Analysis of coupled biophysical modes from downscaling models

- A. J. Hermann (UW-JISAO)
- K. Aydin (NOAA-AFSC)
- N. A. Bond (UW-JISAO)
- W. Cheng (UW-JISAO)
- E. N. Curchitser (Rutgers U)
- G. Gibson (UAF-IARC)
- K. Hedstrom (ARSC)
- Y. Ortiz (NOAA-AFSC)
- P. J. Stabeno (NOAA-PMEL)
- M. Wang (UW-JISAO)

Integrated Modeling

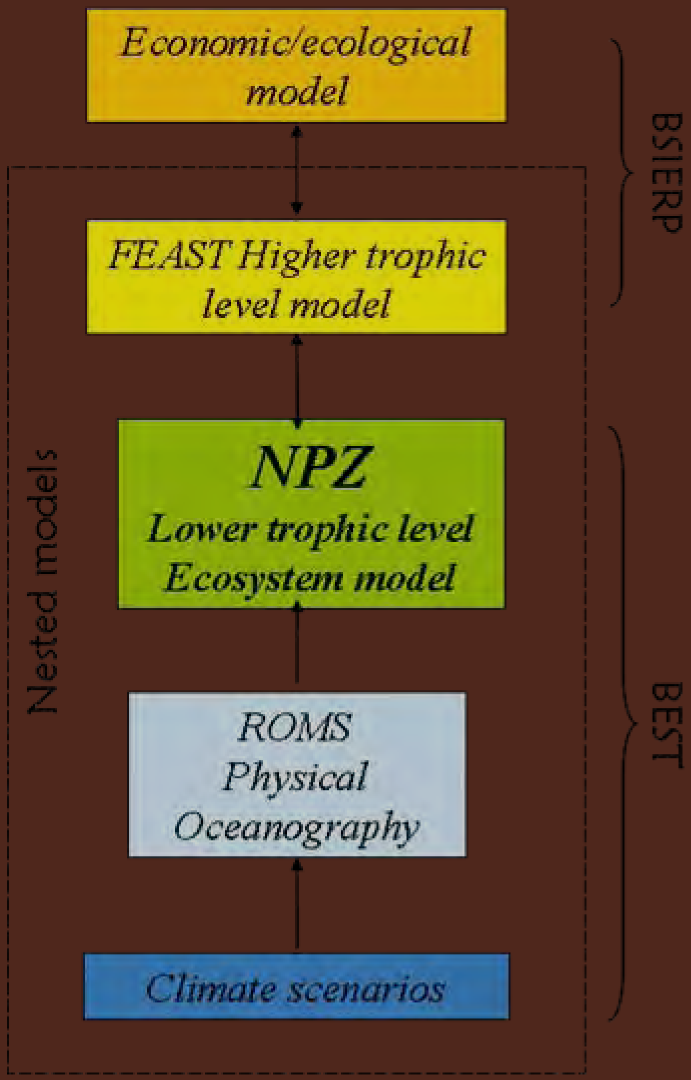
Higher trophic levels
(Pollock etc.)

Secondary Producers
(Zooplankton)

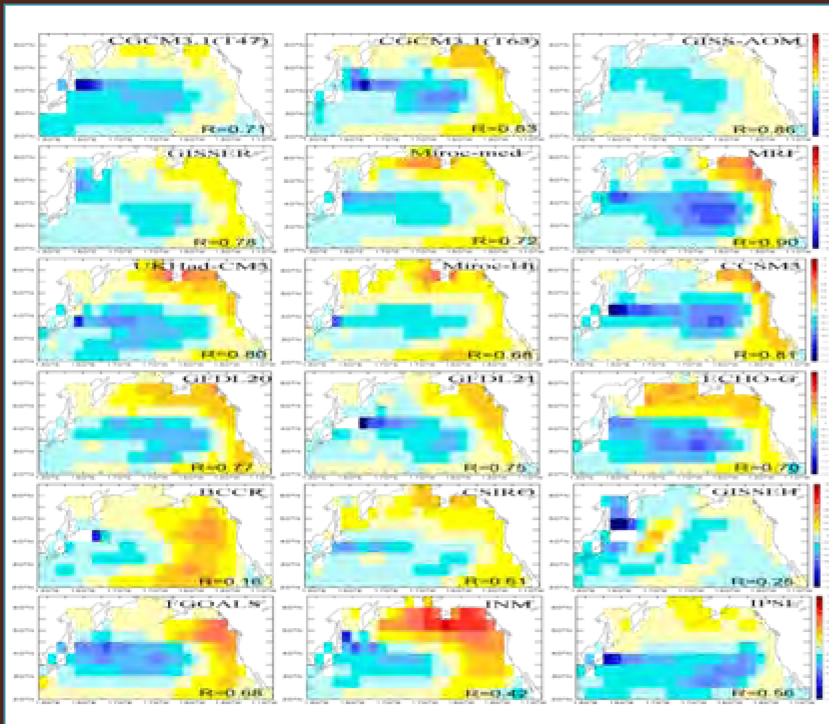
Primary Producers
(Phytoplankton)

Nutrients
NO_3, NH_4…

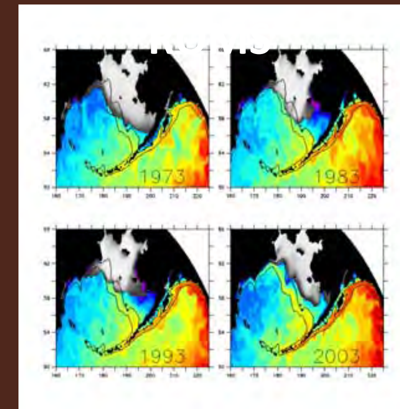
Physical Forcing
(Wind, temp, sun)



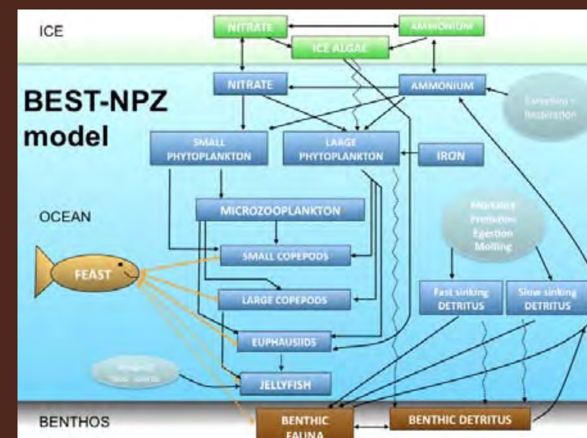
Climate models provide BCs/ICs to *regional coupled models*



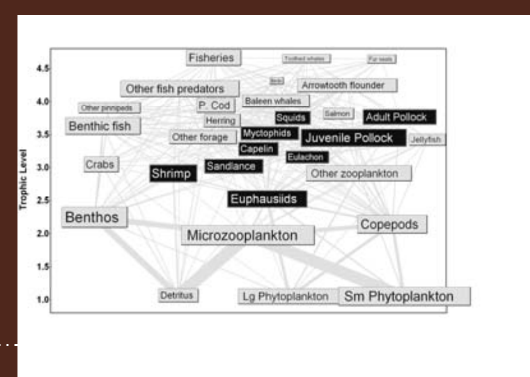
ensemble of runs



NPZ



FOOD WEB (FEAST)



ensemble of projected futures

GOAL:
mutidecadal
projections of physics and biology in the Bering Sea

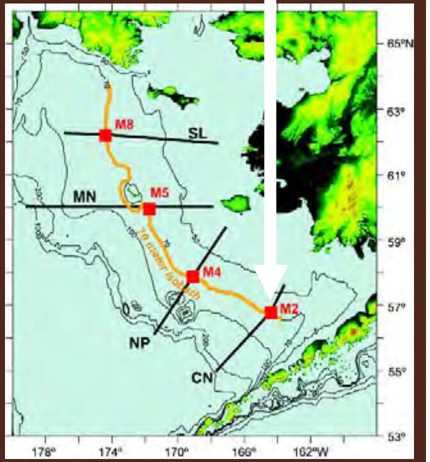
Northeast Pacific (NEP-5) and Bering Circulation Models

