ECOSYSTEM MODELING PREDICTIONS – HOW RELIABLE ARE THEY?

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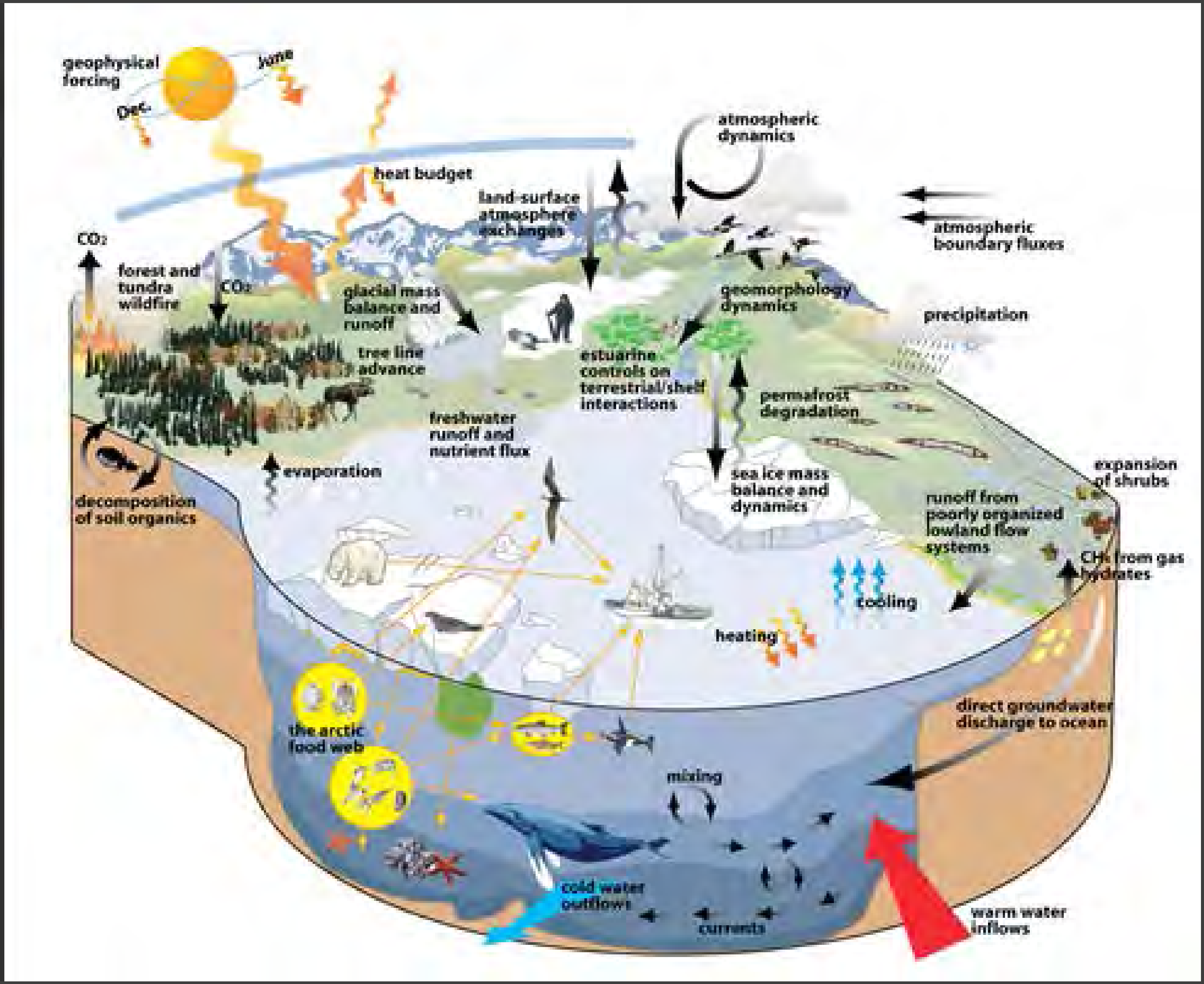
Models project ecosystem response to changing conditions.

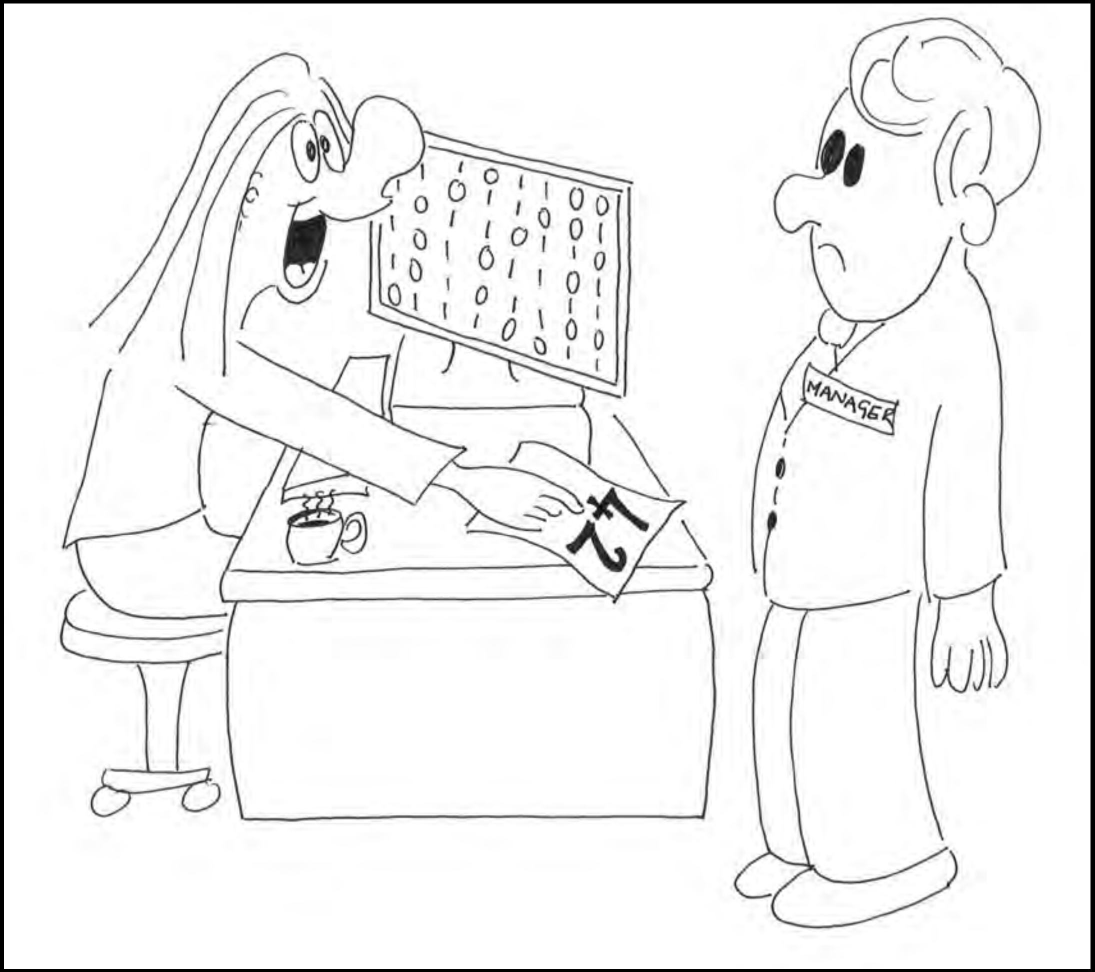


Recognition of the need for ecosystem modeling expanding – moving from theoretical to applied.

Models increasingly used to support management decisions.

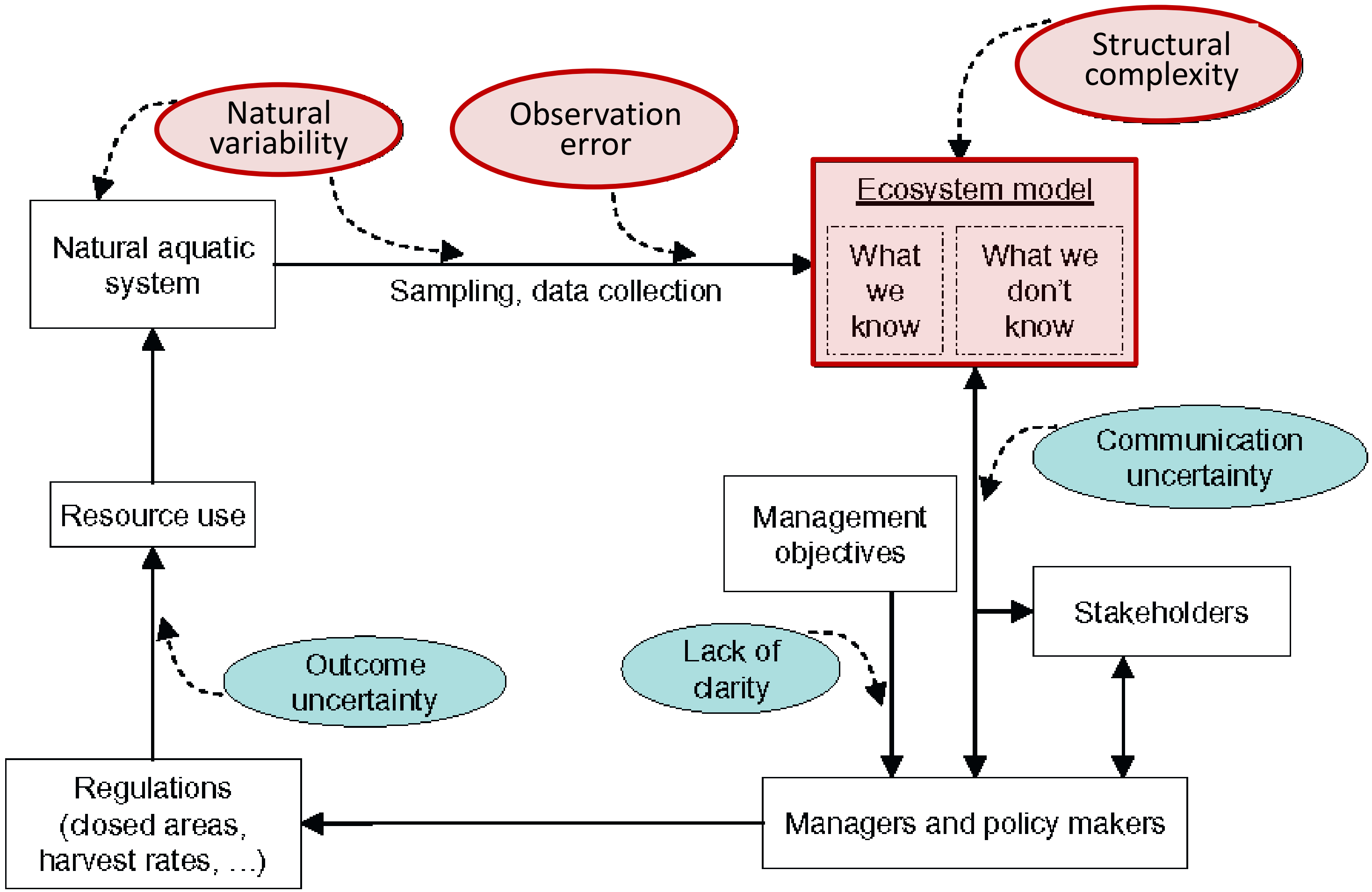
Credit: alaska-in-pictures.com

"To fully use ecosystem models [in ecosystem-based fisheries management] and have their outputs adopted, there is an increasingly recognized need to address uncertainty associated with such modeling activities."
(Link et al., 2012)



