Outcomes from UGROW project: Forecast errors in across lead times

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UGROW-IO: Forecast errors in the Eastern Indian Ocean

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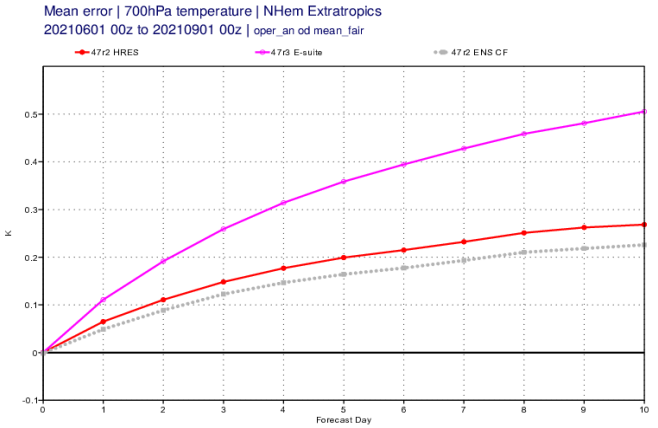
ECMWF

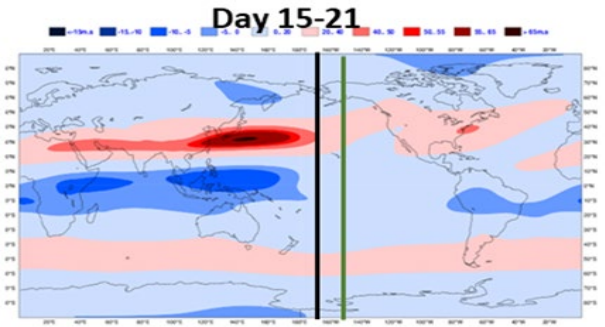
6th WGNE workshop

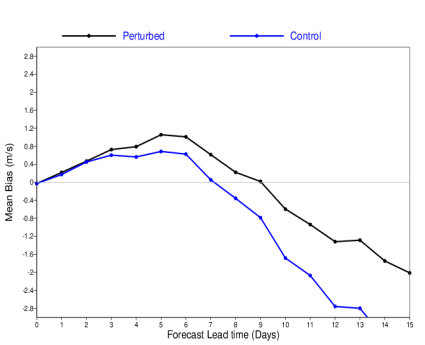
UGROW subtopics

1. UGROW- TM: Temperature warm bias in Mid Troposphere NH
   - Most prominent in boreal winter, over land masses, peaking over Eastern Asia
   - Canonical medium range error: Fast error growth and saturation.
   - Magnusson et al 2022. ECMWF Techmemo 891

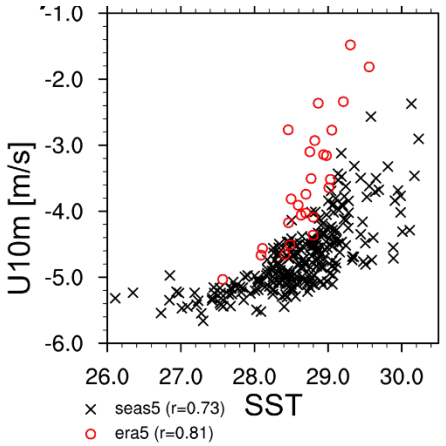


2. UGROW-JET: Westward retraction of the NH Pacific subtropical jet
   - Grows slowly, only visible at subseasonal time scales
   - Likely non-local origin. Vitart et al 2022. ECMWF Techmemo 889



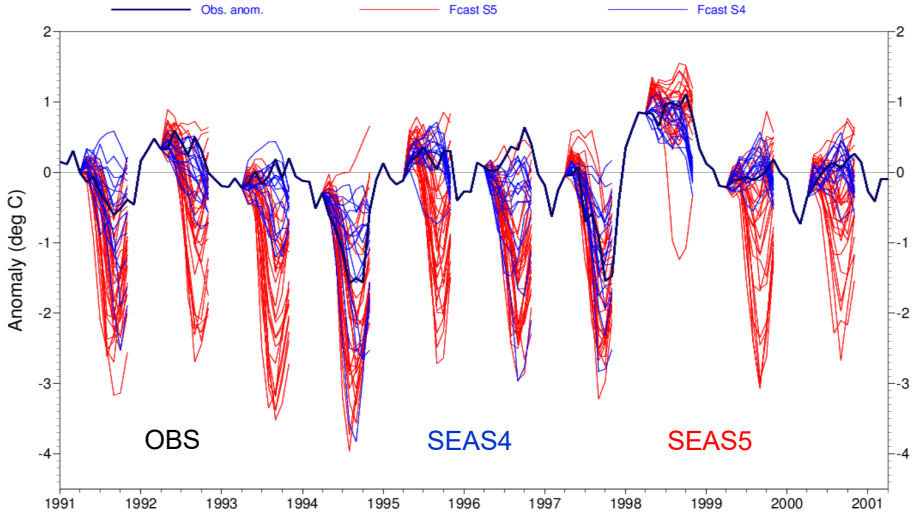


3. UGROW Eastern Indian Ocean.
   - Errors in both atmosphere and ocean models that amplify by coupled processes.
   - Dominant in seasonal forecasts. Mayer et al 2022. ECMWF Techmemo 898

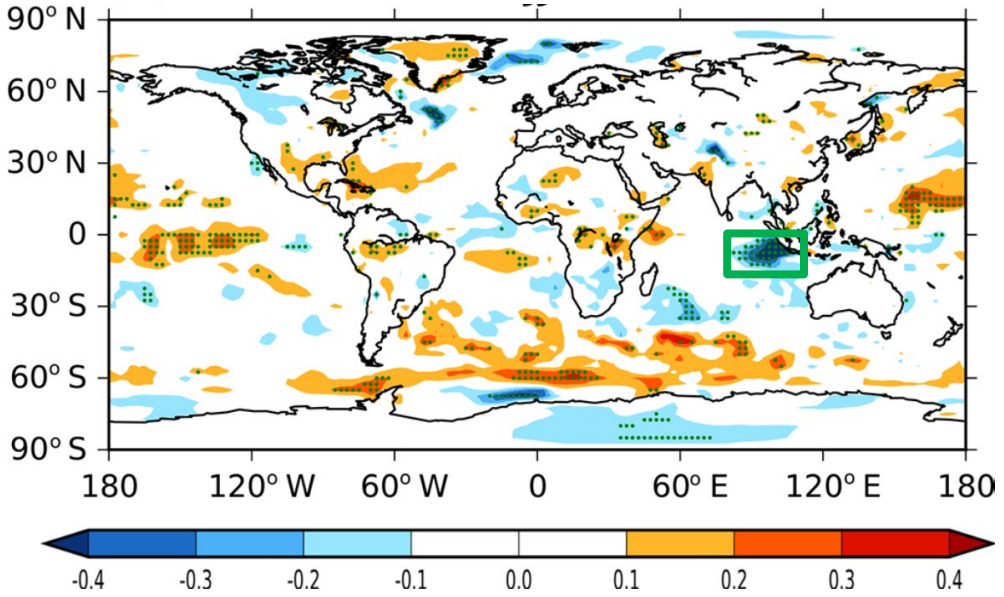


Background

EEIO reforecast anomaly timeseries for May starts



SEAS5 – SEAS4 SST forecast skill JJA



from Johnson et al. (2019)

