

# **Arctic Ocean primary productivity and climate change**

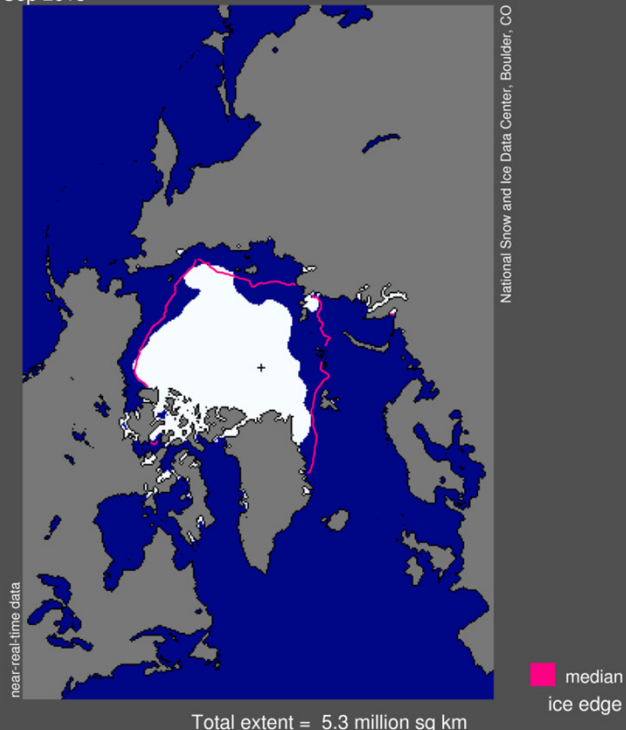
**Patricia Matrai**

**Bigelow Laboratory for Ocean Sciences**

**with help from many colleagues!**

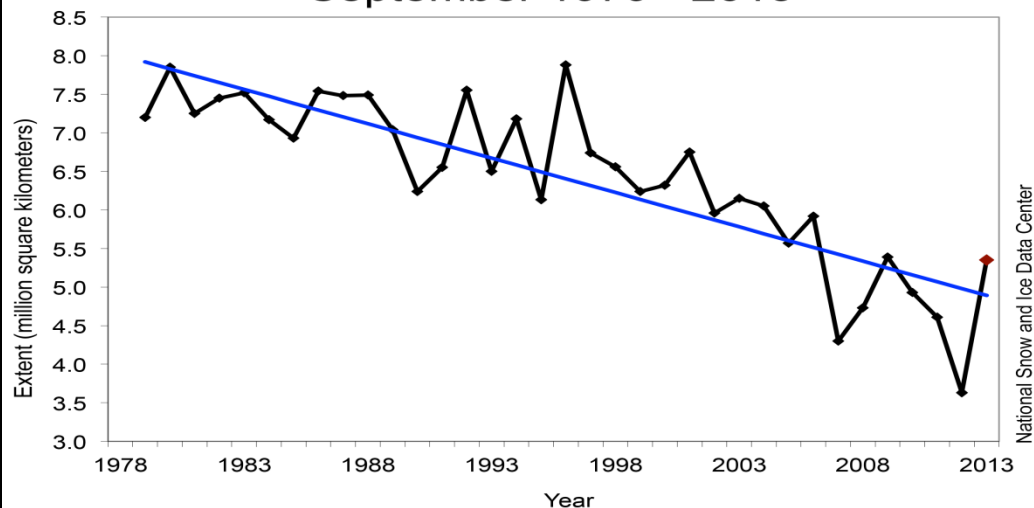


Sea Ice Extent  
Sep 2013



# Arctic sea ice loss

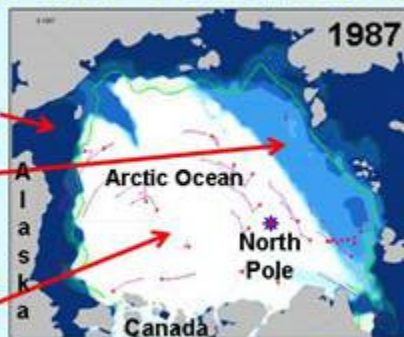
Average Monthly Arctic Sea Ice Extent  
September 1979 - 2013



## Age and Thickness of Sea Ice has Decreased

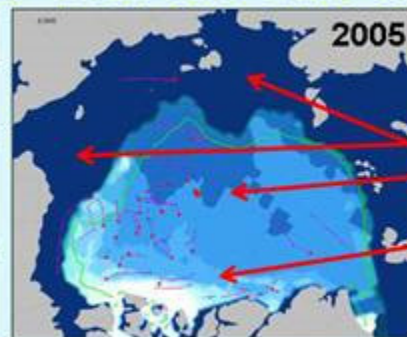
1980's:

- Less open water (OW)
- Less younger, thinner ice
- More older, thicker ice



2000's  
to PRESENT:

- More open water
- More younger, thinner ice
- Less older, thicker ice



Age:OW 0 1 2 3 4 5 6 8 10+ Years

# Snow cover loss



Ice melt and surface warming result in stratification that prevents vertical mixing

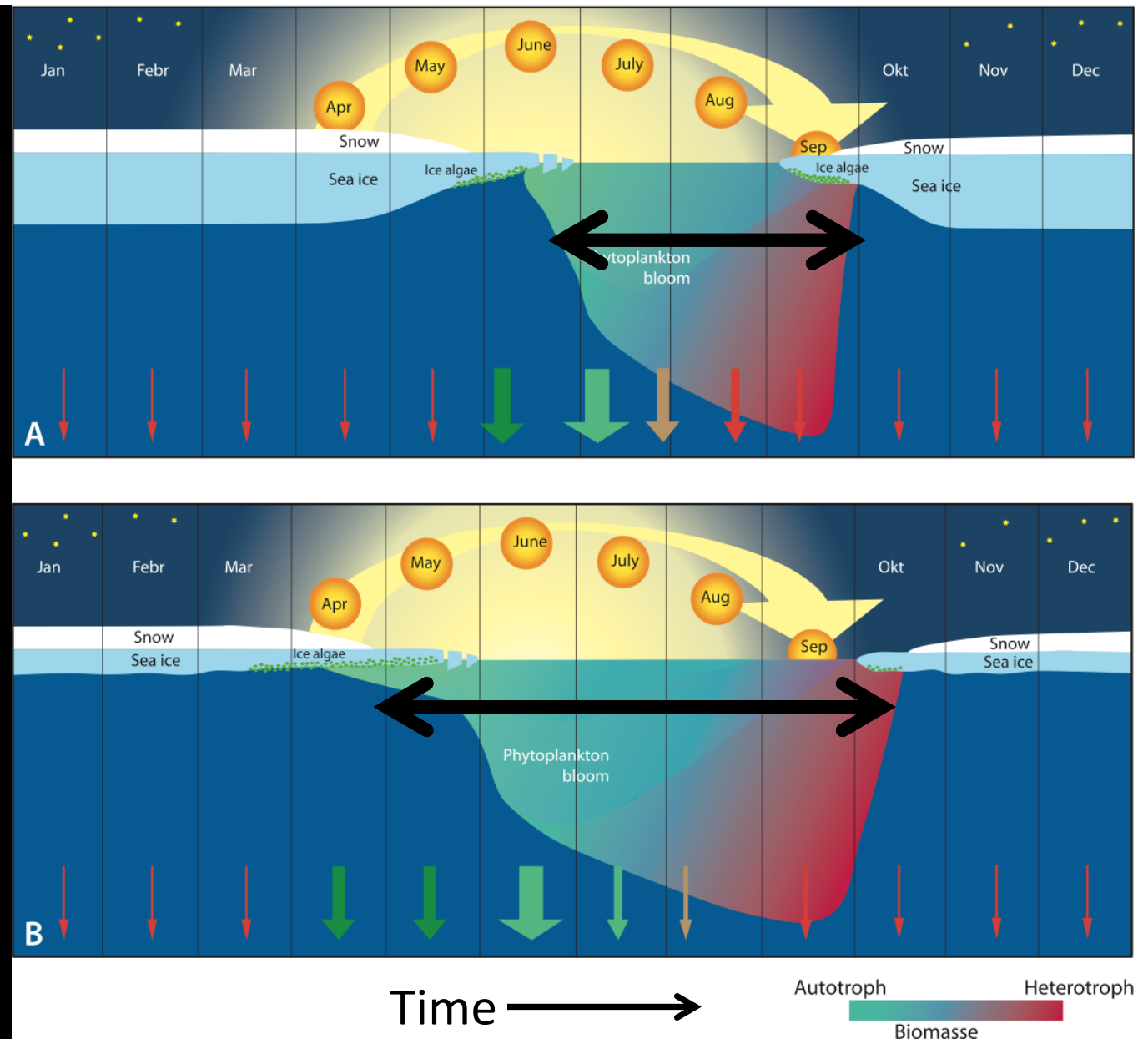
Low (?) nutrient supply to surface and thus low harvestable productivity

Low (?) light supply through surface coastal waters (snow + ice, CDOM, suspended solids)



Today's extreme  
seasonal  
variation  
disappears

Sub-ice blooms  
increase?



