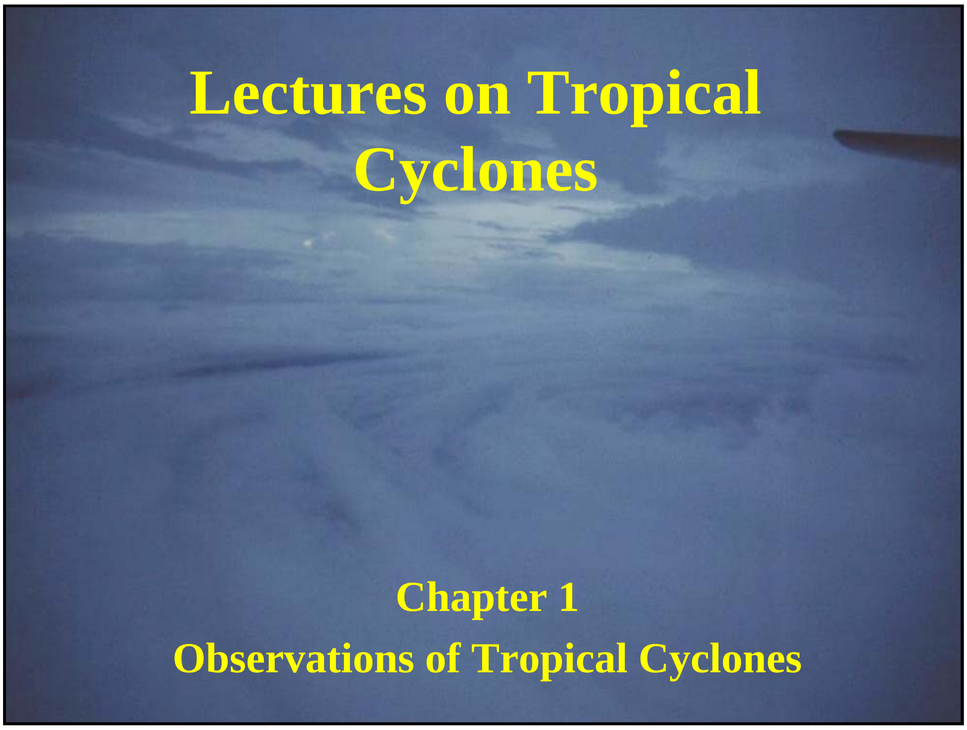


Outline of course

- Introduction, Observed Structure
- Dynamics of Mature Tropical Cyclones
  - Equations of motion
  - Primary circulation
  - Tropical-cyclone boundary layer
  - The role of moist convection
  - The sloping eyewall
  - The tropical-cyclone eye
  - A model for the tropical-cyclone boundary layer

Outline of course

- Dynamics of Mature Tropical Cyclones (continued)
  - Radiative cooling
  - The Emanuel steady-state model
  - Vortex intensity change
  - The secondary circulation
- Tropical cyclone motion
  - Vorticity-streamfunction method
  - The partitioning problem
  - Prototype problems

Outline of course

- Vortex asymmetries, vortex waves
  - Axisymmetrization
  - Vortex Rossby waves
- Baroclinic vortex flows
  - Steady solutions
  - The effects of vertical shear
- Moist processes vortex flows
  - Idealized modelling studies
  - Other modelling studies

Outline of course

- Tropical cyclone prediction
- Advanced topics
  - Vortex stiffness
  - Potential radius coordinates
  - Asymmetric balance theory

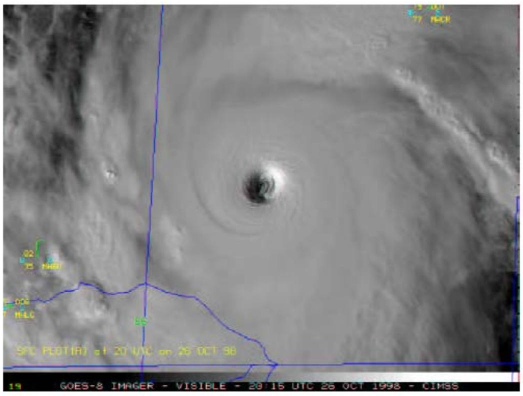
Reading material

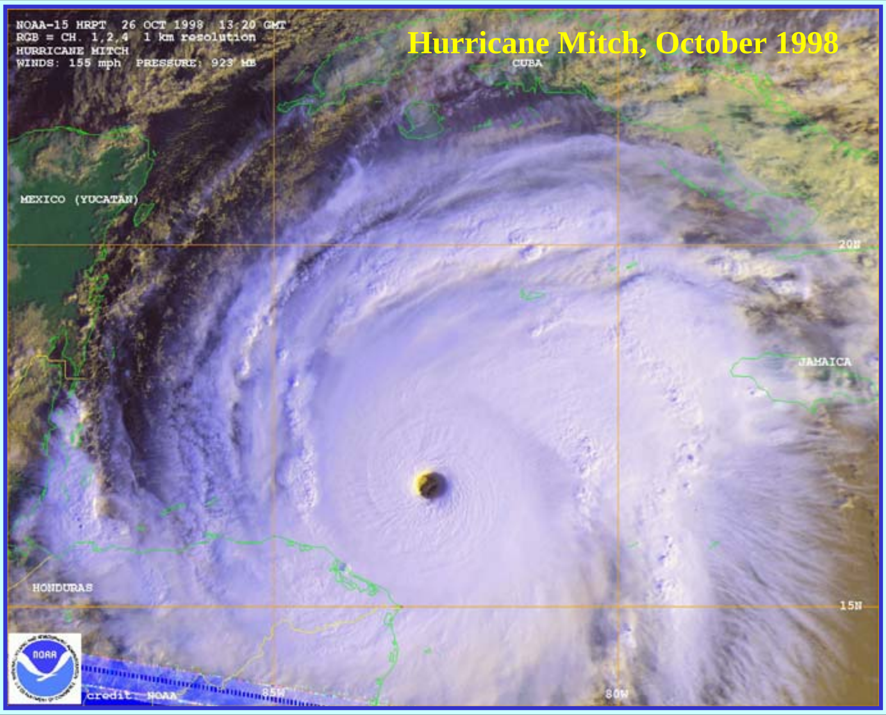
- Anthes (1970), Tropical Cyclones, AMS Monograph
- Anthes (1974), The dynamics and energetics of mature tropical cyclones, *Rev. Geophys. Space Phys*., 12, 495-522
- WMO Tech. Note (1995) *Ed. R. L. Elsberry*
  - *H. E. Willoughby* Mature structure and evolution
  - *J. L. McBride* Tropical cyclone formation
  - *I. Ginis* Ocean response to tropical cyclones

