Upwelling-initiated algal bloom event in the coastal waters of Bay of Bengal during post-northeast monsoon period (2015)

A monospecies bloom of diatom *Asterionellopsis glacialis* was observed in the coastal waters of Kalpakkam, Tamil Nadu, India (12°33′N lat. and 80°11′E long.) during a regular coastal water monitoring programme. The bloom was dense and created brownish-coloured patches near the surf zone (Figure 1). The entire bloom extended to several kilometres along the coast. The present study is the second report of *A. glacialis* bloom from the same locality. The first observation of *A. glacialis* was reported about two decades ago[1]. Blooms of *Noctiluca scintillans*[2] and *Trichodesmium erythraeum*[3,4] have also been reported from this coast. Such total preponderance of *Asterionella* sp. has also been reported earlier along the Visakhapatnam coast[5], Gopalpur coast[6,7], Rushikulya estuary[8] and Bahuda estuary[9]. Interestingly, all the six *Asterionella* blooms have been reported only from the Indian coastal waters of Bay of Bengal (BOB), east coast of India[10].

The nearshore water was monitored for a week (14–21 January 2015) in order to study the bloom dynamics. Water, phytoplankton and zooplankton samples were collected for assessment of possible impacts of the bloom on the ecosystem. Samples were collected about 150–200 m inside the sea (surf zone), from the prototype fast breeder reactor (PFBR) jetty, and analysed for physico-chemical parameters following standard methods[11]. The phytoplankton density was estimated using Utermohl's sedimentation technique[12] and counted using Sedgwick Rafter counting chamber with the aid of inverted research microscope (Zeiss Axiovert 40). Identification of phytoplankton was done following standard taxonomic monographs[13–17].

Though relatively high density (2.95×10^7 cells l^{-1}) of *A. glacialis* was observed on 14 January 2015, there was no discolouration of the sea surface. The highest cell density (5.63×10^7 cells l^{-1}) of *A. glacialis* was observed on 17 January 2015, accompanied with brownish discolouration. On the contrary, samples collected beyond the surf zone, at about 500 m inside the sea, showed relatively less *A. glacialis* density (9.61×10^6 cells l^{-1}) on 17 January 2015, indicating the existence of dense bloom near to the surf zone. The contribution of other phytoplankters during these days was relatively low, which showed that it was a monospecies bloom of *A. glacialis*. The highest *A. glacialis* density observed in the present study was relatively low compared to the value reported by Subba Rao[5] (9.32×10^7 cells l^{-1}), and considerably higher than that reported by Mishra *et al.*[7] (3.92×10^7 cells l^{-1}). A gradual temporal decrease in *A. glacialis* density was observed (Figure 2). During 20 and 21 January 2015, the density was reduced to normal level at this location[18,19]. Contribution of *A. glacialis* during the peak bloom period was 97.12% of the total phytoplankton density. Similar observations of contribution of *A. glacialis* varying from 85% to 99% of total phytoplankton density have been reported earlier[8,9]. During the bloom event, 115 species of phytoplankton consisting of 64 centrales, 36 pennates, 12 dinoflagellates and three cyanobacteria were identified. It showed that the costal waters were relatively more diverse during the bloom period as the number of phytoplankton species observed was relatively high for a short period of study of this kind[18,19].

Physico-chemical properties did not show any significant variation during the study. However, significantly high concentration of total nitrogen (TN) and total phosphorus (TP) was observed on the day of peak bloom (Table 1). Similarly, the highest concentration of chl *a* (15.99 mg m^{-3}) coincided with highest cell density. Though the cell density was found to be on the relatively higher side during 18 and 19 January, chl *a* concentration decreased significantly. From the above observation it can be inferred that the bloom was in waning phase when the peak density was observed by us. Moreover, the increased TN and TP suggested the release of nitrogen and phosphorus from the dead bloom biomass, which was supported by the observed decrease in chl *a* content.

In order to obtain a clear picture of the bloom event, satellite data were used. The bloom was correlated with sea-surface temperature (SST) using NASA MODIS-Terra satellite sensor dataset for the period 14–19 January 2015. The surface temperature was observed to be reduced by about 0.8°C to 1.2°C in the coastal waters along northern Tamil Nadu compared to the offshore water (Figure 3 *a* and *b*). This indicates the occurrence of upwelling along the coastal waters and the convection of bottom water to the surface. The coastal-upwelling along the western boundary of BOB has been reported during pre-southwest monsoon and southwest monsoon[20–22]. Moreover, Tomczak and Godfrey[23] have reported upwelling in this region from January to July and downwelling from August to December. The cooling of water along northern Tamil Nadu and southern Andhra coast has been reported to be the causative factor enhancing the phytoplankton bloom in the southwest BOB water[7]. The SST image during 14–16 January 2015 (three-day composite) was observed to be in the lower range (25–26°C) than the non-bloom water types in the offshore region, which ranged from 26.5°C to 28°C and higher.

