

4. NORTHERN INDIAN OCEAN

4.1. TOPOGRAPHY

The Northern Indian Ocean and the surrounding Asian continent constitutes half of NAVPACMETOCEN WEST/JTWC's AOR. A basic understanding of the topography and ocean features is necessary to understanding the climatic features that affect this region.

4.1.1. SOUTHEAST ASIA: CAMBODIA, LAOS, VIETNAM, THAILAND, MALAYSIA, INDONESIA, BURMA, ANDAMAN & NICOBAR ISLANDS

4.1.1.1. CAMBODIA

The Cardamom Mountains in the southwest dominate the border with Thailand. The Dangrek Mountains dominate the border with Laos in the north. The Mekong River flows through Cambodia from its origin in Laos to Vietnam. Fertile plains from the Tonle Sap and Mekong Rivers cover about one-third of the country. Dense forests dominate the remainder of the country. (Fig 4.1.1)

4.1.1.2. LAOS

The majority of the country lies within the Mekong Basin between the Mekong River and the Annamite Range. Rugged plateaus and mountains dominate the landscape in the north and along the eastern border. (Figure 4.1.1)

4.1.1.3. VIETNAM

The southern part of Vietnam is dominated by the estuary of the Mekong River system, making the country low, flat and frequently marshy. The rich soil in the Mekong Delta makes this area the most fertile in the country, particularly for rice. The area immediately north and east of Ho Chi Minh City is much more varied -- low-lying tropical rain forest, upland forest and the rugged terrain of the Annamite Mountain chains.

The northern part of Vietnam is mountainous or hilly. The rugged highland areas are covered by a thick canopy of jungle about half the total land area. The lowlands consist principally of the Red River Delta and coastal plain, which extends northeast and south from the delta. Heavily populated and intensively cultivated, the lowlands are almost entirely covered by rice fields. Much of the delta region is seasonally flooded; a complex network of dikes and levees prevents serious flood damage. (Figure 4.1.1)

4.1.1.4. THAILAND

The country of Thailand extends from the northern border on the Asian mainland to the southern border on the Malaysian Peninsula. The topography of Thailand consists of four general areas:

1. The Northern Region lies between the Mekong and Salween Rivers. The terrain is mountainous with parallel ranges running north-south.

2. The Eastern Region is dominated by the Khorat Plateau which extends from the mountains in the north to the Laos border. (Figure 4.1.1)
3. The Central Region consists of a low, flat river valley which is formed by the Chao Phraya River and several of its tributaries.
4. The Southern Region is a long, narrow isthmus joining the land mass with Malaysia. The terrain is dominated by mountains along the central of the isthmus and low-lying tropical forests along the coast.

4.1.1.5. MALAYSIA

Low, swampy plains are found along the coastal areas and jungle-covered interior mountains of Malaysia. Peninsular Malaysia is separated from East Malaysia in Borneo by 400 mi (644 km) of the South China Sea. (Figure 4.1.2)

4.1.1.6. INDONESIA

The Republic of Indonesia is an archipelago of more than 13,000 islands extending 3,000 mi (4,830 km) along the Equator from the mainland of Southeast Asia to Australia. The archipelago forms a natural barrier between the Indian and Pacific Oceans, making the straits between the islands strategically and commercially important. Consisting of the former territories of the Netherlands East Indies and Portuguese Timor, Indonesia's main islands are Sumatra, Java, Sulawesi (formerly Celebes), Kalimantan (the Indonesian part of the island of Borneo) and Irian Jaya (the western part of Papua-New Guinea). The republic shares land borders with Malaysia and Papua-New Guinea and sea borders with Australia, India, Singapore, Vietnam, the Philippines and the Territories of the Pacific Islands. (Figure 4.1.2)

4.1.1.7. BURMA

Burma is the largest country on the southeast Asian mainland. Facing the Bay of Bengal and the Andaman Sea on the west and south, it shares borders with Thailand, Laos, China, India and Bangladesh. Burma is rimmed on the north, east and west by mountain ranges, with elevations up to 15,000 ft (4,575 m) along the Chinese border and 8,000 ft (2,440 m) along the Indian border. The mountains have contributed to Burma's isolation from neighboring countries and dense forest discourages east-west movement. The Irrawaddy River is the major transportation system. (Figure 4.1.2)

4.1.1.8. ANDAMAN ISLANDS/ NICOBAR ISLANDS

These islands are volcanic in origin. Being an extension of the Arakan Mountains in Burma, there are several authentic mountains throughout the island chain. Coupled with Andaman Islands, the Nicobar Islands form an arc from Sumatra to Cape Negris at the mouth of the Irrawaddy River in Burma. (Figure 4.1.3)

4.1.2. SOUTH ASIAN CONTINENT: BANGLADESH, NEPAL, INDIA, PAKISTAN, MALDIVES, LACCADIVE/MINICOY/AMINDIVE ARCHIPELAGOES

4.1.2.1. BANGLADESH

Bangladesh is a low-lying, riverine country located in South Asia with a marshy jungle coastline of 370 mi (596 km) on the northern littoral of the Bay of Bengal. The lowlands were formed as a deltaic plain at the confluence of the Ganges (Padma), Brahmaoutra (Jamuna) and Meghna Rivers, as well as their tributaries. Bangladesh's alluvial soil is extremely fertile but vulnerable to flood and drought. It is bordered on three sides by India and on the east by Burma. Bangladesh's irregular border is not based on any natural feature but rather represents a political demarcation during the partitioning of British India. (Figure 4.1.3)

4.1.2.2. KINGDOM OF NEPAL

The Kingdom of Nepal is located in Central Asia along the southern slopes of the Himalayan Mountains. A landlocked country about 500 mi (805 km) long and 100 mi (161 km) wide, it is bordered by India and the Tibetan region of China. It has three distinct regions, each running laterally the length of the kingdom. In the south, a flat, fertile strip of territory is part of the Ganges Basin plain. Central Nepal is crisscrossed by the lower Himalayas and by swiftly flowing mountain rivers. The high Himalayas (with eight of the ten highest peaks in the world) form the border with Tibet in the north. (Figure 4.1.3)

4.1.2.3. INDIA

India dominates the South Asian subcontinent geographically and has three main topographical areas:

1. The sparsely populated Himalaya Mountains, extending along the northern border;
2. The heavily populated Ganges Plain, a well-watered and fertile area in the north; and
3. The Deccan Plateau (peninsula), which is of moderate elevation. (Figure 4.1.3)

4.1.2.4. PAKISTAN

Pakistan is divided into four topographical regions:

1. The Northern and Western Highlands are an extension of the Himalayas and are extremely mountainous. The region includes Mt. Godwin Austen, which is the second highest in the world. Numerous passes exist between Pakistan and its neighbors, including the Khyber Pass into Afganistan.
2. The Punjab and Sind Plains dominate the eastern region. These plains are alluvial with soil deposited by the Indus River and its tributaries.
3. The Baluchistan Plateau, in the southwestern portion, is mainly dry and rocky with very little vegetation.
4. The Thar Desert, in southeast Pakistan, is a sandy wasteland which extends into western India. (Figure 4.1.3)

