

PHYSICS OF THE SEA FOR THE SEAFARERS

C.S.. Murty and M.P. Tapaswi

INTRODUCTION

Oceans, occupying over 70% of the surface of the globe, have been the scene of action for members of the business community since time immemorial as a means for cheap transport of the merchandise. Sailing is a well-accepted adventurous activity by the Europeans, especially the Phoenicians and Greeks. The maritime commerce by the seafarers from these empires made Mediterranean and adjacent seas well known even before the time of Homer (ca. 850 BC). However, it took time and extraordinary courage for these seafarers to venture westward and out into the broad reaches of the Atlantic beyond the Straits of Gibraltar and eastward into the Indian Ocean. Lack of systematic records provide a less authentic documentation in respect of Chinese sailing to Indian Ocean. It is believed that Chinese reached India much earlier than the sailors from the West. The same could be well applied in the case of merchants from Mecca. These sailings were mainly for food and commerce. The sailing for food used to be in waters much closer to the respective countries – territorial waters (~12 n.m.) of today. In contrast, the seafarers went to far-off places for trade and commerce not complying to well-defined pathways like our National Highways on the land.

According to Herodotus, King Necho of Egypt sent an expedition to the Red Sea and along the east coast of Africa in about 600 BC. This was manned with Phoenician sailors. Three years later, the ship was believed to have returned to the Mediterranean, by way of Gibraltar. This expedition should have established the existence of Africa as a separate continent. Surprisingly, this did not happen. The geographical knowledge about the Persian Gulf, the Red Sea, the Arabian Sea was filled in by the expedition eastward to the Indus River led by Alexander the Great during 329-325 BC.

The traffic in the Indian Ocean for trade started considerably earlier as compared with other major oceans. However, the seafarers had a fair amount of knowledge of the monsoons. The west monsoon of the Northern

Hemisphere summer permitted ships of the Greek and Arab traders to infiltrate into the Arabian Sea and the Bay of Bengal, and return during the periods of dry monsoon of the Northern Hemisphere winter, reconciling the favourable winds for their homeward journey. It was the reversing currents associated with the monsoon winds of the northern Indian Ocean that favoured most of this traffic which was made fruitful by the ready markets for oriental products in the Roman world. With the fall of Rome, the trade dwindled, but not the knowledge the Greeks and Romans possessed. This wealth of information was available with the Arabs when Europe was obscured by the Dark Ages.

After a long and quiescent period lasting nearly fifteen centuries of the Christian era, the zeal for exploration of the seas and the natural world has once again surfaced among the people of these early seagoing countries. At this time the Portuguese mariners were re-visiting the West Coast of Africa, venturing beyond the terminal points of Hanno's expedition. Africa was circumnavigated from west to east in 1487 by Vasco da Gama, who believed in and found a sea route between Europe and India by skirting round the coasts of Africa. During their voyages the Portuguese absorbed knowledge of climatic conditions and the currents of the waters on which they were sailing. They also recorded that information for subsequent generations. One of such examples¹ is reproduced from Vasco da Gama's Diary (figure 1). However, since trade was the objective of the seafarers, systematic exploration of the sea remained neglected at that time.

The *Challenger* expedition (1873 to 1876) represented the first systematic attempt to examine the depth and breadth of the world's oceans from the chemical, physical, and biological points of view. However, about 20 years earlier to this expedition, the empirical studies of the ocean circulation had begun by Matthew Fontaine Maury (1806-1873). As a result of physical injury while a lieutenant in the US Navy, Maury was forced to spend most of his service career ashore in charge of the Depot of Charts and Instruments. This personal misfortune had a silver lining as it brought to the attention of Maury the piles of mariners' logs containing numerous daily observations in the form of notes on the wind and water currents experienced during the sailings. Maury assembled these informative logs and transferred the essence

to the cartographic medium – seeds of the hydrographic charts of modern times. From these exercises, Maury discovered that the average prevailing ocean currents are related to the broad wind patterns and can be characterized by great eddy like motions that change somewhat with the seasons. This discovery not only made possible the management of slow-moving ships under sail by taking advantage of favourable winds and currents, but also laid the foundations for the studies on Physical Oceanography of the seas. The information / data collected from the ocean during these voyages effectively formed the basis of the science(s) of oceanography as practised today.

As has already been mentioned above, the Indian Ocean was least explored from scientific point of view. One of the main reasons, plausibly, is that none of the leading oceanographic research nations shared or formed close links with coastal areas of the Indian Ocean. Even though many large-scale expeditions have investigated this ocean to some detail, the first systematic attempt of the study of the Indian Ocean was carried out during 1962-1965 under the banner International Indian Ocean Expedition (IIOE), when about 40 research vessels from 5 nations participated in the exploration of the waters of this area. This has been the endeavour of this century - importantly being the last of this millennium. This expedition, duly realizing the importance of the monsoons over this part of the globe as one of the basic contributors to the well understood oceanography and the related meteorological responses to the large-scale global wind systems through detailed studies from the rest of the globe, aided by the advances in technology during the first half of the century. The knowledge so acquired is well described in many books.^{2,3,4}

Having known now about the climatic conditions and circulation patterns in the Indian Ocean an attempt has been made in this presentation to correlate how the seafarers of earlier days, and for that matter many large ships even today, do make the best use of these phenomena in their sailings journey. This study, however, is limited to the sailings along the Indian subcontinent and the East Coast of Africa.

