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Surface marine heatwave prediction skill in the Canadian Seasonal to Inter-annual Prediction System (CanSIPS)

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Canada

MHWs: Extensive Ecological Impacts

Northeast Pacific 2013-2016: “The Blob”

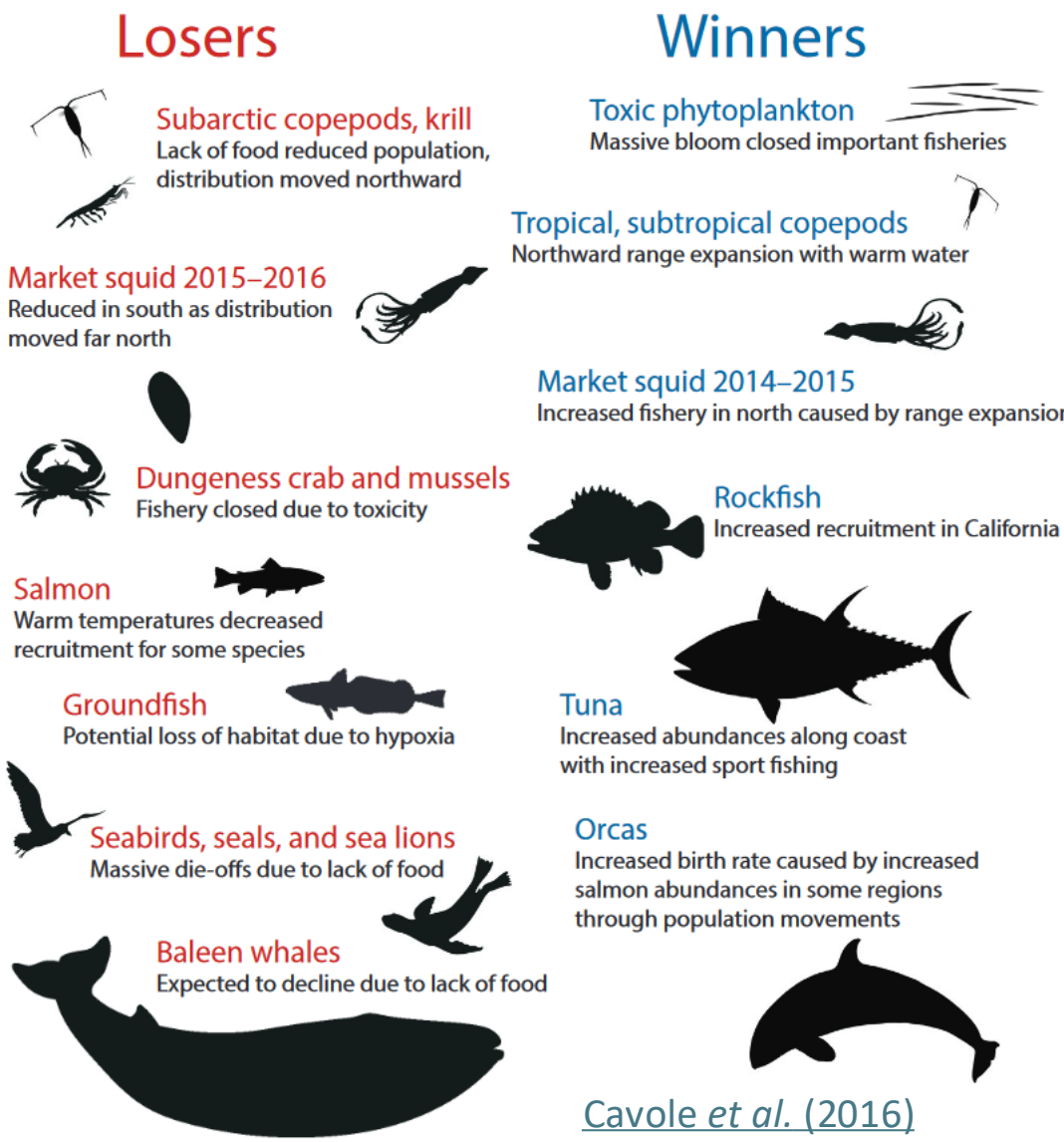
Biological Impacts of the 2013–2015 Warm-Water Anomaly in the Northeast Pacific

Winners, Losers, and the Future

- **Species shifts (tropical copepods, pelagic red crabs, tuna; tropical mackerel expanded to Vancouver Island)**
- **Reductions in cold-water copepods impacted coho salmon and Alaskan pollack**
- **Record-breaking 2015 harmful algal bloom (*Pseudo-nitzschia*, domoic acid, amnesic shellfish poisoning; additional species associated with paralytic and diarrhetic shellfish poisoning)**
- **Fisheries closures**
- **Marine mammal and seabird strandings**

By Letícia M. Cavole, Alyssa M. Demko, Rachel E. Diner, Ashlyn Giddings,

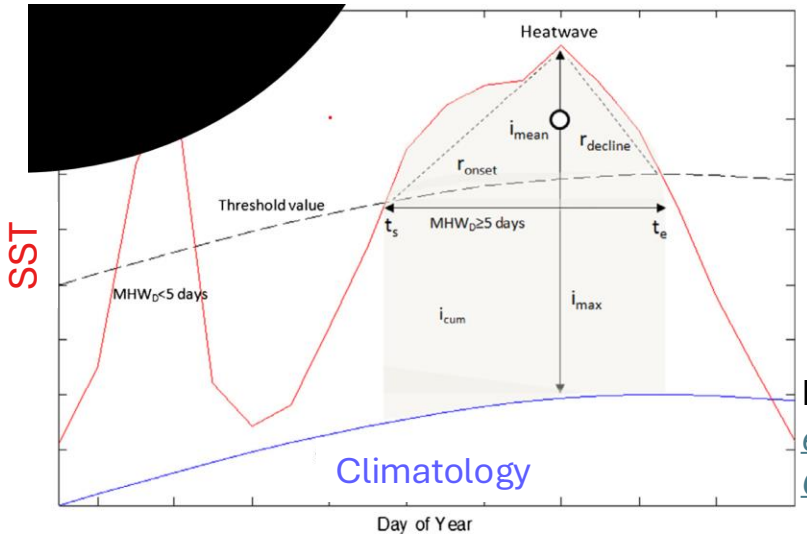
ABSTRACT. A large patch of anomalously warm water (nicknamed “the Blob”) appeared off the coast of Alaska in the winter of 2013–2014 and subsequently



Cavole *et al.* (2016) *Oceanography* Figure 5

MHW Diagnosis in ECCC's CanSIPS: Canadian Seasonal to Inter-annual Prediction System

