A wide-angle photograph of a vast Arctic sea ice field. The ice consists of numerous small, irregular floes of varying sizes, some appearing as large, flat sheets and others as smaller, more jagged chunks. The ice is a pale, milky white color, with some areas showing a slight blue tint, likely due to the thickness of the ice or the way light reflects off its surface. The background is a clear, pale blue sky, suggesting a bright, sunny day. The overall scene is a desolate and expansive natural landscape.

PPARR-5: Primary Production Algorithm Round Robin in the Arctic Ocean

Patricia Matrai¹, Younjoo Lee¹

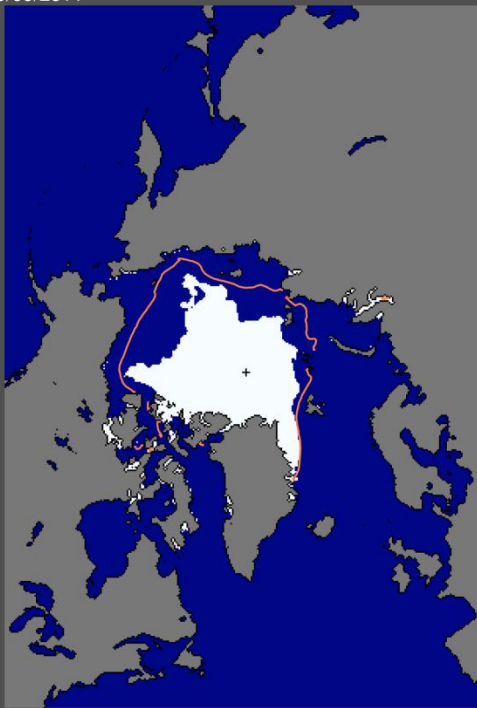
Marjorie Friedrichs², Vincent Saba³

¹Bigelow Laboratory for Ocean Sciences

²VIMS

³NOAA/NMFS/GFDL



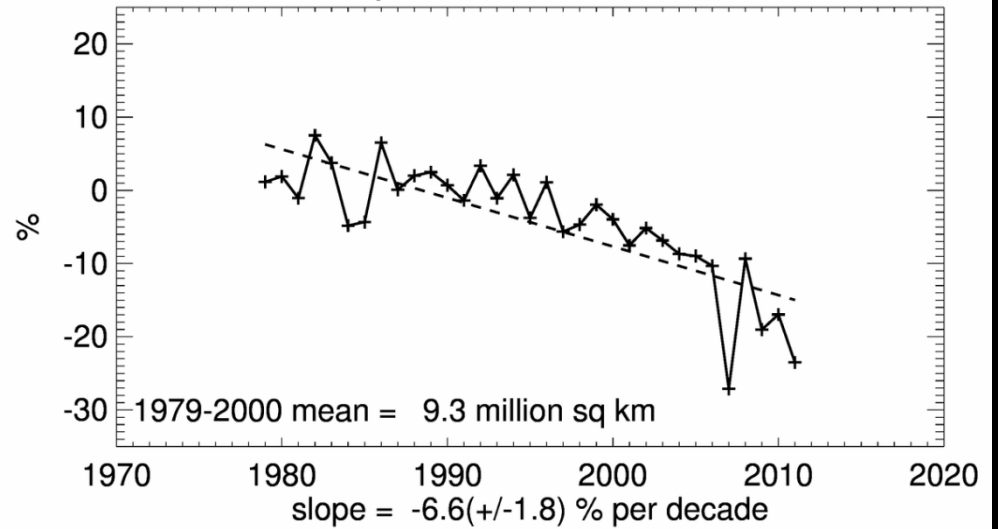


National Snow and Ice Data Center, Boulder, CO

median
1979-2000

Arctic sea ice loss

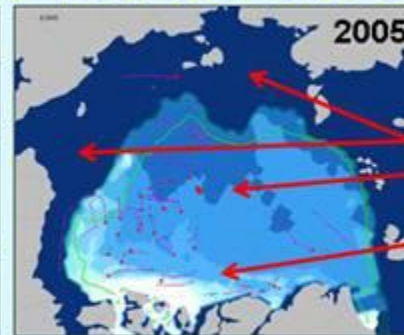
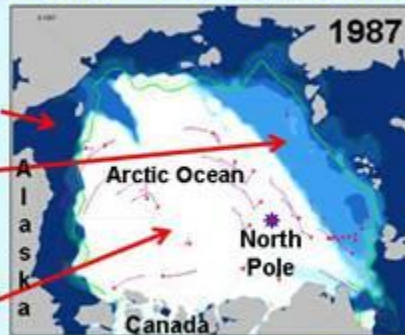
Northern Hemisphere Extent Anomalies Oct 2011



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

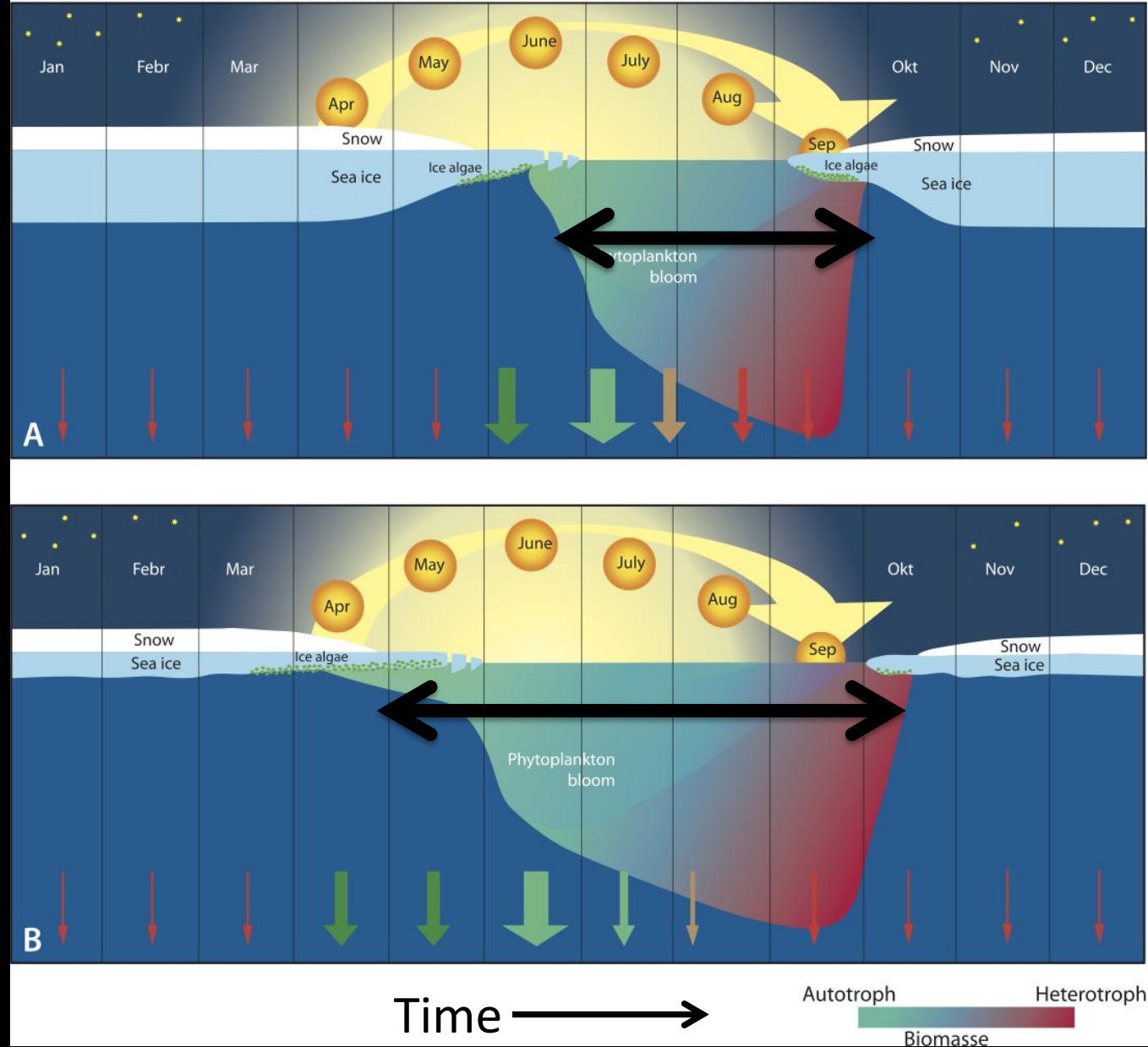
Ice melt and surface warming result in stratification that prevents vertical mixing

