Subsurface chlorophyll maximum and water column primary productivity in Kongsfjorden

Divya David T[1*], Archana Singh[2], Shridhar Jawak[3], Subeesh M. P[4] and N Anilkumar[5]

[1,2,5] National center for Polar and Ocean Research, Ministry of Earth Sciences, Vasco da Gama, Goa 403804, India

[3]Svalbard Integrated Arctic Earth Observing System (SIOS), SIOS Knowledge Centre, Svalbard Science Centre, P.O. Box 156, N-9171 Longyearbyen, Norway

[4]Khalifa University, P. O. Box No. 127788, Abu Dhabi, United Arab Emirates

*Corresponding author: divya@ncpor.res.in

Abstract

Subsurface chlorophyll maximum (SCM) maintained by vertical supply of light and nutrients is important to the Arctic pelagic system. This high chlorophyll concentration at the subsurface stays longer in the water column than that at the surface and hence can have abiding biogeochemical and ecological implications. Not incorporating SCM in the quantifications and modeling may underestimate its contribution in the water column primary production (PP), for the entire growing period. In this study we investigated subsurface chlorophyll_a and related PP in Kongsfjorden, a west Svalbard fjord in the Norwegian Arctic. From our long term summertime monthly averages of chlorophyll_*a* vertical profiles over the period 2011 to 2021, we observed SCM between 20 m and 50 m depths. Within this SCM depth range, we have continuous hourly time-series biogeochemical and physical measurements at two nominal depths around 25 m and 40 m obtained from the Indian mooring in Kongsfjorden. The data at these depths have been used to estimate the subsurface PP. We used the Copernicus Marine Environment Monitoring Service (CMEMS) global ocean biogeochemistry hindcast for the upper 50 m depth integrated PP. The study reinforces understanding the role of SCM in PP and incorporating it to improve the algorithms of PP for Kongsfjorden and similar fjord systems.

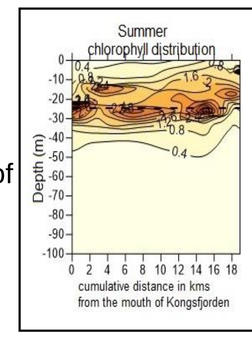
Introduction

SCM and PP in the Arctic Ocean

- After the spring bloom of phytoplankton, nutrients are exhausted in the surface layer of the Arctic Ocean due to strong vertical stratification.
- During summer, the stratification blocks surface nutrient replenishment leading to SCM - subsurface peaks of phytoplankton- where enough light and nutrients are available.
- PP in ocean is the rate of fixing inorganic carbon dioxide to produce organic carbon biomass by phytoplankton, the primary producers.
- PP has been widely estimated by satellites using chlorophyll_a, a photosynthetic pigment in phytoplankton.
- Changes in oceanic PP helps in understanding climatic impacts on marine ecosystems.
- In-situ PP estimation using radioisotope methods are time consuming, labour-intensive, and available only at discrete locations → affects accurate areal estimations of PP.
- Satellite ocean colour sensors that has spatial coverage of chlorophyll fail to detect SCMs and hence, its contribution is not included in the Arctic Ocean PP estimates.
- The annual magnitude of error in depth integrated satellite-based PP estimates without SCM show 0.2 to 16 % spatial variation. In summer, PP has been underestimated by 75% in the entire Arctic Ocean.
- The contribution of SCM towards PP is still completely unknown.

Study Area

- Kongsfjorden, an identified research spot for climate change studies in the west Svalbard fjord, is known for strong seasonality in its physical and biogeochemical characteristics such as the blooms in spring and secondary production in summer.
- Increase in warming, and Atlantic water intrusions over the two decades has made the fjord almost sea-ice free. Open waters leads to more interaction processes with the atmospheric forcings and implicates the fjord physics and biogeochemistry
- Fjord is affected by increasing glacial meltwater input.
- Summer SCM is a prominent feature in Kongsfjorden, the climatological value of SCM shows a depth range of 20-50 m.
- A very few studies exist in Kongsfjorden, on the role of SCM in PP estimations.



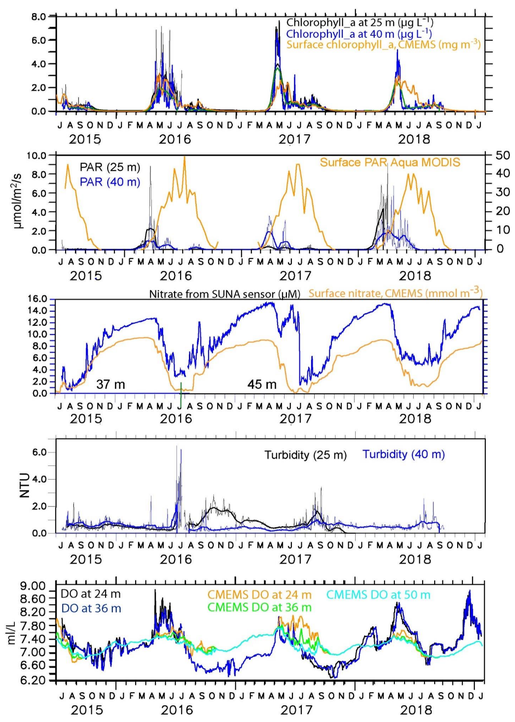
Average chlorophyll distribution in Kongsfjorden from July CTD profiles during 2011 to 2020 showing SCM higher than the surface values

