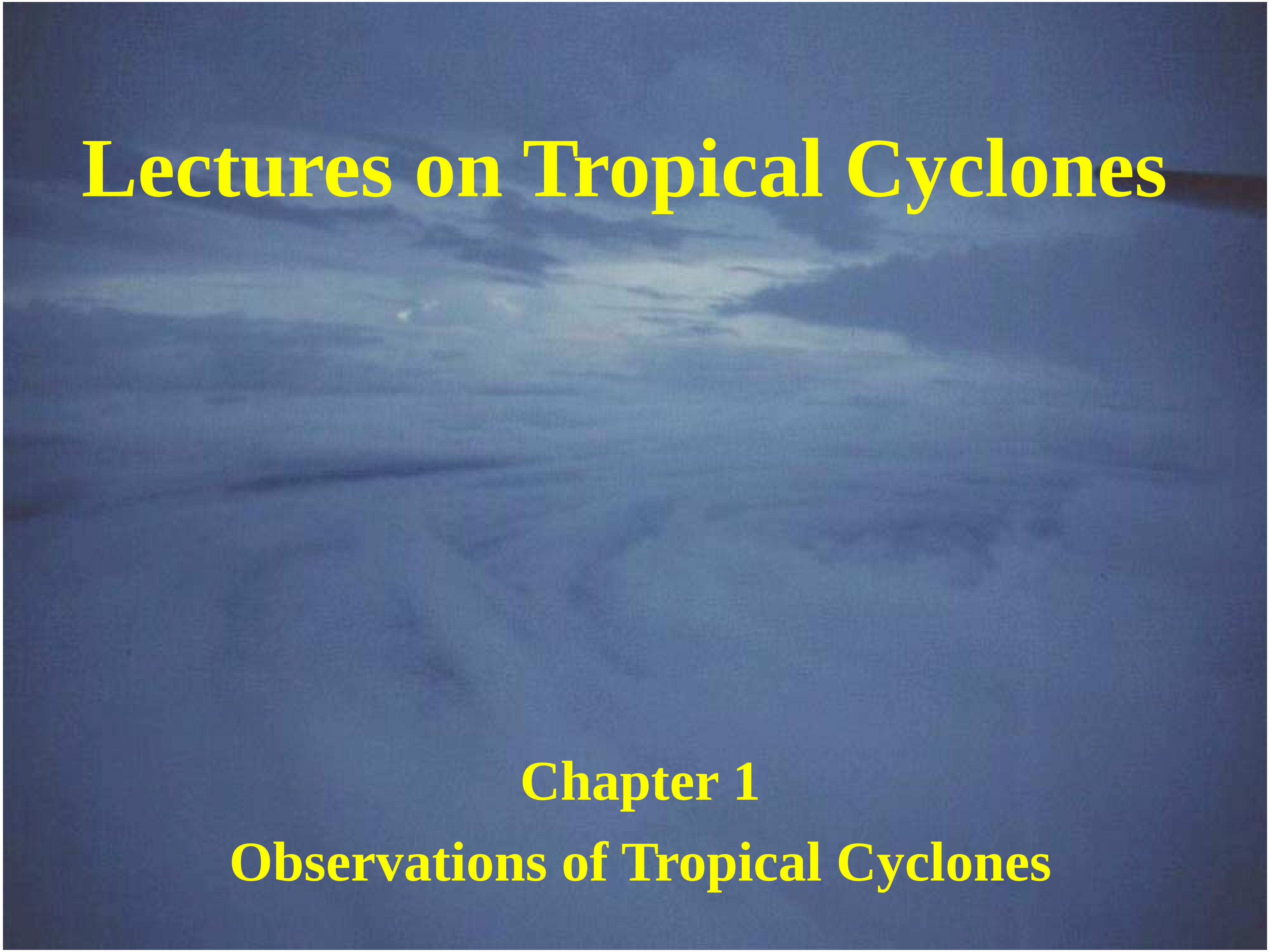


Lectures on Tropical Cyclones

Chapter 1

Observations of Tropical Cyclones

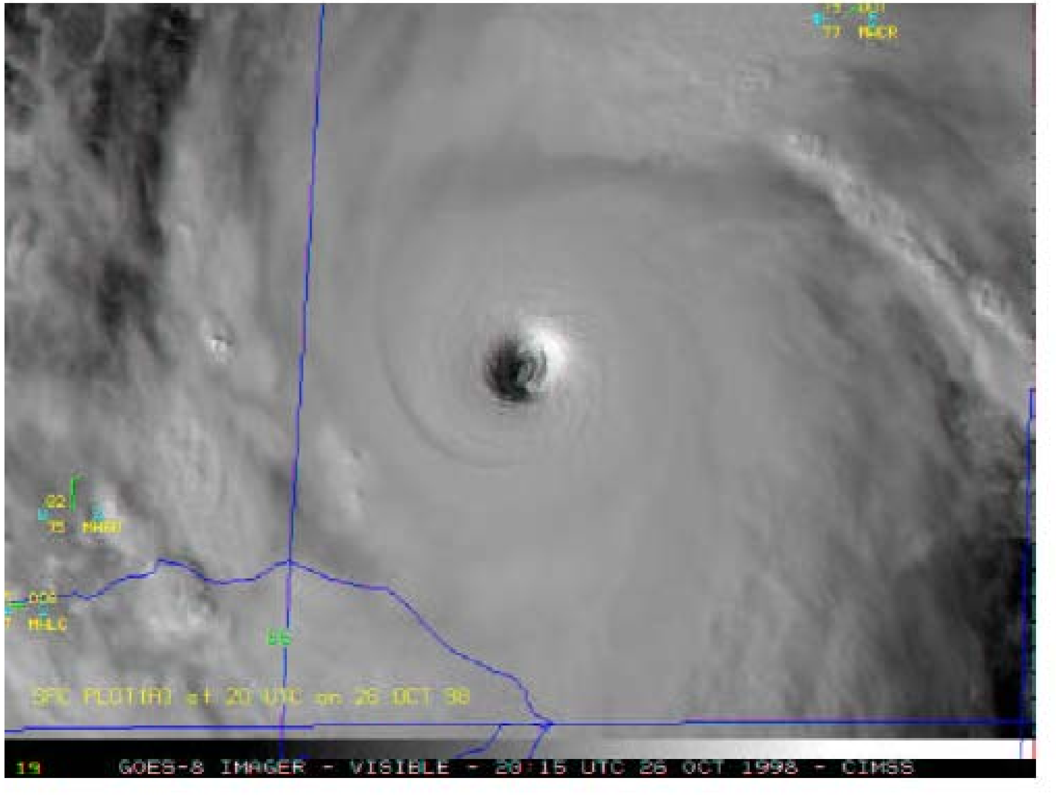
Reading material

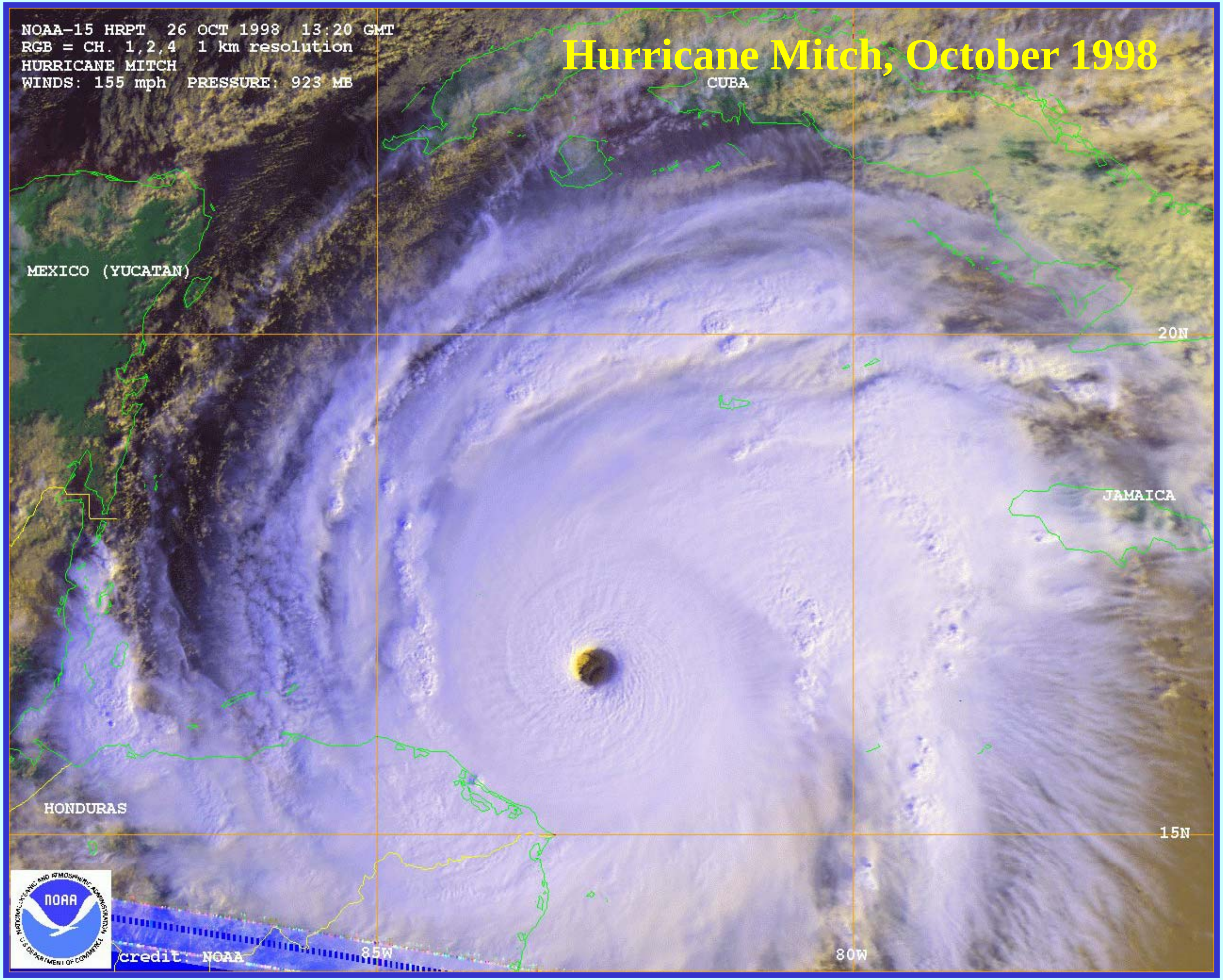
- **Anthes (1970), Tropical Cyclones, AMS Monograph**
- **Anthes (1974), The dynamics and energetics of mature tropical cyclones, *Rev. Geophys. Space Phys*., 12, 495-522**
- **WMO Tech. Note (1995) *Ed. R. L. Elsberry***
  - ***H. E. Willoughby* Mature structure and evolution**
  - ***J. L. McBride*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

LECTURES ON TROPICAL CYCLONES

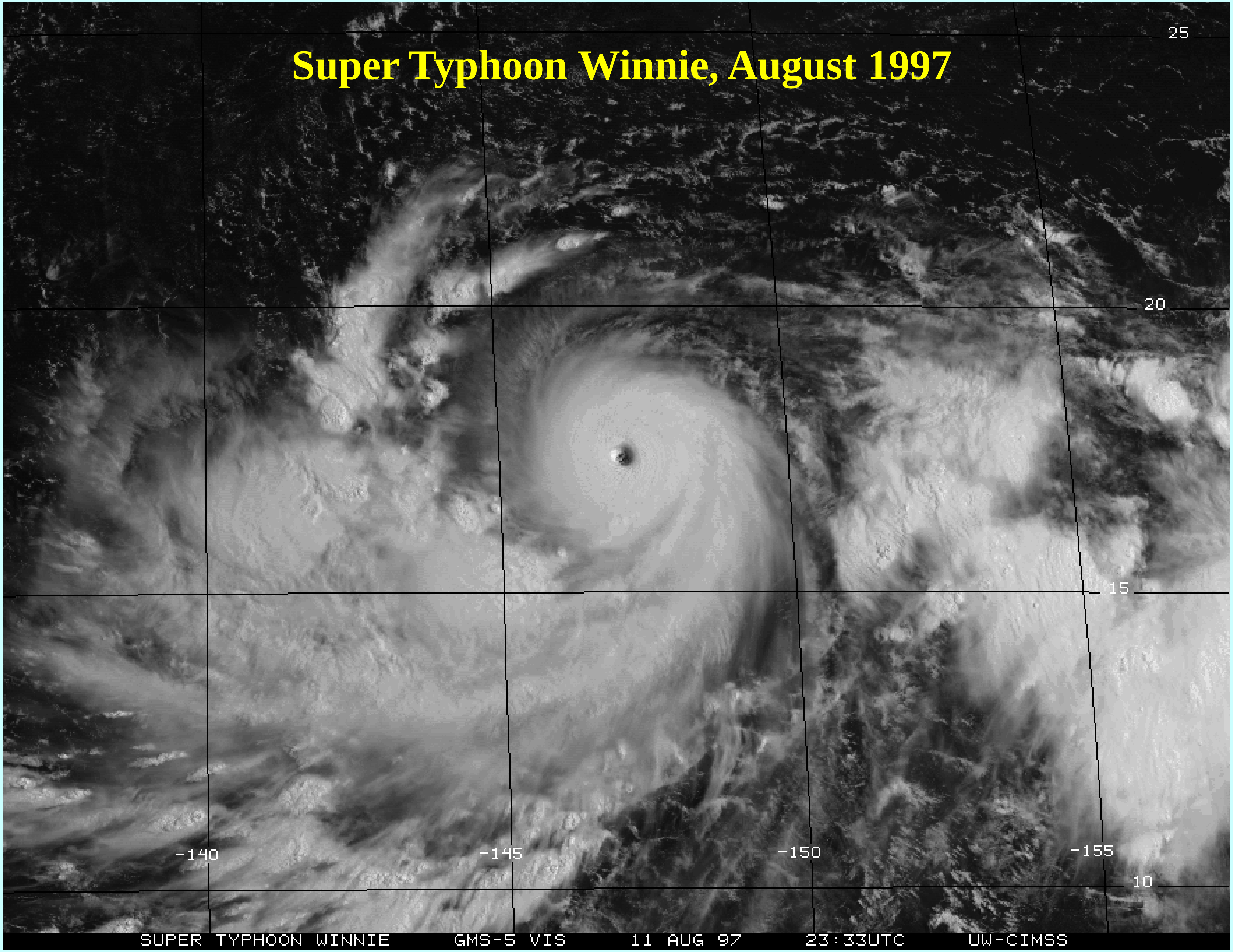
Roger K. Smith

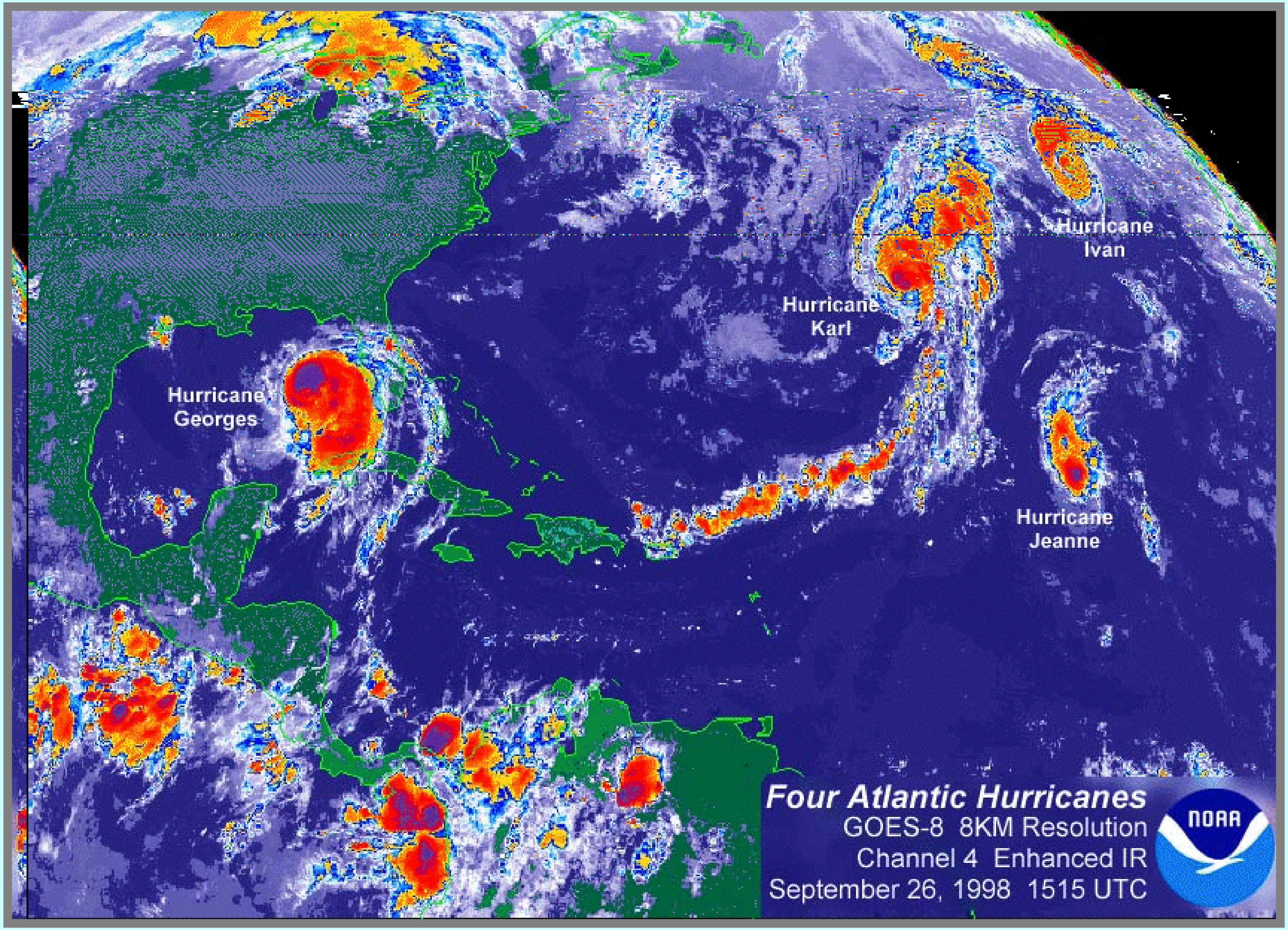
http://www.meteo.physik.uni-muenchen.de/~roger/TCs.pdf



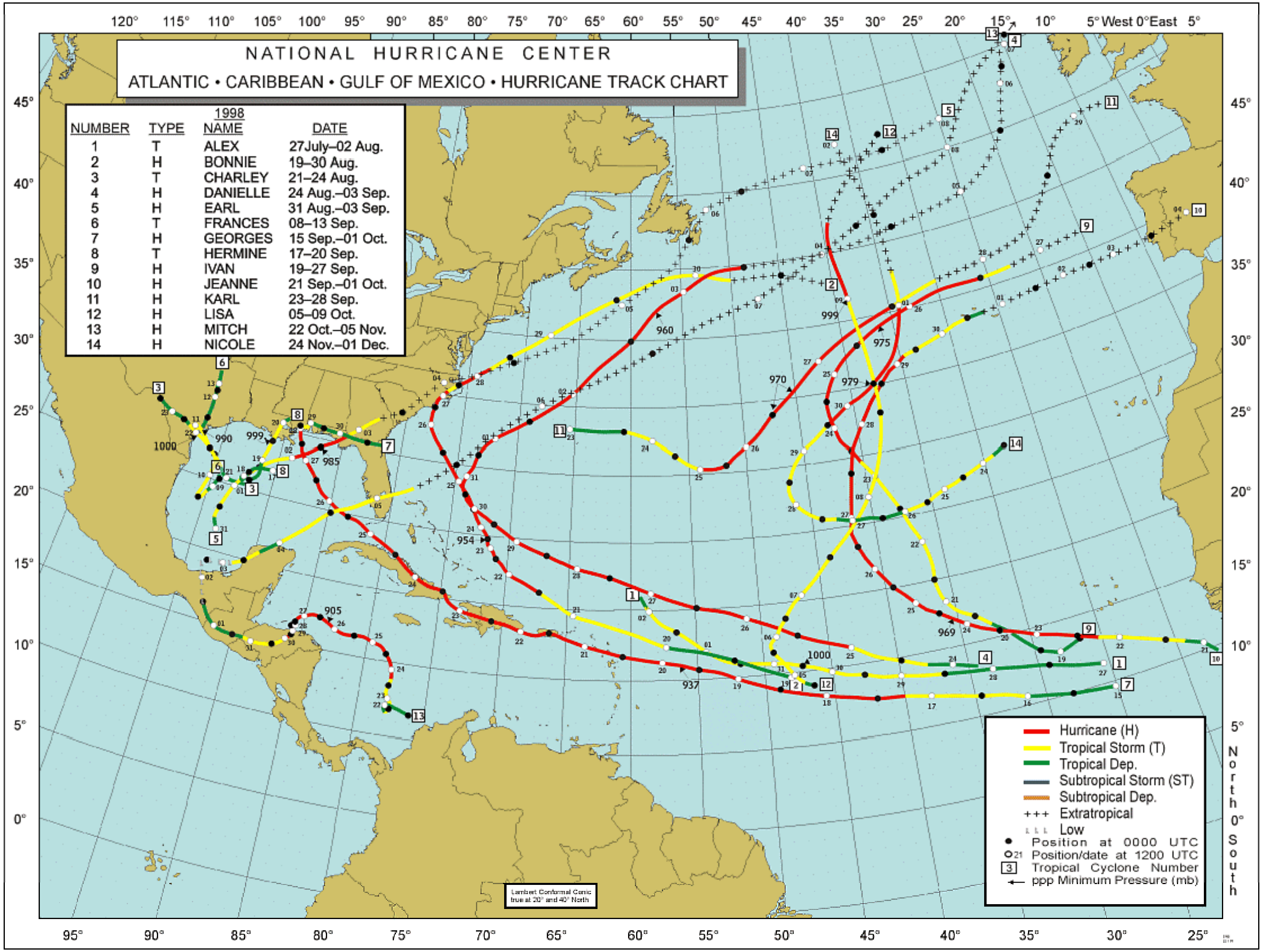

NOAA-15 HRPT 26 OCT 1998 13:20 GMT
RGB = CH. 1,2,4 1 km resolution
HURRICANE MITCH
WINDS: 155 mph PRESSURE: 923 MB
Hurricane Mitch, October 1998
CUBA
MEXICO (YUCATAN)
20N
JAMAICA
HONDURAS
15N
NOAA
credit: NOAA
85W
80W

