Copertina

Corso di Fisica dell'Atmosfera

Cicloni tropicali e extratropicali.

Giaiotti Dario & Stel Fulvio

Trieste, anno accademico 2012/2013

Sommario della lezione

- I cicloni atmosferici come sorgente di rischio
- Caratteristiche fisiche dei cicloni tropicali
- Cicloni tropicali e cambiamenti climatici
- Caratteristiche fisiche dei cicloni extra tropicali
- Cicloni tropicali e cambiamenti climatici

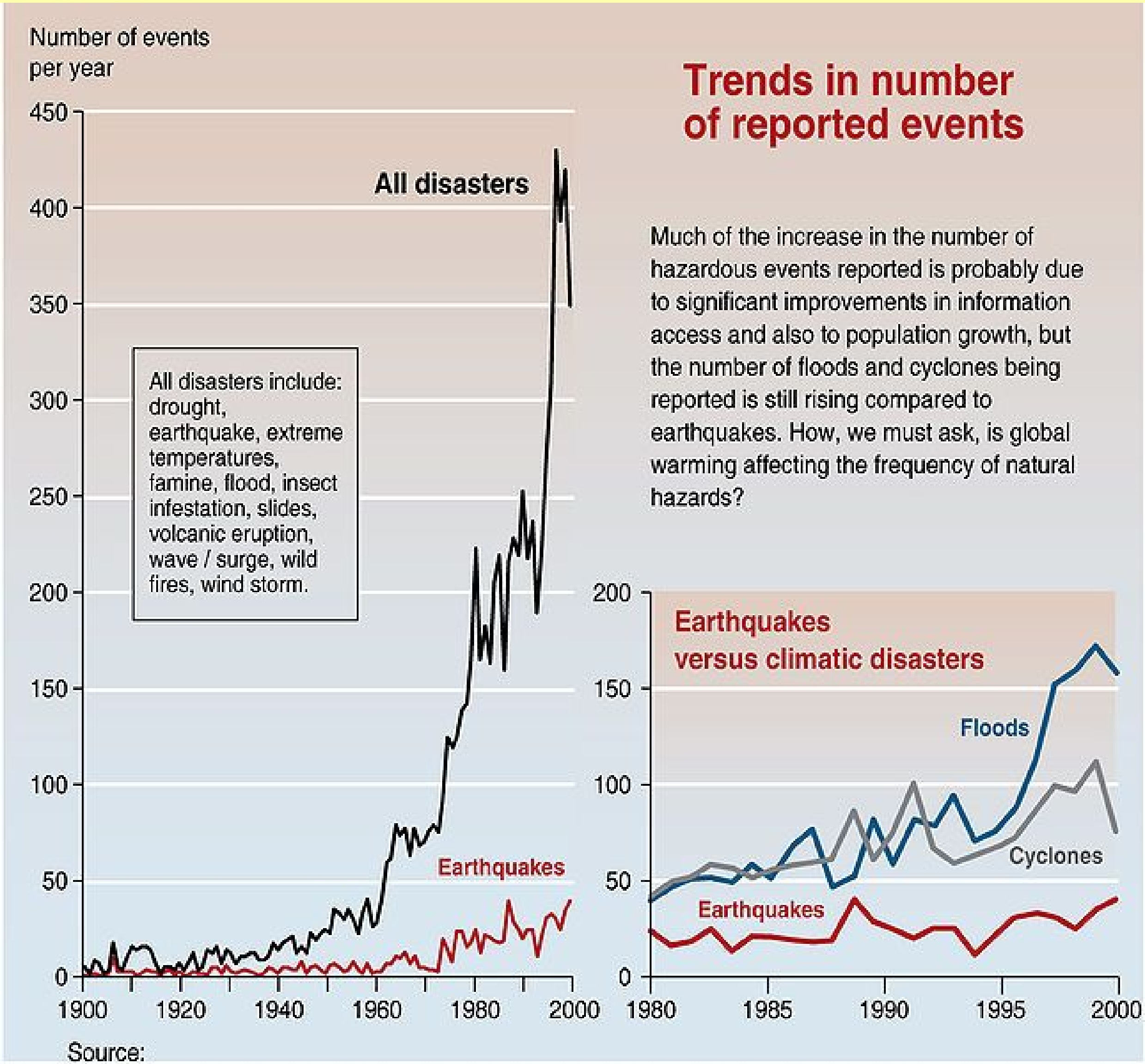
Cyclones are sources for extremes in two important weather fields:

- Wind – transfer of momentum from air to other systems
- Precipitations – efficiency in condensating water vapor

Cyclones produces secondary extremes and related risks

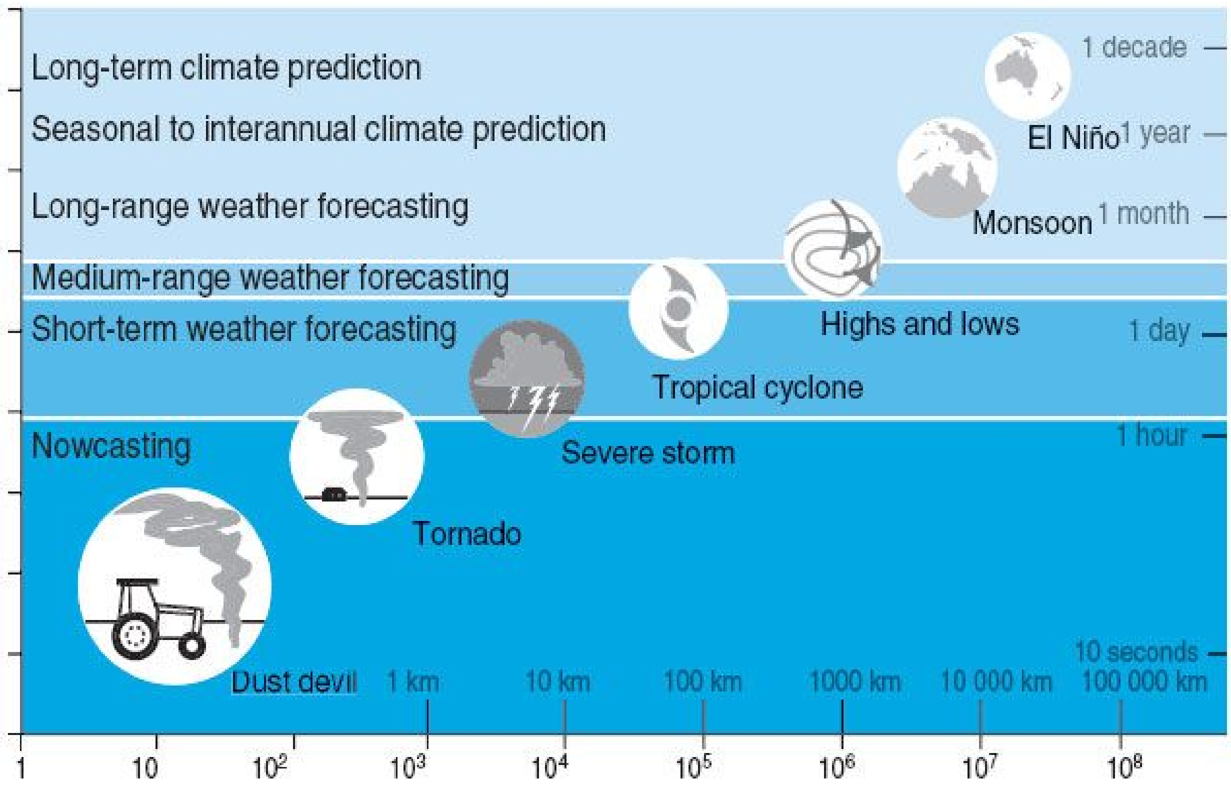
- Surges, runoff

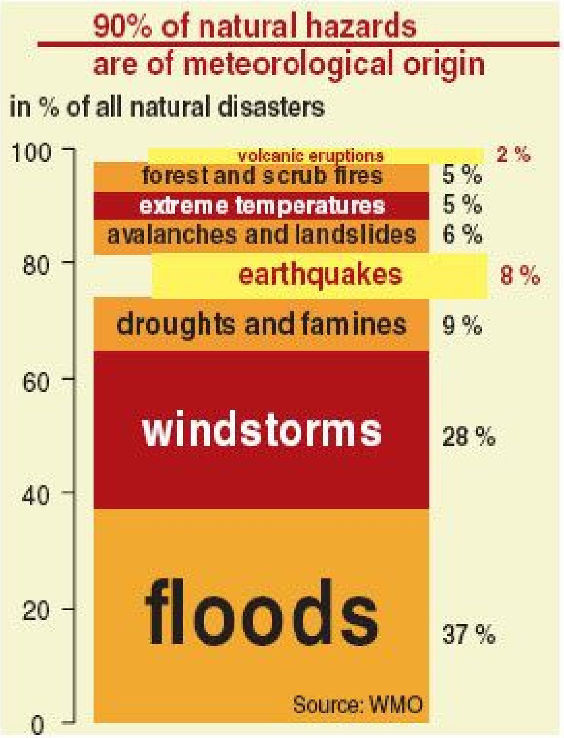
Tropical and extra-tropical cyclones accounts for a significant fractions of natural disasters



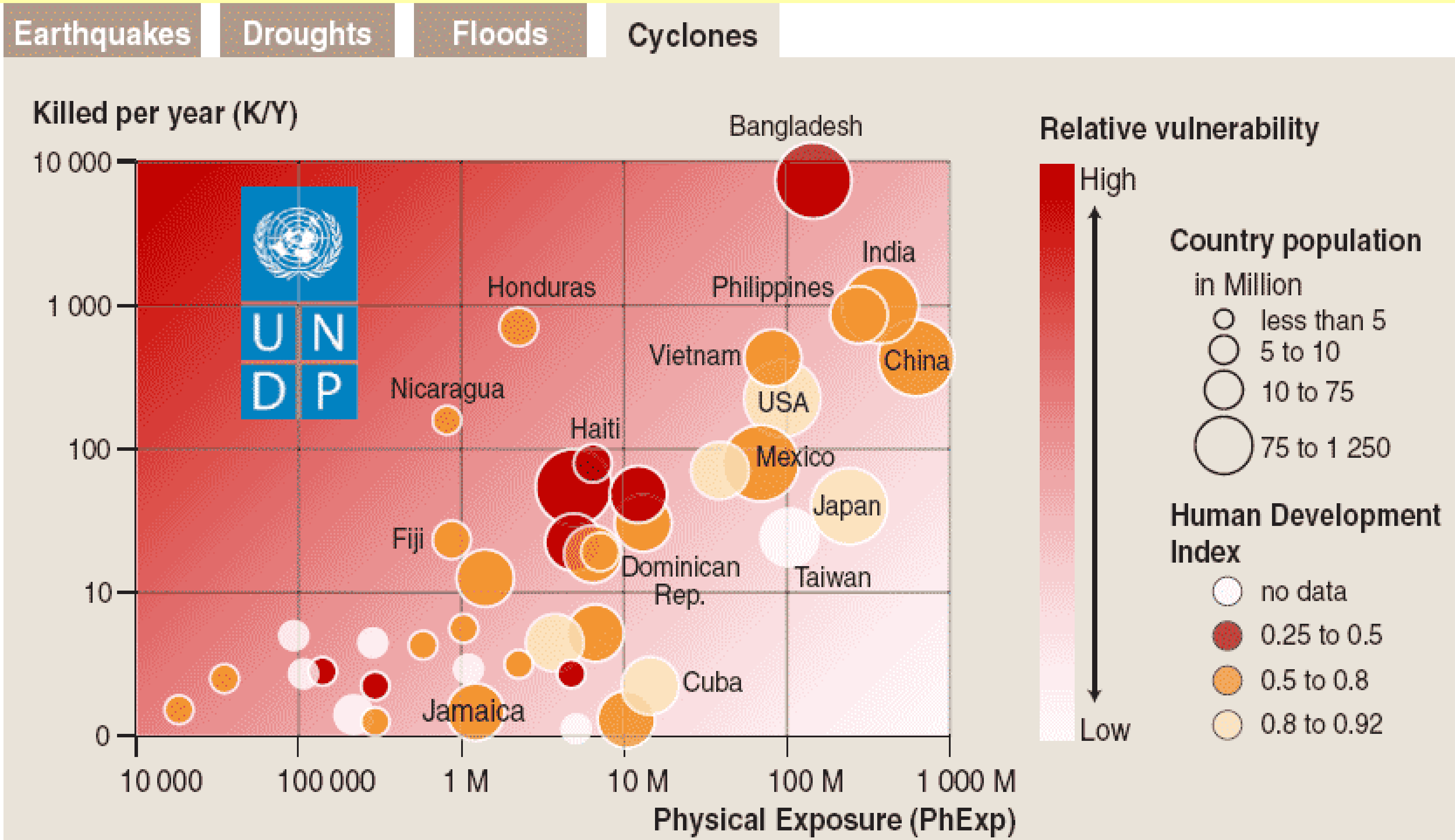
Note the observational bias

The most important fraction of natural hazards is due to meteorological extreme events.





Cyclones accounts for a large fractions of natural disasters



The Disasters Risk Index Analysis Tool

allows users to access and manipulate statistics about disasters, including country profiles.
http://gridca.grid.unep.ch/undp/

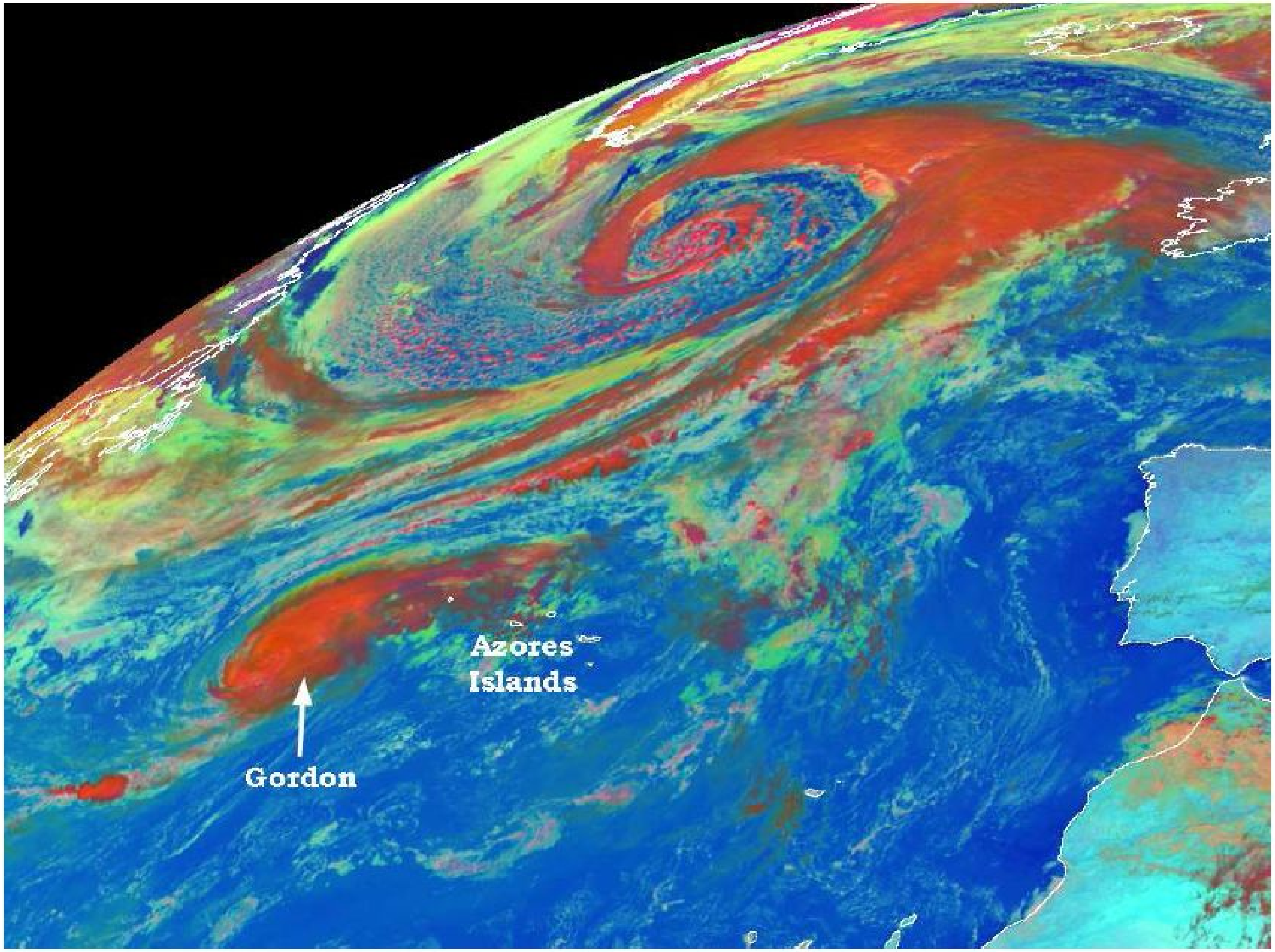


FIGURE 14. The tropical cyclone Gordon seen from METEOSAT on September 19, 2006 12 UTC. Compare it with the extratropical cyclone present in the Northern Atlantic. Sizes, time-life, trajectories and evolution are different because their dynamics is different, copyright 2006 EU-METSAT

