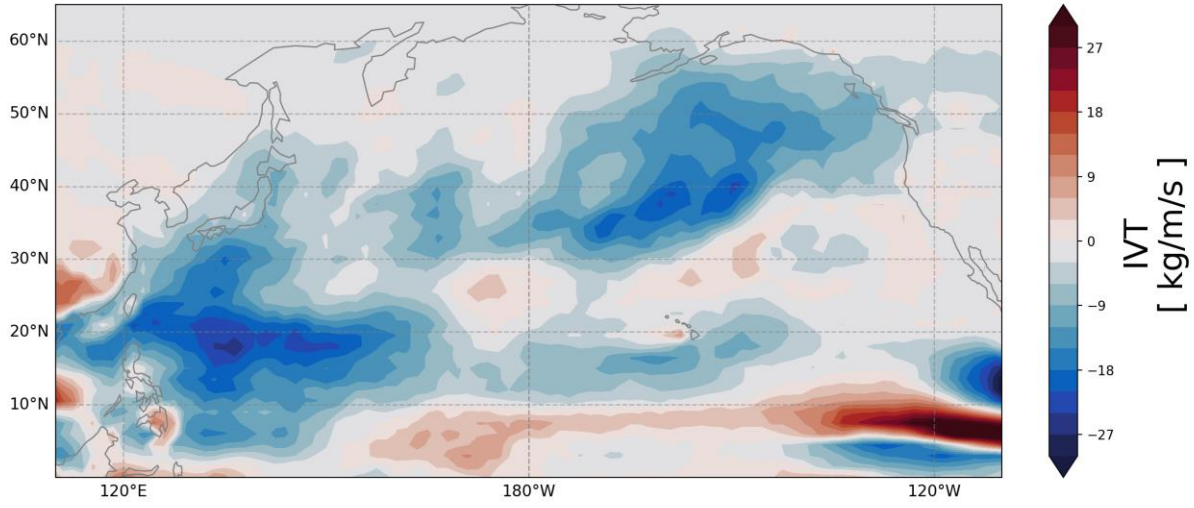
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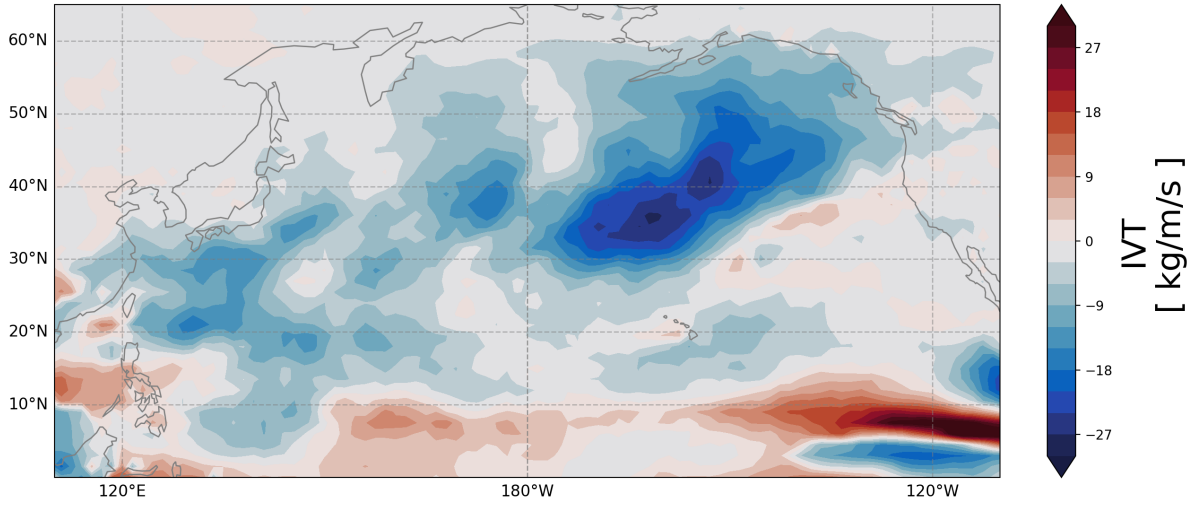
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