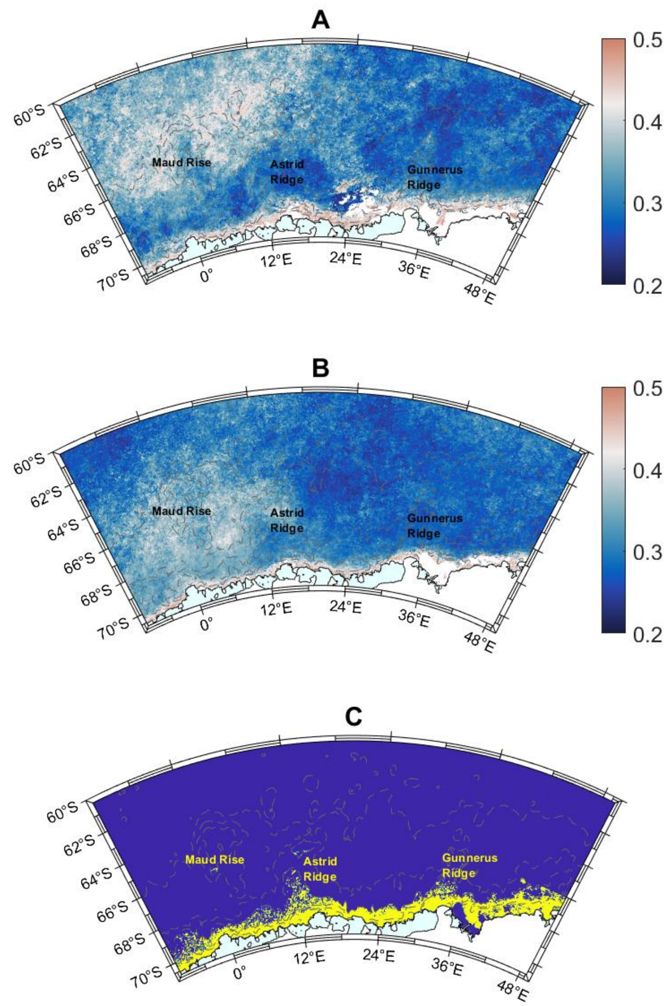
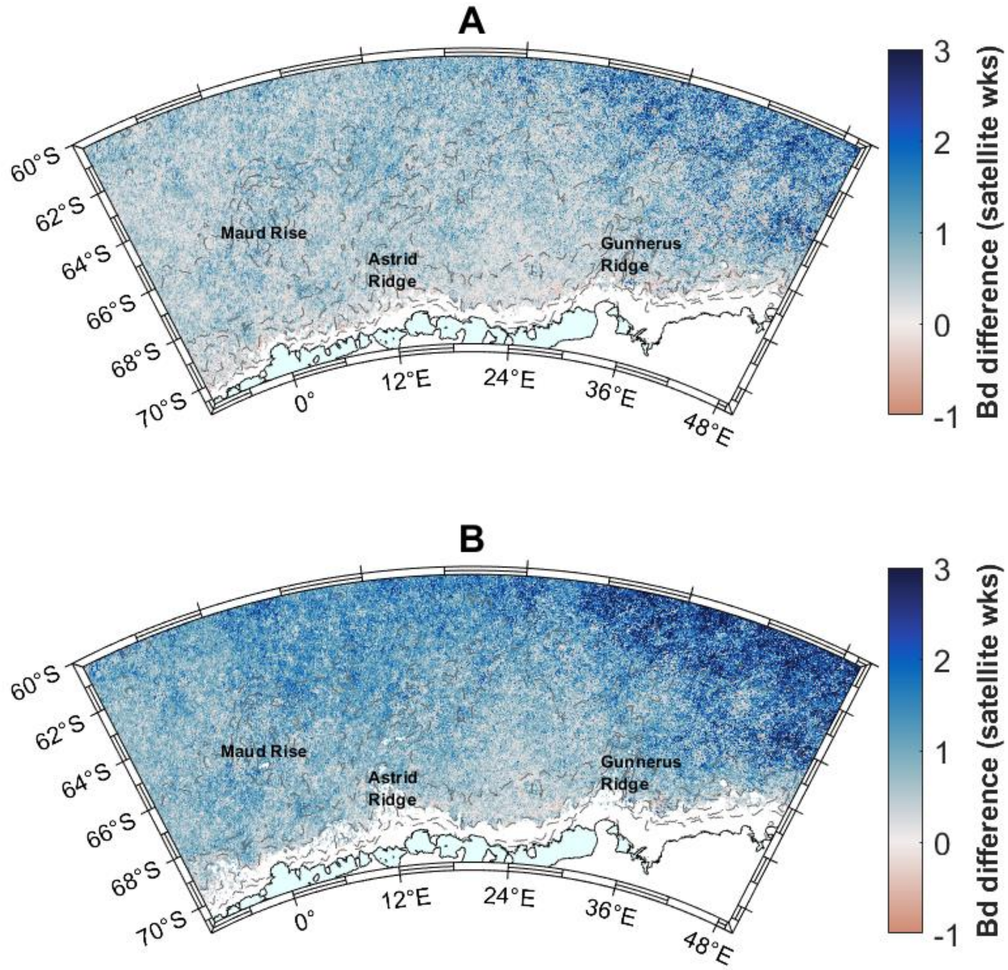
# *Supplementary Material*

