Tropical cyclone simulations in the very high resolution global climate models

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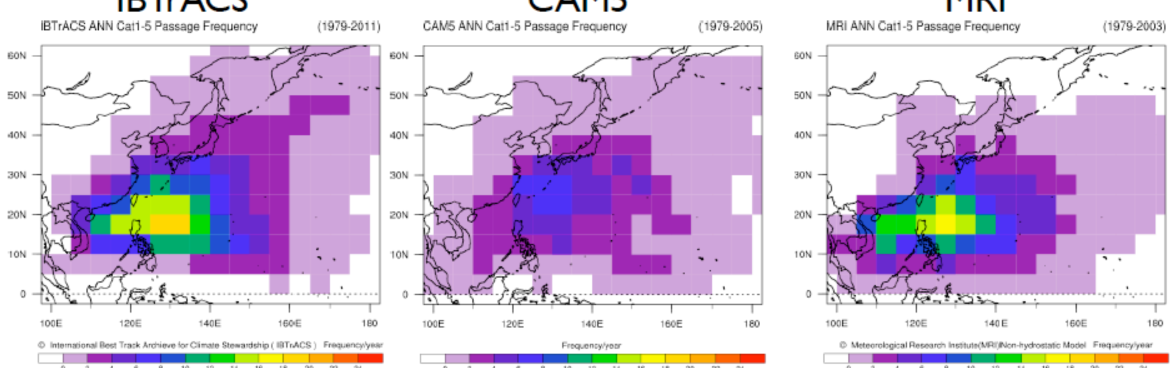
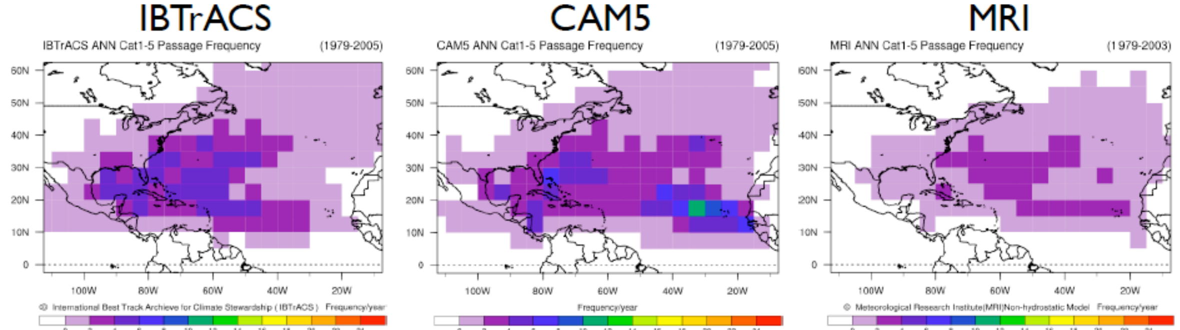
NW Pacific Typhoon (Cat1-5) Track Density



N Atlantic Typhoon (Cat1-5) Track Density



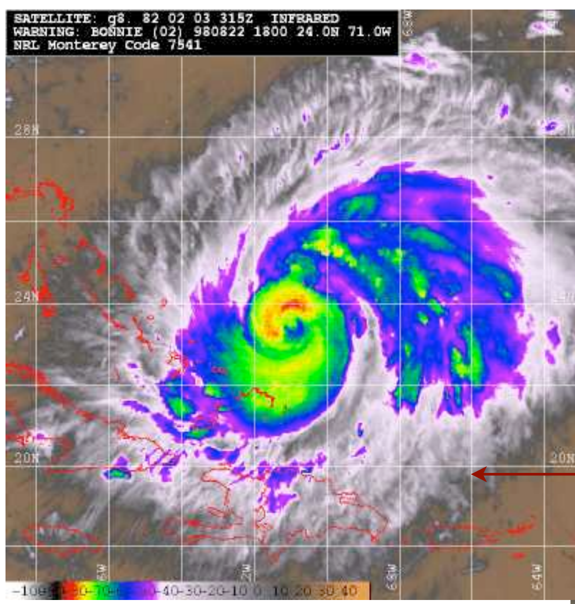
- Long-term high resolution models are required to properly simulate tropical cyclone (TC) intensity and climate-TC interactions
- Model validation and comparison:
  - Mean characteristics and structure
  - Seasonal cycle and interannual variability
  - Rainfall associated TC

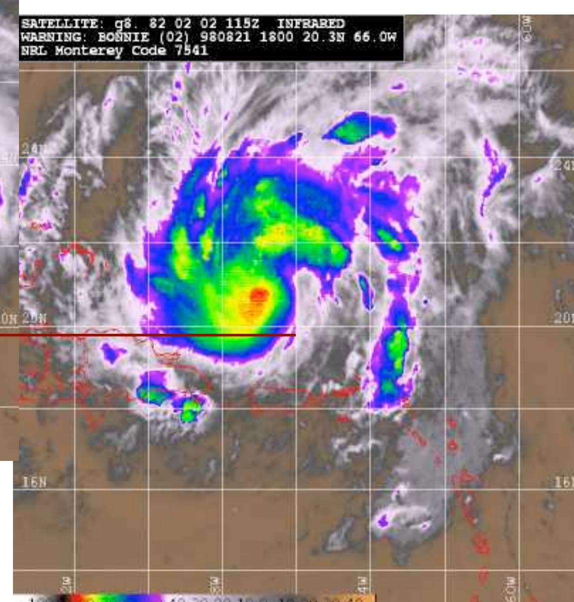
US CLIVAR Hurricane Workshop 2013/06/05-07

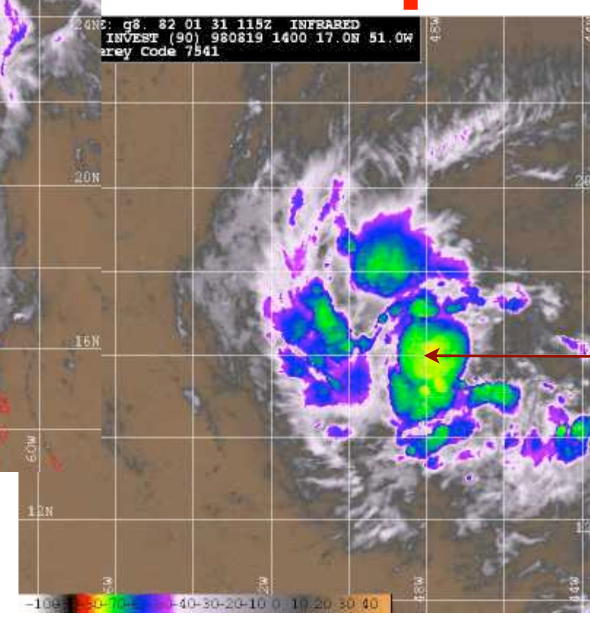
Dynamics and physics of tropical cyclogenesis

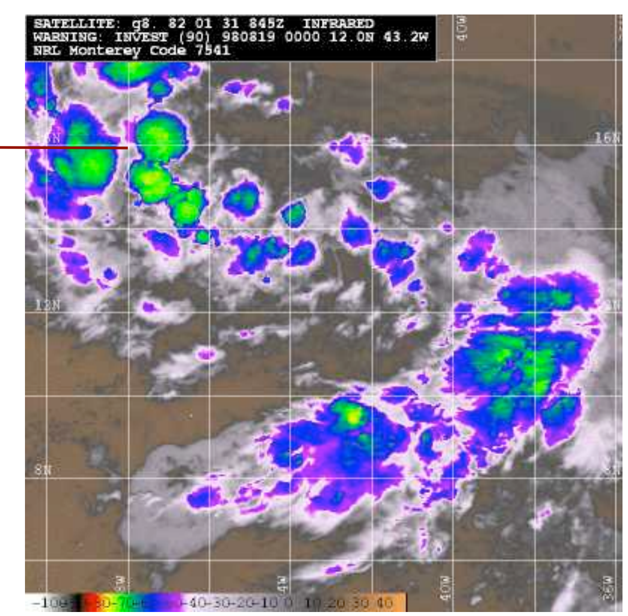
"Transformation of a group of disorganized convections into a self-sustaining synoptic-scale vortex"

Is it difficult for climate model to satisfy all the favorite conditions and capture such transformation?

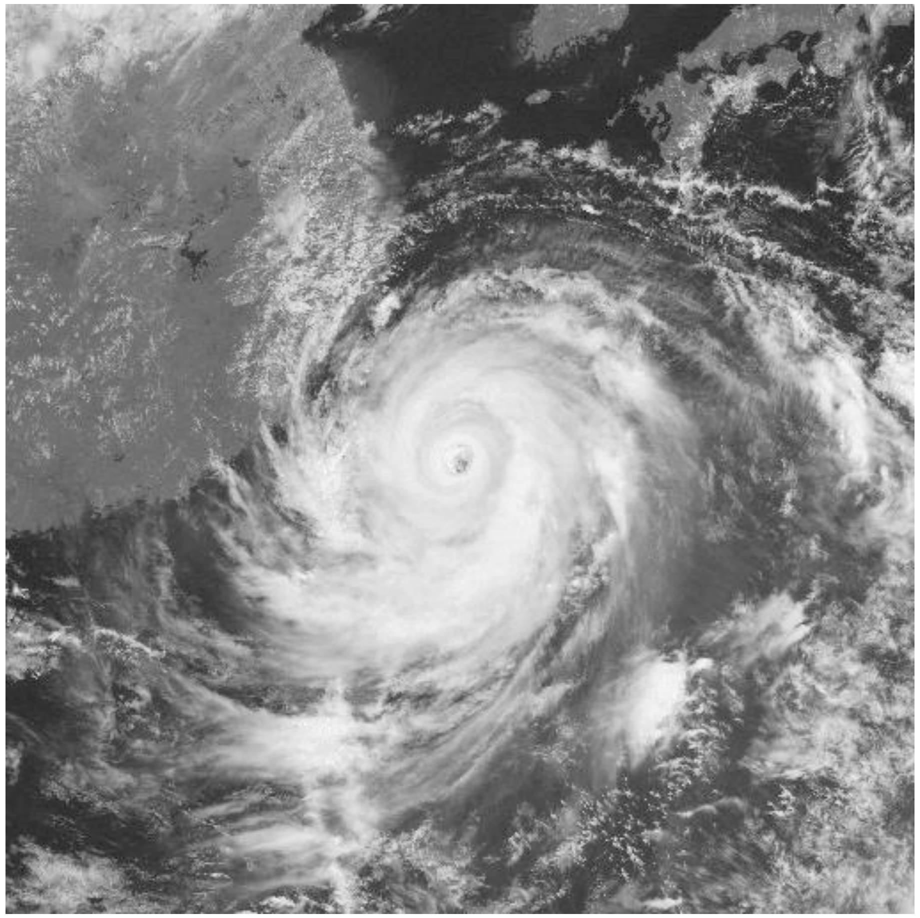


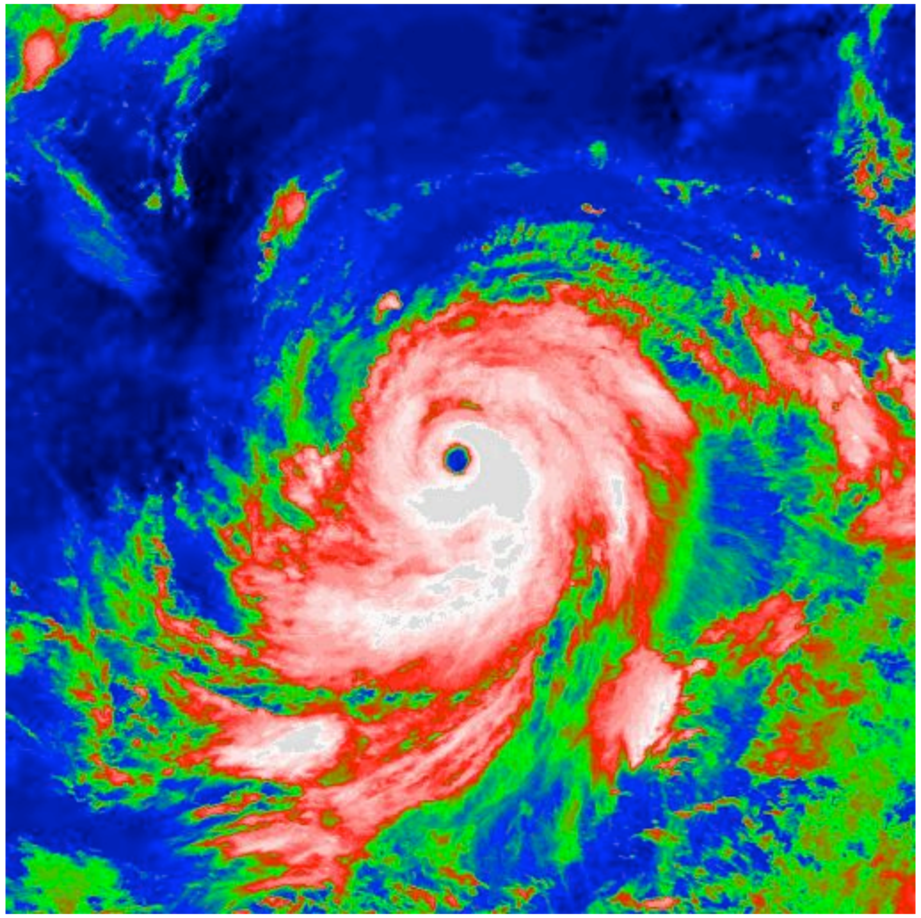




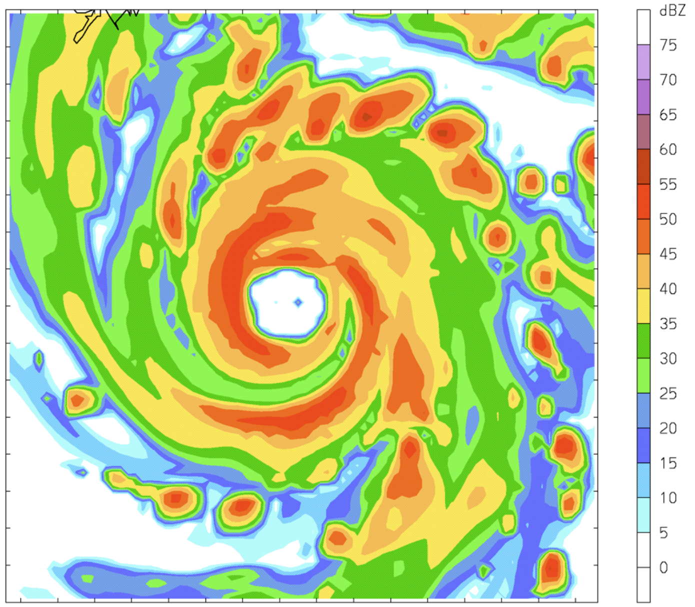


High resolution model is needed to properly simulate tropical cyclone



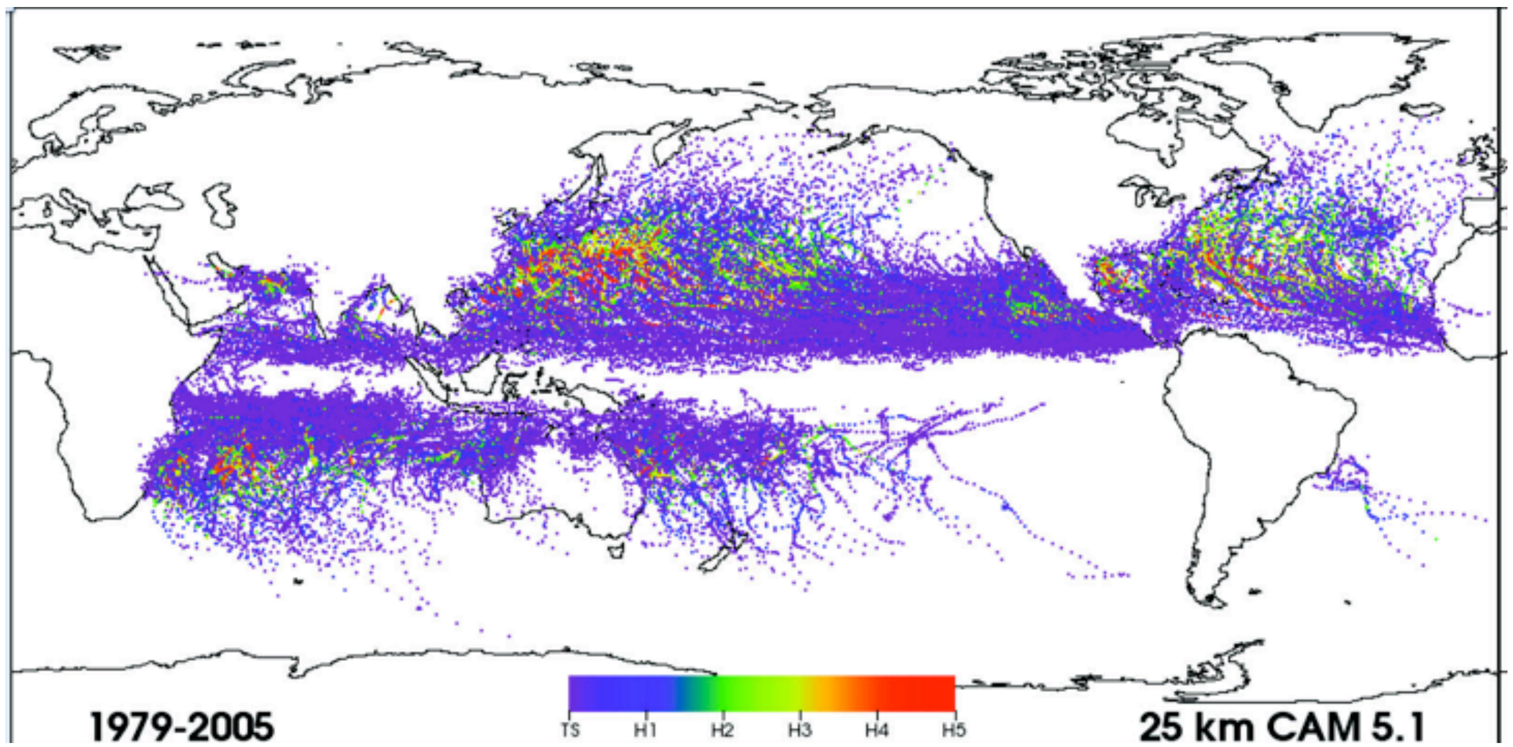


Typhoon Herb

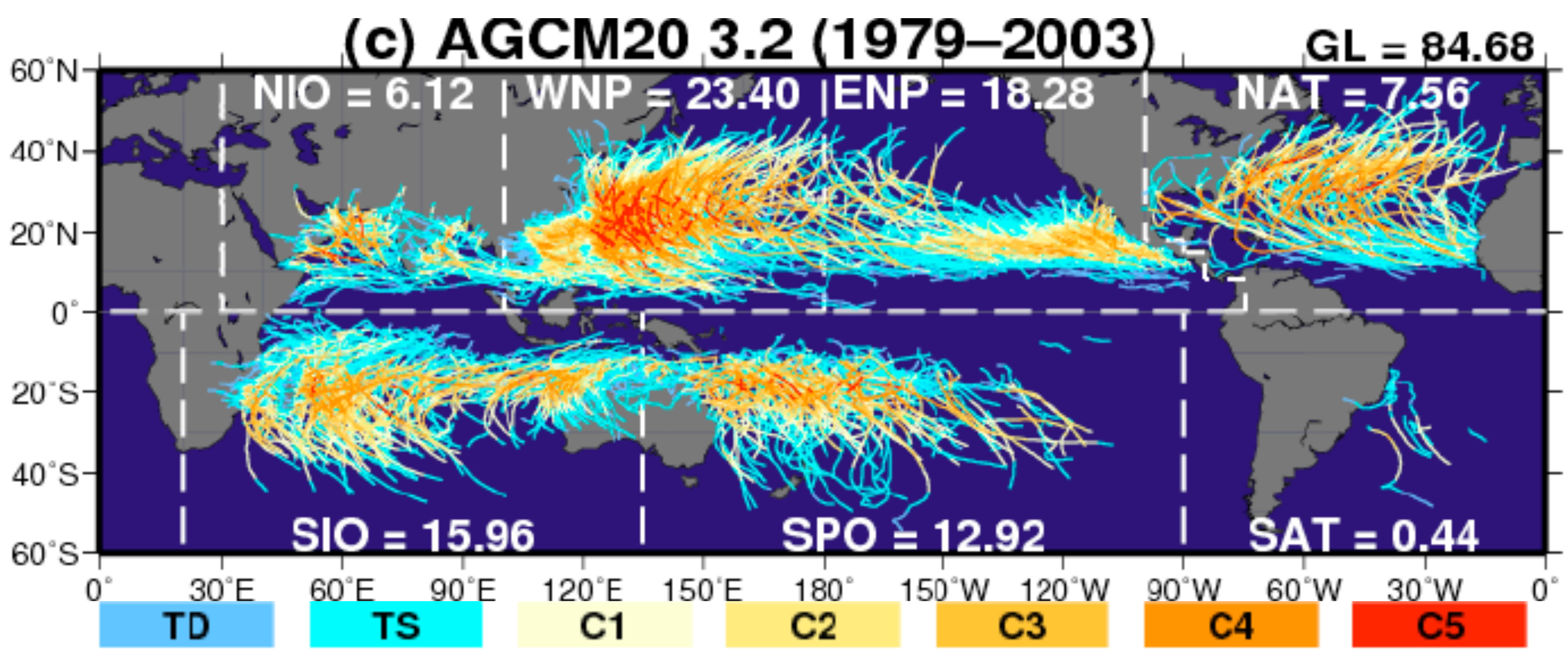


WRF simulation at 4 km resolution

Limited by computational resources, only a few high resolution global climate models can really reproduce intense tropical cyclone (major hurricane or super typhoon)



Wehner et al. (in prep.)

