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# 1 BASIC DESCRIPTION

## 1.1 COMMAND MISSION

The mission of NAVPACMETOCCEN WEST Guam as set forth in NAVMETOCCOMINST 5450.9 is: “To provide, within areas of responsibility as assigned by the Commander, Naval METOC Command, operational METOC services to U.S. and Allied units operating within the Fifth and Seventh Fleet Areas of Responsibility (AOR).” Click [here](#) for command logo.

### 1.1.1 Geographic Location

The island of Guam is located in the Mariana Island Chain approximately 1500 mi (2415 km) east of Manila and 3300 mi (5313 km) west-southwest of Honolulu. The islands are the dividing line between the Philippine Sea to the west and the Pacific Ocean to the east. Guam is the southernmost and largest island, totaling 212 sq mi (549 sq km), which equals the combined area of the other 14 Marianas islands. It is shaped like a "footprint" 35 mi (56 km) long and varies in width from 4 to 9 mi (6.5-14.5 km).

The climate of Guam is predominately warm and humid throughout the year. Afternoon temperatures are typically in the mid to upper eighties (Fahrenheit) and nighttime temperatures fall to the mid to lower seventies (Fahrenheit). Although temperatures and humidity vary only slightly throughout the year, rainfall and wind conditions vary markedly.

There are two primary seasons on Guam: the dry season which extends from mid-January through mid-May and the rainy season which extends from mid-July to mid-November. June and December are considered transition months.

### 1.1.2 Command Location

NAVPACMETOCCEN WEST Guam is located in Building 200 on Nimitz Hill, at an elevation of 565 ft (172 m) above mean sea level (MSL). NAVPACMETOCCEN WEST Admin is located on the second deck of Bldg. 200. JTWC Admin spaces are also located on the second deck. Command Operations, including JTWC, are located in Bldg. 200 Annex.

## 1.2 AREA OF RESPONSIBILITY ([AOR](#))

Naval Pacific Meteorology and Oceanography Center West/Joint Typhoon Warning Center (NAVPACMETOCCEN WEST/JTWC) Guam's AOR encompasses the marine areas of the Pacific and Indian Ocean basins (including the Arabian Gulf) from the southern tip of Africa to 60° South along 17° East on the western boundary. The eastern boundary extends from 66° North, southward along the International Dateline to 60° South. For WEAX/OTSR and High Wind/Sea Warnings 180° serves as the eastern boundary for purposes of simplification.

## 1.3 COMMAND ORGANIZATION

NAVPACMETOCCEN WEST consists of the Joint Typhoon Warning Center, Equipment Support Department and the Operations Department.

### 1.3.1 Joint Typhoon Warning Center

The only defense against a tropical cyclone is adequate preparation. Adequate preparation is dependent upon timely warning which is, in turn, based upon the receipt of data and accurate forecasts of tropical cyclone formation, position, movement, intensity and wind distribution.

The Joint Typhoon Warning Center (JTWC), a joint Navy and Air Force organization, is co-located within the command and under the direction of the Commanding Officer of NAVPACMETOCEN WEST Guam. JTWC provides tropical cyclone warning support to all Department of Defense activities in the Western Pacific and Indian Ocean regions. NAVPACMETOCEN WEST/JTWC, in conjunction with the National Weather Service, provides tropical warnings to the governments of the Commonwealth of the Northern Mariana Islands, The Republic of the Marshall Islands, The Republic of Belau, The Federated States of Micronesia, Wake Island and Guam.

#### 1.3.1.1 Mission

The mission of the Joint Typhoon Warning Center (JTWC) is defined by USCINCPACINST 3140.1W and includes the following primary functions:

1. Continuous monitoring of all tropical weather activity in the Northern and Southern Hemispheres, from 180° longitude westward to the east coast of Africa, and the prompt issuance of appropriate advisories and alerts when tropical cyclone development is anticipated.
2. Issuance of warnings on all significant tropical cyclones in the above area of responsibility (AOR).
3. Determination of requirements for tropical cyclone reconnaissance (primarily satellite) and assignment of appropriate priorities.
4. Post-storm analyses of all significant tropical cyclones occurring within the western North Pacific and North Indian Oceans.
5. Coordination with the Fleet Numerical Meteorology and Oceanography Center (FNMOC); the Naval Research Laboratory (NRL), Monterey, California; and Space and Naval Warfare Systems Command (SPAWAR/PMW-175) on the maintenance and operational evaluation of tropical cyclone models and forecast aids and the development of new techniques to support operational forecast requirements.

#### 1.3.1.2 Organization

Since its establishment in 1959, JTWC has functioned with the USN as the lead agency through the Commanding Officer, NAVPACMETOCEN WEST/JTWC, Guam.

1. USAF billets include the Director, Typhoon Duty Officers and Typhoon Duty Assistants.
2. USN billets at JTWC include the Deputy Director, Typhoon Duty Officers, Typhoon Duty Assistants and a Civilian Technical Assistant.

### 1.3.2 ESD

The Equipment Support Department (ESD) is staffed by Electronics Technicians (ET), specifically trained in the repair of meteorological equipment, Data Systems Technicians (DS) and Data Processing Technicians (DP). ESD is responsible for the installation, maintenance and upgrades of all equipment, software and buildings in the command.

On a limited by-request basis, repair and calibration services can be provided to inport units, such as:

- **Aneroid Barometer** (ML-448/UM Precision Aneroid Barometer or the SK-12509 General Purpose Aneroid (Taylor) Barometer)
- **Wind Measuring Device (UMQ-5)**
- **Portable Wind Measuring Kit (AN/PMQ-3)**
- **Electric Psychrometer (ML-450/UM)**
- **Mini Rawinsonde System (MRS)**
- **AN/SMQ-11**
- **Tactical Environmental Support System (TESS (3))**

### **1.3.3 Operations**

The Operations Department (OPS) consists of assigned METOC Officers and AG personnel. OPS is responsible for the preparation and transmission of AOR forecast products, WEAX, OTSR, Wind/Sea warnings not associated with tropical cyclones and special exercise METOC support.

#### **1.3.3.1 FSO**

The Fleet Services Office (FSO) is responsible for the Fleet Liaison program, OTSR and WEAX services within the AOR and the Ship Liaison program. FSO is also responsible for OTSR/WEAX services for Fleet exercises, Defense Mapping Agency (DMA) matters and information, the Fleet Users Guide and quality control of OTSR/WEAX products.

#### **1.3.3.2 MSO**

The Meteorological Services Office (MSO) is responsible for the content and maintenance of NPRNET/SIPRNET websites, content of the Fleet Broadcasts (both GFAQ and PMHH/GMWW), climatological requests, Operations Floor products and the quality control program. MSO acts as a coordination center to work with NCTS Guam concerning outages and connectivity. Additionally, MSO is responsible for outage contingencies, PLA verification and special exercise broadcasts.

#### **1.3.3.3 TSO**

The Tactical Services Office (TSO) is responsible for oceanographic and acoustic products and requests. TSO will also act as a coordination center for products and services during fleet exercises and investigate new products and services along with their application within the AOR.

## **1.4 LOCAL COMMANDS SUPPORTED**

NAVPACMETOCCEN West/JTWC Guam provides environmental services to local commands, fleet units and various DOD and Non-DOD assets within the AOR.

### **1.4.1 COMNAVMAR**

Commander, Naval Forces Marianas (COMNAVMARIANAS) is the largest Naval facility on Guam and provides all administrative and support functions for tenant activities as well as port facilities. COMNAVMARIANAS is the Navy representative to the Commonwealth of Northern Mariana Islands, Federated States of Micronesia, Republic of the Marshall Islands, Guam and Republic of Belau. Local warnings issued by the National Weather Service are forwarded through the AUTODIN system and via phone. Routine services provided to NAVACTS include tropical cyclone warnings, thunderstorm advisories affecting Naval Magazine and small craft advisories for MWR sailing facilities. When a tropical cyclone threatens Guam, heavy weather briefs are held to prepare commands for the onset of damaging winds and to inform all ships in the harbor of sortie plans.

### **1.4.2 NCTS Guam**

Naval Computer and Telecommunication Station (NCTS) Guam is responsible for all communication circuits serving Seventh Fleet. NCTS Guam antennas are highly sensitive to high winds associated with tropical cyclones; therefore, warnings are coordinated with NCTS Guam personnel.

### **1.4.3 Naval Hospital Guam**

NAVHOSP is responsible for the medical care of active duty and retired military personnel on Guam. Routine services provided to NAVHOSP are tropical cyclone warnings and high wind warnings affecting emergency helicopter operations.

### **1.4.4 Andersen AFB**

ANDERSEN Air Force Base is located on the northern end of the island and is responsible for all Air Force operations within the western Pacific region. Close liaison exists between JTWC and the 36OSS Weather Office at Andersen AFB.

### **1.4.5 NPMOD Diego Garcia**

NAVPACMETOC DET Diego Garcia is located near 07° S 72° E in the Indian Ocean. The detachment provides standard aviation weather forecasts for transiting aircraft and in-port forecasts for pre-positioned ships of the Military Sealift Command. Routine services include dissemination of synoptic data via Fleet broadcasts. Special products and services are provided upon request.

### **1.4.6 NCMOF Bahrain**

NAVCENTMETOC FAC Bahrain is located in the Arabian Gulf. The detachment provides meteorological and oceanographic services to components of the Fifth Fleet, USNAVCENT and others operating within the Arabian Gulf, Red Sea and the North Arabian Sea. Routine services include a bulletin board system, local area and specialized forecasts and high wind and sea warnings for the Fifth Fleet AOR.

### **1.4.7 Fleet Support**

NAVPACMETOCEN West/JTWC Guam also provides tailored support to COMSEVENTHFLT, components of SEVENTH Fleet including all Task Forces (CTF 70 - 79), components of FIFTH Fleet, U.S. Naval Forces Central Command, U.S. Southern Command, U.S. Coast Guard units, U.S. Army units, Allied Naval Forces, U.S.N.S. and Military Sealift Command (MSC) units throughout the AOR.

## **2 METOC COMMUNICATIONS**

### **2.1 MESSAGE ADDRESSES**

#### **2.1.1 AUTODIN**

Routine and higher precedence Automatic Digital Network (AUTODIN) traffic, except Top Secret, is received on the Operations floor via dedicated phone line from NCTS GUAM. Operational and administrative traffic is transmitted via the AUTODIN Gateway (GATEGUARD) Terminal.

METOC observations and requests for services in the Pacific and Indian Oceans should be addressed to Collective Address Designator (CAD) "OCEANO WEST". The CAD includes the following action addressees:

- NAVPACMETOCEN PEARL HARBOR HI
- NAVPACMETOCEN WEST GU

- FLENUMMETOCCEN DATA MONTEREY CA
- NAVOCEANO DATA STENNIS SPACE CENTER MS
- AFGWS OFFUTT AFB NE

Ships transiting between Atlantic and Pacific Oceans and Atlantic and Indian Oceans should include "OCEANO EAST" as info addee on all observations and requests.

NAVPACMETOCCEN WEST is also included on AIG's SIX ONE and FIVE FIVE for receipt of MOVREPS/MOVORDS.

## 2.1.2 AWN

The U. S. Air Force holds the responsibility for collecting and distributing environmental data via the Automated Weather Network (AWN) There are three major Automatic Digital Weather Switches (ADWS): Croughton AB, England, serving Europe via the European Meteorological Environmental Data System (EURMEDS); Hickam AFB, HI, serving the Pacific via the Pacific Meteorological Environmental Data System (PACMEDS) and Tinker AFB, OK, serving the Continental United States via the CONTEL Meteorological Workstation (CMW).

## 2.2 METOC BROADCASTS

### 2.2.1 Fleet Broadcast

NAVPACMETOCCEN WEST monitors two 75bps radioteletype broadcasts which are carried on channel 8 on the WESTERN PACIFIC FLEET BROADCAST (PMHH) and INDIAN OCEAN FLEET BROADCAST (IMOO) respectively. These broadcasts are designed for units with METOC personnel embarked. Data requirements and contingencies are routed to ADWS TINKER AFB which originates the broadcast via dedicated circuits. Unclassified environmental data keystreams are routed to NCTS GUAM via ADWS HICKAM AFB Hawaii and ANDERSEN AFB Guam where data is encrypted and classified data is inserted. Circuit designator and conductivity paths are detailed in local directives and SOP's.

### 2.2.2 GFAX

The Guam Fleet Facsimile Broadcast (GFAX) is a METOC HF facsimile broadcast, controlled by SEVENTHFLT and administered by NAVPACMETOCCEN WEST when requested. The broadcast consists of FNMOC Monterey derived analyses and prognostic charts and selected value-added charts produced by NAVPACMETOCCEN WEST Operations forecasters. GFAX is an unencrypted broadcast available to anyone with facsimile reception capabilities. GFAX reception is subject to atmospheric propagation anomalies experienced by all HF broadcasts. Units experiencing reception problems should submit a COMSPOT via immediate AUTODIN message to NCTS GUAM, info NAVPACMETOCCEN WEST GU.

The Western Pacific GFAX supports SEVENTHFLT assets located in the western Pacific Basin. Product coverage extends from 66° North to 20° South and from 100° East to 180°. Value-added products for this area include 36, 84 and 120 HR Weather Depictions and a 36 HR Combined Sea Height Prog, as well as numerical products. WESTPAC GFAX broadcast frequencies:

| TRANSMISSION    | FREQUENCIES   |
|-----------------|---------------|
| Barrigada, Guam | 10255 LSB/USB |
|                 | 1629.6 LSB    |
|                 | 19860 LSB/USB |
| Totsuka, Japan  | 4965 USB      |
|                 | 12775 USB     |
|                 | 22324.5 USB   |

The Indian Ocean GFAQ supports SEVENTHFLT and FIFTHFLT assets located in the Indian Ocean, Arabian Gulf and Red Sea. Product coverage extends from 60° North to 20° South and from 20° East to 100° East. Value-added products include the 36 HR Combined Sea Height and 36 HR Weather Depiction. IO GFAQ broadcast frequencies:

| TRANSMISSION    | FREQUENCIES         |
|-----------------|---------------------|
| Barrigada, Guam | 5260 LSB/USB        |
|                 | 23010 LSB           |
| Diego Garcia    | 7580 USB (24 HRS)   |
|                 | 12894 USB (00Z-12Z) |
|                 | 20300 USB (12Z-00Z) |

## 2.3 EQUIPMENT

### 2.3.1 AWDS

The Automated Weather Distribution System (AWDS) ingests graphic and alphanumeric data for display. There are three functional areas (FA) available at JTWC: the C/DM, BWS and SWO. The C/DM FA (Communications/Data Manager Functional Area) ingests, processes and stores all incoming data to the AWDS. Data requirements are established by the AWDS System Manager. The BWS FA (Base Weather Station) processes, stores and displays all data requested. The BWS also contains the printing capability of the system. The SWO FA (Staff Weather Officer) performs all the functions of the BWS but does not have local printing capability.

The alphanumeric data comes via long haul circuit (KDNY) to the C/DM from Det 7 AFGWC, Tinker AFB OK. All alphanumeric data is handled much the same way as with PACMEDS. Alphanumeric data cannot be used for graphical display or to derive other data types. The graphics data comes via long haul circuit (KDNX) to the C/DM from AFGWC. There are four basic types of graphics data: vector, FBD, UGDF and Raster Scan. Vector graphic data are pregenerated fields and usually contain some form of manual interpretation of those fields. FBD (Formatted Binary Data) are surface and UA observations formatted into a graphical plot for display on a map. UGDF (Uniform Gridded Data Fields) are raw grid point, modeled fields. The model in use is the AFGWC GSM, but AFGWC plans to transfer to the NOGAPS model as the source for these fields. These fields can be displayed in plots as the FBD or used to derive and plot isopleths for other fields on predetermined maps. Finally, Raster Scan data is 8 grayshade DMSP data from the AFGWC Satellite Global Data Base.

### 2.3.2 Satellites

The Geostationary Satellite Receiving System (GSRS) is capable of receiving direct read-out of high-resolution imagery and selected data from selected geostationary satellites. The GSRS processes data, allowing the forecaster to display, manipulate and print METOC products. The real-time collection allows for viewing data as it is received and manipulating data after ingest.

The M1000 is a stand-alone CPU connected to the NIPRNET via the LAN. The Satellite Weather Data Imaging System (SWDIS) allows connectivity to other similarly equipped METOC GSRS systems for retrieval of satellite imagery through File Transfer Protocol (FTP). Non-satellite files may also be transferred to the LAN via NIPRNET.

JTWC has three satellite systems that are available for data retrieval and may be used in forecasting tropical cyclones. The MARK IV is a stand-alone system capable of retrieving both geostationary and polar orbiting satellites. The MISTIC system receives Special Sensor Microwave/ Imagery (SSM/I) data via NIPRNET from FLENUMMETOCEN Monterey. SSM/I calculates wind speeds based on sea surface disruption. The MIDAS system is used to analyze tropical systems. This system utilizes both the MARK IV and GSRS imagery.

### **2.3.3 JMCIS**

The Joint Maritime Command Information System (JMCIS) integrates Command, Control, Communications, Computers and Intelligence (C4I) functions into an automated networked system. A variety of computer platforms, software and network and communications interfaces form the JMCIS architecture.

The Joint Operational Tactical System II (JOTSII) is an automated Command, Control, and Communications display and decision-aid system. It is designed to meet the tactical situation assessment needs of battle group/force commanders, warfare commanders, ship CO's and shore command centers. It receives tactical information from a variety of sources and automatically correlates this data with its existing tactical contact database, which is used to generate computer graphic images for use by tactical decision makers. JOTSII communication capabilities allow for transmission and receipt of OPNOTES between NAVPACMETOCCEN WEST and similarly equipped units. Our JOTSII address is "NPMOCW GU."

The Navy Integrated Tactical Environmental Subsystem (NITES) consists of a collection of application programs and system services. Its primary purpose is to collect, manage, display and disseminate environmental data sets which are useful as tactical decision aids to tactical commanders and operators. The TESS Remote Workstation (TRWS) receives gridded field data from the main TESS-3 computer for manipulation and display via JOTS II overlay. Nites Central Site Product Display (NCSPD) allows the user to retrieve, display, annotate and save METOC data from either the TESS-3 system or directly from FLENUMMETOCCEN Monterey. Integrated Refractive Effects Prediction System (IREPS) uses a mathematical model to predict the performance of radar systems and Electronic Support Measure receivers based on radar attributes, target attributes and environmental data. The Imageviewer allows the viewing of satellite imagery received from TESS-3, SMQ-11 or from remote sources via FTP.

### **2.3.4 NODDS**

Naval Oceanography Data Display System (NODDS) provides the capability to define a region of interest and display different types of data for that region. All standard meteorological fields are available from FLENUMMETOCCEN Monterey and can be displayed along with a wide range of oceanographic, satellite and acoustic products. NODDS also has the ability to overlay up to three different fields on a single chart or display individual sequence loops.

Naval Oceanography Data Display System Facsimile Broadcast (NODDSFAX) uses the basic NODDS program described above to download NODDS data and then transfer the data fields to our WPAC and IO GFAX broadcasts. A recurring schedule and data download is programmed into the system allowing for a continuous 24-hour broadcast of environmental data.

### **2.3.5 Weather Radar**

The Weather Surveillance Rader (WSR-88D) is the second-generation Doppler radar replacing the non-Doppler meteorological radars. The Radar Data Acquisition (RDA) detects and estimates the meteorological phenomenon being studied. The Radar Product Generator (RPG) performs the meteorological data analysis and preformats the output products for remote display. Both of these units are located at Andersen AFB. The Principal User Processor (PUP) provides user interface and is located in the JTWC Operational spaces. Data received from the WSR-88D is invaluable in forecasting tropical cyclone wind speeds as these systems approach Guam.

### **2.3.6 MODAS**

The Modular Ocean Data Assimilation System (MODAS) provides a modular approach to the analysis of ocean data in support of ocean/acoustic and sensor predictions. It is designed to assimilate observed random ocean data, synthetic data, climatology and a first-guess field to generate a quality controlled, smoothed, gridded analysis field.

### **2.3.7 JDISS**

The Joint Deployable Intelligence Support System (JDISS) provides software/hardware capabilities allowing connectivity and interoperability with remote intelligence systems required to support forces in-garrison and deployed in peacetime, crisis and war.