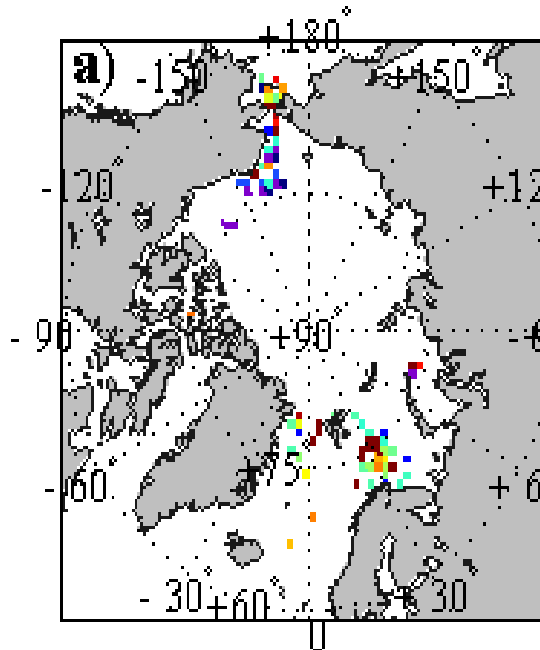
Where is Arctic Primary Production now?

# Integrated Annual Net Primary Production (NPP)

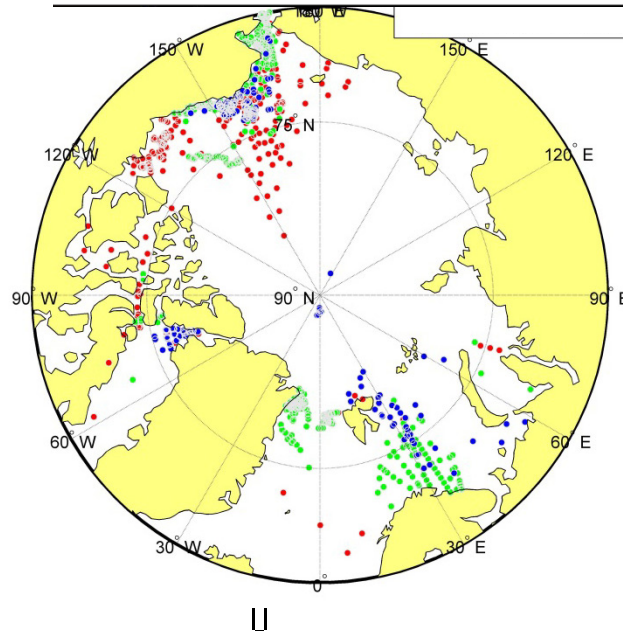
(1954-2007 field data)

(1998-2007 satellite data)

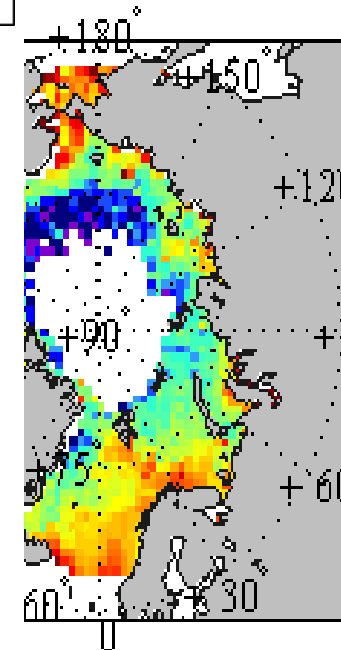
- New Data: 2003-2011
- ARCSS-PP: 1959-1996
- ARCSS-PP: 1997-2007



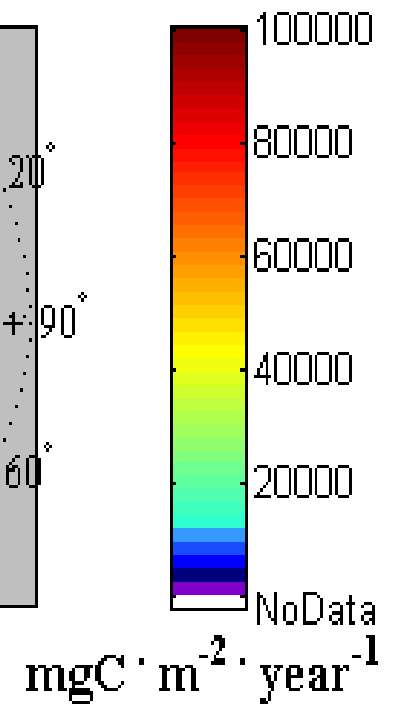
Observed PP



Observed Chl-PP



Satellite PP



Algorithm-estimated NPP based on:

