Proceedings of the First Science Symposium – September, 2002
Faculty of Science, University of Ruhuna, Matara, Sri Lanka
1: 15-21

Surface Temperature Variability of Ocean Waters Around Sri Lanka

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Abstract
NOOA-derived surface temperature data of waters around Sri Lanka within area of latitudes between 4.5N-11N and longitudes between 78E-84.5E have been analyzed for the period between 1996-1998. Raw data of 1 km resolution have been processed to produce daily maps and monthly and seasonal composites of sea surface temperature (SST). The seasons for the Indian Ocean region are defined approximately as follows: Northeast Monsoon (December-February), First Inter Monsoon (March-April), Southwest Monsoon (May-September) and Second Inter Monsoon (October-November). The variability in time and space has been studied by selecting seven smaller rectangular sub areas of varying sizes in each of the six directions; West, Southwest, South, Southeast, East and Northeast, in the ocean surrounding the country. Small patches of missing data due to cloud cover within sub areas were replaced by nearest neighbour averages using a 3x3 median filter, where necessary. Regions with heavy cloud cover were excluded from the analysis.

Highest sea surface temperatures up to 30.5 ^{0}C can be observed in April of 1997 in many of the above sub oceanic regions around the country. The year 1997 appears to be the warmest of all three years used in this study. Sub areas in the Northeastern region records lowest temperatures during the Northeast Monsoon season as generally expected. A sharp increase of mean temperature of up to 2 ^{0}C can be observed when moving from the Northeast Monsoon to First-Inter Monsoon period in the areas in Northeast region. The western waters show lower temperatures around 27 ^{0}C during the Southwest Monsoon period. A repeated seasonal cycle of changing temperatures can be observed in all regions with few exceptions in some study areas.

Introduction
Sea surface temperature (SST) is an important oceanographic parameter, which is being used extensively by ocean scientists as an important tool in understanding many phenomena occur due to ocean-atmosphere interaction processes. Accurate measurements of spatial and temporal variations of sea surface temperature are currently possible with advances in satellite technology. Monitoring of SST from earth-orbiting infrared (IR) radiometers has been used extensively in marine science. Continuous satellite measurements of sea surface temperature offer scientists easy access to large-scale instantaneous data. Trends in global warming and sea level rise are few of many problems that can be addressed with the knowledge of variability in surface temperatures of world oceans. Variations of SST can be indications of processes such as heat transfer by ocean currents, absorption of solar energy and heat loss by evaporation.

Sea surface temperature is determined by variation of thermal radiation received by the sensor in near infrared (0.7 – 1.1 μm) and in thermal infrared regions (between 10 and 12 μm) of the electromagnetic spectrum. At these wavelengths and for small zenith angles, the thermal emission by the sea surface is substantially greater than the reflected solar radiation in the daytime. On the IR waveband of interest, the atmosphere interacts with incident radiation by absorption, and by re-emitting radiation at a different wavelength, rather than by molecular or aerosol scattering as in visible wavelengths. Thus, an application of good atmospheric correction is required in the derivation of SST. The multiple AVHRR (Advanced Very High Resolution Radiometer) thermal infrared channels provide best estimations of atmospheric attenuation by atmospheric water vapour, which is necessary for the high precision required in computing SST.

Methodology

Raw data (for the period from January 1996 – December 1998) of 1km resolution from daytime measurements from the radiometer aboard NOAA 12, 14 and 15 satellites were obtained from NOAA's (National Oceanic and Atmospheric Administration) Satellite Active Archive (SAA) for processing. The days with heavy clouds were left unprocessed, as no SST information was available after atmospheric corrections. The processed sea surface temperature data (using Terascan software) were mapped for the area of latitudes between 4.5N – 11N and longitudes between 78E – 84.5E. The land areas are masked out for clarity. The number of relatively cloud free daily files available after processing for each separate year from 1996 to 1998 is 72, 68 and 42, respectively. Composite averages for each month and for each season are also made. Figure 1(a) and 1(b) are two examples of such monthly composites, namely, for the months of February and April in 1997. The seasons are defined (Tomczaik and. Godfrey 1994) approximately as follows: Northeast Monsoon (NE) (December – February), First Inter Monsoon (FI) (March – April), Southwest Monsoon (SW) (May – September) and Second Inter Monsoon (SI) (October – November).

