

# SeaWiFS-derived Chl anomaly and related nutrient sources in the Queensland continental shelf waters

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**Abstract.** Existing studies suggested that inshore parts of the Great Barrier Reef (GBR) lagoon are already or will soon become eutrophic as a result of anthropogenic nutrient enrichment. GBR phytoplankton dynamics generally displays a seasonal pattern, with algal standing stock (Chl) at an annual maximum during the summer wet season. Observations suggest that fluvial discharge is a primary source of nutrients for algal growth in this region, although upwelling, biological nitrogen fixation, and rainfall are also sources of new nutrients. Aeolian mineral dust deposition is thought to be a critical source of dissolved iron (dFe) for phytoplankton growth in some oceanic regions. However, research on aeolian dust delivery of nutrients to GBR waters has been very limited in comparison with fluvial nutrients. In this study, 8-day Chl anomalies in the Queensland continental shelf waters were computed from 8-day binned Chl and 8-day Chl climatology derived from SeaWiFS satellite data. Positive anomalies were initially examined in relation to fluvial discharge, upwelling, and dust storm events. Results indicated significant positive Chl anomalies in near-shore areas during the wet season may be due to fluvial nutrients and sediment. Significant positive Chl anomalies extended offshore in the southern area of the GBR lagoon during October and November of 2002 and 2009. This may reflect the impact of dust-derived nutrients from dust storm events in eastern Australia. Unusual positive Chl anomalies in the continental shelf waters from Fraser Island to the Gold Coast may be the result of seasonal upwelling.

**Key words:** SeaWiFS, Chl Anomaly, Great Barrier Reef, Aeolian Dust, Fluvial Discharge, Upwelling.

## Introduction

Eutrophication of coastal water bodies is a global problem resulting in enhanced algal biomass, altered community compositions and changes to ecosystem structure and functioning (Smith 2003). Current scientific consensus is that inshore regions of the central and southern Great Barrier Reef (GBR) are at risk of impacts from increased nutrient (as well as sediment and pesticide) loads delivered to Reef waters (Brodie et al. 2011). Brodie et al. (2007) indicated that phytoplankton dynamics also display a seasonal pattern, with algal standing stock (Chl) at an annual maximum during the summer wet season. These observations suggested that fluvial discharge is a primary source of nutrients for Chl growth in this region although upwelling, biological nitrogen fixation, and rainfall are also sources of new nutrients (Brodie et al. 2007; Brodie et al. 2011). Satellite data can provide very good estimates of Chl concentration in clear open ocean waters; however, the fluvial sediment and dissolved organic matter in the Great Barrier Reef lagoon may cause error in the estimation of near-shore Chl concentration (Gohin et al. 2002).

Aeolian mineral dust input is thought to be a critical source of dissolved iron (dFe) for phytoplankton growth in some oceanic regions (Karl et al. 2002). In the North Atlantic Ocean, aeolian dust deposition has

been shown to stimulate blooms of diazotrophs (nitrogen-fixing cyanobacteria) by increasing the level of dFe within the water column (Lenes et al. 2001). However, research on aeolian dust delivery of nutrients in Australia has been very limited in comparison with research on fluvial transport of nutrients (Shaw et al. 2008).

Several studies have shown a moderate correlation between the modelled flux of dust-derived iron and satellite-derived Chl in the Southern Ocean south of Australia and off the Queensland coast (Cropp et al. 2005; Shaw et al. 2008; Gabric et al. 2010). The sensitivity of phytoplankton growth in central and southern Queensland coastal waters to dust deposition after a severe dust storm on 23 October 2002 was demonstrated by examining changes in satellite-derived Chl concentration and aerosol optical depth (AOD) (Shaw et al. 2008). However, there has been no long term high resolution study on the influences of mineral dust deposition on algal blooms along the Queensland coast. In this paper, SeaWiFS-derived Chl anomalies in the Queensland continental shelf waters are examined in relation to fluvial discharge and dust deposition. The spatial relation between high Chl and low sea surface temperature (SST) as evidence of upwelling is also examined.

## Material and Methods

Binned 8-day SeaWiFS-derived Chl data were acquired from the NASA Ocean Color project (<http://oceandata.sci.gsfc.nasa.gov/SeaWiFS/>). An 8-day Chl climatology was computed by averaging 8-day binned Chl for the whole SeaWiFS mission (1997-2010) using SeaDAS software for the Queensland continental shelf which includes the GBR lagoon and continental shelf waters from Gold Coast to Fraser Island (Fig. 1). The Chl anomaly for a specific octad was computed by simple subtraction from Chl climatological value.