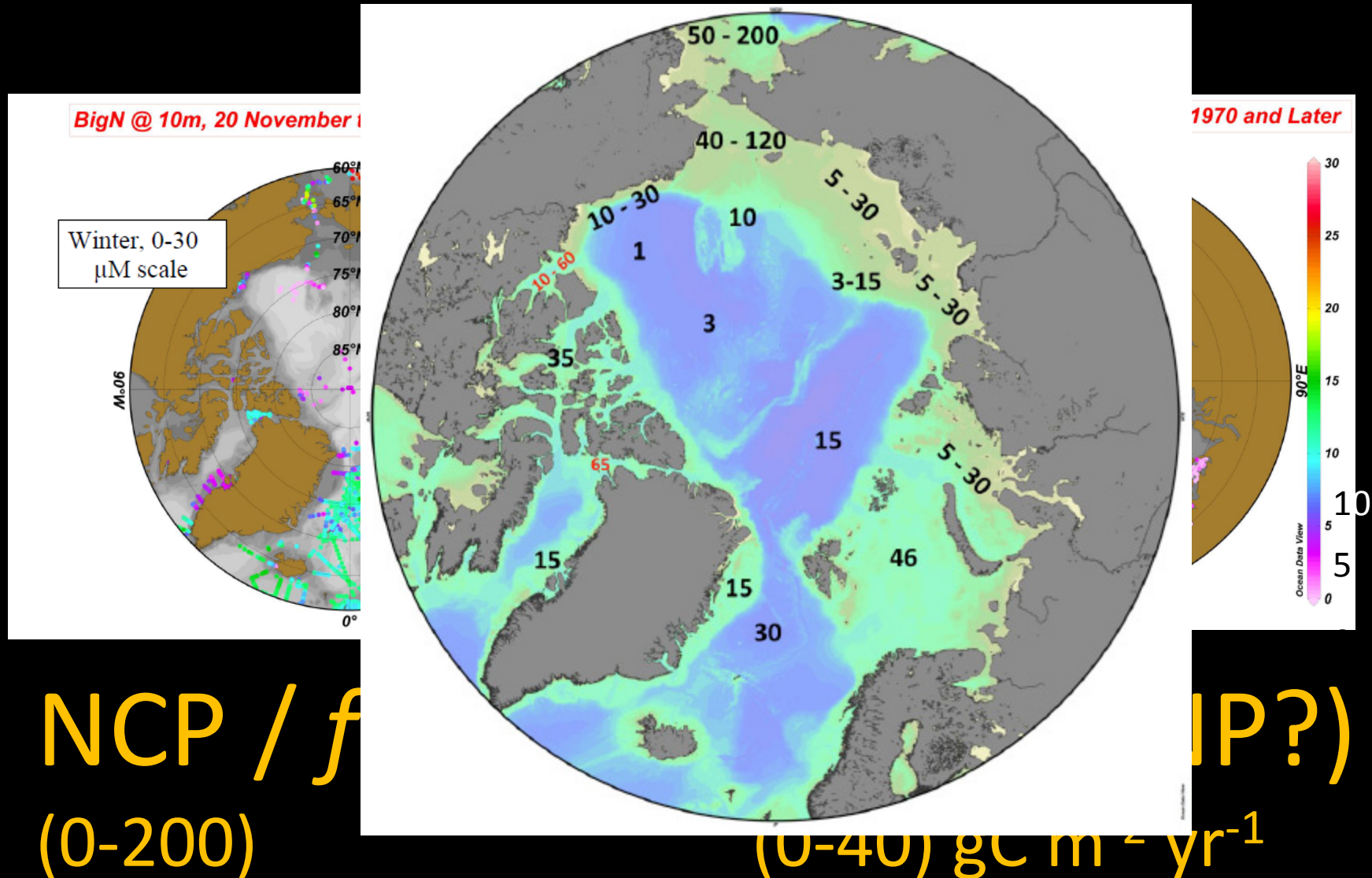
Field Chl

SeaWiFS Chl

**0-100  $\text{gC m}^{-2} \text{yr}^{-1}$**

Hill, Matrai et al. 2013

# Net Community Production



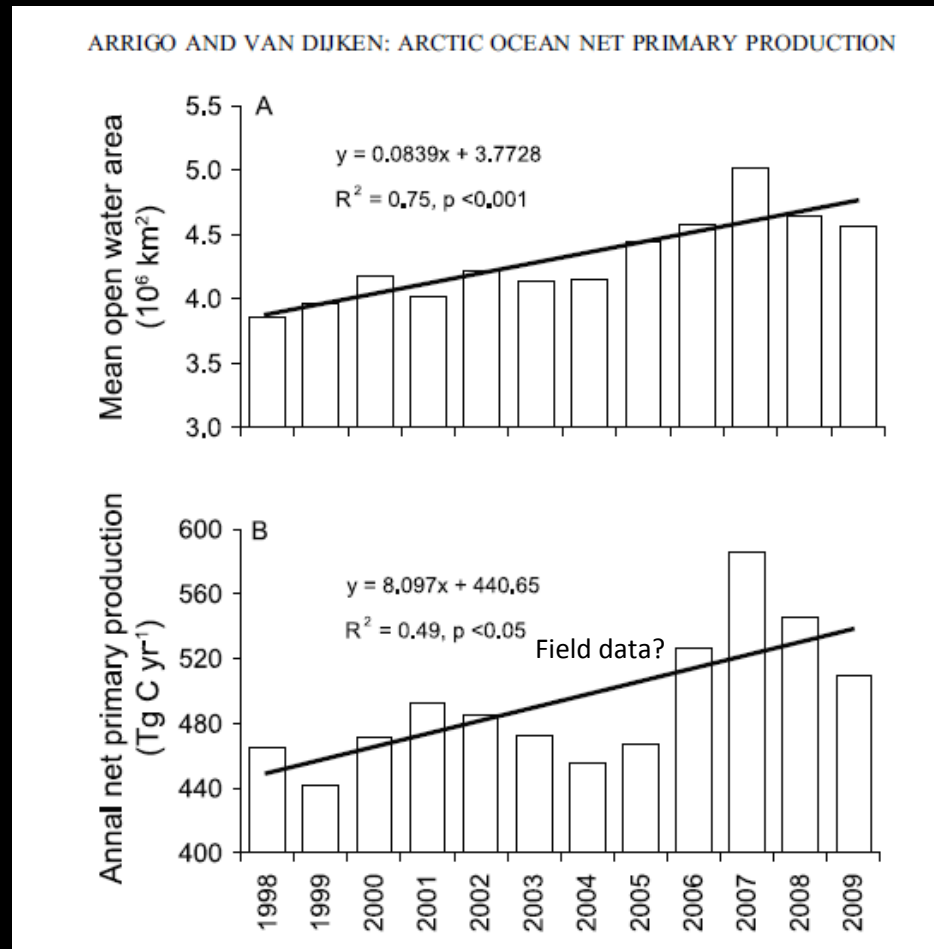
Codispoti, Matrai et al. 2013

# A biological model applied regionally... using ocean color and sea ice satellite data

## Pan-arctic decadal trend

Open  
water  
↓  
Light!

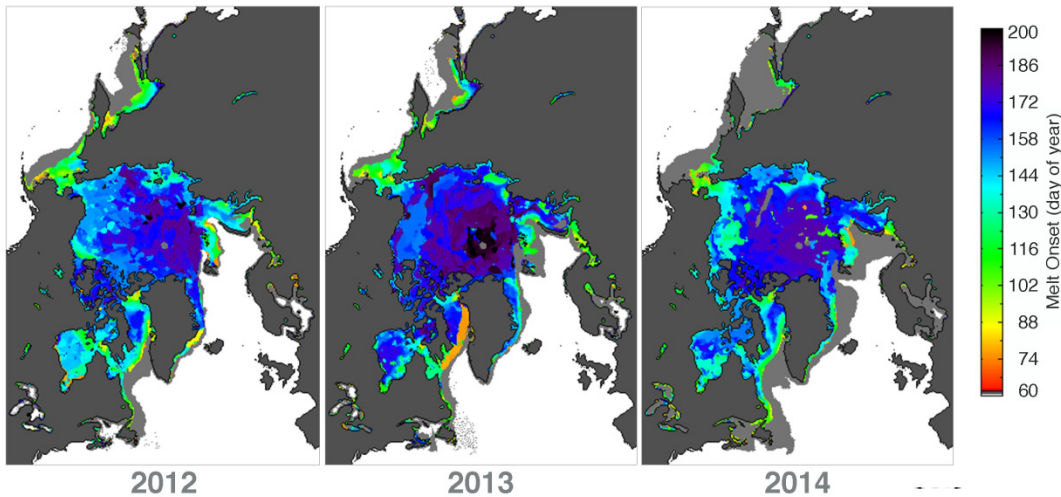
Annual  
net PP





## Melt onset dates

NSIDC

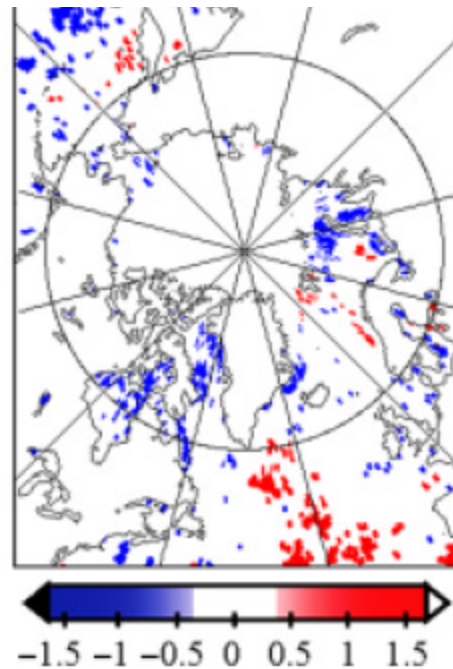


Is the light field changing?  
We have proxies...

Kahru et al. 2011

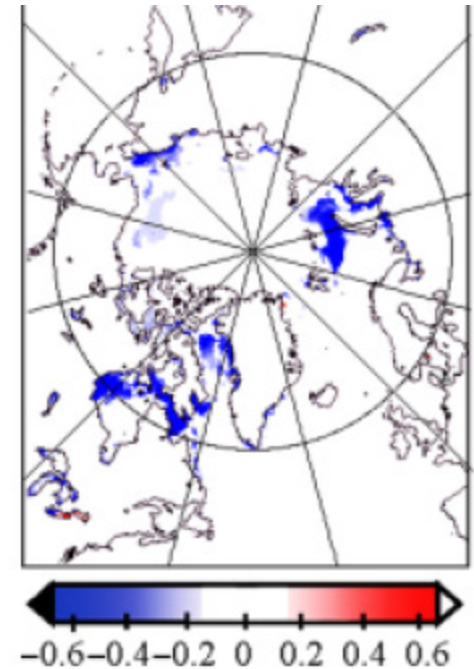
With respect to satellite median for:

Change in timing of annual  
Chl max



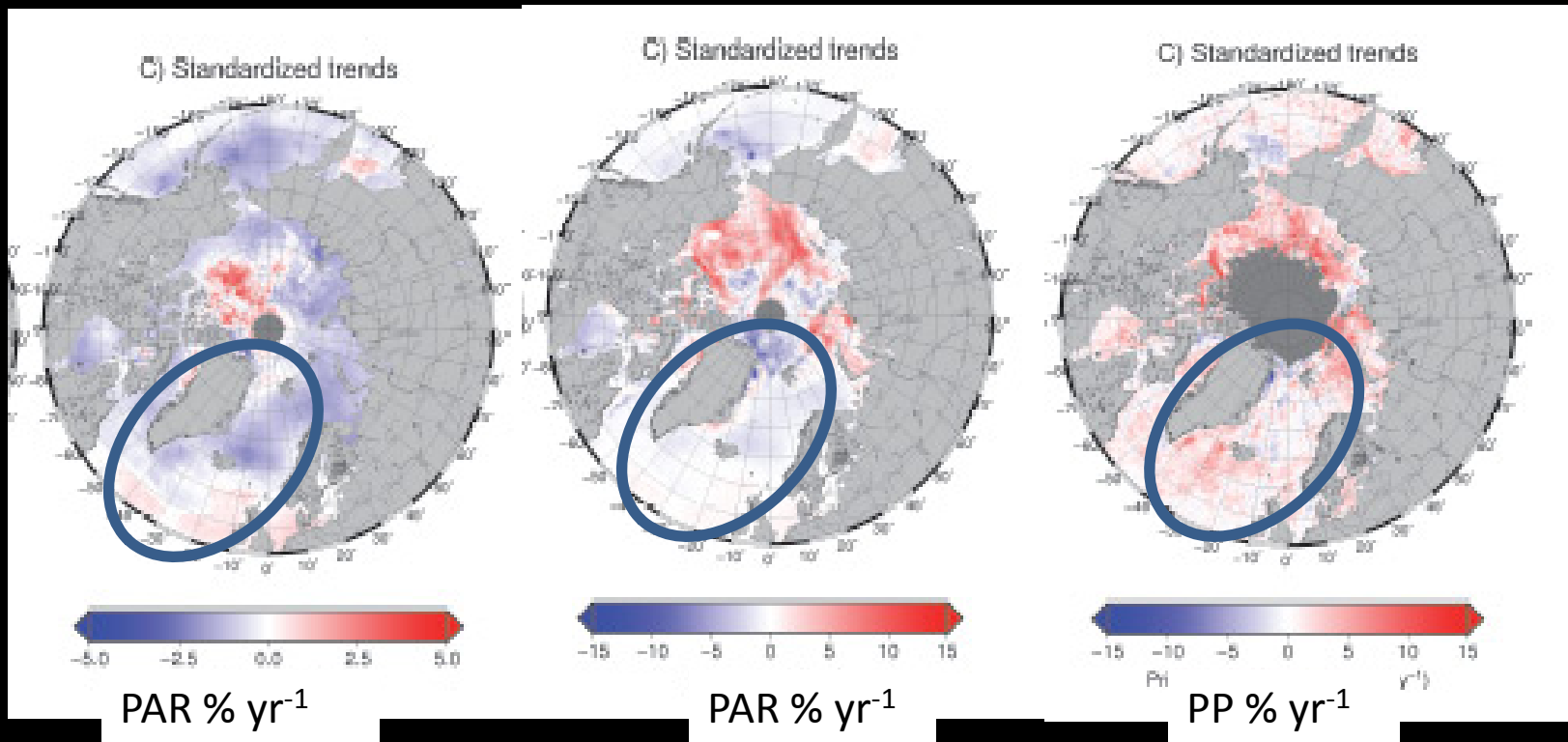
1997-2009 Chl

Change in June ice  
concentration



1979-2007 ice fraction change  $\text{yr}^{-1}$

# Clouds and light (satellite data: 1998-2009)



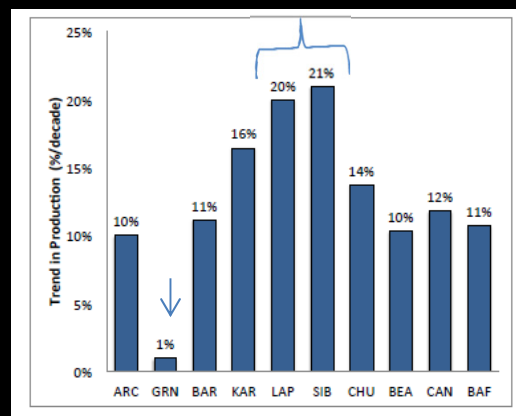
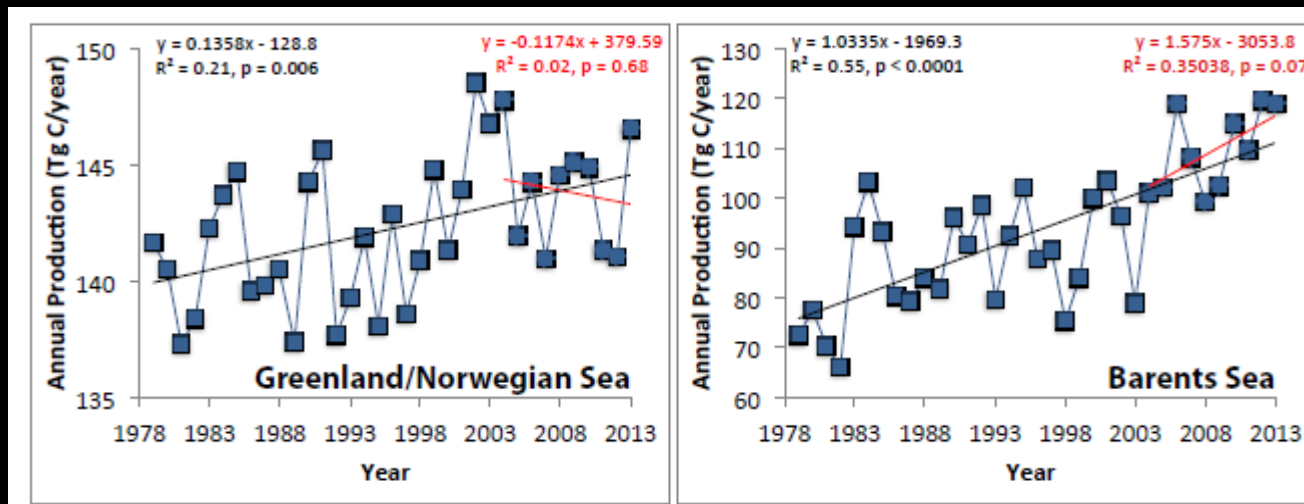
+ clouds =  
Light **decrease**  
(8-20%)  
**ABOVE**  
sea (ice) surface

+ clouds =  
Light **change**  
(+3 to -3%)  
**JUST BELOW**  
sea (ice?) surface

PP increase estimated below  
sea (ice?) surface  
  
- GIN/Barents Sea  
~21-26% reduction

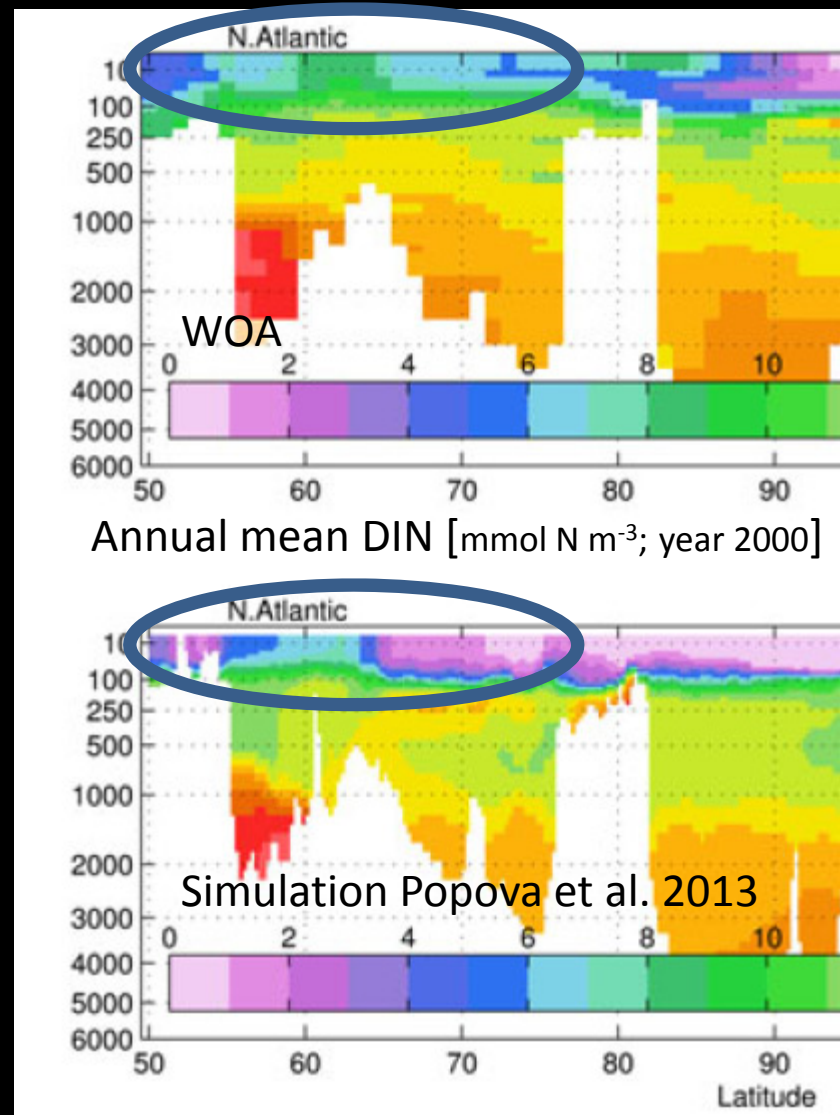
A biological model applied regionally...  
using ocean color and sea ice satellite data

## Variable regional decadal trends



# Nutrients? Nutrients!!

- That's a whole 'nother talk!

