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Outline of climate and oceanographic conditions in the Indian Ocean: an update to mid-2017

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Several descriptors of the ocean climate conditions are examined to depict the inter-annual trend and to track major changes that may affect the large pelagic ecosystem. Details on the database and methods used can be found in Marsac (2013) except that the surface temperature data set used to compute the Dipole Mode Index is the version 4 of the ERSST (Huang et al, 2015). All data have been updated to August or September 2017 (depending on the dataset).

After the development of strong positive Indian Ocean Dipole during the second semester of 2015, coinciding with highly negative Indian Oscillation Index and Southern Oscillation Index, the situation reversed into a negative dipole phase in January 2016, reaching its mature condition in July 2016. The Indian Ocean dipole was back to neutral conditions in December 2016, and continued to grow into another positive status during the first quarter 2017, peaking in July 2017 and gradually returning to neutral situation during the 3rd quarter 2017 (Fig.1-4). Current forecasts give a 55-60% chance that La Niña develops during October-2017 through the first quarter 2018 (NOAA, 2017) (Fig.5). By contrast, most models predict a neutral dipole mode during the 4th quarter 2017 (BoM, 2017) (Fig.6). The main oceanographic features over 2015-2017 are summarized as follows (Fig.7a-c):

- The Indian Ocean surface warming that occurred from June 2015 to May 2016 (+1.5° to +2°C) developed through the whole ocean basin, therefore no significant East-West temperature gradient was noticeable.
- However, deeper than normal thermocline depth (+40 to +60 m) was observed in several locations of the West Indian Ocean (WIO) from November 2015 to April 2016.
- During this warm episode, surface chlorophyll was lower than normal in the West and Central Indian Ocean, denoting a lower surface ocean primary productivity, whereas normal conditions prevailed in the East Indian Ocean (EIO).
- The 2016 southwest monsoon (June to September) generated cool conditions (-1° to -2°C), with a strong Somalia upwelling , shallower than normal thermocline depth in the WIO (rise of 30-40 m) and anomalously deep thermocline in the EIO (deepening of 40-50 m).
- The surface chlorophyll was high in the WIO, especially during July-August 2016, and depleted in the EIO, off Sumatera (Indonesia).
- Overall, sea surface temperature was normal during the 4th quarter 2016, and low anomalies started to develop from February to May 2017 in the WIO (-2°C) in a restricted area (60°E-70°E / 0°-10°N). The thermocline depth became shallower than normal in the West and Central Indian Ocean from January to June 2017. Sea surface chlorophyll was considerably

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enhanced (>0.4 mg.m^{-3}) in the North Indian Ocean from September 2016 through March 2017. The chlorophyll hot spots were located in the Gulf of Aden, along the coast of Iran, Pakistan, along the west coast of India and Sri Lanka. The whole Arabian sea had a high chlorophyll concentration over most of its area in February-March 2017.

The yearly trend in chlorophyll concentration for 5 sub-areas distinguishes three groups with similar patterns (Fig.8-9):

- Somali basin (SOM) and Mozambique Channel (MOZ) are the most productive areas (0.30 to 0.54 mg.m^{-3}), as a consequence of the seasonal upwelling along the Somalian coast and the intense mesoscale activity in the Mozambique Channel. The chlorophyll concentration has steadily increased since 2014 in those regions;
- West equatorial zone (WEQ) and Maldives (MAL) have intermediate values (0.11 to 0.22 mg.m^{-3}); they have displayed similar yearly changes since 2005. However, for 2017 the chlorophyll content continued to increase in WEQ whereas it declined slightly in MAL;
- The East tropical region (ETR) is less productive than the two former groups, with values ranging from 0.08 to 0.12 mg.m^{-3}). The chlorophyll concentration has steadily increased since 2014. The provisional value for 2017 (Jan-Aug) equals the maximal level recorded in 1999.

The overall rate of change is defined as the increase or decrease in % from the average 1998-2016. For 2016, the rate is based on the annual average for the series, whereas it is based on the January-August average for 2017 to account for the incomplete data for that year (Table 1).For both years, the primary productivity was above the 19-year average, however the rate of increase has been much higher for 2017 compared to 2016. This indicates better foraging conditions for intermediate and high trophic levels.

The seasonal SST, 20°C isothermal depth and surface chlorophyll concentration for each of the 5 sub-areas, 1998-2017, are shown in Figs 10 to 14.

Table 1 – Rate of change (in %) of surface chlorophyll concentration

	SOM	**MAL**	**WEQ**	**ETR**	**MOZ**
2016 (all year)	+2.4	+1.6	+9.6	+9.8	+9.9
2017 (Jun-Aug)	+12.1	+16.7	+3.9	+23.1	+5.6

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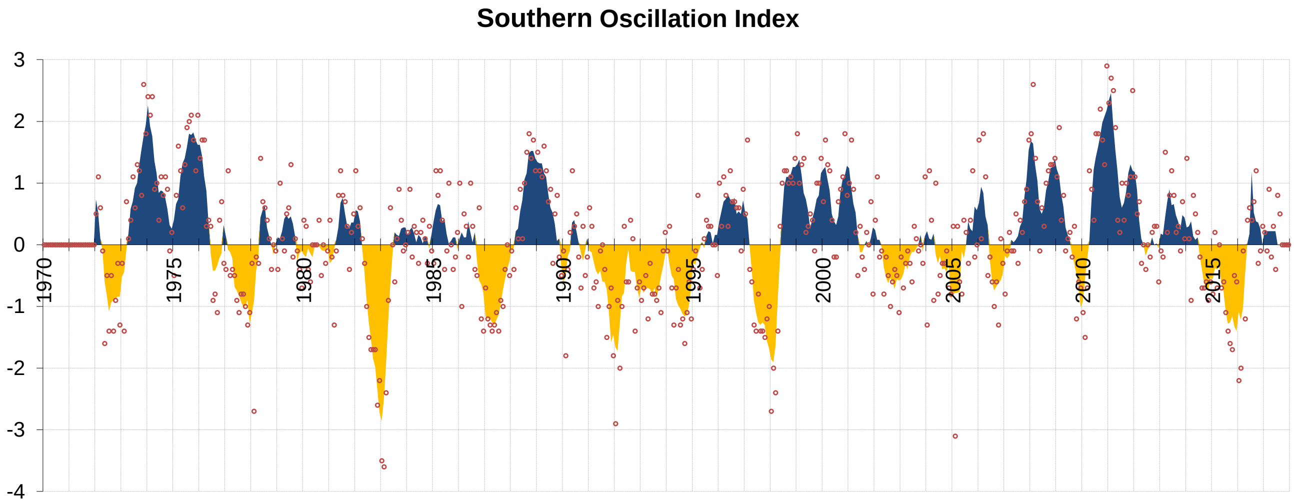

Fig.1 – The Southern Oscillation Index (SOI), January 1970 to August 2017 (top). The color shaded area represents the 5-month moving average, whereas observed monthly values are shown in red dots. El Niño events correspond to the extreme negative values whereas La Niña events are described by the extreme positive values.

