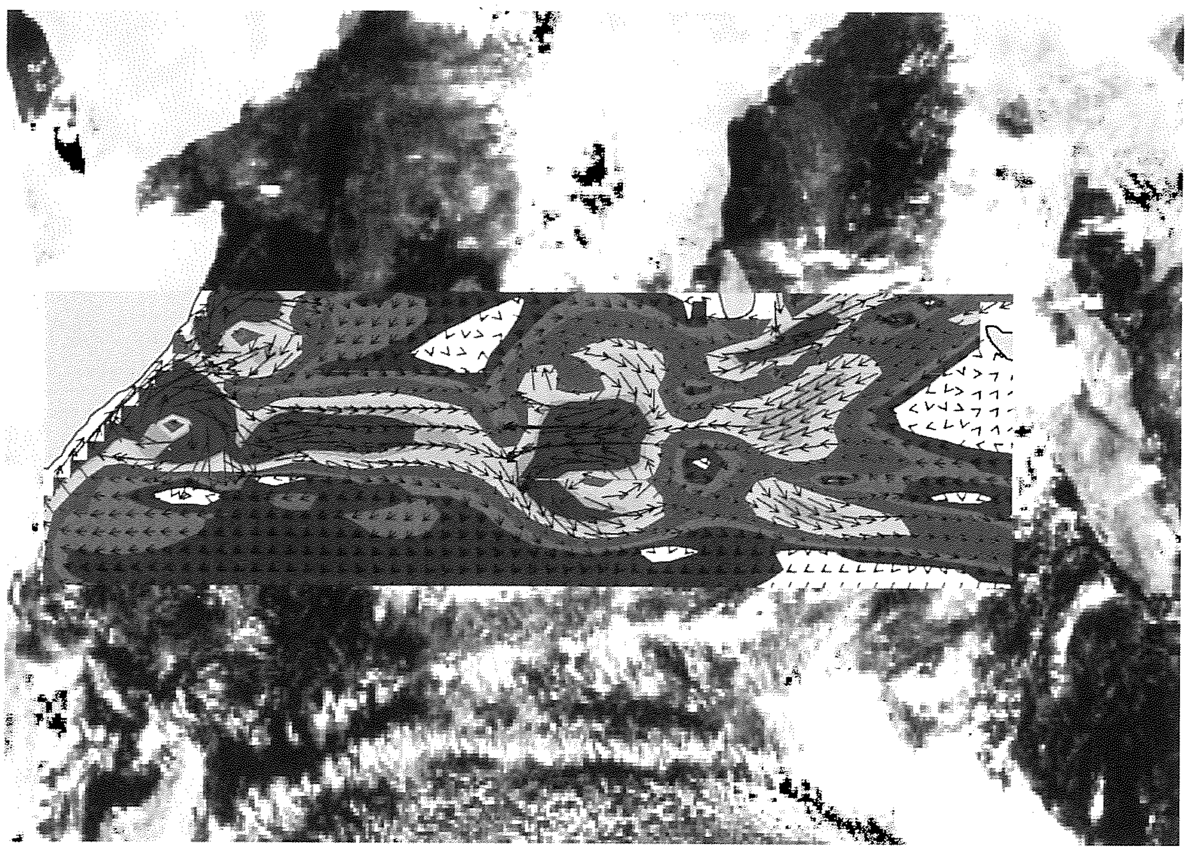
Westward moving Mesoscale Gyres in the Equatorial Indian Ocean during mid-monsoon season as identified from MSMR winds.



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IITM-SAC
(IRS-P4 MSMR Application)
Collaborative Project

Research Report

Westward moving Mesoscale Gyres in the Equatorial Indian Ocean during mid-monsoon season as identified from MSMR winds.

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Contents

Abstract

A new signal is detected from a 10-year (1992-2001) analysis of surface circulations simulated by the Reduced Gravity Ocean model using daily NCEP(1992-2000) and six hourly Oceansat –1 satellite (1999,2000,2001 July's) surface wind forcing. Twin westward advecting gyres, unusual and unexpected in the well-studied Indian Ocean, form by late May through July (60 days) every year between 5^0N and 5^0S. The results call for the inevitable need of using daily data in modeling studies as monthly data hide many temporal and spatial dynamics, which may finally contribute in the evolution of major ocean-atmospheric phenomena. Results obtained with 6 hourly Multichannel Scanning Microwave Radiometer (MSMR) wind data are more or less same as those obtained by using daily data. Hence, the study brings out the need of daily data to diagnose mesoscale circulations.

1.Introduction

Indian Ocean enacts a very active and independent role (Webster et al, 1999) in climate variability but is independent of forcing by external phenomena such as ENSO (Meehl, 1994,1997; Nicholls, 1997,1983). Ocean currents move large volumes of warm and cold water around the globe, so circulation has an important effect on the climate. The prominent global ocean currents are part of the world's five gyres, two in the Atlantic, and two in the Pacific and one in the south Indian Ocean. A gyre is actually an enormous rotating mound of water that can occupy an entire ocean basin, which stores momentum in its circulation and is linked to the changes in the climate. Ocean numerical models have become quite realistic (Semtner, 1995) in simulating the seasonal and interannual large-scale circulations. It is now being realized that very simple models, which can be run on relatively inexpensive computers, can provide results different from, but just as useful as those produced by high resolution simulations, Pillard (2002). The basin scale Reduced Gravity 1½ layer ocean model, here after referred as the IITM Reduced Gravity (IRG) model, has been proven to simulate realistic observed surface currents on both monthly and seasonal scales as seen by Behera and Salvekar (1996, 1998). Earlier studies by Luther et al. (1985), Woodberry (1989), Potemra et al. (1991) and by Jensen (1993) with monthly and seasonal winds fail to simulate the twin gyres. This is first time the impact of daily winds in model simulations is being studied using IRG model. Reddy et al. (2003,a) have shown that these model-simulated currents can be treated equivalent to observations in the data sparse regions. Indian ocean has been extensively studied using seasonal or the monthly forcing. However, what happens to the model simulations when the time scale is fractured to daily forcings has not been studied so extensively. As expected, the results encompass all the features that are simulated with Seasonal and Monthly forcing plus something more than that the Seasonal and the Monthly forcing had been missing since the past. Daily climatologically simulated upper layer currents reveal westward advecting anticyclonic Twin Mesoscale gyres on either side of the equator during midmonsoon months. Though the equatorial Indian Ocean has been very well studied by Wyrtki (1973), this feature was missing till now. The small-scale processes, whose influence on large-scale processes is just beginning to emerge would bring radical changes in ocean modeling (Quadfasel, 2002). Relation of such small-scale processes to the dynamics of the Indian Southwest monsoon and its subsequent impact on the global climate needs to be further investigated. In the following sections the model details, data and methodology, results and discussion and finally the conclusions are provided.

2. Model, Data and Methodology

The model used in this study has one active layer, overlying a deep motionless inactive layer, i.e., zero pressure gradient in the lower layer that effectively filters the fast barotropic mode. The model equations are based on vertically integrated shallow water equations over a layer, assuming no vertical shear in the horizontal fields.

