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# Cyclogenesis

- Definition and theory
- Necessary conditions
- How does a circulation spin up?


- Acknowledgments:
- Kevin Tory CAWCR
- Tory and Frank: Tropical Cyclone Formation, Chapter 2 in Global Perspectives on Tropical Cyclones 2010.
- Aiyyer, IWTC VIII 2014

http://www.wmo.int/pages/prog/arep/wwrp/new/documents/IWTC_VIII_Topic2_1_Cyclogenesis_Final.pdf

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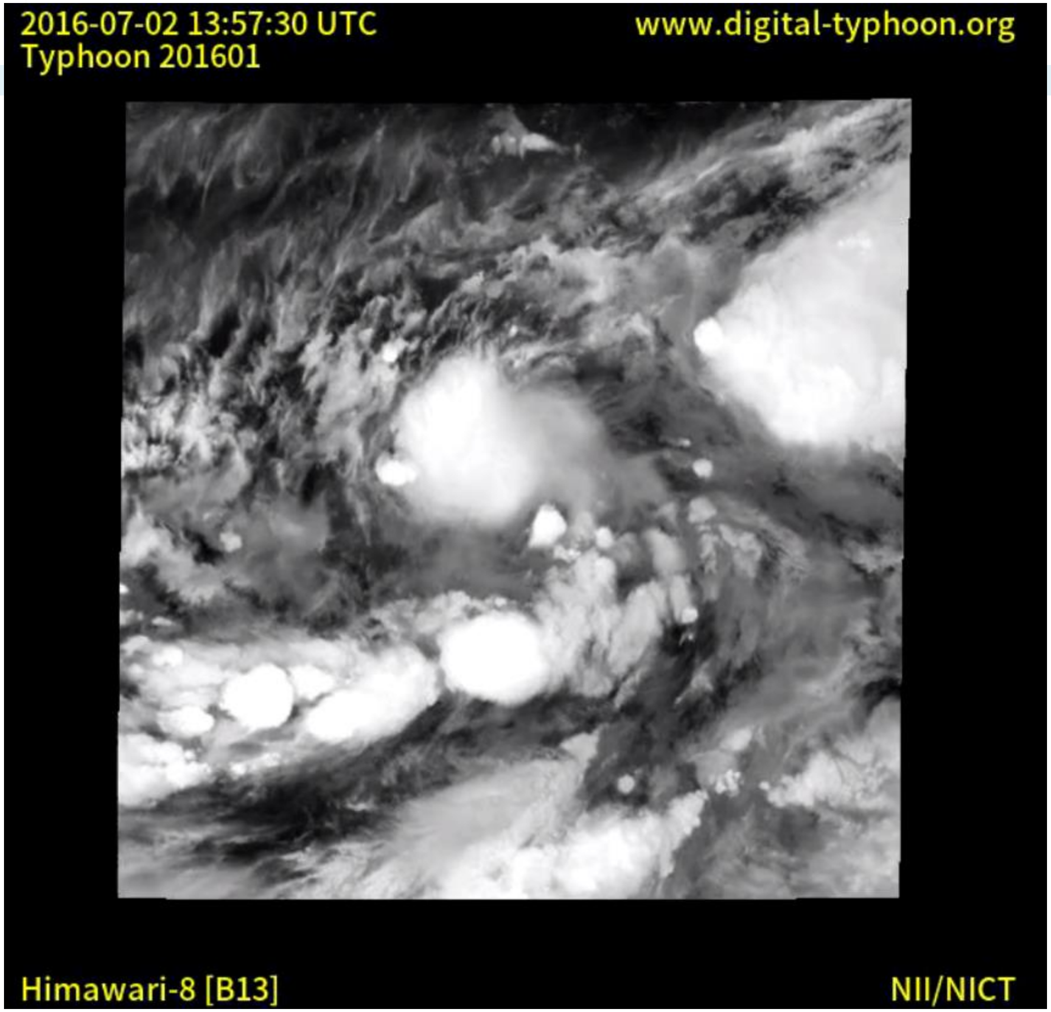
# Typhoon Nepatrak




Courtesy: www.digital-typhoon.org

http://agora.ex.nii.ac.jp/digital-typhoon/animation/wnp/r3/B13/mp4/201601.mp4

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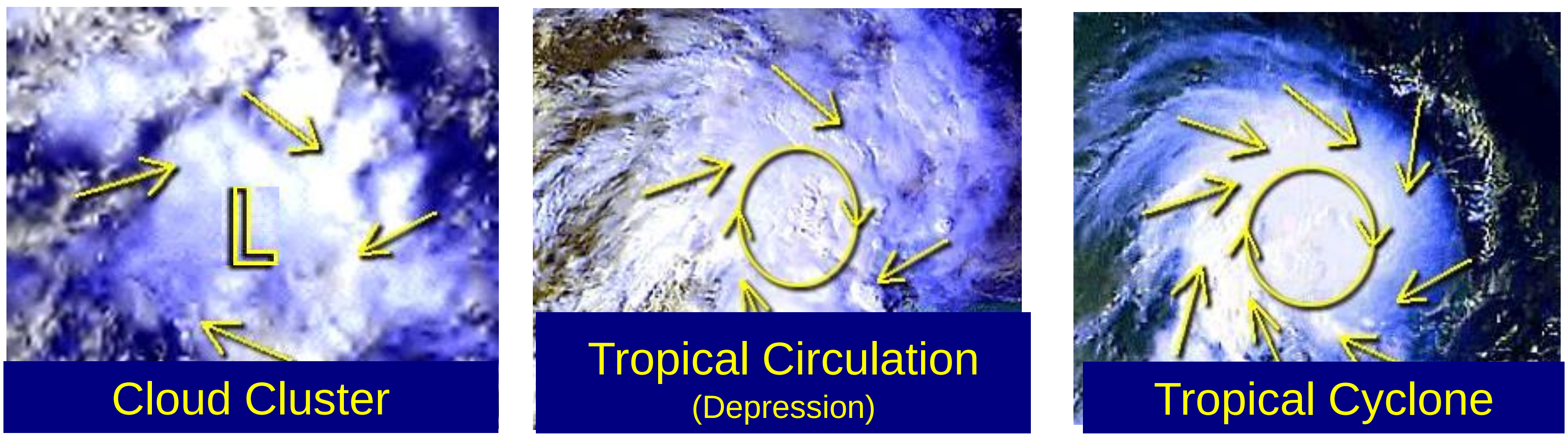
# Cyclogenesis Definition(s)

## The genesis process involves the transformation from

*A sequence of events that lead to the development of a warm-cored tropical vortex of sufficient strength to allow it to continue to intensify solely due to its own interactions with the warm underlying sea*. Montgomery et al 2006




At what point is genesis complete?

~ Self-sustaining (theorist)

~ Warm-cored (modeller)

~ Tropical Cyclone (gale force - forecaster)

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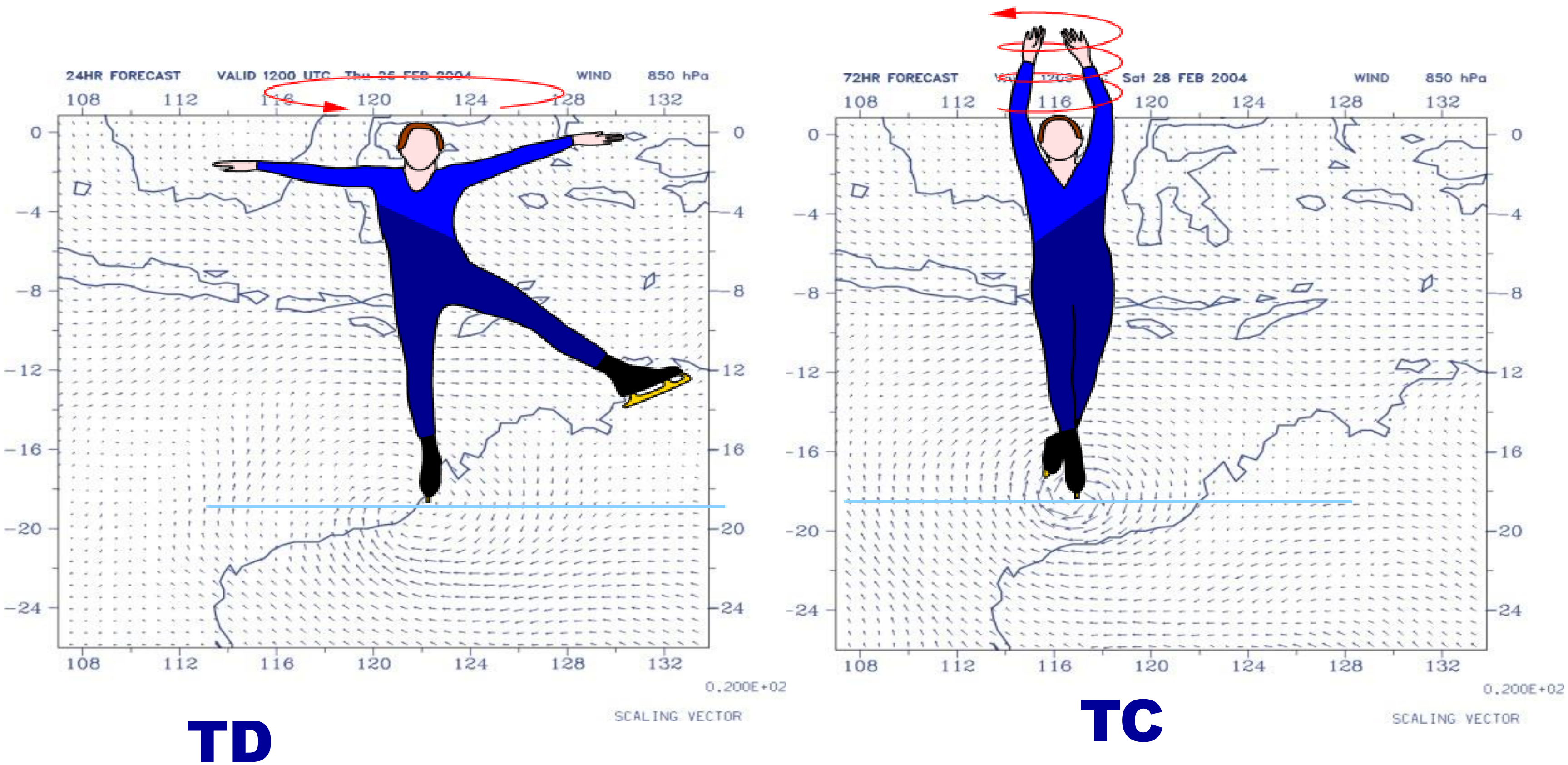
# TC genesis in its simplest form




Cyclogenesis: the concentration of absolute vorticity over an area of a few hundred kilometres to an area of tens of kilometres.

# Genesis: Necessary conditions

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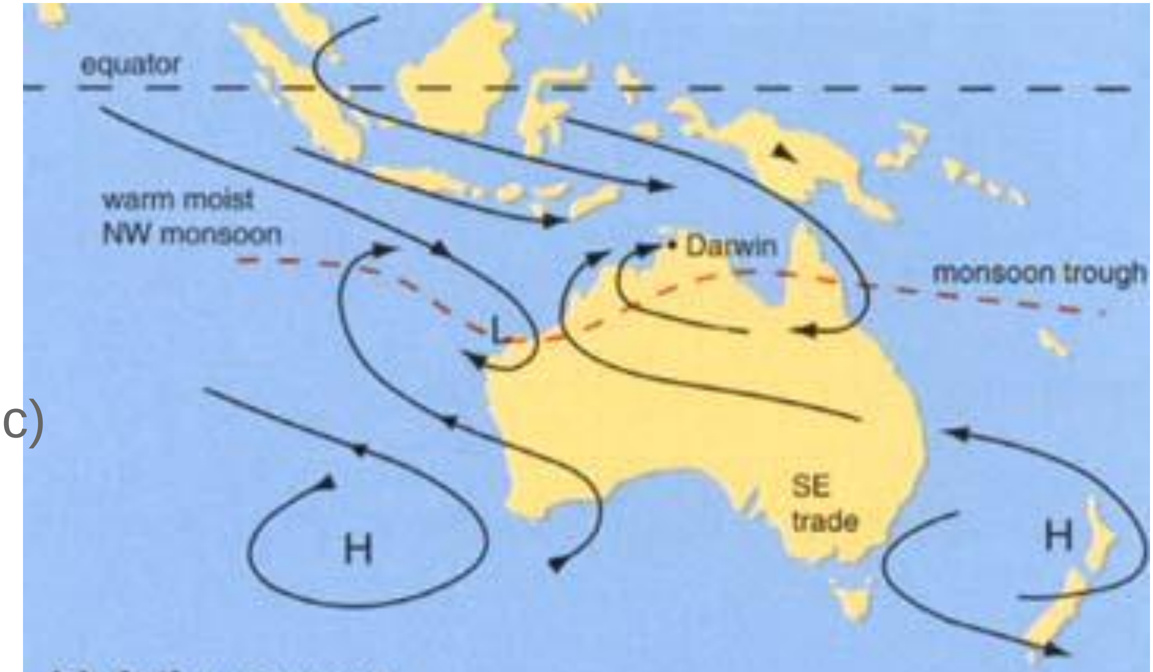
1. Coriolis
2. Moist unstable air mass
3. Warm SST
4. Convection
5. Weak vertical wind shear
6. Low-level vorticity

- Large values of 1 and 6 = large $\zeta_a$, which increases spin-up efficiency

Source of cyclonic vorticity:
Monsoon Trough
ITCZ (more so in Pacific/Atlantic)
  Equatorial westerlies
  Cross Eq. surges
  SE trade surges



(a) Active monsoon

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# Genesis: Necessary conditions

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- Large values of 1 and 6 = large $\zeta_a$, which increases spin-up efficiency
- Large values of 4 = large upward mass flux that drives the secondary circulation and system intensification.
- Large values of 2 = increased potential for convection.