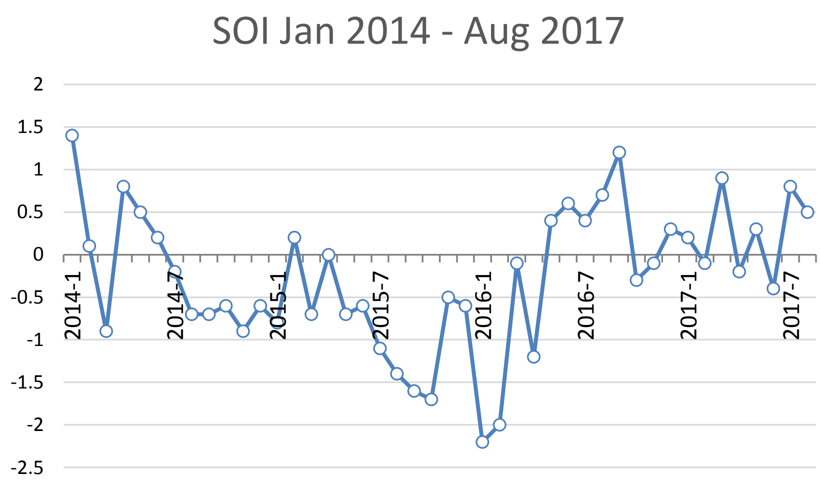

Fig.2 - Non-smoothed monthly SOI for January 2014-August 2017 (bottom)

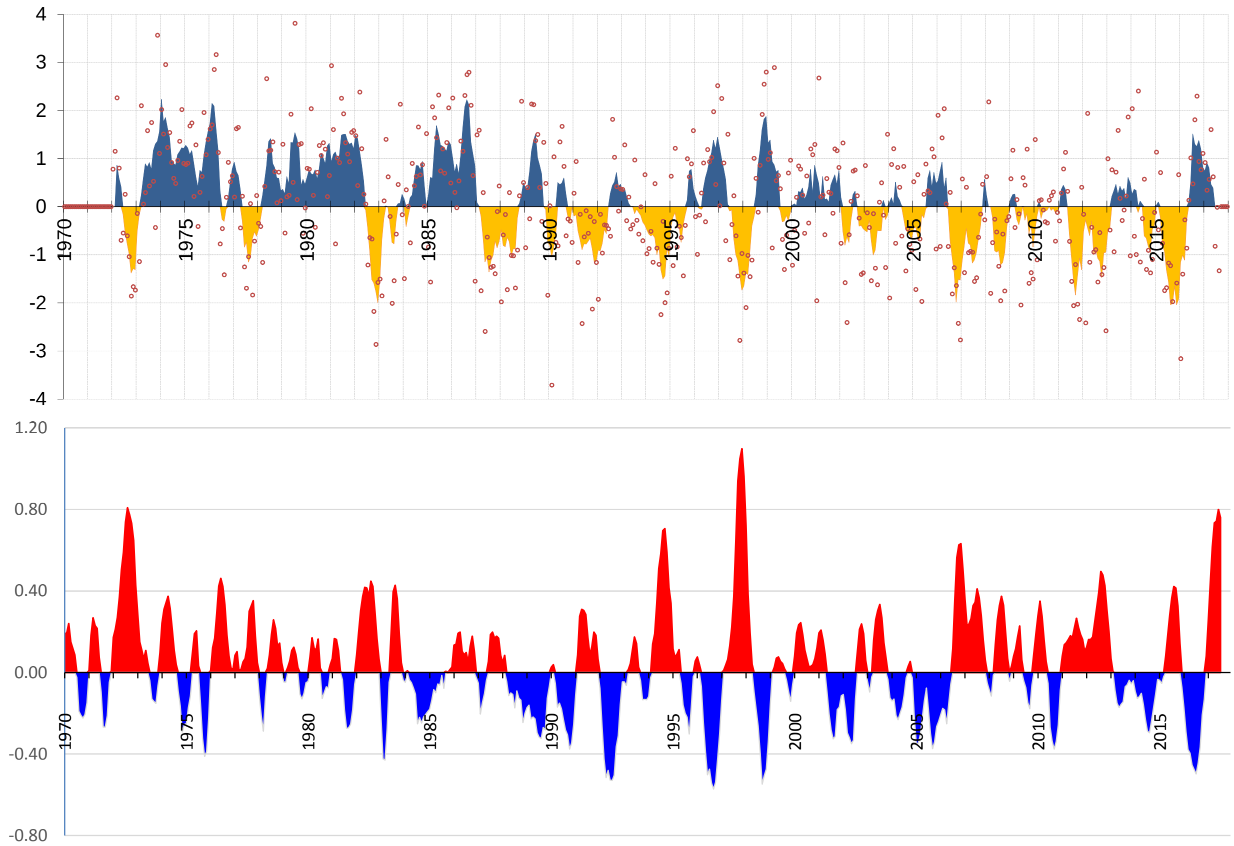

Fig.3 - Indian Oscillation Index (top) and dipole mode index (bottom) over the period January 1970 – August 2017. The shaded area of IOI is a 5-months moving average whereas observed monthly values are represented in red dots. The DMI series is 5-month moving average. Warm (cold) events are represented by negative (positive) IOI and positive (negative) DMI. For a given anomaly, IOI and DMI are opposite sign.