Physical setting

The Indian Ocean is the smallest of all oceans (including Southern Ocean). The absence of a temperate and polar region as is found north of the equator is one peculiarity of the Indian Ocean. It has a north-south extent of 9,600 km from Antarctica to the inner Bay of Bengal and spans 7,800 km in east-west direction between southern Africa and western Australia. Without its Southern Ocean part it covers an area of 48 million sq. km. The mean depth of the Indian Ocean is 3,800 m, which is between that of the Pacific and Atlantic Oceans. Most basins show depths well below 5,000 m; in the east, Wharton Basin exceeds 6,000 m depth. The Arabian Sea reaches depths below 3,000 m over most of its area. The depth in the Bay of Bengal decreases gradually from 4,000 m south of Sri Lanka to 2,000 m and less at 18° N. Three Mediterranean seas influence the hydrographic properties of the Indian Ocean water masses. The Persian Gulf is the smallest of the three; with a mean depth of 25 m and a maximum depth of only 90 m. the sill rises barely above the mean depth and its impact is not felt much beyond the Gulf of Oman. The Red Sea has very deep basin. It has a maximum depth of 2,740 m. The mean water depth is about 490 m and the sill depth is about 110 m. The Australasian Sea, a series of very deep basins with depths exceeding 7,400 m, communicates with the Indian Ocean through various passages between the Indonesian islands where the depth lies in the range 1,100m to 1,500 m.

The Indian Ocean is characterized by two important ridges. The Central Indian ridge with numerous fractures and depressions making blocks for water flow at that level. The eastern Indian or Ninety East Ridge stretches in a nearly north-south direction from the Andaman Islands to 33°S. It is much narrower and less fractured than the other ridges.

The Climate

The Indian Ocean is in several respects very different from other oceans. The most striking difference is the seasonal summer and winter monsoon (the term monsoon is derived from Arabic, meaning seasonally reversing winds). The effects of the monsoons on the ocean currents in the

Northern Hemisphere are marked. The monsoon dominates the northern Indian Ocean and its effects are felt far into the subtropics of the southern hemisphere. The Northeast or Winter Monsoon determines the climate of the northern Indian Ocean during the northern hemisphere winter (December-March). It is characterized by high pressure over the Asian landmass and northeasterly winds (figure 2) over the tropics and northern subtropics. This type of situation is common over the Pacific except that the Inter-Tropical Convergence Zone (ITCZ) and the Doldrums are located south of the equator (near 5°S latitude) rather than north. The wind over the northern Indian Ocean represents the great trade winds of the tropics. However, because of the seasonality they have been recognized as the Northeast monsoon winds. The air pressure gradients over the ocean are small because the Tibetan Plateau retards most of the winds. Hence, unlike the Pacific Northeast trades, trade winds over the Indian Ocean have been protected from the fury.

The situation over the southern hemisphere however, has been determined by the pressure gradient between the tropical low and the subtropical high-pressure belts. The axis of low pressure in the tropics is near 10° S, while the subtropical high-pressure belt, comes under the influence of air pressure maximum 1,000 km north of the Kerguelen Islands.

The Southwest or Summer Monsoon determines the climate of the northern Indian Ocean during the Northern Hemisphere summer (June-September). An intense heat low develops over northern Arabia and Pakistan. The Australian heat low of the southern summer is replaced by a centre of high pressure, while the atmospheric high, north of the Kerguelen Islands, is shifted eastward towards southern Africa. During the winter monsoon, weak north-south pressure gradient prevails from Arabia to Madagascar. However, during summer monsoon, the pressure gradients increase in magnitude and act in the opposite direction. As a result the winds in the northern Indian Ocean reverse completely (figure 3) and are no longer like the trade winds anywhere. A wind jet, believed to be an atmospheric version of a western boundary current in the sea, develops along the high east African topography. Further east along the equator the winds weaken (brings in moderate rainfall) but there is still a southerly component throughout the entire Ocean

everywhere north of 30°S. On the Northwest shelf the wind blows directly offshore with moderate strength.

The position of ITCZ over the ocean changes little between the seasons. During the Southwest monsoon, frequent weather disturbances break away and settle south of the Himalayas, bringing with them most of the season's rainfall. Winds at the equator change direction but remain weak throughout the year. Because of the near meridional (north-south) orientation, the associated Ekman transport does not support development of field of divergence at the equator. There is, therefore, no equatorial upwelling in the Indian Ocean. Strong equatorial downwelling occurs during the transition months (May and November) when the winds turn eastward at the equator, producing convergence of the water transport within the Ekman layer.

The current system

The surface currents and the general settling through the seasons show (figure 4) prominently the North Equatorial Current (NEC) in January and March when the Northeast Monsoon is fully established. It runs as a narrow current from Malacca Strait to southern Sri Lanka, where it bends southward and accelerates to reach 0.5 – 0.8 m s⁻¹ speed between 2°S and 5°N latitude belt in the region between 60°E and 75°E longitude. The South Equatorial Current (SEC) occupies the region south of 8°S. Between these westward flows runs the Equatorial Counter Current (ECC) in the west but gets weaker in the east. The intense Indian Equatorial Jet characterizes the transition from Northeast to Southwest Monsoon during May. It has been documented that the ECC system is irregular in its trans-oceanic coverage and occasionally been reported to be even absent – may mean not developed (!). The trans-oceanic surface current features are nearly well established with variations in space and in magnitude, the shift in the latitudinal positions, however, could contribute to unnoticeable impacts for the sailings – be they are for trade or for explorations.

