Response to comments on the submitted manuscript: Greaves et al. - *The Southern Annular Mode (SAM) influences phytoplankton communities in the seasonal ice zone of the Southern Ocean*

23 December 2019

We thank the reviewer for their valuable feedback on this manuscript. These have identified several areas for improvement of the manuscript, which we have addressed below:

RC1 - Anonymous Referee #1, 16 November 2019

In this manuscript entitled "The Southern Annular Mode (SAM) influences phytoplankton communities in the seasonal ice zone of the Southern Ocean", the authors examine the role of SAM on phytoplankton communities in the SIZ of the Southern Ocean.

I think the document is not yet ready to be published, although the subject and results are really interesting.

- Certainly, the results are very interesting

The structure of the document is really difficult to follow at the moment.

- We will carefully review and improve the structure of the manuscript in reference to the comments of both reviewers

I have listed some improvements that could be made to improve the clarity of the manuscript.

General comments: My main concern is related to the structure of the document, to many subsections, particularly in the sections on results and discussion (8 subsections for discussion, and 2 sentences for conclusion, 1 sentence in the section on results (3.1). The document, as it is now, is unbalanced and difficult to read and needs to be reorganized around major themes (seasonal, interannual variability and impact on phytoplankton communities for example for the discussion).

- We will refine manuscript structure

In this paper, the authors examined the role of SAM and seasonal variability on changes in phytoplankton communities, but some key environmental factors are really missing in this study, (1) mixing estimates (by estimating the depth of mixed layers, deriving wind stress)

- We don't have this information for each sample, or for the time periods prior – we are surmising that SAM influences wind-speed and subsequently mixed-layer-depth from the previously published observed and predicted positive relationship between the SAM and wind speed.

and (2) light measurements (in situ or satellite data)?

- We don't have this information for each sample

Because it can be suspected that changes in the intensity of the SAM will directly influence light-mixing regimes, and therefore changes in the composition of phytoplankton communities at the time of sampling?

This is particularly important given that the authors mention the interaction between mixing and phytoplankton dynamics in the discussion.

- It has been previously reported that SAM has been observed and predicted to relate to wind intensity – thus we used this to help explain how the identified maxima in SAM relationship with phytoplankton taxonomic composition could be plausible

In addition, the authors focused on understanding changes in the relative abundance of the main phytoplankton groups, but we have no idea how phytoplankton biomass could change annually with the SAM.

- Previous researchers have concluded that long term changes in the SAM will influence productivity: "*Lovenduski and Gruber (2005) predicted that increased SAM would support higher phytoplankton productivity, and subsequent analyses by Arrigo et 90 al. (2008); Boyce et al. (2010), and Soppa et al. (2016) have confirmed a positive relationship between the SAM and phytoplankton standing stocks and productivity south of 60°S in the SIZ*" (from line 88)
- We will add NASA satellite total chlorophyll estimates which we had been able to obtain for 49 of the 52 samples, which also show a positive relationship with SAM, i.e. higher SAM is associated with higher NASA satellite total chlorophyll (new Table 3 below, was Table 2 in previous manuscript)
- The peak of SAM influence in the preceding autumn was also detected in response surfaces for NASA satellite total chlorophyll (correlation between SAM in autumn and NASA total chlorophyll is 0.5) and nutrient levels (correlation between SAM in autumn and [PO_4] was -0.64 for all samples, and -0.84 for the later-in-season half of the samples) – these response surfaces will be included in the extra material (as drafted below). NASA satellite total chlorophyll and [PO_4] are observationally independent of the taxonomic counts, so similar prior-autumn maxima for the correlation with SAM and these traits are supportive of our finding that "*time-averaged SAM signal in autumn influences phytoplankton community composition in spring to summer*"