4.1.2.5. SRI LANKA

Sri Lanka is a pear-shaped island off the southeast coast of India. At its closest point, Sri Lanka and India are separated by only 18 mi (29 km). A plain only slightly higher than sea level makes up the entire northern end of the island and extends around the coast of the southern half. The south-central portion of the island is hilly and mountainous. (Figure 4.1.3)

4.1.2.6. MALDIVES

The Maldives are located in the northern Indian Ocean. The archipelago is a chain of 19 atolls extending 502 mi (808 km) from north to south. The atolls comprise 1,200 coral islands, which seldom exceed an elevation of 6 ft (2 m) above sea level. The southern tip of the archipelago is located 1° North of the Equator. The islands are administered by Sri Lanka. (Figure 4.1.3)

4.1.2.7. LACCADIVES, MINICOY AND AMINDIVE ARCHIPELAGOES

The Laccadives, Minicoy and Amindive are other coralline archipelago located just to the north of the Maldives. They are claimed and administered by India. They are coralline in origin and of very limited aerial extent. (Figure 4.1.3)

4.1.3. SOUTHWEST ASIA: IRAN, IRAQ, KUWAIT, SAUDI ARABIA, BAHRAIN, QATAR, UNITED ARAB EMIRATES, OMAN, YEMEN

4.1.3.1. IRAN

Iran is in the highlands of southwest Asia, bordered by Ukraine and the Caspian Sea to the north, the Arabian Gulf and Gulf of Oman to the south, Iraq and Turkey to the west and Afghanistan and Pakistan to the east. Iran consists of a rugged, mountainous rim surrounding a high interior basin. The basin is composed of desert plains and two smaller mountain ranges. The few lowland areas are confined to three relatively small plains:

1. A narrow strip bordering the Caspian Sea,
2. The Plain of Khuistan in the southwest, and
3. A long, barren, discontinuous coastal strip along the Arabian Gulf and Gulf of Oman.

The mountainous rimland, comprising about one-half of Iran, is dominated by two major mountain chains. The largest, the Zagros, stretches from northwest Iran southwestward to the eastern shores of the Gulf, then eastward, fronting the Gulf of Oman. Joining the Zagros in the northwest, and paralleling the Caspian Sea's southern shore, is the narrower Elburz Range. The central region, one of the most arid in the world, has no external drainage. It occupies a series of closed basins, with large areas in the north covered by salt flats interspersed with hard, gravel plains. This extensive area, known as the Dasht-e Kavir Desert, and the Dasht-e Lut Desert in the southwest, are prominent features of the region. (Figure 4.1.4)

4.1.3.2. IRAQ

Iraq is bordered by Kuwait, Iran, Turkey, Syria, Jordan and Saudi Arabia. The country slopes from mountains along the border of Iran and Turkey to reedy marshes in the southeast. Much of the land is desert or wasteland. The mountains in the northeast are an extension of the alpine system that runs eastward from the Balkans into southern Turkey, northern Iraq, Iran and Afghanistan, terminating in the Himalayas. (Fig 4.1.4)

4.1.3.3. SAUDI ARABIA

Saudi Arabia occupies about four-fifths of the Arabian Peninsula. From mountain ranges along the coast of the Red Sea, the land slopes gently eastward toward the Arabian Gulf. The topography is mainly desert, including the Rub Al-Khali, a vast uninhabited expanse of land. Saudi Arabia has no permanent rivers or bodies of water. Major regions within Saudi Arabia include:

1. The Hijaz, paralleling the Red Sea coast;
2. The Asir, a mountainous area along the southern Red Sea coast;
3. Nejd, the heartland of the country;
4. The Eastern Province (also called Al-Hasa), bordering the Arabian Gulf; and
5. The Northern Region. (Figure 4.1.4)

4.1.3.4. BAHRAIN

Bahrain is an archipelago consisting of 33 islands, of which only five are inhabited. The main island is mostly desert with a low interior plateau and low hills dominating the interior. (Figure 4.1.4)

4.1.3.5. QATAR

Qatar is a small peninsula that extends approximately 110 mi (177 km) into the Arabian Gulf. Qatar borders Saudi Arabia on the south-southwestern border and the United Arab Emirates on the south-southeast border. The terrain is mostly flat, barren desert except for a few areas of fertile land along the coast. (Figure 4.1.4)

4.1.3.6. KUWAIT

Kuwait is located in the northeastern corner of the Arabian Peninsula, bounded on the north and west by Iraq, on the south by Saudi Arabia and on the east by the Arabian Gulf. The majority of the land is arid desert with some areas of marsh along the coastal regions. (Figure 4.1.4)

4.1.3.7. UNITED ARAB EMIRATES (UAE)

The United Arab Emirates borders Qatar to the northwest, Saudi Arabia along the western and southern borders, Oman to the east and the Arabian Gulf to the north. Swamp and salt marches are found along the northern coast. Inland areas are mostly desert. Hills and mountains cover much of the eastern part of the country. (Figure 4.1.4)

4.1.3.8. OMAN

Oman is located in the eastern part of the Arabian Peninsula. Oman borders Saudi Arabia and the United Arab Emirates. The border with Yemen is under dispute. Oman's eastern border is located on the Gulf of Oman and the Indian Ocean. The strategically important Musandam Peninsula which overlooks the Strait of Hormuz is separated from the remainder of the country by the UAE. (Figure 4.1.4)

4.1.3.9. SOUTH YEMEN (PEOPLE'S DEMOCRATIC REPUBLIC OF YEMEN)

South Yemen (People's Democratic Republic Of Yemen) is bordered by North Yemen on the northwest, Saudi Arabia on the north and northeast, Oman on the east and the Gulf of Aden on the south. The coastal areas are sandy and flat; the interior is mountainous. The Island of Socotra in the Gulf of Aden and the Island of Perim in the Red Sea also belong to South Yemen. (Figure 4.1.4)

4.1.3.10. NORTH YEMEN (YEMEN ARAB REPUBLIC)

North Yemen (Yemen Arab Republic) is located in the southwestern corner of the Arabian Peninsula, just north of the Bab el-Mandeb Strait which joins the Red Sea to the Gulf of Aden. The Tihama, a hot, sandy, semi-desert strip about 40 mi (64 km) wide, separates the Red Sea coast from the generally less arid mountainous area of the interior. A normally sufficient rainfall and agreeable mountain climate make it one of the most important agricultural areas of the Arabian Peninsula. (Figure 4.1.4)

4.1.4. NORTHEASTERN AFRICA: EGYPT, SUDAN, ERITREA, ETHIOPIA, DJIBOUTI, SOMALIA

4.1.4.1. EGYPT

Egypt is located in the north-northeastern corner of Africa bordering Libya to the west, the Mediterranean Sea to the north, Sudan to the south and the Red Sea to the east. There are four distinct regions:

1. The Nile River and Delta Region: Mainly rich soil deposited by the Nile when it floods. The Nile is the chief source of water for the agricultural region.
2. The Eastern Desert: Part of the Sahara that extends from the banks of the Nile to the mountains bordering the Red Sea.
3. The Western Desert: Covers two-thirds of Egypt and is the easternmost part of the Sahara desert.
4. The Sinai Peninsula: Mountainous desert separated from the main portion of Egypt by the Suez Canal. (Figure 4.1.4)

4.1.4.2. SUDAN

Sudan, the largest country in Africa, lies across the middle reaches of the Nile River. From south to north, Sudan has tropical rainforest and savanna, vast swamplands, open semitropical savanna, scrublands and sandy, arid hills lying between the Red Sea and the Libyan and Sahara Deserts. Through these diverse regions, the White Nile, the main artery of the Nile River, flows northward. The extreme desert of the northwest gives way to sandy steppes north of Khartoum. (Figure 4.1.5)

4.1.4.3. ERITREA

Eritrea is bounded on the north and west by Sudan and on the south by Ethiopia. The eastern boundary is formed by the Red Sea. Sandy, arid hills dominate most of the country except for coastal swampland areas.

4.1.4.4. ETHIOPIA

Ethiopia is located in the Horn of Africa. The country has a high central plateau that varies from 6,000-10,000 ft (1,830-3,050 m). Elevation is generally highest just before the point of descent to the Great Rift Valley, which splits the plateau diagonally. A number of rivers cross the plateau -- notably the Blue Nile rising from Lake Tana. The plateau gradually slopes to the lowlands of the Sudan on the west and the Somali plains to the southeast. (Figure 4.1.5)

4.1.4.5. REPUBLIC OF DJIBOUTI

The Republic of Djibouti is located in northeast Africa and has three principal regions: the coastal plain, the mountains and the plateau rising behind the mountains. The land is bare, dry and desolate, marked by sharp cliffs, deep ravines, burning sands and thorny shrubs. (Figure 4.1.5)

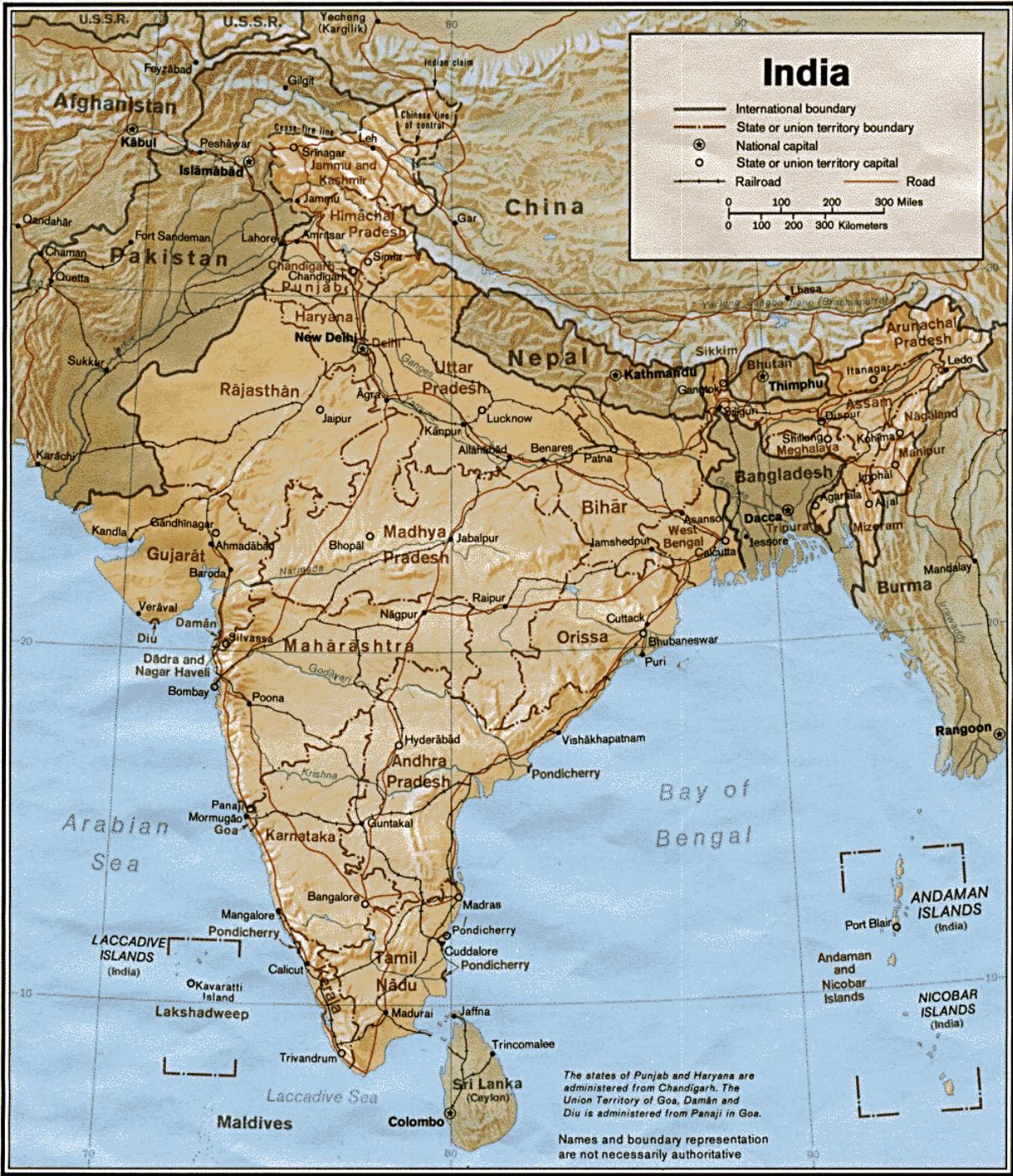
4.1.4.6. SOMALIA

Somalia is located on the east coast of Africa north of the Equator and is often referred to as the Horn of Africa, along with Ethiopia and Djibouti. The northern part of the country is hilly and in many places the altitude ranges between 3,000-7,000 ft (915-2,135 m). The central and southern areas are flat, with an average altitude of less than 600 ft (183 m). The Juba and Shebelle Rivers rise in Ethiopia and flow south across the country toward the Indian Ocean. (Figure 4.1.5)



Base 505843 (A01868) 8-85

Figure 4.1.1 INDOCHINA



Base 504178 6-79

Figure 4.1.3 INDIA

Arabian Peninsula and Vicinity



Figure 4.1.4 ARABIAN PENINSULA

Horn of Africa



Figure 4.1.5 HORN OF AFRICA

4.2. OCEANOGRAPHY

4.2.1. BOTTOM TOPOGRAPHY

4.2.1.1. GULF OF THAILAND

The Gulf of Thailand is a shallow offshoot of the South China Sea. The eastern side is generally more shallow and flat than the rocky steep slopes of the western coast. Although the mouth of the Gulf is about 200 nm wide at the surface, the channel connecting the basins is only 30 nm wide.