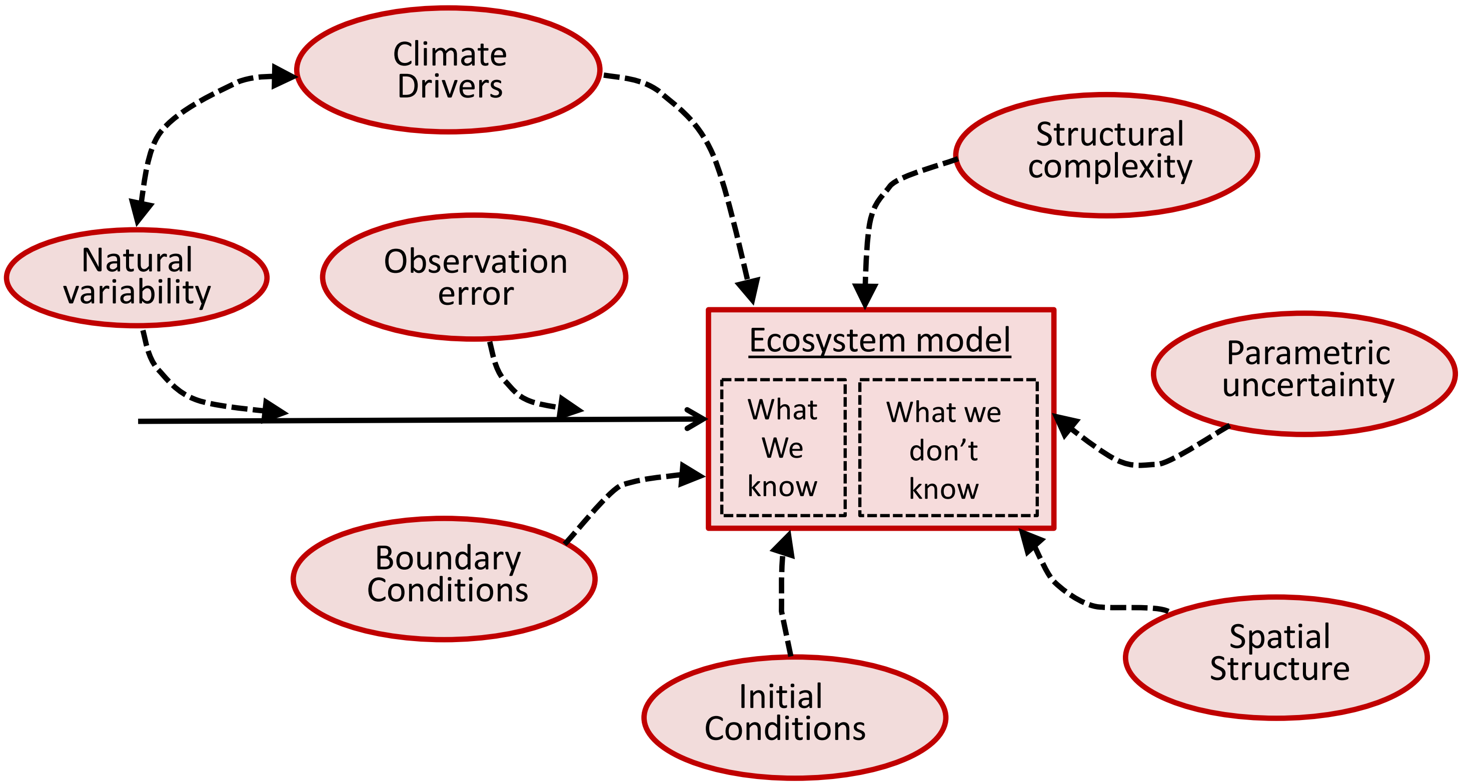
UNCERTAINTY : How accurately do our models describe the true dynamics of the ecosystem?

Sources of model uncertainty



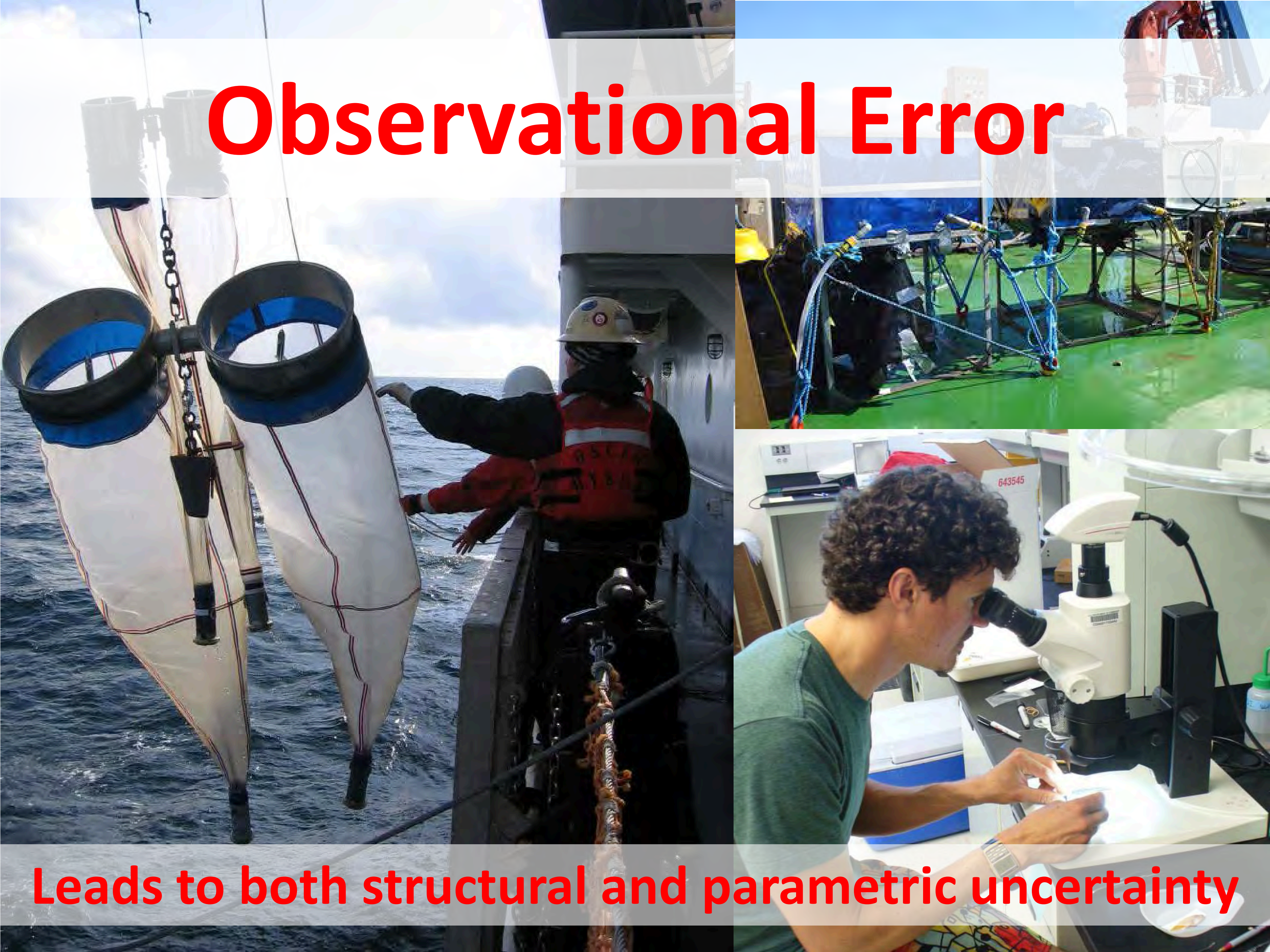
Link et al., / progress in Oceanography 102 (2012) 102-114

Sources of model uncertainty



Many types of uncertainty are generic for any natural resources modeling endeavor

Observational Error

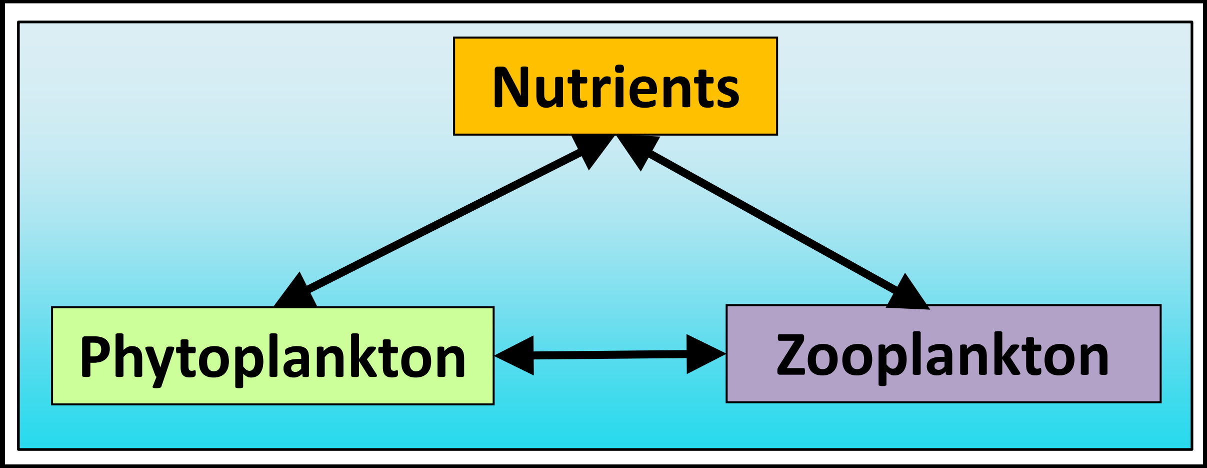


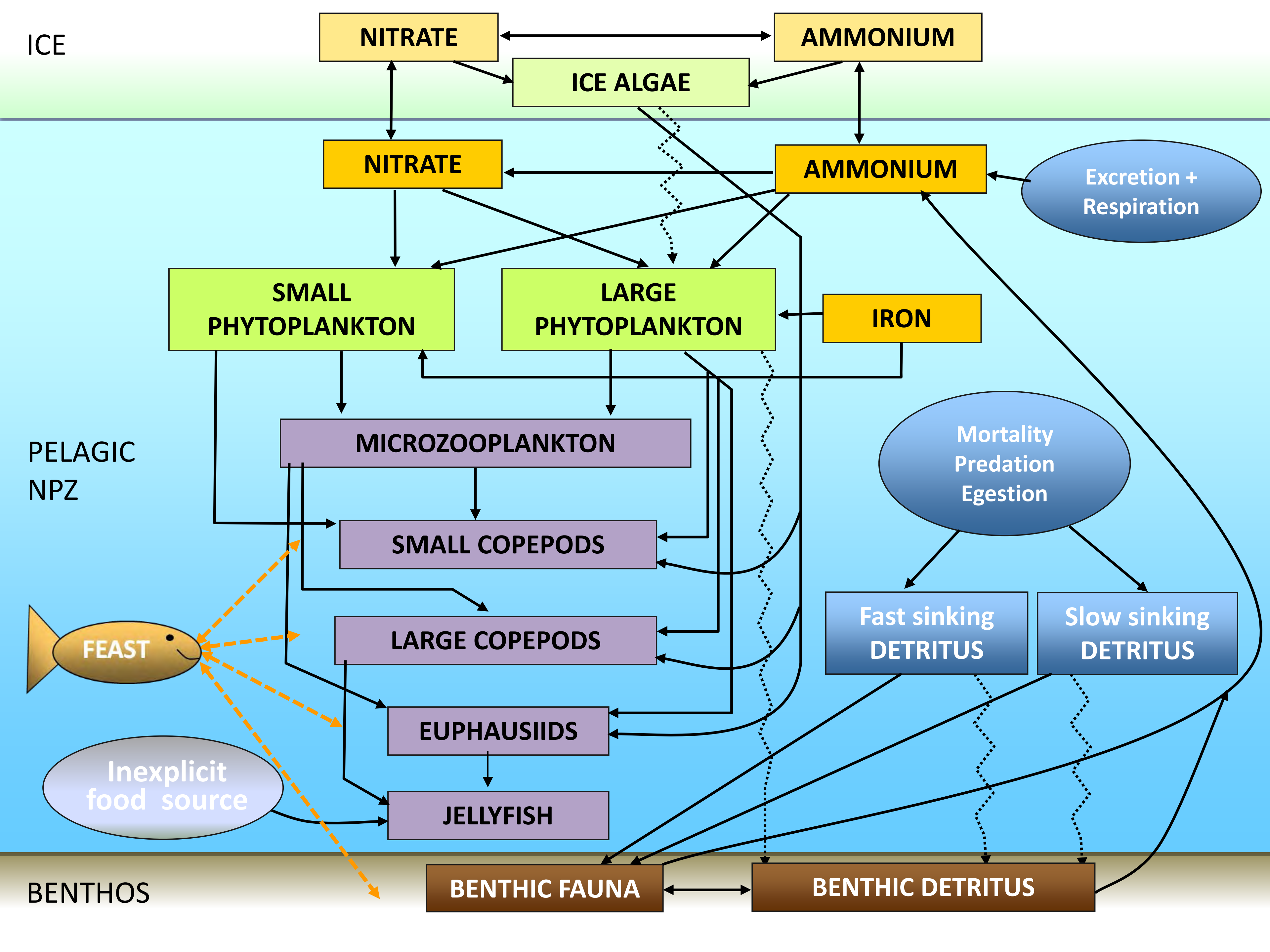
Leads to both structural and parametric uncertainty

Structural Complexity

Uncertainty in which components, parameters and processes to include.