### **2.3.8 MIDDS**

MIDDS consists of multi-tasking software products which are designed to collect and display high-resolution satellite imagery, DIFAX charts and RADAR.

### **2.3.9 Websites**

NAVPACMETOCEN WEST Guam maintains a website accessible via either Siplrnet or Niplrnet. Numerous products are available on the website including satellite pictures of the Western Pacific and Indian Oceans, locally produced short, medium and long range weather depictions and specialized forecasts.

## **3 WESTERN PACIFIC REGION**

### **3.1 TOPOGRAPHY**

The physical structure of eastern Asia and adjacent ocean areas exert a significant influence on the weather of the region. The many meteorological conditions described herein are the result of airmass trajectory coupled with modifications imposed by the land and water areas over which the air mass travels. A careful study of the topography of eastern Asia and the bathymetry of adjacent water areas is essential to successful forecasting.

#### **3.1.1 Kamchatka And The Kuril Islands**

The peninsula of Kamchatka extends south-southwestward from the Arctic Circle to approximately 51° North. The Koryak Mountain Range dominates the peninsula, extending the length of Kamchatka. Elevations commonly exceed 8,000 ft (2440 m) with individual peaks ranging between 11,000-16,000 ft (3355-4880 m). Forty volcanoes are known to exist on the peninsula, of which approximately 15-20 are active.

Extending southwest from the tip of Kamchatka are the Kuril Islands. Volcanic in nature, more than 100 cones form the island chain, of which approximately 40 are active.

#### **3.1.2 Siberia (Russia)**

The coastal area of Siberia is mountainous. The Kolyma and Dzugdzhur Ranges extend from the Arctic Circle to 55° North, encircling the western Sea of Okhotsk. Elevations range from 3,000 to 7,500 ft (915 m to 2288 m). Approximately 400 mi (644 km) inland, the Okhotsk-Kolyma Range exceeds 8,000 ft (2440 m).

The Siberian Plateau extends from the Verkhoyansk Range (135° East) to the Ural Mountains (60° East). The eastern region consists of mountains areas, the central region consists of barren highlands and the western area consists of lowlands.

The Sikhote Alin Mountain Range is located northeast of Vladivostok, averaging 3,000-5,000 ft (915-1525 m). North of Vladivostok lie the open plains of the Ussuri River Valley. The plains average 500 ft (153 m) below sea level and 60 mi (97 km) wide along the coast, forming a natural outlet for northerly winds.

### **3.1.3 Japan**

The Japanese Archipelago is composed of four main islands: Hokkaido, the northern-most island; Honshu, the largest and main island; Shikoku, located to the east of southern Honshu; and Kyushu, the southern-most island. Four-fifths of the country is mountainous, including approximately 165 volcanoes (45 of which are still active). The Japan Alps, located in the central region of Honshu, is the major mountain chain of the Japanese islands, averaging 5,000-12,000 ft (1525-3660 m) in elevation. The mountains of Hokkiado constitute the second major chain, averaging 5,000-6,000 ft (1525-1830 m). The third chain is found on the island of Kyushu, averaging only 5,000 ft (1525 m).

The Ryukyu Island chain forms a 750 mi (1208 km) arc between Japan's southern-most main island of Kyushu and the northern-most tip of the island of Taiwan. This island chain forms a natural boundary between the East China Sea to the west and the Pacific Ocean to the east.

### **3.1.4 China**

The coastal areas of eastern mainland China are characterized by extensive low-lying mountain ranges, which have elevations commonly below 3,000 ft (915 m).

The Nangnim Range (southwest of Vladivostok) continues into eastern Manchuria and into northern Korea with elevations of 8,000 ft (2440 m). The Manchurian Plain extends from the foothills of the Nangnim to the Greater Khingan Range on the edge of the western Gobi Desert. The extreme western extent of the Himalayan Mountains dominates central and western China.

### **3.1.5 Mongolia**

Mongolia lies in central Asia with Russia to the north and China to the south. The Gobi desert, in the southeast region, supports no vegetation and is sparsely populated. Funneling of winds between the ranges of western Mongolia and Manchuria can cause strong winds over the desert area. Airborne sand has been observed as far away as the Yellow Sea and the Sea of Japan. The northern extension of the Himalayas dominates the terrain of northwestern Mongolia.

### **3.1.6 Korea**

The Korean Peninsula extends 600 mi (966 km) from 44° North to 33° North and has a total area, including off-shore islands, of 75,250 sq mi (194,899 sq km). The Peninsula extends to within 120 mi (193 km) of Honshu and the Shantung Peninsula of China.

North Korea extends about 445 mi (716 km) from the southwest to the northeast and is approximately 225 mi (362 km) wide. It is bordered by China to the north and by Russia to the extreme east. About 80% of North Korea is mountain ranges and uplands. The Kaema Plateau, average elevation 3280 ft (1,000 m), bisects the country. The Hamgyong Mountains rim the eastern edge of the plateau, rising to over 8200 ft (2,501 m). The eastern lowlands are a very narrow strip between the plateau and the coast. The western lowlands are a much wider strip.

South Korea also has an abundance of mountain ranges—approximately 70% of the total landmass. The main range, the Taebaek Mountains, roughly parallels the east coast. The other four major ranges (the Charyong, the Kwangju, the Sobaek and the Noryong) form 90° angles from the Taebaek Mountains. Most of the lowlands are located in the western portion of the Peninsula.

### **3.1.7 Taiwan**

Taiwan is mostly mountainous, with peaks of 12,743 ft (3,887m) and 13,114 ft (4,000 m) in the northern and central areas of the island.

### **3.1.8 Micronesia**

Micronesia consists of more than 2,500 islands and islets, a total land area of 1100 sq mi (2849 sq km) spread over an ocean area of 2.5 million sq mi (6.5 million sq km). Micronesian islands are classified as high or low, depending on their elevation, and as continental or oceanic according to their geological substructure. A low island will have an elevation of a few feet while a high island may have an elevation of 2,000 ft (610 m). A continental island has a substructure that is built upon piles of lava that have been extruded from volcanic fissures in the sea floor. Many of these islands are ringed or topped by coral growths forming varying types of outer reefs. Oceanic islands have a substructure that does not reach the surface. Rather coralline growths that have accumulated over the centuries are exposed. Most of these formations are atolls, consisting of a barrier or a fringing reef enclosing a number of tiny islets around an interior lagoon.

The Belau (Palau) group, Yap and the southern four islands of the Marianas are examples of continental high islands. Chuuk (Truk), Pohnpei and Kosrae in the Eastern Carolines are examples of oceanic high islands. The remaining Micronesian islands are classified as low oceanic islands.

### **3.1.9 Philippine Islands**

The Philippine islands consist of more than 7,000 individual islands. The islands are grouped into three regions: the Luzon region in the north, the Visayas region in the center and the Mindanao region in the south.

Many of the larger islands have narrow coastal plains and interior highlands and mountain ranges. These ranges, generally oriented north and south, cover almost the entire length of the islands. Three major ranges dominate the island of Luzon: the Sierra Madre in the north and central area, the Ilocos range along the extreme western coast and the Zambales located along the extreme western coast of central Luzon. Many of the larger islands within the Visayas region have ranges that extend their entire length. Mindanao has extensive mountain ranges dominating the eastern and western coastal areas, with a third range dividing the island.

## **3.2 OCEANOGRAPHY**

The oceanic regions of the western North Pacific include both marginal seas and deep ocean areas. Significant differences in physical properties exist between these ocean regimes that impact temperature profiles, salinity and bottom characteristics. These differences determine the region's sound speed profile, which affect acoustic propagation characteristics. Critical features and effects of bottom topography, ocean fronts and eddies and ocean currents will be briefly covered.

### **3.2.1 Bottom Topography**

#### **3.2.1.1 Western North Pacific**

For purposes of this handbook, the western North Pacific (NWPAC) is limited to the ocean areas west of 180°, to the Japanese and Kuril Islands and from 66° North 180° to the Equator.

The majority of ocean area discussed here is comprised of open ocean, deep basins and trenches.

A fundamental characteristic of the Pacific Basin is the semi-continuous belt of trenches. The Kuril Trench (27,880 ft/8,503 m) parallels the Kuril Island chain, with maximum depths found between Hokkaido and the central Kuril Islands. The Japan Trench (35,440 ft/10,809 m) is located just to the east of northern Honshu, continuing south-southeastward to near 30° North. The Bonin Trench (28,405 ft/ 8,664 m) is found along the eastern edge of the Bonin Island chain. The Mariana Trench extends from the base of the Bonin Trench to approximately 10° North on the eastern periphery of the Mariana-Bonin ridge. The Challenger Deep, at 35,800 ft (10,919 m), is the deepest trench in the world. The Yap-Palau Trenches extend from the base of the Mariana-Bonin Ridge to approximately 7° North along the southeastern periphery of the Kyushu-Palau Ridge.

West of these deep trenches, the bottom slopes are quite extreme, rising rapidly to the relatively shallow continental shelf of Japan, the Kuril islands and the Bonin islands.

### **3.2.1.2 Sea Of Okhotsk**

The Sea of Okhotsk is one of the marginal seas of the Pacific, situated in the northwestern part of the ocean. It is separated from the Pacific by the Kuril Island chain and the Kamchatka Peninsula. The Kuril Straits connect the Sea of Okhotsk with the Pacific Ocean and the Tartar and Soya Straits with the Sea of Japan.

The Sea of Okhotsk lies within the transition zone from the continent to the floor of the Pacific Ocean proper. There are three categories of bottom topography: continental and island shelves, the central portion and the southern deep-water basin. The shelf area constitutes more than 40% of the entire sea area. Bottom composition is mainly sand and silt. The central shelf consists of a series of ridges and troughs with depths ranging from 656 ft (200 m) to 5,740 ft (1,751 m). The Kuril Basin runs along the inner edge of the Kuril Islands with a maximum depth of 10,253 ft (3,107 m). The basin is surrounded on all sides by steep slopes as steep as 15-20°. Sedimentary cover over the nearshore summits and slopes of marine rises is mainly pebbly gravel and sand. The majority of the basin is covered in bands of silts, clay and ooze.

### **3.2.1.3 Sea Of Japan**

The Sea of Japan is a marginal sea of the western north Pacific, surrounded on the east by the Japanese Islands and on the west by coastal Asia. Openings to the Pacific and other seas are through the Tsushima (Korean) Strait to the south, Tsugaru Strait between the islands of Hokkaido and Honshu, the Soya (La Perouse) Strait between Hokkaido and Sakhalin Island and the Tartar Strait between Sakhalin Island and the Asian mainland. The significance of these straits will be covered in later sections.

The central Sea of Japan is dominated by the Japan Basin and Japan Abyssal Plain. The Tartar Trough extends southward from between Siberia and Sakhalin Island to the Japan Basin. The most prominent individual topographical feature in the Sea of Japan is the Yamato Rise, which is divided into the Kita-Yamato Ridge and the Yamato Ridge by the Yamato Trough. Most of the continental shelf area is very narrow except in the extreme northern portion near Hokkaido and Sakhalin Island. Steep slopes of over 30° bound the ridge and trough features.

The Tsushima/Korea Strait is oriented northeast-southwest between the southern Korean coast and the southwestern coast of Honshu. The strait is comprised of East and West channels which are located on either side of Tsushima Island. The topography of the strait is basically a continuation of the continental shelf of the East China Sea. A relatively flat bottom dominates the strait. Major topographical features include: Tsushima Island located approximately in the middle of the straits, the irregular coastlines of Korea to the north and Japan to the south and a depression centered off the northwest coast of Tsushima Island in the West Channel.

### **3.2.1.4 Yellow Sea**

The Yellow Sea is bounded by the People's Republic of China to the west and north, North Korea to the northeast, South Korea to the east and the East China Sea to the south-southeast. The geographic configuration allows for division into three segments: the Gulf of Pohai to the northwest, Korea Bay to the northeast and the Yellow Sea. For purposes of this handbook the Yellow Sea and Korea Bay will be called the Yellow Sea Proper.

The Yellow Sea Proper and Gulf of Pohai form a partly enclosed, wide, flat, shallow marine embayment. The entire area is part of the continental shelf with depths averaging from 197-252 ft (60-77 m). Numerous sand ridges and channels run perpendicular to the coast. Strong tidal currents and numerous rivers carry suspended sand particles into the Sea which then are sorted by the currents. The bottom of the central basin and the Chinese side of the Pohai Bay is composed mainly of muddy silt.

### **3.2.1.5 East China Sea**

The East China Sea bathymetry is divided into two contrasting areas: the continental shelf which makes up the shallow water area and the Okinawa Trough which constitutes the deep water area.

The shelf area is relatively narrow and elongated. Widths vary from 170 mi (274 km) near Taiwan to 450 mi (725 km) near the northern boundary (33° North). There are a few scattered islands near the outer edge of the shelf. Outflow from the Yangtze (Yellow or Changjiang) River is the primary origin of shelf material. General composition consists of a 85 mi (139 km) belt of mud from the shore with a broader paralleling zone of fine-grained sediments changing to sand at the outer shelf area.

The Okinawa Trough borders the continental shelf with the western side defining the continental slope. The trough extends from Taiwan to Kyushu along the inner Ryukyu Island arc.

### **3.2.1.6 Philippine Sea**

The limits of the Philippine Sea are defined by the Philippine islands of Luzon, Samar and Mindanao on the southwest; the island of Belau (Palau), Yap and Ulithi on the southeast; the Mariana Islands on the east; the Bonin and Volcano Islands on the northeast; the Japanese islands of Honshu, Shikoku and Kyushu on the north; the Ryukyu Islands on the northwest and Taiwan on the west.

The Philippine Sea is an abyssal zone with depths generally greater than 6,500 ft (2,000 m). The bottom topography consists of deep trenches (over 19,600 ft/5,978 m in depth), belts of seamounts and deep basins. The abyssal deep basin is separated into east and west basins by the Kyushu-Palau Ridge. The bottom sediments are pelagic red clays and oozes with volcanic material along the island arcs.

### **3.2.1.7 South China Sea**

The South China Sea (SCS) is bordered on the north through west by the Asian mainland, the southern limit of the Gulf of Thailand and the Malay Peninsula on the southwest through the southern side, the Philippine Islands and Taiwan to the east and northeast.

The China Sea Basin, located in the north central portion of the sea, dominates the majority of the South China Sea with a maximum depth of 17,400 ft (5,307 m). The central portion of the SCS is an abyssal plain. Large reef-studded shoal areas occur within the basin in the southern area.

Mud and sediments dominate the bottom in the vicinity of coastal areas extending outward along the continental shelf. Clay is the main sedimentary feature in the deeper portions of the basin. Volcanic ash is found in layers throughout the basin as a result of numerous volcanic eruptions in the East Indies, most notably the enormous eruption of Krakatao.

### **3.2.1.8 Sulu Sea**

The Sulu Sea is bounded on the south-southwest by Borneo, to the west-northwest by the Palawan Island, to the north through southeast by the Philippine Islands and to the southeast by the Sulu Archipelago. The Sulu Sea is divided into a northwestern and a southeastern portion by a row of banks with depths of less than 650 ft (198 m). These banks run parallel to Palawan Island and the Sulu Island group.

The southeastern basin is characterized by steep slopes covered in calcium carbonate ooze except in the vicinity of the Sulu Islands where a zone of coral mud and sand dominates the abyssal plain. Volcanic and terrigenous muds are present off the coast Mindanao.

The northwestern basin has irregular but gentler slopes than the southeastern area. Calcium carbonate ooze dominates the abyssal plain.

### **3.2.1.9 Sulawesi (Celebes) Sea**

The Sulawesi Sea is located between Borneo and the southern Philippine Islands with the Sulu Archipelago and the southwest coast of Mindanao to the north. To the east are a string of islands which connect the Philippine Islands with Sulawesi. The northern arm of Sulawesi constitutes the southern boundary, and Borneo is the western boundary. The northern opening of the Makassar Strait is located in the southwest corner and connects the Sulawesi Sea to the Flores Sea.

The Sulawesi Basin is of uniform depth and flat with the exception of isolated minor irregularities along the western rim. Terrigenous mud dominates the northern area in the vicinity of Mindanao. A broad area extending across the center of the sea is composed of terrigenous and volcanic mud with volcanic mud dominating the eastern region.

### **3.2.1.10 Molucca Sea**

The Molucca Sea is bordered on the west and the east by rows of volcanic islands, the North Sulawesi-Sangir islands and Halmahera and associated islets. The northeast limit is formed by the Snellius Ridge. The southern border is a line from Obi Major to Sulawesi.

The floor of the Molucca Sea can be divided into three north-south zones. The most western zone dominated by the Sangir trough connects the Davao Gulf in Mindanao with the Gorontalo Gulf. The central zone consists of a broad ridge. The Talaud and Miangas Islands in the north and the Maju and Tifore Islands near the center are part of the ridge. The third zone is composed of a series of depressions with Talaud and Morotai depressions in the north and Mangole-Batjan basins in the south. Bottom sediment consists mainly of terrigenous mud with calcium carbonate found in the basin areas. Coralline mud and sand are conspicuously concentrated around reefs and coral islands.

## **3.2.2 Major Ocean Fronts And Currents**

### **3.2.2.1 North Equatorial Current (Pacific)**

The beginning of the North Equatorial current can be found off the coast of Central America, traversing the Pacific in a east-west set analogous to the trades. These winds apparently dictate the strength and speed of the current. The North Equatorial Current is an integral portion of the transport system to return northern waters to southern regions. Characteristic speeds of this current is 0.5-2 knots.

### **3.2.2.2 Kuroshio Current**

The Kuroshio (translated as Black Stream) Current is the dominant ocean current of the western Pacific and resembles the Gulf Stream of the Atlantic. The Kuroshio begins east of northern Luzon in the Philippine Sea before flowing into the East China Sea northeast of Taiwan. In the East China Sea, the Kuroshio follows the Okinawa Trough between the continental shelf and the Ryukyu Ridge. The current then splits into two parts, with the major portion flowing east to south of Shikoku then northward along the southern coast of Japan. The minor branch flows northward through the Korean Strait as the Tsushima current.

During the northeastward set, the current accelerates to 2-5 kt with maximum speed occurring between 132° East and 137° East. While flowing northward, the current parallels the 3,000-9,000 ft (915-2,745 m) contour.

### **3.2.2.3 Kuroshio Extension**

The Kuroshio Extension is a continuation of the Kuroshio Current extending eastward from coastal Japan near 140° East to 160° East and meandering between 35° and 38° North. This meandering path forms a transition zone between the cold waters to the north and the warm subtropical waters to the south.

### **3.2.2.4 Oyashio Current**

The Oyashio Current originates in the Bering Sea and flows southwest off Kamchatka Peninsula and the Kuril Islands, entraining water from the Sea of Okhotsk. The Oyashio current then flows along the eastern coasts of Hokkaido and Honshu before curving eastward to parallel the Kuroshio Current before gradually merging with the Kuroshio Extension beyond 160° East.

### **3.2.2.5 Perturbed Area (Northwest Pacific)**

The Perturbed Area is the boundary between the warm Kuroshio Extension Current and the cold Oyashio Current to the north. The area is roughly 200-300 nm wide and extends well past 160° East.

This boundary area is typically composed of a series of eddies and meanders. Warm eddies, 80 nm in diameter or larger, tend to be stationary and short-lived, while those at least 150 nm in diameter will have a lifetime of at least one year. These large eddies are formed when large northward meanders of the Kuroshio Current break off from the main current just off the eastern coast of Honshu.

### **3.2.2.6 Sea Of Japan Oceanic Polar Front**

The Sea of Japan is divided into two sectors based on currents: the warm sector on the Japanese side and a colder sector on the Korean and Siberian side. The warm sector is comprised of the Tsushima current and its extension, the warm East Korea, Tsugaru and Soya currents. The cold sector is comprised of the Liman, North Korean and Mid-Japan Sea Cold currents. (These currents will be covered in following sections.)

A persistent, year-round oceanic “Polar Front” along 38-40° North separates the two sectors. Eddy circulation patterns exist in the frontal zone with accompanying large horizontal variations of physical properties.

## **3.2.3 Secondary, Coastal And Counter Currents**

### **3.2.3.1 Equatorial Countercurrent**

The Equatorial Countercurrent is a west to east flowing current related to the region of low winds speeds located between the northeast and southwest trades. It has its origins along the coast of the Philippines, moving eastward to the American coast. This current, present year round, lies just to the north of the Equator in winter and migrates northward with the shifting weather patterns in the summer. Speeds of up to 2 knots have been observed at the surface.

