The Bering Sea Integrated Ecosystem Research Program: downscaling climate change to a subarctic region with coupled biophysical models

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The continental shelf of the Bering Sea is one of the most productive areas of the global ocean. As an element of the Bering Sea Integrated Ecosystem Research Program (BSIERP), we are downscaling a subset of IPCC model projections of global climate change to the physics and biology of this shelf, using a 3D primitive equation regional hydrodynamic model. Ultimately our work entails an ensemble of coupled (physical, NPZ, food web) runs, to better capture the nonlinear effects of climate change as they cascade through the trophic levels of the ecosystem. The circulation model (ROMS) includes both ice and tidal dynamics. The NPZ model includes multiple size classes of phytoplankton and zooplankton, as well as significant fish prey such as euphausiids. The higher tropic level model (FEAST) as presently designed includes ~50 length classes each of pollock, cod, and arrowtooth flounder, with allometric relationships relating fish size to food preference.

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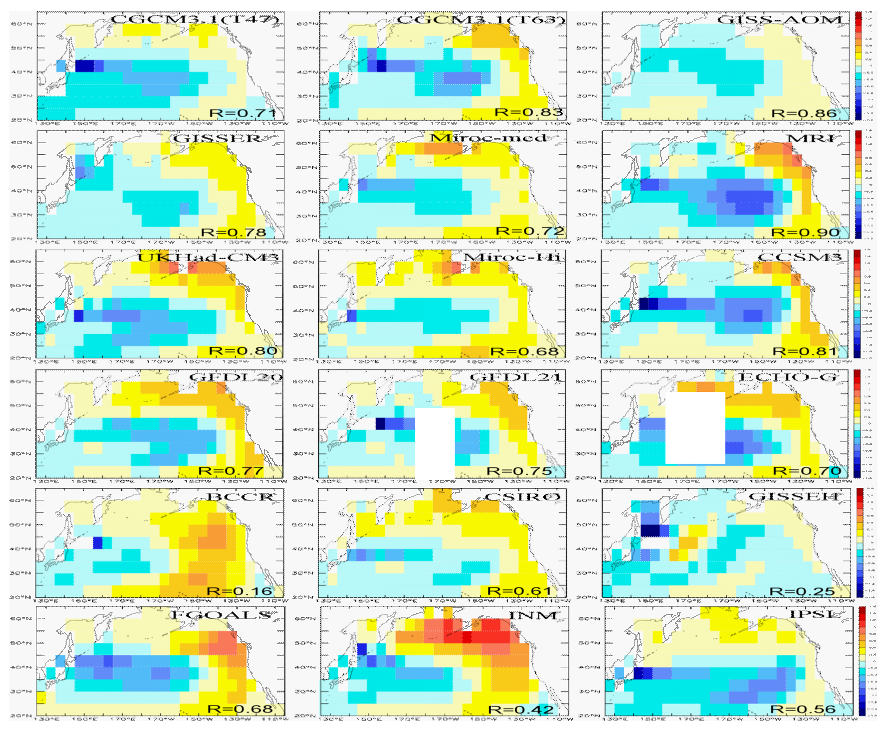
Large-scale drivers for the regional model are derived from IPCC projections of future climate

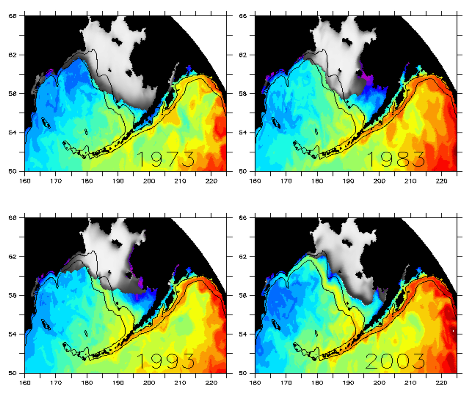


shown here: major mode of SST variability in the NE Pacific (PDO) from several of the IPCC models