The model equations in Cartesian co-ordinate are:

$$U_t + (UU/H)_x + (UV/H)_y - fV + (g'/2)(H^2)_x = A_H \nabla^2(U) + \tau_{xz} / \rho_1 \quad (1)$$

$$V_t + (UV/H)_x + (VV/H)_y + fU + (g'/2)(H^2)_y = A_H \nabla^2(V) + \tau_{yz} / \rho_1 \quad (2)$$

$$H_t + U_x + V_y = w_e \quad (3)$$

Where U and V are zonal and meridional components of transports obtained from vertically integrating upper layer velocity field, f is the Coriolis parameter. H is the upper layer thickness, g' = g $(\rho_2 - \rho_1)/\rho_2$ (where ρ1 and ρ2 are the densities of the layers) is the reduced gravity ($0.03 ms^{-2}$). A_H is the horizontal eddy viscosity coefficient ($2250\ m^2 s^{-1}$) and 'τ_{xz}' 'τ_{yz}' are the components of the wind stress applied as a body force. w_e is a source term representing entrainment from deep motionless layer to the upper active layer. This entrainment is introduced only to prevent the interface from surfacing that happens when a small initial upper layer thickness is considered. This term is positive for upper layer in case layer thickness becomes less than preset minimum depth H_{min}.The term is determined through a simple function as suggested in McCreary and Kundu (1988). Initial upper layer thickness i.e. H is taken as 100m. Other details of the model formulations are same as in Behera and Salvekar (1998). The effect of this entrainment on the upper layer density, momentum and kinetic energy balance has been neglected. It is assumed that the entrained water engulfed into the upper layer, has zero velocity and is instantaneously adjusted to the density ρ_1. The model equations are solved numerically on a finite difference mesh staggered in space (Arakawa C-grid) and integrated with respect to time (Δt =30 min) using leapfrog finite-difference scheme. An Euler scheme is applied at every 49th step to eliminate the spurious growth that usually arises due to time splitting in leapfrog scheme. The horizontal domain used in the model extends from 35°E to 115°E and from 24°S to 23°N. Boundary conditions are no slip (U = V = 0) at land boundaries and modified radiation boundary condition by Camerlango and O'Brien (1980) at the open boundaries. The reduced gravity model has realistically simulated most of the circulation features in the Indian Ocean as referred by Luther et al (1985), Simmons et al (1988). The model is integrated by using daily climatology, obtained for the period Jan 1992 – Dec 2000 of NCEP winds, interpolated to the model grid resolution (0.5° X 0.5°) and the spin up time to reach the steady state is 10 years. The detection and measurement of small changes in the Earth's climate requires extremely precise observations on a daily scale (Frank, 2000) from the satellites. To see the impact of still more reduced time scales than the daily data we acquired 6 hourly surface winds over the north Indian ocean during the mid monsoon month of July for the years 1999,2000 and 2001. These winds are analyzed Multichannel Scanning Microwave Radiometer (MSMR) winds and were produced in the following manner. The scalar winds derived by MSMR onboard Oceansat -1 were ingested into the objective analysis scheme of the National Center for Medium Range Weather Forecast to produce 6 hourly gridded wind vectors. These winds having an initial grid resolution of 1.48°×1.48° are interpolated to reduced gravity model resolution of 0.5°×0.5°. The steady state solution for June using daily reanalysis NCEP climatology is considered as the initial condition and the model is further integrated for the month of July using interannual MSMR winds for 1999,2000 and 2001. Similar numerical experiments are also carried out using MSMR daily data by averaging every 6 hourly winds (i.e.00, 06,12,18Hrs). It is interesting to see that the results do not differ by considering either 6 hourly winds or daily winds. Therefore, the results are discussed for daily data.

3.Results and Discussion

The twin gyres that arise due to strong ocean – atmosphere interactions having anticyclonic circulation patterns initiate by May end at (5°S-5°N along 85°E-90°E), propagate westwards with a speed of 25 Km/day approximately and by last week of June they are well organized (1100Km length, 550Km width). Thereafter around 5^{th} of July they are very well established between 5°S-5°N along 70°E-80°E as seen in the Fig1 (a) of NCEP climatology (1992 – 2000). Once the twin gyres are well established, the speed increases to 50 Km/day as seen in the Figs 1 (b to d) for 10^{th}, 15^{th} and 20^{th} of July respectively (moving 2500Km west). After crossing 60°E the gyres simultaneously begin to weaken and by 25^{th} of July Fig1 (e) the twins merge back into the basic ocean flow before reaching the Somali coast, almost leaving no trail of a gyre structure. These features are also present when interannual winds are used to force the model. The results for 3 years (1999,2000 and 2001) when MSMR winds are used are shown in Figs 2,3,4(a, b, c) for 5^{th},15^{th}, 25^{th} of July respectively. Fig 2a(the number inside the figure indicates the speed of the current) for the 5^{th} of July clearly shows the presence of the Twin Gyres along 80°E. These gyres are moved from east equatorial Indian Ocean as reflected Rossby waves. At the center of the gyres downwelling is seen which is consistent with the anticyclonic nature of the gyres. Computations of ULTD (upper Layer Thickness Deviation) show positive anomaly at the center of the gyre and the same is verified with the TOPEX Sea Surface Heights (SSH) at the corresponding Grid point. As the gyres move west (Fig 2b &2c) the positive SSH also moves westwards.

Similar results are seen for the year 2000 & 2001 in Figs. 3&4. There is very little interannual variability in the actual location of the twin gyres for a particular date in all the three years but the main features of these Gyres are more or less same in all the three years.

In an earlier study (Reddy et al, 2003, b) it has been shown that the model results regarding the occurrence of the gyre structure are supported by the observational results of surface currents that were obtained with the ADCP (Acoustic Doppler Current Profiler) data from the WOCE (World Ocean Circulation Experiment). Analysis of the available ADCP data during the period July – August 1995 over the EQ-5S and 64E-70E supports the model observations as seen in Fig.5.

We have also carried out numerical experiments with inter annual daily NCEP winds for the period 1992-2000. It is interesting to note that irrespective of the El Nino (1997), La Nina (1998) and the Dipole (1994) years the twin gyres are seen in the mid-monsoon (July) season (Fig.6. a, b) if the model is forced by daily winds. When monthly winds are used as the forcing the twin gyres are absent (Fig 7a to d).

The results presented above suggest that the Indian Ocean exhibits a strong ocean – atmosphere interaction that is self-maintaining and could produce significant perturbations in the annual cycle. The periodic occurrences of the gyres suggest that the ocean is not wholly chaotic and unpredictable (Jacobs, 1994) as generally believed. The results strongly emphasize the role of daily data in decoding the details of ocean surface circulation, which is an important component in understanding the air-sea interactions. Based on these results we wish to recommend a closer look into the use of daily data to understand the complex phenomena. In view of the results of daily data, a data spectrum is formulated in order to project the performance of the IRG with Seasonal, Monthly, Daily and Hourly forcings. The model has the ability to simulate circulations of different scales depending on the scale of input. Hence when Seasonal and Monthly forcings are used as input [e.g. Luther et al (1985), Woodberry (1989) and by Jensen (1993)] large scale features like the equatorial jet and the Somali gyres are well simulated, but to simulate mesoscale features like the Twin Gyres the daily data plays a very crucial role. Since the results of the numerical experiments with daily data as well with six hourly data are unaltered we can say that the use of 6 hourly data did not add any extra features. This concept is graphically represented in the Fig. 8.

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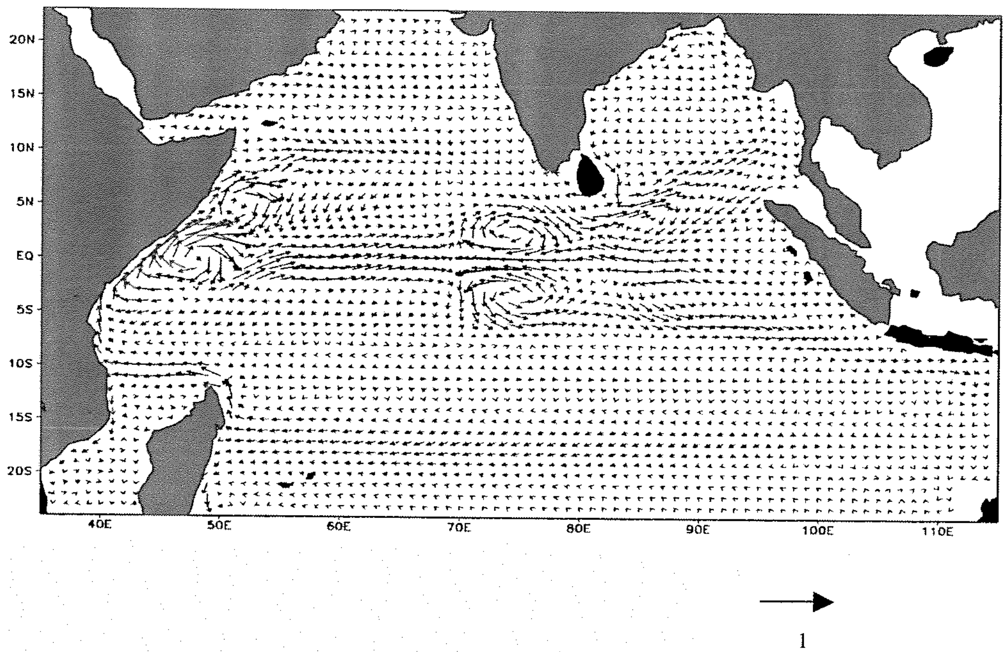
Figure 1