Often several plausible alternatives.

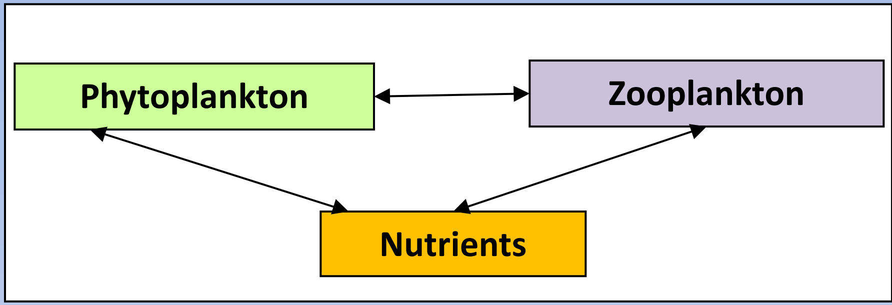




ICE
NITRATE
AMMONIUM
ICE ALGAE
NITRATE
AMMONIUM
Excretion + Respiration
SMALL PHYTOPLANKTON
LARGE PHYTOPLANKTON
IRON
PELAGIC NPZ
MICROZOOPLANKTON
Mortality Predation Egestion
SMALL COPEPODS
Fast sinking DETRITUS
Slow sinking DETRITUS
FEAST
LARGE COPEPODS
EUPHAUSIIDS
Inexplicit food source
JELLYFISH
BENTHOS
BENTHIC FAUNA
BENTHIC DETRITUS

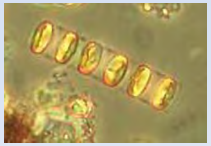
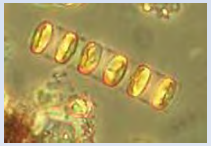
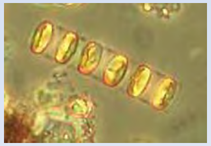
Biological Model Equations

Develop equations to describe how components change with time….



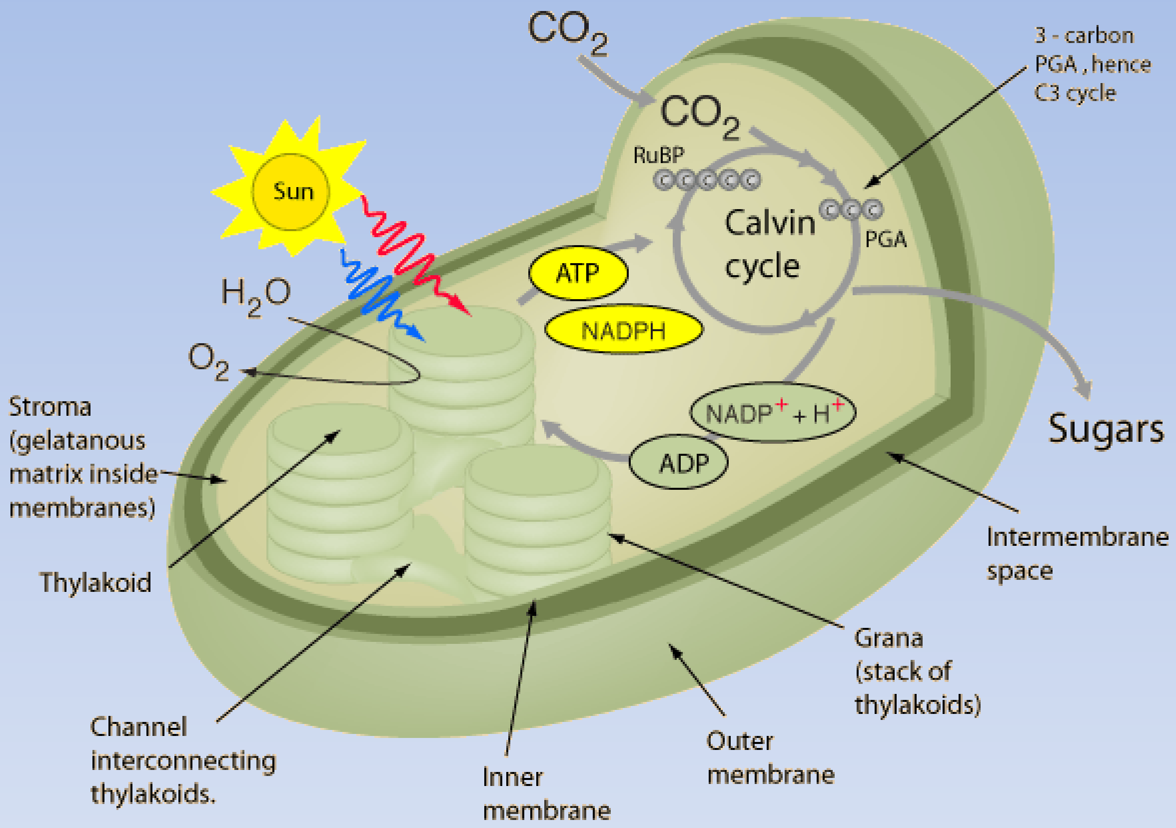
The change in phytoplankton with time:

$$\frac{dP}{dt} = \text{Growth} - \text{Natural Mortality} - \text{Grazing by zooplankton} + \text{Physical Processes}$$

Model Complexity

Phytoplankton

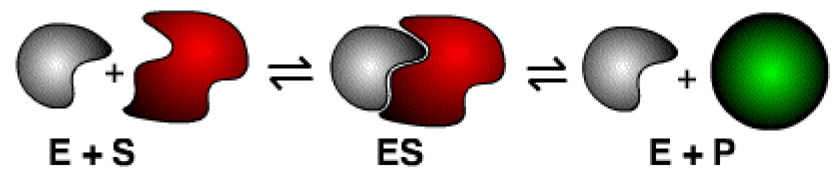


Models simplify complicated biological processes.

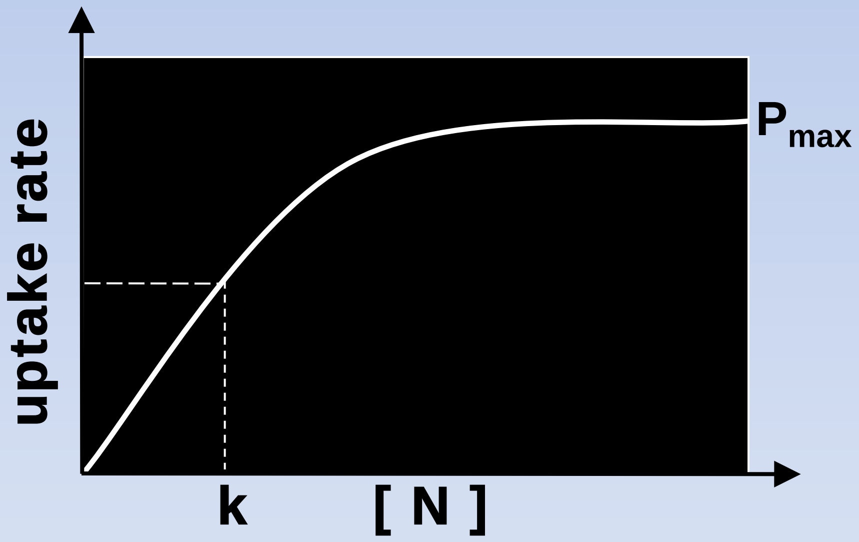
How much detail needed to address your question ?

Biological Model Equations

$$\text{Growth} = [P] * P_{max} * \frac{N}{(k + N)}$$



Michaelis-Menten Kinetics



P_{max} = max. photosynthetic rate
K = half saturation constant

Will need to define many parameters:
Literature, field work and lab experiments

Mathematical equation describes the functional form of each biological process in the model

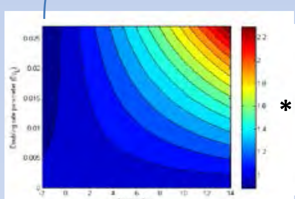
Biological Model Equations

Growth $= [P] \quad * \quad P_{max} \quad * \quad \dfrac{N}{(k + N)}$

Growth = [P] * Pmax * Nitrate Lim. * Light Lim. * Iron Lim.

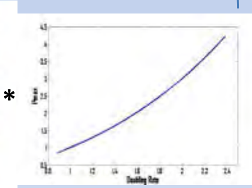
Growth = [P] * f(Doubling rate, temp) * f(NO3, NH4, KNO3) * f(PARz, α, C:chl-a) * f(Fe,Kfe)

Growth = [P] *



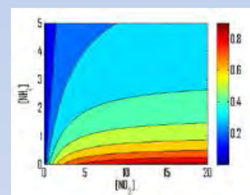
Doubling rate

*



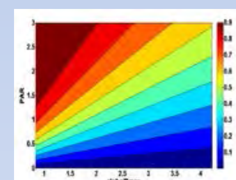
Temp. response

*



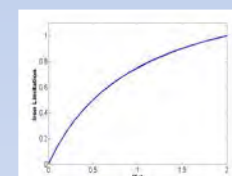
Nitrate Limitation
[0->1]

*



Light Limitation
[0->1]

*

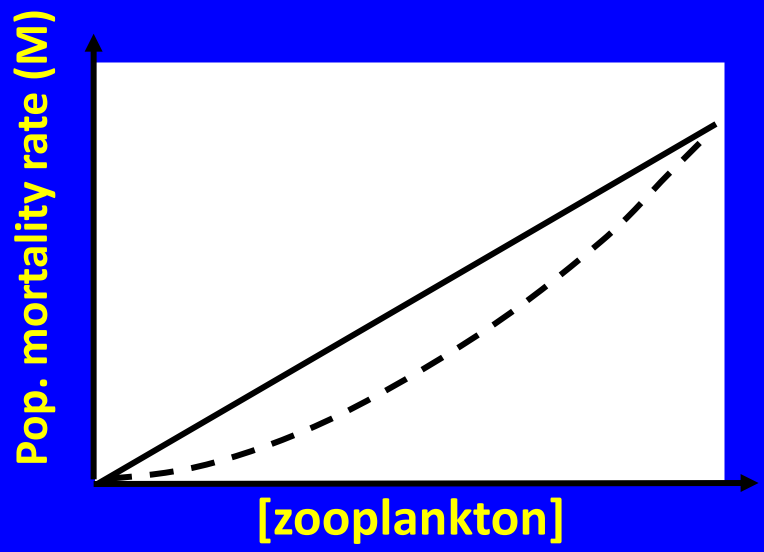


Iron Limitation
[0->1]

-Different species/size classes of phytoplankton have different parameters for each equation.

-Several functional forms for each process have been used, ranging from simple linear responses to non-linear forms. Have to choose which to use.

