Environment and Climate Change Canada | Environnement et Changement climatique Canada

Seasonal ocean predictions for Canada: Progress and directions

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Canada

Outline:

Overview of Seasonal Ocean Prediction Development Activities in Progress within the Climate Modelling Research Division, Environment and Climate Change Canada

1) Skill of Marine Heatwave (Re)Forecasts based on version 3 of the Canadian Seasonal to Inter-annual Prediction System (CanSIPS)

2) Initial investigations into the suitability of biogeochemical simulations with the physical ocean state nudged toward reanalysis temperature and salinity fields as initial states for biogeochemical forecasts

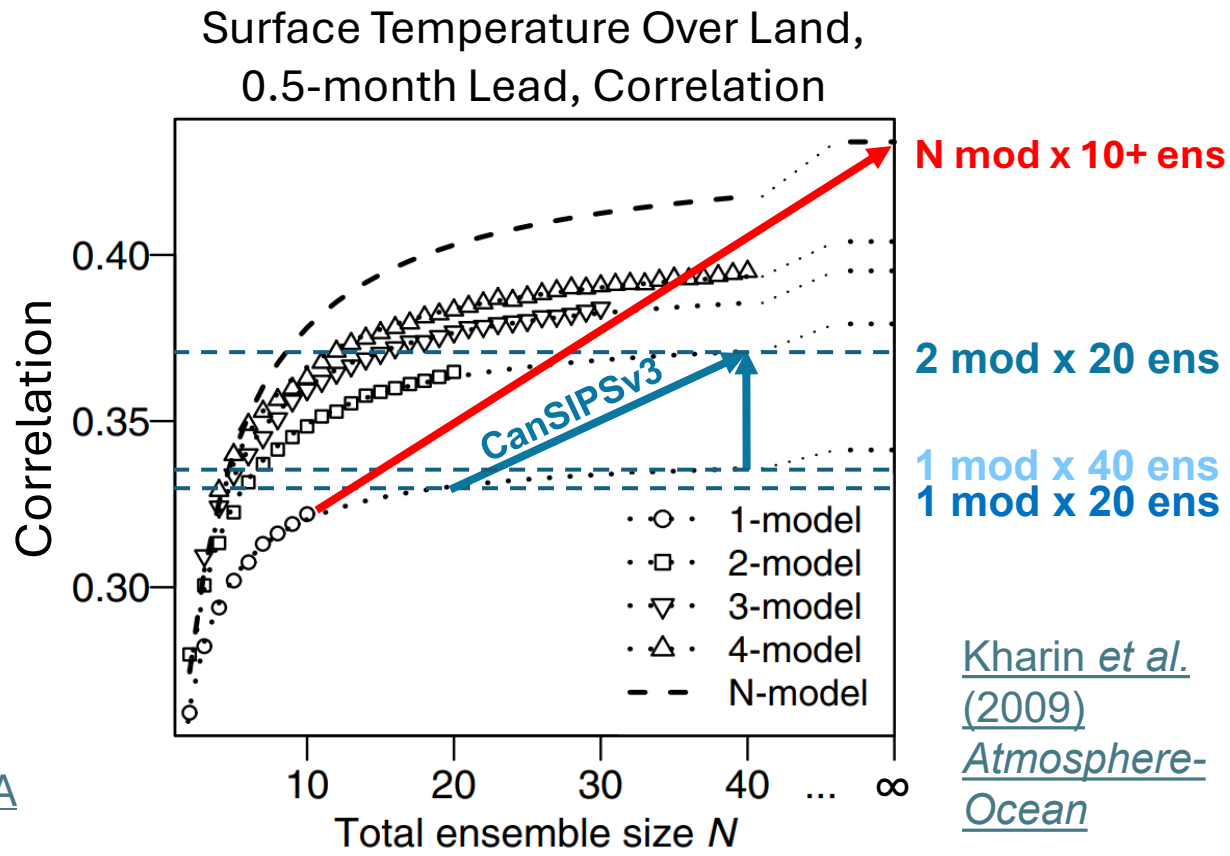
3) Plans to apply the Canadian Three-Oceans Downscaling System (CanTODS), currently under development at ECCC, to downscale CanSIPS predictions

ECCC's CanSIPS v3: Canadian Seasonal to Inter-annual Prediction System

- **2 coupled atmosphere-ocean-land models**: GEM5.2-NEMO (ISBA/SPS, GEM5.2 1°, NEMO3.6 1°) & CanESM5 (CLASS3.6, CTEM, CanAM5 2.8°, NEMO3.4.1 1°, CMOC)
- **Forcing, initialization, ensemble generation and online atmosphere/ocean bias correction** (Diro *et al.*, 2024, technical note)
- 30-year seasonal hindcast: **20 Ensemble members from each model** initialized near the start of each month from 1991 to 2020

Multi-Model Approach:

- ECCC: 2 models 20 ensemble members each
- NMME: numerous models from different centers, 10+ ensemble members per model



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

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

1) Marine Heatwave (MHW) Prediction

- Extreme events such as MHWs can impact marine ecosystems
  - Northeast Pacific - "The Blob" - Cavole *et al.* (2016) *Oceanography*:
    - species shifts
    - reduced cold-water copepods impacted coho salmon and Alaskan pollack harmful algal blooms,
    - fisheries closures, marine mammal & seabird strandings
- Approach: 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** (mitigating drift from observation-constrained initial state toward unforced model state)
  - **Trend removed** (for analyses shown here)
  - **90th percentile threshold** specific to time of year
- **Skill in CanSIPSv3** referenced to NOAA OISSTv2.1 (next slide)
- Demonstration of **parametric calibration** in Northeast Pacific (next + 1)
- Skill of **Pentadal (5-day) Predictions** compared to Monthly (next + 2)
- **Target: Canada-focused, skillful and reliable MHW forecasts**
  - Provide operational product to end-users in areas such as fisheries management, aquaculture, and beyond (in collaboration with H. Dosser, Canadian Centre for Climate Services)