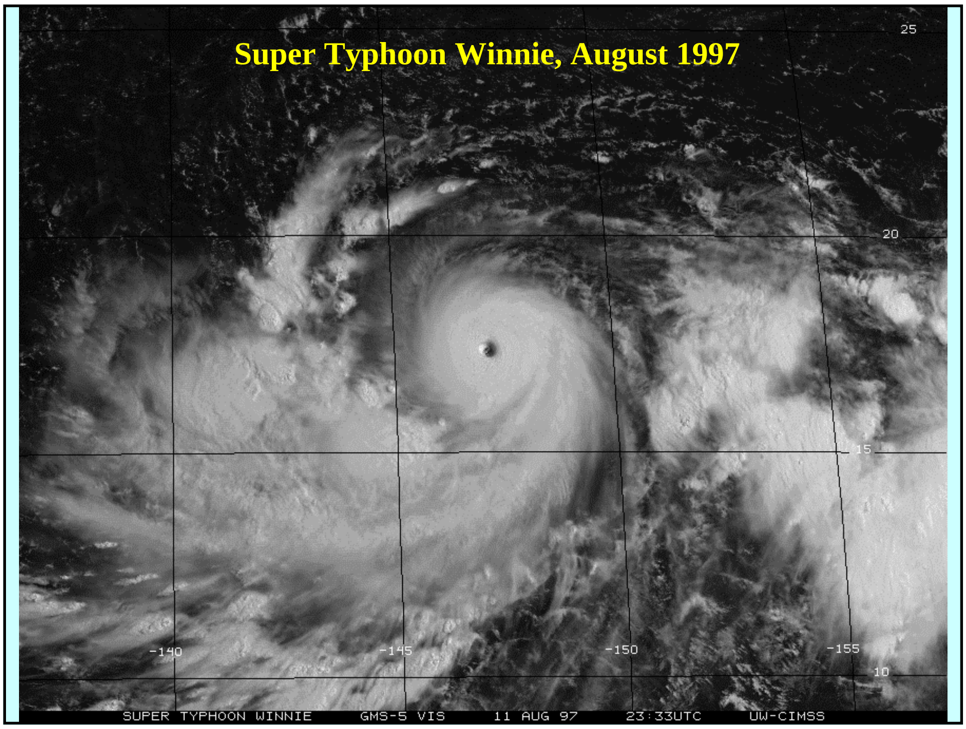
LECTURES ON TROPICAL CYCLONES

Roger K. Smith

http://www.meteo.physik.uni-muenchen.de/~roger/TCs.pdf






Super Typhoon Winnie, August 1997
25
20
15
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-140
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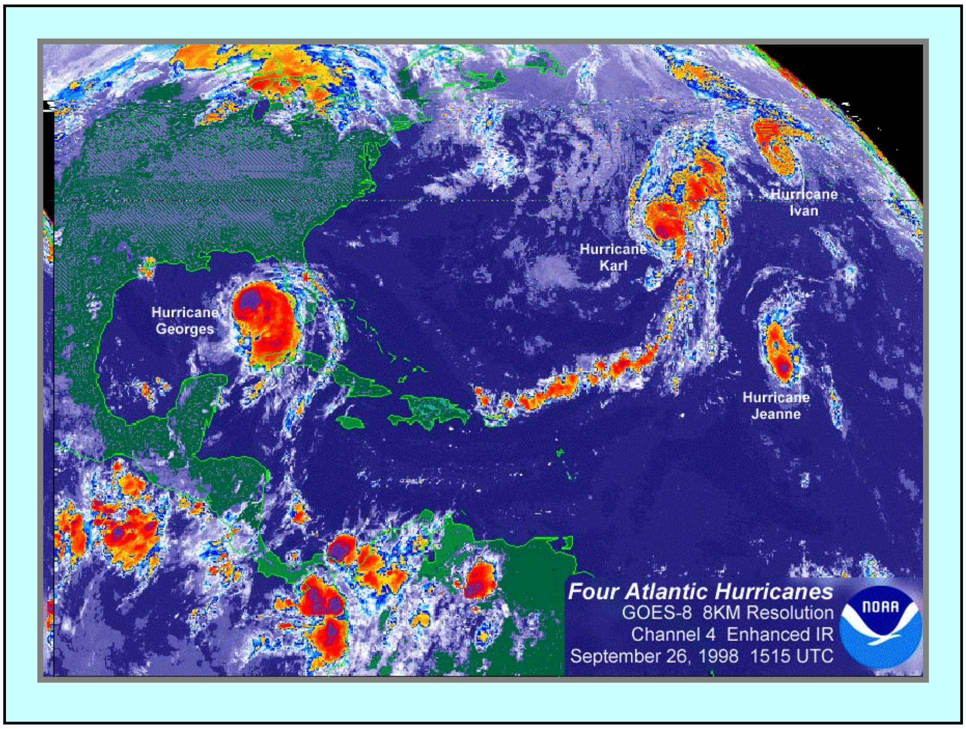
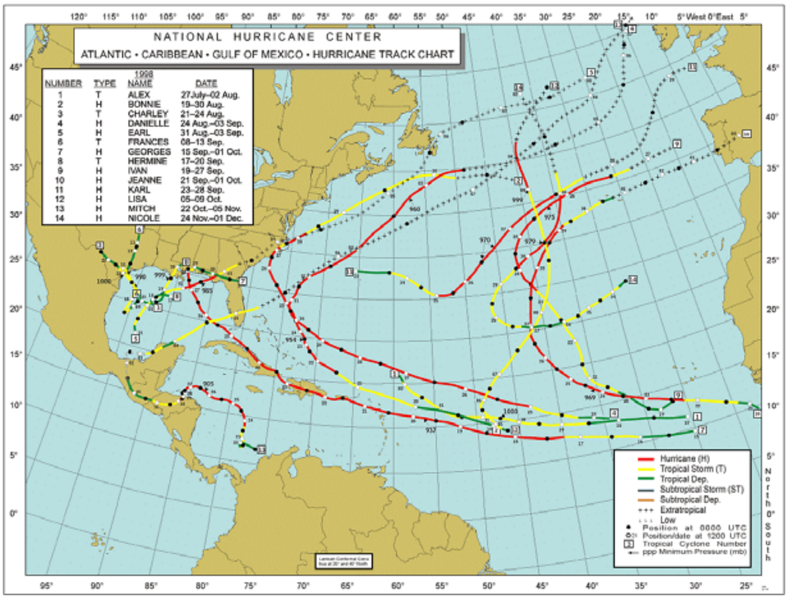
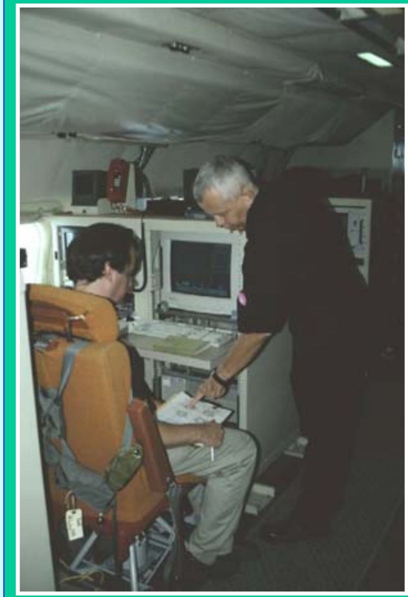
-155
SUPER TYPHOON WINNIE GMS-5 VIS 11 AUG 97 23:33UTC UW-CIMSS