4.2.1.2. ANDAMAN SEA

The Andaman Sea extends from the Irrawaddy Delta southward to the Malacca Straits. Waters of the Andaman Sea and the Bay of Bengal communicate through several channels. The northern and eastern third of the Andaman Sea is comprised of the submarine Irrawaddy-Salween Delta and Mergui Platform. From these shallow shelves, the sea bottom drops off rapidly into a large central basin and two smaller basins to the north and south. A north-south arc of volcanic islands and seamounts separates the basins.

4.2.1.3. BAY OF BENGAL

The Bay of Bengal is the northeastern offshoot of the Indian Ocean lying between peninsular India and Burma. The sea floor shows a broad, U-shaped basin open to the south. This shape shows the bottom has been tectonically stable for long periods.

One of the submarine features is the north-south Indonesian Trench, near the Nicobar-Sumatra mainland. The Ganges Canyon begins in the shallow water off the Ganges delta and indents into the Ganges Fan in a northeast-southwest direction.

Terrigenous deposits are found in the northern and shallower portions of the bay and are dispersed throughout by turbidity currents. An ooze made of a mixture of shell and mud is present mainly in the central and deeper parts of the bay.

4.2.1.4. ARABIAN SEA

The Arabian Sea boundaries are from the southern coast of India, along the west side of the Laccadive Islands to the Equator, then to the coast of Africa near Mombassa, excluding the Gulfs of Aden and Oman.

The Arabian Sea is divided by the northern extension of the Mid-Indian Ridge into two major basins: the Arabian Basin in the northeast and the Somali Basin in the southwest with depths in excess of 15000 ft (4575 m). The Somali Basin also connects with the Mascarenes and Madagascar Basins.

Sediments of terrigenous origin cover the Arabian Sea continental slope with red clay deposits over the basins.

4.2.1.5. ARABIAN GULF

The Arabian Gulf is a land-locked body of water with a length of 615 nm. It varies in width from a maximum of 210 nm to a minimum of 35 nm in the Straits of Hormuz, which is the only opening to the Arabian Sea. The broad shallow shelf, generally less than 180 ft (55 m) in depth, has a complex topography with numerous banks and shoals. There are some small islands, which are salt plugs, surrounded by reefs and rims of sediment extending southeast away from the dominant northwest wind and wave attack. The bottom sediments consist predominantly of skeletal sands with variable amounts of coarser shell debris, calcilutite and some insolubles.

4.2.1.6. RED SEA

The Red Sea extends northwestward from the Strait of Bab-el-Mandeb in the south to the Suez Canal in the north. The Red Sea separates the African continent from Arabia. The shores are bordered by broad, reef-studded shelves which are less than 150 ft (46 m) deep. These drop off abruptly to shelves about 1500 ft (458 m) deep which flank a deep, narrow, central trough in which depths reach 4500-6000 ft (1372-1830 m). The Sinai Peninsula divides the northern extremity into the shallow Gulf of Suez on the west and the deep, narrow, high-silled Gulf of Aqaba on the east.

4.2.1.7. INDIAN OCEAN

The Indian Ocean is the smallest of the three “great” oceans and much of it is also young, geologically speaking. Its boundaries are as follows:

1. Western Limits: The meridian of Cape Agulhus to Antarctica (Queen Maud Land);
2. Eastern Limits (south of Australia): The western boundary of Bass Strait, then to northeastern Tasmania, then to Antarctica near Fisher Bay; and
3. Eastern Limits (north of Australia): The northeastern boundary runs from island to island through the Lesser Sunda Islands to Java and Sumatra and then to Singapore.

There are five major divisions within the Indian Ocean bed:

1. **CONTINENTAL MARGINS:** The continental shelves of the Indian Ocean are somewhat narrower on the average than in the Atlantic Ocean, ranging from a few hundred yards/meters around islands to 322 nm off Bombay. The continental slope, marginal escarpments and the landward slopes of trenches mark the boundary of the continental blocks. Numerous submarine canyons indent the slope, with several prominent canyons near the Ganges and Indus Rivers. The Java Trench bordering the Indonesian arc forms the northwestern boundary of the Indian Ocean between Burma and Australia.

2. **OCEAN-BASIN FLOOR:** The most conspicuous provinces of the ocean-basin floor are the abyssal plains, some of the flattest surfaces on earth. Except for isolated peaks of buried hills and mid-ocean canyons, local relief does not exceed 3-6 ft (1-2 m). These abyssal plains, although well-developed in the northern and southern parts, are relatively poorly developed off Australia.

3. **MICROCONTINENTS:** Some of the most notable features of the Indian Ocean are the generally north-south tending microcontinents. From west to east, the following north-south tending non-seismic microcontinents can be recognized:

- a. The Mozambique Ridge;
- b. The Madagascar Ridge, of which the island of Madagascar is a clear example of a microcontinent;
- c. The Mascarene Ridge, of which the Seychelles is a example;
- d. The Chagos-Laccadive Plateau supporting the Chagos Archipelago which rise from a long, broad, slightly curved plateau; and
- e. The Ninetyeast Ridge which is perhaps the longest and straightest ridge in any ocean.

These microcontinents can be easily distinguished from mid-ocean ridges based on morphological grounds. Microcontinents are generally higher, blockier features with lower local relief.

4. **MID-OCEANIC RIDGE:** The most conspicuous feature of the Indian Ocean is the Mid-Indian Ocean Ridge. The ridge is “Y” shaped in the center of the Ocean. Along the axis of the ridge is a seismically active rift.

5. FRACTURE ZONES: The Indian Ocean is cut by several prominent fracture zones which offset the axis of the ridge. These include:

- a. The Owen Fracture Zone which lies east of Arabia and Gulf of Aden;
- b. The Wheatley Trench which drops 3000 ft (915m) below the India Abyssal Plain;
- c. The Malagasy Fracture Zone lies to the east of the Madagascar Ridge; and
- d. The Amsterdam Fracture Zone near the center of the ocean.

The Indian Ocean floor is covered by sediments which can be divided into two categories. The boundaries are not precise but merge into one another:

1. PELAGIC TYPE SEDIMENTS are distributed over most of the Indian Ocean basin:
 - a. RED CLAY dominates about 25% of the total area, especially between 10° North and 40° South, in the eastern half of the ocean and away from islands and continents.
 - b. CALCAREOUS OOZE covers some 45% of the ocean floor, mainly where the depth is not excessive and in areas of warmth and very high organic productivity.
 - c. DIATOM OOZE covers about 20% of the total area in the sub-polar areas beyond 50° South.

