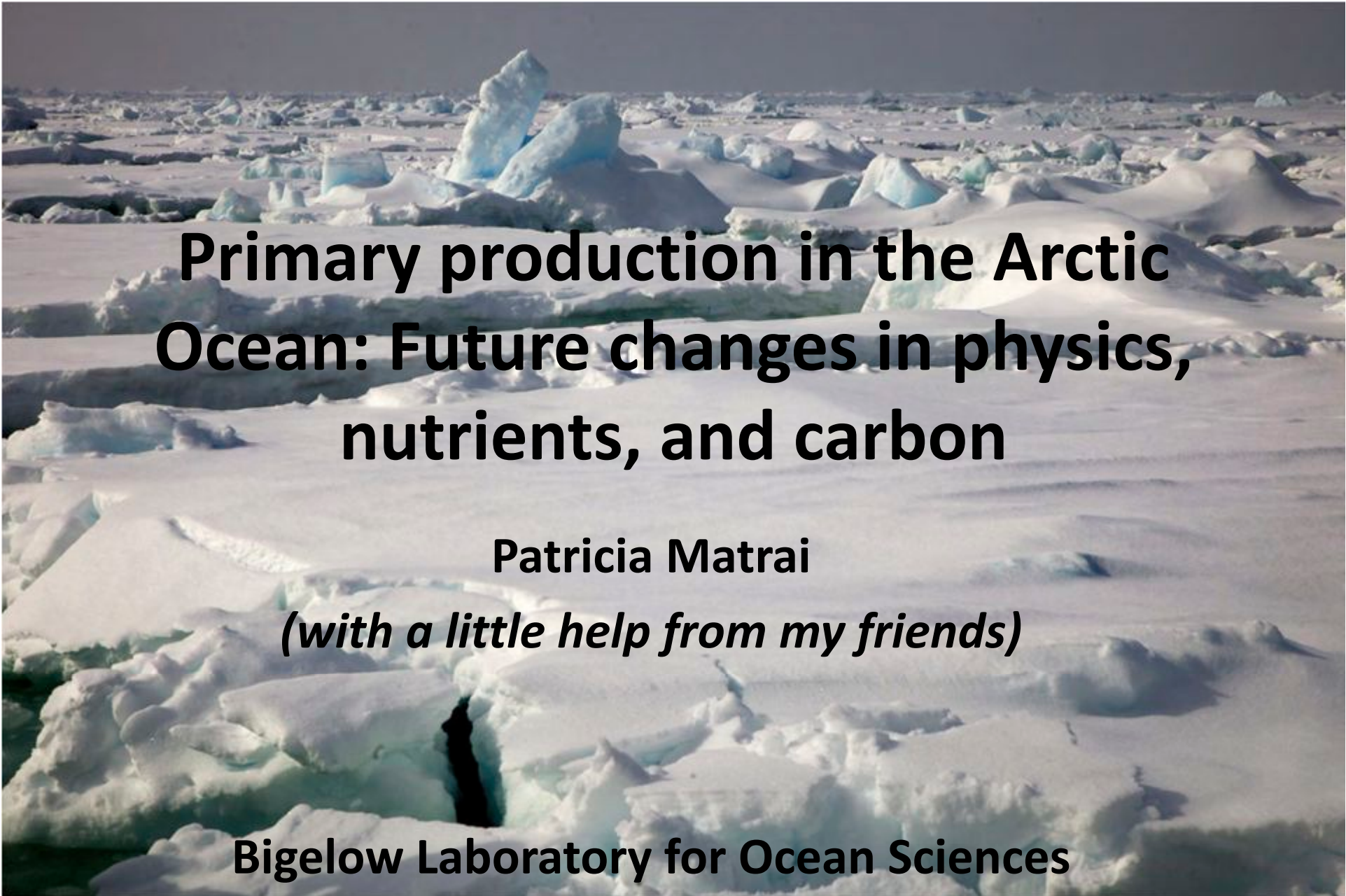


A wide-angle photograph of a vast Arctic landscape covered in snow and numerous icebergs of various sizes. The icebergs have sharp, jagged edges and some show a blueish tint. The sky is a pale, overcast grey.

Primary production in the Arctic Ocean: Future changes in physics, nutrients, and carbon

Patricia Matrai

(with a little help from my friends)

Bigelow Laboratory for Ocean Sciences





Foto:National Geographic









Photo: Mike Brittain



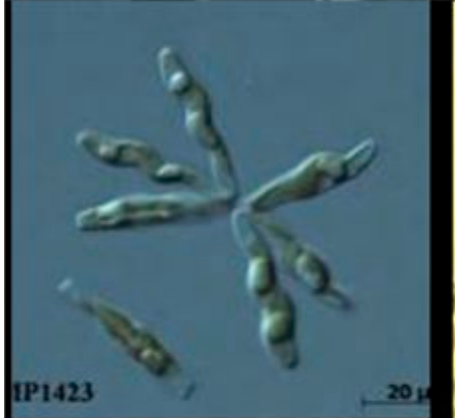
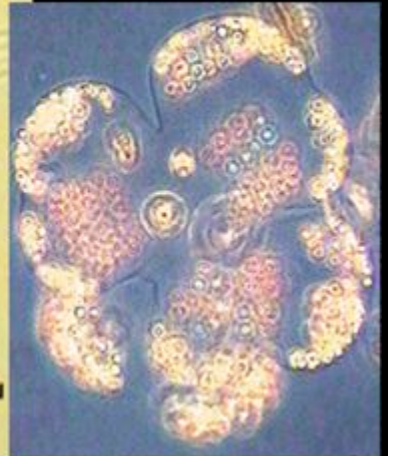
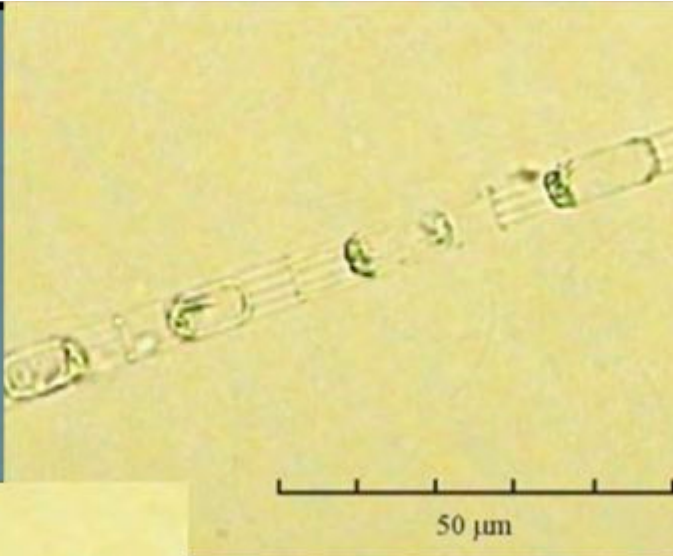
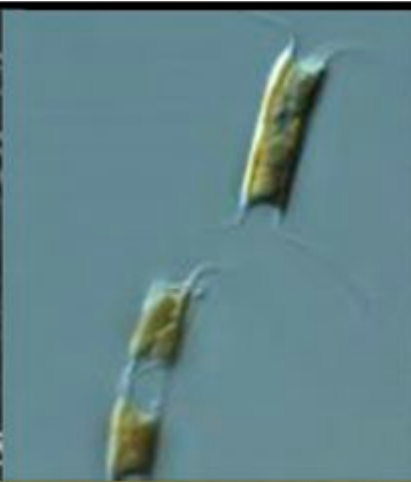
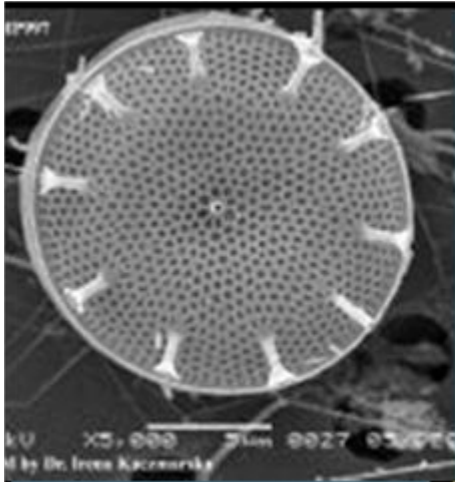
www.audunrikardsen.com

