

## Primary production and zooplankton in the polar regions - indicators or actors of climate change?

The Arctic warms nearly 4 times and the Barents area in particular as much as 7 times faster than the globe (Isaksen, K., et al. Sci Rep. 2022, Rantanen et al. Nat. Commun. 2022). Intertwined with the warming is a reduction in sea ice cover, which increases the amount and duration of solar insolation at the ocean surface.

**Phytoplankton** exhibit a pronounced seasonal cycle, highly dependent on solar insolation, with a maximum during spring (April - May) and a minimum in the winter and early spring (January-March). However, the inter-annual variability is high. The spring bloom duration lasts typically 3-4 weeks and is followed by a reduction due to exhaustion of nutrients (phytoplankton need nutrients like nitrogen (N)), grazing by zooplankton, vertical mixing and advection from lower latitudes.

**Zooplankton** play an important role in the Arctic ecosystem by transferring energy from the primary producers to animals higher in the food chain, as part of the so-called food web. Hence, the zooplankton biomass depends both on primary production and predation pressure (e.g. fish; capelin, herring, cod, and larger plankton; krill, chaetognaths)

Plankton are often indicators of ecosystem change. Warming and sea ice reduction in the Arctic Ocean cause an increase in the primary production, zooplankton and krill. Phytoplankton blooming depends heavily on available sunlight. Hence, more open water due to sea ice loss in the Arctic Ocean promotes increased growing season and production of phytoplankton. However, several of the CMIP6 models exhibit a reduction in phytoplankton associated Chl *a* in the Barents Sea in the future scenarios (SSPs).

### Main research questions:

- Seasonal cycle: do you find a relationship between NPP, open water area and duration, sst, and what about zooplankton? Do models at all agree with the observations?
- Research studies indicate that increases in total primary productivity of the Arctic Ocean are driven in large part by reductions in the persistence and extent of sea ice cover. Do you find a similar relationship in CMIP6 models?
- Does the strong relationship between sea ice cover and total annual NPP hold for the past when sea ice cover was greater, and in the future, as sea ice continues to decline. Is there a threshold for sea-ice area below which this relationship no longer holds? How about a new steady state?

### Mini-research questions for guidance:

- The zooplankton grazes on the primary producers, do you find a dependency in the data?
- Do you find a significant increase in annual NPP?
- Do you find a significant correlation between NPP and mean annual open water area? How about the NPP and length of the open water cycle?
- Is there an increase in the trends? Significance?
- Some studies suggest that climate models fail to capture AA due to the cooling effect of increased/brighter cloud cover, which will also impact the insolation at the ocean surface. Do you find this effect in the data?
- How is the timing of the peak in NPP correlated with open water peak, annual NPP, sea ice cover, mean Chl *a* ?

### Data:

- NPP / Chl *a* concentration
- sst, sea-ice area, sunlight absorbed by ocean surface
- open water (less than 50% ice cover) area and duration (daily data)
- Barents Sea is defined by: 15°E to 55°E, 60°N to 90°N

- the length of the phytoplankton bloom (the number of days that mean daily net primary production exceeded 500 mgC m<sup>-2</sup> d<sup>-1</sup>)
- Numbers from the papers listed below (Arrigo, K. R., and van Dijken, G. L. (2011), Lewis et al., Science 369, 198–202 (2020))

#### Observations:

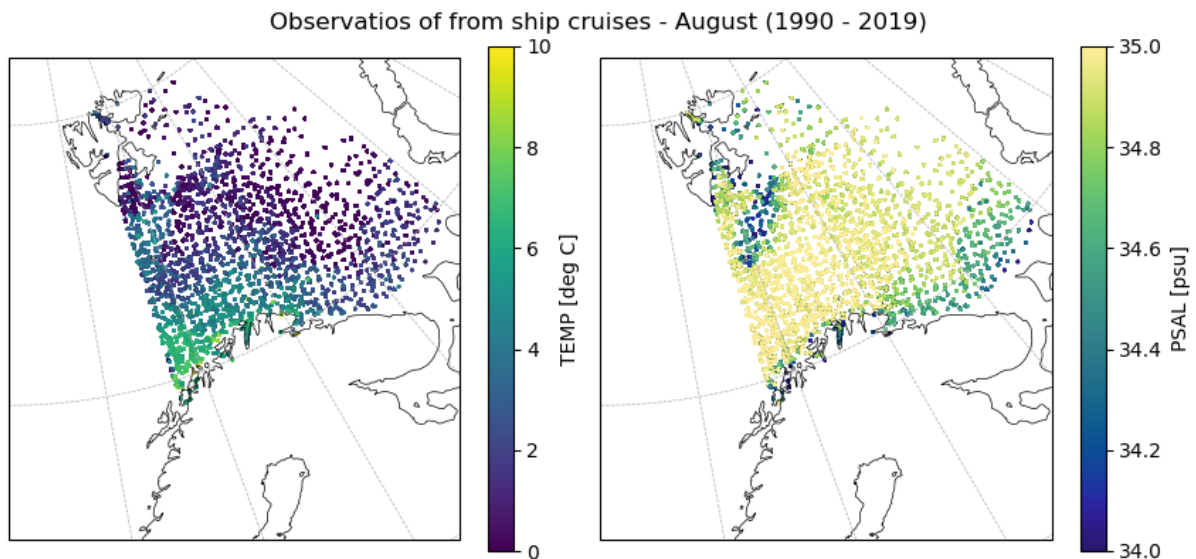
- **net primary production (npp):**
  - satellite retrievals (SeaWiFS and MODIS Aqua ocean color data) of chlorophyll a (Chl a) ([http://orca.science.oregonstate.edu/npp\\_products.php](http://orca.science.oregonstate.edu/npp_products.php)), years 2002 - 2021
  - samples from CTD mounted water bottles. Transects Nord Norge - Bjørnøya, years 1977 - 2017
  - /projects/NS9252K/ESGF\_betzy/obsdata/Tier2/ESACCI-OC/OBS-ESACCI-OC\_sat\_fv3.1\_Omon\_chl\_199701-201712.nc
- **Zooplankton:** samples from ship cruises. Transects Nord Norge - Bjørnøya
  - [https://www.st.nmfs.noaa.gov/copepod/content/region\\_arctic.html](https://www.st.nmfs.noaa.gov/copepod/content/region_arctic.html)
  - Havforskningsinstituttet (xl-ark)
- **Sea ice edge:**
  - <https://osi-saf.eumetsat.int/products/osi-450>
  - <https://cryo.met.no/nb/sjoe-is-klima-produkter>
  - <https://modis.gsfc.nasa.gov/data/dataproduct/mod29.php>
- HadISST:
  - <https://www.metoffice.gov.uk/hadobs/hadisst/>