Because Chl and SST can be derived from a MODIS Aqua image, level 2 MODIS-derived Chl and SST were also acquired from the NASA Ocean Color archive. The spatial relation between Chl and SST derived from the same images of continental shelf waters from Fraser Island to the Gold Coast was examined visually to see if there was any correlation between decreased SST and increased Chl (an indicator of upwelling).



Figure 1: The study area - Queensland continental shelf waters.

Fluvial discharge data was acquired from the Water Monitoring Data Portal, Department of Environment and Resources Management, Queensland Government (<http://watermonitoring.derm.qld.gov.au>). Data plots of fluvial discharge of the Burnett and Fitzroy rivers during 1997-2010 were extracted. The discharges of these rivers were visually examined and compared with Chl anomalies to identify the relationship between Chl anomaly and peak fluvial discharge.

Annual dust concentration observed at several regions in Queensland coast was obtained from the Dust Watch Australia (<http://www.dustwatch.edu.au>). Data plots of dust concentration during 1960-2011 were extracted to examine the relation between dust storm events and any subsequent Chl anomaly.

## Results and Discussion

Several significant positive Chl anomaly events were observed in the GBR lagoon (Fig.2). In January 1998, there was an unusual positive Chl anomaly in the near-shore area of the northern and central areas of the GBR lagoon. There were remarkable positive Chl anomalies in the central area of the GBR lagoon extending as far as the outer reefs in March 2003, January and February 2005. During February 2007, February and March 2009, and March 2010, there were several significant positive anomalies in near-shore areas of central and southern areas of the GBR lagoon. These unusual positive anomalies may be caused by enrichment of nutrients and sediment from terrestrial sources as a result of fluvial discharge (Brodie et al. 2010).

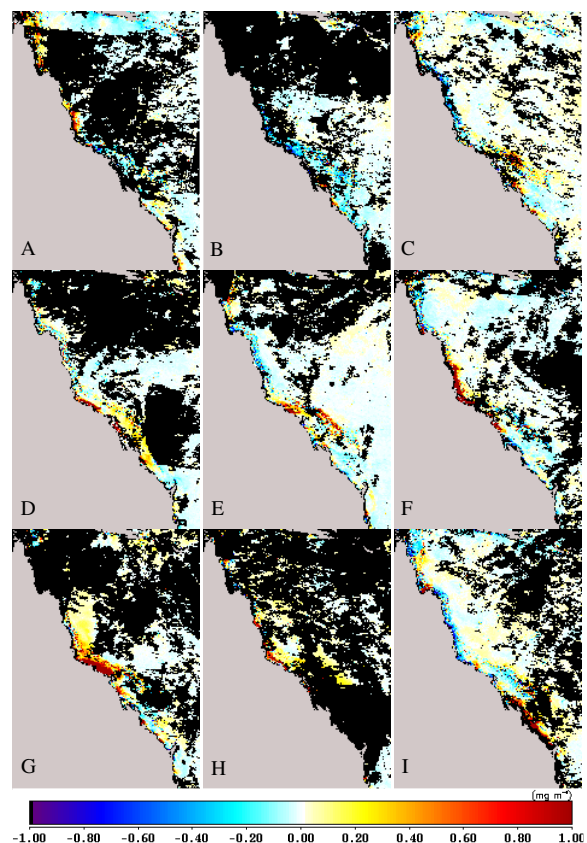


Figure 2: 8-day Chl anomaly in near-shore areas of GBR lagoon: (A) 25-31 January 1998; (B) 18-25 February 2003; (C) 14-21 March 2003; (D) 25-31 January 2005; (E) 02-09 February 2005; (F) 10-17 February 2007; (G) 18-25 February 2009; (H) 06-13 March 2009; (I) 07-14 March 2010.

Visual comparison of Chl anomalies and fluvial discharge plots for the Burdekin and Fitzroy rivers during 1997-2010 (Fig. 3) shows coherence between high fluvial discharge and positive Chl anomaly in January 1998, March 2003, January 2005, February 2007, February 2009, and March 2010. However, the load of fluvial sediment and dissolved organic matter may cause error in the estimation of Chl concentration in near-shore areas of the GBR lagoon. The fluvial nutrient source may be a cause of subsequent algal bloom in offshore areas of the GBR lagoon. A quantitative analysis of the correlation between fluvial discharge and daily Chl in each region is needed to determine the fluvial impact on sediment and nutrient enrichment in the GBR lagoon.

