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Studies on the drift of ocean colour features using satellite-derived sea surface wind for updating potential fishing zone

*[1]R Vinu Chandran, H U Solanki[2], R M Dwivedi[2], Shailesh Nayak[2], A Jeyaram[1] & S Adiga[3]

[1]Regional Remote Sensing Service Centre (ISRO), Kharagpur 721 302, India

[2]Marine and Water Resources Group, Space Applications Centre (ISRO), Ahmedabad 380 015, Gujarat, India

[3]Indian Space Research Organisation Headquarters, Bangalore 560 094, India

*[E-mail: vinuchandran@lycos.com]

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Ocean colour features like chlorophyll fronts are widely used for the prediction of Potential Fishery Zones (PFZs). These mesoscale features are dynamic since ocean surface is always in motion. They tend to drift because of surface advective movements. The present study is an attempt to understand the relationship between wind speed and drift of ocean colour features, which can be used to update the location of PFZ mesoscale features. Ocean colour images from IRS-P4 Ocean Colour Monitor (OCM) were atmospherically corrected and Ocean Chlorophyll-2 bio-optical algorithm was applied to derive the sea surface chlorophyll. QuikSCAT (NASA) scatterometer wind data was obtained from the global 25 km^2 gridded dataset. A mathematical relationship between wind speed and drift was derived. The relation was validated on a second set of time series images. Results show that the relation can be used for updating the location of PFZ features in the northeast Arabian Sea for up to 96 hr within an error of 12%.

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Introduction

Ocean is a cornucopia of resources. The full potential of oceanic resources is being appreciated during the past 2-3 decades. Even though food resources from maritime sources are explored, fishery resources are not exploited to its full potential. Barton[1] opined that effective utilization of fishery resources could be achieved by using remote tracking devices to locate shoals of fish more quickly. At present, instruments like SONAR, RADAR and satellites are used for locating sites of fish aggregation. Operational application of satellite data to commercial fishing operation started along the pacific coast[2] as early as from 1975. In earlier days, potential fishing zone (PFZ) forecasts were solely based on sea surface temperature (SST) maps. For the first time, ocean colour from CZCS (Coastal Zone Color Scanner) along with SST from NOAA (National Oceanographic and Aerospace Administration) AVHRR (Advanced Very High Resolution Radiometer) was used by Muller & La Violate[3]. They found that the temperature contours and chlorophyll contours were offset by a few kilometers. Laurs *et al.*[4] used CZCS and SST images to study the distribution of tuna population. While the information on satellite-derived SST is limited only to the surface layer of a few micrometers of the ocean, ocean colour images can give information from several meters of depth in non-turbid waters (one attenuation depth)[5]. Regions of high phytoplankton concentration can be identified from the chlorophyll images as features like eddy, meander, coastal jet, etc[6]. Present satellite-based PFZ forecast relies upon these mesoscale features (PFZ features) supplemented by SST maps. PFZ features are not stationary and tend to move with surface water currents. Hence the PFZ information generated needs to be updated to account for the drift.

Harmful Algal blooms are noxious and can cause mass mortality of fishes and other marine living resources. Studying the dispersion and growth of algal blooms is still a major challenge[7] and it is known that surface currents play a major role in their dispersion. An understanding of the relationship between wind and currents can help in the mitigation of harmful algal blooms. Mainly two forces, the advective type or wind-driven circulation and the convective type or thermohaline circulation drive currents in the ocean. The pattern of wind-driven circulation is very similar to the pattern of the surface winds. Hence, the study

of wind in relation to the movement of PFZ features is relevant. Such a study can also help in understanding the movement and dispersion of algal blooms.

A couple of reports are available on the relation of wind to other physical processes. Laurs & Brucks[8] conducted case study using Seasat-A Scatterometer System (SASS) wind data to establish, quantify and document the extent and variability of wind induced ocean flow indices on surface-layer transport. Sasaoka *et al.*[9] used multi-sensor wind and chlorophyll data to study the spatial and temporal variation in chlorophyll *a* and primary productivity in the North Pacific Ocean. In the present work, the drift of mesoscale ocean colour features in relation to wind speed has been studied.

