# Environmental controls and phenology of sea ice algae growth in a future Arctic

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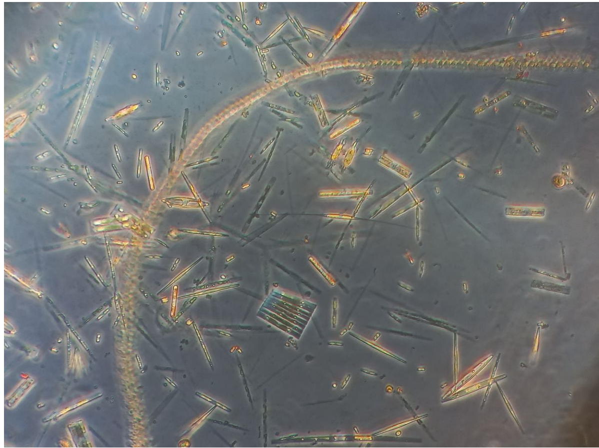
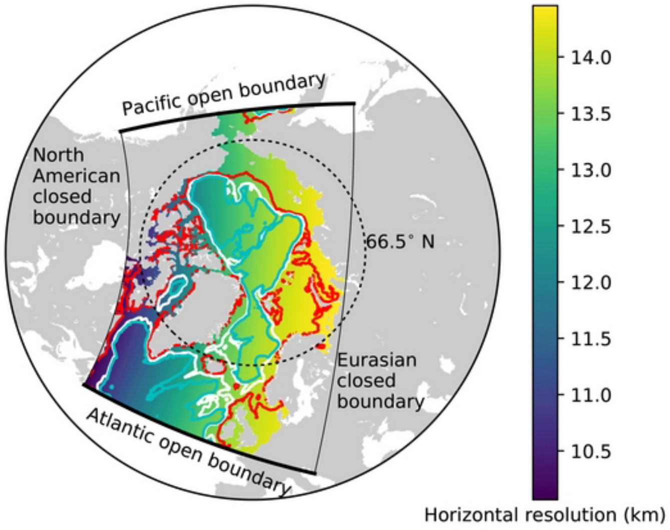
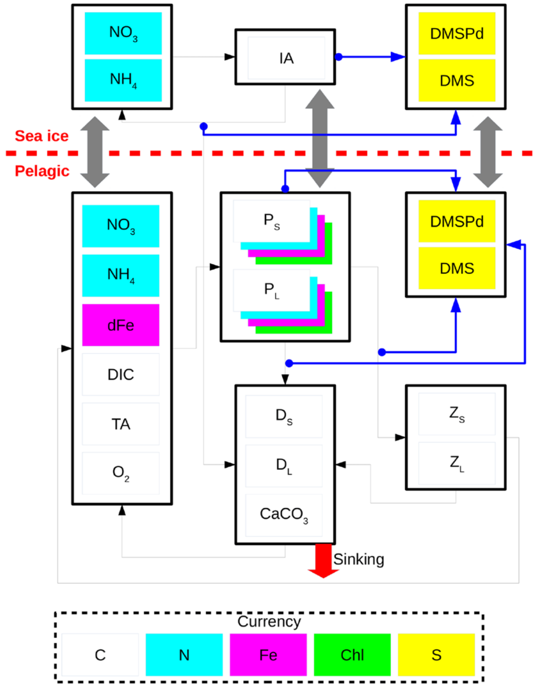


# Ocean and sea ice model

- NEMO 3.4 + LIM2
- Historical (1979-2015)
  - Atmosphere: DFS
  - Lateral boundaries: ORAS4
- RCP8.5 (2016-2085)
  - Atmosphere: CanRCM4
  - Lateral boundaries: CanESM2




**CSIB** (Canadian Sea Ice Biogeochemistry model)
- Skeletal layer
- Ice algae
- N, S biogeochemistry

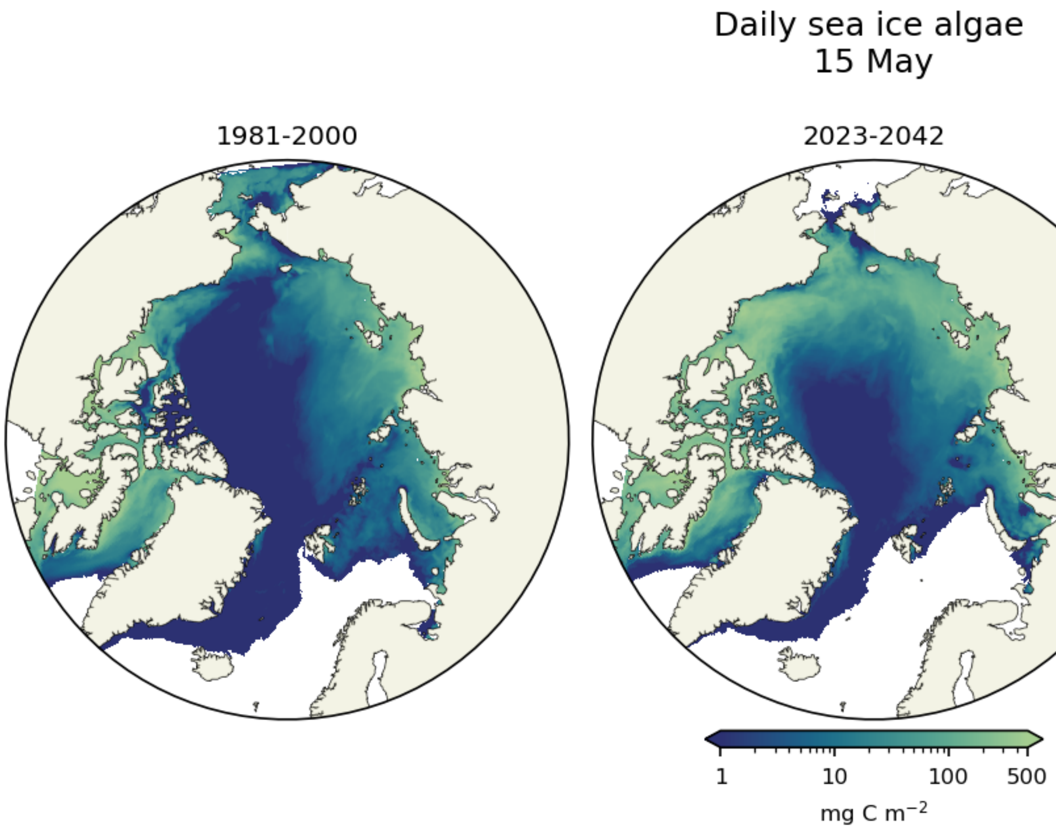
**CanOE** (Canadian Ocean Ecosystem Model)
- 2 phytoplankton
- 2 zooplankton
- 2 detritus
- C, N biogeochemistry