- Starting from monthly SST predictions, following **Jacox et al. (2022)** and **Hobday et al. (2016)**, over 1991-2020 analysis period
- SST anomalies relative to lead-dependent climatology
- 1991-2020 trend removed
- climatological 90th percentile SST anomaly is estimated over centered 3-month windows
- Evaluate skill in CanSIPS referenced to NOAA OISSTv2.1



90th %ile Threshold

Figure from Hobday *et al.* (2016) *Prog. Oceanogr.*

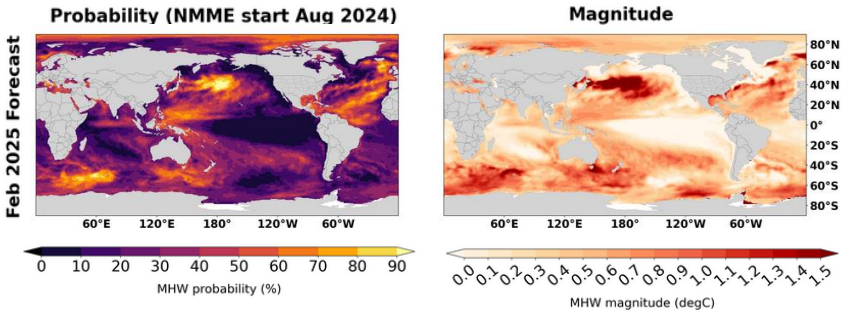
OISSTv2.1: Huang *et al.* (2020) Journal of Climate

Global seasonal forecasts of marine heatwaves

Michael G. Jacox, Michael A. Alexander, Dillon Amaya, Emily Becker, Steven J. Bograd, Stephanie Brodie, Elliott L. Hazen, Mercedes Pozo Buil & Desiree Tommasi

Nature **604**, 486–490 (2022) | Cite this article

NOAA MHW forecast



Shifting baseline

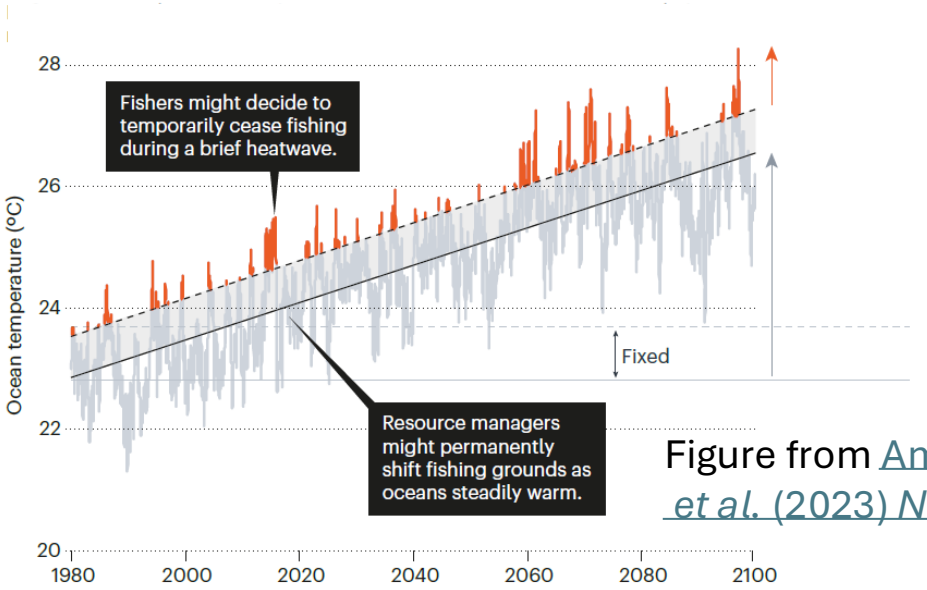
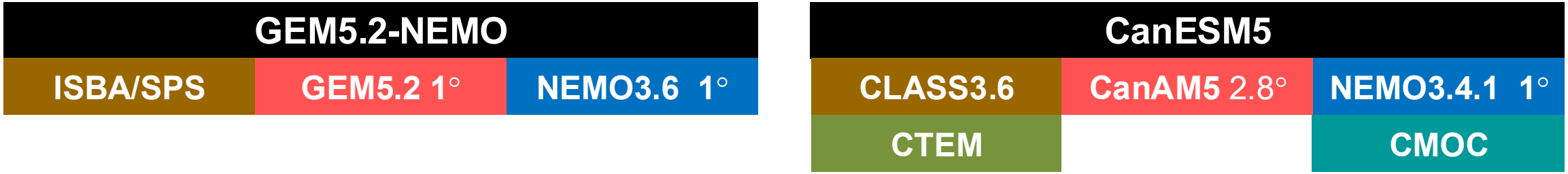


Figure from Amaya *et al.* (2023) *Nature*

CanSIPSv3: Canadian Seasonal to Inter-annual Prediction System

- 2 coupled atmosphere-ocean-land models



- Forcing, initialization, ensemble generation and online atmosphere/ocean bias correction for v3 described in Diro *et al*. (2024, technical note)

