CMIP6 evaluation of marine ecosystem stressors in the Arctic

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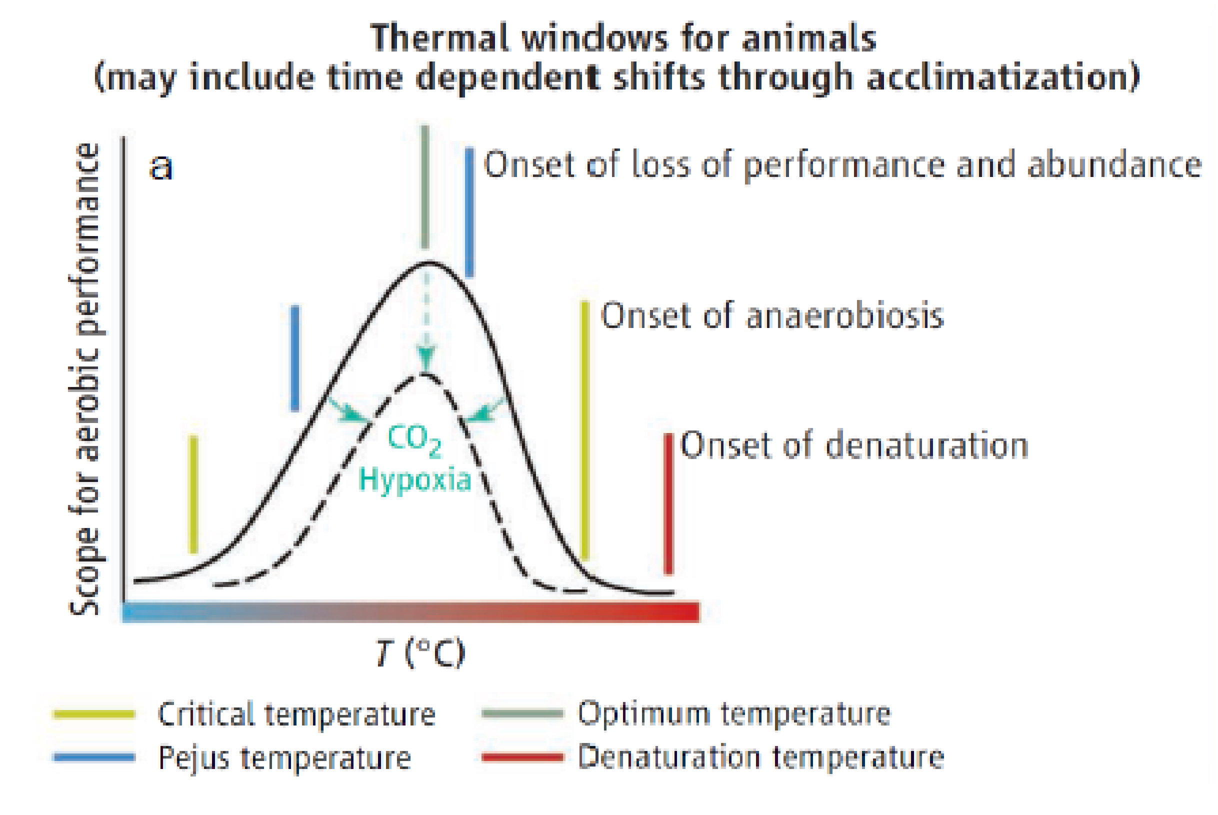
1. Motivation – Why multi-stressor analysis? – Why multi-model analysis?
2. Models, regions and depth intervals for CMIP6 marine stressor evaluation
3. Results: Regional differences (timeseries and trends)/ Model differences/ Scenario differences/ Heatmaps/ Annual cycle
4. Key messages

Why a multi-stressor analysis ?



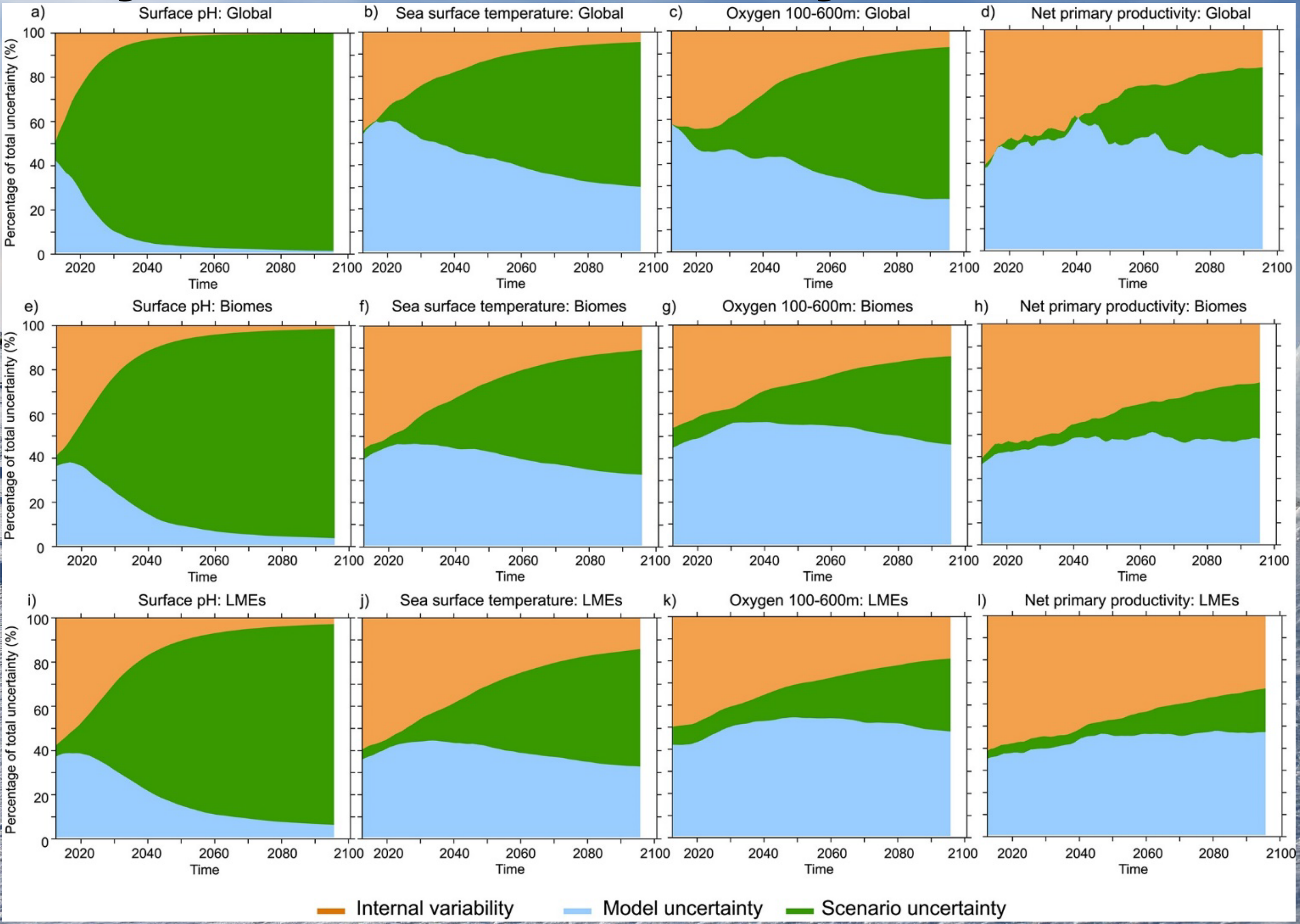
From Pförtner & Farrell, 2008

Species performance is primarily a function of temperature

Species concentrate in habitats where performance is optimal

Pfortner & Farell, 2008 suggest that the thermal window is narrowed by additional stressors – decreasing the range of optimal performance

Why a multi-model analysis ?



Model uncertainty remains a key factor of uncertainty for biogeochemical variables.

