EVALUATION OF LONG-TERM OBSERVATION OF OCEANIC CURRENTS IN THE COASTAL AREAS OF THE OMAN SEA (MOKRAN COAST) USING COASTAL HIGH- FREQUENCY RADARS

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ABSTRACT:

Ocean currents are of interest to all who deal with marine affairs. Since they can be predicted, as a result, they are essential as renewable energy for us. We can use it in many applications like navigation, generating electricity, and port constructions. So, studying them and discovering the factors that create and influence them is significant. Using the instrumentation that we can use continuously and do not have many problems is preferred. Therefore, using new technologies instead of old traditional methods is crucial. In this study, we discuss ocean currents in the Oman Sea, suggest high-frequency radars (HFR) as new technology, and represent its advantages instead of ADCP. We use Mike 21 to get tidal current constituents and compare them with other data. The results show that values of two components, Mm and MSF, are more respective to astronomical-driven currents. Therefore, the amount of tidal current on the coast of Mokran is low, and other factors cause the current, which short-term observations in this region cannot be achieved. Thus, we need data in a more extended period to find present generating forces and predict them. HFR can be an efficient and valuable tool in such areas.

1. INTRODUCTION

One of the waters moving in oceans is the tidal current. Two essential factors influence tidal current. The astronomical factor is a periodic component, and it is due to the Moon and Sun's forces that are related to their location (Foreman, 1979). The random factor, for example, wind, temperature, etc., are categorized as metrological parameters. As regards tidal current depends on the Moon and Sun's situation; when Moon, Sun, and Earth are located in a line, we have "perigean current," and when they have a 90-degree angle, we have "apogean current." The apogean current is an overall trend weaker than the perigean current (Foreman, 1979). Or when we have a new or full Moon, the tidal current speed is high, called "spring current" (Foreman, 1979). In contrast, when Moon is located in the first or third quarter phase, the speed of the tidal current is weak and called "neap current" (Foreman, 1979). An important factor influencing tidal current is bays' shape and physical factors. (currents2, 2022). Also, earth circulation leads to Coriolis force that causes the tidal current in the northern hemispheric to turn to the right and in the southern hemispheric is completely vice versa(currents, 2011). We can measure the tidal current, drive constituents, and predict it for many applications. There are two types of current measurement a) Eulerian method: record in-depth as pointwise, linear, and profile. b) Lagrange method: record on the surface in any place with a drifting buoy (Ohlmann, White et al., 2007). ADCP (Acoustic Doppler Current Profiler) is a device that measures current speed and direction based on the Doppler effect (Fig. 1) ((ADCP), 2022). It is usually installed on the sea bed and records currents in different cells' profiles. ADCP has a high cost for maintenance, but its temporal resolution is increased. Satellite altimetry can measure currents on a large scale but has disadvantages, including low accuracy, unsuitable for coastal areas, and impractical atmospheric effects (Liu and Weisberg, 2007; Vignudelli, Cipollini et al., 2005). High frequency radar (HFR) is used as a new method in recent years. Between 2000 and 2010 HFR were accepted as practical and reliable device (Roarty, Cook et al., 2019). In 2012 the Global HFR Network was constituted as part of the Group on Earth (Roarty, Cook et al., 2019). In 2017, worldwide HFR was introduced as an observer of the Global Ocean Observing System (GOOS) by Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM). Paduan and Washburn (2013) examine the detection and improvement of HFR. HFR can measure surface current to the radius of 200 km with a 3-50

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(MHZ) frequency that is harmonized with the wavelength of electromagnetic wave that origin is wind in the ocean. In the research on the Rhine River, ocean currents measure with a coastal radar called WERA. It has been expanded by SCAWEX (surface current and wave variability experiment) (Gurgel, Antonischki et al., 1999). There are two radars installed in north and south of Rhine that have a high temporal resolution (9-18 min) (Gurgel, Antonischki et al., 1999). WERA is the advanced version of CODAR (Coastal Ocean Dynamic Application Radar) that has more flexibility. Also, it quickly measures the current surface with an intended algorithm helpful in studying ocean dynamics in coastal areas (Gurgel, Antonischki et al., 1999). Research conducted in Monterey Bay mentioned that the difference between ADCP and HFR is because of the wind (Paduan and Rosenfeld, 1996). The use of CODAR and its good accuracy are mentioned for long _term studies and real-time applications (Paduan and Rosenfeld, 1996). This study aims to evaluate the benefits and use of HFR in the Oman Sea and suggest suitable locations.

