Australian Government
Bureau of Meteorology

1. Tropical Cyclones: Fundamentals and basic processes

- Definitions and naming
- Life cycle
- Structure
- Processes
- Broadscale influences

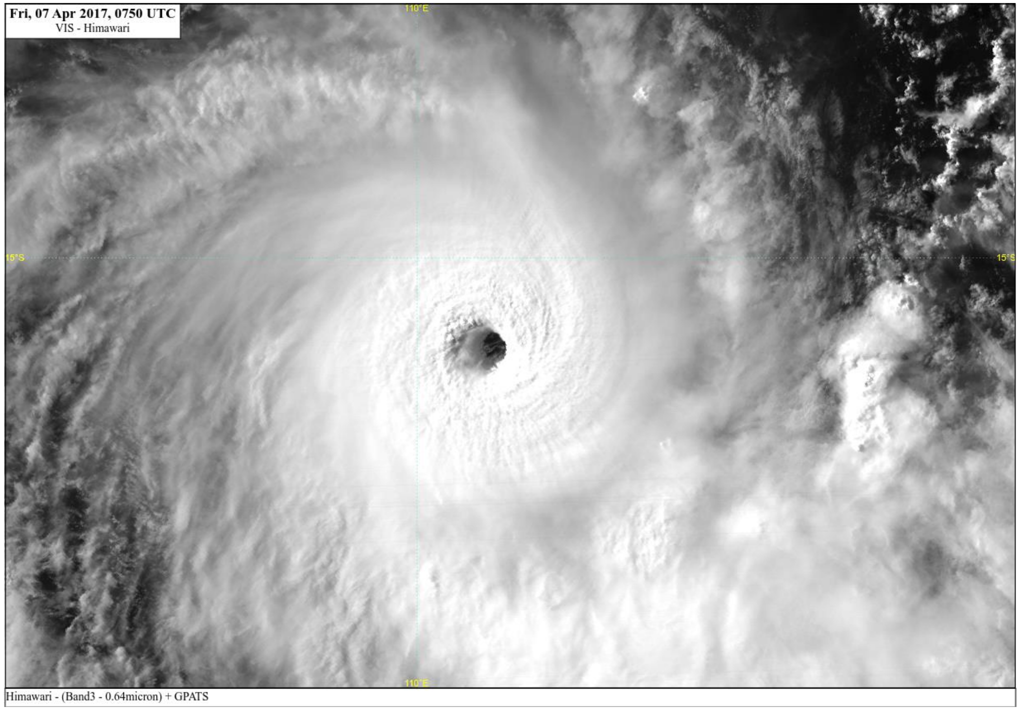
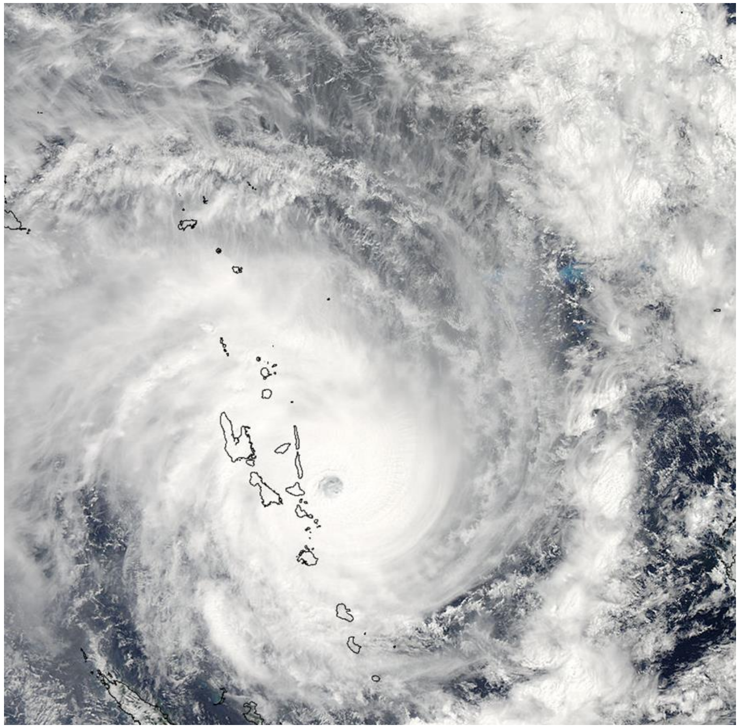


Image courtesy of BoM/JMA

Australian Government
Bureau of Meteorology

What is a TROPICAL CYCLONE ?

A low pressure system that forms over warm waters having organised deep convection and gales near the centre

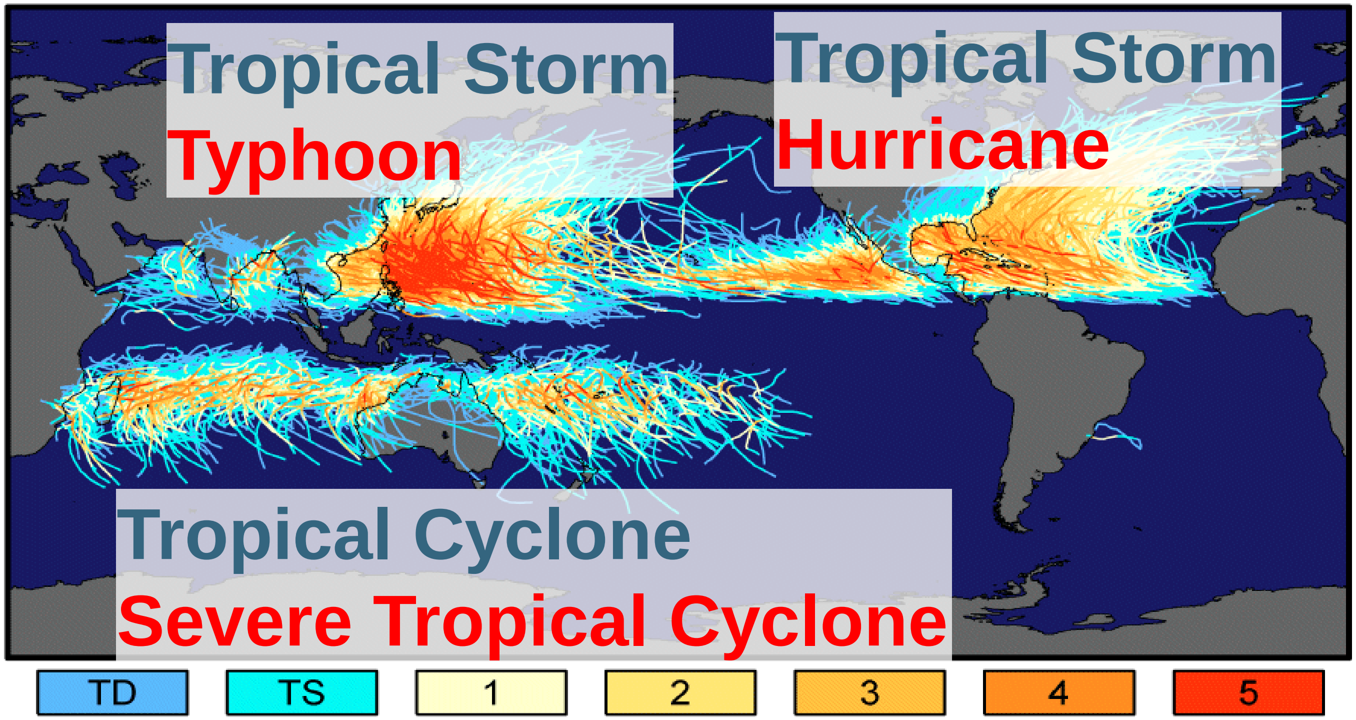


Modis Image of Pam courtesy of NASA

+ Australia: extending more than half way around the system centre and persisting for at least six hours.

