Cyclogenesis

- Definition and theory, Necessary conditions
- How does a circulation spin up?
- Tropical Waves
- Operational process
- Products

- 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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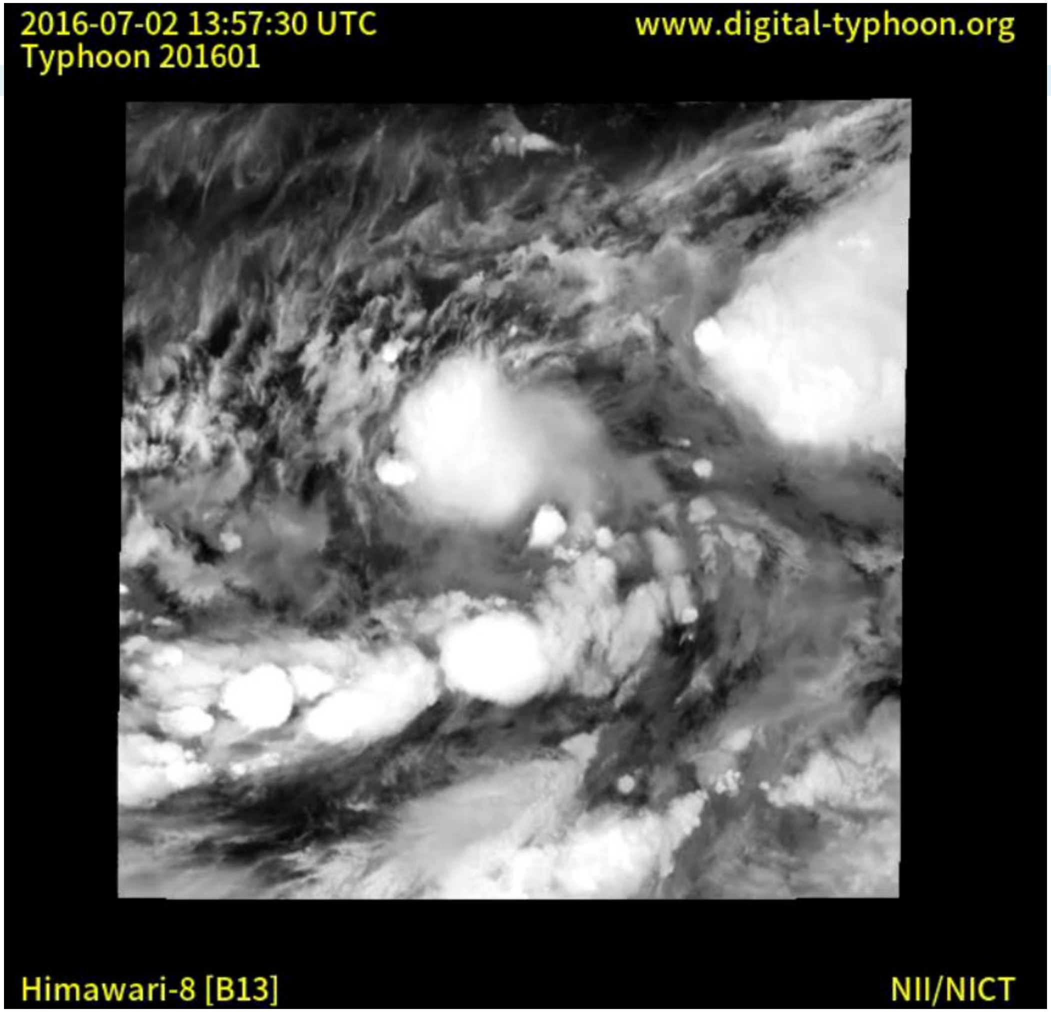
Typhoon Nepatrak



Courtesy: www.digital-typhoon.org

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

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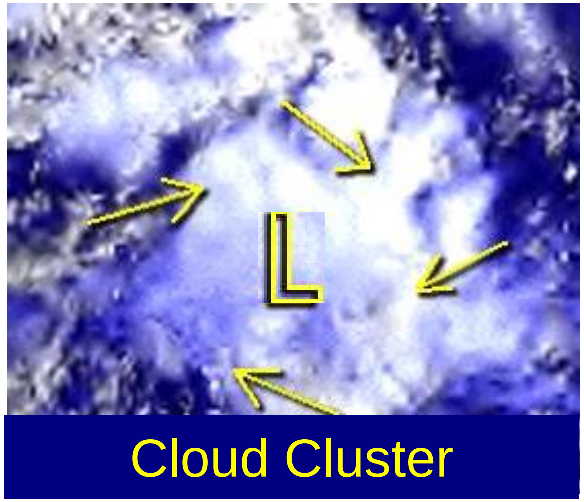
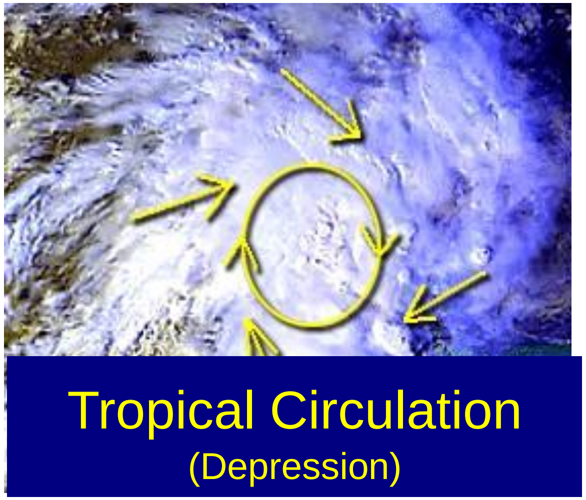
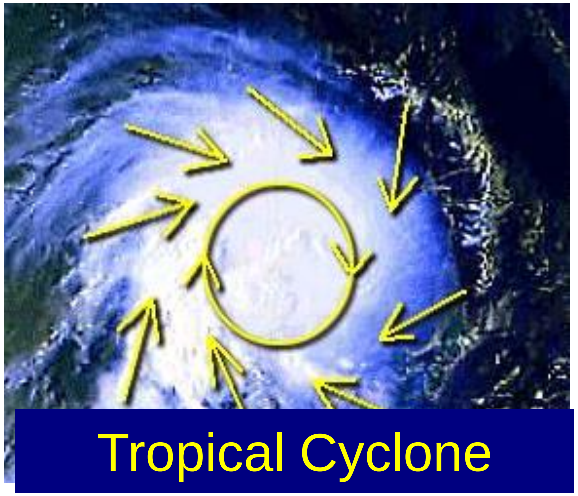
Cyclogenesis Definition(s)

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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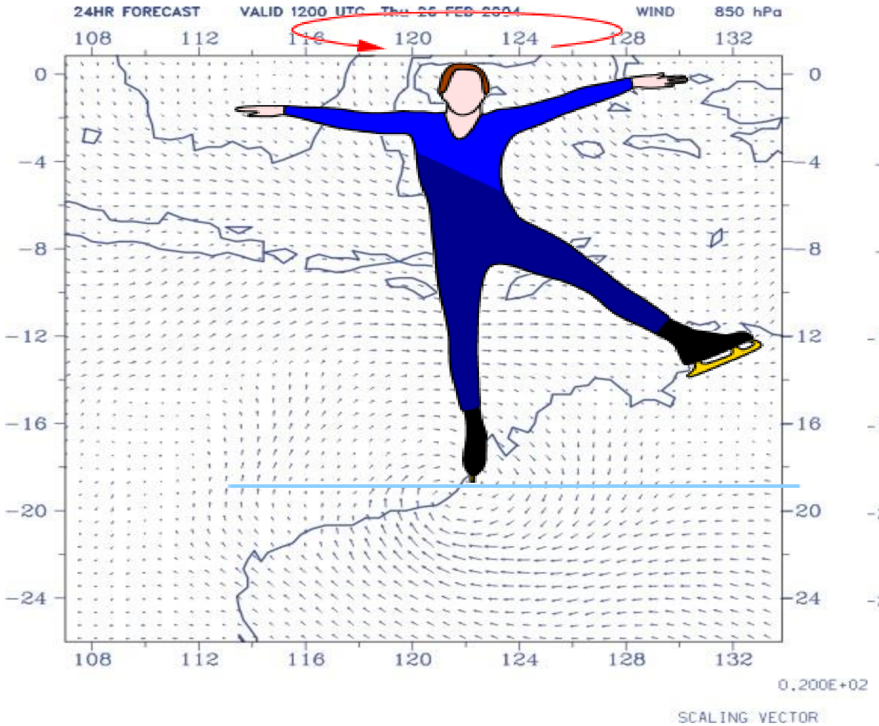
TC genesis: vorticity perspective

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



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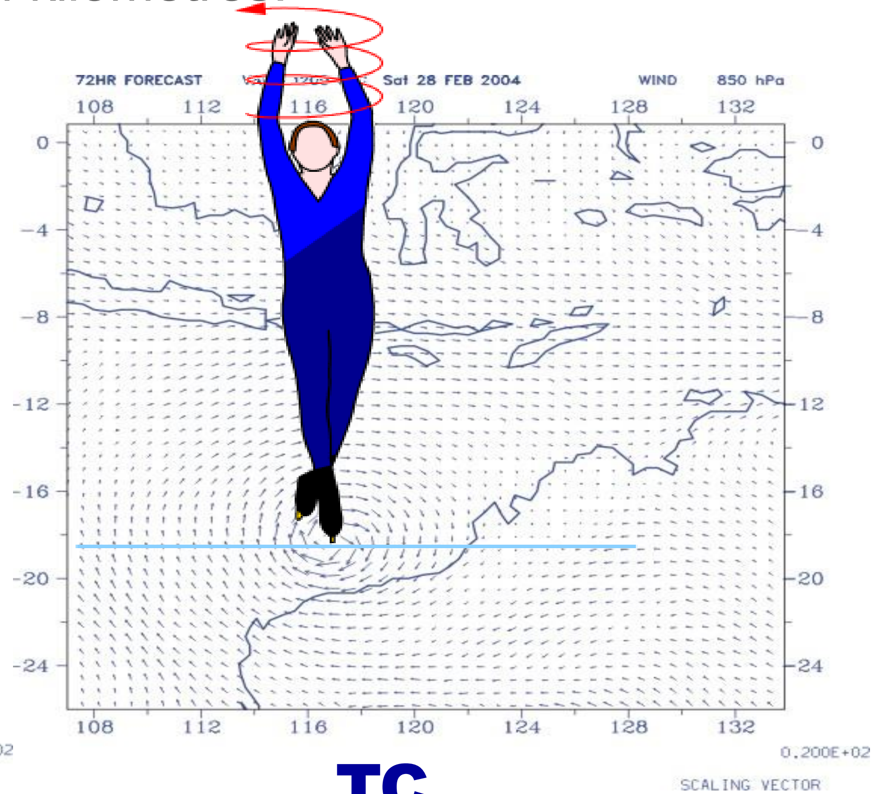

TC

Genesis: Necessary conditions

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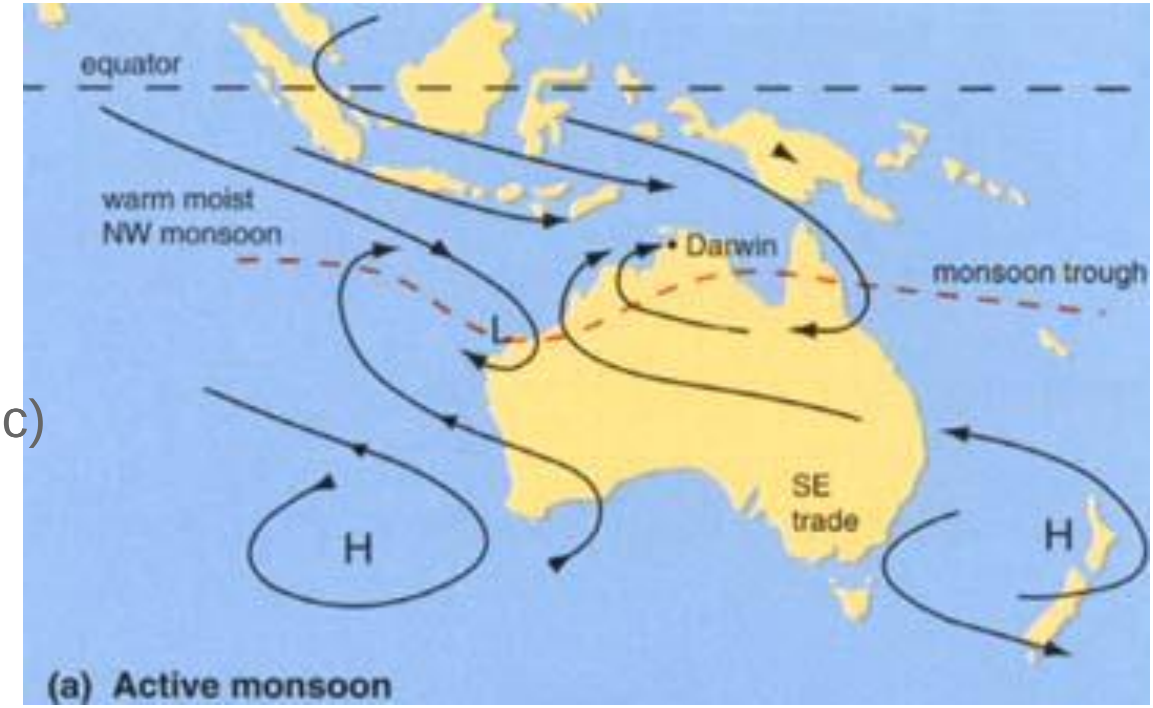
1. Coriolis
2. Moist unstable air mass
3. Warm SST
4. Deep Convection
5. Weak vertical wind shear
6. Low-level vorticity

- Large values of 1 and 6 = large ζ_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



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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.

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

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.

