天 氣 學 二
(Synoptic Meteorology II)

上課時間: 10:20～12:10 Wednesday, B105

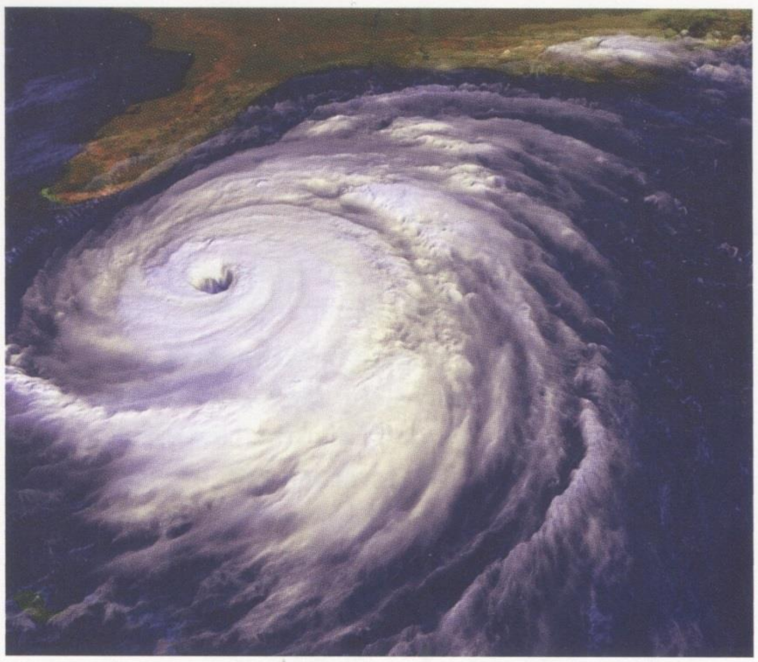
授課教師: 游政谷

email: yuku@ntu.edu.tw

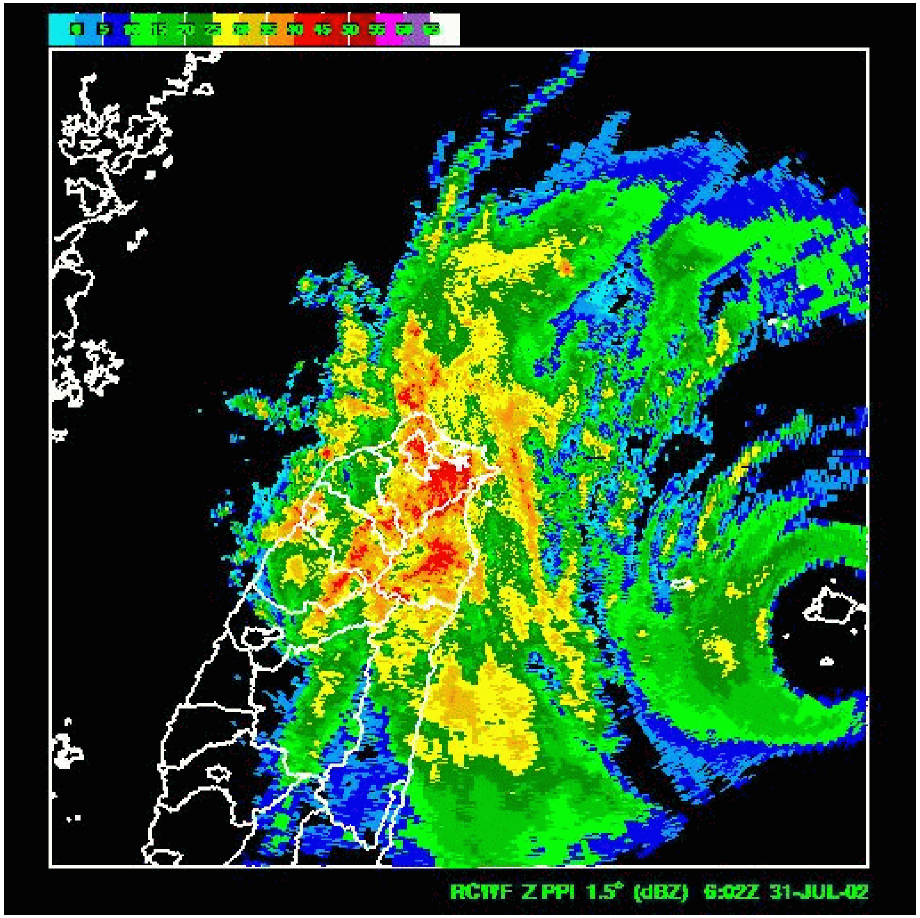
Chapter 3 Tropical Cyclones

3.1 Introduction

Definition: A cyclone that originates over the tropical oceans



The cloud pattern associated with Hurricane Floyd September 14, 1999. The eye of the hurricane is clearly visible. The radius of the associated cloud system is ~600 km. Data from NOAA GOES satellite imagery. [Photograph courtesy of Harold F. Pierce, Laboratory of Atmosphere, NASA Goddard Space Flight Center.]



Animation of radar echoes
for Typhoon Herb (1996)

TABLE 1.1. **Natural disasters (1964–1978) (Compiled from Encyclopaedia Britannica by Southern, 1979).**

Disaster	Total deaths in 14 years	Greatest single event
Tropical cyclones	416 972	300 000 (Bangladesh, 1970)
Earthquakes and tidal waves	195 328	66 794 (Peru, 1969)
Floods	26 724	8000 (S. Vietnam, 1964)
Tornadoes, severe local storms	4062	540 (Bangladesh, 1969)
Avalanches and landslides	5790	1450 (Peru, 1974)
Volcanic eruptions	2572	2000 (Zaire, 1973)
Extratropical cyclones	1860	166 (USA, 1966)
Heat (cold) waves	505	291 (India, 1973)

The 80–100 tropical cyclones that occur each year cause an average number of 20 000 deaths and a total economic loss of $6–7 billion (Southern, 1979). Table 1.1 compares the deaths caused by tropical cyclones with deaths caused by other natural disasters during the period 1964–78 as chronicled in the annual books of Encyclopaedia Britannica (Southern, 1979). Tropical cyclones were far ahead of any other disaster as killers, accounting for about 64% of the total lives lost. Individual tropical cyclones are capable of causing catastrophic losses of life, as shown in Table 1.2.

Look at how AMS Glossary of Meteorology introduces tropical cyclones

tropical cyclone

The general term for a cyclone that originates over the tropical oceans.

This term encompasses **tropical depressions, tropical storms, hurricanes, and typhoons**. At maturity, the tropical cyclone is one of the most intense and feared storms of the world; winds exceeding 90 m s^{-1}(175 knots) have been measured, and its rains are torrential. Tropical cyclones are initiated by a large variety of disturbances, including easterly waves and monsoon troughs. Once formed, they are maintained by the extraction of latent heat from the ocean at high temperature and heat export at the low temperatures of the