Australian Government
Bureau of Meteorology

Same thing … different names



Tropical cyclone is generic term for Tropical Revolving Storm

Hurricane, Typhoon, Severe Tropical Cyclone (sustained winds >= 64 knots).

(Non-severe) tropical cyclone, tropical storm (winds >= 34 knots, < 64 knots)

From http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=17447

Australian Government

Bureau of Meteorology

Cyclone Names: by region

Australia; SPAC (FMS); PNG; BMKG; JMA (NWPAC)

	Australian Region Names (Pronunciation in brackets)				
A	Anika	Anthony	Alessia	Alfred	Ann
	(ah-ni-ka)	(an-thuh-nee)	(ah-les-ee-uh)	(al-fred)	(an)
B	Billy	Bianca	Bruce	Blanche	Blake
	(bil-ee)	(bee-ahng-kuh)	(broos)	(blanch)	(bleyk)
C	Charlotte	Courtney	Catherine	Caleb	Claudia
	(shahr-luht)	(kawrt-nee)	(kath-rin)	(kei-luhb)	(klaw-dee-uh)
D	Dominic	Dianne	Dylan	Debbie*	Damien
	(dom-uh-nik)	(dai-an)	(dil-uhn)	(deb-ee)	(dei-mee-uhn)
E	Ellie	Errol	Edna	Ernie	Esther
	(el-ee)	(er-uhl)	(ed-nuh)	(ur-nee)	(es-ter)
F	Freddy	Fina	Fletcher	Frances	Ferdinand
	(fred-ee)	(fee-nuh)	(flech-er)	(fran-sis)	(fur-din-and)
					Gretel
					(gre-tuhl)
					Harold
					(har-uhld)
					Imogen
					(im-uh-jen)
					Joshua
					(josh-oo-uh)
					Kimi
					(kim-ee)
					Lucas
					(loo-kuhs)
					Marian
					(mar-ee-uhn)
					Noah
					(noh-uh)
					Odette
					(oh-det)
					Paddy
					(pad-ee)
					Ruby
					(roo-bee)
					Seth
					(seth)

Jakarta TCWC Area of Responsibility^

List A	List B
Anggrek	Anggur
Bakung	Belimbing
Cempaka	Duku
Dahlia	Jambu
Flamboyan	Lengkeng
Kenanga	Mangga
Lili	Nangka
Mawar	Pisang
Seroja	Rambuta
Teratai	Sawo

South Pacific Ocean

List A	List B	List C	List D	List E (Standby)
Ana	Arthur	Atu	Amos	Alvin
Bina	Becky	Bune	Bart	Bela
Cody	Chip	Cyril	Colin	Cook
Dovi	Denia	Daphne	Donna	Dean
Eva	Elisa	Evan	Ella	Eden
Fili	Fotu	Freda	Frank	Florin
Gina	Glen			
Hagar	Hettie			
Irene	Innis			
Judy	Joni			
Kerry	Ken			
Lola	Lin			
Mal	Mick			
Nat	Nisha			
Olo	Oli			
Pita	Pat			
Rae	Rene			
Sheila	Sarah			
Tam	Tomas			
Urmil				
Vaianu	Vania			

Port Moresby's Area of Responsibility*

List A	List B (Standby)
Alu	Nou
Buri	Obaha
Dodo	Paia
Emau	Ranu
Fere	Sabi
Hibu	Tau
Ila	Ume
Kama	Vali
Lobu	Wau
Maila	Auram

http://www.bom.gov.au/cyclone/about/names.shtml

http://severe.worldweather.org/tc/au/tcname.html

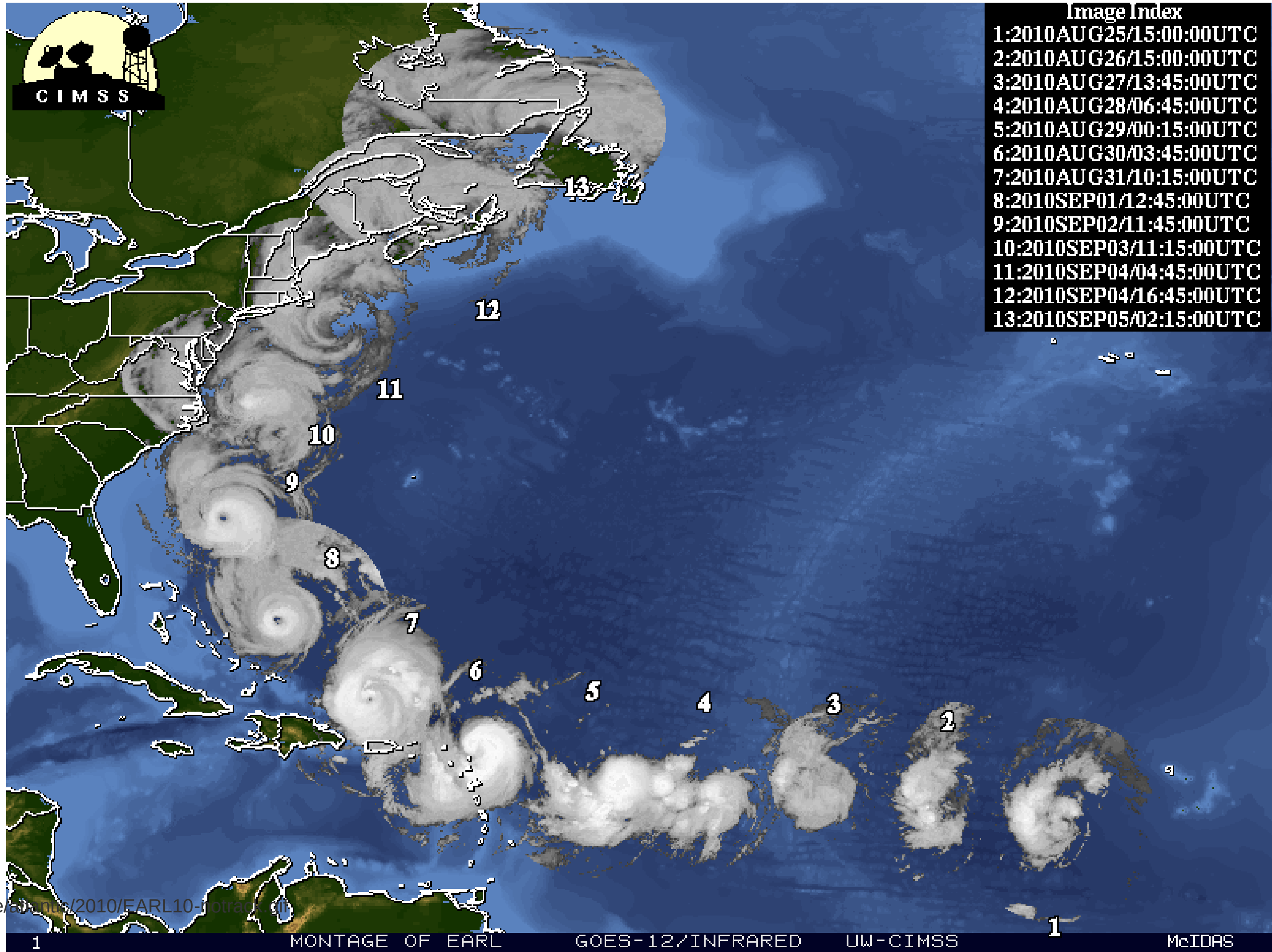
http://www.vmgd.gov.vu/vmgd/index.php/forecast-division/tropical-cyclone

