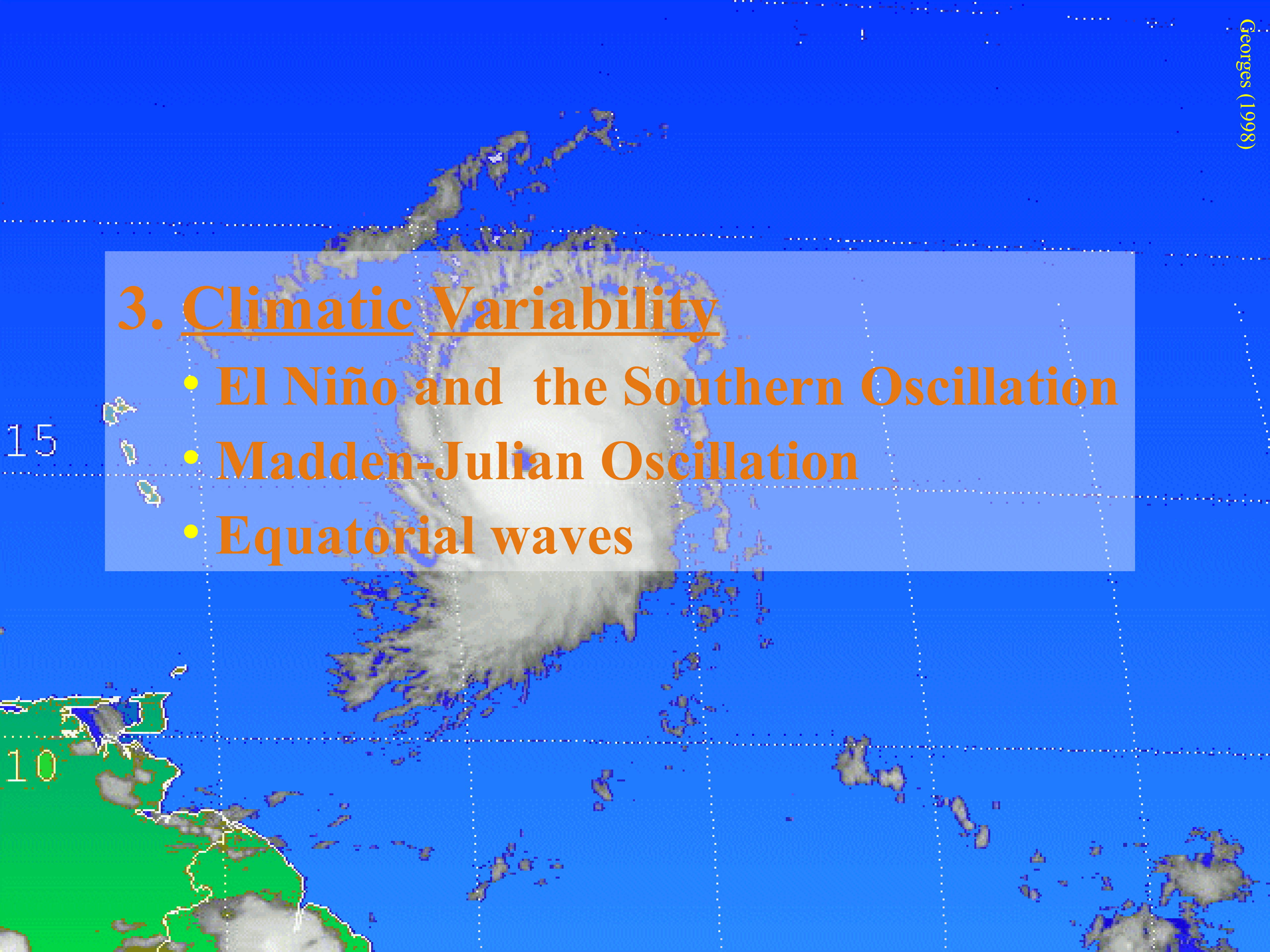
3. Climatic Variability

- El Niño and the Southern Oscillation
- Madden-Julian Oscillation
- Equatorial waves



ENVIRONMENTAL CONDITIONS FOR TROPICAL CYCLONES TO FORM AND GROW

- Ocean surface waters warmer than 26°C ;
- An unstable atmosphere to allow convection to develop ;
- Relatively moist layers in the mid-troposphere ;
- A minimum distance of 5-10° from the equator;
- A pre-existing disturbance near the Earth's surface with sufficient cyclonic vorticity and convergence ;
- Low values of vertical wind shear between the surface and the upper troposphere .

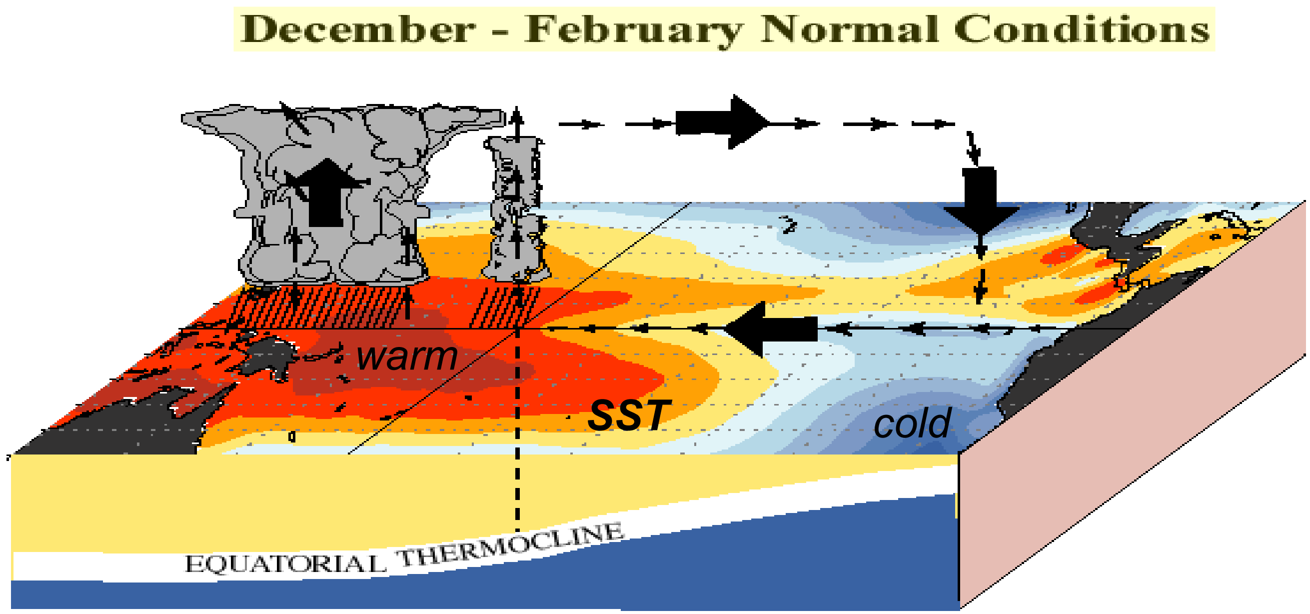
VARIATIONS IN THESE CONDITIONS AFFECT TROPICAL CYCLONE ACTIVITY

- Seasonal variations in tropical cyclone activity depend on changes in one or more of the six parameters
  (*e.g. N Indian : no TCs during the monsoon due to increased wind shear*)

- Variations in these parameters (both before and during the tropical cyclone season) can be used to understand and, in some cases, predict seasonal tropical cyclone activity.

- ENSO (El Niño – Southern Oscillation) is the primary driver of interannual variability of tropical cyclone activity.

« NORMAL » ATMOSPHERIC AND OCEANIC CONDITIONS OVER THE PACIFIC OCEAN (1)

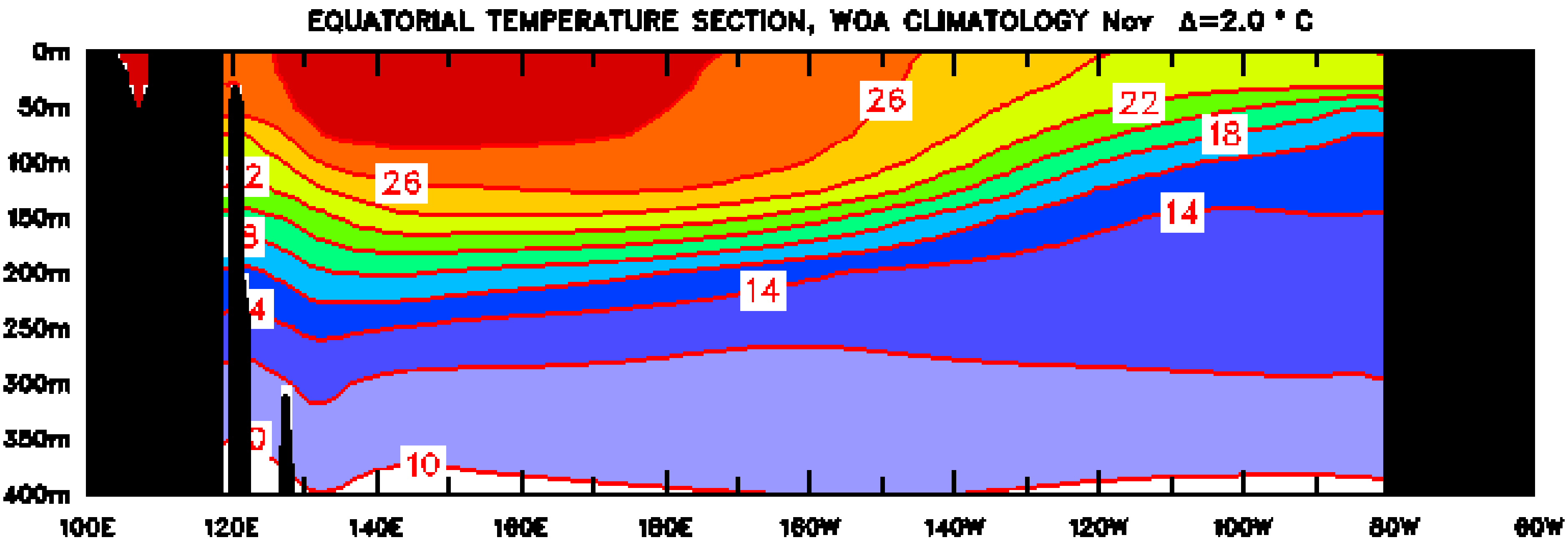


This distribution of SST and precipitation results from easterly (trade) winds in the lower troposphere and westerly winds aloft.

Over the equatorial western Pacific, a low pressure zone is associated with mean upward motions. High surface pressure et mean downward motions prevail to the east.

This « Zonal Walker Cell » represents the « normal » atmospheric circulation over the tropical and equatorial Pacific ocean.

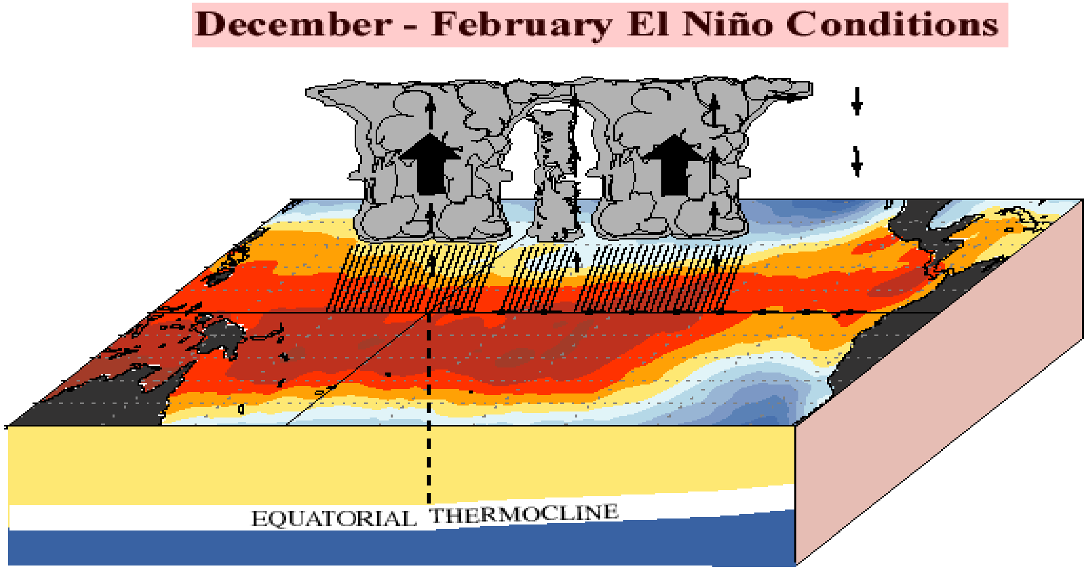
« NORMAL » ATMOSPHERIC AND OCEANIC CONDITIONS OVER THE PACIFIC OCEAN (2)



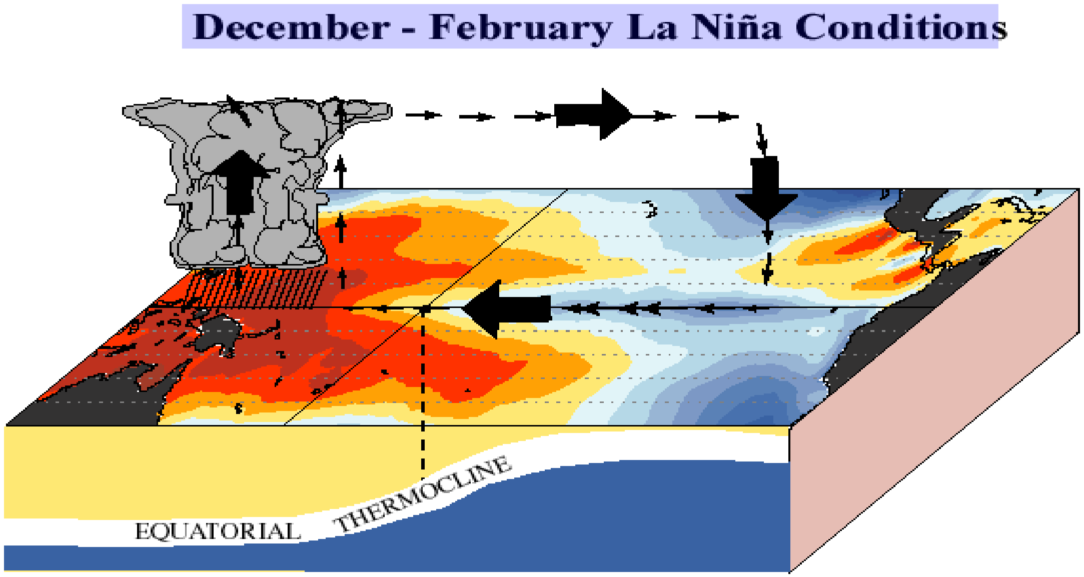
The thermal structure of equatorial and tropical Pacific reveals une <u>deep warm</u> *(SST > 27°C)* <u>layer to the west</u>, and a <u>cooler</u> *(SST<23°C)* <u>and thinner mixed layer to the east</u>.