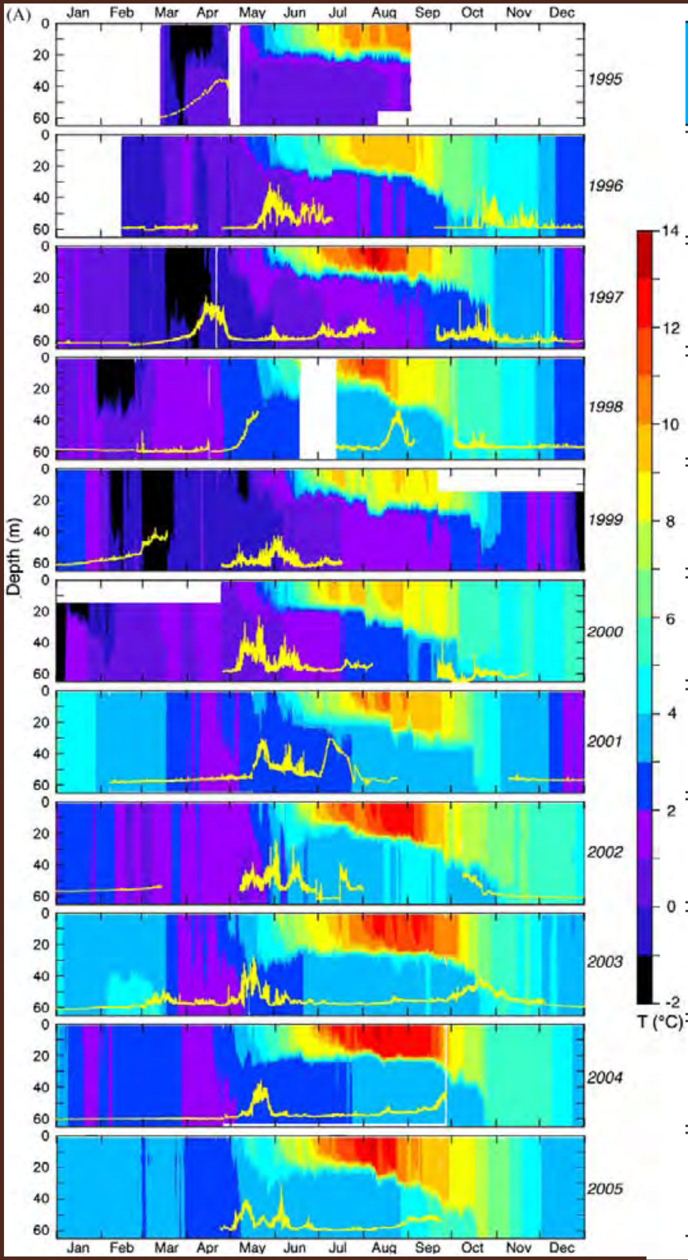
- Regional Ocean Modeling System (ROMS)
- Primitive Equations
- Terrain-following vertical coordinates (60 vertical levels)
- Mixed layer physics: K-Profile Parameterization
- Ice physics
- Tidal physics
- Vetted IPCC models used for
  - initial conditions
  - boundary conditions
  - atmospheric forcing
- Implemented on massively parallel (distributed memory) computers