**Significant relative humidity in the mid-troposphere**

A relative humidity > 70% in the 700-500hPa .This amount:

- Reduces entrainment of drier air
- Makes precipitation formation more efficient

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# Genesis: Necessary conditions

1. Coriolis
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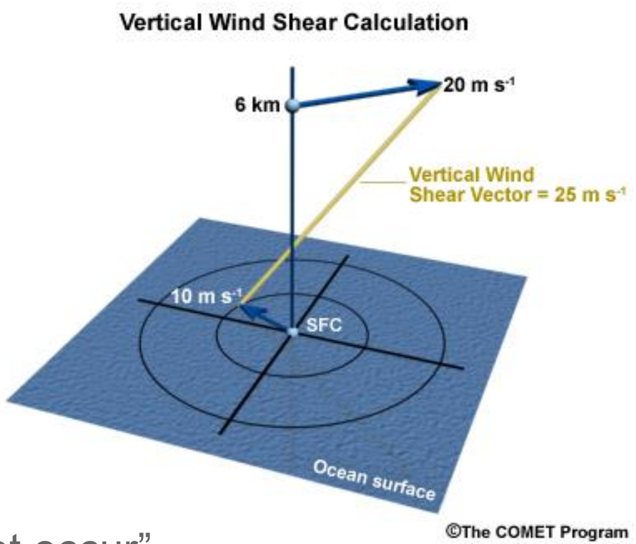
3. Warm SST
4. Convection
5. Weak vertical wind shear
6. Low-level vorticity

5 allows a deep vertically aligned vortex to develop unhindered by the destructive effects of vertical shear. Shear offsets latent heating from low level vortex and disrupts circulation.




## How much shear?

According to Zehr, tropical cyclone development "simply does not occur" when the low-upper tropospheric (850-200 hPa) vertical wind shear **exceeds 20-25 knots;**

**Australian experience: shear less than 20 kn for any development**

**Low <=10kn Moderate 10-20kn High >20kn**

**Fine print: there are always exceptions to the rule so beware!**

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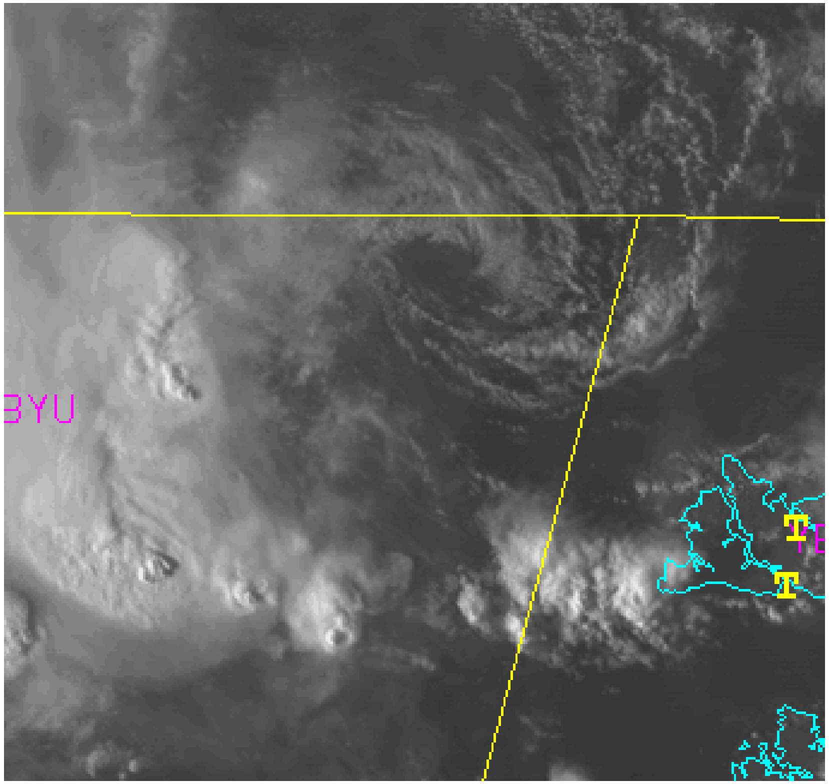
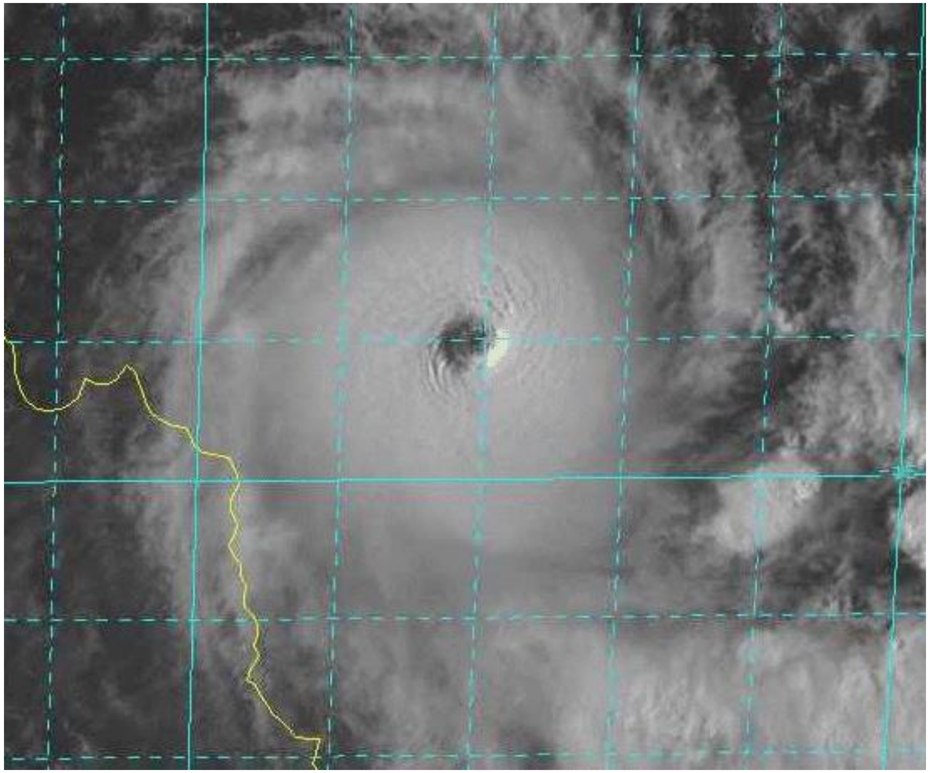
# Vertical Wind shear



High Environmental Shear
(Low near Timor, 1 March 2006)



Low Environmental Shear
(TC Ingrid near Cape York 9 March 2005)

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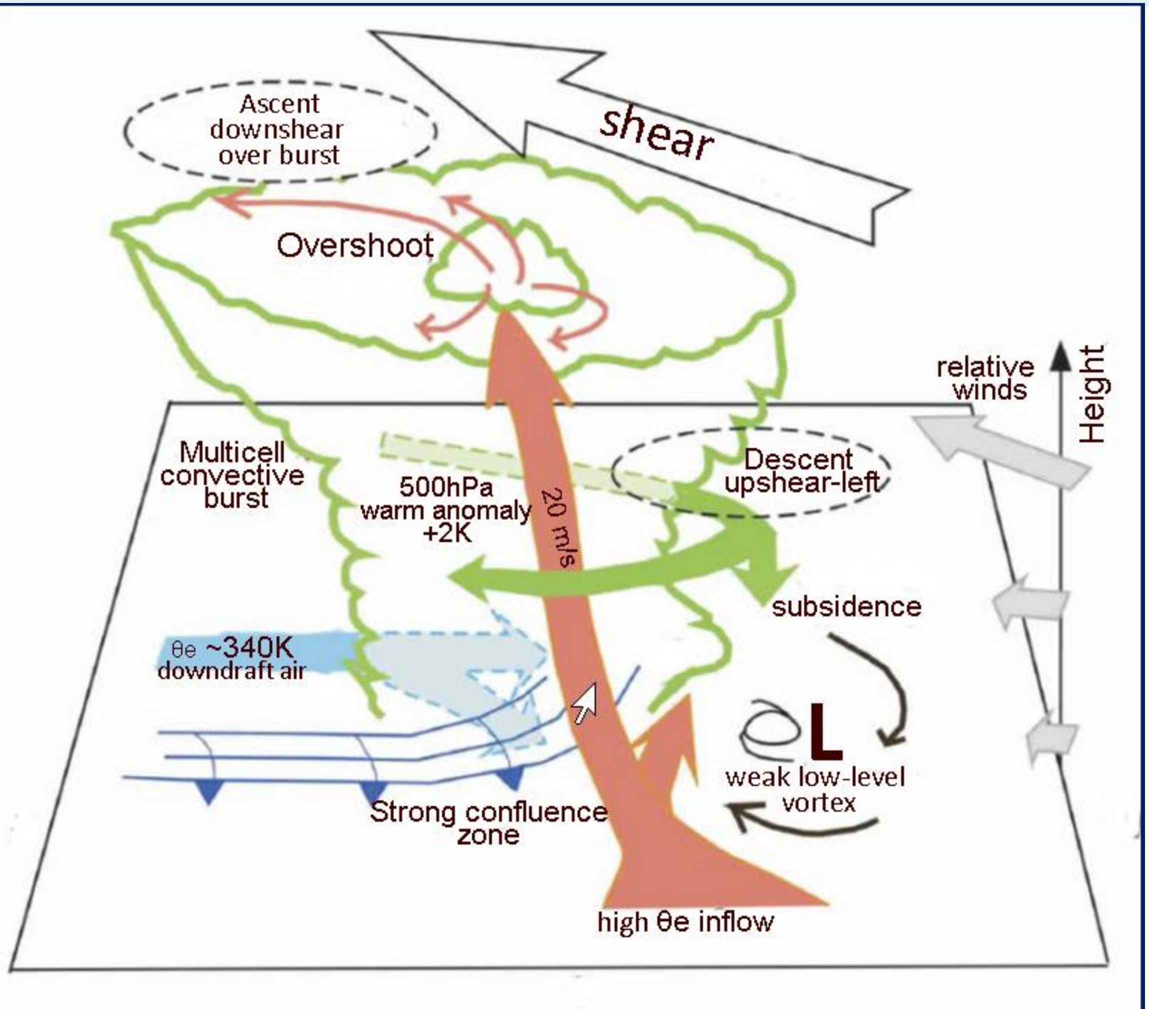
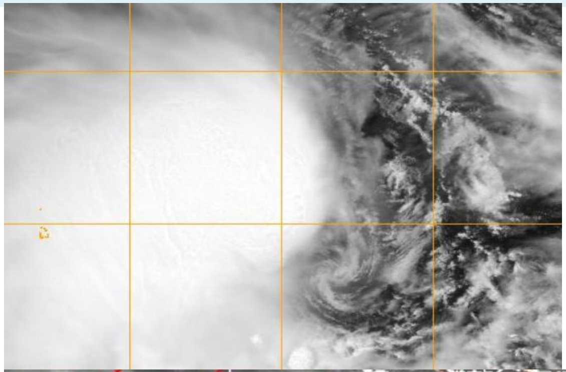
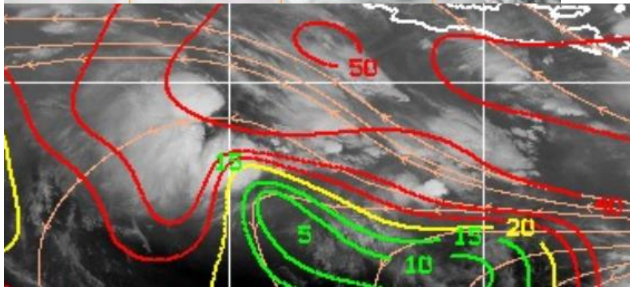
# Vertical Wind shear






*Ref: Southern Hemisphere version from Heymsfield et al., 2006.*

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# Genesis: Necessary conditions

1. Coriolis
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- Large values of 4 = large upward mass flux that drives the secondary circulation and system intensification.
- Large values of 2 = increased potential for convection.
- 5 allows a deep vertically aligned vortex to develop unhindered by the destructive effects of vertical shear.

- 3, The greater the air-sea temperature differential, the greater the heat and moisture fluxes from sea to atmosphere.

# Thermal Potential - Ocean thermal energy

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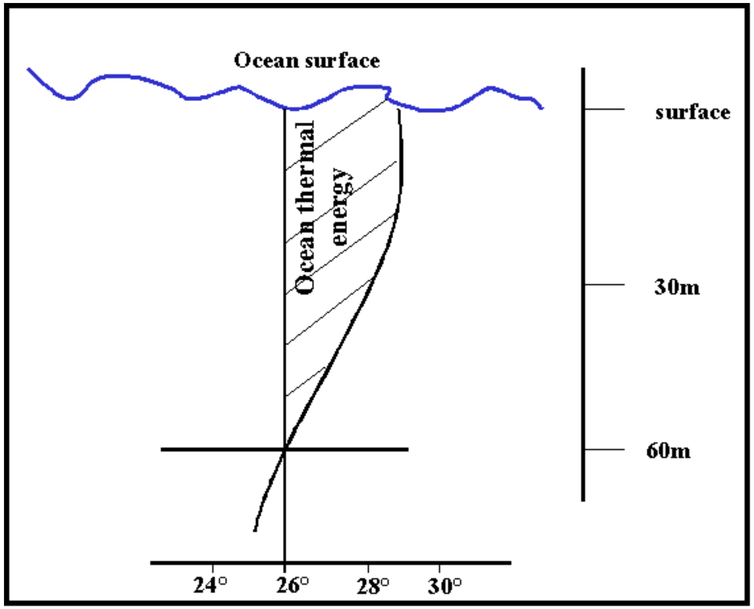
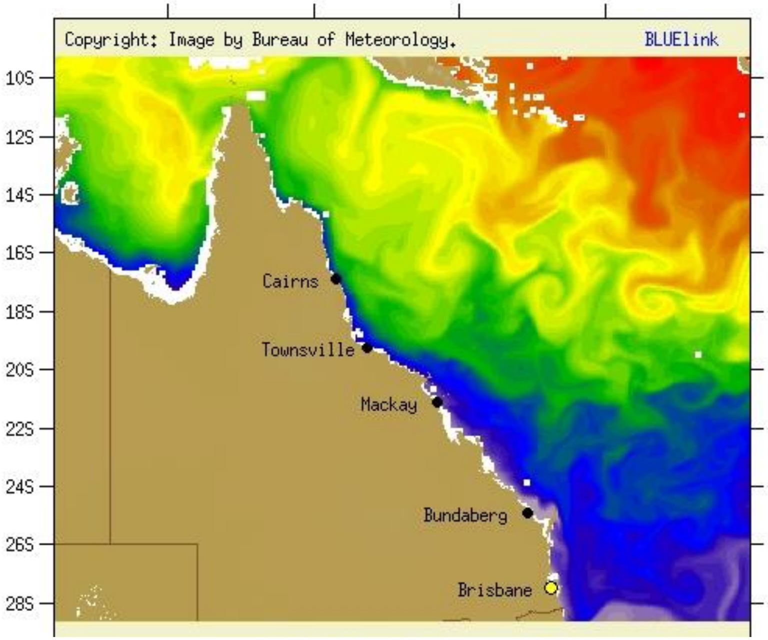
$$E = \int_{SURFACE}^{Z(T=26)} \rho_W c_W (T - 26) dz$$