**What are these
(charismatic megafauna)
resources based upon?**

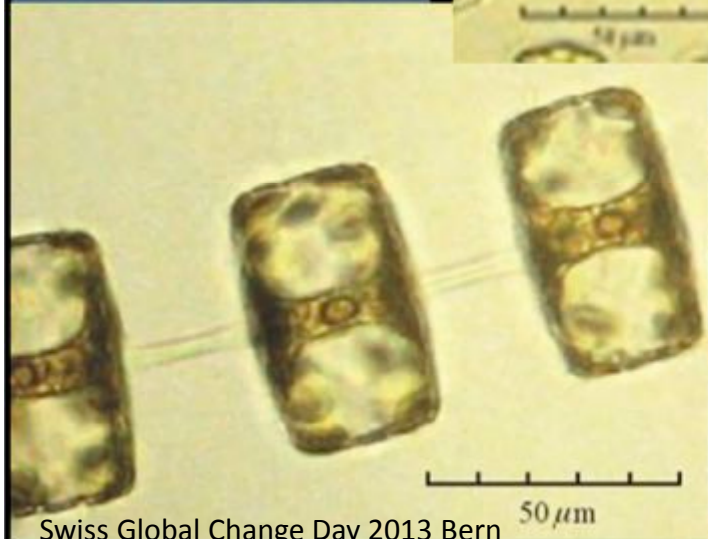
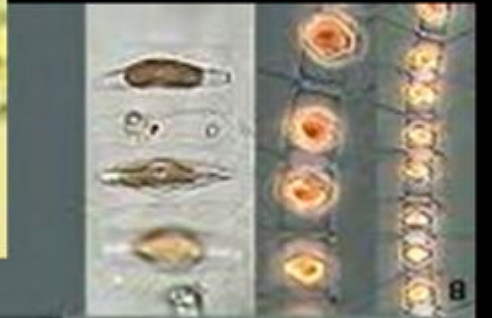


Charismatic microflora!

Plant (phyto) plankton: Different diatoms
(hundred micrometres in size, stained)



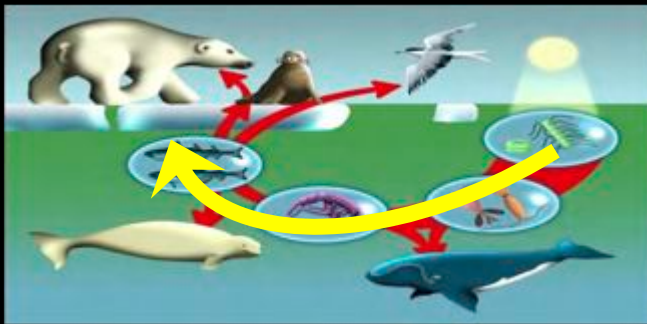
Phytoplankton



How can productivity be influenced by change?

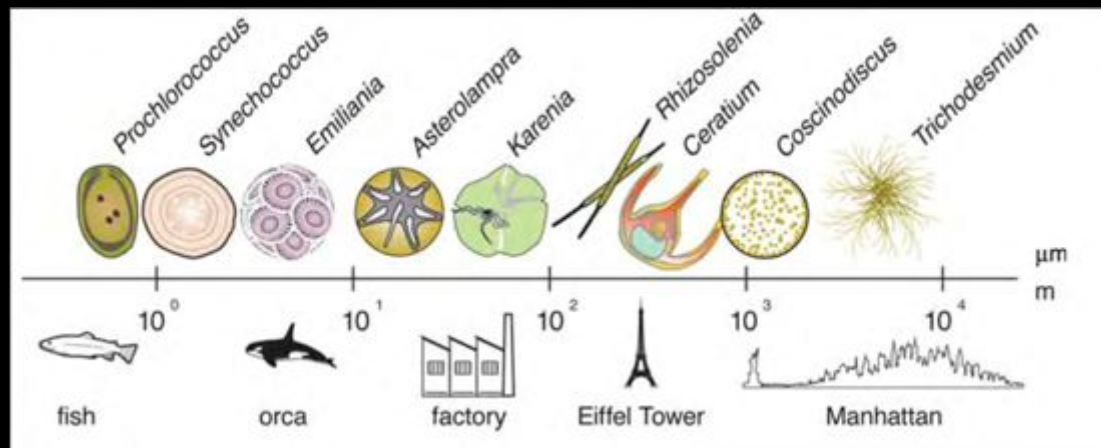
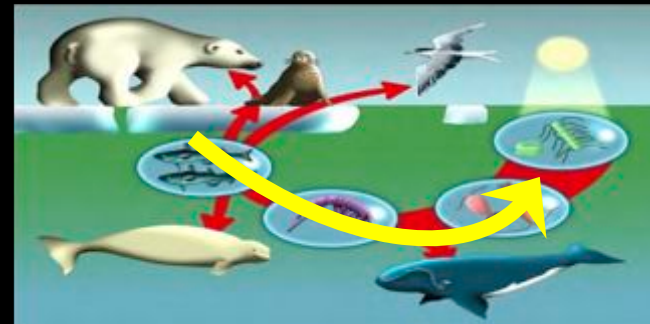
1. Bottom-up effects:

Environmental change affects consumers by modulating the productivity, timing and/or size of primary producers.



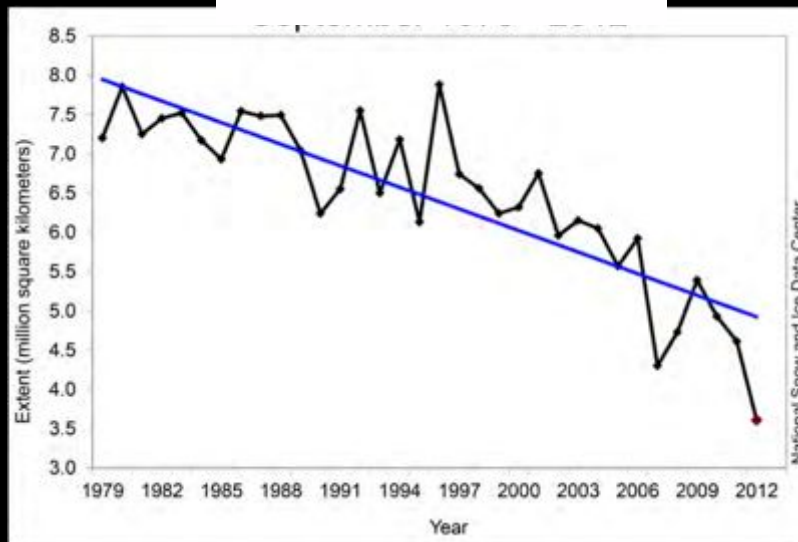
2. Top-down effects:

Altered predation by consumer affects the structure and/or productivity of lower food web.



