

Tropical Cyclones - How do they form and in what ways do they represent a hazard to people?

Learning Objectives: To be able to describe the conditions leading to tropical cyclone development and the ways they represent a hazard to people.

Curriculum Links:

OCR Advanced GCE in Geography H483

The study of the development of tropical storms to illustrate:

- The atmospheric and surface conditions that give rise to their development
- An understanding, with examples, of how such systems develop
- Through examples, the hazards they present to particular areas and the impacts that these hazards can have.

AQA Advanced GCE in Geography Unit 3 GEOG3

The climate of one tropical region (tropical wet/dry savanna or monsoon or equatorial)

-Tropical revolving storms. Their occurrence, their impact and responses to them. Two case studies of recent (within the last 30 years) tropical revolving storms should be undertaken from contrasting areas of the world.

Edexcel Advanced Subsidiary GCE in Geography Unit 2 6GE02

-Defining and examining the nature and distribution of different types of extreme weather such as tropical cyclones.

-Researching meteorological processes such as a hurricane sequence

-Research how the impacts of extreme weather vary in intensity and in different parts of the world.

Materials:

- World map, sentence rearranging activity (Figure 4) or picture rearranging activity (figure 5), Saffir-Simpson scale (figure 6).
- If completing the latent heat experiment: Heat proof mat, tripod, evaporating dish, measuring cylinder, water, Bunsen burner, thermometer, stopclock.
- If completing the convection experiment: Potassium Permanganate crystals, 250ml beaker, gauze, tripod, tweezers, candle, matches.

Suggested activities:

Following PowerPoint:

- **Starter** - What is the name of the meteorological phenomenon that means the same as all the words given? Tropical cyclone
- **Students mind map** what they already know regarding the definition of a tropical cyclone, where they form and the ingredients required for their formation.

-Answers on following slide.

- **Question** - What is the difference between typhoons, hurricanes and cyclones?

Show students the world map with all known tropical cyclone tracks on. The following slides give details of the naming conventions for each region.

- **Students label these on a world map.** Slide 8 can be used to test their world geography or the world map shown on slide 9 can be used to speed up activity. Tropical cyclone statistics for discussion on following slide. **OR Figure 7 gives data which could be plotted to show these trends.**

- **Tropical Cyclogenesis** - There is a lot of information to get across here.
 - Students could take notes as you talk through process.
 - They could draw a flow diagram at the end in groups or individually.
 - They could rearrange key diagrams into the correct order to describe the process using figure 5. Then add their own description.
 - Students could rearrange statements describing cyclogenesis using figure 4.

Using PowerPoint:

- 1) Existing converging air gives rise to local thunderstorms
- 2) These sometimes form on waves which arrive on the ITCZ as shown.
- 3) A cold upper-level trough can enhance convection.
- 4) Latent heat released by water condensing causes air to warm and a high pressure to form aloft.
- 5) The diverging air aloft and further convection lead to continued lowering of surface pressure causing surface wind speed to increase and air to spiral into the storm.
- 6) A feedback mechanism then occurs a) Air now reaching centre is warm and moisture laden after travelling over choppy warm seas b) This adds extra fuel to the thunderstorms increasing their growth rate c) The surface pressure drops further d) Surface winds increase e) Sea becomes more choppy f) Extra warmth and moisture in air and so on!

Convection Experiment - Place a single potassium permanganate crystal (Refer to CLEAPSS for risk assessment and safety advice) carefully in a beaker of water using tweezers. Heat gently below using a candle. This experiment shows convection currents clearly to enable students to visualise the atmospheric process.

Latent Heat Experiment - If a lab is available, students could measure the amount of energy required to evaporate a given amount of water. This will be equivalent to the amount of heat released when it condenses in a thunderstorm. *Note - Please follow your own risk assessment policy.*

Method: Add 50ml of water to an evaporating dish. Measure the time taken for all of the water to evaporate ONCE it has already started boiling. The amount of energy given to the water can be calculated by multiplying the time taken by 9800J/s (the power of a Bunsen Burner).

The latent heat released can then be calculated from

$$L=Q/m$$

Where L is the latent heat, Q is the energy supplied to the water and m is the mass of water in kg (i.e. 0.05kg for this experiment).

