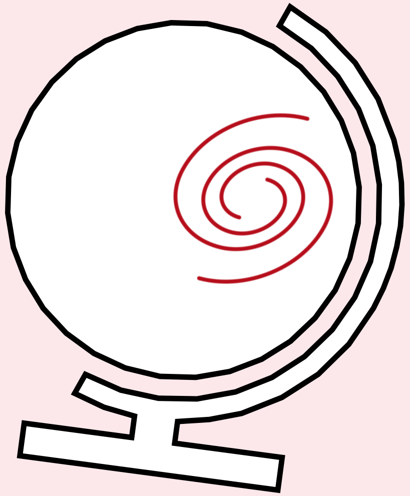

Tropical Cyclones in Global High-Resolution Simulations using the IPSL Model

Preprint in Climate Dynamics

SCAN ME

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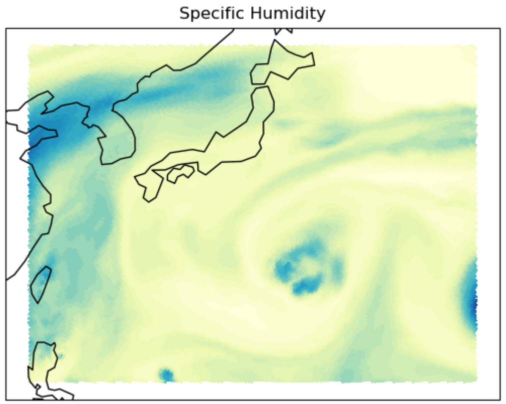
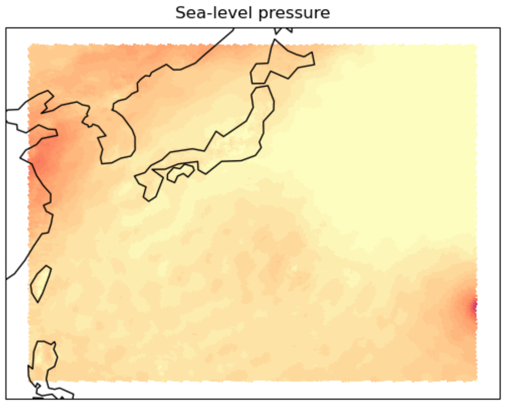
[1] LSCE / IPSL

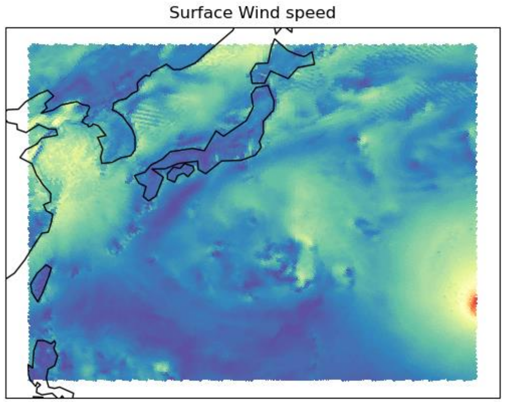
[2] IPSL

[3] LMD / IPSL

October 3rd, 2023 — LMDZ days

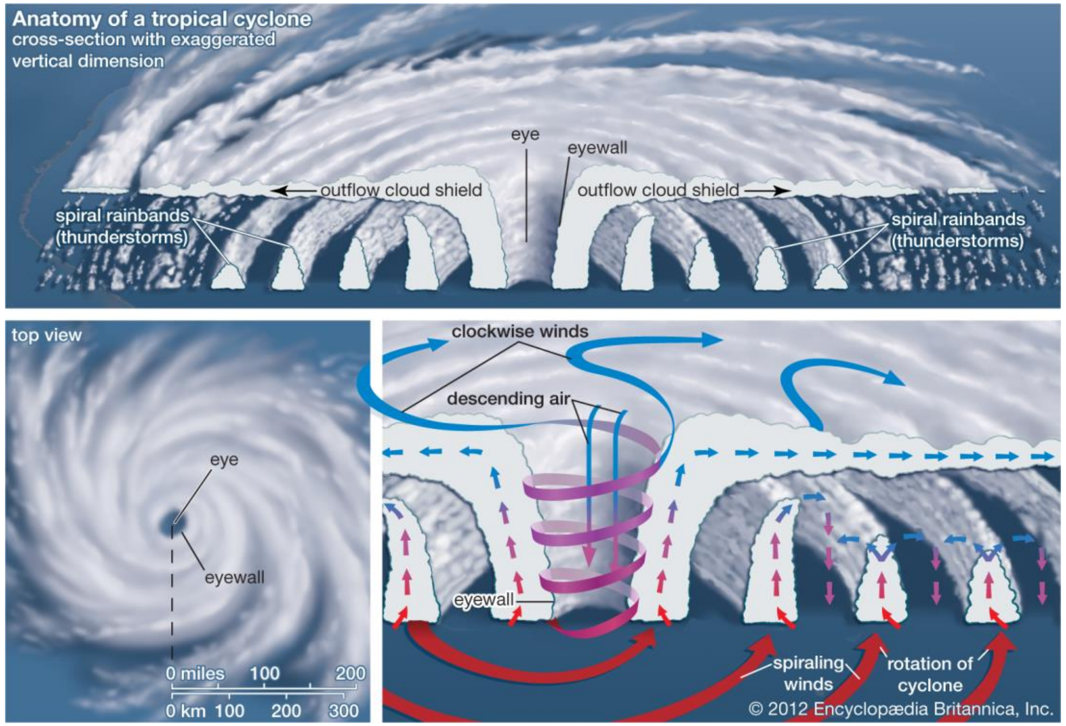




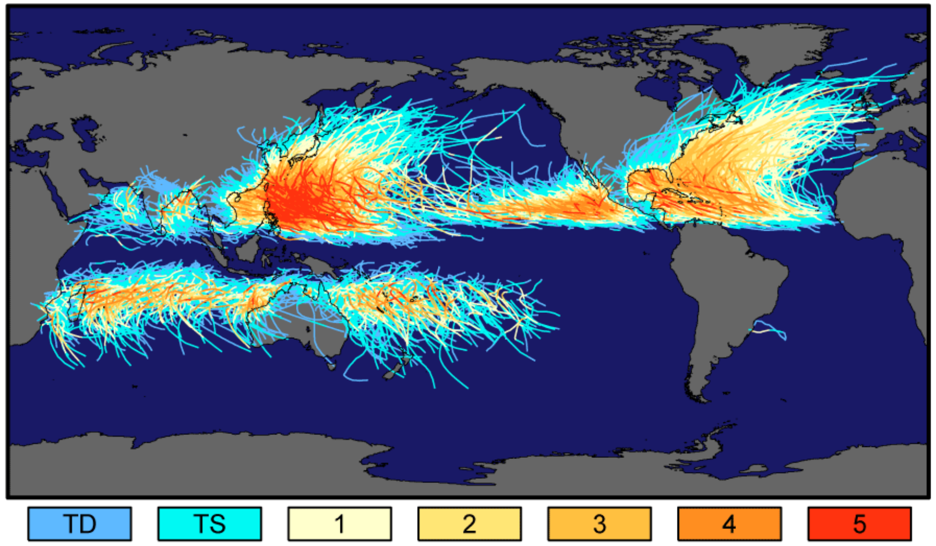


Tropical cyclones

- « cyclone » en français = ouragan, typhon
- Vents et precip. Intenses
- ~80-90 / an
- Impacts énormes:
  - Désastre le plus coûteux
  - Deuxième type de désastre le plus mortel (UNDDR)



Trajets et intensités des cyclones tropicaux



Echelle d'intensité des cyclones de Saffir-simpson

Context:
Why do we need GCMs to study TCs?

- Risk associated with Tropical Cyclones (TCs) in the future remains uncertain (IPCC)
  - What sets the frequency? (Sobel et al., 2021)

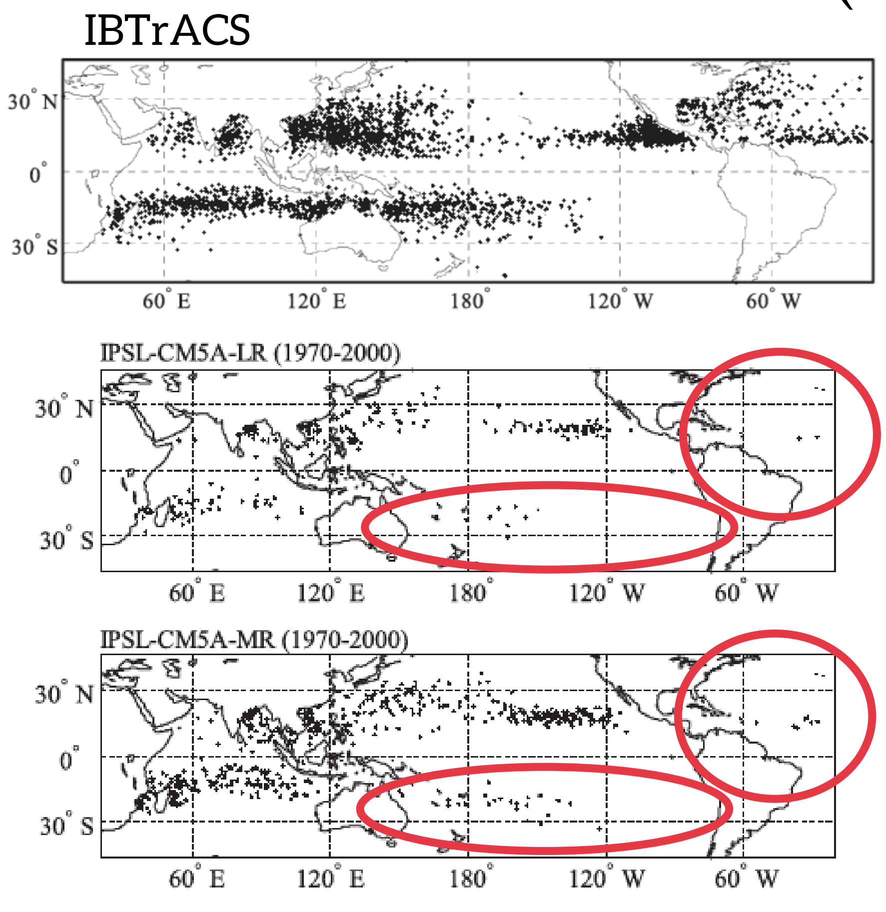
- Observations are very scarce
  - 40 years of satellite observations
  - Challenge to obtain measurements within TCs.

→We need models to simulate TCs

→ Global Climate Models (GCMs) that simulate realistic TC climatologies can be useful in investigating links between TCs and the environment

- Ability to simulate TC varies a lot among the models, but improves systematically with resolution (Roberts et al., 2020a)

At the IPSL ? TCs in previous versions of the IPSL model (coupled version)



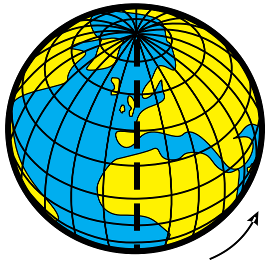
Genesis points in the observations and the IPSL model, from Tory et al. (2013)

- No dedicated assessment.
- IPSL included in a number of CMIP comparaison, but never commented (and often removed because too low frequency)
- TC climatology highly flawed…
  - Very low frequency
  - No TC in the North Atlantic and South Pacific
- … for understandable reasons
  - Coarse resolution, mainly
- Slight improvement with resolution.

The IPSL-CM6A-ATM model

Dynamico allows increasing the resolution.
→ Opportunity to study new phenomena !

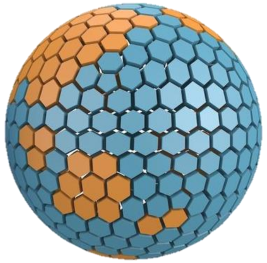
Is the IPSL model at high resolution a suitable tool for studying TCs?



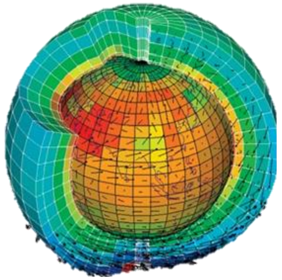
Lon-Lat

OR

DYNAMICO



✚



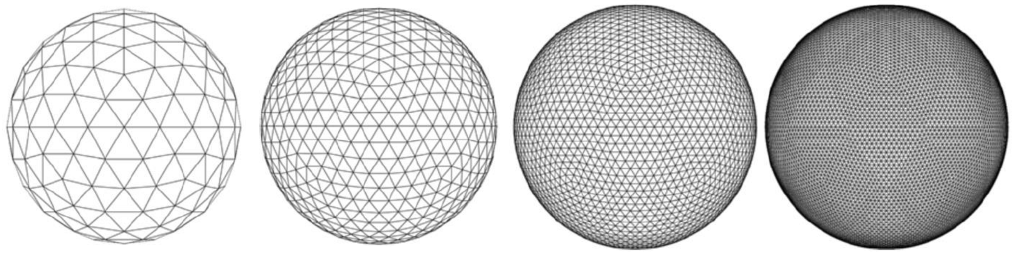
Physics:
LMDz

✚

Land surface:
ORCHIDEE

HighResMIP simulations

Image from Satoh et al., 2014



Lon-Lat

LR		HR	
2°		½°	
200 km		50 km	

ICO

LR	MR	HR	VHR
2°	1°	½°	¼°
200 km	100 km	50 km	25 km

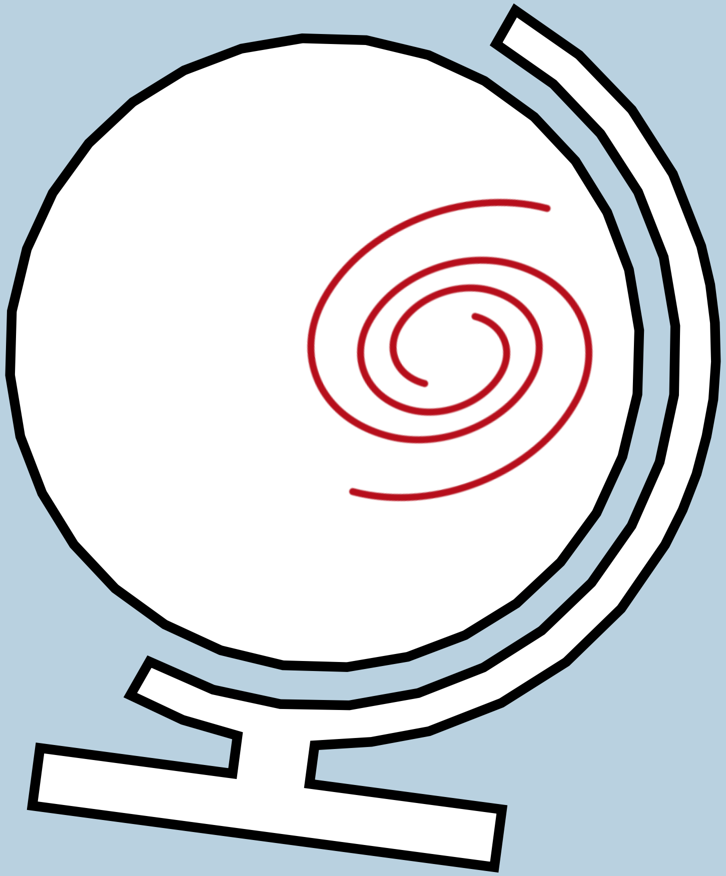
HighResMIP framework:

- Atmosphere-only
- global
- forced SST
- 65 historical years
  - 1950-2014

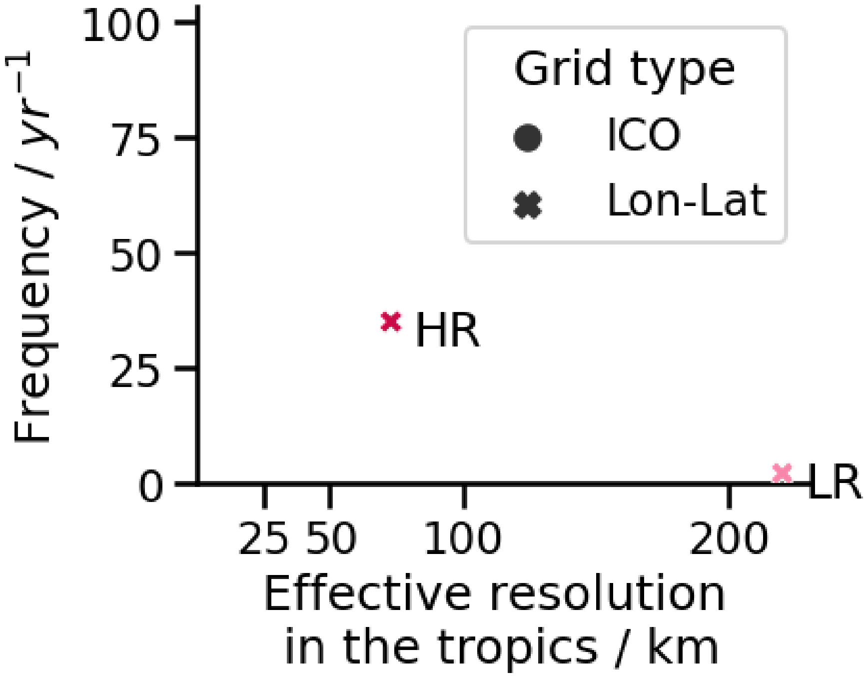
TC tracked with UZ/TempestExtremes

(Zarzycki & Ullrich, 2017)

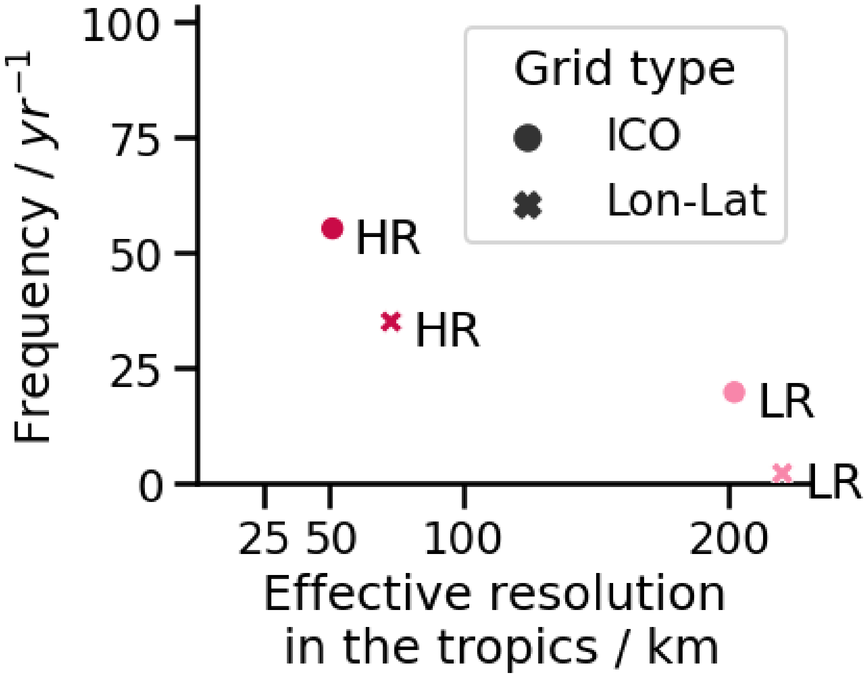
Results



Lon-Lat vs. ICO

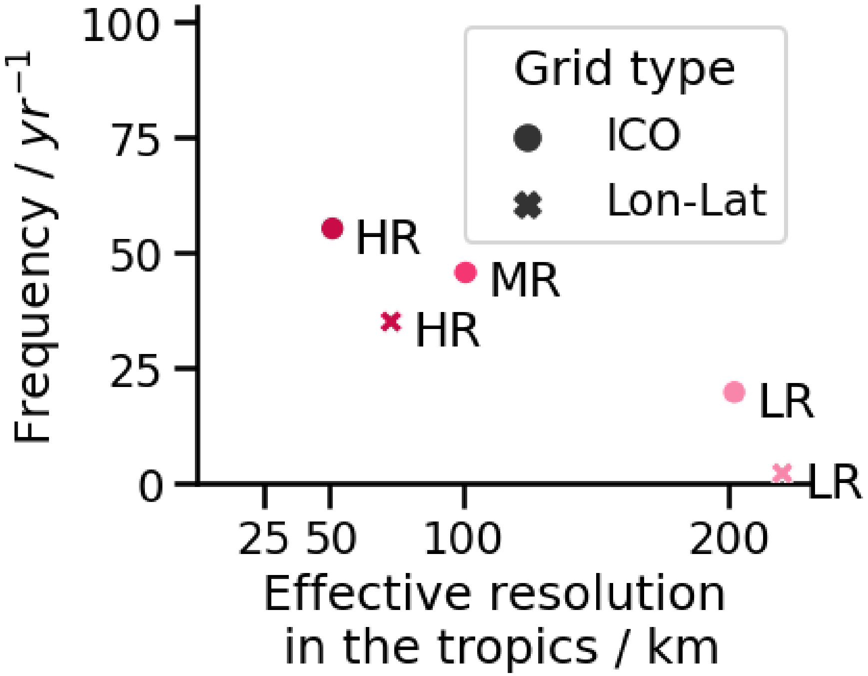


Lon-Lat vs. ICO



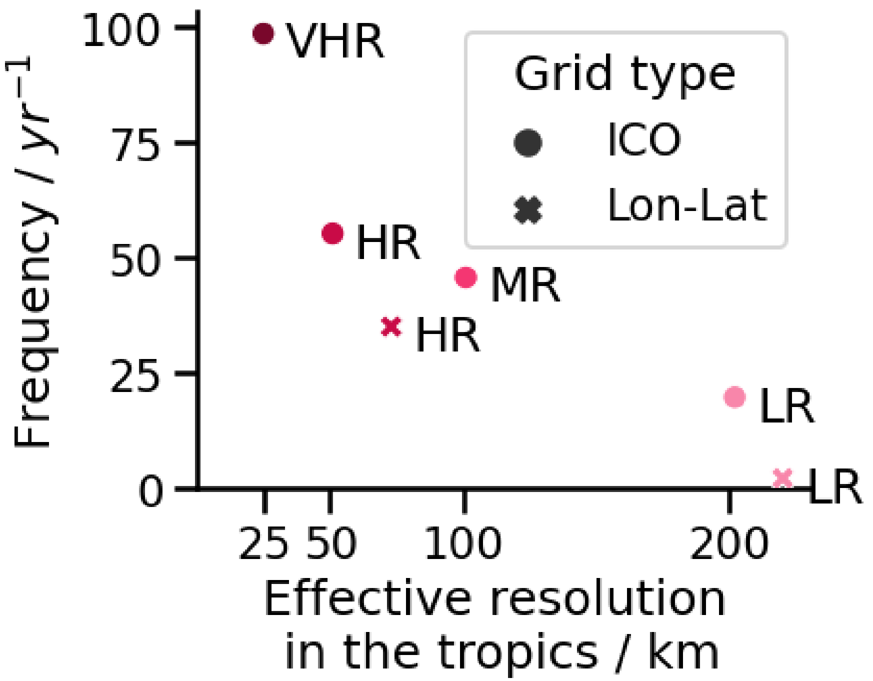
- Activity is comparatively lower in simulation with the Lon-Lat core at same nominal resolution
  - Because effective resolution in the tropics is lower

Lon-Lat vs. ICO



- Activity is comparatively lower in simulation with the Lon-Lat core at same nominal resolution
  - Because effective resolution in the tropics is lower
- Frequency in Lon-Lat HR is below ICO-MR
  - Likely effect of dissipation

