Comparison of IBM and concentration based approaches to modeling krill growth and population dynamics

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Progress Toward Adding a Stage-Structured Model of Krill to NEMURO

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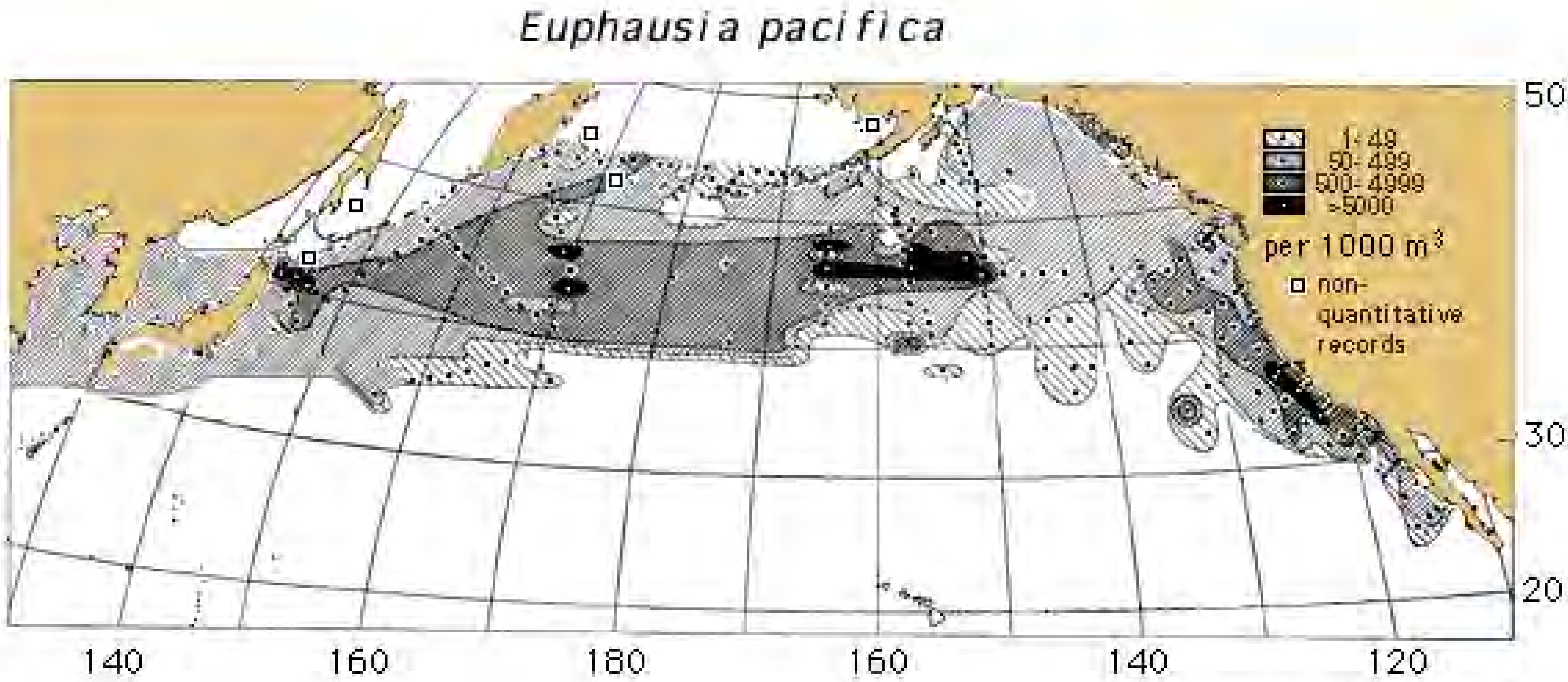


- Distributed around Pacific Rim and across open ocean
- Occupies a broad variety of habitats from cold subarctic waters to warm subtropical waters.
- A key species in food chains as grazer and prey for commercially-important fishes, as well as many birds and mammal species.
- How might climate change affect distribution, population dynamics and production of this species in different regions of the Pacific?

Recent emphasis on developing ecosystem forecasts using CLIMATE SCENARIOS

1) Forecasts means models.

2) "Start with simple toy models. Then move to full 3D models."

3) Test every step of model development.

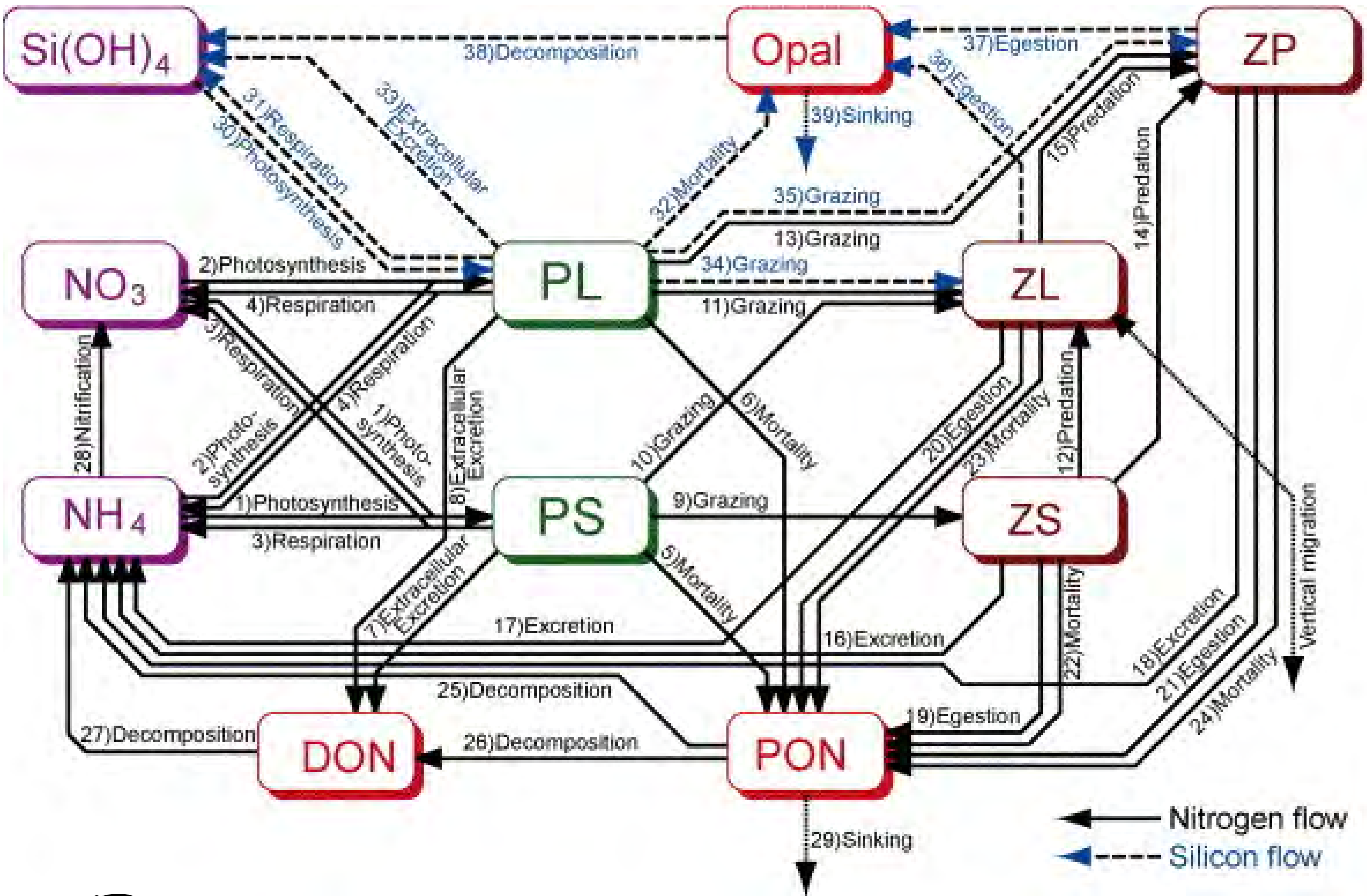
This talk: 2 models

A toy model (0-D).

A 2-D model.

Continuous Distributions or IBMs?

Depends on the question.