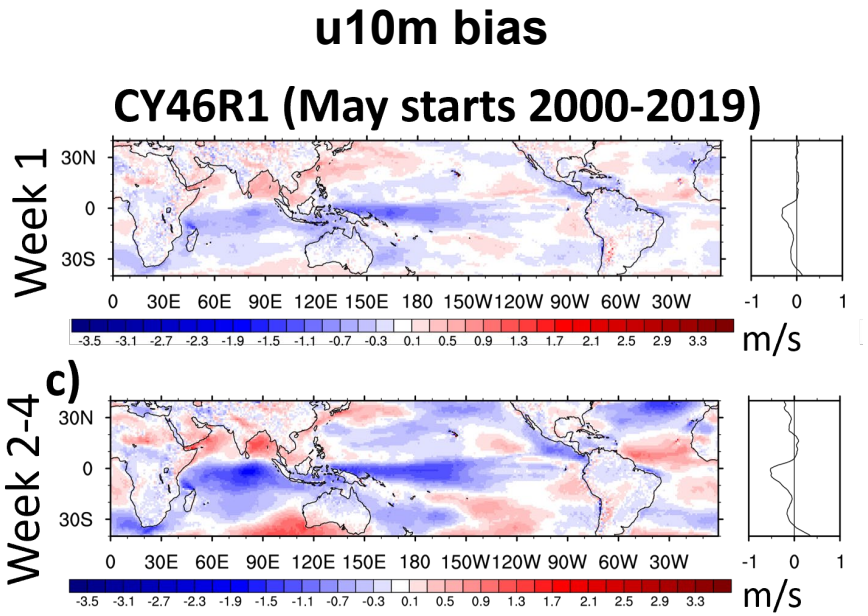
- In SEAS5, cold SST anomalies in the Eastern Equatorial Indian Ocean (EEIO) are too large, too variable and too frequent.
- Reduced skill of ECMWF's seasonal system SEAS5 in EEIO motivated assessment of forecast errors
- UGROW-IO: Internal project at ECMWF to investigate biases across lead times

- ***Summary of results in***: *Mayer, M., M. A. Balmaseda, S. Johnson, L. Magnusson, C.D. Roberts, H. Zuo (2022). Outcomes from UGROW-IO: Forecast errors in the Eastern Indian Ocean across lead times, ECMWF Tech Memo 898.*
- ***paper in preparation…***

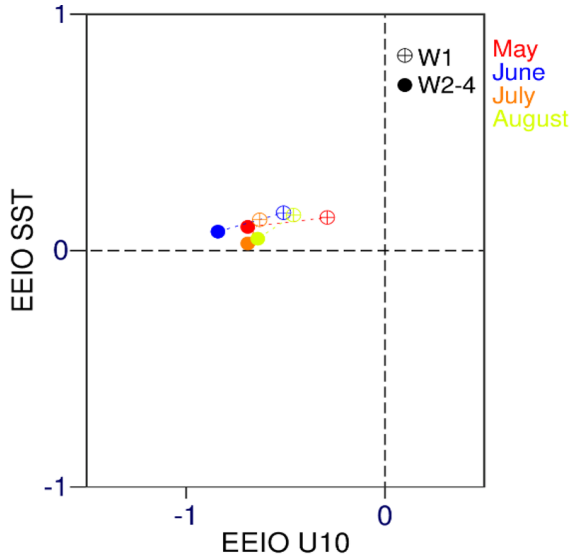
Forecast bias in ECMWF system across lead times

- Forecasts in boreal summer have an easterly wind bias in the equatorial Indian Ocean, appearing already at very short lead times (~day 2)

Extended-range forecasts

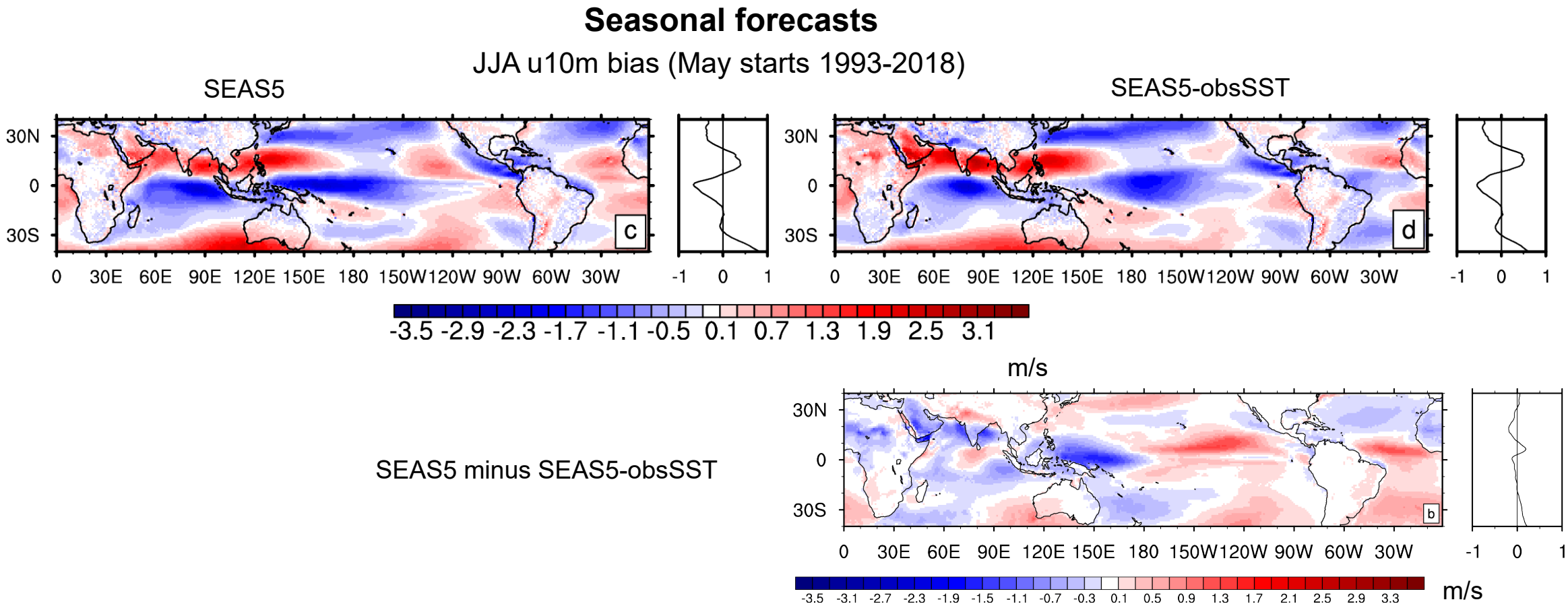


Similar behaviour for different start months



Forecast bias in ECMWF system across lead times

- Forecasts in boreal summer have an easterly wind bias in the equatorial Indian Ocean, appearing already at very short lead times (~day 2)
- Zonal wind biases strengthen on seasonal time scales and are amplified in coupled mode due to a developing cold SST bias in the EEIO