When the Southwest Monsoon is fully established during July and September, the entire region north of 5° S is dominated by the eastward flow of the Southwest Monsoon Current (SWMC), the only exception being a narrow strip along the equator in July. The SEC expands slightly towards the

north, reaching 6° S in September. The Equatorial Jet again characterizes the transition before the onset of the Northeast Monsoon in the month of November. Concentrating all eastward flow in a 600 km wide band along the equator it reaches its peak in November and disappears in early January, when the annual cycle is repeated.

Seasonal reversal of the currents dominates the two major subdivisions of the northern Indian Ocean as well, but the opposing flows occupy periods of very different length, and the transitions are less well defined than in the equatorial zone. Weak westward flow, an extension of the NEC, dominates in the Arabian Sea at the peak of the Northeast Monsoon season. North-westward flow along the western Indian shelf begins as early as November and persists into January, with a width of some 400 km and a depth of about 200 m in the south (10° N), getting narrower and deeper as it flows along the continental slope. This current flows against the prevailing Northeast Monsoon and thus cannot be wind driven. The East Indian Winter Jet supplies low-density, fresh water from the Bay of Bengal at this time, while on the north Indian coast cold continental winds contribute to cooling and convective overturn of the waters.

Westward flow prevails south of 15° N and west of 65° E until late April, while in the remaining area currents are less and less well defined and change gradually into the weak anti-cyclonic pattern. The Somali Current responds quickly to the onset of the southwest monsoon in April; northward flow develops strengthening the pattern in the west. By mid-May the East Arabian Current (EAC) gets fully established. At the same time the anti-cyclonic pattern breaks up from the east where the flow joins the Equatorial Jet around southern India and Sri Lanka. Moderate eastward flow, an extension of the Somali and SWMC, dominates the region during the next 4-5 months. In June and July it reaches at peak but weakens rapidly in October when the second occurrence of the Equatorial Jet concentrates most eastward transport in the equatorial zone and outflow from the Bay of Bengal begins to oppose eastward flow around Sri Lanka. By mid-November currents are again diffuse; south of 15° N they are weak but already westward. General westward flow is again established by early December.

The circulation in the Bay of Bengal is characterized by anti-cyclonic flow during most months and strong cyclonic flow during November. In January currents are weak and variable. In the west, the East Indian Current (EIC) strengthens as the Northeast Monsoon becomes stronger in March and remains strong until May / June. Throughout this time the current runs into the wind, apparently as an extension of the NEC. During the Southwest Monsoon season currents in the entire bay are weak and variable again.

An indication of a current reversal in the west is seen in September. Currents are consistently southwestward and strong north of 15°N , and close to the shelf a southwestward flow prevails. Complete reversal of the EIC into the East Indian Winter Jet is not achieved until late October, when water from the Equatorial Jet enters the Bay in the east and a cyclonic circulation is established. The East Indian Winter Jet is a powerful western boundary current. It follows the topography south of Sri Lanka and feeds its water into the Arabian Sea. Very little exchange occurs with the Equatorial Jet south of Sri Lanka; currents in the separation zone between the two jets (near 3°N) are weak and variable. The East Indian Winter Jet fades away from the north in later December, its southern part merging with the developing North Equatorial Current (NEC).

While this is the case of the surface circulation of the water in the northern Indian Ocean, the currents along the western boundary of the ocean east of Madagascar integrate the flow. The ship drift currents show separation of the SEC into northern and southern branches. The distribution of their transports varies little over the year. The contribution of the northern branch to the circulation in the Southern Hemisphere is the development of Mozambique Current. The southern branch feeds the East Madagascar Current. On transiting the southern tip of Madagascar, the surface current pattern exhibits splitting of the flows - apparently in three paths. One path continues north along the west coast to return south with the Mozambique Current. The second path is directed towards west. Both these paths feed the Agulhas Current. The third path affects a complete retroflexion south of Madagascar, separating the East Madagascar Current from the Agulhas Current.