NEMURO

75 parameters

Kishi et al. (2007; EcMod)

Vitals:
320 lbs, 7’6”;

$\stackrel{?}{=}$

Vitals:
~320 lbs,

Euphausia pacifica life stages

In Zooplankton, Individual Size

- Impacts preferred prey type (abundance/size)
- Impacts growth rate
- Impacts size-dependent mortality
- Impacts behavior
- Impacts internal pools (lipid reserves)

Stage-specific CW

Euphausia pacifica life stages

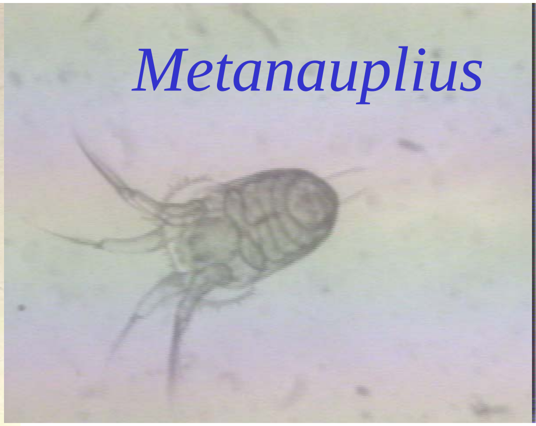
N2

~3.2 μg ind^{-1}

1250 indiv.

ΣR=633.6 ug C d^{-1}

Metanauplius



~7 μg ind^{-1}

571 indiv.

ΣR=529.2 ug C d^{-1}
ΣG=519.6 ug C d^{-1}
R/G=1
Assim/Wt=0.26

Adult

ΣR=122.9 ug C d^{-1}
ΣG=26 ug C d^{-1} R/G=4.7
Assim/Wt=0.04

~4000 μg ind^{-1}

1 indiv.

Advantages of IBMs

1) Biology is often mechanistically explicit. (not hidden in differential equations).

2) Biological-Physical-Chemical Interactions are clearly detailed.

3) Individual is the fundamental biological unit, thus it is natural and intuitive to model at that level, rather than at the population level.

4) Allows explicit inclusion of an individual's history and behavior (e.g, Interindividual Variability)—no longer modeling the dynamics of the MEAN CONDITION.

5) History-Spatial Heterogeneity interactions '*easily*' handled.

Costs Involved in IBM Approach

1) Difficult to implement feedback from IBM (Lagrangian) to underlying Eulerian model, esp. across multiple trophic levels
2) Requirement for Large Numbers of Particles
   - Difficult to simulate realistic abundances
3) Difficult (Impossible?) to simulate density dependence
4) Extensive Computation Penalty

For many research questions, we can live with these IBM problems (or work around them).

But, when considering future climate change scenarios and responses of ecosystem structure and function, it is difficult to ignore biomass density (concentration).

Consequently, the dominance of Eulerian concentration based models in climate scenario assessment.

Can we mimic some of the advantages of IBMs in Eulerian models?

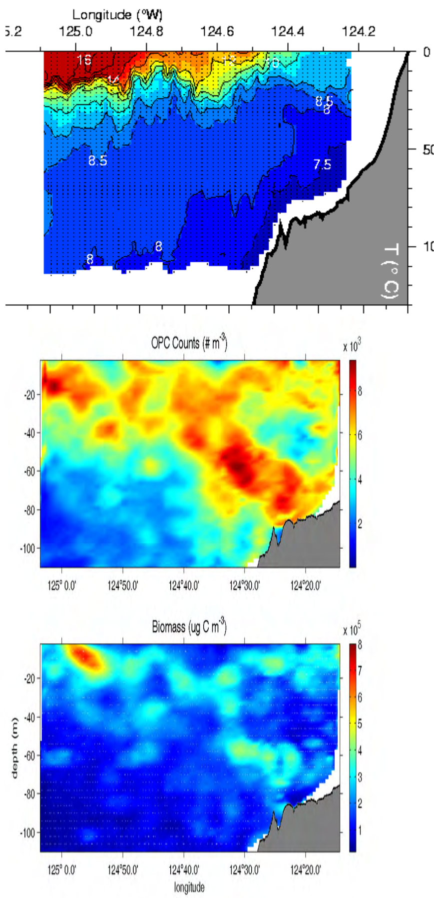
Newport Oregon Line — A Rich Dataset

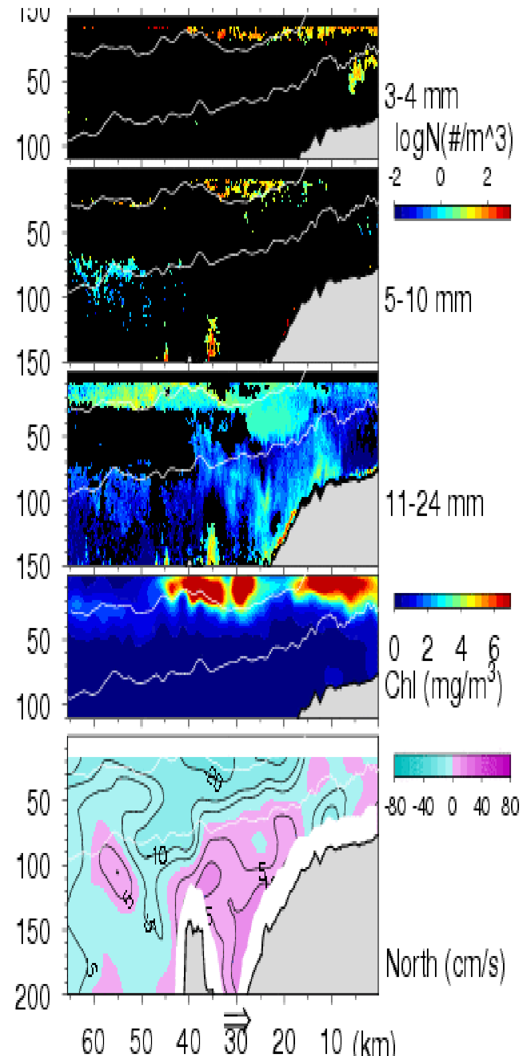
W0008A Line 1 4-Aug-2000

Temp

OPC counts #/m3

OPC Biom. ug C/m3





3-4 mm (late furcilia)

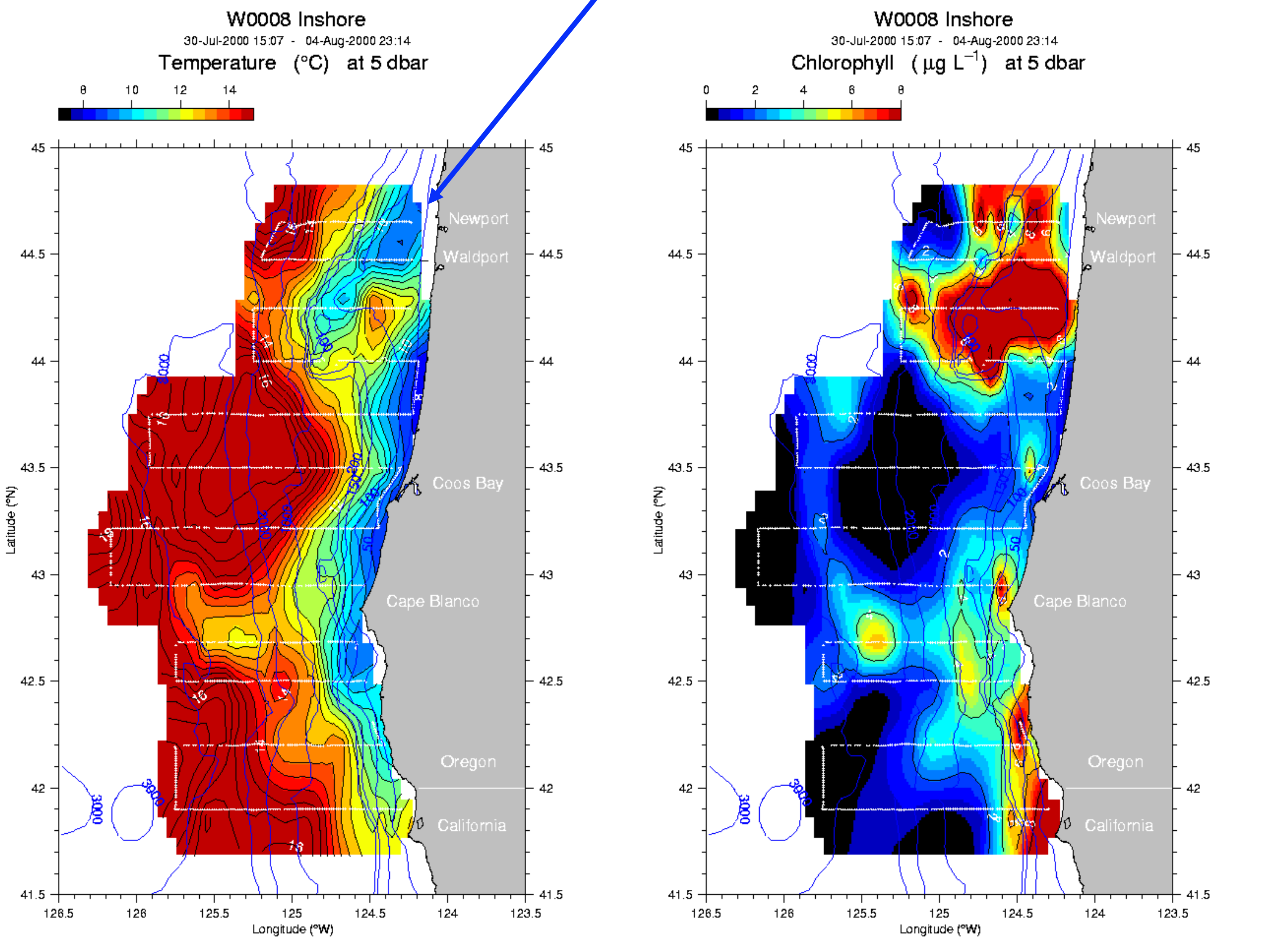
5-10 mm (juvy krill)