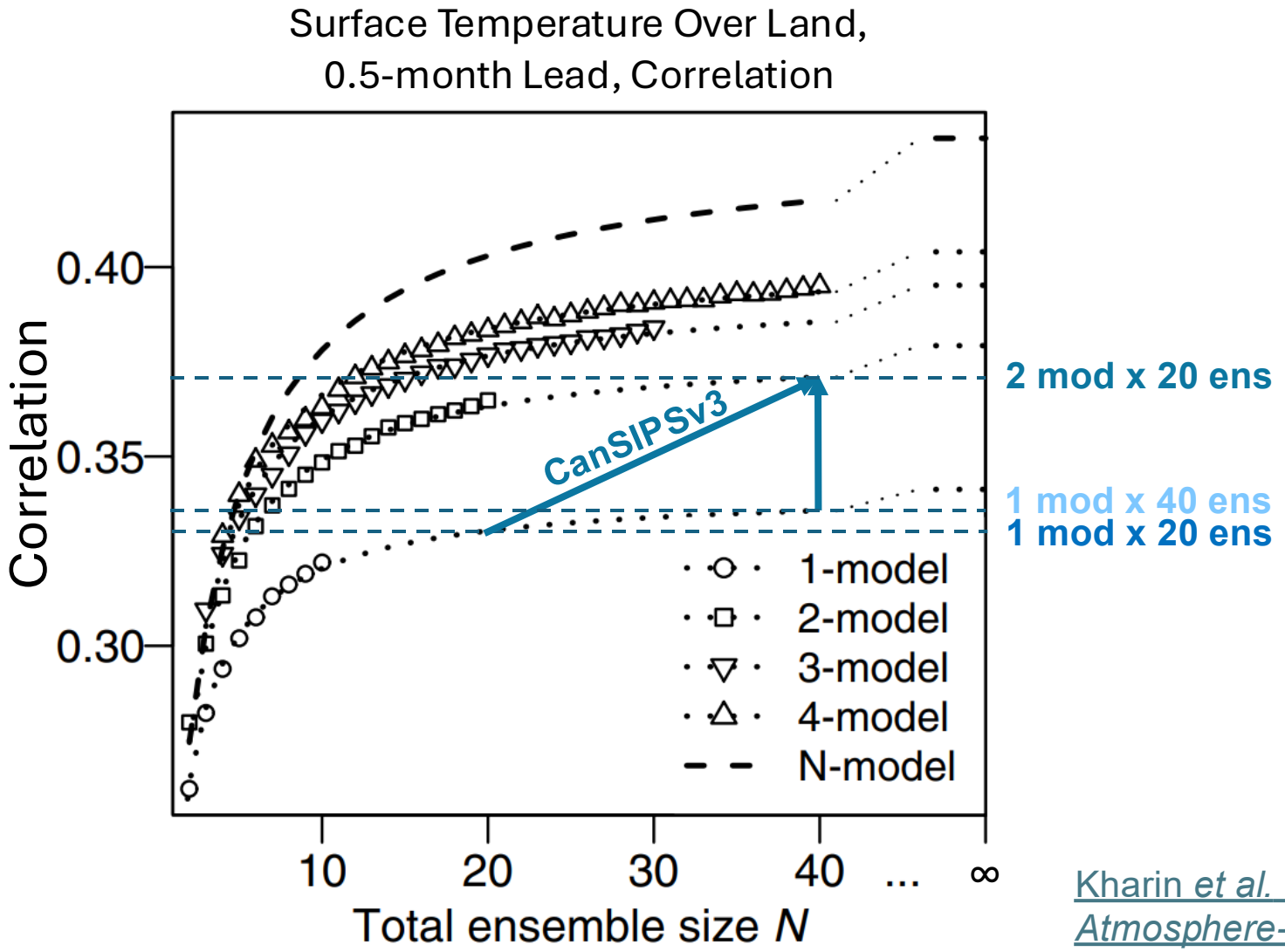
GEM5.2-NEMO	Hindcast	Forecast
Atmosphere	ERA5	GEPS
Ocean T,S,U,V,SSH	ORAS5	GIOPS
Forcing	WMO GHG Bulletin etc.	2023 GHG

CanESM5	Hindcast	Forecast
Atmosphere	ERA5	GDPS analysis
Ocean T,S	OISSTv2.1, ORAS5	GDPS, GIOPS
Forcing	CMIP6 historical, SSP2-45	SSP2-45

- 30-year seasonal hindcast: 20 Ensemble members for each model initialized near the start of each month from 1991 to 2020

Multi-Model Approach

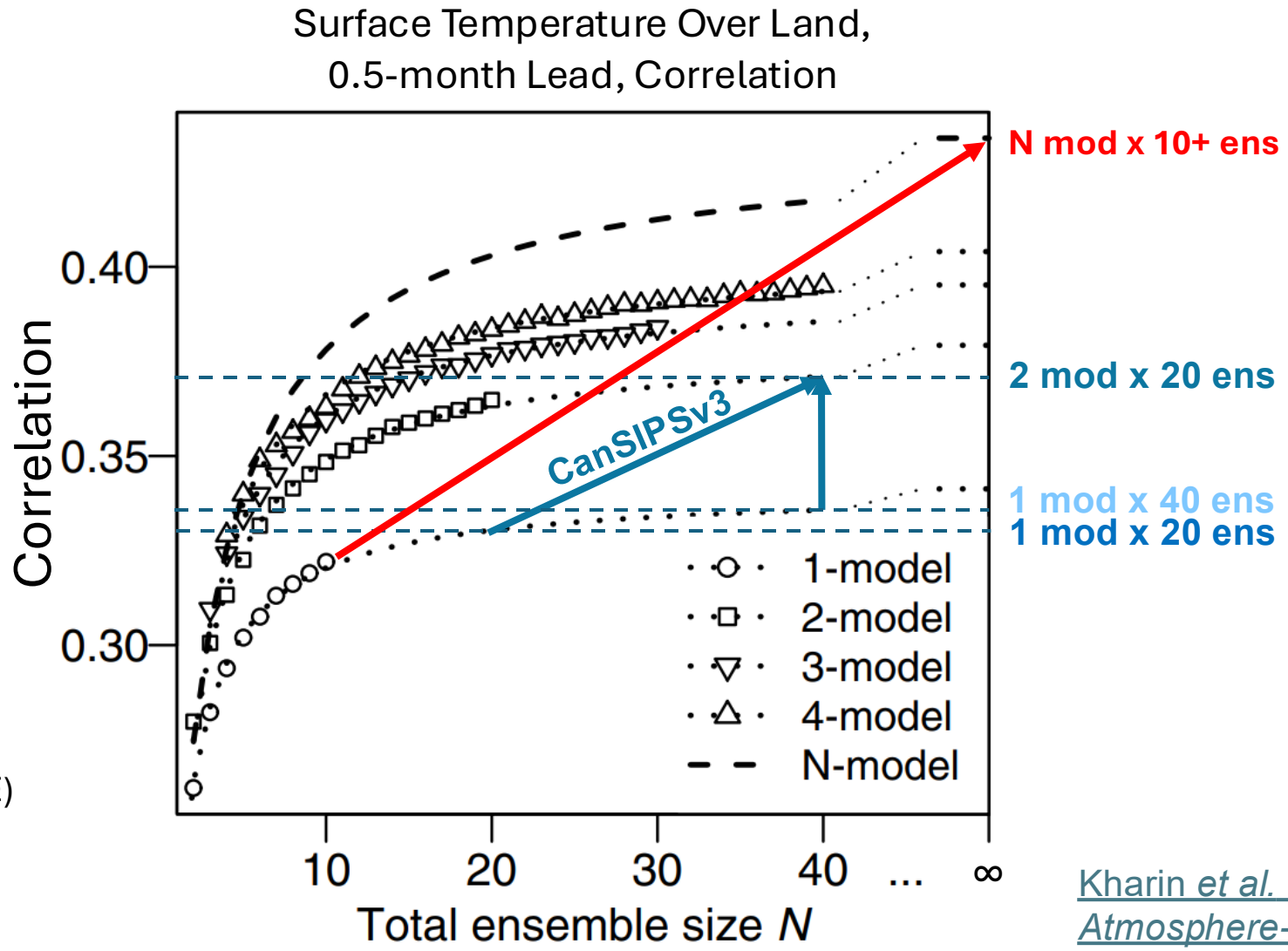
- ECCC leverages skill advantage of N ensemble members from each of 2 models, as compared to 2N ensemble members from 1 model