2. TERRIGENOUS TYPE SEDIMENTS are distributed close to continents and island belts:

- a. Transport of sediments to various trenches, troughs and basins is mainly by turbidity currents but partly by volcanic action or submarine slumping. These trenches, troughs and basins of several different classifications are located around the northern periphery of the Indian Ocean basin.
- b. Lava and ash accumulations mark the mid-ocean volcanic areas which lie mainly in the western half of Indian Ocean.
- c. Fine and coarse material is provided by melting of ice floes and bergs and is distributed in circum-polar belts which are marginal to the Antarctic glaciated regions.

4.2.2. MAJOR OCEAN CURRENTS

4.2.2.1. NORTHEAST MONSOON

The Northeast Monsoon Season dominates the Northern Indian Ocean from November to March. The North Equatorial Current or the Northeast Monsoon Drift is well developed during this period, flowing to the west and southwest in response to the wind flow from the Indian subcontinent. The strength of the Northeast Monsoon Drift is directly proportional to the speed of the wind. During the Northeast Monsoon, the Equatorial Countercurrent sets in November and is formed by confluence of the current flowing southwest off the Somali coast and the East African coastal current flowing northward north of Cape Delgado. (Figure 4.2.2)

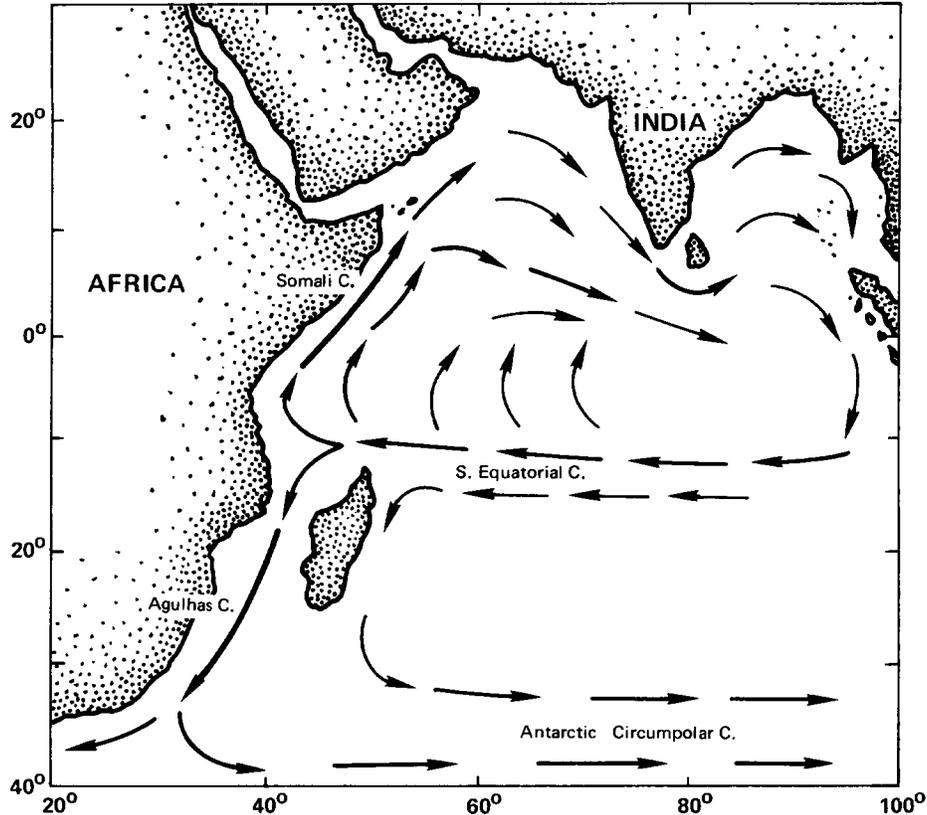


Figure 4.2.1 Southwest Monsoon Ocean Current

4.2.2.2. SOMALI CURRENT

The Somali Current is an extension of the South Equatorial Current. In the northern hemisphere summer with the southwest monsoon, it flows northeastward along the coast of Somali to the Horn Of Africa. The northeast current starts in April when the monsoon changes. In July and August, the maximum surface current reaches 4 kt , occasionally 7 kt.

In September, when the monsoon starts to change, the northeastward flow is still strong near the coast, but it is weakened offshore. In November, the southwest current occurs as often as the northeast current. In January and February, the current flows northeastward again while the current offshore is to the northwest. (Figure 4.2.2)

4.2.2.3. SOUTHWEST MONSOON

During the Southwest Monsoon from April to October, the North Equatorial Current disappears and is replaced by the Southwest Monsoon drift which flows eastward south of India. The speed south of Sri Lanka is 1-2 kt, occasionally up to 3 kt. Its branches flow clockwise in the Arabian Sea and Bay of Bengal, following the coastlines. (Figure 4.2.1)

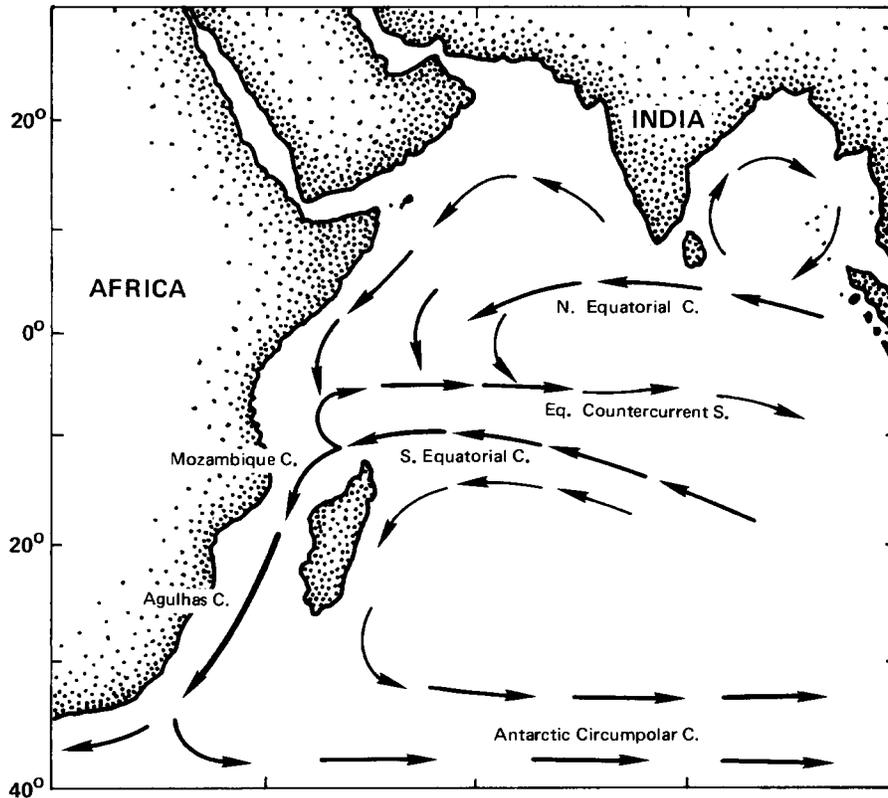


Figure 4.2.2 Northeast Monsoon Ocean Current

4.2.3. SECONDARY CURRENTS

4.2.3.1. ANDAMAN SEA

The tropical monsoonal regime is the controlling factor on currents in the Andaman Sea. During most of the year, northwestward currents of 0.3-2 kt flow into the southern Andaman Sea from the Strait of Malacca. From June to August, the southwest monsoon drives Bay of Bengal waters into the Andaman Sea. By November, the northeast monsoon begins to blow over the Sea, maintaining southwestward currents through February.