http://severe.worldweather.org/tc/sp/tcname.html

Australian Government
Bureau of Meteorology

The life cycle of a cyclone: genesis, maturing, weakening, decay Every cyclone is unique!

brief Vs long,
weak Vs strong,
small Vs big,
impacts



Hurricane Earl Aug 2010
Image courtesy of CIMSS
http://tropic.ssec.wisc.edu/storm_archive/montage/atlantic/2010/EARL10-track.gif

Australian Government
Bureau of Meteorology

The life cycle of a cyclone

Examples CIMSS

March 2015 http://tropic.ssec.wisc.edu/archive/data/stettner/11MAR15/11MAR15.html

What do you notice?

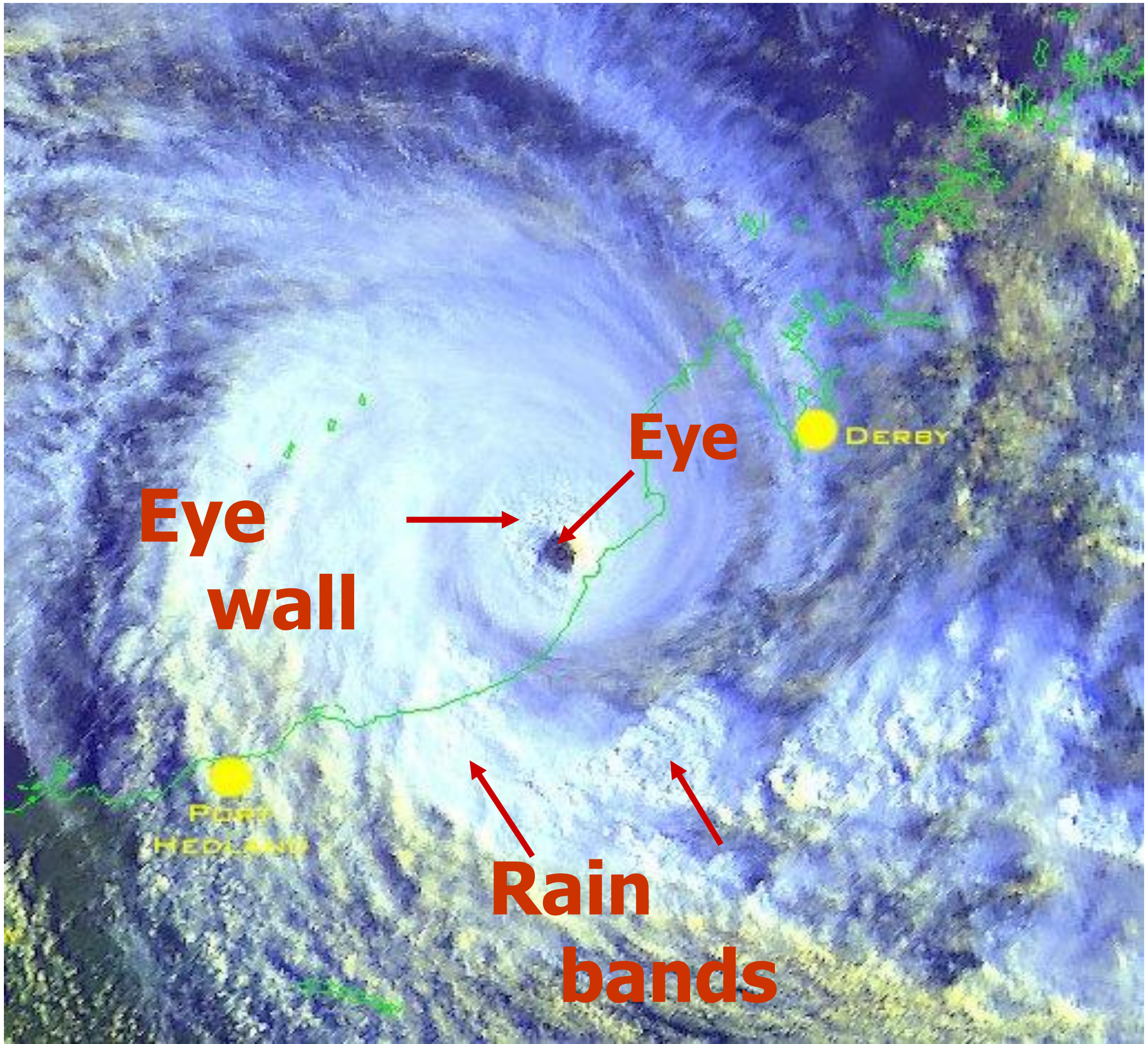
Hires Himawari shows variations over shorter time scales

ST Noul (May15) http://cimss.ssec.wisc.edu/goes/blog/wp-content/uploads/2015/05/150509-10_himawari8_visible_band3_STY_Noul_anim.gif

Yasi http://www.bom.gov.au/cyclone/history/yasi-satellite.shtml

Australian Government
Bureau of Meteorology

Anatomy of a tropical cyclone inner and outer circulations



Australian Government
Bureau of Meteorology

Technical parameters

Intensity: max wind, central pressure
Size: Gale radius, ROCI (POCI)