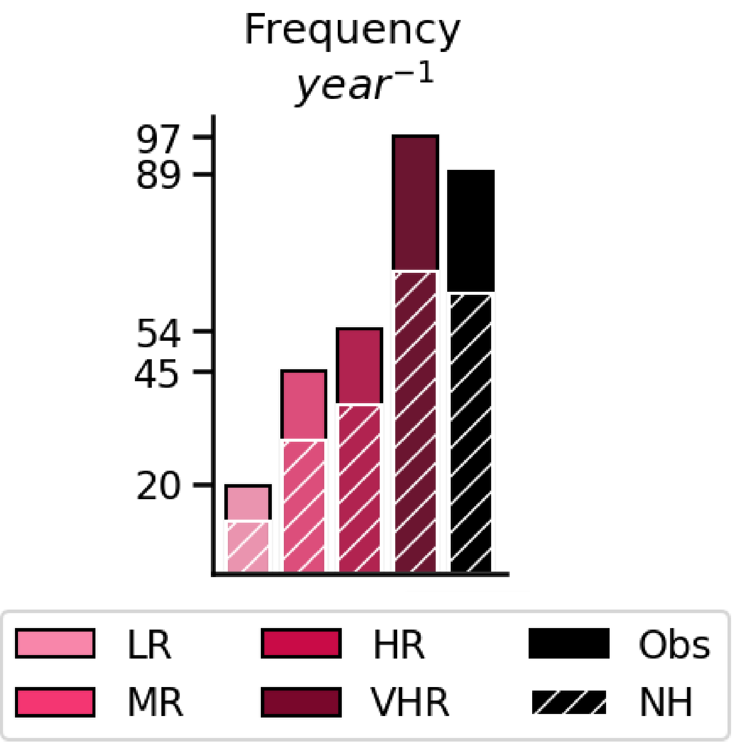
Lon-Lat vs. ICO



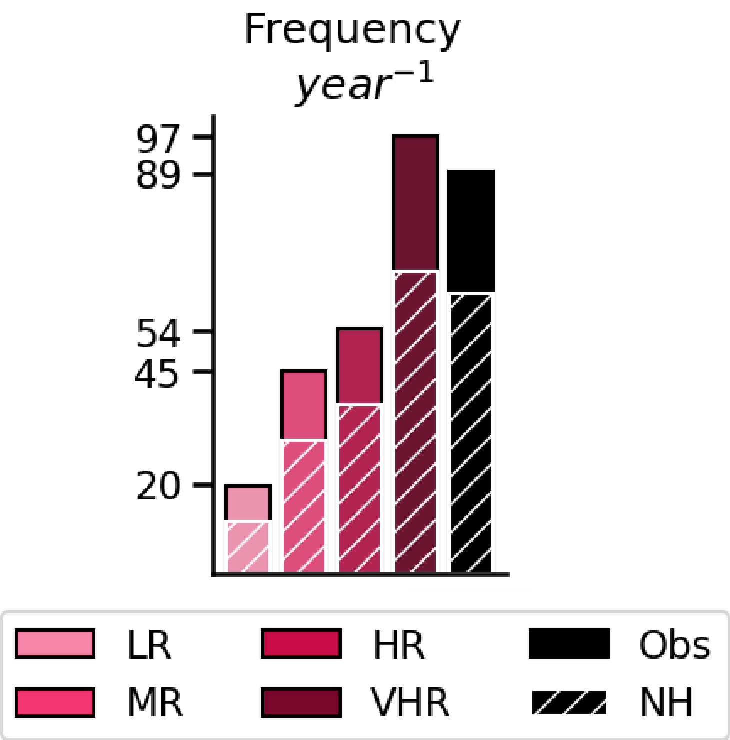
- Activity is comparatively lower in simulation with the Lon-Lat core at same nominal resolution
  - Because effective resolution in the tropics is lower
- Frequency in Lon-Lat HR is below ICO-MR
  - Likely effect of dissipation

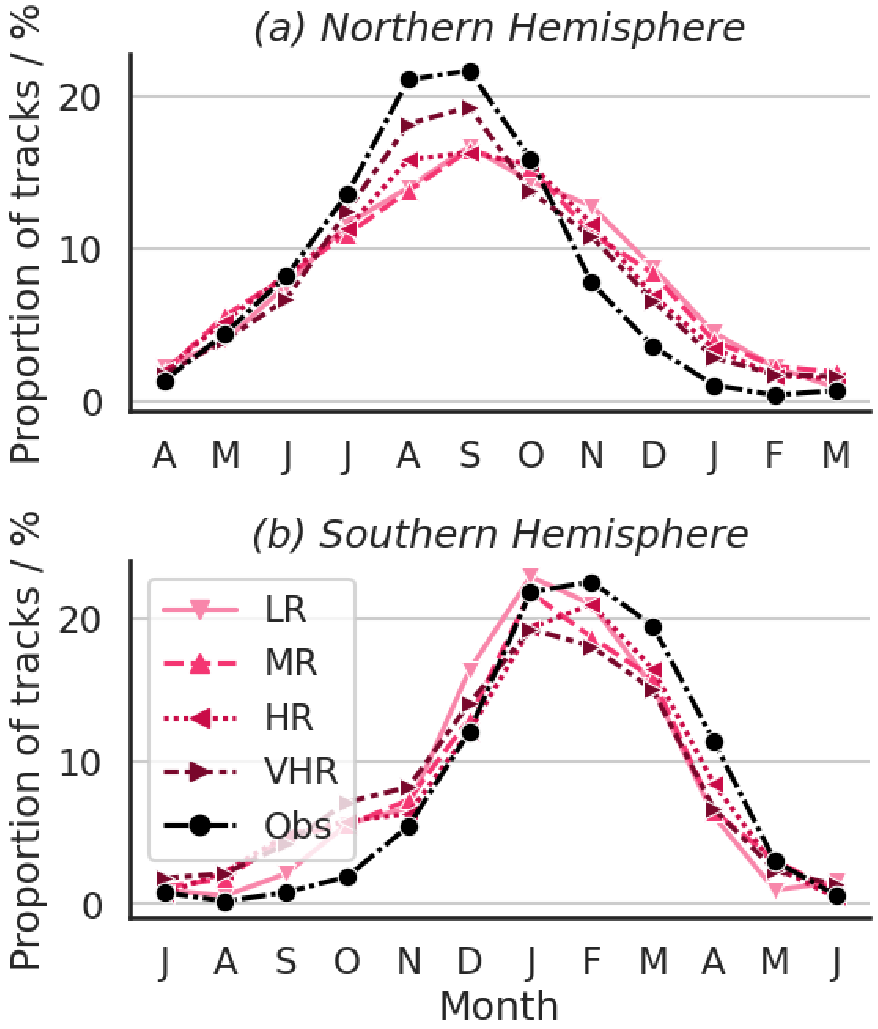
DYNAMICO is an advantage because we can have higher resolution and lower dissipation

Global activity

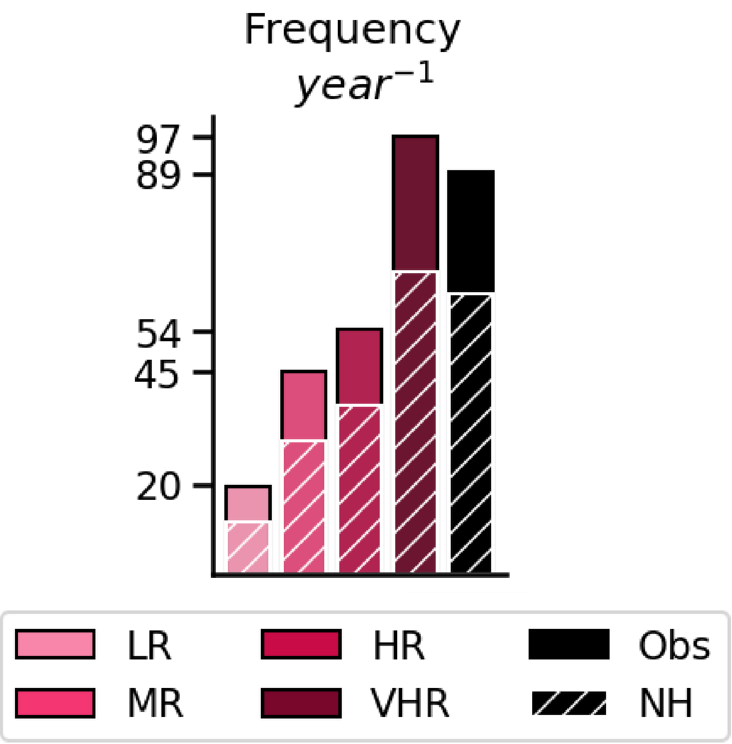


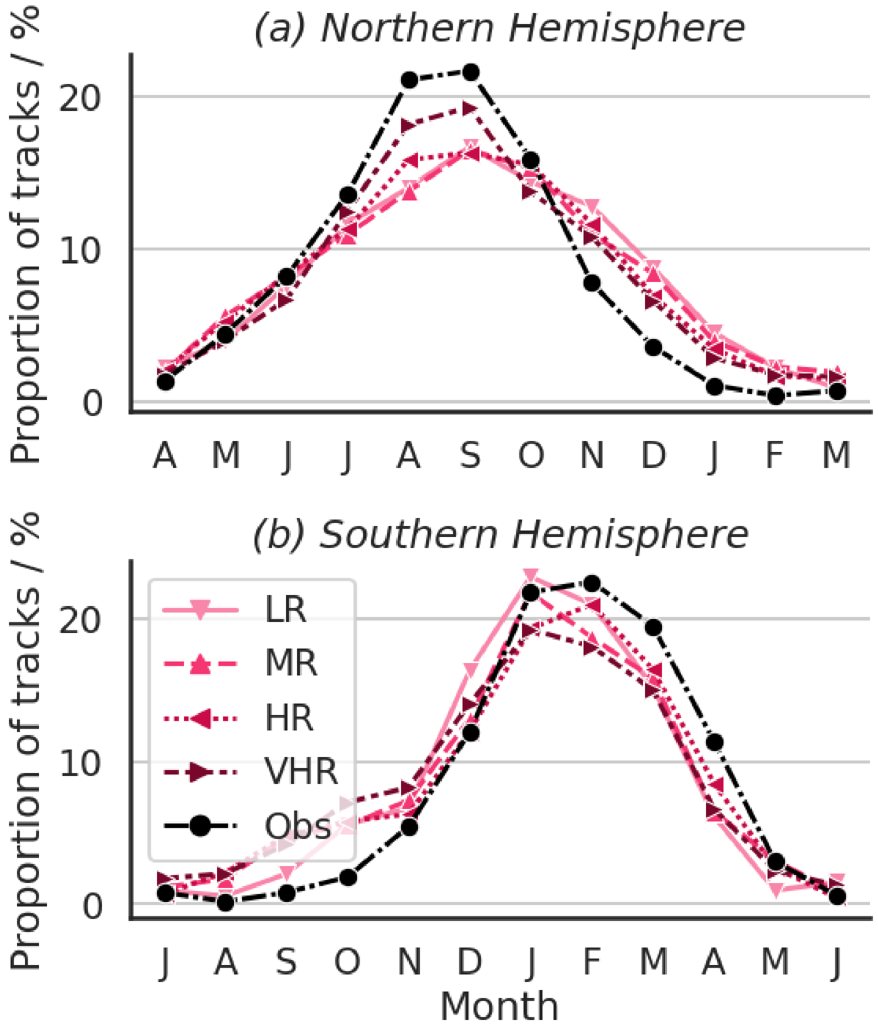
Global activity





Global activity





Activity increases globally with resolution, up to observed levels.
Seasonnal cycle are good.

Other results

At the regional scale

- The distribution of TCs improves among the basins, and within them when resolution is increased.
- Frequency increases in all the basins.

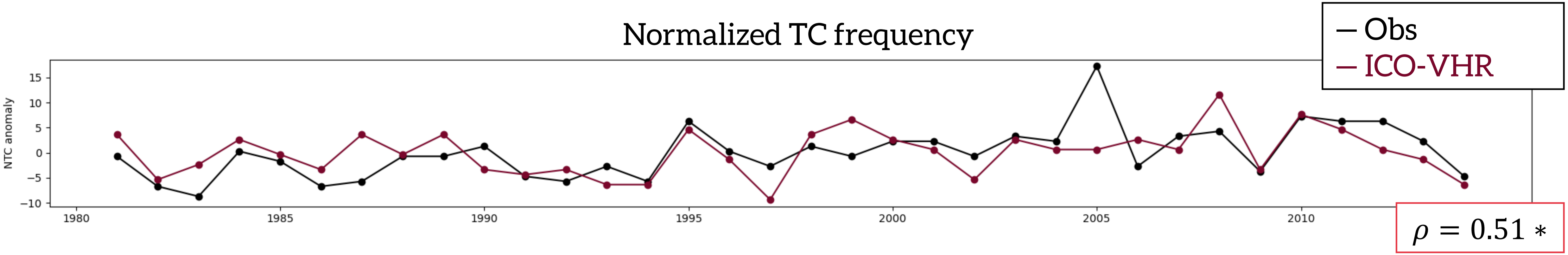
At the TC scale

- Intensity increases, but not up to observed values
- The structure of the TC is better represented when resolution is increased.
- Intensification is not fast enough, except in the last 6 hours.

Increase in résolution brings huge improvement in the TC climatology
In the North Atlantic in particular, and with the exception of the West Pacific

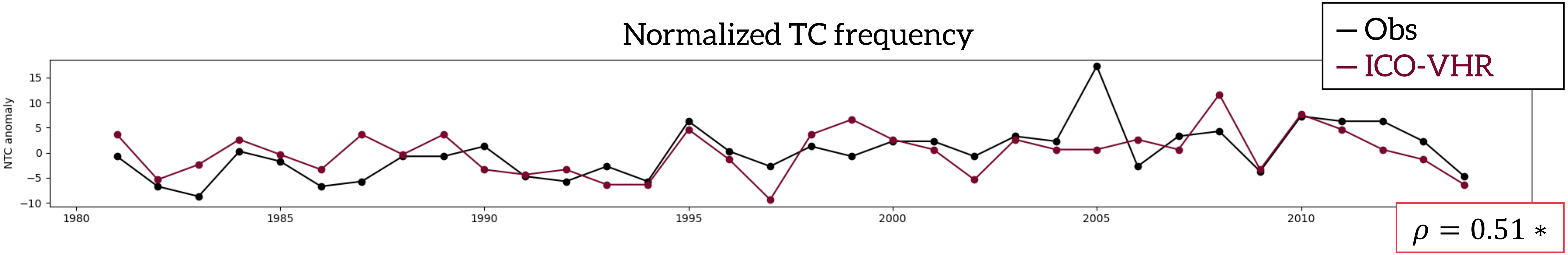
Zoom on two basins in ICO-VHR

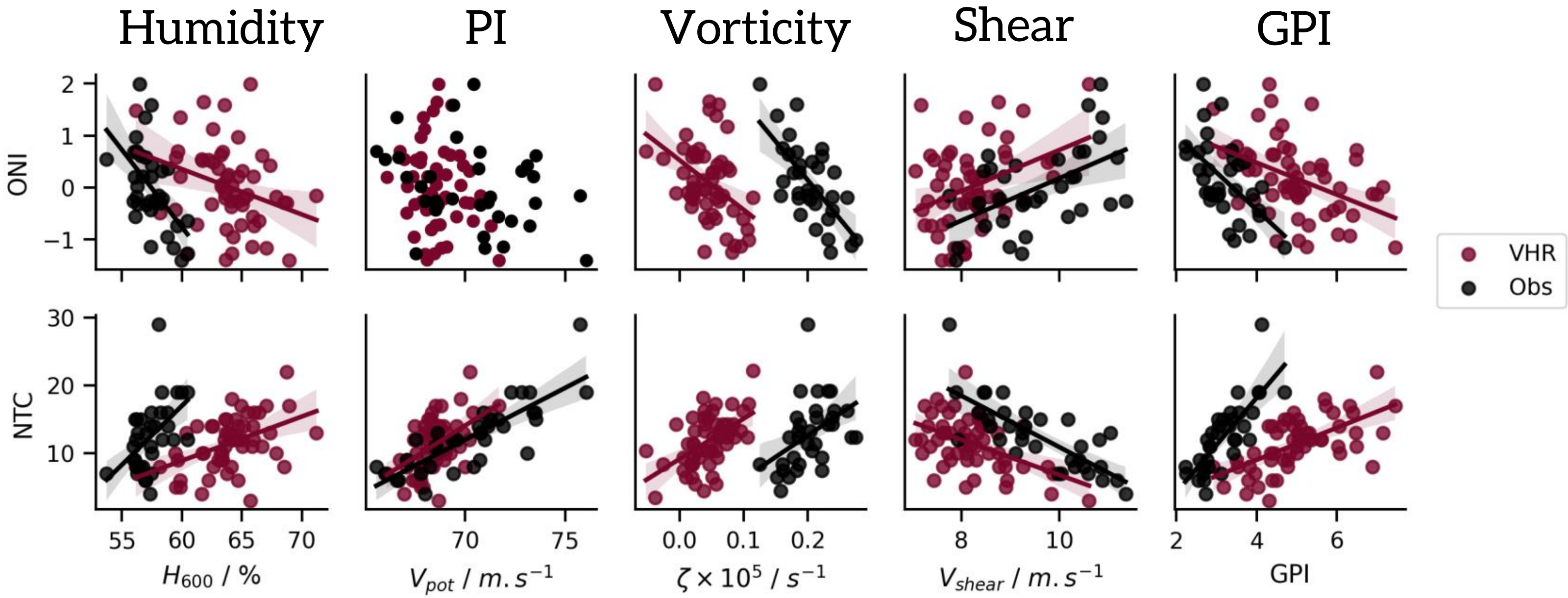
1/ North Atlantic



The model reproduces well the observed variability.

1/ North Atlantic



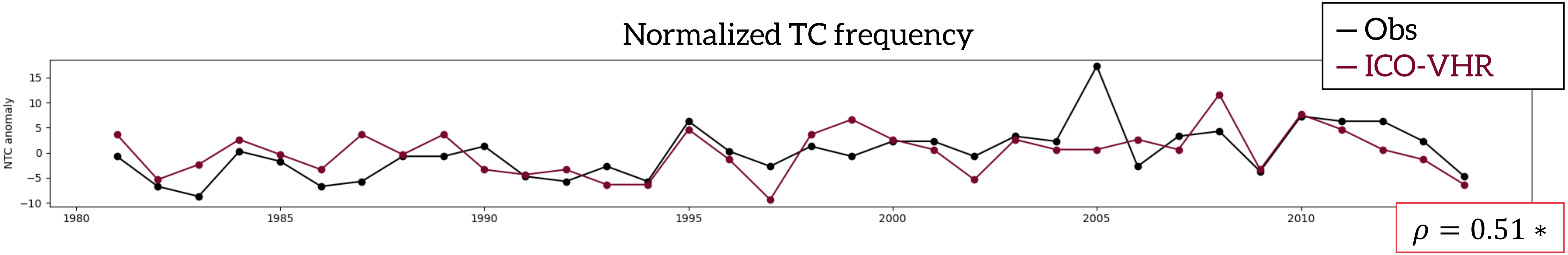


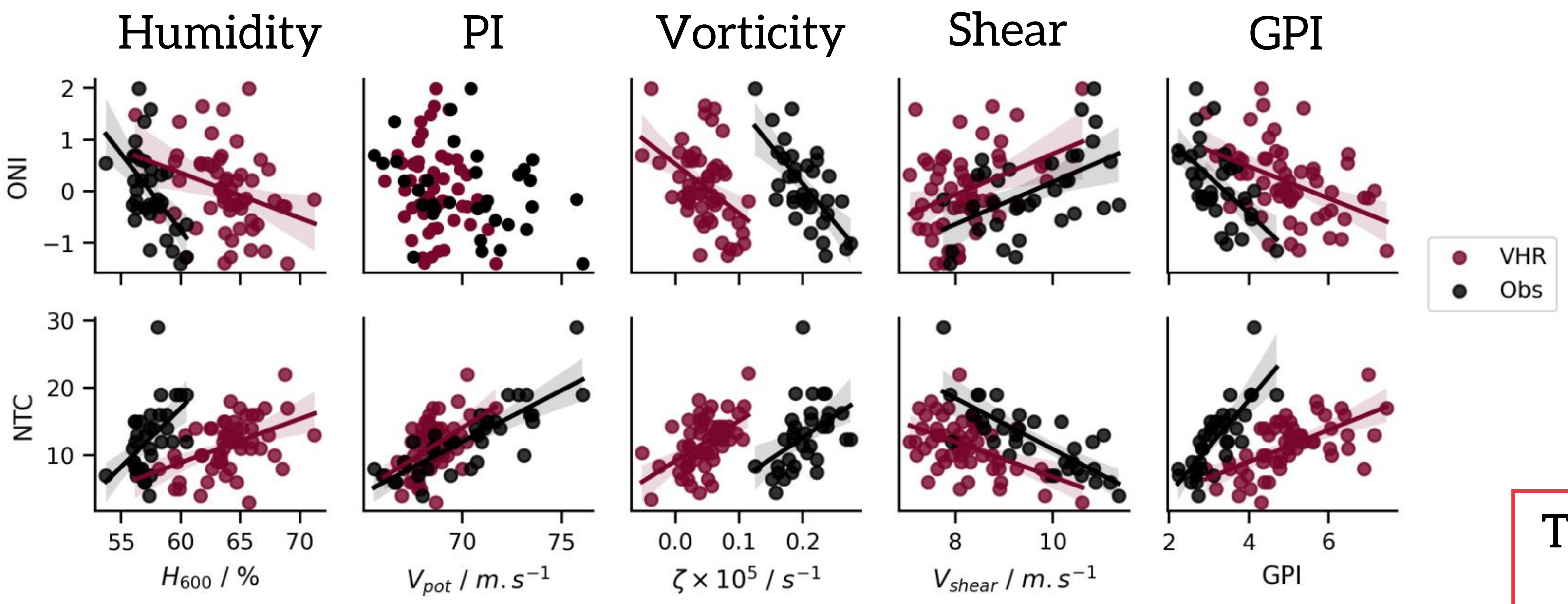
The model reproduces well the observed variability.

Why?

Because it reproduces well how ENSO modulates the large-scale environment, and the large scale environment forces the TC activity as expected.

1/ North Atlantic





The model reproduces well the observed variability.

Why?

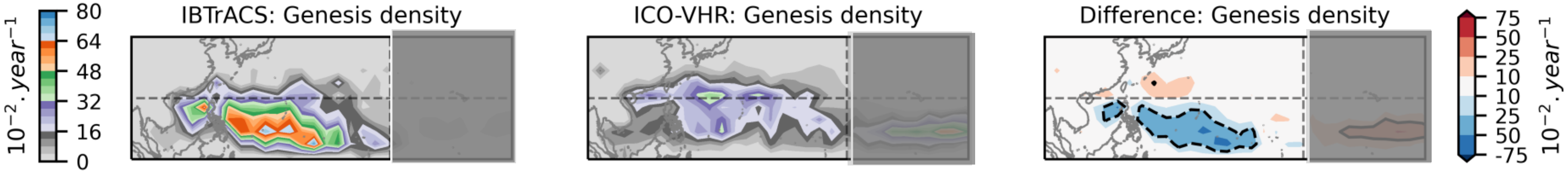
Because it reproduces well how ENSO modulates the large-scale environment, and the large scale environment forces the TC activity as expected.

The IPSL model performs well in a basin that is challenging for most models!