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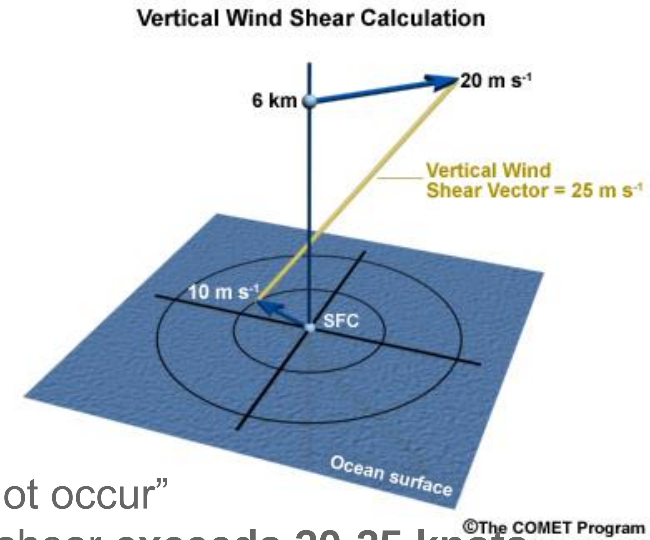
4. Deep Convection
5. Weak vertical wind shear
6. Low-level vorticity



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**

but…this can still happen;

Australian experience: shear less than 25 kn for development

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

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

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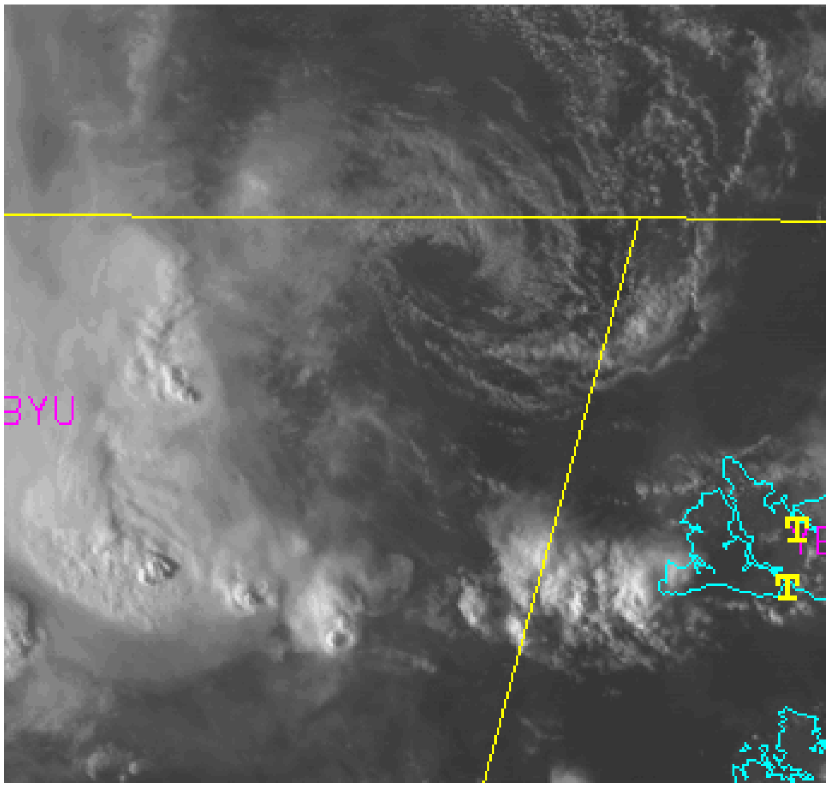
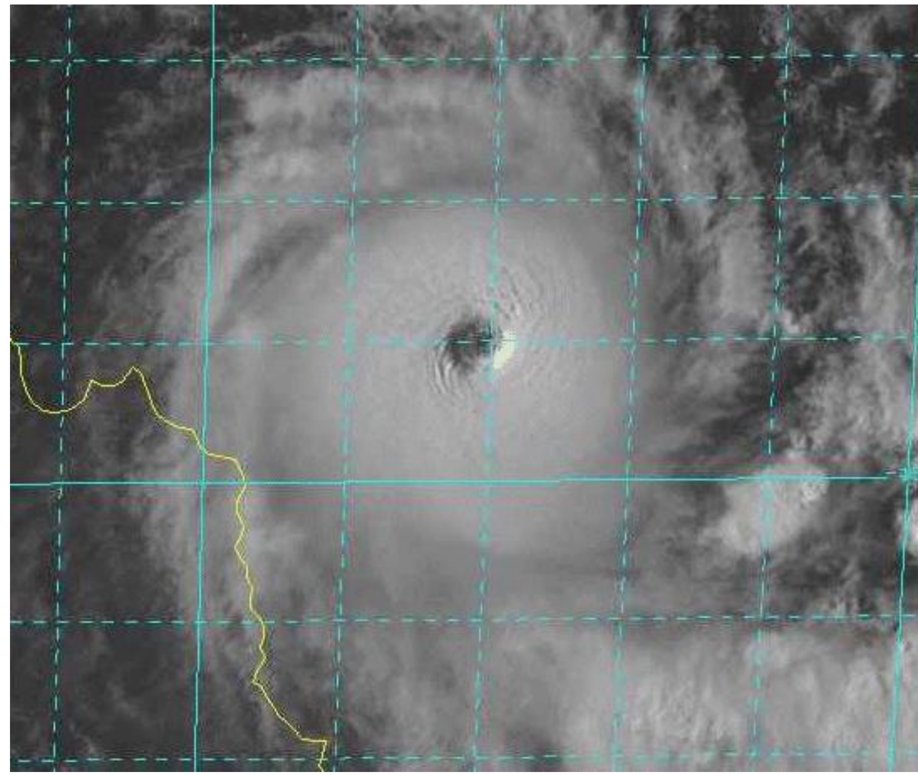
Vertical Wind shear



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



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

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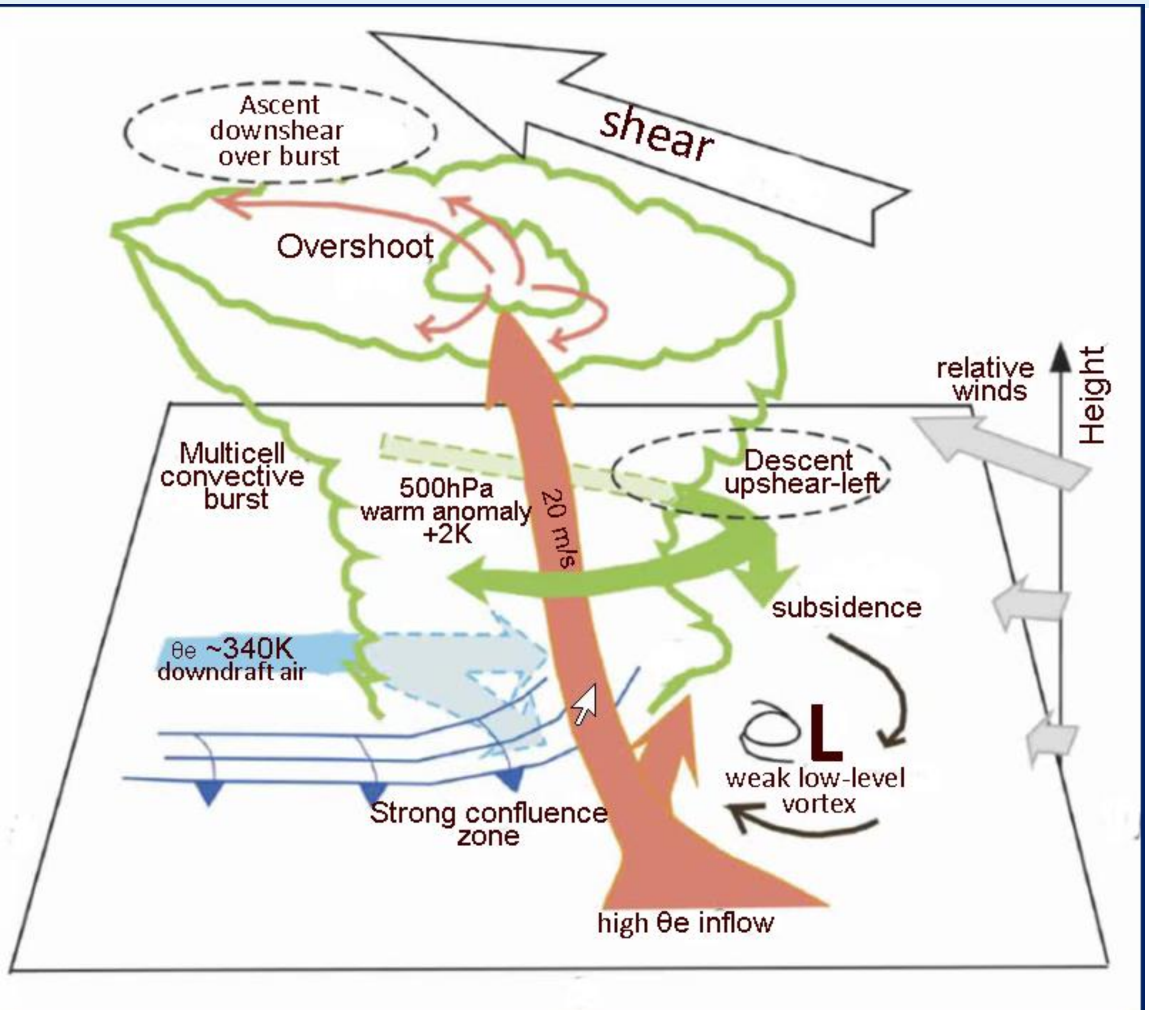
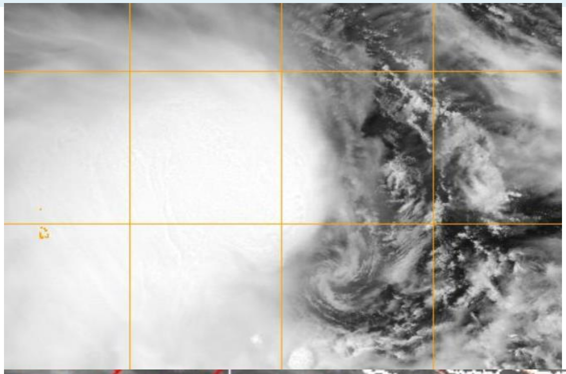
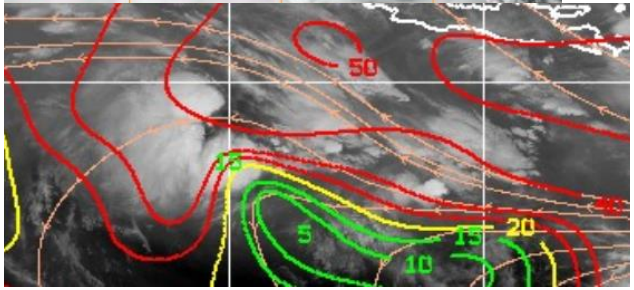
Vertical Wind shear







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

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Genesis: Necessary conditions

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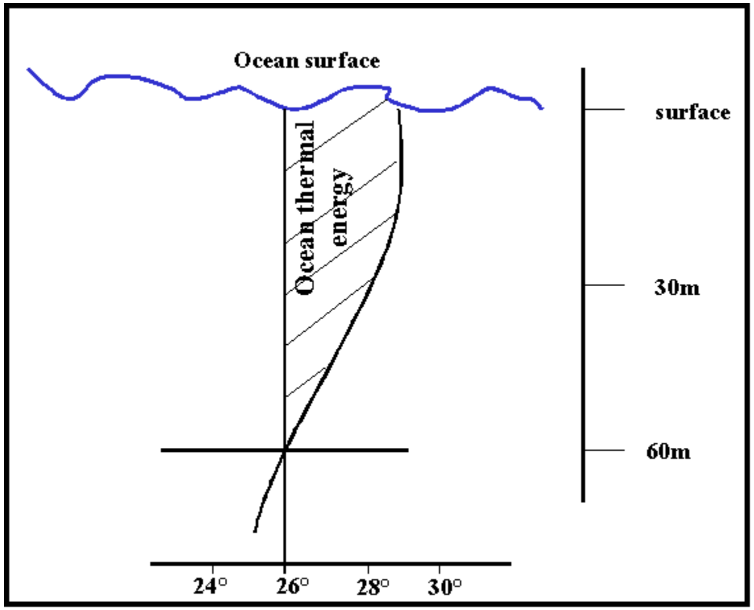
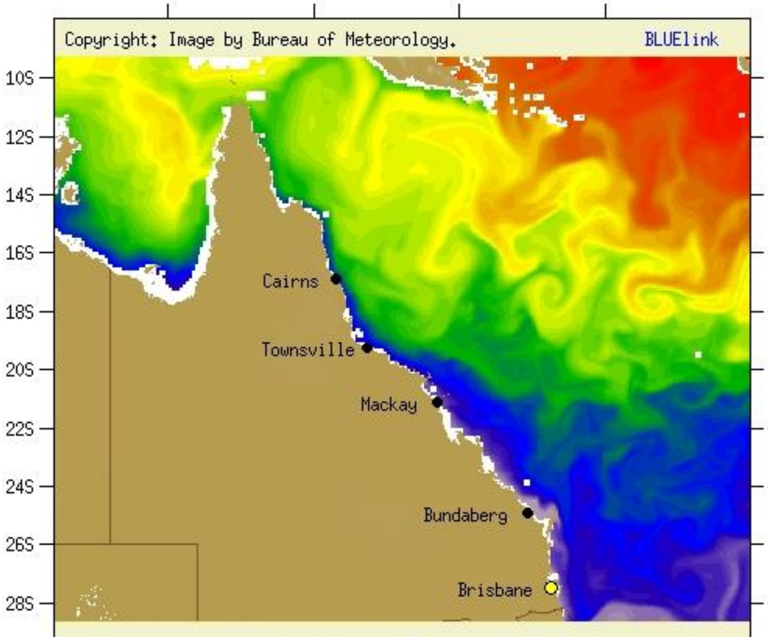
$$E = \int_{SURFACE}^{Z(T=26)} \rho_W c_W (T - 26) dz$$

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
http://oceancurrent.imos.org.au/