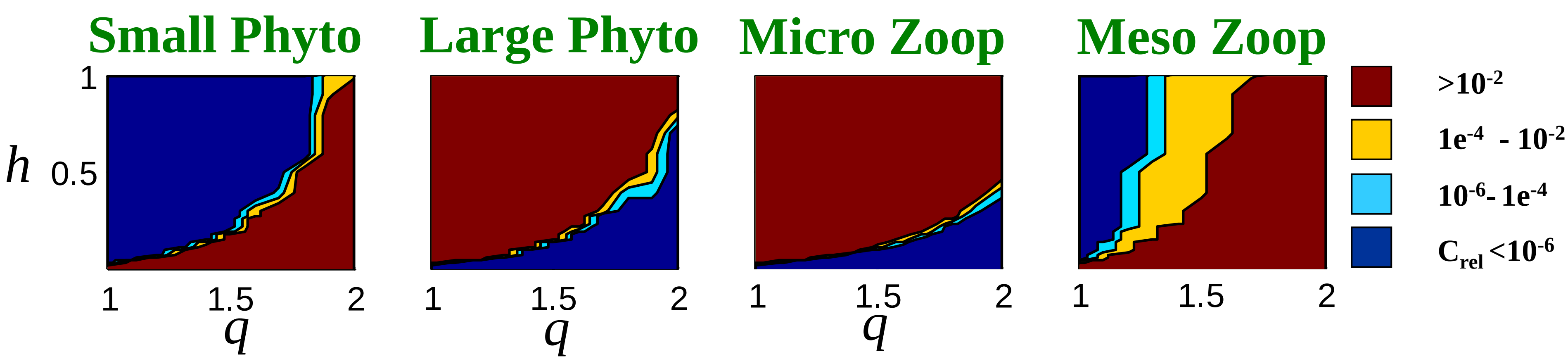
Output uncertainty due to structural uncertainty



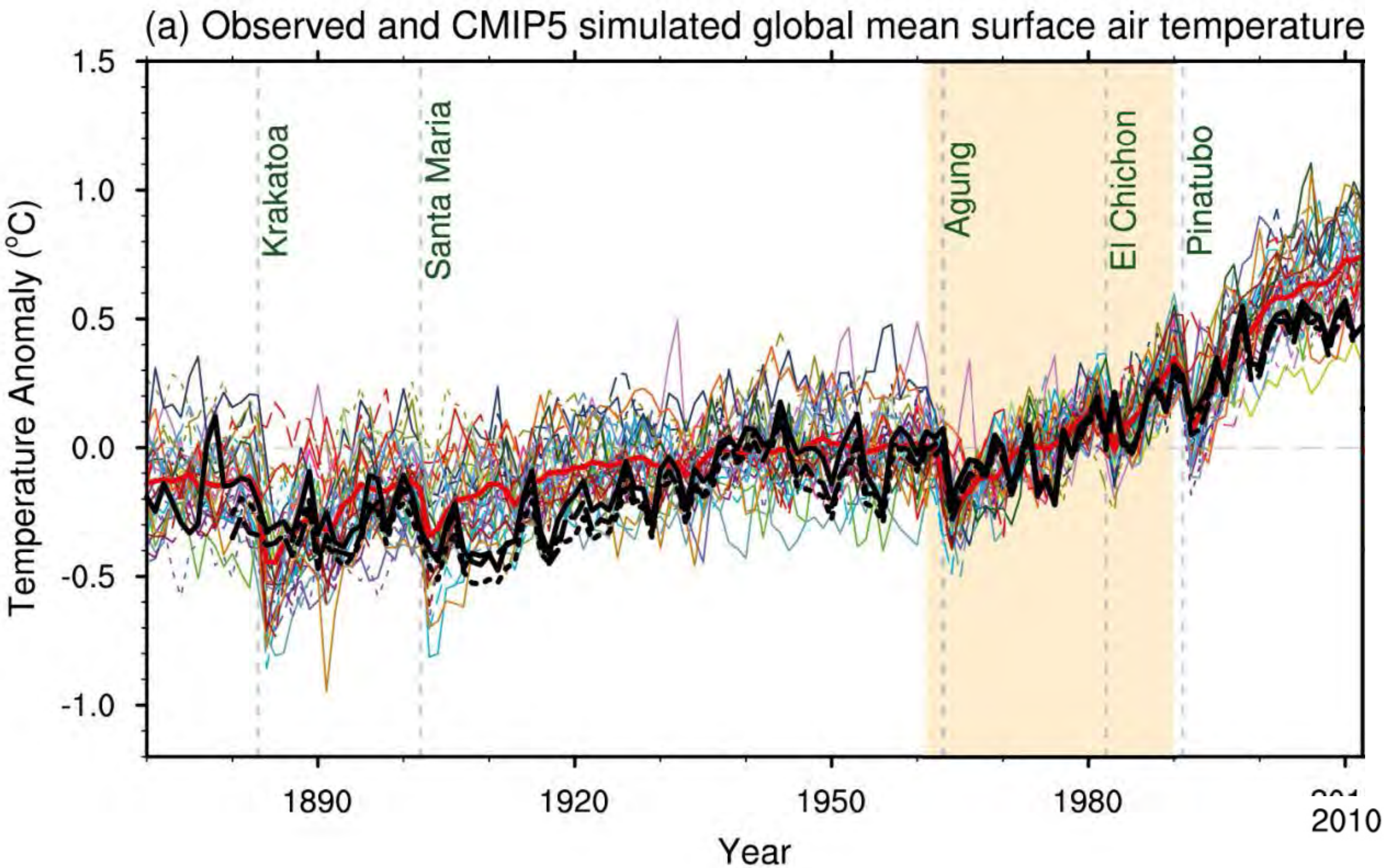
Linear Mortality M= hZ

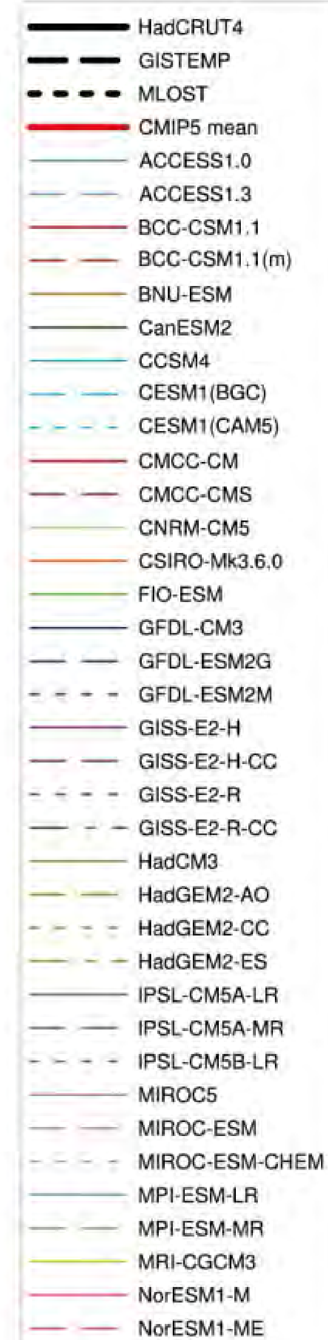
Quadratic mortality M= hZ^2

Predation (M) = hZ^q



Suites of models to bound uncertainty.





Climate Model Inter-comparison Project – massive international undertaking, still not reduced uncertainty.

More model data, observations & process understanding should increase confidence in a projection – even if uncertainty remains unchanged (Knutt & Sedláček, 2012)

Exploring output uncertainty in ecosystem models due to structural uncertainty

MAREMIP

MARine Ecosystem Model Intercomparison Project

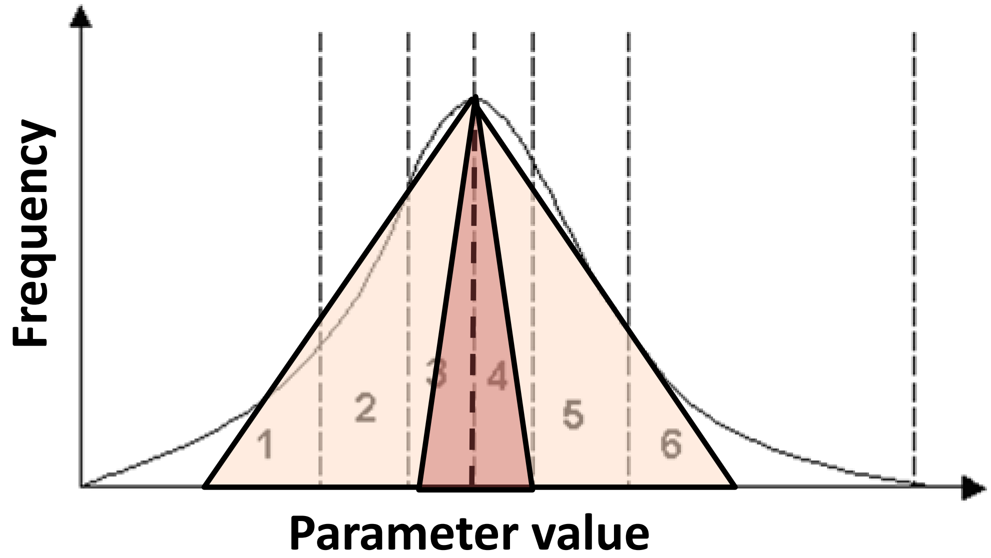
- Requires models to be geographically and temporally portable.
- Ecosystem modeling efforts tend to be regionally focused.
- Big challenge to apply a diverse range of models.

- CAMEO -

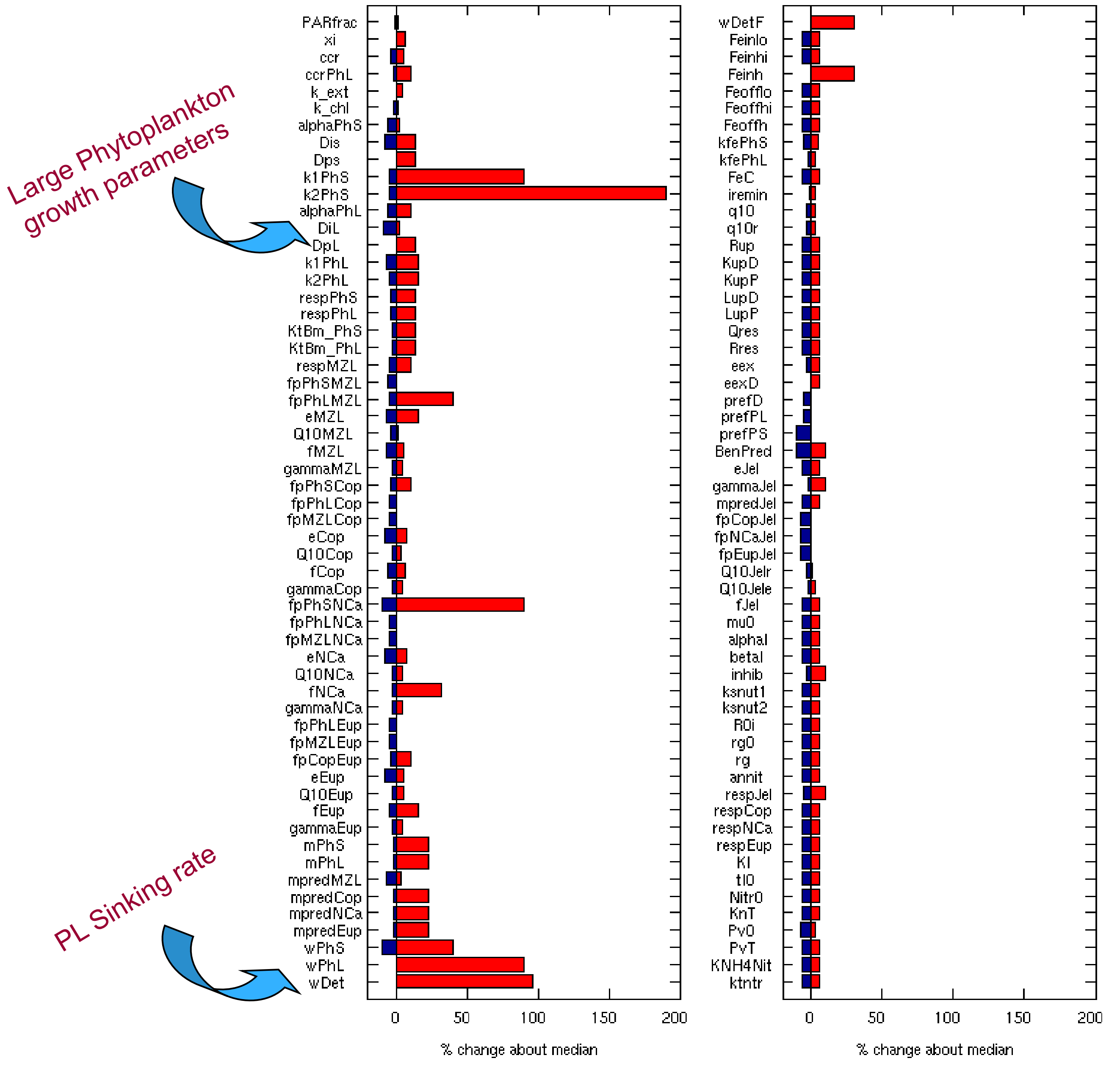
Comparative Analysis of Marine Ecosystem Organization

Parameter Uncertainty

- Ecosystem models can have tens-hundreds of parameters.
- Sensitivity analysis relates the uncertainty in the output of a model to
- different sources of uncertainty in its inputs.
- Typically use a Monte Carlo style analysis – thousands of model runs.
- Parameters randomly drawn from specified probability distributions.
- All parameters varied simultaneously.