Multi-model analysis provide a measure of this uncertainty

Limited runs in model downscaling efforts can then be put into context with ESM-multi-model analysis

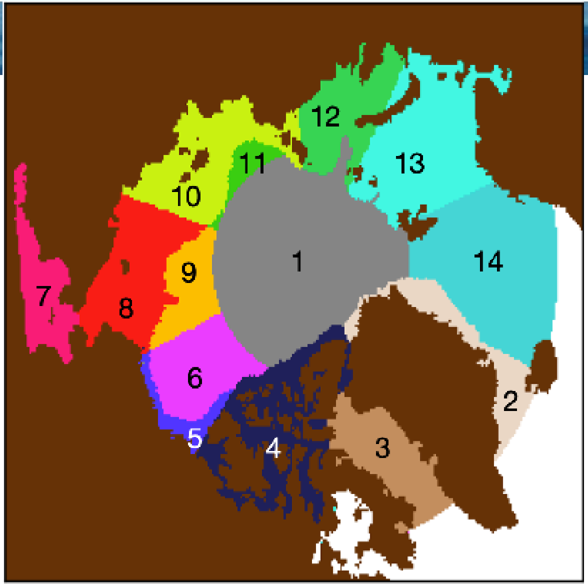
Frolicher et al. 2015: Fraction of total uncertainty explained by internal variability uncertainty (orange), model uncertainty (blue), and scenario uncertainty (green) in projections of annual mean surface pH, SST, O2 averaged over 100 to 600 m, and NPP integrated over the top 100m for (a–d) global projections, (e–h) projections averaged over 17 biogeographical biomes,

Multiple stressors in CMIP6 – 10 models

- CESM2-WACCM
- CNRM-ESM2-1
- ACCESS-ESM1-5
- GFDL-ESM4
- MIROC-ES2L
- UKESM1-0-LL
- NorESM2-MM
- MRI-ESM2-0
- MPI-ESM1-2-HR
- CanESM5-CanOE
- CanESM5
- mean
- ORA-S5

"Stressors":
- Temperature
- Ocean acidification (Ωa, Ωc, pH)
- Oxygen
- Sea-ice

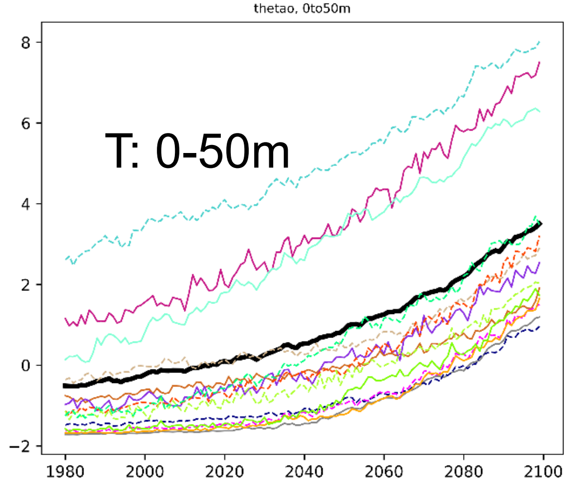
O7: Bering
O8: Chukchi

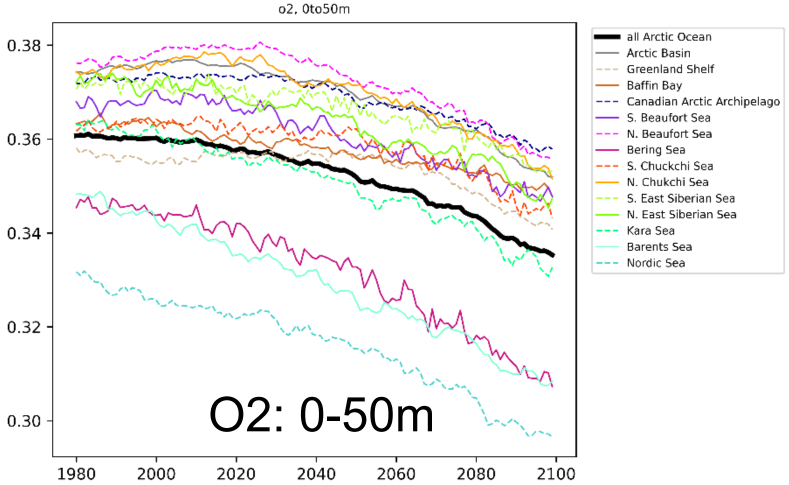


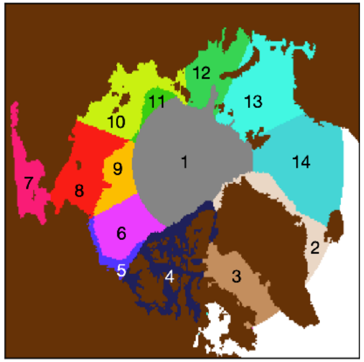
14 regions

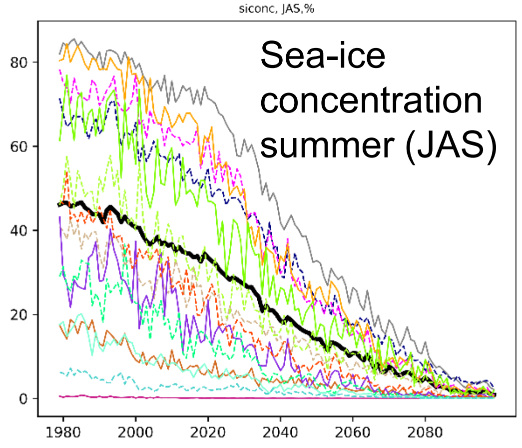
Vertical averaging following species assemblages identified in the Beaufort Sea Marine Fishes Project (Majewski et al. 2017)
0-50m,
50-200m,
200m-500m,
>500m

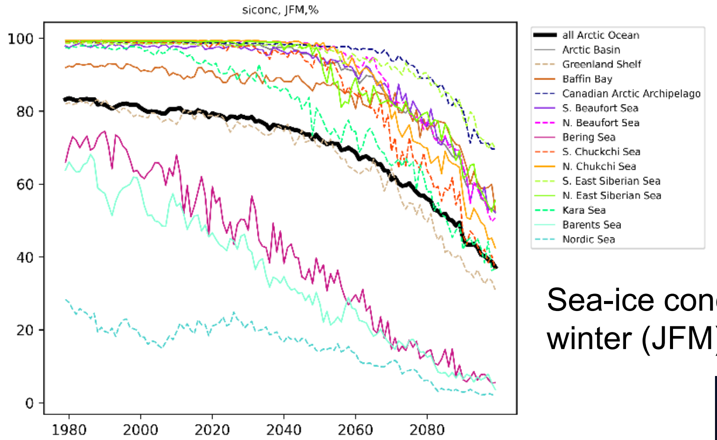
CMIP 6 model mean SSP585 – regional differences in T and O2, sea ice







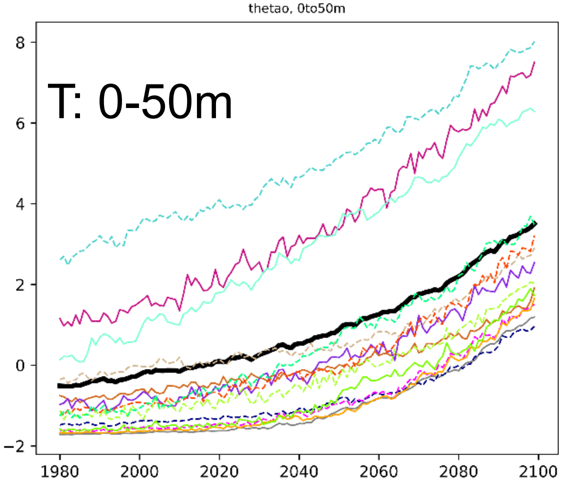


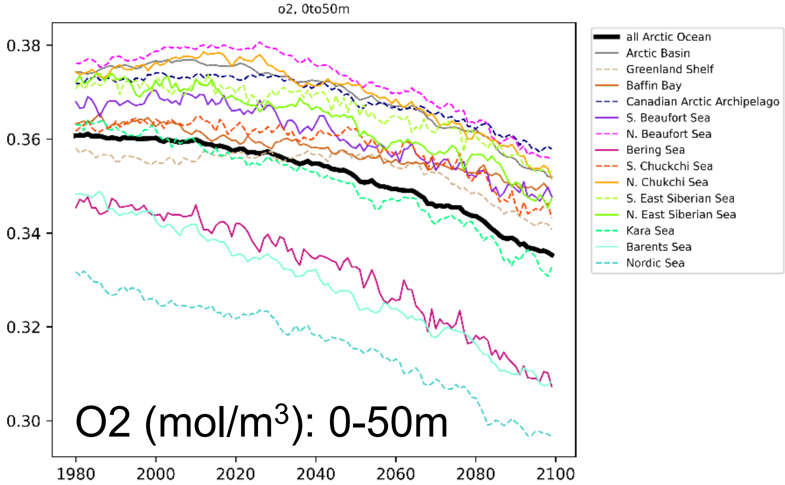


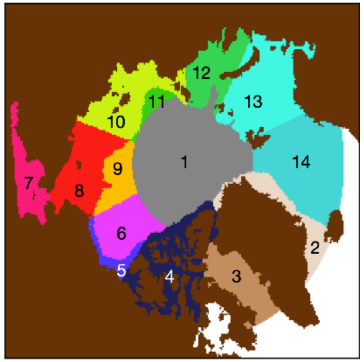
Sea-ice concentration winter (JFM)