Materials and Methods

The study area was northeast Arabian Sea (coastal region of Maharashtra and Gujarat, along north west coast of India lat.15°-25° N and lon. 63°-73° E) where high primary productivity and frequent algal blooms are observed, which give vivid chlorophyll features. Average chlorophyll concentration and primary productivity ranges are 0.4-0.5 $mg.m^{-3}$ and 0.3 $gC.m^{-2}.d^{-1}$ to 1.1 $gC.m^{-2}.d^{-1}$ respectively, for the region[10]. High pigment concentration occurs in certain regions (15 $mg.m^{-3}$ in the southeast). A number of studies were carried out by Space Applications Centre on PFZ and fishery of the region[5,11,12]. The area is also known for its high annual fish landing[13] (6.45×10^5 mT for the year 1999).

Two different satellite data sets were used for the study *viz.* IRS-P4 OCM images and QuikSCAT winds. OCM images were procured from National Remote Sensing Agency, Hyderabad. This sensor has 8 spectral bands, which are exclusively designed for ocean studies. Time series OCM images (path/row, 9/13 and 9/14) were used along with QuikSCAT wind data of the same period. Chlorophyll maps were derived from the OCM images. QuikSCAT data for the study were procured from the NASA Physical Oceanography Distributed Active Archive Center (PODAAC) at the Jet Propulsion Laboratory/ California Institute of Technology. The SeaWinds on QuikSCAT Level-3 data set consists of 25 km^2 gridded values of scalar wind speed and the corresponding meridional and zonal components of velocity. Wind speed and direction were calculated from QuikSCAT Level-3 data.

OCM data were atmospherically corrected before deriving the chlorophyll concentration since a considerable percentage of the light reaching the sensor is from atmosphere (>90% of light measured). For atmospheric correction, the approach of Mohan *et al.*[14] was followed. An empirical algorithm (OC-2, O'Reilly *et al.*[15]) was used for deriving the chlorophyll from the geometrically corrected images. This algorithm operates with five coefficients.

$$C = 10^{**}[0.341 - 3.001 * R + 2.811 * R2 - 2.041 * R3 + (-0.040)] \quad \ldots (1)$$

for $0.01 \le C \le 50$ $mg.m^{-3}$

where C = chlorophyll concentration in $mg.m^{-3}$; $R = \log_{10} [Rrs(490)/ Rrs(555)]$, R_{rs} is the remote sensing reflectance. Chlorophyll images thus derived were colour coded based on chlorohyll concentration for easy identification of prominent features. The data processing method is shown in Fig. 1.

QuikSCAT wind data (U and V components for the required area lat. 15°-25° N and on. 63°-73° E) were extracted as ASCII files from the archived files supplied in Heirarchial Data Format. Data for both the ascending and descending passes were obtained. The ASCII values were plotted as wind vectors with the help of Surfer software. The plots were then exported

