Modelled changes in extreme environmental conditions within Eastern Beaufort Sea beluga habitat

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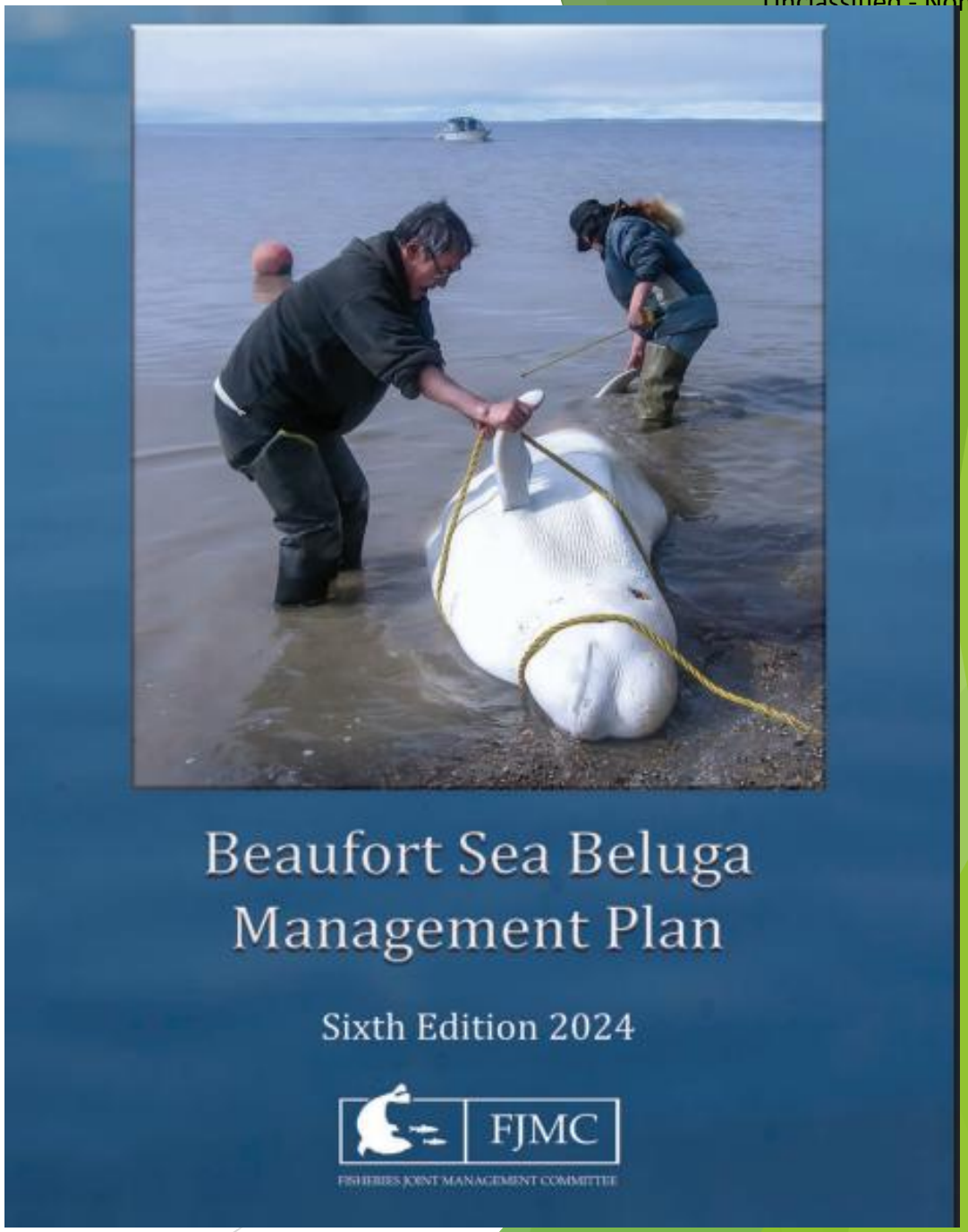
Land acknowledgement: W̱SÁNEĆ, *Inuvialuit*

Belugas in the ISR

- Pacific-Arctic Migratory species
- Key subsistence species
- Longterm beluga management
- Longest beluga monitoring timeseries
- Active conservation areas (TNMPA, ANMPA)
- Annual harvests and longterm collaboration with researchers
- Tagging and telemetry programs
- Impacts of climate change – direct and indirect (via food chain- Arctic cod)



Unclassified - Non-Classifié

Study design

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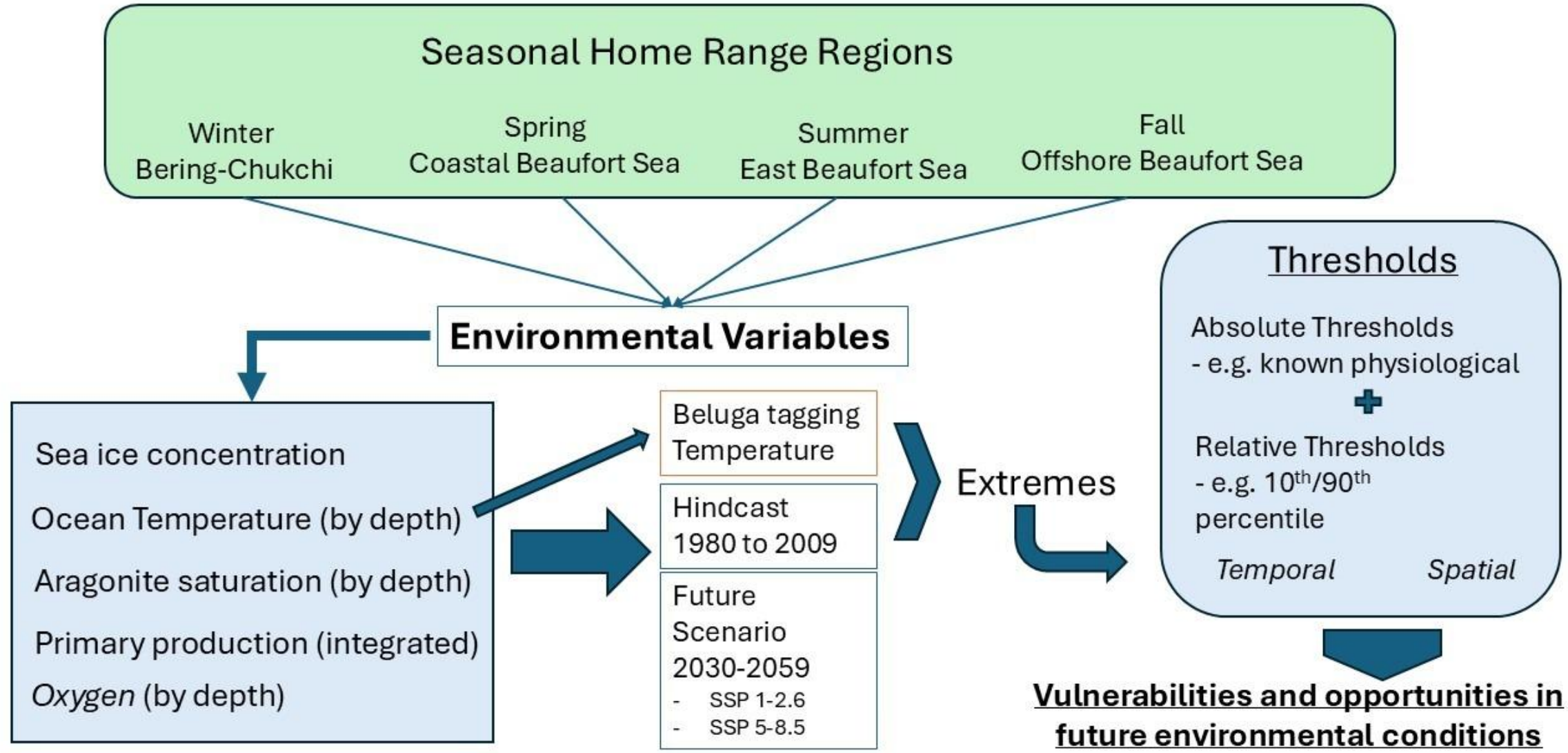
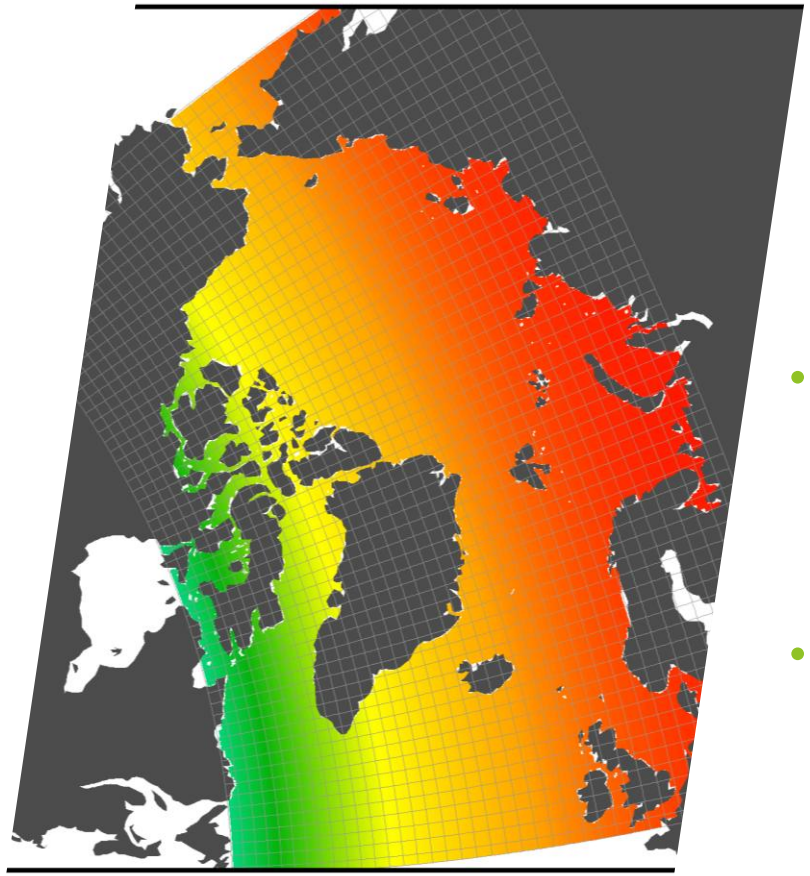
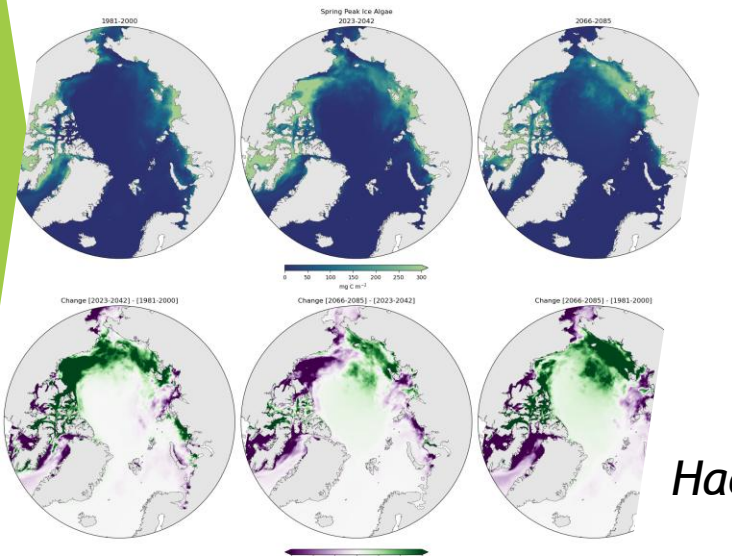




