Primary production in the Arctic Ocean: Oh, the tales we can tell!

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(with a little help from my friends)

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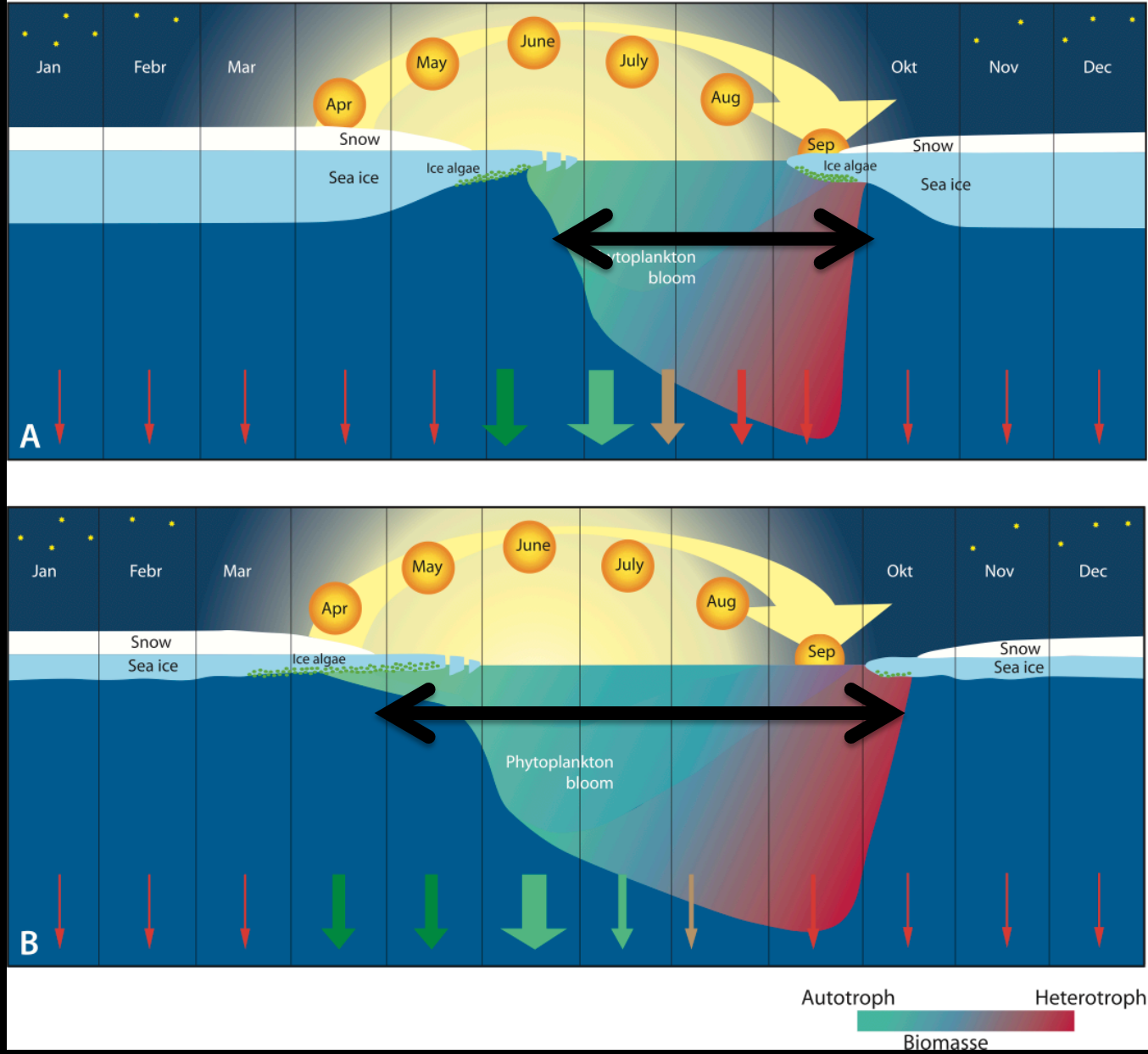
Ice melt and surface warming result in stratification that prevents vertical mixing

Low nutrient supply to surface and thus low harvestable productivity

Courtesy P Wassmann

Today's extreme seasonal variation disappears

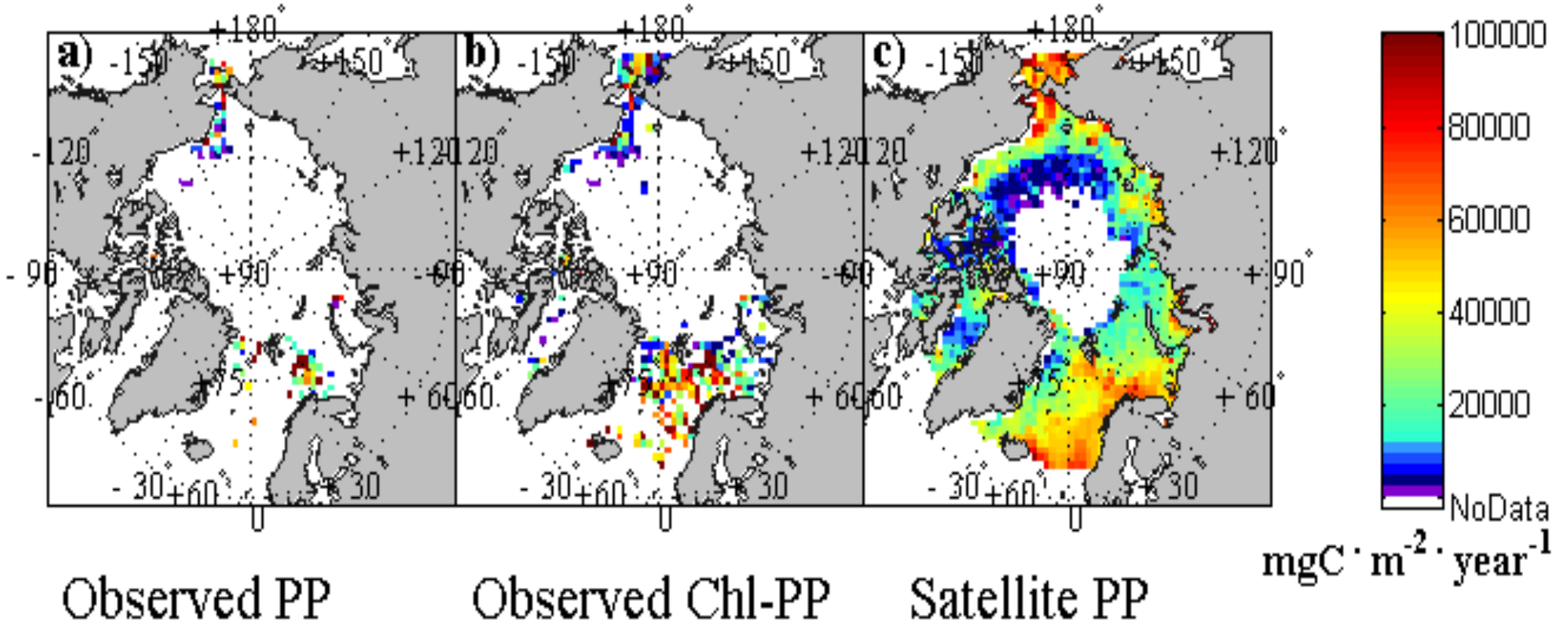
Sub-ice blooms increase?



Wassmann 2011, and those before him

Where is Arctic Primary Production now?

Integrated Annual Net Primary Production (NPP)