#### CMIP6 output (there exist plenty more):

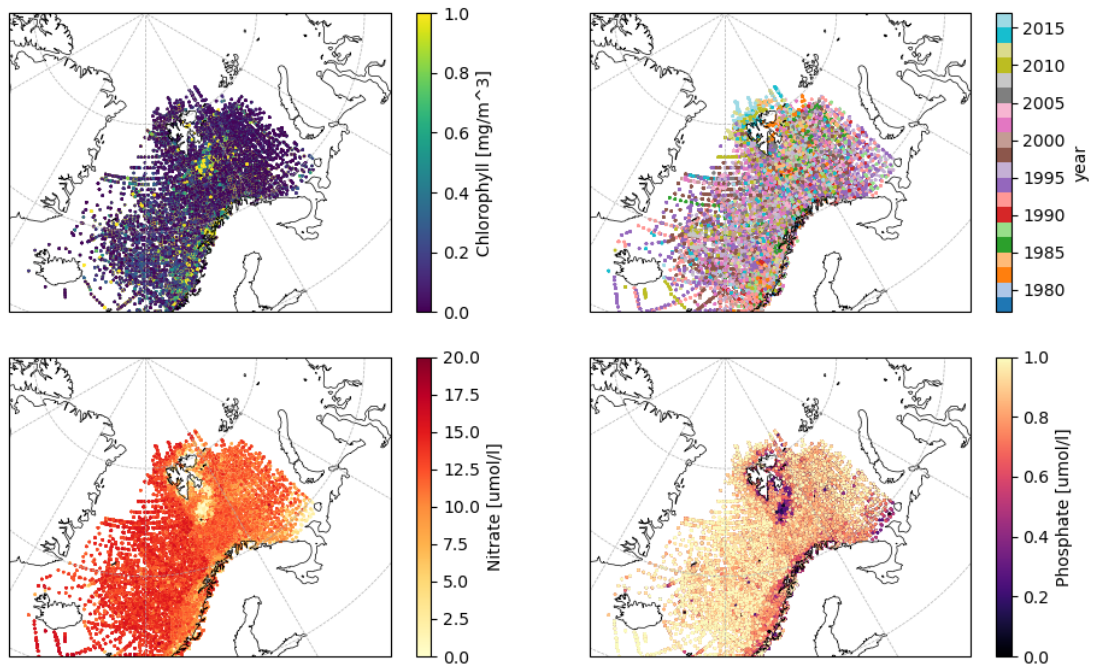
Component and frequency	Variable name	Description
Sday	siconc	sea ice concentration
Oday	cholos	surface mass concentration of total Phytoplankton expressed as Chlorophyll in seawater
Oday	phycos	sea surface Phytoplankton carbon concentration
Oday	omldamx	mean daily maximum ocean mixed layer thickness
Oday, Omon	tos	sea surface temperature
Oday, Omon	sos	sea surface salinity
Oday	ppint	integrated primary production (noresm raw data)
Omon	zooc	zooplankton carbon concentration
Omon	zoocos	surface zooplankton carbon concentration
Omon	rsntds	net downward shortwave radiation at sea water surface
Omon	mlotstmax	maximum ocean mixed layer thickness
Omon	phyc	phytoplankton carbon concentration
Omon	phyfeos	surface mole concentration of total phytoplankton expressed as iron in seawater
Omon	phynos	surface mole concentration of Phytoplankton nitrogen in seawater
cmip6	models	NorESM2-LM,, CESM2, CNRM-ESM2-1
cmip6	experiments	omip1, esm-hist, historical, esm-ssp585, ssp585

## References:

- omip: <https://noresm-docs.readthedocs.io/en/latest/configurations/omips.html#omip-type-experiments>
- <https://earthobservatory.nasa.gov/features/Phytoplankton>
- <https://earthobservatory.nasa.gov/images/51765/bloom-in-the-barents-sea>
- <https://www.whoi.edu/know-your-ocean/ocean-topics/ocean-life/ocean-plants/phytoplankton/>
- <https://www.whoi.edu/know-your-ocean/ocean-topics/ocean-life/jellyfish-other-zooplankton/>
- <https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2011JC007151>
- <https://www.nature.com/articles/s41558-020-0905-y>
- <https://www.science.org/doi/full/10.1126/science.aay8380>
- <https://doi.org/10.5194/tc-13-49-2019>
- <https://gmd.copernicus.org/articles/10/2169/2017/gmd-10-2169-2017.pdf>



Observations of from ship cruises



MODIS: net primary production (units of  $\text{mg C} / \text{m}^2 / \text{day}$ ) based on the standard vgpm algorithm