2/ Western North Pacific

Frequency too low : 19TC/year instead of 26 TC/year
Poorly correlated with large-scale environement

TC Genesis

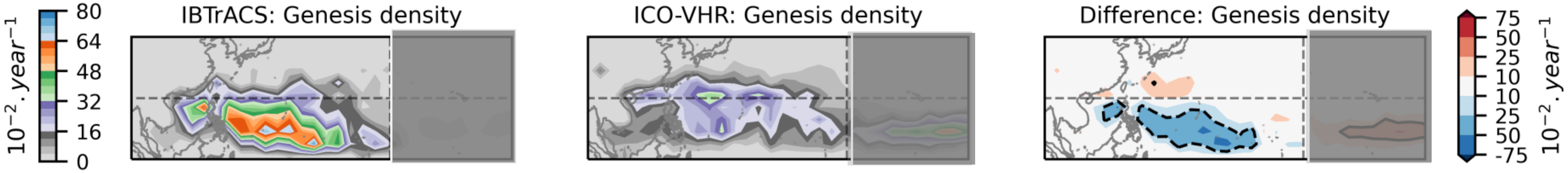


Genesis deficit in the south-west of the basin…

2/ Western North Pacific

Frequency too low : 19TC/year instead of 26 TC/year
Poorly correlated with large-scale environement

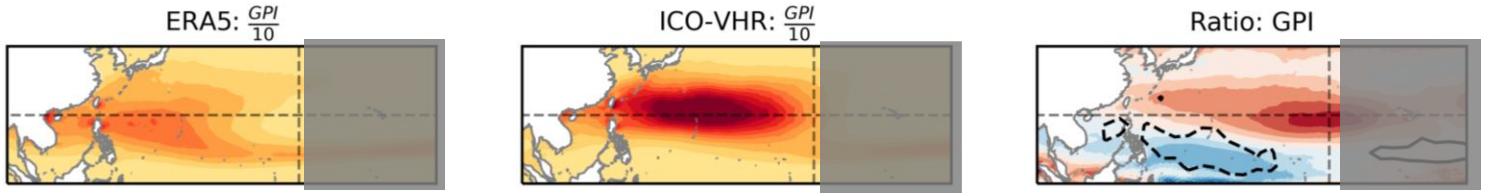
TC Genesis



Genesis deficit in the south-west of the basin…

Genesis potential index

(Climatology over the WNP cyclonic season)



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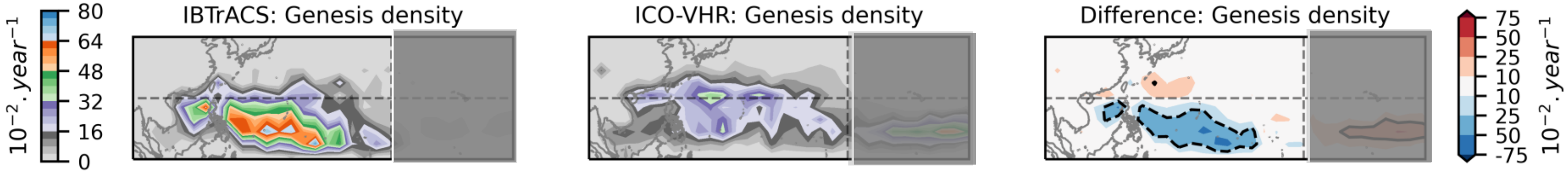
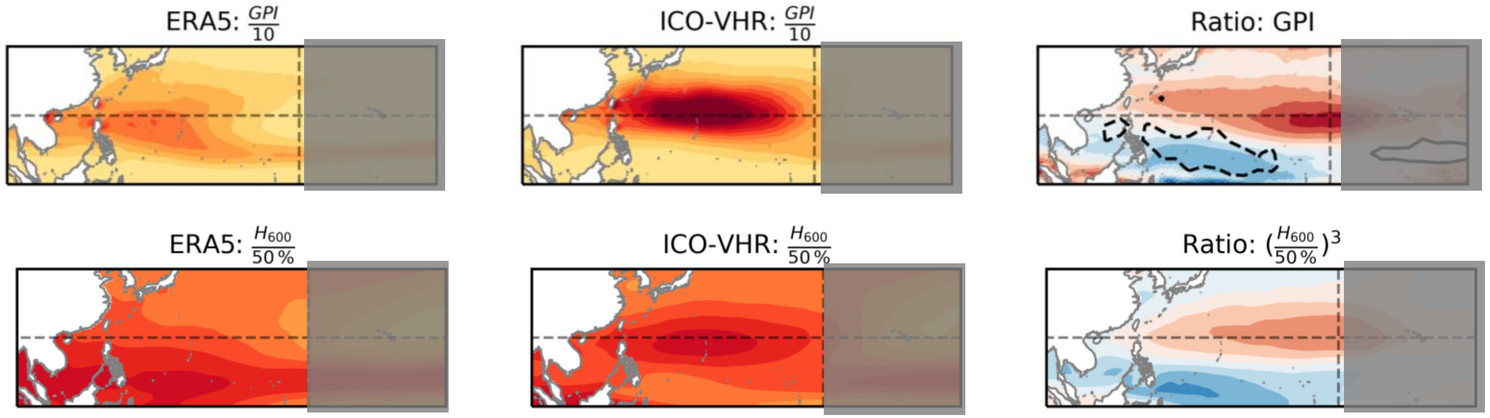


Genesis deficit in the south-west of the basin…

Genesis potential index

(Climatology over the WNP cyclonic season)

Humidity



… Associated with a climatological humidity bias

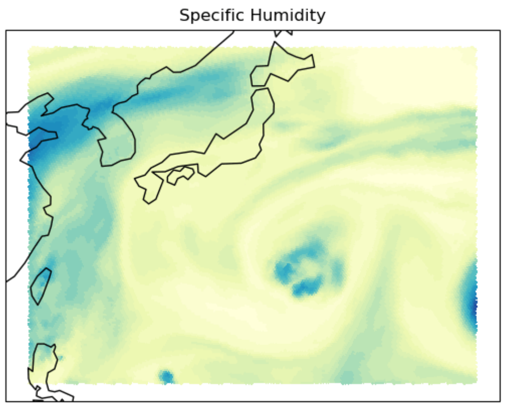
Conclusion

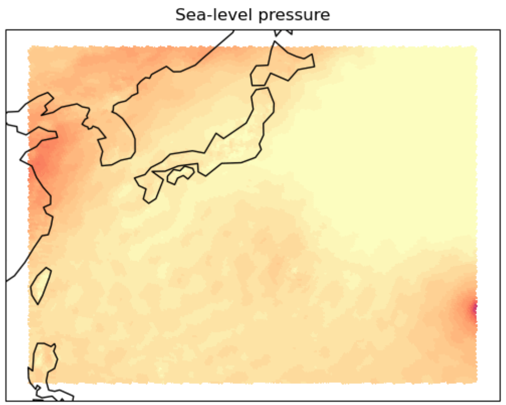
TCs in the IPSL model at 25 km:

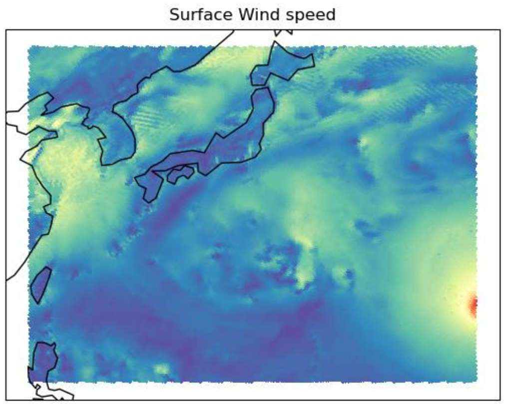
- 97 TCs/year
- Well distributed in the basins
- Up to category 2 in winds and 5 in pressure
- Realistic structure
- Especially good in the North Atlantic

→ Model fit for most purpose

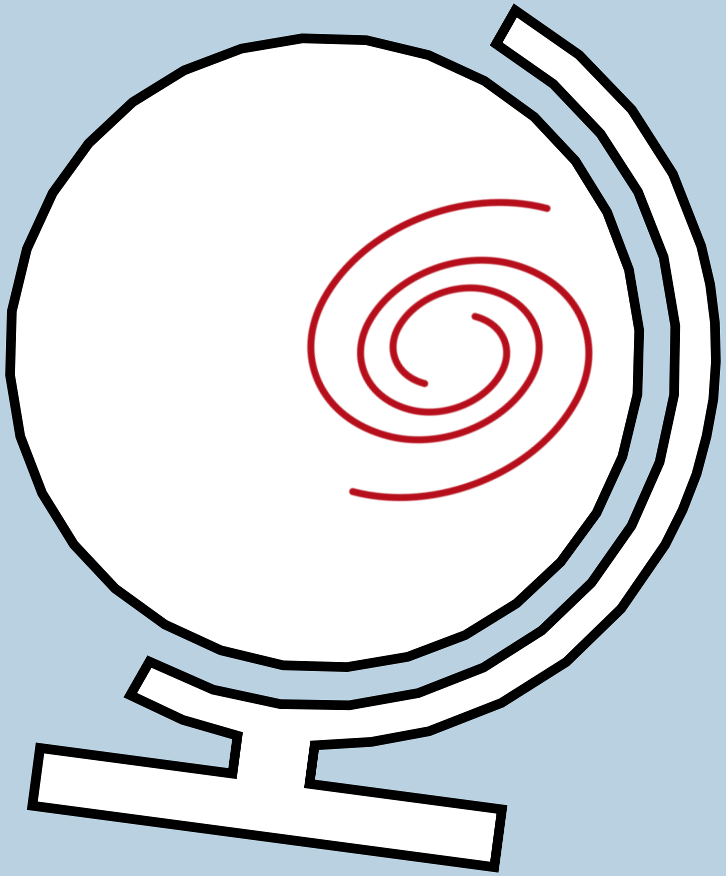
- Biases in the convection in the western pacific at high-resolution

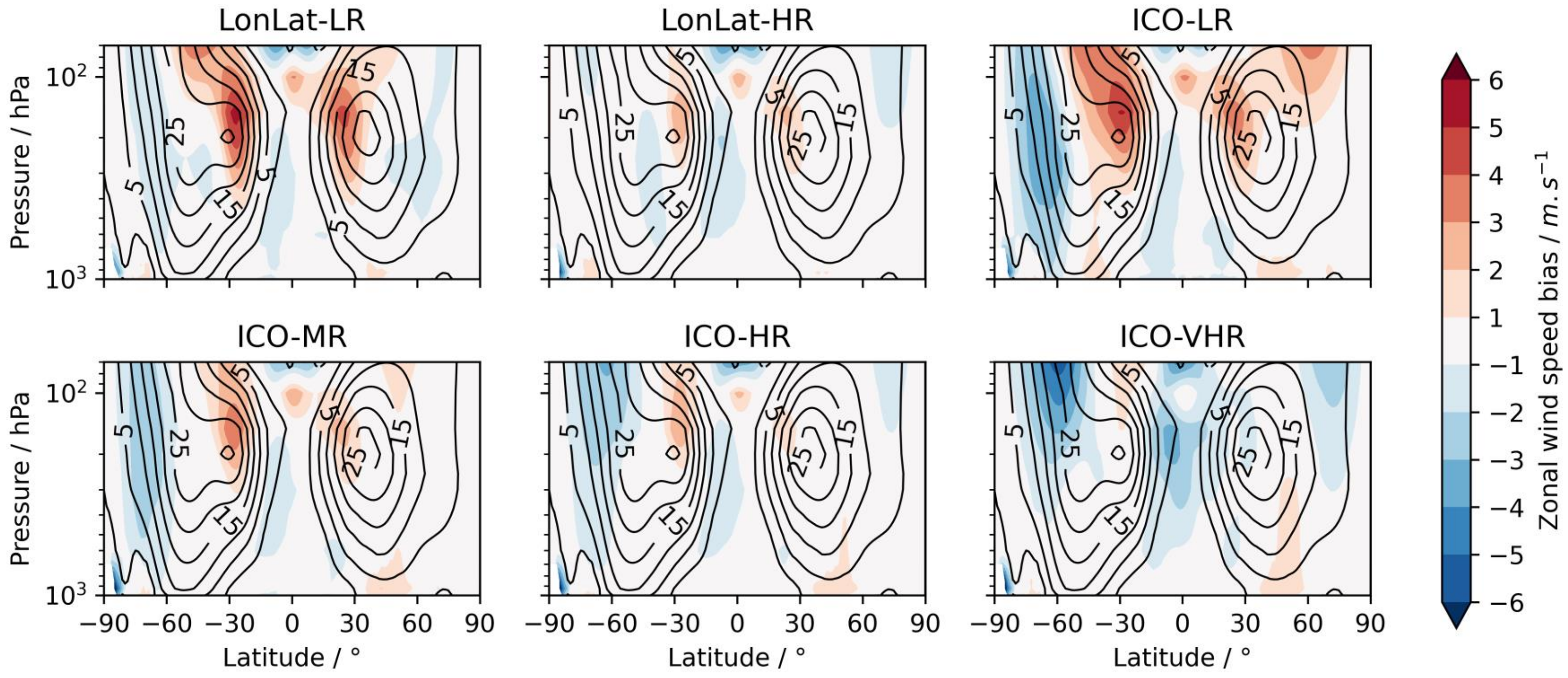


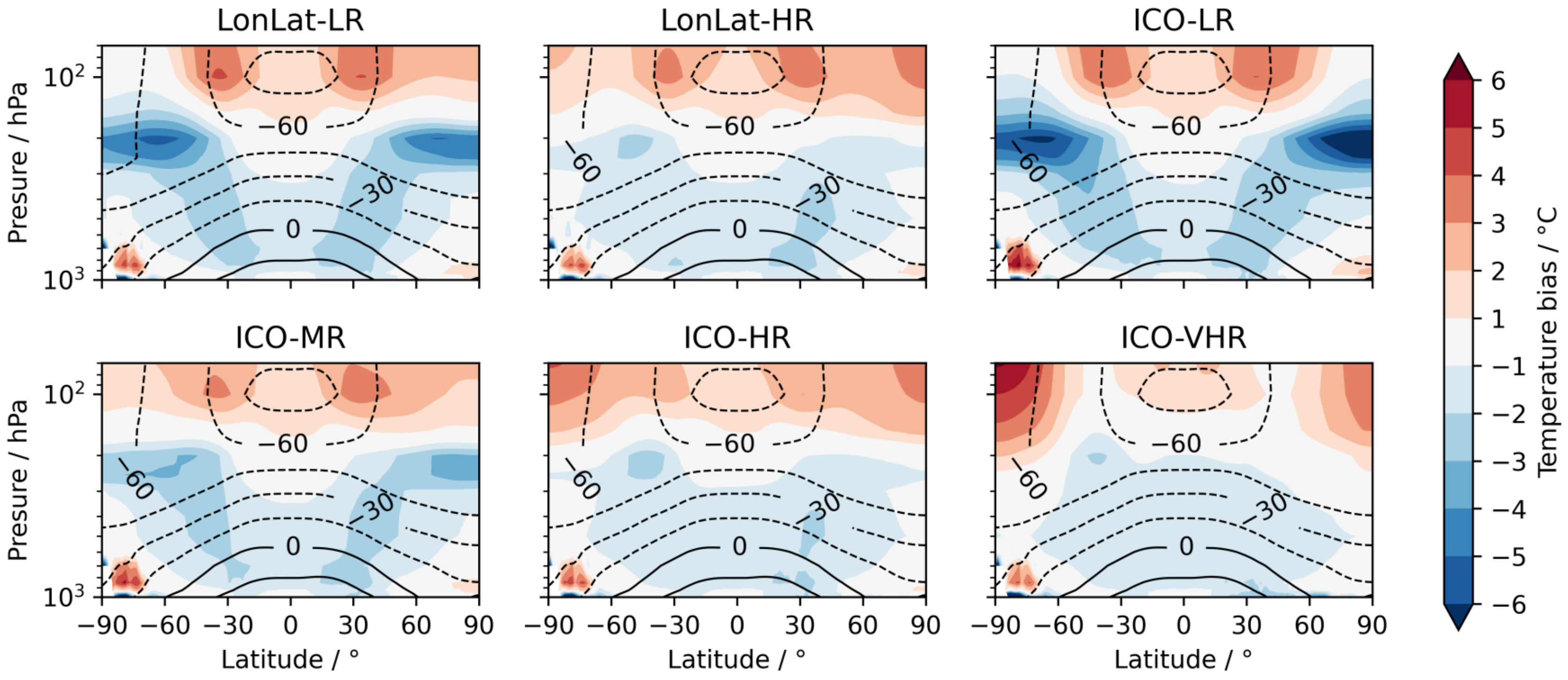




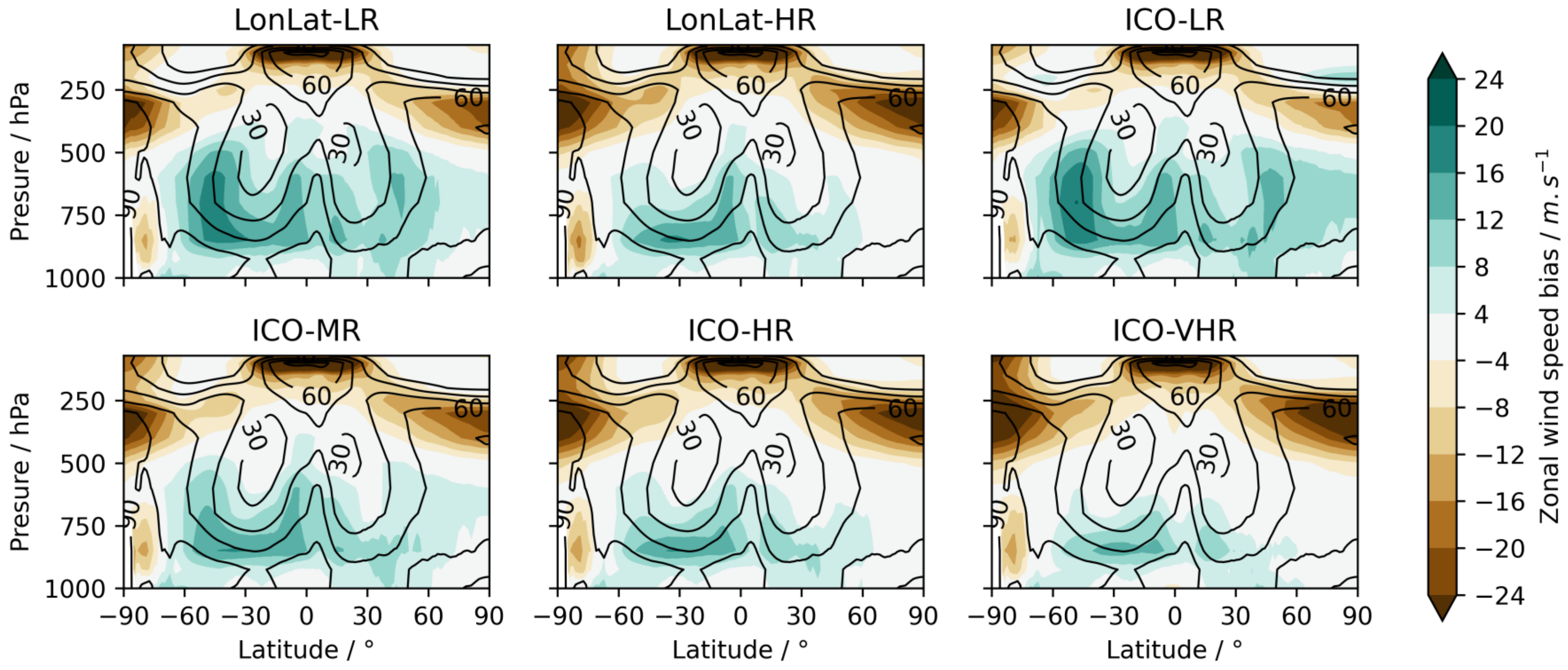
Appendices



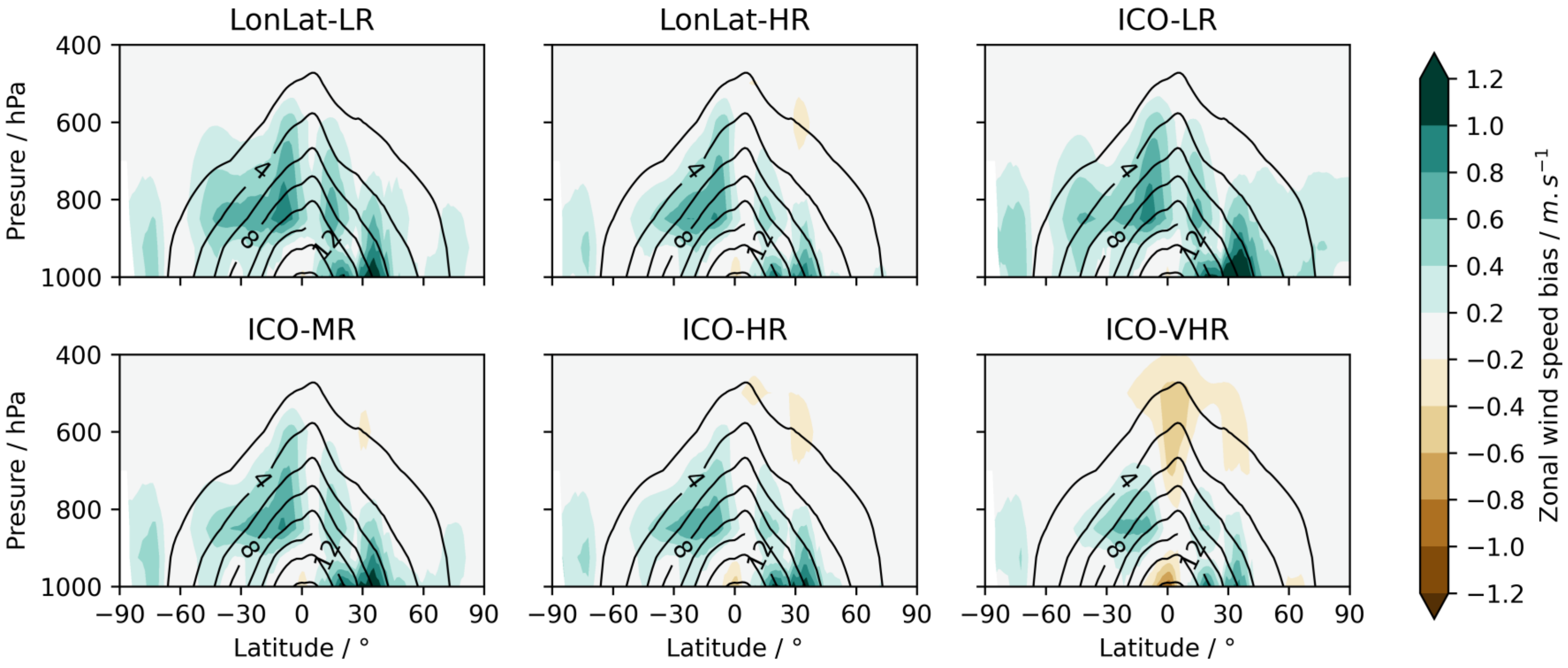

LonLat-LR
LonLat-HR
ICO-LR
ICO-MR
ICO-HR
ICO-VHR
Pressure / hPa
10^2
10^3
Latitude / °
−90 −60 −30 0 30 60 90
Zonal wind speed bias / $m.s^{-1}$
6 5 4 3 2 1 −1 −2 −3 −4 −5 −6
5
15
25

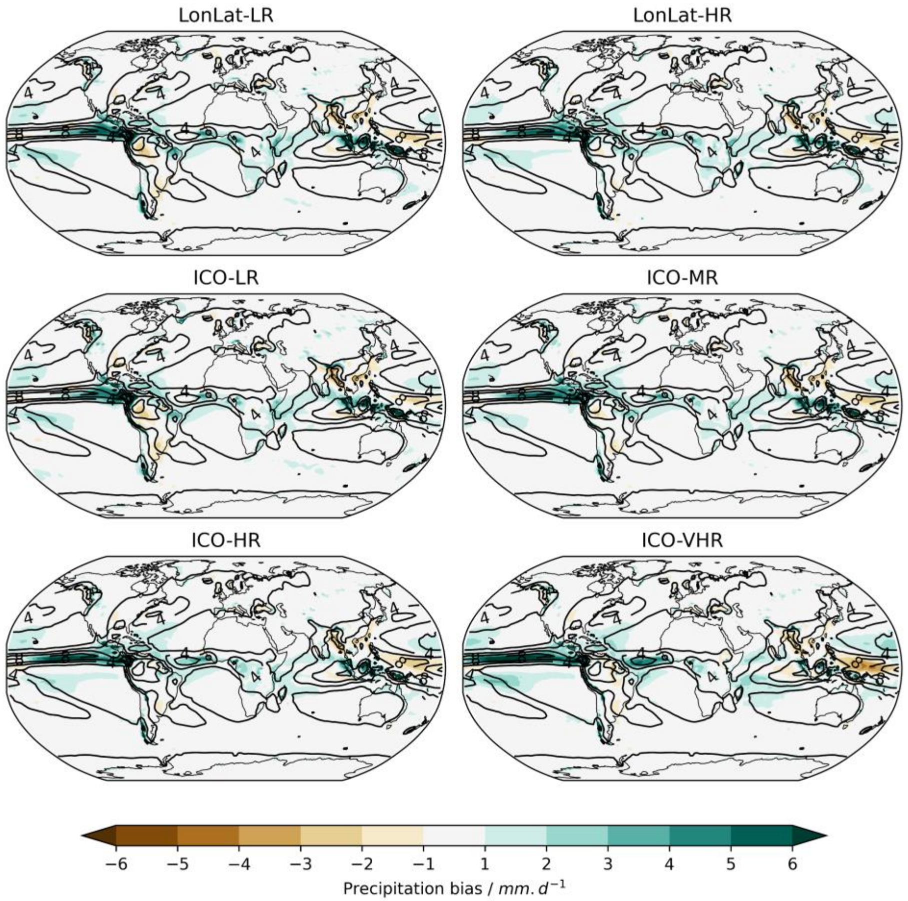


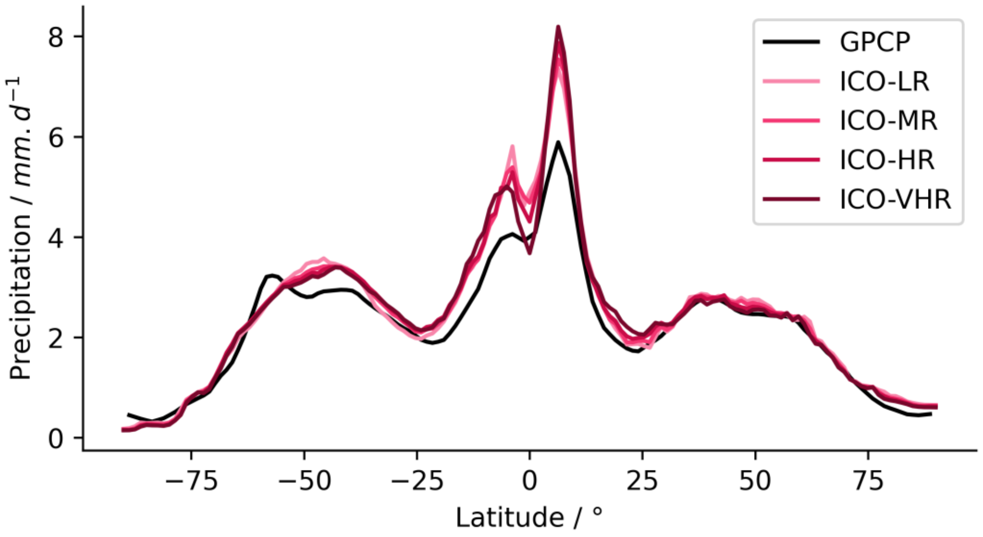
LonLat-LR
LonLat-HR
ICO-LR
ICO-MR
ICO-HR
ICO-VHR
Presure / hPa
Latitude / °
−60
−30
0
−90 −60 −30 0 30 60 90
Temperature bias / °C
6 5 4 3 2 1 −1 −2 −3 −4 −5 −6