Require warm ocean surface (T > 26°C)

To a depth of 60 metres (deep thermocline) .
(T > 28°C) important for major Hurricanes in the Atlantic Basin (Michaels et al 2006) and Australian experience.




http://www.aoml.noaa.gov/phod/cyclone/data/ and http://www.bom.gov.au/marine/sst.shtml

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# Summary of necessary ingredients

1. Background rotation – e.g. monsoon low, tropical wave; plus coriolis

   *The stronger the background rotation the faster the circulation spins-up.*

   *All TCs form from cyclonically rotating "seedling circulations".*

2. Convection in a very moist and well mixed atmosphere

   *The potential for evaporative downdrafts is reduced as the atmosphere approaches saturation and moist neutrality.*

3. Small vertical wind shear

   *If the shear is too strong the developing cyclone core gets tilted and torn apart.*

4. Warm sea-surface temperature (> 26.5-27.0C)

   *The warmer the sea the more energy (heat and moisture) is transferred to the atmosphere, to feed the convection.*

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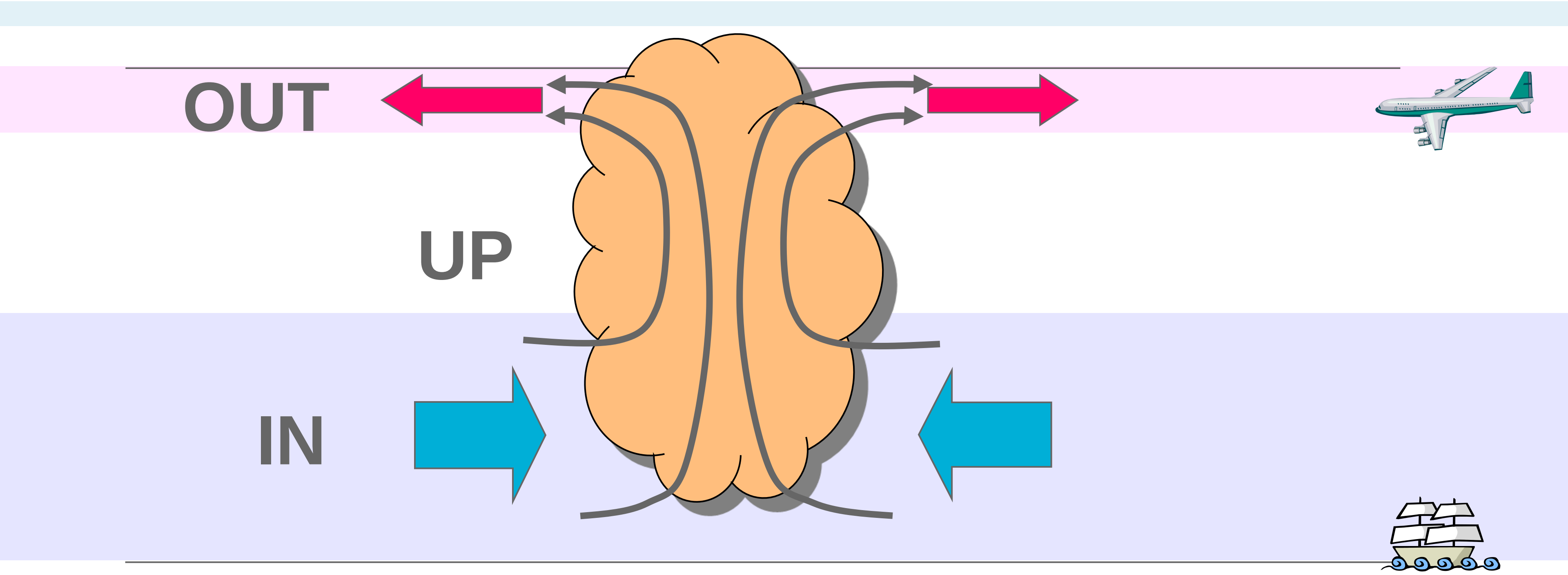
# How does a tropical cyclone Spin-up?




Tropical Cyclones: sustaining the IN – UP – OUT process
Large convective complexes “suck up” air from the lower to upper troposphere

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# How does a tropical cyclone Spin-up?


Like water flowing down a plug hole the air swirls faster and faster as it is sucked inwards

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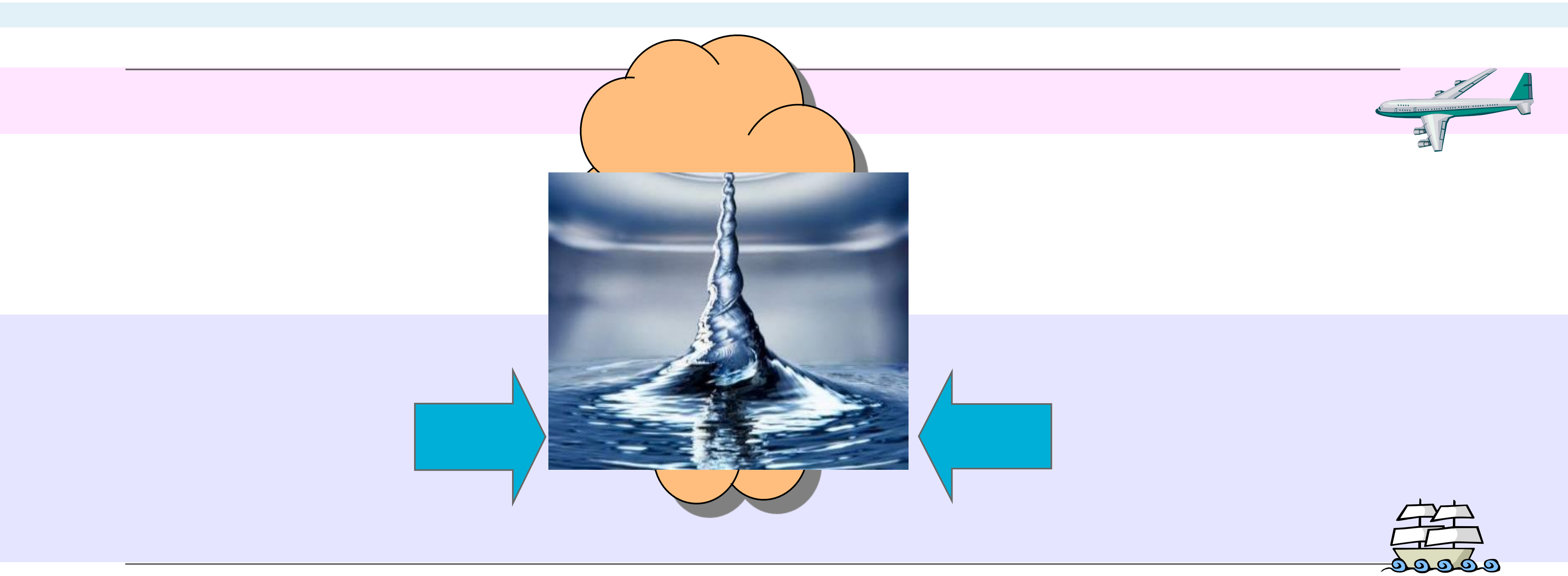
# How does a tropical cyclone Spin-up?



Of course the air is sucked inwards and upwards, so we invert the plughole image

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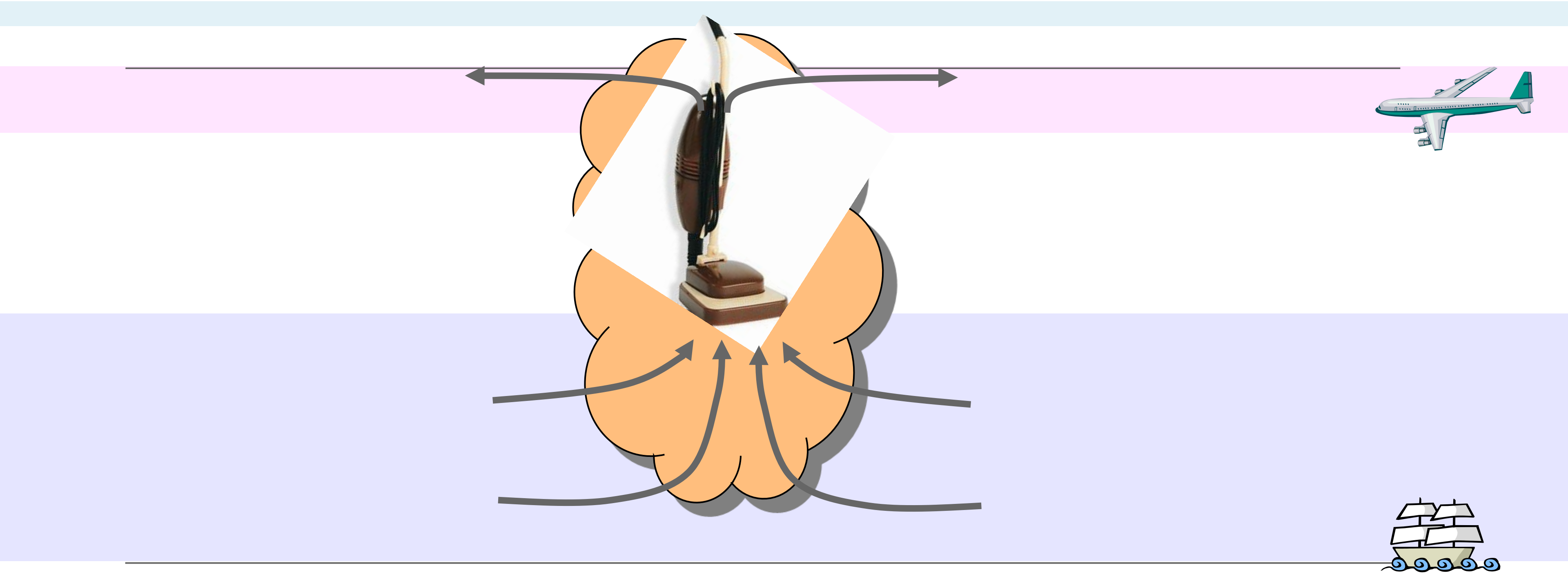
# How does a tropical cyclone Spin-up?



The convective complexes can be thought of as a giant vacuum cleaner. The longer and harder it draws air upwards the more the air swirls inwards and the faster it rotates.

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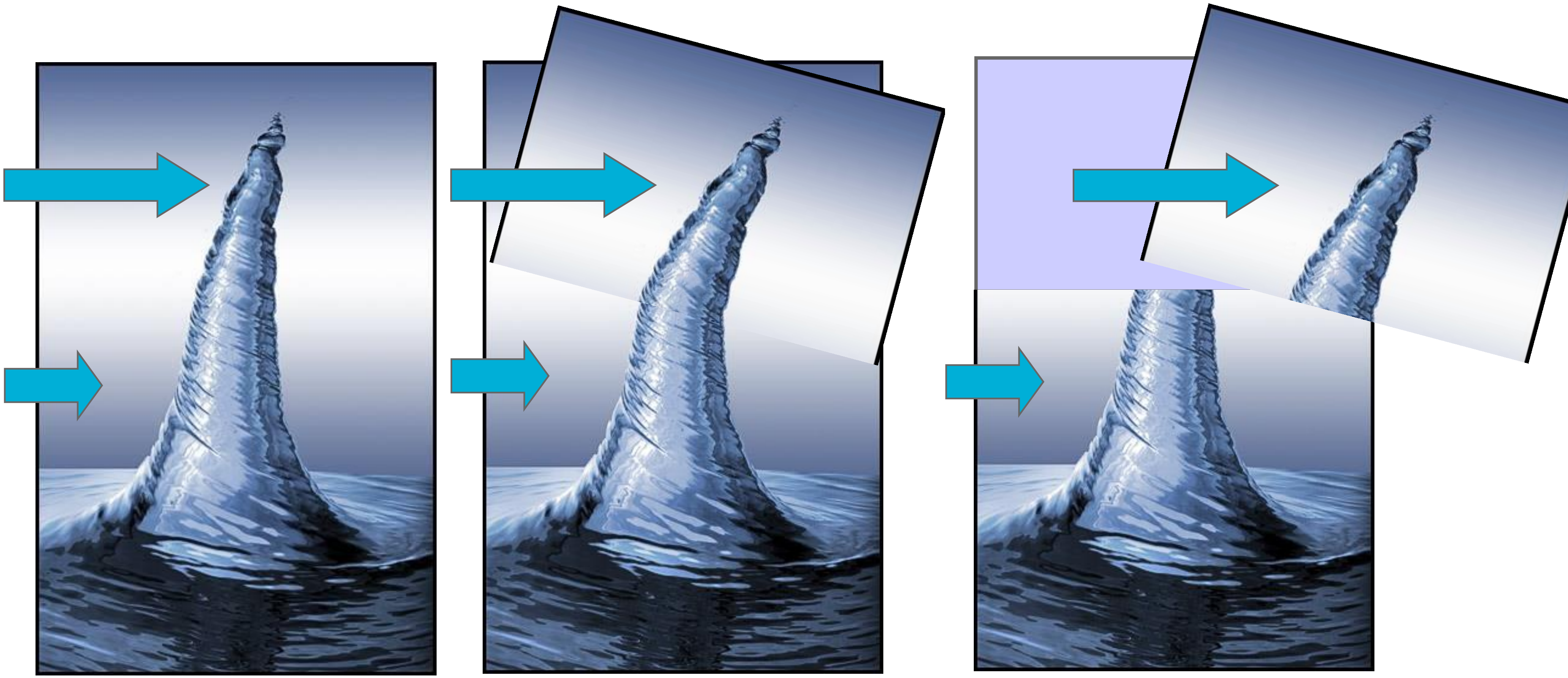
# Why doesn't every convective complex spin-up a tropical cyclone?

