



Widespread changes in Southern Ocean phytoplankton blooms linked to climate drivers

In the format provided by the authors and unedited

Supplementary Material

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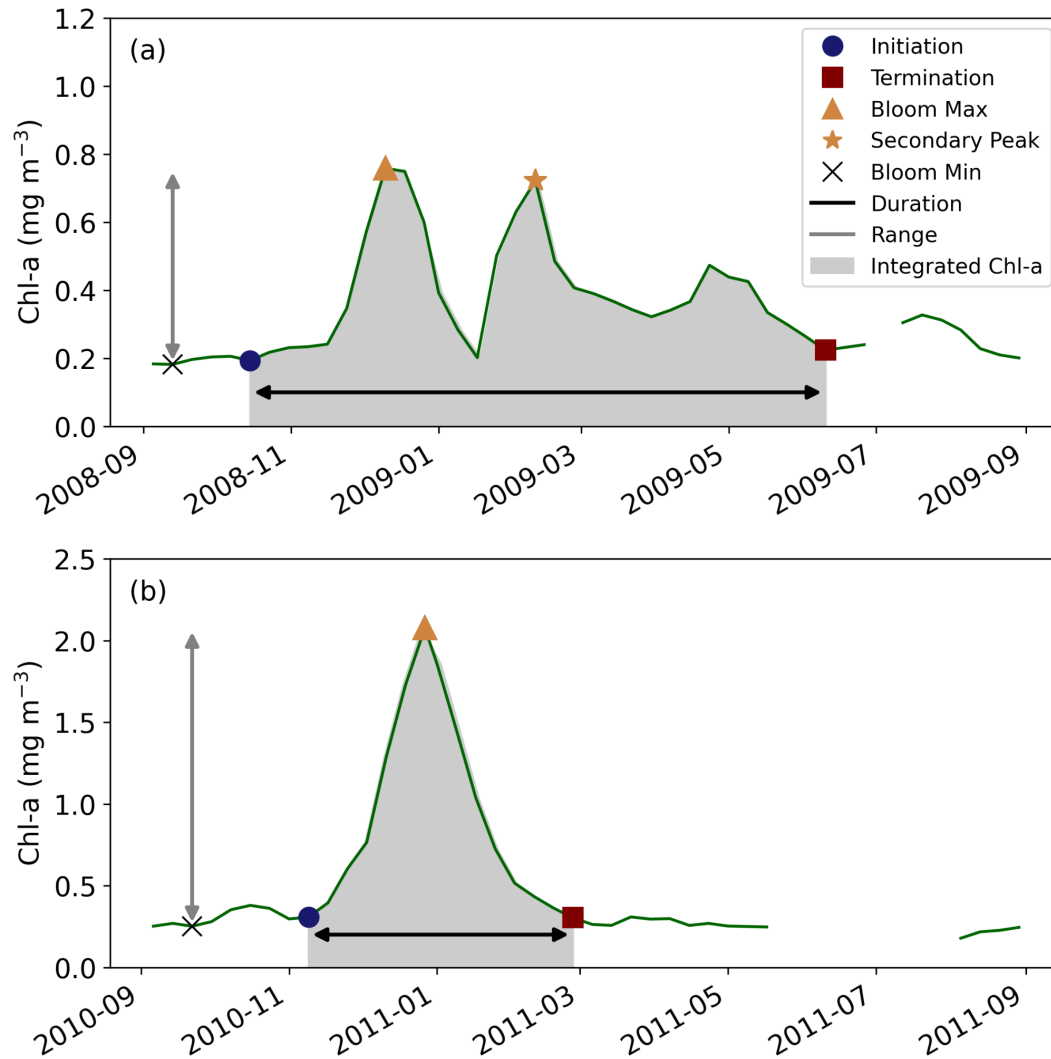


Figure S1: Visual representation of the approach to determine seasonal metrics from two example pixels. The chlorophyll-a (Chl-a) time series from (a) 45°S 7.5°W and (b) 50°S 0°E are used to demonstrate the criteria and resultant phytoplankton seasonal metrics; including bloom initiation, termination, duration, maximum, minimum, the range and integrated bloom chl-a. Included in panel a is a secondary peak which met the criteria of being identified as such with a chl-a concentration $\geq 75\%$ of the maximum Chl-a concentration and occurring within the time constraints of at least 24 days after the maximum. Please note the different scales in panels a and b.

