# Examining the predictability limits of NPZ-fish dynamics in the Coastal Gulf of Alaska and the Bering Sea using a numerical model

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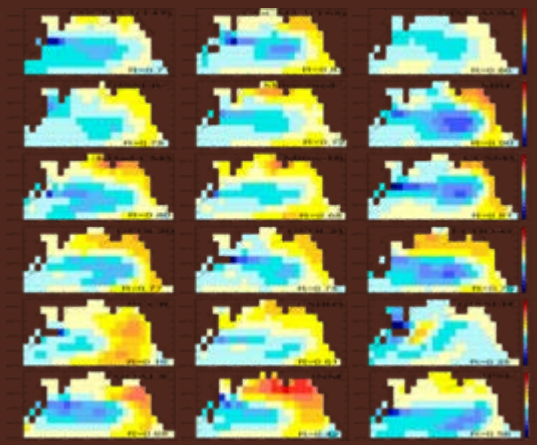
# What we mean by “predictability”

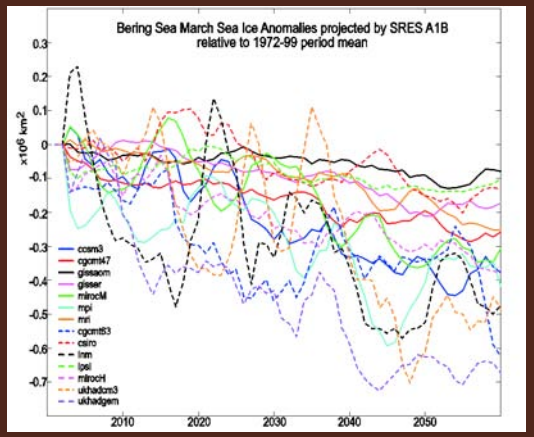
- The ability to forecast some aspect of the environment with demonstrable skill
- Not known a priori what quantities are more predictable BUT:
  - Spatial and temporal averages are typically more predictable than point measurements
  - Trophic averages (combinations of species) ought to be more predictable than single species

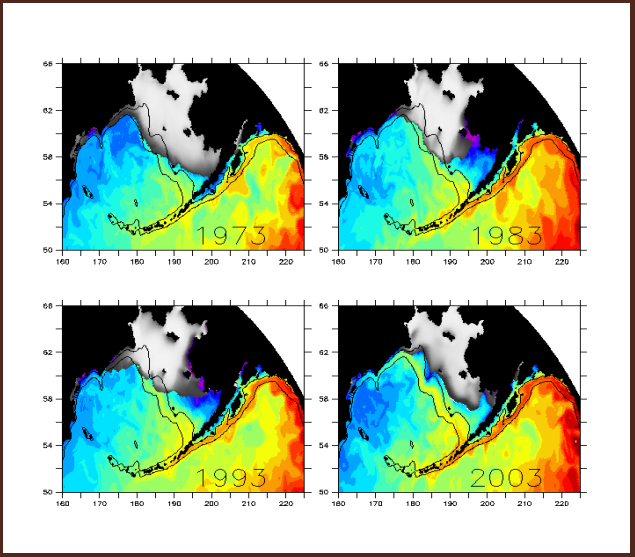
# Predicting ocean futures

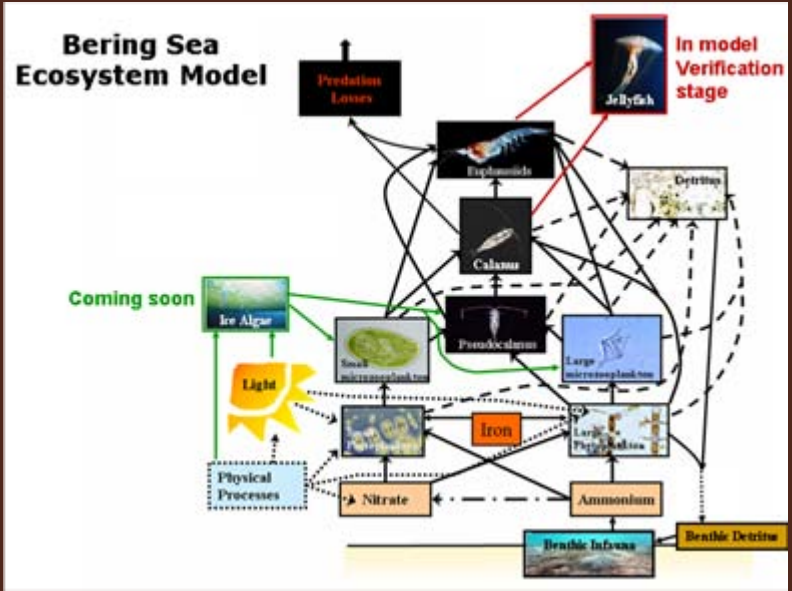
- There are many possible ocean futures; wish to estimate the most likely outcome in a way which includes nonlinearity of the systems
- Both physics and biology are highly nonlinear; hence the mean physics is not adequate to estimate the mean biology. Different temporal paths will have different endpoints!

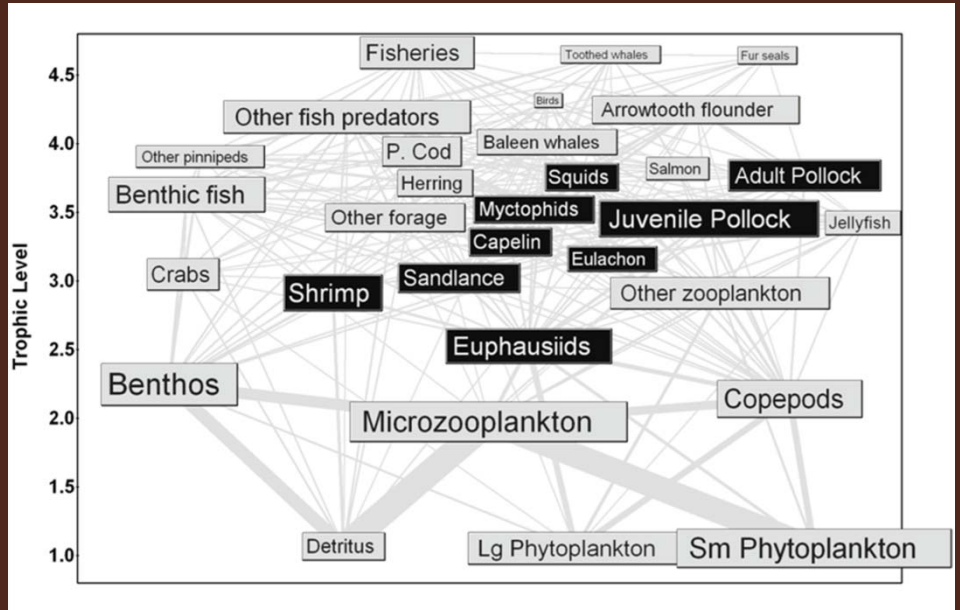
# BEST/BSIERP overview





# Characterizing ocean futures

- Can look at the predictability of individual variables in coupled models, but gets complicated due to many variables. Can we look for fewer indices?
- One possible approach:
  - Use mutivariate statistics to determine *modes of variability* produced by possible futures
  - Weight these modes using the probability distribution of the forcing
- Modes show the basic relationships among uncertainty of each variable

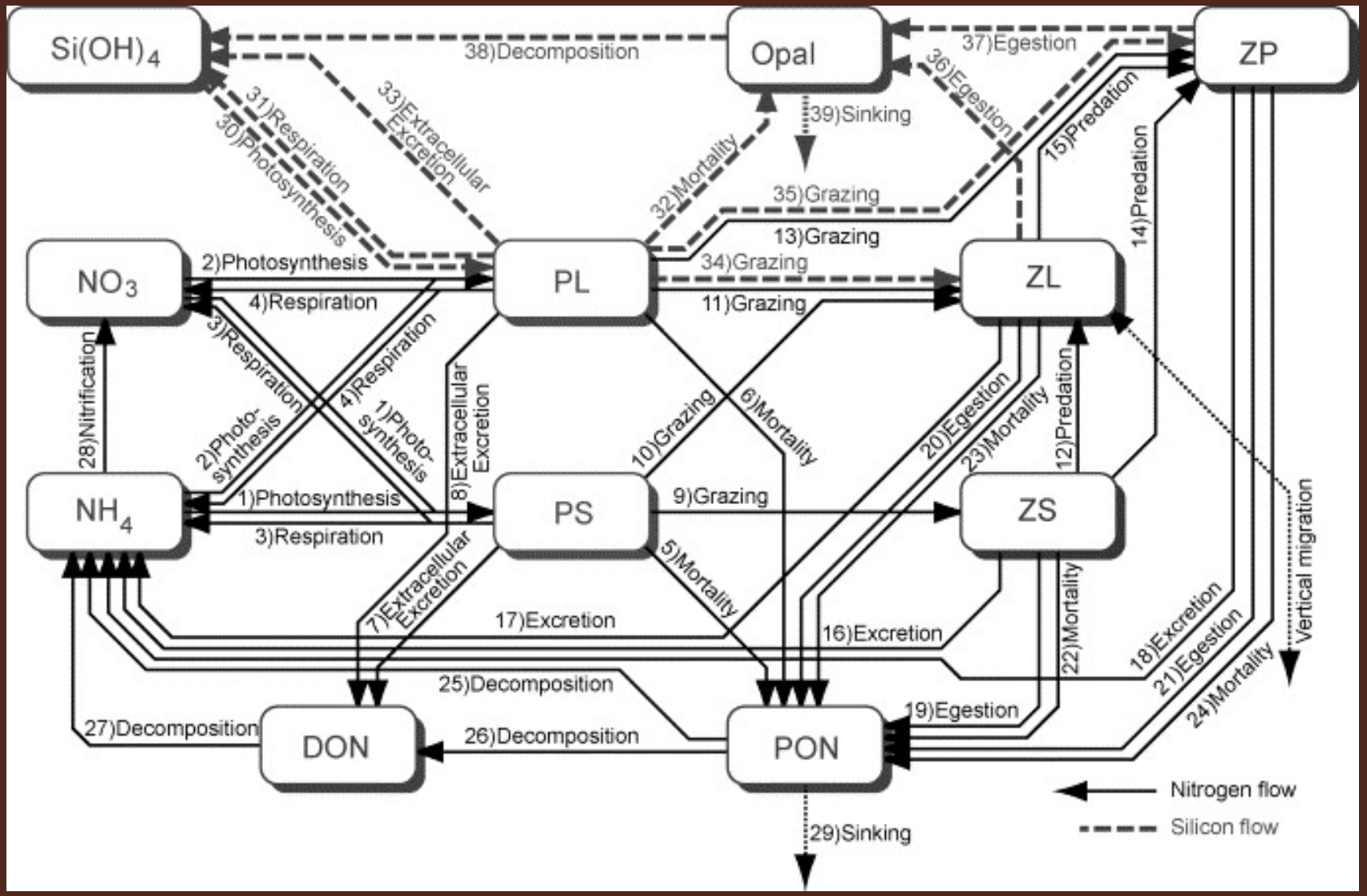
# Bering Sea modes

- Ice has a strong effect on the structure of the ecosystem
- An ice-free Bering is fundamentally different from one with ice cover; expect these “modes” to emerge in the analysis

# Procedure

- Run the NEMUROMS modes (NEMURO in ROMS) on a 1D grid
  - Choose coefficients appropriate to each region
- Force with a range of global warming scenarios
- Calculate annual means which eventually result from each scenario
- Calculate multivariate EOFs on normalized variables for
  - Coupled physical/biological modes
  - Trophic (P and Z categories only) modes
- Convolve results with probability of warming scenarios to get most likely outcomes and variance

# NEMURO structure



# ROMS structure for this experiment

- ROMS = Regional Ocean Modeling System
- NEMURO is embedded on the same grid
- LMD mixed layer physics
- Bulk flux algorithms for wind stress, heat flux
- Analytical wind, air temperature, shortwave inputs
  - Choose simple curves appropriate to Bering and CGOA
  - Increase air temperature according to various scenarios

# EOFS for this analysis

- Typical oceanographic use of EOF is for capturing spatial structure of a single variable
- Here, use EOFs across variables to explain variance produced by temperature scenarios (each treated as an *independent realization*)
- Use *depth/time average* of each model variable over the last 12 months of the simulation as our independent variables for EOF calculation

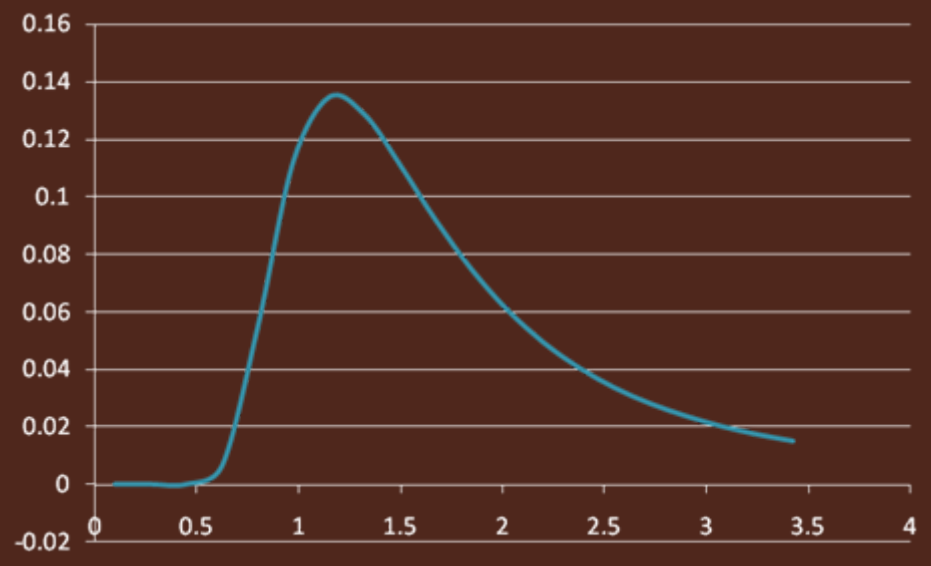
# How to normalize the variables for the EOFs?

- For biophysical modes, normalize raw values by standard deviation (hence all are unit normals).
- For trophic modes, use log transform then normalize by standard deviation. The log transform emphasizes *fractional change* of each category (needed since some are smaller than others)

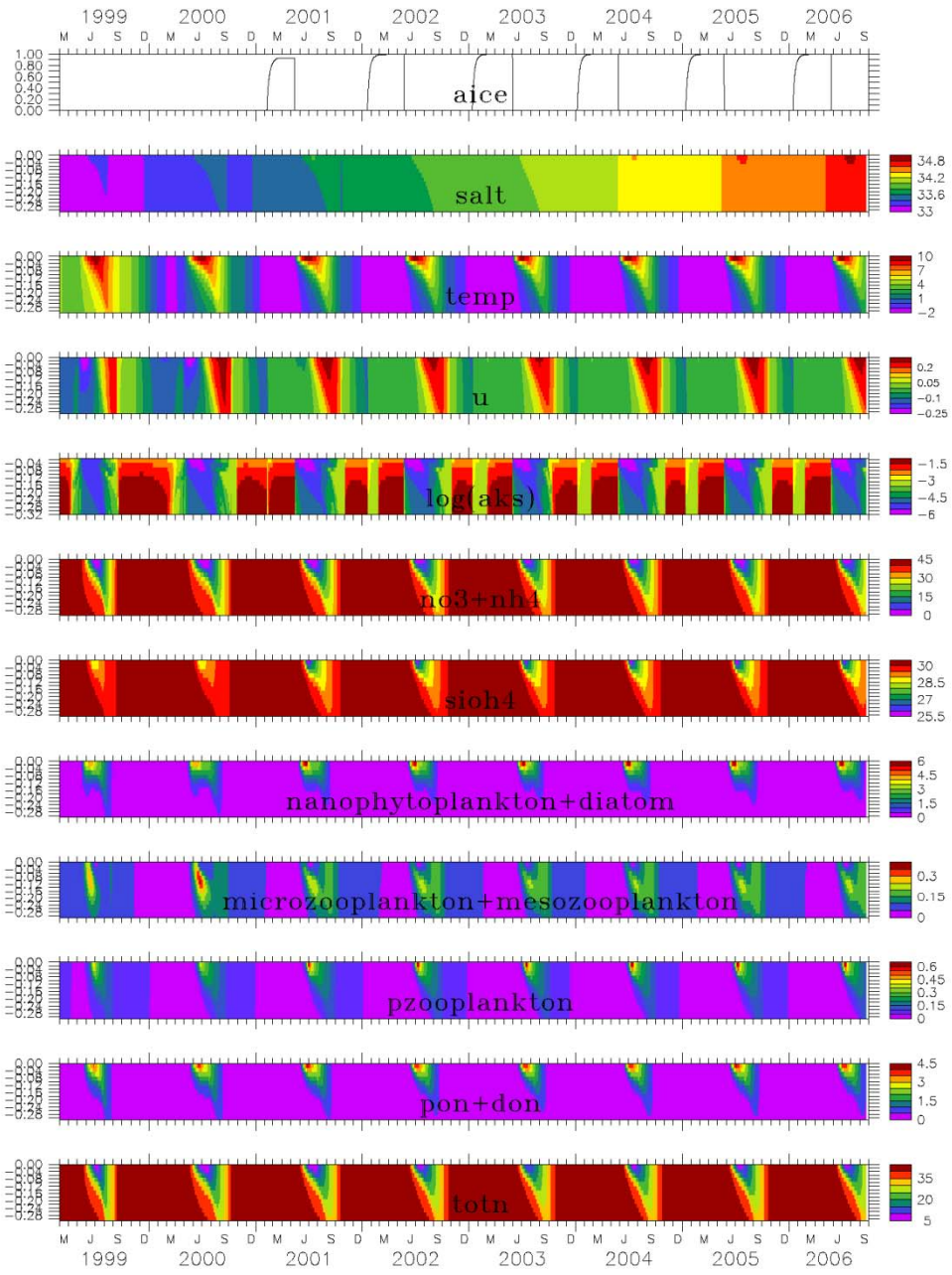
# Temperature scenarios

- Linear increase of air T with time (run for 7 years; “foreshortened” in time)
- Roe and Baker suggest *skewed probabilities* of different scenarios

Probability of this scenario actually happening!