Forecast bias in ECMWF system across lead times

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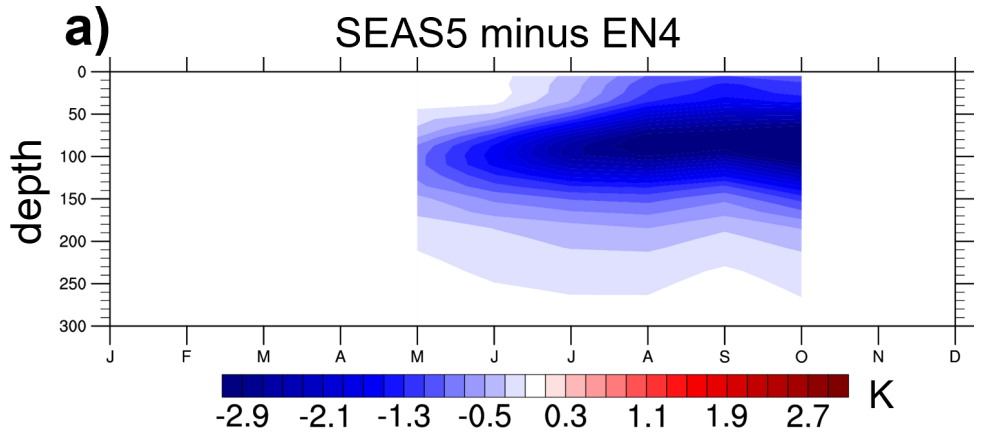
- Zonal wind biases strengthen on seasonal time scales and are amplified in coupled mode due to a developing cold SST bias in the EEIO
- The cold SST bias arises from a rapidly shallowing thermocline in the EEIO

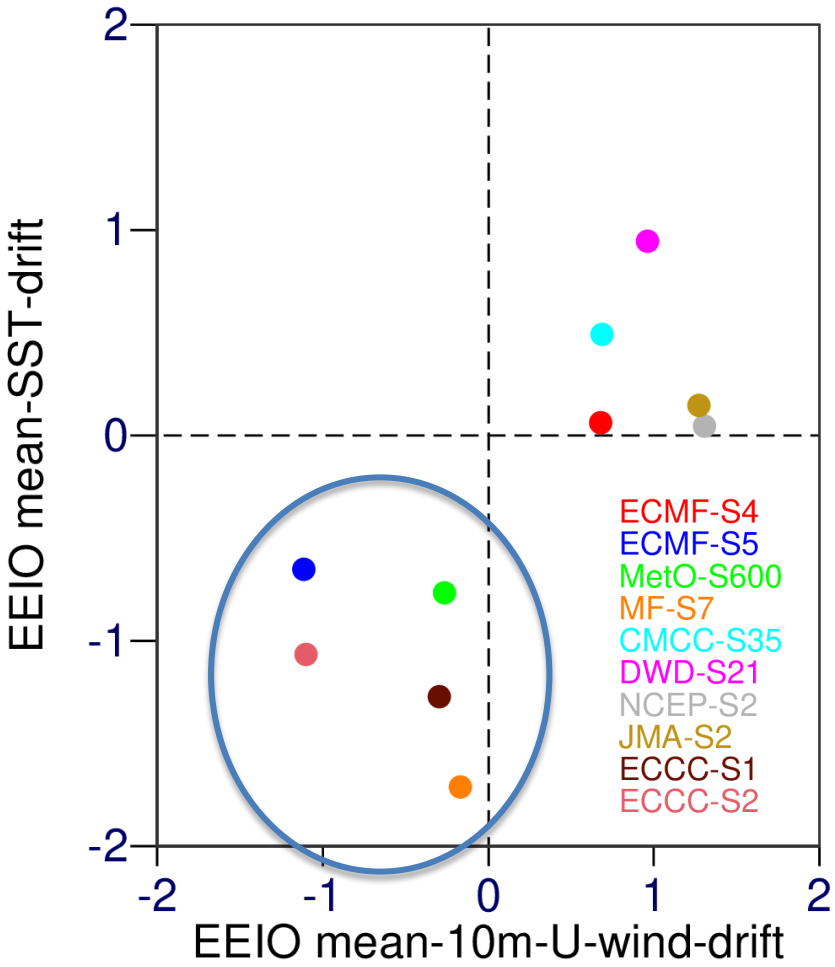
Seasonal forecasts

Subsurface temperature bias (May starts 1993-2018)