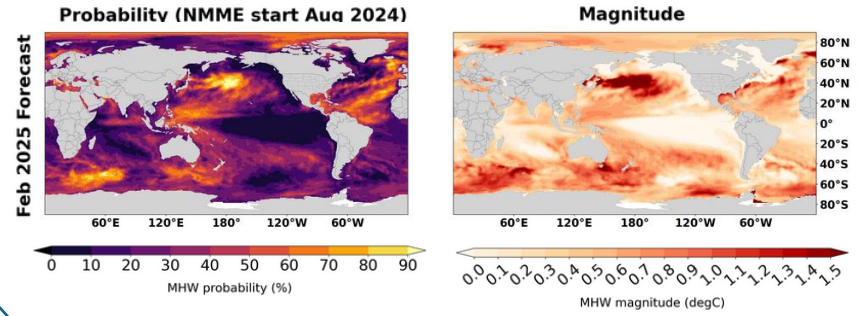
OISSTv2.1: Huang *et al.* (2020) Journal of Climate

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

Screen grab of NOAA PSL MHW forecast:



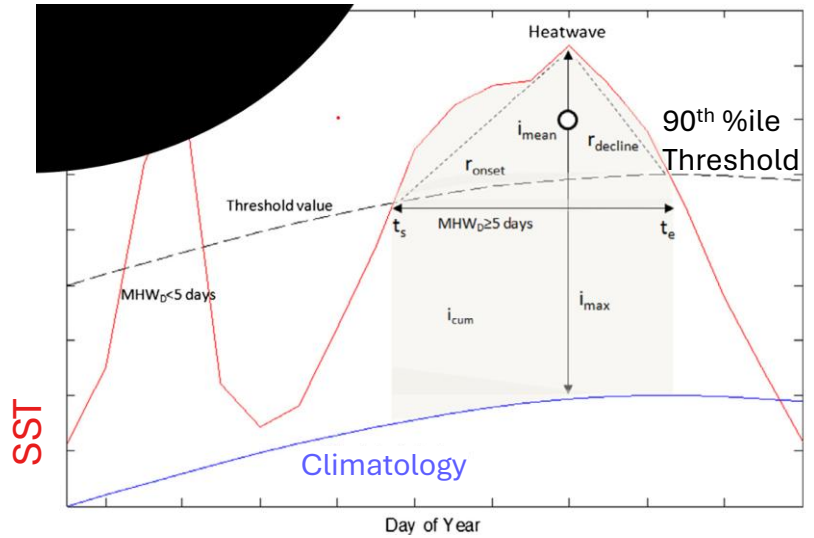
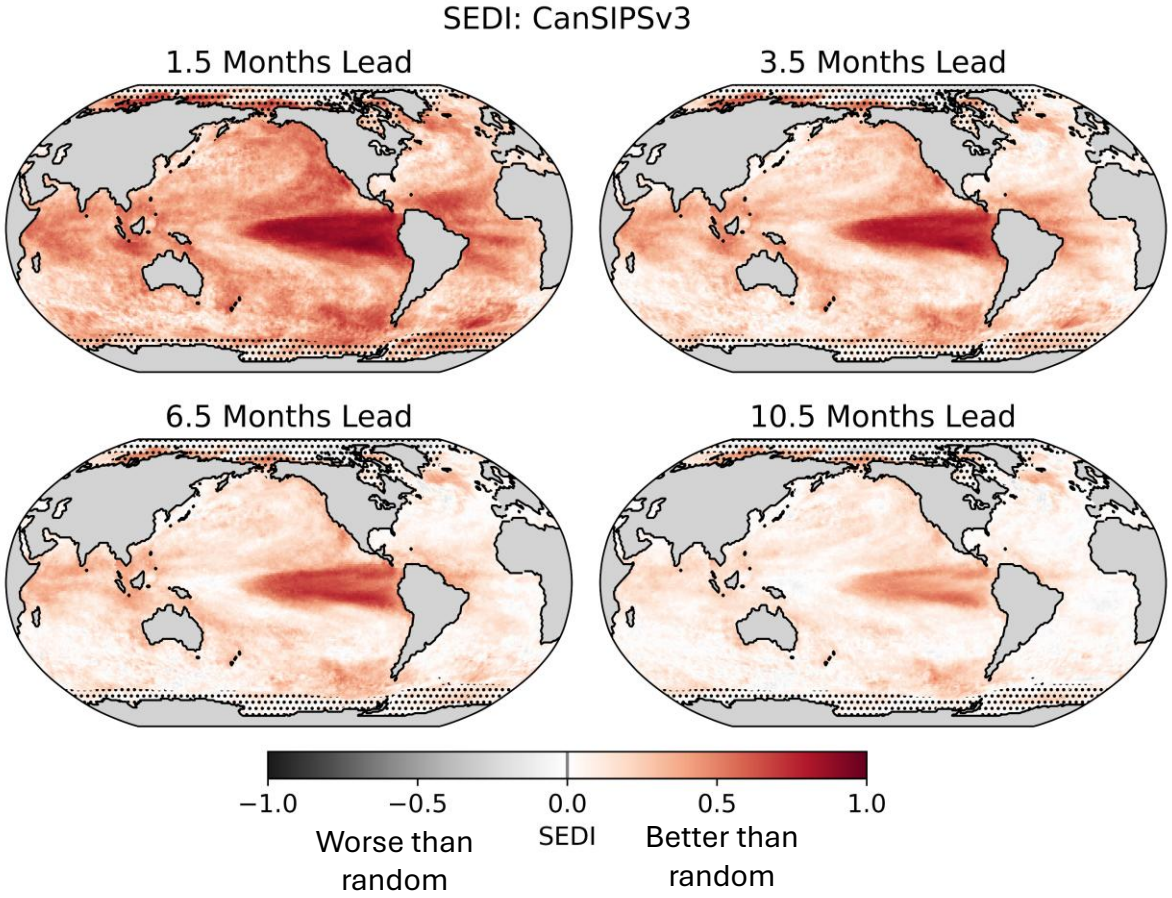
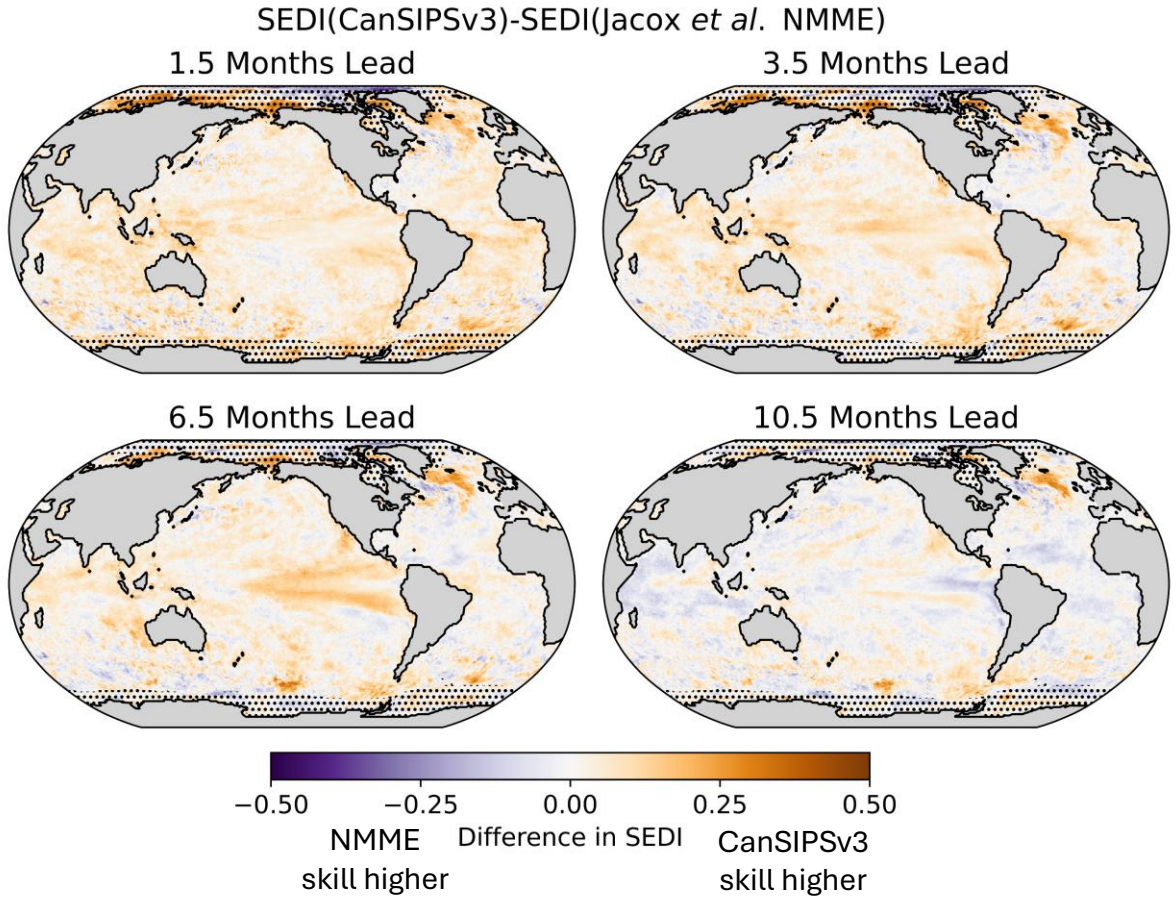


Figure from Hobday *et al.* (2016) *Prog. Oceanogr.*

Monthly CanSIPSv3 MHW Prediction Skill in Comparison to Full NMME*

* includes an earlier CanSIPS version

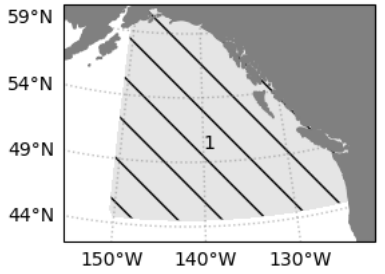




- Lead= time from initialization to forecast target date
- Skill is highest in the ENSO-influenced Eastern Equatorial Pacific
- MHW skill in the Western Equatorial Pacific increased relative to previous CanSIPS versions (not shown)
- CanSIPSv3 has skill out to at least 10.5 months lead, particularly in the ENSO-influenced Eastern Pacific

