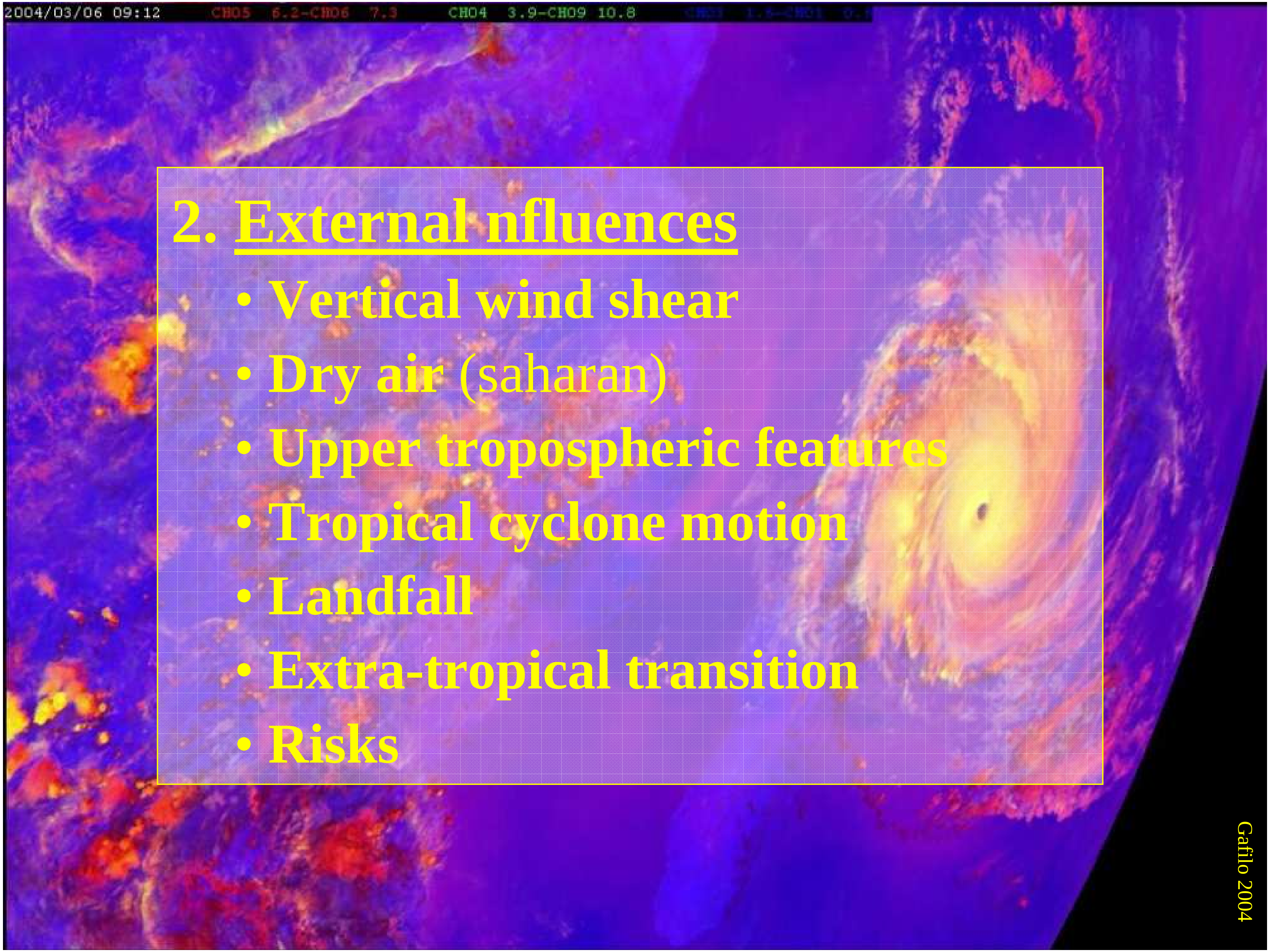
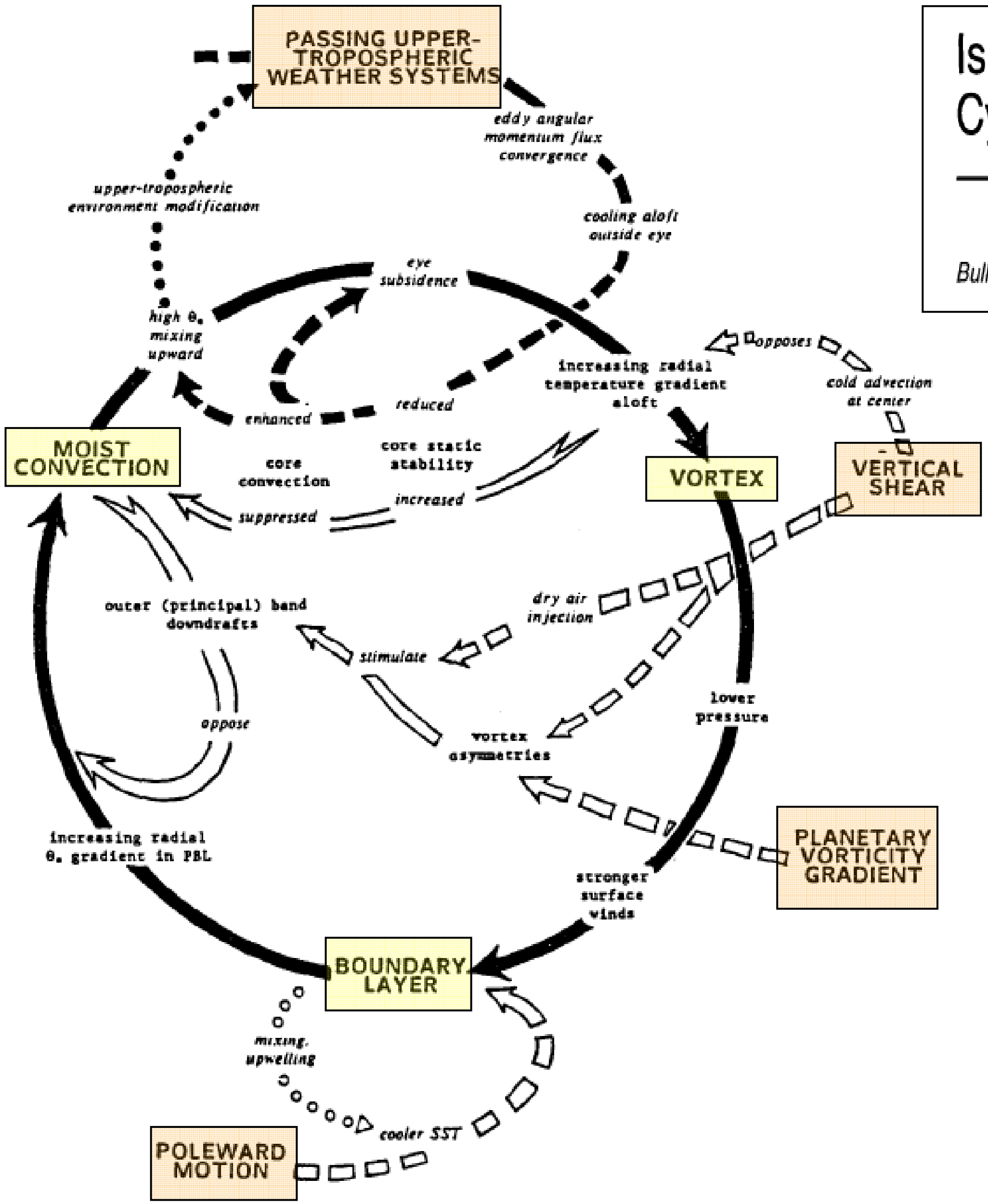


2. External nfluences

- **Vertical wind shear**
- **Dry air** (saharan)
- **Upper tropospheric features**
- **Tropical cyclone motion**
- **Landfall**
- **Extra-tropical transition**
- **Risks**

Gafilo 2004

EXTERNAL INFLUENCES



Is There Any Hope for Tropical Cyclone Intensity Prediction? —A Panel Discussion

Russell L. Elsberry*, Greg J. Holland+, Hal Gerrish**, Mark DeMaria++, Charles P. Guard***, Kerry Emanuel+++

Bulletin American Meteorological Society Vol. 73, No. 3, March 1992

Processes influencing tropical cyclone intensity change.

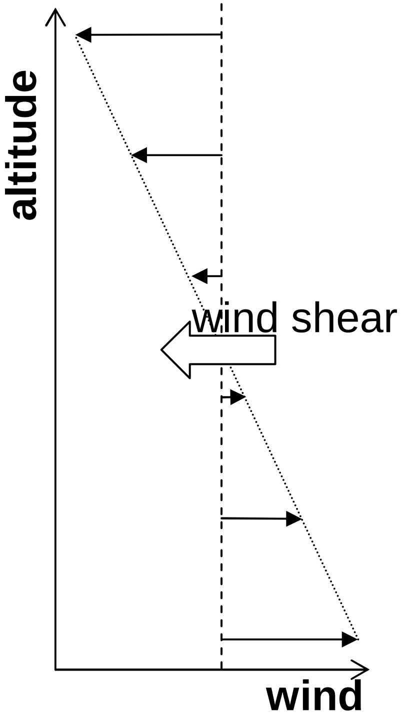
The black circle represents internal positive feedbacks between the vortex, the boundary layer, and moist convection.

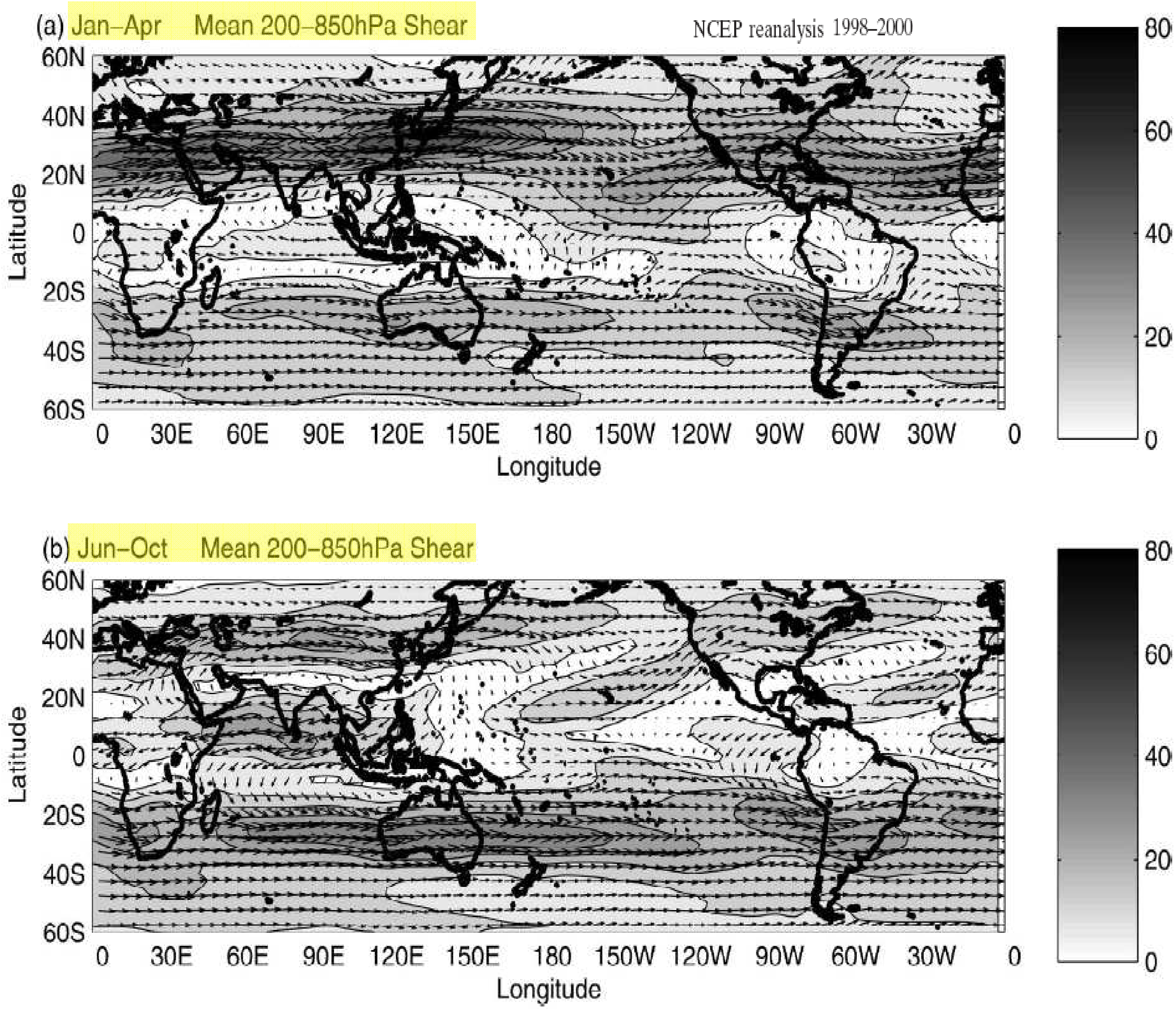
Negative internal feedbacks are shown as white arrows.

Dashed arrows indicate positive (black)/negative (white) environmental influences

dotted arrows denote modification of the environment by the tropical cyclone

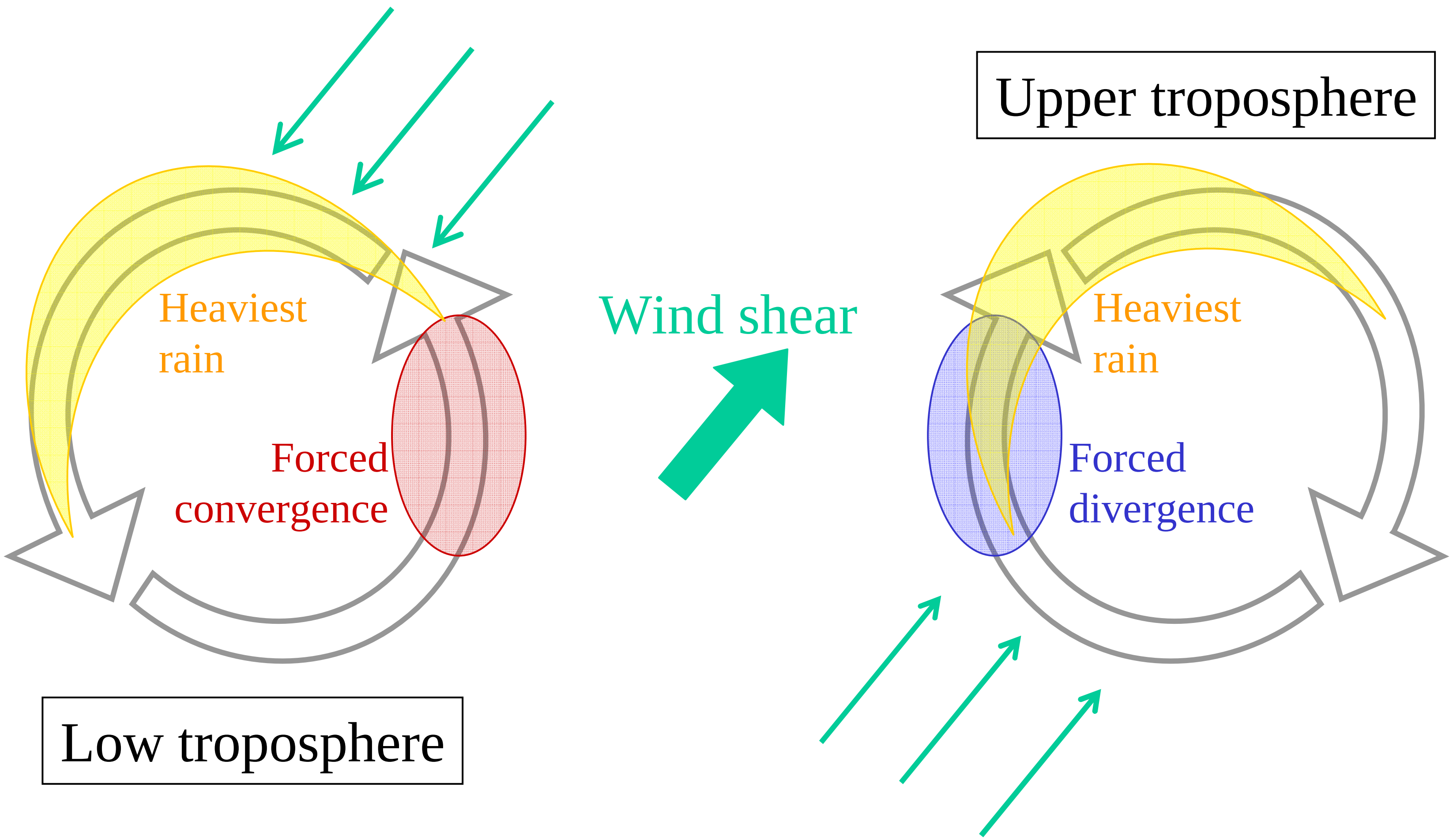
VERTICAL WIND SHEAR (1)





