

## **Response to comment on “Impacts of aeolian dust deposition on phytoplankton dynamics in Queensland coastal waters”**

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In our earlier paper (Shaw *et al.* 2008, hereafter SGM) we related an increase in phytoplankton biomass in the coastal waters of Queensland, Australia, to the large October 2002 dust storm. Mackie (in press) has questioned these findings, stating that: (i) the timing of the phytoplankton response precludes the dust storm as a causative agent for the chlorophyll (CHL) increase, and that (ii) it is not clear that there was actually any change in CHL in response to the dust storm.

Mackie highlights that for the three regions where a CHL response was observed that the increase in CHL concentration begins during the 8-day period ending on the 23<sup>rd</sup> of October in two regions and on the 8-day period ending on the 15<sup>th</sup> of October in one of the regions. We agree with Mackie that these increases are not related exclusively to the large October 23 dust storm. As stated in SGM, we believe this initial increase to be in response to smaller dust events prior to the major dust event. In our paper we provided aerosol optical depth (AOD) data that supported this hypothesis. Mackie questions whether AOD is a reliable indicator of particulate load during the dust storm. As noted in SGM the magnitude of the AOD value does not necessarily reflect the concentration of dust. However, AOD has been widely used in similar studies (e.g. Lenes *et al.* 2001; Gabric *et al.* 2002; Boyd *et al.* 2004) and we believe that, when used in conjunction with dust transport models, it is an appropriate

method to indicate the presence of dust, although it does have limitations in determining dust loads.

In further support of our hypothesis that there were smaller dust storms in the drought conditions prior to the CHL response, Australian Bureau of Meteorology (BoM) records show that there were dust storms in western Queensland on eight of the 22 days leading up to the October 23 dust storm (BoM 2009). This activity peaked on the 19th October with an intense dust storm in the Birdsville area (reducing visibility to 300 m) associated with a small low pressure system. The red dusts from this localised event in the Simpson Desert-Channel Country would have been much more highly enriched in iron (Bullard *et al.* 2007) than the 23<sup>rd</sup> October event which sourced dusts from a much larger area of diverse soils. Independent evidence of these events is available from the Earth Probe Total Ozone Mapping Spectrometer (EP/TOMS) aerosol data. Daily aerosol index (AI) data, calculated with the version 8 algorithm, were obtained for October 2002 from the National Aeronautics and Space Administration (NASA, <http://macuv.gsfc.nasa.gov>). TOMS AI measurements have been used to determine the sources and distributions of aerosols and have been shown to be an effective measure of atmospheric dust loading (Israelevich *et al.* 2002 and references therein).

EP/TOMS images of AI are shown in Figure 1, where positive index values indicate the presence of UV-absorbing aerosols. High AI values can be seen in western Queensland on October 6-8 (Fig. 1a-c), in agreement with the BoM record that there were dust storms at this time. From these images, the region of high AI value shifts east, where moderate AI values can be seen off the Queensland coast on the 8<sup>th</sup> and 9<sup>th</sup> of October (Fig. 1c-d). Similarly, very high AI values were observed over central Australia during October 17-20 (Fig. 1e-h), corresponding with dust storm records in Queensland on October 17 and 19 (BoM 2009). On October 20, high AI values were observed off the coast of Queensland and New South Wales (Fig. 1h). Therefore we contend that these dust storms, which occurred prior to the major 23<sup>rd</sup> October event, resulted in deposition of dust into Queensland coastal waters and resulted in the initial increase in phytoplankton biomass prior to October 23.

The second argument put forward by Mackie is that the CHL concentration did not increase further following the major dust event in two of the three regions in which a response was observed and therefore it was concluded that the dust storm had no effect on phytoplankton biomass. This conclusion only relates to the intensity of the bloom and fails to acknowledge any effect that the major dust event had on prolonging the duration of the phytoplankton response. Aperiodic phytoplankton blooms are often short-lived events where high biomass is rapidly attained in response to the addition of new nutrients (Behrenfeld *et al.* 1996; Cloern 1996). Nutrients are rapidly taken up by large populations of phytoplankton and are quickly depleted, causing the dissipation of the bloom. The duration of the phytoplankton response observed in our study was approximately one month (Shaw *et al.* 2008). In comparison, when iron was artificially enriched in the eastern equatorial Pacific during the large-scale IronEx I and IronEx II experiments, the duration of the phytoplankton response was much shorter. Phytoplankton biomass peaked two days after iron enrichment during IronEx I and in IronEx II, where iron was enriched initially at day zero and again on days three and seven, phytoplankton biomass peaked at day eight and returned to background levels by day thirteen (Behrenfeld *et al.* 1996).

It was also stated by Mackie that the data in our paper is insufficient to exclude other potential causes of the phytoplankton response. We excluded the possibility of wind-driven resuspension and fluvial input of nutrients, which we believed to be the most likely alternative explanations. Mackie suggests as an example that “wind induced shoaling of the mixed layer” could be a possible alternate cause for the observed increase in CHL (Mackie in press). However we do not believe this to be a viable alternate explanation as increased wind speeds cause mixed layer deepening, not shoaling.

Finally, we disagree that the observed increase in CHL represented only a modest response to the large October 2002 dust event. Our results showed an increase in CHL of 1.5-2 times the long-term mean value. In comparison, CHL values during the Queensland wet season are approximately 1.5 fold greater than in the dry season (Brodie *et al.* 2007). As discussed earlier in this paper we also believe the duration of

the event to be significant. We therefore maintain our original conclusion that October 2002 dust events resulted in a significant phytoplankton response.

## References

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### **Figure Captions:**

**Figure 1:** Aerosol index values over Australia on the (a) 6<sup>th</sup>, (b) 7<sup>th</sup>, (c) 8<sup>th</sup>, (d) 9<sup>th</sup>, (e) 17<sup>th</sup>, (f) 18<sup>th</sup>, (g) 19<sup>th</sup> and (h) 20<sup>th</sup> of October 2002