Hurricane Ivan
Hurricane Karl
Hurricane Georges
Hurricane Jeanne
Four Atlantic Hurricanes
GOES-8 8KM Resolution
Channel 4 Enhanced IR
September 26, 1998 1515 UTC
NOAA

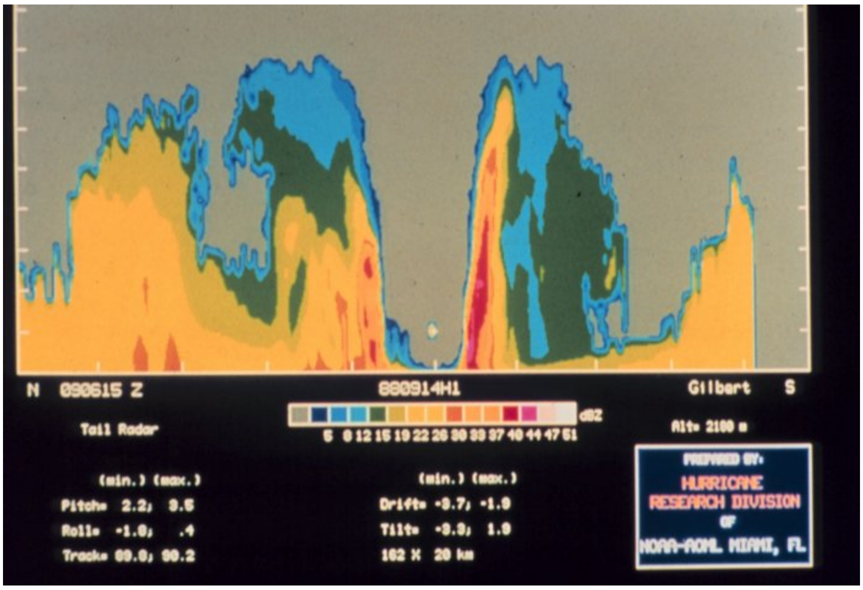
Atlantic hurricane tracks in 1998



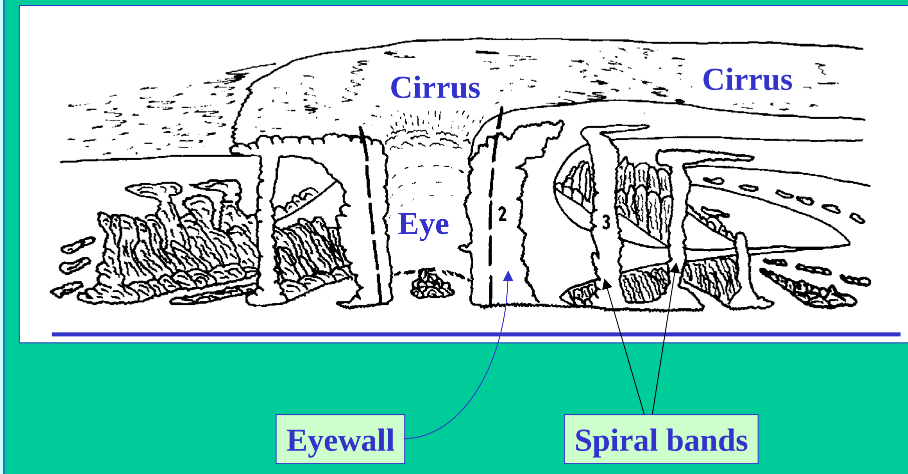
Hurricane Research Aircraft, NOAA WD-P3



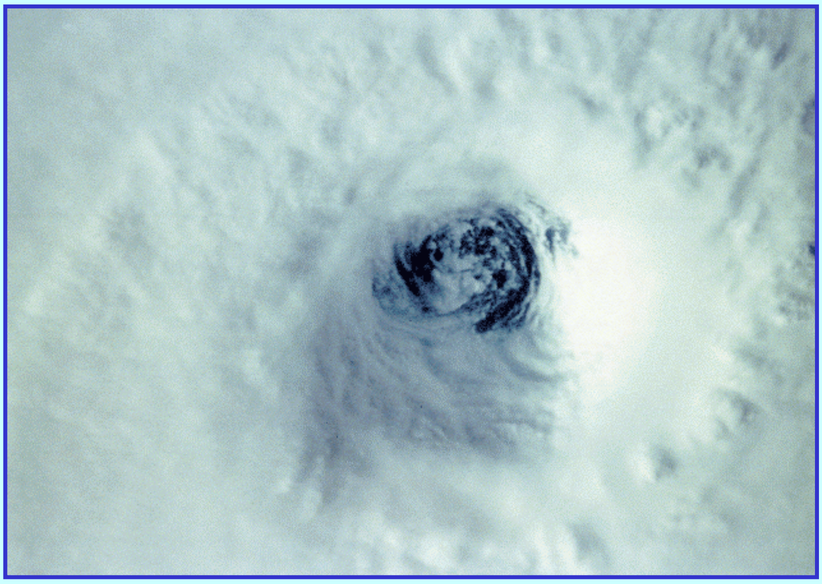
Radar display from the tail radar



Schematic cross-section through a hurricane

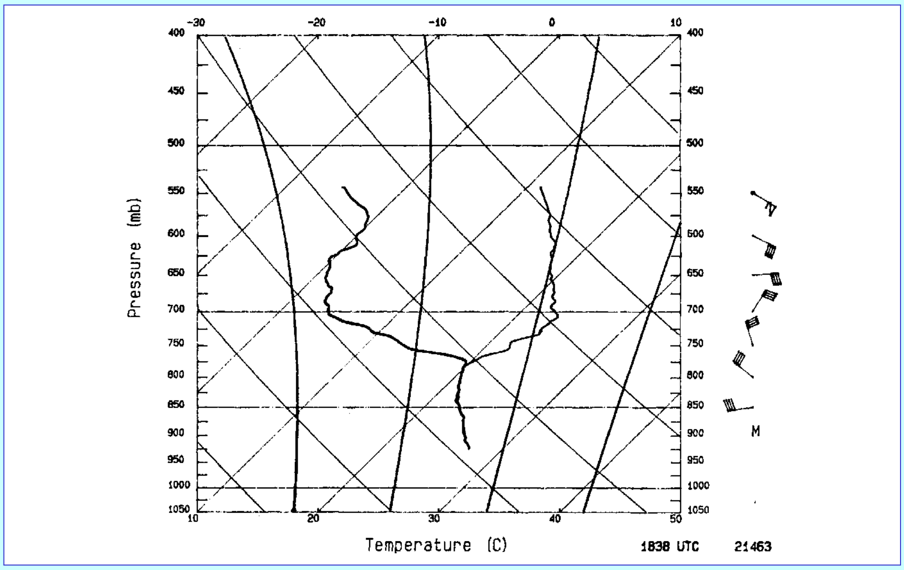


Close up photograph of the eye



The eye of Hurricane *Lili* (2002)