a 05 July climatology - NCEP



b 10 July climatology - NCEP

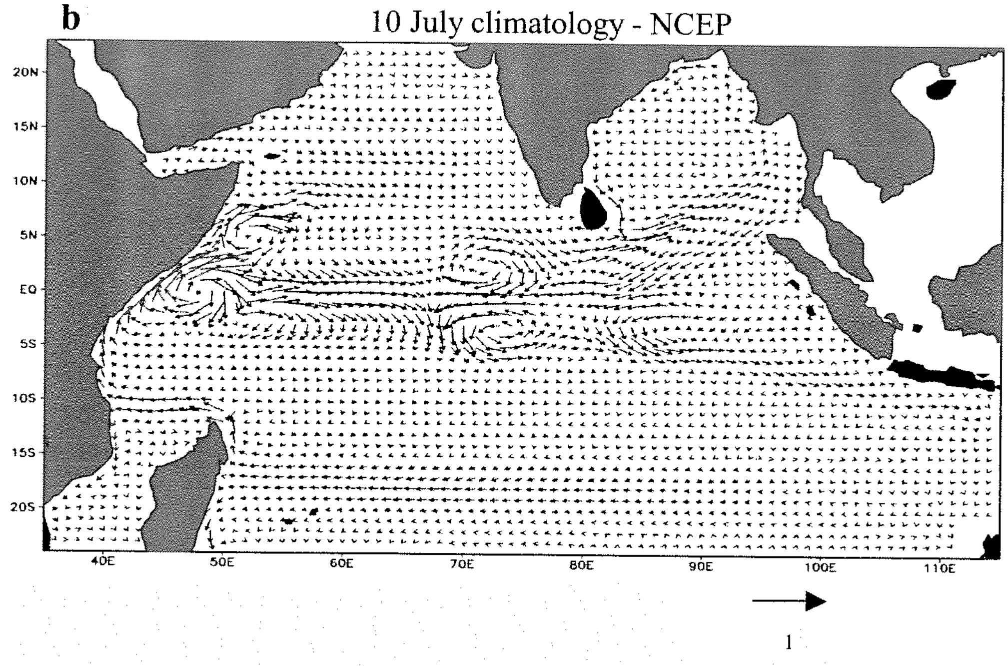
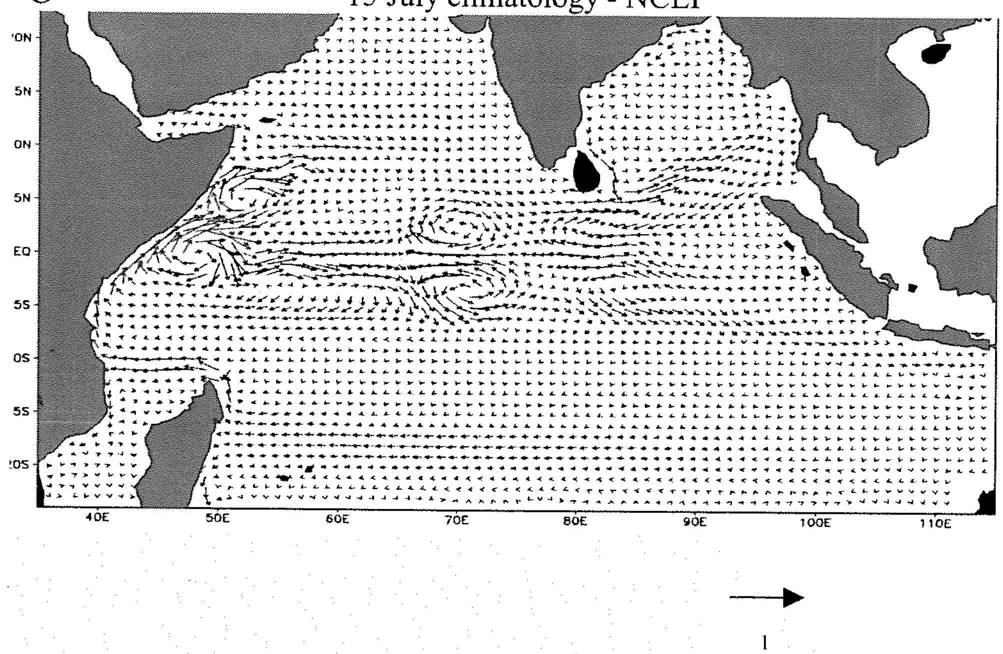