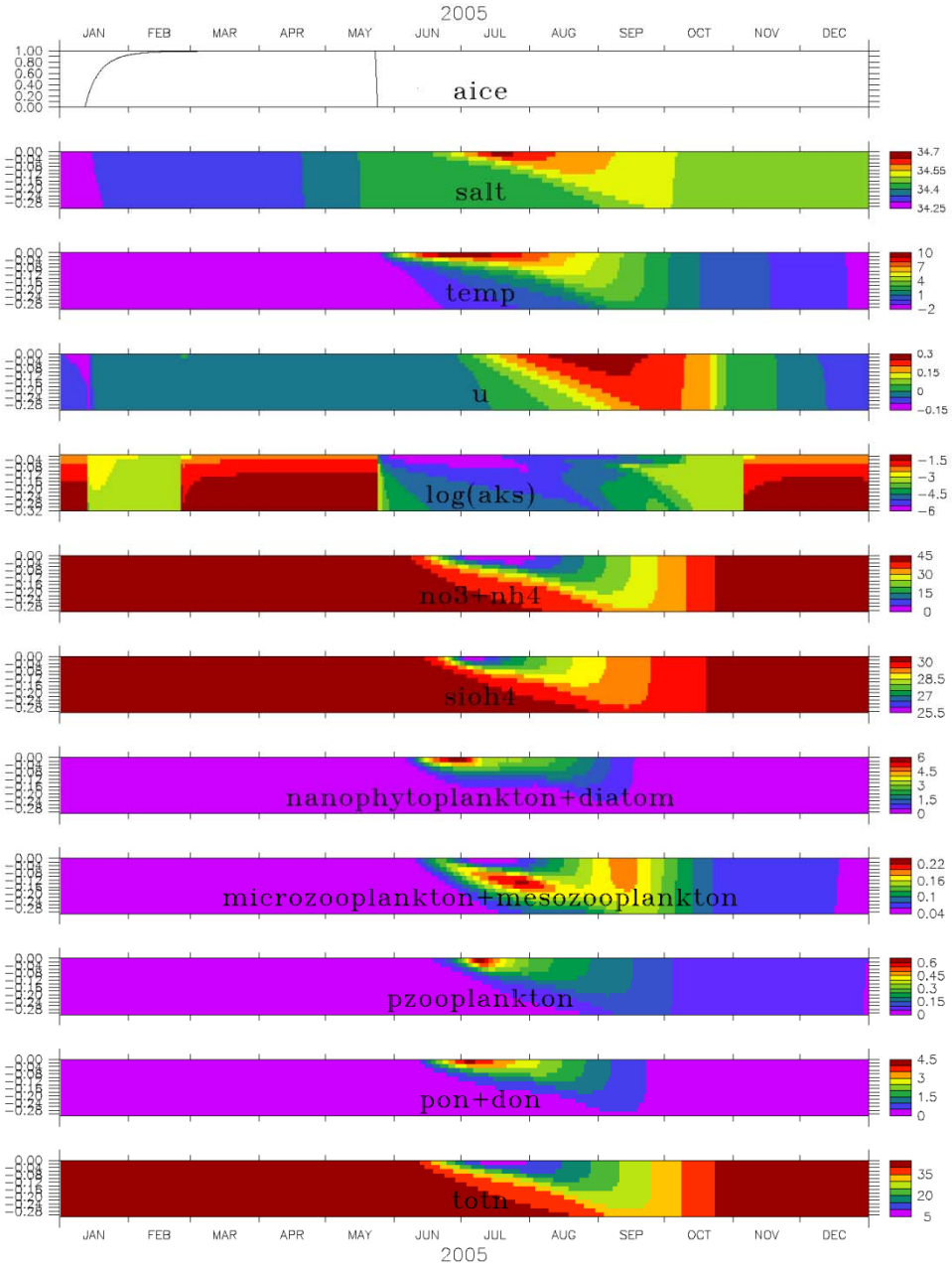



Temperature increase at end of run

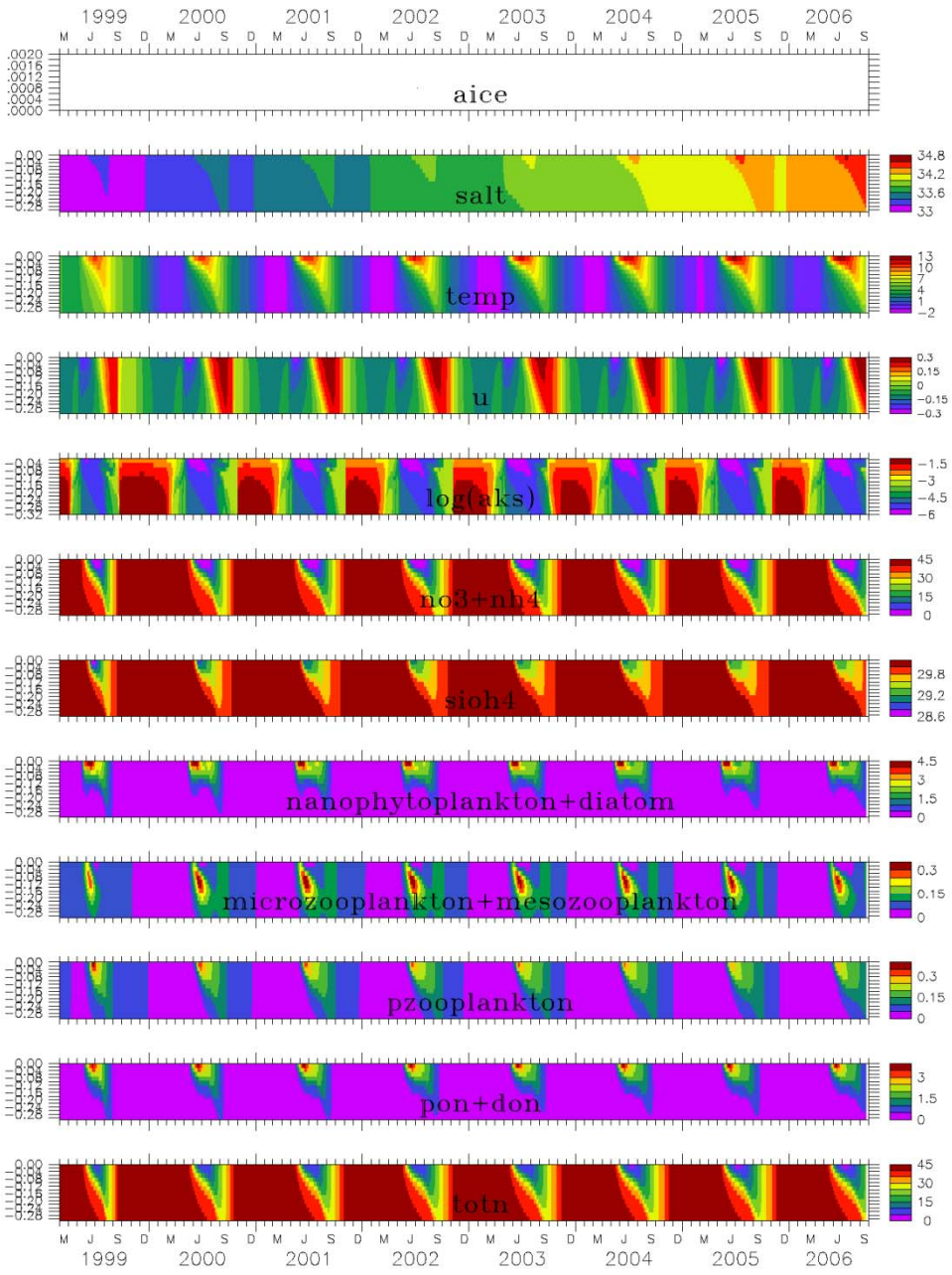



Bering “no warming” scenario

get repeating pattern

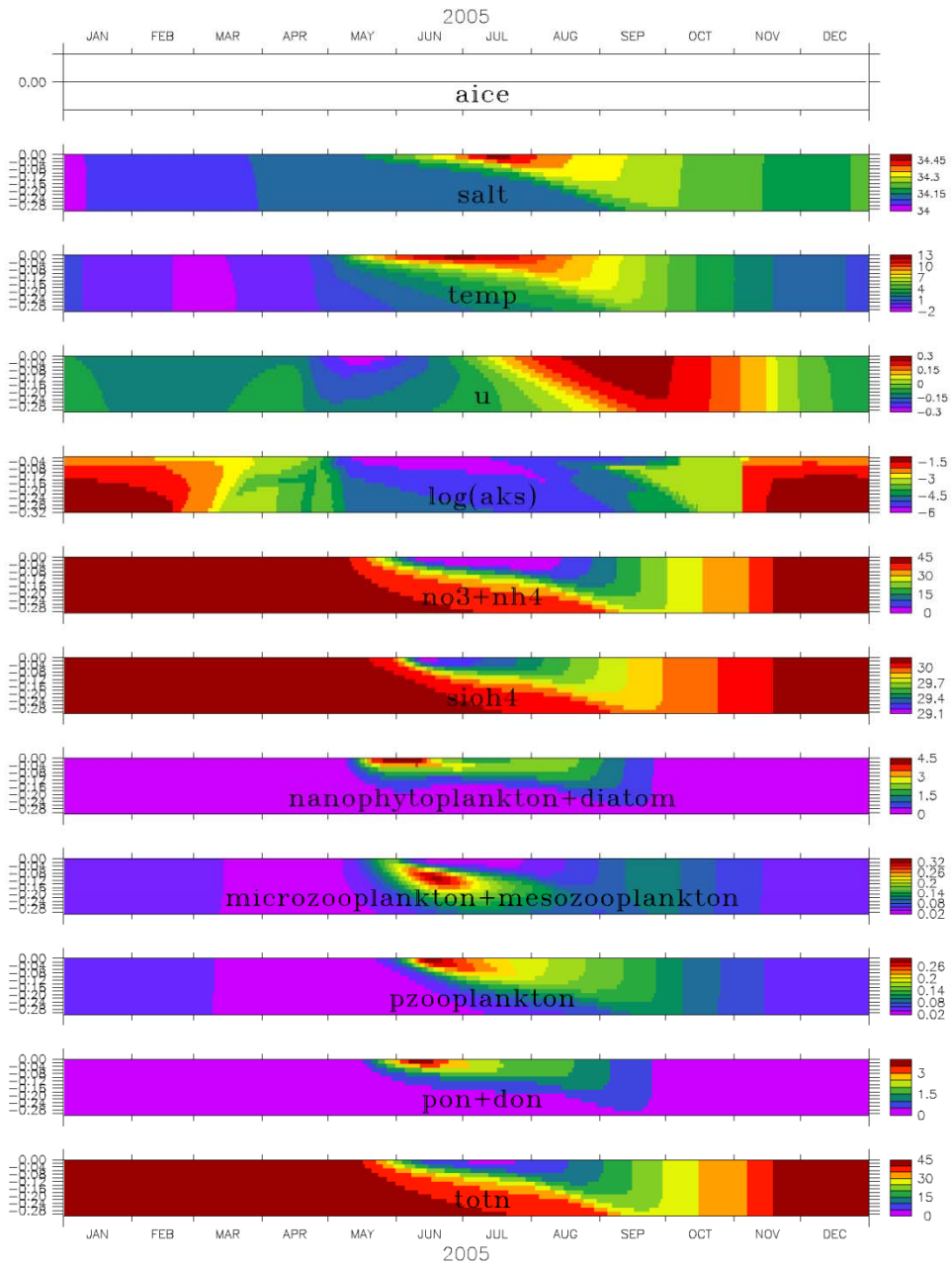



# Bering “no warming” scenario after 7 years




# Bering “severe warming” scenario

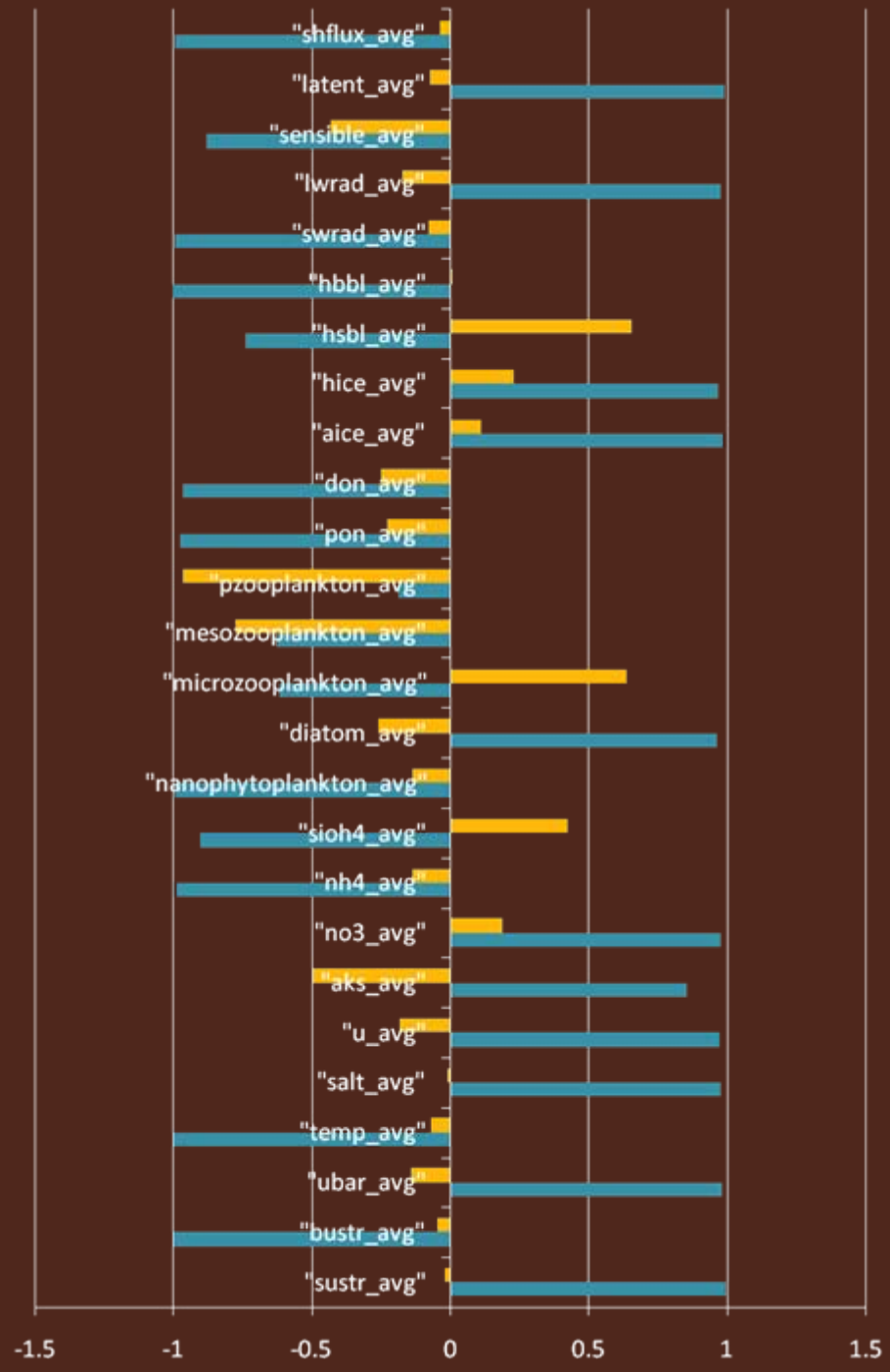
note warming trend at surface

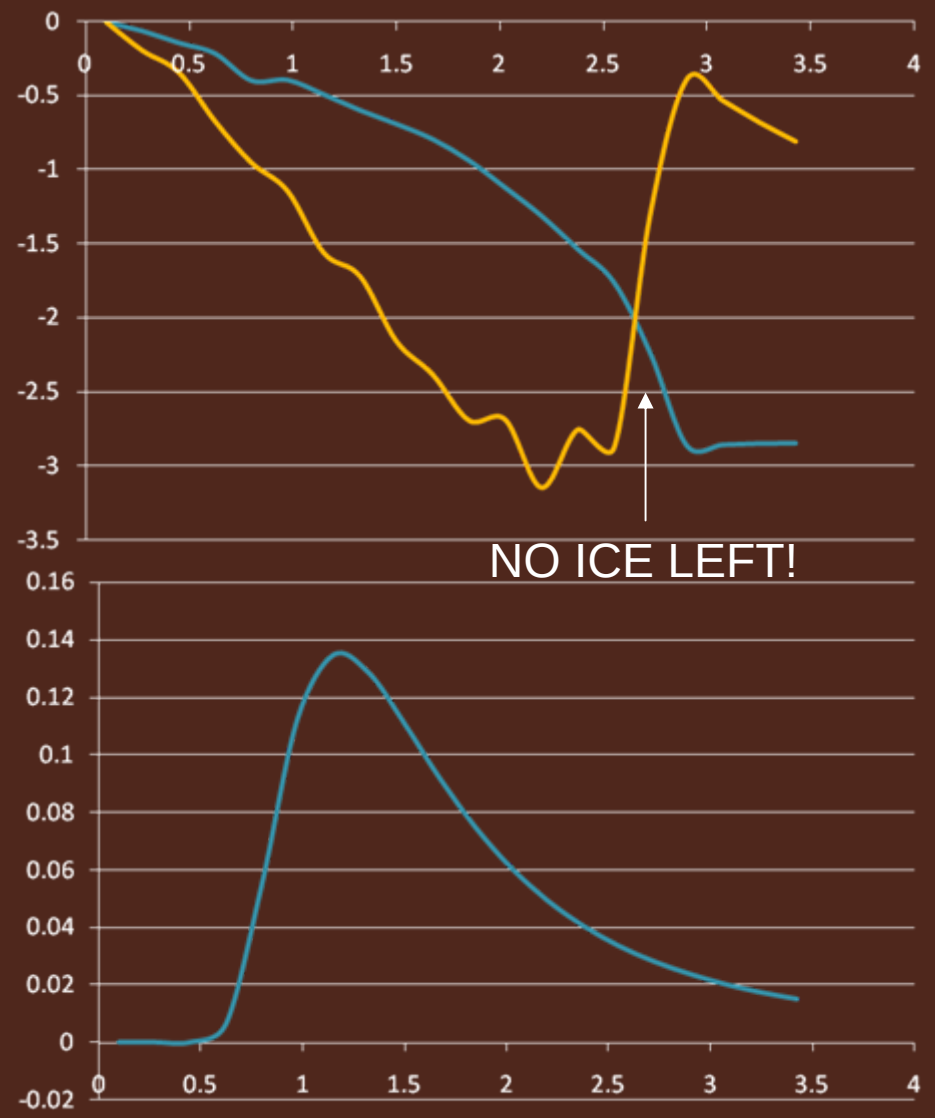



# Bering “severe warming” scenario after 7 years

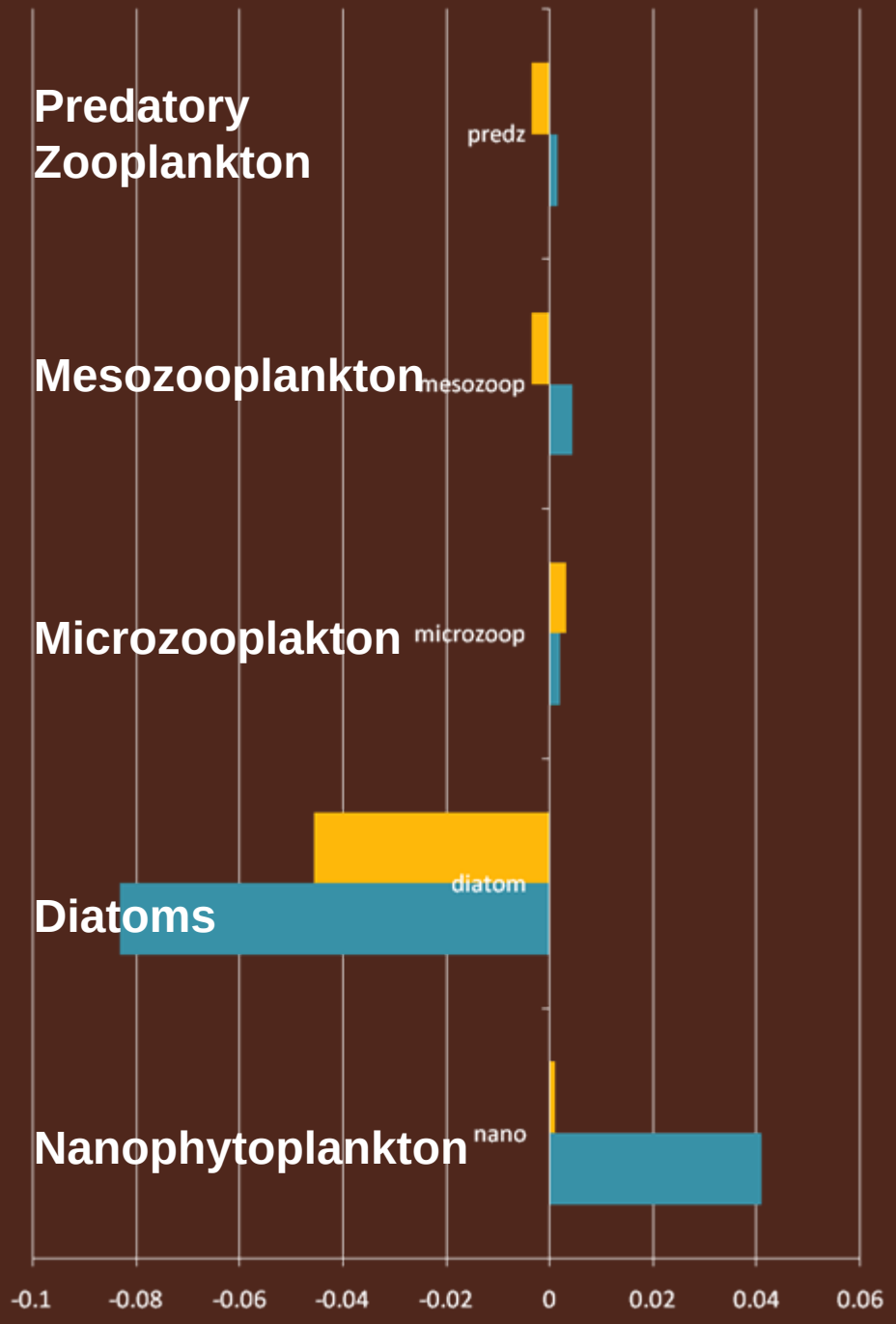