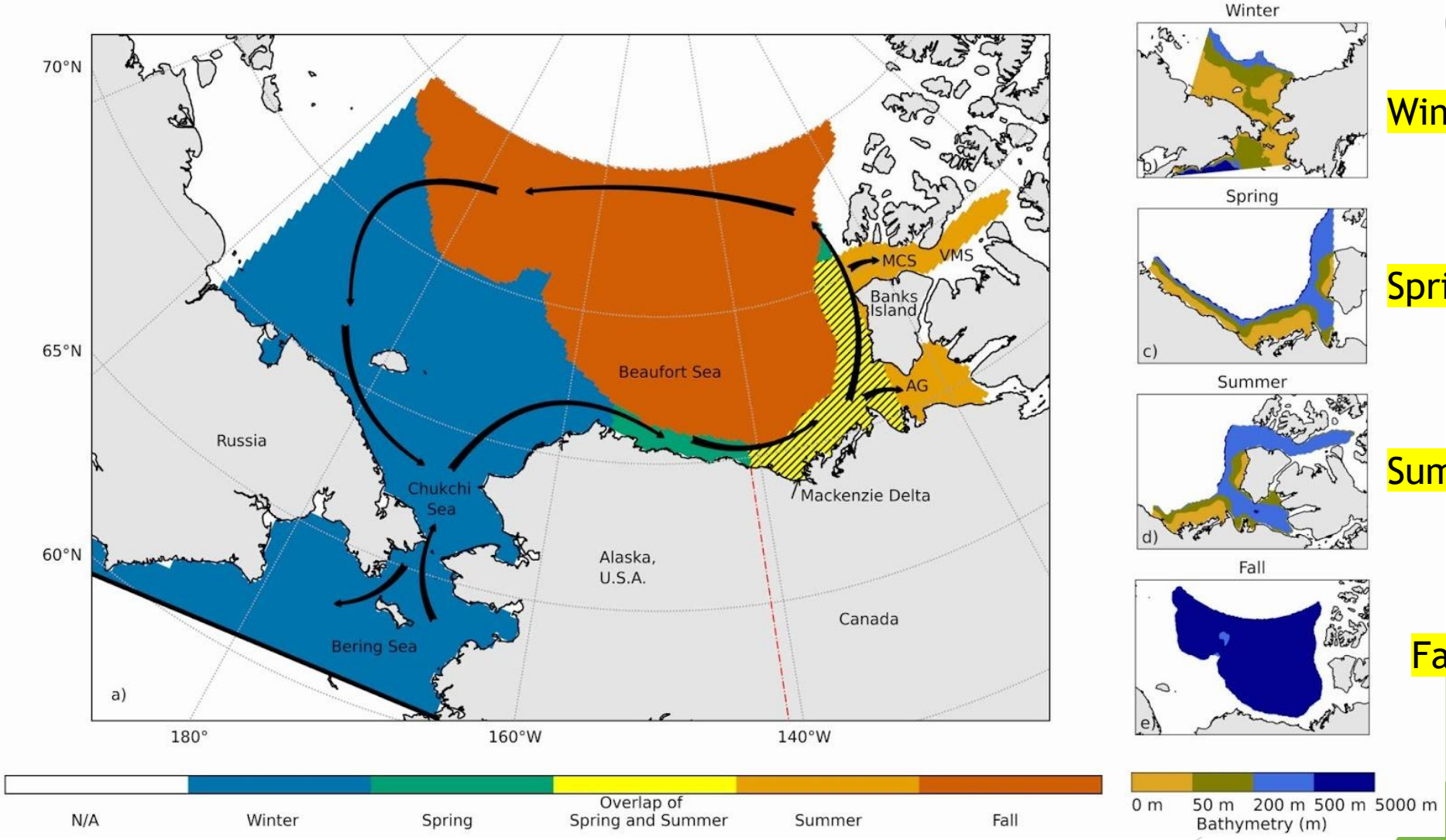


Model

- Assess “Near-term” future to inform beluga management & conservation (2030-2059 compared to 1980-2009)
- Model: Nemo 3.4 + LIM2 + Canoe + CSIB (SSP2-1.6, SSP5-8.5 – bracket expected range)
- Obs: Satellite sea ice - temperature from beluga dives/ tagging program (with permission from the Inuvialuit Fisheries Joint Management Committee)