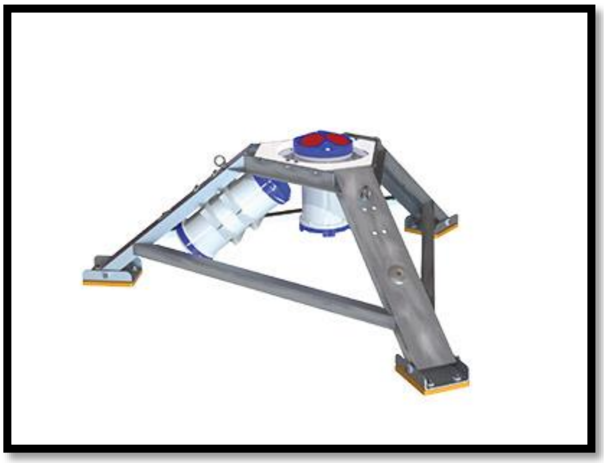

Figure 1. An example of an ADCP device (news, 2018).

2. HIGH-FREQUENCY RADARS

HFR is part of the latest and the most effective method for measuring physical oceanography that is a science for studying physical and dynamical characteristics like salinity, density, and temperature as well as surface currents (Roarty, Cook et al., 2019). They are appropriate for coastal areas and have no other methods gaps (Fujii, Heron et al., 2013). They install on coasts and record data remotely. They use radio waves that have high frequency (3-50 MHz) and, depending on the type of frequency, can measure from 500 (m) to six (km) (Currents, 2022). HFR send signals to the ocean and then receive them for measurement. Further, they collect data every hour that indicate time resolution, but there is high temporal resolution too. One of the most critical parameters that HFR record is ocean current (Gurgel, Antonischki et al., 1999; Paduan and Rosenfeld, 1996). According to the extracted information, speed and direction can be predicted simultaneously. But note that only components are predictable and other parameters like density and salinity need different measurements (Currents, 2022). HfR's accuracy for speed is 10(cm/s) and for direction is 10 degrees (Currents, 2022). It is also worth noting that the most significant factor that causes the difference between observed current and predictions is wind, and the following parameter is local metrological (Currents, 2022). HFR has many usages, for instance: Ocean surface current (Gurgel, Antonischki et al., 1999; Paduan and Rosenfeld, 1996), trace oil stains (Abascal, Castanedo et al., 2009), and other pollution, navigation, and marine traffic (Breivik and Sætra, 2001), environment management, coastal circulation, monitoring climate change, map of wind direction , prediction of the storm and tsunami (Gurgel, Dzvonkovskaya et al., 2011; Lipa, Barrick et al., 2006), designing precise military operations at sea, ocean modeling, port constructions, detection of ship (Maresca, Braca et al., 2013; Ponsford, Sevgi et al., 2001)oil platform, pipeline laying, dredging, energy harvesting (Rivera, Felix et al., 2020). HFR receiver antenna is stable because of the radio wave wavelength. Two procedures are used in the HFR systems: Direction funding that compares experimental phase and amplitude with an inversion algorithm of different direction-finding like CODAR (Barrick and Lipa, 1985; Roarty, Cook et al., 2019). Beam formatting: with the Least square method, adjust the phase and amplitude of the received signal to calculate direction like WERA, LERA, Pisces, and OSCAR (de Paolo and Terrill, 2007; Roarty, Cook et al., 2019). Frequency is directly related to the height

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of the wave. In other words, the higher the frequency, the greater the ability to determine the size of the wave (Lipa and Nyden, 2005). Also, suppose the frequency is lower than the threshold, leading to environmental noise affecting it, and estimating the wave height will be wrong, or the frequency is higher than the threshold. In that case, we will not be able to interpret spectra (Roarty, Cook et al., 2019). HFR systems are different in terms of transmission approach and use distinct forms of waves like pulse continues (C.W.), frequency modulated continues (FMCW), and interrupted (FMICW) (Mantovani, Corgnati et al., 2020). According to these approaches, we can choose separated or co-located receiver and transmitter antenna and resolving methods (Mantovani, Corgnati et al., 2020). Considering that a wide area of the territory of Iran with a length of more than 5800 km is formed by the shores of the Caspian Sea, the Persian Gulf, and the Sea of Oman, as well as the existence of vast sources of oil and gas reserves, the high volume of ship traffic, the strategic location and rich environmental resources in these coasts and water bodies, the necessity of building HF oceanographic radars and creating radar networks wide oceanography across the beaches of the Persian Gulf, the Oman Sea and the Caspian Sea are revealed. There are more than 400 HFR worldwide, and in the middle east, Saudi Arabia, with six radars in the Red Sea, is the leader (Roarty, Cook et al., 2019).