Low nutrient supply to surface and thus low harvestable productivity



Today's extreme seasonal variation disappears

Sub-ice blooms increase?



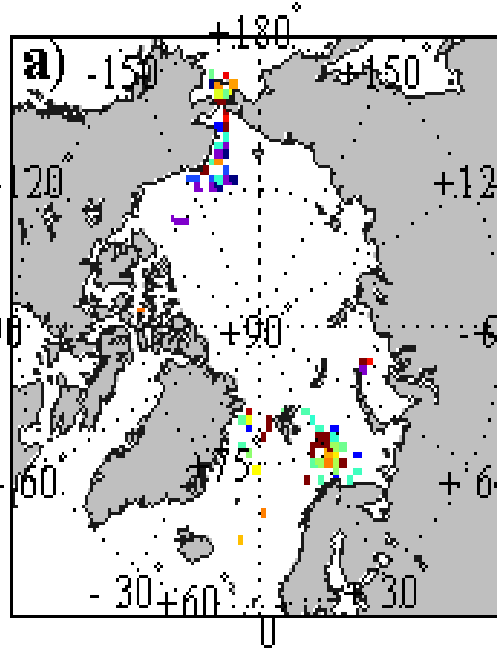
Where is Arctic Primary Production now?

Integrated Annual Net Primary Production (NPP)

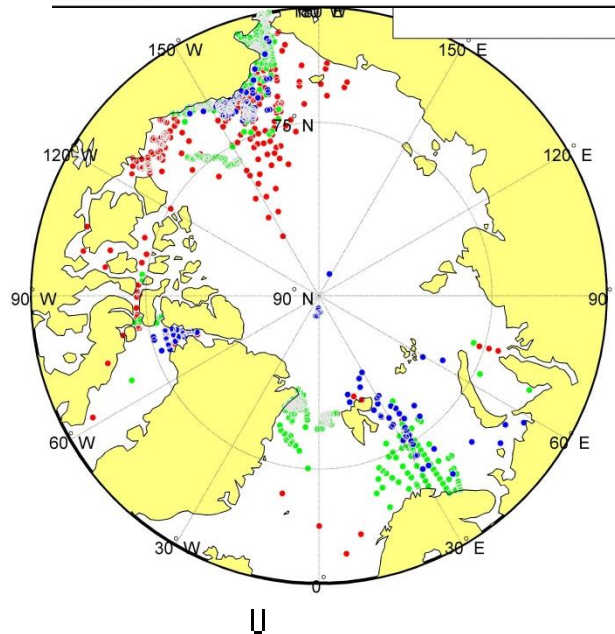
(1954-2007 field data)

(1998-2007 satellite data)

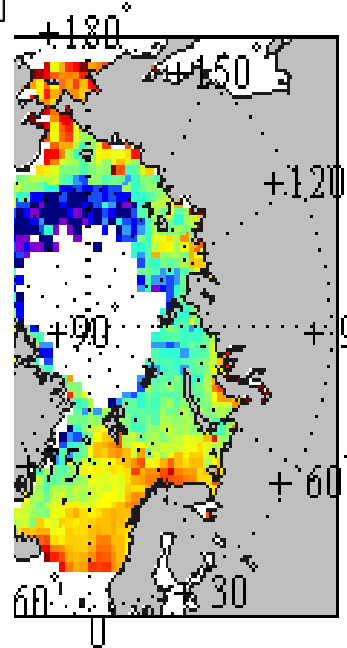
- New Data: 2003-2011
- ARCSS-PP: 1959-1996
- ARCSS-PP: 1997-2007



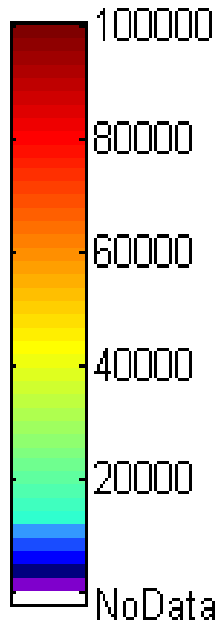
Observed PP



Observed Chl-PP



Satellite PP



Algorithm-estimated NPP based on:

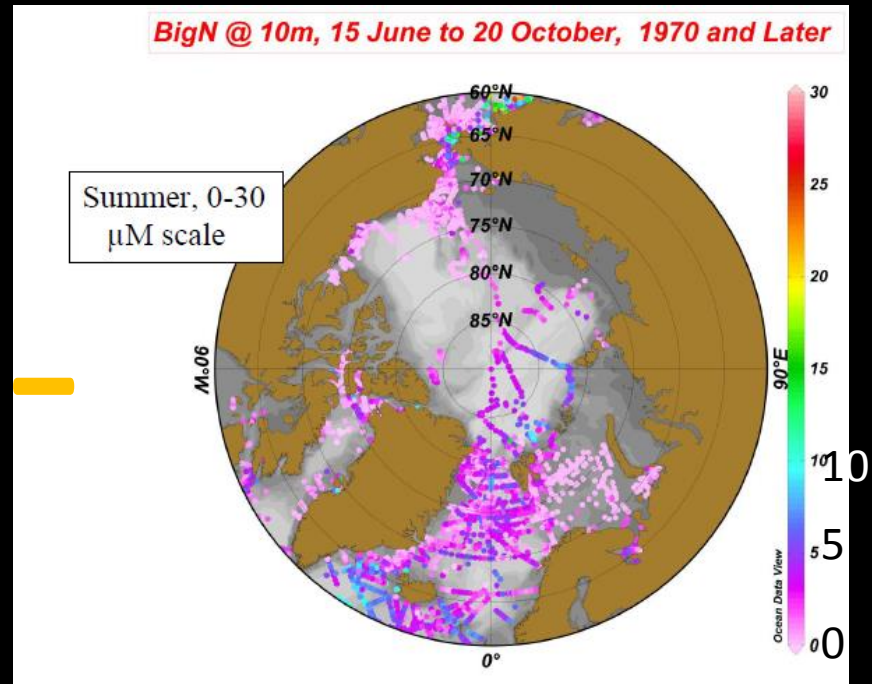
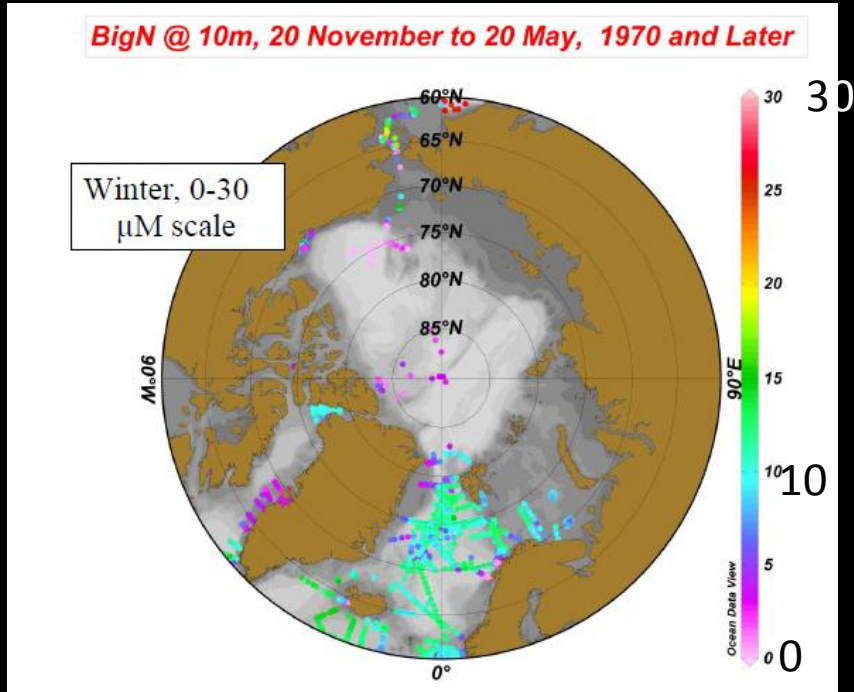
Field Chl

SeaWiFS Chl

0-100 gC m⁻² yr⁻¹

Hill, Matrai et al. 2013

Net Community Production

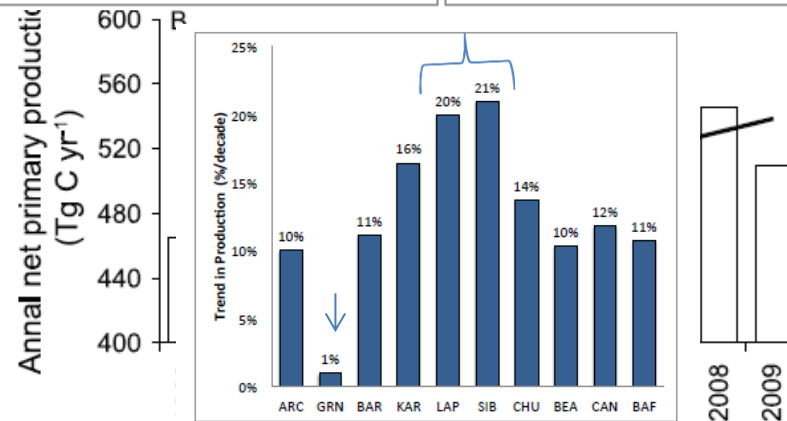
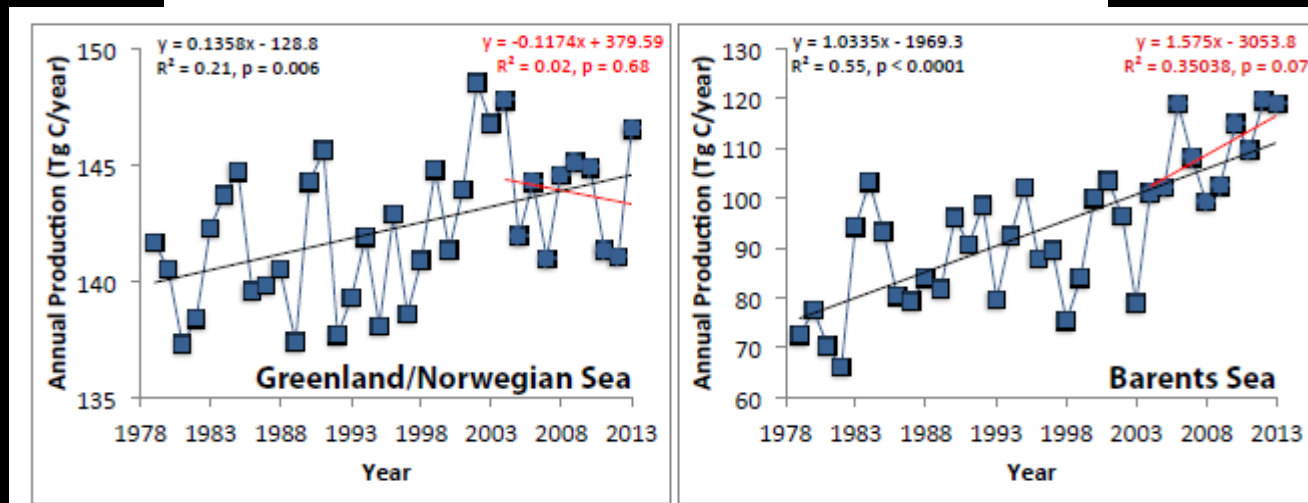


