# Impact of Climate Change on Polar Ecology

## Focus on Arctic

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TAKUVIK

Reports and Monographs of the International
Ocean-Colour Coordinating Group

An Affiliated Program of the Scientific Committee on Oceanic Research (SCOR)
An Associated Member of the Committee on Earth Observation Satellites (CEOS)

IOCCG Report Number 16, 2015

# Ocean Colour Remote Sensing in Polar Seas

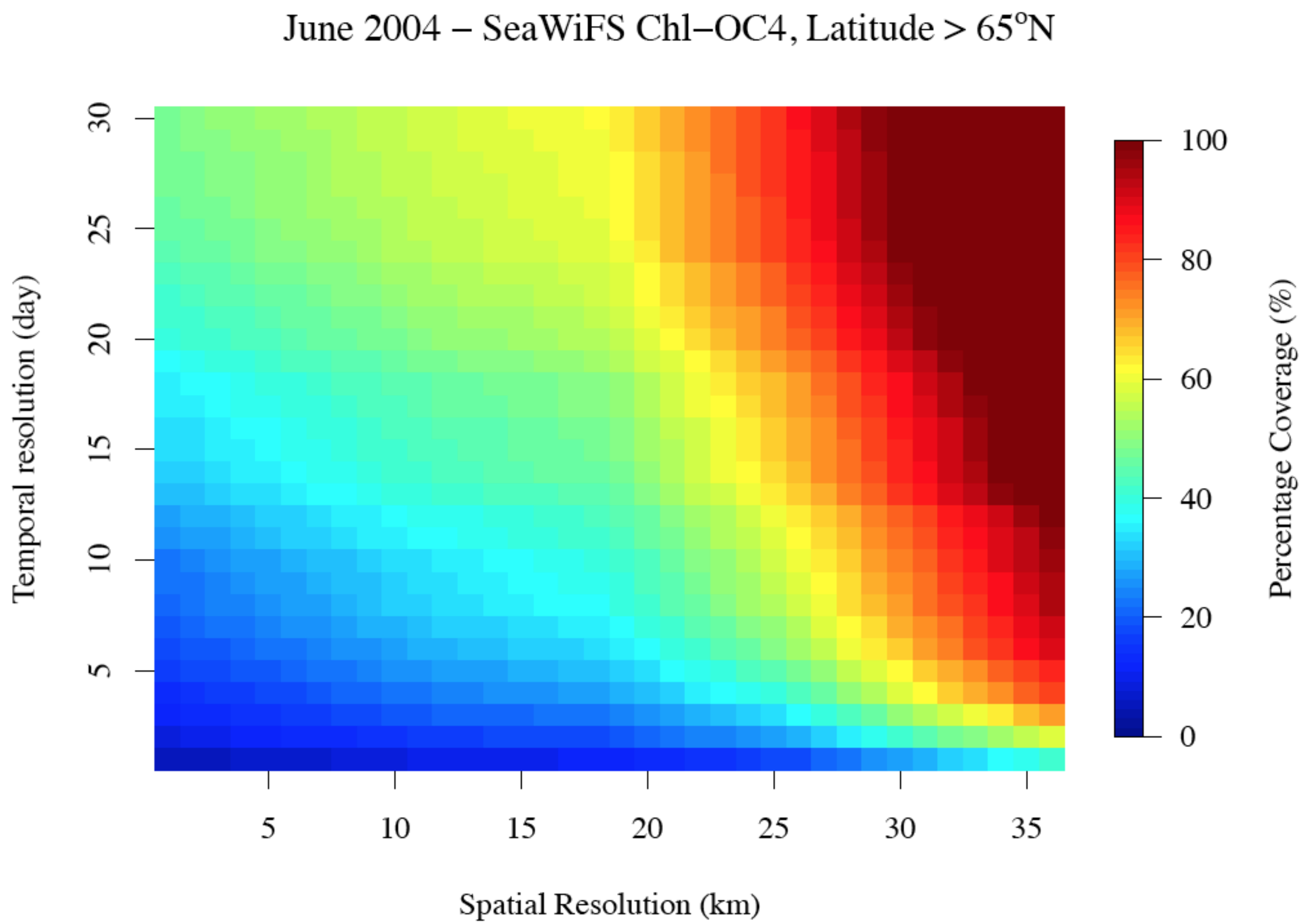
Authors:
Babin, M., Arrigo, K., Bélanger, S., Benoît-Gagné, M., Comiso, J., Forget, M-H., Goyens, C., Frouin, R., Hill, V., Hirawake, T., Matsuoka, A., Mitchell, G., Perovich, D., Reynolds, R., Stamnes, K., Wang, M.

# Limitations of OCRS in Arctic

- Low Sun elevation
  - No data for $\theta_s > 70°$
  - Affect atmospheric corrections
- Elevated cloudiness
  - Periods of the year with no data
- Presence of sea ice
  - Contamination by sub-pixel ice floes
  - Adjacency effect at the ice edge
- Unusual inherent optical properties
  - Underestimate of Chl due to pigment packaging
- Prevalence of deep-chlorophyll maxima
  - Possible underestimate of depth-integrated PP
- Underice blooms
  - Not documented by OCRS
- Unusual photosynthetic parameters
  - Error in PP estimates

One example…

# Cloudiness and data binning

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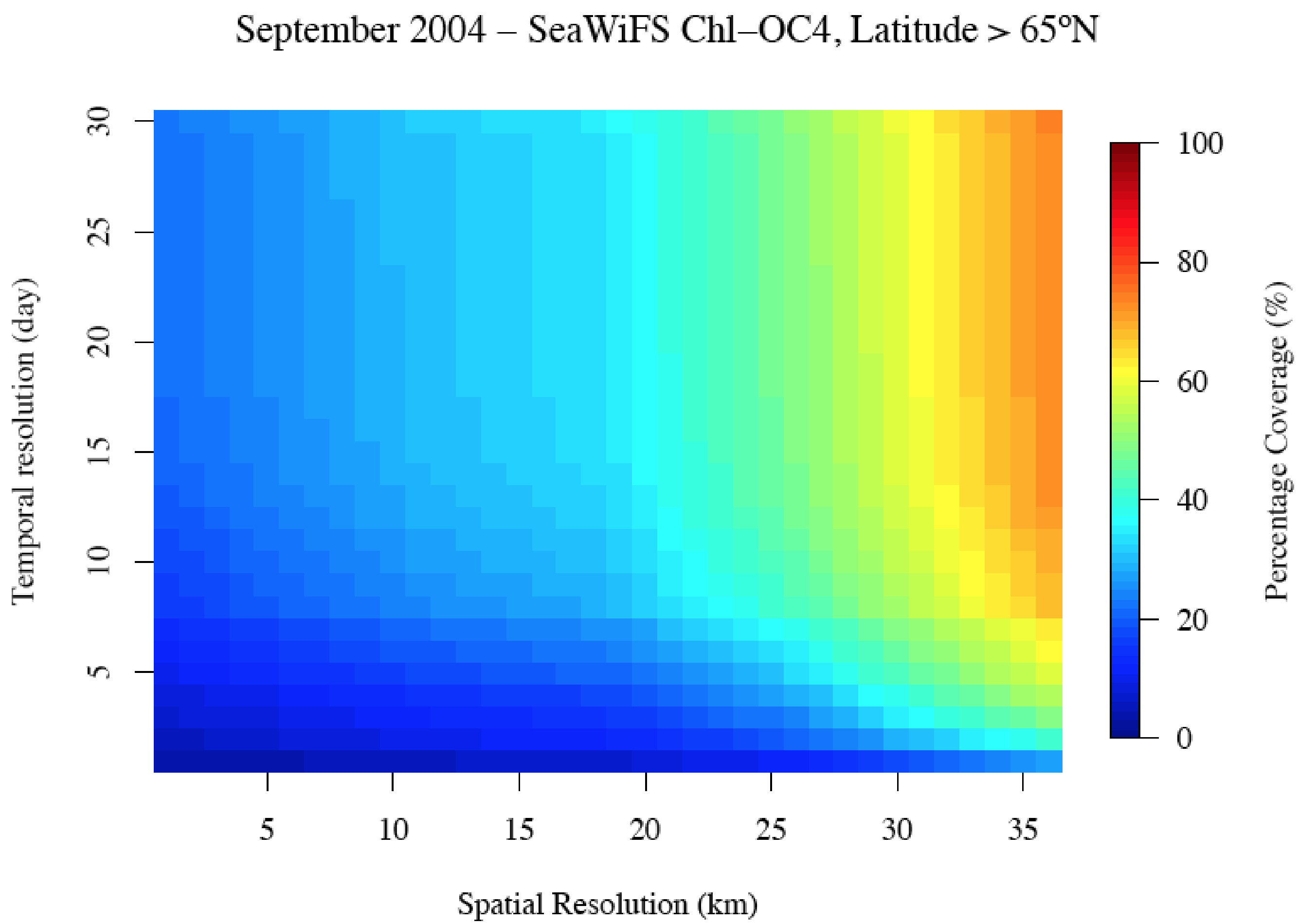



Unpubl.

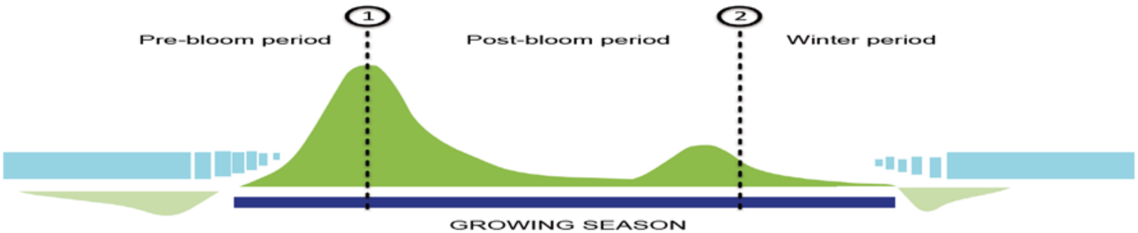
Nevertheless, much can be achieved using ocean color remote sensing…

# Scope

1. The phytoplankton phenology

# Why should we care about it?

**While at first sight a simple phenomenon, it reflects several key processes that shape ecosystem dynamics, including:**




- Phytoplankton growth
- Species succession
- Nutrient dynamics
- Physical mechanisms (optical and mechanical)
- Top-down control
- Transfer of energy and matter through the food web
- Carbon fluxes

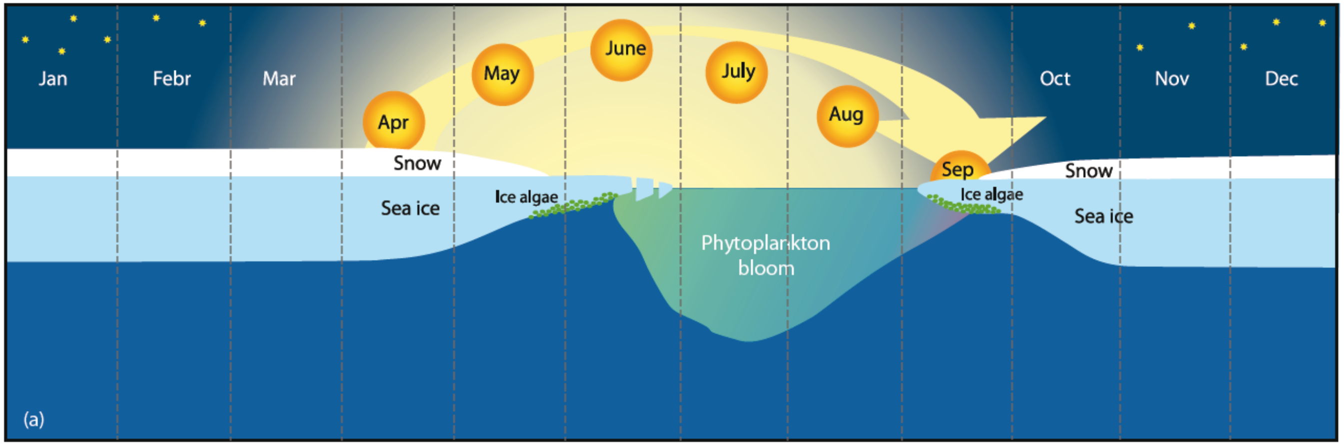
**It is a sentinel of ongoing changes in the functioning of the Arctic marine ecosystems.**

**Still a matter of debate for the global ocean (cf. Sverdrup hypothesis…)**

# Scope

1. The phytoplankton phenology
2. What has recently been documented using ocean color remote sensing (OCRS)
3. What cannot be documented using OCRS
4. Other biogeochemical components recently studied using OCRS in Arctic

Not exhaustive!!