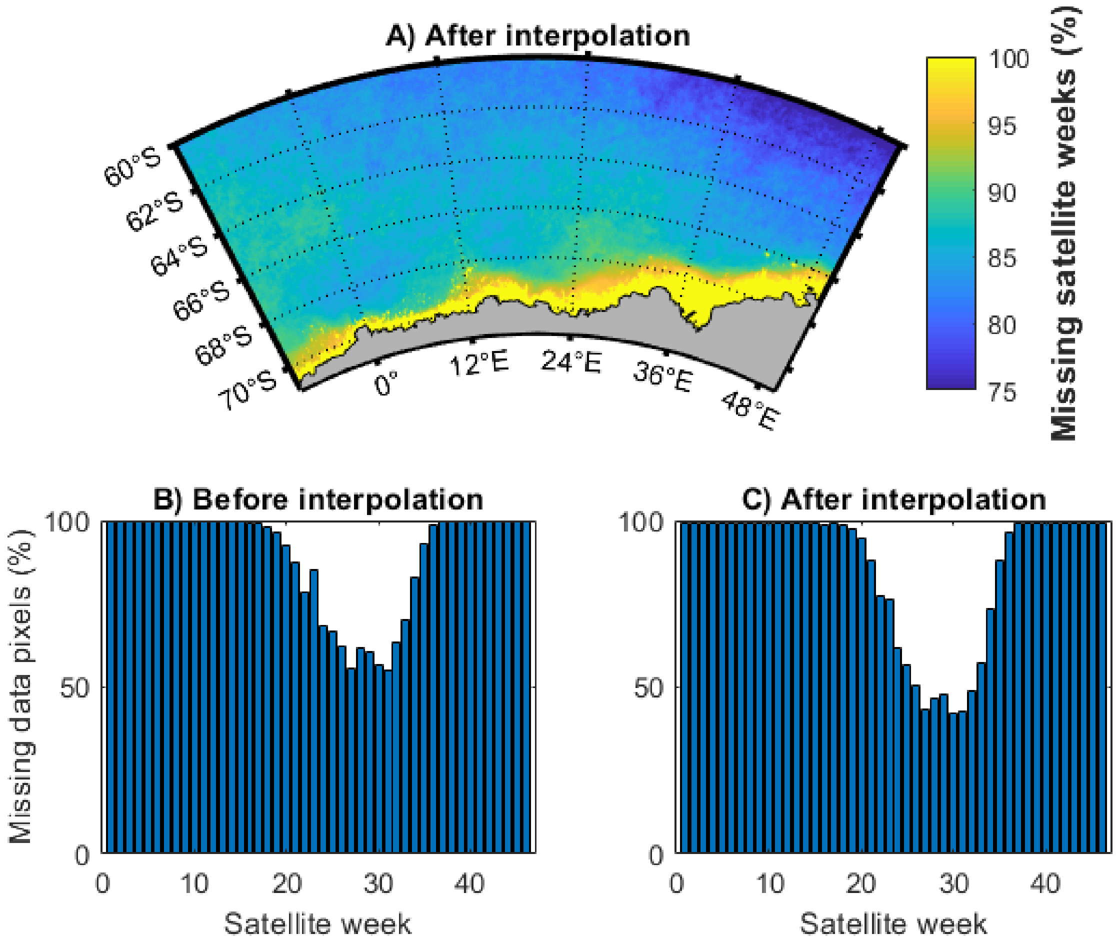
## 1 Supplementary Figures



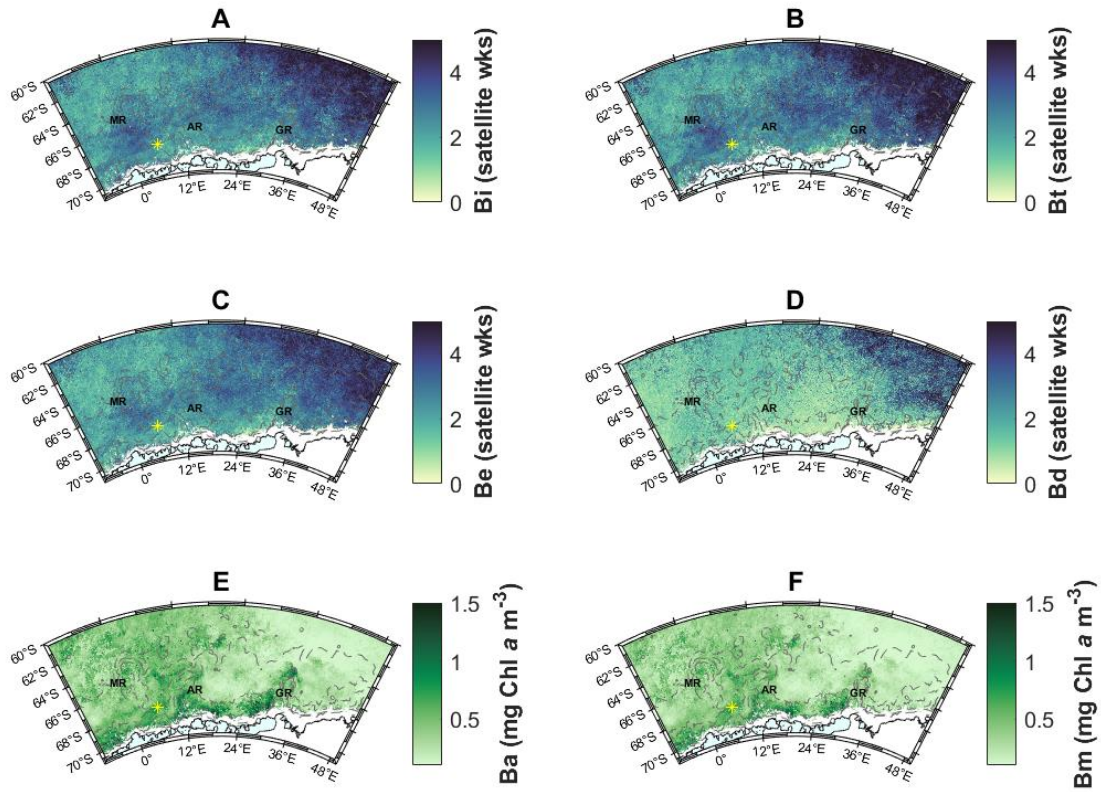

**Supplementary Figure 1.** OC-CCI satellite remote sensing chlorophyll *a* (Chl *a*) product root mean square deviation (RMSD) values (averaged over the years) for A) week 24 (beginning of January) and B) week 30 (end of February). The cutoff value of 0.42 is the highest value reported for the different optical water classes for OC-CCI version 1 in Sathyendranath et al. (2019). Besides a band along the coast with permanently elevated values, higher values are associated with high biomass areas. C) Coastal mask (in yellow) based on maximum geographical appearance of the out-of-range weekly mean RMSD values along the coast (areas south of 66 °S and with <3000 m bottom depth).