- It is necessary to define a weather event.
  - Max wind intensity
  - Surge hight
  - Maximum daily (hourly) precipitation
  - Minimum value o pressure at the ground
  - ....
- It is necessary to have a set of weather events.
  - Observations at one location.
  - Remote sensing identification.
  - Damages reports.
- It is necessary to group the events in homogeneous sub sets.
  - Usually an index is used
  - One of the features can be used (max wind, etc).
- Possibly to give a rank to the sub sets.
  - Easy to do when index is available

A tropical cyclone, TC, is a significant trough, a depression area or a geopotential low evolving in the tropics.

Tropical cyclones are classified as:

tropical depressions, *tropical storms* and **hurricanes** (Atlantic Ocean) (**typhoons** - Pacific Ocean) (**Cyclones** – Indian Ocean) according to the increase of the maximum wind speed.

- Tropical depression (average wind speed < 18 m/s)
- Tropical storm (18 m/s=< average wind speed < 33 m/s)
- Hurricane (33 m/s=< average wind speed)

Weather services usually give personal names to the tropical cyclones to facilitate their identification on weather charts in case of two or more systems in the area at the same time.

Typical eye shape of a tropical cyclone

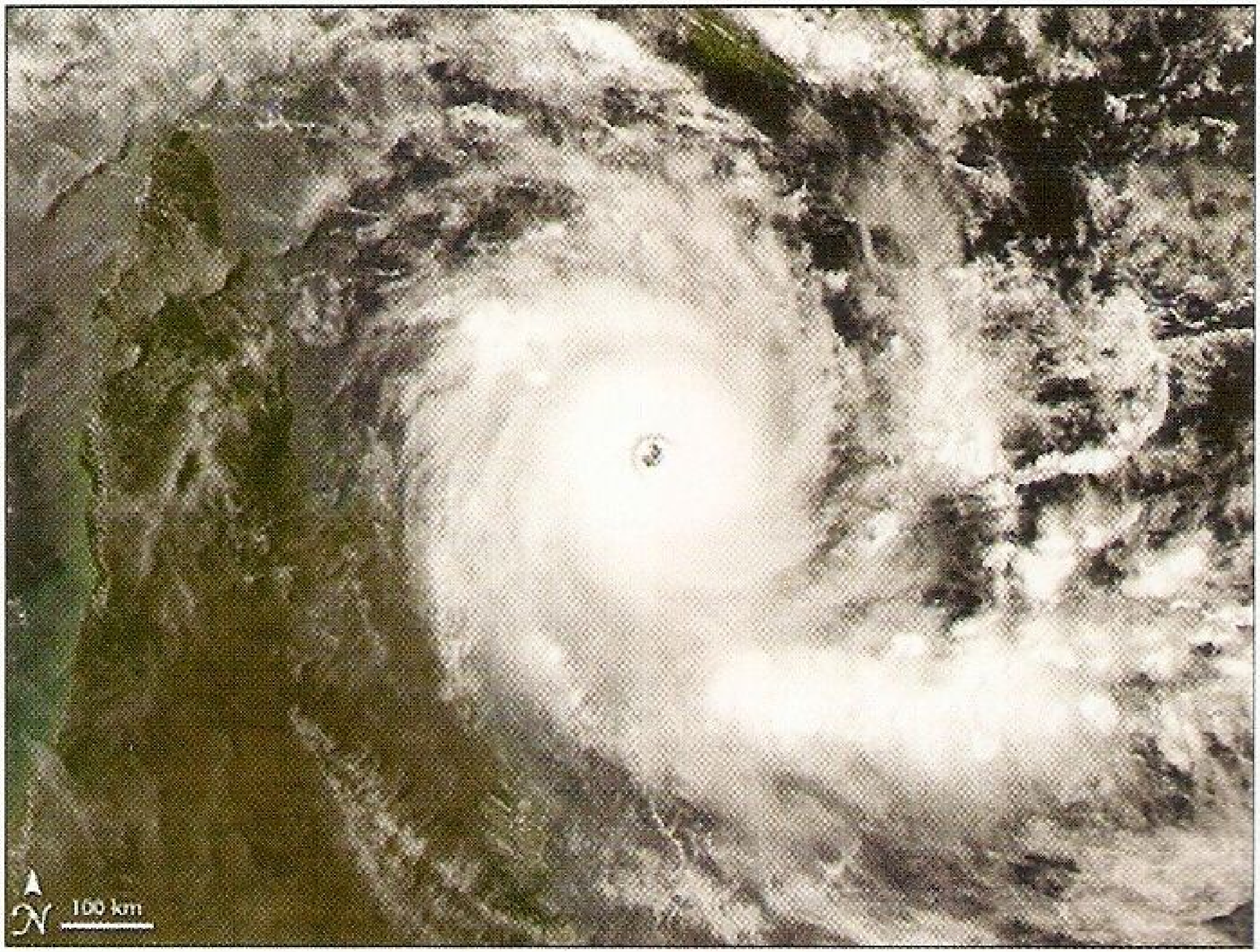


Figure 2:*Cyclone Ingrid - captured by the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Aqua satellite, 8/3/05.*

Thanks to NASA http://www.nasa.gov

Features of the tropical cyclones (a)

Almost circular isobaric pattern at the sea level around a low center. Circular wind streamlines, but asymmetric wind intensity distribution.

Maximum wind speed are in the right front of the storm and minimum wind speeds in the eye of the storm.

Decrease of the wind intensity with height.

Rainbands associated to cumulus nimbus are embedded in the cyclone and they move towards the center according to the cyclonic circulation, while upper cirrus at the top o the troposphere move anticyclonically.

Typical size is of the order of 100 of km. Cirrus top may reach 1000 km

The structure of the Tropical cyclones is easy to identify

Satellite imagery is a very useful source of information

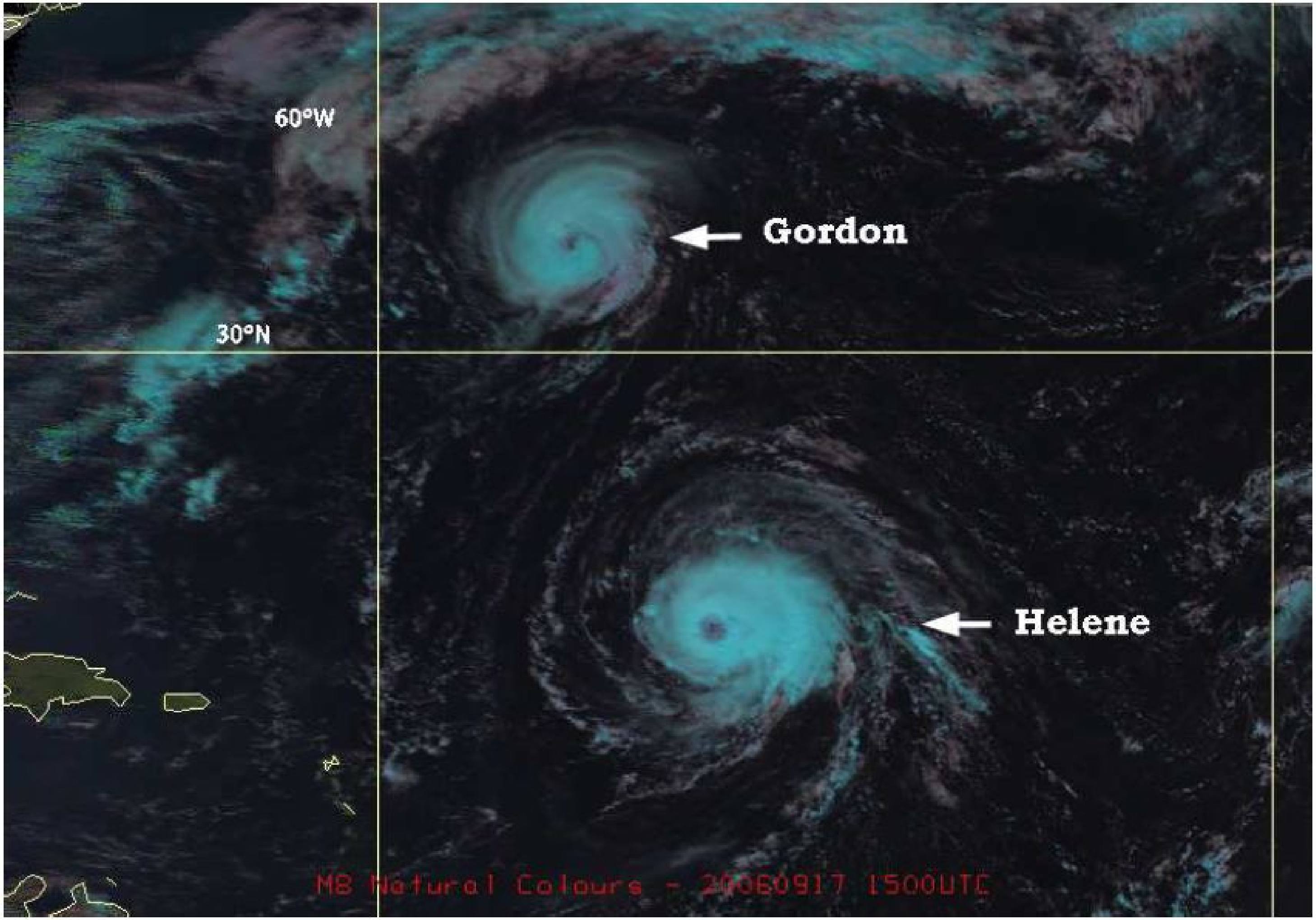


FIGURE 12. The tropical cyclones Gordon and Helene seen from satellite on September 17, 2006 15 UTC, copyright 2006 EUMETSAT