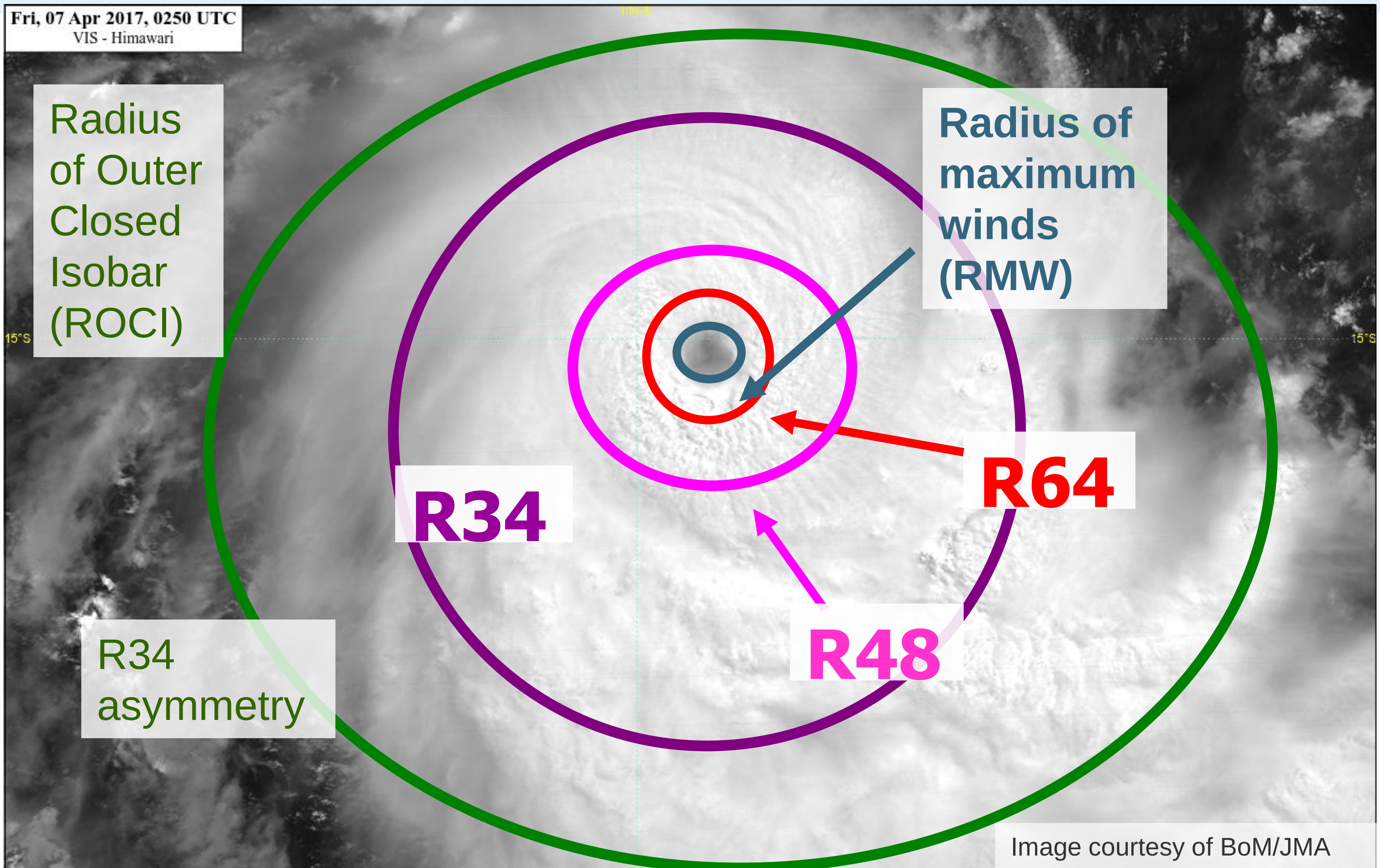


Image courtesy of BoM/JMA

Australian Government
Bureau of Meteorology

Australian Intensity Scale

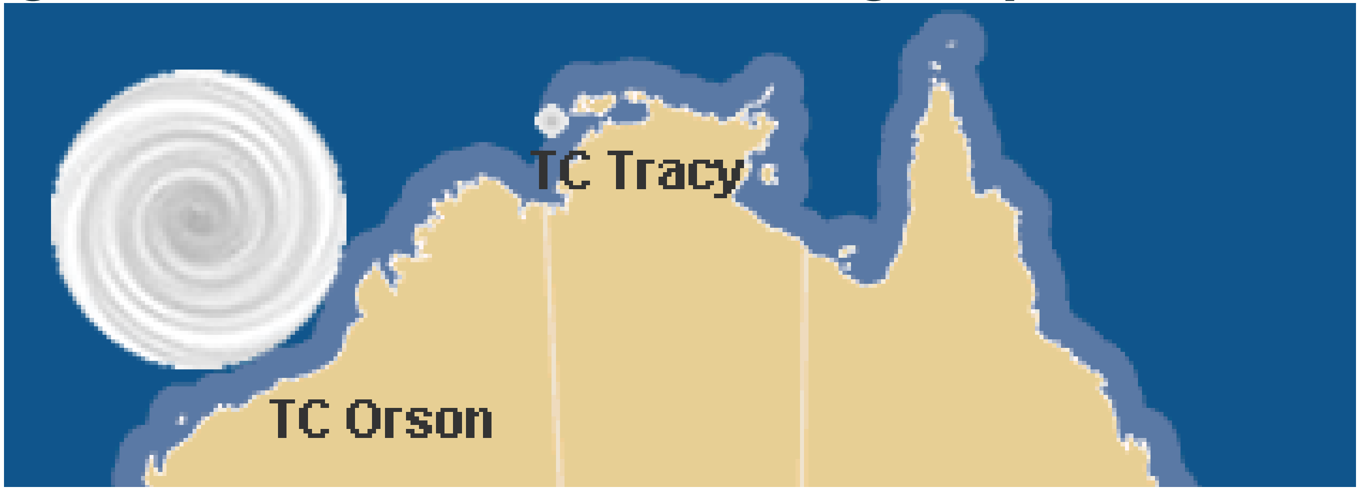
Cat. No.	Max wind (kn)		Wind Impact
1	34-47	"Damaging" winds	Minor
2	48-63	"Destructive" winds	Moderate
3	64-85	SEVERE	Major
4	86-106	"Very destructive"	Tracy, Yasi*
5	> 106		EXTREME Monica