Between the upper mixed layer and the deep water below, the <u>thermocline</u>, <u>varies in depth</u> from west (150-200m) to east (50-100m).

« PERTURBED » ATMOSPHERIC AND OCEANIC CONDITIONS OVER THE PACIFIC OCEAN

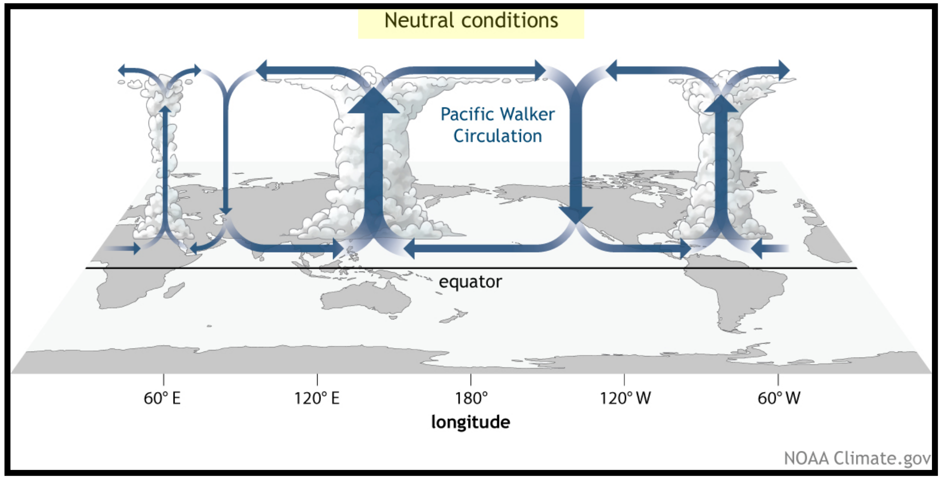


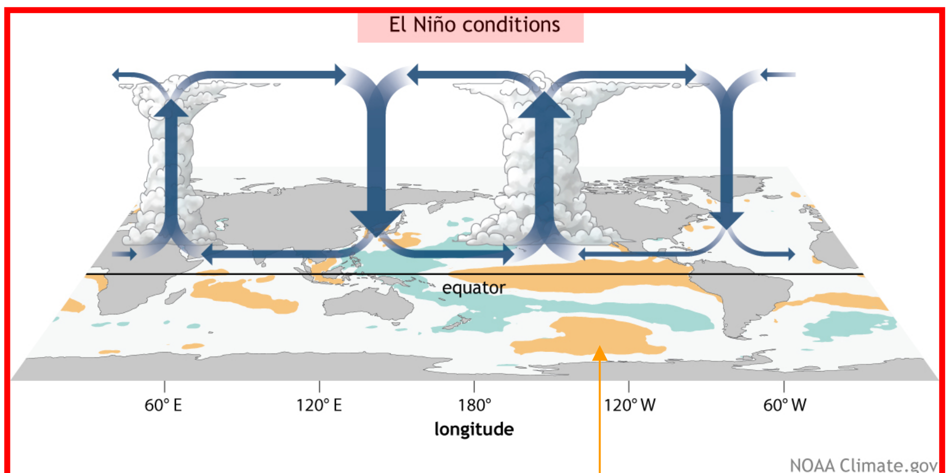
El Niño : The low-level easterly trade winds and the upper-tropospheric westerly winds are weaker, in relation with a less intense Walker Circulation.

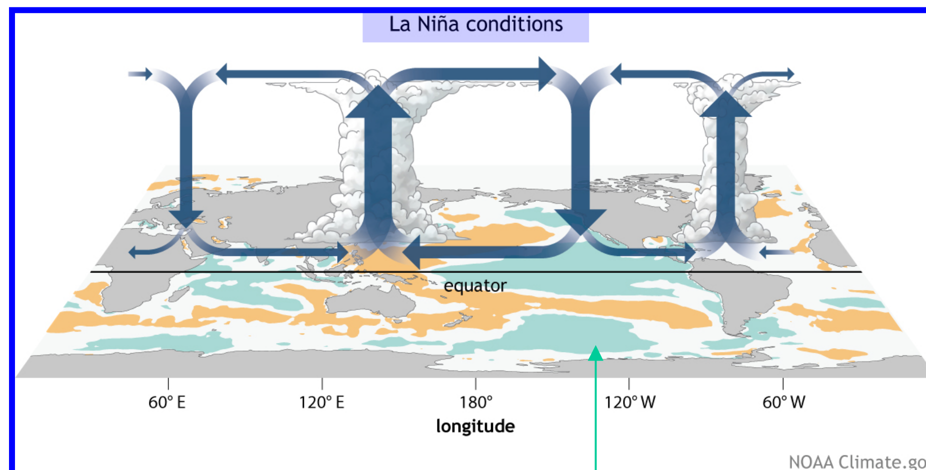


La Niña : The low-level easterly trade winds and the upper-tropospheric westerly winds are stronger, in relation with a more intense Walker Circulation.

« PERTURBED » GLOBAL WALKER CIRCULATION



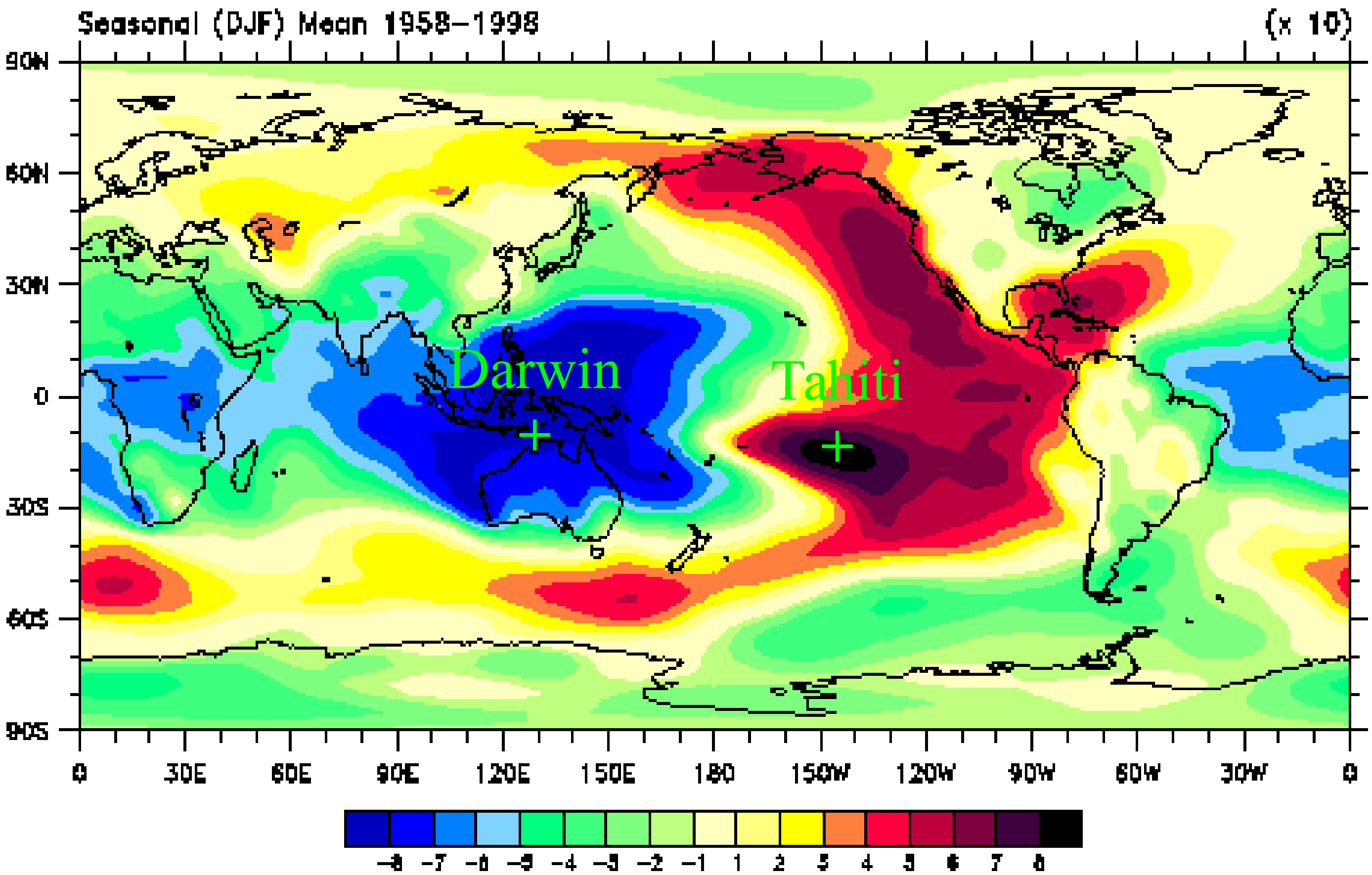




$\Delta SST > 0$

$\Delta SST > 0$

THE GLOBAL INFLUENCE OF ENSO

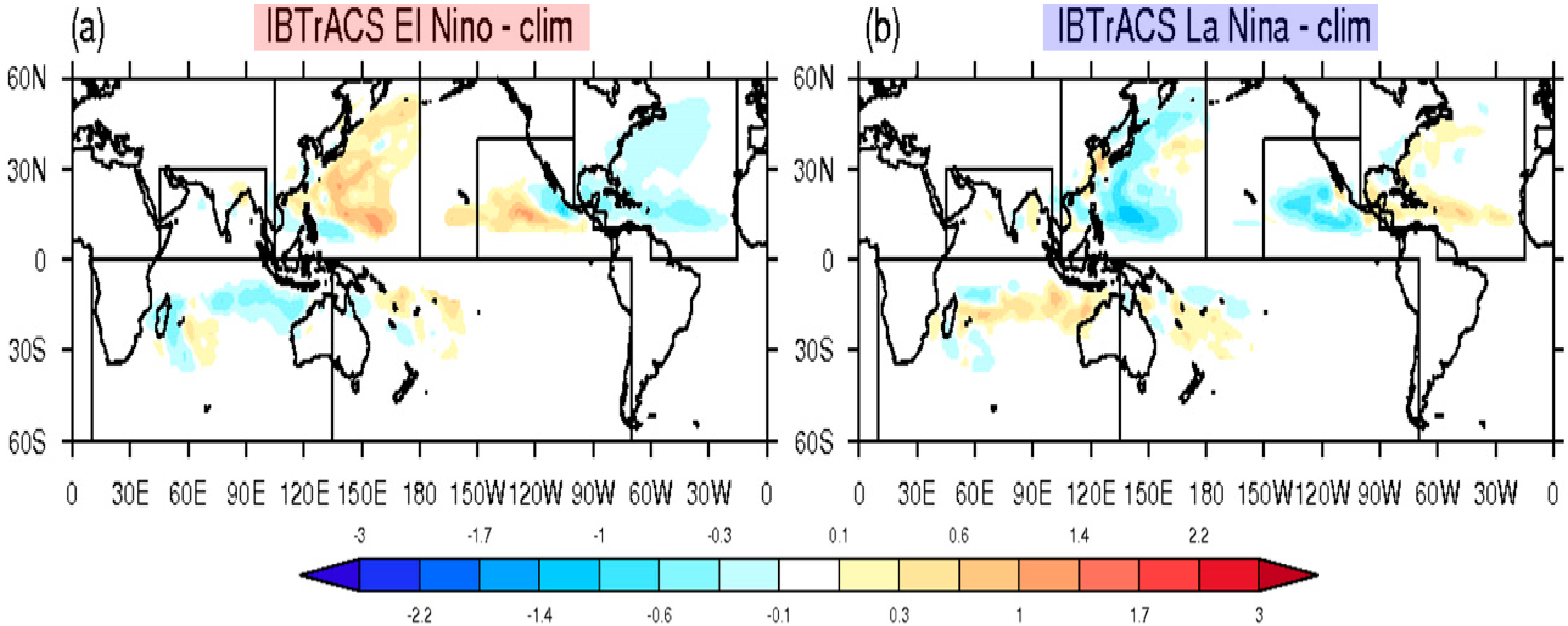


The map of <u>global correlations of sea-level pressure (SLP) with Tahiti</u> *(Central Pacific : 17° 52' S - 149° 56' W)* reveals the very large atmospheric influence zone of ENSO.

<u>Darwin</u> *(N Australia, 12° 28' S - 130° 51' E)* can be considered as the opposite pole to Tahiti.