Hurricane – wind speed spatial distribution

Wind speed patterns

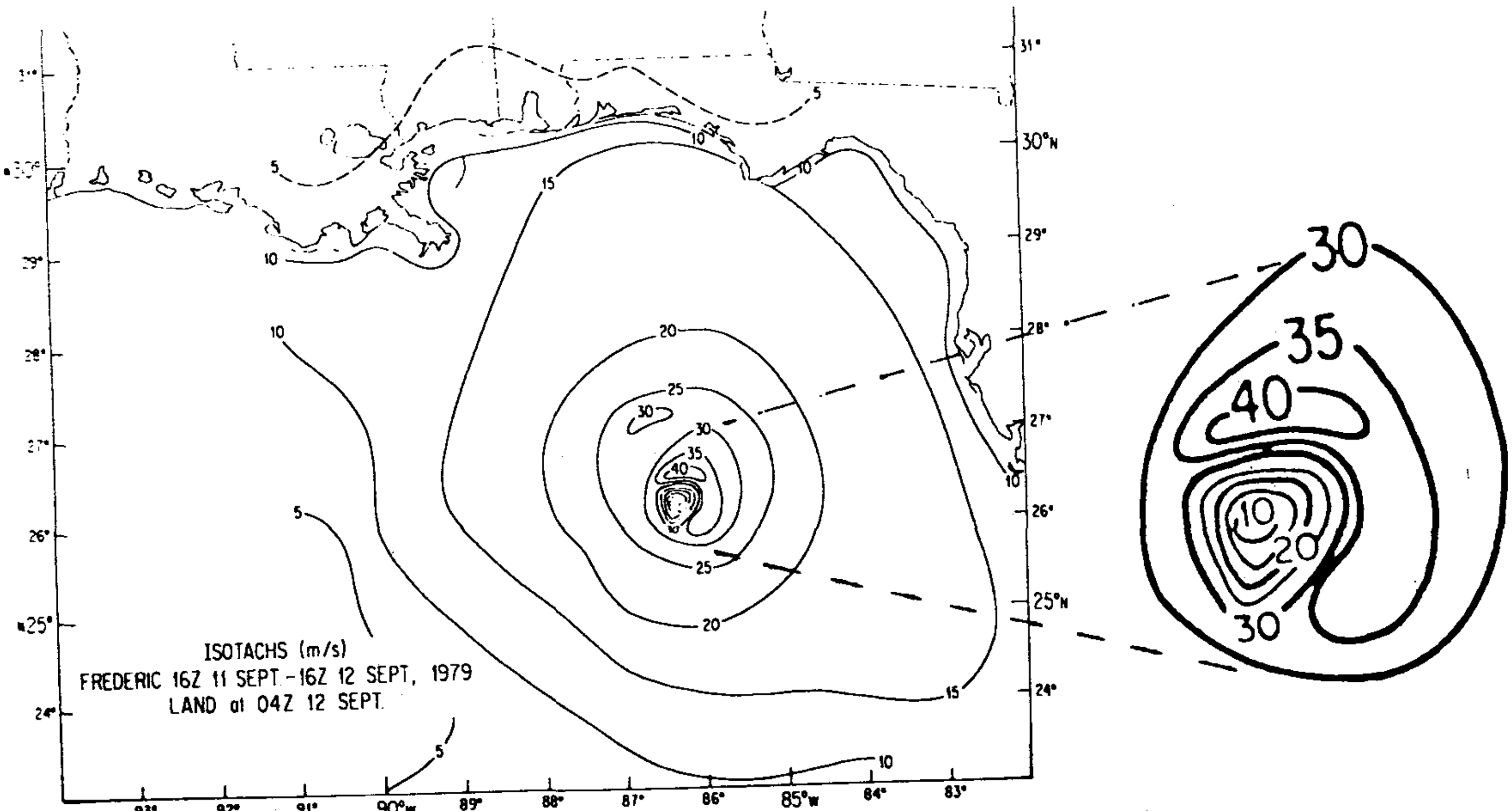
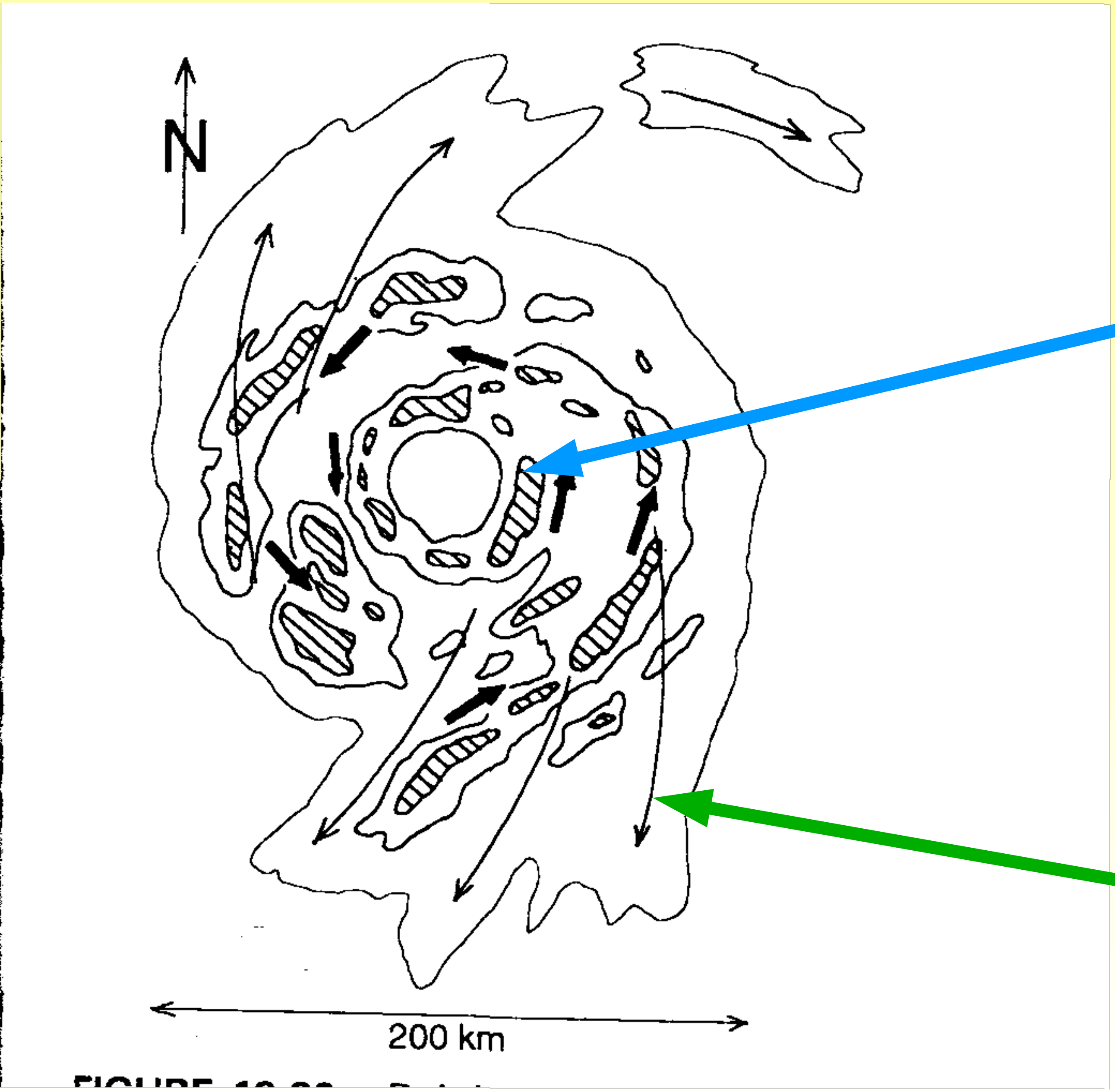


FIGURE 12-23. Wind speed ($m\ s^{-1}$) in Hurricane Frederic in the Gulf of Mexico. Storm motion was toward 330° at 5 $m\ s^{-1}$. The central portion is enlarged on the side so that the low speed (less than 10 $m\ s^{-1}$) in the eye can be noticed more easily. From Powell (1982).

Hurricane inner circulation



At the bottom clouds enter the structure.

Precipitation area

At top they escape from the center.

Cirrus clouds

In the Tropical areas with high SST and where Corilis acceleration is still significant

They develop over the oceans having a high surface water temperature (> about 26 °C).

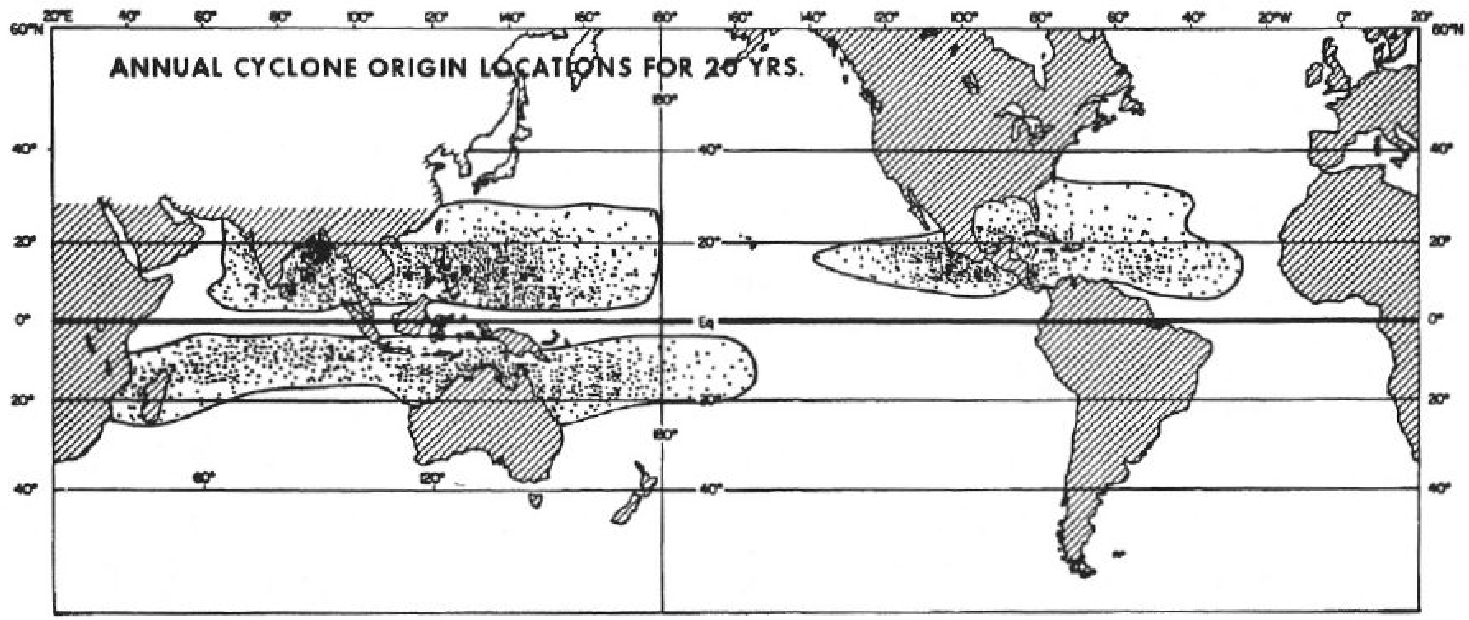
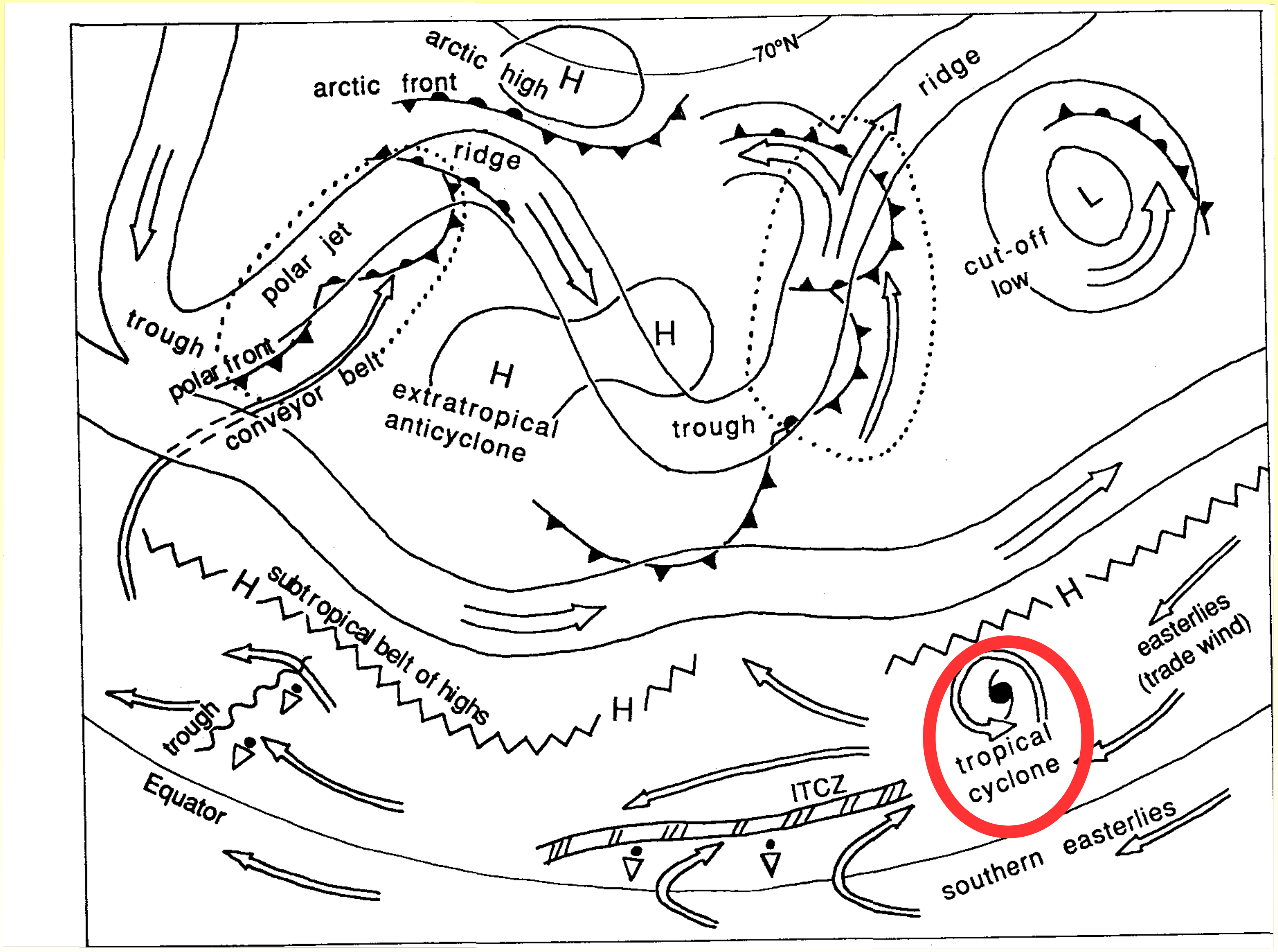


FIGURE 11. The areas of the world where tropical cyclones have been observed in a 20 years period during the second half of the XX century. Picture taken from Gill (1982).

Where the cyclones form – Horizontal view

Some researches found that the most intense tropical cyclones develop in the intertropical front while the smaller ones develop in the easterlies