- + S cycle
- - Fe limitation

Hayashida et al. 2019. *CSIB v1 (Canadian Sea-ice Biogeochemistry): A Sea-Ice Biogeochemical Model for the NEMO Community Ocean Modelling Framework.*

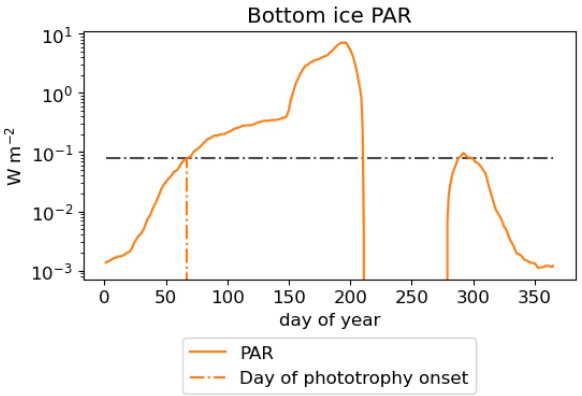
Christian et al. 2022. *Ocean Biogeochemistry in the Canadian Earth System Model Version 5.0.3: CanESM5 and CanESM5-CanOE.*

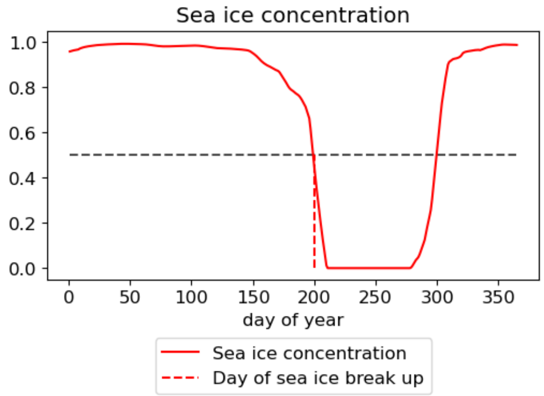
20-year means
Plotted over ice extent: area with sea ice concentration > 15%




20-year means
Plotted over ice extent: area with sea ice concentration > 15%

# Key dates




## Day of phototrophy onset

- PAR = 0.36 μmol photons $m^{-2}$ $s^{-1}$
- Lowest reported ice algal light compensation intensity
- Start of net growth from photosynthesis

## Day of sea ice break up

- First day sea ice concentration < 50%
- End of bloom

**Phototrophic period**

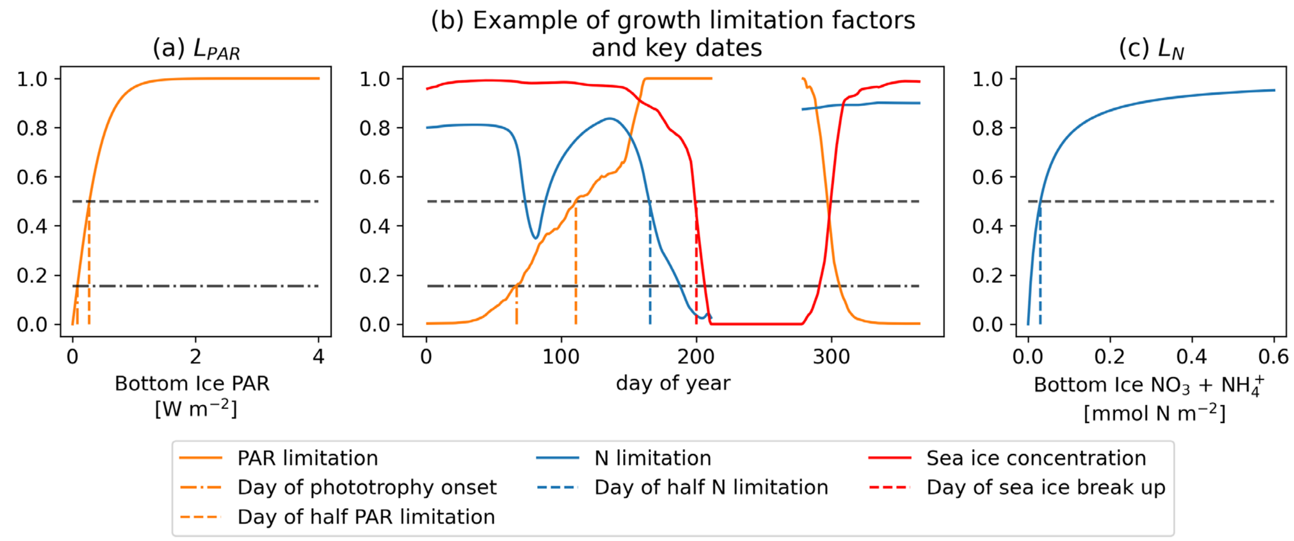
- Number of days from phototrophy onset to SI break up