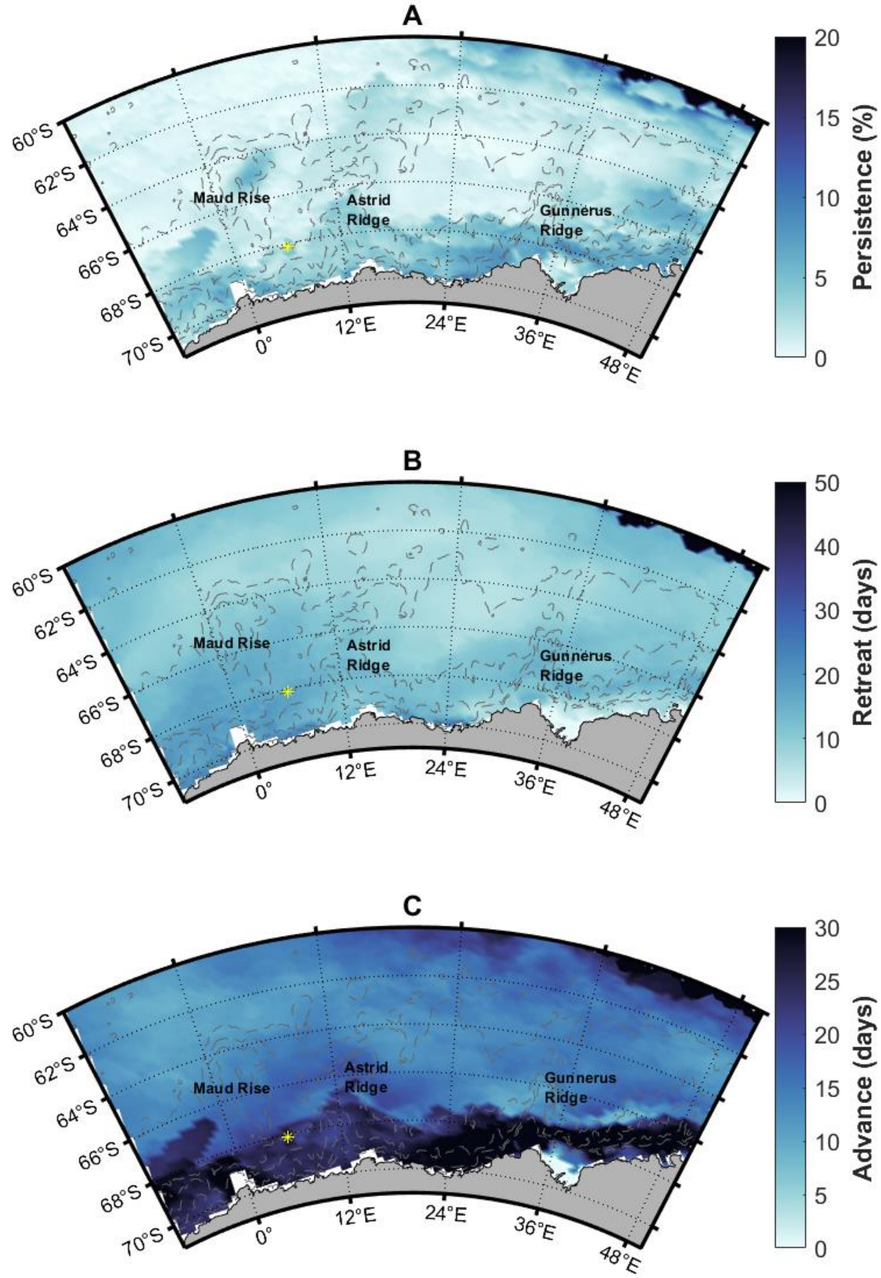

**Supplementary Figure 2.** Comparison of bloom duration (Bd) results obtained with differentially interpolated OC-CCI Chl *a* product. A) Bd from fully interpolated and filtered product minus Bd from only spatially interpolated product. B) Bd from fully interpolated and filtered product minus Bd from non-interpolated product. Blue colour (positive difference values) thus means that interpolation leads to longer bloom duration. Changes in both the bloom initiation and bloom end contribute to this pattern (not shown). Note also that without interpolation, more data gaps exist and the long-term means have less yearly values included for each pixel.




**Supplementary Figure 3.** Spatial (A) and temporal (B, C) distribution of missing data in our study area in the merged OC-CCI Chl a dataset, both before (B) and after (A, C) spatial and temporal interpolation. See main text for interpolation methods. In A, the colour shows the percentage of missing weeks over the whole time series (1997 – 2020). Coastal areas were permanently masked due to higher uncertainty in data in these areas. In B and C, averages of yearly values per satellite week are shown; there are 46 satellite weeks in a year. Week 1 starts here in the beginning of July to capture the southern hemisphere productive season within one year. Weeks 24 to 30 are in January – February.




**Supplementary Figure 4.** Standard deviations of the long-term mean phytoplankton bloom phenology indices (according to the threshold method). Bloom A) initiation, B) maximum timing, C) end, D) duration, E) amplitude and F) mean concentration. MR = Maud Rise, AR = Astrid Ridge, GR = Gunnerus Ridge. Station 53 is shown with a yellow asterisk.




**Supplementary Figure 5.** Standard deviations of sea ice phenology indices. Sea ice A) persistence B) retreat C) advance. See main text for calculation methods and definitions. Station 53 is shown with a yellow asterisk.