Super Typhoon Winnie, August 1997




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

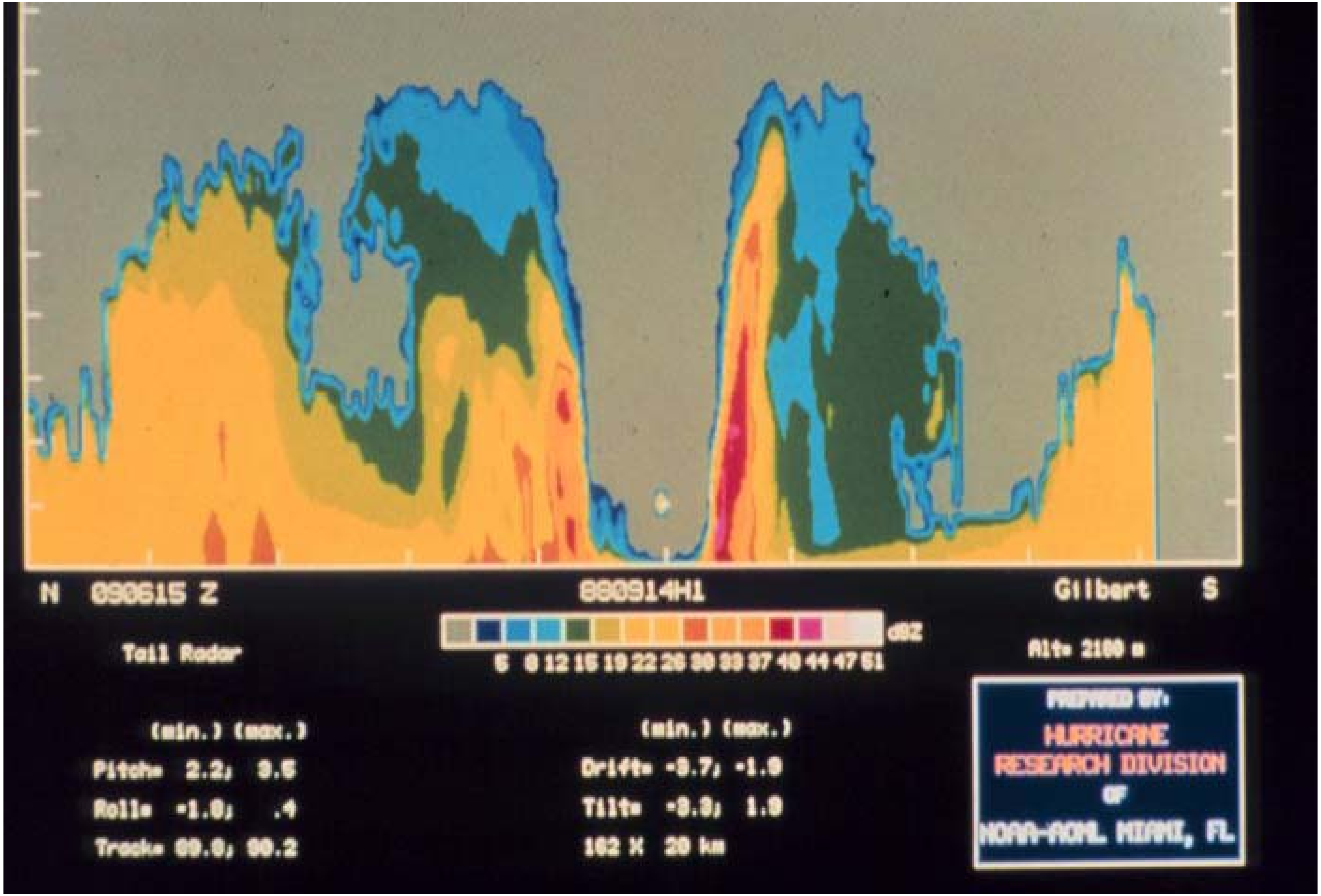
Atlantic hurricane tracks in 1998



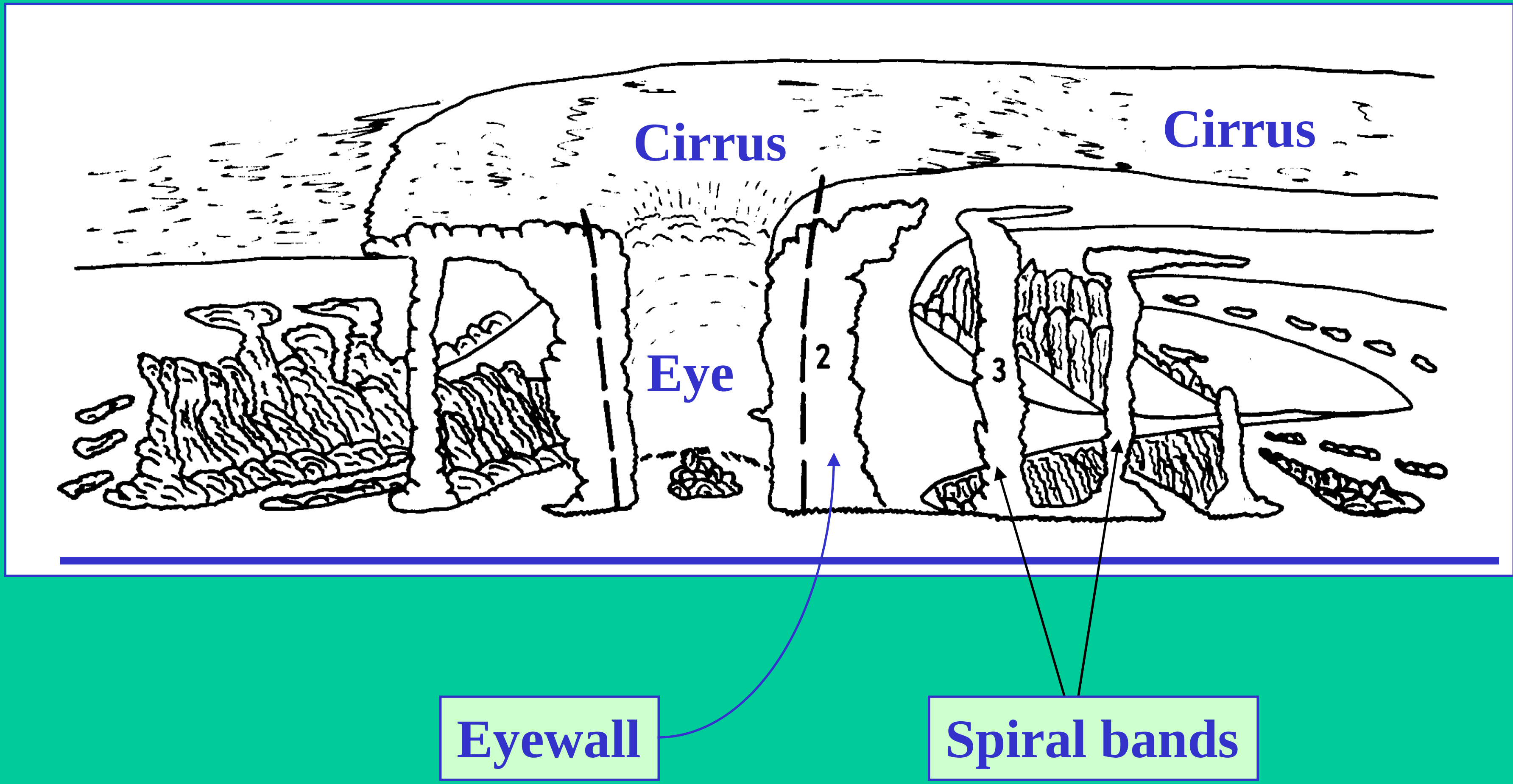
Hurricane Research Aircraft, NOAA WD-P3


SONY
SONY
SONY
SONY

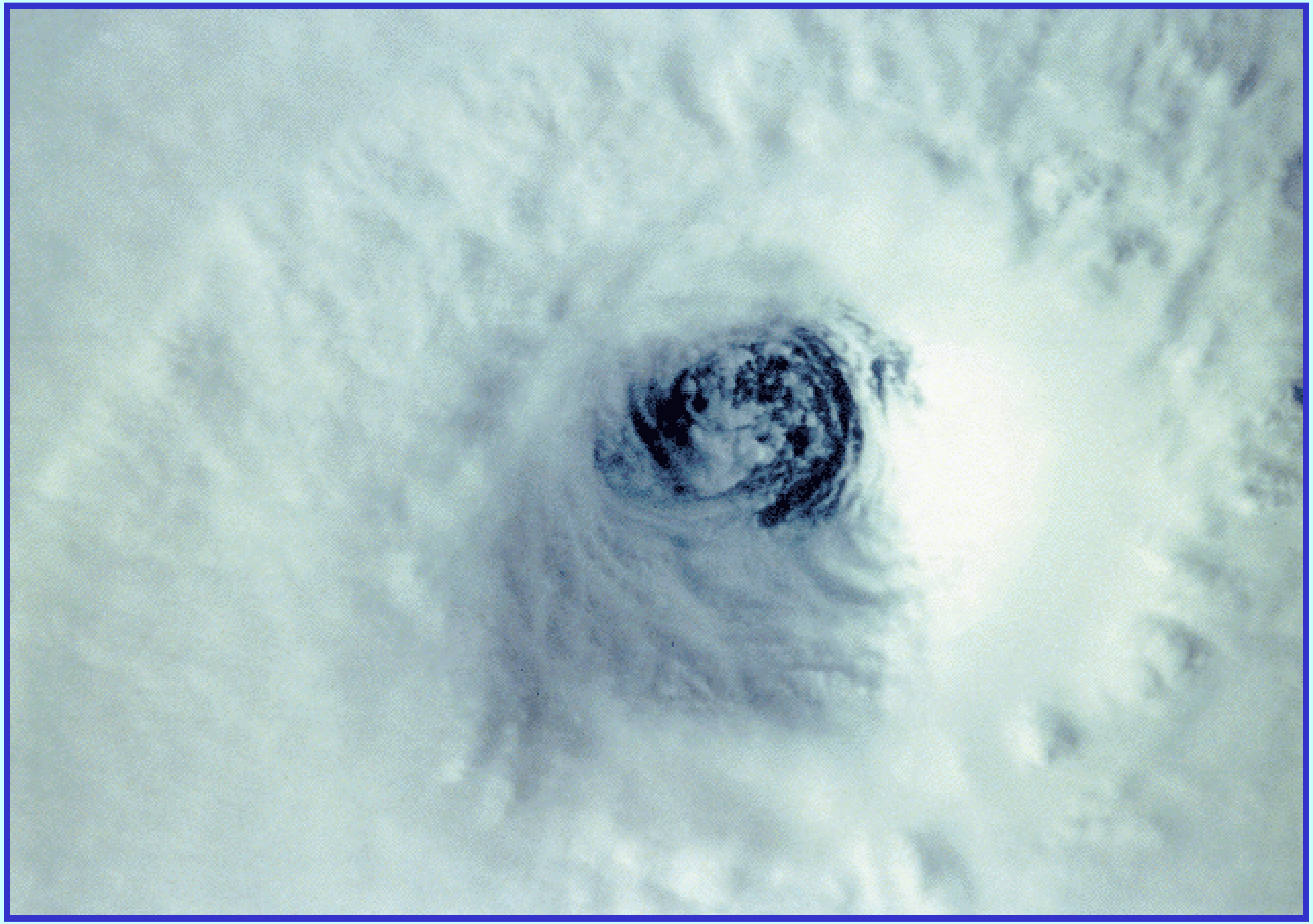
Radar display from the tail radar



Schematic cross-section through a hurricane

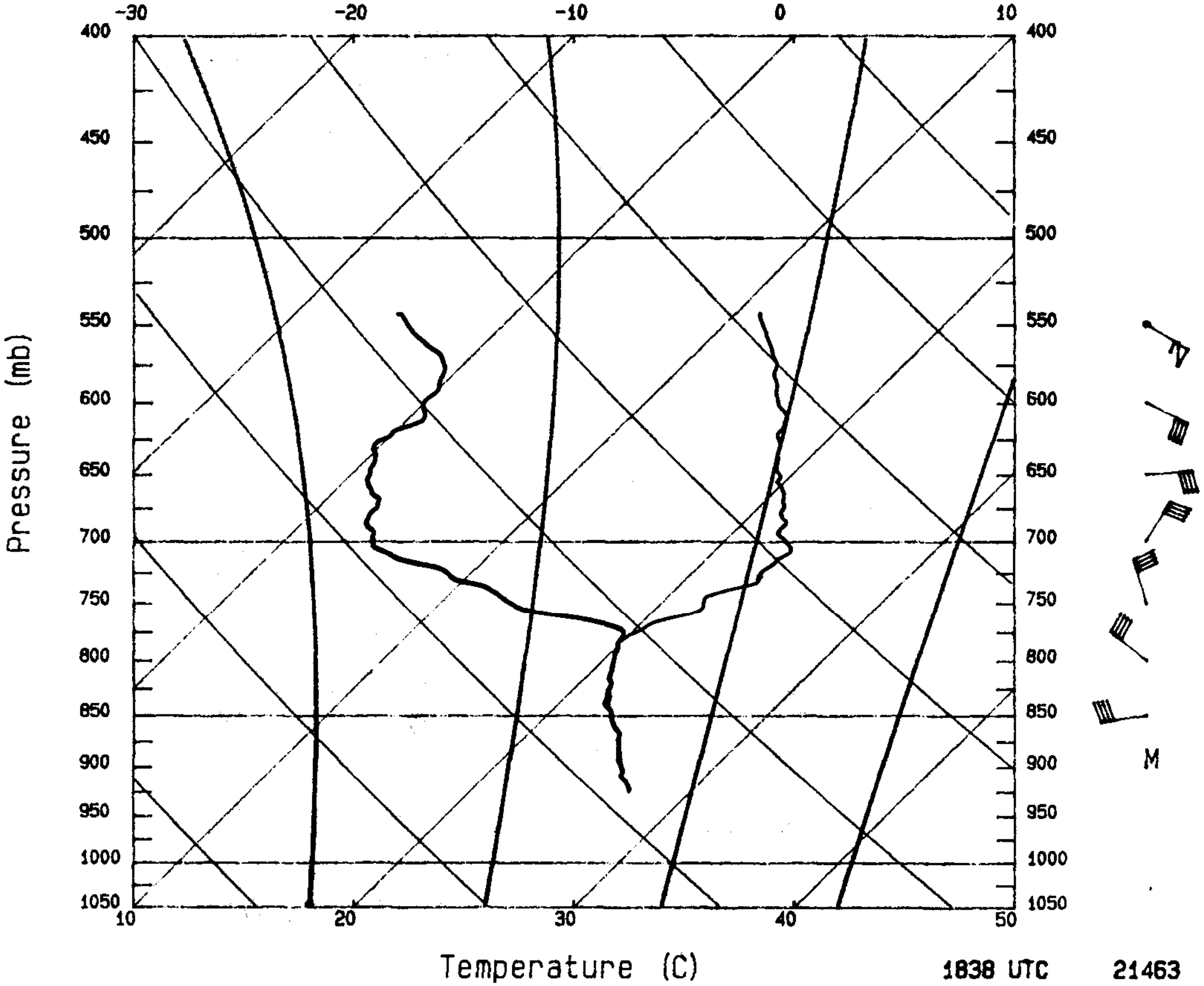


Close up photograph of the eye



The eye of Hurricane *Lili* (2002)

Dropwindsonde sounding in the eye of a hurricane



From Willoughby (AMM, 1988)

Radar PPI in Hurricane Gilbert (1988)

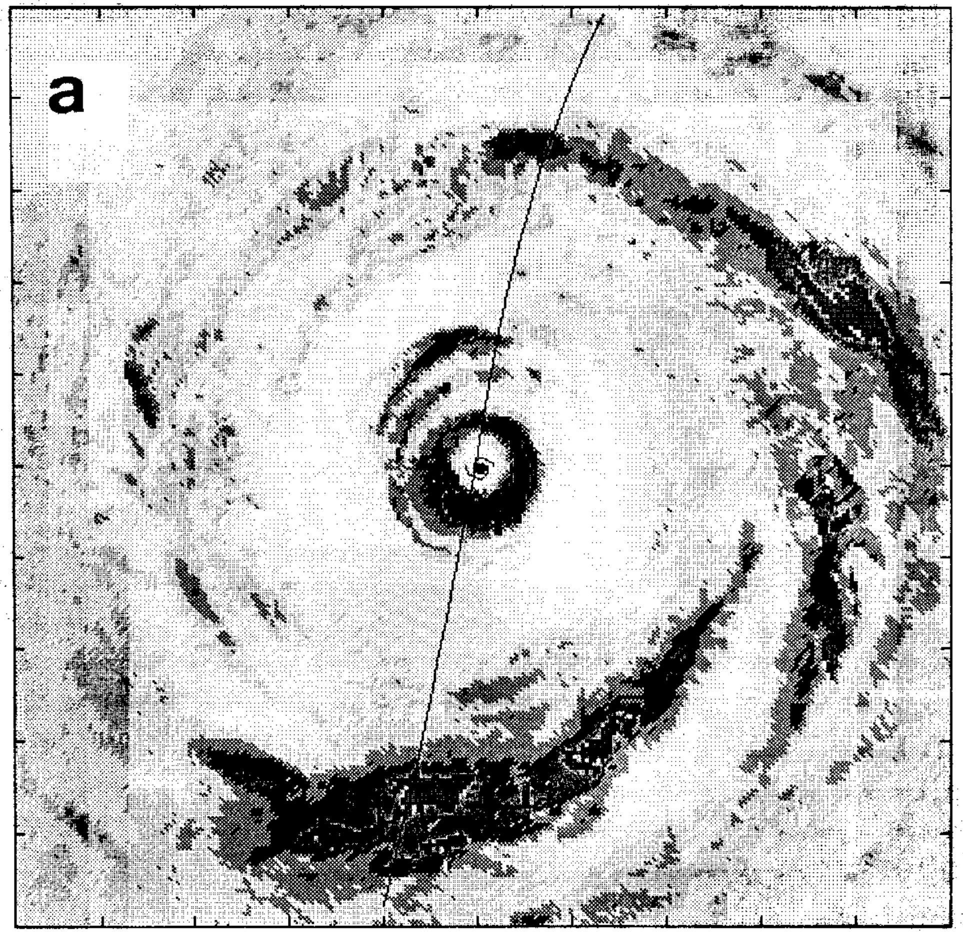
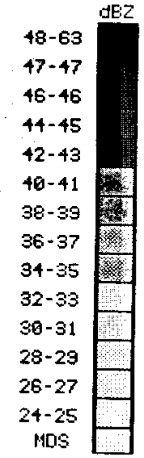
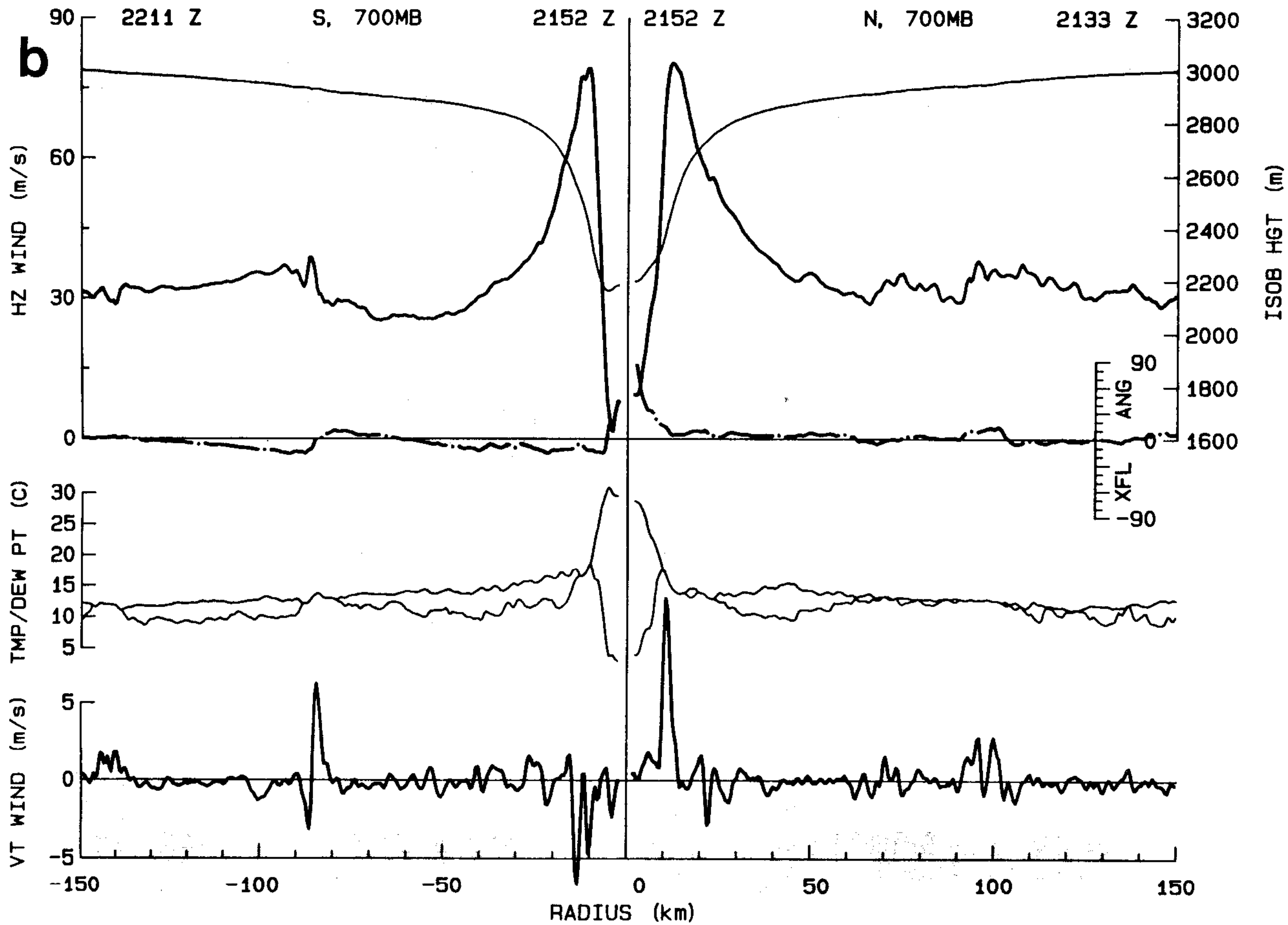


Fig. 2.4 (*a*) Plan-position indicator (PPI) radar reflectivity composite of Hurricane Gilbert at ~2200 UTC 13 September 1988, when it was at maximum intensity near 19.9°N, 83.5°W. (*b*) Flight-level measurements from research aircraft. The abscissa is distance along a north-south pass through the center. 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).