## Ice Algae Growth rate

$$\mu_{IA} = \mu_{\max} f(T) \min\left(L_N, L_{PAR}\right)$$

Growth limitations :

- $L_{PAR}$ photosynthetically active radiation (PAR)
- $L_N$ nitrogen ($NO_3$ + $NH_4$)




### Day of PAR half limitation

- First day $L_{PAR}$ > 0.5
- Start of high light

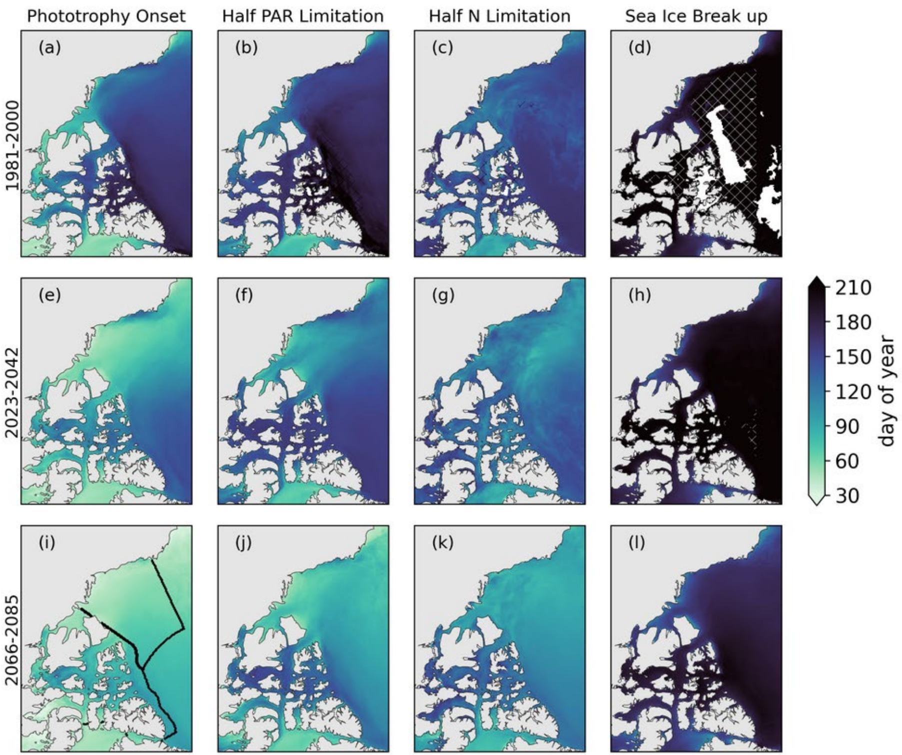
### Day of nutrient half limitation

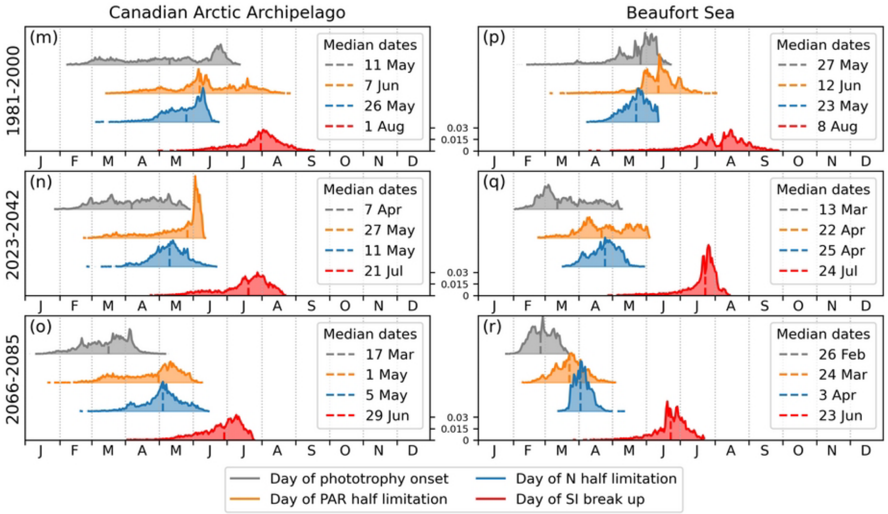
- Last day when $L_N$ > 0.5
- End of high growth