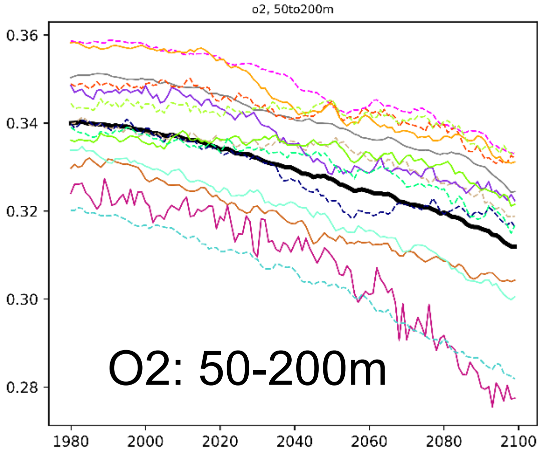
O7: Bering
O8: Chukchi

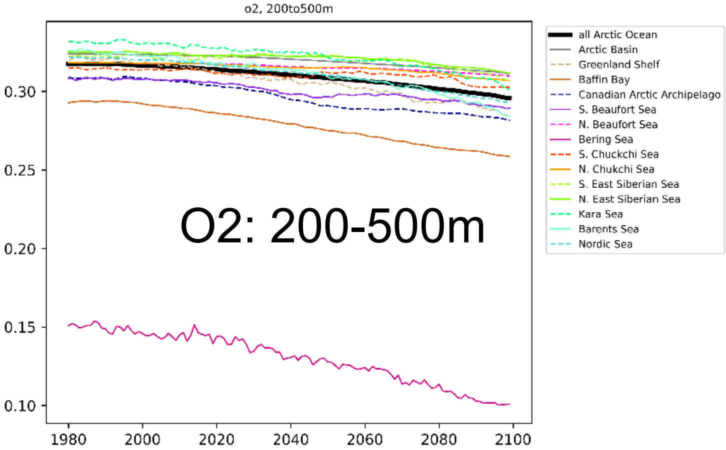
CMIP 6 model mean SSP585 – regional differences in T and O2 (0-50m), sea ice





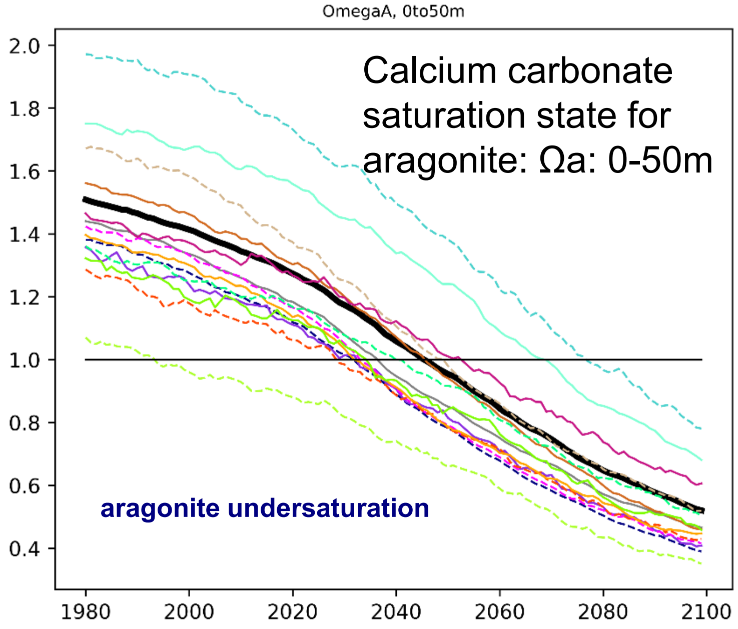


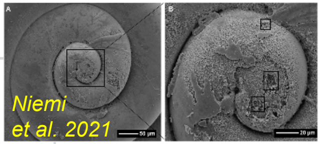




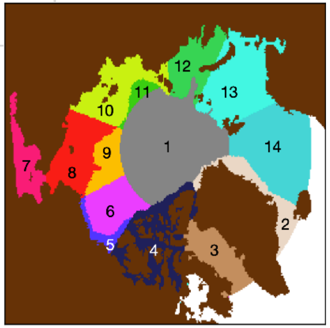
O7: Bering
O8: Chukchi

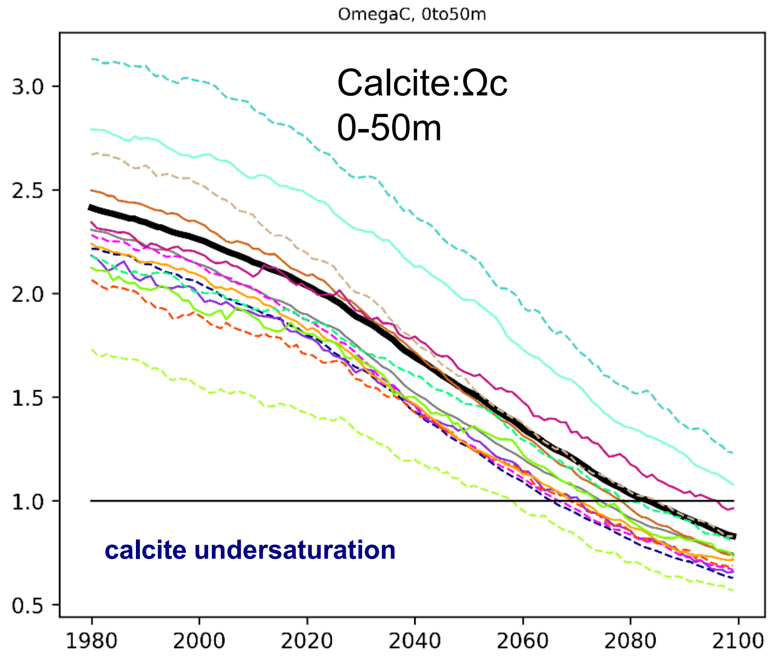
CMIP6 multi-model mean – SSP585 regional differences in $CaCO_3$ saturation state, Ω





Regions





SSP585: all Arctic regions show aragonite undersaturation by 2080

O7: Bering
O8: Chukchi

The Arctic shows distinct regional differences, with most advanced ocean acidification (lowest pH and $CaCO_3$ saturation states) in the East Siberian and Laptev Seas.

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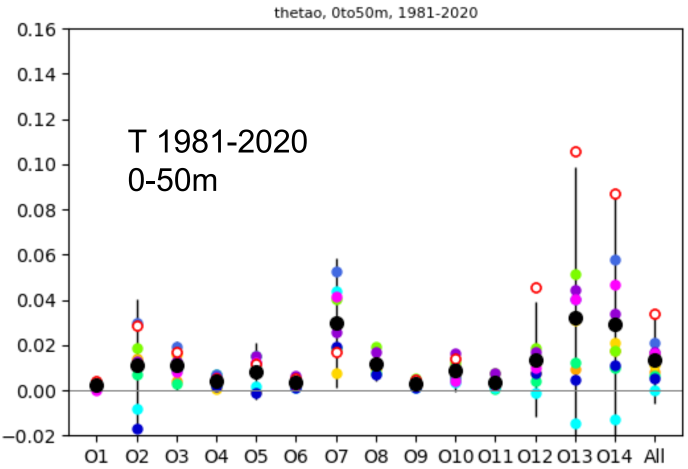
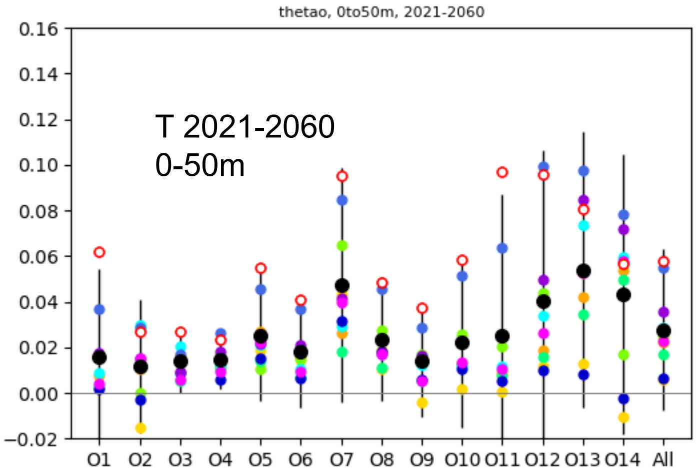
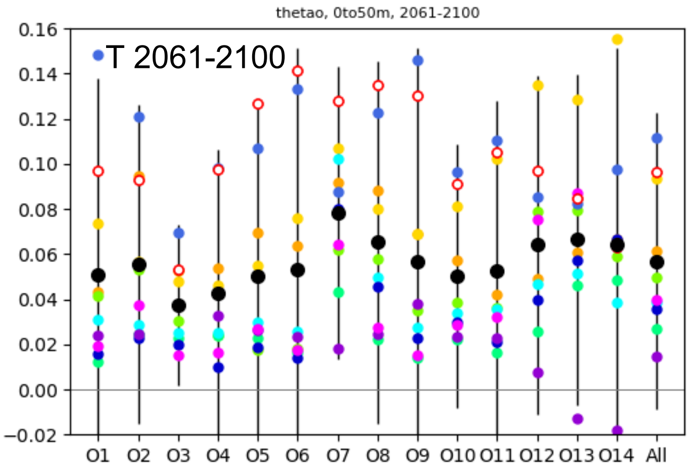
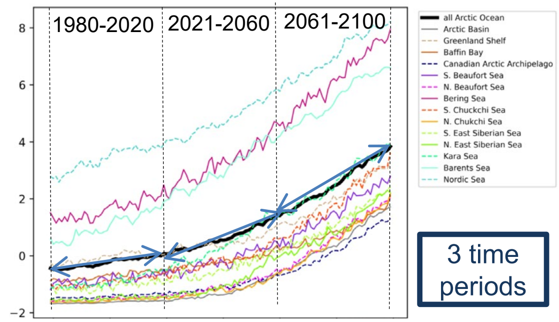
O7: Bering
O8: Chukchi