Location of the Tropical cyclones in the globe

Tropical areas

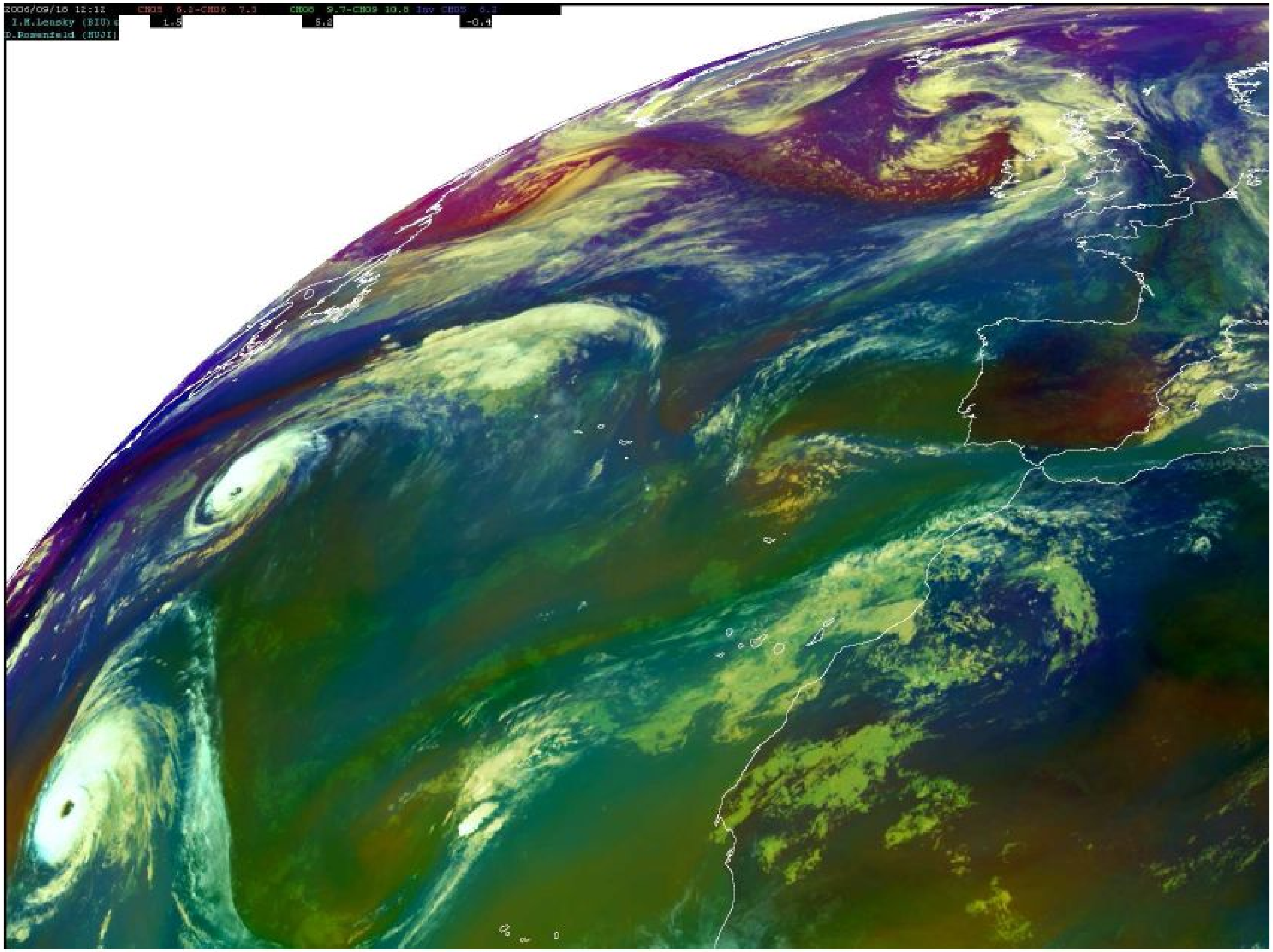
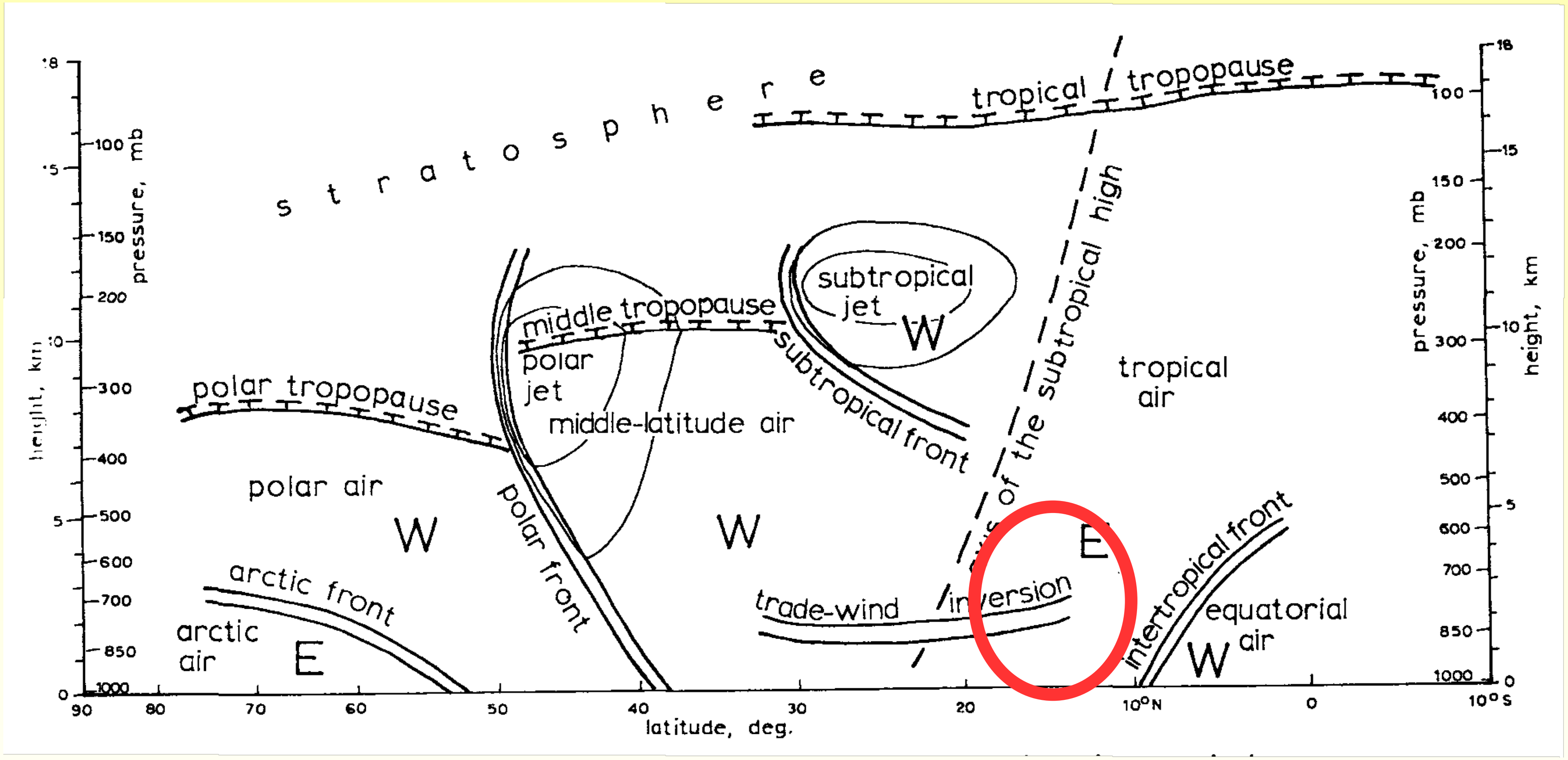


FIGURE 13. The tropical cyclones Gordon and Helene seen from METEOSAT on September 18, 2006 12 UTC, copyright 2006 EUMETSAT

Where the cyclones form – Vertical cross section

Coriolis acceleration (no tropical cyclones have been observed within 3° from the equator and they are very rare closer to 10° of latitude.



Because of Coriolis acceleration the Tropical cyclones have always a cyclonic circulation

Tropical cyclones ingredients - summary

- high sea surface temperatures (> 26°C);
- warm air
- latent heat release (convection) due to condensation of water vapor + sensible heat.

Evolution of the Tropical cyclones

Hurricane season (Atlantic) from June to November, while typhoon season in Asia has a bimodal distribution with two peaks, one before and one after the monsoon period (June-August) because of the cooling of the lower troposphere due to precipitations.

The evolution of tropical cyclones:

- they develop in the tropical warm oceans
- they evolve moving along the easterlies (a few days)
- they move northward (northern hemisphere) or southward (southern hemisphere)
- they dissipate when they reach the continents or a cooler ocean surface (20° - 40° of latitude)
- some of them, continue to move far from the tropics and turn towards east in the belt of westerlies as extra-tropical storms when enough latent or sensible heath is available.

Trajectories of tropical Cyclones

TC move westward along the easterlies and then they turn poleward

duration usually one week, a few dissipate in less than one day, while some others may last for more than one week.

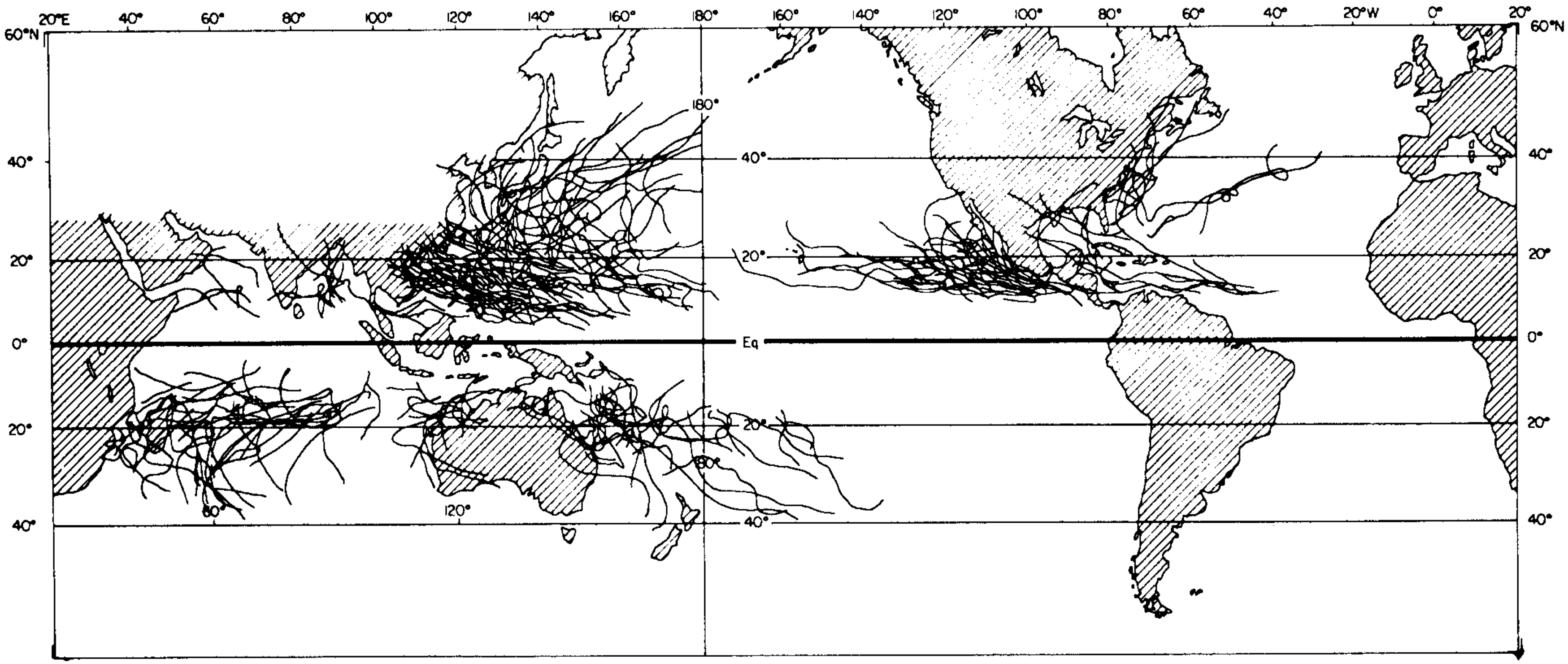


FIGURE 12-22. Tracks of tropical cyclones for a 3-y period. Figure by W. M. Gray, as reproduced by Elsberry (1987).

Southern Hemisphere Tropical storms paths

Tropical cyclone typical paths in Australia – the case of Vance

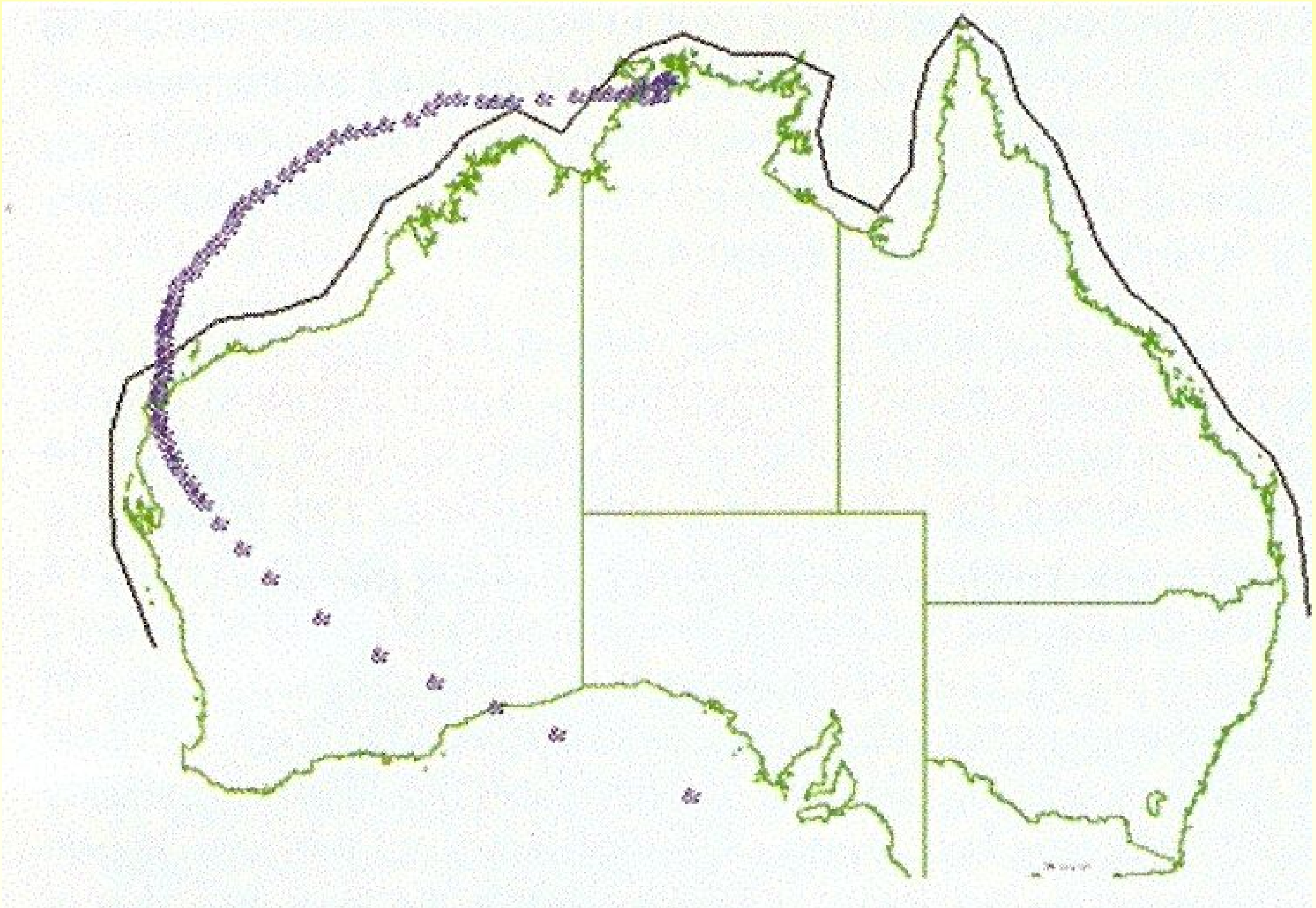


Figure 1. *TC Vance (17-24 March 1999)*

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Features of the tropical cyclones (physics)

Warm core

Deep moist convection and synoptic scale synergy

Deep atmospheric convection embedded in the structure. So mesoscale extreme weather events may be hosted by a tropical cyclone, namely, supercells, tornadoes hail storms, squall lines.

Geopotential structure of the tropical storm at upper tropospheric leves (i.e. 500 hPa) in not so evident as at the ground level.

Potential temperature profiles and tropical cyclones

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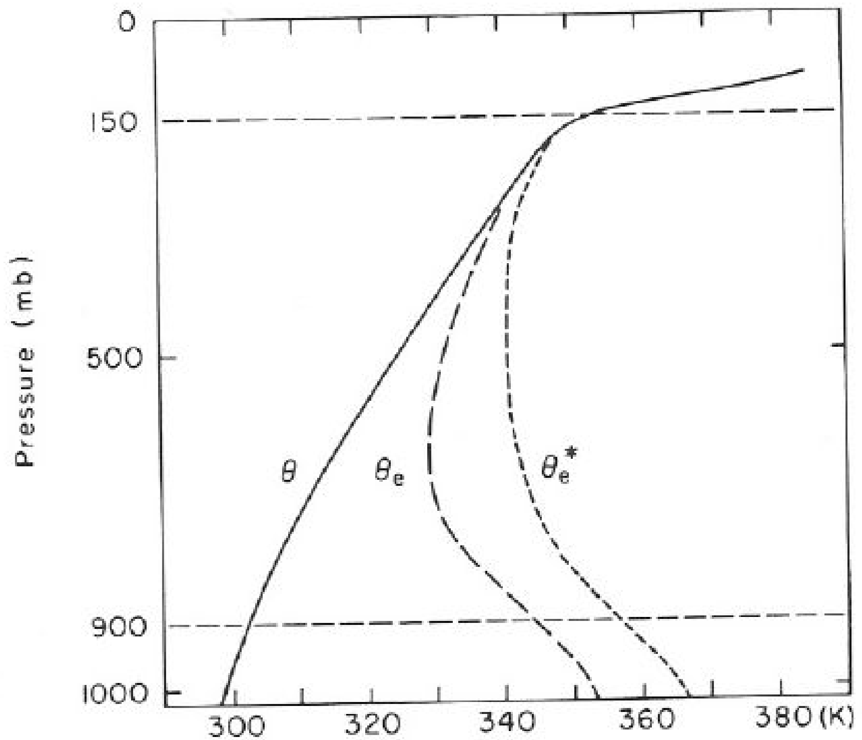

.1 Typical sounding in the tropical atmosphere showing the vertical profiles of potential temperature θ, equivalent potential temperature θ_e, and the equivalent potential temperature θ_e^* of a hypothetically saturated atmosphere with the same temperature at each level. This figure should be compared 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.)