Figure 1

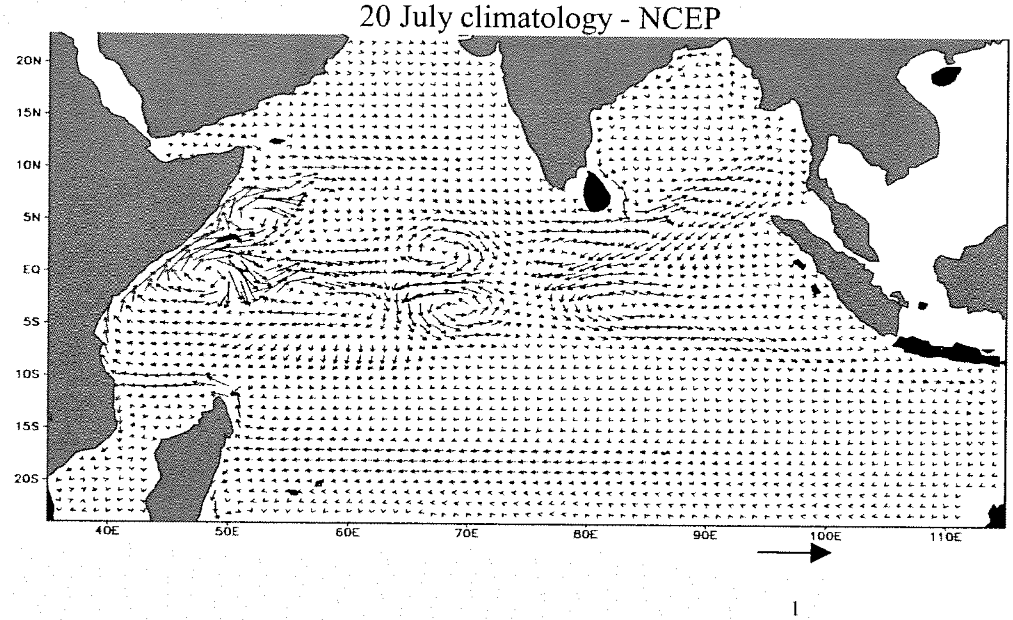
C

15 July climatology - NCEP



d

20 July climatology - NCEP



e

25 July climatology - NCEP

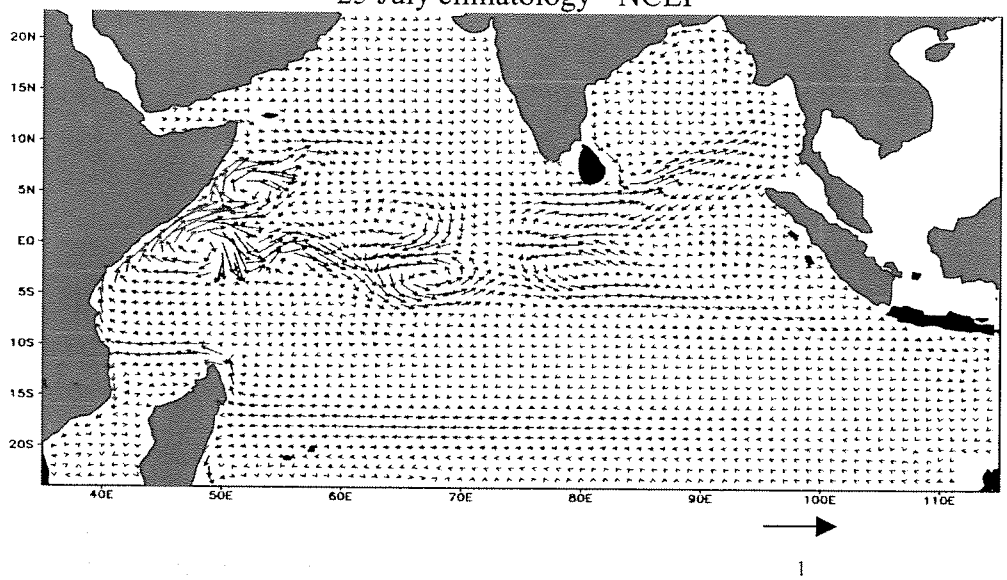
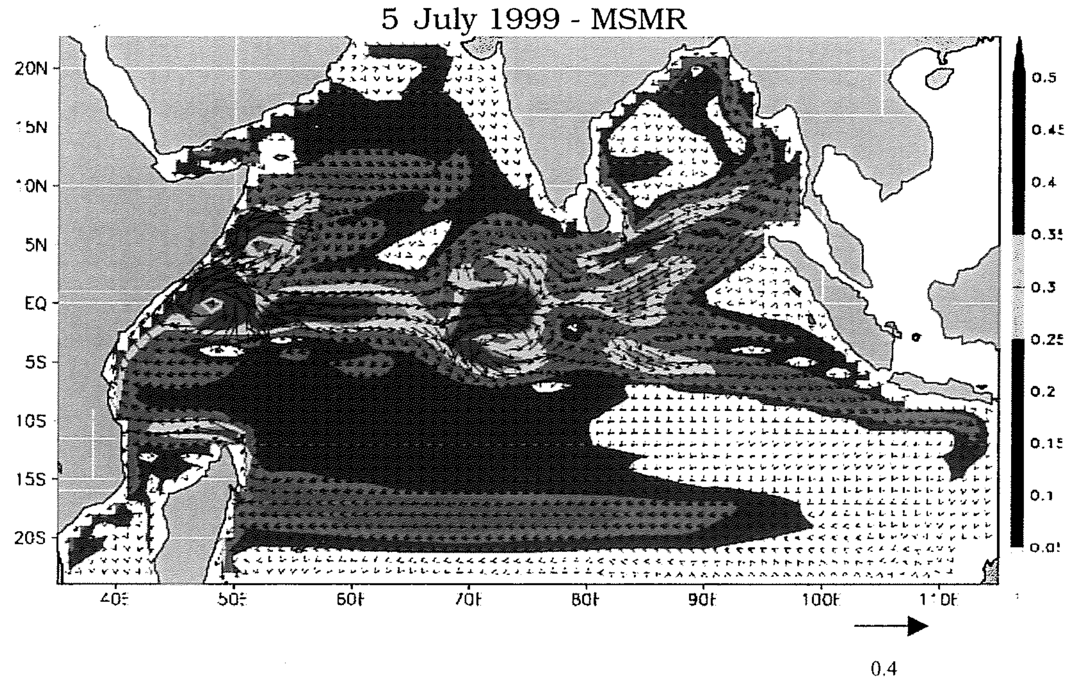


Figure 1 Currents for the July climatology (1992– 2000) showing the twin gyres for the dates 05th, 10th, 15th ,20th and 25th in a, b, c, d and e respectively.

Figure 2

a



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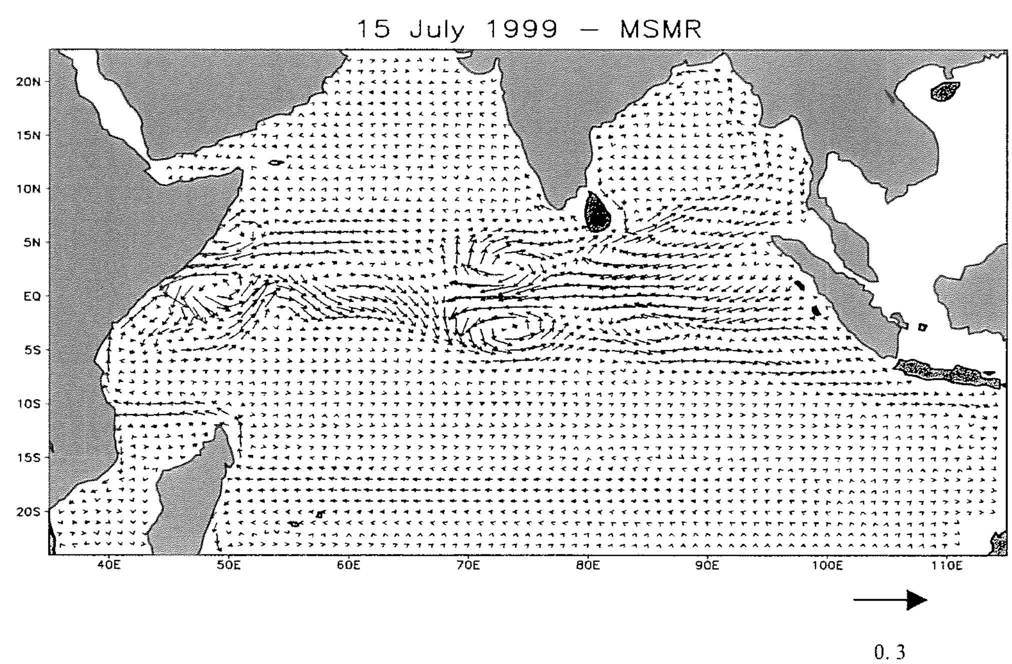

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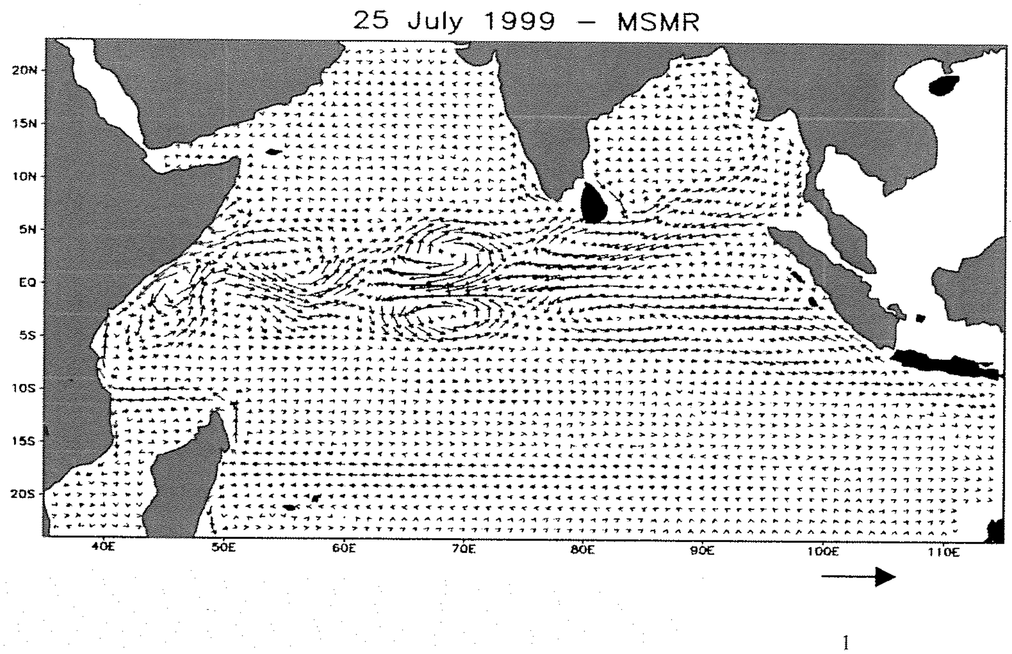
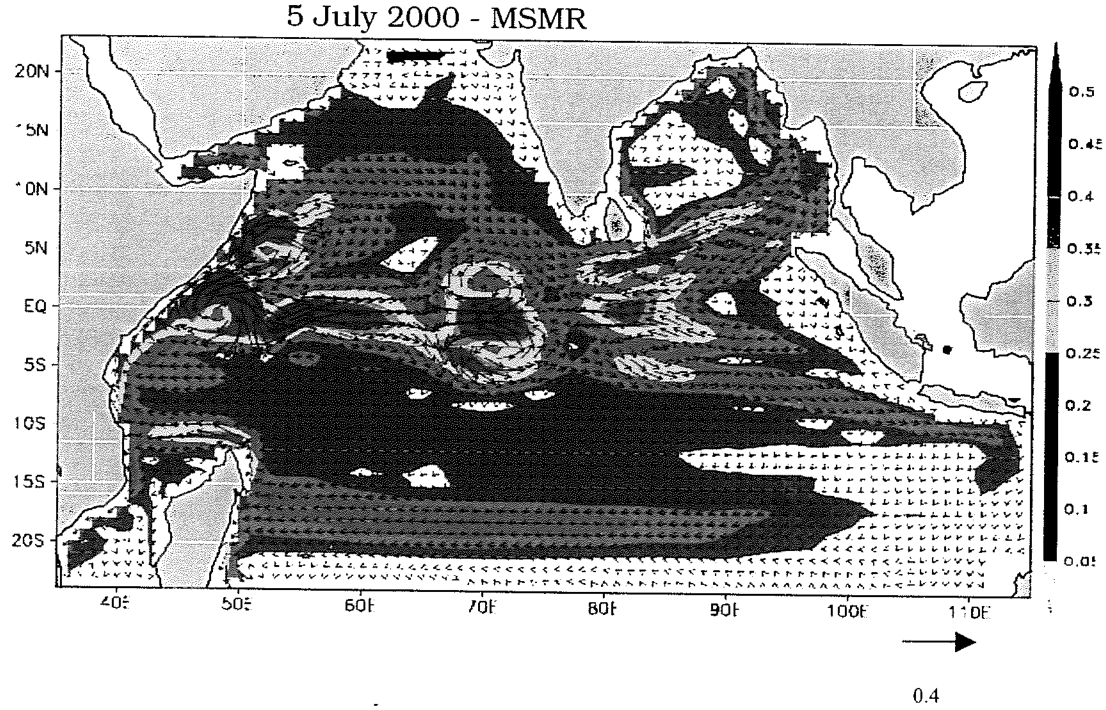