- CanSIPSv3 outperforms NMME at many locations globally out to at least 6.5 months lead
- We conclude the system is suitable for Canadian MHW prediction, particularly in the Northeast Pacific at a few months lead; proceed with further investigation

Calibrated MHW Forecast Reliability for the Northeast Pacific



$$\mathrm{CRPS}(P_f, P_0) = \int_{-\infty}^{\infty} [P_f(x) - P_0(x)]^2 dx$$

$P_f(x)$ = cumulative forecast distribution

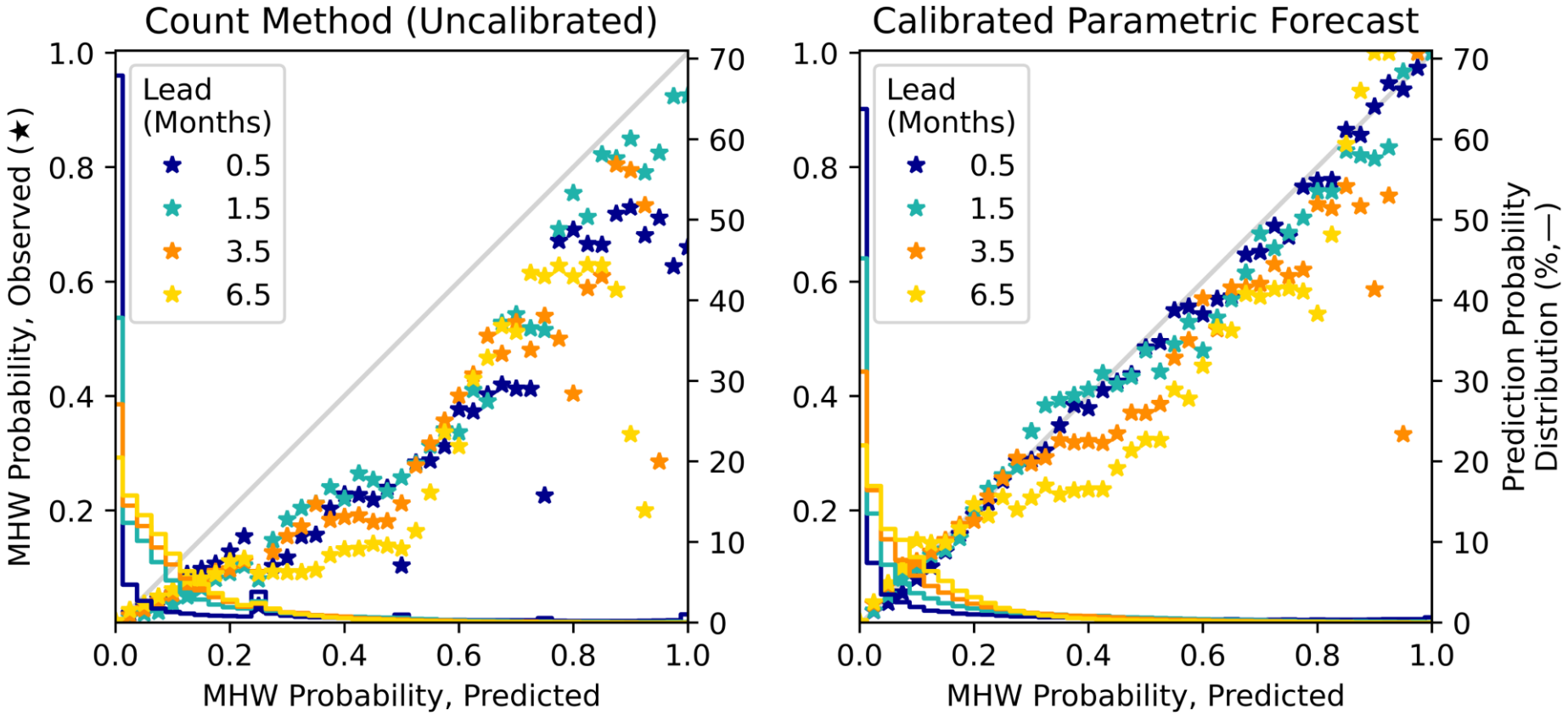
$P_0(x) = H(x - x_0)$ = cumulative obs. distribution

H = Heaviside step function

Parametric forecast calibration (Kharin *et al.*, 2017)

- **Fit normal distribution** to ensemble of forecasts (for a given target period)
- **Rescale normal distribution parameters** (mean, standard dev.) based on relationship between observations and hindcasts over a reference period
  - Subject to the constraint that total observed variance match total forecast variance for a given month over the reference period
  - Calibration coefficients optimized by **minimizing the CRPS** (continuous ranked probability score)