$$\text{NCP} / f \text{ factor} = \text{NPP (or NP?)}$$

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

A biological model applied regionally... using satellite data

Variable regional decadal trends
Pan-arctic decadal trend



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**

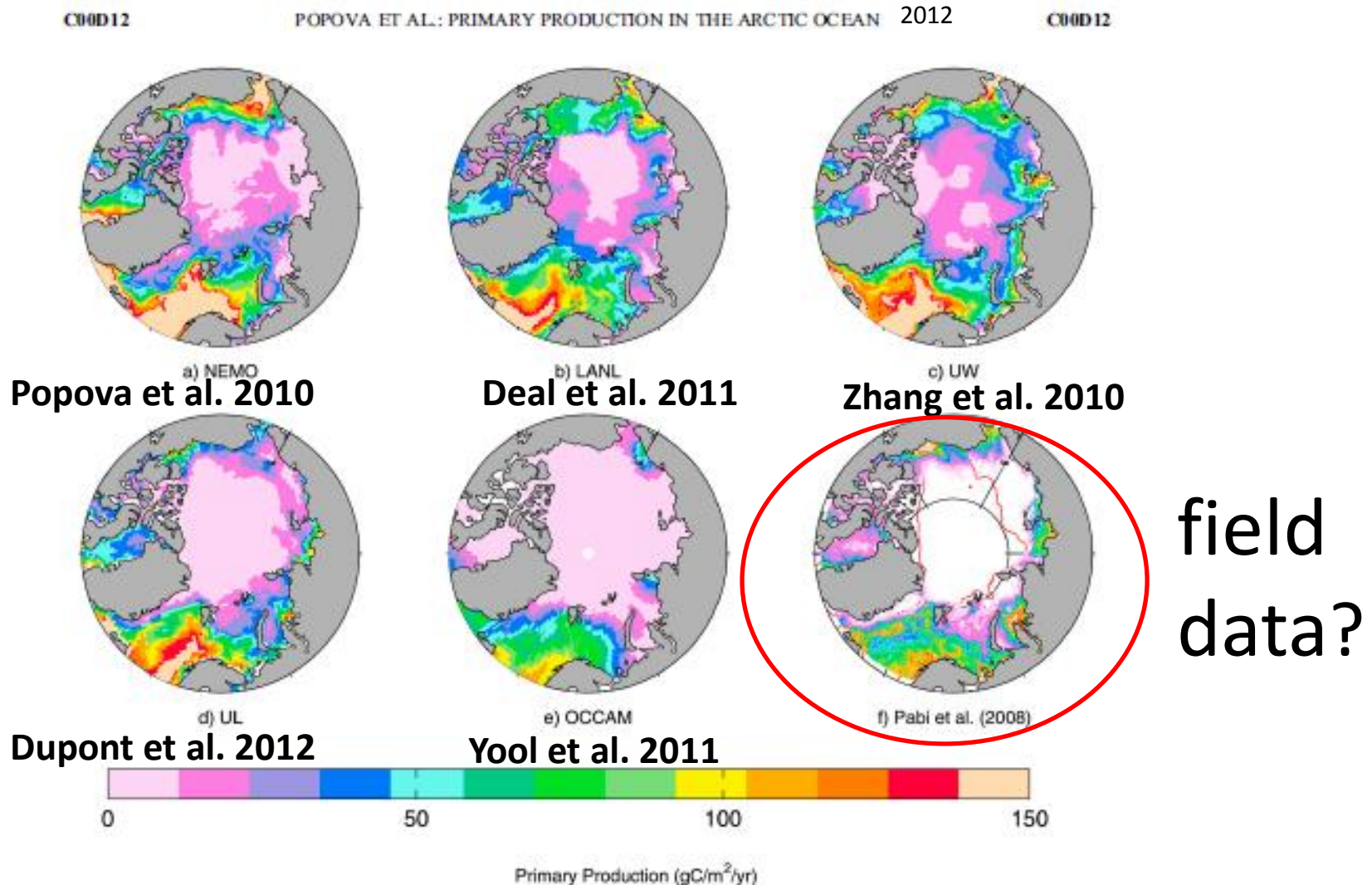
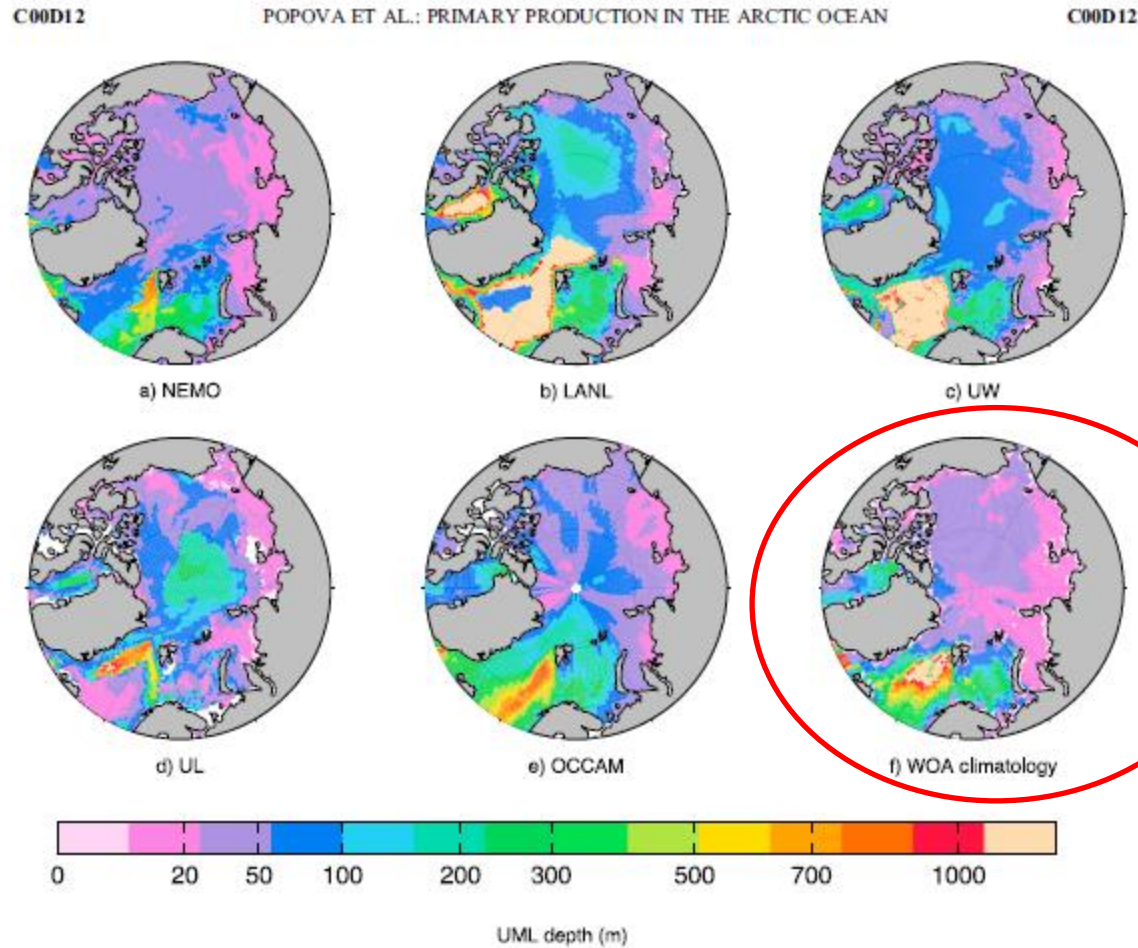


Figure 1. Mean annual water column primary production (in $\text{g C m}^{-2} \text{yr}^{-1}$) for (a) NEMO, (b) LANL, (c) UW, (d) UL, (e) OCCAM, and (f) satellite-derived estimates of Pabi et al. [2008].