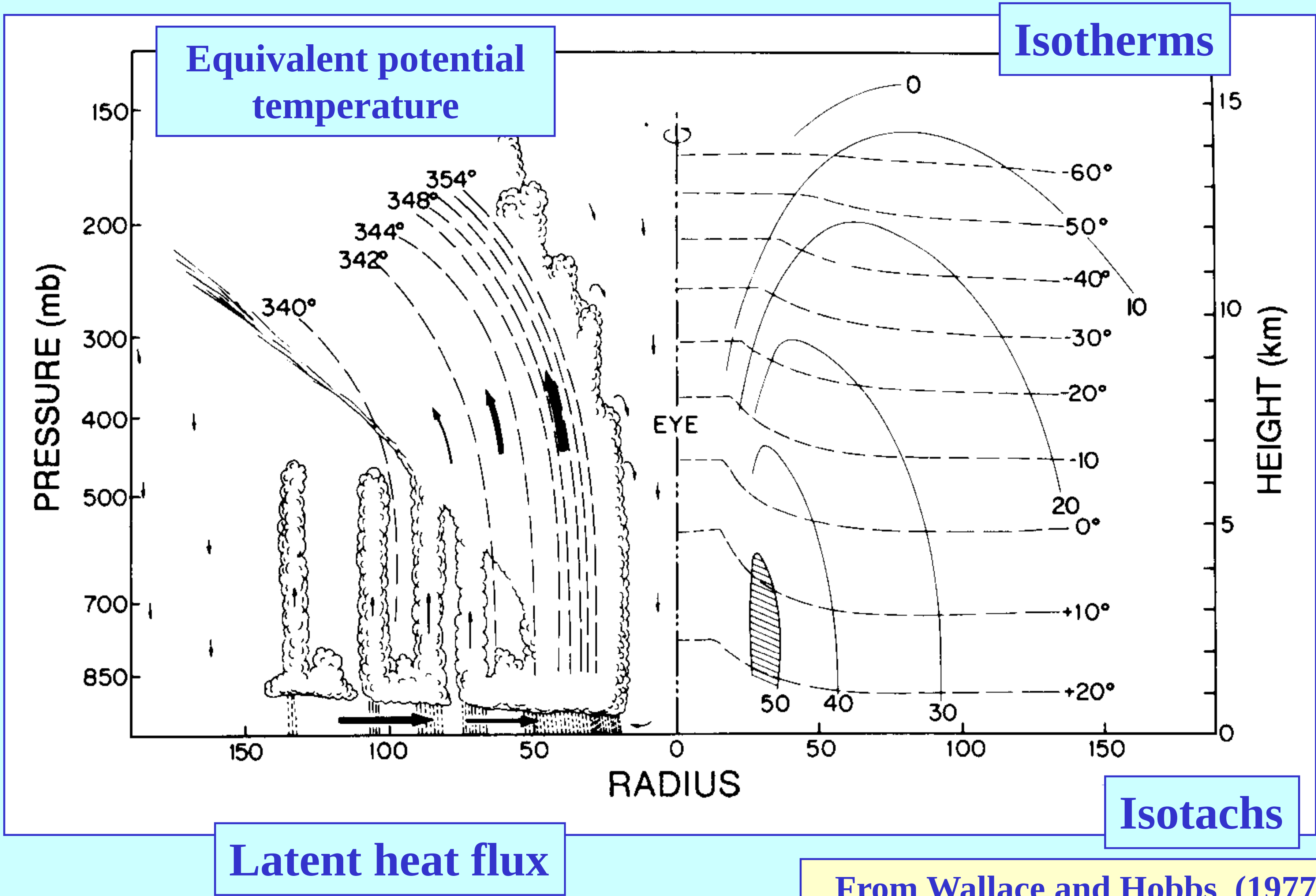
From Black & Willoughby (JAS, 1992)

Flight level data from a Hurricane traverse

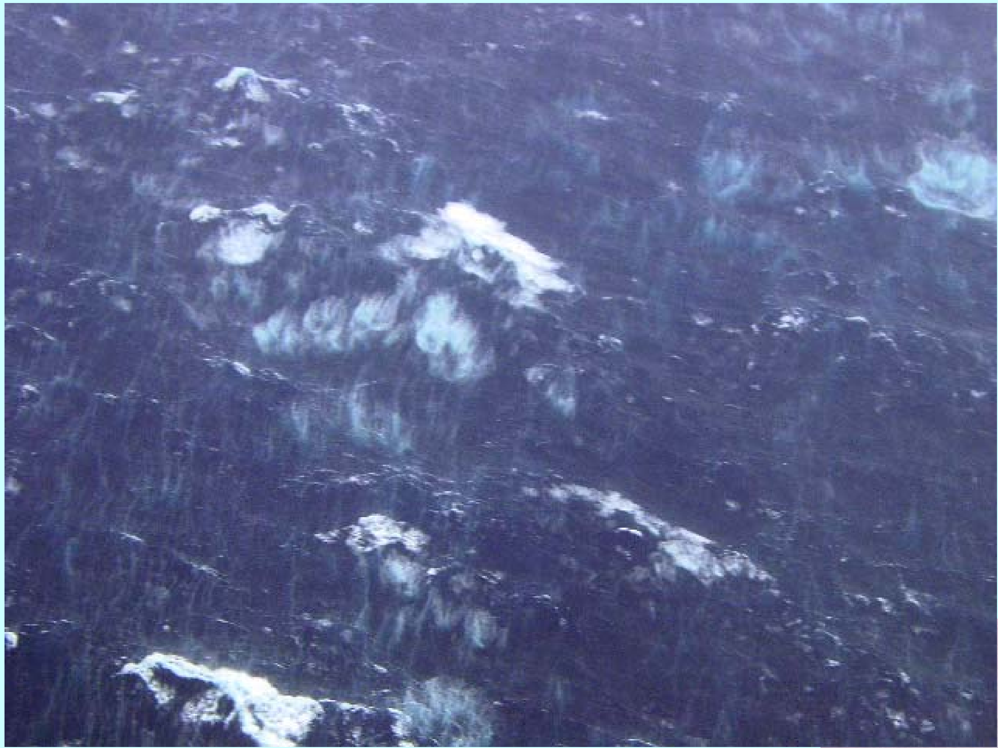


From Willoughby (WMO, 1995)

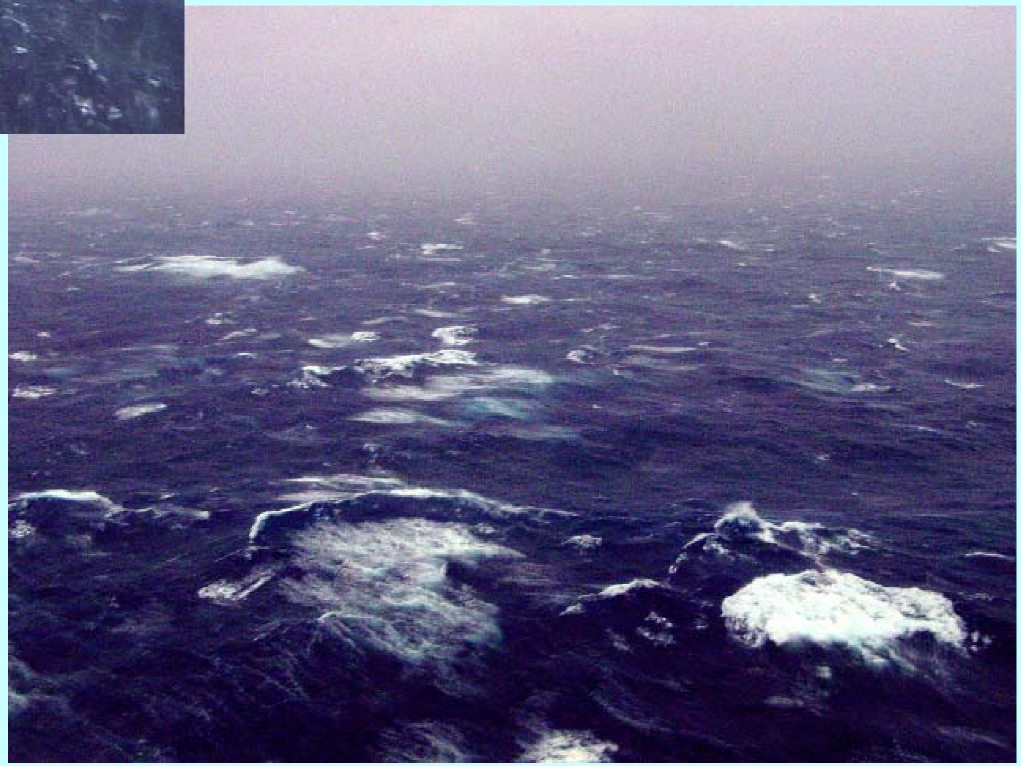
Vertical-radial cross-section through a hurricane



From Wallace and Hobbs (1977)

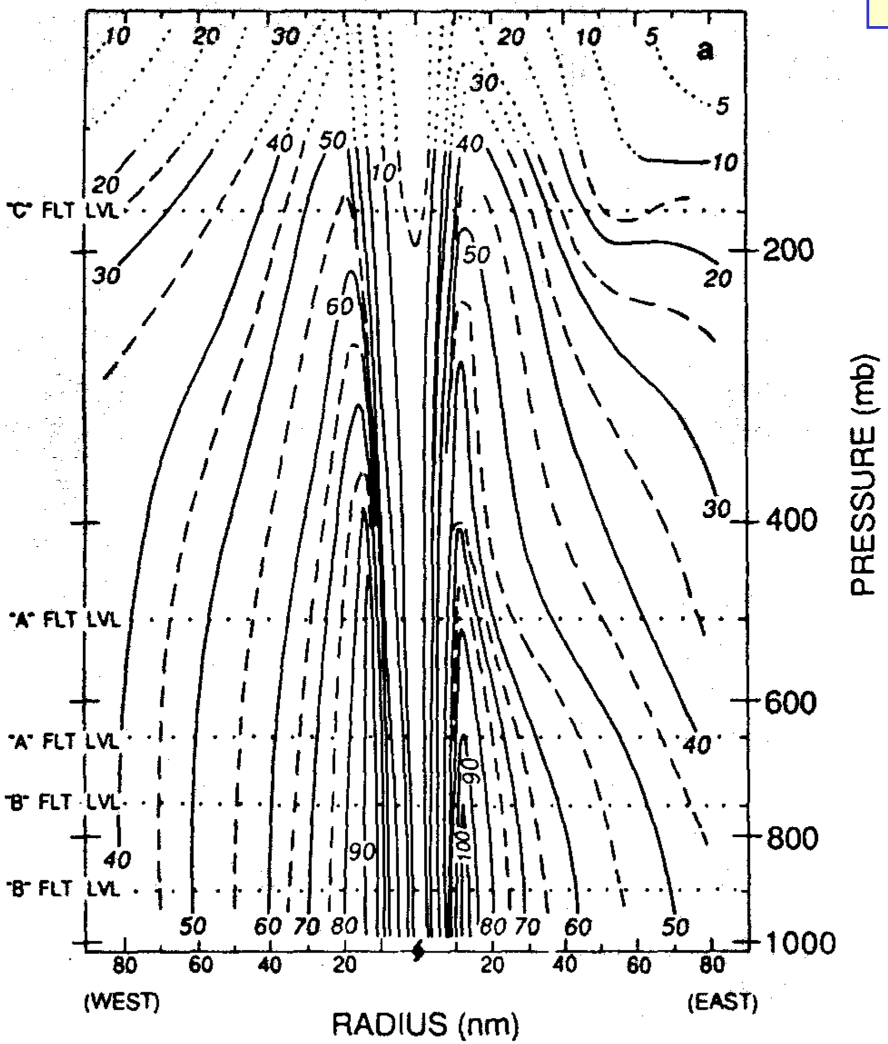


Sea surface fluxes

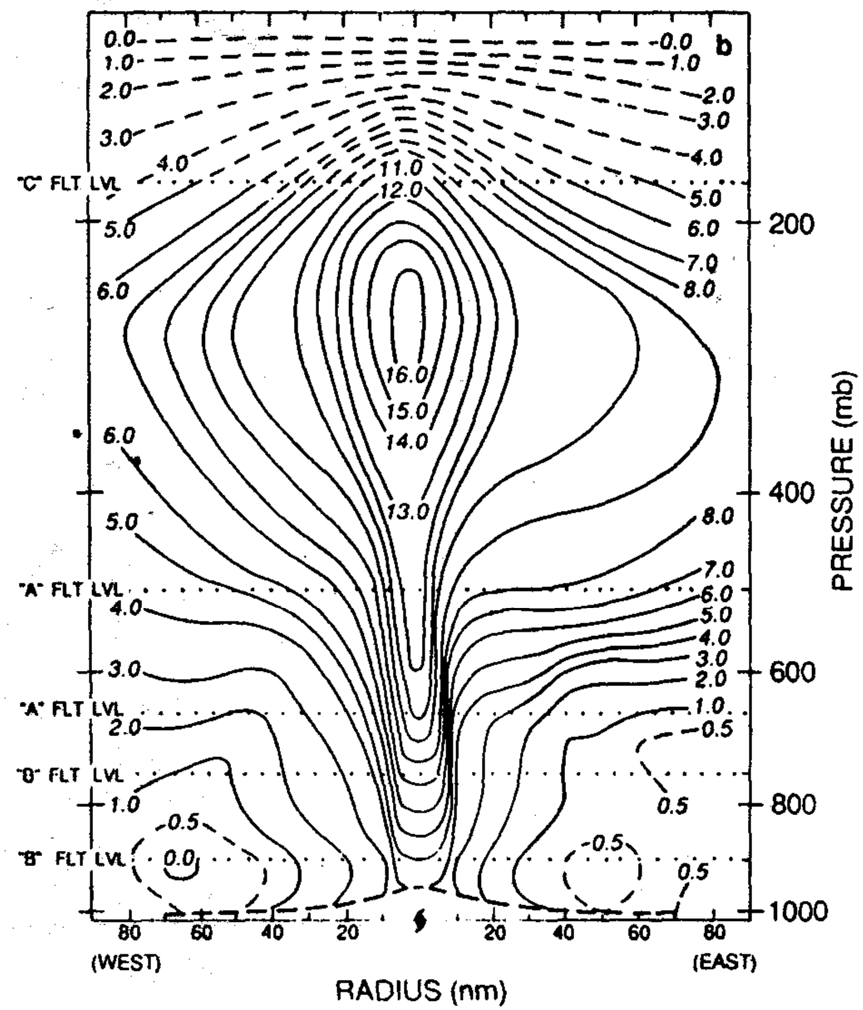


Vertical cross-section of Hurricane Hilda (1964)

From Hawkins and Rubsam (MWR, 1988)

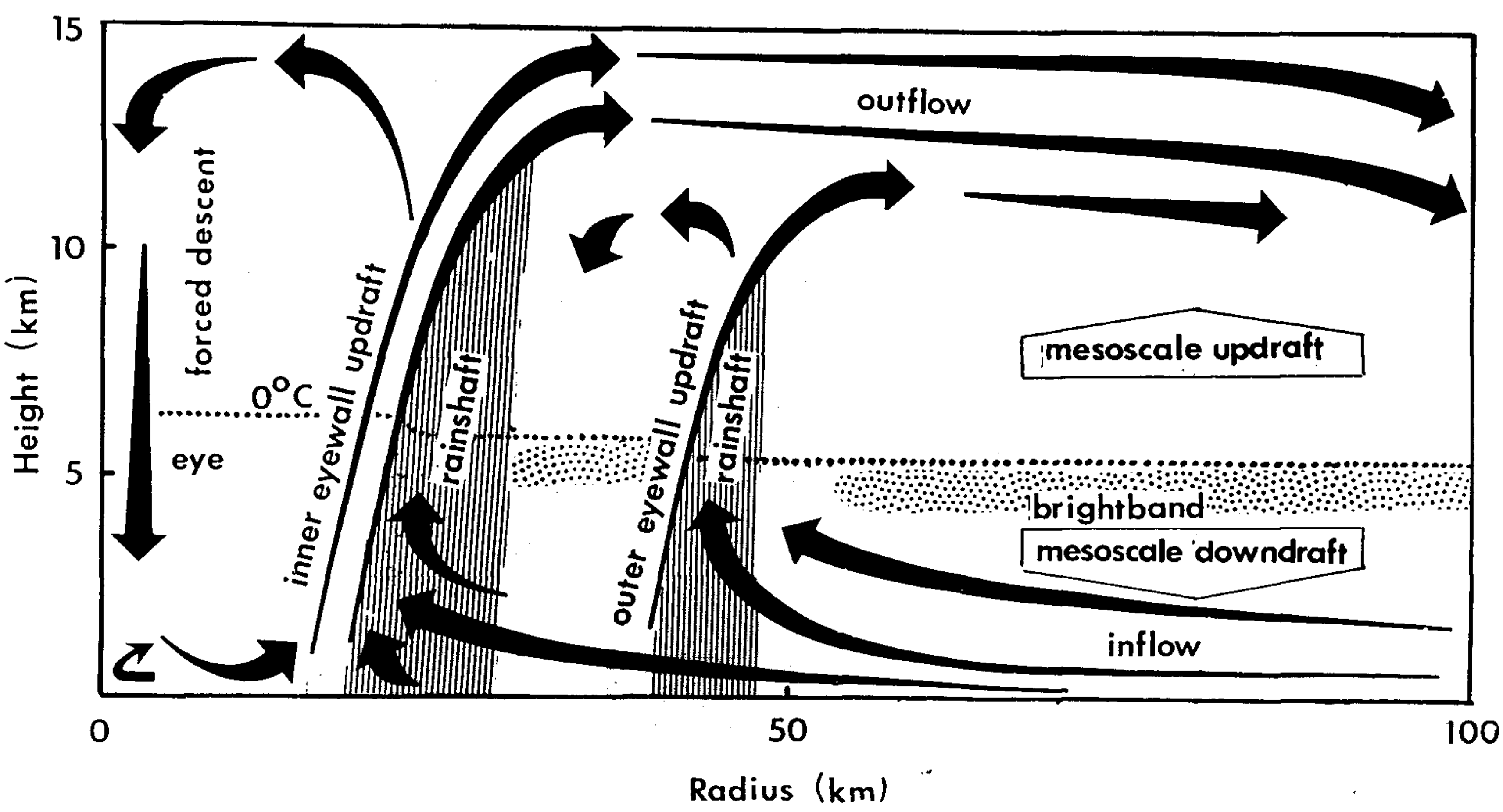


Azimuthal wind



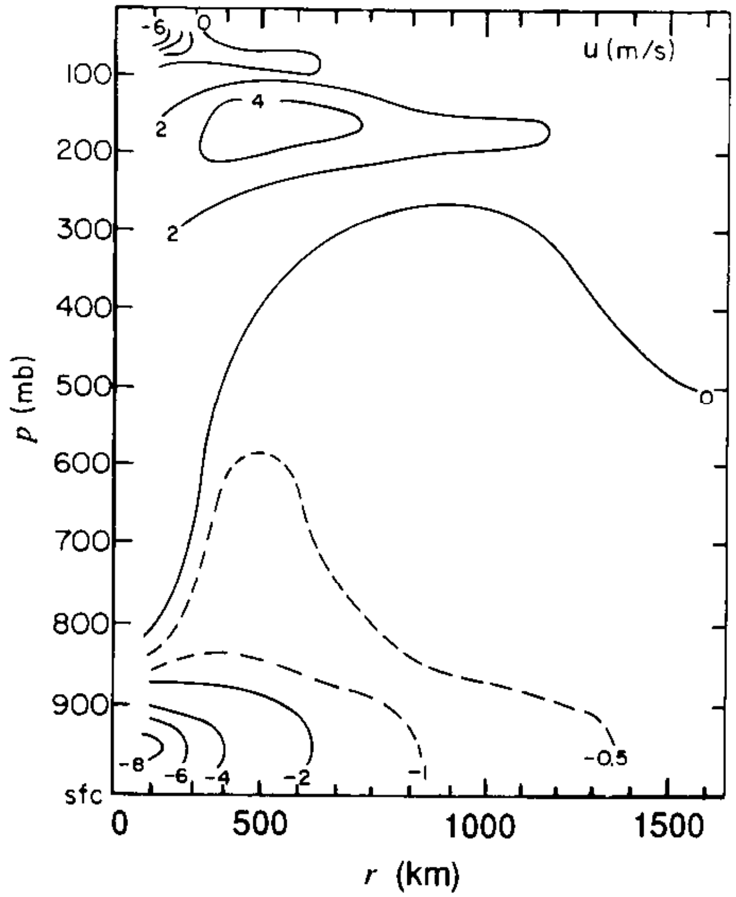
Temperature anomaly

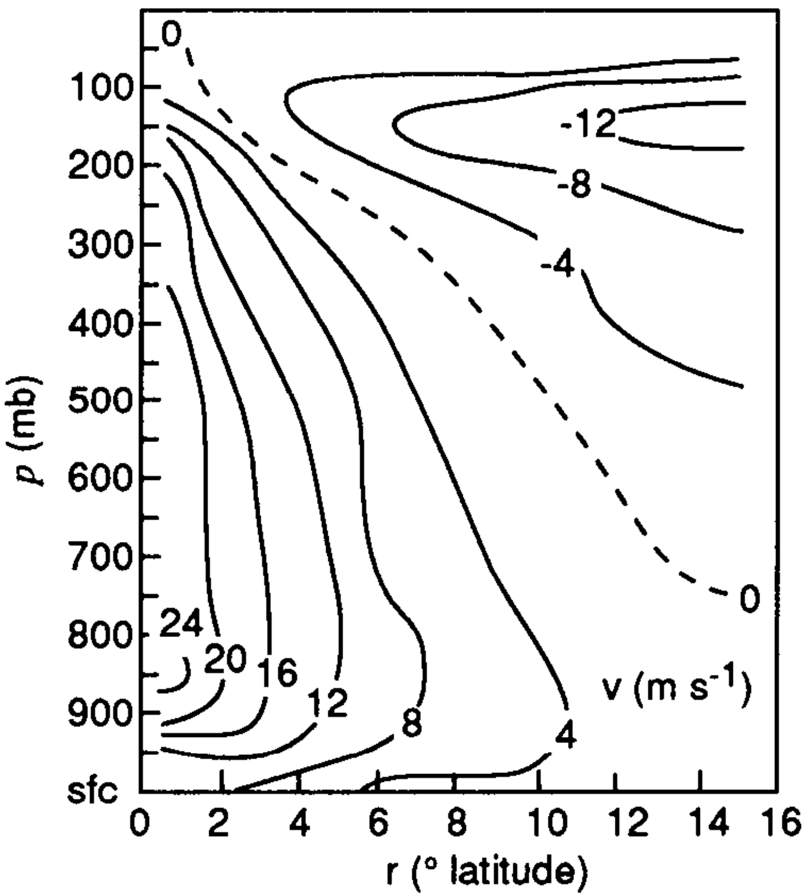
A TC with a double eyewall



From Willoughby, WMO (1995)