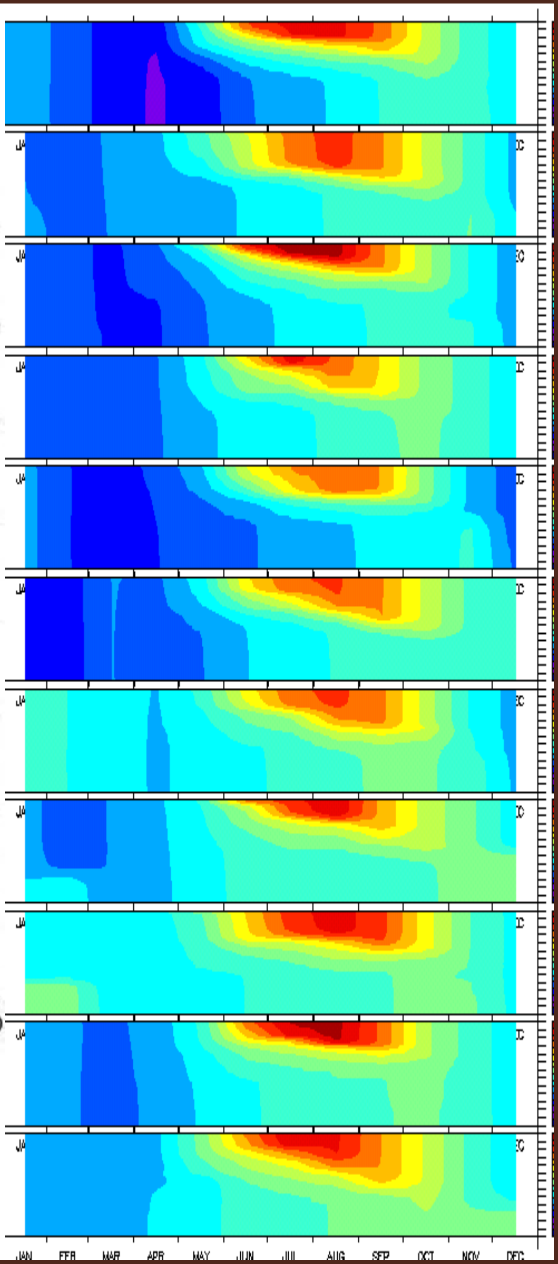
Data

Model

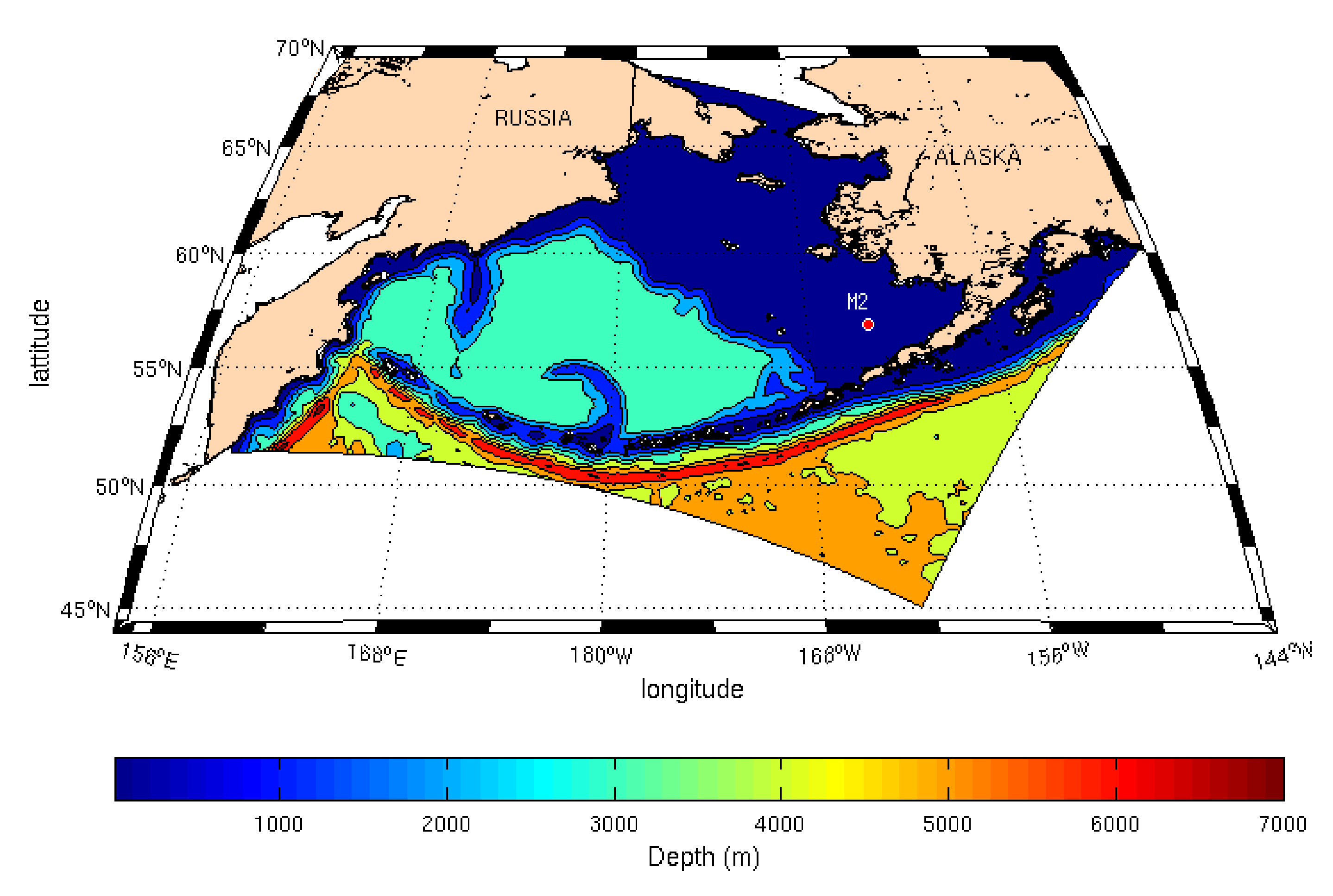
T at M2





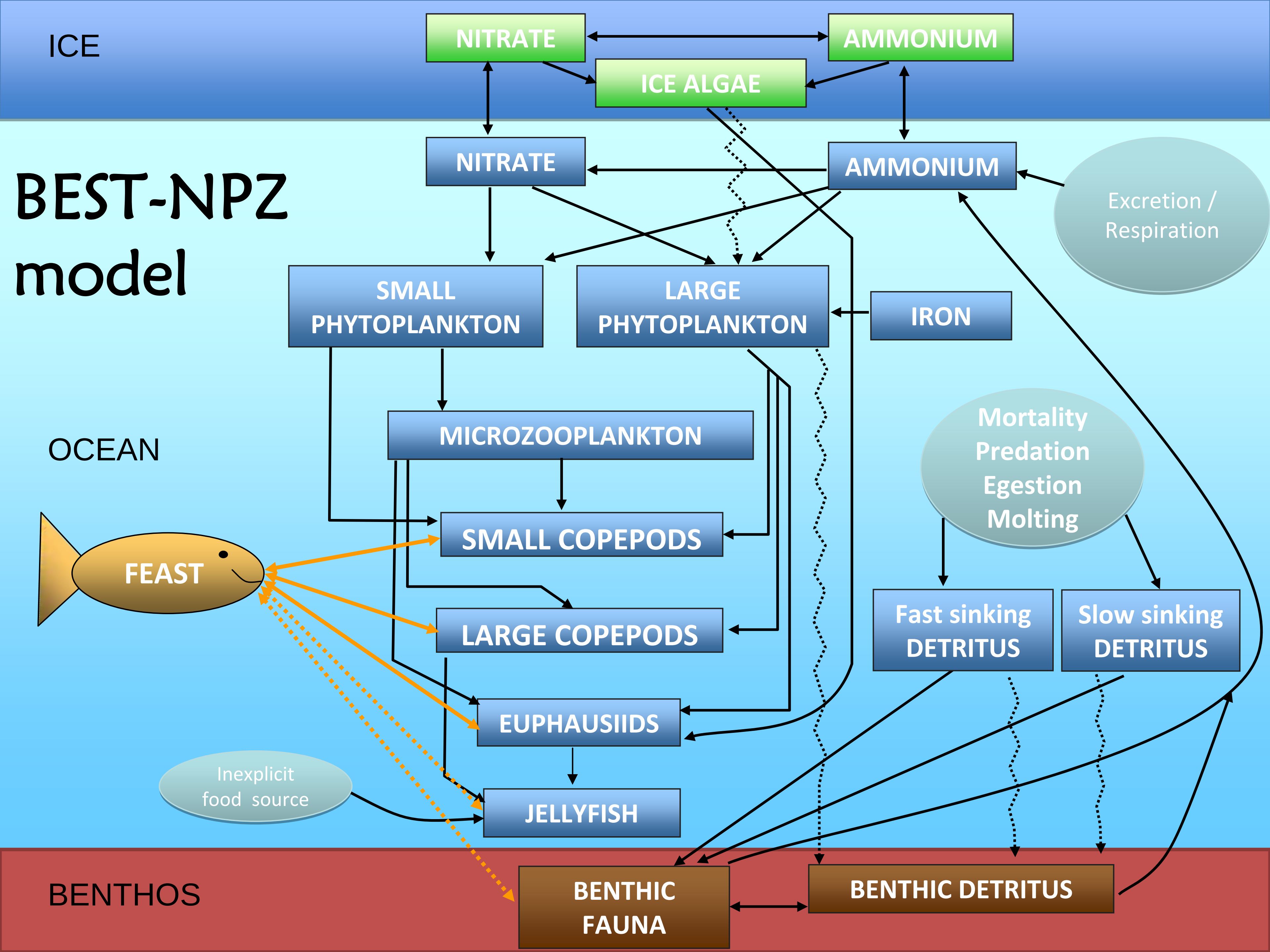


Model Grid for NPZ and FEAST



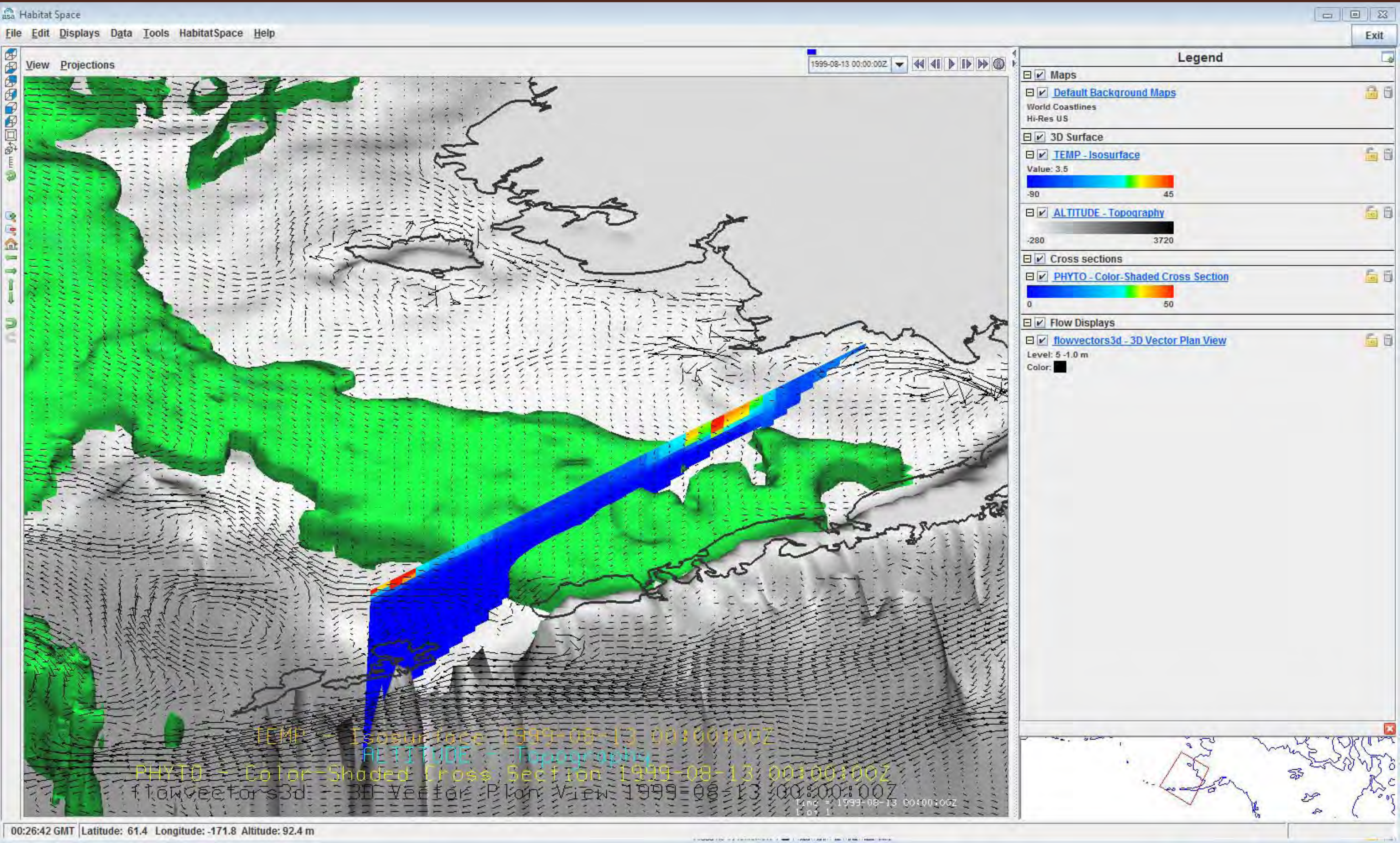
Grid size = 180*256*60

3D grid has 10km resolution



ICE
NITRATE
AMMONIUM
ICE ALGAE
BEST-NPZ model
NITRATE
AMMONIUM
Excretion / Respiration
SMALL PHYTOPLANKTON
LARGE PHYTOPLANKTON
IRON
MICROZOOPLANKTON
OCEAN
Mortality Predation Egestion Molting
SMALL COPEPODS
FEAST
LARGE COPEPODS
Fast sinking DETRITUS
Slow sinking DETRITUS
EUPHAUSIIDS
Inexplicit food source
JELLYFISH
BENTHOS
BENTHIC FAUNA
BENTHIC DETRITUS

BEST/BSIERP modeling results: cold pool, phytoplankton and velocity



Bering Sea modes

- Expect ice to have a strong effect on the structure of the ecosystem
- Various scenarios (e.g. “Oscillating Control Hypothesis”) relate ice to secondary production and fish
- If an ice-free Bering is fundamentally different from one with ice cover, expect biophysical “modes” to emerge in a statistical analysis of models and data

Statistical Analysis: Multivariate EOFS

- The problem: how to make sense of 3D biophysical output. EOF-like analysis can help "tell a story"
- Typical biological use of Principal Components looks for coupled modes of variability in multivariate samples (these may be time series or just scattered samples in space and time)
- Typical physical use of Empirical Orthogonal Functions (EOFS) looks for spatial structure of a *single* variable