Three main reasons:

1. Sheared winds "blow" the top off the developing tropical cyclone.



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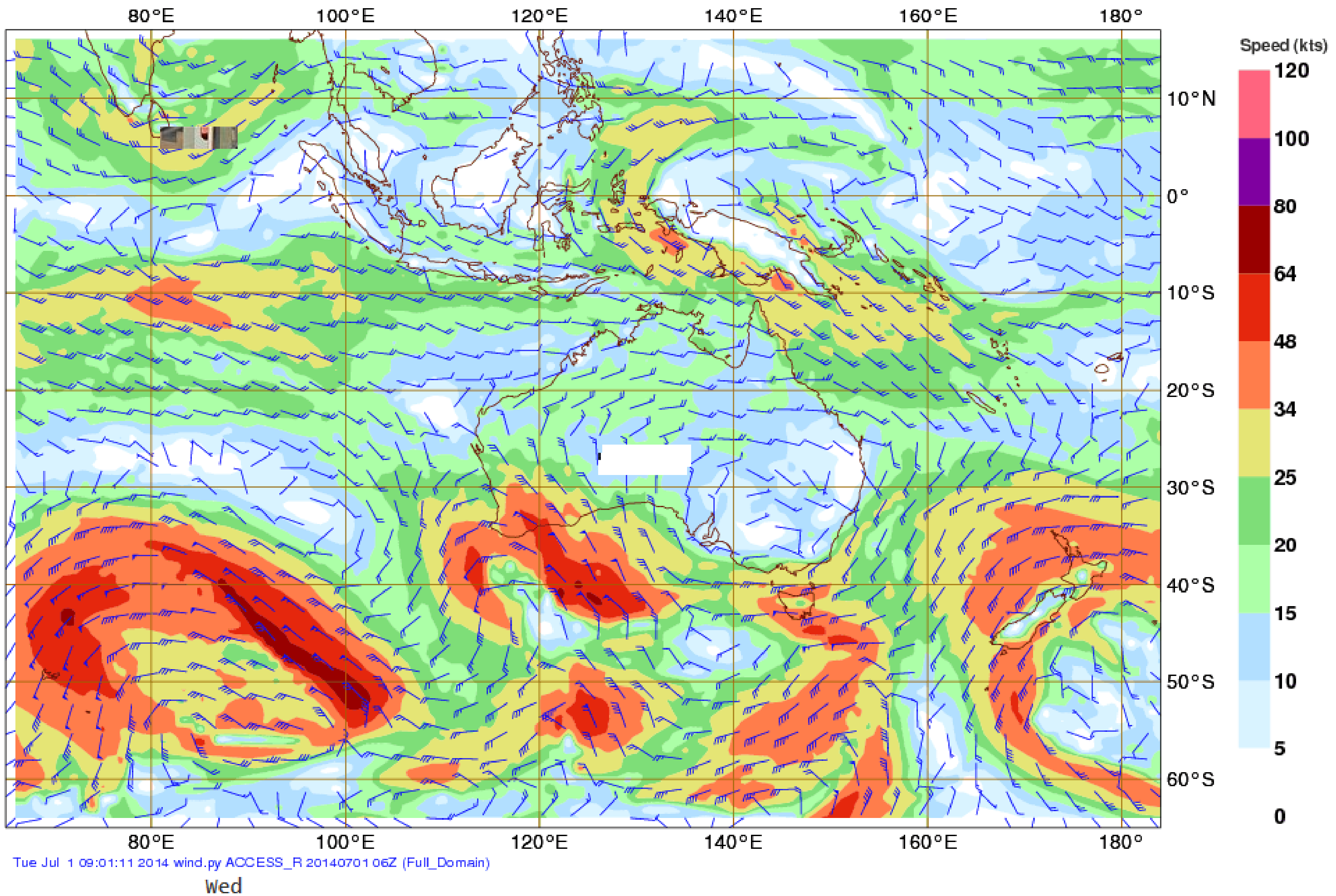
# Why doesn't every convective complex spin-up a tropical cyclone?

2. The 'background' rotation is insufficient.



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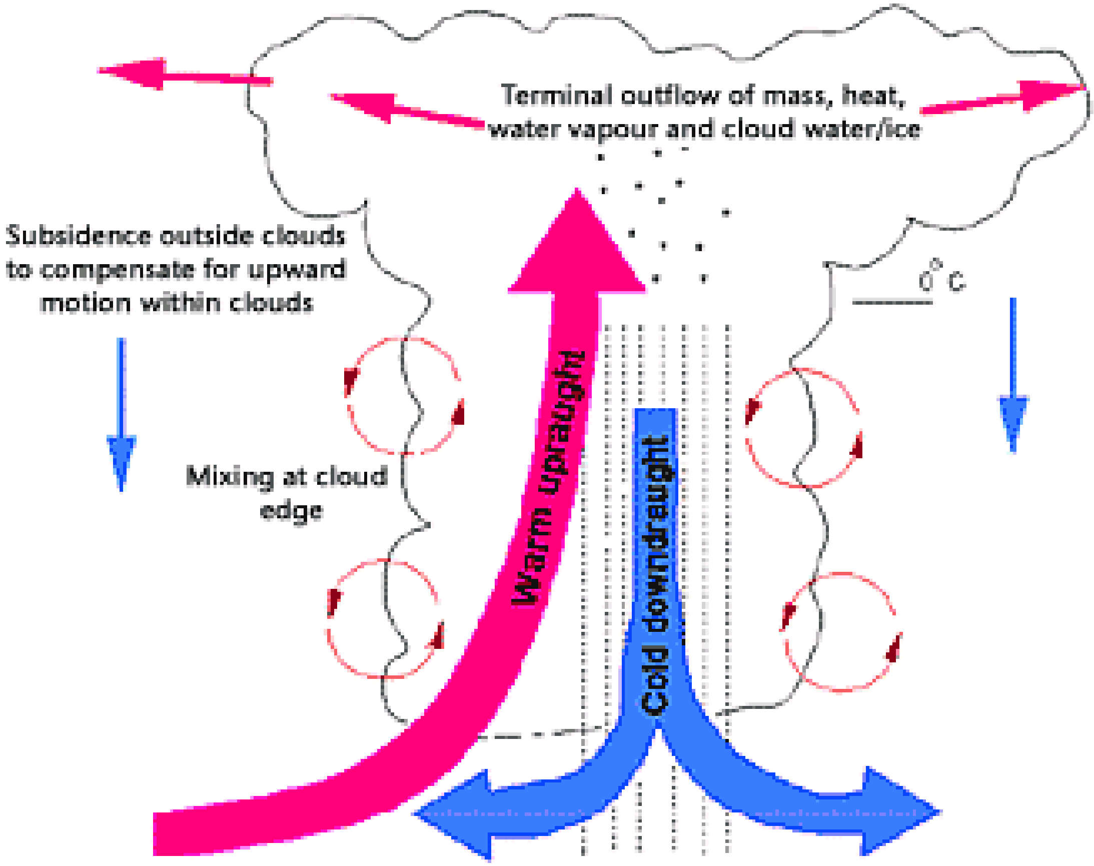
# Why doesn't every convective complex spin-up a tropical cyclone?

3. The convection is not quite "right".
*The vacuum cleaner is faulty.*

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# Why doesn't every convective complex spin-up a tropical cyclone?

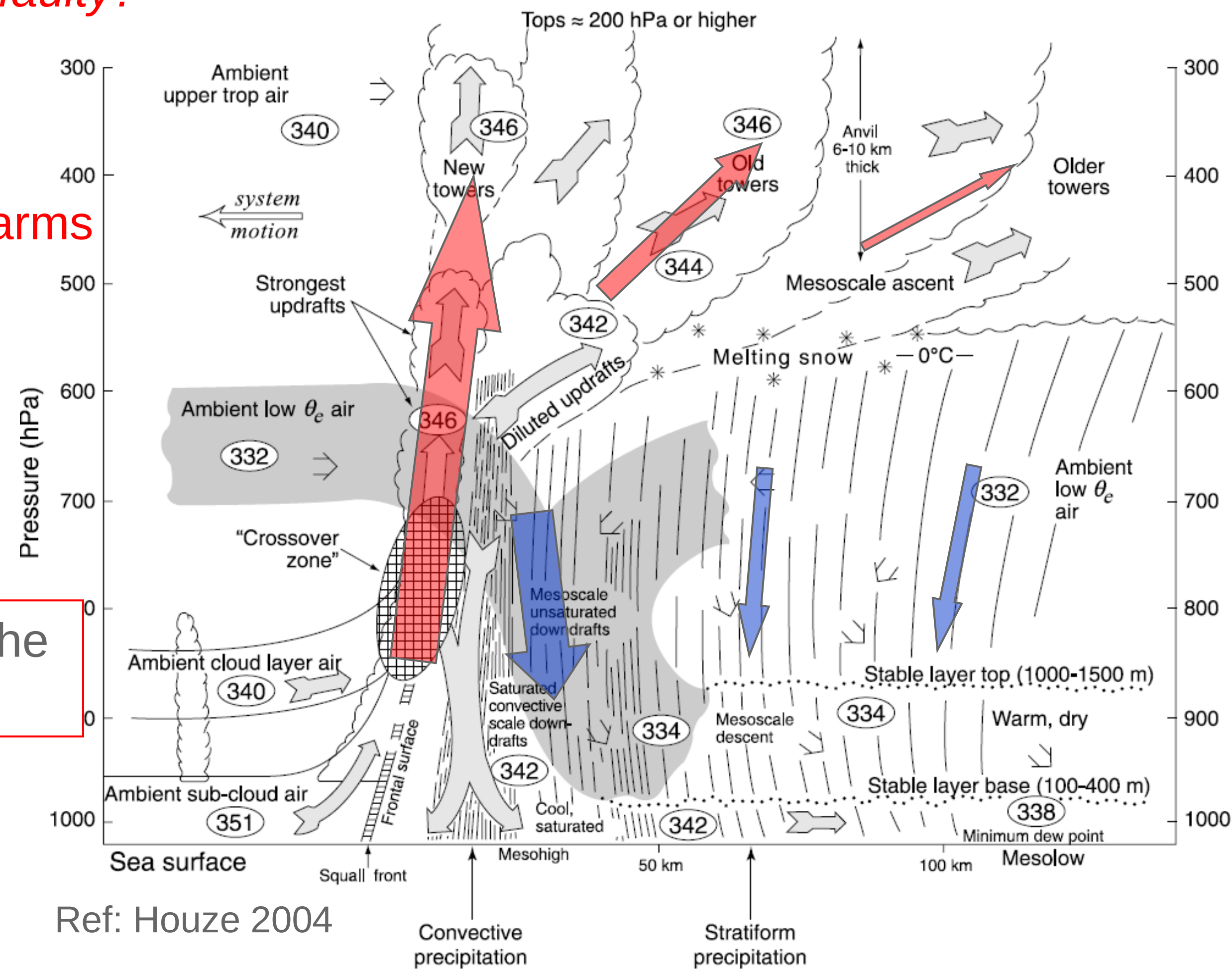
The convection is not quite "right".

*Why is the vacuum cleaner faulty?*

Heating from condensation warms the air, causing it to rise.

Evaporation cools the air, causing it to sink.

*Evaporation* is responsible for the "faulty vacuum cleaner".




Ref: Houze 2004

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# What ingredients are necessary for a a tropical cyclone to develop?

1. Background rotation – e.g. monso… …ve
   *The stronger t… …tation the faster the circulation spins-up.*

   **(Somewhat) common***

2. Convection in a very moist and well mix… …e
   *The potential for ev… …rafts is reduced as the atmosphere approa… …ation and moist neutrality.*

   **Relatively Rare**

3. Warm sea-surface temperature
   *The warmer the s… …gy (heat and moisture) is transferred to the at… …e, to feed the convection.*

   **Very Common**

4. Small vertical wind shear
   *If the shear is too stron… …g cyclone core gets tilted and torn ap…*

   **(Somewhat) common***

*How common are these ingredients in cyclone formation areas?*

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# What ingredients are necessary for a a tropical cyclone to develop?

2. Convection in a very moist and well mixed atmosphere

   *The potential for evaporative downdrafts is reduced as the atmosphere approaches saturation and moist neutrality.*

*So, how does the atmosphere become very moist and well mixed?*

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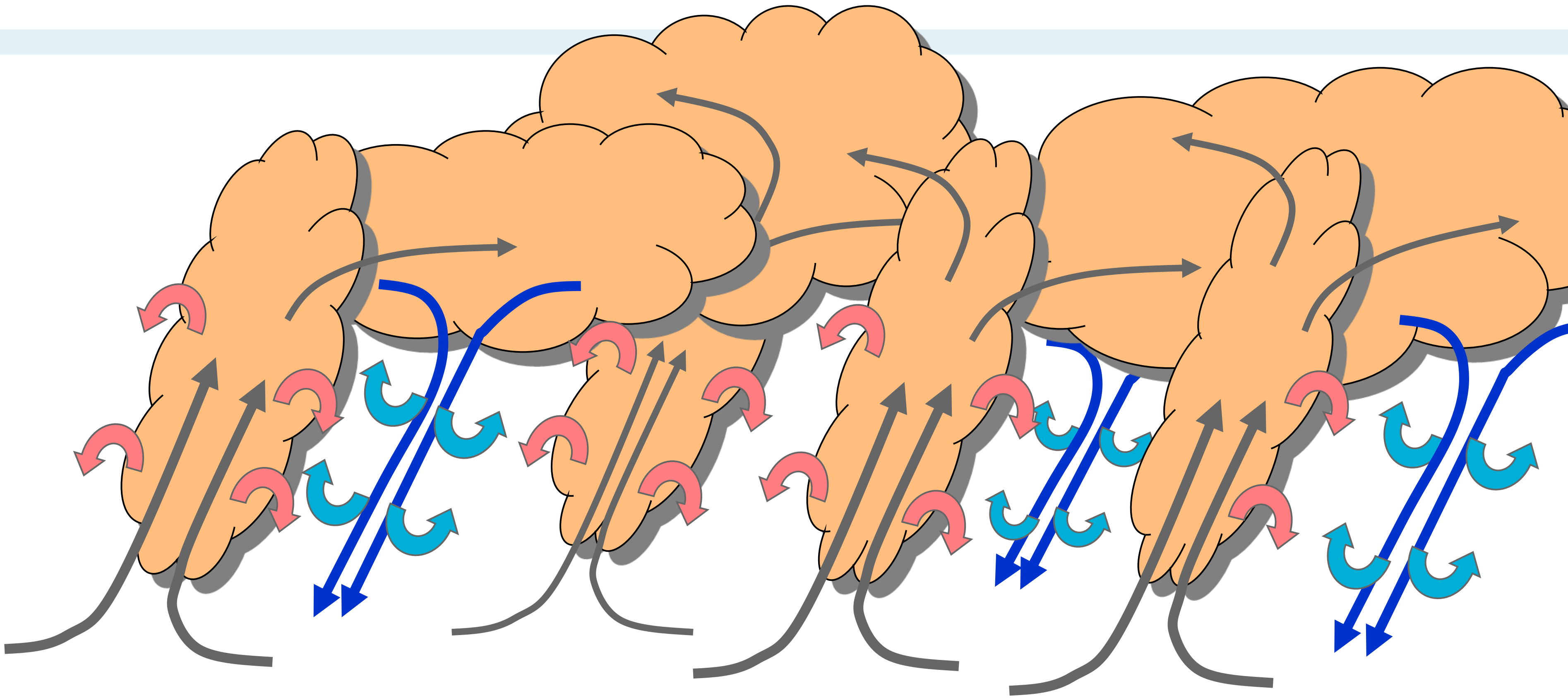
# How does the atmosphere become very moist and well mixed?