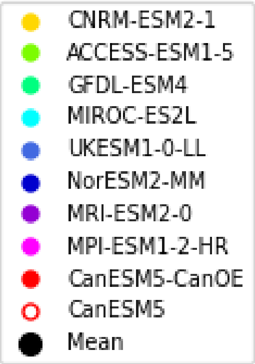
CMIP6 model trends 3 40-year timeperiods – SSP585 Temperature 0-50m







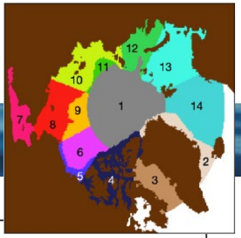




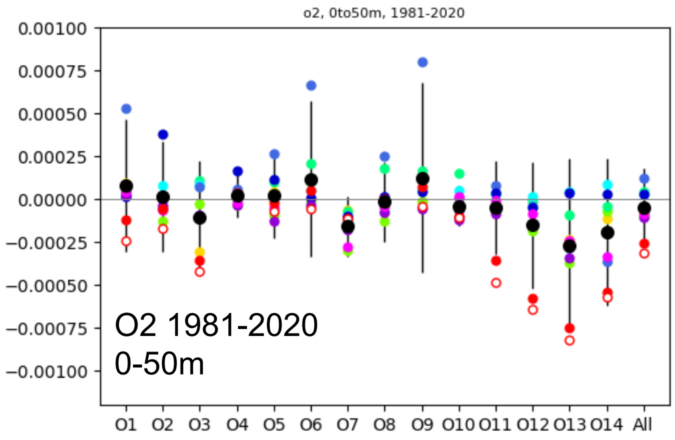
Models show distinct regional differences in trends and large spread among models (increasing over time). Subregional differences are greatest in the middle period when large sea-ice changes are occurring at different rates.

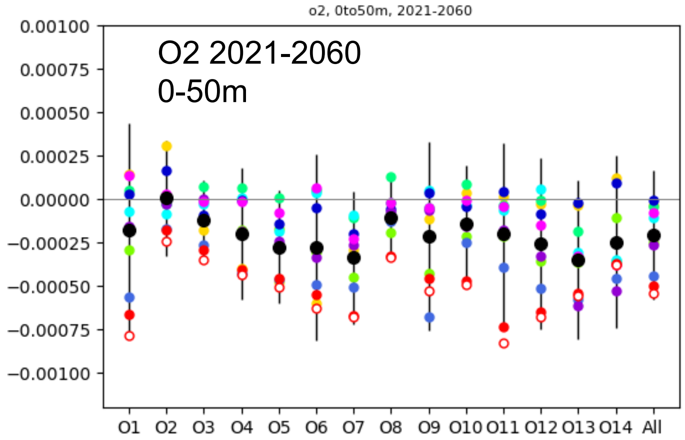
Canada

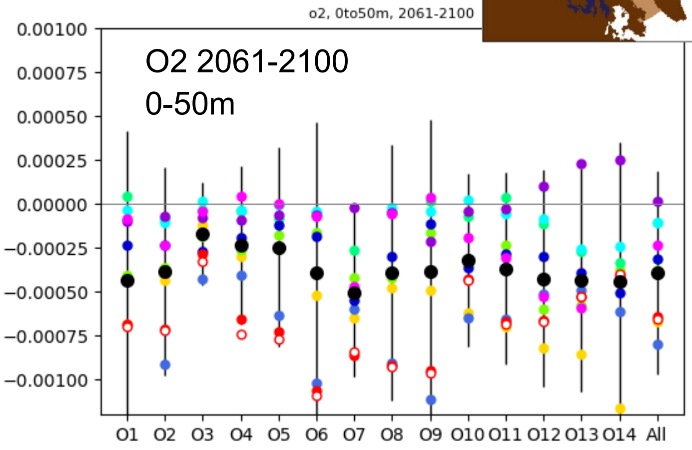
O7: Bering
O8: Chukchi

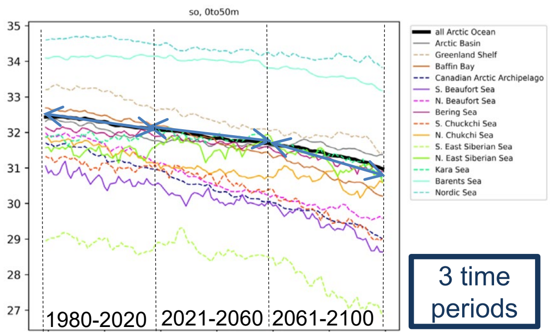


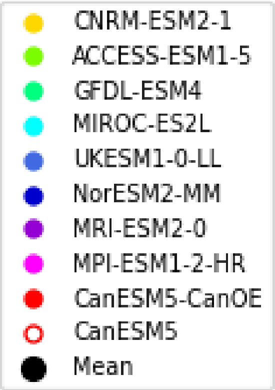
CMIP6 model trends 3 40-year timeperiods – SSP585 Oxygen 0-50m







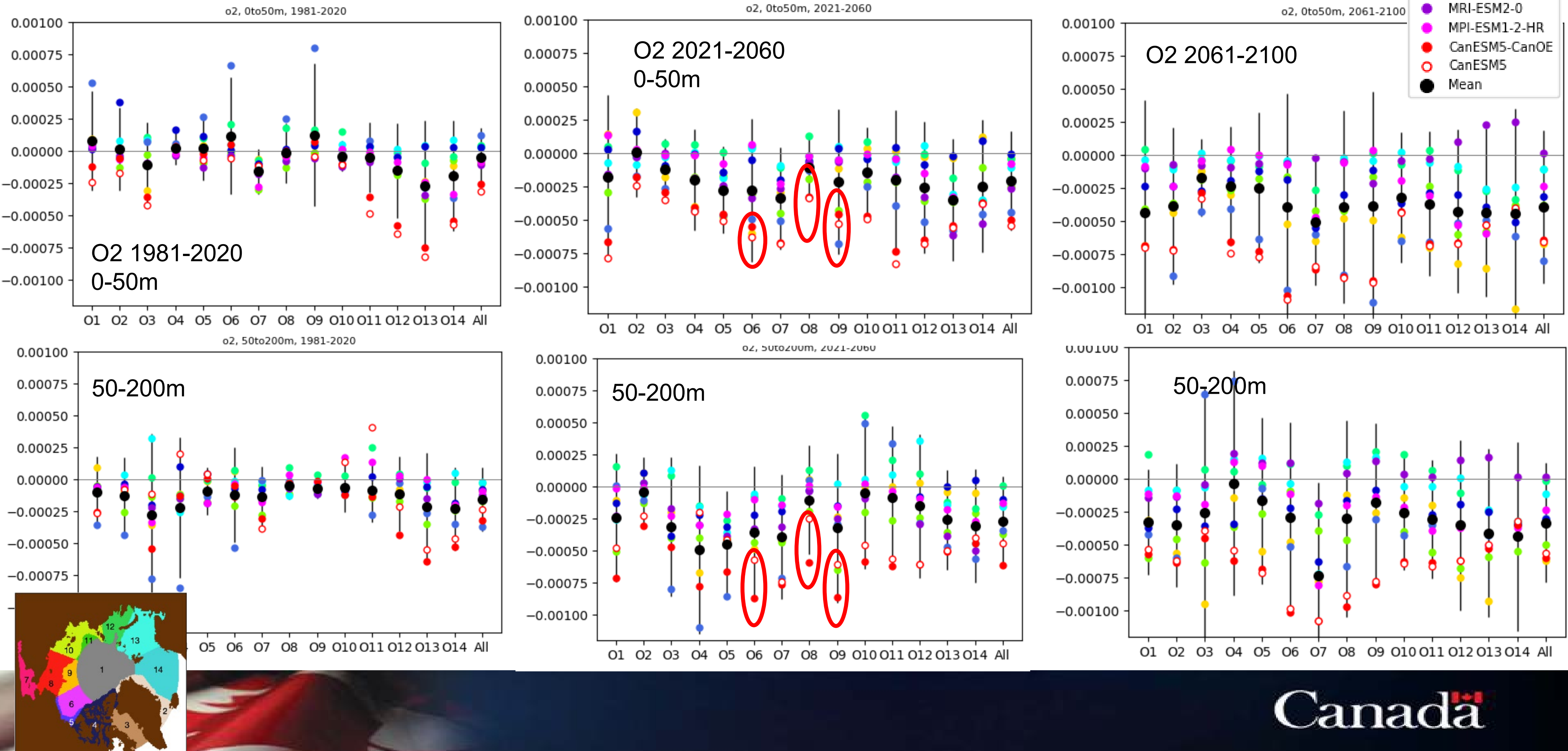




Models show distinct regional differences in trends with increasing spread over time following the T-trend pattern. CanESM comparison indicates that despite consistent T-trends O2 trends show varying trend biases by region. This indicates that the model differences in O2 are not solely due to the physical parametrizations driving T, but to some extent based on the biogeochemical model (e.g. CMOC vs CanOE).