Figure 2. An example of high-frequency radars (Noaa, 2022).

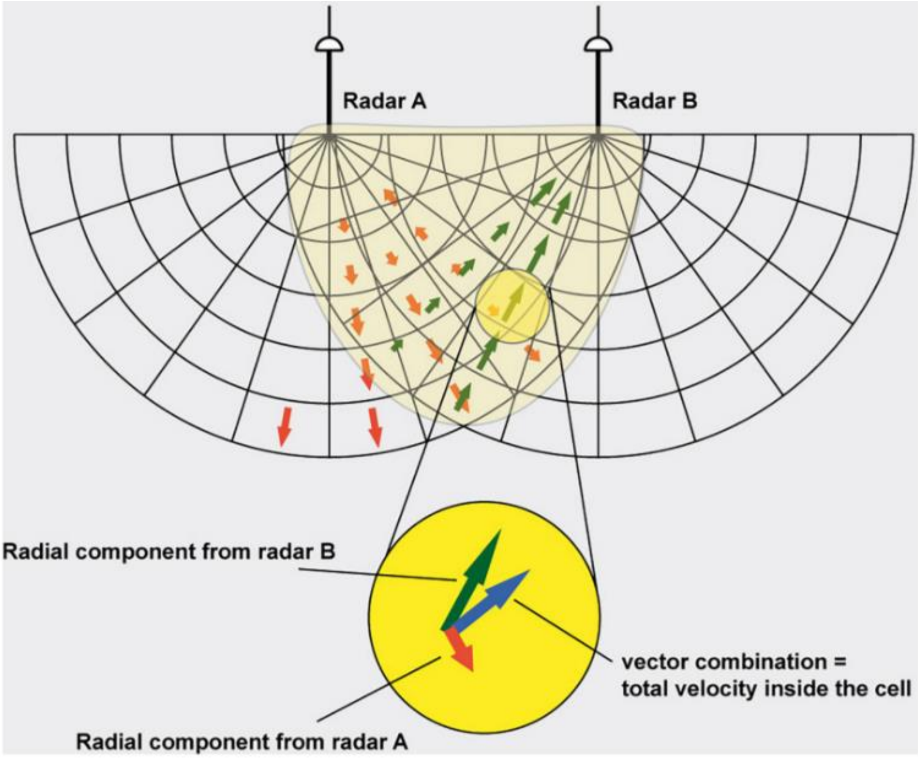

Figure 3. The concept of surface current extraction from two HFR site networks (Mantovani et al., 2020).

3. DATA

This study uses Oman's current sea tidal data from 2016/03/12 until 2016/04/25. The in-situ station Tang location with X= 790213 and Y=2802990 with 25 (m) depth is shown in Fig. 4. Also, we record three types of tidal current, surface, bottom, and middle, each one concludes current speed and current direction.

4. CASE STUDY

In this paper, our case study is Oman's Sea, a region bounded on the west by the Persian Gulf, on the north by Iran, on the east by the Indian Ocean, and on the south by Oman. It has 545 (km) in length and 181000 (m^2) in total area (Zahed, Rouhani et al., 2010). In contrast, it has more depth than the Persian Gulf. Oman's sea depth around the Chabahar is approximately 3398 (m). When we move to the west side, its depth decreases dramatically, so that near the strait of Hormoz reaches 73 (m). Iran's coastline adjacent to the Oman Sea is about 637 (km), and the maximum depth in the coastal waters of Iran gets to over 2000 (m).