4.2.3.2. ARABIAN GULF

Strong tidal currents (up to 4 kt) are found on the southern side of the Strait of Hormuz. Elsewhere in the Gulf, tidal currents are not strong, usually 1-1.5 kt, but they may attain high velocities at the entrance to lagoons, estuaries and in narrow straits. Surface drift due to wind is sometimes so great that tidal streams will fail to fully overcome its effect.

4.3. METEOROLOGY

4.3.1. SOUTHEAST ASIA: THAILAND, CAMBODIA, LAOS, VIETNAM, MALAYSIA, BURMA

Southeast Asia has a monsoon climate that is characterized by distinct wet and dry seasons. In general, the Southwest Monsoon (mid-May to September) has heavy and frequent precipitation, high humidity and except at higher elevations, high temperatures. In contrast, the Northeast Monsoon (November to mid-March) usually brings little precipitation, lower humidity and cooler temperatures. These major seasons are separated by short transitional periods, each with fairly marked characteristics.

The climate is controlled primarily by the large semi-permanent pressure systems of Asia and adjacent oceans and by the resultant large-scale monsoonal airflow. These currents bring greatly modified continental air from the Asian landmass during the Northeast Monsoon and warm, moist air from the tropical oceans during the Southwest Monsoon.

Migratory pressure also affect the climate, but not as much as other factors. Most of this area lies south of the normal cyclone track which crosses southern China. Occasional lows will track across the northern portion of the area, primarily in January through March. Fronts associated with these migratory lows are generally oriented east-west and triggered by surges of polar air from the Siberian High. Although the monsoonal surges are blocked by the mountains of northern Vietnam, the fronts bulge southward along the coastal plains.

4.3.2. SOUTH ASIAN CONTINENT: BANGLADESH, NEPAL, INDIA, PAKISTAN, MALDIVES

The most significant meteorological phenomenon affecting the northern Indian Ocean is the monsoon. The Indian Ocean Monsoon is unequalled in persistence or severity anywhere else in the world. The monsoon is a surface wind which flows in response to temperature and pressure gradients. The term "monsoon" originated from the Arabic word "mausin", which means season. It originally applied to the wind regimes of the Arabian Sea where winds blow for six months from the northeast (Winter Monsoon) and six months from the southwest (Summer Monsoon).

The most important factor contributing to the monsoon is topography: The Himalayan and Hindu Kush mountain ranges average over 14,000 feet (600 mb) and extensive areas exceed 18,000 feet (500 mb). This acts as an effective barrier to any surface interaction between the Indian Ocean and the Eurasian mainland north of the mountains. Throughout the year, it is impossible for cool air to intrude southward past the barrier. The Tibetan Plateau does, however, have a significant effect upon the Southwest Monsoon. With the change from a semi-permanent high to a semi-permanent low over the plateau, the resultant cyclonic circulation enhances and aids the general circulation south of the Himalayas.

Monsoon regions, meteorologically speaking, is defined as regions in which:

1. The prevailing wind direction shifts by at least 120 degrees between January and July,
2. The average frequency of prevailing wind direction in January and July exceeds 40%,
3. The mean resultant winds in at least one of the months exceed 3 m/sec, and
4. Fewer than one cyclone-anticyclone alternation occurs every two years in either month in a

5° latitude-longitude rectangle. It should be noted that this definition does not include any weather requirements (i.e., rainy-dry season) thus, areas such as the Sahara Desert can rightfully be included in the monsoonal area.

There are basically four seasons in the North Indian Ocean which are defined by the wind regimes. The following list includes the four seasons, the approximate time of onset and some common names:

- | | | |
|--|---------|--------------------------------|
| 1. Northern Monsoon (Winter Monsoon) | Dec-Mar | Cool Season |
| 2. Spring Transition Season (Hot Season) | Apr-May | Pre-Monsoon Transition Season |
| 3. Summer Monsoon (Rainy Season, India) | Jun-Sep | Monsoon, India |
| 4. Fall Transition Season | Sep-Nov | Post Monsoon Transition Season |

4.3.2.1. NORTHEAST MONSOON

In the winter, the relative cooling of the Indian plateau and Middle East with respect to the fairly stable ocean temperature establishes a low level pressure gradient between the land and water along the south coast of Asia with resultant off-shore winds. These "northeasterly" winds signal the start of the Northeast or Winter Monsoon. (Figure 4.3.1)

The Himalayan - Hindu Kush and Iranian mountain barriers prevent the extremely cold air of Central Asia from penetrating into the area. Thus, the temperature gradient between the land south of the barrier and ocean remains relatively weak and the Northeast Monsoon is relatively weak, showing none of the "surges" prevalent in the East and South China Seas. Unequal heating of the deserts of Africa causes a north-south temperature and pressure gradient during winter. At this time of year, the Sahara becomes relatively cool compared to the Kalahari desert of South Africa and the resultant cross-equatorial flow extends the Northeast Monsoon into the Southern Hemisphere. This allows the formation or extension of the Monsoon Trough into the Eastern and Central Indian Ocean during the Northeast Monsoon regime.

Due to the relatively persistent though gentle northeast flow, an eddy often forms near the southwest tip of India. This eddy sometimes has a diameter of several hundred miles as the westerlies on the south side of the low advect moisture into the low bringing lowered ceilings and intermittent rain and showers. This phenomenon may not be as pronounced in January as it is in November. In addition, it has been reported that an attendant lee trough generally lies oriented west-northwest to east-southeast from 30° North 49° East to 24° North 60° East.