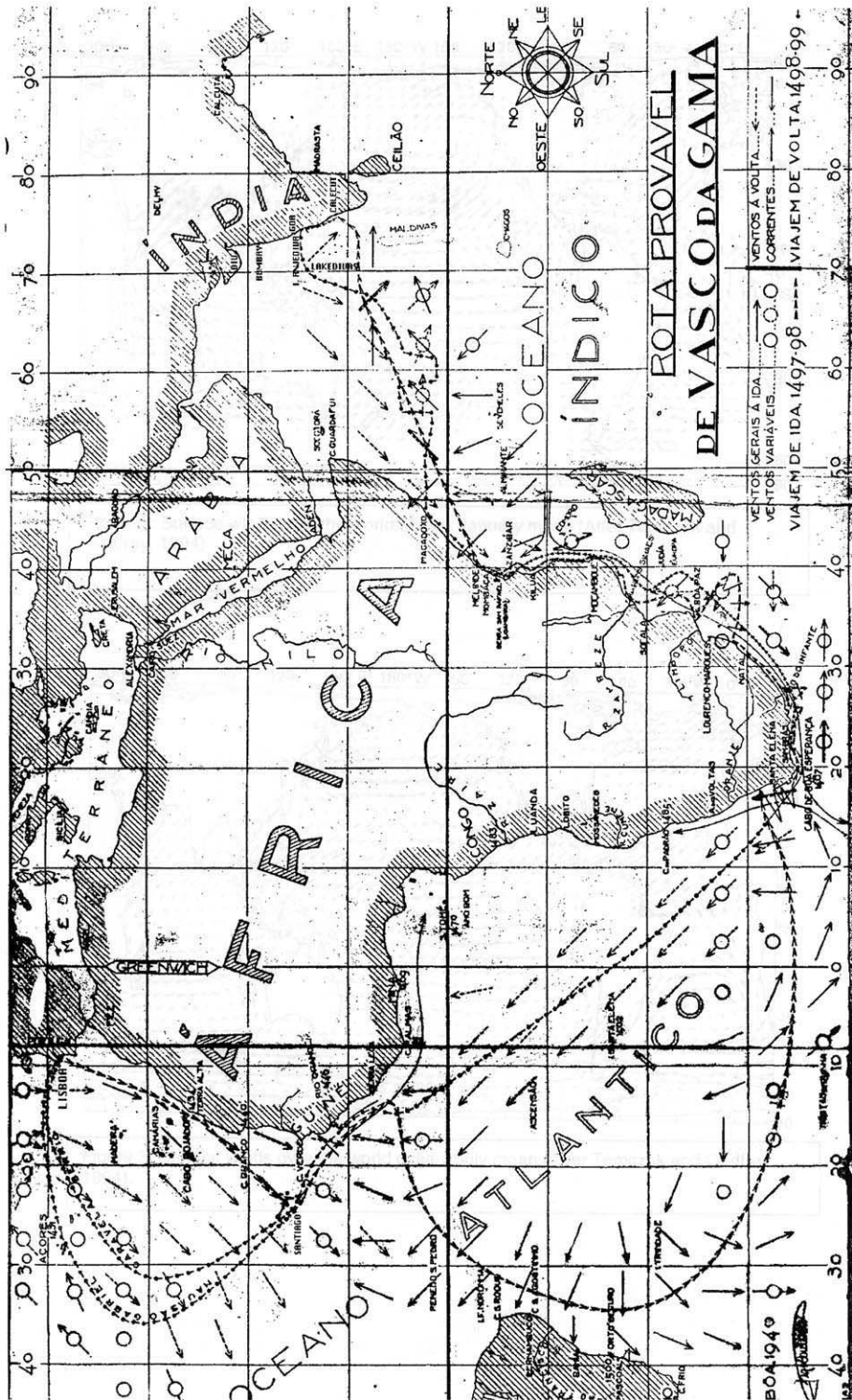
Conclusion

The sea surface current and prevailing wind structure in and over the Indian Ocean favoured seafarers in their endeavour and sailings in the Indian Ocean from the southern tip of Africa (Cape of Good Hope) during the month of May. After the entry into the Indian Ocean, the seafarers continued to sail in the northerly direction along the coastline of Africa (aided by the strong Somali Current and the East Arabian Current) towards the Arabian Sea. The physical environmental conditions over the sea and the external prevailing weather helped the seafarers reach places up to the west coast of India. As this sea surface current extend towards the east coast of India, the sailors were greatly assisted by the surface current as they sailed along.

During November, when the East Indian Winter wind reverses in its direction and begin to blow from the northeast, the sailors prepare for their return journey. While this observational finding that the sailors of the medieval era did follow or made better and profitable use of the freely available and natural external wind forcings over the past, today's efforts by way of improved navigation facility come mainly from the principal effect of the external demands for cutting down the running time as well as fuel requirements for operation and to make all weather operations possible. The winds that generate the waves contributes to reduction in the otherwise required travel time for the sailings between any given two points of departure and arrival. The natural and external forces help the sailors making their journey / expedition more economical and fuel efficient.

NOTES

- 1 Franz Hummerich, Estudo Crítico sobre O 'Roteiro' da Primeira Viagem de Vasco da Gama (1497- 1499), in Damaião Peres, ed., *Diário da Viagem de Vasco da Gama*, vol. 11, Porto: Civilização, 1945, 173-542.
- 2 Rao, T.S.S. and Griffiths, R.C. (1998), *Understanding the Indian Ocean.Perspectives on Oceanography*, IOC Ocean Forum II, Unesco Publishing, France, 187 pp.
- 3 Tomczak, M. and Godfrey, J.S. (1994), *Regional Oceanography: An Introduction*, Pergamon, Oxford, UK, 422 pp.
- 4 von Arx, W.S. (1962), *An Introduction to Physical Oceanography*, Addison-Wesley, USA, 422 pp.