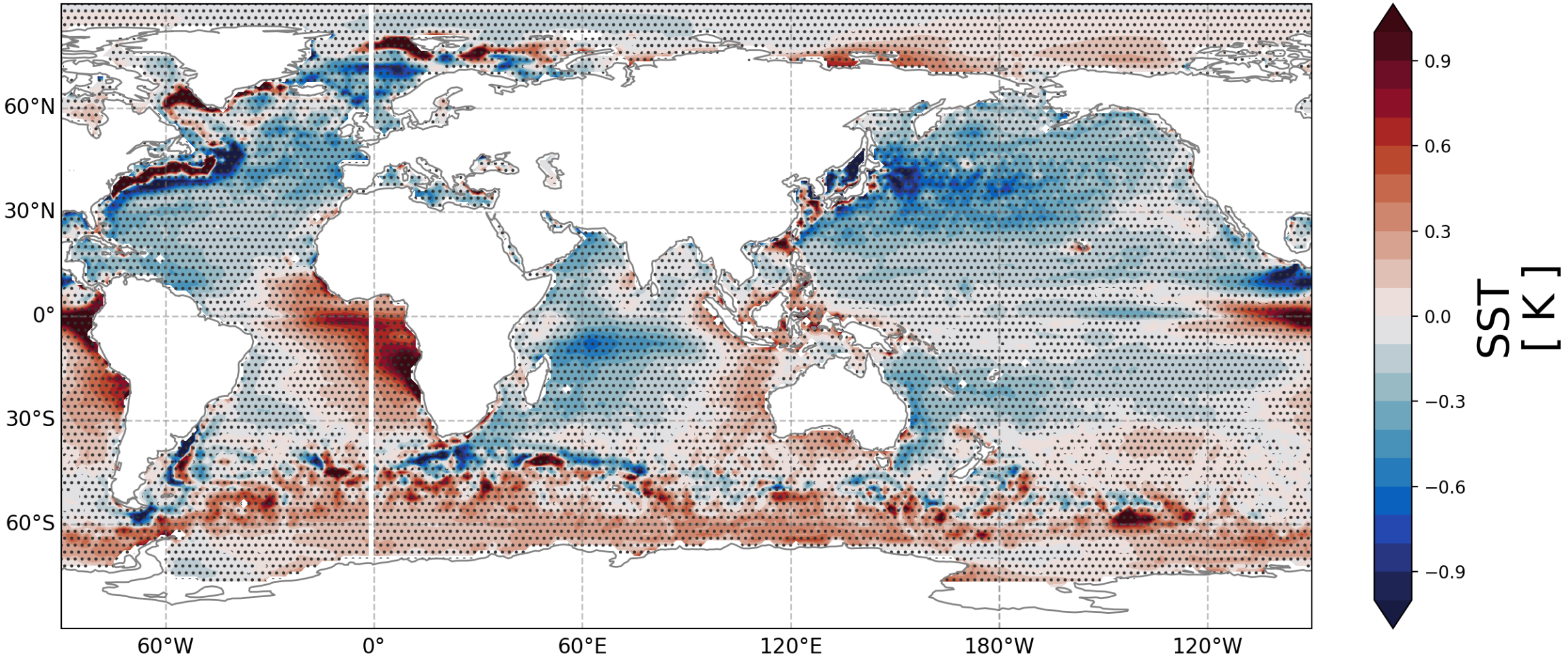
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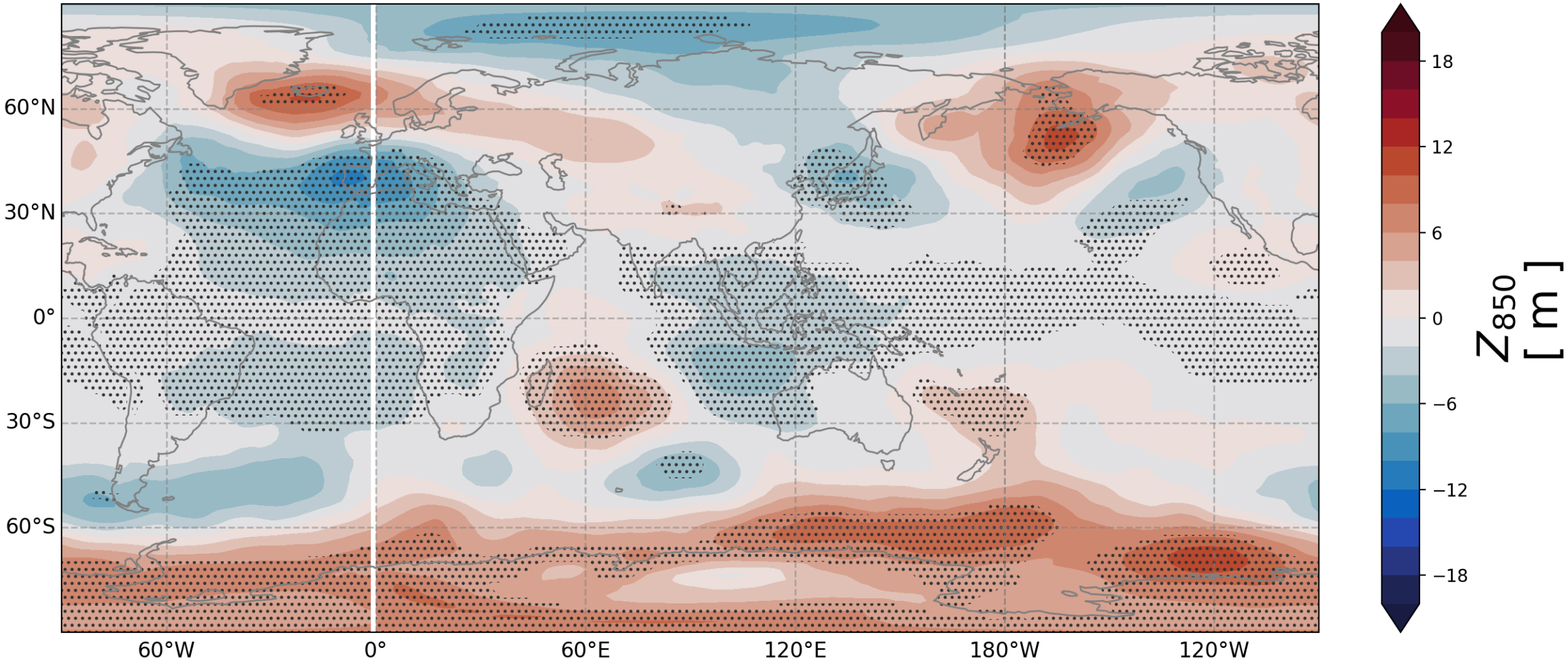