- Here, we use *mutivariate* EOFs (space/variable/time) to extract coupled biophysical modes which vary through time (Note: these time series need not be continuous)

“PRINCIPAL COMPONENTS” use timeseries at a single location:

$N(x_1,t_1)$, $N(x_1,t_2)$, $N(x_1,t_3)$,……$N(x_1,t_N)$
$P(x_1,t_1)$, $P(x_1,t_2)$, $P(x_1,t_3)$,……$P(x_1,t_N)$
$Z(x_1,t_1)$, $Z(x_1,t_2)$, $Z(x_1,t_3)$,……$Z(x_1,t_N)$

OR a set of multivariate observations scattered in space and time

$N(x_1,t_1)$, $N(x_2,t_2)$, $N(x_3,t_3)$,……$N(x_M,t_N)$
$P(x_1,t_1)$, $P(x_2,t_2)$, $P(x_3,t_3)$,……$P(x_M,t_N)$
$Z(x_1,t_1)$, $Z(x_2,t_2)$, $Z(x_3,t_3)$,……$Z(x_M,t_N)$

“EMPIRICAL ORTHOGONAL FUNCTIONS” use timeseries of a single variable at multiple locations:

$T(x_1,t_1)$, $T(x_1,t_2)$, $T(x_1,t_3)$,……$T(x_1,t_N)$
$T(x_2,t_1)$, $T(x_2,t_2)$, $T(x_2,t_3)$,……$T(x_2,t_N)$
$T(x_3,t_1)$, $T(x_3,t_2)$, $T(x_3,t_3)$,……$T(x_3,t_N)$

MULTIVARIATE EOFS: combine the two:

$N(x_1,t_1)$, $N(x_1,t_2)$, $N(x_1,t_3)$,……$N(x_1,t_N)$
$P(x_1,t_1)$, $P(x_1,t_2)$, $P(x_1,t_3)$,……$P(x_1,t_N)$
$Z(x_1,t_1)$, $Z(x_1,t_2)$, $Z(x_1,t_3)$,……$Z(x_1,t_N)$
$T(x_1,t_1)$, $T(x_1,t_2)$, $T(x_1,t_3)$,……$T(x_1,t_N)$

$N(x_2,t_1)$, $N(x_2,t_2)$, $N(x_2,t_3)$,……$N(x_2,t_N)$
$P(x_2,t_1)$, $P(x_2,t_2)$, $P(x_2,t_3)$,……$P(x_2,t_N)$
$Z(x_2,t_1)$, $Z(x_2,t_2)$, $Z(x_2,t_3)$,……$Z(x_2,t_N)$
$T(x_2,t_1)$, $T(x_2,t_2)$, $T(x_2,t_3)$,……$T(x_2,t_N)$

.
.
.
$N(x_M,t_1)$, $N(x_M,t_2)$, $N(x_M,t_3)$,……$N(x_M,t_N)$
$P(x_M,t_1)$, $P(x_M,t_2)$, $P(x_M,t_3)$,……$P(x_M,t_N)$
$Z(x_M,t_1)$, $Z(x_M,t_2)$, $Z(x_M,t_3)$,……$Z(x_M,t_N)$
$T(x_M,t_1)$, $T(x_M,t_2)$, $T(x_M,t_3)$,……$T(x_M,t_N)$