EEIO averages

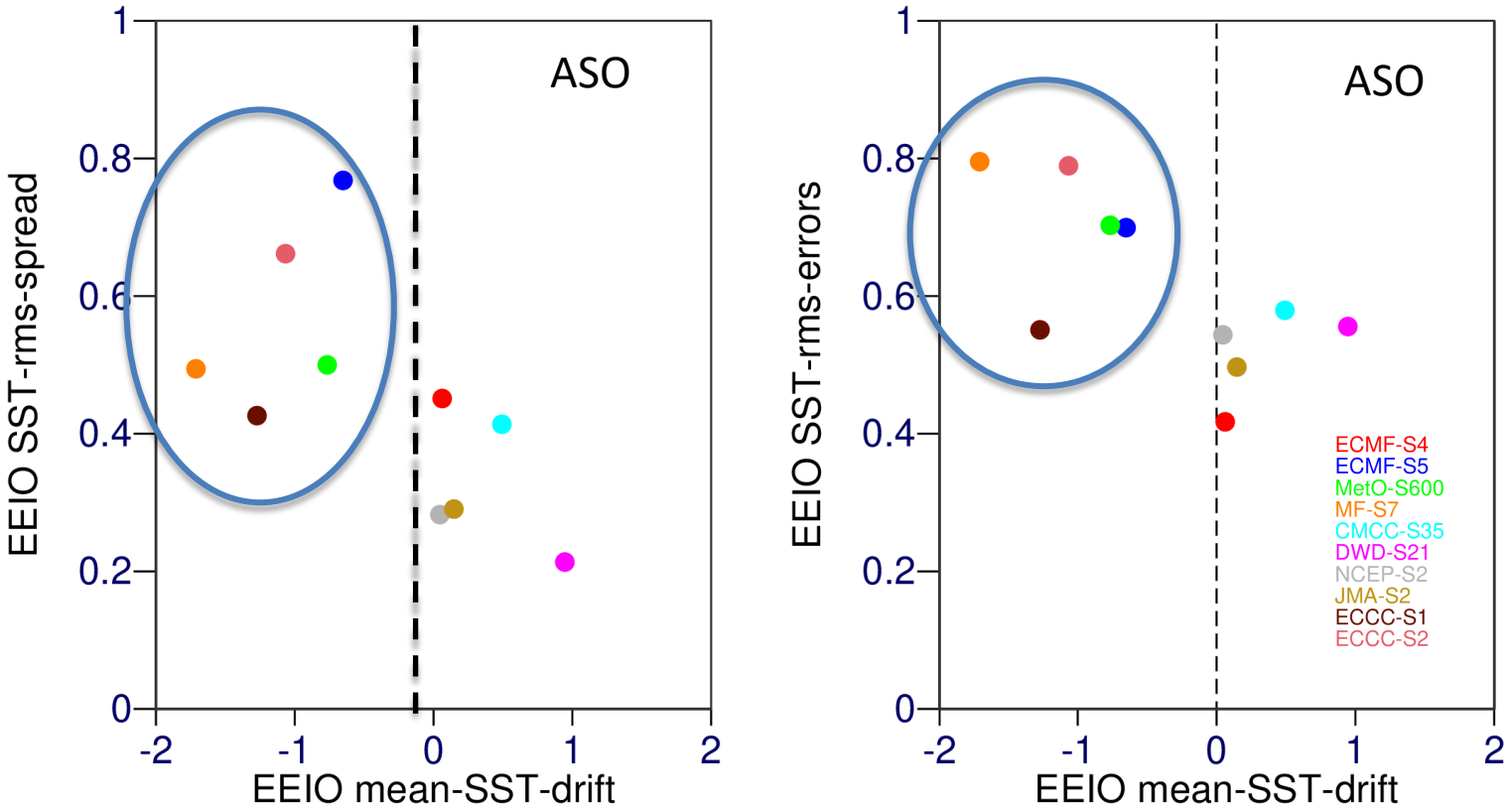
SST-wind relationships in the C3S models



ASO means, 10 members, 1993-2016

SST drift and 10 m wind drift are usually the same sign (i.e excess wind bias is associated with a cold SST bias), but there is little relationship beyond that.

SST relationships in the C3S Models



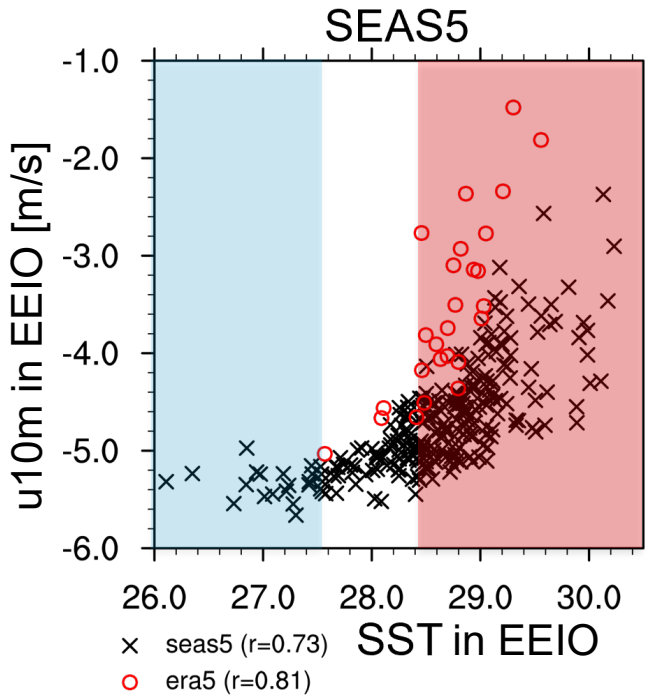
ASO means, 10 members, 1993-2016

Several of the C3S models show a similar error – cold SST bias, large spread and large RMS errors.

Larger SST drifts are associated with larger RMS errors in the C3S models.

State-dependence of u10m errors

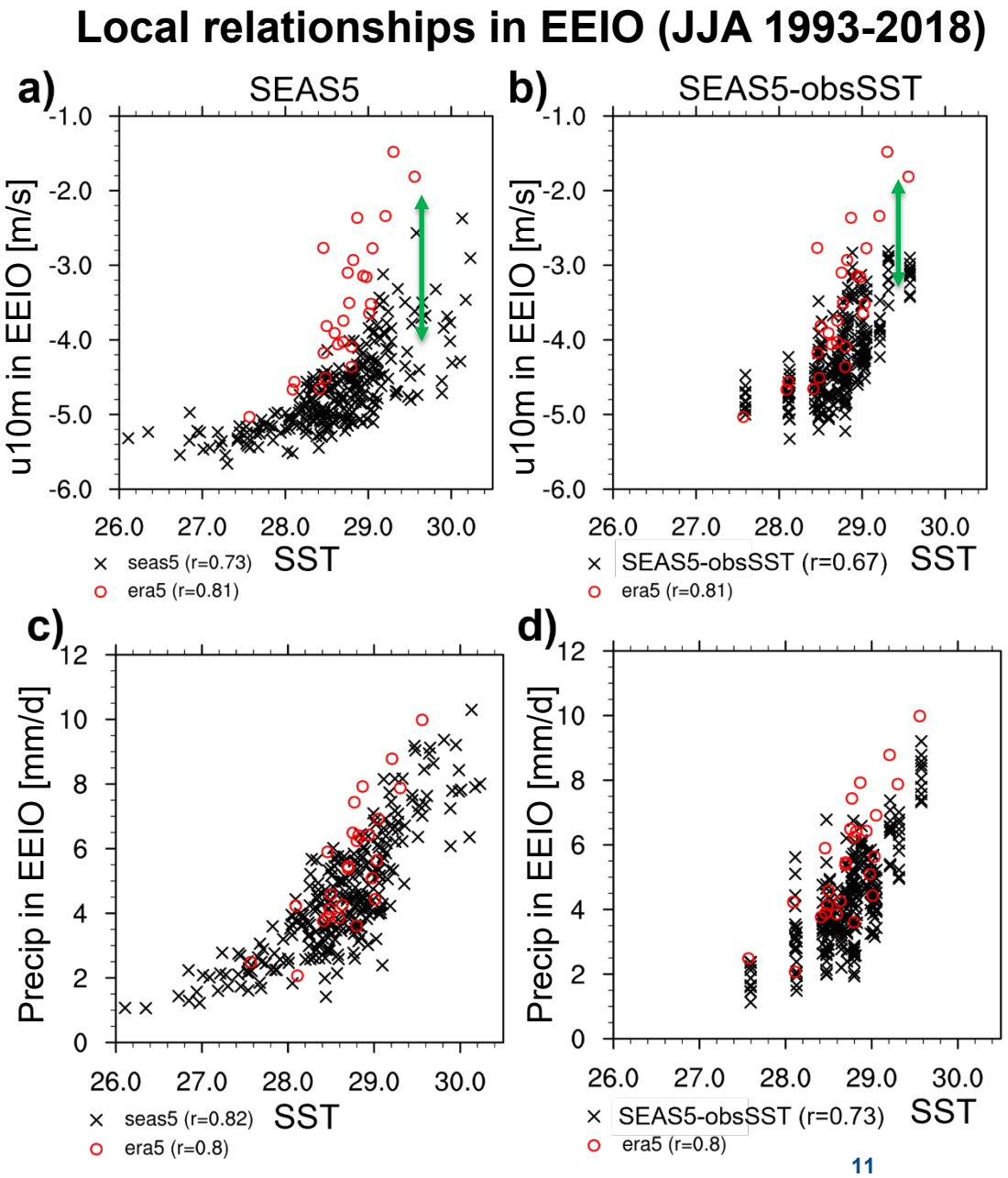
- **SEAS5 has too strong easterlies in the EEIO for a given SST**
  → it develops a prominent negative SST bias by JJA → „cold regime bias“
  → it exhibits a very weak wind sensitivity to local SSTs → „warm regime bias“