### High growth days

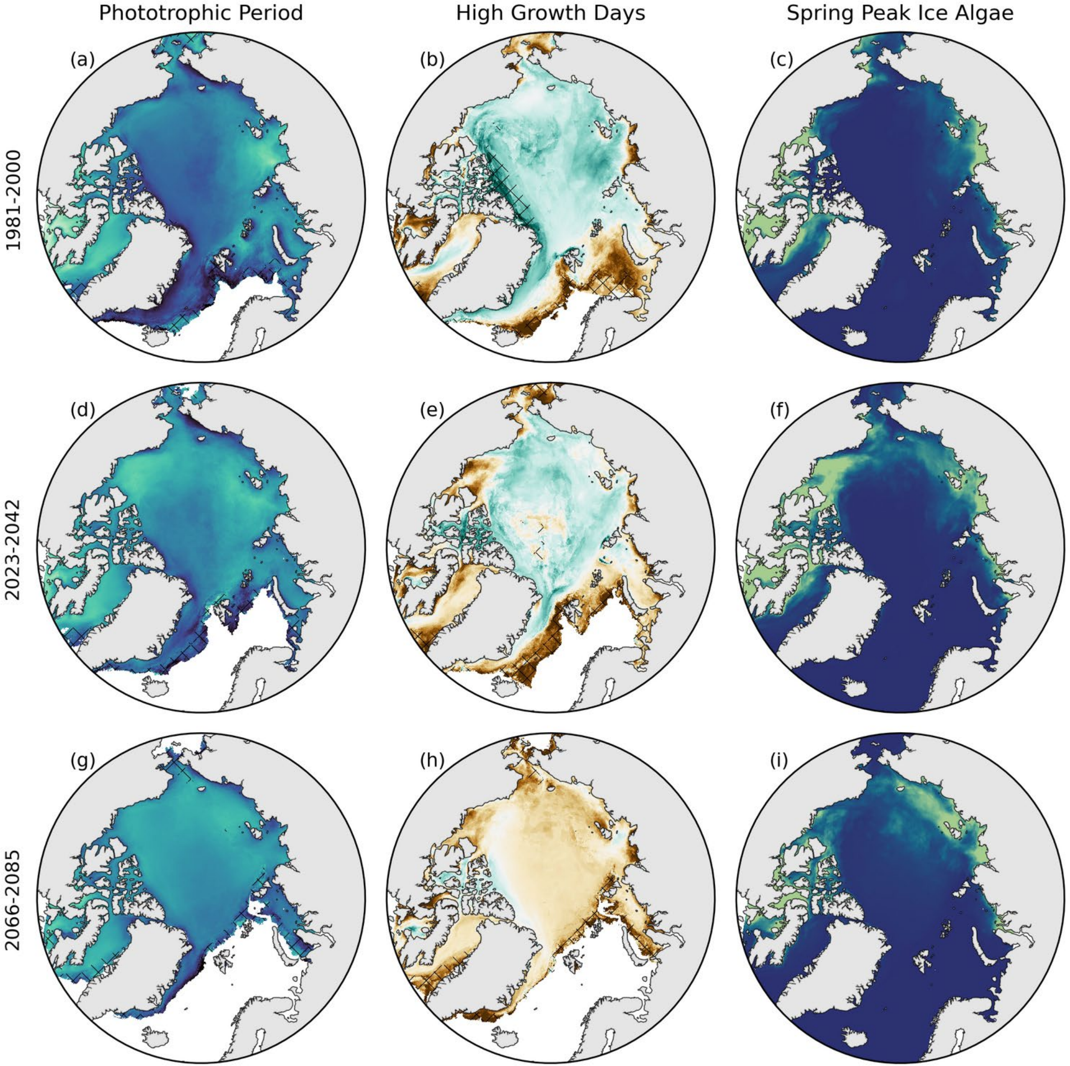
- Number of days between PAR half limitation and N half limitation
- Negative if N limitation before PAR limitation

# Key dates of ice algae blooms



# Growth periods




***Phototrophic period***: Number of days from phototrophy onset to SI break up

***High growth days***: Number of days between PAR half limitation and N half limitation

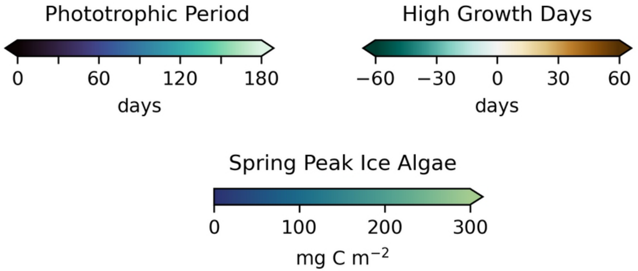
- Negative if N limitation before PAR limitation

➔ Timing of environmental conditions controls growth

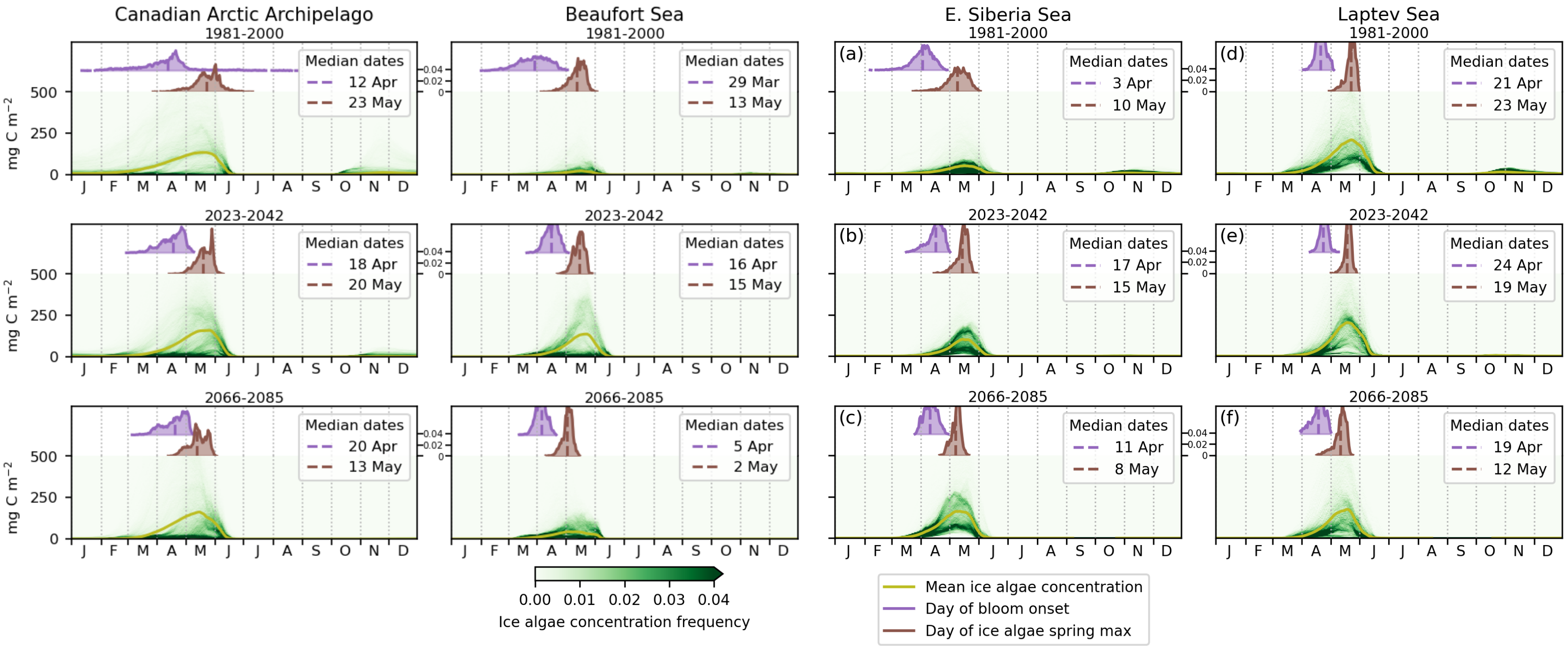
- Need enough time with sufficient light
- Synchrony of light and nutrient availability

