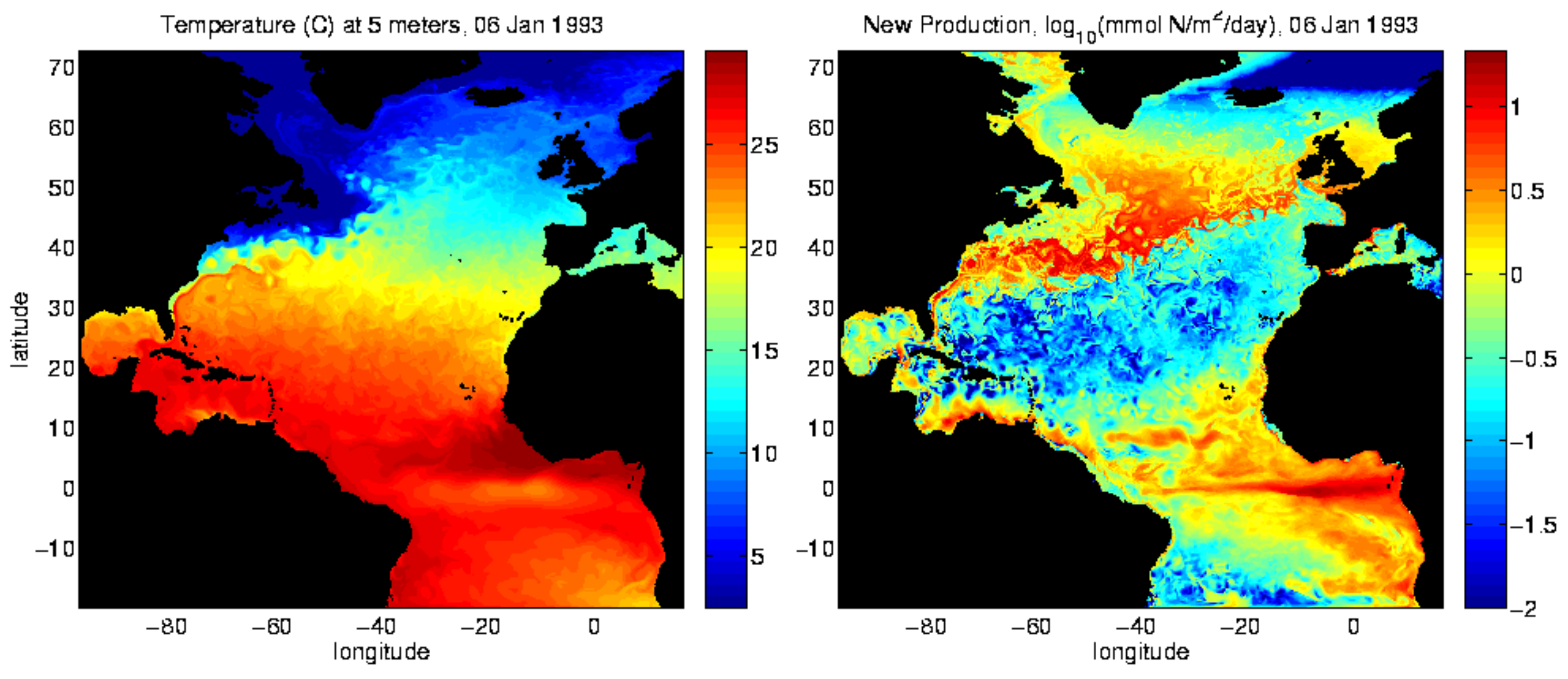
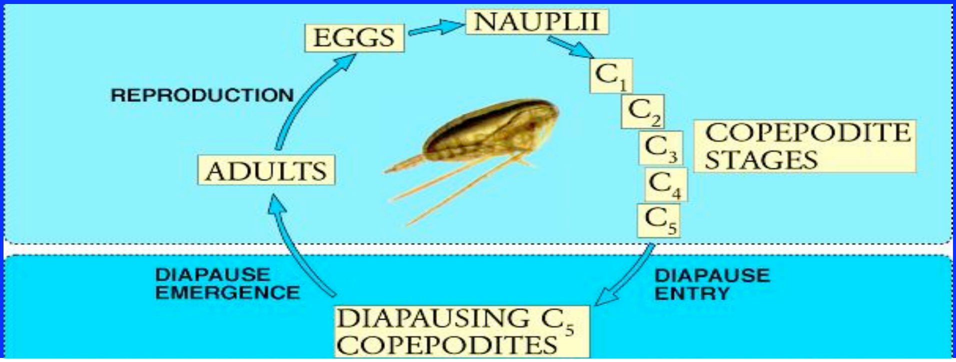
# Physical-biological interactions and population dynamics of *Calanus finmarchicus*