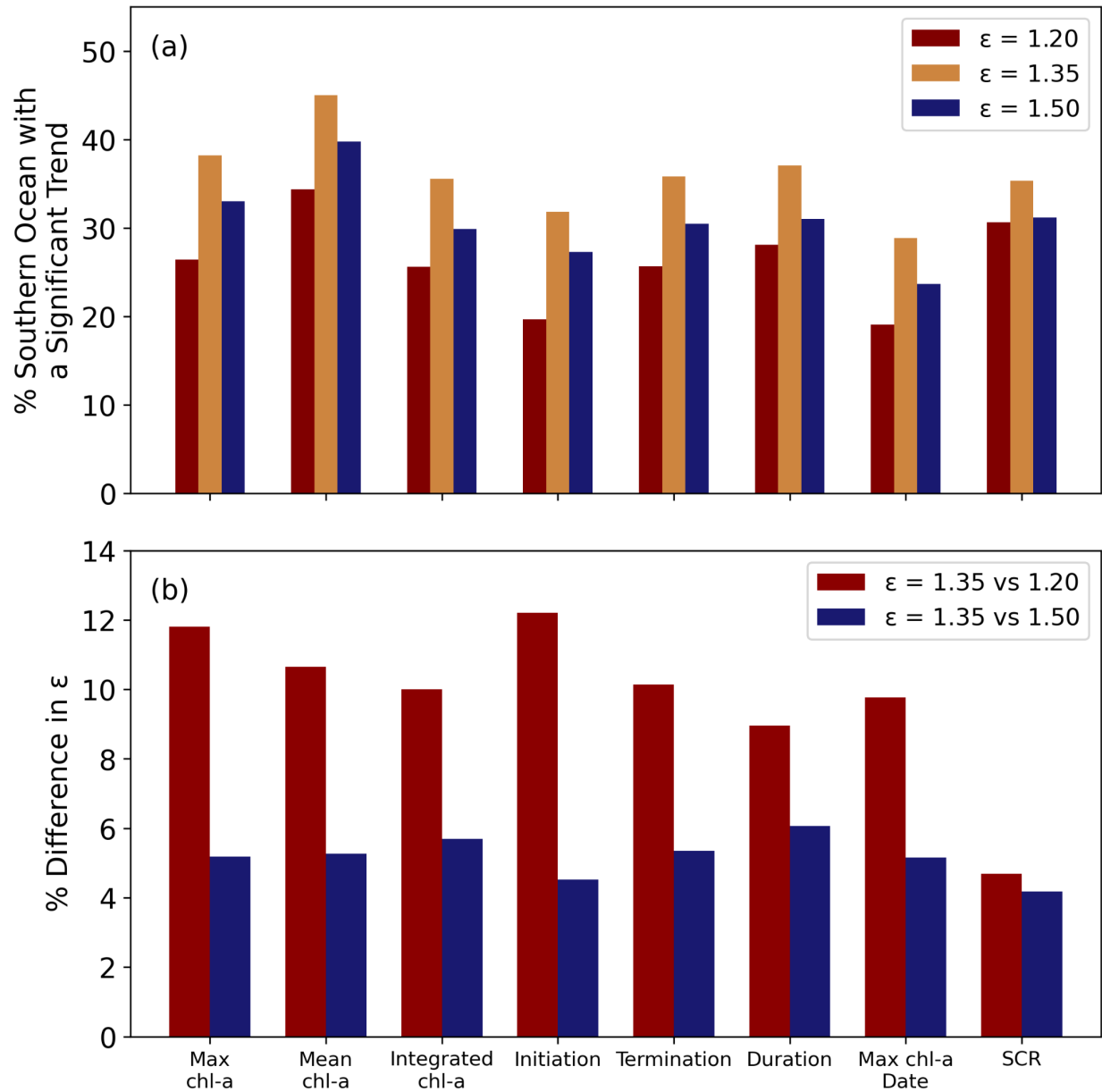


Figure S2: Sensitivity analysis of choice in Huber-Regressor ϵ value. In a) bars depict the % of the Southern Ocean displaying a significant trend when using a Huber-Regressor ϵ value of 1.20 (red), 1.35 (yellow) or 1.50 (dark blue). In b) bars depict the % difference of the Southern Ocean displaying a significant trend when using a Huber-Regressor ϵ value of 1.35 versus 1.20 (red) or 1.35 versus 1.50 (dark blue). The seasonal metrics are from left to right: bloom max chlorophyll (Max chl-a), mean chl-a over bloom duration (Mean chl-a), integrated chl-a over bloom duration (Integrated chl-a), bloom initiation, bloom termination, bloom duration, bloom max chl-a date and seasonal cycle reproducibility (SCR).

