## 3.3 JTWC Forecasting Philosophies

Forecasters in the Philippine Islands and at JTWC are deeply interested in the formation, movement and intensity of tropical cyclones. The environmental conditions used to forecast these three features are now described.

### 3.3.1 Formation

Using satellite and conventional data, the forecaster can anticipate the formation of a tropical cyclone by being alert to the existence of the following necessary, but not sufficient conditions (Elsberry et al. 1987):

- Sea surface temperature $\geq$26.5°C.
- Large sustained cloud clusters identified by satellite, indicating weak vertical wind shear and large mid-level moisture.
- Low-level cyclonic circulation, identified by synoptic reports or satellite imagery.
    1. This feature is enhanced by the commencement of the Southern Hemisphere winter which provides low-level cross-equatorial southerly winds which are deflected to the right to become the westerly flow providing the cyclonic shear with the easterly trade winds located to the north. The area identified by this cyclonic shear is commonly called the monsoon trough.
    2. Residual cyclonic shear associated with an equatorward moving front (or shear line) may also provide the low-level circulation or cyclonic shear.
- Mean upward motion in the vicinity of the disturbance. This condition may be identified by anticyclonically curved cirrus on satellite imagery. As identified in the southwest monsoon section, the tropical upper tropospheric trough (TUTT) is often present over the Pacific Ocean near 200 mb. Cyclonic centers, "cells", within the TUTT, often have diffluent flow, immediately to their east, providing the needed divergence aloft.

### 3.3.2 Movement

The task of separating the tropical cyclones that move straight toward the west or northwest before making landfall in Asia from the tropical cyclones that recurve[5] toward the northeast (i.e., come under the steering of the mid-latitude "westerlies") is a very difficult task, indeed.

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[5] Convention dictates that TCs undergoing even their first change of direction into the mid-latitude westerlies, i.e., their direction of movement changes from NW to N to NE (poleward of the axis of the mid-tropospheric subtropical ridge), be called "recurvers".

- Most TCs have their genesis within the monsoon or near-equatorial trough, and are initially transported (or steered) in a generally westward or north-westward direction. This drift toward the northwest can be shown to be the result of the variation of the Coriolis Parameter[6] with latitude (known as the "beta"-effect[7]), but will not be discussed here.

- However, as the TC drifts farther poleward, it crosses the axis of the subtropical ridge or moves around the western periphery of the subtropical ridge, and then is steered (or advected) by the flow in the mid-tropospheric "westerlies".

- Whenever synoptic-scale troughs from the mid-latitudes (or extratropics) extend equatorward (or disrupts the dominance of the subtropical ridge), then the embedded TC is expected to be steered—at least initially—more northward, and eventually with an eastward component. The approach of an extratropical trough (normally from the west) can be forecast by synoptic experience, judgement, and satellite interpretation, but most often the forecaster relies upon the prognoses of numerical models to predict the position of the troughs, especially in 36, 48 and 72 hours .

- Even in the absence of an identifiable approaching upper-level trough, the forecaster is often presented with a prognosis of a numerical model which depicts the retreat of the subtropical ridge to the east (a condition that might prompt the forecast of "recurvature") or of the penetration of the subtropical ridge farther westward (a condition that would suggest that the TC follows a straighter track).

- As discussed in the formation section above, TCs often form within the monsoon trough. This trough normally lies on an axis from near the central Philippines (the Visayas) extending toward the southeast. Subsequently, vortices developing along this axis typically move toward the northwest, in the direction of the PI. However, during the northern hemisphere summer there are periods when the monsoon axis rotates counterclockwise, and thus lies on an axis extending northeastward from the Visayas. Tropical cyclones developing in this anomalously oriented monsoon trough frequently move initially toward the northeast, and thus are often to the north of the PI before commencing their movement toward the northwest (Mark Lander (1990, personal communication)). In addition, in August the monsoon trough generally moves northward with the sun, leading to cyclone development north of the Philippine Islands.

- The Typhoon Duty Officers (TDOs) at JTWC are provided with movement objective aids displayed in Table 3.2. In combination with the $\beta$-effect, the last three aids in the table provide the option of using steering from deep or shallow layers.

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[6] Coriolis Parameter, $f = 2 \cdot \Omega \cdot sin\phi$ where: $\Omega =$ Earth's rotation rate and $\phi =$ °Latitude.

[7] Beta $= \beta = \partial f / \partial y$.