http://www.bom.gov.au/cyclone/about/#severity

Australian Government
Bureau of Meteorology

Importance of Size

Size: warning area, duration, waves, surge, spin down rate



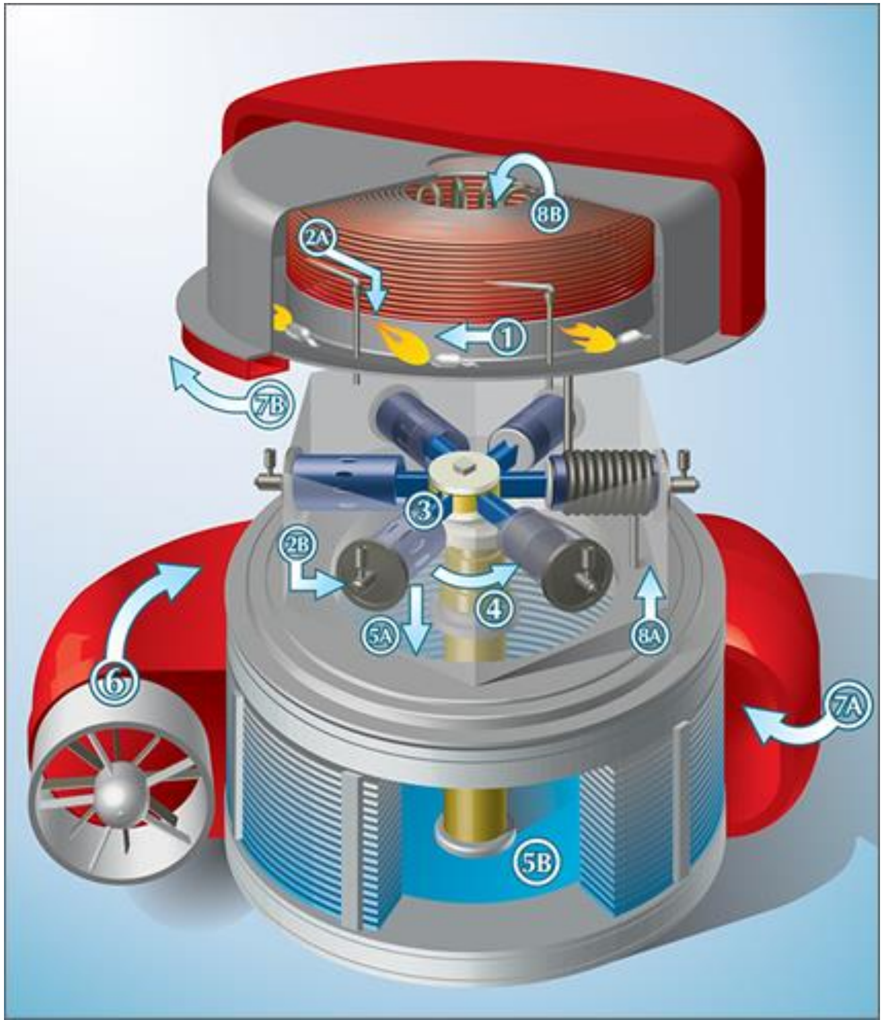
R34: 'midget' <60nm; ave 80-100nm; large >120nm

Eye diameter: ~5-20nm

RMW: 5-30nm;

