

Drifting and Meandering of Olive Ridley Sea Turtles in the Bay of Bengal: Role of Oceanic Rossby waves

Shree Ram, P¹, Suryachandra A. Rao¹ and Y. Sadhuram²

Corresponding author: P. Shree Ram

¹ *Indian Institute of Tropical Meteorology
Dr. Homi Bhabha Road, Pashan
Pune – 411008
INDIA
Tel: +91-20-25893600
Fax: +91-20-25893825*

² *National Institute of Oceanography
Regional centre
176, Lawson's Bay colony
Visakhapatnam- 530017
India
Tel: +91-891-2539180
Fax: +91-891-2543595*

Running Title: Meandering Turtles in the Bay of Bengal

ABSTRACT

Olive Ridley turtles in the Bay of Bengal are previously thought to migrate southward from their nesting ground, along East coast of India (Orissa coast), towards Sri Lanka. Surprisingly, three of the four Platform Transmitter Terminal (PTT) attached turtles in April-June, 2001 meandered off the east coast of India for about 2 months. It is found that these turtles meandered at the peripherals of cold core cyclonic eddy surrounded by warm core eddies on either side. Concentrations of prey for the turtles in those frontal regions are known to be abundant. Only one of the four PTT attached turtles migrated to the south along the frontal regions in the direction of geostrophic currents. It is found that the locations of these thermal fronts in the Bay of Bengal are primarily determined by the Oceanic Rossby waves and local Ekman pumping.

Key Words: Bay of Bengal, Circulation, Cyclonic and Anti-cyclonic Eddies, Olive Ridley Turtles

INTRODUCTION

Orissa coast in India has the largest sea turtle rookeries in the world. Among five species of sea turtles that nest along the east coast of India, *Olive Ridley* turtles are most numerous (Pandav *et al.*, 1998). There has been considerable concern over the mortality of the Olive Ridley turtles along the Orissa coast. The major cause of this mortality is the incidental capture of turtles in trawl-fishing nets. A detailed review on the population, mortality and hatching patterns of the Olive Ridley turtles can be found in the earlier studies (Pandav *et al.*, 1998; Shanker, 2002; and Shanker *et al.*, 2003). Under a United Nations Development Program-Government of India (UNDP-GOI) collaborative project, an experiment to monitor the movement of sea turtles by satellite tracking was conducted in the year 2001. Between 17th and 19th April 2001, four Olive Ridley turtles fitted with PTTs were released from the Devi river mouth located in Orissa along the east coast of India. Only one turtle traveled southward up to east of Sri Lanka by 21st August 2001 and the remaining three turtles meandered off the east coast of India (Shanker, 2002). Full details of the program can be found at www.wii.gov.in/webs/about.htm (last accessed on 24th October 2008).

The Bay of Bengal is a semi-enclosed tropical basin in the northern Indian Ocean. The circulation in the Bay is driven by local monsoonal winds, equatorial winds, rainfall and river discharge (Haugen, *et al.*, 2002). The upper layer circulation in the Bay of Bengal consists of an anticyclonic gyre from February to April, with a poleward East Indian coastal current (EICC) as its western boundary current. During the southwest monsoon (June-September), EICC is seen as a weak poleward flow in the southern parts of Indian coast and as an equatorward flow in the north (Shankar *et al.*, 1996; McCreary *et al.*, 1996). Two types of planetary oceanic long waves (Rossby

and Kelvin waves) have been shown to play an important role in determining the above circulation in the Bay (McCreay *et al.*, 1996 and references therein; Vinayachandran *et al.*, 1996; Rao, 1998). In addition, the Bay is also dominated by upwelling-derived plumes, wedges of cold waters and oceanic eddies (Vinayachandran and Yamagata, 1998; Gopalan *et al.*, 2000).

In this study, an attempt is made to find the role of large scale ocean dynamics in determining the movements of sea turtles in the Bay of Bengal. For the first time any such attempt has been made in the Bay of Bengal if not in the Indian Ocean.