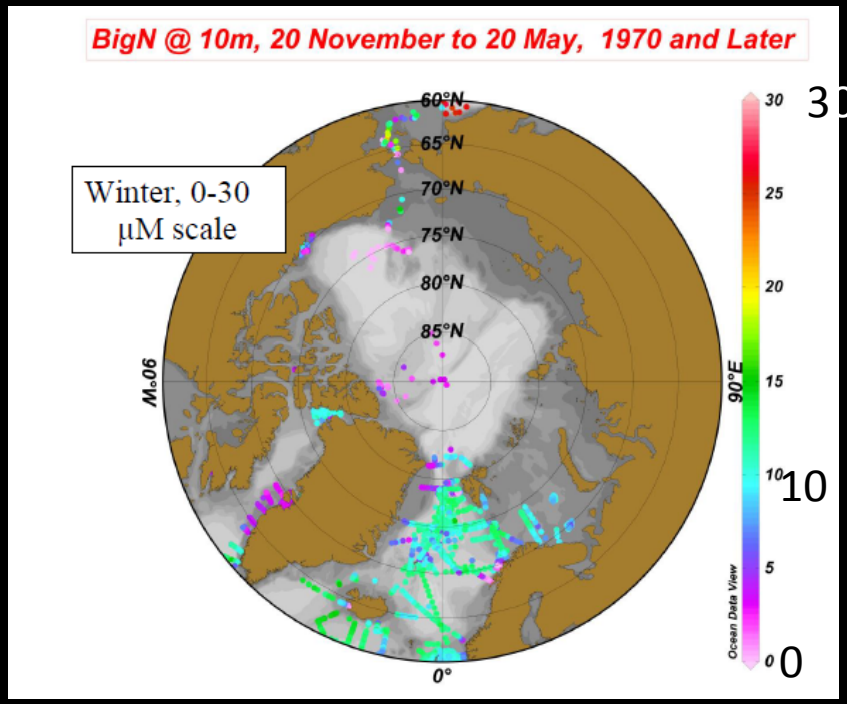


Algorithm-estimated NPP based on:
Field Chl **SeaWiFS Chl**

0-100 gC m^{-2} yr^{-1}

Hill, Matrai et al. 2013

Net Community Production



30

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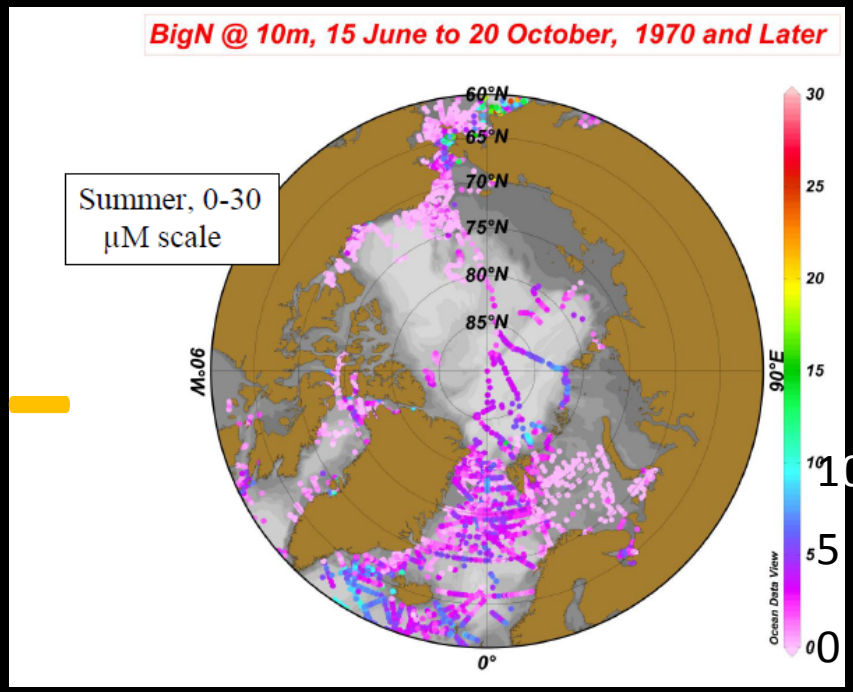


10

=

NCP * *f* factor = NPP (or NP?)

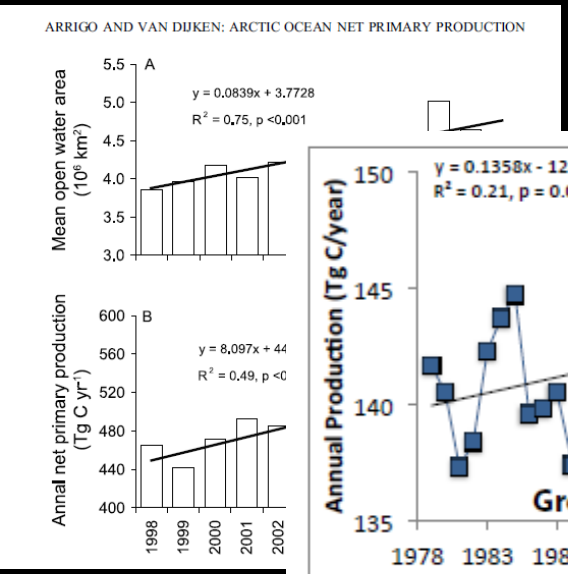
(0-200) (0-40) gC m^{-2} yr^{-1}

Coupled N. Atlantic-Arctic System Wkshp. 2014

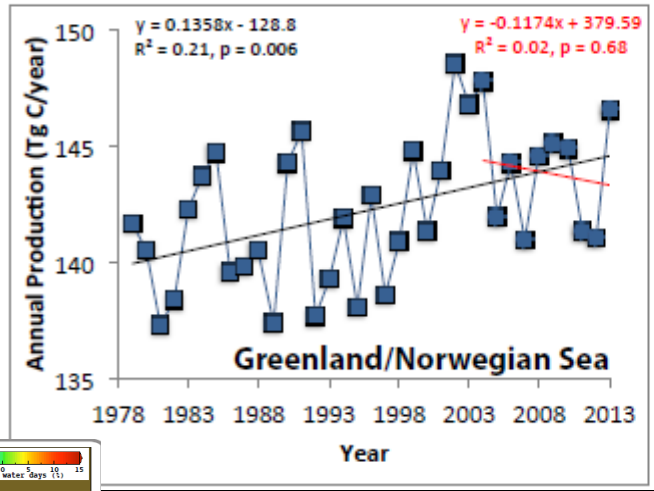
Codispoti , Matrai et al. 2013

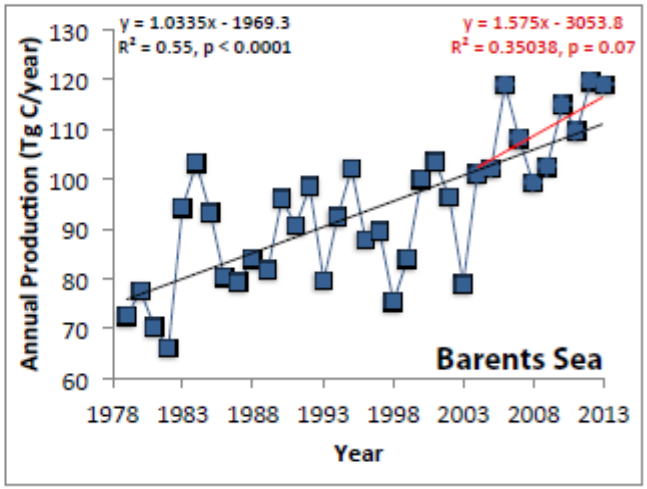
A biological model applied regionally… using satellite data