Australian Government
Bureau of Meteorology

Simplified: Cyclones as heat engines

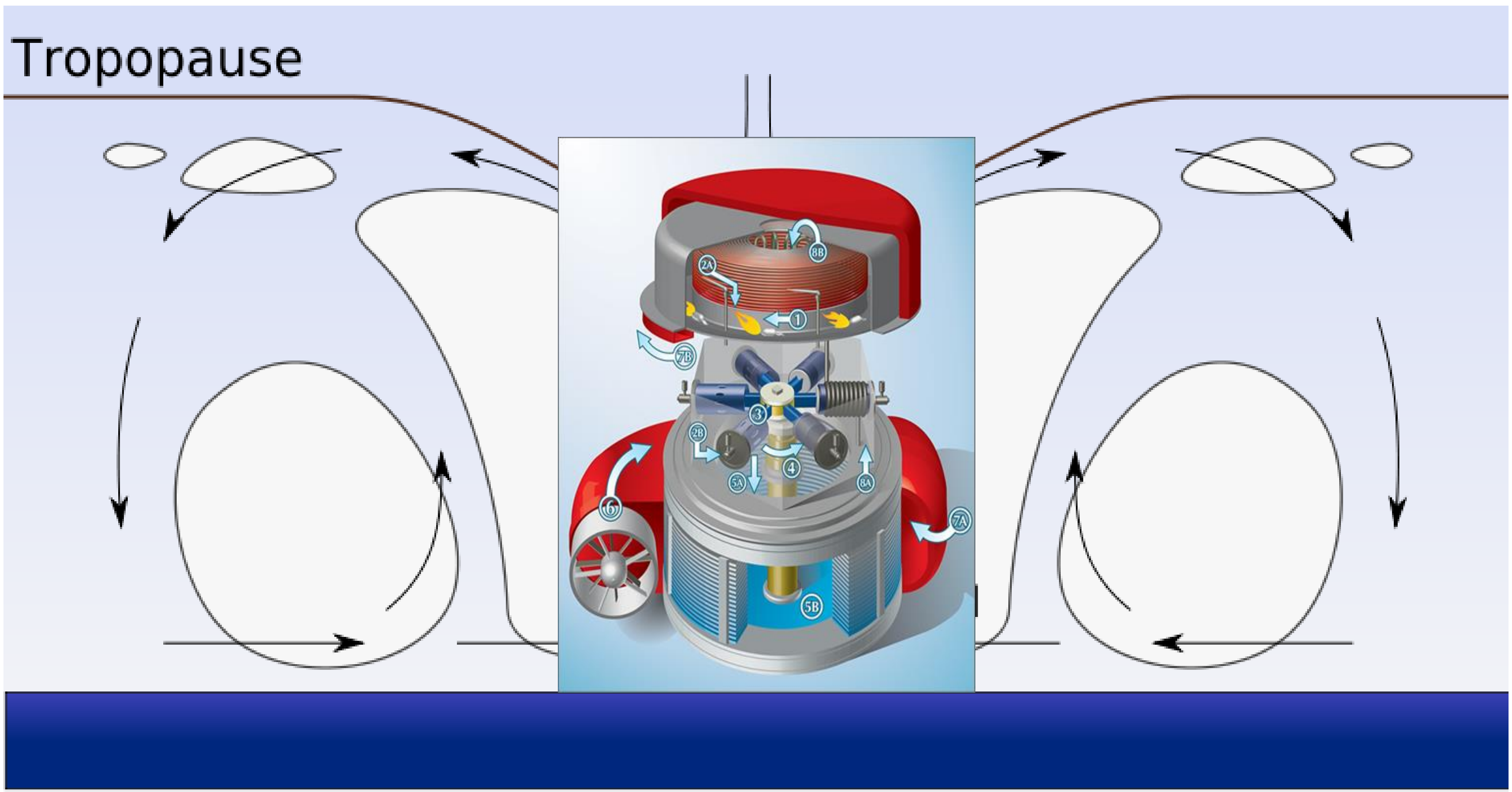


Australian Government

Bureau of Meteorology

Cyclones as heat engines

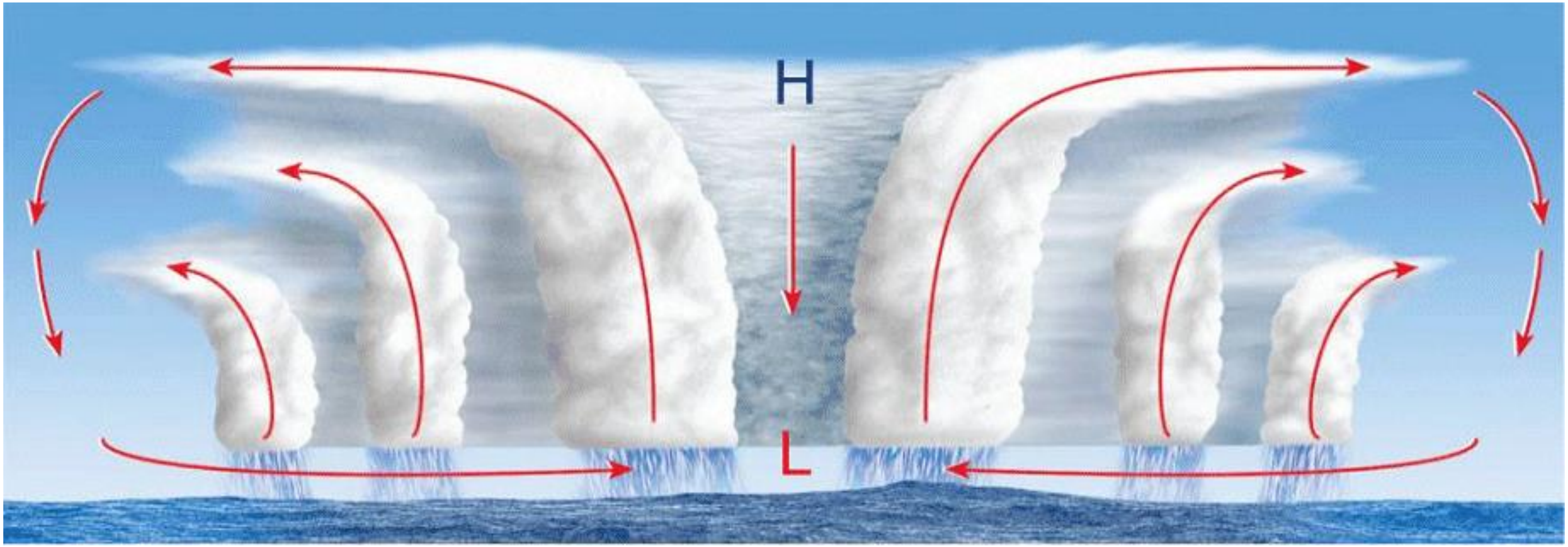
IN, UP and OUT



Australian Government
Bureau of Meteorology

TC Meteorology Key Terms

Convergence &Vorticity (IN), Convection (UP), Outflow (OUT)

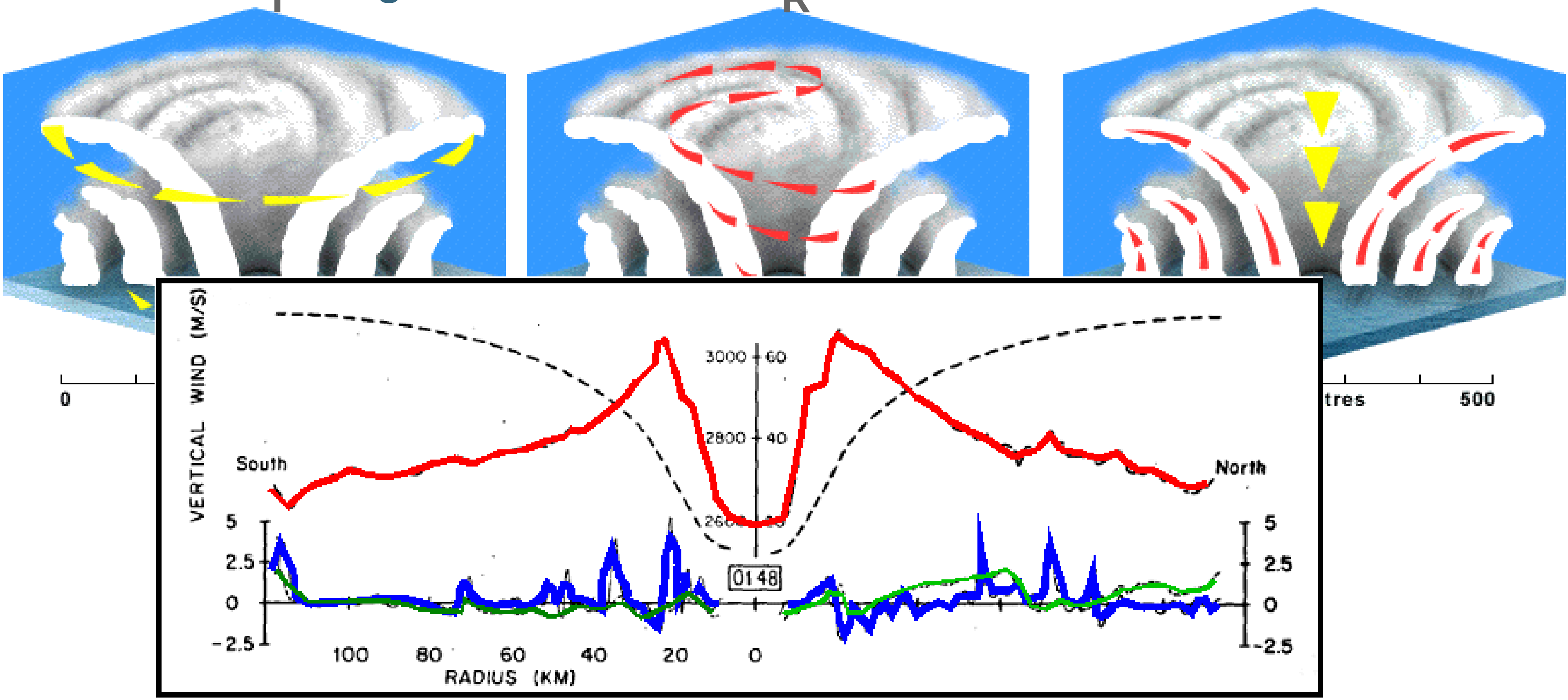


IN, UP and OUT

Australian Government
Bureau of Meteorology

The 3 Dimensional Wind Structure
Which one has the highest winds?