Haddon et al. 2024

Seasonal Migration of EBS belugas – Model regions



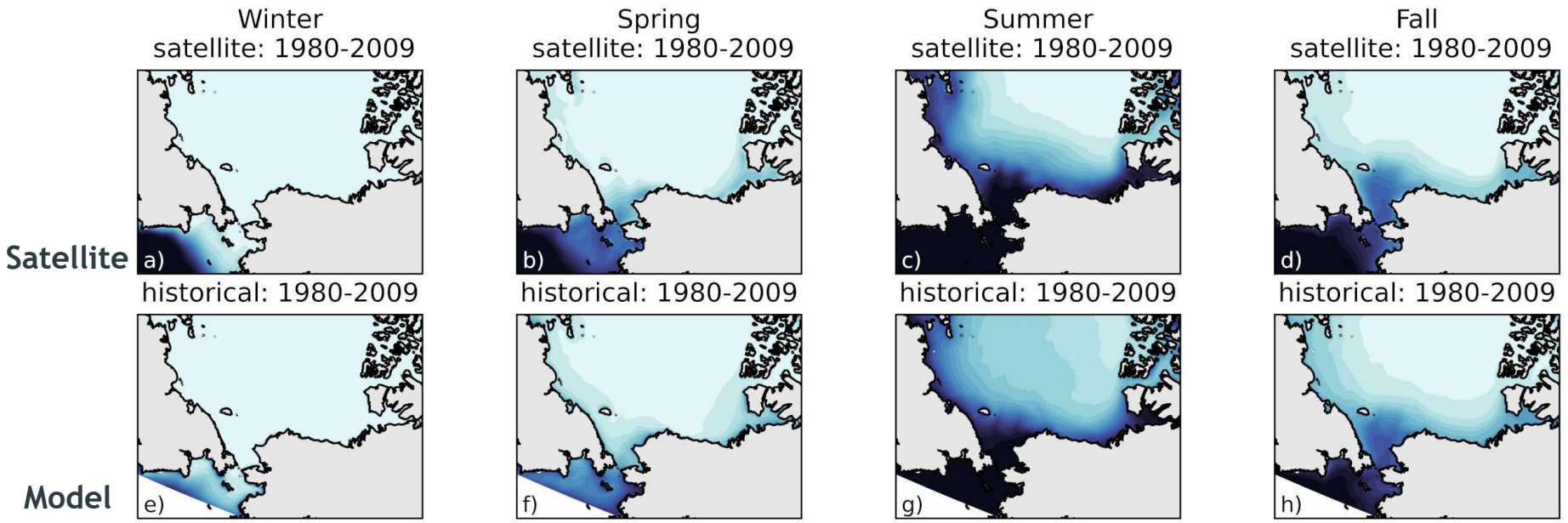
Winter

Spring

Summer

Fall

Sea Ice

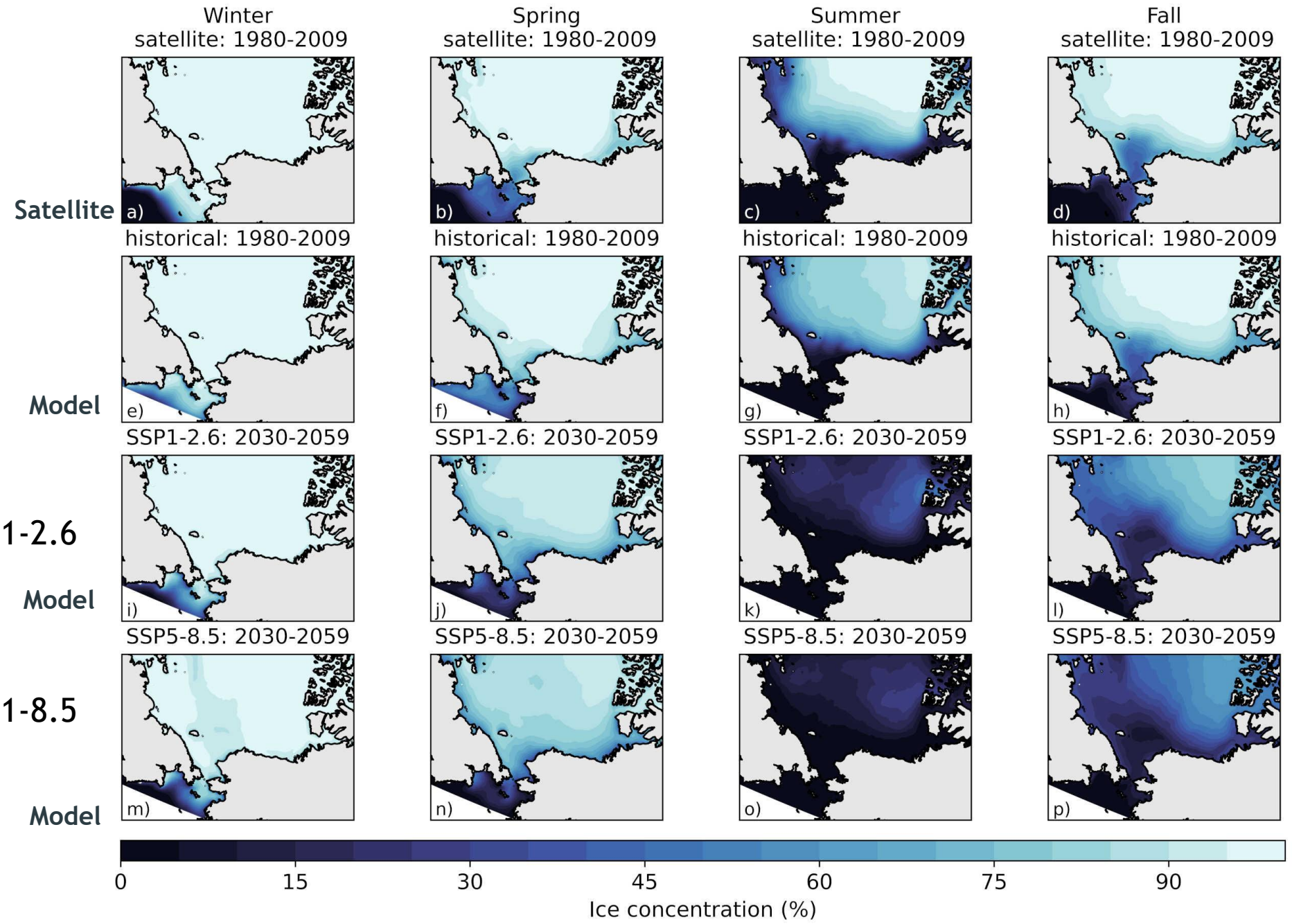


Evaluation: Compare past observations and model to evaluate model performance
=> Good correspondence between satellite and model for all seasons

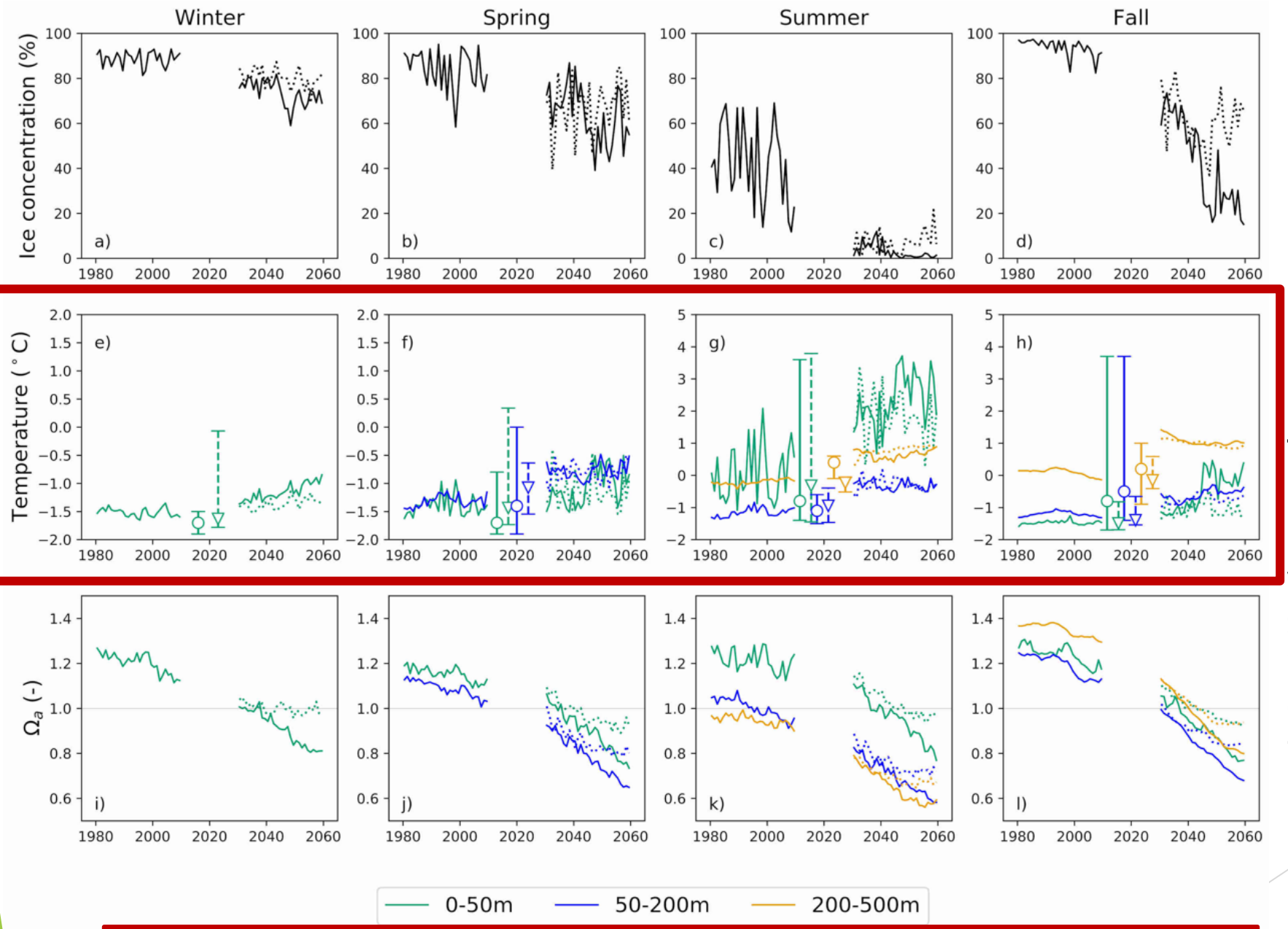


Sea Ice

Similar projected ice retreat across SSPs, earlier and longer open water, impacting in and out migration



Modeled timeseries



Decreased sea ice, increased T, reduced Ωa (and O2). Increased variability in spring and fall. Scenario differences from 2050.

Circles – T from tagged beluga – triangles model with 10/90th percentile

Extremes - Methods

- **Relative thresholds**: daily values of all cells for 1980 -2009:

Temperature: threshold set as 90th percentile of all the values, cells with T > threshold are extreme.

Ω_a: threshold set as 10th percentile, cells with Ω_a < threshold are extreme.

- **Extreme map**: Duration of extremes (in % of the respective season), averaged over the 30 year time period. E.g., a value of 30% refers to extreme conditions for 30% of the 90-92 day season averaged over the years 2030-2059.

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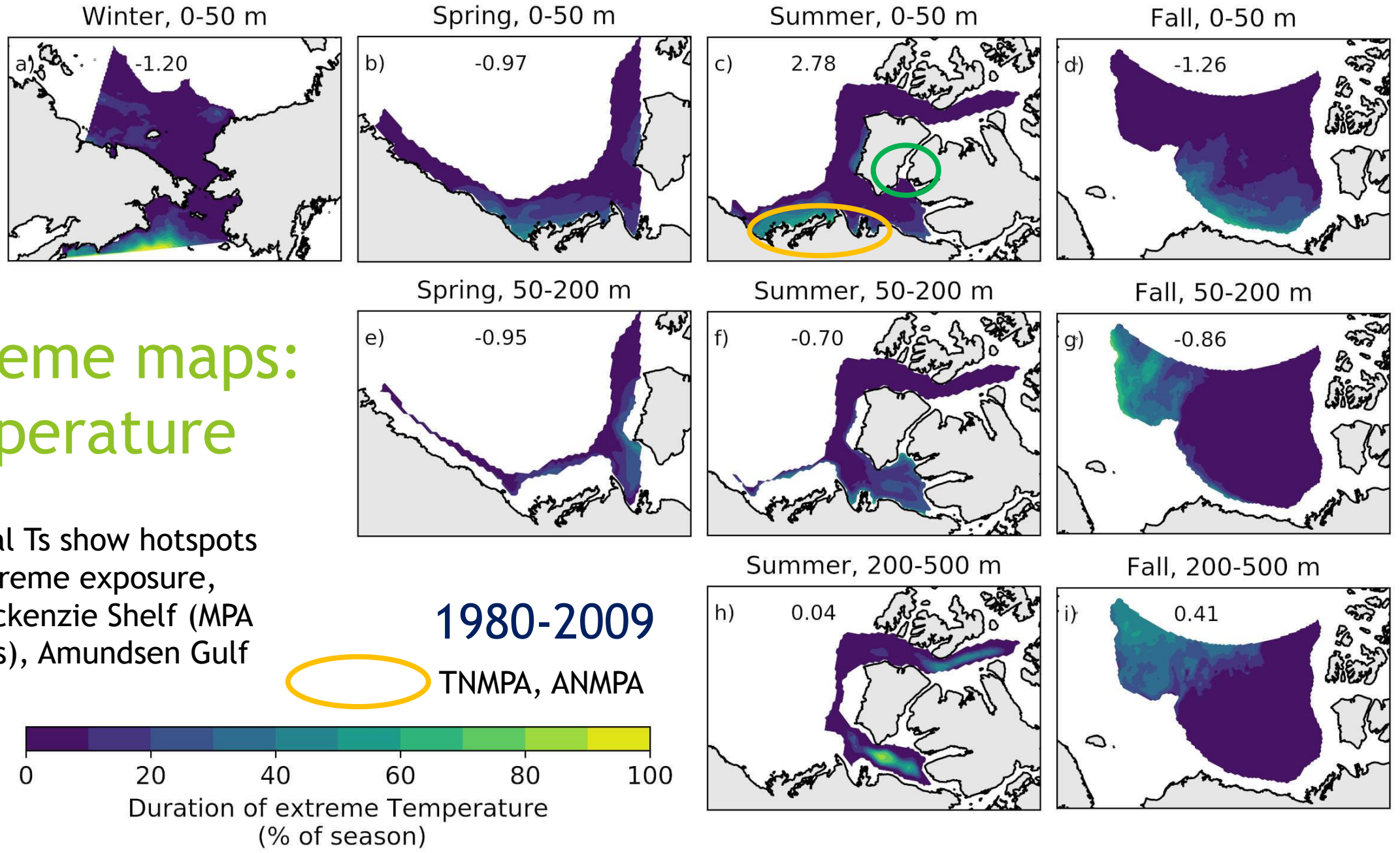
Extreme maps: temperature