Convective complex

Sustained convection - moistens and mixes

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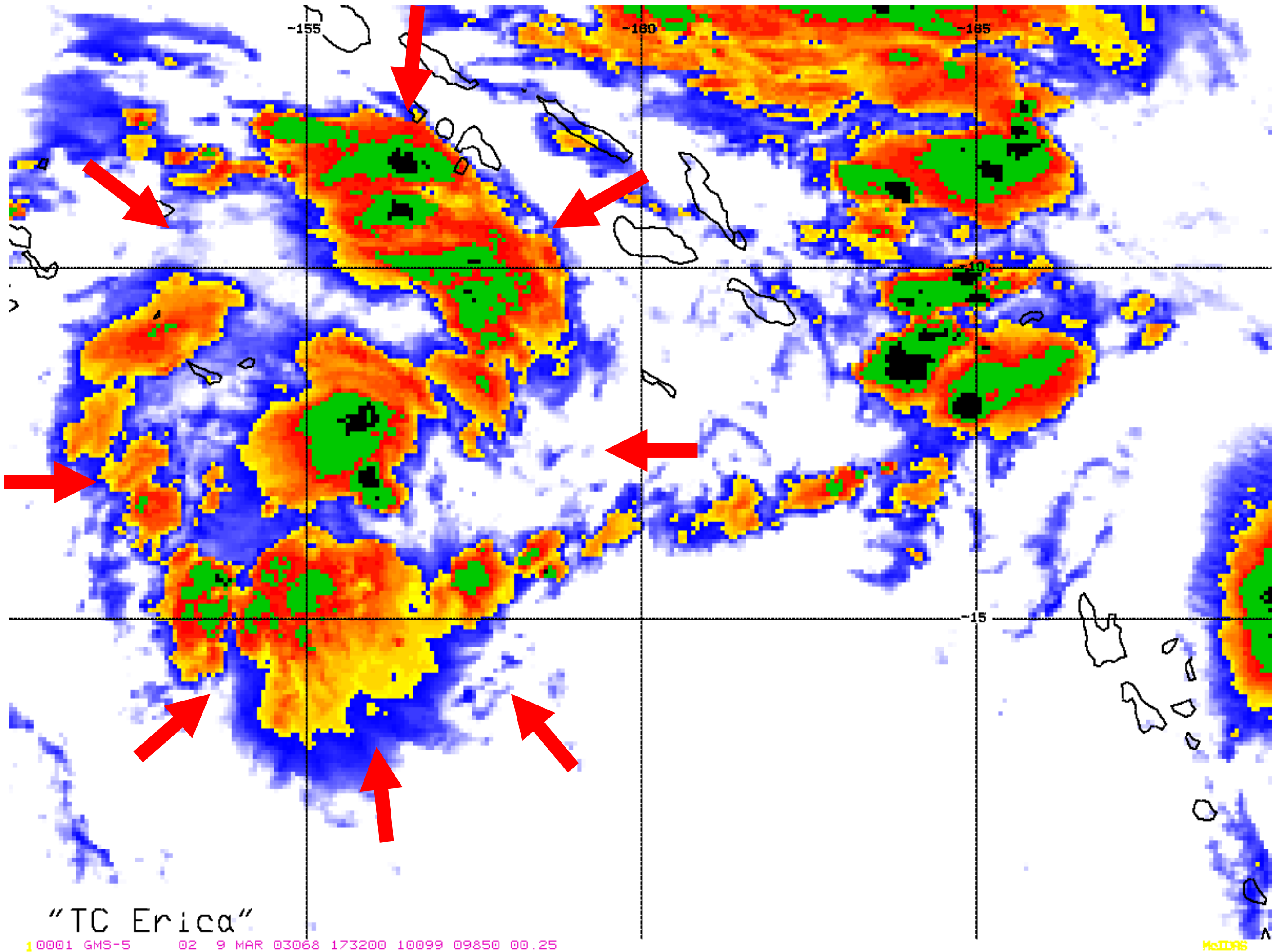

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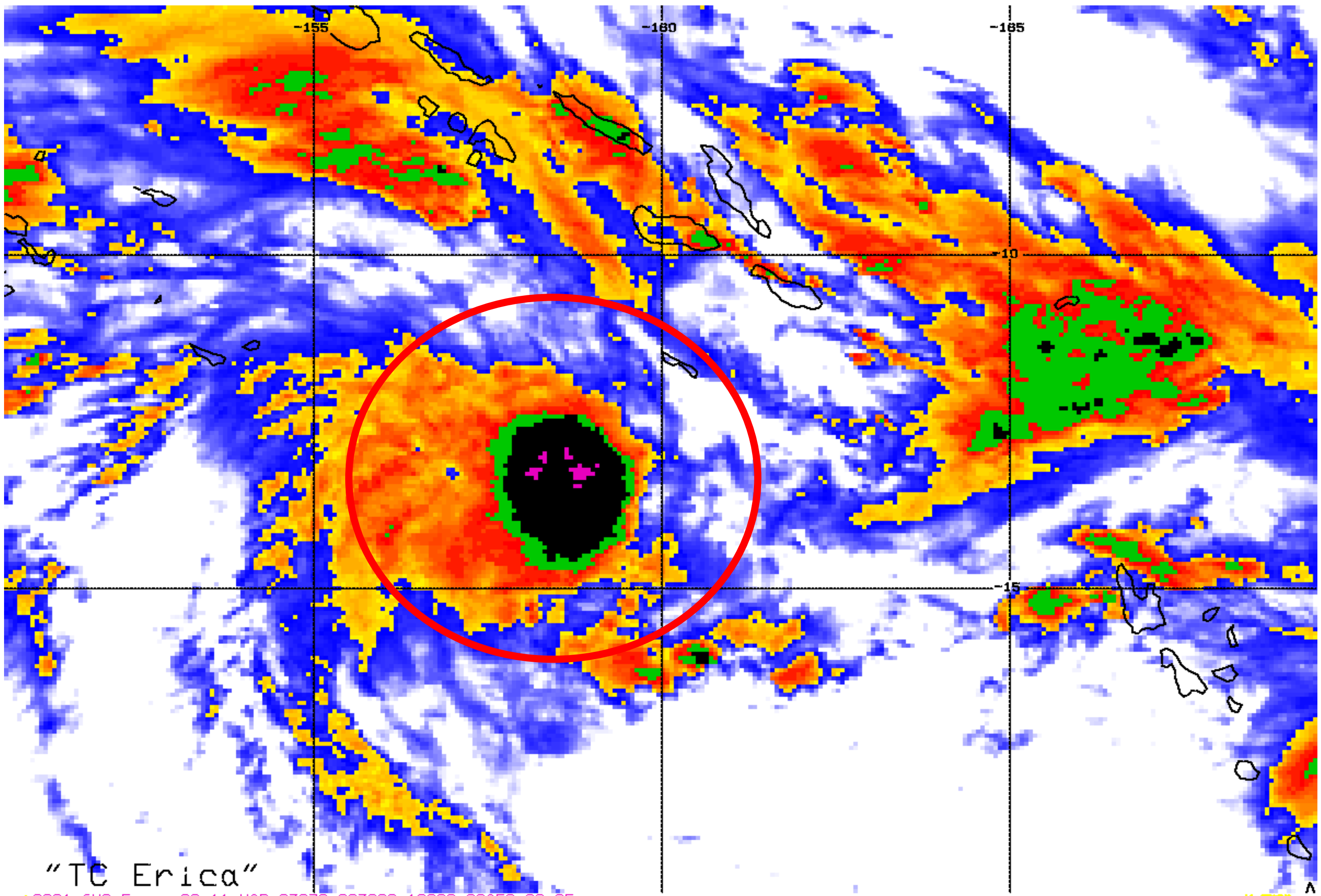

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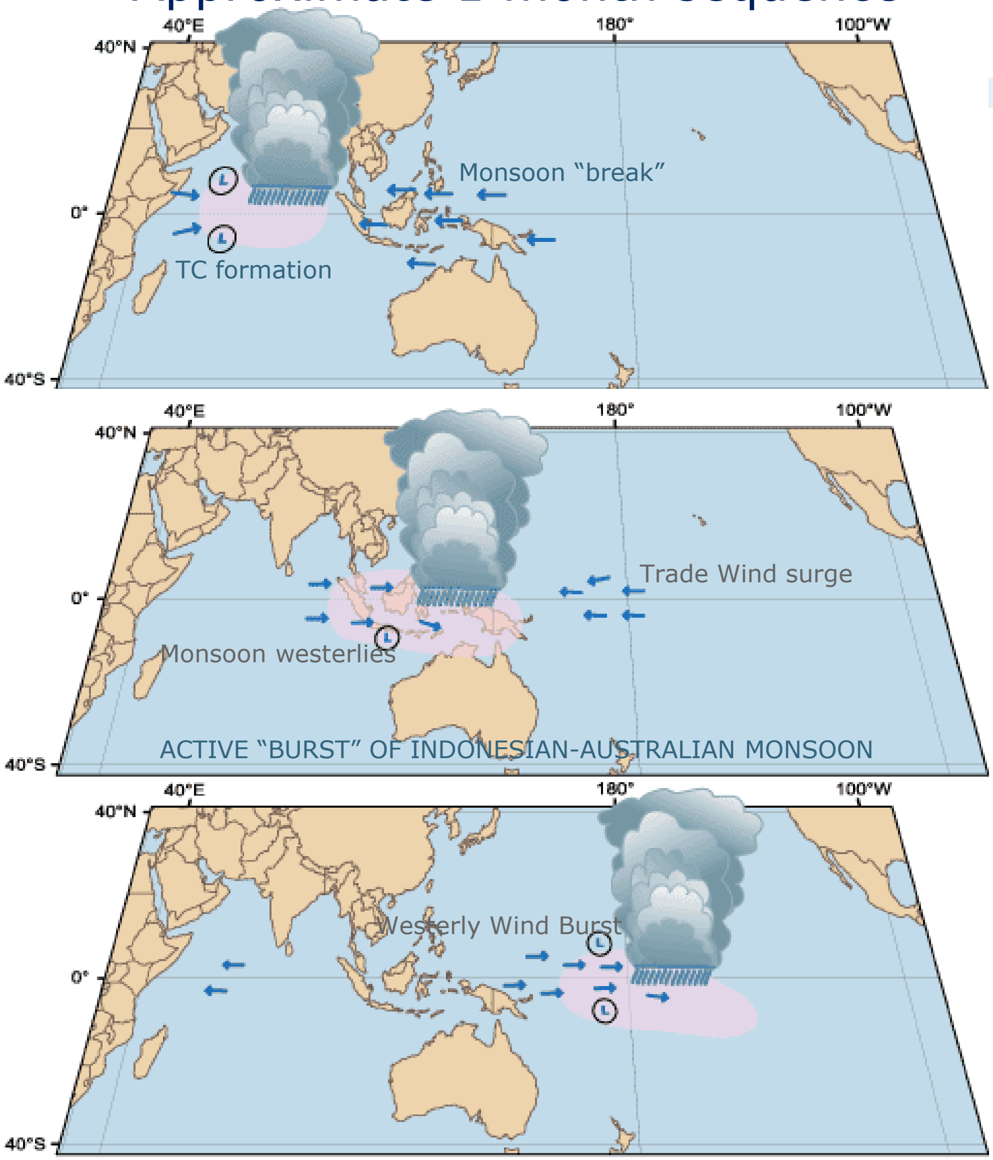
# Questions

1. What are the six necessary conditions for cyclogenesis?
2. How much shear is low shear? Moderate shear? High shear?
3. There is strong easterly shear affecting a tropical low. Where would you expect deep convection to form. a. east side b. south c. west. d. north.
4. What level would you look at for relative humidity for cyclogenesis? What approximate RH threshold is favourable for formation?

# Tropical Waves: The MJO

## Approximate 1 month sequence




- 30 to 80-day period slow eastward propagation.
- Also called 40-50 day wave, or Intraseasonal Oscillation (ISO).
- First described by Madden and Julian in the early 1970s.
- Is the strongest mode of intra-seasonal variability.
- Generates many of the bursts and breaks of the monsoons.
- affects TC formation, extra-tropical weather, and underlying ocean.
- Is predictable out to ~20 days!