➔ Limitation functions are saturating functions

- Beyond certain values, growth rate not higher
- More nutrients: longer period of high growth

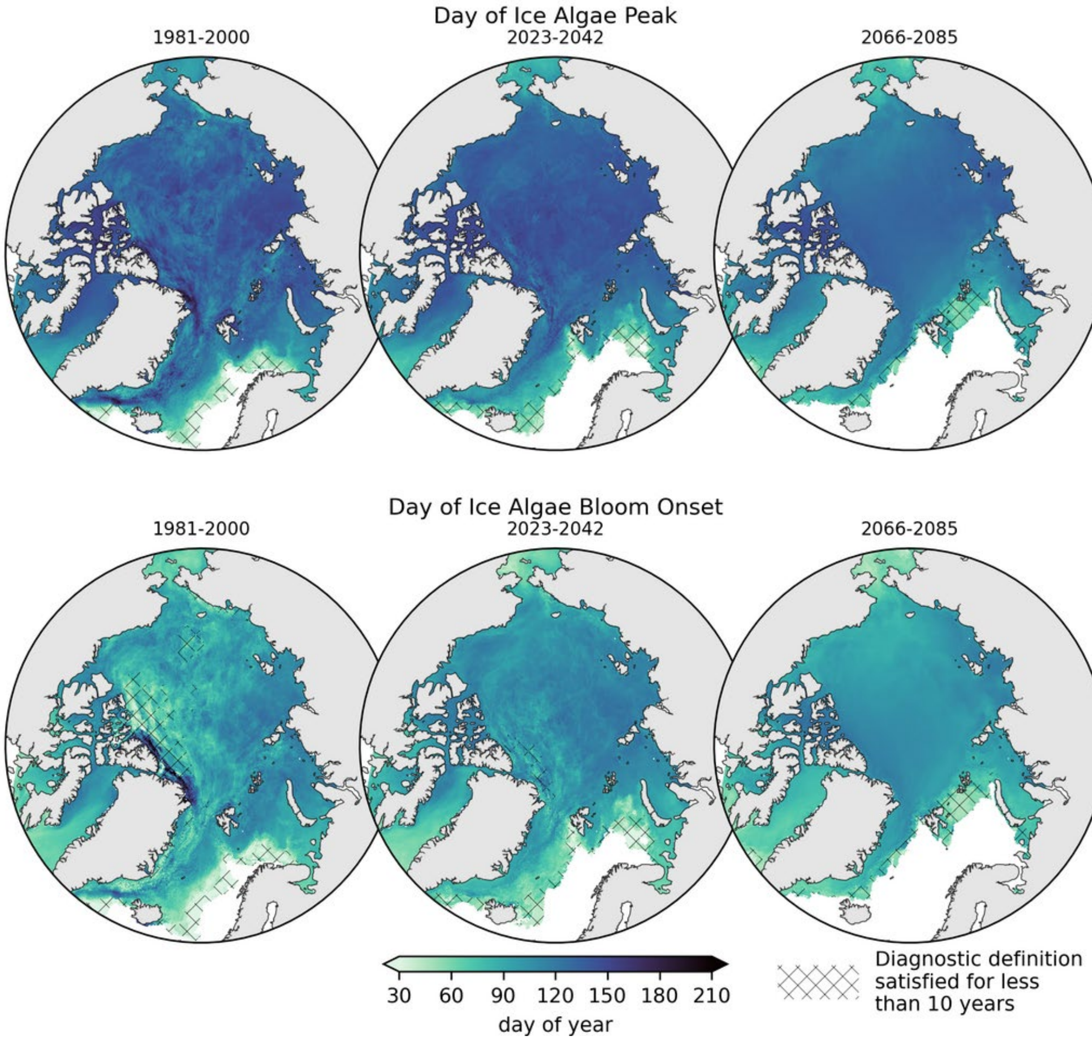


# Ice algae bloom timing




**Day of ice algae bloom onset**
Day ice algae reaches 1 standard deviation of the ice algae concentrations calculated over the period from 1 January to 31 August.

