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Coastal Physical-Biogeochemical Processes Enhance Subsurface Acidification Rates on the Bering Sea Shelf

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Abstract

Seasonal manifestations of ocean acidification (OA) are already occurring in the Bering Sea, in the form of late summer bottom water conditions that are undersaturated with respect to aragonite. Although these more acidic conditions are generated by natural processes, OA is projected to increase their duration, magnitude, and spatial extent. It is therefore critical to develop skillful predictions and projections of these more acidic water conditions to support sustainable fisheries management over long- and short-term time scales. We use a regional ocean biogeochemical model to simulate changes in ocean carbon chemistry for the Bering Sea shelf from 1970-2022. Over this timeframe, surface waters display negative trends in Ω_{arag} and pH similar to global ocean acidification rates, however bottom water trends are greater in magnitude than surface waters by a factor of 2-2.75. In addition, bottom waters are already relatively more acidic, thus they pass key threshold values much sooner than surface waters. This amplified subsurface acidification is driven by an enhanced productivity-remineralization cycle, whereby increasing primary productivity generates increased surface ocean carbon uptake and bottom water carbon remineralization. Furthermore, this bottom water remineralization signal accumulates downstream of the along-shelf currents, leading to greatly accelerated acidification rates in the northwest Bering Sea shelf and Gulf of Anadyr. These results highlight the importance of accurately resolving high-resolution coastal shelf processes in order to produce reliable model-based products of OA to support fisheries management.

Background

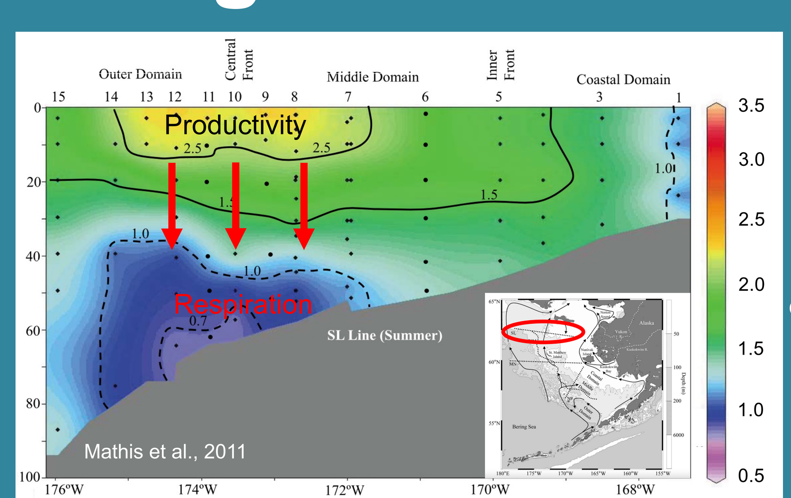

Figure 1: Transect of Ω_{arag} along the SL line (red circle, insert) during the summer of 2008. Image modified from original source

- Substantial seasonal primary productivity on Bering Sea shelf supports rich ecosystem but generates relatively acidic bottom water conditions due to respiration and remineralization
- Recent work has noted accelerated acidification trends in the neighboring Chukchi Sea due in part to increased productivity and biological respiration (Qi et al., 2022)
- Global subsurface acidification rates can outpace surface rates due to lower buffer capacity (Fassbender et al., 2023)