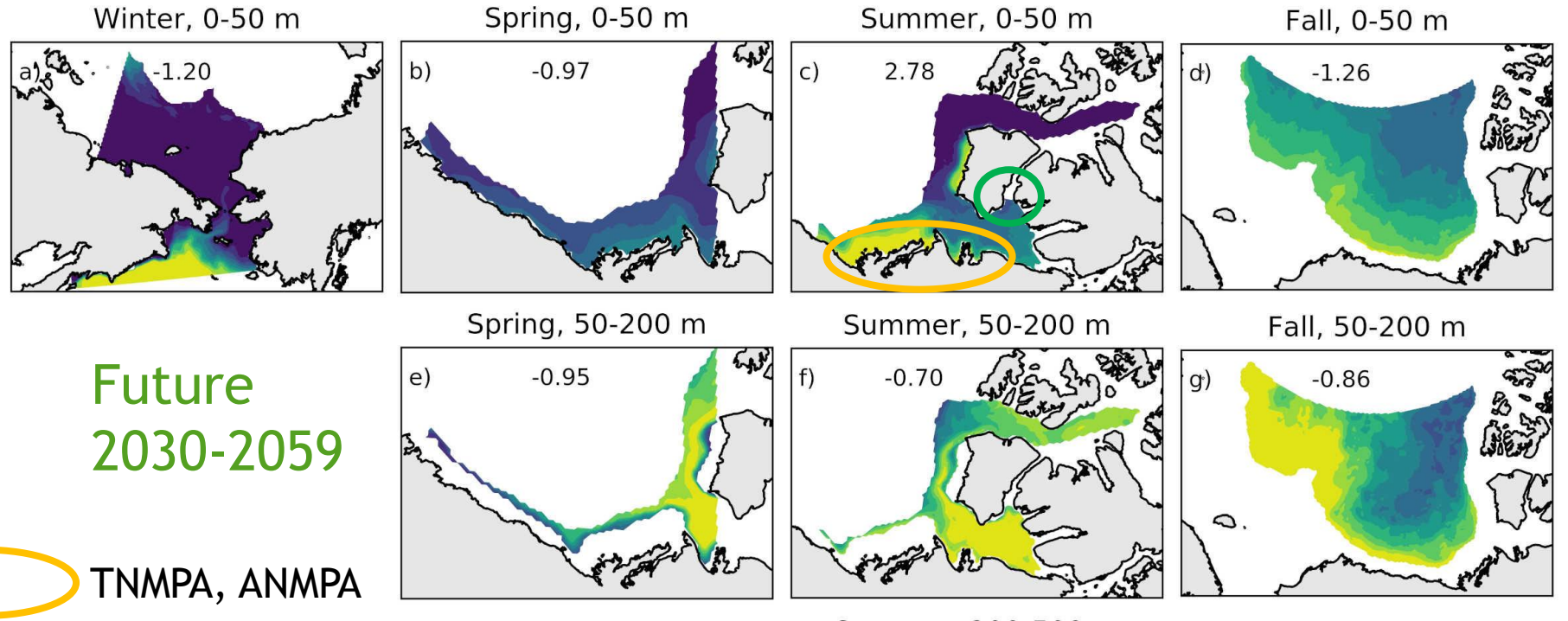
Historical Ts show hotspots with extreme exposure, incl. Mackenzie Shelf (MPA locations), Amundsen Gulf



Extreme maps: temperature

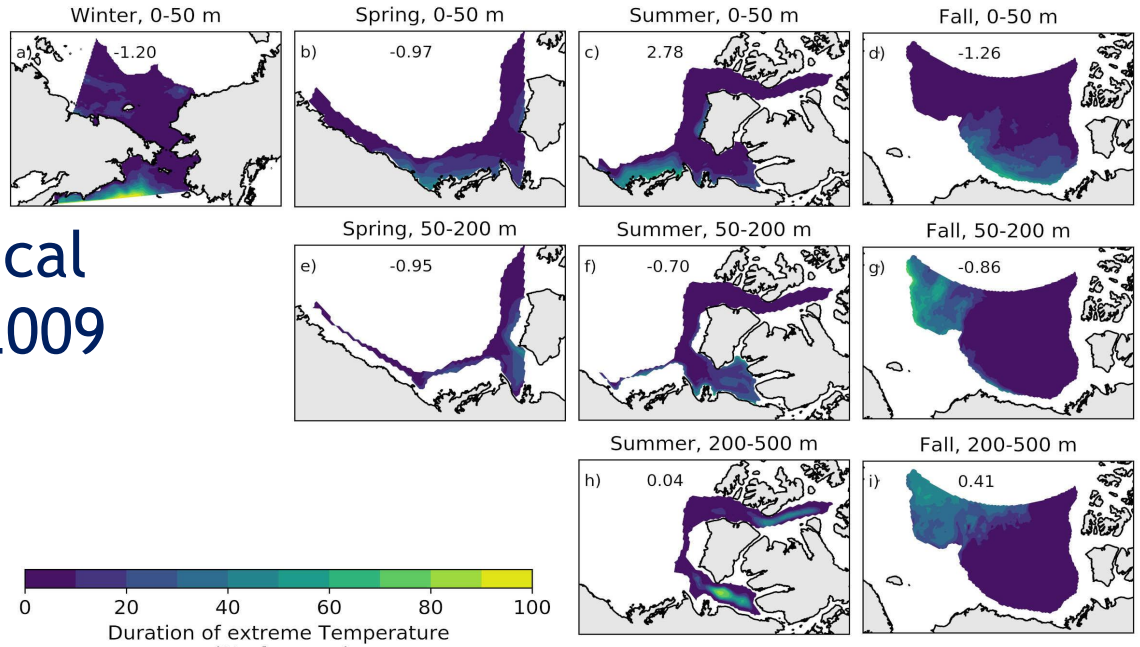
Extended time of extreme exposure and expansion of hot spots. Seasonal shifts (e.g., earlier arrival – less exposure)

