

Tidal currents mapping and residual currents using VHF radar measurements in the Normand Breton Gulf (France)

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ABSTRACT

This paper presents an analysis of very high frequency (VHF) radar measurements of sea surface currents acquired during the EPEL program (Evaluation and Forecasting of the coastal environment), supported by the SHOM (French Naval Hydrographic and Oceanographic Service). Evaluation of the VHF COSMER radar performances has been made in a region dominated by tides and strong tidal currents. Tidal components were extracted from one month measurements by harmonic analysis. Residual surface currents were mapped and simulation of lagrangian trajectory for particles is presented to evaluate performances of this measurements in operational mode of coastal surveillance.

KEYWORDS: VHF radar, surface currents, Doppler, remote sensing, ground wave radar, residual currents.

1. INTRODUCTION

To improve coastal environment control, regional coastal hydrodynamics models for representing circulations, sea levels and sea states (Forecasting), as well as quantitative or qualitative systems of measurement (Evaluation) are required. Remote sensing by High Frequency (HF) and Very High Frequency (VHF) radars (typically between 5 and 50 MHz) is an important tool available now for about several decades (Crombie 1955, Barrick et al., 1977). HF radar surface currents measurements are representative of the total horizontal current, i.e. the interactive sum of geostrophic, tidal, wave and wind generated components, which include influence of the weather conditions and circulations on a large scale. Their principal advantage is to provide quasi real time measurements on maritime surface going from a few hundreds of km² to several thousands of km² within the direct vicinity of the coast. Measurements are made with high spatial and temporal resolution. In operational mode, the radar is at sea level, on the shore and the propagation of the electromagnetic signal is mainly done by ground wave propagation. HF radars are able to estimate wave spectrum, currents velocity and wind direction. Surface ocean currents are calculated using the “Bragg scattering” principle for the sea-surface gravity waves. Bragg scattering is a coherent reflection of energy transmitted by ocean surface waves traveling away from or towards the radar, the wavelength of which is exactly one-half the transmitted radar wavelength. The echo Doppler spectrum consists of two distinct peaks, symmetrically positioned about the radar frequency. In the absence of ocean currents, the Doppler frequency shift always occurs at a known position in the frequency spectrum and the frequency f_v of the two peaks is given by

$$f_v = (g / (\lambda_{radar}))^{1/2} \quad (1)$$

where λ_{radar} is the radar wavelength and g is the acceleration due to gravity.

If there is a surface current, the frequency of the scattered signal is shifted. Doppler frequency shift depends on the velocity of the component of the current moving towards or away from the radar:

$$\Delta f = 2 \frac{\Delta v}{\lambda_{radar}} \quad (2)$$

where Δv is the radial component of the effective surface current.

To allow calculation of the resultant surface current speed and direction, it is necessary to combine the components along two radar beams coming from two radar stations. Computed surface vector current maps are particularly useful for the validation and calibration of numerical hydrodynamic models, because the models produce average currents over the water column and over grid spaced pixels in the same style as the currents maps. For this study, different aspects of the measurement were analyzed, such as extraction of tidal components and residual surface currents, considering the importance of the influence of meteorological conditions. Radar measurements get an important role in term of operational surveillance, because of their high temporal resolution (every 30 minutes) and large scale domain. Thus, we choose to present a study of lagrangian circulation made using General NOAA Oil Modeling Environment software (ASCE. 1996) for several situations, such as spring tide and neap tide period.

2. EXPERIMENT

A very high frequency coastal radar operating at 45 MHz and 47.8 MHz was deployed during the program EPEL (Evaluation and Forecasting of the coastal environment), supported by the SHOM (French Naval Hydrographic and Oceanographic Service). VHF COSMER radar (Oceanic Surface Currents Measured by Radar) is a radio-oceanographical instrument, developed by the LSEET group (Laboratoire de Sondages Electromagnétiques de l'Environnement Terrestre, University of Toulon, France). This system includes two VHF Doppler radars, set on the coast. It allows the mapping of ocean surface currents in a coastal area of about 25 km by 25 km. The pulse and beam width determine the horizontal resolution of several kilometers. The radar yields spatially and temporally averaged surface currents measurement. In operational mode (Table 1), coastal ocean surface currents were mapped over the domain with radial resolution of 600 m and beam width of 14° (8 phased array antenna). The radar derives vertically averaged quantity over 0.25m depth. Measurements were made at 30 minutes sample intervals (integration time: 9 minutes). Eastward and northward components of ocean surface currents were estimated on a 1 by 1 km grid. Radar measurements were acquired continuously during 28 days, including spring tide, and surface currents maps were sent daily, in quasi real time, on the Internet site of the SHOM (<http://www.shom.fr/>) throughout the period. Normand Breton Gulf is well-know for the highest tide in Europe (SHOM, 1996, Orbi, 1986). This experiment shows the influence of tidal currents on the Bragg waves (gravity waves: 3 m - 0.7 Hz - group velocity: 1.1m/s) as well as on the total wave spectrum.