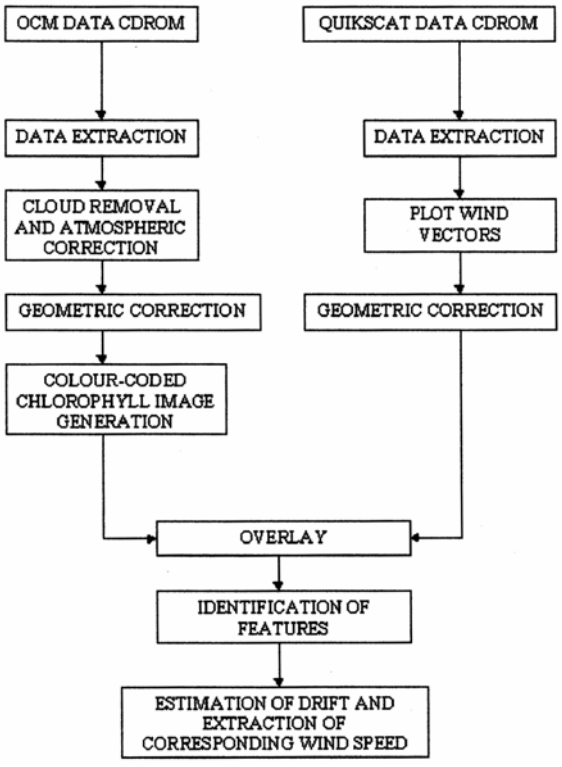

Fig. 1—Flow chart of the methodology adopted for data processing and analysis.

to JPEG format. These JPEG images were converted to ERDAS IMAGINE format and geocorrected. Further processing of the images was done using ERDAS IMAGINE ver 8.5. Geocorrected images were then overlaid on the chlorophyll maps (as in Fig. 2) for identifying the suitable mesoscale features for study. After recording the position of suitable features (latitude and longitude), wind speed for the corresponding grid (25 km^2) was obtained from the ASCII data for the corresponding days. Data from two adjacent grids were compared to verify the consistency.

To study the temporal variation in mesoscale features, time series chlorophyll images of 14-26 March 2000 and 13, 17 and 19 December, 2000 were generated and chlorophyll features that were persistent for not less than 2-4 days were identified. Displacement and the direction of drift of these features were measured from the images procured in the subsequent 48/96 hours. Distance between the