ensemble of runs

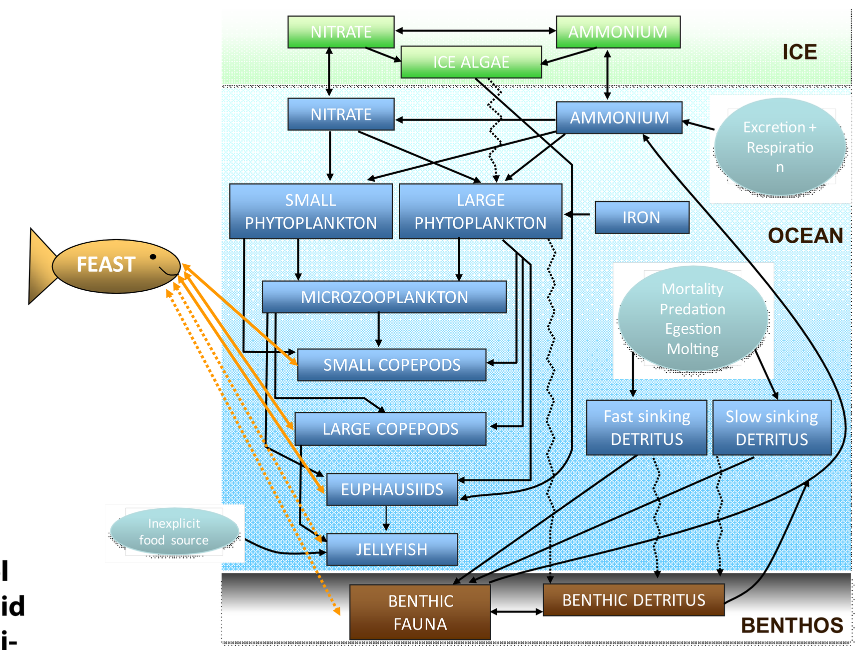
Component physical and biological models are designed/run on the same spatial grid to capture nonlinear interactions

ROMS regional circulation model



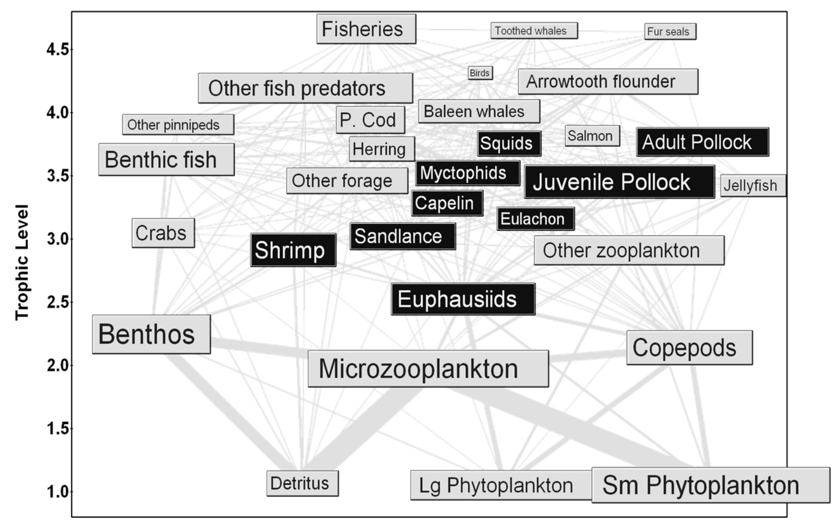
The Regional Ocean Circulation Model (ROMS) in impemented on a 10-km grid spanning the Bering Sea, with 60 vertical layers. This implementation includes both tides and ice (Curchitser and Hedstrom).

NPZ model



The lower trophic level (NPZ) model (Gibson et al.) includes multiple size classes of phytoplankton, zooplankton, and detritus, as well as ice algae and benthos.