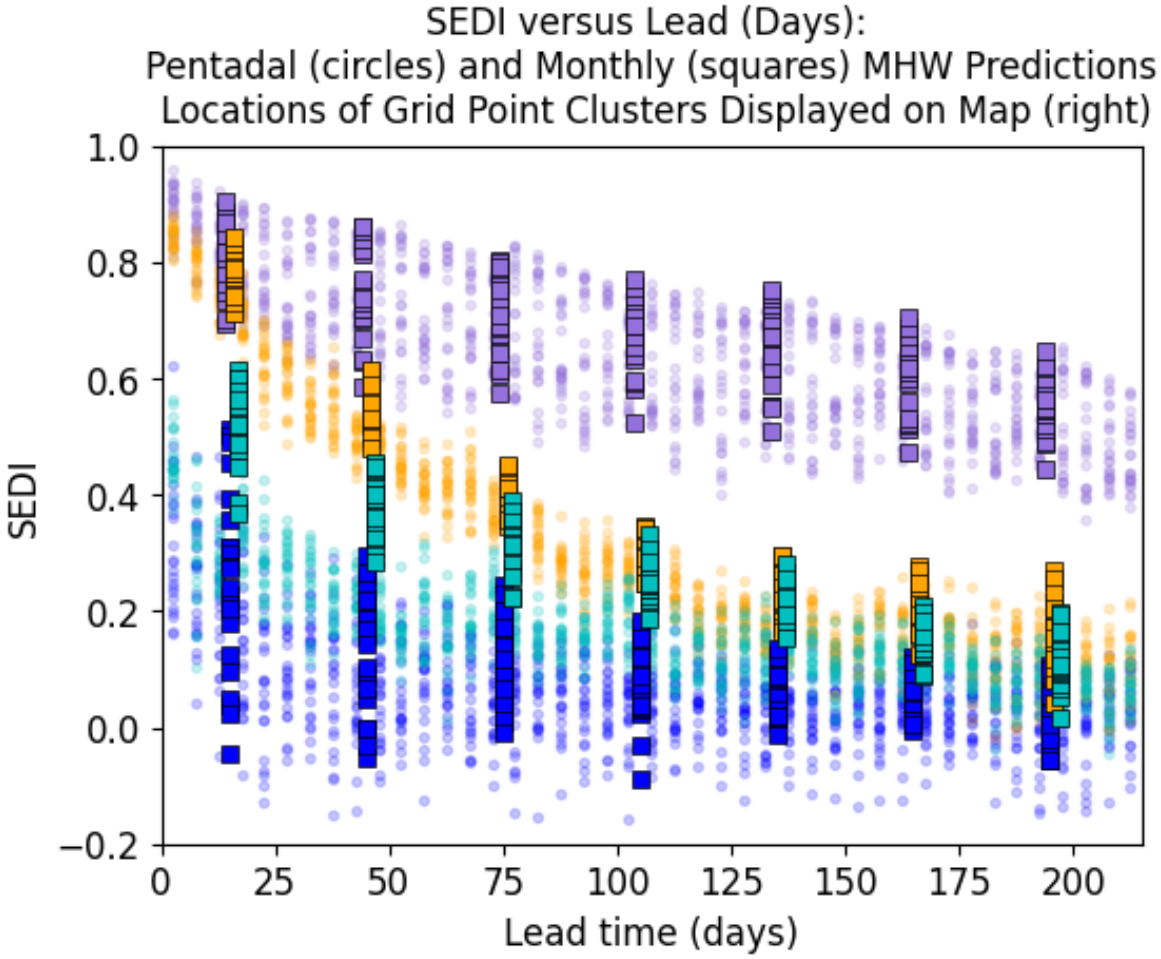
➢ **Probabilistic forecast**—probability of exceedance of the 90th (or other) percentile—calculated from calibrated distribution