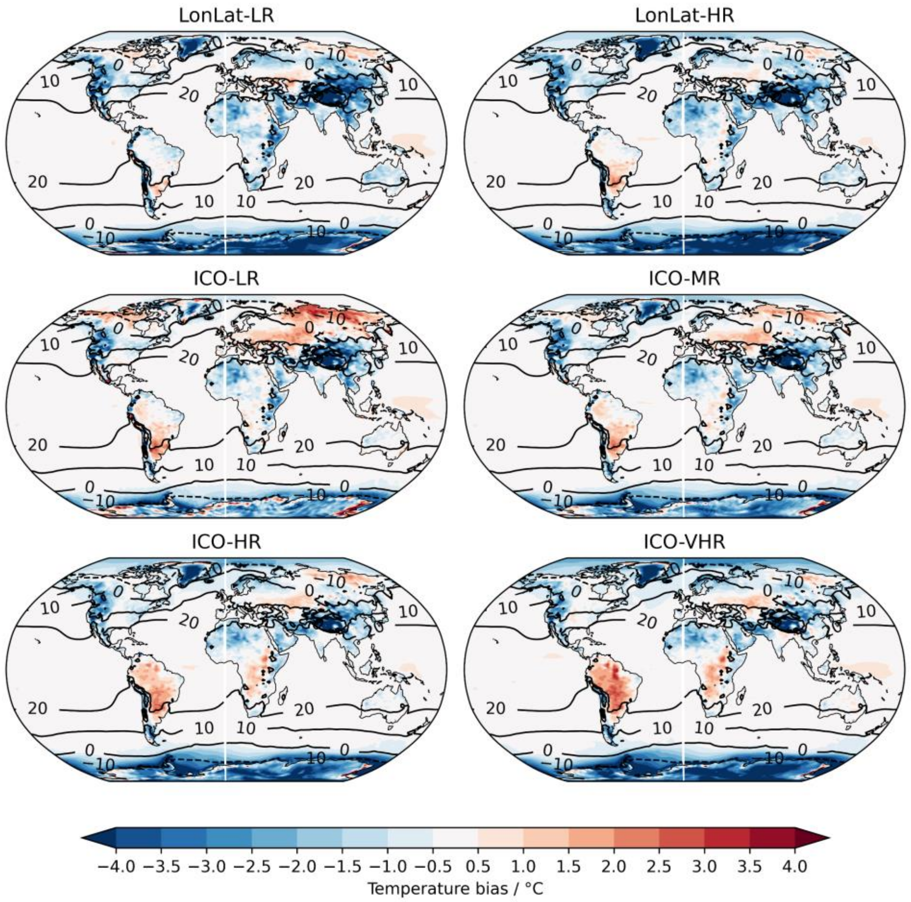


LonLat-LR
LonLat-HR
ICO-LR
ICO-MR
ICO-HR
ICO-VHR
Presure / hPa
250
500
750
1000
60
30
90
−90 −60 −30 0 30 60 90
Latitude / °
24
20
16
12
8
4
−4
−8
−12
−16
−20
−24
Zonal wind speed bias / $m.s^{-1}$


LonLat-LR
LonLat-HR
ICO-LR
ICO-MR
ICO-HR
ICO-VHR
Presure / hPa
400
600
800
1000
−90 −60 −30 0 30 60 90
Latitude / °
4
8
12
Zonal wind speed bias / $m.s^{-1}$
1.2
1.0
0.8
0.6
0.4
0.2
−0.2
−0.4
−0.6
−0.8
−1.0
−1.2


LonLat-LR
LonLat-HR
ICO-LR
ICO-MR
ICO-HR
ICO-VHR
−6 −5 −4 −3 −2 −1 1 2 3 4 5 6
Precipitation bias / $mm.d^{-1}$

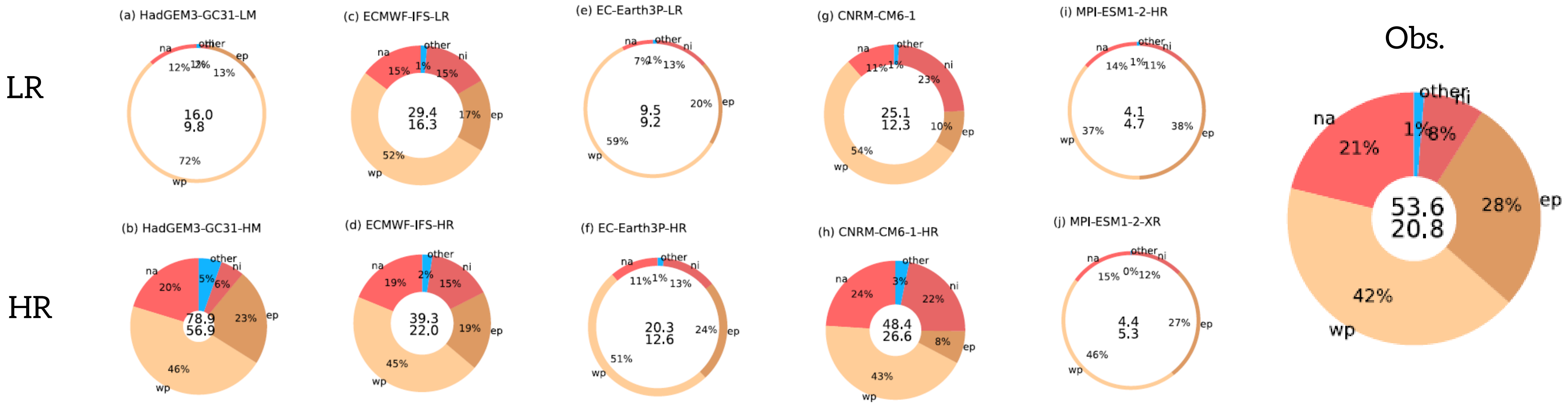

GPCP
ICO-LR
ICO-MR
ICO-HR
ICO-VHR
Precipitation / $mm.d^{-1}$
0
2
4
6
8
−75 −50 −25 0 25 50 75
Latitude / °


LonLat-LR
LonLat-HR
ICO-LR
ICO-MR
ICO-HR
ICO-VHR
−4.0 −3.5 −3.0 −2.5 −2.0 −1.5 −1.0 −0.5 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0
Temperature bias / °C

Roberts et al. 2020b (Figure 2)

TC activity at low- and high-resolution in 5 HighResMIP models

Thickness represent cyclonic activity level

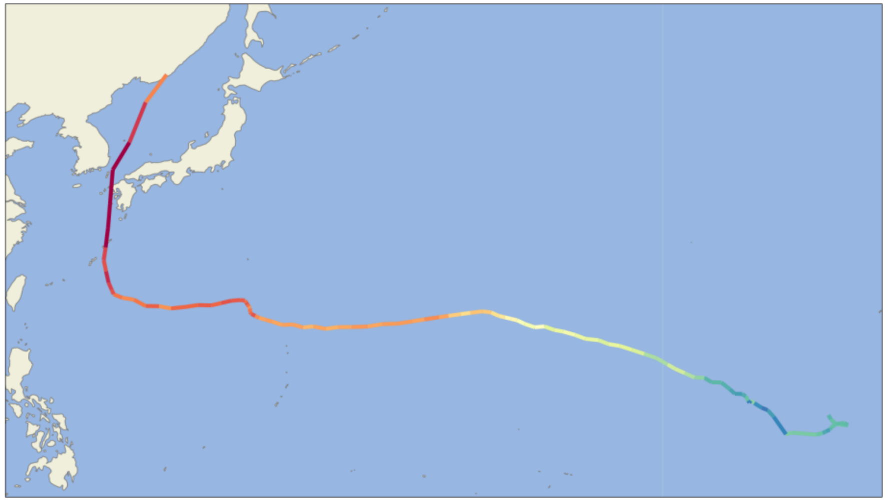


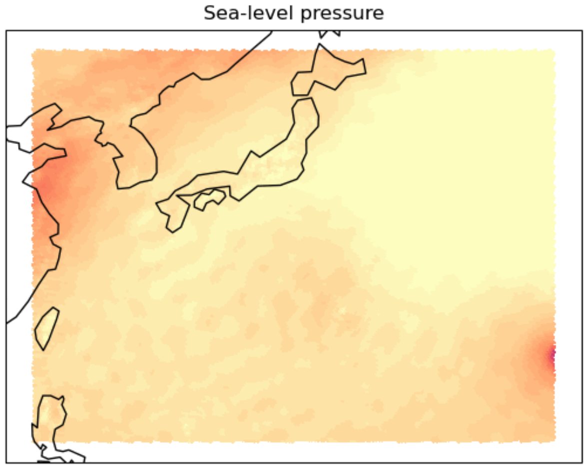
Roberts, Camp, Seddon et al. 2020b in Journal of Climate

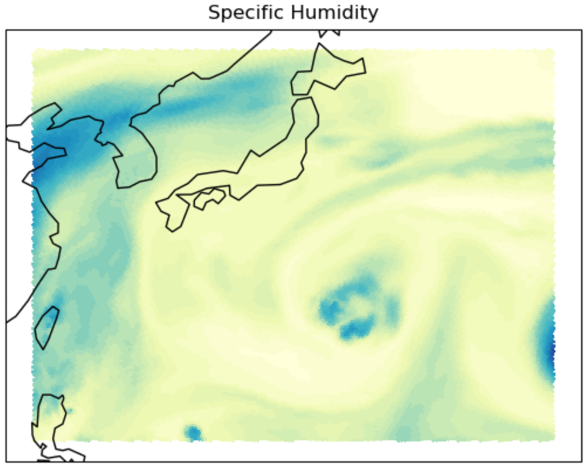
Ability to simulate TCs varies among models.
Increasing resolution improves TC climatology.

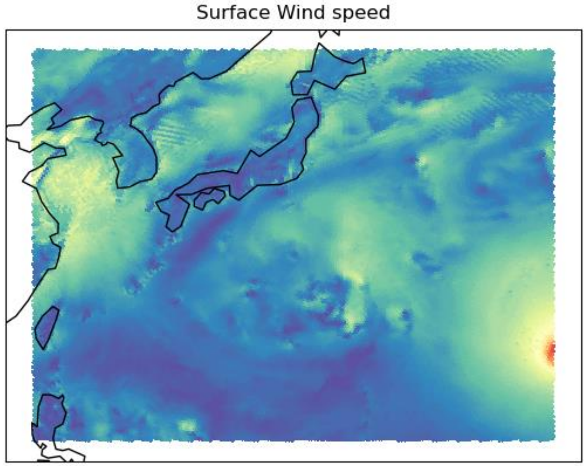
It works!

Example: The most intense TC in ICO-VHR



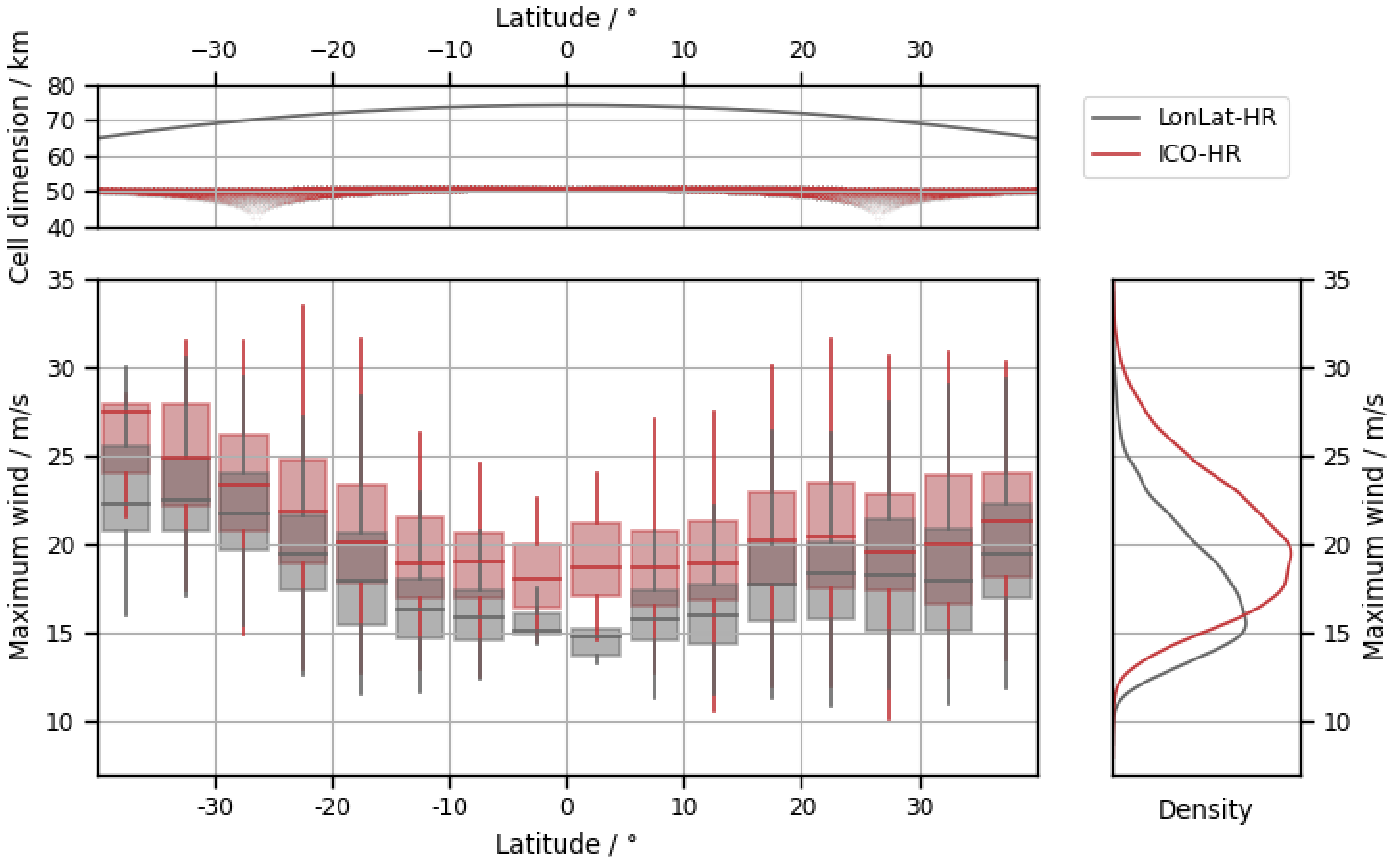






There are Tropical Cyclones in the simulations.

Impact of irregular grid



Irregular grid in LonLat-HR makes difference with ICO-HR more proeminent near the equator

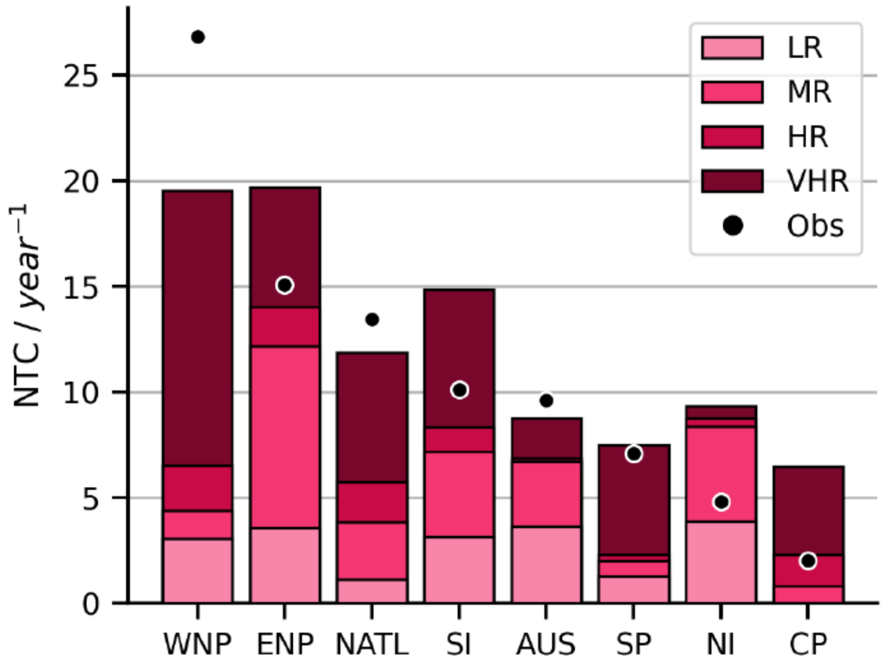
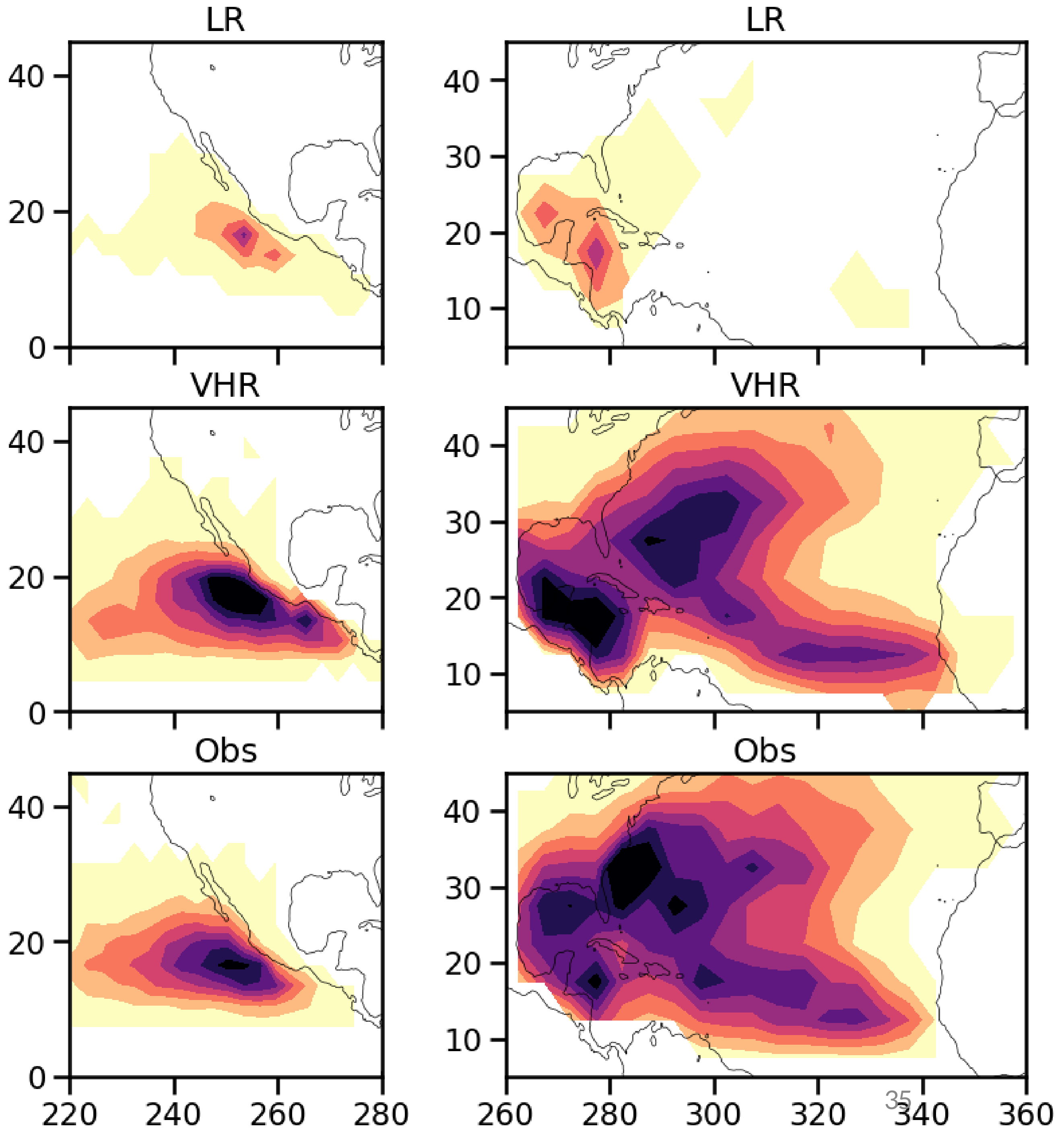


Figure 6. TC frequencies in each basin and each simulation and in the observation. Basins are displayed in order of decreasing frequencies in the observations.

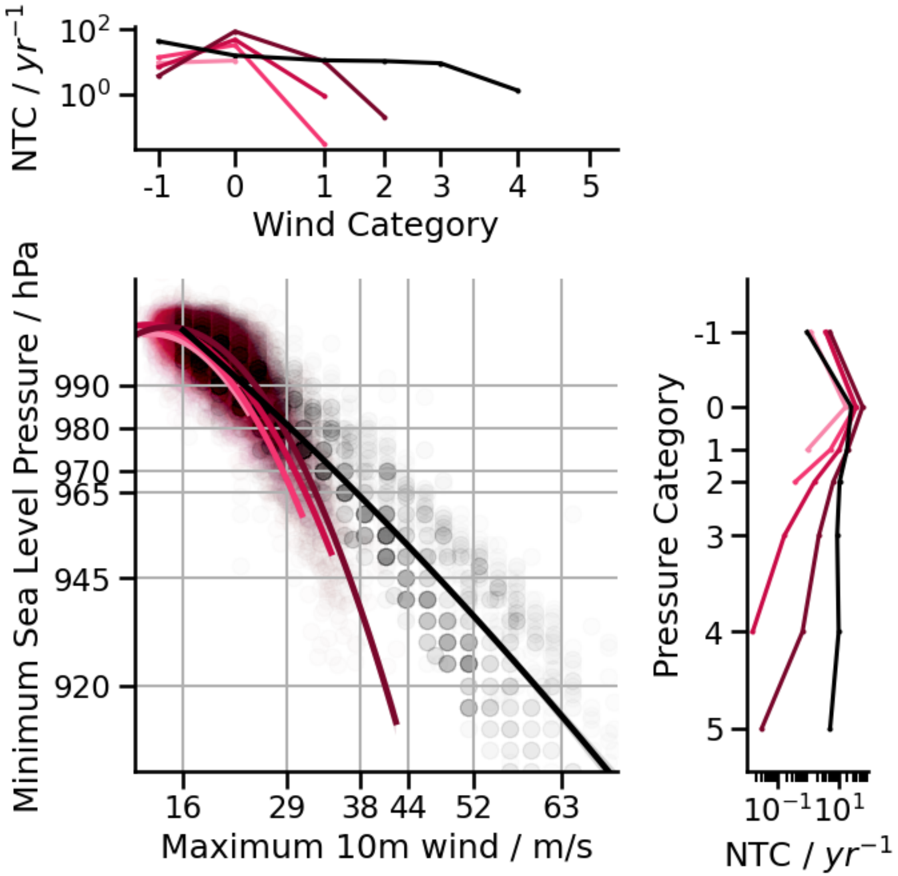
Regional activity

With increasing resolution…
- Activity ↗ in all basins
- Geographical distribution improve

With disparities among basins, esp. WNP, see later.

