THE ROLE OF TYPHOONS IN THE DRYING OF THE MARITIME CONTINENT

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Outline

- **T**ropical **C**yclones:
  - brief introduction

- **TC** research at CMCC:
  - General Circulation models and TCs

- How **TC**s modulate the Maritime precipitation:
  - Data and Methods
  - Results
  - Discussion
  - Summary

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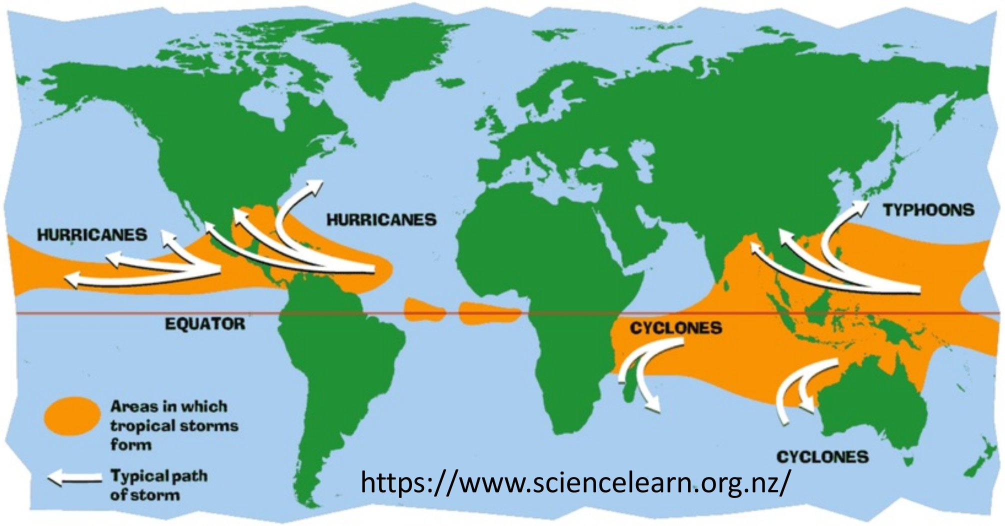
Tropical Cyclones

A Tropical Cyclone (TC) is one of the most destructive natural forces on Earth. TCs feed on heat that is released from the moist air and condensation of the oceans.

Favorable environmental conditions for TC development:

- ***Warm ocean waters*** (at least 26.5°C) throughout a depth of about 50m.
- An ***atmosphere*** that cools fast enough with height such that it is potentially ***unstable*** to moist conv.
- Relatively ***moist air*** near the mid-level of the troposphere (5000m).
- Generally a **minimum distance of at least 500 km from the equator**.
- A **pre-existing near-surface disturbance**.
- **Low** values of **vertical wind shear** (change in wind speed and direction at different height) between the surface and the upper troposphere.

Ref: Graham et al. 1987; Gray, W.M. 1979; Palmen, E. H., 1948



About 90 TCs x year at the global scale

Intense ***Tropical Cyclones*** in the Atlantic Ocean or Eastern Pacific are known as ***Hurricanes***. Those in the Western Pacific are known as ***Typhoons***.

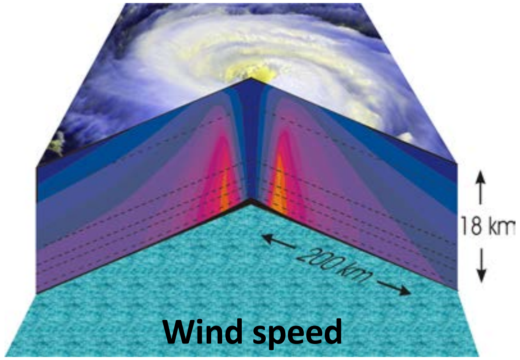
Saffir-Simpson Category	Maximum sustained wind speed		
	mph	m/s	kts
1	74-95	33-42	64-82
2	96-110	43-49	83-95
3	111-130	50-58	96-113
4	131-155	59-69	114-135
5	156+	70+	136+

Tropical Cyclones

Tropical cyclones (TCs) in their most intense expression (**hurricanes or typhoons**) are the **main natural hazards known to humankind**.

The destructive effects of TCs are mainly caused by **three factors:**

- **strong wind**
- **storm surge**
- **extreme precipitation**



Source:
Emanuel K., Divine Wind, 2005

These TC-induced effects contribute to the annual worldwide damage **of the order of billions of dollars and a death toll of thousands of people**.

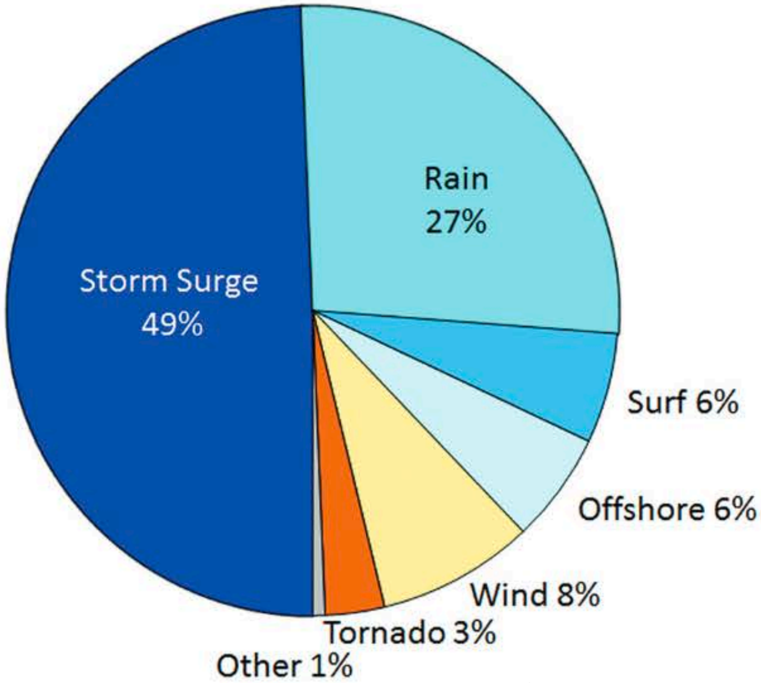
Ref: Scoccimarro Oxford Univ. Press. 2016

Tropical Cyclones

Cause of death in the United States directly attributable to Atlantic Tropical Cyclones

- strong wind — 8% +
- storm surge — 49% +
- extreme precipitation — 27% =

84%



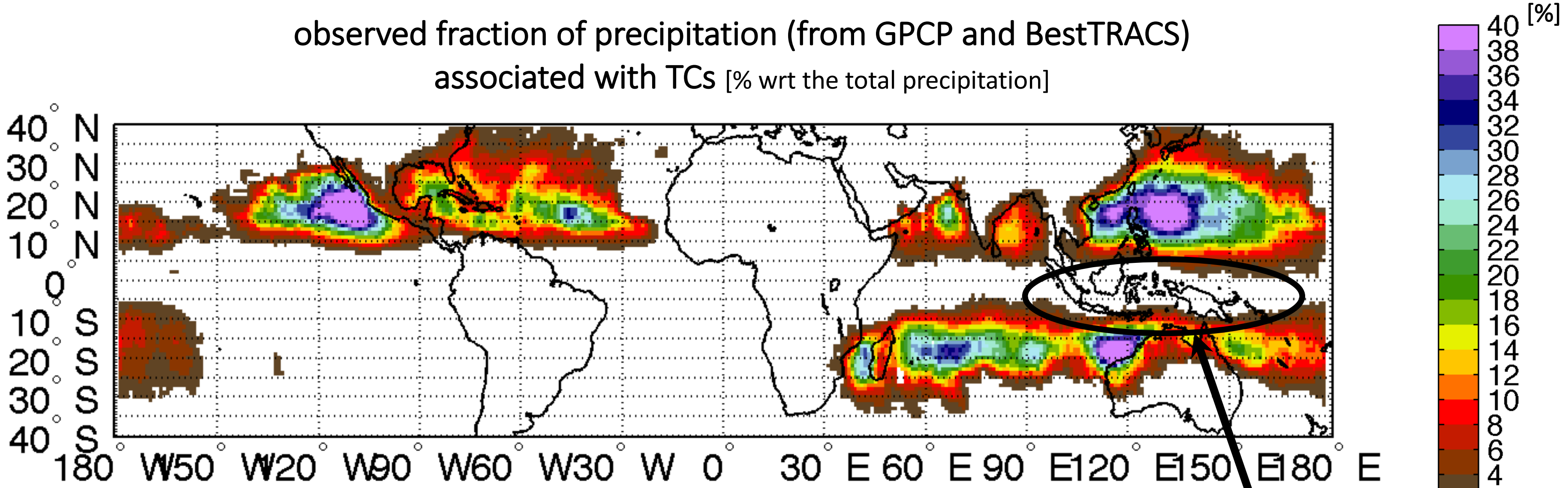
Ref: Rappaport, BAMS 2014 (period:1963-2012)

Thus TC associated precipitation is responsible for a huge fraction of damages.
In this work, instead, we will focus for the first time on the opposite role of TCs. In fact we will investigate their interplay with the surrounding environment in terms of *drying* of a particular portion of the tropical domain: The Maritime Continent.

How Tropical Cyclones (TCs) modulate the Maritime precipitation

- In terms of amount of precipitation reaching the surface of the planet in a year, **the amount induced by TCs reaches 40% of the total amount over some ocean regions**.

observed fraction of precipitation (from GPCP and BestTRACS) associated with TCs [% wrt the total precipitation]



Scoccimarro et al. 2014. Larson et al. 2015. Dare et al. 2012

- There is no direct contribution by TCs to the precipitation over the **Maritime continent**

- But it is well known that the circulation over the **Maritime Continent** is fundamental in determining the atmospheric dynamics at the global scale.

- Is there any effect of TC activity on the circulation over the Maritime Continent suggesting a TC potential role in modulating the convection associated with rising branches of the Walker Circulation over the Maritime continent?

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TC research at CMCC

Fully Coupled Climate Model development

Under the World Climate Research Programme (WCRP) the Working Group on Coupled Modelling (WGCM) established the **Coupled Model Intercomparison Project** (**CMIP**) as a standard experimental protocol for studying the output of coupled atmosphere-ocean general circulation models (AOGCMs).
Models results are used to perform research of relevance to climate scientists preparing the **Intergovernmental Panel on Climate Change Asssessment Reports (IPCC-AR)**

INGV-SXG
↓
2008: **CMIP3** (~25 models) → **4° IPCC Assesment Report AR4**

Max horiz. resolution
~100 km
Able to represent weak TCs

CMCC-CM
CMCC-CMS
CMCC-CESM
↓
2013: **CMIP5** (~60 models) → **5° IPCC Assesment Report AR5**

Max horiz. resolution
~80 km
Able to represent category 1 TCs

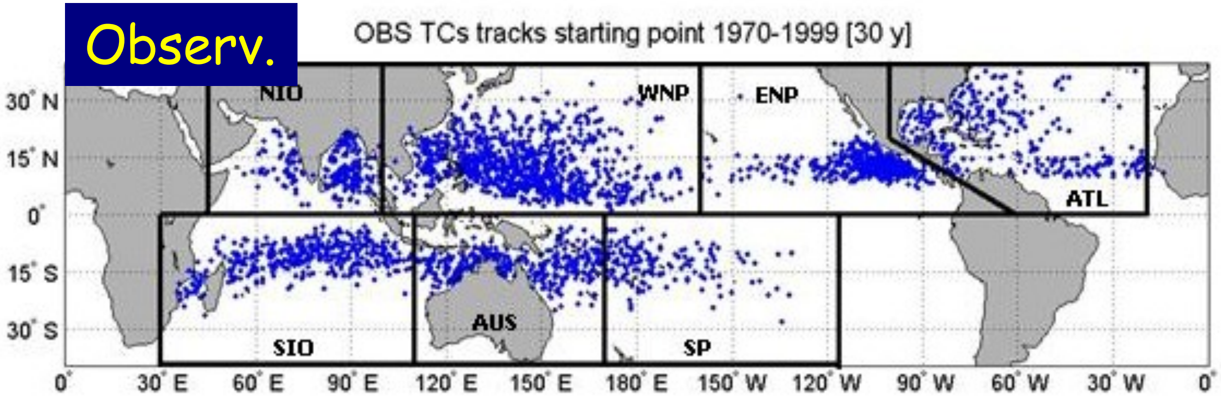
CMCC-CM2-SR5 **CMCC-ESM2**
CMCC-CM2-HR4 **CMCC-CM2-VHR4**
↓
2019: **CMIP6** (>100 models) → **6° IPCC Assesment Report AR6**

Max horiz. resolution
~25 km
Able to represent category 5 TCs

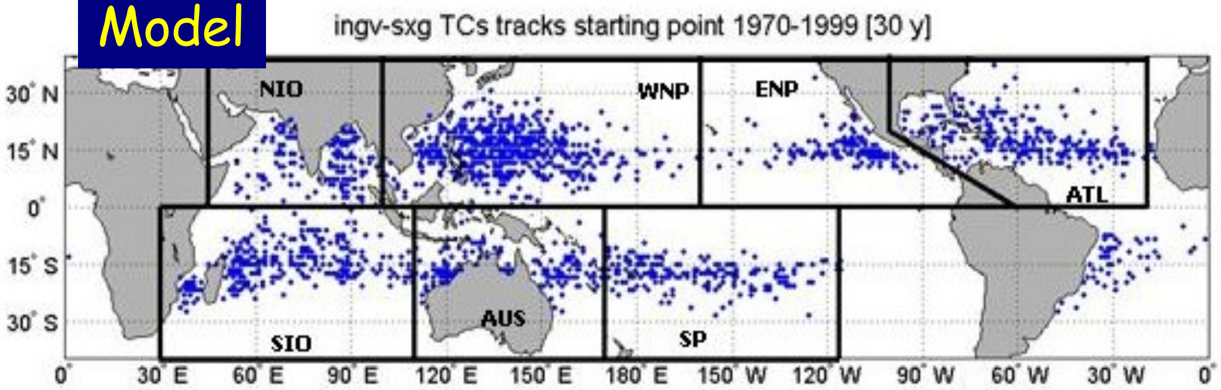
TC research at CMCC

Tropical Cyclone Genesis Point

Observ.



Model



INGV-SXG (100 km)
Tropical Storms

CMCC-CM (80 km)
Cat 1 Hurricanes

CMCC-CM2-VHR4 (25 km)
Cat 5 Hurricanes

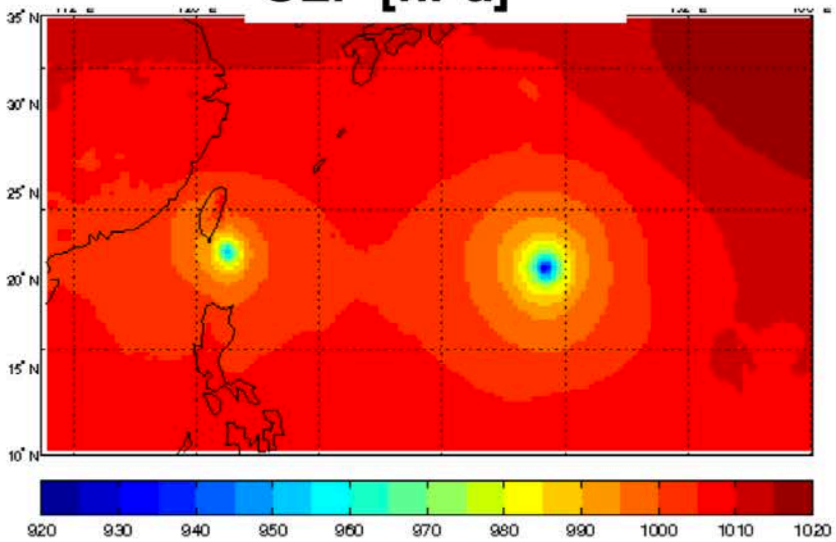
Actually, only **3** climate models worldwide demonstrated ability in representing cat-5 Hurricanes: **CMCC-CM2-VHR4**, HiFLOR , CESM

[Scoccimarro et al. 2017, 2020] [Murakami et al. 2015] [Small et al. 2014]

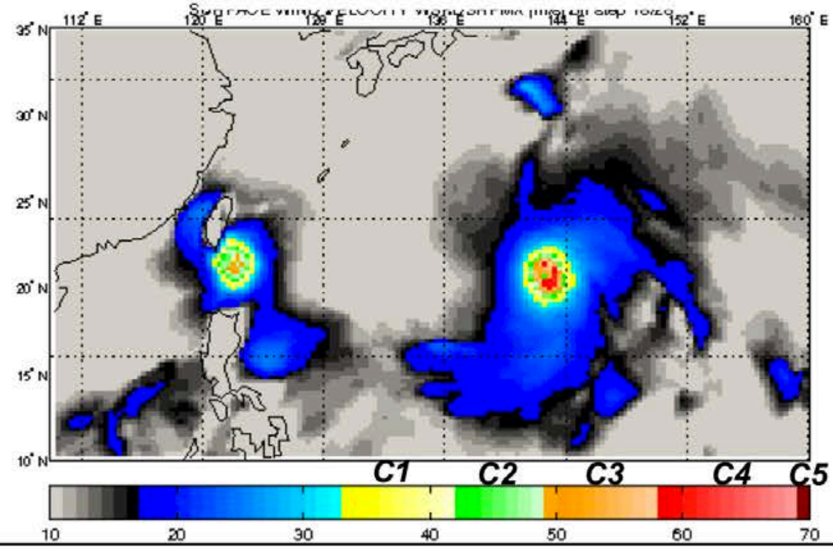
CMCC-CM2-VH4R 25 km horizontal resolution in both Atmosphere and Ocean components is able to represent Cat5 TCs.