11-24 mm (adult krill)

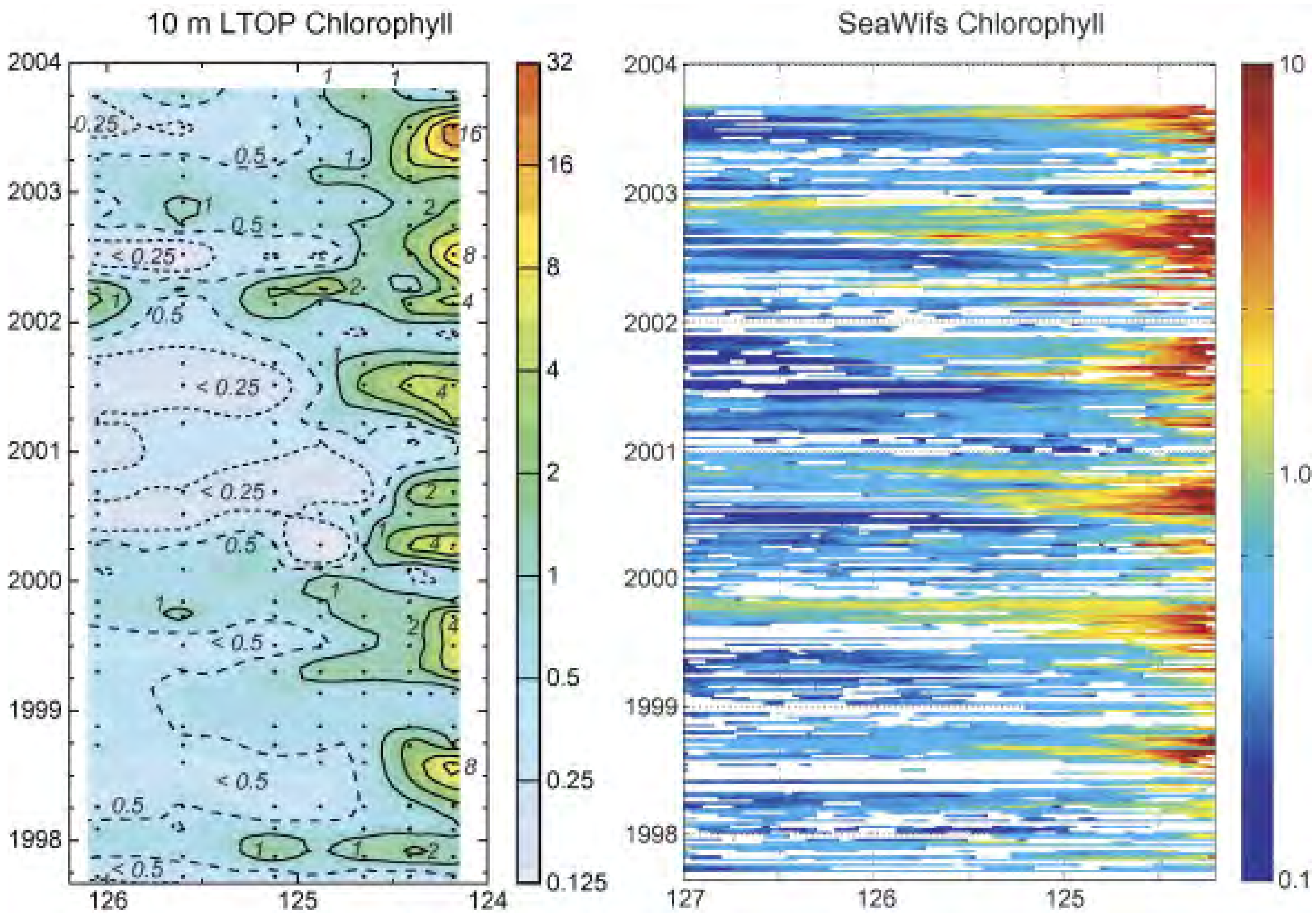
Chl mg/m3

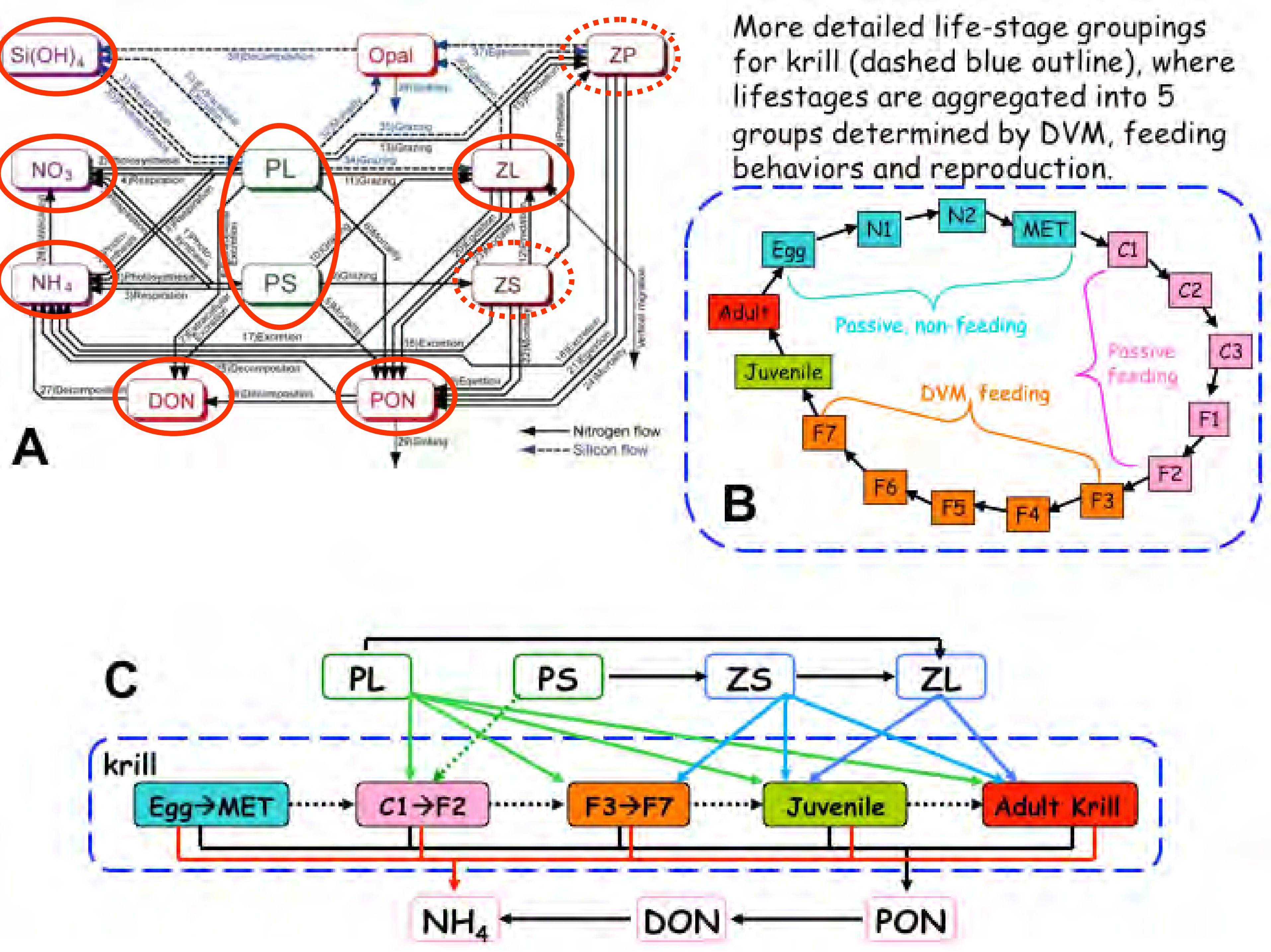
Northward velocity cm/s

Newport Oregon Line



Newport Oregon Line





A
Si(OH)4
Opal
ZP
NO3
PL
ZL
NH4
PS
ZS
DON
PON
Nitrogen flow
Silicon flow
More detailed life-stage groupings for krill (dashed blue outline), where lifestages are aggregated into 5 groups determined by DVM, feeding behaviors and reproduction.
B
Egg
N1
N2
MET
C1
C2
C3
F1
F2
F3
F4
F5
F6
F7
Juvenile
Adult
Passive, non-feeding
Passive feeding
DVM, feeding
C
PL
PS
ZS
ZL
krill
Egg→MET
C1→F2
F3→F7
Juvenile
Adult Krill
NH4
DON
PON

A Stage Progression Model