Cross-section from composite data



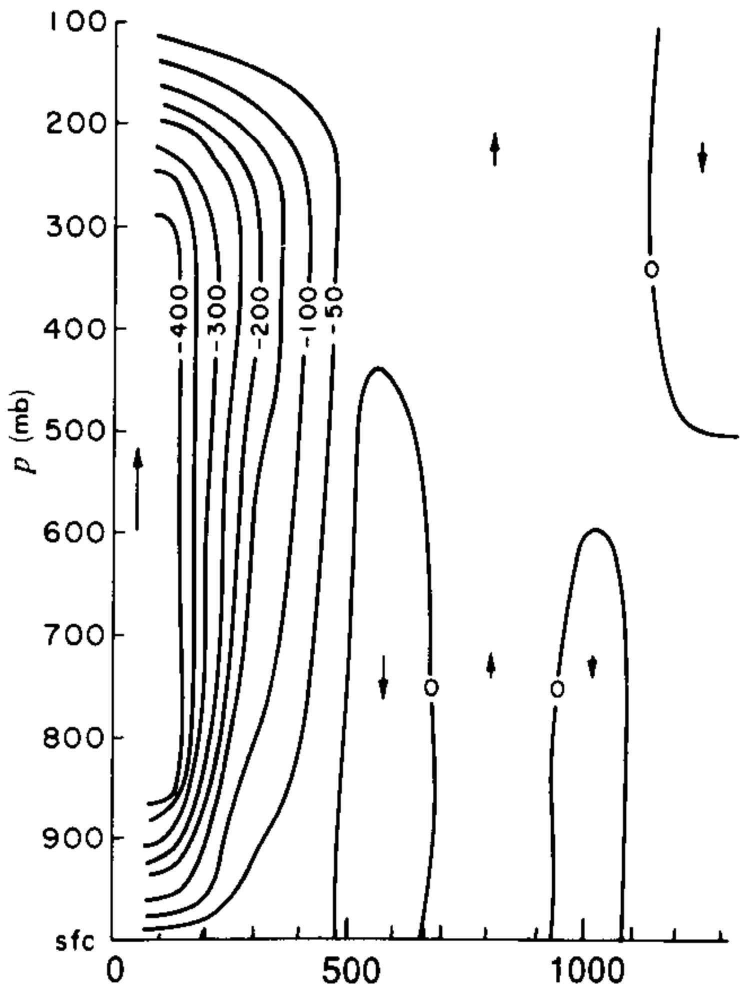


Radial wind

Azimuthal wind

From Gray (1979)

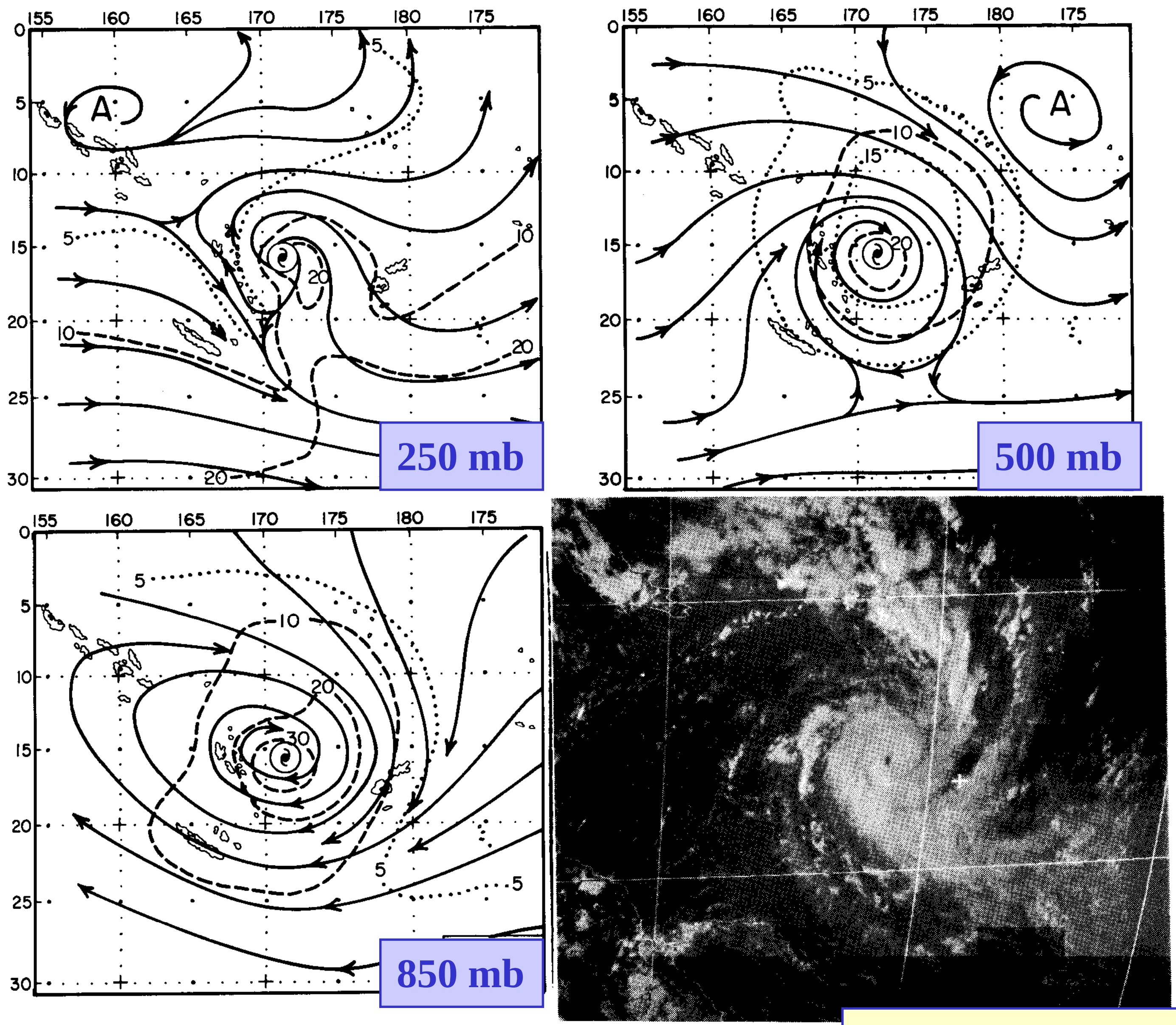
Vertical motion



From Frank (MWR, 1977)

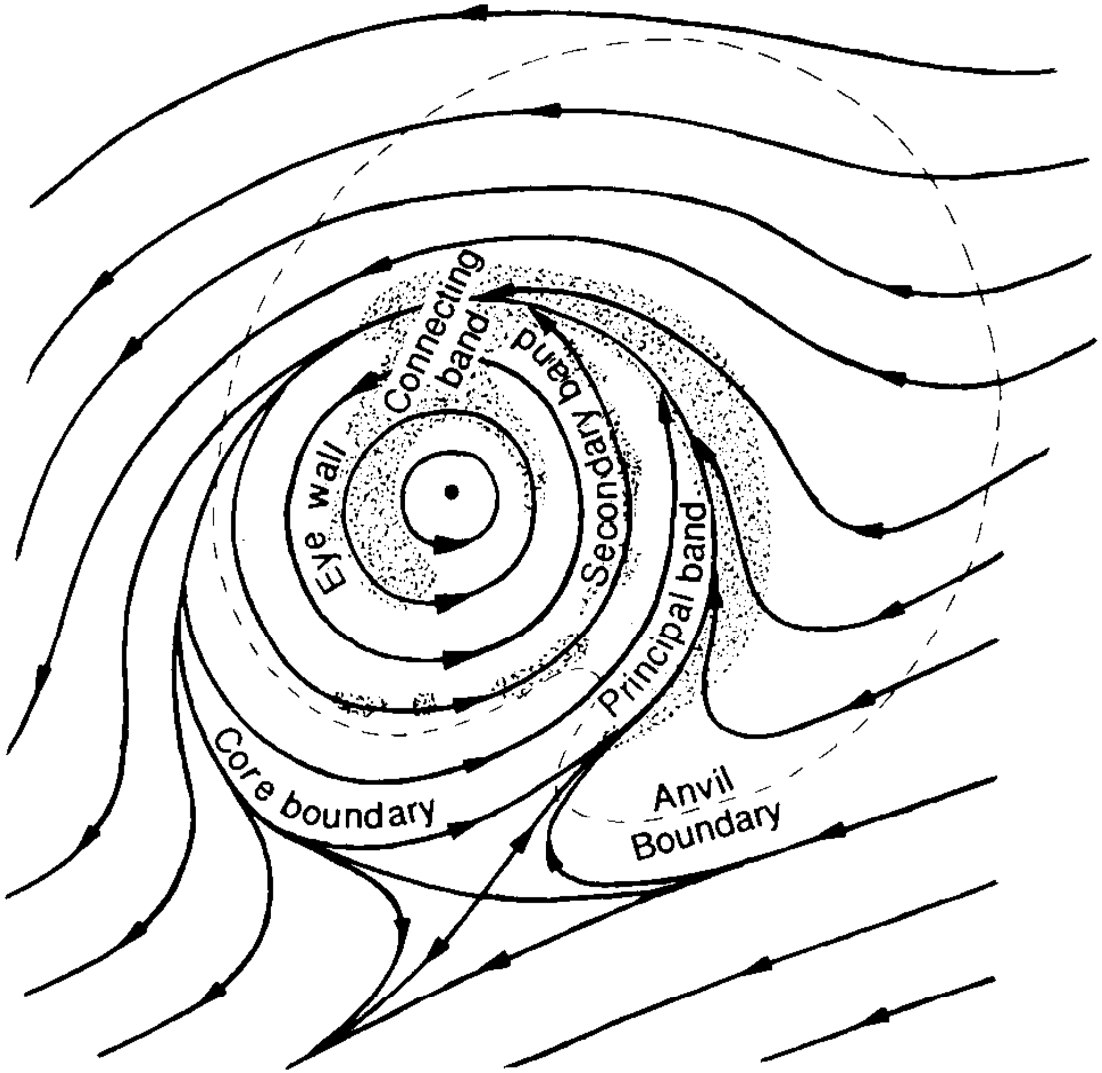
Vertical cross section of the mean vertical air motion (mb per day) in typhoons. Analysis is a composite of data collected in many storms.

Asymmetries



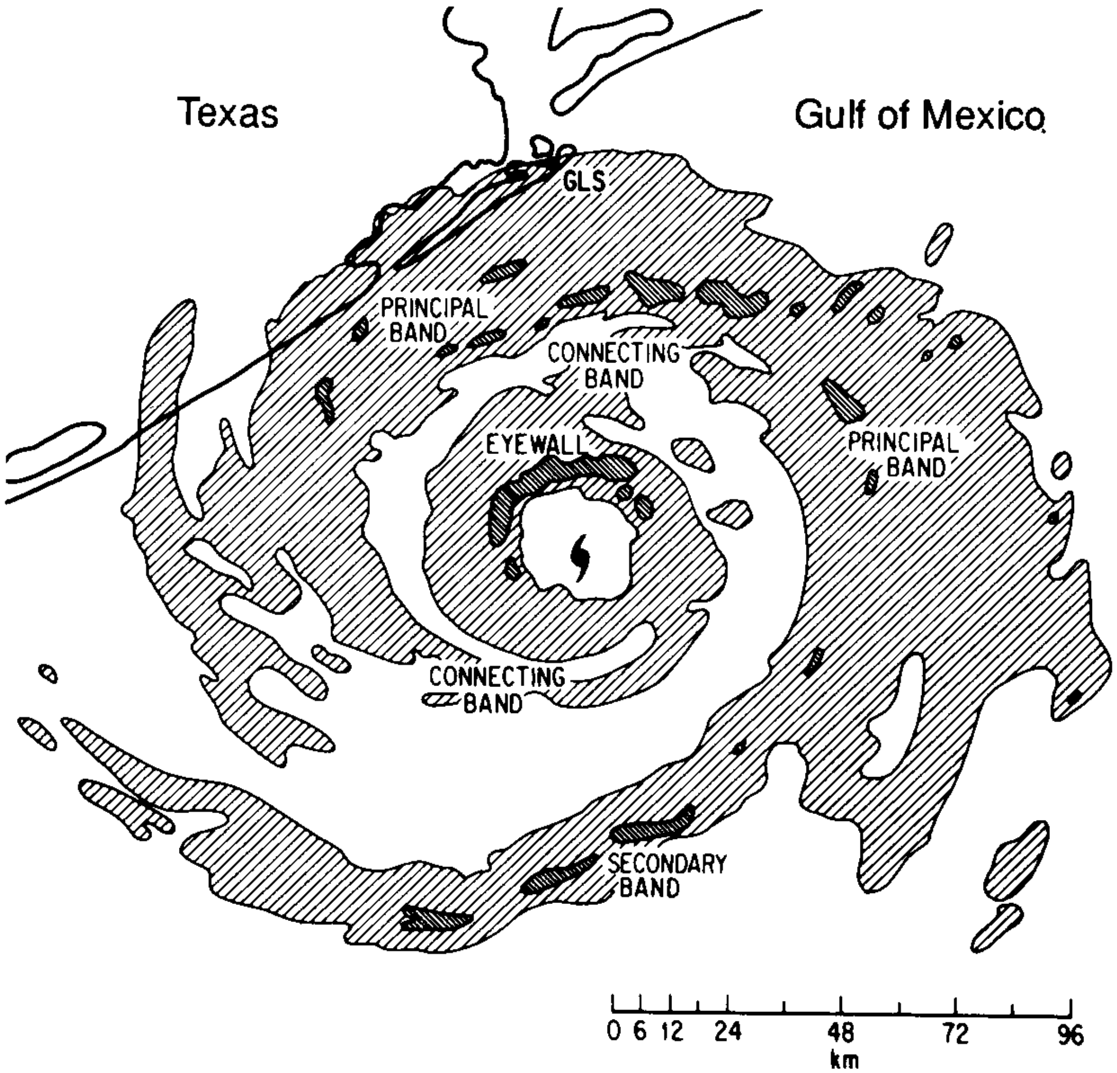
From Holland (AMM, 1984)