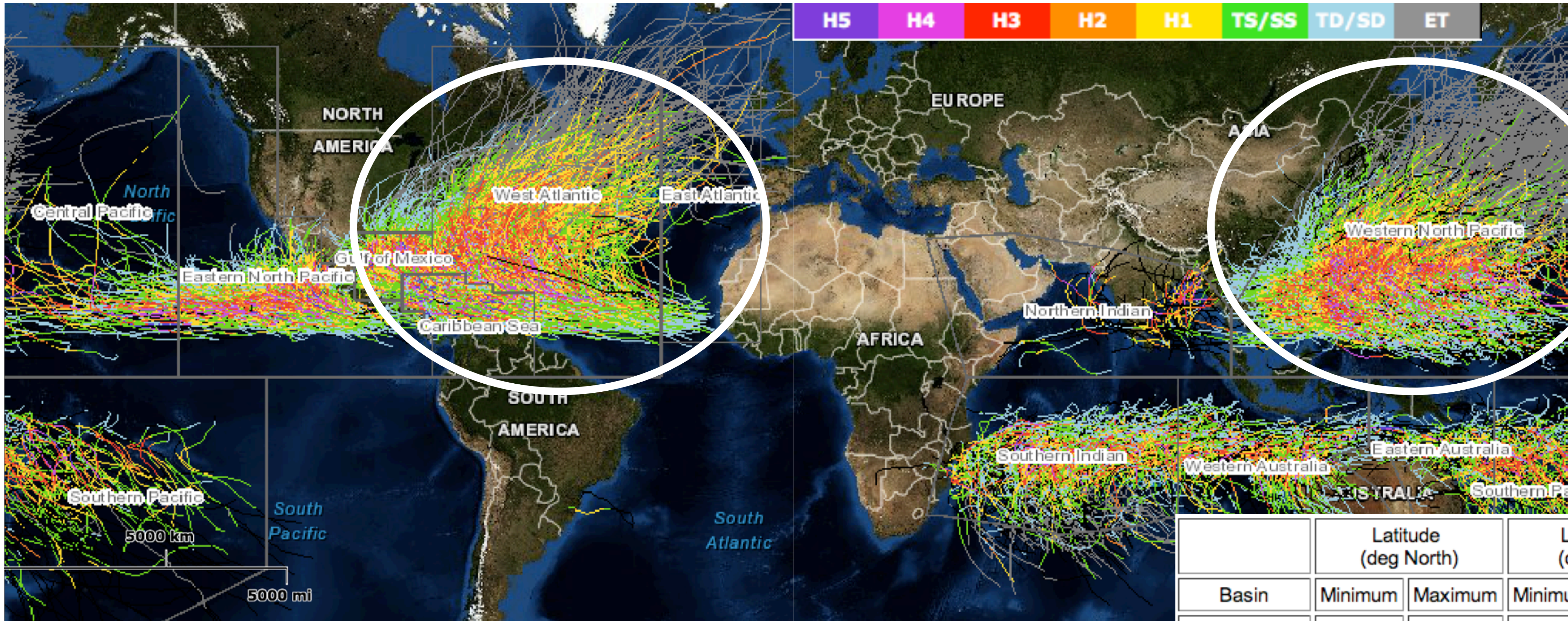


Murakami et al. (2012)

For studying hurricane-climate interaction, climate models need to reproduce:

- Large-scale climatology of tropical cyclone (TC) season
- Conditions for TC genesis
- Seasonal evolution of TC genesis locations, tracks and intensity
- Response to climate perturbation and large-scale environment change

IBTrACS



	Latitude (deg North)		Longitude (deg East)	
Basin	Minimum	Maximum	Minimum	Maximum
North Indian	0	90	30	100
West Pacific	0	90	100	180
East Pacific	0	90	180	Variable
North Atlantic	0	90	Variable	30
South Indian	-90	0	10	135
South Pacific	-90	0	135	-70
South Atlantic	-90	0	-70	10

- Data version v3r4 (most recent)
- Focus on West Pacific and North Atlantic
- Genesis of tracks start from the location when max wind larger than 35 knots (Tropical Storm and Cat 1-5 Hurricane)
- From 1979 to 2011
- Conversion of 10 min average wind to 1min (/0.88) over W Pacific

High-resolution AGCM Time Slice Experiments

Present-day climate experiment (1979-2003 MRI or 2005 CAM)

observed sea surface temperature (SST) and sea-ice concentration

MRI AGCM 3.2

- Based on operational JMA-GSM
- Resolution: TL959(20km) with
- Vertical level: 64 layers (top 0.01 hPa)
- Physics
  - Cumulus convection: Yoshimura scheme (Mizuta et al 2012)
  - Cloud: Tiedtke (1993), ECMWF (2004)
  - Radiation: JMA (2007)
  - Land hydrology: MJ-SiB: SiB with 4 soil-layers and 3 snow-layers
  - PBL: Mellor & Yamada (1974,1982) level-2 closure model
  - Gravity wave drag: Iwasaki et al. (1989) + Rayleigh friction

NCAR CAM5.1

- Standard release version 5.1 with time dependent prescribed aerosol forcing. No further tuning.
- Observed ozone, CO2, solar forcing
- Resolution: 0.23 x 0.31
- Vertical level: 30 layers (top 2 hPa)
- Physics
  - Deep convection: Zhang and McFarlane (1995)
  - Shallow convection: Park and Bretheerton (2009)
  - Radiation: RRTMG (Iacono et al. 2008)
  - Land: Community Land Model CLM2 (Bonan et al., 2002)

Tropical Cyclone **Detection** and **Tracking** Scheme

(Knutson et al., 2007; Vitart et al., 1997, 2003)

- Local relative vorticity maximum at 850hPa > $1.6 \times 10^{-4}\ s^{-1}$.
- The closet local minimum sea level pressure is detected and defines the center of the storm. Must exist within a 2°x2° radius of the vorticity maximum. The minimum sea level pressure must increase by 4hPa in all directions from storm center within 5° distance.
- The closest local maximum in temperature averaged between 200hPa and 500hPa is defined as the center of the warm core. The distance from the warm core center and the storm center must exist within a 2°x2° radius. The temperature must decrease by at least 0.8K in all directions from the warm core center within a distance of 5°.
- For a given storm, we examine whether there are storms that appear on the following time step (6hr) at a distance of less than 400 km. If there is no such storm, then the trajectory is stopped.
- To be considered as a model tropical storm trajectory, a trajectory must last at least 2 days and have a maximum wind velocity > 17 m/s during at least 2 days (not necessarily consecutive)

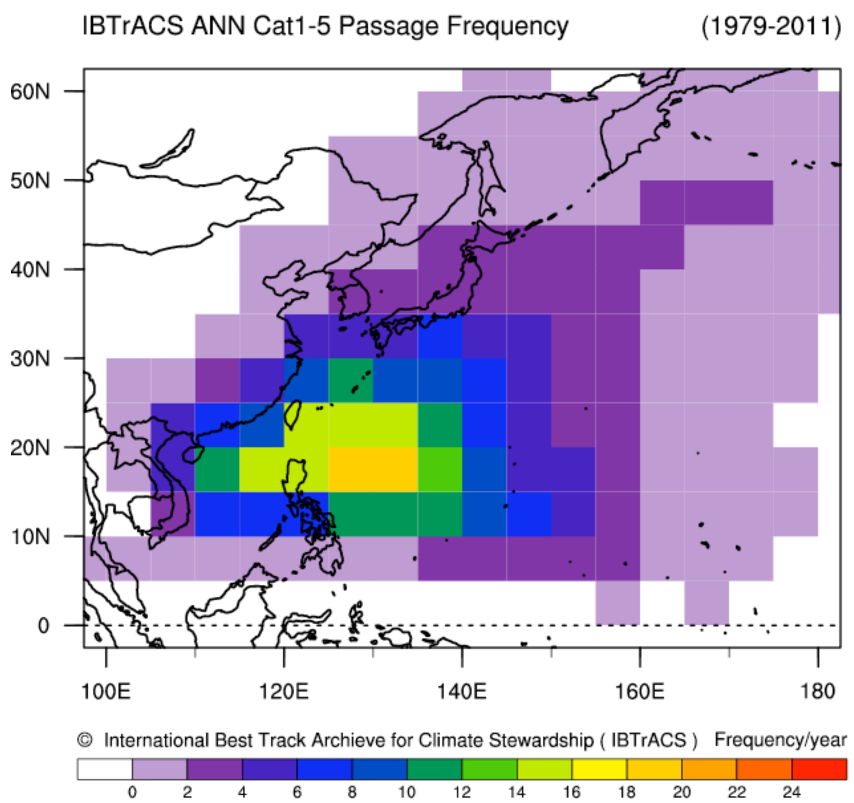
MRI Tropical Cyclone Detection and Tracking Scheme

(Murakami et al., 2012)

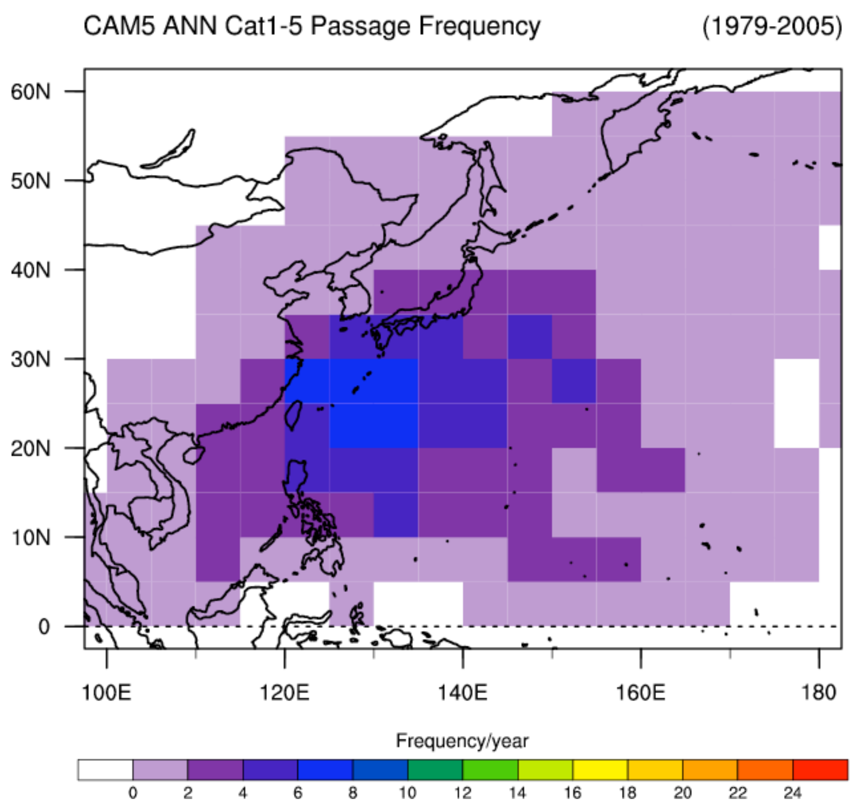
- Local relative vorticity maximum at 850hPa > $2.0 \times 10^{-4}\ s^{-1}$.
- The maximum wind speed at 850 hPa exceeds 17 m/s.
- There is an evident warm core aloft. Namely, the sum of the temperature deviations at 300, 500, and 700 hPa exceeds 2K. The temperature deviation for each level is computed by subtracting the maximum temperature from the mean temperature over the 10° x 10° grid box centered nearest to the location of maximum vorticity at 850hPa.
- The maximum wind speed at 850 hPa is greater than the maximum wind speed at 300 hPa.
- The duration of each detected storm must exceed 36 hours. When a single TC satisfies all the criteria intermittently, it is considered as multiple TC generation events. To prevent multiple counts of a single TC, a single time-step failure is allowed.

NW Pacific Typhoon (Cat1-5) Track Density

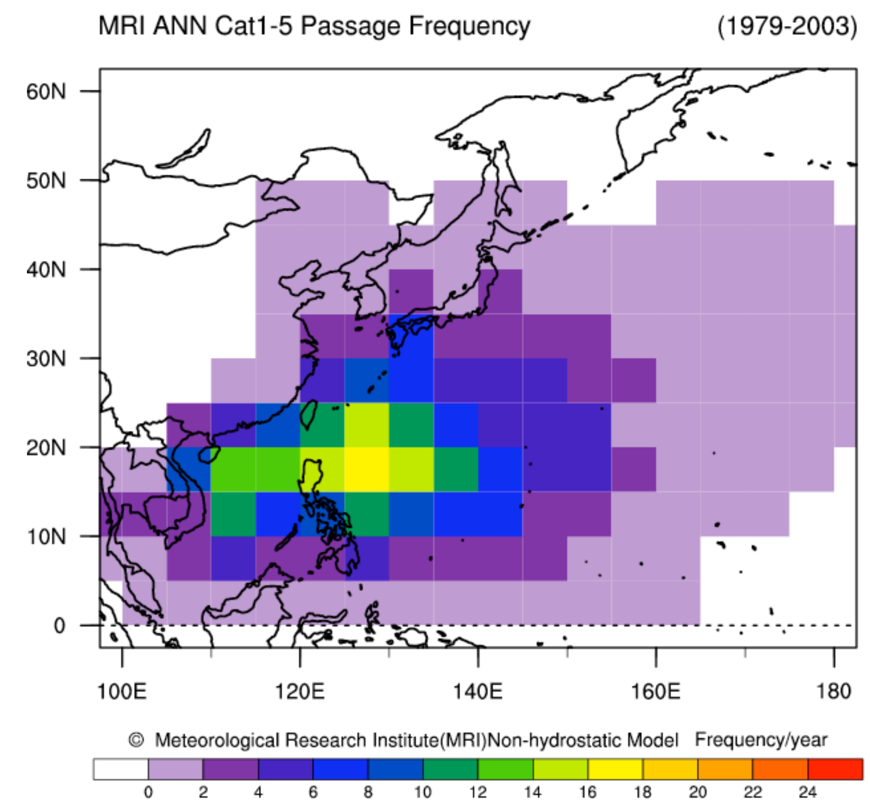
IBTrACS



CAM5

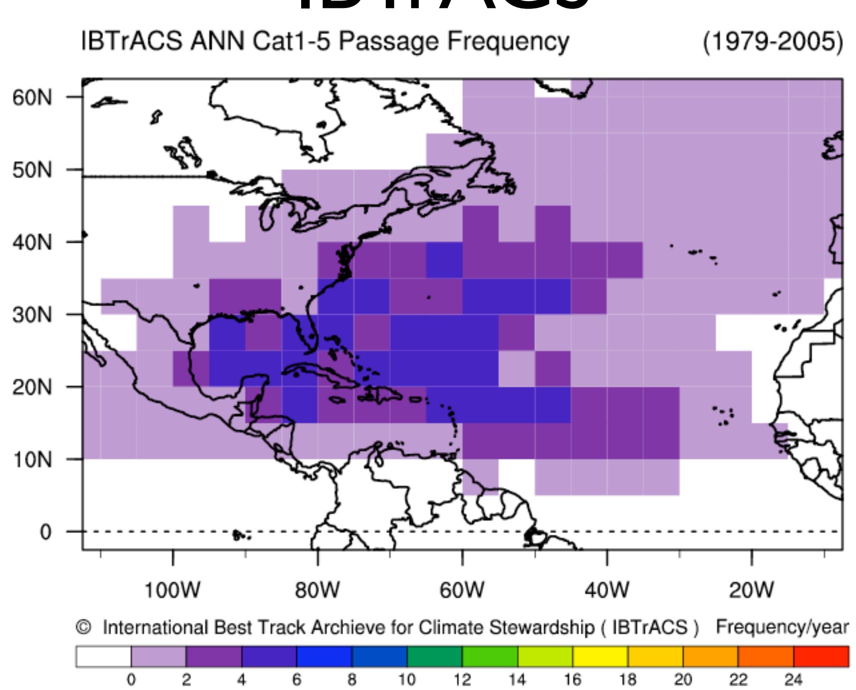


MRI



N Atlantic Typhoon (Cat1-5) Track Density

IBTrACS



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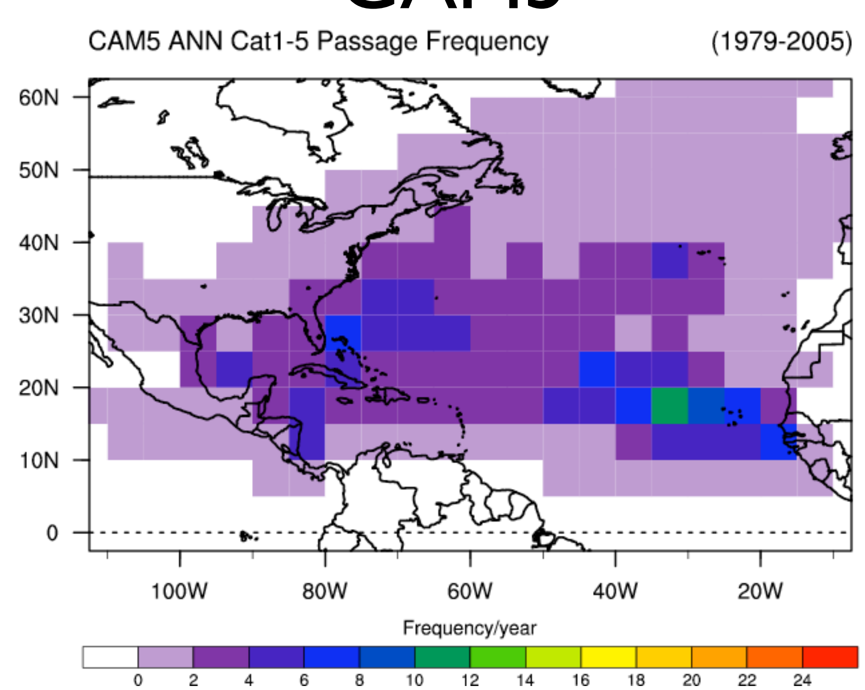
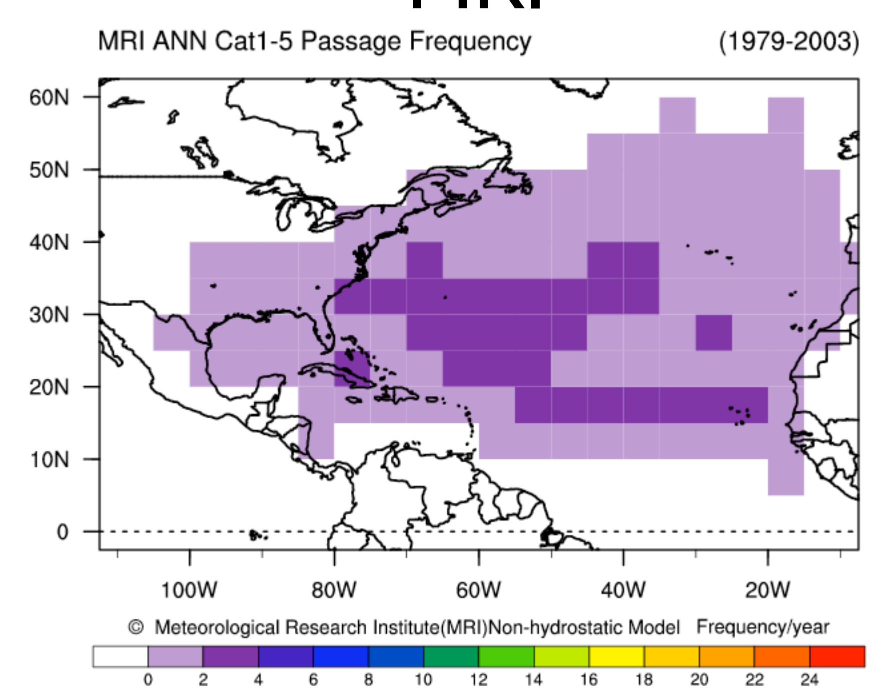
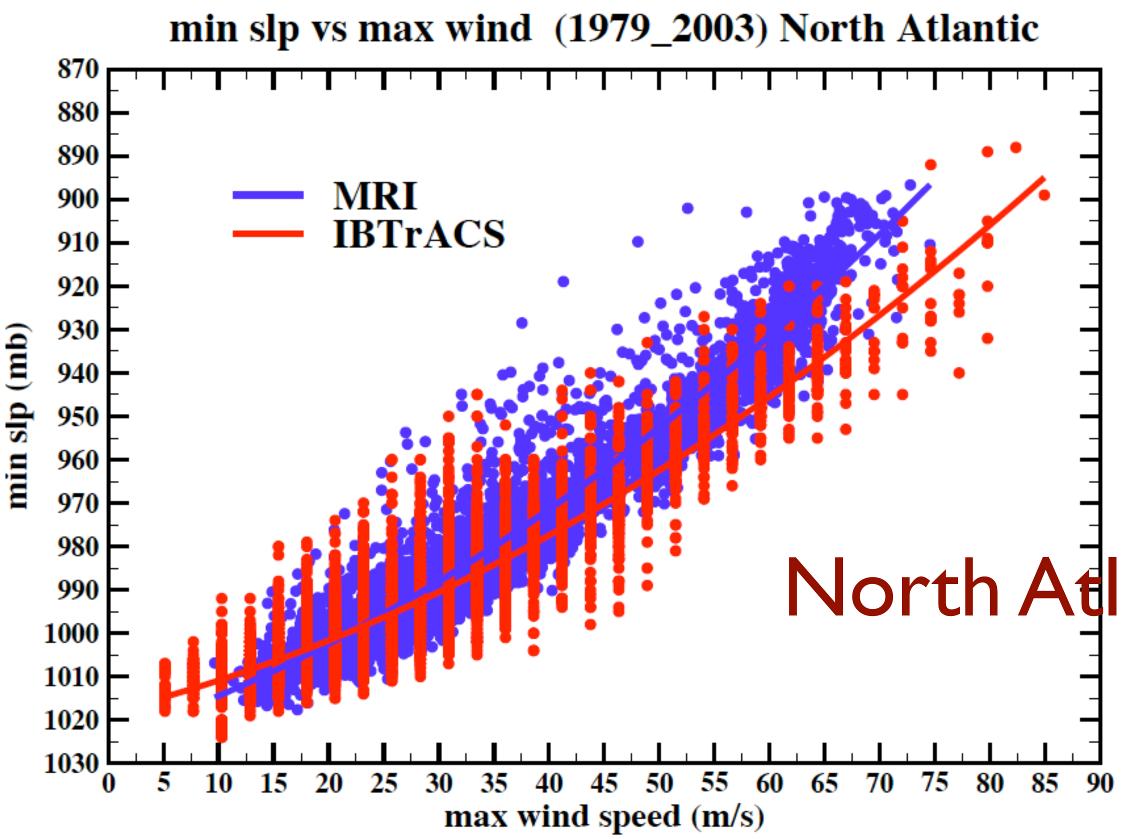
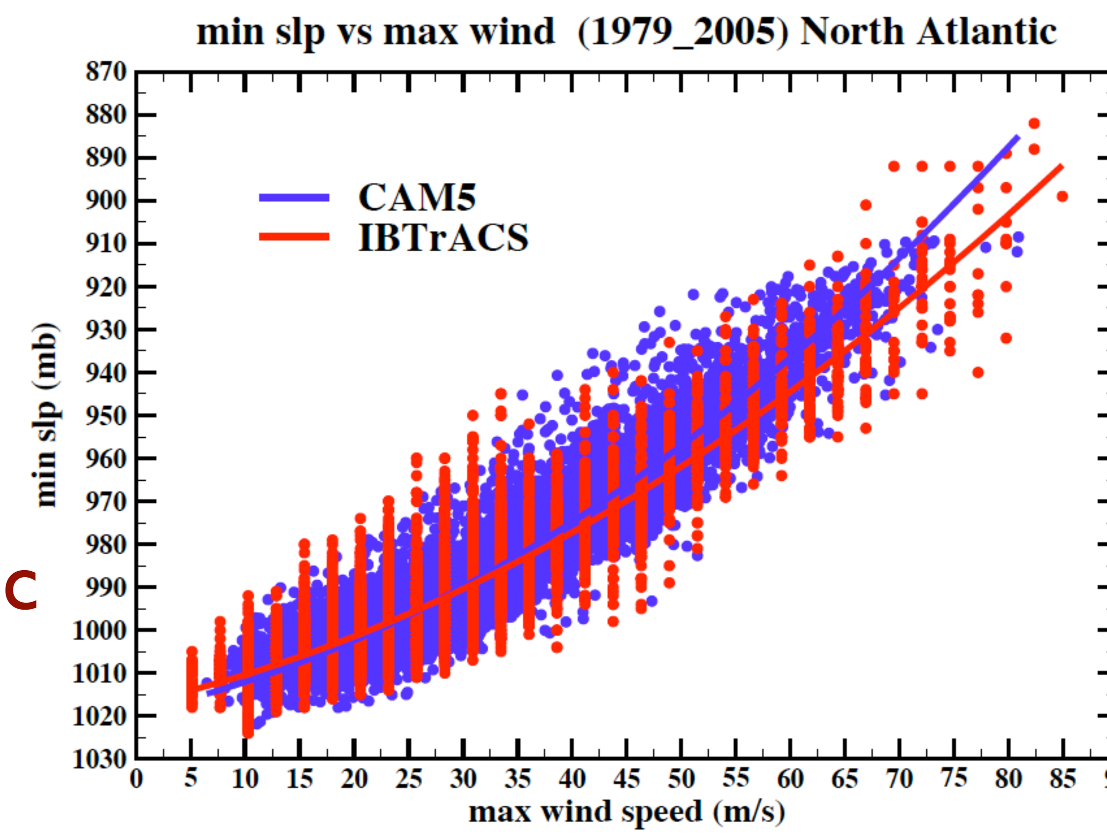


