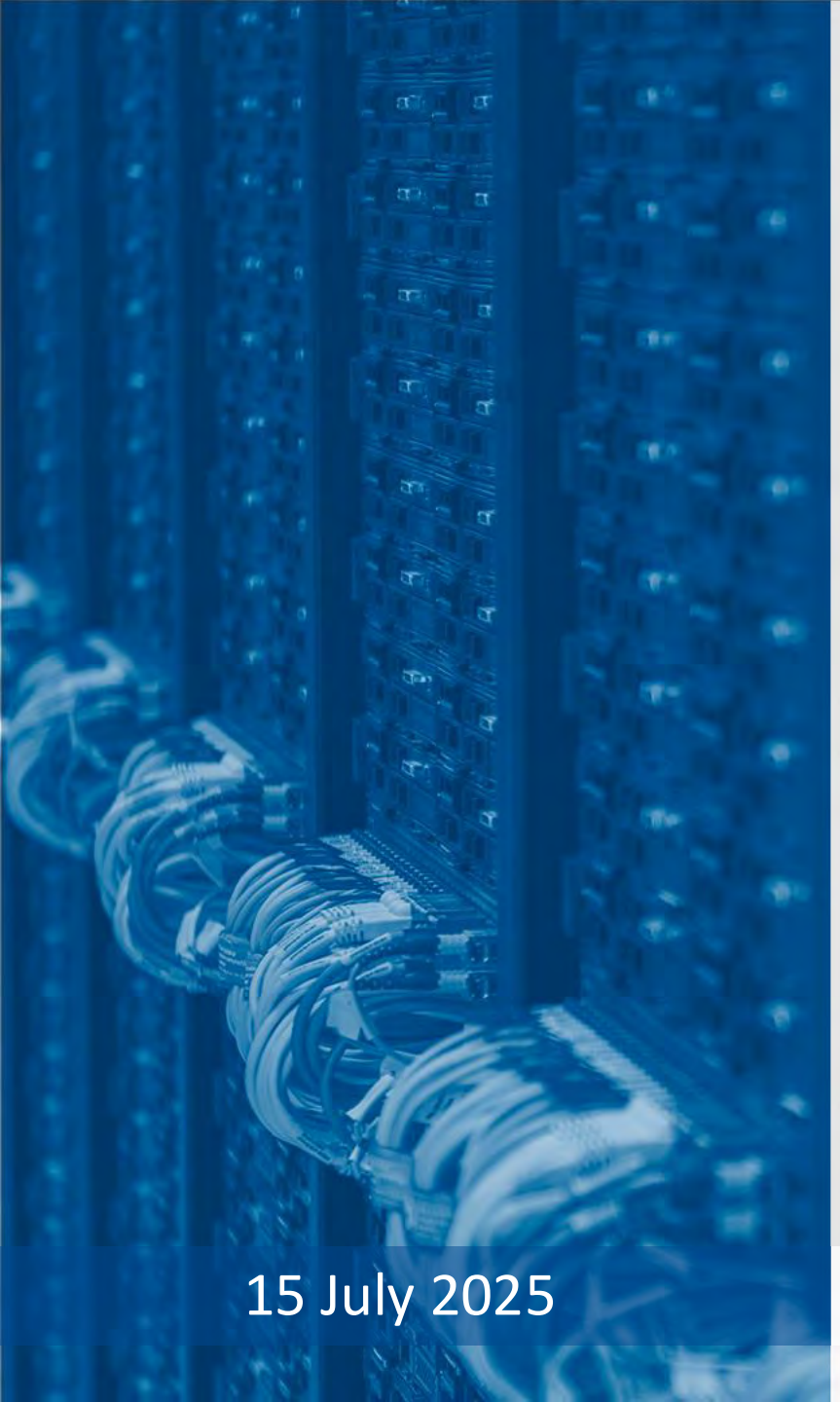

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Towards understanding the sources of forecast signals and skill in interannual to decadal climate predictions