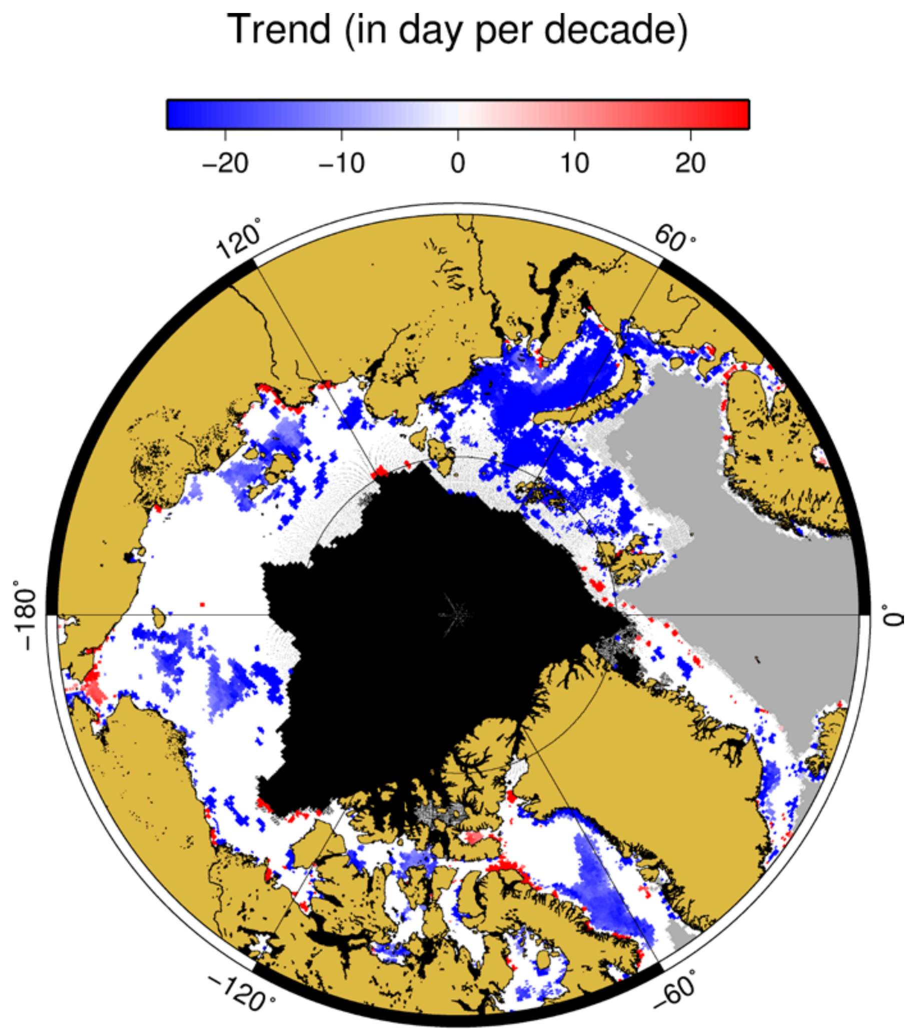



Modified from Wassmann & Reigstad (2011)

**The key features in phytoplankton phenology:**

- Break-up and freeze-up time that determine the duration of the open-water period
- Coincidence with the seasonal light cycle
- Properties of the snow-ice system
- Nutrient dynamics
- Top-down control

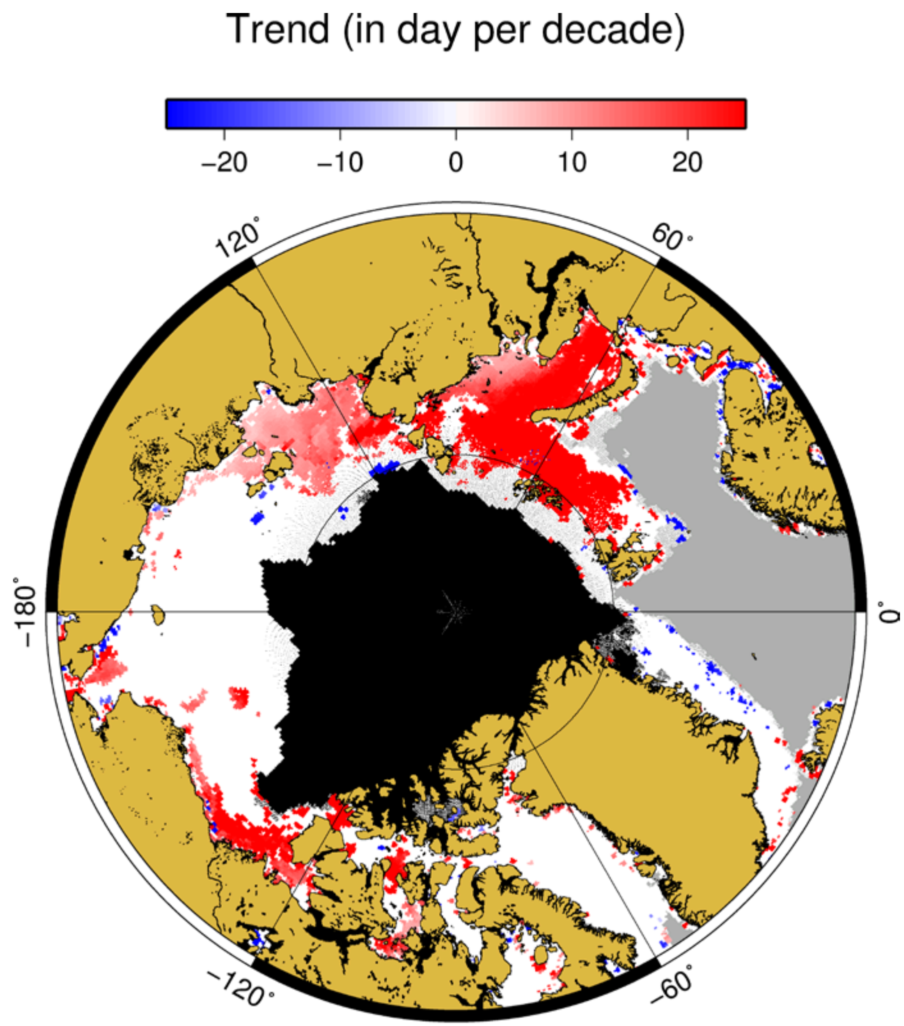
# Change in the break-up day




*Slope (p−value < 0.05) of the trend of the onset of the ice melt for the period 1998−2013 using sea−ice concentration from DMSP SSM/I−f13 and DMSP SSMIS−f17 passive microwave sensors with a 25 km resolution downloaded from NSIDC.org.*

Unpubl.

# Change in the freeze-up day

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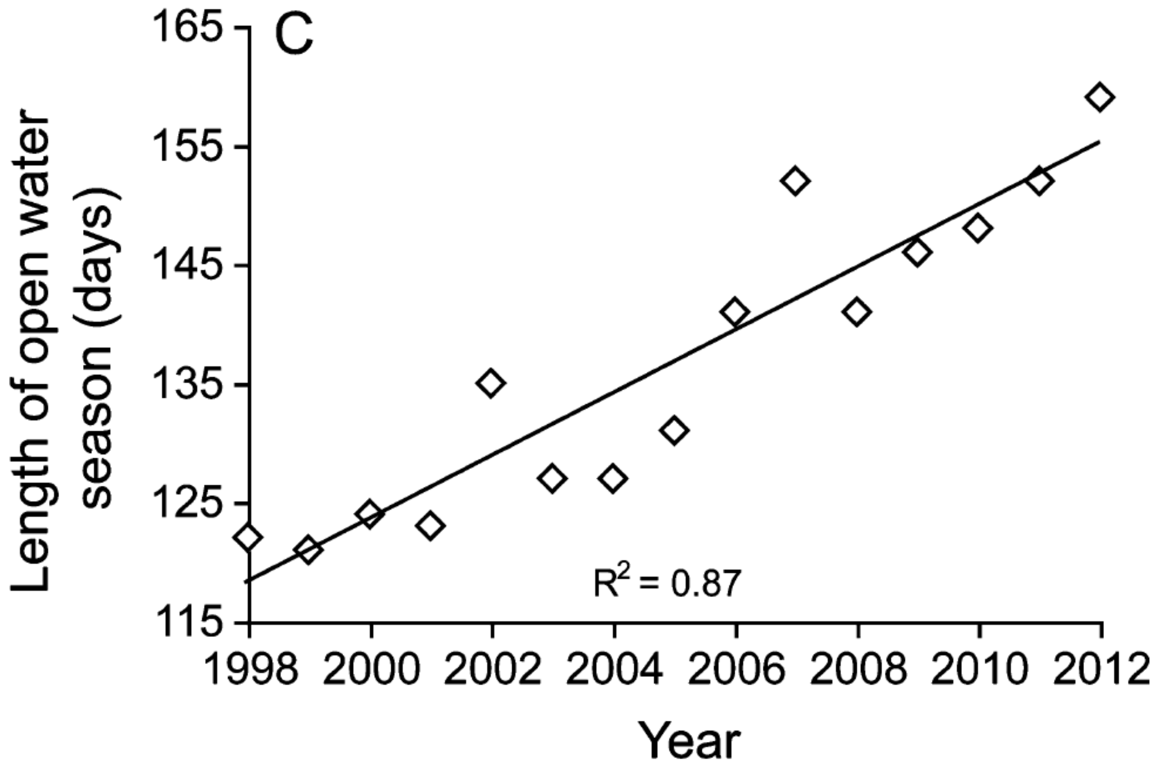
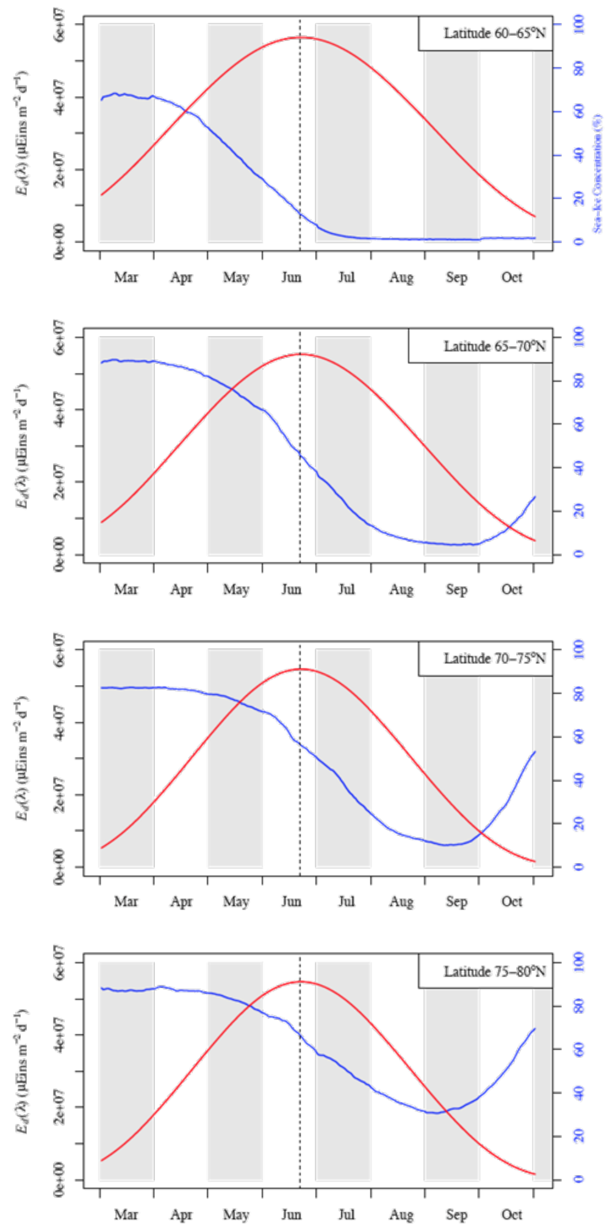
Unpubl.




Arrigo and van Dijken (2015)

Coincidence between the sea ice and light seasonal cycles

➔ Critical at the highest latitudes




60-65°N

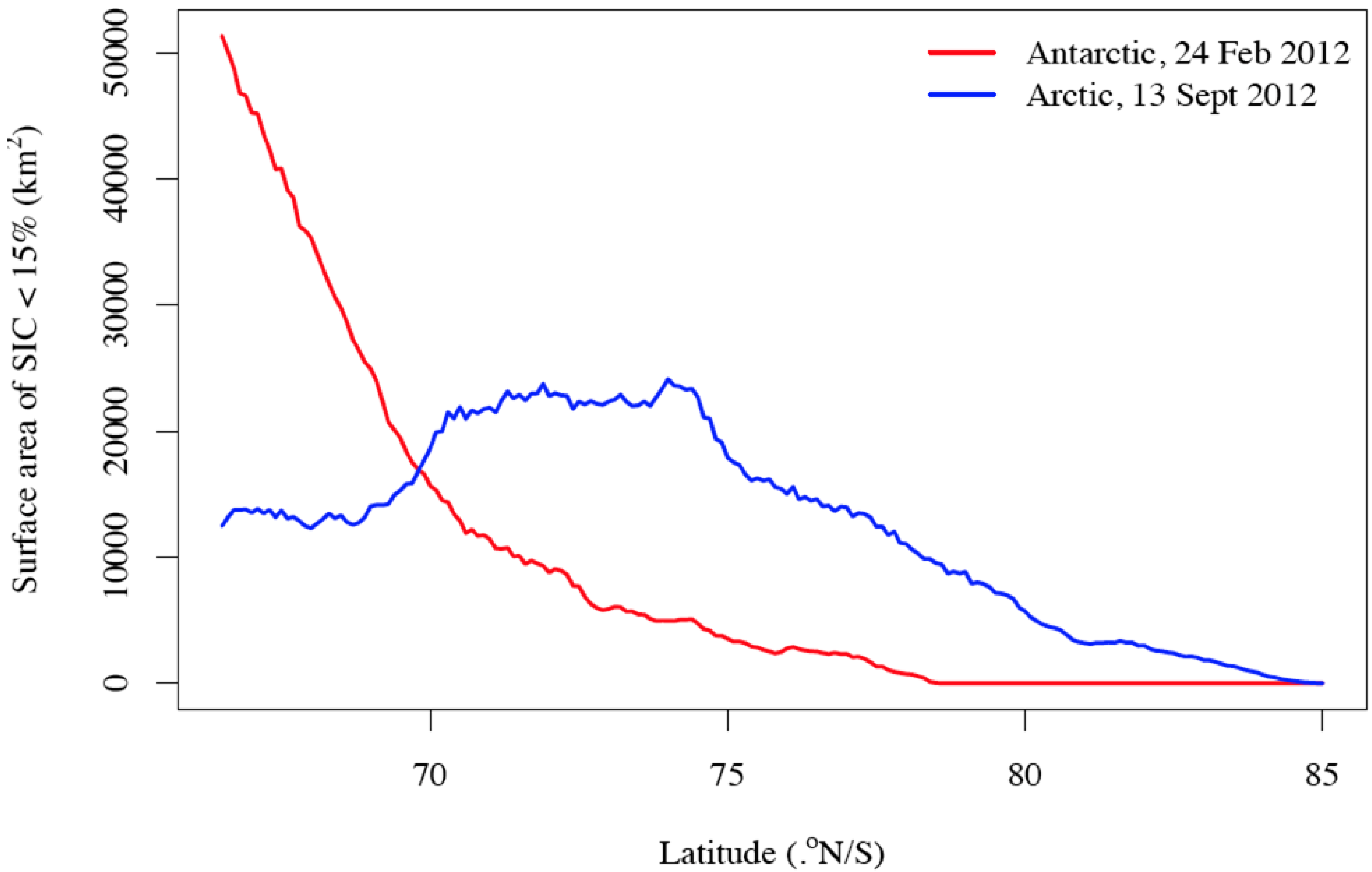
65-70°N

70-75°N

75-80°N

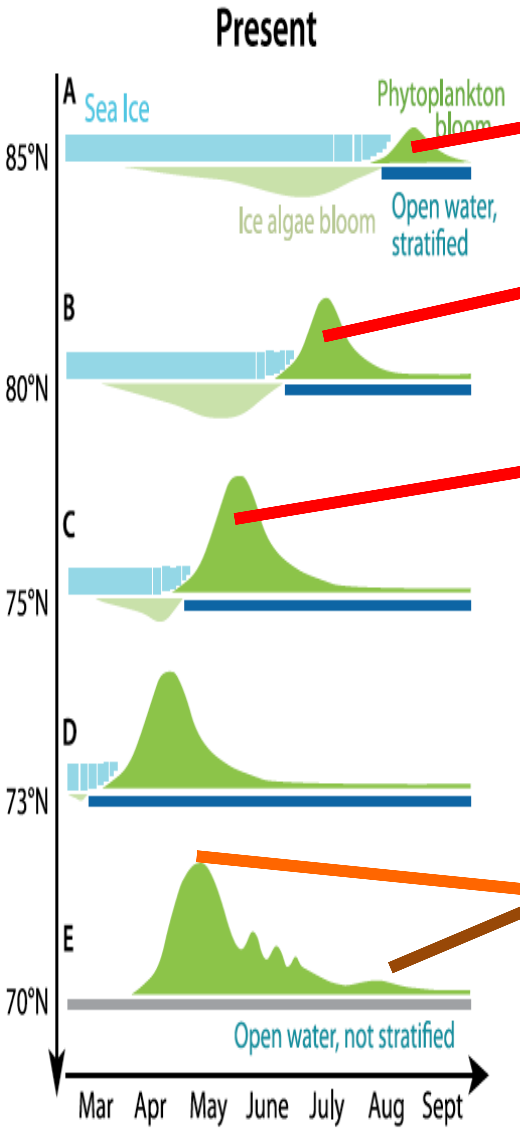
Unpubl.