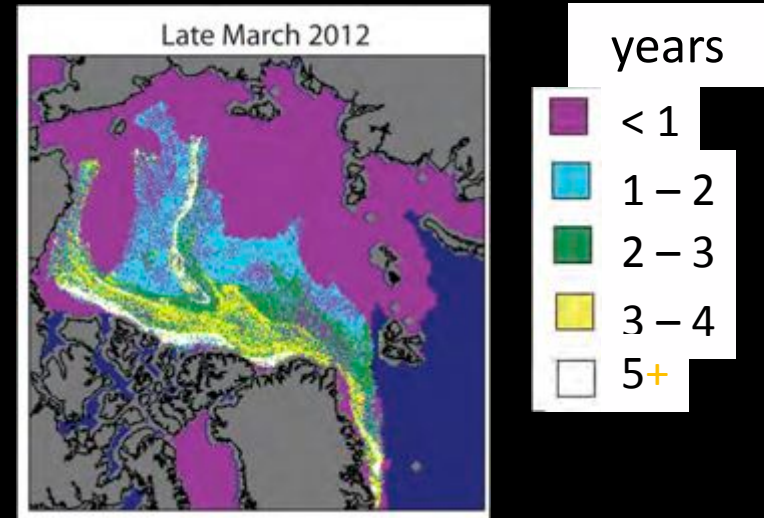
Bottom-up change: less ice = more light

1. Extent (September minimum)



Source: NSDIC

2. Age (thickness)

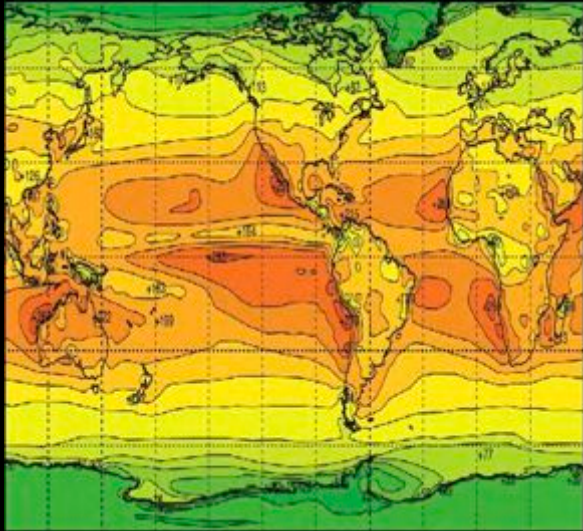


Source: NSDIC

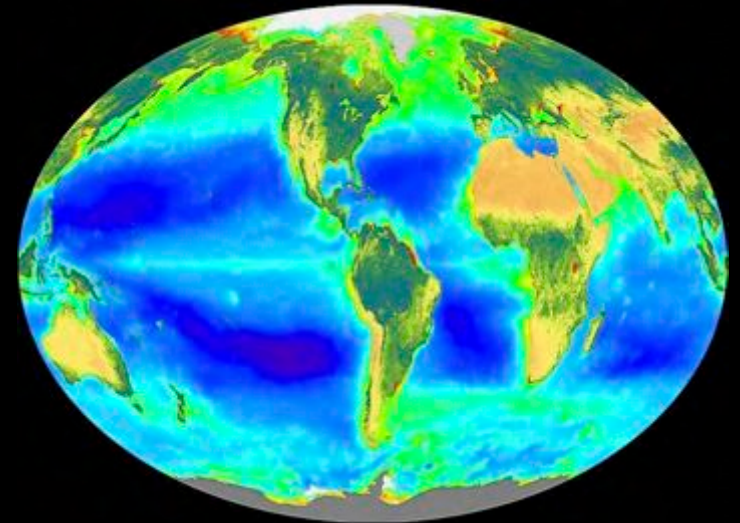
3. Seasonal persistence of annual ice: - 2 to 13 days per decade



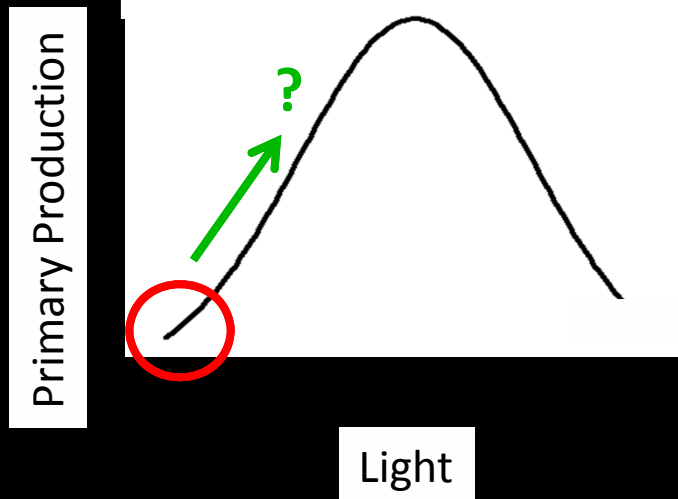
Primary production patterns are not a simple function of light



Mean annual incident
insolation ($20 - 350 \text{ W m}^{-2}$)
Kallberg et al. (2005).



Mean annual chlorophyll
(= phytoplankton biomass)
NASA



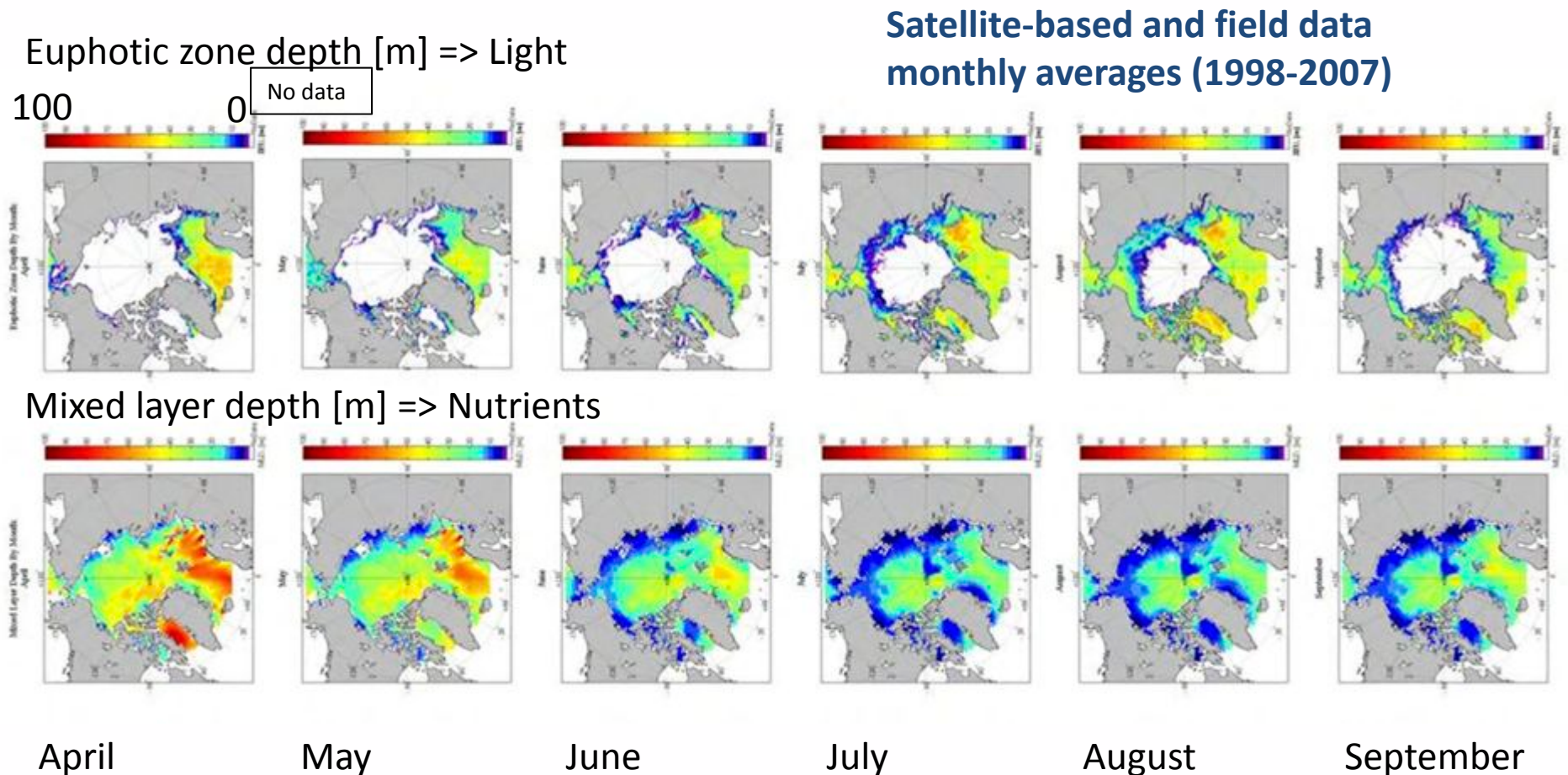
Ice melt and surface warming result in stratification that prevents vertical mixing