tropical upper troposphere. After formation, tropical cyclones usually move to the west and generally slightly poleward, then may "recurve," that is, move into the midlatitude westerlies and back toward the east. Not all tropical cyclones recurve. Many dissipate after entering a continent in the Tropics, and a smaller number die over the tropical oceans. Tropical cyclones are more nearly circularly symmetric than are frontal cyclones. Fully mature tropical cyclones range in **diameter from 100 to well over 1000 km**. The surface winds spiral inward cyclonically, becoming more nearly circular near the center. The wind field pattern is that of a circularly symmetric spiral added to a straight current in the direction of propagation of the cyclone. The winds do not converge toward a point but rather become, ultimately, roughly tangent to a circle bounding the eye of the storm. Pressure gradients, and resulting winds, are nearly always much stronger than those of extratropical storms. The cloud and rain patterns vary from storm to storm, but in general there are spiral bands in the outer vortex, while the most intense rain and winds occur in the eyewall. Occasionally, multiple eyewalls occur and evolve through a concentric eyewall cycle. Tropical cyclones are experienced in several areas of the world. In general, they form over the tropical oceans (except the South Atlantic and the eastern South Pacific) and affect the eastern and equatorward portions of the continents. They occur in the tropical North Atlantic (including the Caribbean Sea and Gulf of Mexico), the North Pacific off the west coast of Mexico and occasionally as far west as Hawaii, the western North Pacific (including the Philippine Islands and the China Sea), the Bay of Bengal and the Arabian Sea, the southern Indian Ocean off the coasts of Madagascar and the northwest coast of Australia, and the South Pacific Ocean from the east coast of Australia to about 140°W. By international agreement, tropical cyclones have been classified according to their intensity as follows: 1) tropical depression, with winds up to 17 m s^{-1}(34 knots); 2) tropical storm, with winds of 18–32 m s^{-1}(35–64 knots); and 3) severe tropical cyclone, hurricane or typhoon, with winds of 33 m s^{-1}(65 knots) or higher. It should be noted that the wind speeds referred to above are 10-min average wind speeds at standard anemometer level (10 m), except that in the United States, 1-min average wind speeds are used.