May starts 1993-2018

Warm regime errors: Wind-SST relationships

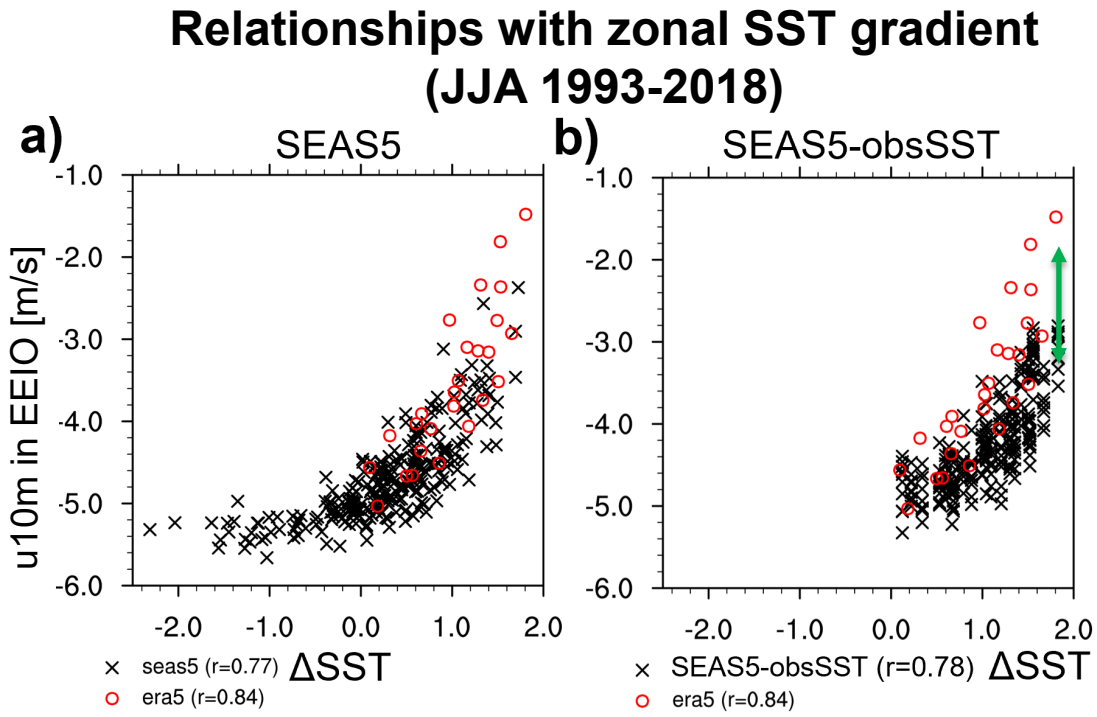
- Easterlies too strong for a given SST
- Too weak response of winds to a warm SST perturbation
- Local precipitation response to SSTs only slightly underestimated
- Wind response in SEAS5-obsSST only modestly improved



Non local response: Wind-SST relationships

- Now look at relationships of u10m/precip in EEIO with ΔSST (=SST in EEIO minus WEIO)
- SEAS5: ΔSST can get negative – never happens in observations
- SEAS5: u10m response to ΔSST looks better than for local SSTs → some compensation from WEIO warm SST bias

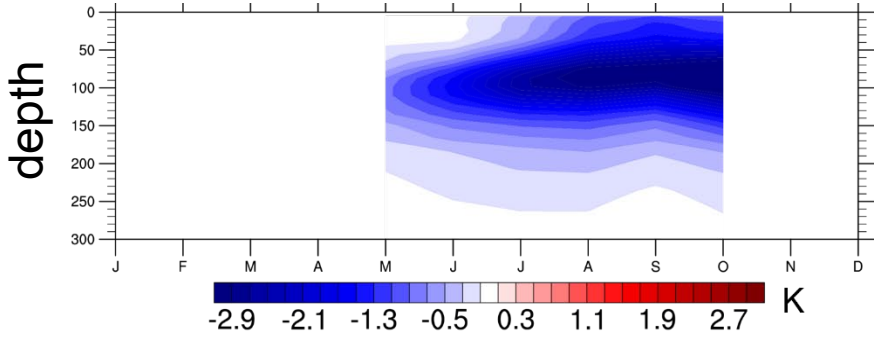
- SEAS5-obsSST: weak u10m response does not improve, likely related to too weak sensitivity of monsoon circulation to EEIO SSTs



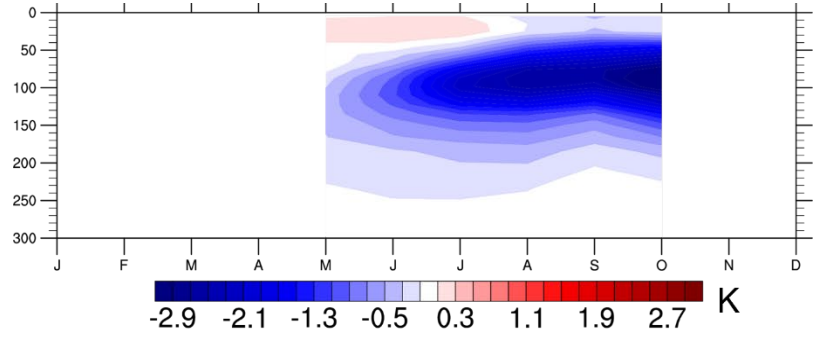
Cold regime errors: role of ocean ICs

- Cold thermocline bias from lead month 1, which subsequently strengthens with lead time
- Dependent on resolution and model version how strongly it impacts the surface