The spatial and temporal variability of SST has been studied by dividing the mapped region of waters around Sri Lanka into seven smaller sub areas as shown in Figure 2. The top left and bottom right coordinates of the regions are chosen as follows: (a) Area **1** in the west (78E, 8N and 79.5E, 6.5N) (b) Area **2** in the southwest (78E, 6N and 79.5E, 4.5N) (c) Area **3** in the south (80E, 5.5N and 81.5E, 4.5N) (d) Area **4** in southeast (82.5E, 6.5N and 84.5E, 4.5N) (e) Area **5** in the east (83E, 8.5N and 84.5E, 7N) (f) Area **6** in the northeast (80.5E, 11N and 82.5E, 10N) and (g) Area **7** in the northeast (82E, 11N and 83.5E, 9.5N). Temperatures of all pixels in a given sub area have been used in calculating the mean temperature for each box. Small patches of cloud cover are replaced by nearest neighbour pixel averages using a 3x3 filter, when necessary. Missing data for a given month in a given year was replaced by the mean value of the corresponding months in other two years, when necessary. Then monthly and seasonal averages for each box area are computed for time series analysis.

Results and Discussion

Figure 1(a) shows the distribution of mean temperature for the month of February in 1997. The eastern waters exhibit temperatures of around 26.5 ^{0}C while western waters vary around 27 ^{0}C. Southwestern waters have temperatures around 28 ^{0}C. The distribution of mean temperature for the month of April in 1997 is shown in Figure 1(b). Northern waters in Palk Strait seems to exhibit very high temperatures of around 32 ^{0}C while eastern waters show average temperatures between 30 - 31.5 ^{0}C.