From February 24 to March 23, 2003, surface currents measurements by VHF COSMER radar have been acquired continuously in Normand Breton Gulf. The locations of the two radars are shown in Fig.1. One of the radar has been deployed in north of Cancale (Pointe du Grouin, 48°42'N, 1°50'W) and the other in north Saint-Malo (Pointe de la Varde, 48°41'N, 1°58'W). Fig.1 also shows surface currents maps as measured during the period. In both images, the arrows represent speed and direction of the surface velocity. On the left, the image represents surface currents for the maximum flow (speed around 2m/s) at spring tide (March 22, 2003 19:00 UT+1) and the image on the right is for the maximum ebb, at neap tide (March 13, 2003 09:30 UT+1).

3. DATA ANALYSIS

Semidiurnal tidal components were extracted from one month measurements by harmonic analysis, based on the least square method. This is a mathematical process by which the observed tide or tidal currents at any place is separated into basic harmonic constituents. Currents are analyzed by using the same process as tides' analysis. The dominant astronomical tidal components are semi-diurnal tidal waves M_2 and S_2 (largest amplitude). The largest component M_2 is shown as tidal ellipses in Fig. 2. These tidal ellipses are particularly useful for calibrating the numerical models. Using harmonic analysis in radar measurements, many tidal constituents are determined. As expected, the semidiurnal M_2 tidal currents dominate the surface currents, with mean amplitude of 80 cm.s^{-1} . Spatially, the M_2 tidal currents ellipses were coherent over the VHF radar domain, except in an area in the northern and eastern region, classified as "anomalous regions". In this regions, in eastern direction, certain anomalous behavior in the Doppler spectra appeared, mainly due to side lobes in antenna pattern and presence of sea water (Mont Saint Michel Bay). The validity of these maps is demonstrated by comparison with known tidal flows in Normand Breton Gulf.

Subtracting the tidal signal due to the harmonic components leaves the residual current shown in Fig. 3. These surface residual currents are representative of the period of time measurements, as well as meteorological conditions. In order to integrate this information in numerical models, it would be important to have larger period of measurements, which could include more atmospheric variations. At least, one year period would be necessary.

Using the measurements, simulation of a particle trajectory has been done. For this study, the General NOAA Oil Modeling Environment (GNOME) has been used. This is an oil trajectory model that predicts how wind, currents, and other processes might move and spread oil that has spilled on the water. This software is available on the internet (<http://response.restoration.noaa.gov/software/software.html>). In this study, it is interesting to show trajectory of a particle taken in a precise point, at the period of neap tide, spring tide and to compare the time taken by the particle to leave the area of measurements. Several simulations were made. Fig. 4 shows three different trajectories: the red line simulates a trajectory for a particle released with the position $48^{\circ}46'N$, $1^{\circ}54'W$ at time of high water (1:24, UT+1) on March 13, 2003, in period of neap tide. The blue line simulates a trajectory for a particle with the same initial position as previously, released at time of high water (8:34, UT+1) on March 20, 2003, in period of spring tide. Each point of the curves corresponds to a position every hour. It is noted that the ways carried out by the particle in period of spring tide, are much larger than those of neap tide. The particle spends 9 hours (on March 13, 2003) and 4 hours (on March 20, 2003) to leave the field of measurement, carried by the ebb. It is also interesting to observe the drift of a particle in the course of time. This simulation is made in period of neap tide. The green curve on Fig. 4 represents a simulation of trajectory of particle taken with the position $48^{\circ}45'N$, $1^{\circ}53'W$. This simulation begins on March 10, 2003 at 11:00 (UT+1) and is made, like the previous ones, without wind influence. To date, the high water is estimated at 10:50 (UT+1) and the low water at 17:36 (UT+1) in period of neap time on March 13, 2003. The particle, released close to the coast, then takes a trajectory towards the North-West, carried by the ebb, then towards the North-East, carried by the flood. When in North, the particle takes a different trajectory, directed South-western with the ebb and South-east with the flood. The particle leaves the field of measurements of the system after 68 hours. The precise weather data not available, simulations were made with and without wind. Simulations including wind influence (not shown) showed a division of the particle in several parts, throughout its trajectory. This model also shows how spilled oil is predicted to change chemically and physically ("weather") during the time that it remains on the water surface. Other simulations have been made during this study (not shown), including oil spill, with or without wind. GNOME creates and displays an oil spill animation showing the predicted trajectory of the oil spilled.