**Day of maximum ice algae**
Day the maximum concentration is reached between 1 January and 31 August

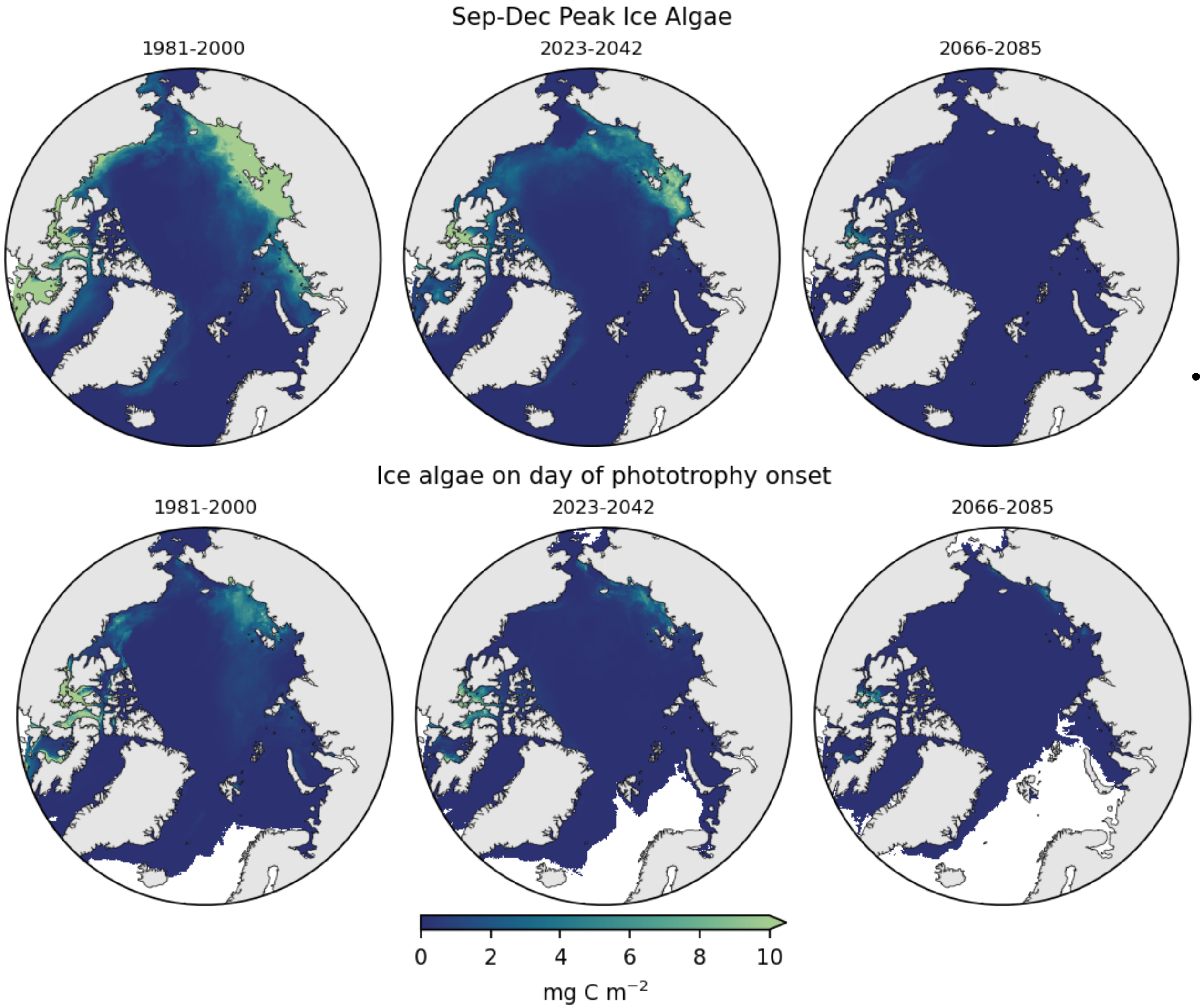



**Day of maximum ice algae**

- Maximum just before the biomass begins to decrease
  - ➔ Indicative of bloom termination timing
- Bloom termination due to flushing of ice algae
  - ➔ Indicative of changes in onset of ice melt

**Day of ice algae bloom onset**

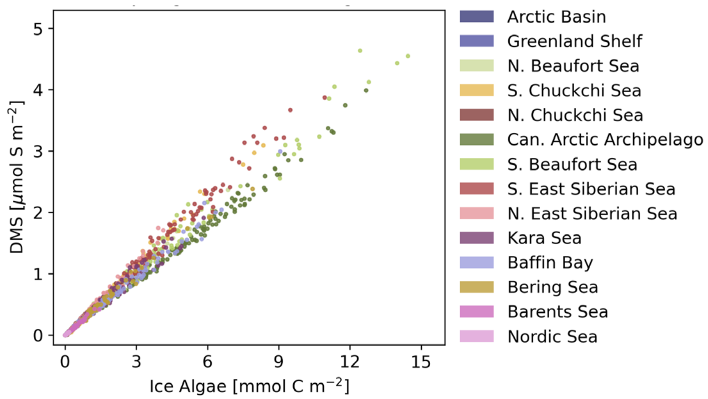
- Earlier onset of phototrophy:
  - ➔ Earlier growth
- Model : exponential growth
  - ➔ Low PAR: doubling time 35 days
  - ➔ Low biomass : Delay in development of bloom




- Later freeze-up in future
  - → Ice formation from seawater with less phytoplankton
  - → Lower accumulation of ice algae during ice growth
  - → Lower initial ice algae at the beginning of spring