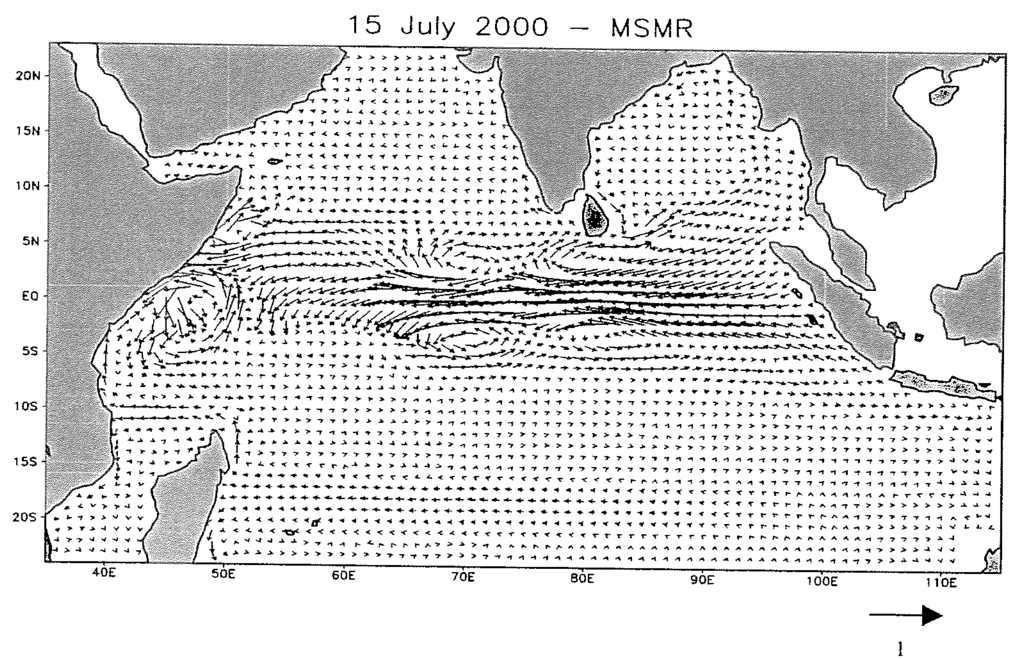
Figure 2 Currents for the month of July 1999 showing the twin gyres for the dates 05th, 15th and 25th in a, b and c respectively.

Figure 3

a


5 July 2000 - MSMR
20N
15N
10N
5N
EQ
5S
10S
15S
20S
40E
50E
60E
70E
80E
90E
100E
110E
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0.4

b


15 July 2000 – MSMR
20N
15N
10N
5N
EQ
5S
10S
15S
20S
40E
50E
60E
70E
80E
90E
100E
110E
1

c

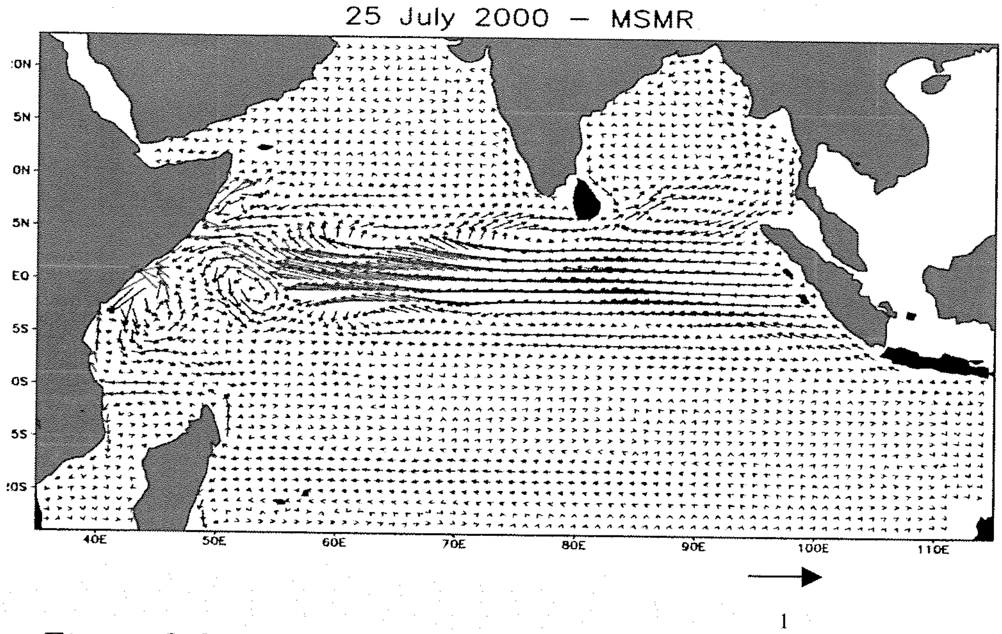
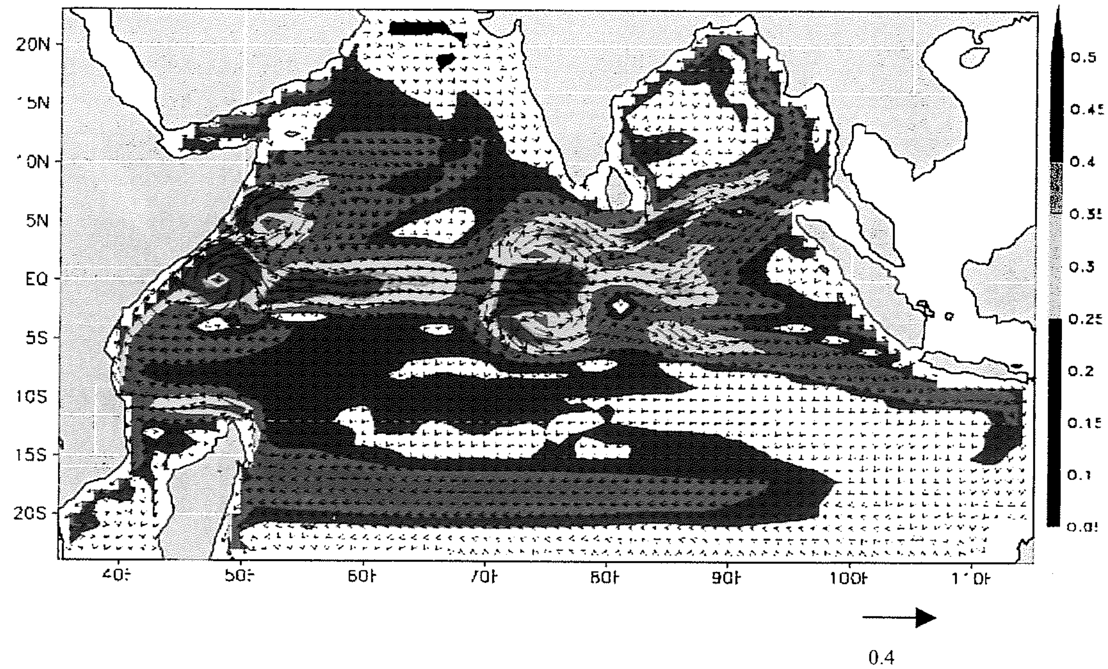