TROPICAL CYCLONES VARIABILITY
ENSO / Global

Bell *et al.* 2014: *J. Climate*, **27**, 6404–6422

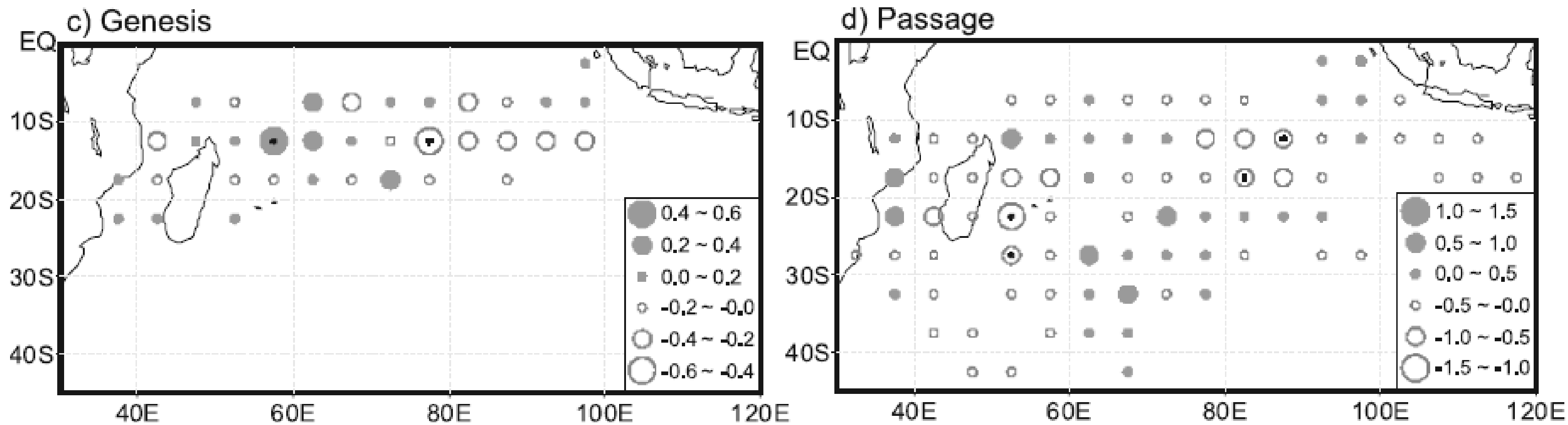


Tropical cyclone track density (nb storms / month / 10^6 km^2)
from IBTrACS during May–November in the Northern Hemisphere and October–May in the Southern Hemisphere
(a) El Niño years minus 1979–2010 climatology,
(b) La Niña years minus 1979–2010 climatology.

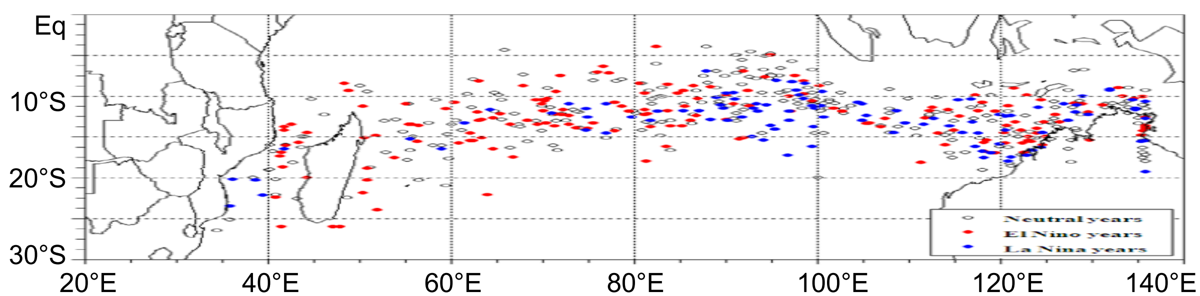
TROPICAL CYCLONES VARIABILITY
ENSO / South Indian (2)

Ho *et al.* 2006 : *J. Geophys. Res.*, <u>111</u>, D22101

El Niño minus La Niña



Kuleshov *et al.* 2006 : *Ann. Geophys.*, <u>27</u>, 2523-2538



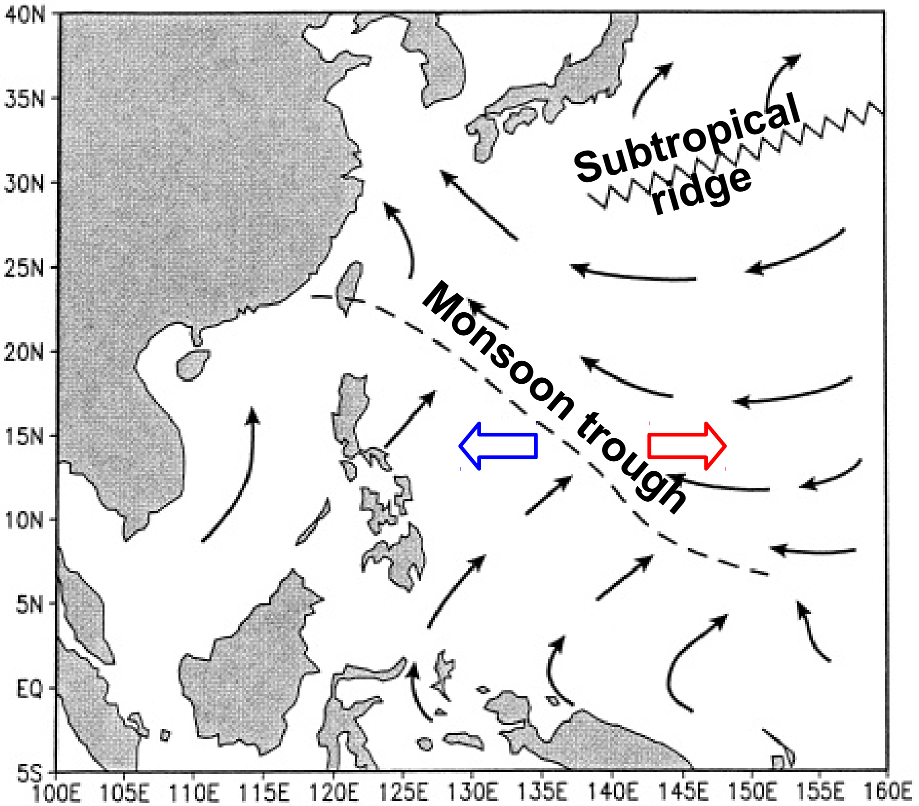
The <u>formation area</u> for tropical cyclones in the south Indian ocean tends to shift west in El Niño compared to La Niña seasons (*changes in SST, low-level vorticity, mid tropospheric humidity, wind shear ?*)

TROPICAL CYCLONES VARIABILITY
ENSO / western North Pacific (1)

The "monsoon trough" over western North Pacific is marked by moist, southwest monsoon flow to the south, and drier easterly trades to the north.

Tropical disturbances often form in the trough where there is a weak cyclonic rotation.

The monsoon trough is displaced eastward during an El Niño, westward during La Niña, so will the associated tropical storms and cyclones.

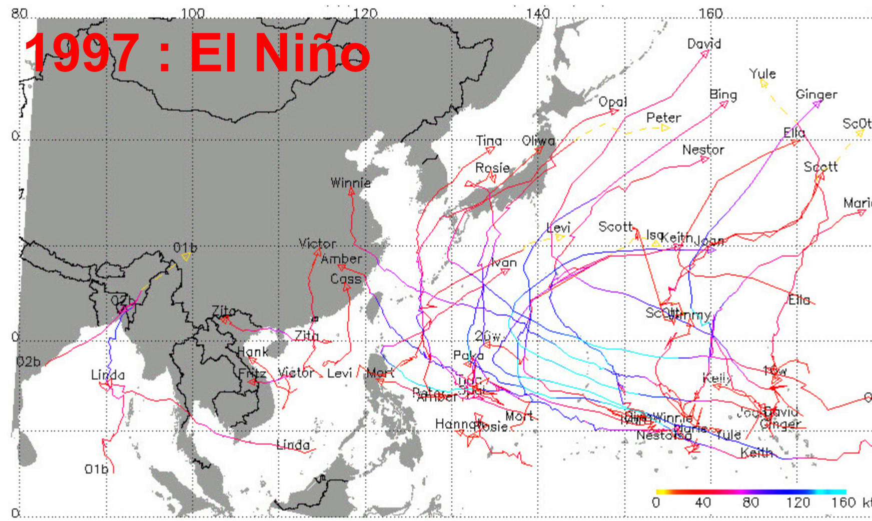


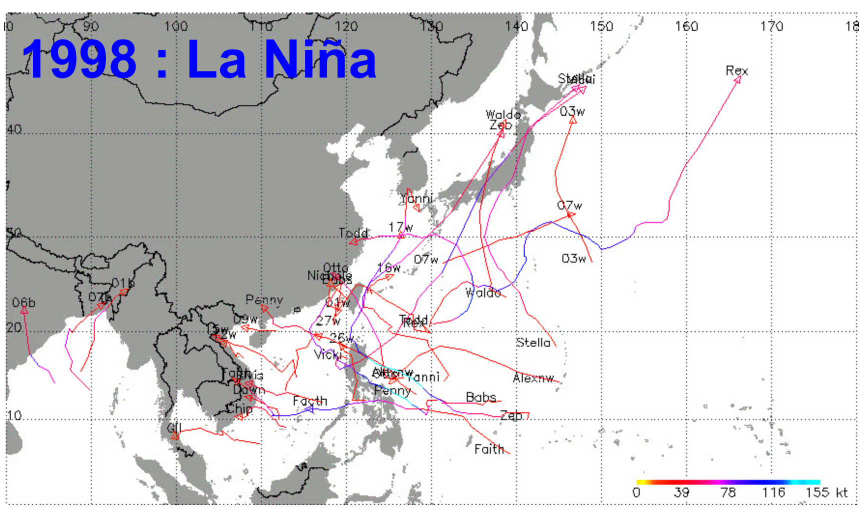
Schematic showing the long-term mean surface circulation in August in the western North Pacific. The monsoon trough axis is denoted as a broken line, and the ridge axis is denoted as a zigzag line. Wind directions are indicated by arrows.

Chu, P.S., 2004 : « *ENSO and Tropical Cyclones* », in « *Hurricane and Typhoons Past, Present, Future* », R.J. Mundane & K.B. Liu eds., pp. 297-332, New York, Columbia University Press.

TROPICAL CYCLONES VARIABILITY
ENSO / western North Pacific (2)

During El Niño years, the eastward and equatorward shift in origin location allow TCs to maintain a longer lifespan while tracking westward over open water. Interactions with transient midlatitude synoptic systems result in more recurved trajectories toward NE Asia.

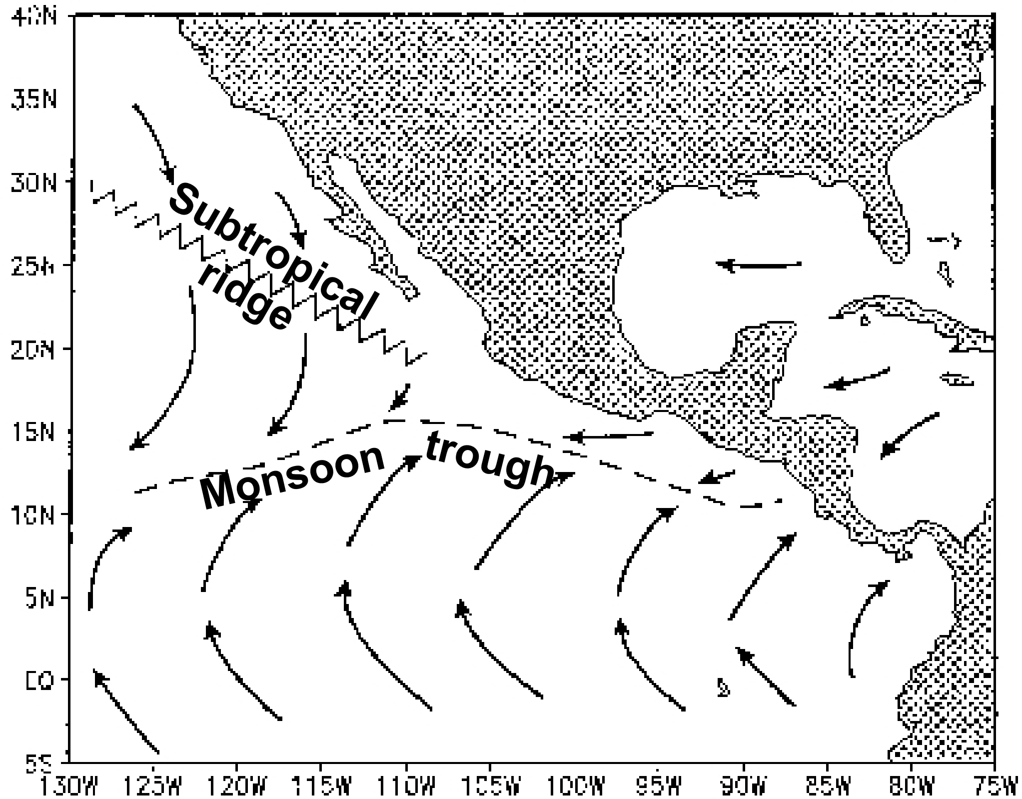




During La Niña years, the monsoon trough is short and confined in the western extreme of N Pacific. Landfalls are more common in the SE Asia shores.

TROPICAL CYCLONES VARIABILITY
ENSO / eastern North Pacific (1)

A majority of storms form along the axis of the <u>monsoon trough</u>, but TCs might also be triggered by <u>tropical Easterly Waves</u> from West Africa and the Atlantic.



Schematic showing the long-term mean surface circulation in August in the eastern North Pacific. The monsoon trough axis is denoted by a broken line, and the ridge axis by a zigzag line. Wind directions are indicated by arrows.