Rota mais provável seguida por Vasco da Gama na sua viagem de Portugal à Índia, em 1497-1499, segundo a versão estudada pelo almirante Gago Coutinho

(1497-1498)

98 99

Figure 1 : Vasco-da-Gama's route to India from Portugal and return (1497-1498) (After Coutinho. 1945)

Fig.1: Vasco da Gama's route to India from Portugal (1497-98) and return (1498-99) (After Coutinho. 1945)

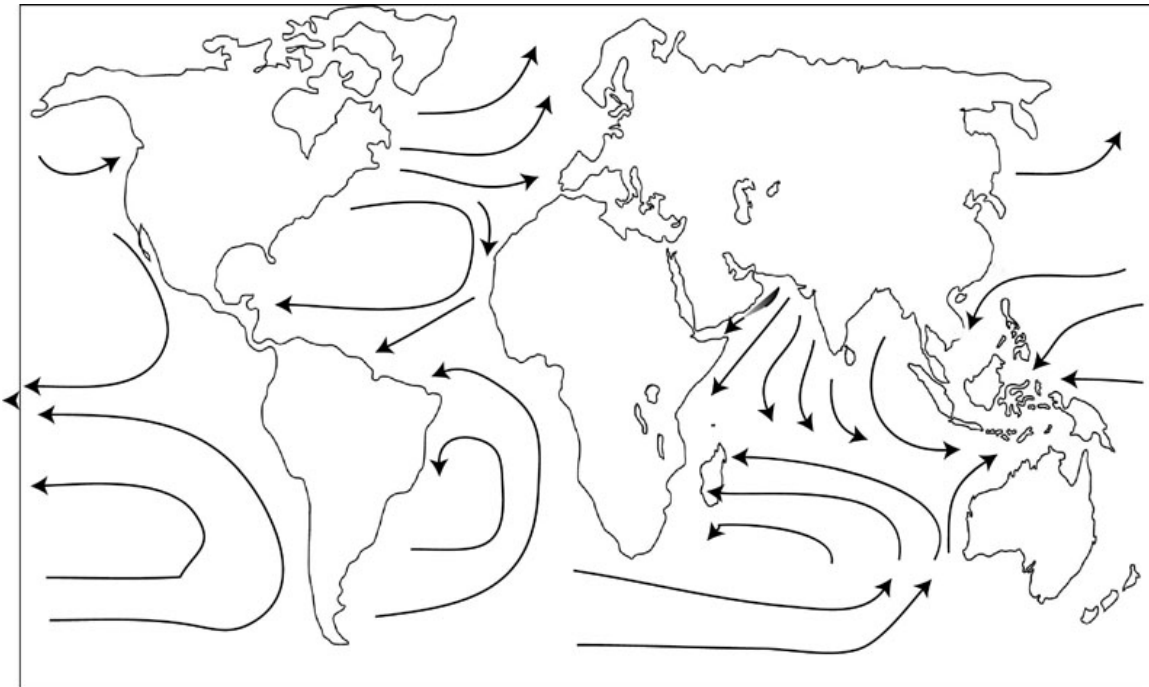


Fig.2: Direction of surface winds over the world ocean January mean

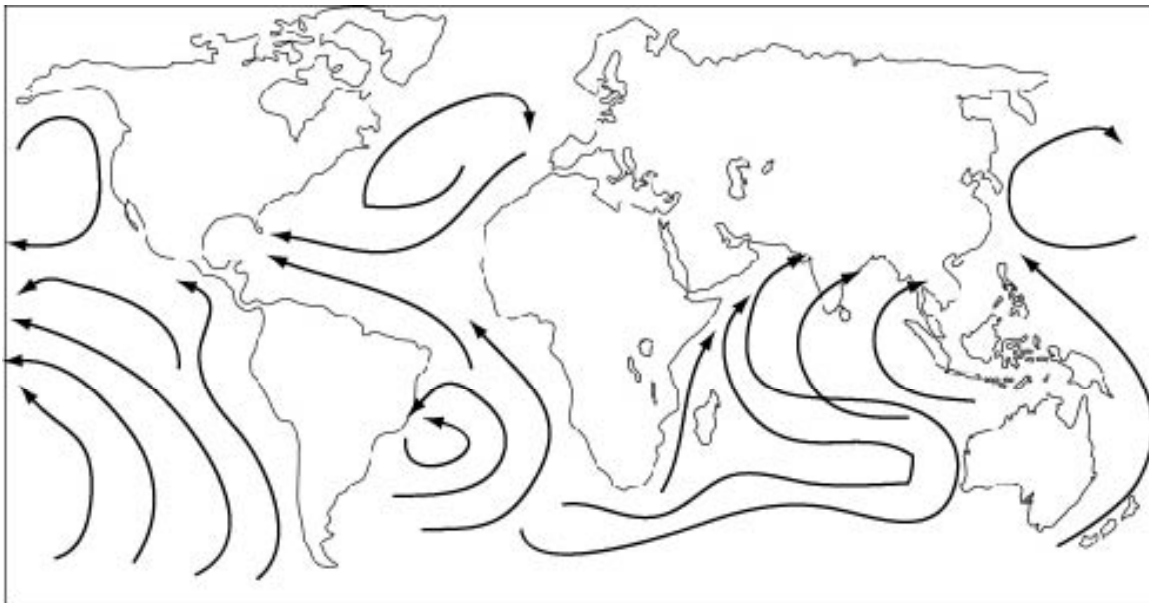


Fig.3: Direction of surface winds over the world ocean July mean

Fig.4: Surface currents in the northern Indian Ocean during different months

- Abbreviations used: EAC: East Arabian Current, ECC: Equatorial Counter-Current, EIC: East Indian Current, NEC: North Equatorial Current, SEC: South Equatorial Current, SWMC: Southwest Monsoon Current.