6h steps covering two days

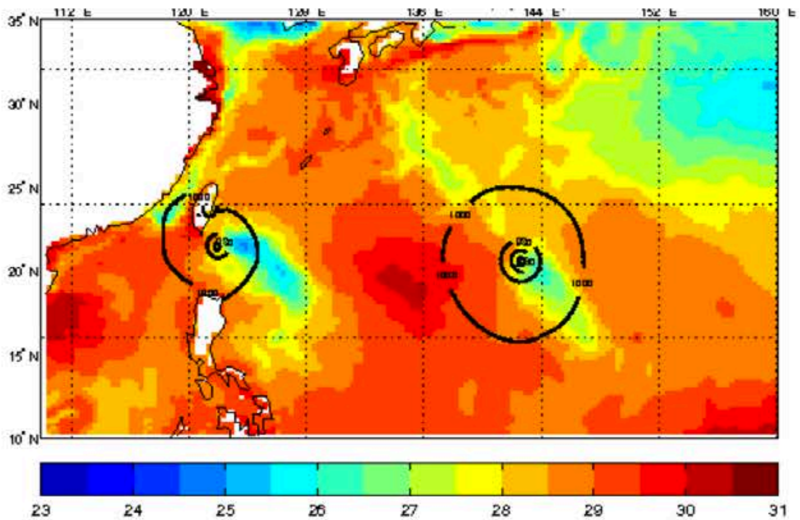
SLP [hPa]

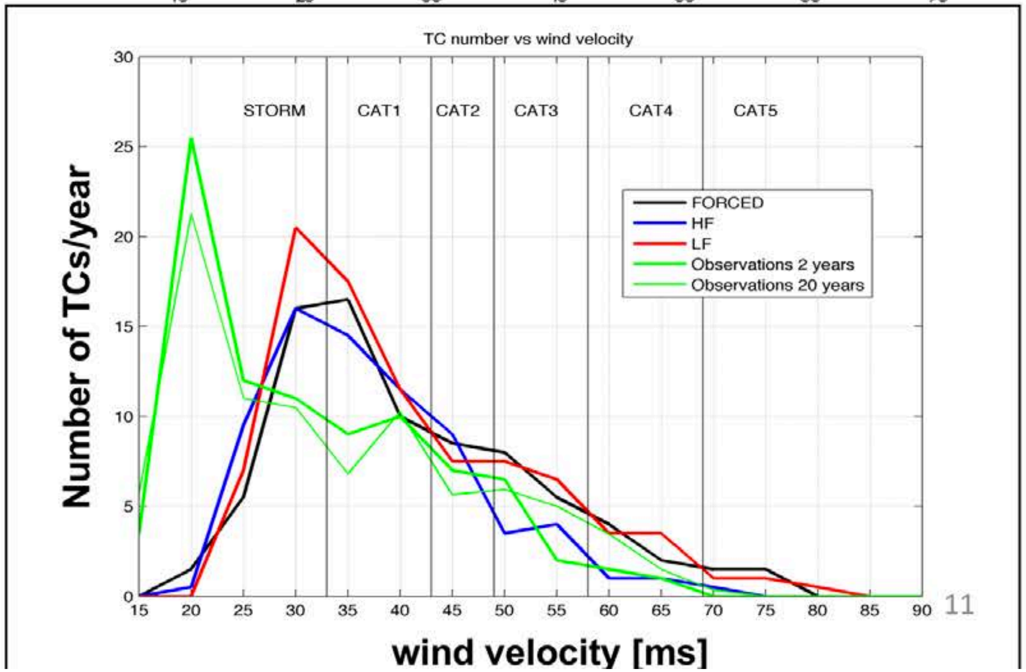


10m wind [m/s]



SST [°C] and SLP [contours]





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How Tropical Cyclones (TCs) modulate the Maritime precipitation

Data and Methods:

TC tracks (position, wind speed): *6 hourly* best-track data from the *Japan Meteorological Agency Regional Specialized Meteorological Center Tokyo**.

Precipitation (PR): *daily Global Precipitation Climatology Project* (**GPCP** v2.2**)
daily **JRA-55** atmospheric reanalysis***

Vertically integrated water transport: *daily atmospheric Japanese Reanalysis* **JRA-55** reanalysis*** saved by the model on model levels and integrated vertically as:

Zonal component: $\mathbf{UWV} = \int_{vert} \mathbf{q^*u}\, dz$ where q = specific humidity

Meridional component: $\mathbf{VWV} = \int_{vert} \mathbf{q^*v}\, dz$ u,v = wind velocity components

Data are collected over the period 1979-2015 from June to August (JJA)

All of the mentioned data are referred to as "observations" in the next slides

*https://www.jma.go.jp/en/typh/
**Adler et al., 2003 The version-2 Global Precipitation Climatology Project (GPCP) J. Hydrometeorol.
***Kobayashi, S. et al. 2015: The JRA-55 Reanalysis: General specifications and basic characteristics. JMSJ.

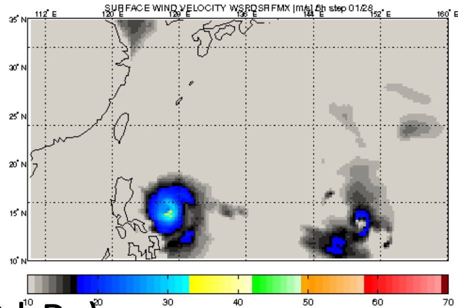
How Tropical Cyclones (TCs) modulate the Maritime precipitation

Data and Methods:

In addition to **observation**, we also build on 30y present climate simulations with two **CMCC Fully Coupled General Circulation Models**, sharing the same ¼ degree ocean component But with a different horizontal resolution in their atmospheric component :

MODEL NAME	Ocean Model horizontal resolution	Atmospheric model horizontal resolution
CMCC-CM2-HR4	25 km	100 km
CMCC-CM2-VHR4	25 km	25 km

The same parameters (**PR, UWV, VWV**) described in the previous slide are provided based on model output. In addition a **tracking procedure** is also necessary to track **TCs**:



Potential TC conditions are identified in the models based on **6-hourly**

- -850-hPa **relative vorticity**,
- -**maximum wind**,
- -local **sea level pressure**,
- -**warm core** (based on temperature averaged between 300 and 500 hPa).

Then, TCs are tracked, verifying, for each potential TC condition, the presence of TCs during the following 6-h time period within a distance of 400 km. If no TC condition is found, the trajectory is considered finished. A tracked trajectory is qualified as a TC if it lasts at least 3 days*.

*Scoccimarro et al. 2017: Tropical cyclone interaction with the ocean: the role of high frequency (sub-daily) coupled processes JCLI 2017

How Tropical Cyclones (TCs) modulate the Maritime precipitation

Data and Methods:

Based on observations and model results we compute the **Accumulated Cyclone** Energy from **June to August** (JJA) **for each year** in the **1979 – 2015** period over the **West North Pacific** (WNP)

Accumulated Cyclone Energy

$$\mathrm{ACE} = \sum v_{\max}^2$$

where $\boldsymbol{v}_{\mathbf{max}}$ is the sustained **wind speed**.
This value is **accumulated** over
- all of the **6h time steps** of the TC track
- For **all TCs in that season** over the basin

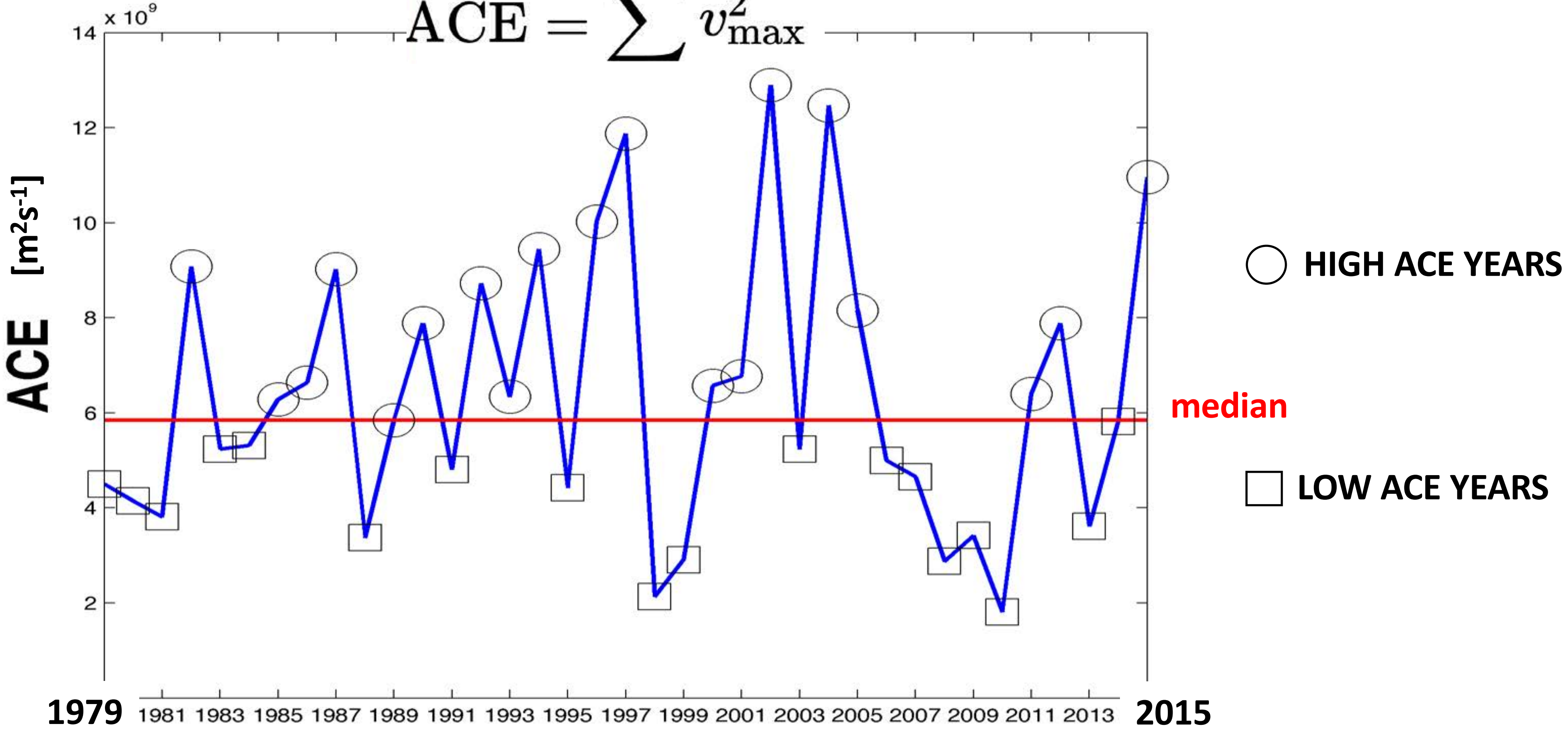
Although **ACE** is a value proportional to the energy of the system, it is not a direct calculation of energy but it **is used to quantify the TC activity** since **considers count, duration and intensity**: as the duration of A storm increases, more values are summed and the ACE also increases such that longer-duration storms may accumulate a larger ACE than more-powerful storms of lesser duration.

In this work we use seasonal (JJA) time series (1979-2015) of **ACE** for both
- **correlation** with **precipitation**
- **comparison of PR, UWV and VWV averages** associated to **LOW** and **HIGH ACE** seasons (**below or above the ACE median**)

How Tropical Cyclones (TCs) modulate the Maritime precipitation

Data and Methods:

$$ACE = \sum v_{max}^2$$



- **comparison of PR, UWV and VWV averages** associated to **LOW** and **HIGH ACE** seasons (**below or above the ACE median**)

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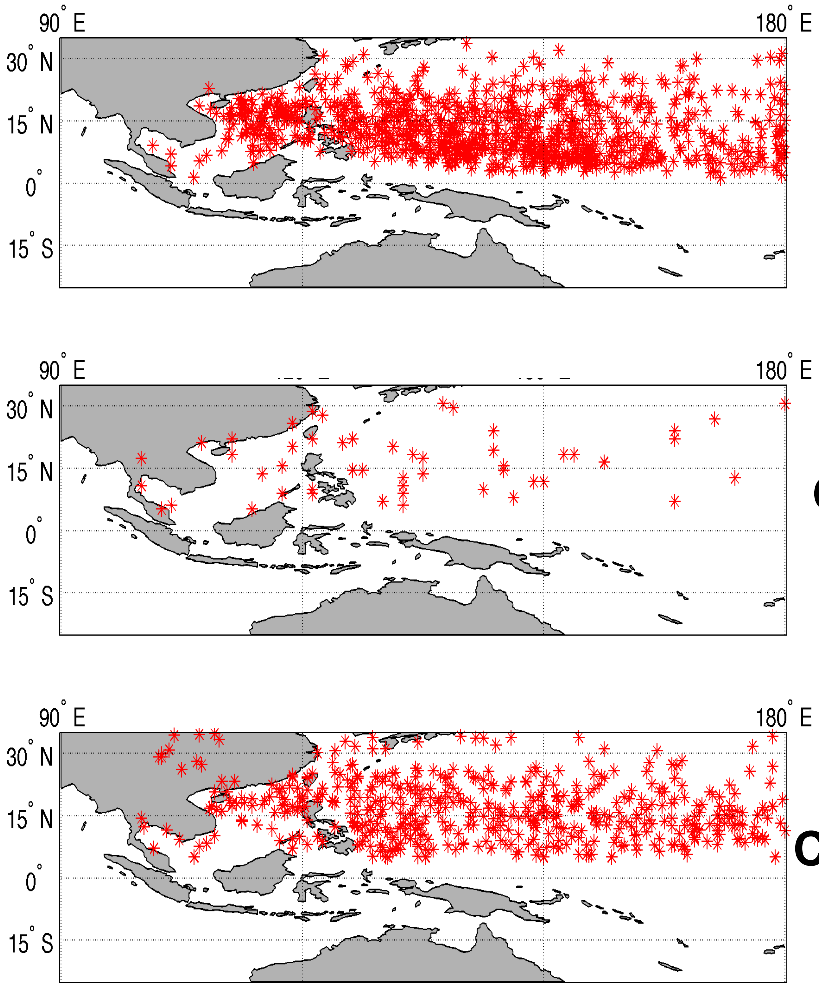
How Tropical Cyclones (TCs) modulate the Maritime precipitation

Results:

30y TC GENESIS POINTS

ACCUMULATED CYCLONE ENERGY

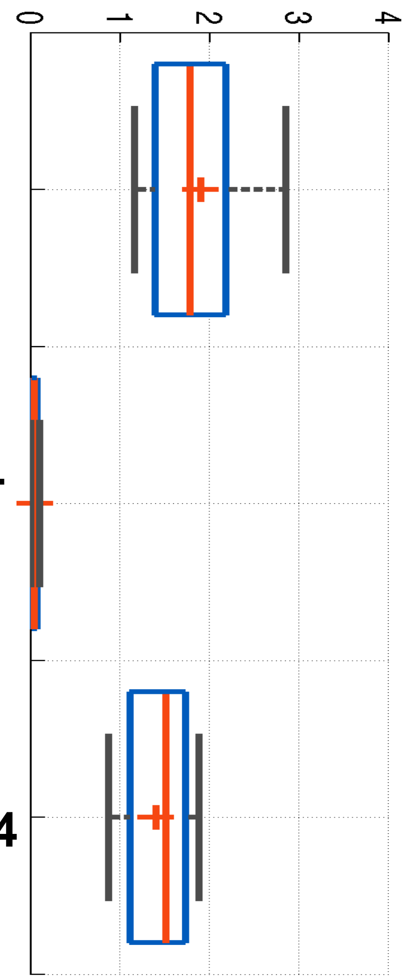
ACE [$10^{10}m^2s^{-1}$] $\mathrm{ACE} = \sum v_{\max}^2$



Observations

CMCC-CM2-HR4
(100 km horiz.res.)

CMCC-CM2-VHR4
(25 km horiz.res.)