E. pacifica Belehradek function for time to stage as function of temperature

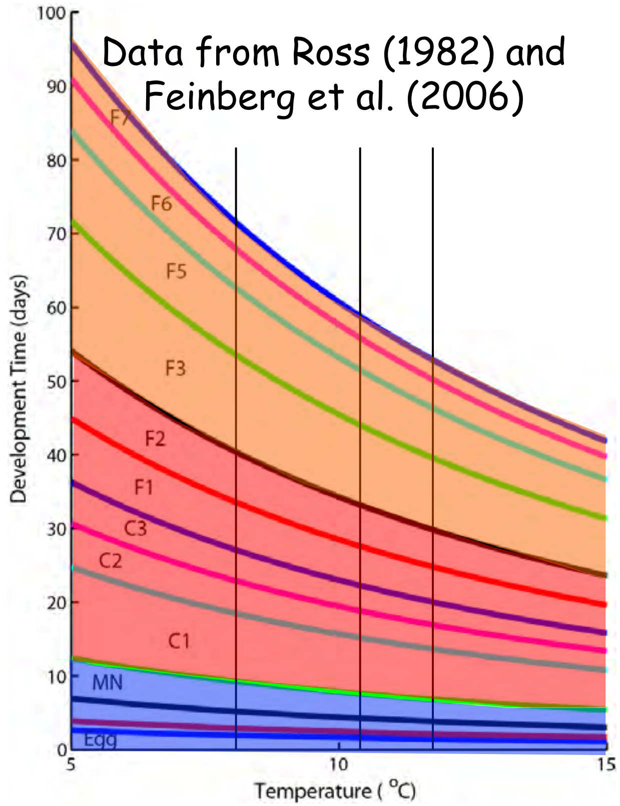
Basic Form is: $D_i = a_i (T + b)^c$

D_i is the time (days) from egg to stage i

a_i is a stage specific constant

b is a stage-independent shift in temperature

c is assumed to be -2.05 (commonly observed from experiments; determines the curvature)

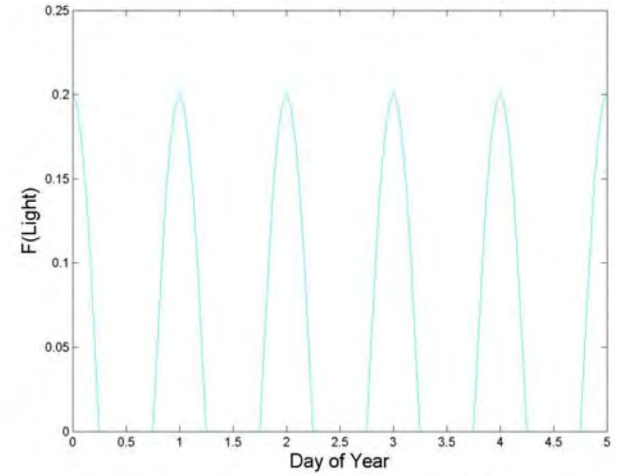


$MR_i = 1/[a_i (T + b)^c]$ ➔ Leads to numerical diffusion

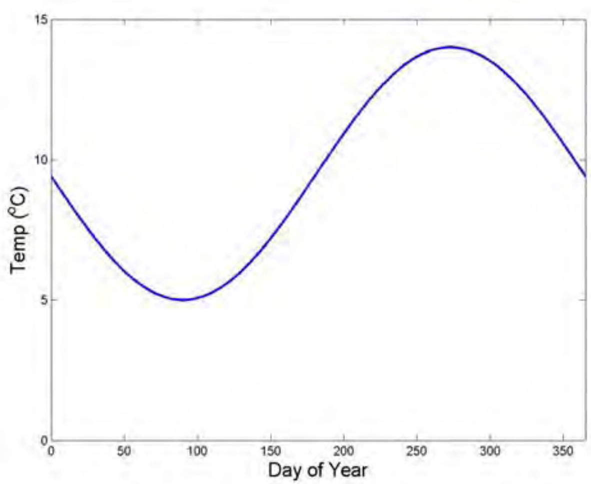
$MR\text{-}corr_i$ based on Hu et al. (2008; MEPS) algorithm that uses mean age of $state_i$ and a probability density function of transfer.