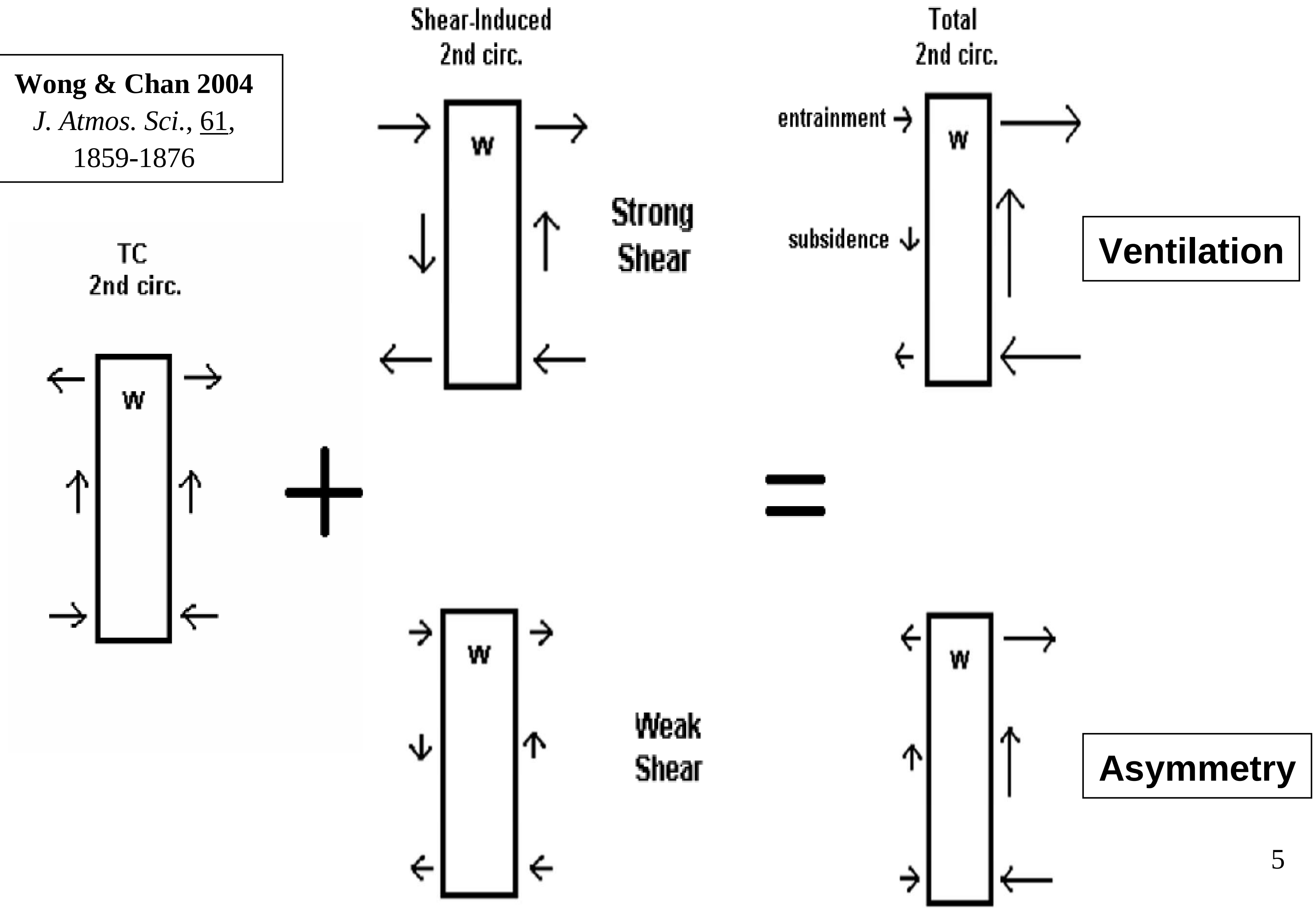
Chen *et al.* 2006
Mon. Wea. Rev., 134,
3190-3208

VERTICAL WIND SHEAR (2)



VERTICAL WIND SHEAR (3)

Wong & Chan 2004
J. Atmos. Sci., 61,
1859-1876



Braun & Wu 2007
Mon. Wea. Rev., 135,
1179-1194

VERTICAL WIND SHEAR (4)

Hurricane Erin (Sep 01)

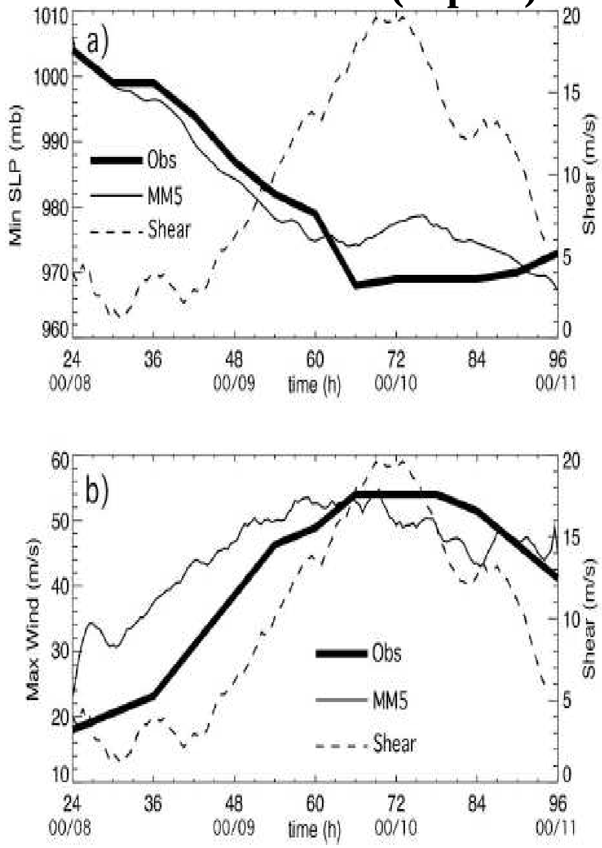


FIG. 3. Time series of simulated (thin solid line) and observed (thick line) (a) minimum sea level pressure and (b) maximum wind speed at the lowest model level. The dashed line shows the magnitude of the 850–200-mb vertical wind shear averaged over a circle of radius 300 km. I

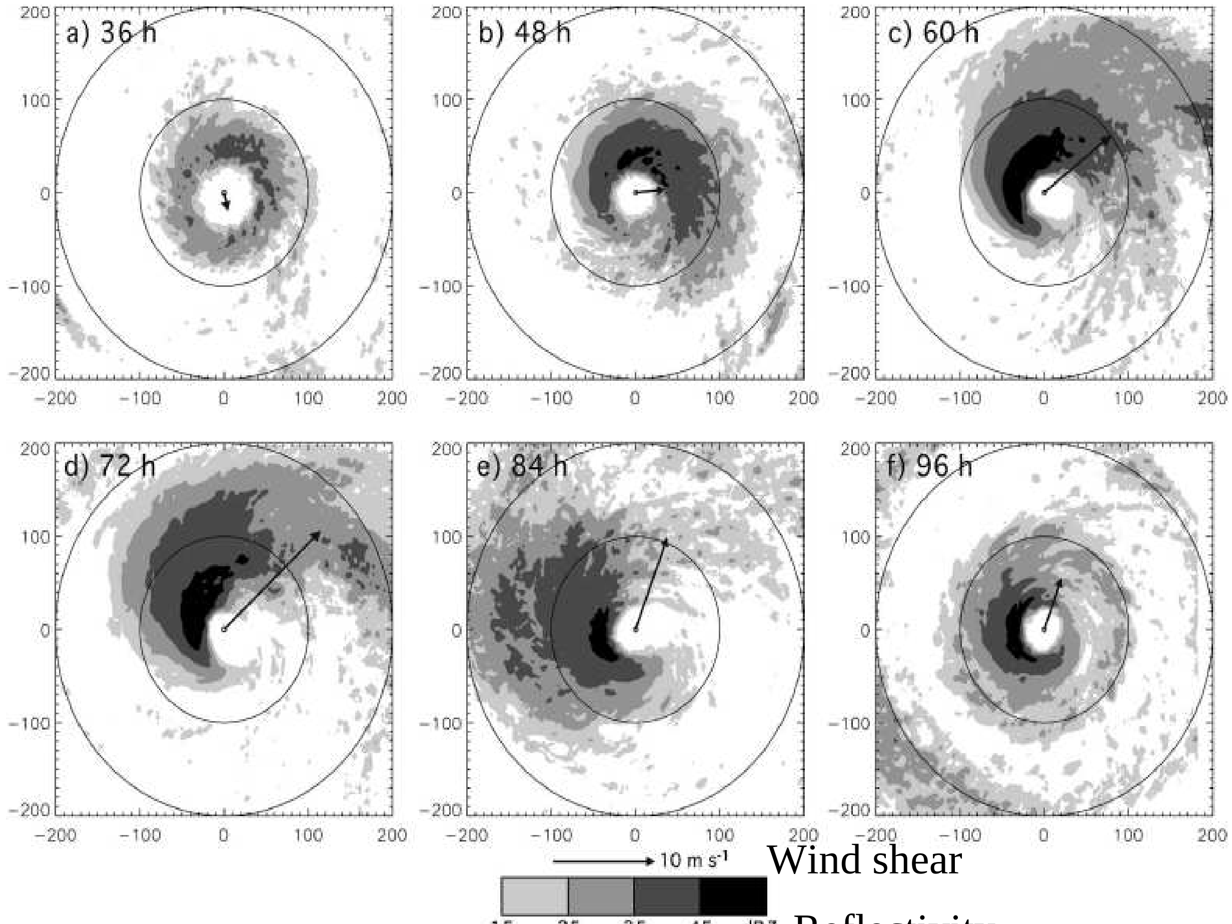
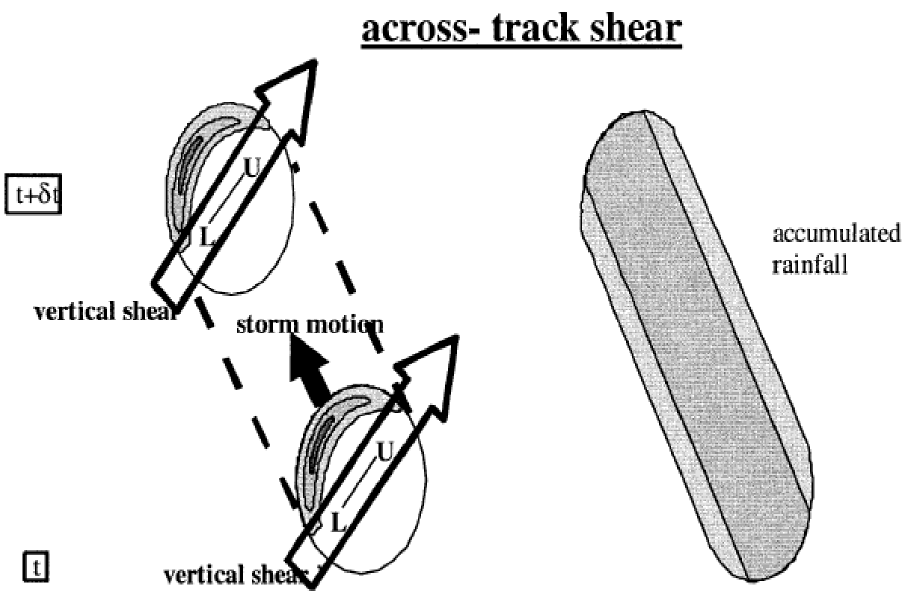


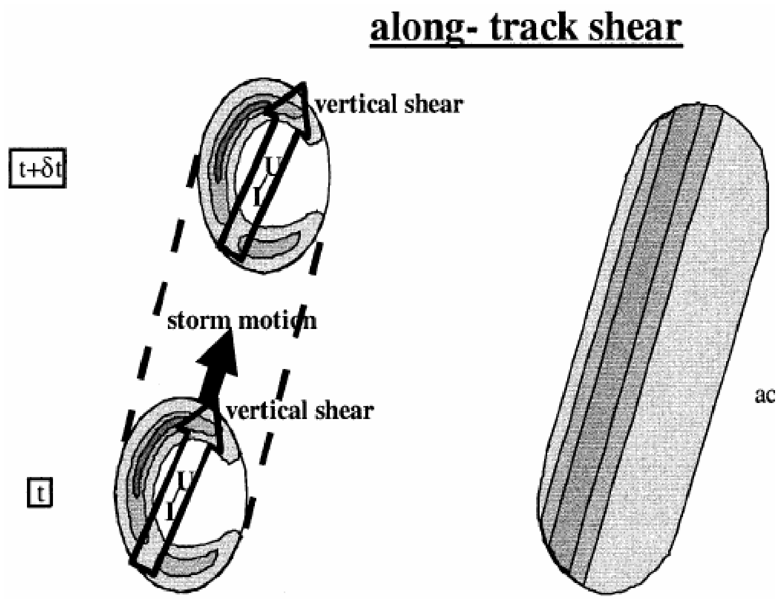
FIG. 5. Simulated radar reflectivity structure at the lowest model level (38 m). Contours show the simulated radar reflectivity averaged over the 6-h period ending at the indicated time. Arrows show the 6-h-averaged 850–200-mb vertical wind shear vector. Axis labels are in km with the origin at the storm center.

VERTICAL WIND SHEAR (5)

Rogers *et al.* 2003
Mon. Wea. Rev., 131, 1577-1599

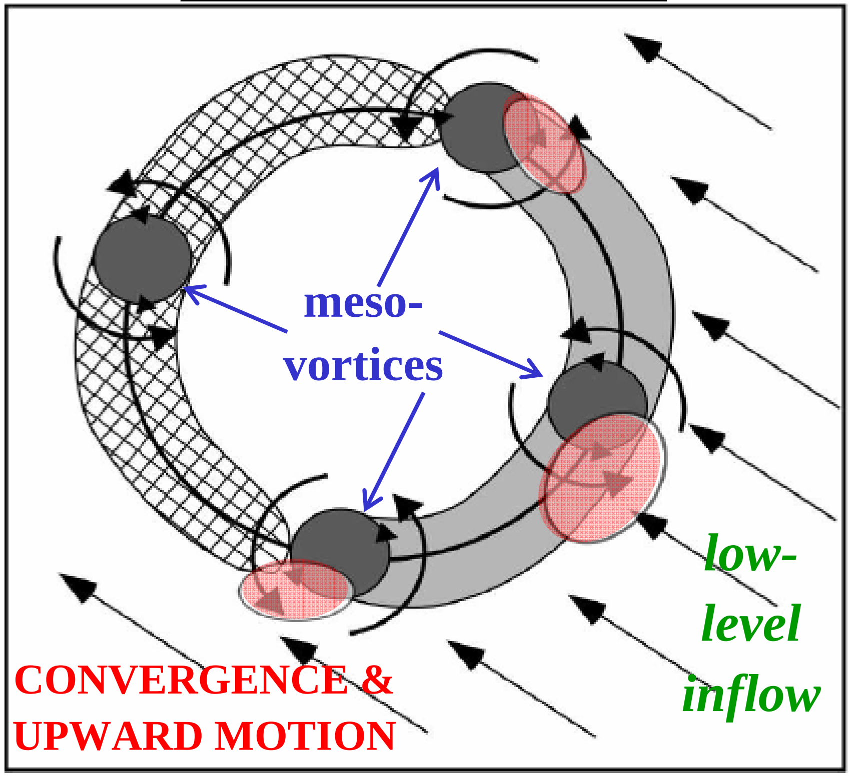
The strongest convection in the core is generally located on the downshear left side of the shear vector. The vortex shows a downshear tilt from vertical.
The accumulated rainfall is ditributed symmetrically across the track of the storm when the shear is across track.
It is distributed asymmetrically across the track of the storm when the shear is along track.