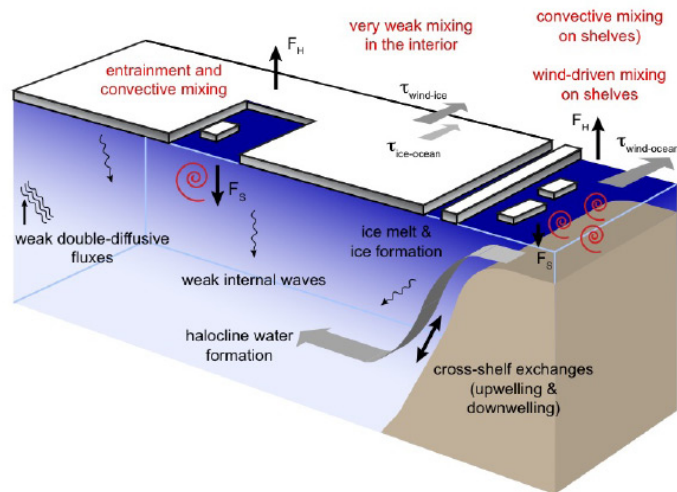




Wind! => wind-driven turbulence

Upwelling => nutrients

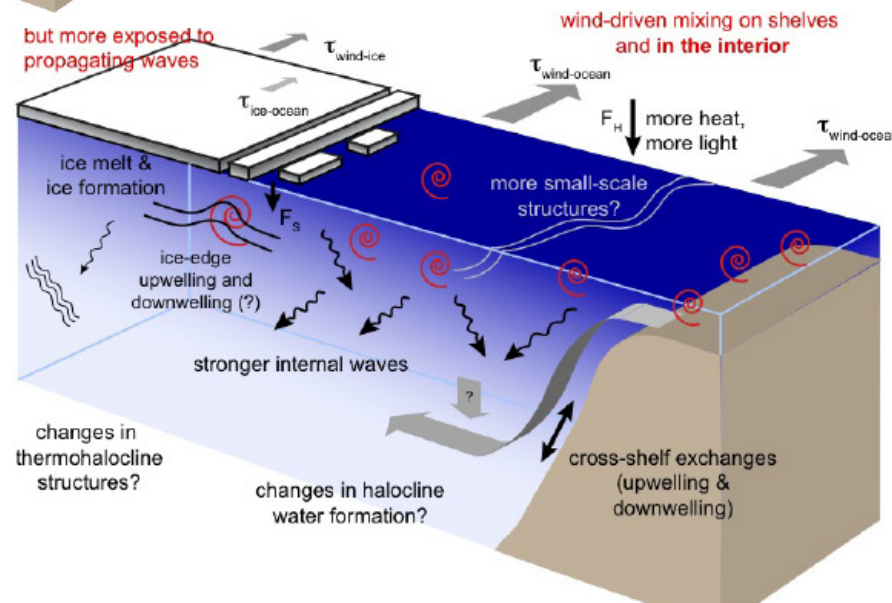
Eddies => mixing, +/- nutrients?, nitrate consumption