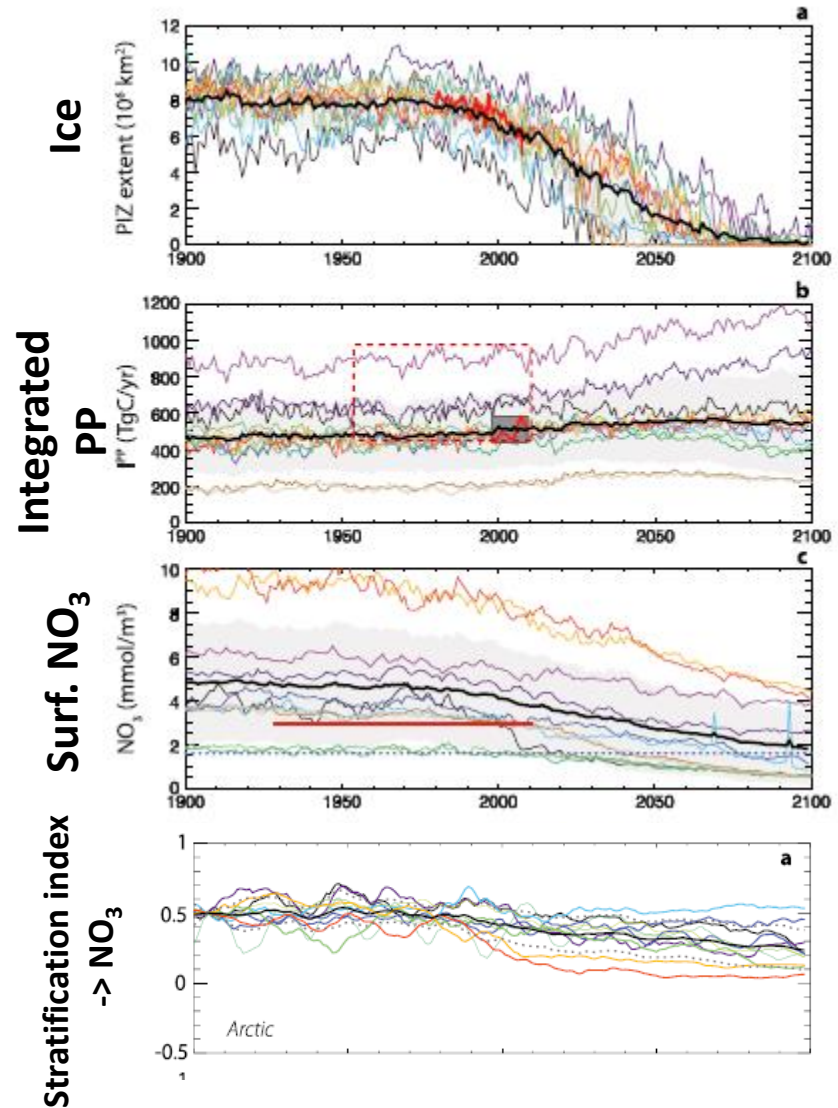
Simulated mixed layer depth examples



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.

ESMs in the Arctic: CMIP5 simulation for 2100



How deep? Light vs. nutrient balance

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

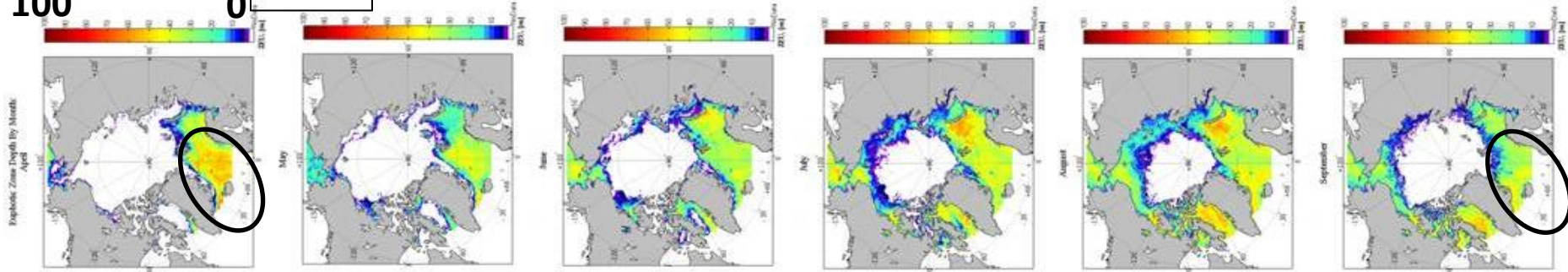
Satellite-based and field data
monthly averages (1998-2007)

Euphotic zone depth [m] => Light

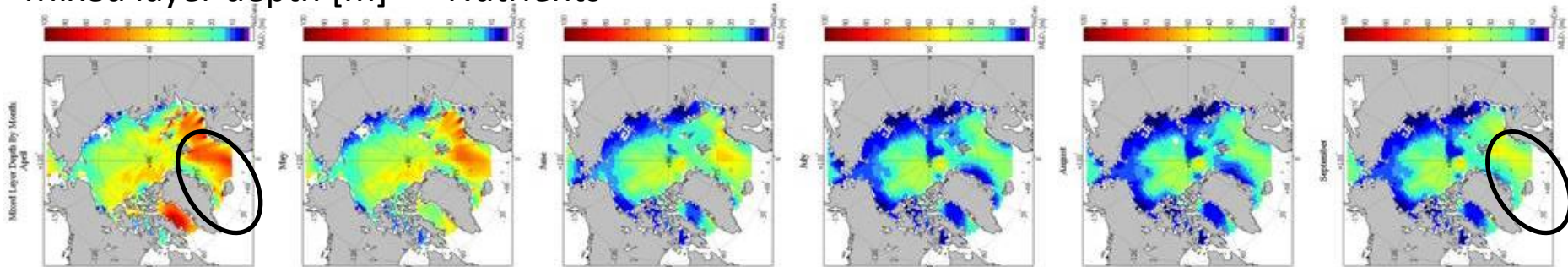
100

0

No data



Mixed layer depth [m] => Nutrients



April

May

June

July

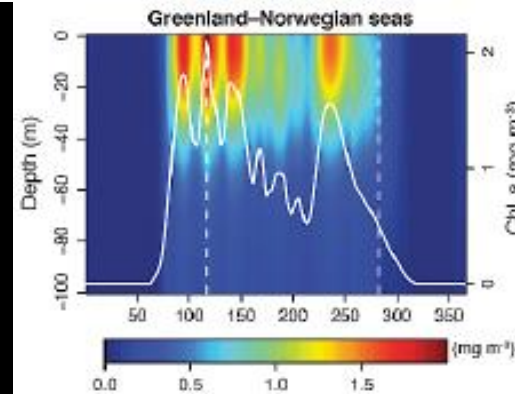
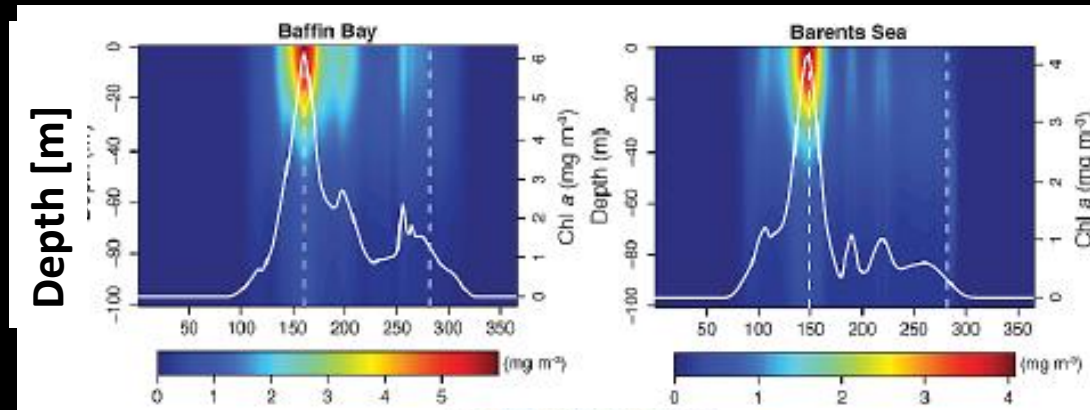
August

September

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

Where are the phytos and when?