Figure 3 Currents for the month of July 2000 showing the twin gyres for the dates 05th, 15thand 25th in a, b and c respectively

Figure 4

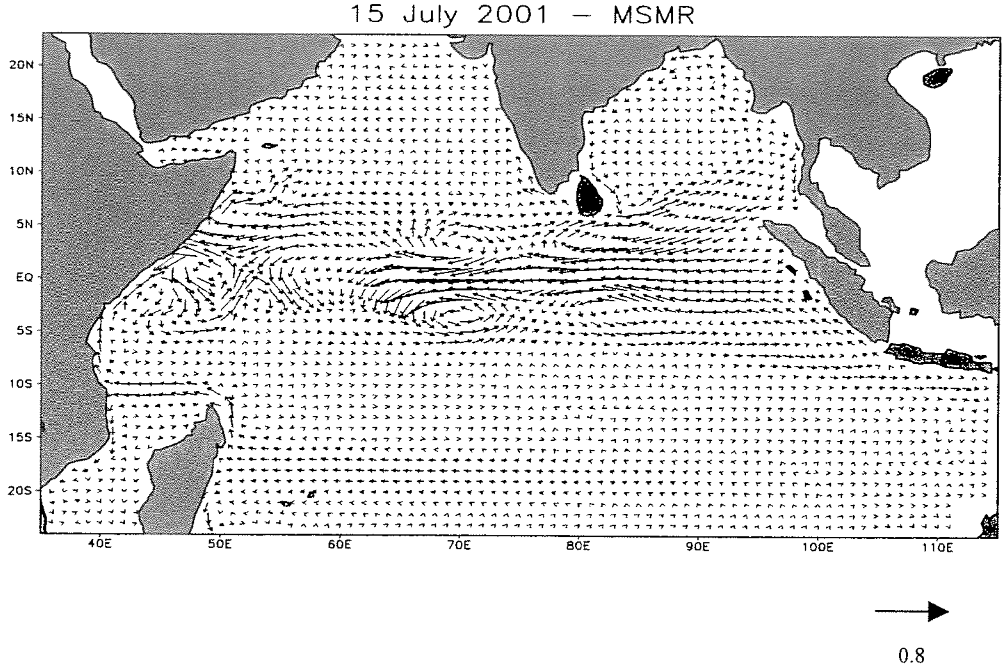
a

5 July 2001 - MSMR



b

15 July 2001 – MSMR



c

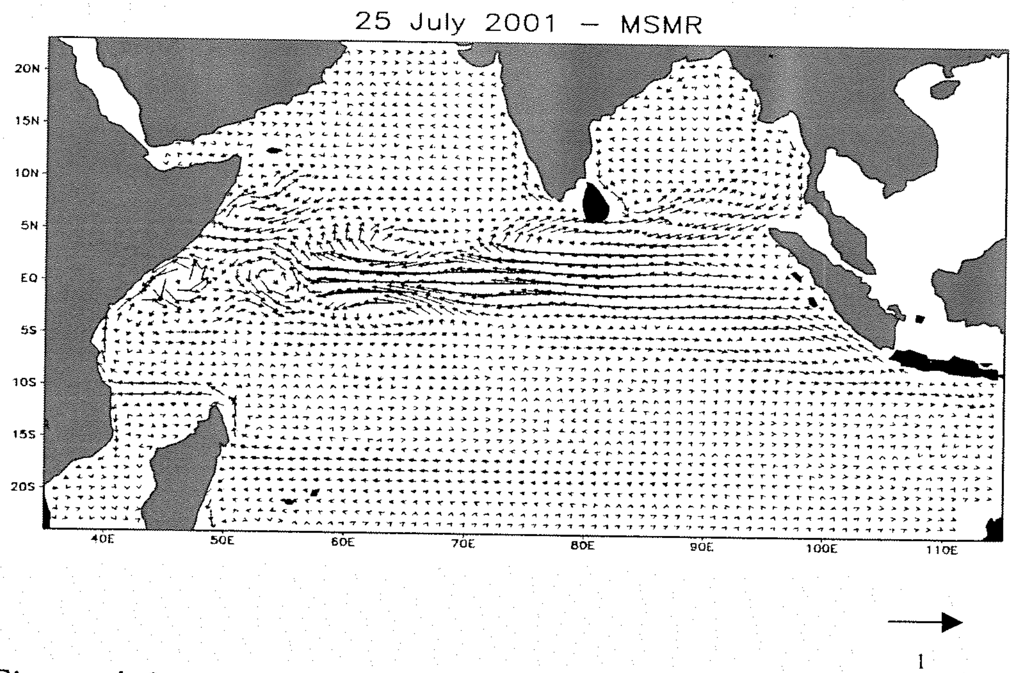
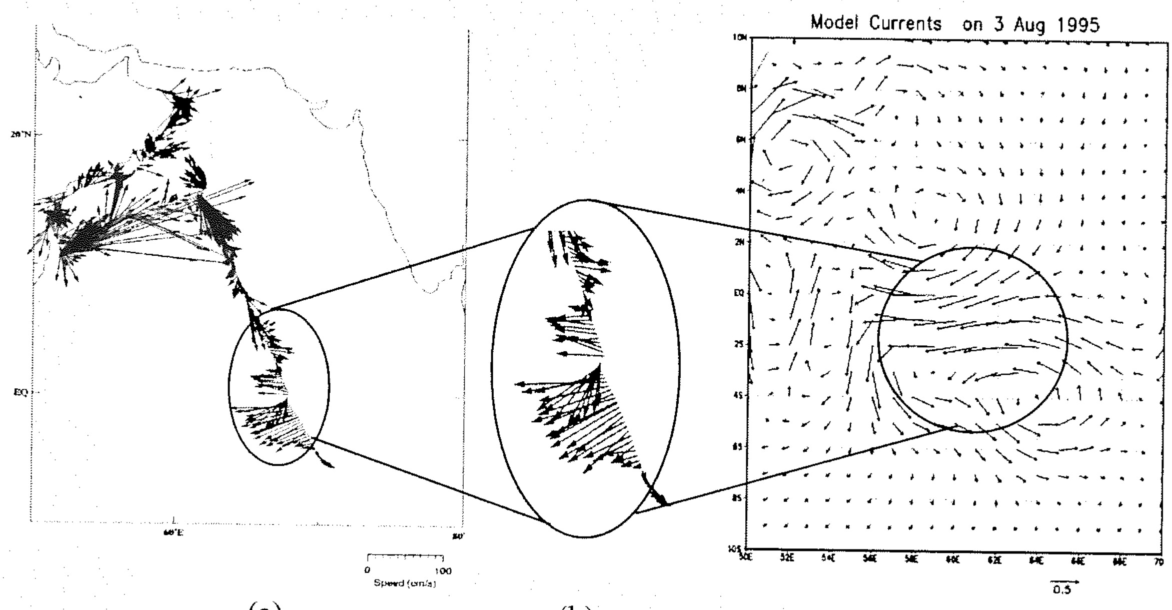


