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Control of Sea-Ice Dynamics on the Inter-annual Variability of Net Community Production in the Western Antarctic Peninsula Region of the Southern Ocean

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1. Background

The Western Antarctic Peninsula region of the Southern Ocean has experienced a rapid rise in temperature (~6ºC) since 1950 (Vaughan *et al.*, 2003). This ongoing temperature increase has led to a decrease in sea ice extent (~40%), and likely impacted the local ecosystem at multiple levels (Clarke *et al.*, 2007). Here, we examine the relation of sea-ice dynamics to the inter-annual variability in net community production (NCP). The NCP is defined as the difference between gross primary production and community respiration (Figure 1).

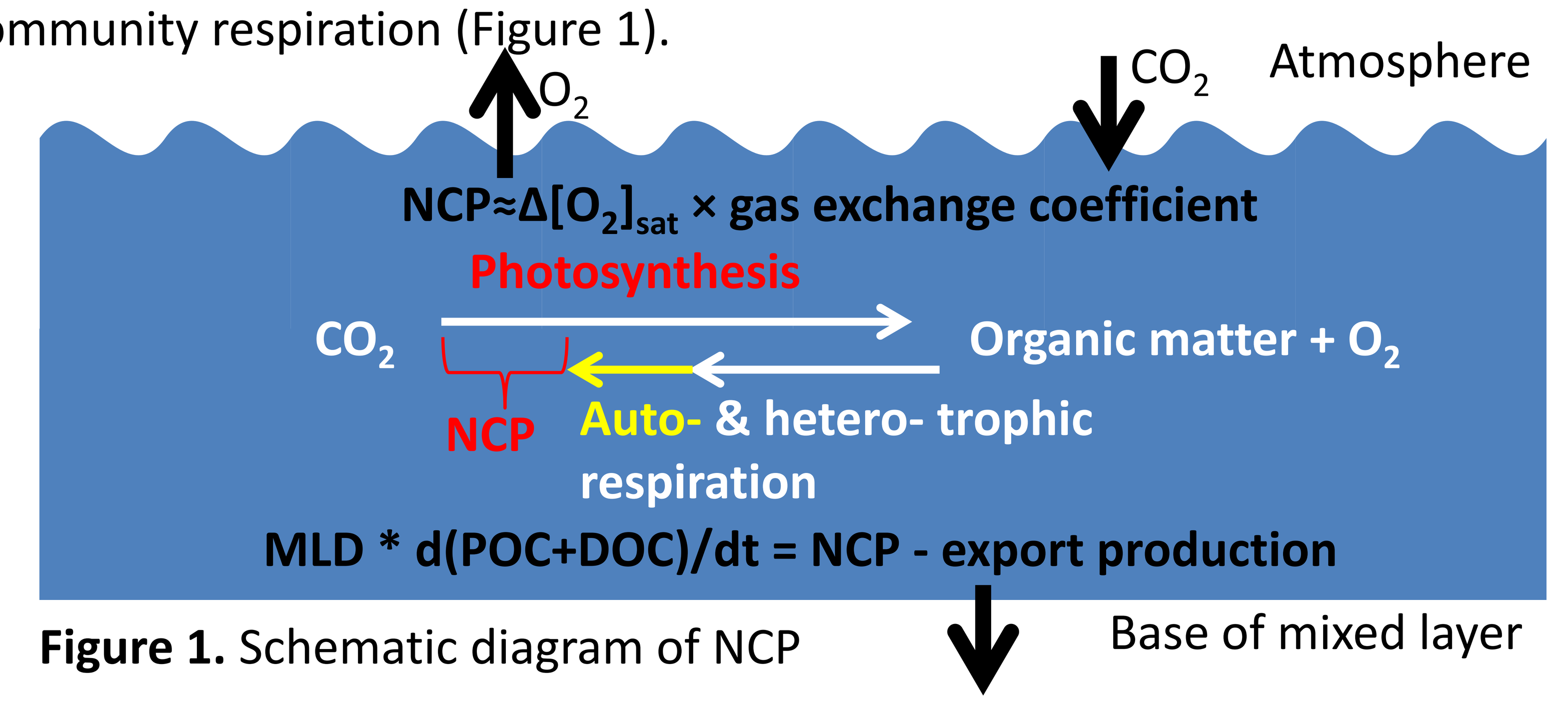

Figure 1. Schematic diagram of NCP

2. Data

Remotely sensed observations

1) Ocean color:
   - SeaWiFS (9km*9km, month, 1997-2007)
   - MODIS (9km*9km, month, 2002-2014)
2) Photosynthesis active radiation (PAR) (9km*9km, month, 1997-2014)
3) Sea surface temperature (SST) (9km*9km, month, 1997-2014)

***In-situ* data**

1) Particulate organic carbon (POC) and Chlorophyll *a* ([Chl]) (Figure 2).