Asymmetric structure



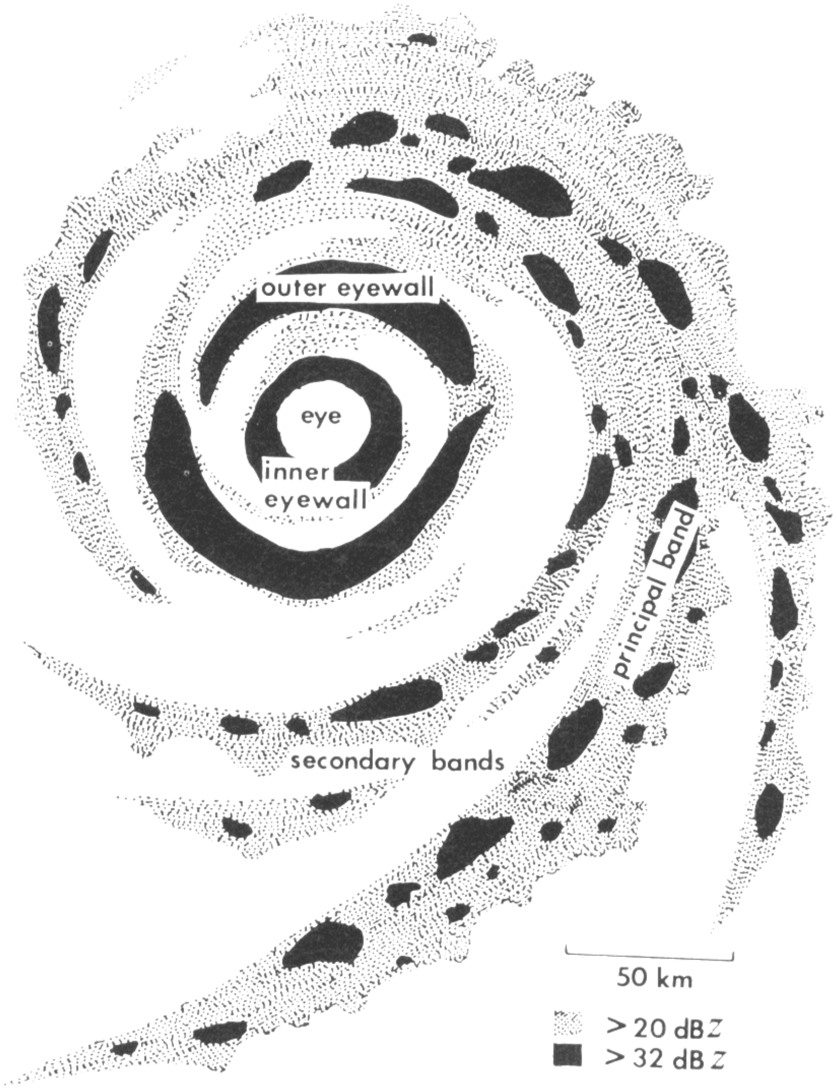
From Houze

Typical radar echo pattern



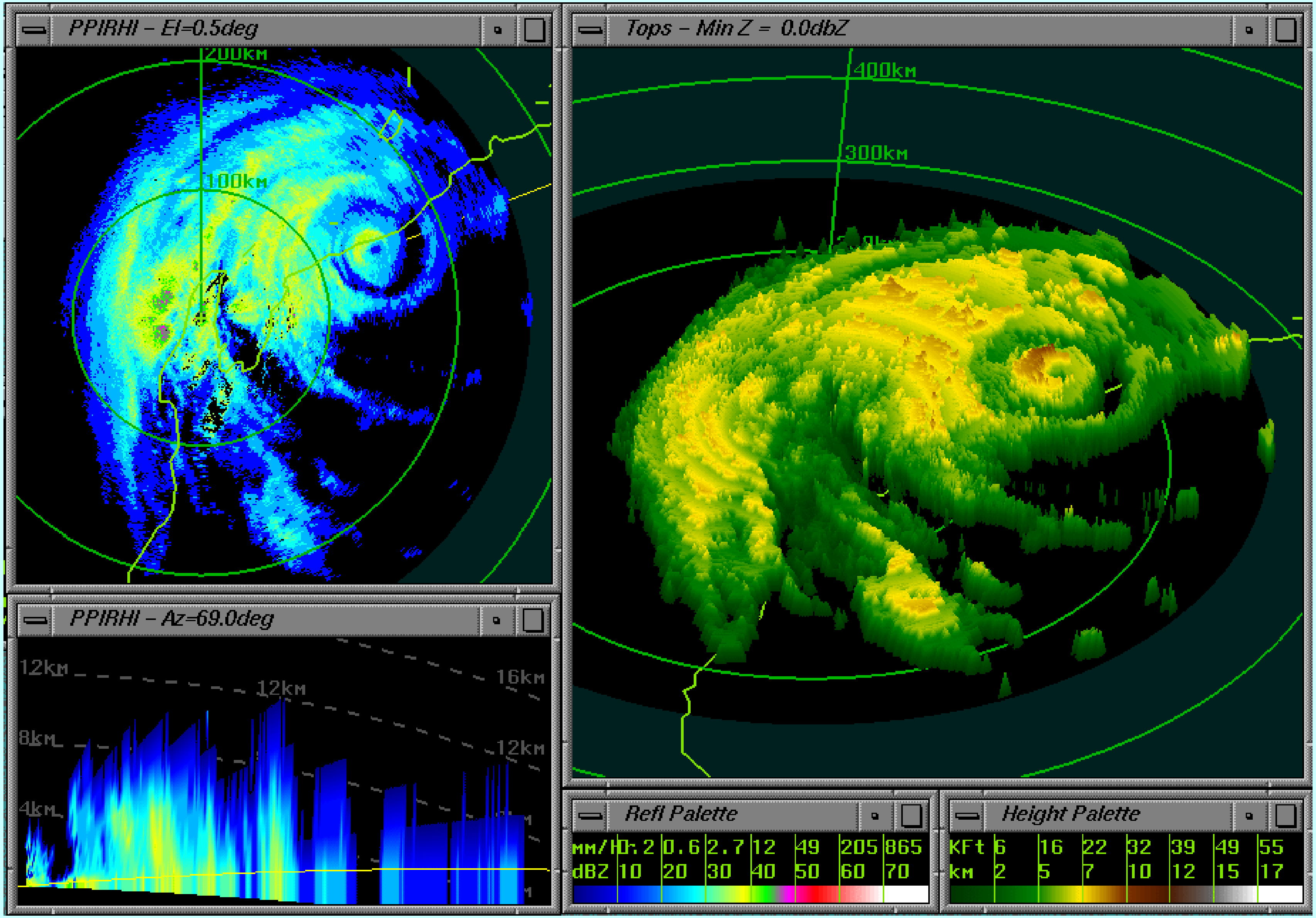
From Marks and Houze, 1987

A TC with a double eyewall

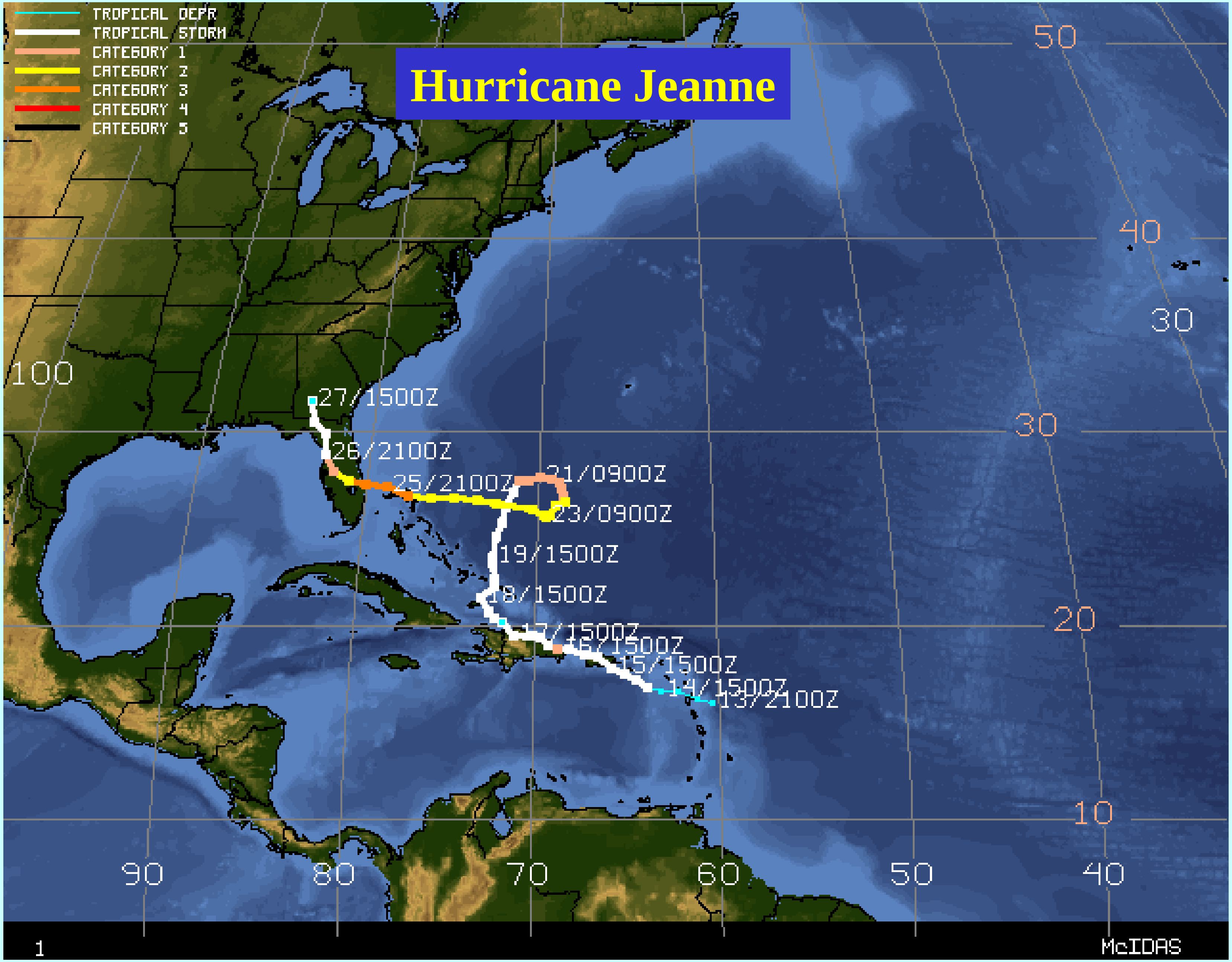


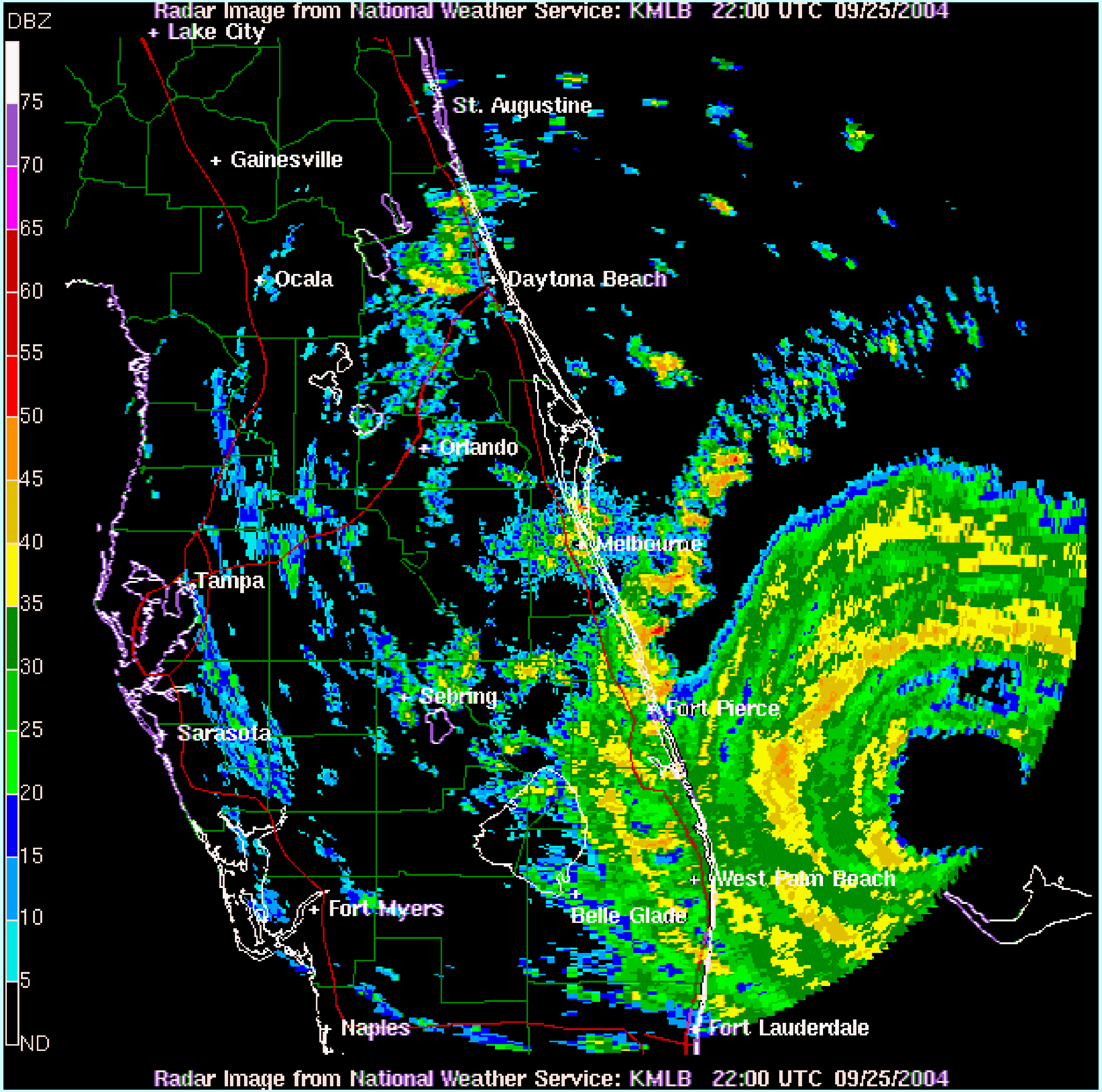
From Willoughby, AMM (1988)

Western Australia: TC Bobby



Hurricane Jeanne




Radar Image from National Weather Service: KMLB 22:00 UTC 09/25/2004
DBZ
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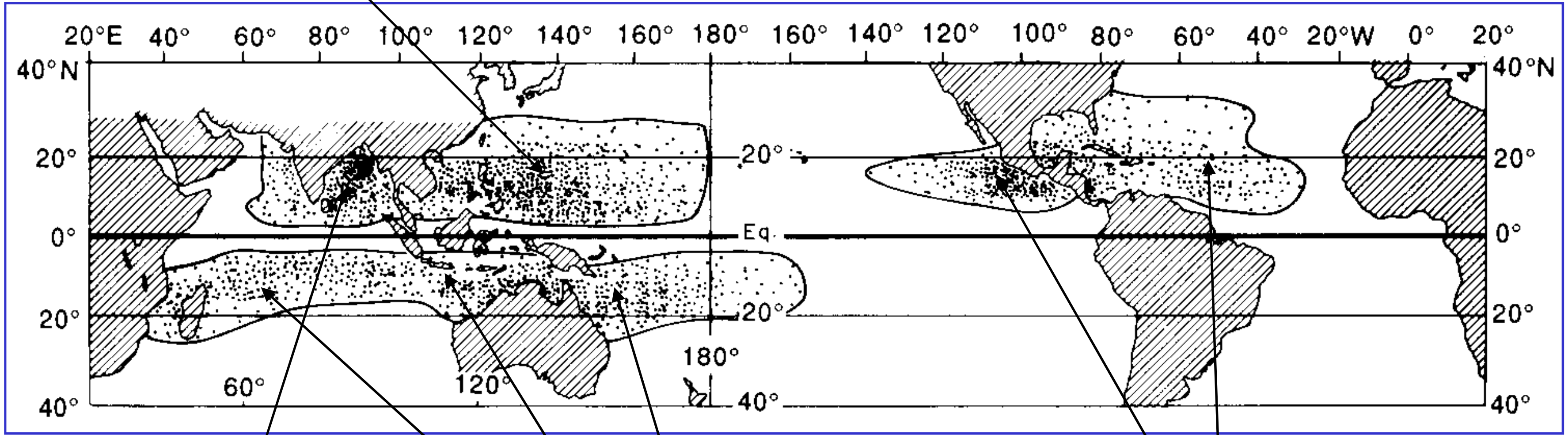
ND
Lake City
St. Augustine
Gainesville
Ocala
Daytona Beach
Orlando
Melbourne
Tampa
Sebring
Fort Pierce
Sarasota
West Palm Beach
Belle Glade
Fort Myers
Naples
Fort Lauderdale
Radar Image from National Weather Service: KMLB 22:00 UTC 09/25/2004

Regions of TC formation

Typhoons



Cyclone

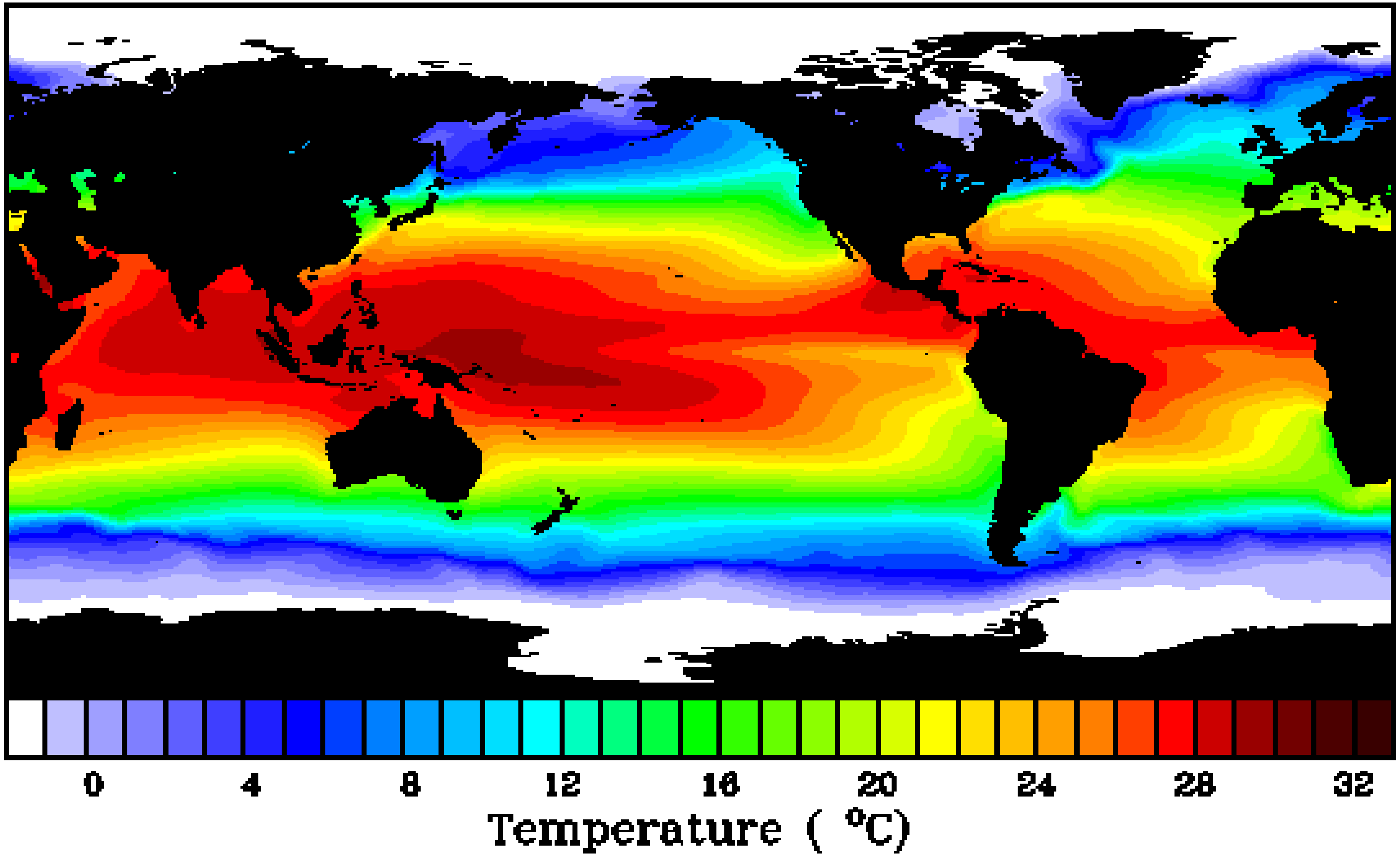
Tropical Cyclone

Hurricane

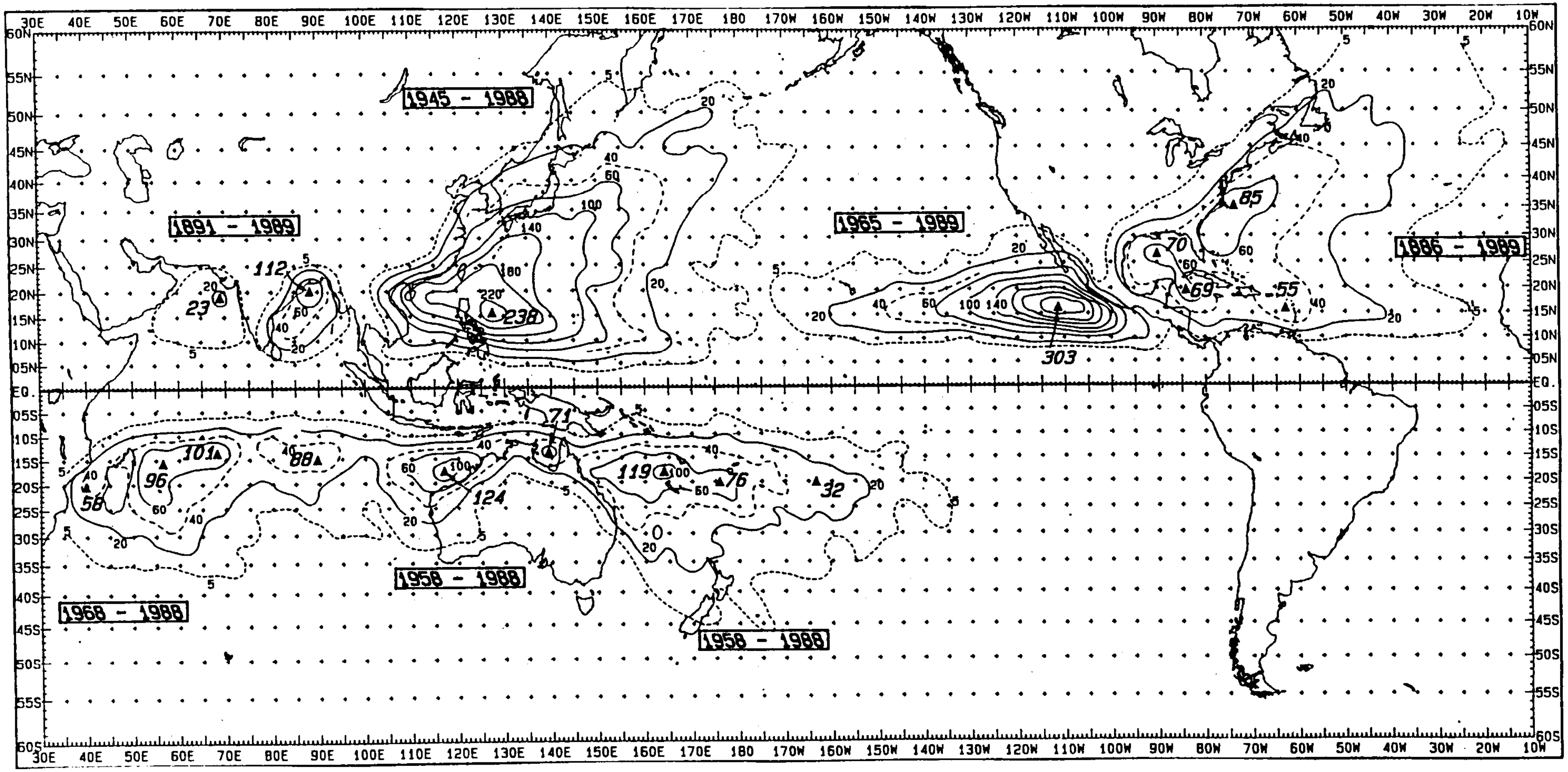
Tropical cyclogenesis requires a water temperature of at least 26.5 °C

From Gray (1975)

Annual mean sea surface temperatures

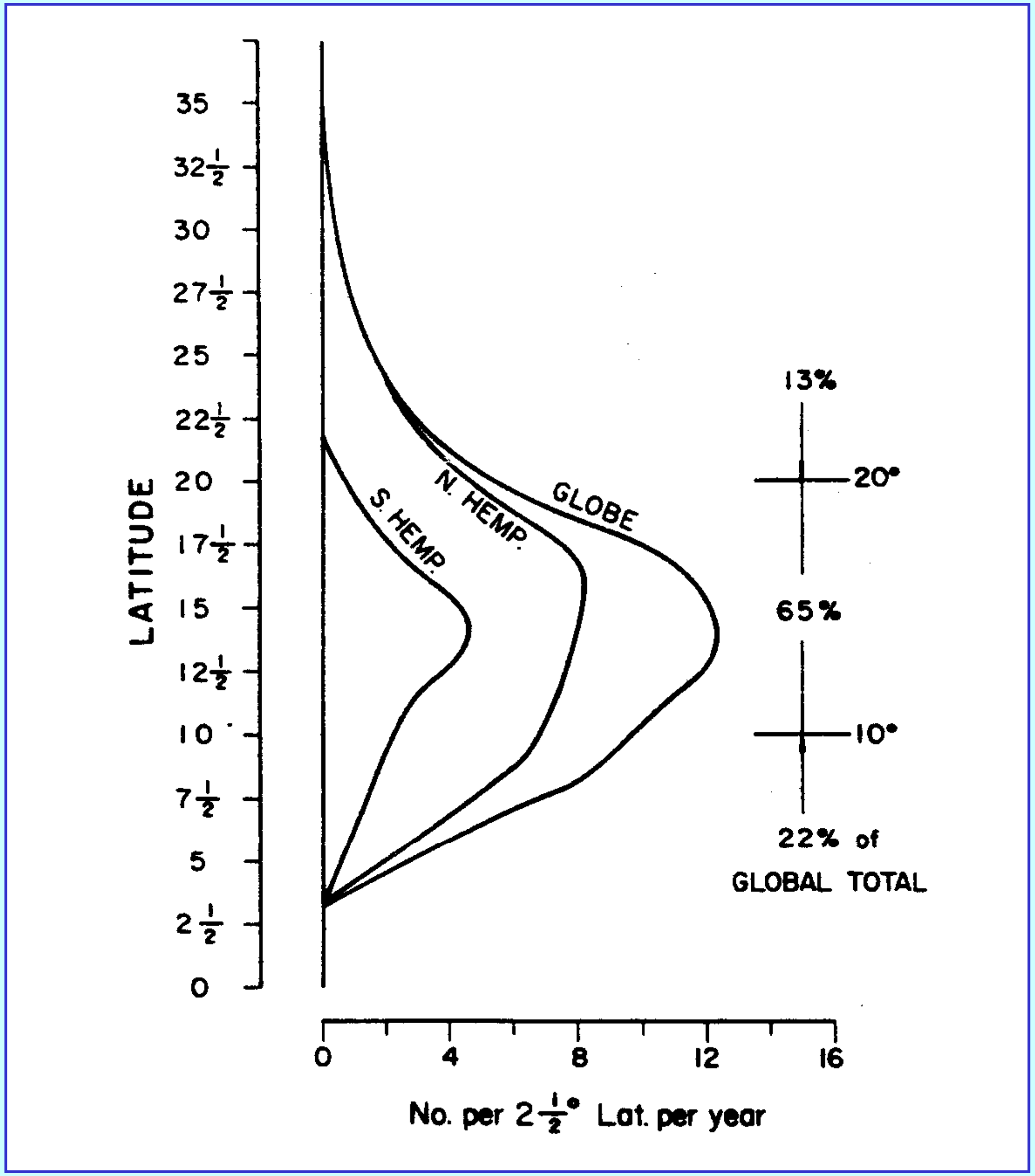


Frequency of TCs per 100 years



From WMO (1993)