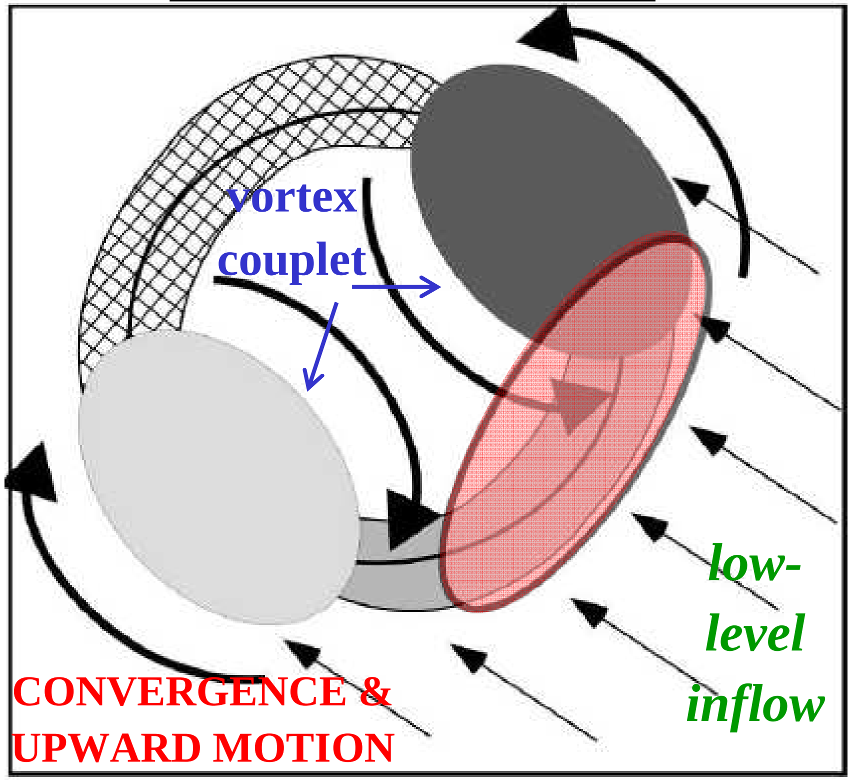
VERTICAL WIND SHEAR (6)

WEAK SHEAR



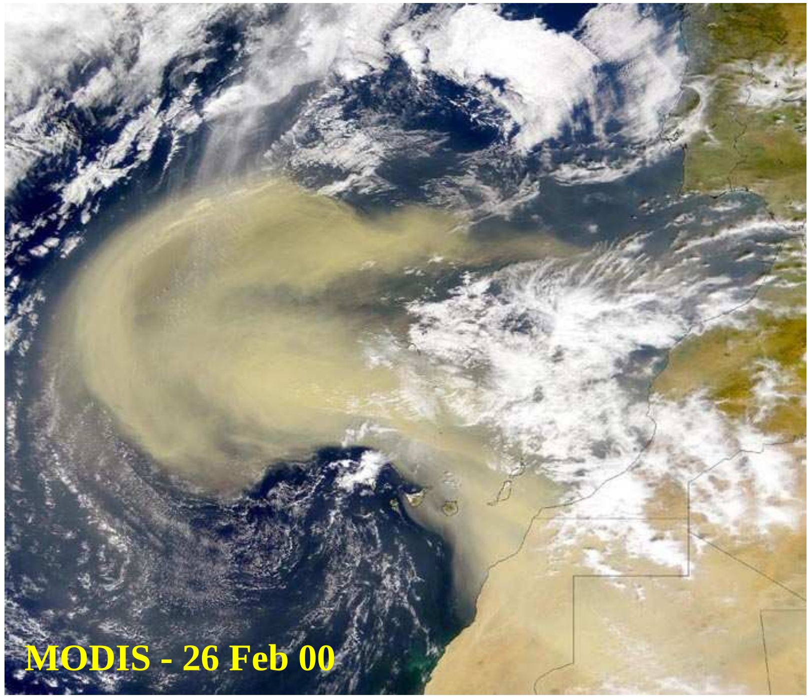
Eyewall mesovortices are associated with convective-scale updrafts. They move around the eyewall at a speed slower than the maximum tangential wind

STRONG SHEAR

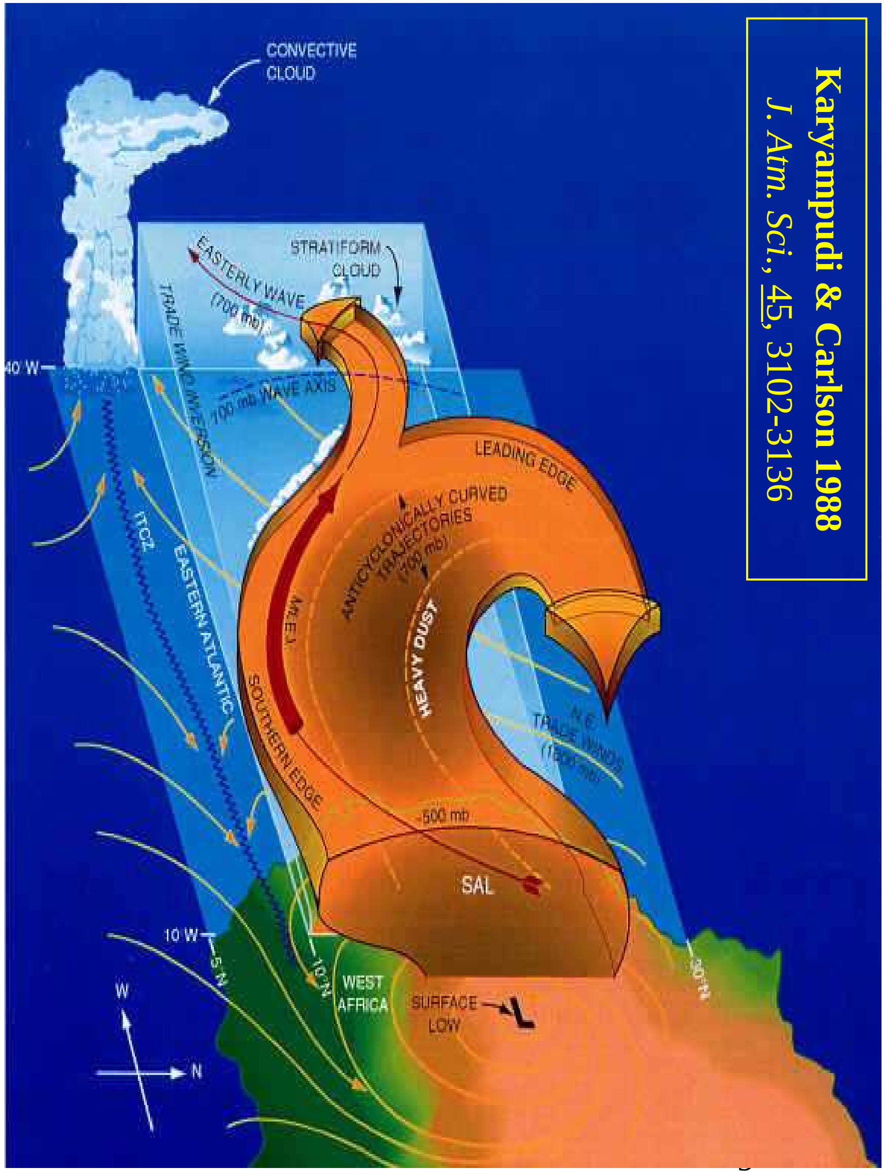


The eyewall is dominated by a cyclonic-anticyclonic vortex couplet producing a strong flow across the eye which converges with the low-level inflow and induces a strong asymmetric updraft.

(SAHARAN) **DRY AIR**



Large zones with very dry air (RH <50%), loaded with aerosols, emerge sporadically from Sahara and propagate westward over the tropical Atlantic. These air masses extend from 1500 to 6000 m and they are associated with strong winds (10-25 ms^{-1}) in the mid-troposphere (900-500 hPa).



Impact on Atlantic hurricanes :

- Low-level inversion with $\Delta T_{SAL} \approx$ 5-10°C
- Dry air intrusion at 850-600 hPa
- Stronger vertical wind shear
  (stronger African Easterly Jet near 700 hPa)
- Influence of aerosols on microphysics ?

- Saharan air propagate over large distances, without major changes of its characteristics
- Satellite images help to detect such events

Dunion & Velden 2004
Bull. Amer. Meteor. Soc., 84, 353-365

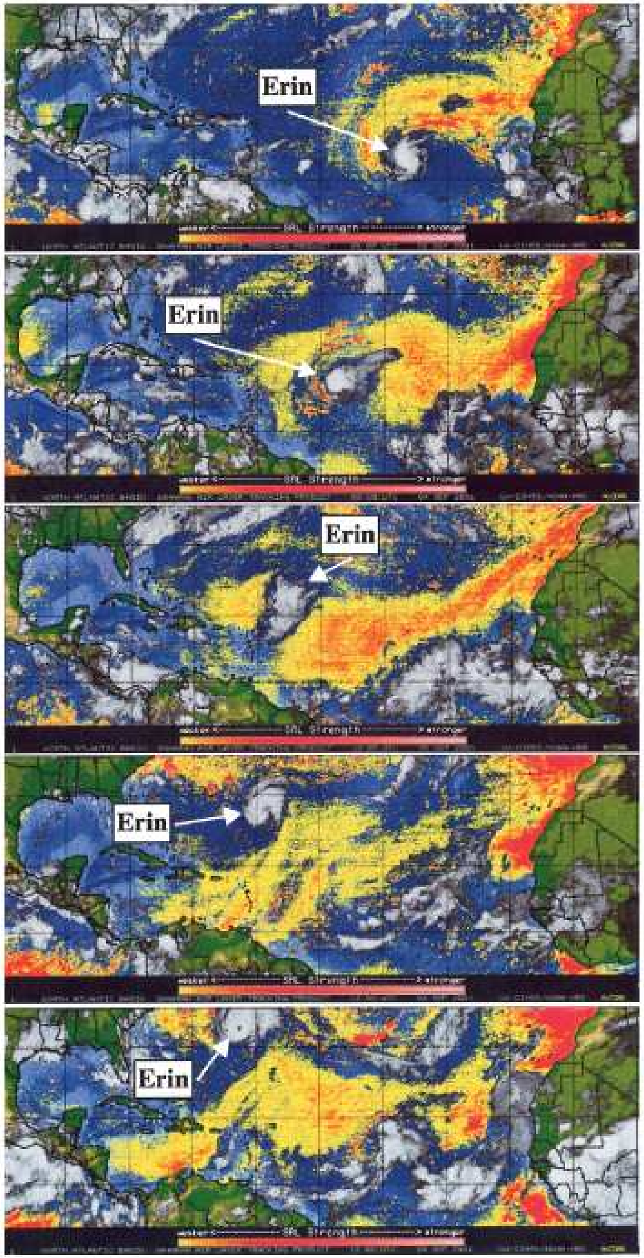


FIG. 9. GOES SAL-tracking imagery time series showing Hurricane Erin's interaction with the SAL at (top to bottom) 0000 UTC 2 Sep 2001, 0000 UTC 4 Sep 2001, 1800 UTC 5 Sep 2001, 1200 UTC 8 Sep 2001, and 1800 UTC 9 Sep 2001. The yellow–red shading indicates likely SAL regions with increasing amounts of dust content and dry lower-tropospheric air, as detected by the GOES imagery.

A.T. Evan *et al.* 2006,
Geophys. Res. Let., 33, L19813

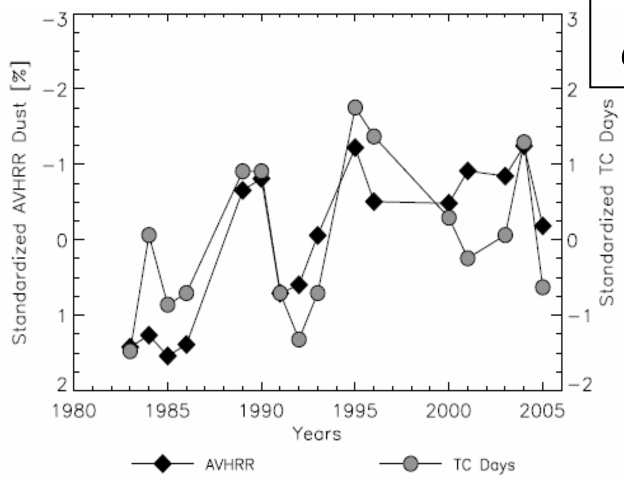
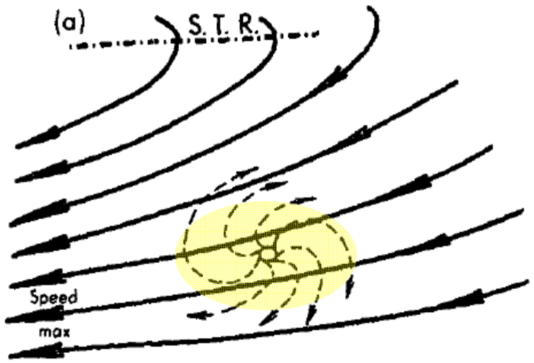


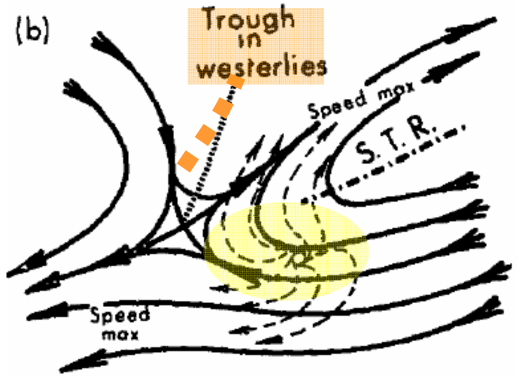
Figure 4. Same description as Figure 3 except that data points from three positive phase (1982, 1987 and 1997), and two negative phase (1998 and 1999) ENSO events, and a year with missing satellite data (1984) are removed. The correlation coefficient between the two time series is 0.71, significant at the 99.9% level.

UPPER TROPOSPHERIC FEATURES (1)

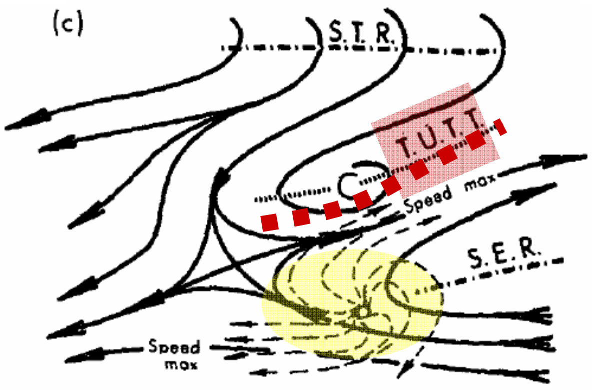
Sadler 1976
Mon. Wea. Rev., 104, 1266-1278



S of Sub-Tropical Ridge → the NE flow leads to stronger wind shear & weakened divergent anticyclonic circulation to the north
→ Unfavorable conditions



Autumn :
E of a mid-latitude trough → the SW flow leads to stronger divergent anticyclonic circulation to the north
→ Favorables conditions



Summer :
« Tropical Upper Tropospheric Trough » north of a TC, the divergent anticyclonic circulation aloft is stronger
→ Favorables conditions

UPPER TROPOSPHERIC FEATURES (2)

Hanley *et al.* 2001
Mon. Wea. Rev., 129, 2570-2584

TUTT – TC interactions

Favorable factors :

- enhanced divergent flow in altitude
- angular moment flux convergence

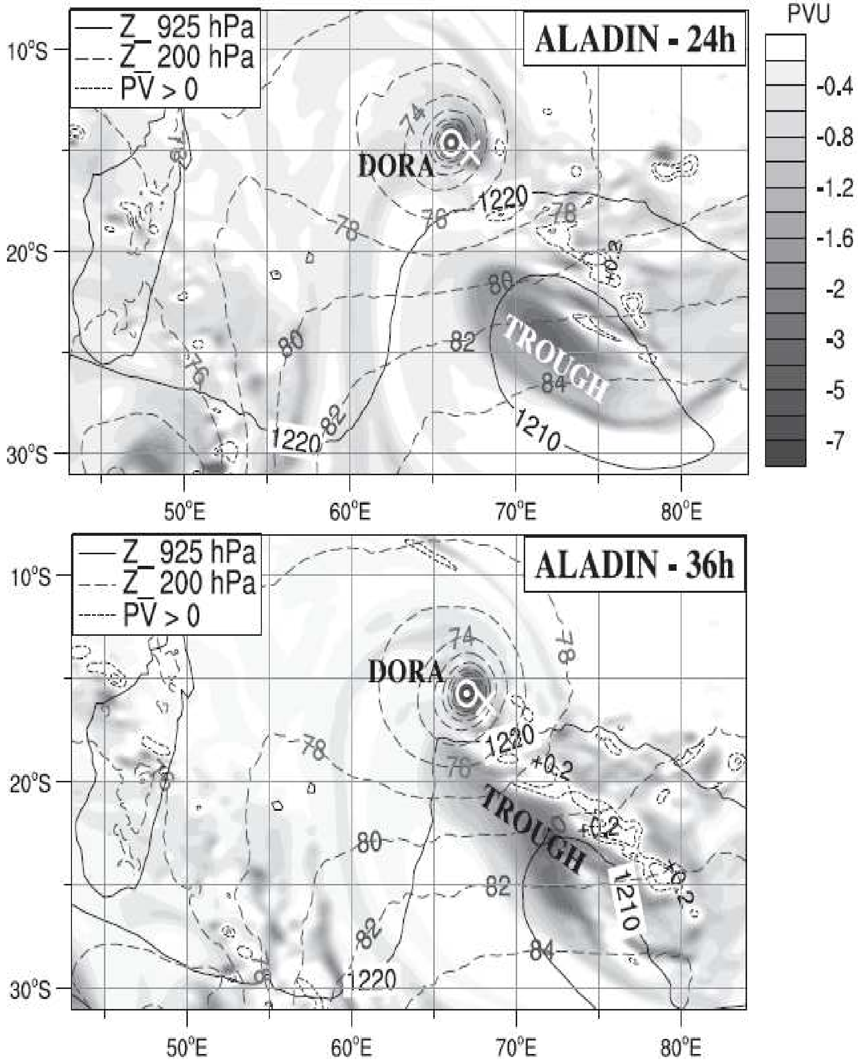
Unfavorable factors :