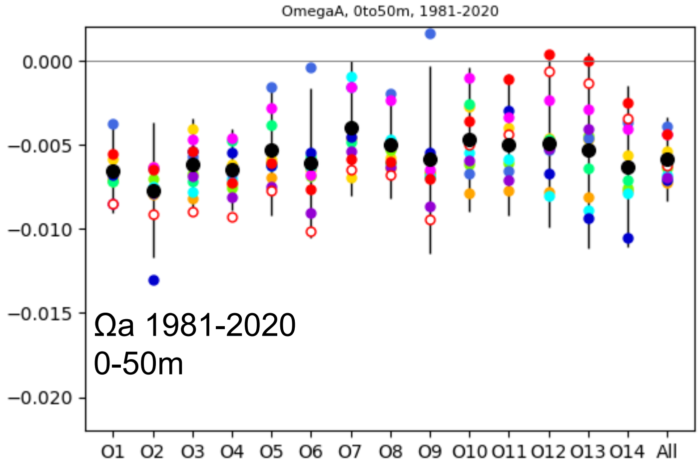
O7: Bering
O8: Chukchi

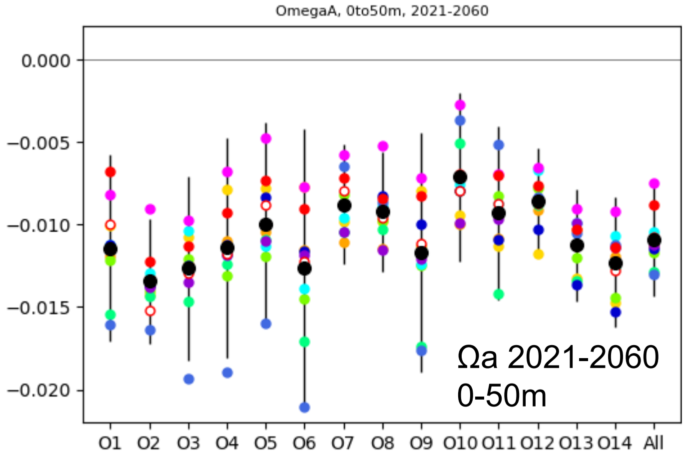
CMIP6 model trends 3 40-year timeperiods – SSP585 Oxygen 0-50m & 50-200m

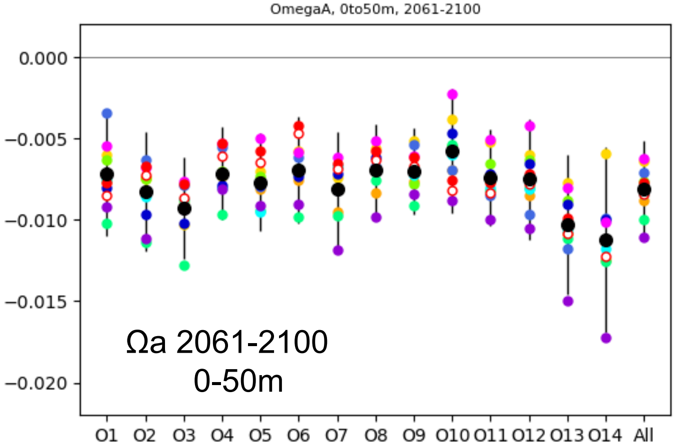


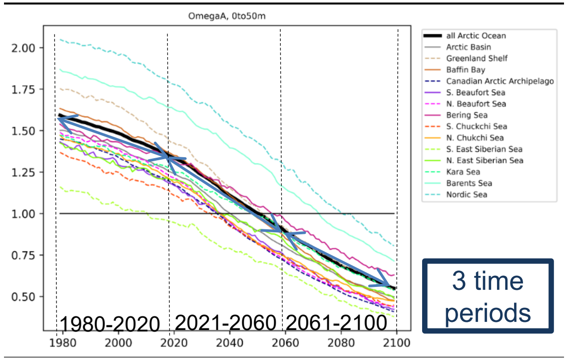
O7: Bering
O8: Chukchi

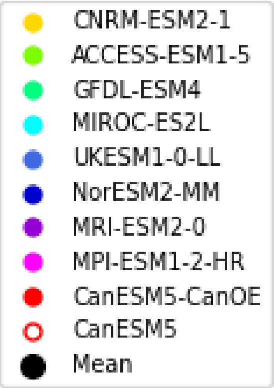
CMIP6 model trends 3 40-year timeperiods – SSP585 Omega_a 0-50m







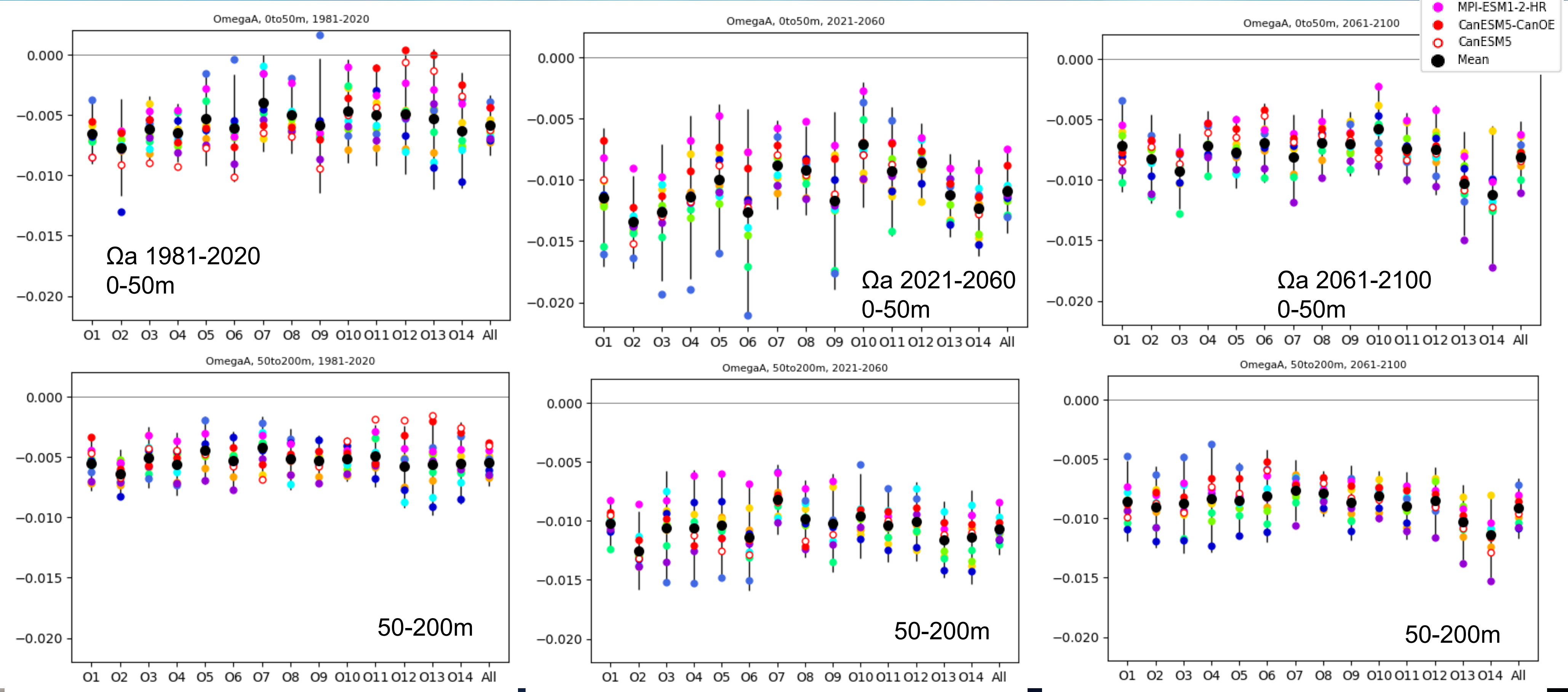




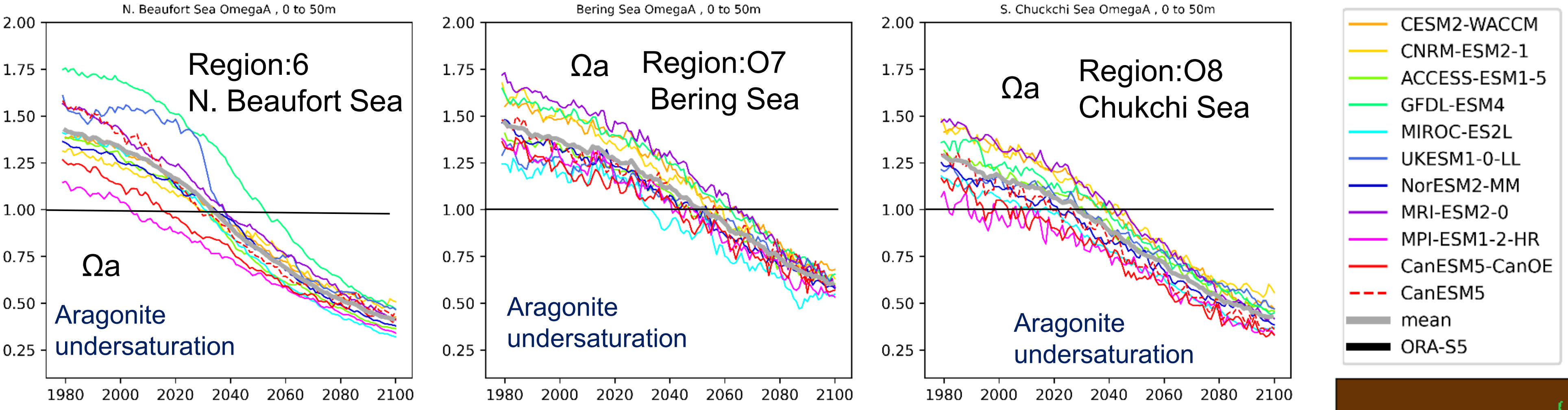
Models show regional differences in trends with decreasing spread over time. CanESM comparison indicates that Ω trends show varying trend biases by region. This indicates that the model differences in Ω are to some extent based on the biogeochemical model (e.g. CMOC vs CanOE).