DATA AND METHODOLOGY

Merged Sea Level data obtained from a complete reprocessing of TOPEX/POSEIDON, Jason and ERS-1/2 Satellites at $1/3^\circ$ grid resolution and ocean surface winds derived from QuikSCAT scatterometer are used in this study. The Sea Surface Height deviation (SSHD) is calculated by removing the 7 years mean (January 1993 to December 1999). The tracks of Olive Ridley turtles are derived from Figure 3 in Shanker (2002). From this figure we could digitize two tracks that represent the movement of all four turtles. The other two tracks which were mostly located in the meandering path of the turtles are not digitized due to poor quality of color plot in Shanker (2002). The equatorward migrating sea turtle (Fig. 1, white colour curve) was released on 17th April 2001 and traveled all along the east coast and reached Sri Lanka by 10th August 2001, then disappeared or no signal received there after. The meandering turtle (Fig. 1, curve shown with black dots) was released on 18th April 2001 and last signal received was on 14th June 2001.

RESULTS AND DISCUSSION

Selected SSHD weekly maps superimposed (dates are centered on the week) by the geostrophic currents for different dates of each month from April to August 2001, are shown in the Fig. 1. Also, shown in this figure are two turtle tracks, one in white colour which traveled all the way to Sri Lanka, the other track is shown in the curve drawn with black dots shows the meandering path of the rest of the three turtles. Locations of the turtles at different times are also shown as white stars.

A strong anti-cyclonic gyre (warm core eddy) centered at 17° N with SSHD above 30 cm is observed in the western Bay of Bengal from April to June (Fig. 1 a-f). Due to space limitations, figures with important features are only presented. Further north, another warm core eddy located at 20° N in the western Bay, though not as strong as the southern one, is observed from April to early June (Fig. 1a-b). A cyclonic eddy (cold core) with negative SSHD (-30 cm) is located between these two anti-cyclonic (warm core) eddies. Gradual strengthening of this cyclonic eddy with time is observed (Figs.1a-1c). Three out of the four turtles released from Orissa coast, meandered around this cyclonic eddy from April to June (black curve in Fig. 1). Meanwhile, another cyclonic (anti-clockwise) eddy is seen on 30th May west of anti-cyclonic eddy at 15°N. Equatorward propagating turtle during this time is located between these two eddies (cyclonic on east and anti-cyclonic on west). In late June, an anti-cyclonic eddy developed east of Sri-Lanka and intensified in the following months. This large-scale eddy is popularly known as Sri Lanka dome following Vinayachandran and Yamagata (1998). Before termination of transmission, the equatorward migrating turtle meandered around this dome. In general, the turtles positioned themselves in the frontal regions between warm core and cold core eddies with the cold core eddy to its

left. Further, the turtles are migrating in the same direction as geostrophic currents; this suggests that these turtles may be simply drifting with the currents. Unfortunately, we do not have access to the accurate positions of these turtles, that otherwise would allow us to compare the speeds of the turtles with geostrophic velocities.

The majority of the eddy patterns explained above appears to be propagating from east to west as seen in Fig. 2. Three zonal transects across the Bay of Bengal are selected to show the westward propagation of SSHD. At these transects the equatorward migrating turtle followed a curvature path. Westward propagation of eddies is also clearly seen in Fig.2, particularly between 14°N and 16°N. These westward propagating features are well-known as Rossby waves and the phase speeds of these waves decrease with latitudes away from the equator. For example, the Rossby wave at 12°N takes about 96 days to cross the Bay, while same Rossby waves takes about 184 days to cross the Bay at 18°N. These calculations are based on long-wave theory (e.g. *Philander, 1990*) $C_r = \beta c^2 / f^2$ cm.s⁻¹, where C_r is Rossby wave phase speed, β is variation of Coriolis (f) with latitude, c is characteristic speeds of Kelvin wave (1st mode $c=264$ cm.s⁻¹; 2nd mode $c=167$ cm.s⁻¹). The above given Rossby wave speeds are for first baroclinic mode waves. The paths of theoretical Rossby waves for first baroclinic mode (thin black lines in Fig. 2) coincide with the observed phase speeds (bold dashed black lines in Fig. 2). However, the observed waves are found to be little slower than the theoretical Rossby waves. This is either due to the simplicity of the linear theory or due to the fact that observed waves are composed of first and second baroclinic Rossby waves (*Rao et al., 2002*).