Pitfalls of "orthogonal" analysis 1: Space/time averaging

- Some features are highly correlated but lagged in time and /or space:
  - larval life history, adult recruitment
  - Some features are in perfect quadrature:
    - N vs P vs Z
- Solutions:
  - average in time prior to analysis
  - Analyze in frequency space (complex EOFs)
  - Use time lagged EOFs ("Extended" EOFs)

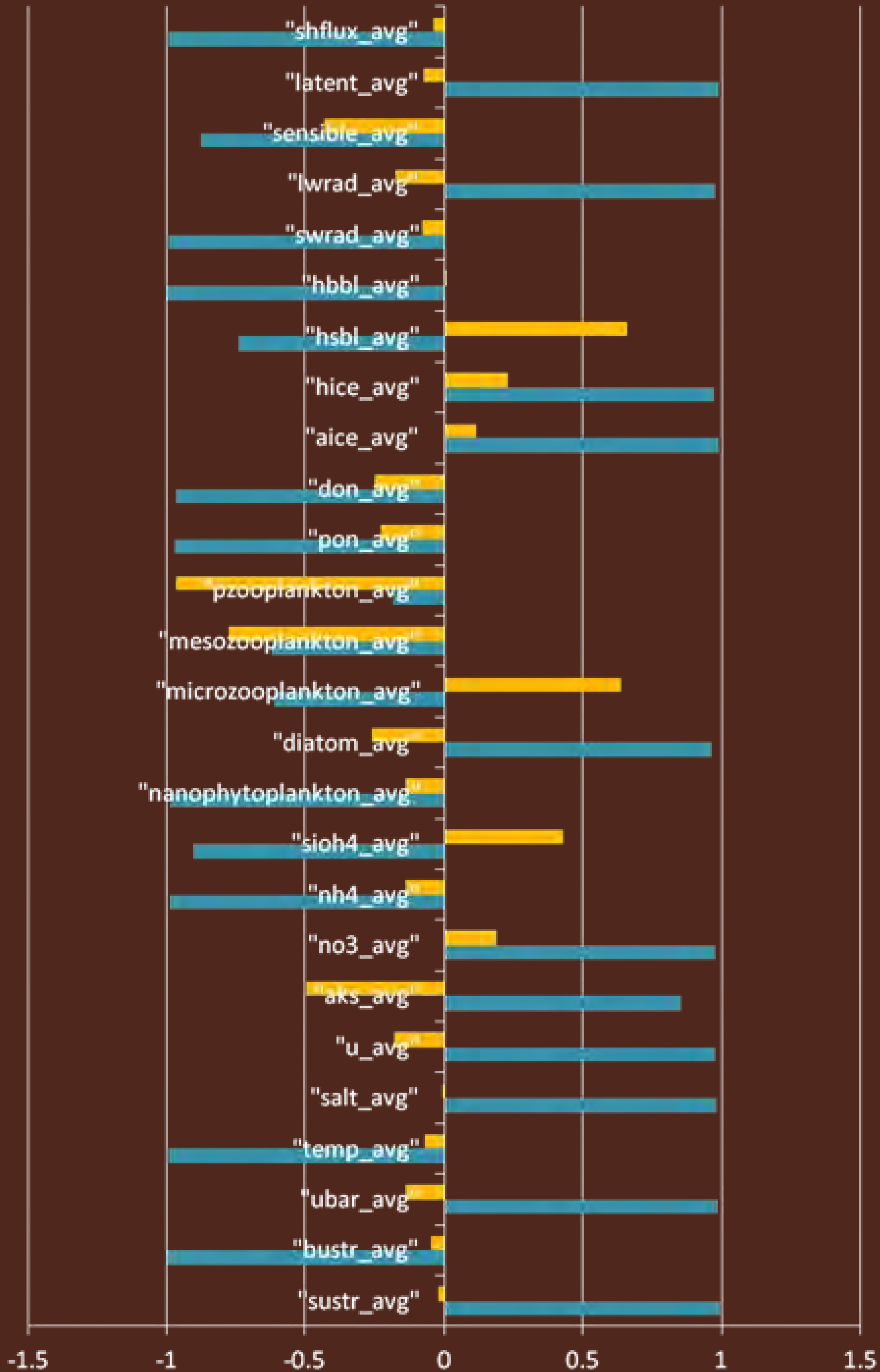
Pitfalls of “orthogonal” analysis 2: Normalization of multivariate series

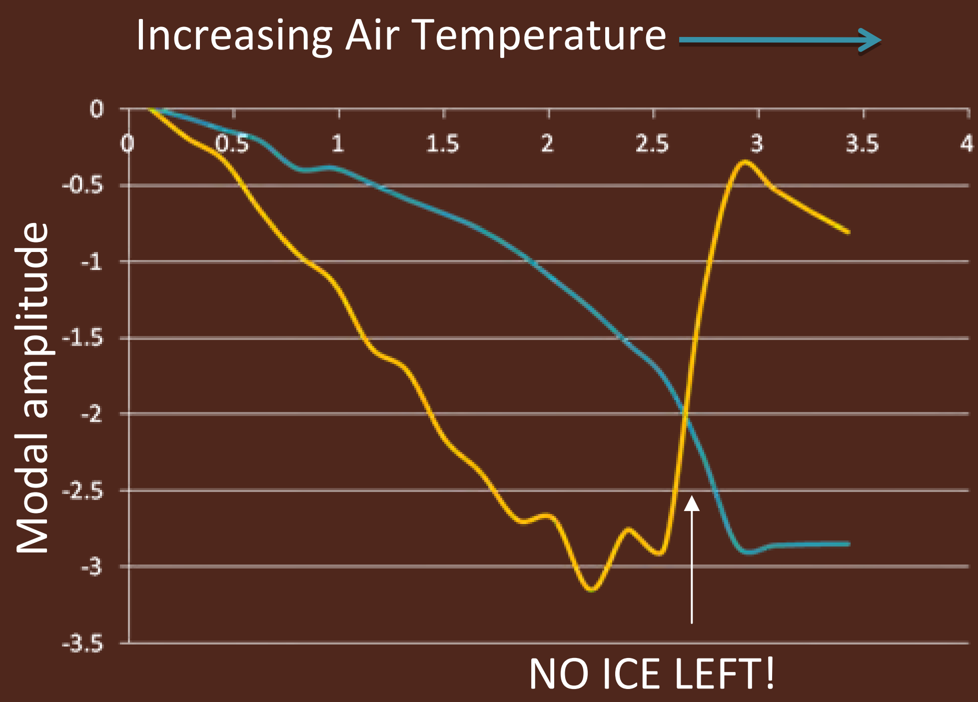
- Standard EOF analysis uses the covariance matrix of all time series
- For biophysical modes, we wish to give all of the variables an equal chance to influence the results
- Normalize each series by the standard deviation; this takes care of different units AND emphasizes *relative* change for each variable

1D Bering Sea modes

- Use NEMURO-ROMS at a representative location (station M2, SE Bering Sea shelf)
- Run with different future air temperature scenarios (range from 0-4 degrees C)
- Calculate annual averages of atmospheric and depth-integrated ocean properties
- Calculate multivariate EOFs based on these annual averages
- Examine how the different modes (the “predictands”) relate to air temperature (the “predictor”)