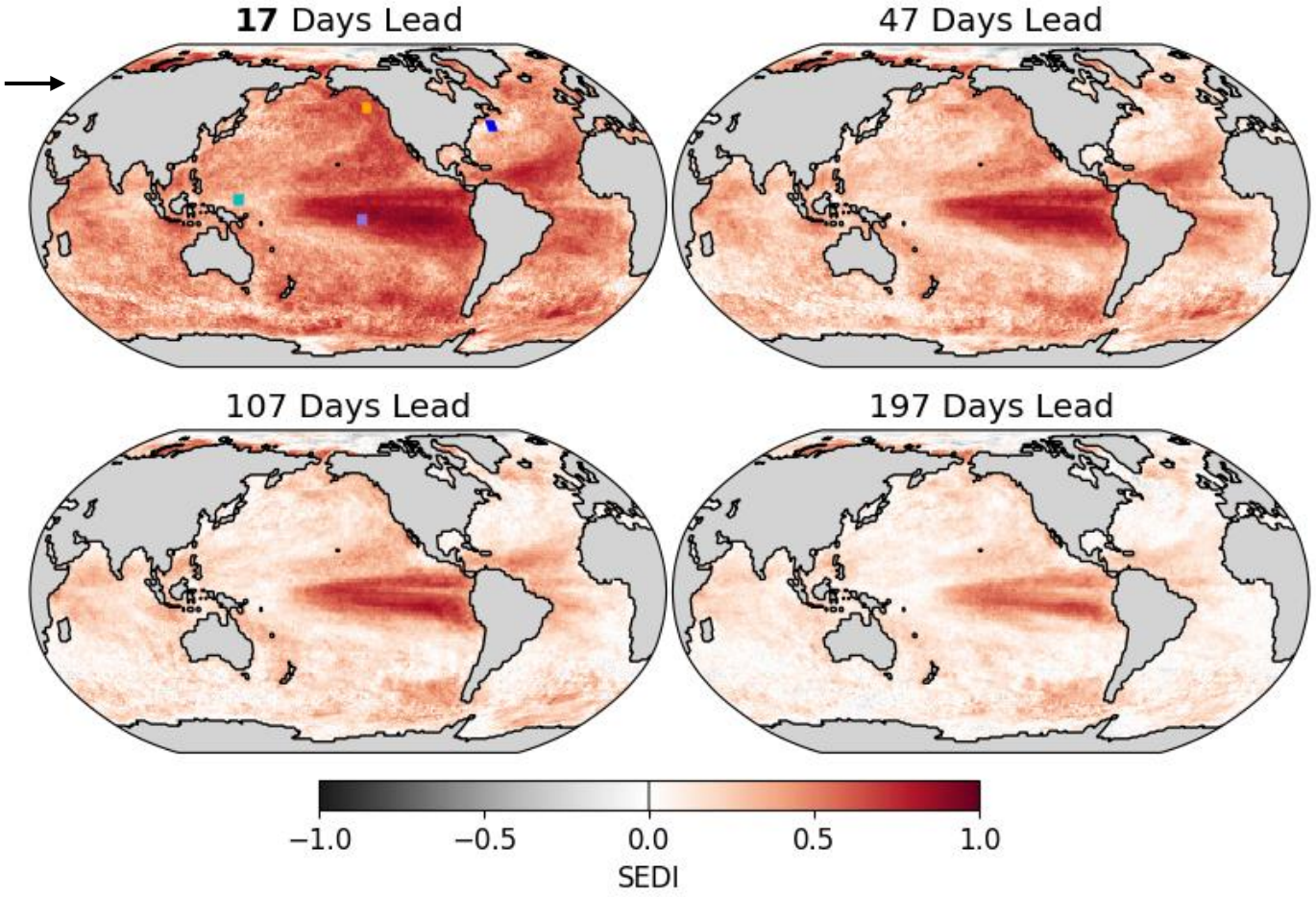


Pentadal MWH Hindcast Skill Based on 20 CanESM5 Ensemble Members

For **pentadal predictions**, the monthly MHW diagnosis **procedure is modified** to reduce the impact of high frequency variability on climatology and trend by:

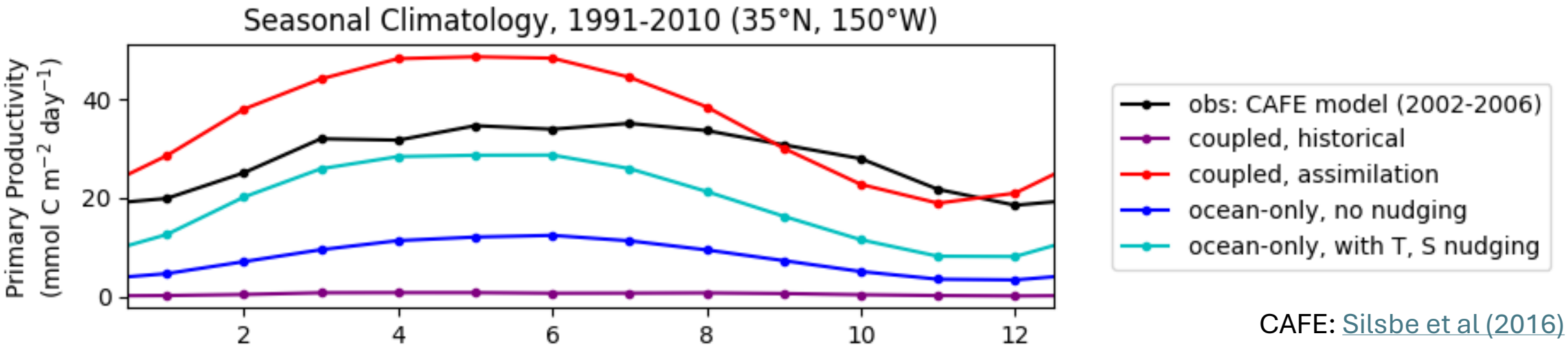
- **smoothing** the climatology (20-day triangular filter)
- **pooling** lead times (±15 days) for calculating lead-dependent trends





2) Initialization of Biogeochemistry (BGC)

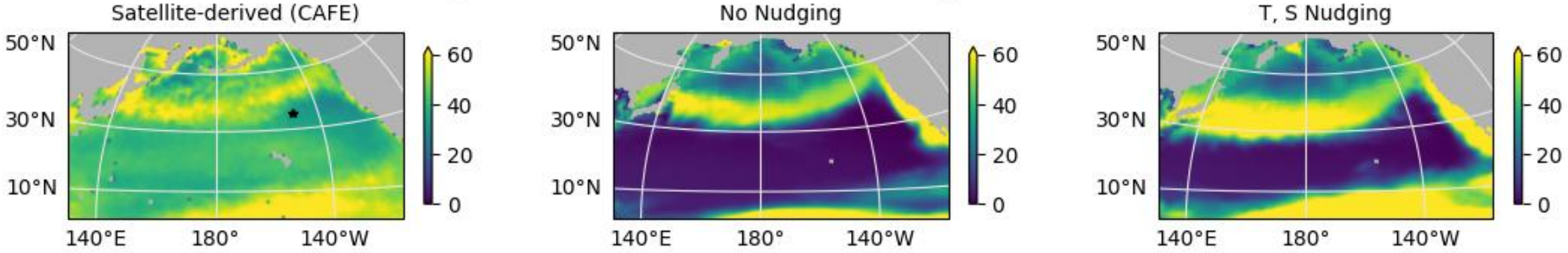
- So far, CanESM5-based BGC predictions have been i**nitialized from coupled assimilation runs** in which ocean T, S, and atmospheric physics are nudged toward reanalyses, but **BGC runs freely**
- Climatological **comparisons between historical climate simulations and assimilation runs** suggest:
  - **upper water column structure** of BGC fields in some regions is brought closer to observations through assimilation of T and S
  - With a long spinup, **deep concentrations can drift** farther from observed values for some variables
  - With nudging, BGC tracers were **not conserved** to the same degree as in free-running climate simulations
- Preliminary **ocean-only assimilation runs** (with nudging of T and S) have been carried out following an upgrade from NEMO v3.4 to **NEMO v4.2**
  - So far, BGC tracer is **conserved** at a similar level to free-running simulations
- Additional experiments to isolate the source of some of the BGC changes in the assimilation runs
  - **Pair of ocean-only runs** (CMOC: NPZD with Chl, O_2, DIC, Alk), identical forcing (ERA5), **with and without nudging** of ocean T and S toward (ORAS5) reanalysis