The cyclonic eddy appeared between 18°N and 19°N in late May to late June is propagated from west as upwelling Rossby wave from eastern Bay of Bengal. This

Rossby wave was earlier radiated by upwelling coastal Kelvin wave propagating along the east coast of Bay. Using numerical simulations, Han and Webster (2002) suggested that the above mentioned processes are involved in development of cold core eddy in May/June. Similar mechanisms are also attributed to the presence of cold core eddy between 14°N and 15°N.

However, at some locations, Ekman pumping (Fig. 3) appears to be one of the major forcing for the observed eddy structure in the Bay of Bengal. One such dominant region is located east of Sri Lanka. The Sri Lanka dome is dominantly forced by positive Ekman pumping situated over the dome (Fig. 3), as pointed out by Vinayachandran and Yamagata (1998). At this location, we observe continuous upwelling favorable Ekman pumping velocities from May to August. Though the cyclonic eddy at 18°N, is primarily forced by Rossby waves from east (Fig. 2), its local intensification is due to local Ekman pumping after 30th May. At this location also we observe continuous positive Ekman pumping velocities. Between 14-15°N the low sea level (left of the turtle position; star in Fig. 2b) is primarily due to long Rossby waves in early June, as the local Ekman pumping is downwelling favorable at this location.

It is very interesting to see that the movement of Olive Ridley turtles is almost coinciding with the circulation features described above (Fig. 1) and always follow the frontal regions between warm core and cold core eddies. Similar migrating paths are also observed previously in Atlantic (Ferraro *et al.*, 2004) and Pacific (Polovina *et al.*, 2004). However, to our knowledge, this is the first study which demonstrates that the Olive Ridley turtles in the Indian Ocean (at least in the Bay of Bengal) follow frontal paths as in the Pacific and the Atlantic. Turtles prefer these frontal zones, to

forage along productive fronts where their main prey, gelatinous plankton, is concentrated (Myers and Worm, 2004). Recently, Prasannakumar *et al.*, (2004) also have shown the enhanced productivity in these frontal zones in Bay of Bengal for two regions with high Chlorophyll_a concentration ($\sim 0.3 \text{ mg/m}^3$), one was located between 9° and 12° N and the other was located between 18° and 20° N.

CONCLUSIONS

SSHA and geostrophic circulation derived from Satellites showed a very rich eddy structure in the Bay of Bengal. Interestingly, the post-nesting Olive Ridley turtles which were released from Orissa coast were moving along the frontal regions of cold core and warm core eddies. Three of the four PTT fitted turtles drifted with geostrophic currents around the cyclonic eddy off the coast of Orissa for about two months. The other turtle drifted southward along the frontal regions with cold core eddy situated towards its left. Further, we found that these frontal regions are, in general, controlled by large scale ocean dynamics through Rossby waves and local Ekman pumping.

ACKNOWLEDGEMENTS

Thanks to CLS Space Oceanography Division and CNES for making the SSHA data available on the internet. Authors are also thankful to Dr. Mahendra of INCOIS, Hyderabad for helping us in digitizing the turtle tracks using ERDAS software. The altimeter products (downloaded from <ftp://ftp.cls.fr/pub/oceano/msla>) were produced by the CLS Space Oceanography Division as part of the Environment and Climate EU ENACT Project (EVK2-CT2001-00117) and with support from CNES.