External Forcing

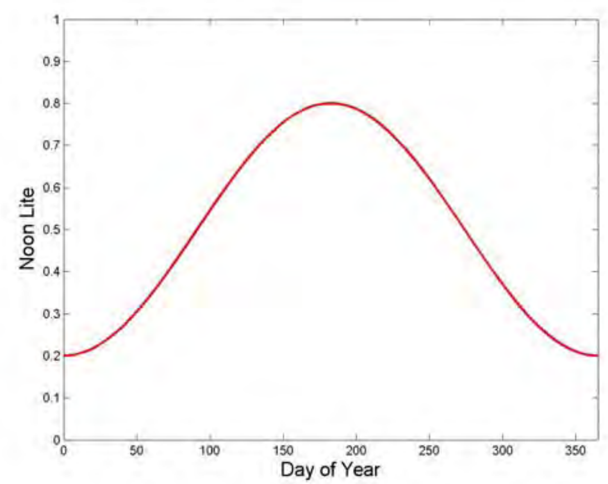
Diurnal Light Cycle

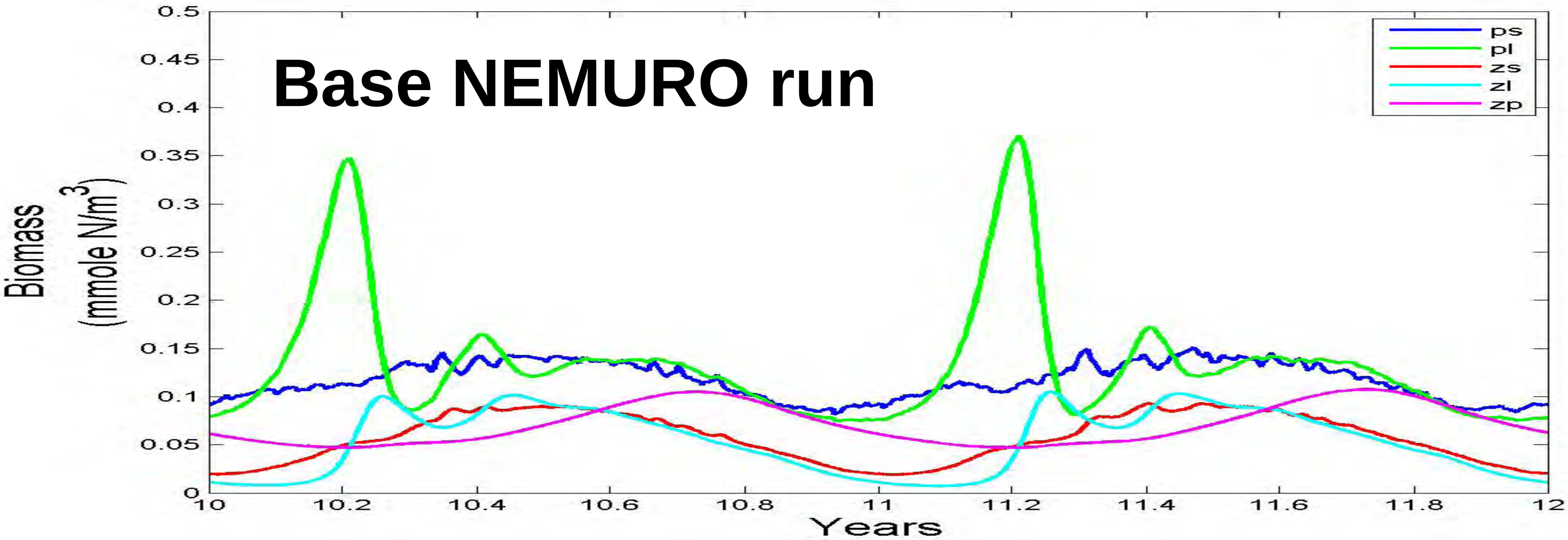


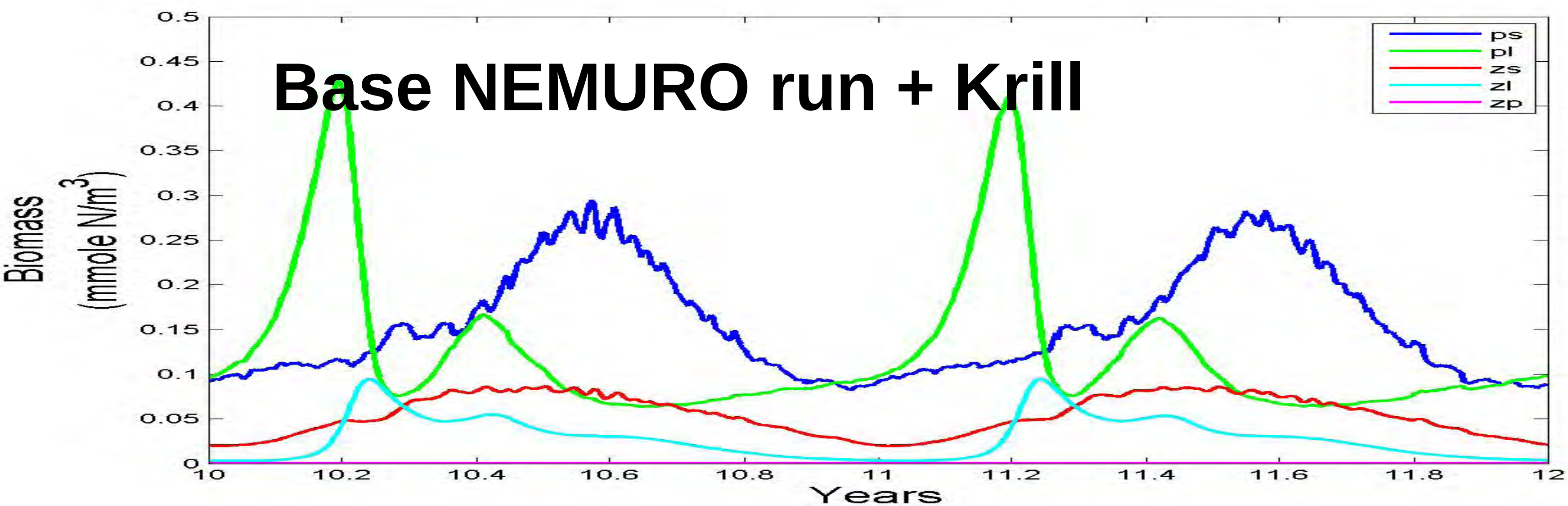
Annual Temp Cycle

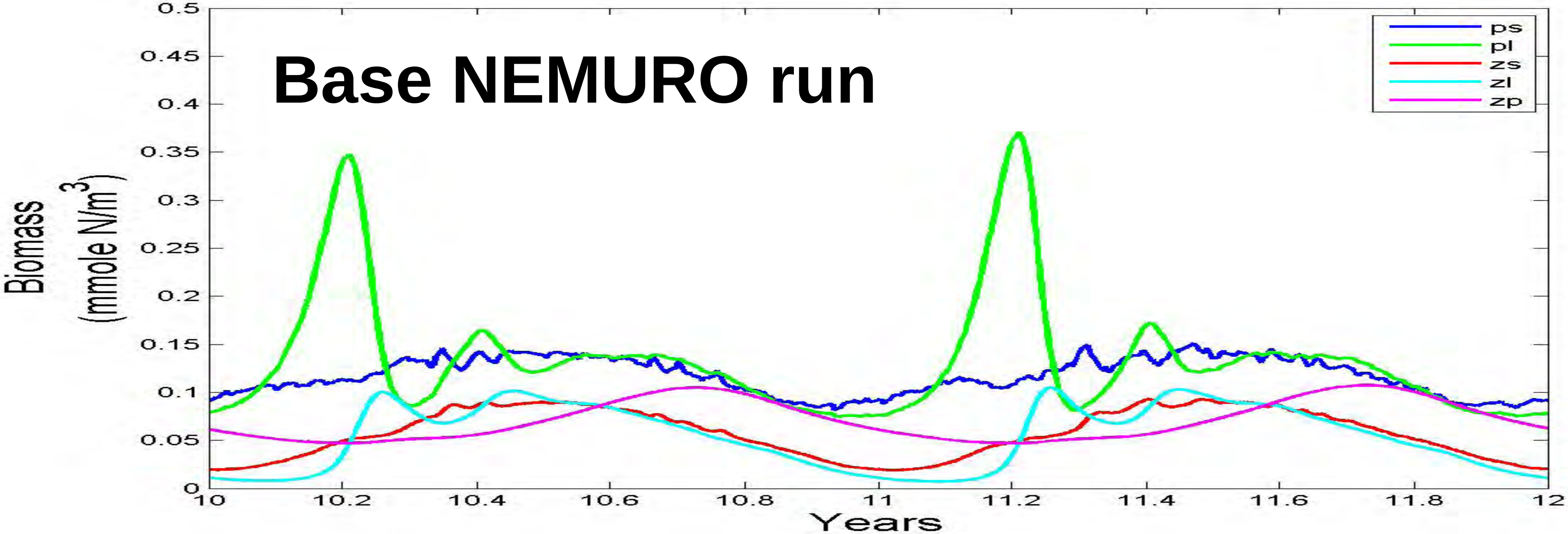


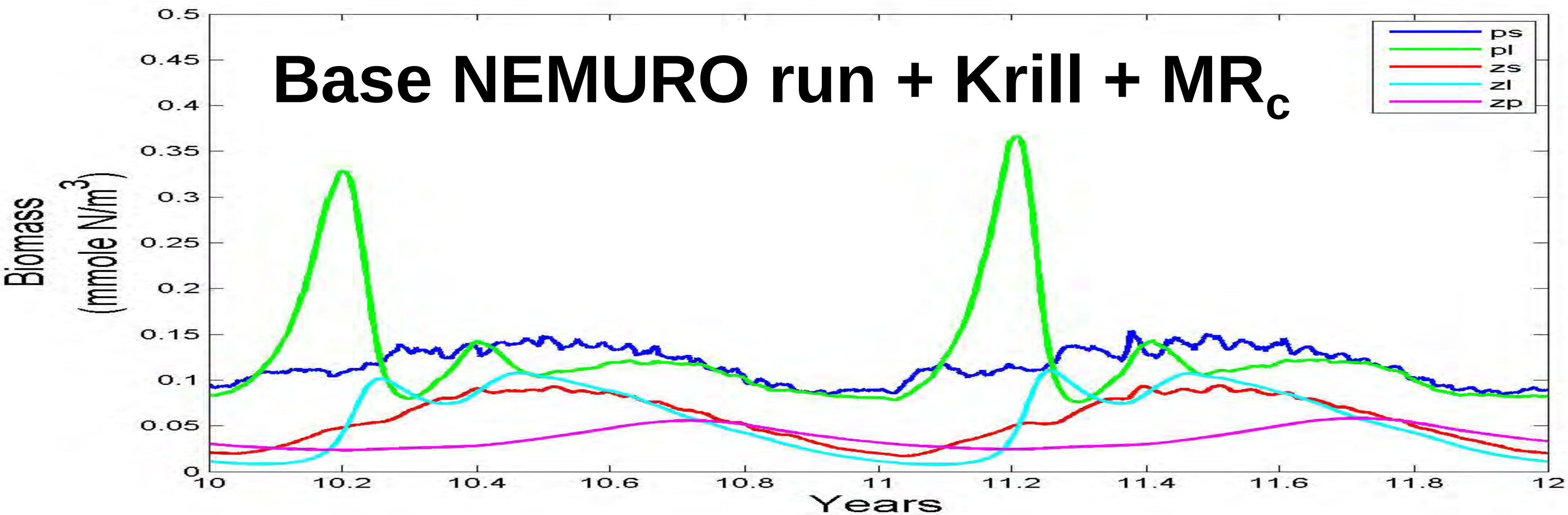
Annual Light Cycle

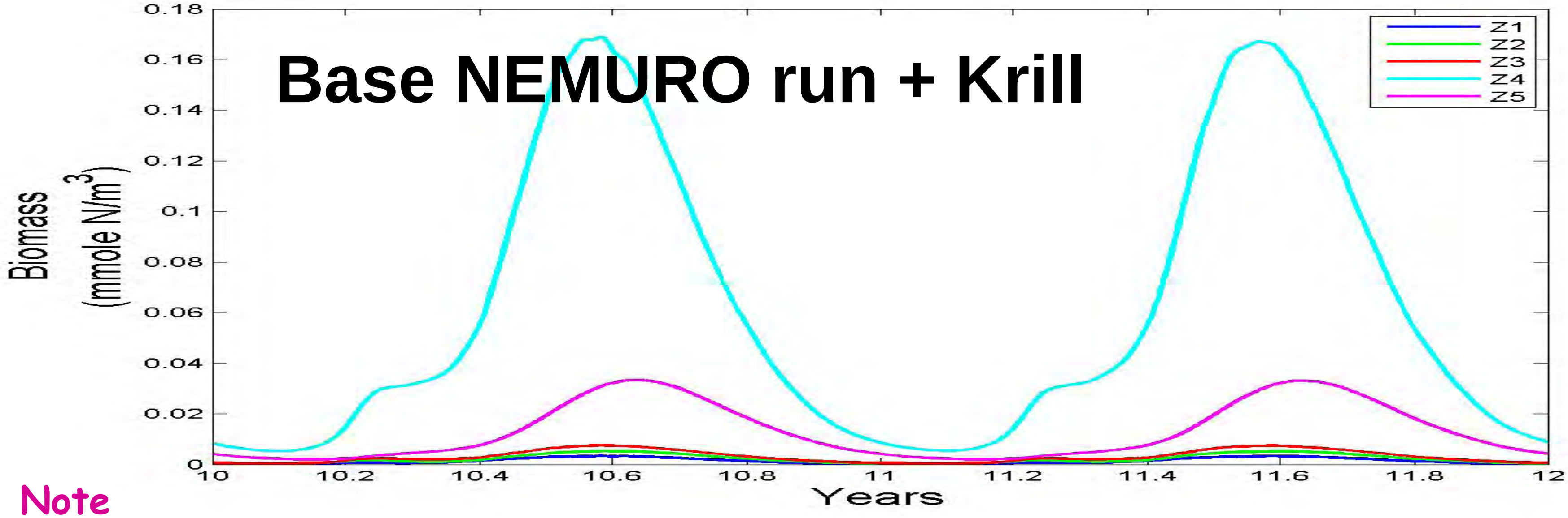



Base NEMURO run
Biomass
(mmole N/m3)
Years
ps
pl
zs
zl
zp
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
10
10.2
10.4
10.6
10.8
11
11.2
11.4
11.6
11.8
12


Base NEMURO run + Krill
Biomass
(mmole N/m3)
Years
ps
pl
zs
zl
zp
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
10
10.2
10.4
10.6
10.8
11
11.2
11.4
11.6
11.8
12

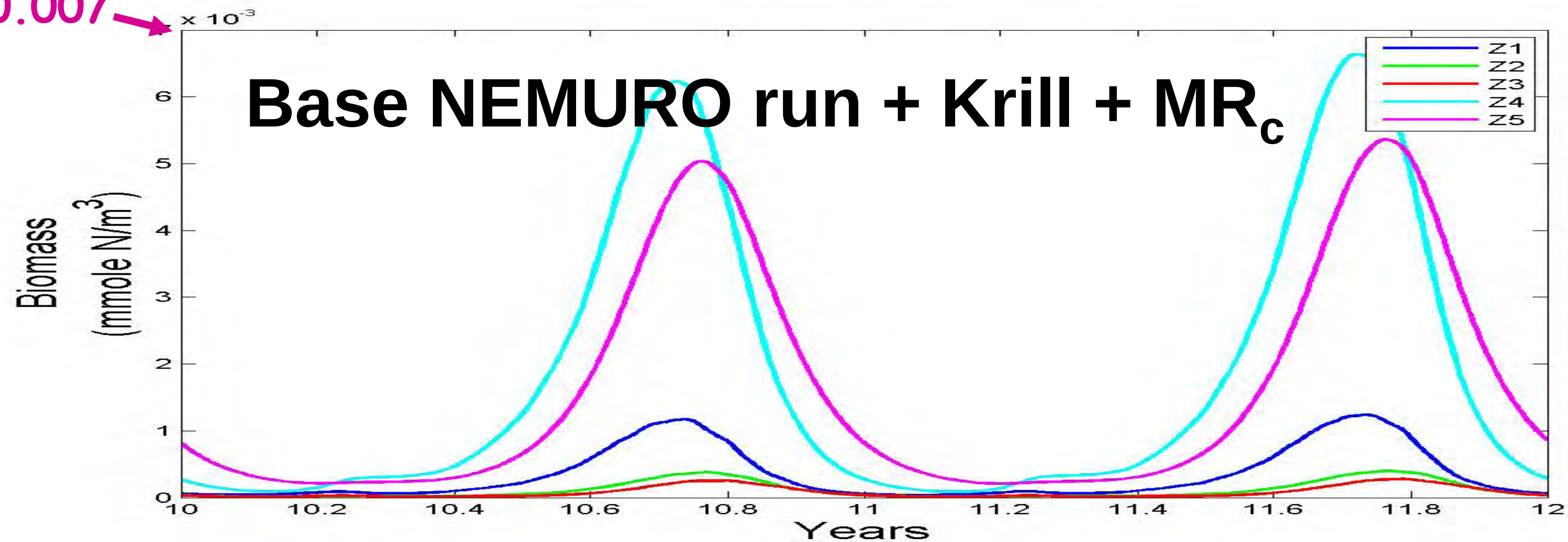

Base NEMURO run
ps
pl
zs
zl
zp
Biomass
(mmole N/m3)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
10
10.2
10.4
10.6
10.8
11
11.2
11.4
11.6
11.8
12
Years


Base NEMURO run + Krill + MRc
ps
pl
zs
zl
zp
Biomass
(mmole N/m3)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
10
10.2
10.4
10.6
10.8
11
11.2
11.4
11.6
11.8
12
Years



Base NEMURO run + Krill
Biomass (mmole N/m^3)
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
10
10.2
10.4
10.6
10.8
11
11.2
11.4
11.6
11.8
12
Years
Z1
Z2
Z3
Z4
Z5

Note
0.007



x 10^{-3}
Base NEMURO run + Krill + MR_c
Biomass (mmole N/m^3)
6
5
4
3
2
1
0
10
10.2
10.4
10.6
10.8
11
11.2
11.4
11.6
11.8
12
Years
Z1
Z2
Z3
Z4
Z5

0-D Model Summary

1) Adding krill to NEMURO decreases ZL and ZP, the latter to extinction, and increases PS (through a trophic cascade).