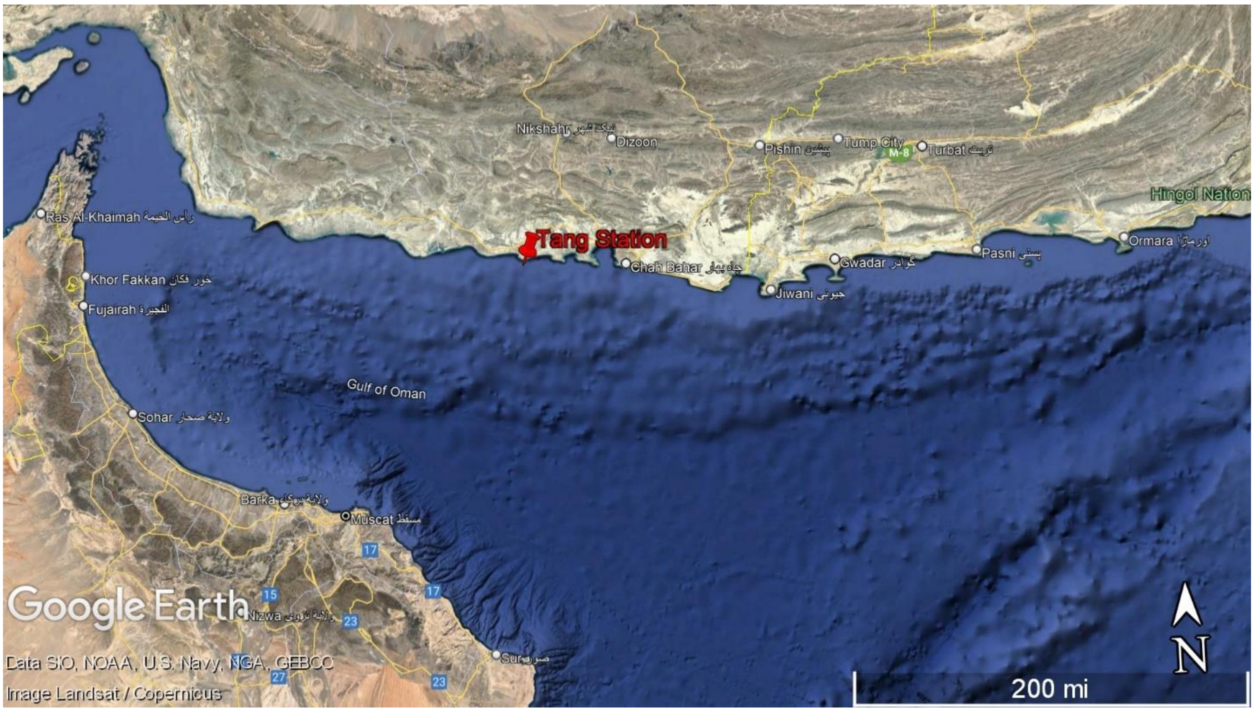

Figure 4. Tang station

5. METHODOLOGY

At first, we plot our current observation (speed and direction) with MATLAB (Fig. 5). It is evident that there is no periodic trend in our data. Then we calculate constituents (Fig. 6) with mike21 Tidal tools to see the prominent tidal components (M2: Principal lunar semidiurnal component. This component represents the rotation of the Earth concerning the Moon; S2: Principal solar semidiurnal component. This element represents the rotation of the Earth concerning the Sun; K1: Lunisolar diurnal constituent. This component, with O1, expresses the effect of the Moon's declination. They account for diurnal incongruence and, at extremes, daily tides. With P1, it describes the impact of the Sun's declination; O1: Lunar diurnal constituent) (Oceanic and . 2000) and compares results with other stations to discover what is happening in the Oman sea.

6. RESULTS

By comparing the results obtained from the calculation of tidal constituents, we understand that in the Oman Sea, current constituents appear completely different from what we expected (Fig. 6). The component of Mm expresses the efficacy of irregularities in the Moon's rate of change of distance and speed in orbit (Oceanic and . 2000) and MSF (Lunisolar synodic fortnightly constituent) (Oceanic and . 2000) are seasonal components as well as more effective as a result in short period time while the main tidal current constituents are weak in this area. In Tang station, we have so weak tidal current; the rest is shelf current with an oceanic source like weather, density, wave and etc. So, we need more long-term observation to find the behavior of currents in the Oman Sea. But in Shahid Rajaei's and Tang ports, four constituents (M2, S2, K1, O1) (Fig. 6) that are the main tidal currents constituent are significant. In this port, the tidal current is dominant. Moreover, N2 (Larger lunar elliptic semi-diurnal constituent) (Oceanic and . 2000) is one of the most important constituents is 0.0922 (m/s).