REFERENCES

- Ferraroli, S., Georges, J.Y., Gaspar, P., & Le Maho, Y 2004. Where leatherback turtles meet fisheries. *Nature*, 429, 521-522.
- Gopalan, A. K. S., Gopala Krishna, V.V., Ali, M.M., & Rashmi Sharma 2000. Detection of Bay of Bengal eddies from TOPEX and insitu observations. *Journal of Marine Research*, 58, 721-734.
- Han, W., & Webster, P. J 2002. Forcing Mechanisms of Sea Level Interannual Variability in the Bay of Bengal. *Journal of Physical Oceanography*, 32, 216-239.
- Haugen, V.E., Johannessen, O.M., & Evensen, G 2002. Indian Ocean: validation of the Miami Isopycnic Coordinate Ocean Model and ENSO events during 1958-1998. *Journal of Geophysical Research*, 107(C5): doi.10.1029/2000JC000330.
- McCreary, J., Han, W., Shankar, D., & Shetye, S.R 1996. Dynamics of East India Coastal Current, 2, Numerical Solutions. *Journal of Geophysical Research*, 101, 13,993-14,010.
- Myers, R.A., & Worm, B 2003. Rapid worldwide depletion of predatory fish communities. *Nature*, 423, 280-283.
- Pandav, B., Choudhury, B.C., & Shankar, K 1998. The Olive Ridley sea turtle (*Lepidochelys olivacea*) in Orissa: an urgent call for an intensive and integrated conservation programme. *Current Science*, 75, 1323-1327.
- Philander, S. G 1990. *El Niño, La Niña and the Southern Oscillation*. Academic Press, 293 pp.
- Polovina, J.J., Balaz, G. H., Howell, E.A., Parker, D.M., Seki, M. P., & Dutton, P. H 2004. Forage and migration habitat of loggerhead (*Caretta caretta*) and olive ridley (*Lepidochelys olivacea*) sea turtles in the central North Pacific Ocean. *Fisheries Oceanography*, 13, 36-51.
- Prasannakumar, S, Nuncio, M., Narvekar, J., Kumar, A., Sardesai, S., de Souza, S. N., Mangesh, G., Ramaiah, N., & Madhupratap, M 2004. Are eddies trigger to enhance biological productivity in the Bay of Bengal?. *Geophysical Research Letters*, 31, L07309, doi:10.1029/2003GL019274.
- Rao, A.S 1998. Rossby waves in the Bay of Bengal: observations and simulations. Ph. D thesis, Andhra University, Visakhapatnam, India.
- Rao, S. A., Behera, S. K., Masumoto, Y., & Yamagata, T 2002. Interannual variability in the subsurface Indian Ocean with special emphasis on the Indian Ocean Dipole. *Deep Sea Research-II*, 49, 1549-1572.
- Shankar, D., McCreary, J., Han, W., & Shetye, S.R 1996. Dynamics of East India Coastal Current, 1, Analytic Solutions forced by interior Ekman pumping and local along shore winds. *Journal of Geophysical Research*, 101: 13,975-13,991.
- Shanker, K 2002. Tracking turtles through time and space. *Resonance*, 53-66.
- Shanker, K., Pandav, B., & Choudhury, B.C 2003. An assessment of the Olive Ridley turtles (*Lepidochelys olivacea*) nesting population in Orissa. India, *Biol. Cons.*, 115,149-160.
- Vinayachandran, P.N., Shetye, S.R., Sengupta, D., and Gadgil, S 1996. Forcing mechanisms of the Bay of Bengal circulation. *Current Science*, 71, 753-763.
- Vinayachandran, P. N., & Yamagata, T 1998. Monsoon response of the sea around Sri Lanka; generation of Thermal domes and anti cyclonic vortices. *Journal of Physical Oceanography*, 28, 1946-1060.

FIGURE CAPTIONS:

Fig.1: Weekly averaged sea surface height deviations (SSHD; in cm.) for different weeks are shown from April to August 2001(a-f), the geostrophic currents (black arrows) and turtle tracks are super imposed.

Fig.2: Time-longitude plots of SSHD averaged between (a) 18-19°N, (b) 14-15°N and (c) 11-12°N. Thick (thin) dashed lines represent the propagation paths of observed (theoretical) low SSHD. Black stars indicate the approximate positions of the turtles.

Fig. 3: Ekman pumping velocities ($\times 10^{-5}$ cm. sec⁻¹) derived from QuikSCAT winds corresponding to the dates shown in Fig.1.