Pan-arctic decadal trend

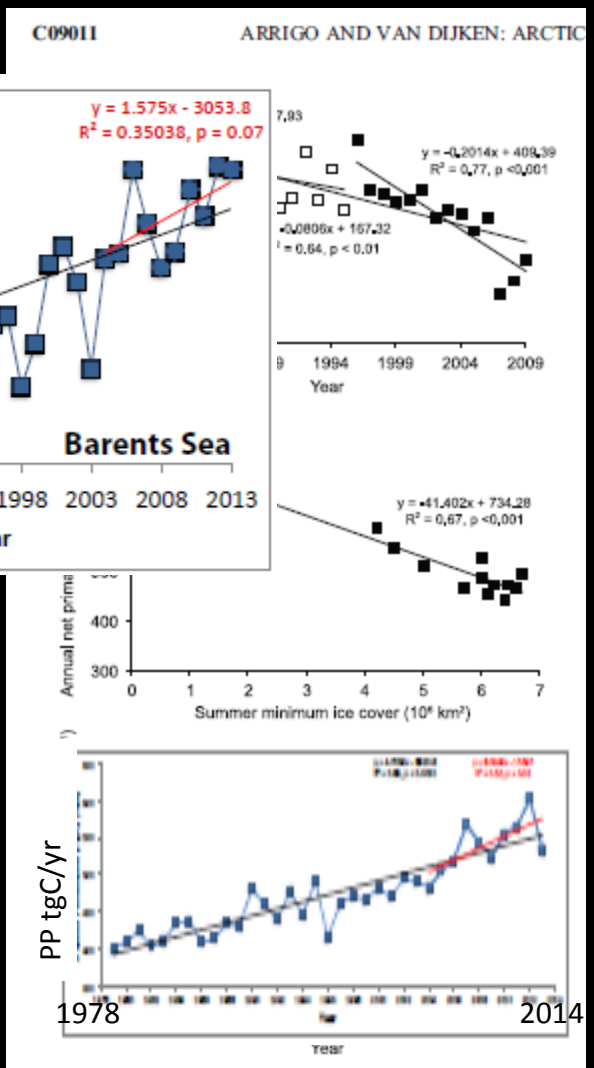


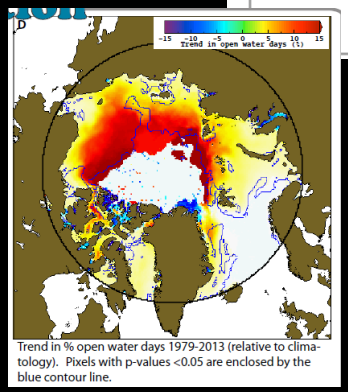
Variable regional decadal trends



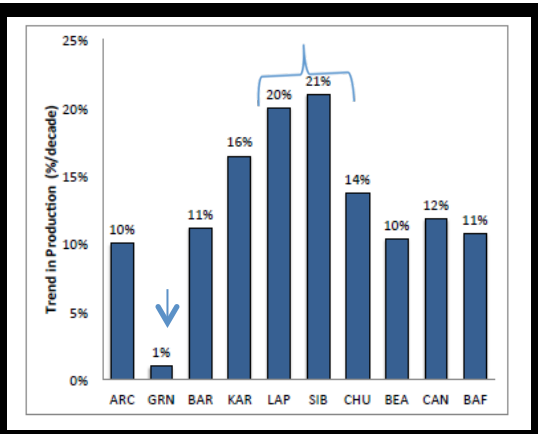


Hindcasting into the 1970s





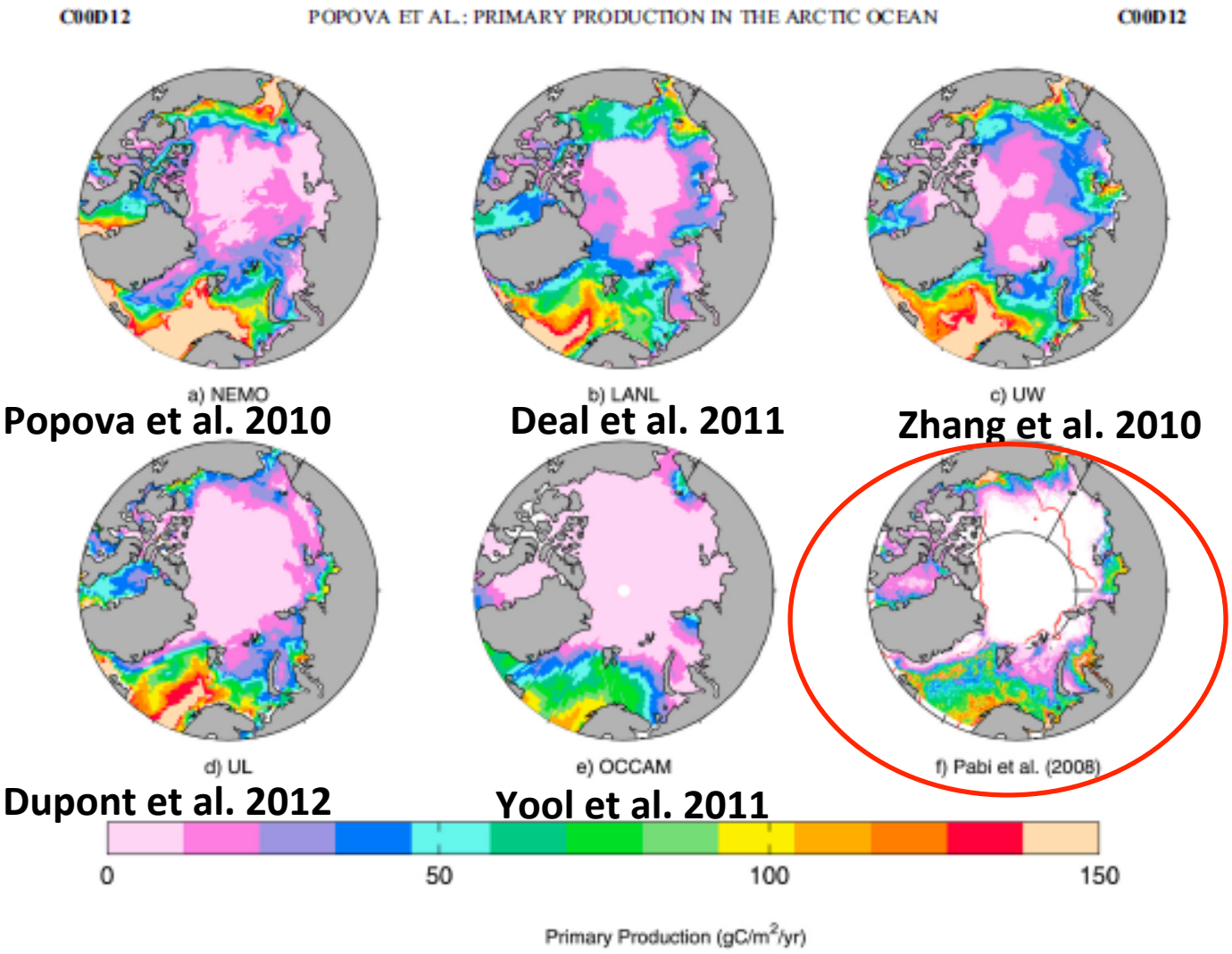
Trend in % open water days 1979-2013 (relative to climatology). Pixels with p-values <0.05 are enclosed by the blue contour line.



Pabi et al. 2008
Arrigo & van Dijken 2011
Van Dijken & Arrigo 2014

Pan-Arctic representation of the present

Mean annual water column PP [gC m^{-2} y^{-1}] by 5 models and a satellite-derived estimate



Popova et al. 2010

Deal et al. 2011

Zhang et al. 2010

Dupont et al. 2012

Yool et al. 2011

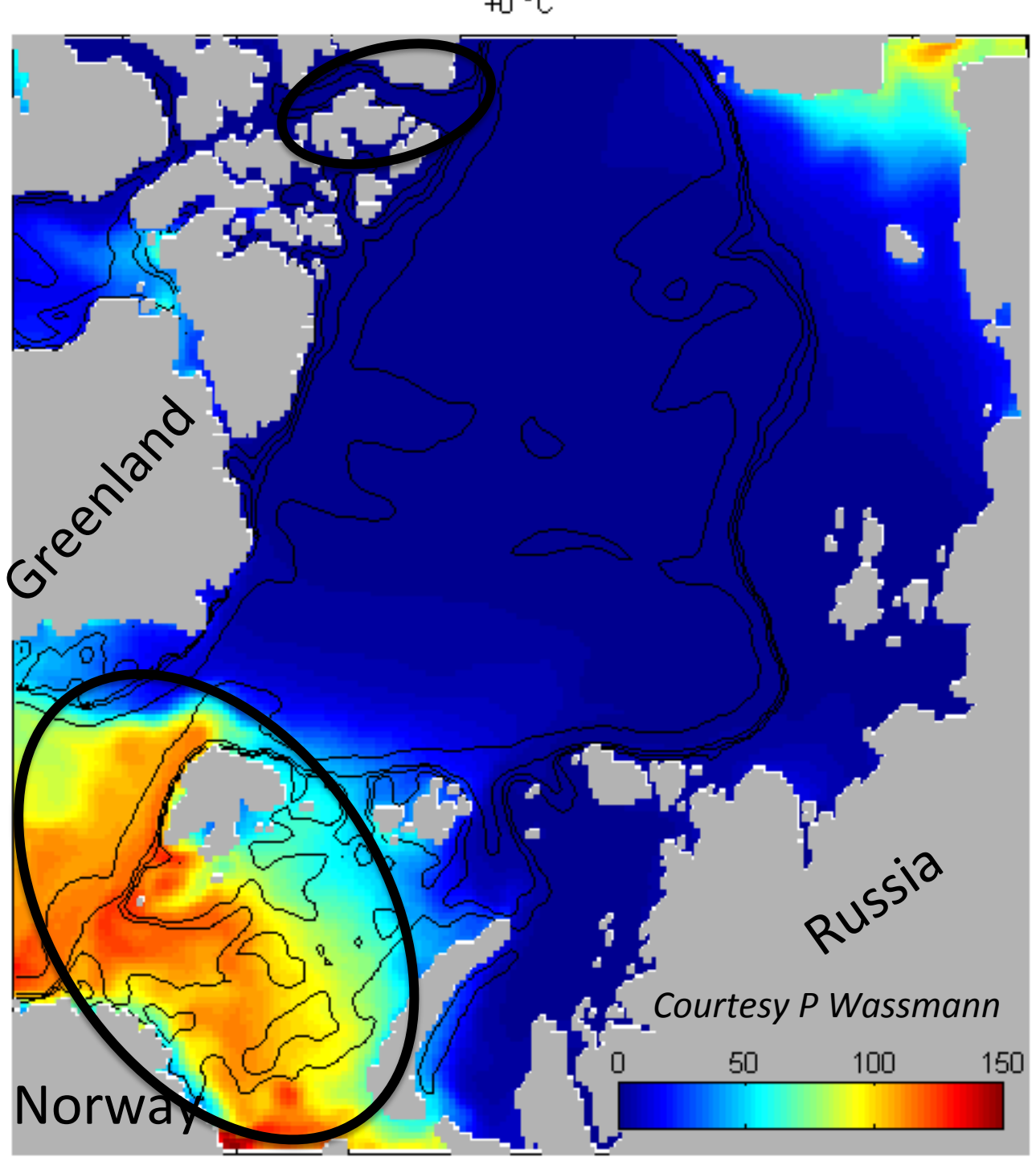
field data?