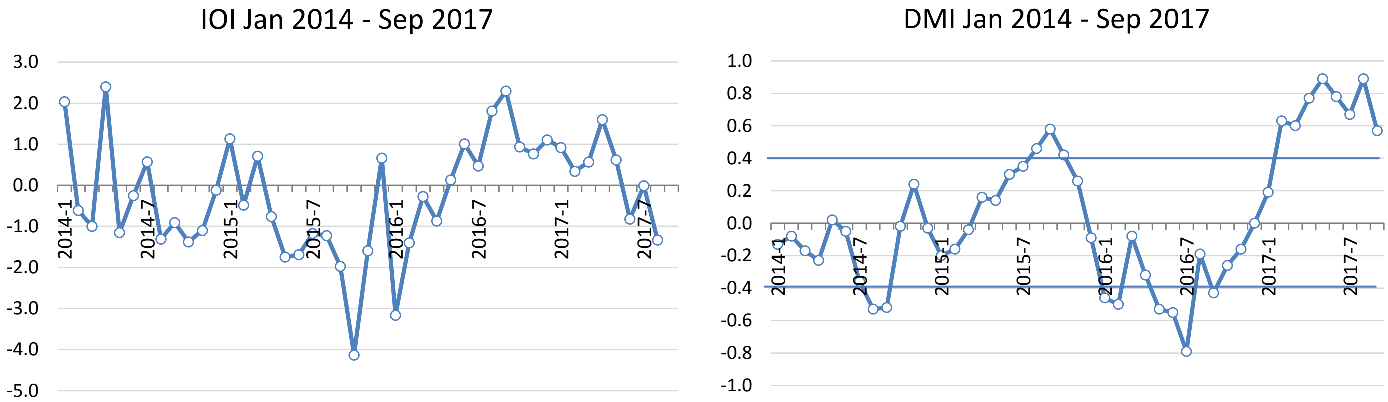

Fig.4 -Non-smoothed monthly IOI (left) and DMI (right) for January 2014-August 2017

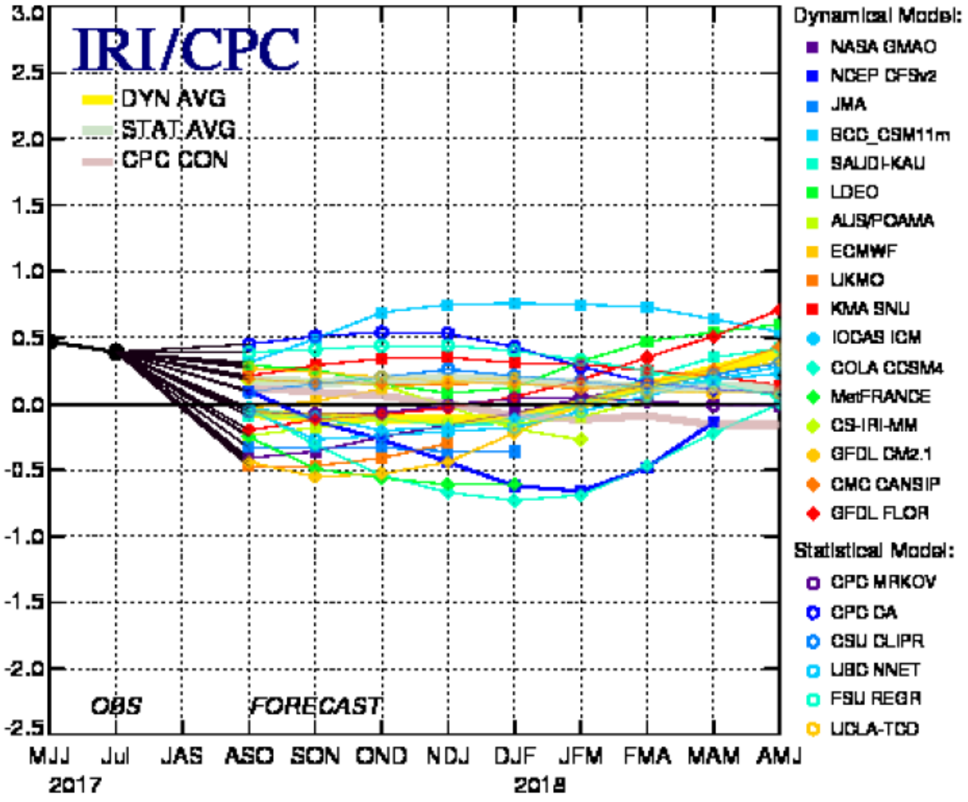

Fig.5 – Mid-September 2016 plume of Model ENSO predictions
(Source : Climate Diagnostic Bulletin, Aug 2017, NOAA)

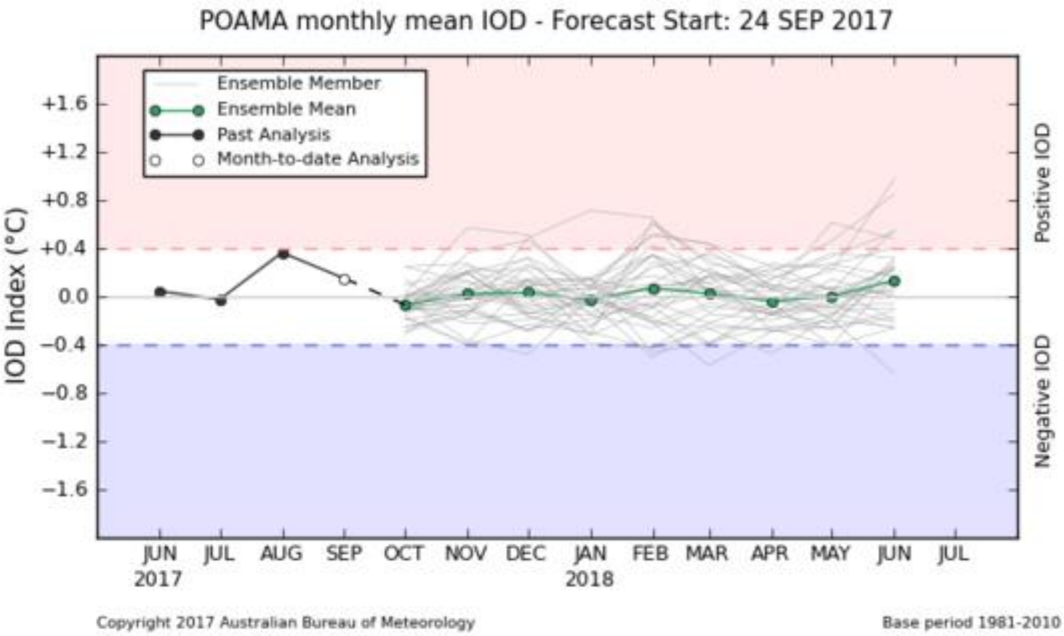

Fig. 6 - Indian Ocean Dipole forecast analysis (Australian Bureau of Meteorology, Aug 2017)