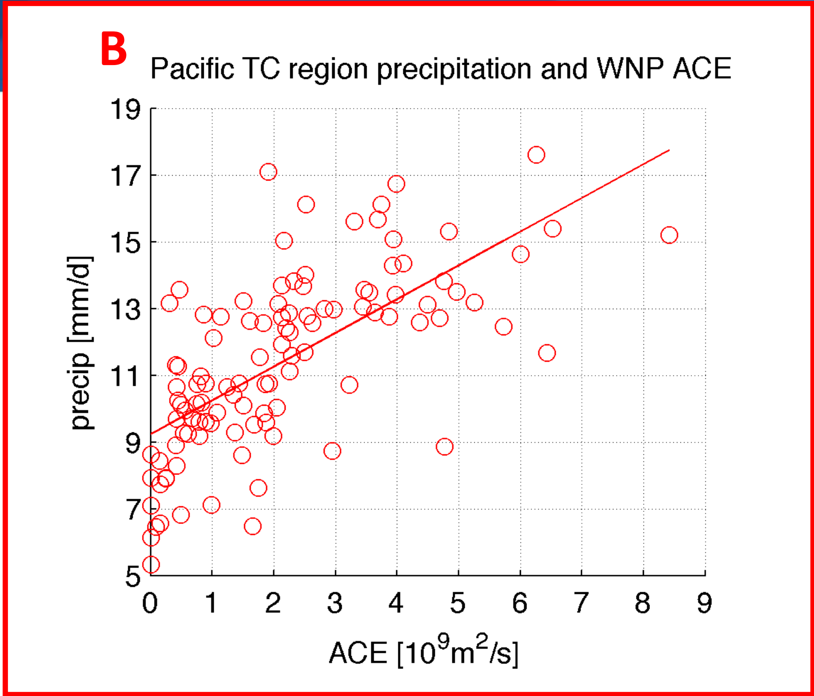
CMCC-CM2-HR4 low resolution model is **not able to** reasonably **represent TCs** both in terms of number and intensity.
On the other hand **CMCC-CM2-VHR4** high resolution model **shows results close to the observations.**

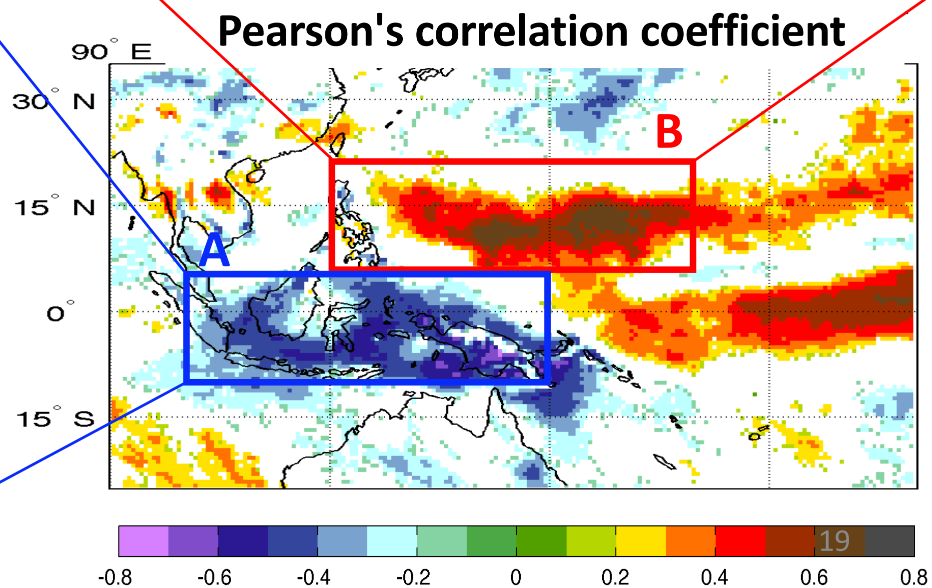
How Tropical Cyclones (TCs) modulate the Maritime precipitation

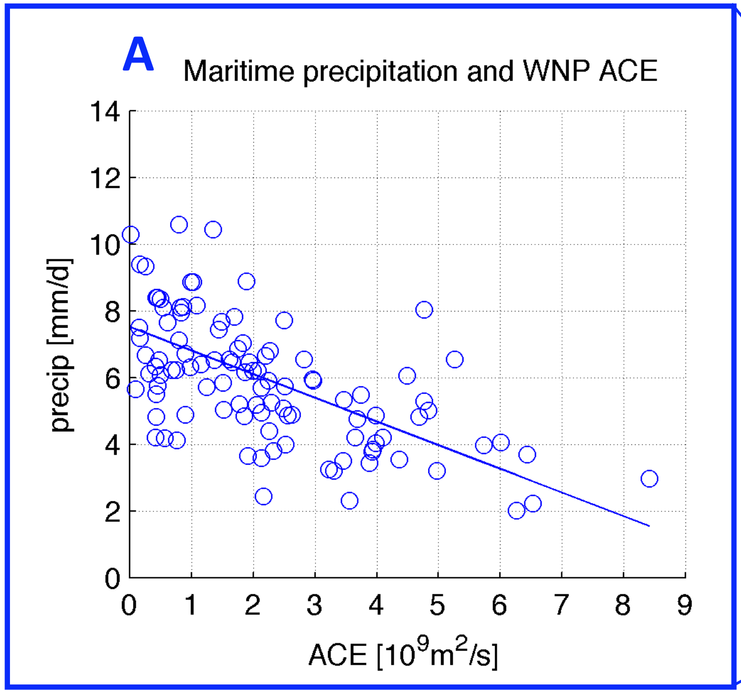
Results:

CORRELATION between
Accumulated Cyclone Energy (ACE) and **Precipitation**
based on time series of
JJA averages from 1979 to 2015

Important: in all of the slides ACE is computed considering the whole West North Pacific basin (0N:40N, 90E:190E)



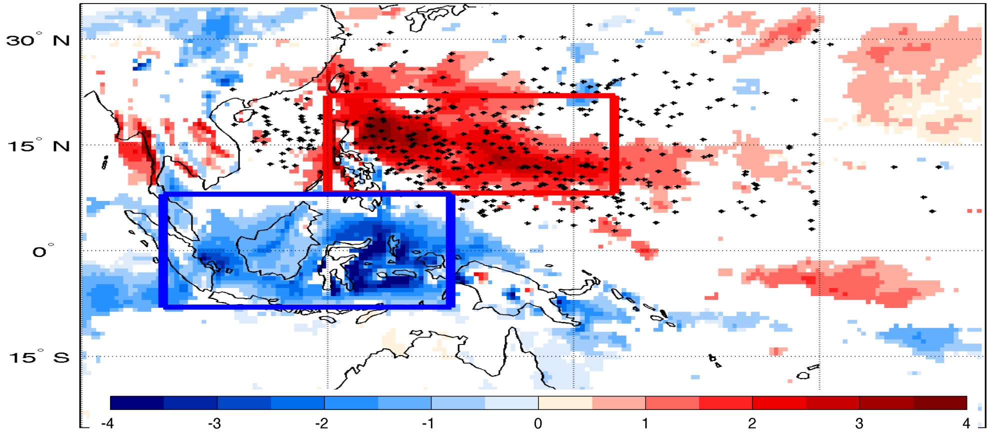




How Tropical Cyclones (TCs) modulate the Maritime precipitation

Results:

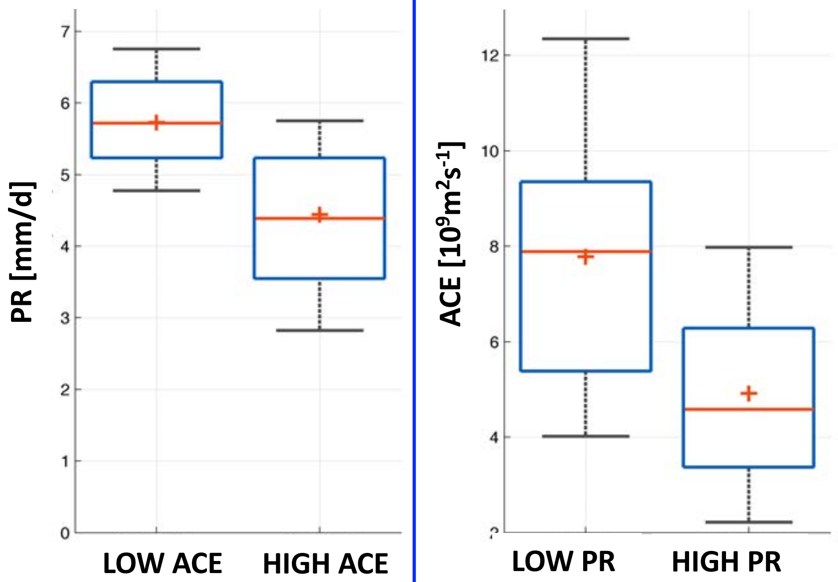
PRECIPITATION difference HIGH-LOW ACE [mm\d]



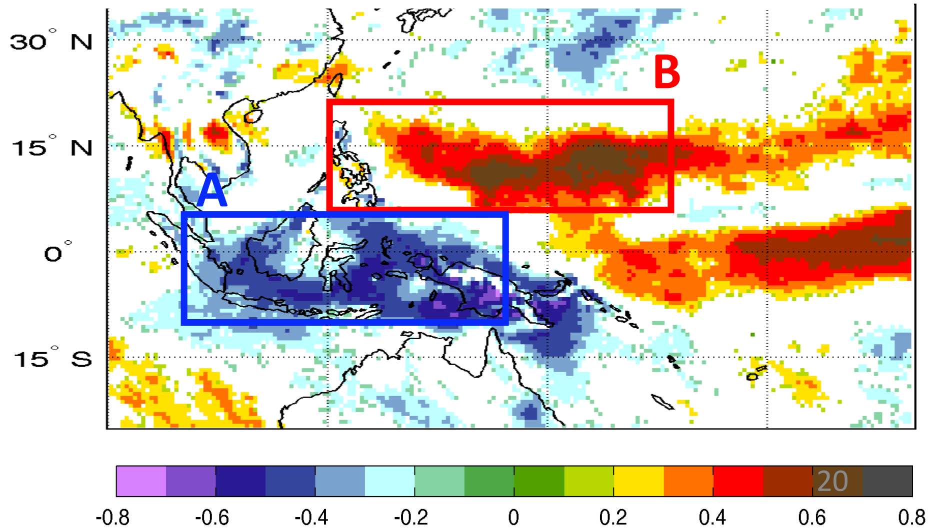
Important: in all of the slides ACE is computed considering the whole West North Pacific basin (0N:40N, 90E:190E)

The **less pronounced** precipitation **during years with strong TC activity** (HIGH ACE years) **over the maritime continent**, compared to years with moderate TC activity (LOW ACE years) is made evident by the **precipitation difference between HIGH and LOW ACE years**.

Precipitation amount in HIGH and LOW ACE years | **ACE amount in HIGH and LOW PR years**



ACE – Precipitation
Pearson's correlation coefficient



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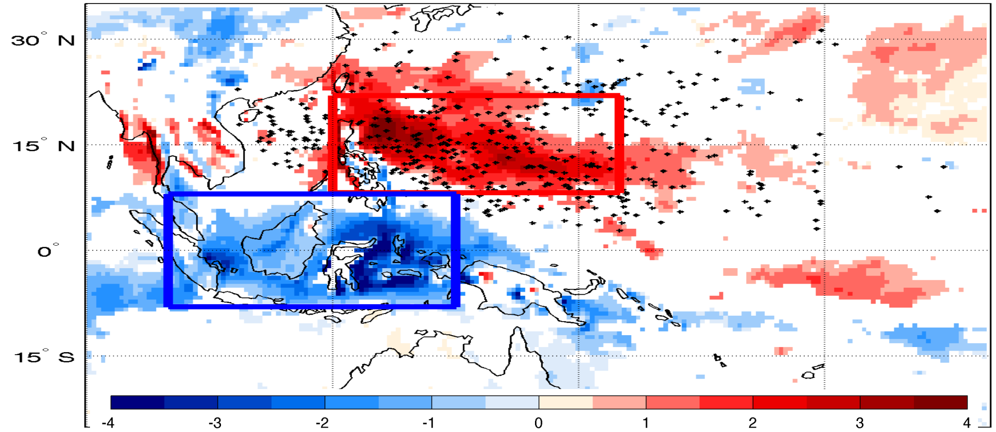
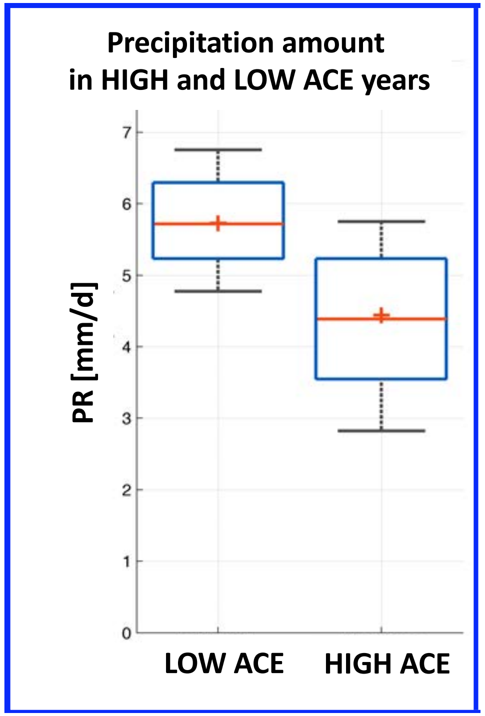
Discussion:

PRECIPITATION difference HIGH-LOW ACE [mm\d]





Important: in all of the slides ACE is computed considering the whole West North Pacific basin (0N:40N, 90E:190E)

Is there any role played by a third actor, modulating both ACE and PRECIPITATION? such as:

ENSO (El Nino Sourthern Oscillation)*

MJO (Madden and Julian) **

PJ (Pacific Japan pattern) ***

Hadley cell (intensity/position) ****

…………

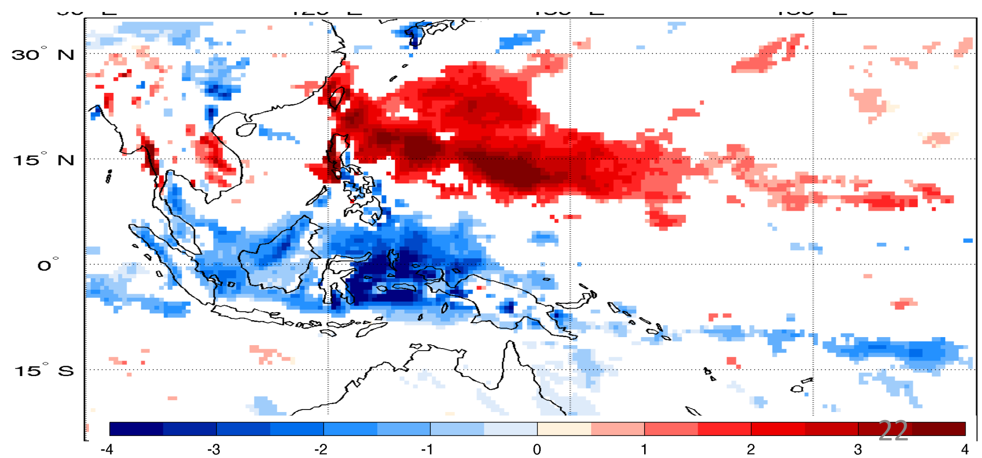
*NOAA ENSO Index.