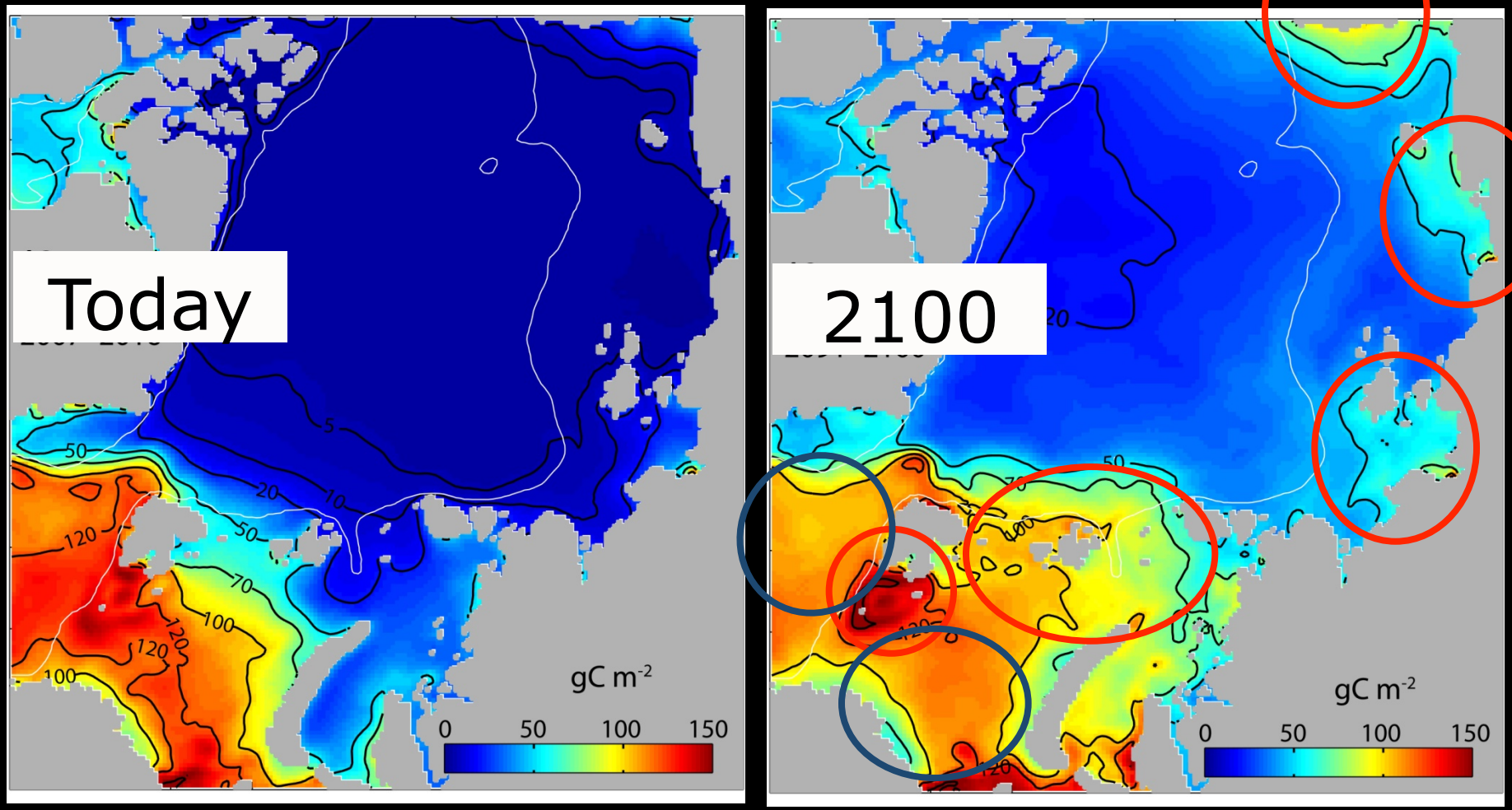
Figure 1. Mean annual water column primary production (in g C m^{-2} yr^{-1}) for (a) NEMO, (b) LANL, (c) UW, (d) UL, (e) OCCAM, and (f) satellite-derived estimates of *Pabi et al.* [2008].

Pan-arctic annual primary production ($gC\ m^{-2}\ yr^{-1}$)

Average of the last 17 years

Slagstad, Wassmann et al. SINMOD nested 3D physical-biological ocean model





Slagstad, Wassmann et al. SINMOD model

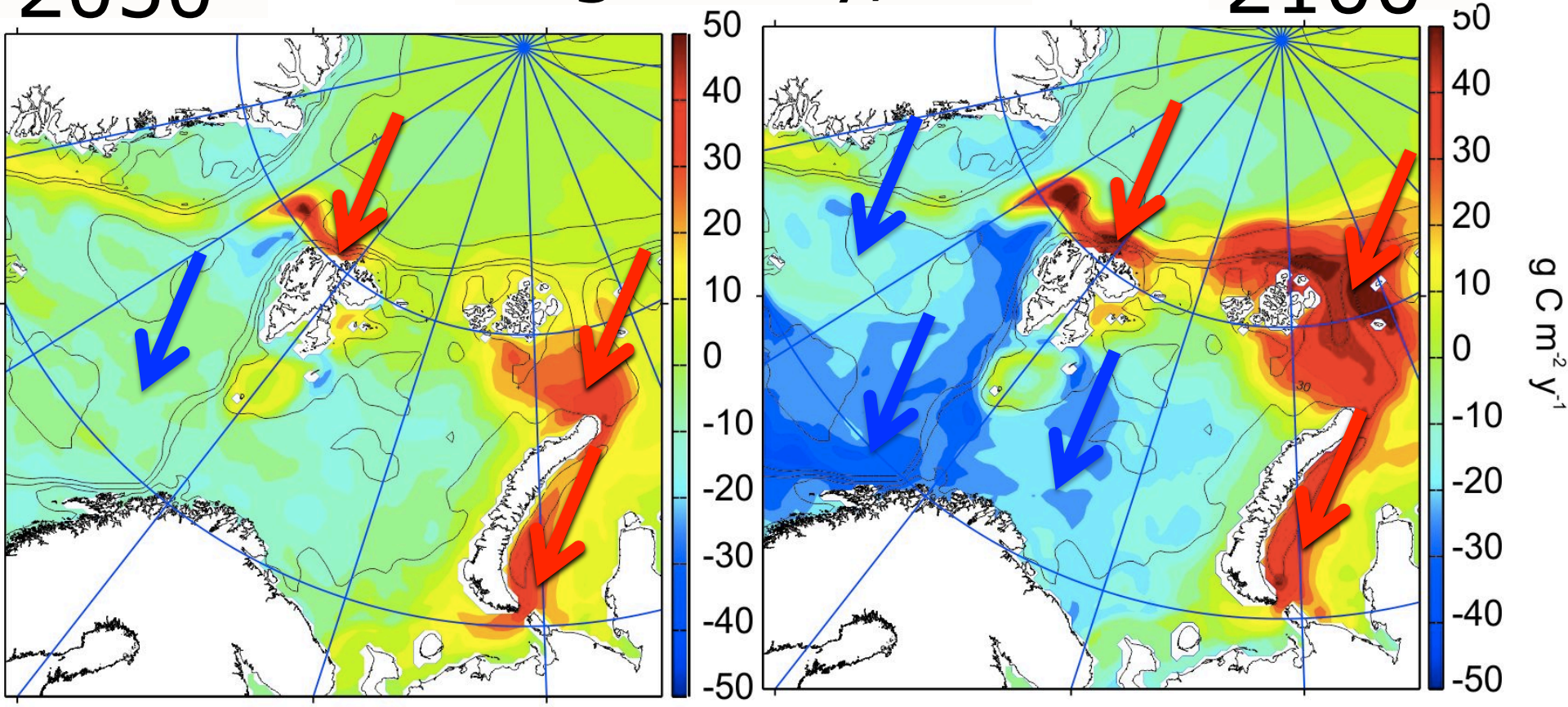
Primary production (g C m^{-2} y^{-1})

Courtesy P Wassmann

Regionally, …

2050

2100



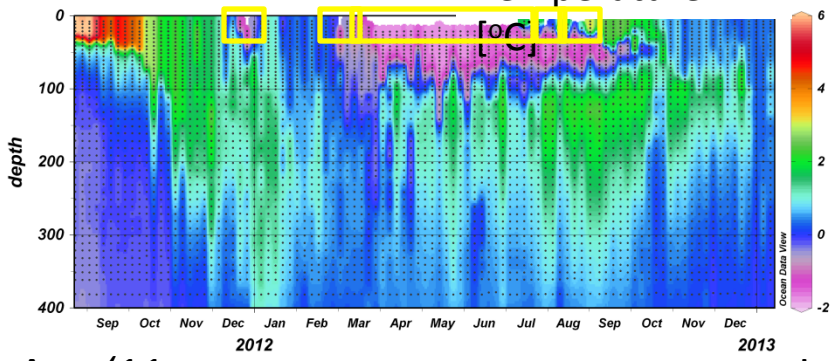
Increase and decrease of phytoplankton primary production

Slagstad, Wassmann et al. SINMOD model

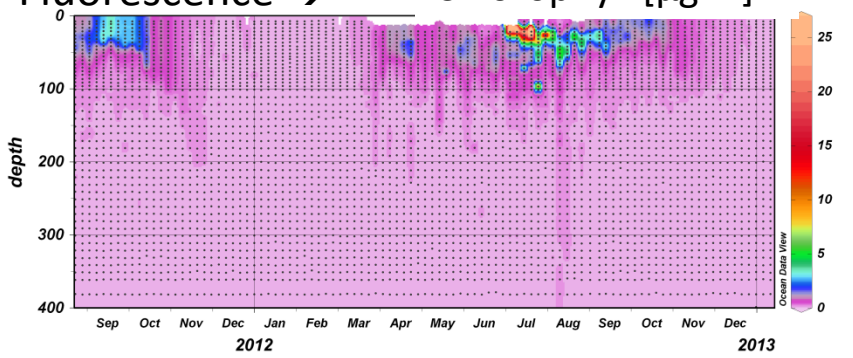
Courtesy P Wassmann

Greenland Sea: Autonomous Bio-Floats 2011-2014

Temperature [°C]



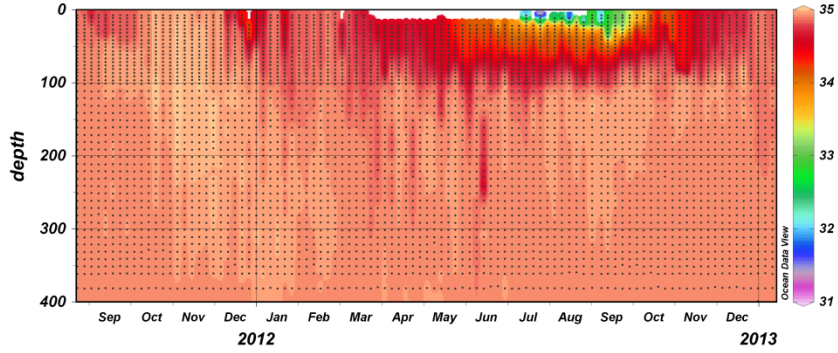
Fluorescence → Chlorophyll [µg l^{-1}]