Temperature (C) at 5 meters, 06 Jan 1993

New Production, $\log_{10}$(mmol N/m$^2$/day), 06 Jan 1993



EGGS

NAUPLII

$C_1$

$C_2$

$C_3$

$C_4$

$C_5$

COPEPODITE STAGES

REPRODUCTION

ADULTS

DIAPAUSE ENTRY

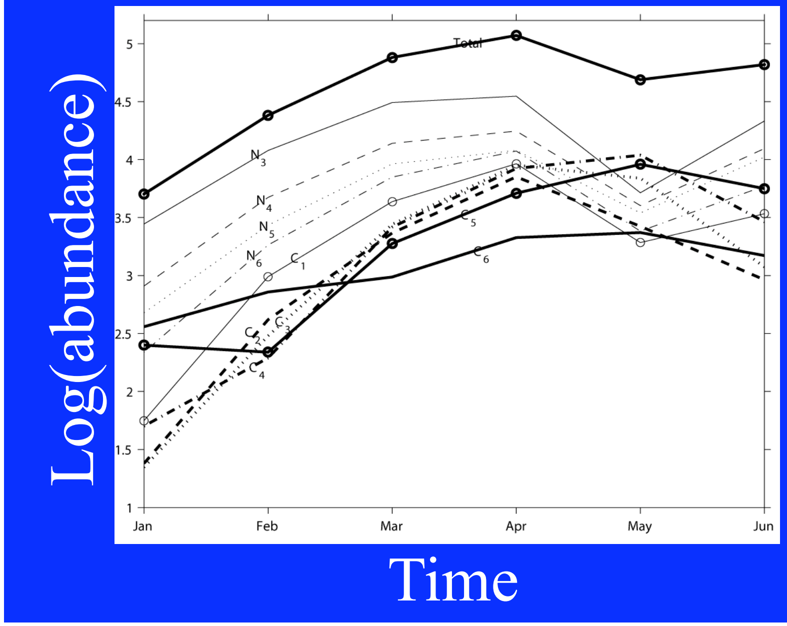
DIAPAUSE EMERGENCE

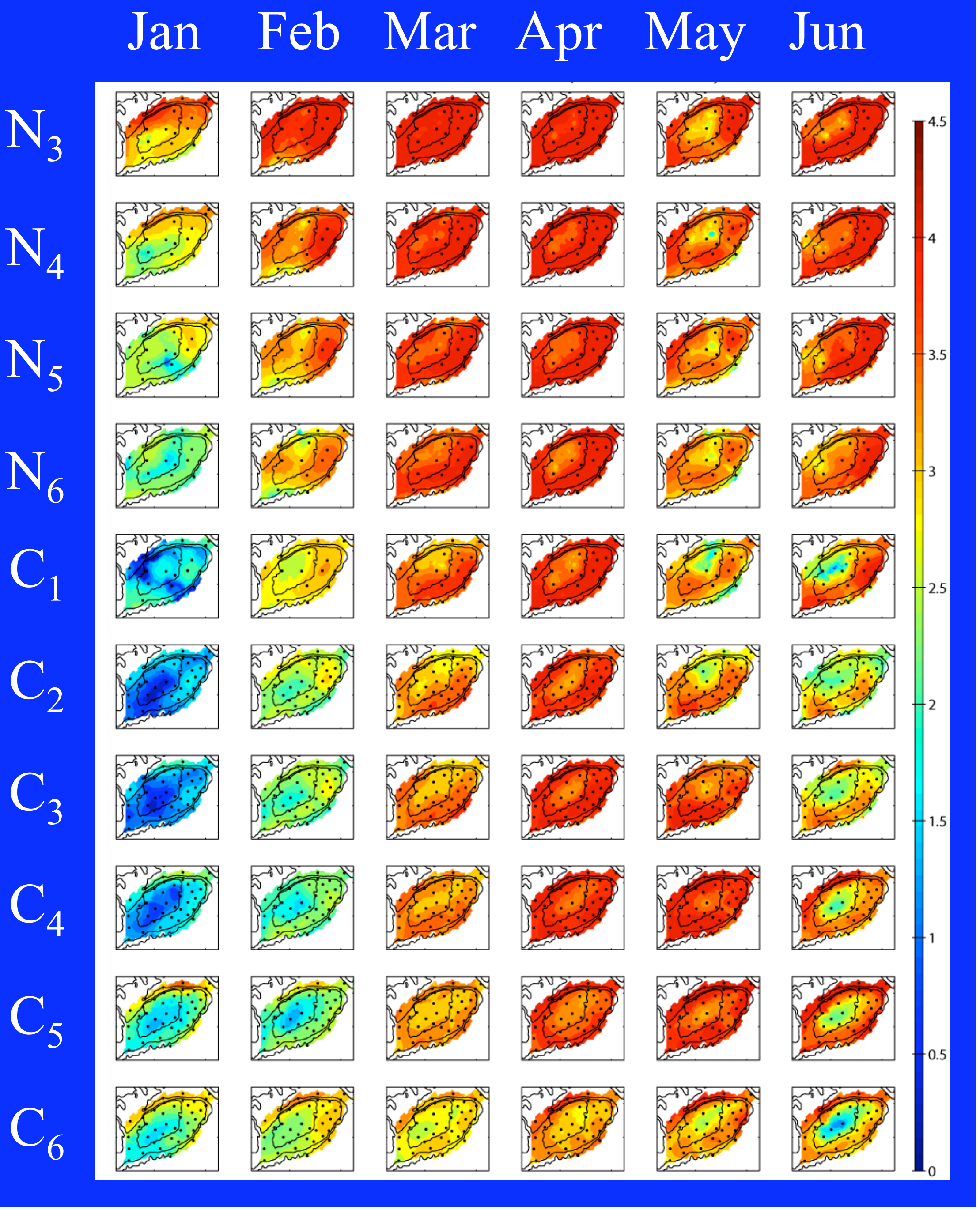
DIAPAUSING $C_5$ COPEPODITES

Mark Benfield

# *C. finmarchicus* climatology: Globec Broadscale surveys 1995-1999

Durbin et al.
http://globec.gso.uri.edu/

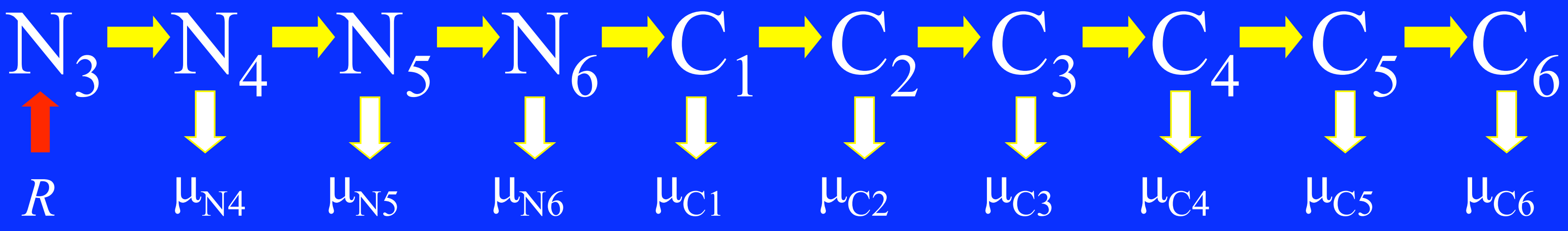




# *C. finmarchicus* model

$$\frac{\partial C_i}{\partial t} + v \cdot \nabla C_i - \nabla \cdot (K \nabla C_i) = \delta_{i1} R - F_i + (F_{i-1} - \mu_i C_i)(1 - \delta_{i1})$$

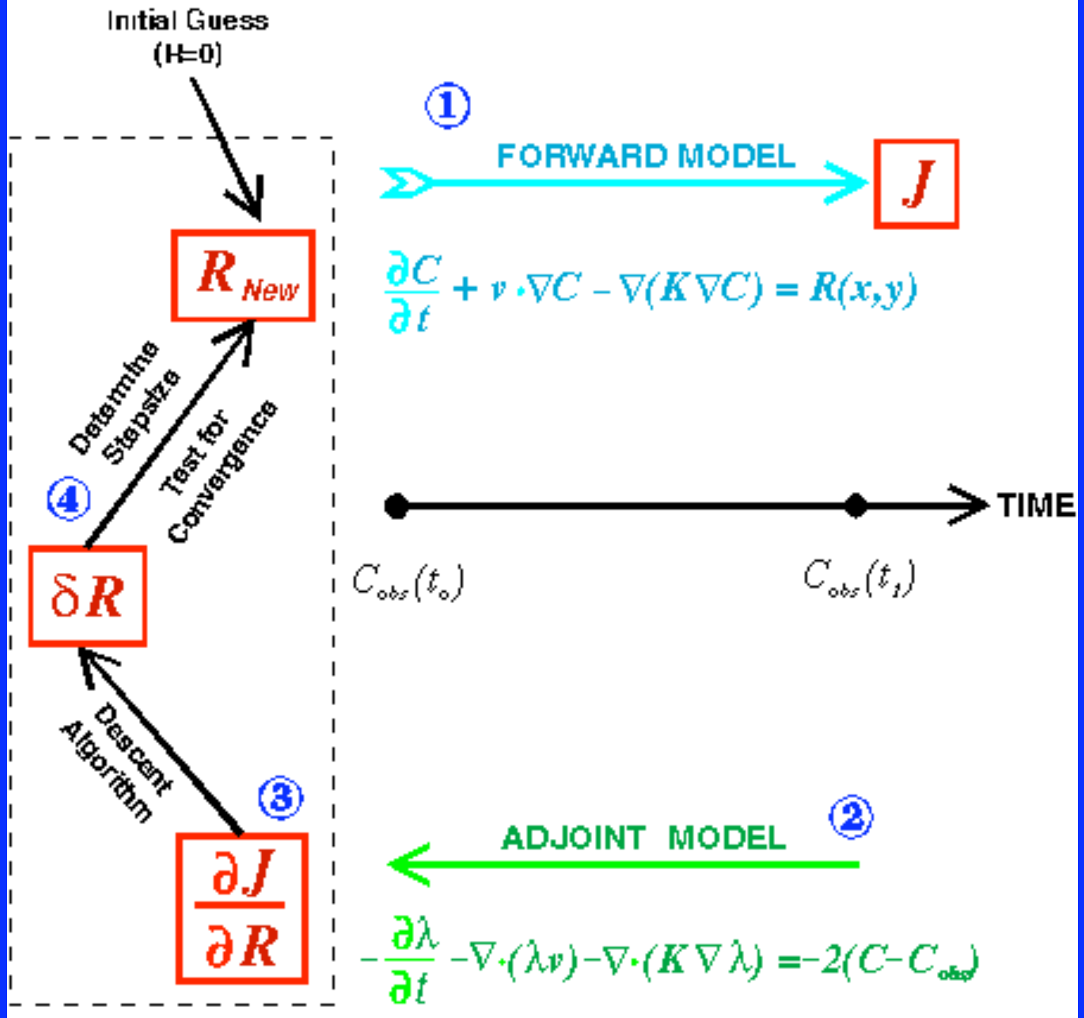
| | | |
|---|---|---|
| $F_i$: molting flux | ➡ | $F_i(T, Chl)$ computed (Campbell et al. 2001) |
| $R$: sources of $N_3$ | ⬆ | Inferred (monthly) |
| $\mu_i$: mortality | ⇩ | Inferred (monthly) |
| $C_i$ off-bank | | Inferred (initial conditions) |



$$N_3 \rightarrow N_4 \rightarrow N_5 \rightarrow N_6 \rightarrow C_1 \rightarrow C_2 \rightarrow C_3 \rightarrow C_4 \rightarrow C_5 \rightarrow C_6$$

$R$   $\mu_{N4}$   $\mu_{N5}$   $\mu_{N6}$   $\mu_{C1}$   $\mu_{C2}$   $\mu_{C3}$   $\mu_{C4}$   $\mu_{C5}$   $\mu_{C6}$

# *AN ADJOINT DATA ASSIMILATION PROCEDURE TO INVERT FOR R(x,y)*

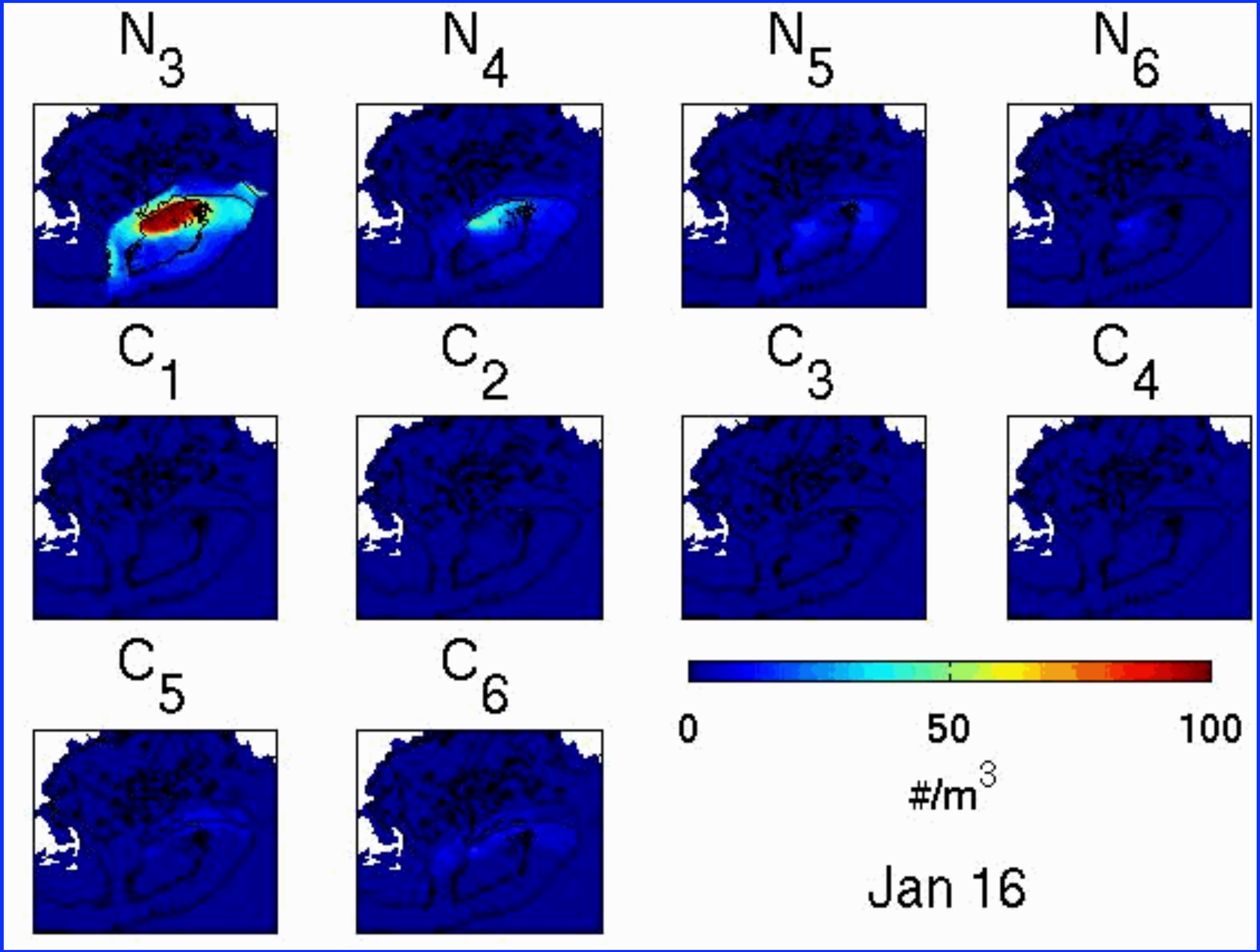


$$\frac{\partial C}{\partial t} + v \cdot \nabla C - \nabla(K \nabla C) = R(x,y)$$