Kharin *et al.* (2009) *Atmosphere-Ocean*

Multi-Model Approach

- ECCC leverages skill advantage of N ensemble members from each of 2 models, as compared to 2N ensemble members from 1 model
- NMME aggregates numerous models from different centers, each having 10+ ensemble members



North American Multi-Model Ensemble (NMME)
Becker *et al.* (2022) *BAMS*
Available from NCEI/NOAA

Kharin *et al.* (2009) *Atmosphere-Ocean*

Skill metric: Symmetric Extremal Dependence Index

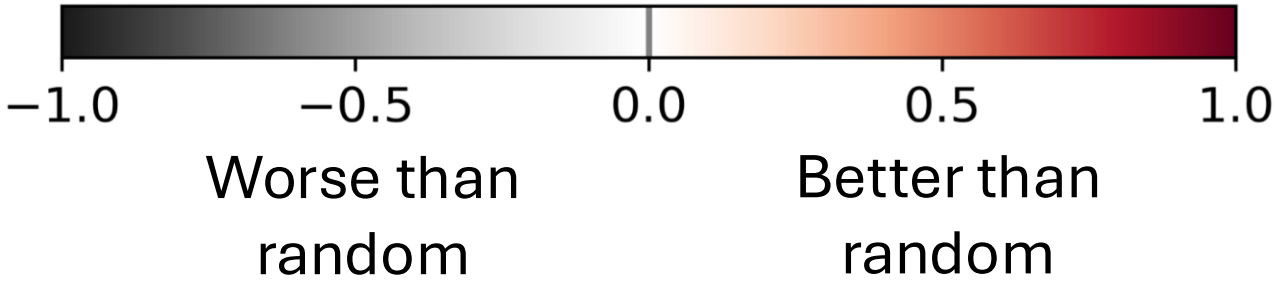
(SEDI, Ferro and Stephenson, 2011; used by Jacox *et al.*, 2022)

$$\mathrm{SEDI} = \frac{\log F - \log H - \log(1-F) + \log(1-H)}{\log F + \log H + \log(1-F) + \log(1-H)}$$

H= hit rate = correctly forecast positives / observed positives = TP/(TP+FN)

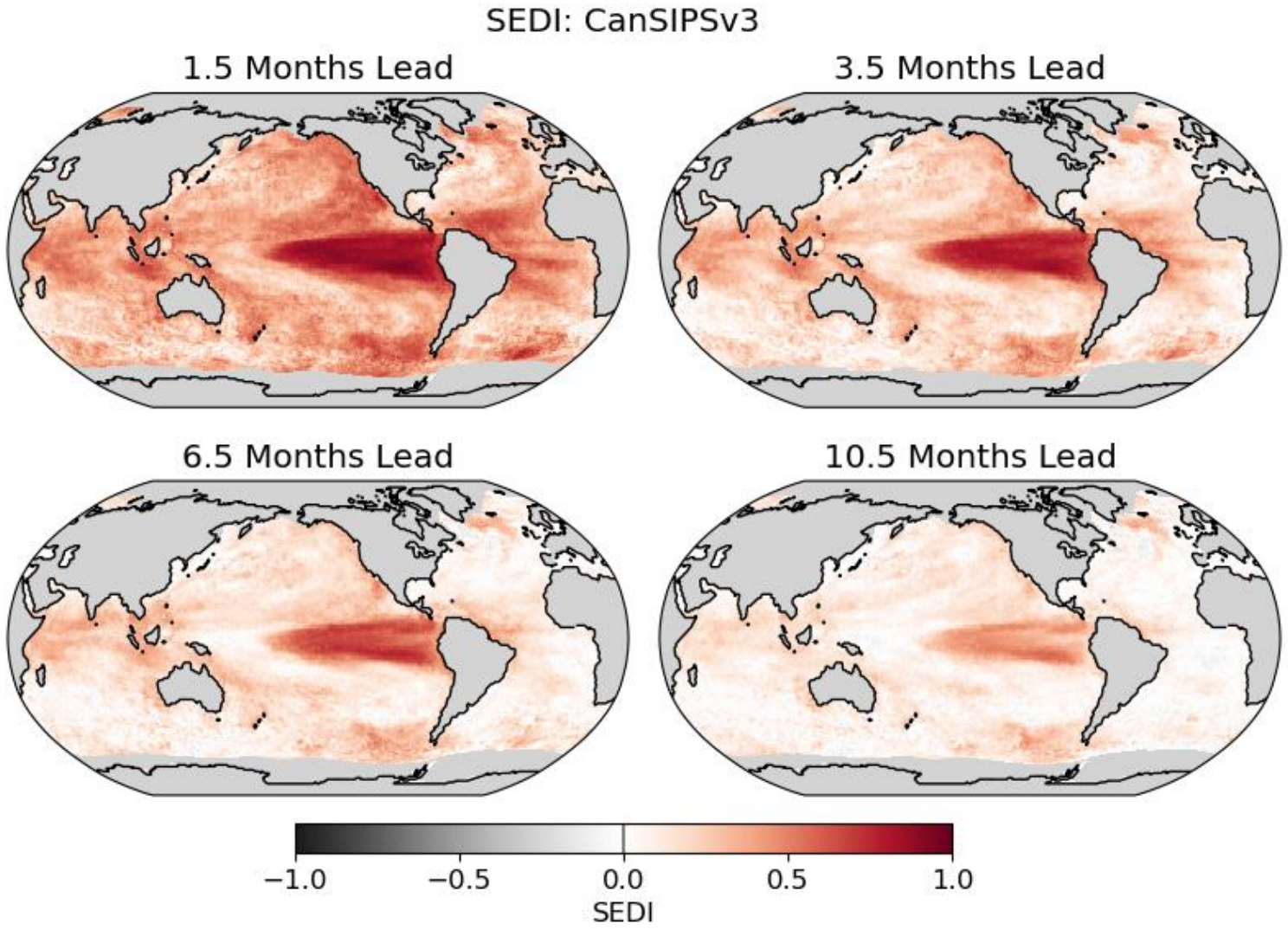
F= false alarm rate = incorrectly forecast positives / observed negatives = FP/(FP+TN)

Purpose: skill estimate for **rare binary events** (base-rate independent)