Low nutrient supply to surface and thus low harvestable productivity

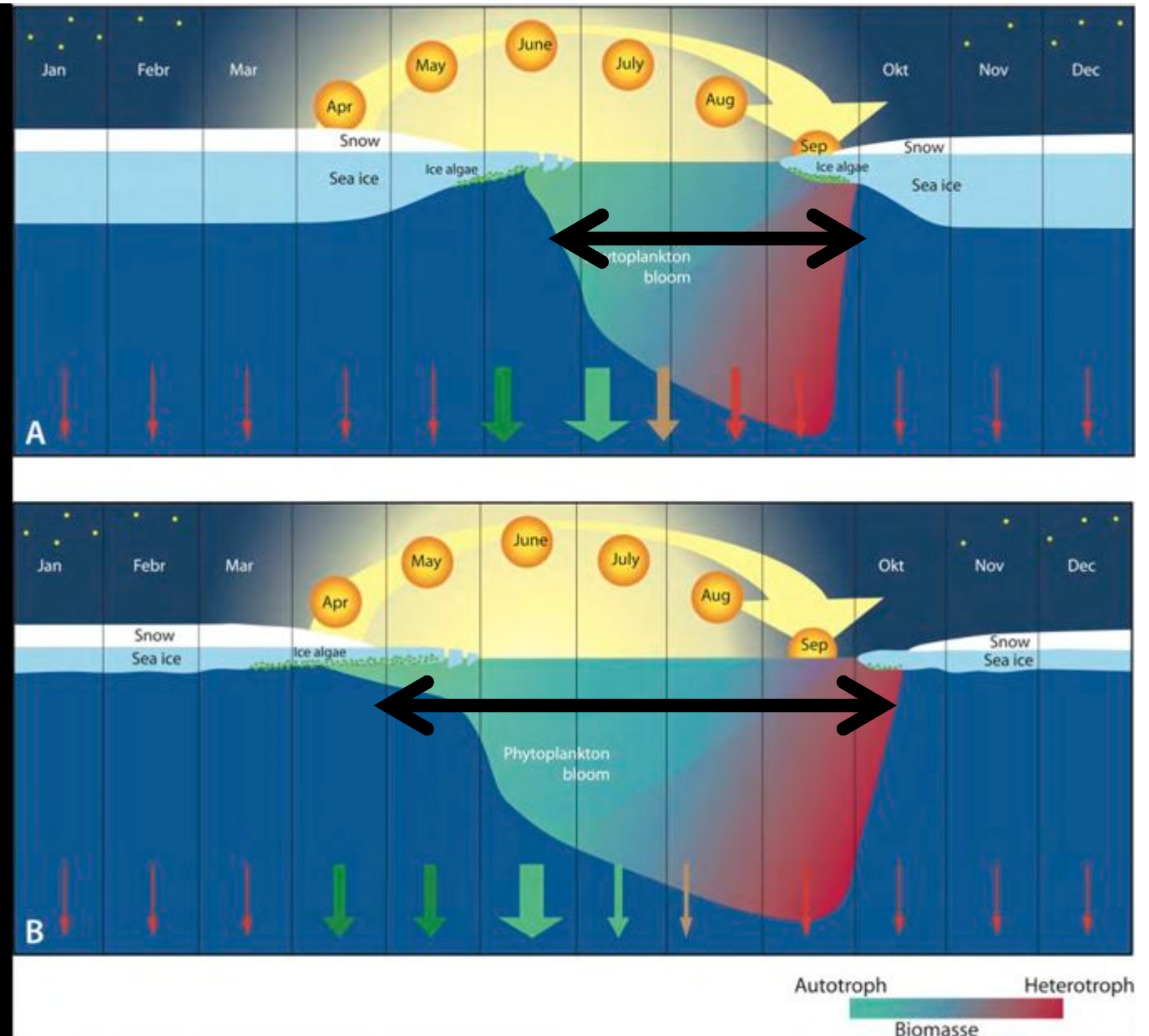


How deep?

Seasonal distribution of euphotic zone and mixed layer depths from spring to fall in the Arctic Ocean



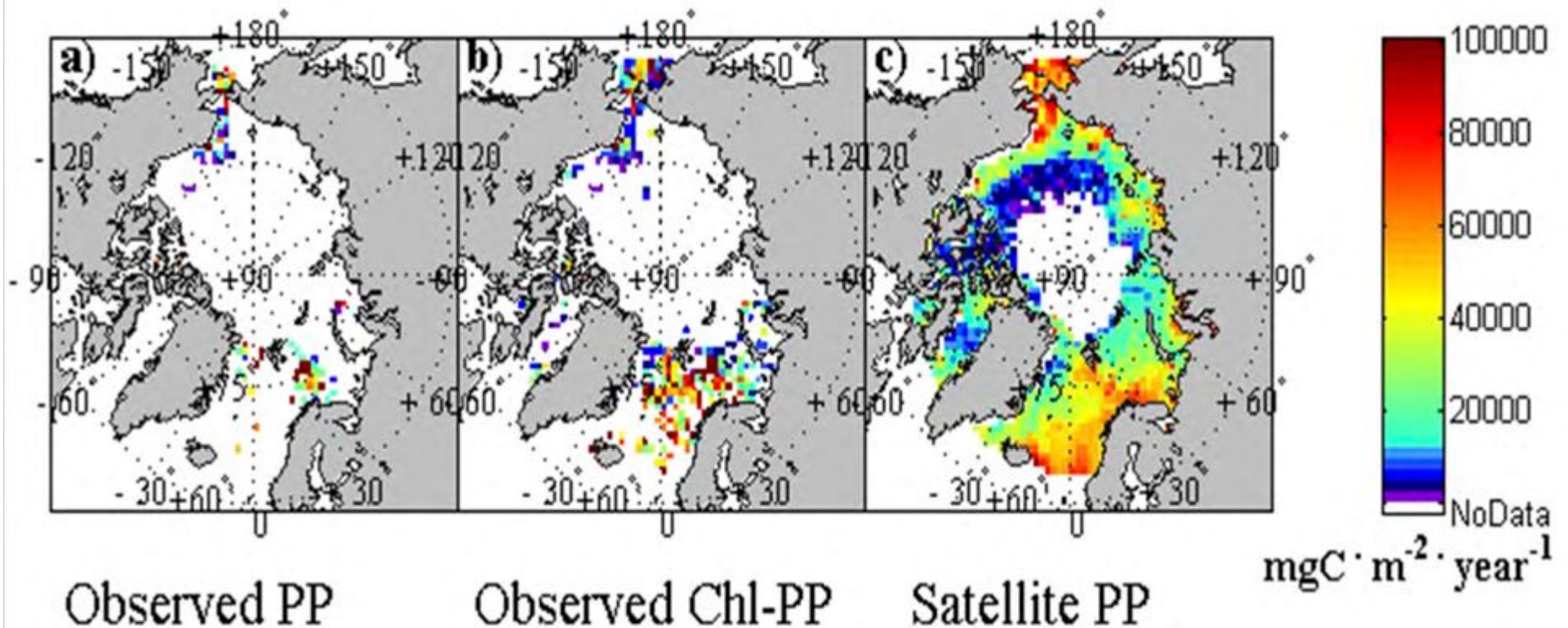
Today's extreme
seasonal
variation
disappears