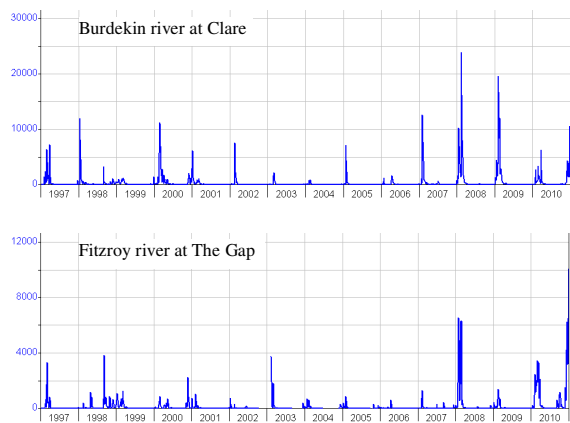


Figure 3: Stream discharge (Cumecs) of Burdekin river at Clare (above) and Fitzroy river at The Gap (below) during 1997-2010 (Source: <http://watermonitoring.derm.qld.gov.au>).

During the SeaWiFS mission, there was only negligible variation in the Chl anomaly from May to August in the study area. This suggests that there is a minor variability in standing stock during the winter dry season.

However, from September to November, there were significant positive Chl anomalies in several areas in the continental shelf waters from Fraser Island to the Gold Coast in several years (1997, 2000, 2002, 2003, 2004, 2005, 2007, 2008, and 2009) (Fig. 4). This may be due to seasonal upwelling at the continental shelf break to the east of Fraser, Moreton, and Stradbroke Islands.

Because there was no SST data acquired by the SeaWiFS sensor, level 2 Chl and SST derived from MODIS Aqua satellite data was used for more efficient data analysis. Spatial distribution of MODISA-derived Chl and SST at 1 km resolution in continental shelf waters from Fraser Island to the Gold Coast was visually compared. There was a clear spatial coherence between high Chl and low SST in the waters south of Fraser Island (Fig. 5). These relations occurred regularly in waters to the south east

of Fraser Island, and sometimes in waters to the east of Moreton Island and Stradbroke Island. Fig. 6 shows good spatial correlation between Chl and SST in southeast Fraser Island waters in late 2009. This is evidence of upwelling that occurred in this area. This upwelling may occur at the continental shelf break when the East Australian Current (EAC) peaks (November to December in the GBR) (Steinberg 2007). Existing literatures indicate that upwelling in the central GBR is caused by the EAC (Berkelmans et al. 2010) and in the southern GBR is caused by the Capricorn Eddy (Weeks et al. 2010). This upwelling is possibly caused by the Ekman current which can occur when there is a consistent wind flow along a coastal morphology such as at Fraser Island and Stradbroke Island. Thus, wind data in this region should be acquired to examine if consistent northerly wind occurred prior to high Chl concentration and low SST.

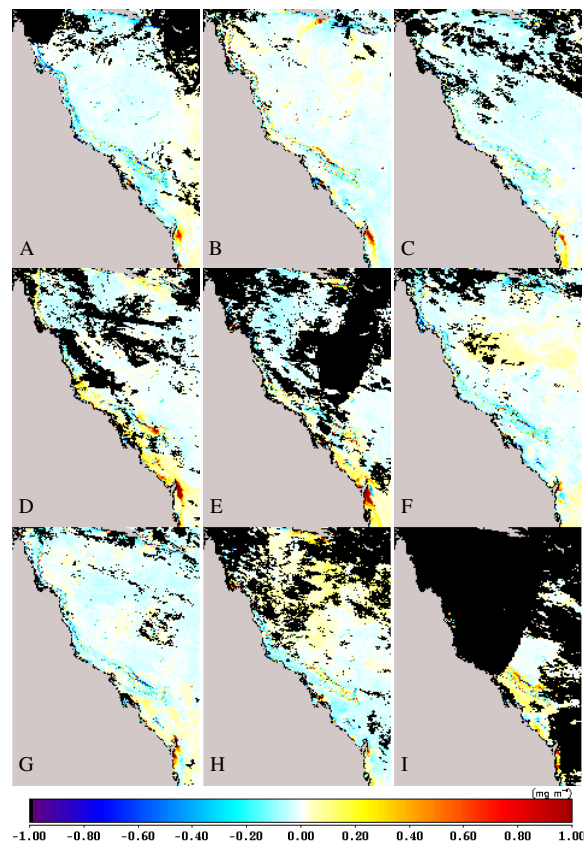


Figure 4: 8-day Chl anomaly in the continental shelf waters from Fraser Island to the Gold Coast: (A) 8-15 October 1997; (B) 5-12 September 2000; (C) 22-29 September 2002; (D) 24-31 October 2003; (E) 23-30 October 2004; (F) 6-13 September 2005; (G) 6-13 September 2007; (H) 13-20 September 2008; (I) 8-15 October 2009.