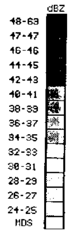
Dropwindsonde sounding in the eye of a hurricane



From Willoughby (AMM, 1988)

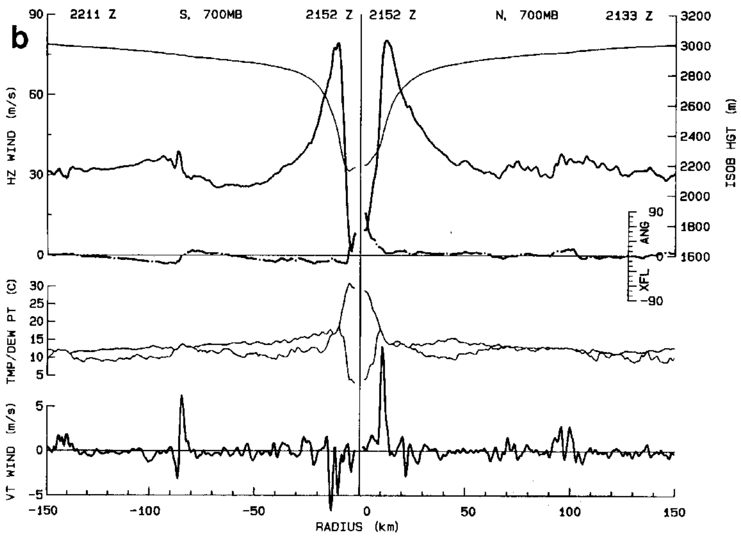
Radar PPI in Hurricane Gilbert (1988)

Fig. 2.4 (*a*) Plan-position indicator (PPI) radar reflectivity composite of Hurricane Gilbert at ~2200 UTC 13 September 1988, when it was at maximum intensity near 19.9°N, 83.5°W. (*b*) Flight-level measurements from research aircraft. The abscissa is distance along a north-south pass through the center. The top panel shows wind speed (dark solid line), 700 mb height (light solid line), and crossing angle ($\tan^{-1} u/v$, dash-dotted line). Winds are relative to the moving vortex center. The middle panel shows temperature (upper curve) and dewpoint. When $T_D > T$, both are set to $1/2(T+T_D)$. The bottom panel shows vertical wind (Black and Willoughby 1992).



From Black & Willoughby (JAS, 1992)

Flight level data from a Hurricane traverse

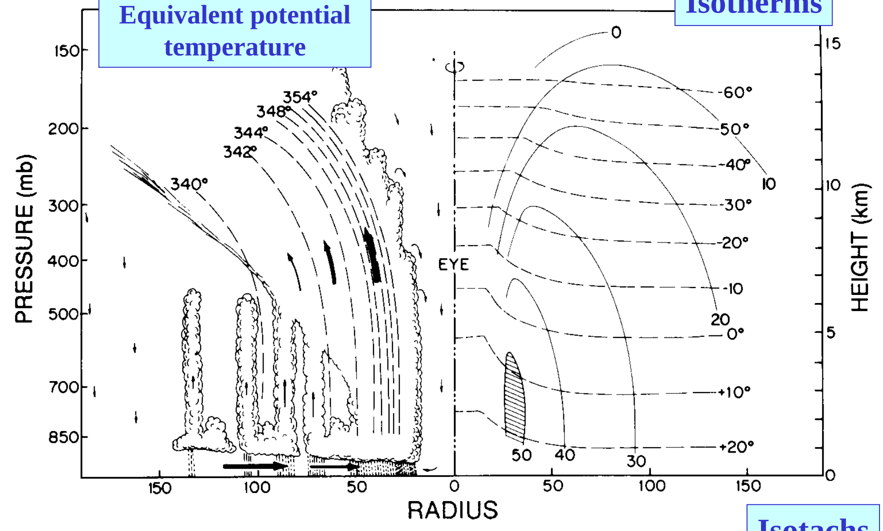


From Willoughby (WMO, 1995)

Vertical-radial cross-section through a hurricane

Equivalent potential temperature

Isotherms



Latent heat flux

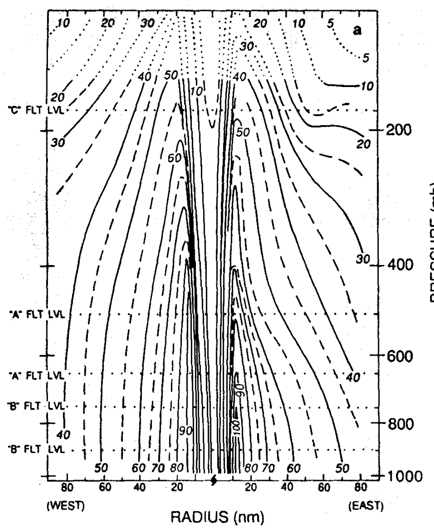
Isotachs

From Wallace and Hobbs (1977)

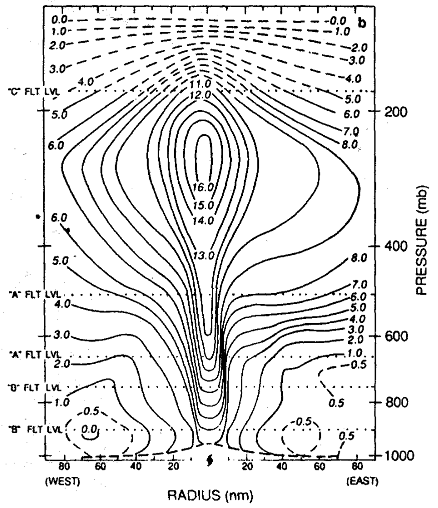
Sea surface fluxes

Vertical cross-section of Hurricane Hilda (1964)

From Hawkins and Rubsam (MWR, 1988)