Where is Arctic Primary Production now?

Integrated Annual Net Primary Production (PP)

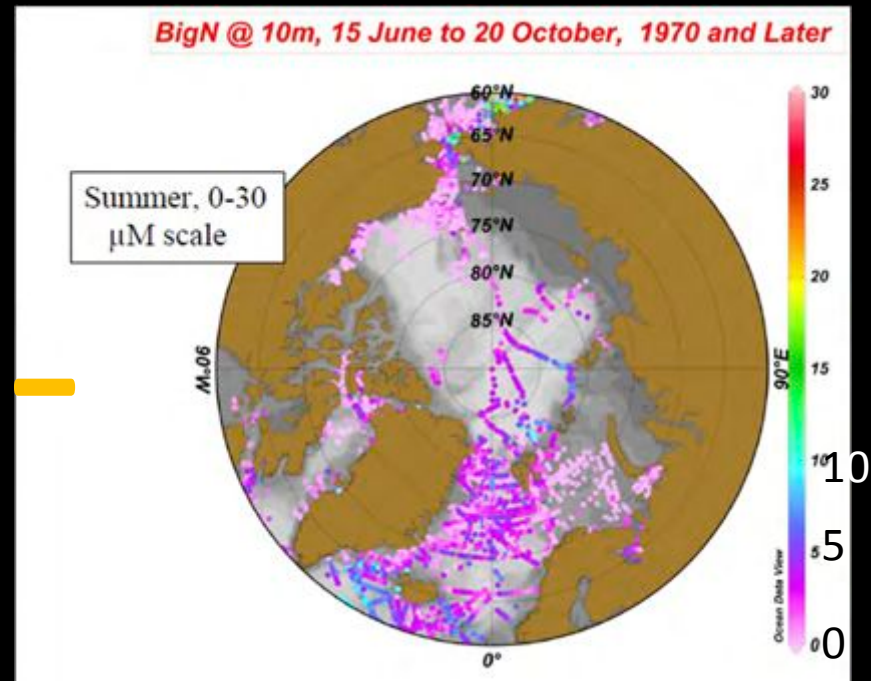
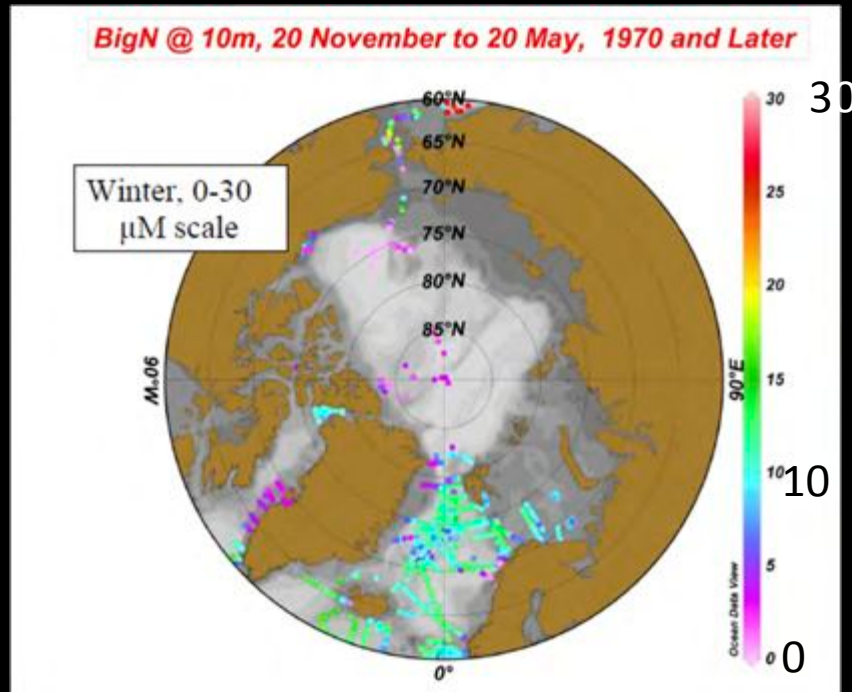
(1954-2007 field; 1998-2007 satellite data)



Algorithm-estimated NPP based on:
Field Chl Sat Chl

0-100 gC m⁻² yr⁻¹

Net Community Production



$$\text{NCP} * f \text{ factor} = \text{NPP (or NP?)}$$

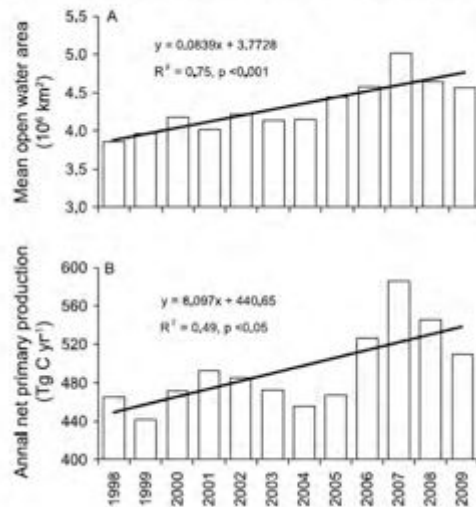
(0-200) (0-40) $\text{gC m}^{-2} \text{ yr}^{-1}$