SEAS5 minus EN4 (EEIO average)

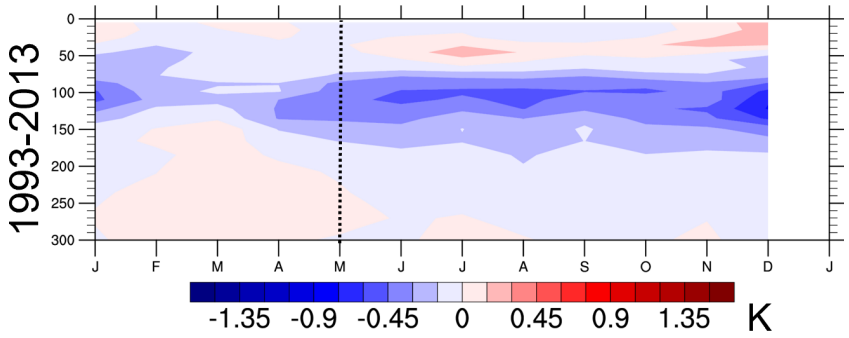


SEAS5-LR-ORAS4 (EEIO average)

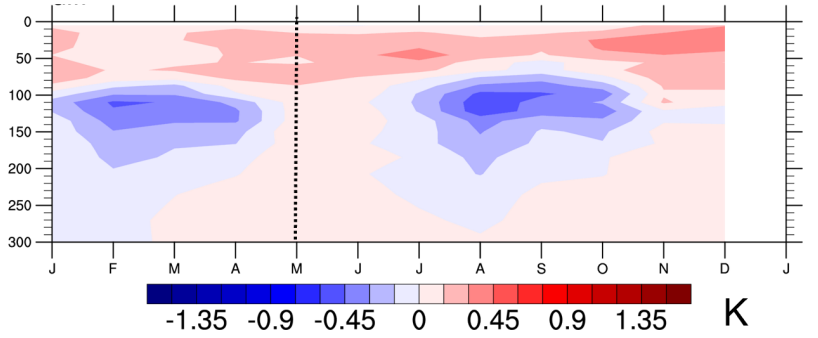


- A cold thermocline bias is already present in the ocean initial conditions from ORAS5, but not in ORAS4 → ocean model plays a role

ORAS5 minus EN4



ORAS4 minus EN4



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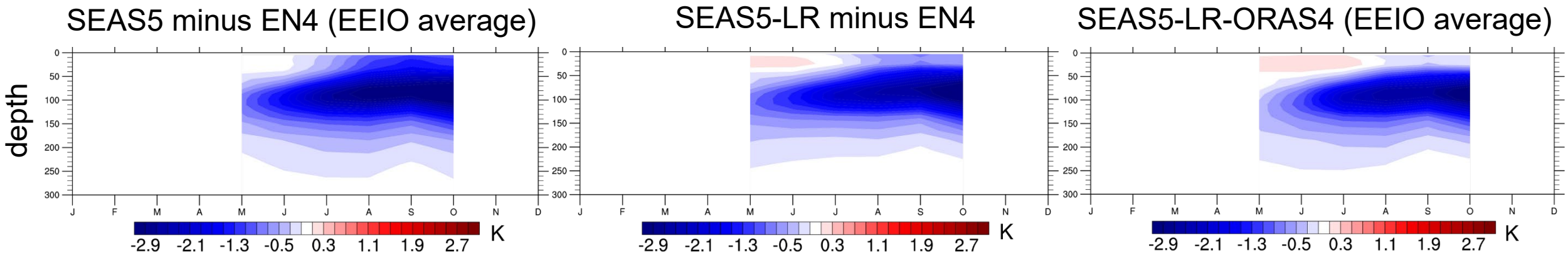

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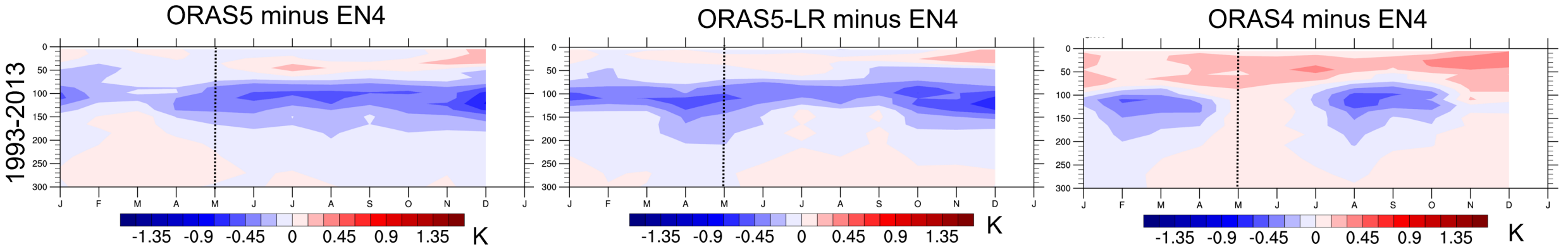
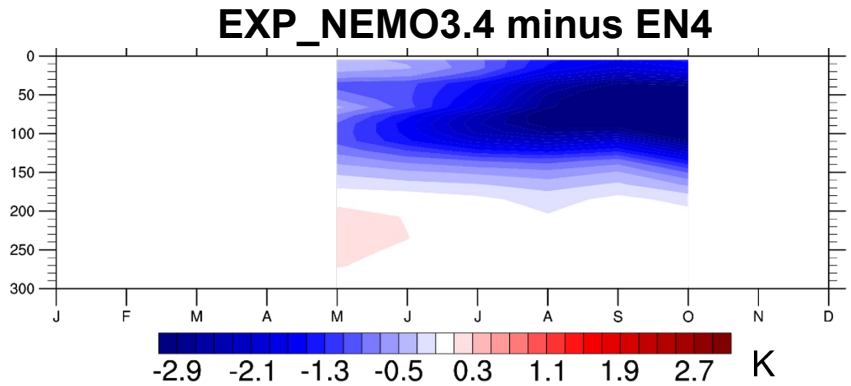


Cold regime errors: role of ocean forecast model

Experiment name	Description
EXP_NEMO3.4	Coupled forecasts with NEMO3.4 model (NEMO3.4 ICs)
EXP_NEMOX	Coupled forecasts with NEMOX model (NEMOX ICs)