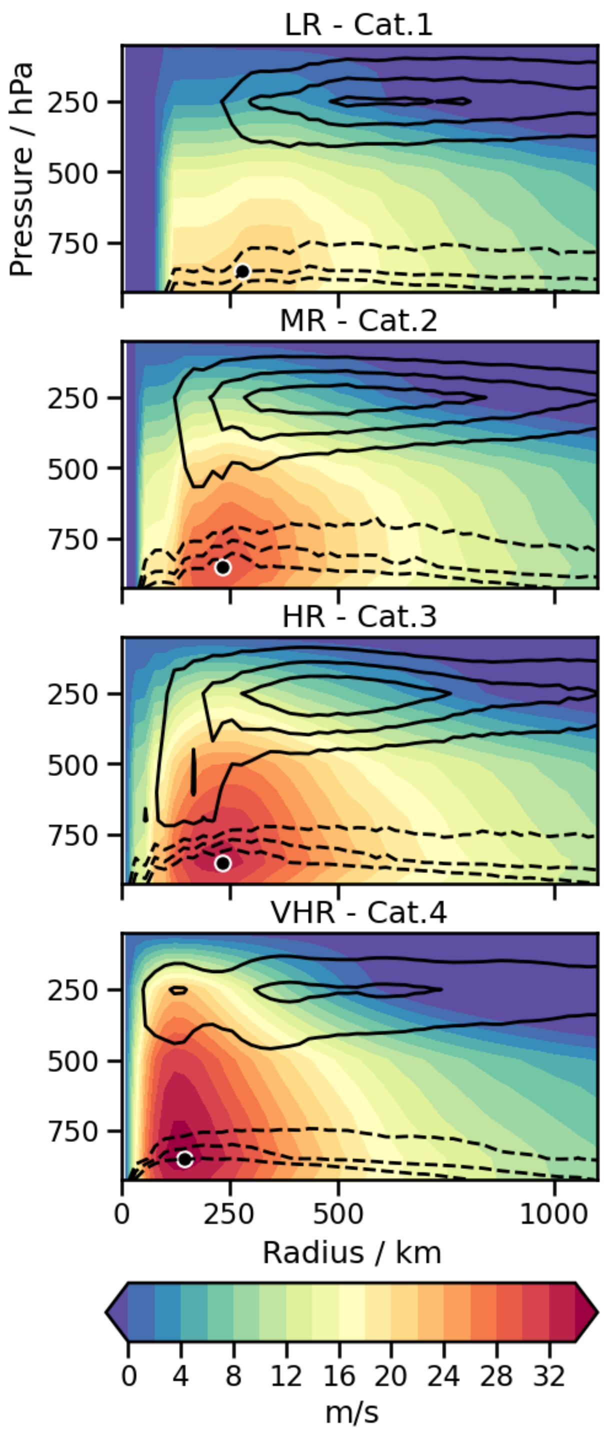


Intensity & Structure



Contour: Radial wind

Shading: Azimuthal wind →

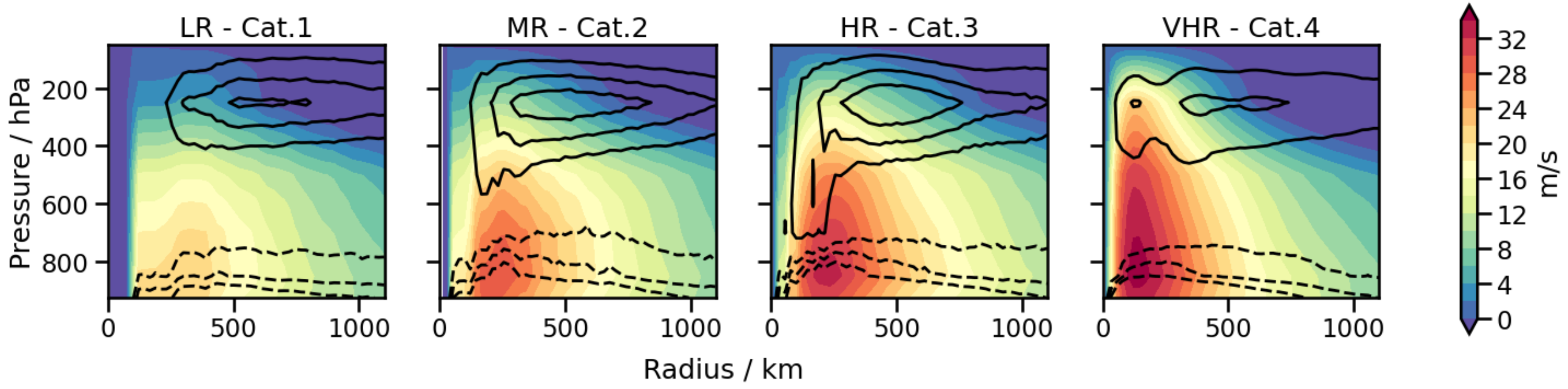


With increasing resolution, TCs become <u>more intense</u>, …

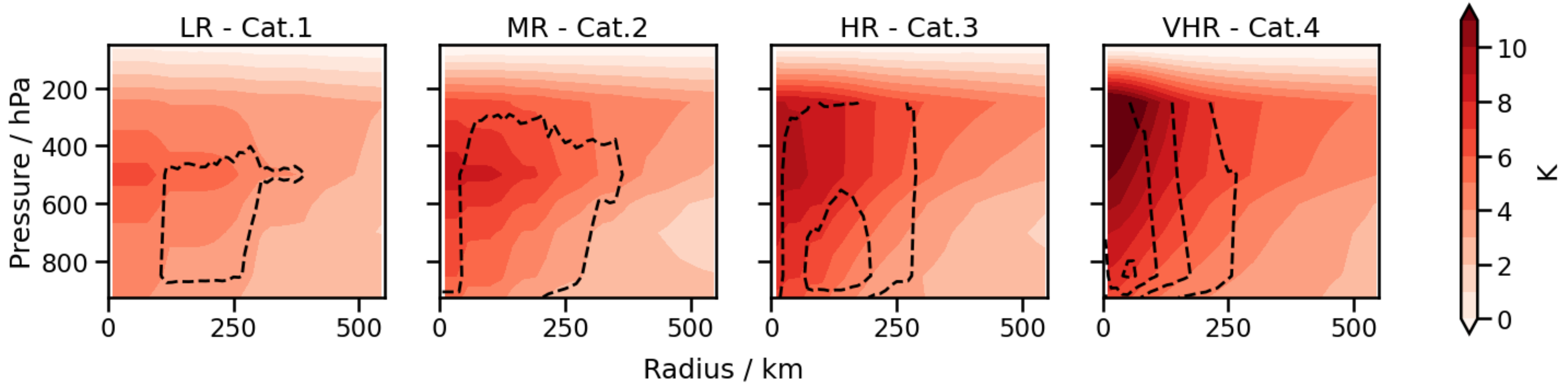
… and the primary circulation <u>tightens</u> around the eye

TC properties : Composites

Contour: Radial wind --- Shading: Azimuthal wind



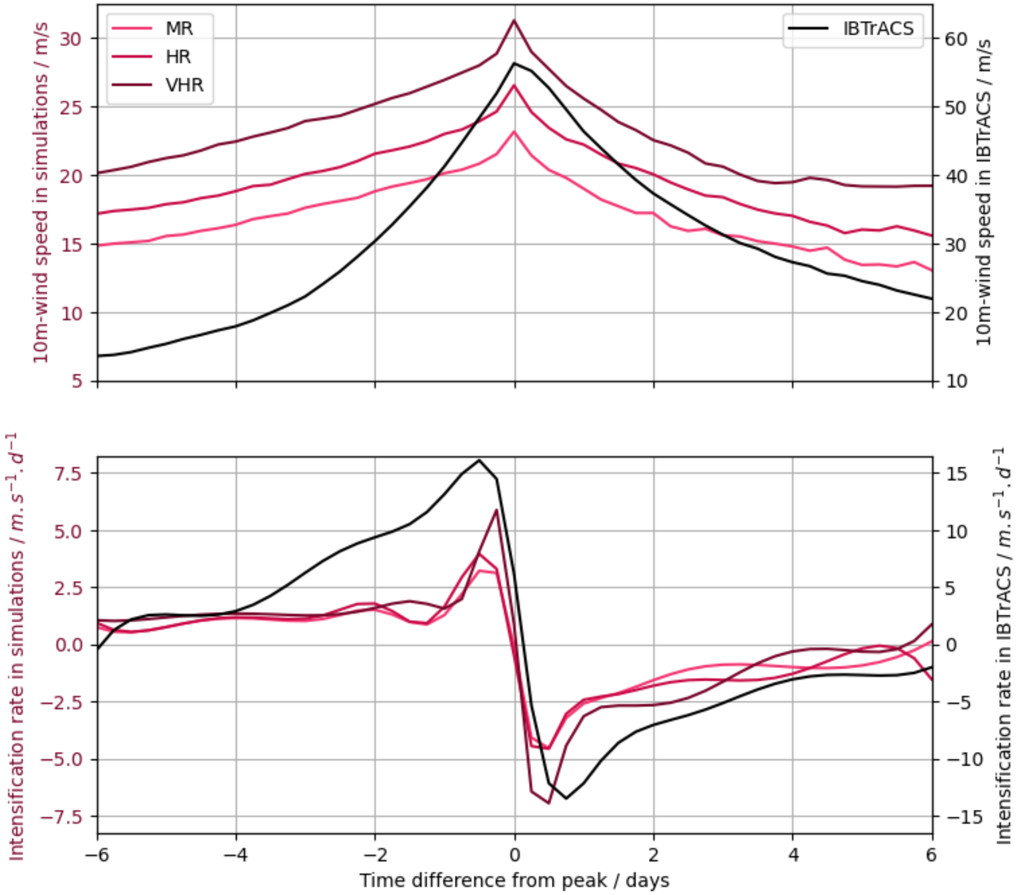
Contour: Temperature anomaly --- Shading: Vertical velocity



With increasing resolution...

- TC structure become <u>more intense</u>,
- Primary circulation <u>tightens</u> around the eye,
- <u>Realism</u> improves.

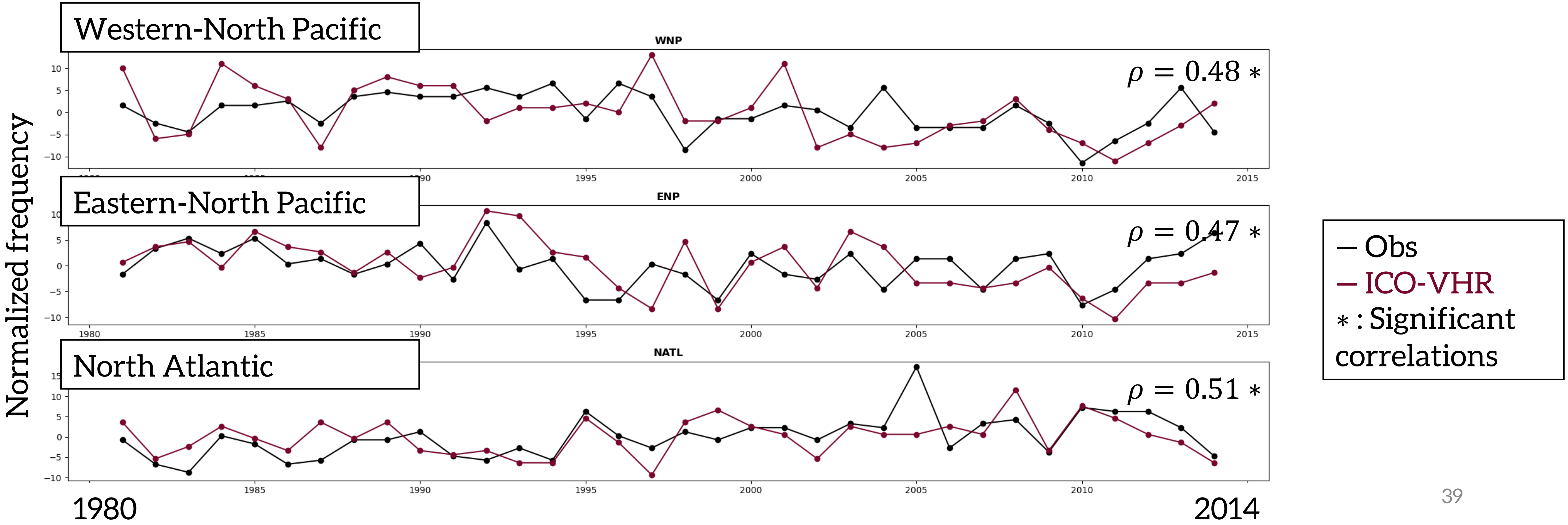
Lifecycle



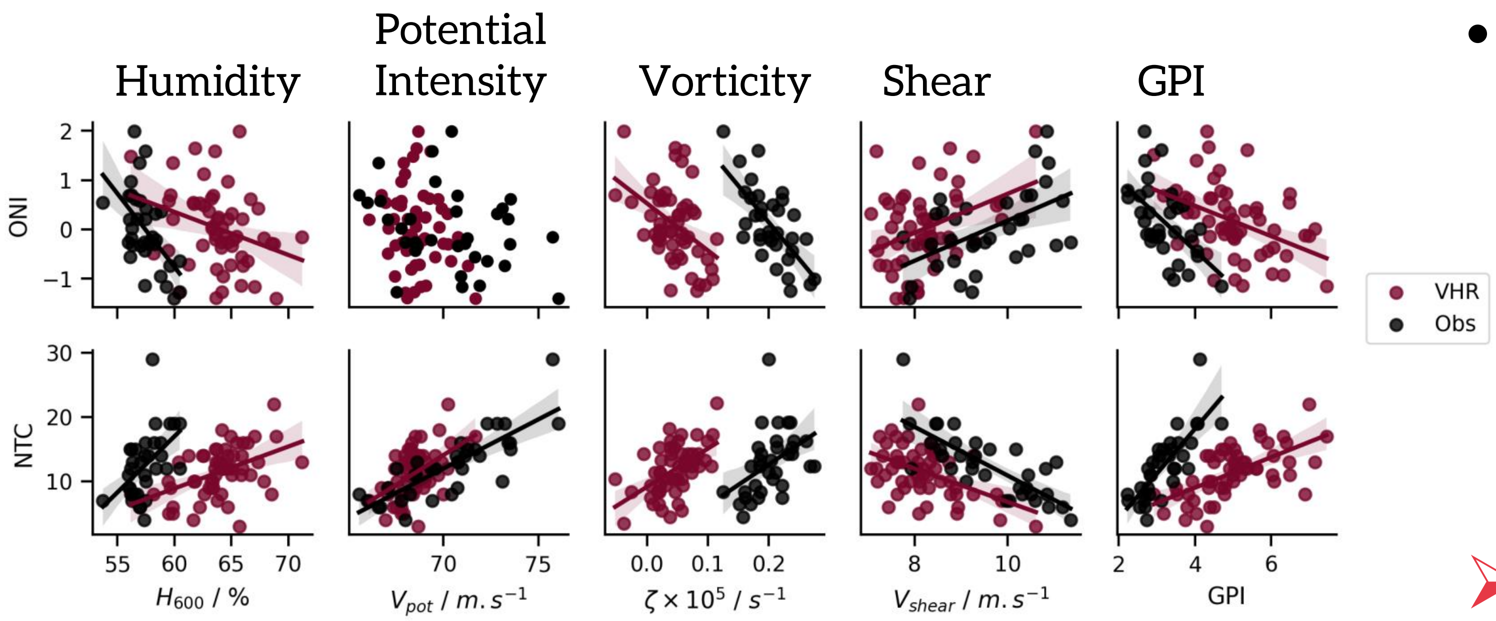
MR
HR
VHR
IBTrACS
10m-wind speed in simulations / m/s
10m-wind speed in IBTrACS / m/s
Intensification rate in simulations / $m.s^{-1}.d^{-1}$
Intensification rate in IBTrACS / $m.s^{-1}.d^{-1}$
Time difference from peak / days

Inter-annual variability

Correlations increase with resolution, and are robust only for NATL & ENP.



North Atlantic basin

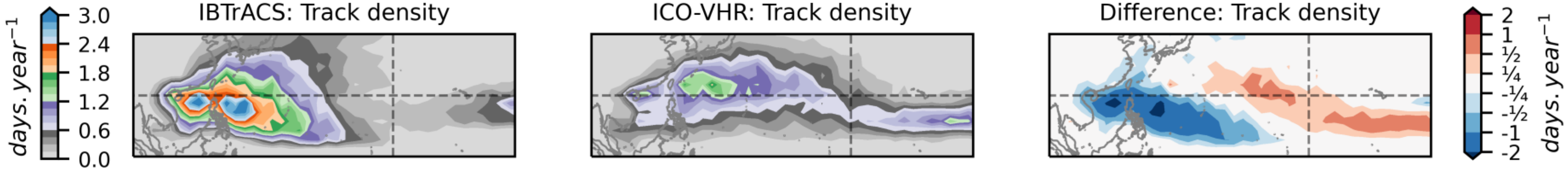


ONI and NTC vs. Large-scale environment variables
(Linear regression drawn when correlation significant.)

- In the North Atlantic:
  - Link between ENSO and large-scale environment is well reproduced
  - Link between large-scale environment and TC activity is well depicted

➢ Inter-annual variability and its correlation with ENSO is well simulated

Track density



ENSO

- ENSO is an important mode of variability for TC activity in the Pacific and Atlantic basins
- Affects TC large-scale environment
  - Sea-surface temperature
  - Wind shear
  - Humidity
  - Circulation

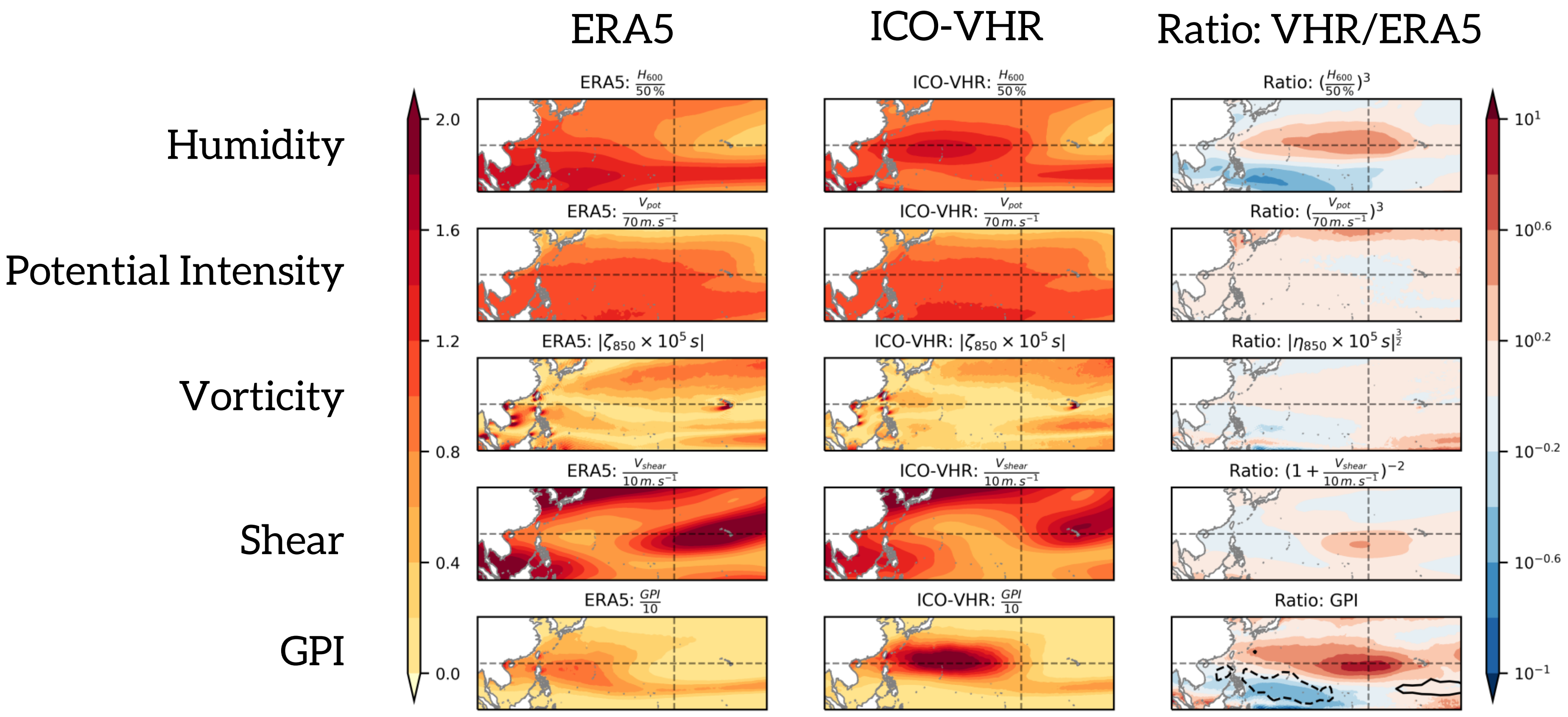
Variable	Data	WNP	ENP	NATL
ACE	Obs	**0.47***	**0.16***	**-0.23***
	ICO-VHR	0.01	**0.15***	**-0.20***
NTC	Obs	0.00	**0.21***	**-0.30***
	ICO-VHR	0.0	0.00	**-0.34***

Table 4. Correlations coefficient (and associated p-value in parenthesis) between the yearly ACE or NTC and the mean of the ONI index between August to October of the same year. * and bold denote significant correlations ($p < 5e-2$) .

Correlation between ONI index and TC activity
(Bold = significant)

Link between ENSO and TC activity is well reproduced in the NATL, not in the Pacific

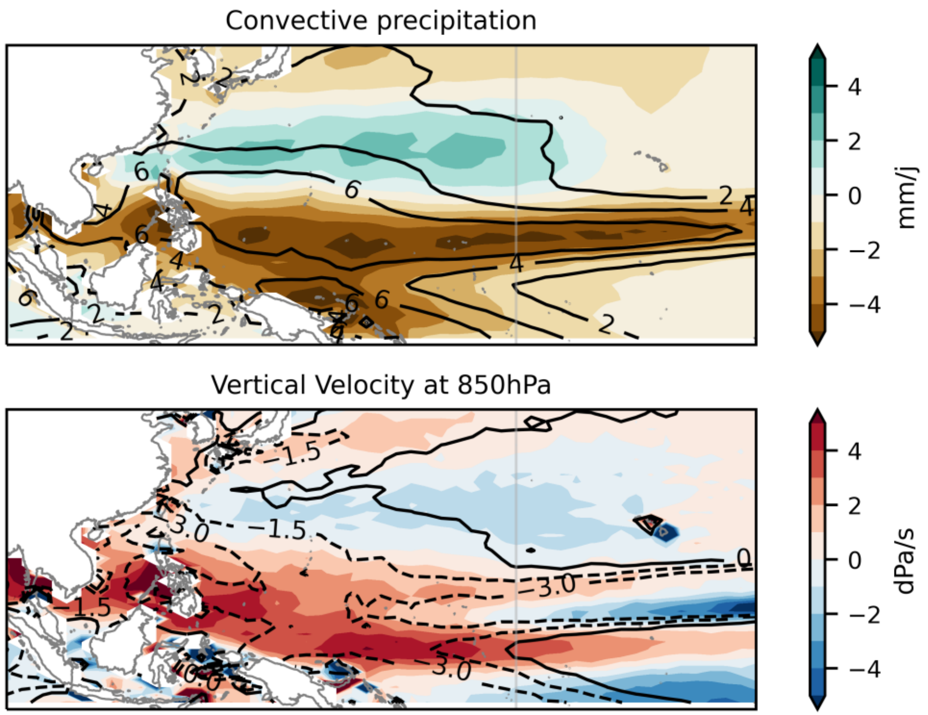
Western North Pacific



Climatology during the months of July to October

Deficit in genesis is associated with a deficit in GPI, for which deficit in humidity is mainly responsible

A problem with convection in the warm pool?