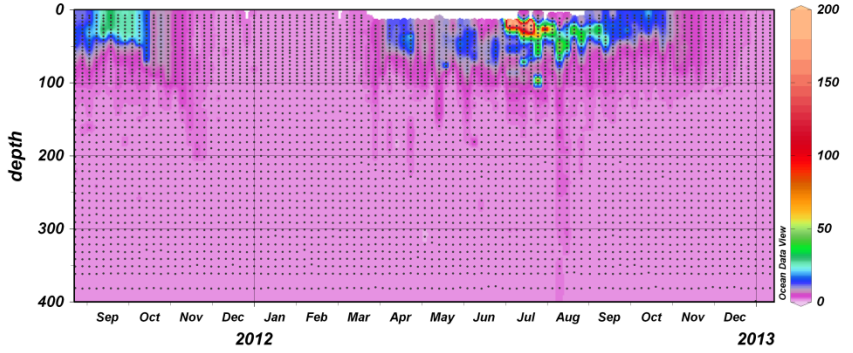
Aug ‘11

Salinity

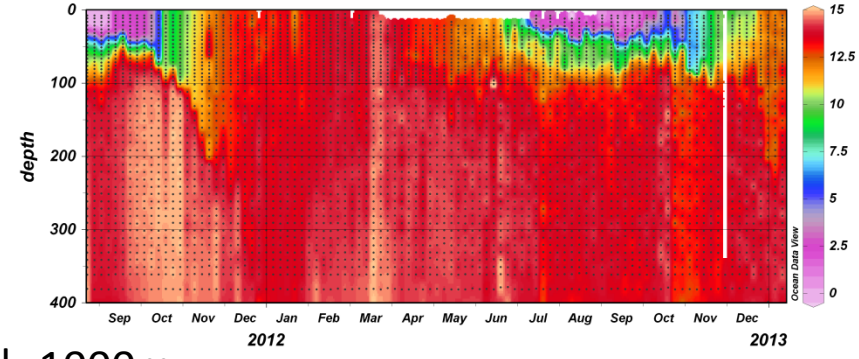
Jan ‘13



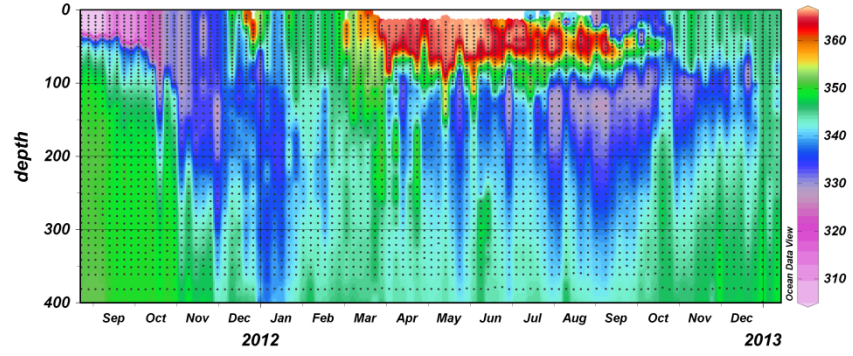
Chlorophyll → NPP [µg C l^{-1} d^{-1}]



Nitrate [µM]



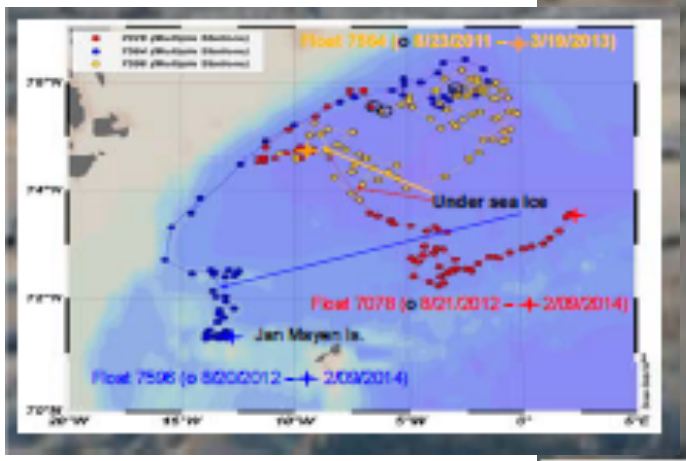
O_2 saturation [%]