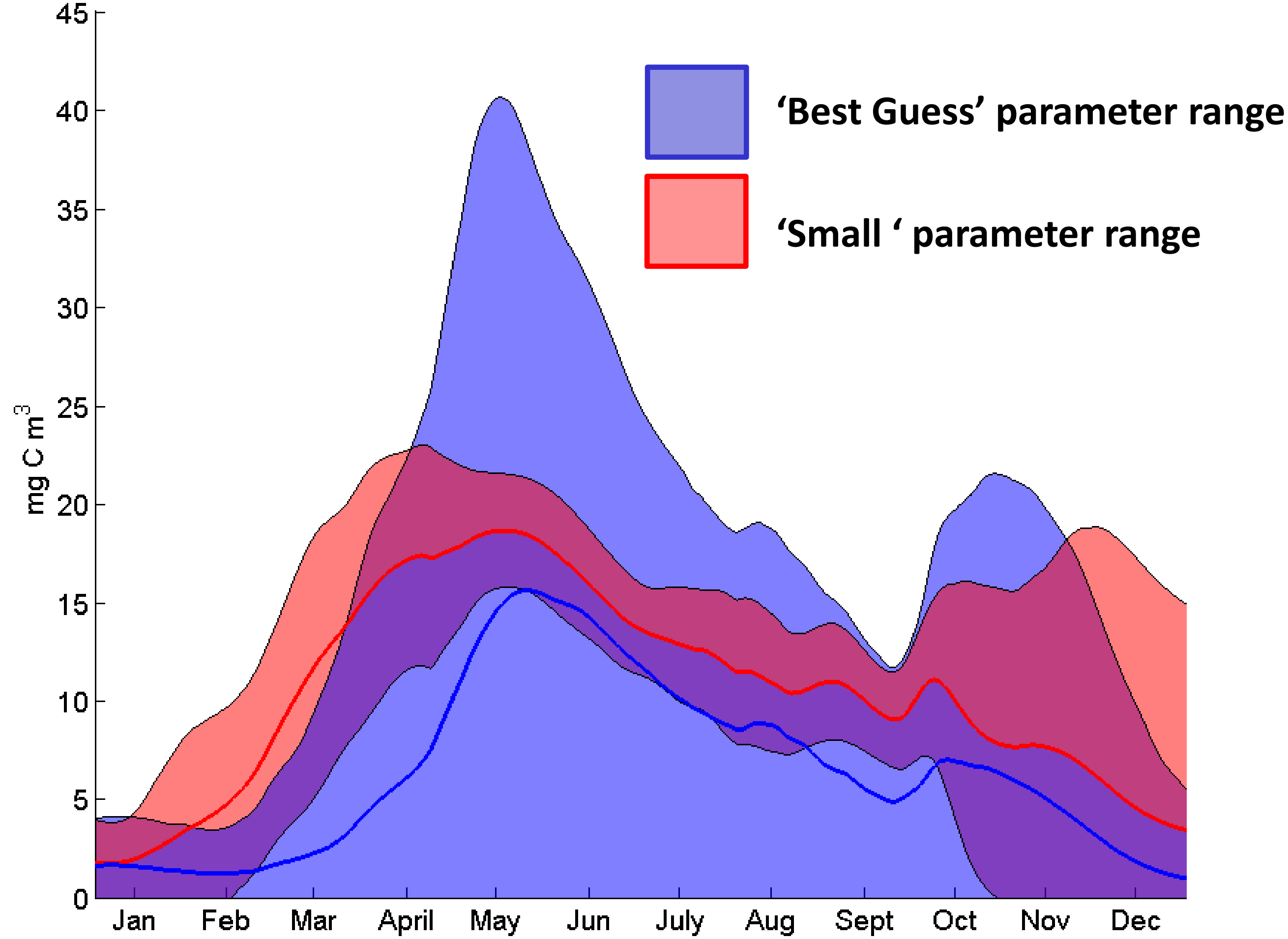


Relative Parameter Range



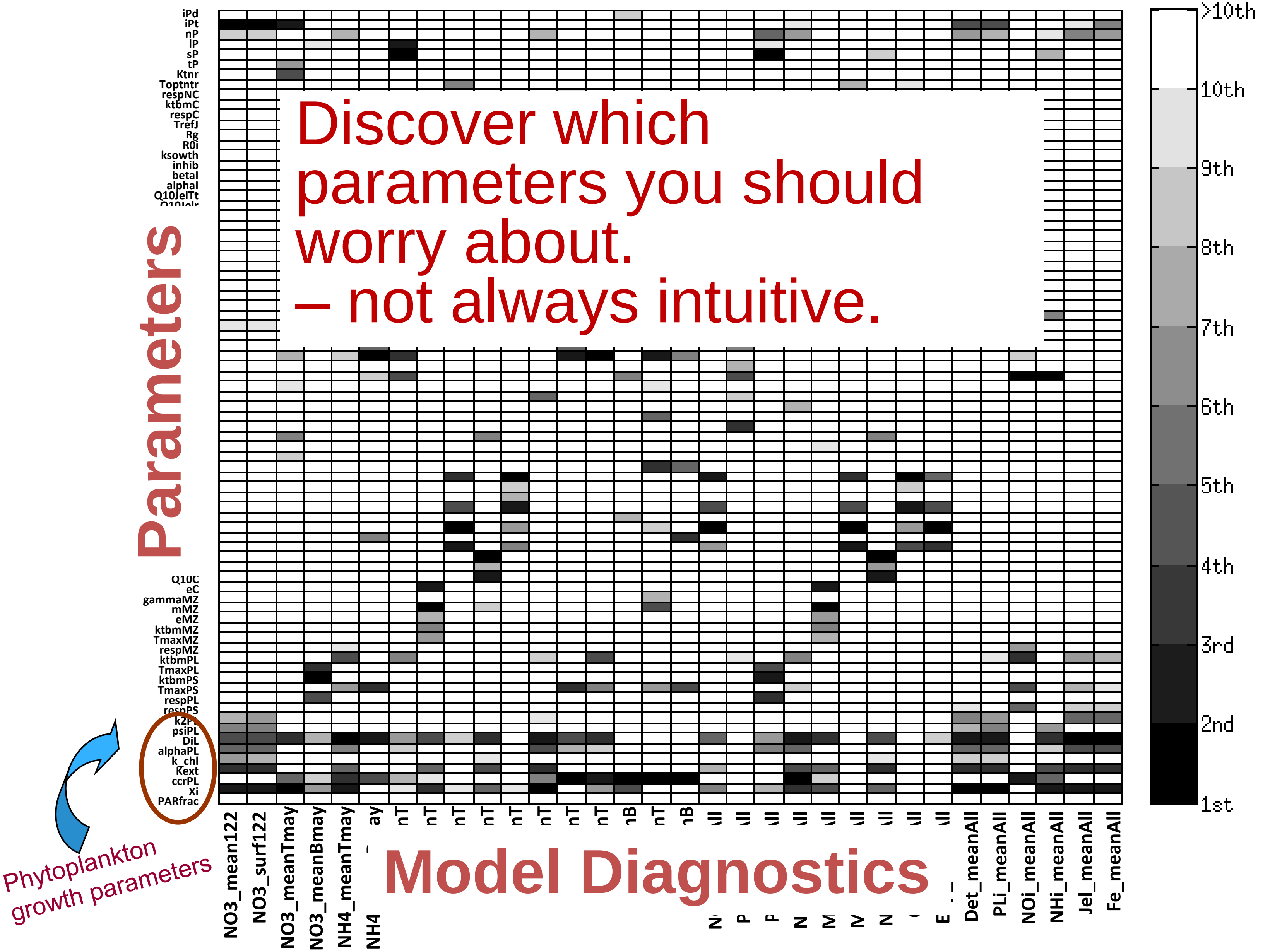
Output Uncertainty due to Parameter Uncertainty

Mesozooplankton Biomass

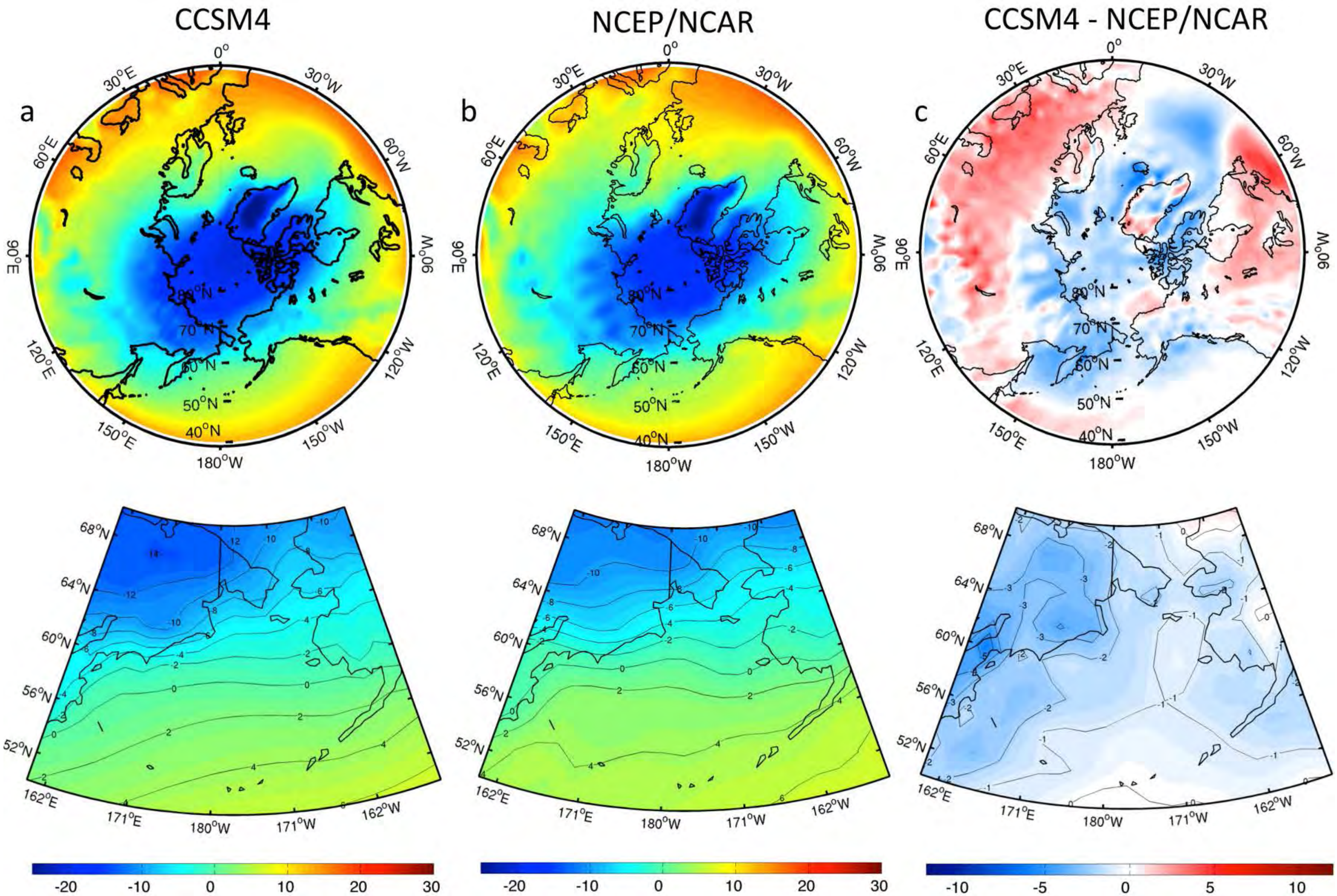


To constrain models, focus on constraining biological parameters indentified as important.