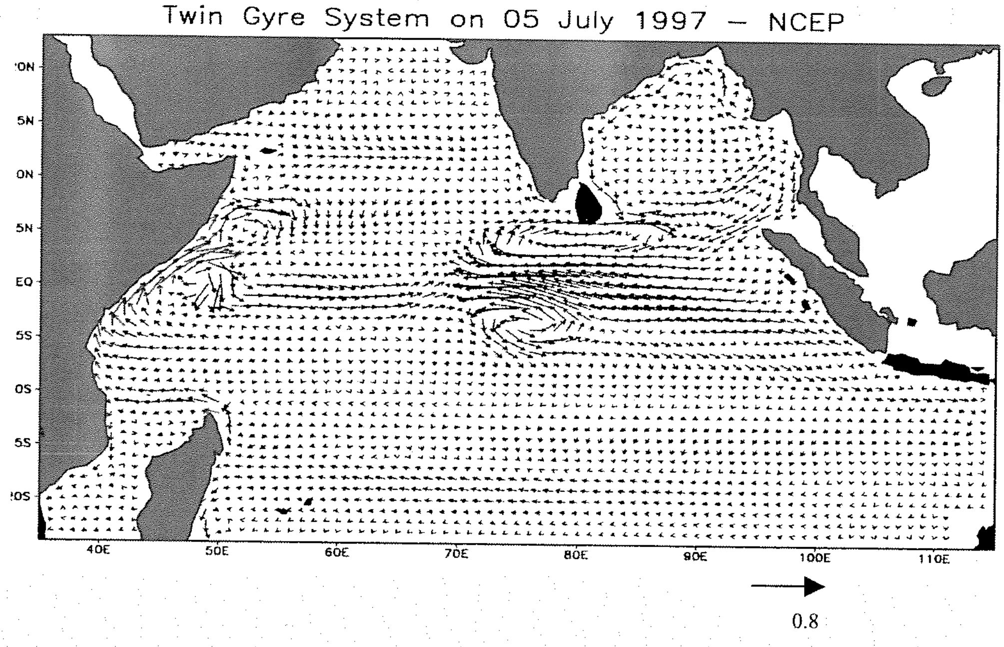
Figure 4 Currents for the month of July 2001 showing the twin gyres for the dates 05th, 15th and 25th in a, b and c respectively.



(a) (b) (c)

Figure 5. (a)The vector plots of surface circulations (25m to 35m) from the WOCE along 50E-80E, 10S-30N during 7th July – 26th August 1995. (b) A closer view (65E-70E,Eq-5S) from 1st to 3rd Aug1995. (c) The model simulated surface currents along 60E-64E,Eq-5S for 3/08/1995 (for details please refer Reddy et al, 2003 b).

a



b

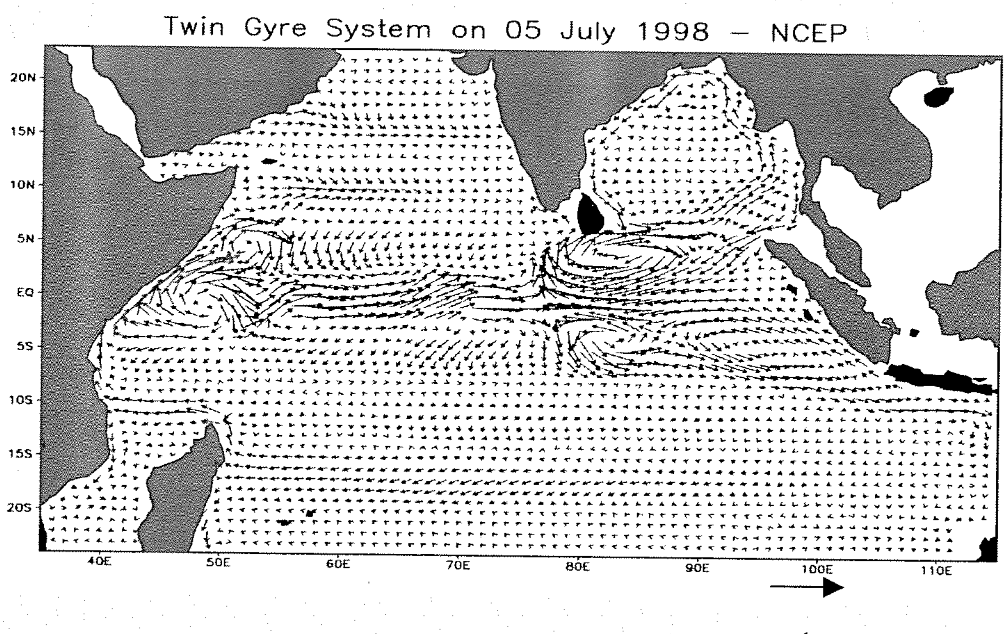
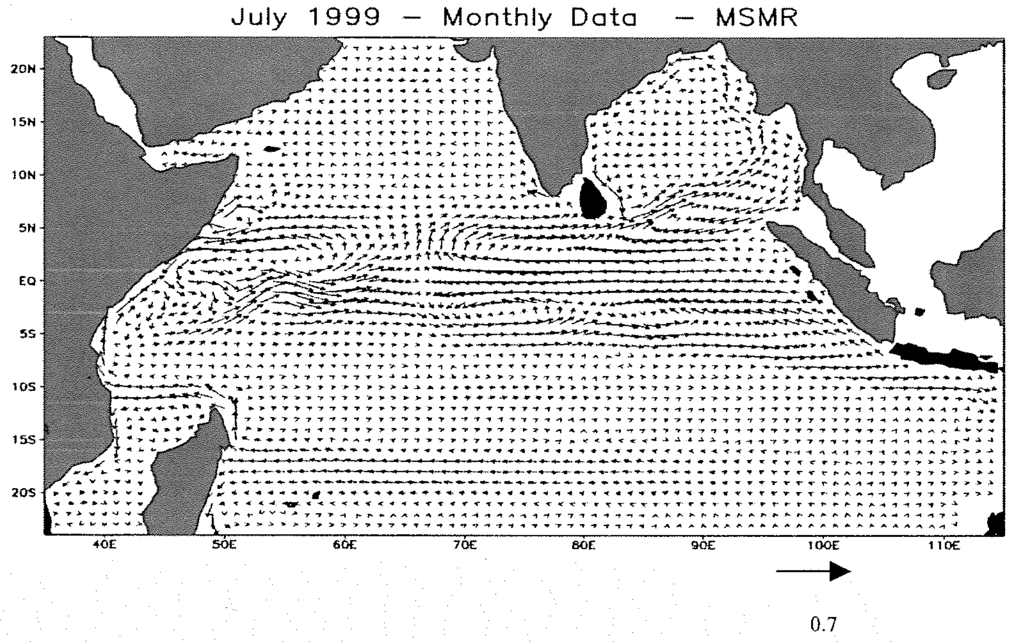


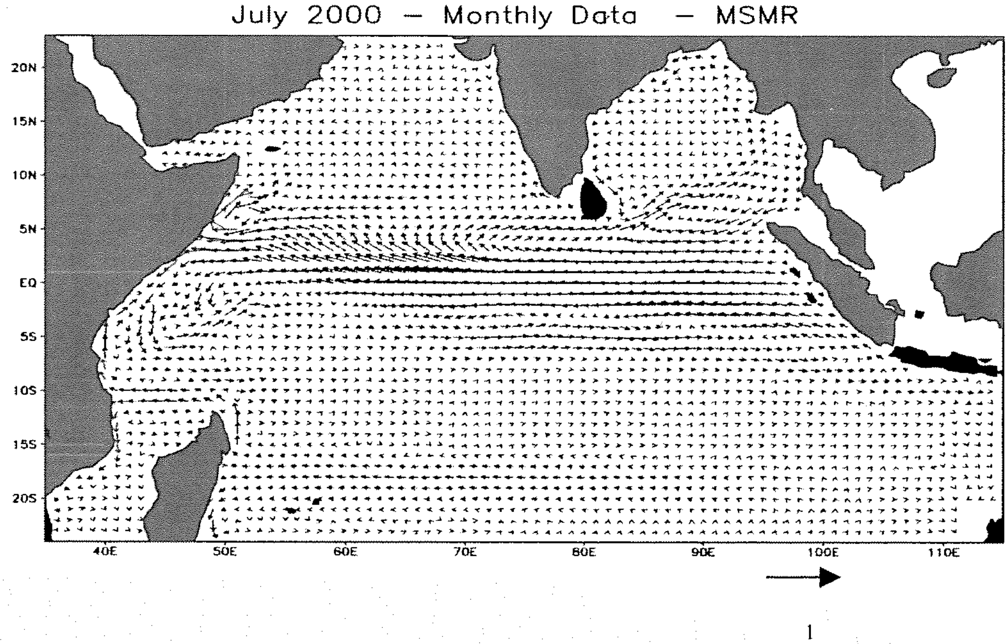
Figure 6 Twin gyres as seen in the contrasting ElNino years (a) 5th July 1997 (b) 5th July 1998.