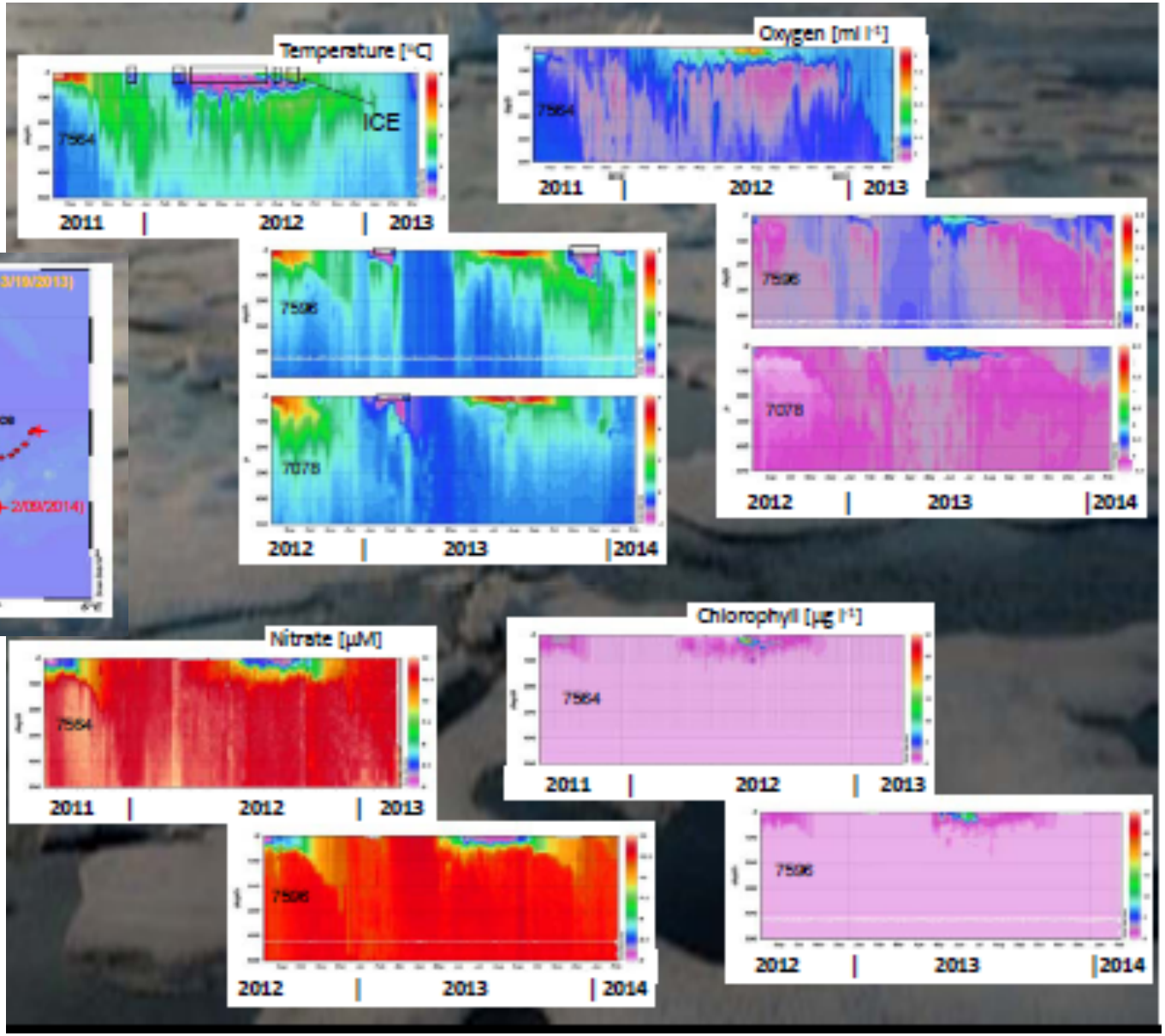


↓ 1000m

Matrai & Steele in prep

Greenland Sea: Autonomous Bio-Floats 2011-2014

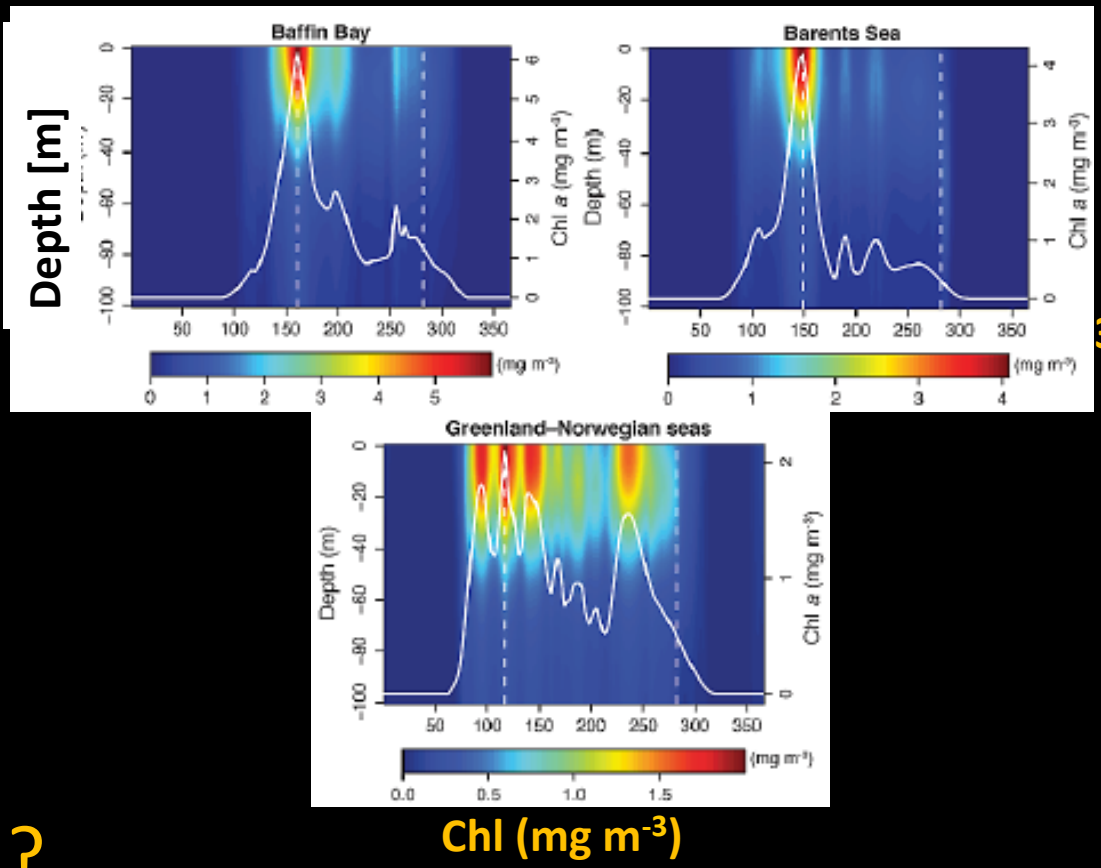




Matrai & Steele in prep

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

Where are the phytos and when?

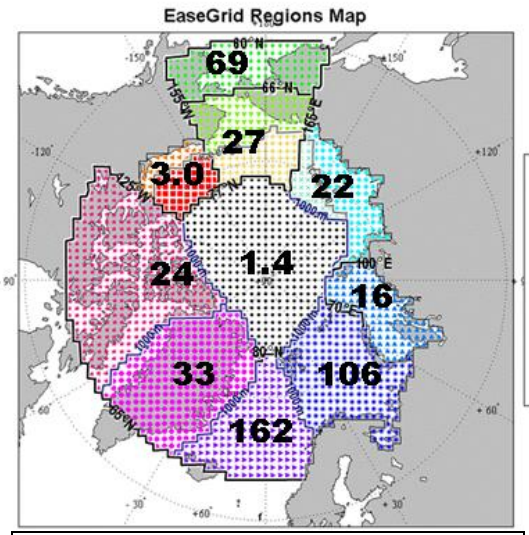


Which spp.?

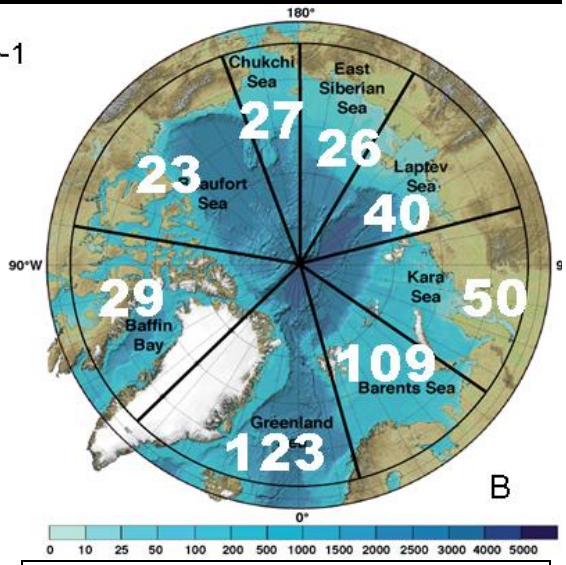
GIN Seas: Canada, UK, Norway, Denmark, Germany

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

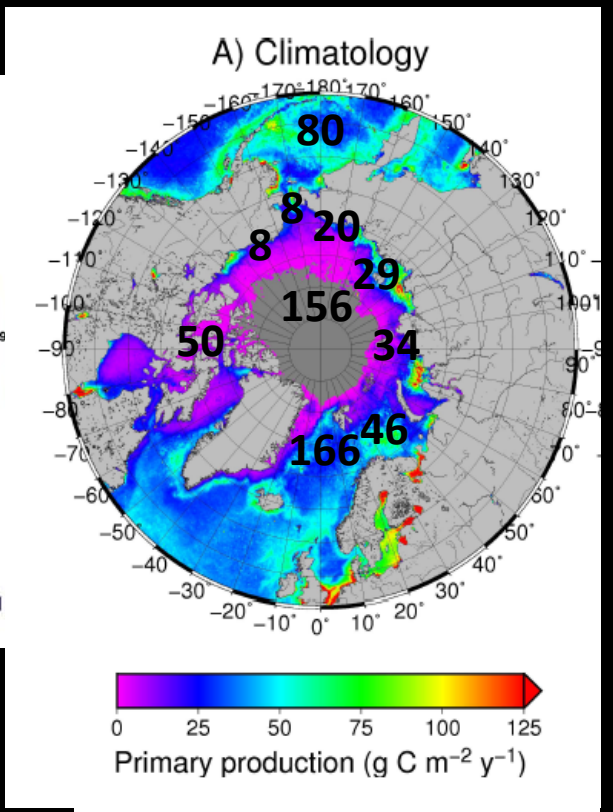
Three empirical estimates of Arctic annual, regional, integrated PP…



Hill et al. 2013



Pabi et al. 2008; Arrigo and Dijken 2011



Bélanger et al. 2013

	GIN Seas (Tg C y^{-1})
Sakshaug 2004	42
Arrigo & van Dijken 2011	148
Hill et al. 2013	118
Ardyna et al. 2013	230 (104 gC m^{-2} y^{-1})
Wassmann et al. 2014	70-100 gC m^{-2} y^{-1}

PPARR-5 Arctic Ocean!
SOLAS/SCOR BEPSII
FAMOS, IOC…

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!

Modeled mixed layer depth examples

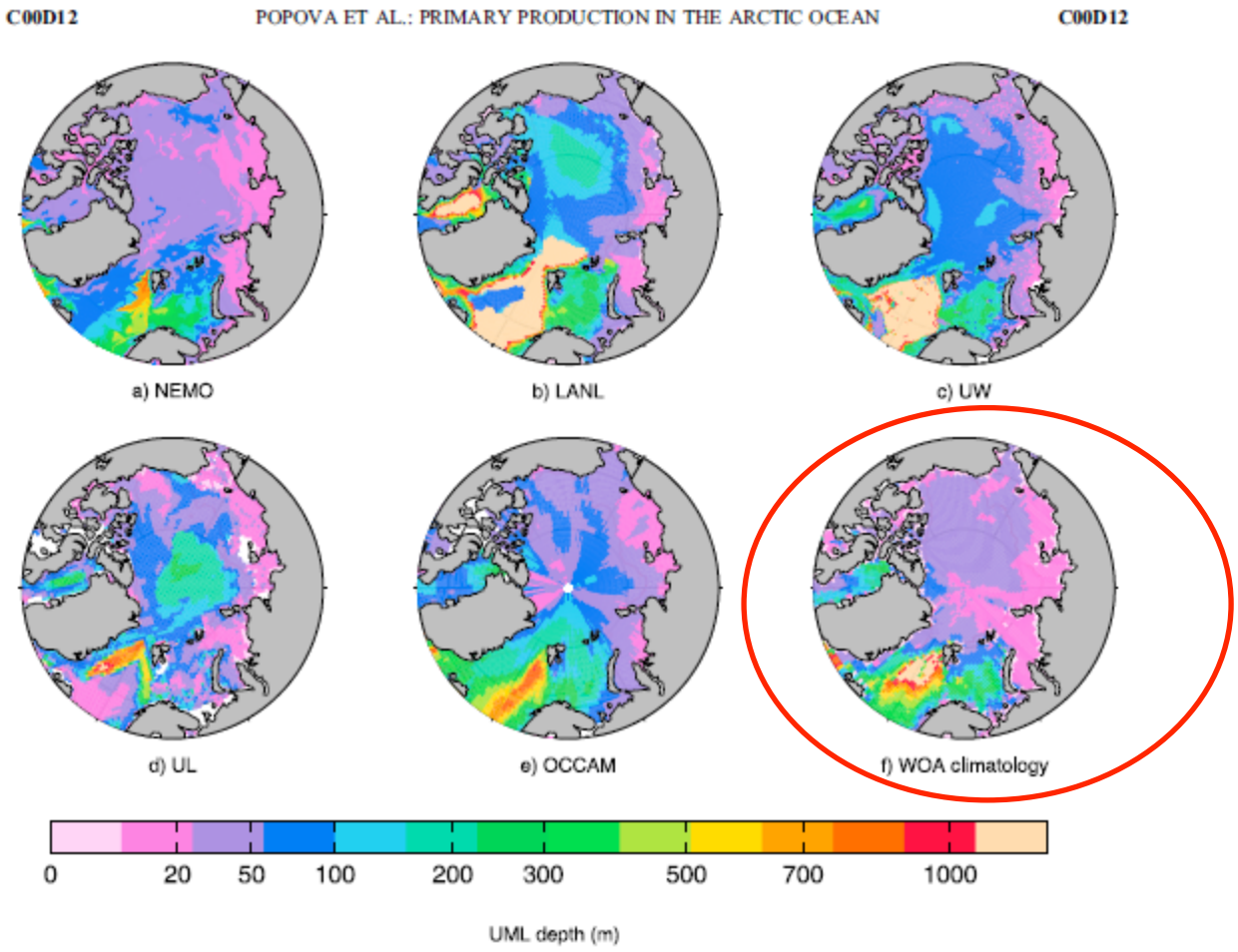


Figure 4. Maximum depth of UML during the year on the basis of monthly averaged values (m; note non-linear color scale) for (a) NEMO, (b) LANL, (c) UW, (d) UL, (e) OCCAM, and (f) WOA climatology.