Ferro and Stephenson (2011) *Weather and Forecasting*

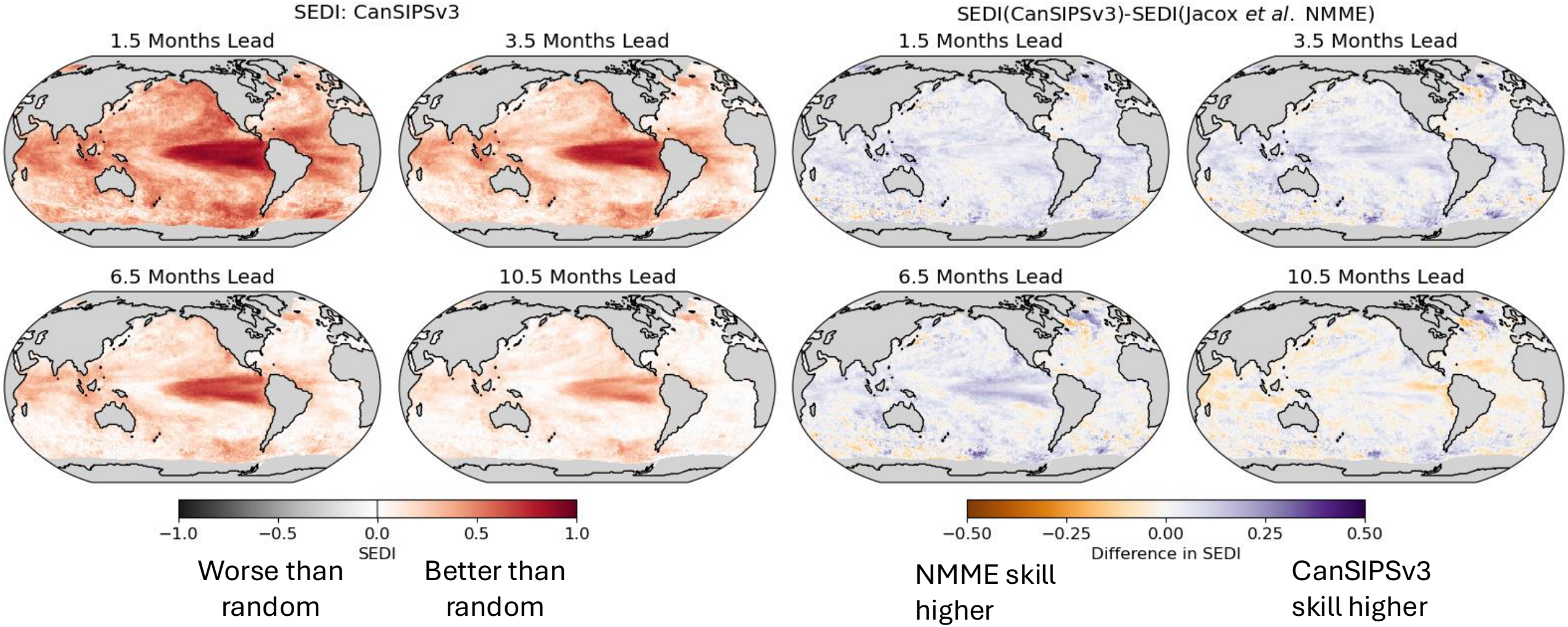
CanSIPSv3 Skill



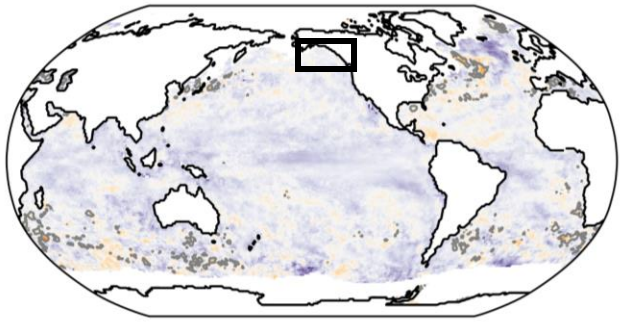
- Lead: time from initialization to forecast target date
- Skill is highest in the ENSO-influenced Eastern Equatorial Pacific
- MHW skill in the Western Equatorial Pacific has increased relative to previous CanSIPS versions (not shown)

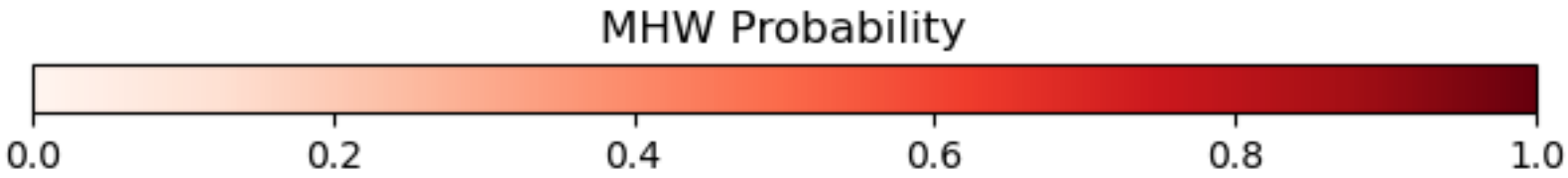
CanSIPSv3 Skill and Comparison with Full NMME

- CanSIPSv3 has skill out to at least 10.5 months lead, particularly in the ENSO-influenced Eastern Pacific
- Outperforms the NMME at many locations globally out to at least 6.5 months lead