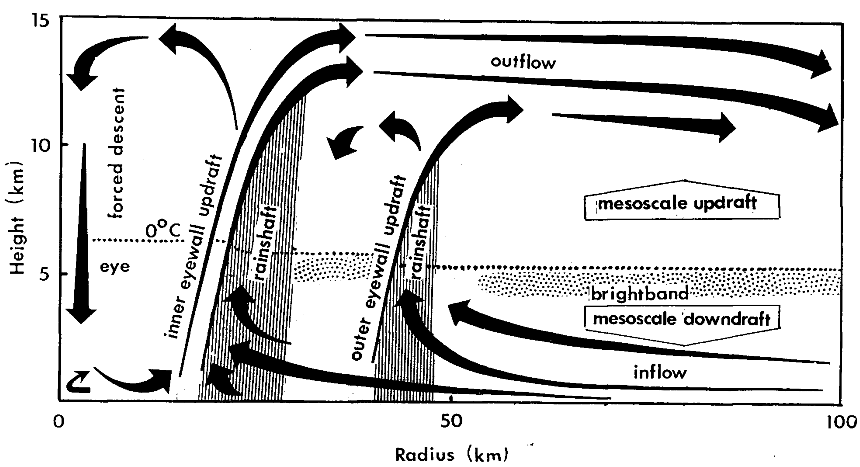


Azimuthal wind



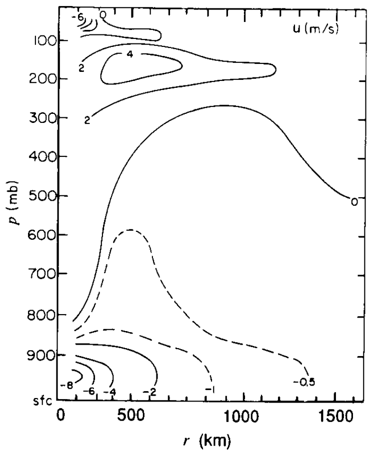
Temperature anomaly

A TC with a double eyewall

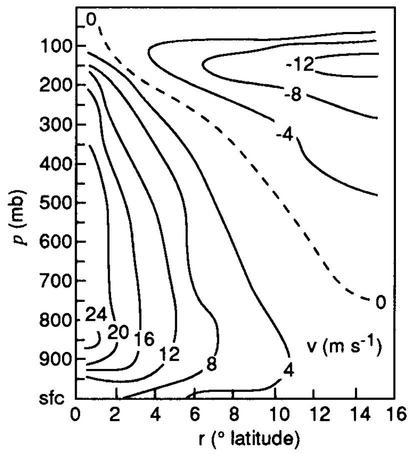


From Willoughby, WMO (1995)

Cross-section from composite data



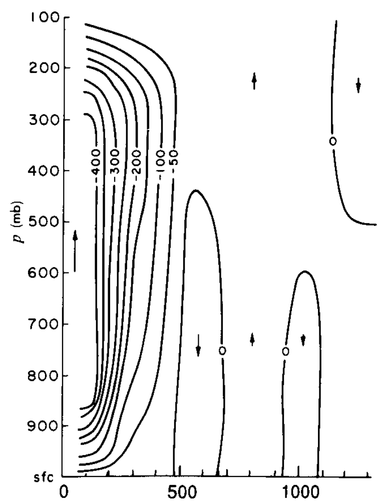
Radial wind



Azimuthal wind

From Gray (1979)

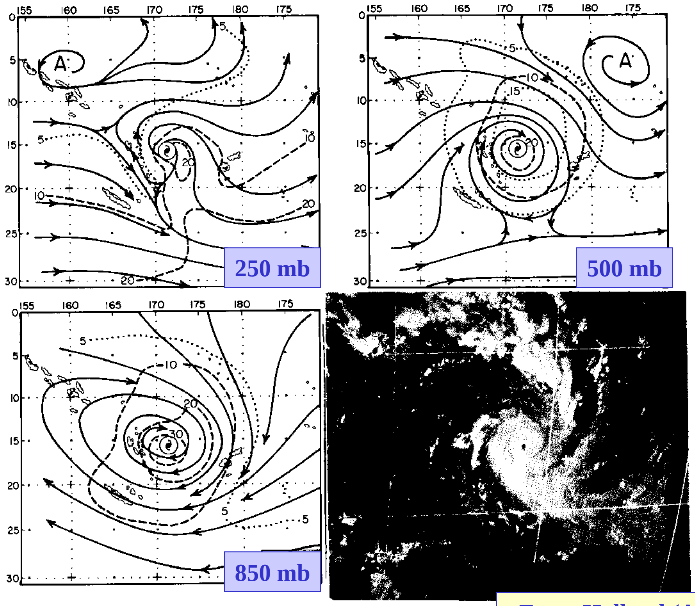
Vertical motion



From Frank (MWR, 1977)

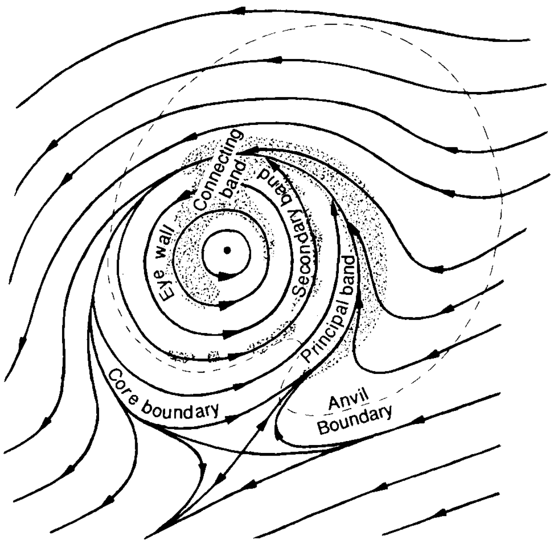
Vertical cross section of the mean vertical air motion (mb per day) in typhoons. Analysis is a composite of data collected in many storms.

Asymmetries



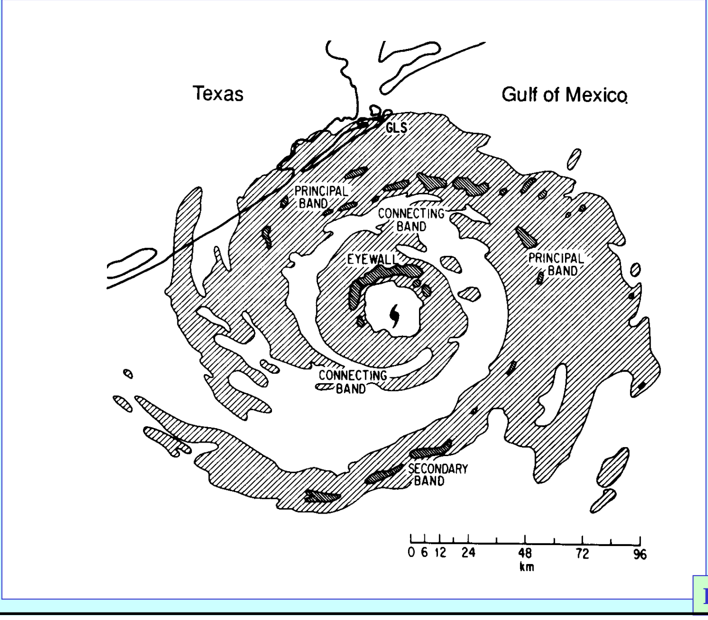
From Holland (AMM, 1984)