Same for DIN fields

Popova et al. 2012

ESMs in the Arctic: CMIP5 simulation for 2100

Stratification index -> NO_3

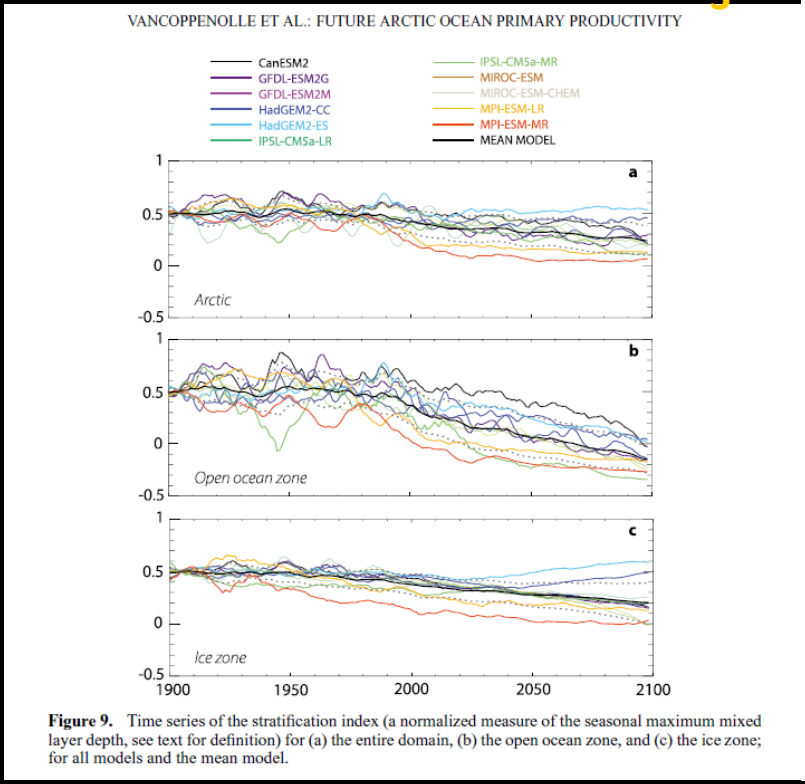


Figure 9. Time series of the stratification index (a normalized measure of the seasonal maximum mixed layer depth, see text for definition) for (a) the entire domain, (b) the open ocean zone, and (c) the ice zone; for all models and the mean model.

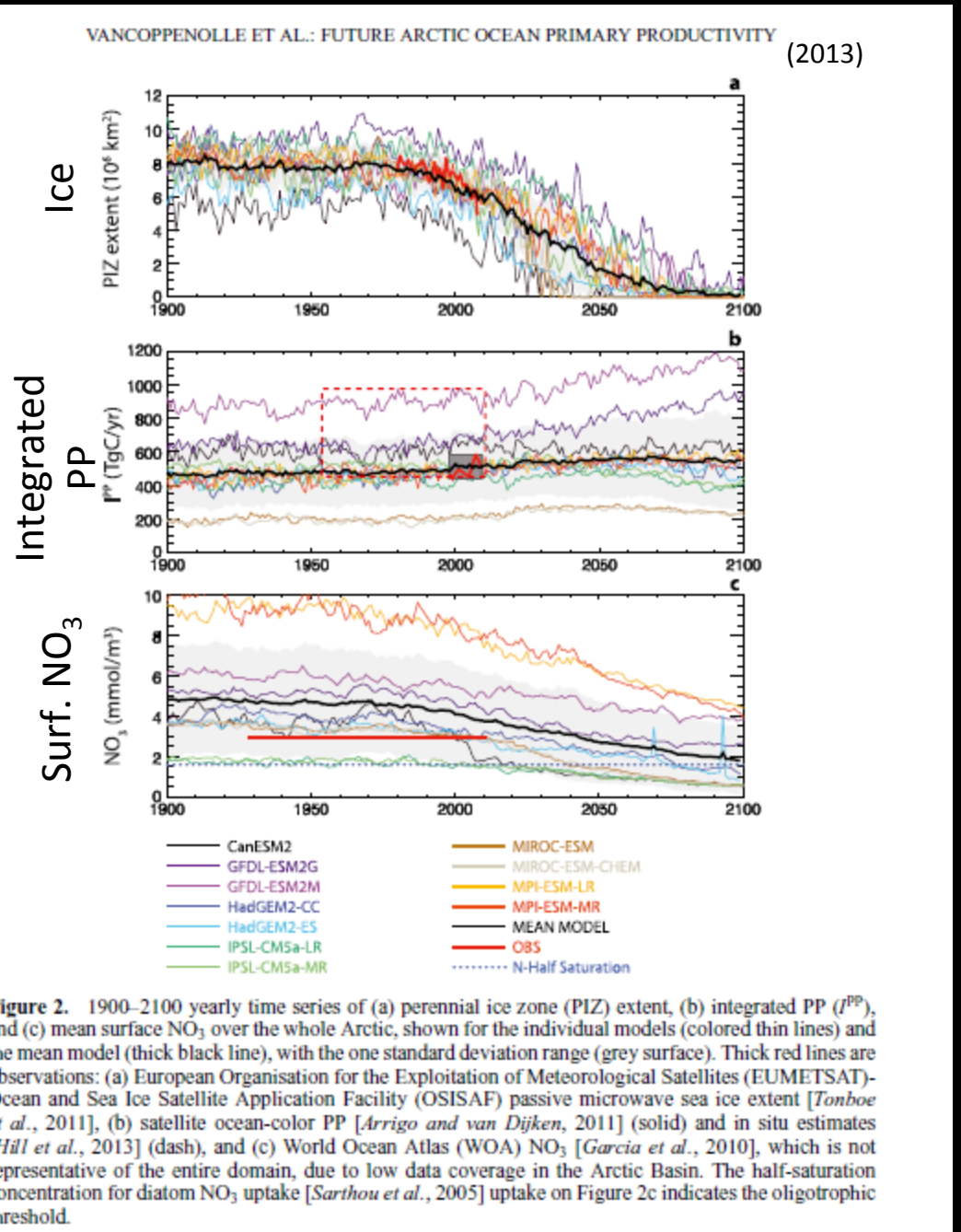
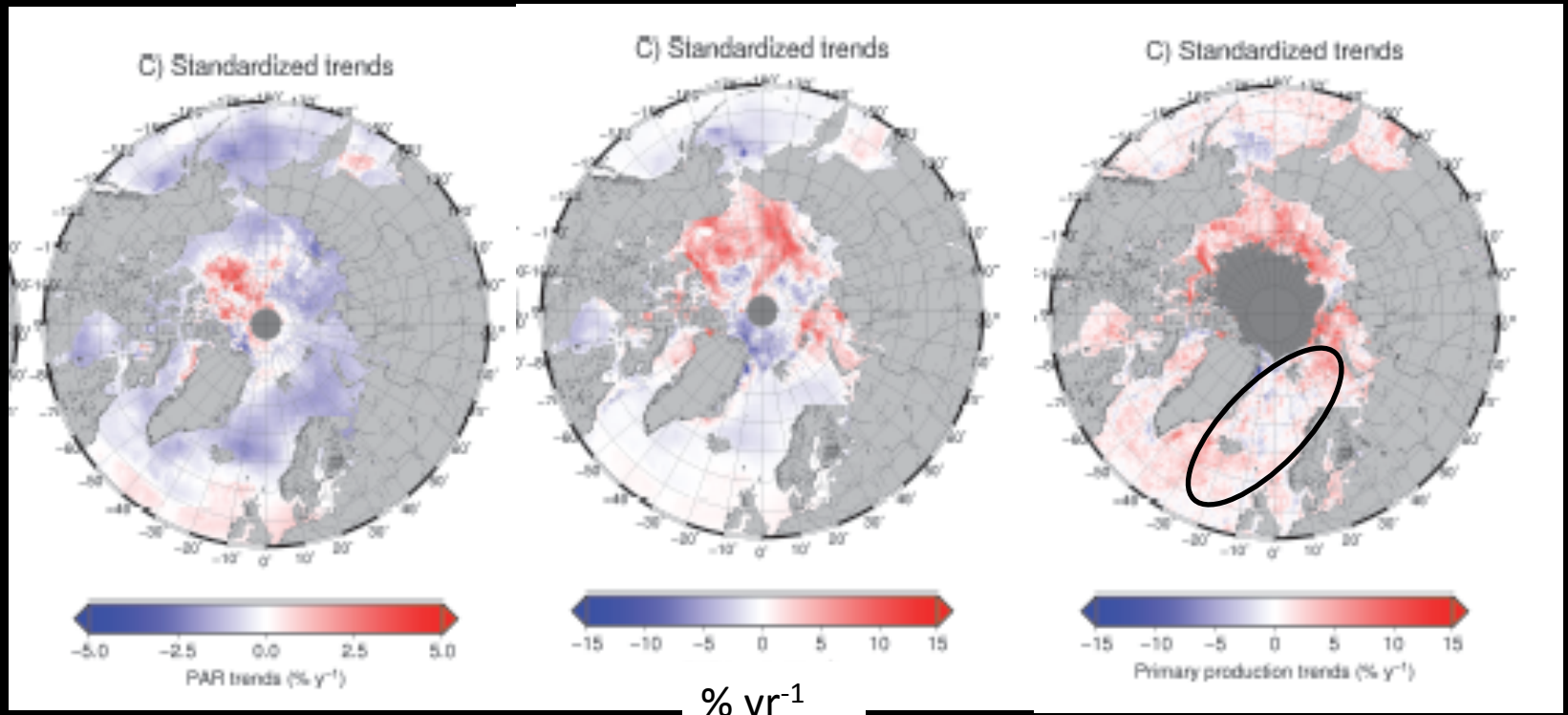