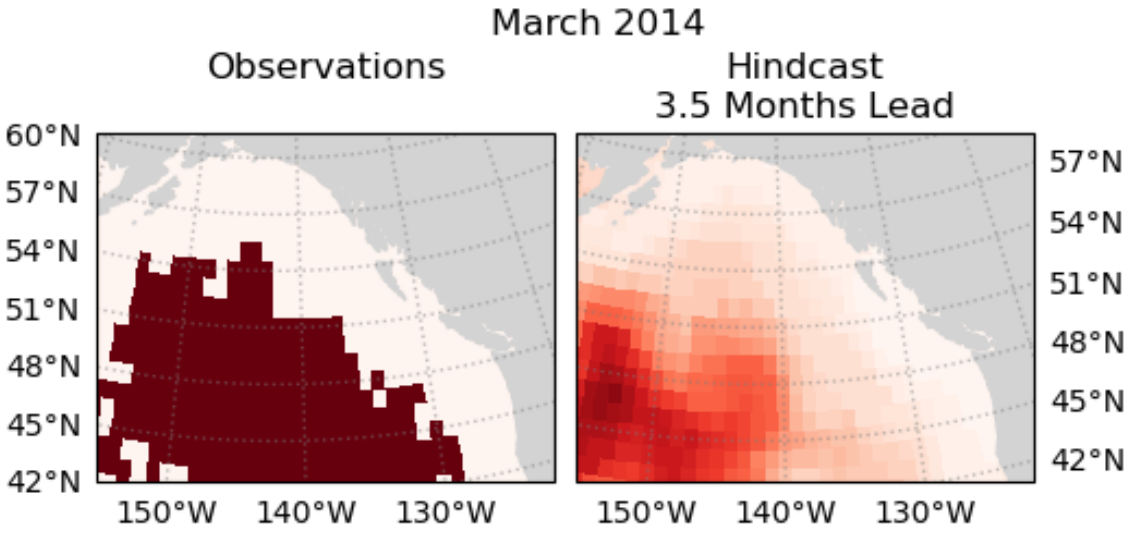


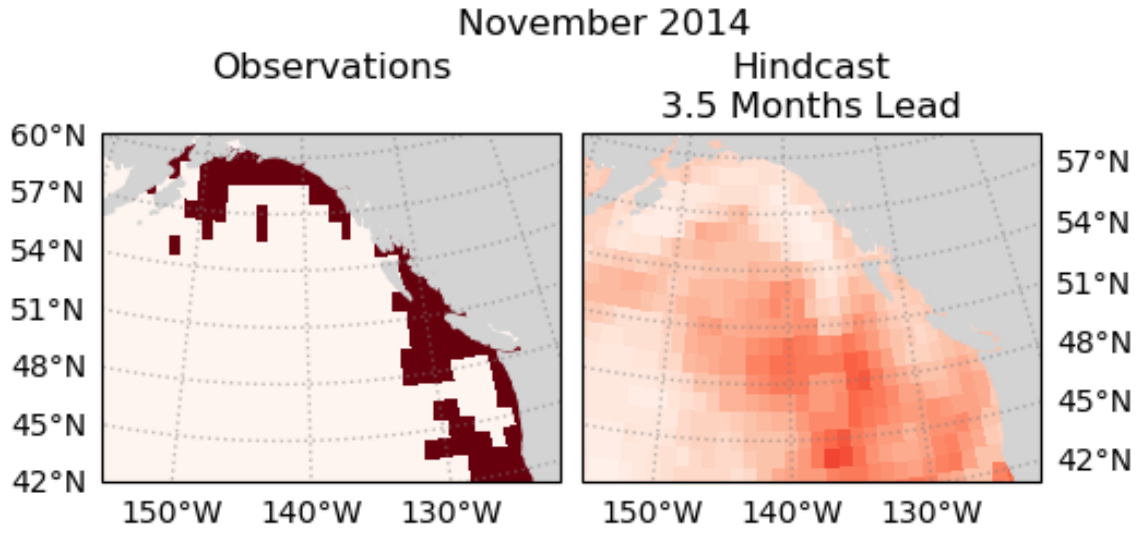
Northeast Pacific 2014: “The Blob”





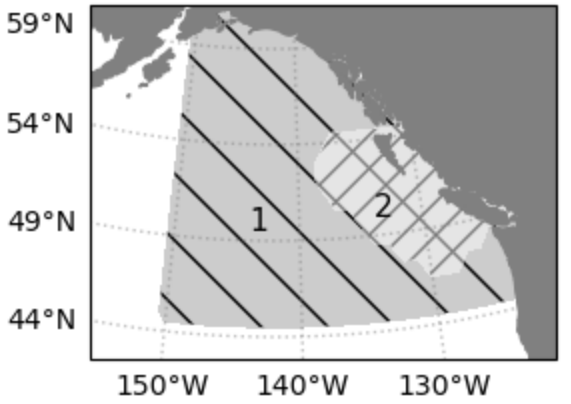
- Observations have only 1 realization, so probability is 0 (no MHW) or 1 (MHW)
- Forecasts have 40 ensemble members and probabilities are estimated by the “count method” as the fraction of members exhibiting MHW conditions

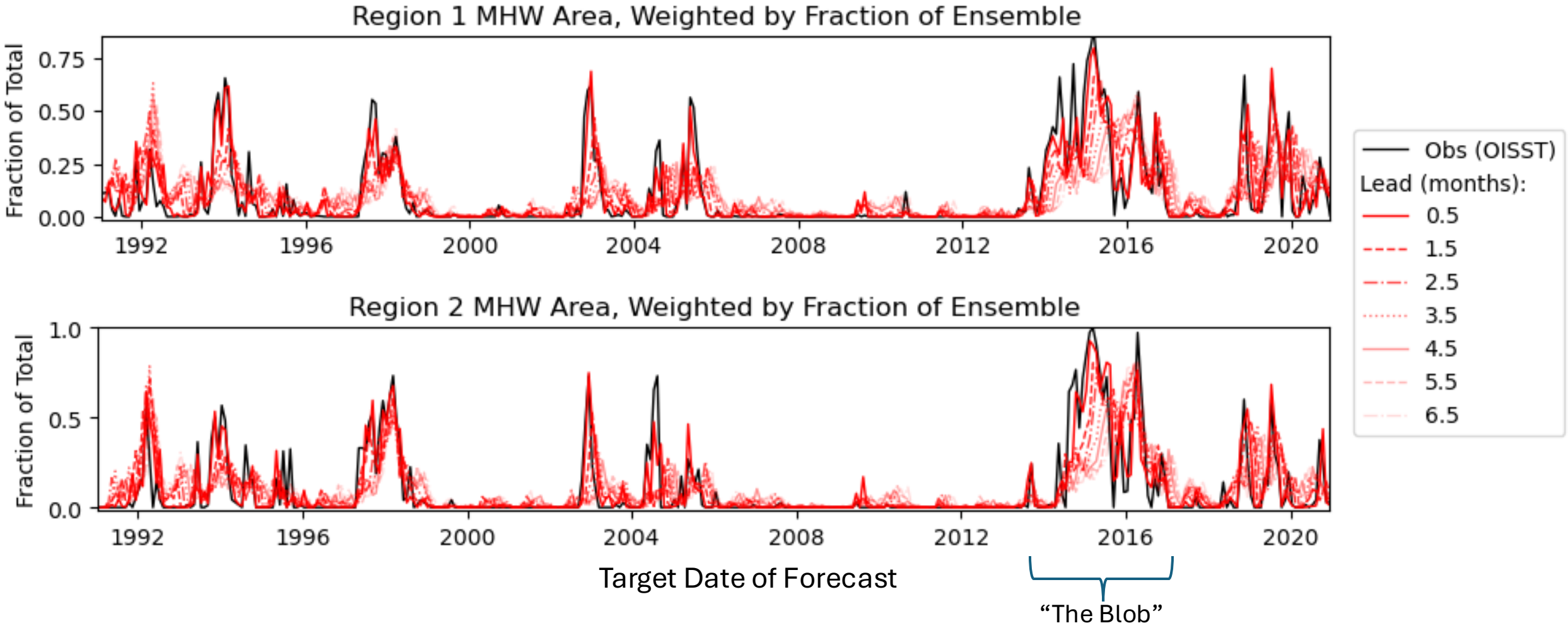




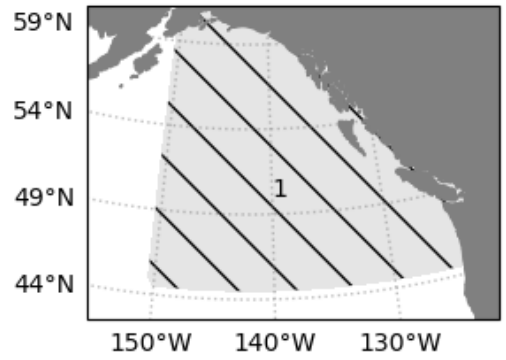
- Spatial agreement is stronger at some times than others
- MHW area (next slide) is estimated as the spatial integral of MHW probability (probability-weighted area)