- stronger vertical wind shear

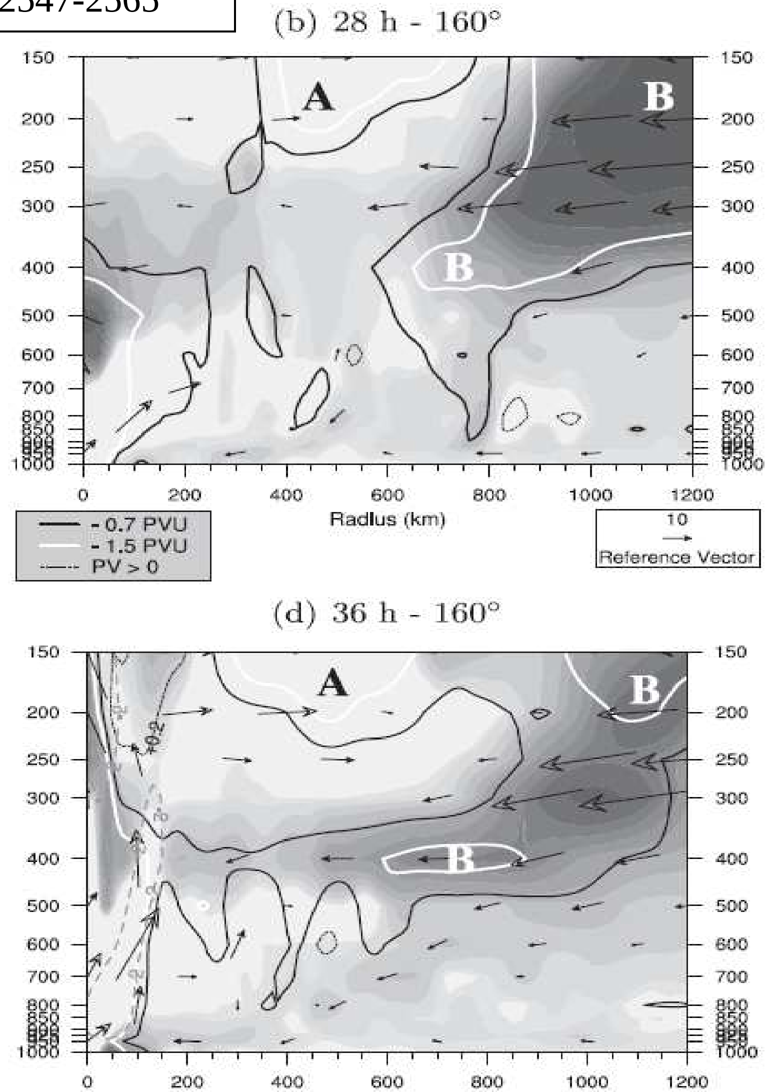
No definite conclusion (geometry is important …)

UPPER TROPOSPHERIC FEATURES (2)

Leroux *et al.* 2013
J. Atmos. Sci., 70, 2547-2565

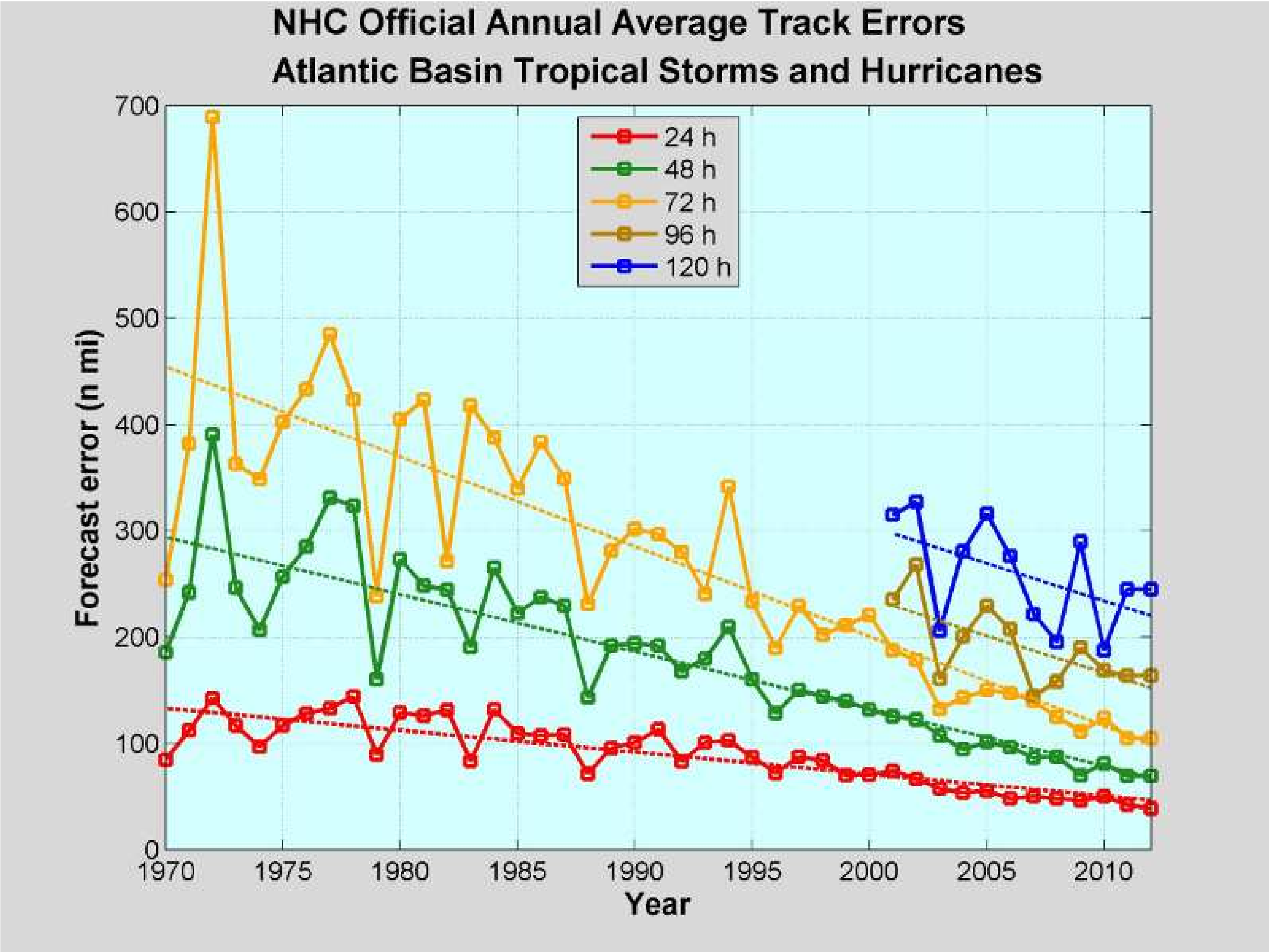


Aladin-Reunion forecast for TC Dora from 0600 UTC 31 Jan 2007



Radius–pressure cross sections of PV radial advection

TROPICAL CYCLONE MOTION (1)

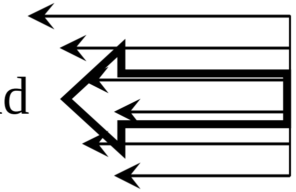


Average mean absolute errors for official TC track predictions
at various lead times in the North Atlantic basin from 1970-2014
[*National Hurricane Center, Miami, FL, USA*]

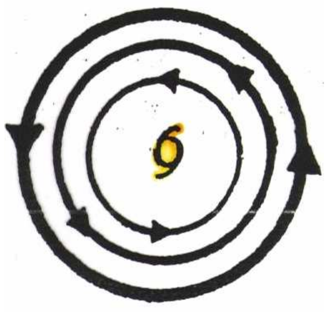
TROPICAL CYCLONE MOTION (2)

Many components have to be taken into account :

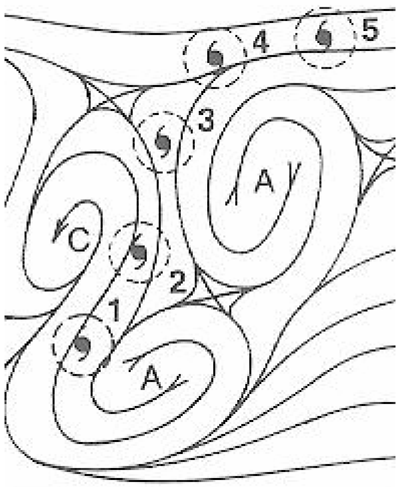
•The mean wind

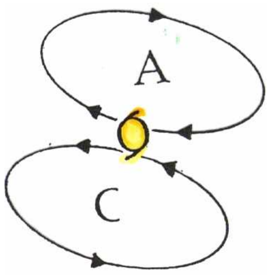


• The mean vortex



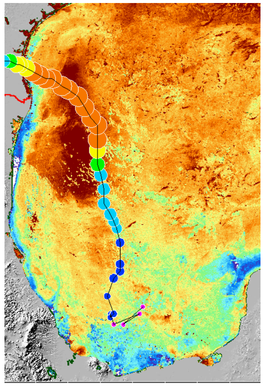
• Nearby perturbations



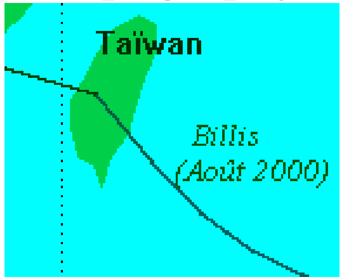


• Asymmetries

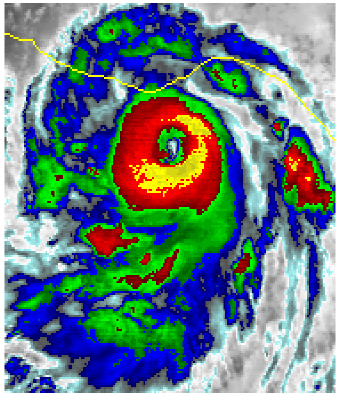
• SST



• Topography



• Convection in the eyewall and in the external rainbands



TROPICAL CYCLONE MOTION (3)

Chan 2005 : «The Physics of Tropical Cyclone Motion»
Ann. Rev. Fluid Mech., 37, 99-128

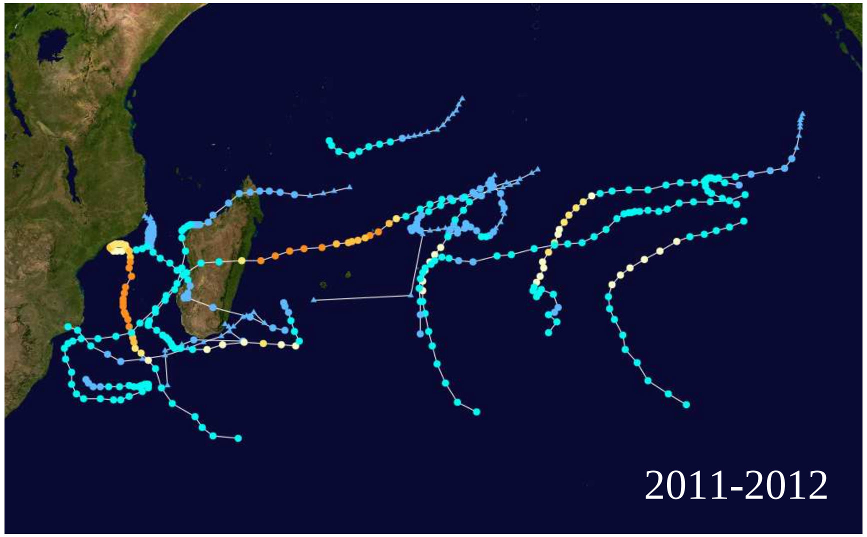
- **Barotropic environment ($\partial_h T$, $\partial_z V_H \approx 0$) :**
  - Advection by the mean flow
  - β (meridional gradient of planetary vorticity) drift
  - Horizontal gradients of relative vorticity

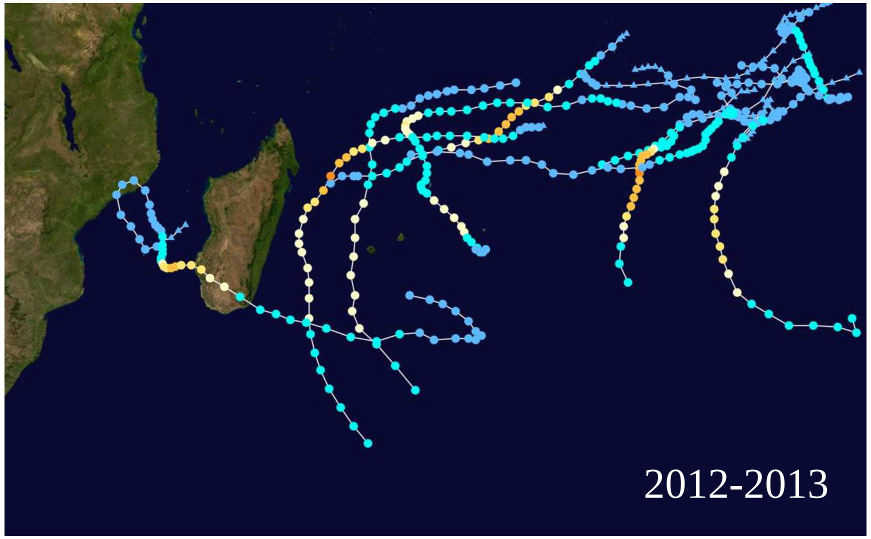
- **Baroclinic environment ($\partial_h T$, $\partial_z V_H \neq 0$) :**
  - Low (*mid*) latitudes : to the right (*left*) of vertical wind shear
  - Shift toward maxima of ∂_t**PV**

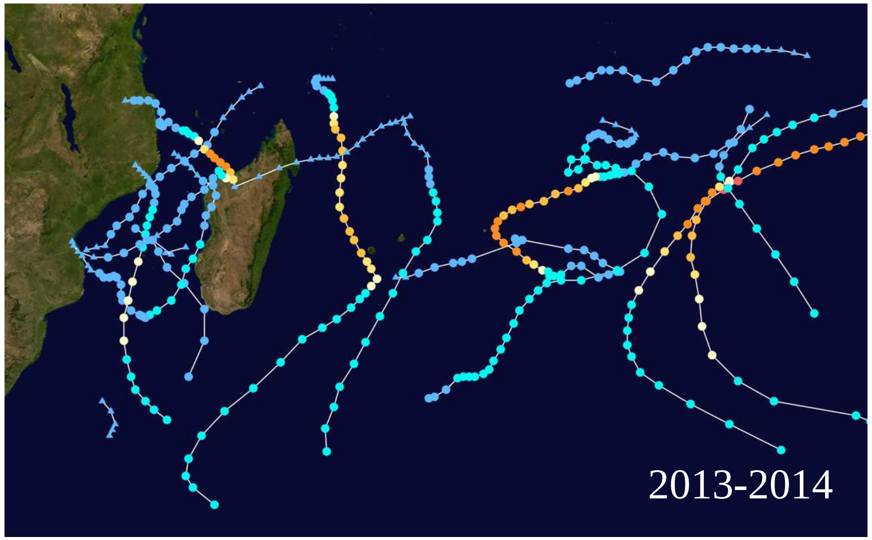
    $\rightarrow$ Advection by the mean flow (mid latitudes)