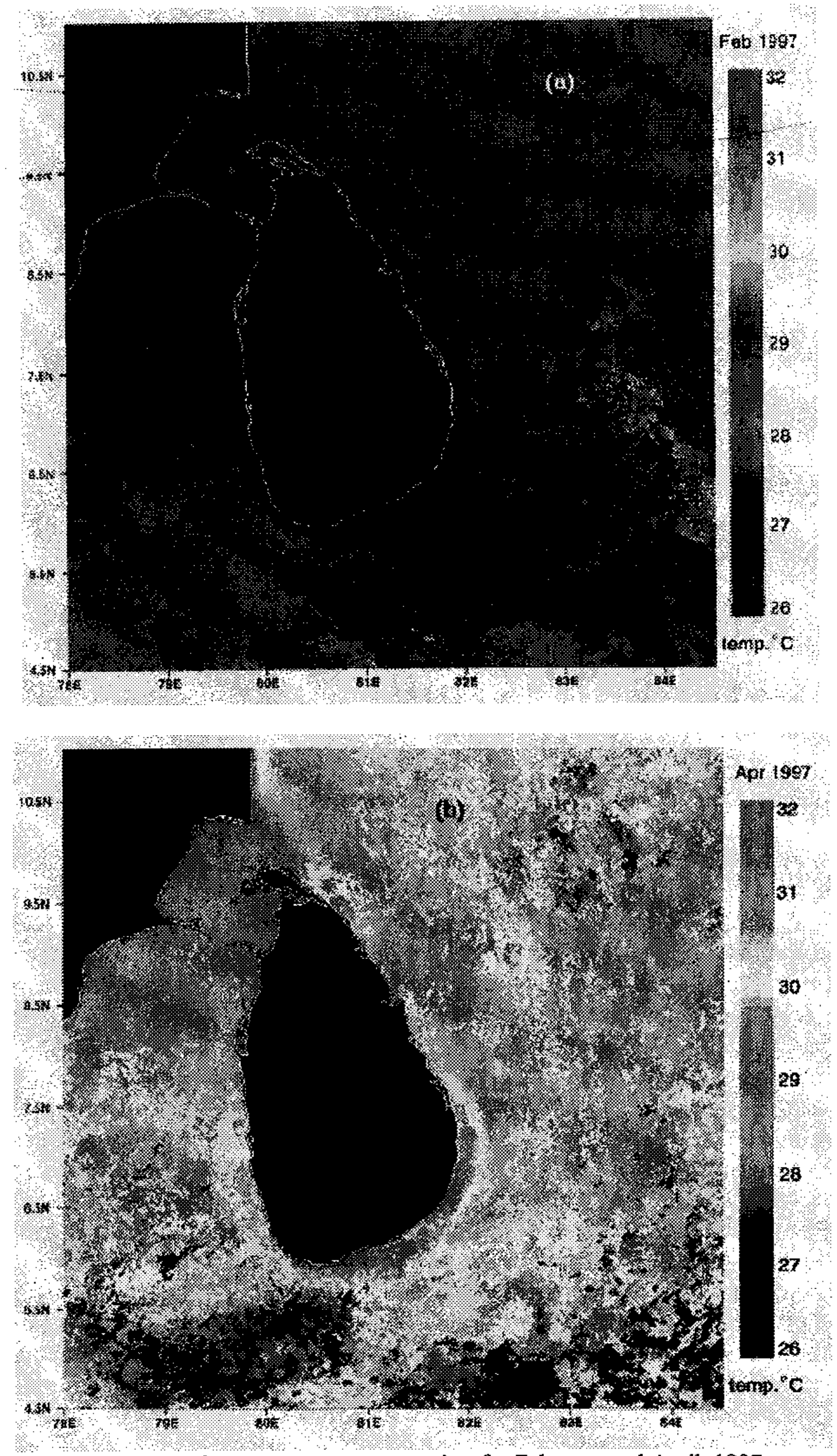

Figure 1. Sea surface temperature composites for February and April, 1997.