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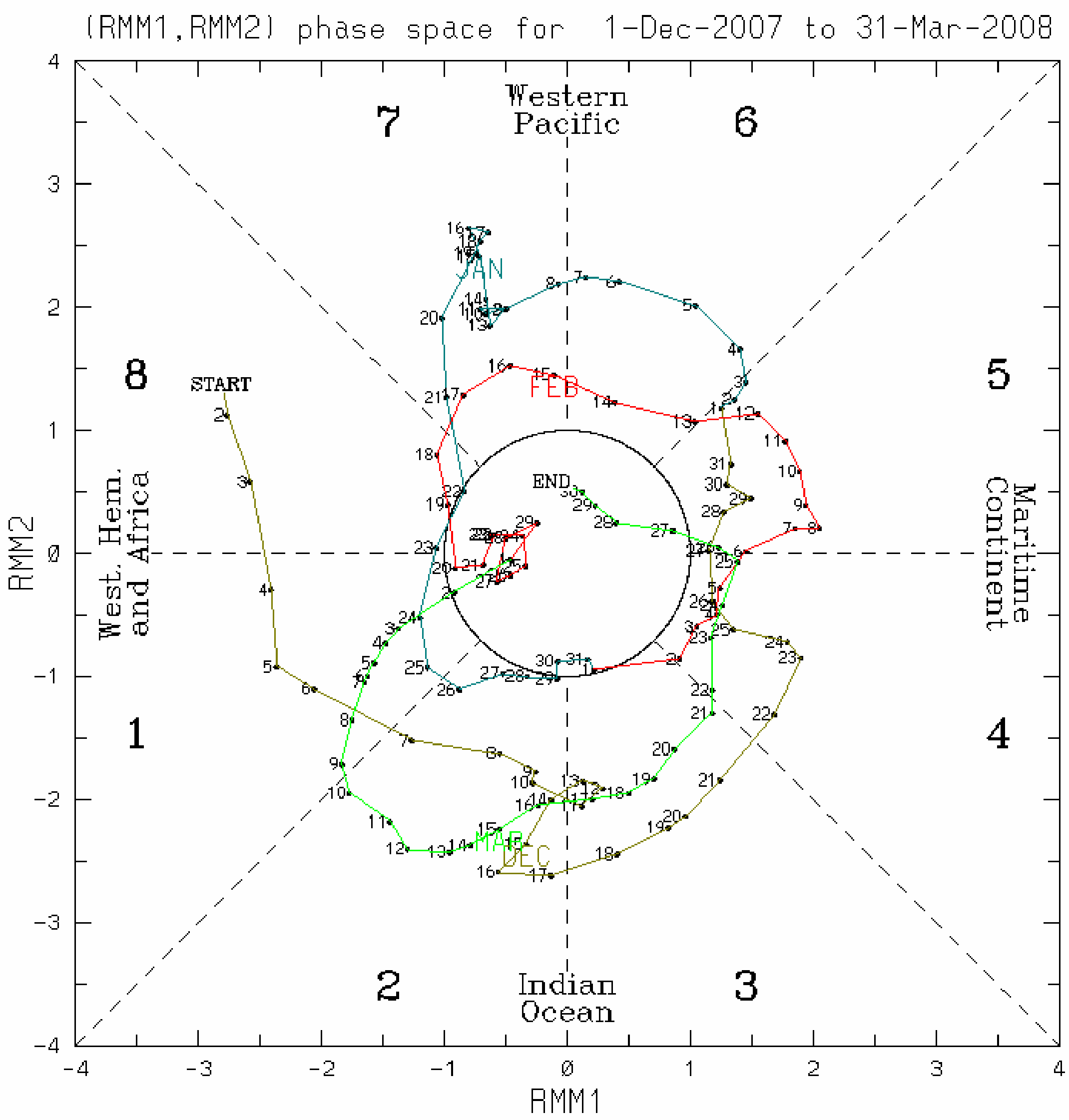
# MJO Phases: RMM- real-time multivariate MJO

Define MJO Phases 1-8 for the generation of composites and impacts studies.

‘Weak MJO’ when amplitude < 1.0

Projection on EOF2




Projection on EOF1

# MJO Phases: RMM- real-time multivariate MJO

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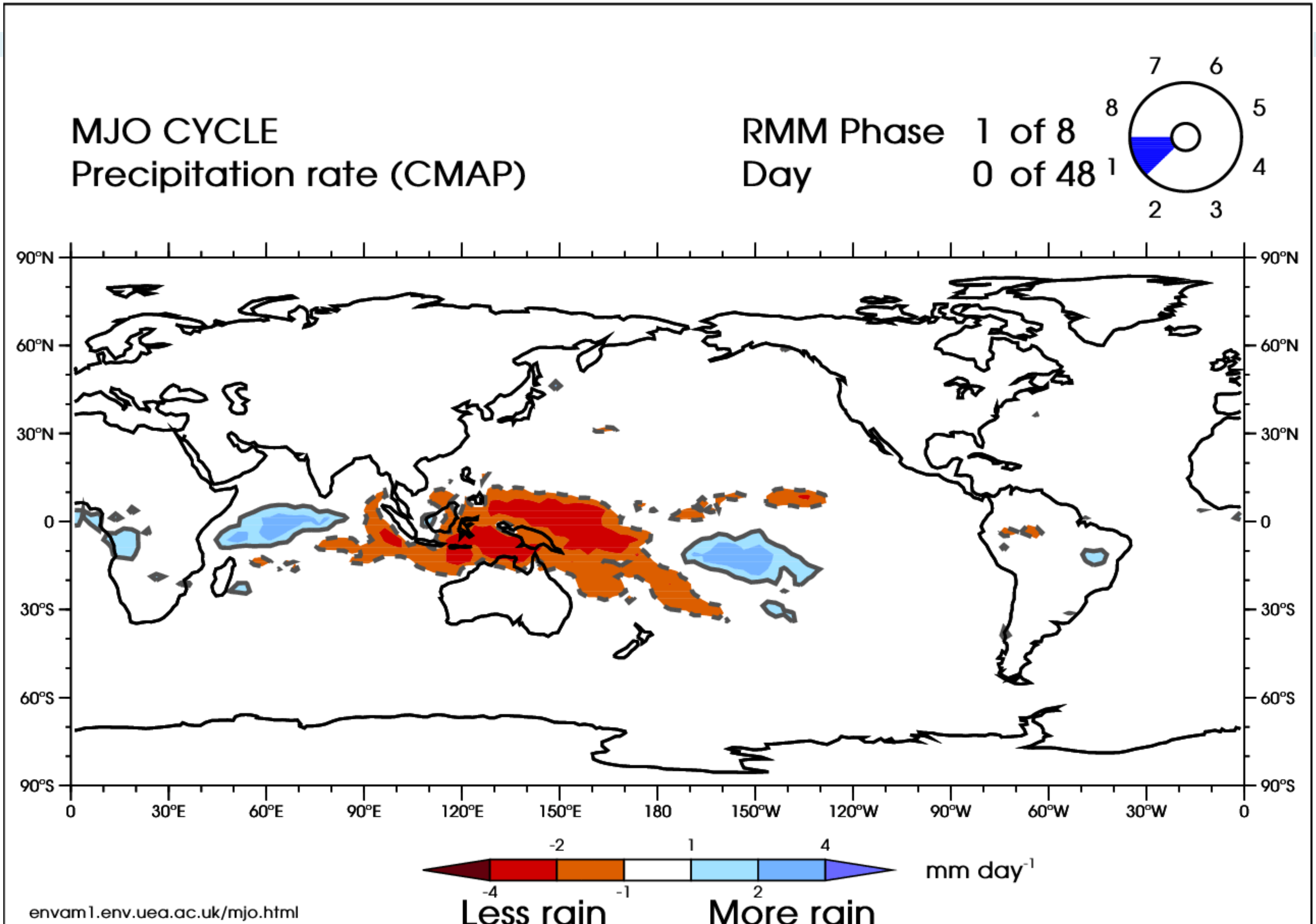
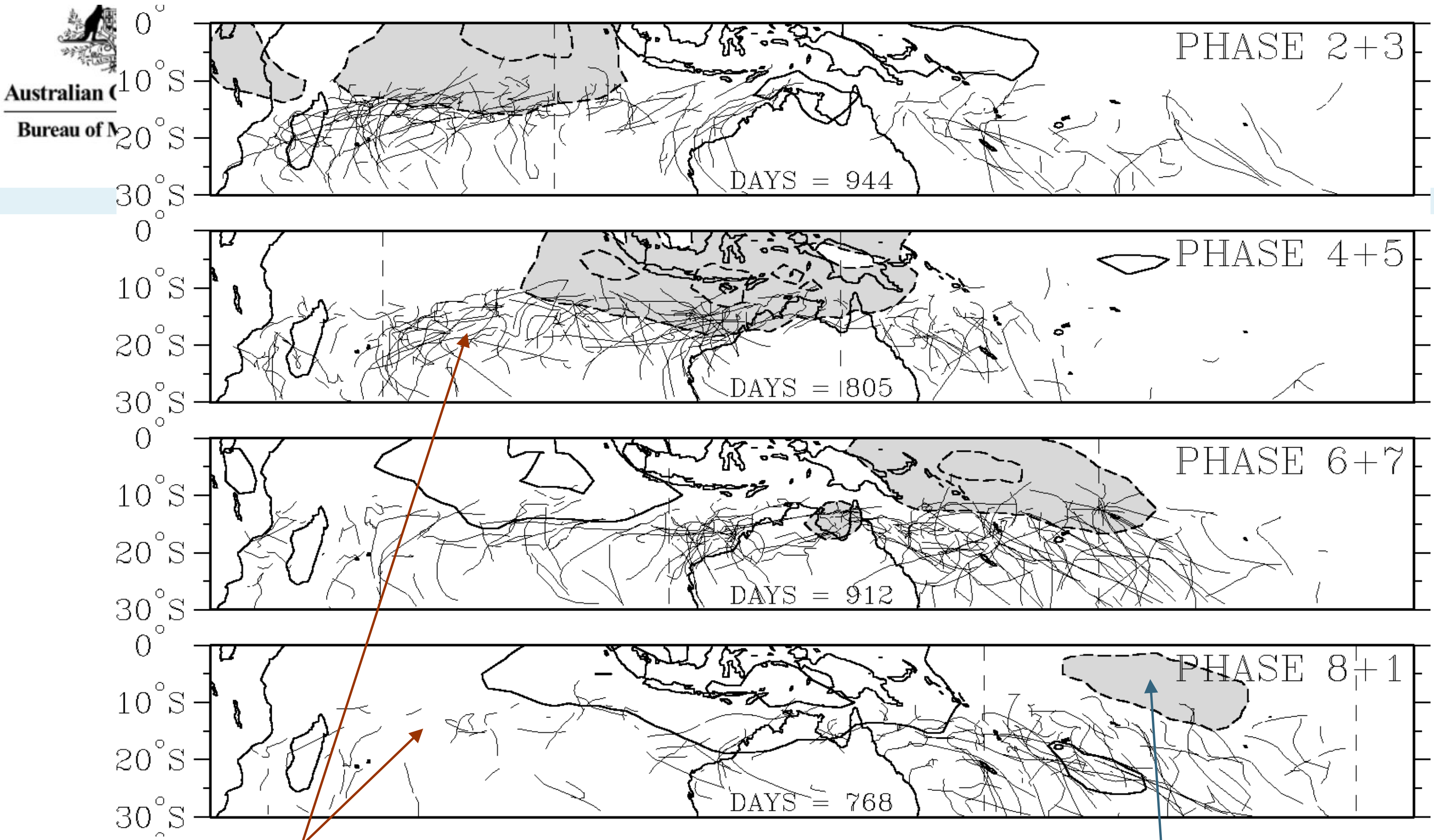


# MJO-TC impact using the RMM phases




*The modulation of TC probabilities is about 4:1 in the South Indian Ocean.*

MJO convective envelope

This result has obvious importance for multi-week predictions of TC activity

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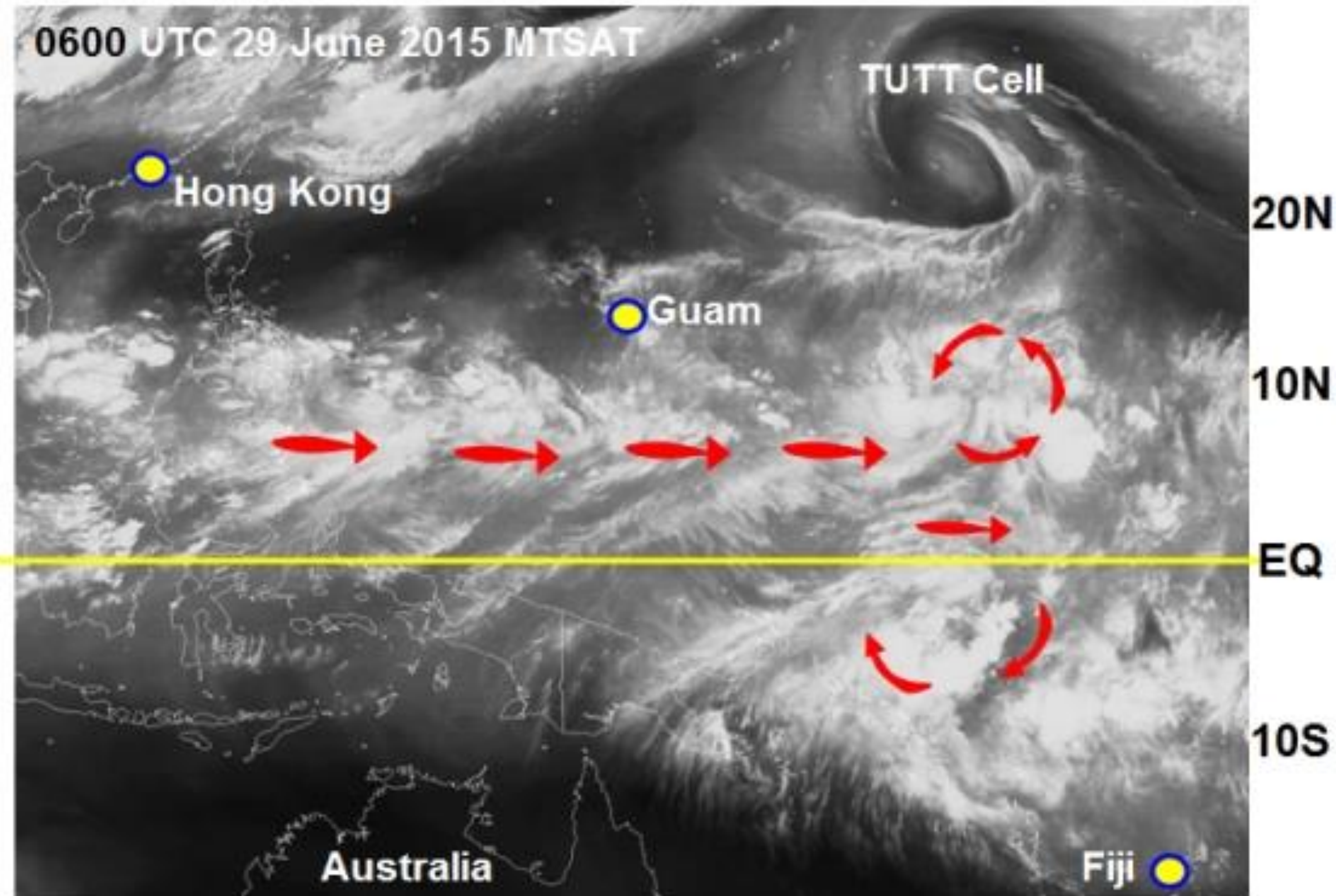
# Convectively-coupled equatorial waves
# Equatorial Rossby waves

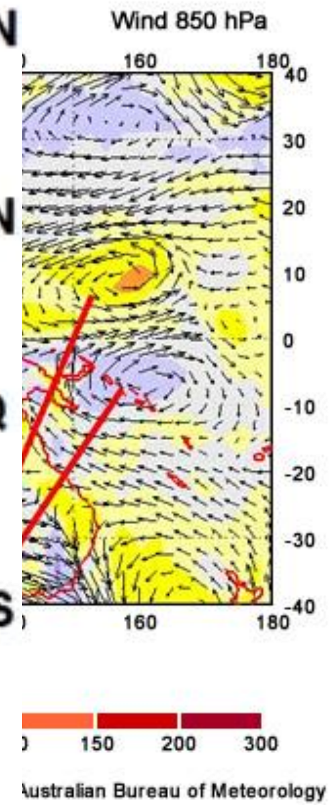
Equatorial Rossby waves: 'travel' east to west.