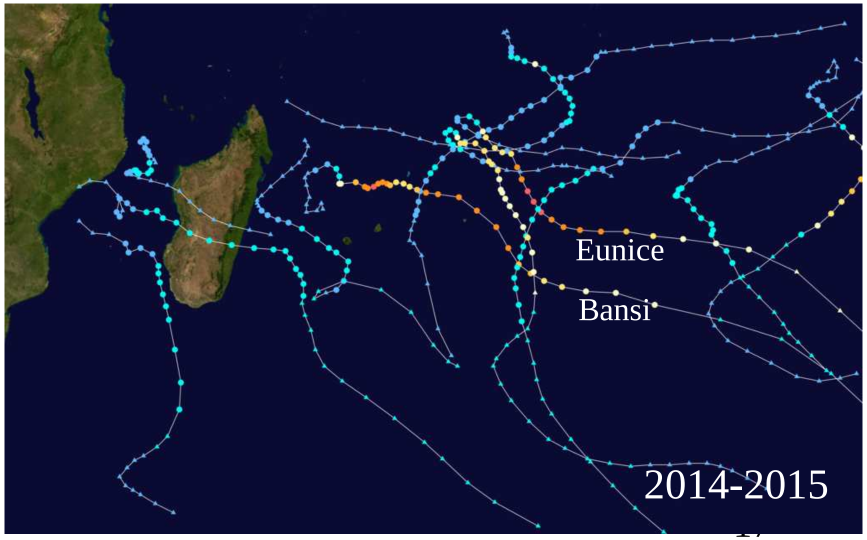
    $\rightarrow$ Latent heat release

TROPICAL CYCLONE MOTION (4)



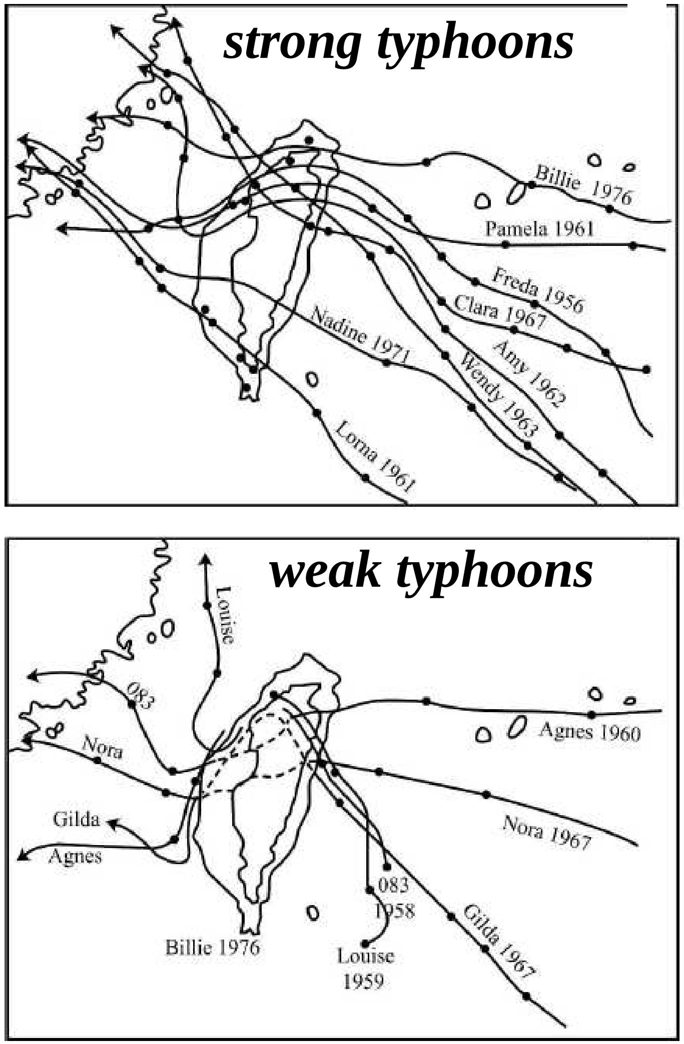


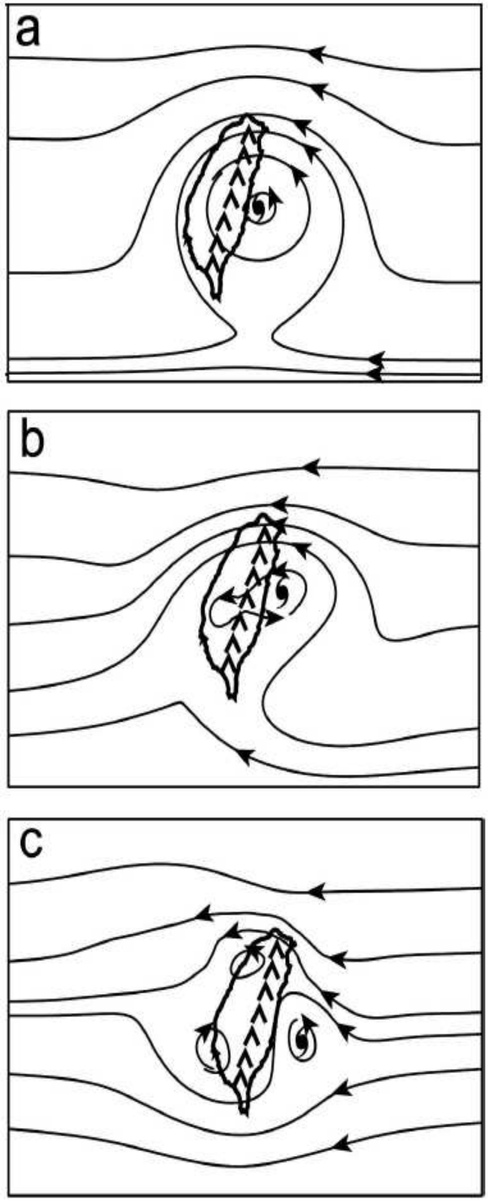




LANDFALL (1)

Lin *et al.* 2006
Mon. Wea. Rev., 134, 3509-3538





Weak blocking : *northward upstream, then southward downstream deflection, continuous track.*

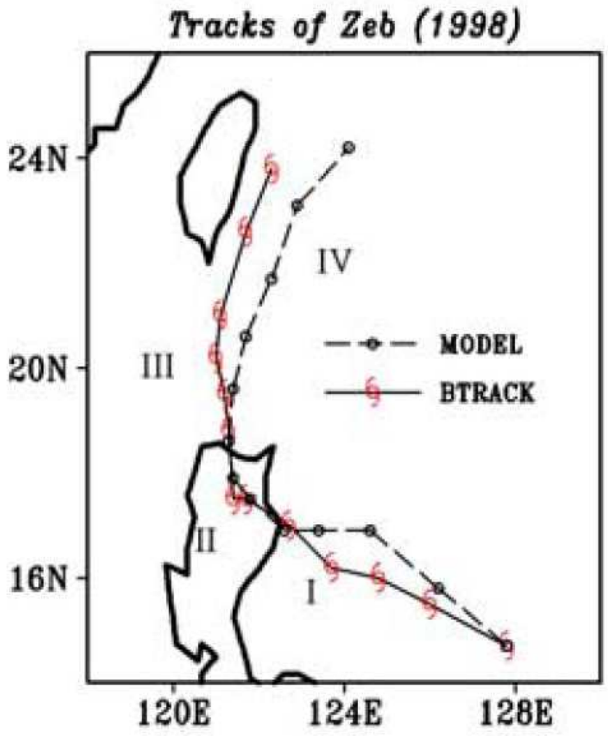
Moderate blocking : *northward upstream deflection, secondary vortex on the lee side, discontinuous track.*

Strong blocking : *souththward upstream deflection, secondary vortices on the lee side, discontinuous track.*

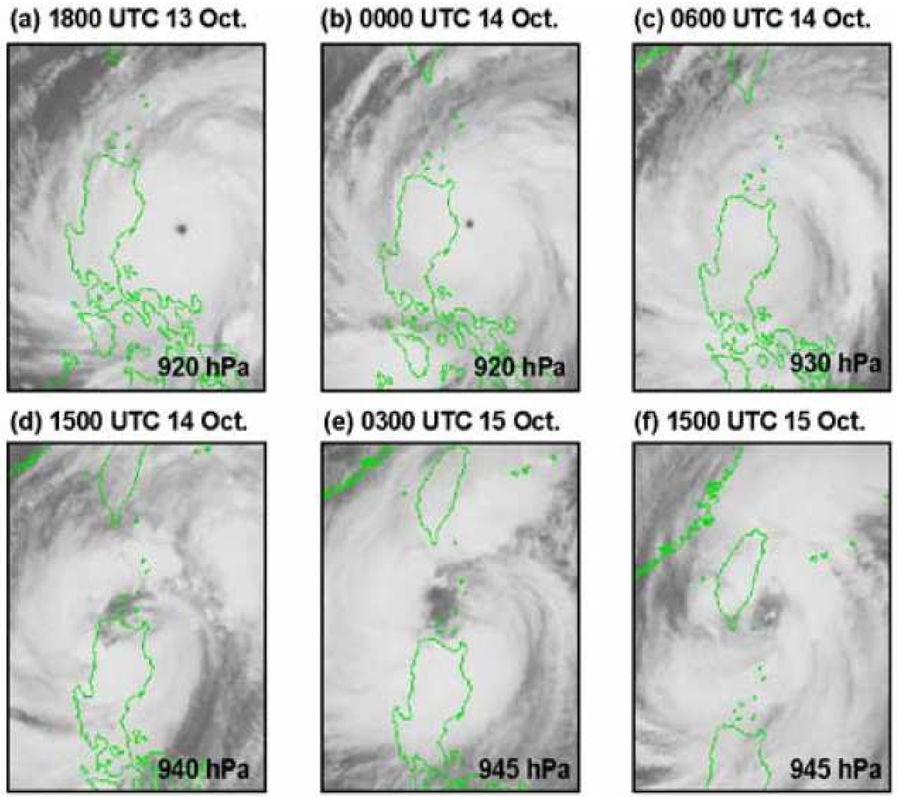
LANDFALL (2)

Wu *et al.* 2003 [*Geophys. Res. Let.***,** 30, 6.1-4]

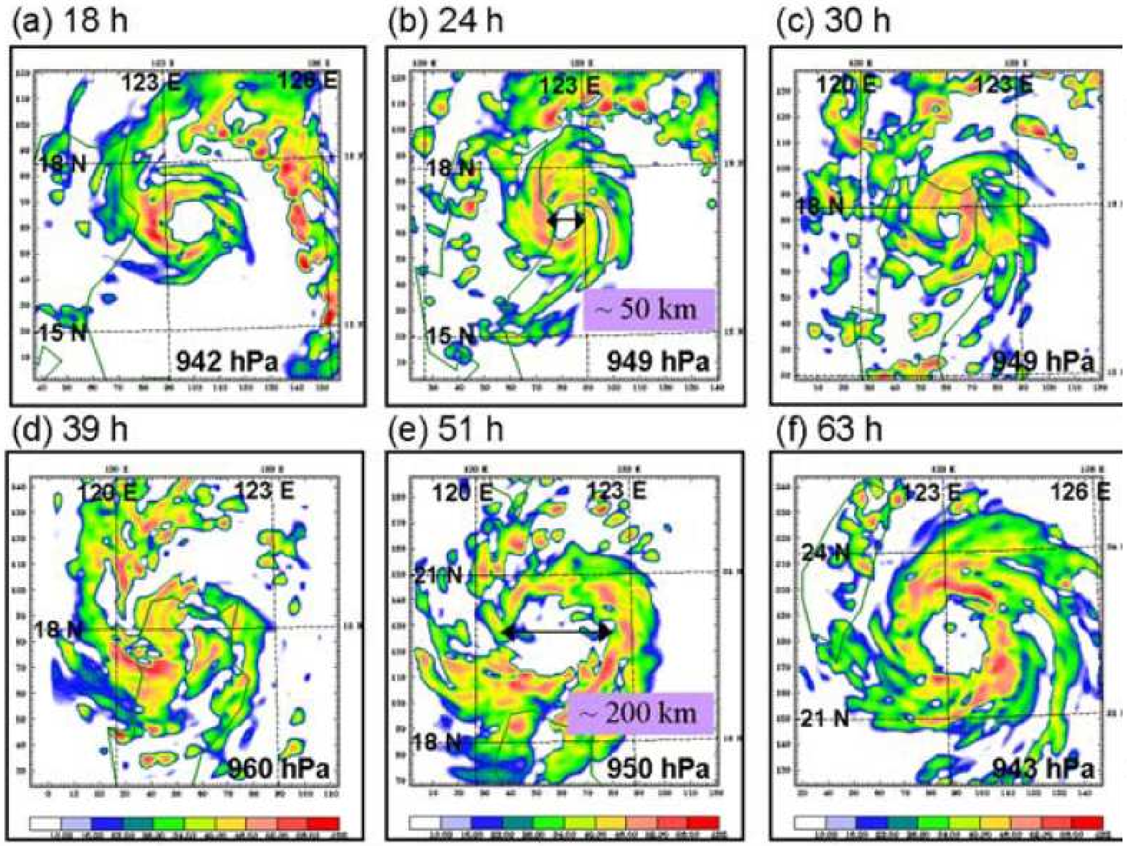
- Evolution of typhoon Zeb (1998) before, during and after its landfall at Luzon documented with satellite observations and MM5 (45 / 15 / 5 km, 72 h simulation starting 00 UTC 13 Oct 98, 24 h prior to landfall)
- The terrain plays a critical role in the observed evolution : eyewall contraction just before landfall, a following breakdown, and eyewall reformation after the storm returned to the ocean



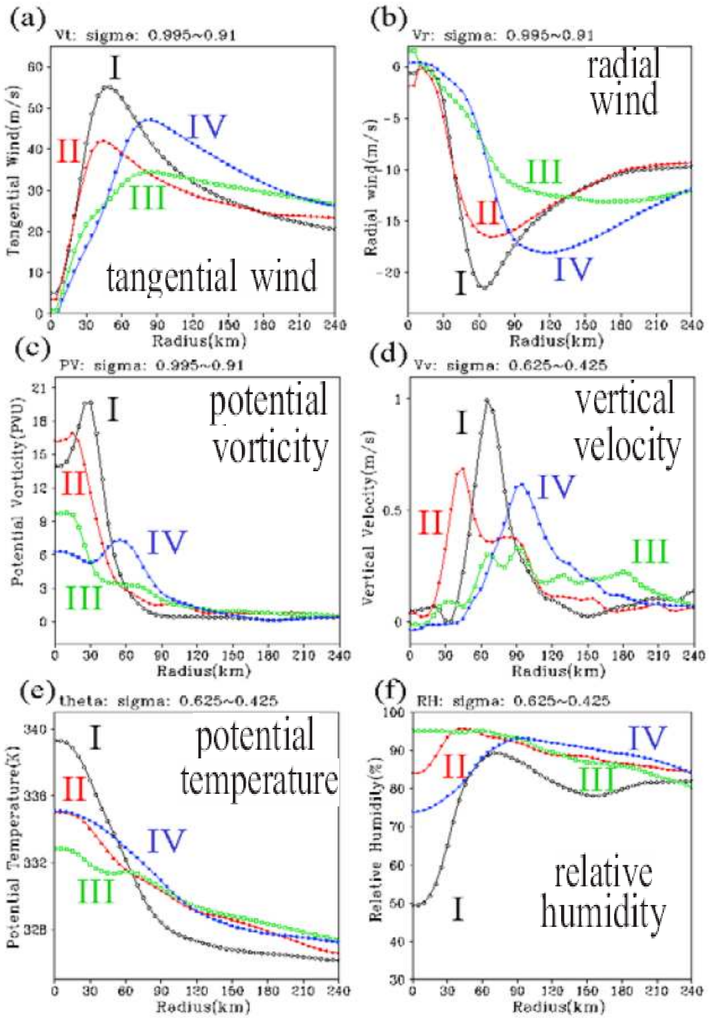
GMS satellite IR images



LANDFALL (3)



model-simulated radar reflectivity (dBZ) at 700 hPa



Time, azimuthal and vertical average

I : before landfall , II : landfall begins , III : inland , IV : return to the ocean