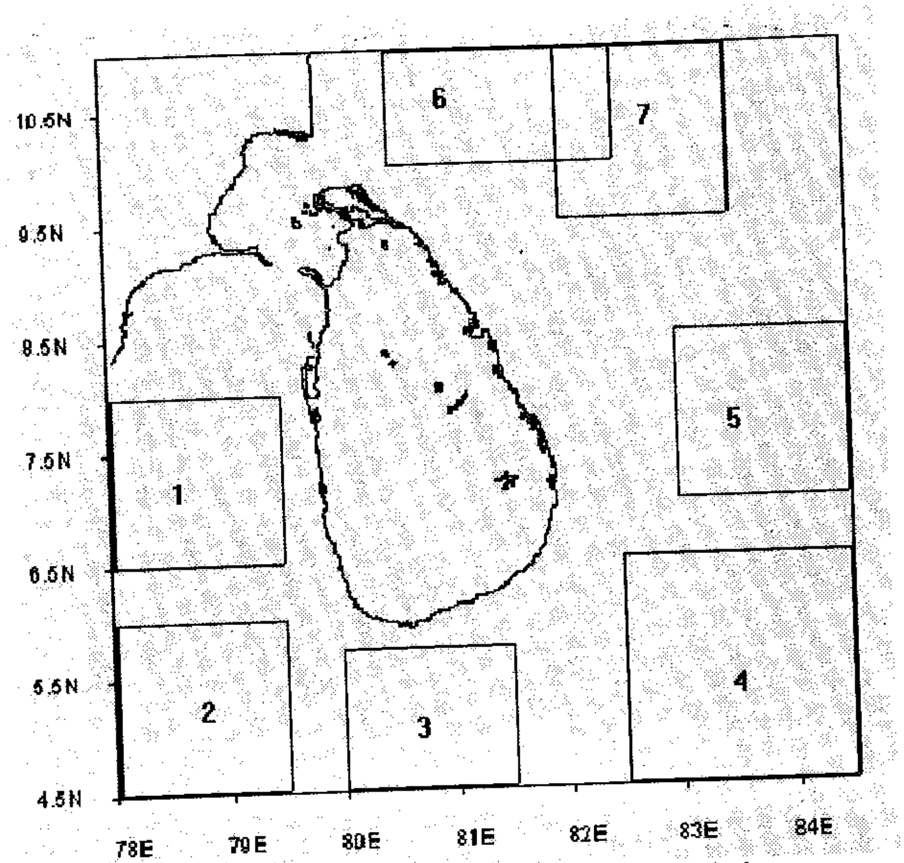

Figure 2. Map of study area showing sub areas used for the analysis.

Southern waters are somewhat cooler and temperatures vary between 28.5 – 30 °C. Monthly time series plots of mean temperatures for the marked seven sub areas are shown in Figure 3 whereas seasonal temperature variations for the areas 1 - 6 (area 7 is excluded from this figure for clarity) are given in Figure 4. In the discussion given here, both Figures 3 and 4 are referred to alternatively. The plot (a) in Figure 3 for Area 1 exhibits lower temperatures in the range 26 °C and 27 °C during months of July – September whereas higher temperature of about 30 °C is seen in the month of April. This pattern of temperature variation is expected as the southwest monsoon peaks during months of July – September and Area 1 is located right in the SW monsoon regime. Lower temperatures during SW monsoon and higher temperatures during First Inter Monsoon are visible in Figure 4 for Area 1 as well. The cooler waters from Arabian Sea carried by Southwest Monsoon Current (Schott and McCreary, 2001; Vinayanachandran, *et al.*, 198) (SMC) towards west of Sri Lanka from Arabian Sea may contribute to lower temperatures exhibited in the area in addition to the contributing factors such as heavy rains and winds produced during the SW monsoon period. Figure 3 (b) shows similar variation of temperature as the Areas 2 and 3 located in the Southwestern and Southern oceans of Sri Lanka and face similar Monsoonal effects. Area 2 exhibits comparatively lower temperatures during the months of July - September.