The latent heat tells you the amount of energy required to turn a kg of water from a liquid to a gas (or energy given out when it turns from a gas to a liquid). The number you are aiming for in this experiment is 2.3million Joules per kg. It is likely the experiment will lead to a different number due to the large sources of error.

If the students are now told that approximately 1billion kg (1,000,000,000kg) of water are condensed per second in a tropical storm they should be able to work out how much energy is released every second ($1,000,000,000 \times 2,300,000 = 2.3 \times 10^{15} \text{J}$). This is the equivalent of exploding a 10 megaton nuclear bomb every 20 minutes!

Note - Science students may notice we haven't taken into account the specific heat capacity of water (i.e. energy required to change its temperature without a state change e.g. 30-20°C). This number will be very small compared to the latent heat release. We have also only performed a back of the envelope calculation to show orders of magnitude rather than a definitive number.

- **Students make notes as mentioned above** (Figure 4 & 5) and then sketch a cross-section of hurricane. Further details on the eye and eyewall are given on the following slides. Discuss factors which limit or cease the growth of tropical storms.
- **Students discuss in pairs dangers of tropical cyclones.**
Storm surge (video linked), wind damage, flying debris (video linked), damage to infrastructure.
- **Students mind map social, economic and environmental issues of tropical storms.**
Some answers given on PowerPoint.
- **Saffir-Simpson scale for discussion.** Link to official National Hurricane Center scale and BBC animation.
- **Five tropical cyclone case studies are provided, each with videos.** These are intended as an overview. For homework **students should research at least two further or an ICT room could be booked for class-time research.** Extension - Discuss how future development planning could incorporate tropical storm preparedness designs. - OR Argue whether we should continue building in these areas at all.
- **Hurricane Debate** - Students are given roles of responsibility of people preparing for a major hurricane landfall on the southern US coast. E.g.
-Meteorologist advising authorities

- Governor of state
- Emergency services on the ground
- Homeowner
- Business owner
- Storm chaser!

Each should argue their case for staying put or evacuating. This could raise various issues such as

- Weighing public safety versus allowing people to make their own decision
- Issues with accuracy of forecast and last minute shifts to landfall location
- Homeowners wanting to stay to protect their property but being forced to leave by police.
- Loss of money to businesses and reputation if Governor makes the wrong decision

Resources:

Figure 4a - Tropical Cyclogenesis - Answers

A low pressure system may develop on the ITCZ - These are known as 'waves'. Forecasters watch these areas for signs of tropical cyclogenesis.

Thunderstorms begin to form. These require converging air at the surface i.e. a low pressure system such as a wave on the ITCZ. These have anticlockwise winds (in the N.hemisphere) and so only form >500km either side of the equator (between 5° and 20°) because they require a strong Coriolis 'force'.

If a cold upper-level trough from mid-latitudes moves into the area of thunderstorm development then the air becomes convectively very unstable and the thunderstorms will start to grow very large.

As latent heat is released by the condensing water vapour, the cold air aloft warms and increases in pressure.

The diverging air aloft 'sucks' air up from the surface and with continued convection causes the surface low pressure to drop further. Surface winds now increase and begin to spiral inwards. This makes the sea rougher which makes the winds turn further to the centre of the developing storm.

The feedback mechanism:

- Air now reaching centre is warm and moisture laden after travelling over choppy warm seas.
- This adds extra energy in the form of latent heat to the thunderstorms, increasing their rate of growth
- The surface pressure drops further
- Surface winds increase
- Sea become more choppy
- Extra warmth and moisture transferred to the air
- And so on!
- When 35-64 knot wind speed is reached we call it a tropical storm and when it increases to 65 knots we call it a tropical cyclone.

This growth will continue until:

- Moisture is cut off - i.e. Cyclone moves over land
- Heat is cut off - i.e. Cyclone moves too far north or south
- Wind shear (wind strength increasing with height) increases - This tears the cyclone apart - Common near Hawaii.
- Cyclone becomes 'full' of thunderstorms so latent heat release is limited.