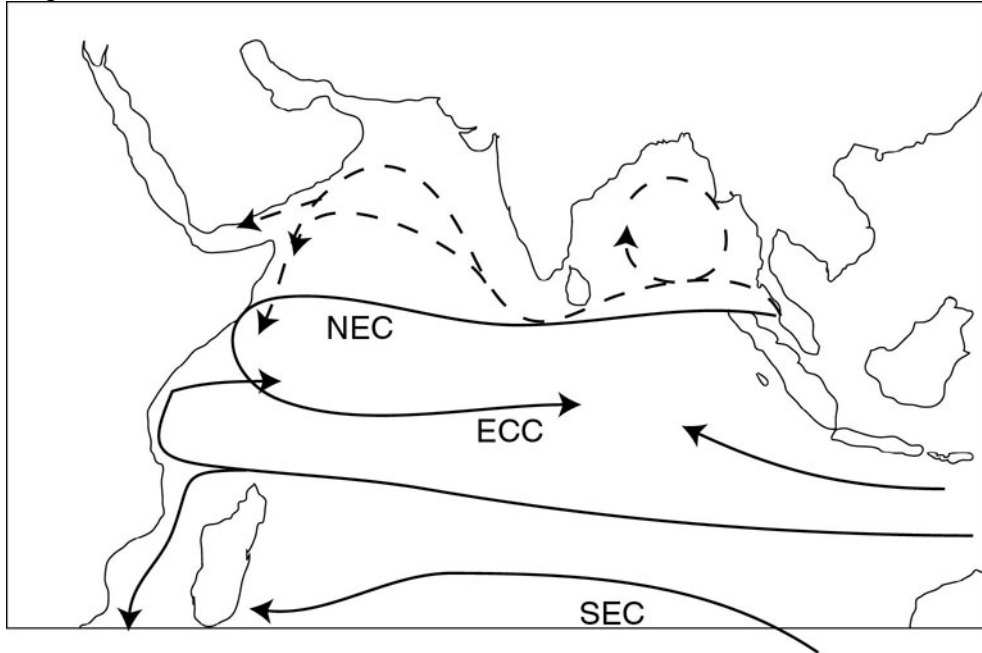


Fig.4a: January

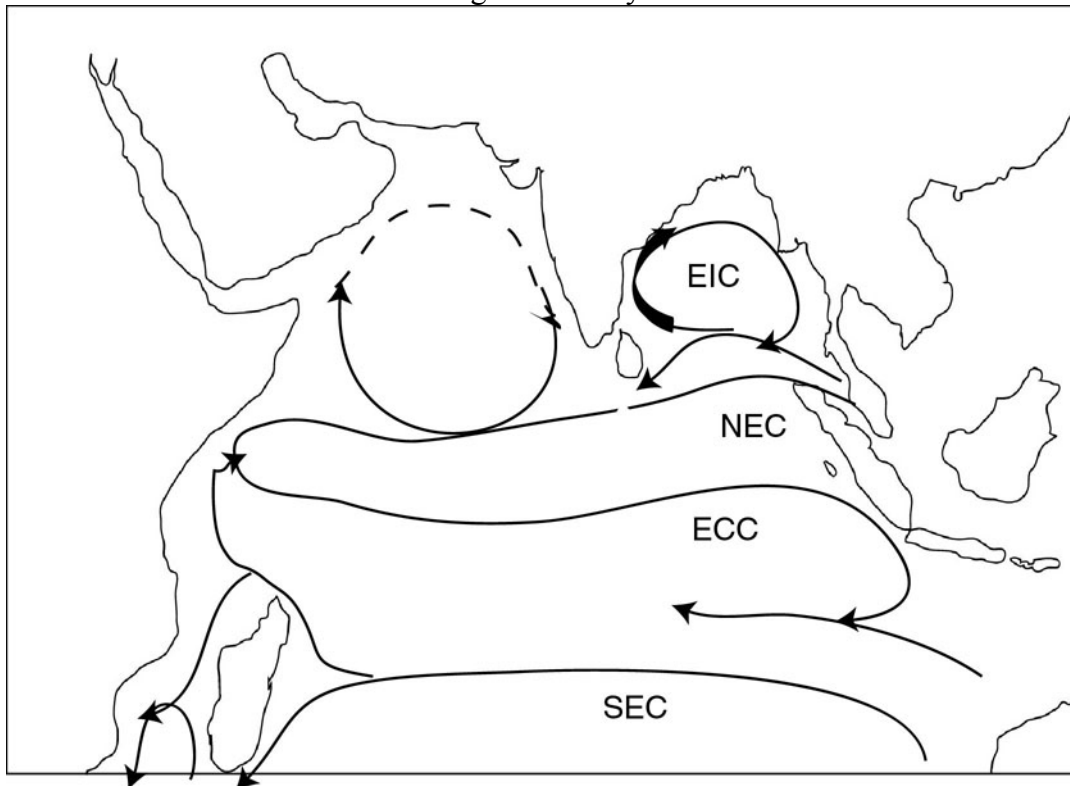


Fig.4b: March