# More critical for Arctic than Antarctic Ocean!



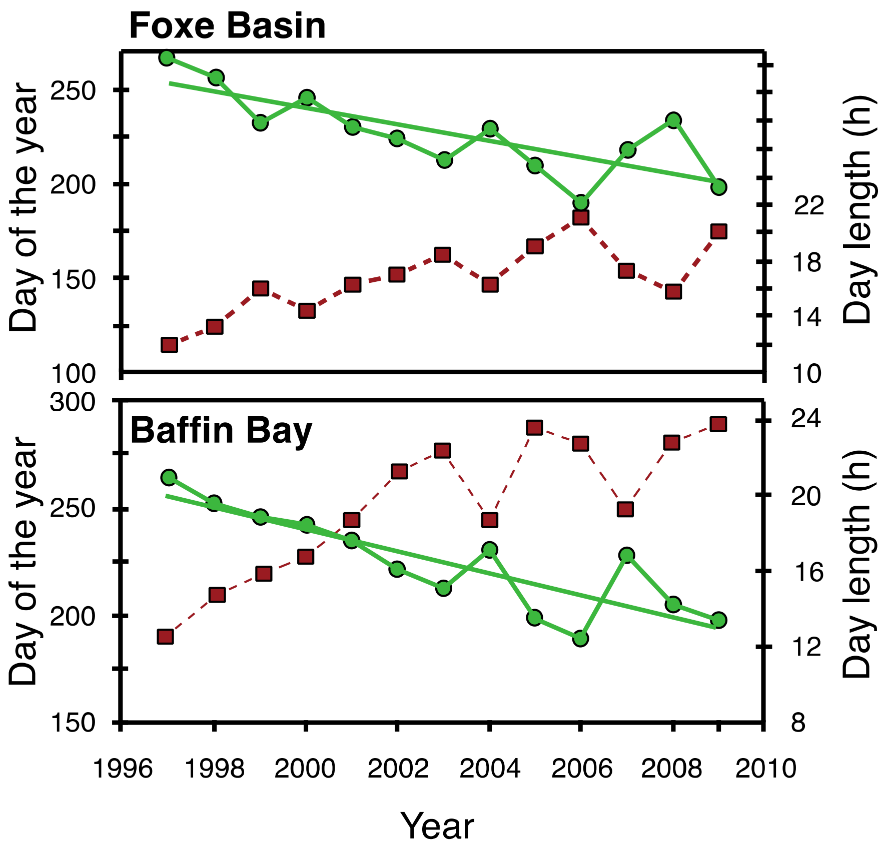

Unpubl.

Wassmann and Reigstad (2011)




1. Earlier spring bloom in the seasonal ice zone
2. More intense bloom at high lat
3. Decrease production at low lat
4. Increasing occurrence of fall bloom

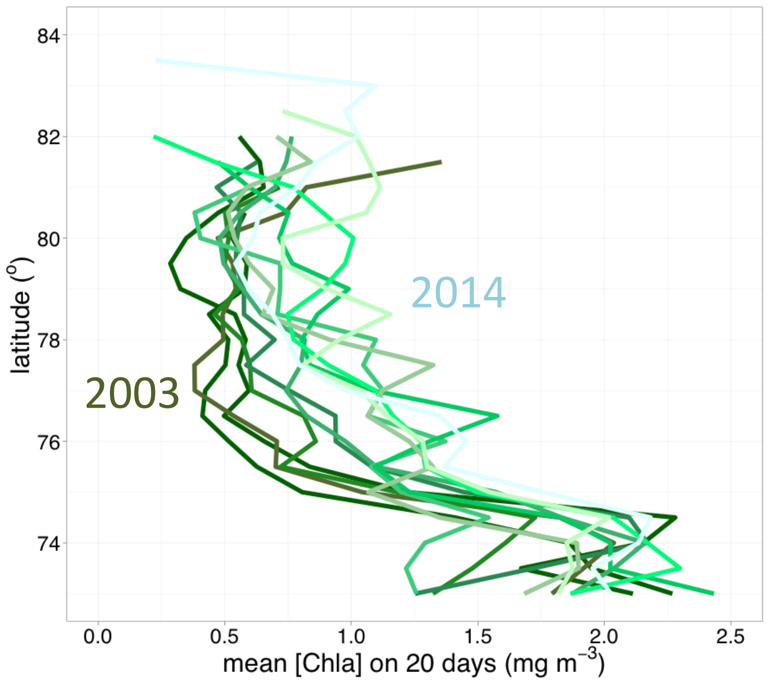
# 1- Earlier spring bloom in the seasonal ice zone

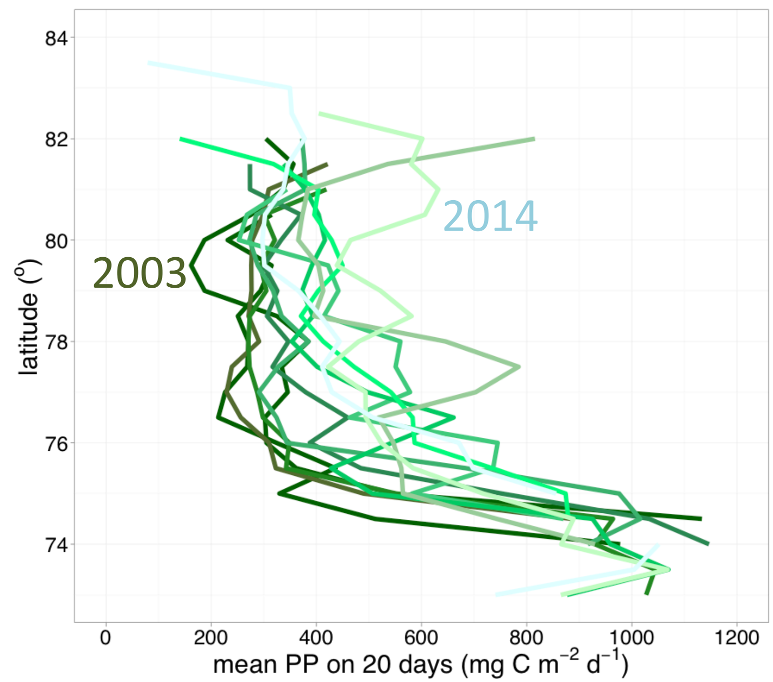



Kahru et al. (2010)

# 2- More intense bloom at high latitude

POSTER # 122

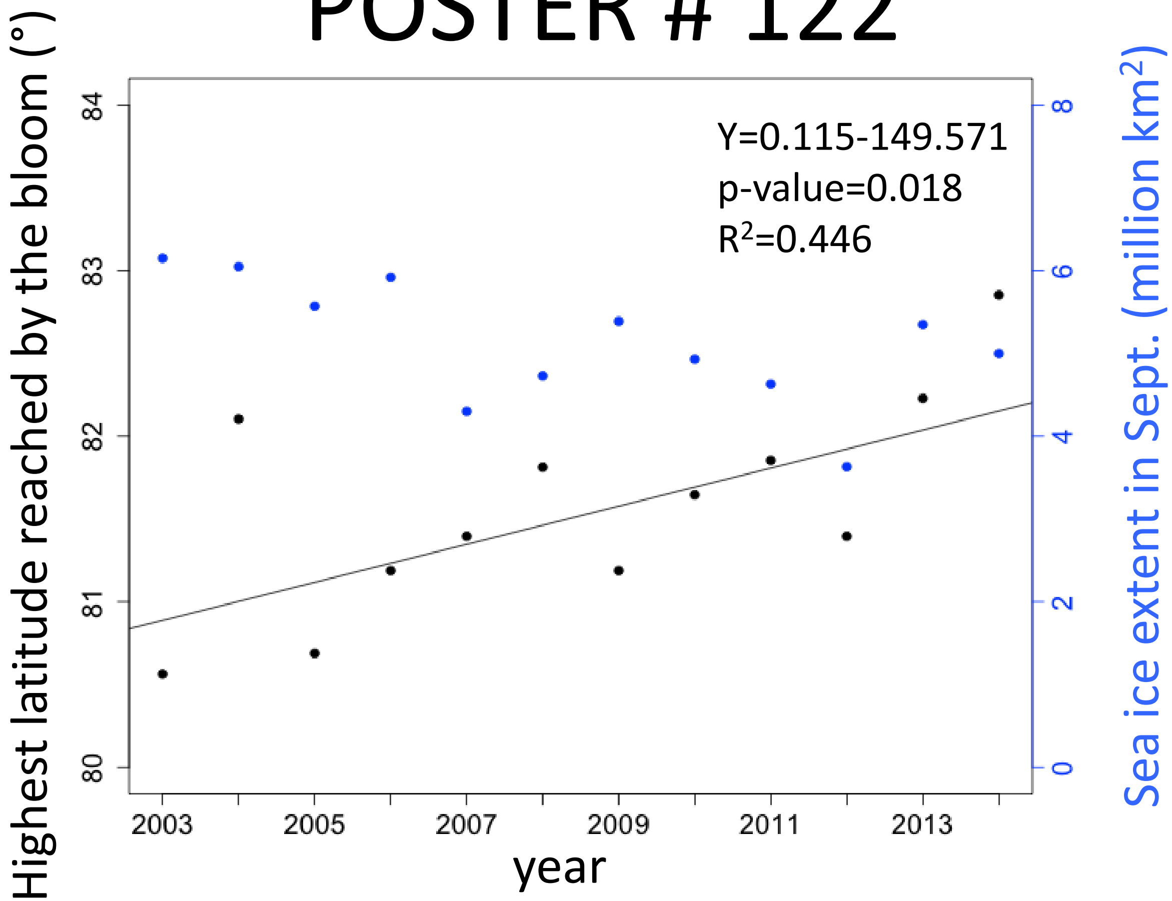



Renaut et al. (unpubl.)

# Highest latitude reached by the spring bloom is increasing

# POSTER # 122

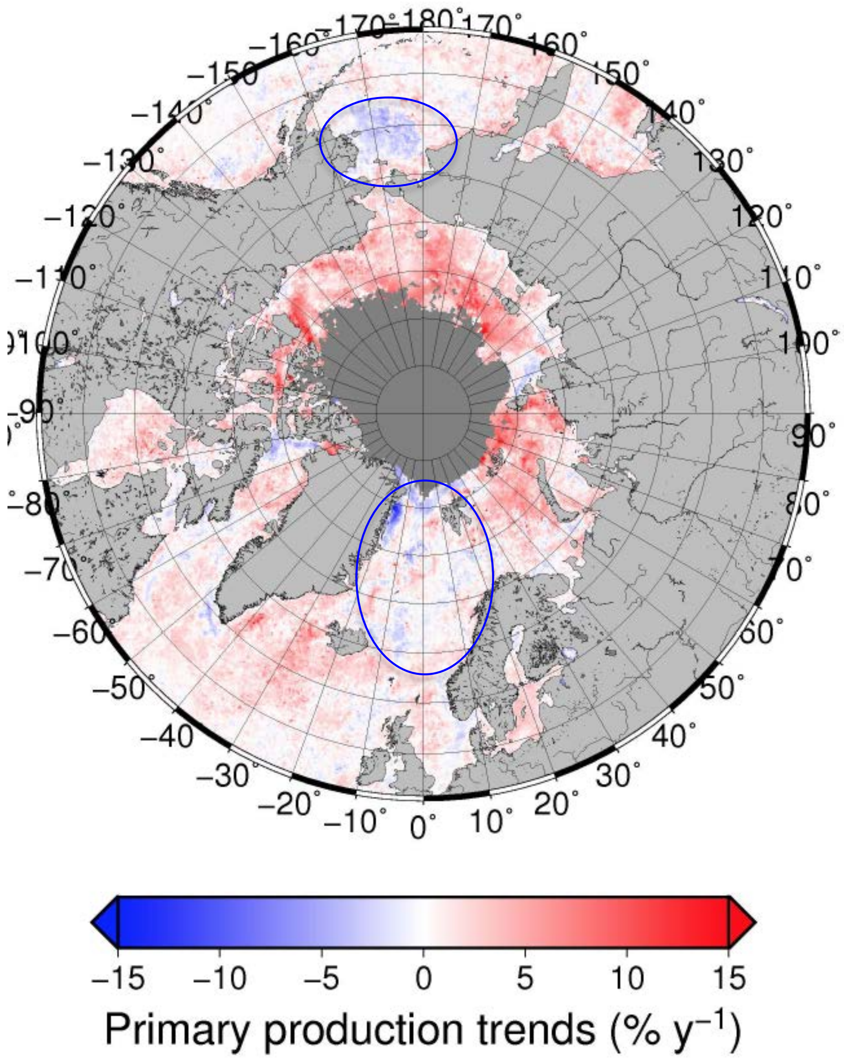



Renaut et al. (unpubl.)