Locations and tracks of tropical cyclones during 1970-1989

Yellow shading indicates regions with SST > 26.5 ^{o}C

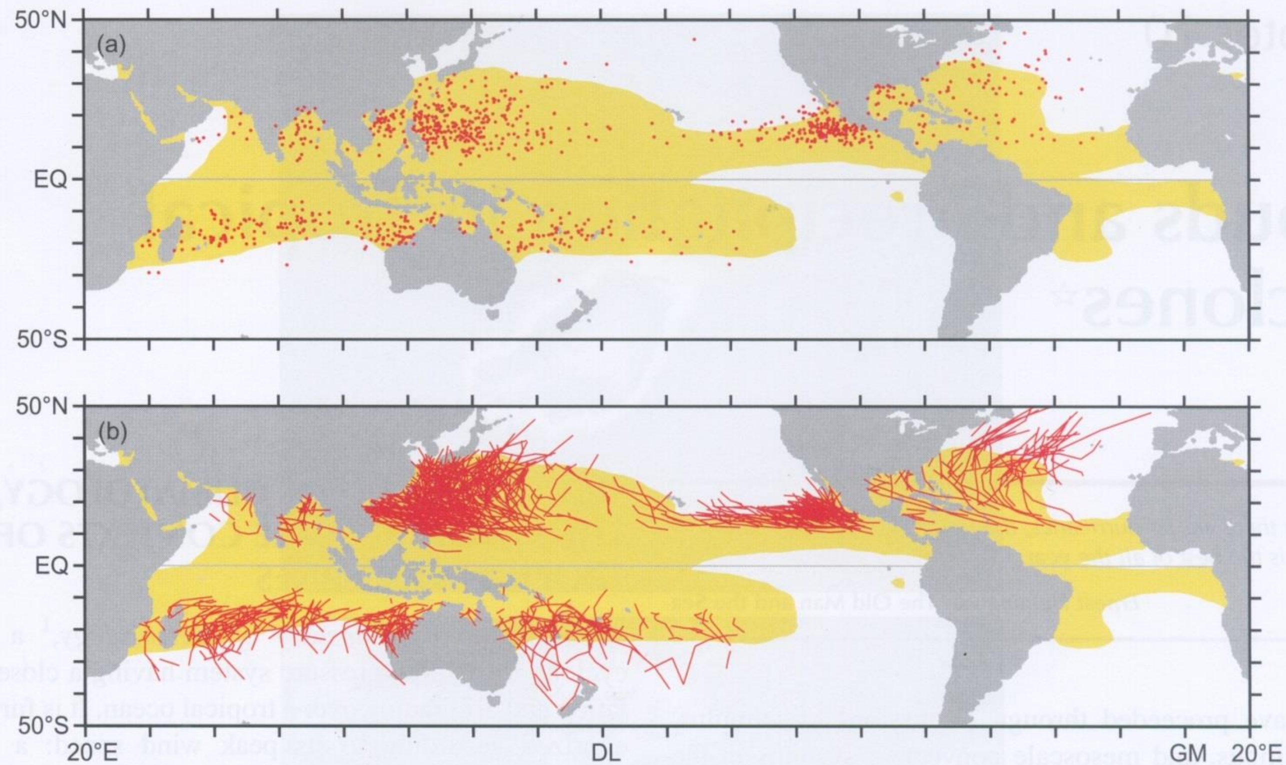


FIGURE 10.1 Locations and tracks of tropical cyclones for the years 1970–1989 relative to the global surface temperature analysis of Legates and Willmott (1990). (a) Locations of tropical cyclones on the first day with tropical cyclone force winds (> 32 m s^{-1}). (b) Tracks of tropical cyclones. The yellow shaded oceanic regions are where SST exceeds 26.5 °C in summertime, represented by August in the Northern Hemisphere and February in the Southern Hemisphere. *Figure created by T. Mitchell and published in Houze (2010). Republished with permission of the American Meteorological Society.*

