Application of QuikSCAT SeaWinds data to improve remotely sensed Potential Fishing Zones (PFZs) forecast methodology: Preliminary validation results

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In this study, we used chlorophyll concentration and sea surface temperature (SST) images derived from IRS P4-OCM and NOAA-AVHRR, respectively, to delineate the oceanographic features exhibiting different oceanic processes. QuikSCAT-SeaWinds derived wind vectors were used to understand, establish, quantify and to demonstrate the variability of wind induced watermass flow as well as their impacts on features/oceanographic process. Oceanographic features like eddies, rings and fronts were found shifted as per movement and direction of the wind. The movement of water mass due to wind provides insight of environmental factors relevant to dispersal of fishery resources. An algorithm was developed to compute water mass transport and feature shift. Based on these studies an approach for incorporating QuikSCAT-SeaWinds data to improve PFZs forecast methodology has been developed. The improved PFZs forecast methodology was validated through near real time fishing operations. About 82-85% success rate was reported during validation experiments carried out during 2004. The improved methodology would prolong the validity of PFZs forecast.

[Key words: Ocean colour, OCM, SeaWinds, QSCAT, fishing zones]

Introduction

The promise of satellite remote sensing technology for marine research and management has been recognized since, the late 1960’s when the first visible and infrared images of Earth’s surface were obtained from orbit. However, it has been mostly in the last decade that significant strides, progress and expansion have been made in the utilization of satellite remote sensing for measuring and monitoring the ocean conditions. This utilization of satellite data has come primarily because of i) increases in the availability and improvements in the access to satellite data, ii) the development of easy to use satellite data processing and display techniques combined with low cost computer hardware systems and iii) the increasing awareness of the success in the application of technology to marine fisheries. Variations in the marine environmental conditions affect the distribution, abundance and availability of marine fish populations. Hence, in order to understand, model and predict the effects of ocean conditions on marine fish populations the information on the changing ocean is essential. The prediction of marine ecosystem structures and functions depends on a thorough understanding of the physical and biological processes which govern the abundance, distribution and productivity of the organisms on a wide range of time and space scales.

Synergistic analysis of SeaWiFS derived chlorophyll concentration (CC) and NOAA-AVHRR derived sea surface temperature (SST) showed that chlorophyll concentration features were coincided within temperature boundaries at some locations. Solanki et al. developed an approach for integration of chlorophyll concentration and sea surface temperature features for fishery resources exploration using OCM derived CC and AVHRR derived SST. The methodology for integration of CC and SST were validated through direct fishing and ~ 70% success rate was observed. In India, satellite derived chlorophyll concentration (CC) and SST are being used for operational fishery forecast by the Indian
National Center for Ocean Information Services (INCOIS, Hyderabad).

Wind induced ocean flow affect the oceanographic processes through surface-layer transport and vertical transport of water mass. The knowledge of the surface layer transport processes is important in fisheries because the dispersal mechanism controls the distribution of early life stages, thereby influence the recruitment and fishery stock. Wind velocity also affects the formation, persistence and decay of different types of oceanographic features. The shift in the oceanographic features due to wind was observed in OCM chlorophyll images.

Present study emphasizes on development of an improved PFZs forecast methodology with incorporation of QuikSCAT SeaWinds derived wind vector and its validation. The SeaWinds scatterometer uses a rotating dish antenna with two spot beams that sweep in a circular pattern. The antenna radiates microwave pulses at a frequency of 13.4 GHz across broad regions on Earth's surface. The instrument collects data over ocean, land, and ice in a continuous, 1,800-kilometer-wide band centered on the spacecraft's nadir subtrack, making approximately 1.1 million ocean surface wind measurements and covering 90% of Earth's surface each day. The SeaWinds scatterometer design used for QuikSCAT is a significant departure from the fan-beam scatterometers flown on previous missions (Seasat SASS and NSCAT). QuikSCAT employs single 1 m parabolic dish antennas with twin offset feeds for vertical and horizontal polarization. The antenna spins at a rate of 18 rpm, scanning two pencil-beam footprint paths at incidence angles of 46° (H-pol) and 54° (V-pol).