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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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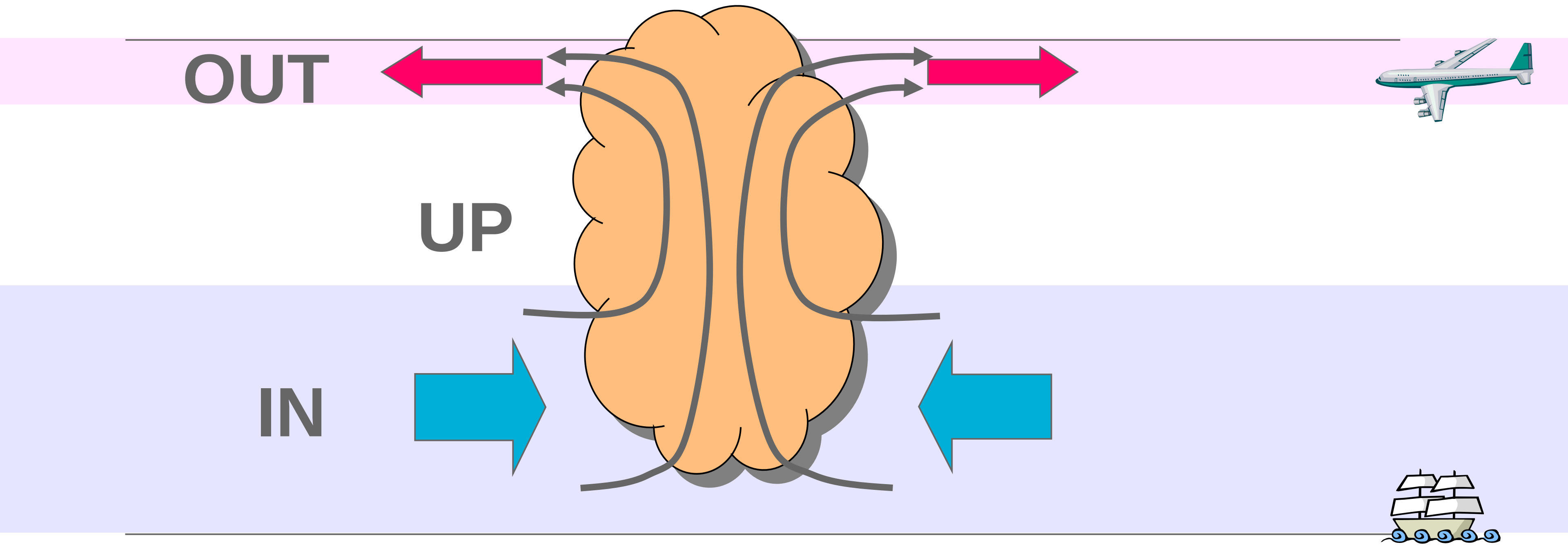
How does a tropical cyclone Spin-up?



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

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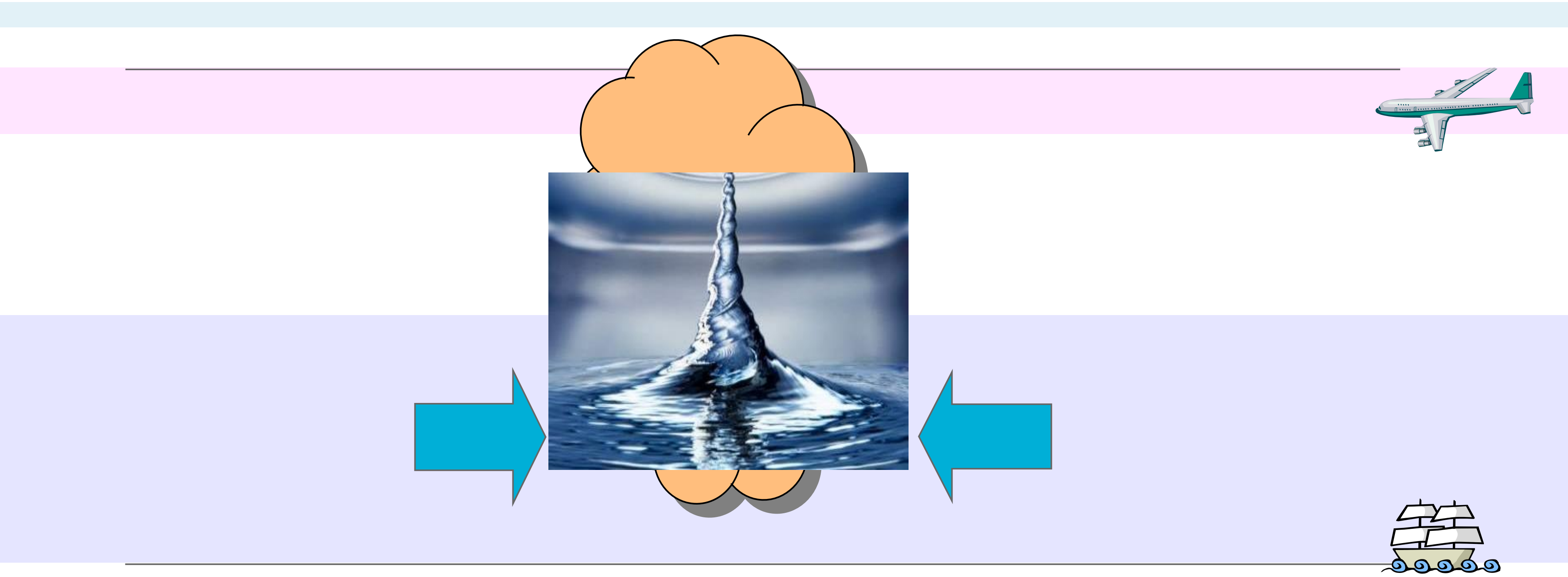
How does a tropical cyclone Spin-up?

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

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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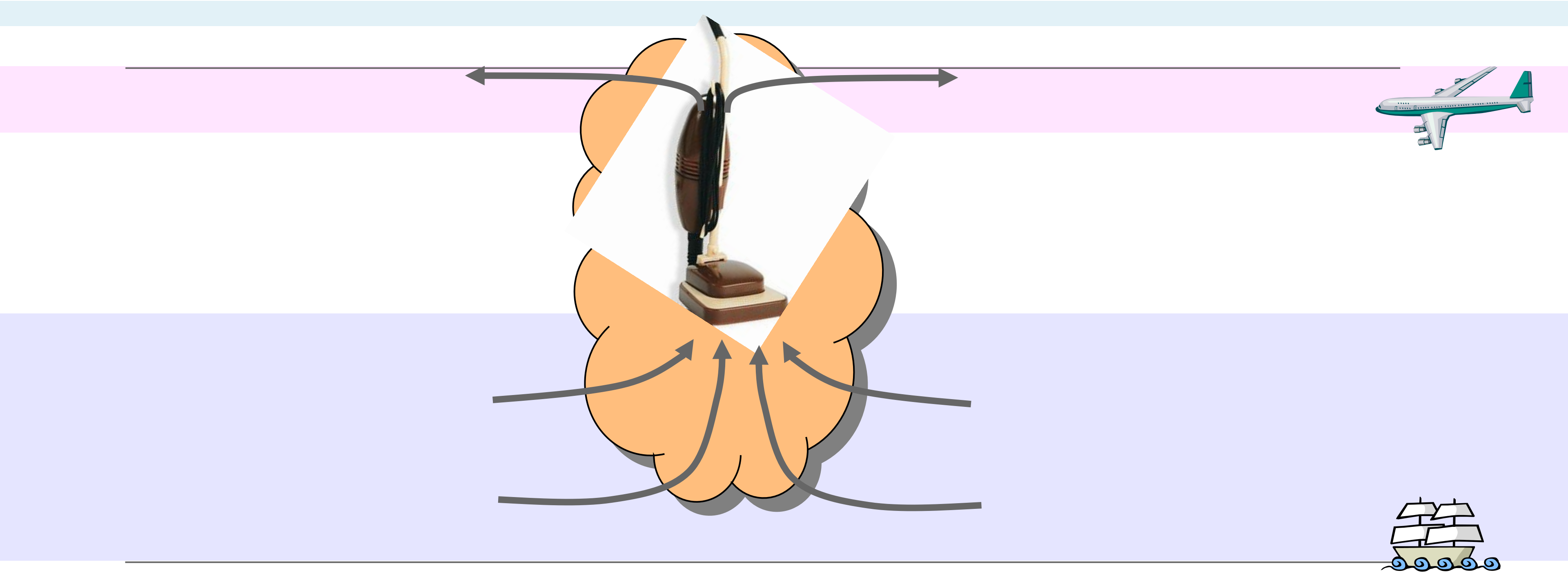
How does a tropical cyclone Spin-up?



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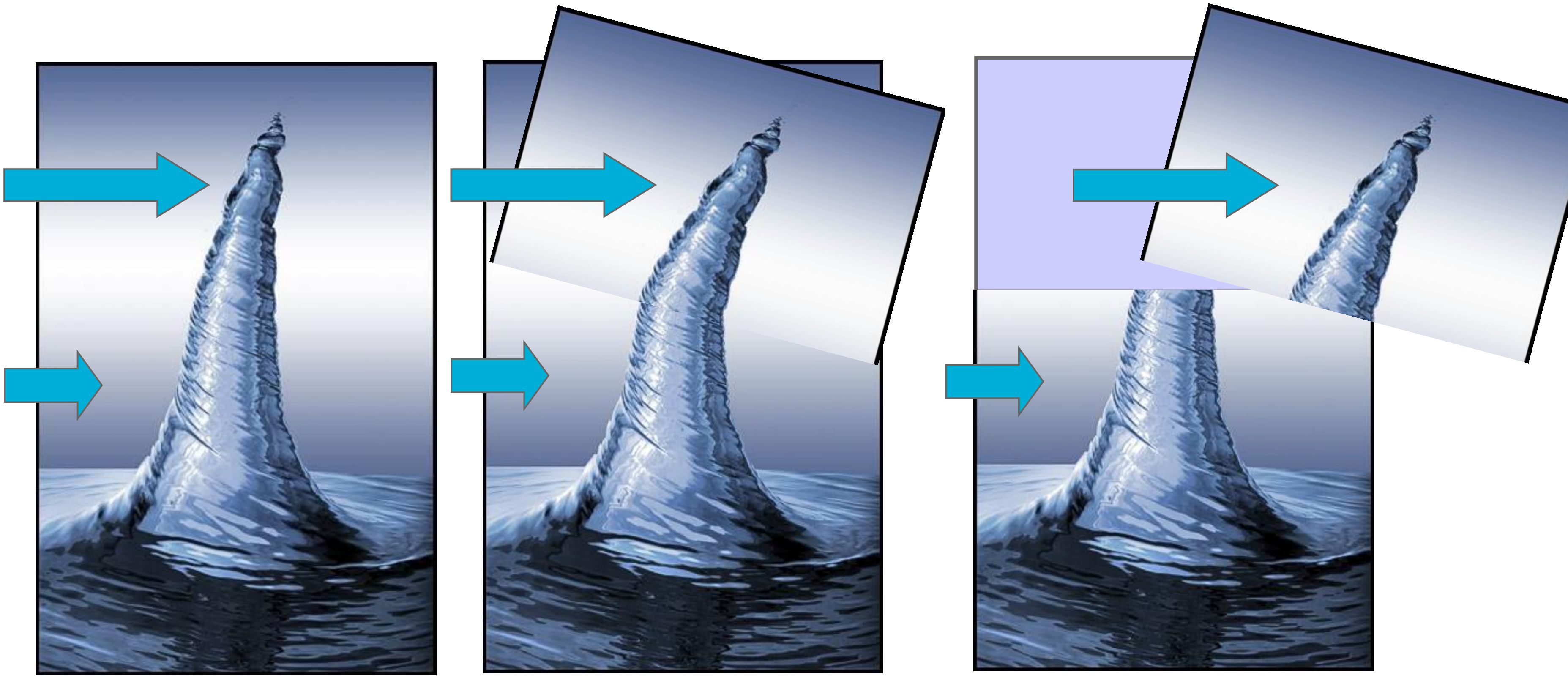
Why doesn't every convective complex spin-up a tropical cyclone?

Three main reasons:

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



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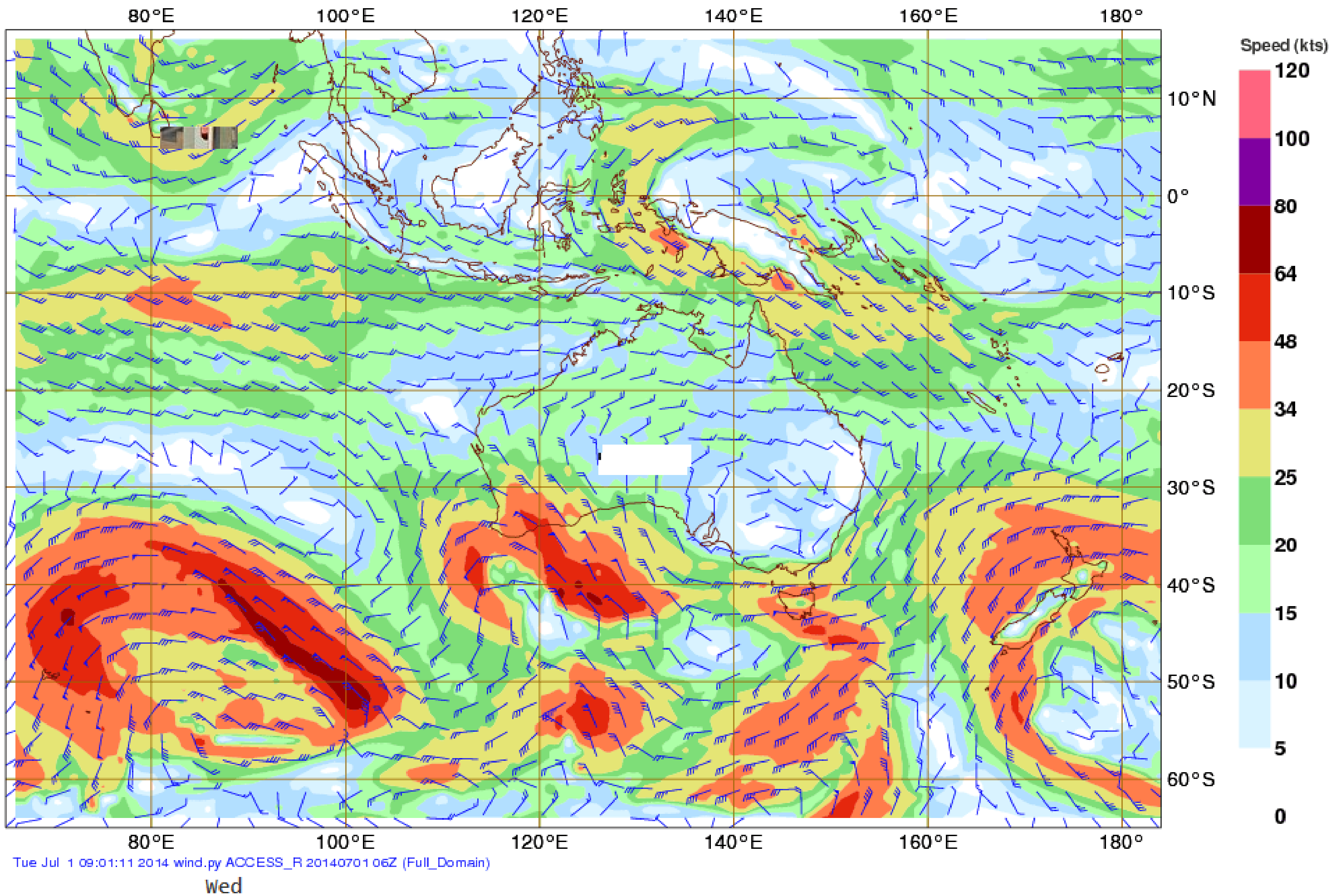
Why doesn’t every convective complex spin-up a tropical cyclone?