1. Tropical cyclones do not form within 4-5^{o} of the Equator
2. The majority forms in the zone between 10^{o} and 20^{o} of the Equator
3. Roughly 80 tropical cyclones form each year
4. Existence of a threshold SST for the formation of tropical cyclones
5. Absence of tropical cyclones in the South Atlantic and eastern South Pacific

Physical parameters related to tropical cyclogenesis (Gray 1968; 1979) include:

1. Sea surface temperature and depth of warm water

2. Degree of convective instability

3. Middle tropospheric relative humidity

4. Low-level absolute vorticity

5. Vertical shear of the horizontal wind

6. Interaction of the disturbance with the larger scale tropical circulation or with itself through nonlinear processes

These parameters are not all independent; for example, the first three parameters are relevant to each other

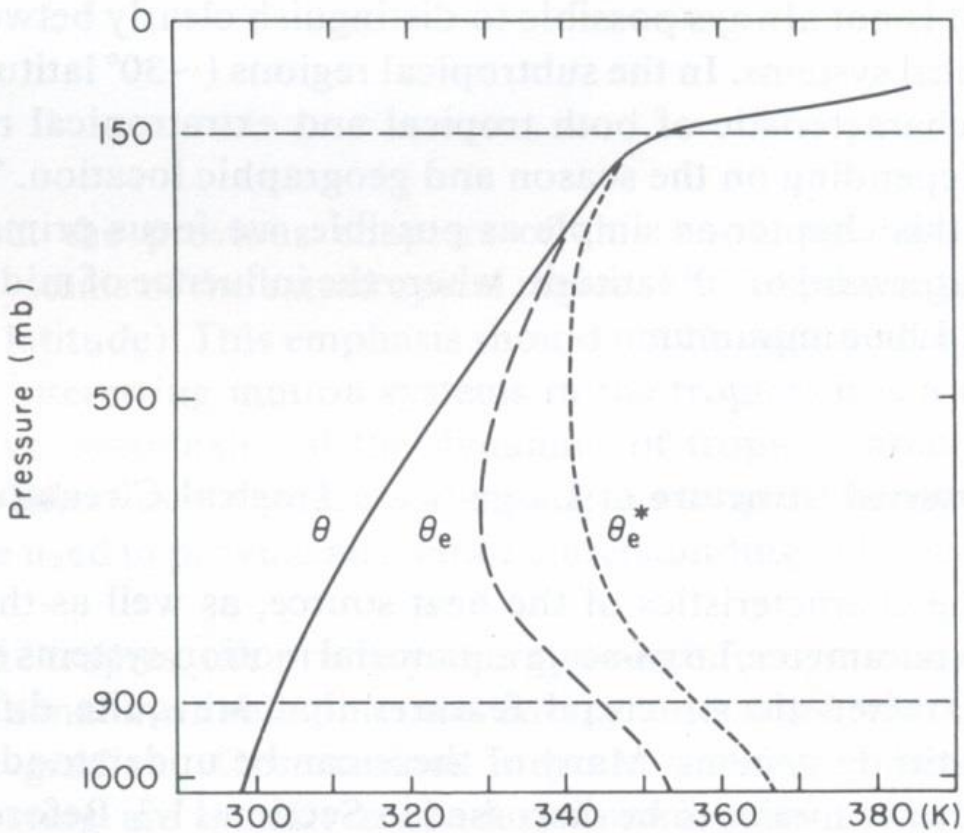
1. Sea surface temperature and depth of warm water

- Saturation vapor pressure increases with temperature
- It is not obvious why there should be such a sharp cutoff in formation at 26.5 ^{o}C
- Why should no storms form with SST below 26.5 ^{o}C