CAFE: Silsbe et al (2016)

Ocean-only Simulations With and Without T, S nudging

May Average 2002-2006 Primary Productivity (PP) (mmol C m^{-2} d^{-1})



- Slight improvement to low latitude spatial pattern, but overshoot of rates in high primary productivity (PP) locations

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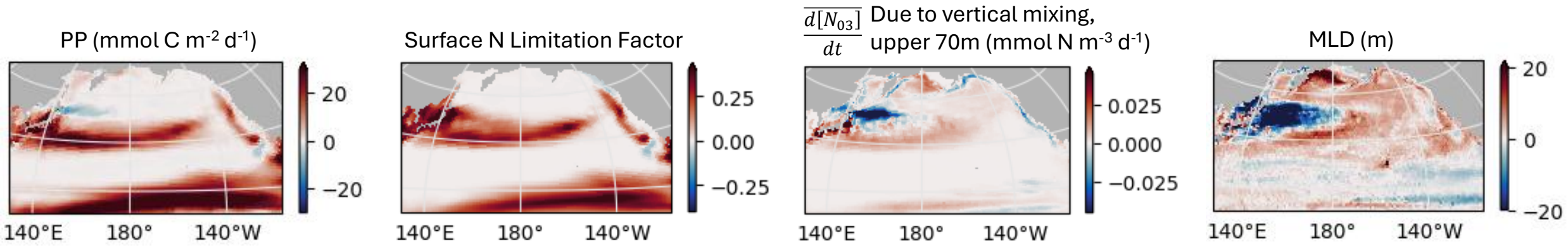
Difference Plots: T, S Nudging Run – No Nudging Run, 1991-2010 Mean

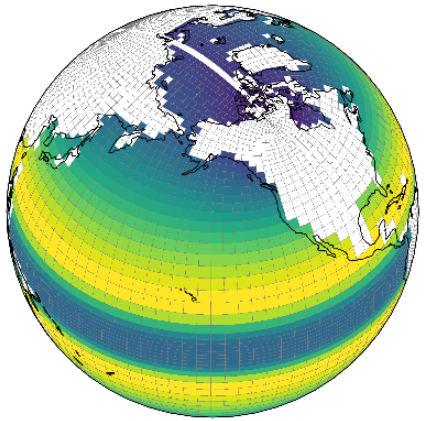


- Increased PP due to alleviation of nitrogen limitation
- In some locations, deepening (red) or shallowing (blue) of the MLD is associated with increase (red) or decrease (blue) in the mean rate of change of nitrate concentration due to vertical mixing
- Lateral advection contributes non-local effects

CAFE: Silsbe et al (2016)

3) Downscaling Predictions with CanTODS (Planned)