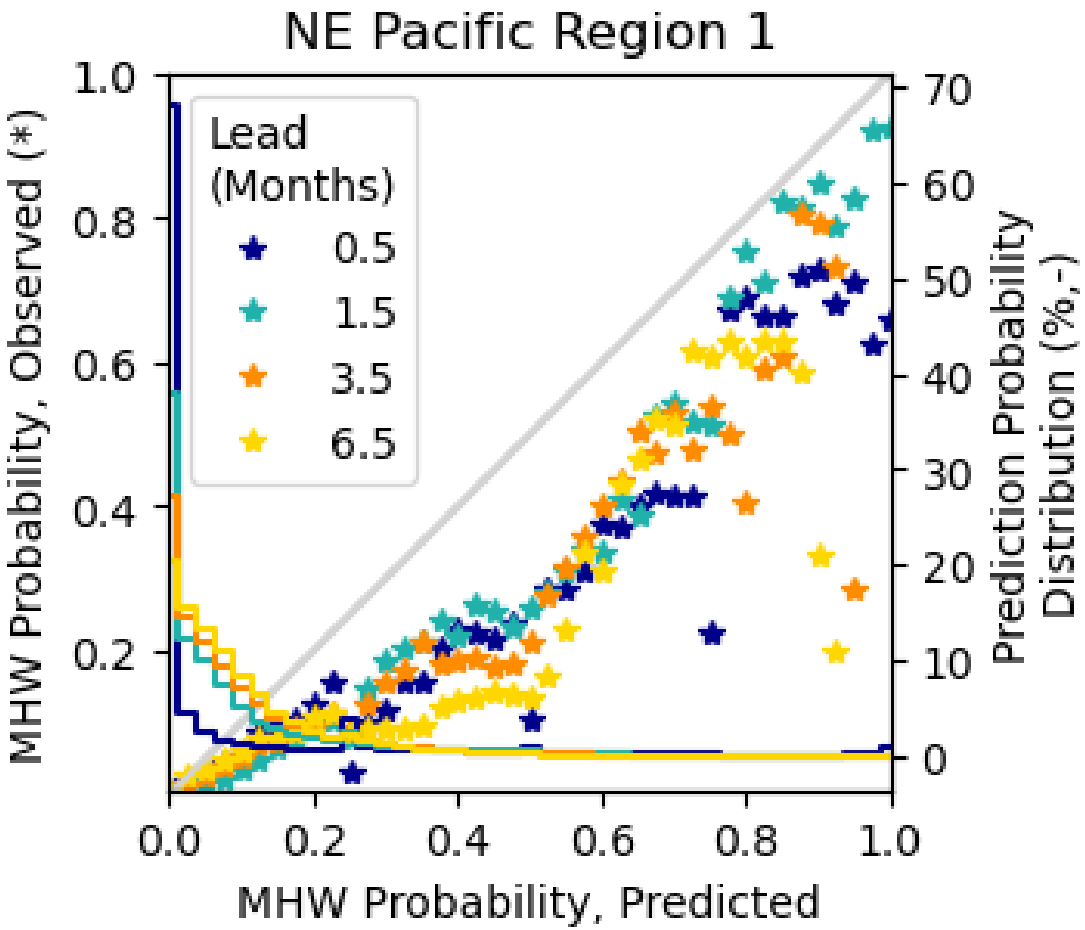
Northeast Pacific and Canada's West Coast