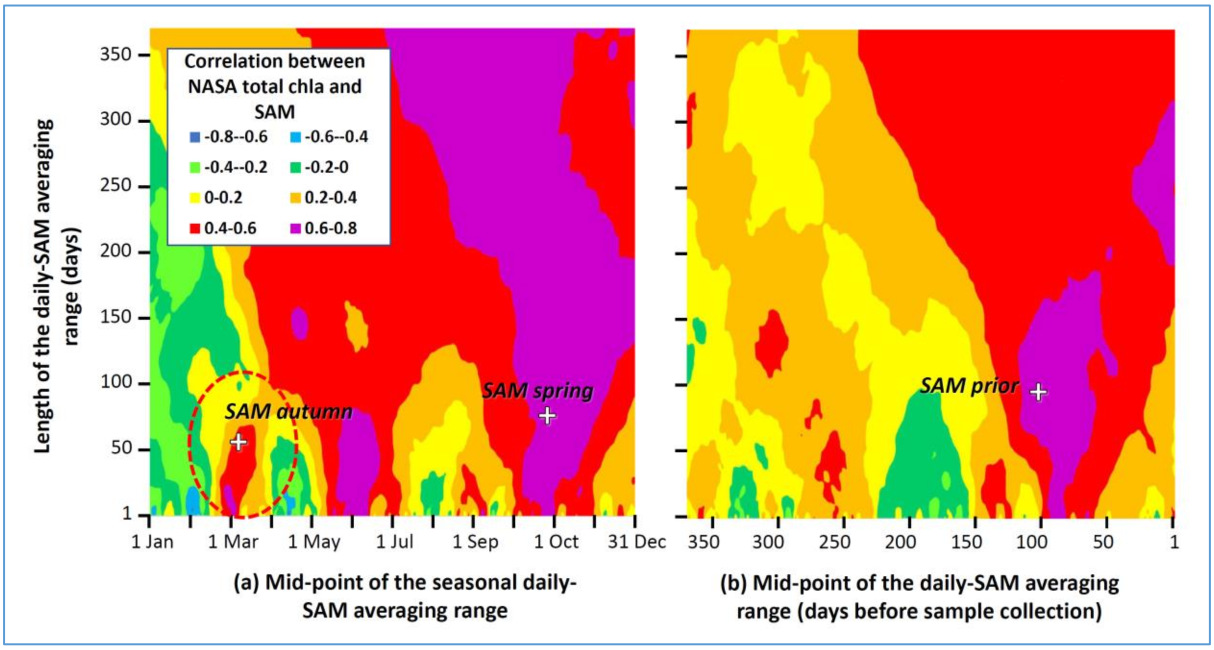

Figure [Supplementary material]: Response surfaces of the correlation between NASA satellite total chlorophyll and the averaged SAM, versus timing and length of the SAM period. The SAM period is the number of days of daily-SAM averaged (vertical axis) and the timing of the range of averaged daily-SAM (horizontal axis). The SAM maxima identified in Figure 3 are shown (SAM autumn, SAM spring). Evident maxima in autumn are indicated with red broken line loops. (a) Analysis includes all available data (n=51), (b) analysis includes only half of the samples, being those collected later in the spring-summer productive season (n=26).

The authors mentioned this briefly in the discussion (5.3), but can you access to any vertically integrated biomass proxies (vertically integrated chlorophyll, PP and satellite-derived estimates)?

- The last paragraph in the (existing) results section states that total volume and inferred biomass was estimated but not found to be related to SAM: "*Neither relative taxonomic total cell volume, estimated using the method of Hillebrand et al. (1999), or inferred relative 275 taxonomic total cell biomass, estimated using the method of Menden-Deuer and Lessard (2001), showed influence of any of the SAM indices (results not shown)*." (line 274)
- The only productivity effect was that inferred from nutrient drawdown, which showed reduced nutrients with more positive prior SAM indices, with the relationships with prior SAM indices (***SAM spring***, ***SAM prior***, and ***SAM autumn***) all being stronger when only the samples collected later in the season (the later half of samples) were included. In the SIZ of the Southern Ocean, surface-water nutrition is replenished through the winter by upwelling of deep ocean water at the Antarctic Divergence. The nutrient contents later in the spring-summer better reflect the total production over the spring-summer than do all samples, including those collected earlier in the spring-summer (as tabulated in the new Table 3 below). We will include the response surfaces for the correlation between the SAM and [PO_4] [depicted below] in Supplementary Material.