NOAA OCEAN ACIDIFICATION PROGRAM

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Methods

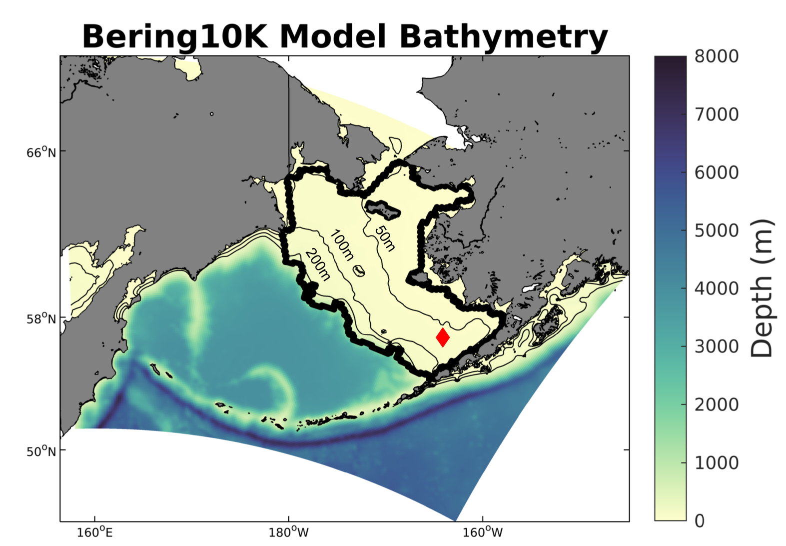

Figure 2: Map of model bathymetry with 50,100, and 200m isobaths representing inner, middle, and outer shelf domains respectively. Black outline denotes Bering Sea shelf region, red diamond is M2 mooring location

- 10km horizontal resolution with 30 vertical layers
- BESTNPZ ecosystem model (Kearney et al., 2020) with carbonate chemistry (Pilcher et al., 2019)
- Atmospheric forcing and horizontal boundary conditions from CORE 1970-1994 and CFSR 1995-2022
- Previous model validation in Pilcher et al., 2019

Longterm Carbon Chemistry Trends

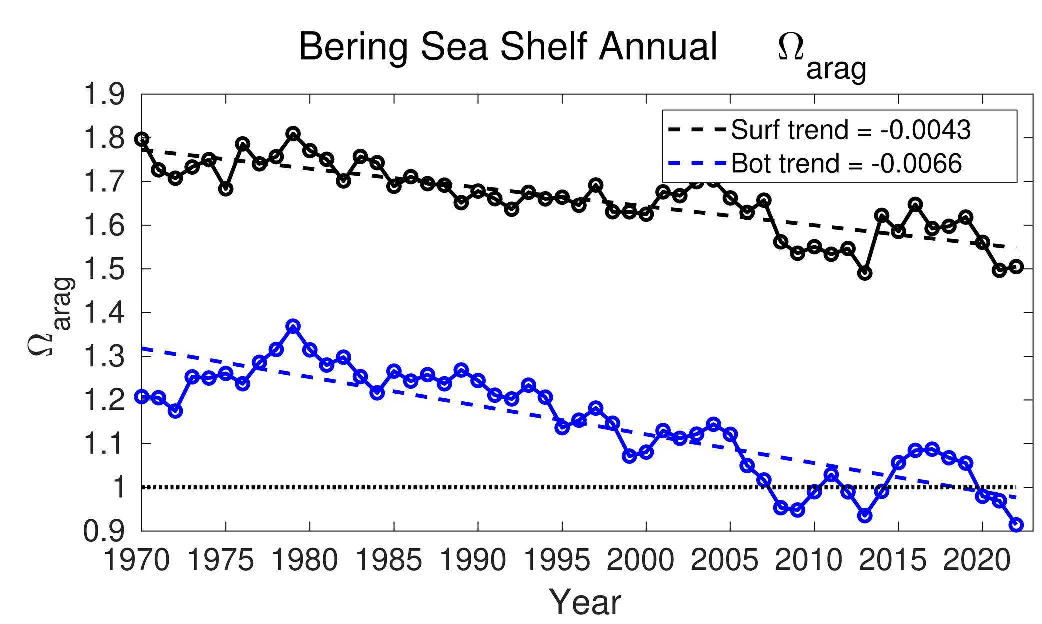

Figure 3: Timeseries of modeled annual average surface (black line) and bottom (blue line) Ω_{arag} along with linear trends (dashed lines)