Future 2030-2059



TNMPA, ANMPA

Historical 1980-2009

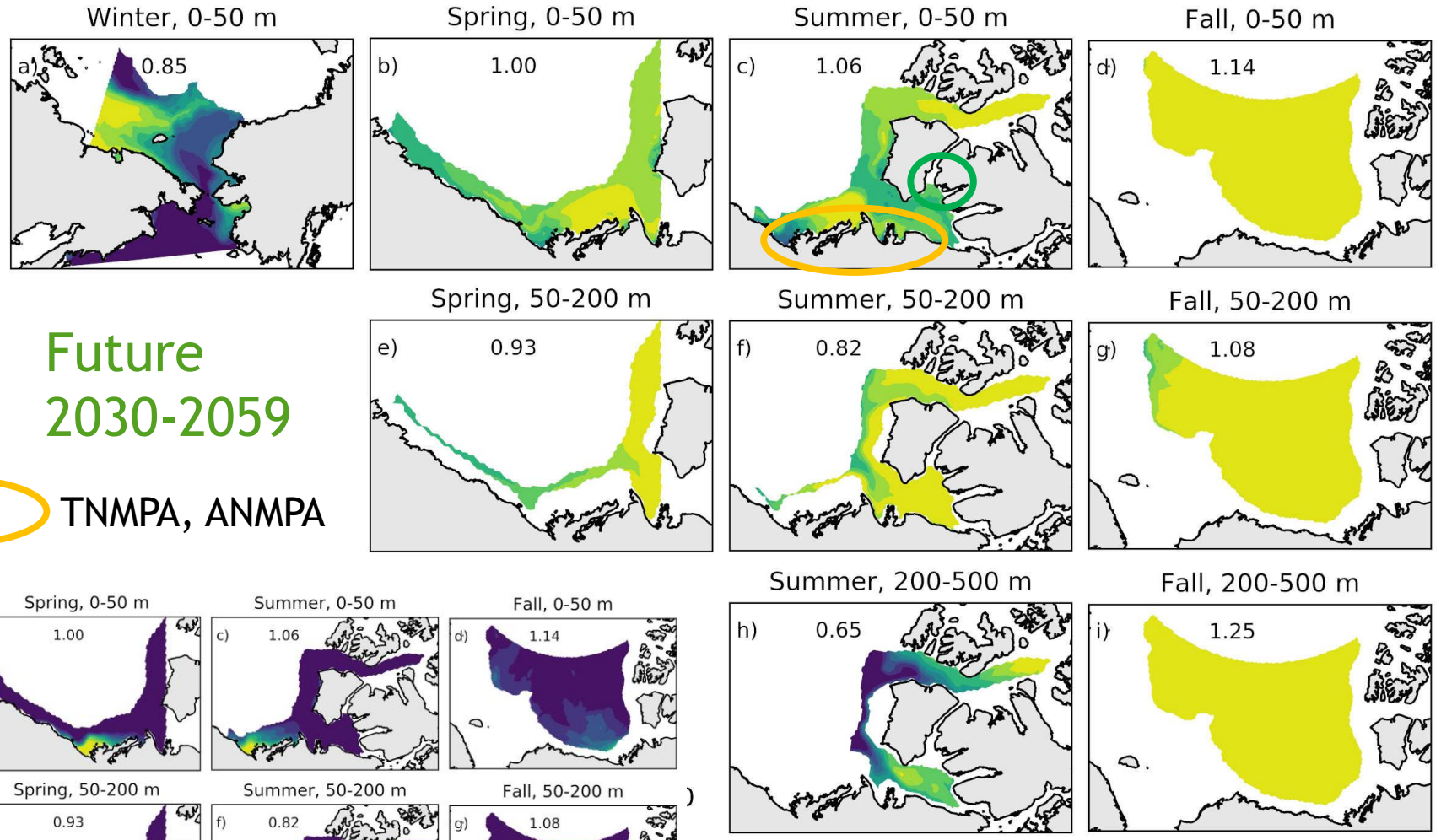


Extreme maps: aragonite saturation state

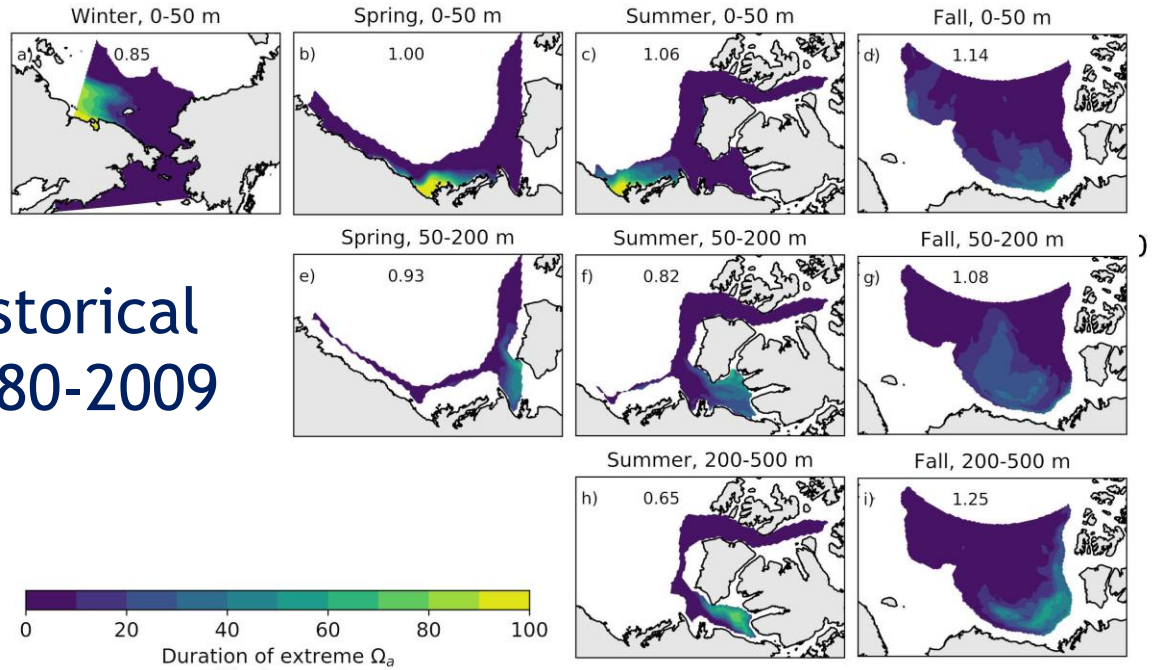
Extended time of extreme exposure and expansion of hot spots

TNMPA, ANMPA

Future 2030-2059



Historical 1980-2009



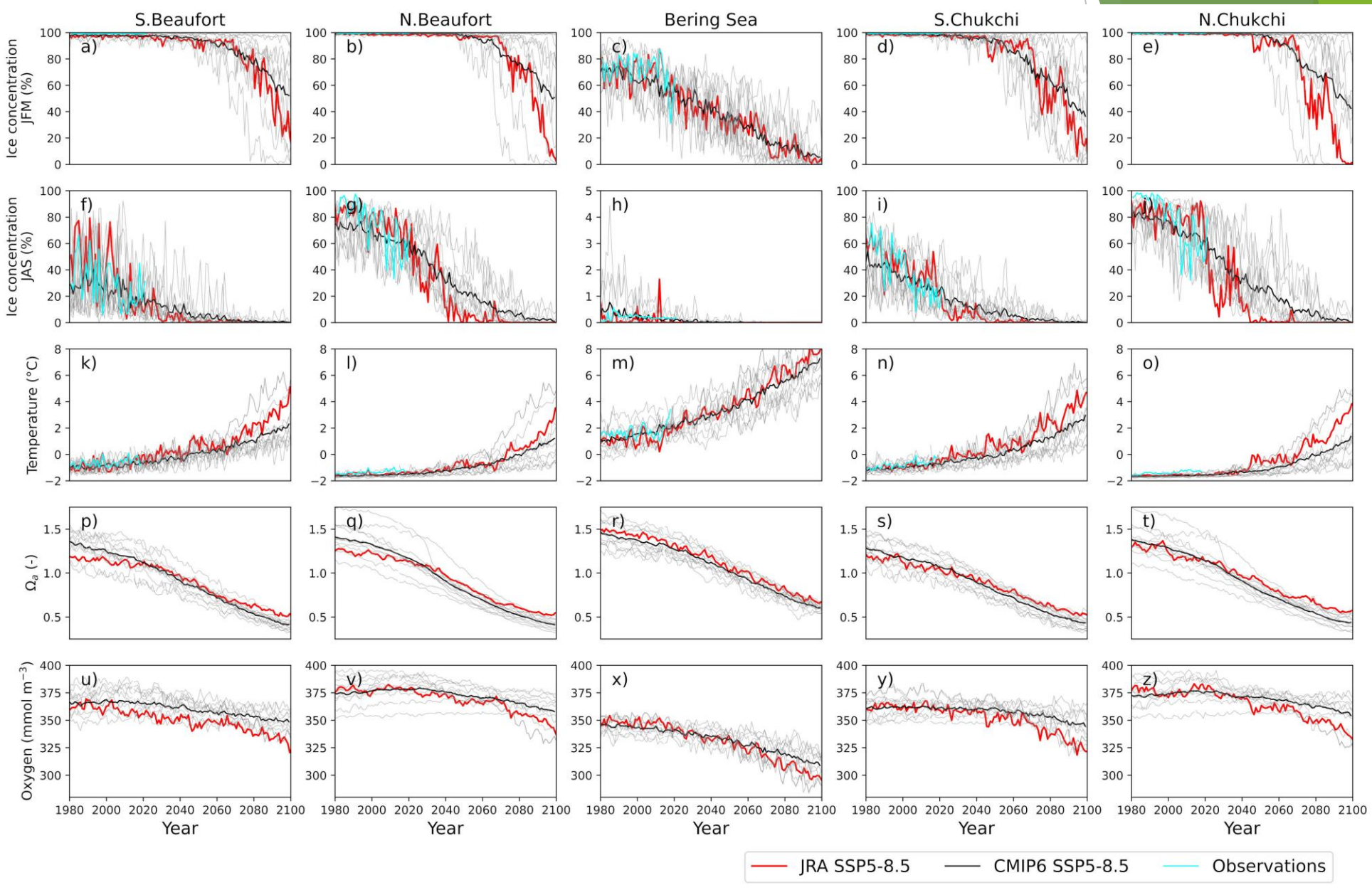
CMIP6 comparison - uncertainty estimates

Good overlap with observed SIC (mean and range of variability)

Good overlap with CMIP6 MMM for most regions: Exception: from ~2070 faster ice retreat and warming.

Slower OA in the Beaufort Sea

Comparison to Steiner and Reader 2024



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Impacts on beluga

- Sea-ice: migration pathways and timing
- Temperature: direct impacts (stress, health), indirect impact: food chain- Arctic cod
- Ocean acidification: direct impacts unknown, indirect impacts: food chain – Arctic cod, pteropods
- Primary production: mostly reduced ice algae, increased ocean PP = Impacts on food chain
- Single and compound extremes (T, OA) in key beluga and prime Arctic cod habitat, incl. MPAs
- Seasonal shifts may avoid extreme states
- Additional impacts on beluga and harvesting: weather & waves, pollutants, ship traffic

Communication challenges with Inuit communities

- Modelling Beluga (and Seal) habitat ⇒ Important but triggering
  - Ex: “Does DFO allow us to do these projections?”
    ⇒ IGC asked for clarifications

- Why is it so challenging? Some hypotheses:
  - Different from observations or assessments, yet often unclear
  - In modelling, averages help overcome uncertainties but create a distance with observations and direct interpretations
  - Over-interpretation or decision-maker misuses in the past
  - Accountability issues:
    - How can we talk about "potential" future(s) without compromising knowledge-holders' accountability towards the next generations ?
    - Who has authority to "tell the future" ? (→linked to DFO allowing …)

Questions ?