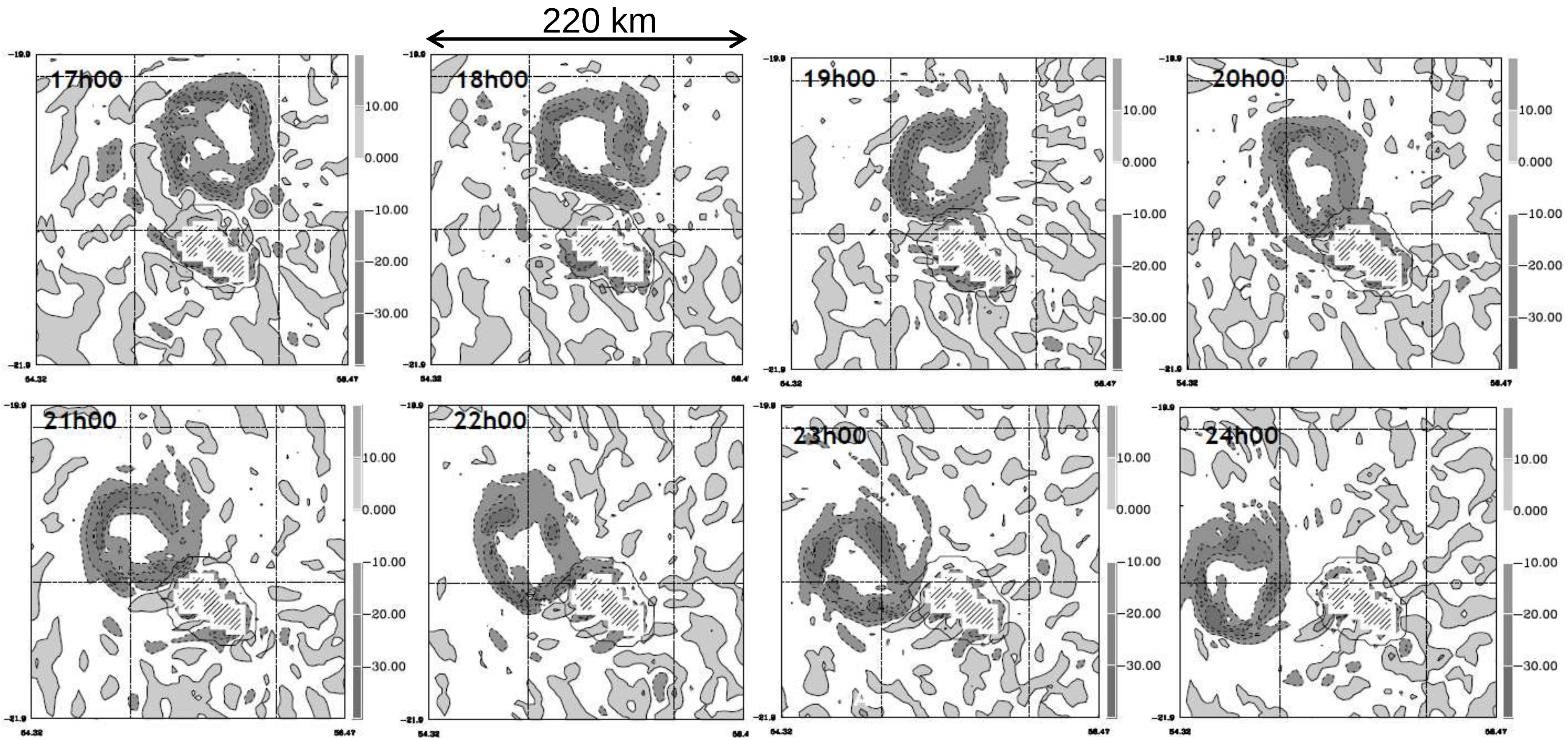
(i) What are the key parameters determining the evolutionary processes of a landfalling TC?

(ii) How does the eddy (the asymmetric component) interact with the mean flow (the symmetric component)

(iii) What kind of roles do the terrain, surface drag, and ocean heat flux play relative to those eyewall processes?

LANDFALL (4)

Jolivet *et al.* 2013 [*Ann. Geophys.*, 31, 107-125]
« A numerical study of orographic forcing on TC Dina (2002) in SW Indian ocean »

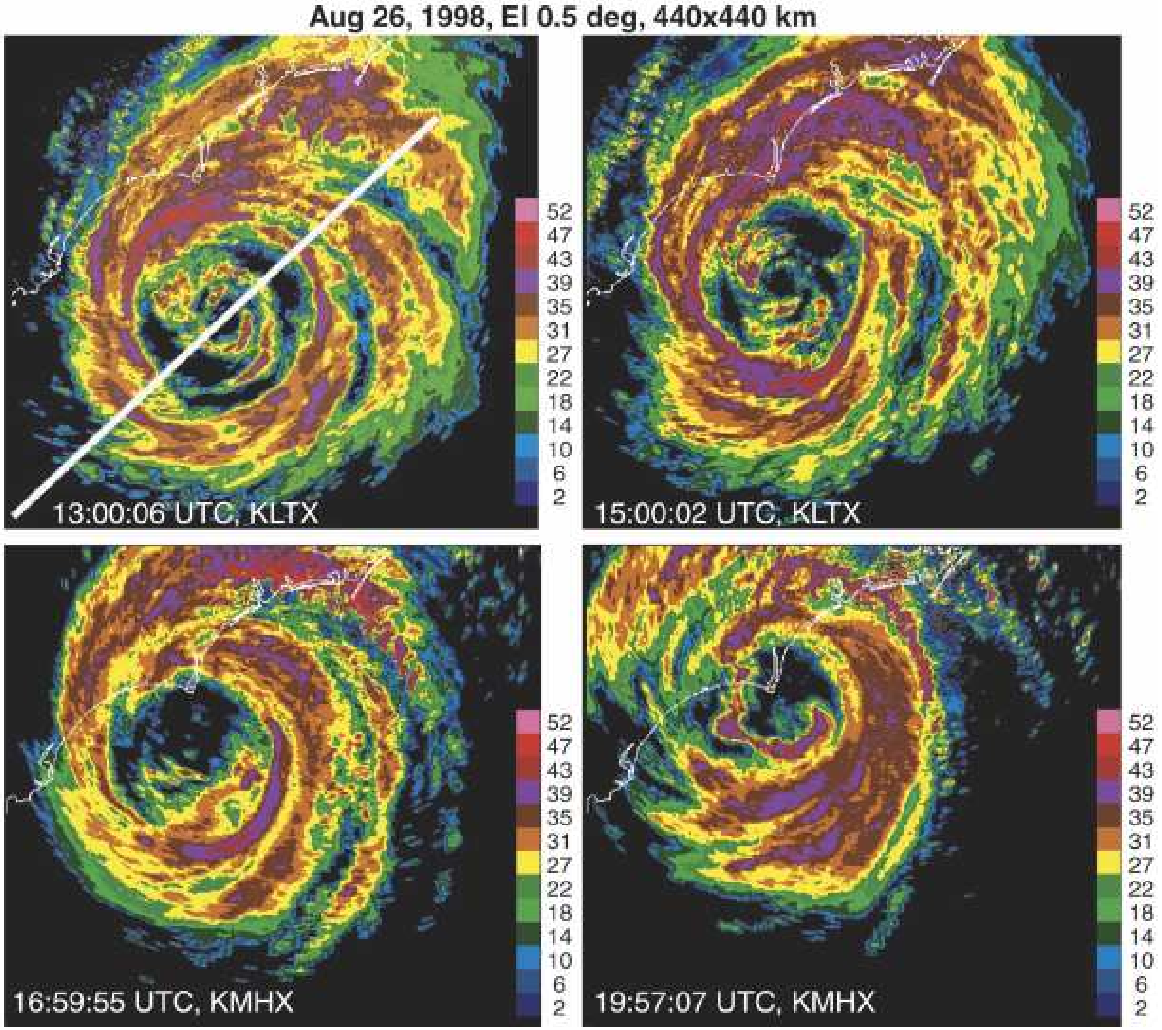


Potential vorticity fields (shaded = cyclonic, PVU = 10^{-6} m^2 s^{-1} K kg^{-1})
from the 4-km model at 1000 m altitude

LANDFALL (5)

Schneider & Barnes, 2005
Mon. Wea. Rev., 133, 3243-3259

Hurricane Bonnie



Land (N Carolina) →

Atlantic Ocean →

Eyewall structure disorganizes

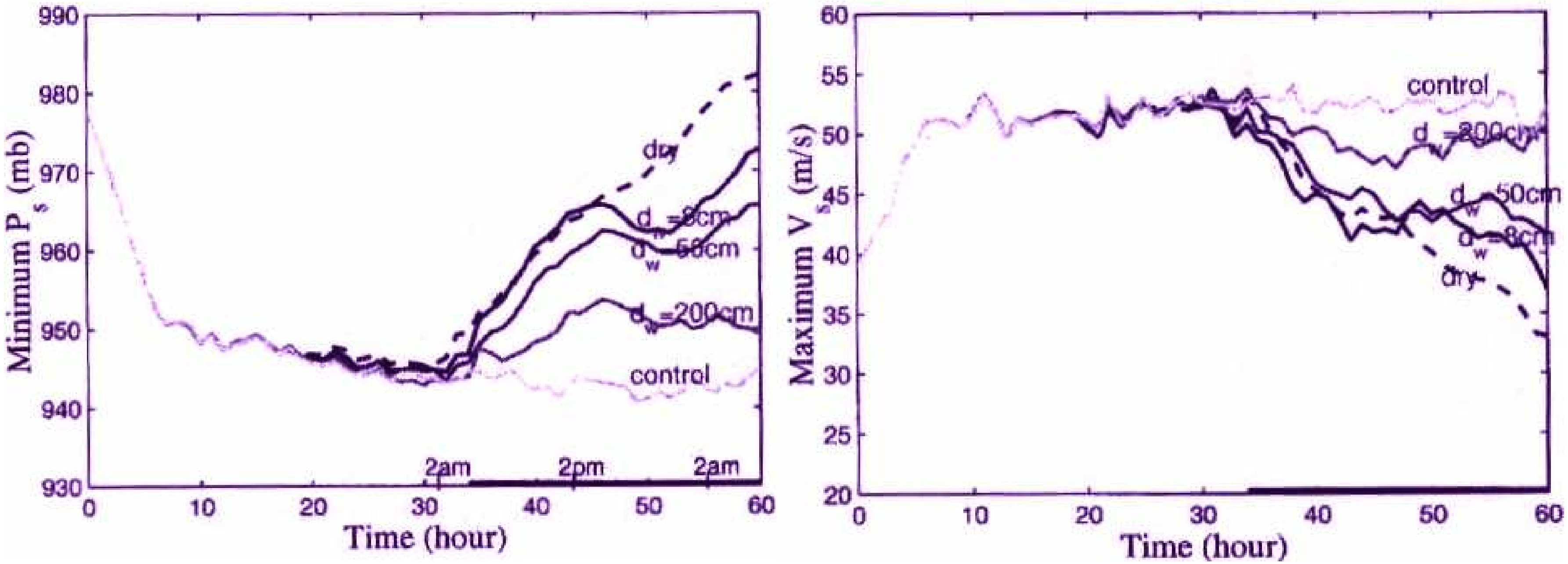
Enhanced convergence over land → NW part of the storm intensifies

Inland rainband weakens and SE part of the storm intensifies

LANDFALL (6)

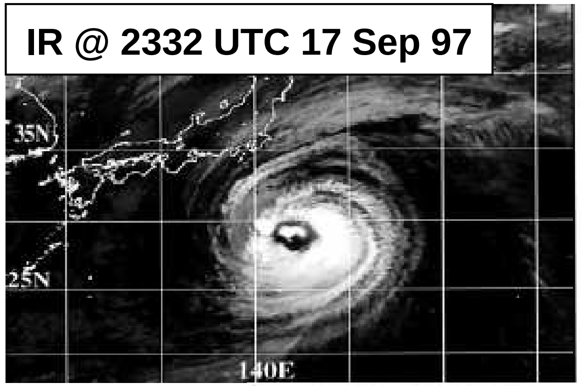
Shen *et al.* 2002 [*J. Atmos. Sci.***,** 59, 789-802]

- Little is known on the effect of surface water over land during decay of a landfalling tropical cyclone.
- Different water depths and surface conditions are considered [GFDL model, 1° / 1/3° / 1/6°]
- a layer of 0.5 m water can noticeably reduce landfall decay
- increase of surface roughness reduces the surface winds, but barely change the surface temperature and evaporation patterns.

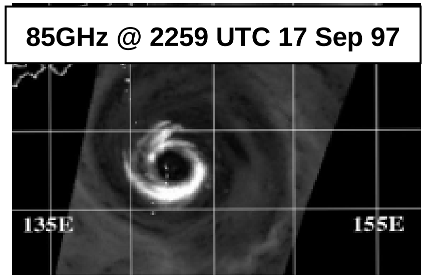


EXTRA-TROPICAL TRANSITION (1)

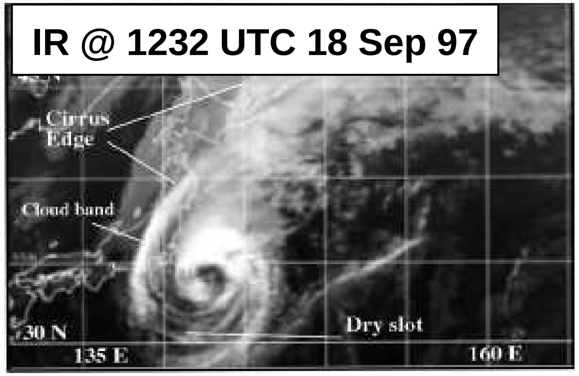
Typhoon David (1987)