Figure 4b - Tropical Cyclogenesis

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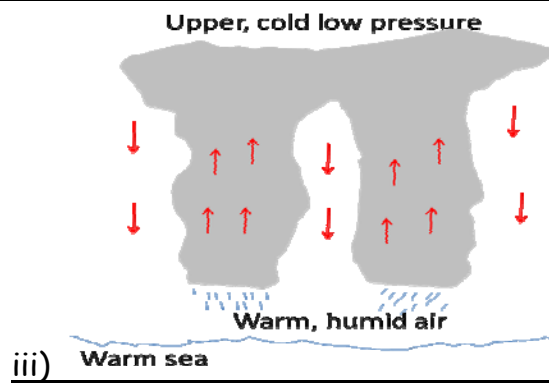
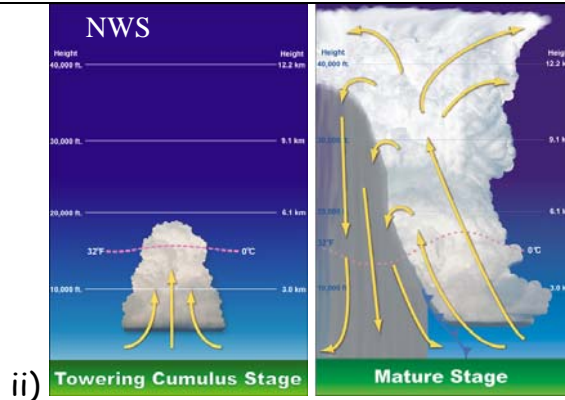
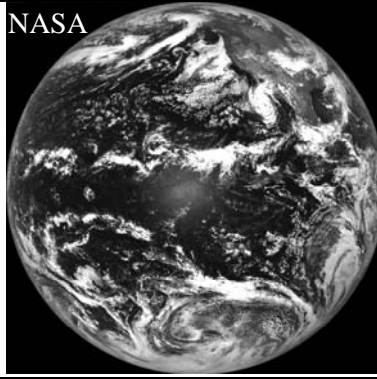
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Figure 5a - Flow diagram sort - Answers



iv) **Latent Heat Release**

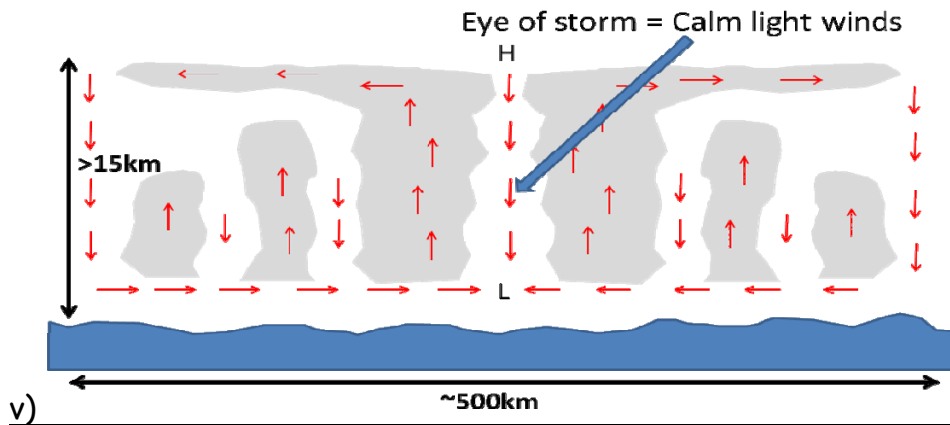
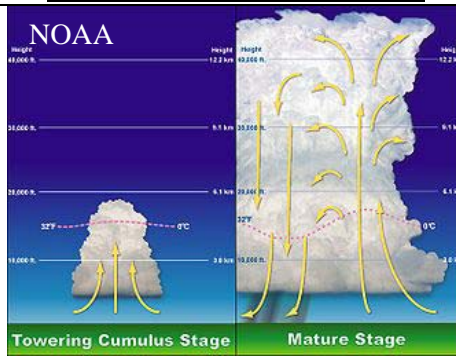
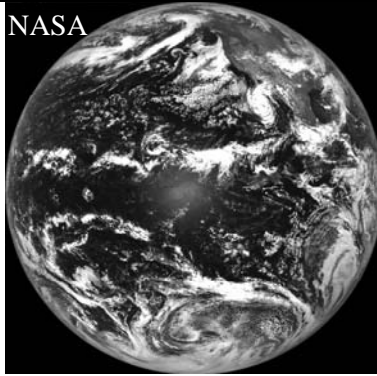
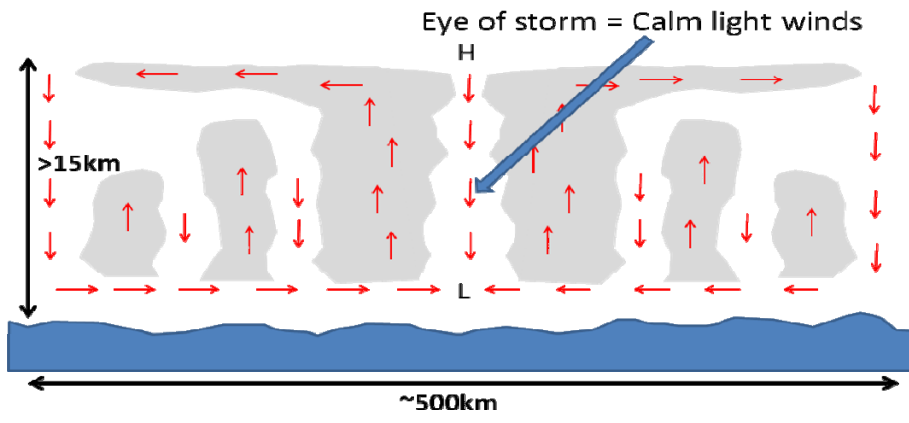