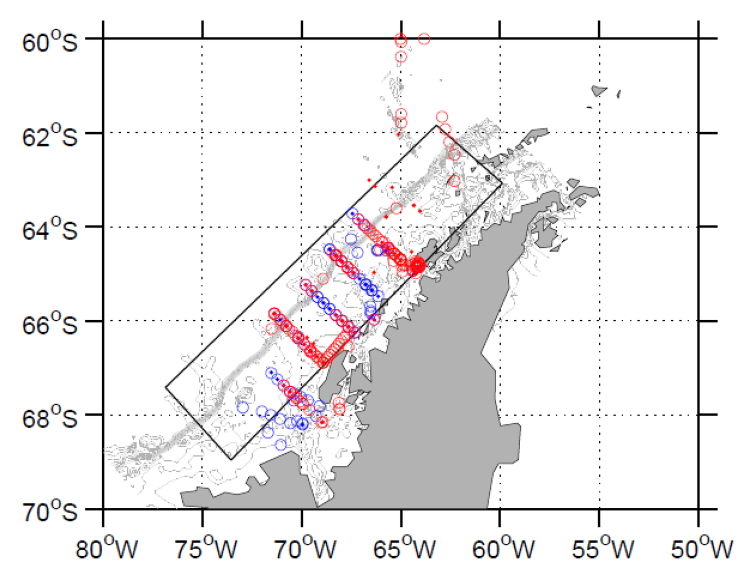

Figure 2. Locations of [Chl] (circle) and POC (dot) *in-situ* measurements. Red (blue) represents the sample matched to SeaWiFS (MODIS) observations. Quadrilateral is Pal-LTER regional grid.

3. Methods

1) Development of regional [Chl] algorithm that minimizes the discrepancy between SeaWiFS and MODIS (Compared with POC, [Chl] can be more accurately predicted by satellite data, and we will not show POC results)

$$[Chl] = 10^{-2.2980*log10(MB_s)+0.6874}$$
$$MB_s = \max\left\{\frac{Rrs(443)}{Rrs(555)}, \frac{Rrs(490)}{Rrs(555)}, \frac{Rrs(510)}{Rrs(555)}\right\}$$
SeaWiFS

$$[Chl] = 10^{-2.7127*log10(MB_m)+0.7207}$$
$$MB_m = \max\left\{\frac{Rrs(443)}{Rrs(547)}, \frac{Rrs(488)}{Rrs(547)}\right\}$$
MODIS

2) Calculation of NCP time series using a regression between O_2/Ar-derived NCP and [Chl] (Huang *et al.* in prep), and satellite [Chl] derived from monthly SeaWiFS and MODIS data from 1997 to 2014
3) Calculation of annually-integrated NCP from 1997 to 2013
4) Decomposition of annually-integrated NCP into spatial and temporal variability through empirical orthogonal function (EOF) analysis
5) Correlation analysis between first PCs and potential control factors