Materials and Methods

The study area is located on the Gujarat coast, (off NorthWest coast of India) which is part of the north Arabian Sea (Fig. 1). This area has a wide continental shelf and is known for of pelagic and demersal fisheries.

IR P4 Ocean Colour Monitor data during January – April 2004 were used to derive chlorophyll concentration. QuikSCAT Level 3 products produced by SeaWinds on QuikSCAT Science Working Team members were obtained from the QuikSCAT web site. QuikSCAT SeaWinds derived wind vector were used in the study to understand the shifting in the features. Surface wind data of Buoy (SW1, SW2 and DW1) (laid by of National Institute of Ocean Technology (NIOT, Chennai, India) in the study area were used for validation of satellite derived wind data.

Satellite sensor data analysis

**OCM data analysis**

The estimation of chlorophyll concentration from IRS P4 OCM includes a series of steps as reported
earlier. Atmospheric correction of OCM data was carried out using a method suggested by Gordon & Clark and modified by Mohan et al. The OC2 algorithm was applied to atmospherically corrected radiance for estimation of chlorophyll concentration.

**QSCAT-SeaWinds data analysis**

Space borne scatterometers transmit microwave pulses to the ocean surface and measure the backscattered power received at the instrument. Since the atmospheric changes themselves do not substantially affect the radiation emitted and received by the radar, scatterometers use an indirect technique to measure wind velocity over the ocean. Wind stress over the ocean generates ripples and small waves, which roughen the sea surface. These waves modify the radar cross section ($\sigma_0$) of the ocean surface and hence the magnitude of backscattered power. In order to extract wind velocity from these measurements, one must understand the relationship between $\sigma_0$ and near-surface winds — this relationship is known as the geophysical model function.

QuickSCAT SeaWinds level 3 data for the study was taken from NASA’s website. This data consist of 25 km² gridded values of scalar wind speed and corresponding meridional and zonal components of velocity. The U and V component data containing file is in HDF (Hierarchical Data Format) format. This was converted into ASCII format data file. The wind vectors were plotted using surfer software and these vectors were overlaid on the chlorophyll images.

**Validation of SeaWinds data**

QuickSCAT SeaWinds derived wind speed was validated with buoy data. The buoy data of February and March 2004 were procured from NIOT, Chennai, for buoy SW1, SW2 and DW1. The correlation co-efficient was derived through regression analysis.

**Feature tracking and shift analysis**

Oceanographic features were delineated on the OCM derived chlorophyll concentration. Well-defined prominent features were identified and marked on the images. They were monitored using time series data. This allows us to understand the temporal variations in the meso-scale features. The displacement in terms of distance and direction were measured in the subsequent images. The observations of distance were used to calculate the speed of drift of each feature per day. Correlation analysis between wind speed and drift was performed to derive co-efficient. An algorithm was developed using these co-efficients to estimate the shift in location of the feature.

**Validation of shift prediction**

Validation of shift prediction was made using near real time series data analysis. The predicted coordinates of features due to shift were marked on images. The actual location of shift in feature position was marked in images on subsequent day images. The distance of predicted and actual position was calculated and used for error computation.

**Wind-driven currents and mass transport**

Steady winds blowing on the sea surface produce a thin, horizontal boundary layer and the Ekman layer. Effective frictional force exerted by the wind upon the ocean surface results in the wind-driven currents. These currents flow 45° of the wind direction and the current velocity decreases rotating clockwise with depth. For neutrally stable boundary layer, the stress exerted by the surface wind (at 10 m above the sea surface) can be estimated for an approximate average air density ($\rho_a$) using the relationship between the drag coefficient ($C_D$) and wind speed ($W_{10}$). We used variable drag coefficient by Yelland & Taylor.