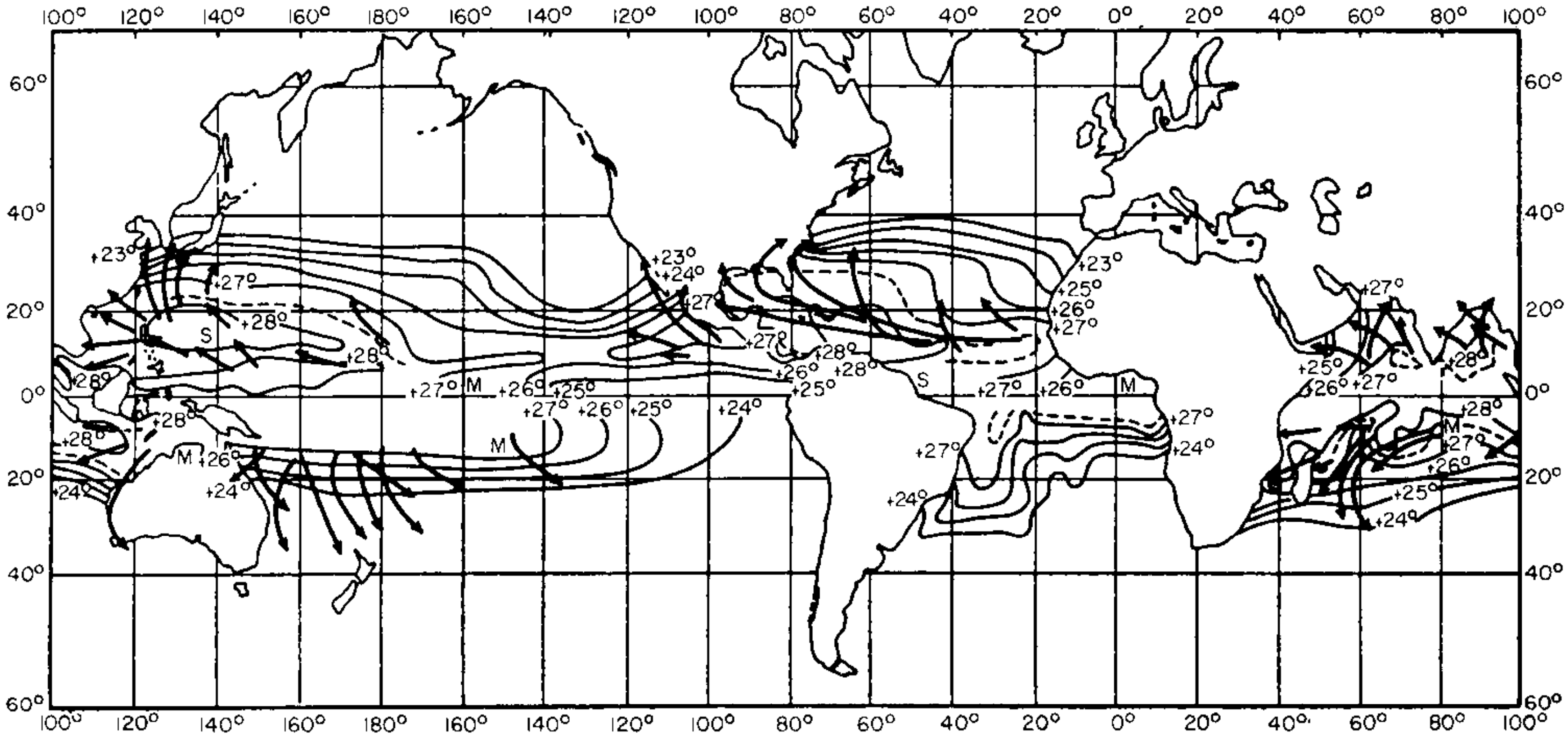
Mean latitude of formation



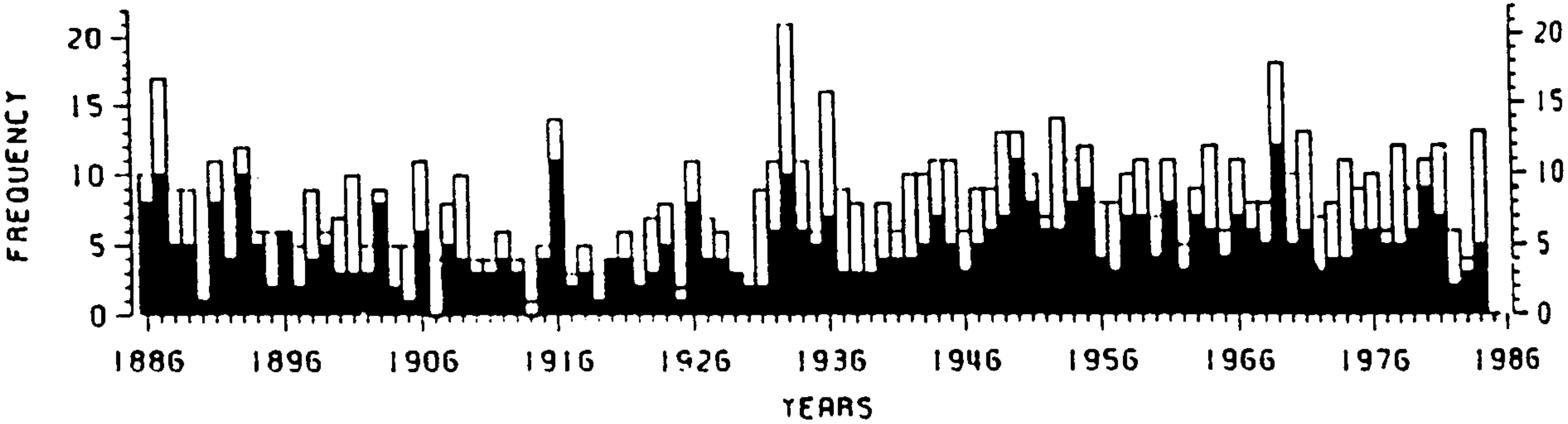
Latitudes at which initial disturbances later became tropical cyclones were first detected

From Gray (MWR, 1975)

Tracks of TCs in relation to SST

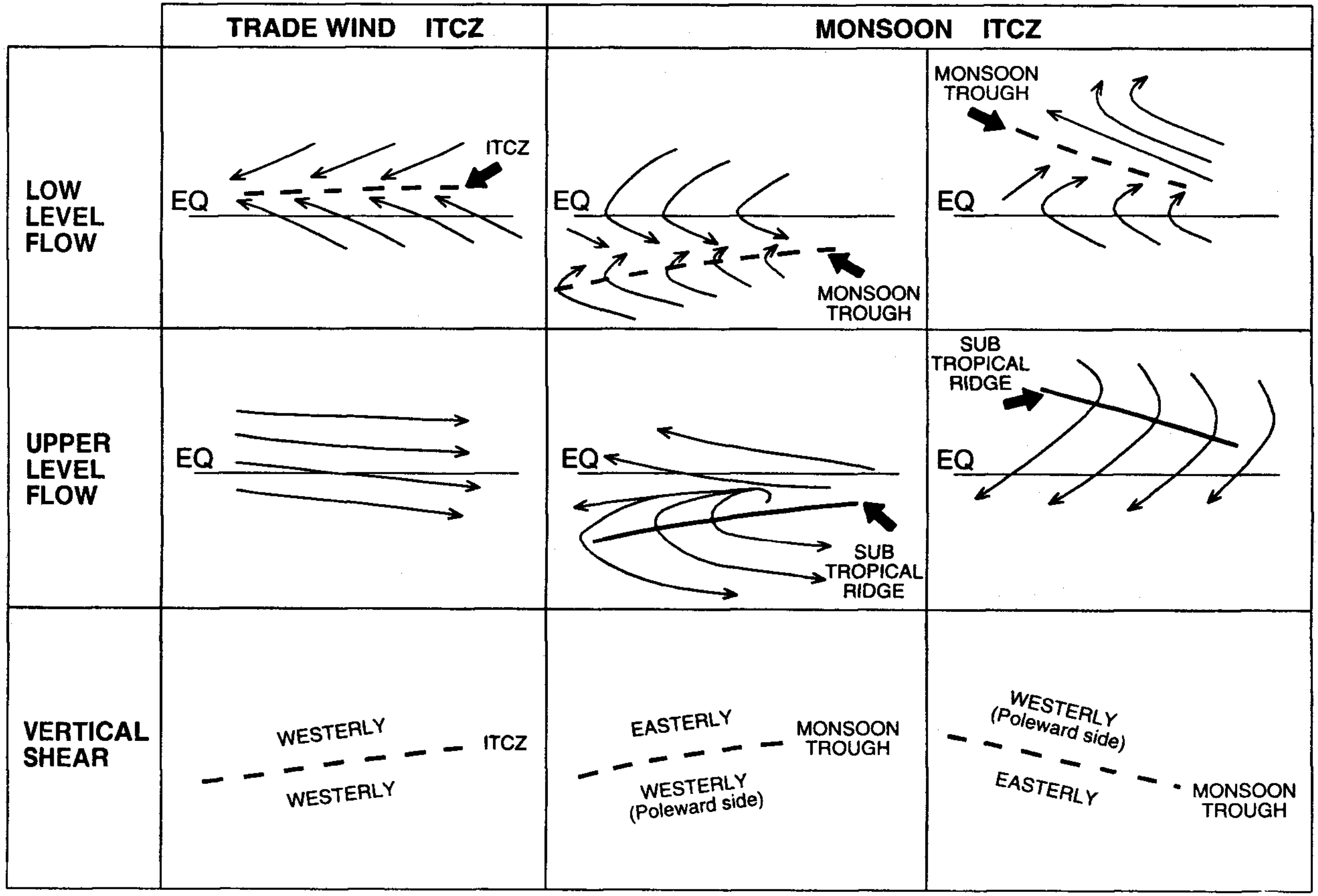


Climatology in Atlantic Basin



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

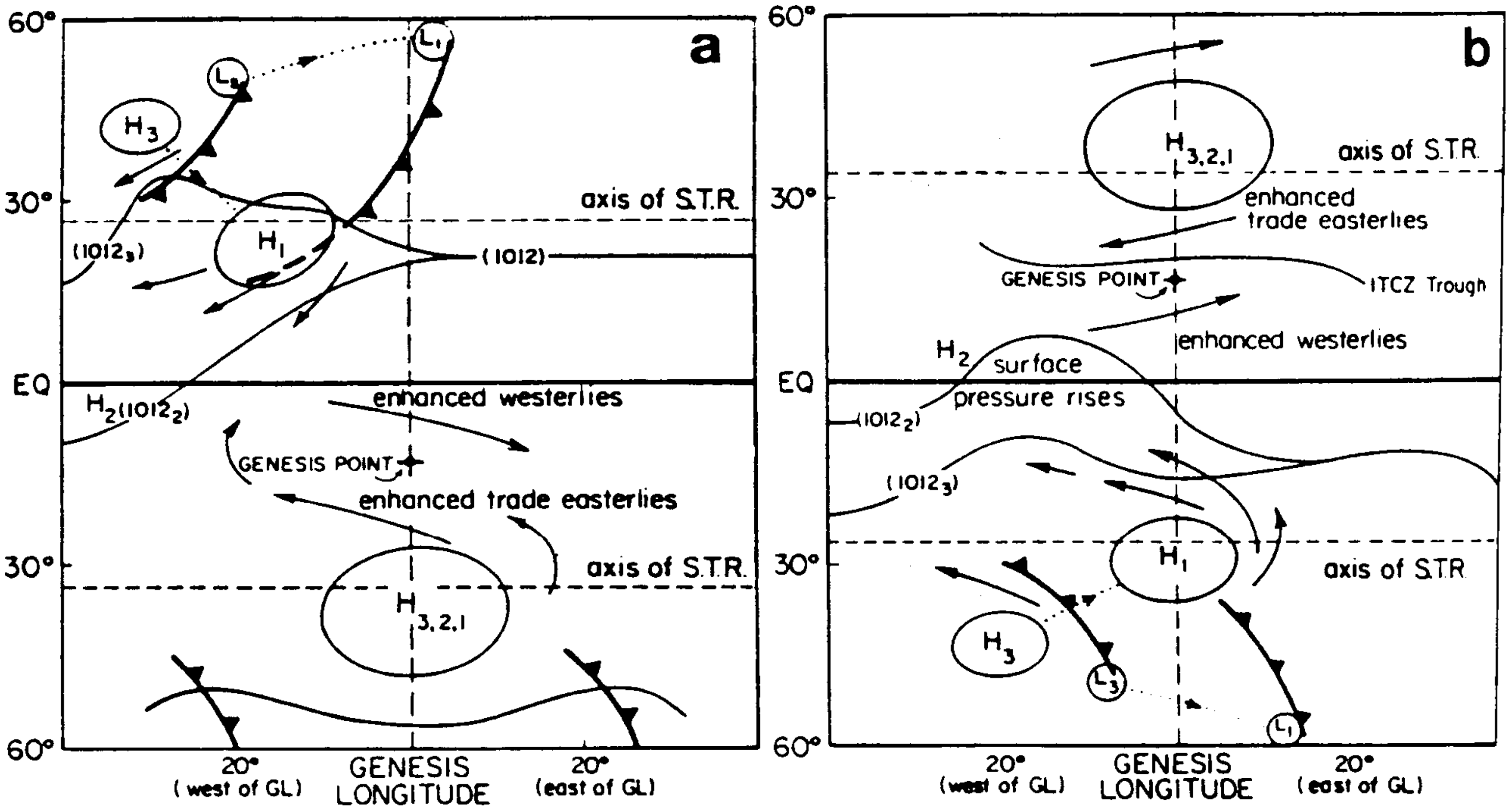


Fig. 3.19 Schematic surface map of the positions of important synoptic-scale features 3 days and 1 day before cyclone genesis in (a) Southern and (b) Northern Hemisphere. Subscripts on the highs (H) and lows (L) denote days before genesis (Love 1982).

Satellite imagery - classification

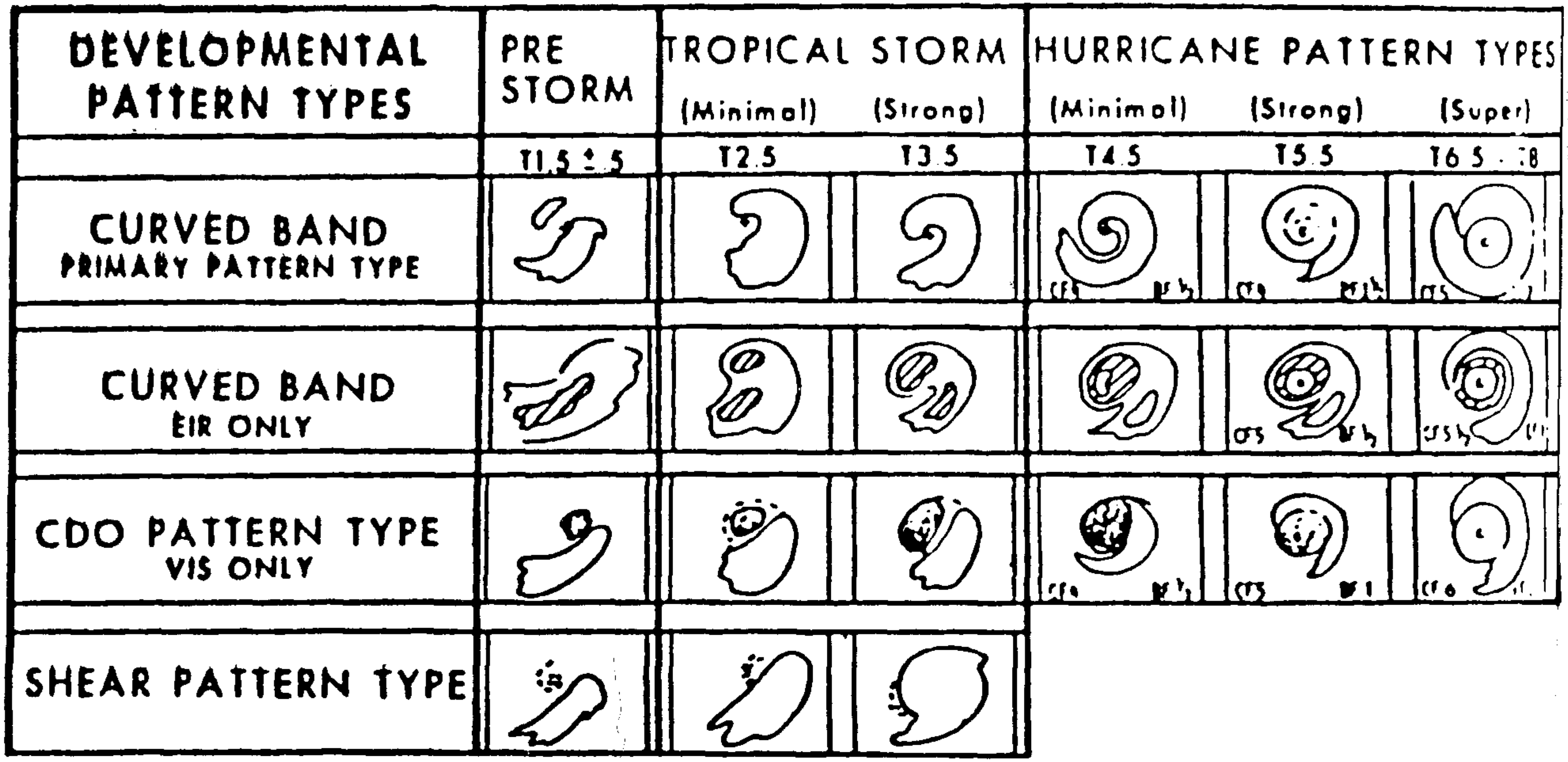


Fig. 3.20 Cloud pattern types in the tropical cyclone intensity analysis based on satellite imagery. Pattern changes from left to right are typical 24-hourly changes (Dvorak 1984).

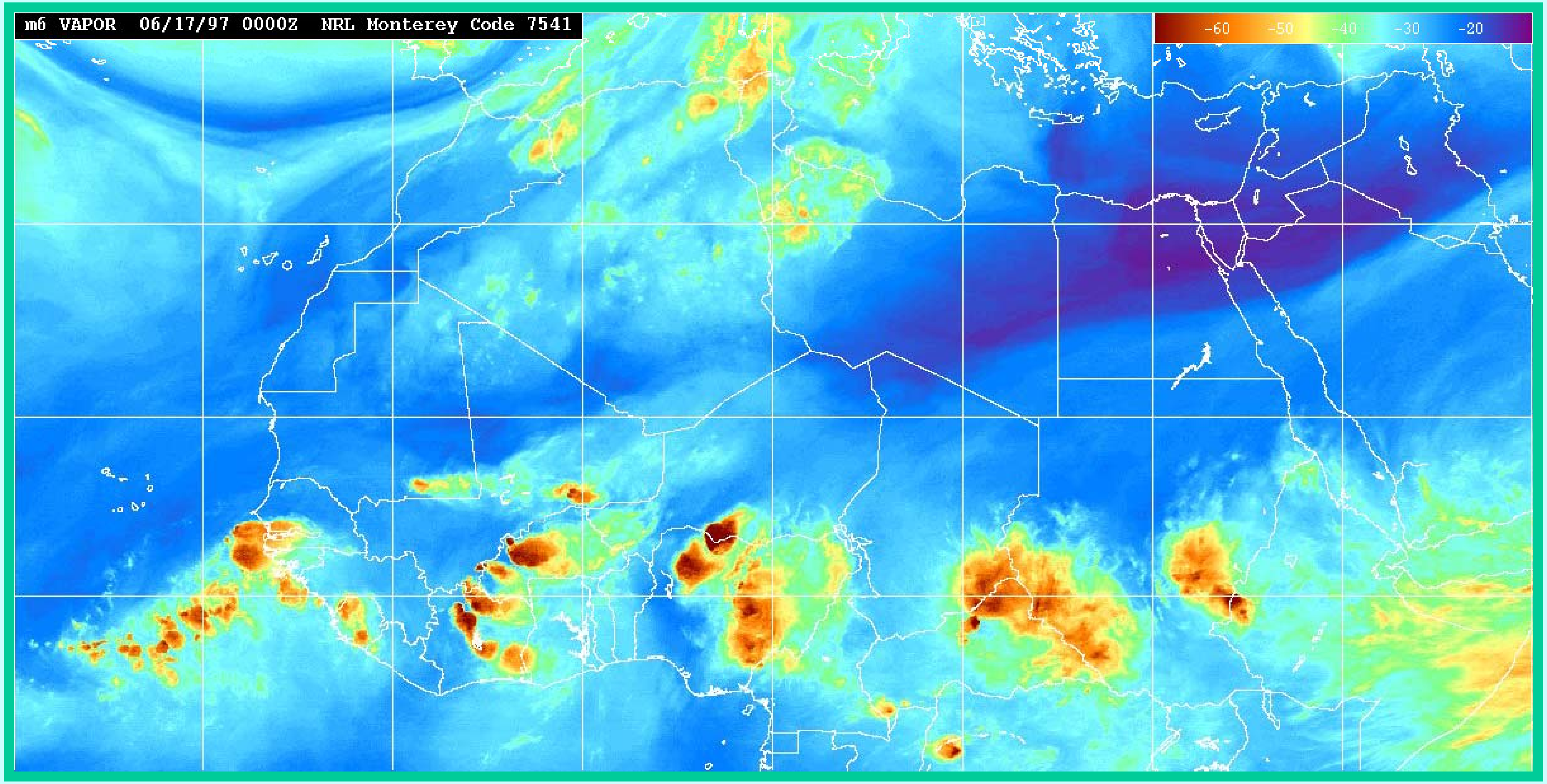
Large-scale conditions for formation

- 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.