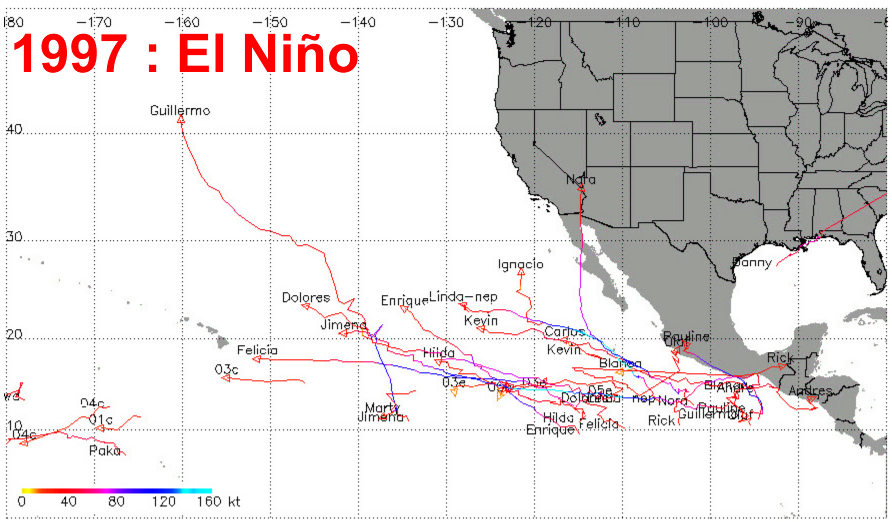
!! when TCs are <u>active in the eN Pacific</u>, they tend to be <u>suppressed over the Atlantic</u> and vice versa !!

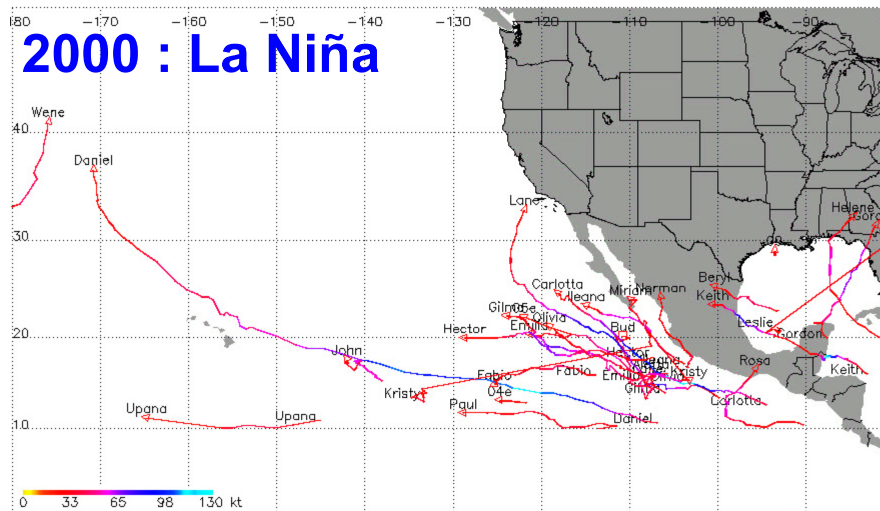
TROPICAL CYCLONES VARIABILITY
ENSO / eastern North Pacific (2)

There is no obvious impact of ENSO on the overall TC frequency in the eN Pacific.

TC tracks expand westward during El Niño years, and retreat eastward during La Niña.

If only intense storms (Saffir-Simpson category ≥3) are considered, the ratio during El Niño to La Niña years is about 1.7.

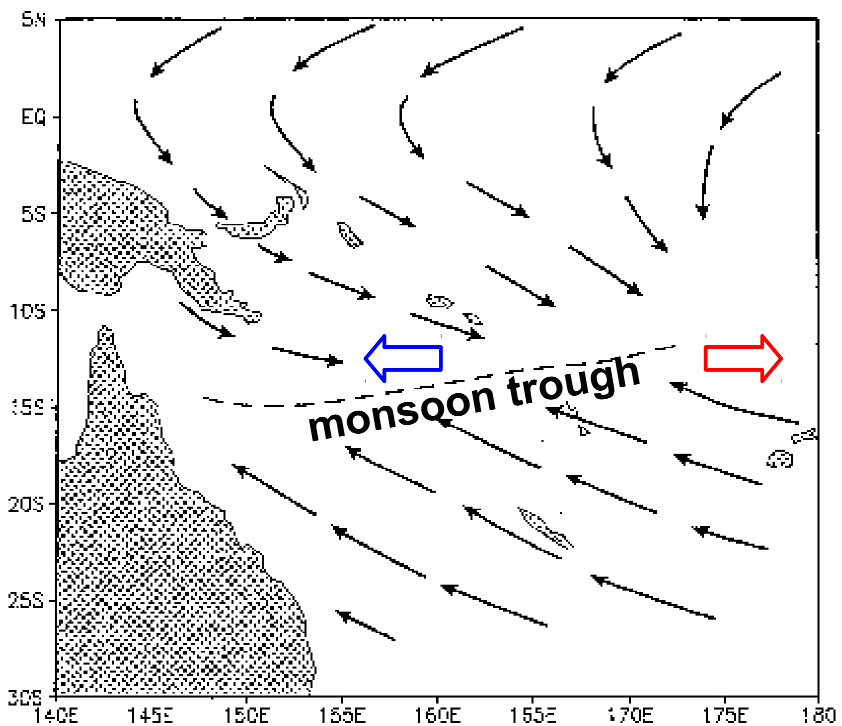




TROPICAL CYCLONES VARIABILITY
ENSO / western South Pacific (1)

There is a strong correlation between the SOI and TC days in the **Australian region (105°E – 155°E).**

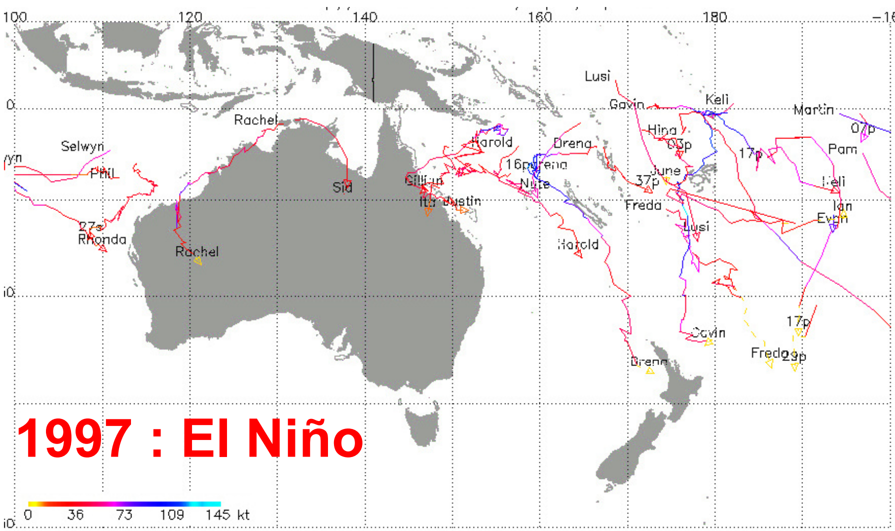
Higher SLP, cooling of ocean surface, and the sinking branch of the Walker circulation during El Niño years combine to produce unfavourable conditions for TC formation.

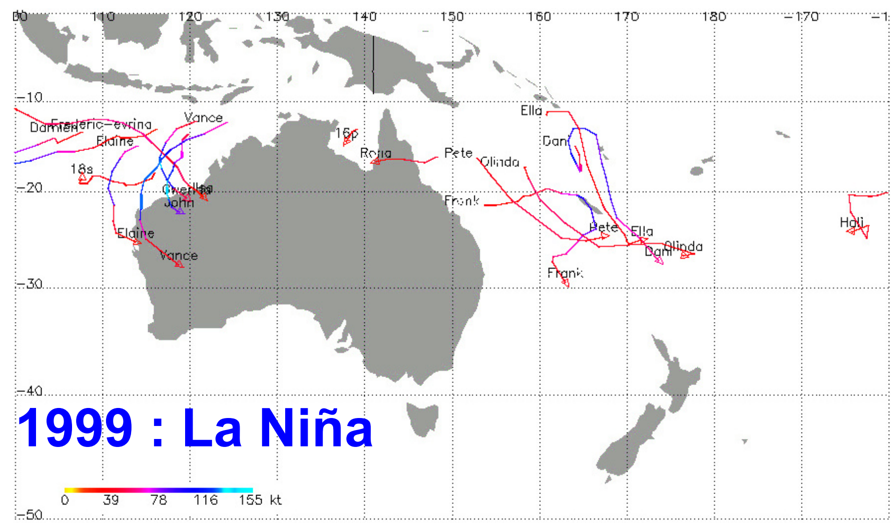


Schematic showing the long-term mean surface circulation in February in the southwestern Pacific. The monsoon trough axis is indicated by a broken line. Wind directions are indicated by arrows.

In the **wS Pacific (>155°E)**, the eastern end of the monsoon trough is usually near 175°E, but it can extend as far east as 140°W during El Niño years.

TROPICAL CYCLONES VARIABILITY
ENSO / western South Pacific (2)

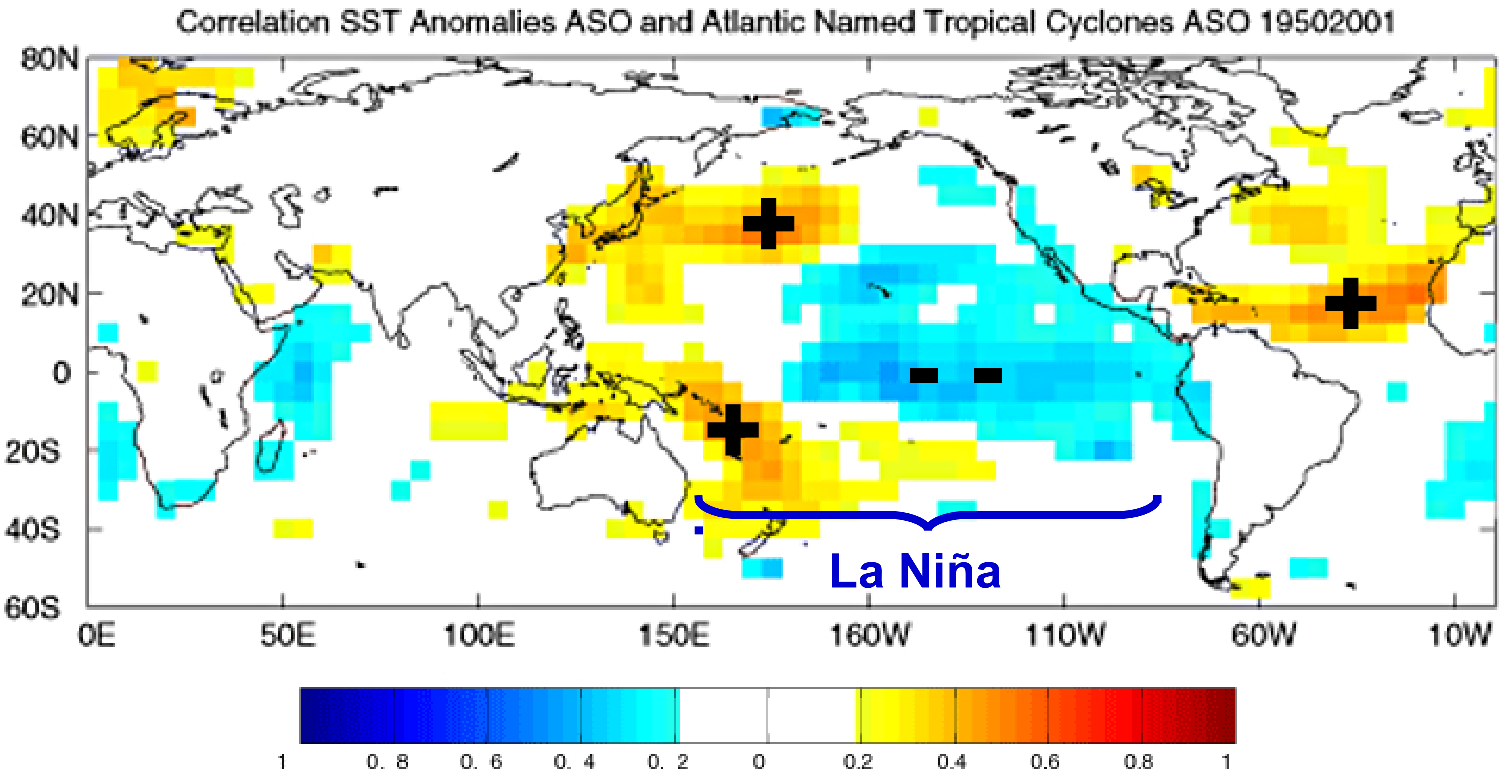




During El Niño years, the median location of TC genesis points is about 20° eastward from the climatological mean.

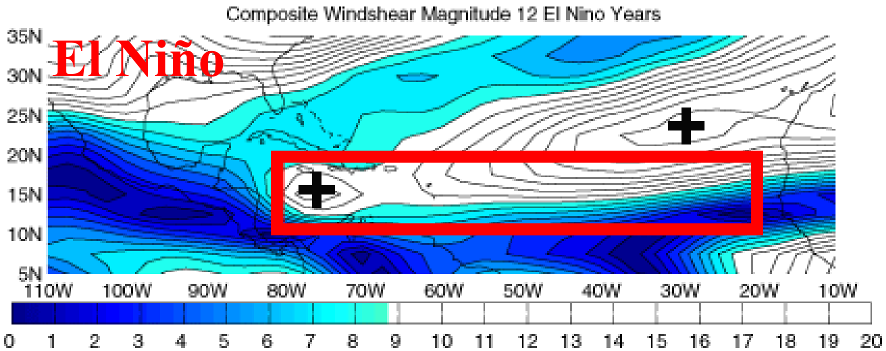
During La Niña years, TCs form more closer to Australia with a higher risk of landfall.