Figure 5b - Flow diagram sort



Latent Heat Release

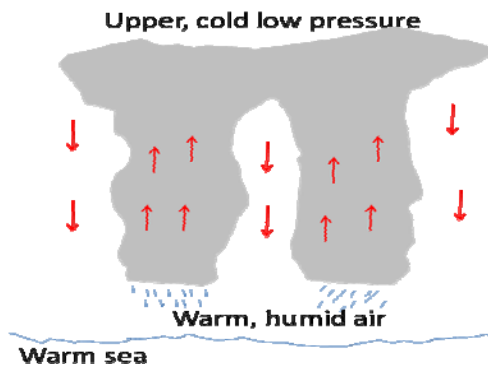


Figure 6 The Saffir-Simpson Scale

Saffir-Simpson Hurricane Scale		
Category	Wind speed	Storm surge
	mph (km/h)	ft (m)
5	≥156 (≥250)	>18 (>5.5)
4	131–155 (210–249)	13–18 (4.0–5.5)
3	111–130 (178–209)	9–12 (2.7–3.7)
2	96–110 (154–177)	6–8 (1.8–2.4)
1	74–95 (119–153)	4–5 (1.2–1.5)
Additional classifications		
Tropical storm	39–73 (63–117)	0–3 (0–0.9)
Tropical depression	0–38 (0–62)	0 (0)

Figure 7 - Frequency of tropical storms and hurricanes by month - Source NOAA

Total and Average Number of Tropical Storms by Month (1851-2009)						
Month	Tropical Storms		Hurricanes		U.S. landfalling hurricanes	
	Total	Average	Total	Average	Total	Average
JANUARY	2	*	1	*	0	*
FEBRUARY	1	*	1	*	0	*
MARCH	1	*	1	*	0	*
APRIL	1	*	0	*	0	*
MAY	18	0.1	4	*	0	*
JUNE	80	0.5	31	0.2	19	0.12
JULY	109	0.7	54	0.3	25	0.15
AUGUST	352	2.2	226	1.4	75	0.48
SEPTEMBER	540	3.4	376	2.4	104	0.67
OCTOBER	314	2	187	1.2	51	0.33
NOVEMBER	85	0.5	56	0.3	5	0.03
DECEMBER	16	0.1	6	*	0	*
YEAR	1519	9.6	932	5.9	279	1.78



Background Information:

Hurricanes, typhoons, cyclones (or even Willy-willy's in Australia!) are all words used for the same weather phenomena - A tropical cyclone. The different terms are used in different parts of the world (Hurricane is used in the N. Atlantic Ocean, NE Pacific Ocean and S. Pacific Ocean, Typhoon is used in the NW Pacific Ocean and Cyclone is used in the SW Pacific Ocean).

As their name suggests, tropical cyclones form almost exclusively in the tropical regions but can move out of these to affect other areas. They differ from European winter depressions and American nor'easters by the fact they are warm-core and so a different meteorological process is occurring - Convection.