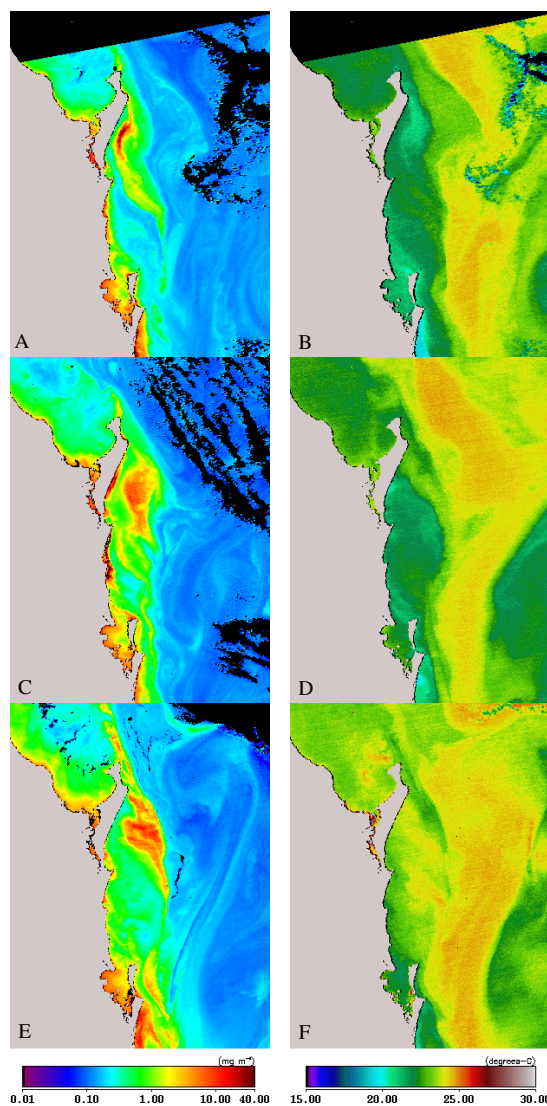


Figure 5: Comparing spatial relation of MODIS-derived Chl and SST in the continental shelf waters from Fraser Island to the Gold Coast: (A) Chl on 11 September 2009; (B) SST on 11 September 2009; (C) Chl on 20 September 2009; (D) SST on 20 September 2009; (E) Chl on 15 October 2009; (F) SST on 15 October 2009.

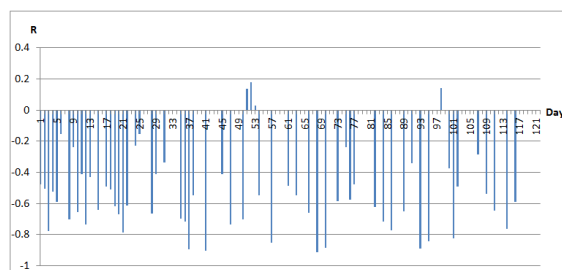


Figure 6: Correlation Coefficient (R) of Chl and SST in southeast Fraser Island waters during 1 September - 31 December 2009

Extreme dust storm events on 23 October 2002 and 23 September 2009 in Eastern Australian were recorded (McTainsh et al. 2005; Jayaratne et al. 2011)

and can be seen on MODIS satellite images (Fig. 7). Annual dust concentration in Townsville, Rockhampton, and Brisbane (Fig. 8) shows that there was high dust deposition associated with the dust storm events in October 2002 and September 2009. There were positive Chl anomalies in the central and southern areas of the GBR lagoon from October to December in 2002 and 2009 extending over large areas and up to a hundred km offshore (Fig. 9). These Chl anomalies may be related to nutrient (dFe) enrichment by dust deposition (Shaw et al. 2008) and subsequent blooms of nitrogen fixers such as *Trichodemium* (Bell 1992).

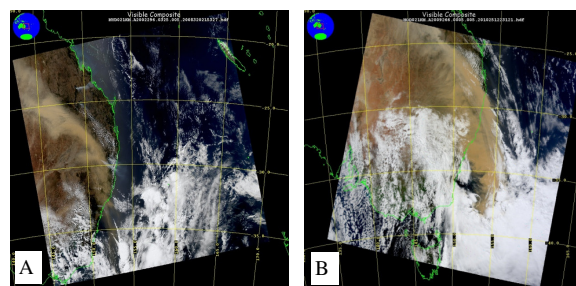


Figure 7: MODIS true color composite images show dust events in the Eastern Australia: (A) MODIS Aqua on 23 October 2002, (B) MODIS Terra on 23 September 2009.