FEAST foodweb model

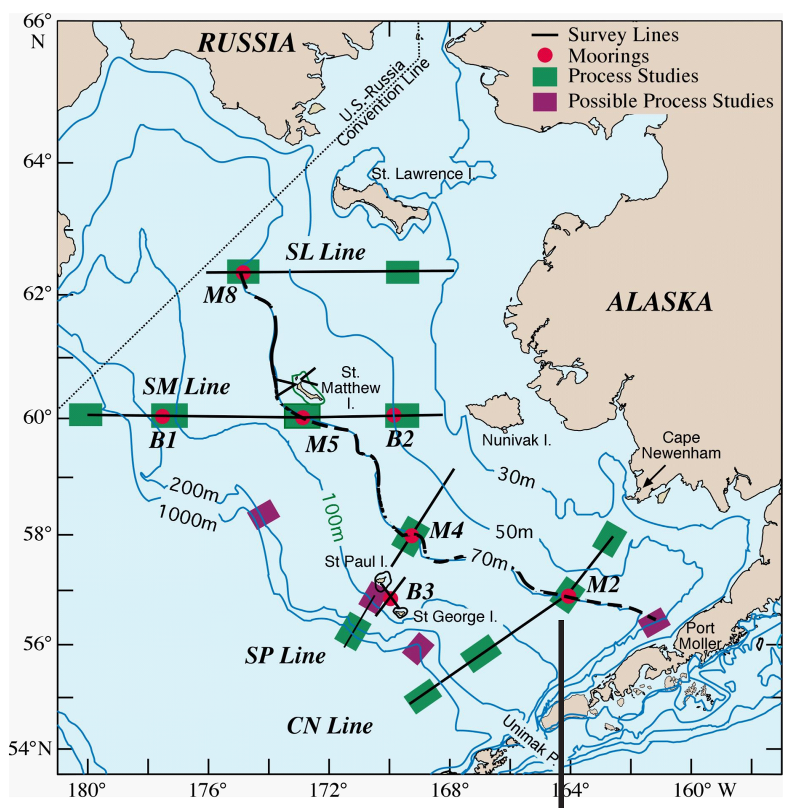


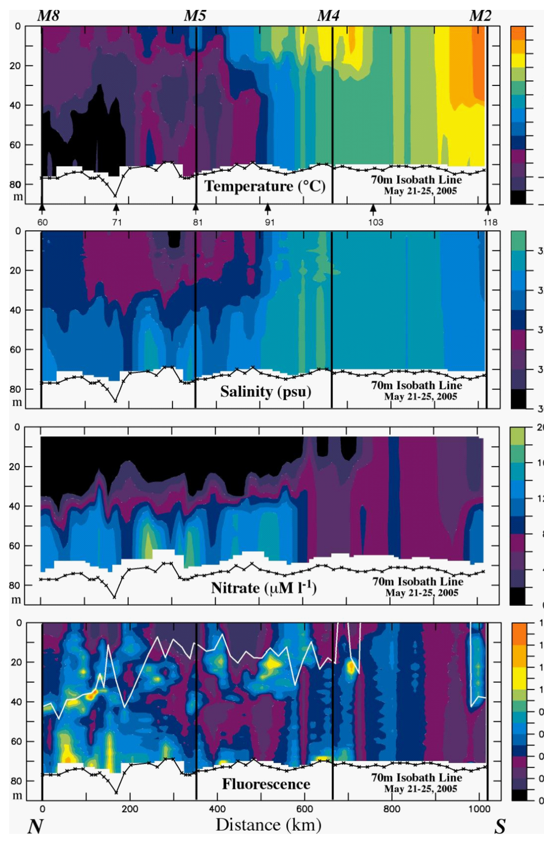
The FEAST model (Aydin et al.) includes major forage species and their predators, as well as grazing by birds, mammals and fishing. Central species are pollock, cod, and arrowtooth flounder. The model is Eulerian (not IBM) and depth-integrated, but runs on the same horizontal grid as ROMS and NPZ models. Feedback between fish and NPZ is included to assess top-down effects.