Biases in ICO-VHR with respect to ERA5
Over the cyclonic season (July to October)
(contour = ERA5, shading = difference)

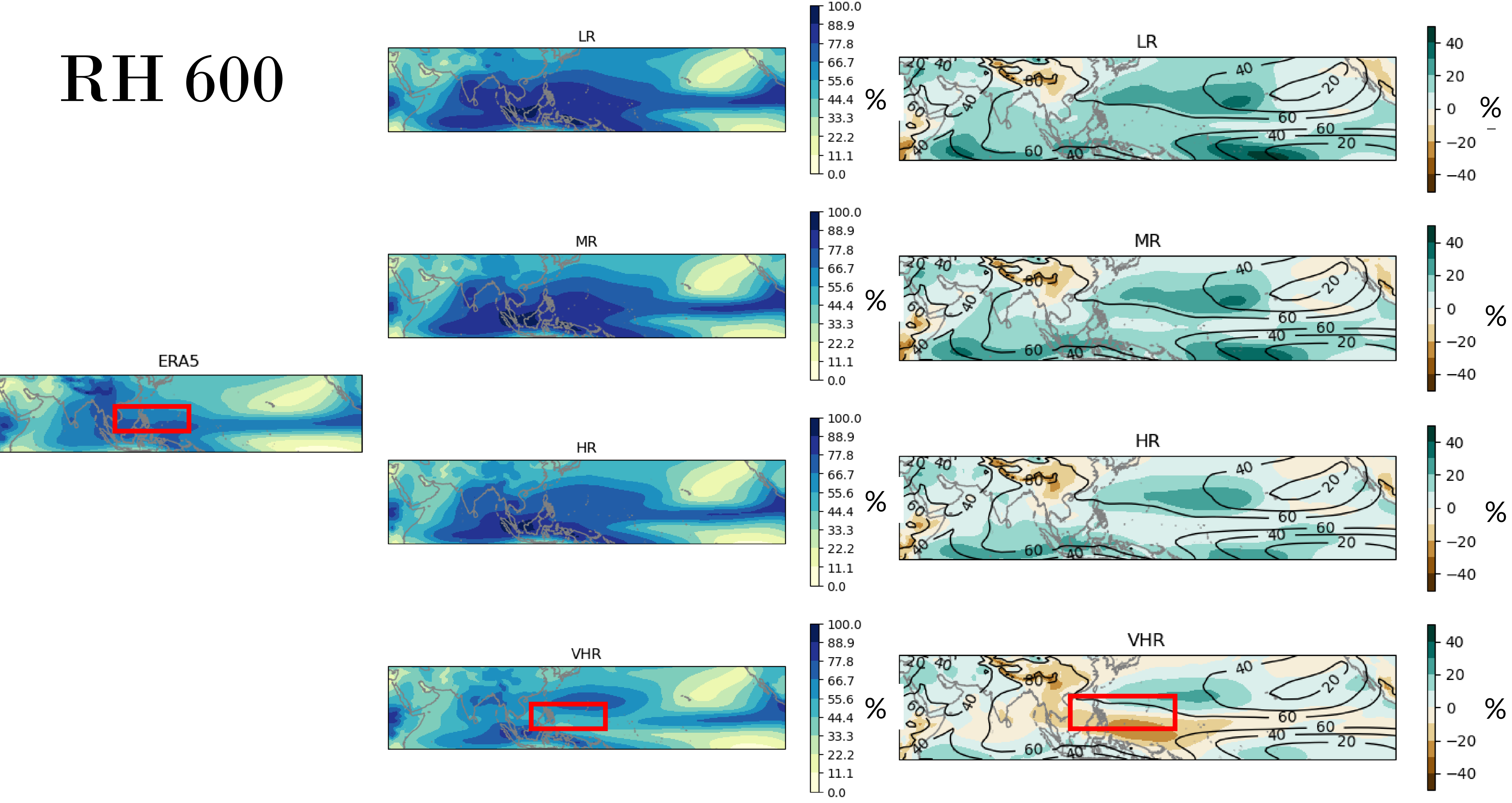
(More variables at different resolutions in appendix)

In the WNP TC genesis area

- Convective precipitation are very low
- Climatological circulation is subsident
- Associated with problem in large-scale circulation (zonal wind, vorticity)

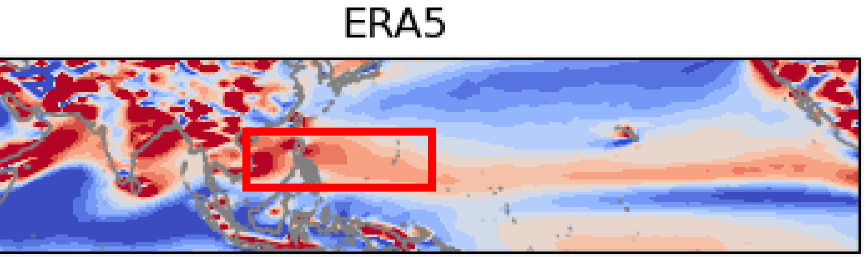
Dynamical bias is present at all resolutions, humidity & precip bias accentuates with increasing resolution.

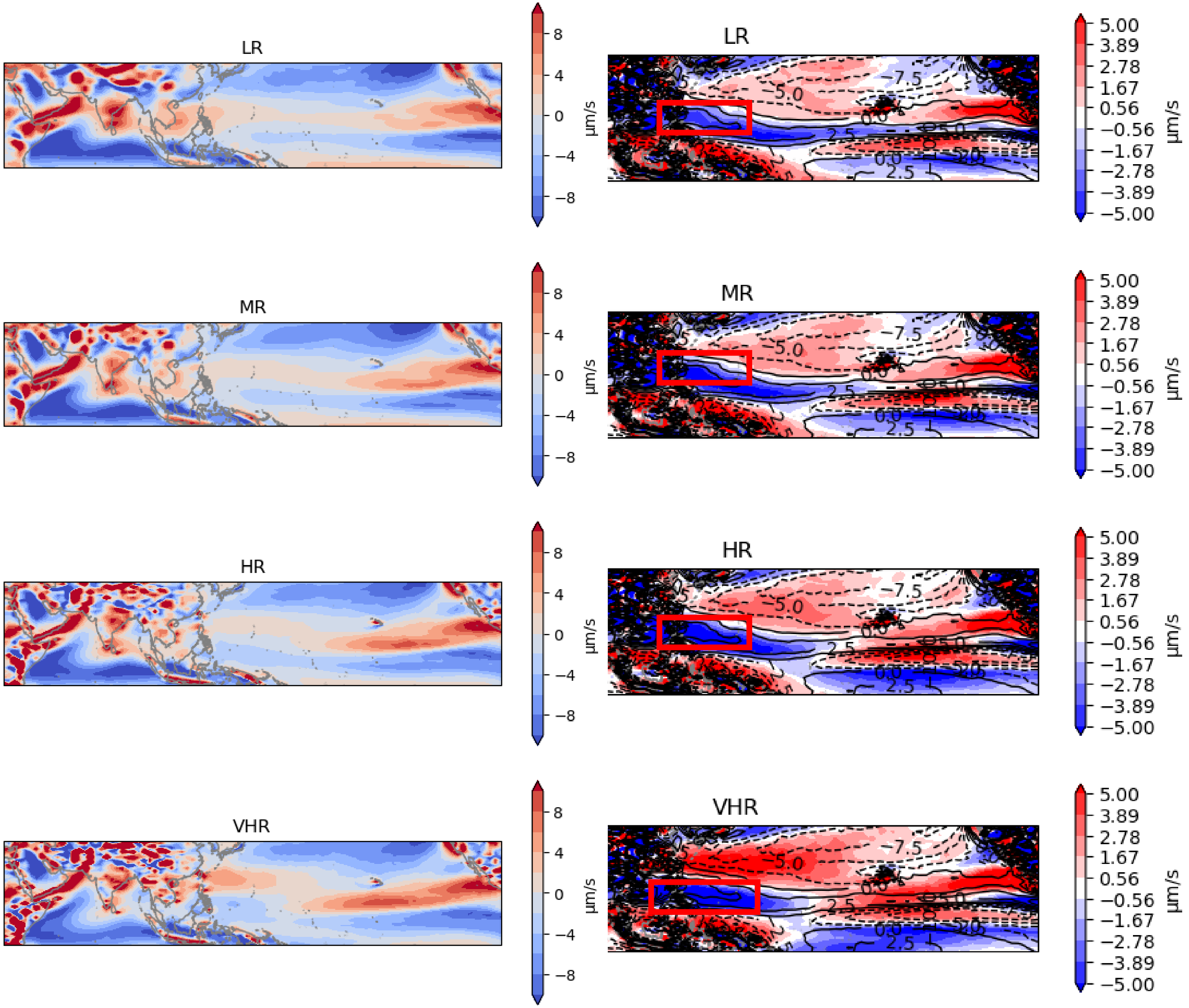
RH 600



LR
MR
HR
VHR
ERA5
100.0
88.9
77.8
66.7
55.6
44.4
33.3
22.2
11.1
0.0
%
40
20
0
−20
−40
%

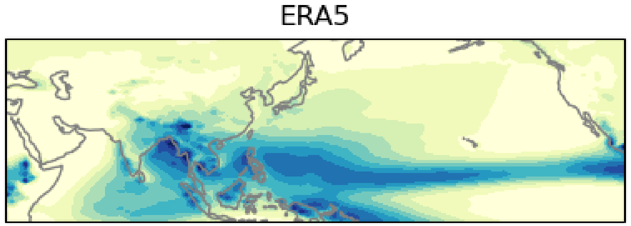
VO850

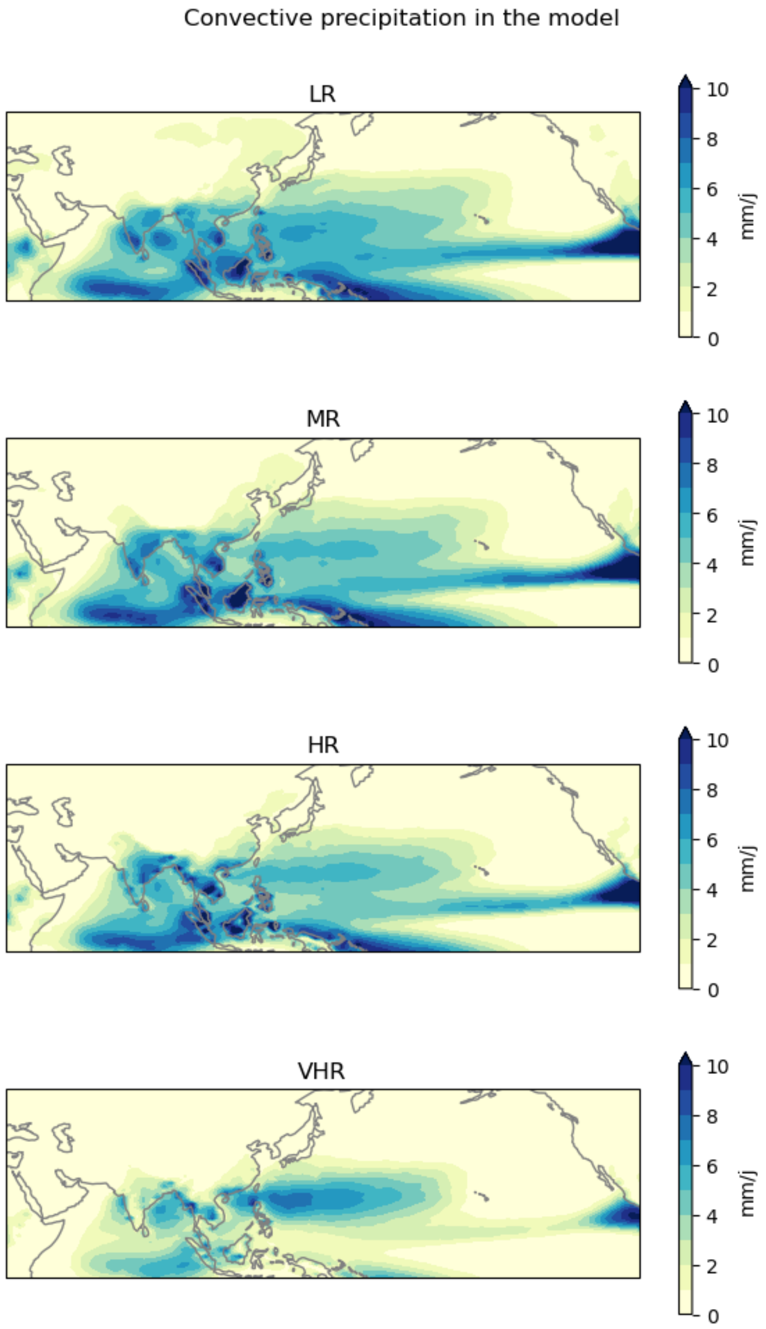


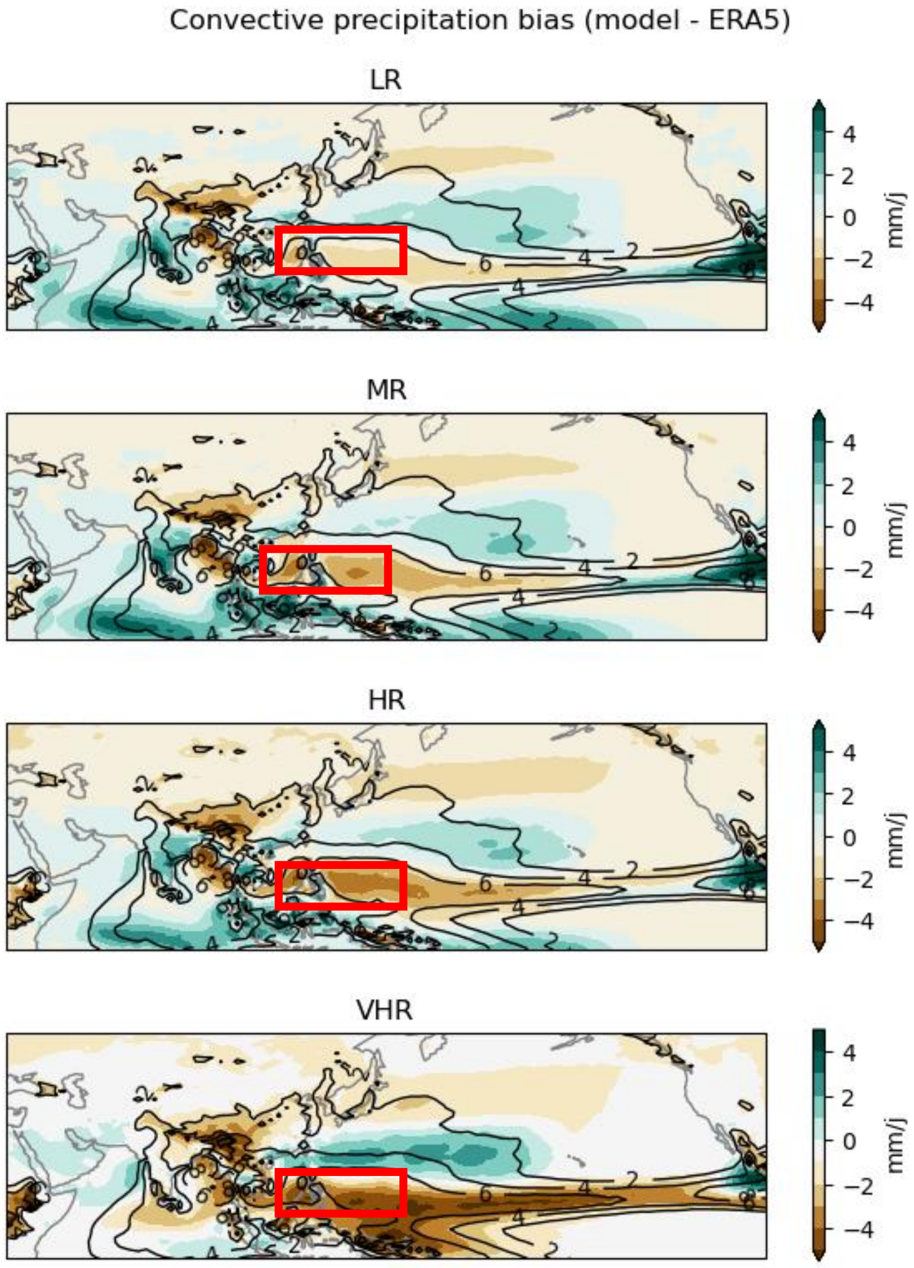


Deficit de vorticité à toutes les résolutions

Precipitations convectives



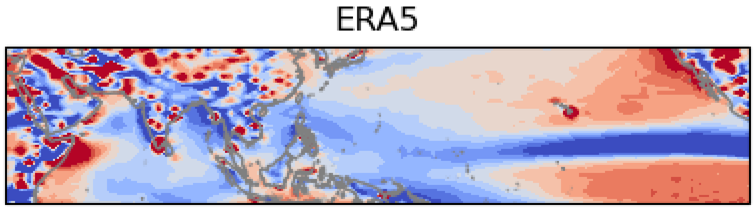




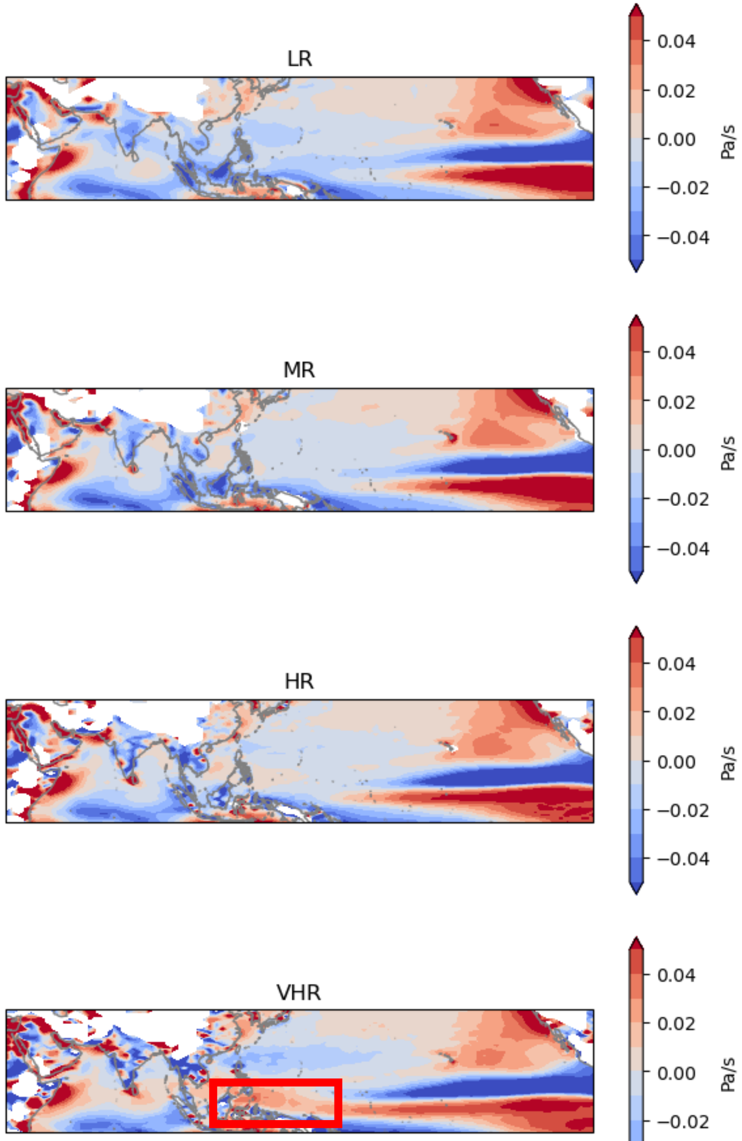
Déficit de précipitation convective à toute les résolutions, s'accentue avec la résolution

Vitesses verticales 850hPa

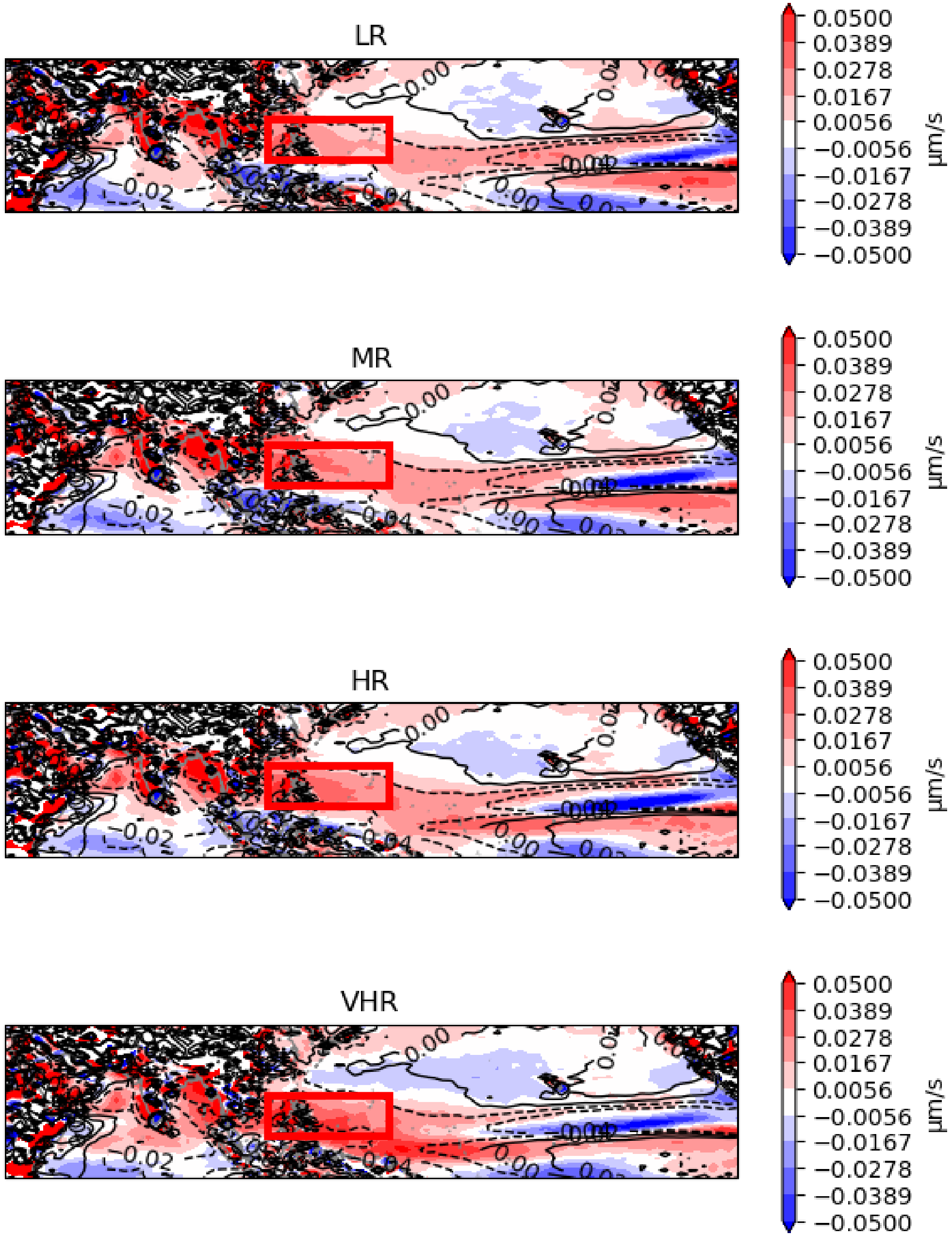
/ !\ w>0 = descente
et biais de w>0 veut dire que ça monte pas assez ou descend trop
Remplacer um/s par Pa/s



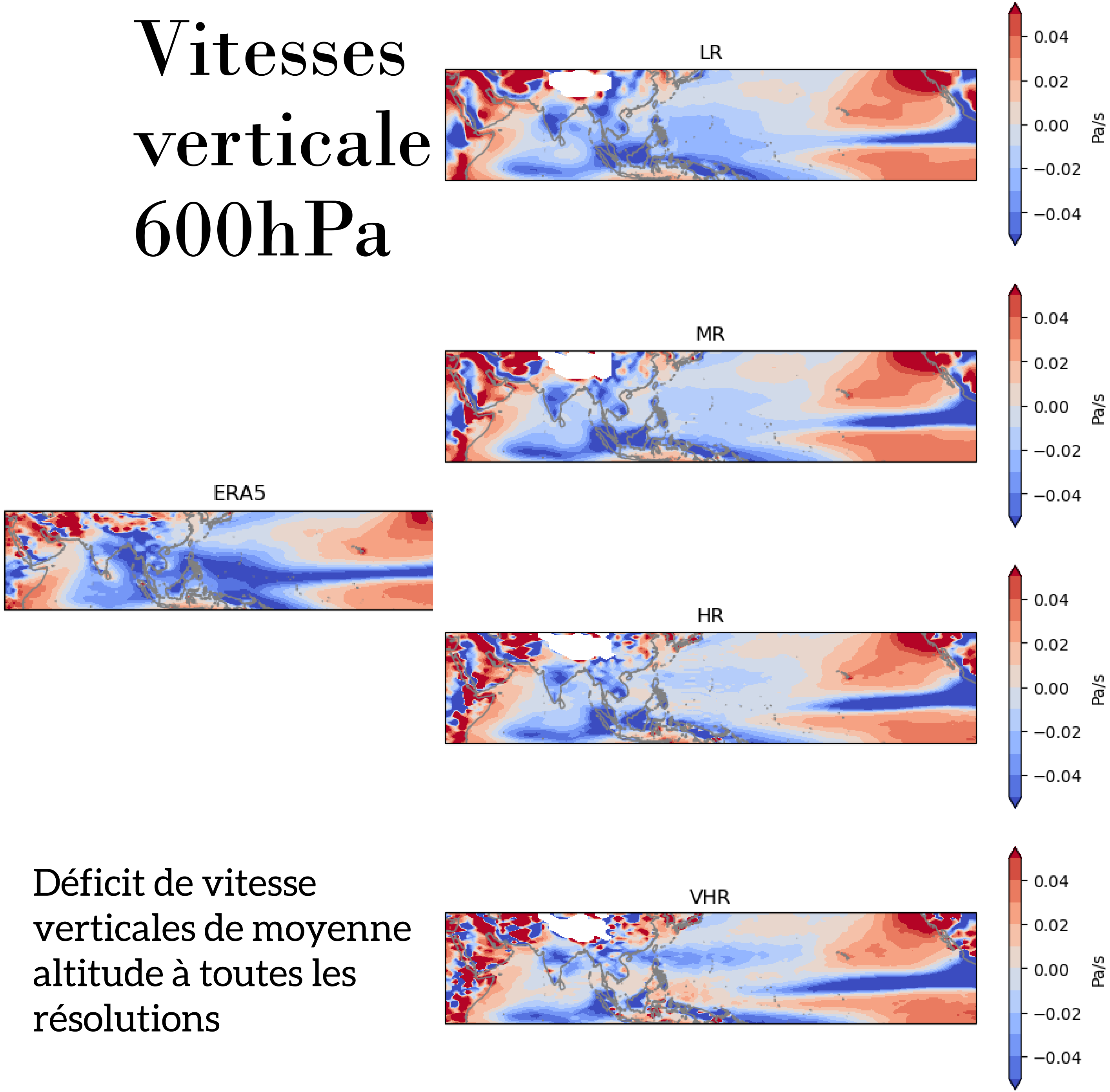
Déficit de vitesse verticales de basse altitude à toutes les résolutions