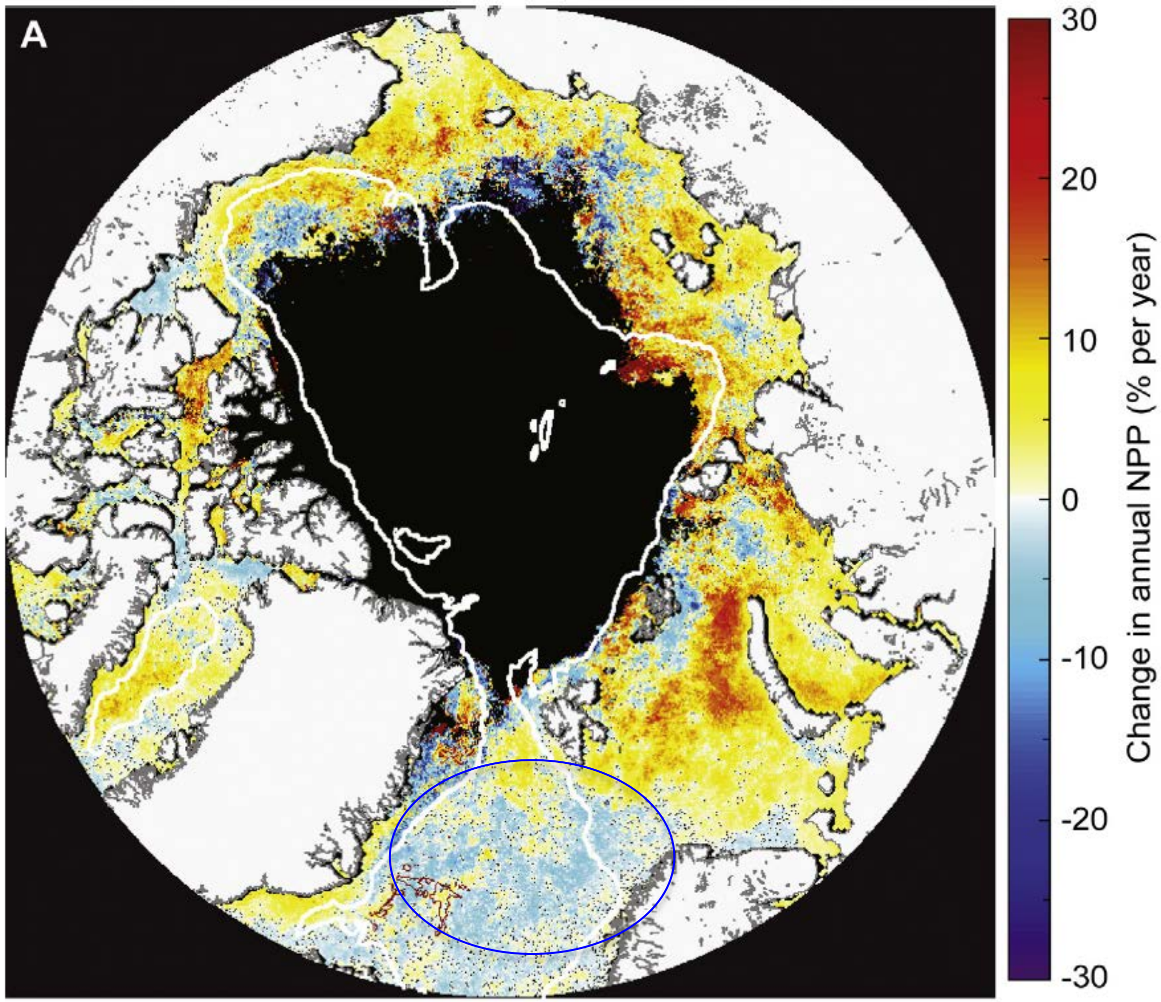
# 3- Decrease production at low latitude

Annual pan-Arctic:
Increase by 15-30%

Pabi et al. (2008)
Arrigo et al. (2008)
Arrigo et al. (2011)
Bélanger et al. (2013)
Petrenko et al. (2013)
Arrigo & van Dijken (2015)

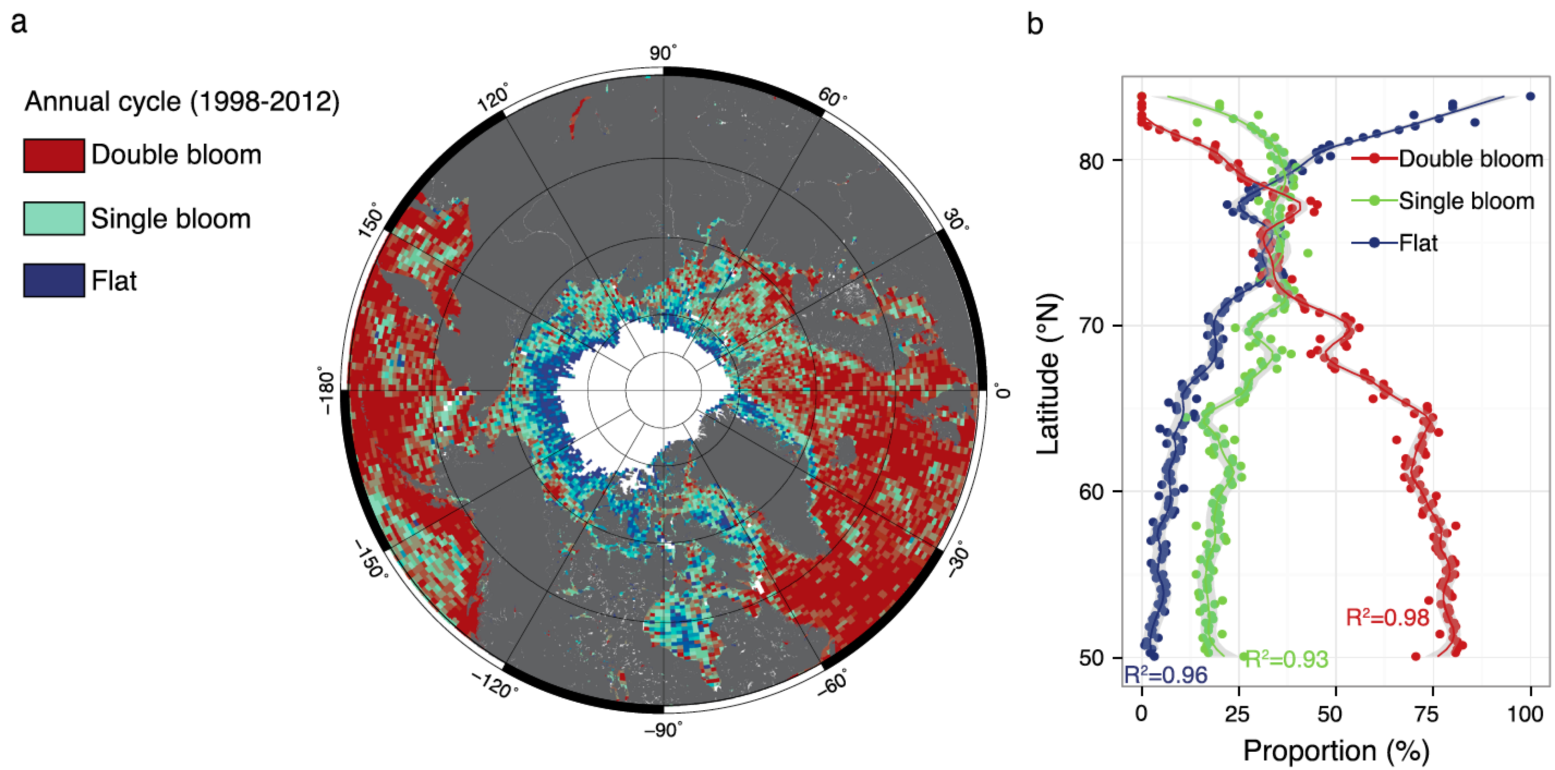



Bélanger et al. (2013)




Arrigo and van Dijken (2015)

# 4- Increasing occurrence of fall bloom

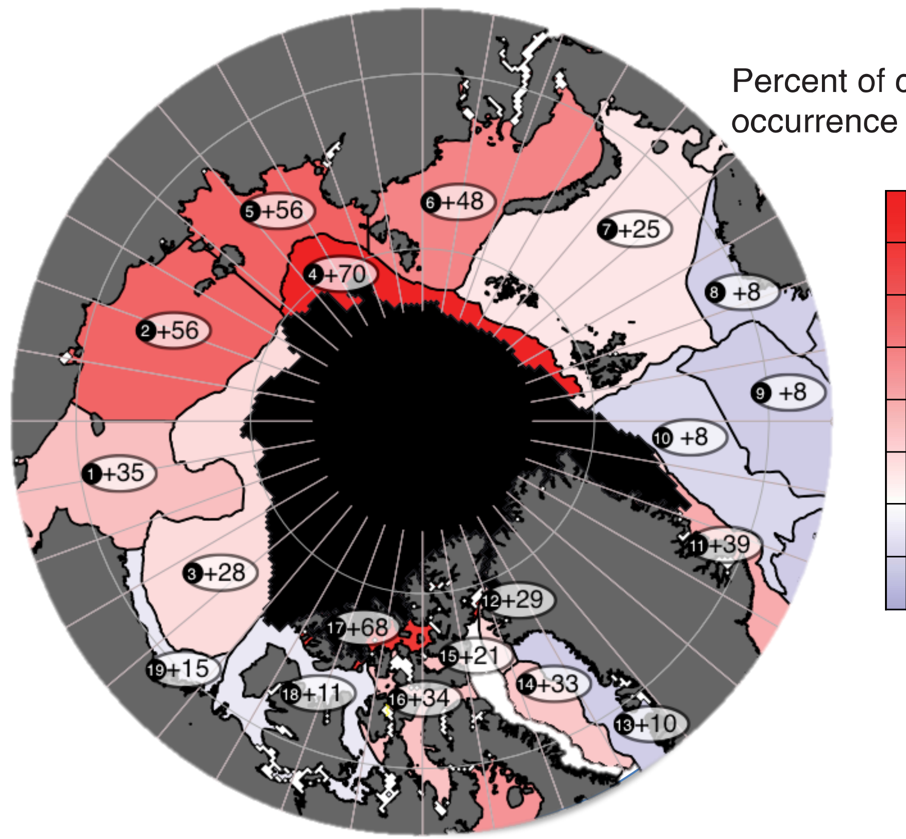



Ardyna et al. (2014)

# Increase in the occurrence of fall blooms

Flat

Proportion (%)



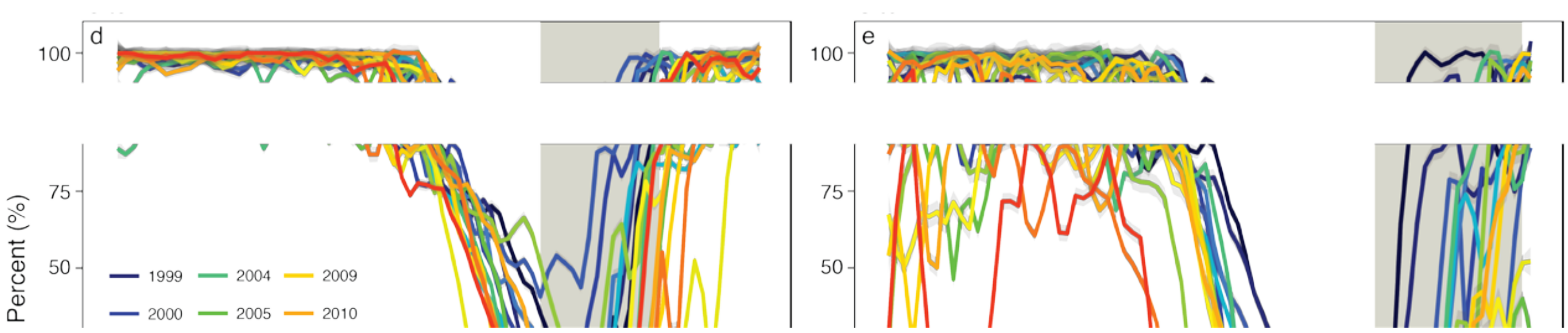

s

Ardyna et al. (2014)

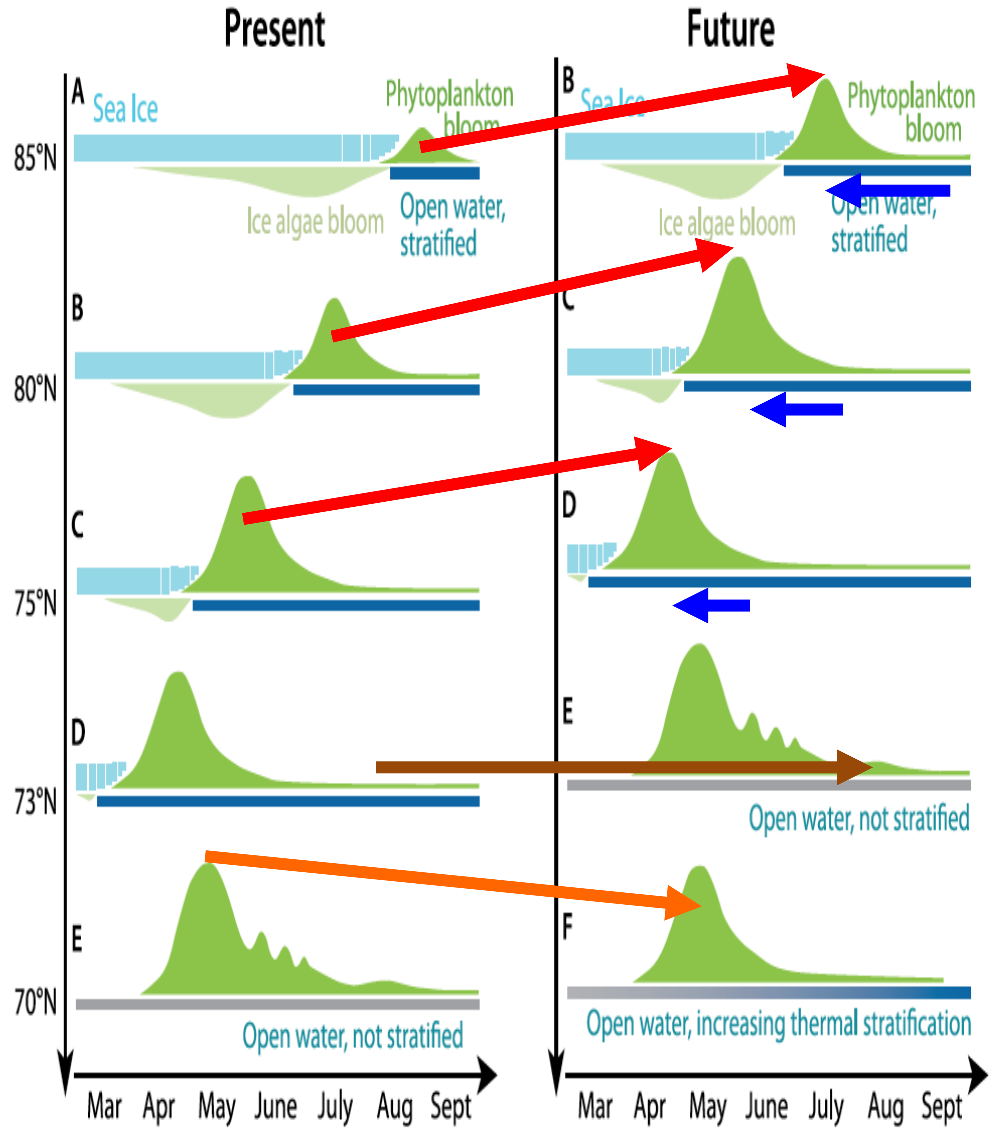
# Coincidence between ice and wind seasonal cycle