Data

- Fjord: IndARC mooring data (July 2015 to December 2018)- daily average chlorophyll_a, turbidity (ECO-FLNTUS at 25 and 40 m), photosynthetically active radiation (ECO-PAR at 25 and 40 m), nitrate (Satlantic SUNA at 37 and 45 m), dissolved oxygen (DO), temperature, salinity (SBE37- CTD ODO at 24 and 36 m).
- Remote sensing and reanalysis: 8 day composite MODIS Aqua surface PAR and daily Copernicus Marine Environment Monitoring Service (CMEMS) global ocean biogeochemistry hindcast chlorophyll, DO, nitrate and PP at ¼ degree resolution

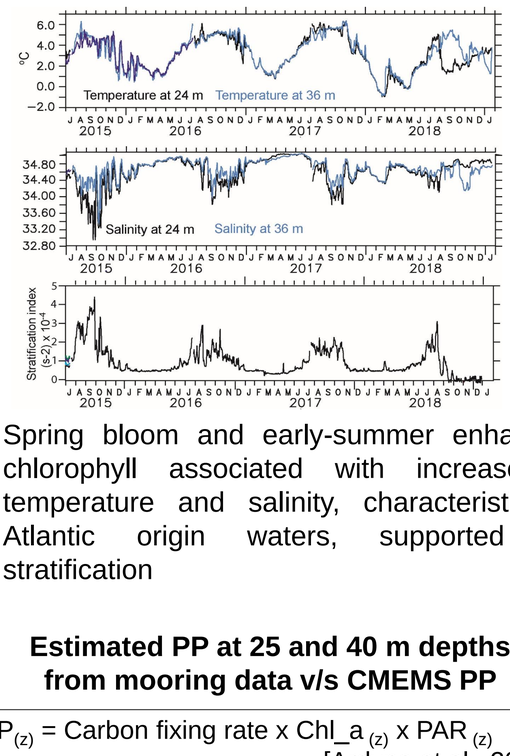
Results and discussion

Time series mooring and CMEMS biogeochemical variables



- Strong seasonal signature with almost zero chlorophyll in winter, bloom in spring, nutrient depletion in summer, and diminished light in autumn.
- Higher subsurface chlorophyll at 40 m than at 25 m.
- The subsurface values in spring are higher than the surface CMEMS chlorophyll while they were comparable in summer.
- The surface nitrate values from CMEMS were lower than the subsurface values as expected.
- Nitrate difference between the depths was minimal in summer, due to subsurface nitrate consumption by subsurface chlorophyll.

Time series temperature, salinity and role of stratification

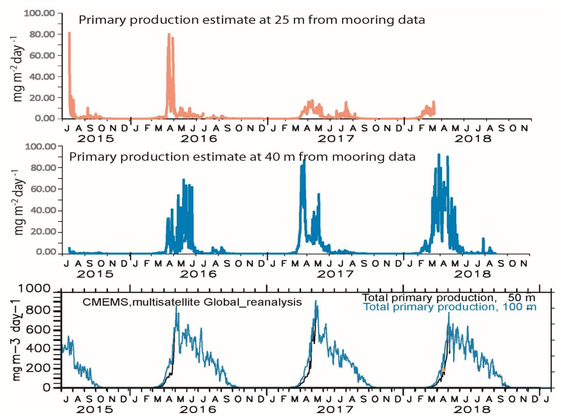


- Spring bloom and early-summer enhanced chlorophyll associated with increase in temperature and salinity, characteristic of Atlantic origin waters, supported by stratification

Estimated PP at 25 and 40 m depths from mooring data v/s CMEMS PP

$PP_{(z)}$ = Carbon fixing rate x $Chl\_a_{(z)}$ x $PAR_{(z)}$ [Ardyna et al., 2013]

Carbon fixing rate in Arctic Ocean, 1.7 mg C (mg Chl a−1) h−1 [Huot et al. 2013]



- Higher PP at 40 m reinforces the importance of deep chlorophyll including SCM in PP estimations.

Conclusion and future direction

- The three year continuous time-series mooring biogeochemical data from the IndARC mooring emphasizes the importance of including SCM in PP estimations in Kongsfjorden under the changing environmental conditions.
- The study will be continued to further quantify the annual and seasonal subsurface PP in Kongsfjorden, and to establish its contribution in the water column PP.
- The estimations will be used to improve the algorithms of PP for Kongsfjorden

References

- Archana et al., 2019. Estuarine Coastal and Shelf Science, 243.
- Ardyna et al., 2013. Biogeosciences, 10, pp. 4383-4404.
- Arrigo et al., 2011. Journal of Geophysical Research- Oceans, 116, C11022.
- David and Krishnan., 2017. Polar Sciences,11, pp. 30-41
- Hill et al. 2013. Progress in Oceanography, 110, 107–125.
- Lee et al., 2016. Journal of Geophysical Research- Oceans, 121, pp. 8635-8669
- Tverberg and Hegseth et al., 2019. Advances in Polar Ecology, pp. 173-227.

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