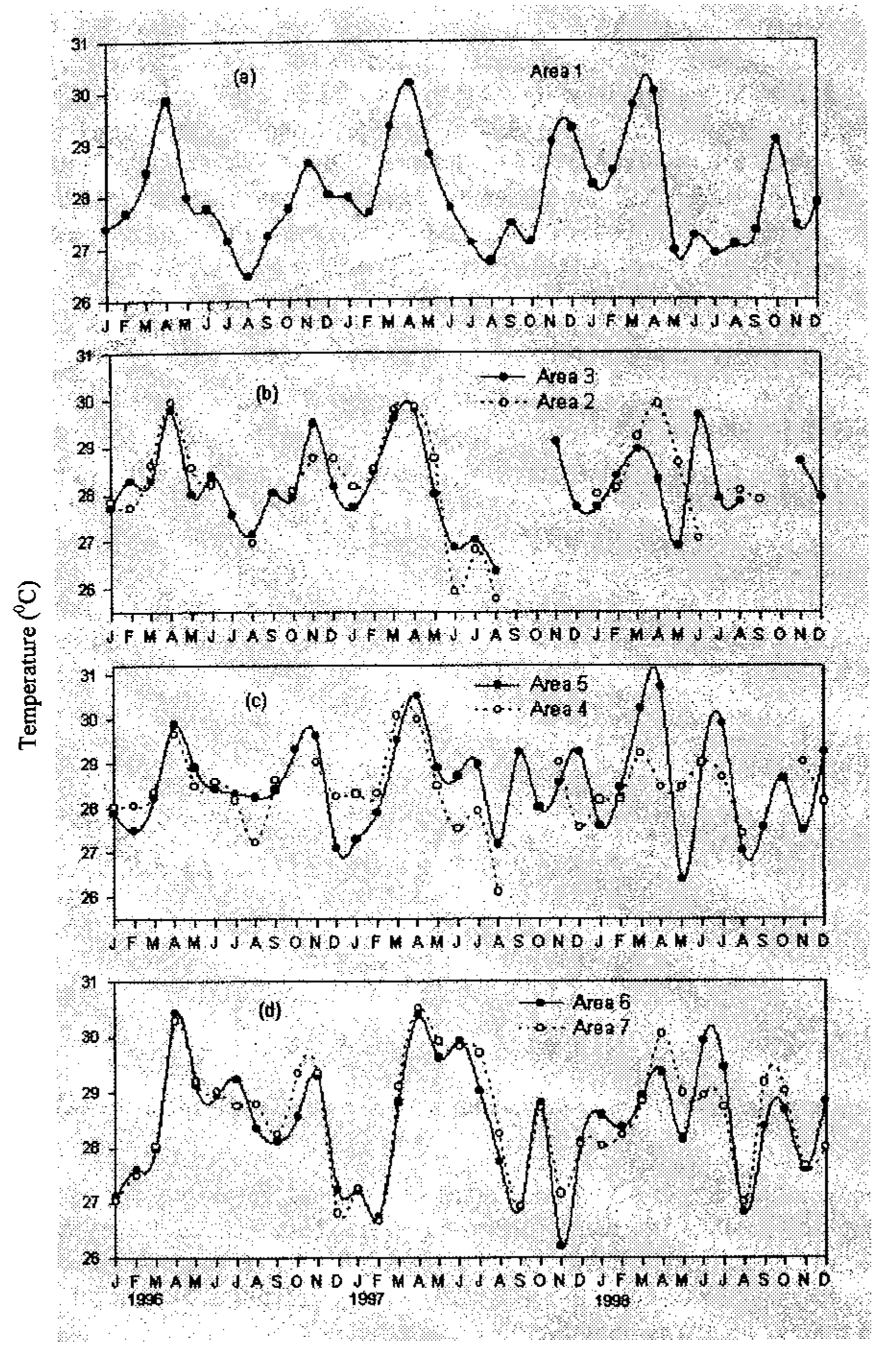

Figure 3. Time series of temperature plots according to defined sub areas in the Figure 2.

Though the peaks and troughs are not as sharp as that for Area 1, seasonal feature of temperature is apparent for these areas as seen from Figures 3 and 4. Plot (c) in Figure 3 represents mean temperatures for Areas 4 and 5, located in the Southeastern and Eastern directions of Sri Lanka. Both Southwest and Northeast Monsoons affect waters in Area 4. Thus, temperatures are lower during SW monsoon period in the years 1996 (Yapa,

1999) and 1997 as compared to Area 5. Figure 3 (d) shows monthly mean temperature variation for Areas 6 and 7. The two areas are located in the Southeast direction of Sri Lanka. Thus, the waters in these areas are more affected by the Northeast Monsoon. During the NE Monsoon period the East Indian Coastal Current (Schott and McCreary, 2001, Vinayanachandran *et al.* 198) (EICC) starting from Bay of Bengal flow south towards Sri Lanka brining cooler waters towards East. This produces lowest mean temperatures during the months of December-March. Mean temperatures show higher values during the months from May – August as SW Monsoon doesn't have much effect on these waters.