Ω_{arag}: Bottom trend **1.5x greater** than surface

pH: Bottom trend **2.0x greater** than surface

[H^+]: Bottom trend **2.75x greater** than surface

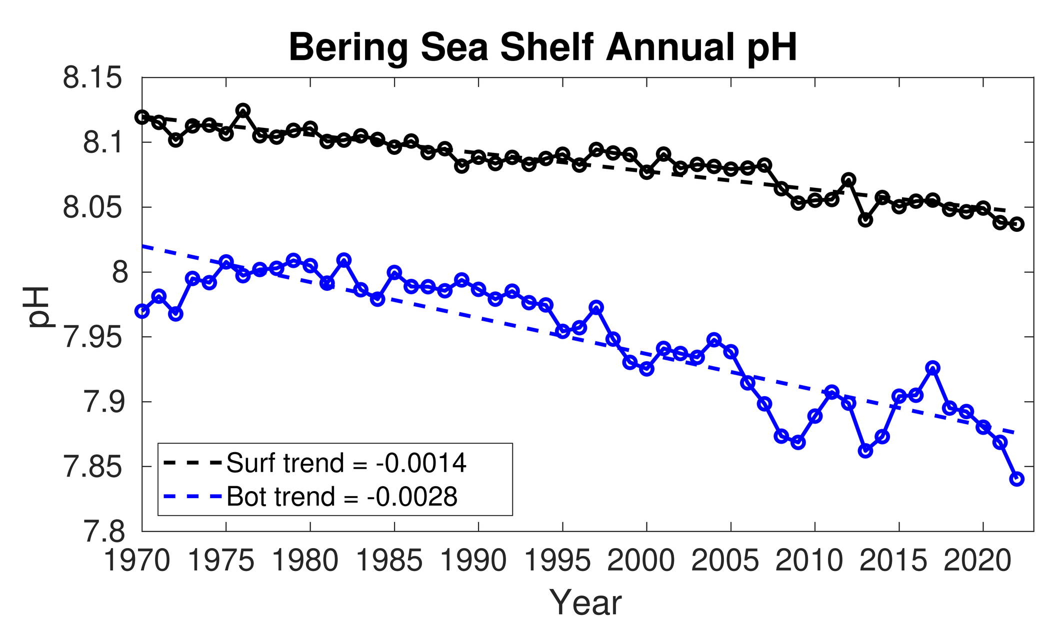

Figure 4: Timeseries of modeled annual average surface (black line) and bottom (blue line) pH along with linear trends (dashed lines)

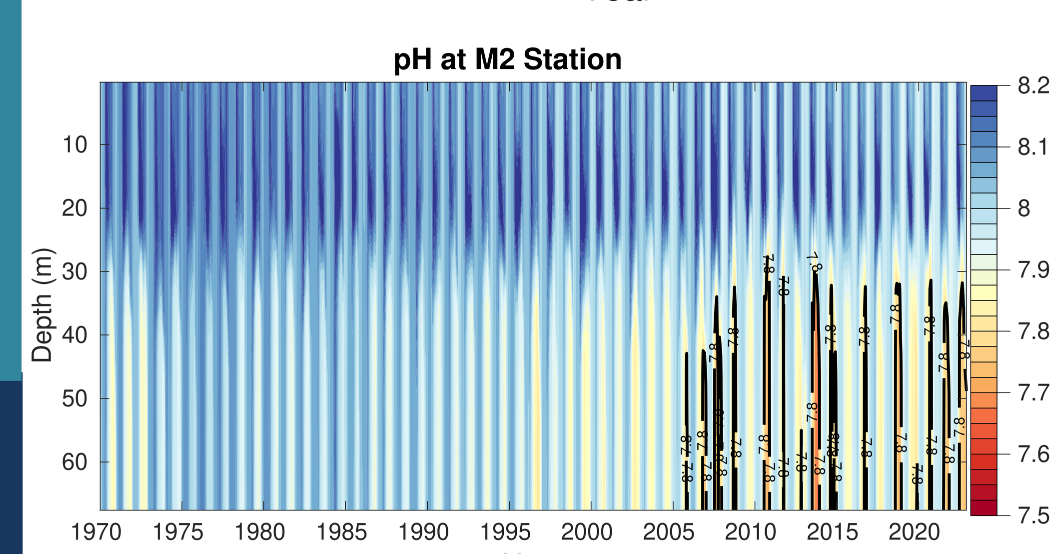

Figure 5: Model monthly averaged pH over the entire model timeseries at the M2 mooring approximate model location. The black contour line denotes the threshold for pH values < 7.8

Lower initial values combined with greater trends generates conditions harmful to red king crab much faster in subsurface waters

pH < 7.8 harmful to red king crab growth and survival (Long et al., 2013)