# 2 Rate of change as the bloom initiation detection method

## 2.1 Introduction

Different methods have been used to detect the bloom initiation/onset, and are often either based on defining a certain threshold in the biomass indicator (such as Chl *a* or phytoplankton carbon concentration) or on the rate of change of the biomass indicator (Brody et al., 2013). In addition, the biomass indicator can be based on surface observations, or integrated over a certain depth with the help of additional data (such as vertical profiles of Chl *a* and mixed layer depths (MLD)). The rate of change based methods aim to distinguish between bloom onset (the first time the growth rate exceeds loss rates and the rate of change becomes positive), bloom climax (the highest rate of increase) and bloom apex (when the rate of change first becomes negative after bloom onset). Brody et al. (2013) state that the rate of change method captures smaller and earlier increases in biomass than the threshold method (when both are based on surface data), and that the bloom initiation determined with the threshold method may correspond with mixed layer shoaling and thus conditions stated in the critical depth hypothesis (Gran and Braarud, 1935; Sverdrup, 1953 - though see Behrenfeld and Boss, 2018 for clarification on the hypothesis content). According to a modelling study of the Southern Ocean by Llort et al. (2015), using surface Chl *a* concentrations leads to detect the bloom climax (the highest rate of increase) of the depth-integrated bloom (using the rate of change method), whereas the “true” or “strict” onset of the bloom, that is the time when the gain in biomass first exceeds losses but biomass can still be low, occurs ca. 2 months earlier. Based upon these studies, different methods would capture and define bloom initiation in the following order: the rate of change methods (using depth-integrated biomass); the rate of change method (using surface biomass); the threshold method (using surface biomass). The first one(s) may correspond to the disturbance-recovery hypothesis (Behrenfeld, 2010; Behrenfeld and Boss, 2018) emphasizing grazing and loss rates as the controlling factor, and the latter one(s) may correspond with hypotheses emphasizing favourable growth conditions, enabling high growth rates and rapid biomass accumulation (bloom climax). Llort et al. (2015) noted that the climax-phase was bottom-up controlled and iron played a significant role during this phase, whereas the timing of the bloom maximum was top-down controlled.