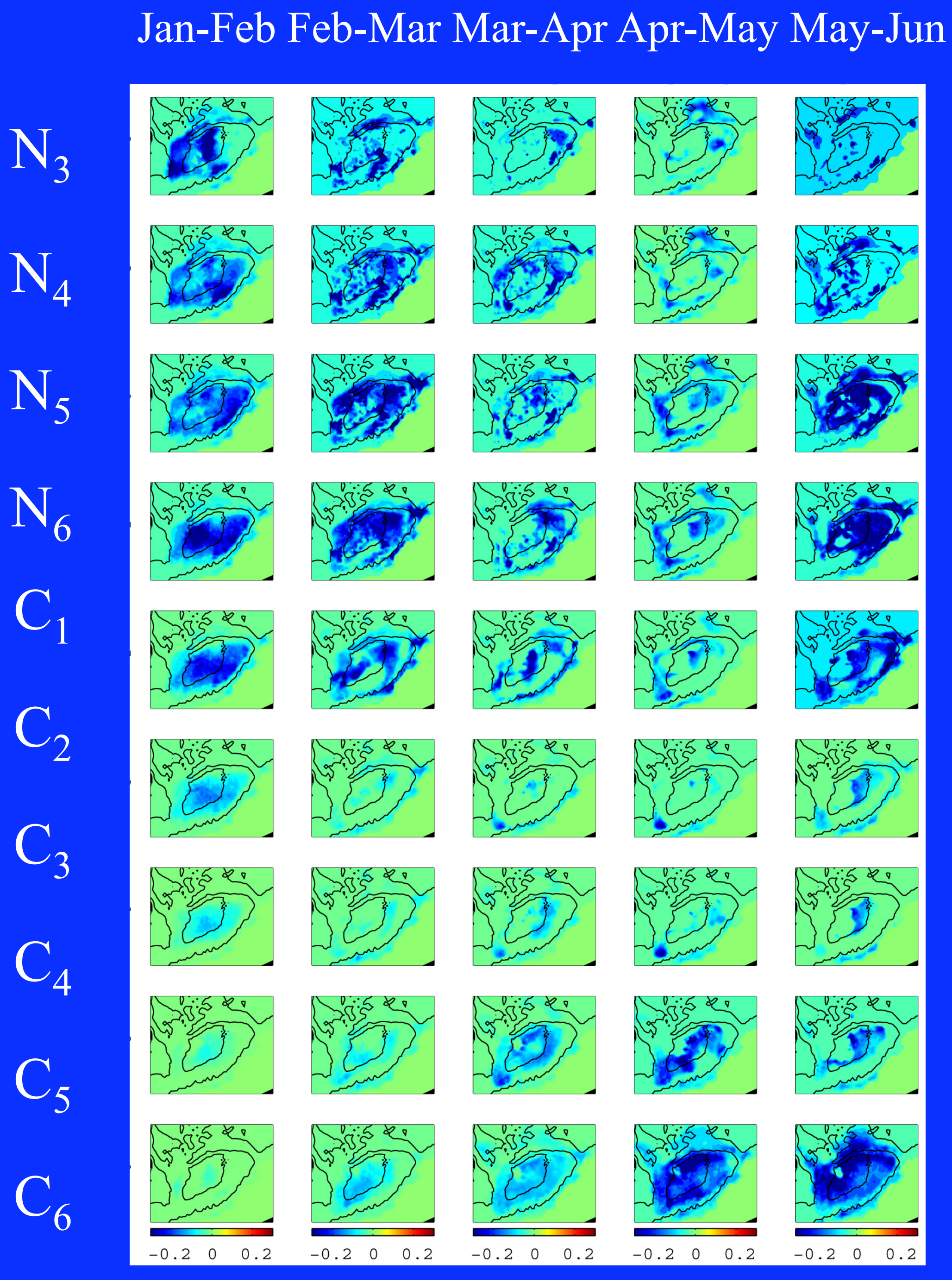
$$-\frac{\partial \lambda}{\partial t} - \nabla \cdot (\lambda v) - \nabla \cdot (K \nabla \lambda) = -2(C - C_{obs})$$

$$J = \int_{-L_x}^{L_x} \int_{-L_y}^{L_y} \int_{t_o}^{t_1} (C - C_{obs})^2 \, dx\, dy\, dt$$

# *C. finmarchicus* solution: January- June



# Inferred Mortality



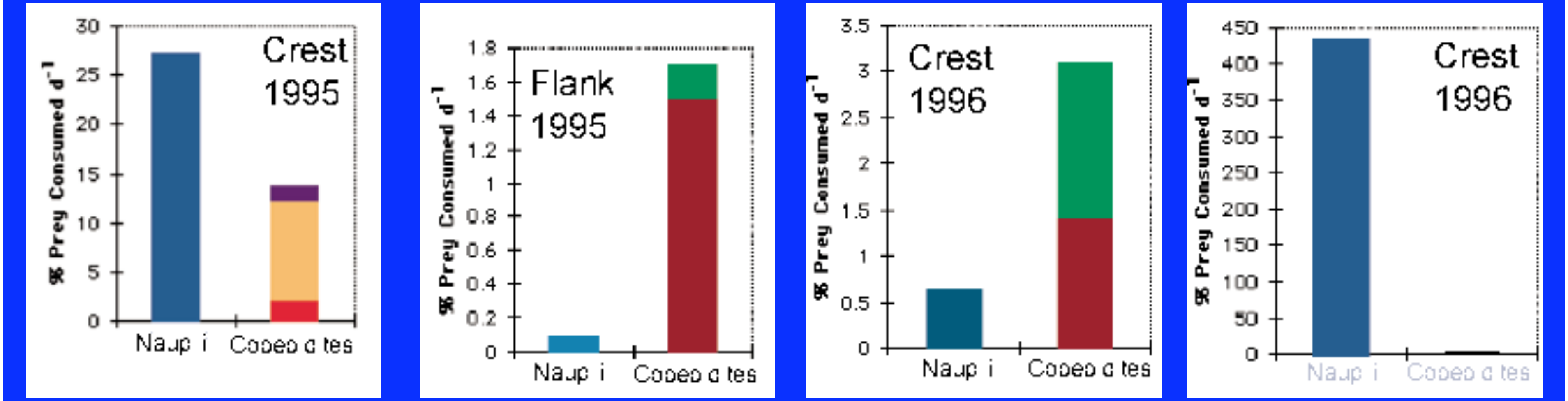
# Are the inverse solutions ecologically realistic?

Predation potential:

Model predicted rates of 3-10% day$^{-1}$

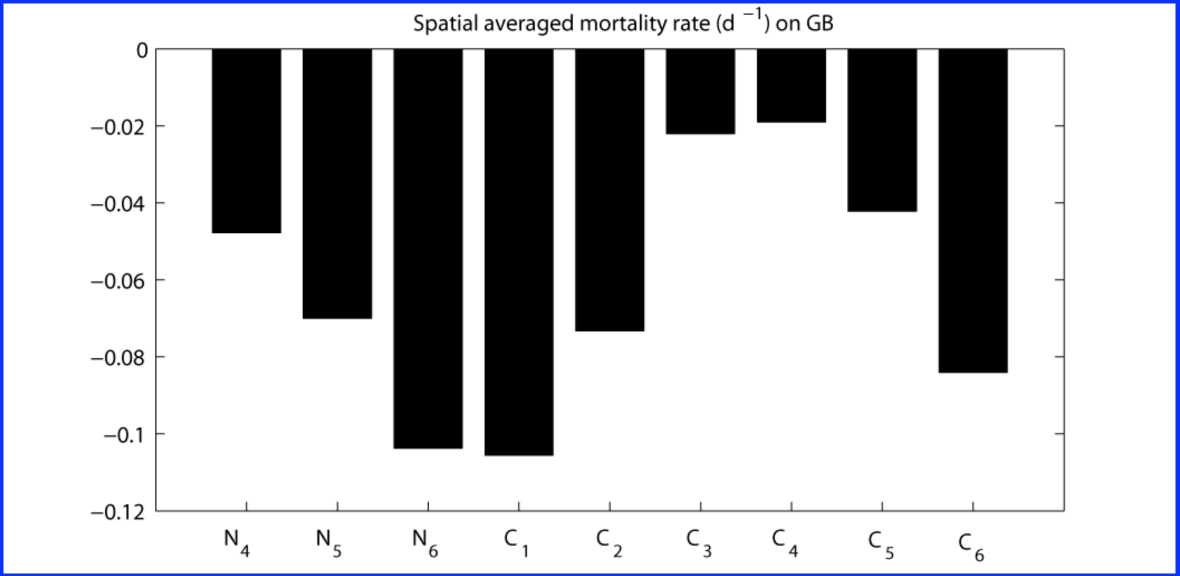
Bollens et al. specific rates of predation on *C. finmarchicus* and *Pseudocalanus* spp. copepodites based on observed predator abundance and feeding rates

🟦 Clytia
🟧 Herring
🟥 Sagitta
🟪 Bolinopsis
🟩 Themisto



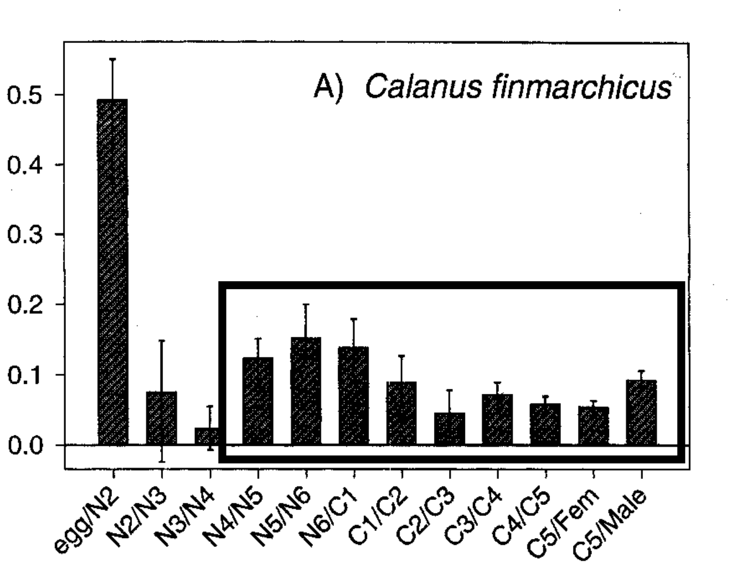
http://userwww.sfsu.edu/~bioocean/research/gbpredation/gbpredation1.html