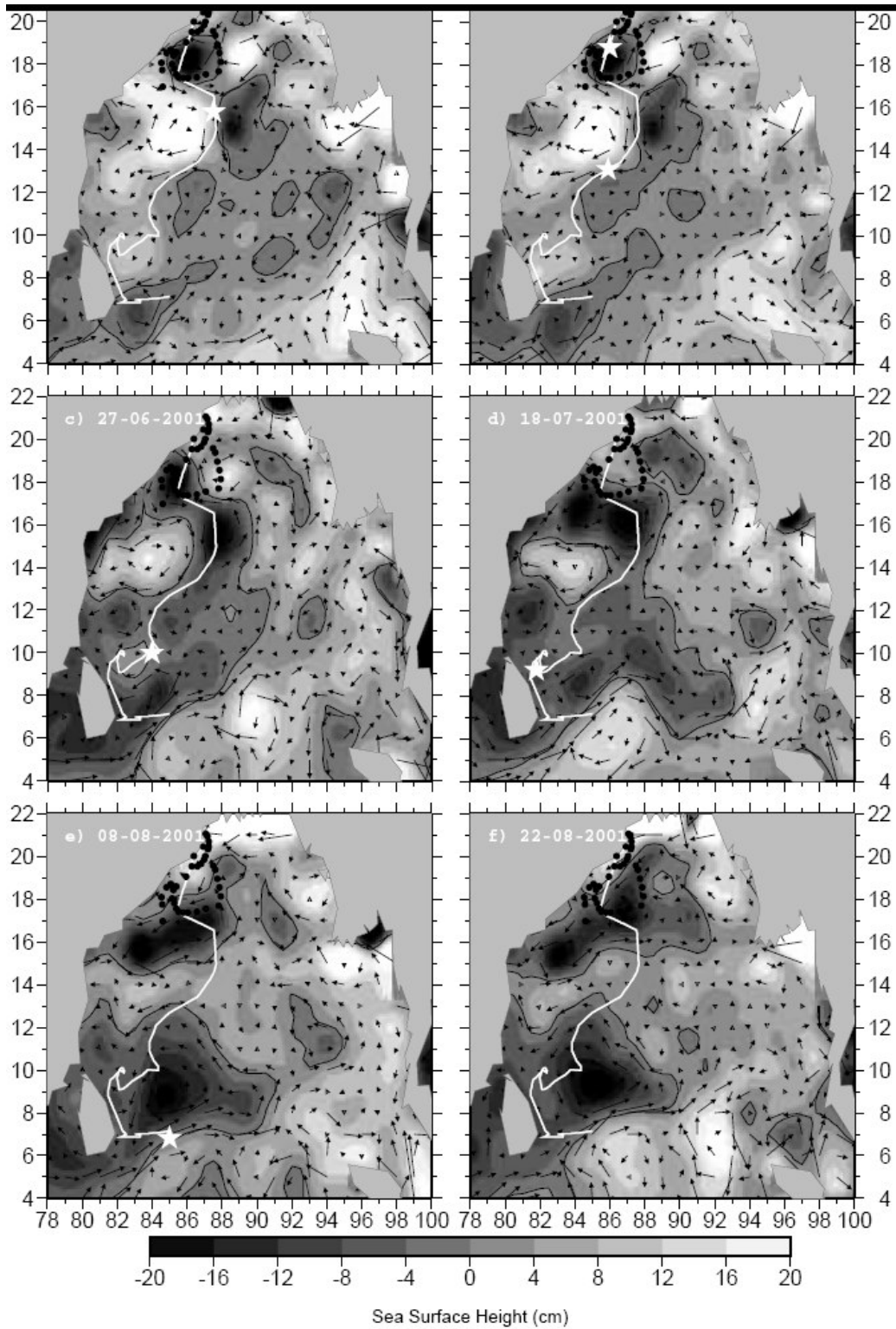


Fig.1

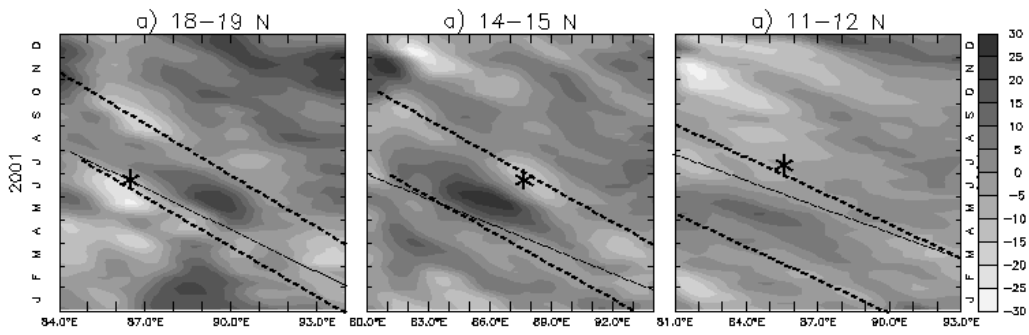