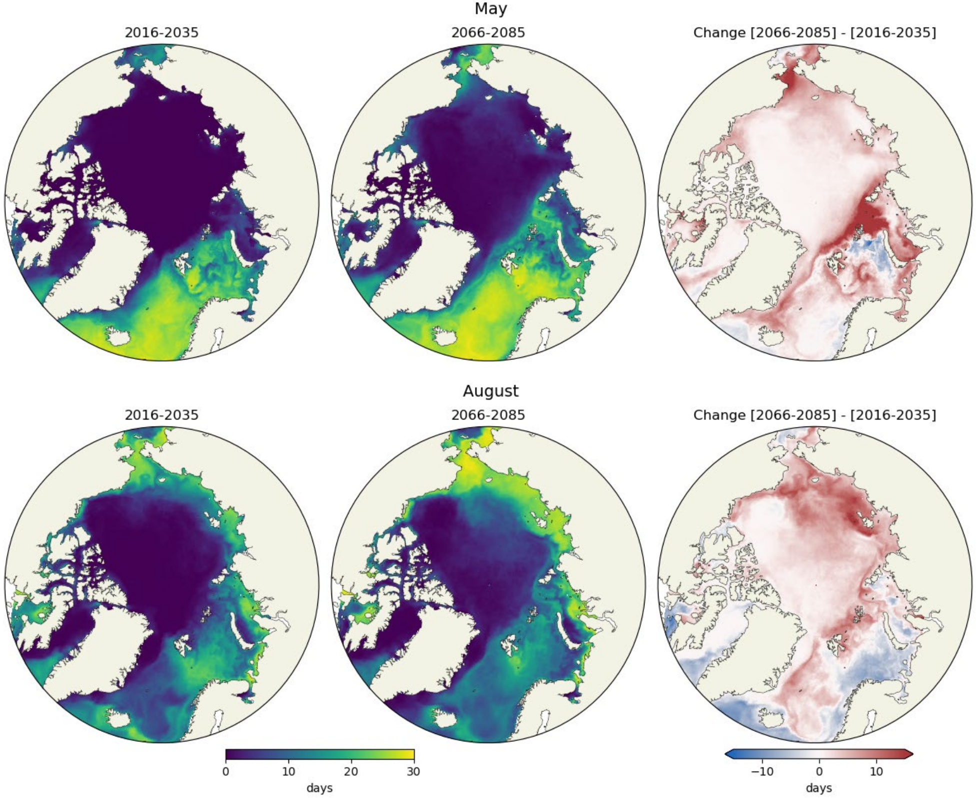
# Sea ice – climate interactions: DMS

Bottom Ice DMS and Ice Algae




Regional spring means (March, April, May and June) each point represent a year.

Mean number of days DMS emissions > 2.5 μmol $m^{-2}$ $d^{-1}$




*Aerosol nucleation threshold for remote regions:*

- For DMS fluxes > 2.5 μmol $m^{-2}$ $d^{-1}$ linear relationship between CCN number concentration and the DMS flux (Pandis 1994)

# Key points

Key dates diagnostics

- Timing of environmental conditions controls ice algae growth

→ Extension to ocean?
Different growth parametrizations?

Future of ice algae blooms

- Loss of ice thickness, limited changes in sea ice break-up timing
- Longer growth periods, emergence of new productive regions
- Impact of ice extent loss limited to lower latitudes before 2085
- Limited change to timing of ice algae peak

→ Acceleration after 2085?
Ice Algae Model Intercomparison
IAMIP2 : Yuanxin Zhang poster

Timing of bloom onset

- Earlier light compensated by lower initial biomass
- Impact of later freeze-up on following bloom

→ Model validity for bloom initial phase?

Future DMS

- Increased DMS production and emissions
- Earlier emissions from earlier sea ice brake-up
- Emissions burst controlled by wind