### **3.2.3.2 Kuroshio/Subtropical Countercurrent**

The Kuroshio Countercurrent (KCC) flows north to south along the eastern edge of the Kuroshio transporting large amounts of water southward. Water transport is dependent on the strength of the Kuroshio Meander. The development or continuity of the countercurrent depends on the displacement north of the Kuroshio. It sometimes consists of only sporadic portions along the Kuroshio.

The Subtropical Countercurrent (STCC) connects with the Kuroshio Countercurrent. The STCC will normally be found between 20° North and 24° North. Found throughout all seasons, it is usually best developed during winter.

### **3.2.3.3 East Sakhalin Current**

The East Sakhalin Current is part of the cyclonic circulation (Okhotsk Gyre) flow that dominates the Sea of Okhotsk. This oceanic circulation is connected with the atmospheric circulation above the Sea of Okhotsk and the Western Pacific.

The East Sakhalin Current is a narrow nearshore counterclockwise current. It begins in the southeast basin near Kamchatka where water is forced from the Pacific through the northern Kuril Island Straits.

### **3.2.3.4 Soya Current**

The Soya Current flows through the LaPerouse (Soya) Strait that separates the islands of Hokkaido and Sakhalin. The complex topography and extended shelf (depths of less than 650 ft/198 m) results in large fluctuations in volume, speed and path of the warm current flowing into the strait. The Sea of Japan Oceanic Polar Front (previously discussed) and cold waters to the north and west also hinder flow into the Soya Current. At its strongest, the Soya Current will occupy only the southern portion of the strait with cold water in the northern portion. The resulting oceanic front separating the two water masses is quite sharp with current speeds of 1-2 knots within the warm water.

After exiting the strait, the Soya Current turns south along the coast of Hokkaido. This portion is strongest during late summer and will disappear at the surface during the winter.

### **3.2.3.5 Tsugaru Current**

The Tsugaru Current is an extension of the Tsushima Current. Due to island topography and shallow sill depth (425 ft/130 m), the current through the channel forms a core approximately 11 nm wide. On either side of the core are eddies which appear to be trapped due to topographical configuration. Maximum current speeds reach 4.5-5.5 knots during the spring tidal phase of summer and winter.

The Tsugaru Current extension into the Pacific displays distinct variations in patterns between periods of weak and strong transport. An extensive anticyclonic gyre is observed during strong outflow mainly in the summer and fall seasons. During weak outflow a coastal pattern is observed and seen mainly in the winter and spring.

### **3.2.3.6 Liman, North Korea, Mid-Japan Sea Cold Currents**

The cold sector of the Sea of Japan is comprised of three cold currents: the Liman current which flows along the Siberian coast, the North Korea current from Vladivostok to the central east Korean coast and the Mid-Japan Sea Cold Current which flows eastward into the central portion of the Sea of Japan.

### **3.2.3.7 Tsushima Current**

The Tsushima Current is a warm current that branches off from the left side of the Kuroshio, flowing first through the eastern East China Sea and then entering the Sea of Japan through the Tsushima (Korean) Strait. The main portion of the Tsushima current flows northeastward through the eastern portion of the Sea of Japan.

The Tsushima Current is the source of all the warm currents within the Sea of Japan. The Tsugaru and Soya Warm Currents are the northern extension of the Tsushima as it flows out of the Sea of Japan through the Tsugaru and Soya Straits, respectively. The East Korea Warm and Yellow Sea Currents are western extensions of the Tsushima Current

### **3.2.3.8 East Korea Current**

The East Korea Current diverges from the Tsushima Current upon entering the Sea of Japan. It then flows northward along the Korean coast as far north as Yongil Bay, turning southeast to rejoin the Tsushima Current near 39° North.

### **3.2.3.9 Yellow Sea Current**

The Yellow Sea Current branches from the Tsushima Current near western Kyushu and flows northward into the middle of the Yellow Sea. The speed of the current is less than 0.5 knot. It develops in spring and summer and decays in the fall and winter.

### **3.2.3.10 China Coastal Current**

Completing the gyre of the Yellow Sea is the China Coastal Current which flows southward along the coast. Although present year round, the current strengthens during the winter as it is accelerated by the strong, persistent Northeast Monsoon.

### **3.2.3.11 South China Sea Currents**

The monsoon winds control the surface currents flowing into the South China Sea. In the winter, the surface flow is from the north through the Taiwan Straits and Bashi Channel and from the east through the Balabac Strait. The flow is generally south. The outgoing flow is mainly through the south into the Java and Flores Seas through the Karimata and Gaspar Straits and a little to the west through the Malacca Straits.

During summer months, the surface flow will reverse moving from the Flores/Java Seas through the Karimata and Gasper Straits and entering the South China Sea between Malaysia and Borneo. The flow is generally to the northeast.

### **3.2.3.12 Sulu Sea Currents**

During the summer, surface currents in the Sulu Sea are generally southward at rates up to 1.5 knots. During winter, a counterclockwise current system exists in the Sea.

### **3.2.3.13 Sulawesi (Celebes) Sea Currents**

Surface currents, during the summer, are mainly directed from Mindanao toward the Makassar Strait. During winter months, the south and southwestward current systems are maintained for the larger part of the sea.

### **3.2.3.14 Mindanao Current**

The Mindanao Current is formed when the North Pacific Equatorial Current encounters the Philippine Islands. Part of the water carried by this current is directed southward toward Mindanao Island. The Mindanao Current carries a significant portion of the North Pacific Equatorial Current along the Philippine Islands between 10° and 5° North before it turns eastward. It merges with several other currents to form the North Equatorial Countercurrent that returns eastward.

## **3.2.4 General Oceanographic Conditions**

A complete review of ocean thermal and acoustic properties and resulting sound propagation characteristics is beyond the scope of this handbook. General oceanic and acoustic conditions will be discussed.

### **3.2.4.1 Western North Pacific**

The change in thermal properties across the Kuroshio Extension and Oyashio Currents is one of the largest found in the open oceans. The thermal variation is most pronounced below the seasonal surface layer and above the deeper stable waters. The gross structure of thermal features across this boundary zone can be detected in satellite infrared imagery during the seasons when the surface has not been heated sufficiently to mask thermal contrasts.

The depth of the Sound Channel Axis (SCA) rises rapidly northward across the Perturbed Area, being very near the surface poleward of 42° North during the warmer months. This is due to the surface warming of the waters. During the colder months, the sound speed minimum reaches the surface and the sound channel will disappear north of 42° North. Sound energy is then transmitted by half-channel mode.

South of the Kuroshio Extension, a deep sound channel is found between 4200-4750 ft (1281-1450 m) in the western area, rising to about 3700-4000 ft (1150-1450 m) near 160° East.

Generally, the highest sea state is found during the winter as the strongest mid-latitude systems migrate through the area. Sea ice may be found during the late fall through early spring along the seaward areas of Kamchatka, the Kuril islands and Hokkaido.

### **3.2.4.2 Sea Of Okhotsk**

The sound channel axis is located at the surface during the colder months and half-channel mode conditions prevail. During the warmer months, the surface heating results in a near surface sound speed maximum and a shallow SCA. The Sea of Okhotsk begins to freeze in coastal locations during November, reaching its peak ice coverage during March and is nearly ice free by June. Coastal ice will form first in the northeastern and northwestern extremes, then along the remainder of the northern and western boundaries and the Kamchatka Peninsula. The ice edge then advances toward the center of the basin, reaching maximum coverage by March. The sea surface will not completely freeze over except during an unusually cold year.

### 3.2.4.3 Sea Of Japan

Large seasonal changes occur in the thermal properties of the near-surface waters. During late summer and autumn, a convectively mixed two-layered thermal structure prevails. As the cold air flows over the surface removing heat from the near surface-layer, the seasonal mixed layer and thermocline are destroyed resulting in a surface-to-bottom homogeneity in the cold sector. In the warm sector, a deep thermocline persists throughout the year as the winter cooling is not sufficient to completely remove the heat and destroy the thermocline.

Full channel conditions exist throughout the entire Sea of Japan in the summer and autumn and year-round in the warm sector. During winter and spring, half-channel conditions are found in the cold sector. Highly variable conditions will be found in the vicinity of the frontal zone.

A general decrease in depth of the sound channel axis occurs from east to west and south to north. The deepest axis is found in the Korean Strait 1640-2000 ft (500-600 m) in association with the Tsushima Current. Near the central Japan Islands, in the area of the Tsushima Current, the axis is found near 1300-3000 ft (397-915 m). Values off the Siberia coast range from surface to 650 ft (0-198 m).

Sea ice begins to form in the Tartar Straits around mid-November and in the northern Sea of Japan by mid-February. Along the northern coast of Korea, sea ice is limited to coastal bays and harbors.

### 3.2.4.4 Yellow Sea

The circulation of the Yellow Sea is strongly influenced by regional atmospheric forcing and bottom topography. The major ocean currents play only a limited role in the circulation. The atmospheric monsoon regime that prevails over the area provides cyclic seasonal changes that dominate the region's oceanographic processes. Atmospheric forcing occurs in two modes: in winter, cooling and mixing occur due to strong, cold, dry northerly winds; and in the summer, extensive precipitation, river run-off and solar heating occur which produces a well-stratified water column with a warm, low-salinity surface layer. Seasonal conditions are further agitated by strong winter cold outbreaks and occasional summer typhoons.

The Yellow River is the major source of fresh water influx into the southwest region of the Pohai. Other sources include the Luanhe and Liaohe Rivers entering the western and northern Pohai and the Yalu, Han and lesser rivers of Korea.

Two regions of upwelling are found in the Yellow Sea: the eastern region of the Shandong Peninsula and off the southern tip of Liaodong Peninsula. Water temperatures off the tips of these two peninsulas are found to be 3-5° C lower than surrounding areas during May and August. Cold water from upwelling extends seaward 15-30 nm off the Shandong Peninsula, while the Liaodong Peninsula upwelling is limited to about 10 nm off the coast.

Sea ice is observed as far south as 36° North along the Korean coast and south of the Shangdong Peninsula. The major concentration of sea ice (0.1-0.4 octaves coverage) is limited to the western and northern Gulf of Pohai and eastern Korea Bay.

### 3.2.4.5 East China Sea

The East China Sea is influenced by the same atmospheric forcing as discussed in the Yellow Sea. The conditions within the East China Sea are influenced on the western side by the discharge of the Yangtze River and on the eastern side by the Kuroshio Current, its branches and extensions which mix with coastal waters.

Coastal upwelling occurs off the Zhejiang Peninsula (Chinese coast north of Taiwan to near 30° North), mainly as a summer phenomena and is directly related to the intensity of the Southwest Monsoon surface wind.

Tidal currents show a wide variety of ranges, especially in the vicinity of islands. Maximum heights of 2-3 feet (.5-2.8 m) occur around the Ryukyu Island with tidal current speeds of 2-3 knots. Tidal ranges of 15-20 ft (4.5-6 m) occur around Taiwan and to over 30 ft (9 m) in the mainland Hangchow Bay southwest of Shanghai.

### 3.2.4.6 Philippine Sea

Several major currents affect operations within the Philippine Sea: the North Equatorial Current, the Equatorial Countercurrent, the Kuroshio Countercurrent, the Subtropical Countercurrent and the Kuroshio Current. Origins and tracks of these currents were covered in previous sections.

The correlation between oceanic fronts and large bottom slopes are a common feature within the Philippine Sea. These conditions present special problems to ASW operations as grid point or single point data do not account for the loss or redirection of bottom bounce propagation.

The SCA is quite deep throughout the area with a maximum depth of over 4900 ft (1495 m) year round near 30° North, 135° East. The SCA rises to about 2300-2600 ft (702-793 m) near the western and northern boundaries except during winter when the channel depths are about 2900-3200 ft (886-976 m). Water depths are a limiting factor not only in coastal areas but over the lesser depths along the Ryukyu and Mariana/Bonin Island Chains.

### 3.2.4.7 South China Sea

The temperature structure of the water column between the surface and 650 ft (198 m) is influenced by the seasonal changes that take place over the region.

During the winter season northeast winds dominate the South China Sea deflecting surface water toward the Vietnamese coast. The mixed layer above the sharp thermocline becomes deeper near the coast as surface water is deflected and reaches depths of 500 ft (153 m).

The summer southwest monsoon winds develop strong southerly currents that extend all along the coast and through the South China Sea. The thermocline rises and pronounced upwelling takes place near the coast with the maximum upwelling occurring off the coast of south-central Vietnam.

## 3.3 METEOROLOGY

The climatology discussed within this section covers from the Arctic areas to the Equator. General large scale features will be discussed first. Some generalized local features affecting water areas will also be discussed.

### 3.3.1 Migratory Lows

#### 3.3.1.1 Seasonal Storm Tracks

Numerous storm systems develop, dissipate and regenerate in the Northern Hemisphere. Storms which develop and move across the Atlantic Ocean fall into two general categories as they approach Europe and Asia: (a) storms which move northeastward through Iceland, into the Barents Sea, then southeastward through Asia and (b) the mid-latitude storms which move through the Mediterranean Sea (these will be covered in a future chapter). Tracks of category (a) include:

1. The Icelandic Storm Track is defined as those storms which move through Iceland and the Barents Sea then drop southeastward toward Mongolia.
2. The Siberian Storm Track is defined as those storms which move through Iceland and are routed northward over Franz Josef and Spitsbergen by a sharp amplitude long wave ridge, then drop southward toward the Sea of Japan.
3. The Yellow Sea, Shanghai and Taiwan Storm Tracks (Southern Storm Tracks) are defined as dynamic by-products of the numerous splits in the storm track impulses which move across Asia.

Tropical cyclone tracks will be covered in detail in future chapters.

### **3.3.1.2 Northern Lows**

The Northern Lows will normally generate/regenerate in northern China or southern Russia. The lows will then depart their source regions tracking eastward to the northern Sea of Japan/Sakhalin Island before reaching the Western Pacific. These low pressure systems are all formed by movement of upper level short wave troughs through low pressure source regions. These systems are enhanced by downslope adiabatic warming as they traverse from their mountainous regions toward the coast.

#### **1. Lake Baikal Low**

Develops in the vicinity of Lake Baikal in central Siberia as winter storms progress along the Siberian Storm track. This system may develop during any season but is most common during spring. The average speed of this system is 22 knots. The track of the Lake Baikal Low (similar to the Manchurian Low) passes through the Soya (La Perouse) Straits before entering the northern Western Pacific. Again, very little weather is associated with the Lake Baikal Low until it reaches the open waters of the Pacific.

#### **2. Manchurian Low**

Develops over the northern border of Manchuria, moving eastward over central Sakhalin Island before exiting into the Sea of Okhotsk. This system occurs primarily during the autumn and spring. Average speed of this system is 20 knots. The Manchurian Low generally has very little weather associated with it since the source region of Siberia offers little moisture until reaching the open ocean.

#### **3. South Mongolia Low**

Caused by leeside troughing over the Altai Mountains when a storm impulse aloft approaches from the west along the Icelandic Storm Track. It generally tracks from its source region southeastward to northern North Korea before exiting into the Sea of Japan. The South Mongolian Low will normally turn to the northeast, tracking over Hokkaido before reaching the southern Sea of Okhotsk and the Western Pacific. It can develop during any season, with an average speed of 20 knots.

### **3.3.1.3 Southern Lows**

The Southern Lows generally form over central and southern China, then track eastward to either the Sea of Japan or south of Japan between Kyushu and Okinawa. These systems may occur year round and produce widespread precipitation, low ceilings, poor visibility and occasional squall lines. The source region for the three major systems in this group is the Shanghai area. The generation area of the supporting upper level short wave troughs which form these lows and their subsequent tracks further delineates these systems.

#### **1. Yellow Sea Low**

Occurs primarily during the summer and autumn, tracking at an average speed of 20 knots. It develops in the area between Shanghai and Osan and tracks to the northeast over Korea, through the Sea of Japan and across northern Japan to the western Pacific. This system may also produce a double-eyed system south of Kyushu or Shikoku within 12 to 18 hours after entering the Yellow Sea. Without development of the "double-eye" system, strong southwest winds will develop on the leeside of Japan.

#### **2. Shanghai Low**

Occurs most frequently during the spring. The Shanghai Low is subject to rapid intensification as it moves over the warm waters of the Kuroshio current (much like the "Hatteras Low" along the east coast of the U.S.). It moves from the source region in central China, often developing along a stagnating frontal system, tracks to the east or northeast to the southern coast of Japan. The average speed of the system is 20 knots as it passes south of Kyushu. The main low center sometimes tracks into the Sea of Japan with a secondary low forming on the leeside of Japan near Shikoku. The two low pressure centers of this double-eyed system will track northward together until they merge over northern Honshu/southern Hokkaido and move into the Western Pacific.

### 3. Taiwan Low

Generates over China near 25° North and 100° East, occurring most frequently from autumn through spring. This system will often form as a wave on an active stationary front and track northeastward at an average speed of 25 knots. The Taiwan Low will always pass south of Japan; however, depending on the long wave pattern, the system may pass close enough to Japan to produce precipitation over the islands. Wave formation along the front associated with a Taiwan low is common and forms under several circumstances:

- a. Formation of a migratory high over mainland China with an eastward track over Honshu. A wave will form behind the high as it subsides and the front stagnates. This wave will then move eastward over southern Honshu.
- b. During late spring through early autumn, a cyclone family will form along the polar front generated by low formation. If the system takes a more northerly track, north of 32° North, precipitation will dominate the Japanese islands.

## 3.3.2 Stationary Systems

### 3.3.2.1 Sea Of Okhotsk Low

A stationary system will develop in the Sea of Okhotsk extending from the surface through the 500 mb level. This system serves as the anchor low, indicating that the long wave trough is in the vicinity of 150° East. Lows tracking along the northern storm tracks will be steered toward the anchor low. Northern systems will be relatively dry as migratory lows will not reach the western Pacific. Further development of the Shanghai and Taiwan lows will be supported when strong impulses move along the central and southern storm tracks. Combination of the anchor low with the dynamic system causes a retrograde action of the long wave to a northeast-southwest orientation.

### 3.3.2.2 Mei-Yu (China/Taiwan)/Bai-U (Japan) Fronts

The Mei-Yu/Bai-U front is a quasi-stationary system occurring during the transition period between the Northeast Monsoon in the winter and Southwest Monsoon in the summer. The front initially develops as the western extension of the subtropical high extends over southern China and Taiwan. Dissipation occurs when the seasonal monsoon becomes fully established.

The Mei-Yu/Bai-U front is a subtropical front with differing characteristics than those associated with a Polar front. It is a relatively shallow feature, developing only in the lower troposphere, thus characterized by only a narrow band of precipitation with areas of embedded showers and isolated thunderstorms. A significant low-level jet (LLJ) is also associated with the Mei-Yu/Bai-U front. Jet maxima are located near the 700 mb level and usually 180 nm southeast of the most active areas of convection.

Weak mesoscale circulations, with embedded clusters of convective cells, compose the frontal structure of the Mei-Yu/Bai-U front. Along the active front in the vicinity of Taiwan, frontal lows develop every 17 to 20 hours, moving eastward at 10-15 knots. South of Japan, lows form every 20 hours; however, the speed of movement increases to 25-30 knots. Deepening of these lows will occur if the front interacts with a mid-latitude upper level trough east of 135° East.

### 3.3.3 Cyclogenesis

The east coast of Asia and the south coast of Japan provide a naturally favorable climate for recurring cyclogenesis. Continental polar air masses are either in close proximity to warm maritime air masses or are undergoing rapid modification as they move over the warmer waters of the East China Sea, Yellow Sea or the Sea of Japan. Several synoptic patterns that aid in cyclogenesis or frontogenesis are described in the following sections.

### **3.3.3.1 Bubble High Cyclogenesis**

The most reliable indicator for cyclogenesis in the cool season is the off-shore movement of a cold, migratory high pressure cell from the Siberian High commonly known as a “Bubble High”. Cyclogenesis will normally occur 24 to 48 hours after the high moves off the coast. Its location will roughly correlate with the latitude of the Bubble High. Highs that track north of 35° North will generate lows that move into the Sea of Japan. Highs that track south of 30° North will generate lows that move south of Honshu. Cyclogenesis will normally occur in the Yellow or East China Seas (Yellow Sea or Shanghai Lows respectively).