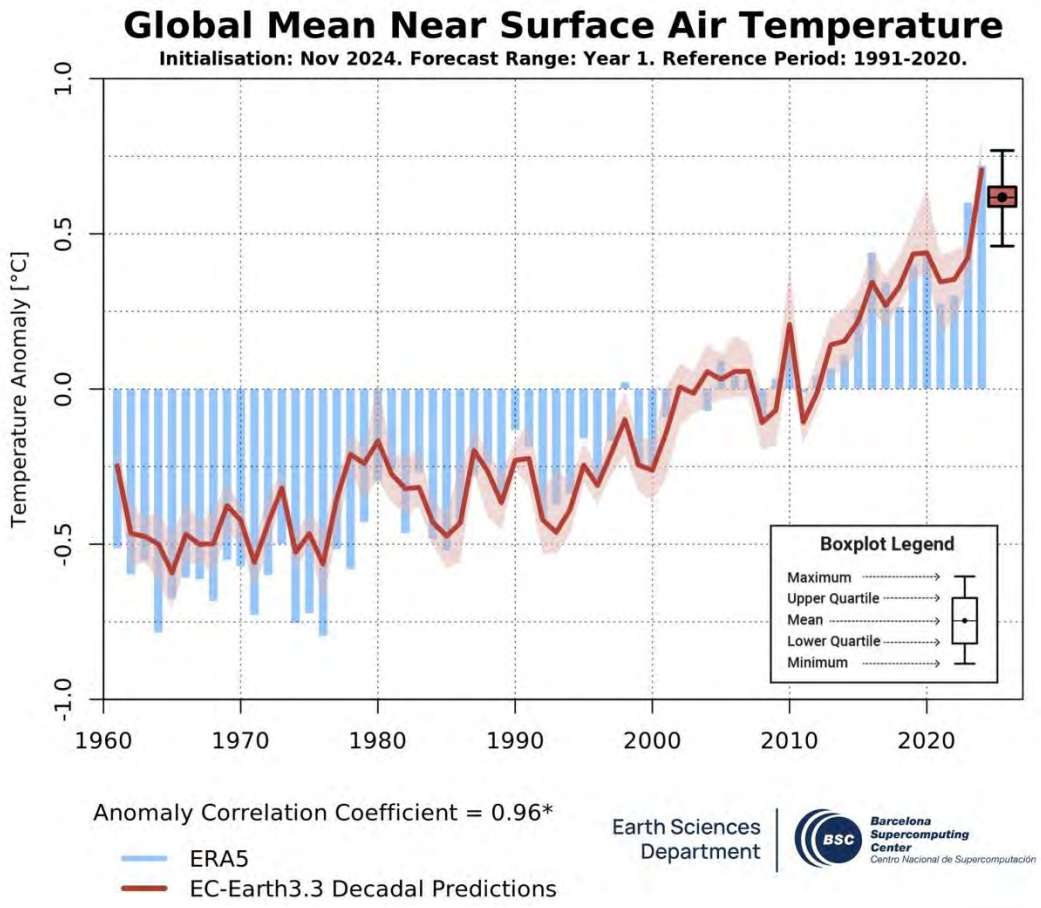
Markus Donat, Paolo De Luca, Rashed Mahmood

15 July 2025

EPESC-LEADER workshop, Busan, Korea

Motivation: Annually updated interannual to decadal predictions

e.g. https://decadal.bsc.es



WMO Global Annual to Decadal Climate Update

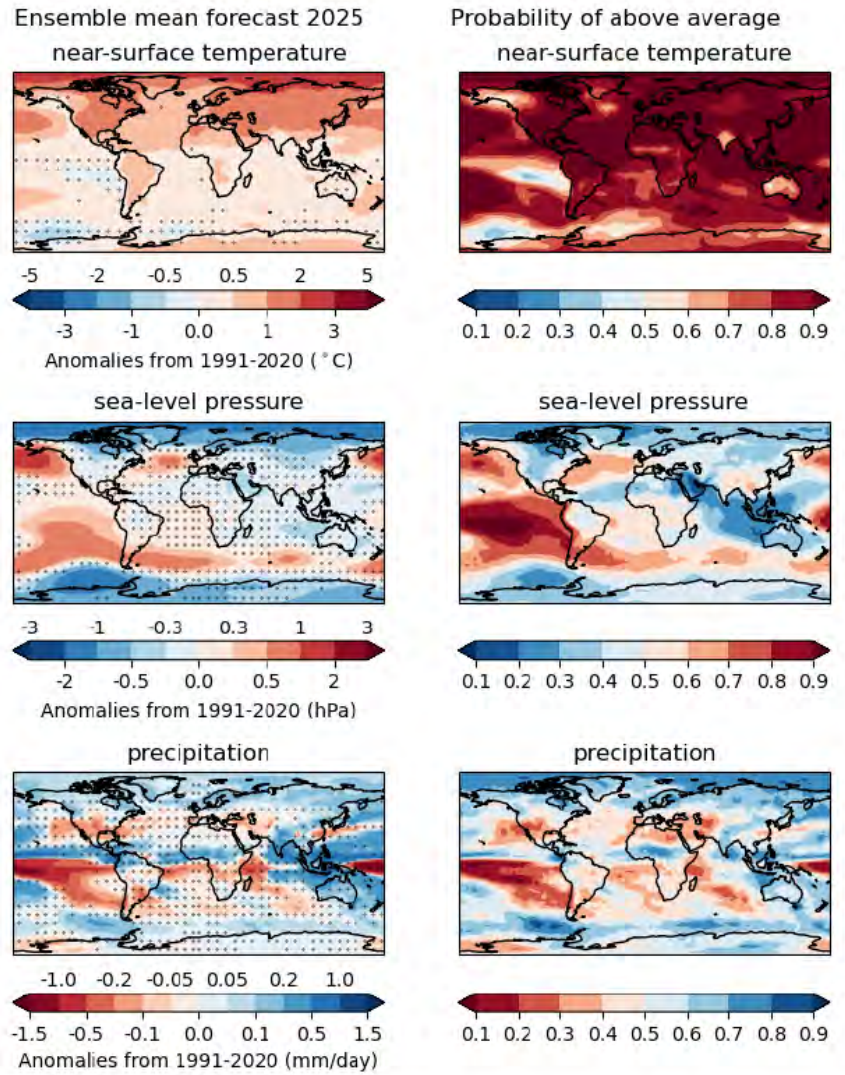


Figure 7: Annual mean anomaly predictions for 2025 relative to 1991-2020. Ensemble mean (left column) for temperature (top, °C), sea level pressure (middle, hPa), precipitation (bottom, mm/day), stippled where more than 1/3 of models disagree on the sign of the anomaly, and probability of above average (right column). As this is an uncalibrated two-category forecast, the probability for below average is one minus the probability shown in the right column.