MRI

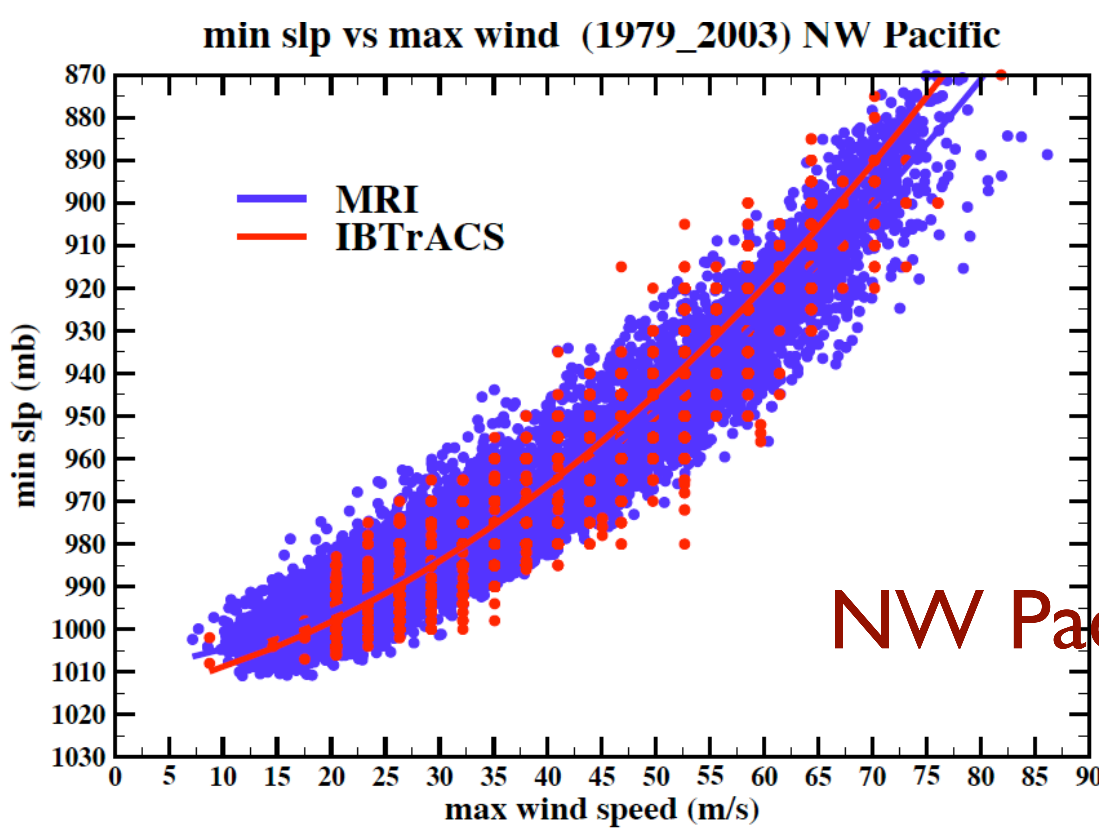


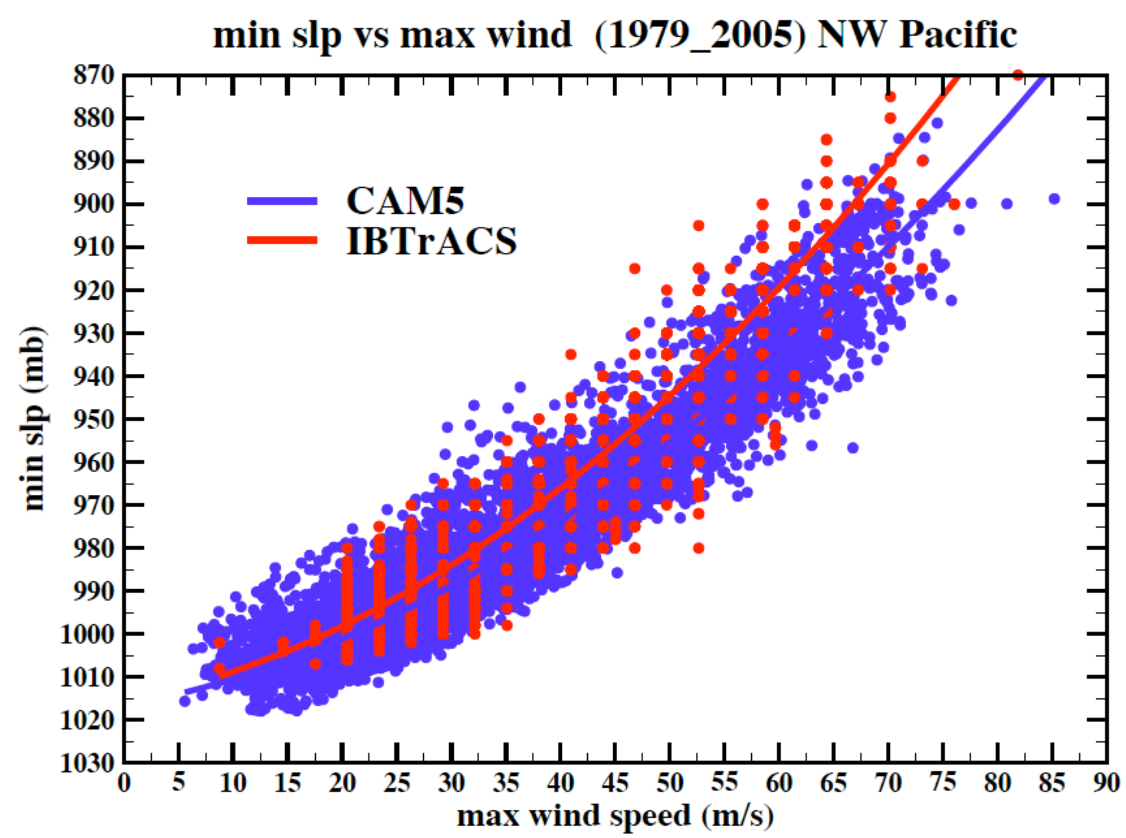
Minimum Sea Level Pressure vs. Maximum wind speed





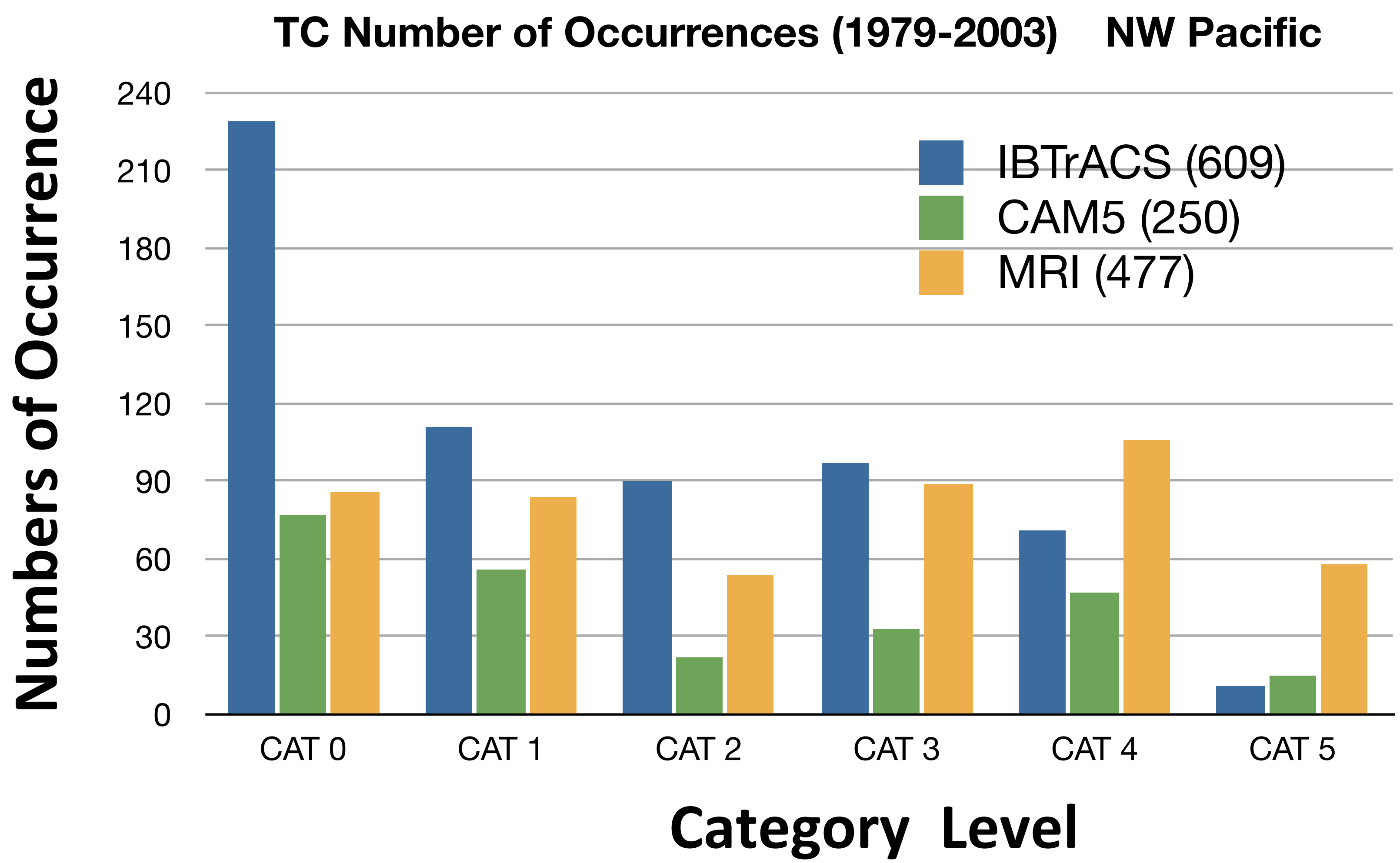
North Atlantic



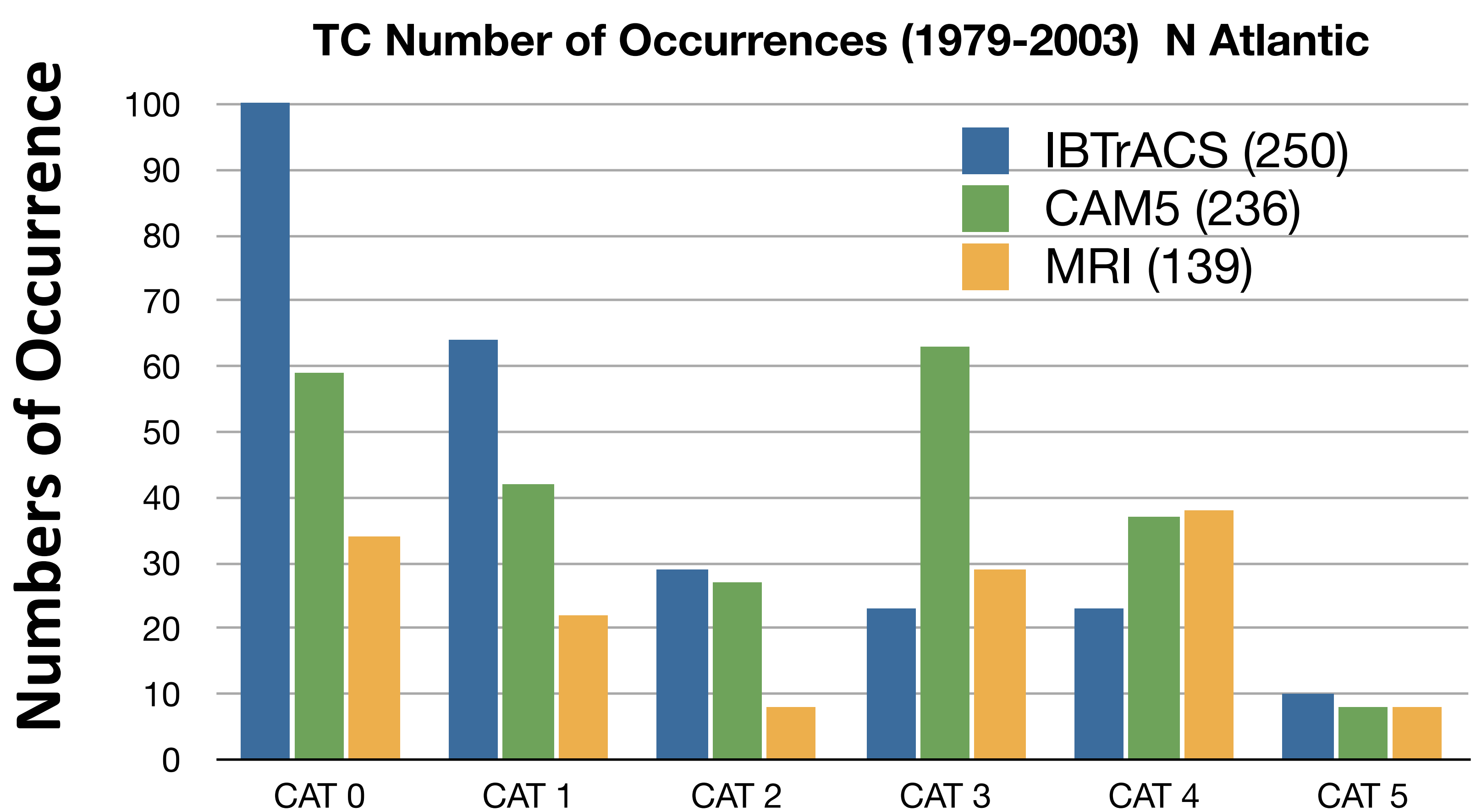


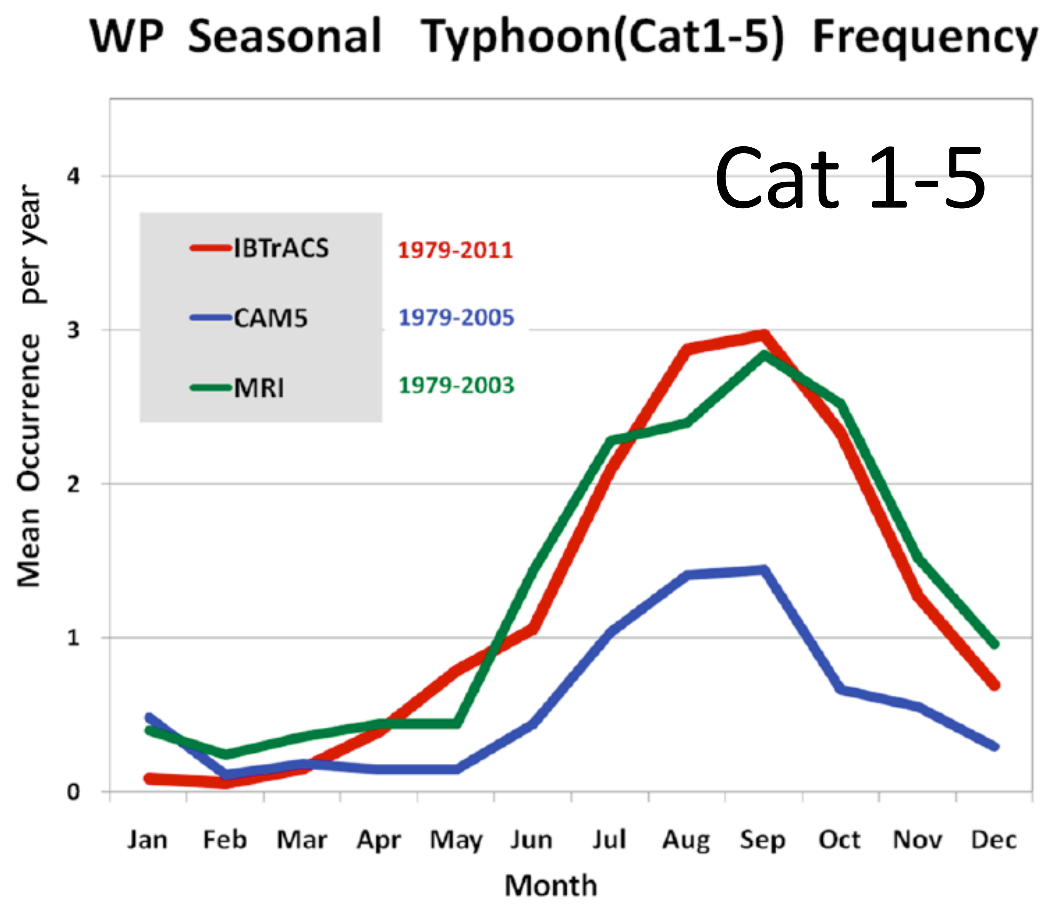
NW Pacific

NW Pacific
(1979-2003)

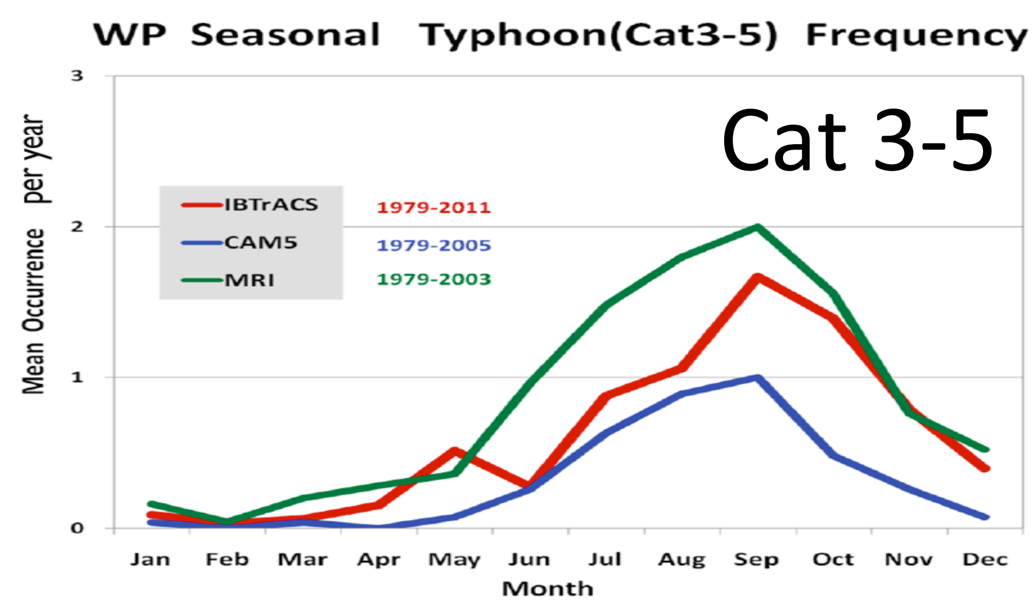


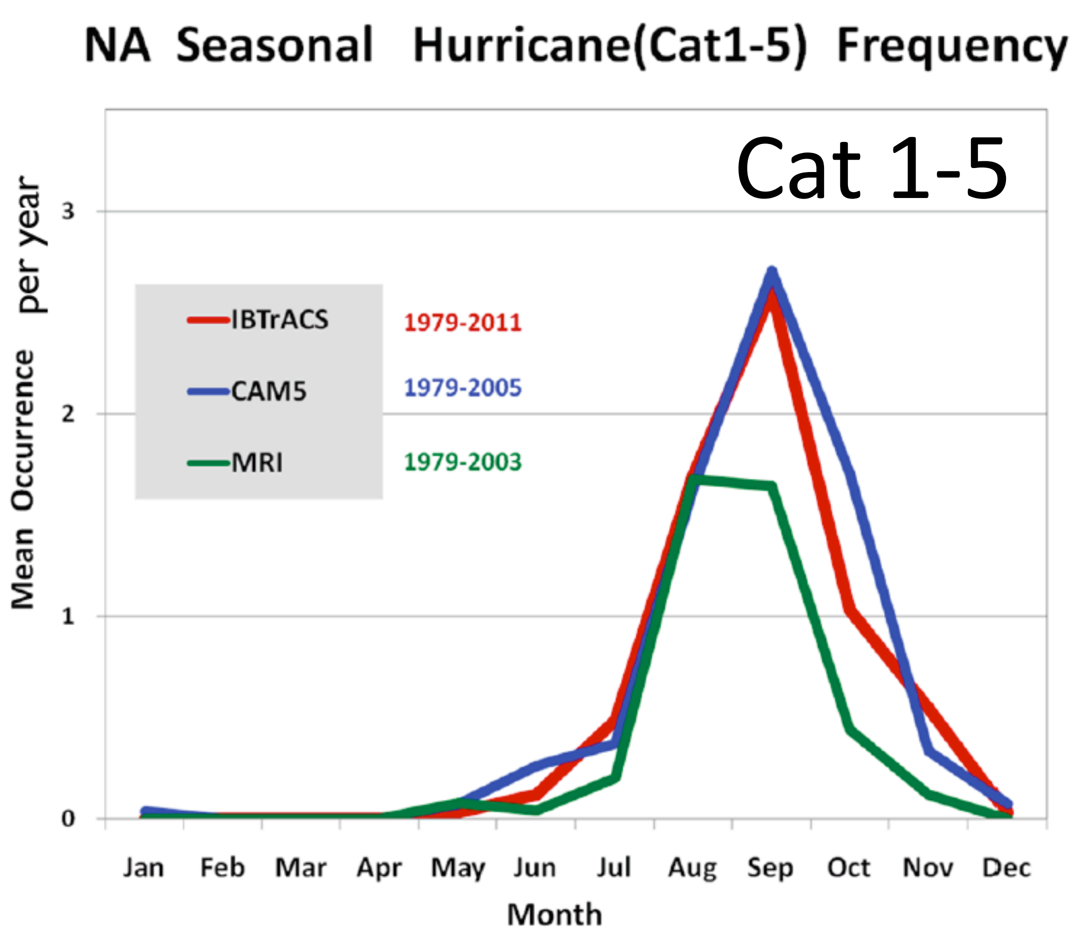
N Atlantic
(1979-2003)