2. The ‘background’ rotation is insufficient.



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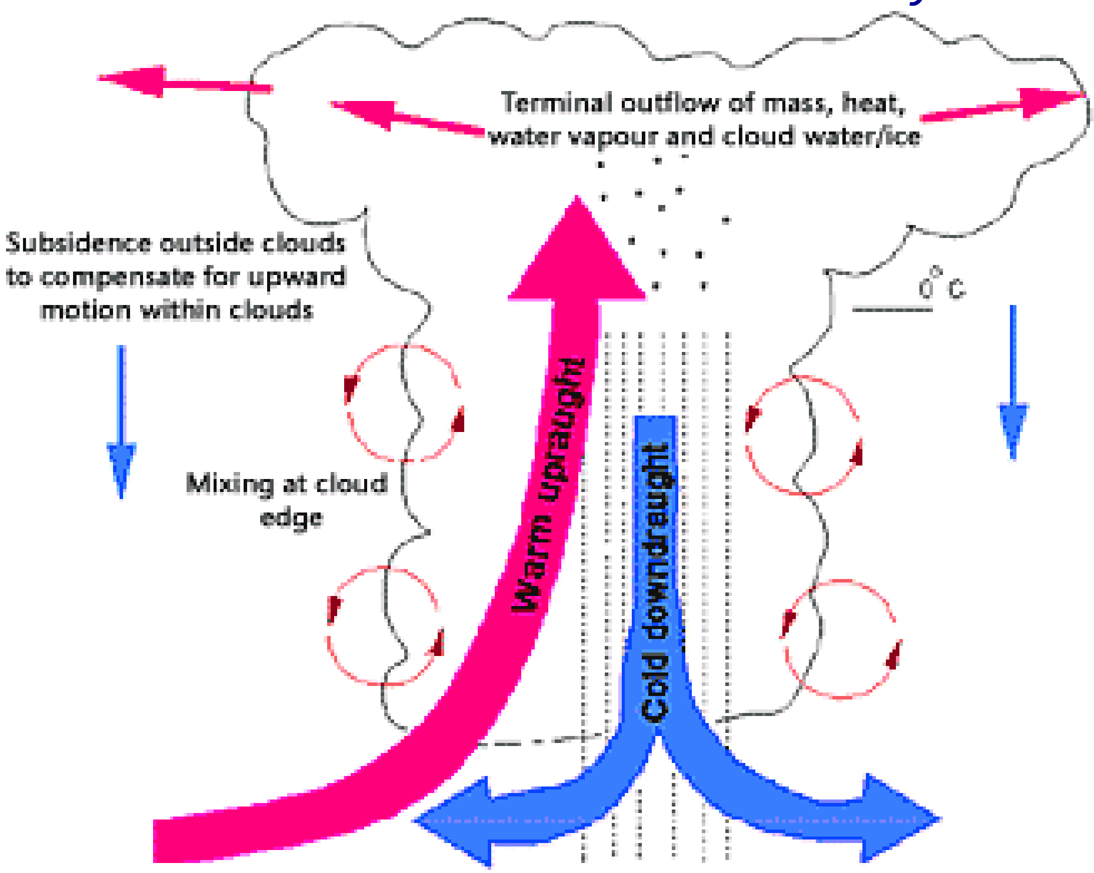
Why doesn’t every convective complex spin-up a tropical cyclone?

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?

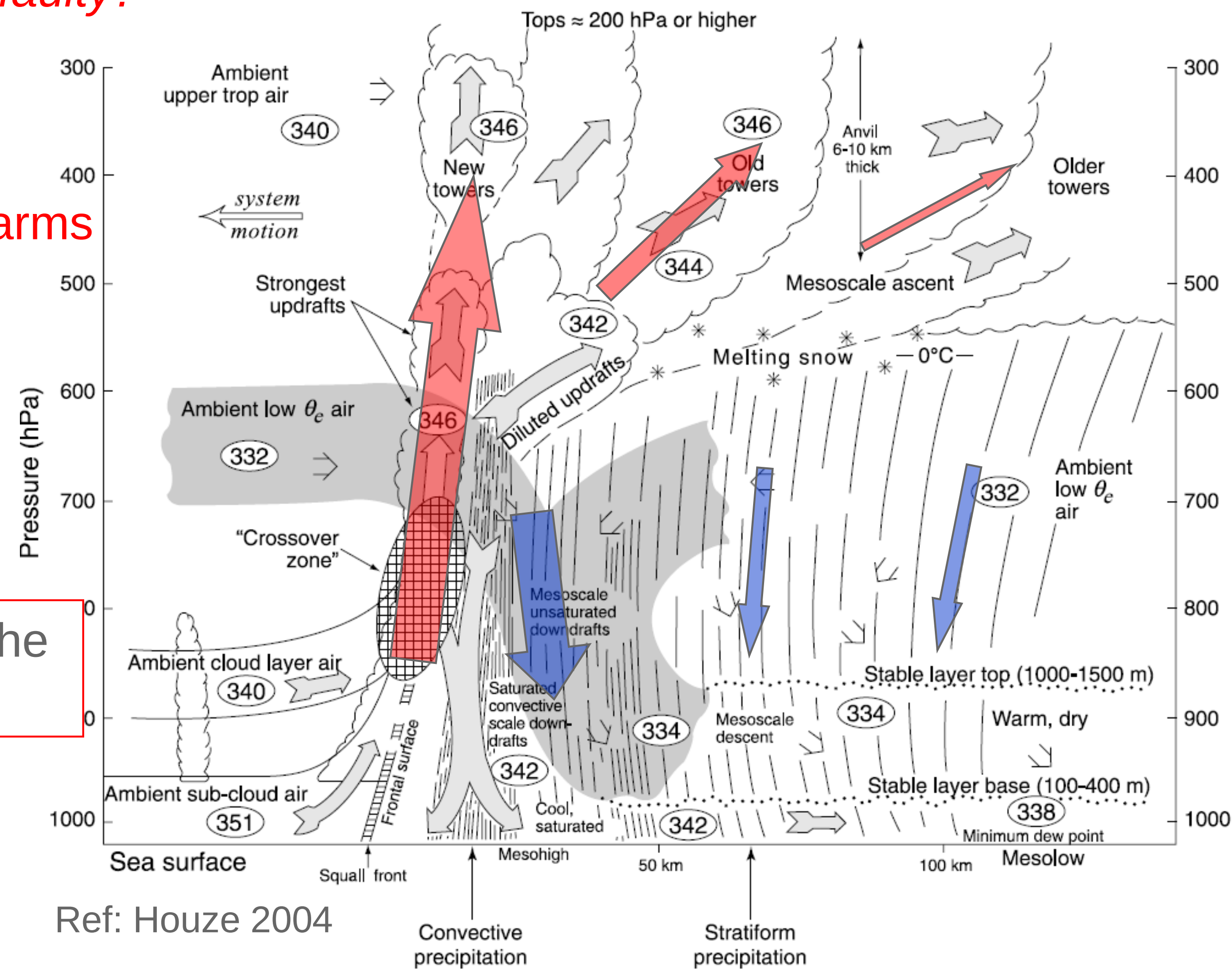
The convection is not quite “right”.

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. monsoo … ve

   The stronger th … otation the faster the circulation spins-up.

   (Somewhat) common*

2. Convection in a very moist and well mix … e

   The potential for c … 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 a…

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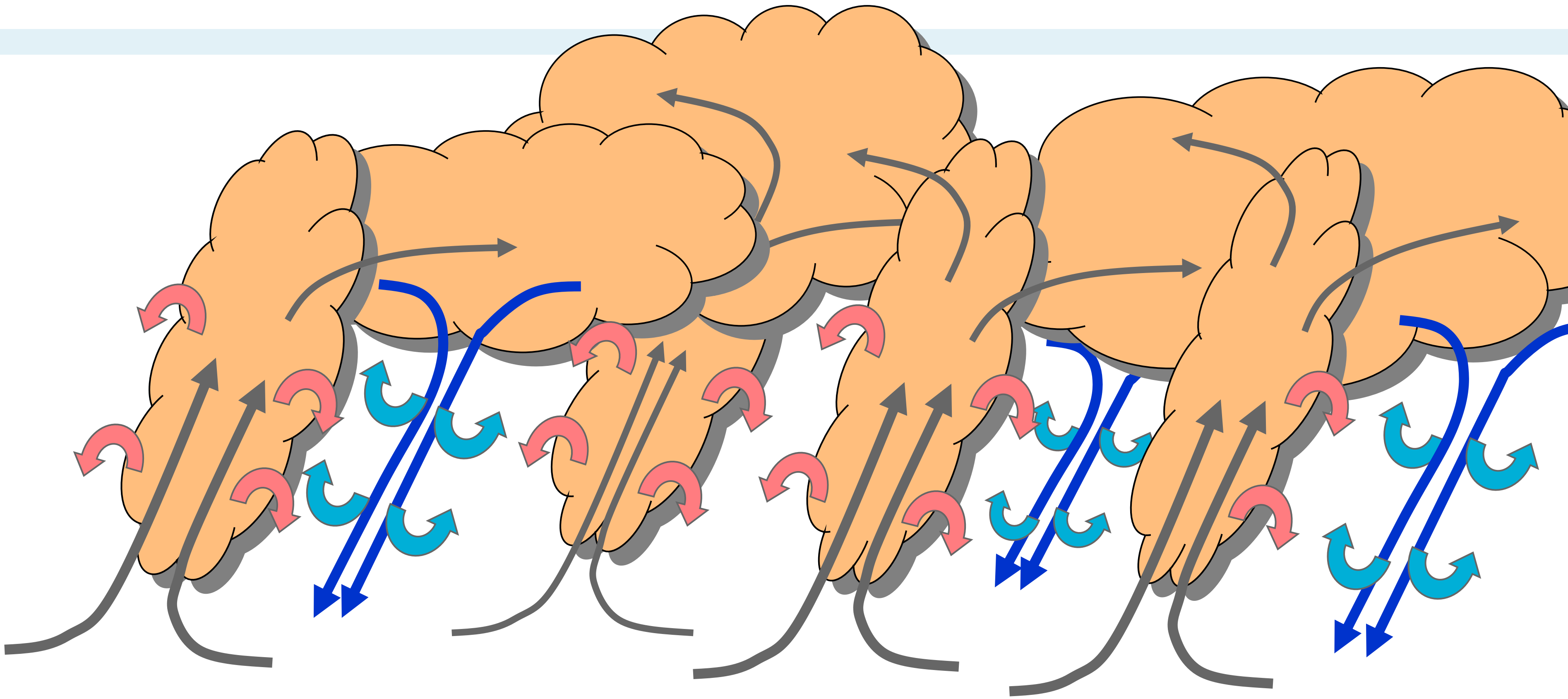
How does the atmosphere become very moist and well mixed?



Convective complex

Sustained convection - moistens and mixes

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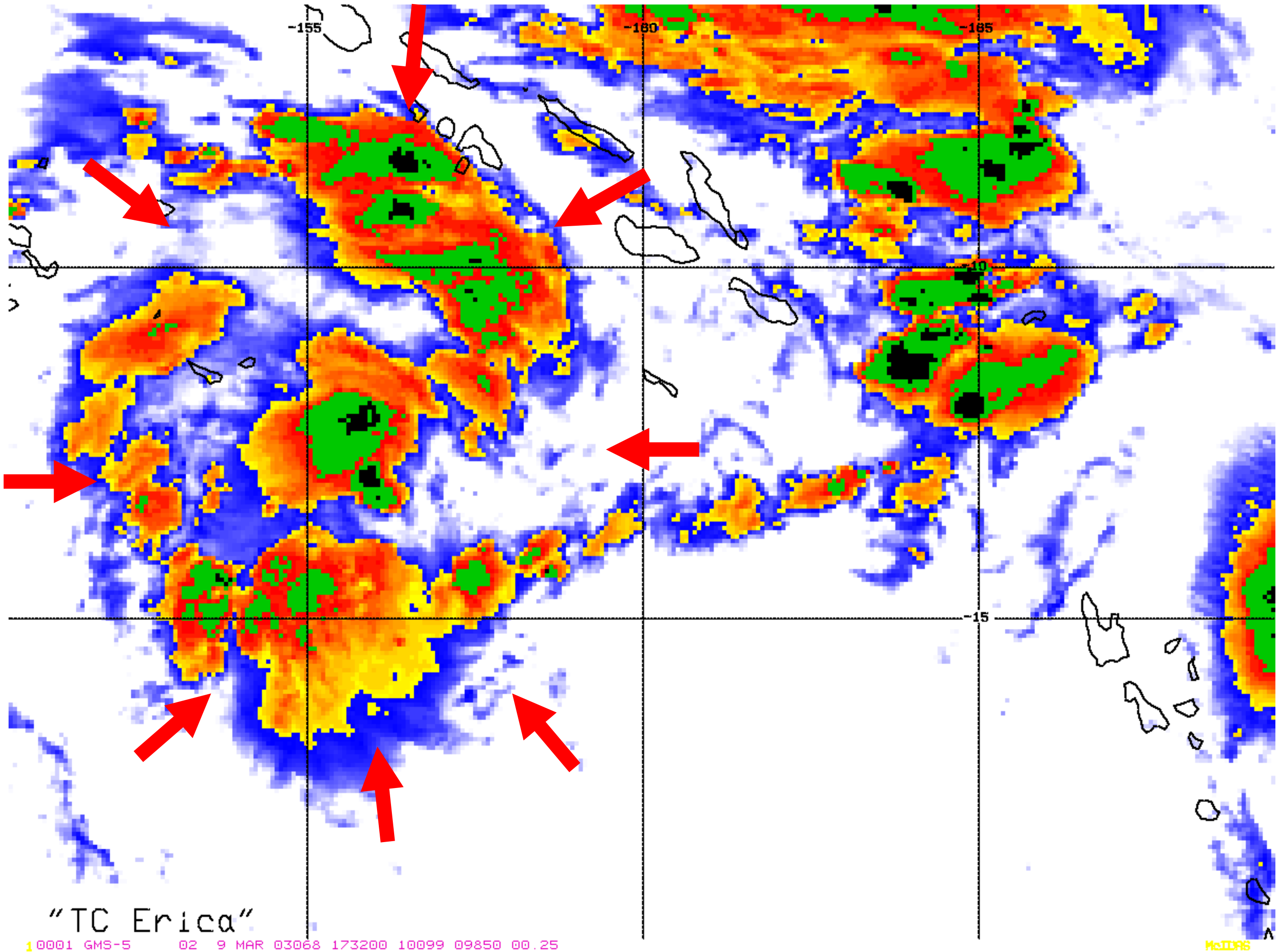