**spring bloom is advanced in time**

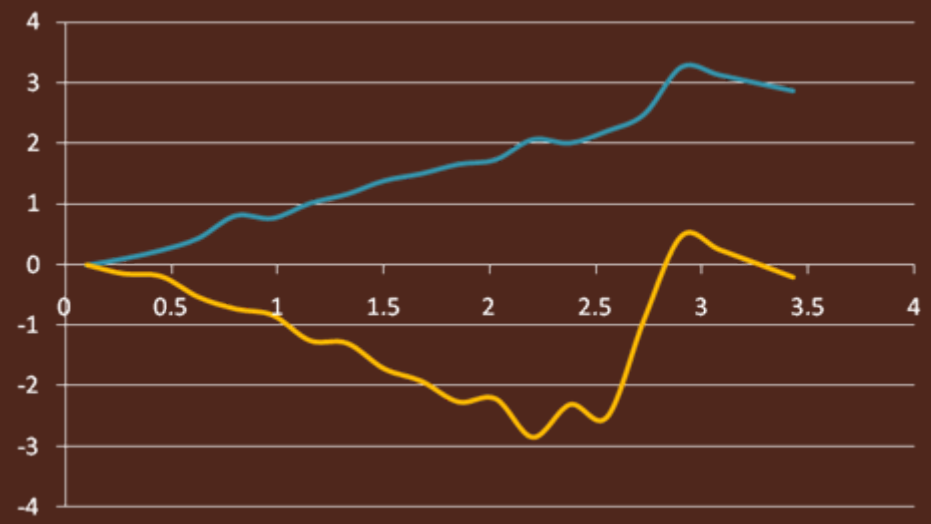
# Bering biophysical modes

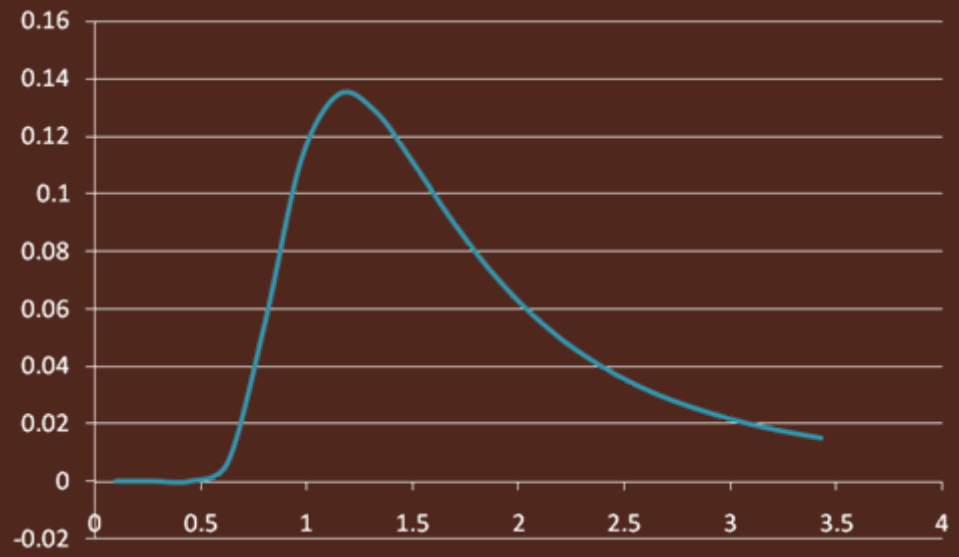


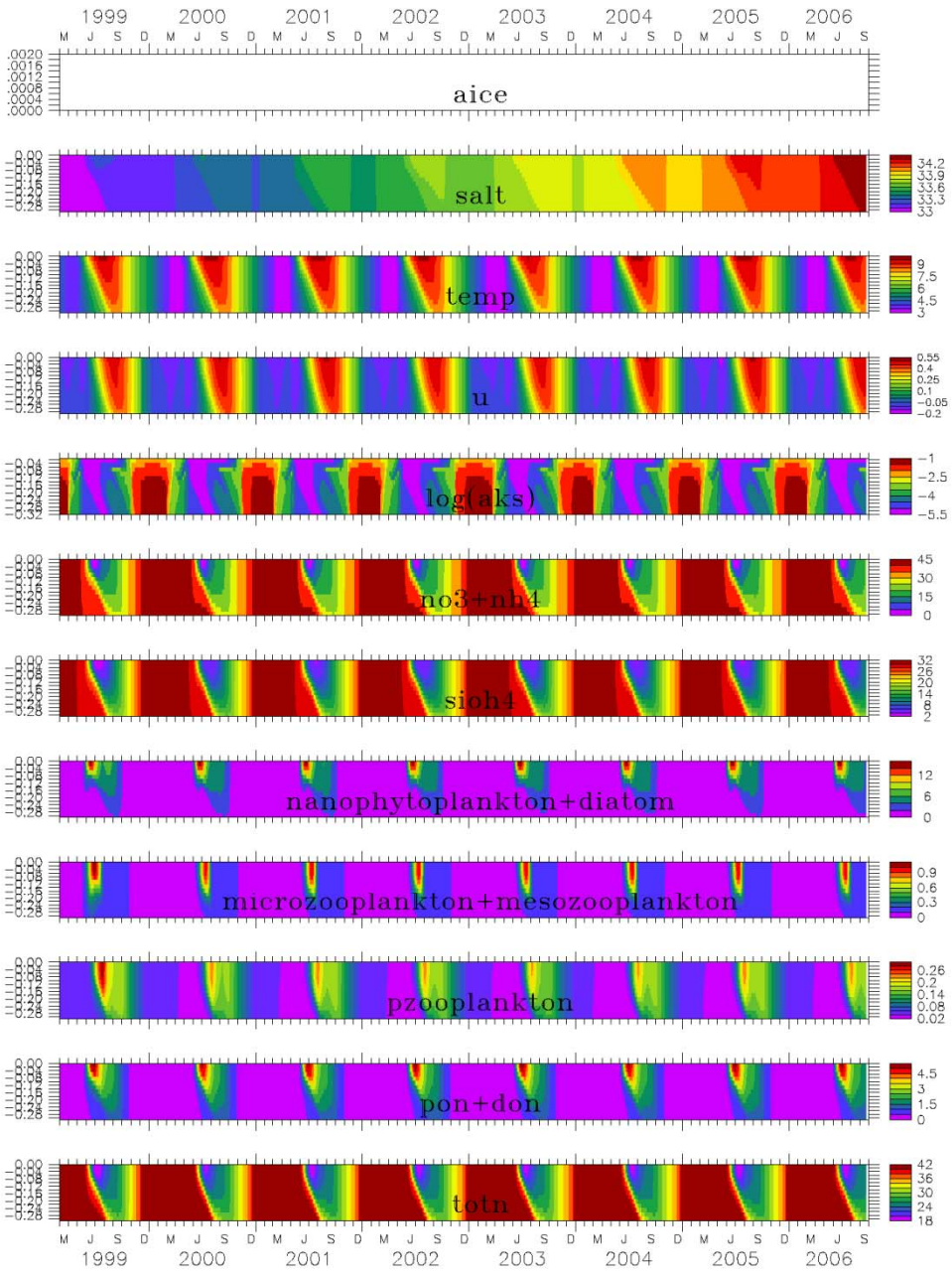



# Bering trophic modes



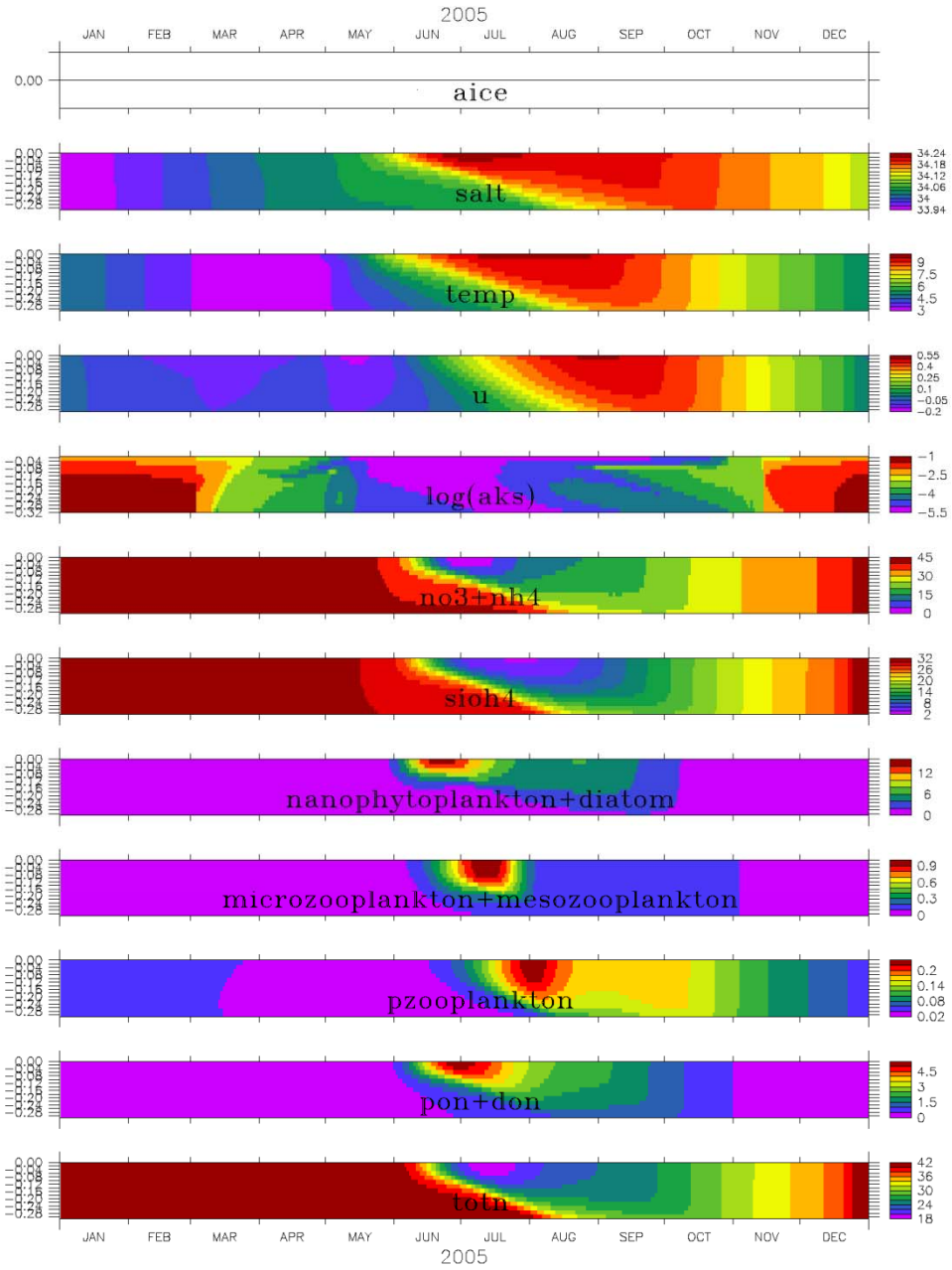



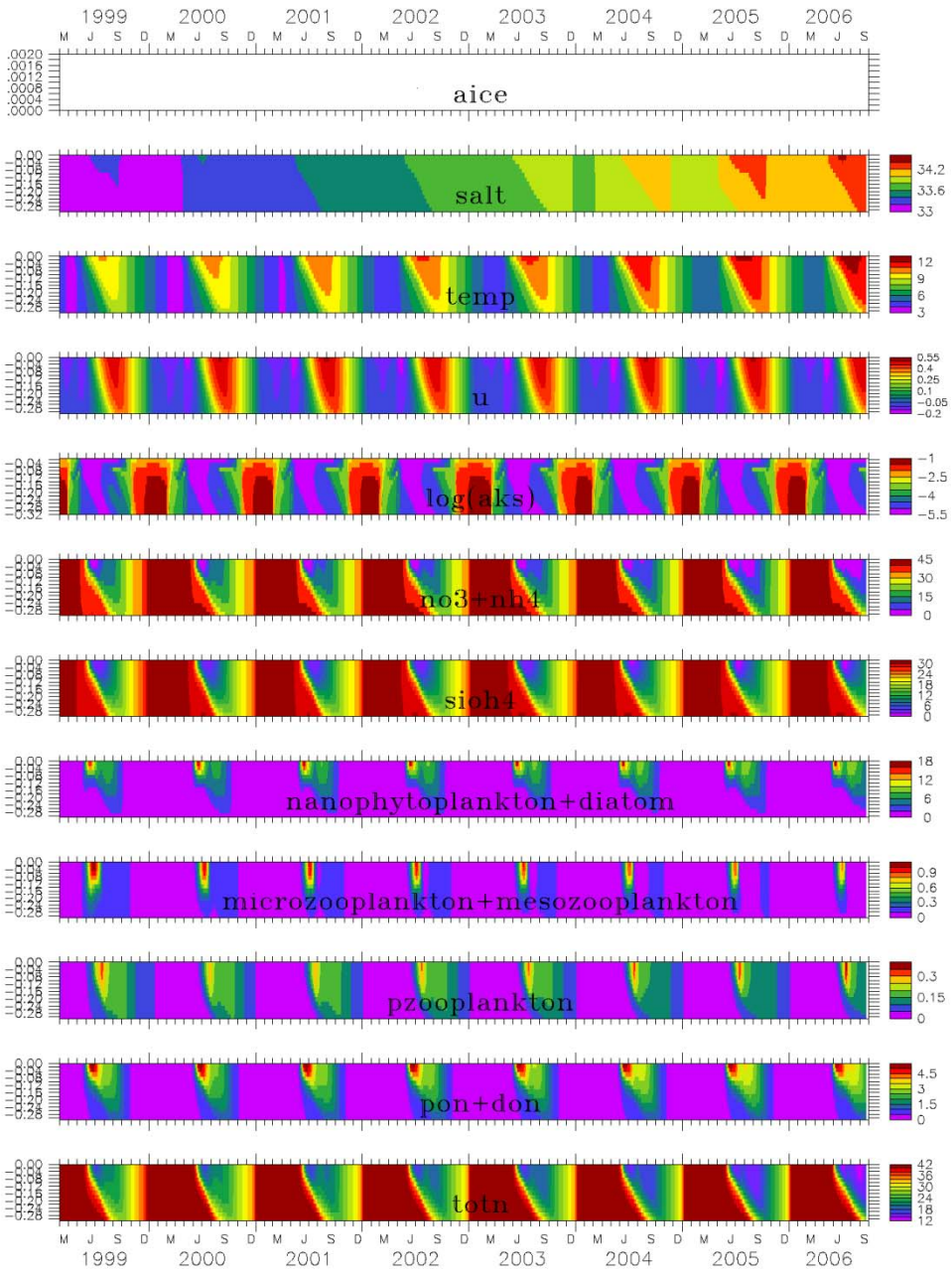



# CGOA “no warming” scenario

get repeating pattern

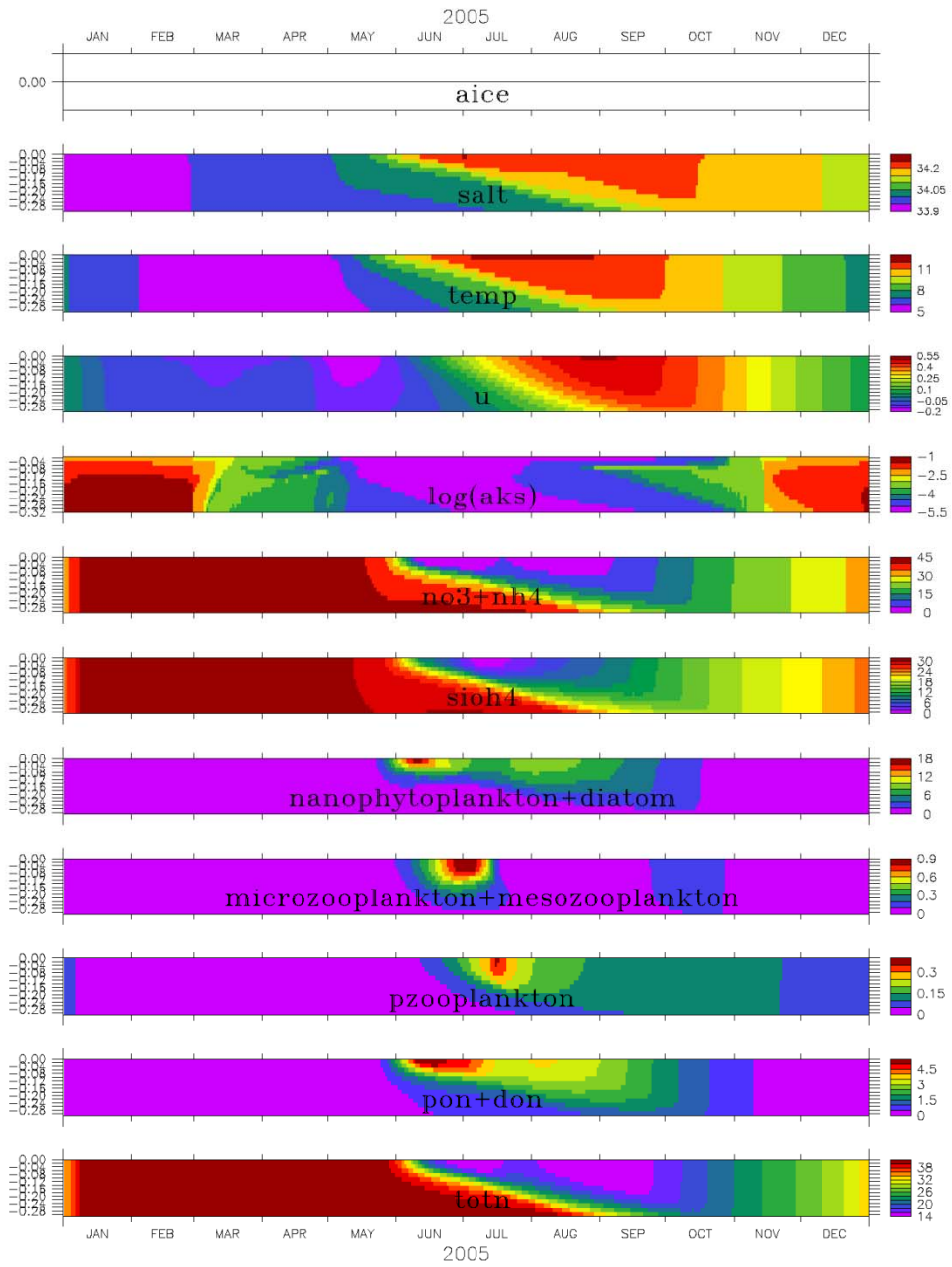



# CGOA “no warming” scenario after 7 years




# CGOA “severe warming” scenario

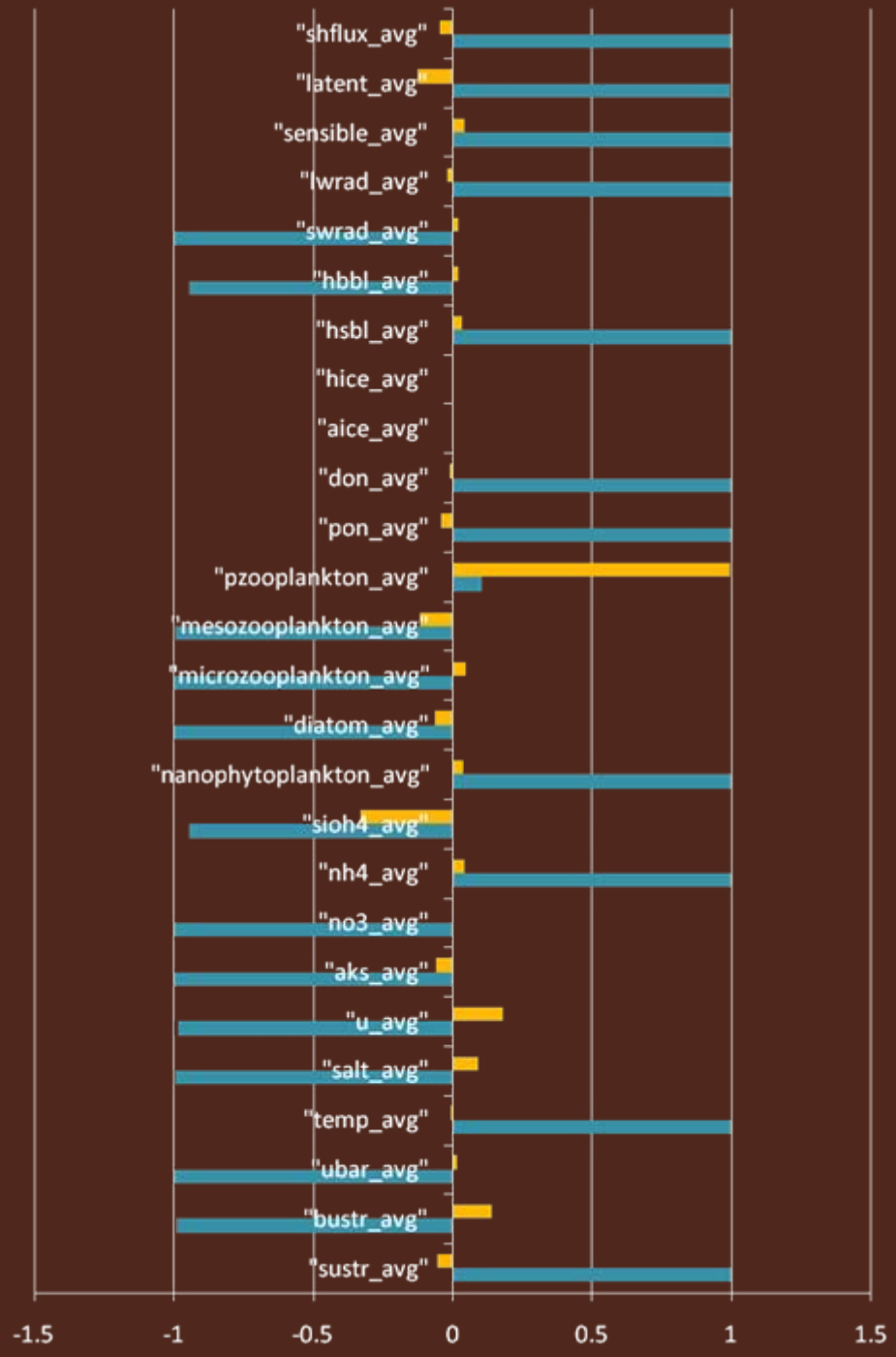