# January-June average mortality rate

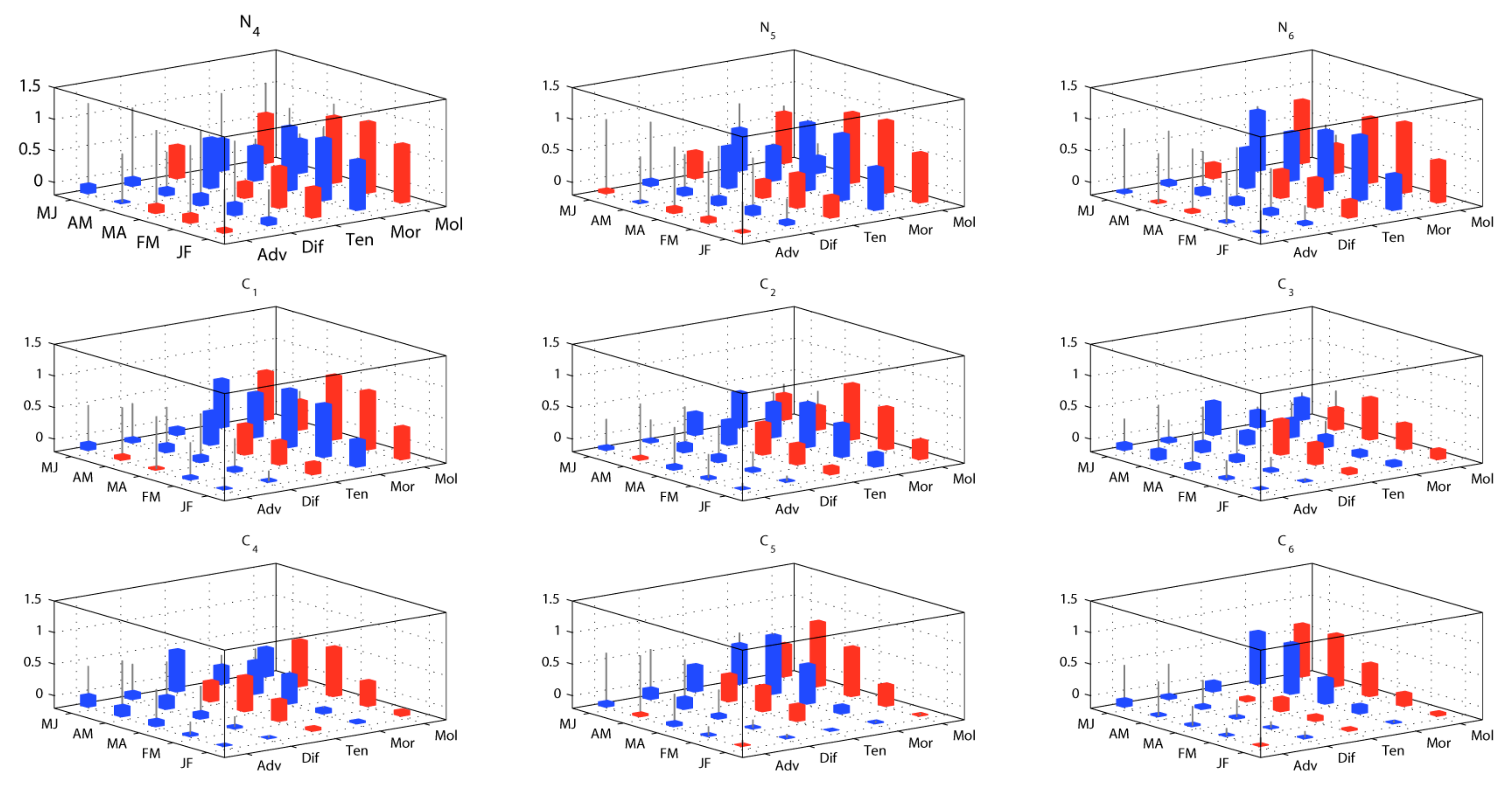


This study

Ohman et al. 2002
Vertical life table



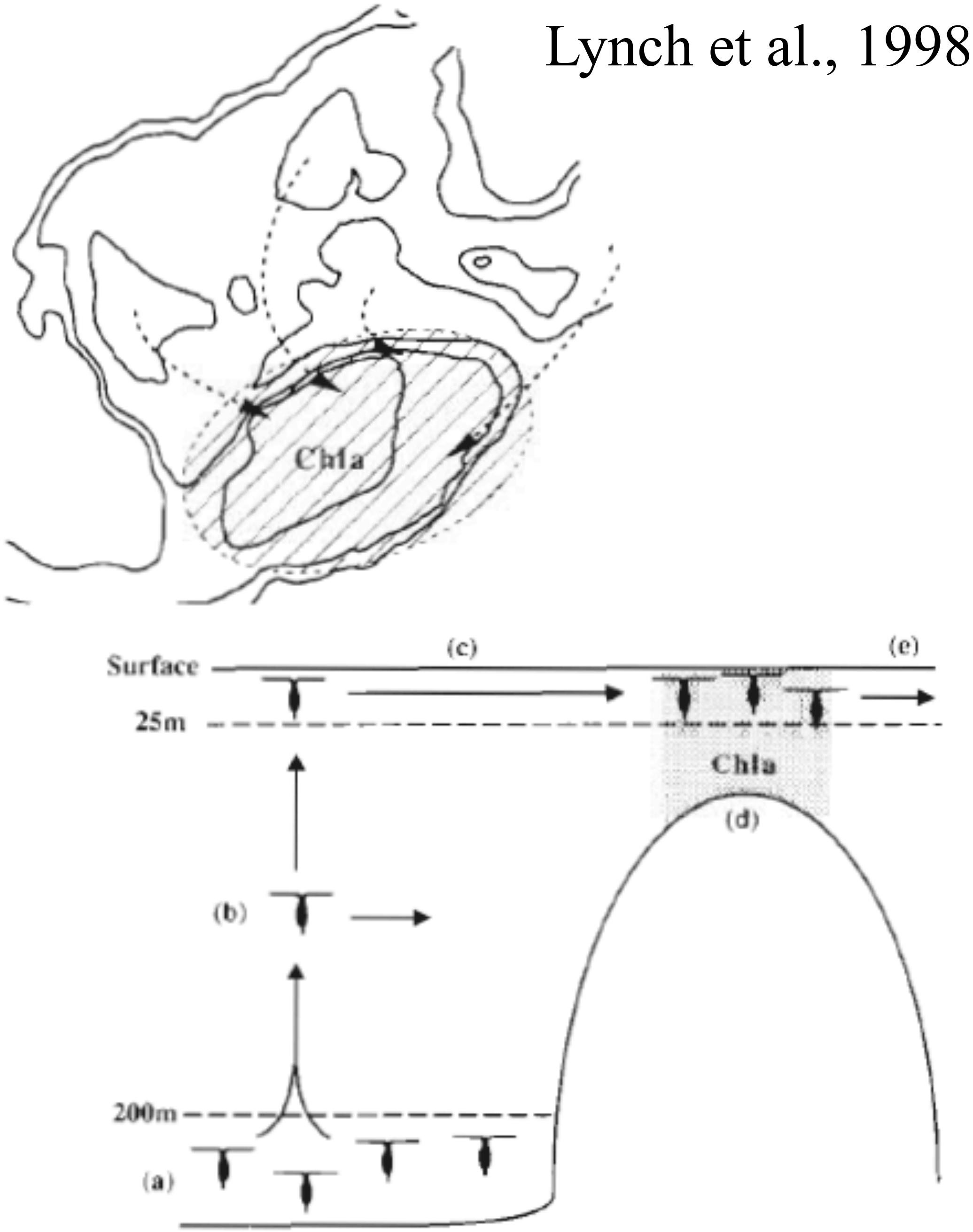
# Term-by-term analysis



Transport terms: large magnitude, but net effect is small

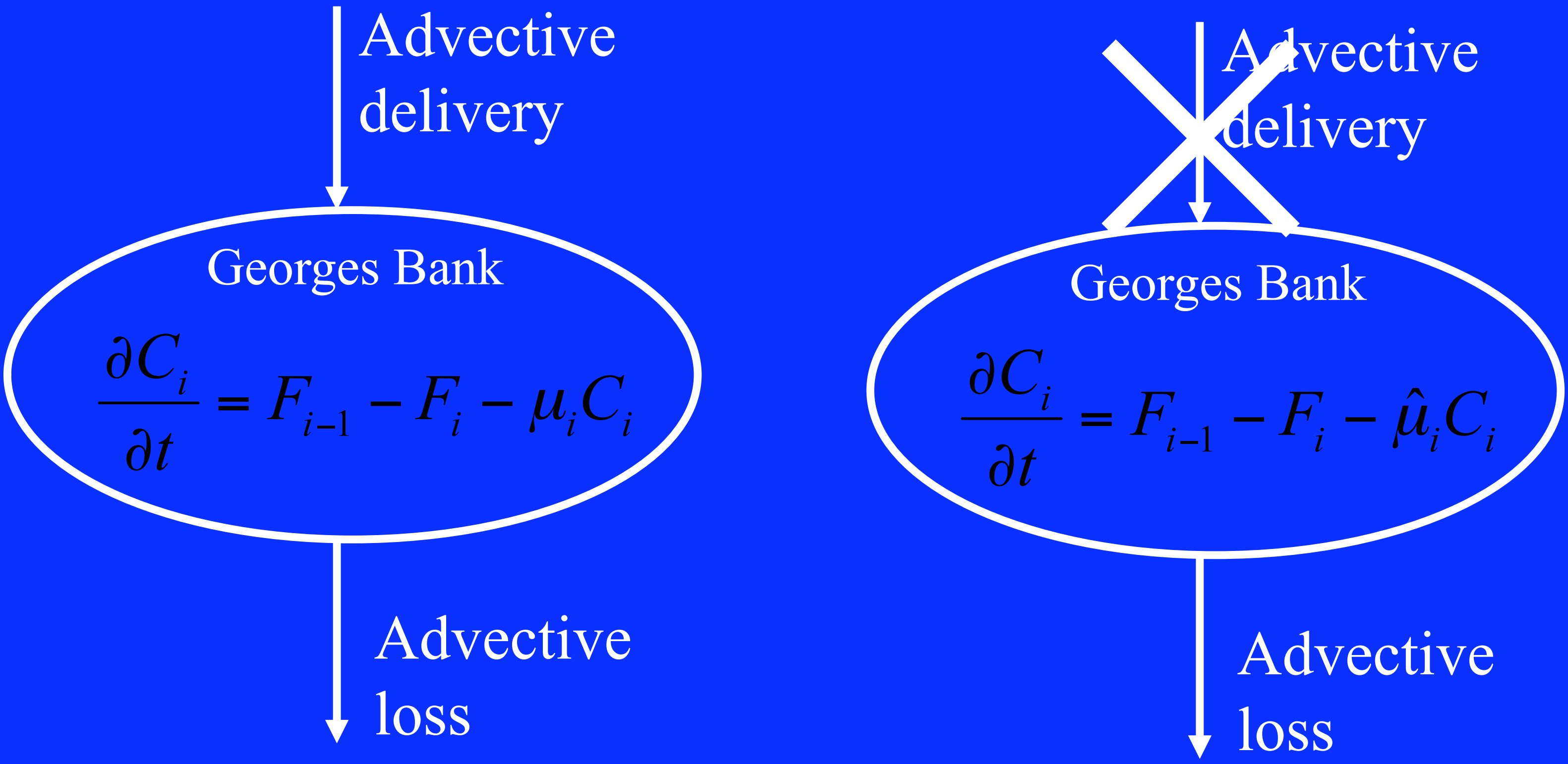
Primary balance: tendency/molting/mortality