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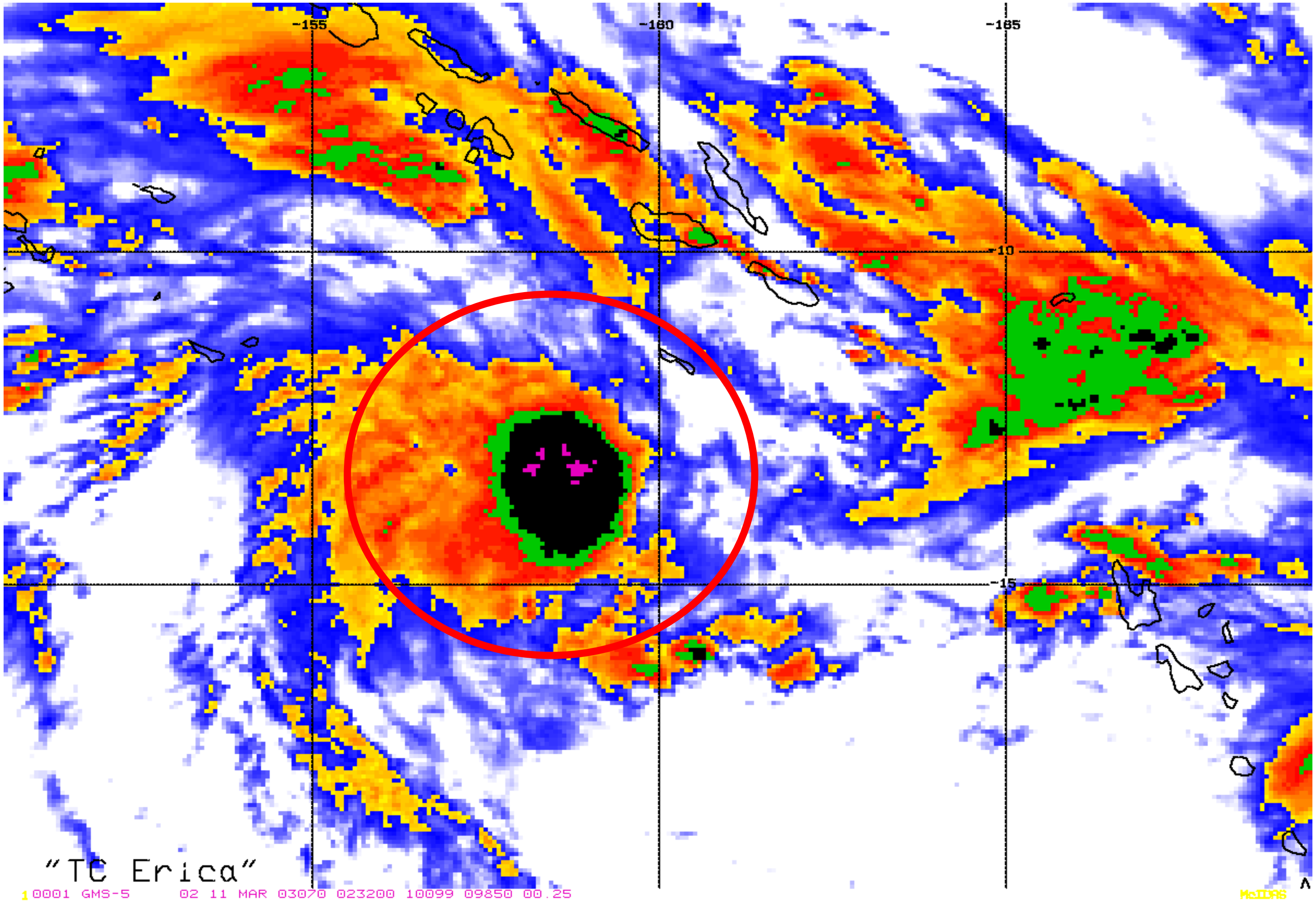


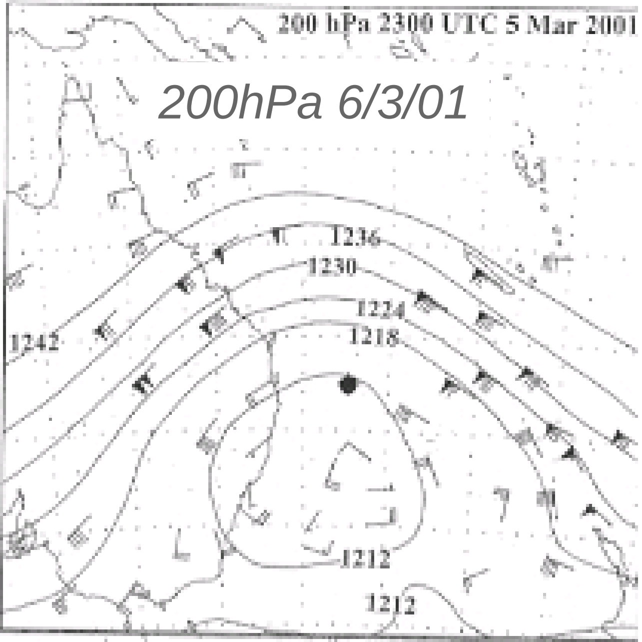
Genesis: Sub-tropical mechanism or ‘hybrids’

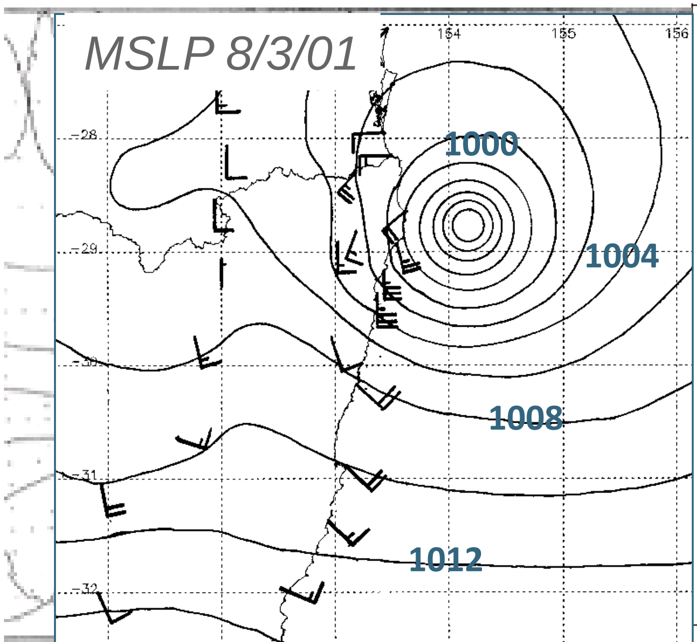
‘Hybrid’ lows – baroclinic to start – then become warm-cored

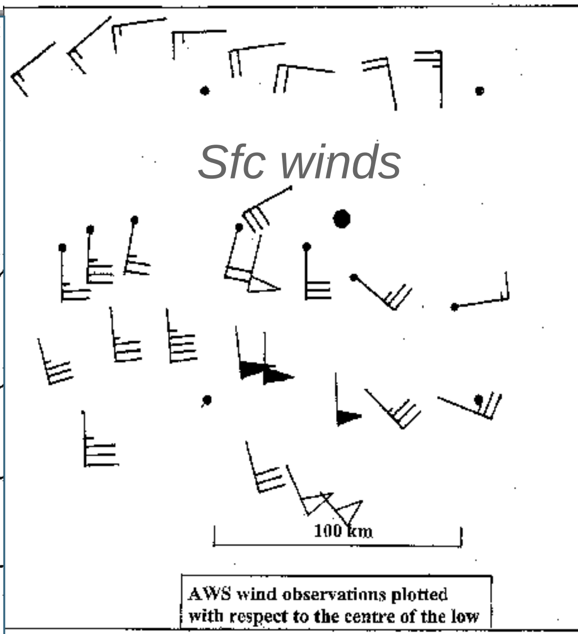
Mid-lat trough – becomes cut-off mid-upper low – enhances convection over warm SSTs

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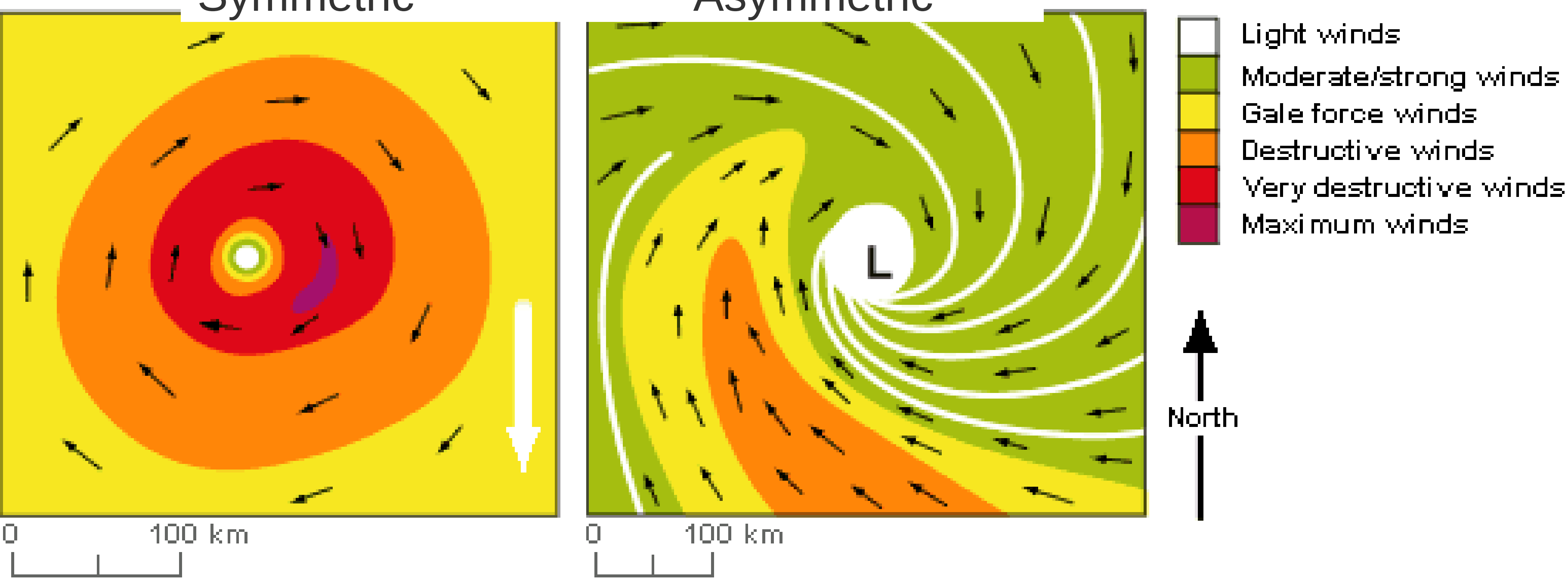
"Hybrid" TCs: esp. for NZ, Tonga; Cooks/Niue?