Asymmetric structure



From Houze

Typical radar echo pattern

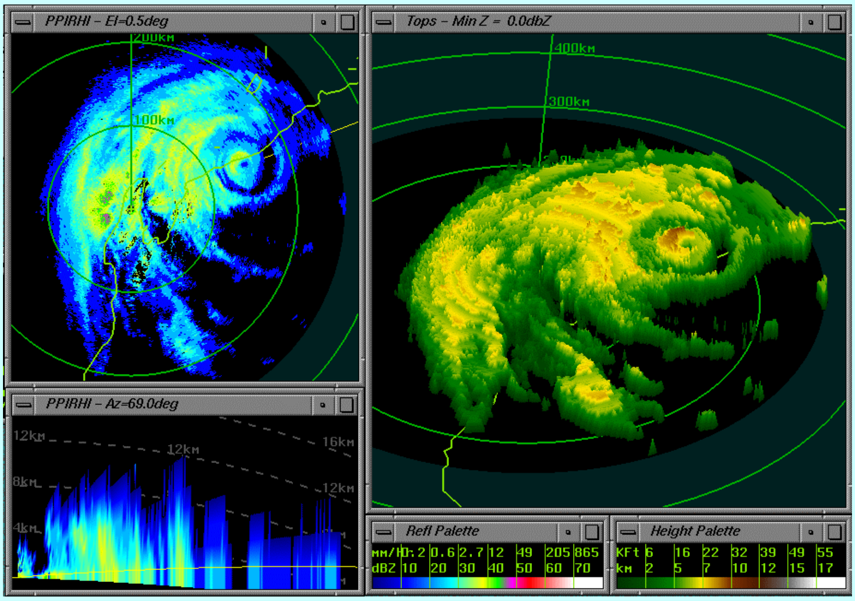


From Houze

A TC with a double eyewall

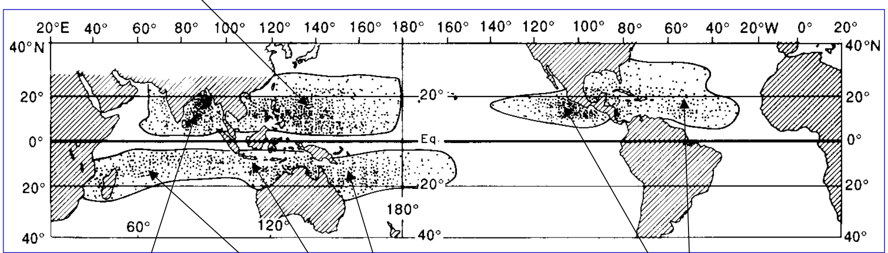
From Willoughby, AMM (1988)

Western Australia: TC Bobby



Regions of TC formation

Typhoons



Cyclone

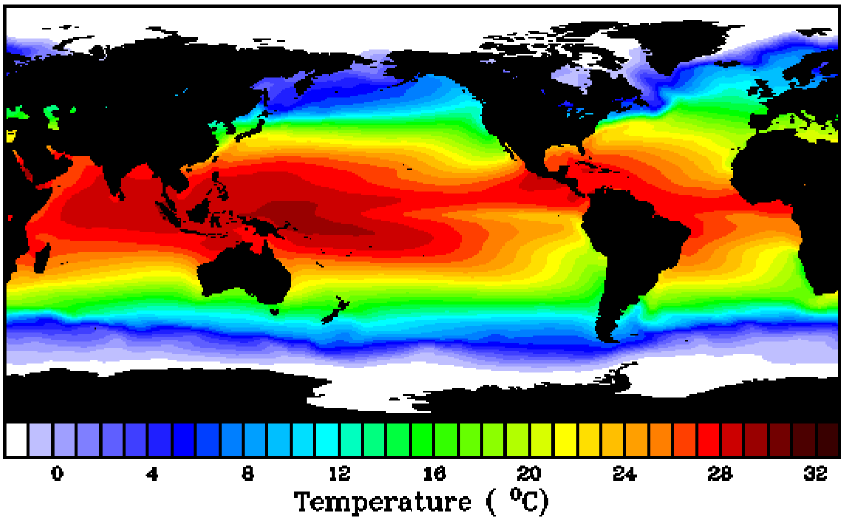
Tropical Cyclone

Hurricane

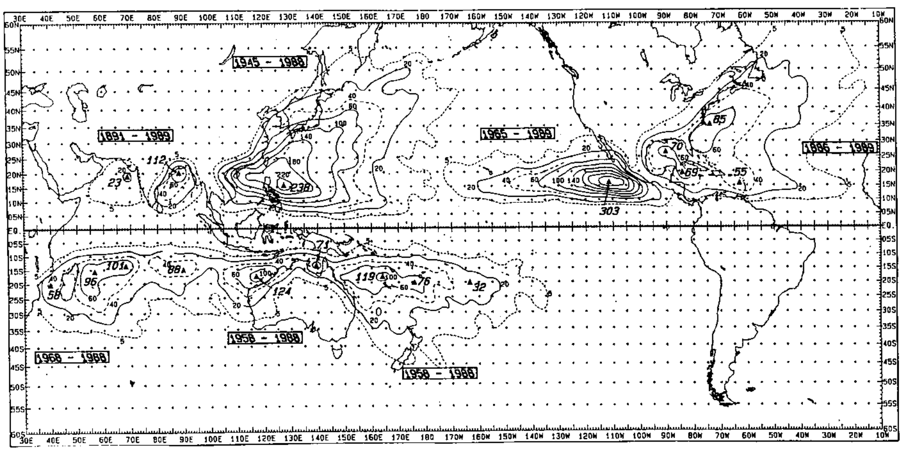
Tropical cyclogenesis requires a water temperature of at least 26.5 °C

From Gray (1975)

Annual mean sea surface temperatures

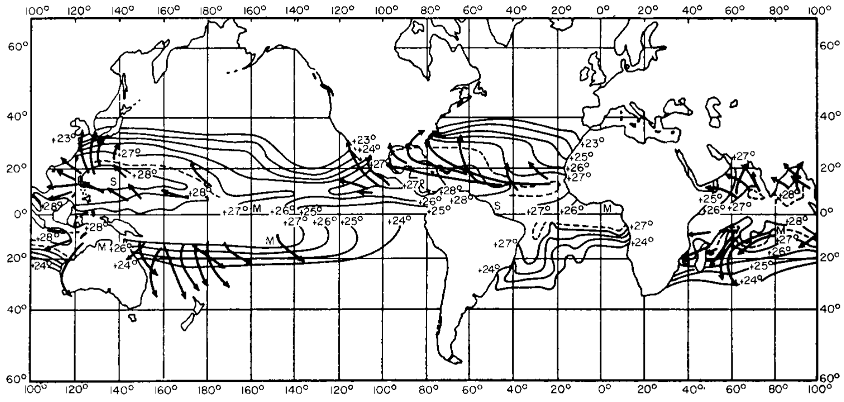


Frequency of TCs per 100 years



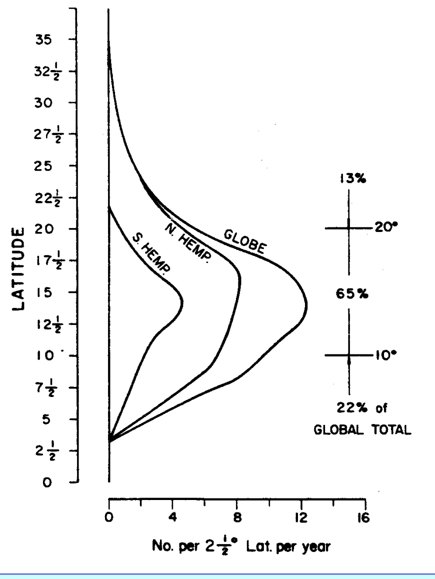
From WMO (1993)