To form, tropical cyclones require large bodies

of warm water (26.5°C over a depth of at least 50m). The atmosphere must also be conducive

to convection (i.e. it must cool rapidly with height to ensure a warm air parcel from the surface will continue to rise to a high enough height to form a cumulonimbus cloud - A thunderstorm). They must form at least 500km (300miles) from the equator to ensure the Coriolis 'force' is strong enough to allow the central low pressure to be maintained, otherwise air would move in too quickly and 'fill' the low pressure killing the storm. An existing area of disturbance (to provide some weak spin) is also required in formation - The storm cannot form spontaneously out of the blue. Finally less than 10m/s of vertical wind shear (how much the wind varies with height). If shear is greater than this than the deep convection will be disrupted and the developing storm can be 'torn' apart.

Tropical cyclones obtain all of their energy from latent heat (the energy released when water cools from water vapour to liquid water i.e. in a cloud). This heat originated in the warm, tropical oceans as mentioned above. If a tropical atmospheric disturbance occurs (such as a tropical wave leaving the west coast of Africa), thunderstorms can begin to develop more widely in the warm, humid tropical air. As air rises into the thunderstorms, further air is entrained into the surface low and this enhances the weak circulation that initiated the thunderstorms. The large quantity of rising air also creates a high pressure system above, leading to diverging air aloft enhancing the upward motion of air in the thunderstorms. As the surface winds increase to between 20-34 knots, the disturbance becomes known as a tropical depression. A distinct area of low pressure usually forms at this point at the centre of the group of thunderstorms and the wind moving faster inwards causes the spin to increase (just as an ice skaters spin increases when they move their arms inwards). The sea now becomes rougher, leading to greater friction and so the winds converge further into the centre of the

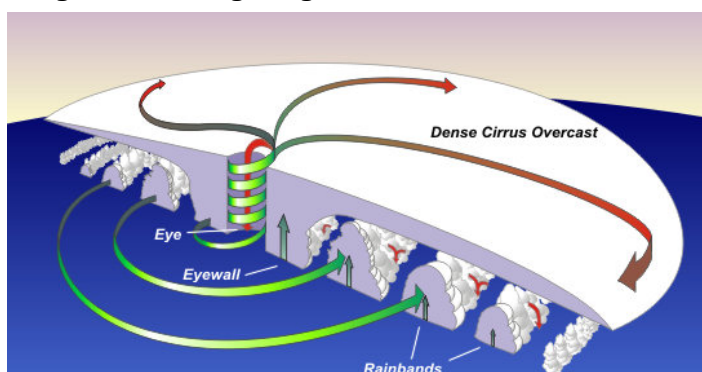


Figure 2 - Tropical Cyclone structure - NWS



Figure 1 - Hurricane Katrina - NASA GOES

low.

A feedback mechanism now occurs. The rising air has extra heat and moisture from the increasingly choppy sea. This results in more and stronger thunderstorms which release more latent heat. This causes the surface pressure to lower further, causing stronger winds, choppier seas and greater

surface convergence of winds. When winds reach between 35-64 knots the weather system is classed as a tropical storm. Above 65 knots we call it a tropical cyclone (or hurricane etc depending on geographic location). By this point the distinctive eye usually forms where slowly sinking air in the centre of the storm creates a region of relative calm (the eye) surrounded by violent winds (the eye wall - figure 2).

This development will continue until the moisture is cut off (the cyclone moves over land), the heat is cut off (the cyclone moves too far north or south), or wind shear increases and shears the storm apart. When the cyclone is 'full' of thunderstorms, latent heat release slows as the entire air mass warms and this also limits cyclone growth. These factors mean that wind gusts in cyclones rarely exceed 200 knots.

Tropical cyclones generally last about a week but this can vary considerably. The oldest cyclone (Hurricane Tina 1992) lasted for 24 days. The average diameter is around 500 km and they extend to a height of around 15 km. Tropical cyclones can release up to 200×10^{18} J per day (approx 1PW = 1×10^{15} Watts!). This is equivalent to exploding a 10 megaton nuclear bomb every 20 minutes!

Obviously when tropical cyclones make landfall the strength of the wind causes considerable damage. However the storm surge is often the most deadly part (~90% of tropical cyclone deaths are due to the storm surge) caused partly by the very low central pressure causing a rise in sea levels but mainly by the winds whipping up the sea by up to 5m! Examples of major tropical cyclone include:

- Hurricane Andrew 1992
- Hurricane Mitch 1998
- Hurricane Katrina 2005 (figure 1)
- Typhoon Saomai 2006
- Cyclone Larry 2005

Figure 3 shows the tracks of all known tropical cyclones.