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How much confidence do we have into these predictions?

Hindcast skill evaluation

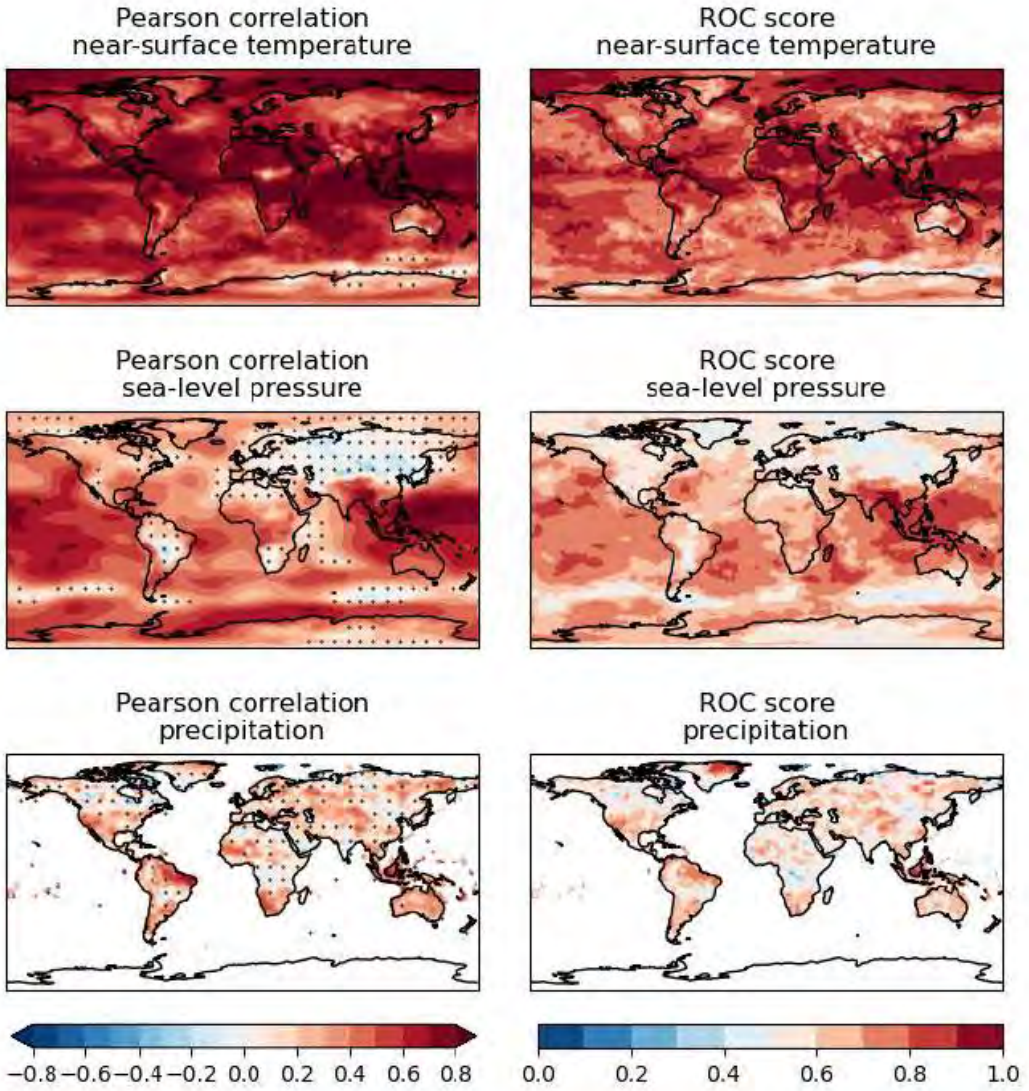


Figure 8: Prediction skill of annual means evaluated using hindcast experiments. Pearson correlation (left) and ROC score for predictions of above average conditions (right). For correlation stippling shows where skill is insignificant (at the 5% level).

- Skill evaluations provide indication of forecast quality during the hindcast period (but forecast skill might differ from hindcast skill)

- Often we do not understand the predicted signals
  - Why do the predictions predict what they predict?
  - Are they right for the right reasons?