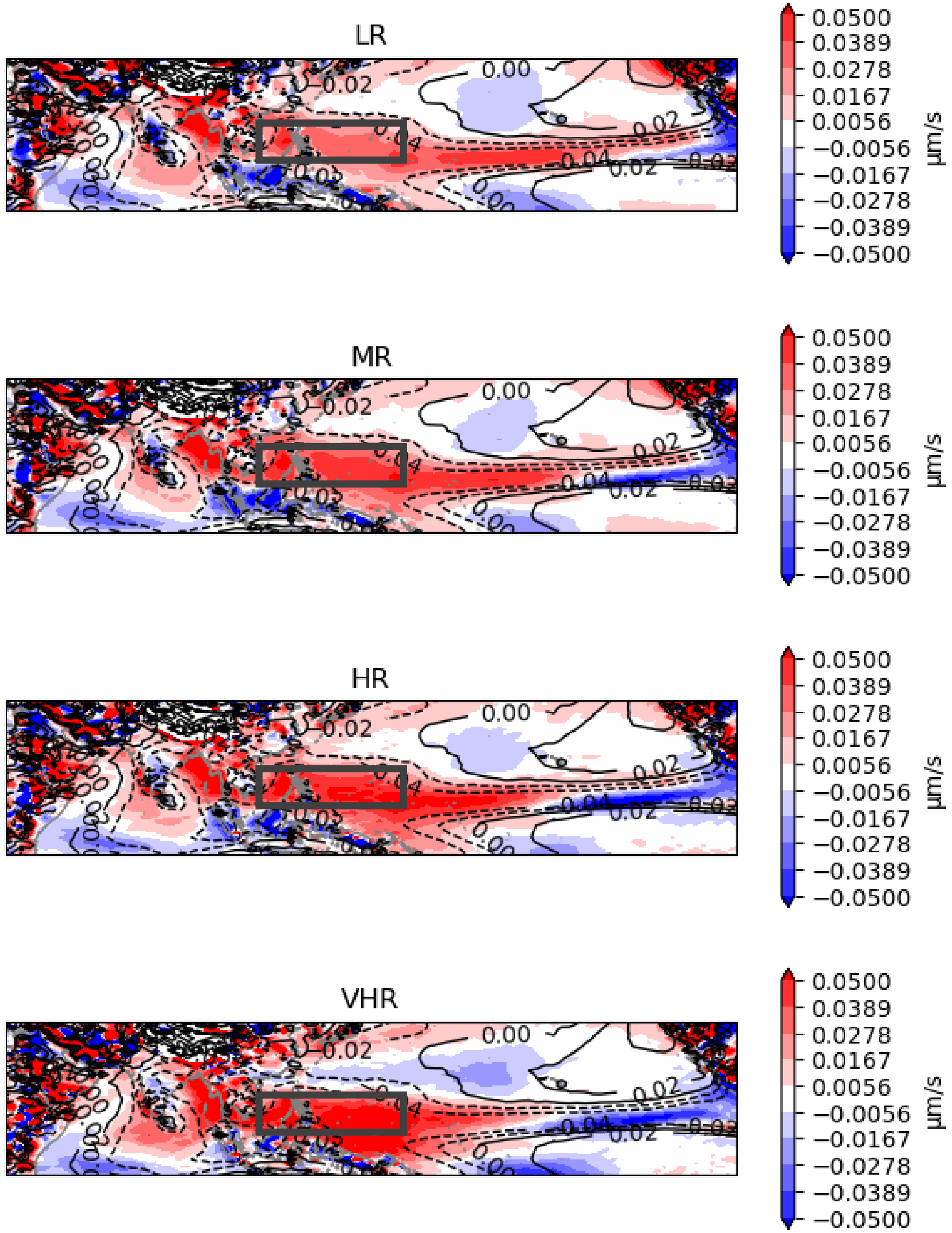


Subsidence climatologique dans la warm pool !



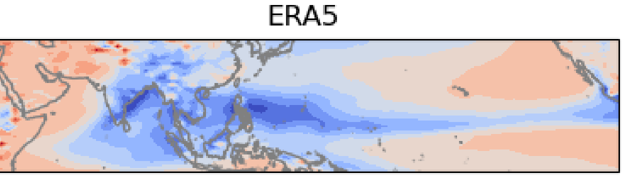
Vitesses verticale 600hPa

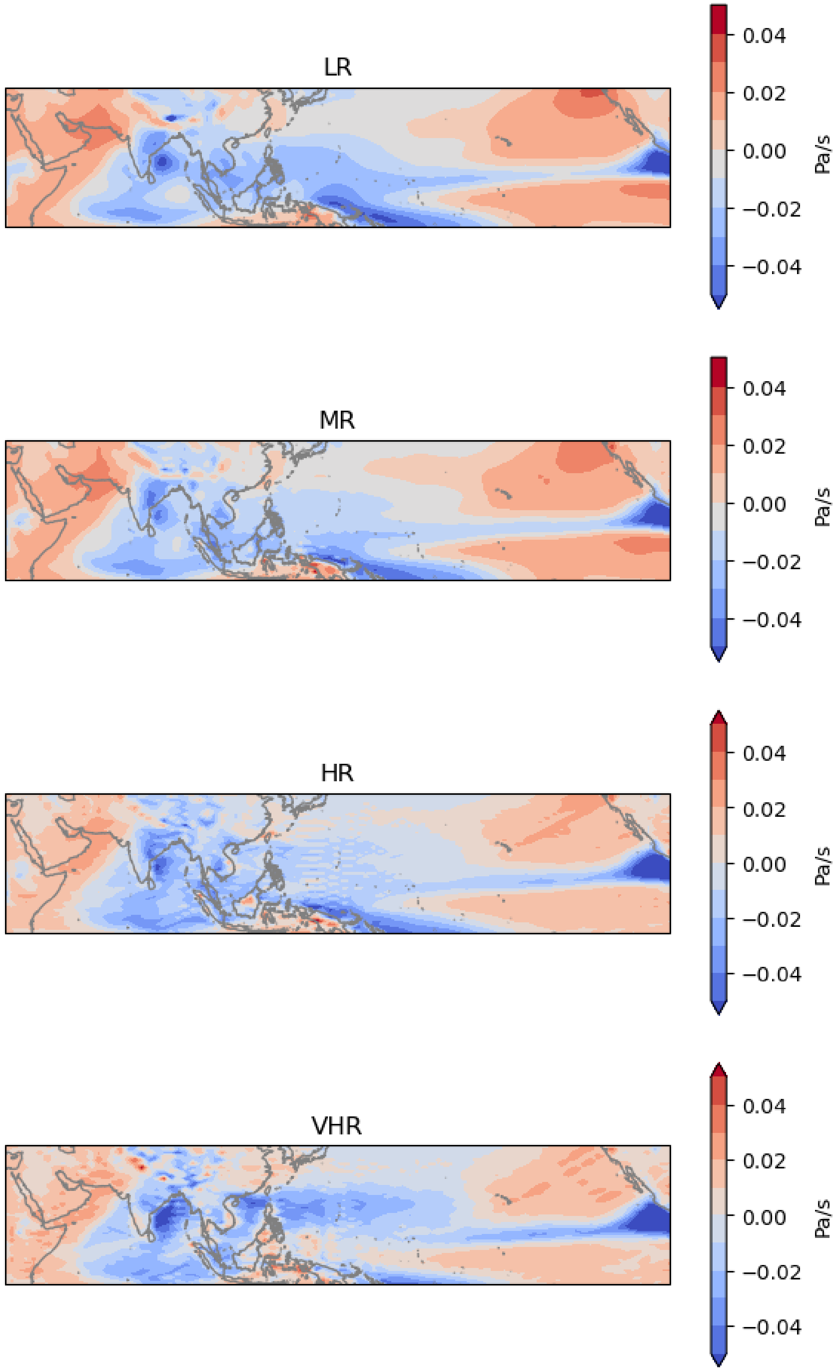


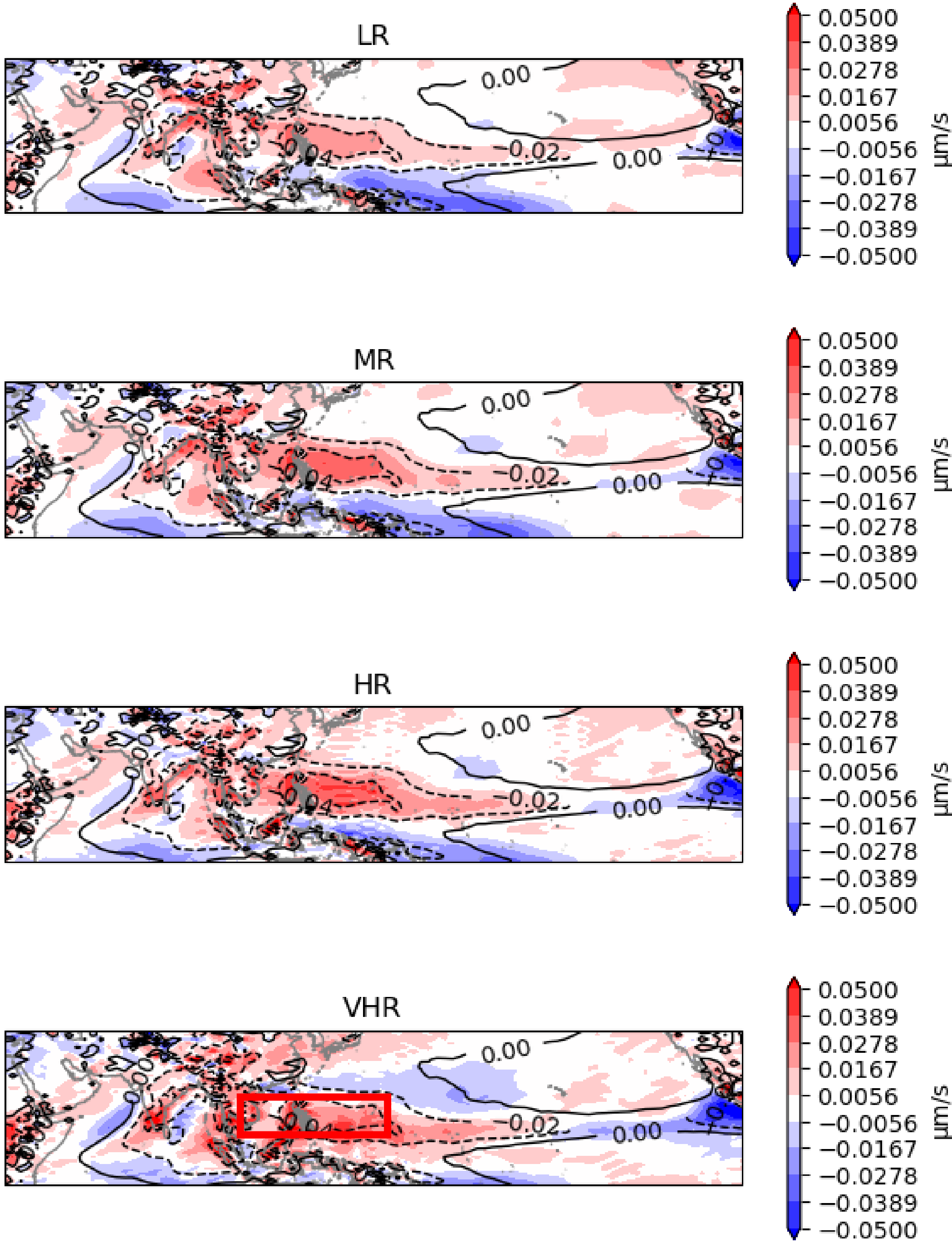


Déficit de vitesse verticales de moyenne altitude à toutes les résolutions

Vitesses verticales 200hPa



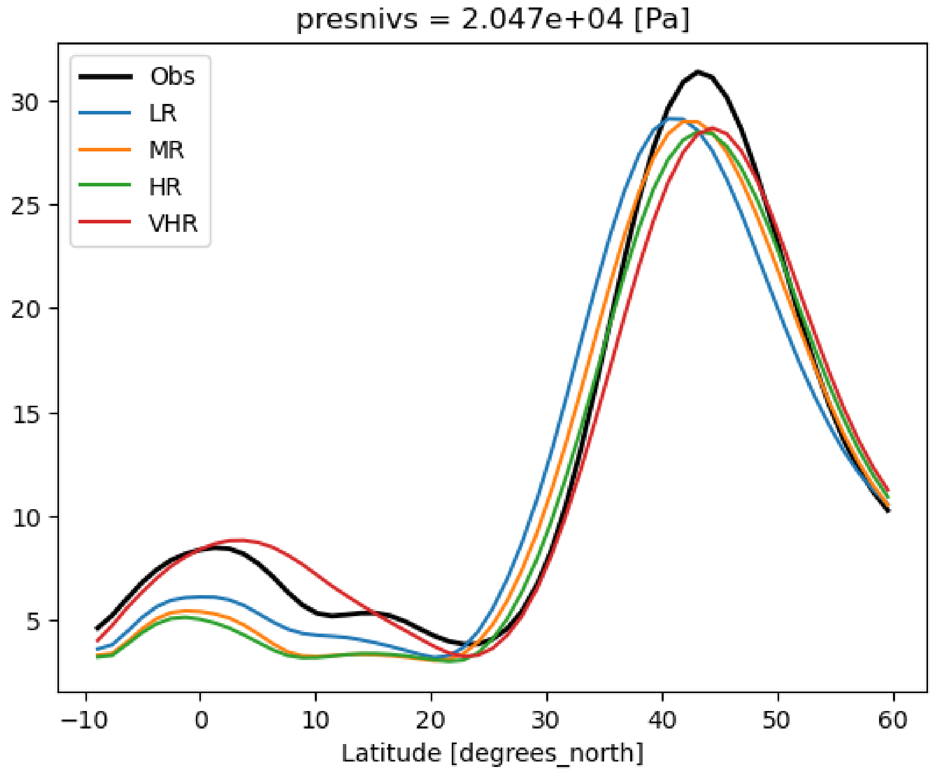




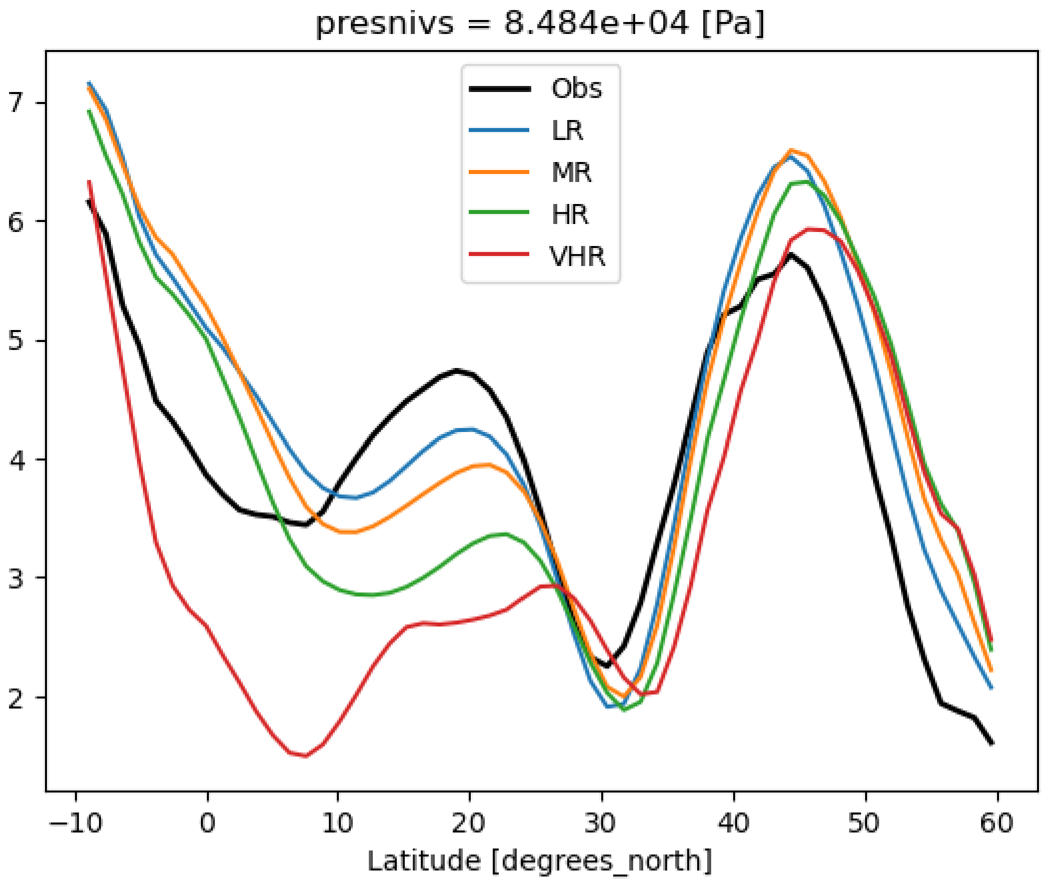
Déficit de vitesse verticales de haute altitude à toutes les résolutions

Zonal wind speed profiles

Moyenne de 125 à 180° longitude

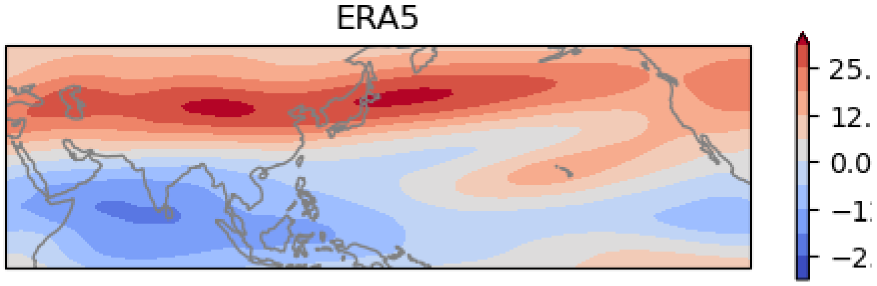


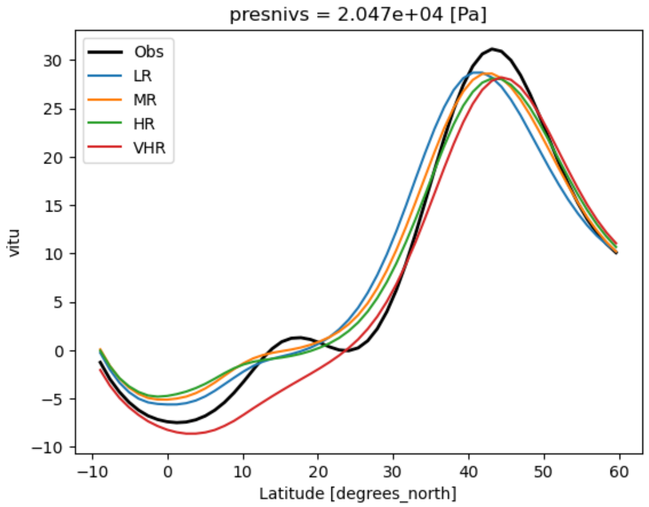
A 200hPa, le champ zonal montre un pic principal au bon endroit, le pic secondaire est moins bien reproduit.

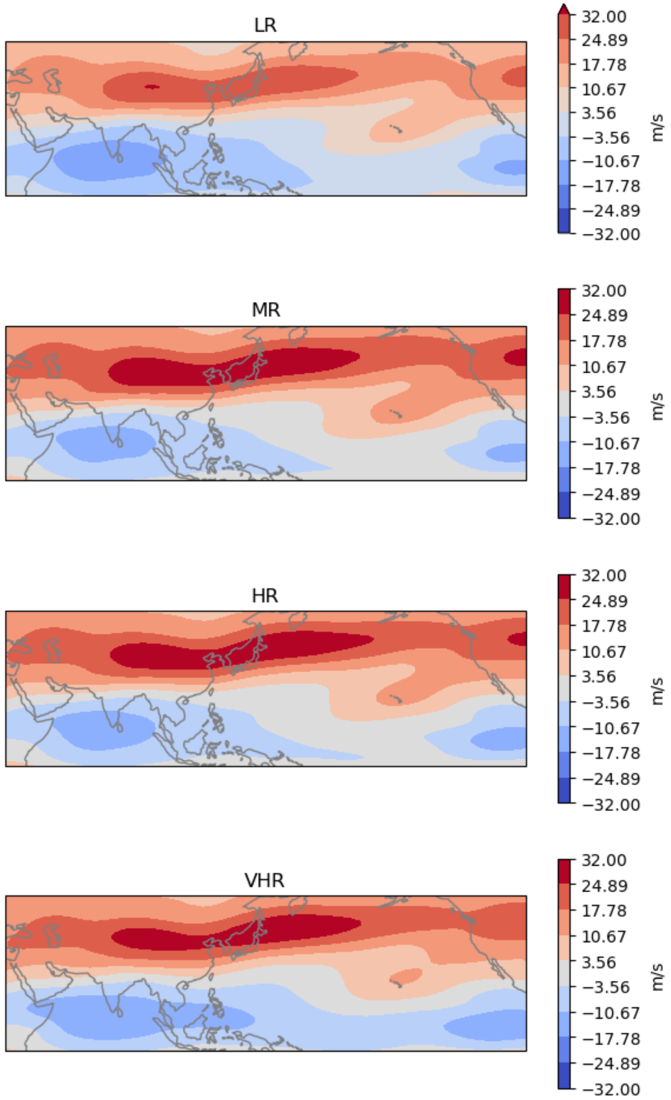


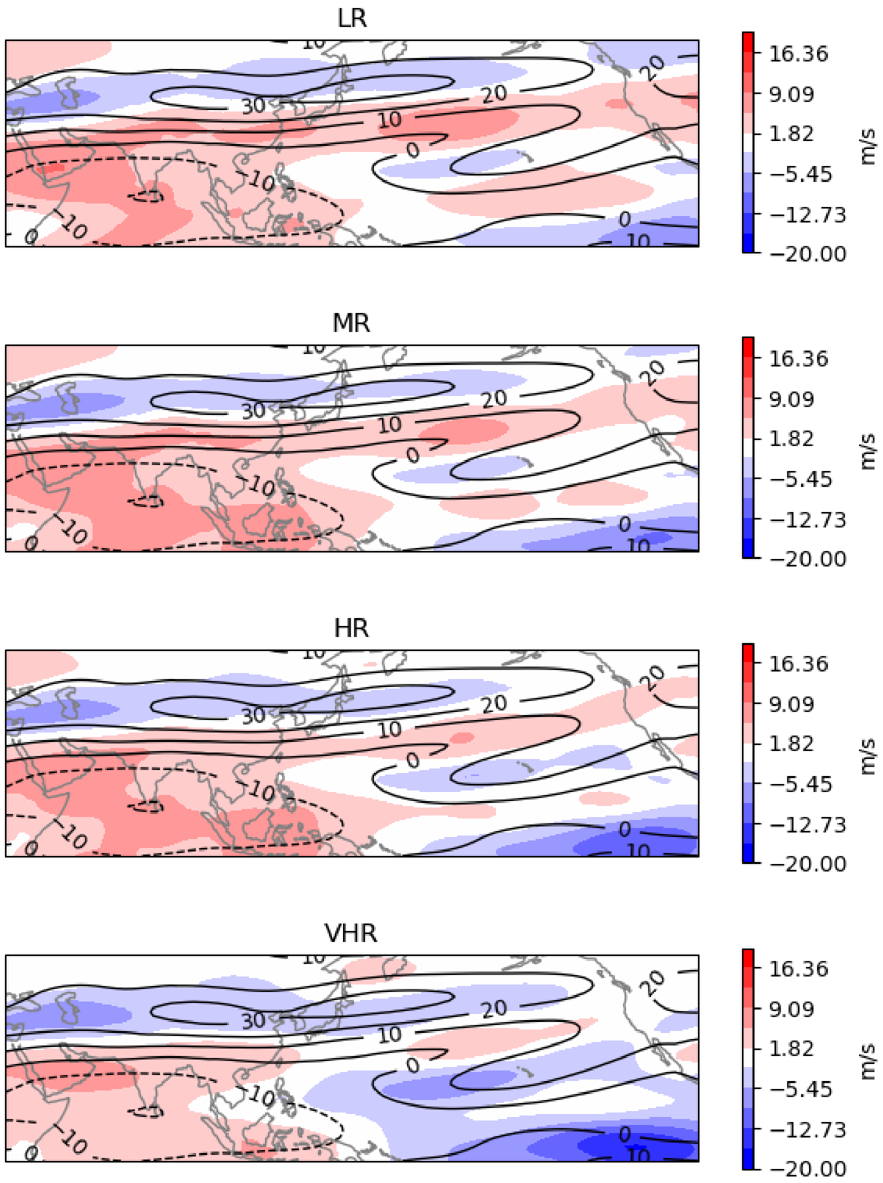
Le pic principal à 45°N est au bon endroit quoiqu'un peu fort et un peu au nord.
Le pic secondaire est trop faible, trop au nord et problématique en VHR.