Why tropical cyclones

The air instability due to high temperatures and water vapor condensation latent heat release are significant ingredients

V about 50 m/s and r about 100km

$$\frac{d\boldsymbol{v}_H}{dt} = -2(\boldsymbol{\Omega} \times \boldsymbol{v})_H - \boldsymbol{\nabla}_H G + \nu \boldsymbol{\Delta} \boldsymbol{v}_H$$

$$\frac{v^2}{r} + fv = -\frac{\partial G}{\partial r}$$

$$\sigma = -\log\left(\frac{p}{p_0}\right) \quad \text{where } p_0 = 1000\, hPa$$

$$\frac{\partial G}{\partial \sigma} = RT$$

$$\left(2\frac{v}{r} + f\right)\frac{\partial v}{\partial \sigma} = -R\frac{\partial T}{\partial r}$$

Features of the tropical cyclones (hazards)

strong wind speeds (up to 80 m/s at the surface) the most important hazardous effect both in open sea and inland.

heavy precipitation the most important hazardous effect inland

sea surges and ocean waves – the most important hazardous effect along the coast, because the rise of the sea level and the inhibition of the rivers runoff.

many Asiatic typhoons attain sizes and wind speed much in excess of not extreme hurricanes

What are the weak aspects in our TC knowledge

- not too long time series records, about 30 years for satellite observations;
- inconsistency between ground and satellite estimates of the TC intensity;
- inhomogeneous definition of TC in the different basins (Atlantic, Pacific, Indian oceans);
- not complete knowledge of the physical and microphysical mechanisms involved in the development of a TC.
- the feedback of the TC on the climate is not known
- the precipitations produced by a TC are not well studied so far, both in observations and theory or simulations;
- the role of the boundary layer in the intensity of the TC is poorly understood;
- land use effects on TC intensity near landfall of the cyclone;
- vertical wind shear and ocean eddies role is not known.

Tropical Cyclones and climate change

There is observational evidence for an increase of intense **tropical cyclone** activity in the North Atlantic since about 1970, correlated with increases in **tropical SSTs**.

It is not clear whether a trend exists or not. (**Large uncertainty**)

Multi-decadal variability and the quality of the tropical cyclone records prior to routine satellite observations in about 1970 complicate the detection of long-term trends in tropical cyclone activity and there is no clear trend in the annual numbers of tropical cyclones.

The numbers of hurricanes in the North Atlantic have been **above normal** (based on 1981–2000) in nine of the years from 1995 to 2005.

Tropical Cyclones and climate change: observations and biases

Recent studies (K. Chen and J. McAneney) have pointed out that the HURDAT (official Atlantic hurricane database, from U.S. National Hurricane Center) is likely to be affected by observational biases in the wind speed and hurricane counts.

- hurricanes in North Atlantic since 1851 to 2008 taking in account for:.
- 1947 aircraft measurements and hurricane reconnaissance,
- 1966 geostationary satellite identification
- 1972 development of Dvorak intensity estimation

Results:

earlier records, namely those before 1943, may be affected by underestimates in large wind speeds records, that is records greater than 100 knots

These results lead to consider carefully the correlations that may arise between past century climate change trends and the trends in frequency and intensity of hurricanes in the northern Atlantic.

Risk Frontiers Quarterly, 2009, Volume 9, Issue 2, December 2009

Tropical Cyclones and climate change: observations and biases

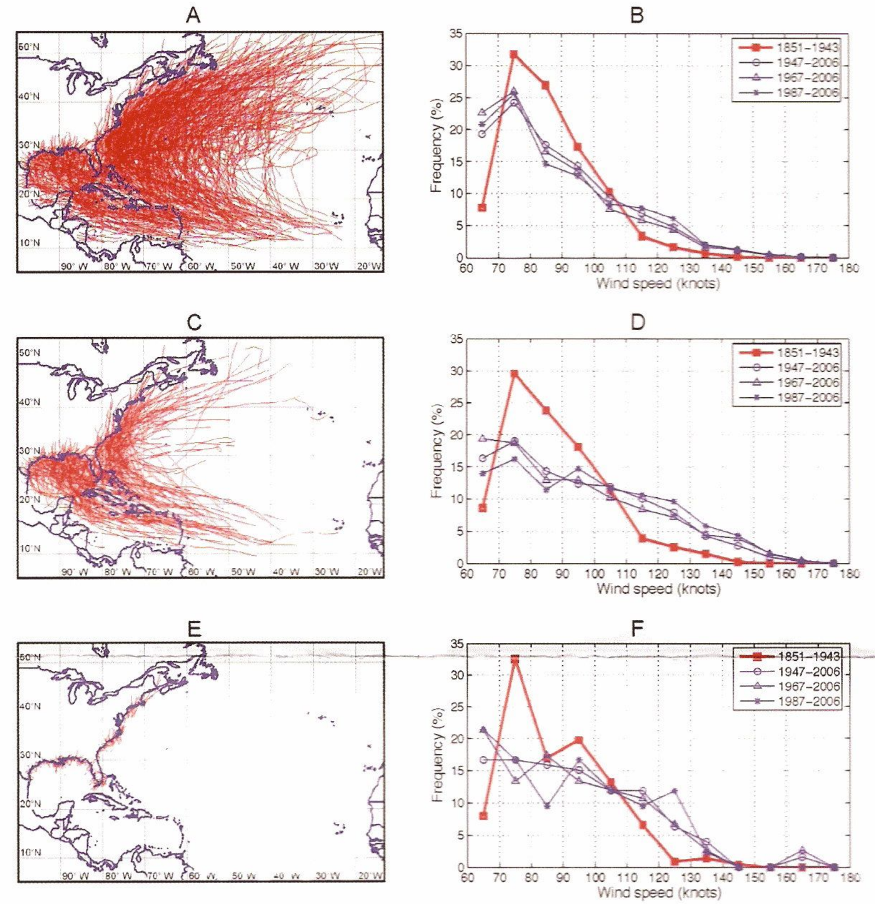

Fig. 1. Atlantic TC track segments (Category 1-5 wind speeds, 1851-2008) at three geographical scales and associated wind speed distributions for four historical periods selected: 1851-1943, 1947-2006, 1967-2006 and 1987-2006. (A) All segments of all Atlantic basin TCs. (B) Wind speed distributions for A. (C) All segments of all TCs that crossed the U.S. mainland. (D) Wind speed distributions for C. (E) U.S. landfalling segments. (F) Wind speed distributions for E.

Risk Frontiers Quarterly, 2009, Volume 9, Issue 2, December 2009

Extreme events – Losses and hazard type

30 year analysis of extreme events in Australia

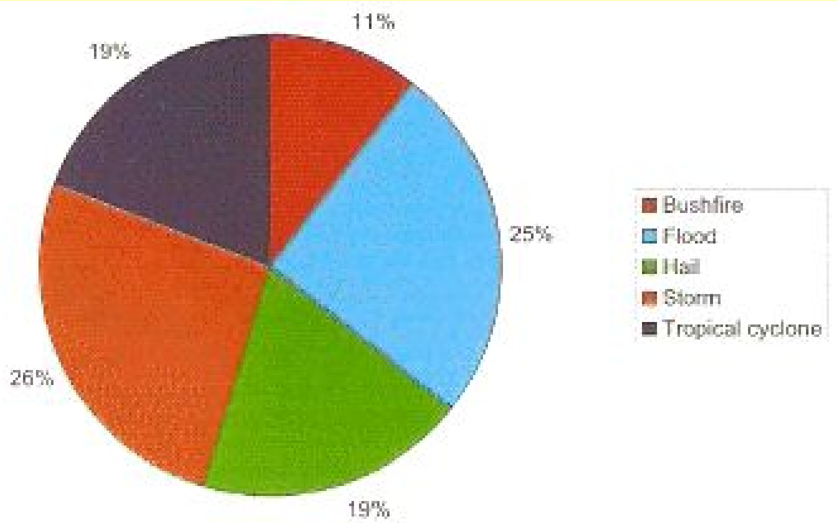

Figure 4 (a): Percentage of the number of weather-related events classified by hazard type.

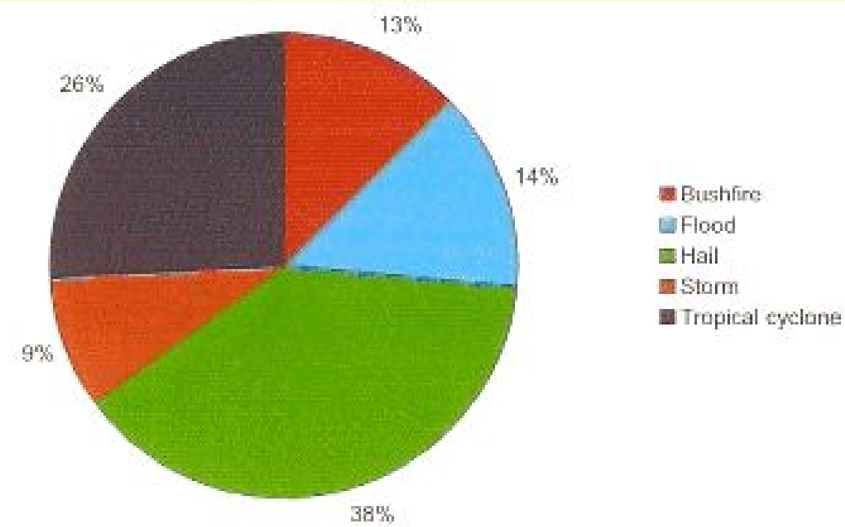

Figure 4 (b): Percentage of the total current loss as at 2004 ($M) of weather-related events classified by hazard type.

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The effects of intense tropical and extra-tropical cyclones

Cyclone Tracy – Darwin Australia
90% destruction 25,000 people evacuated

Katherine River flood 2006 – Australia
10,000 people affected

Figure 1: *Aerial view looking south across the Katherine River towards the Town Centre at 2:42pm Thursday 6th April; i.e. looking approximately from top to bottom of Figure 1. (Source: Department of Defence; photo taken by Leading Aircraftman Steve Duncan from a Hornet F18.)*

In terms of sheer devastation, Cyclone Tracy undoubtedly remains Australia's worst natural disaster. 90% of the dwellings in Darwin were destroyed or severely damaged, requiring the evacuation of more than 25,000 people. Photo courtesy of News Ltd.

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Extreme weather events and losses estimates

Comparison between losses and extreme weather events in Australia

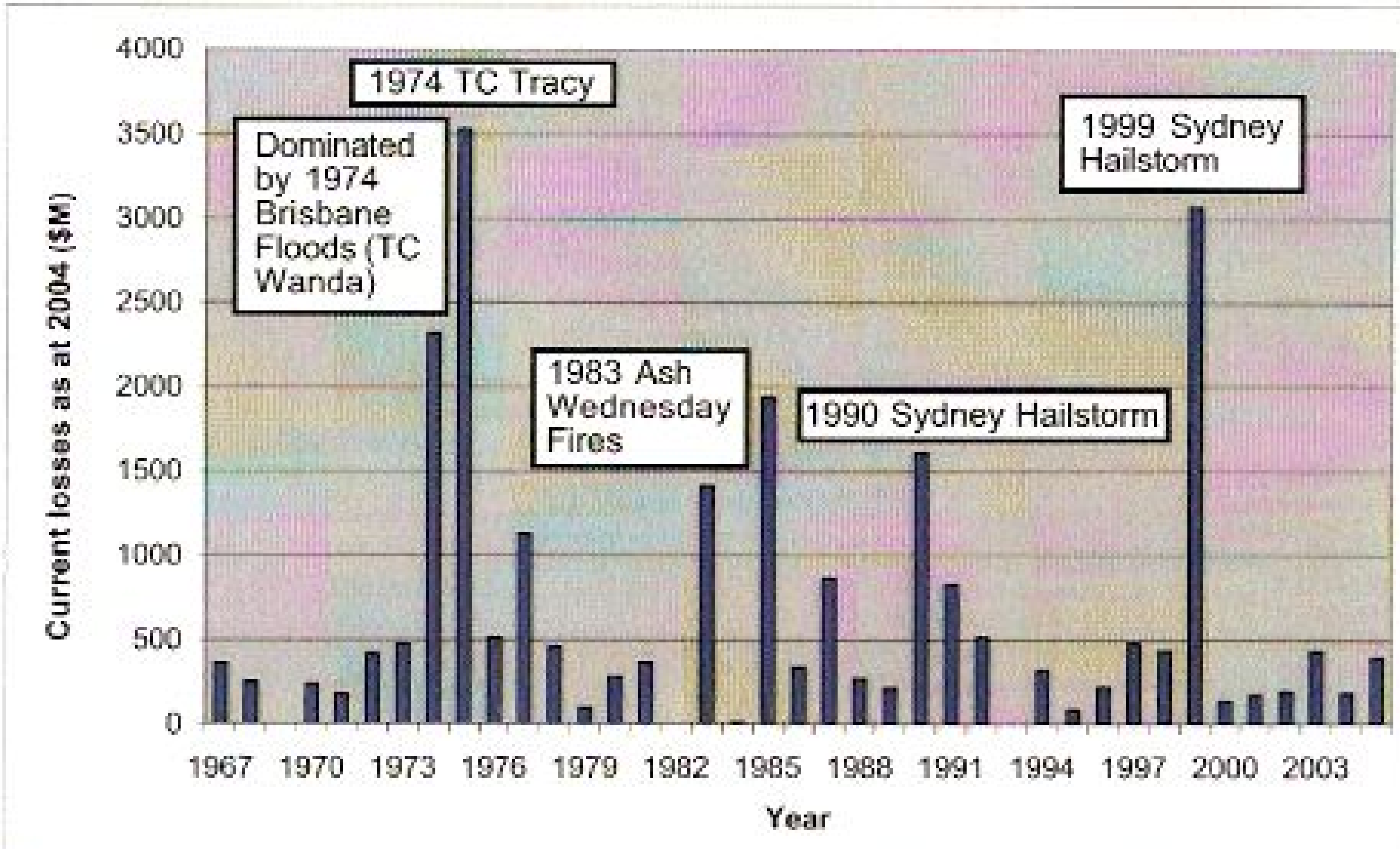

Figure 1: Aggregate insured losses indexed to 2004 dollars for all events in the IDRO database for 12-month periods ending 30 June. Four earthquakes and one tsunami have been eliminated. Tropical cyclone losses have been reduced by 50% to roughly allow for improvements in building codes.