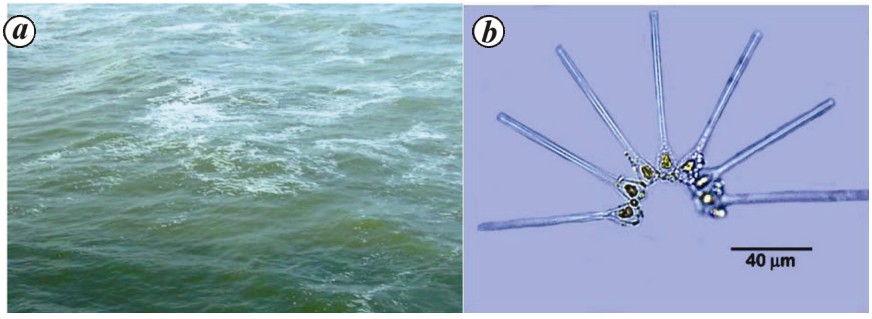

Figure 1. ***a***, *Asterionella glacialis* bloom patches observed in the coastal waters of Kalpakkam, Tamil Nadu. ***b***, A chain of *A. glacialis* observed under light microscope.

Table 1. Physico-chemical properties of coastal waters during the phytoplankton (*Asterionellopsis glacialis*) bloom at Kalpakkam coast, Tamil Nadu

	Temperature (°C)	pH	Salinity (psu)	DO (mg l^{-1})	Nitrite	Nitrate	Phosphate	Ammonia	Silicate	TN	TP	Chl *a* (mg m^{-3})
					← (in μ mol l^{-1}) →							
14 January 2015; 10:00 a.m.	27.2	7.9	32.6	7.1	0.10	1.18	0.07	0.00	3.90	7.06	1.64	5.87
17 January 2015; 09:30 a.m.	26.2	7.7	32.8	7.2	0.07	1.32	0.75	0.00	3.45	40.26	7.03	15.99
17 January 2015; 04:30 p.m.	27.6	7.7	33.4	7.4	0.09	1.05	0.50	0.00	6.60	2.49	1.10	3.21
18 January 2015; 08:30 a.m.	26.1	8.0	31.9	8.0	0.16	1.18	0.55	0.00	3.90	13.28	0.68	1.54
19 January 2015; 10:00 a.m.	27.4	7.8	32.6	7.6	0.02	1.68	0.05	0.00	3.23	8.09	0.05	1.54

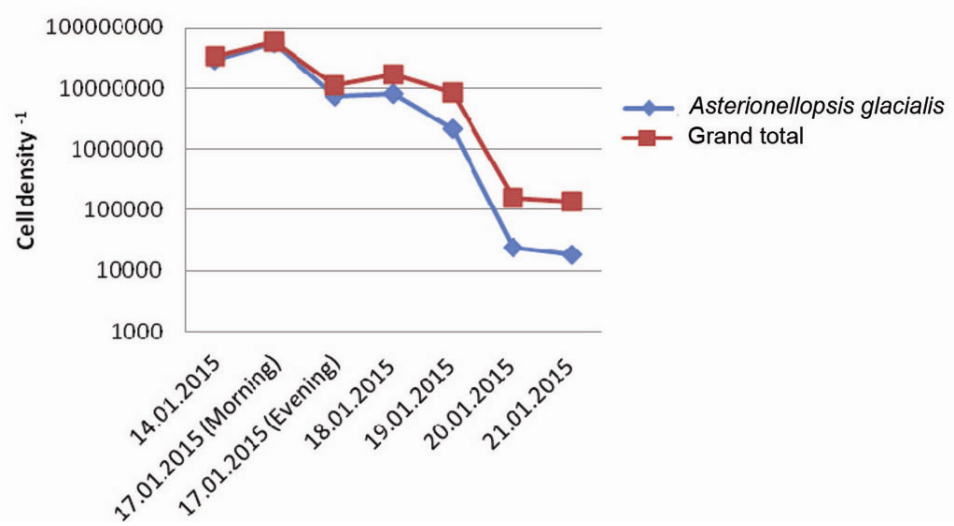

Figure 2. Density (cells l^{-1}) of *Asterionellopsis glacialis* versus total phytoplankton density observed in the coastal waters during 14–21 January 2015.