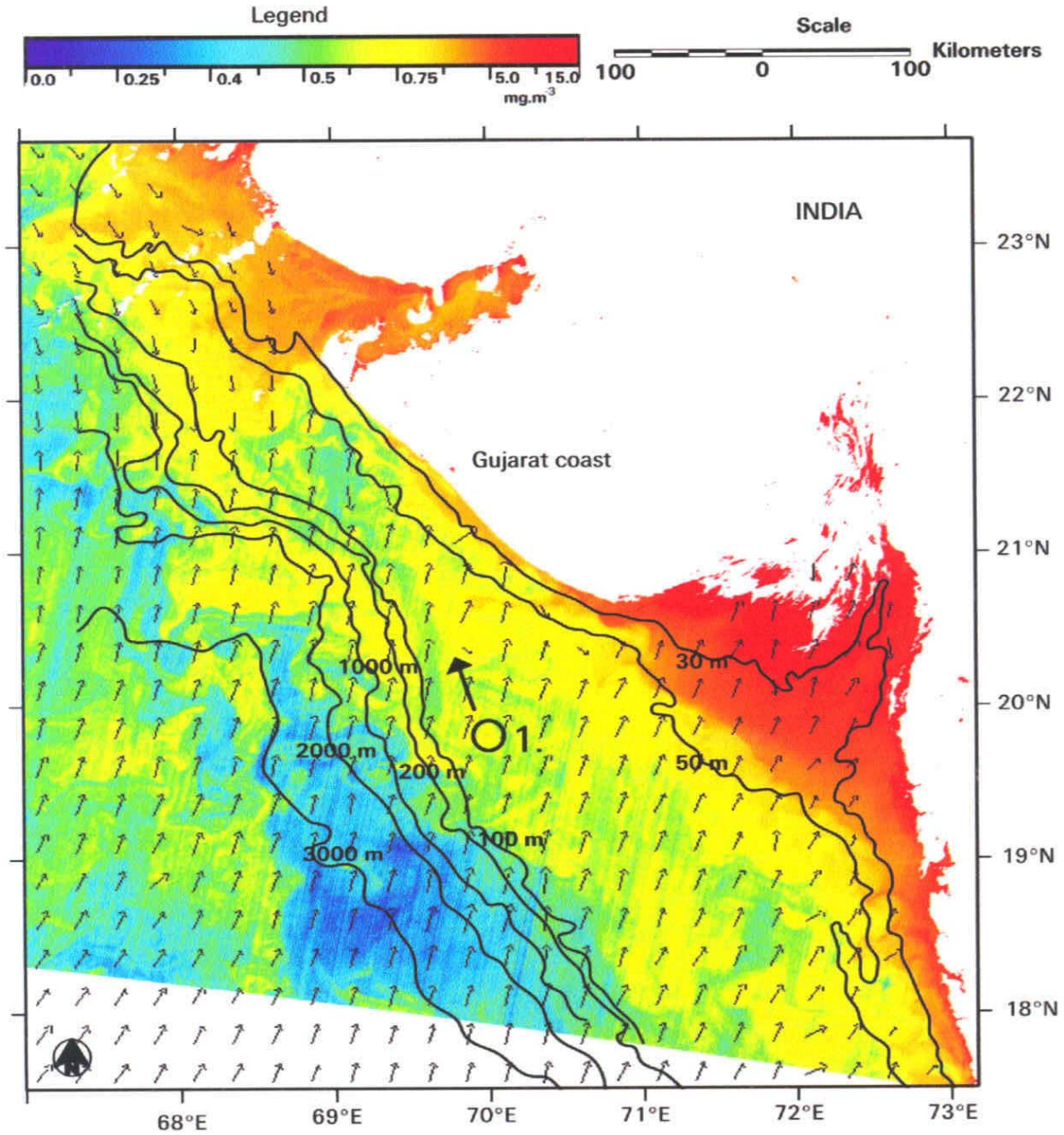

Fig. 2—Chlorophyll image of 13 December 2000, overlaid with wind vectors derived from QuikSCAT of same date. Thick arrow shows the direction of movement of the feature encircled.