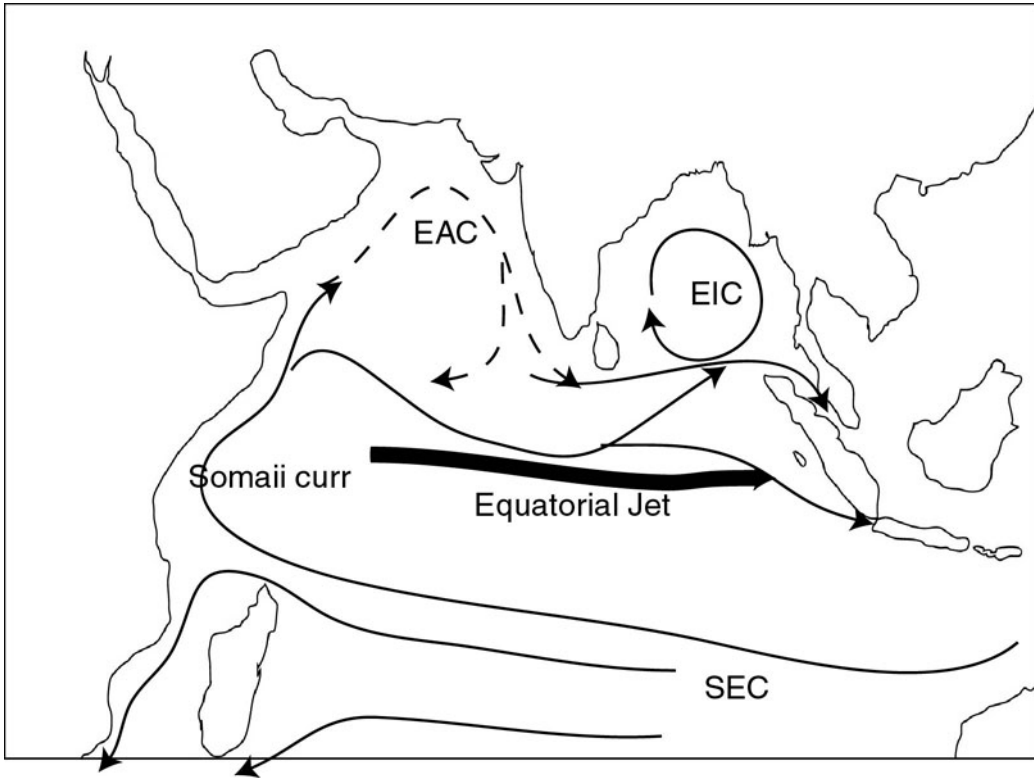


Fig.4c: May

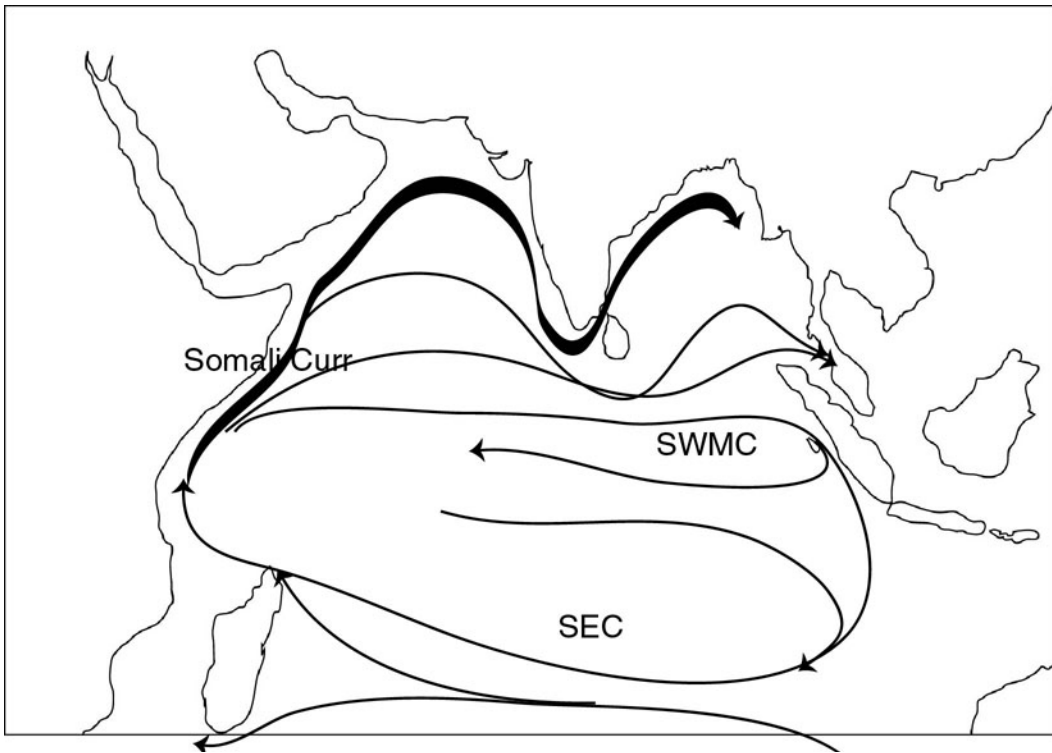


Fig.4d: July