Table 3.2: Summary of JTWC Objective Aids.(U. S. NOCC/JTWC, 1992)

| TYPE | NAME | DESCRIPTION |
|---|---|---|
| Persistence | XTRP | Extrapolation based on past 12-h motion. |
| Climatology | CLIM | Average storm motion based on all storms within seasonal and spatial windows. |
| Half Persistence and Climatology | HPAC | Simple interpolaton between forecast position of XTRP and CLIM. |
| Analog | TOTL | Average of tracks for all tropical cyclones matching current tropical cyclone with respect to position, time of year, past motion, and current intensity. |
| Analog | RECR | Same as TOTL, except only for recurving TC. |
| Statistical | CLIP | Regression equations based on persistence and climatology. |
| Statistical-Dynamic | CSUM | Regression equations for 24-h motion using surface pressure, 500- and 200-hPa heights at various positions relative to the tropical cyclone as predictors. Separate equations for tropical cyclone motion based on the recent direction of track. |
| Dynamic | OTCM | Primitive equation numerical model with three layers, 205-km grid, and one-way influence boundary conditions provided at 12-h interval from NOGAPS prognostic fields. |
| Dynamic | FBAM | NOGAPS deep-layer mean steering (1000-100 hPa) plus empirically derived propagation due to the beta effect. |
| Dynamic | MBAM | Same as FBAM, but with steering computed over 850–500-hPa layer. |
| Dynamic | SBAM | Same as FBAM, but with steering computed over 850–700-hPa layer. |

**NOTE**: (1) The pressure unit "hPa" stands for hecto-Pascal (100 Pascal) and is equal to a millibar (mb). (2) NOGAPS (Navy Operational Global Atmospheric Prediction System) will be discussed in following section. (3) After 1992, refer to the latest JTWC Annual Tropical Cyclone Report for newly-developed objective aids.

- There is a documented reaction between tropical cyclones that are $\leq$750 n.mi. apart. This effect, known as the Fujiwhara effect, and more recently as binary interaction, is often visible as the weaker tropical cyclone is steered cyclonically around the stronger. The effect upon equally strong TCs is more easily perceived when their positions are plotted relative to the mid-point (or "centroid") on the line connecting the two tropical cyclones. Both TCs will then exhibit a component of motion cyclonically around the centroid. (JTWC has developed a computer program to calculate the degree of the Fujiwhara effect and to provide a CLIPER-like forecast of the resultant typhoon track.)

- Unfortunately, the forecasters of tropical cyclone motion must accept the existence of TCs that exhibit large directional changes in motion over short periods of time. These cyclones represent a small percentage of the total; however, they may change direction or loop, often several times. Fortunately, the subtropical ridge is typically located north of the Philippine Islands, providing TC movement in a general westward direction. However, this does not negate the possibility of a looper over the Luzon Strait, the South China Sea or wherever!

### 3.3.3 Intensity

The evolution of the intensity (maximum one-minute sustained winds) of a tropical cyclone, while often "normal" in its developing or weakening, can also be erratic and difficult to forecast, as well as to analyze. Since the U. S. Air Force ceased aircraft reconnaissance flights in 1987 (the U. S. Navy had ceased its operations in 1971), JTWC must primarily use satellite imagery to determine tropical cyclone intensity. (Satellite imagery is also the primary tool for determining location, although limited radar reports and synoptic observations provide a minimal, but important, contribution.)

- Forecasters having satellite imagery—preferably enhanced infrared (IR) imagery—available can perform their own wind analysis/forecast using the Dvorak technique. The technique uses both visible and IR cloud feature measurements and rules based on a model of tropical cyclone development to arrive at the current and 24-hour intensity of the TC. For example, the model would describe a normally developing tropical cyclone as having a T-number (Tropical number) T1 on day one, T2 on day two, etc. After the analyst has determined the final T-number, rules assist the analyst in the determination of a Current Intensity (CI) number (see Table 3.3 for the empirical relationship between the Current Intensity number (CI) and the maximum wind speed (MWS) for tropical cyclones in the western North Pacific Ocean). The Dvorak technique dictates that the T-number and CI number be the same for developing or steady TCs. However, the CI is held higher than the T-number while a cyclone is weakening. This scheme is used because a lag is observed between the time a TC pattern indicates that weakening has begun and the time when the storm's intensity has actually decreased, i.e., the surface wind (spin or momentum) of the TC continues at the higher magnitude, even though the satellite signature (from above) indicates its initial weakening. In practice, the CI number is not lowered until the T-number has shown weakening for at least 12 hours. The Dvorak technique uses many features of the TC's satellite signature: Enhanced IR image (EIR): the spiral arc distance of the curved band surrounding the center, temperature of the eye and of the surrounding cloud tops, the presence of an upper-level "shear" cloud signature, the presence of a "central cold cover" pattern, etc. Visible image: the spiral arc distance of the surrounding curved band, the embedded distance of the eye, the presence of a central dense overcast (CDO), measurements of central features and the (outer) banding features, etc. The EIR technique requires less subjective judgment than the visible technique, and the EIR imagery is available continuously—not just during daylight hours. However, the visual data is used to monitor situations where the EIR technique has weaknesses and may significantly misrepresent intensity. The Dvorak technique is designed for a typical daily rate of development, increasing by one T-number per day. However, depending upon environmental conditions, the rate may be rapid (~ 1.5 T-number per day) or slow (~ 0.5 T-number per day).