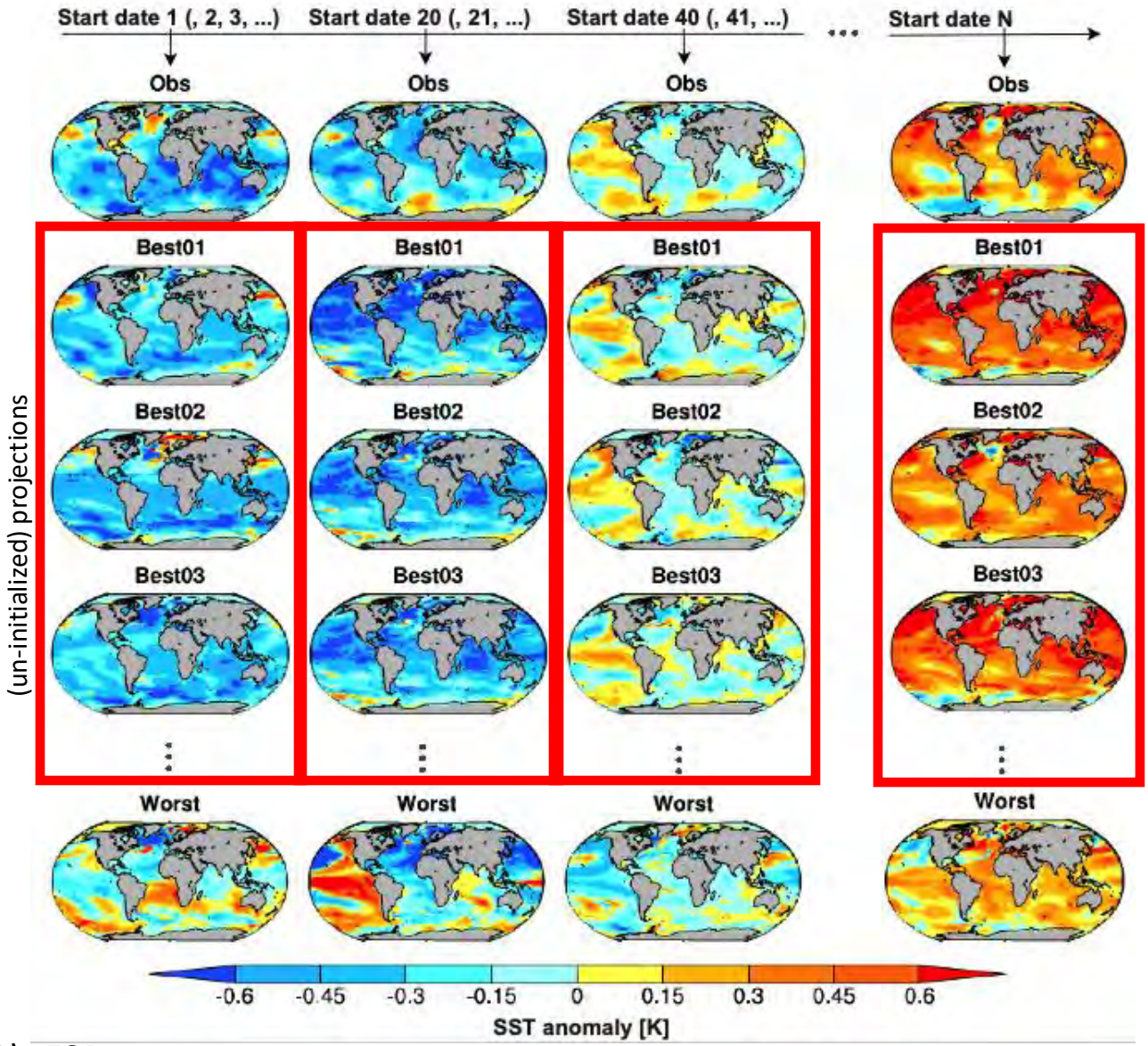
➔ Need to scrutinize predictions for sources of predictability and drivers of predicted signals

Climate predictions from Constraining global (or regional) variability patterns

Constraining projections based on their agreement with global SST anomaly patterns from observations or decadal predictions *('poor-man initialisation' or 'analogue-initialisation')*

(1) Constraining projections **against initialised decadal predictions** [Mahmood et al. 2021, GRL]

(2) Constraining projections **against observations** prior to first forecast year [Mahmood et al. 2022, ESD]