4. Validation of [Chl] algorithm

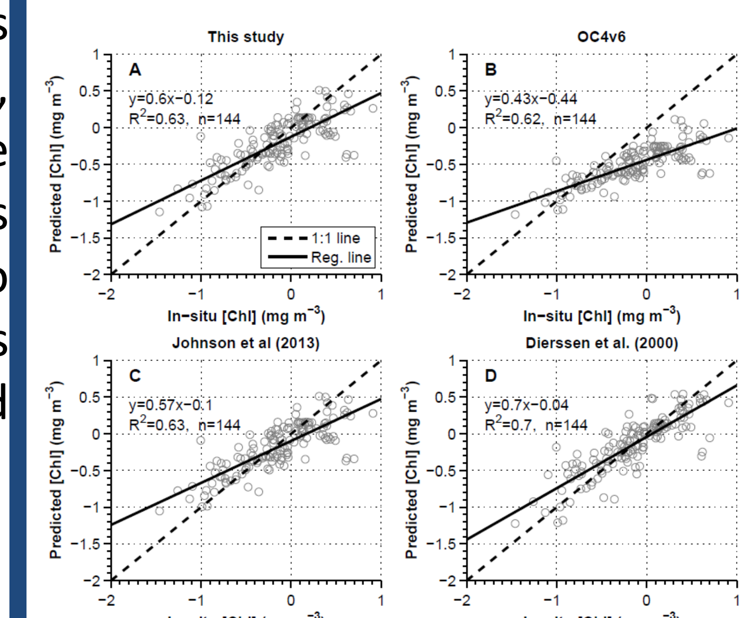

Figure 3. SeaWiFS: Scatterplots between *in-situ* [Chl] and prediction by the algorithm developed by this study (A), the OC4v6 (B), the algorithm developed by Johnson *et al.* (2013) (C), and the algorithm developed by Dierssen and Smith (2000) (D) (both x and y axes are in logarithm scale).

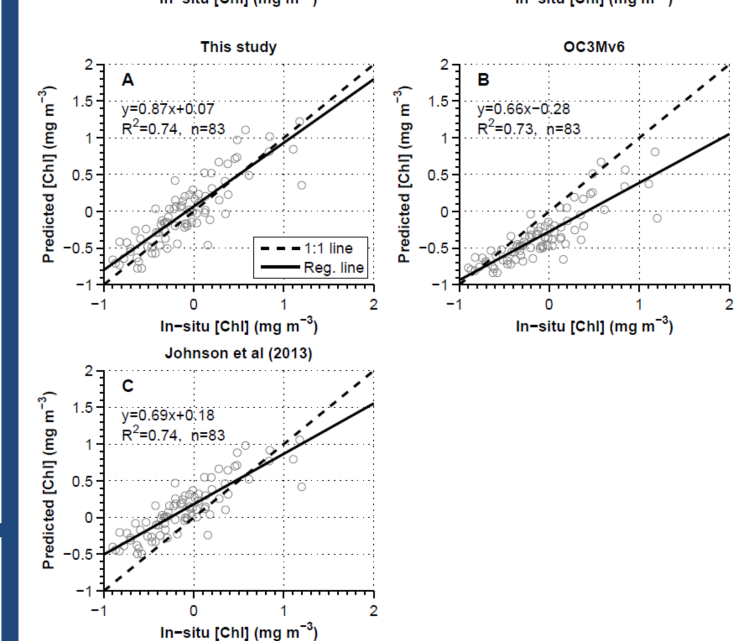

Figure 4. MODIS: scatterplots between *in-situ* [Chl] and prediction by the algorithm developed by this study (A), OC3Mv6 (B), and the algorithm developed by Johnson *et al.* (2013) (C) (both x and y axes are in logarithm scale).