Chukchi

Barents



Wassmann and Reigstad (2011)

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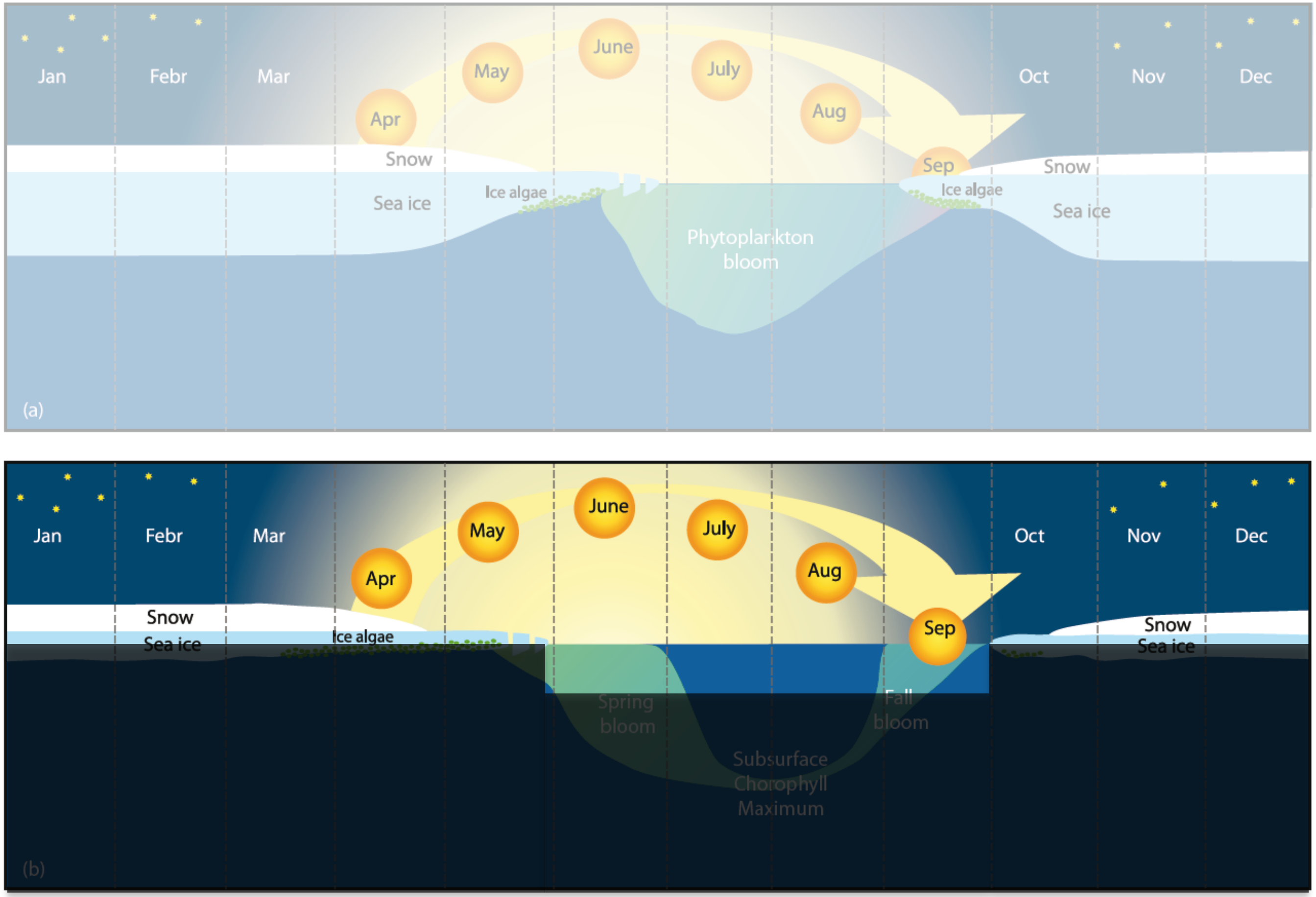
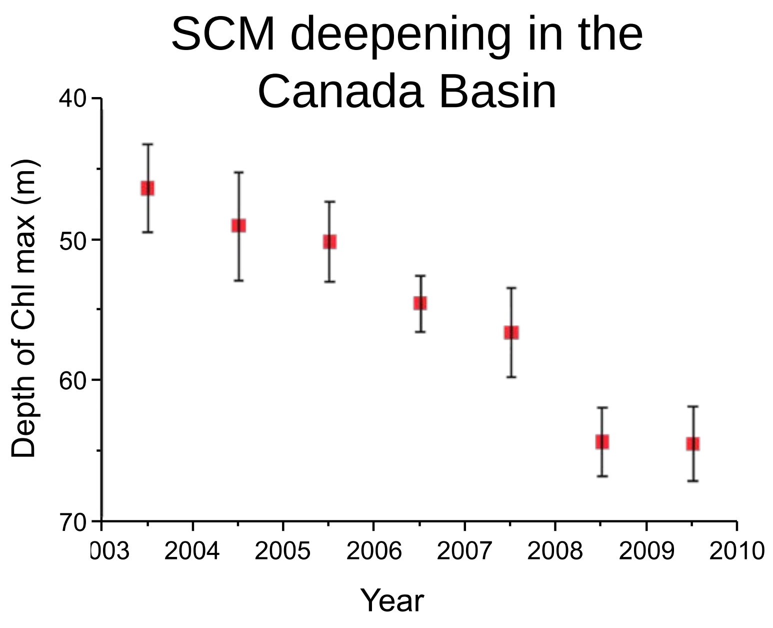



Modified from Wassmann & Reigstad (2011)

# What can’t we achieve using OCRS?

# SCM deeper and more prevalent

Tremblay et al. (2008), Martin et al. (2010)




McLaughlin & Carmack (2010)

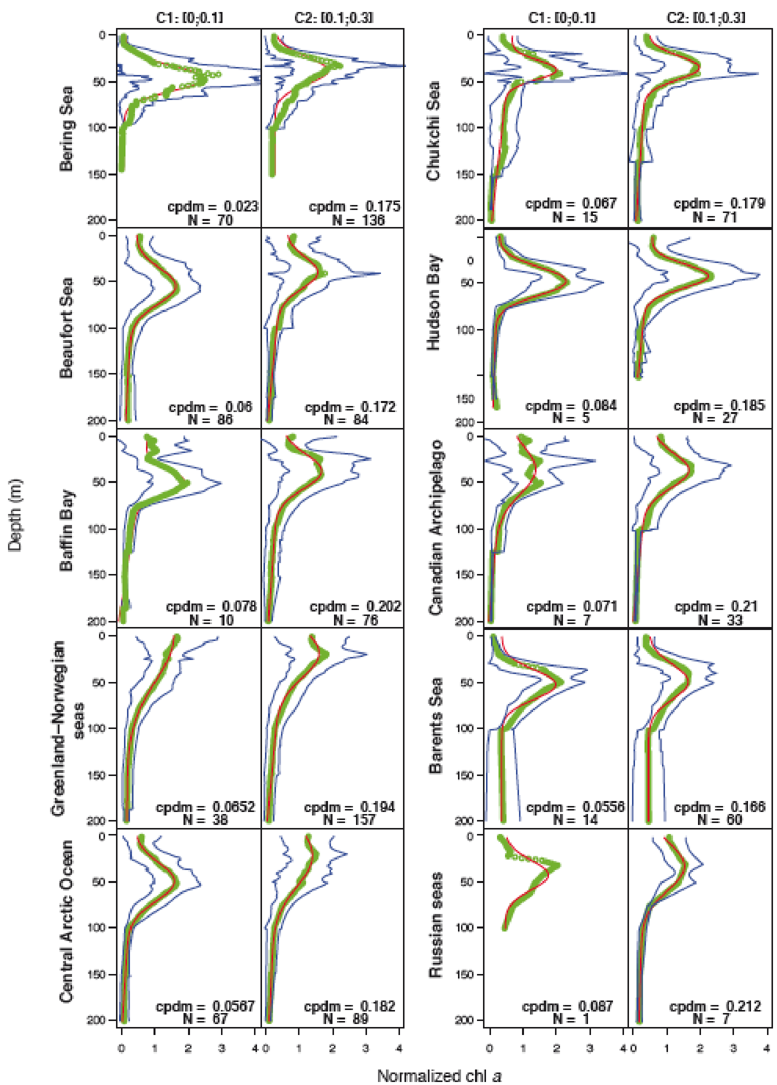
# What impact on PP estimates

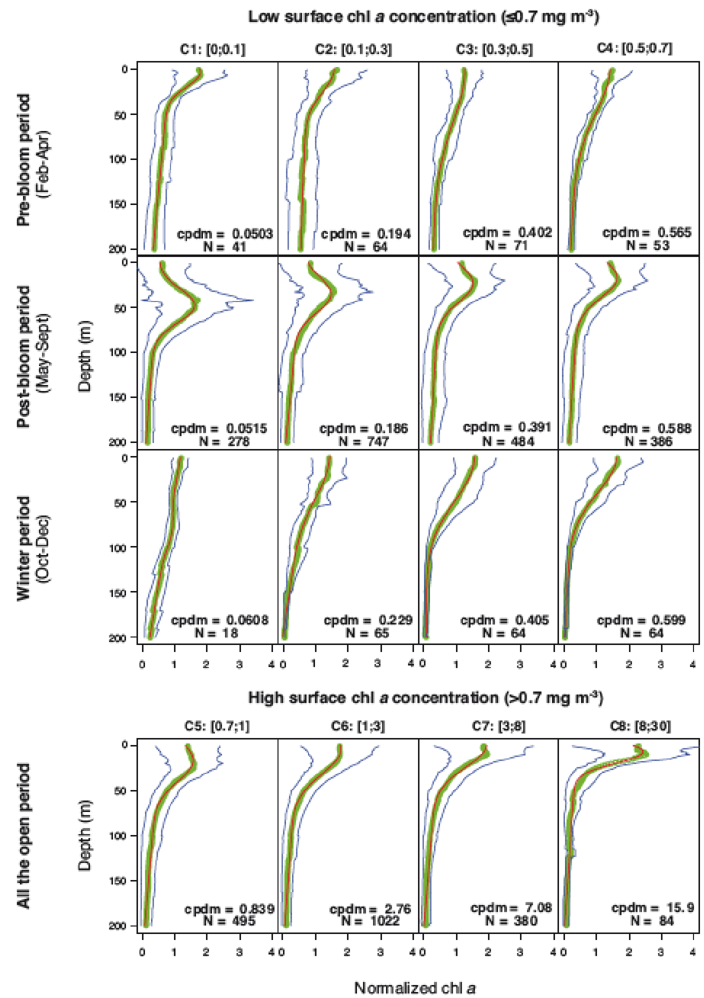
- Little at annual/pan-Arctic scale, significant locally
  - Arrigo et al. (2011)
  - Ardyna et al. (2013)

- Large (50% understimate) at pan-Arctic scale
  - Hill et al. (2013)

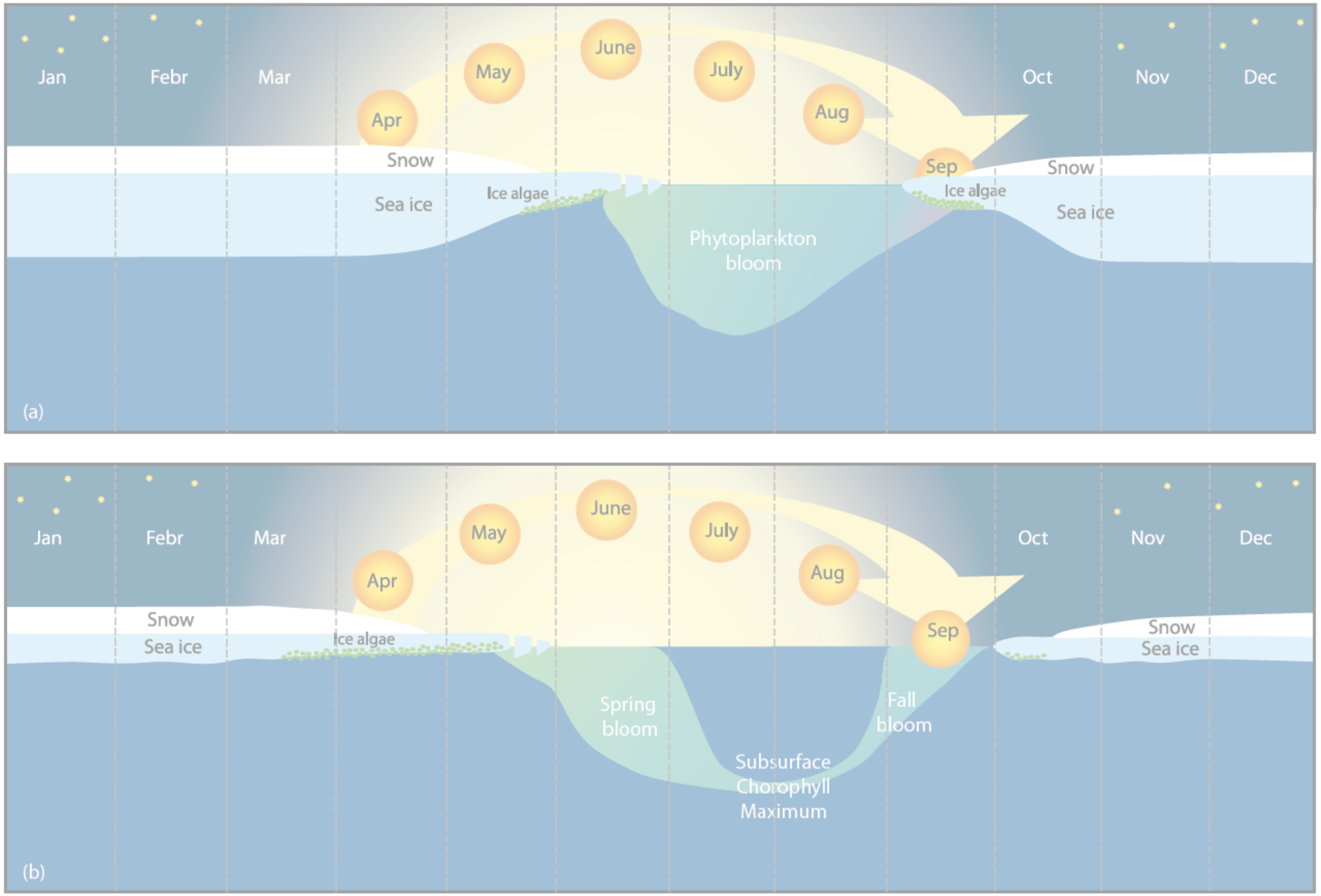
# How to extrapolate from surface to depth?