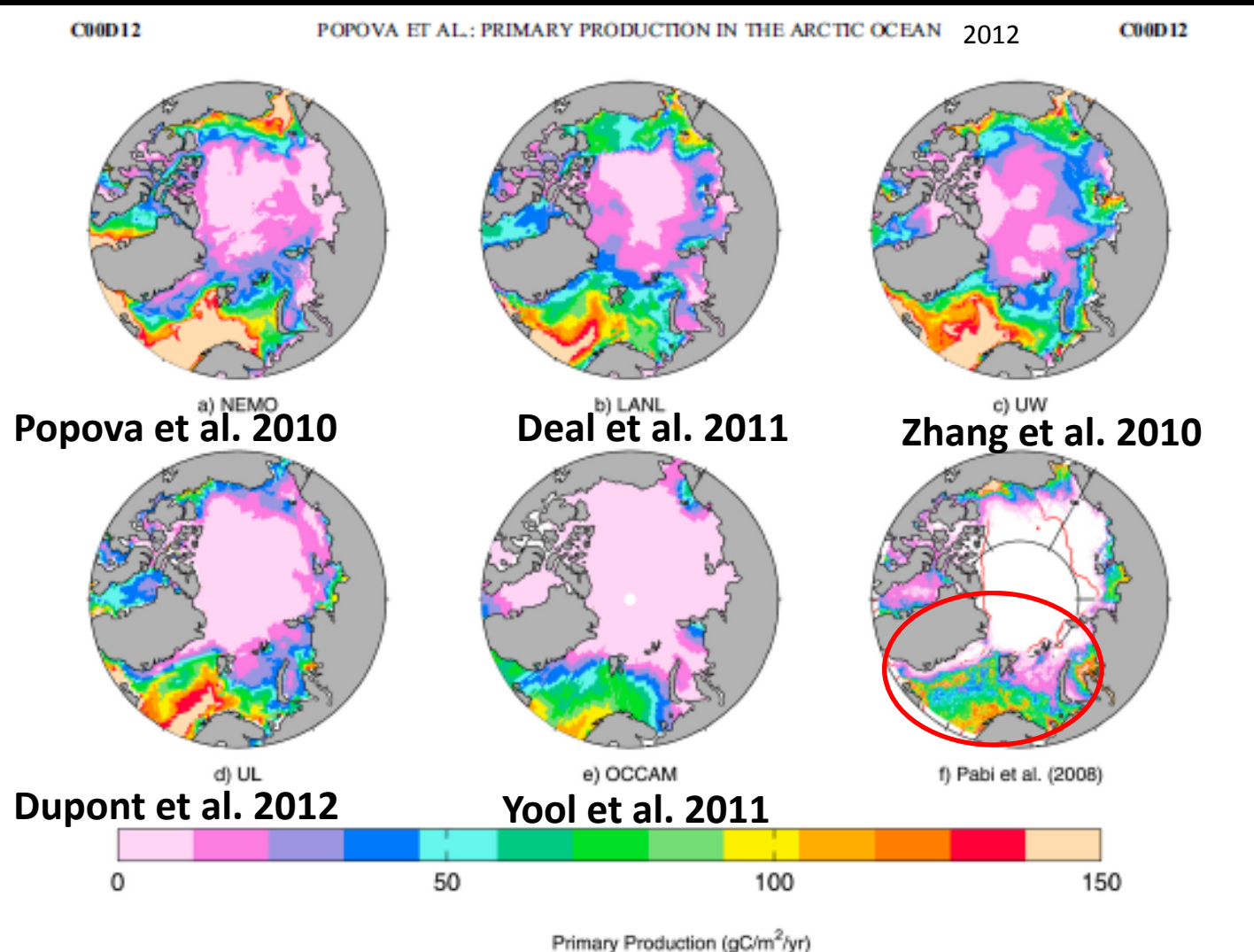
With ice

Mahadevan, Woodgate, Rainville,  
Wang, Matrai, in prep

Without ice

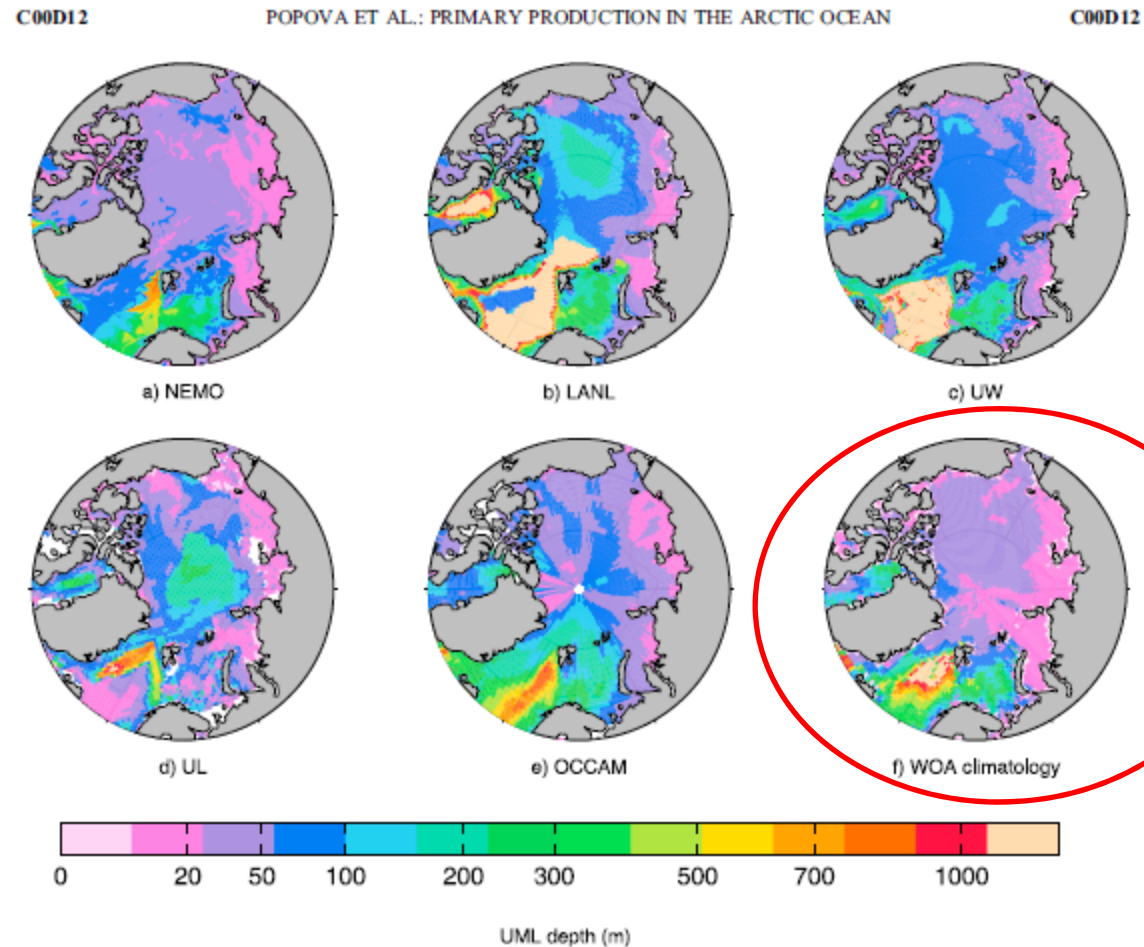


# Mean annual water column PP [ $\text{gC m}^{-2} \text{yr}^{-1}$ ] by 5 models and a satellite-derived estimate



**Figure 1.** Mean annual water column primary production (in  $\text{g C m}^{-2} \text{yr}^{-1}$ ) for (a) NEMO, (b) LANL, (c) UW, (d) UL, (e) OCCAM, and (f) satellite-derived estimates of Pabi et al. [2008].

## Maximum depth of upper mixed layer → Nutrients!



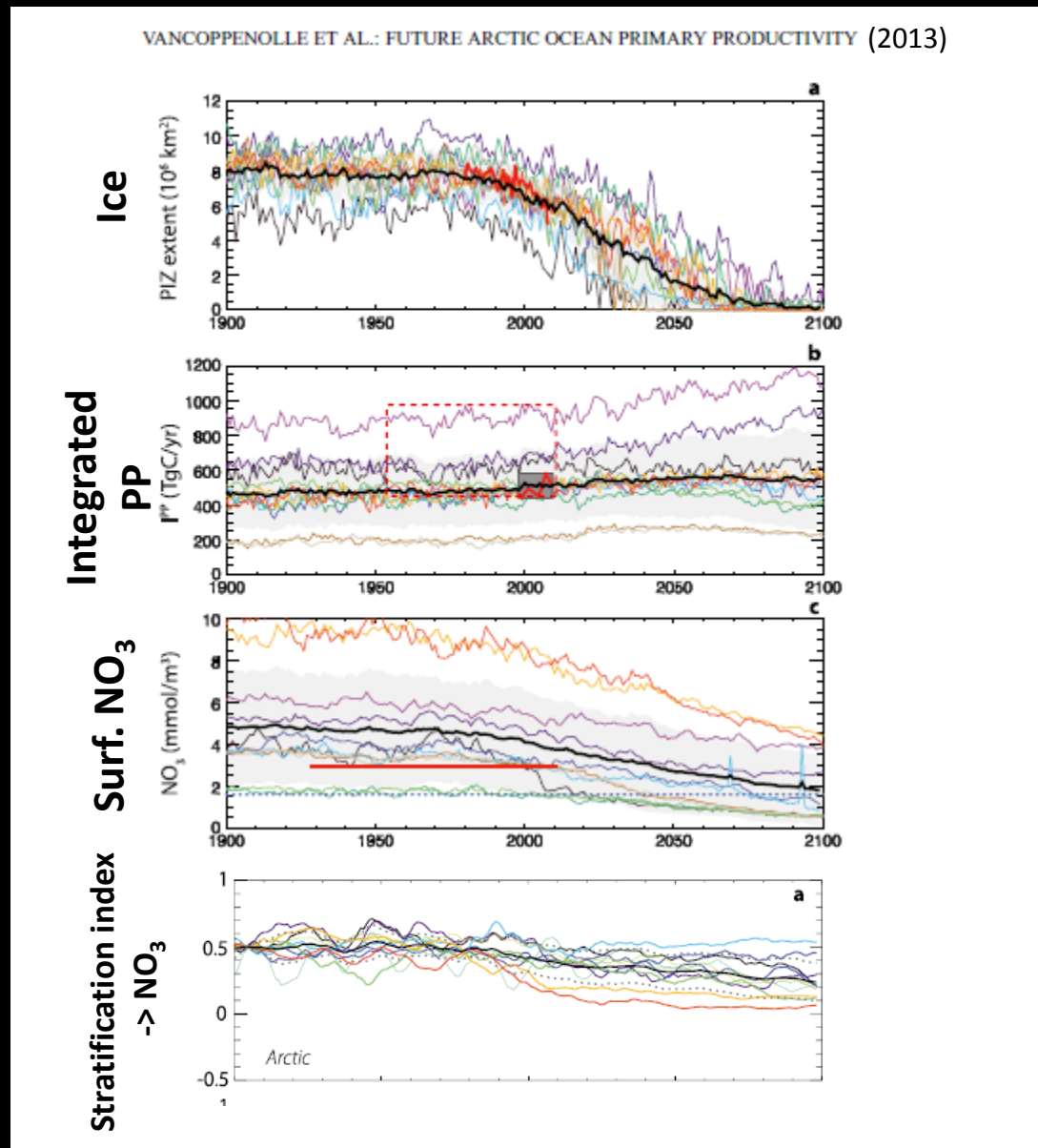
**Figure 4.** Maximum depth of UML during the year on the basis of monthly averaged values (m; note non-linear color scale) for (a) NEMO, (b) LANL, (c) UW, (d) UL, (e) OCCAM, and (f) WOA climatology.

Same  
for DIN  
fields

Popova et al. 2012

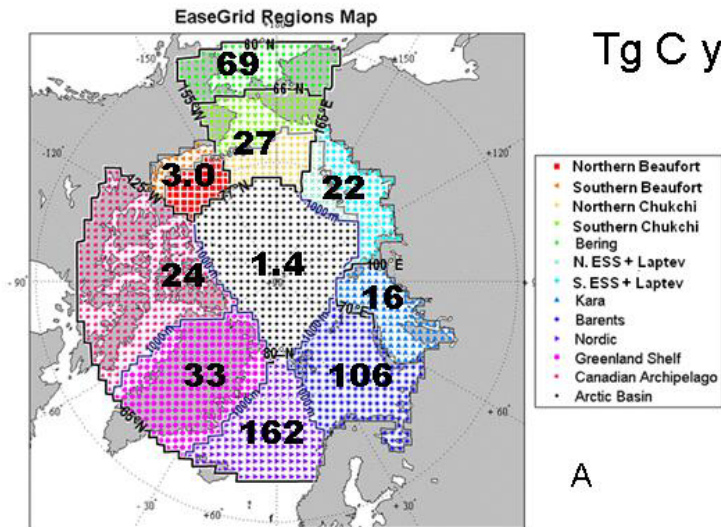
# ESMs in the Arctic: CMIP5 simulation for 2100

But regional GCM  
BIOMAS by Zhang et al.  
2014 does get the  
coastal complexity!