ensemble of projected biophysical futures

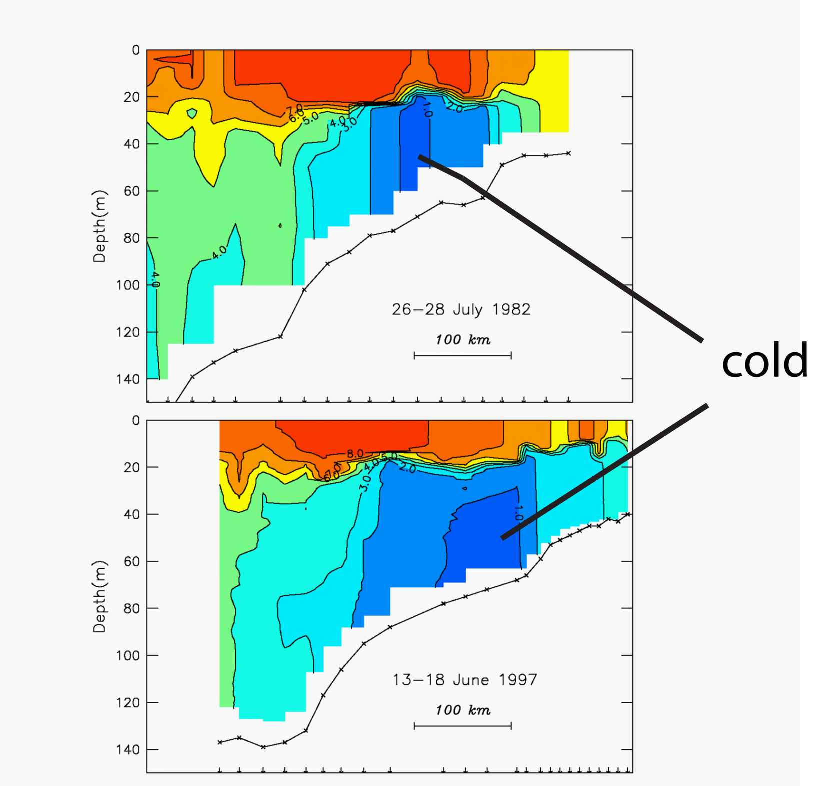
Analyze statistics of the resulting ensemble for means, variances (uncertainties of prediction), and clusters of possible future states

Several cross-shelf lines are being sampled under BEST BSIERP; some of these have already been sampled under previous programs