Highs moving off-shore between 30-35° North produce lows whose movement depends upon their position within the jet stream. Lows that develop north of the jet will initially move southeast toward the southern boundary of the jet, deepening rapidly as they pass under the jet core.

Bubble High Cyclogenesis has been such a consistent weather phenomena that it can be reliably forecasted with little error. The lag period between the high moving offshore and the formation of the low is 24-36 hrs in the winter and 36-48 hrs in the spring and summer.

If a pre-existing low exists to the northwest of the area of cyclogenesis when the high initially moves off-shore, two cyclones or one elongated north-south cyclone south of the bubble high will usually form. This system will become better organized as it reaches the East China Sea, having moved off the central China coast, producing a Shanghai Low. This pattern is typical during the winter and has a lag period of 24 hrs.

When a pre-existing cold front is present to the northwest of the bubble high, cyclogenesis will usually occur along the front in the vicinity of the northern Yellow Sea. The low, with an inactive warm front, will move northeastward through the Sea of Japan. This Yellow Sea Low usually occurs in early or late winter and has a time lag of 24-36 hrs. If cyclogenesis doesn't occur, weather will be restricted to a narrow band along the front.

When no existing low or front is present at the time of cyclogenesis, a wave cyclone will form in the central and southern coastal regions of China and move along the southern coast of Japan, producing a Taiwan Low. These lows usually occur in spring and autumn, with a lag period of 36 hrs and will usually take 3 to 4 days to pass east of the Japanese coast. Once these lows form, they deepen rapidly, averaging a 10-15 mb pressure drop in 24 to 36 hrs. This rapid deepening of the Taiwan Low is due to favorable upper air conditions, but primarily due to the thermal contrast between land and water.

### **3.3.3.2 Cool Season Cyclogenesis**

Cyclogenesis will occur along the southern coast of Japan when surface troughing is evident over the Kuroshio current south of Japan, the pressure gradient is weak, upper level short wave troughs moving through the area are slow and the air-sea temperature difference is greater than 13° F (7° C). Lows developing in this area are called “Oshima Lows” since they develop in the vicinity of Oshima Island. The development of this low is seen as a wave on the 850 mb level with a developing system in the Sea of Japan near 125-130° East. Another indication of low formation is the presence of a low-level jet from the south in the vicinity of Hachijo Jima.

During cool season cyclogenesis, there is a marked onshore flow over southern China with cold continental air in close proximity to cool maritime air. Development of a Taiwan Low is possible during this period. An 850 mb short wave trough bringing a surge of cold air to the area will be a major factor influencing cyclogenesis.

### **3.3.3.3 Warm Season Cyclogenesis**

A short wave trough moving into a well defined cool/cold tongue indicates a possible area of cyclogenesis. Cyclogenesis will usually occur when the short wave trough approaches to within 41-50° F (5-10° C) of the cool tongue of air. Warm Season Cyclogenesis is most prevalent in the Yellow Sea and Sea of Japan.

### **3.3.3.4 Stationary Front Cyclogenesis**

Cyclogenesis along a stationary front south of Japan generally occurs when the following two conditions are met: upper level winds must be from the west to southwest and the front is stalled within 300 nm of the southern Japanese coast. The formation of a lee-side depression between Oshima Island and Hamamatsu will occur when the low-level winds along the southern coast are from the west-southwest and from the north-northeast along the southeastern coast of Honshu. Cyclogenesis will be indicated by thermal packing on the 850 mb chart.

Cyclogenesis along the stationary front will also occur when an upper level, cold low is located in the Manchuria-Siberia region, with cyclonic flow occurring near the polar front.

### **3.3.3.5 Transition Season Cyclogenesis**

An area of possible cyclogenesis will establish itself off southern Kyushu in the deep cool easterly flow, becoming active when the gradient winds along the southern coast of Japan veer northeasterly and the 850 mb winds are light and southerly. This pattern typically occurs in the spring when the ridge line is established over the Kanto Plain.

During late summer and early autumn, the subtropical ridge will establish a deep easterly flow over Japan and low-level cool air is present in the generating area, such as when a cool high pressure system tracks southeastward off southern Japan and advects cold air into the region. The trigger is usually a short wave trough moving over the Korean peninsula.

### **3.3.3.6 Lee-Side Depressions**

Weakening of the local pressure gradient over the Sea of Japan accompanied with moderate to strong west to southwest low level wind flow parallel to the mountains of southeast Japan will generate lee-side depressions/troughs along the southeast coast of Japan.

Lee systems may develop when these conditions exist :

1. Northerly flow along the mountains of south central Honshu.
2. A short wave approaching the area.
3. A low moving through the Sea of Japan.
4. Cold fronts approaching Japan, parallel to the coastal mountains.

Pressure falls and troughing will occur south of Kyushu and/or Shikoku. These systems should be closely monitored for explosive deepening and rapid movement.

## **3.3.4 Lake Baikal Migratory Highs**

Many regions of Asia are favorable high pressure producers due to extensive hours of darkness over vast cold land masses during the winter seasons. As with the low pressure systems discussed above, these high pressure systems follow a definite pattern or track according to the season. There are three significant stagnating, semi-permanent high pressure cells from which dynamic highs affecting the Western Pacific originate. These cells are predominantly cold weather features which disappear during the summer months. They are important to the forecaster since they give a "first-glance" clue to the presence or absence of blocks to winter storm tracks.

### **3.3.4.1 West**

The West Lake Baikal High is a semi-permanent feature which will disappear for short periods under the influence of impulses traveling along the Icelandic track. When the West Lake Baikal High is firmly established, a storm must track either along the Siberian storm track or along the southern track. The West Lake Baikal High has the highest central pressure of any system in the Northern Hemisphere, averaging 1055 mb and reaching 1088 mb during very cold winters.

### 3.3.4.2 East

The East Lake Baikal High is mainly a summer and early autumn feature. This high will generally move to the southeast over northern Korea, through the Sea of Japan and over northern Honshu and Hokkaido.

### 3.3.4.3 Northeast

The Northeast Lake Baikal High is a semi-permanent feature which disappears for short periods of time under influence of strong impulse traveling along the Siberian or Icelandic Storm Tracks. When the high is firmly established, a blocking situation sets up along the northern tracks. At various times during a winter season, the Northeast Lake Baikal and the West Lake Baikal High will combine into one smoothed system, the Siberian High.

## 3.3.5 Western Pacific Monsoons

A significant portion of eastern Asian weather is dominated by the Asiatic monsoon. Monsoon, derived from the Arabic word “Mausim”, was originally applied to the wind regimes of the Northern Arabian Sea. This will be covered in a later chapter. Monsoon is usually defined in terms of seasons. Surface winds will generally blow from one direction during one season and from a markedly different direction during another season.

### 3.3.5.1 Northeast Winter Monsoon

The Northeast Winter Monsoon is a result of the strong high pressure cells which dominate Siberia in the winter. As high pressure cells migrate southeastward, they result in a strong north to northeasterly wind flow over eastern Asia and adjacent waters. The winter monsoon season dissipates as the cold highs weaken during the spring, resulting in the migration of the Polar Front north to its summer position.

### 3.3.5.2 Southwest Summer Monsoon

Conversely, during summer months, thermal lows develop over Asia, creating the Southwest Summer Monsoon. Warm, moist air is transported northward over the coastal areas of Asia. The Southwest Monsoon of Asia is less intense than that of the Indian Ocean. This is due to :

1. Less intense heating at higher latitudes resulting in a weaker thermal pattern.
2. Periodic invasions of cold air from the north.
3. A wider range of sea surface temperature.
4. The periodic formation of an extratropical or tropical cyclone which eliminates the heat low.

Gale force winds seldom occur and then only when associated with strong flow into a tropical cyclone or with channeling through constricted waters such as in the Taiwan-Luzon Straits.

## 3.3.6 Seasons

Generally, the seasons of the northern Western Pacific (north of 35° North) are similar to other mid-latitude areas. The seasons south of 35° North are defined in terms of monsoon activity.

|                           | North of 35° | South of 35° North |
|---------------------------|--------------|--------------------|
| <b>November – March</b>   | Winter       | Northwest Monsoon  |
| <b>March – May</b>        | Spring       | Transition         |
| <b>May – October</b>      | Summer       | Summer Monsoon     |
| <b>October – November</b> | Fall         | Transition         |

These seasons may show variation of up to two weeks. The most reliable transition is in the fall, due to the fast transition of the hot-cold regions of central and southern China and Russian Siberia. The coming of a cold surge signals the end of the southwest monsoon. The spring transition has many vacillations between southwest and northeast before the heat low becomes firmly entrenched in Central Asia.

## 3.4 MODEL TENDENCIES

Forecasters need to understand the climatological aspects of the area for which they are forecasting. Forecasters must also understand the limitations of forecast aids and the effect topography has on these aids. This section will explain model tendencies and local effects gathered over years of experience by many forecasters.

### 3.4.1 NOGAPS

#### 3.4.1.1 Lows - Surface Pressure

Developing oceanic surface lows tend to be underforecast (weak) and slow to deepen with an Average Center Pressure Error (ACPE) of 2 to 3 mb weak by 48/72 hr. Filling oceanic lows tend to be overforecast (deep) and slow to fill after bottoming-out with a center pressure error of -3 to -4 mb by 48/72 hr. Directional bias for deepening or filling lows is very slight. However deepening lows tend to be behind the analyzed track, especially in zonal flow. Mature filling lows tend to be to the left of the analyzed track (toward the cold air) in meridional flow.

Surface lows north of the jet tend to be too deep. Lows forming to the south of the jet and bottom-up type of developing lows are minimally slow to deepen. Land lows are usually deep throughout with an ACPE of -3 to -5 mb by 48 hr.

Initial and secondary cyclogenesis in association with U/L short-wave troughs has improved from previous models. Systems still tend to be weaker and slow to deepen and move. Secondary cyclogenesis is minimally underforecast and slow moving.

Complex lows tend to be merged into one slightly deeper system, especially near the northern Japanese Islands. Lows moving through the Sea of Japan will tend to form leeside systems. Indications of leeside formation are normally 12-24 hr later than actual time. If the model indicates a secondary system, it will be reflected as an elongated isobar rather than a separate system.

Surface lows associated with the formation of U/L cut-off lows, mainly in the cool season, are minimally overforecast (deep). Mature cut-off lows are slow to fill after bottoming out. Occasionally, NOGAPS exhibits a False Alarm forecast tendency by overforecasting the deepening rate of surface cut-off lows, especially at the extended forecast periods. The instances of overforecasting of "cut-off lows" may reflect the occasions where valid ship reports are erroneously rejected by the operational Optimum Interpolation (OI) surface analysis.

Extra-tropical lows associated with former tropical cyclones are significantly underforecast and slow to move.

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.

1. During the primary NWPAC tropical cyclone season, (June through November), cyclone development tends to be overforecast in the size of the circulation even before the automated tropical cyclone bogus input to the OI analysis.
2. NOGAPS tends to overforecast the number of TC systems, especially at the extended forecast period.

#### 3.4.1.2 Highs - Surface Pressure

The western oceanic high pressure cells tend to be slightly stronger by 48 hr.

Mid-ocean high pressure cells tend to be 1 to 2 mb stronger than actual by 48 to 72 hr.

#### 3.4.1.3 Upper Level

Upper level (U/L) troughs moving in zonal flow tend to be "fast to move" at the extended forecast period.

U/L short-wave troughs in strong zonal and broad meridional flow are minimally weak. The associated surface lows tend to be 3-4 mb weak and slow to deepen.

U/L lows north of the polar jet tend to be slightly deep.

U/L highs south of the jet are minimally strong.

The formation of U/L cut-off lows continues to be well forecast. The associated surface low is minimally overforecast (deep) throughout.

Wind speed forecast variability is greatest in the 300-250 mb jet stream region and shows a mean error of 6-7 m/s by 48 hr.

### **3.4.2 NORAPS**

ASIA NORAPS provides a good depiction of cyclogenesis and depicts complex surface lows better than NOGAPS. NOGAPS will often depict a single, deeper low pressure system while NORAPS will often depict two or more centers, especially around Japan.

NORAPS surface low underforecasting tendency is slightly greater than NOGAPS. NORAPS is minimally weaker than NOGAPS during the developing phase. Position and directional bias are minimal, but NORAPS appears slow to move surface lows.

NORAPS 1000 mb and 500 mb forecast heights are generally higher than NOGAPS at 36 hr, indicating a greater positive height bias at both levels.

NORAPS and NOGAPS surface wind forecasts over the West Pacific basin tend to be 5-6 kt weak by 36 hr.

### **3.4.3 GWAM**

The Global Wave Action Model (GWAM) is the primary tool (coupled with experience) used by forecasters for producing the 36 HR Significant Wave Prognosis and the high seas warning. The GWAM converts the marine layer winds and sea surface frictional effect into a unit of energy. These units are then converted into the significant wave heights seen on the prognostic charts. Significant wave height is defined as the height of the highest one-third of the waves.

The GWAM has several limitations:

1. GWAM, in confined areas (South China Sea, Yellow Sea and Sea of Japan), tends to overforecast seas.
2. Small topographic features are not considered; therefore, sea heights for confined straits are usually low. Island chains such as the Kurils that break up long fetches are not considered, so downwind sea height forecasts in these areas are often too high.
3. GWAM consistently underforecasts sea height in tropical areas mainly due to long period swell wave diffusion.
4. Sea heights need to be closely examined when associated with tropical cyclones. GWAM has a 12-24 hr delay in depicting developing and decaying systems. Mature storm sea heights are analyzed well.
5. GWAM does not consider shoaling, which results in sea heights being underforecast in the South China Sea, particularly along the Eastern Vietnam Coast.

## 3.5 LOCAL FORECASTING RULES

### 3.5.1 Cold Surge

The forecaster's challenge during the northeast monsoon is principally one of forecasting cold air surges into the Chinese coastal region and the formation of mid-latitude systems in the East China Sea and the Philippine Sea. During the winter season, cold air from the vicinity of Lake Baikal will surge south-southeastward into China and the adjacent waters every 4-6 days. Following a strong surge, sustained winds may reach 40 knots with seas building to 10-14 ft (3-4 m) in the East China and South China Seas. Gale force winds and seas near 18 ft (5.5 m) will spread rapidly throughout the northern two-thirds of the South China Sea. Winds over the Taiwan Straits will be appreciably higher than the pressure gradient would indicate mainly as a result of the funneling effect between China and Taiwan.

Two conditions must exist for the cold surge to reach the South China Sea:

1. Strong cold air advection must occur in the vicinity of Lake Baikal:  $-04^{\circ}$  to  $-13^{\circ}$  F ( $-20^{\circ}$  to  $-25^{\circ}$  C) at 850 mb and northerly winds of 40 knots.
2. A long wave trough of considerable amplitude must exist or develop along the East China coast.

If these conditions are not present the cold air tracking out of the Lake Baikal area will modify before reaching the coast. A long wave trough over eastern Japan will ensure a surge over the Yellow Sea and northern East China Sea, but the trailing cold front will become stationary before affecting the South China Sea.

### 3.5.2 Mid-Latitude System

The three northern lows (Lake Baikal, Mongolian and Manchurian) are often weak with very little precipitation. Moisture is obtained when the system moves over the open waters of the Sea of Okhotsk and Western Pacific. A typical system may exhibit cloudy skies on both sides of the occlusion or show a cold front with little change in temperature on either side before reaching the ocean. When considerable precipitation and cloudiness are present, the low and frontal system will be associated with unstable air and move rapidly eastward.

During the winter, expect cyclogenesis in the Manchurian basin following cold frontal passage over the Korea-Japan area. Within 24 hours, these lows will deepen and move eastward over the Sea of Japan and form well-defined fronts.

Low level wind flow (surface to 700 mb) from the east through south over Korea/Japan will produce widespread inclement weather over the Sea of Japan, lasting up to 72 hours. A series of waves usually exists over the East China Sea and along the southern coast of Japan. The extent of development depends upon on the proximity of other systems and upper level support.

Southerly wind flow over the NWPAC, near Kamchatka and the Kuril Islands can produce extensive fog. Condensation occurs as the warm air flows over the cold Oyshio current. The fog may persist from several days to two weeks depending on the synoptic situation. High pressure to the east, producing this southerly wind flow, is the optimum situation for persistent fog.

If a low south of Japan moves in a northeasterly direction so that it reaches a position approximately 1,000 nm or more east-northeast of a low in the Sea of Japan, the low in the Sea of Japan will deepen and move northeastward.

If a low south of Japan moves to within 800 nm of a low in the Sea of Japan, the low south of Japan will become the major system. The system over the Sea of Japan will move eastward behind the major system or will be absorbed by the stronger southern system.

A low developing over Manchuria and moving into the Sea of Japan will be influenced by the intensity of the quasi-stationary low pressure system south of Kamchatka and the 700 mb flow. If the lows are within 1,000 nm of each other, the Sea of Japan low will not deepen and will move easterly over northern Honshu. If the distance is greater than 1,000 nm, the Sea of Japan low will deepen rapidly and move northeasterly.

When the isobars are oriented northeast to southwest in line with the islands of Japan, weak cyclones frequently form off southern Kyushu. This type of pattern will often occur when cyclones have passed southern Japan. The trailing cold fronts associated with these lows are often slow moving and tend to stagnate off the coast of Japan.

See also [Bubble High](#) Cyclogenesis.

### 3.5.3 North Wall

The North Wall Effect is a function of a cold air mass moving over the warm Kuroshio Current similar to that seen on the East Coast of the United States. As the air/sea temperature contrast increases, instability increases, creating the possibility of winds stronger than the pressure gradient would indicate.

Two basic scenarios are associated with the North Wall Effect:

1. If the wind flow associated with a cold front is perpendicular to the Kuroshio (northwest), increased winds and seas will be generated at or just downwind from the North wall of the Kuroshio. Maximum seas occur 50-150 nm further downwind. Winds and seas associated with this scenario can increase by as much as 25-50% over what normally would be forecast for the same system.
2. If the wind flow opposes the direction of the Kuroshio (northeast), a more drastic increase in seas may occur. If the wind-driven seas oppose the flow of the current, the wave length decreases and wave height increases. Seas may increase by 50-100% if the sea direction directly opposes any significant ocean current.

Special attention must be paid to the areas offshore southern Honshu. Although not technically a product of the Northwall, increased wind and seas are often reported due to funneling through mountain passes and interaction with the Kuroshio as it flows northward.

### 3.5.4 Shearline

Shearlines are the extreme southern extensions of cold fronts. A shearline separates two air masses that differ mainly in wind speed and direction.

This tropical feature is usually associated with clouds and precipitation resulting from weak to moderate cyclonic shear caused by significant variations in wind velocity to the north and south of the shearline. Cloud types tend to be more stratiform as opposed to the cumuliform cloud types usually found in tropical areas. Movement of shearlines, once they reach the tropics, is slow and erratic (progressive, retrogressive or stationary).

Expect shearline passage over Guam within 12-24 hours after the surface pressure at Chichi Jima reaches 1024 mb.

### 3.5.5 Shipboard Ice Accretion

Shipboard icing is caused by a combination of atmospheric and sea conditions. In sub-freezing temperatures, precipitation can result in the formation of ice layers on exposed portions of the ship. In addition, high winds may cause particularly heavy icing due to dense seawater spray produced by bow slamming.

Major factors affecting shipboard icing are:

1. Air temperature,
2. Wind velocity,
3. Water temperature,
4. Geometry of accreting surface.

There are no exact methods of predicting ice accretion for ships at sea. Icing rates will vary with geometry of structure and orientation to wind and seas. Extensive research and observations by scientists and mariners has led to some fairly reliable indicators that can be plotted graphically.

## 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

##### 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.

##### 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.

##### 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.

##### 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.
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.

#### **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 Indonesia 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.

#### **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.

#### **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.

### **4.1.2 Indian Subcontinent**

#### **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), Brahmaputra (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.

#### **4.1.2.2 [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.

#### **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
3. The Deccan Plateau (peninsula), which is of moderate elevation.

#### **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 Afghanistan.
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.

#### **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.

#### **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.

#### **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.

### **4.1.3 Middle East**

#### **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.
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.

#### **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 marches 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.

#### **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.
5. The Northern Region.

#### **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.

#### **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.

#### **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.

#### **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.

#### **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.

#### **4.1.3.9 South 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.

#### **4.1.3.10 North Yemen**

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.

