Increasing cloudiness in Arctic damps the increase in phytoplankton primary production due to sea ice receding

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Supplementary Information

1. Arctic and sub-Arctic Seas

The regional analysis was carried on by integrating the data within the limits of oceans and seas defined by the International Hydrographic Organization (IHO) (1953). All seas infested by sea ice or above the Arctic Circle were considered in the analysis (Fig. S1).

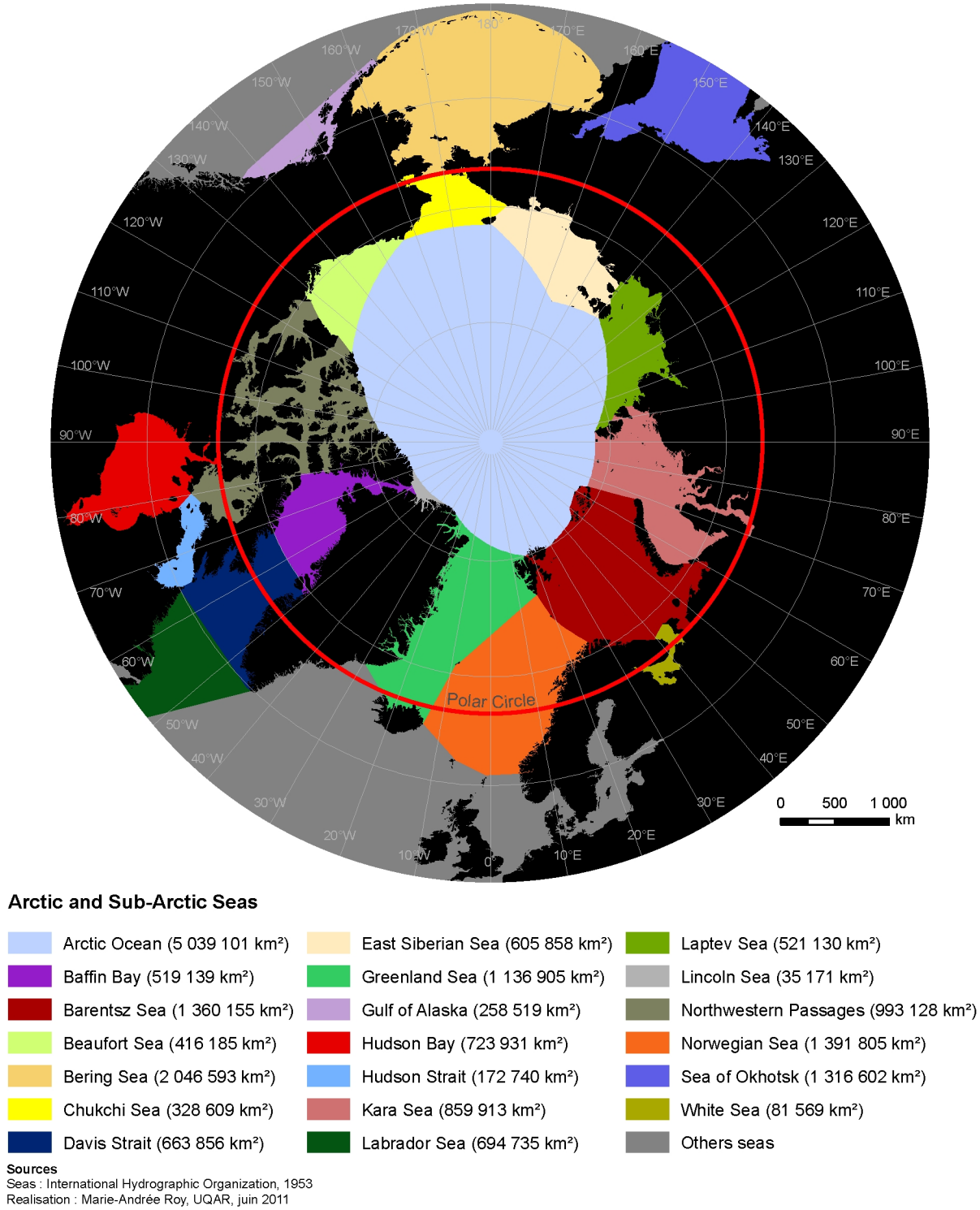

Figure S1 – Limits of Oceans and Seas considered as Arctic and sub-Arctic (IHO, 1953). The area of each sea was calculated using ArcMap 9.0 (ESRI).

2. Relationship between depth-integrated primary production and satellite-derived ocean optical properties

Platt and Sathyendranath (1993) demonstrated, using a dimensional analysis, that most depth-integrated primary production (PP) model assuming homogenous ocean can be generalized by a simple expression (eq. 5) that shares a common dependency to CHL/K_{PAR}. Here photosynthetically usable radiation (PUR) was used instead of PAR, so our PP model is proportional to CHL/K_{PUR}. This dependency can also be demonstrated mathematically by integrating eq 1 with some assumptions. Here daily PP is calculated using

$$PP = CHL \cdot P_m^B \int_{z=0}^{\infty} (1 - e^{-\frac{PUR(0-)\exp(-K_{PUR} \cdot z)}{E_k}}) dz \tag{S1}$$

where CHL is the chlorophyll *a* concentration, P_m^B is the light-saturated CHL-normalized carbon fixation rate (in mg C (mg CHL)$^{-1}$h^{-1}), and E_k the saturation irradiance (mol photon m^{-2} s^{-1}).

The factor $(1 - e^{-\frac{PUR(0-)\exp(-K_{PUR} \cdot z)}{E_k}})$ tends to decrease exponentially with depth following the exponential attenuation of the downwelling scalar irradiance (i.e. $\exp(-K_{PUR} \cdot z)$). The depth integration of the factor $(1 - e^{-\frac{PUR(0-)\exp(-K_{PUR} \cdot z)}{E_k}})$ is also proportional to the irradiance just below the sea surface (i.e. PUR(0-)). As in eq. 5, the non-linearity of the P vs I curves can be replaced by the factor f(PUR), which includes the variability of E_k. Thus, eq. S1 can be simplified as

$$PP \approx CHL \cdot P_m^B \cdot f(PUR) \int_{z=0}^{\infty} PUR(0-) \exp(-K_{PUR} \cdot z) dz \tag{S2}$$

We can put the sub-surface irradiance outside the integral, leading to

$$PP \approx CHL \cdot P_m^B \cdot PUR(0-) \cdot f(PUR) \int_{z=0}^{\infty} \exp(-K_{PUR} \cdot z) dz \tag{S3}$$

Integrating the equation yield:

$$PP \approx CHL \cdot P_m^B \cdot PUR(0-) f(PUR) \Big|_0^{\infty} \frac{\exp(-K_{PUR} \cdot z)}{-K_{PUR}} dz$$

$$PP \approx CHL \cdot P_m^B \cdot PUR(0-) f(PUR) (\frac{1}{K_{PUR}}) \tag{S4}$$

PP can be normalized to PUR(0-) (PP*) in order to remove the dependency to surface irradiance:

$$\frac{PP}{PUR(0-)} \approx P_m^B \cdot f(PUR) (\frac{CHL}{K_{PUR}}) \tag{S5}$$

References

International Hydrographic Organization (IHO): Limits of Oceans and Seas, International Hydrographic Organization., Bremerhaven, PANGAEA, 1953.

Platt, T., and Sathyendranath, S.: Estimators of Primary Production for Interpretation of Remotely Sensed Data on Ocean Color. J. Geophys. Res., 98 (C8): 14561-14576, 1993.