U200

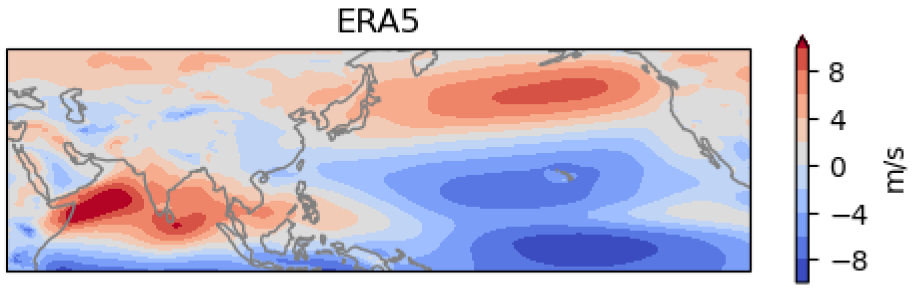

ERA5
25.
12.
0.0

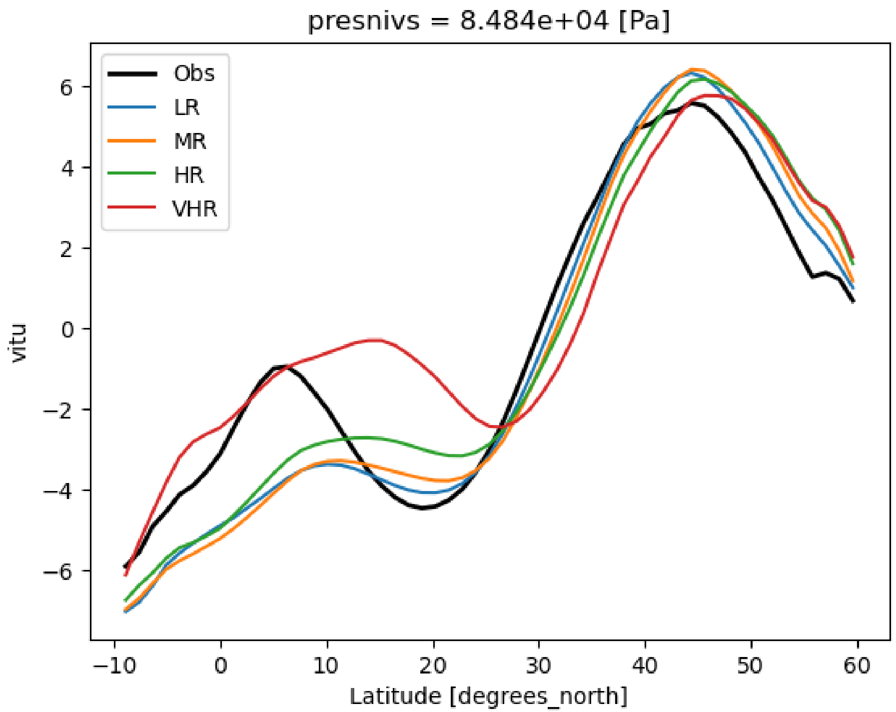

presnivs = 2.047e+04 [Pa]
Obs
LR
MR
HR
VHR
vitu
Latitude [degrees_north]

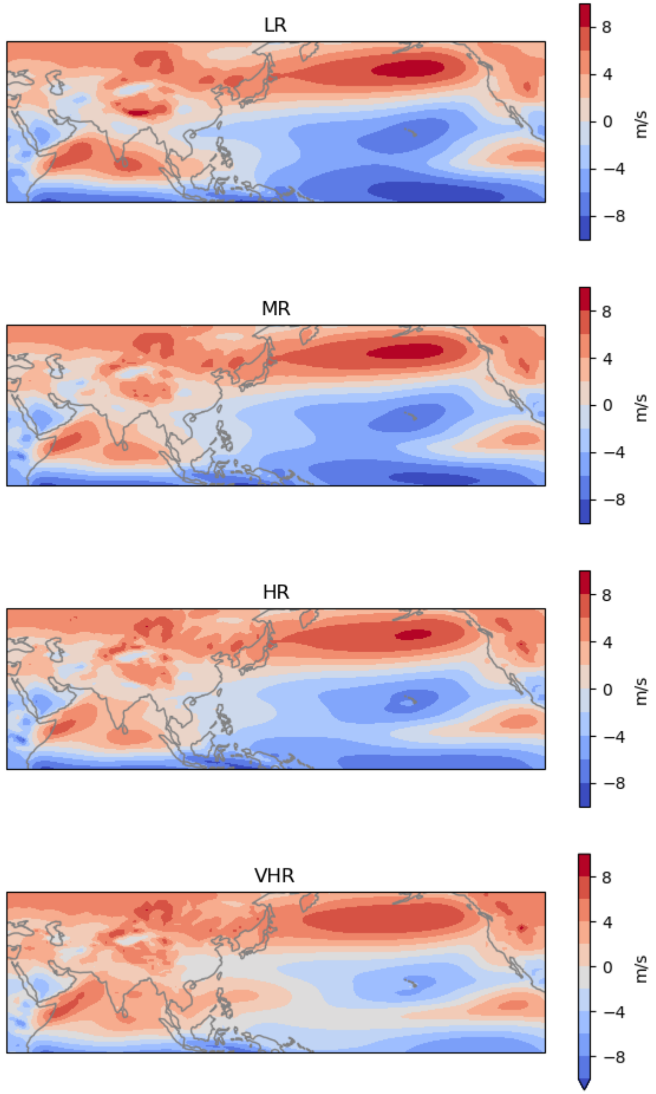

LR
MR
HR
VHR
32.00
24.89
17.78
10.67
3.56
−3.56
−10.67
−17.78
−24.89
−32.00
m/s

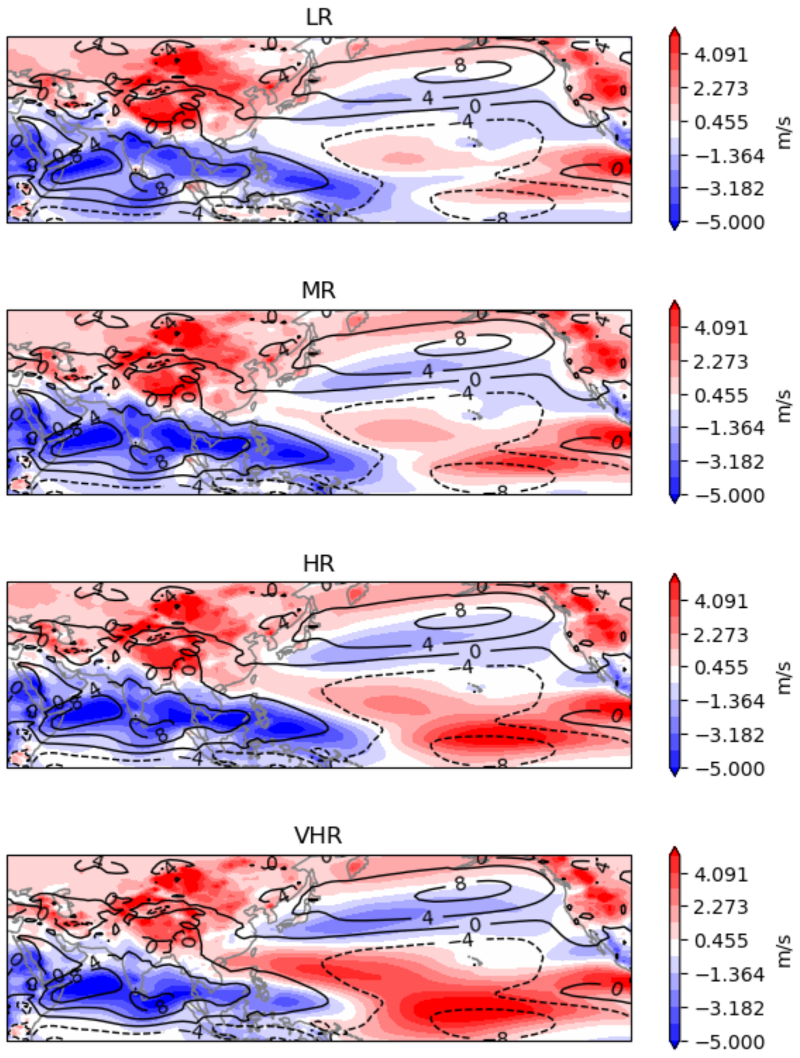

LR
MR
HR
VHR
16.36
9.09
1.82
−5.45
−12.73
−20.00
m/s

U850



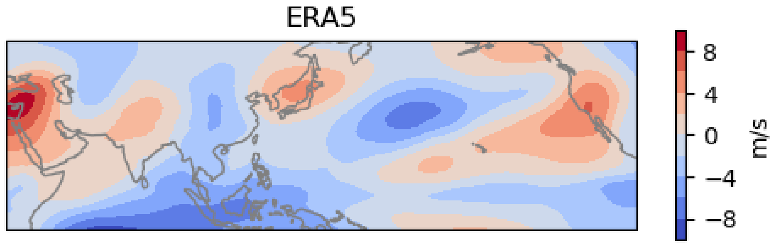


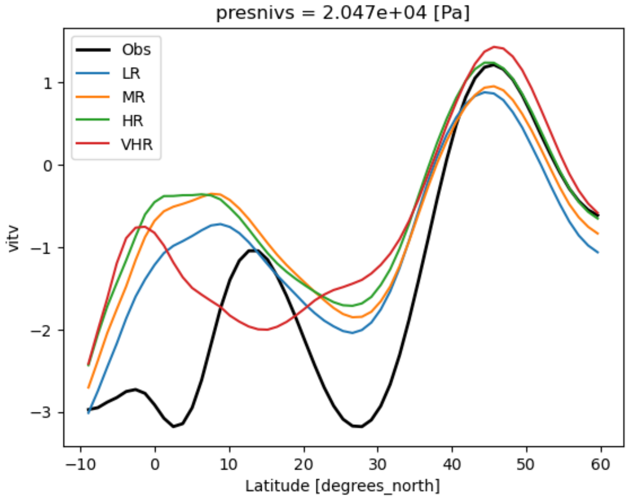


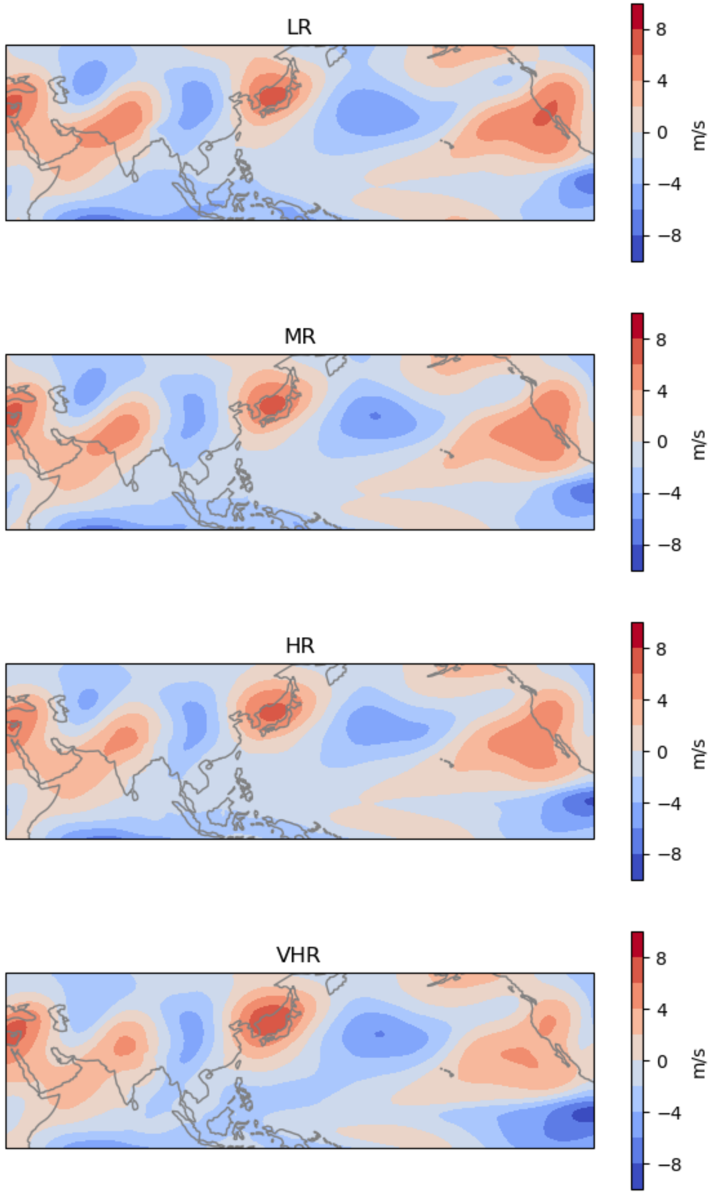


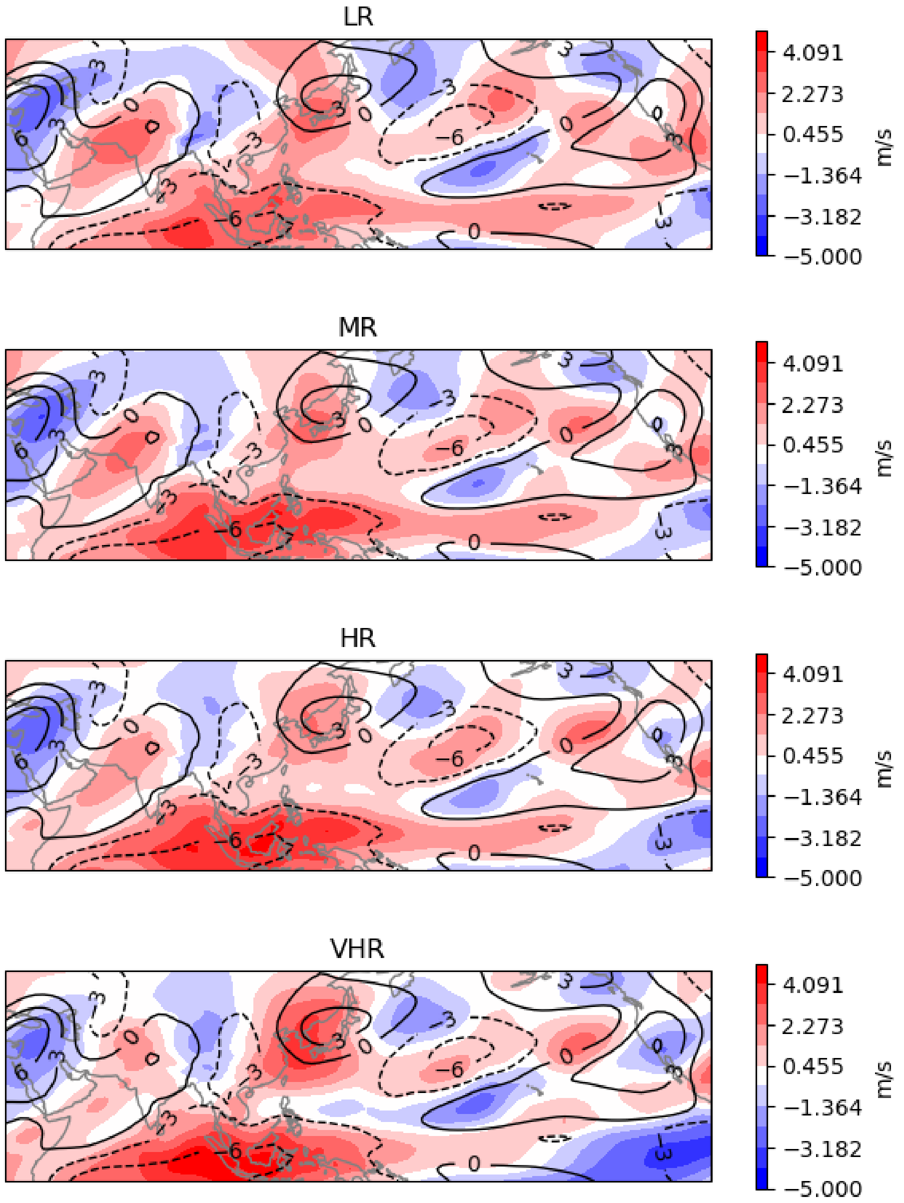
Pic principal assez bien reproduit, minimum à 20°N trop au nord en VHR

V200

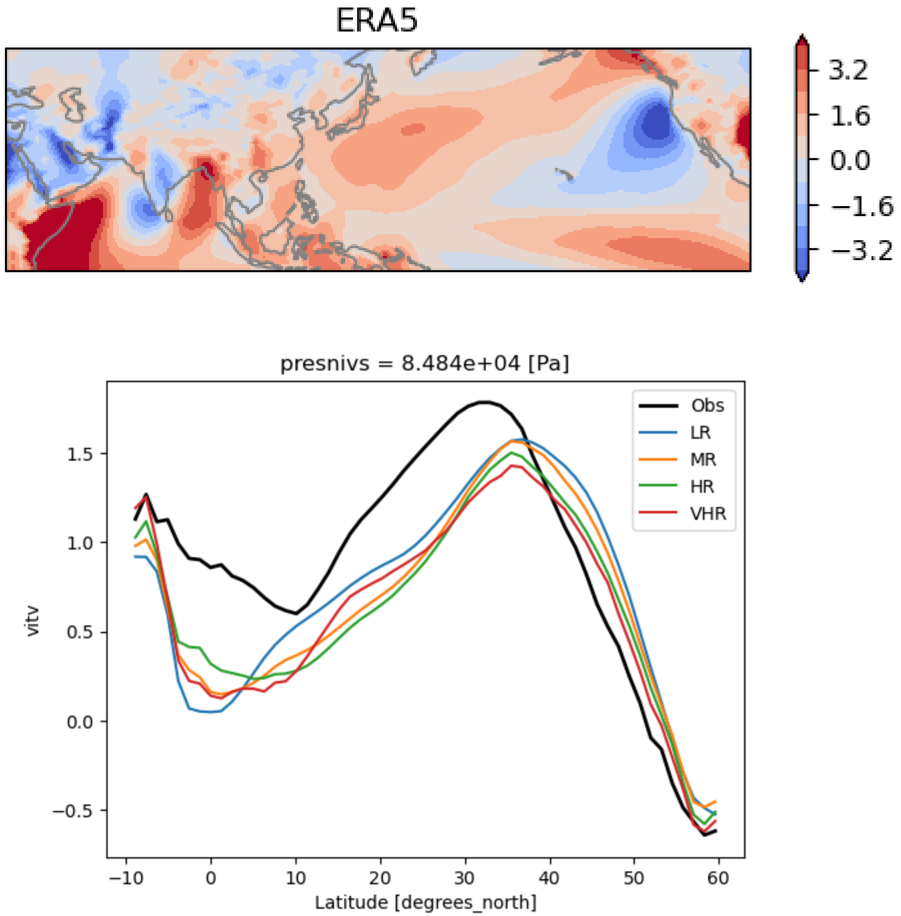

ERA5
8
4
0
−4
−8
m/s

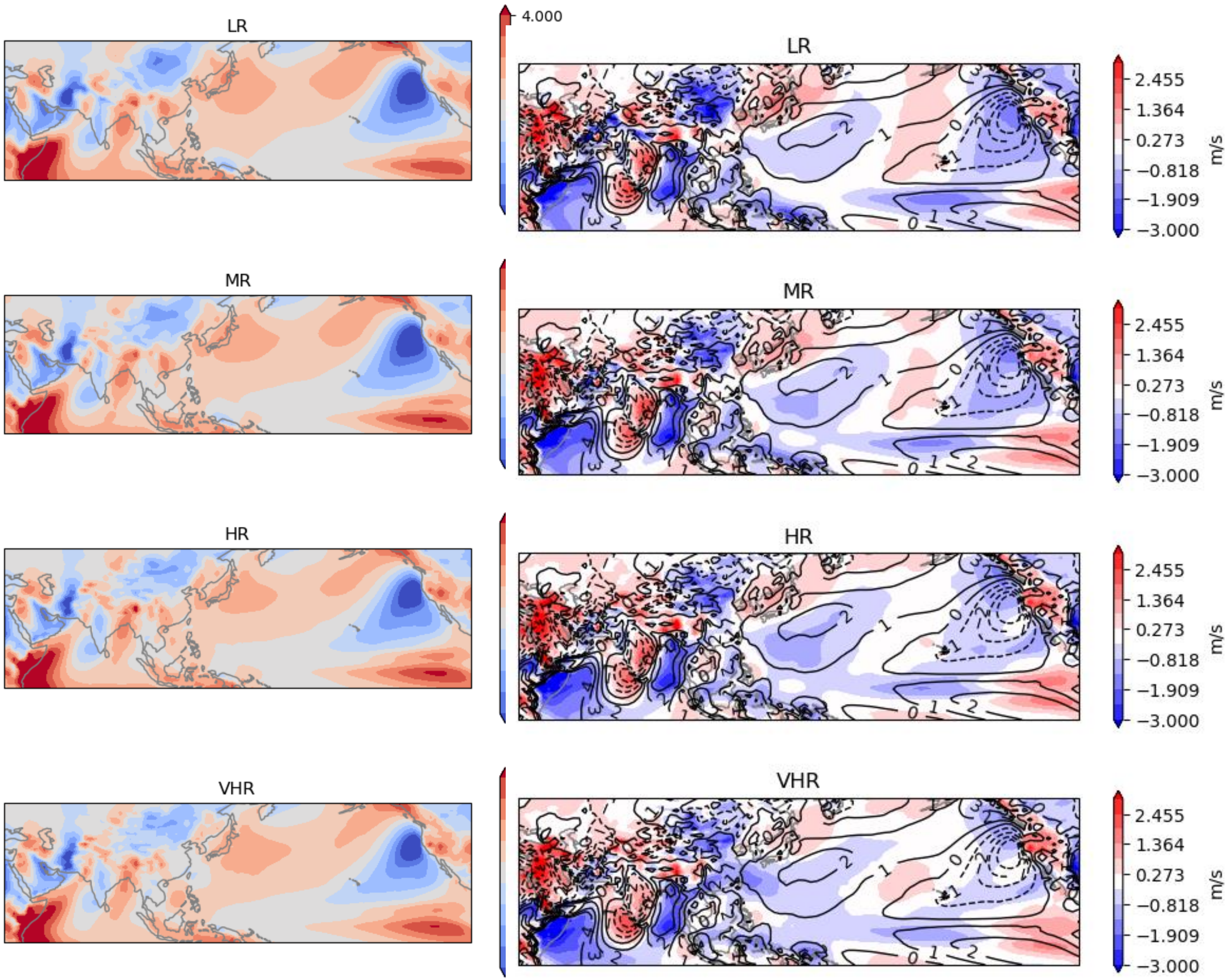

presnivs = 2.047e+04 [Pa]
Obs
LR
MR
HR
VHR
vitv
Latitude [degrees_north]
−10
0
10
20
30
40
50
60
1
0
−1
−2
−3


LR
MR
HR
VHR
8
4
0
−4
−8
m/s


LR
MR
HR
VHR
4.091
2.273
0.455
−1.364
−3.182
−5.000
m/s

V850


ERA5
3.2
1.6
0.0
−1.6
−3.2
presnivs = 8.484e+04 [Pa]
Obs
LR
MR
HR
VHR
vitv
Latitude [degrees_north]


LR
MR
HR
VHR
4.000
2.455
1.364
0.273
−0.818
−1.909
−3.000
m/s