CMIP6 model trends 3 40-year timeperiods – SSP585 Omega_a 0-50m

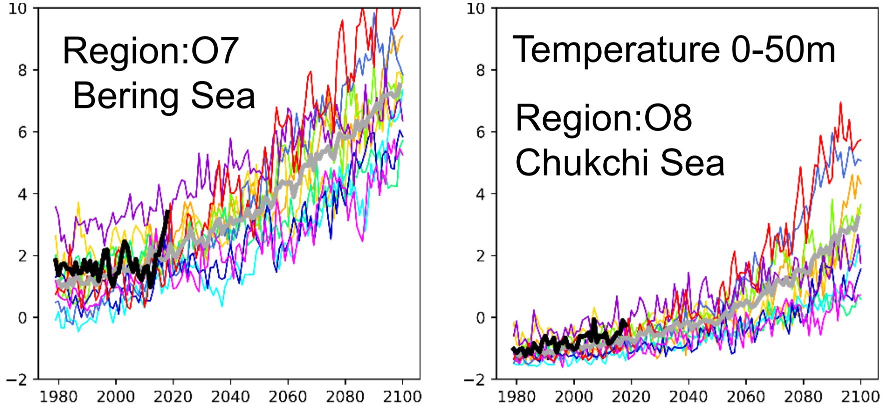
O7: Bering
O8: Chukchi

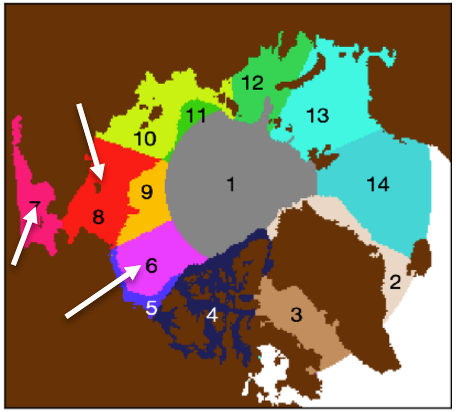


CMIP6 models – $CaCO_3$ saturation state Ωaragonite - SSP585 - 0-50m average

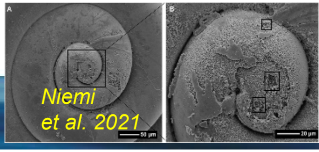


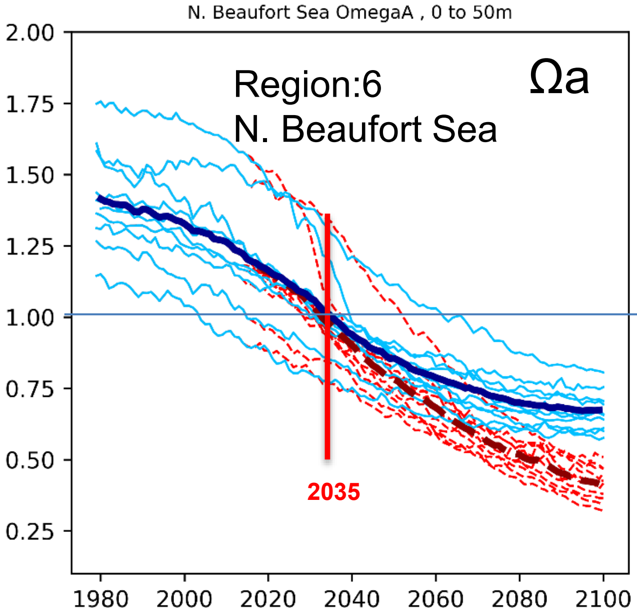
For saturation states, biases and uncertainty decrease over time (with decreasing sea-ice). Uncertainty in initial state maybe related to limited observational constraints ? Spin-up?

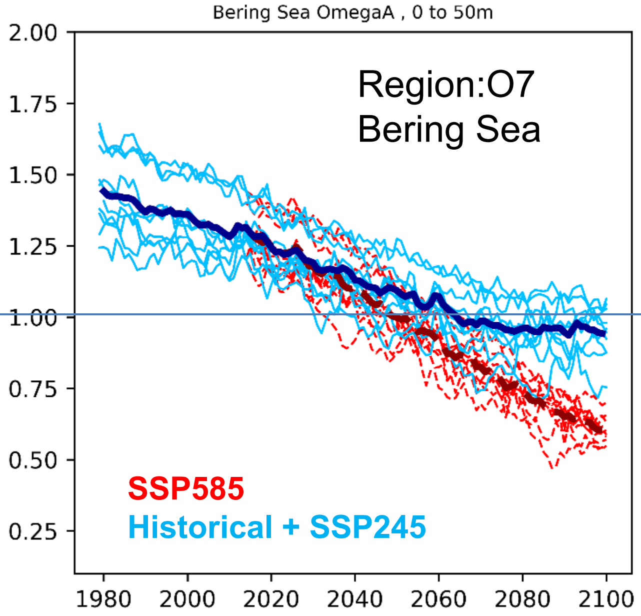


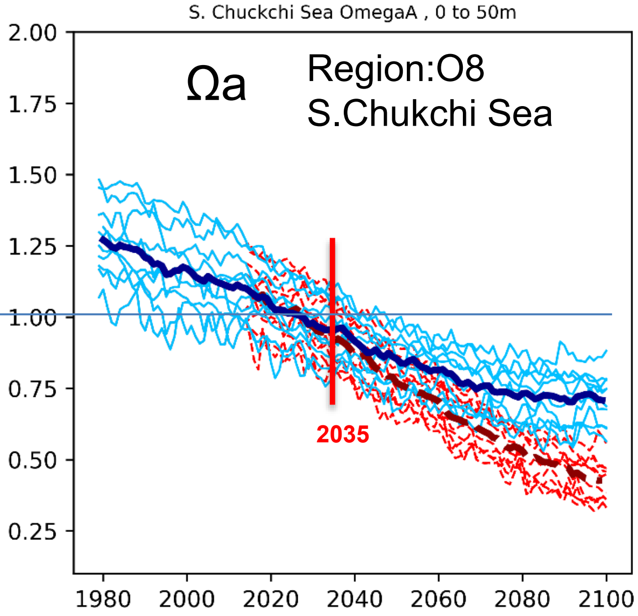


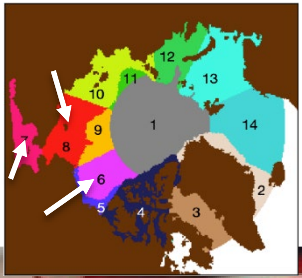
CMIP6 models – Ωaragonite - SSP585 & SSP245 - 0-60m average











Ocean acidification until ~2035 is already defined by past emissions after which higher emission scenarios show faster acidification progression. For regions with most advanced acidification aragonite undersaturation will be reached in all scenarios, for other regions lower emissions can avoid undersaturation.