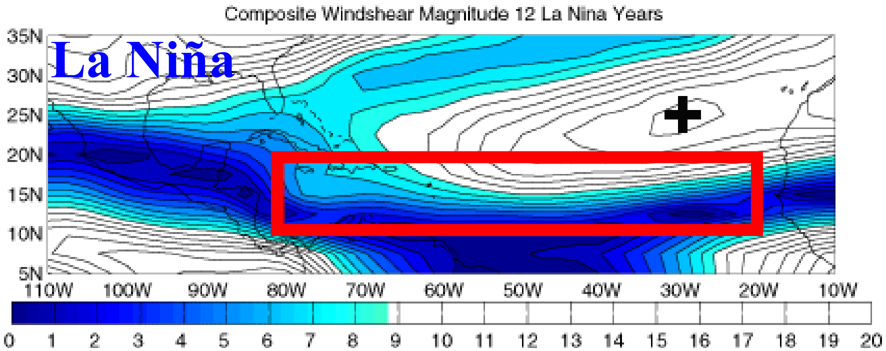
TROPICAL CYCLONES VARIABILITY
ENSO / Atlantic (1)

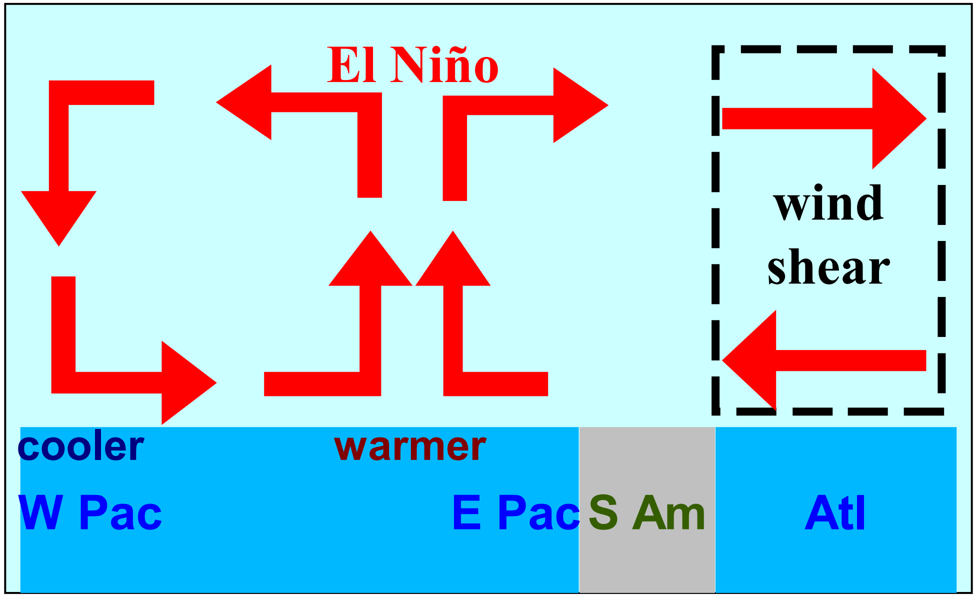


There are <u>more storms</u> over the Atlantic during La Niña years than during El Niño years

TROPICAL CYCLONES VARIABILITY
ENSO / Atlantic (2)

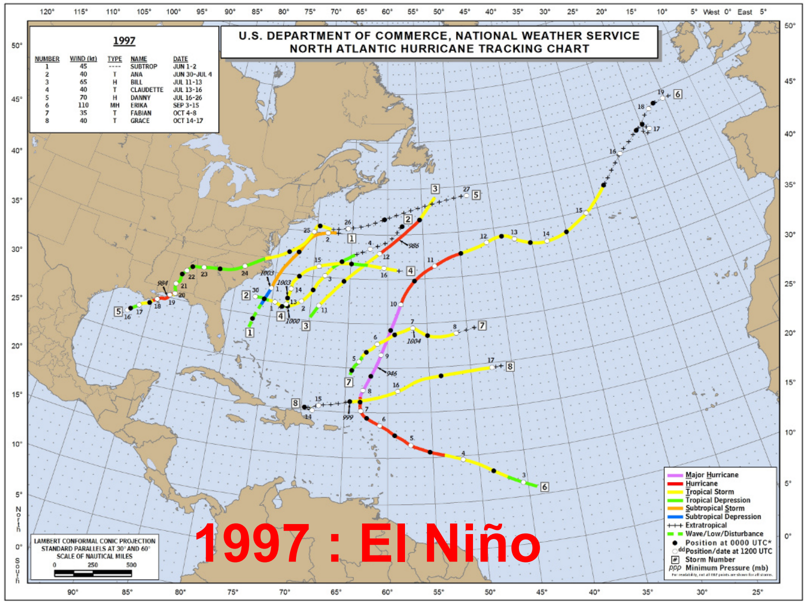






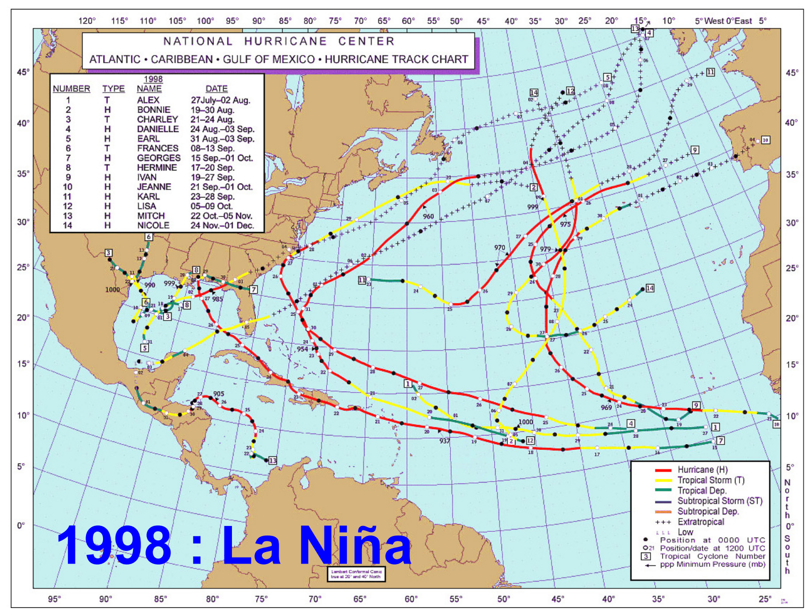
<u>Changes in the vertical wind shear</u>
are the most important environmental factor
in modulating the TC activity over the Atlantic.

TROPICAL CYCLONES VARIABILITY
ENSO / Atlantic (3)

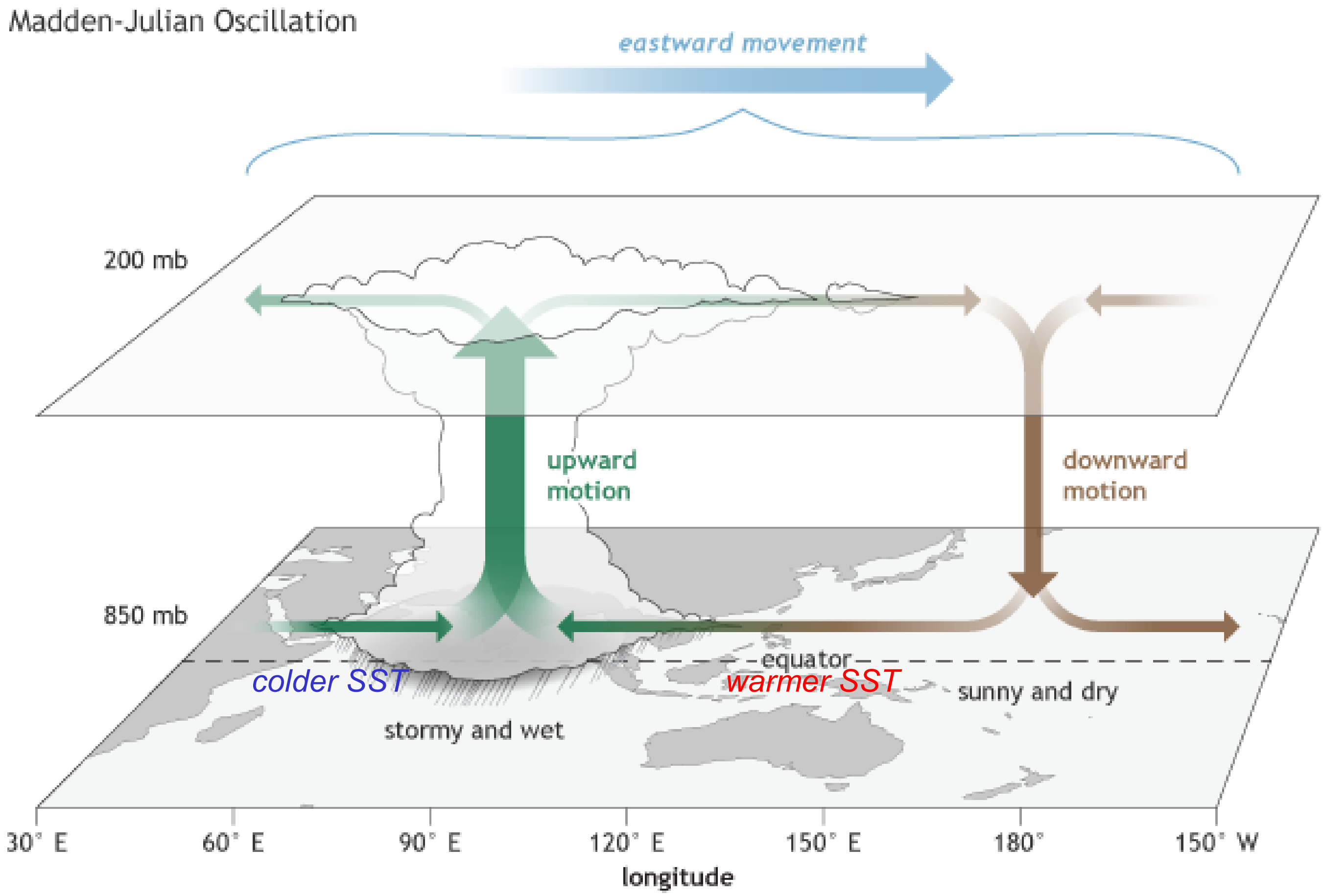


During "El Niño", <u>enhanced upper-level divergent outflows</u> from the Walker circulation cause <u>subsidence</u> and upper-level westerly winds <u>intensifying the vertical wind shear</u>, over the Caribbean and tropical Altantic.

"La Niña" has a profound impact on hurricane <u>number</u>, <u>lifetime</u>, <u>intensity</u> and <u>landfall probability</u>. There is a <u>20:1 ratio in median damage per year</u> during the opposite phases (*3 billion US$ in La Niña vs. 150 million US$ in El Niño*).

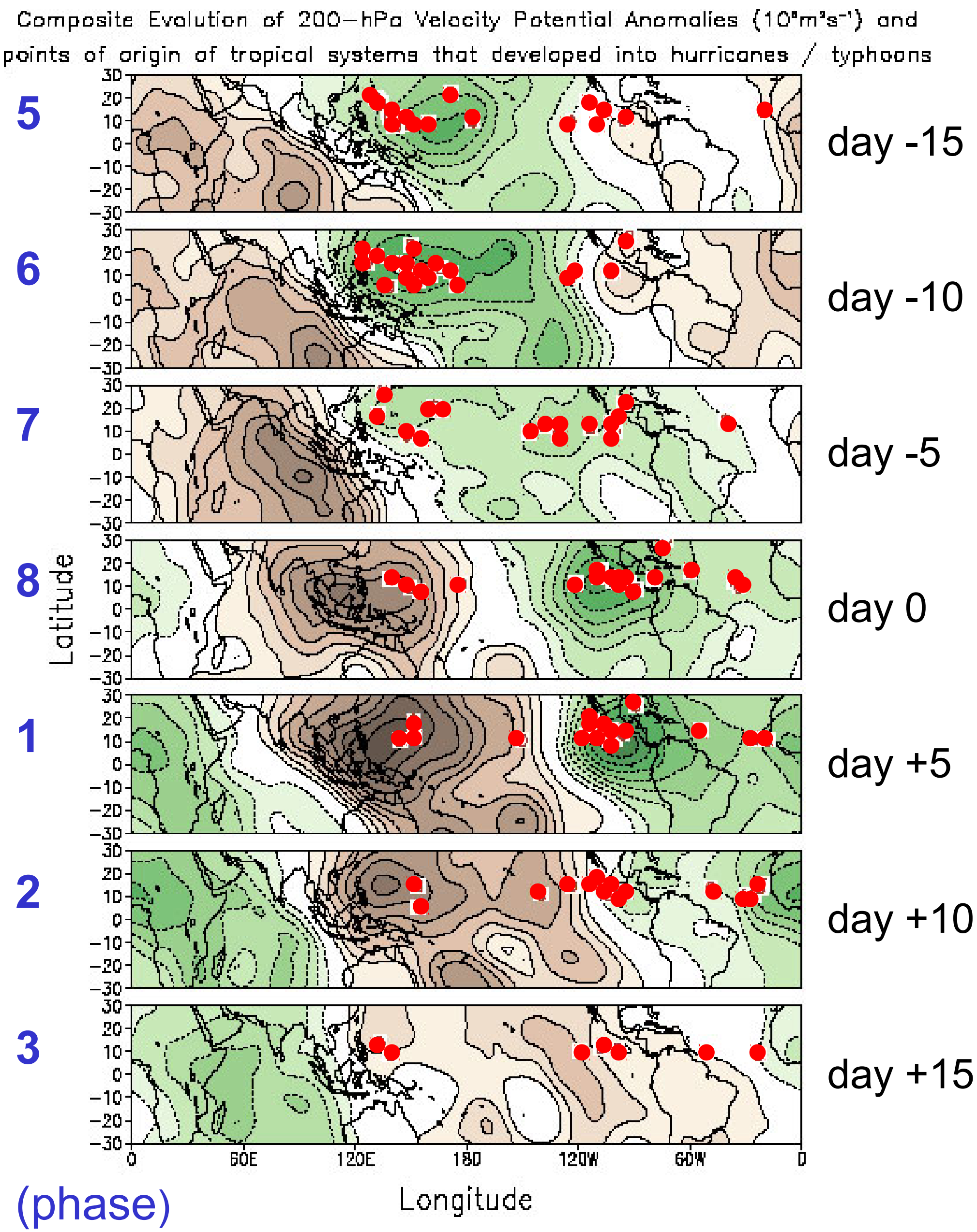


Madden-Julian Oscillation – MJO (1)



The Madden–Julian oscillation (MJO) is the largest element of the intraseasonal (30- to 90-day) variability in the tropical atmosphere. It is a large-scale coupling between atmospheric circulation and tropical deep convection. The MJO is a traveling pattern that propagates eastward at 4 to 8 m/s, through the atmosphere above the the tropical Indian and Pacific oceans. This overall circulation pattern manifests itself most clearly as anomalous rainfall.