note warming trend at surface

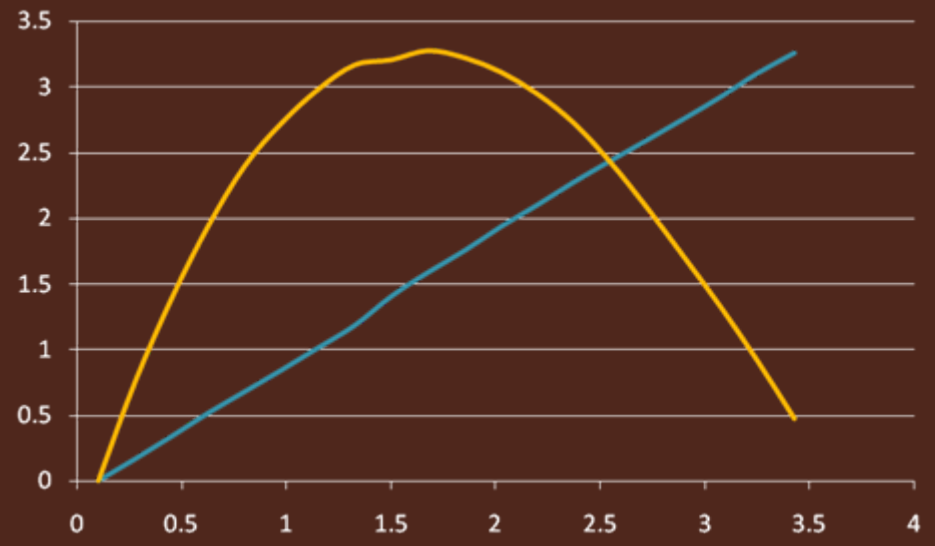


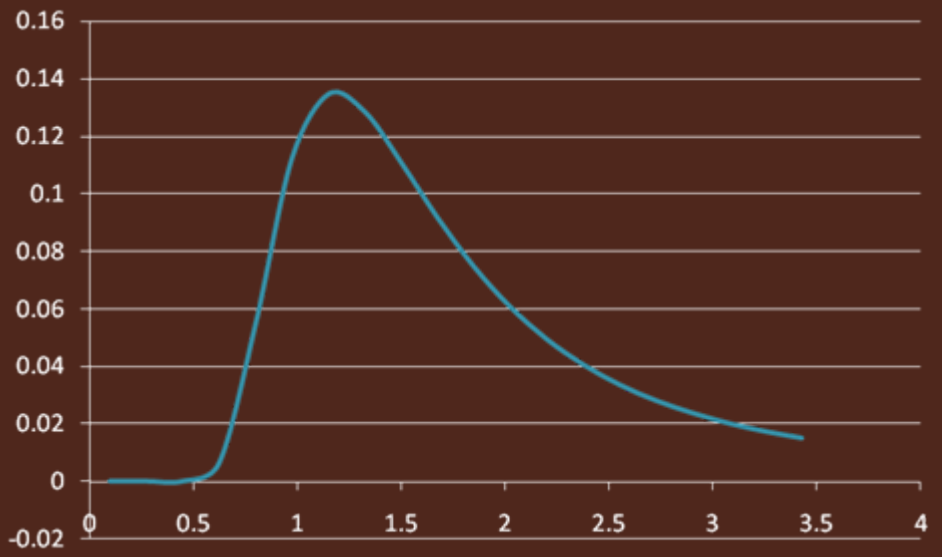

# CGOA "severe warming" scenario after 7 years

**spring bloom only slightly advanced in time**

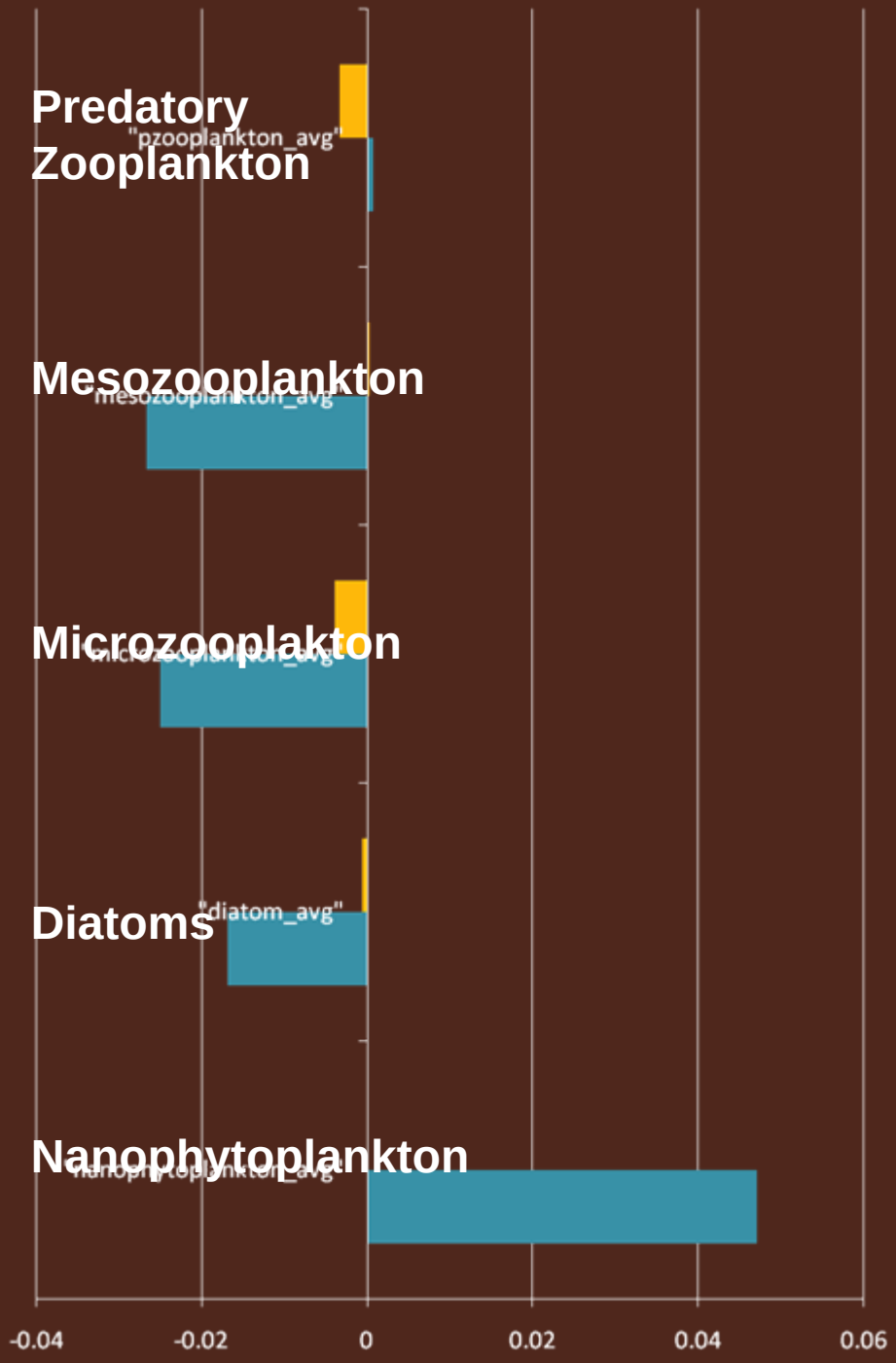
# CGOA biophysical modes

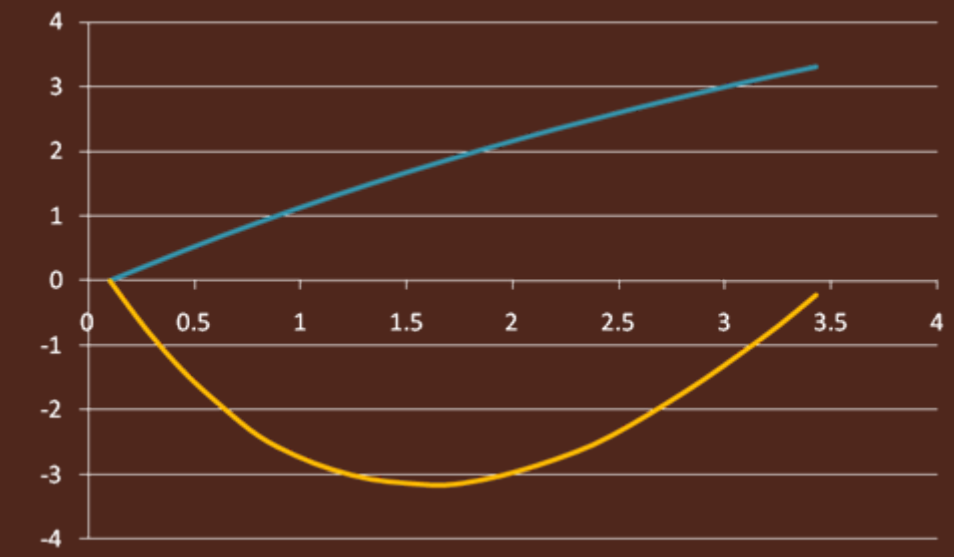


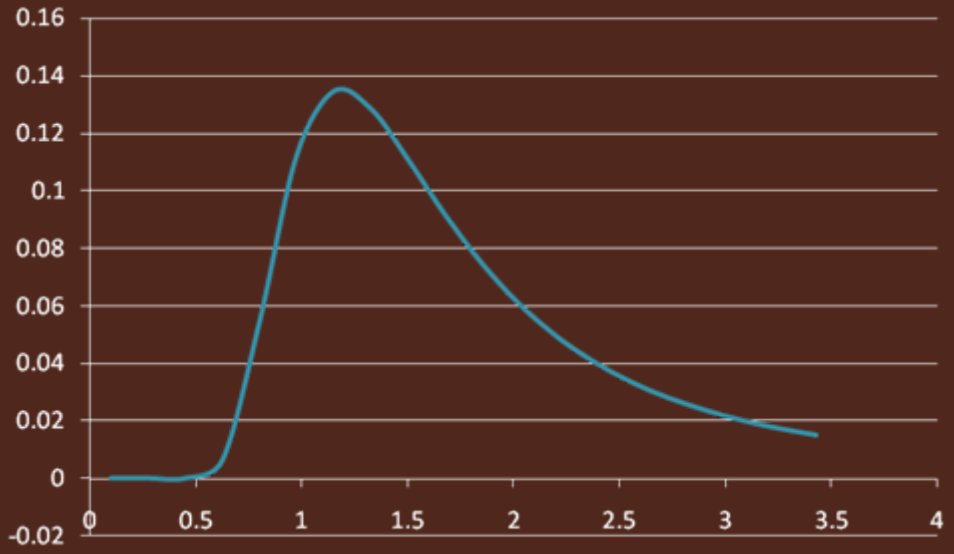



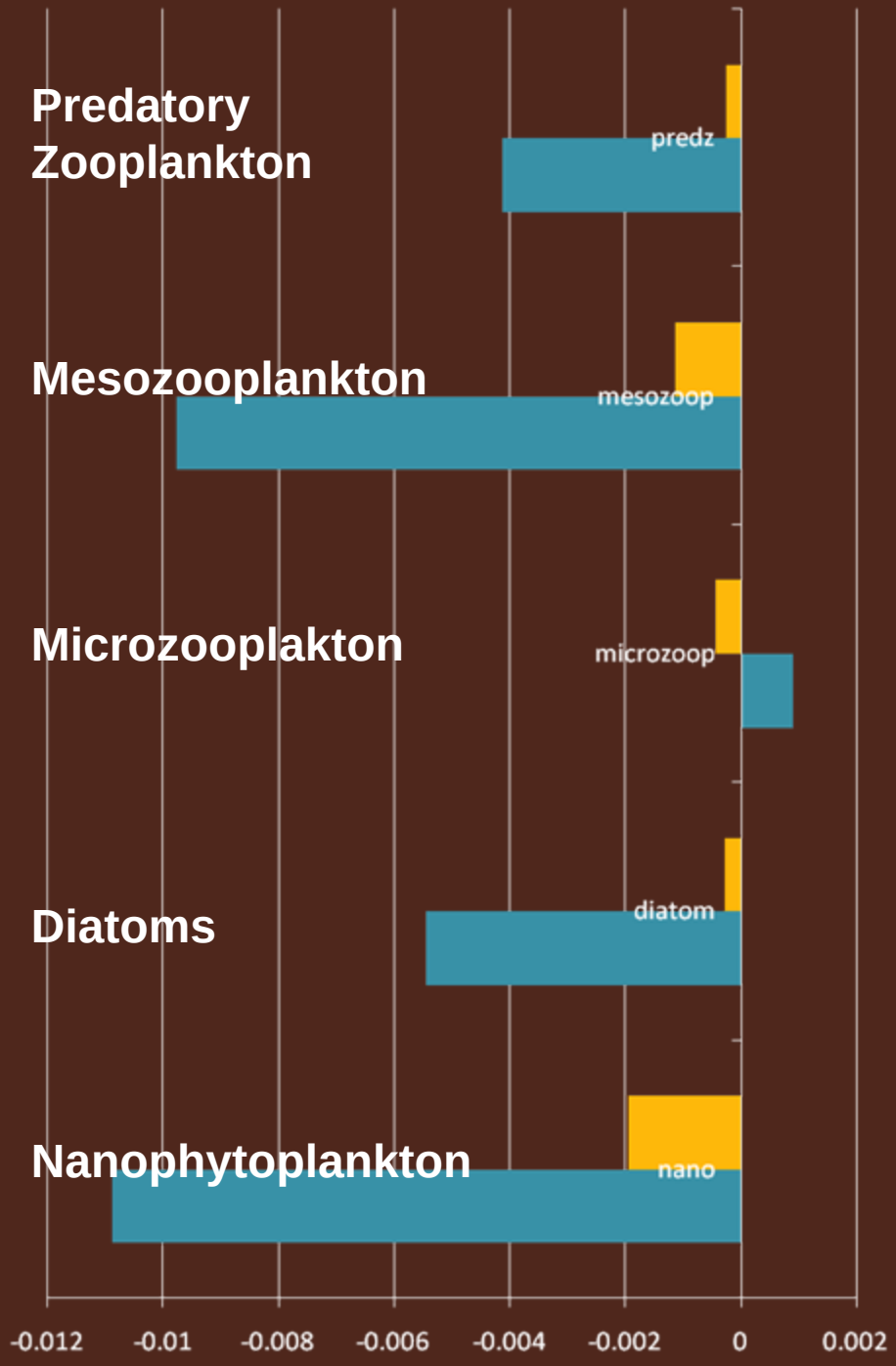
# CGOA trophic modes

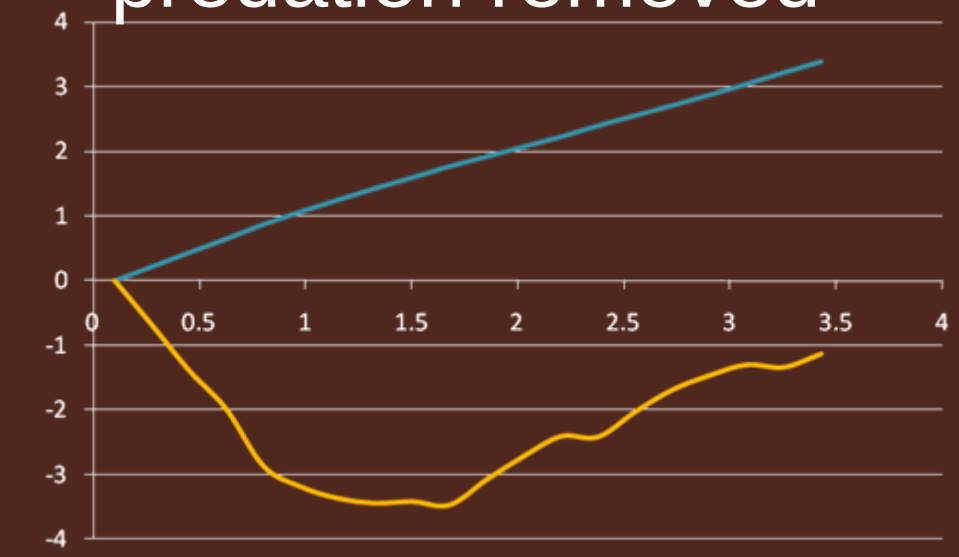


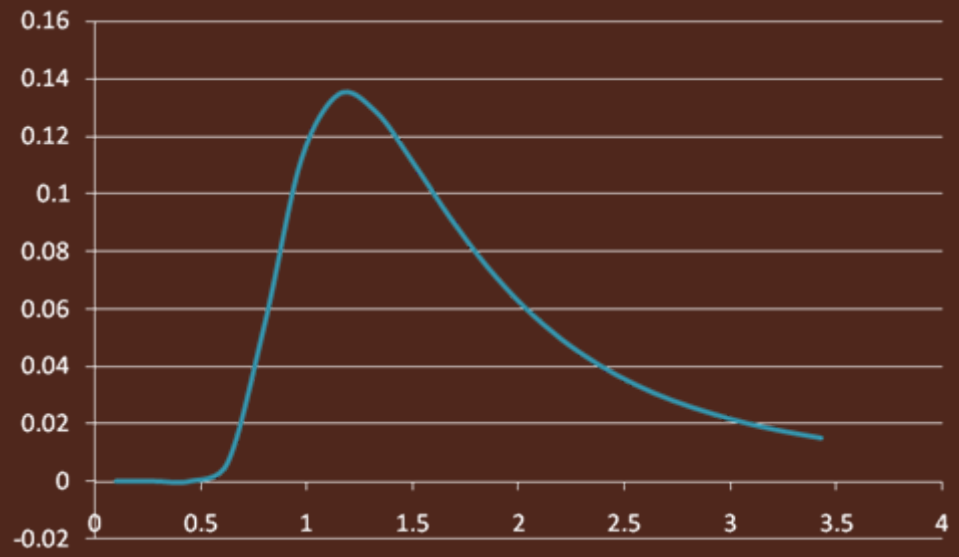