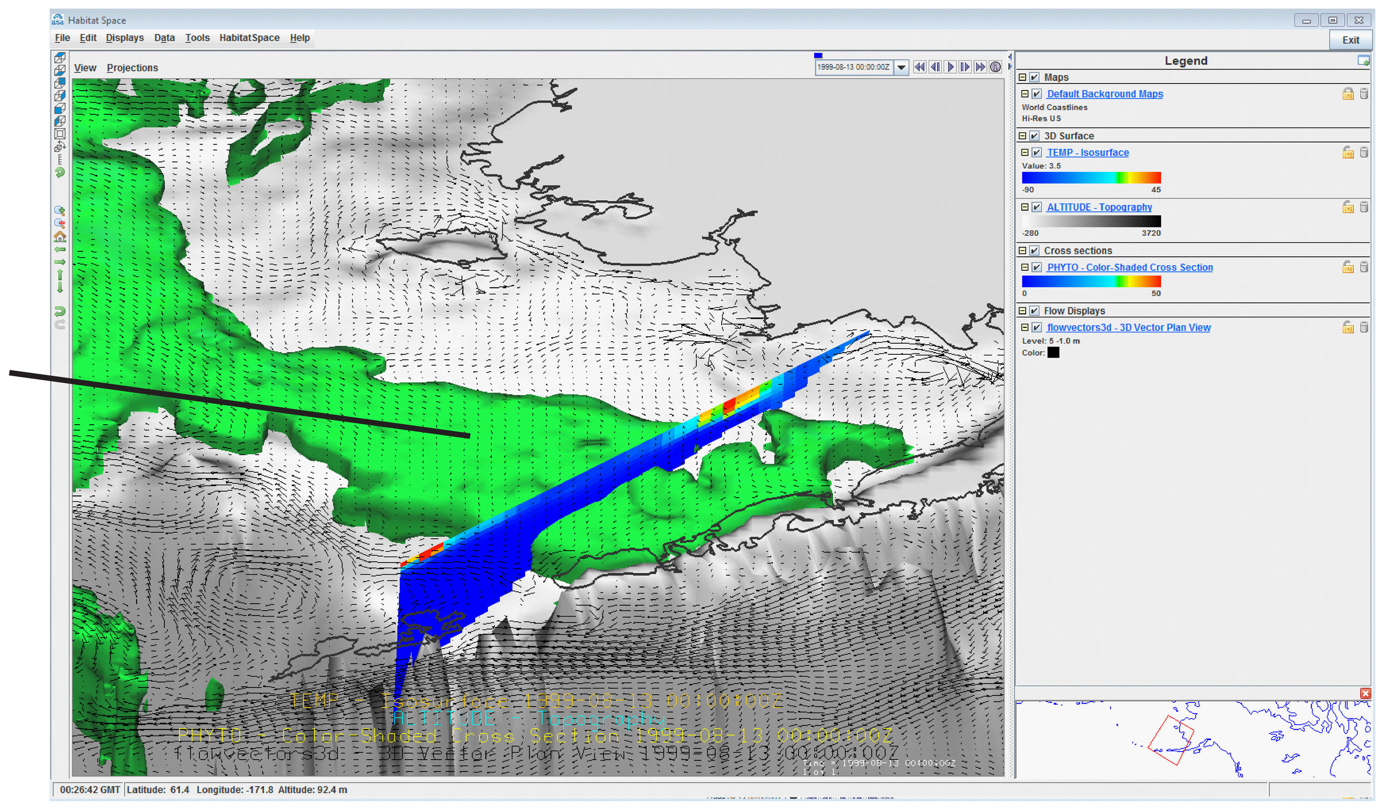




Sampling along the 70m isobath reveals strong north-south variability, driven largely by the presence/absence of ice.