\[
C_D = \begin{cases} 
0.29 + \frac{3.1}{W_{10}} + \frac{7.7}{W_{10}^2} & \text{for } (3 \leq W_{10} < 6 \text{ m s}^{-1}) \\
0.60 + 0.07W_{10} & \text{for } (6 \leq W_{10} \leq 26 \text{ m s}^{-1})
\end{cases}
\]  

Knowing the wind stress, the wind-driven surface currents can be calculated using the Ekman's solution, the simplified form relating the surface current and wind stress can be written as:

\[
\bar{V}_0 = \frac{\bar{\tau}}{\sqrt{\rho_w A_z f}}
\]

where, $\rho_w$ is the seawater density (~1025 kg m⁻³); $A_z$ is vertical eddy viscosity coefficient (~10²;
Hastenrath & Greischar; \( f \) is the Coriolis parameter (varies as a function of latitude). The surface currents flow at 45° right (left) of the wind direction in northern (southern) hemisphere. The zonal \( (u) \) and meridional \( (v) \) components of surface current will be

\[
u(0) = V_0 \cos\left(\frac{\pi}{4}\right); \quad v(0) = V_0 \sin\left(\frac{\pi}{4}\right)
\]

\[\ldots (4)\]

Flow in the Ekman layer at the sea surface carries mass. Calculation of mass transports is much more robust than calculations of velocities in the Ekman layer, and that the results are more likely to be correct. Thus one need not know the velocity distribution in the Ekman layer or the eddy viscosity for calculating mass transport. The Ekman mass transport \( M_E \) is defined as the integral of the Ekman velocity \( u(z), v(z) \) from the surface to a depth ‘\( d \)’ below the Ekman layer. The two components of the transport are \( M_{Ex}, M_{Ey} \): 

\[
M_{Ex} = \int_{-d}^{0} \rho u(z) dz; \quad M_{Ey} = \int_{-d}^{0} \rho v(z) dz \quad \ldots (5)
\]

However, a few hundred meters below the surface the Ekman velocities approach zero. Thus, mass transport is due only to wind stress at the sea surface \((z = 0)\). So The two components of the Ekman mass transport can be calculated easily, if we incorporate the momentum equations for a homogeneous, steady-state, turbulent boundary layer above or below a horizontal surface in Eq (5):

\[
M_{Ey} = -\frac{\tau_{xz}(0)}{f}; \quad M_{Ex} = \frac{\tau_{yz}(0)}{f}
\]

\[\ldots (6)\]

where, the symbols have their usual meaning.

**Approach development**

An approach was developed based on above studies to incorporate QuikSCAT-SeaWinds derived wind information to improved PFZS forecast methodology. This approach required the analysis of wind vectors from wind speed and direction, computation of shift in features using shift algorithm and wind driven surface mass transport computation to generate the vectors of surface current from wind speed and direction. The buffer of predicted shift in feature could be assigned based on the shift computation and direction of the wind driven currents. The shift of features was incorporated to improve PFZs methodology.

**Validation of methodology**

PFZs forecasts based on incorporation of feature shift and water mass transport were suggested for near real time fishing operations. The fishing was carried out by FSI fishing vessels. Fish catch data of fishing operation were normalized to compute CPUE (Catch Per Unit Effort). The mean CPUE in PFZs were compared with mean CPUE of non-PFZs. Per cent success rate was calculated based on these comparison.

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**Fig. 2**—Feature displacement due to wind speed. Features marked as 1, 2, and 3 are monitored in for feature shift analysis to develop an algorithm to compute probable shift in the feature.
Results and Discussion

Shift in the features

The shift in the features was monitored using time series data of OCM derived chlorophyll concentration. Wind vectors of respective date were overlaid to understand the impact of wind of the shifting feature. Figure 2 shows the typical image showing the shift of features during February 23 – March 25, 2003. The features marked as 1, 2 and 3 in the circle were monitored for the shift due to surface wind. We have used different data for development of equation. Correlation between wind speed and speed drift of feature yielded $r^2 = 0.82$ (Fig. 3). The displacement of the features can be calculated from the following equation.
Displacement of feature (km/day) =\(1.3668X + 1.7422\) ... (7)

where \(X\) = wind speed (m.s\(^{-1}\))

Here the displacement in feature due to wind speed and direction only considered. However, displacement of feature or mass water transport also depends on the feature type, strength of feature (energetic consideration of features like energetic eddies), their persistence and the biological production status. Some features indicated increasing trend and some showed decreasing trend in chlorophyll concentration within a particular feature. This may be due to developmental stage of different type of feature and time lag between the formation of features and maturation.