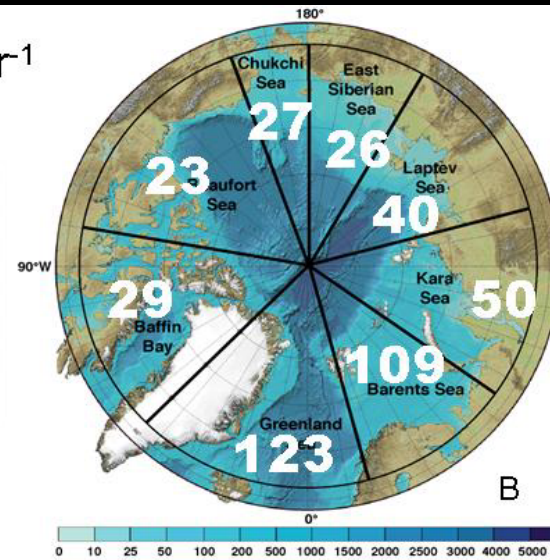
# Three empirical estimates of Arctic annual, regional, integrated PP...



Hill et al. 2013

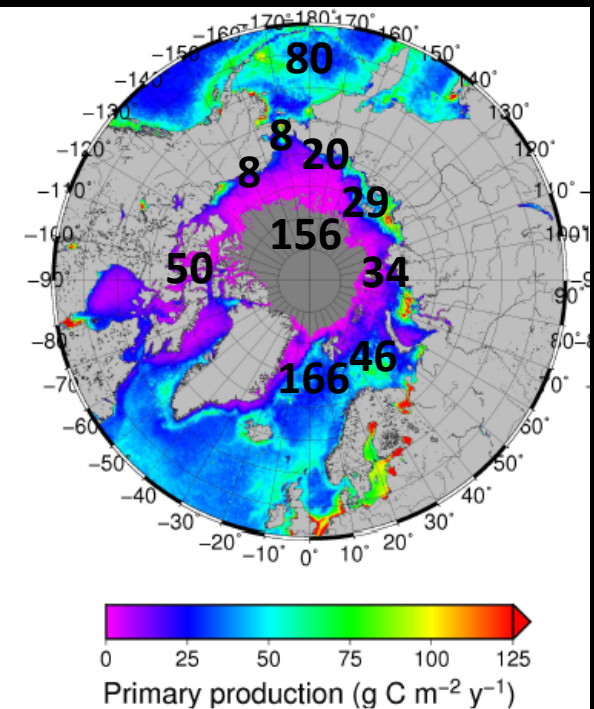
Tg C yr<sup>-1</sup>

A



B

Pabi et al. 2008; Arrigo and Dijken 2011



Bélanger et al. 2013

## GIN Seas (Tg C y<sup>-1</sup>)

Sakshaug 2004	42
Arrigo & van Dijken 2011	148
Hill et al. 2013	162
Ardyna et al. 2013	230 (104 gC m <sup>-2</sup> y <sup>-1</sup> )
Wassmann et al. 2014	70-100 gC m <sup>-2</sup> y <sup>-1</sup>

**SOLAS/SCOR BEPSII  
FAMOS, IOC...**

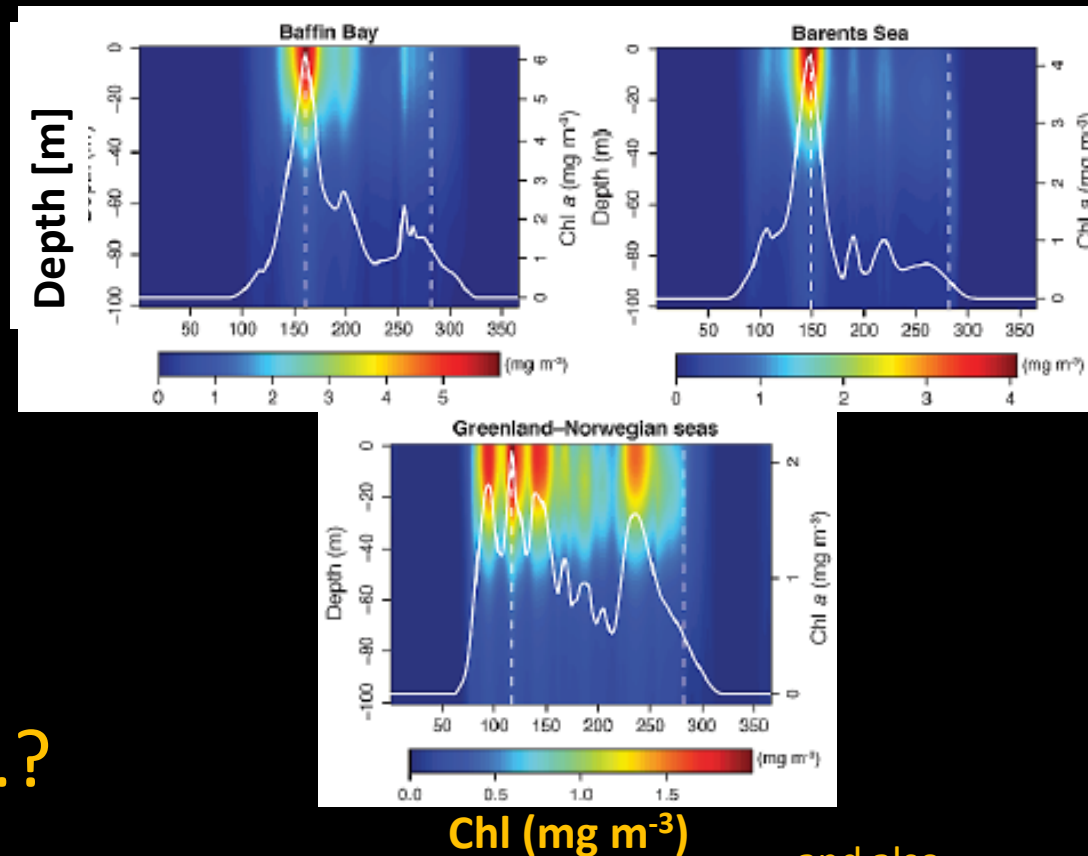
**PPARR-5 Arctic Ocean!**

Who?

# Simulated subsurface chlorophyll maximum (surf. Chl + Ardyna, Bélanger, Babin et al. 2013 model):

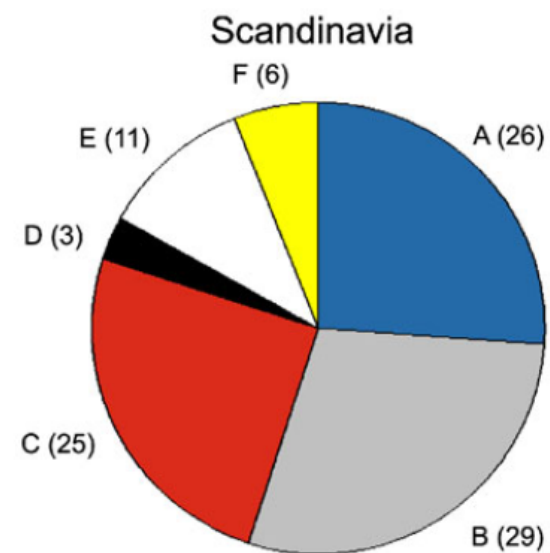
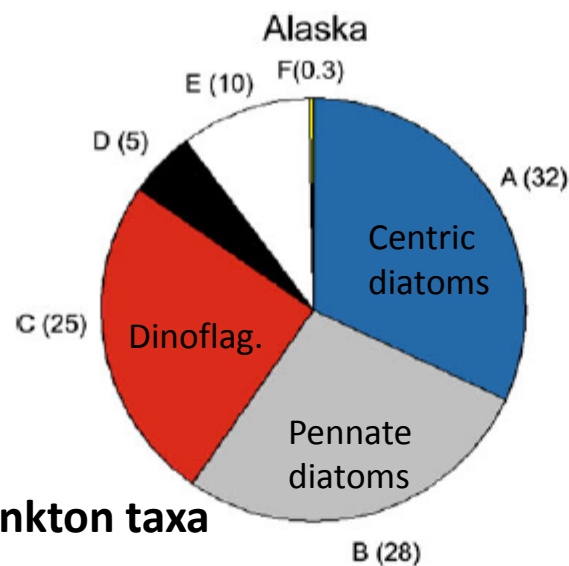
Where are  
the phytos  
and  
when?

Which spp.?