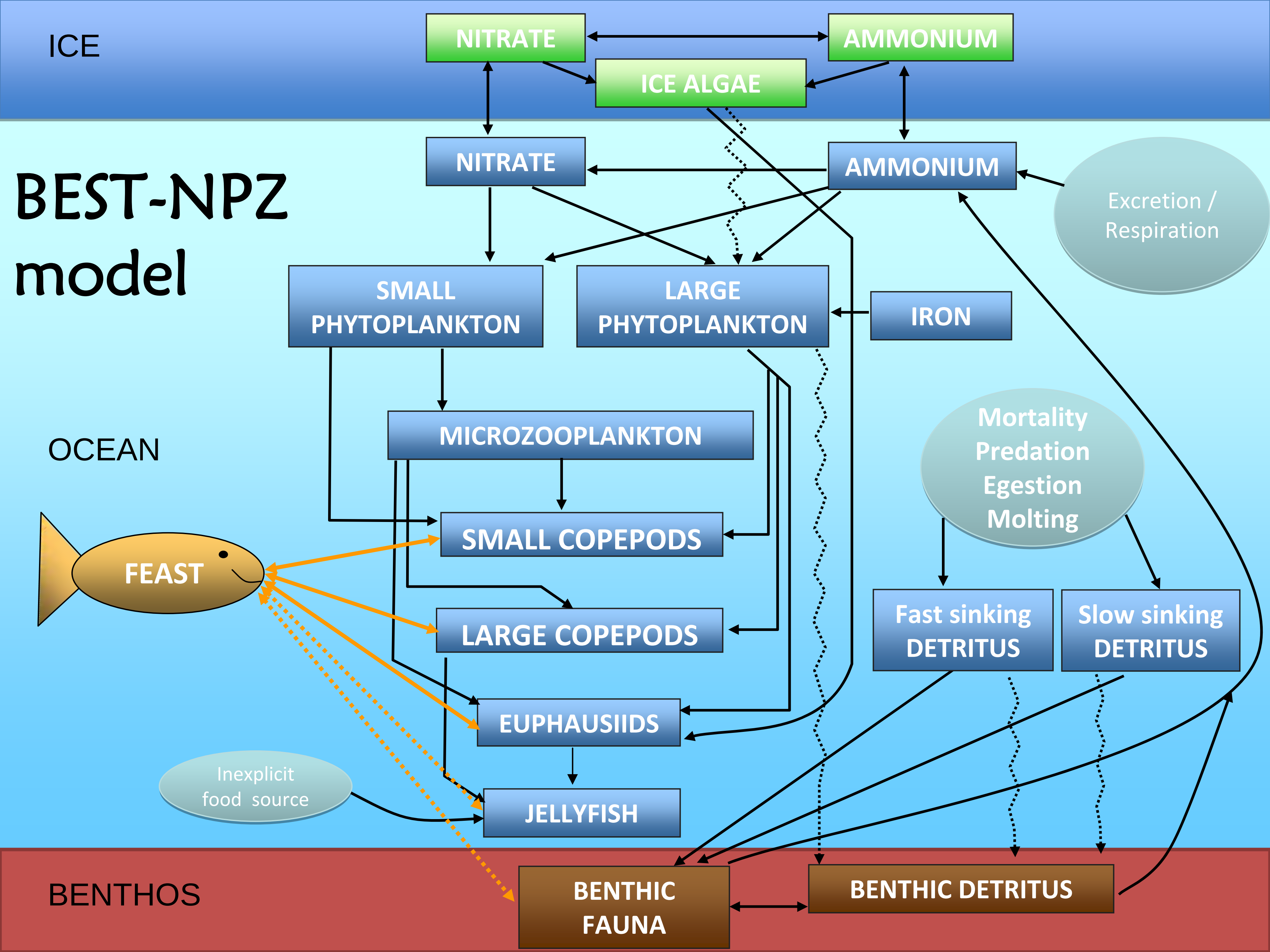
1D modal amplitudes as a function of increased air temperature





3D Bering Sea modes

- Run the BEST-NPZ model on the 3D grid, but with 5 layers only (coarse but fast; retains most basic behaviors)
- Force with some recent years (1999-2004) and some future projections from the CCCMA-t47 model (2010, 2030, 2040)
  - Single-year runs with identical initial conditions
  - Run for 6 months in each case (Jan-June)
- Calculate annual climatologies based on these runs; derive anomaly time series and normalize
- Calculate multivariate EOFs from these anomaly time series


ICE
NITRATE
AMMONIUM
ICE ALGAE
BEST-NPZ model
NITRATE
AMMONIUM
Excretion / Respiration
SMALL PHYTOPLANKTON
LARGE PHYTOPLANKTON
IRON
MICROZOOPLANKTON
OCEAN
Mortality Predation Egestion Molting
SMALL COPEPODS
FEAST
LARGE COPEPODS
Fast sinking DETRITUS
Slow sinking DETRITUS
EUPHAUSIIDS
Inexplicit food source
JELLYFISH
BENTHOS
BENTHIC FAUNA
BENTHIC DETRITUS

Variables used for 3D model analysis

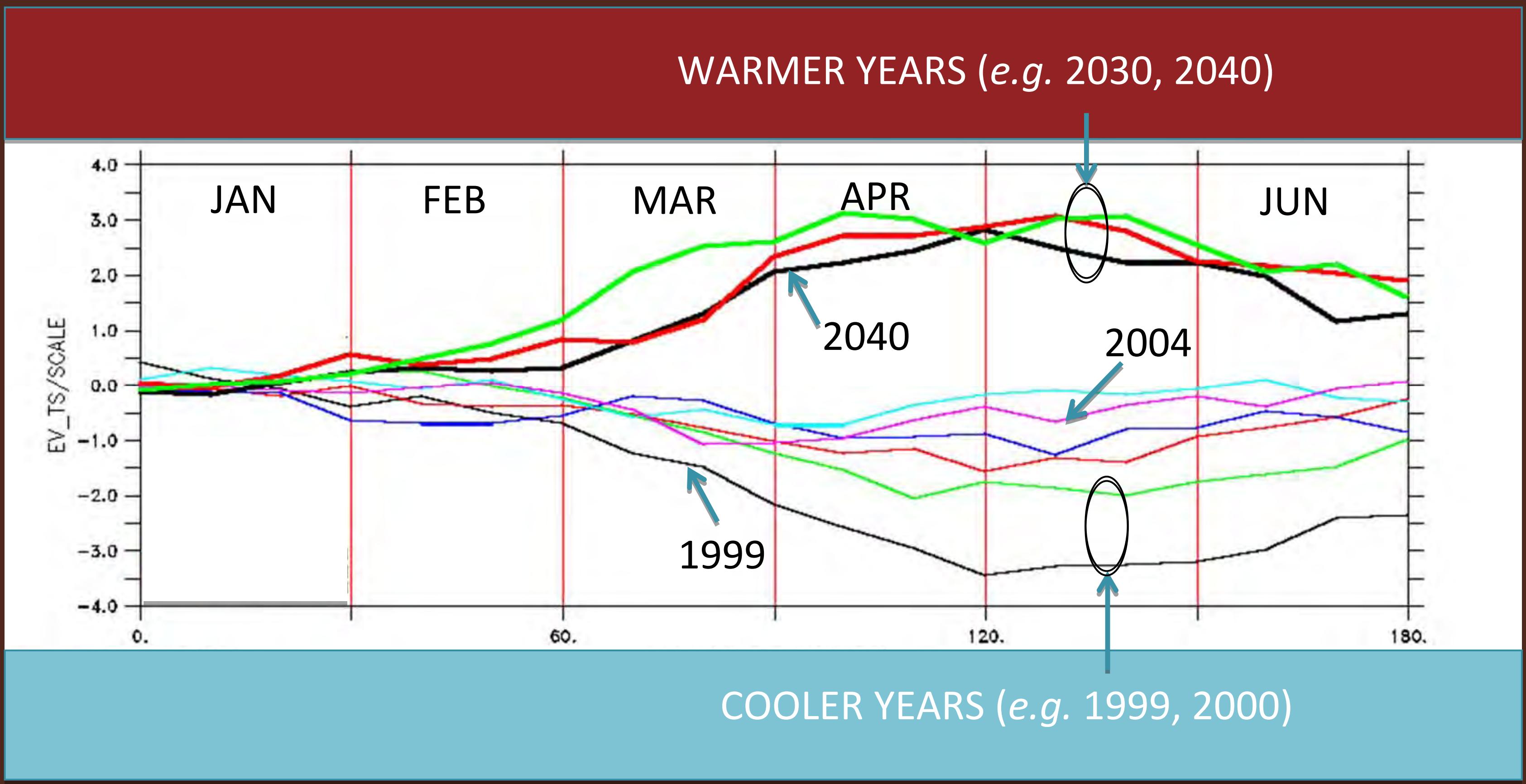
PHYSICAL (ROMS)