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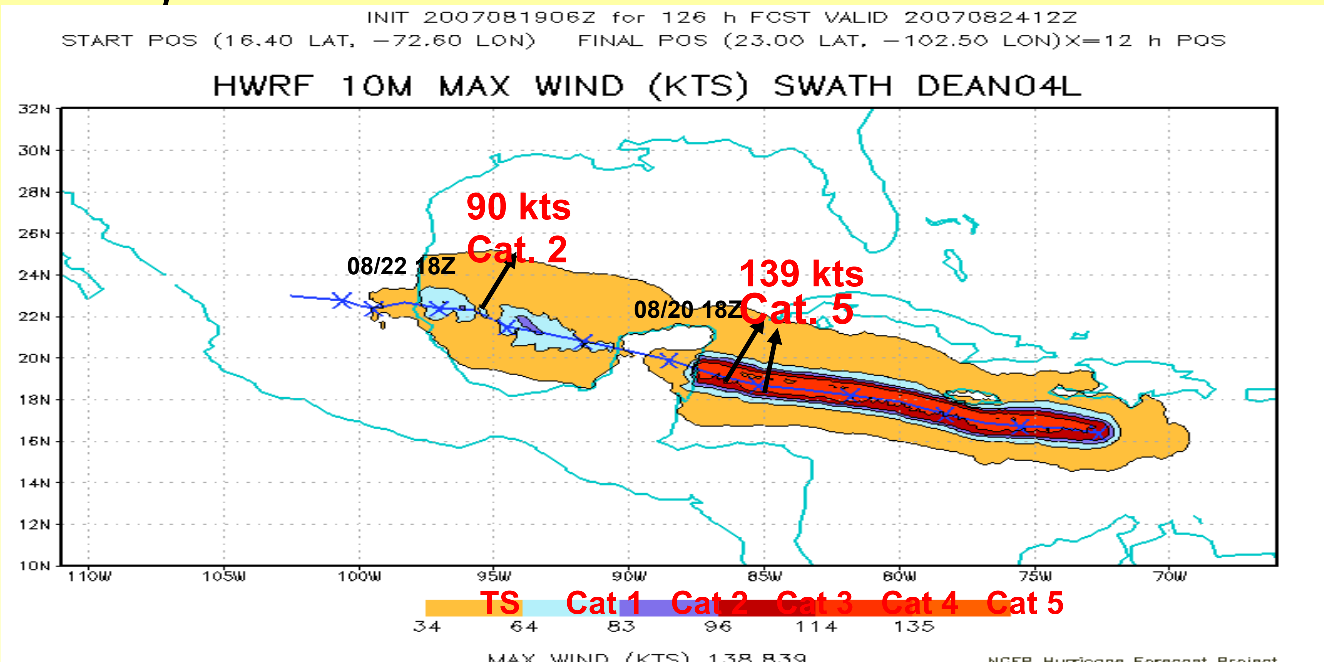
Forecasts of the tropical cyclones

Nowadays forecasts of tropical cyclones evolution and intensity in an operational and reliable practice that is performed by deterministic methods, that is numerical models.

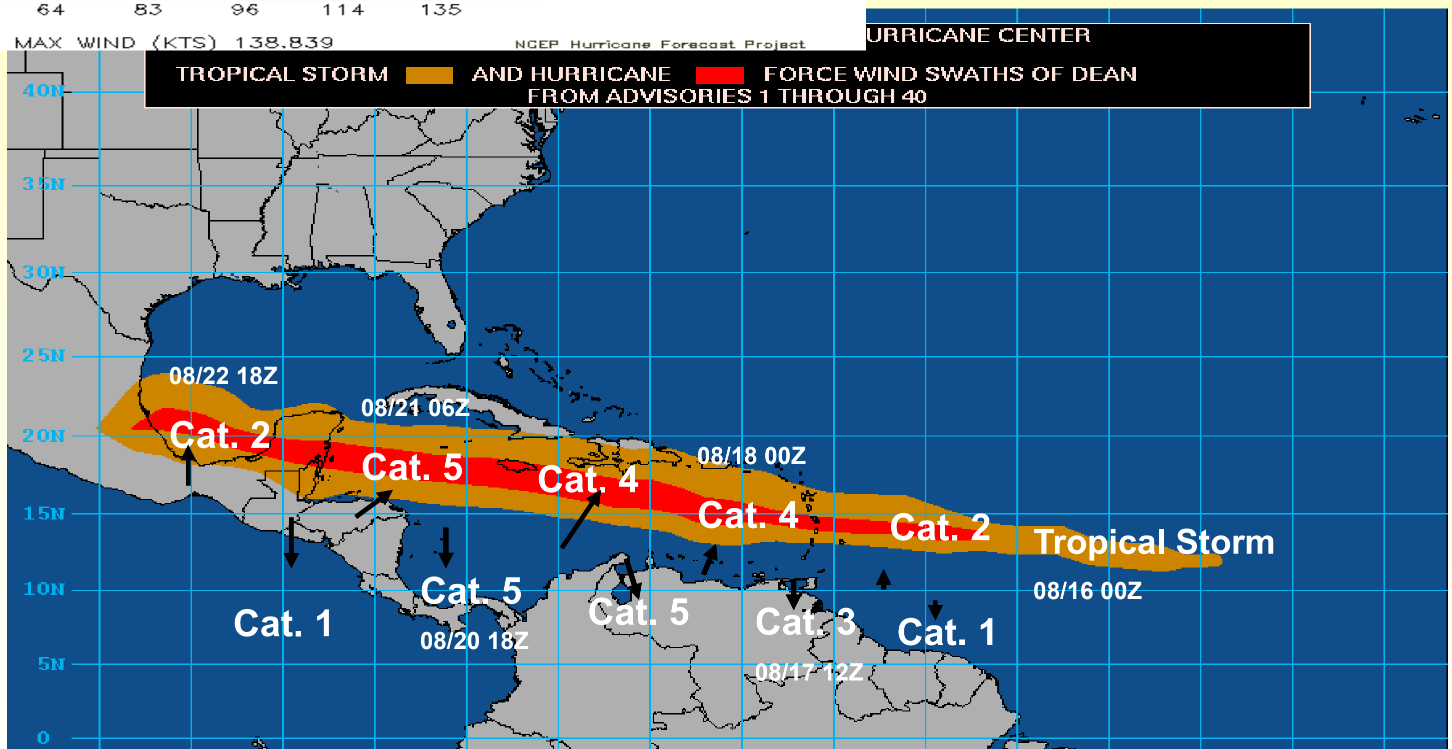
Probabilistic forecasts are much less reliable and they are not used anymore, especially for the prediction of the cyclone path.

Example of hurricane forecast



Hurricane Dean 5 day forecasts of maximum winds

starting from 8/19/06Z



Example of hurricane forecast

WRF ARW simulations using LES technique – 6 nestings

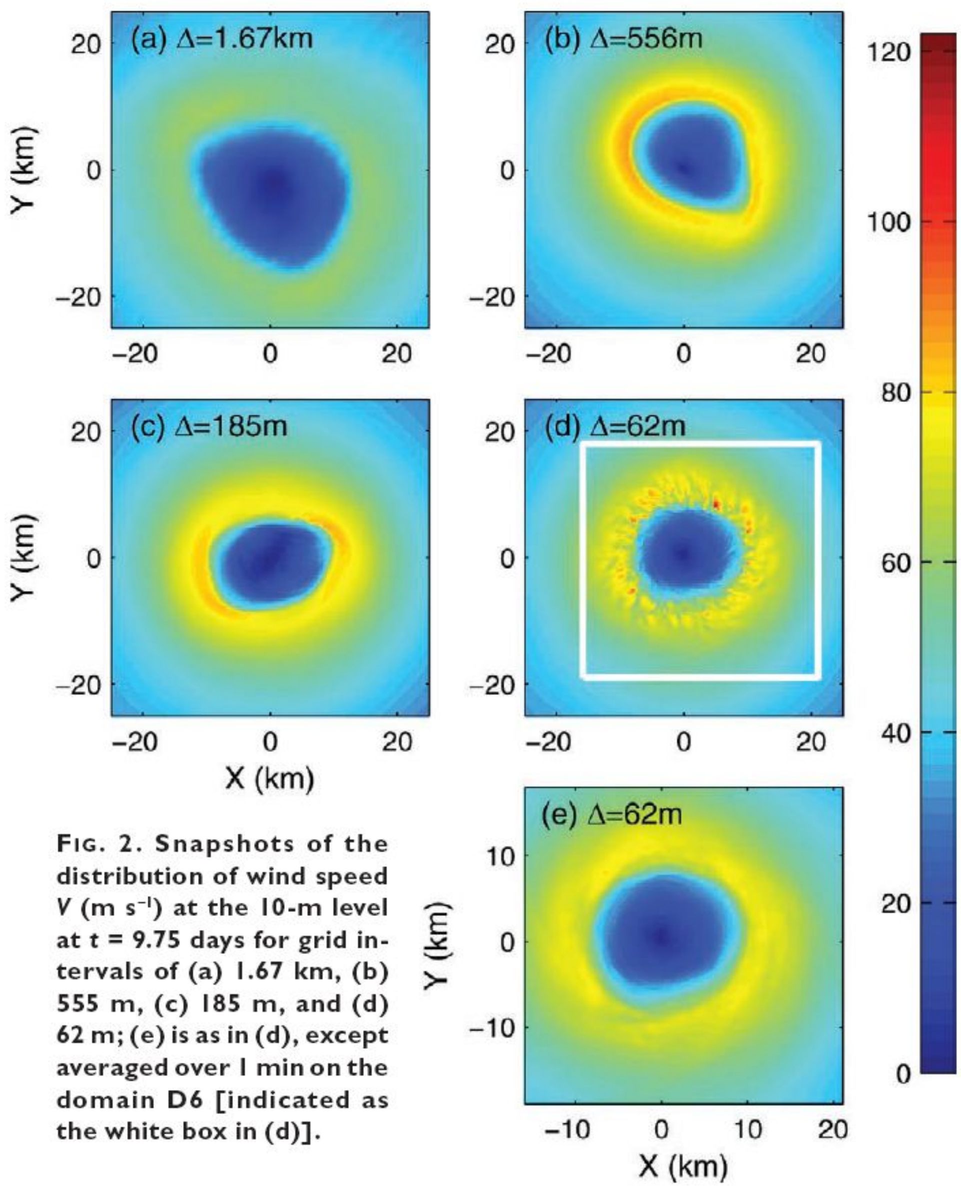


FIG. 2. Snapshots of the distribution of wind speed V (m s^{-1}) at the 10-m level at t = 9.75 days for grid intervals of (a) 1.67 km, (b) 555 m, (c) 185 m, and (d) 62 m; (e) is as in (d), except averaged over 1 min on the domain D6 [indicated as the white box in (d)].

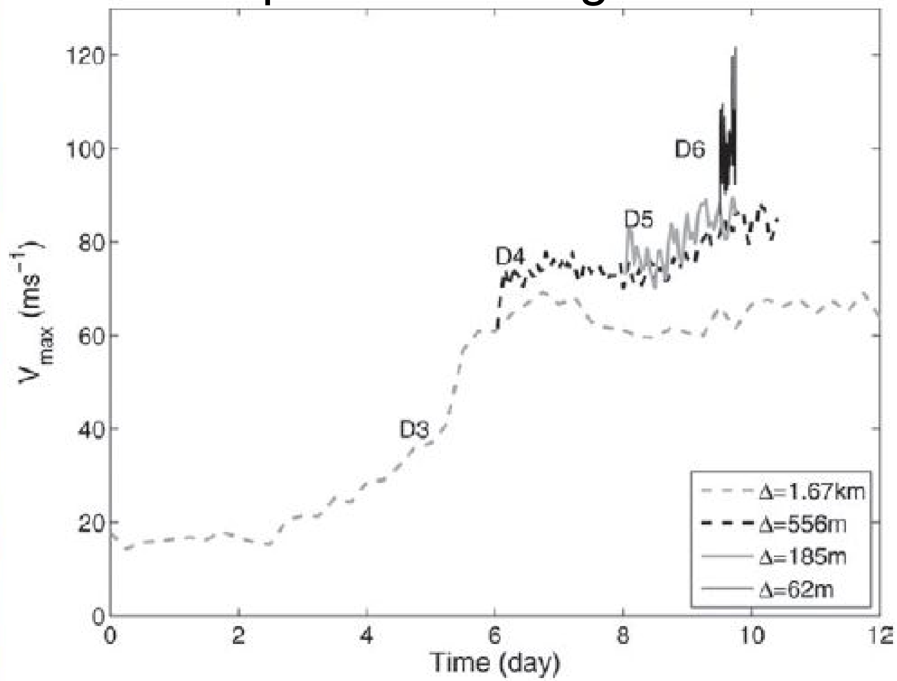


FIG. 1. Time series of the maximum wind speed V_{max} at the 10-m level for integrations with decreasing grid size in the inner core of the tropical cyclone.

AFFILIATIONS: ROTUNNO, CHEN, WANG, DAVIS, DUDHIA, AND HOLLAND—National Center for Atmospheric Research, Boulder, Colorado
CORRESPONDING AUTHOR: Richard Rotunno, NCAR, P.O. Box 3000, Boulder, CO 80307-3000
E-mail: rotunno@ucar.edu

DOI:10.1175/2009BAMS2884.1

Extra-tropical cyclones

Extra-tropical cyclones (ETC) are large scale atmospheric vortexes, with horizontal winds streamlines curved around a low center. A special case of extra-tropical cyclones are the polar lows

Ingredients for extra-tropical cyclones formation are:

- baroclinic instability;
- geostrophic balance

Extra-tropical ones – a IR view

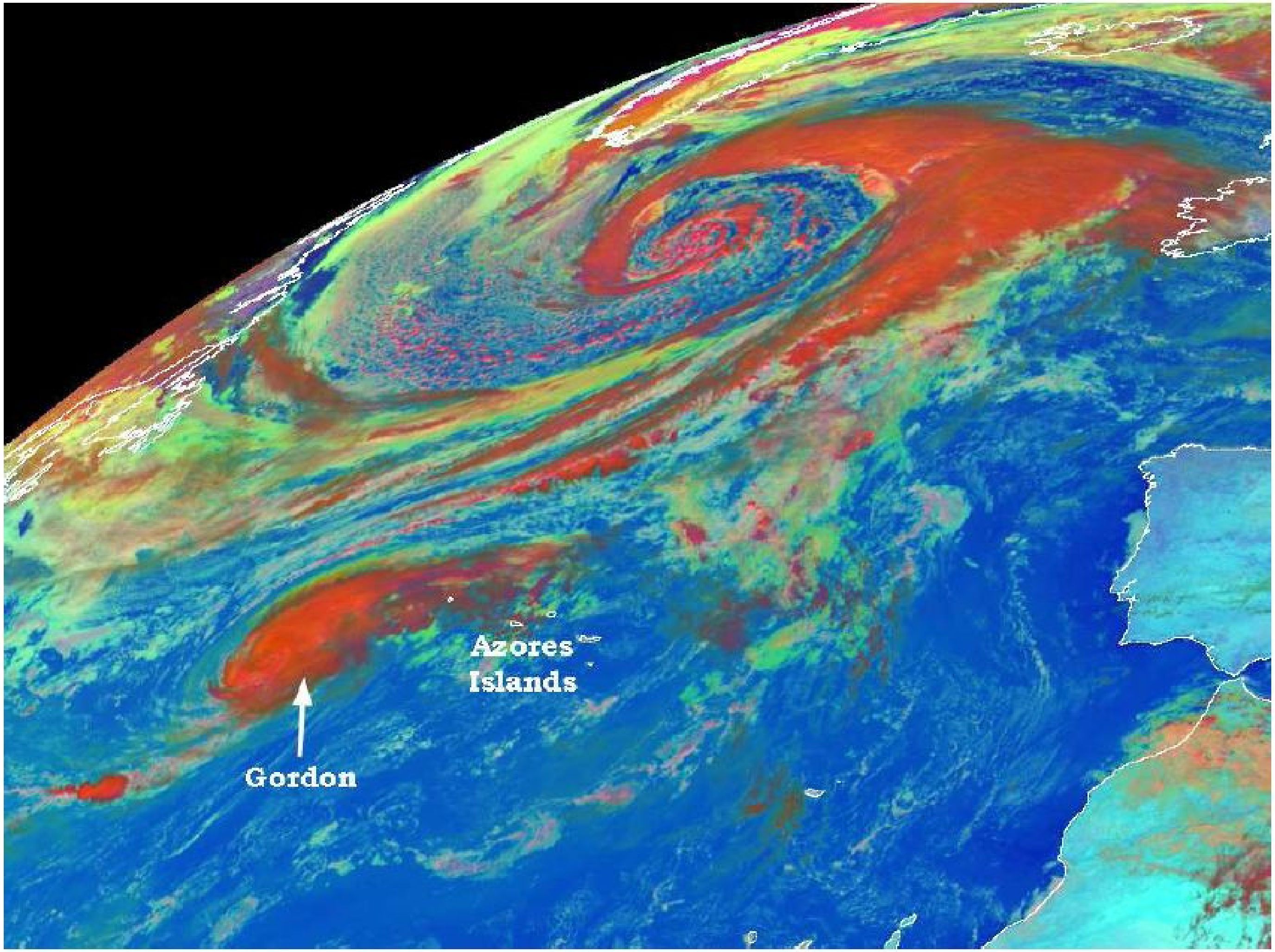


FIGURE 14. The tropical cyclone Gordon seen from METEOSAT on September 19, 2006 12 UTC. Compare it with the extratropical cyclone present in the Northern Atlantic. Sizes, time-life, trajectories and evolution are different because their dynamics is different, copyright 2006 EUMETSAT