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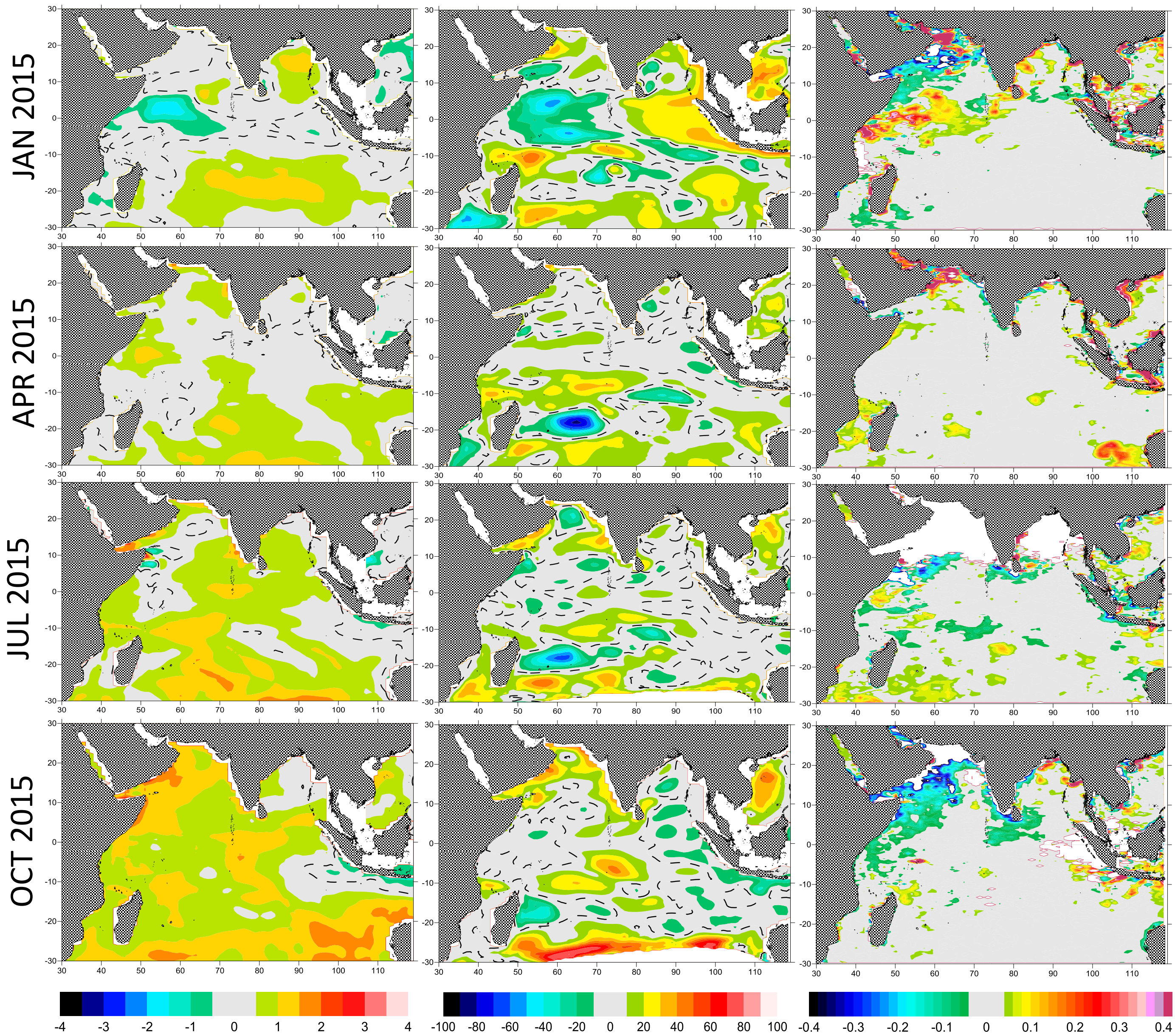


Fig. 7a – Geographic distribution of anomalies for sea surface temperature (°C, left), 20°C isothermal depth (m, middle) and sea surface chlorophyll (mg.m^{-3}, right) in 2015. Grey shading indicates minor anomalies about the mean. Thus, the more significant anomalies (colour shading) are displayed.