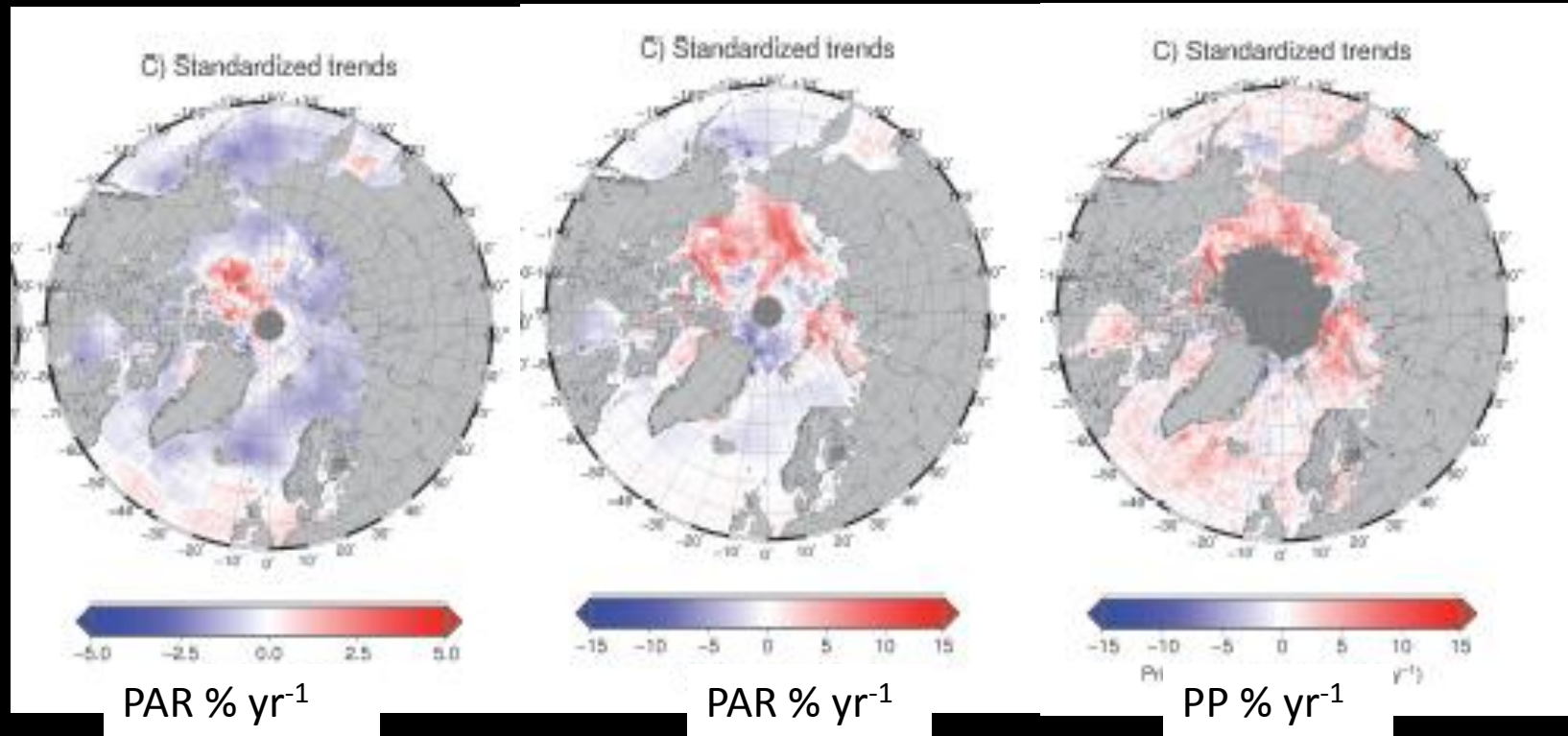
Which spp.?



Chl (mg m⁻³)

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

Clouds and light (1998-2009)



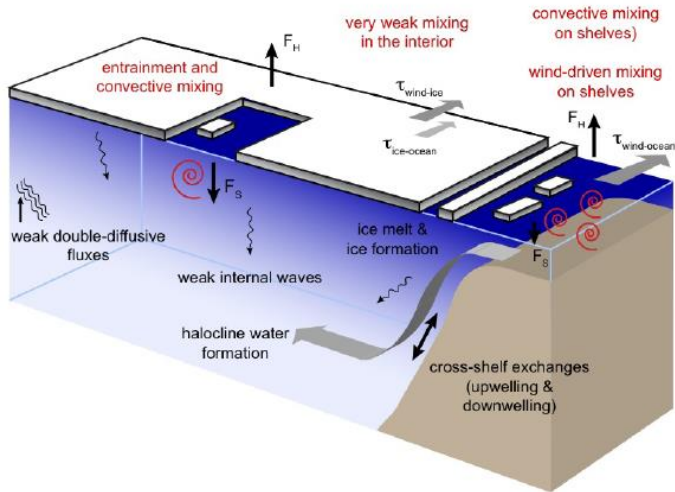
+ clouds =
Light decrease
(8-20%)
ABOVE
sea (ice) surface

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

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

Bélanger et al. 2013 BG

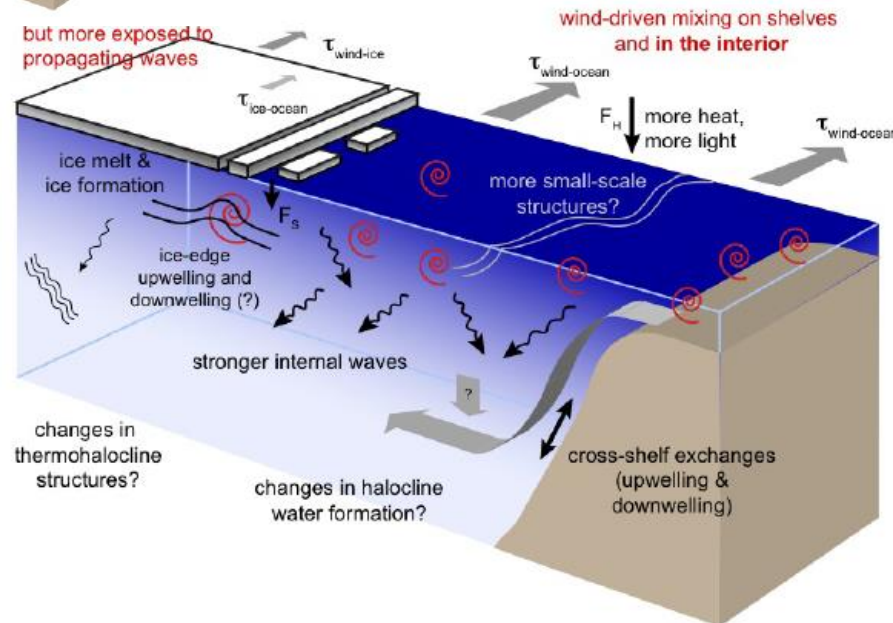
Wind! => wind-driven turbulence and eddies => mixing, nitrate consumption