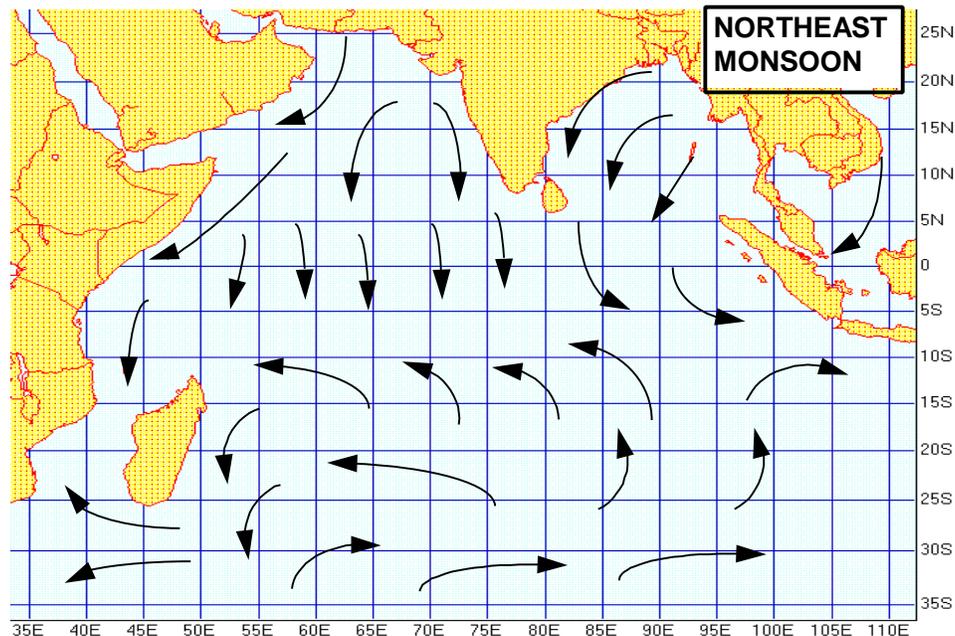


Figure 4.3.1 Northeast Monsoonal Wind Flow

4.3.2.2. SOUTHWEST MONSOON

The Indian Southwest or Summer Monsoon is far stronger and more complex than the Winter Monsoon. Interaction between the two hemispheres; Africa, the Middle East, the Tibetan Plateau and India in the Northern Hemisphere and the Mascarene High of the Southern Hemisphere combine to produce a monsoon unequaled anywhere else in the world. (Figure 4.3.2)

As summer approaches the Northern Hemisphere, thermal lows begin to form over the land surrounding the Arabian Sea. Thermal lows form a trough that extends from Somalia into West Pakistan (the position of the principal low). The thermal belt connects with the equatorial trough which has moved northward to a position paralleling the base of the Himalayas. Wind flow at the surface reverses becoming southwest as the upper level flow becomes predominately east to northeast. The Himalayan mountains prevent the relatively cooler air to the north from flowing southward from the higher latitudes in Asia. The intensity of the heat trough increases so that the basic intensity of the Southwest Monsoon is greater than that of the Northeast Monsoon.

Unlike the Northeast Monsoon, the Summer Monsoon is influenced by the Southern Hemisphere subtropical high and the deserts of northern and eastern Africa. In May, when the transition from the winter to Summer Monsoon is taking place, the deserts of Africa, being closer to the equator, have undergone greater heating. The pre-monsoon southeast flow is deflected to the right as it crosses the equator. This additive effect of cross equatorial flow combined with the initial acceleration of the flow along the deserts of Africa results in the Summer Monsoon being much stronger, with winds often reaching gale force during the peak of the Southwest Monsoon. Fetch areas exceed 1,000 mi (1610 km) and average swell heights in the Arabian Sea often exceed 18 ft (5.5 m) off the Somalia coast during the height of the monsoon.

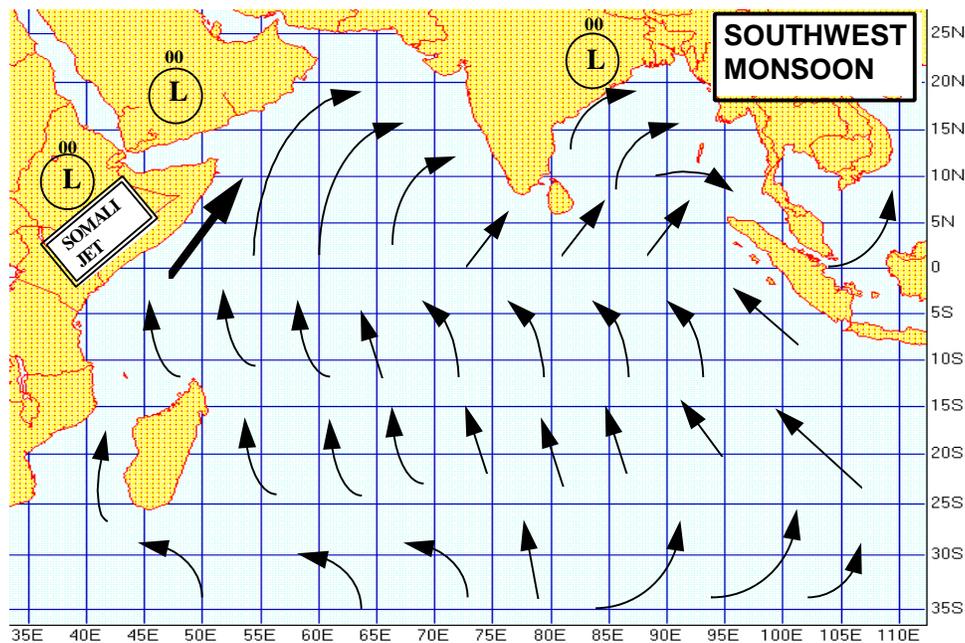


Figure 4.3.2 Southwest Monsoonal Wind Flow

4.3.3. SOUTHWEST ASIA: IRAN, IRAQ, KUWAIT, SAUDI ARABIA, BAHRAIN, QATAR, UNITED ARAB EMIRATES, OMAN, YEMEN

4.3.3.1. SHAMAL FORECASTS

"Shamal" is the name given to seasonal northwesterly winds that occur during winter and summer in the Arabian Gulf region. The summer shamal generally occurs from early June through mid July and is much less significant than the winter shamal in terms of wind strength and weather conditions. The summer shamal is also known as the "Great" or "40-day Shamal". Average wind speed during this period is 13 knots; however, 25 to 35 knot wind speeds are reached which actually constitutes a shamal. Although the winter shamal is rare, its abruptness and force have great potential for adversely affecting Navy operations.

The Winter shamal is described as follows:

1. As the upper level trough and its associated low center and frontal system move eastward or northeastward from the eastern Mediterranean into Syria, a second transient low center moves eastward from the Sudan across the Red Sea and the Arabian Peninsula. The resulting pressure gradient over the Arabian Gulf causes moderate to strong southerly winds (Kaus) over the Gulf region. These winds are strengthened by a tightening of the pressure gradient along the Zagros Mountains.

2. As the cold front moves across the Arabian Peninsula, a new low pressure center typically forms on the front in southern Iraq or over the northern Arabian Gulf, eventually becoming the dominate low as the original low moves to the north and the second low to the south weakens.
3. As the upper level trough moves into Iran, cold air is advected over the mountains of Turkey and Iran where it contributes to strong pressure rises west of the low. The resulting strong northerly (Shamal) winds force the cold front rapidly southeastward into the Arabian Gulf basin. If the cold advection is sufficiently strong and the eastward movement of the U/L trough is slow (usually found in a blocking pattern), the cold front will move off the southeast coast of the Arabian Peninsula and extend approximately 800 nm into the Arabian Sea.