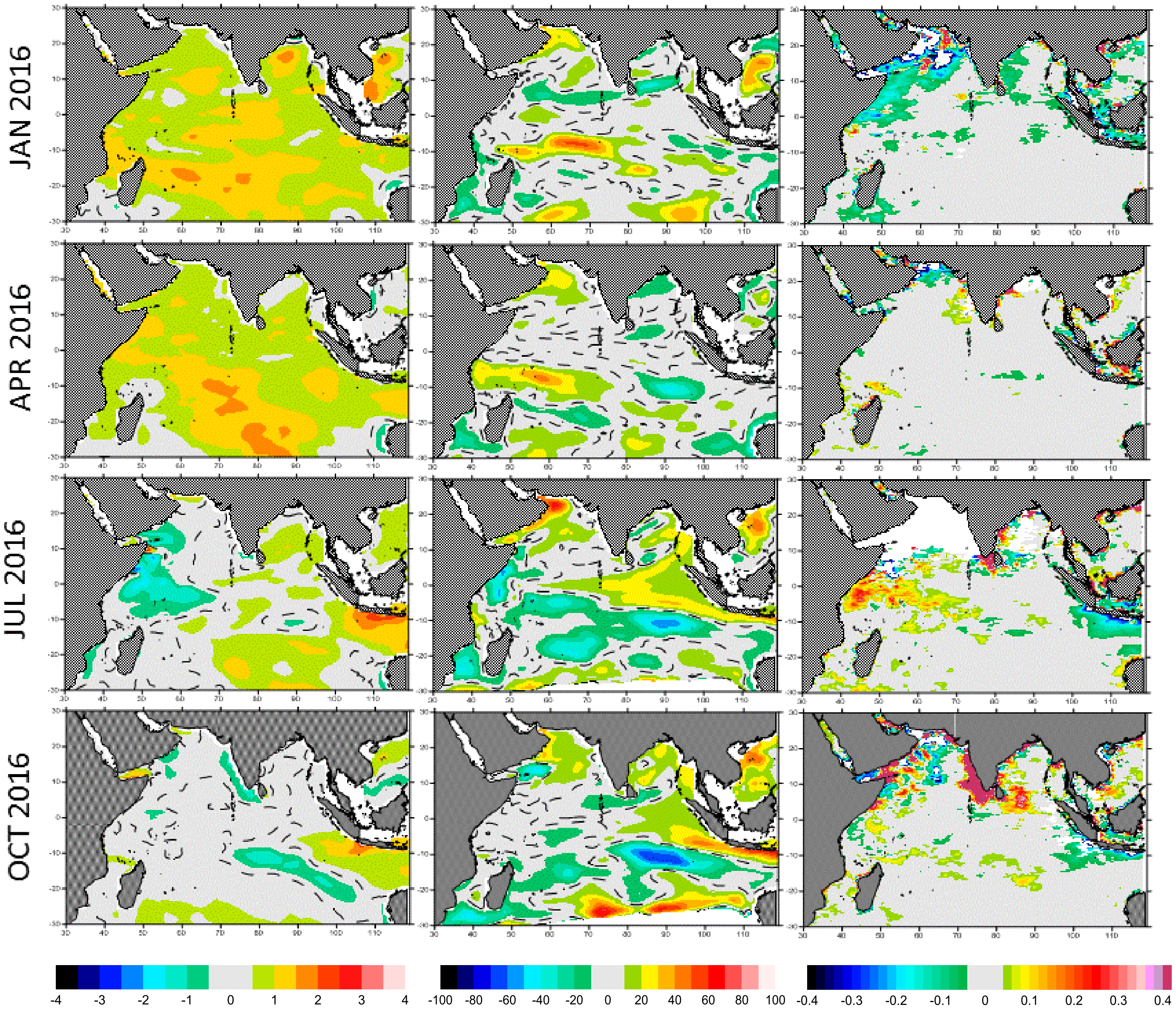


Fig. 7b – Geographic distribution of anomalies for sea surface temperature (°C, left), 20°C isothermal depth (m, middle) and sea surface chlorophyll ($mg.m^{-3}$, right) in 2016. Grey shading indicates minor anomalies about the mean. Thus, the more significant anomalies (colour shading) are displayed.

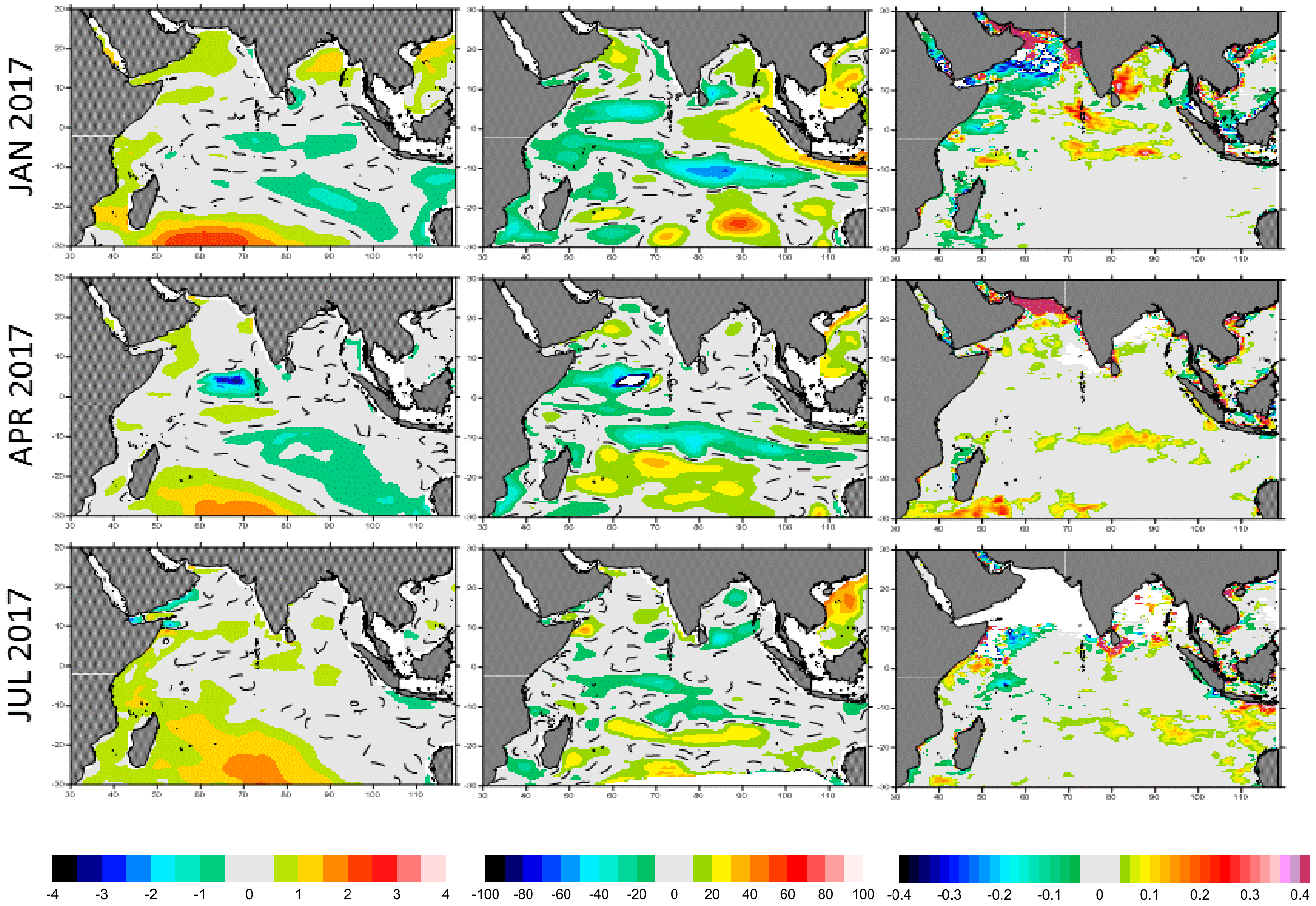


Fig. 7c – Geographic distribution of anomalies for sea surface temperature (°C, left), 20°C isothermal depth (m, middle) and sea surface chlorophyll (mg.m^{-3}, right) in 2017. Grey shading indicates minor anomalies about the mean. Thus, the more significant anomalies (colour shading) are displayed.