# CGOA trophic modes with predation removed

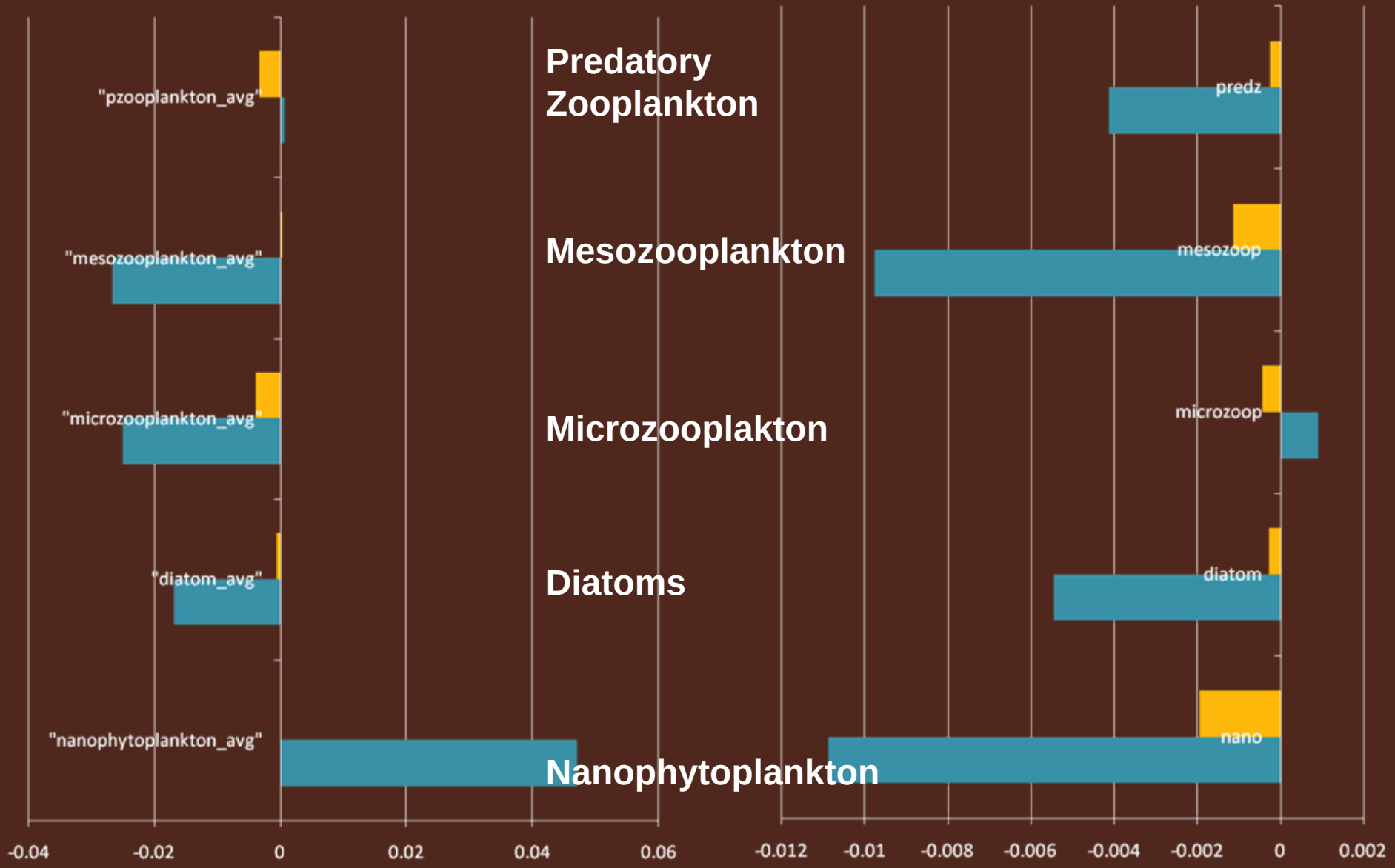


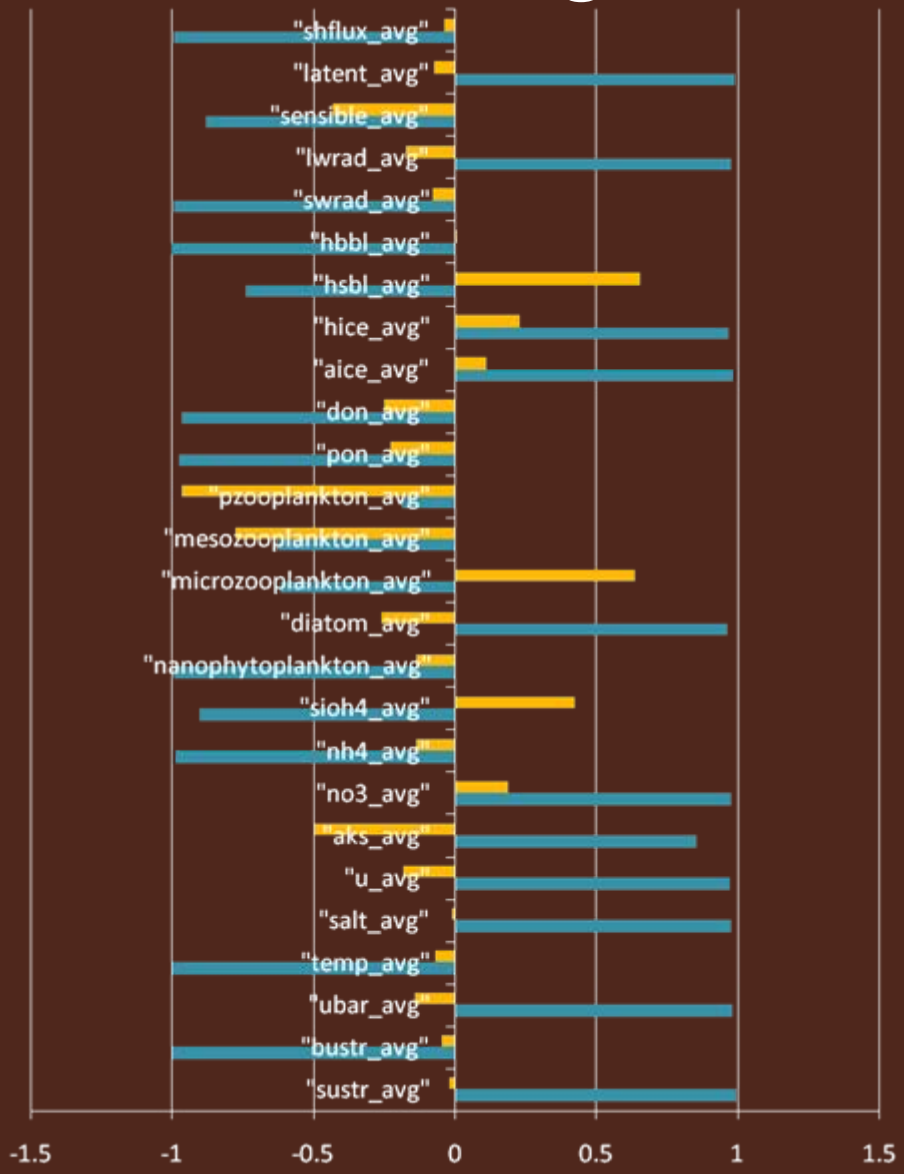
# Compare CGOA models

## predation included  predation removed

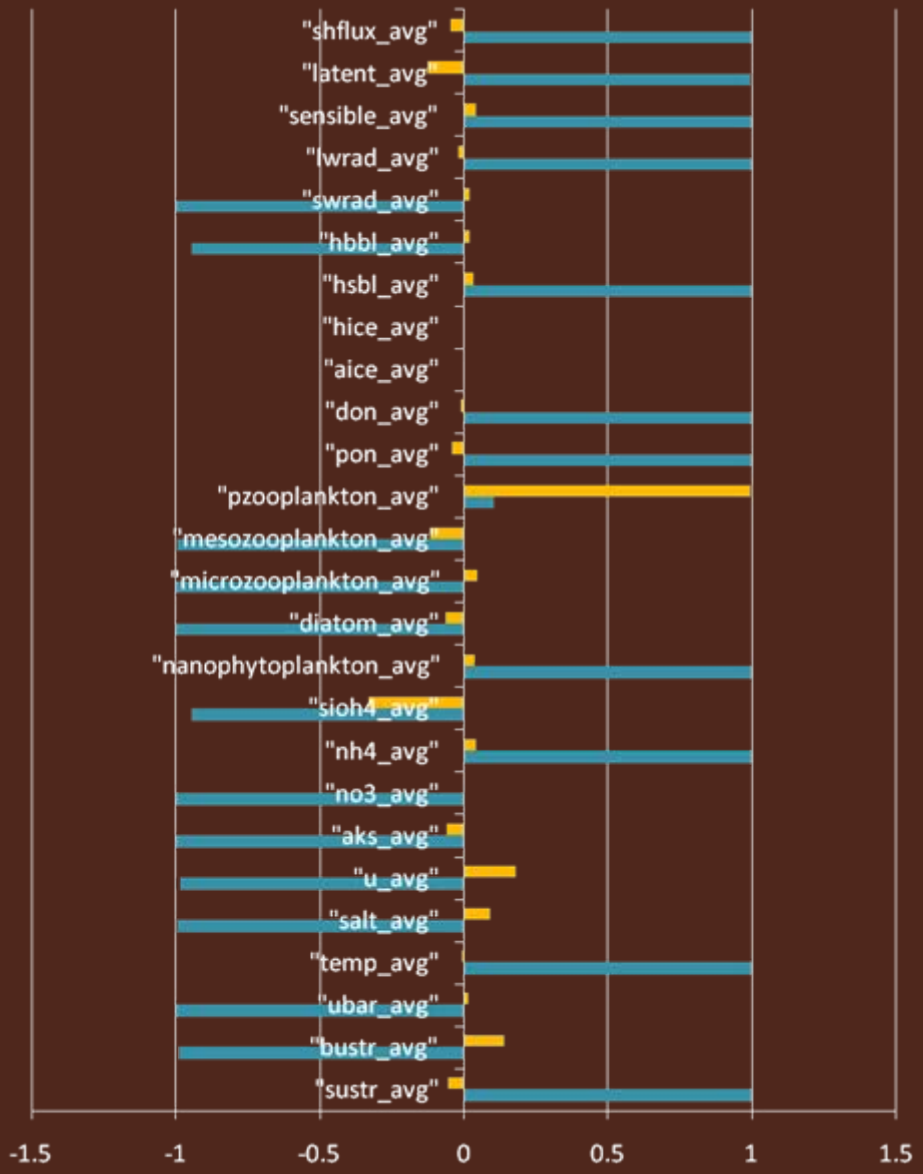


# Compare coupled modes

## Bering

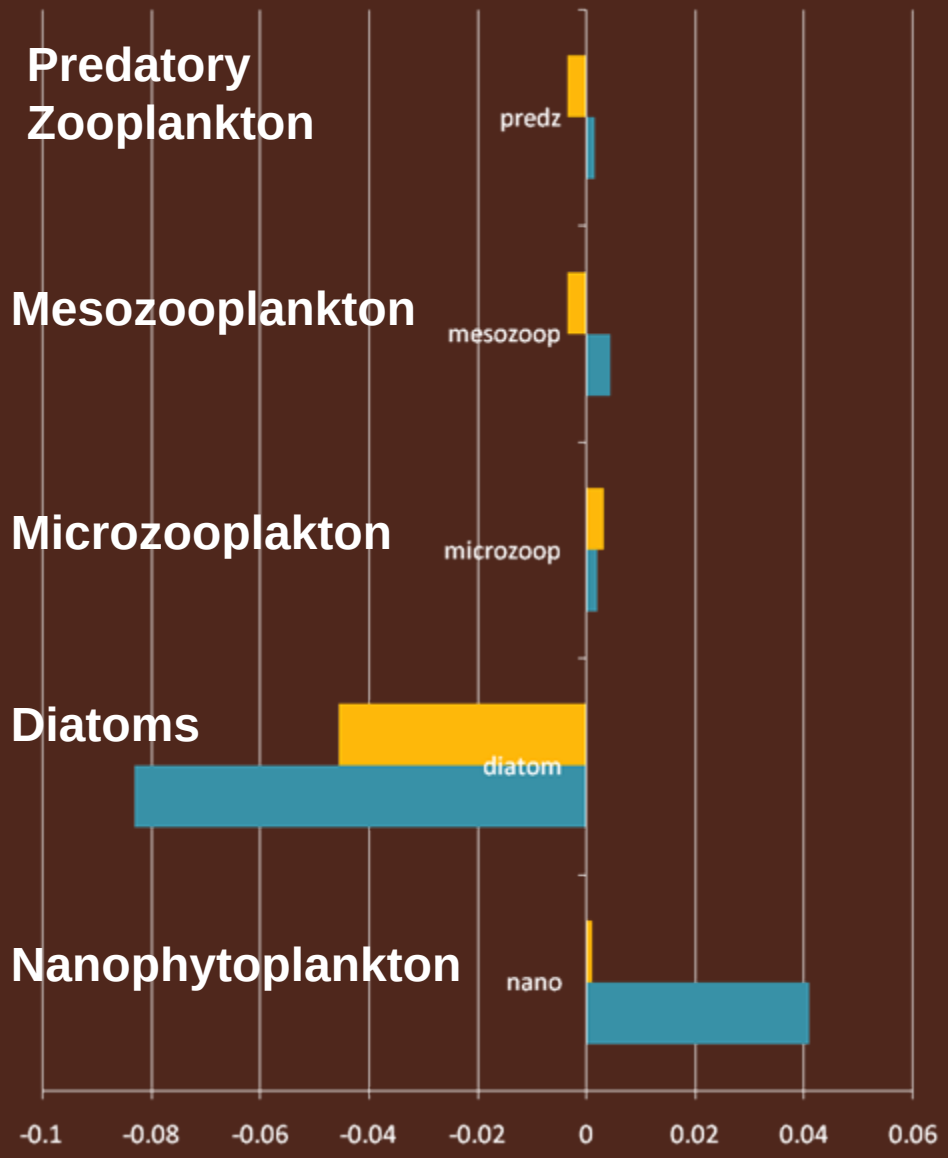



## CGOA

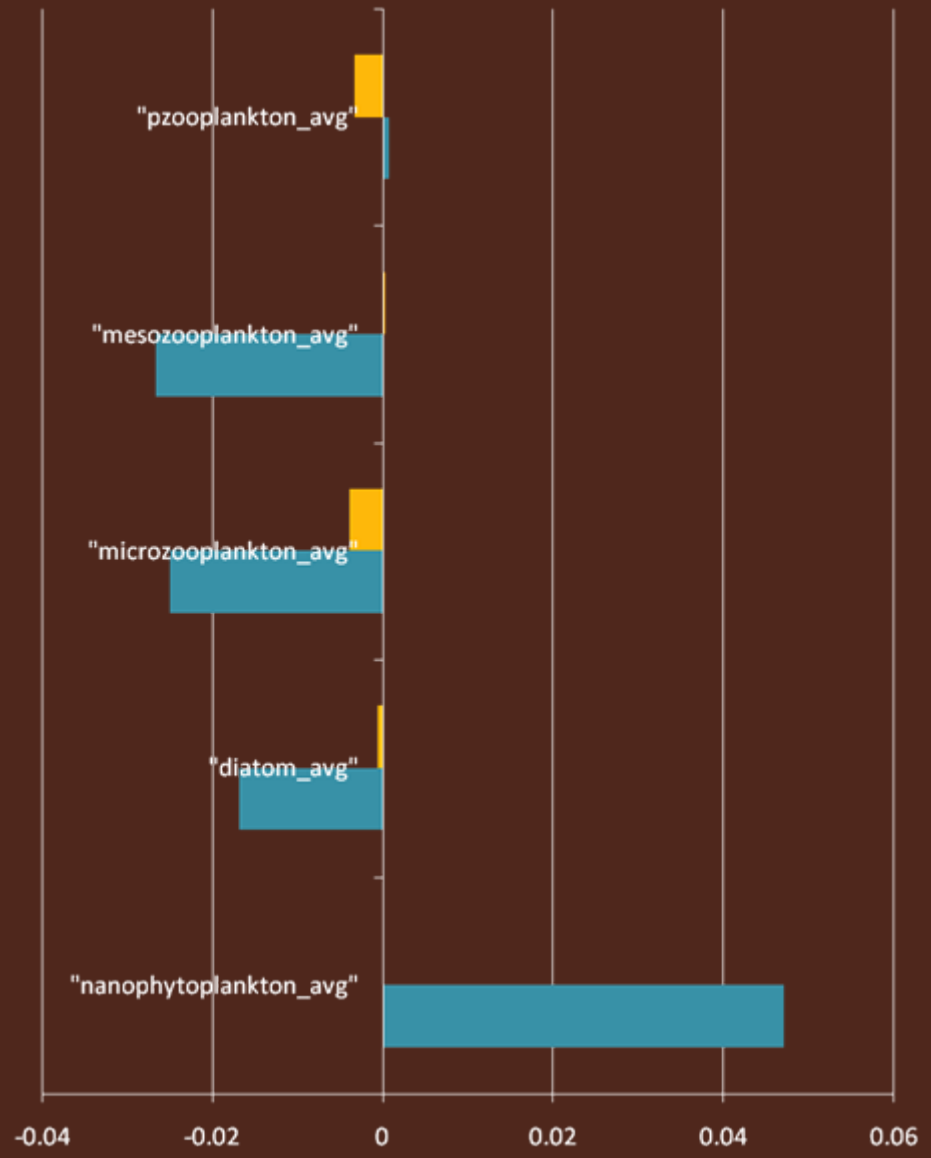


# Compare trophic modes

## Bering




## CGOA

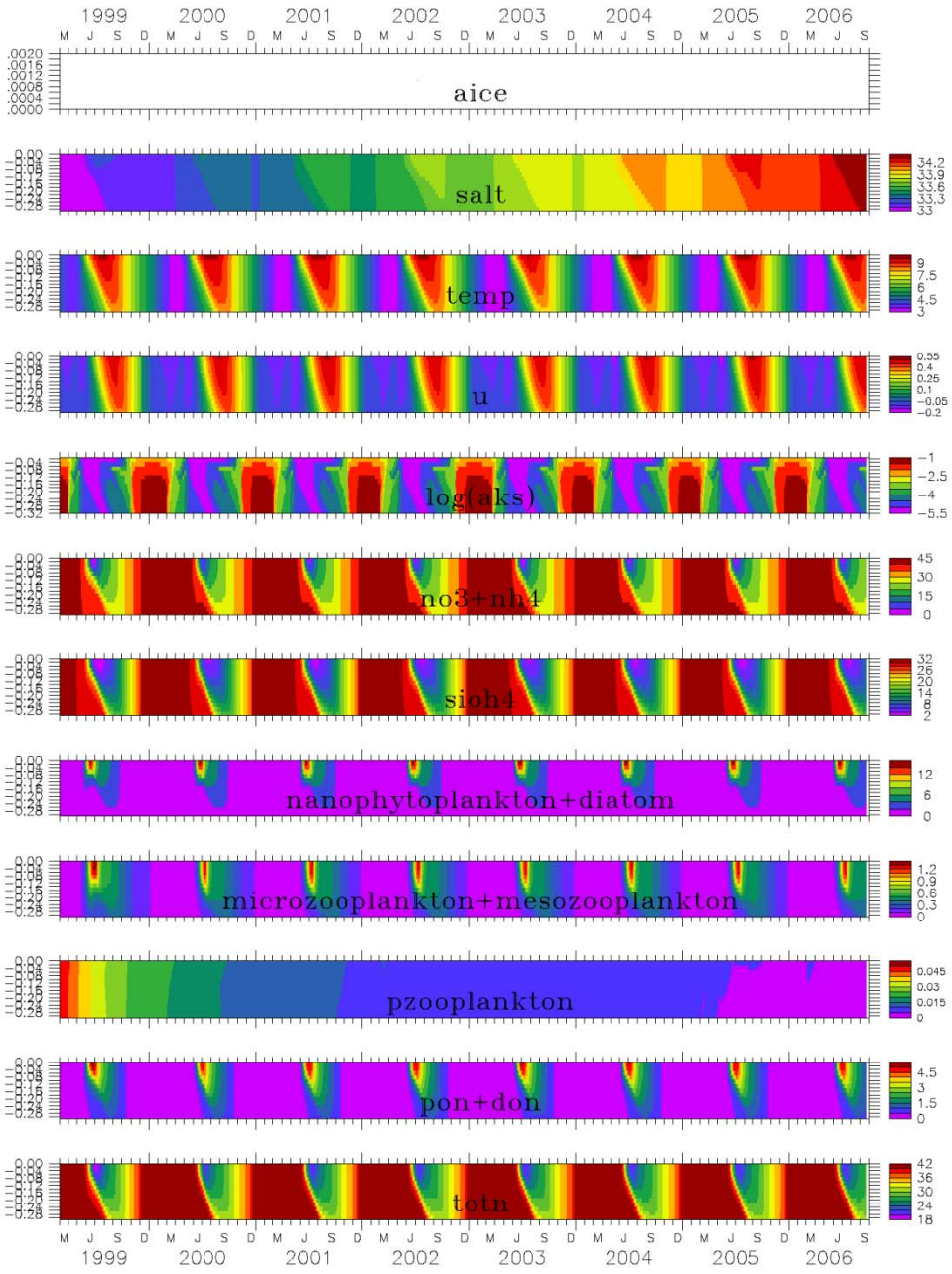


# *Preliminary* Conclusions

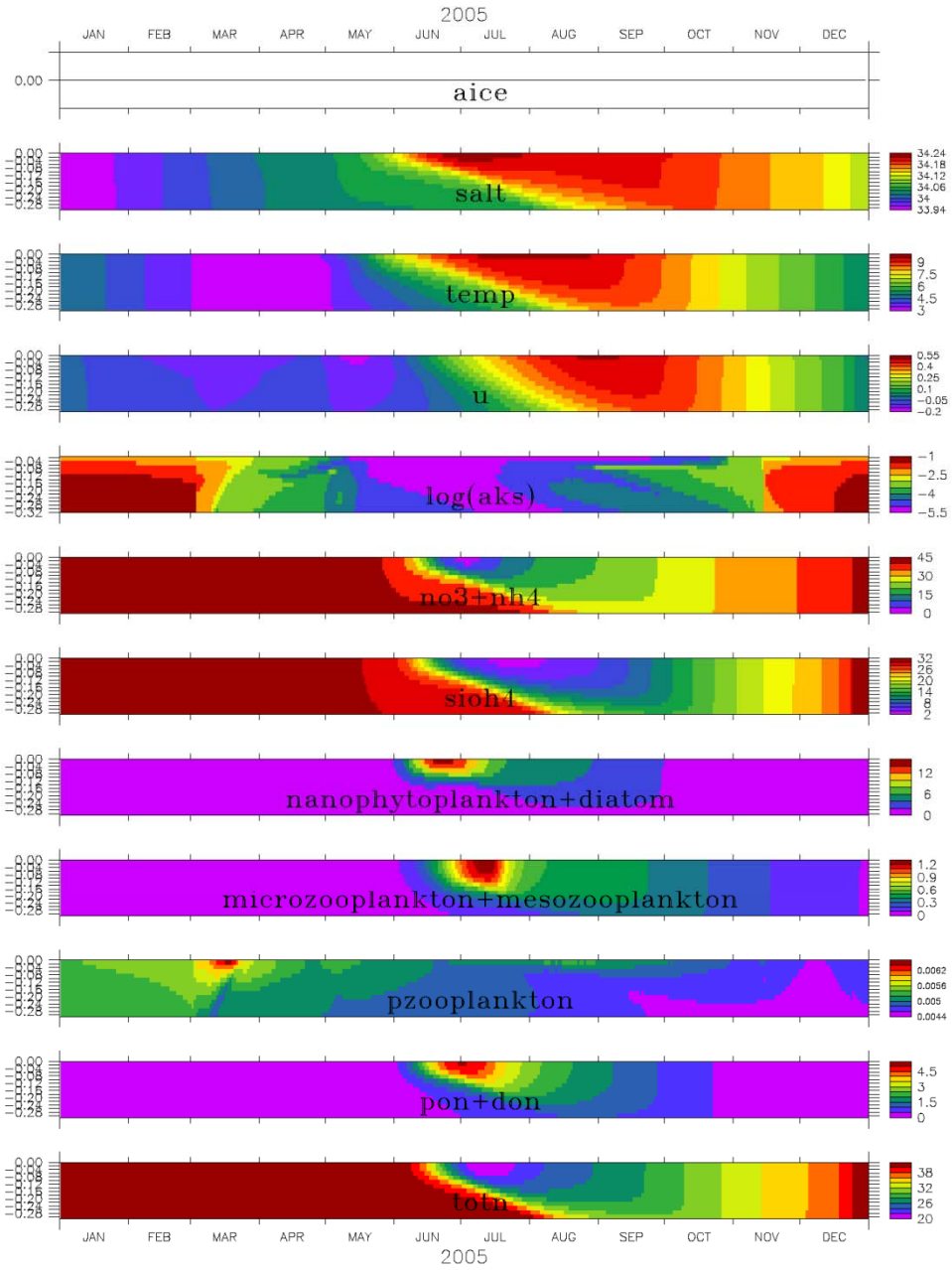