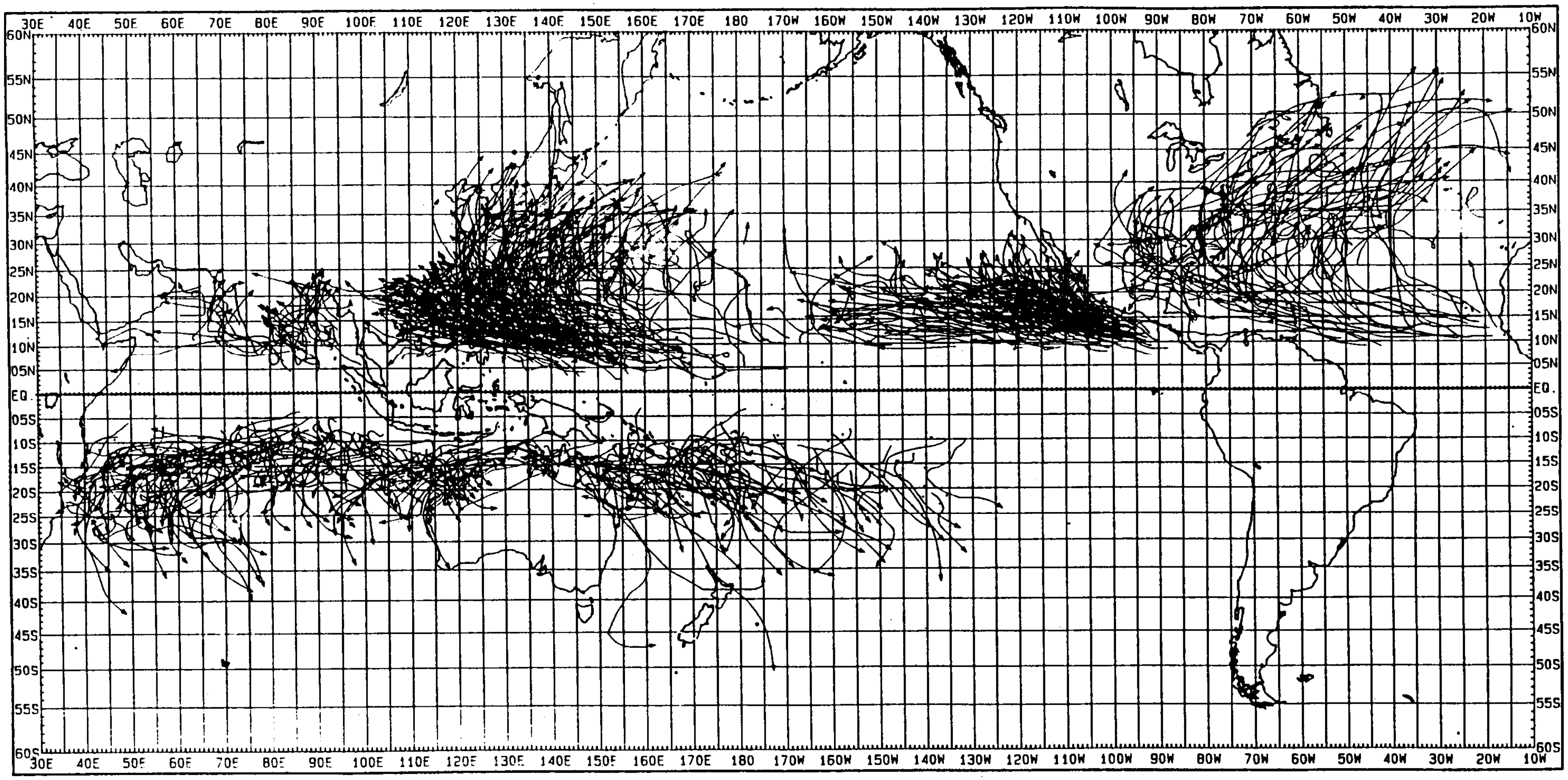
Easterly waves over Africa



WV Imagery 17 June 1997 00Z

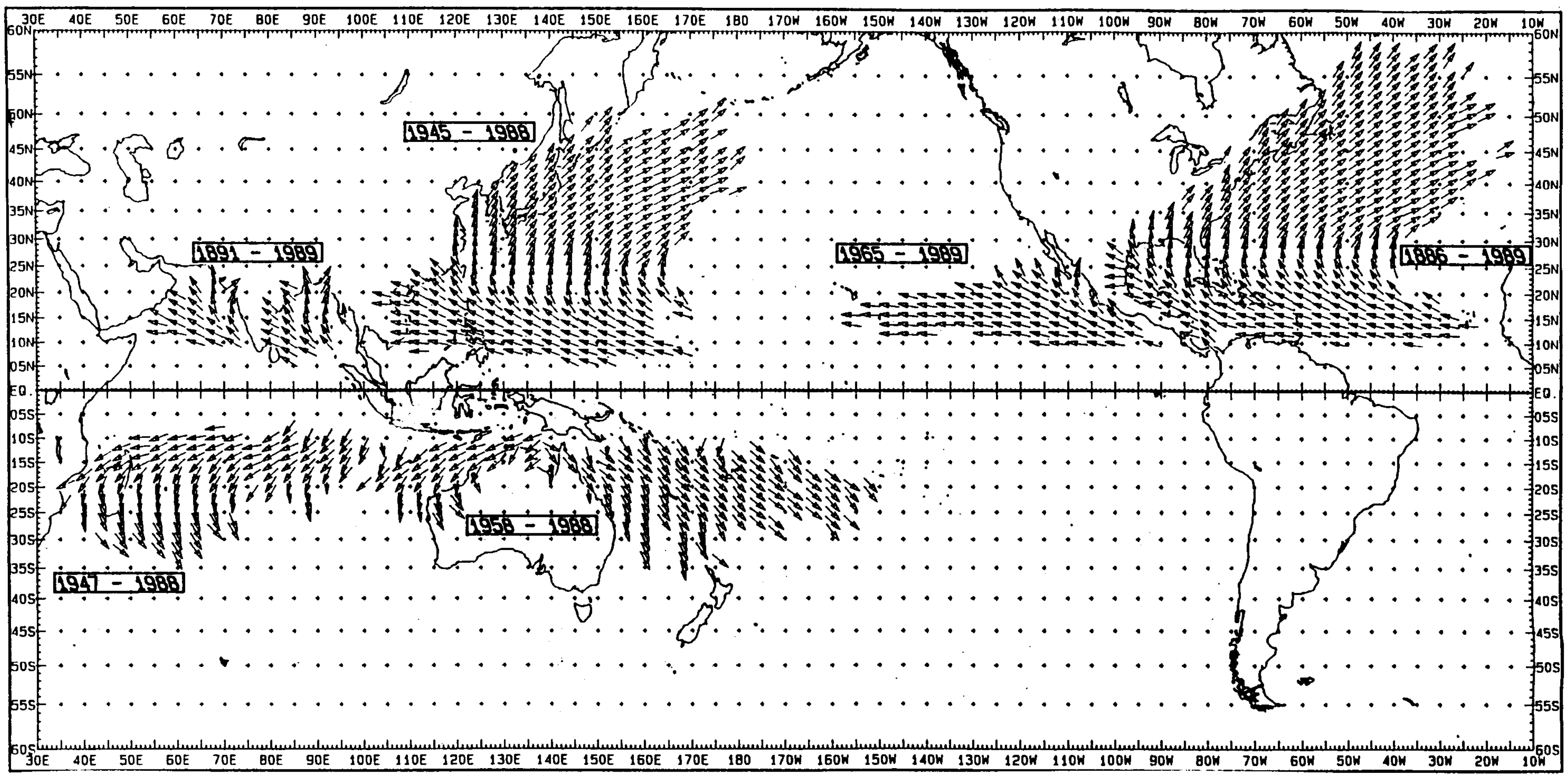
Movie of Atlantic July Basin 2003

Tropical cyclone tracks (1979-1988)



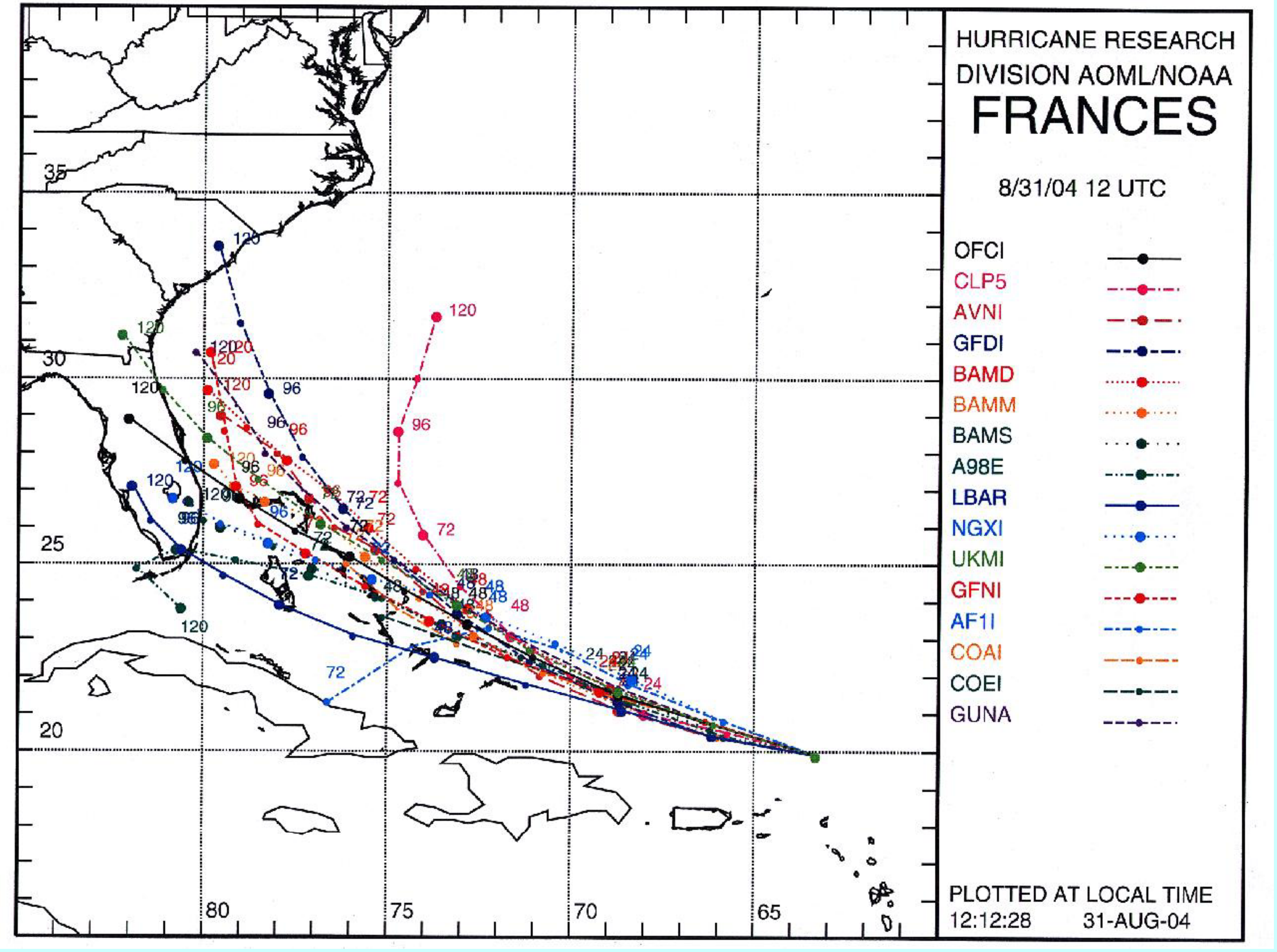
From WMO (1993)

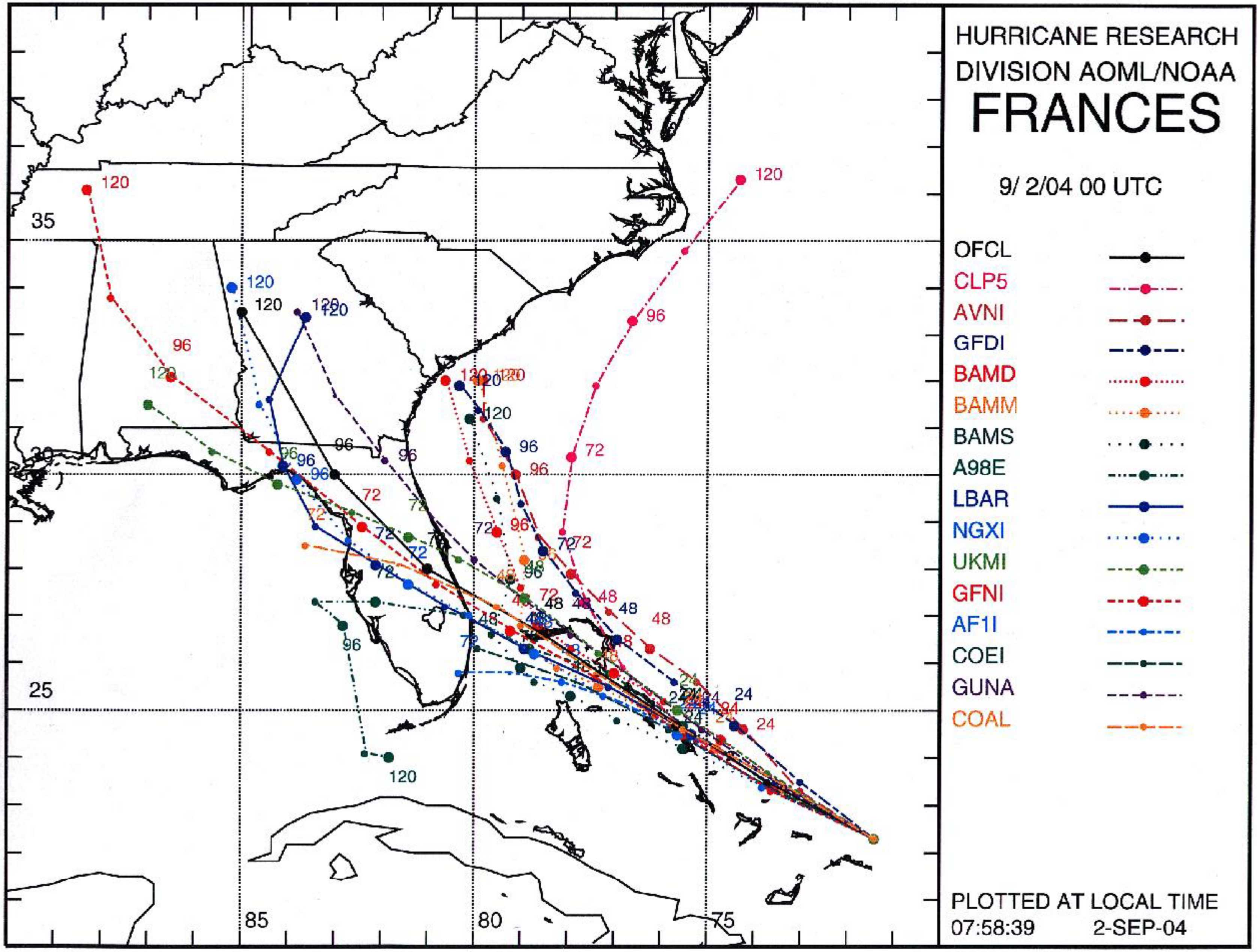
Mean direction of TC motion



From WMO (1993)