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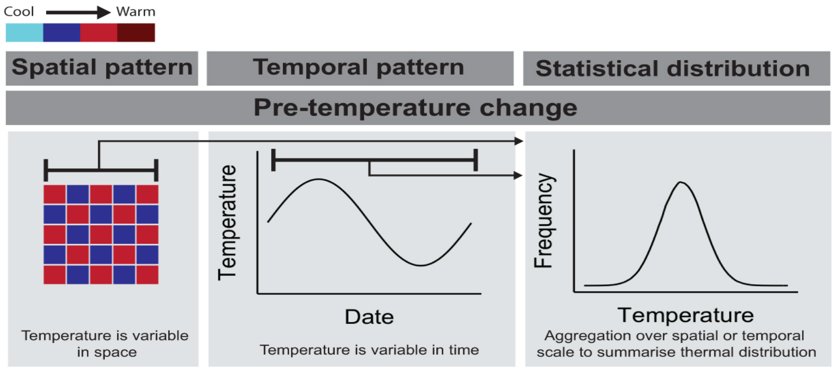
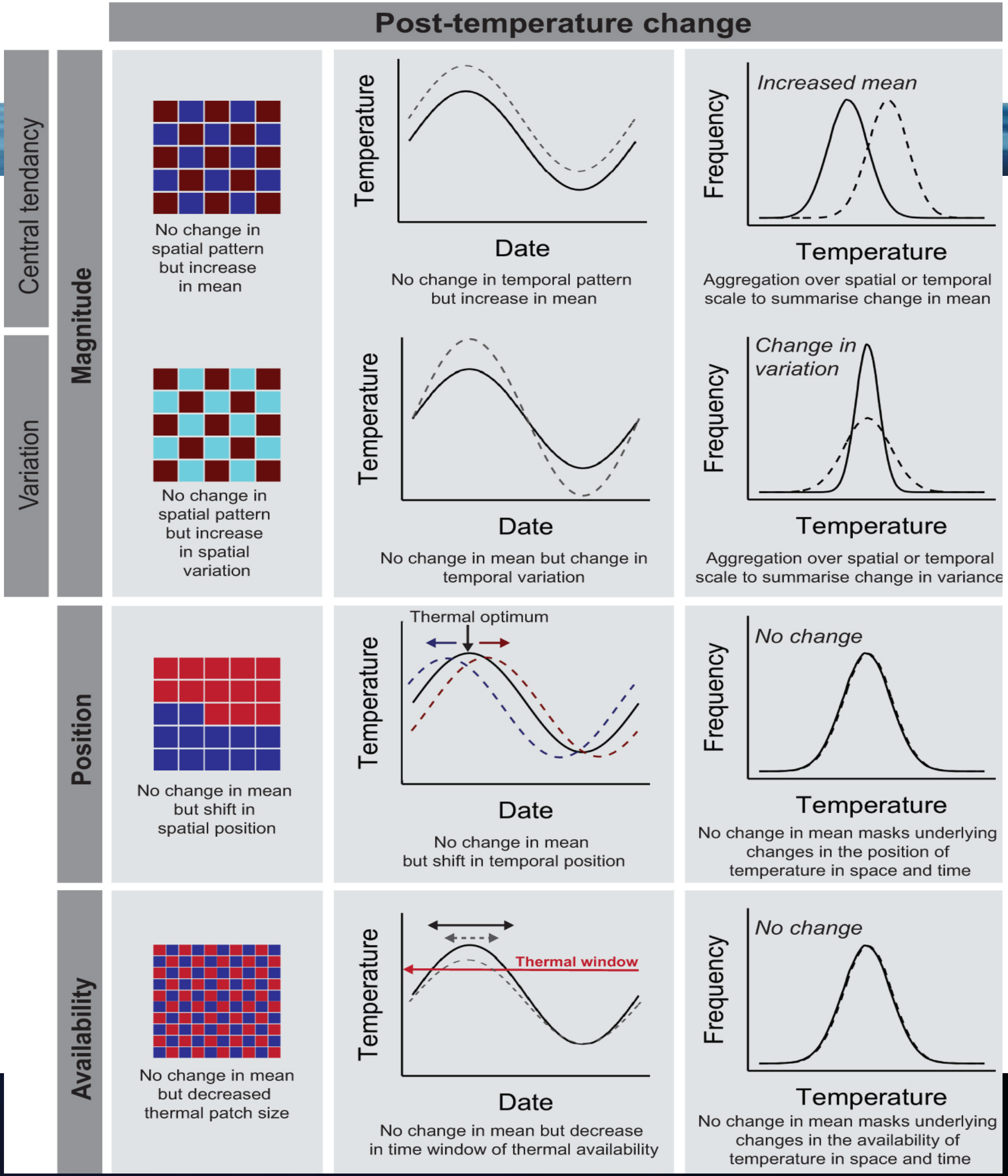
Space and Time/Species relevance

Temperature patterns in defined spatial and temporal units and their change through time.

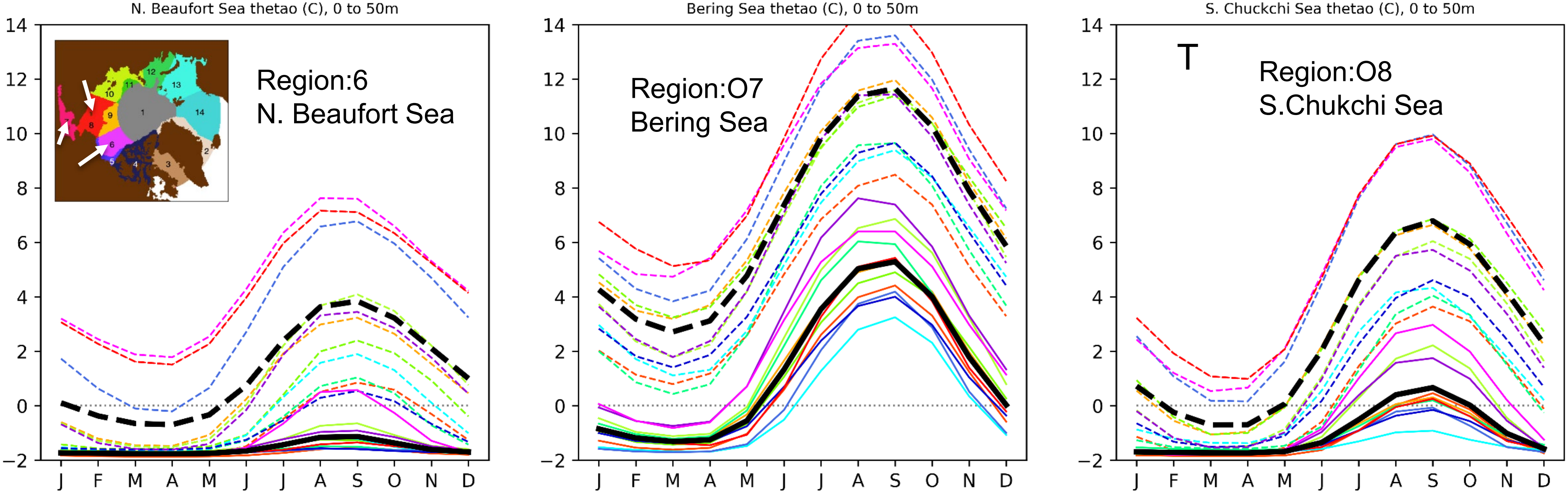




Waldock et al. 2018, BioScience, Volume 68, Issue 11, November 2018, Pages 873–884, https://doi.org/10.1093/biosci/biy096

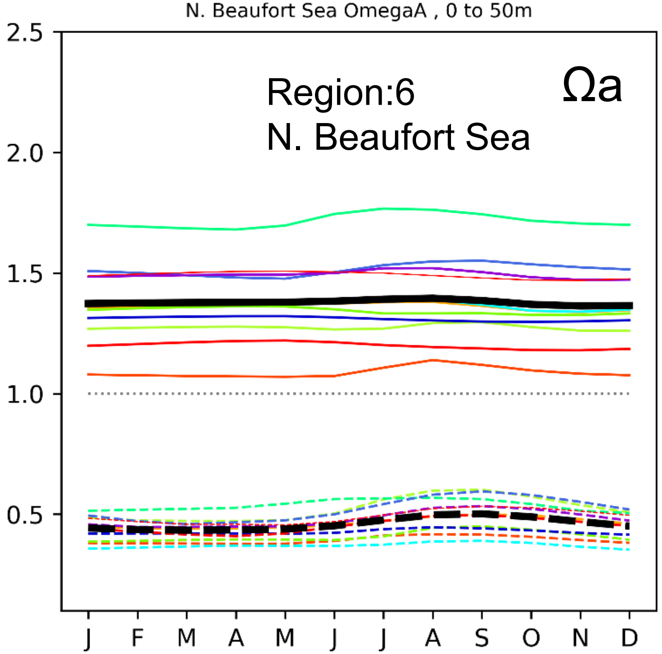
Waldock et al. 2018

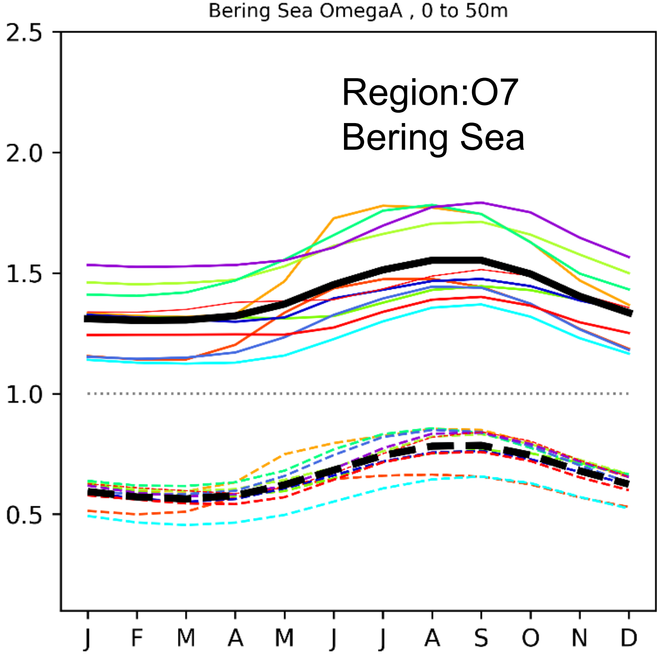
Annual cycle analysis Temperature 0-50m

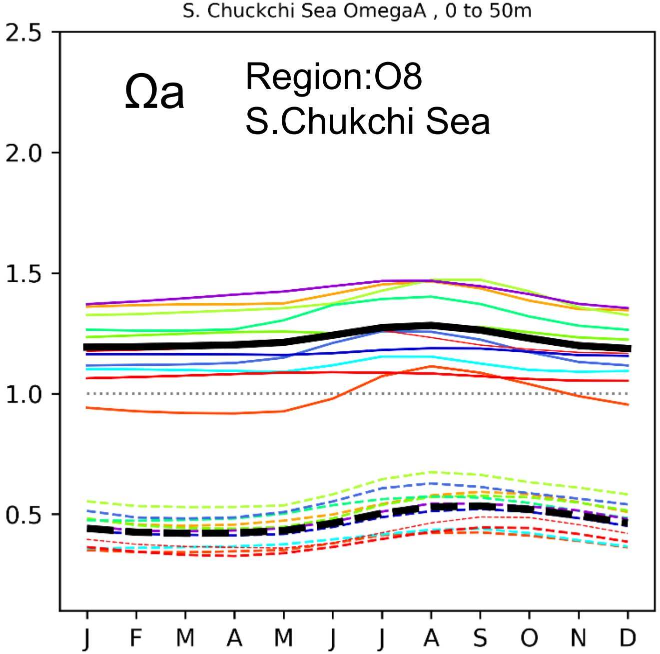


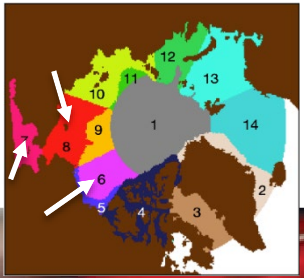
Clear increase in temperature seasonality in the upper 50m due to sea-ice retreat and warming. Large regional differences and high model uncertainty.