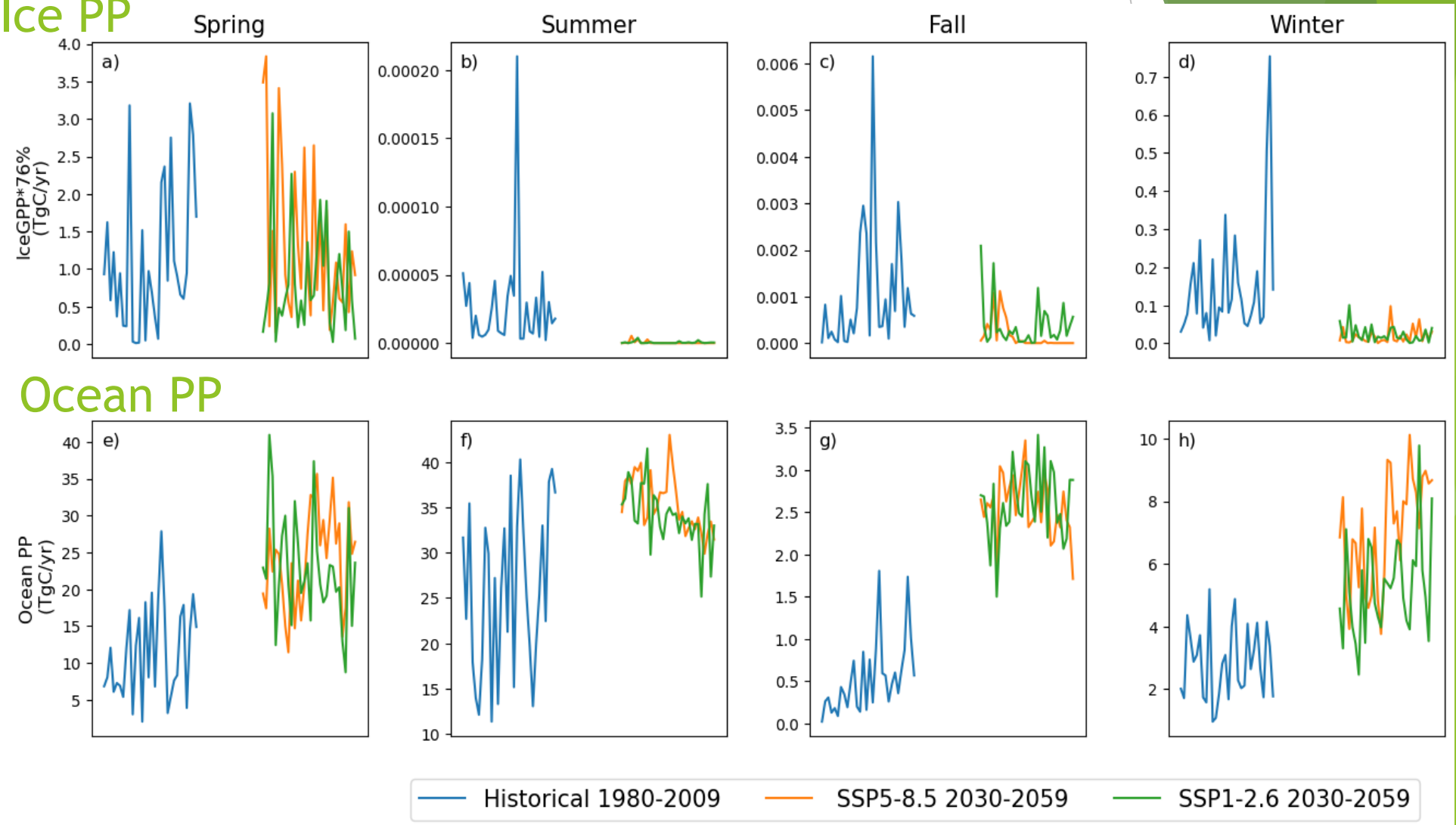
Sea Ice and Ocean Primary Production

Ice PP

Decrease in sea ice PP with initial increase in spring
Increase in oceanic PP

Ocean PP

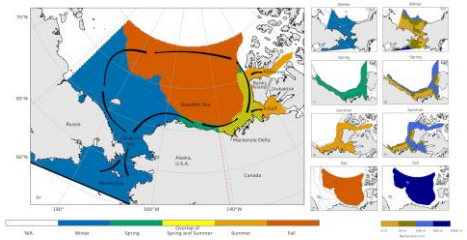
- Suggests food availability retained, although changes in food chain: increased pelagic vs sympagic with potential impacts on Arctic cod



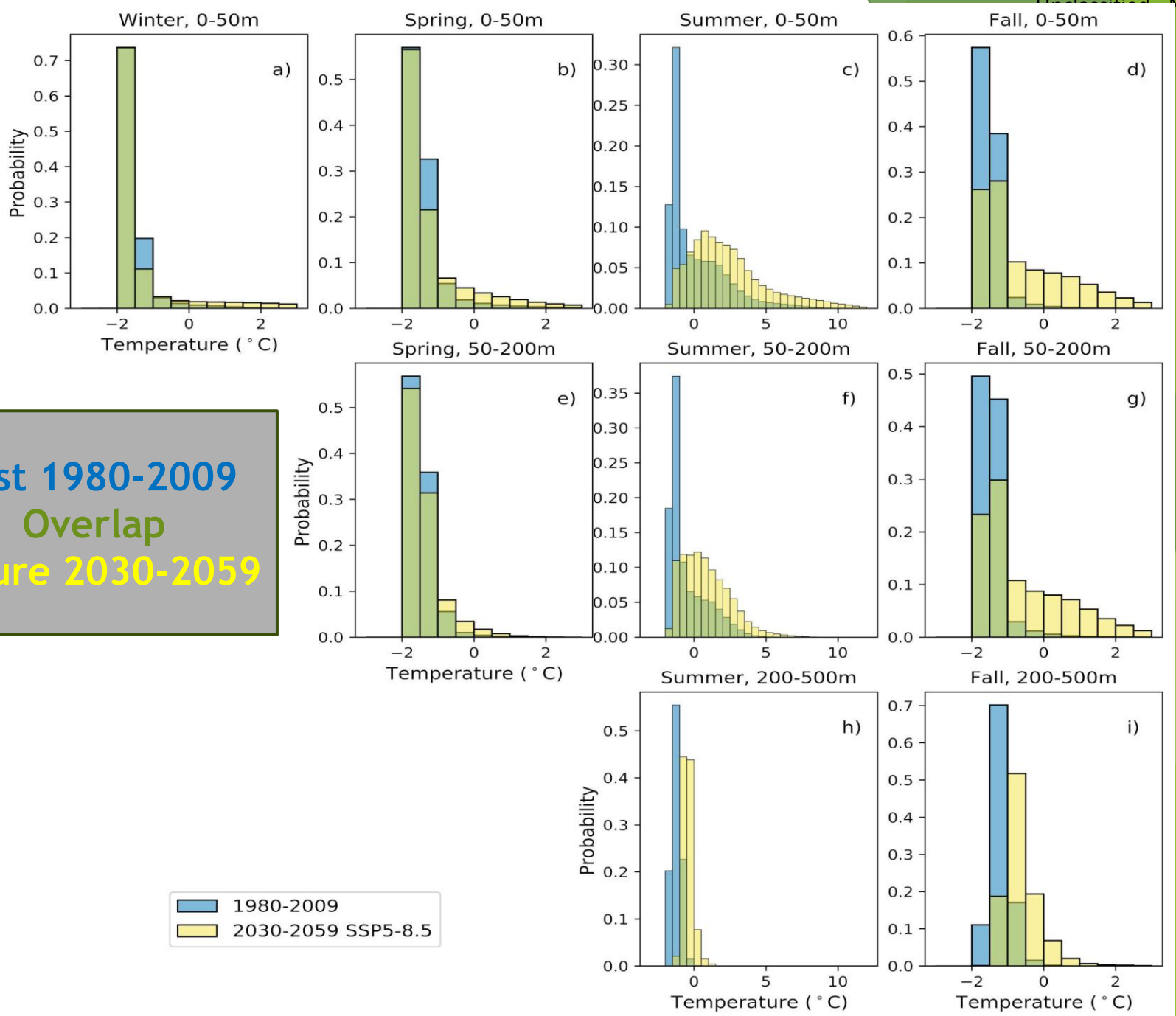
Changes in temperature

1980-2009 to 2030-2059

Shift from predominantly freezing temperatures to a wider range of warmer (>0) temperatures. Largest changes in summer and fall.