Track forecasting




HURRICANE RESEARCH
DIVISION AOML/NOAA
FRANCES
9/ 2/04 00 UTC
OFCL
CLP5
AVNI
GFDI
BAMD
BAMM
BAMS
A98E
LBAR
NGXI
UKMI
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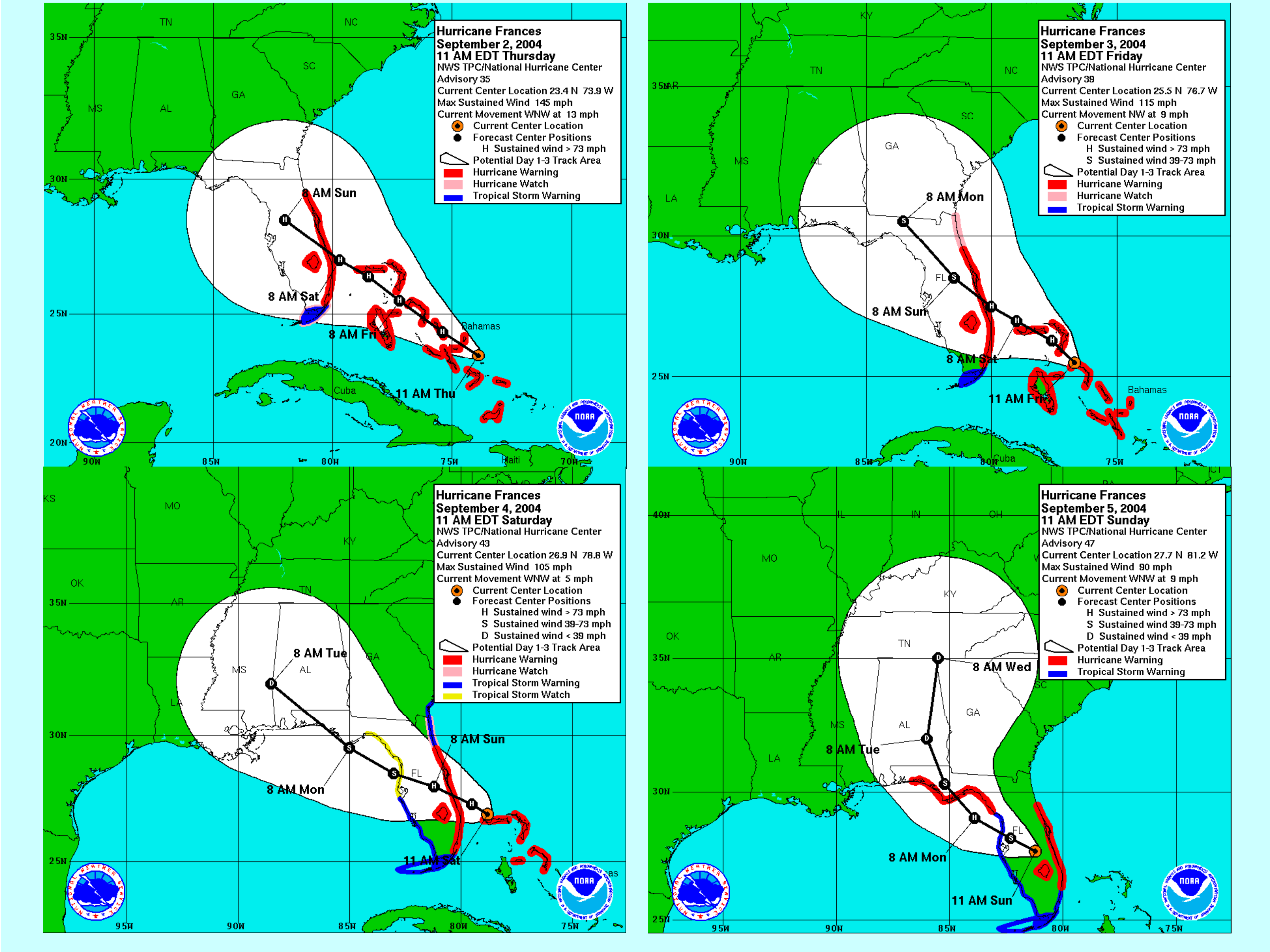
Hurricane Frances
September 2, 2004
11 AM EDT Thursday
NWS TPC/National Hurricane Center
Advisory 35
Current Center Location 23.4 N 73.9 W
Max Sustained Wind 145 mph
Current Movement WNW at 13 mph
Current Center Location
Forecast Center Positions
H Sustained wind > 73 mph
Potential Day 1-3 Track Area
Hurricane Warning
Hurricane Watch
Tropical Storm Warning
8 AM Sun
8 AM Sat
8 AM Fri
11 AM Thu
Bahamas
Cuba
Haiti
TN
NC
SC
GA
MS
AL
35N
30N
25N
20N
90W
85W
80W
75W
70W
Hurricane Frances
September 3, 2004
11 AM EDT Friday
NWS TPC/National Hurricane Center
Advisory 39
Current Center Location 25.5 N 76.7 W
Max Sustained Wind 115 mph
Current Movement NW at 9 mph
Current Center Location
Forecast Center Positions
H Sustained wind > 73 mph
S Sustained wind 39-73 mph
Potential Day 1-3 Track Area
Hurricane Warning
Hurricane Watch
Tropical Storm Warning
8 AM Mon
8 AM Sun
8 AM Sat
11 AM Fri
Bahamas
Cuba
KY
TN
NC
SC
GA
AR
MS
AL
LA
FL
35N
30N
25N
90W
85W
80W
75W
Hurricane Frances
September 4, 2004
11 AM EDT Saturday
NWS TPC/National Hurricane Center
Advisory 43
Current Center Location 26.9 N 78.8 W
Max Sustained Wind 105 mph
Current Movement WNW at 5 mph
Current Center Location
Forecast Center Positions
H Sustained wind > 73 mph
S Sustained wind 39-73 mph
D Sustained wind < 39 mph
Potential Day 1-3 Track Area
Hurricane Warning
Hurricane Watch
Tropical Storm Warning
Tropical Storm Watch
8 AM Tue
8 AM Sun
8 AM Mon
11 AM Sat
KS
MO
KY
OK
AR
TN
MS
AL
GA
LA
FL
35N
30N
25N
95W
90W
85W
80W
75W
Hurricane Frances
September 5, 2004
11 AM EDT Sunday
NWS TPC/National Hurricane Center
Advisory 47
Current Center Location 27.7 N 81.2 W
Max Sustained Wind 90 mph
Current Movement WNW at 9 mph
Current Center Location
Forecast Center Positions
H Sustained wind > 73 mph
S Sustained wind 39-73 mph
D Sustained wind < 39 mph
Potential Day 1-3 Track Area
Hurricane Warning
Tropical Storm Warning
8 AM Wed
8 AM Tue
8 AM Mon
11 AM Sun
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OH
MO
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30N
25N
95W
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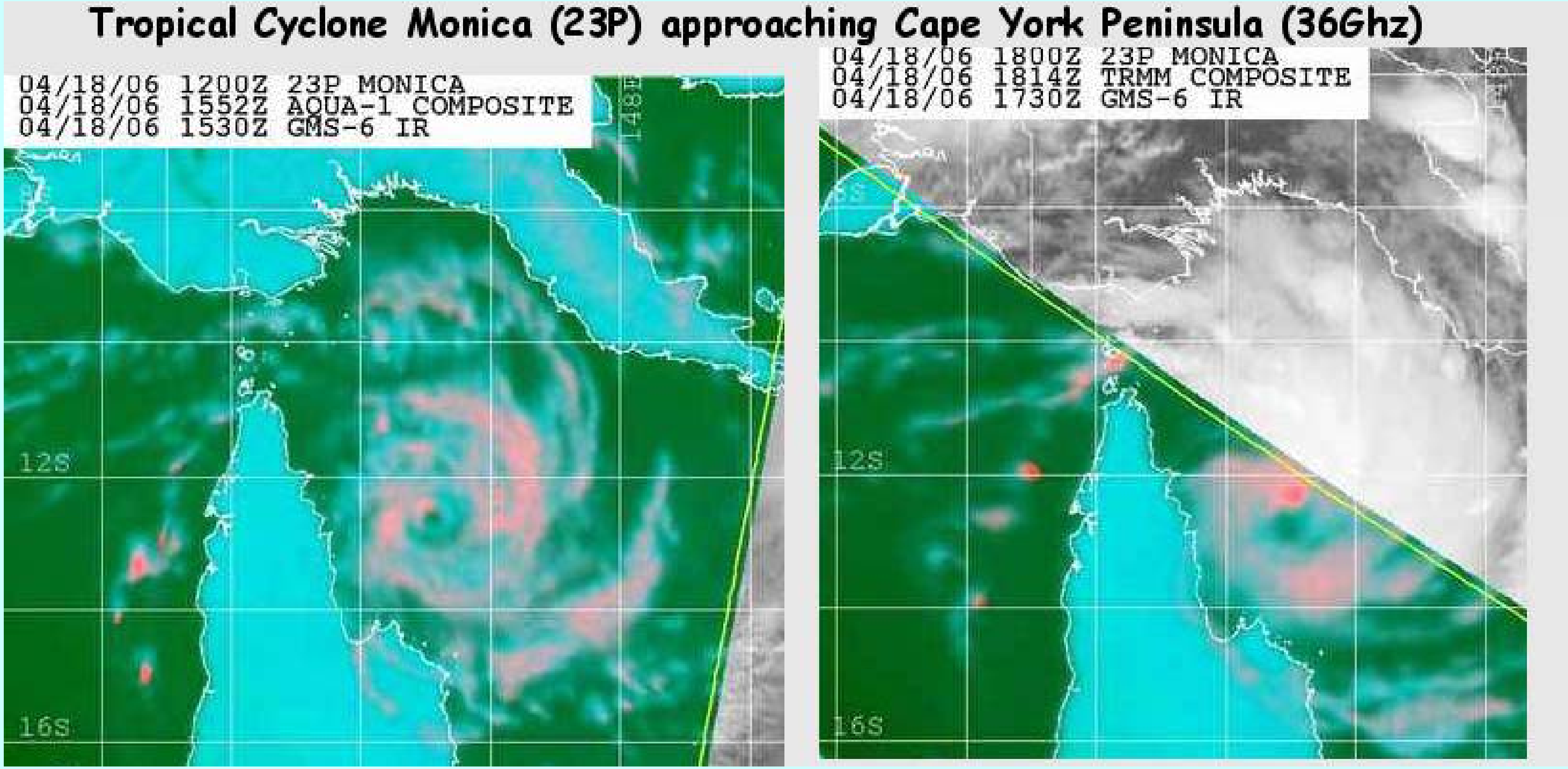
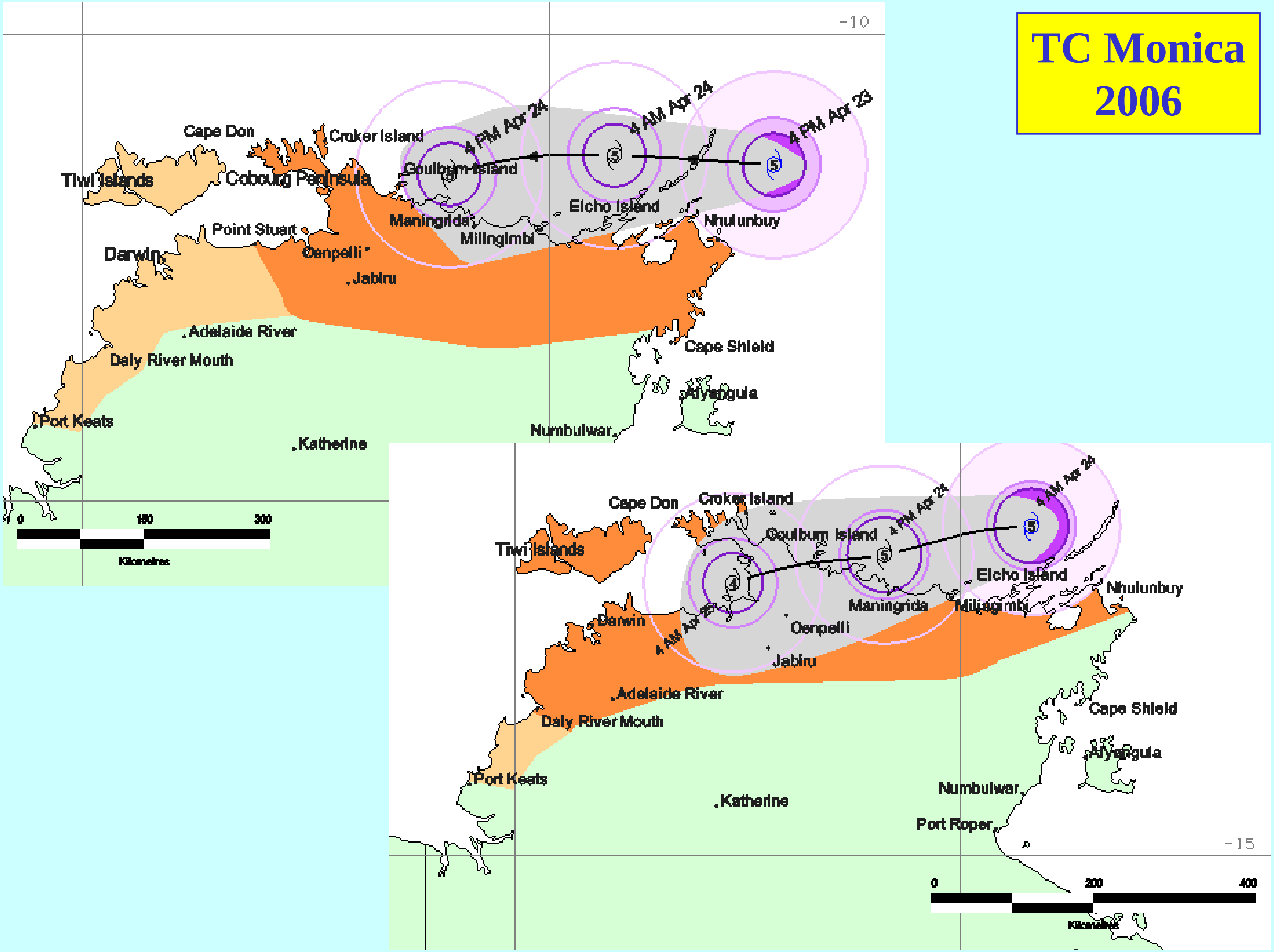
85W
80W
75W

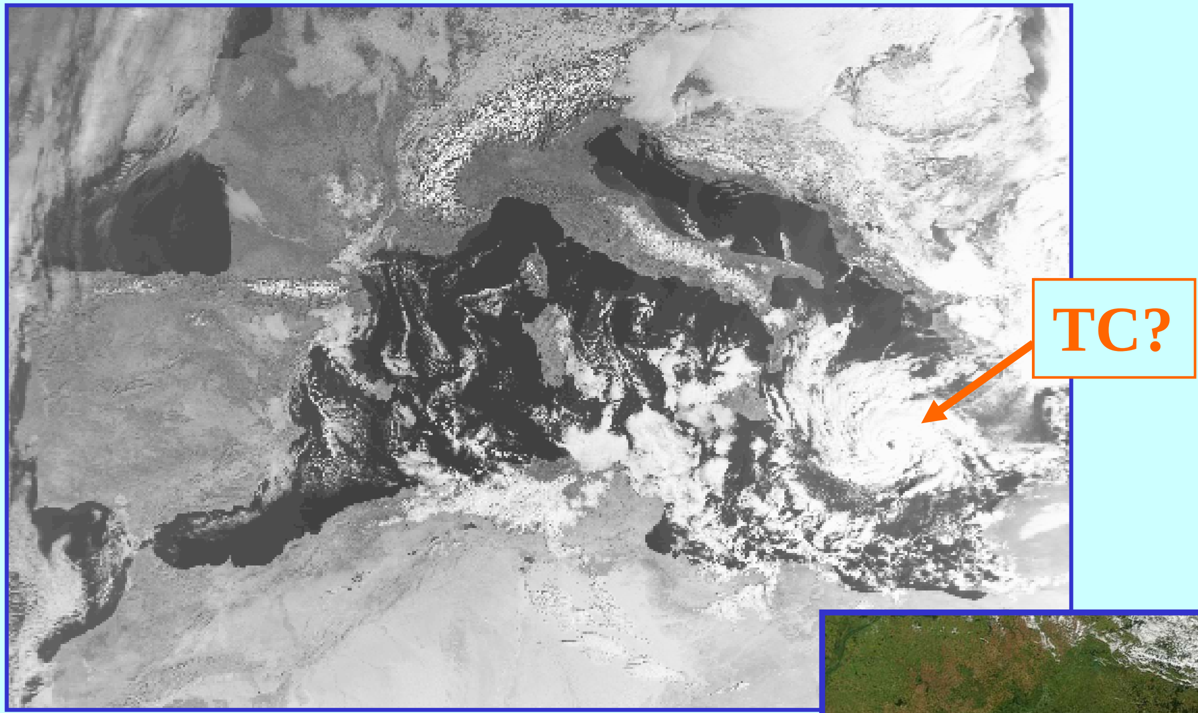
TC Monica 2006

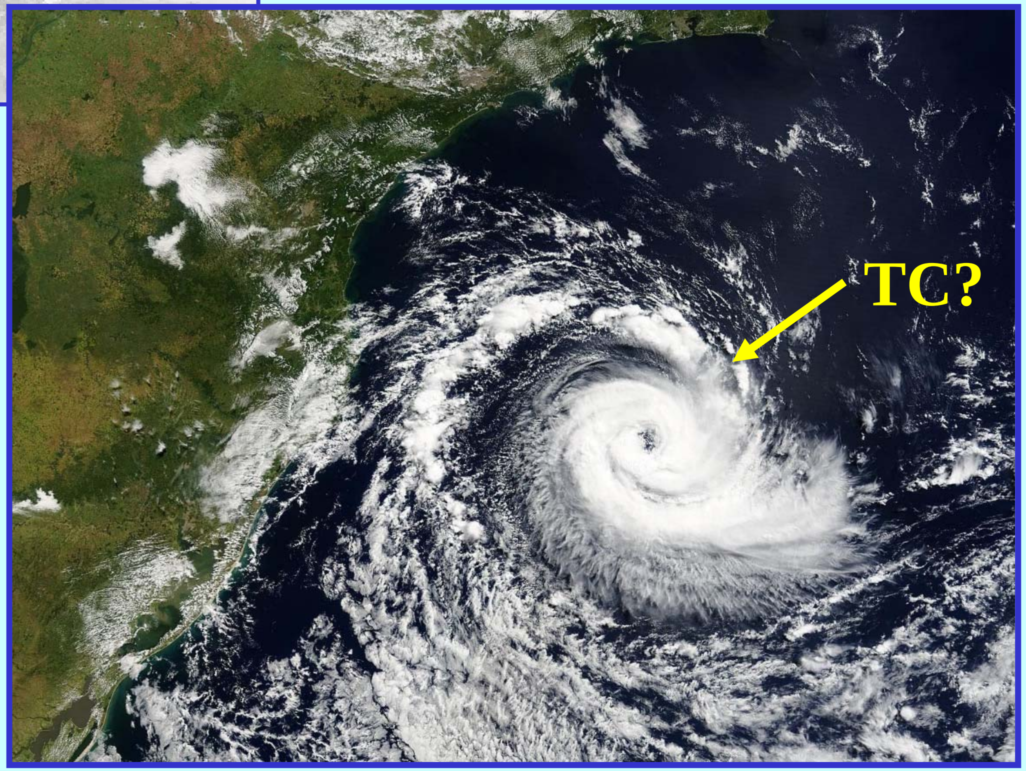


TC Monica 2006

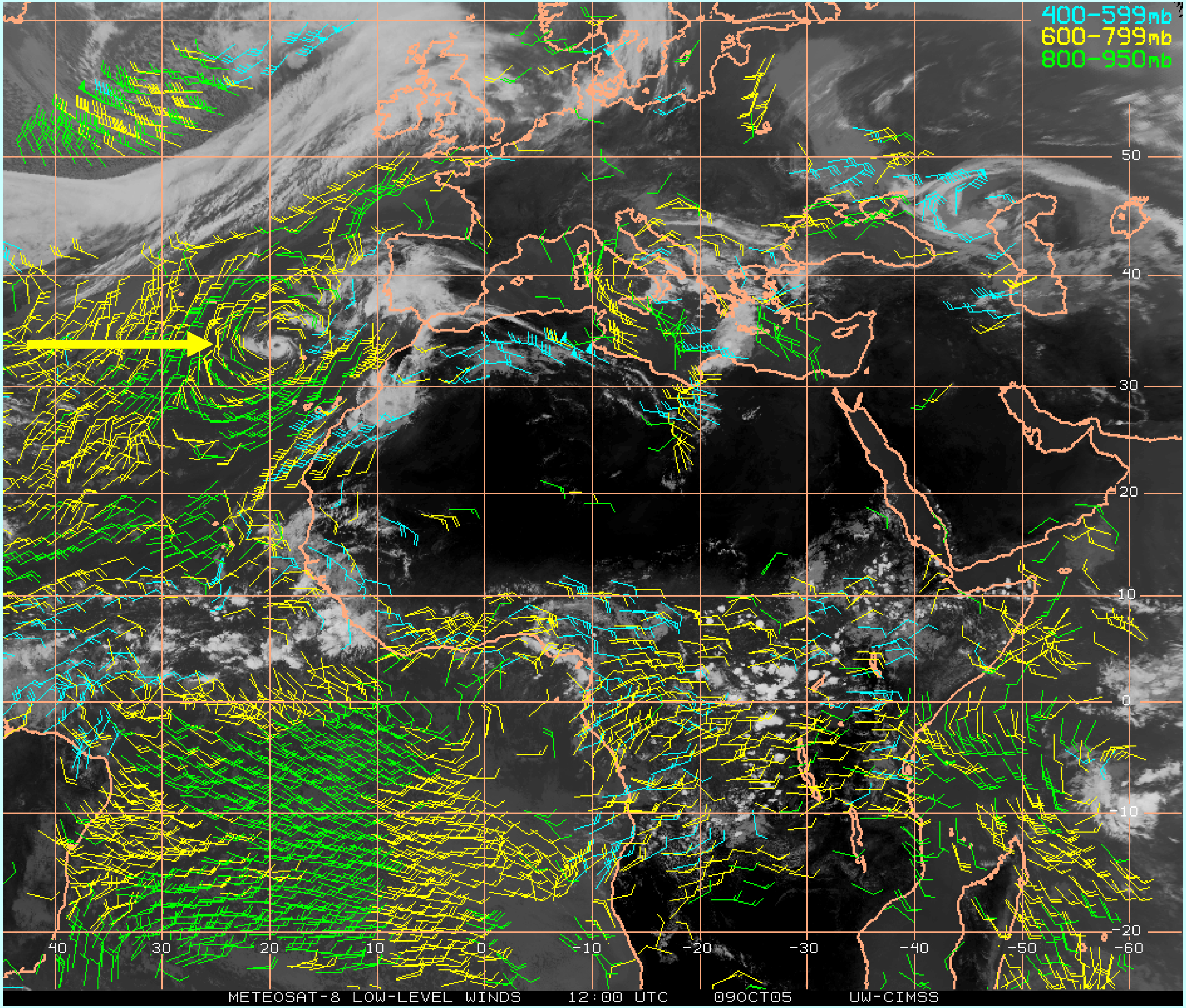


Damage TC Monica 2006





Related phenomena



400-599mb
600-799mb
800-950mb
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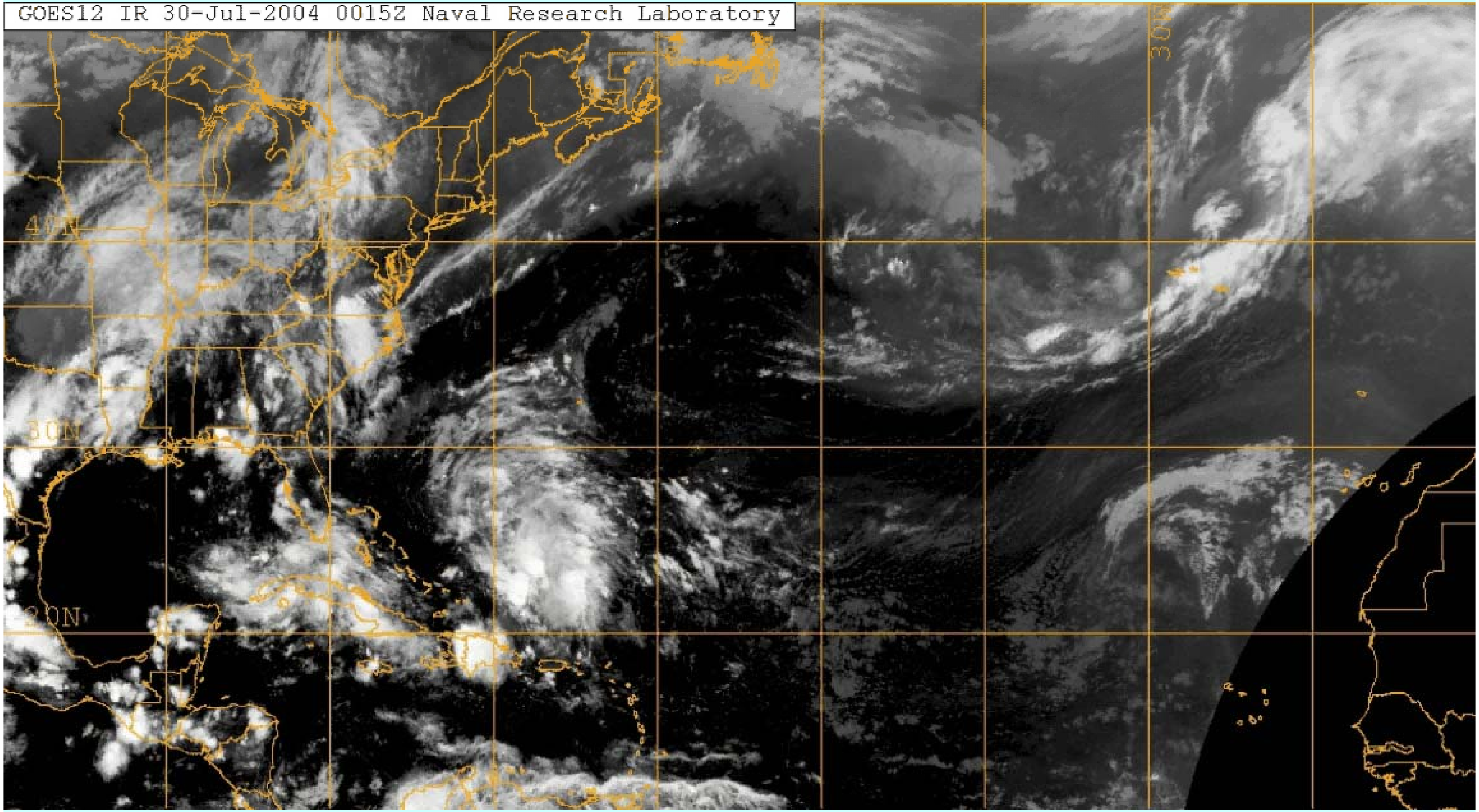
METEOSAT-8 LOW-LEVEL WINDS 12:00 UTC 09OCT05 UW-CIMSS


GOES12 IR 30-Jul-2004 0015Z Naval Research Laboratory
40N
30N
20N


TC "Ingrid"
Cape Don, NT, 13/3/05
Courtesy Jason Preece,
www.capedon.com.au

End