TROPICAL CYCLONES VARIABILITY : MJO



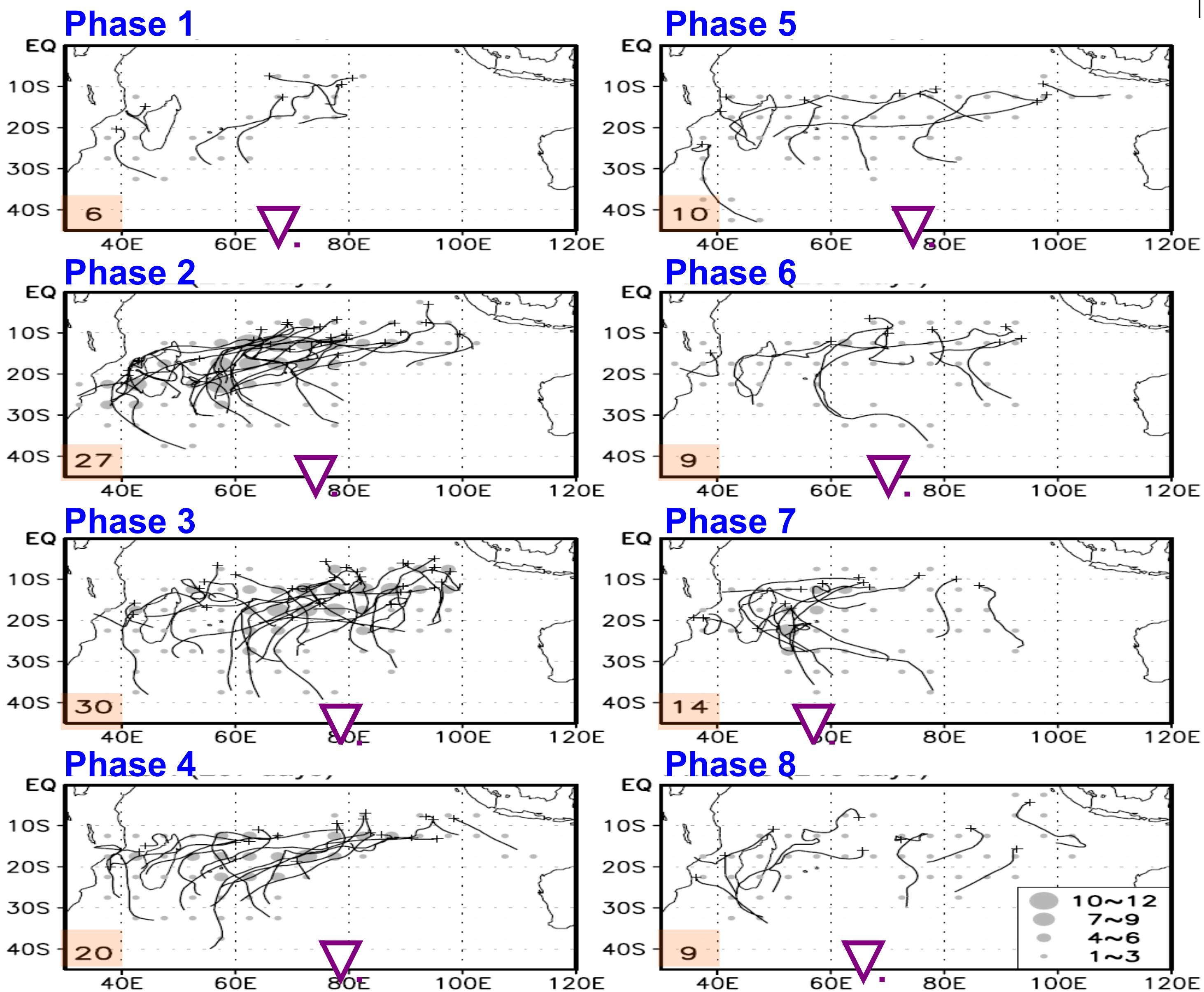
Higgins & Shi 2001 : *J. Climate*, 14, 403-417

*The origins of tropical cyclones that developed into western North Pacific typhoons are shown as red dots. The **green** **(brown)** shading roughly corresponds to regions where **convection is favored (suppressed)** as represented by 200-hPa velocity potential anomalies.*

The MJO produce a strong modulation of TC activity, in relation with associated variations in low- and upper-level winds, vertical wind shear, atmospheric humidity and temperature, organized convection, SST, …

TROPICAL CYCLONES VARIABILITY
MJO / South Indian

Ho et al. 2006 :
J. Geophys. Res., 111, D22101



Genesis and track of TCs for each MJO phase.

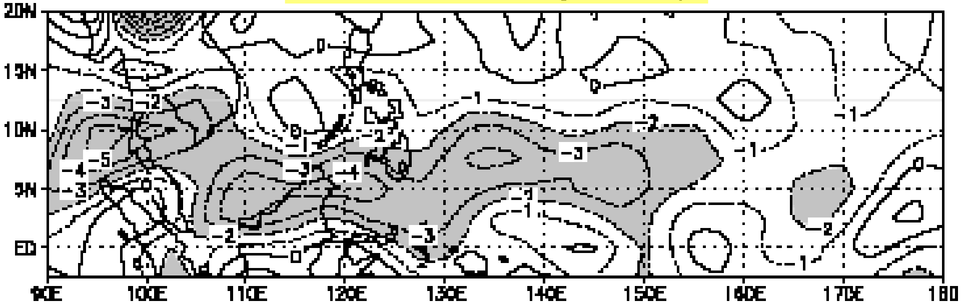
The inverted triangles are the median of genesis longitudes.

TC genesis numbers are shown in the bottom left corner for the corresponding MJO phase.

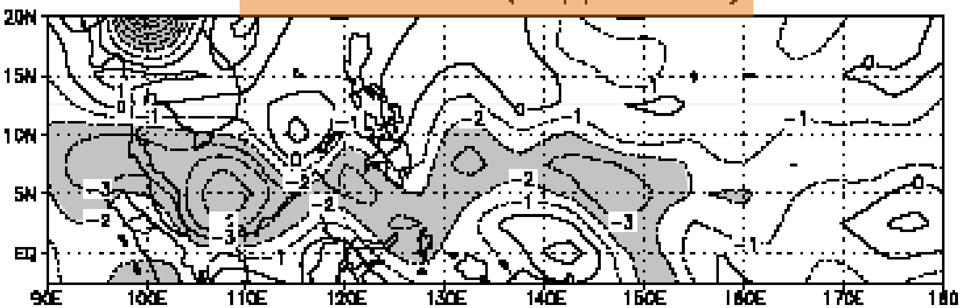
TROPICAL CYCLONES VARIABILITY
MJO / western North Pacific

Sobel & Maloney 2000 :
Geophys. Res. Lett.,
27, 1739-1742

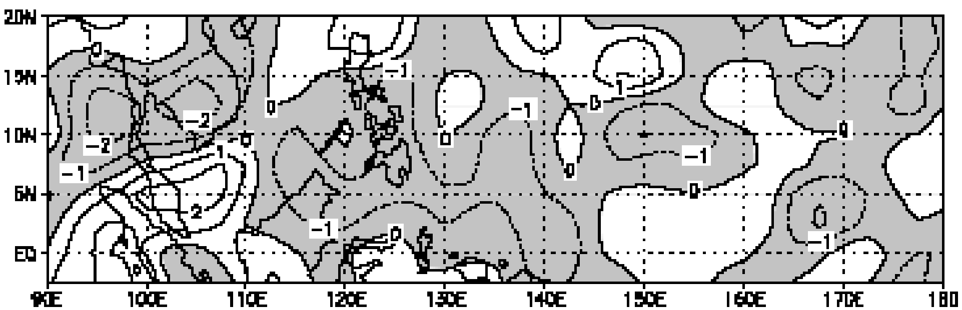
Phases 5–8 (active)



Phases 1–4 (suppressed)



Difference

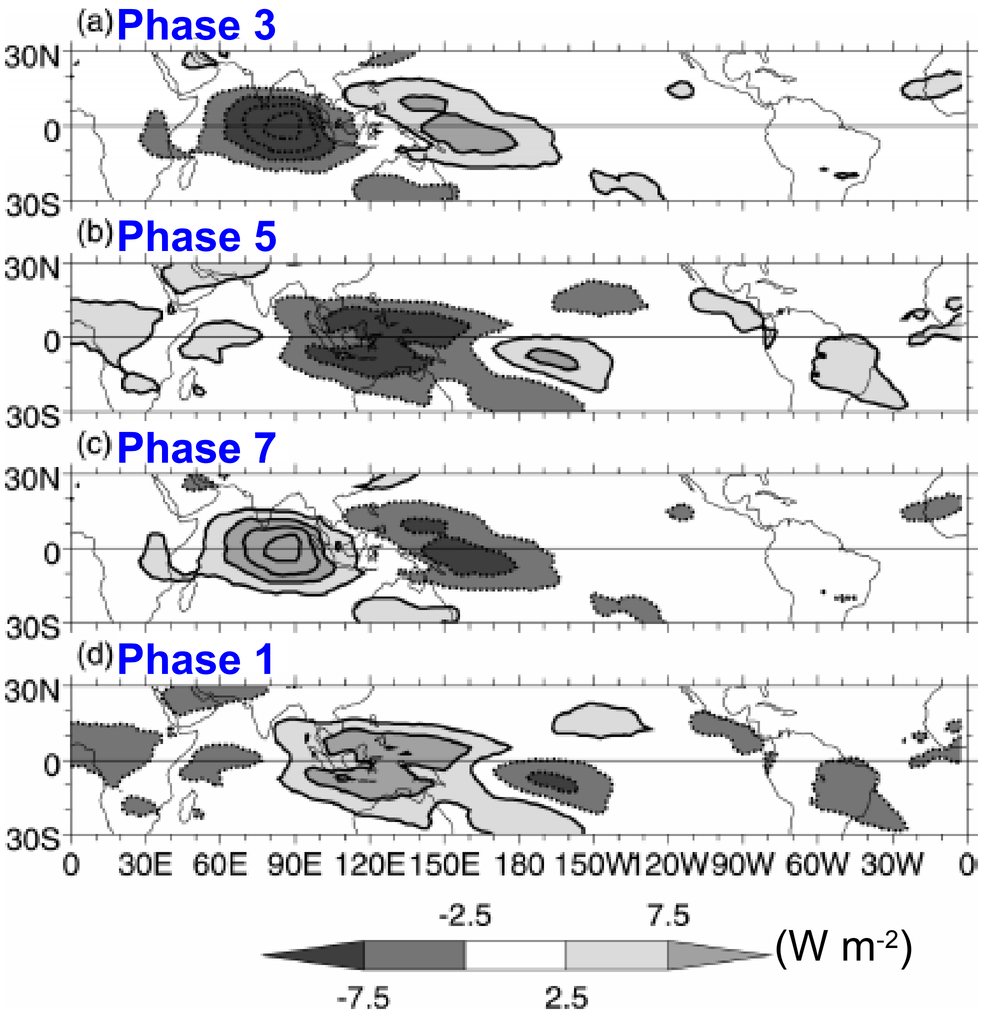


Group velocity divergence at 850 hPa composited over the active (top) and suppressed (middle) phases of the MJO, in units of 10^{-6} s^{-1}.

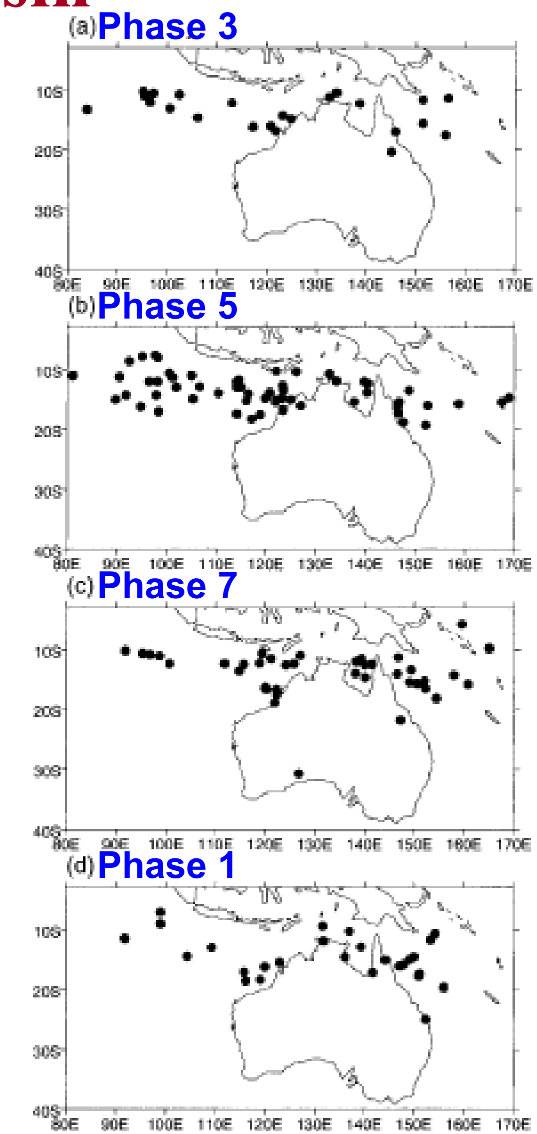
Convergence is larger in the active MJO phase than during the suppressed phase by about 1 x 10^{-6} s^{-1}. The tongue of large convergence also shifts slightly northward in the active phase. wN Pacific tropical cyclones are more frequent during the active phase, because of the existence of a larger number of precursor depressions.