Annual cycle analysis Omega_a 0-50m



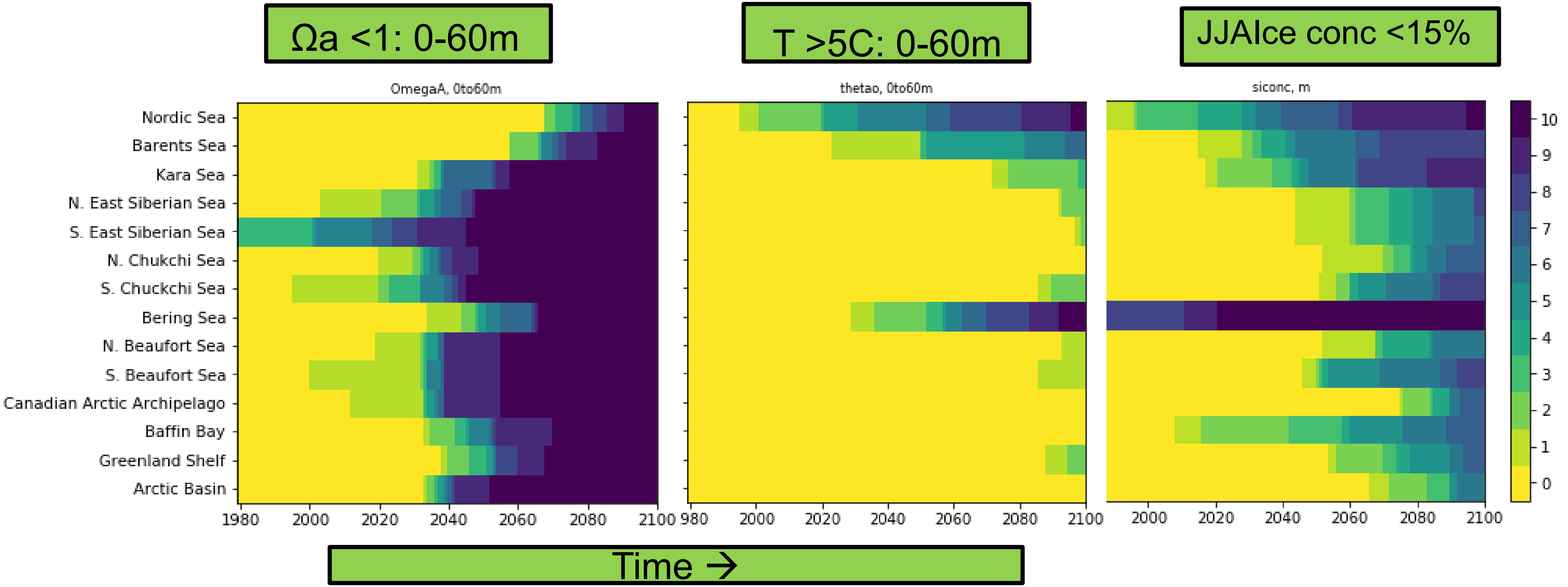






Seasonality remains weak although some shift to a later max is visible. Note that models without representation of the sea-ice carbon pump significantly underestimate the seasonal cycle in the surface ocean.

CMIP6 model thresholds: Omega <1, T >5C (SSP585 0-60m), Ice-A <15% (JAS)



Models show a range of timing for threshold crossings, but consistent regional differences

**Colors indicate number of models crossing threshold*

Steiner & Reader, in preparation

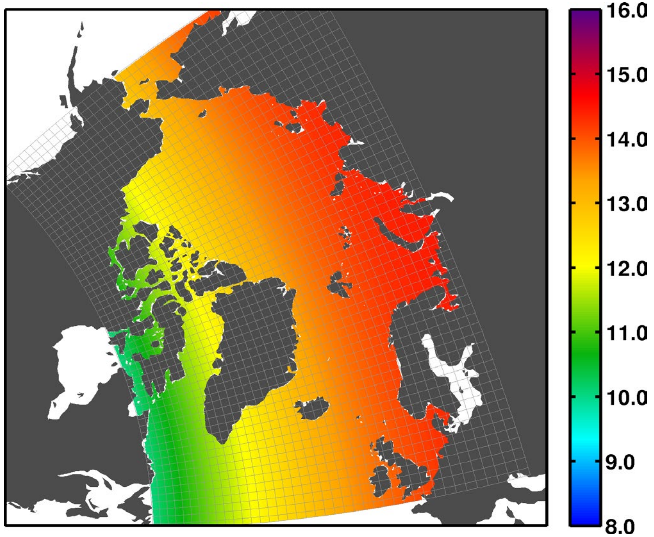
Key Messages

- There is significant regional variability in the Arctic with somewhat consistent patterns across models.
- Models show variations in trends and initial biases among models: reduced spread/ lower uncertainty in Arctic ocean acidification over time (with decreasing sea-ice). Model spread/uncertainty is increasing for temperature and O2 patterns. Some biases are related to the biogeochemical model/parametrizations.
- Annual cycles, relevant for ecosystems, are generally increasing in amplitude over time, particularly in the top 50m. In many cases a seasonal cycle is a "new" feature. This is particularly obvious for O2 where a pronounced September minimum is developing. Some shifts in timing of max/mins are also indicated, particularly for OA (note, missing sea-ice carbon pump underrepresents seasonal cycle).
- Environmental changes until ~2035 are already defined by past emissions after which higher emission scenarios show faster progression (acidification/warming/ice retreat)

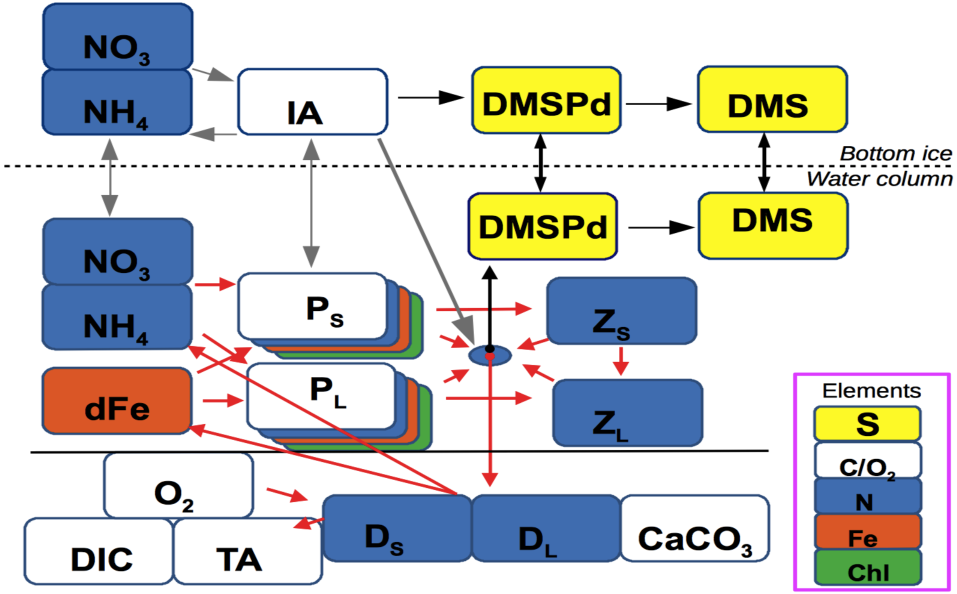
Steiner & Reader , in preparation


Questions??

Regional downscaling: NAA-CanOE-CSIB



Historical runs 1969-2015 & projection runs (RCP8.5, RCP4.5)
- Use CMIP6 evaluation to assess model spread and uncertainty, then use the regional model for more detailed analysis. Evaluation is in progress but has not been done yet for O2



Coupled ocean circulation, sea-ice and biogeochemical models: 2 species of phytoplankton, ice algae, 2 zooplankton and 2 nitrogen forms (ice and ocean), 2 detritus forms, carbon, sulfur and oxygen cycling in sea ice and ocean (1-D and 3D models)

Ocean Ecosystem model CanOE as in CanESM5-CanOE

Hayashida et al 2019, 2020, Mortenson et al 2020