V_T tangential **V_R radial** **ω vertical**



Tangential wind Vertical wind Radial wind

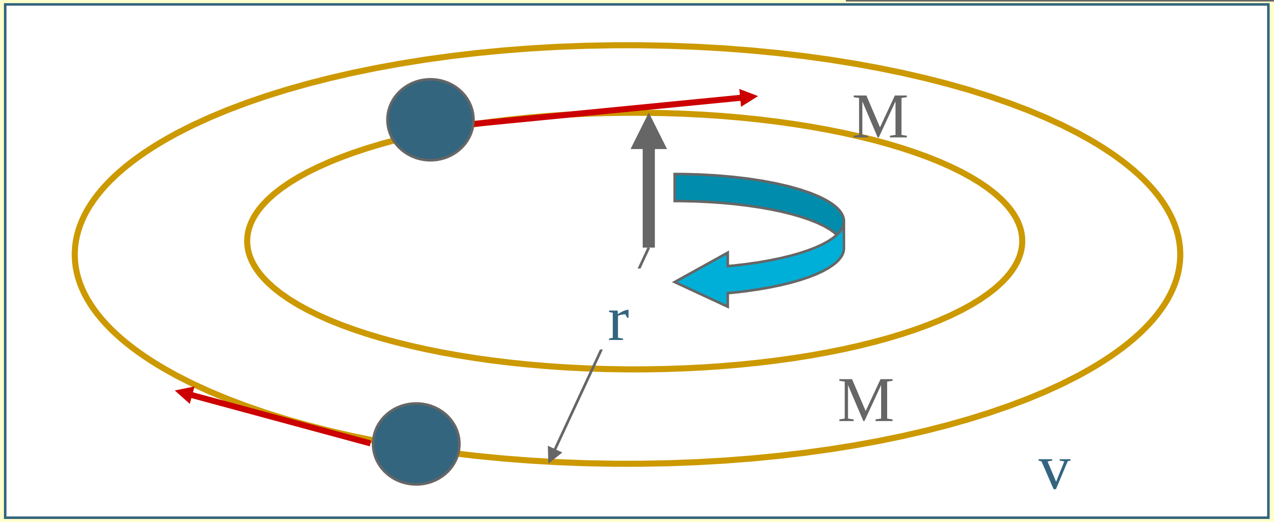
Australian Government
Bureau of Meteorology

Idealised picture: intensification of winds at low levels

Basic principle: conservation of absolute angular momentum:

$$M = rv + \tfrac{1}{2} f r^2$$

f = Coriolis parameter
r = radius
v = tangential wind



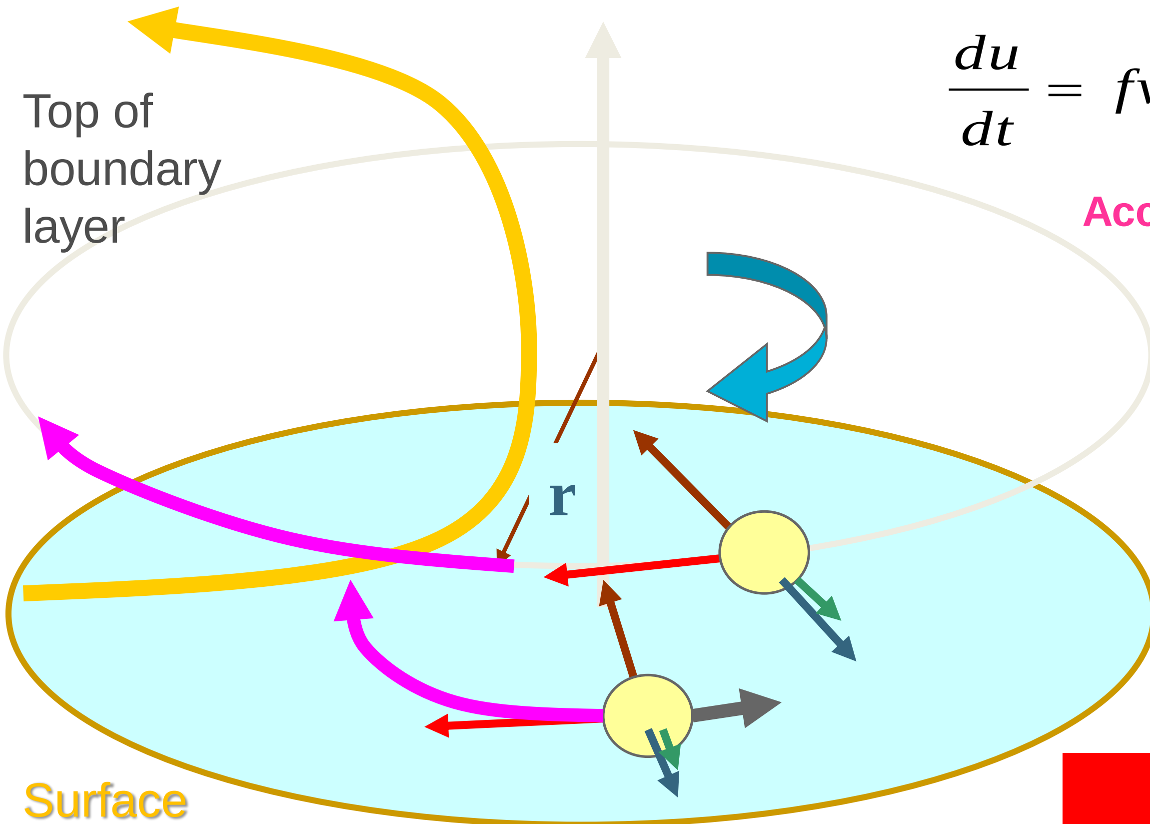
$$v = \frac{M}{r} - \tfrac{1}{2} f r$$

If r decreases, v increases!

Spin up requires radial convergence

Modified from R. Smith, Aspects of TC dynamics: Part 1 the Boundary Layer

More realistic picture – effect of friction



$$\frac{du}{dt} = fv + \frac{v^2}{r} - \frac{1}{\rho}\frac{\partial P}{\partial r} + F_r$$

Acceleration of the radial wind

Acceleration due to radial Pressure gradient

fv = Coriolis force on rotating wind

v^2/r = centrifugal acceleration

Fr = small scale mixing

Frictionally driven secondary circulation

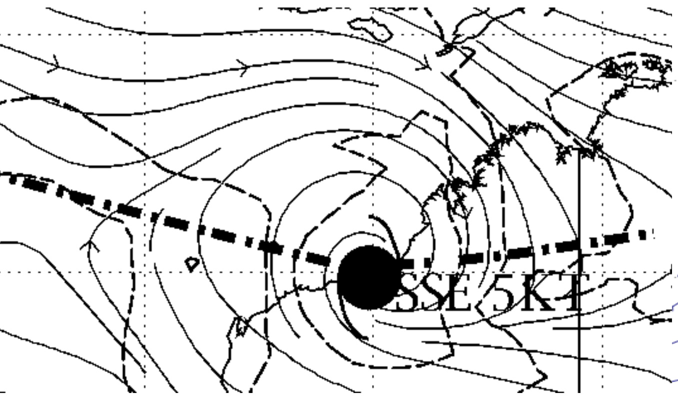
FD = Frictionally driven inflow

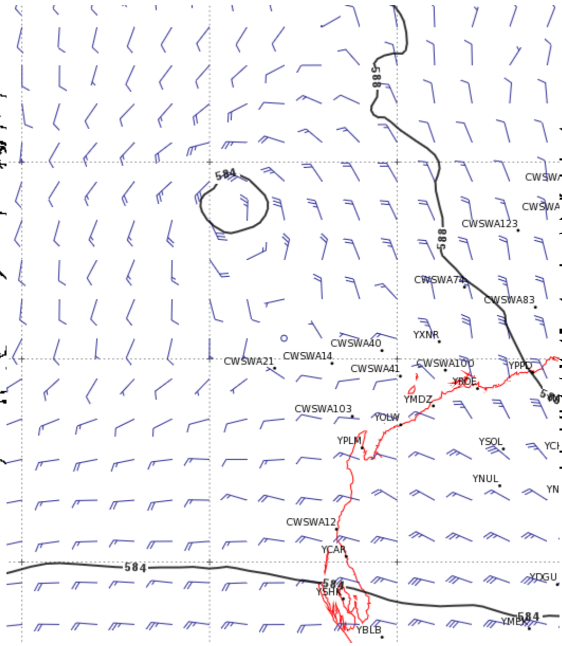
The Planetary Boundary Layer is a momentum sink, Absolute Angular Momentum is not conserved