Mechanisms of Amplified Subsurface Acidification

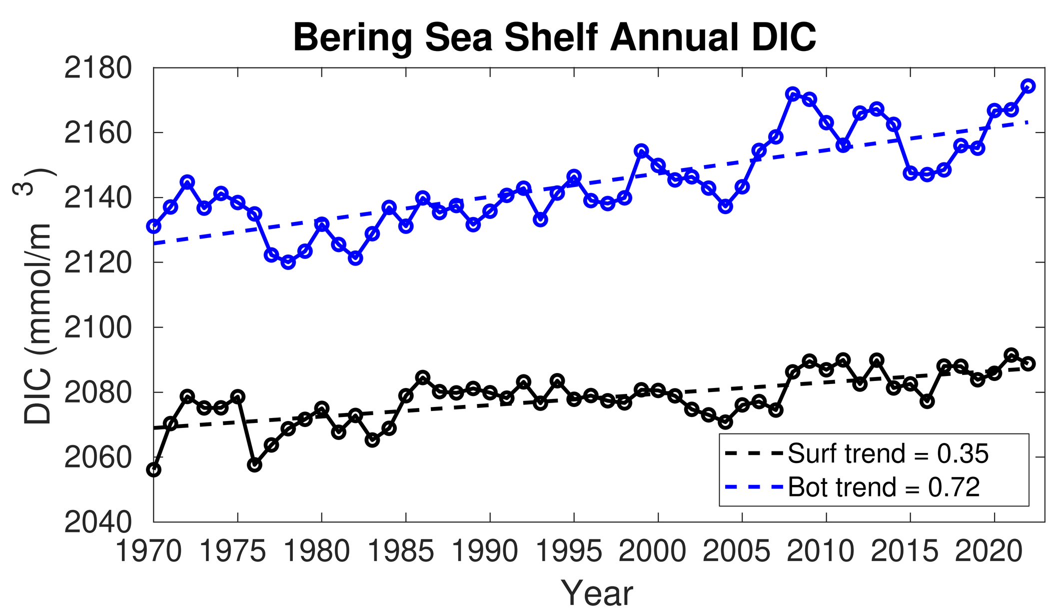

Figure 6: Model timeseries of shelf surface (black line) and bottom (blue line) dissolved inorganic carbon (DIC)

- Bottom DIC trends 2.0x greater than surface
- Suggests anthropogenic CO_2 and reduced buffer capacity are **not** primary mechanisms

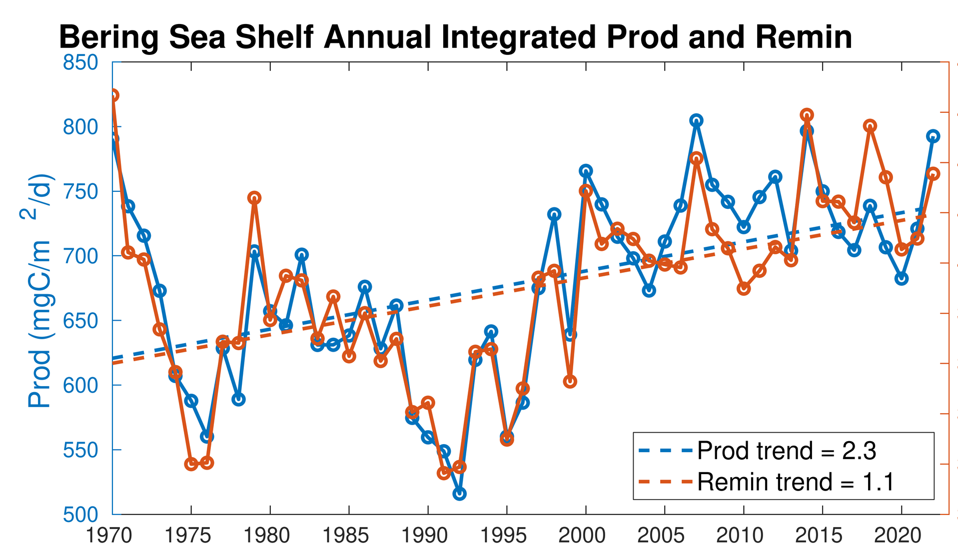

Figure 7: Model timeseries of water column integrated primary production (blue line, axis) and remineralization (orange line, axis)