The hybrid: Upper trough + warm SSTs

Classic TC Symmetric Vs Hybrid Asymmetric

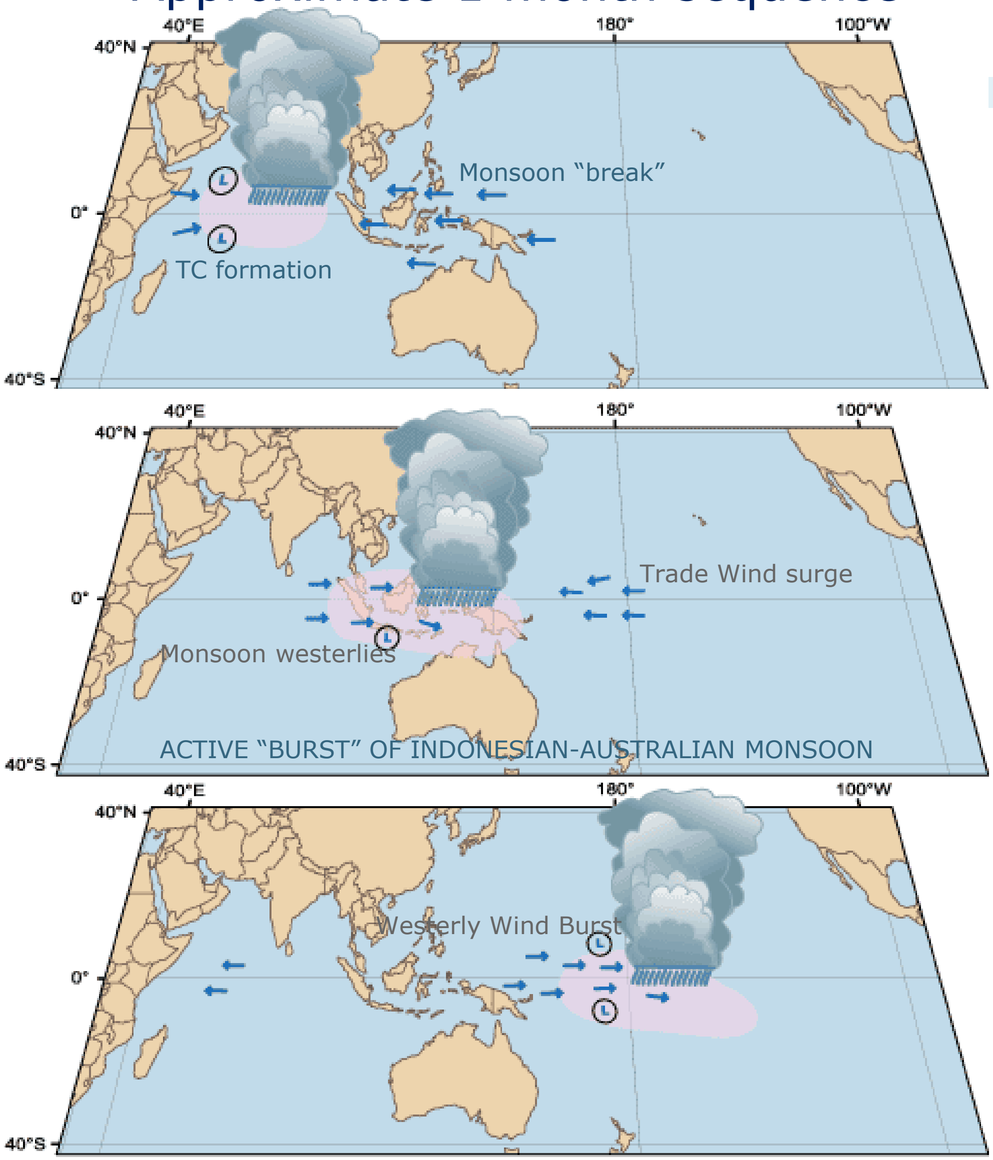


Wind speed flow associated with **mature classical cyclone**.

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

Predictors for genesis 4-28 days 'aves: The MJO

Approximate 1 month sequence



- First described by Madden and Julian in the early 1970s.
- 30 to 80-day period slow eastward propagation (also 40-50 day wave, or Intraseasonal Oscillation (ISO).
- 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 often predictable out to ~20 days

MJO Phases: RMM- real-time multivariate MJO

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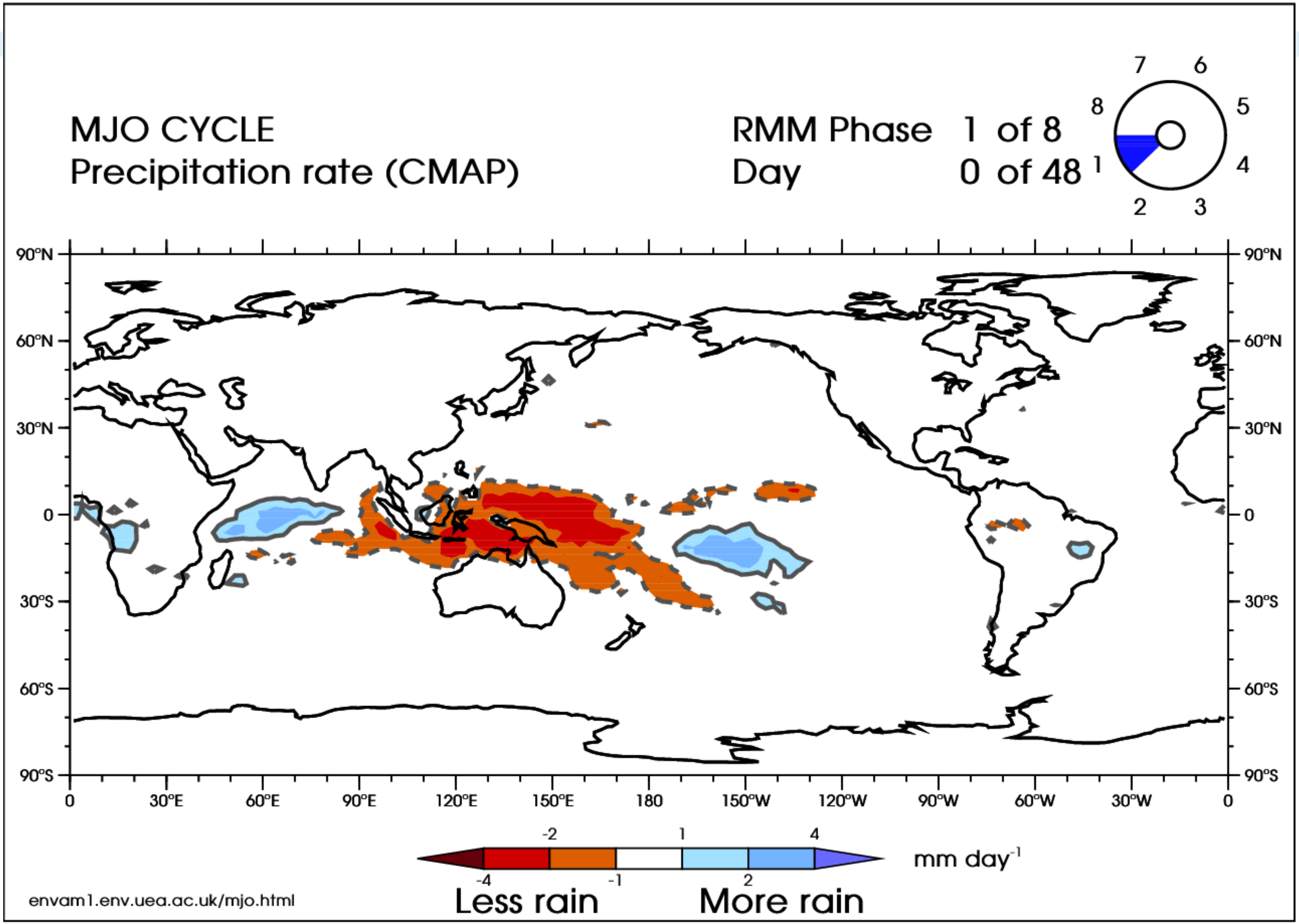
Define MJO Phases 1-8



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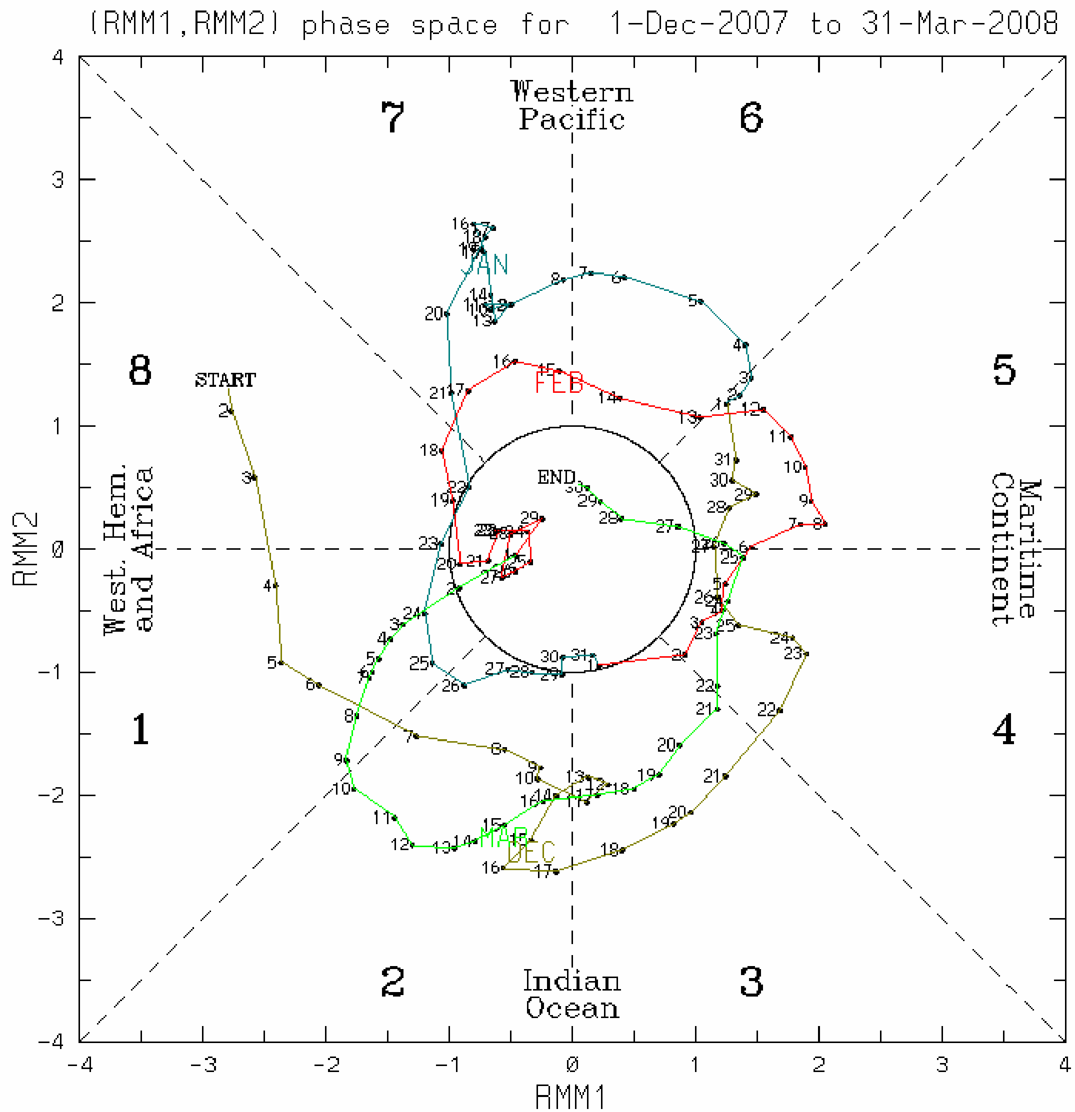
MJO Phases: RMM- real-time multivariate MJO

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

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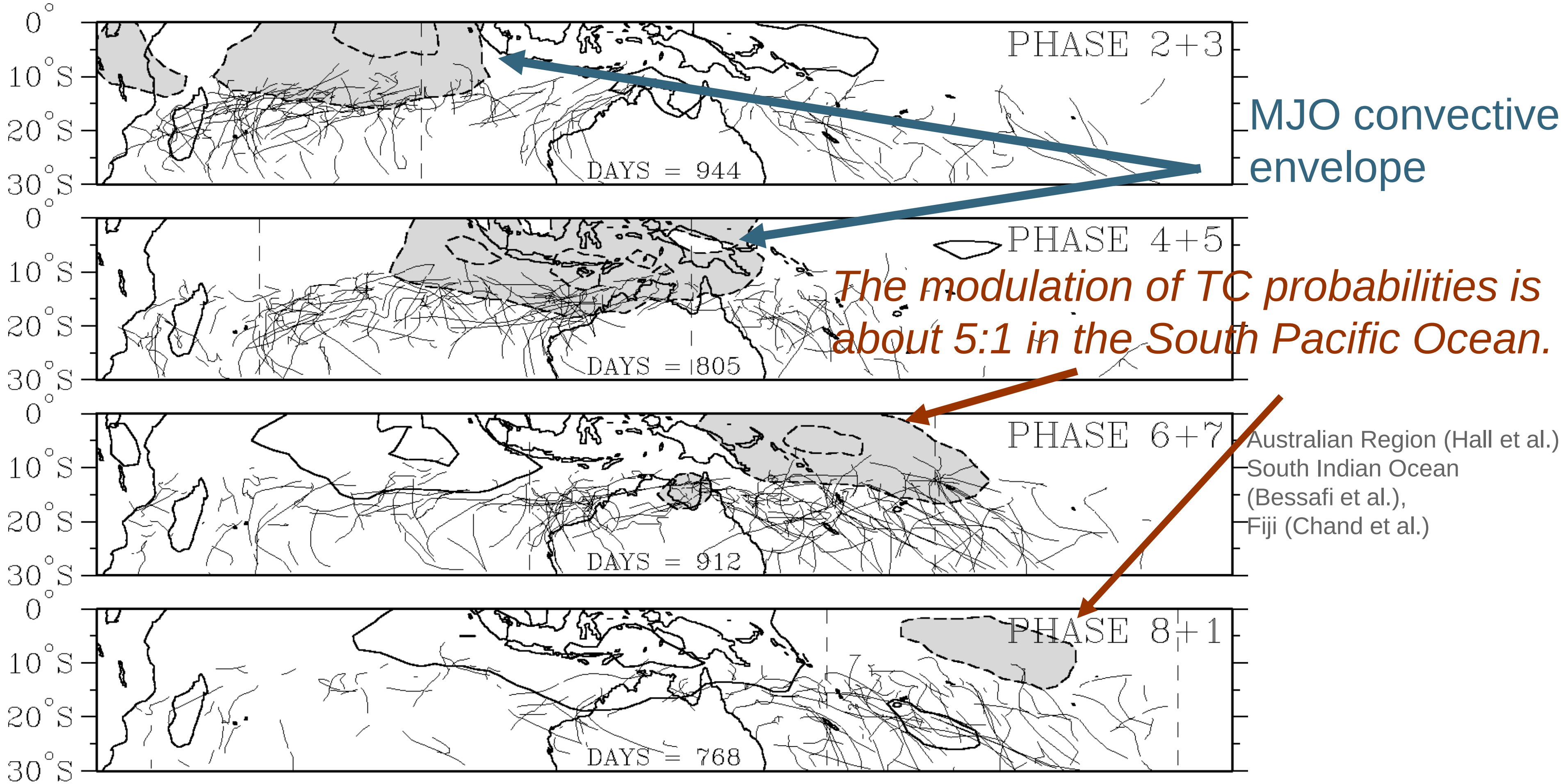
MJO-TC impact using the RMM phases

This result has obvious importance for multi-week predictions of TC activity
In Australian and Fiji regions this relationship is strengthened during El Nino periods



Australian Region (Hall et al.)
South Indian Ocean (Bessafi et al.),
Fiji (Chand et al.)