[GEPS6sub1 minus GEPS5] 1998-2017 month=10, 11, 12, 01, 02, 03, lead_pentad=2.
p value = 0.10

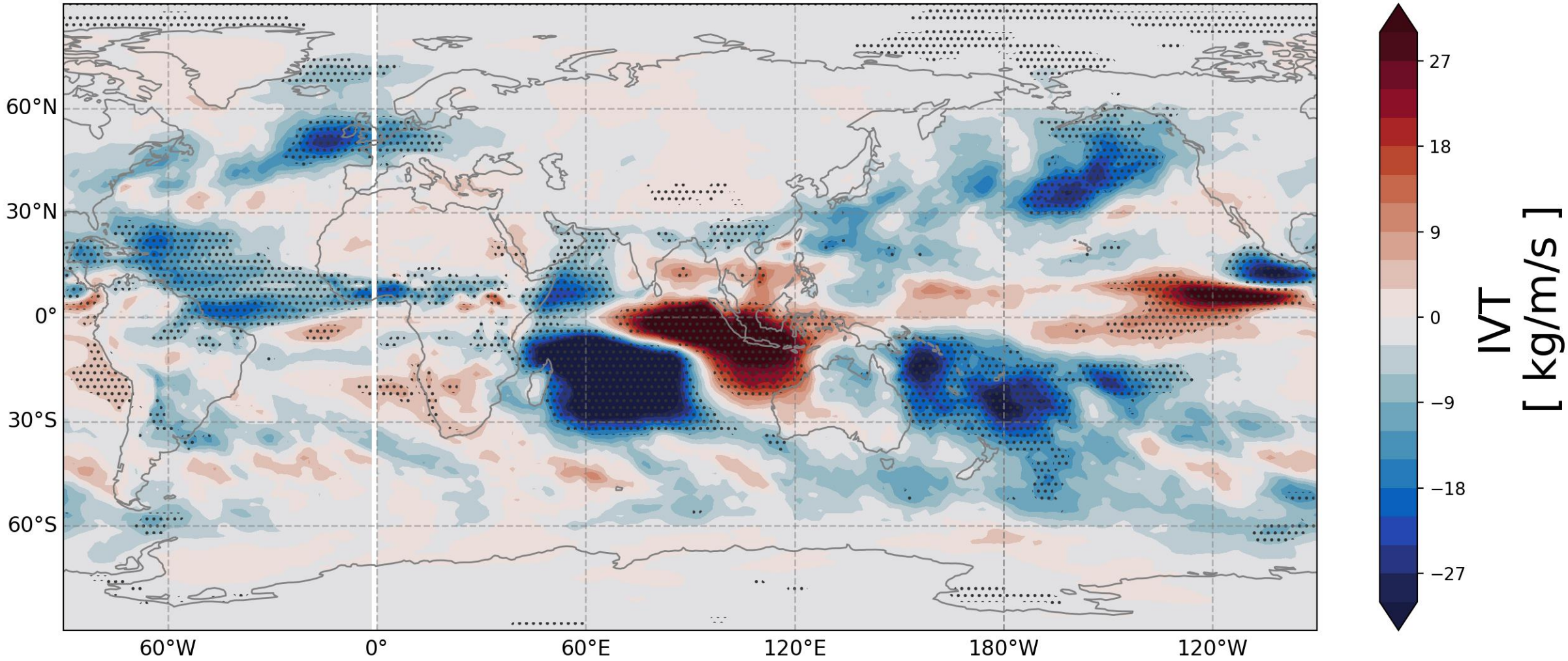


SST difference

[GEPS6sub1 minus GEPS5] 1998-2017 month=10, 11, 12, 01, 02, 03, lead_pentad=2.
p value = 0.10



[GEPS6sub1 minus GEPS5] 1998-2017 month=10, 11, 12, 01, 02, 03, lead_pentad=2.
p value = 0.10



Key statement between GEPS5/6

- “The atmospheric initial conditions *(comment: of GEPS6)* are generated in the same way as in GEPS 5.0.0, i.e., random isotropic perturbations are added to the ERA-interim reanalysis.” – *GEPS Technical Note*
- GEPS5 has no diurnal cycle. No interactive sea ice and SST.