4. CONCLUSION

This project performed the evaluation of VHF COSMER system performances in dominated tides area, where phase speed of deep ocean waves are stronger than group velocity (velocity of deep ocean wave packets). These evaluations proved the capability in mapping coastal ocean surface currents and in extracting tidal components for amelioration of numerical models. Radars offer good opportunity for control and operational survey. In order to make residual surface currents more accurate, a longer time period of measurements should be necessary, as long as several meteorological conditions may be integrated. Further work is to be done to validate VHF radar measurements, by comparing numerical models and in situ measurements (such as Current Meters – CM – and an Acoustic Doppler Current Profiler (ADCP), deployed on the bottom of the sea (around 20 m depth) during the experiment) (Cochin et al., 2004). A new aspect in the use of HF radars measurements as an operational oceanography tool in real time is in preparation. This work is about to use high temporal resolution and large scale domain of the radar measurements to implement new algorithms in detection of anomalies (outliers). Perspectives of such works are to detect changes over the sea surface, such as ship or oil pollution (Cochin et al., 2004).

5. ACKNOWLEDGEMENTS

The authors gratefully acknowledge SHOM and particularly Fabrice Arduin, Annick Pichon, Ronan Le Roy, Bernard Simon, Lucia Pineau and Michel Le Goff for providing data sets and for help in performing some of the harmonic analysis. Tidal components were extracted using software developed at SHOM.

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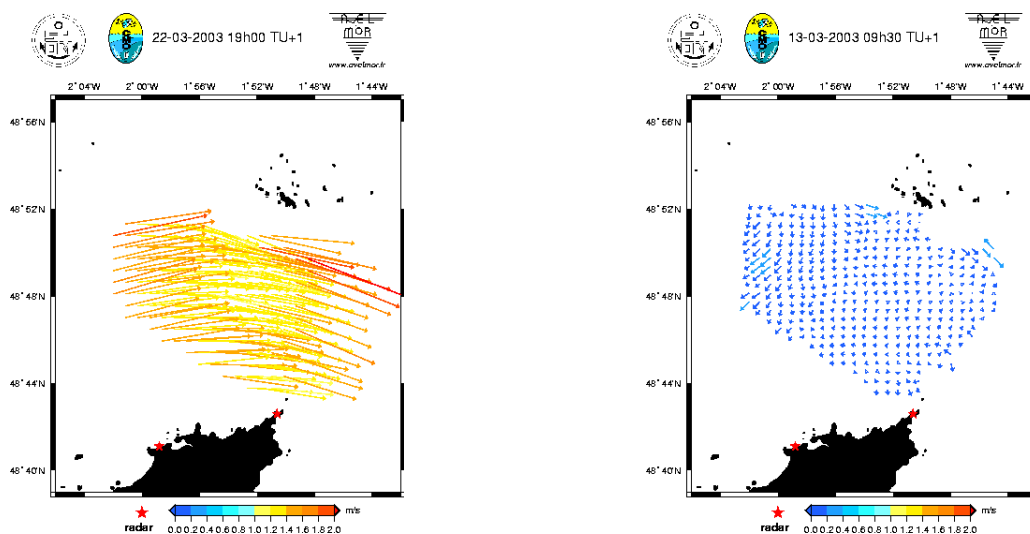


Figure 1 :

Currents surface mapping by VHF COSMER radar on March 22, 2003 at 19:00 (TU+1) (left) and march 13, 2003 at 9:30 (TU+1) (right). The arrows represent speed and direction of surface velocity.