Validation of QuikSCAT-SeaWind derived surface wind

The correlation of wind speed derived from QSCAT-SeaWinds and buoy indicated the correlation co-efficient \(r^2 = 0.78\)

Water-mass transport

The water mass transport was computed as per Eq. 6 using satellite derived wind speed and direction. The output of horizontal water-mass transport at surface has been showed in Fig. 4. This image indicates the direction and speed of the wind as well as surface current. This gives the directional information as well as horizontal transport of features. This information is input in improved PFZs forecast.
methodology along with the feature shift computation (Eq. 7) for prediction of PFZs.

**Validations of feature shift**

The feature shifts in the images were computed based on the wind speed and direction derived from QSCAT-SeaWinds data. The direction of the surface water mass transport was considered for the directional shift of the features. The predicted shifts in the features were assigned the buffers. After the satellite pass the buffers of predicted shifts were overlaid. This enables to understanding and to measure the actual error in shift prediction in the features. The predictions of shifts in the features are with assumption that the wind speed is not changing abruptly during the prediction period. Our observations during February and March 2004 show that the wind speed is not changing drastically for four to five days. About 67% observations were found within the range of the predictions of feature shifts, about 15% features were dissipated with time and about 18% observations were out of the range of the estimated shifts. The typical observations of predicted shift and actual shift in features are shown in Fig. 5.

**Improved PFZs forecast methodology**

Surface wind influences the circulation and transport of the fish egg and juveniles of fishes. Circulation has major impact on the primary production in the euphotic zone due to nutrient enrichment. Surface winds displace the feature, which are important for accumulation of fishery resources. Hence, winds play very important role in distribution of fishery resources and ultimately fish production. The purpose of the inclusion of wind in the present methodology is to predict the shift of features due to water mass transport, which influence the PFZs positions. The estimated shift was included in PFZ forecast methodology (Fig. 6), so as to ensure the prolonged validity of PFZs forecast. The limitations are the abrupt change in the atmosphere, which influence the wind speed and direction. The improved methodology assumes that surface wind speed and directions are not changing very fast temporally. Our observation indicated that the wind speed is not changing very fast abruptly except some episodic events like cyclones, during the season/month. So the assumption is that the wind speed and directions are more or less same for 4-7 days. About 67%
observations indicated shifts within the ranges of predicted areas, this indicates that the PFZs can be prolonged for four to five days.

Results of forecast methodology

Table 1 indicates the fishing efforts in PFZs and the month wise success rate observed during validation experiment carried out during 2004. There is an increase of ~ 12% in success rate due to inclusion of satellite wind data as compared to integrated approach suggested by Solanki et al\textsuperscript{2,3}. Wind fields are most useful in determining the direction and velocity of phytoplankton, zooplankton, fish eggs, juveniles of fishers and nutrient transport. The large-scale wind patterns can provide information critical to determining the movements of surface oceanic features. Winds are the major factor in the initiation of the major oceanic bio-physical processes by mixing the water column. The results of validation experiment indicate that impact of wind on fishing ground can be taken care by this methodology to some extent. Further field validation is suggested for proven technology development.

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References


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<th>Sr. no.</th>
<th>Month</th>
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<th>Suggested areas</th>
<th>Validated areas</th>
<th>No. of Observations</th>
<th>No. observations consist of more CPUE in PFZs</th>
<th>Monthly mean CPUE in other areas (kg/hr)</th>
<th>Monthly mean CPUE in PFZs (kg/hr)</th>
<th>Success Rate (%)</th>
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