TROPICAL CYCLONES VARIABILITY
MJO / Australian basin

Hall et al. 2001 : *Mon. Wea. Rev.,* 129, 2970–2982



Anomaly maps of OLR for MJO category



TC genesis locations for MJO category

TROPICAL CYCLONES VARIABILITY
MJO / eastern North Pacific

Maloney & Hartmann 2000 : *Science* , 287 , 2002-2004

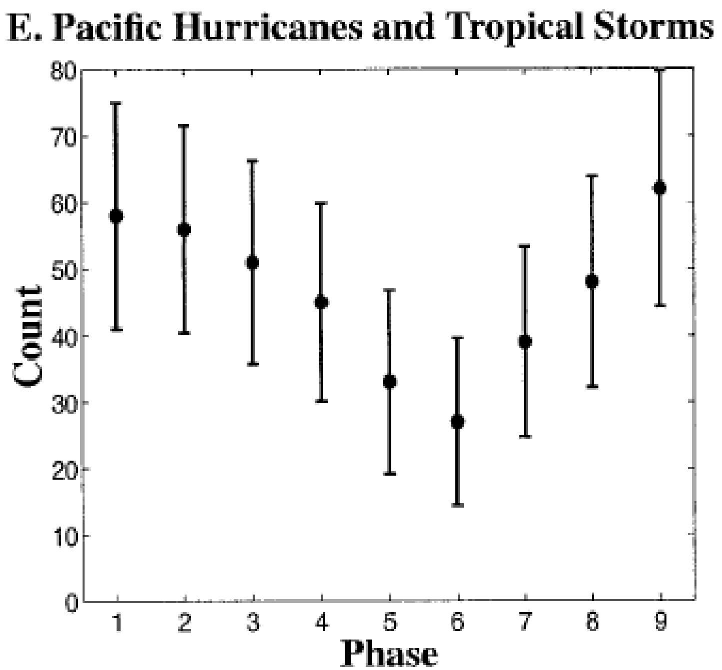


FIG. 10. Number of hurricanes and tropical storms as a function of MJO phase for the eastern Pacific Ocean hurricane region during May–Nov 1979–95. Error bars represent 95% confidence limits.

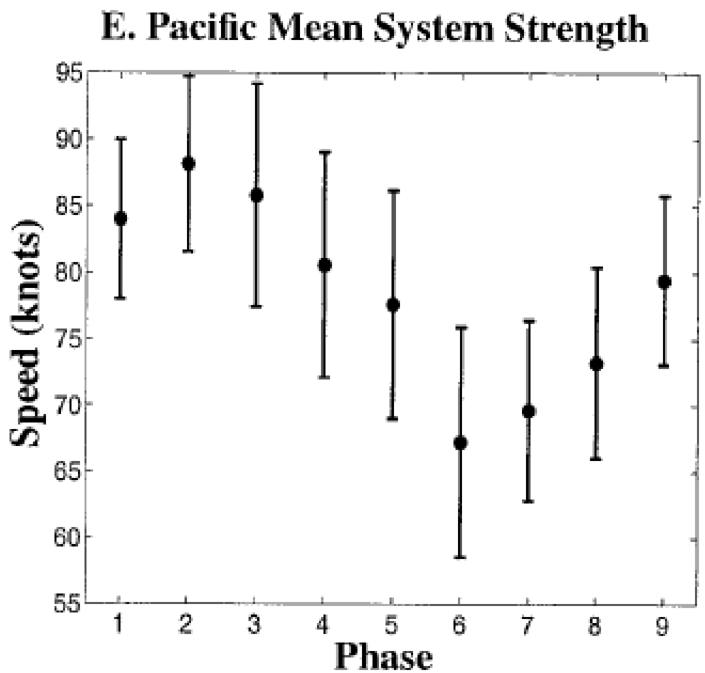


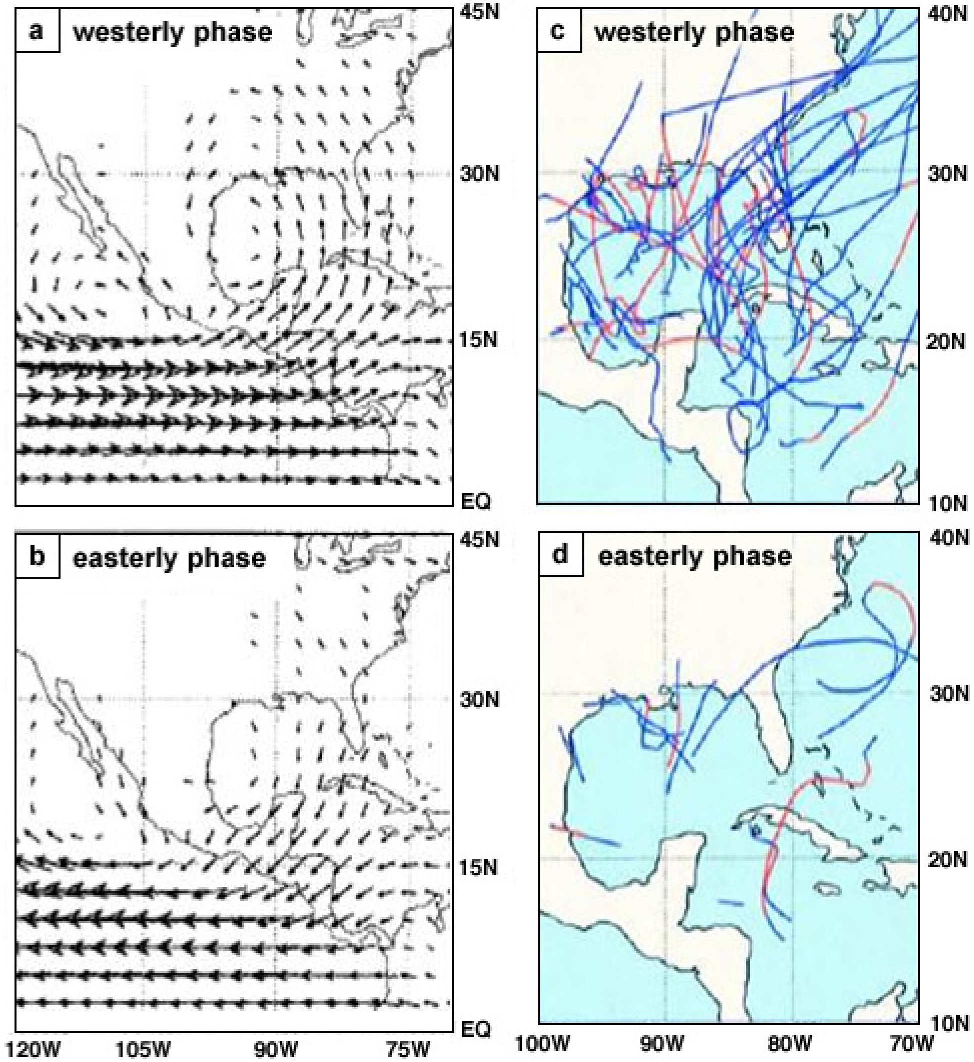
FIG. 11. Average strength (kt) of hurricanes and tropical storms as a function of MJO phase for the eastern Pacific Ocean hurricane region during May–Nov 1979–95. Error bars represent 95% confidence limits.

Over twice the number of named tropical systems exist in Phases 1 and 2. A pronounced cycle in system strength is also seen during the progression through the phases.

TROPICAL CYCLONES VARIABILITY
MJO / Atlantic

Maloney & Hartmann 2000 : *Science* , <u>287</u> , 2002-2004

MJO phase (by 850 hPa Wind Anomalies) and Tropical Cyclone Tracks

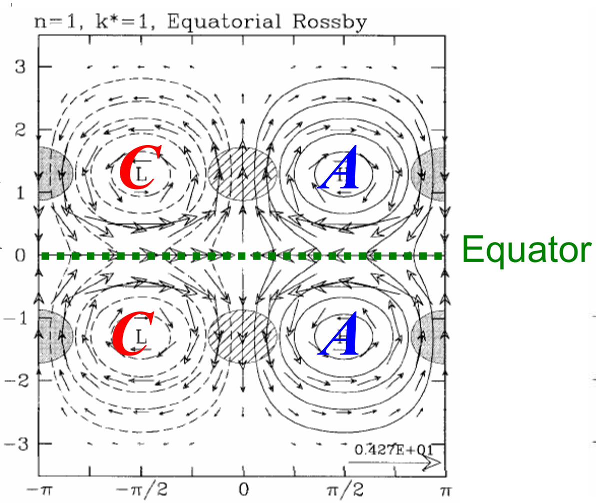


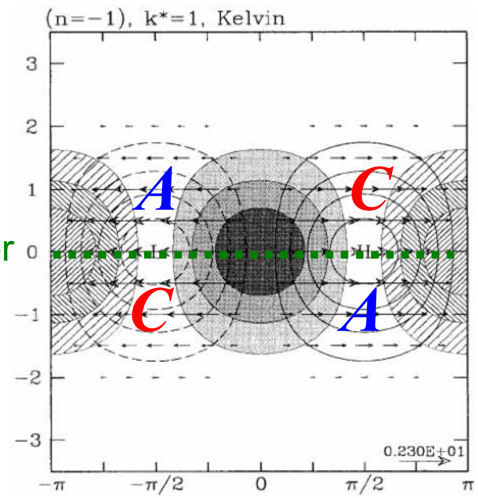
Maloney and Hartmann 2000

TROPICAL CYCLONES VARIABILITY
Convectively coupled equatorial waves (2)

Westward | ***Eastward***

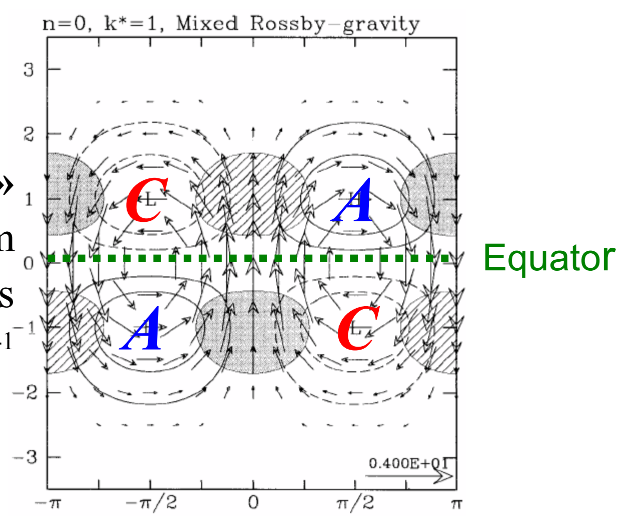
« Equatorial Rossby »
λ : 5000 to 10 000 km
T : 10 to 40 days
c : -4 to -8 m s^{-1}