ANOVA to determine the most important parameters for the diagnostic output variables of interest.



Spatial Uncertainty

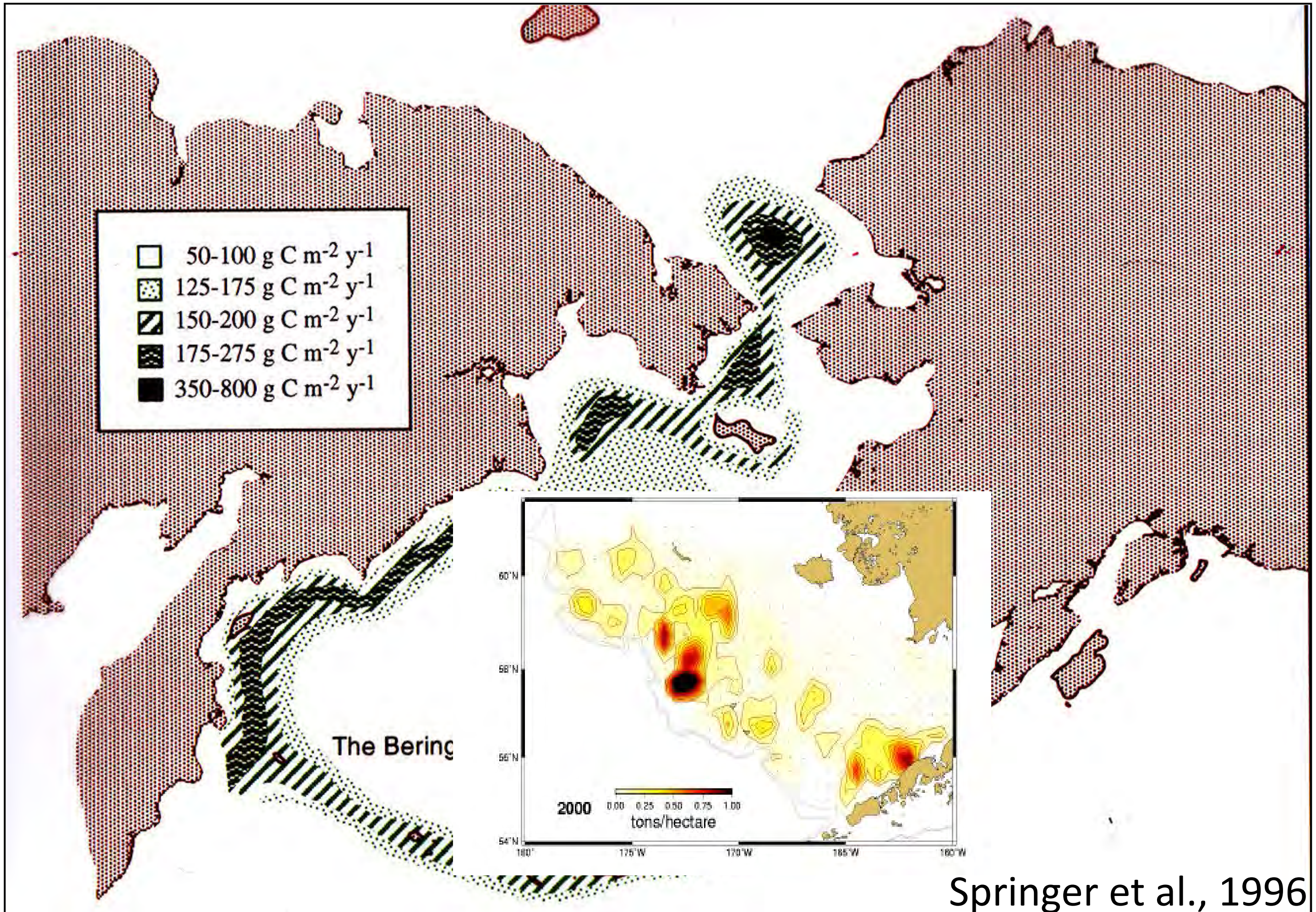


Despite some biases AOGCMs can represent present climate with some fidelity

Walston, Gibson & Walsh, 2013

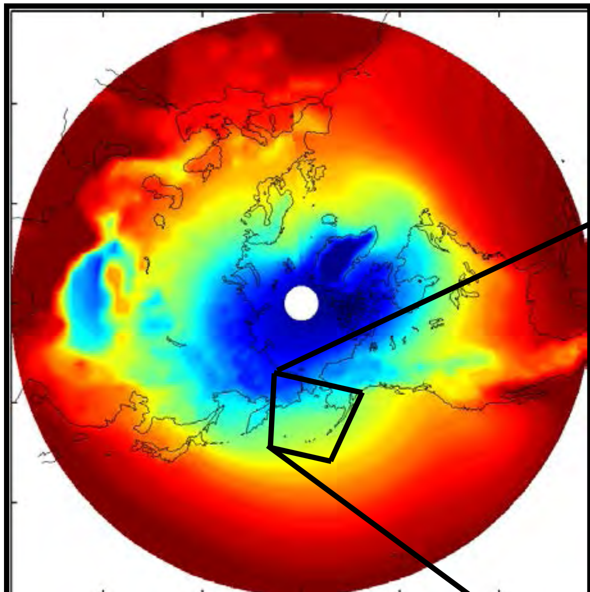
Spatial Uncertainty

Global dynamics-> Meso-scale processes important to biology

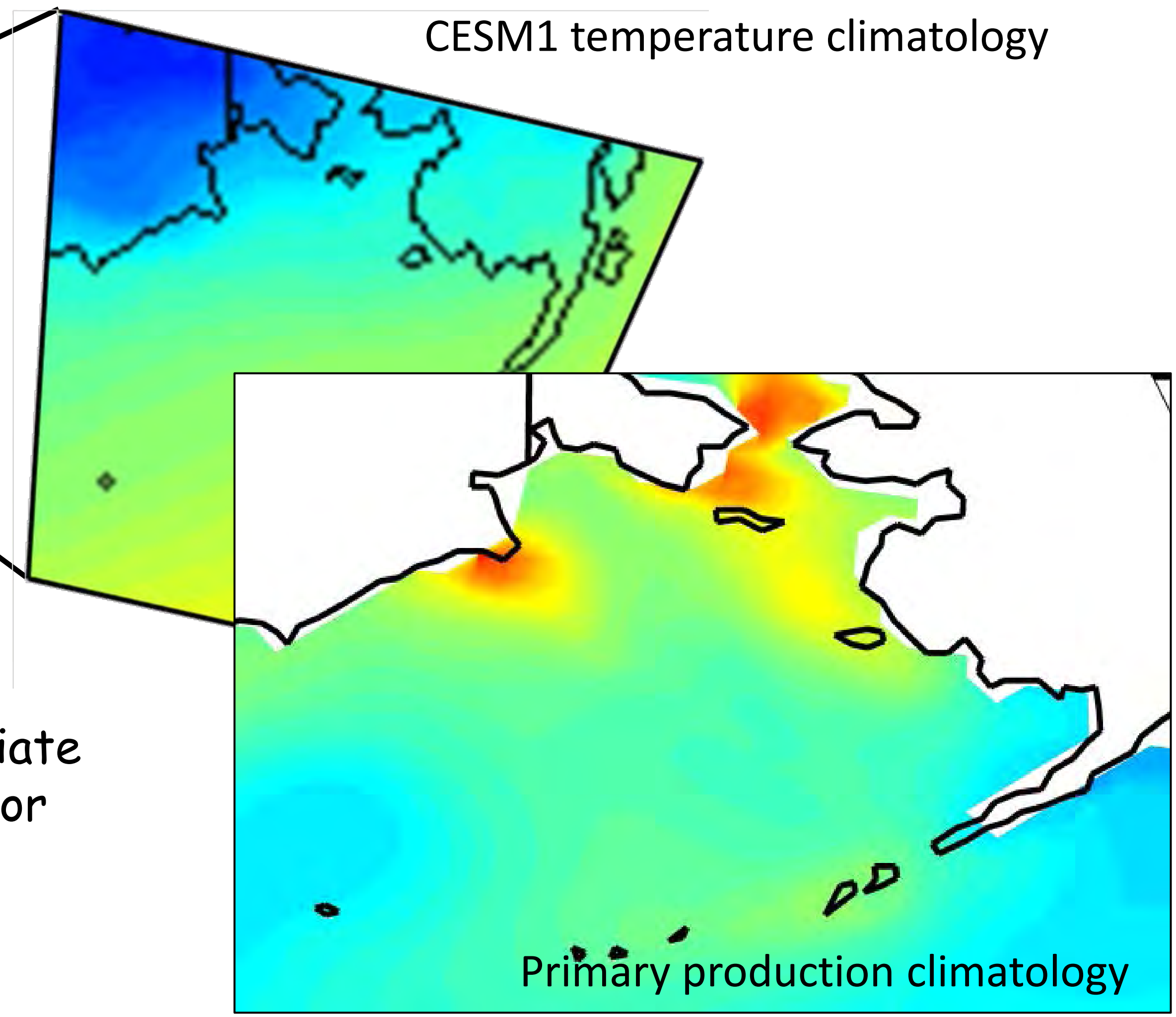


Springer et al., 1996

Spatial Uncertainty

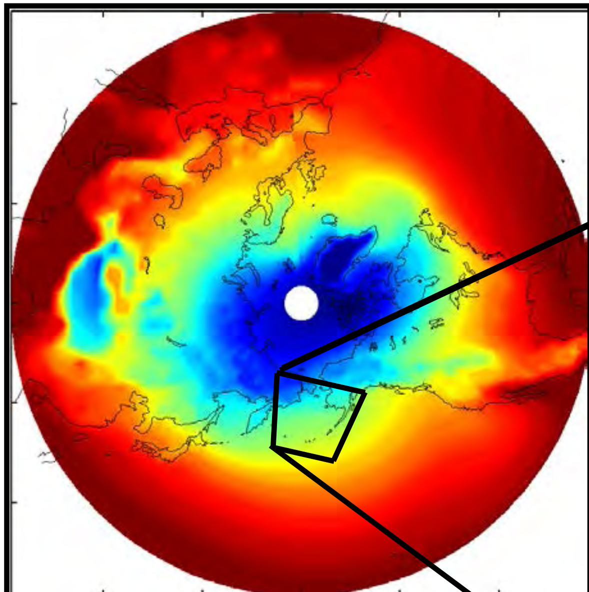


Global Climate Model
~2^{o} resolution



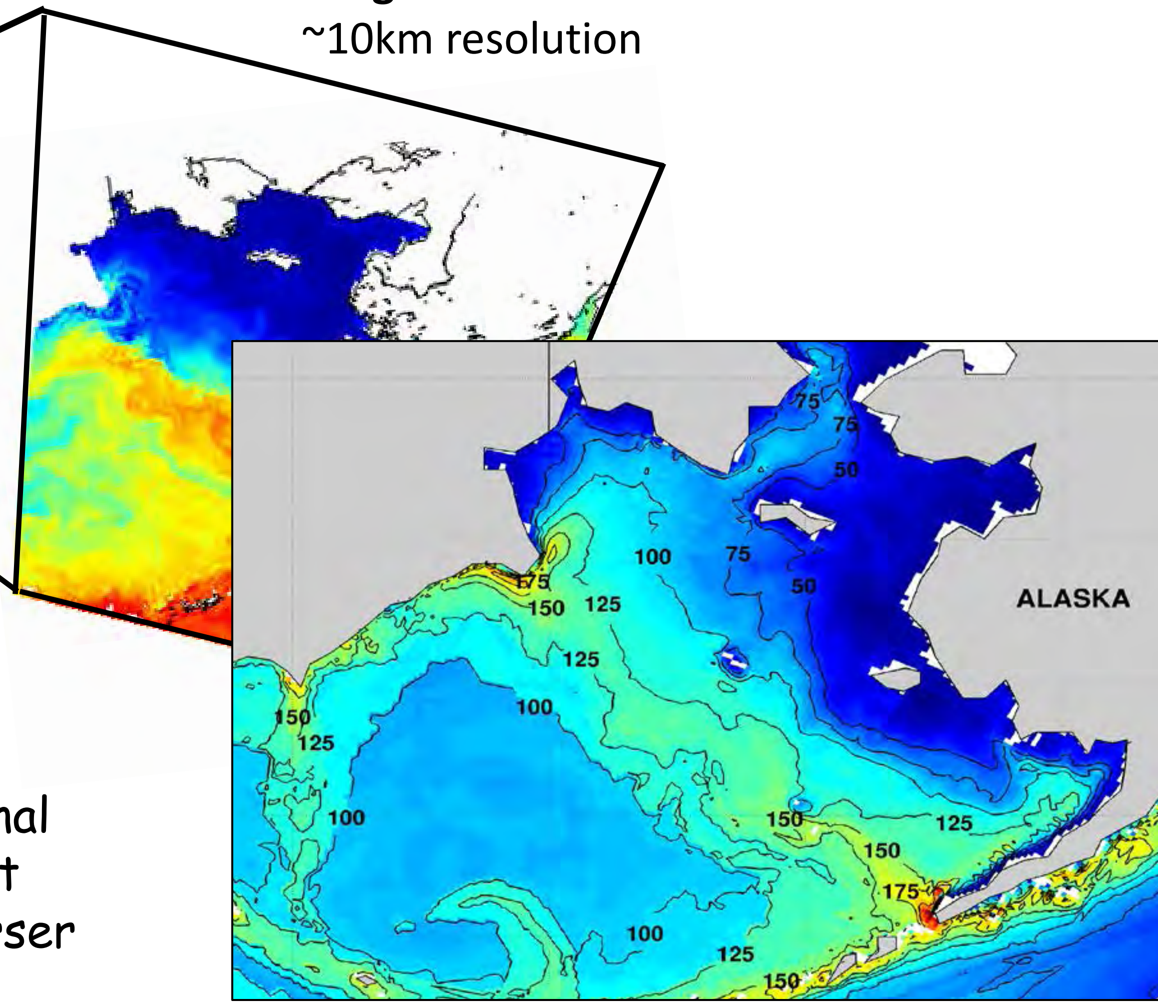
- -Need model with appropriate horizontal resolution for fisheries management.

Dynamical Downscaling



Global Climate Model
~2° resolution

Dynamically Downscale with Regional Model
~10km resolution

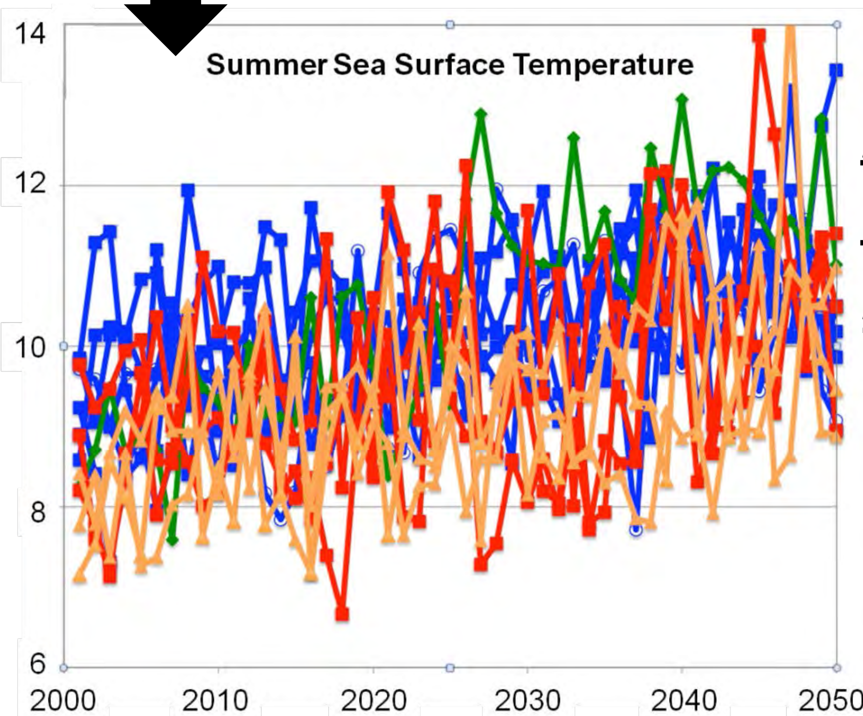


-Cant run high resolution everywhere-yet.

-Small, high resolution regional grids for area of interest nested inside larger courser resolution grids