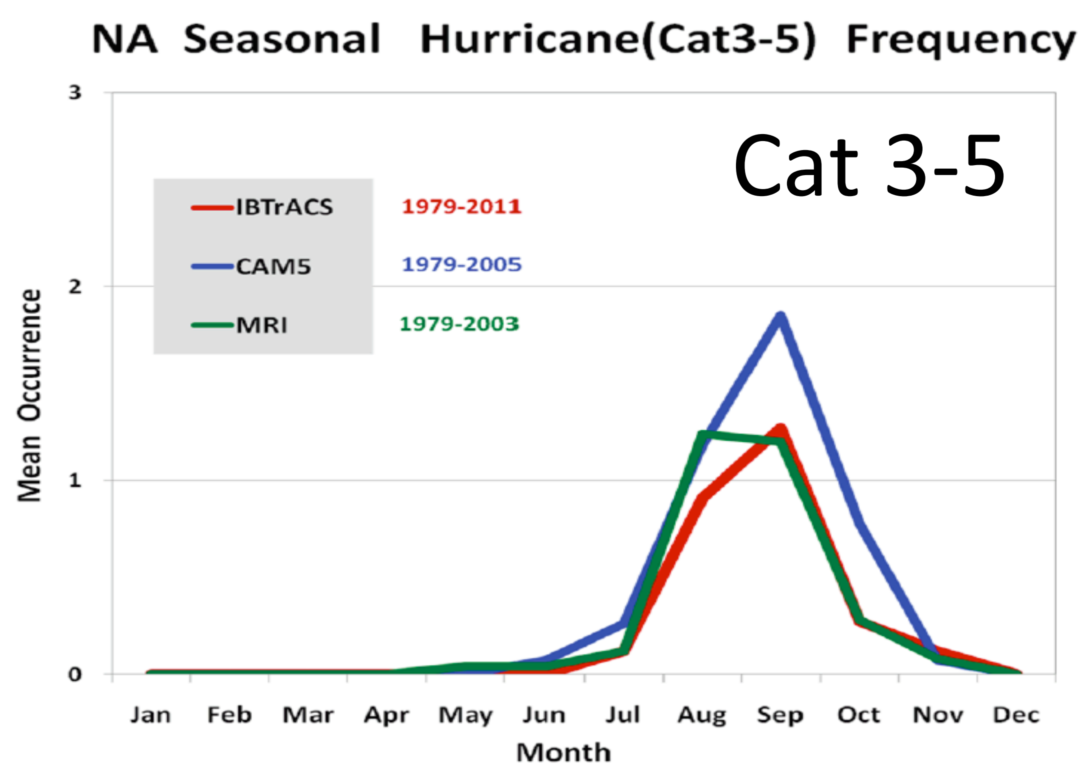


NW Pacific





N Atlantic



Climatological Areas of Typical Hurricane Tracks by Month

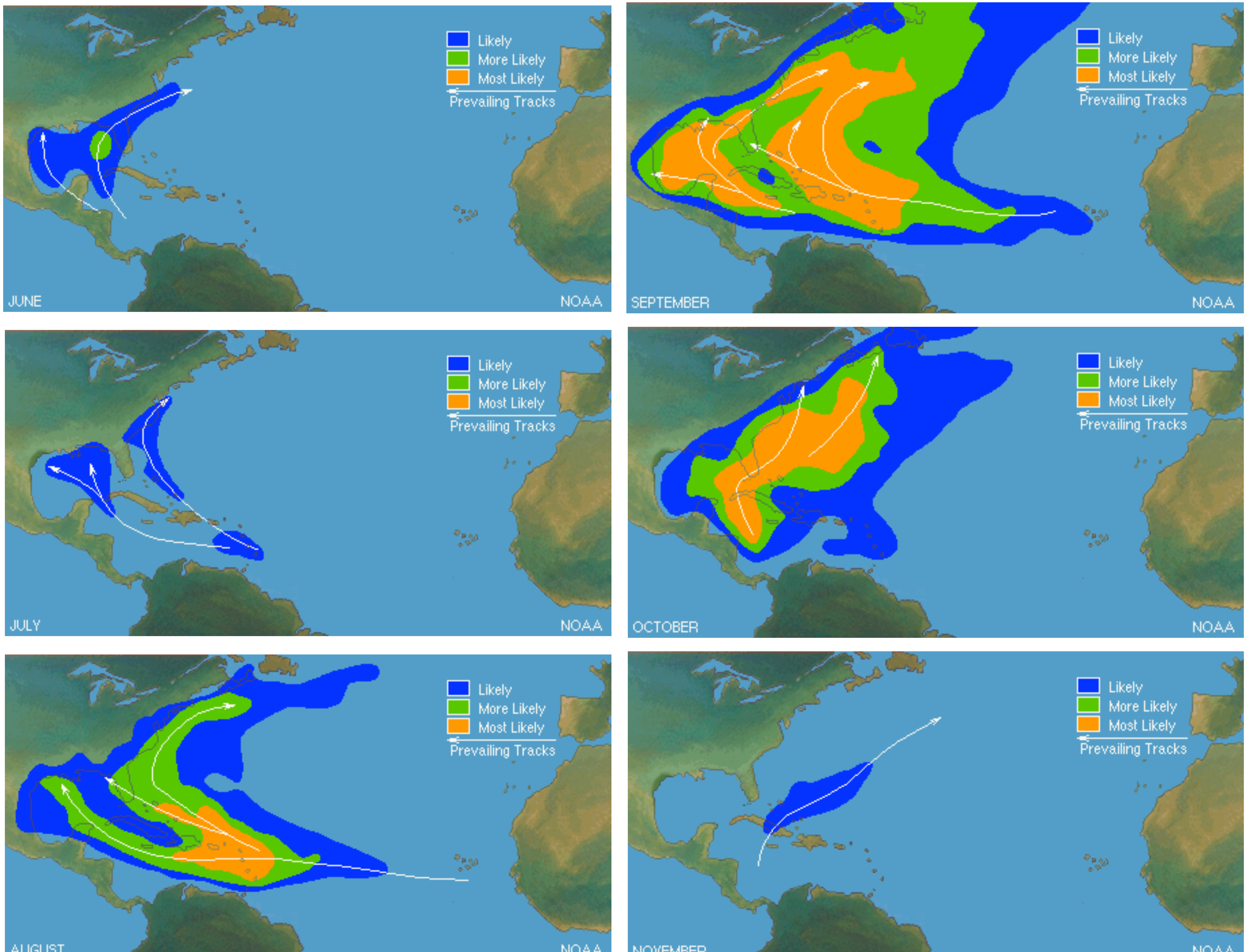
Atlantic

(from National Hurricane Center)

June | Sep.

July | Oct.

Aug. | Nov.

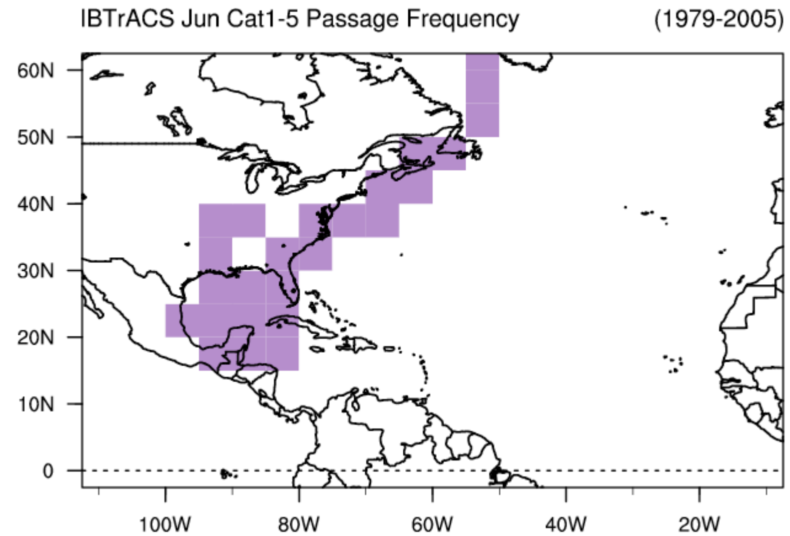


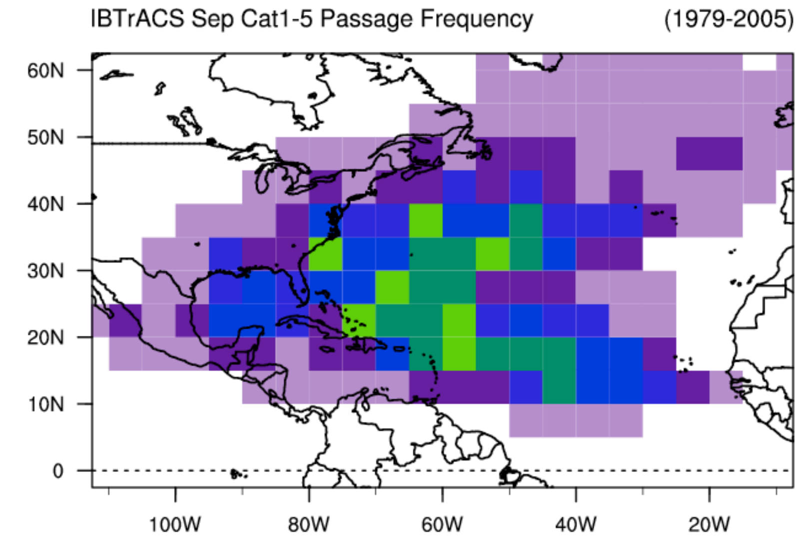
Climatological Hurricane (Cat1-5) Track density by Month

IBTrACS

Atlantic

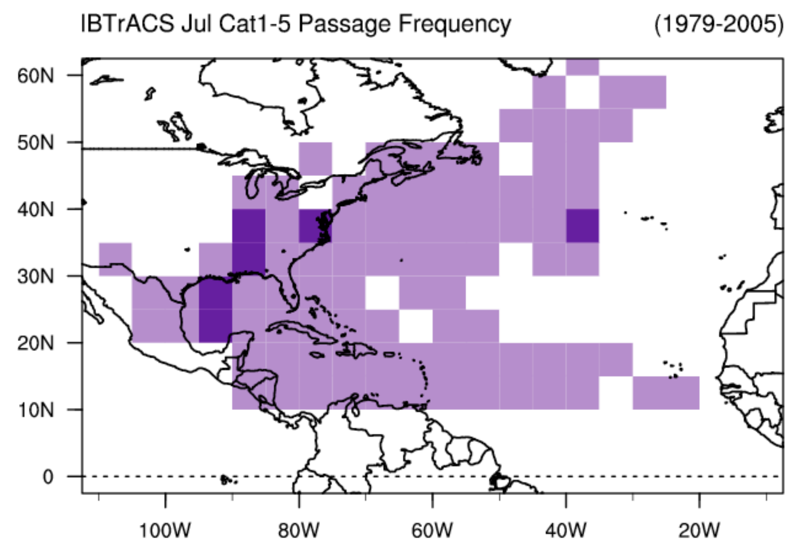
June

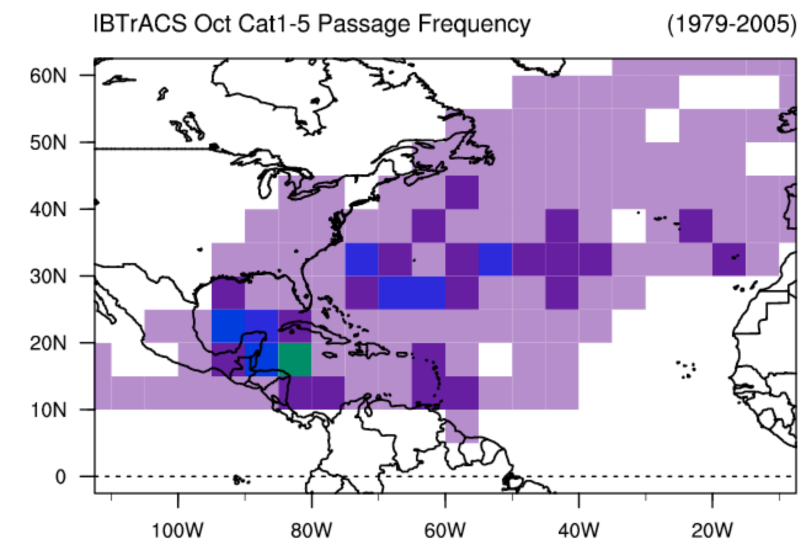




Sep.

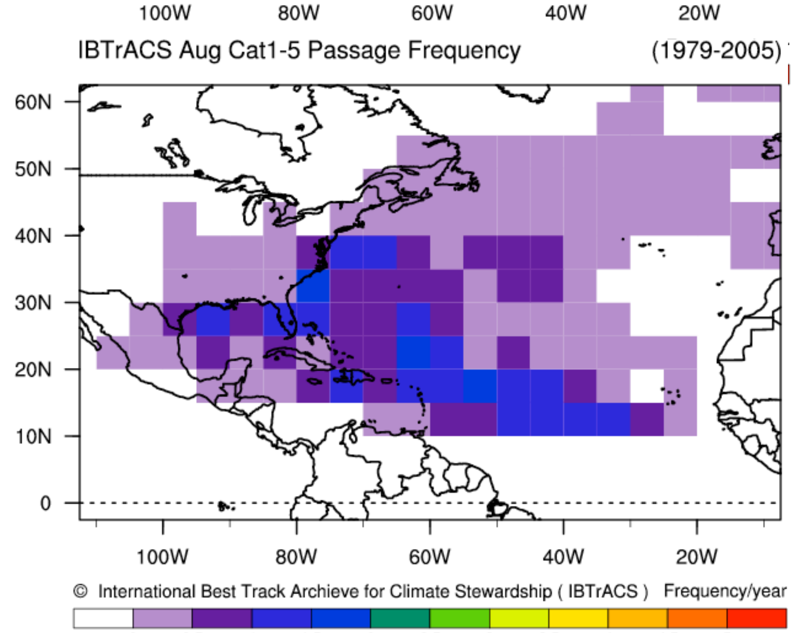
July

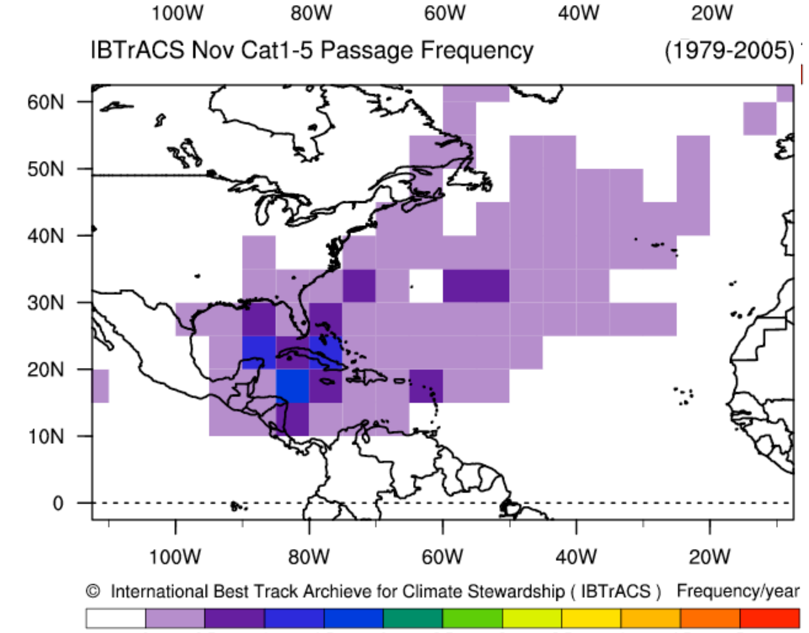




Oct.

Aug.





Nov.

Climatological Hurricane (Cat1-5) Track density by Month

CAM5

Atlantic

June

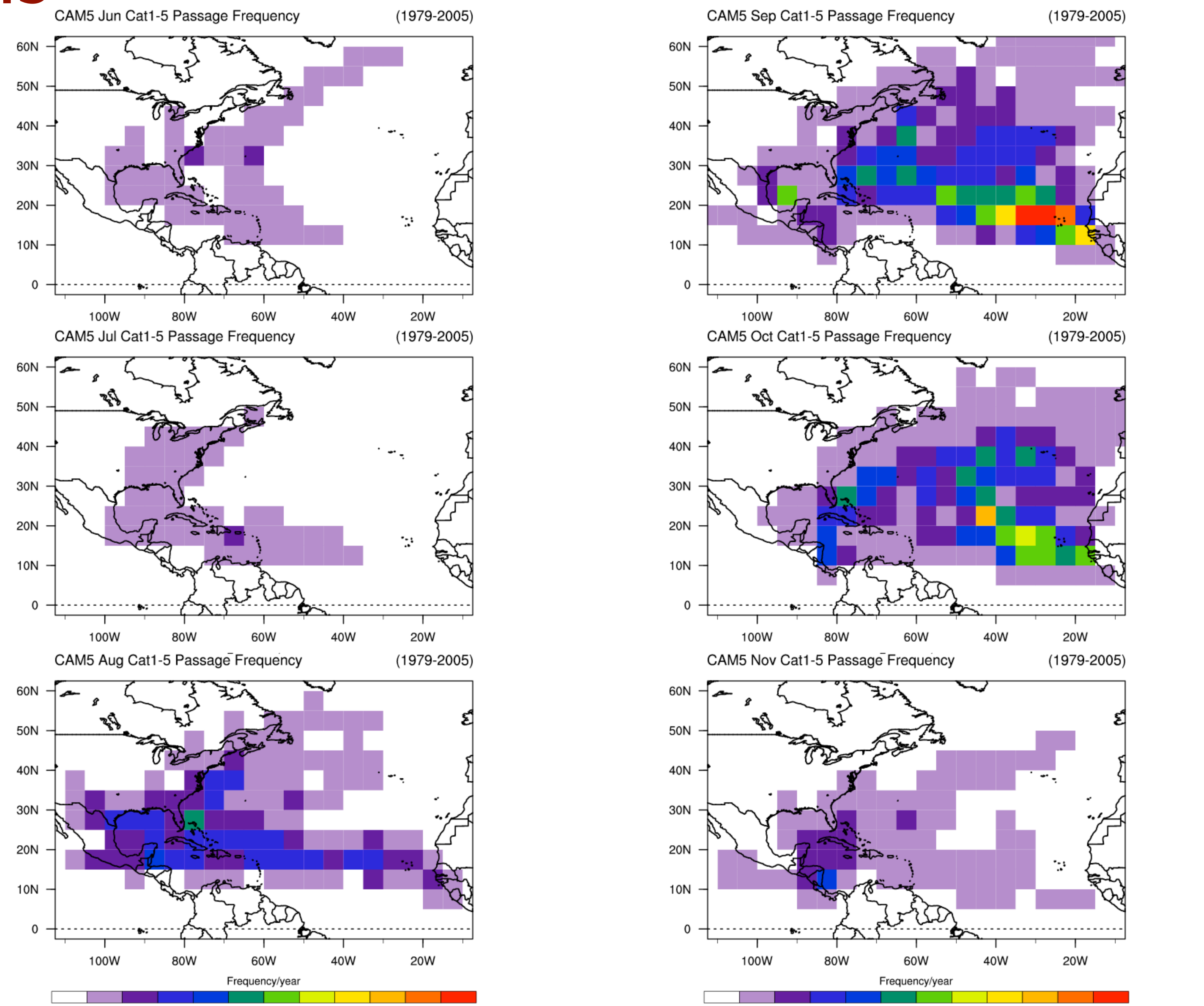
Sep.

July

Oct.

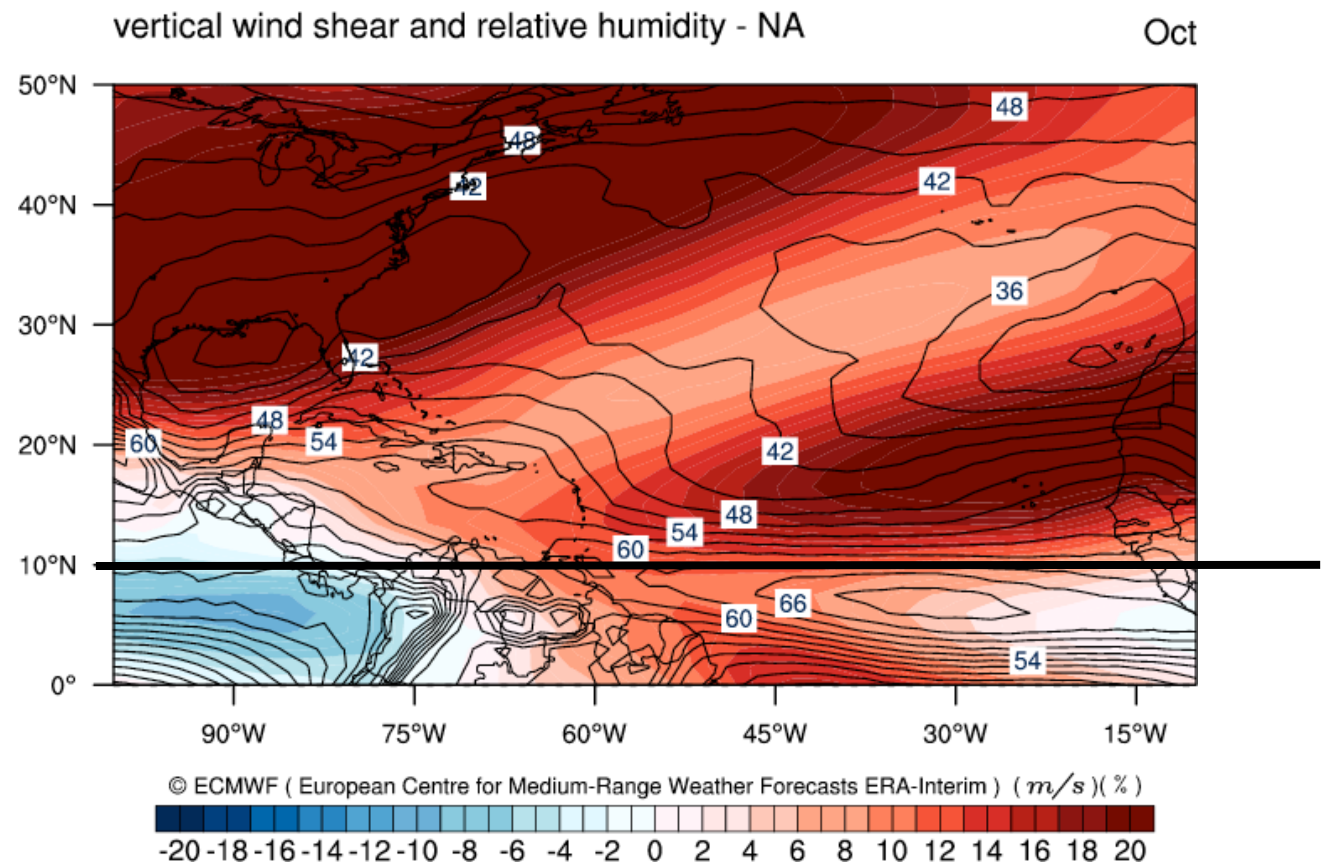
Aug.

Nov.