A biological model applied regionally... using satellite data

Hindcasting into the 1970s

Variable regional decadal trends

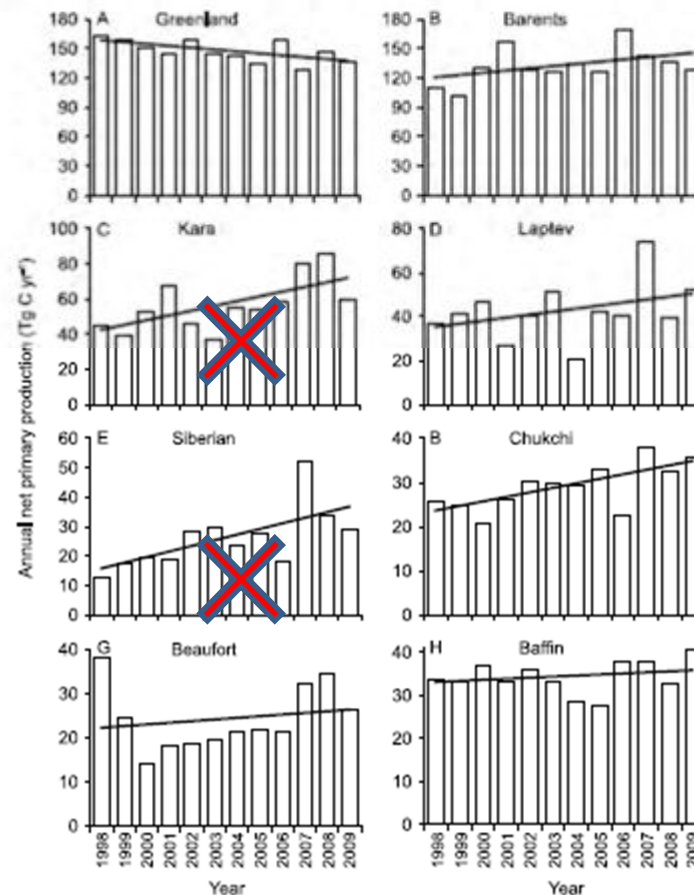
ARRIGO AND VAN DIJKEN: ARCTIC OCEAN NET PRIMARY PRODUCTION



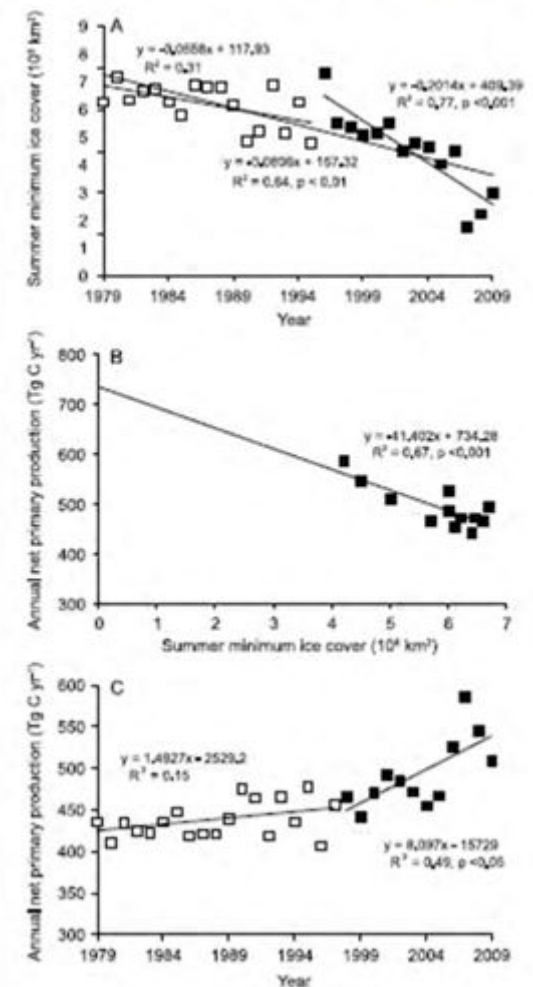
Pan-arctic decadal trend

Pabi et al. 2008
Arrigo and van Dijken 2011

ARRIGO AND VAN DIJKEN: ARCTIC OCEAN NET PRIMARY PRODUCTION



C09011 ARRIGO AND VAN DIJKEN: ARCTIC



Pan-Arctic representation of the present

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

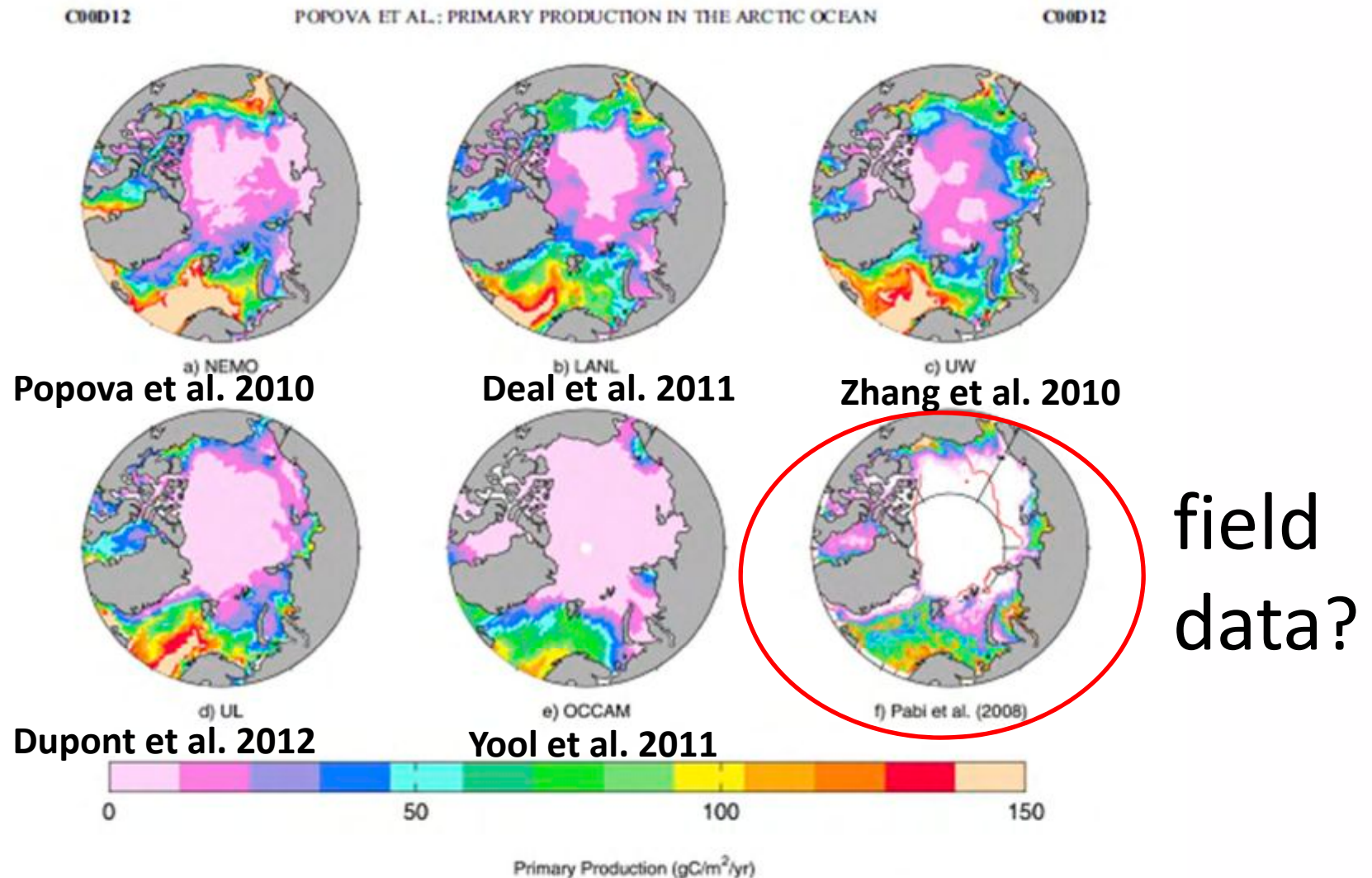
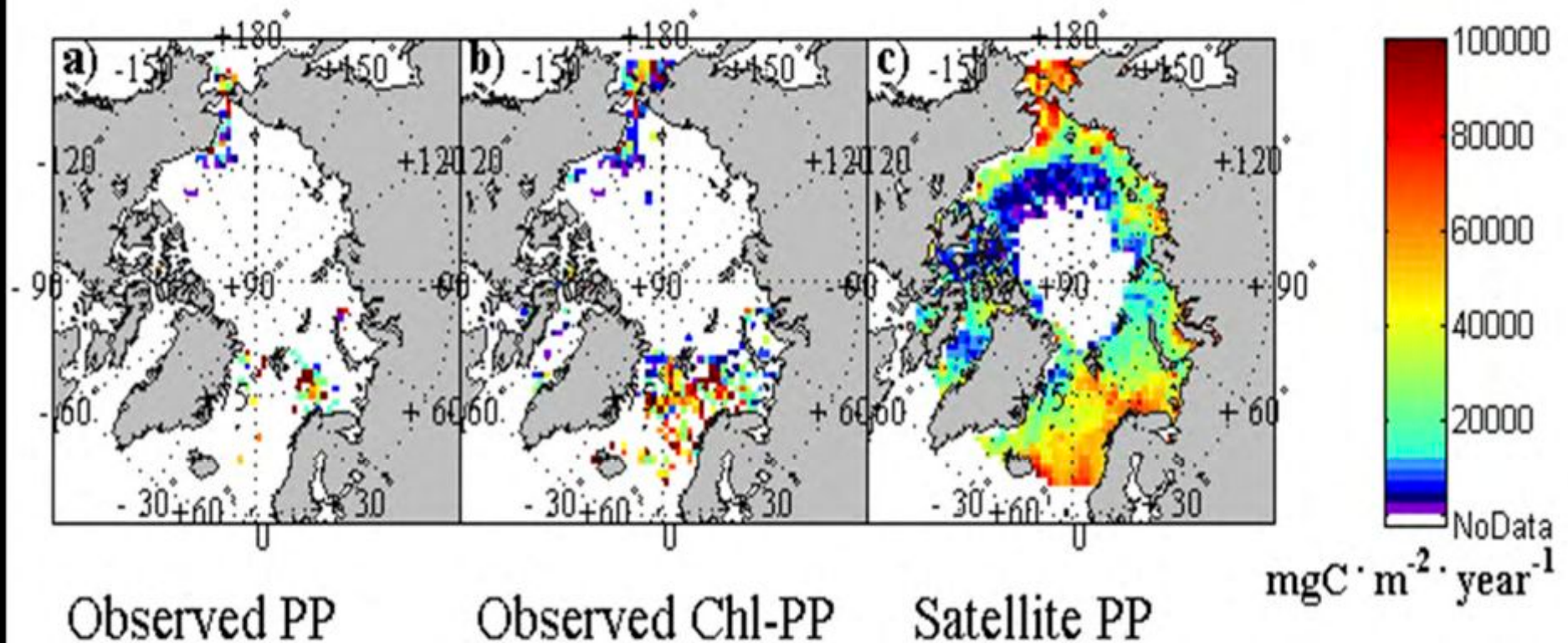