**Madden, R.A. and Julian, P.R. (1994) MWR.

*** Kubota, Het al. (2016) Int. Journal of Climat.

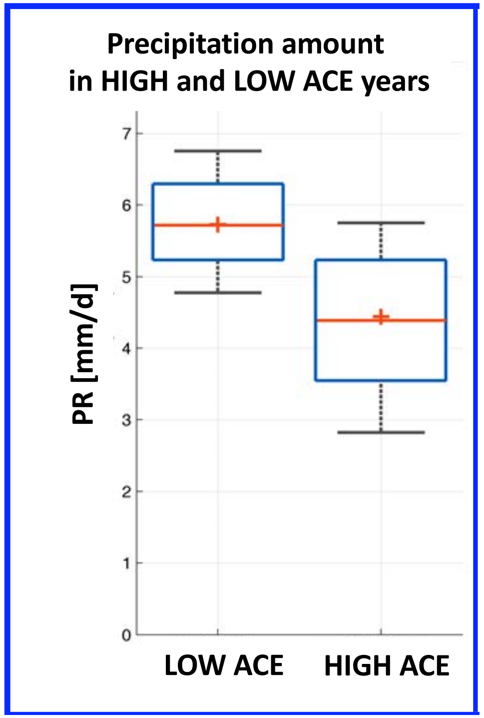
****Nguyen, H., et al. (2013) J. Climate,

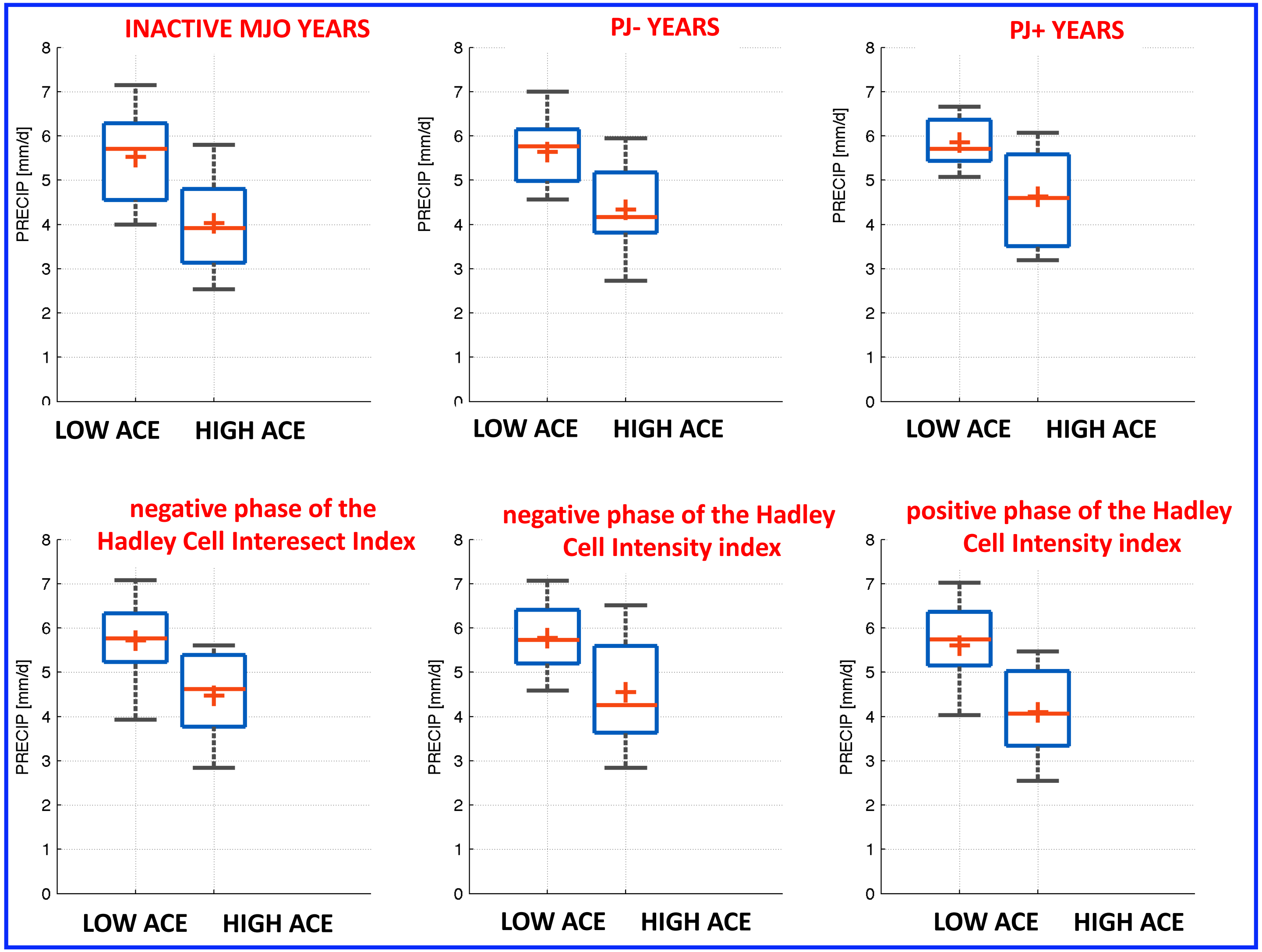
Using ENSO Neutral years only



How Tropical Cyclones (TCs) modulate the Maritime precipitation
Discussion:

Is there any role played by a third actor, modulating both ACE and PR?
such as:
ENSO (El Nino South. Oscill.)
MJO (Madden and Julian)
PJ (Pacific Japan pattern)
Hadley cell intensity/position



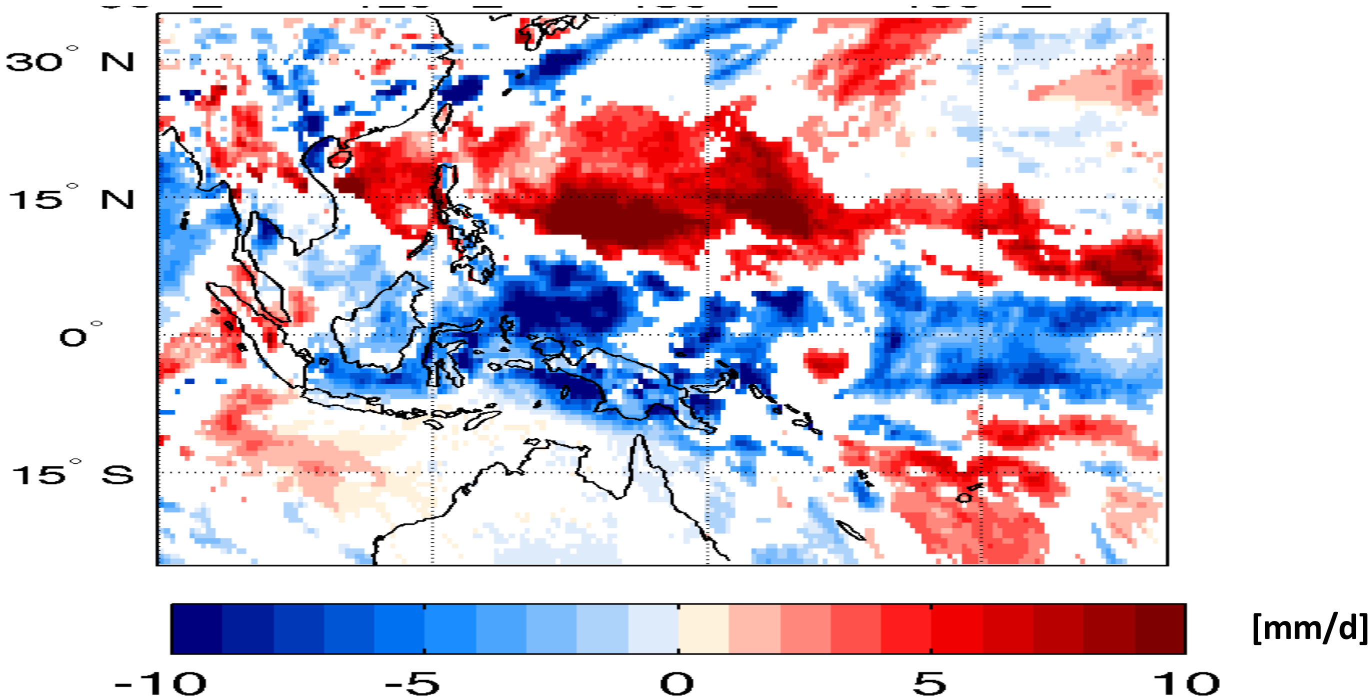


The more pronounced Precipitation over the MARITIME CONTINENT during years with low TC activity seems not driven by a third player.

How Tropical Cyclones (TCs) modulate the Maritime precipitation
Discussion:

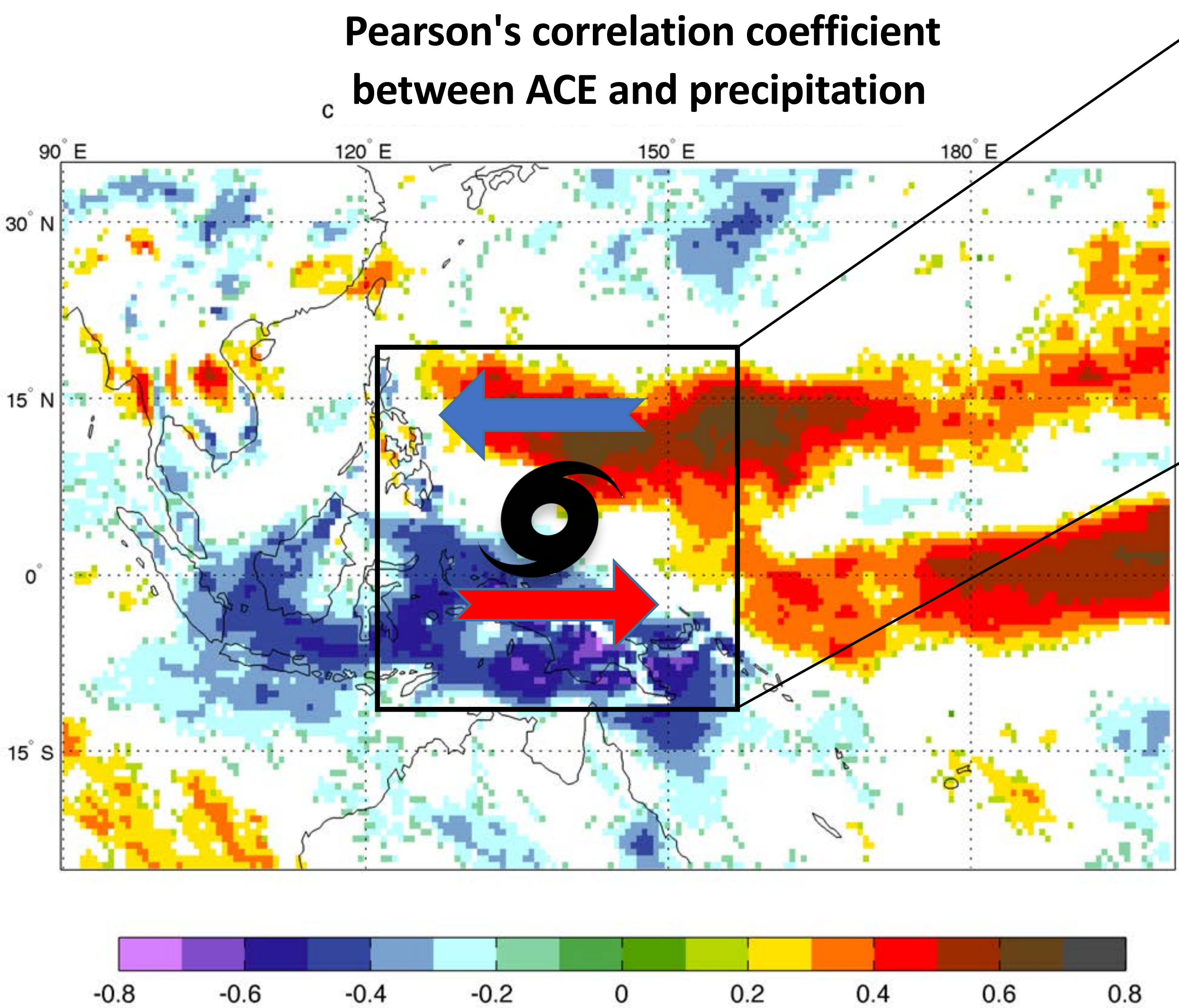
In addition, to further verify the independency on other modes of variability we focused on a single JJA season, **comparing averages during active TC days and inactive TC days**, based on daily data.

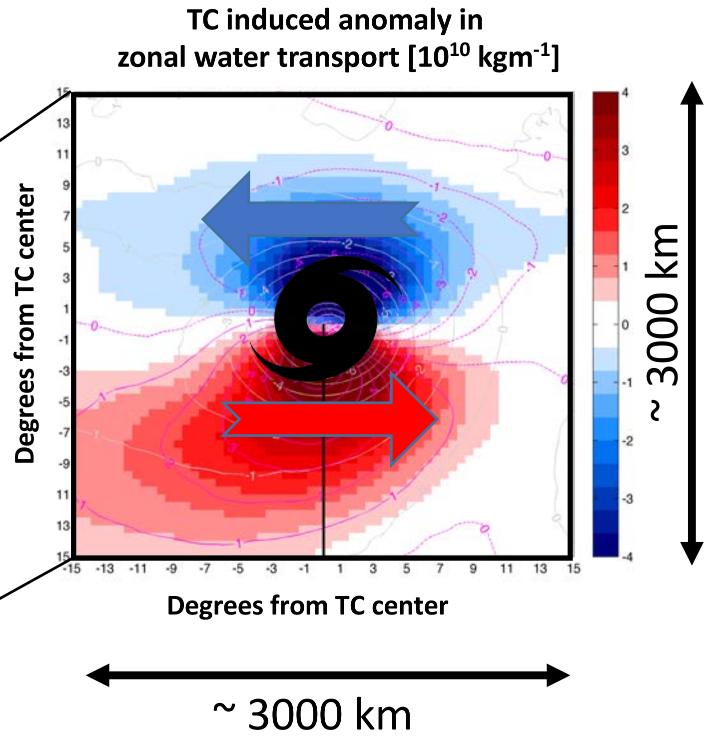
difference between PRECIPITATION averaged during TC active days and non active TC days in the 2002 JJA season



How Tropical Cyclones (TCs) modulate the Maritime precipitation
Discussion:

The process:





TCs travelling at low latitudes in WNP (centered at 10-15°N) act removing water from the atmospheric column of the Maritime Continent, reducing the water available for precipitation over the region.

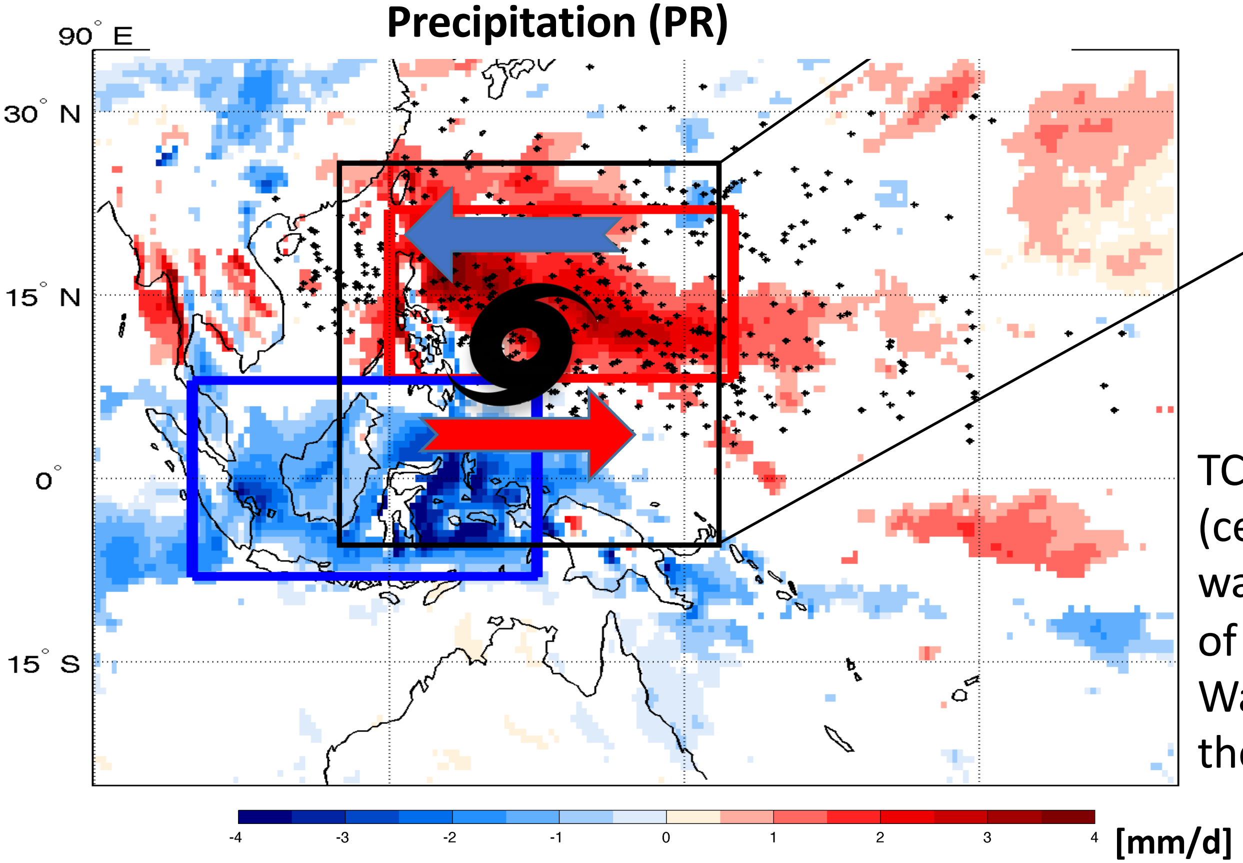
How Tropical Cyclones (TCs) modulate the Maritime precipitation

Discussion:

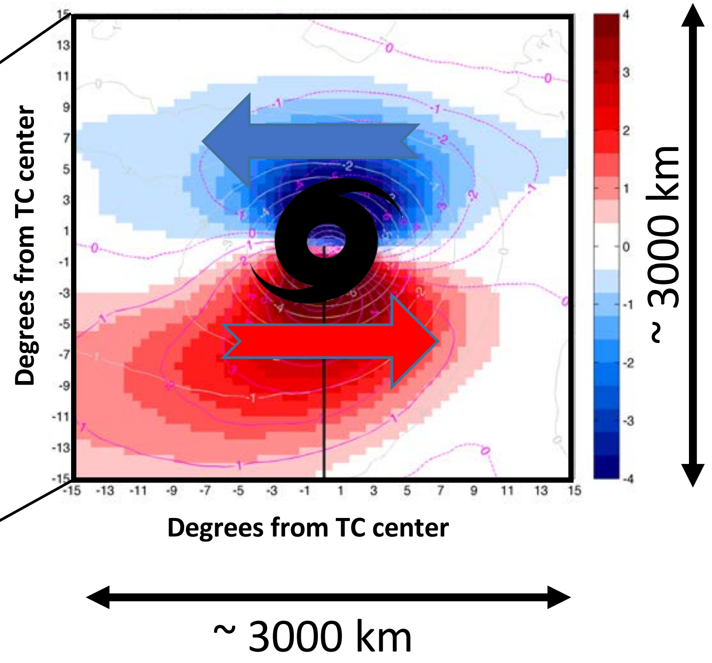
The **difference** in the **amount of precipitation** between **HIGH and LOW ACE years** is **consistent** with the difference in the **zonal water transport over the region** and also with the difference in the **amount of water transported eastward by** the southern flank of **TCs** travelling at low latitudes.