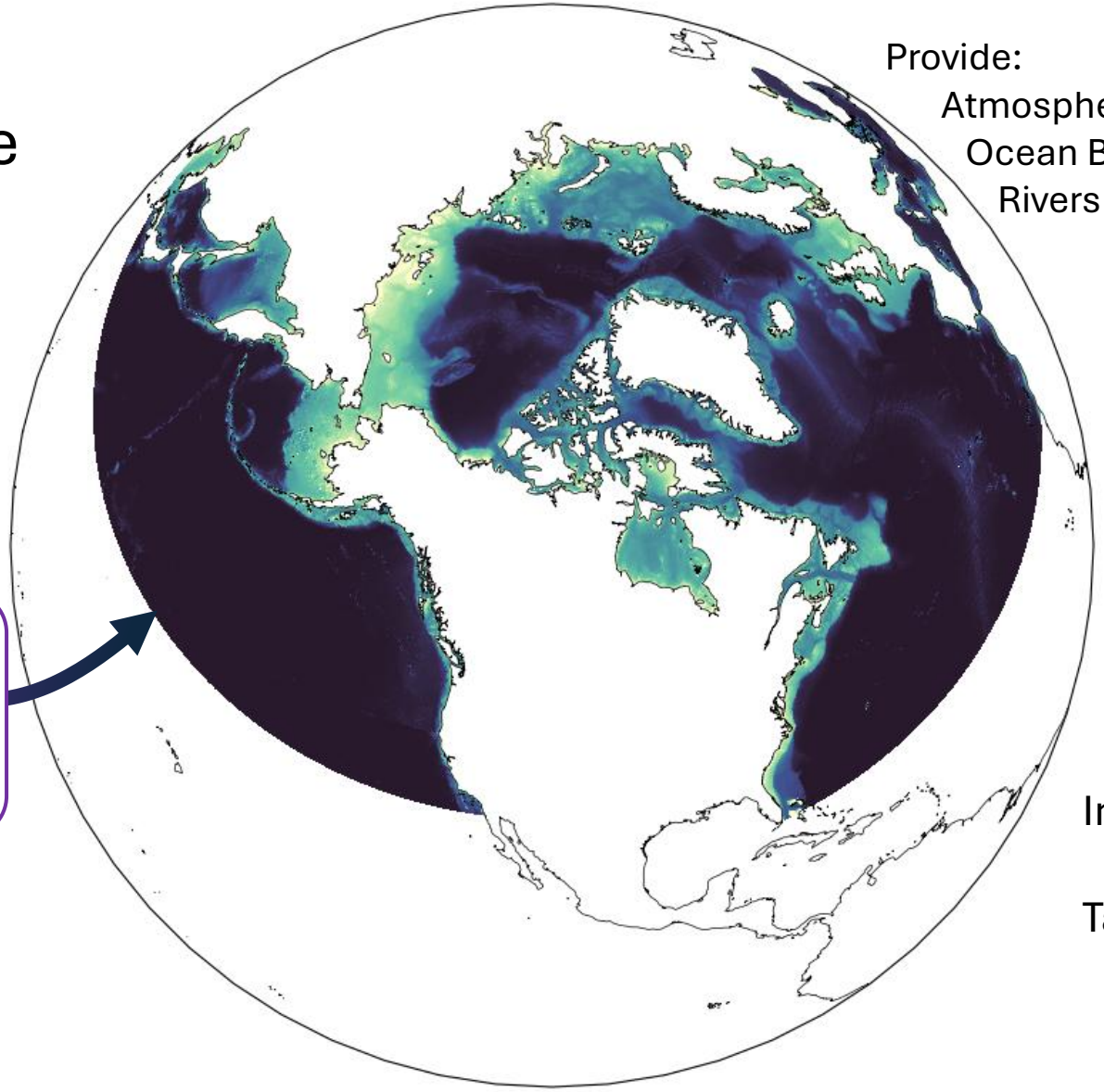
CanTODS* Downscaling Pipeline



Global (Can)ESM (Projection)

CanSIPS (Prediction)

fully coupled
atmosphere, land, ocean



Provide:

Atmospheric Forcing,
Ocean Boundaries (T, S, velocity, SSH, BGC)
Rivers (freshwater)

Shared Infrastructure and Components

NEMO4.2, SI^3, CMOC+CanOE

Initial Development:

1° global → $^1/_4$° regional

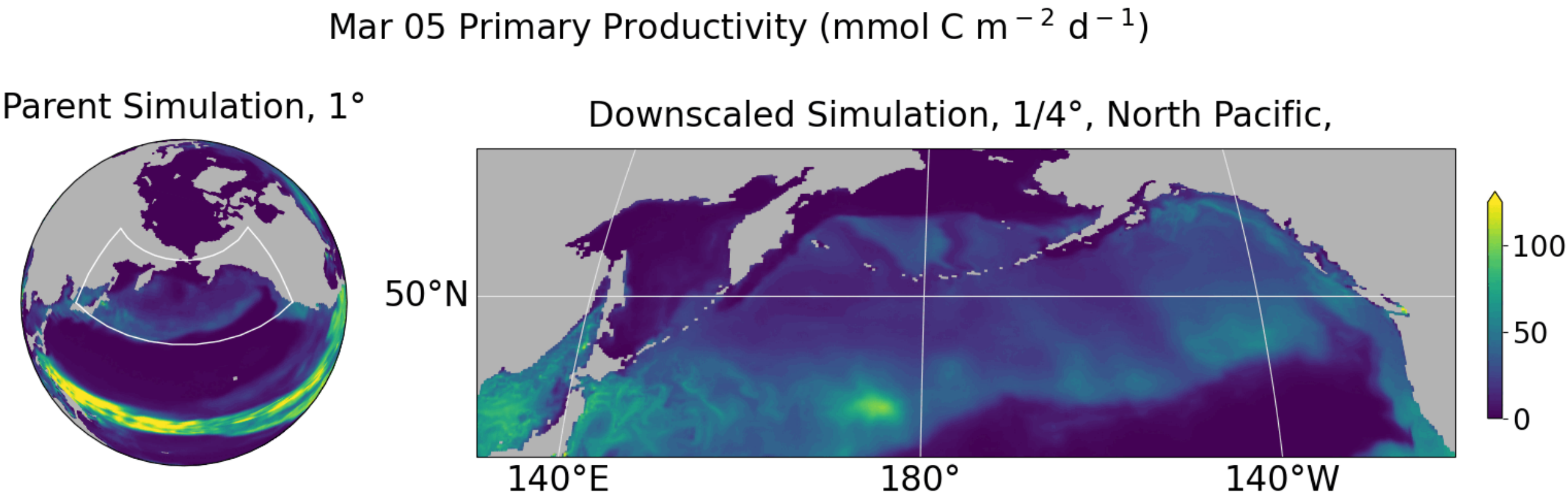
Target:

$^1/_4$° global → $^1/_{12}$° regional

*Many contributors, beyond listed coauthors, incl. N. Swart, G. Stanley, DFO, U Alberta, and others

10 m — **Bathymetry** — 4000 m

Example of Downscaled CanESM Preindustrial Control Run with CMOC (Preliminary)



Summary

- Marine heatwave (MHW) seasonal forecasts are under development at Environment and Climate Change Canada (ECCC), targeting operational dissemination by ECCC's Canadian Centre for Climate Services
- Skill of monthly and pentadal MHW predictions has been diagnosed from CanSIPSv3 SST with encouraging results, particularly for the Northeast Pacific
- Improvement of probabilistic MHW forecast reliability through the innovative application of a parametric forecast calibration method has been demonstrated
- Investigations targeting improved biogeochemical forecast initialization are underway
- Planned application of ECCC's CanTODS downscaling system to seasonal predictions, targeting a 1/12 degree Canada-focused domain
- Further discussion? Please contact elise.olson@ec.gc.ca or find me during a break!