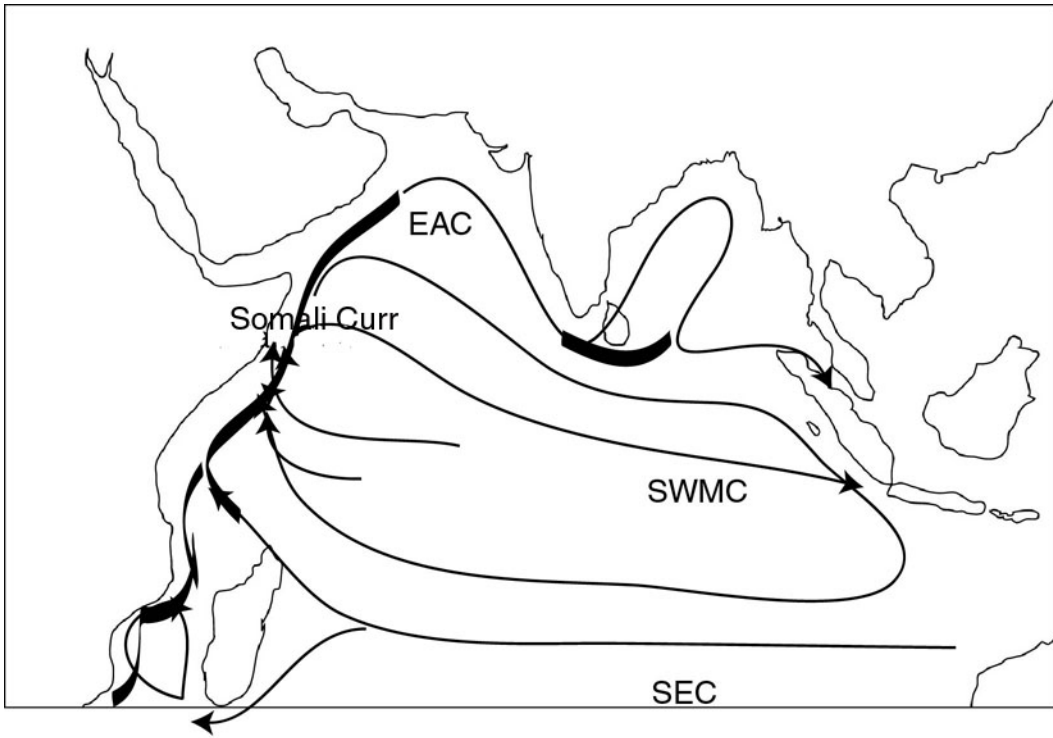


Fig.4e: September

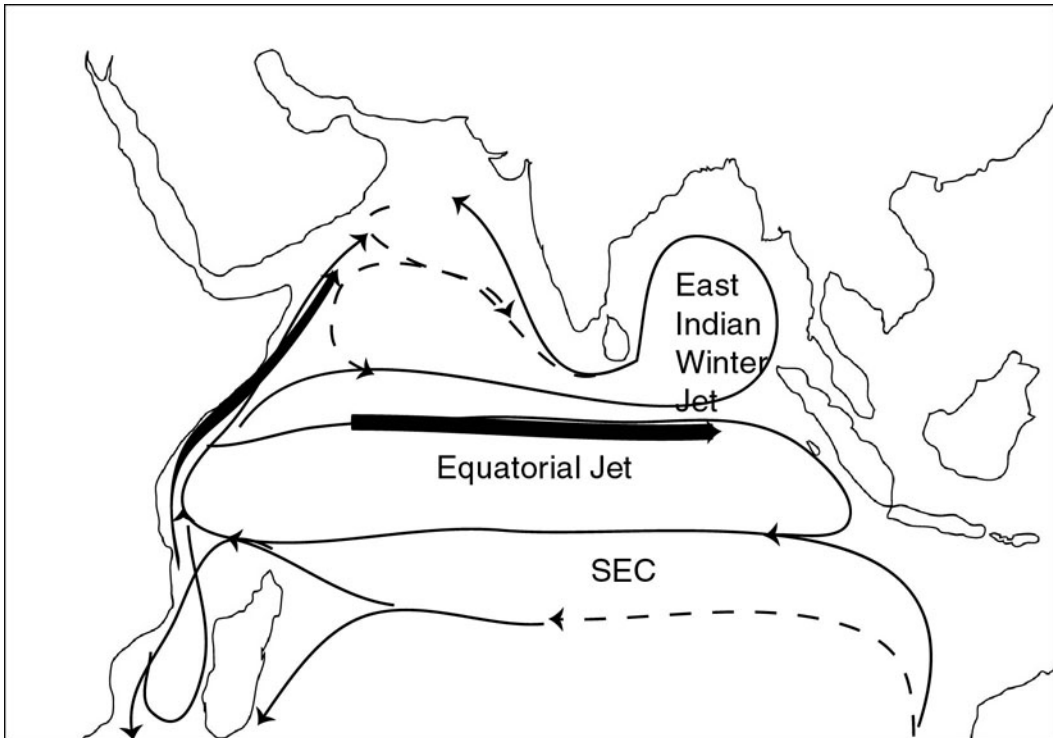


Fig.4f: November