## **4.1.4 Northeastern Africa**

### **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.

### **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.

### **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.

### **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.

### **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.

## **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

##### 1. Boundaries

- Western Limits: The meridian of Cape Agulhus to Antarctica (Queen Maud Land).
- Eastern Limits (south of Australia): The western boundary of Bass Strait, then to northeastern Tasmania, then to Antarctica near Fisher Bay
- 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.

##### 2. Major Divisions

###### a. 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.

###### b. 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.

###### c. 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:

- The Mozambique Ridge.
- The Madagascar Ridge, of which the island of Madagascar is a clear example of a microcontinent.
- The Mascarene Ridge, of which the Seychelles is an example.
- The Chagos-Laccadive Plateau supporting the Chagos Archipelago which rise from a long, broad, slightly curved plateau.
- 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.

###### d. 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.

###### e. Fracture Zones

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

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

### 3. Sediment Types

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:

#### a. Pelagic Type Sediments

- distributed over most of the Indian Ocean basin:
  - 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.
  - 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.
  - DIATOM OOZE covers about 20% of the total area in the sub-polar areas beyond 50° South.

#### b. Terrigenous Type Sediments

- distributed close to continents and island belts:
  - 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.
  - Lava and ash accumulations mark the mid-ocean volcanic areas which lie mainly in the western half of Indian Ocean.
  - 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.

### 4.2.2.2 [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.

### 4.2.2.3 [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.

## **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**

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**

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.
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 table includes the four seasons, the approximate time of onset and some common names:

|                   |                         |         |                     |
|-------------------|-------------------------|---------|---------------------|
| NorthEast Monsoon | Winter Monsoon          | Dec-Mar | Cool Season         |
| Spring Transition | Pre Monsoon Transition  | Apr-May | Hot Season          |
| SouthWest Monsoon | Summer Monsoon          | Jun-Sep | Rainy Season, India |
| Fall Transition   | Post Monsoon Transition | Sep-Nov |                     |

#### 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.

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.

#### 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 unequalled anywhere else in the world.

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.

### **4.3.3 Southwest Asia**

#### **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 MODEL TENDENCIES**

### **4.4.1 NOGAPS/NORAPS**

#### **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 GWAM

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.

### 4.5 LOCAL FORECASTING RULES

#### 4.5.1 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.
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.

## 4.5.2 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.

## 4.5.3 "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.

## 4.5.4 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° F/-25° 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:

| DT    | F  | C  |
|-------|----|----|
| 30 kt | 18 | 10 |
| 35kt  | 27 | 15 |
| 40 kt | 36 | 20 |
| 45    | 45 | 35 |

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.

## 5 SOUTHERN HEMISPHERE

### 5.1 TOPOGRAPHY

The Southern Hemisphere oceans extend virtually uninterrupted from the west coast of South America to the east coast of Africa. In the Southern Pacific, other than Australia and New Zealand, islands make up most of the land mass within the area. Until reaching the eastern coast of Madagascar and Africa, a scattering of coral islands make up the land mass of the southern Indian Ocean.

NAVPACMETOCEN WEST/JTWC is responsible for a large area of the southern hemisphere extending from the Equator south to 60° South and from 180° West to 17° East. WEAX forecasts are issued for all requesting units transiting or operating in the Southern Hemisphere. Tropical warnings are issued by JTWC for cyclones developing from the International Date Line to the eastern coast of Africa.

#### 5.1.1 South Pacific

##### 5.1.1.1 [Australia](#)

Australia is the smallest continent. Australia extends from 10° South to 44° South and from 113° East to 154° East. It is approximately 2,500 mi (4025 km) from east to west and 2,000 mi (3220 km) from north to south. Australia is divided into four general regions:

1. A low, narrow, sandy eastern coastal plain.
2. The eastern highlands (Cape York to Tasmania), ranging from 1,000-7,000 ft (305-2135 m) in elevation.
3. The central plains (almost 75% of the continent), consisting largely of north-south series of drainage basins.
4. The “western plateau”, covered with great deserts and “bigger plains” (regularly spaced sand ridges and rocky wastes from the eroding dissection of old plateaus).

With less than 75% of the land area being over 2,000 ft (610 m) in elevation, the dominant features of the Australian landscape are great plains and plateaus. The eastern highlands (Great Dividing Range) are cut by fairly deep forested valleys, with a few small coastal plains or wider valleys such as those near Brisbane and Sydney. However, the coasts of Australia are fairly smooth and few deep bays or rugged capes exist except for Cape York Peninsula in the northeast and the Great Australian Bight in the south, where mostly rugged coastlines prevail.

##### 5.1.1.2 [New Zealand](#)

New Zealand consists of the North Island, the South Island, Stewart Island and several outlying small island groups, between 33° South and 53° South and 162° East and 173° West. The islands are volcanic in origin. Recent volcanic activity has been limited to the North Island. Less than 25% of the land mass is below 650 ft (198 m). Landscapes are spectacular with snow capped mountains, geysers, deep fjords and rolling hill country. The North Island is far less mountainous than South Island, with peaks less than 6,000 ft (1830 m), except for four active volcanoes (7000-9000 ft/2135-2745 m). The coastline is sharp with many bays, capes and fjords. Both peninsulas have an irregular coastline with wide shallow bays; however, in the north, at Ninety Mile Beach, the sweeping west coast is smoothed by vast accumulations of sand. The South Island is mountainous with the Southern Alps running the entire length of the island. It has seventeen peaks exceeding 10,000 ft (3050 m).

## 5.1.2 Tropical South Pacific

The islands of Melanesia and Polynesia, west of 180°, are very much the same as those of Micronesia. They are mostly low-lying coral atolls interspersed with relatively high islands which are the peaks of submerged mountains and/or extinct volcanoes with the attendant coral reefs flanking the peaks.

### 5.1.2.1 Solomon Islands

These islands are essentially volcanic with numerous coral atolls. They extend from 5° South to 13° South and 155° East to 170° East. The eight largest Solomon Islands are very mountainous, the highest peak being on Guadalcanal at over 8,000 ft (2440 m). These island mountains have a definite influence on the local weather and contribute to windward-leeward rainfall distribution. The islands are subject to the southeast trades and rainfall averages about 120 in (305 cm) on the windward slopes and 75 in (191 cm) on the leeward side. The average temperature ranges from 72°-95° F (22°-35° C).

### 5.1.2.2 Gilbert And Ellice Islands

These islands are United Kingdom dependencies. They extend from 4° North to 11° South and from 172° East to 180°. There are thirty-seven coral atolls, with Ocean Island being the only volcanic island. Rainfall varies from 40-120 in (102-305 cm) per year. Most of the islands are subject to the southeast trade winds.

### 5.1.2.3 Papua-New Guinea

These islands include the islands of New Guinea, the Bismarck Archipelago of which New Britain, New Ireland and Manus are the largest islands; Bougainville and Buka Islands in the Western Solomon Islands and the Trobriand, Woodlark, D'Entrecasteaux and Louisiade Island groups to the east of the New Guinea mainland. They extend from the Equator to 8° South and from 130° East to 155° East. Papua-New Guinea is the largest and most rugged island. The central highlands range from 8,000-15,000 ft (2440-4575 m) and occupy the center of the island with numerous spines extending in all directions. All the people and industry inhabit the narrow coastal plain. The ranges are broken by deep rushing rivers and mountains that make land transportation and communication difficult. The remainder of the islands are volcanic in origin and very precipitous. All-weather roads are almost non-existent. The area's weather is subject to the migration of the monsoon trough and has a southwestern-southeastern flow regime, with heavy rain through most of the year. Variations are acute between islands and even on the same island due to the orographic effects of the rugged terrain.

### 5.1.2.4 New Hebrides, Loyalty, Samoan And Fiji Islands

These islands are all volcanic, though not as rugged as the Solomon Islands or Papua-New Guinea. They extend from 13° South to 23° South and 165° East to 177° West. The islands east of 180°, excluding portions of Samoa and Fiji, extending to 155° West, are a combination of coral atolls and volcanic islands and make up the Cook and Tonga Islands. The Tonga Islands extend from 15° South to 23.5° South and from 173° West to 177° West. The Cook Islands lie North to South from 8° South to 23° South and from 156° West to 167° West. There are approximately 540 islands within the area between 180° and 155° West with sizes ranging from a few square yards/meters to 7055 sq mi (18272 sq km), and from a few feet/meters above sea level to 6090 ft (1857 m) on Savai Western Samoa.

### 5.1.2.5 Brunei Darussalam

Brunei Darussalam is situated on the northwest coast of the island of Borneo. It is surrounded on three sides by the east Malaysian state of Sarawak and to the north by the South China Sea. It is divided into two parts by Sarawak. To the west is the main part consisting of three districts: Brunei-Muara, Tutong and Belait and in the eastern portion, Temburong. The terrain in the west is predominantly hilly lowlands rising to about 900 ft (275 m). The eastern area is a wide coastal plain that reaches up to the more mountainous regions. Vegetation in the interior consists mainly of primary and secondary tropical rain forests. Mangrove swamps and sandy beaches lie along the coastal plains.

## 5.1.3 South Indian Ocean

### 5.1.3.1 The [Chagos Archipelago](#)

The Chagos Archipelago is administered as the British Indian Ocean Territory (BIOT) which roughly covers from 43° East to 73° East between 10° South and the equator. In this area are Gan and Diego Garcia islands, both of which are major British and U.S. military installations. The Chagos Archipelago is coralline in origin with very limited vertical extent; thus, they have very little effect on even local synoptic features.

### 5.1.3.2 [Kenya](#)

Kenya is split by the equator with Somalia, Ethiopia and Sudan to the north; Uganda and Lake Victoria to the West; Tanzania to the south and the Indian Ocean to the East. The northern three-fifths of the country is arid. South of the Tana River, along the coast, tropical temperatures dominate. The region west of the plateau contains great volcanic mountain chains, of which the principal peak is Mount Kenya 17,058 ft (5203 m). The southern and southeastern portions of the country are heavily forested, and in the west, the immense depression of the Great Rift Valley is marked by a steep cliffline. The Great Rift Valley extends south from Lake Turkana. The land gradually descends from the western rift formation to the shores of Lake Victoria.

### 5.1.3.3 [Tanzania](#)

Tanzania is bordered on the north by Kenya, on the east by Rwanda and Burundi and on the south by Zaire, Zambia and Mozambique. The famed island of Zanzibar lies just off shore the northeastern coast. The Great Rift Valley runs through the central portion of the country. The Serengeti Plain extends from the southern shore of Lake Victoria in the northeastern corner to the border with Zaire/Zambia in the south. Savannah and tropical rainforest dominate the eastern third of the country.

### 5.1.3.4 [Mascarene Islands](#)

Mauritius is located about 500 mi (805 km) east of Madagascar. The island was formed by a series of volcanic craters from north-northeast to south-southwest along the center of the island with gently sloping land to the coast. It is surrounded by a reef. The highest peak is 2,711 ft (827 m) with a general area of highlands and peaks about 2,500 ft (763 m) in the southwestern and western portions of the island. Mauritius is an independent nation. Port Louis, a seaport and major city, is on the west coast and averages 40 in (102 cm) of rain annually.

La Reunion is also volcanic in origin and very mountainous. A coastal plain from 0.5-3 mi (.8-4.8 km) wide surrounds the volcanic massif of the interior with the west central area containing several peaks over 9,000 ft (2745 m). Around the massif are wide basins which, in turn, are surrounded by plateaus which descend abruptly to the coastal plain. The climate is dominated by the southeast trade winds from April to October when the northern and western sides are dry and torrential orographic rains fall on the south and east. A trace of snow was once recorded on La Reunion. The rest of the year very light winds prevail, with the coastal lowlands being extremely humid. Elsewhere, temperature, rainfall, and humidity vary tremendously according to altitude. La Reunion is a department of France, similar to a state. The main port is Pointe des Galets in the west.

### 5.1.3.5 [Seychelle Archipelago](#)

The Seychelles are located in the Indian Ocean about 1,000 mi (1,610 km) east of Kenya. The nation comprises an archipelago of 92 tropical islands with two distinct types of islands, some granite and some coral. The Mahe group consists of 40 granite islands, all within a 35 mi (56 km) radius of the main island of Mahe. These islands are rocky and most have a narrow coastal strip and a central range of hills rising as high as 3,000 ft (915 m). Mahe is the largest island and is the site of Victoria, the capital. The coral islands are flat with elevated coral reefs at different stages of formation.

### **5.1.3.6 Mozambique**

Lowlands make up almost one-half of Mozambique's land mass and mainly consists of coastal areas. The central uplands are formed by plateaus, while mountains lie along the western frontier. Africa's fourth largest river, the Zambezi, divides the country in half north to south.

### **5.1.3.7 Malagasy Republic**

The Malagasy Republic includes Madagascar and numerous islands off the east coast of Africa. Madagascar, one of the largest islands in the world, lies almost entirely in the tropics, from 12° to 26° South. The islands of the Malagasy Republic are volcanic and granitic in origin with the volcanic plateau comprising the backbone of the island, with peaks from 2,500-4,500 ft (763-1373 m) high. A narrow 30 mi (48 km) wide coastal zone lies to the east and low plateaus with vast plains extend to the west and south, 60-125 mi (97-201 km) wide. The coast is precipitous with numerous rocky inlets in the south (Fort Dauphin) and river estuaries and deltas in the northeast and northwest (Diego Suarez).

### **5.1.3.8 South Africa**

The Republic of South Africa is bordered on the north by Namibia, Botswana, Zimbabwe, Mozambique and Swaziland; on the east and south by the Indian Ocean; and on the west by the Atlantic Ocean. The topography of South Africa consists primarily of a great plateau, which occupies about two-thirds of the country. The plateau reaches its greatest heights along the southeastern edge, which is marked by the Drakensberg Mountains. The Drakensberg Mountains are part of a range that makes up a portion of the Great Escarpment, which separates the plateau from coastal areas.

Within the plateau three regions may be distinguished: the Highveld, the Bushveld and the Middle Veld. The Highveld, which covers most of the plateau, ranges in elevation from 4000-6000 ft (1220-1830 m) and is characterized by level or gently undulating terrain. The northern limit of the Highveld is marked by a rock ridge, called the Witwatersrand. North of the Witwatersrand is the Bushveld or Transvaal Basin. The Bushveld, much of which is broken into basins by rock ridges, slopes downward from east to west toward the Limpopo River. The Bushveld averages less than 4000 ft (1220 m) in height. The western section of the plateau, known as the Middle Veld, also slopes downward in a westerly direction. The elevation of the Middle Veld varies from 2000-4000 ft (610-1220 m). Between the edge of the plateau and the eastern and southern coastline, the land descends seaward in a series of abrupt grades, or steps.

The interior step is a belt of hilly country, called the Eastern Uplands. The exterior step is a low-lying plain, called the Eastern Lowveld. On the south, the steps, proceeding from the interior to the coast, are a plateau called the Great Karroo, or Central Karroo; a lower plateau called the Little Karroo, or Southern Karroo; and a low-lying plain. The Swartberg, a mountain range, lies between the Great Karroo and the Little Karroo. Between the latter area and the coastal plain is another mountain range, the Langeberg. On the southern coast, just south of Cape Town, is an isolated peak, Table Mountain about 3563 ft (1087 m). On the southwestern coast the edge of the plateau is marked by a range of folded mountains, irregular in character and direction, which descends abruptly into a coastal plain. South Africa also includes a part of the Kalahari Desert in the northwest and a section of the Namib Desert in the west.

## 5.2 OCEANOGRAPHY

### 5.2.1 Bottom Topography

#### 5.2.1.1 Southwest Pacific Ocean

The Southwest Pacific Ocean is generally recognized as extending from the Equator through the Cook Islands and south to the region of the Subtropical Convergence near 45° South. The whole of the easternmost part of the Southwest Pacific Ocean consists of the Southwestern Pacific Basin with depths to 18000 ft (5490 m). From the basin arise numerous individual islands and seamounts together with dominantly linear island chains. The western margin is formed from north to south by the Tonga and Kermadec Ridges and by the Subantarctic Slope east of New Zealand. The central portion of the Southwest Pacific Ocean is occupied by the New Zealand Plateau and by three major ridges - Lord Howe Rise, Norfolk Ridge and Tonga-Kermadec Ridge. In the western part of the ocean are several major basins -- the Tasman, Coral Sea, South Fiji and North Fiji, with depths ranging from 12000-16000 ft (3660-4880 m).

The dominant sediment is calcareous ooze. Below 15000 ft (4575 m) calcite dissolves and the bottom sediment in deeper water is a residual or red clay. Volcanic ash sediments dominate the bottom around highly active areas. Terrigenous debris dominates the New Zealand Plateau out to approximately 3000 ft (915 m).

#### 5.2.1.2 Coral Sea

The Coral Sea is bounded by the coast of Queensland on the western side to include the Torres Straits, extending northward to New Guinea, then eastward to the New Hebrides and New Caledonia to 30° South, back to the coast of Australia. The three largest barrier reefs in the world are located within the Coral Sea:

1. The Great Barrier Reef of Queensland on the northeast Australian continental shelf.
2. The Tagula Barrier Reef of southeastern Papua and the Louisiade Archipelago.
3. The New Caledonia Barrier Reef surrounding the island.

There are three major basins: the Coral Sea Basin including the Carpenter Deep at 16060 ft (4898 m), the New Hebrides Basin and the Santa Cruz Basin. There are three of the world's great trenches near the eastern margin of the Coral Sea: the San Cristobal Trench, forming an arc around the Solomon Ridge, the Torres Trench joined to the San Cristobal Trench, extending north-south on the west side of the Santa Cruz Plateau and the New Hebrides Trench around the south end of the islands.

The Coral Sea basin is covered mainly by pelagic red clay. The large plateau areas are largely covered by coral sands and carbonate muds. There are extensive volcanic sediments around the new Hebrides.

#### 5.2.1.3 Tasman Sea

The Tasman Sea lies between Australia and New Zealand and correlates roughly with a deep basin known as the Tasman Basin. This basin extends as far south as the Macquarie Island-Tasmanis Ridge. The floor of the basins marked by a number of seamounts. In the north, the Tasman Sea extends into the Coral Sea taking in the Lord Howe Rise, the New Caledonia Trough and Norfolk Ridge. The eastern borders are marked by the New Zealand Plateau.

#### 5.2.1.4 Arafura Sea

The boundaries of the Arafura Sea are the Outer Banda Arc, West Irian (former Dutch New Guinea), Torres Strait, the Gulf of Carpentaria and 130° East. The Arafura Sea covers a large shallow bank, the Arafura Shelf, which is a part of the Northern Australian Shelf. The Arafura Sea is separated from other basins by the Aru Trench in the north and west and the Timor Trough in the east.

Depths in the Arafura Sea range from 150-240 ft (46-73 m) with deeper areas near the trenches. The Aru islands form the most extensive land areas on the shelf.

### **5.2.1.5 Flores Sea**

The Flores Sea is bounded by the southern entrance of Makassar Strait, South Salawesi Peninsula in the north to a line from southeast Sulawesi to the eastern tip of Flores Island to the Lesser Sunda Islands, then to the Paternoster Islands.

The Flores Sea covers four regions with different bottom configurations. The westernmost region is a submerged plateau with depths less than 3000 ft (915 m). Atolls are common on its submarine elevations. There are two deep channels: one near the Sunda Shelf boundary in the southwest and the other off the coast of South Sulawesi. These channels connect the deeper parts of the Flores Trough with Makassar Strait. The second subdivision is comprised of the deep, central Flores Trough with an irregular bottom relief and gently sloping sides. The third region consists of two parallel ridges with an intervening depression. The easternmost portion of the Flores Sea covers the area south of the Bone Gulf where it merges into the Banda Sea.

The broad, almost featureless, bank in the western part is covered by volcanic and terrigenous muds. The area around the Flores Trough and the Makassar Strait is covered by volcanic mud and coralline mud.

### **5.2.1.6 Gulf Of Carpentaria**

The Gulf of Carpentaria is defined as the large rectangular embayment bounded by Cape York on the east and Arnhem Land on the west. The whole area of the Gulf is rather shallow, not exceeding 228 ft (70 m), and generally between 150-210 ft (46-64 m). There are two major fault zones: one along the eastern shore and one along the western shore. The center portion of the Gulf is mainly a basin, with a depression adjacent to the eastern fault. Three distinct sedimentary layers are found in the Gulf: green marine mud, dark gray clay or fine silt and a white clay.