Past 1980-2009
Overlap
Future 2030-2059



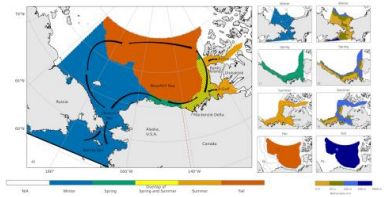
Changes in aragonite saturation state

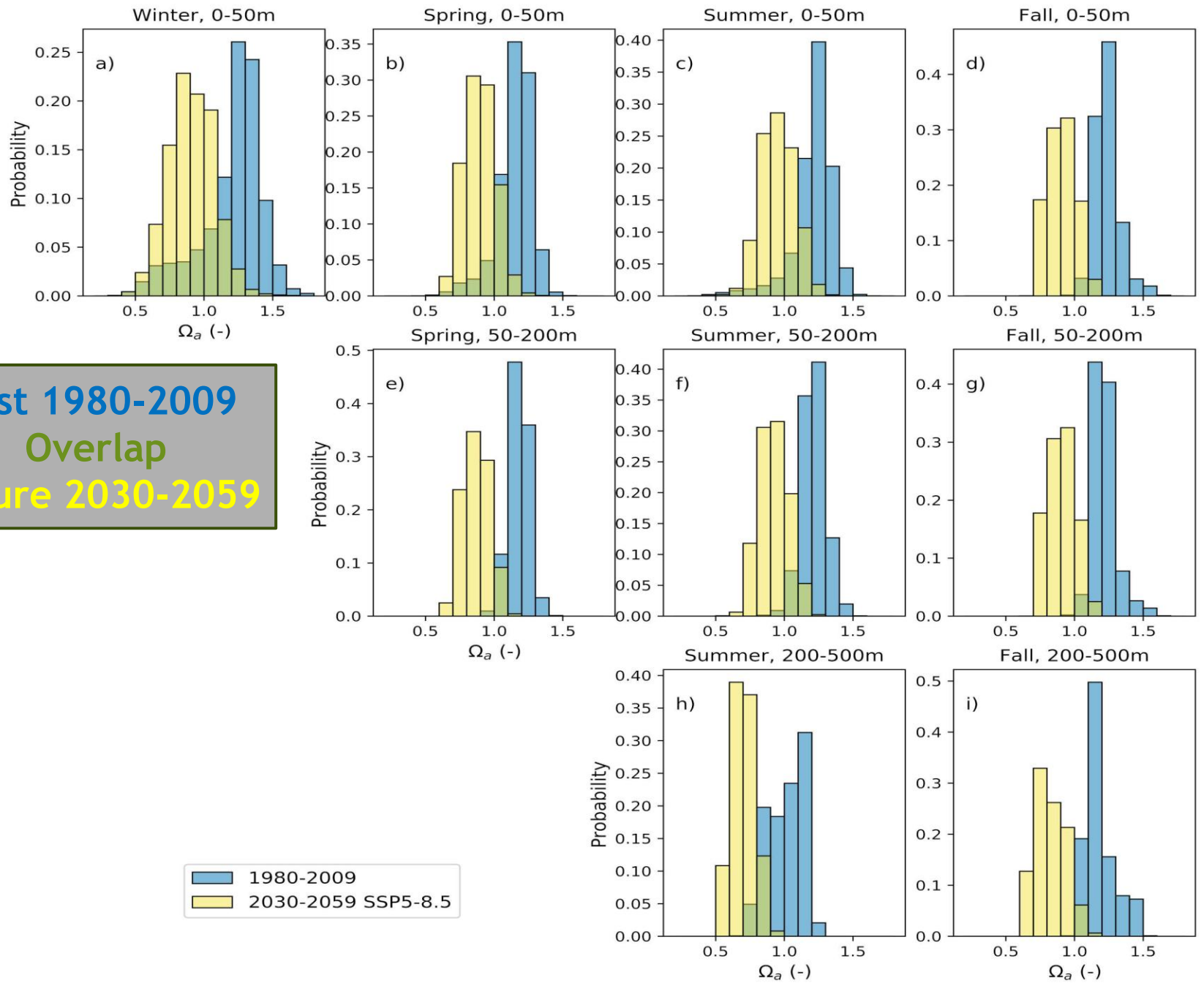
1980-2009 to 2030-2059

Past 1980-2009
Overlap
Future 2030-2059

Ωa: Clear shifts from supersaturated to undersaturated waters in all seasonal regions

O2: reductions but low concern – not included

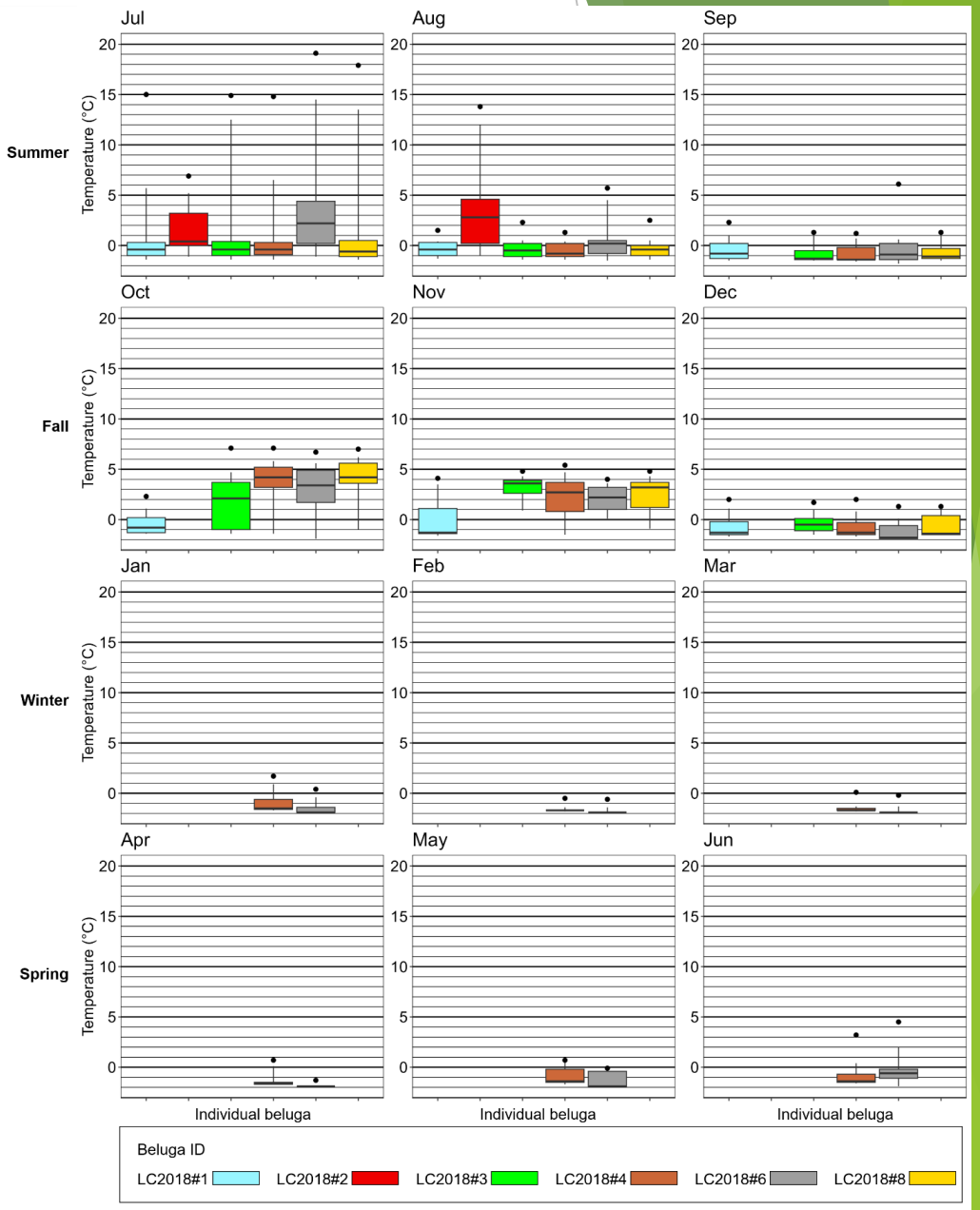




Beluga tagging data
-Temperature ranges-

- Calculated thresholds and ranges compared to beluga tagging data
- Similar ranges except for fall …
- Evaluation in progress …

Season	Variable	0-50m	50-200m	200-500m
Spring	Temperature	-0.97	-0.95	
Summer	Temperature	2.78	-0.70	0.04
Fall	Temperature	-1.26	-0.86	0.41
Winter	Temperature	-1.20		
Spring	Omega_a	1.00	0.93	
Summer	Omega_a	1.06	0.82	0.65
Fall	Omega_a	1.14	1.08	1.25
Winter	Omega_a	0.85		



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Extremes - Methods

- **Absolute thresholds**: based on species responses/physiology
- **Relative thresholds**: daily values of all cells are sorted within a seasonal region and depth interval for the time period 1980 -2009 in ascending order. For temperature, threshold is set as the 90th percentile of all the values within each category, i.e. cells with T > threshold are extreme. For Ω_a, the 10th percentile is used, cells with Ω_a < threshold are extreme.

- **Extreme fraction**: Time series of the proportion of the region (in %) that exceeds the threshold (higher for temperature, lower for Ω_a).
- **Extreme map**: Spatial map showing the duration of extremes (in % of the respective season) for each grid cell, averaged over the thirty year time period. E.g., a value of 30% refers to a cell experiencing extreme conditions for 30% of the 90-92 day season averaged over the years 2030-2059.