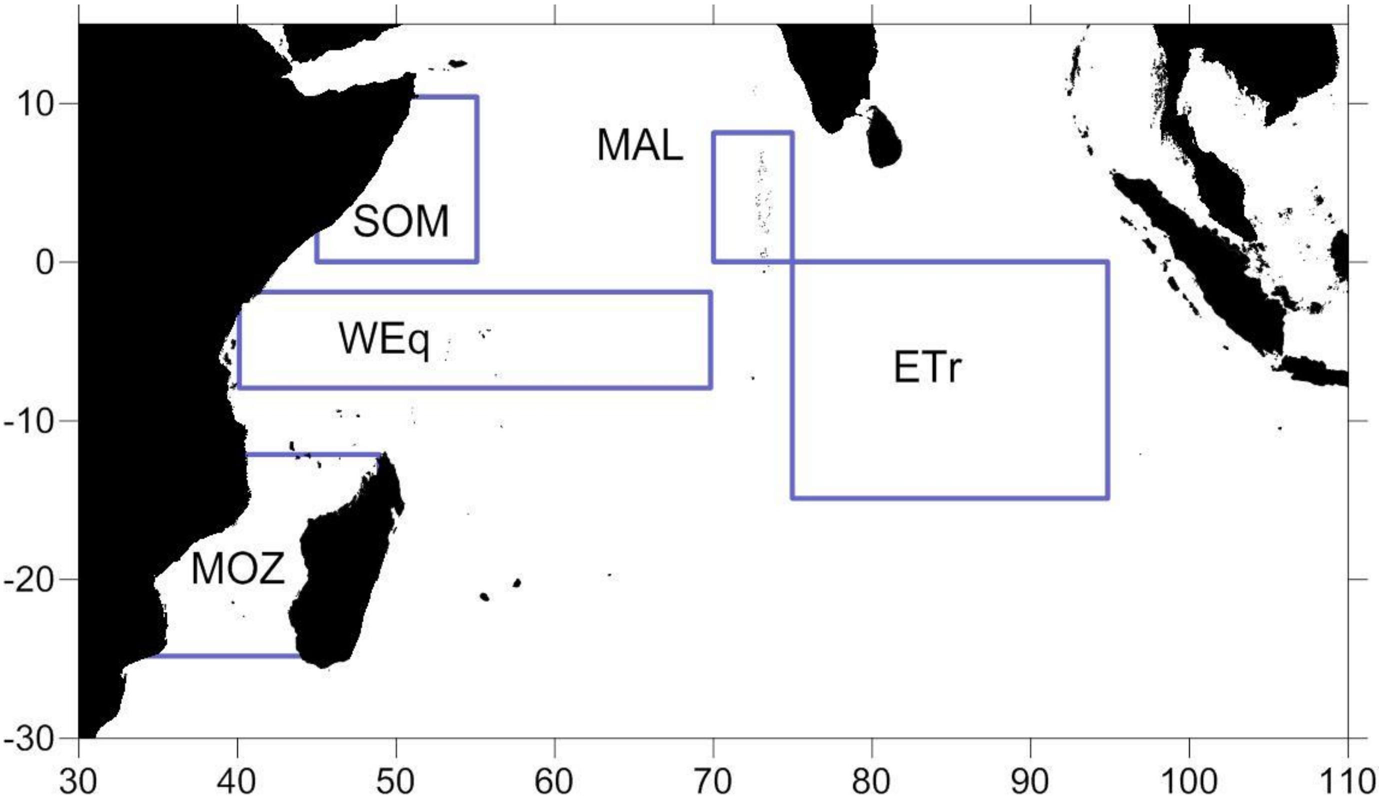


Fig. 8 - Area stratification used for the regional analysis.