Mahmood et al (2022), ESD

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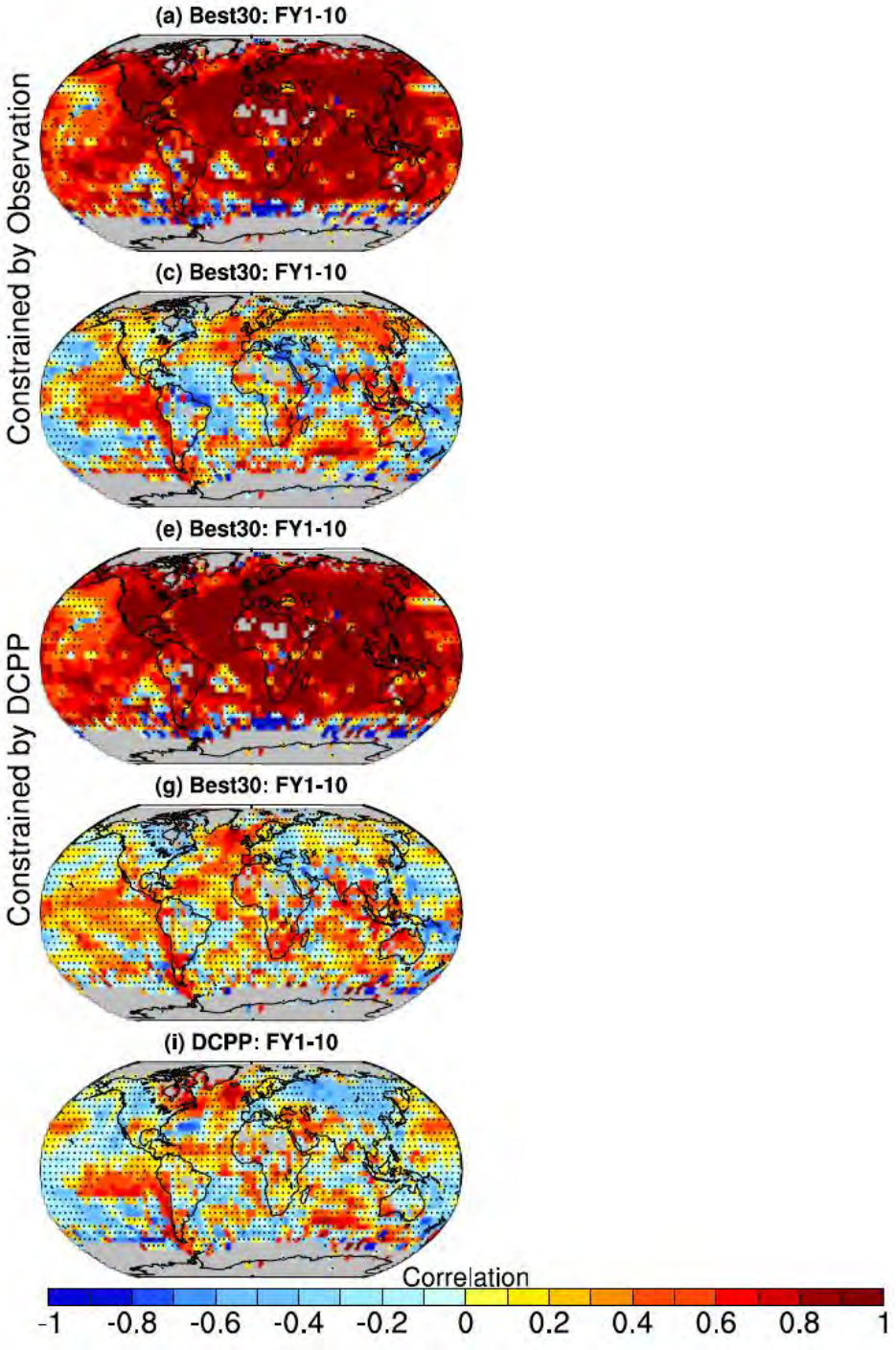
Constraining a large CMIP6 multi-model ensemble

Projections ensemble: **311 members** from 37 models constrain based on agreement of global SST anomalies:

- In **observations** (ERSST): during 5 years prior to 'initialisation'
- In the **DCPP ensemble mean** based of 93 ensemble members from 9 different models: during 5 years after initialisation

Sub-selecting the 30 projections members in closest agreement with SST anomaly patterns from observations / DCPP

skill for *tas*:



Anomaly correlation *(tas)*

Residual correlation *(against un-constrained)*

Anomaly correlation *(tas)*

Residual correlation *(against un-constrained)*

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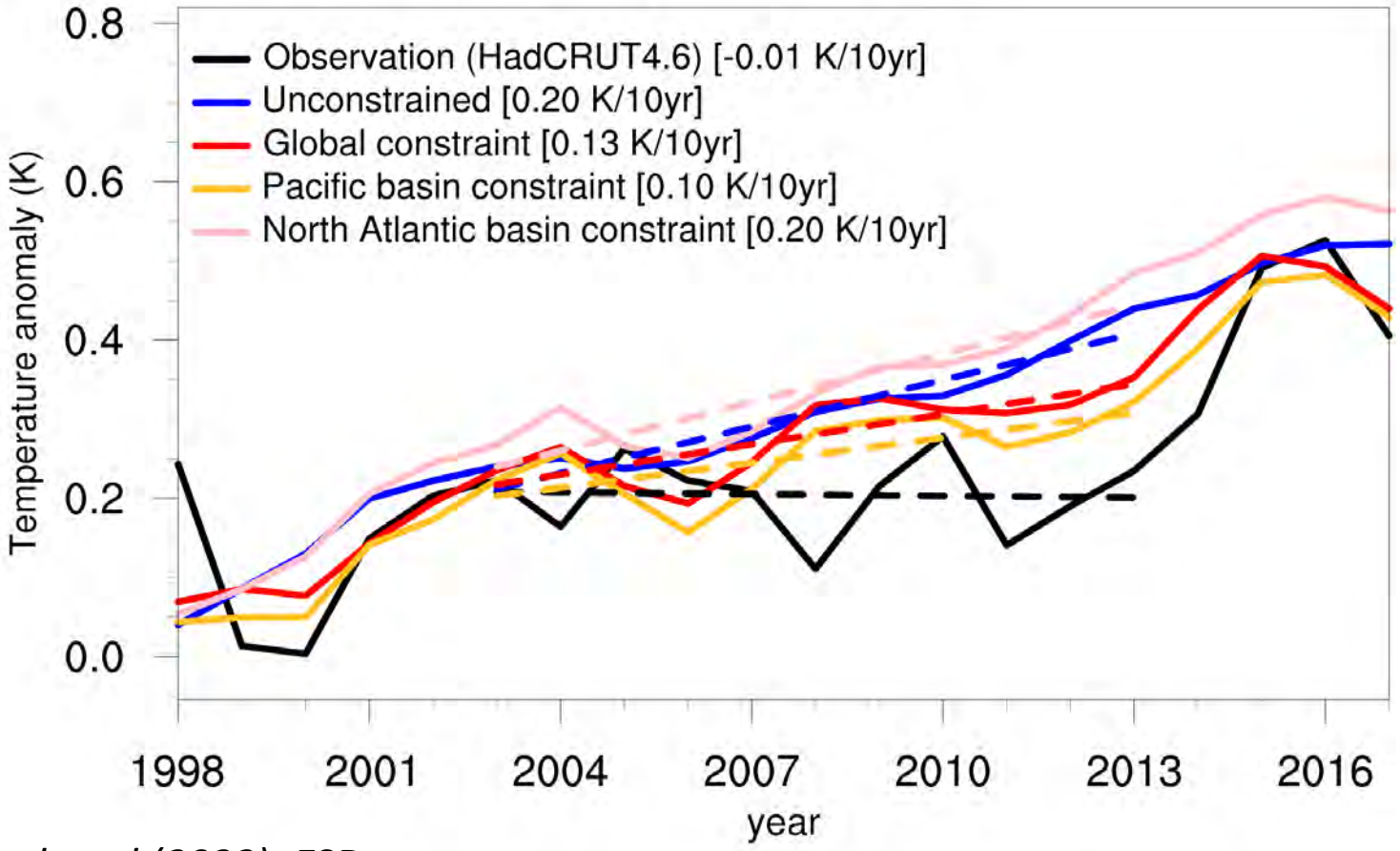
Donat et al (2024), ERCL