2. Degree of convective instability

- Tropical atmosphere is generally convectively unstable in both winter and summer
- Daily variations of convective instability are small and apparently unrelated to individual cases of cyclogenesis
- As long as instability exists, the intensity and properties of cumulus convection are correlated with other parameters

Typical sounding in the tropical atmosphere



Typical sounding in the tropical atmosphere showing the vertical profiles of potential temperature θ, equivalent potential temperature θ_e, and the equivalent potential temperature θ_e^* of a hypothetically saturated atmosphere with the same temperature at each level. This figure should be compared with Fig. 9.10, which shows similar profiles for a midlatitude squall line sounding. (After Ooyama, 1969. Reproduced with permission of the American Meteorological Society.)

3. Middle tropospheric relative humidity

- Regions with low relative humidities in the middle troposphere are unfavorable for tropical cyclogenesis. Why?
- This parameter does not differ significantly in convective systems which intensify into tropical cyclones and those which do not

4. Low-level absolute (relative) vorticity

- A strong positive correlation between the location of tropical cyclones and large values of low-level relative vorticity
- Rotational flow can be generated by convection more efficiently over regions with larger vorticity
- Surface friction produced upward motion in regions of positive vorticity

Relative vorticity at ~950 mb for July-September

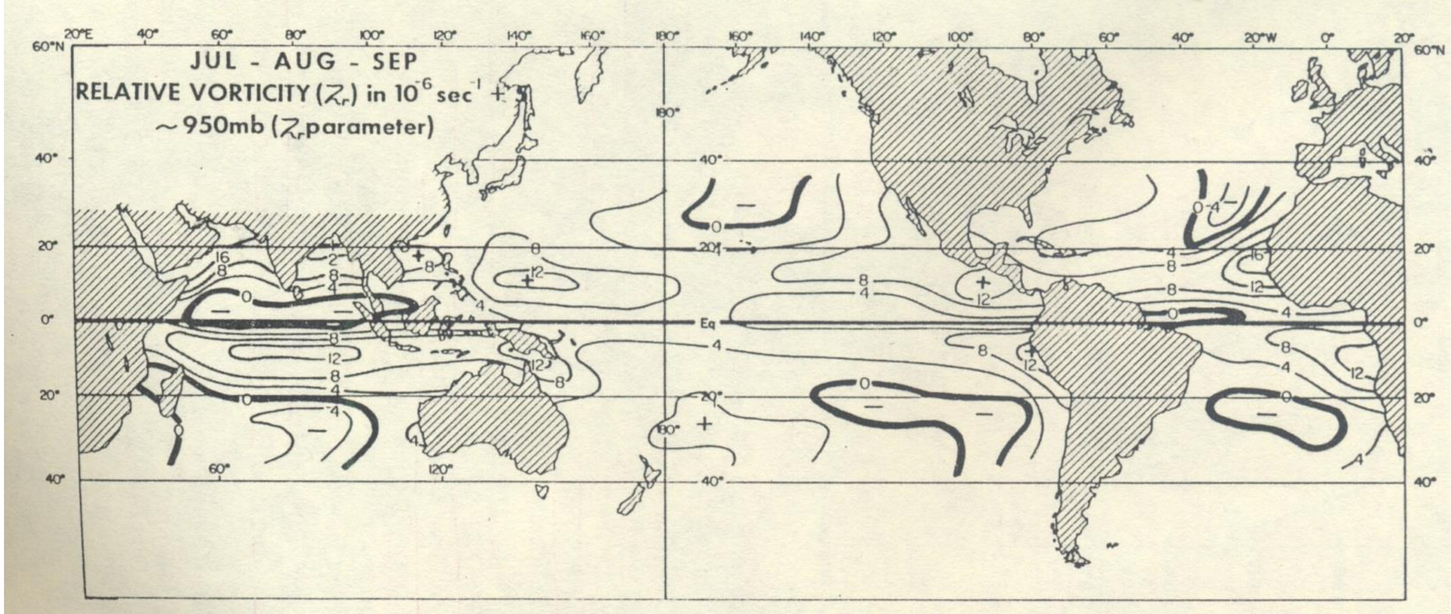
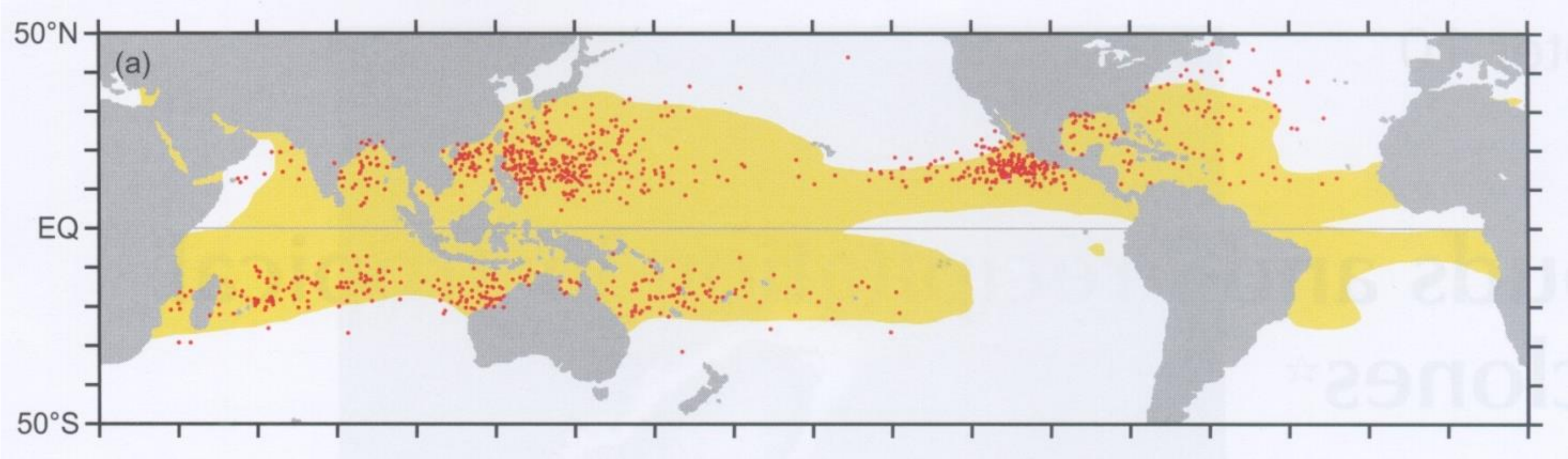