# A prior model of *C. fin* in the region



Lynch et al., 1998

# A numerical experiment: turn off the upstream sources of *C. finmarchicus* to GB



Advective delivery

Georges Bank

$$\frac{\partial C_i}{\partial t} = F_{i-1} - F_i - \mu_i C_i$$

Advective loss

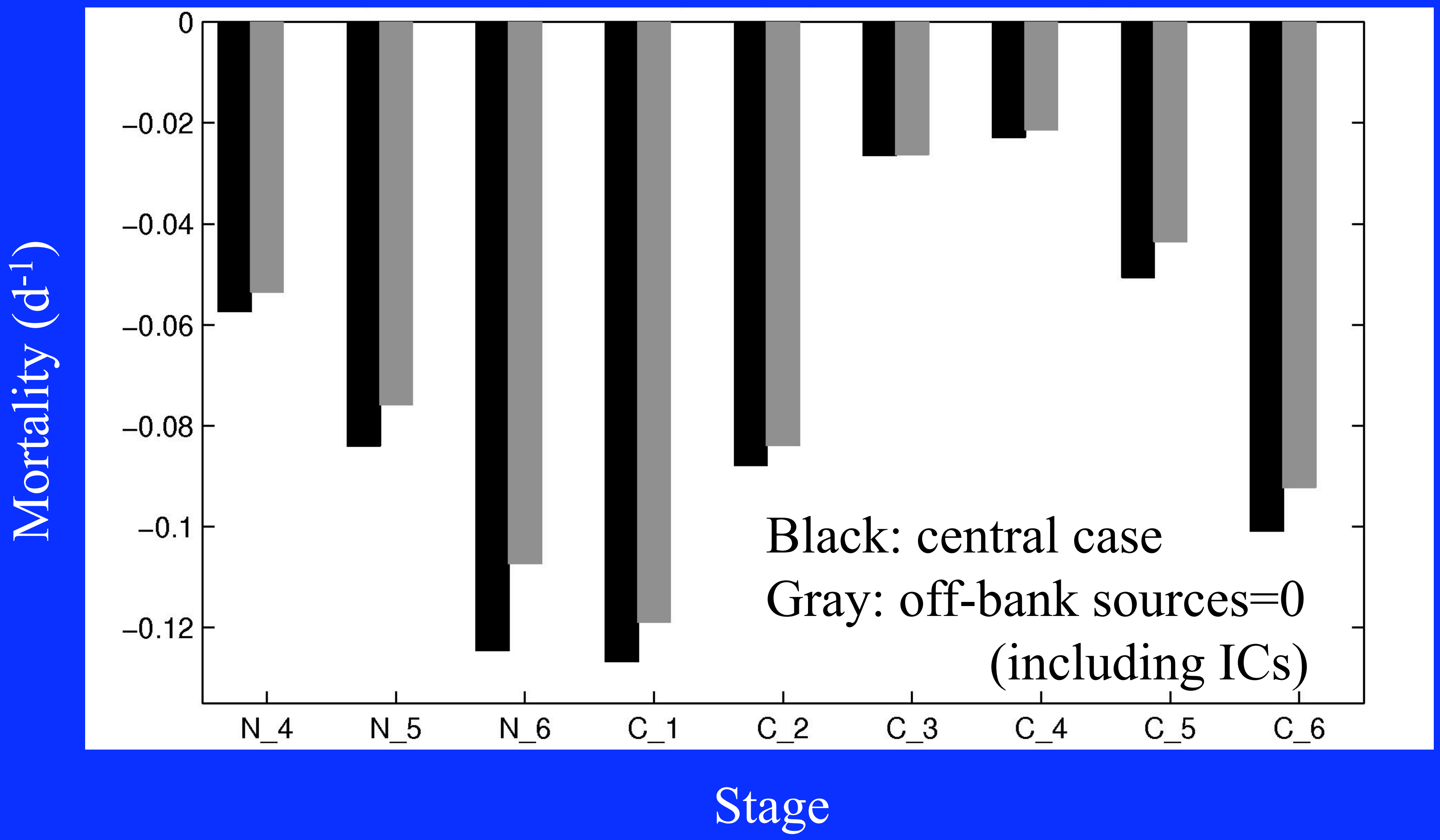
~~Advective delivery~~

Georges Bank

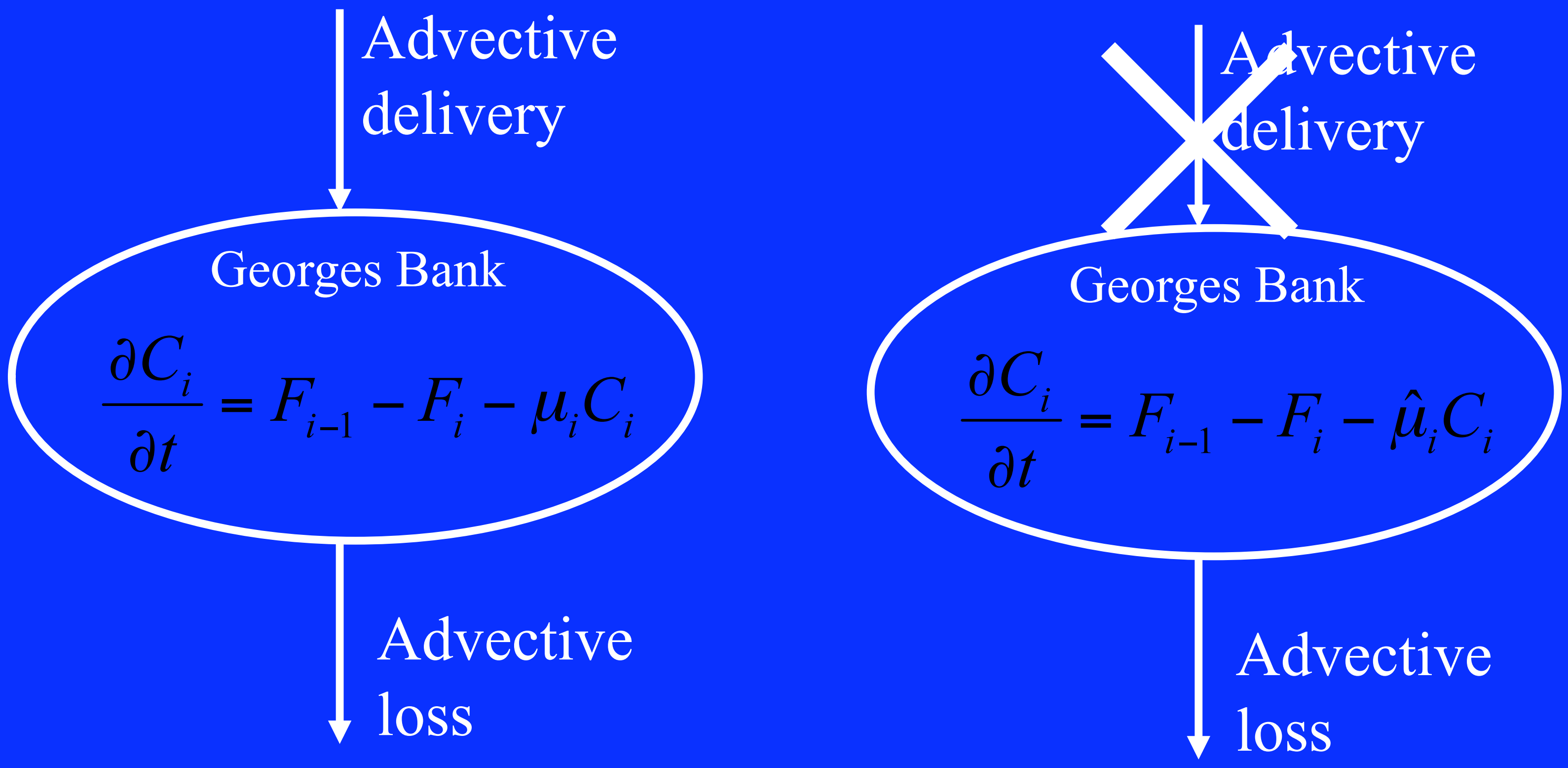
$$\frac{\partial C_i}{\partial t} = F_{i-1} - F_i - \hat{\mu}_i C_i$$