# Use of a statistical model



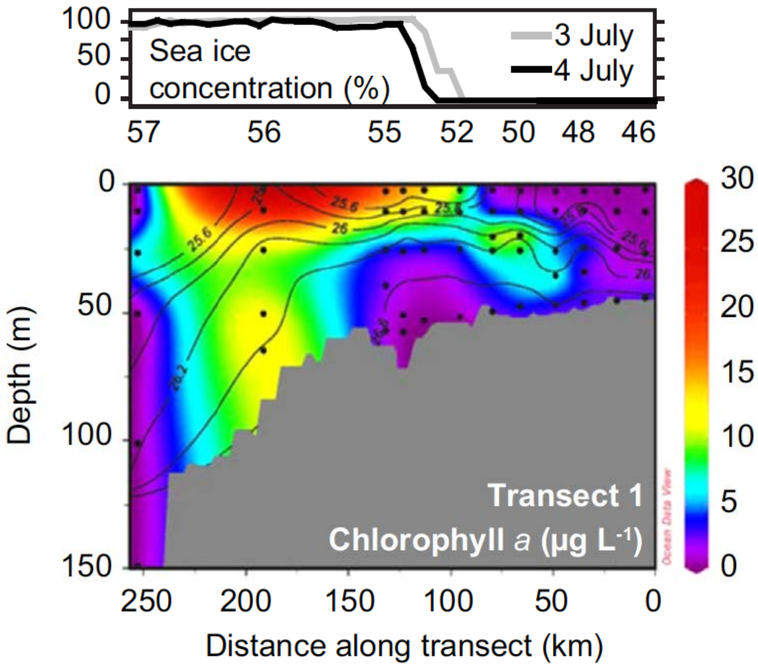




Ardyna et al. (2013)

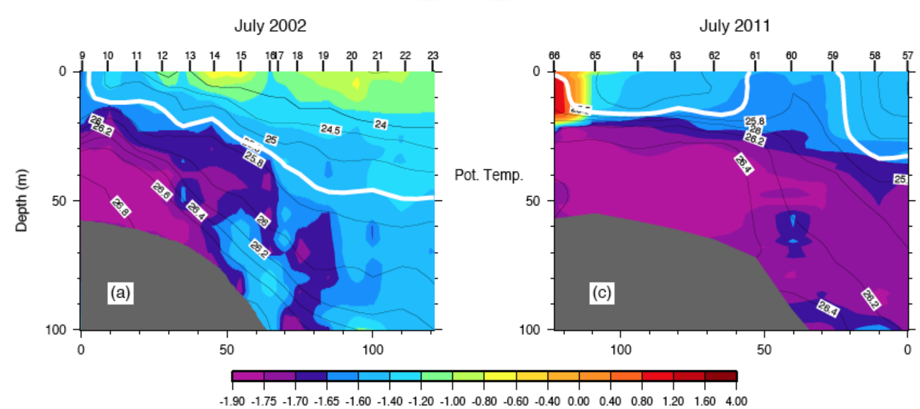



Modified from Wassmann & Reigstad (2011)

# Massive large-scale under-ice blooms have recently been observed



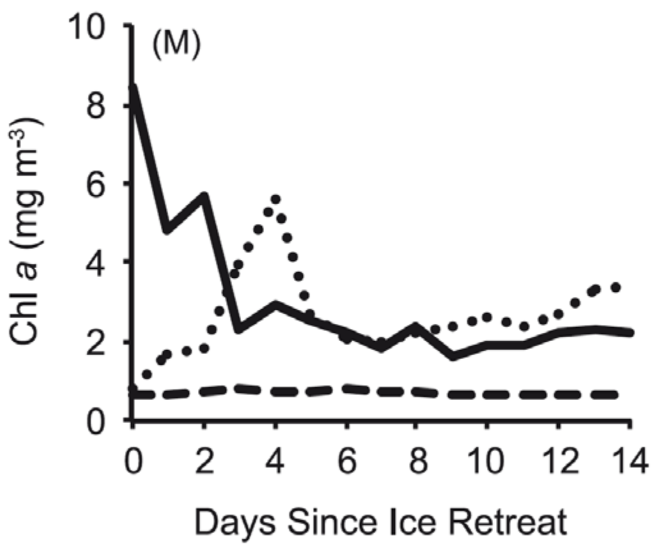

Arrigo et al. (2012, 2014)




Spall et al. (2014)

# What contribution by UI blooms?

➔ A guess using ocean color remote sensing




**>70% in Chukchi Sea!**

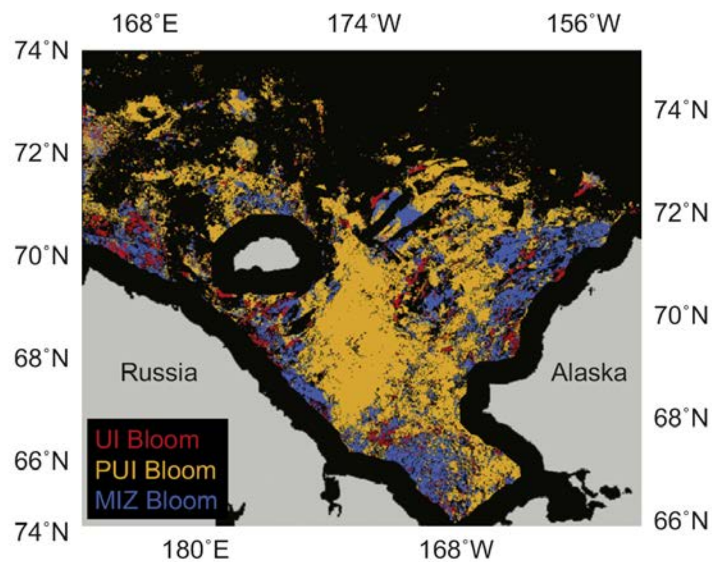



**Fig. 10.** Dominant bloom type map, calculated from the cumulative bloom type maps (Fig. 9). Each pixel is assigned to the bloom type that occurred most frequently over the time series. Black = no data or multiple dominant bloom types.

Lowry et al. (2014)

# More to be expected from remote sensing?

➔ To estimate light propagation through snow and sea ice, roughly or better

# More to be expected from remote sensing?

**Roughly:**

- Snow / no snow
- Ice type (first vs. multi-year)
- Melt pond, leads

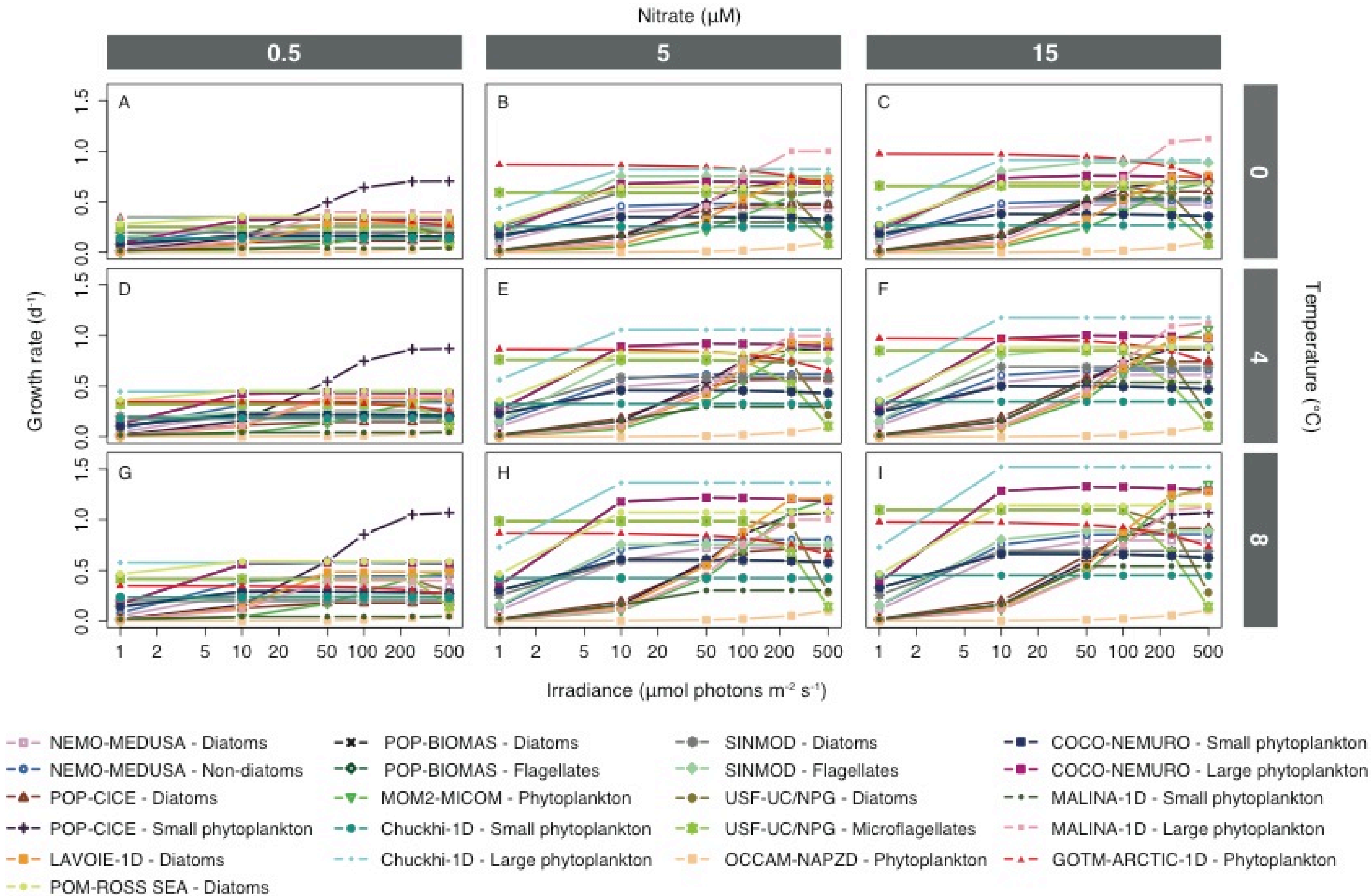
**Better:**

- Snow type, snow cover thickness
- Ice thickness
- Ice optical properties (Barber 2005)

# More to be expected from remote sensing?

If PAR($0^-$) is reasonably well estimated, then what?

1. Establish a threshold beyond which a phytoplankton bloom can start under ice
2. Run a 1-D coupled physical biological model, assuming initial nutrient load from climatology




Babin et al. (in press)

# More to be expected from remote sensing?

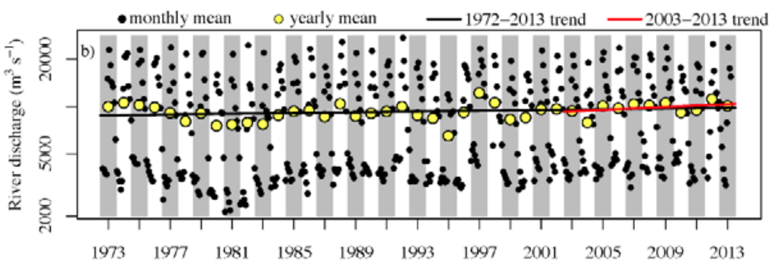
If PAR($0^-$) is reasonably well estimated, then what?