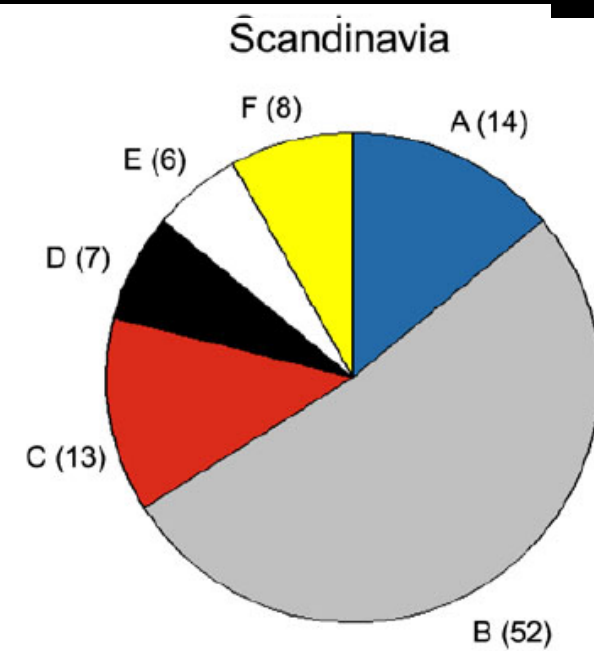
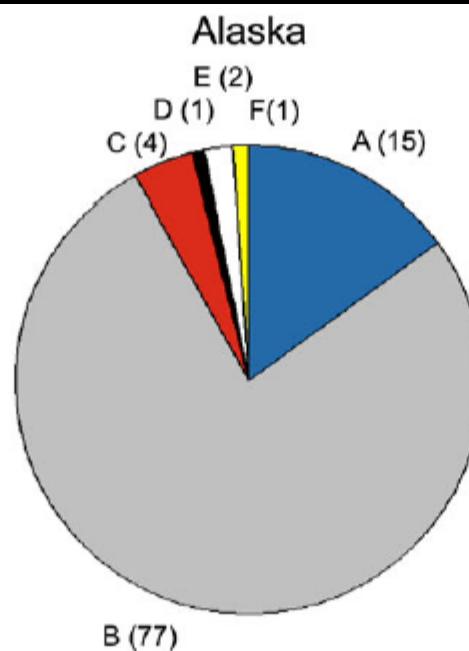
and also  
Hill, Matrai et al. 2013  
Arrigo, Matrai, van Dijken 2011

Fig. 1 Relative proportion (%) of marine phytoplankton taxa recorded from the Alaskan, Canadian, Scandinavian including Greenland and Russian Arctic. *A* centric diatoms; *B* pennate diatoms; *C* dinoflagellates; *D* other stramenopiles; *E* remaining groups; *F* incertae sedis + choanoflagellates (refer to Table 1)



### (Micro) Phytoplankton taxa

Fig. 2 Relative proportion (%) of marine sea-ice eukaryote taxa recorded from the Alaskan, Canadian, Scandinavian including Greenland and Russian Arctic. *A* centric diatoms; *B* pennate diatoms; *C* dinoflagellates; *D* other stramenopiles; *E* remaining groups; *F* incertae sedis + choanoflagellates (refer to Table 1)



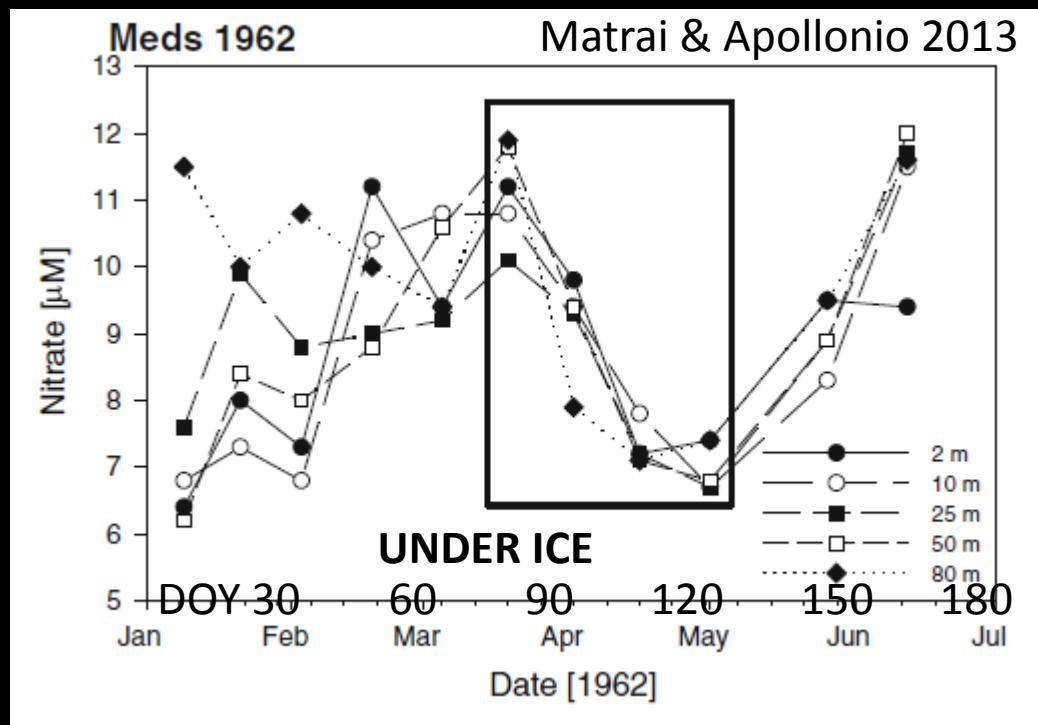
### Ice algae taxa

Poulin et al. 2011

Nano/Picoplankton: flagellates (e.g. *Micromonas*; no marine cyanobacteria) =%??



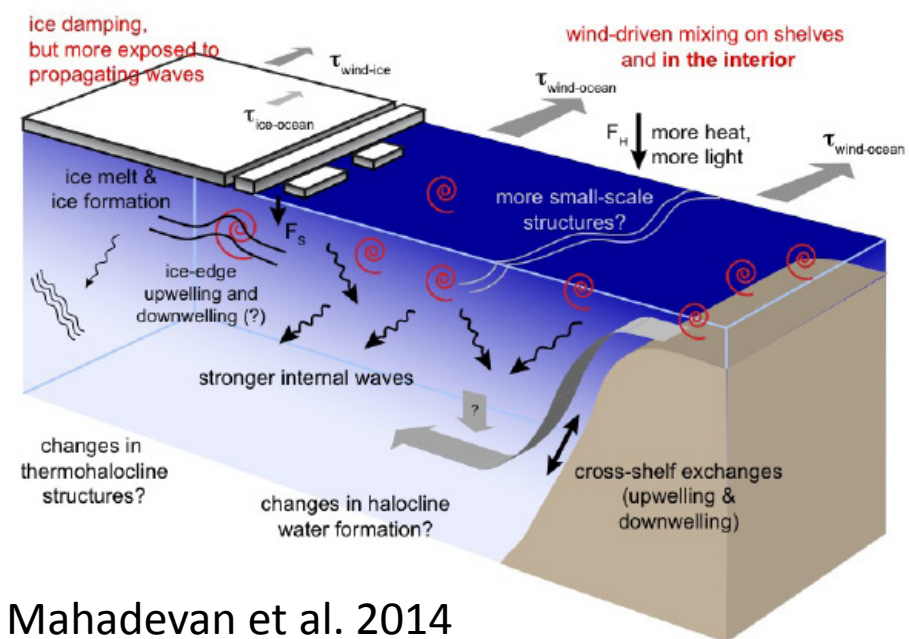
More than late spring and summer!



..."Thus, a whole microbial food web develops much before the spring bloom appears. We know very little about this food web, but it certainly sets the stage for later biological and biogeochemical developments in the spring."...



More than  
bottom up  
processes!



OCB 2014, WHOI

Mahadevan et al. 2014



# Summary

- Sea ice is thinning, ice extent is reduced, especially in summer, and snow cover is changing
- Primary production season is expected to increase in duration (light) but not in PP magnitude (nutrients) at pan-arctic scales
- Primary production and productivity increase in certain continental shelves and breaks; and move => Whose fisheries!?
- Primary production and productivity are not expected to increase in the deep Arctic Basin (not enough nutrients)
- The ecosystems of the Arctic Ocean will change their present day equilibrium. We do not know how the new equilibrium will support ecosystem services
- Our predictions are only as good as our process understanding and validating data are

A black and white photograph of a vast, flat, icy landscape, likely a frozen body of water or a tundra. The foreground and middle ground are covered in a complex pattern of ice floes and dark, open water. The horizon is flat and distant. The sky is filled with dramatic, layered clouds, and a bright sun is visible in the upper right quadrant, casting a glow across the scene.

Thank you!