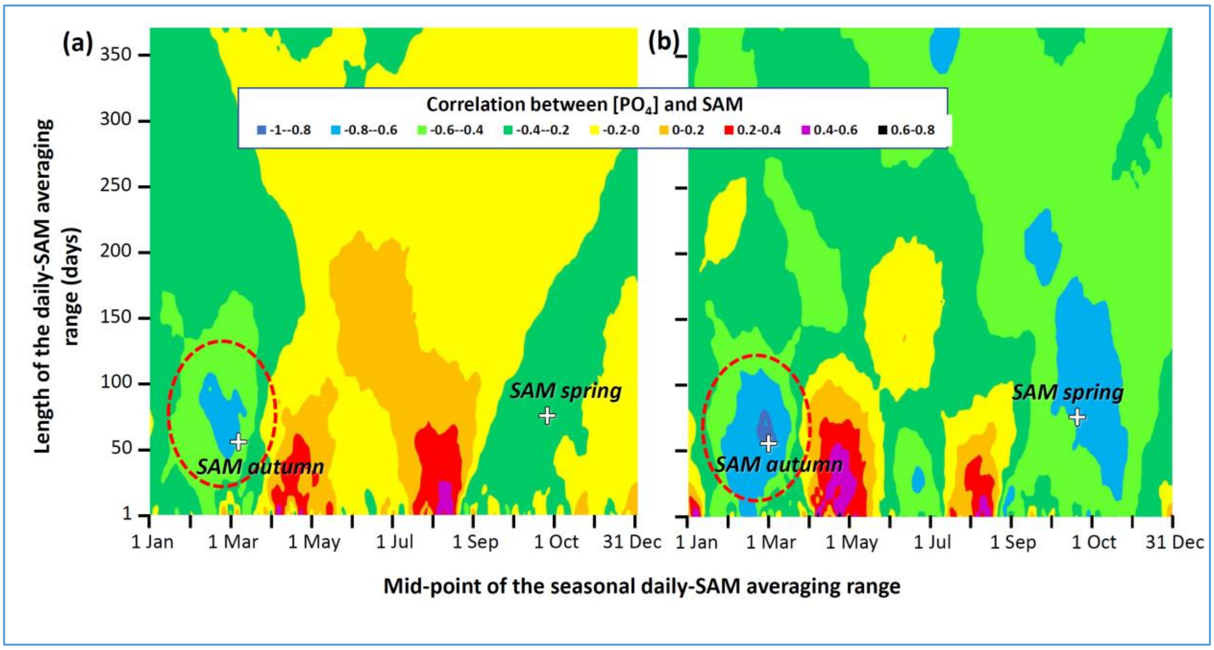

Figure [Supplementary material]: Response surfaces of the correlation between [PO_4] and the averaged SAM, versus timing and length of the daily-SAM averaging range, i.e. the calendar date of the mid-point of the date range (horizontal axis), and the number of days over which those indices were averaged (vertical axis), respectively. The SAM maxima identified in Figure 3 are shown (SAM autumn, SAM spring). Evident maxima in autumn are indicated with red broken line loops. (a) Analysis includes all available data (n=51), (b) analysis includes only half of the samples, being those collected later in the spring-summer productive season (n=26).

- More positive SAM in the prior autumn may lengthen the prior productive season, resulting in greater nutrient drawdown in the prior productive season, which might reduce the degree to which nutrients are replenishment through the winter? – we will consider this in the discussion.
- We will add NASA satellite total chlorophyll estimates which we had been able to obtain for 49 of the 52 samples, which also show a positive relationship with SAM, i.e. higher SAM is associated with higher NASA satellite total chlorophyll (new Table 3 below, was Table 2 in previous manuscript)