Tracks of TCs in relation to SST



From Gray (MWR, 1975)

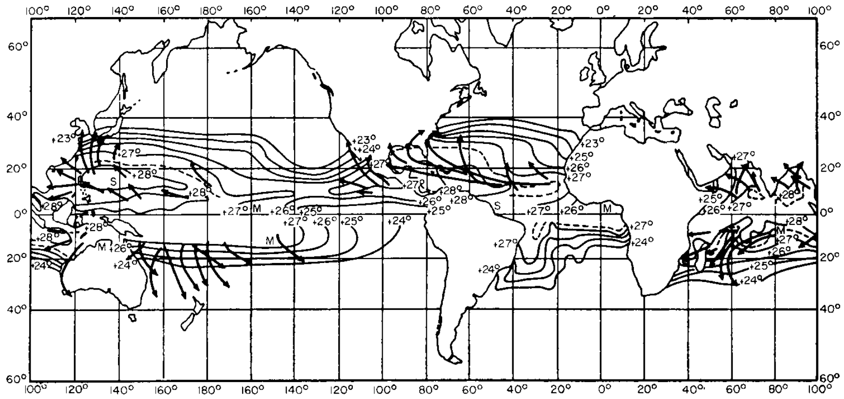
Mean latitude of formation



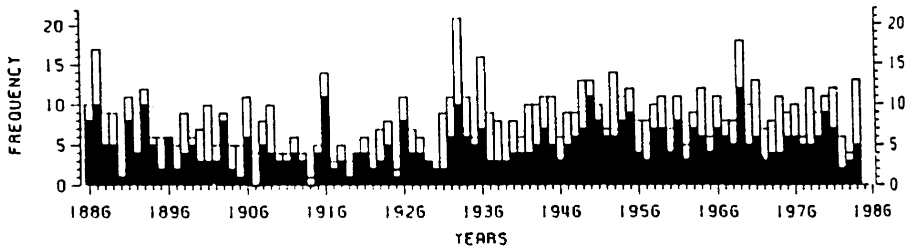
Latitudes at which initial disturbances later became tropical cyclones were first detected

From Gray (MWR, 1975)

Tracks of TCs in relation to SST

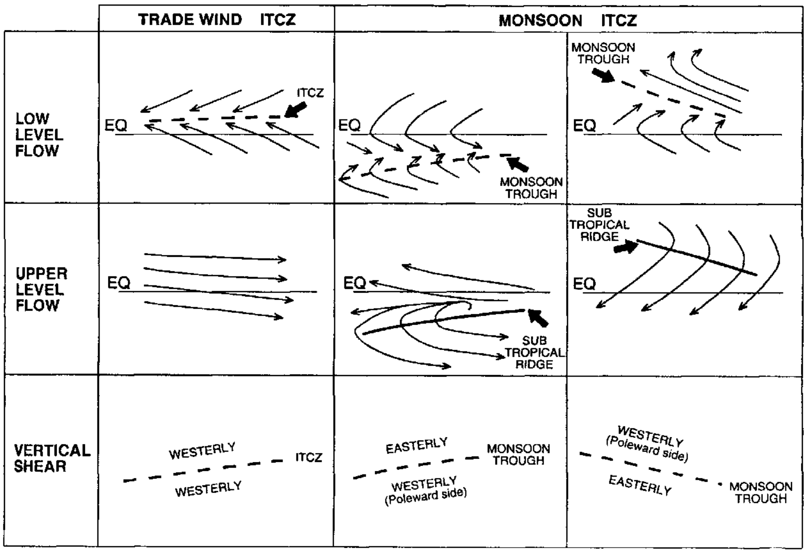


Climatology in Atlantic Basin



Number of North Atlantic tropical cyclones reaching at least 17.5 m s^{-1} (34 kt) intensity (open bar) and reaching at least 33 m s^{-1} (64 kt) intensity (solid bar) each year during 1886-1985. (From McBride, 1995)

Trade wind and monsoon flow regimes



Genesis conditions

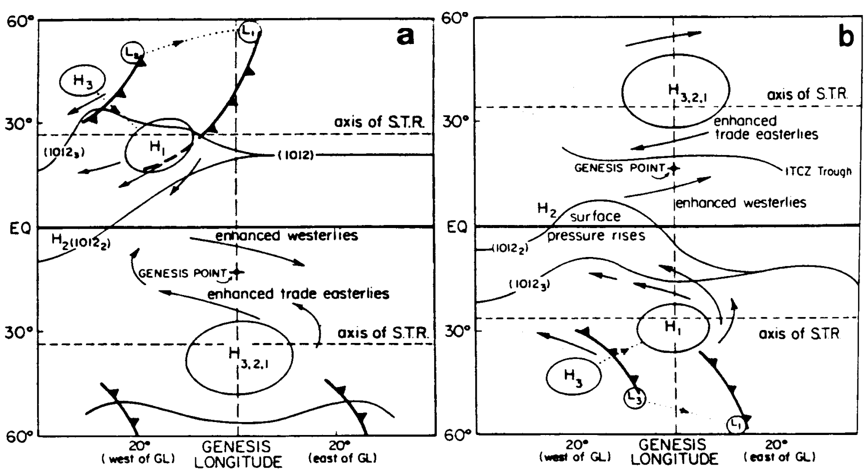


Fig. 3.19 Schematic surface map of the positions of important synoptic-scale features 3 days and 1 day before cyclone genesis in (a) Southern and (b) Northern Hemisphere. Subscripts on the highs (H) and lows (L) denote days before genesis (Love 1982).

Satellite imagery - classification

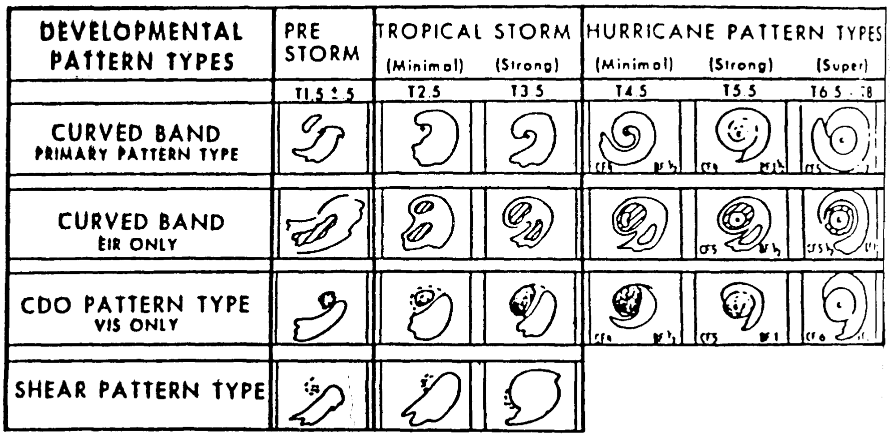


Fig. 3.20 Cloud pattern types in the tropical cyclone intensity analysis based on satellite imagery. Pattern changes from left to right are typical 24-hourly changes (Dvorak 1984).