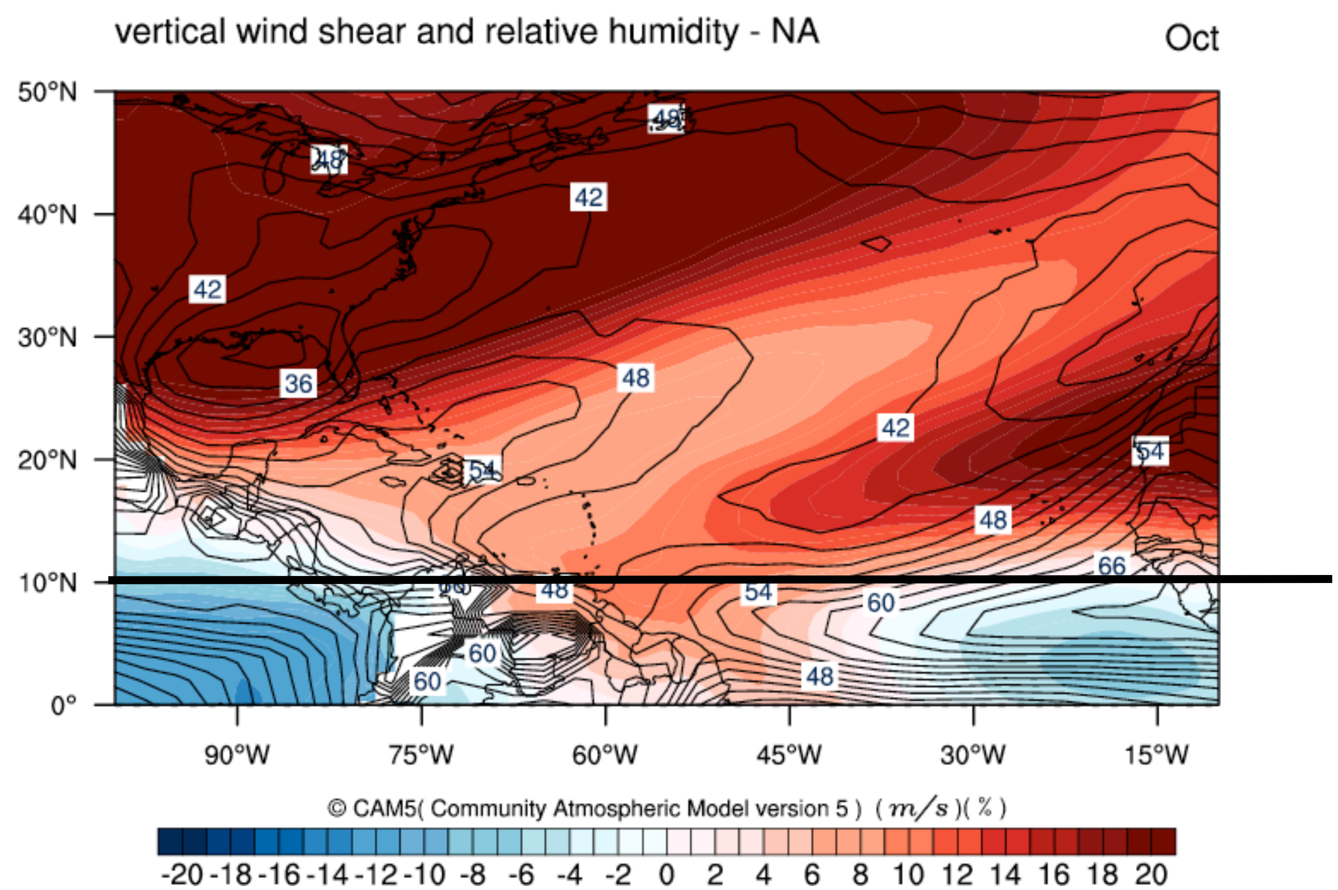


October zonal wind shear (shading) and RH (contour)

ERA interim



CAM5

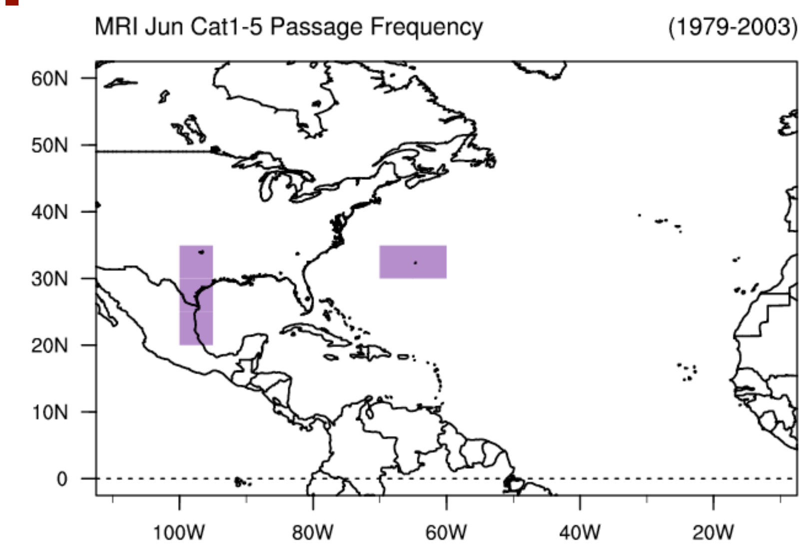


Climatological Hurricane (Cat1-5) Track density by Month

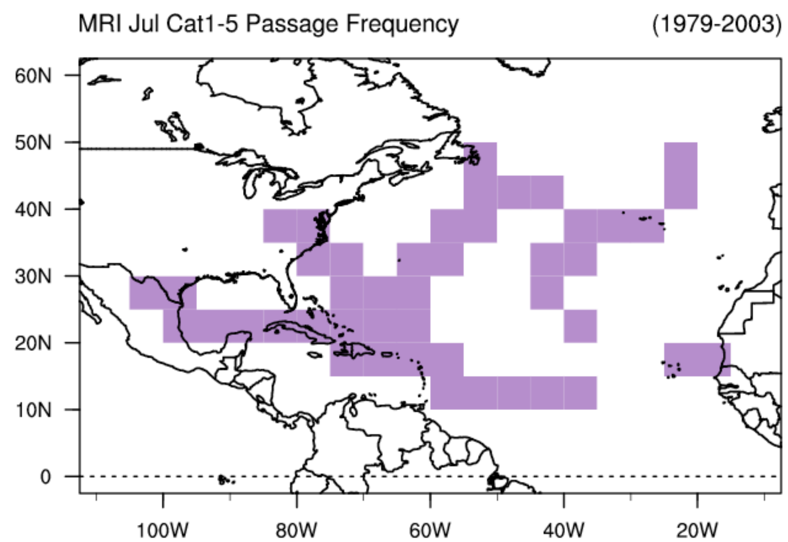
MRI

Atlantic

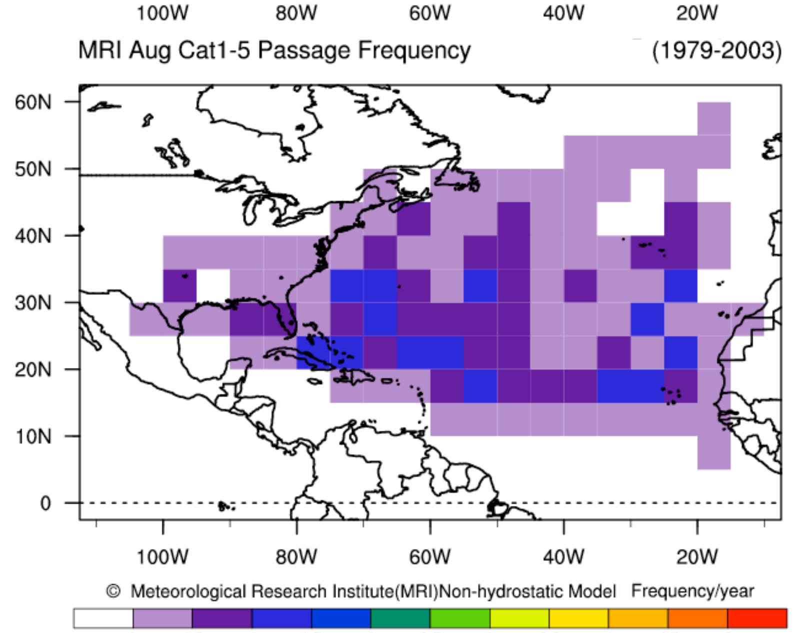
June



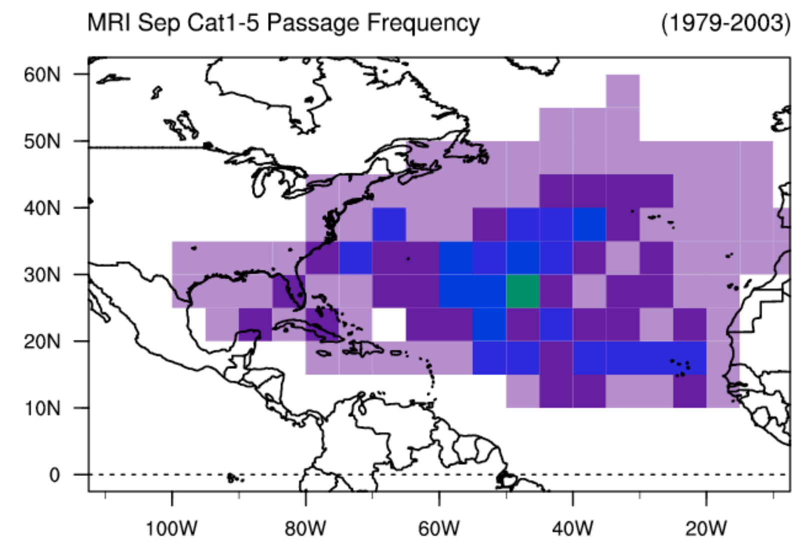
July



Aug.



Sep.



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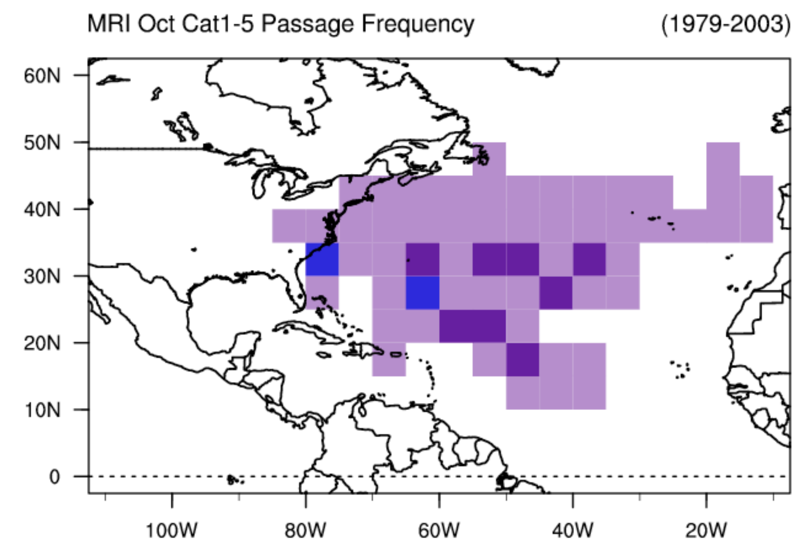
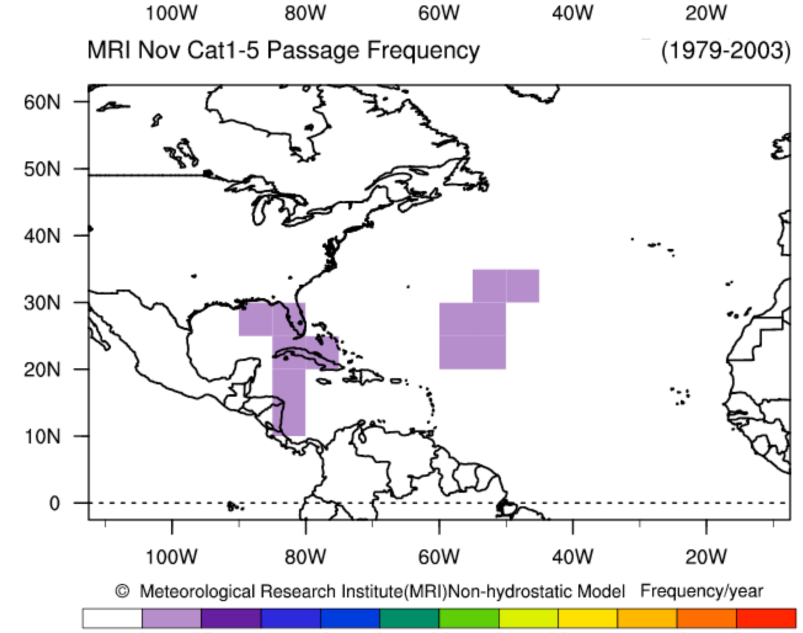


Nov.

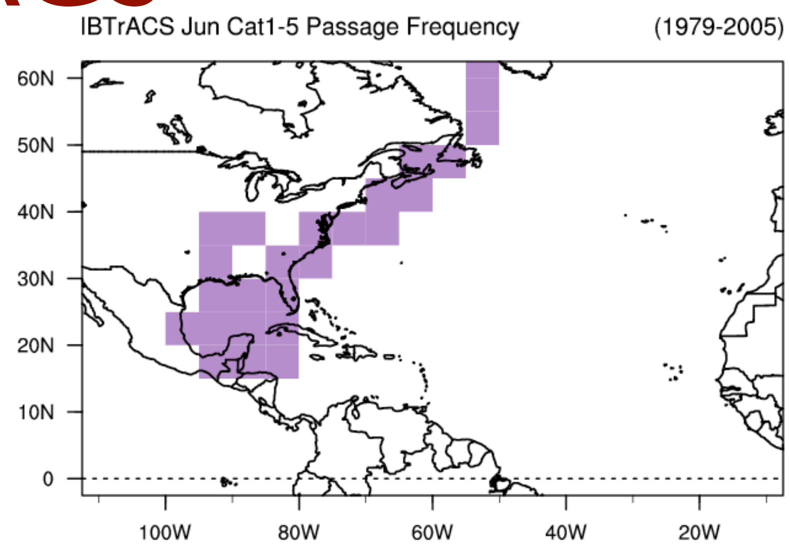


Climatological Hurricane (Cat1-5) Track density by Month

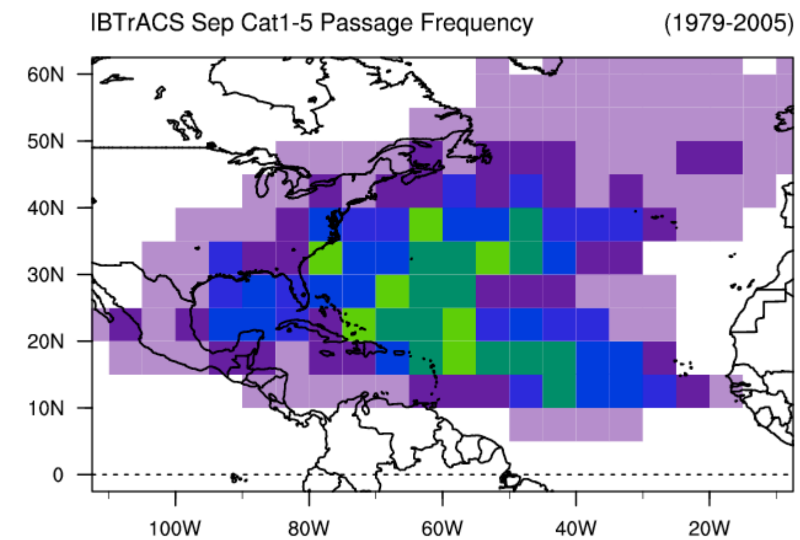
IBTrACS

Atlantic

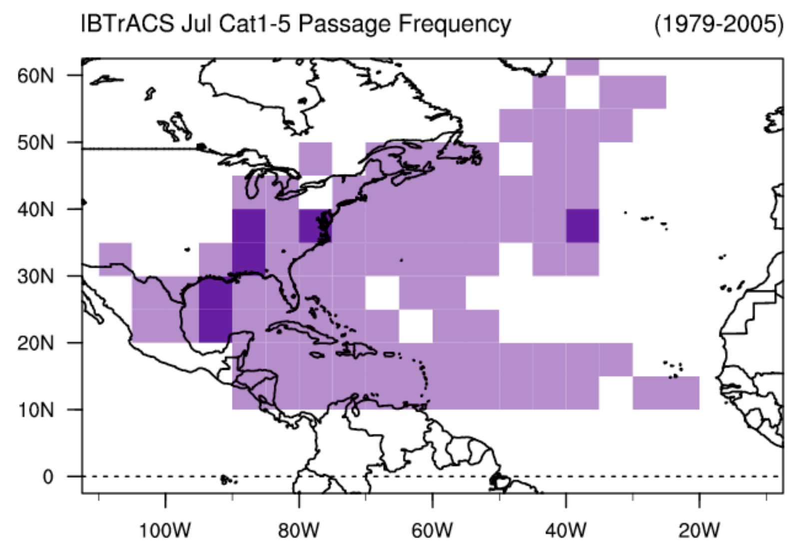
June



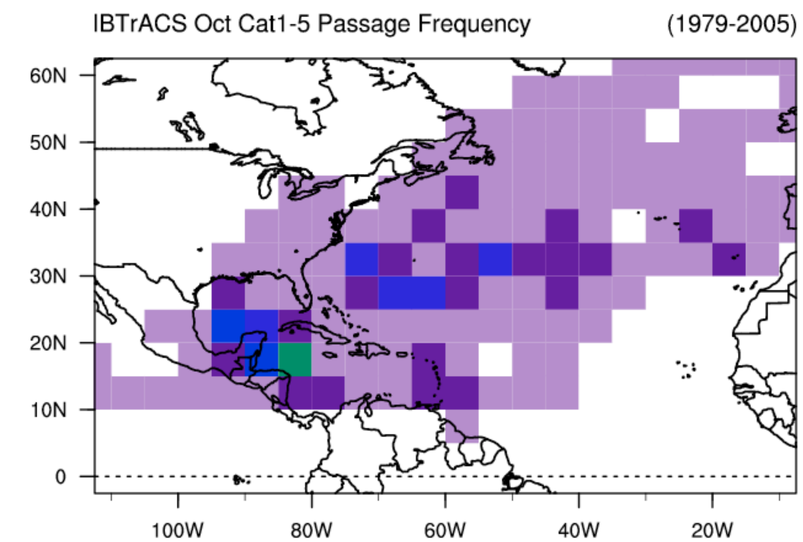
Sep.



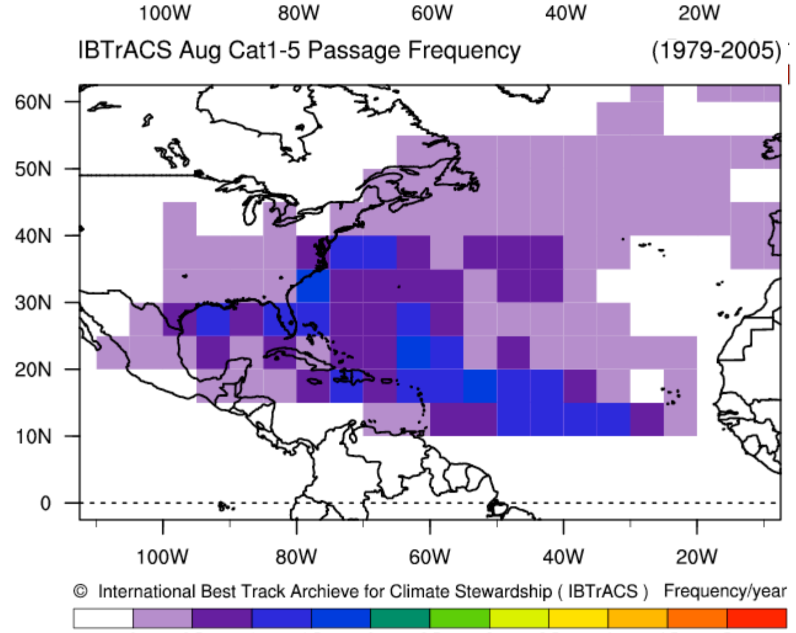
July



Oct.



Aug.



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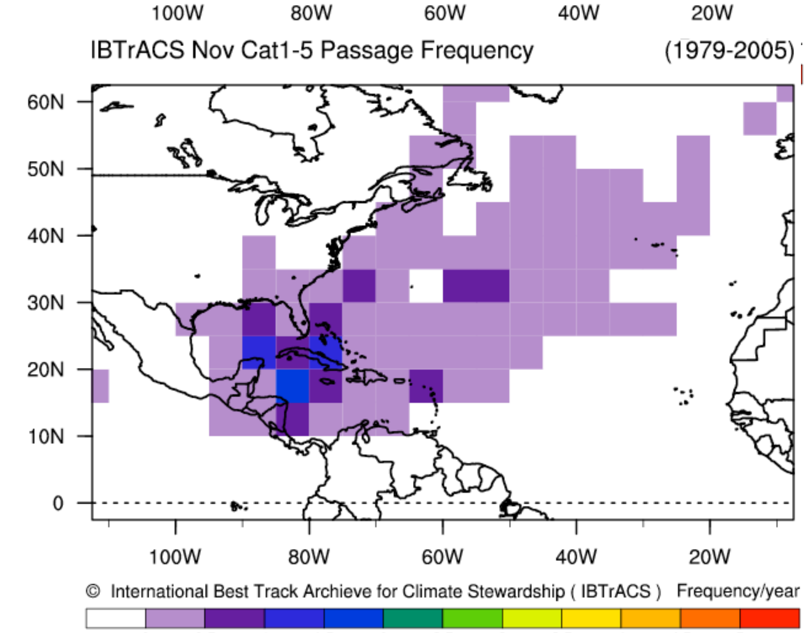
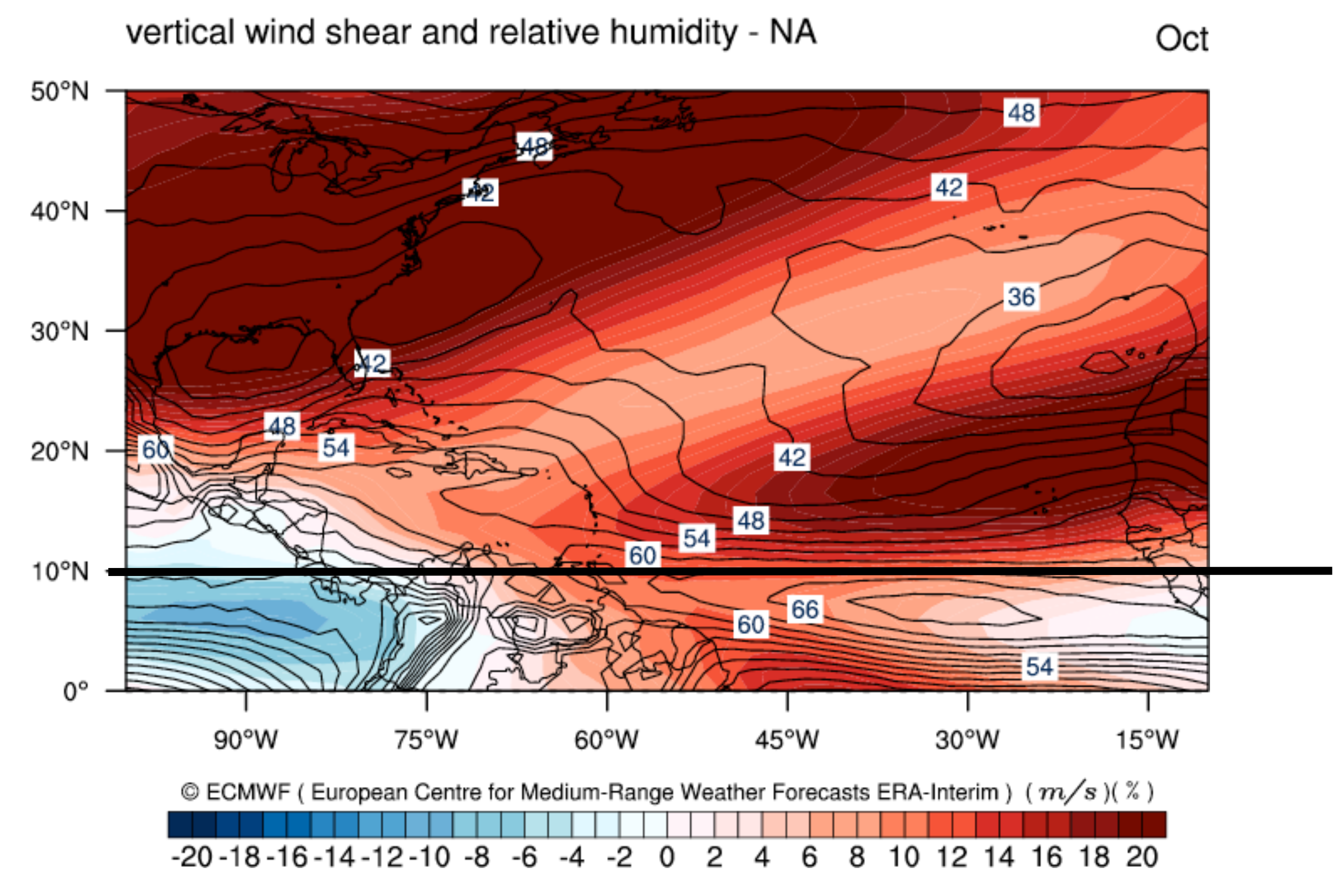
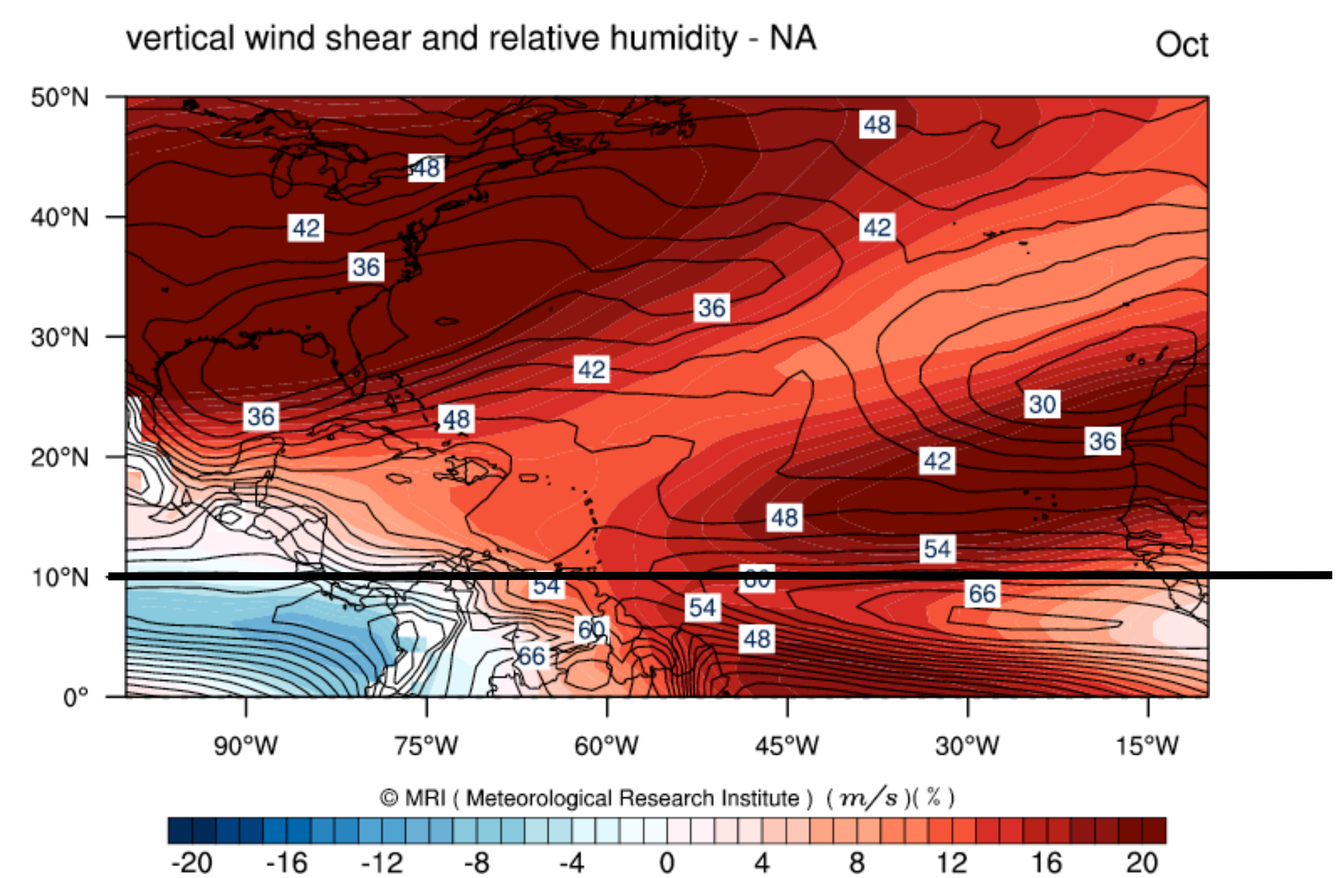


October zonal wind shear (shading) and RH (contour)

ERA interim



MRI



For NW Pacific, monthly mean genesis position are closely associated with the position and movement of the mean monsoon trough from June to November.