- Surface Temperature
- Surface Salinity
- Ice (fractional coverage)
- Mixed Layer Depth

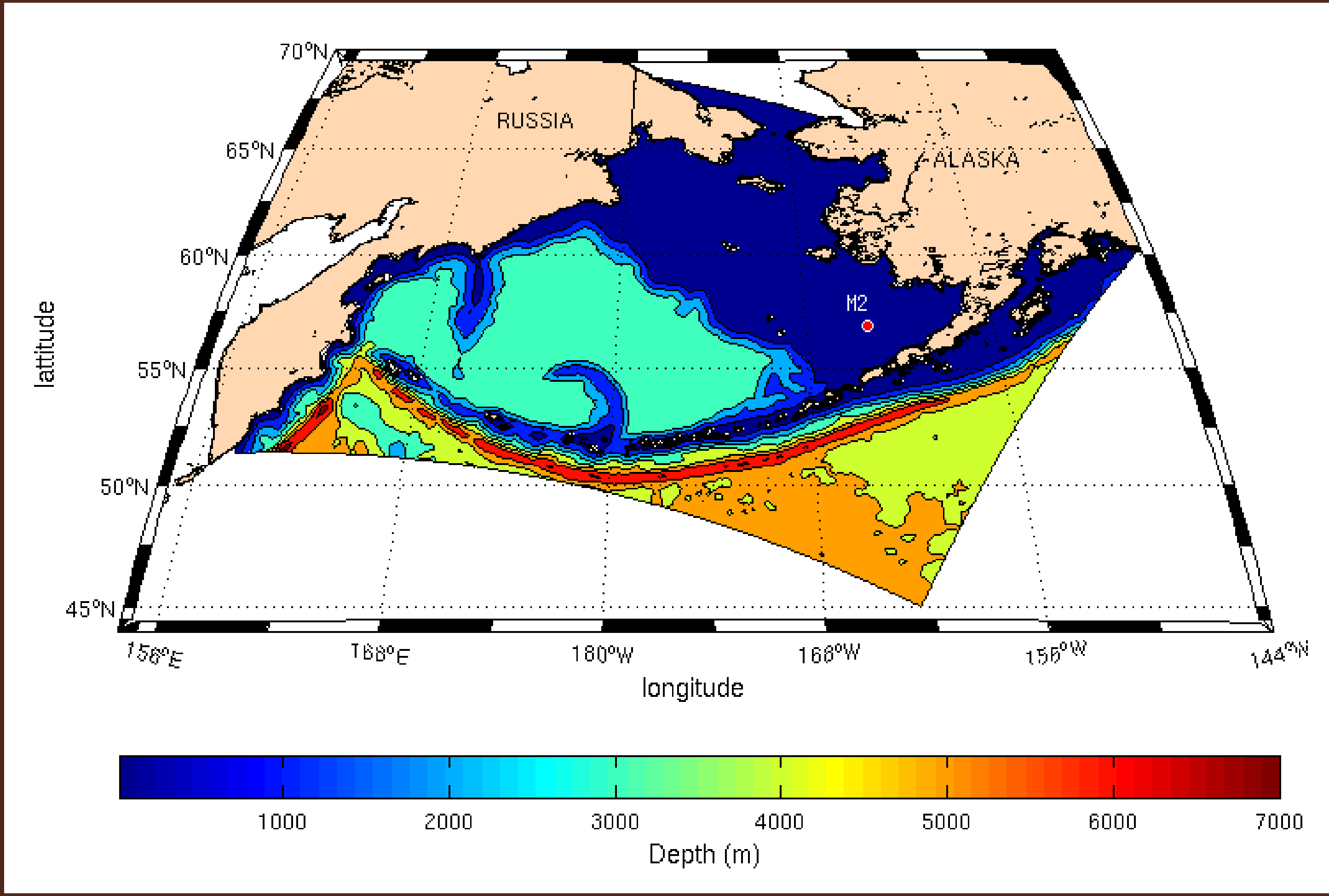
BIOLOGICAL (BEST-NPZ)

- Nitrate + Ammonium
- Ice Phytoplankton
- Phytoplankton
- Microzooplankton
- Copepods
- Euphausiids
- Benthic detritus
- Benthic infauna

Jan-Jun time series for the dominant mode (contains 17% of total variance)