Substantial variability, but overall net enhancement of productivity-remineralization cycle, similar to recent work in the neighboring Chukchi Sea

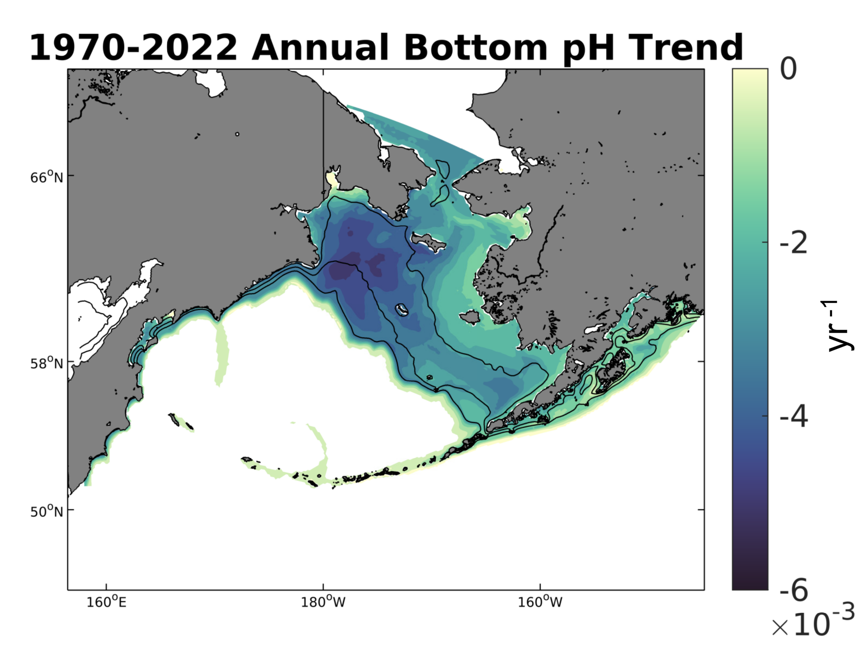

Figure 8: Model bottom pH annual linear trend from 1970-2022

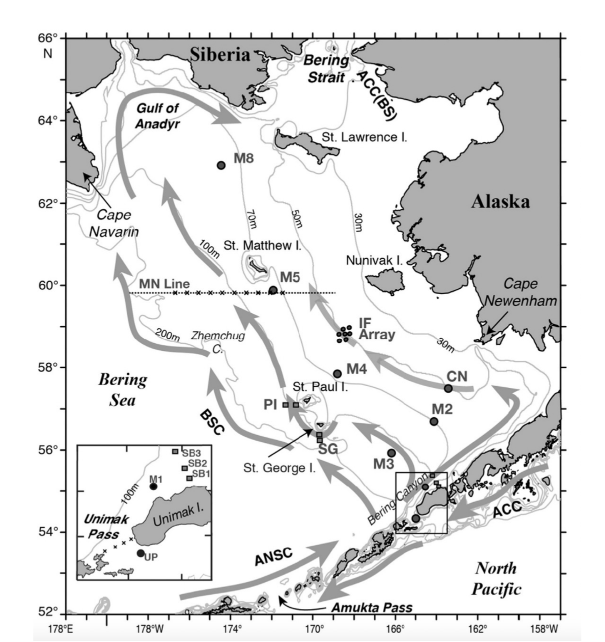

Figure 9: Schematic of dominant shelf circulation from Stabeno et al., 2016

- Bottom pH trends strongest in northwestern shelf on middle and outer shelf domain near Gulf of Anadyr
- This region tends to contain relatively high subsurface carbon concentrations and low water buffer capacity
- Shelf subsurface circulation is primarily along shelf isobaths
- Productivity-remineralization changes dispersed throughout shelf, however circulation may be accumulating impacts downstream
- Intrusions of water from deep Bering Sea basin also transport low pH water, with notable modeled events occurring from 2018-present

Conclusions

1) Model surface trends are similar to global ocean acidification trends, however, bottom water trends are substantially greater, particularly for pH and [H^+]
2) Amplified subsurface trends driven by enhanced coastal shelf productivity-remineralization cycle
3) Shelf circulation generating a buildup of remineralized carbon in northwestern shelf near Gulf of Anadyr