Difference HIGH – LOW ACE years

Precipitation (PR)



TC induced anomaly in zonal water transport [10^{10} kgm^{-1}]



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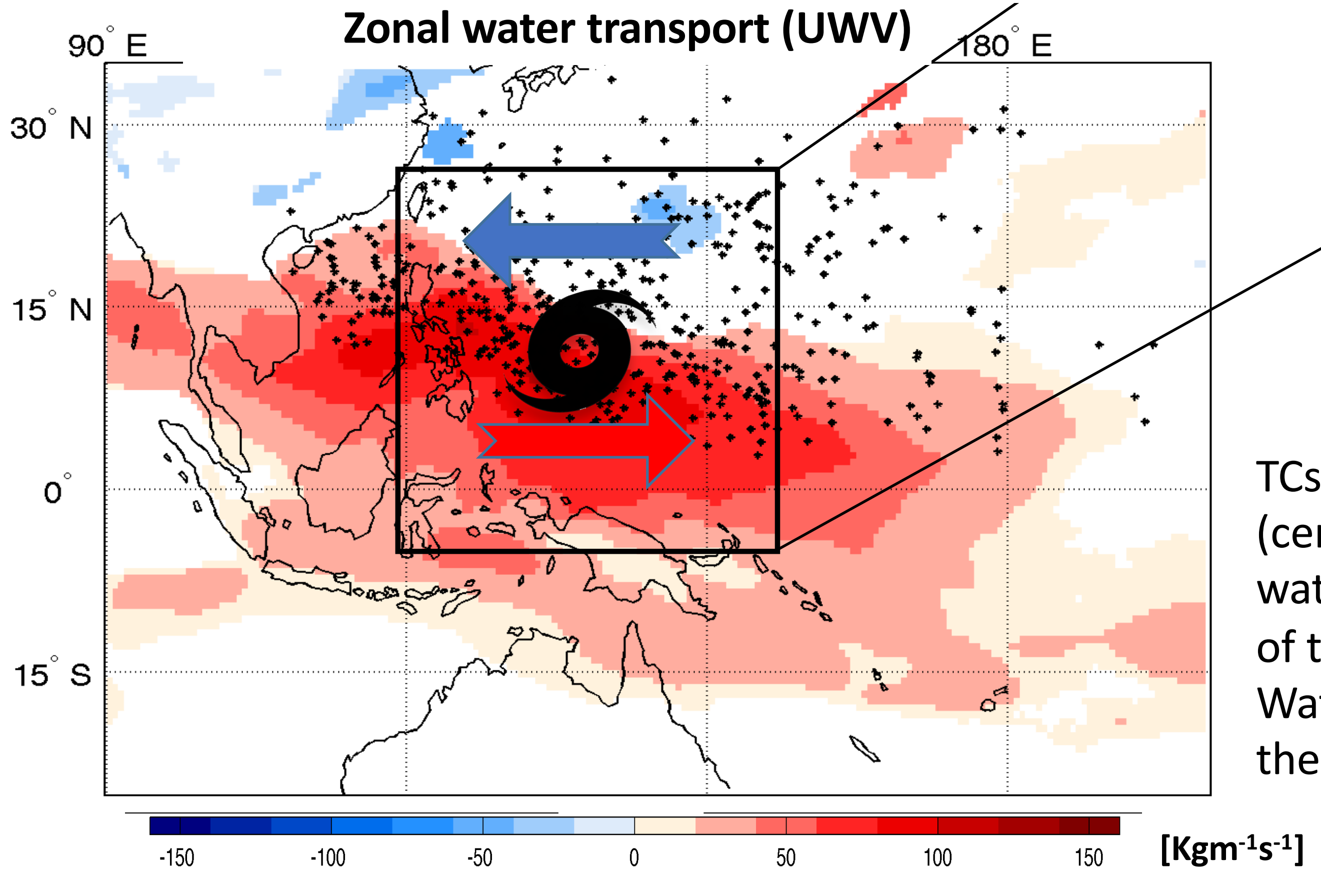
Difference HIGH – LOW ACE years

Zonal water transport (UWV)



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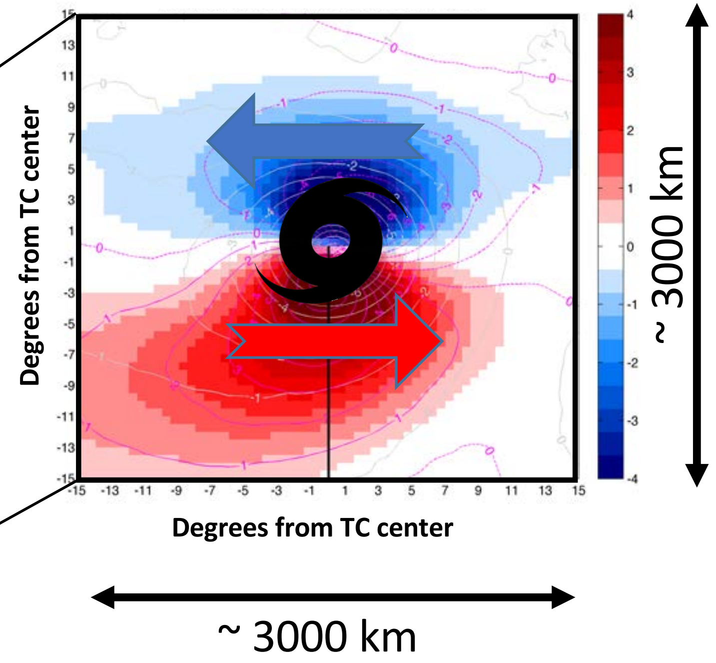

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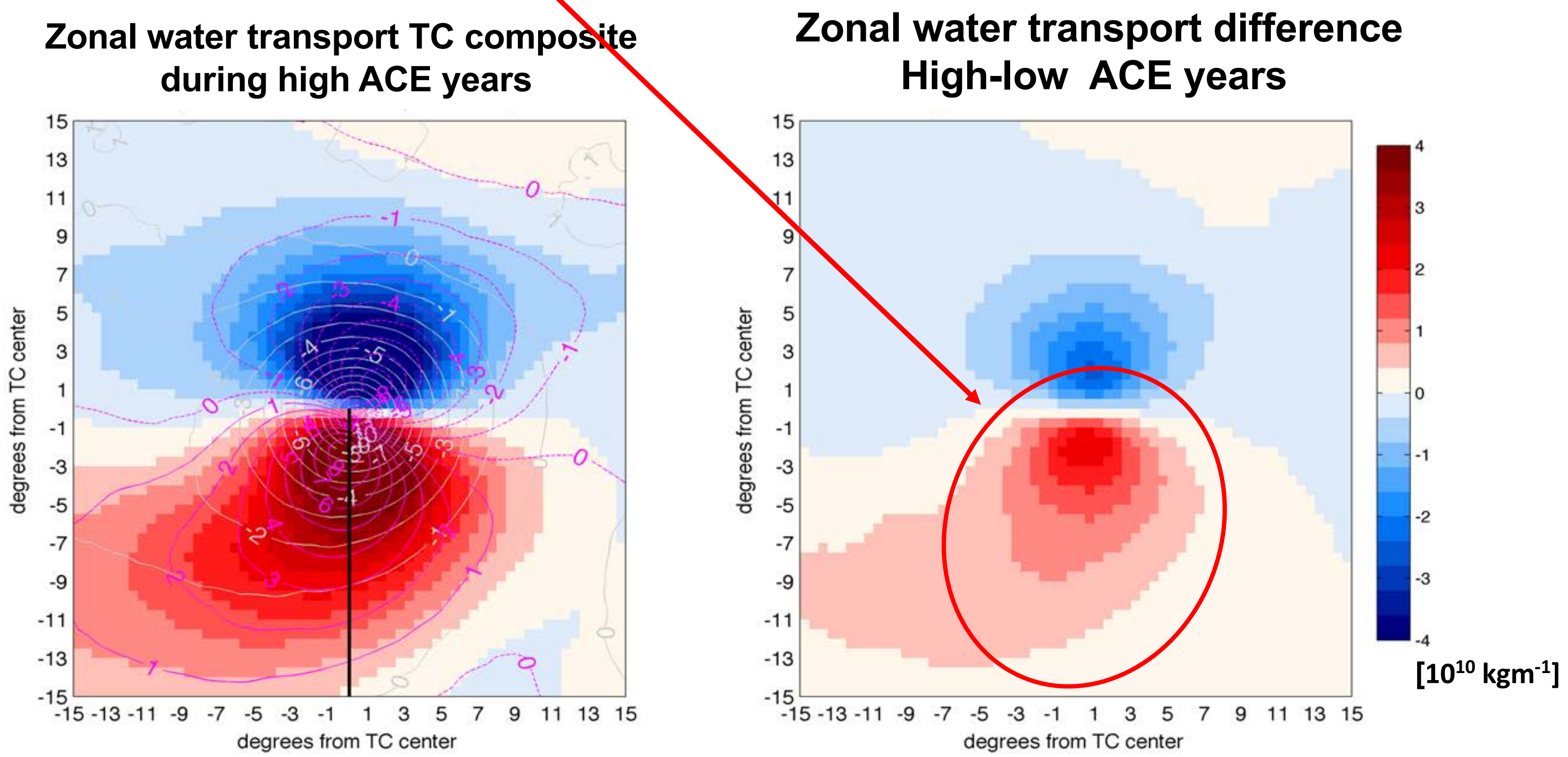
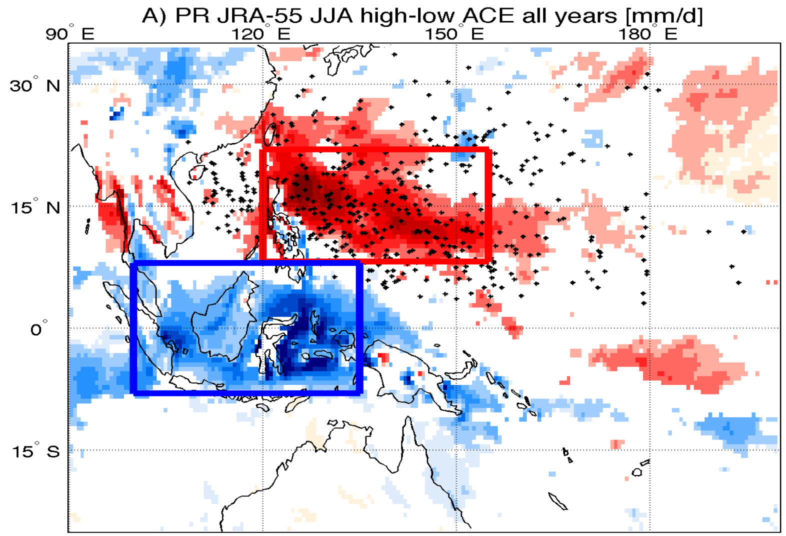


How Tropical Cyclones (TCs) modulate the Maritime precipitation
Discussion:

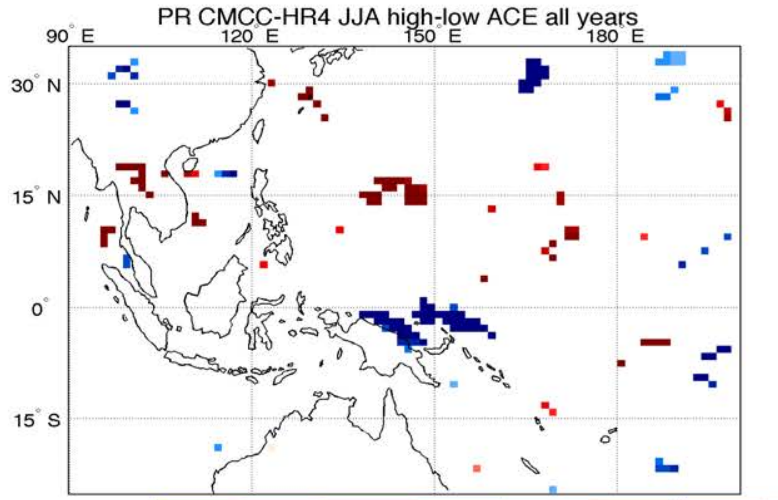
The corroboration through CLIMATE MODEL results:

Difference HIGH – LOW ACE years of PRECIPITATION (PR)

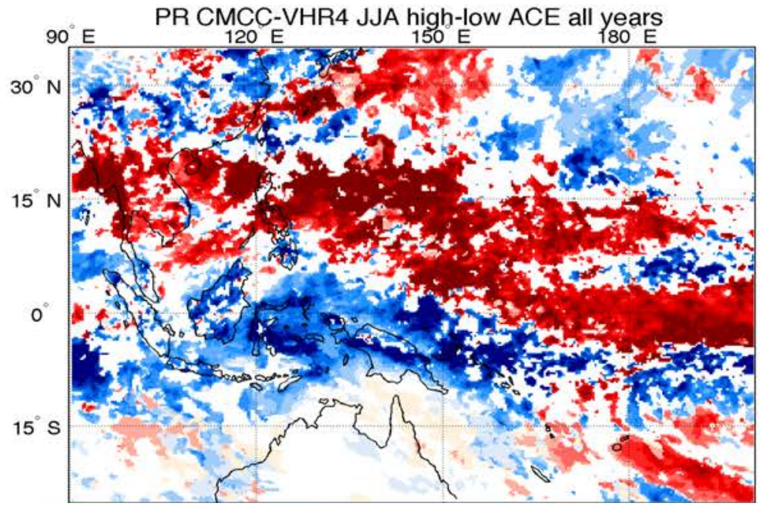
OBSERVATIONS

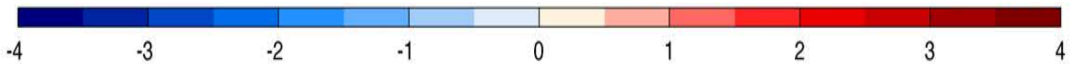


CMCC-CM2-HR4
(100 km horiz res)



CMCC-CM2-VHR4
(25 km horiz.res)





[mm/d]

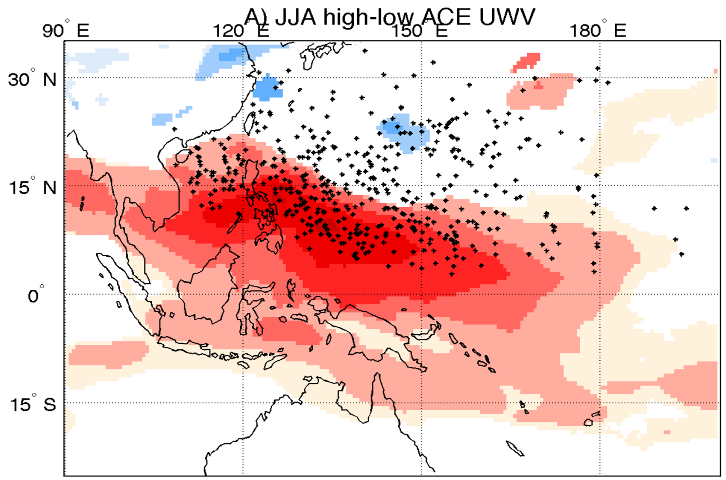
How Tropical Cyclones (TCs) modulate the Maritime precipitation

Discussion:

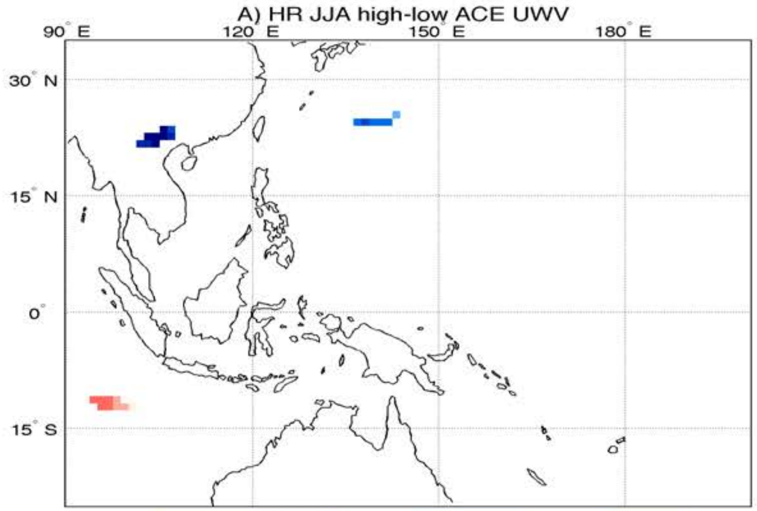
The corroboration through CLIMATE MODEL results:

Difference HIGH – LOW ACE years of zonal water transport (UWV)

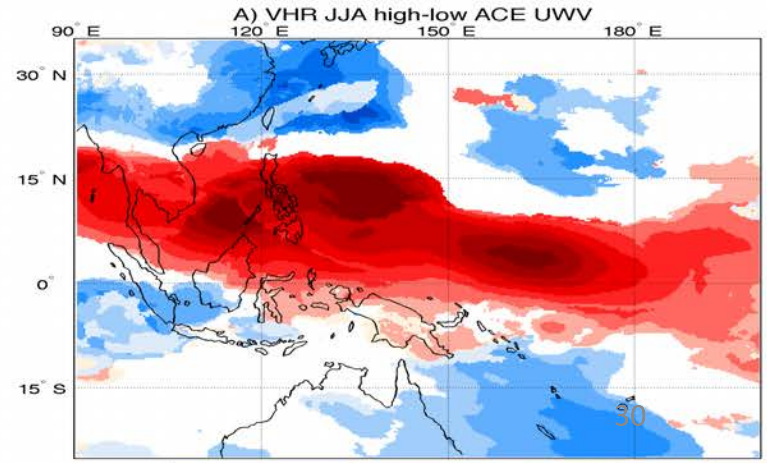
OBSERVATIONS

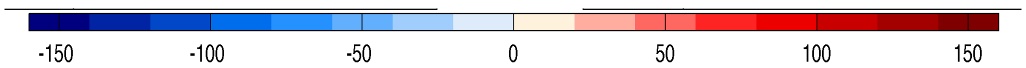


CMCC-CM2-HR4
(100 km horiz res)



CMCC-CM2-VHR4
(25 km horiz.res)





[$Kgm^{-1}s^{-1}$]

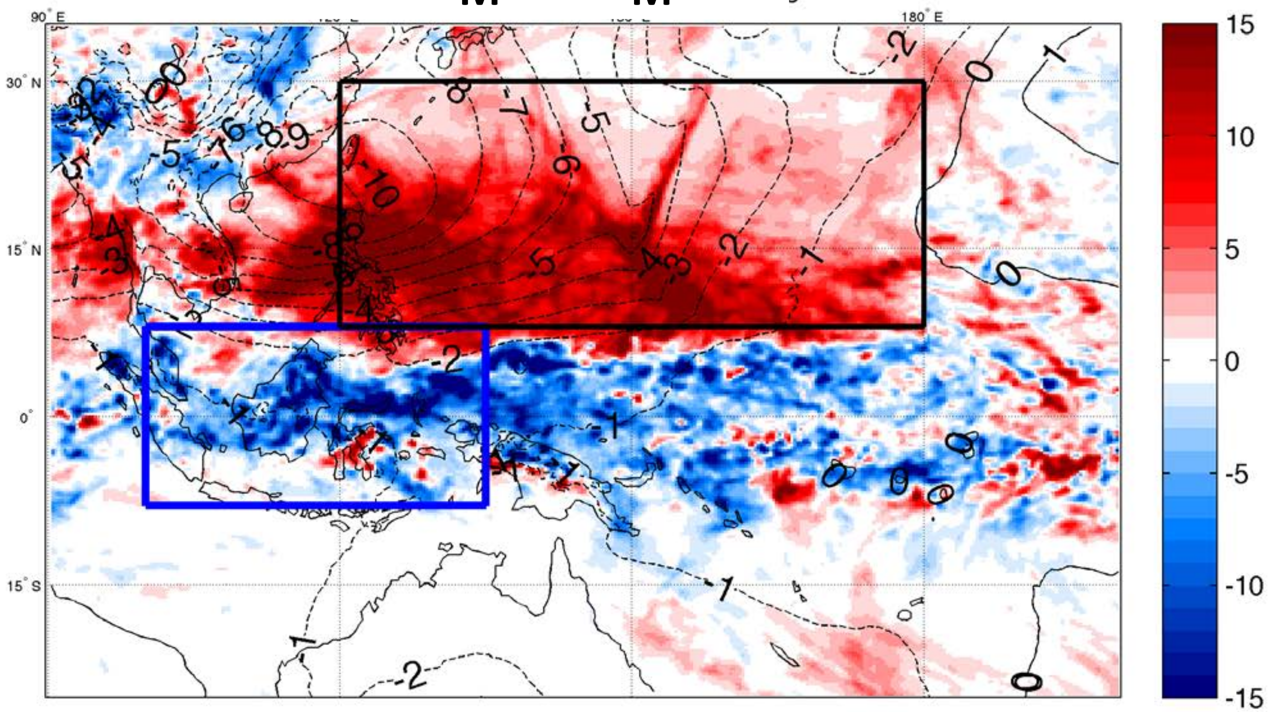
How Tropical Cyclones (TCs) modulate the Maritime precipitation
Discussion:

The corroboration through CLIMATE MODEL results:

In addition, we run an experiment with the high resolution model **CMCC-CM2-VHR4:**

- We identified the most TC active month (**M**) in the 30y time series over the WNP domain
- We rerun that month (**M***), with the same initial condition, but inhibiting the TC development putting to zero the evaporation flux when/where the TC tries to develop.
- We Compared the averaged precipitation in the two experiments as difference $PR_M - PR_{M*}$

$PR_M - PR_{M*}$



contours show slp differences (dashed lines for negative values)

[mm/d]

The experiment with TC free to develop (**M**) shows more precipitation between 8°N and 20°N where they develop and shows less precipitation where TCs tend to reduce water availability through eastward water transport, If compared to the experiment with no TC free to develop (**M***).

Scoccimarro et al. *PNAS*, 2020

Outline

- **T**ropical **C**yclones:
  - brief introduction
- **TC** research at CMCC:
  - General Circulation models and TCs
- How **TC**s modulate the Maritime precipitation:
  - Data and Methods
  - Results
  - Discussion
  - Summary

How Tropical Cyclones (TCs) modulate the Maritime precipitation

Summary:

- Horizontal resolution of State of the art **General Circulation Models** (GCMs) is sufficient to **represent** the most intense Tropical Cyclones (**Category 5 hurricanes/typhoons**)

- **GCMs help us to understand** the relationship between **Tropical Cyclones and the Climate System**.

- Despite their tracks are at latitude higher than 5-10 degrees, **Tropical Cyclones** play **a role in** the **reduction of water available for precipitation over** equatorial regions such as the **the Maritime Continent**, with **most active TC years associated to drier conditions** during the corresponding June to August season.

- Through this mechanism **TCs modulate the onset and duration of the dry season** over the **Maritime Continent**.

- Since the convection over the Maritime continent is fundamental to define the global circulation, we plan to investigate the **potential role of TCs in modulating processes such as El Nino Southern Oscillation** through the mechanism explained here.

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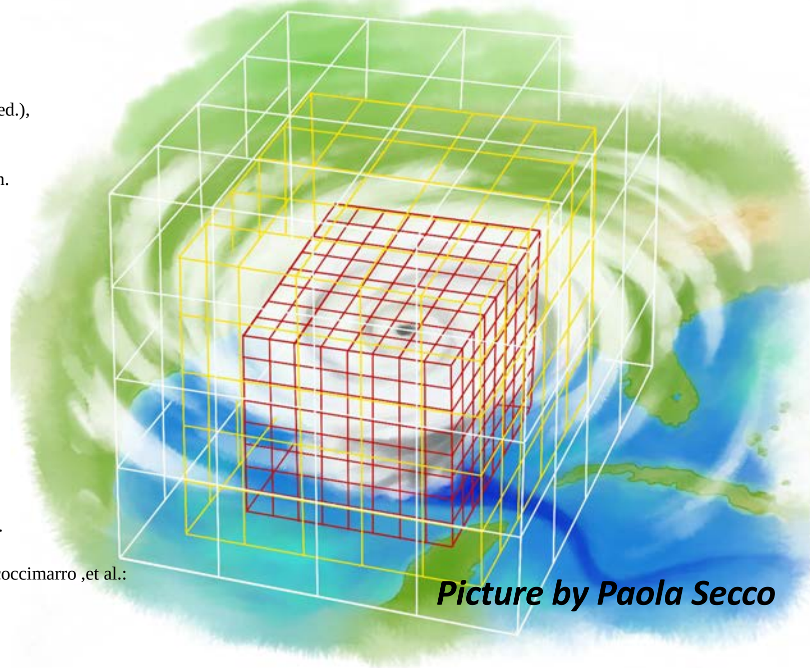
Journal of Climate, doi:10.1175/JCLI-D-19-0500.1. (**2020**)



Picture by Paola Secco

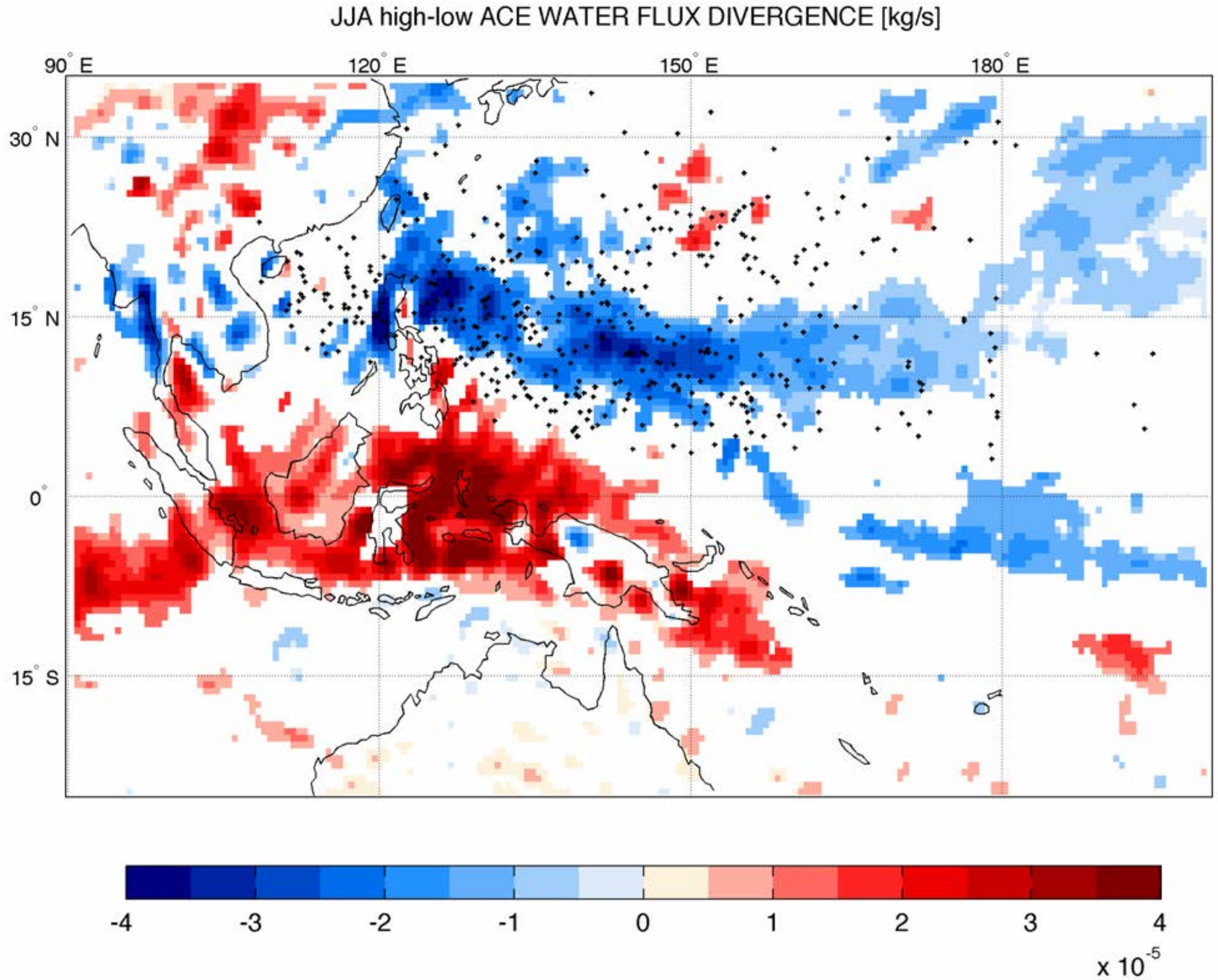
THE ROLE OF TYPHOONS IN THE DRYING OF THE MARITIME CONTINENT

THANK YOU !

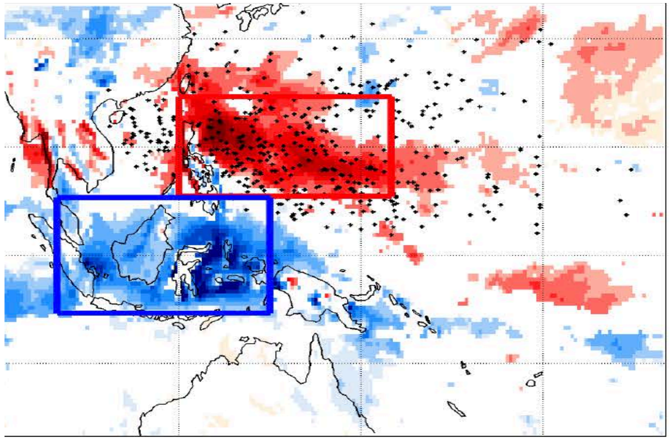
enrico.scoccimarro@cmcc.it

Reference:
Scoccimarro E., Gualdi S., Bellucci A. , Peano D., Cherchi A., Vecchi G.A. , Navarra A., 2020:
"The typhoon-induced drying of the Maritime Continent"
Proceeding of the National Academy of Sciences - ***PNAS*** doi: 10.1073/pnas.1915364117.

How Tropical Cyclones (TCs) modulate the Maritime precipitation
Discussion:



How Tropical Cyclones (TCs) modulate the Maritime precipitation
Discussion:

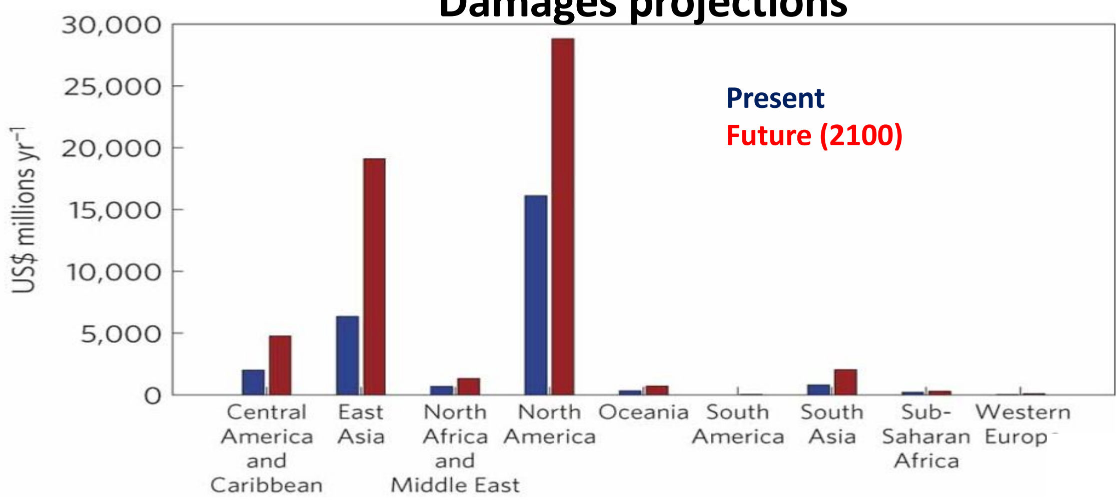


	Flow boundary East	Flow boundary West	Flow boundary North	Flow boundary South	Downward Flow (P-E)
HIGH ACE	-1002.7	2.9	3073.7	-1916.6	121.3
LOW ACE	-2037.5	236.2	2767.3	-1887.9	1135.7
HIGH-LOW	1034.8	-233.3	306.4	-28.7	-1014.4

Table 1 Integrated flows during Jun-Aug over the Maritime Continent box (8^oS:8^oN-100^oE:135^oE box, see Fig.2 panel A) across its boundaries (East, West, North, South, surface) based on JRA-55 re-analysis data. Composite over High and Low ACE years, are shown in the first and second row respectively, while the third row contains the difference of the two. The vertical extent considered for the integration reaches the top of the modelled atmosphere. Positive values refer to flows leaving the box. Units are [10^{12}kg].