5. NCP climatology

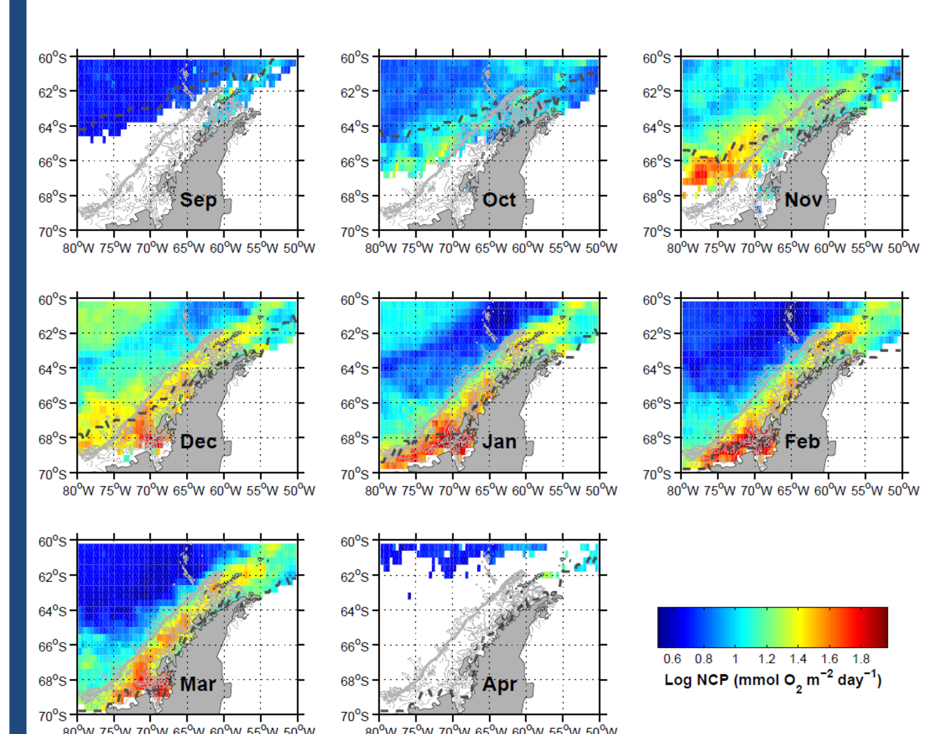

Figure 5. Monthly NCP climatology calculated using [Chl] derived from SeaWiFS and MODIS monthly ocean color from 1997-2014. Grey line represents bathymetry. Thick-dashed line represents climatology of ice edge. White area is covered by sea ice or cloud (NCP in logarithm scale).

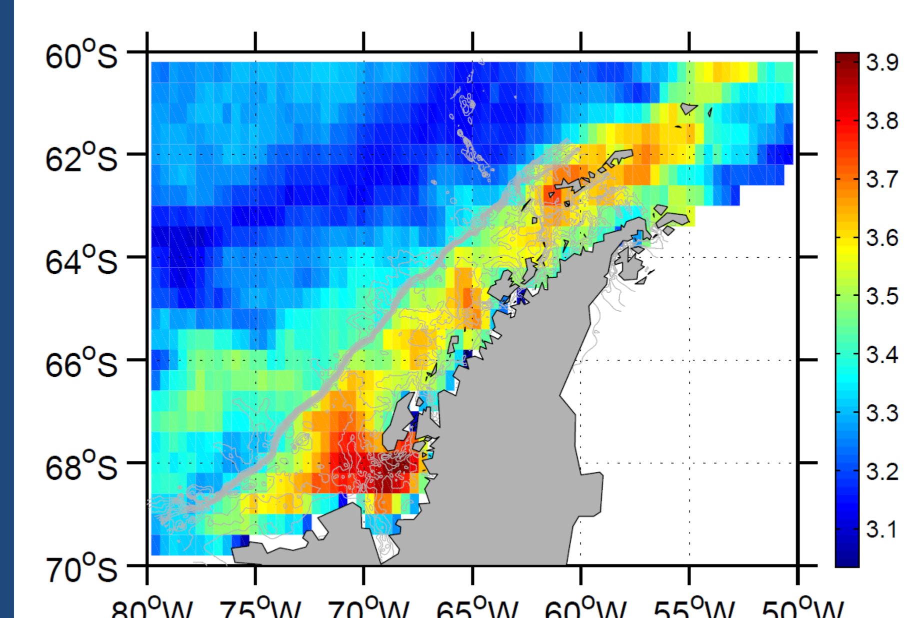

Figure 6. Climatology of annually-integrated NCP calculated from monthly NCP from 1997 to 2014. Grey line is bathymetry. White area is covered by sea ice or cloud (NCP in logarithm scale).

Acknowledgements

We would like to acknowledge NASA Earth and Space Science Fellowship for ZL and P. Sloan Fellowship for NC, and thank our O_2/Ar collaborators for providing field observations.

References

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Dierssen, H.M., and R.C. Smith (2000), *Journal of Geophysical Research-Oceans*, *105*(C11), 26301-26312.
Johnson, R., P.G. Strutton, S.W. Wright, A. McMin, and K.M. Meiners (2013), *Journal of Geophysical Research-Oceans*, *118*(7), 3694-3703.
Vaughan, D.G., G.J. Marshall, W.M. Connolley, C. Parkinson, R. Mulvaney, D.A. Hodgson, J.C. King, C.J. Pudsey, and J. Turner (2003), *Climatic Change*, *60*(3), 243-274.