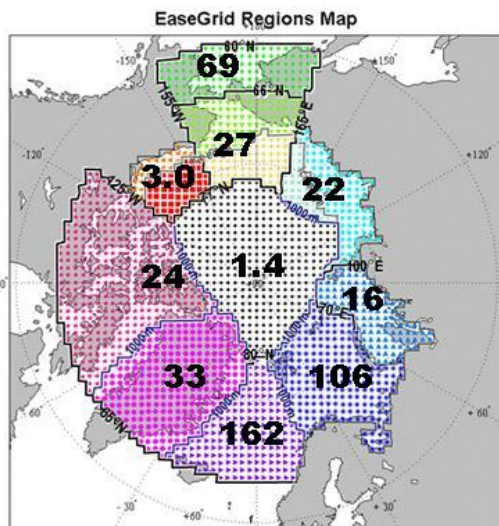
With ice

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

Without ice



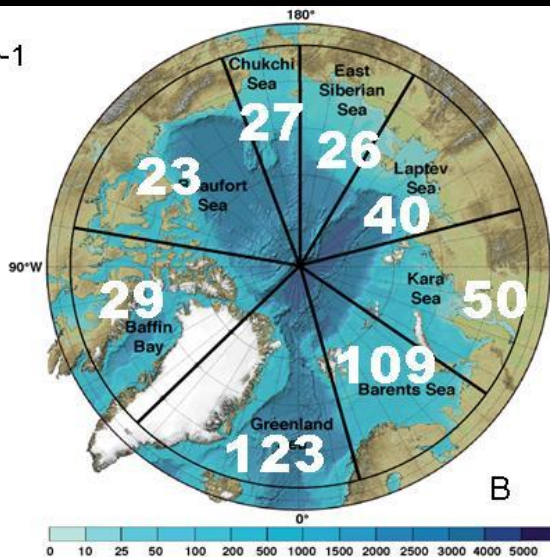
Three empirical estimates of Arctic annual, regional, integrated PP...



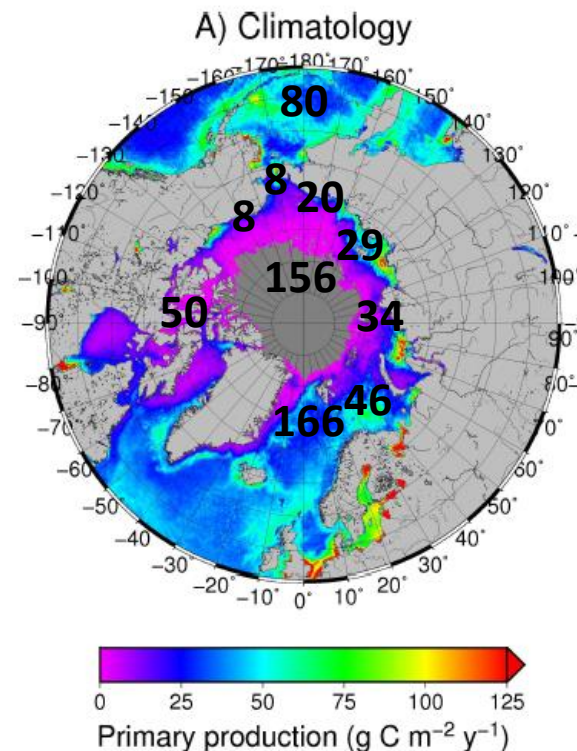
Hill et al. 2013

Tg C yr⁻¹

- Northern Beaufort
- Southern Beaufort
- Northern Chukchi
- Southern Chukchi
- Bering
- N. ESS + Laptev
- S. ESS + Laptev
- Kara
- Barents
- Nordic
- Greenland Shelf
- Canadian Archipelago
- Arctic Basin



Pabi et al. 2008; Arrigo and Dijken 2011



Bélangier et al. 2013

GIN Seas (Tg C yr⁻¹)

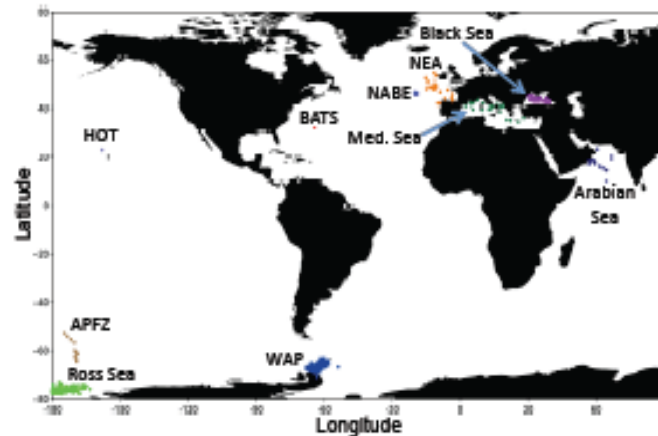
Sakshaug 2004	42
Arrigo & van Dijken 2011	148
Hill et al. 2013	118
Ardyna et al. 2013	230 (104 gC m ⁻² y ⁻¹)
Wassmann et al. 2014	70-100 gC m ⁻² y ⁻¹

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

PPARR-5 Arctic Ocean!

Previously NASA-funded PPARRs

Biogeosciences, 8, 489–503, 2011
 www.biogeosciences.net/8/489/2011/
 doi:10.5194/bg-8-489-2011
 © Author(s) 2011. CC Attribution 3.0 License



An evaluation of ocean color model estimates of marine primary productivity in coastal and pelagic regions across the globe

V. S. Saba^{1,2}, M. A. M. Friedrichs¹, D. Antoine³, R. A. Armstrong⁴, I. Asanuma⁵, M. J. Behrenfeld⁶, A. M. Ciotti⁷, M. Dowell⁸, N. Hoepffner⁸, K. J. W. Hyde⁹, J. Ishizaka¹⁰, T. Kameda¹¹, J. Marra¹², F. Mélin⁸, A. Morel³, J. O'Reilly⁹, M. Scardi¹³, W. O. Smith Jr.¹, T. J. Smyth¹⁴, S. Tang¹⁵, J. Uitz¹⁶, K. Waters¹⁷, and T. K. Westberry⁶

PPARR-4: Ocean color and GCM models; field and satellite data; spatial or temporal resolution

Comparison of algorithms for estimating ocean primary production from surface chlorophyll, temperature, and irradiance

Janet Campbell,¹ David Antoine,² Robert Armstrong,³ Kevin Arrigo,⁴ William Balch,⁵ Richard Barber,⁶ Michael Behrenfeld,⁷ Robert Bidigare,⁸ James Bishop,⁹ Mary-Elena Carr,¹⁰ Wayne Esaias,⁷ Paul Falkowski,¹¹ Nicolas Hoepffner,¹² Richard Iverson,¹³ Dale Kiefer,¹⁴ Steven Lohrenz,¹⁵ John Marra,¹⁶ Andre Morel,² John Ryan,¹⁷ Vladimir Vedernikov,¹⁸ Kirk Waters,¹⁹ Charles Yentsch,⁵ and James Yoder²⁰