Tropical Cyclones

Damages projections



Changes in income will increase future tropical cyclone damages in 2100 in every region **even if climate does not change**.
Changes are larger in regions experiencing faster economic growth,
such as East Asia and the
Central America–Caribbean region.

Future tropical cyclone damages will increase in 2100 in every region **even if climate does not change**.
But we know that Climate is projected to change
Thus **we can expect different changes in TC damages** compared to the aforementione baseline
for the end of the century induced by the projected increased number of strong TCs.

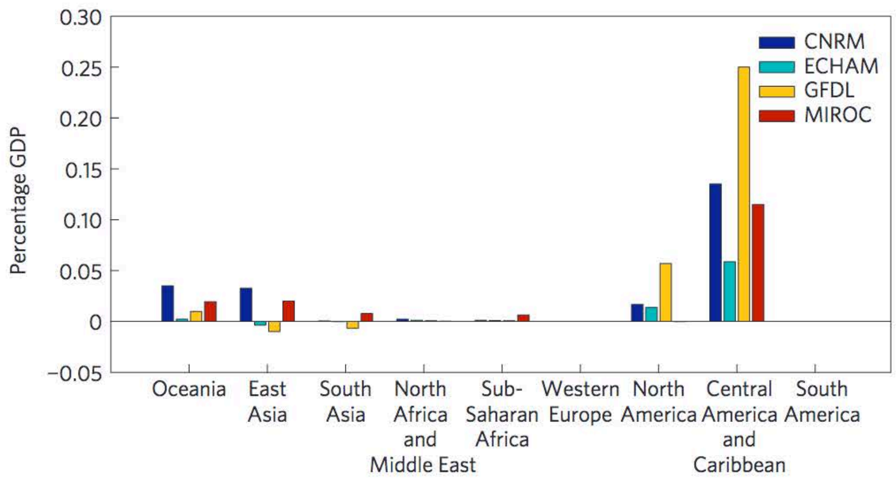


Figure 5 | Climate change impacts on tropical cyclone damage divided by GDP by region in 2100. The ratio of damage to GDP is highest in the Caribbean–Central American region but North America, Oceania and East Asia all have above-average ratios.

Ref: Mendelsohn et al. NCC 2012

TC research at CMCC

The CMIP6 CMCC fully coupled model: CMCC-CM2

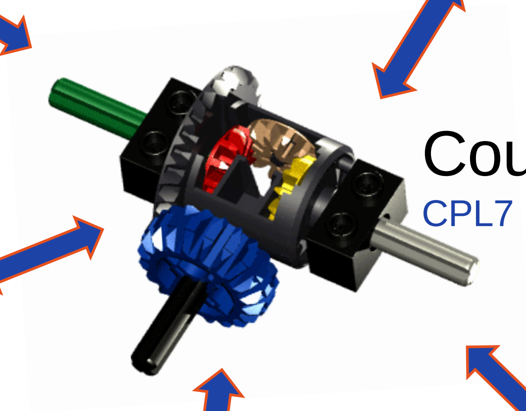
CMCC-CM2-SR5
CMCC-ESM2
CMCC-CM2-HR4
CMCC-CM2-VHR4

River routing

River Transport Model RTM (0.5°)

Atmosphere

Community Atmosphere Model*
CAM4/5 (FV, 1° & 1/4°, 26 levels, interactive & prescribed aerosols)



Coupler / Driver

CPL7

Sea Ice

Community Ice CodE CICE4 (multi-category, same resolution as ocean)

Ocean

Nucleus for European Modelling of the Ocean NEMOv3.6 1/4°; 50 levels)

Land/ Vegetation

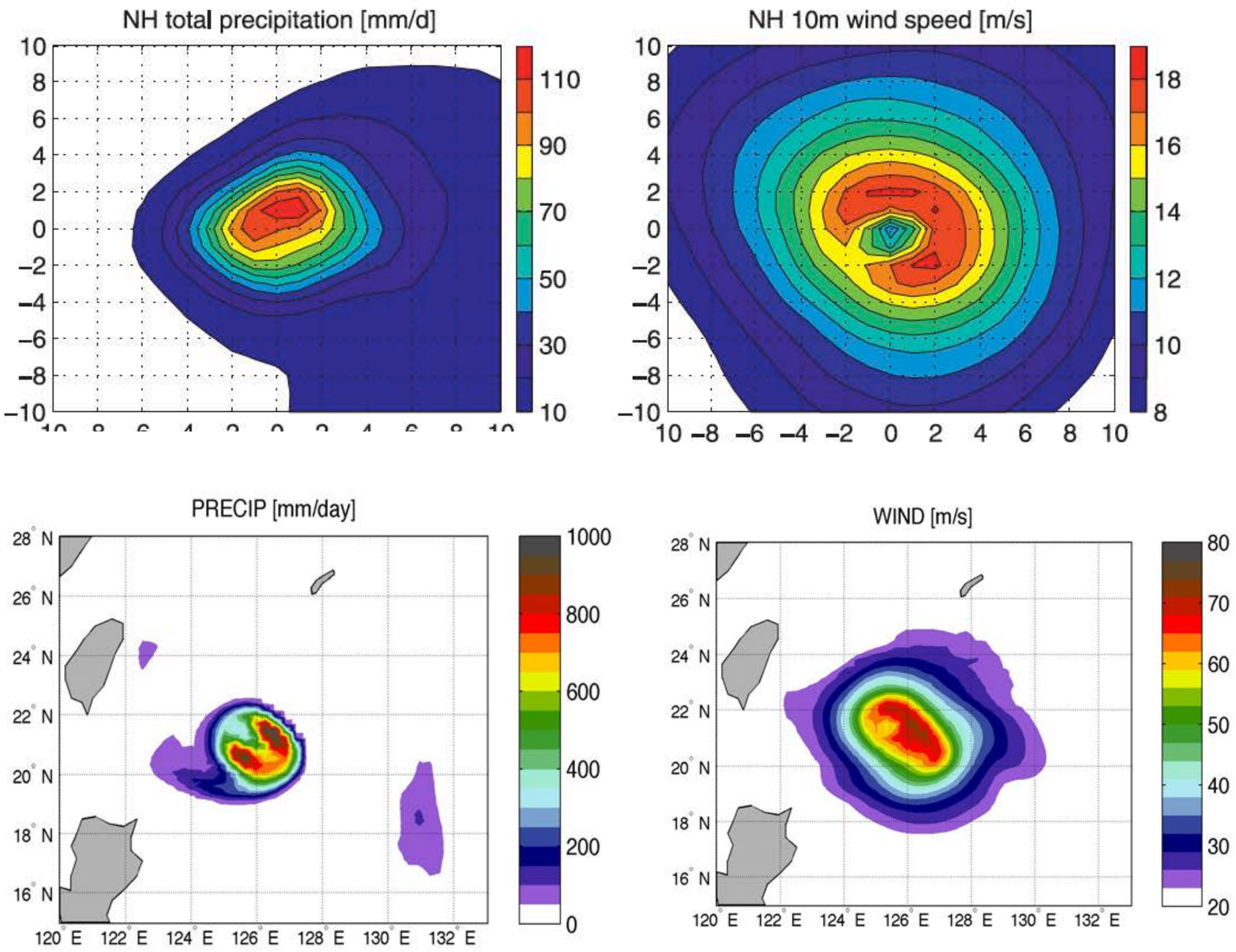
Community Land Model CLM4.5

Ref: Fogli et. al 2014, Scoccimarro et al. jcli 2017, Cherchi e al. james 2018, Scoccimarro et al. pnas 2020

TC research at CMCC

General Circulation Models are able to realistically represent TCs and also their dependency on the mean climate

PRECIPITATION **WIND**



Scoccimarro et al. JCLI 2011, 2017

CMCC-CM
80 km resolution GCM

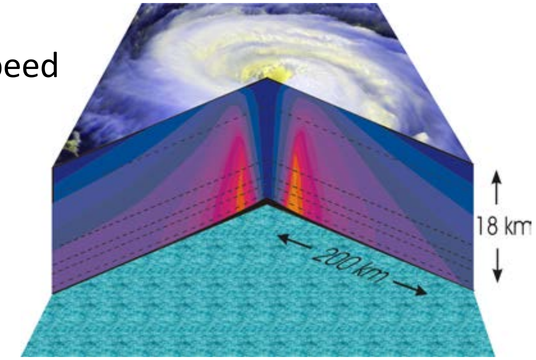
CMCC-CM2
25 km resolution GCM

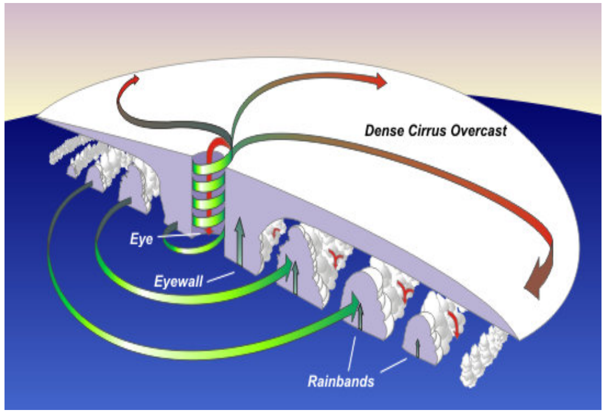
Tropical Cyclones

A **Tropical Cyclone** is the generic term for a non-frontal synoptic scale **low-pressure system** over tropical or sub-tropical waters **with organized convection** (i.e. thunderstorm activity) and **definite cyclonic surface wind circulation** (Holland 1993).

TC structure:

Wind speed



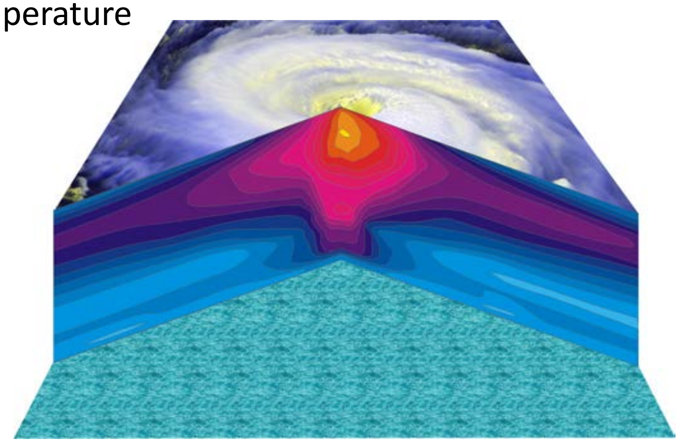


The Eye: the TC's center is a relatively calm, clear area usually 20-40 miles across

The Eyewall: the dense wall of thunderstorms surrounding the eye has the strongest winds within the storm.

The Spiral Rainbands: the storm's outer rainbands (often with hurricane Force winds) can extend a few hundred kilometers from the center.

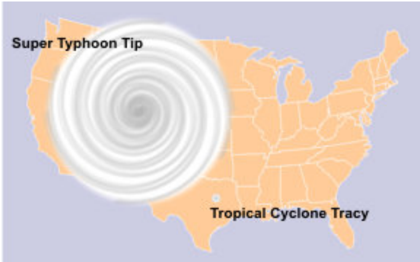
Temperature



Source: Emanuel: Divine Wind, 2005

On record, **Typhoon Tip** (1979) was the **largest** storms with gale force winds (39 mph/63 km/h) that **extended** out **1087 km** in radius in the Northwest Pacific on 12 October, 1979. The **smallest** storm was **Tropical Cyclone Tracy** with gale force winds that only extended **48 km radius** when it struck Darwin, Australia, on December 24, 1974.

TC size:



Source: NOAA https://www.weather.gov/jetstream/tc_structure

Tropical Cyclones

CLASSIFICATION:

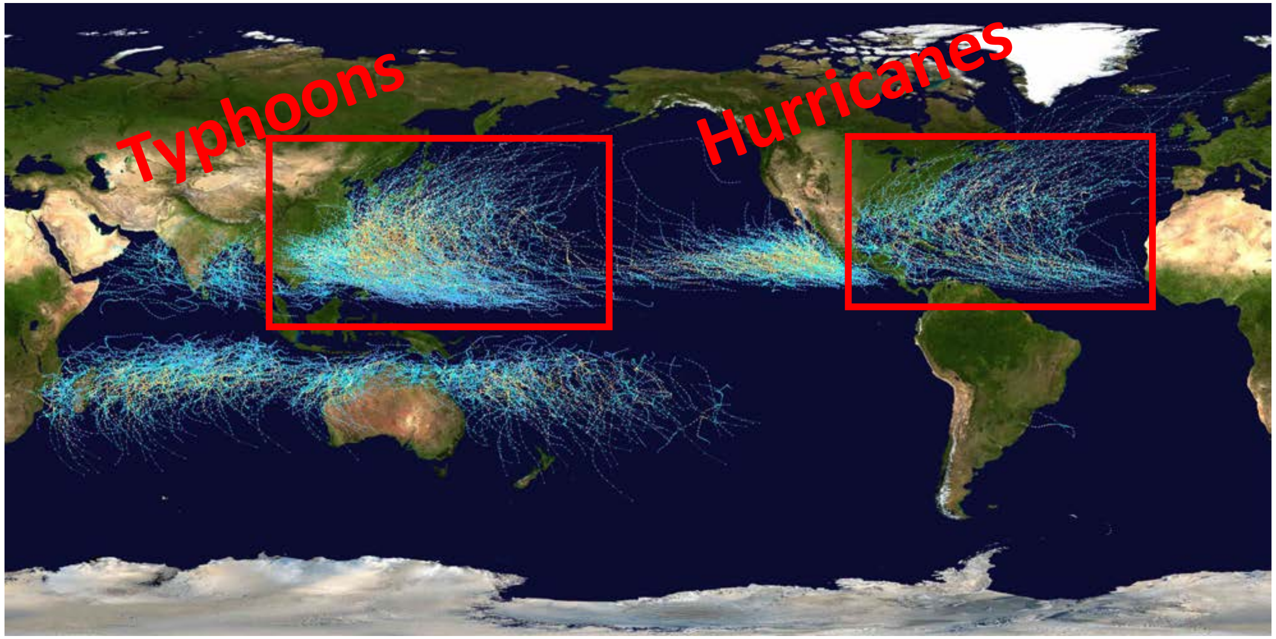
Tropical cyclones with maximum sustained surface winds of less than 17 m/s are usually called "tropical depressions".
Once the tropical cyclone reaches winds of at least 17 m/s they are typically called a "*tropical storm*" or in Australia a Category 1 cyclone and are assigned a name.
If winds reach 33 m/s then they are called:
"*hurricane*" (the North Atlantic Ocean, the Northeast Pacific Ocean east of the dateline, or the South Pacific Ocean east of 160E)
"*typhoon*" (the Northwest Pacific Ocean west of the dateline)
"*severe tropical cyclone*" (the Southwest Pacific Ocean west of 160°E or Southeast Indian Ocean east of 90°E)
"very severe cyclonic storm" (the North Indian Ocean)
"tropical cyclone" (the Southwest Indian Ocean)

Ref: Neumann 1993

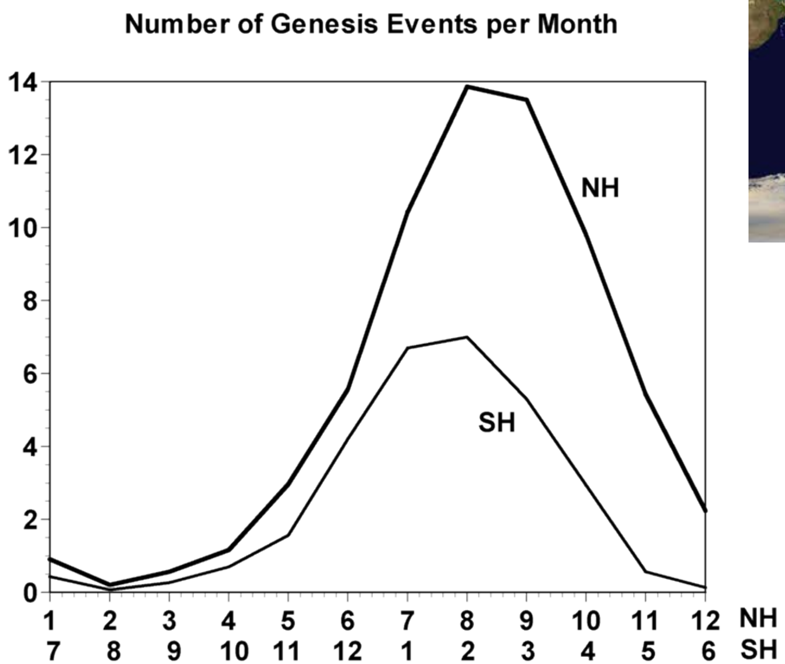
Saffir-Simpson Category	Maximum sustained wind speed		
	mph	m/s	kts
1	74-95	33-42	64-82
2	96-110	43-49	83-95
3	111-130	50-58	96-113
4	131-155	59-69	114-135
5	156+	70+	136+

Tropical Cyclones

TC tracks and number :



Source: NOAA https://oceanservice.noaa.gov/news/historical-hurricanes/



About 90 TCs x year at the global scale

Tropical Cyclones

- **strong wind**

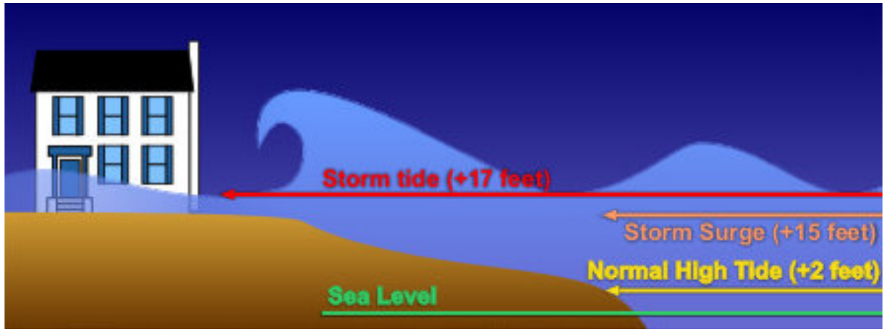
TC winds are among the most powerful on Earth.
Below the eyewall, they often exceed 200 km/h and **can reach 350 km/h**.
Only **tornadoes produce stronger winds**, but **on smaller scales** and **for shorter periods** of time.
When a cyclone passes, **debris of all sizes carried by the wind becomes projectiles** that hit everything
However, it is not the sustained winds that cause the most damage, but rather **variations in intensity and direction of gusts and squalls** that **weaken the structures**.
Variability increases inland as **topography generates small-scale** (a few kilometers) and locally **more intense circulations**

Source: NOAA https://www.weather.gov/jetstream/tc_hazards

Tropical Cyclones

- **storm surge**

TCs produce **strong winds** that **push the water into shore**,
which can **lead to flooding**. This makes storm surges very dangerous for coastal regions.
This advancing **surge combines with the normal tides to create** the **storm tide**,
which can increase the average water level 5m or more.



