

Response to reviewers on 'Spring Blooms in the Baltic Sea have weakened but lengthened from 2000 to 2014' by P. M. M. Groetsch et al.

Anonymous Referee #2

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- The use of the term "variable-threshold" could still lead to confusion (i.e., annual median vs. climatological median). I suggest using "spatially variable-threshold" or similar.
- The sentence: "The observed negative trend in peak concentration introduces an artificial negative trend in bloom duration" can create confusion, because it actually does not (as it is explained afterwards). I suggest changing to "was expected to introduce".

Authors' response: We implemented both recommendation in the manuscript.

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diff --git a/AlgalineSpringBloom.tex b/AlgalineSpringBloom.tex
```

```
index e2e11b6..47a062b 100644
```

```
--- a/AlgalineSpringBloom.tex
```

```
+++ b/AlgalineSpringBloom.tex
```

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@@ -114,7 +114,7 @@ Alg@line chla concentrations (see section \ref{ssec:algalin  
e}) were resampled to
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1) Chl_a concentration exceeding a fixed-threshold of mg m^{-3} as defined as bloom by \cite{Fleming2006}, further referred to as \texttt{const5}. A 21-day centred-running-mean filter was used to keep results comparable to the other metrics considered, whereas \cite{Fleming2006} used a 7-day centred-running-median filter.

2) \cite{Siegel2002} proposed a **spatially** variable-threshold metric based on the 5 %-above-median concentration, but reported small quantitative differences for thresholds between 1 and 30 %-above-median. Their threshold is based on the complete annual cycle, while here only the spring bloom period from day-of-year 31 to 160 is considered. We refer to this metric as \texttt{median5}.

3) Distributions proposed to describe bloom phenology include shifted-Gaussian \cite{Platt2009}, Gamma \cite{Vargas2009}, and Weibull distributions \cite{Rolinski2007}. The shifted Gaussian is symmetric in shape, whereas Gamma distributions allow for different slopes of bloom rise and decline. In addition, Weibull functions recognize non-zero offsets before and after the bloom phase. The latter has proven essential to obtain a good fit for the transition phase between spring and summer bloom with the here analysed data set. A modified Weibull-function, as proposed by \cite{Rolinski2007}, was fitted non-linearly to the preprocessed and scaled (to a range of zero to one) chl_a concentrations. The bloom initiation and end are defined as the 10th and 90th percentiles before and after the bloom peak, respectively. This metric is further referred to as \texttt{weibull}.

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@@ -137,7 +137,7 @@ Determination of the fluorescence yield was supported by an  
'adaptive regression
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Figure \ref{fig:diurnal_variability}A shows normalized fluorescence observations as a function of sampling time-of-day. Results are presented separately for summer (May to August), winter (November to February) and the transition periods (autumn, spring). Diurnal variability was most pronounced in summer, when the fluorescence signal varied on average 50 % over the course of a day. In winter and during the transition periods (spring, autumn) a diurnal variability of 35 and 38 %, respectively, was contained in the fluorescence signals. This seasonal effect is likely caused by variations in average irradiance intensity, which are modulated primarily by sun elevation, but also by atmospheric conditions (e.g. cloud cover, aerosol optical thickness) and optical properties of the water body (e.g. ice cover, attenuation). Figure \ref{fig:diurnal_variability}B depicts normalized fluorescence as a function of solar elevation. In this representation seasonal differences in diurnal variability are essentially absent and the correspondence between solar elevation and average fluorescence response was approximately linear for daytime observations.

\subsection{Bloom Intensity and Timing}

Blooms generally developed first in the south and progressed towards the north (see Fig. \ref{fig:phenology_geo_timing} and Table \ref{tab:bloomstats}). Bloom peak timing (not influenced by choice of metric) followed this pattern, as did metric-dependent bloom start and end dates. The fixed-threshold bloom metric \texttt{const5} suggested longer blooms in high-biomass sea areas like the \textsc{gof}, compared to low-biomass areas such as the \textsc{sbs}. The **spatially** variable-threshold metric \texttt{median5} applies area-specific bloom thresholds (\textsc{gof}: mg m^{-3} , \textsc{got}: mg m^{-3} , \textsc{sbs}: mg m^{-3} , \textsc{bom}: mg m^{-3}) and resulted in approximately stable bloom duration in all sea areas. The \texttt{weibull} metric, which is not sensitive to absolute bloom intensity, also resulted in comparable bloom durations for all sea areas. The year-to-year variability of start, peak, and end days generally increased towards the south for all metrics.