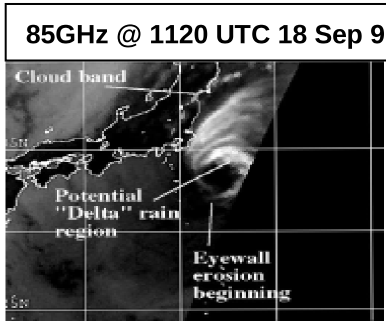
IR @ 2332 UTC 17 Sep 97



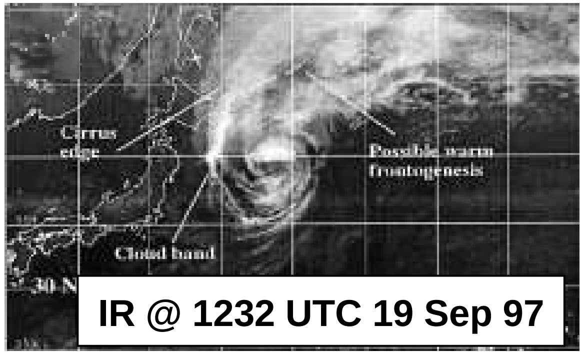
85GHz @ 2259 UTC 17 Sep 97



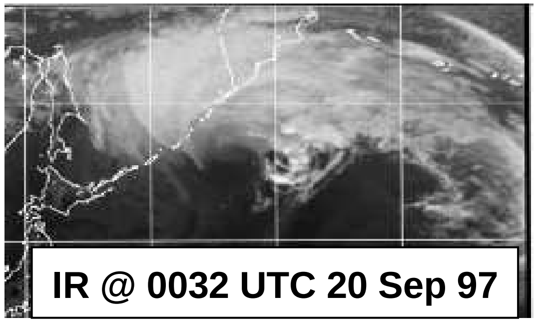
IR @ 1232 UTC 18 Sep 97



85GHz @ 1120 UTC 18 Sep 97

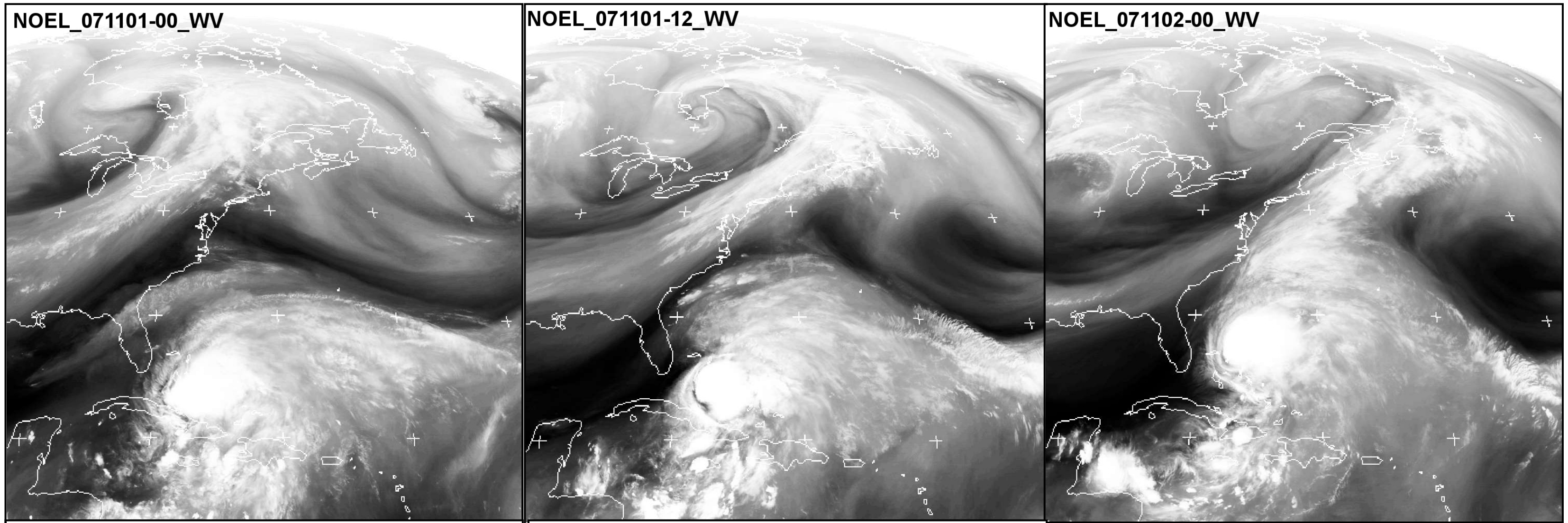


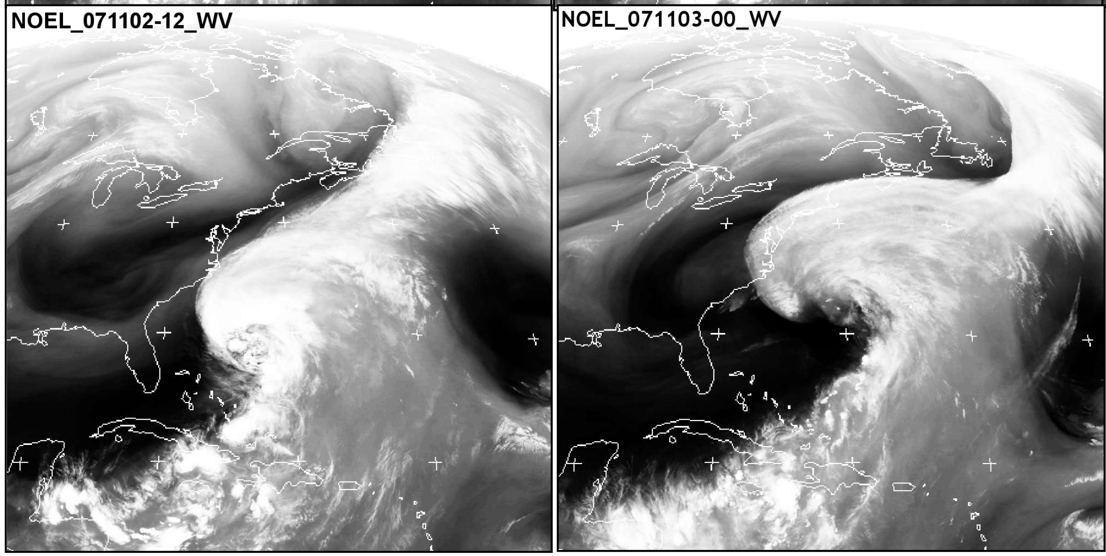
IR @ 1232 UTC 19 Sep 97


IR @ 0032 UTC 20 Sep 97

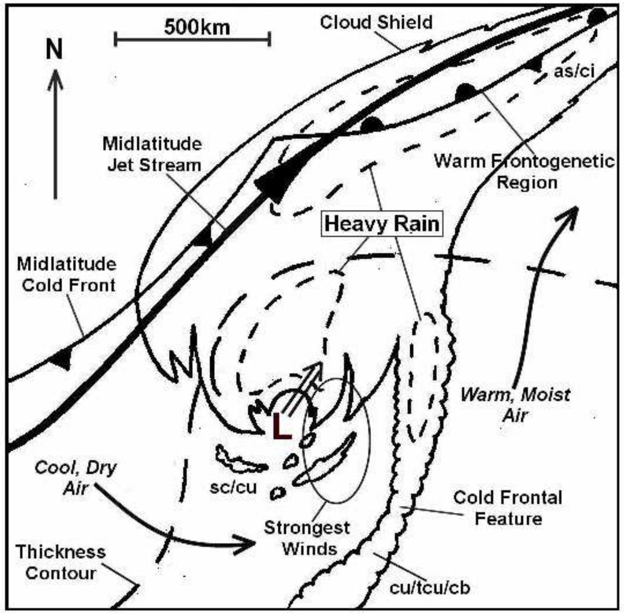
Klein *et al.*, 2000
Wea. Forecasting, 15, 374-395

EXTRA-TROPICAL TRANSITION (2)

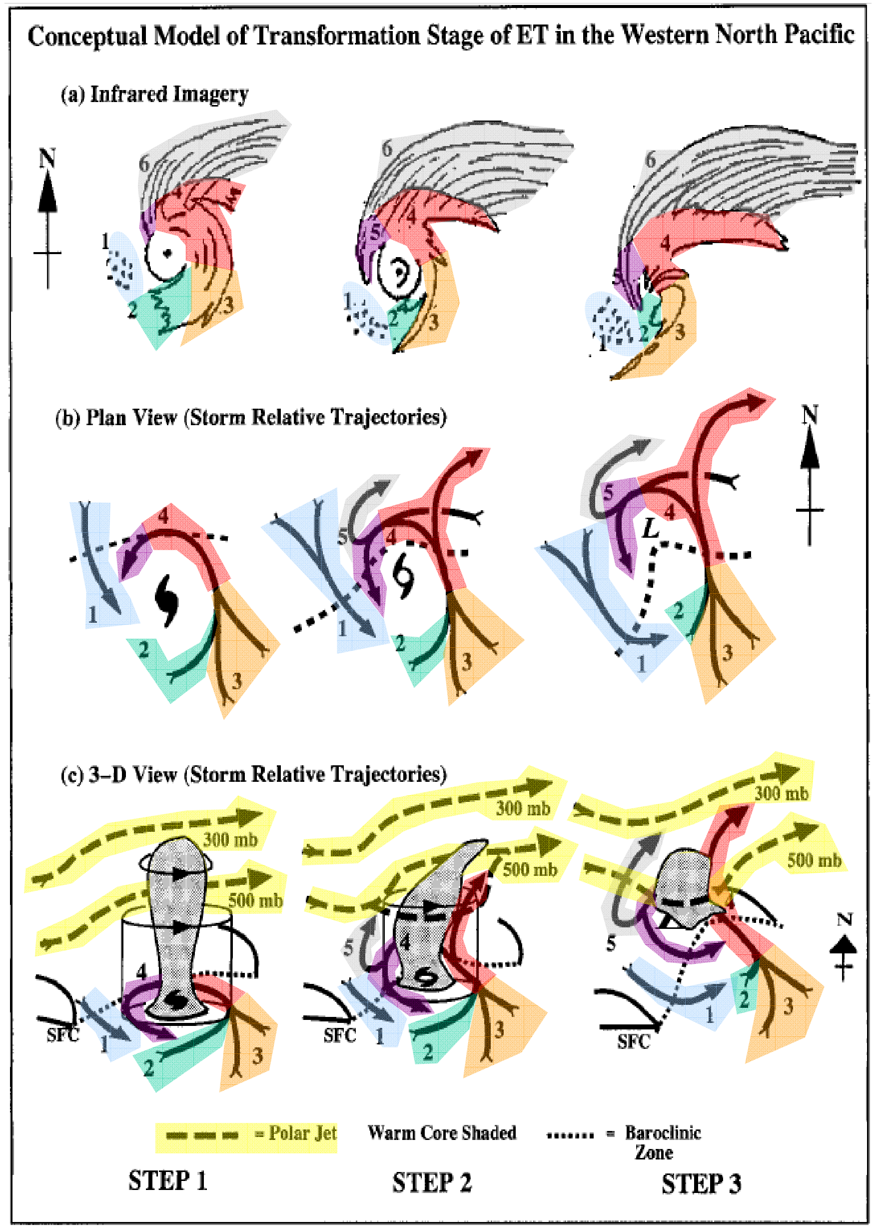




ET SCHEMATIC



EXTRA-TROPICAL TRANSITION (3)

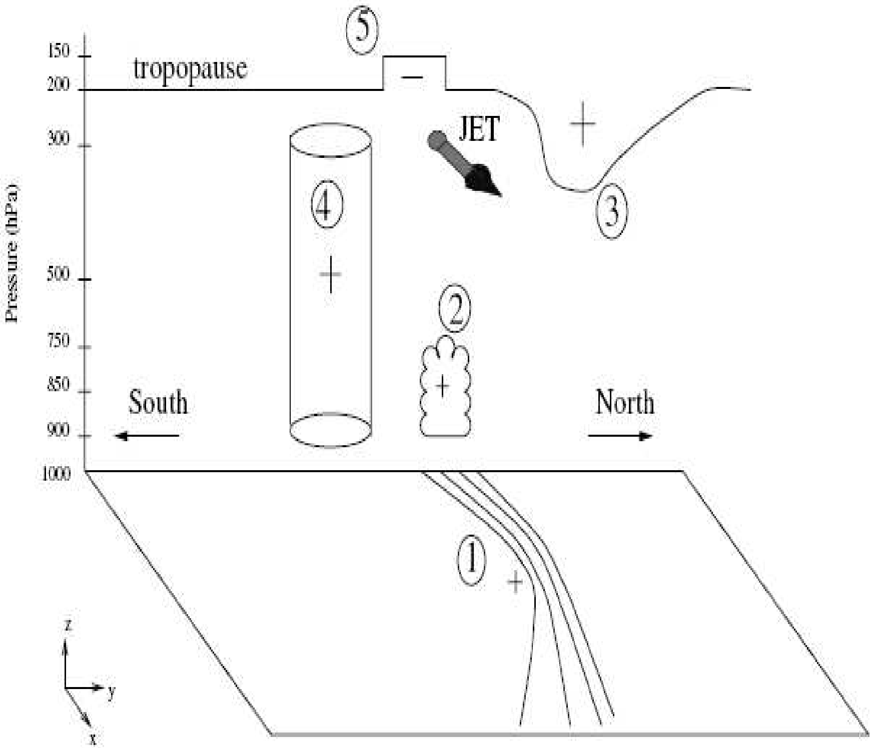


1. Environmental equatorward flow of cooler, drier air with associated low-level convection ;
2. Decreased tropical cyclone convection in the western quadrant (the « dry slot » progressively extends throughout the southern quadrant) ;
3. Environemental poleward flow of warm, moist air maintains convection in the eastern quadrant and results in an asymmetric distribution of cloud and precipitation ;
4. Ascent of warm and moist inflow over the tilted isentropic surfaces associated with baroclinic zone (« warm front ») ;
5. Wrapping ascent produces cloudbands westward and equatorward around the storm center ; dry-adiabatic descent close to the circulation center erodes the eyewall convection in STEP 3
6. Cirrus shied with a sharp cloud edge extends poleward.

EXTRA-TROPICAL TRANSITION (4)

Agusti-Paneda *et al.*, 2004
Quart. J. Roy. Meteor. Soc., 130, 1047-1074

Figure 1. Schematic showing potential vorticity (PV) anomalies and other anomalies featuring in the extra-tropical transition process: (1) a surface thermal anomaly on a baroclinic zone, (2) diabatically-generated positive PV anomalies along the baroclinic zone, (3) a positive PV anomaly associated with a midlatitude upper-level trough, (4) the tropical-cyclone's positive PV anomaly and (5) the negative PV anomaly associated with the tropical-cyclone's outflow. The arrow represents an upper-level jet. The strength of the jet is associated with the horizontal gradient of PV at upper-levels, i.e. the steepness of the tropopause.



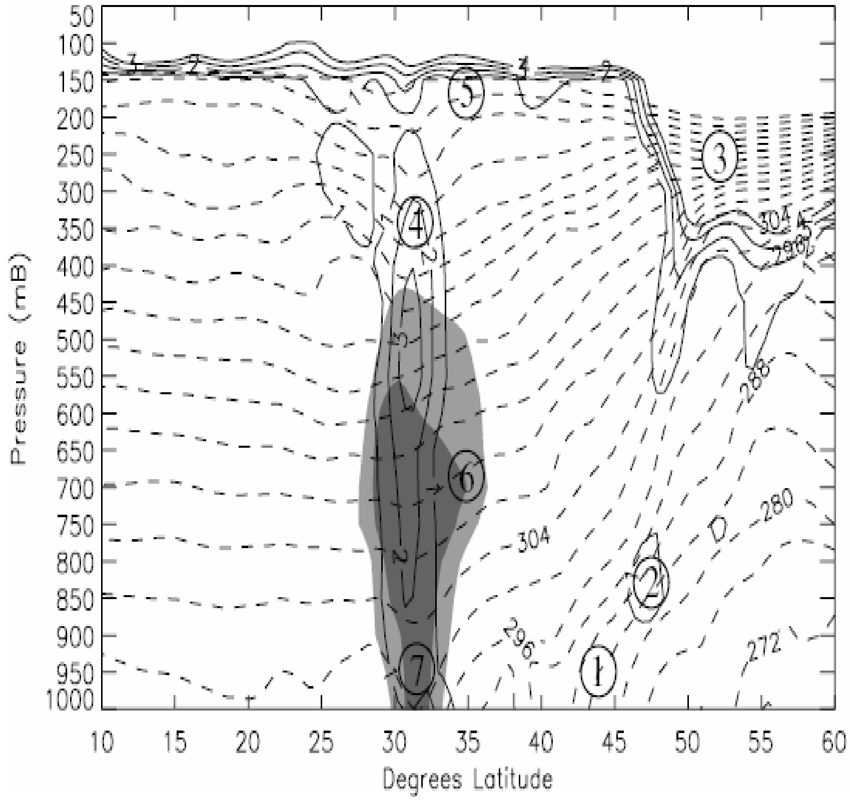


Figure 3. Potential vorticity (PV) and other anomalies involved in the extratropical transition of hurricane *Irene* (12 UTC 17 October 1999) shown by a north–south vertical cross-section of PV (full contours of 1, 2, 3 and 4 PVU), potential temperature from 272 K to 356 K (dashed contours with 4 K interval) and mixing ratio in grey scale (from 3×10^{-3} to 5×10^{-3} kg kg^{-1} in light grey and from 5×10^{-3} to 7×10^{-3} kg kg^{-1} in dark grey) from the Met Office analysis. The anomalies associated with *Irene* are a positive PV tower (4), a moisture anomaly (6), an upper-level negative PV anomaly depicted as a tropopause lift (5) and a surface potential-temperature anomaly (7). The anomalies associated with the extratropical environment are a baroclinic zone (1), diabatically-generated PV along the baroclinic zone (2) and an upper-level positive PV anomaly (3).