### **5.2.1.7 Southern Indian Ocean**

The bottom topography of the [Southern Indian Ocean](#) is covered in detail in Chapter 4

## **5.2.2 Major Ocean Currents**

### **5.2.2.1 [West Wind Drift](#)**

The West Wind Drift (Antarctic Circumpolar Current) is a circumpolar current completely encircling the Antarctic continent at approximately 50° South. The main flow of water is from the west to east under the influence of the prevailing westerlies. The West Wind Drift is the boundary between the sub-tropical waters to the north and the Antarctic waters to the south.

### **5.2.2.2 [East Australian Current](#)**

The East Australian Current flows south along the coast of Australia and forms the western part of the anticyclonic circulation in the South Pacific. The current is formed at 20° South between the Great Barrier Reef and the Chesterfield Reef. From January to March, it is supplied with equatorial water driven west-southwest by the monsoon winds. From April to December, subtropical water masses entering the Coral Sea, from the east, supply the water.

The East Australian Current is strongest off Cape Byron, where its average speed is 1.2 kt from December to April (summer). During the rest of the year, the current averages 0.8-1.0 kt. In June and July (winter), when southerly winds are frequently very strong, a countercurrent flowing north develops farther offshore.

South of 32° South, the East Australian Current becomes broader, weaker and disintegrates into an eddy system. These eddies drift along the coast as far as Tasmania. Most of the water turns northeast, flowing across the Tasman Sea and moves north of New Zealand.

### **5.2.2.3 West Australian Current**

The West Australian Current flows northerly along the western coast of Australia at an average speed of 0.4-0.7 kt during the summer.. The current becomes southerly and weak during the winter.

### **5.2.2.4 South Equatorial Current**

The South Equatorial Current is the northern leg of the gyre which is a continuation from the West Australian Current at the Tropic of Capricorn due to the effects of the Southeast Trades. The eastern part of the current reaches its greatest velocity (above 1 kt) during the southern winter when the westward flow north of Australia from the Pacific Ocean reinforces it.

### **5.2.2.5 Agulhas And Mozambique Currents**

The Mozambique Current is an extension of the South Equatorial Current that flows between the African continent and the Island of Madagascar. The Mozambique Current joins with another extension of the South Equatorial Current that flows down the eastern side of Madagascar. Either or both of these currents flow into the Agulhas, which then flows southward toward the Cape of Good Hope before doubling back to join with the West Wind Drift. The interaction between the Agulhas and the West Wind Drift can produce rogue waves. As it is nearly impossible to forecast rogue waves, great care must be taken when transiting this area.

The Agulhas Current flows in a southwesterly direction parallel to the coast of Africa. It is quite strong and very narrow. The axis of maximum current speed tends to coincide with the 100 fathom depth contour. The following are rules for forecasting waves associated with the Agulhas:

1. If strong southerly waves/swell are expected, a ship should track as close to shore as safe navigation will permit (particularly if on a southerly track). If this is not feasible, stay well offshore (outside the 100 fathom contour)
2. If the predominant wave/swell is from the northeast, the most comfortable track will be found near the 100 fathom contour.
3. If expected waves are slight to moderate from any direction, the effect of the Agulhas Current on the ship's speed made good is probably the most important factor in tracking a ship around the Horn.

## **5.2.3 Secondary Currents**

### **5.2.3.1 Coral Sea**

The South Equatorial Current enters the Coral Sea between the Solomon Islands and the New Hebrides from January to March under monsoonal flow. During the remainder of the year, the Trade Wind Drift flows into the area. Both of these currents feed the East Australian Current.

### **5.2.3.2 Flores Sea**

Surface currents during the southern winter are toward the southwest at 1-1.5 kt. During the southern summer the direction is reversed at rates of 0.5-1 kt in the western half of the Sea and 1-1.5 kt in the eastern half.

### **5.2.3.3 Arafura Sea**

Surface currents north of 8° South have irregular directions and are generally unsteady. South of this latitude the currents are predominately westward, running at 1-2 knots during the winter. During the southern summer the currents have no general directions.

## 5.3 METEOROLOGY

### 5.3.1 South Pacific

#### 5.3.1.1 Australia

The climate of Australia is generally warm and dry. There is, however, a diversity of climate due to the span of latitude. Because of Australia's position and size, climatic differences are generally a function of latitude but can be influenced by tropical air masses or extratropical storms in the westerlies. Temperatures range from mild in the south to hot in the interior and north. The north exhibits comparatively little seasonal change (20° F/11°C) along the coast. In the interior, seasonal temperature ranges exceed 30° F/17° C and a monsoonal (i.e., wet summer, dry winter) regime affects the northern third of the continent. Rainfall varies greatly across the continent. About 80% of the continent is either desert or subhumid, with droughts and floods possible over large areas. The three major factors influencing Australian rainfall are:

1. Latitudinal position
2. The monsoonal effect, with high pressure dominating the north in the dry winter and the equatorial trough and associated tropical showers during the summer
3. The long hilly coast of the Great Dividing Range, which is exposed to the southeast trade winds that bring consistent annual rainfall to the eastern highlands.

The climate of the western two-thirds of the continent is typically monsoonal north of 20° South and is Mediterranean south of 30° South. The eastern coast of Australia is dominated by the southeast trades. Most of the inclement weather comes in the summer (December through April) as a result of westerly monsoonal flow and the resulting tropical belt of low pressure. The intermediate desert zone lies too far north of the extratropical rain bearing storm track to receive rainfall regularly either in summer or winter. The northward movement of the Intertropical Convergence Zone (ITCZ) and the establishment of the semi-permanent high brings good weather in the winter seasons (May through November). The weather along the south to southeastern coast of Australia is largely controlled by an eastward progression of anticyclones, which make up a semi-permanent belt of high pressure. Between these migratory highs are troughs and low pressure areas. The axis of the climatological anticyclone lies across southern Australia in winter, drifts southward over the Great Australian Bight during spring and lies south of 35° South in summer. Gales are most likely in winter when storms from the "Roaring 40's" or "Whistling 50's" are able to penetrate northward. Troughs can penetrate as far north as 25° South.

#### 5.3.1.2 New Zealand

New Zealand has a moist temperate ocean climate without marked seasonal variations in temperature or rainfall. Prevailing winds are westerly. Strong winds occur in Cook Strait. Cyclonic activity is one of the important contributing factors to the general moderate precipitation. Cyclones cross New Zealand either from the west or the northwest. During summer, cyclones generally move to the south and primarily influence the North Island. The South Island experiences migratory low pressure systems during all seasons of the year. New Zealand is subject to the regular passage of extratropical storms. The generally mountainous nature of the country causes extraordinary contrasts in volume and character of precipitation between the eastern and western sides of the Southern Alps. The mountainous terrain causes turbulent mixing which prevents formation of extensive low and mid cloud sheets. This results in high percentages of insolation. Thus, the mountains act as a mild heat source at higher altitudes.

### 5.3.2 Southern Pacific And Indian Oceans

Because of the predominance of water in these areas, atmospheric circulation is far less complex than in the Northern Hemisphere. In the Southern Hemisphere winter, an extensive, warm, high pressure ridge dominates much of the oceanic region along 30° South. This produces southeasterly trades in the northern portion and westerlies in the south. In southern summer, a warm low forms to the northeast of Australia, with weak troughing over the continent, resulting in a southward shift of the westerlies in the South Pacific Ocean. Migratory lows which are present over the southern oceans originate in one of three well-defined source regions:

1. The majority of the lows form in the South Atlantic off the coast of Argentina and move rapidly eastward, passing south of the Cape of Good Hope.
2. A secondary region of cyclogenesis lies off the east coast of Africa, south of the Malagasy Republic, Madagascar and is a dominant feature of the southern winter season.
3. A small number of lows originate as waves on the Antarctic front which develop closed circulations and move northward ahead of outbreaks of very cold polar air masses from Antarctica.

### **5.3.3 Africa**

The climate of the area is chiefly dominated by the Southeast Trades which blow throughout the year but with variations in steadiness and extent. North of 10° South, the cross equatorial monsoon wind flow prevails from November to March with the Southeast Trades extending north from April to September when it is continuous with the Southwest Monsoon of the Northern Hemisphere.

The region below 30° South comes under the influence of migrating mid-latitude systems. The western region of South Africa, with its plateau region, will weaken systems as they move across the southern tip. An area of cyclogenesis exists just off the eastern coast between South Africa and Madagascar.

## **5.4 FORECASTING RULES**

When forecasting for the Southern Hemisphere, several basic environmental factors must be understood. The southern summer occurs during northern winter. Lows in the Southern Hemisphere turn in a CLOCKWISE direction and southern highs in a COUNTER-CLOCKWISE direction. An easy way to remember this is: the wind feathers on an easterly wind should face away from Antarctica when plotted on the wind stem; a westerly wind stem would have the wind feathers pointing toward Antarctica on the stem.

NOGAPS 3.4 will tend to be quick to deepen and slow to fill lows. Speed of movement must be carefully monitored. Systems in the Southern Hemisphere, especially at 40° South and below, have been known to track at 40 kt or better. Because there are no land masses to interfere with speed of movement, close attention should be paid to 500 mb and even 700 mb winds when tracking systems.

The major areas of cyclogenesis, outside frontal wave formation, is the western side of the Cape of Good Hope after fronts depart the African continent and around the western Bight region of Australia. Both areas offer contrasts in air and sea temperatures, induced cyclonic turning and air mass contrasts.

GWAM 4.0 appears to have trouble with long period swell much in the same way as in the Northern Hemisphere. Sea and swell associated with a dynamic system is handled extremely well. Land - sea interface is of little concern except around the Tasman Sea area of Australia and the Cape of Good Hope. Care must be taken when forecasting conditions in the Tasman Sea, the Bass Straits (due to funneling), near the Cape of Good Hope and New Zealand.

# **6 TROPICAL CYCLONES**

## **6.1 INTRODUCTION**

The term "tropical cyclone" applies to a non-frontal low pressure system of synoptic-scale, developing over tropical or subtropical waters and having a definite organized circulation. However, the term is generally used in a more restrictive sense to include only potentially destructive warm-core systems; thus, the operational definition excludes monsoon depressions, mid-tropospheric and subtropical cyclones.

Warm-core tropical cyclones are the most destructive weather phenomena for their size in the tropics. These weather systems function as natural, but very inefficient, “heat engines”. Most of the latent heat energy that is released is expelled high in the atmosphere. Only a small percentage of the energy is converted into kinetic energy in the form of wind and waves. Nevertheless, the destructive power of an intense tropical cyclone is awesome, with surface wind speeds near the cyclone center often exceeding 100 knots. Torrential rains falling from the spiral convective cloud bands several hundreds of miles from the center can cause flash flooding and landslides. The storm surge propagating ahead of the cyclone can completely inundate low-lying coastal areas. The combined effects of destructive winds and phenomenal seas can swamp and sink vessels unfortunate enough to be caught in its path.

The combination of potentially destructive winds, rains and high seas poses a threat to life and property that cannot be ignored. The following examples of tropical cyclone destruction clearly illustrate this point:

|      |                            |  |
|------|----------------------------|--|
| 1737 | Calcutta, India            | 300,000 people killed                              |
| 1876 | Backergunge, India         | 100,000 to 400,000 people killed                   |
| 1944 | Philippine Sea             | three U.S. Navy destroyers sunk and 800 lives lost |
| 1970 | East Pakistan              | 300,000 people killed                              |
| 1974 | Darwin, Australia          | 90 percent of the city destroyed                   |
| 1977 | Near Andhra Pradesh, India | Near Andhra Pradesh, India: 10,000 people killed   |
| 1991 | Bangladesh                 | 138,000 killed                                     |

## 6.2 TERMS AND DEFINITIONS

Most countries within JTWC’s AOR are actively involved in tropical cyclone forecasting. A lack of standardized terminology can be a source of confusion when interpreting bulletins from other forecasting agencies or when exchanging information with foreign meteorologists. To minimize such confusion, JTWC adheres to definitions and classifications adopted by the U. S. National Weather Service. Forecasters are to interpret bulletins from other countries in terms of reported maximum sustained wind speeds and apply the appropriate U. S. definition. Note that NAVPACMETOCEN WEST/JTWC uses a one minute maximum sustained wind average as opposed to the ten minute wind average used by WMO International warning agencies. When exchanging information with foreign meteorologists, stress the use of maximum sustained 1-minute winds rather than classification terms. Maximum sustained wind speeds provide a common reference for exchange and interpretation of tropical cyclone information.

### 6.2.1 Tropical Cyclone Classifications.

#### 6.2.1.1 Standard

1. United States (maximum sustained 1-minute mean surface wind speed in knots)
  - a. Tropical depression <34
  - b. Tropical storm 34 to 63
  - c. Typhoon/Hurricane >63
2. World Meteorological Organization (maximum sustained 10-minute mean surface wind speed in knots)
  - a. Tropical depression <34
  - b. Tropical storm 34 to 47
  - c. Severe tropical storm 48 to 63
  - d. Typhoon (or local synonym) >63

#### 6.2.1.2 Non-Standard

1. JTWC (maximum sustained 1-minute mean surface wind speed in knots)
  - a. Super typhoon >129
2. Mauritius and Southwest Indian Ocean (maximum sustained 10-minute mean surface wind speed in knots)
  - a. Tropical depression <34
  - b. Moderate tropical depression/storm 34 to 47

- |                                     |           |
|-------------------------------------|-----------|
| c. Severe tropical depression/storm | 48 to 63  |
| d. Tropical cyclone                 | 64 to 90  |
| e. Intense tropical cyclone         | 91 to 115 |
| f. Very intense tropical cyclone    | >115      |
3. India, Bangladesh and Pakistan (maximum sustained 10-minute mean surface wind speed in knots)
- |   |          |
|---|----------|
| a. Depression   | <28      |
| b. Deep depression  | 28 to 33 |
| c. Severe cyclonic storm                                    | 48 to 63 |
| d. Severe cyclonic storm with core of hurricane force winds | >63      |

## 6.2.2 Glossary

**Best Track** -- A subjectively smoothed path (versus a precise and very erratic fix-to-fix path) used to represent tropical cyclone motion.

**Binary Interaction** -- The interaction between two tropical cyclones (more commonly known as the Fujiwhara effect) when they are within about 750 nm of each other that usually results in the storms rotating cyclonically (occasionally they may rotate anticyclonically) about a central point between them. This interaction may end in one of three ways:

1. The destruction of one vortex (by movement over land or dissipation, for example)
2. By merger of the two cyclones The Fujiwhara effect refers specifically to the interaction between two cyclonic vortices, where mutual attraction and coalescence takes place (Brand, 1970; Dong and Neumann, 1983, Lander and Holland, 1993).
3. By escape.

**Center** -- The vertical axis or core of a tropical cyclone that is usually determined by cloud vorticity patterns, wind and/or pressure distribution (i.e. isobaric pattern).

**Explosive Deepening** -- A rapid decrease in the minimum sea-level pressure of a tropical cyclone at the rate of 2.5 mb/hr for 12 hours or 5.0 mb/hr for at least six hours (Dunnavan, 1981).

**Extratropical** -- A term used in warnings and tropical weather summaries to indicate that a cyclone has lost its "tropical" characteristics. The term implies both a poleward displacement from the tropics and the conversion of the cyclone's primary energy source, the release of latent heat of condensation, to baroclinic instability. It is important to note that cyclones can become extratropical and still maintain winds of typhoon or storm force.

**Eye** -- The central area of a tropical cyclone that is more than half surrounded by a wall cloud.

**Intensity** -- The maximum sustained 1-minute mean surface wind speed, typically within one degree of the center of the tropical cyclone.

**Maximum Sustained Wind** -- The highest surface wind speed averaged over a one-minute period of time. (Peak gusts over water generally average 20-25 percent higher than sustained winds.)

**Mei-yu Front** -- The term "mei-yu" is the Chinese expression for "plum rains". The mei-yu front is a persistent east-west zone of disturbed weather during spring which is quasistationary and stretches from the east China coast, across Taiwan and eastward into the Pacific Ocean south of Japan.

**Monsoon Depression** -- A tropical cyclonic vortex characterized by:

1. Its large size, (the outer-most closed isobar may have a diameter about 600 nm)
2. A loosely organized cluster of deep convective elements
3. A low-level wind distribution which features a 100-nm diameter light-wind core which may be partially surrounded by a band of gales
4. A lack of a distinct cloud system center.

Note: Most monsoon depressions which form in the western North Pacific eventually acquire persistent central convection and accelerated core winds marking its transition into a conventional tropical cyclone.

**Monsoon Gyre** -- A mode of the summer monsoon circulation in the western North Pacific characterized by:

1. A very large nearly circular low-level cyclonic vortex that has an outer-most closed isobar with a diameter on the order of 1200 nm
2. A cloud band rimming the southern to eastern periphery of the vortex/surface low
3. A relatively long (two week) life span. (Initially, a subsident regime exists in its core and westerly and northwesterly quadrants with light winds and scattered low cumulus clouds; later, the area within the outer closed isobar may fill with deep convective cloud and become a monsoon depression or tropical cyclone.)
4. The large vortex cannot be the result of the expanding wind field of a pre-existing monsoon depression or tropical cyclone.

Note: A series of small or very small tropical cyclones may emerge from the “head” or leading edge of the peripheral cloud band of a monsoon gyre (Lander, 1994).

**Rapid Deepening** -- A sharp decrease in the minimum sea-level pressure of a tropical cyclone at the rate of 1.25 mb/hr for 24 hours (Holliday and Thompson 1979).

**Recurvature** -- The turning of a tropical cyclone from an initial path toward the west and poleward to a subsequent path toward the east and poleward, after moving poleward of the mid-tropospheric subtropical ridge axis.

**Reverse-oriented Monsoon Trough** -- The distinguishing characteristics of the a reverse-oriented monsoon trough are:

1. A SW-NE orientation (as opposed to the normal NW-SE of the trough axis)
2. The penetration of the trough axis into subtropical areas which are normally the province of easterly flow.

**Significant Tropical Cyclone** -- A tropical cyclone becomes “significant” with the issuance of the first numbered warning by the responsible warning agency.

**Size** -- The areal extent of a tropical cyclone, usually measured radially outward from the center to the outer-most closed isobar. Based on an average radius of the outer-most closed isobar, size categories in degrees of latitude are as follows:

|          |            |
|----------|------------|
| 1° to 2° | Very small |
| 3°       | Small      |
| 4° to 5° | Medium     |
| 6° to 9° | Large      |
| > 9°     | Very Large |

(Brand, 1972 and a modification of Merrill, 1982).

**Strength** -- The average wind speed of the surrounding low-level wind flow, usually measured within one to three degrees of the center of a tropical cyclone.

**Subtropical Cyclone** -- A low pressure system that forms over the ocean in the subtropics and has some characteristics of a tropical circulation but does not contain a central dense overcast (CDO). Although occasionally associated with an upper-level cold low or low-level baroclinicity, a sub-tropical system can still transition to a tropical cyclone if organized deep convection develops and persists, resulting in a warm innercore.

**Super Typhoon** -- A typhoon with maximum sustained 1-minute mean surface wind speed of 130 kt or greater.

**Tropical Cyclone** -- A non-frontal, migratory low-pressure system, usually of synoptic scale, originating over tropical or subtropical waters and having a definite organized circulation.

**Tropical Depression** -- A tropical cyclone with maximum sustained 1-minute mean surface wind speed of 33 kt or less.

**Tropical Disturbance** -- A discrete system of apparently organized convection, generally 100-300 nm in diameter, originating in the tropics or subtropics, having a non-frontal, migratory character and having maintained its identity for 12-24 hours. It may or may not be associated with a detectable perturbation in the wind field. It is the basic designation which, in successive stages of development, may be classified as a tropical depression, tropical storm, typhoon or super typhoon.

**Tropical Storm** -- A tropical cyclone with maximum sustained 1-minute mean surface wind speed of 34-63 kt, inclusive.

**Tropical Upper-tropospheric Trough** -- A dominant climatological system and a daily upper-level synoptic feature of the summer season, located over the tropical North Atlantic, North Pacific and South Pacific Oceans (Sadler, 1979). Cold-core vortices embedded in the TUTT are generally referred to as TUTT cells or TUTT lows.