FIG. 2.25. Relative vorticity at approximately 950 mb for July–September (Gray, 1979).



The time required to reach a hurricane vorticity value from initial values of vorticity and a constant divergence

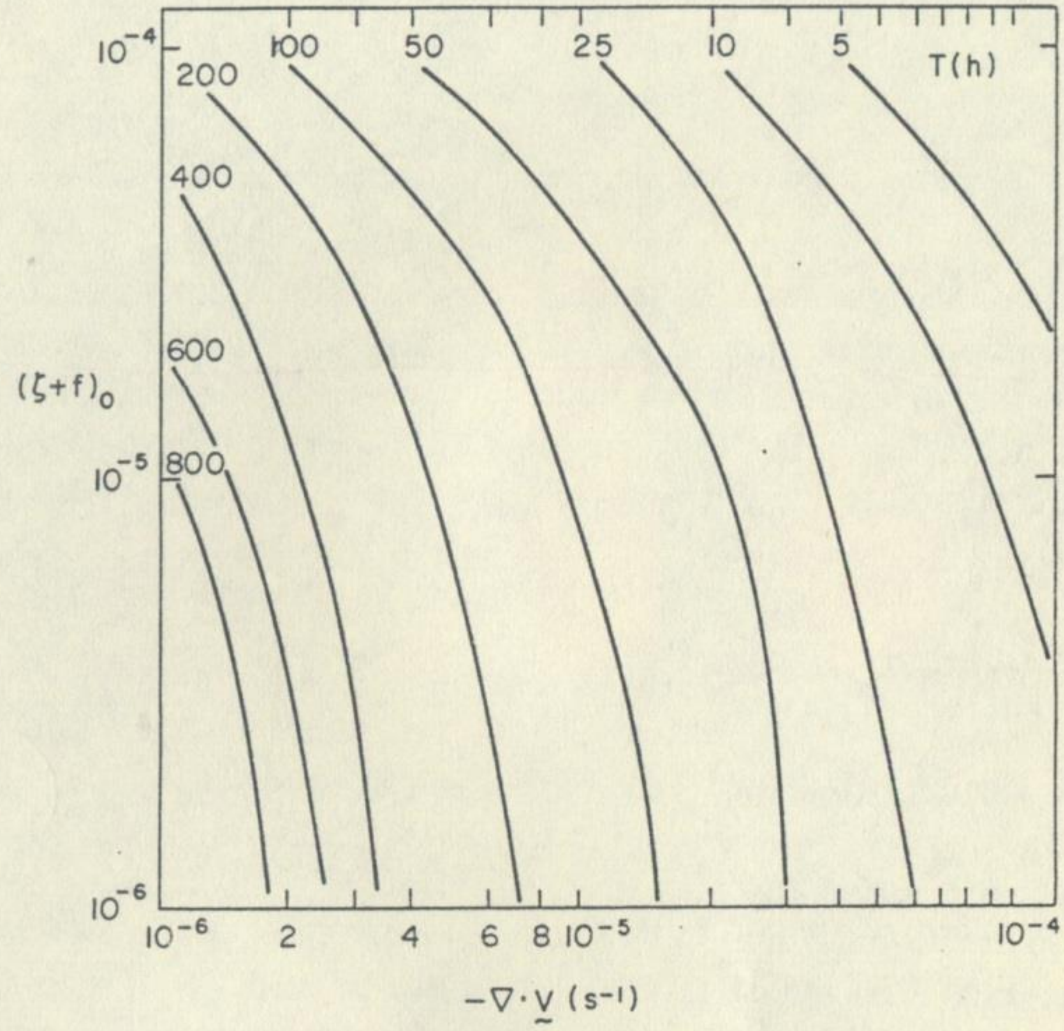


FIG. 2.26. Time (hours) required for a parcel of air to reach a hurricane vorticity value of $2 \times 10^{-4}\ s^{-1}$ for initial values of vorticity $(\zeta + f)_0$ and a constant divergence $(\nabla \cdot V)$ under the assumption of frictionless flow.

Following Bond and Fleagle (1985), the vertical velocity at the top of the boundary layer:

$$W_t = \frac{1}{\rho f} \nabla \times \tau \cdot \hat{k}$$

$$\tau = \rho C_d (V - V_s)(\vec{V} - \vec{V}_s)$$

$$W_t = \frac{1}{\rho f}\left[\frac{\partial C_d \rho |\vec{V}| v}{\partial x} - \frac{\partial C_d \rho |\vec{V}| u}{\partial y}\right]$$

u: east-west flow component

v: north-south flow component

$$C_d = (0.49 + 0.065V) \times 10^{-3}$$ (Large and Pond 1982)

τ : surface stress ρ : air density *f* : Coriolis parameter

C_D : drag coefficient *V*: horizontal velocity

V_s: horizontal velocity of the ocean surface

5. Vertical shear of the horizontal wind

- Tropical cyclone development is favored when the vertical shear is small
- In the small shear case, the advection of heat and moisture relative to the moving disturbance is small

6. Interaction of the disturbance with the larger scale tropical circulation or with itself through nonlinear processes

- An example to show the importance
- More complicated and less understood for these aspects

Influence of divergence associated with an upper-level trough on the development of Typhoon Iris (1970)