	DaysAfter1Oct	SAM_autumn	SAM_prior	SAM_spring	Long.E	DaysSinceSeaIce	SST	Salinity	year	NASA.chla
unit	days	index	index	index	˚E	days	˚C	PSS	austral summer	WHAT
average	96	-0.04	0.06	-0.16	142.0	65	0.63	33.7	-	0.29
min	20	-0.66	-1.35	-1.49	135.8	-26	-1.80	33.2	2002	0.07
max	151	0.62	1.96	1.14	147.9	366	2.98	34.1	2012	0.70
n	52	11	52	11	52	52	52	52	11	49
SAM_autumn	0.32									
SAM_prior	-0.06	0.51								
SAM_spring	0.04	0.56	0.83							
Long.E	-0.63	-0.17	0.10	0.05						
DaysSinceSeaIce	0.56	0.18	-0.03	0.07	-0.27					
SST	0.92	0.27	-0.14	-0.03	-0.68	0.60				
Salinity	-0.43	-0.14	0.31	0.21	0.23	-0.13	-0.41			
year	0.18	0.27	0.35	0.32	-0.24	0.02	0.27	-0.06		
NASA.chla	-0.02	0.50	0.72	0.69	0.11	-0.08	-0.15	0.14	0.43	
ca	-0.15	0.55	0.57	0.63	0.20	-0.01	-0.20	0.22	0.13	0.37
cc	0.37	0.36	0.27	0.35	-0.07	0.27	0.25	-0.14	0.11	0.25
cca	-0.36	-0.02	0.26	0.20	0.41	-0.12	-0.36	-0.07	-0.07	0.20
cd	0.48	0.38	0.31	0.29	-0.13	0.37	0.35	-0.17	0.20	0.36
cn	-0.70	-0.06	0.42	0.24	0.48	-0.40	-0.69	0.56	-0.04	0.33
cyc	0.13	0.09	-0.10	-0.03	0.02	0.32	0.12	0.02	-0.11	0.03
da	0.18	0.37	0.34	0.27	-0.06	0.18	0.13	-0.08	0.06	0.37
dcx	-0.57	0.15	0.06	0.24	0.52	-0.11	-0.57	0.21	-0.15	0.21
ds	-0.78	-0.17	0.30	0.14	0.68	-0.41	-0.75	0.36	-0.14	0.17
dt	-0.18	-0.44	-0.08	-0.16	0.16	-0.19	-0.17	0.23	-0.02	-0.10
ehx	-0.28	-0.38	-0.42	-0.38	0.21	0.12	-0.25	-0.01	-0.37	-0.24
fcx	0.26	-0.06	-0.08	-0.09	-0.58	-0.08	0.35	-0.12	0.24	-0.15
fk	0.23	0.52	0.16	0.25	-0.07	0.19	0.22	-0.46	-0.05	0.07
fps	-0.13	0.22	-0.02	0.22	-0.10	-0.05	-0.03	0.12	0.22	0.02
fr	0.16	-0.39	-0.58	-0.57	-0.13	0.13	0.22	-0.12	-0.24	-0.59
fri	0.11	-0.10	0.00	-0.03	-0.02	0.02	0.10	-0.03	0.03	-0.01
guc	0.09	0.12	-0.06	-0.06	0.05	0.17	0.10	-0.03	-0.02	0.12
nix	-0.47	-0.45	-0.29	-0.31	0.42	-0.32	-0.46	0.09	-0.22	-0.19
parm	-0.60	-0.29	0.15	-0.09	0.42	-0.42	-0.65	0.36	-0.28	0.16
pet	-0.25	-0.13	-0.27	-0.08	0.15	-0.17	-0.25	0.02	-0.02	-0.04
psl	-0.35	0.39	0.19	0.37	0.36	-0.09	-0.35	0.18	0.01	0.26
ta	-0.16	0.32	0.12	0.16	0.15	-0.11	-0.11	-0.19	-0.15	0.00
[NOx]	-0.77	-0.39	0.23	0.04	0.53	-0.43	-0.72	0.54	-0.14	0.12
[PO4] (n=51)	-0.73	-0.56	-0.07	-0.26	0.62	-0.52	-0.70	0.39	-0.13	-0.10
[SiO4]	-0.56	-0.42	0.26	-0.05	0.40	-0.49	-0.63	0.39	0.09	0.22
[NOx] (n=26: later in	-0.18	-0.58	-0.05	-0.25	-0.23	-0.19	0.02	0.27	-0.17	
[PO4] season	-0.13	-0.74	-0.51	-0.68	0.09	-0.31	-0.01	0.03	-0.02	
[SiO4] samples)	-0.10	-0.51	-0.04	-0.31	-0.16	-0.35	-0.44	-0.05	0.34	

This comment is related to the last one, but we have no idea where we stand with respect to phytoplankton phenology. In Figure 1, it would be nice to have satellite-derived time series of chlorophyll a, for example. The problem I see here is that the SAM could perhaps also change the phytoplankton phenology (bloom duration or timing for example).

- We will obtain time-series NASA satellite total chlorophyll and consider including in Figure 1

And perhaps what the authors have defined as interannual variability driven by the SAM can simply be related to a sampling of different phenological states. It would be important for me to check this point.