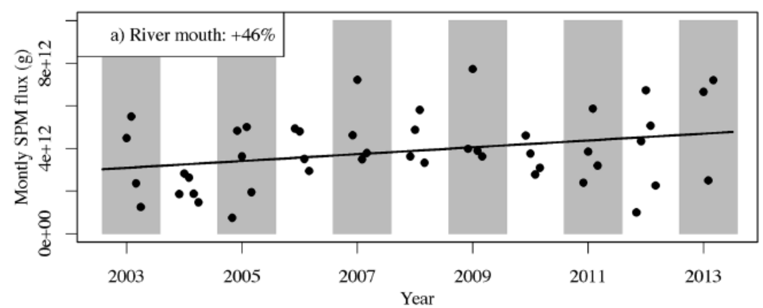
1. Establish a threshold beyond which a phytoplankton bloom can start under ice
2. Run a 1-D coupled physical biological model, assuming initial nutrient load from climatology
3. Run a 3-D coupled physical biological model, if processes that drive nutrients are reasonably well resolved

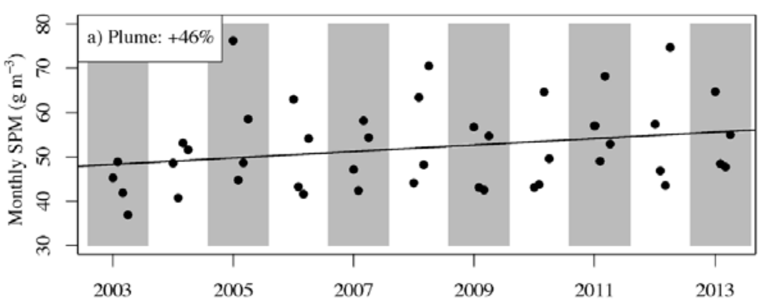
# Other recent results on biogeochemical fluxes obtained using OCRS

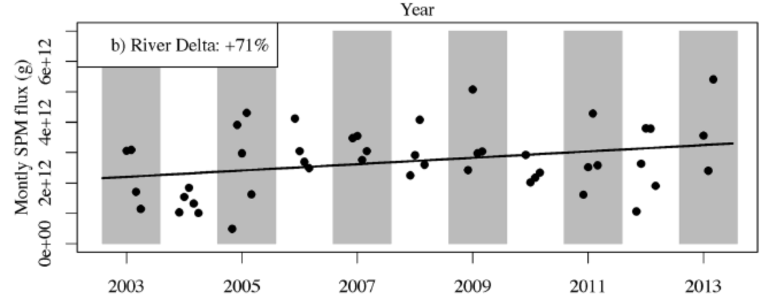
# POCt export to the ocean

# Significant increase in particle export from the Mackenzie river



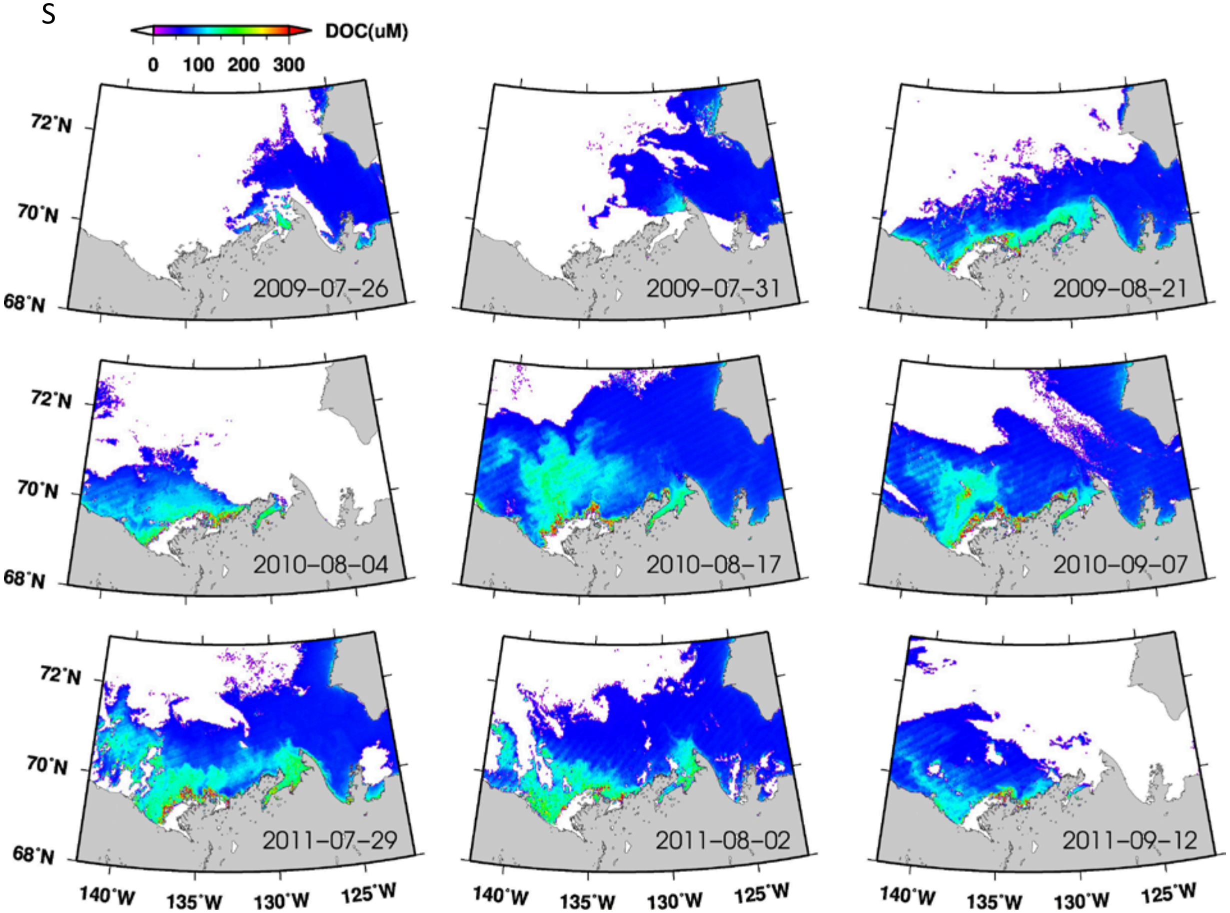

Doxaran , Devred & Babin (2015)

# DOCt export to the ocean

# Spatio-temporal variability in dissolved organic carbon (DOC) concentrations in the Southern Beaufort Sea

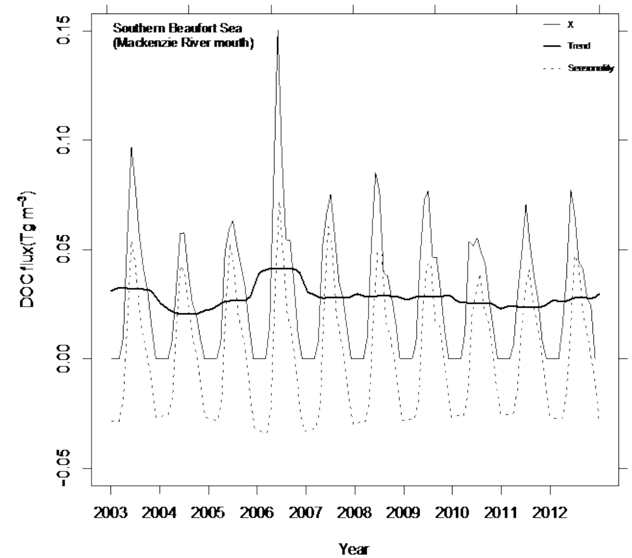
## DOC concentrations estimated from space

Aqua/MODIS



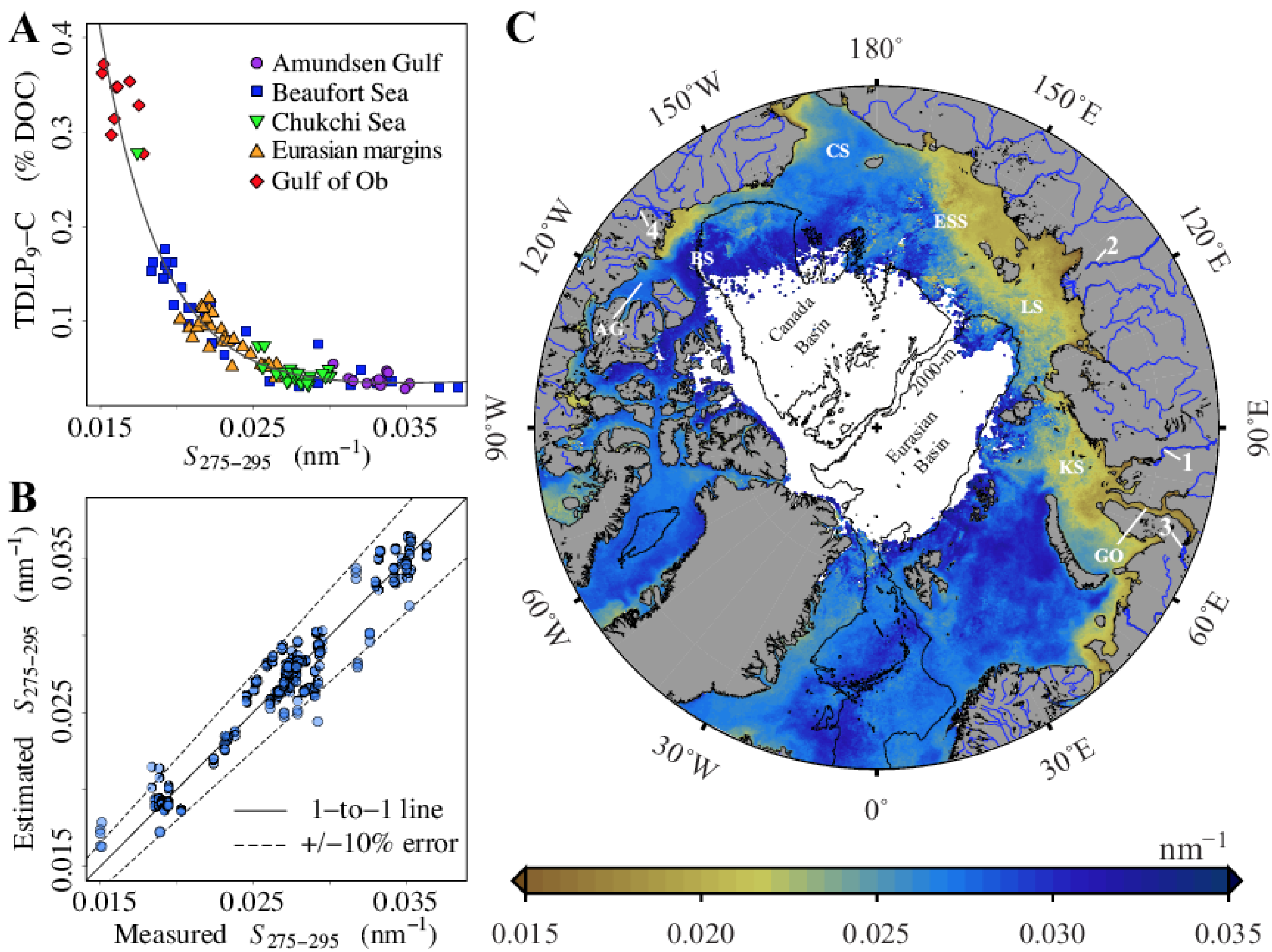

[Matsuoka et al., 2014]

## Inter-annual trend in DOC concentrations in the last decade




X: DOC conc. from space
T: Inter-annual trend
S: Seasonal trend

[Matsuoka et al., in prep.]