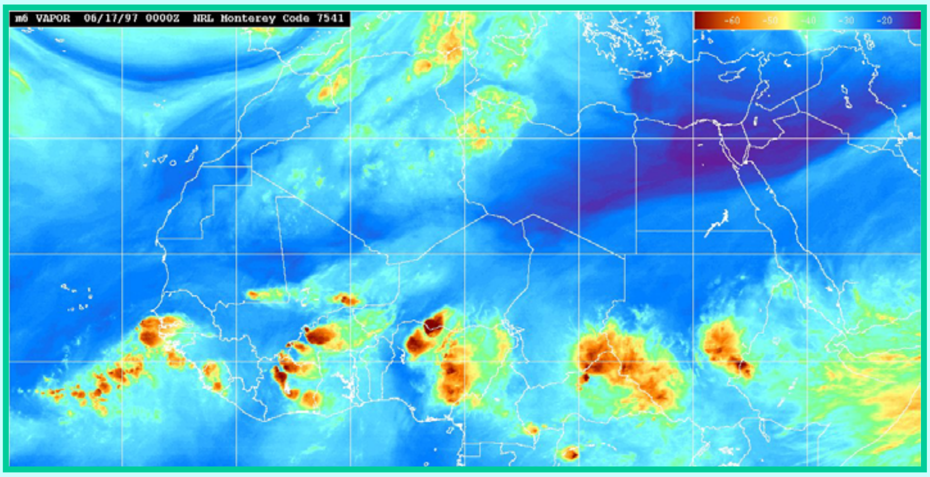
Large-scale conditions for formation

- Tropical cyclones form from pre-existing disturbances containing abundant deep convection;
- The pre-existing disturbance must acquire a warm core thermal structure throughout the troposphere;
- Formation is preceded by an increase of lower tropospheric relative vorticity over a horizontal scale of approximately 1000 to 2000 km;
- A necessary condition for cyclone formation is a large-scale environment with small vertical wind shear;

Large-scale conditions for formation (cont)

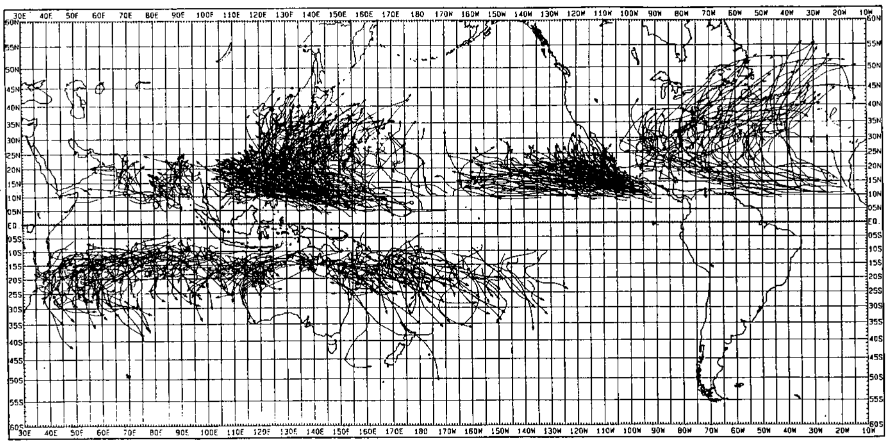
- An early indicator that cyclone formation has begun is the appearance of curved banding features of the deep convection in the incipient disturbance;
- The inner core of the cyclone may originate as a mid-level meso-vortex that has formed in association with a pre-existing mesoscale area of altostratus (i.e., a Mesoscale Convective System or MCS); and
- Formation often occurs in conjunction with an interaction between the incipient disturbance and an upper-tropospheric trough.

Easterly waves over Africa



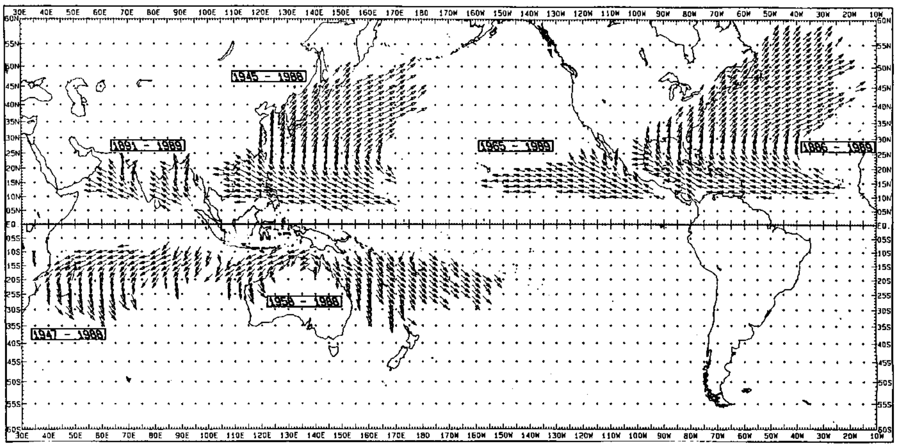
WV Imagery 17 June 1997 00Z

Tropical cyclone tracks (1979-1988)

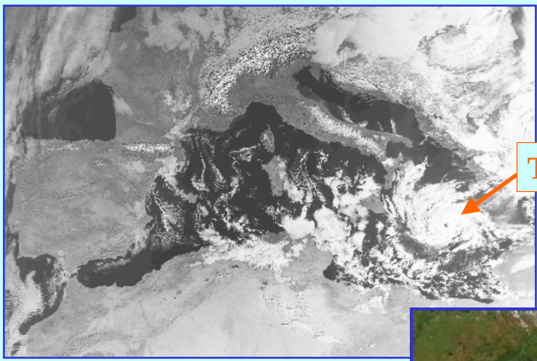


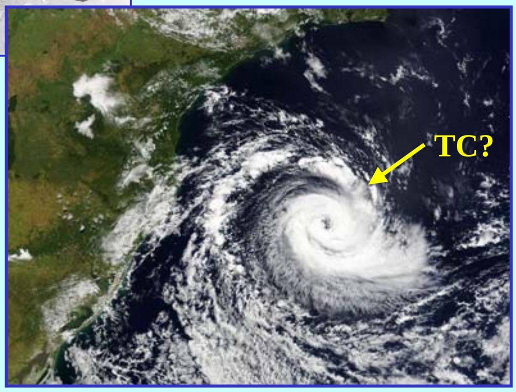
From WMO (1993)

Mean direction of TC motion



From WMO (1993)





Related phenomena

End