EEIO averages

Cold regime errors: role of ocean forecast model

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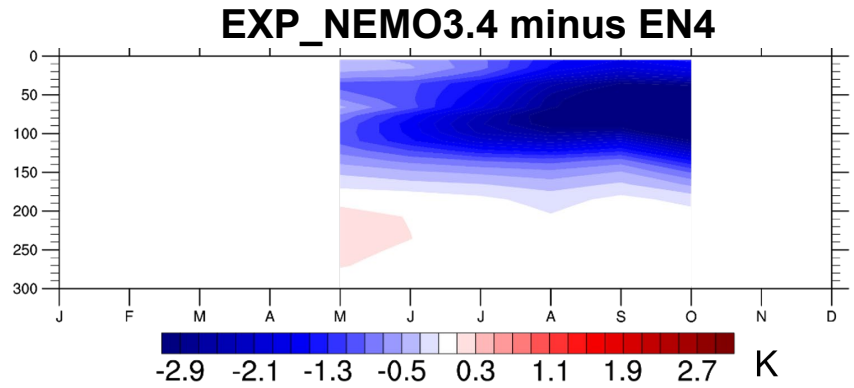
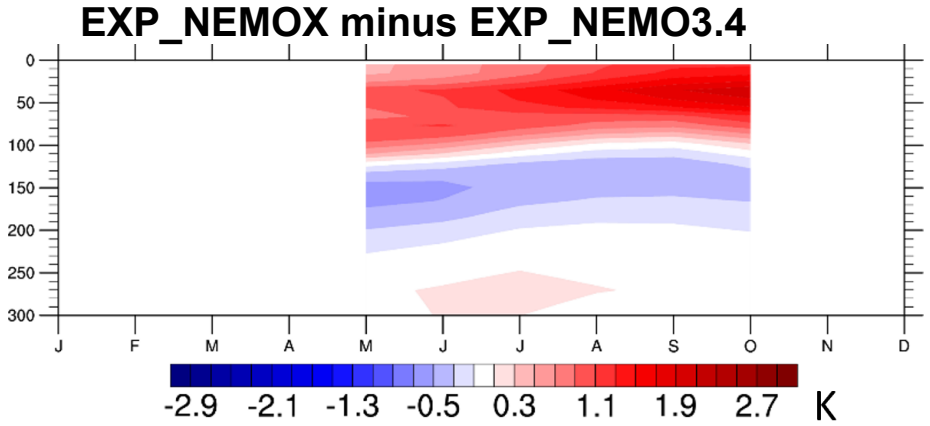
- Seasonal forecasting experiments using development version of NEMO (EXP_NEMOX) produce warmer EEIO compared to similar NEMO3.4 experiments (EXP_NEMO3.4)





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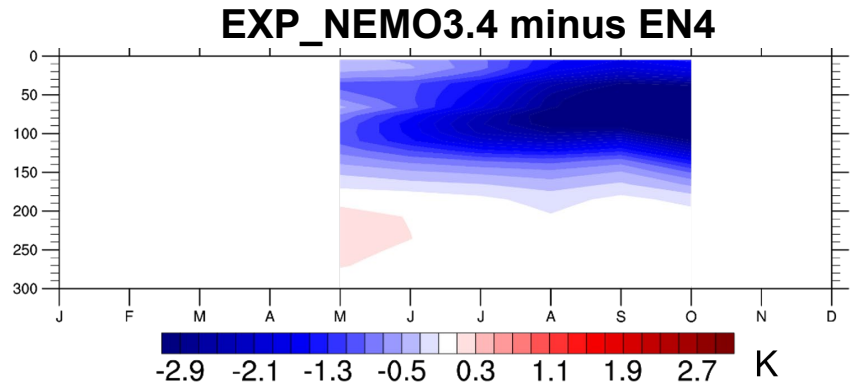
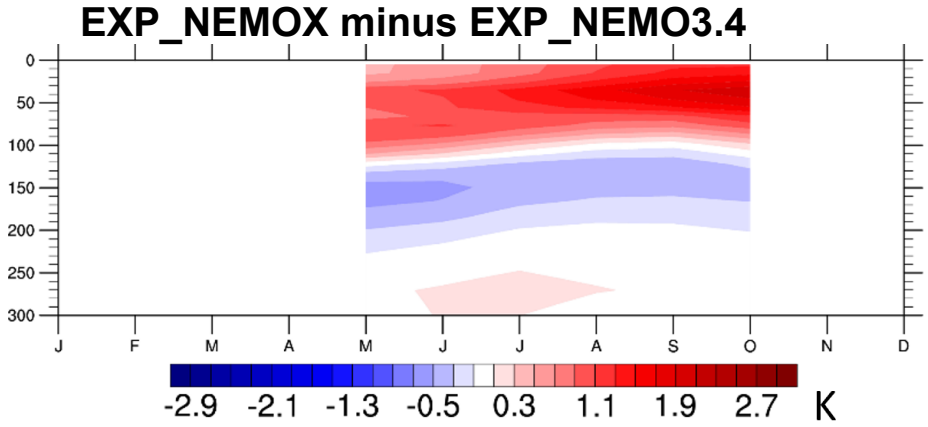
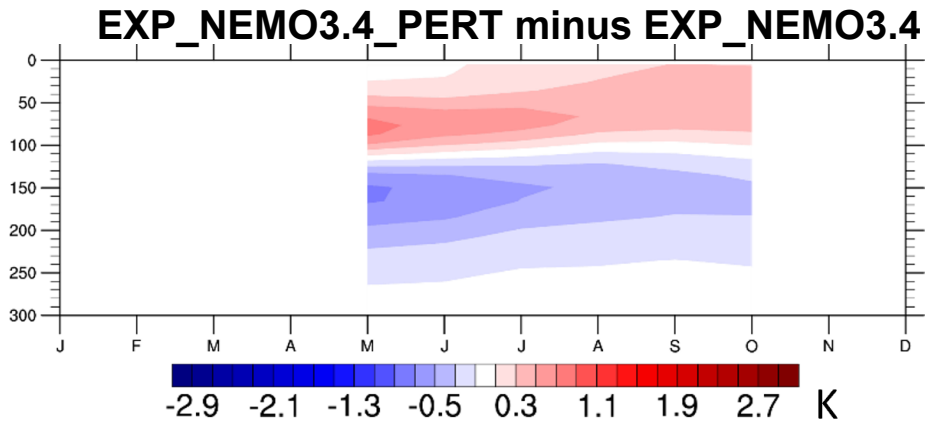
EXP_NEMOX	Coupled forecasts with NEMOX model (NEMOX ICs)
EXP_NEMO3.4_PERT	As EXP_NEMO3.4, but with NEMOX warm perturbation of ICs in EEIO