- Coupled modes help to characterize the system
- In both cases, the dominant mode is strongly correlated with the forcing
- In the Bering, warming is associated with
  - more nanophytoplankton
  - less diatoms
- In the CGOA, warming is associated with
  - more nanophytoplankton
  - less diatoms, microzooplankton, mesozooplankton
- Who is the most variable (least predictable)?
  - Diatoms in the Bering
  - Nanophytoplankton in the CGOA
- Major sensitivity to presence of predators

# Future work

- More comparison with data!
- Refine coefficient values
- Calculate expected values and variances
- Apply these techniques to 3D results in BEST/BSIERP




# CGOA no pred “no warming” scenario

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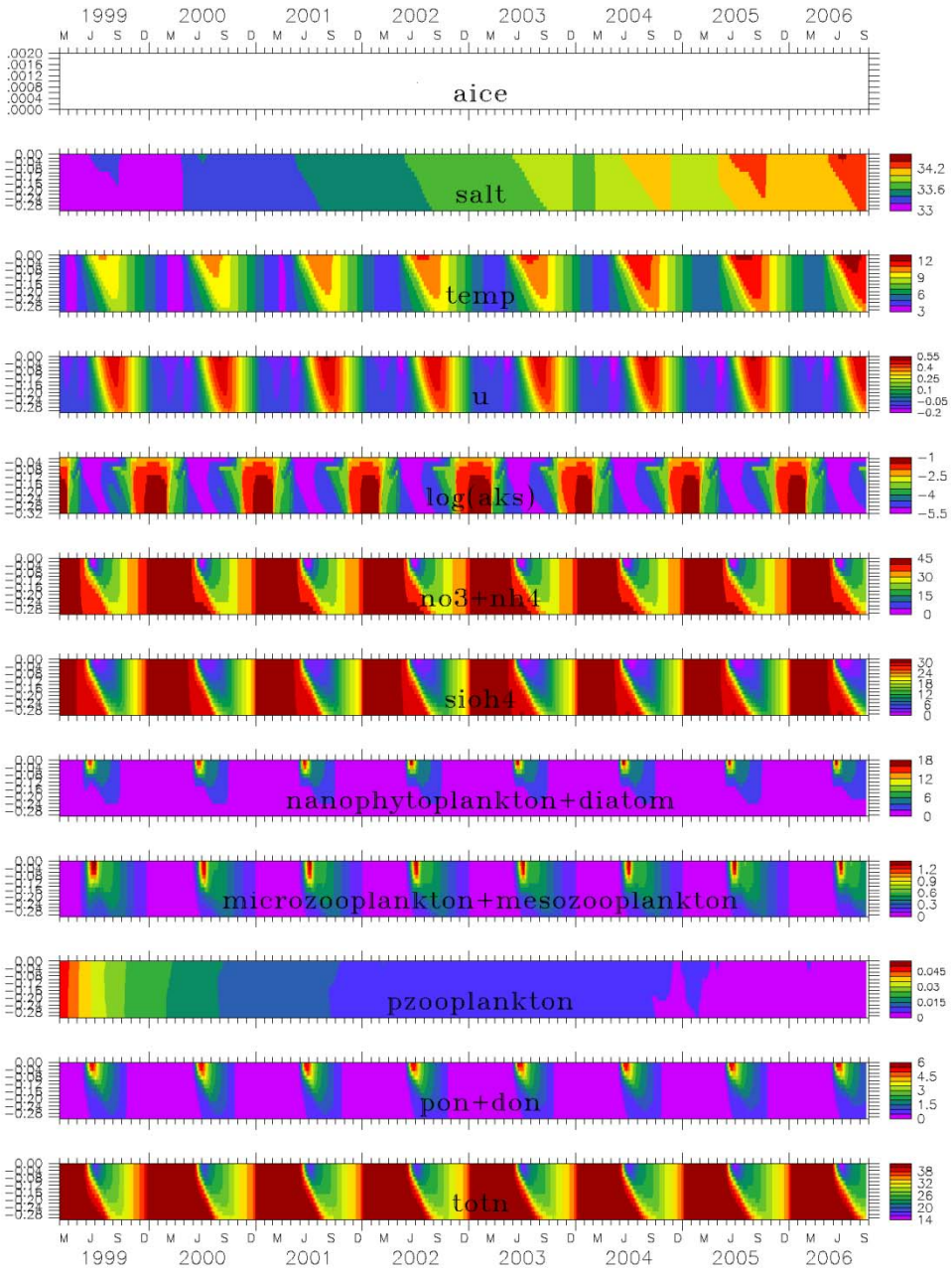


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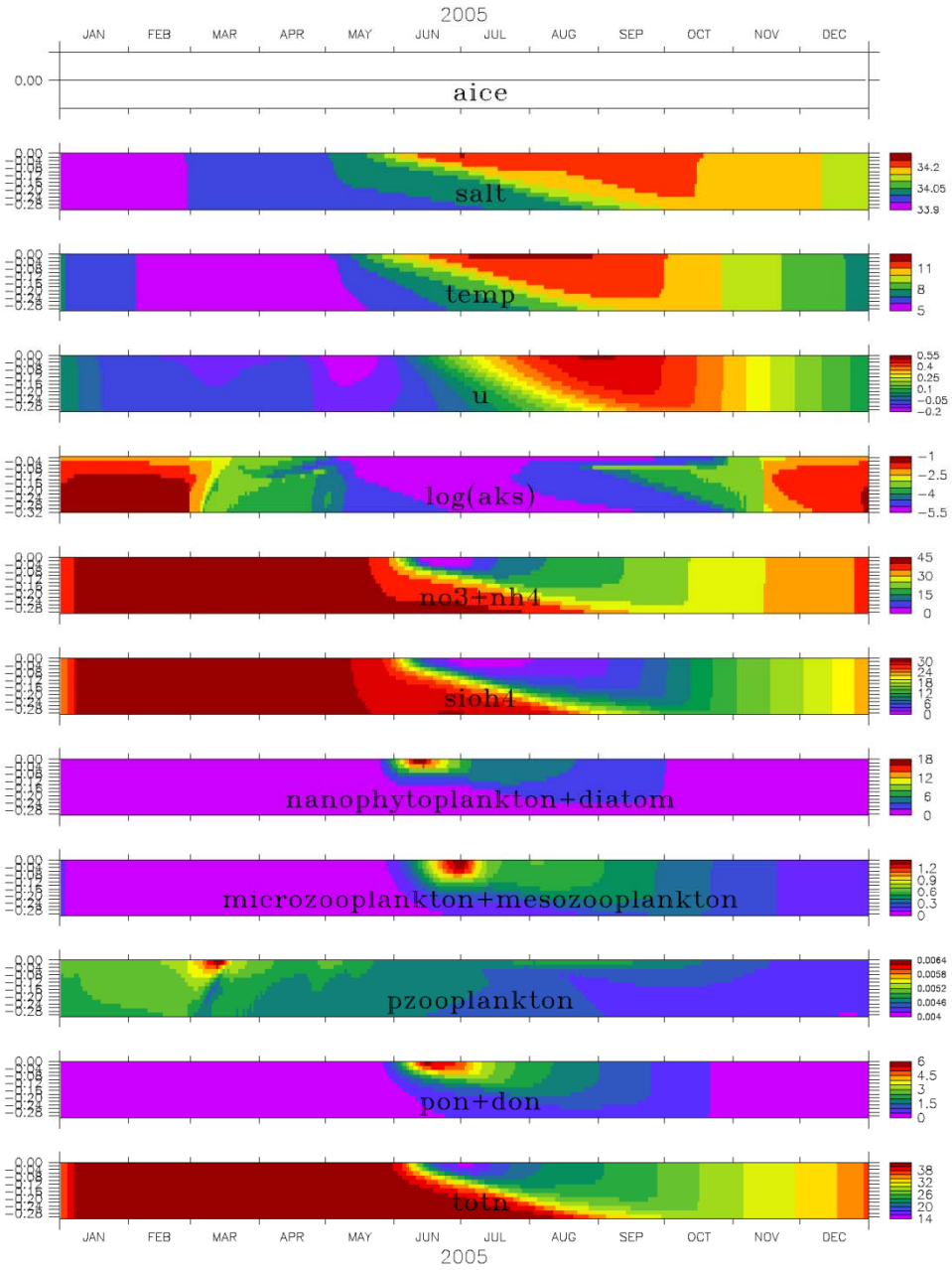
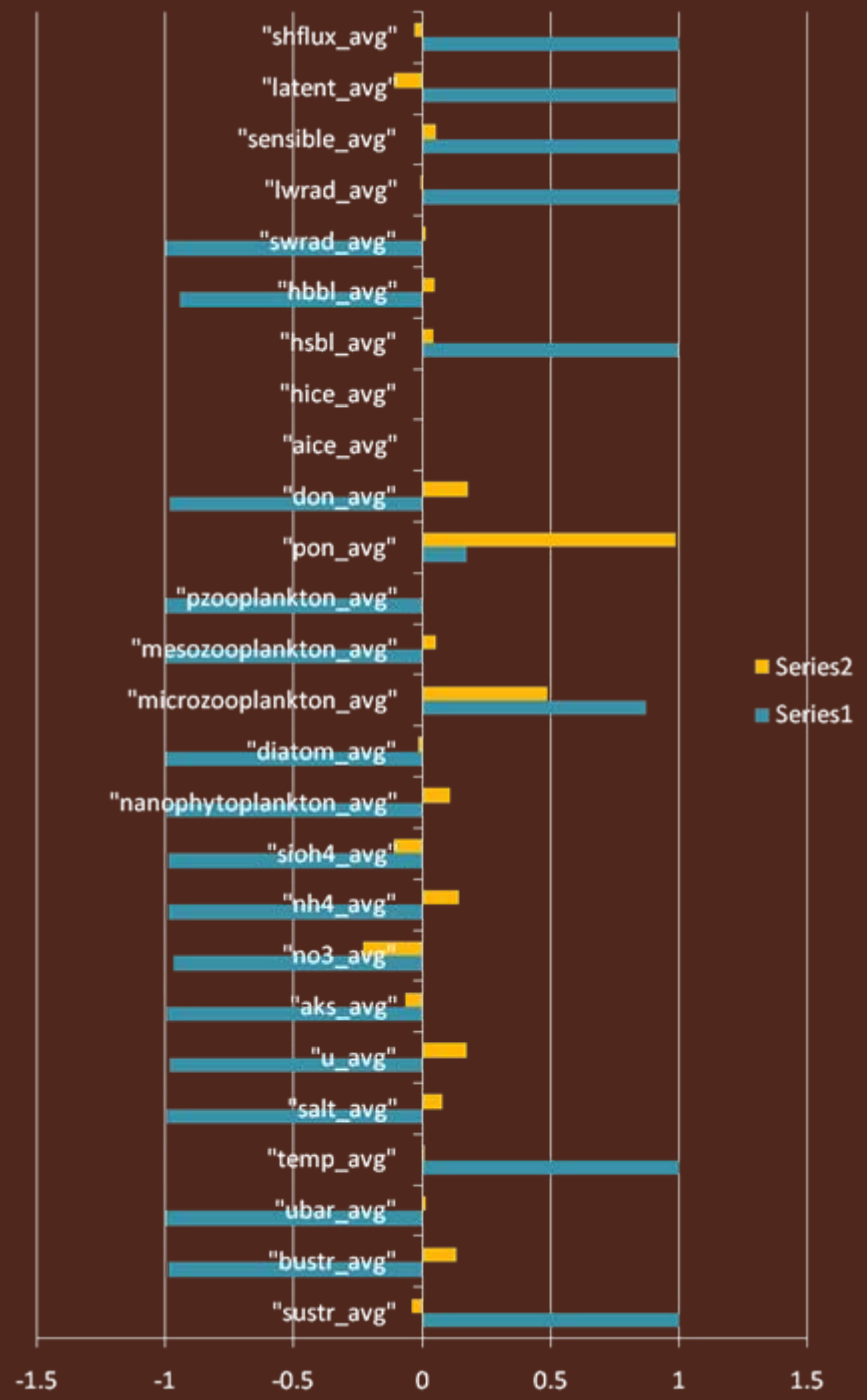
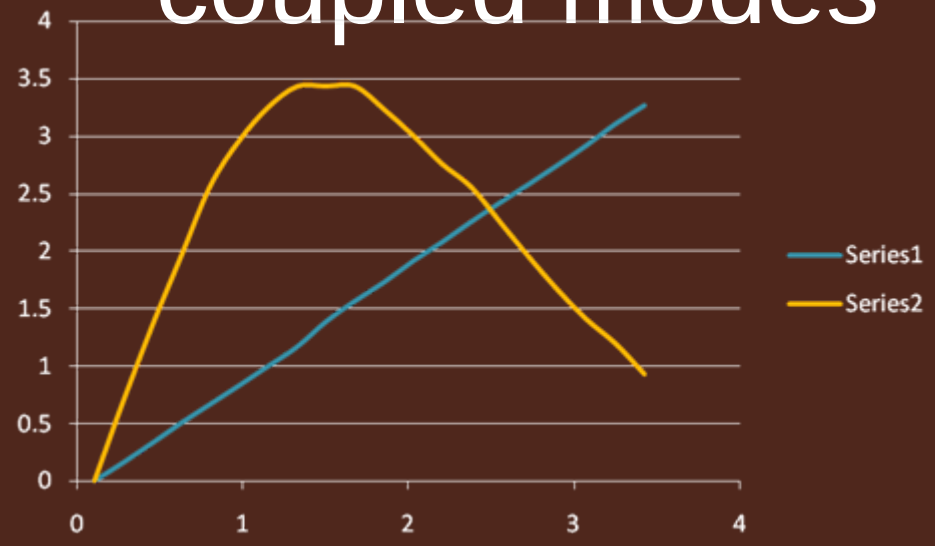
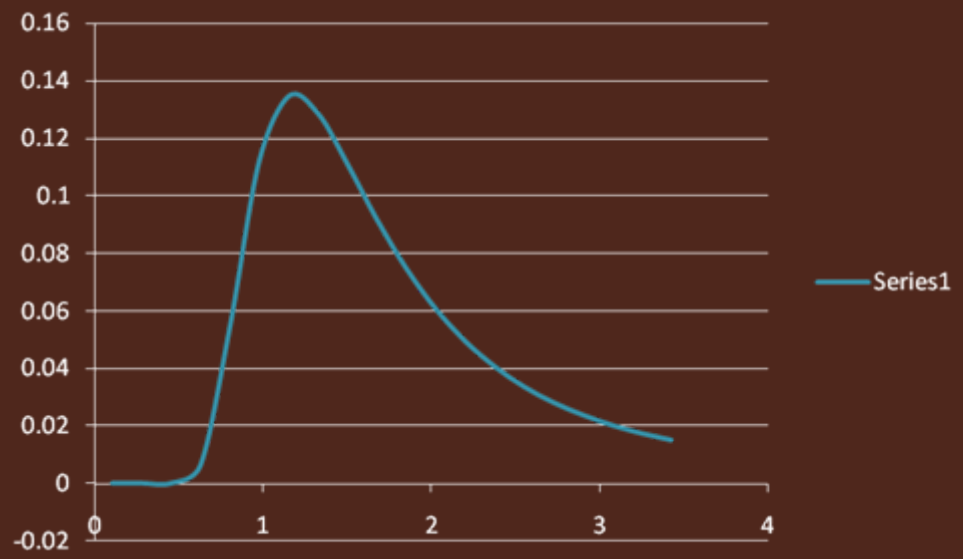