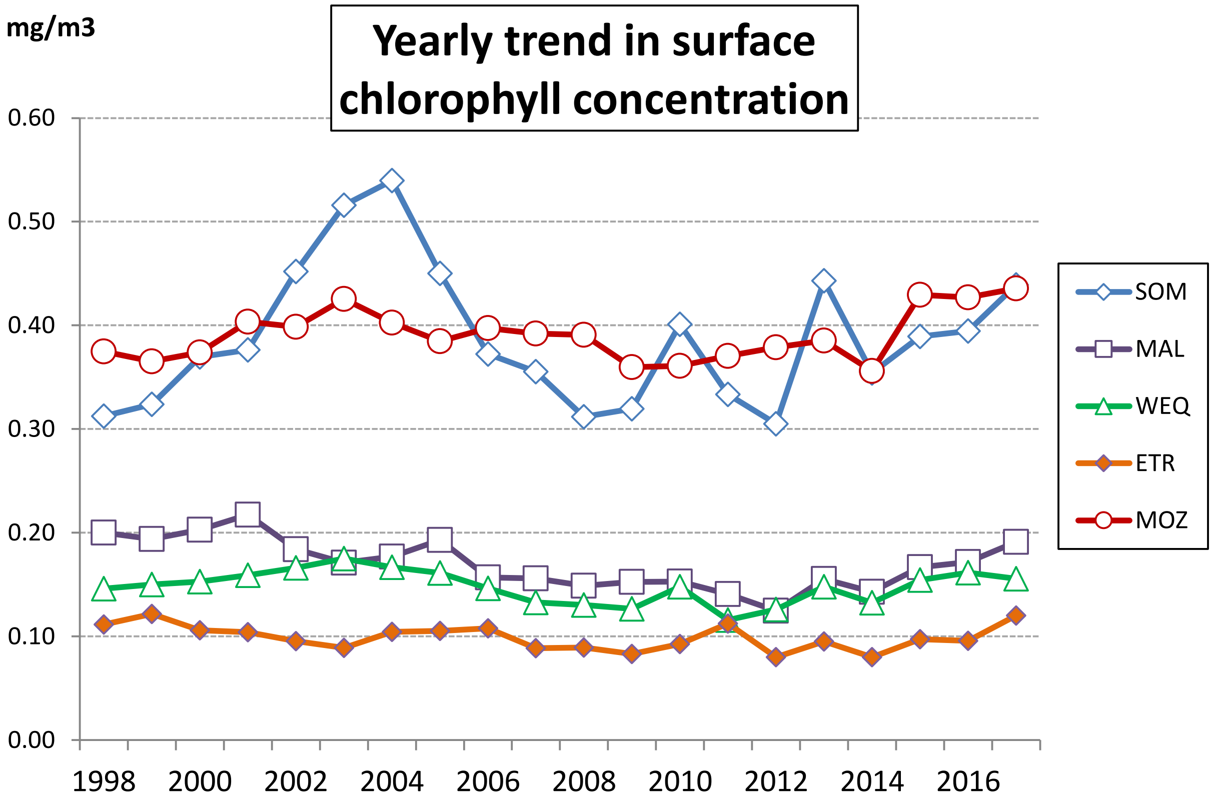


Fig.9 – Yearly trend of sea surface chlorophyll concentration measured by satellite, 1998-2017 (Seawifs 1998-2002 / Modis since 2003). Note that 2016 is incomplete (ends in August).

SOMALI BASIN

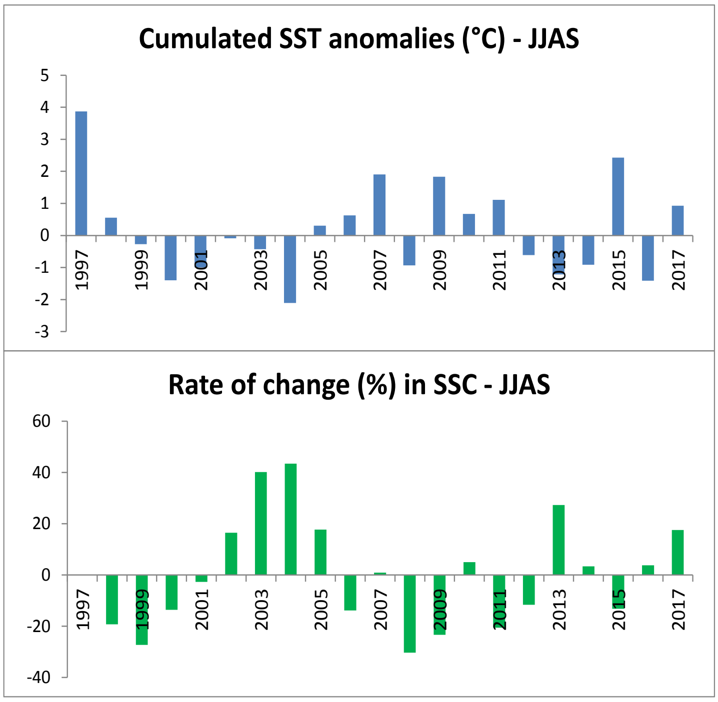


Fig. 10 – SST and surface chlorophyll (SSC) trends during the south-west monsoon, average June to September, in the Somalian basin. SST anomalies are cumulated over the season. Chlorophyll is expressed as rate of change about the 1998-2017 mean, June to September.

MOZAMBIQUE CHANNEL

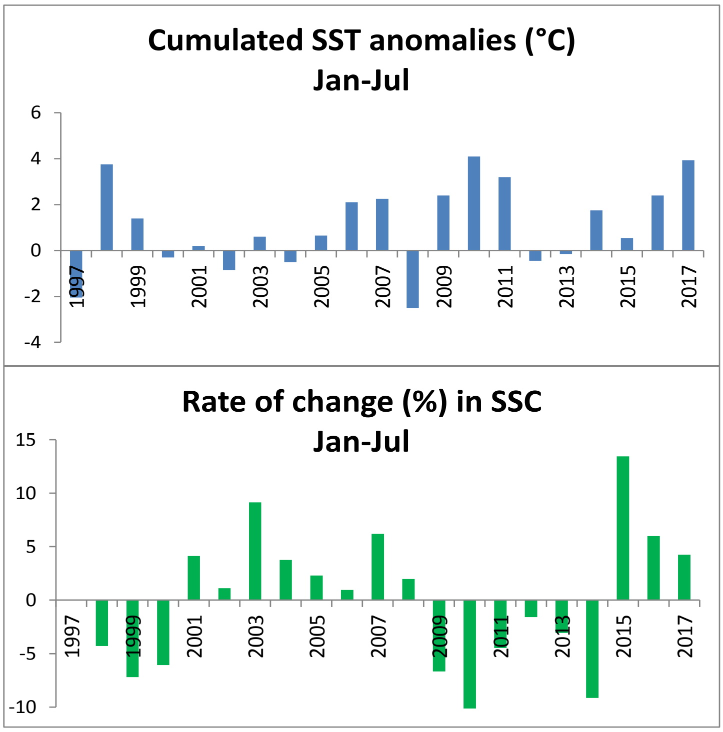
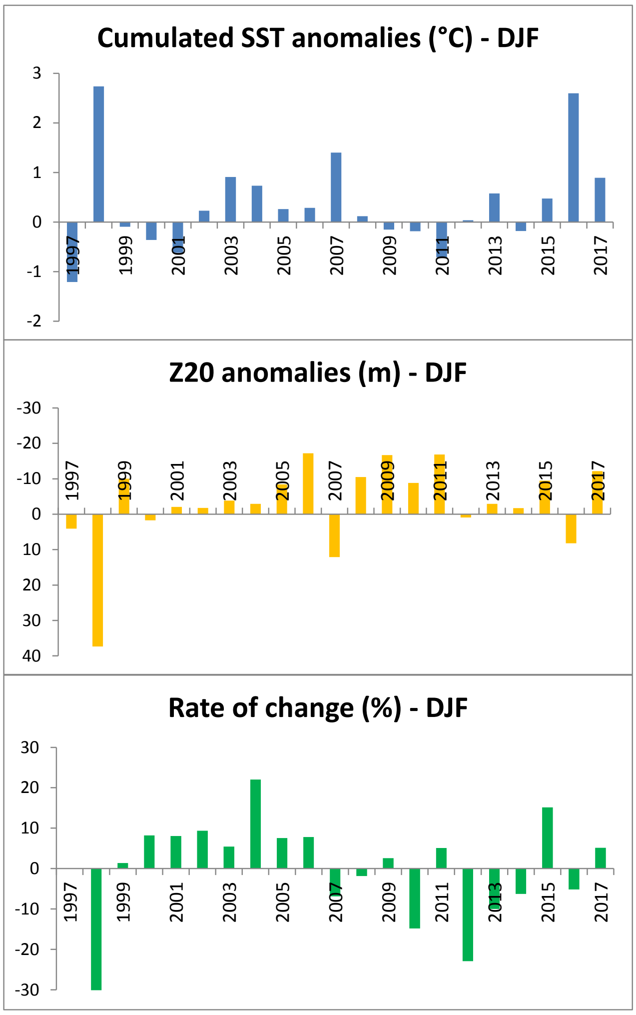