Spring bloom intensity was described by three parameters: the metric-independent bloom peak

peak concentration (peakheight), the chl_a concentration average during bloom conditions (concavg), and the sum of daily chl_a concentrations over the bloom period (bloomidx). Similar patterns were observed for all these parameters and bloom metrics, as illustrated in Fig. [\ref{fig:phenology_geo_intensity}](#). The highest bloom intensity was found in the gof and nbp , followed by the bom . Low-intensity blooms were observed in the sbp and the got . Variability was generally proportional to bloom intensity, highest in the high-biomass and coastal gof and bom . Variability in bloomidx was comparable to that in peakheight , while concavg was considerably more stable. All calculated bloom phenology parameters can be found in the supplementary material.

@@ -183,7 +183,7 @@ Interannual variability in coastal systems exceeds long-term trends by orders of

[\cite{Helcom2014}](#) reported stable or increasing chl_a concentrations for the period 2007-2011 in several Baltic Sea areas despite signs of declining nutrient concentrations. More recently, eutrophication trend reversal and oligotrophication processes were reported by [\cite{Andersen2015}](#), based on analysis of 112 years of consolidated Baltic Sea observations. Both reports considered surface-layer chl_a concentration in summer as one of the direct indicators for eutrophication, but did not include spring bloom in their assessment. The time series for 2000-2014 that we present here fills this gap: a negative trend in bloom intensity was also found for spring bloom, providing further evidence for their hypothesis of gradual nutrient load reduction.

Thresholds of const5 and median5 are fixed for the whole time series. The observed negative trend in peak concentration **introduceswas expected to introduce** an artificial negative trend in bloom duration because an increasingly higher percentile of the distribution is seen below the bloom threshold (Fig. [\ref{fig:trend_scheme}](#)). Contrary to this expected behaviour, however, const5 and median5 revealed no significant trends in bloom duration. This indicates that the anticipated negative trend in bloom duration was countered by a positive trend, e.g. in bloom intensity. The Weibull-metric is based on concentration distribution-ratios that are calculated individually for each bloom. Therefore, Weibull-metric results for bloom duration are not sensitive to long-term trends in peak concentration. Weibull-distribution metrics confirmed a highly significant, positive trend in bloom duration. These two sets of results corroborate the conclusion that spring blooms in the Baltic Sea have become longer, while chl_a peak and average concentration levels declined.

This 'flattening' of the concentration distribution is supported by the absence of a trend in time-integrated biomass bloomidx and by shifts in nutrient concentration timing (earlier nutrient peak concentration, later 25 %-of-peak-value day). These results indicate that annually generated spring bloom biomass has not changed significantly over the study period, in contrast to bloom timing. [\cite{Kahru2014}](#) found a similar development for cyanobacterial summer surface bloom, and reported decadal oscillations, yet no long-term trend, of surface area covered by cyanobacteria in the period 1979-2013. In the same period, summer bloom initiation moved to earlier dates by $\text{SI}\{-0.6\}\{\text{day}\per\text{year}\}$. These results suggest that the gap has decreased between dinoflagellate- and diatom-dominated spring bloom and cyanobacterial summer bloom. Due to the shorter period covered here as compared to the time series presented by [\cite{Kahru2014}](#), it cannot be ruled out that the spring bloom trends are caused by decadal oscillation. Moreover, [Algaline](#) nutrient records often did not commence sufficiently early in the season to record bloom onset. Trends in bloom start and nutrient peak timing can therefore not be derived at the same accuracy and precision as the other phenological parameters. In future, additional data and longer time series may revise this analysis. To this end, nutrient metrics derived in this work are provided in the appendix.