2) Adding krill+MRc reduces ZP by about 50% from the base NEMURO, but has little effect on other Z's and P's in NEMURO.

3) The ZP reduction (krill+MRc) or extinction (krill) must be occurring through competition, since no life stage of krill feeds directly upon ZP.

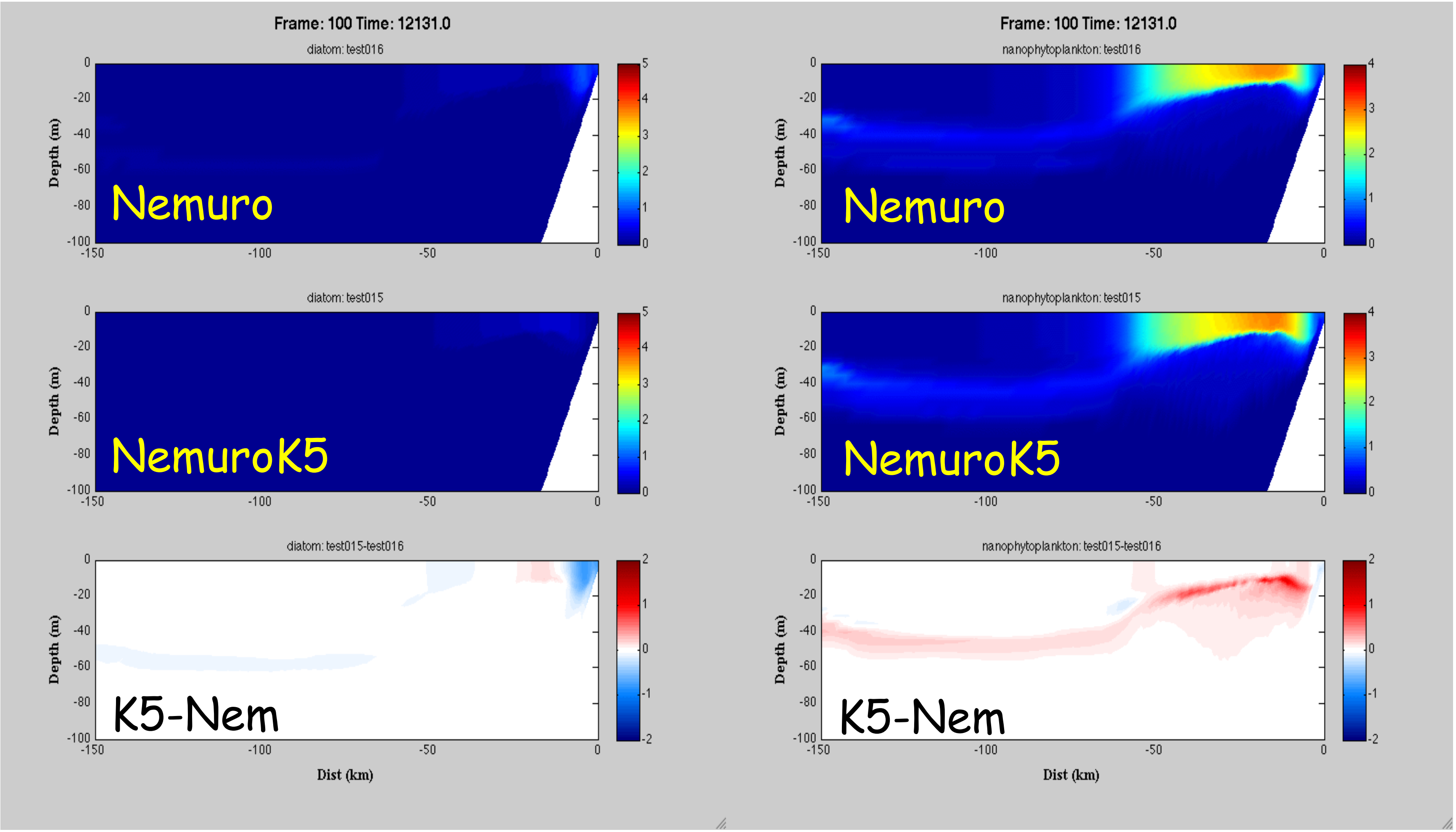
4) Krill concentrations with MRc are much lower (~4%) of concentrations in the krill model w/o MRc. Delayed transfer from young stages of krill to older stages exposes krill to the higher mortality rates of the younger stages for a long time.

5) The mean age & concentration approach of Hu et al. (2008) can be applied to molting of krill in Eulerian models, and will have value also for implementing DVM behaviors (swimming speeds) in Eulerian models.

On to a 2D simulation…

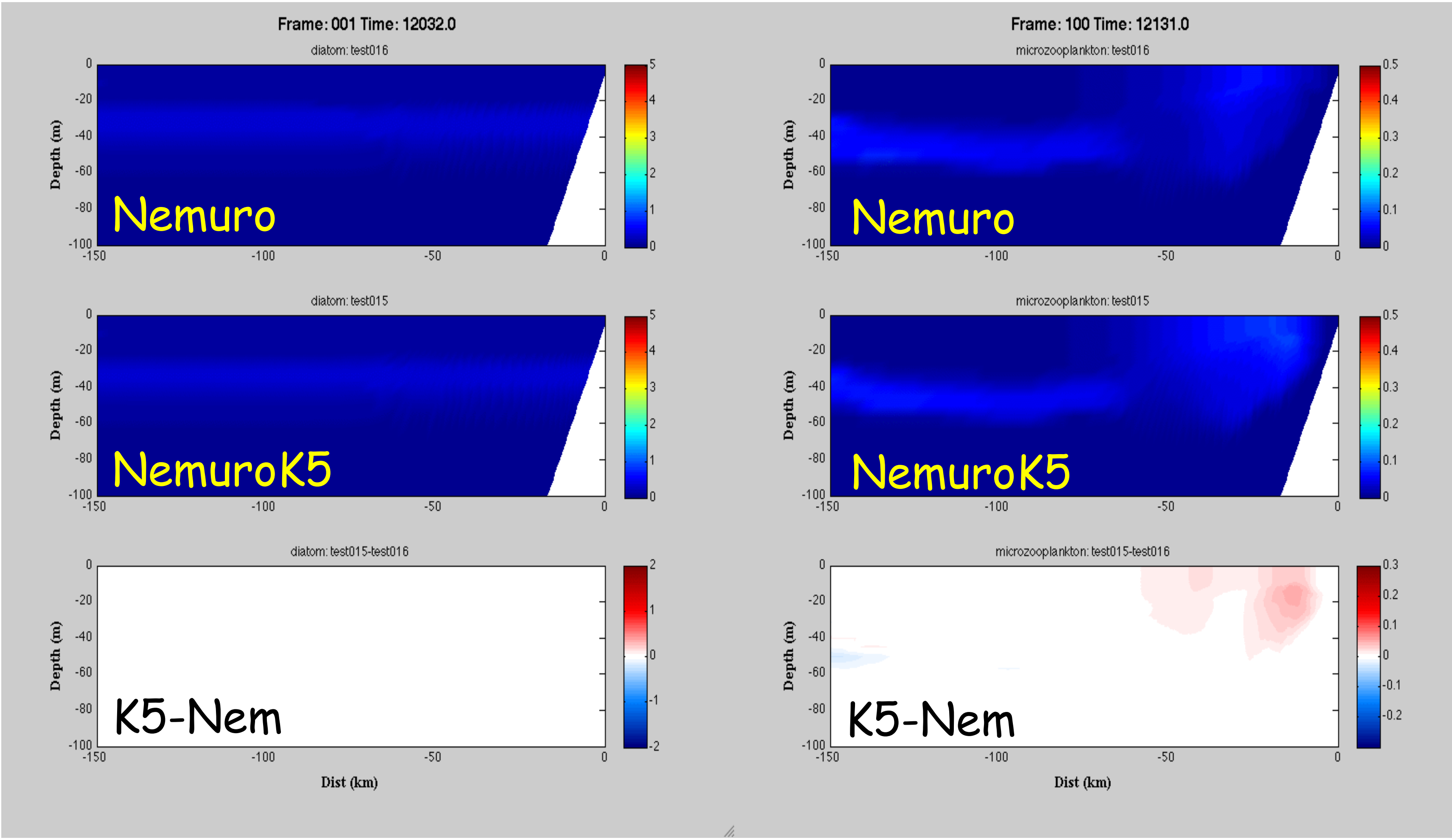
Note: Next two slides are video animations that are not possible in a PDF.