Advective loss

# Spatially averaged mortality rate



# Biological control of the vernal population increase of *C. finmarchicus* on Georges Bank



Advective delivery

Georges Bank

$$\frac{\partial C_i}{\partial t} = F_{i-1} - F_i - \mu_i C_i$$

Advective loss

Advective delivery

Georges Bank

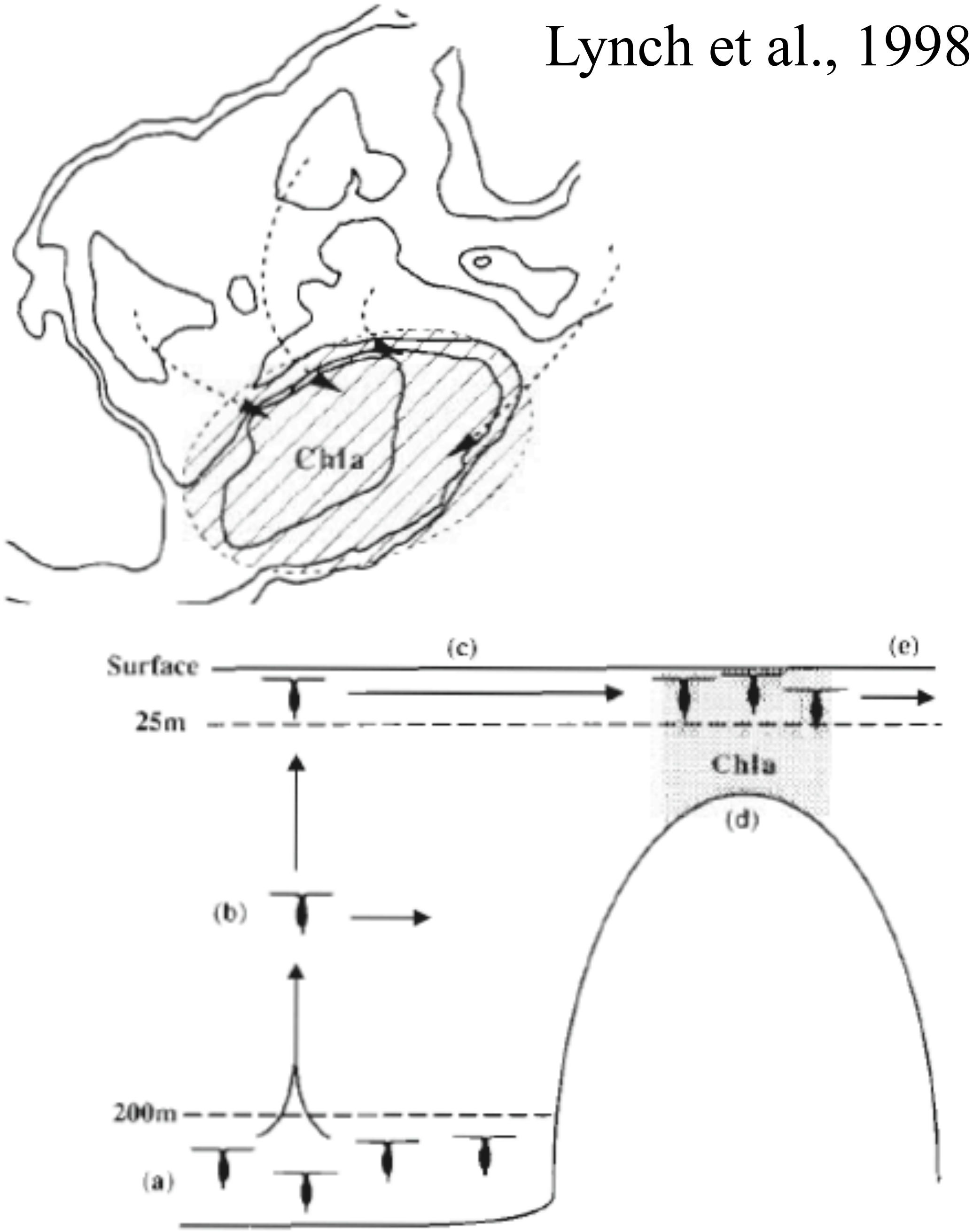
$$\frac{\partial C_i}{\partial t} = F_{i-1} - F_i - \hat{\mu}_i C_i$$

Advective loss

$\hat{\mu}_i$ only slightly smaller than $\mu_i$

Li et al., 2006

# Models as tools for hypothesis testing

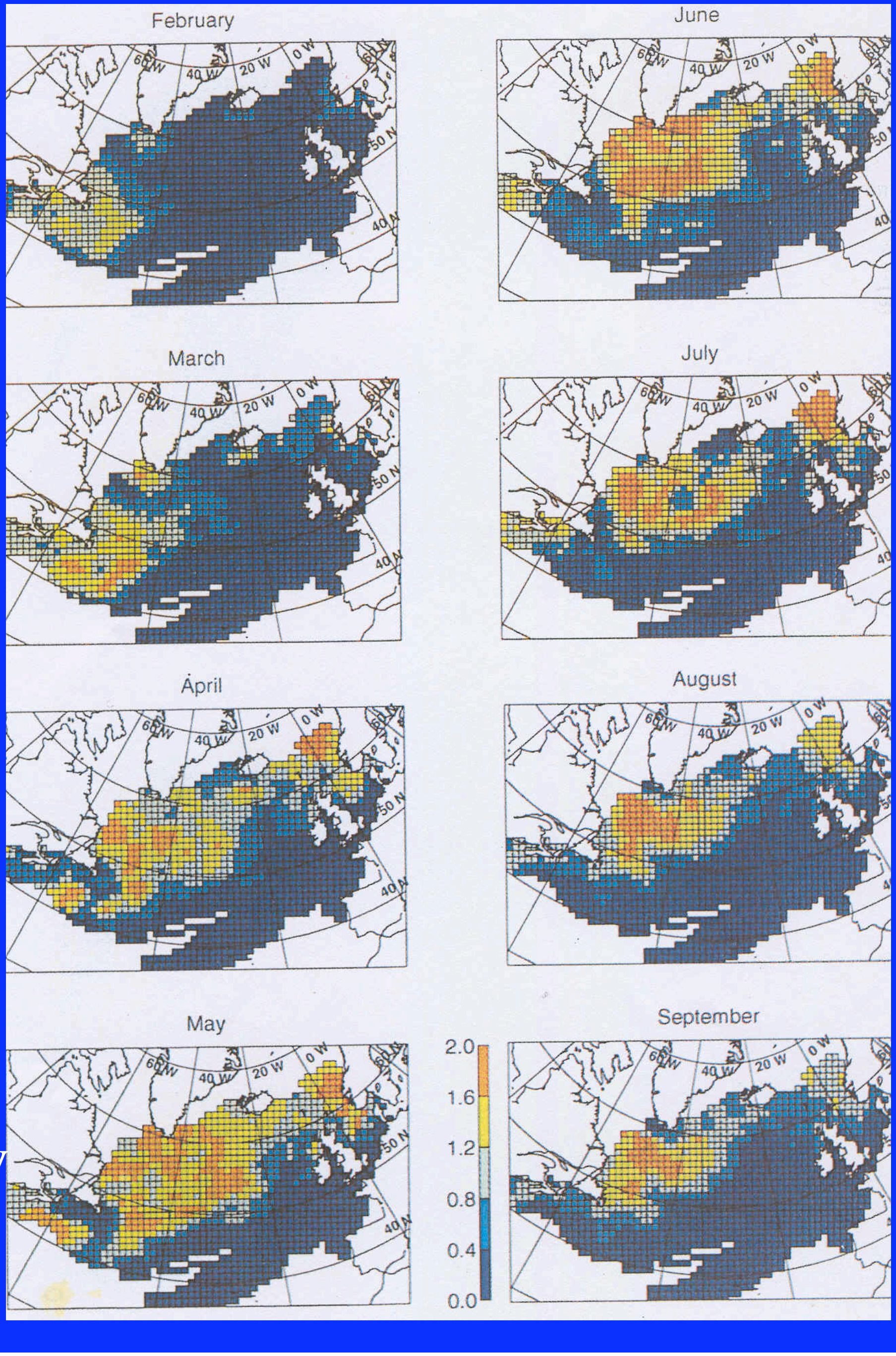


Lynch et al., 1998

# Climate forcing of *C. finmarchicus* populations of the North Atlantic

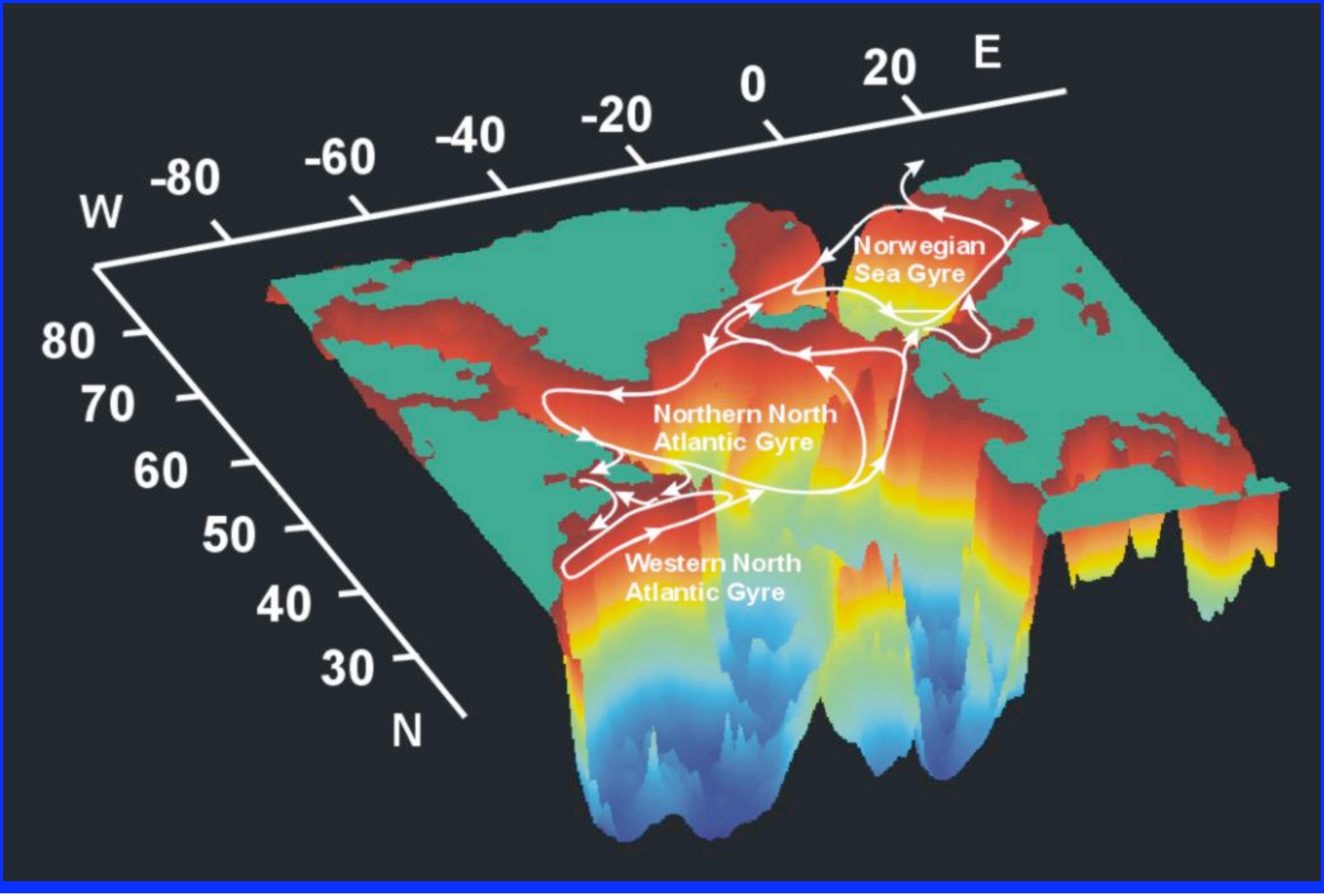
McGillicuddy, Bucklin, Haidvogel, Wiebe

*C. finmarchicus* climatology from the Continuous Plankton Recorder (Planque et al., 1997; recent update by G. Beaugrand)