Why extra-tropical cyclones form

Planetary and Rossby waves

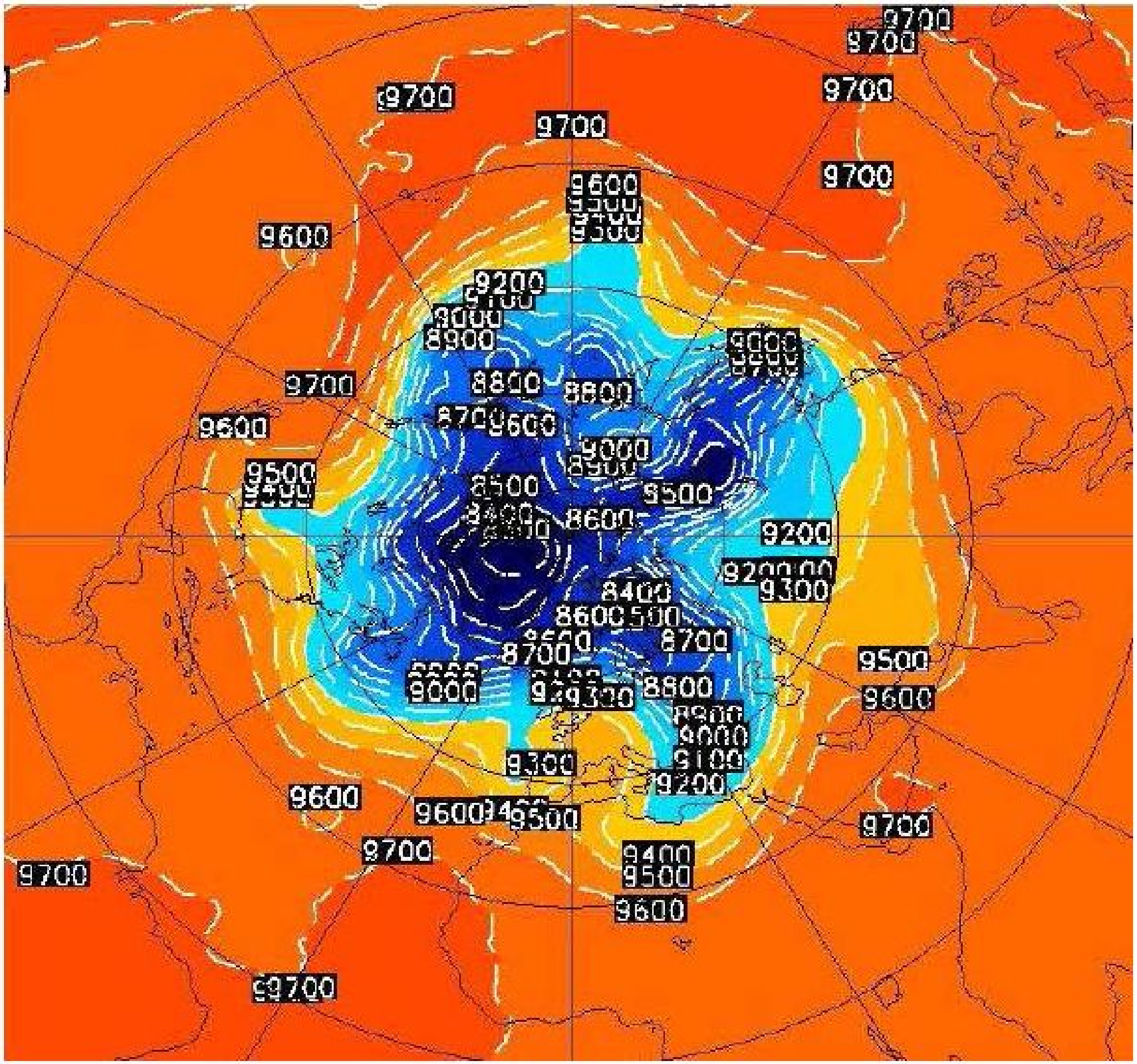
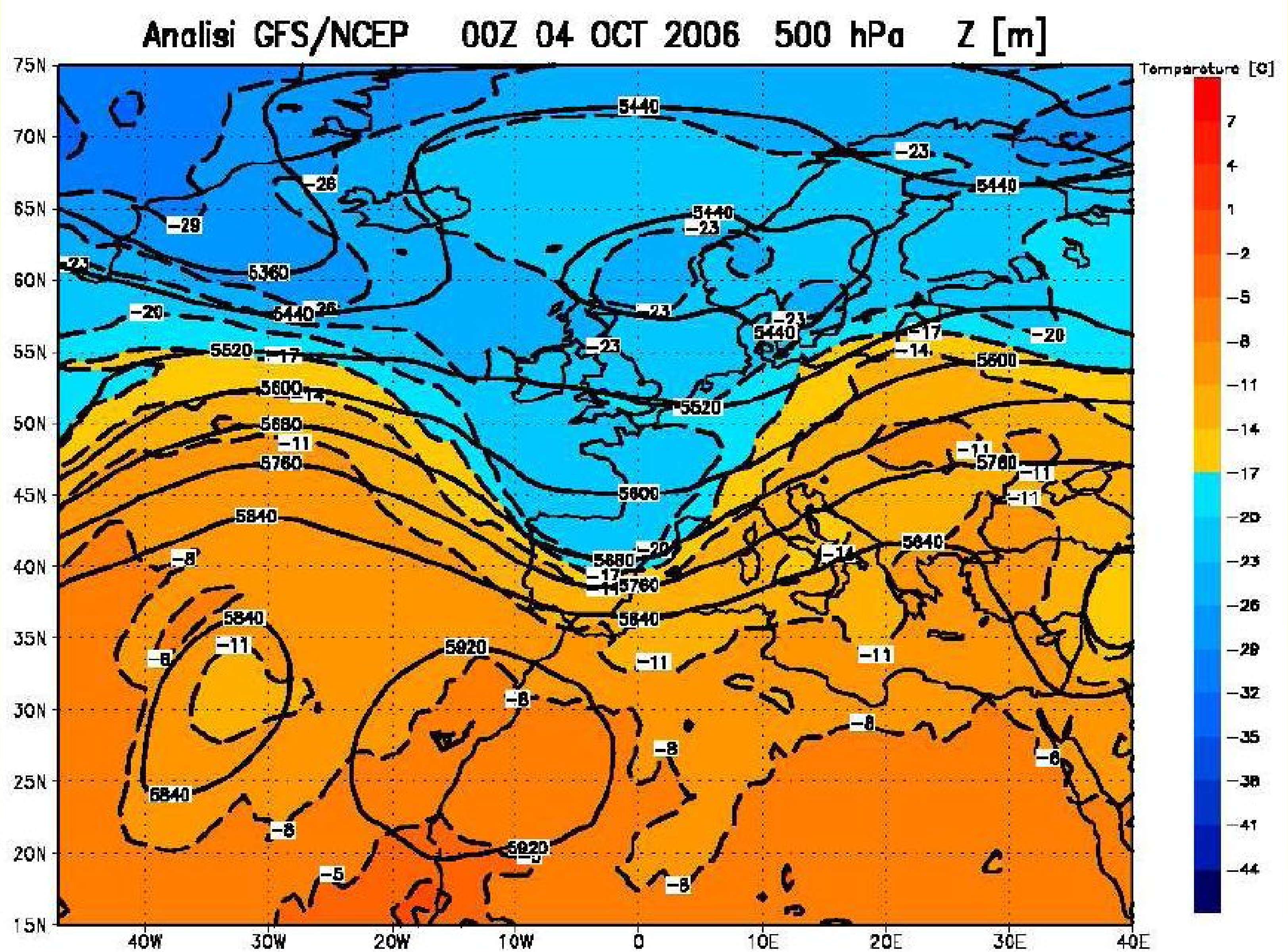


FIGURE 8. Example of planetary and Rossby waves. Geopotential height for the 300 hPa isobaric surface at 00 UTC of the 07 November, 2006. AVN analysis.

The baroclinic feature of the mid latitudes troposphere



Rossby waves from the satellite

Waves in the horizontal motions are related to vertical velocities

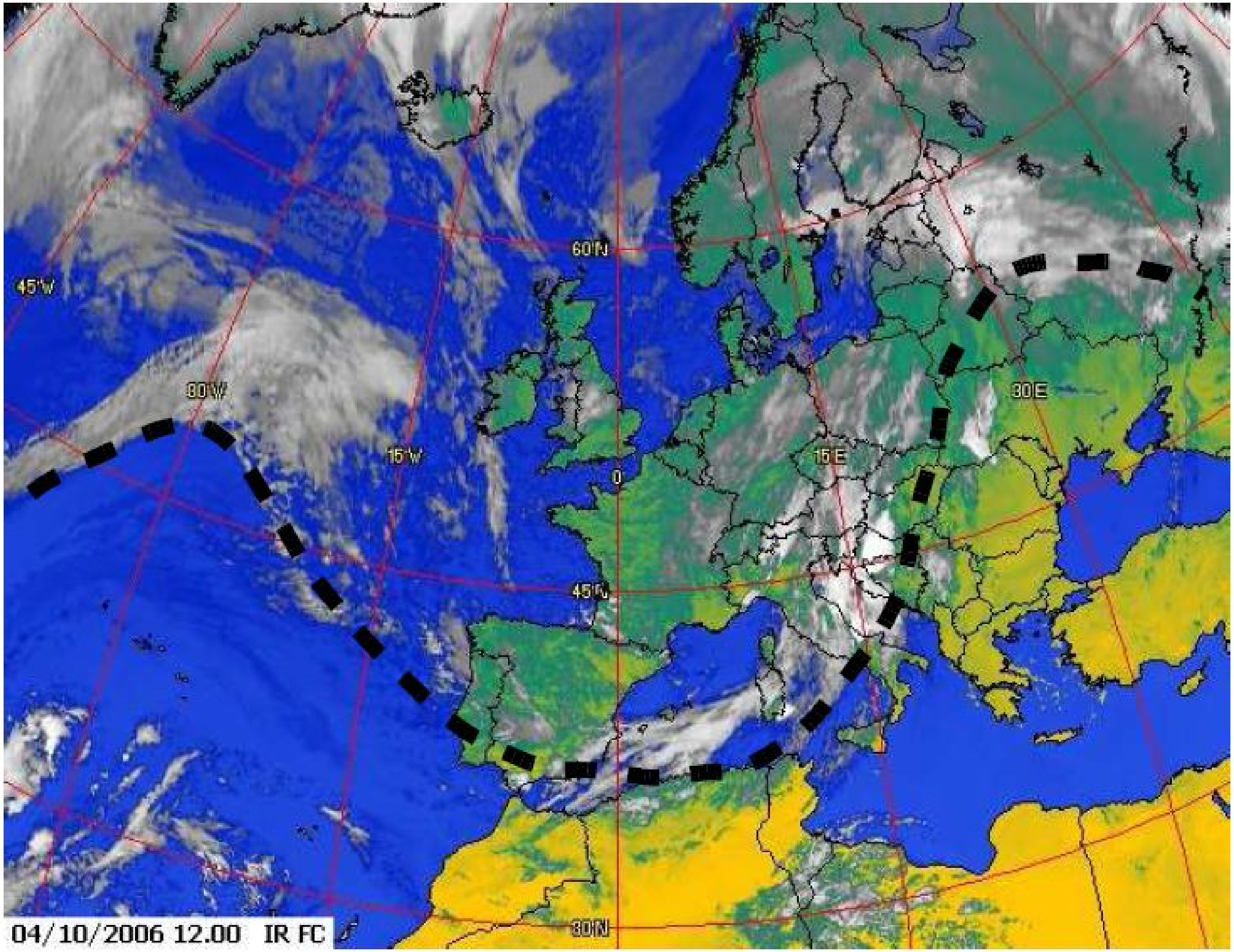
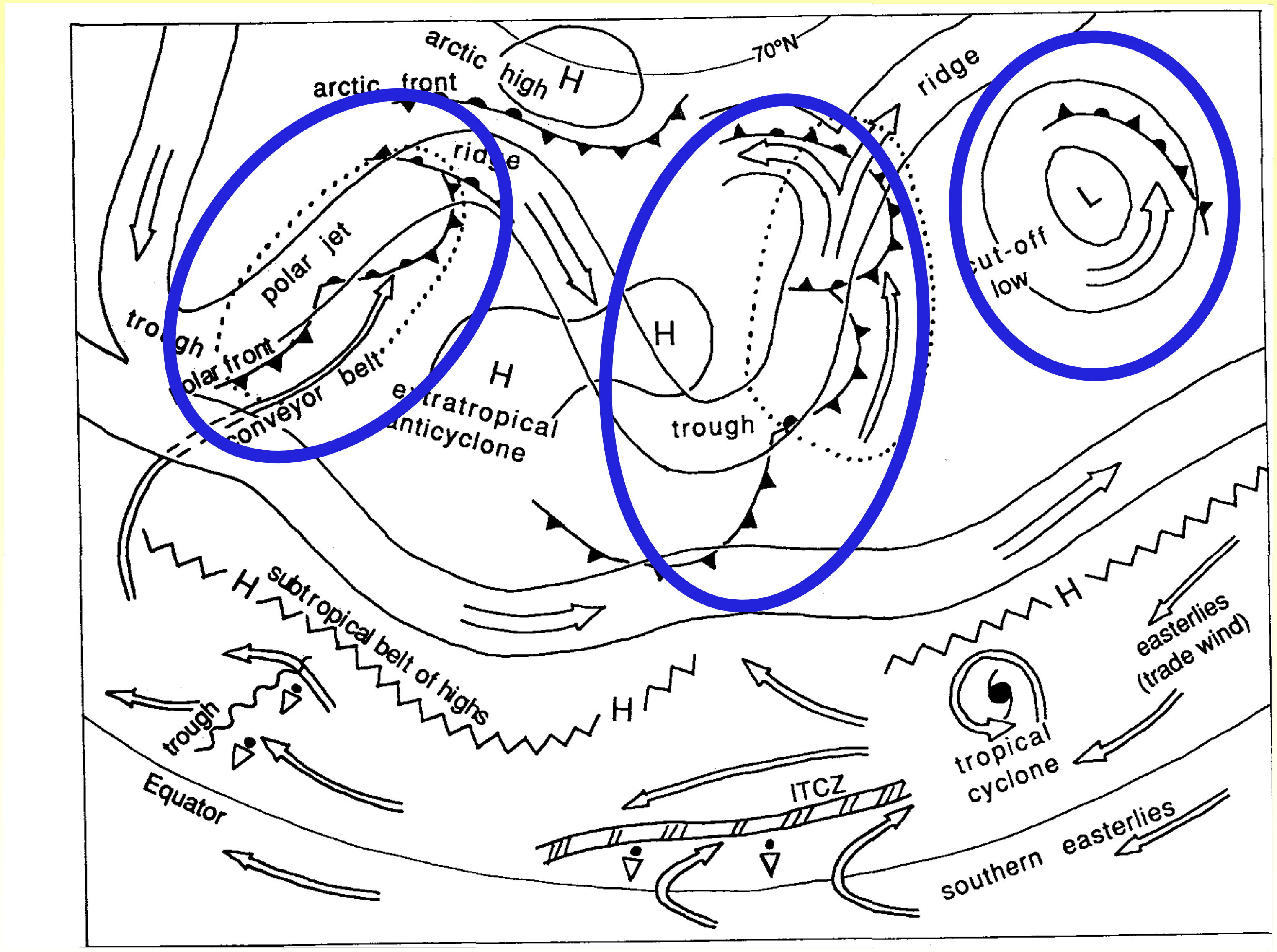
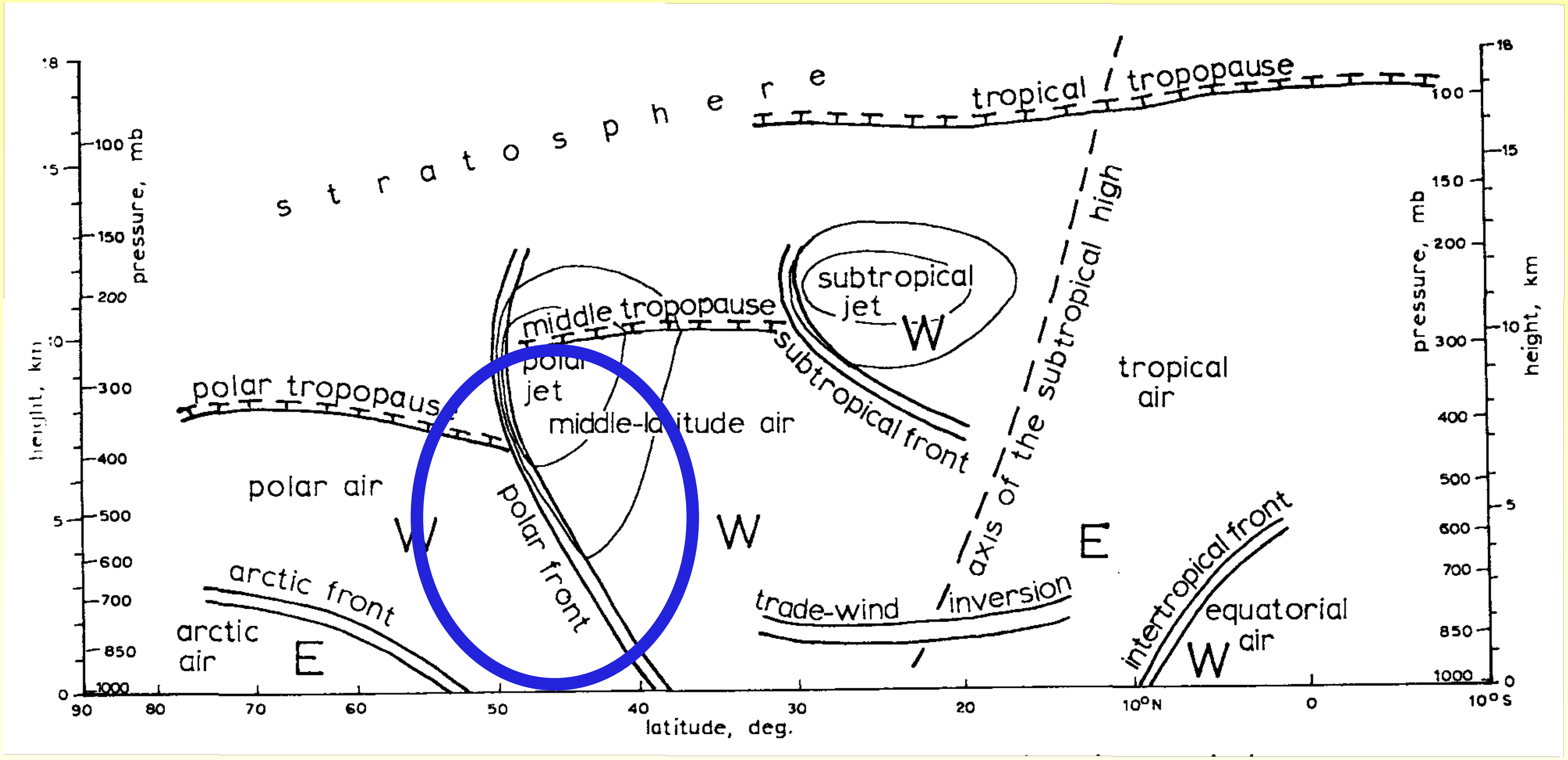