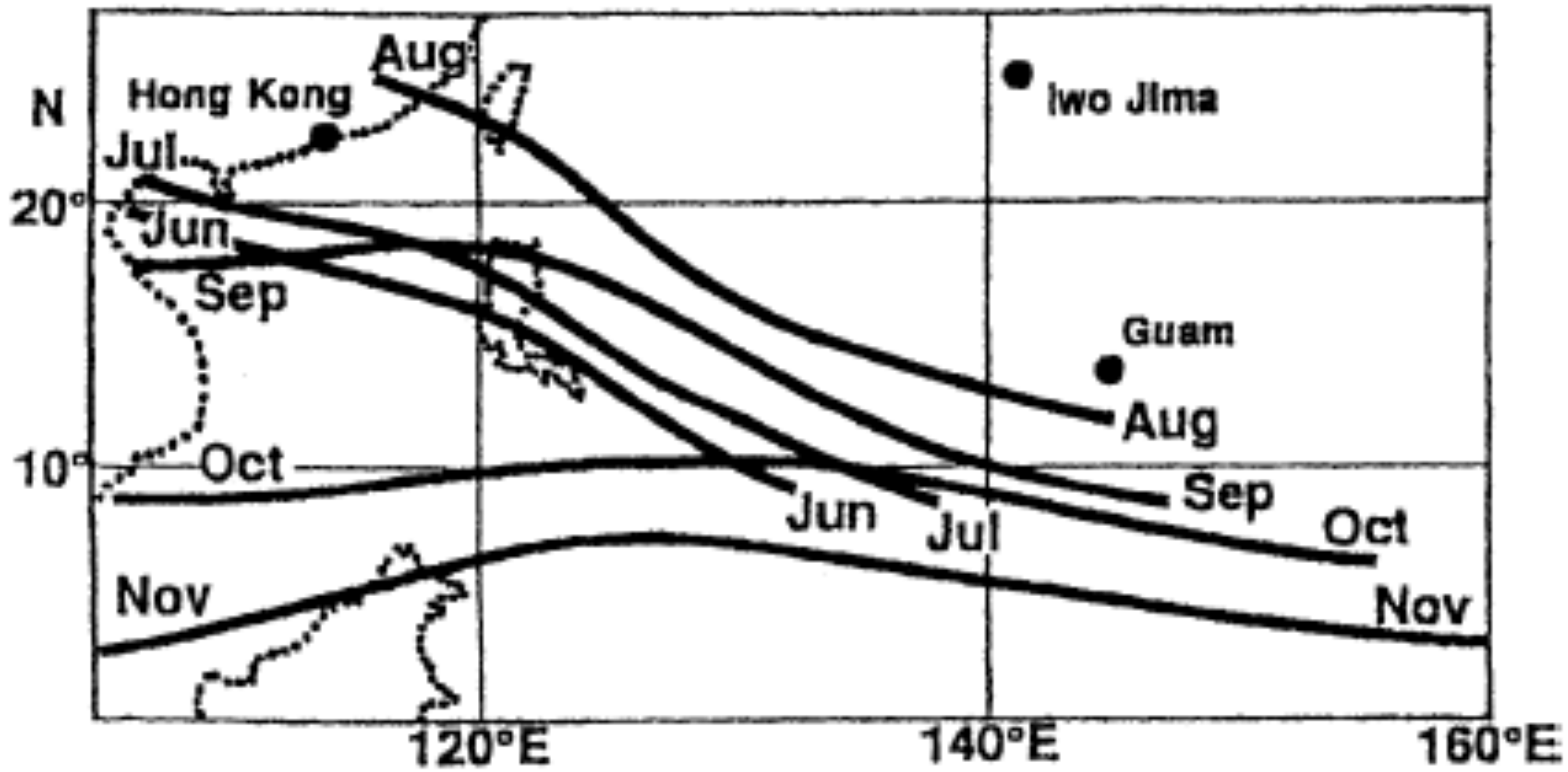


FIG. 3. Typical migration of the axis of the monsoon trough indicated by its mean monthly positions during Jun–Nov (after Atkinson 1971).

Chia and Ropelewski (2002), after Atkinson (1977)

Climatological Typhoon (Cat1-5) Genesis by Month

IBTrACS

NW Pacific

June

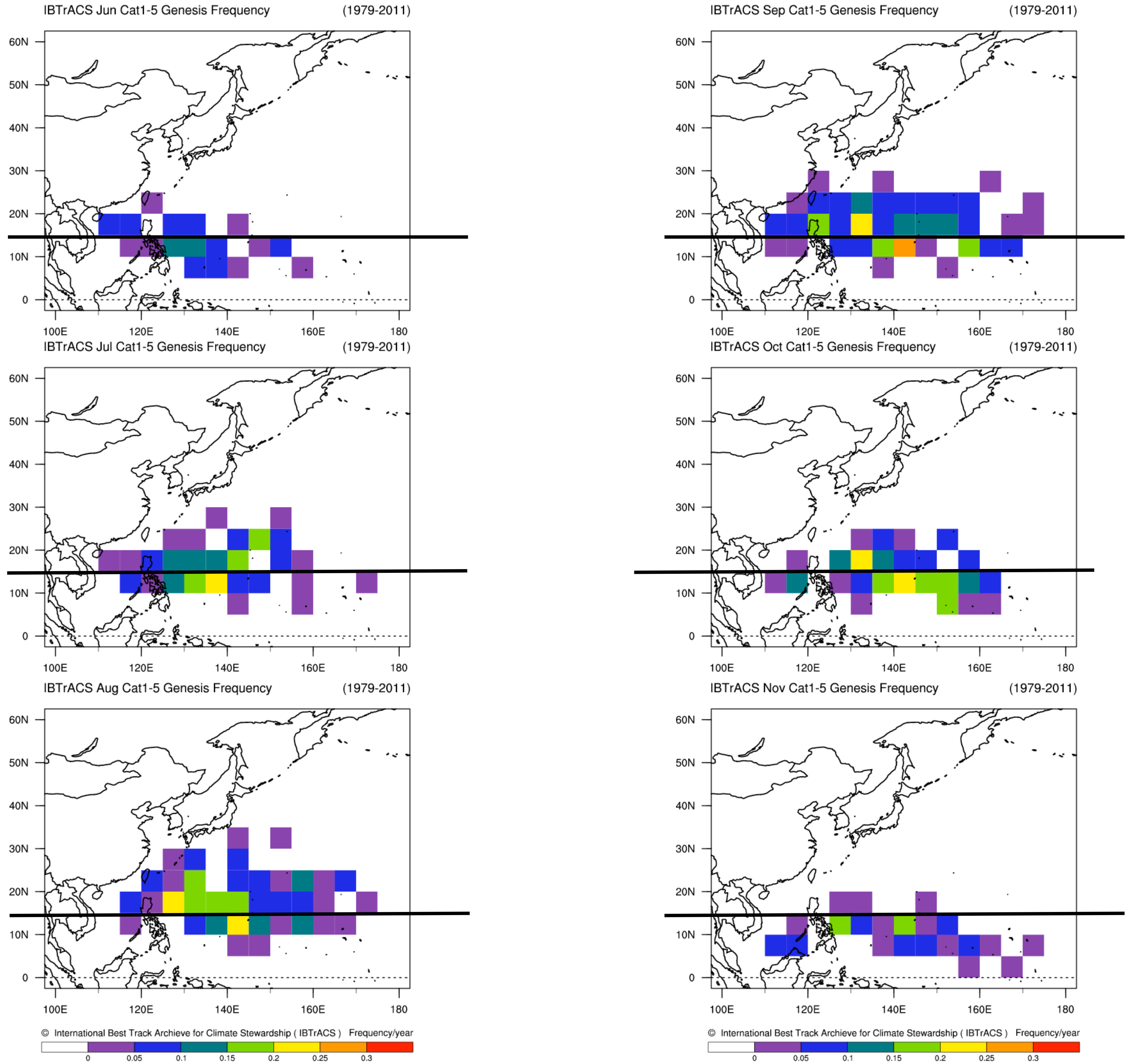
Sep.

July

Oct.

Aug.

Nov.



Climatological Typhoon (Cat1-5) Genesis by Month

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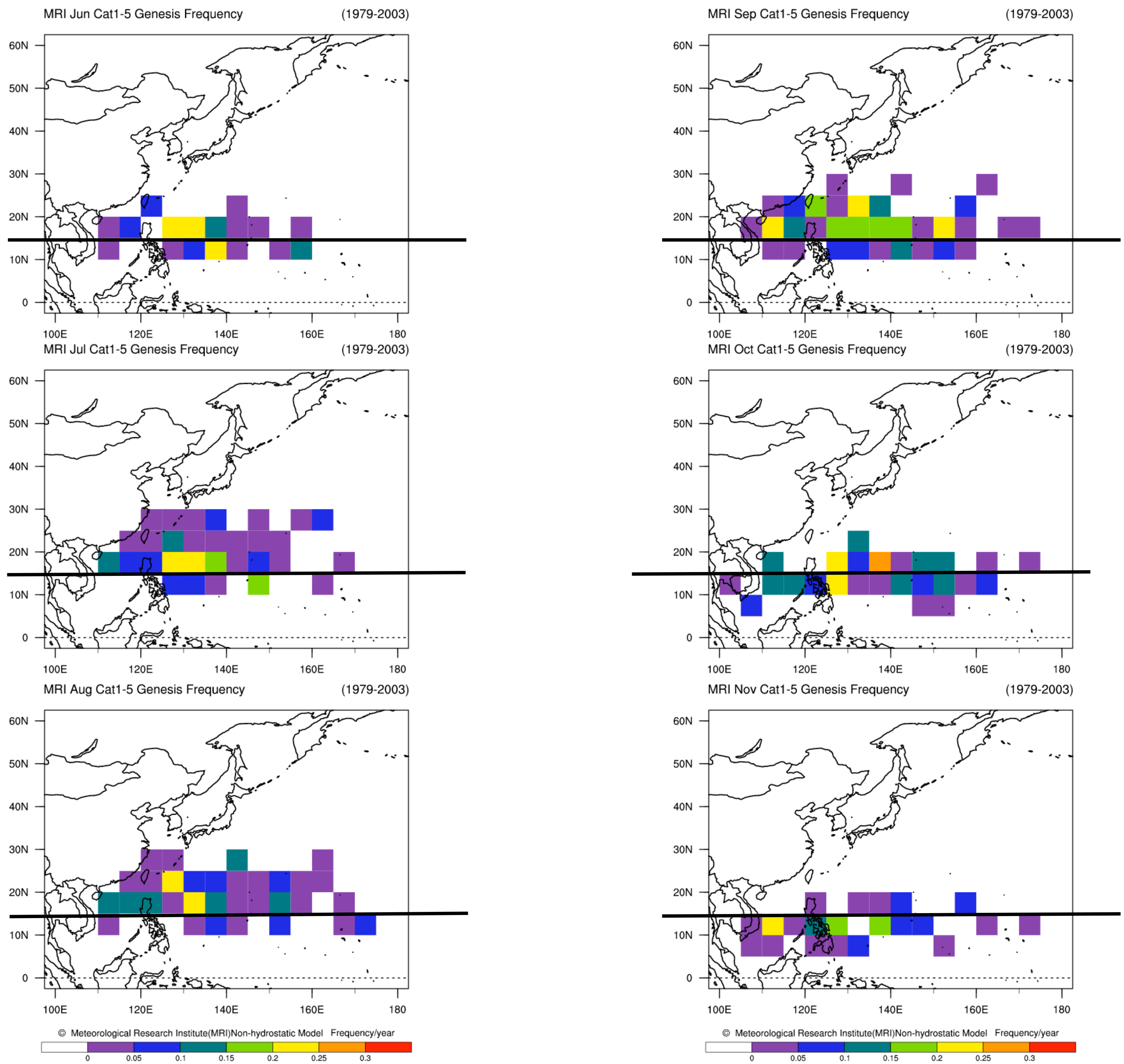

Sep.

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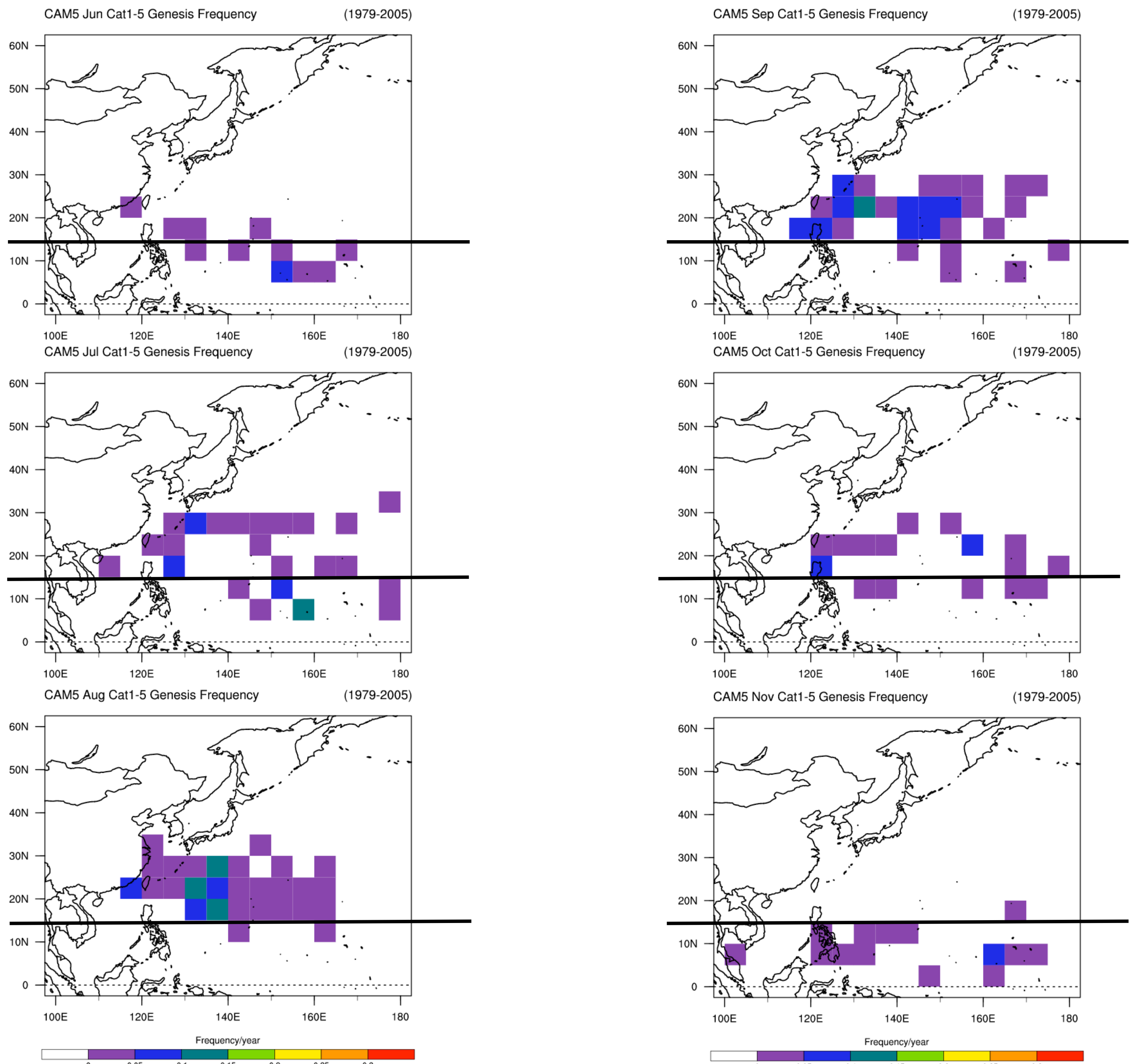

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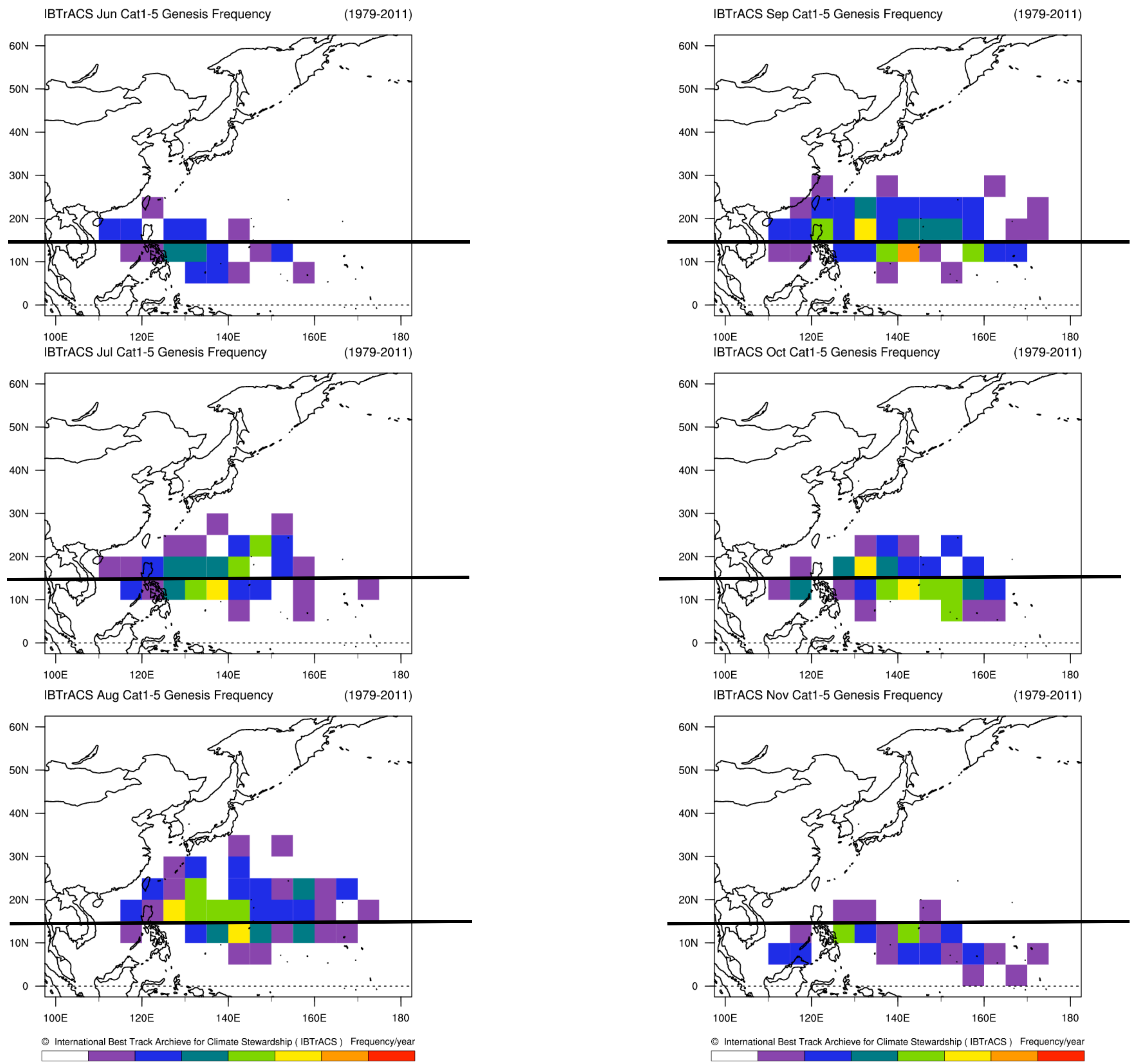