## 2.2 Methods

To test the sensitivity of the bloom initiation results to the choice of detection method, we tested a method based on the rate of change in the Chl *a* concentration based on surface satellite remote sensing observations (see main text for further details). The rate of change method is used in several studies (e.g. Behrenfeld, 2010; Mayot et al., 2020) and is calculated with the following equation:

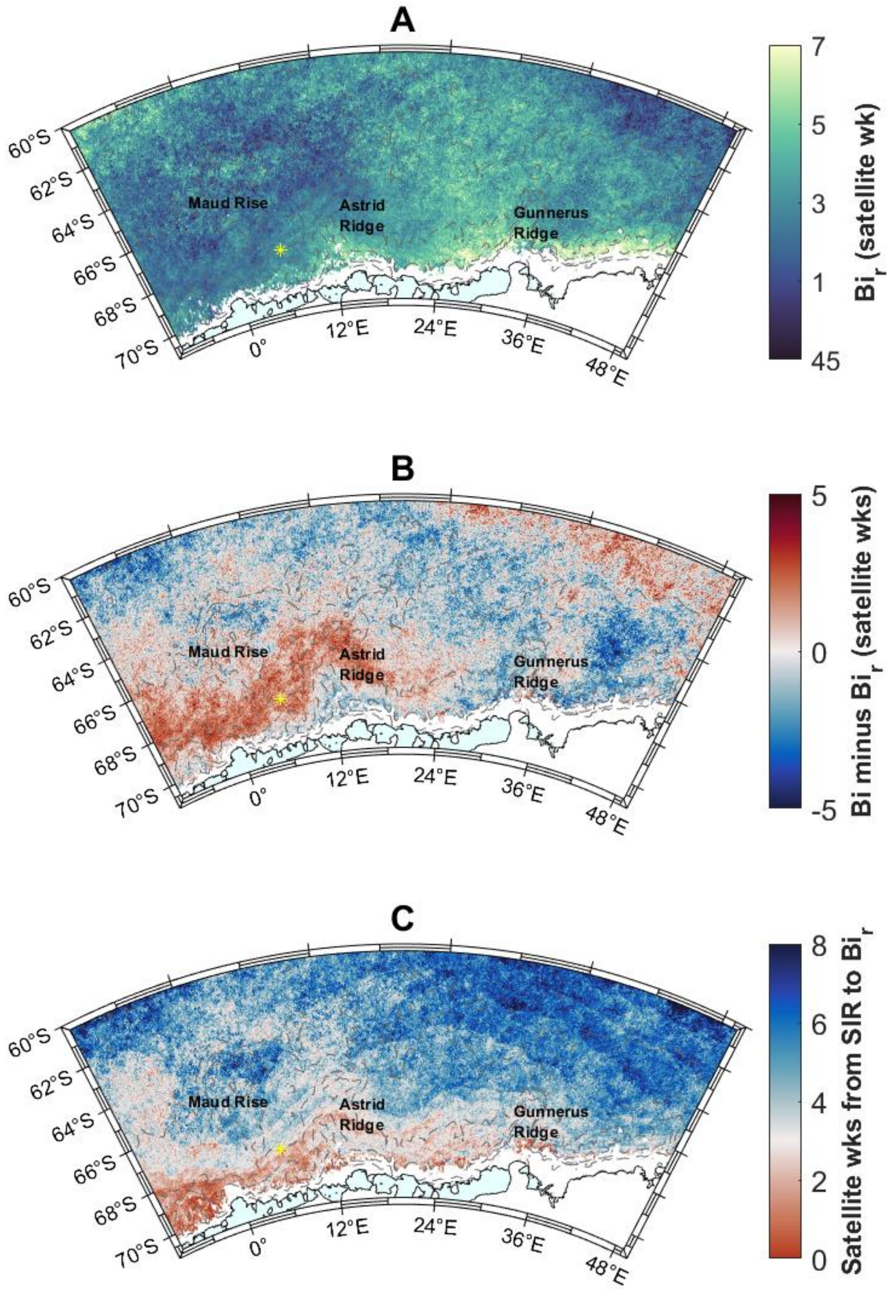
$$r = \ln(\mathrm{Chl}a_{t1}/\mathrm{Chl}a_{t0})/\Delta t$$