Regional Ecosystem Ensemble

1 Emission scenario
(A1B =avg CO_2 increase)

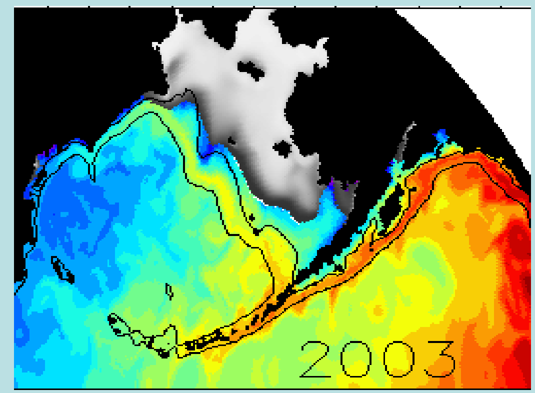


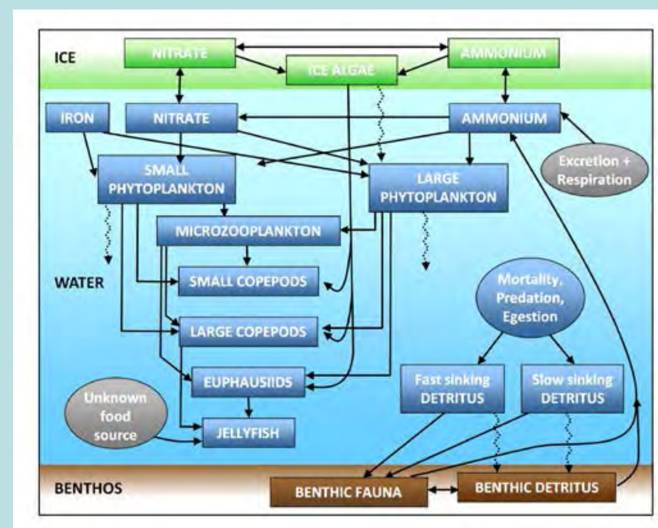
MIRCOM-M

CCCMA

ECHO-G

Coupled Physical-Biological Regional Model

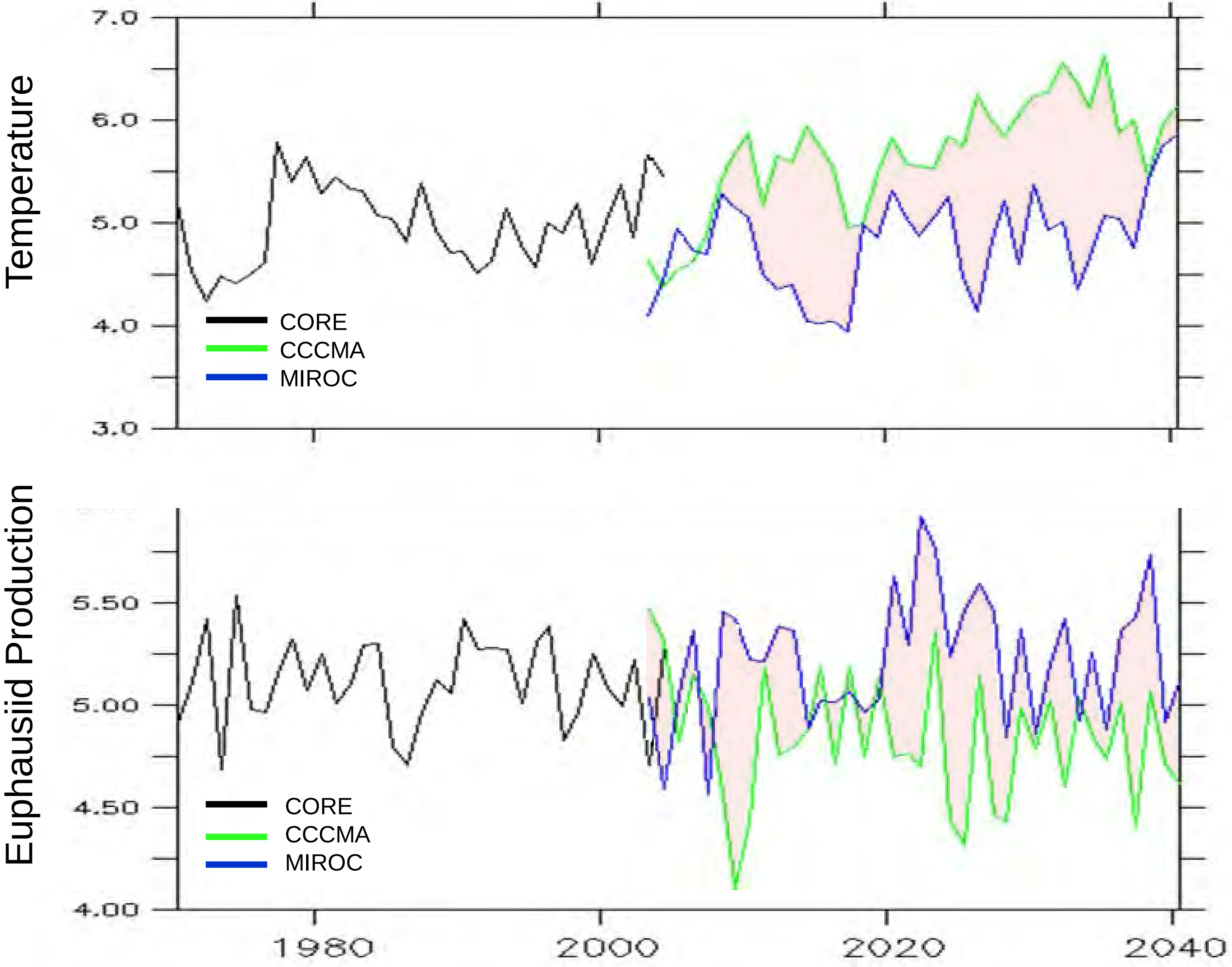




Ensemble of ecosystem projections

Hermann et al in prep

Ecosystem Projections



Hermann et al in prep

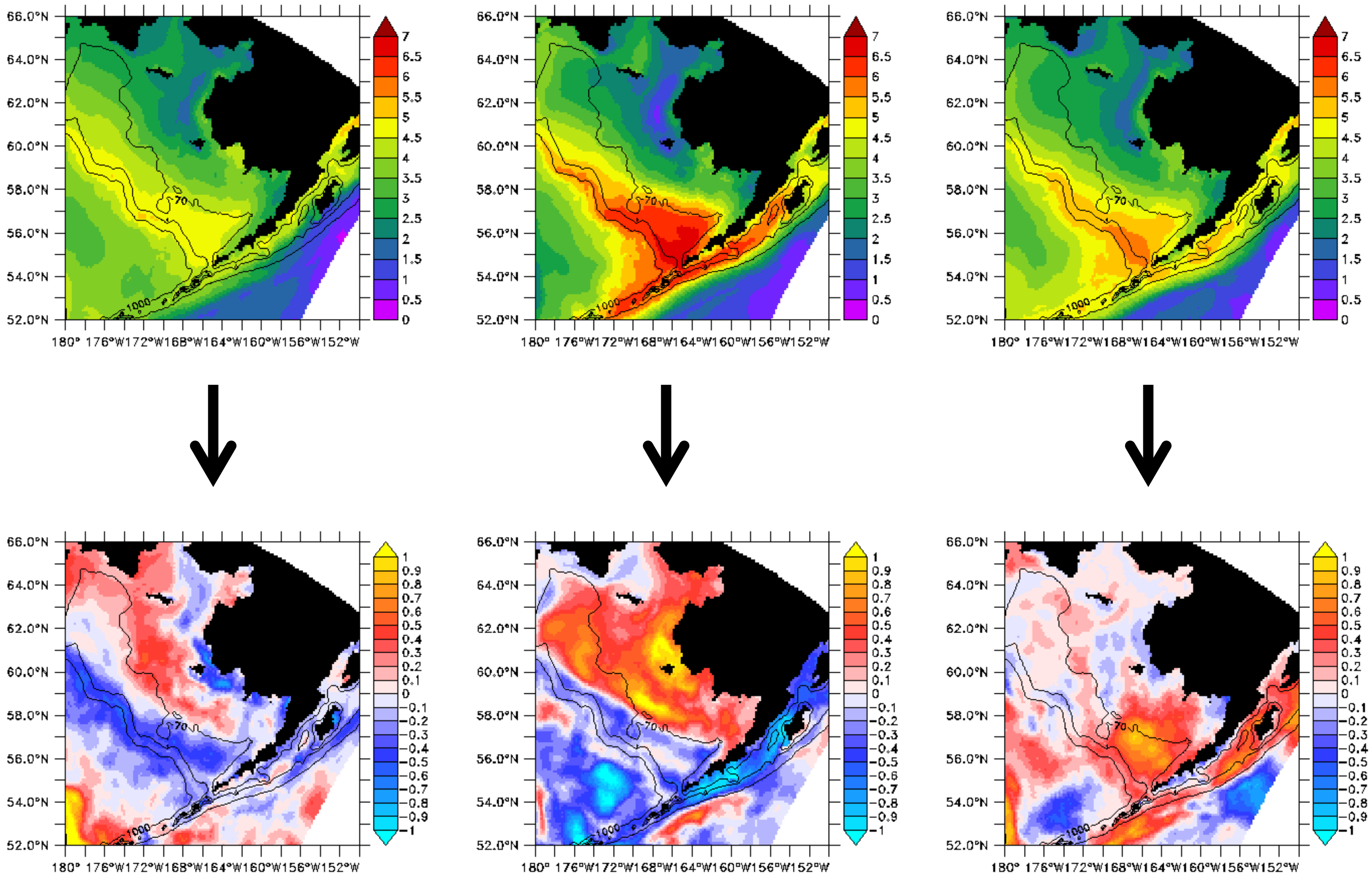
Spatial Uncertainty

Large Crustacean Zooplankton (mgC m^{-3})

CGCM3 MIROC ECHOG

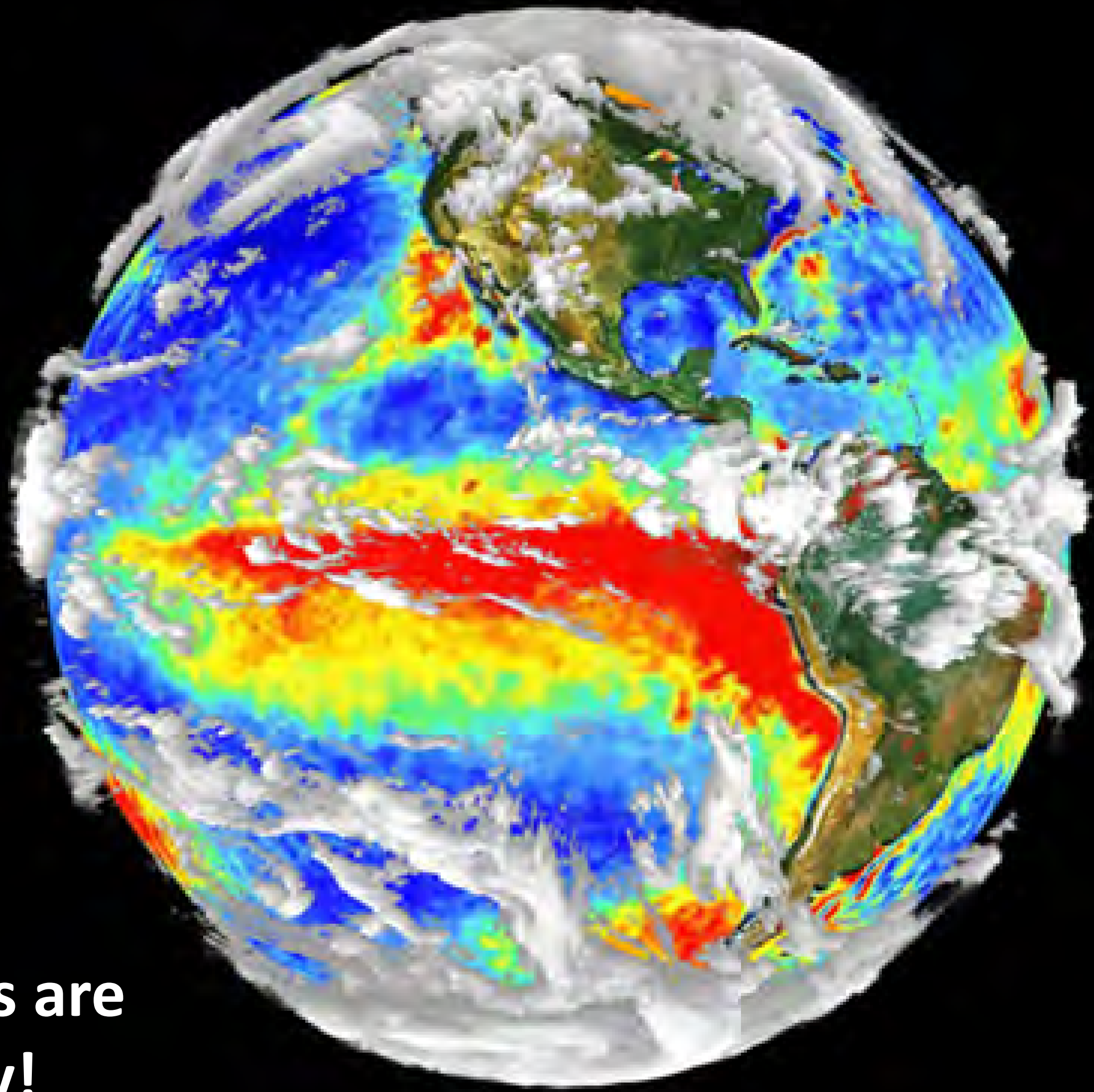
"Present" (2003-2012)

"Future" (2031-2040) *w.r.t.* present



Uncertainty Due to Natural variability

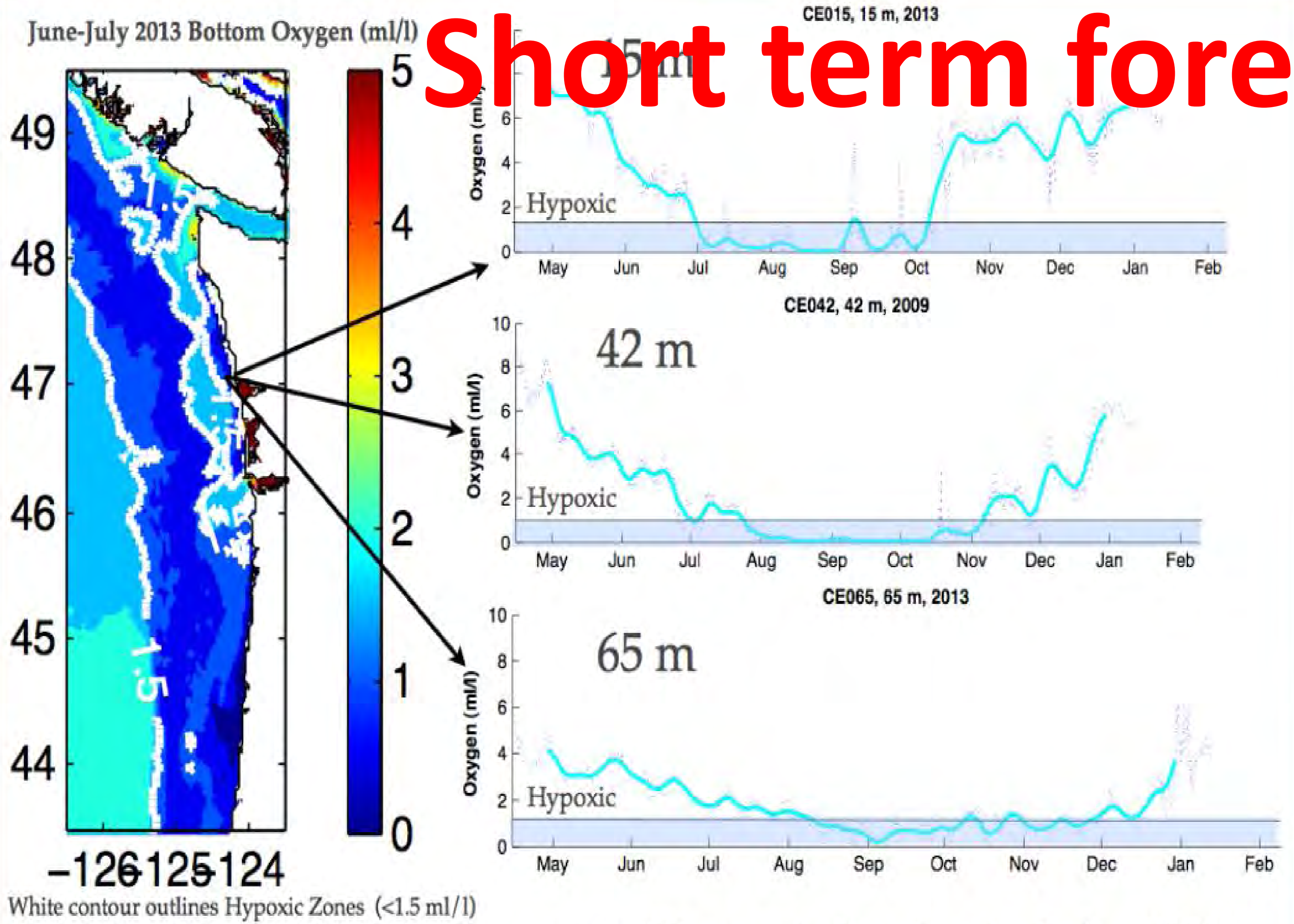
Climate models do capture the statistics of climate variability modes i.e. ENSO, PDO but can't be expected to get the phase right.



But fine-scale events are important to biology!

Photo credit: http://cires.colorado.edu

Short term forecasts



White contour outlines Hypoxic Zones (<1.5 ml/l)

J-SCOPE

Forecast: Hypoxia begins in July, 2013 for Cape Elizabeth region of WA coast

Oxygen model - Siedlecki et al, in prep

Resource Limitations

Summary

- Uncertainties in model structure and parameterizations are often the main source of uncertainty in predictive model simulations.
- Strategies have been identified for addressing quantifying both forms of uncertainty.
- Observation and modeling efforts need to be better integrated.
- Communication with end users (managers) important. What can be predicted ? – with what uncertainty ?– Is intended use for prediction appropriate?
- Short term, regional, ecosystem forecasts seem feasible, useful and testable. Long-term forecasts useful for strategic planning.
- Despite uncertainty – individual model runs still useful for understanding mechanistic processes.

Conclusions

Ecosystem Models can provide decision makers and stakeholders with information about a range of possible outcomes.

Don't avoid addressing Ecosystem Model uncertainty just because it seems difficult – this is an emerging fields that needs to accumulate wisdom (NEMoW II).

Identifying, characterizing and communicating sources of uncertainty as best you can is a good first step.