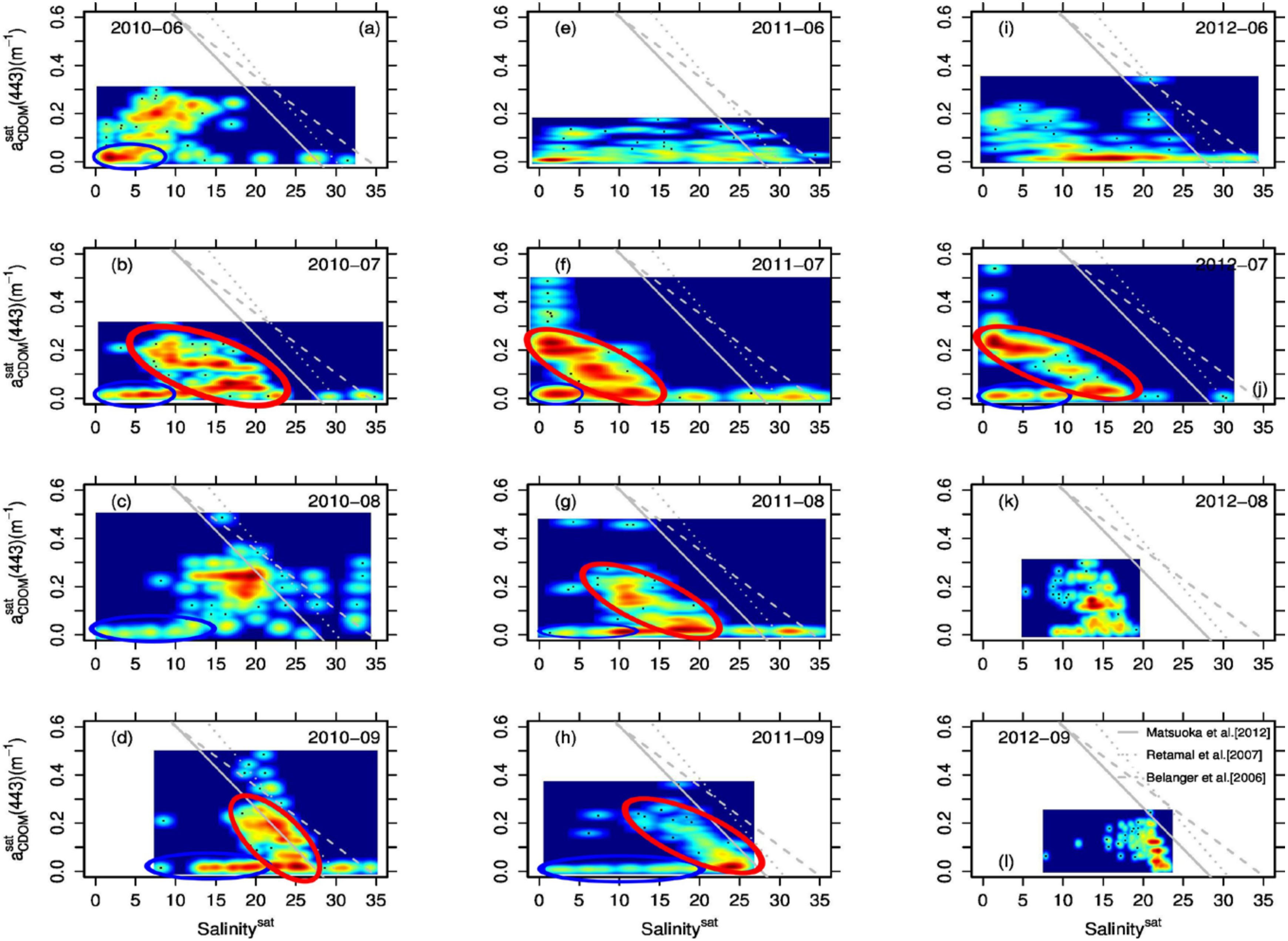



MALINA

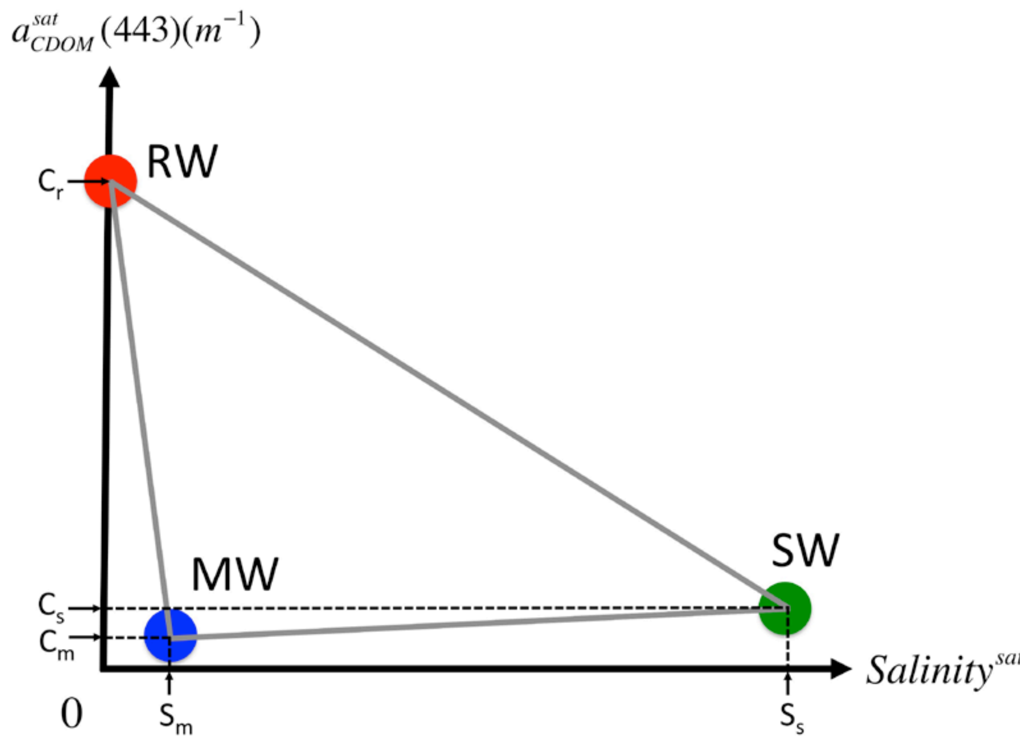
NASA ICESCAPE 2010 - 2011

Fichot et al. (2013)

# Combining OCRS and SMOS data




Matsuoka & Babin (in preparation)

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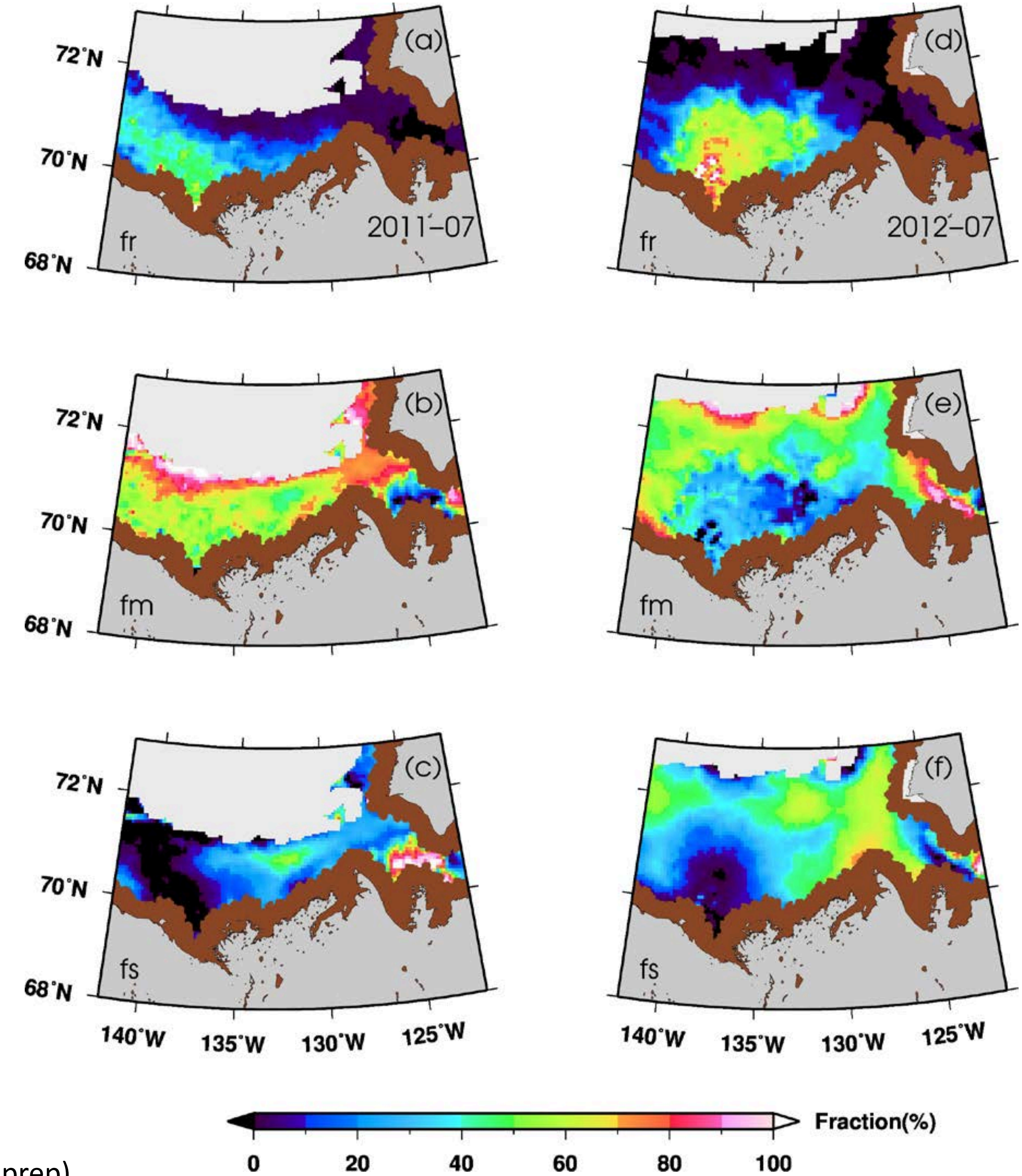



Matsuoka & Babin (in prep)

# Conclusions

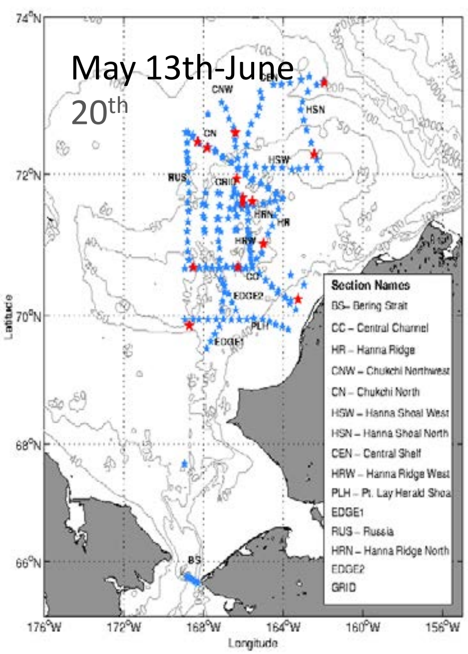
- Marine ecosystems are changing drastically in Arctic in response to climate change
- Biogeochemical fluxes are changing too
- Much insight can be gained from OCRS
- But new methods must be developed

# Some of the important pending questions on Arctic phytoplankton in Arctic that remote sensing could help answer

- Is community composition changing?
- More nutrients to support more PP? What physical processes?
- Some areas actually getting less productive?
- …

# Some ongoing projects on optics and phytoplankton in Arctic

# SUBICE

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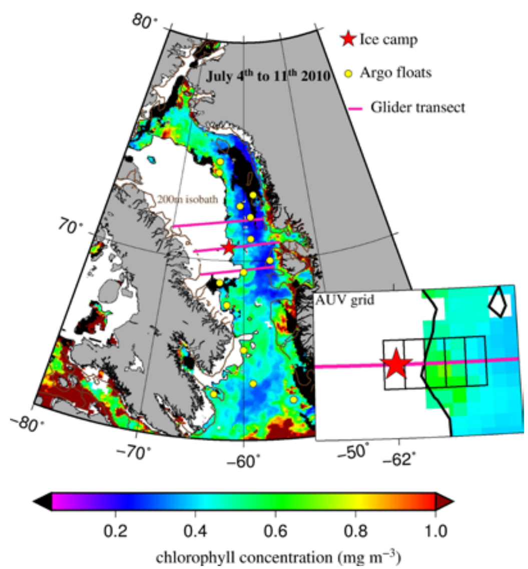
# GREEN EDGE

http://www.greenedgeproject.info/

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Arctic in Rapid Transition
PS92 19 MAY - 28 JUNE 2015
ARK XXIX/1


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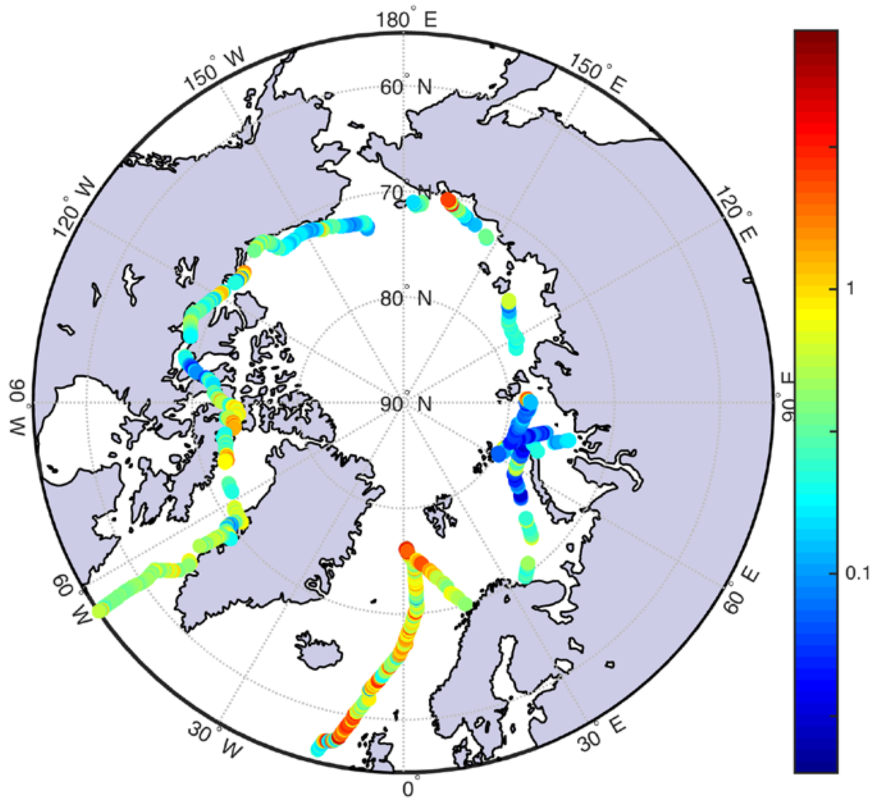
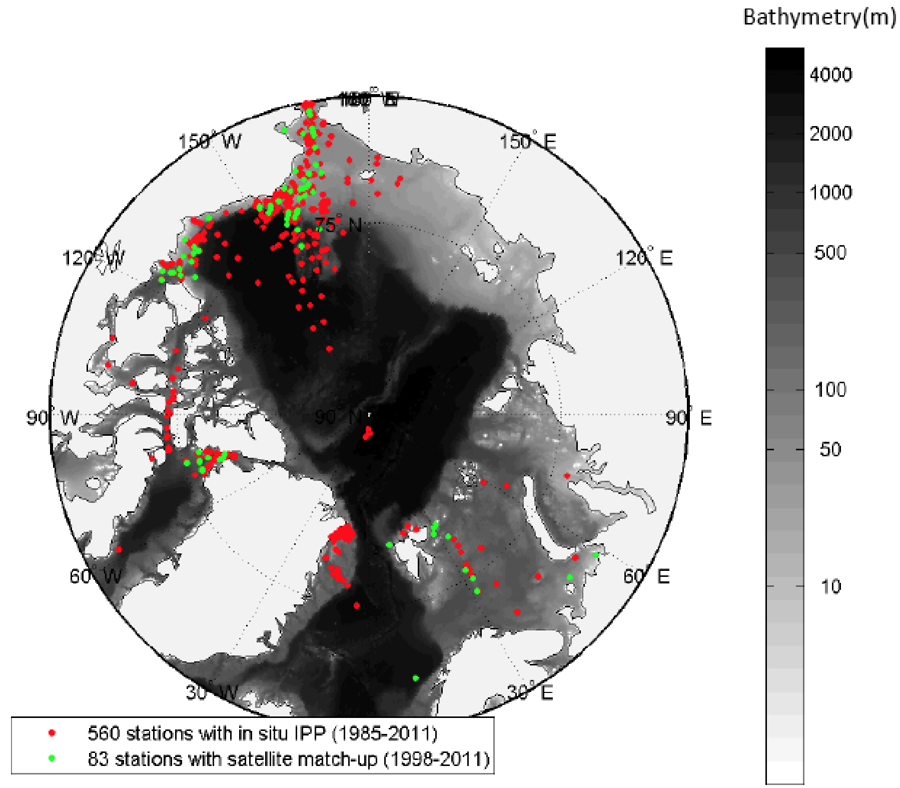
Polar Circle Expedition (2013): optics and microbial diversity



# Recommendations with regard to OCRS

- Combine data from multiple polar orbiters to mitigate the impact of clouds on data availability
- Develop methods for flagging and correcting contamination of the signal by sea ice
- Improve atmospheric corrections and push their limit in terms of maximum $\theta_s$ (eg 70° ➔ 74° provides an additional 7 $Mkm^2$)
- Tune and validate semi-analytical IOP algorithms in the Arctic
- Validate and implement empirical models of Chl(z)
- Document the atypical phytoplankton photophysiological parameters in Arctic to improve PP estimates
- Develop new approaches for dealing with under-ice phytoplankton blooms
- Explore new avenues for PFTs specific to the Arctic Ocean




# PPARR5 Ocean Color-based Model (OCM) analysis: Preliminary Results (ver1.2)

10/13/2014

prepared by Younjoo Lee (ylee[at]bigelow.org), Paty Matrai, Marjy Friedrichs, and Vince Saba.