Constraining based on different SST domains to attribute predictability, example: global average temperature ‘hiatus’



Projections constrained in 1998 predict a global warming slow-down in the early 2000s using

- global SSTs
- Pacific SSTs;

but not when constraining in the North Atlantic

Mahmood et al (2022), ESD

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Understanding decadal predictability of drought in SE Australia

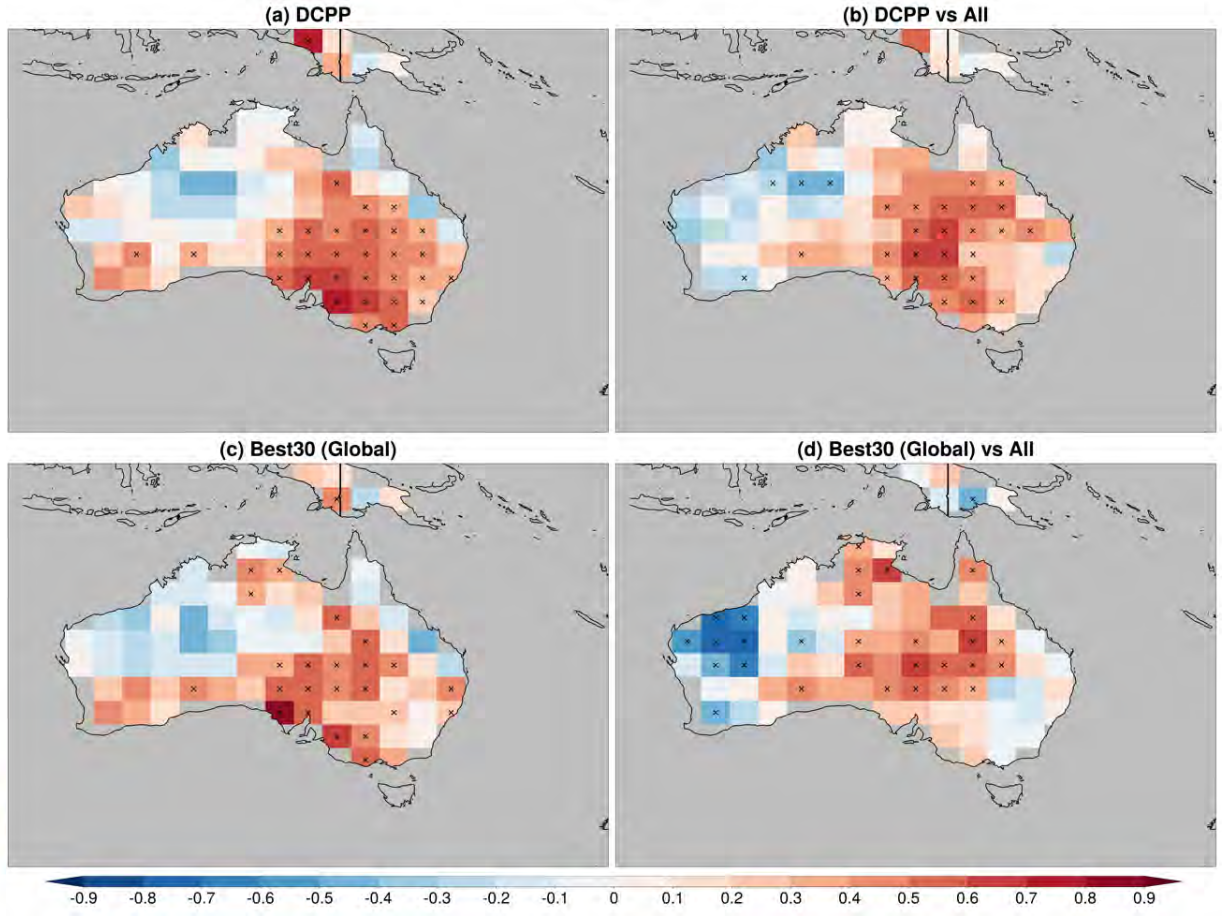
Predicting the drought frequency (months) when SPEI < -1, during austral summer (DJF), forecast years 2-10 average