# CGOA no pred “severe warming” scenario

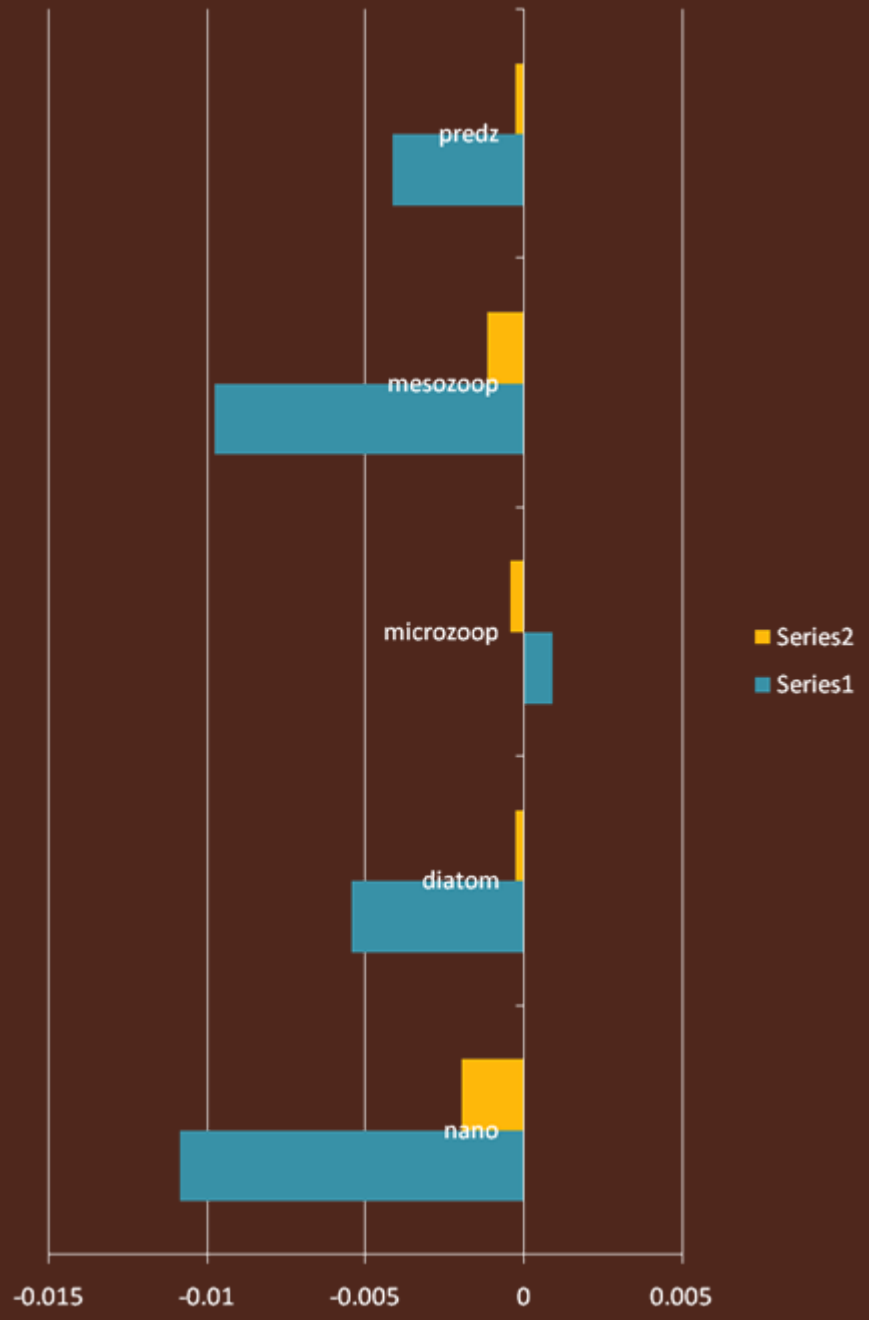
# CGOA no pred coupled modes

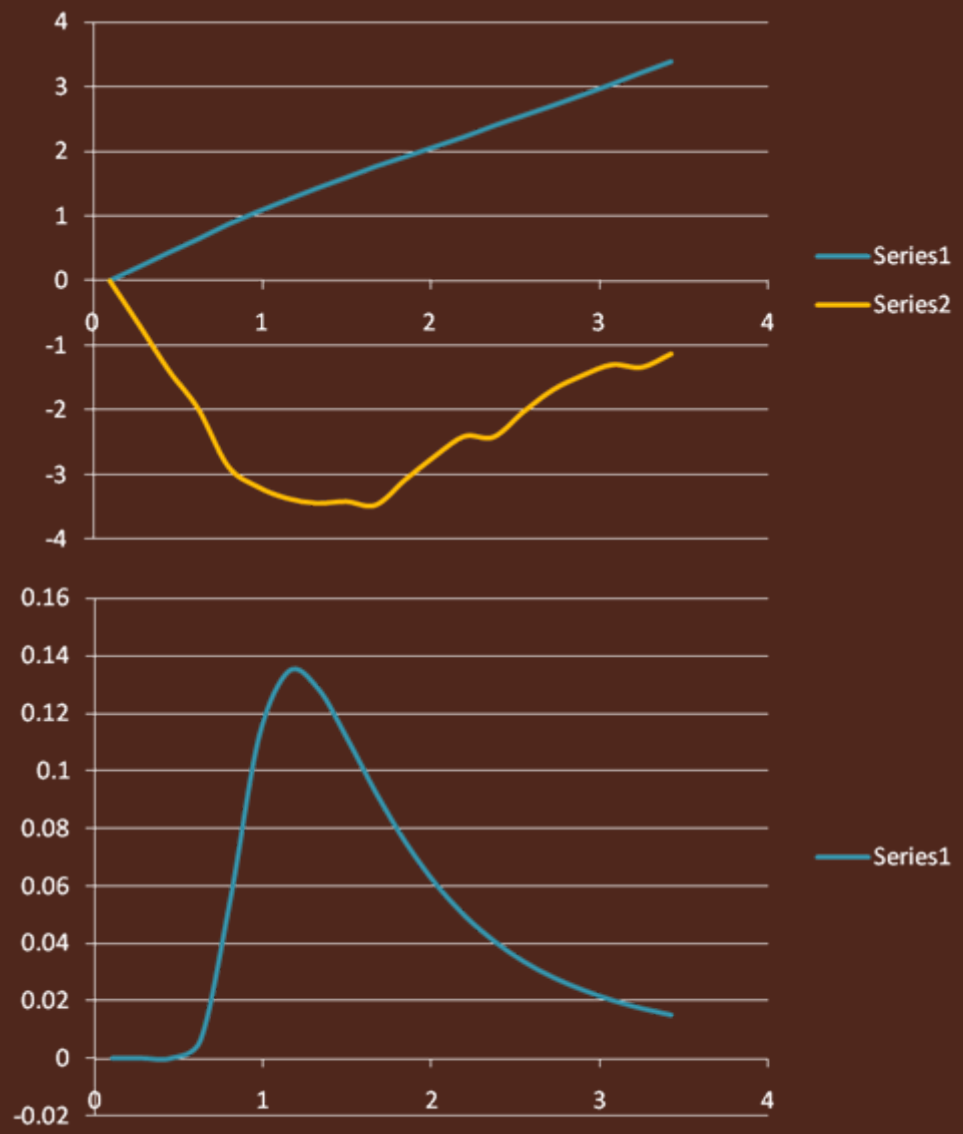


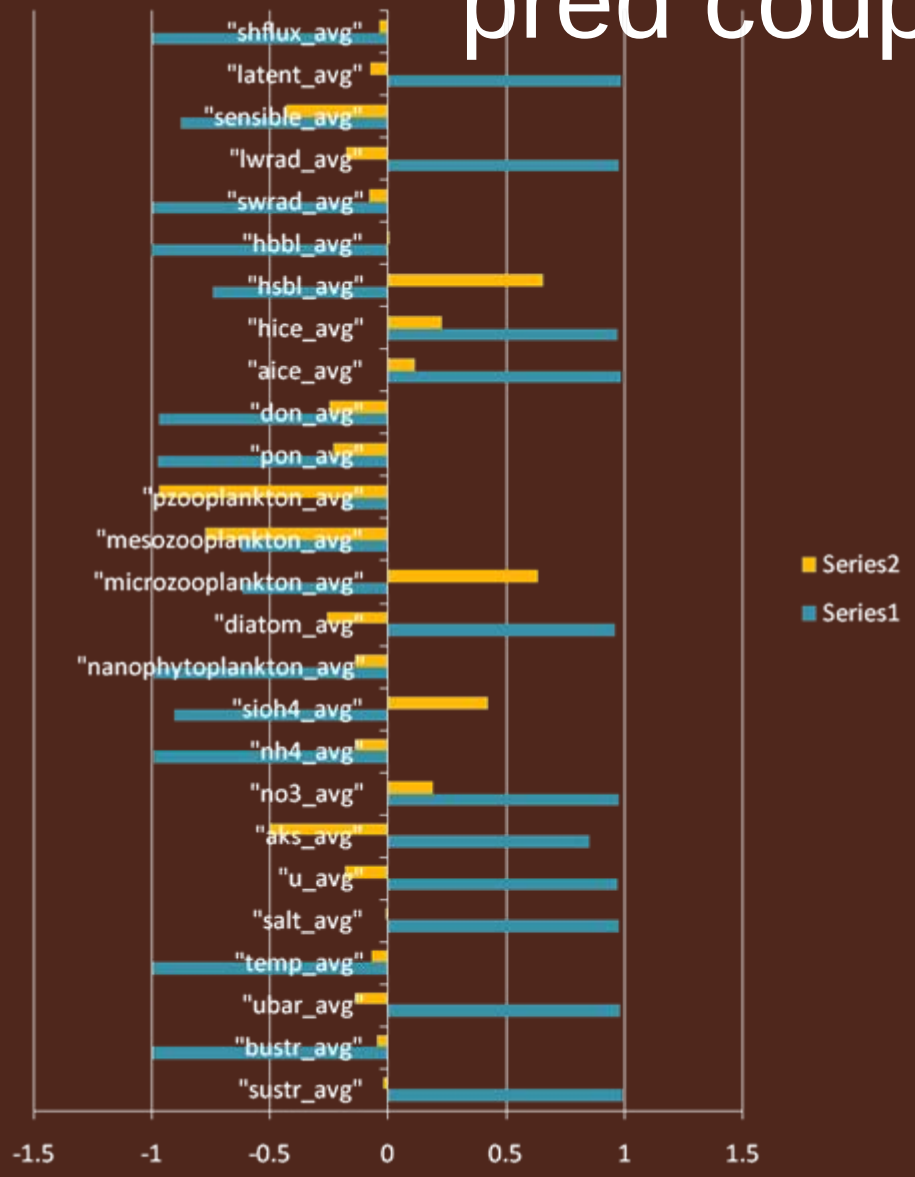



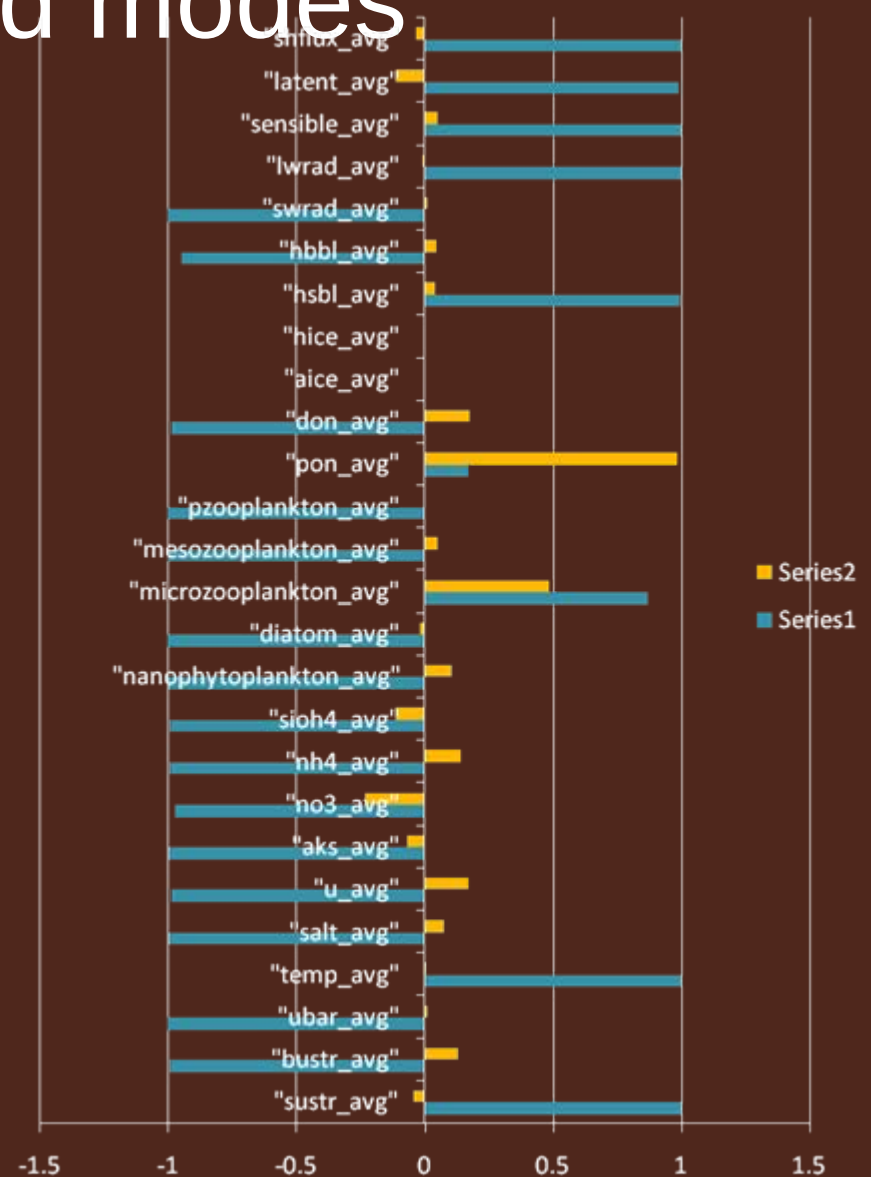
# CGOA no pred bio modes



# Compare Bering and CGOA no pred coupled modes



# Compare Bering and CGOA no pred bio modes