Figure 7

a


July 1999 – Monthly Data – MSMR
20N
15N
10N
5N
EQ
5S
10S
15S
20S
40E
50E
60E
70E
80E
90E
100E
110E
0.7

b


July 2000 – Monthly Data – MSMR
20N
15N
10N
5N
EQ
5S
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15S
20S
40E
50E
60E
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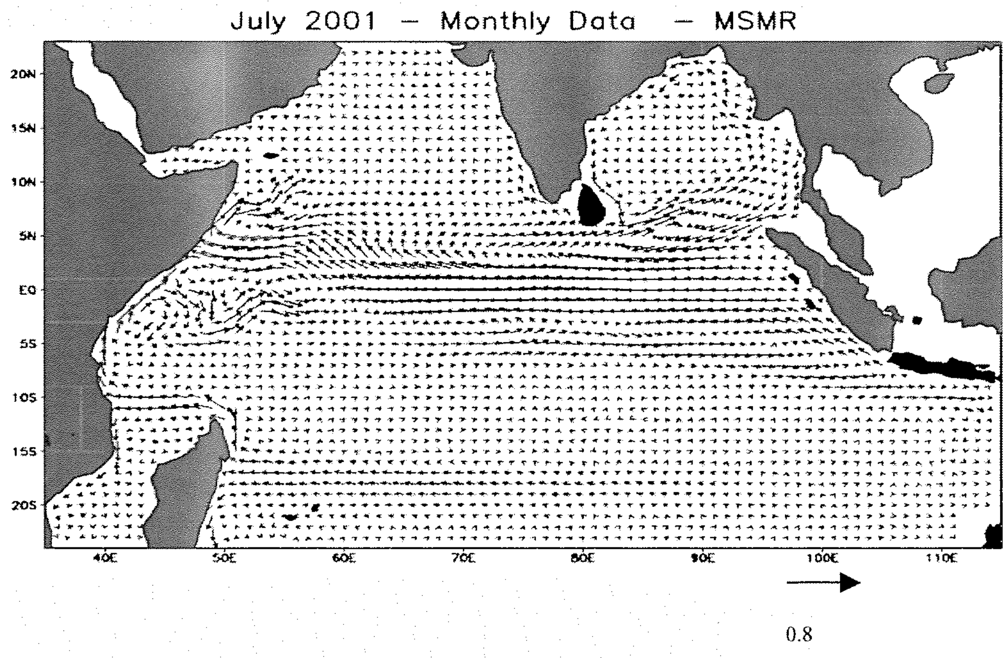
90E
100E
110E
1

c



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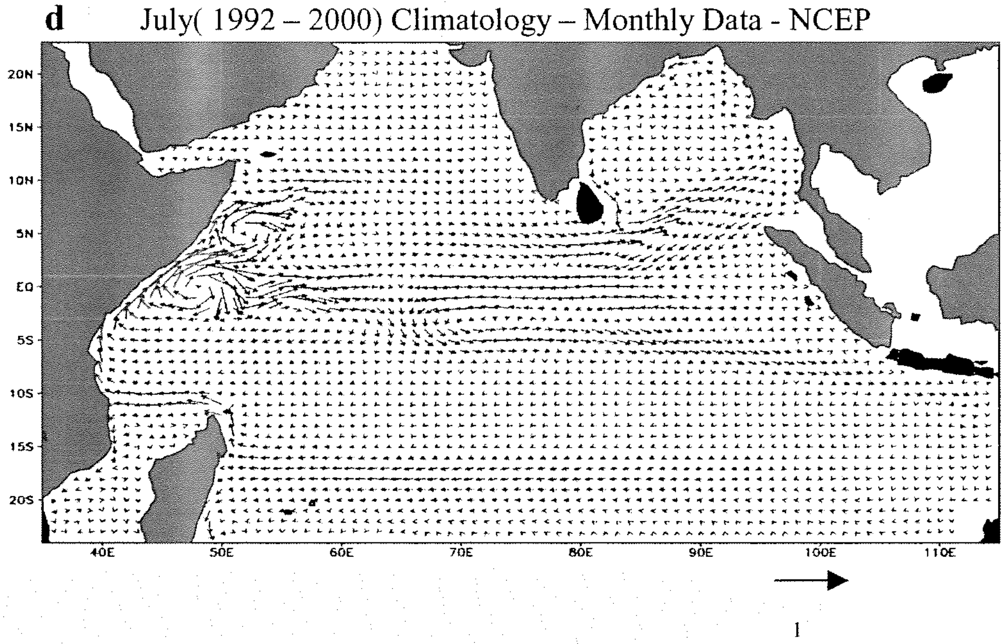

Figure 7 The Twin Gyres are not seen when the Monthly winds are used a, b, and c for MSMR winds, d for NCEP climatology winds.

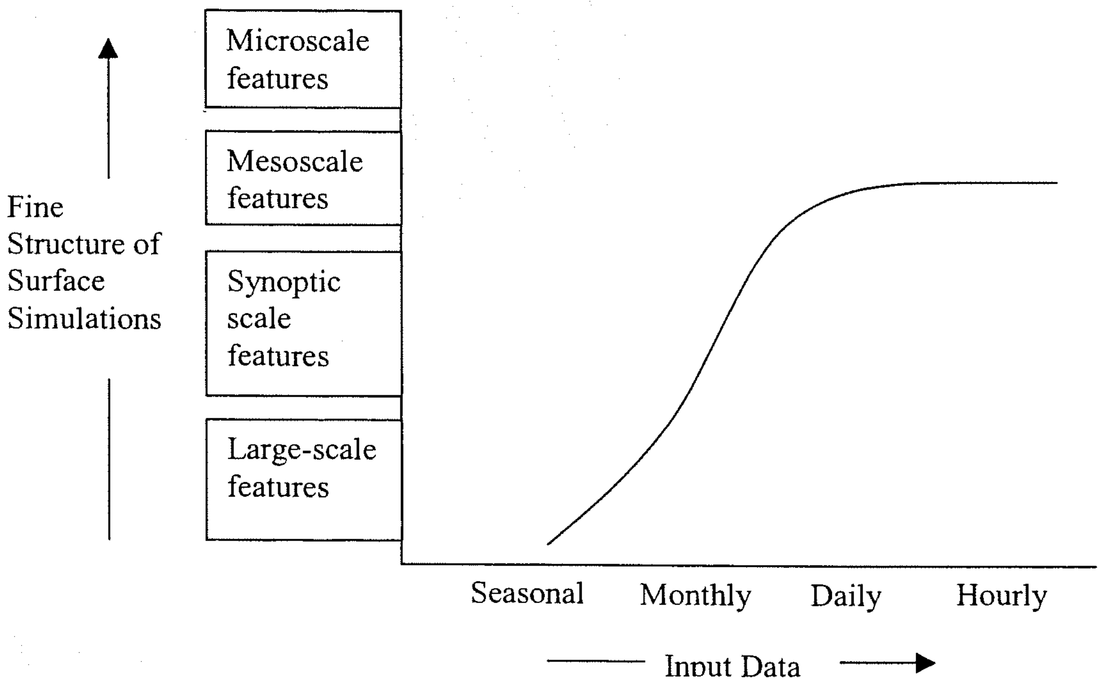

Figure 8 The variations in the Fine structures of surface simulations with Input Data.