- No way to confirm this for certain, however:
- More positive SAM in the prior spring (***SAM spring***) and ***SAM prior*** (SAM prior to each sample) may result in the productive season commencing earlier, and thus organisms that show a decline in relative abundance through the season might show a lower relative abundance at a given time with higher ***SAM spring*** and ***SAM prior*** : 10 of the 22 taxa showed a significant correlation the time through the spring-summer of collection, of these, with 4 taxa showed a relationship with both ***SAM spring*** and ***SAM prior*** supporting the possibility that ***SAM spring*** and ***SAM prior*** were leading to an effective sampling later in the phenotypic succession (i.e. three taxa having negative relationship with sampling date and both ***SAM spring*** and ***SAM prior***, one taxon having positive relationship with sampling date and both ***SAM spring*** and ***SAM prior***). However, the other six taxa showing significant relationship with sampling date did not confirm this relationship.

Specific comments: l.186-186: Can you add a table in the paper or in the supplementary materials listing these taxa (the 4 in all the samples, and the 11 in 90% of the samples)?

- New Table will be added as Table 2:

Table 2: Identified taxa: taxa-code, cells counted, average individual cell volume, abundance: cells/ml (average, minimum and maximum), relative abundance, total taxa-group volume (µm³/ml), relative taxa-group volume, and percentage of samples in which each taxon was identified.

taxon		cells counted: number	cells meas-ured: number	average individual cell volume (μm^3)	abundance (cells/ml) average	min	max	fraction of abun-dance: average	average total cell volume (μm^3/ml)	average fraction of total cell volume	samples with taxon
Chaetoceros atlanticus	*ca*	589	479	1,316	51	0	364	2.2%	81,382	1.4%	***90%***
Chaetoceros castracanei	*cca*	49	34	940	6	0	38	0.3%	18,616	0.4%	48%
Chaetoceros concavicornis/curvatus	*cc*	303	200	3,443	20	0	135	0.7%	78,443	1.4%	77%
Chaetoceros dichaeta	*cd*	2,719	1943	491	423	0	2,503	13%	145,999	2.9%	***94%***
Chaetoceros neglectus	*cn*	650	488	176	83	0	697	3.5%	11,906	0.2%	81%
Cylindrotheca closterium	*cyc*	122	50	121	17	0	79	0.7%	4,106	0.1%	77%
Dactyliosolen antarcticus	*da*	748	472	61,899	44	0	195	1.6%	1,860,680	27%	***98%***
Dactyliosolen tenuijunctus	*dt*	2,121	1350	3,828	296	7	1,315	9.9%	895,367	16%	***100%***
Dictyocha speculum (silicoflagellate)	ds	110	84	4,920	10	0	69	0.5%	99,301	1.5%	48%
discoid centric diatoms	*dcx*	1,280	1280	8,572	133	12	696	5.2%	437,556	7.3%	***100%***
Emiliania huxleyi (haptophyte)	*coc*	173	50	**add**	24	0	192	0.8%	3,552	0.1%	58%
Fragilariopsis cylindrus/curta	*fcx*	3,987	3013	70	632	0	8,796	17%	44,167	0.9%	***98%***
Fragilariopsis kerguelensis	*fk*	4,428	4055	3,748	167	0	1,054	5.8%	369,492	6.5%	***98%***
Fragilariopsis pseudonana	*fps*	170	115	355	26	0	201	0.9%	18,999	0.4%	69%
Fragilariopsis rhombica	*fr*	4,542	3469	36	658	29	2,070	22%	23,359	0.6%	***100%***
Fragilariopsis ritscheri	*fri*	46	19	572	7	0	86	0.2%	11,020	0.2%	35%
Guinardia cylindrus	*guc*	119	81	10,405	15	0	79	0.6%	225,921	4.1%	67%
Nitzschia acicularis/decipiens	*nix*	1,133	509	251	162	0	977	5.7%	46,705	1.0%	***98%***
Parmales spp. (chrysophyte)	*parm*	322	2	8	38	0	668	1.7%	334	0.0%	27%
Petasaria heterolepis (other)	*pet*	45			7	0	187	0.3%	2,667	0.1%	6%
Pseudonitzschia lineola	*psl*	703	403	1,093	91	4	376	4.1%	84,460	1.5%	***100%***
Thalassiothrix antarctica	*ta*	287	269	(63,000)	13	0	172	0.6%	314,424	4.8%	85%

Table: Table 1: Long.E is indicated two times as variable, is it an error?

- Yes, a typing error – the second occurrence of Longitude in Table 1 should be Latitude