6. Spatiotemporal variability in NCP

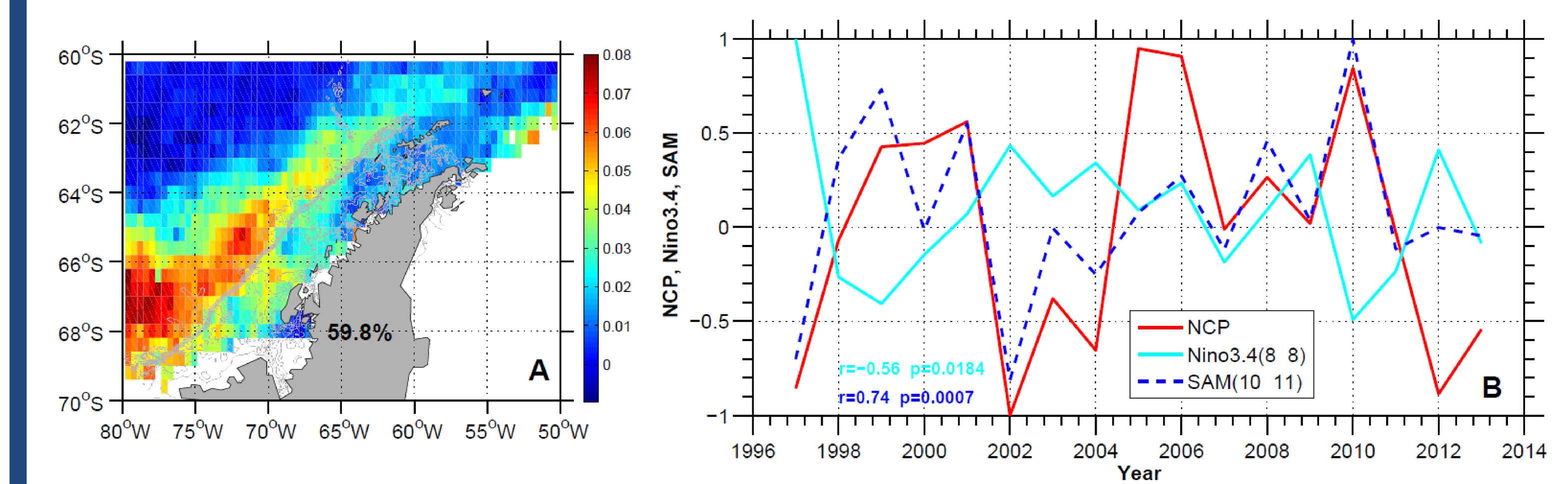

Figure 7. The first mode of annually-integrated NCP. Subplot A shows the first EOF, and subplot B shows the first PCs together with climate indices of SAM and Niño 3.4. The time series of climate indices are the mean in a time window where the mean value shows the highest correlation with the first PCs of annually-integrated NCP. Each time series is normalized to [-1,1]. Red region has high NCP variability.

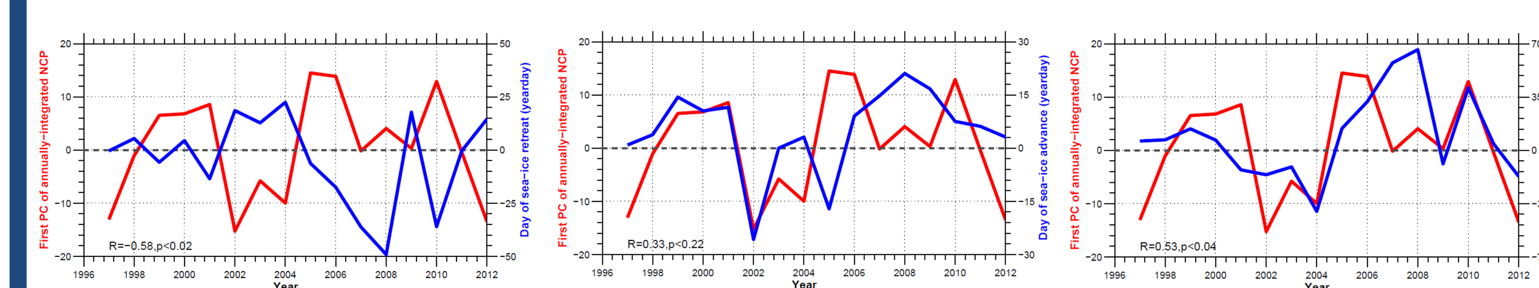

Figure 8. First PCs of annually-integrated NCP versus day of sea-ice retreat (left), day of sea-ice advance (middle), and sea-ice free day (right) in the high NCP variability region.