**Typhoon** -- A tropical cyclone with maximum sustained 1-minute mean surface wind speed of 64 to 129 kt, inclusive. West of the 180°, they are called typhoons and east of the 180°, they are called hurricanes.

**Wall Cloud** -- An organized band of deep cumuliform clouds that immediately surrounds the central area of a tropical cyclone. The wall cloud may entirely enclose or only partially surround the center.

## 6.3 DEVELOPMENT CLIMATOLOGY

Five of the seven major ocean basins for tropical cyclone development occur within JTWC's AOR. The AOR experiences an annual average of 56 tropical cyclones which is 72% of the average annual global total of 78 tropical cyclones (reaching tropical storm intensity or greater ([Origins Chart](#))). The western Northern Pacific basin, which includes the South China Sea (development area), is by far the most active with an annual average of 26 tropical storms and typhoons (33% of average annual global total). See ([Frequency Chart](#)) for the frequency of occurrence of tropical storm or typhoon force winds by month for each major basin (Neumann, 1993). A discussion of these areas follows:

### 6.3.1 Western North Pacific Ocean

This region experiences more than twice as many tropical cyclones as any other development area and is the only area in which tropical cyclones can occur in any month of the year. August is normally the most active month, and 90% of the storm activity occurs during the period May through December. More than 80% of tropical disturbances that reach depression stage further intensify into tropical storms or typhoons, and two-thirds of the tropical storms eventually reach typhoon intensity.

### 6.3.2 South China Sea

Data for this region is normally included with those of the western North Pacific. However, stratifying data from the two areas reveals that the South China Sea experiences a slight double maximum in storm formation -- the first in May and the second in September. This double maximum is related to the northward and southward oscillation, respectively, of the monsoon trough.

### 6.3.3 Bay of Bengal

Two distinct tropical storm seasons occur in the Bay of Bengal

1. Pre-monsoon period from April to June.
2. Post-monsoon period from September through December.

In contrast to tropical storm activity, the development of tropical cyclones that reach only the depression stage occurs in all months except March, with most occurring in the northern Bay of Bengal during the southwest monsoon and early post-monsoon period from June to October.

### **6.3.4 Arabian Sea**

The Arabian Sea has the fewest cyclones of all regions with an average of slightly over one depression and one tropical storm per year. The region also experiences two seasons (April to June and September to December) associated with the monsoon transition seasons and the seasonal movements of the monsoon trough.

### **6.3.5 Southwestern Indian Ocean**

This area includes the Southern Hemisphere - Indian Ocean area from the coast of Africa to 100° East and experiences an average of eight cyclones per year of tropical storm intensity or greater. A significant increase in the number of storms reported in this basin has occurred subsequent to the advent of continuous satellite coverage. The season extends from December to April, with over 70% of the storms occurring from January to March.

### **6.3.6 Australian/Southeastern Indian Ocean**

This basin includes the southern Indian Ocean from 100°-142° East and is an area that has shown a marked increase in tropical storm observations in recent years due to the availability of satellite imagery. The season extends from December through April, with most storms occurring from January to March.

### **6.3.7 Australian/Southwestern Pacific Ocean**

This area includes the Southern Pacific Ocean area east of 142° East. This basin averages about seven tropical cyclones per year, and the monthly occurrence of tropical cyclones is similar to the South Indian Ocean frequency. Nearly 75% of the tropical cyclones in this area occur from January through March. There is a tendency for these tropical cyclones to form simultaneously in both the North and South Pacific during the transition months (April, November and December).

## **6.4 STRUCTURE**

The physical structure of mature tropical cyclones has been studied in detail. NAVPACMETOCEN WEST/JTWC Guam's forecasters use their understanding of typical features of tropical cyclones to interpret available satellite and synoptic data. A discussion of typical structure follows.

### **6.4.1 Mature Tropical Cyclone**

1. An outer region with inward increasing cyclonic winds and limited convection extending 176-264 nm from the center.
2. An inner belt in which winds reach typhoon intensity and convective activity is concentrated in spiral rainbands.
3. A ring-shaped wall cloud region characterized by maximum wind speeds and violent convective activity.
4. A central eye inside a transition zone through which there is a rapid decrease in wind speed. The eye is characterized by light winds, the absence of strong convection and confused seas.

### **6.4.2 Vertical Cross-Section**

The winds of a tropical cyclone consist of cyclonic inflow near the surface, rising motion in the eyewall and rainbands, outflow at the top of the storm and sinking motion some distance away.

Tangential velocities increase rapidly in the inflow layer, remain relatively constant in the eye wall to a height of about 19536 ft (5954 m), then gradually decrease with height up to the outflow level. At the outflow level, wind speeds decrease rapidly and change direction from cyclonic to anticyclonic.

### 6.4.3 Horizontal Cross-Section

Maximum winds are located to the right of the storm track due to the tropical cyclone's forward motion being added to the storm's wind speed in that sector.

## 6.5 FORMATION AND DEVELOPMENT

The primary indicator of impending tropical cyclone development is the existence of persistent low-level convergence in an area of favorable conditions. Typhoon Duty Officers use an empirically developed "Tropical Cyclone Formation Alert Checklist" to assign points to the relative strengths of the conditions of tropical cyclone genesis. A Tropical Cyclone Formation Alert (TCFA) is issued once a minimum number of points is reached. The TCFA is discussed in more detail later. Since all tropical cyclones develop in limited areas and are highly seasonal, specific environmental conditions are required to accomplish the transition from a loosely organized convective disturbance to an intense vortex. By examining the climatology of cyclone genesis in relation to large-scale variables, some of the important physical relationships associated with cyclone formation can be inferred.

### 6.5.1 Large Scale Parameters

The large scale climatological parameters associated with tropical cyclogenesis are summarized as follows:

1. Warm Seas -- A large ocean area is necessary with surface temperatures warm enough to provide sufficient moisture and sensible and latent heat such that when air is lifted from near the surface and expands pseudo-adiabatically, it will remain warmer than the surrounding tropical atmosphere to a height of about 39,600 ft (12,069 m). Minimum sea surface temperatures of 79°F (26° C) are required.
2. Minimum Coriolis Parameter -- Almost all cyclones are observed to form poleward of 5° latitude, since a strong rotation in the wind field can be generated only where the Coriolis parameter exceeds a certain minimum value.
3. Weak Vertical Wind Shear -- Weak vertical wind shear through a deep tropospheric layer is necessary to permit vertical development of the cyclone. Strong shear can displace the deep convection and the associated warm column away from the low-level circulation, resulting in weakening or dissipation of the system.
4. Pre-existing Disturbance -- Cyclonic horizontal wind shear or a low-level surface vortex is required to initiate convergent flow near the surface. Deep convection can then become concentrated and the latent heat released can result in the development of a warm-core system.
5. Divergence Aloft -- An anticyclone or well-defined ridge near the 200-mb-level transports excess heat and mass away from the system center, allowing continued decrease in the central pressure. Some systems develop beneath a pre-existing upper-level anticyclone and eventually link up with it. Those systems located in low- or no-vertical wind shear environments develop their own upper-level anticyclone.

Although the above criteria exists over a large portion of the tropical oceans for extended periods of time, tropical cyclogenesis remains a relatively infrequent occurrence. Gray (1975) hypothesized that cyclones only form during periods when the above conditions depart significantly from their regional climatological means. See ([Genesis chart](#)) for regions of the world that have atmospheric conditions that are favorable for these significant departures.

### 6.5.2 Environmental Patterns

There are certain environmental patterns or phenomena that create conditions favorable for tropical cyclone genesis:

1. Monsoon Trough Development -- The monsoon and near-equatorial troughs are seasonal phenomena that are related to the season. In the spring and early summer, solar heating near the equator produces the near equatorial troughs. As the summer continues, the trough moves poleward. Westerly wind bursts further contribute to the development of the monsoon trough. The summer and early autumn monsoon trough is, without doubt, the greatest breeder of tropical cyclones.

2. Tropical Upper-tropospheric Trough (TUTT) -- A surface disturbance can be induced by upper-level divergence associated with the eastern side of a cyclonic cell in the TUTT (Sadler, 1976). This type of development occurs most frequently during the August to October timeframe due to the strength of the TUTT and accounts for 10% to 20% of the tropical cyclones that develop. These disturbances, which usually occur between 15° to 25° North, undergo [three stages of development](#)
3. Low-level Westerly Surges -- Tropical cyclone development can be initiated by a westerly wind surge or “burst” equatorward of the monsoon trough or near-equatorial trough axis (Keen, 1982; Lander, 1990).

## 6.6 DISSIPATION AND EXTRATROPICAL TRANSITION

Tropical cyclones ultimately either dissipate or transform into extratropical cyclones. Dissipation is primarily due to two effects:

1. Interaction with land masses, which:
  - a. cuts off the main source of fuel for the heat engine (the latent heat release from the warm moist air off the ocean) and
  - b. introduces increased frictional effects and disruption to the low-level inflow.
2. Strong vertical wind shear, which:
  - a. strips away the persistent central clouds and
  - b. destroys the vertical circulation that is needed to maintain the cyclone’s heat engine.

## 6.7 MOTION

The movement of a tropical cyclone (TC) was formerly believed to be determined primarily by four major factors:

1. Coriolis effect
2. Asymmetrical distribution of pressure falls about the cyclone center
3. Integrated steering flow from the surface through the upper troposphere
4. Interaction with other systems.

Additionally, numerous studies have shown that the size of the TC affects its propagation relative to the environmental steering and may significantly alter its environment (Carr and Elsberry 1994; Chan and Williams 1987; Fiorino and Elsberry 1989). This interdependence of TC track, intensity and size has led to the JTWC’s adoption of the “**Systematic and Integrated Approach to Tropical Cyclone Track Forecasting**” (Carr and Elsberry 1994) as its primary forecasting technique. The details of the “Systematic Approach” cannot be adequately addressed in this document. The “Systematic Approach” defines a set of conceptual models (TC-environment models) to assist the forecaster in formulating a comprehensive understanding of how the mutual influence of the TC and its environment determines TC motion.

The general principles describing model group interaction and evolution with time completes the “Systematic Approach.” The conceptual models are organized into three groups:

1. Environmental Structure -- Characterizations of environmental flows, excluding the symmetric circulation of the TC. Two subsets, based on scale, define the environment
  - a. Large scale environmental surroundings based on the existence and orientation of various synoptic features, such as cyclones, anticyclones, ridges and troughs are called **Synoptic Patterns**.
  - b. Smaller areas within synoptic patterns are called **Synoptic Regions** and characterize directions of steering.
2. TC Structure -- Characterizations of the intensity and size of the symmetric TC. The TC structure is defined by its size (Midget, Small, Average, and Large) and intensity (Exposed Low Level, Tropical Depression, Tropical Storm, Typhoon, Intense Typhoon).
3. TC-Environment Transformation -- Characterizations of one- and/or two-way advections or energy exchanges between the TC and the environment. Five transformation models are defined:
  - a. Basis Beta Effect Propagation
  - b. Vertical Wind Shear

- c. Ridge Modification by Large TC
- d. Monsoon Gyre-TC Interaction
- e. Tropical Cyclone Interactions

## 6.8 TRACK TYPE

There are four tropical cyclone track categories with various types and locations of synoptic features associated with each category of motion:

1. Straight Runner -- TC's embedded in the deep easterly flow equatorward of a continuous mid-level subtropical ridge.
2. Recurver -- TC's that move around the western edge of, or through breaks in, the mid-level subtropical ridge. The track changes orientation from westward and poleward to eastward and poleward.
3. North Oriented -- TC's embedded in a reverse oriented trough. Low latitude TCs may move eastward before developing a slow, somewhat erratic northward track. Other storm TCs will slow their westward motion and assume a northward track.
4. Other/Erratic Mover -- TC's embedded in weak or climatological steering flow. Examples include:
  - a. TUTT-induced TC's that form near the axis of the subtropical ridge or TC's in the summer that form along the monsoon trough and track to the north or northeast and don't recurve.
  - b. TC's in the South China Sea are often of this variety.

Click [here](#) for Average Cyclone Tracks

# 7 PRODUCTS AND SERVICES

## 7.1 METOC PRODUCTS

NAVPACMETOCEN WEST/JTWC issues area and specialized forecasts for units in its AOR. Area forecasts include high wind/seas forecasts, tropical warnings and prognostic blend charts valid to 120 hours. Specialized forecasts include WEAX, OTSR services and acoustic forecasts as requested.

### 7.1.1 Prognostic Blend Charts

Prognostic blend charts are prepared by NPMOCW forecasters. These charts form the basis of all warnings and forecasts (except tropical cyclone warnings issued by JTWC).

#### 7.1.1.1 Western Pacific Outlooks

This series of locally produced surface prognoses depicts surface winds, pressure centers, ice edge, frontal boundaries, high wind and seas warning areas valid for the time period and tropical cyclone warnings. These charts are based upon satellite analyses, synoptic observations, numerical models (NOGAPS, NORAPS, NCEP, ECMWF and JMA) and input from JTWC. The series includes:

1. WestPac 36 HR Outlook
2. WestPac 84 HR Outlook
3. WestPac 120 HR Outlook

Tropical cyclone positions and intensities for the 36 products are derived from warnings issued by JTWC. Tropical cyclone positions and intensities for the 84- and 120-hr products are based on interpolation of current model runs and coordination with the Typhoon Duty Officer.

### **7.1.1.2 Westpac 36-Hour Sig Wave Prog**

This chart depicts the significant wave height and direction based on the numerical WAM model and the 36 HR WX Depiction. Sea heights are indicated by 3, 6, 9, 12, 18 and 24 foot contours. The height and position of the maximum seas are indicated inside the highest contour.

### **7.1.1.3 Indian Ocean 36-Hour Outlook**

This locally produced surface prognoses depicts surface winds, pressure centers, frontal boundaries, areas of cloud cover 5/8 or more, high wind and seas warning areas valid for the time period and tropical cyclone warnings. This chart is based upon satellite analyses, synoptic observations, numerical models (NOGAPS, NCEP and ECMWF) and input from JTWC. Tropical cyclone positions and intensities are derived from warnings issued by JTWC.

### **7.1.1.4 Indian Ocean 36-Hour Sig Wave Prog**

This chart depicts the significant wave height and direction for the Bay of Bengal, North Arabian Sea, Arabian Gulf and Red Sea based on the numerical WAM model. Sea heights are indicated by 3, 6, 9, 12, 18 and 24 foot contours. The height and position of the maximum seas are indicated inside the highest contour.

## **7.1.2 Weax And Otsr**

1. The purpose of Enroute Weather Forecasts (WEAX) is to provide requesting units operating within the AOR detailed, timely weather/METOC forecasts, in accordance with NAVMETOCCOMINST 3140.1 (series). WEAX forecasts are issued daily for units operating under normal conditions. Units operating under heavy weather conditions, towing or conducting special operations will be issued WEAX twice daily, at a minimum.
2. Optimum Track Ship Routing (OTSR) is an advisory service provided to requesting units transiting the AOR. OTSR provides recommended ship routes and revisions, if needed. Recommendations are designed to minimize time enroute and the risk of damage resulting from environmental phenomena. OTSR takes into consideration individual ship and cargo characteristics. For more detailed information, refer to NAVMETOCCOMINST 3140.1 (series).

## **7.1.3 High Wind And Seas Warnings**

1. The High Wind and Seas warnings are issued twice daily for the WESTPAC and INDIAN OCEAN areas. The WESTPAC warning (WWPW 30/31) covers the area from 120° East to 180° and from 66° North to the Equator. The Bay of Bengal and Northern Arabian Sea (north of the Equator) are covered by the Indian Ocean Warning (WWIO 30/31). Arabian Gulf and the Red Sea wind and seas warnings (MASR 1 PGFW) are issued by NAVPACMETOC DET BAHRAIN.
2. The following are standard criteria used by all centers for their warnings:
  - a. Areas of wind speed of 35-49 knots (Gale); wind speeds of 50 knots or greater (Storm) not covered by a tropical warning.
  - b. Areas of sea heights greater than or equal to 12 feet. Warnings also contain maximum height and approximate positions of the maximum seas.
3. The High Wind and Seas Warnings are transmitted from NAVPACMETOCCEN WEST GU via AUTODIN to AIG 127 for WESTPAC warnings and AIG 498 for Indian Ocean warnings. Warnings are also broadcast via the Fleet Broadcast, as an overlay on JMCIS and on the website.

## **7.1.4 Horizontal Refractivity Depiction**

This product describes areas of electromagnetic similarities. The HRD incorporates propagation loss, topography, local upper air soundings and synoptic patterns into the analysis.

### **7.1.5 Wpac Fronts And Eddies**

This product contains positions and intensities of fronts and eddies in the Western Pacific Ocean. Major fronts normally included are: Kuroshio, Oyashio, Tsushima, Liman-Tsushima, Korean Coastal and Yellow Sea. A number of unnamed fronts are also addressed. Resources for analysis include: sea surface temperature, enhanced infrared and visual satellite imagery, previous analyses and computer derived products. This product is transmitted twice weekly via AUTODIN and JOTSII.

### **7.1.6 Indian Ocean Fronts And Eddies**

This product contains positions and intensities of fronts and eddies in the Arabian Gulf, Gulf of Oman, Red Sea, Northern Indian Ocean and the Bay of Bengal. This product is transmitted twice weekly via AUTODIN and JOTSII.

### **7.1.7 Energy Savings Using Ocean Currents**

This product identifies the geometry and intensity of the Kuroshio Current to aid ships in transiting between the South China Sea and Yokosuka, Japan. This product is derived from the FNMOC model products and transmitted twice weekly via AUTODIN only.

### **7.1.8 Surf Forecasts**

In response to requests from amphibious units, surf forecasts are prepared by the duty watch section. The section will prepare a surf forecast, providing detailed bathymetry near the operating area beaches and required graphic extracts from the Joint Surf Manual.

## **7.2 JTWC PRODUCTS**

Two general types of products are provided by JTWC: routine and tropical cyclone related. The routine products include the Significant Tropical Weather Advisories for the Western Pacific and Indian Oceans. The tropical cyclone products are Tropical Cyclone Formation Alerts, Tropical Cyclone/Tropical Depression Warnings and Prognostic Reasoning Messages.

1. Significant Tropical Weather Advisory -- Issued at 0600Z for the Pacific and 1800Z for the Indian Ocean or more frequently as needed, to describe all tropical disturbances and their potential for further (tropical cyclone) development during the advisory period. For any suspect area mentioned, the words "poor", "fair" or "good" are used to describe the potential for development. "Poor" is used to describe a tropical disturbance in which further development is unlikely during the next 24 hours under the current meteorological conditions, and issuance of a Tropical Cyclone Formation Alert (TCFA) is not anticipated. "Fair" is used to describe a tropical disturbance in which conditions are improving and the issuance of a TCFA is likely within the next 24 hours. "Good" describes a tropical disturbance on which a TCFA is in effect. A separate scheduled bulletin is issued for the Western Pacific and Indian Ocean.
2. Tropical Cyclone Formation Alert (TCFA) -- Issued when synoptic and/or satellite data, or other germane data, indicate the development of a significant tropical cyclone is likely within the next 24 hours in a specified area. A TCFA will specify a valid period not to exceed 24 hours and must be either canceled, reissued or superseded by a warning prior to expiration.
3. Tropical Cyclone / Tropical Depression Warning -- Issued periodically throughout the day to provide forecasts of position, intensity and wind distribution for tropical cyclones within JTWC's AOR. There are two types of warnings: Tropical Cyclone warnings and Tropical Depression warnings.

- a. Tropical Cyclone Warning -- Issued when a closed circulation is evident and maximum sustained winds are forecast to reach 34 kt or greater within 48 hours, or when a tropical cyclone is in such a position that life or property may be endangered within 72 hours. In addition, warnings are issued for the Northwest Pacific when tropical systems reach 25 kt. Each Tropical Cyclone warning is numbered sequentially and includes:
- (1) Current position of the surface center
  - (2) Estimate of the position accuracy and the supporting reconnaissance (fix) platforms
  - (3) Direction and speed of movement during the past six hours (past 12 hours in the Southern Hemisphere)
  - (4) Intensity and radial extent of over 35, 50 and 100-kt surface winds when applicable.

At forecast intervals of 12, 24, 36, 48 and 72 hours (12, 24, 36 and 48 hours in the Southern Hemisphere), information on a tropical cyclone's anticipated position, intensity and wind radii are provided. In addition, vectors indicating the mean direction and mean speed of motion between forecast positions are included in all warnings.