→ Representations of leads: emissions during ice brake-up

# Thank you for your attention!

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CRiceS

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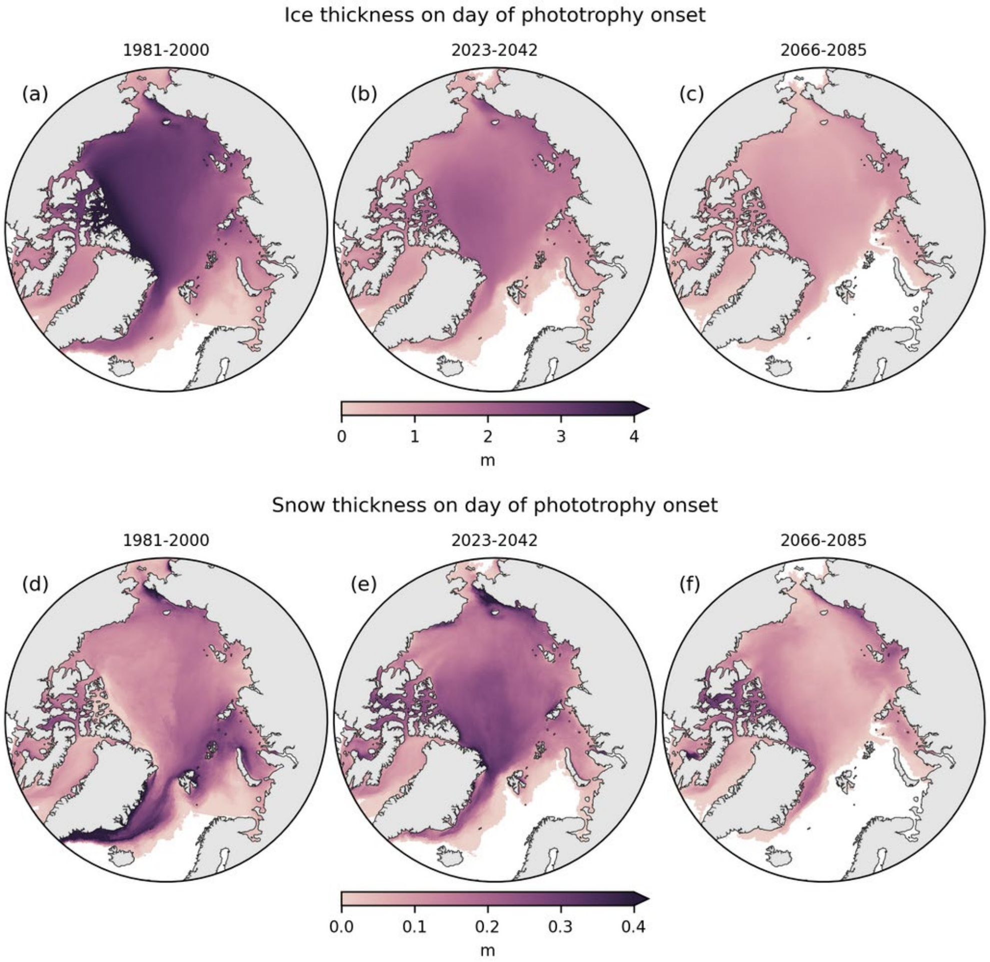
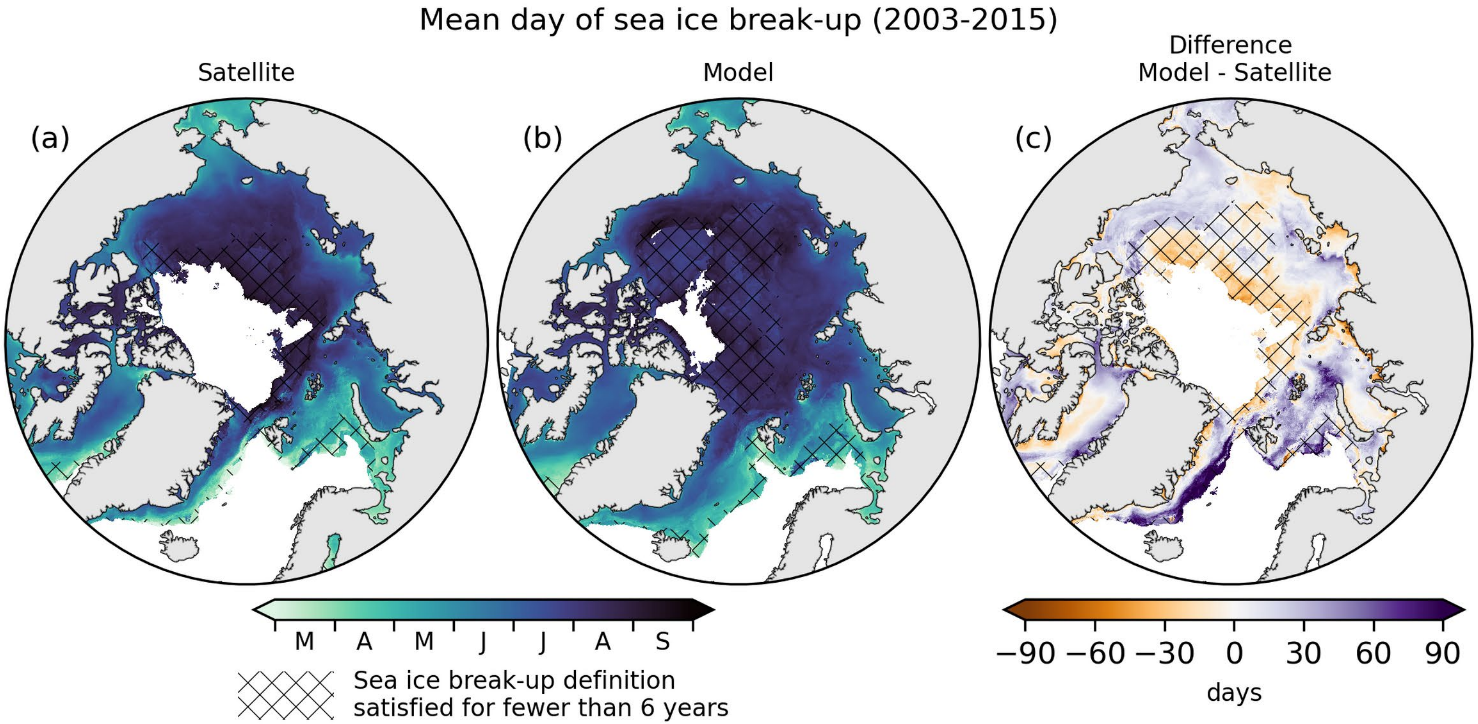
# What controls the onset of phototrophy?



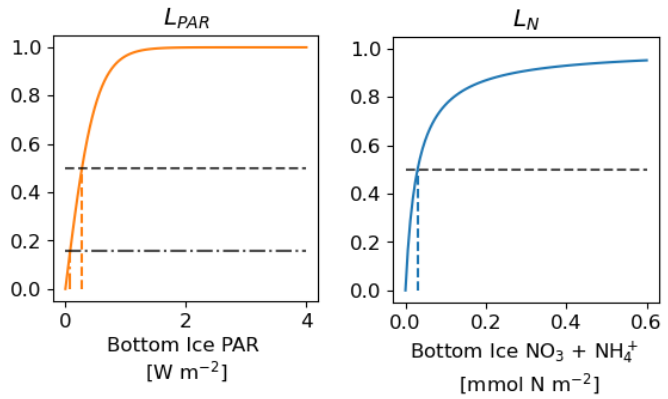
# Model evaluation: timing




Satellite daily sea ice concentration datasets :
AMSR-E ASI (version 5.4, June 2002 to September 2011, Melsheimer and Spreen (2020))
AMSR2 ASI (version 5.4, July 2012 to December 2019 Melsheimer and Spreen (2019))

# Ice algae dynamics

$$\frac{\partial IA}{\partial t} = \underbrace{\mu_{\max} f(T) \min\left(L_N, L_{PAR}\right) IA}_{\text{Growth}} - \underbrace{\left(m_1 f(T) IA + m_2 IA^2\right)}_{\text{Mortality}} + \text{Transport}$$




- Minimum: need synchrony of light and N
- Limitation functions are saturating functions
  ➔ Beyond certain values, growth rate not higher
  ➔ More nutrients: longer period of high growth
- Temperature constant in skeletal layer

During high growth days, neglecting quadratic mortality and transport:

$$\frac{dIA}{dt} \approx \mu IA$$

with μ independent of PAR and N,
but period of integration over growth period

➔ $IA(t) \approx IA(t_0) \exp\left(\mu \left(\text{length of high growth period}\right)\right)$