Table 3. Data Sets Used to Test Algorithms^a

Data Set	Region
AMERIEZ	Antarctica
SUPER	North Pacific
EqPac nonequator	Tropical Pacific
NABE	Northeast Atlantic
EqPac equator	Equatorial Pacific
Arabian Sea	Arabian Sea
PROBES	Bering Sea
MARMAP	Northwest Atlantic
Palmer LTER	Antarctica

PPARR-1, 2: Ocean color models; field data only

color and GCM models;

iences

006) 741-770

www.elsevier.com/locate/dsr2

of marine primary production in color

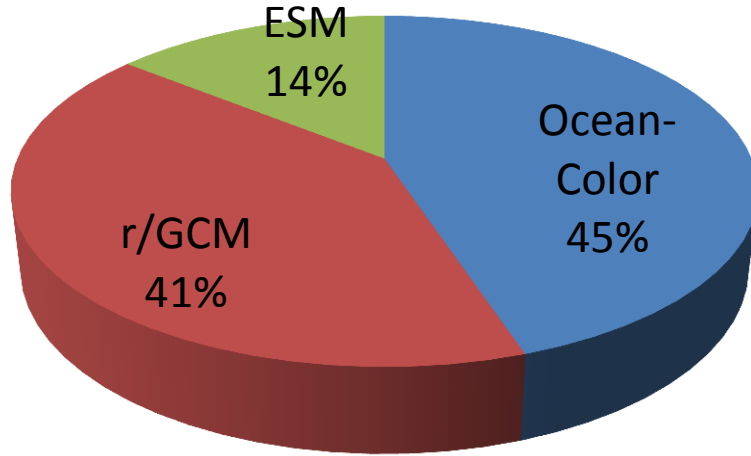
Friedrichs^{b,bb}, Marjorie Schmelz^a, Kevin R. Arrigo^e, Ichio Asanuma^f, Michael Behrenfeldⁱ, Robert Bidigare^j, Aurea Ciotti^m, Heidi Dierssenⁿ, Bernard Gentili^d, Watson Gregg^q, Nicolas Hoepffner^r, Joji Ishizaka^s, Takahiko Kameda^t, Le Quéré^{k,u}, Steven Lohrenz^v, John Marra^w, Frédéric Mélin^o, André Morel^d, Tasha E. Reddy^e, John Ryan^y, Michele Scardi^z, Kevin Turpie^q, Gavin Tilstone^f, Kirk Waters^{aa}, Yasuhiro Yamanaka^c

PPARR-5 Arctic Ocean Strategy

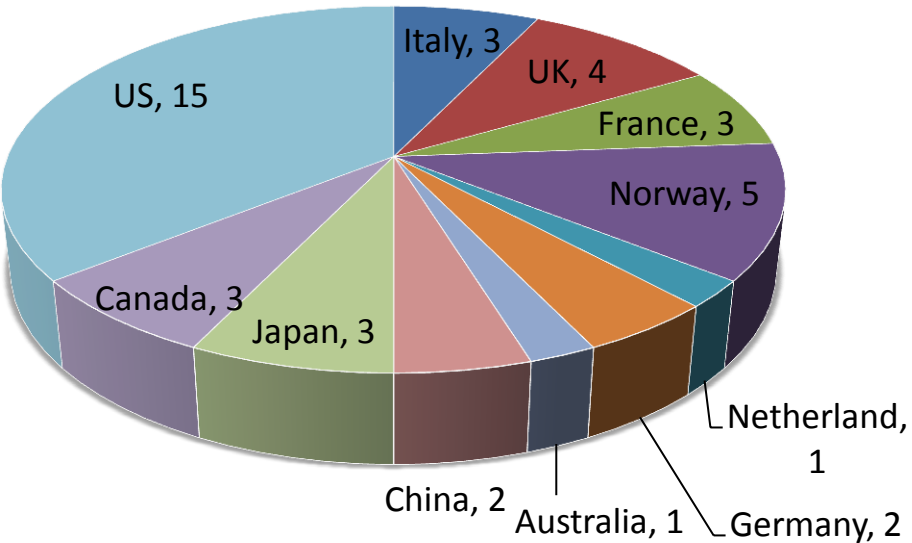
- Compilation, quality control, and characterization of field and remotely-sensed data: **Done**
- 1-D biological or biogeochemical, ocean color, phys-biol coupled ocean, GCM, ESM models invited : **Now**

5th Primary Production Algorithm Round Robin

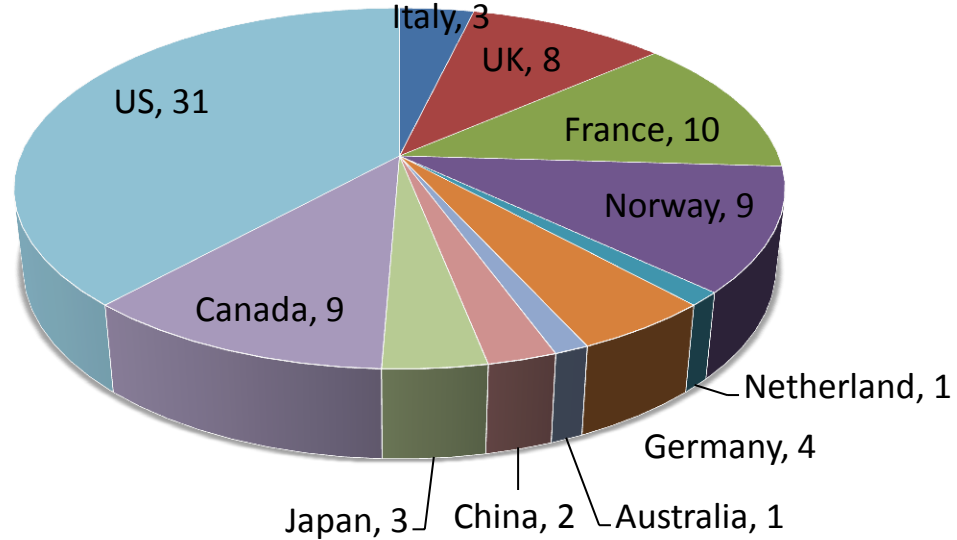
Participating Model Types



of Modeling Groups: 42 + 3!



of Participants: 81+



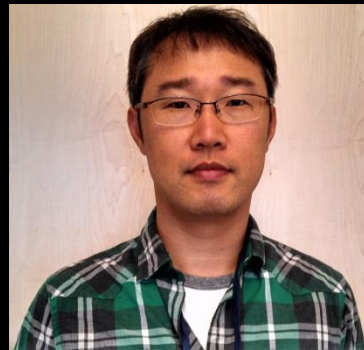
Over the next 1.5 years:

- Statistical analyses of the observed and modeled NPP
- Feedback and iterations with the modelers on model performance
- Inter-model comparisons of Arctic NPP historical and future projections

- **Contact us!**

Younjoo Lee

ylee@bigelow.org





Thank you!