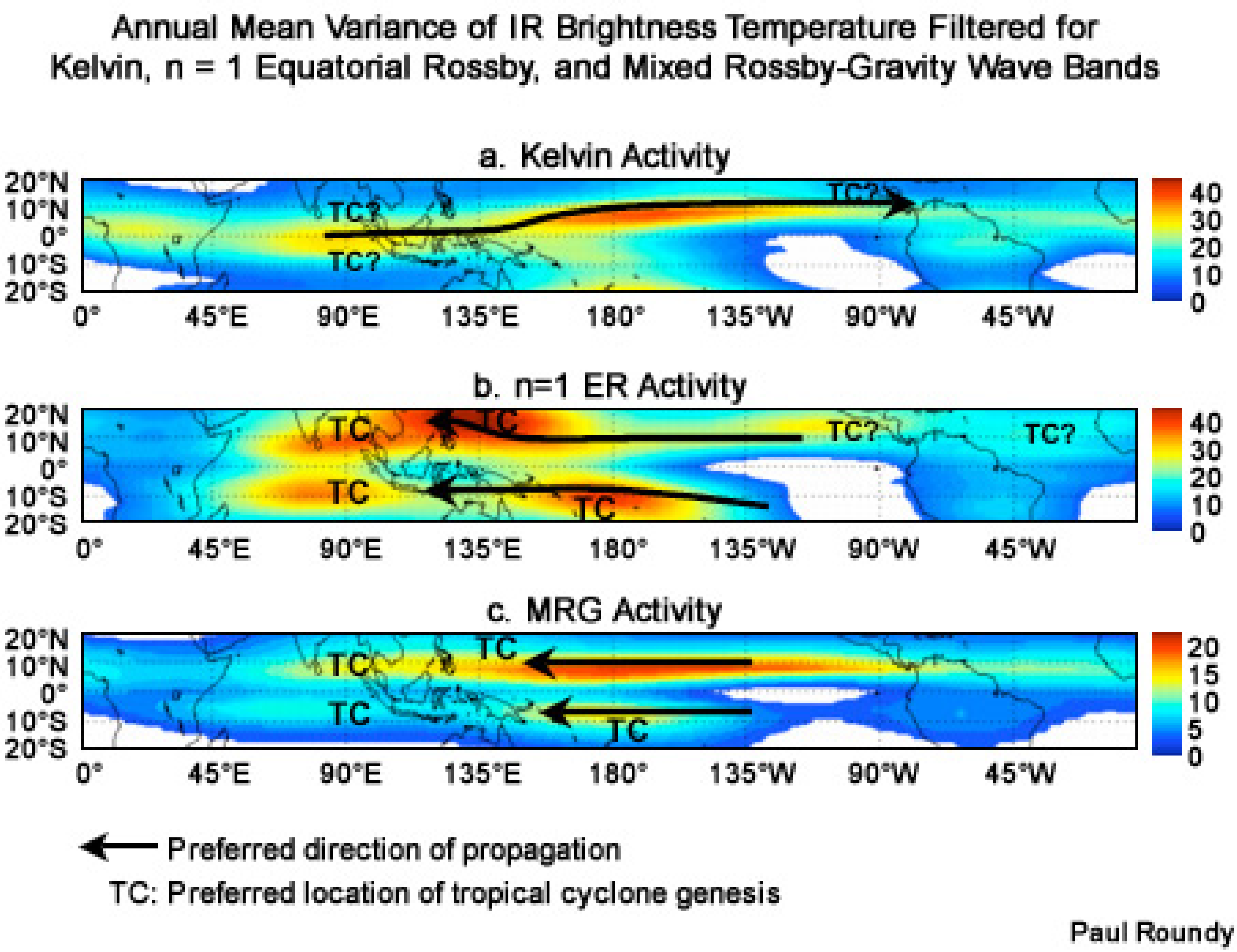


« Kelvin »
λ : 5000 to 10 000 km
T : 3 to 20 days
c : 10 to 25 m s^{-1}

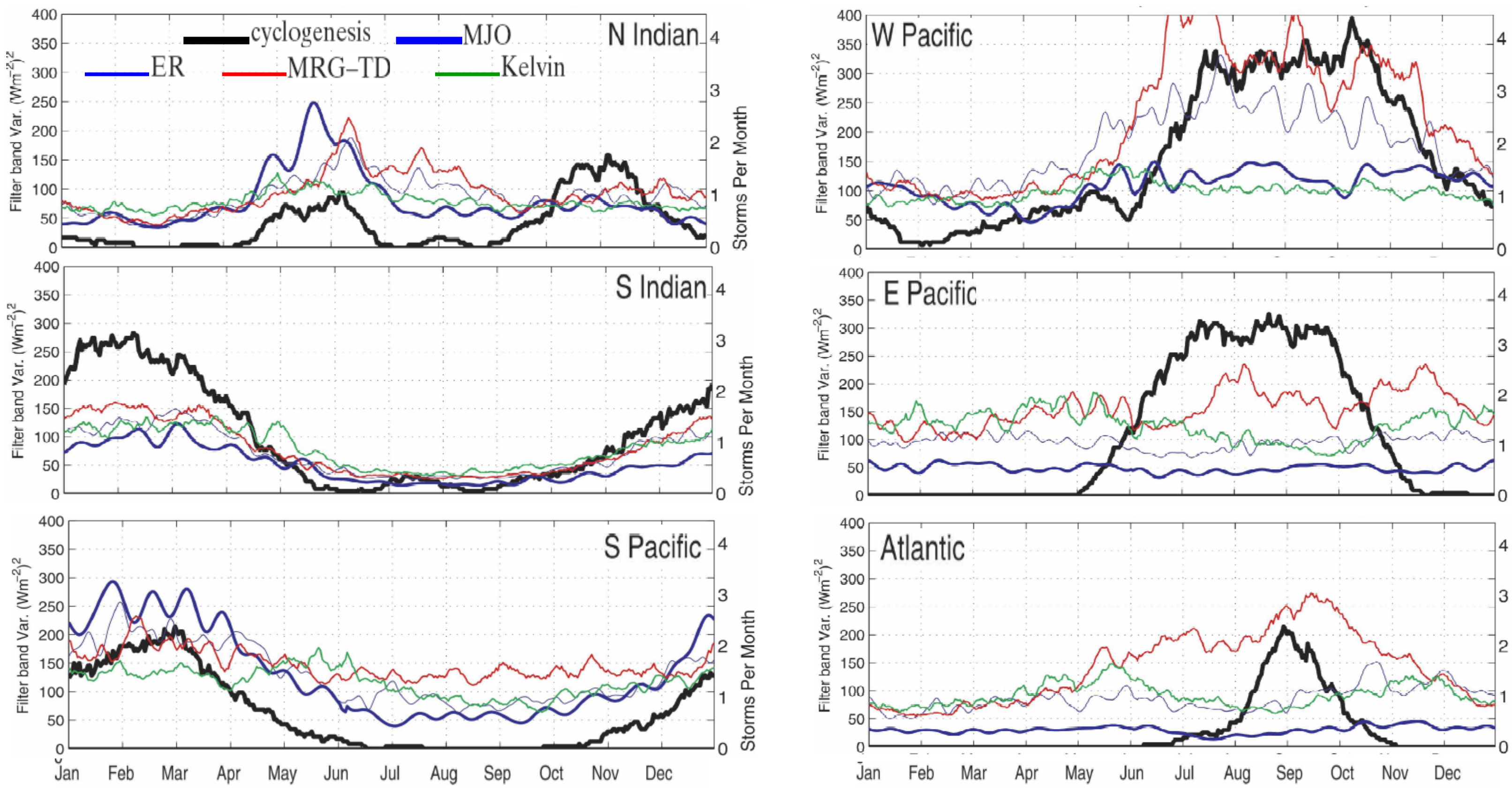
« Mixed Rossby-Gravity »
λ : 1000 to 5000 km
T : 3 to 10 days
c : -8 to -12 m s^{-1}



TROPICAL CYCLONES VARIABILITY
Convectively coupled equatorial waves (3)



TROPICAL CYCLONES VARIABILITY
Convectively coupled equatorial waves (4)



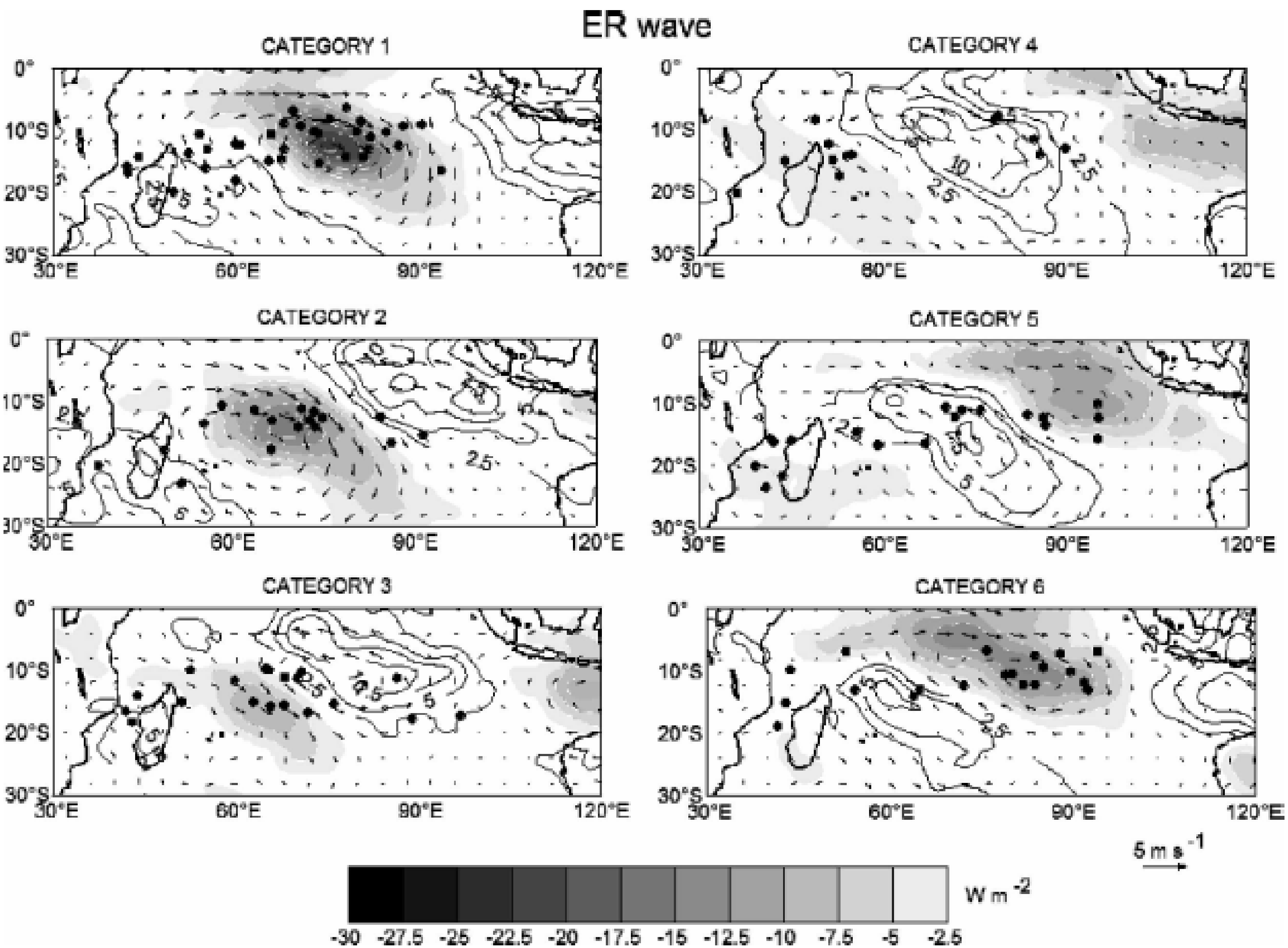
Comparing Figs. 2 and 4 it is clear that the low-frequency MJO band and ER band variances that dominate the Southern Hemisphere spectrum are strongly seasonal, and they vary in phase with the cyclone season in the two Southern Ocean basins and for the first peak of the North Indian season. Activity in the Kelvin band tends to follow the same pattern, though the cycles are somewhat less distinct than for the MJO and ER bands.

All of the wave types (except the MJO) are more active in the Northern than in the Southern Hemisphere. This is particularly true for the MRG–TD-type band, which varies strongly and in phase with the cyclone season in the North Atlantic and the northwest Pacific.

Frank & Roundy 2006 :
Mon. Wea. Rev., 134, 2397-2417

TROPICAL CYCLONES VARIABILITY
Equatorial Rossby waves / S Indian (1)

Bessafi & Wheeler 2006: *Mon. Wea. Rev.*, 134, 638-656

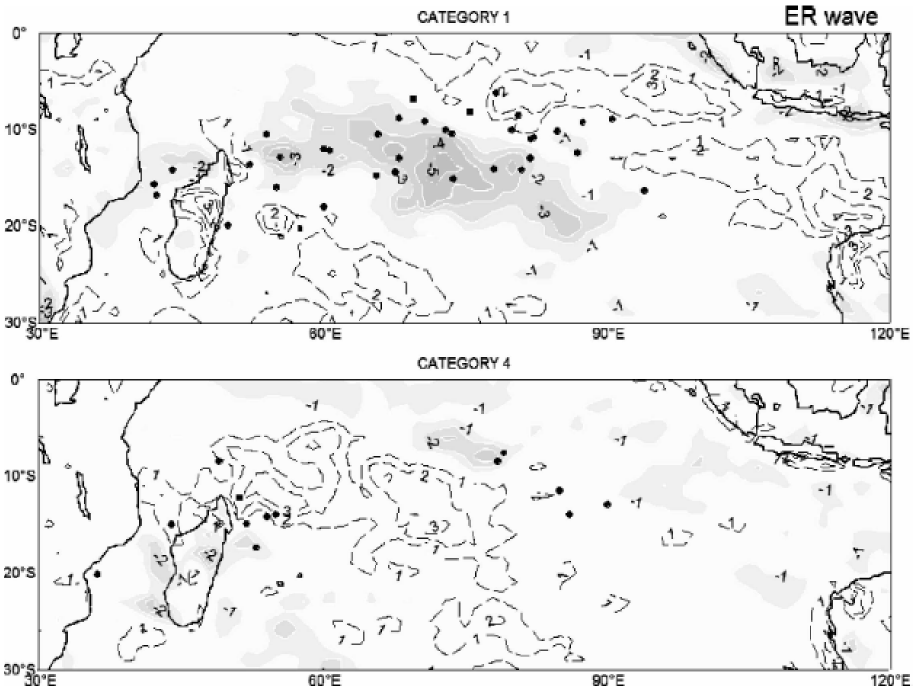


*Composite 850-hPa wind (vectors) and OLR anomalies (<0 : shading, >0 : contours) for **each category of the ER-wave**.*

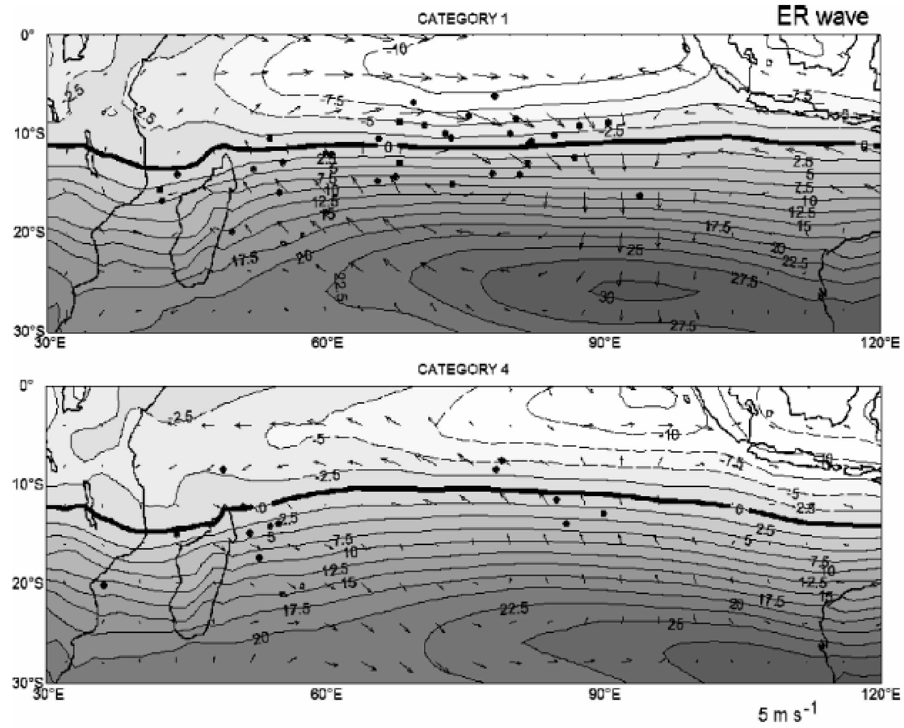
Dots represent the TC genesis location for each category

TROPICAL CYCLONES VARIABILITY
Equatorial Rossby waves / S Indian (2)

850-hPa vorticity anomaly & TC genesis



850-hPa wind anomaly & wind shear



The large modulation of TC genesis in the SW Indian ocean by the ER-waves is attributable to the large variation of the low-level vorticity and coincidence with enhanced convection.

The smaller changes in vertical wind shear appears less important.

TROPICAL CYCLONES VARIABILITY

- TC genesis in the different basins has a clear modulation signal by large-scale atmospheric variability.
- Intraseasonal and interannual disturbances have some predictability. These time scales are relevant for extending the current TC predictability (> 10 days?).
- Future high resolution (convection permitting) global models will promote realistic process-resolving intraseasonal simulations.