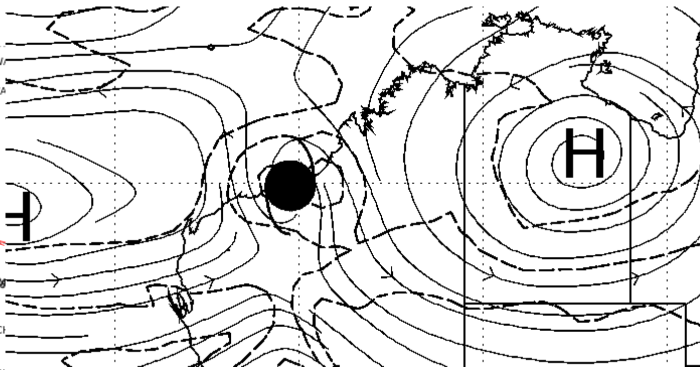
Modified from R. Smith, Aspects of TC dynamics: Part 1 the Boundary Layer

Australian Government
Bureau of Meteorology

Circulations at different levels
(streamlines and isotachs)







Low levels (Gradient- 850 hPa)
Boundary Layer
- large scale inflow
- convergence not uniform
- max winds near core

Mid levels
(700-400 hPa)
- the 'steering' level

Upper levels

(100-300 hPa)

-cyclonic core for strong TC

- peripheral outflow as anticyclonic (peripheral ridge)

Australian Government
Bureau of Meteorology

Upper level behaviour – the anticyclonic outflow

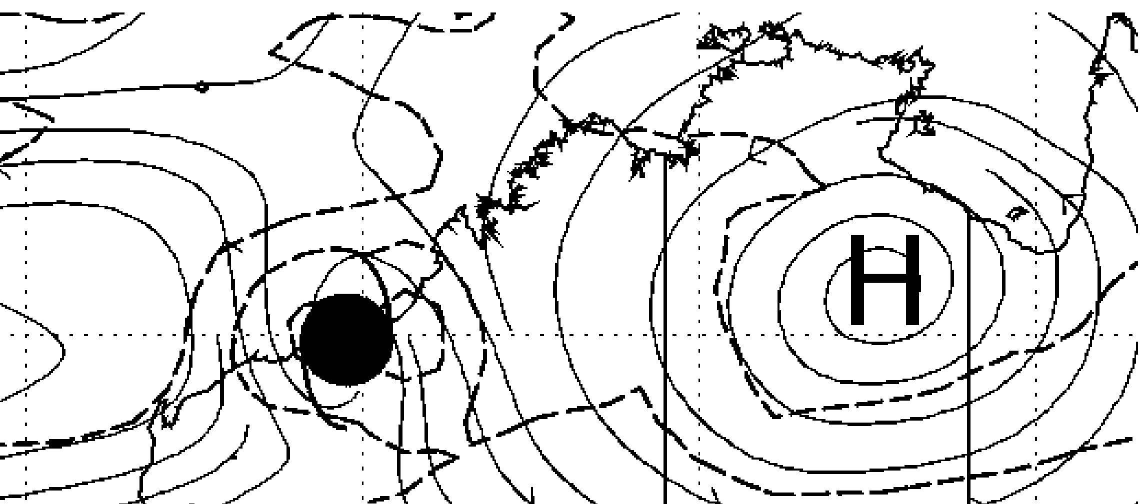
upward spiralling air in the core spreads out with height (it diverges) & slows.

Cyclonic movement decelerates, so 0 tangential velocity ~ 200km from the centre of the TC.

Anticyclonic upper air movement builds a peripheral ridge (Ri)

Away from the core winds are the prevailing (environmental) upper winds.

Vorticity = rotation of air around a vertical axis.



Australian Government
Bureau of Meteorology

The inner & outer regions of a TC

Inner region (0-100 km) – Convection dominates

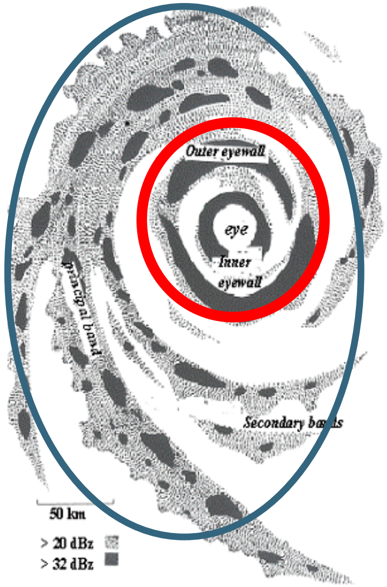
•Large absolute vorticity, small radius of rotation

•Coriolis effect small – cyclostrophic balance

•Inertially very stable (will resist changes in radial displacement of winds by the environment)

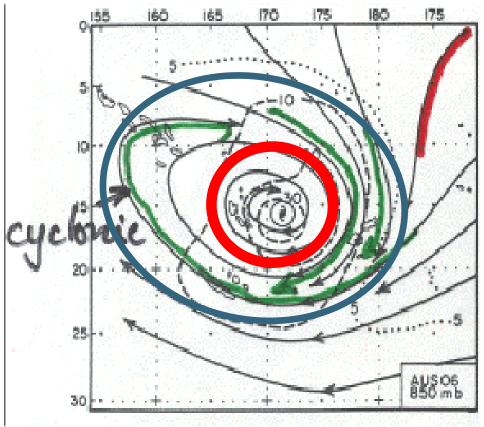
•Very symmetric (does not interact much with surroundings)

•Winds adjust to changes in the mass field (heating/cooling, convergence/divergence will lead to changes in the wind).



Outer region (100-600 km) environmental infl.

•smaller absolute vorticity, larger radius
•Coriolis effect significant – gradient balance.
•not so symmetric – influenced by environmental flow (eg monsoon, STR)
•mass adjusts to the wind field



Australian Government
Bureau of Meteorology

Summary

- Defined TCs and naming convention
- Simplified view of TC engine: IN-UP-OUT
- Key terms convergence, convection, vorticity, outflow
- The strongest winds are tangential winds, and are located in the eyewall and within the boundary layer
- Complex dynamics and processes within TCs