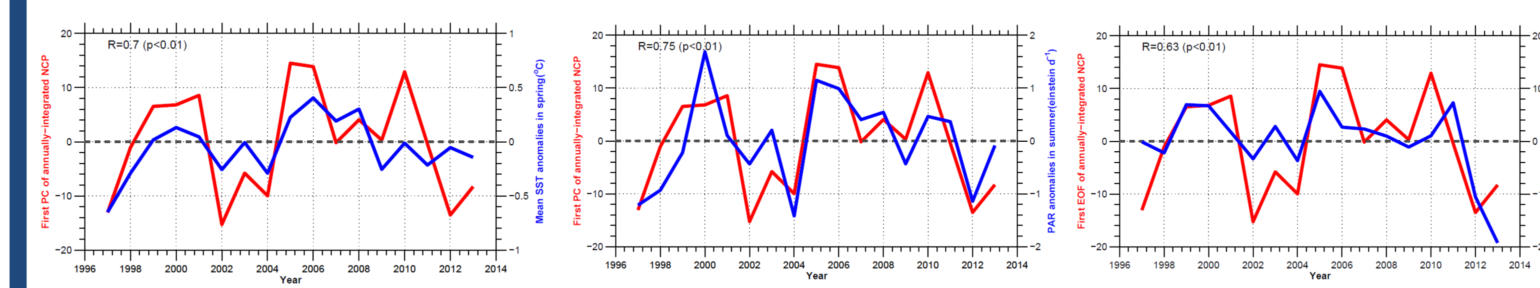

Figure 9. First PC of annually-integrated NCP versus SST anomalies in spring (left), and average PAR anomalies in summer (middle) and the whole growing season (right) in the high NCP variability region .

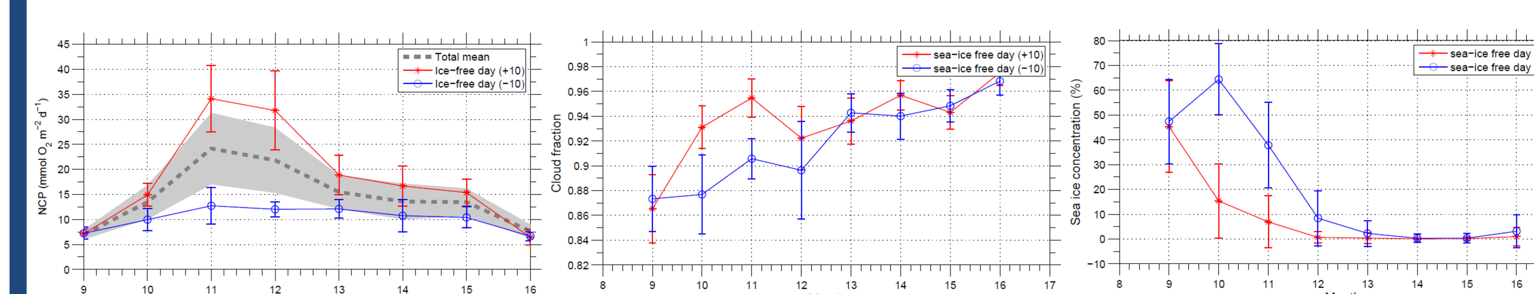

Figure 10. The mean NCP (left), cloud fraction (middle), and sea ice concentration (right) in the high NCP variability region for the year with ice-free day > 10 and <10 days. The total mean (grey dashed line) is calculated from 1997-2013.

7. Summary

1) Monthly NCP peaks in Nov seaward of the shelf break, and peaks in Jan and then plateaus out in the coastal/shelf region;
2) Monthly NCP shows positive (negative) on-to-offshore gradient in annually-integrated NCP before Nov (after Dec);
3) Coastal/shelf region and canyons are more productive than seaward of the shelf break (maximum difference = ~10 times), but latter shows higher inter-annual variability in annually-integrated NCP;
4) The inter-annual variability in NCP is dictated by the sea-ice dynamics (e.g. earlier sea-ice retreat in the seaward of shelf break corresponds to higher NCP) potentially because: (a) less sea ice duration leads to stronger winter mixing and/or higher iron in the mixed layer, and (b) water column is stabilized by fresh water when sea ice retreats.