Figure 1. Mean annual water column primary production (in $\text{g C m}^{-2} \text{yr}^{-1}$) for (a) NEMO, (b) LANL, (c) UW, (d) UL, (e) OCCAM, and (f) satellite-derived estimates of Pabi et al. [2008].

Reality check or validation

- Our projections are only as good as our data are:
 - Enough biological data to validate?
 - Year-round; arctic-wide; under-ice and ice-edge blooms
 - Appropriate physical and biological models?
 - Current parameterizations of mixed layer depth, nutrient fields, vertical distribution of phytoplankton biomass
 - Factors with “new” or unintended effects?
 - Clouds, winds, fresh water stratification

Integrated Annual NPP



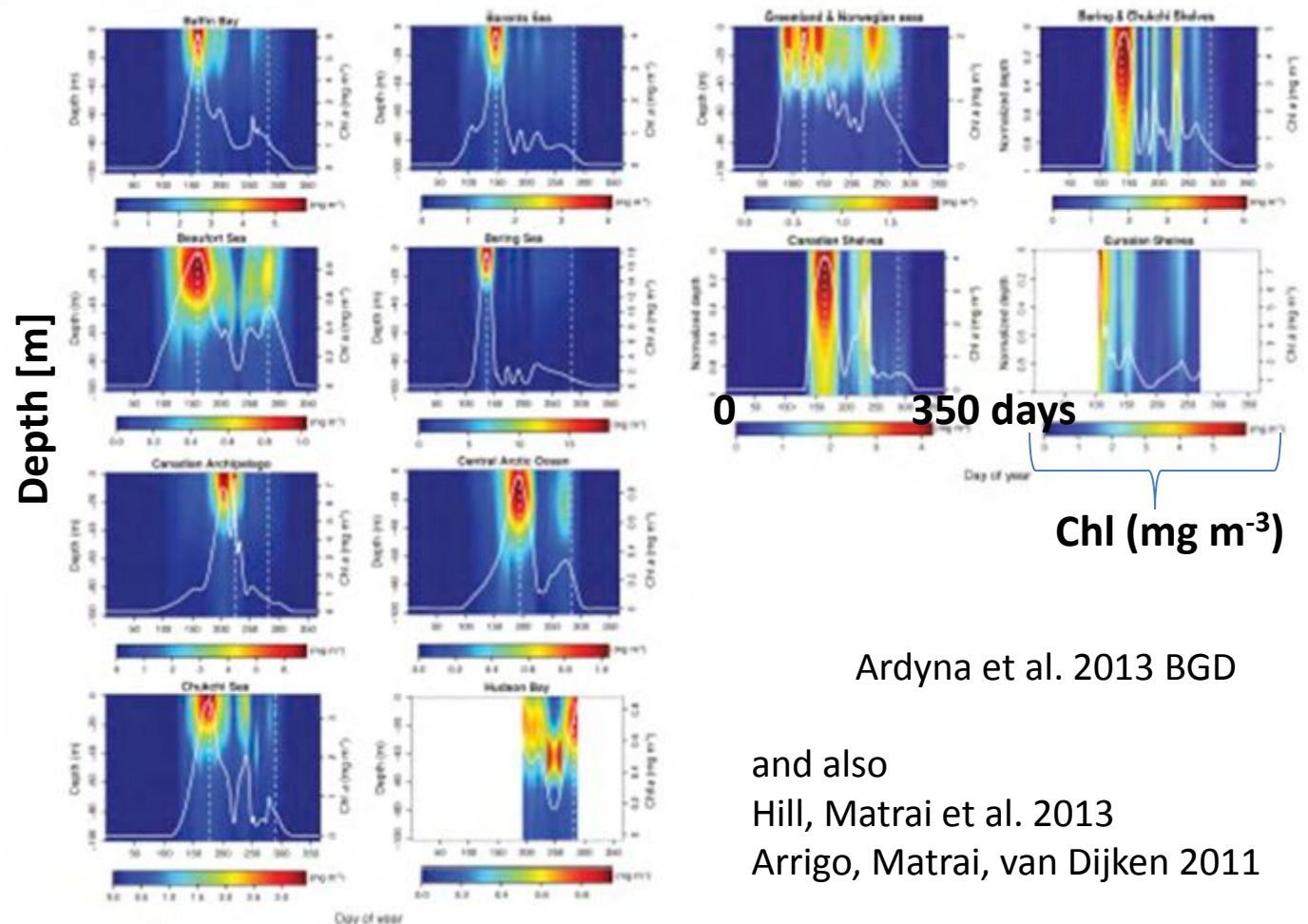
ARCSS PP & nutrients data sets 1954-2007
(www.nodc.noaa.gov)