SST difference between GEPS5/6

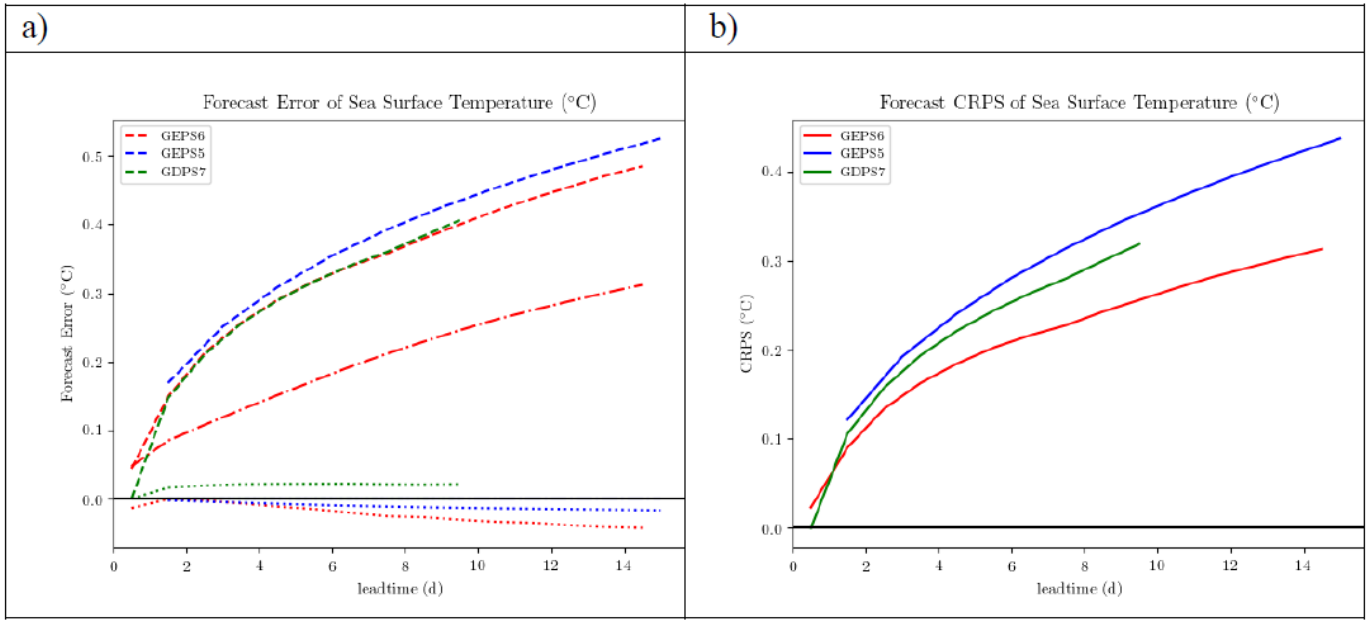


Figure 24. a) Root Mean Square Error (RMSE; dashed line), mean error (dotted line), and ensemble variance (dot-dashed line) for SST in the summer forecast set relative to the validating analysis. Plotted are the errors for the ensemble mean GEPS 6.0.0 forecast (red), the persisted anomaly SST used in GEPS 5.0.0 (blue) and in GDPS 7.0 (green). GEPS 6.0.0 and GDPS 7.0 were validated against the first 24h GDPS forecast (and therefore GDPS 7.0 has zero error at 12h), while GEPS 5.0.0 was validated against CMC SST. b) Continuous Ranked Probability Score (CRPS) for SST in GEPS 6.0.0 (red), GEPS 5.0.0 (blue), and GDPS 7.0 (green) using