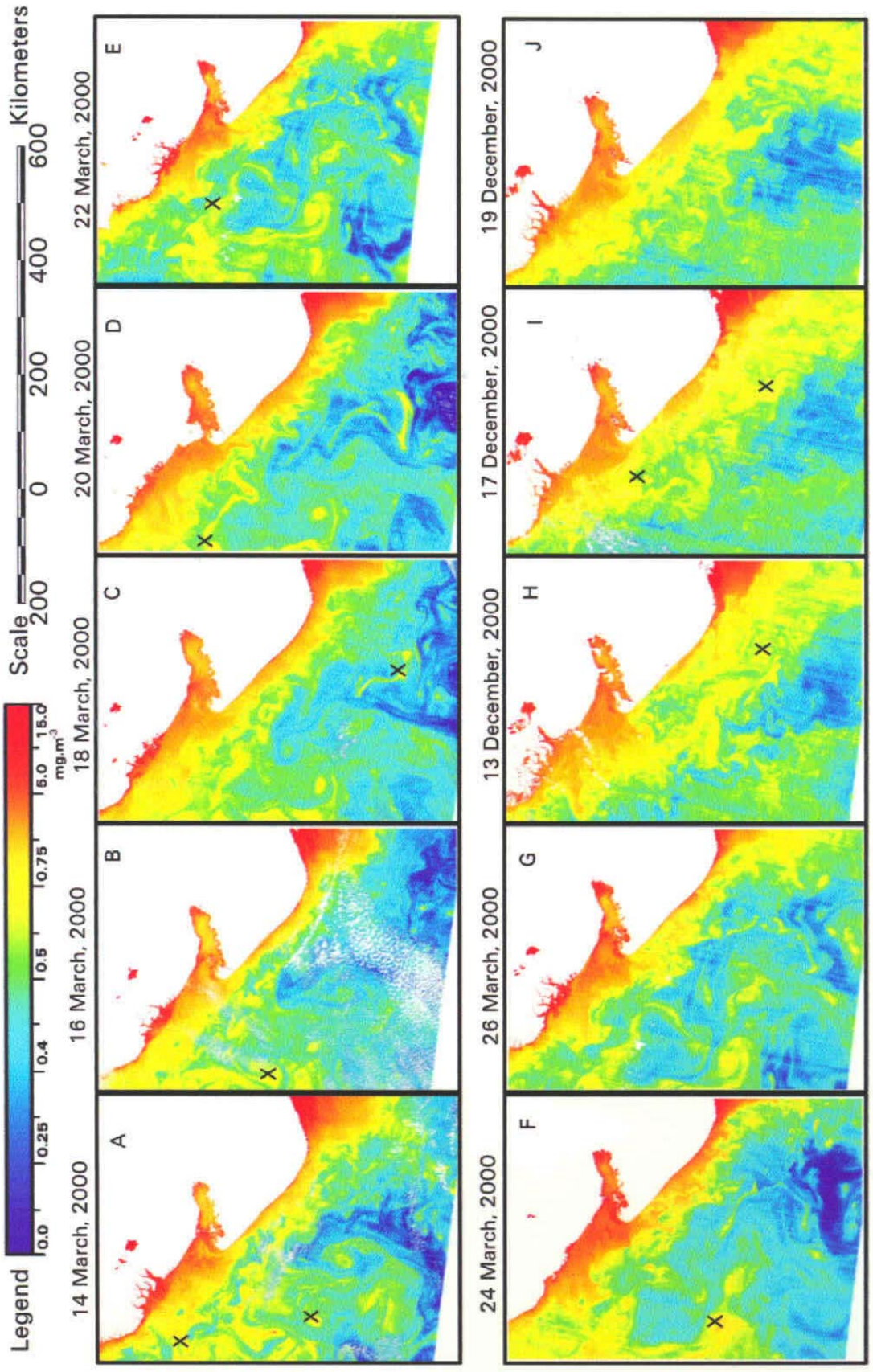

Fig. 3—Time series chlorophyll images derived from IRS-P4 OCM for northeast Arabian sea for March 2000 and December 2000. Prominent features identified for the study are marked 'X'.

central points of the features in two images was measured with the help of 'measure' utility of 'Erdas Imagine' software. From the observations, the speed of drift of the features was calculated. Even though about 20 prominent features could be identified from the ocean colour images, concurrent wind data were available only for 12, and the others happened to be in data gaps of the QuikSCAT winds. More images of March 2000 were used since the features were more prominent. Correlation analysis between wind speed and the speed of drift was performed and regression curve was fitted. The relation was validated on time series chlorophyll images of 2nd, 4th and 6th November 2001. A prominent feature was identified on the chlorophyll map of 2nd November (see Fig. 5). From the wind speed, displacement for the subsequent days was calculated using equation 2. The direction of drift was noted from two consecutive images. Calculated position of the feature was plotted on the subsequent image of the series. Distance between the original position and the calculated position was measured to quantify the error.

Results and Discussion

Analysis of ocean colour features and wind speed

From the observations, it was found that the PFZ features were displaced 6-20 km in 48 hr. Figure 3 shows the time series images (path/row 9/13) of IRS-P4 OCM acquired during March and December 2000. Prominent features studied are marked 'X' in the respective images. A feature developing into a ring (PFZ as described by Solanki *et al.*[5]) can be seen in Fig 3 H, this was drifted in the northwest direction in subsequent images. The feature was fully developed after 96 hr and a drift of 40.5 km (as measured from Fig. 3 H and I) in this time period was noted. During further 48 hr time period, there was a drift of 26 km (Fig. 3 I and J). The rate of drift was calculated approximately as 2 km.day^{-1}.unit wind speed^{-1}. Details of the wind speed, chlorophyll, etc. are given in Table 1. A circular feature was identified from the images 4 A-D. From images E-G, a developing fringe front was identified (upper half in Fig. 3 E). Overlay of the wind vectors on the chlorophyll images showed that the direction of drift of the mesoscale features was offset by 0-20 degrees from the direction of wind.