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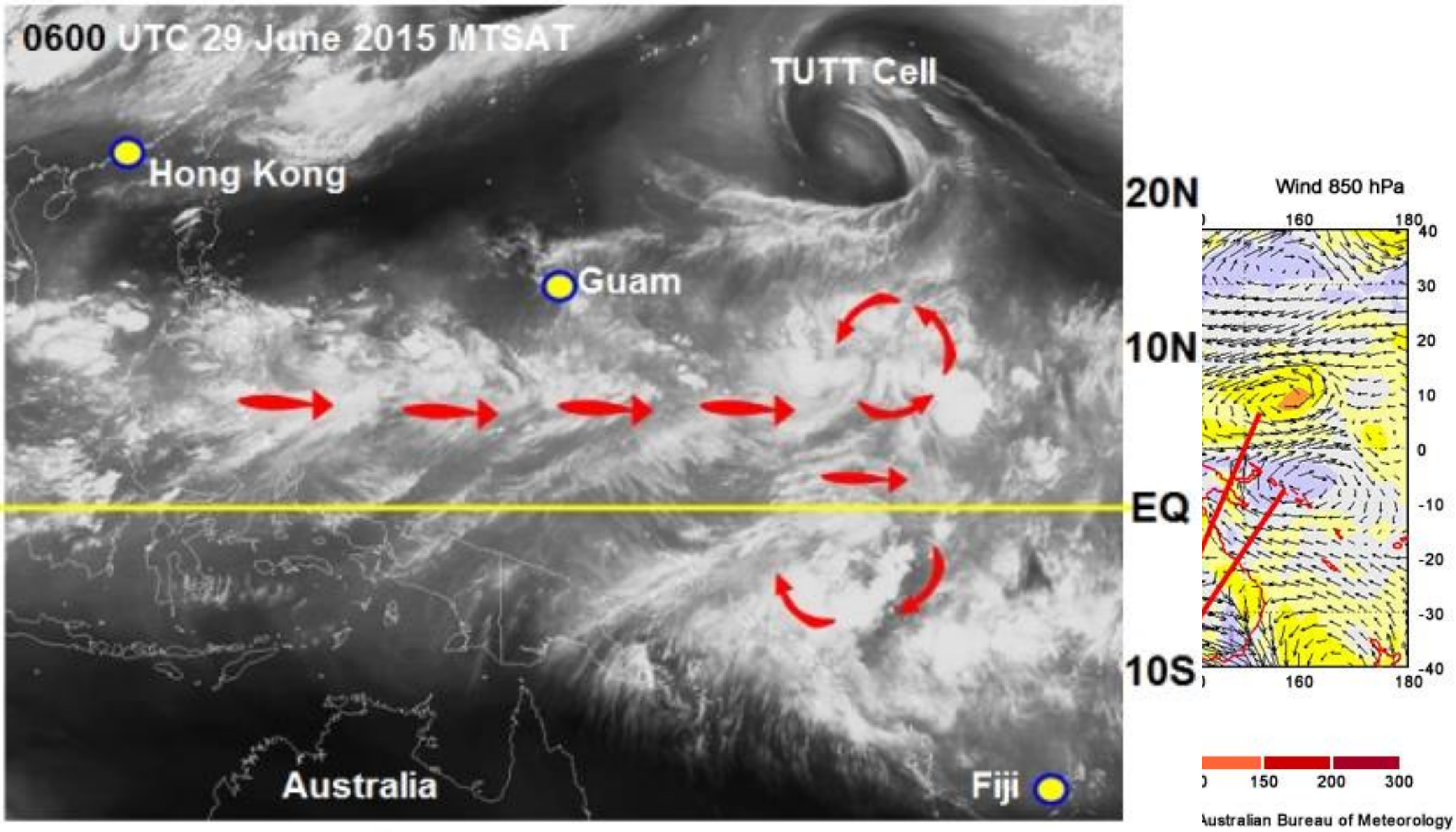
Convectively-coupled equatorial waves
Equatorial Rossby waves

Equatorial Rossby waves: 'travel' east to west.

Enl

Las

Spi



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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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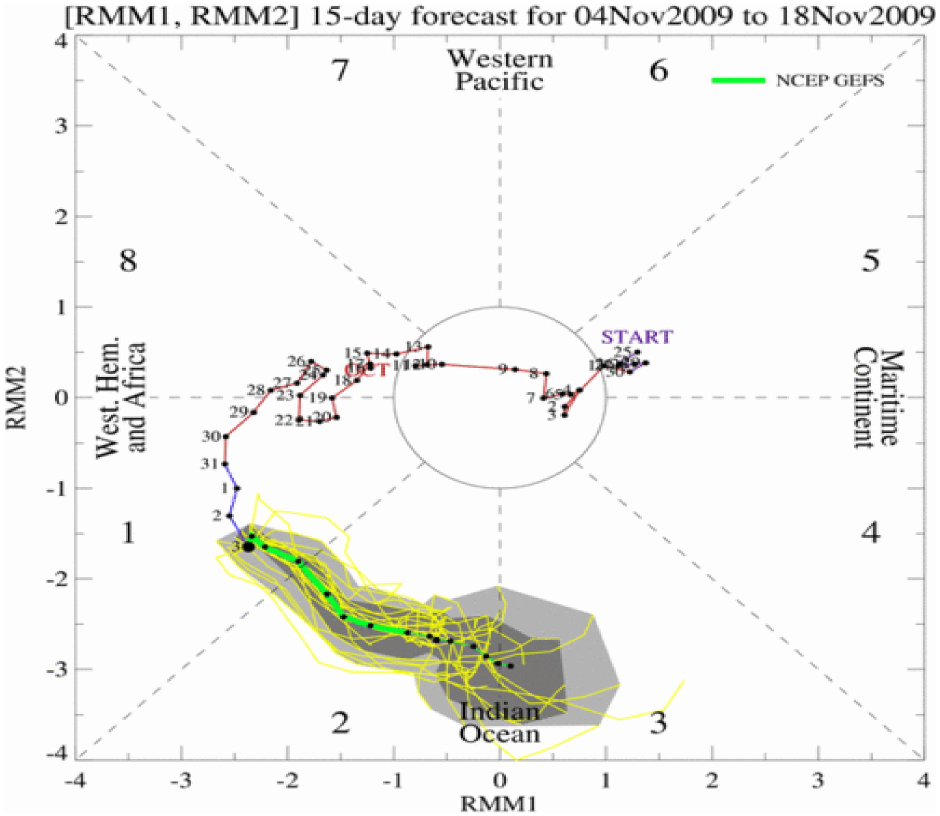
Display of MJO Forecast

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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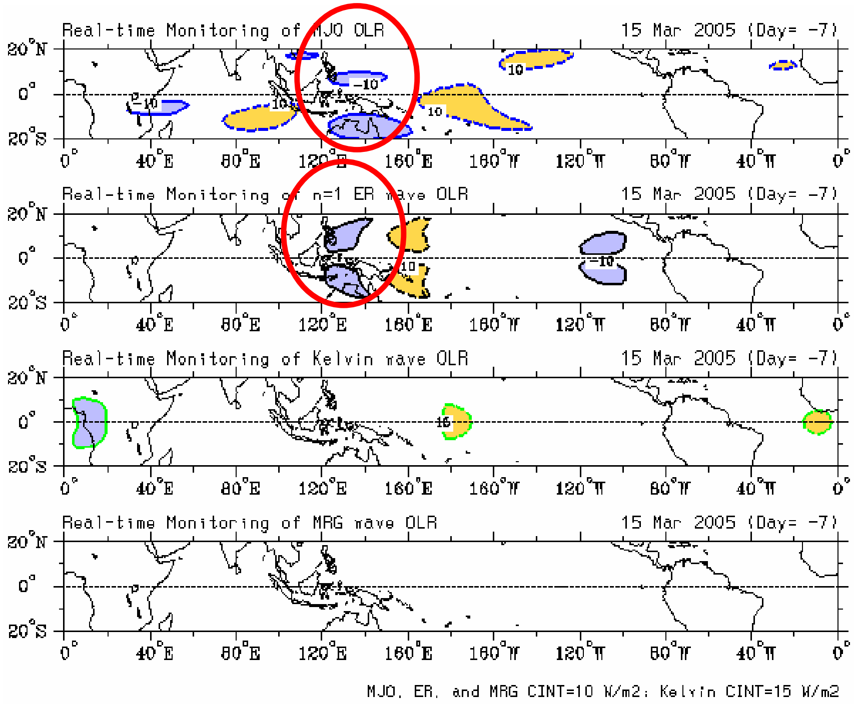
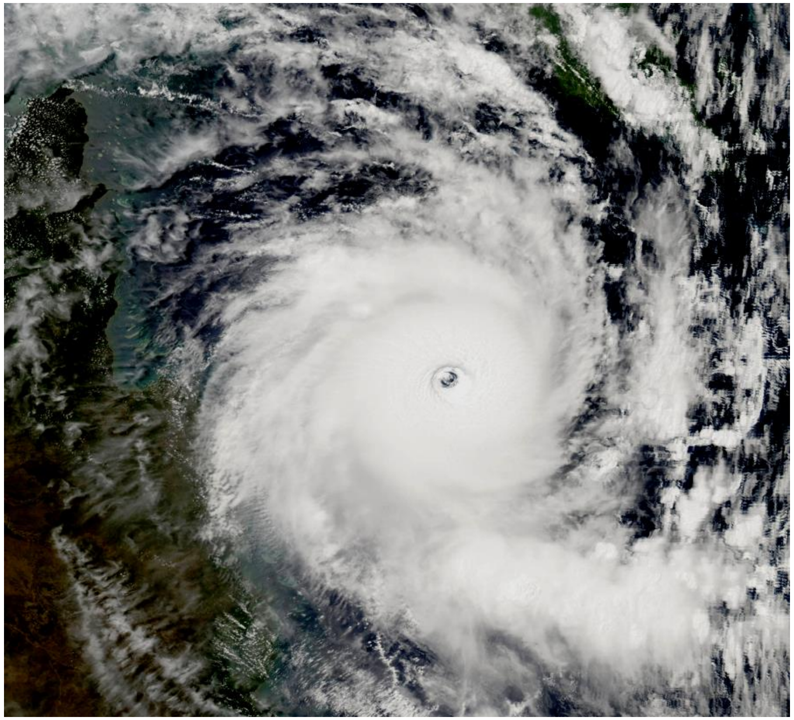
MJO and ER waves

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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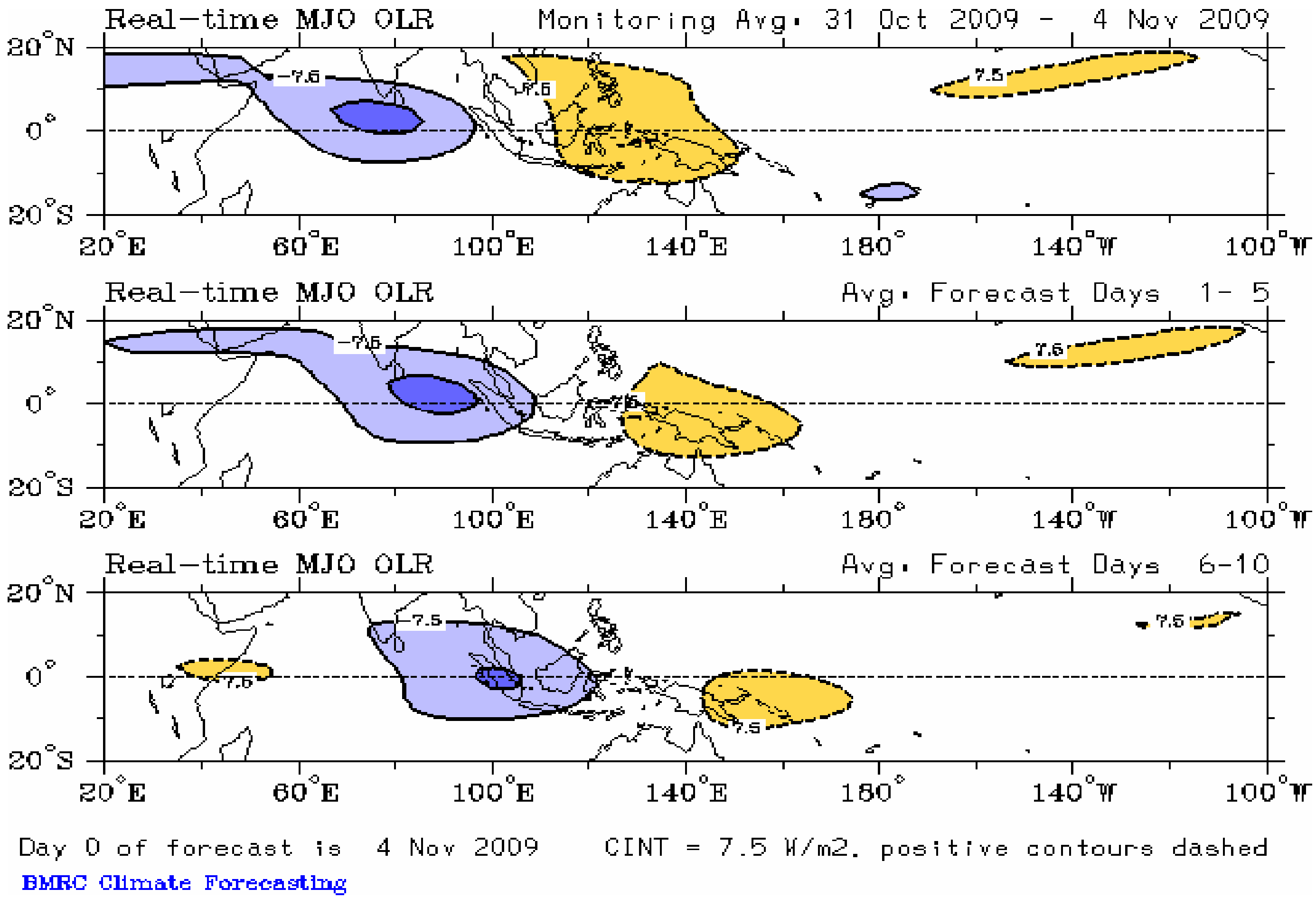
MJO Forecast Display for 7 day TC Outlook

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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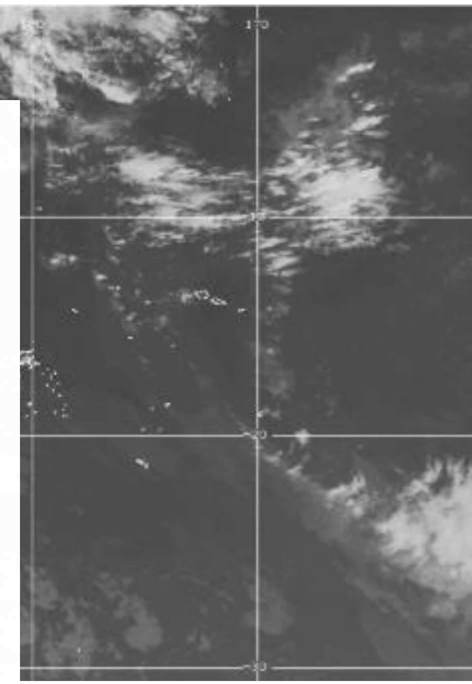
Daily monitoring
Will a TC develop?
What should we be looking for?



