

Response to Referee 1 (Douglas Campbell)

General: The referee is thanked for his constructive comments on the discussion paper. We appreciate the generally positive assessment of the contribution and suggestions to improve presentation context for different readerships. The revised manuscript has incorporated all of these suggestions.

Specific responses:

Figure 1: Nice conceptual figure. But there is a fairly extensive literature from the physiological/molecular side on the different response curves of repair rate and primary photoinactivation (damage). I understand that Biogeoscience is not a physiological/molecular journal, but it would be good to refer to some of the work ...

We agree that better connections between biological oceanographers and physiologists stands to benefit both fields. However, more mechanistic work is needed to understand the physiological basis of the E_{\max} -type repair rate response. Perhaps our results will help motivate more work on this subject in the future.

Action taken: We have added a new paragraph to the discussion as follows:

Overall, the E_{\max} model clearly provided the best prediction of inhibition of photosynthesis in both studied strains of *Synechococcus*. Together with previous studies using the "T" model (Sobrino et al., 2005; Sobrino and Neale 2007; Sobrino et al., 2009), these results suggest that there is an upper limit to repair rate in many phytoplankton during exposure to high UV+PAR. The physiological mechanism(s) limiting absolute repair rates are presently not known and more work is needed. The dynamics of photosynthetic complexes involved in photoinhibition and recovery, particularly PSII, has received considerable study (recent reviews Vass, 2012 and Tyystjärvi, 2013) and lead to development of models of PSII damage and repair (Campbell and Tyystjärvi, 2012). However, these models presently assume a fixed rate constant for repair (equivalent to the E model). Nevertheless, it is also recognized that repair, e.g. of PSII, is a multi-step process involving degradation of damaged components, their re-synthesis and reintegration into a reactivated complex (recent review Takahashi and Murata, 2008). The rate of any of these steps, or a step in the repair of another complex such as RUBISCO, could reach a maximum under high exposure and set the upper limit of repair rate. Furthermore, there is increasing evidence that repair itself can be inhibited under irradiance stress (Takahashi and Murata, 2008). Such inhibition could account for the tendency of even the E_{\max} model to over-estimate photosynthesis at very high exposure (cf. Fig. 3).

Fig. 2 good data, but I think the rather cryptic panel titles should either be expanded, or explained in the legend....

Good point, we have prepared a revised figure in which the panels are now labeled with 1% and 50% cutoff wavelengths and are color coded to indicate their relative position in the UVB or UVA.

...it is confusing to see some panels (GG395) looking like classic P vs. I curves, and other panels (WG280) jumping up and down (even though the model is working well).

This issue is already mentioned in the text but additional revisions have been made to the figure and legend to assist the reader in understanding the source and significance of this variability, which arises from spectral variation within the Xe beam, in particular for the shorter wavelengths.

Actions taken: Figure has been revised (see attachment). Examples of points affected by spectral variation are circled in the figure, and legend now reads (new text italicized):

Figure 2. Representative set of photosynthesis measurements from a *Synechococcus* photoinhibitor experiment, shown are results from the exposure of a HL 26°C WH8102 culture plotted vs. PAR exposure (W m^{-2}) of each treatment. Observed rate of photosynthesis (open circles) and predicted rate of photosynthesis by the $\text{BWF}_{E_{\max}}\text{-PE}$ model (x's). *Panel titles give the 1% and 50% wavelength cutoffs of the spectral treatment shown in each panel, color coded on a gradient from short wavelength UVB (magenta) to long wavelength UVA (blue), further details are listed by panel letter in Table 1. Due to heterogeneity in the Xe lamp emission, spectral composition varies somewhat even within a spectral treatment. This causes some scatter in the P-E relationship (e.g. circled points), but does not affect the generally good agreement between observed and fitted. The root mean square error (RMSE) for the fit is $0.53 \text{ (mg C mg Chl}^{-1} \text{ h}^{-1}\text{)}$.*

Fig.4: On my screen there is not enough distinction between the light and heavy lines; I am not sure which is full and which is part.

The Figure 4 in the revised text has been changed to be similar to Figure 6, i.e. the light line has been replaced with a heavy dashed line (see attachment). It should now be easier to tell the difference between the curves.

Figure 8: *Very nice. Good to compare to diatom. Is the strain of *Thalassiosira pseudonana* a reasonable choice for co-occurrence with *Synechococcus*?*

We chose *T. pseudonana* because the data was available to fit the E_{\max} model. The objective is to illustrate the difference in sensitivity between *Synechococcus* and previously studied eukaryotic nanoplankton.

Materials & Methods: Two temperatures are tested. Might I suggest that a successor paper could test different nutrient levels? I think in this paper cultures were under

nutrient repletion; Milligan et al. show big photophysiological effects of nutrient limitations.

We agree with the referee that it would be very interesting to do a follow-on study working with nutrient limited cultures. Our previous work with dinoflagellates (Litchman et al. 2002) also showed an increased sensitivity to UV under nutrient limited conditions which was partially explained by decreased repair.

In response to referee 1, we no longer use GRB to abbreviate Gamma Ray Burst and corrected the cited misspelling.

Attachments: Revised Figures 2 and 4.

Neale et al. bg-2013-505 Revised Figure 2.