Correlation analysis between wind speed and drift yielded positive *r*-value (r^2 = 0.805) (Fig. 4). *r*-value was significant at 5% level. Wind speed showed variation from 0.5-7.5 m.s^{-1}. There was no significant

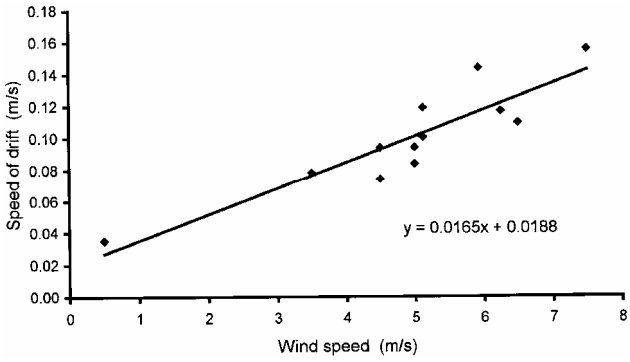

Fig. 4—Scatter plot of wind speed vs. speed of drift.

Table 1—Date, location, wind speed and displacement/day of features from the time series chlorophyll images.

S. no.	Day 1	Location Day 1 (lon.[°N], lat.[°E])	Day 2	Location Day 2 (lon.[°N], lat.[°E])	Distance (km)	Time (hr)	Displacement/ day (km)	Wind speed (m.s^{-1})	Chl. (Day 1) (mg.m^{-3})	Chl. (Day 2) (mg.m^{-3})
1.	13.12.00	70.001, 19.798	17.12.00	69.697, 20.045	40.461	96	10.115	6.25	1.010	0.980
2.	17.12.00	69.697, 20.045	19.12.00	69.570, 20.258	26.932	48	13.466	7.50	0.980	1.032
3.	17.12.00	68.287, 21.874	19.12.00	68.135, 21.904	16.301	48	8.151	5.00	1.148	0.792
4.	14.03.00	67.598, 20.570	16.03.00	67.645, 20.570	6.0643	48	3.032	0.50	0.838	0.980
5.	14.03.00	66.870, 22.892	16.03.00	66.748, 22.945	14.527	48	7.264	5.00	0.868	0.815
6.	16.03.00	66.352, 21.140	18.03.00	66.512, 20.995	24.874	48	12.437	5.93	0.771	0.858
7.	18.03.00	69.559, 19.153	20.03.00	69.665, 19.069	12.805	48	6.403	4.50	0.939	0.575
8.	20.03.00	67.144, 22.385	22.03.00	67.282, 22.347	13.523	48	6.762	3.50	0.774	0.605
9.	20.03.00	66.285, 18.129	24.03.00	65.981, 18.233	32.529	96	8.132	4.50	0.491	0.496
10.	22.03.00	67.282, 22.347	24.03.00	67.464, 22.286	18.974	48	9.487	6.50	0.605	0.697
11.	24.03.00	67.038, 20.648	26.03.00	67.015, 20.511	20.573	48	10.287	5.12	0.782	0.741
12.	24.03.00	67.022, 20.656	26.03.00	67.045, 20.519	17.397	48	8.699	5.12	0.835	0.758

Distance moved is measured as the distance between two positions in the consecutive images. Wind speed of day one and chlorophyll concentration (average of nine pixels) at the location are given.