Fig.2

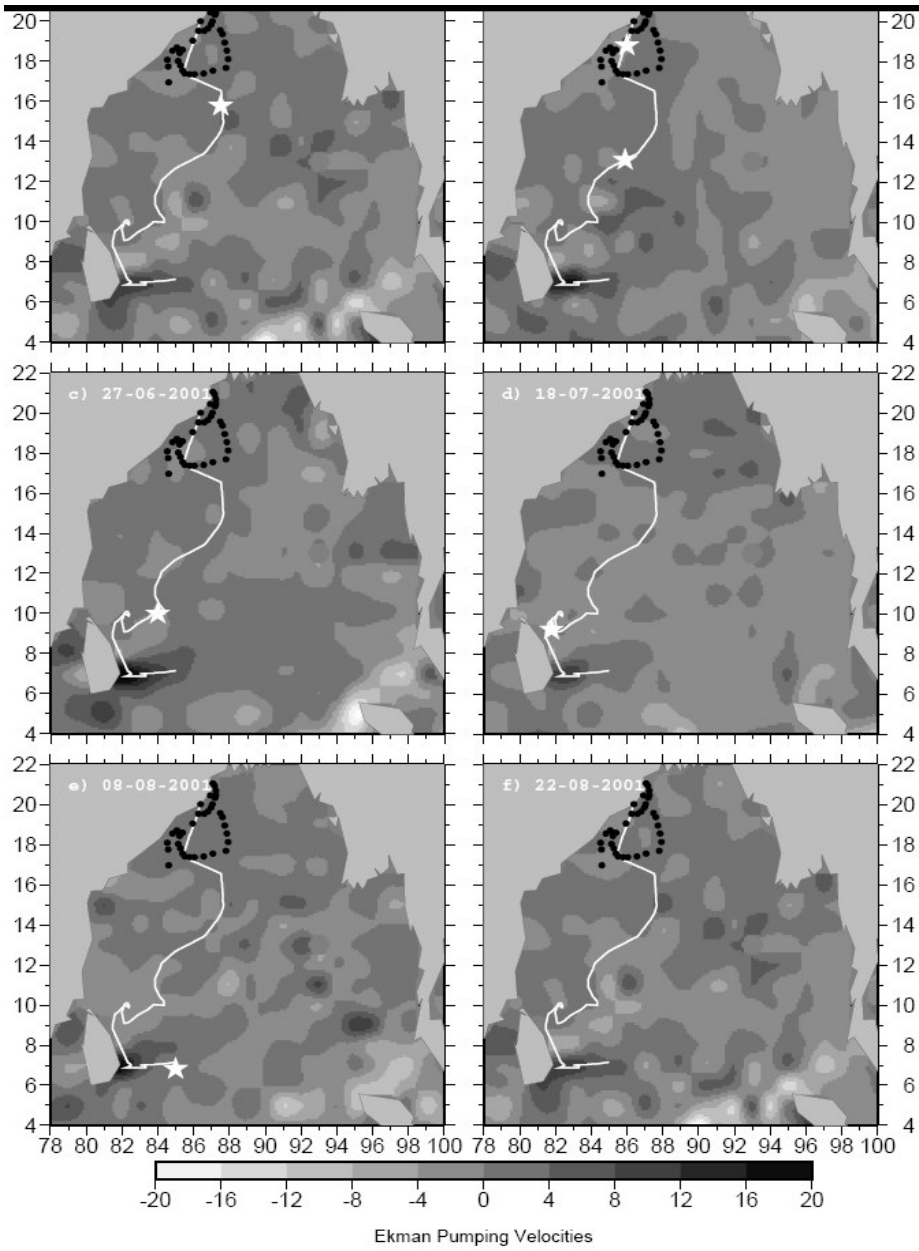


Fig 3