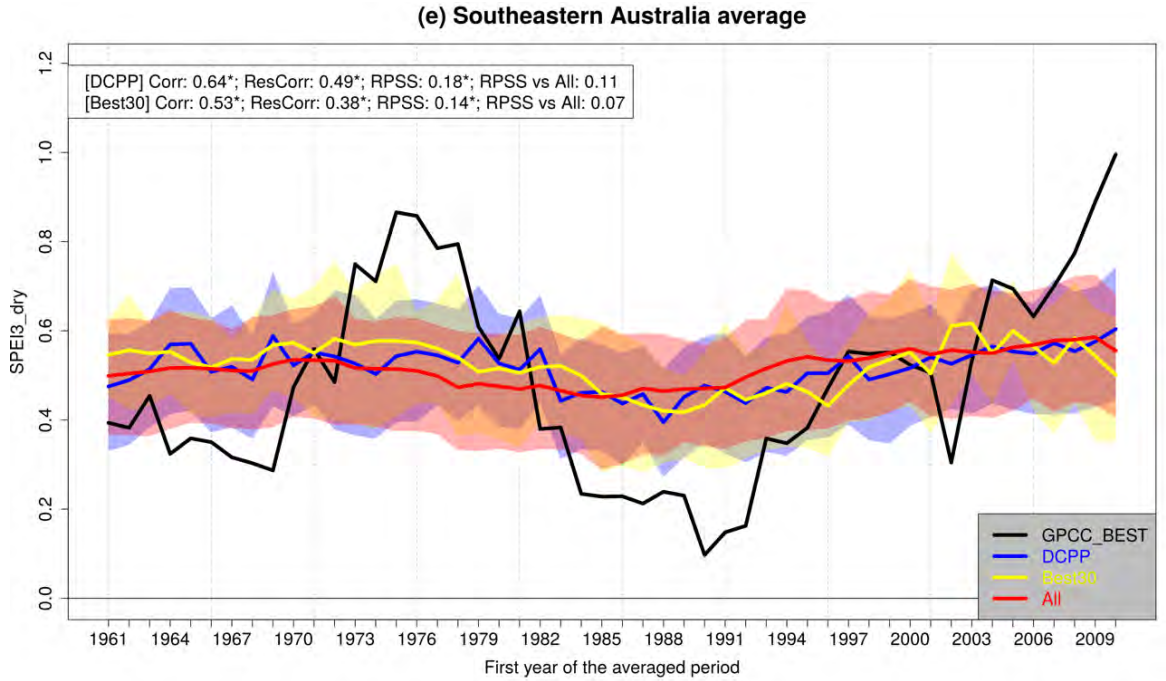
Anomaly correlation

Residual correlation relative to CMIP6 mean

DCPP

SST-constrained

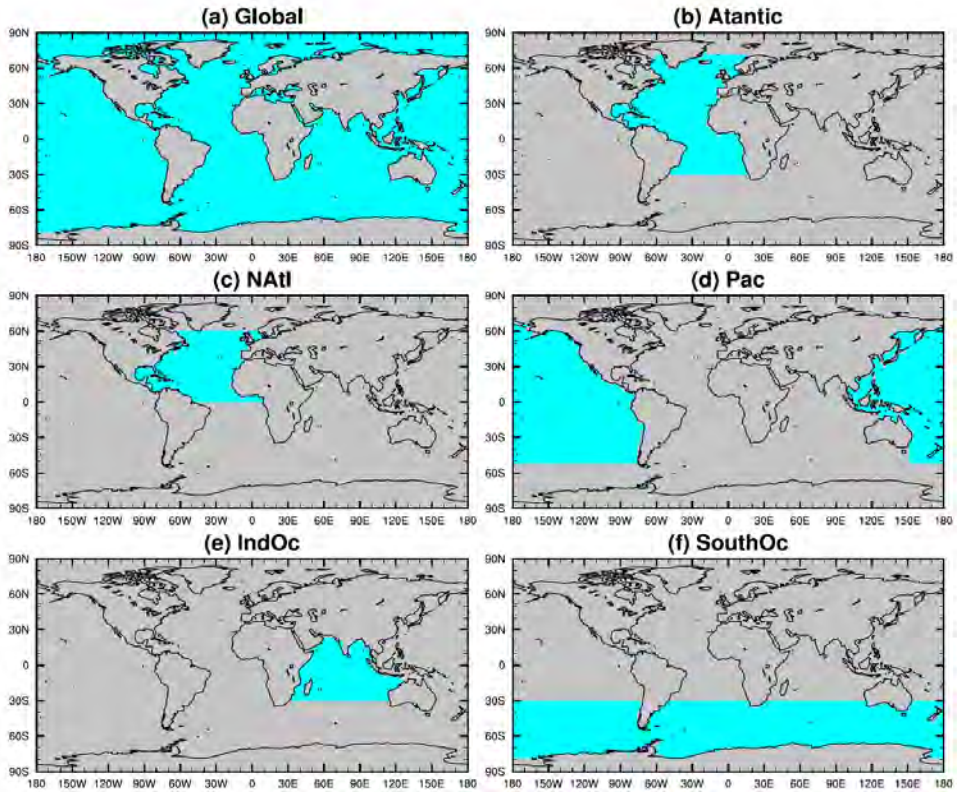




De Luca et al., *in prep*

Regional sources of prediction skill for drought in SE Australia

'initialising' (constraining) specific ocean regions



	DCPP	Global	Atlantic	NAtl	Pac	IndOc	SouthOc
Corr	0.64*	0.53*	0.45*	0.54*	0.50*	0.64*	0.57*
ResCorr	0.49*	0.38*	0.20	0.21	0.29*	0.49*	0.38*
RPSS	0.18*	0.14*	0.10	0.10	0.11*	0.16*	0.09
RPSS vs All	0.11	0.07	0.03	0.02	0.04	0.09*	0.01

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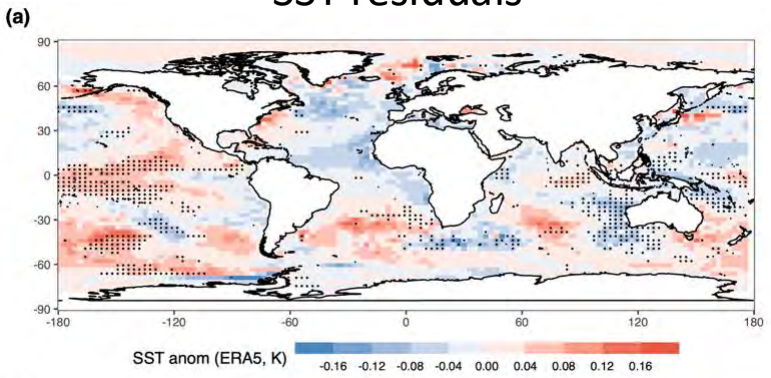
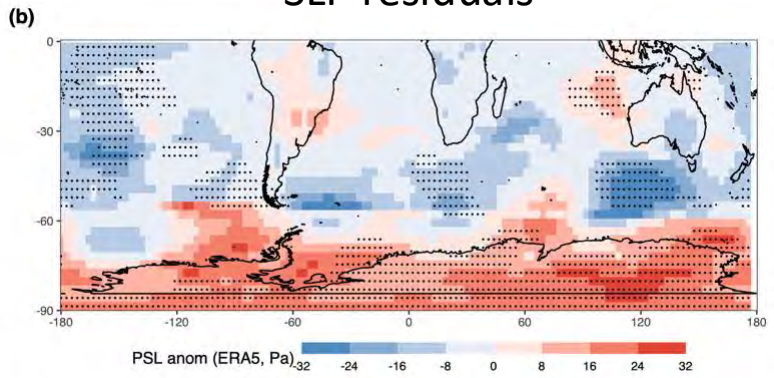
De Luca et al., *in prep*

Large-scale patterns associated with (observed and predicted) drought in SE Australia

SST residuals



SLP residuals



Composites of SST/SLP residuals associated with observed drought months (residuals calculated by regressing out the CMIP6 mean)

DCPP residuals, composite of conditions associated with observed drought occurrence

Variability-constrained ensemble residuals, composite of conditions associated with observed drought occurrence

De Luca et al., *in prep*

Take-home messages

- Constraining global or regional SST anomaly patterns in transient climate simulations provides skillful decadal to multi-decadal climate predictions, overall comparable with DCPP for 10-year predictions

- Constraining ('poor-men initialising') specific ocean regions allows to determine specific oceanic sources of skill:
  - Pacific SST anomaly patterns predicted early-2000s warming slowdown (based on observed SST until 1997)