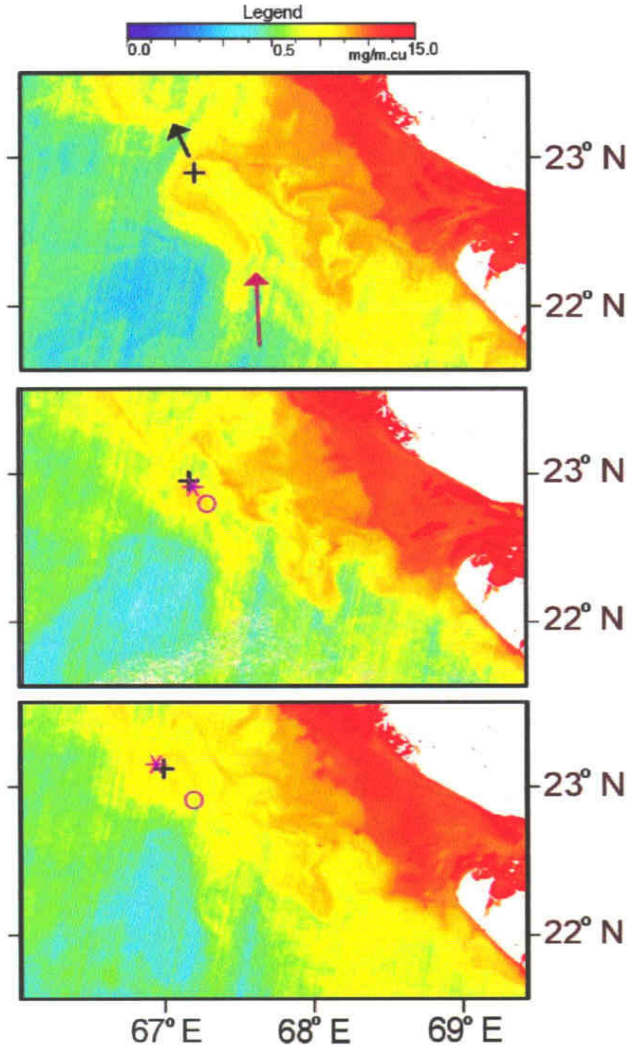

Fig. 5—Time series chlorophyll images of November 2001 showing the actual and calculated position of a feature. '+' shows the observed position, 'O' the original and '*' calculated.

change in the direction of wind during the period of analysis. Chlorophyll concentration of the features ranged from 0.5-1.1 mg.m^{-3} and did not show considerable variation during the period of analysis (Table 1). Displacement of the mesoscale features can be calculated using the following relation:

$$\text{Displacement (km/day)} = 1.426 \times \text{wind speed (m.s}^{-1}\text{)} + 1.624 \quad \ldots (2)$$

Validation

Accuracy of the empirical relationship was verified using time series images of 2nd, 4th and 6th November 2001. For the first 48 hr (*i.e.* from 2nd to 4th), calculated and measured distances were 11.02 and 13.31 km respectively (wind speed was 6.25 m.s^{-1}). For the next 48 hr (*i.e.* from 4th to 6th) it was 20.35 and 18.08 km respectively (wind speed was 7.5 m.s^{-1}). Error of estimation was found to be reasonably less (12 %). As stated earlier, it was found that the direction of drift was offset by up to ± 20 degrees from the direction of wind. Calculated and observed positions of the feature are marked by '*' and '+' respectively in Fig. 5. As observed from the figure, a reasonably good estimate of updated mesoscale fronts can be obtained since the features are spatially large. Since fishes tend to aggregate in chlorophyll and thermal fronts, ocean colour features demarcated from the satellite imagery are predicted as PFZs. Information about satellite-based PFZs reaches the end user after 24-48 hr due to time involved in data reception, processing and dissemination. Displacement of the mesoscale features can be calculated in two ways (1) by using equation 2 and (2) by manually measuring displacement and calculating speed from previous set of images. First method requires concurrent wind data, which is now available on a daily basis. Direction of movement can be obtained from the images of previous series. Once the displacement and direction are known, new location of the PFZ feature can be calculated based on the time delay between data reception and actual fishing operation. Region-specific relations can be computed for different regions to extend the technique. In shallow waters, the relation may not hold true due to turbulent flow. The results obtained from this study are encouraging and further improvement in accuracy can be achieved by incorporating the wind direction and bathymetry for modeling the surface currents.

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