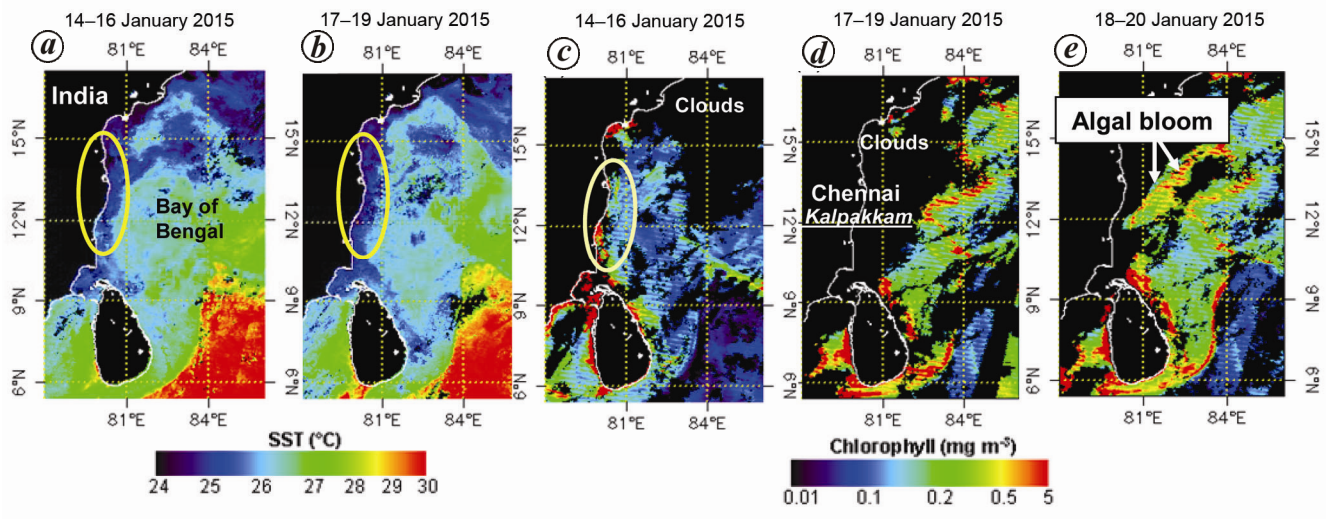

Figure 3. NASA MODIS-Terra satellite sensors-derived three-day composite images of sea-surface temperature (SST) indicating the cooling zones (***a***, ***b***) and chlorophyll images (***c***–***e***) that reflect the phytoplankton bloom water along southwest Bay of Bengal.

The *in situ* measurement of temperature in the nearshore waters also corroborated with the satellite data.

MODIS satellite ocean colour data of lower resolution ~4 km pixel coverage were used to observe, monitor and elucidate the phytoplankton bloom features from synoptic scale images. Chlorophyll images were retrieved using NASA

Moderate Resolution Imaging Sensor for the period 14–20 January 2015. The satellite images showed the presence of three-types of water mass with respect to chlorophyll concentration (Figure 3 *c*–*e*). They are: highly eutrophic/bloom water (yellow and red colour patches – chl conc.: 0.30–5.0 mg m^{-3}); eutrophic/productive/non-bloom water (green colour – chl conc.: 0.1–0.3 mg m^{-3}), and less productive/oligotrophic water (cyan and blue colour – chl conc.: 0.01–0.10 mg m^{-3}). The composite image of chlorophyll during 14–16 showed that the high chlorophyll concentration patches (0.5–5.0 mg m^{-3}) were distributed in clusters along northern Tamil Nadu and southern Andhra coastal waters, indicating occurrence of the bloom (Figure 3 *c*). The *in situ* chlorophyll values observed corroborated with satellite data of relatively high concentrations during the early phase of the bloom. Similarly, datasets of three-day composite images during 17–20 January 2015 showed the presence of bloom patches and irregular stripes mainly in the offshore waters and those surrounding the far-off Sri Lankan coast (Figure 3 *d* and *e*).

A. glacialis is the third dominant bloom forming species with seven (including the present observation) bloom appearances (*Trichodesmium* spp. – 35 times; *Noctiluca* spp. – 24; mixed blooms and other species – 18 times) since the first report of algal bloom in India[10,24] and has contributed about 8% of the total number of algal blooms reported from Indian coastal waters[10]. Nutrient enrichment during the post northeast monsoon period[25] along with occurrence of upwelling in the coastal waters[26] during the same period could have triggered the *A. glacialis* bloom. Though the above two processes might be occurring in the coastal waters every year, a detailed investigation on the water mass characteristics, plankton community structure and physical processes (current, wave, upwelling, etc.) would be useful to understand the bloom phenomenon.

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