Hill, Matrai et al. 2013

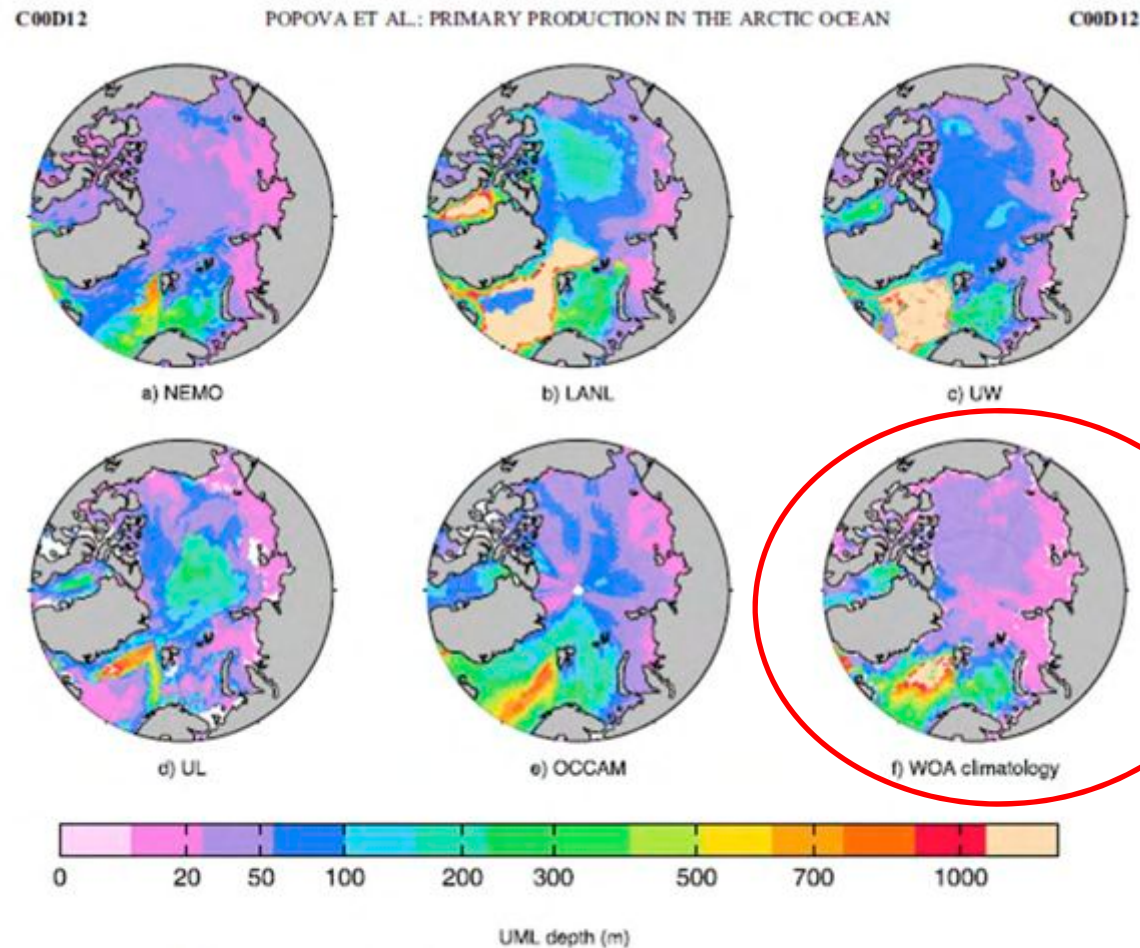
Also see Ardyna et al. 2013 BGD

Subsurface chlorophyll maximum (=phytoplankton biomass): seasonal and regional vs. annual and pan-arctic scales

Where are
the phytos
and
when?



Modeled mixed layer depth examples

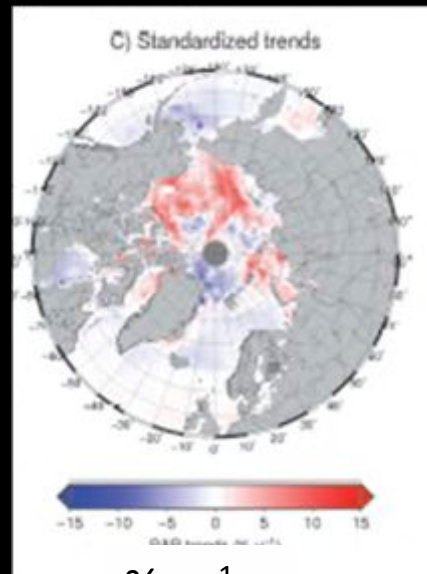
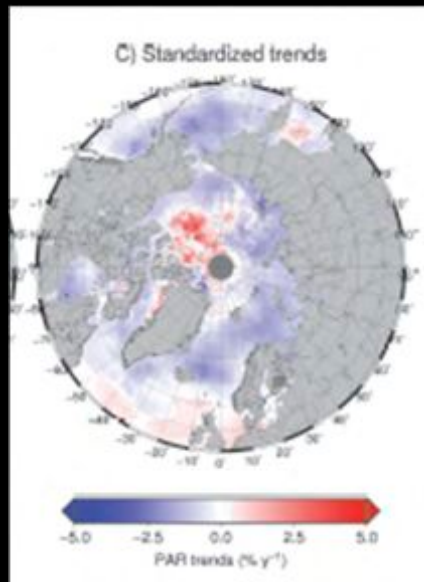


Same
for DIN
fields

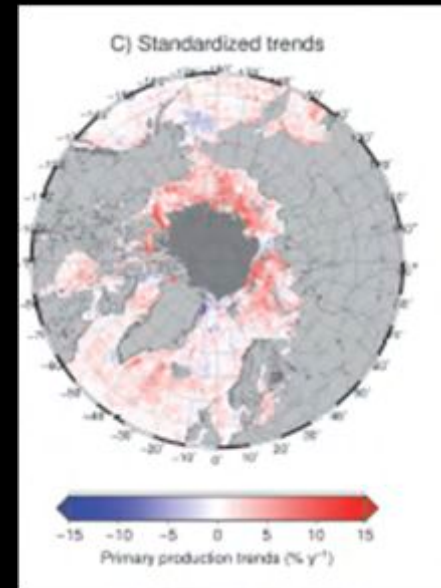
Figure 4. Maximum depth of UML during the year on the basis of monthly averaged values (m; note non-linear color scale) for (a) NEMO, (b) LANL, (c) UW, (d) UL, (e) OCCAM, and (f) WOA climatology.

Popova et al. 2012

Clouds and light



% yr⁻¹



Light decrease
(8-20%)
(+ clouds)
(1998-2009)
ABOVE sea
(ice) surface

Light change (+3
to -3%) (1998-
2009) JUST
BELOW
sea (ice?) surface

PP increase
(1998-2009)
estimated
below sea
(ice?) surface

Bélanger et al. 2012 BGD

Wind! => wind-driven turbulence and
eddies => mixing, nitrate consumption

With ice vs. Without Ice

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

Much to be done on the modeling side:

AOMIP

(<http://www.whoi.edu/page.do?pid=29836>)

4th Primary Production Algorithm Round Robin

(contact pmatrai@bigelow.org)

Summary

- Sea ice is thinning and extent is reduced, especially in summer
- Primary production season is expected to increase in duration (light) but not in 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 is 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 validating data and process understanding are

Thank you!