Warnings in the western North Pacific and North Indian Ocean are issued every six hours valid at standard synoptic times of 0000Z, 0600Z, 1200Z and 1800Z. Warnings in the Southern Hemisphere are issued every 12 hours at 0000Z and 1200Z or 0600Z and 1800Z unless U.S. assets are threatened then warnings are issued every six hours with forecasts valid out to 72 hours. All warnings are released to the communications network no earlier than synoptic time and no later than synoptic time plus two and one half hours. This ensures recipients of having all warnings in hand by synoptic time plus three hours (0300Z, 0900Z, 1500Z and 2100Z).

- c. Tropical Depression Warning -- Issued only in the western North Pacific for tropical cyclones that are not expected to reach tropical storm intensity. A Tropical Depression warning is issued under the standard MANOP and contains the same information as a Tropical Cyclone Warning but is only issued every 12 hours at standard synoptic times and only extends to the 36-hour forecast period.
4. Prognostic Reasoning Message -- Issued with the 0000Z and 1200Z TC warnings (0600Z and 1800Z as needed), in the western North Pacific to discuss the forecast rationale for the specific JTWC warning. Prognostic reasoning messages are technical in nature and are prepared for meteorologists to complement each warning. In addition to this message, limited prognostic reasoning information is provided in the remarks section of warnings whenever significant forecast changes are made or when deemed appropriate by the Typhoon Duty Officer (TDO).

Note: JTWC coordinates the transfer of tropical warning responsibility for tropical cyclones entering or exiting its AOR. For tropical cyclones crossing 180° in the North Pacific Ocean, JTWC coordinates with the Central Pacific Hurricane Center (CPHC), Honolulu via Naval Pacific Meteorology and Oceanography Center (NPMOC), Pearl Harbor. For the South Pacific Ocean, JTWC coordinates with NPMOC. In the event JTWC should become incapacitated, the Alternate Joint Typhoon Warning Center (AJTWC), collocated with NPMOC, assumes JTWC's functions. When a tropical cyclone is forecast to become an extratropical cyclone, JTWC coordinates the transfer of warning responsibility with the appropriate Naval Pacific Meteorology and Oceanography Regional Center, which assumes warning responsibilities for the extratropical cyclone.

## 7.2.1 Data

To monitor all tropical weather activity in JTWC's AOR, numerous sources of data are used. The following items make up a comprehensive list of data sources available:

### **7.2.1.1 Conventional**

These data consist of land/ship surface synoptic, buoy, commercial and military aircraft (AIREPS) observations recorded within six hours of synoptic times. These data are hand-plotted and hand analyzed in the tropics for the surface/gradient and 200-mb levels. These analyses are prepared twice daily from 0000Z and 1200Z synoptic data. Also, FNMOC supplies JTWC with computer generated analyses and prognoses (from 0000Z and 1200Z synoptic data) for the surface, 850-mb, 700-mb, 500-mb, 400-mb and 200-mb levels and for the deep layer mean winds. Conventional data are also plotted hourly, or as needed, when tropical cyclones pass near observing stations.

### **7.2.1.2 Computer**

Numerical and statistical guidance and fields are routinely available from FNMOC. Other sources of selected numerical data and fields are available from other sources including: the National Meteorological Center, Japanese Meteorological Agency, Australian Bureau of Meteorology and UK Meteorology Office.

### **7.2.1.3 Meteorological Satellite**

Imagery recorded at USAF/USN ground sites and USN ships provides day and night coverage in JTWC's AOR and is the primary source of tropical cyclone surveillance. Interpretation of imagery provides a TDO with tropical disturbance and tropical cyclone position estimates and estimates of current and forecast intensities (Dvorak, 1984). Tactical satellite sites and AFGWC receive and analyze Special Sensor Microwave/Imagery (SSM/I) data to provide estimates of the radial extent of 35-kt winds near tropical cyclones.

### **7.2.1.4 Radar**

Land-based radar observations (RADOB) are used to position tropical cyclones based on spiral rainband features and/or wall cloud signatures. Once a well-defined tropical cyclone moves within range of radar sites, RADOBs are invaluable for determining tropical cyclone position and motion. Doppler radar's, such as the WSR-88D on Guam, have added a new dimension, radial velocity, to describe the structure of a tropical cyclone. Along the air routes, pilot reports from transiting aircraft, using their airborne radar's, also provide supplemental airborne radar fixes of tropical cyclones.

### **7.2.1.5 Drifting Buoys**

Using Service ARGOS, drifting buoys transmit data to the TIROS-N polar orbiting satellites, which in turn, re-transmit the data. If the satellite is above the horizon, the re-transmission is received and decoded by a Local User Terminal (LUT) located at JTWC. In addition to re-transmissions, all buoy data is stored aboard these satellites for later download to major processing centers. NOAA/NESDIS disseminates these processed data via the Automated Weather Network (AWN) and Global Telecommunications Service (GTS).

### **7.2.1.6 AMOS**

With the cooperation of the Naval Meteorology and Oceanography Command, NOAA and the Department of the Interior a network of 20 Automatic Meteorological Observing Stations (AMOS) sites are planned for Micronesia. These sites have a primary transmission capability to geostationary satellite data collection systems (DCS) with a backup to Service ARGOS on the NOAA polar orbiters. As of 1 January 1996, 11 of the 20 AMOS sites were installed. Additionally, NWS maintains two HANDAR sites on the islands of Rota and Tinian, which uplink data to geostationary DCS, and four HANDAR sites on Guam with landline readouts.

## **7.2.2 Objective Forecast Aids**

JTWC's objective aids are classified into one of four categories. A brief discussion of each aid is listed below:

### **7.2.2.1 Climatological**

This aid uses past motion of the tropical cyclone and average motions of selected historical tropical cyclones without application of any regression analysis to minimize average forecast error for some dependent data set. Applicable JTWC aids are: extrapolation (XTRP), climatology (CLIM) and typhoon analogs (TYAN). TYAN guidance is stratified into two separate outputs. The first output, straight (STRT), is based on all straight-running tracks. The second output, recurver (RCVR), uses only those tropical cyclones that subsequently recurve. CLIM and TYAN use the same historical data bases, but TYAN applies more restriction to which tropical cyclones are selected for producing the forecast.

### **7.2.2.2 Statistical**

The common feature of these aids is regression analysis is used to minimize forecast error for a dependent data set. Usually the 24, 48 and 72-hour forecast positions are the results of regression equations that use various types of measured quantities for input. These inputs may be any combination of parameters from the present tropical cyclone, historical storms, (climatology), synoptic analyses and numerical prognoses. Statistical regression models that use only climatology and past motion of the present tropical cyclone are known as CLIPER-class models (climatology and persistence). JTWC's CLIPER-class model is known as CLIP and is run in every basin in the AOR. Guidance that uses only present storm data and data from synoptic analyses is known as statistical-synoptic models, such as the tropical cyclone acceleration prediction technique (TAPT) which correlates track type and movement with features in the upper-level wind field. Models that use present tropical cyclone data and data from numerical prognoses are called statistical-dynamic. JTWC's Colorado State University Model (CSUM) which is used only in the Northern Hemisphere is a statistical-dynamical model. JTWC92 (JT92) is also a statistical-dynamical model used for the western North Pacific. Based on NOGAPS deep-layer mean flow, five internal sub-models are blended and repeated to produce the final JT92 guidance, which yields tropical cyclone 12-hourly positions out to 72 hours.

### **7.2.2.3 Dynamic**

These aids are based on numerical integration with mathematical equations that approximate the physical behavior of the atmosphere to varying degrees of sophistication. Numerical guidance is derived in two different ways. The most sophisticated approach is to actually track the movement of a tropical cyclone vortex which is either explicitly resolved by or bogussed into a global or regional numerical model. Such guidance is available to JTWC from FNMOC's NOGAPS (NGPS) global model, NGPS vortex tracker (NGPX) and the One-way influence Tropical Cyclone Model (OTCM). NGPS, NPGX and OTCM guidance are available throughout JTWC's AOR. A simpler approach in numerical forecasting is to use either global or numerical model wind fields to compute a steering flow that advects a point vortex. The FNMOC beta and advection model (FBAM) is an operational steering model that uses NGPS deep-layer mean fields to compute steering. In addition, selected guidance is available from the Japanese Meteorological Agency's (JMA) Typhoon Model (JTYM), United Kingdom Meteorological (UKMet) Office at Bracknell (EGRR) and National Meteorological Center (NMC).

### **7.2.2.4 Hybrid**

These aids combine elements of two or more of the above categories. Half persistence and climatology (HPAC) equally weights the forecasts given by XTRP and CLIP. The blended (BLND) aid uses a simple average of JTWC's primary forecast aids: OTCM, CSUM, FBAM, JT92, CLIP and HPAC. Weighted (WGTD) uses the same input as BLND, but performs a weighted average: OTCM (29%), CSUM (22%), FBAM (14%), JT92 (14%), CLIP (7%) and HPAC (14%). The dynamic average (DAVE) aid takes a simple average of the following dynamic guidance: NGPS, OTCM, CSUM, OTCM, JT92, FBAM, EGRR and JTYM. The principal advantages and disadvantages of the four categories of aids follow:

## **1. Climatological**

With the expectation of error in present tropical cyclone position, the principal advantage of these aids is their generally insensitivity to initialization problems caused by insufficient and/or misrepresentative data. The principal disadvantage is, by definition, they can only give the average behavior of tropical cyclones under the conditions specified. That is, climatology can never handle acclimatological situations well. The analog approach attempts to minimize this problem by restricting the historical data base to a small subset that hopefully represents synoptic conditions that are fairly close to those influencing the present tropical cyclone.

## **2. Statistical**

By seeking to minimize the error of some dependent data set, the principal advantage of the statistical aid is it automatically accounts for known and unknown systematic biases caused by data distribution, etc. The principal disadvantage is, like climatology, statistical regression gives forecasts that conform to the average behavior of storms in the dependent data set used in the regression analysis. Again, acclimatological situations are generally not handled well. The statistical-synoptic and statistical-dynamic aids are also subject to the negative influences of erroneous or missing data that affect the dynamic models.

## **3. Dynamic**

The principal advantage is that they are sensitive to the current and future synoptic structure of the atmosphere, as represented by the model, and thus can better handle acclimatological situations. The principal disadvantage of numerical models is their sensitivity to insufficient or erroneous data (typically inducing a "misplaced vortex") which results in forecasts that, even in the short term, are initialized with the wrong direction/speed. Interestingly, the more sophisticated the numerical model is, the more sensitive it is to inaccurate initialization due to data limitations. Also, the more sophisticated the model, the more degrees of freedom it has, and the more rapidly its forecasts can depart from reality due to nonlinear growth of data-induced initialization error. As a result of this weakness, numerical models often have a persistence feature added, to ensure the model vortex at least starts out in the right direction.

## **4. Hybrid**

These aids attempt to capitalize on the strengths of the other types of aids by applying statistical weighting factors based on their past performance.

### **7.2.3 Analysis (Detection)**

The first indication of the formation of a tropical cyclone will vary with the type of system and data available. Satellite data usually provides the first indication of significant tropical cyclone development, even in data rich areas, and are often the only source of detection over many ocean areas.

#### **7.2.3.1 Positioning**

With regard to positioning, in general, it is important to avoid reacting too quickly to apparent radical changes in cyclone direction or speed indicated by the last fix. All positioning methods are accurate only to within certain limits and short term oscillations of a cyclone center about the main track are common. These oscillations may result from the actual "wobble" (trochoidal motion) of the center of the tropical cyclone, or be due to errors in the raw fix data or, a combination of both.

##### **1. Satellite**

Satellite imagery provides the primary source of tropical cyclone fixes. Land radar, synoptic and airborne radar on transiting aircraft are secondary sources. Each satellite derived tropical cyclone position is assigned a Position Code Number (PCN) which is a measure of the positioning confidence. The PCN is determined by a combination of the availability of visible landmarks in the image that can be used as references for precise gridding of the image and the degree of organization of the tropical cyclones cloud system. In the absence of any noted landmass features, the satellite nodal point is used for gridding which is not nearly as accurate as land mass gridding.

## 2. Radar

Radar positions of tropical cyclone centers are very reliable when a cyclone is within a radar stations range of coverage and the rainbands are well organized. However, the accuracy of radar fixes for well defined cyclones, or for cyclones with poorly defined rainbands, should be expected to decrease as the radar range increases.

## 3. Synoptic Reports

Synoptic reports are of great value if the tropical cyclone passes over, or very near, a land station, buoy or ship. Center fixes constructed using synoptic data that is displaced from the center of tropical cyclone are usually not very accurate. Transiting aircraft can provide airborne radar fixes when the tropical cyclone is near their flight path.

## 4. Extrapolation

Extrapolation becomes the basis for the warning only if no fixes are available for 6 hours before the starting valid time for the warning.

### 7.2.3.2 Intensity

For tropical cyclones in JTWC's AOR, satellite intensity measurements are frequently the only data available. These estimates are based on the Dvorak (1984) technique. The Dvorak intensity estimation technique provides a good estimate of the current intensity of a tropical cyclone, and involves procedures and rules which combine meteorological analysis of satellite imagery with a model of expected tropical cyclone development. The current intensity follows from the final [T-number](#). The current intensity relates to a maximum sustained 1-minute mean surface wind and return a minimum sea-level pressure.

### 7.2.3.3 Wind Radii

The analysis of a tropical cyclones wind radii is accomplished using a combination of conventional and satellite data. The usefulness of conventional land buoy and ship surface observations are generally limited to helping define the 35-kt radius, due to the sparsity of the observation sites and low probability of any given tropical cyclone passing very near a reporting point. Special Sensor Microwave Imagery (SSM/I) data may also be available to assist in further defining the 35-kt radius, depending on tropical cyclones location and polar orbiter satellite coverage. Additionally, scatterometer data from the European Space Agency's (ESA) Remote Sensing Satellite (ERS) provides surface wind vectors over the ocean areas. The upper limit for both the SSM/I and ERS wind speed is 50 kt. Conventional surface observations may occasionally assist in defining the 50-kt or greater wind radii. For tropical cyclones for which the Dvorak intensity analysis exceeds 100 knots, the 100-kt wind radius is inferred from the satellite-based estimation of eye size.

## 7.2.4 Forecasting

### 7.2.4.1 Track

In preparing the JTWC official forecast, the TDO evaluates a wide variety of information and employs a number of objective and subjective techniques. Because tropical cyclone track forecasting has and continues to require a significant amount of subjective input from the TDO, detailed aspects of the forecast-development process will vary somewhat from TDO to TDO, particularly with respect to the weight given to any of the available guidance. JTWC uses a standardized, three-phase tropical cyclone motion forecasting process to improve not only track forecast accuracy, but also intensity forecast accuracy and forecast-to-forecast consistency.

#### 1. Field Analysis Phase

NOGAPS analyses and prognoses at various levels are evaluated for position, development, and movement of not only the tropical cyclone, but also relevant synoptic features such as:

- subtropical ridge circulations

- mid-latitude short/long-wave troughs and associated weaknesses in the subtropical ridge
- monsoon surges
- cyclonic cells in the Tropical Upper-Tropospheric Trough (TUTT)
- other tropical cyclones
- the distribution of sea surface temperature.

This process permits the TDO to develop an initial impression of the environmental steering influences to which the tropical cyclone is and will be subjected to as depicted by NOGAPS. The NOGAPS analyses are then compared to the hand-plotted and analyzed charts prepared by the TDO and to the latest satellite imagery in order to determine how well the NOGAPS-initialization process has conformed to the available synoptic data and how well the resultant analysis fields agree with the synoptic situation inferred from the imagery. Finally, the TDO compares both the computer and hand-analyzed charts to monthly climatology in order to make a preliminary determination of to what degree the tropical cyclone is, and will continue to be, subjected to a climatological or non-climatological synoptic environment. Noting latitudinal and longitudinal displacements of the subtropical ridge and long-wave midlatitude features is of particular importance and will partially determine the relative weights given to climatologically- or dynamically-based objective forecast guidance.

## **2. Objective Techniques Analysis Phase**

By applying the guidance of the "Systematic and Integrated Approach"(Carr and Elsberry, 1994), the TDO can relate the latest set of guidance given by JTWC's suite of objective techniques with the NOGAPS model prognoses and currently observed meteorological conditions. This allows the TDO to evaluate the objective techniques guidance to the following principles. First, the degree to which the current situation is considered to be, and will continue to be, climatological is further refined by comparing the forecasts of the climatology-based objective techniques, dynamically-based techniques, and past motion of the present storm. This assessment partially determines the relative weighting given the different classes of objective techniques. Second, the spread of the set of objective forecasts, when plotted, is used to provide a measure of the predictability of subsequent motion, and the advisability of including a moderate probability alternate forecast scenario in the prognostic reasoning message or warning (outside the western North Pacific). The directional spread of the plotted objective techniques is typically small well-before or well-after recurvature (providing high forecast confidence), and is typically large near the decision-point of recurvature or non-recurvature, or during a quasi-stationary or erratic movement phase. A large spread increases the likelihood of alternate forecast scenarios.

## **3. Construct Forecast Phase**

The TDO then constructs the JTWC official forecast giving due consideration to the: 1) extent to which the synoptic situation is, and is expected to remain, climatological; 2) past statistical performance of the various objective techniques on the current storm; and 3) known properties of individual objective techniques given the present synoptic situation or geographic location. The following guidance for weighting the objective techniques is applied:

- a. Weight persistence strongly in the first 12 to 24 hours of the forecast period.
- b. Give significant weight to the last JTWC forecast at all forecast times, unless there is significant evidence to warrant a departure. (Also consider the latest forecasts from regional warning centers, if applicable.)
- c. Give more weight to the techniques that have been performing well on the current tropical cyclone and/or are expected to perform well in the current and anticipated synoptic situations.
- d. Stay within the "envelope" determined by the spread of objective techniques forecasts unless there is a strong specific reason for not doing so (e.g., all objective forecasts start out at a significant angle relative to past motion of the current tropical cyclone).
- e. Apply the "Systematic and Integrated Approach" (Carr and Elsberry, 1994), using conceptual models of recurving, dynamically-related meteorological patterns with the traits of the numerical and objective aid guidance associated with the specific synoptic situation.

### **7.2.4.2 Intensity**

The empirically derived Dvorak (1984) technique is used as a first guess for the intensity forecast. The TDO then adjusts the forecast after evaluating climatology and the synoptic situation. An interactive conditional climatology scheme allows the TDO to define a situation similar to the system being forecast in terms of location, time of year, current intensity and intensity trend. Synoptic influences such as the location of major troughs and ridges, and the position and intensity of the TUTT all play a large part in intensifying or weakening a tropical cyclone. JTWC incorporates a checklist into the intensity forecast procedure. Such criteria as upper-level outflow patterns, neutral points, sea-surface temperatures, enhanced monsoonal or cross-equatorial flow and vertical wind shear are evaluated for their tendency to enhance or inhibit normal development, and are incorporated into the intensity forecast process through locally developed thumb rules. In addition to climatology and synoptic influences, the first guess is modified for interactions with land, other tropical cyclones and extratropical features. Climatological and statistical methods are also used to assess the potential for rapid intensification (Mundell, 1990).

### **7.2.4.3 Wind Radii**

Since the loss of dedicated aircraft reconnaissance in 1987, JTWC has turned to other data sources for determining the radii of winds around tropical cyclones. The determination of wind radii forecasts is a three-step process:

1. First, low-level satellite drift winds, SSM/I 35-kt wind speed analysis and synoptic data are used to derive the current wind distribution.
2. Next the first guess of the radii is determined from statistically-derived empirical wind radii models. JTWC currently used three models: the Tsui model, the Huntley model, and the Martin-Holland model. The latter model uses satellite-derived parameters to determine the size and shape of the wind profile associated with a particular tropical cyclone. The Martin-Holland model also incorporates latitude and speed of motion to produce an asymmetrical wind distribution. These models provide wind distribution analyses and forecasts that are primarily influenced by the intensity forecasts. The analyses are then adjusted based on the actual analysis from step 1. and the forecasts are adjusted appropriately.
3. Finally, synoptic considerations, such as the interaction of the cyclone with mid-latitude high pressure cells, are used to fine-tune the forecast wind radii.