the same validating analysis as for errors. GEPS 5.0.0 and GDPS 7.0 were treated as single ensemble members.

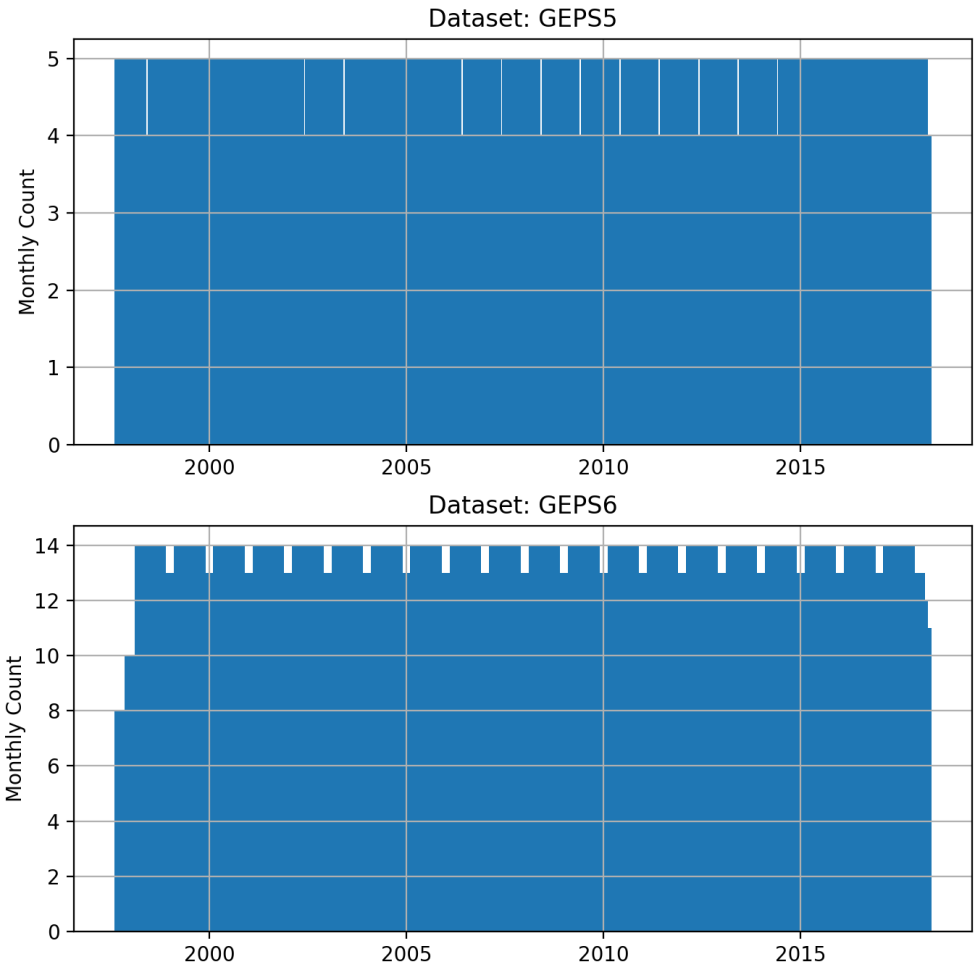
Model output information

Hindcast	GEPS5 (persistence SST)	GEPS6 (Fully coupled)
First start time	1998-01-03	1998-01-07
Last start time	2017-12-27	2017-12-26
Number of start times	908	2598
Number of ensemble members	4	4
Common start times:	1998~2017: 06-20, 06-27, 07-04, 07-11, 07-18, 07-25	

Forecast	GEPS5	GEPS6
First start time	2018-09-20	2019-06-27
Last start time	2019-06-20	2021-12-02
Number of start times	40	128
Number of ensemble members	20	20
Common start times:	None	

Data density of start times (hindcast)

All months in all years



By months