Figure 2. 1900–2100 yearly time series of (a) perennial ice zone (PIZ) extent, (b) integrated PP (I^{PP}), and (c) mean surface NO_3 over the whole Arctic, shown for the individual models (colored thin lines) and the mean model (thick black line), with the one standard deviation range (grey surface). Thick red lines are observations: (a) European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT)-Ocean and Sea Ice Satellite Application Facility (OSISAF) passive microwave sea ice extent [*Tonboe et al.*, 2011], (b) satellite ocean-color PP [*Arrigo and van Dijken*, 2011] (solid) and in situ estimates [*Hill et al.*, 2013] (dash), and (c) World Ocean Atlas (WOA) NO_3 [*Garcia et al.*, 2010], which is not representative of the entire domain, due to low data coverage in the Arctic Basin. The half-saturation concentration for diatom NO_3 uptake [*Sarthou et al.*, 2005] uptake on Figure 2c indicates the oligotrophic threshold.

Clouds and light



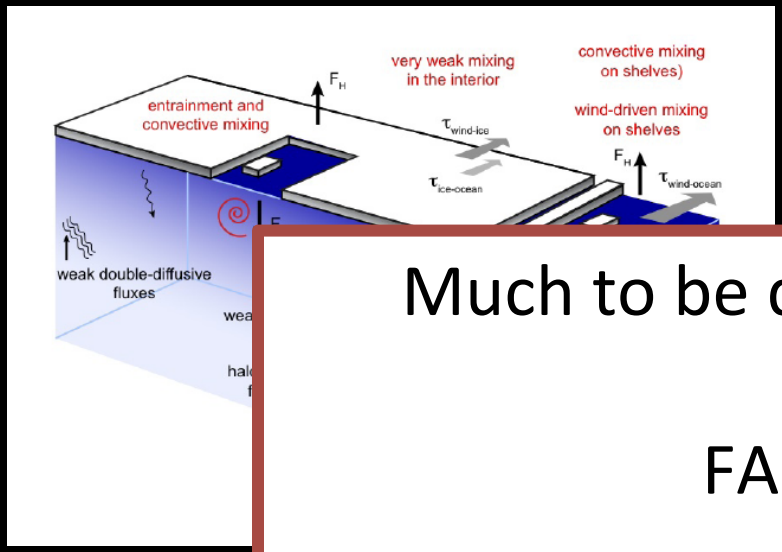
Light decrease (8-20%) (+ clouds) (1998-2009) **ABOVE** sea (ice) surface

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

PP increase (1998-2009) estimated below sea (ice?) surface
- GIN/Barents Sea ~21-26% reduction

Bélanger et al. 2013 BG

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



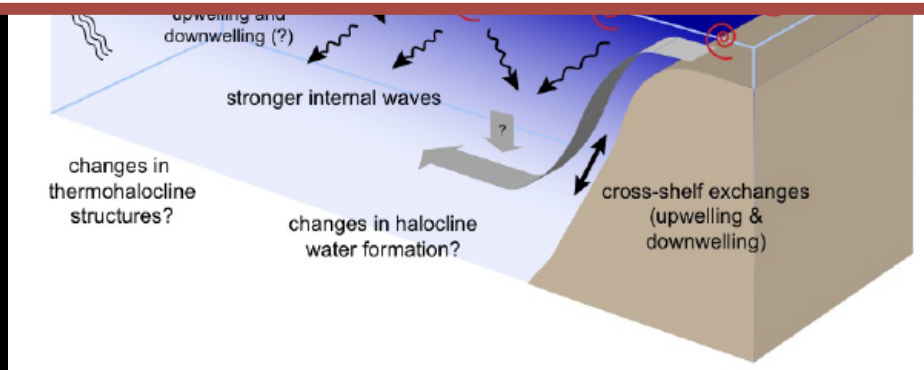
With ice

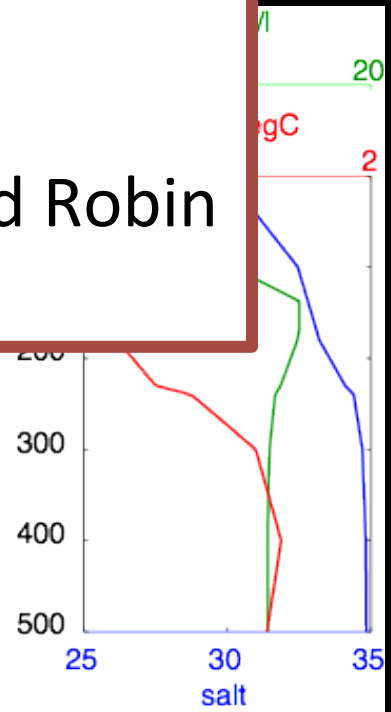
Much to be done on the modeling side:

FAMOS (ex-AOMIP)

5th Primary Production Algorithm Round Robin (40 modeling groups)

Without ice





How deep? Light vs. nutrient balance

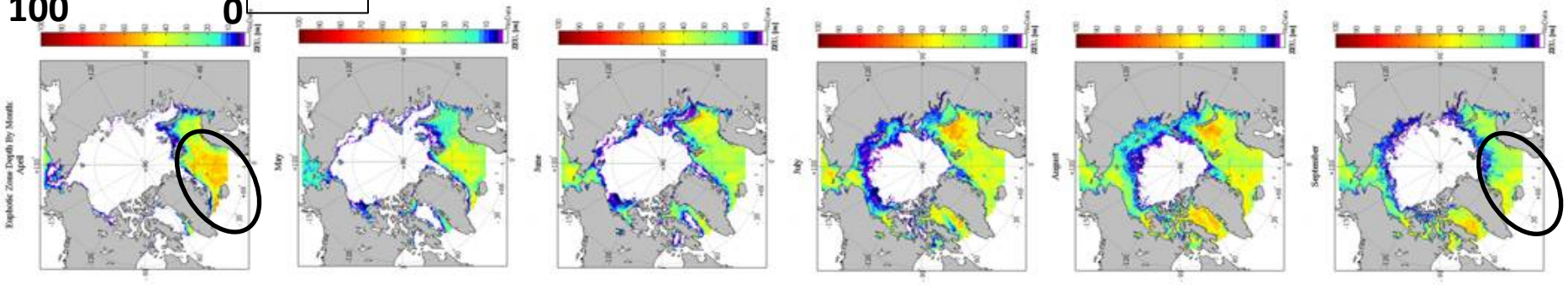
Seasonal distribution of euphotic zone and mixed layer depths from spring to fall in the Arctic Ocean

Satellite-based and field data monthly averages (1998-2007)

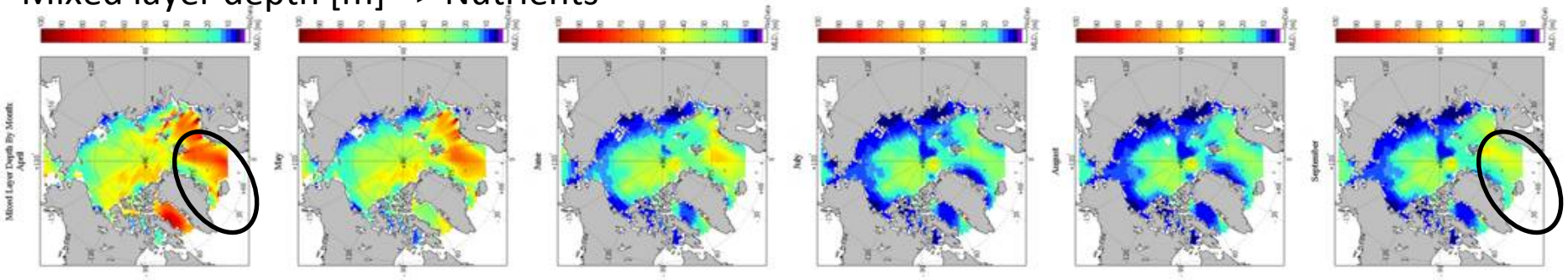
Euphotic zone depth [m] => Light

100 0

No data



Mixed layer depth [m] => Nutrients



April May June July August September

Hill, Matrai et al. 2013