The strength of a tropical cyclone is rated on the Saffir-Simpson scale (See figure 6).

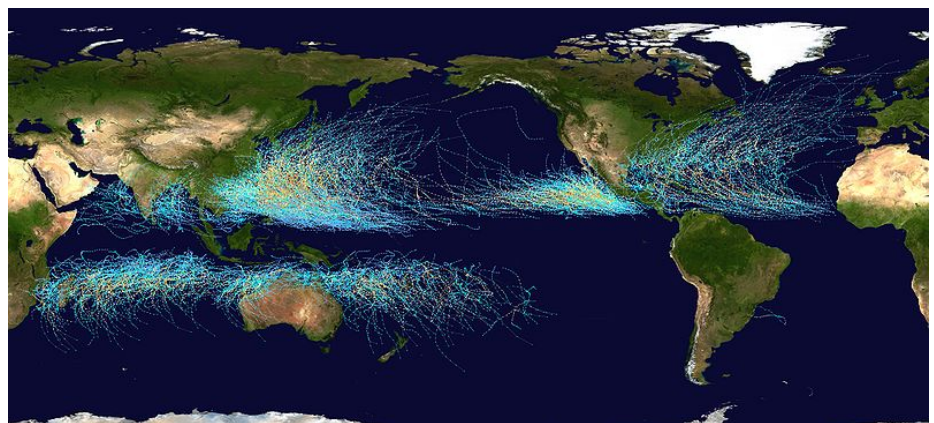


Figure 3 - Tropical cyclone tracks 1985-2005 Courtesy of Wikipedia Commons.

References and Useful Links:

- 1) The National Hurricane Center - <http://www.nhc.noaa.gov>
- 2) Video of hurricane Felicia being sheared apart - <http://www.youtube.com/watch?v=PiQWpnRtxOQ>
- 3) Video of hurricane Luis eye from space - <http://www.youtube.com/watch?v=S5725Etc4bI>
- 4) Video of a hurricane storm surge - <http://www.youtube.com/watch?v=XTvkrLESrwU&feature=channel>
- 5) Video of hurricane damage - <http://www.youtube.com/watch?v=H9VpwmtnOZc>
- 6) NHC Saffir-Simpson Scale - http://www.nhc.noaa.gov/sshws_table.shtml?large
- 7) BBC animated guide to hurricanes - <http://news.bbc.co.uk/1/hi/sci/tech/4588149.stm>
- 8) Hurricane Andrew Video - <http://www.youtube.com/watch?v=w3luqrnCKRc&feature=related>
- 9) Hurricane Mitch video - <http://www.youtube.com/watch?v=+Vm0qJ6Dj9M>
- 10) Hurricane Katrina Video - <http://www.youtube.com/watch?v=s76Qn7bpCsQ&feature=Playlist&p=F790B303DDF23282&playnext=1&index=1>

- 11) Super Typhoon Saomai - <http://www.youtube.com/watch?v=taKxL1pD7Kq>
- 12) Cyclone Larry video - <http://www.youtube.com/watch?v=OoEVmexaNTU&feature=related>
- 13) Top image - NOAA - <http://www.publicaffairs.noaa.gov/photos/1989hugorad1.gif>

Images:

Figure 1 - NASA GOES - <http://www.katrina.noaa.gov/satellite/images/katrina-08-28-2005-1545zd2.jpg>

Figure 2 - NWS - http://www.srh.noaa.gov/jetstream//tropics/tc_structure.htm

Figure 3 - Wikipedia Commons - http://en.wikipedia.org/wiki/File:Global_tropical_cyclone_tracks-edit2.jpg

Figure 4 - Author

Figure 5i - NASA - http://disc.sci.gsfc.nasa.gov/oceancolor/additional/science-focus/ocean-color/science_focus.shtml/convergence.shtml

Figure 5ii - NWS - <http://www.srh.weather.gov/jetstream/tstorms/life.htm>

Figure 5iii Author

Figure 5iv Author

Figure 5v Author

Figure 6 - Wikipedia http://en.wikipedia.org/wiki/Saffir%E2%80%93Simpson_Hurricane_Scale

Figure 7 - NOAA - <http://www.aoml.noaa.gov/hrd/tcfaq/E17.html>

Book:

- Meteorology Today - C Donald Ahrens