Where $r$ is the rate of change in phytoplankton biomass, $\mathrm{Chl}a_{t1}$ and $\mathrm{Chl}a_{to}$ are the Chl *a* concentration at two points in time and $\Delta t$ is the change in time (8 days for the satellite product used here). Bloom initiation is defined as the first time $r$ is positive in the defined year, and marked here as $\mathrm{Bi}_r$.

## 2.3 Results

Bloom initiation is in January (satellite weeks 1 to 4, January 1st to February 1st) in the majority of the study area (Figure S6A). Earlier bloom initiation (in December) occurs in the north-east corner of the study area and in small areas around Maud Rise. Blooms initiate earlier in the west of Astrid Ridge and north-east corner compared to the area in between (east of Astrid Ridge), as opposed to a latitudinal pattern. The differences between the two methods regarding bloom initiation are shown in Figure S6B. Blooms initiate earlier according to the rate of change method than the threshold method most notably at a band around Astrid Ridge continuing westward and in the north-east corner of the area.

In comparison with the sea ice retreat, the geographical pattern is largely similar between the two bloom initiation methods. With the rate of change method, a larger area than with the threshold method shows bloom initiation within three weeks of sea ice retreat, notably the areas around Maud Rise (Figure S6C).




**Supplementary Figure 6.** A) Bloom initiation according to the rate of change method ($Bi_r$). B) Difference between the threshold (Bi) and rate of change methods ($Bi_r$) with regard to bloom initiation. C) Time difference from sea ice retreat (SIR) to bloom initiation according to the rate of change method. Station 53 is shown with a yellow asterisk.

## 2.4 Discussion

Both methods show largely similar results both in the timing of the initiation and the relationship to sea ice retreat. Similarly, in a phenology method comparison study using surface observations, Brody et al. (2013) concluded that major phenology patterns are similar between methods, and that discrepancies depend on study locations. Some geographical differences were nevertheless visible in our method comparison. In the light of the literature review presented above, it is not surprising that the rate of change method detected an earlier bloom initiation in some parts of the study area.The area just west of Astrid Ridge has been recognized as an open-ocean bloom area characterized by a late-season bloom (i.e., early fall; see main text). For that particular area the threshold method may capture the bloom from significant biomass build-up, whereas the rate of change method may capture small biomass increases earlier in the season. The southern ACC (north-east of our study area) also stands out as an area with earlier bloom initiation when using the rate of change method. The rest of the study area has patches of both earlier and later initiation between the two methods, with mainly small differences (around two weeks), which may reflect variability (noise) in the data rather than geographical patterns.

In summary, both methods yield similar bloom initiation in January for the majority of the study area, which supports the robustness of the result. Regarding the relationship to sea ice retreat, it should be taken into account that the rate of change method indicates sea-ice control on bloom initiation for a somewhat larger area than the threshold method. Further insight into bloom phenology would be gained using vertically integrated biomass estimates, however, we chose to concentrate on surface values due to the relatively low resolution and data coverage of the MLD product in our area. In addition, satellite Chl *a* observations are not available from winter due to sea ice cover and the polar night. Therefore, the bloom initiation used here may be regarded as the bloom climax if considering the vertically integrated bloom.

## 2.5 References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