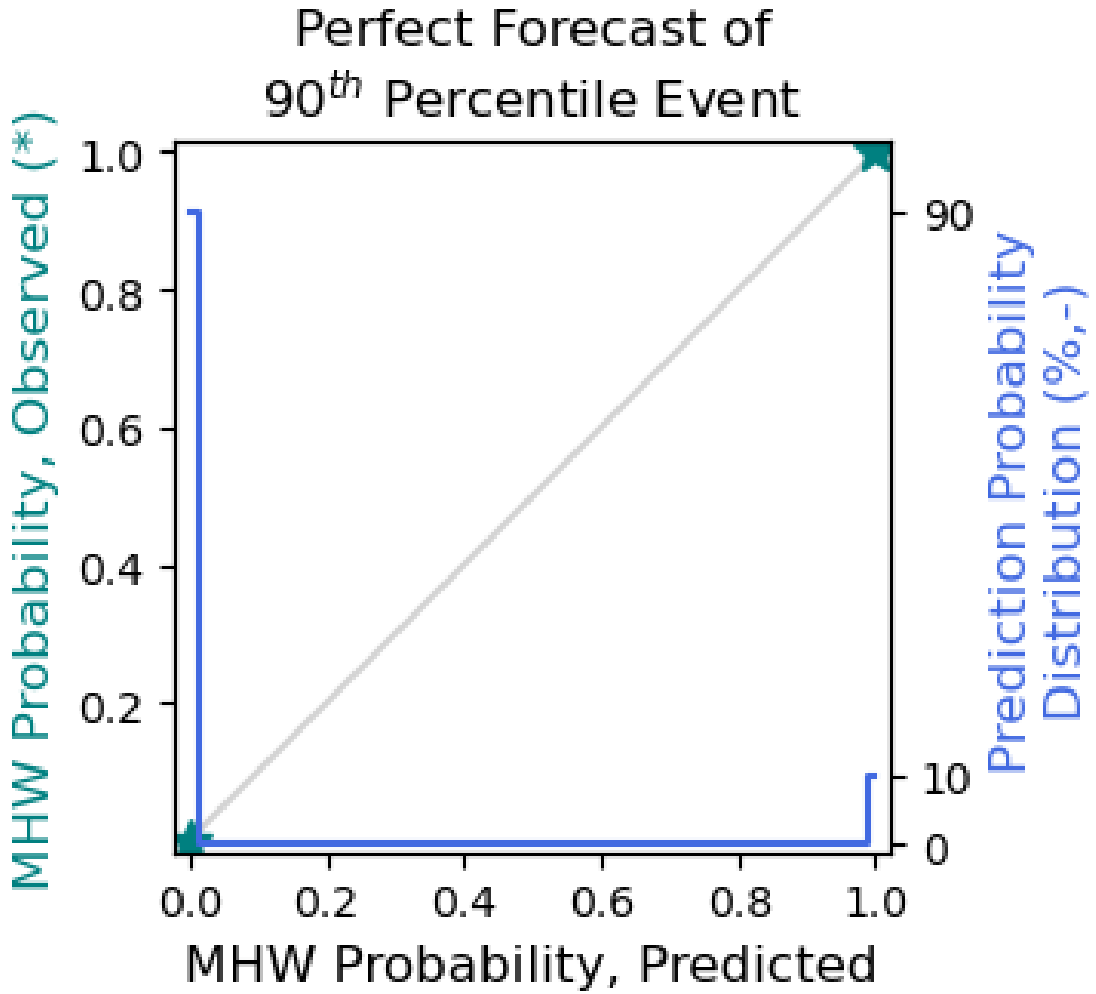




Northeast Pacific: Forecast Reliability



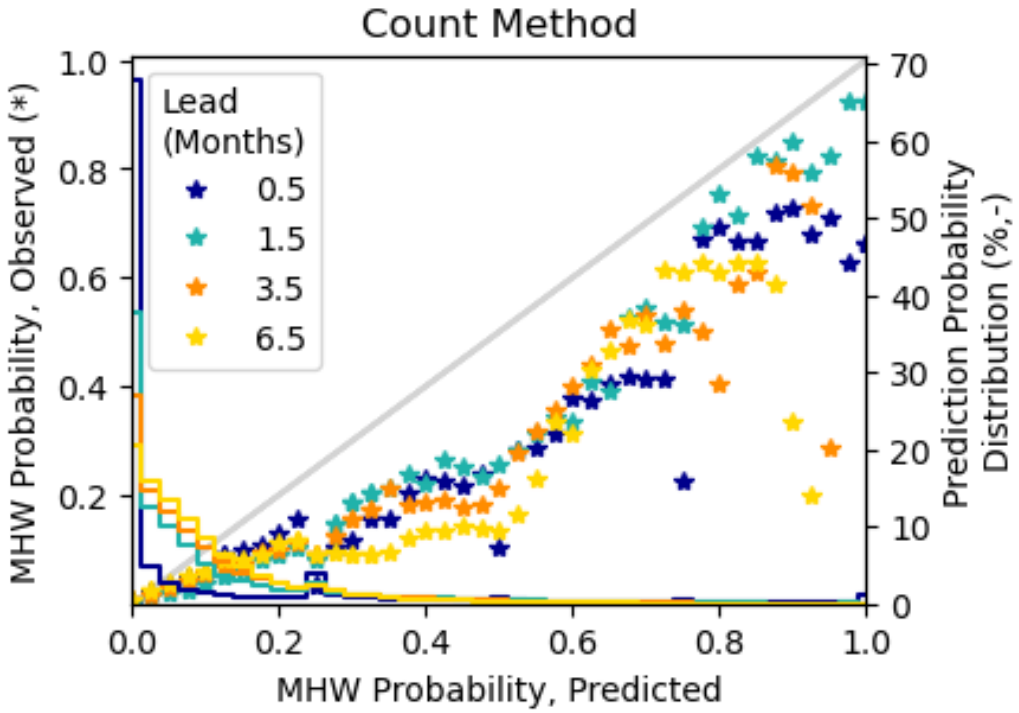


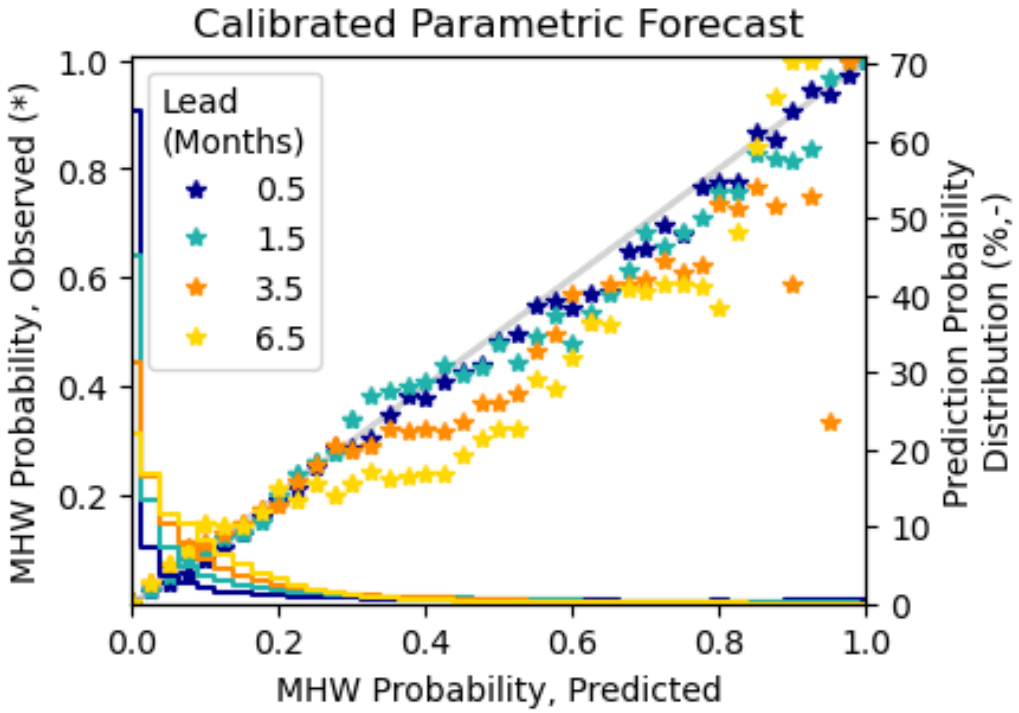


Calibrated Forecast Reliability for Northeast Pacific

Parametric forecast calibration (Kharin et al., 2017, *Monthly Weather Review*), implemented and run by Julia Velletta

- Fit a normal distribution to an ensemble of forecasts (for a given target date)
- Based on comparisons between observations and hindcast over a reference period, rescale the normal distribution parameters: mean and standard deviation
  - Subject to the constraint that the total observed variance matches the total forecast variance for a given month over the reference period
  - The continuous ranked probability score (CRPS) is minimized
- Probabilistic forecast—probability of exceedance of the 90th (or other) percentile—can then be calculated





Future Plans

- Further skill assessment and experimentation with calibration at daily/5-day/monthly scales
  - Look at performance of MHW predictions beyond 1991-2020 reference period
  - Extend analysis to seasonally ice-covered areas
- Development of a Canada-focused regional model domain is in progress at CCCma to be run at $1/12$ degree, and eventually to be used for downscaling of global forecasts
  - Local marine heatwave forecasts
  - Biogeochemical forecasts (acidification, low O_2, bloom timing, biomass)

Thank you