FIGURE 2. Infrared satellite image of clouds associated to a Rossby wave.

Where the cyclones form – Horizontal view



Where the cyclones form – Vertical cross section



The evolution of extra-tropical cyclones

- They develop and evolve in along the westerlies in the mid latitudes.
- The polar front is always associated to a ETC
- Extra-tropical cyclones are cold lows

Extra-tropical cyclones - features

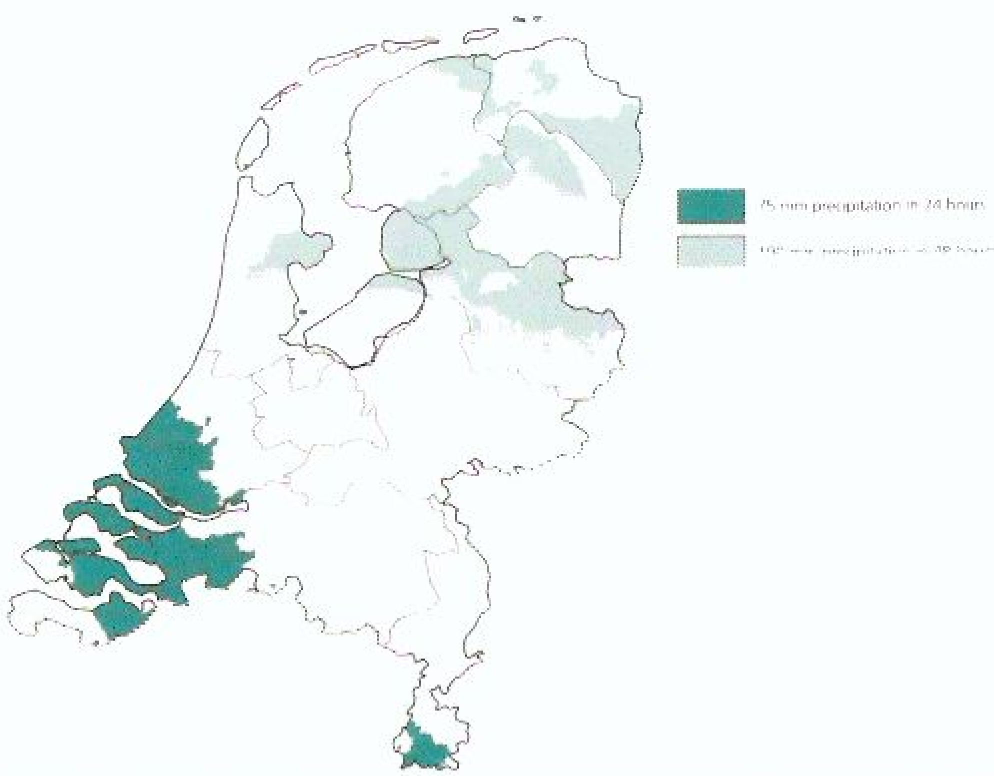
- Strong winds
- Heavy precipitations
- surges, runoffs associated to precipitation and winds
- about 1000 km size and several days duration
- deep atmospheric convection is embedded in the ETC (cold front)

Extra-tropical cyclone effects – 1998 floods in the Netherlands

75 mm of rain in 24 hours + 100 mm in other 48 hours in Netherlands resulted in damages for 371 Ml of EURO for farmers due to floods

Extreme precipitation and agriculture: In 1998, two extreme events took place in two different regions of the Netherlands. Some regions had 75 mm of rain in 24 hours, others 100mm in 48 hours (Map: Alterra, WUR). Total agricultural damage has been estimated to be 371 million Euro. A part of the damage has been refunded to the farmers by a national law on refunding for natural disasters and large accidents. However, not everything is compensated or even acknowledged as damage by the government.

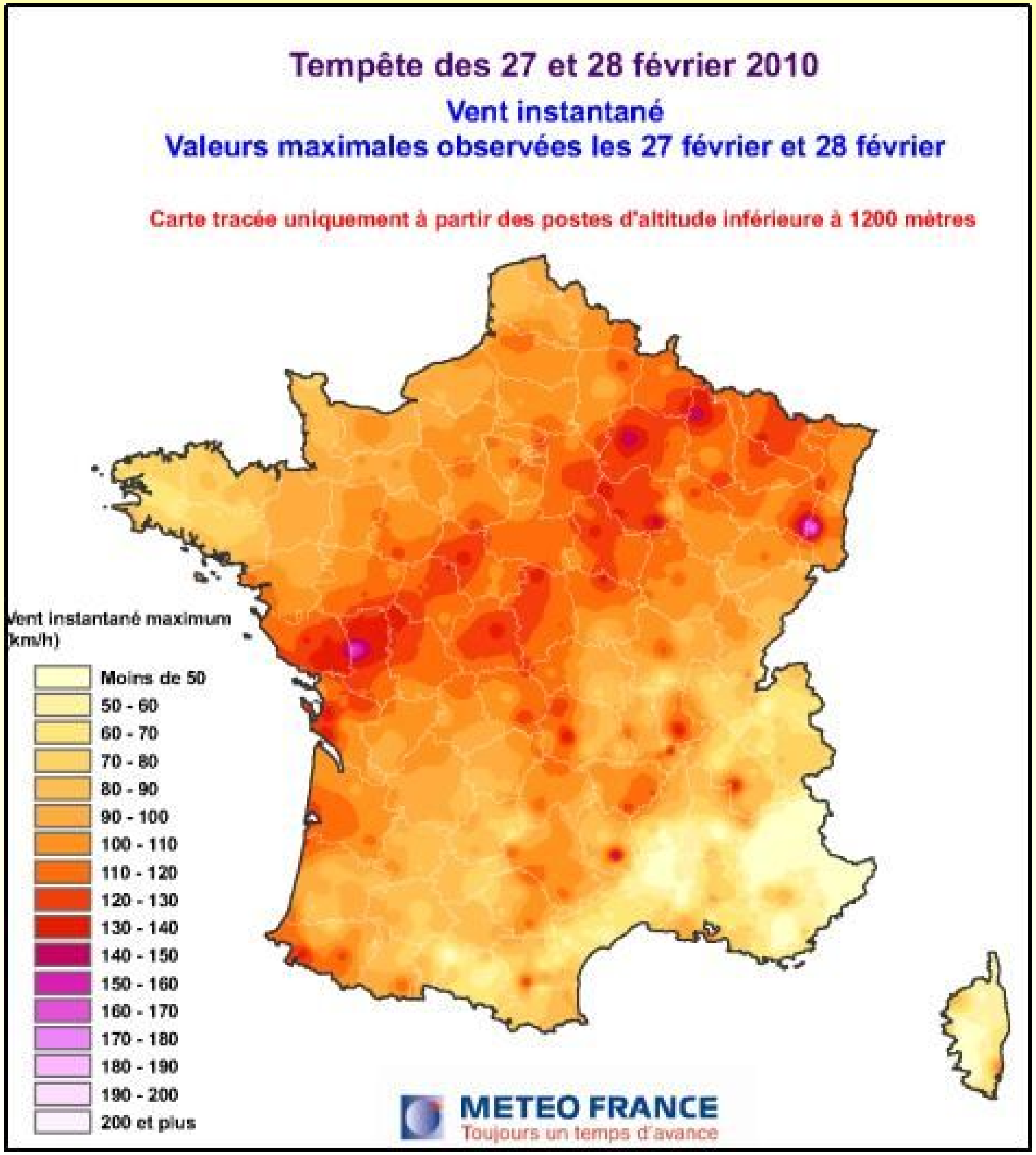
Regions that claimed damage under the 'Compensation Damage by Disasters and Heavy Accidents' (WTS) Act in 1998



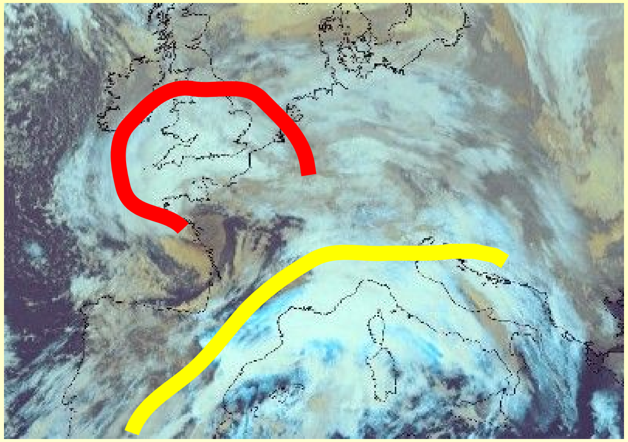
Source: MNP, 2005. The effects of climate change in the Netherlands, Netherlands Environmental Assessment Agency, Bilthoven, the Netherlands

Extra-tropical cyclone – Xynthia February 26-28, 2010

Xynthia was an ETC that hit Portugal, Spain and France



Météo-France satellite image
28/02/2010 02UTC



Not exceptional like (Lothar et Martin December 1999, Klaus January2009) P_min = 969 hPa.

Relevant surges due to positive phase with tide.

Wind speed 160km/h shoreline 130 km/h inland. (Strongest wind gusts: Portugal 166km/h, Spain 228 km/h, France 241 km/h)

ETC Xynthia February 26-28, 2010 – casualties and damages

Countries or regions affected:
Belgium, Denmark, France, England, Germany, Poland, Portugal, Spain, Sweden and South-East England.

Damage €1.3 - 3 billion
Fatalities 62;12 missing

In France at least 51 people were killed, with 12 more said to be missing. Most of the deaths occurred when a powerful storm surge topped by battering waves up to 7.5 m

Transport affected (flooded railway tracks)

Catastrophe risk modeling firm EQECAT estimated wind losses for affected countries (not including Portugal and Spain) as follows:

- Mean damage: €1.3 billion
- Mean insured gross loss: €994 million