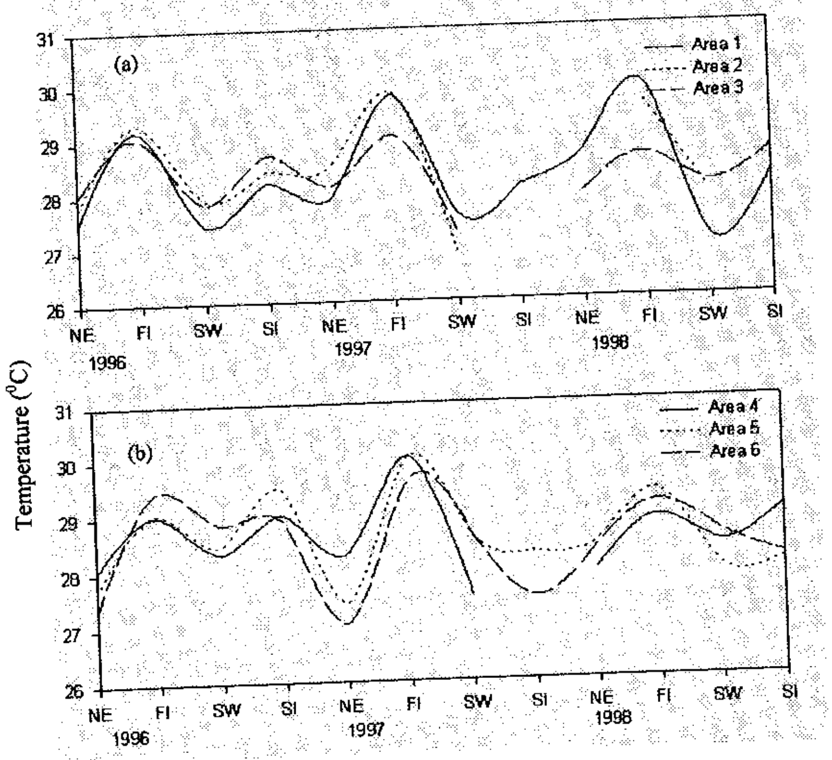

Figure 4. Seasonal temperature variations for areas 1 - 3 in (a) and in 4-6 (b).

Monthly temperature variations in most areas show slight deviations during year 1998 from the patterns exhibited in the two previous years. This may be due to the fact that number of daily data files available for year 1998 (48 files) is less compared to that of years 1996 (72 daily files) and 1997 (68 daily files). A detail statistical analysis for a longer time span is underway including these three years.

Conclusion

The spatial and temporal variability of sea surface temperature of waters around Sri Lanka for the three-year period from 1996 – 1998 is studied here. 1997 is found to be the warmest of the three years considered. Year 1997 was an El Nino year and the warmer temperatures experienced in the Pacific Ocean may have affected waters in the Indian Ocean region as well. The Indian Ocean is connected to the Pacific Ocean through Indonesian Archipelago, which results in direct forcing of the Indian Ocean through

processes in the equatorial Pacific Ocean. However, more Studies are needed to make a strong conclusion in this regard. The temperature of waters in the region of study seems to vary between 26 °C and 32 °C during a year depending on location and time. The average temperatures for each sub area show cyclic variations throughout a year as expected. April is found to have highest recorded surface temperatures for all sub areas considered. The waters in the west and southwest regions show lower temperatures during Southwest Monsoon period, favoring high productivity (Yapa, 2000) in the region. Effects from Northeast Monsoon on waters in the eastern part are apparent from the study, though the features are not as sharp. Further research is underway to study co-variability of physical and biological parameters of these waters.

Acknowledgements

Authors would like to thank the National Science Foundation (under Grant # RG/98/P/01) and National Research Council (under Grant # 99/03) for providing financial assistance in part for the research carried out here. Authors also thank NOAA's Satellite Active Archive for providing raw data and the Ocean Sciences Division, Bedford Institute of Oceanography, Canada for providing facilities for initial processing of some of the raw data. Preliminary results of this work was published in abstract form in Proceedings of the 58th Annual Sessions of the Sri Lanka Association for the Advancement of Science (pg. 240).

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