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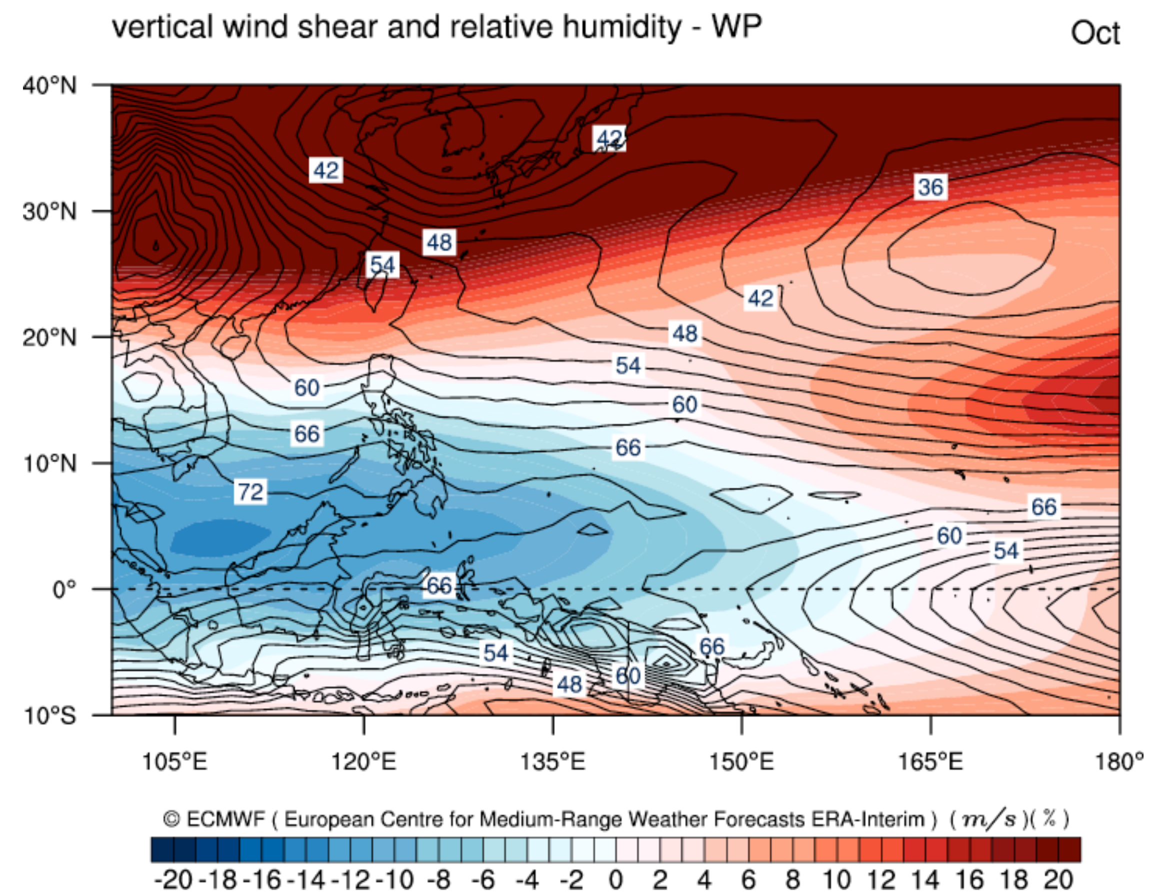
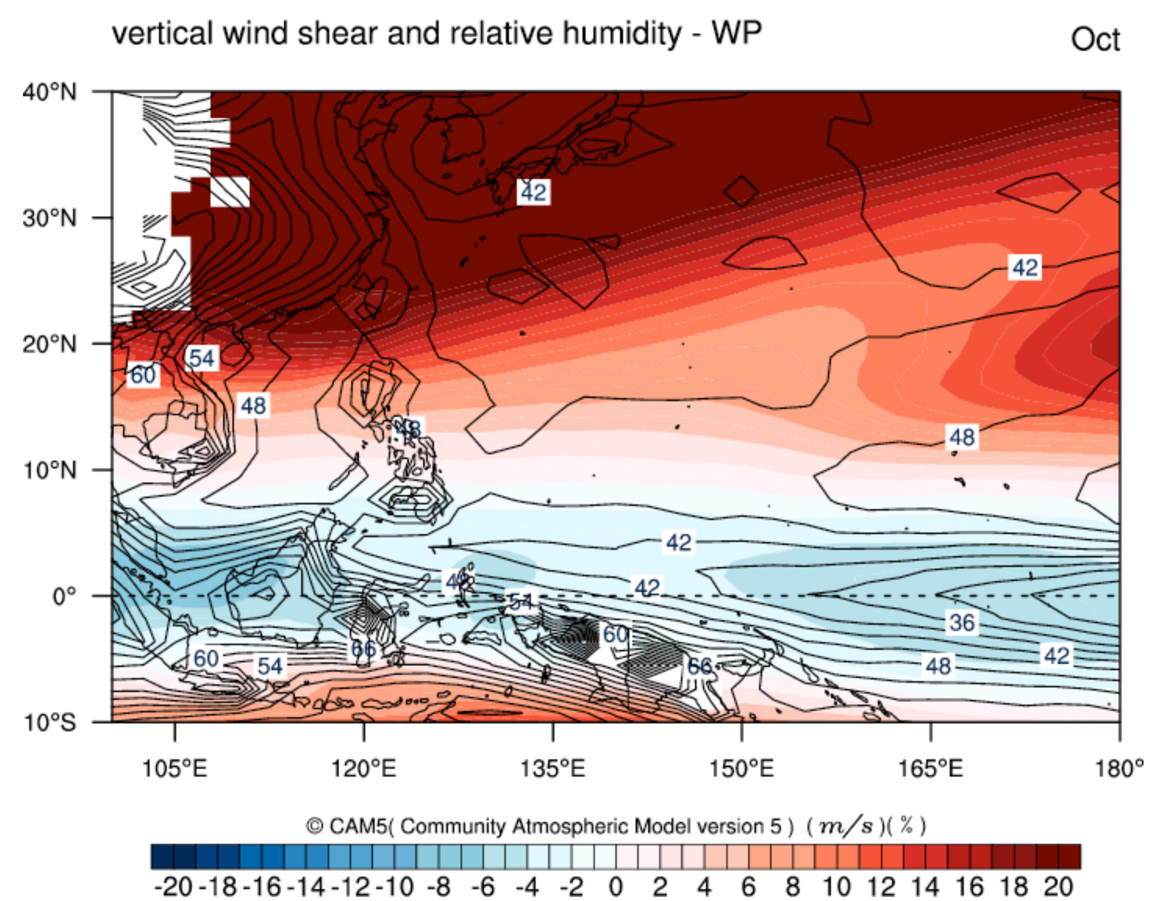
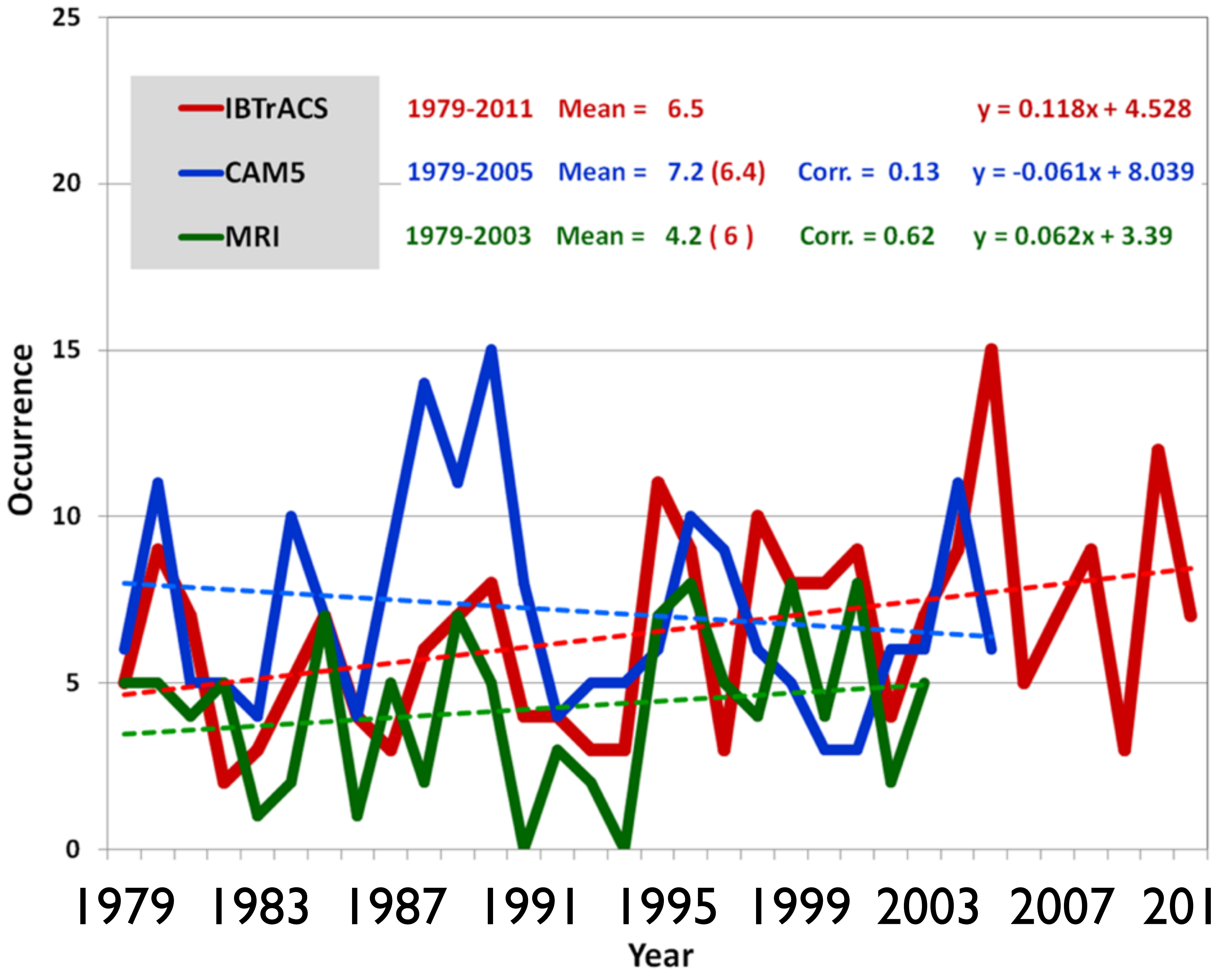


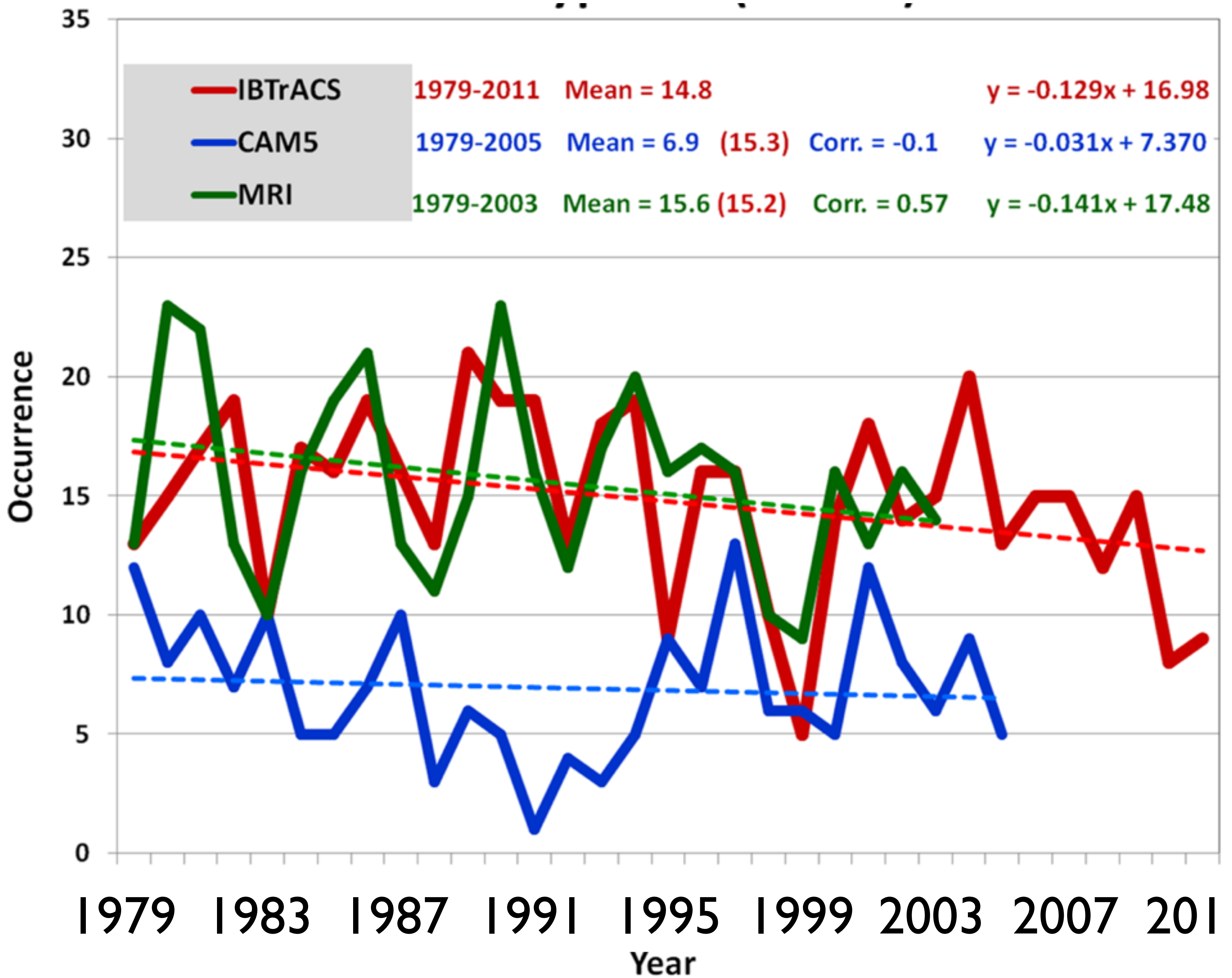
CAM5



Interannual Variability of Hurricane (Cat 1-5)   N Atlantic



Interannual Variability of Typhoon (Cat 1-5)   W Pacific



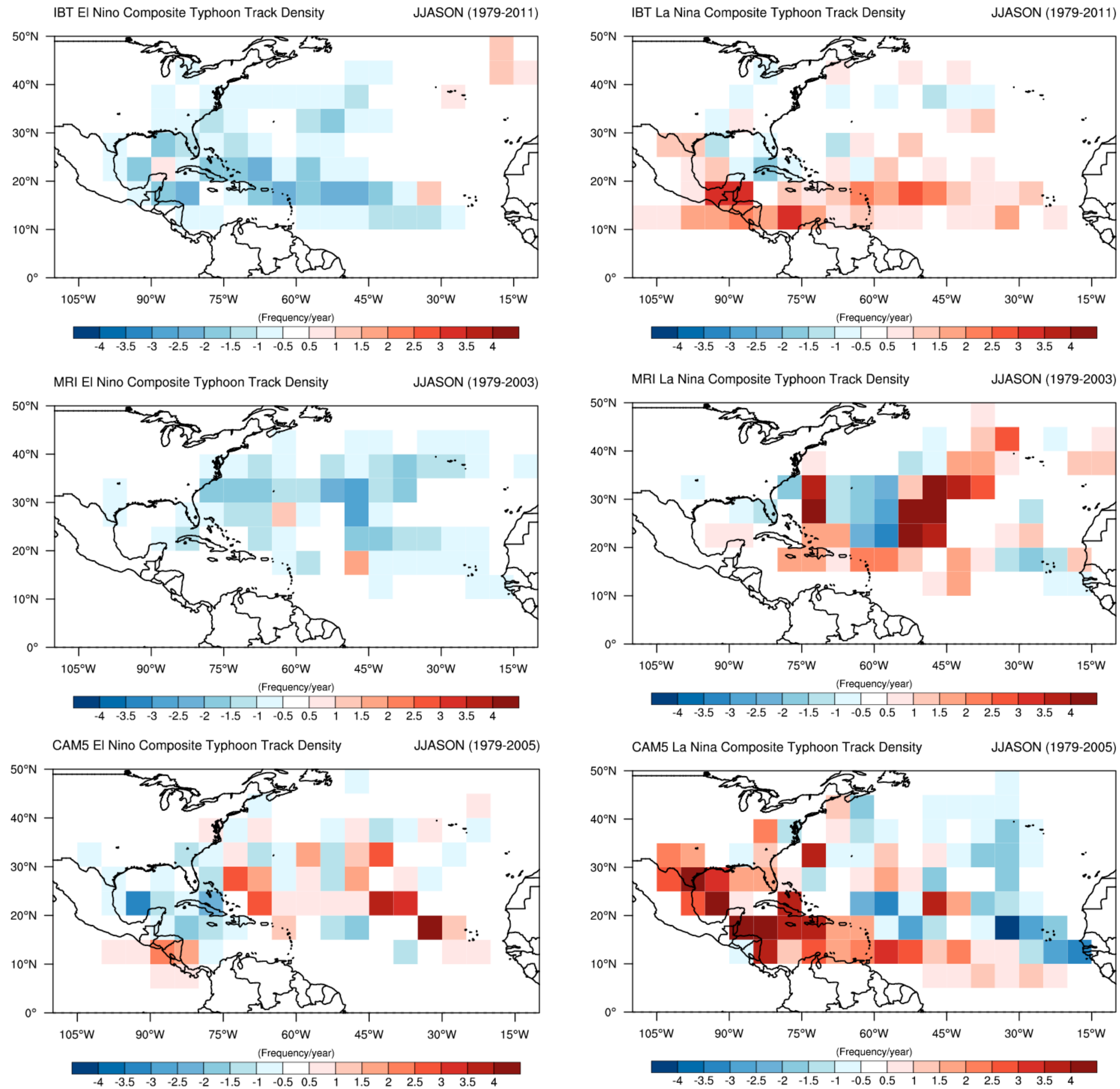
N Atlantic

El Nino | La Nina

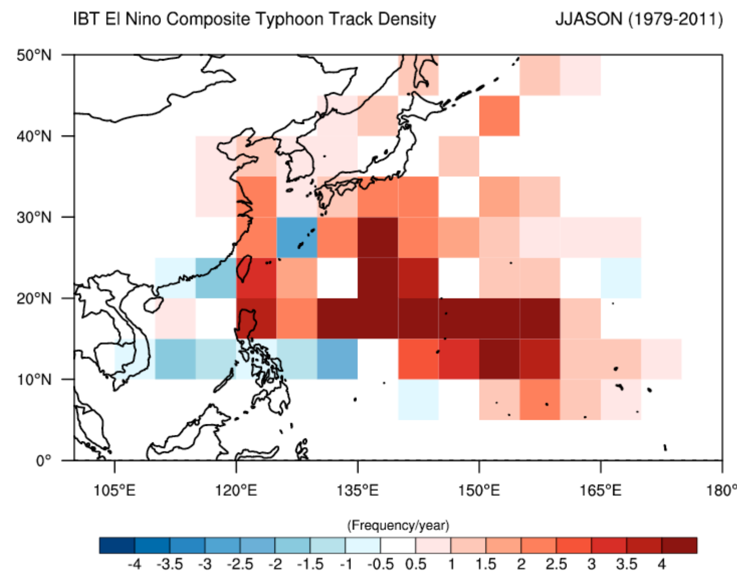
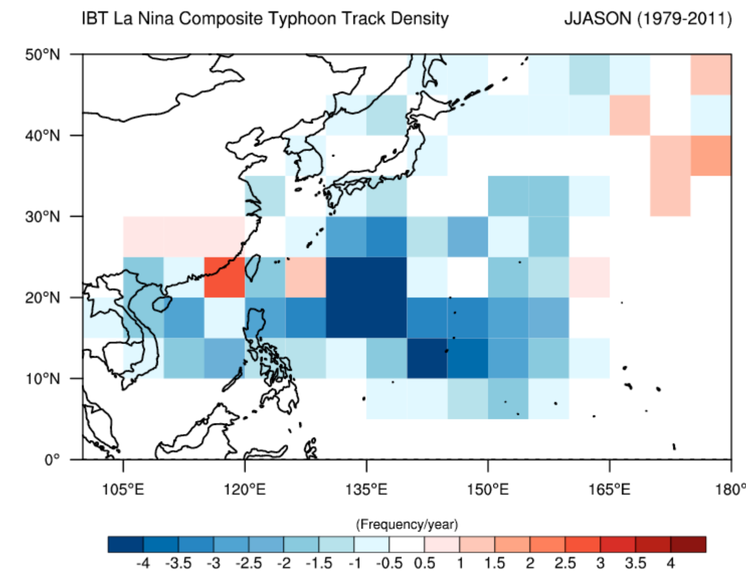
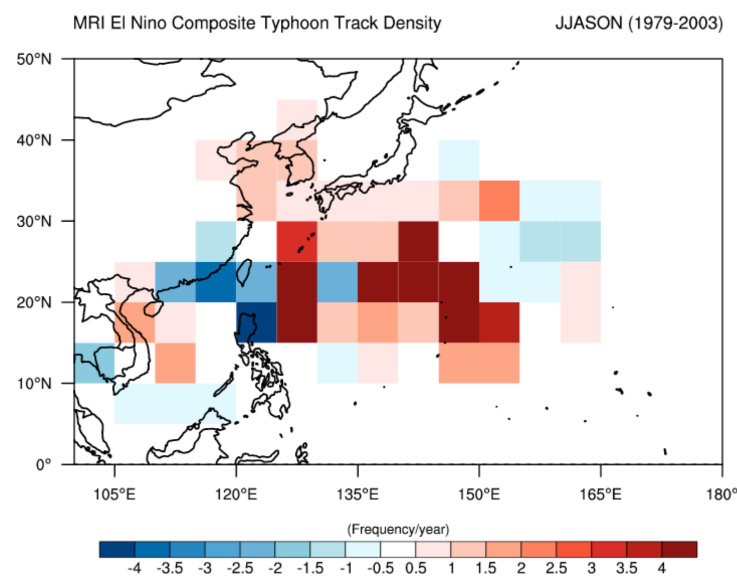
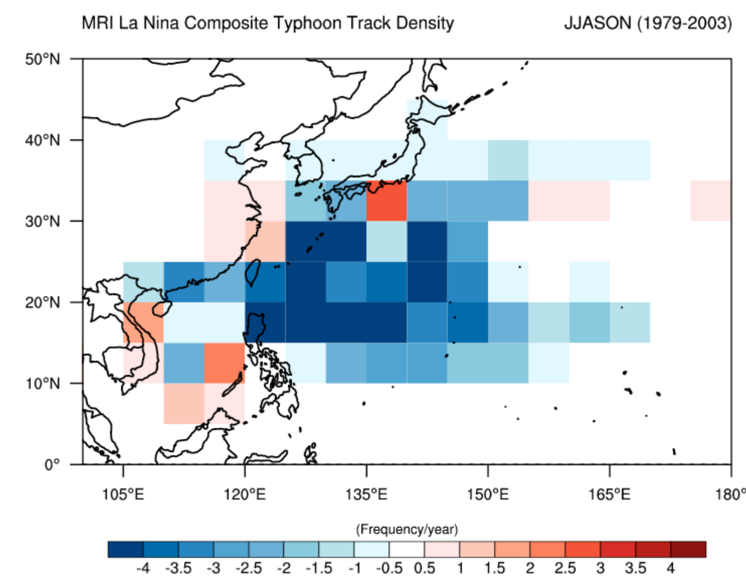
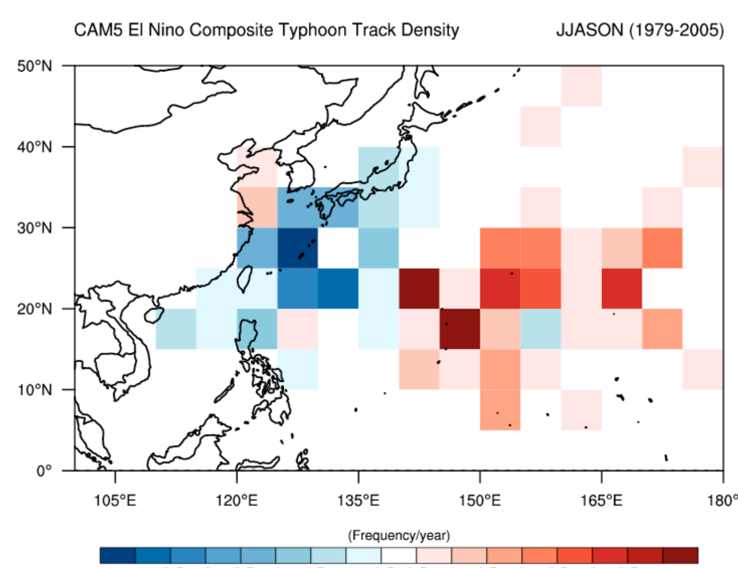
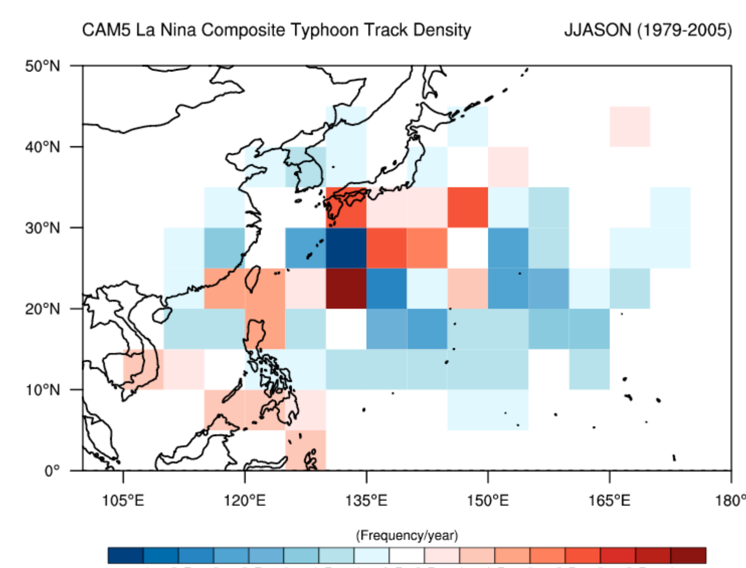
IBTrACS