EXTRA-TROPICAL TRANSITION (5)

Jones *et al.*, 2003
Wea. Forecasting, 18, 1052-1092

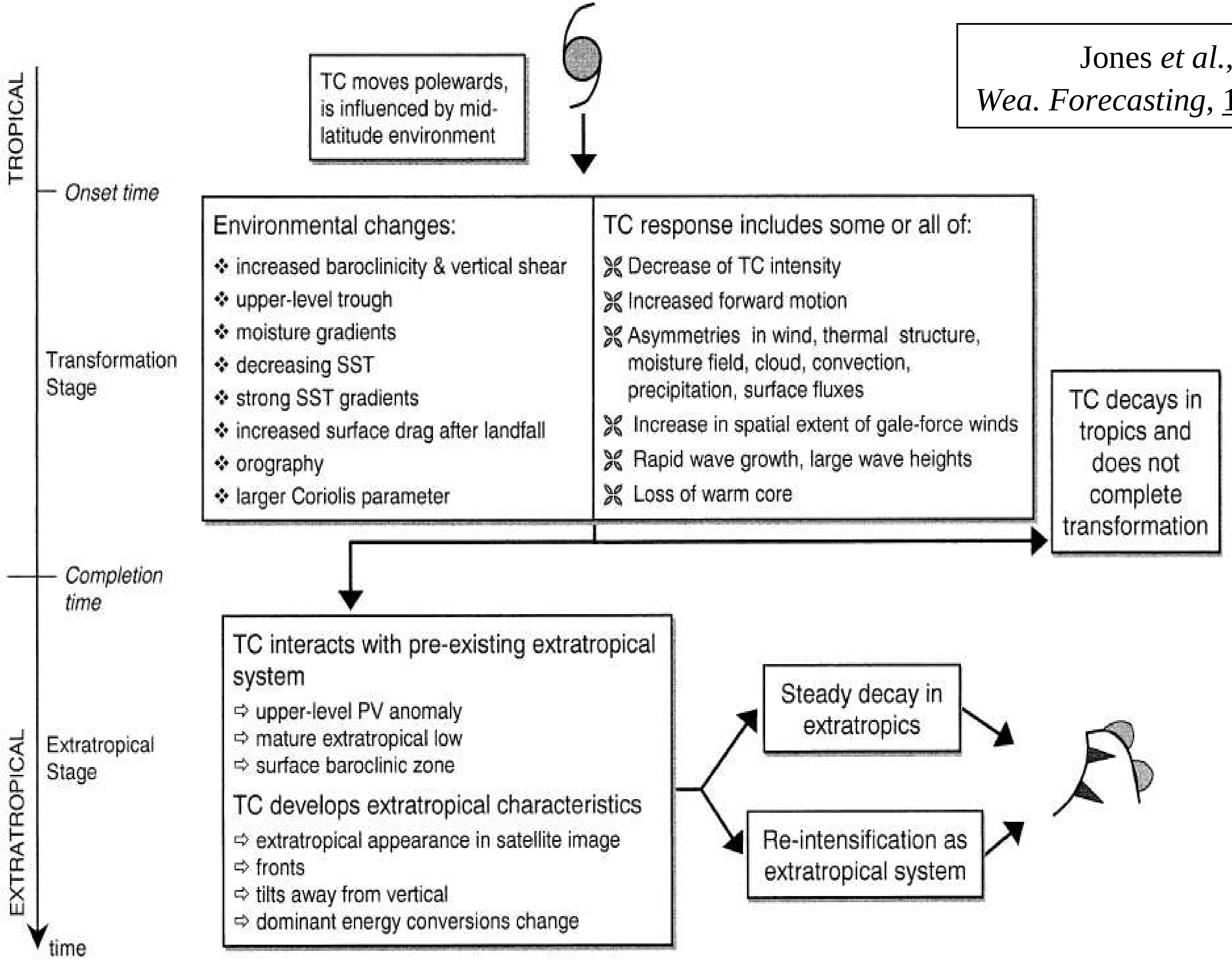
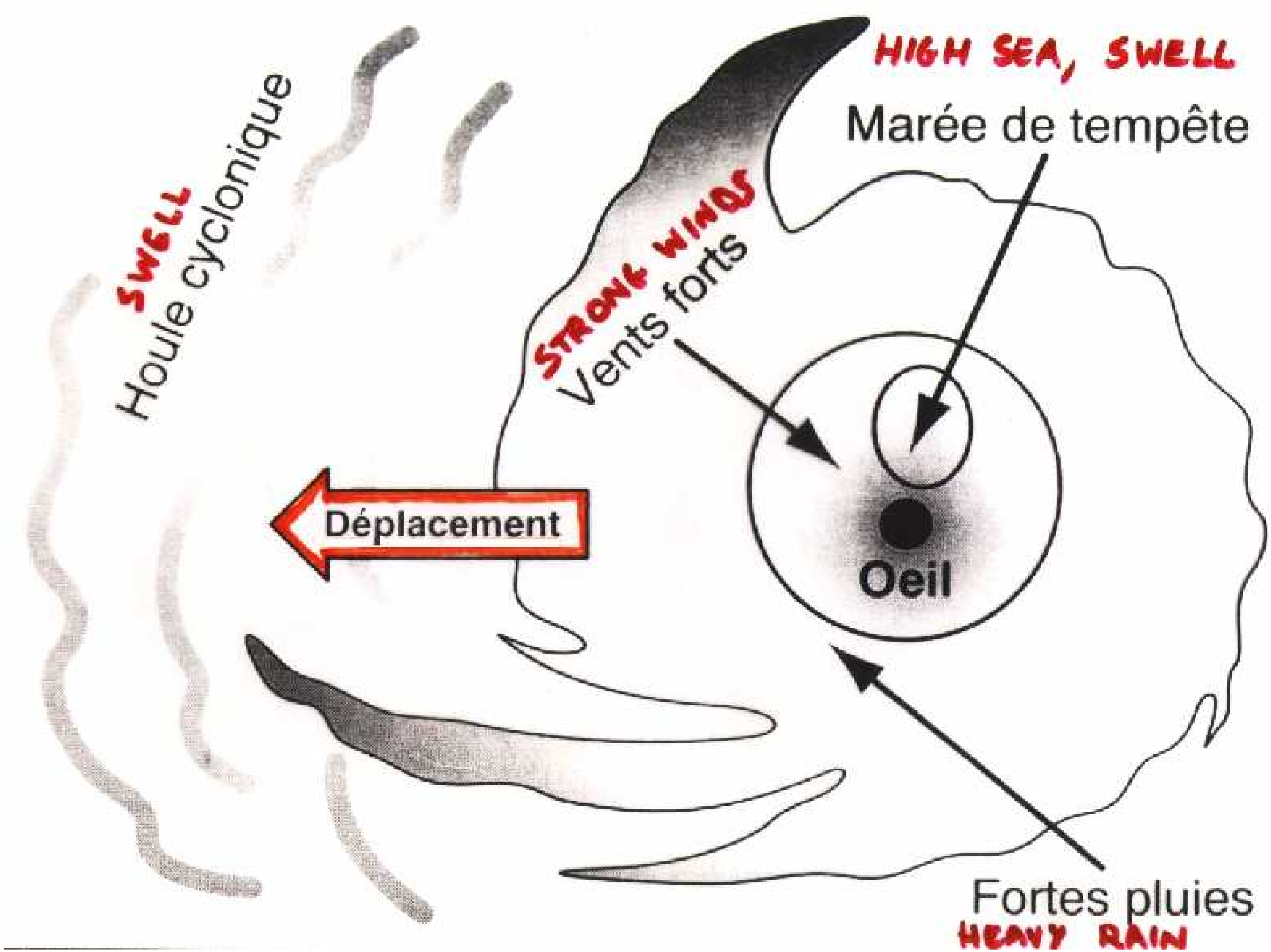


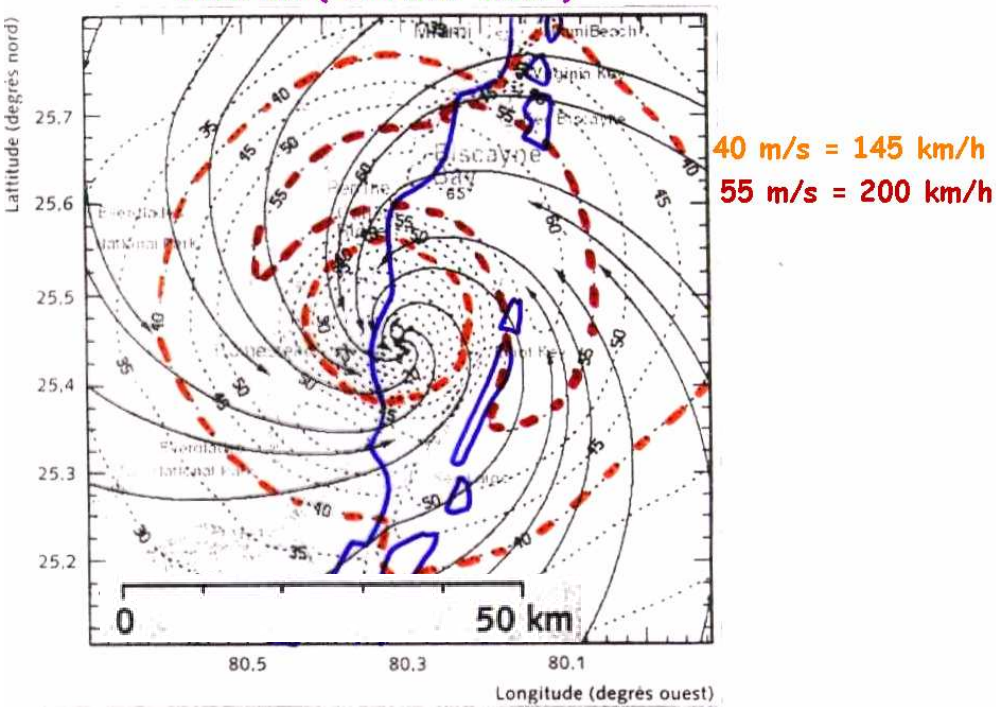
FIG. 11. A two-stage classification of extratropical transition based on the classification of Klein et al. (2000). The onset and completion times correspond to the definitions of Evans and Hart (2003). The "tropical" and "extratropical" labels indicate approximately how the system would be regarded by an operational forecast center.

TC-RELATED RISKS (1)

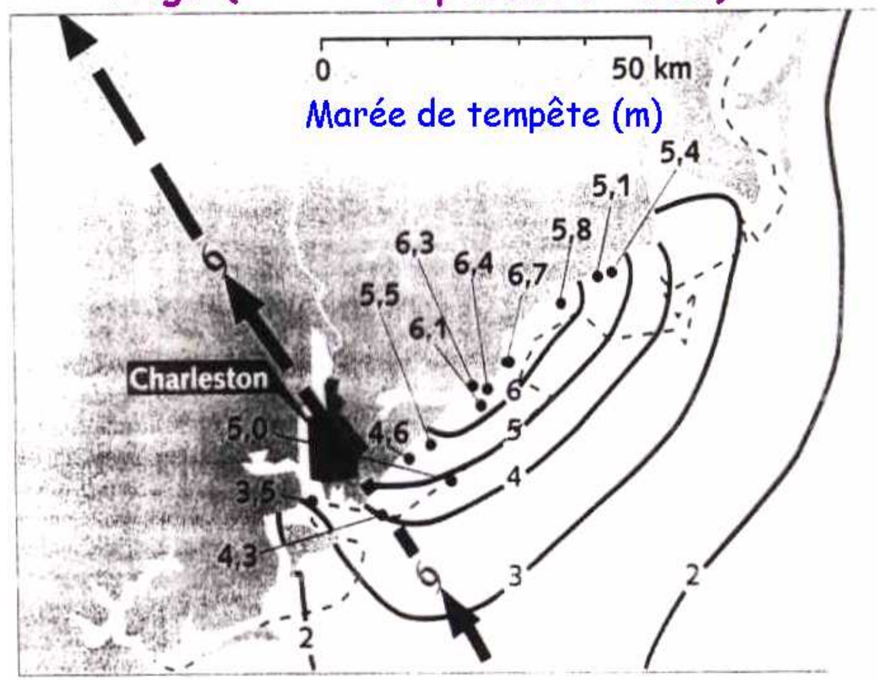


TC-RELATED RISKS (2)

Andrew (24 Août 1992)



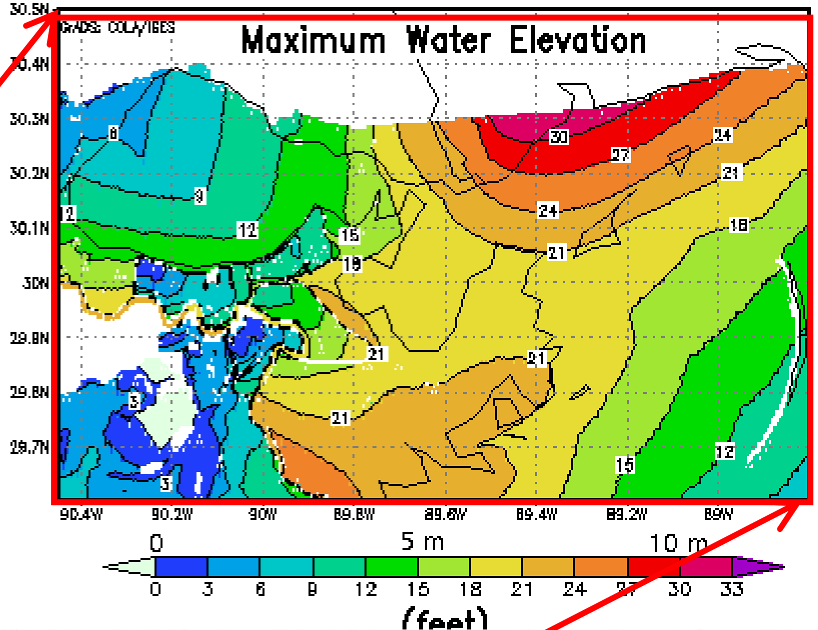
Hugo (21-22 Septembre 1989)

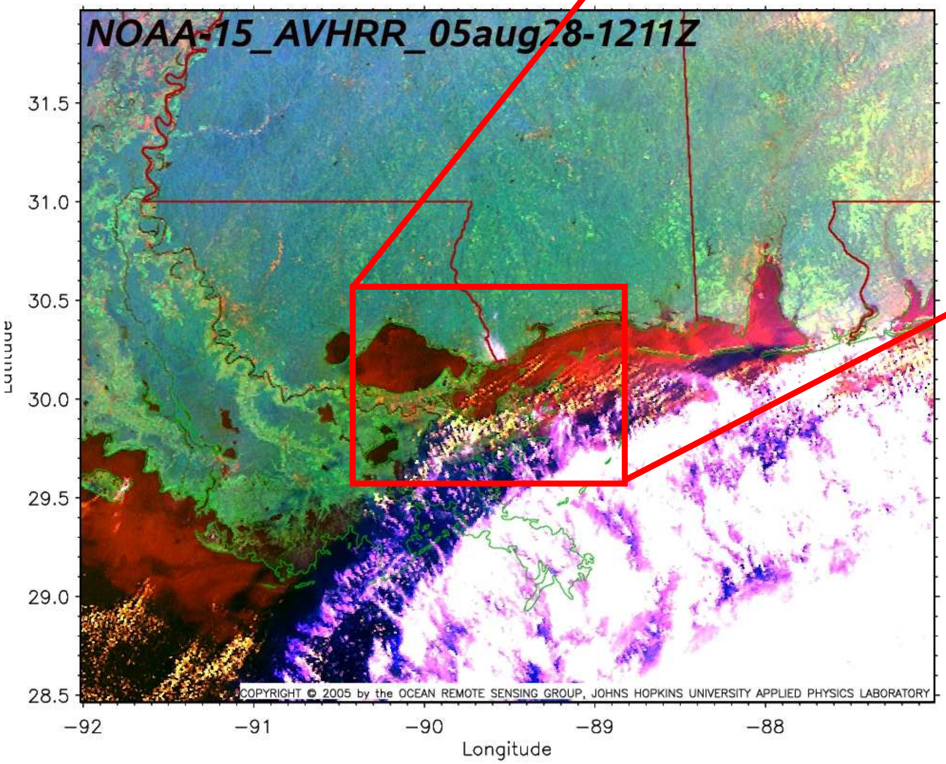


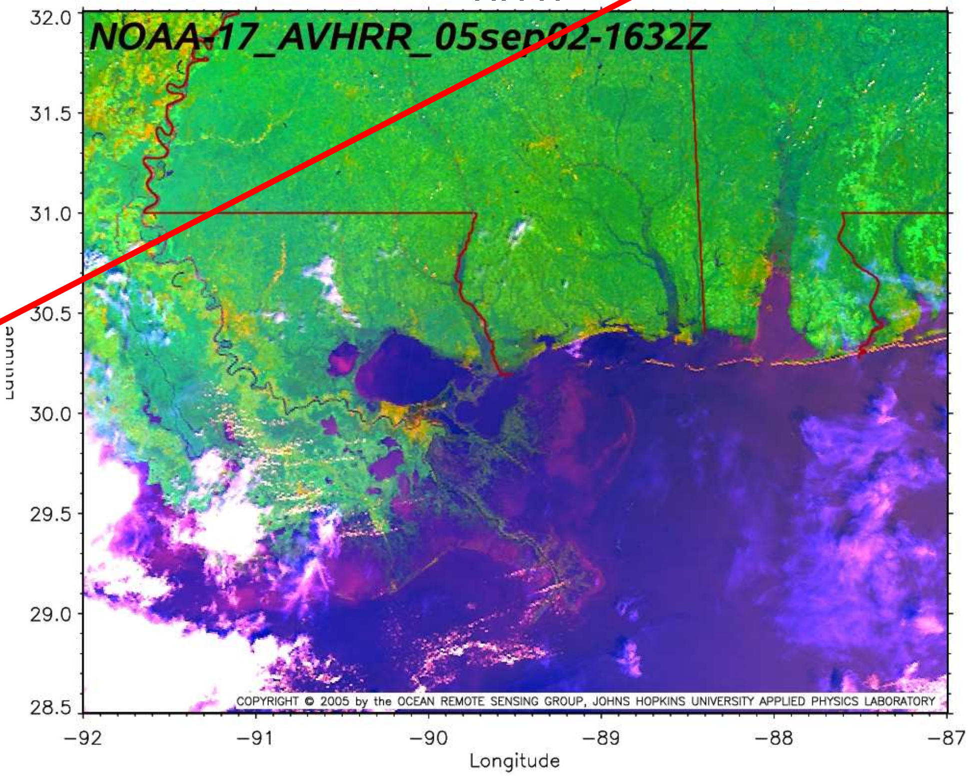
TC-RELATED RISKS (3)

Katrina on 29 August 2005 :

winds>300 km/h, storm surge>12 m







TC-RELATED RISKS (4)

Mitch
(Oct. 1998)