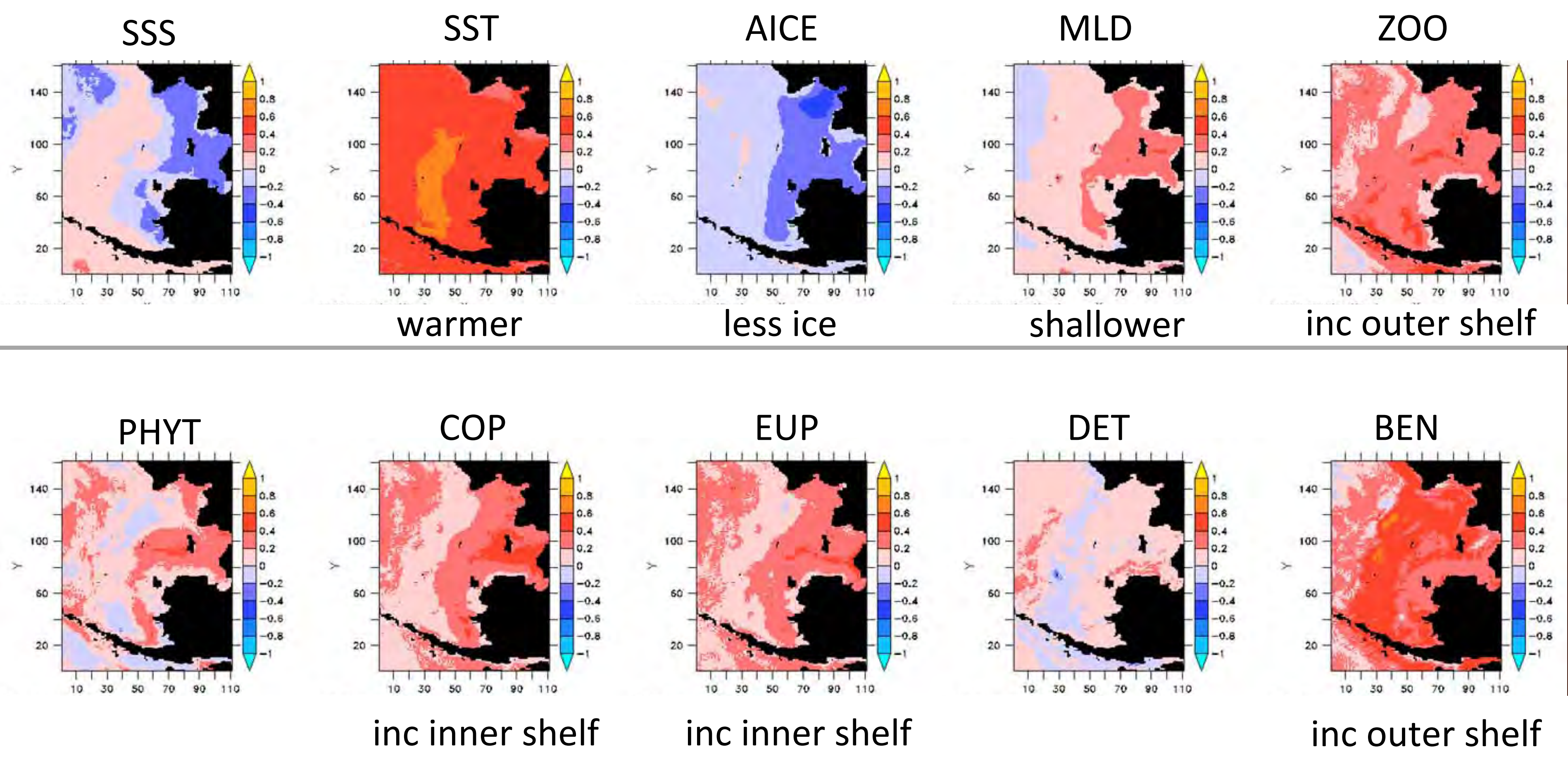
Model Grid for NPZ and FEAST



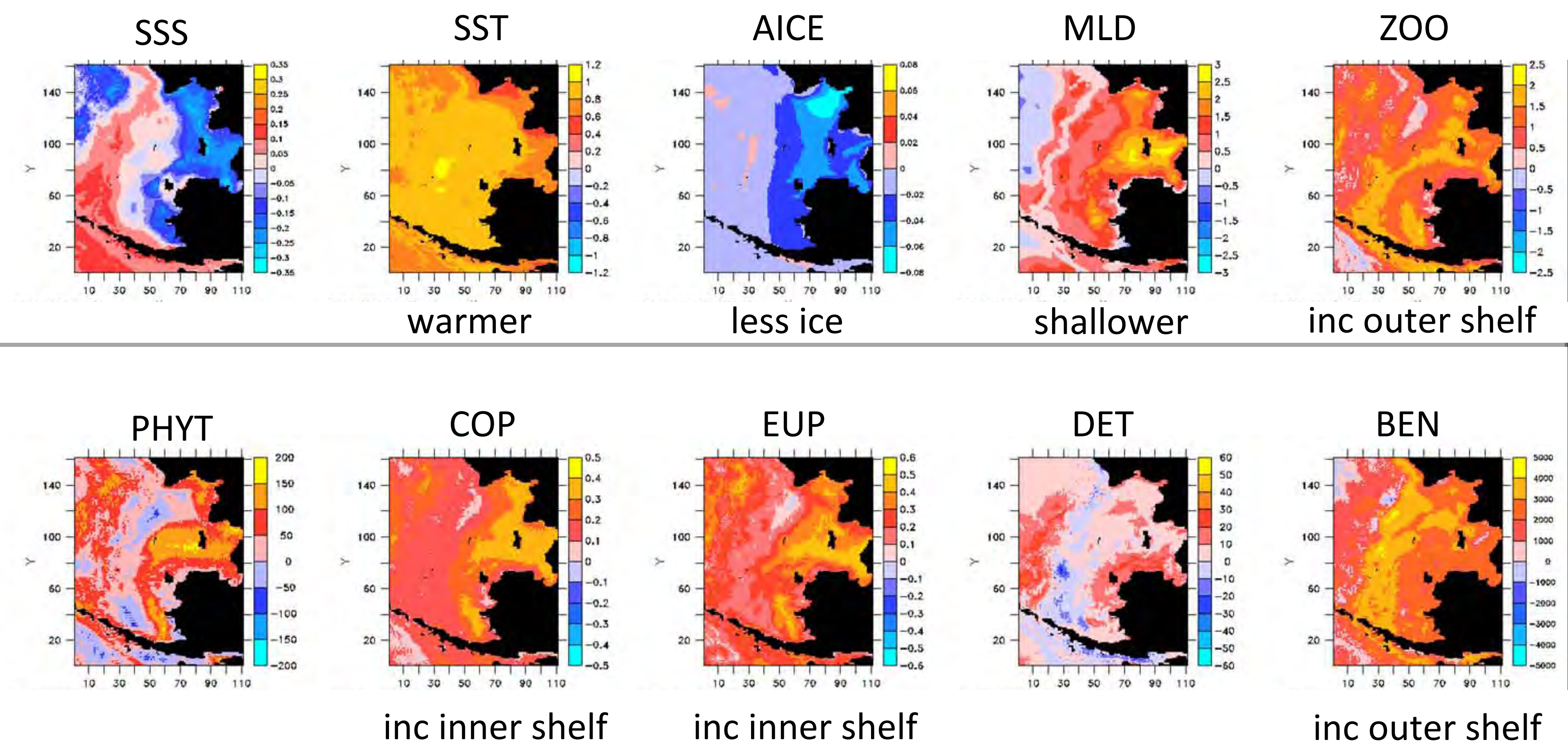
Grid size = 180*256*60

3D grid has 10km resolution

Normalized mode 1 structure:
physical: warmer, less ice, shallower ml,
biological: pelagic shelf, benthic slope



Denormalized Mode 1 structure:
physical: warmer, less ice, shallower ml,
biological: pelagic shelf, benthic slope



Summary/Interpretation

- Coupled biophysical modes appear from multivariate EOF analyses of *spring/early summer* model results
- A primary mode of the 3D model analysis suggests the following trend under continued warming:
  - Increased primary production (light-limited response to increased stratification):
  - Increased secondary production overall
    - ***Small*** zoop are enhanced on *outer* shelf
    - ***Large*** zoop are enhanced on *inner* shelf
  - ***Pelagic*** food chain is enhanced on the *inner* shelf
  - ***Benthic*** food chain is enhanced on the *outer* shelf

Caveats (needed refinements)

- Only 5 layers; need to analyze 60-layer results
- Haven't yet included the recent cold years (2005-2010)
- This analysis includes only Jan-Jun; Oscillating Control Hypothesis involves fall dynamics
- Large zooplankton may depend on a cold spring to thrive in the fall
- No fish component, hence no grazing by fish
- NEED TO COMPARE THESE WITH GRIDDED DATA (e.g. BASIS dataset)

Speculation

- Coupled biophysical modes could be more predictable (i.e. more reliable predictands) than individual time series
  - Spatially, we may be more confident in statements about broad patterns (e.g. EOFs) than statements about a timeseries at a single point
  - Trophically, we may be more confident that a particular assemblage is going to increase, without knowing precisely which species will dominate
- Multvariate time series from monitoring arrays may be better predictors of long-term multivariate trends, than univariate timeseries are of univariate trends

FIN!