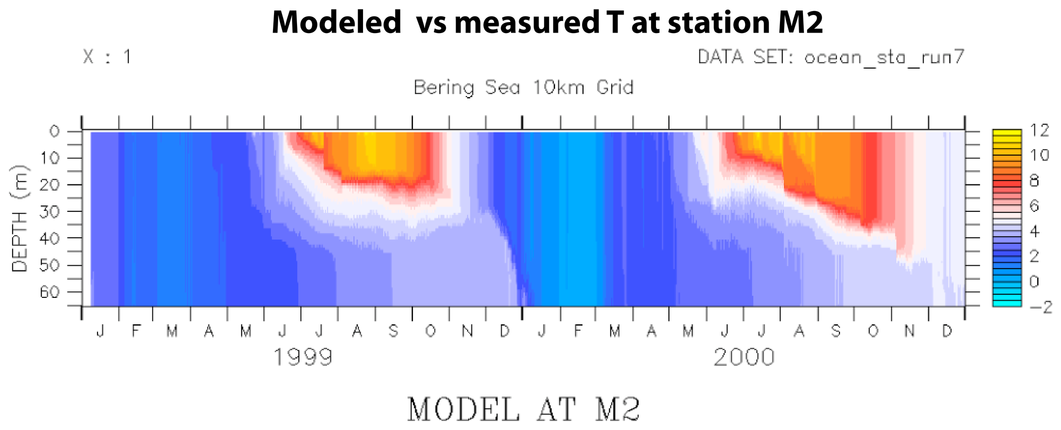


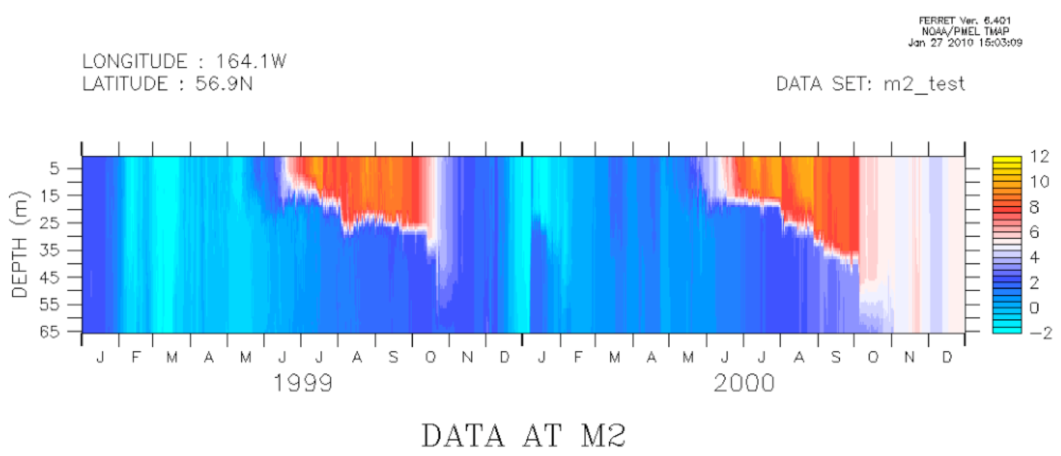
A cross-shelf line through station M2, sampled during warm and cold years. Note the well-mixed inner shelf region in 1982, and the cold pool in both years



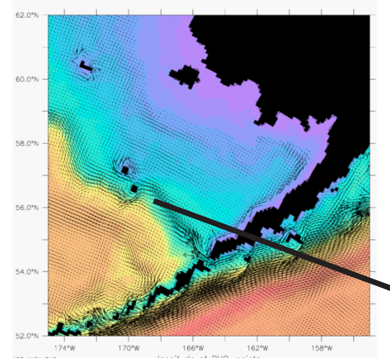
Model results for 1999: The cold pool (3.5 C isosurface, green) with cross-section of small and large phytoplankton and velocity

Modeled vs measured T at station M2





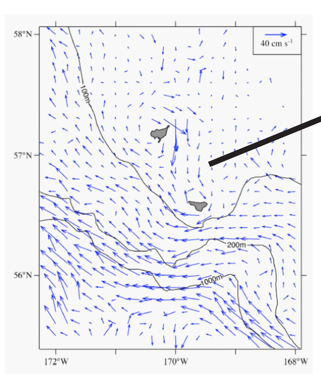
Modeled vs measured velocity at 40m



bathymetry is shaded

May-June model climatology (85-05)

Pribolof Islands



Summer drifter climatology (Stabeno et al.)

FISH MIGRATION ALGORITHM - the search for optimum "happiness"

We are developing a general algorithm which can be used to direct realistic migration of larger fish on our 10km grid. To this end, we define a goal function ***H*** which is a measure of "local happiness". Desirable aspects of the local environment include favorable temperatures, desirable prey, predator avoidance, and proximity to spawning locations. Any of these may shift with time as fish grow and mature:

H (x,y,t) = f(T(x,y),Prey(x,y), Predator(x,y),x,y,.........)

Calculate the magnitude of the spatial gradient of this function:

H_grad = (Hx*Hx + Hy*Hy)^1/2

Maximum swim speed ***V_max*** is a function of fish size and ambient temperature:

V_max = f(length,T)

Assume the fish will swim towards maximum "happiness", at a rate ***V_act*** which is governed by ***H_grad***:

V_act = V_max(1-e(-k*Hgrad))
u_fish = (Hx/Hgrad)*V_act
v_fish = (Hy/Hgrad)*V_act

Note the similarity here to "steepest descent" optimization algorithms. Our initial testing with this algorithm demonstrates its ability to move fish toward a geographic goal (***x_goal,y_goal***), via

H(x,y,t) = exp (-1.e-8 * ((x-x_goal)*(x-x_goal) + (y-y_goal)*(y-y_goal))

NOTE: Movement within a rapidly changing, patchily distributed ***H*** may have unintended consequences, and big local minima/maxima in ***H*** may produce unrealistic local aggregations. We anticipate that smoothing of ***H*** in space and time, and/or diffusion of fish, may be required to replicate the observed patterns.