Table S1. The mean adjustment per decade of the significant trends and the proportional representation of those significant trends per biome. Here we present the mean value of the significant ($p < 0.05$) positive and negative trends for each seasonal metric per biome and for the Southern Ocean as a whole. The % of pixels with significant ($p < 0.05$) positive or negative trends relative to the total number of pixels per biome and for the Southern Ocean as a whole appear in parenthesis (these are the values reflected in the bar graph of Figure 3). The Fay and McKinley²⁸ biomes are from left to right: the subtropical seasonally stratified (STSS), the subpolar seasonally stratified (SPSS), the ice (ICE) biome and all three biomes merged (ALL). The seasonal metrics are from top to bottom: bloom max chlorophyll (Max chl-a), mean chl-a over bloom duration (Mean chl-a), integrated chl-a over bloom duration (Integrated chl-a), bloom initiation, bloom termination, bloom duration, bloom max chl-a date and seasonal cycle reproducibility (SCR).

	STSS		SPSS		ICE		ALL	
	Mean significant positive	Mean significant negative	Mean significant positive	Mean significant negative	Mean significant positive	Mean significant negative	Mean significant positive	Mean significant negative
Max chl-a (mg m ⁻³ decade ⁻¹)	0.13±0.18 (28.60%)	-0.15±0.2 4 (5.12%)	0.13±0.11 (32.12%)	-0.08±0.0 8 (5.23%)	0.35±0.40 (40.90%)	-0.50±0.6 1 (5.09%)	0.18±0.23 (33.05%)	-0.18±0.3 2 (5.15%)
Mean chl-a (mg m ⁻³ bloom ⁻¹ decade ⁻¹)	0.05±0.07 (39.93%)	-0.06±0.2 0 (4.78%)	0.05±0.04 (39.99%)	-0.03±0.0 3 (3.01%)	0.18±0.20 (41.68%)	-0.25±0.2 6 (6.55%)	0.08±0.11 (40.79%)	-0.10±0.2 0 (4.23%)
Integrated chl-a (mg m ⁻³ bloom ⁻¹ decade ⁻¹)	18.6±20.2 (21.21%)	-19.0±24.4 (13.52%)	9.3±7.8 (15.25%)	-9.4±7.2 (14.77%)	19.4±18.0 (45.82%)	-24.2±21.8 (4.75%)	15.4±16.1 (22.94%)	-13.7±16.6 (12.64%)
Initiation (days decade ⁻¹)	25.6±15.7 (17.78%)	-32.6±19.4 (9.67%)	17.0±9.2 (24.82%)	-20.3±15.2 (6.37%)	16.6±7.9 (5.20%)	-16.9±7.8 (37.05%)	19.4±11.9 (18.78%)	-21.3±14.3 (13.05%)
Termination (days decade ⁻¹)	31.6±17.8 (11.01%)	-38.8±20.8 (21.13%)	28.1±21.0 (4.20%)	-25.7±15.9 (35.29%)	13.7±7.5 (14.17%)	-14.9±8.8 (18.70%)	25.5±18.8 (8.53%)	-28.1±18.4 (27.29%)
Duration (days decade ⁻¹)	48.4±21.0 (9.52%)	-53.0±22.4 (25.93%)	35.1±23.6 (4.45%)	-18.8±8.7 (34.18%)	21.2±11.8 (29.37%)	-30.8±20.8 (7.18%)	30.8±20.8 (10.58%)	-43.0±23.5 (26.49%)
Max chl-a Date (days decade ⁻¹)	29.8±17.3 (8.57%)	-26.5±13.5 (22.28%)	14.5±10.0 (7.09%)	-14.9±9.6 (17.16%)	22.7±10.3 (15.85%)	-19.8±9.9 (19.47%)	21.6±14.0 (9.58%)	20.0±12.3 (19.25%)
SCR (% decade ⁻¹)	9.9±3.7 (8.87%)	-12.0±4.5 (33.48%)	14.0±5.2 (21.62%)	-12.6±4.4 (11.88%)	17.3±6.6 (9.89%)	-20.1±7.8 (21.41%)	14.0±5.7 (14.30%)	-14.7±6.7 (21.02%)

Table S2: Discerning the adjustments that the trends in phytoplankton seasonal metrics imply relative to their mean starting point. Here we present the mean of significant (positive and negative) trends for the first year of the time series for bloom maximum chlorophyll (Max chl-a), mean chl-a over bloom duration (Mean chl-a), integrated chl-a over bloom duration (Integrated chl-a), bloom duration and seasonal cycle reproducibility (SCR) The numbers in parentheses represent the significant trends as % change per year relative to the mean of significant pixels of the first year. The Fay and McKinley²⁸ biomes are from left to right: the subtropical seasonally stratified (STSS), the subpolar seasonally stratified (SPSS), the ice (ICE) biome and all three biomes merged (ALL).