Enl

Las

Spi



# Convectively-coupled equatorial waves Kelvin waves

'travel' west to east.
Transient: Last up to 7 days
more convectively active when coincident with active MJO
Slower in Indian Ocean 12-15m/s Vs 15-25m/s
Can help to maintain MJO activity and initiate ENSO

See real-time animation:
http://www.cawcr.gov.au/staff/mwheeler/maproom/OLR_modes/JA.all.50to20.html

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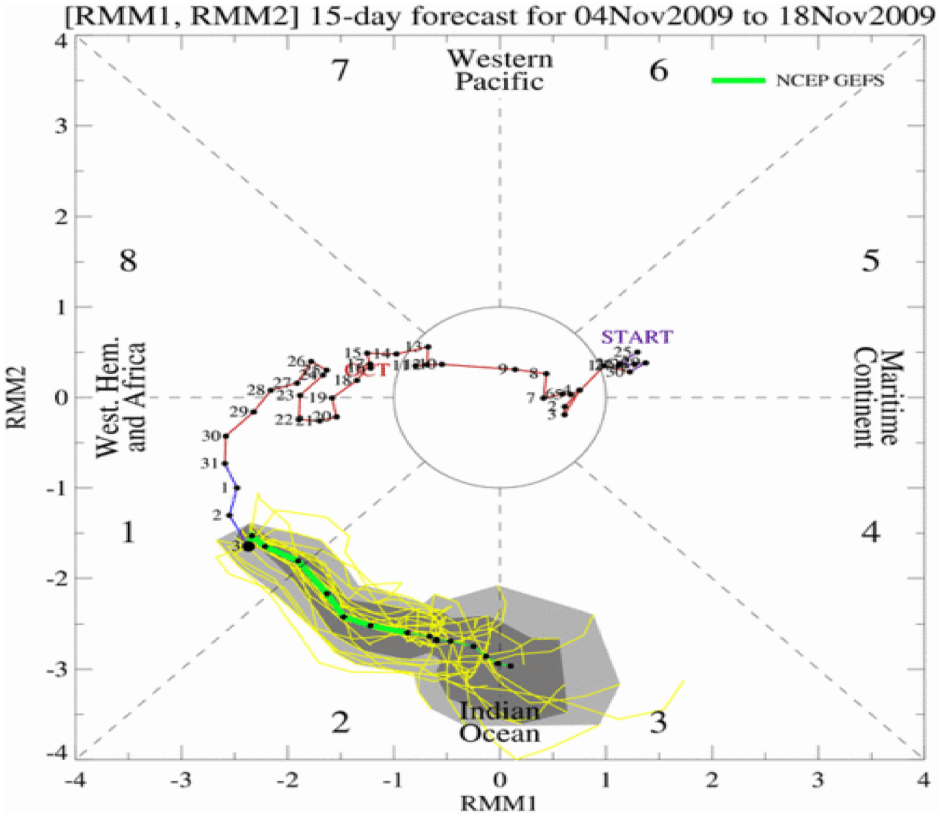
# Display of MJO Forecast

Operational links:
http://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/CLIVAR/clivar_wh.shtml
http://gpvjma.ccs.hpcc.jp/TIGGE/tigge_MJO.html
http://www.bom.gov.au/climate/mjo/



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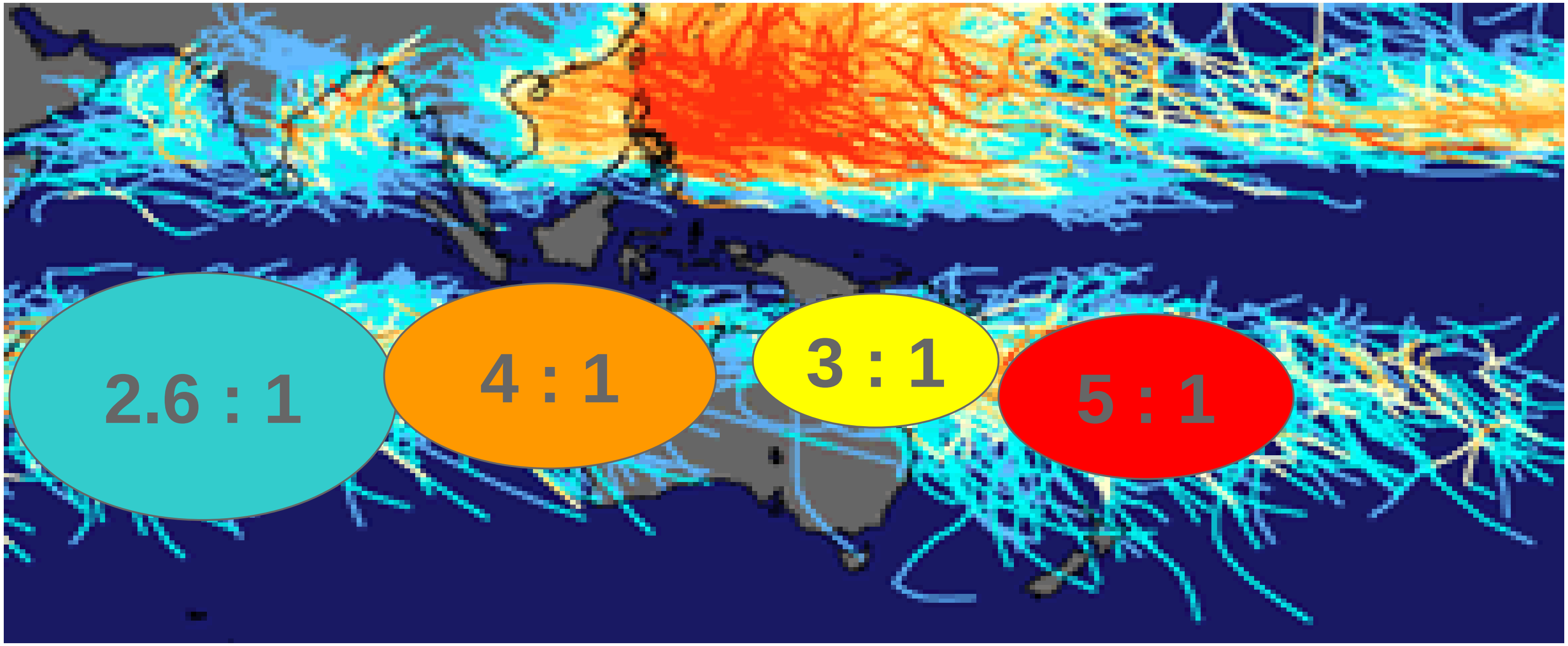
# MJO modulation of TC activity

In Australian and Fiji regions this relationship is strengthened during El Nino periods




Ratio of daily percentage genesis rate for the most conducive category compared to the least conducive category
Australian Region (Hall et al.), South Indian Ocean (Bessafi et al.), Fiji (Chand et al.)

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

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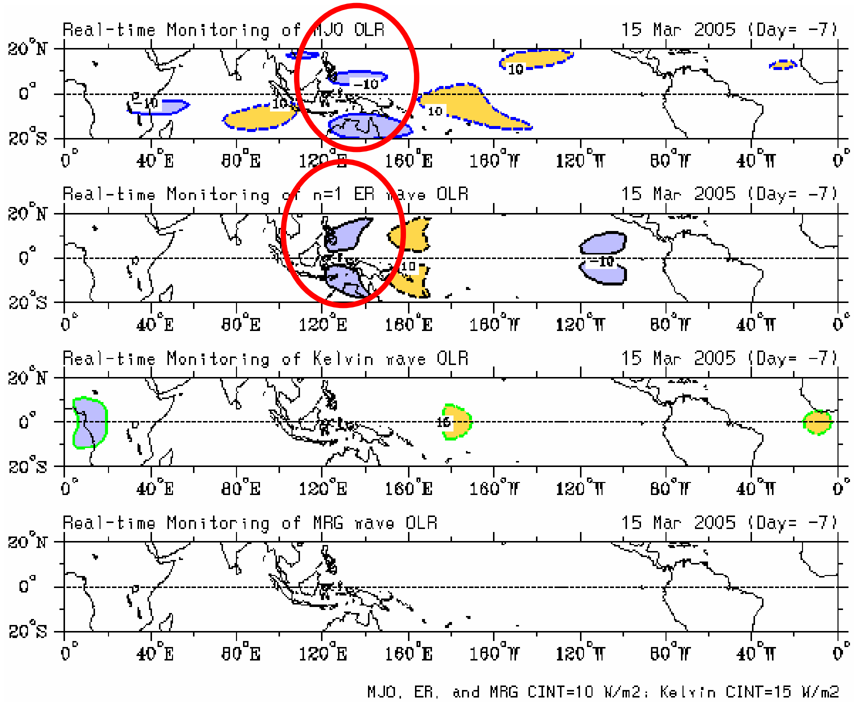
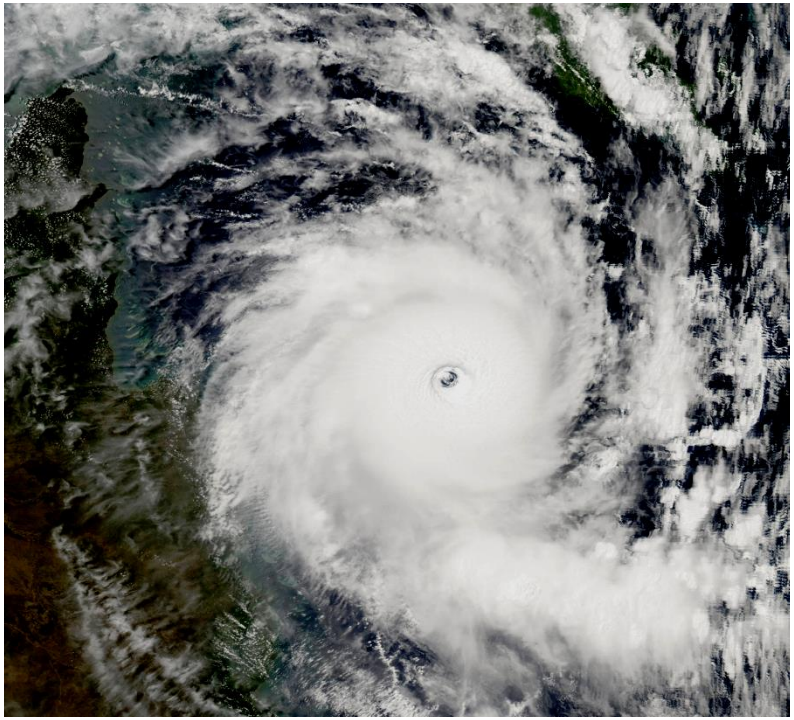
# MJO and ER waves

## TC Ingrid



**Tropical Waves** (MJO and n=1 ER are important)

The above data is at 15 March 05, the time of TC Ingrid

MJO AND ER waves also important for genesis in the Indian Ocean west of 100E (Besafi et al.)