Fig. 11 – SST and surface chlorophyll (SSC) trends in the Mozambique Channel. Statistics are calculated for the period January to July. SST anomalies are cumulated over the period and chlorophyll is expressed as rate of change about the 1998-2017 mean for the study period.



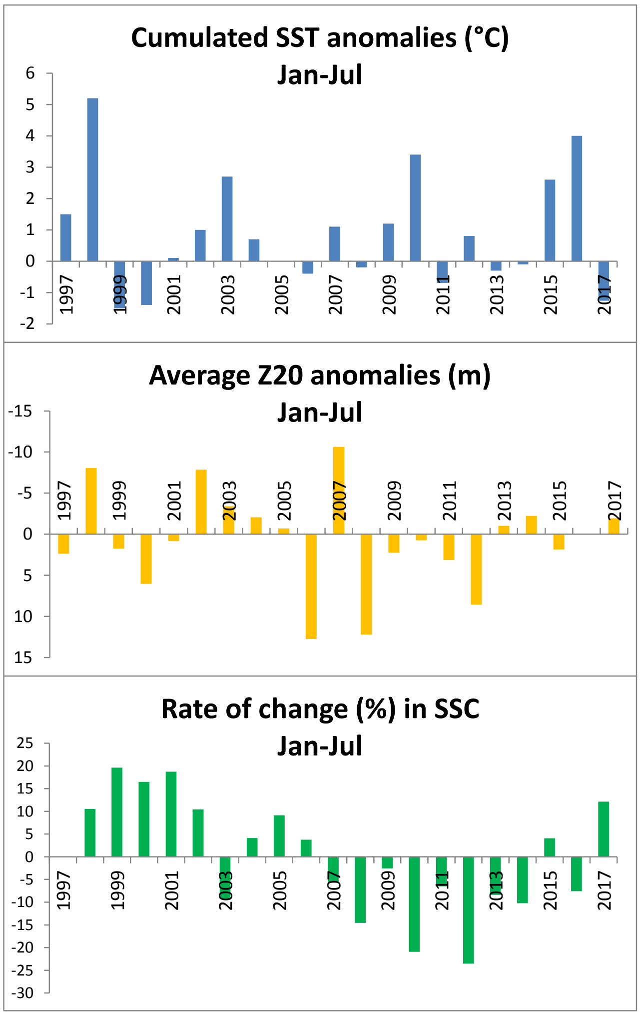


Fig. 12 – SST, 20°C isothermal depth and surface chlorophyll trends in the West Equatorial area, during the core of the north-east monsoon (December to February). SST anomalies are cumulated over the season, Z20 anomalies are the mean over the season and chlorophyll is expressed as rate of change about the 1998-2017 average for the season. Negative (positive) Z20 anomalies denote shoaling (deepening) of the thermocline.

Fig. 13 – SST, 20°C isothermal depth and surface chlorophyll (SSC) trends in the Maldives. Statistics are calculated for the period January to July. SST anomalies are cumulated over the period, Z20 anomalies are the average over the period and chlorophyll is expressed as rate of change about the 1998-2017 for the study period. Negative (positive) Z20 anomalies denote shoaling (deepening) of the thermocline.

WEST EQUATORIAL AREA

MALDIVES

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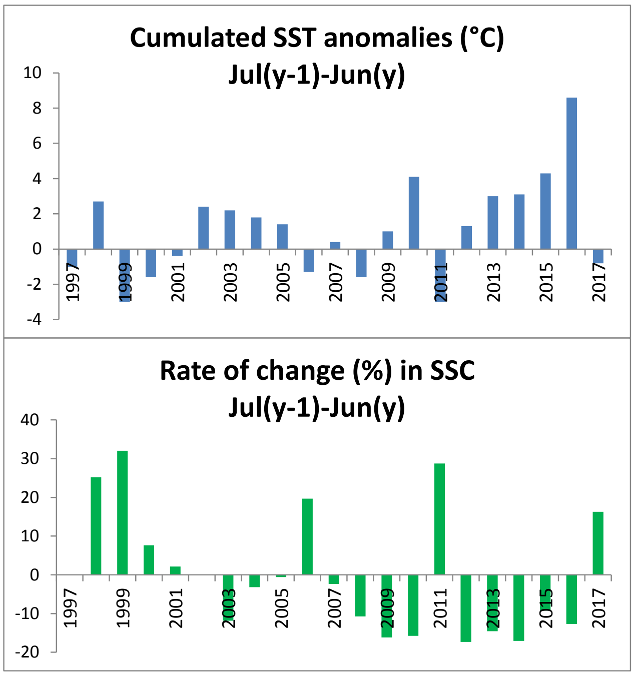

EAST TROPICAL AREA

Fig. 14 – SST and chlorophyll (SSC) trends in the Eastern Tropical Indian Ocean, 12-month average from July (of the preceding year) to June (of the current year). SST anomalies are cumulated over the 12-month period and SSC is expressed as rate of change about the 1998-2017 for the same period.