4.4. FORECASTING RULES

4.4.1. NOGAPS 3.4/NORAPS 6.0 MODEL TENDENCIES

4.4.1.1. EUROPEAN (EUR) REGION

Most of the weather systems that affect the Arabian Gulf region originate in Europe. Forecasters need to be aware of model tendencies for the European region.

1. EUR NORAPS deepening surface lows are weaker over the region than NOGAPS which has an overdeepening bias. NORAPS forecast center pressure (CP) is, however, minimally deep. NORAPS generally depicts the complex nature of lows while NOGAPS usually forecasts a single, deeper surface low.
2. EUR NORAPS/NOGAPS both show a minimal positive height bias at 1000 mb at 36 hr. At 500 mb, NORAPS positive height bias is less than NOGAPS at 36 hr.
3. NORAPS and NOGAPS surface wind forecasts over Europe tend to be 5-6 kt weak at 36 hr.
4. NORAPS surface highs tend to be minimally strong.
5. NORAPS provides good depiction of orographically induced sub-synoptic scale surface lows and reflects the resolution of the NORAPS model with dense observation data and terrain definition over Europe.

4.4.1.2. INDIAN OCEAN REGION

1. Northern Indian Ocean (NIO) NORAPS provides a good depiction of U/L troughs moving southeast over the Arabian Gulf and the potential for Shamal surface winds in the cool season. Forecast surface winds are typically 6-8 kt weak over the Gulf waters by 36/48 hr.
2. Both NORAPS and NOGAPS forecast surface wind speeds over the north Indian Ocean region are 5-6 kt weak at 36 hr.
3. In the warm season (late Spring to early Fall) a false deep surface low is observed in the analyses and forecasts over the very high terrain of the Himalayas. This “lock-in” feature is caused by NOGAPS model reduction of station pressure to sea-level and the surface air temperature of the warmer seasons. NORAPS is similar to NOGAPS in analyzing and forecasting this surface (high terrain) feature. North Indian Ocean NORAPS first-guess analysis is obtained from NOGAPS.
4. Tropical cyclone (TC) development/intensification rate is generally overforecast even before the automated bogus input is made. In the development stage, forecast TC’s are slow to move. After reaching maximum intensity, mature TC’s continue to be slow to move. During the southern hemisphere winter/early spring seasons in the southern equatorial Indian Ocean, several examples of spurious TC genesis have occurred in the NOGAPS forecast. Occasionally, a false TC is depicted in the analysis, normally between 90° to 110° East.

4.4.2. GLOBAL WAVE ACTION MODEL (GWAM) 4.0 MODEL TENDENCIES

The GWAM Model initializes well at the start of the Southwest Monsoon. Due to the stationary nature of the monsoon, GWAM has a tendency to reduce the seas even though the winds remain near-gale

to gale force. The 9 FT contour on the GWAM product typically corresponds to the 12 FT analyzed contour.

4.4.3. LOCAL FORECASTING RULES

4.4.3.1. SOUTHWEST MONSOON

Forecast rules for the “ONSET” of the Southwest Monsoon:

1. Increase in the strength of the Southern Hemisphere tradewinds,
2. Strengthening of the cross-equatorial flow,
3. Speed increase in the southwest flow off the northern African Coast (frequently accompanied by development of an area of enhanced convection),
4. Formation, development and movement northward of the “ONSET VORTEX”,
5. Sharp increase in the precipitation along the southern Indian Coast,
6. Northward spreading of strong southwesterly flow to eventually cover all of the Arabian Sea, and
7. Establishment and strengthening of the upper level easterlies.

The time period from an increase in the Somali Jet to the arrival of an associated surge in the Southwest Monsoon over the southern Indian Coast is 3 to 4 days.

4.4.3.2. GENERAL FORECASTING RULES

General forecasting rules for the Southwest Monsoon:

1. When the Somali Jet intensifies, the Southwest Monsoon flow over the Arabian Sea intensifies 1-2 days later.
2. When subtropical cyclones develop between 700 and 500 mb in the Monsoon Trough over the Bay of Bengal or the northern Indian Coast, forecast low-level wind flow to increase by 10-20 kt off the central Indian Coast -- particularly if there is evidence of the cyclonic circulation penetrating downward.
3. If the maximum surface pressure gradient occurs north of 23° North (over land), forecast “weak” monsoon flow. If the maximum gradient is over water (13° to 21° North), forecast “strong” monsoon flow conditions.
4. During “strong” monsoon conditions, the area north of 22° North usually experiences relatively light surface winds.

4.4.3.3. “BREAKS” IN THE SOUTHWEST MONSOON

Forecast “breaks” in the Southwest Monsoon flow as follows:

1. “Breaks” will not occur when troughs in the mid-latitude westerlies (40°-50° North) move unimpeded across the longitudes 90° to 120° East.
2. Regular development and movement of the mid-troposphere monsoon depression from the Bay of Bengal across India is NOT conducive to a “break”.
3. Development of a blocking high between 35° to 70° North and 90° to 115° East is favorable for a “break” in the flow.

4.4.3.4. WINTER SHAMAL

Typical synoptic conditions for the Winter Shamal are:

1. From the eastern Mediterranean area, and extending south of the Taurus Mountains, a cold long wave trough (at least $-13^{\circ}\text{F}/-25^{\circ}\text{C}$ at 500 mb) with an associated surface low and frontal system moves eastward toward the northern Arabian Gulf.

2. A second low moves eastward across Saudi Arabia from the Red Sea as the "Kaus" (strong southeasterly wind) sets in the Gulf.

3. As the cold front moves over the northern Arabian Peninsula, a new low is formed on the front in the vicinity of the northern Arabian Gulf.

4. The upper level trough moves eastward over Iran, advecting cold air over the mountains of Turkey, resulting in strong northwesterly air flow and pressure rises west of the new surface low, producing gale force winds, high seas, thunderstorms and advecting dust and sand over the Arabian Gulf.

5. Duration of the winter shamal (northwest wind greater than 25 kt) is usually 24 to 36 hours. However, if the long wave trough stalls in the vicinity of the Strait of Hormuz, the shamal will persist for 3 to 5 days.

Forecasting onset wind speed where dT = difference in surface temperature between the central Arabian Gulf and the Tigris-Euphrates Valley:

30 kt for $dT = 18^{\circ}\text{F}/10^{\circ}\text{C}$.

35 kt for $dT = 27^{\circ}\text{F}/15^{\circ}\text{C}$.

40 kt for $dT = 36^{\circ}\text{F}/20^{\circ}\text{C}$.

45 kt for $dT = 45^{\circ}\text{F}/25^{\circ}\text{C}$.

Associated seas for wind speeds of 30-40 knots:

10-12 ft 12 to 24 hours after onset.

12-14 ft 24 to 36 hours after onset.

15-18 ft in the southern Arabian Gulf if shamal lasts longer than 36 hours.

Significant turbulence can be associated with the shamal at all levels of the troposphere. Turbulence may be induced by the mountains in the Arabian Gulf region or in association with the cold front and also due to the upper air pattern of the shamal.