Source: NOAA https://www.weather.gov/jetstream/tc_hazards

Source: Quaz Africa https://qz.com/africa/

The **level of surge** in a particular area is **also determined by the slope of the continental shelf**.
A shallow slope off the coast will allow a greater surge to inundate coastal communities.

Tropical Cyclones

- **extreme precipitation and floods**

Even after the wind has diminished, due to **torrential rains the flooding potential of TCs remains for several days.**

Since 1970, nearly 60% of the 600 **deaths due to floods** associated with tropical cyclones **occurred inland** from the storm's landfall.

Most of these fatalities occur because people underestimate the power of moving water and purposely walk or drive into flooding conditions.

It is common to think the stronger the storm the greater the potential for flooding.

However, this is not always the case. **TC Allison (cat 1) ,** the first named storm of the 2001 Atlantic Hurricane Season, devastated portions of Southeast Texas with **severe flooding spending five days over Southeast and East Texas.**

There are several types of flooding:

- **Flash floods** are rapid occurring events.
- **Urban/Area floods** are also rapid events although not quite as severe as a flash flood.
- **River flooding** occur when the runoff from torrential rains, brought on by decaying hurricanes or tropical storms, reaches the rivers.

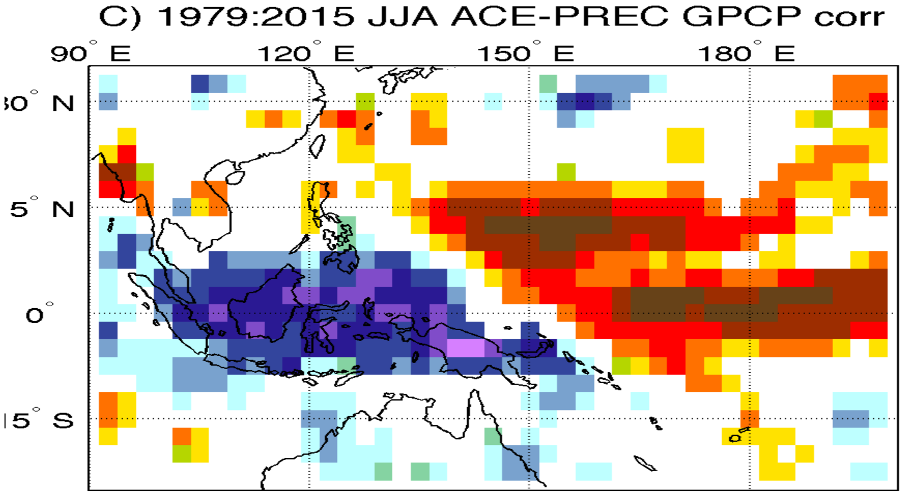
Sources: -NOAA https://www.weather.gov/jetstream/tc_hazards
- Scoccimarro et al. 2014, Villarini et al. 2014

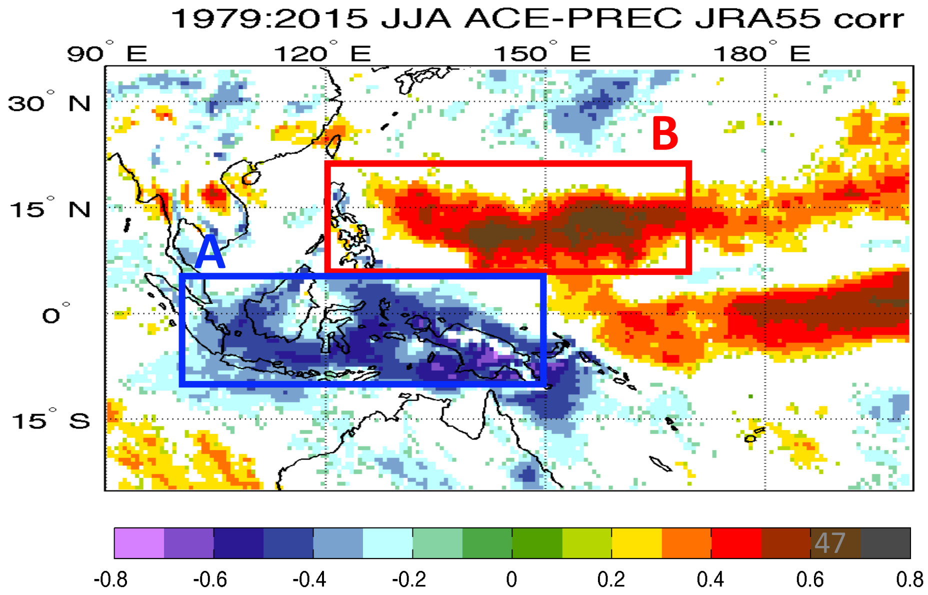
How Tropical Cyclones (TCs) modulate the Maritime precipitation

Results:

CORRELATION between
Accumulated Cyclone Energy (ACE) and **Precipitation**
based on time series of
JJA averages from 1979 to 2015

Important: in all of the slides ACE is computed considering the whole West North Pacific basin (0N:40N, 90E:190E)

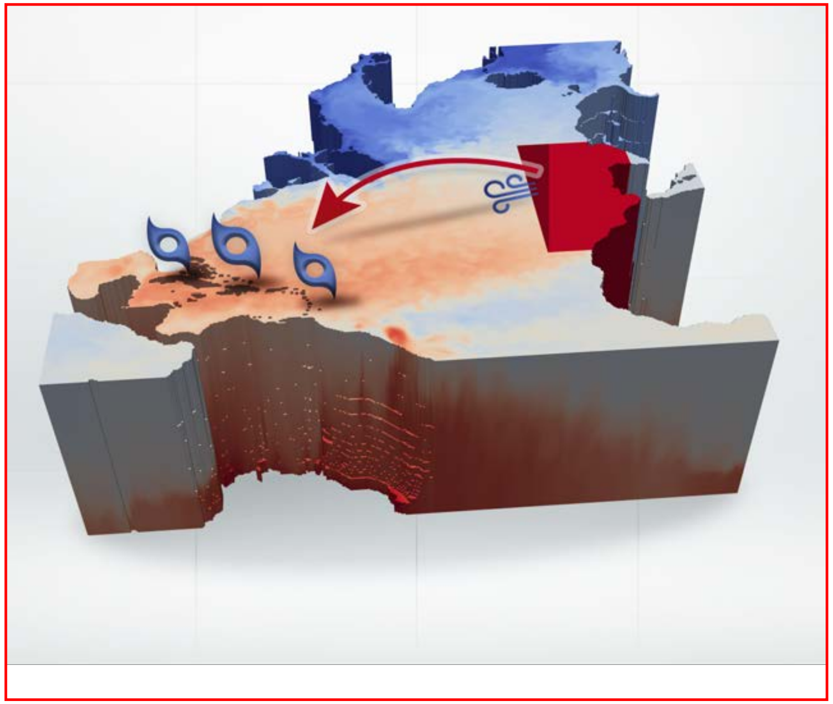




TC research at CMCC

CMCC General Circulation Models are able to realistically represent TCs and also their dependency on the mean climate

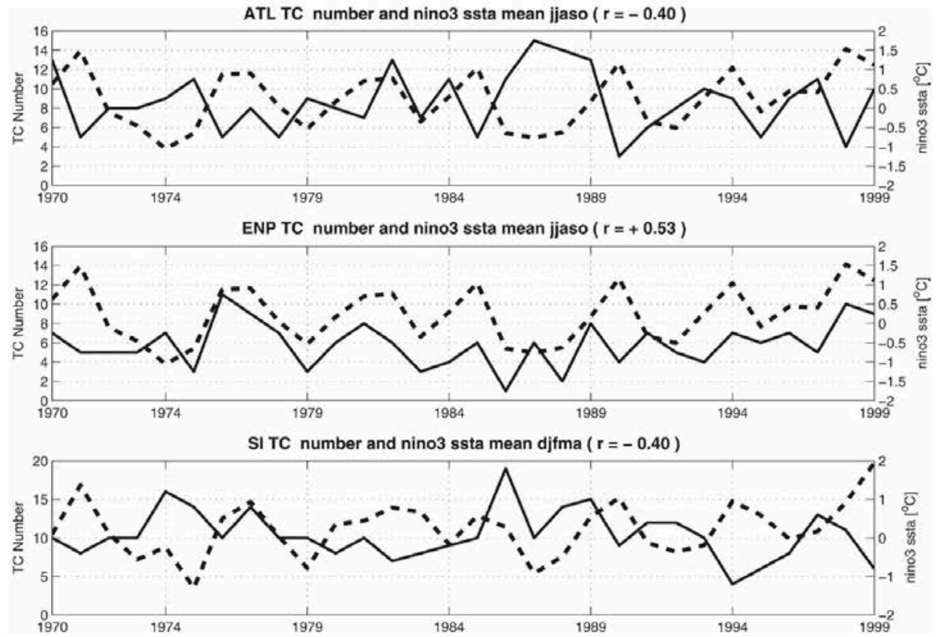
General Circulation Models are also used to investigate the remote role of climate on TC formation



Scoccimarro et al. PNAS 2018

Such as the role of the subsurface ocean in the eastern Atlantic basin in determining TC activity in the western Atlantic basin.

Also the dependency of TC activity on the mean climate modes of variability is kept by General Circulation Models (ENSO, MJO,..)



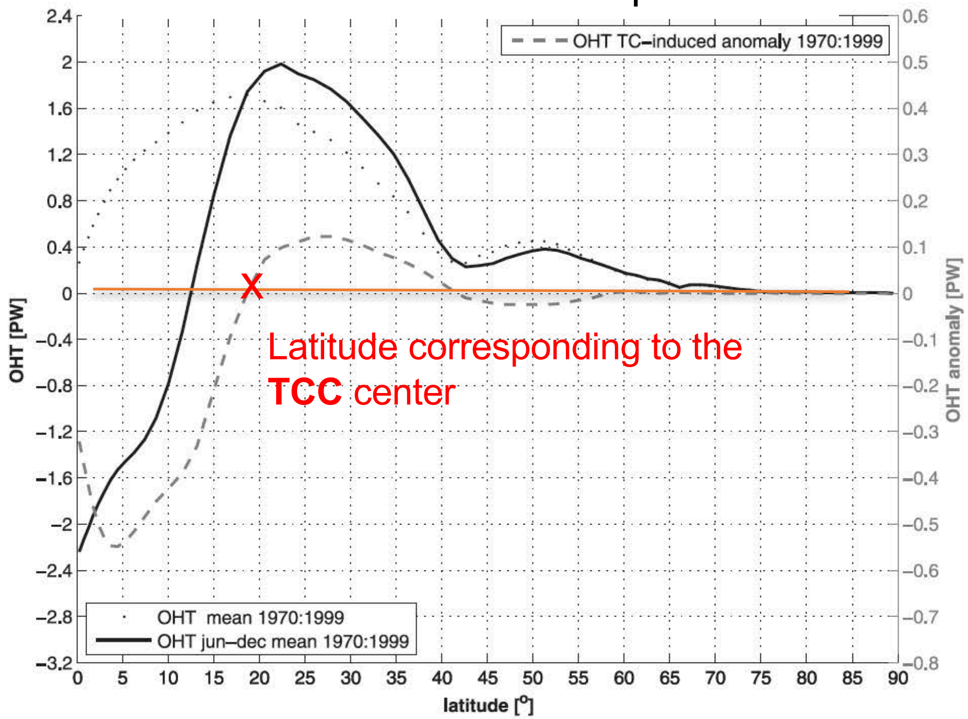
Gualdi et al. JCLI 2008

TC research at CMCC

CMCC General Circulation Models are able to realistically represent TCs and also their effect on the climate system: two examples

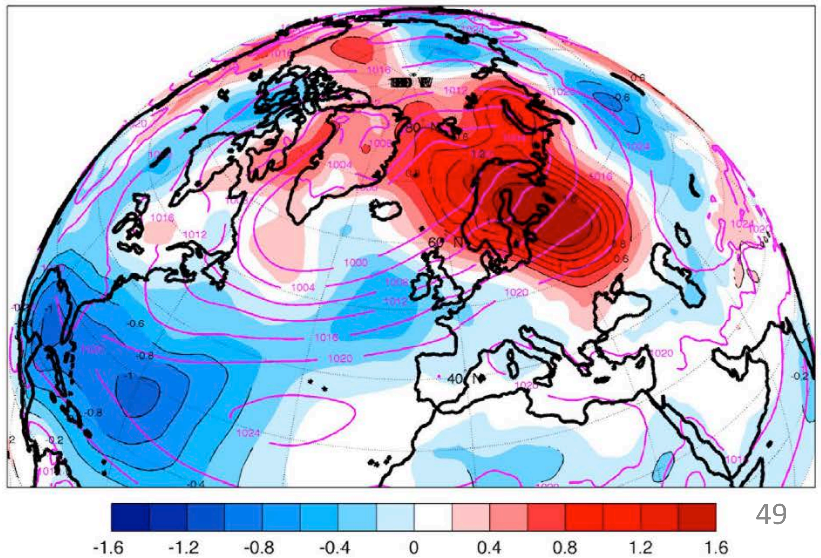
The large **Tropical Composite-Cyclonic** structure (TCC) is identified both using observed and Model data sets. The **TCC** fingerprint on the zonal winds is coherent with the minimum of Sea Level Pressure associated with the TCC center in the sub-tropical ocean. This **is reflected in TC induced ocean heat transport** (Scoccimarro et al. 2011) and **linked to a teleconnection with The Arctic Ocean** (Scoccimarro et al. GRL 2012).

NH Ocean Heat Transport



Scoccimarro et al. JCLI 2011

SLP Hurricane induced anomaly (ERA-Int)



Scoccimarro et al. GRL 2012

TC research at CMCC

CMCC General Circulation Models are able to realistically represent TCs

The role of the high frequency coupling between atmosphere and ocean components:

Power Dissipation Index (**PDI**, Emanuel, 2005) integrated over the entire period, is a well recognized indicator of Tropical Cyclone activity considering both storm frequency and intensity. It is **the cube of the maximum sustained wind integrated along the TC tracks.** Although not a perfect measure of net power dissipation, this index is a **better indicator of tropical cyclone threat than storm frequency or intensity alone**.

global scale	OBS	FORCED	LOW FREQUENCY *daily ATM-OCE coupling*	HIGH FREQUENCY *hourly Atm-Oce coupling*
PDI ([m^3/s^2] *e+12)	**1.52**	2.70	2.56	1.63
PDI BIAS [%]		**+77%**	**+68%**	**+7%**

Scoccimarro et al. JCLI 2017