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

NWP: development; change in environment

- consistency between runs and between models
- Ensemble output for probabilistic outputs

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Interpreting NWP Guidance

Global models and ensembles

Consistency between models; run to run;

ensembles to derive probabilistic likelihood of formation

False alarm tendency at longer lead times +84h –

Ensemble probabilities too high because searches for

Any gales in any quadrant so thinks a monsoon gale

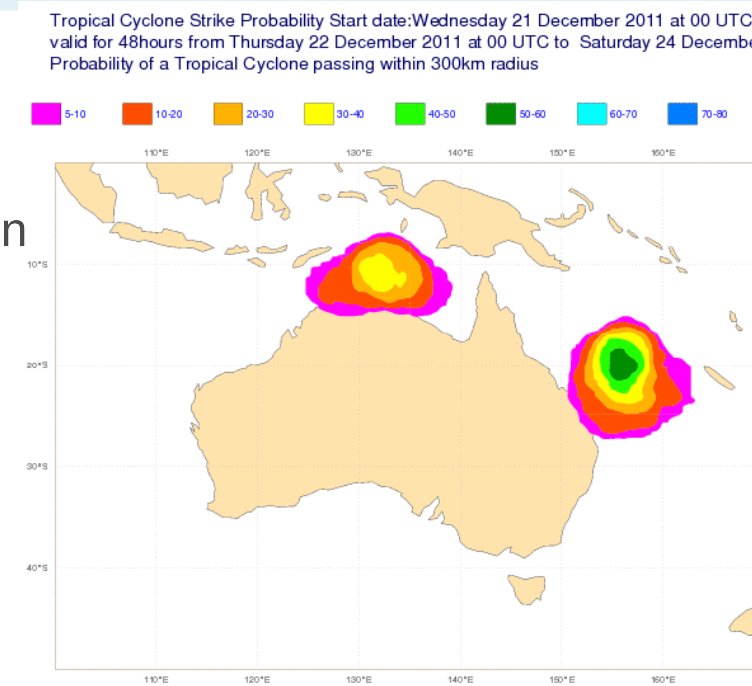
situation is a TC

Strong monsoonal forcing:

  can overdevelop lows at ~day 3+

Weak monsoonal forcing:

  can underdevelop at ~day 2+



Satellite interpretation for genesis

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Scatterometry changes: trough Vs closed circulation; wind strength

Deep convection changes:

- focal area; extent (how much); cloud top temperatures (how deep);
- persistence in convection (esp through diurnal min);
- curvature – low cloud & deep convection.

Dvorak T1 –T2 features

Microwave: 37GHz circulation (cyan ring)

24h changes (takes out the diurnal differences)

More complex – convection and shear intre-relationship – sometimes very strong convection can decrease shear by disrupting upper level flow upshear

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Difficult genesis: small systems

Development either within broad low (MJO/monsoon forced) or in absence of MJO

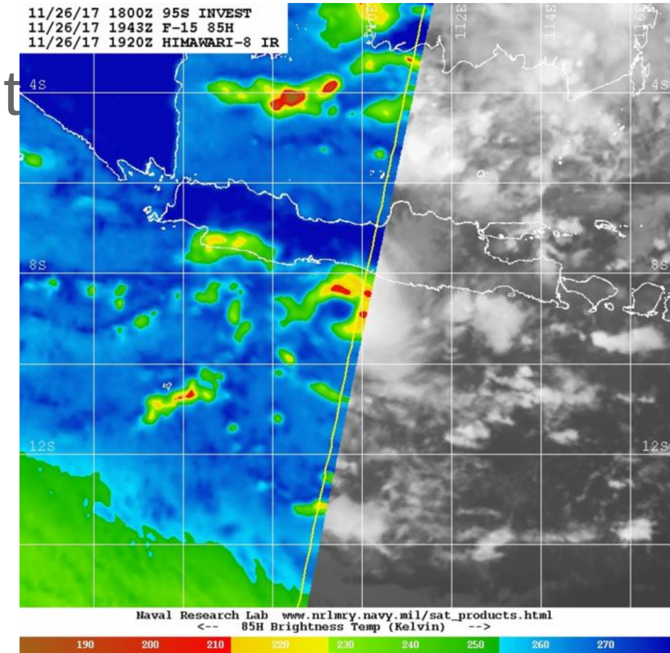
NWP – resolution issues too small to resolve; require high resolution models (ensembles will have weak bias)

Can develop rapidly

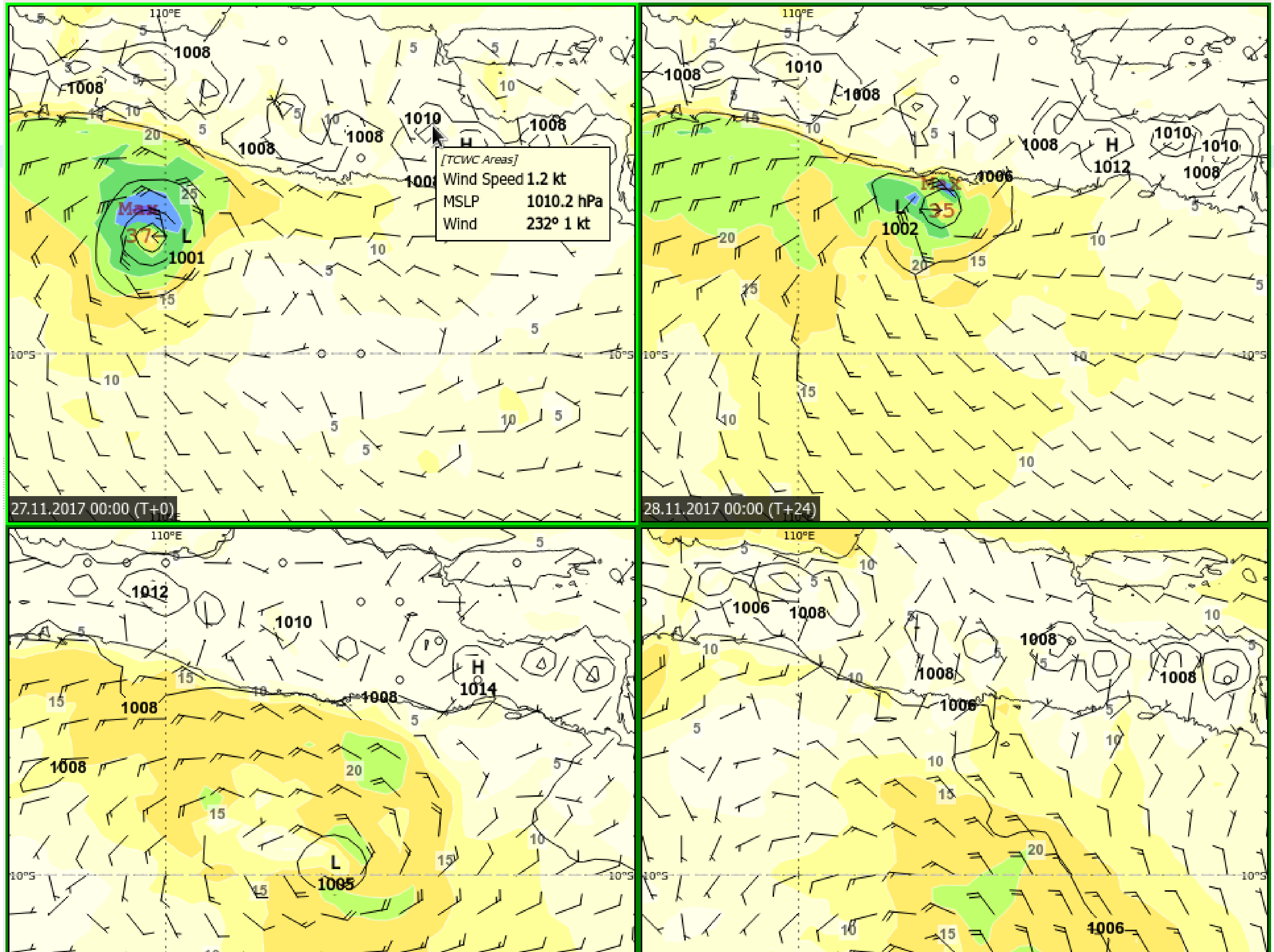
Dvorak development not followed; difficult

Attention on satellite changes

especially microwave and scatterometry

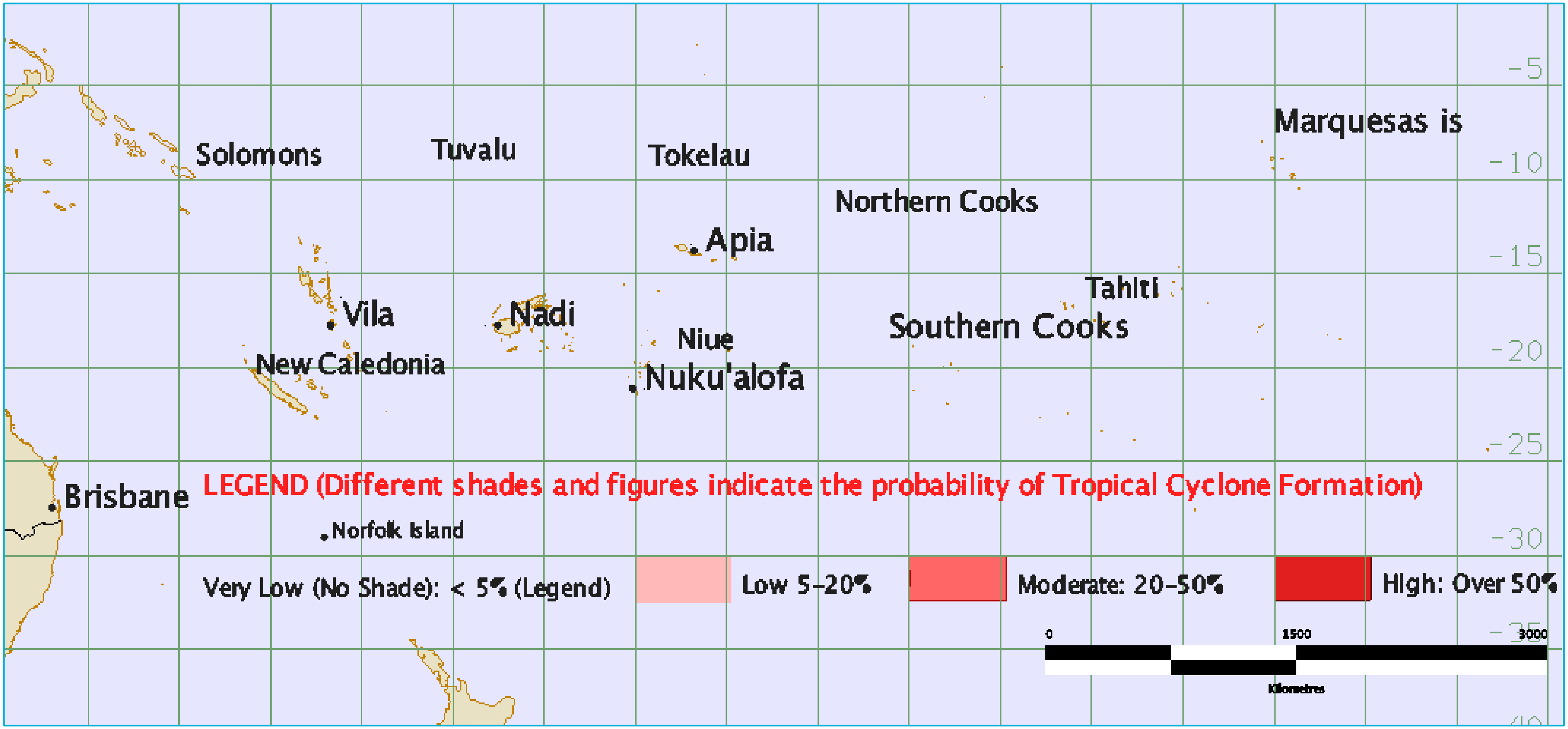


EC Model 27/00Z run for 0, +24, +48, +72h



Products: Fiji RSMC outlook

Highlights areas of very low/low/moderate/high chance of formation for each day to 3 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.
- Tropical waves are useful for heads up for possible formation beyond 5 days
- NWP guidance increasingly helpful in diagnosing likelihoods including using ensemble guidance
- QUIZ questions: socrative

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The genesis game

Teams of 3; dice to be rolled against each factor;

assess genesis overall for Day +1, Day+2, Day+3

Favourable -----------------Unfavourable

	1	2	3	4	5	6
Wind Shear	Low		Mod		High	
Low-mid RH	High		Mod		Low	
Upper outflow	Strong		Mod		Weak	
Low-level inflow	Strong		Mod		Weak	
SST	High >28C		Mild 27-28C		Cool <27	
Convection	Sustained for 2 days		Diurnally varying		disorganised	

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The genesis game

Roll dice for each;
low number means more favourable – high number not favourable
Assess likelihood of genesis at Day 1, Day 2, Day 3

	Team 1	Team 2	Team 3	Team 4
Wind Shear				
Low-mid RH				
Upper outflow				
Low-level inflow				
SST				
Convection				
TC Probability Day +1				
Day +2				
Day +3				