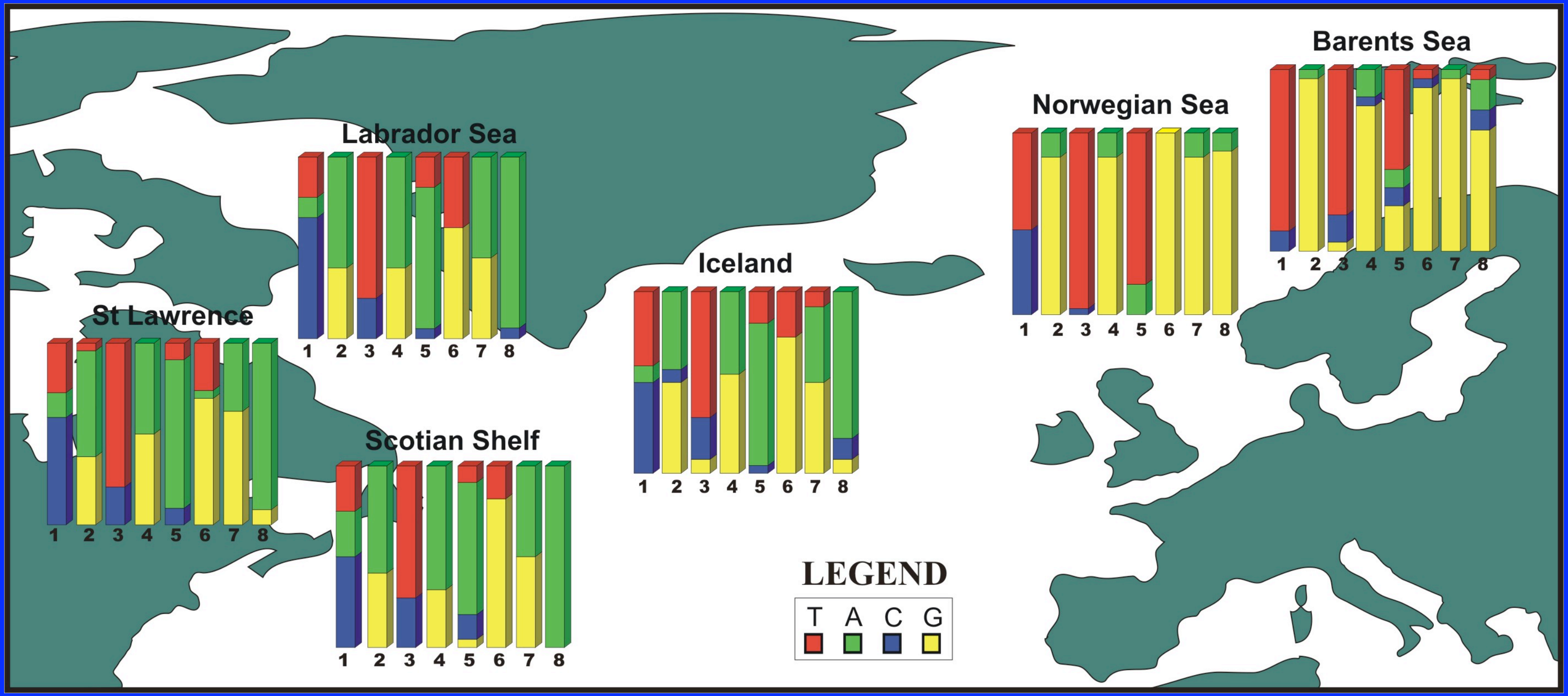
# The three-gyre hypothesis

Bucklin et al., 2000; Wiebe, 2001



# Genetic basis for the three-gyre hypothesis

Bucklin and Unal



Allele frequencies for eight SNPs in the gene encoding a heat shock protein (HSP-70) for six geographic populations of *C. finmarchicus*.

# Overall Objectives

- Inversions of the "mean state"
  - Climatological mean seasonal forcing
  - Diapause entry hypotheses: food, photoperiod
  - Diapause exit hypotheses: development, photoperiod
  - Control parameter: mortality (spatially variable, stage dependent
  - Skill assessment: cross-validation
- Use the genetic data to estimate the rate of population exchange between gyres, and compare with model predictions of same
- Investigate interannual to decadal variability
  - High-NAO state vs. low-NAO state
  - Hindcast 1950s-present

# Three models

1. Advection-diffusion

$$\frac{\partial C}{\partial t} + v \cdot \nabla C - \nabla \cdot (K \nabla C) = 0$$

2. Persistence

$$C(t_1 + \Delta t) = C(t_1)$$

3. Rudimentary biology: geographic source term

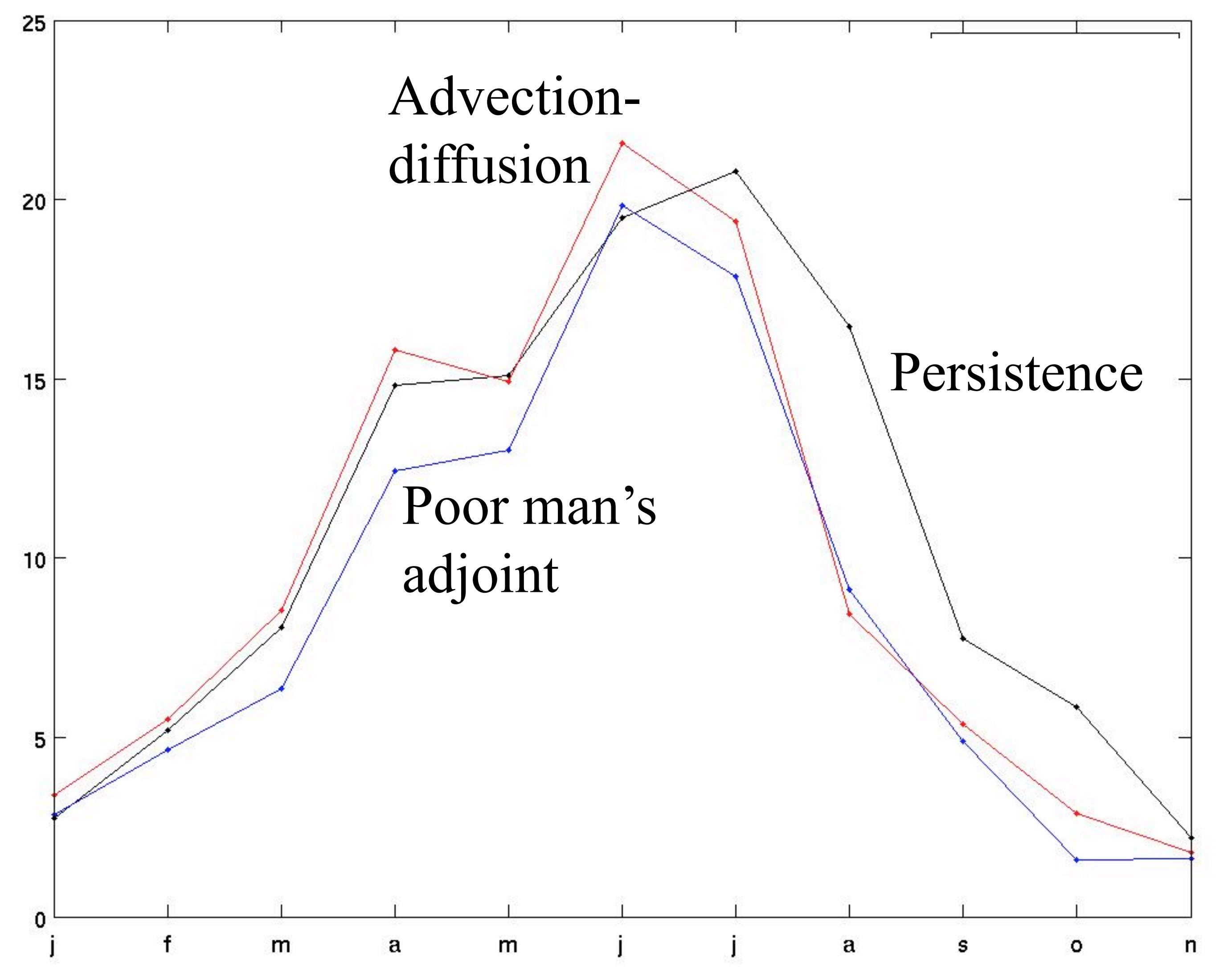
$$\frac{\partial C}{\partial t} + v \cdot \nabla C - \nabla \cdot (K \nabla C) = R(x, y) \qquad C = \max(C, 0)$$

Poor man’s adjoint:

$$R(x, y) = \frac{C_{obs}(t + \Delta t) - C_{obs}(t)}{\Delta t}$$

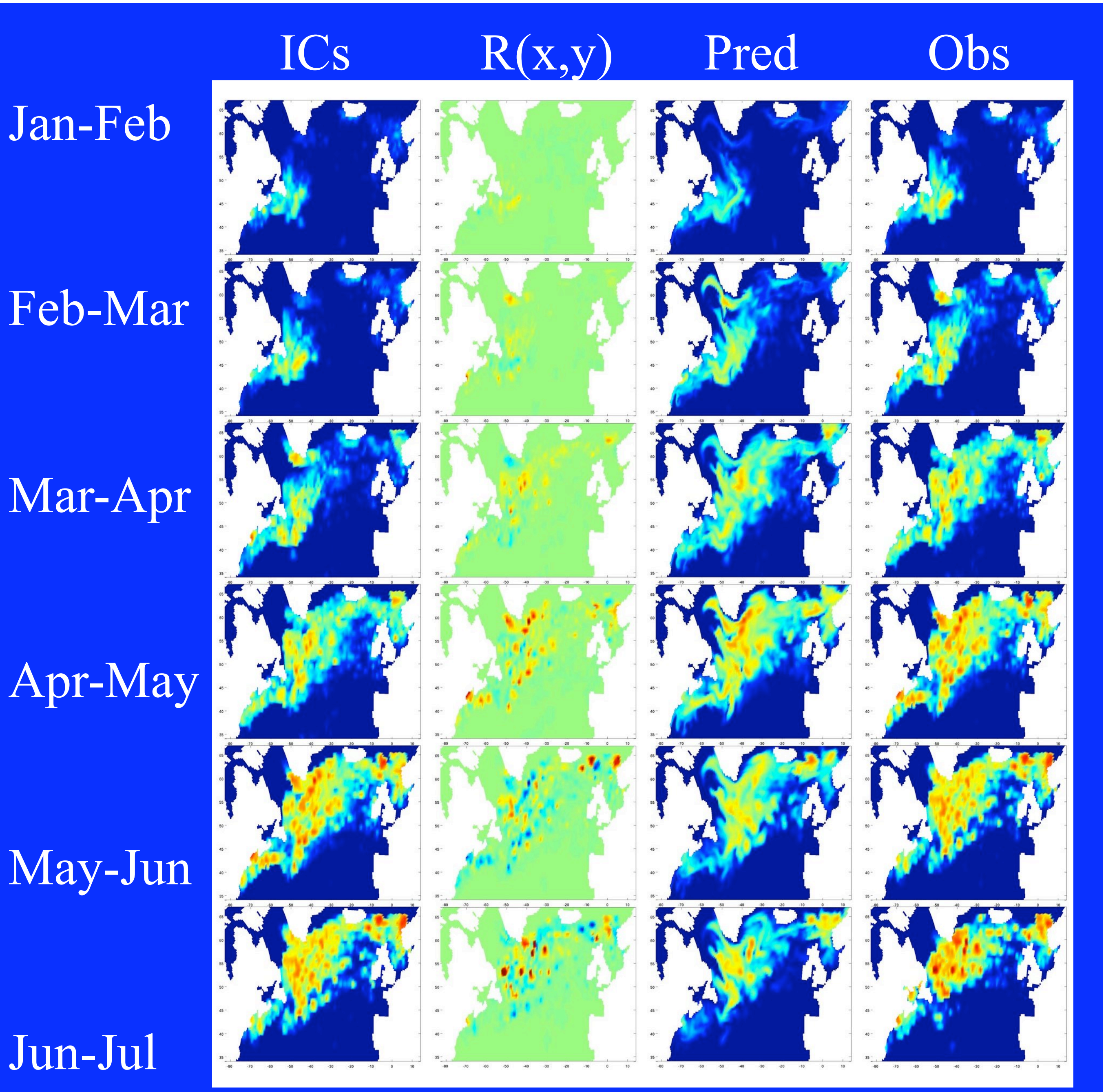
# Skill

RMS
(Pred – Obs)