Nanophytoplankton Microzooplankton



Reduced Microzooplankton, Increased Nanophytoplankton

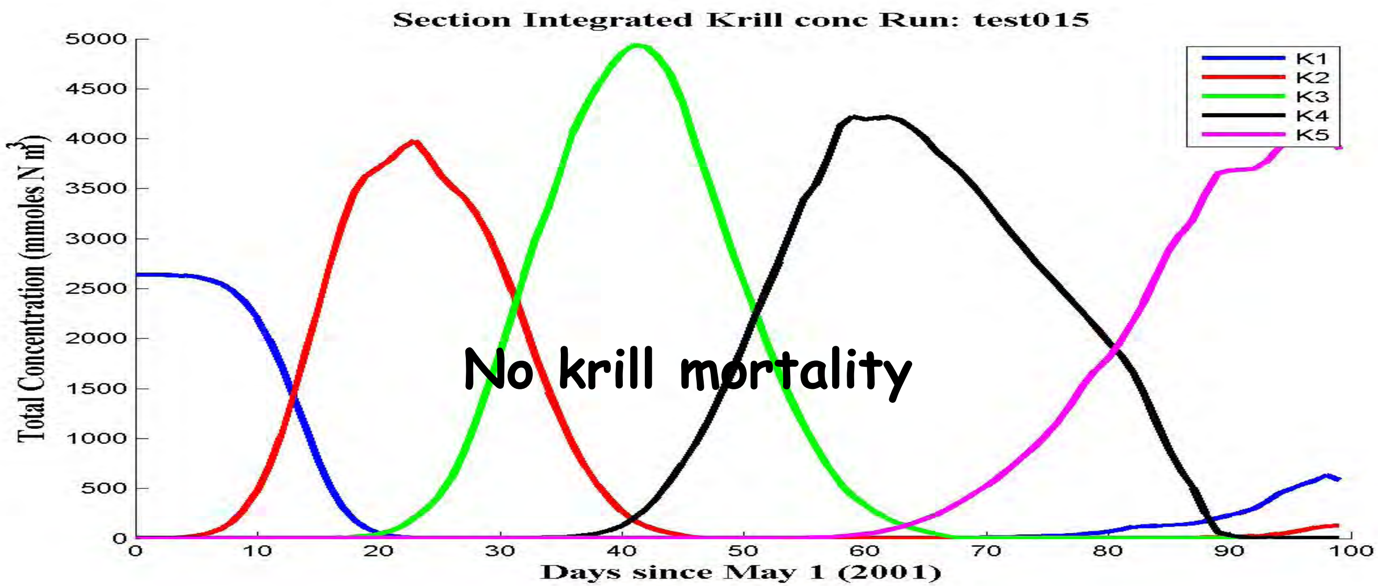
Diatom   Mesozooplankton

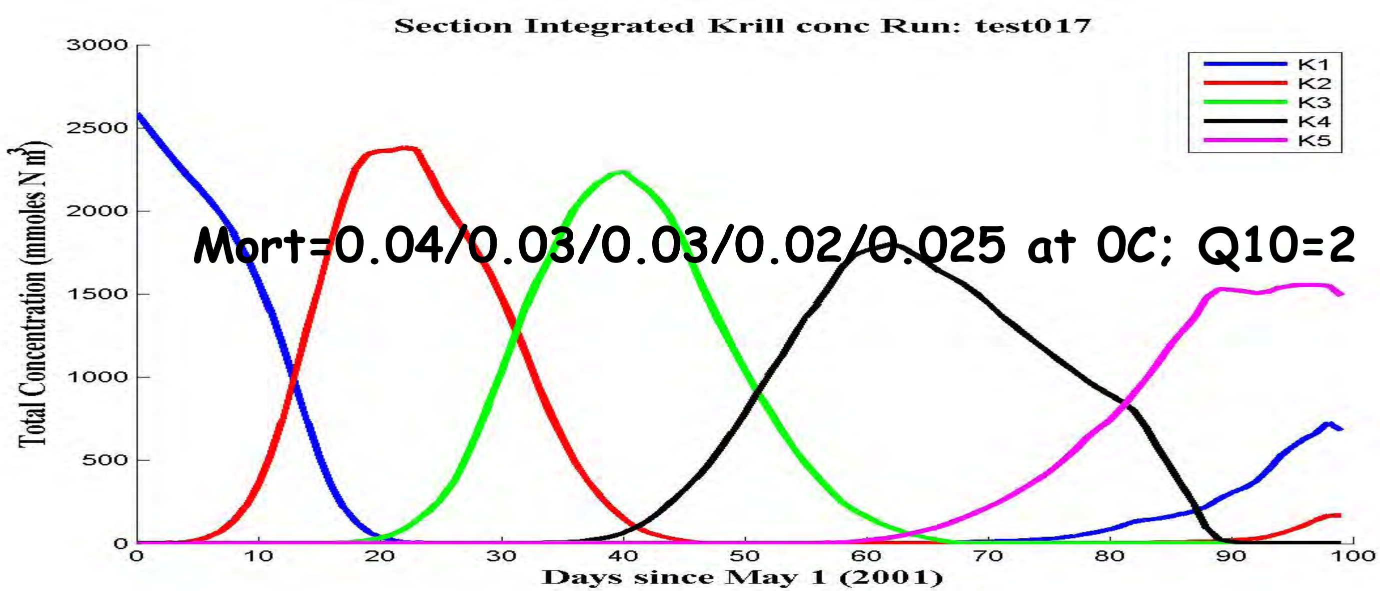


Reduced Diatoms and Reduced Mesozooplankton

Newport Section 2D model

Area Integrated Krill concentration





2-D Model Summary

1) This is a work in progress; difficult to summarize results to date.

2) An approach for handling the evolution of Hu's "Mean-Age" info is implemented for the 5 stage krill model and should generalize to any number of discrete stages. The approach allows proper mixing and advection of biomass and mean age info using "standard ROMS".

3) The transitions of individuals due to temperature dependent molting and the Hu et al. model were tested by examining krill dynamics with no mortality and no bioenergetics (only molting), and found valid.

4) The 2D model was run with Krill-1 stage initialized to 0.5 mmoles N m^{-3} everywhere in the 2D domain. This is clearly an incorrect initial condition.

5) Future Directions
    1) More realistic initial conditions
    2) Better parameterizations of the MANY (10) functional responses of krill consuming "NEMURO" prey.
    3) Develop code for DVM of the stages.
    4) And probably much more…………before comparison to the rich Newport data set.

Methods are available to reduce population numerical (artificial) diffusion, and work well.

DVM can be simulated with Eulerian approaches. But DVM controlled by individual conditions cannot be simulated in continuum models.

Continuum models are unlikely to ever be capable of assessing interindividual variability in intrinsic and extrinsic experiences that are the most significant advantage of IBMs.

Some questions are best answered by IBMs, others by continuum (concentration) methods. Choose the appropriate model for the question.

THE END

Standard NEMURO Model

Phyto Prod: 19

Ingestion: Zoo (21);

Respiration: Phyto (6); Zoo (6)

Mortality: Phyto (4); Zoo (6)

Misc: 13

<u>TOTAL: 75</u>

NEMUROK5 Model

All params at left PLUS…

Krill Ingestion: 32

Respiration: 2

Mortality: 10

Molting: 6

Reproduction: 2

<u>TOTAL: 52</u>