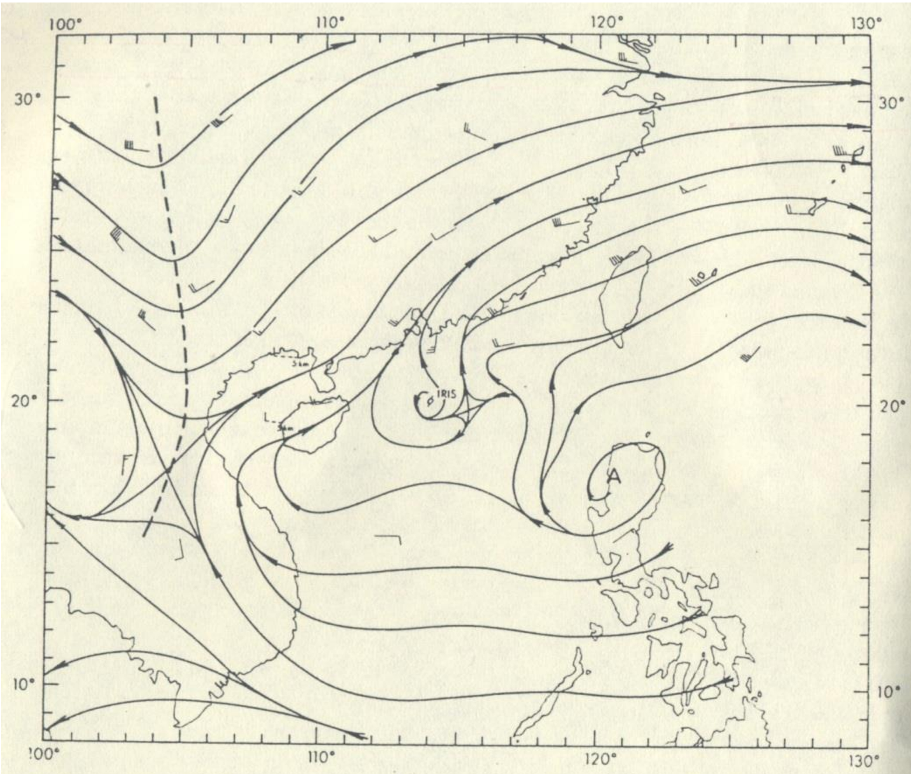


FIG. 2.28a. 200 mb wind (kt) for 1200 GMT 6 October 1970. 1 full barb = 10 kt in Figs. 2.28a and b.

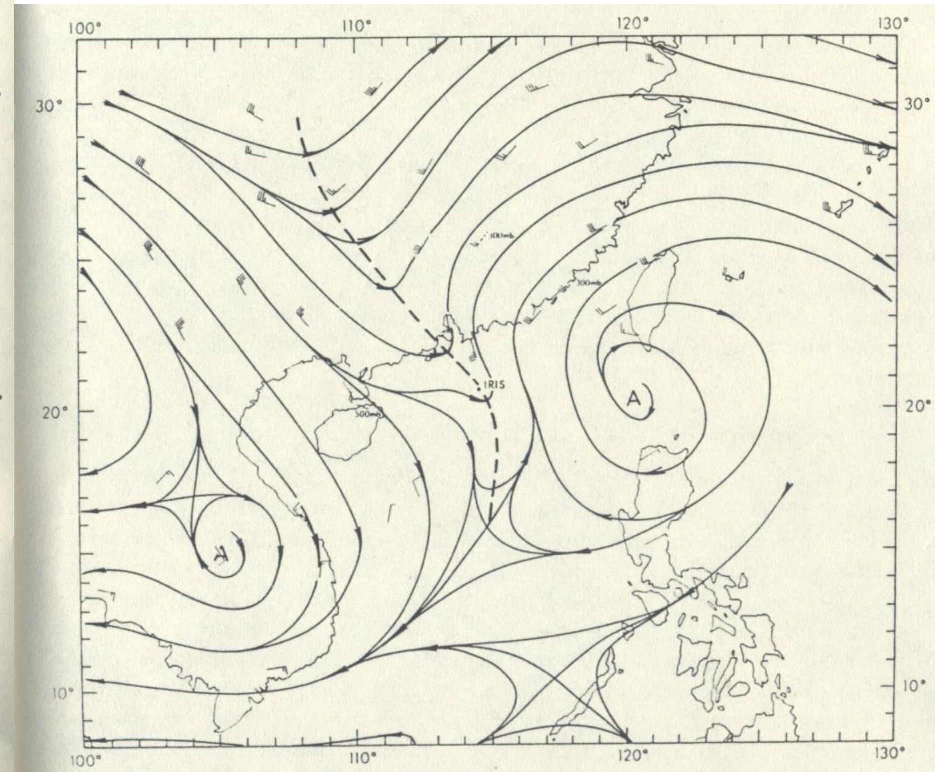


FIG. 2.28b. 200 mb wind (kt) for 0000 GMT 7 October 1970 (Ramage, 1974).

1200 UTC 6 Oct 1970

0000 UTC 7 Oct 1970