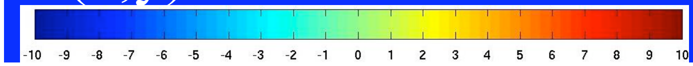


Time

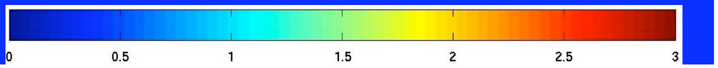
# Poor man's adjoint: Jan-Jun



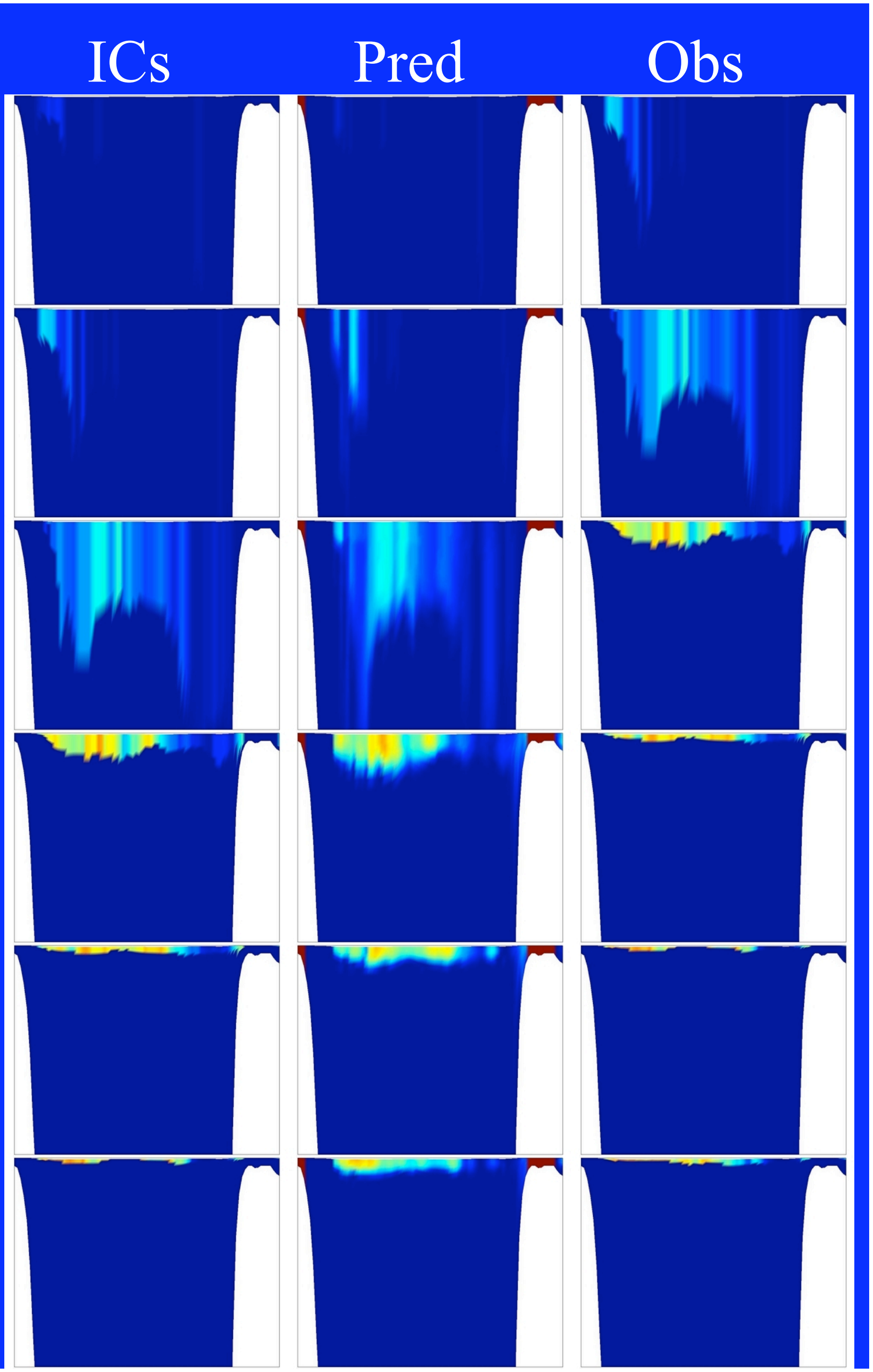
R(x,y): # $m^{-3}$ $d^{-1}$



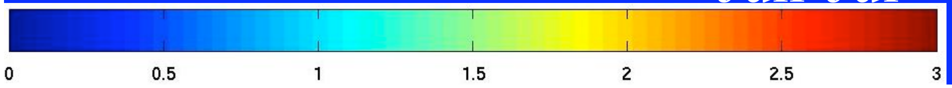
$\log_{10}(C+1)$



# Vertical distribution along 55°N: Jan-Jun



log$_{10}$(C+1)



# Vertical distribution: issues

Assume uniform distribution of *C. finmarchicus* in mixed layer, zero below

MLD deepening

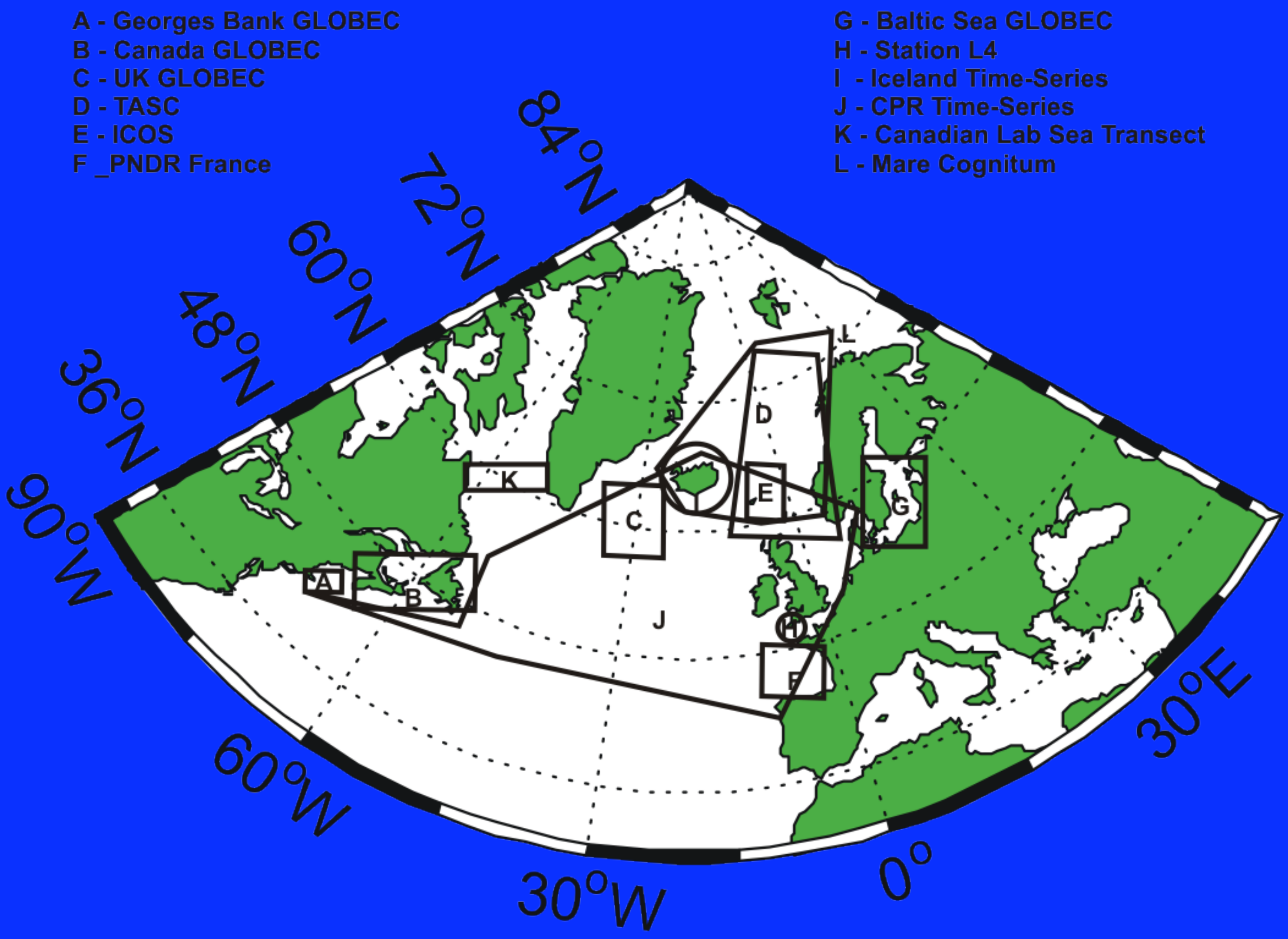
- dilution by entrainment of water with low concentration of *C. finmarchicus*

MLD shoaling

- detrainment of *C. finmarchicus* below the mixed layer

# GLOBEC study sites in the North Atlantic

Wiebe et al., 2007



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