  - Indian Ocean, Southern Ocean and Pacific SST patterns most important sources of decadal skill for summer drought in SE Australia

- Predictions of SE Australian summer drought reproduce observed large-scale pressure patterns associated with drought (SAM- like), but do not consistently reproduce large-scale ocean variability patterns

- Future work could apply the SST pattern constraint to single-forcing large ensembles, to consider effect of different external forcings in combination with initialisation

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Thank you!

Mahmood, R., M. G. Donat, P. Ortega, F. J. Doblas-Reyes, C. Delgado-Torres, M. Samsó, P.-A. Bretonnière (2022), Constraining low-frequency variability in climate projections to predict climate on decadal to multi-decadal time scales – a 'poor-man' initialized prediction system, *Earth System Dynamics,* **13**, 1437–1450, https://doi.org/10.5194/esd-13-1437-2022

Donat, M.G., R. Mahmood, P. Cos, P. Ortega, F. Doblas-Reyes (2024), Improving the forecast quality of near-term climate projections by constraining internal variability based on decadal predictions and observations, *Environmental Research: Climate,* 3, 035013. https://doi.org/10.1088/2752-5295/ad5463

De Luca, P, C. Delgado-Torres, A. Aranyossy, R. Mahmood, A.D. King, M. Samso Cabre, N.S. Keenlyside, A.S. Taschetto, and M.G. Donat (2025), Skillful decadal drought predictions in south-east Australia leverage teleconnections with atmospheric pressure and regional SST anomalies, *in preparation*

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