- Seasonal forecasting experiments using development version of NEMO (EXP_NEMOX) produce warmer EEIO compared to similar NEMO3.4 experiments (EXP_NEMO3.4)
- NEMOX-derived warm perturbation added to ICs of NEMO3.4 forecasts (EXP_NEMO3.4_PERT) gets damped out during forecast
→ ocean model plays an important role in shaping the EEIO also in forecast mode



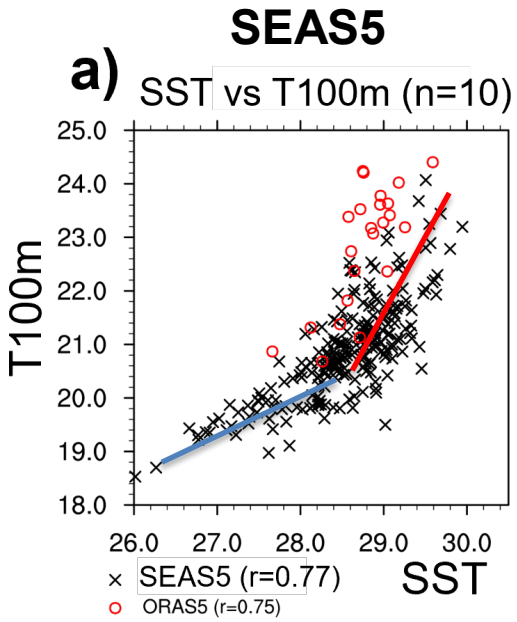




EEIO averages

Cold regime errors: role of ocean ICs

- Two states of thermocline:
  1) Deep thermocline and warm SSTs (warm regime) → weak SST sensitivity to thermocline (wind) changes
  2) Shallow thermocline and cold SSTs (cold regime) → high SST sensitivity to thermocline (wind) changes
- SEAS5 enters cold regime with shallow thermocline too frequently



EEIO averages

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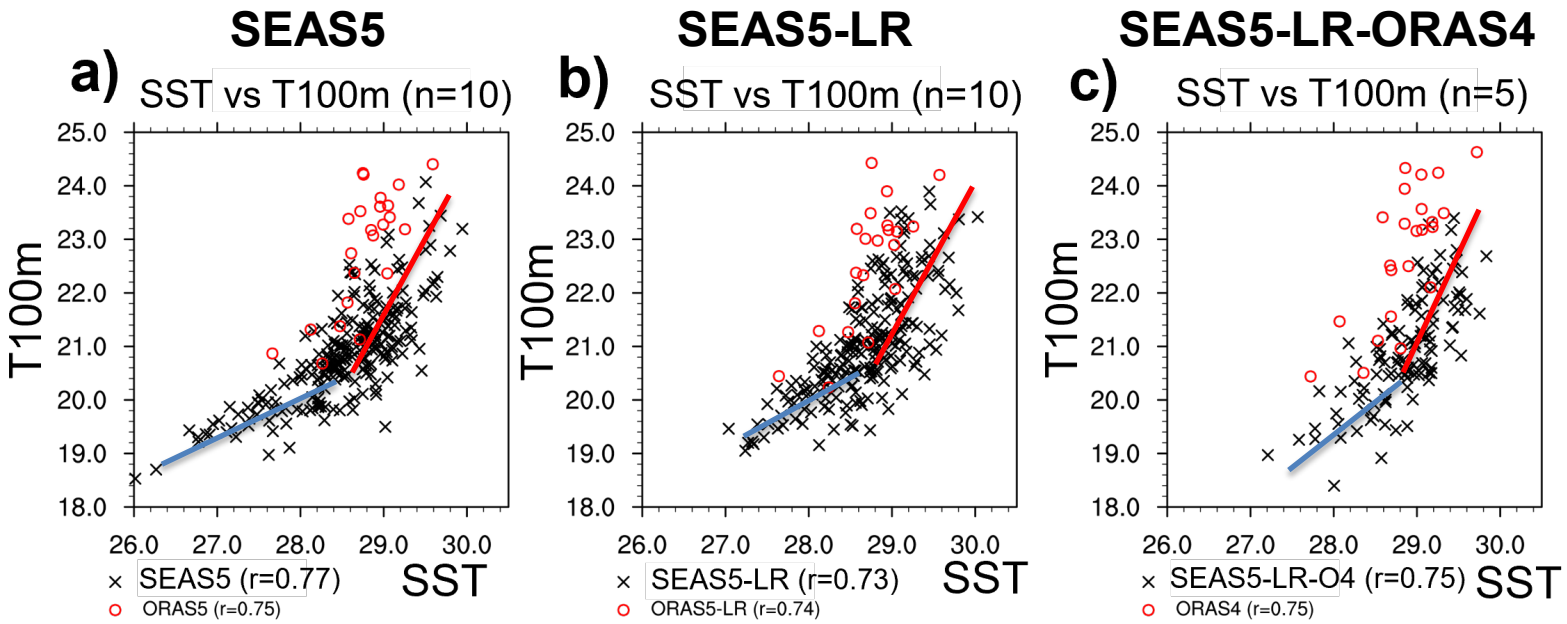
- SEAS5 enters cold regime with shallow thermocline too frequently
- Less clear distinction between regimes when using ORAS4 ICs



EEIO averages

Key points

- **UGROW as a whole: not all errors are easily identifiable in short fc/assimilation.** Do we need models for error propagation?

- **Warm regime errors are of atmospheric nature:**
  → Easterly wind bias develops within first few days of forecast
  → Easterly wind bias more pronounced for warm EEIO SST anomalies,despite OK precipitation (and local diabatic heating) response
  → Observed SST runs show similar wind errors, suggesting biased SST/wind/precip relationships and too stable easterly circulation in the atmospheric model

- **Cold regime errors are of oceanic nature:**
- Easterly wind bias acts to develop a strong cold SST bias in the EEIO in boreal summer
  → Oceanic errors sensitive to ocean resolution: less marked when using low-resolution ORAS5 as ICs
  → Oceanic errors sensitive to ocean model used for ICs: more marked when using ORAS5 (NEMO3.4; with a too shallow thermocline) instead of ORAS4 ICs (NEMO3.0)
  → Amplification or damping of ocean IC perturbation dependent on ocean forecast model

- **C3S systems have similar issues:**
- Results demonstrates the delicate atmosphere-ocean balance in the EEIO that requires close monitoring in system development

Further reading: *Mayer, M., M. A. Balmaseda, S. Johnson, L. Magnusson, C.D. Roberts, H. Zuo (2022). Outcomes from UGROW-IO: Forecast errors in the Eastern Indian Ocean across lead times, ECMWF Tech Memo 898.*