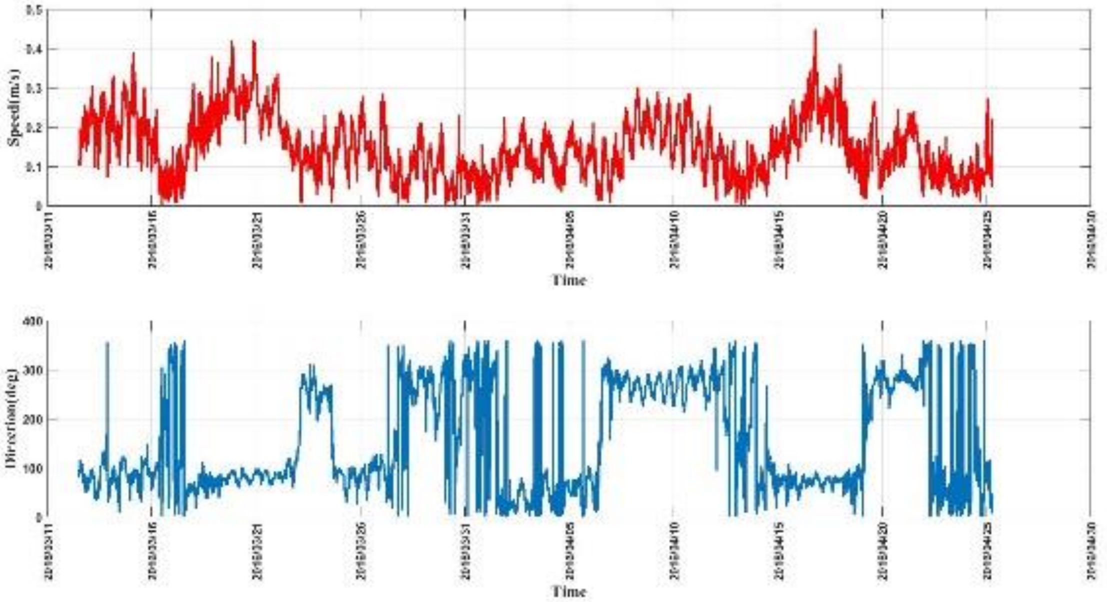

Figure 5. Current observation at Tang station at a depth of 14 meters.

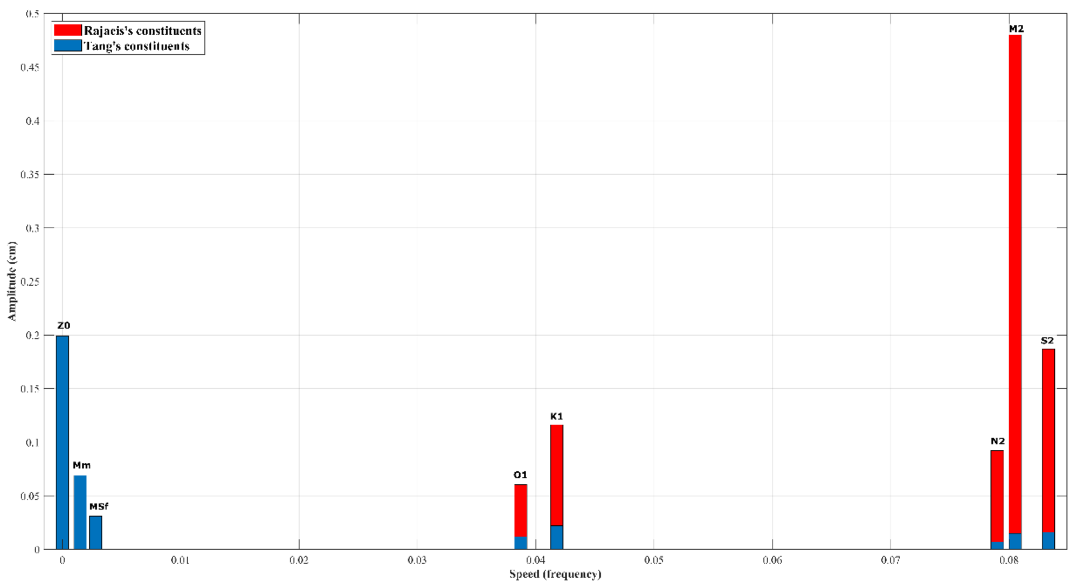

Figure 6. Shahid Rajaei's and Tang ports components.

7. CONCLUSIONS

Overall, on the Persian Gulf coast, tidal current constituents are significant, like M2 is 48 cm. But components like MSF and Mm that indicators of the long-term period are weak, so we have tidal current. In areas like the Oman Sea, the tide is not the dominant current as an influential factor. M2 is 1.5 cm, MSF is 7 cm, and Mm is 3 cm, which has a large amount. Thus, other reasons affect coastal currents on the Mokran coast. We cannot have a good and accurate understanding of tidal current in this area to use them for some applications such as navigation. Generally, if we want to get a good trend, we need to have long-term observations to have a correct picture of the current generation forces in the regions of the Oman Sea. The current in this area is shelf current. For long-term observation, we need a device like the HFR that is very suitable. Because that area is comprehensive and we have open coast by installing some HFR at a distance of fifty kilometers from each other without human intervention, we can harvest points putting the ADCP in the sea bed has many issues like high cost including diver coast, boat cost, maintenance, and information withdrawal as the point. In addition, ADCP deployment is complex. However, HFR is stable at one point on the coast and records current and wave with high temporal resolution. We need at least two or three HFR in the study area. In the figure below, there are three stations we propose to install in Chabahar bay (Fig 7).

Figure 7. Suggested stations

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