Operating frequency for COSMER	45 MHz / 47.8 MHz
Radar wavelength	6.66 m / 6.27 m
Length of sea surface wave (Bragg)	3.33 m / 3.13 m
Average power	30 W
Pulse repetition rate	200 μ s (5 KHz)
Pulse length	4 microsecondes
Range	30 km
Radial resolution	600 m
Depth over which current is averaged	0.25 m ($I_{radar} / 8p$)
Transmit network : « endfire »	4 whip antennas $I_{radar} / 4$, beam width : 90 degrees (-3 dB)
Receive network : « broadside »	8 whip antennas $I_{radar} / 4$, (spacing : $I_{radar} / 2$)
Azimutal resolution (Beam forming)	+/- 7 degrees (-3 dB)
Sampling	30 minutes
Calcul Doppler spectrum :	FFT : 256 points, Sampling frequency : 3Hz, Frequency resolution 0.01 Hz
Integration time	9 minutes

Table 1 :

VHF COSMER system characteristics in operational mode during EPEL-GNB project.

M2 tidal component - from 24-02-2003 09h30 to 24-03-2003 08h00 TU+1

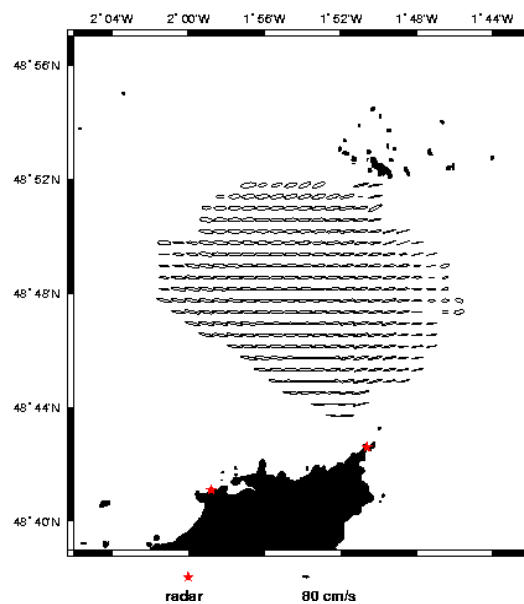


Figure 2 :

Tidal ellipses M2 for VHF radar data for of one month measurements (February - march 2003)

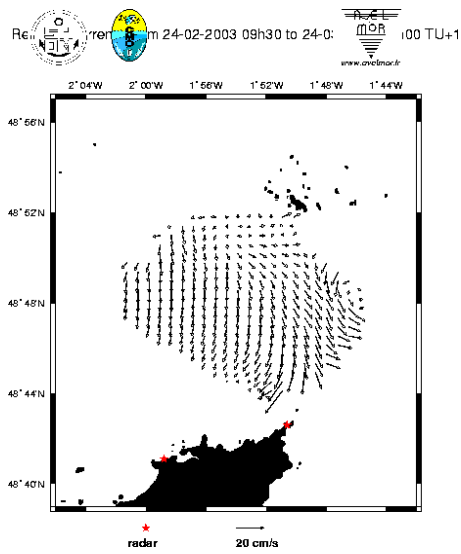


Figure 3 : Residual surface currents map, representative of one month measurements (February - march 2003), which includes weather conditions for that time.

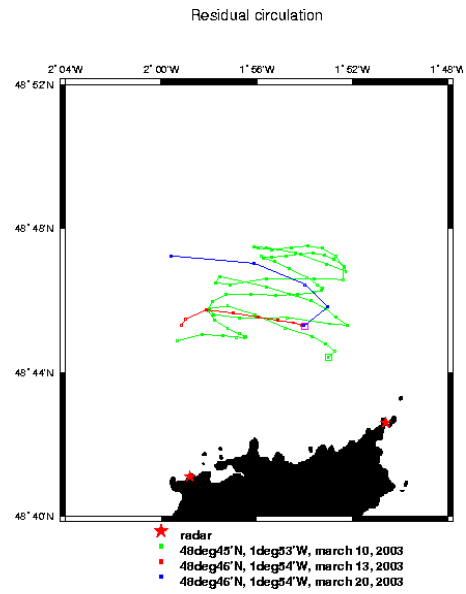


Figure 4 : Lagrangian circulation map. Simulation of particles trajectories made in neap tide (red), ebb tide (green) and another phase (blue).