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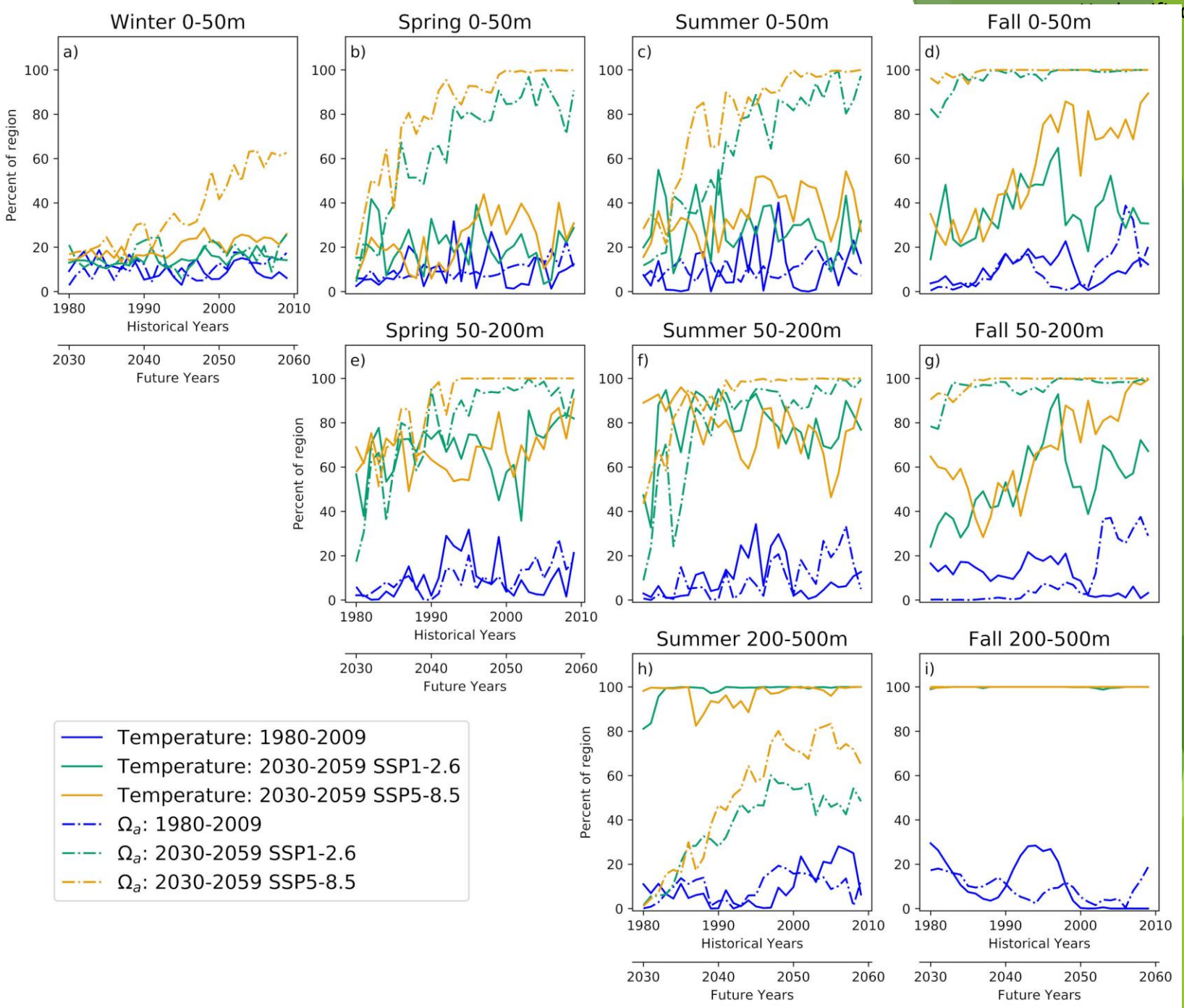
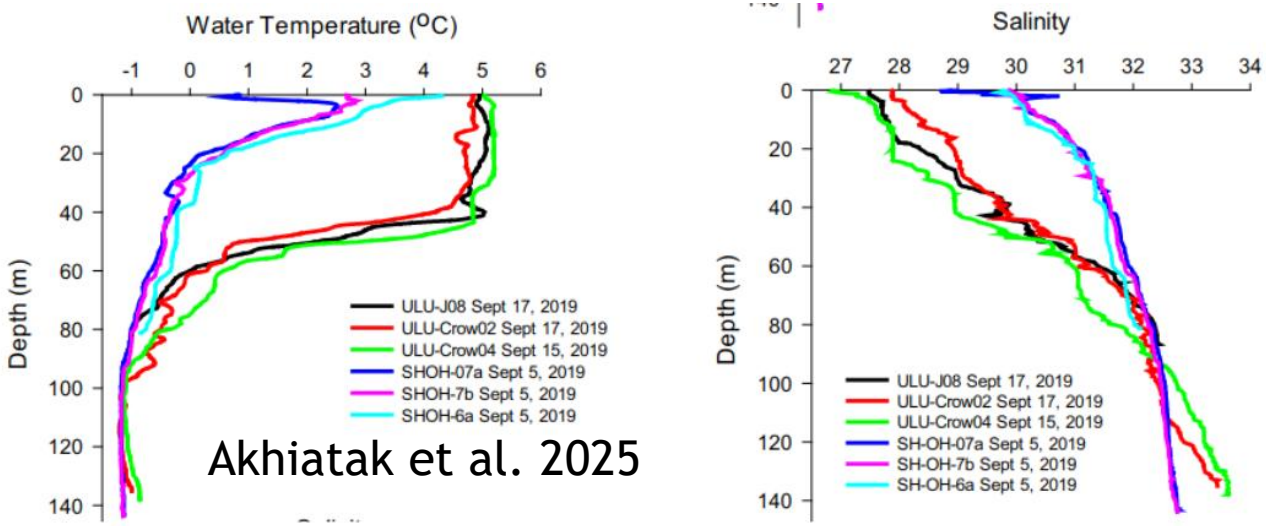
Time series of extreme fraction (% of region exposed to extremes)

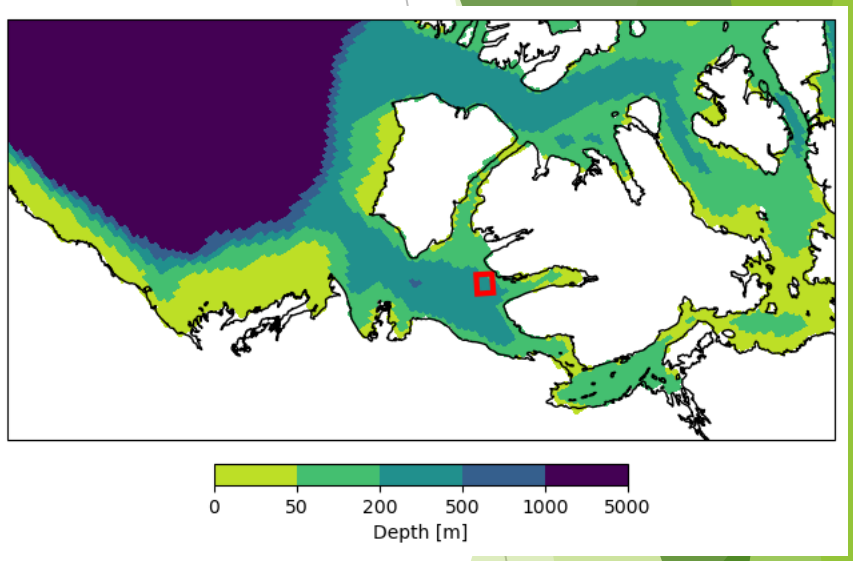
Clear increase in extreme exposure for both T and Ωa, particularly at depth (100%) for both scenarios – depth correspond to prime Arctic cod habitat)

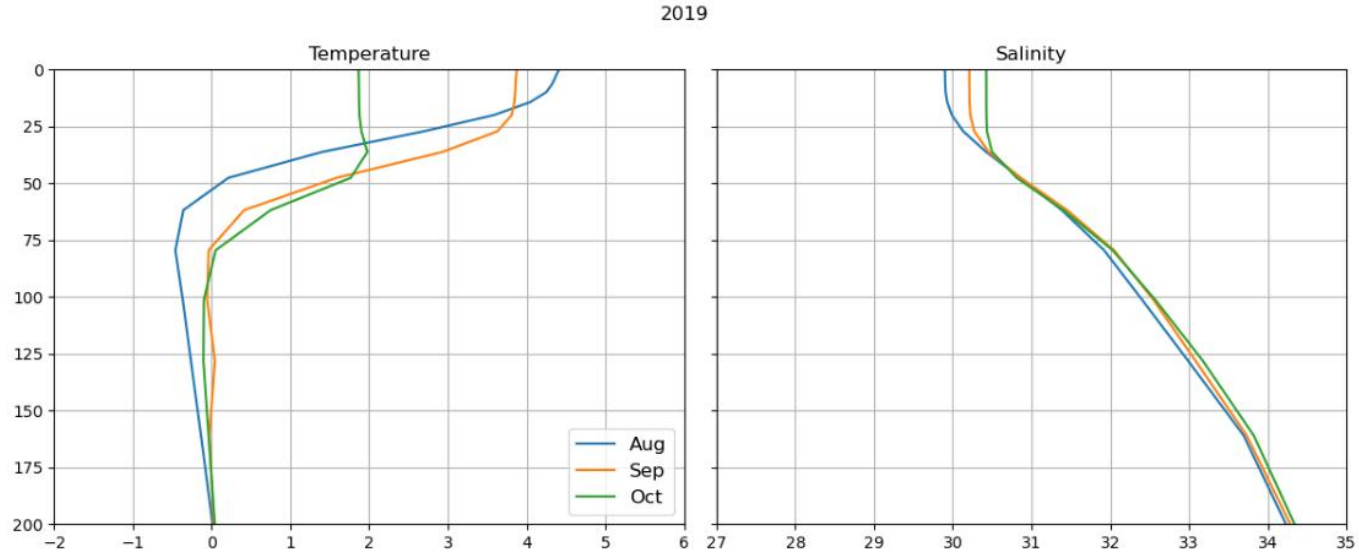


Model – CBM comparison - Ulukhaktok



Akhiatak et al. 2025





Summary & impacts on beluga

- Larger regions and depths exposed to extremes (outside historical values) for all future scenarios.
- Sea Ice changes: - Earlier migration into the Arctic, delayed out-migration, overwintering possible - Potential new habitat further offshore, around Banks island, and in Amundsen gulf.
- New fall conditions similar to historical summer (temporal shifts).
- Current fall habitat and 50-200m level in Amundsen gulf (summer region) show temperature and acidification extremes in the future (prime Arctic cod habitat – impacts on food chain).
- Beaufort shelf and Mackenzie delta: areas of potential increased stress in spring and summer - Key beluga habitat, MPAs (100% extreme => lower outside current time window => accessible/frequented earlier in the year?)
- Changes in ice-algal production and ocean acidification may impact beluga prey (impact on forage species e.g. Arctic cod, pteropods)
- High interannual variability – recovery possible?