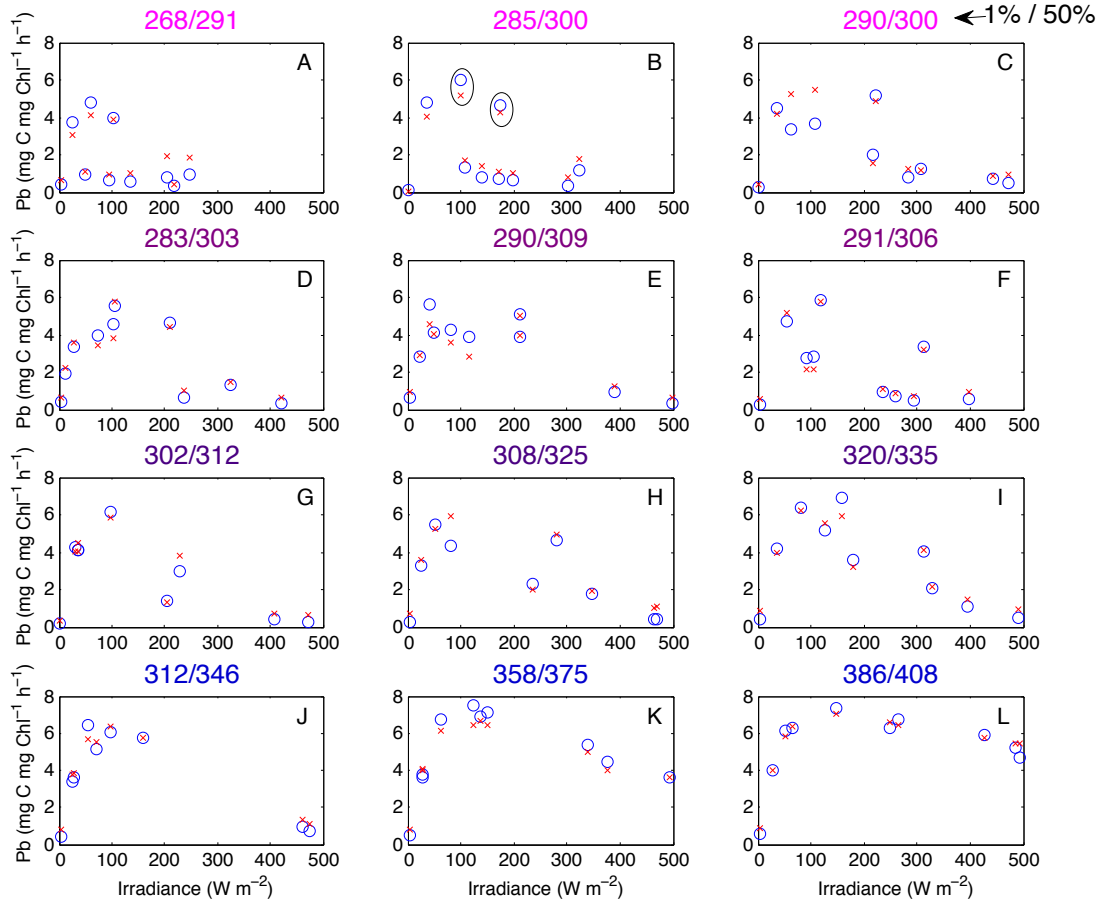


Figure 2. Representative set of photosynthesis measurements from a *Synechococcus* photoinhibitor experiment, shown are results from the exposure of a HL 26°C WH8102 culture plotted vs. PAR exposure (W m^{-2}) of each treatment. Observed rate of photosynthesis (open circles) and predicted rate of photosynthesis by the $\text{BWF}_{E_{\max}}\text{-PE}$ model (x's). Panel titles give the 1% and 50% wavelength cutoffs of the spectral treatment shown in each panel, color coded on a gradient from short wavelength UVB (magenta) to long wavelength UVA (blue), further details are listed by panel letter in Table 1. Due to heterogeneity in the Xe lamp emission, spectral composition varies somewhat even within a spectral treatment. This causes some scatter in the P-E relationship (e.g. circled points), but does not affect the generally good agreement between observed and fitted. The root mean square error (RMSE) for the fit is $0.53 \text{ (mg C mg Chl}^{-1} \text{ h}^{-1})$.

Neale et al. bg-2013-505 Revised Figure 4.

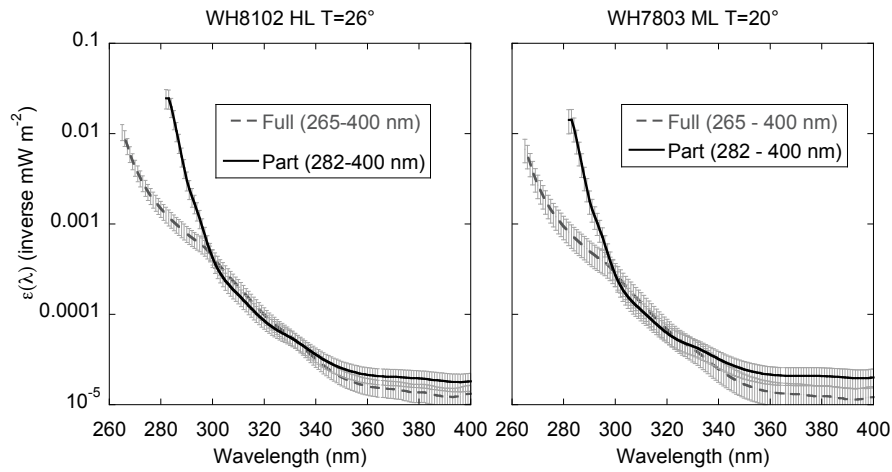


Figure 4. Fitted biological weighting functions (\pm standard error) for UV inhibition of photosynthesis in *Synechococcus* WH8102 (HL 26°C) and 7803 (ML 20°C) comparing results obtained using all the data from each experiment ('full', n=120, shortest treatment wavelength 265 nm) and a reduced data set, omitting the two treatments with spectral irradiance shorter than 282 nm ('part', n=100).