		STSS	SPSS	ICE	ALL
Max chl-a (mg m ⁻³)	Mean significant positive pixels	0.58±0.51 (2.24% yr ⁻¹)	0.43±0.30 (3.02% yr ⁻¹)	0.51±0.88 (6.86% yr ⁻¹)	0.49±0.51 (3.67% yr ⁻¹)
	Mean significant negative pixels	1.15±2.17 (1.30% yr ⁻¹)	0.57±0.43 (1.40% yr ⁻¹)	2.45±3.96 (2.04% yr ⁻¹)	0.99±1.93 (1.82% yr ⁻¹)
Mean chl-a (mg m ⁻³)	Mean significant positive pixels	0.35±0.23 (1.43% yr ⁻¹)	0.25±0.13 (2.00% yr ⁻¹)	0.32±0.50 (5.63% yr ⁻¹)	0.30±0.25 (2.67% yr ⁻¹)
	Mean significant negative pixels	0.57±0.96 (1.05% yr ⁻¹)	0.32±0.20 (0.94% yr ⁻¹)	1.19±1.69 (2.10% yr ⁻¹)	0.60±1.01 (1.67% yr ⁻¹)
Integrated chl-a (mg m ⁻³ bloom ⁻¹)	Mean significant positive pixels	87.72±81.00 (2.12% yr ⁻¹)	40.48±30.65 (2.30% yr ⁻¹)	27.77±36.75 (6.99% yr ⁻¹)	53.01±58.91 (2.91% yr ⁻¹)
	Mean significant negative pixels	111.10±124.40 (1.71% yr ⁻¹)	57.03±33.11 (1.65% yr ⁻¹)	101.12±131.04 (2.39% yr ⁻¹)	80.19±83.56 (1.71% yr ⁻¹)
Duration (days)	Mean significant positive pixels	221.26±74.86 (2.19% yr ⁻¹)	147.60±61.33 (2.38% yr ⁻¹)	77.69±31.84 (2.73% yr ⁻¹)	147.25±84.10 (2.09% yr ⁻¹)
	Mean significant negative pixels	287.58±81.51 (1.84% yr ⁻¹)	207.53±74.31 (0.91% yr ⁻¹)	115.81±51.34 (2.66% yr ⁻¹)	233.94±89.00 (1.84% yr ⁻¹)
SCR (%)	Mean significant positive pixels	28.88±21.30 (3.43% yr ⁻¹)	43.97±27.46 (3.18% yr ⁻¹)	32.13±30.84 (5.38% yr ⁻¹)	37.97±27.83 (3.69% yr ⁻¹)
	Mean significant negative pixels	47.72±18.66 (2.51% yr ⁻¹)	62.04±23.42 (2.03% yr ⁻¹)	60.65±30.57 (3.31% yr ⁻¹)	54.52±24.63 (2.70% yr ⁻¹)

Table S3. The statistics of the trends in all phytoplankton seasonal metrics for the three example pixels presented in Figure ED3. Panel a (43.8°S, 0.6°E), Panel b (47.1°S, 34.4°E) and Panel c (39.4°S, 13.1°W), where * = p<0.05, ** p<0.01, *** p<0.001. The seasonal metrics are from left to right: bloom max chlorophyll (Max chl-a), mean chl-a over bloom duration (Mean chl-a), integrated chl-a over bloom duration (Integrated chl-a), bloom initiation, bloom termination, bloom duration, bloom max chl-a date and seasonal cycle reproducibility (SCR).

	Max chl-a (mg m ⁻³ decade ⁻¹)	Mean chl-a (mg m ⁻³ decade ⁻¹ bloom ⁻¹)	Integrate d chl-a (mg m ⁻³ decade ⁻¹ bloom ⁻¹)	Initiation (days decade ⁻¹)	Terminati on (days decade ⁻¹)	Duration (days decade ⁻¹)	Max chl-a Date (days decade ⁻¹)	SCR (% decade ⁻¹)
Panel a	-6.38 × 10 ⁻²	0.02*	-9.91*	47.26***	-5.92	-29.69	33.18**	-1.14
Panel b	0.08***	0.04***	-16.78**	22.39**	42.38**	-107.27* **	-78.96***	-16.61***
Panel c	0.02	-0.03*	-9.01***	-2.99	-8.71	-12.37	-17.11	-29.40***