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# Daily monitoring

- **What should we be looking for?**

## Analysis

The patterns of convection – refer IR/Vis (Dvorak), microwave

Upper winds; shear diagnostics; mid-level RH; vorticity

Near surface flow – Ascat, MSLP; obs; NWP

Pressure falls: MSLP anals; obs

## Forecast

Range of NWP: consistency between runs and between models

Esp. Ensembles

# Interpreting NWP Guidance

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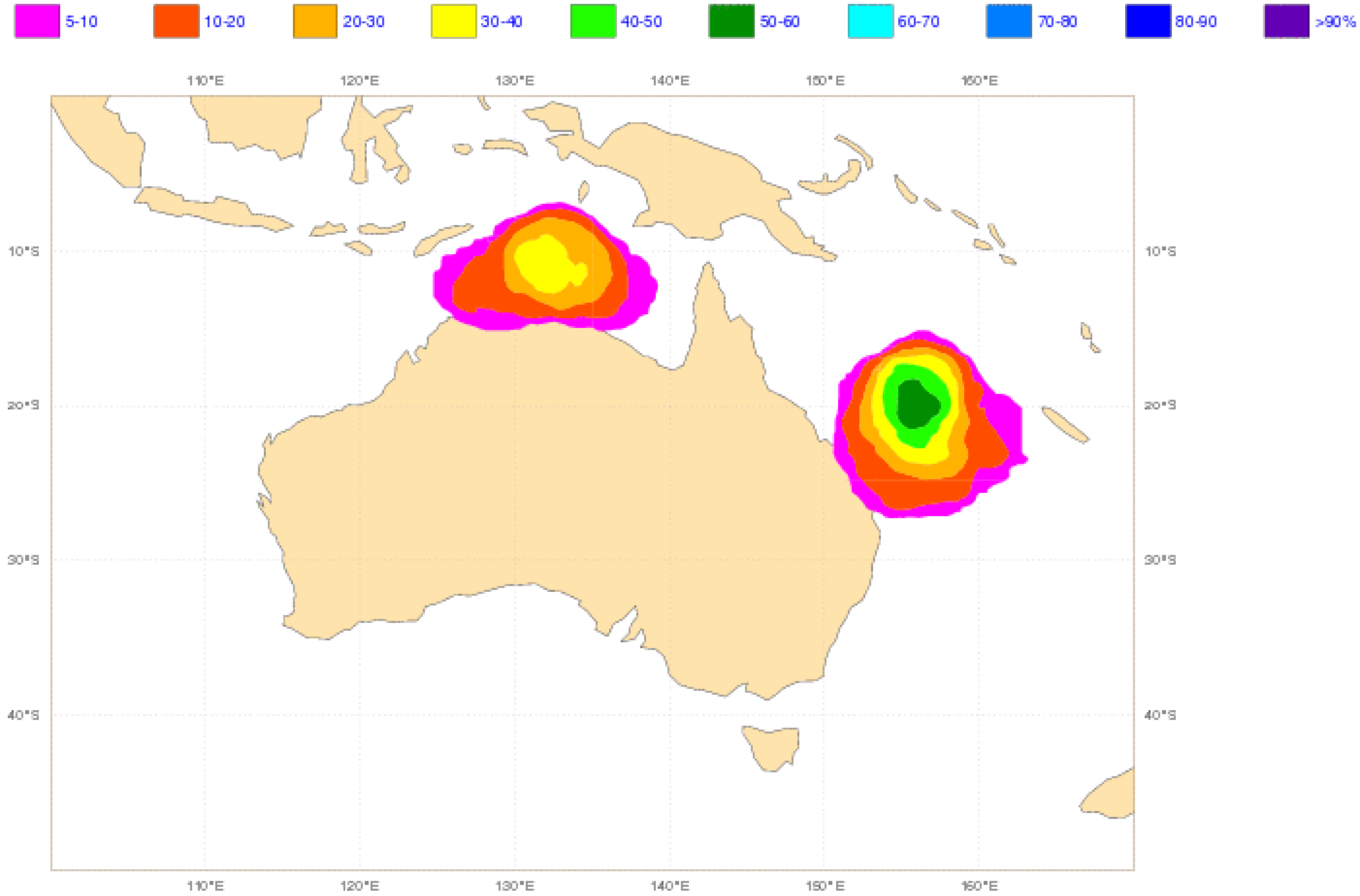
Tropical Cyclone Strike Probability Start date:Wednesday 21 December 2011 at 00 UTC
valid for 48hours from Thursday 22 December 2011 at 00 UTC to Saturday 24 December 2011 at 00 UTC
Probability of a Tropical Cyclone passing within 300km radius



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# Genesis: Sub-tropical mechanism or ‘hybrids’

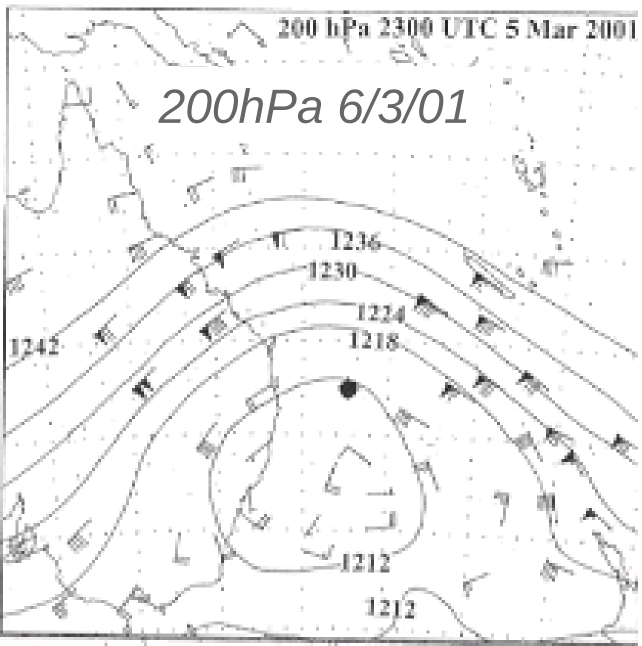
‘Hybrid’ lows – baroclinic to start – then become warm-cored

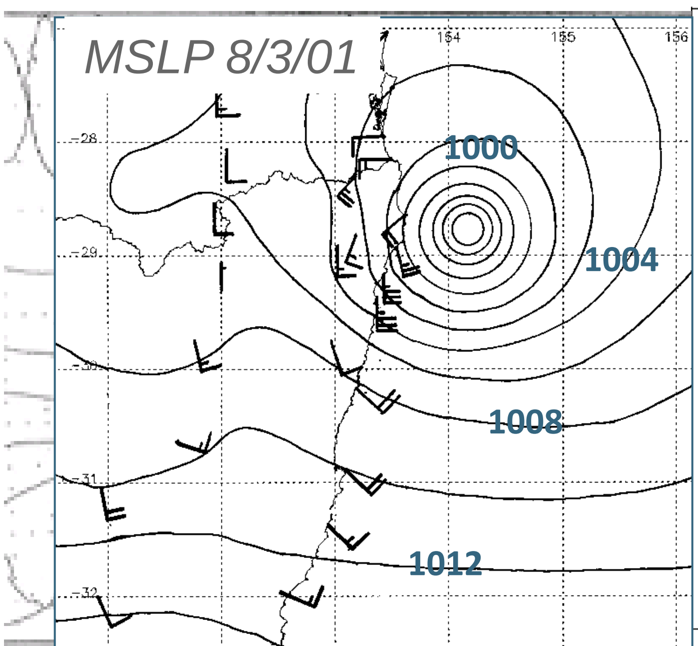
Mid-lat trough – becomes cut-off mid-upper low – enhances convection over warm SSTs

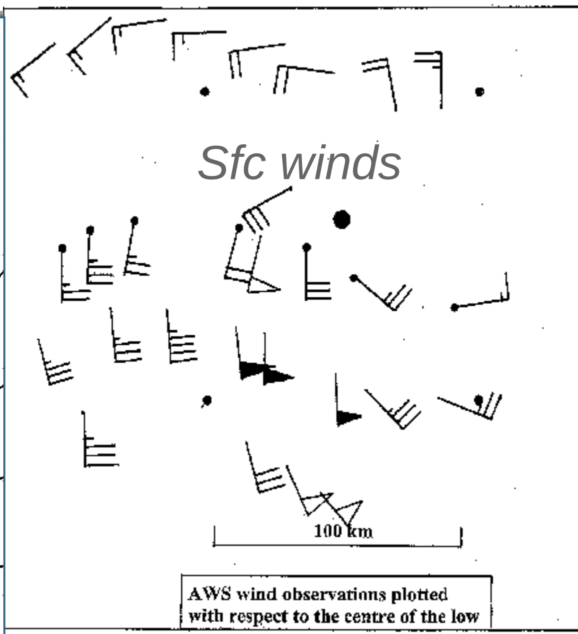
Requires low shear, unstable, warm SSTs (23C+)

Difficult policy for forecasters: Usually outside TCWC system as originates as ECL; refer

Hart phase space http://moe.met.fsu.edu/cyclonephase/



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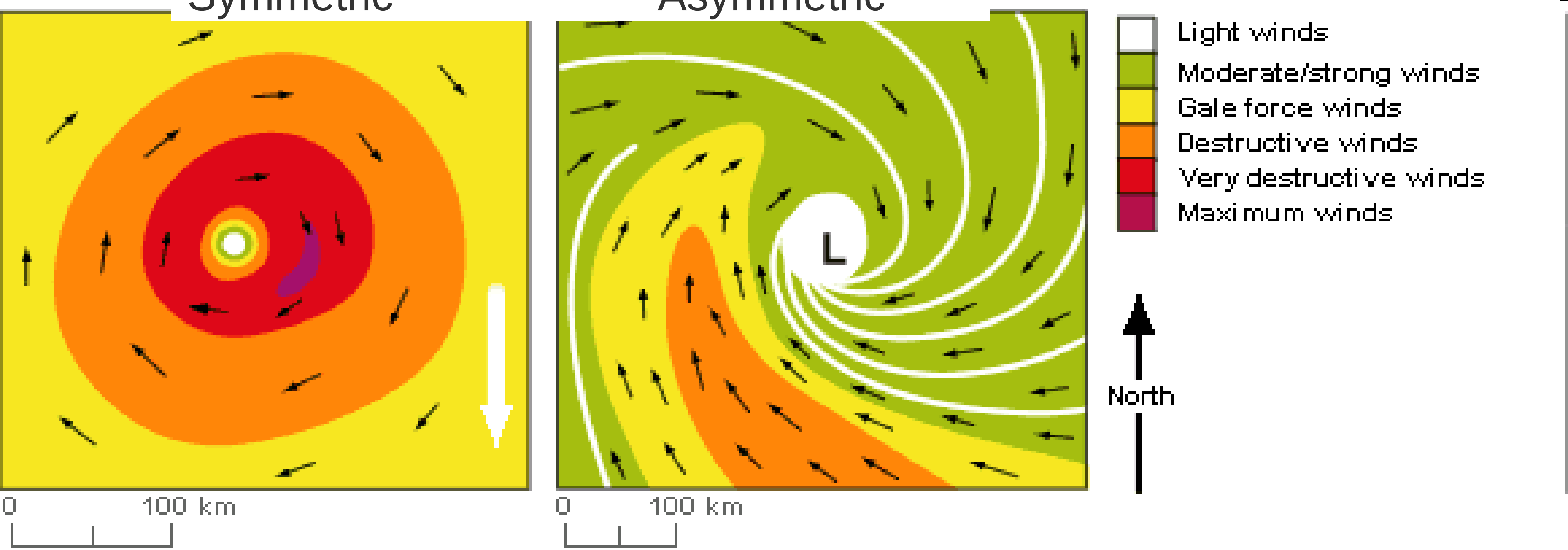
# "Hybrid" TCs: esp. for NZ, Tonga; Cooks/Niue?

## The hybrid: Upper trough + warm SSTs

Classic TC Vs Hybrid
Symmetric Asymmetric




Wind speed flow associated with **mature classical cyclone**.

Wind speed flow associated with **hybrid cyclone**.

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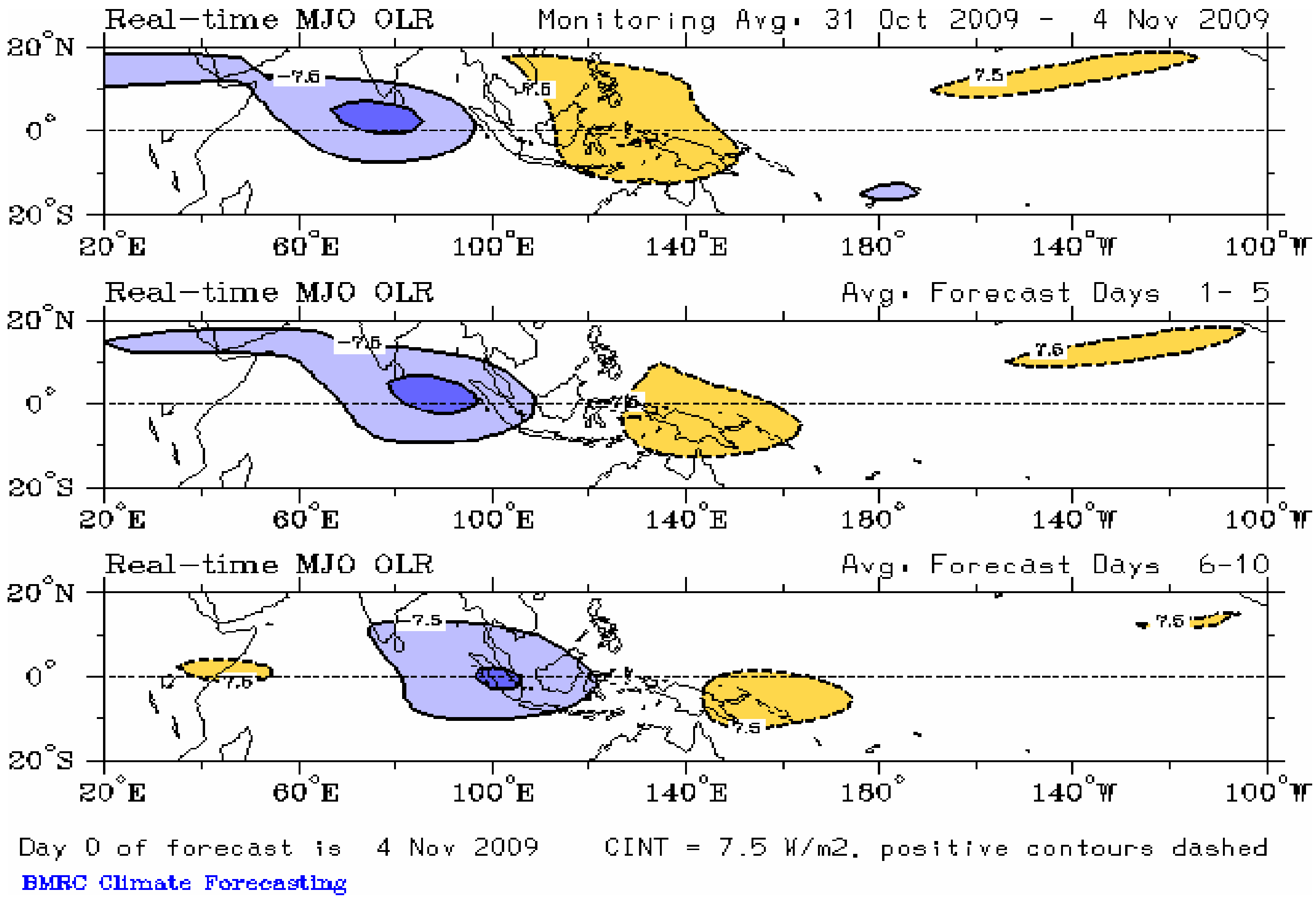
# MJO Forecast Display for 7 day TC Outlook

1. What is your advice for TC outlook for Fiji region in next 10 days?
2. What about Indonesian rainfall for next 10 days?



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# Summary

- Tropical cyclones form when large cloud clusters draw swirling air inwards and upwards.
- The further inward the air goes the faster it swirls.
- TCs form where large-scale convection is favoured (e.g. Monsoon trough, SPCZ).
- TCs form in closed circulations that contain sustained convection.