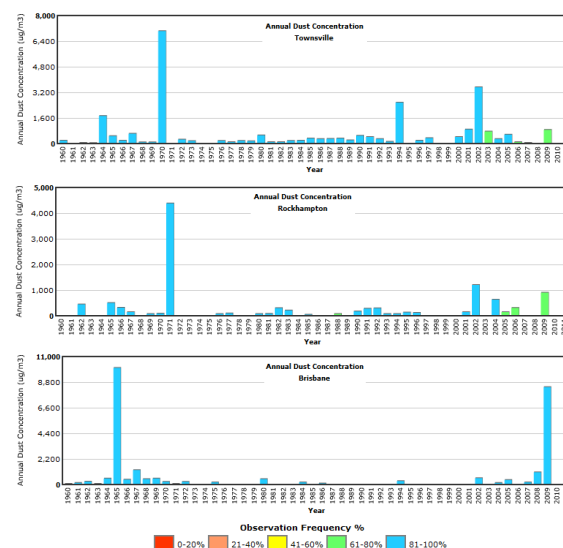


Figure 8: Annual dust concentration in Townsville, Rockhampton, and Brisbane during 1960-2011 (Source Dust Watch Australia <http://www.dustwatch.edu.au/>).

A further analysis of the quantitative correlation between dust deposition and daily Chl concentration in the GBR lagoon should be conducted to determine if dust-derived nutrients are a significant source of nutrients for algal blooms in Queensland continental shelf waters. It is notable that dust source was usually enhanced during prolonged drought period in Eastern Australia between 1998 and 2009 (Gabric et al. 2010).

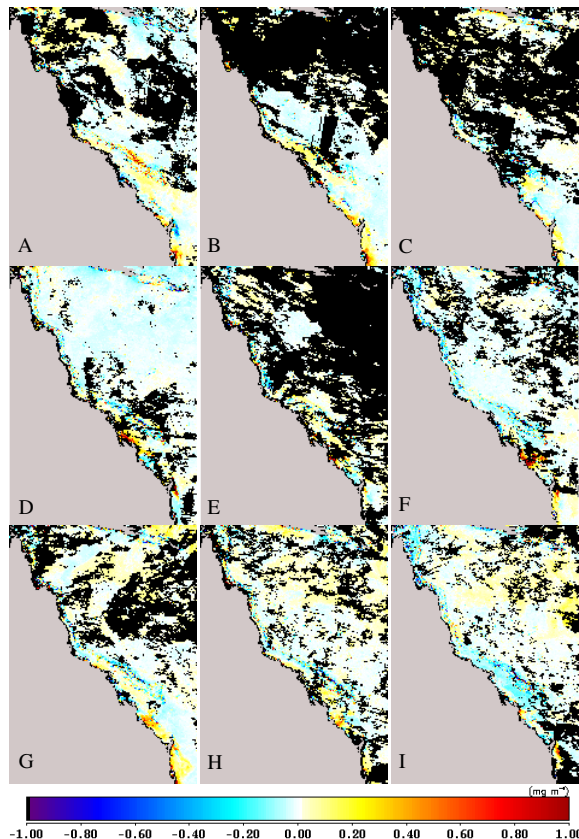


Figure 9: 8-day Chl anomaly in the central and southern areas of the GBR lagoon subsequent dust events in 2002 and 2009: (A) 24-31 October 2002; (B) 01-08 November 2002; (C) 09-16 November 2002; (D) 03-10 December 2002; (E) 09-16 November 2009; (F) 17-24 November 2009; (G) 03-10 December 2009; (H) 11-17 December 2009; (I) 19-26 December 2009.

### Conclusions and Further Work

The significant positive Chl anomalies caused by fluvial discharge and other nutrient sources have been observed from SeaWiFS-derived 8-day Chl anomaly in the GBR lagoon. Unusual Chl anomalies in near-shore areas of the GBR lagoon have been found and related to fluvial discharge during the wet season. Significant Chl anomalies occurred southeast of Fraser Island which may be indicative of upwelling. A remarkable Chl anomaly event that occurred in the southern area of the GBR lagoon in November 2009 may be related to the subsequent dust deposition of dFe and nitrogen fixation of *Trichodemium*. Gaps in data acquired by SeaWiFS sensor and the limited availability of cloud-free data have affected the capability to fully assess Chl anomalies for the whole SeaWiFS mission. Other ocean colour data such as data acquired by MODIS Aqua should be used to fill in these data gaps. Further analysis should be conducted to quantify the correlation of Chl concentration with fluvial discharge, dust deposition, and upwelling.

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