Table 3.3: Current Intensity (CI) Number. The relationship between the current intensity number (CI), the maximum wind speed (MWS) and the minimum sea level pressure (MSLP) in TCs (adapted from Dvorak 1984)

| CI Number | MWS (Kt) | MSLP (NW PACIFIC) | TROPICAL CYCLONE CLASSIFICATION |
|---|---|---|---|
| 1 | 25 kt | | TD |
| 1.5 | 25 kt | | |
| 2 | 30 kt | 1000 mb | |
| 2.5 | 35 kt | 997 mb | TS |
| 3 | 45 kt | 991 mb | |
| 3.5 | 55 kt | 984 mb | |
| 4 | 65 kt | 976 mb | TY |
| 4.5 | 77 kt | 966 mb | |
| 5 | 90 kt | 954 mb | |
| 5.5 | 102 kt | 941 mb | |
| 6 | 115 kt | 927 mb | |
| 6.5 | 127 kt | 914 mb | ST |
| 7 | 140 kt | 898 mb | |
| 7.5 | 155 kt | 879 mb | |
| 8 | 170 kt | 858 mb | |

Obviously, allowance must be made for long-lived TCs whose history extend beyond the typical development period of 4–6 days. While a complete description of the Dvorak Technique cannot be given in this handbook, interested forecasters are referred to Dvorak (1984). Below are two examples of Dvorak classifications included in TPPN bulletins:

T4.0/4.0/D1.0/24hrs

Decoded: T-number = 4.0, CI number = 4.0 (65 kt, typhoon, see Table 3.3)
Indication of ongoing change (BLANK), i.e., past trend continuing
D = Developing (Past change), 1.0 = Amount of past change, +1.0 T-number
24 hrs = hours since previous observation.

T5.0/6.0MINUS/W1.5/24hrs

Decoded: T-number = 5.0, CI number = 6.0 (115 kt, typhoon)
MINUS = Rapid weakening (Indication of ongoing change)
W = Weakening (Past change), 1.5 = Amount of past change, -1.5 T-number
24 hrs = hours since previous observation.

- The following are environmental conditions expected to increase the intensity of the maximum sustained winds of a tropical cyclone.

  1. Colder tops in the clouds surrounding the TC center and/or warmer eye temperatures (Dvorak 1984). These conditions indicate greater convection (upward vertical motion) in the towers surrounding the TC center and greater subsidence into the eye of the TC.
  2. Larger spiral arc distance of the curved band around the TC (Dvorak 1984).
  3. The TC enters a region of increased diffluence aloft. This is often indicated by the presence of multiple outflow channels, i.e., the greater outflow of mass aloft leads to a larger fall in the sea level pressure at the TC's surface center further leading to larger magnitude inflow (larger winds) at the surface. The multiple outflow channels are often directed toward cyclonic cells in nearby branches of a TUTT.
  4. The TC approaches a region of weaker vertical wind shear.
  5. The TCs exits a land area and begins a track over water with its associated smaller surface friction and added latent (and sensible) heat to fuel the tropical cyclone.
  6. The TC enters an oceanic area with a higher sea surface temperature (SST), thus experiencing additional availability of latent and sensible heat.

7. The TC departs a large-scale area of low-level stratus or stratocumulus clouds. This would generally indicate that the TC is leaving a region of lower SST and atmospheric subsidence—this situation is more common in the eastern North Pacific where colder SST is found.

- The following are environmental conditions expected to decrease the intensity of the maximum sustained winds of a tropical cyclone.

  1. Warmer tops in the clouds surrounding the TC center and/or colder eye temperatures (Dvorak 1984). These conditions indicate less convection (less upward vertical motion) in the towers surrounding the TC center and less subsidence into the eye of the TC.
  2. Smaller spiral arc distance of the curved band around the TC center (Dvorak 1984).
  3. The TC approaches a region of larger vertical wind shear. This may happen in the tropics, but is most common when the TC moves poleward and approaches the jet streams of the extratropics. It may also be manifested by southward-moving cirrus appearing less than 10° latitude to the north or west of the storm or a broadscale cyclonically curved cloud band within 25° latitude of a westward moving disturbance (or TC) (Dvorak 1984).
  4. The TC enters a region of decreased diffluence (or a region of increased confluence) aloft. This is often associated with the condition of larger vertical wind shear, i.e., the outflow reduces to one unidirection channel or the efficiency of outflow channels is decreased.
  5. The TC approaches land with its associated increase in surface friction and latent and sensible heat loss.
  6. The TC enters an oceanic area with a lower sea surface temperature (SST) thus experiencing a loss of latent heat.
  7. The TC enters an area of low-level stratus or stratocumulus clouds, which is often associated with colder SST and greater low-level stability.
  8. The TC begins to draw in cooler and dryer environmental air. However, as the colder air reaches the eyewall region, it can increase baroclinicity across the eyewall, causing a large but short-lived intensification (Guard 1992, personal communication).