MRI

CAM5

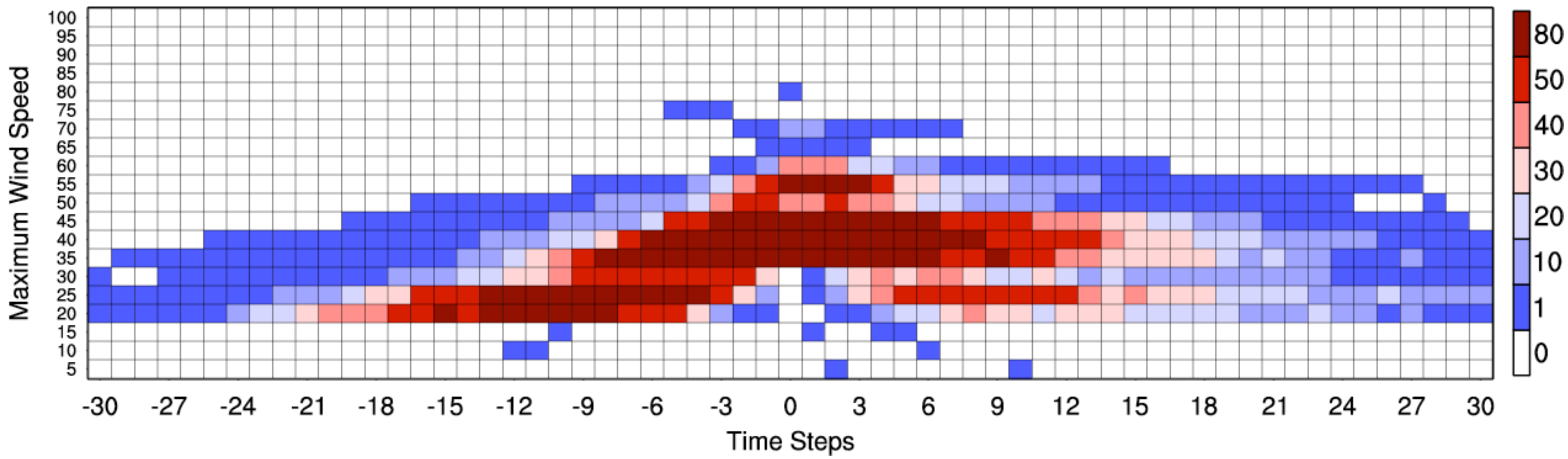


W Pacific

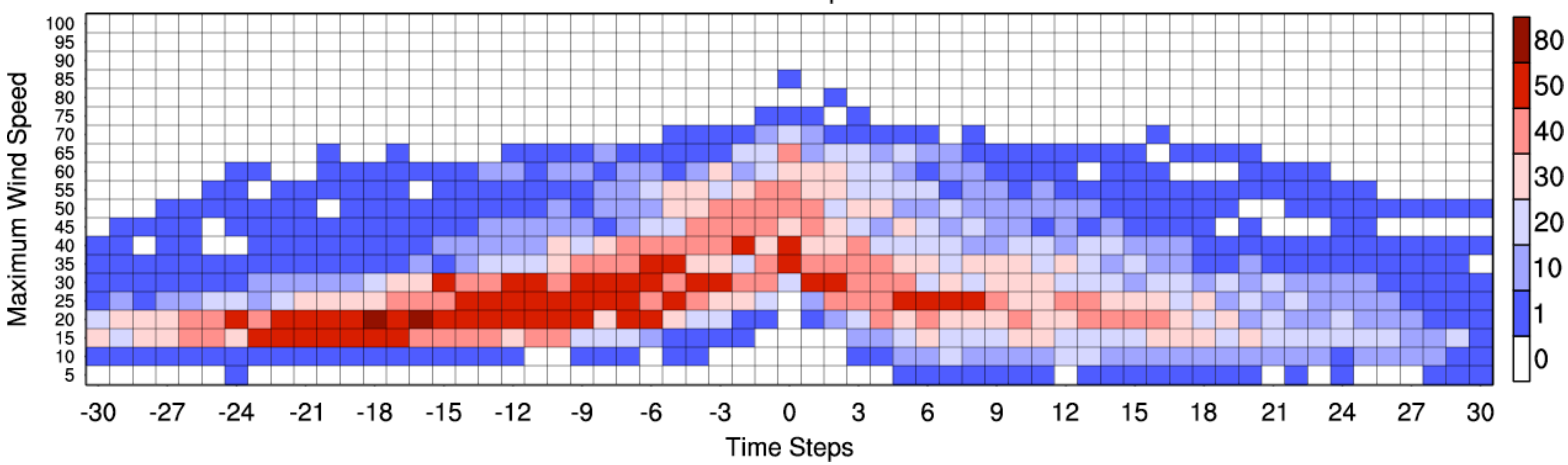
	El Nino	La Nina
IBTrACS		
MRI		
CAM5		

Normalized 2D Frequency Distribution of Max Wind and Time Relative to Peak Intensity

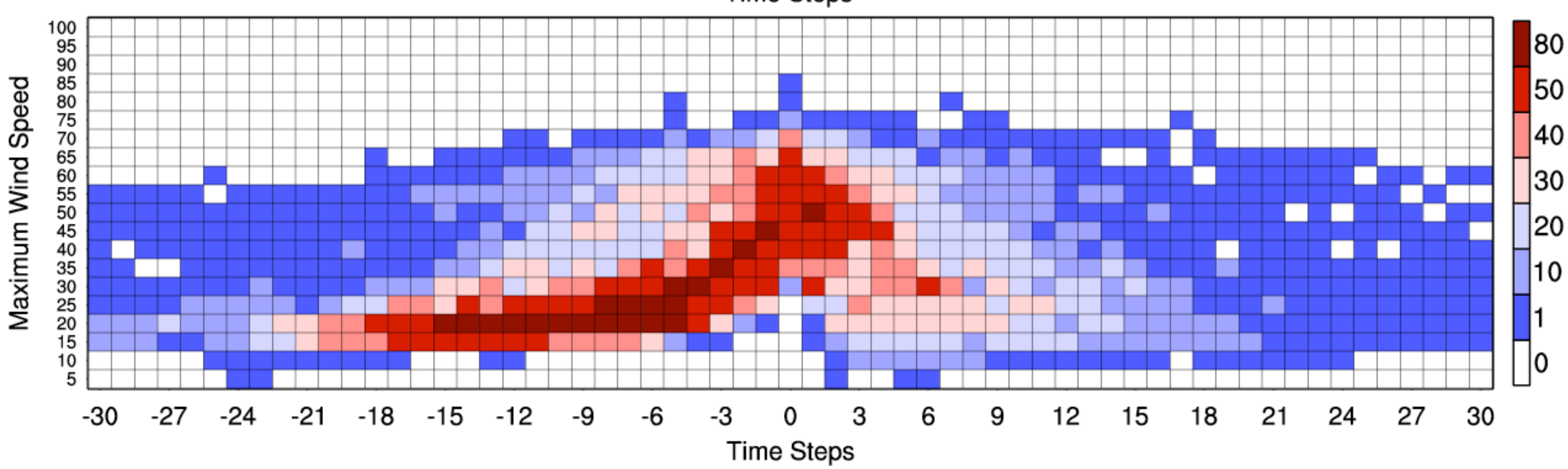
W Pacific



CAM5

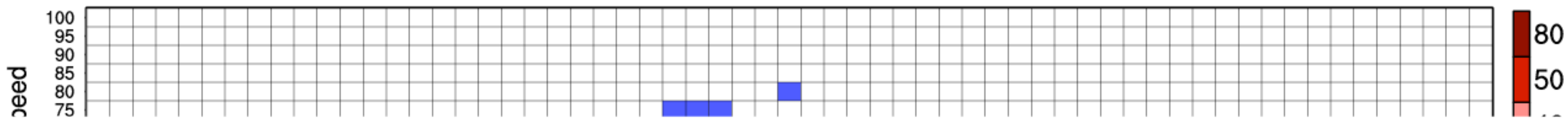


MRI

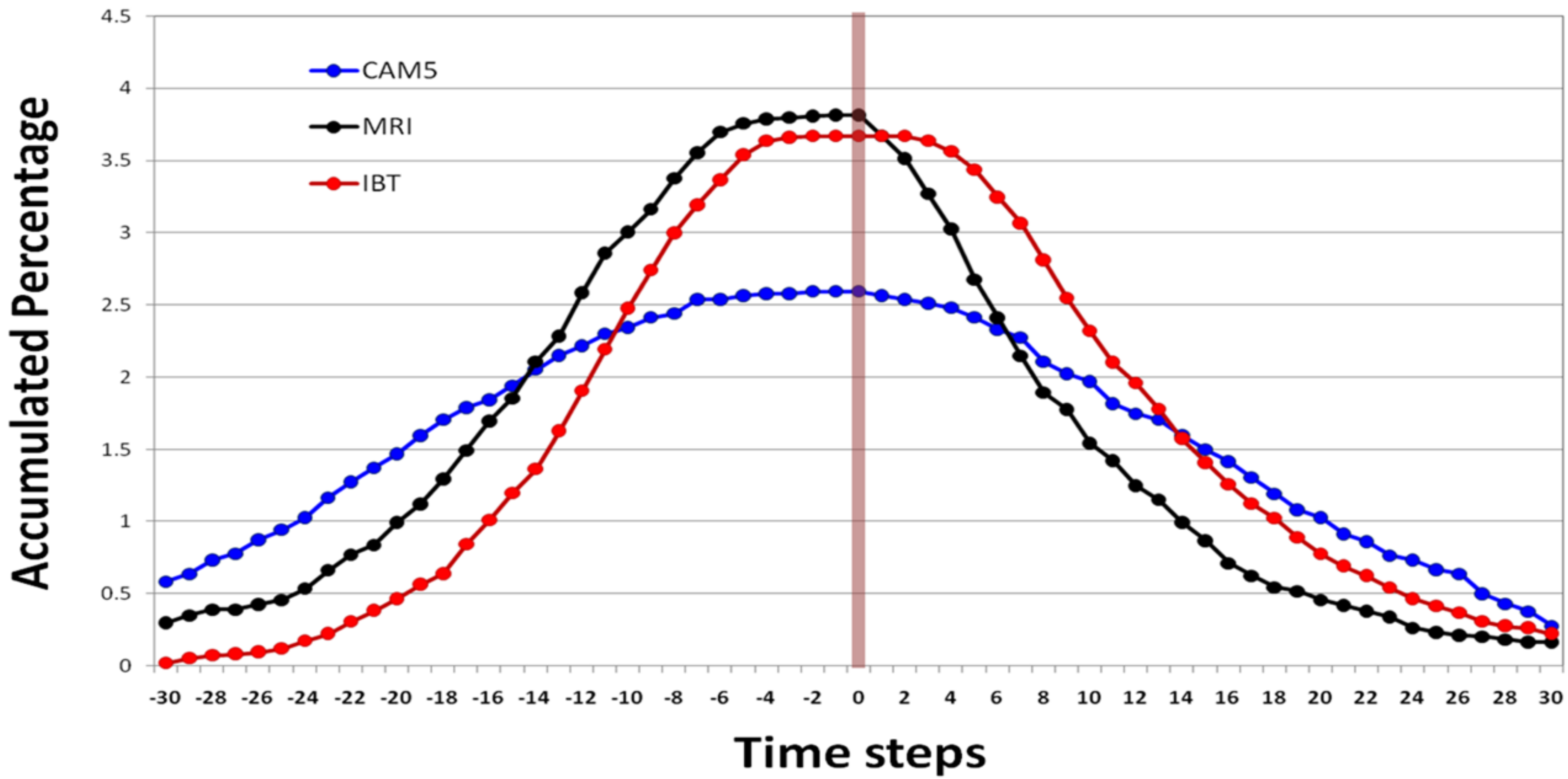


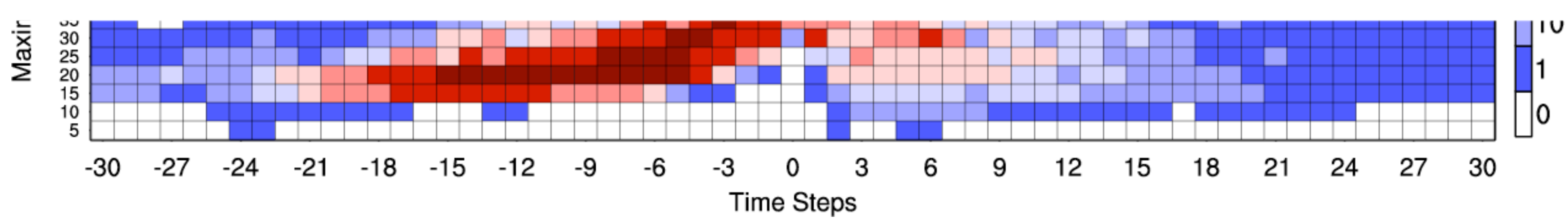
Normalized 2D Frequency Distribution of Max Wind and Time Relative to Peak Intensity

W Pacific

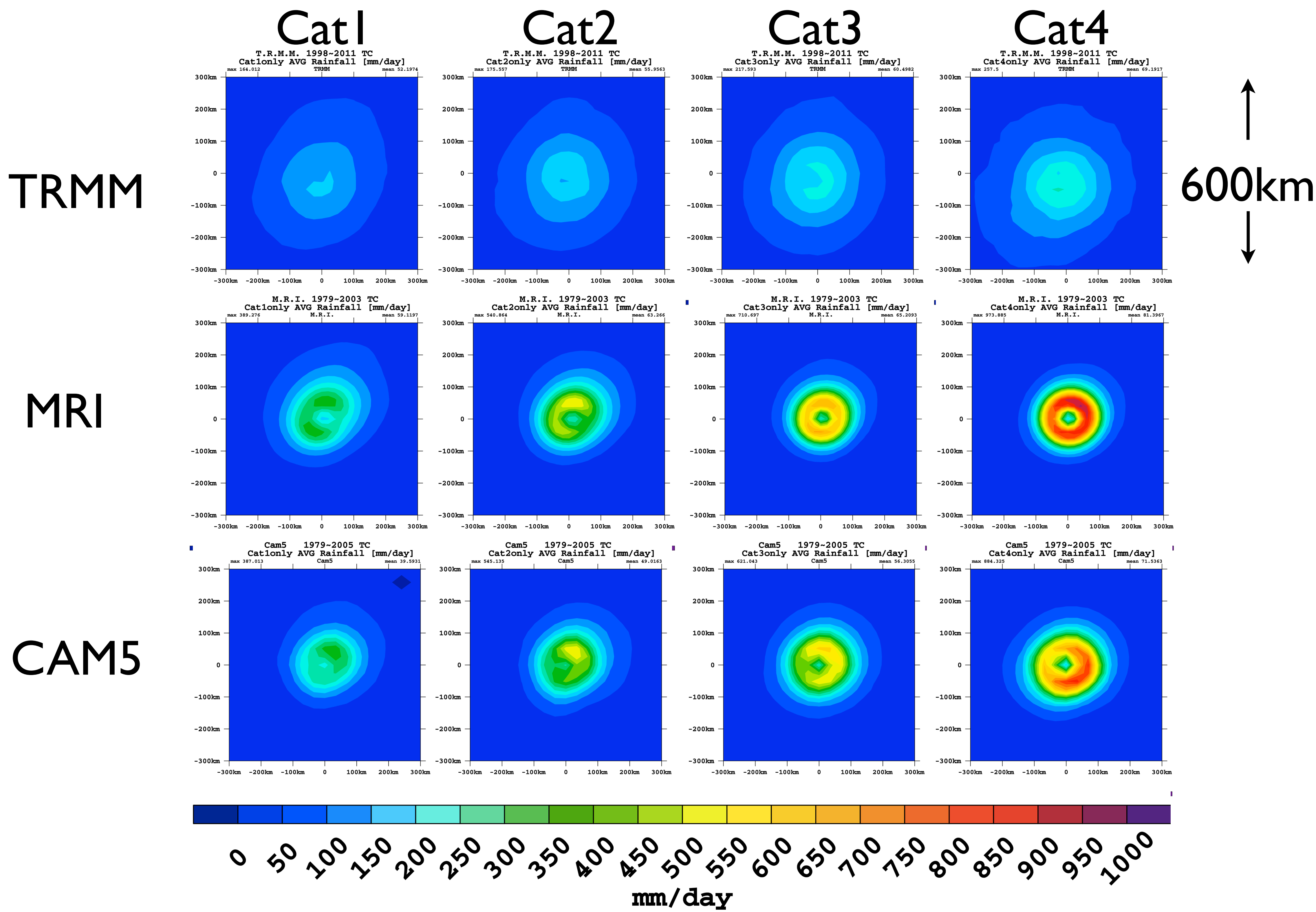


Normalized Frequency of Tracks Relative to Time of Peak Intensity





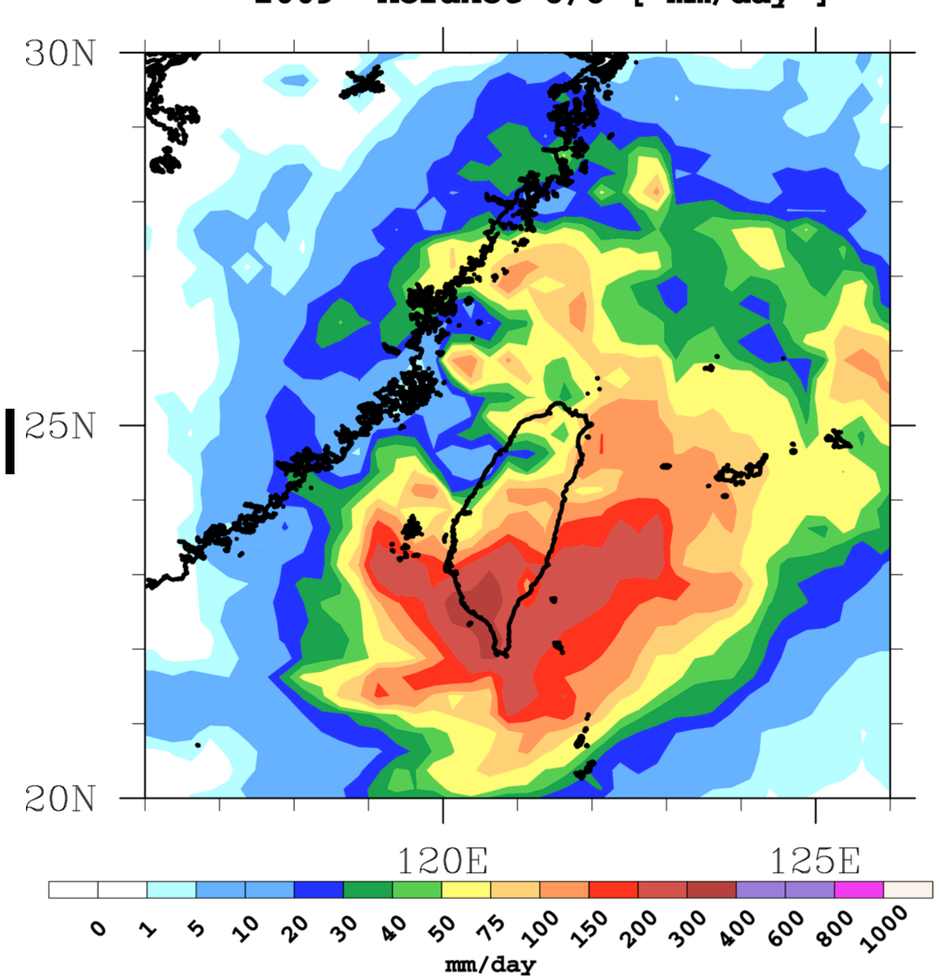
Composite of rainfall associated with tropical cyclone during different intensity stages



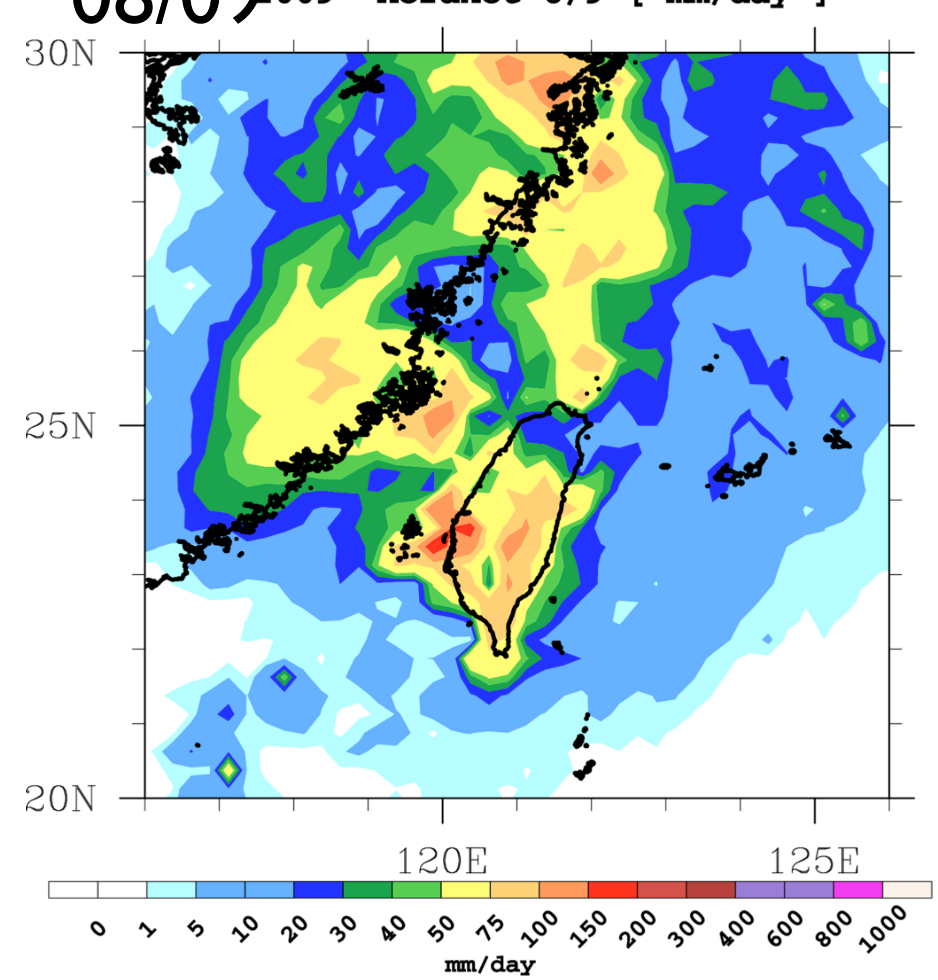
Typhoon Morakot 2009

TRMM
daily rainfall

08/08

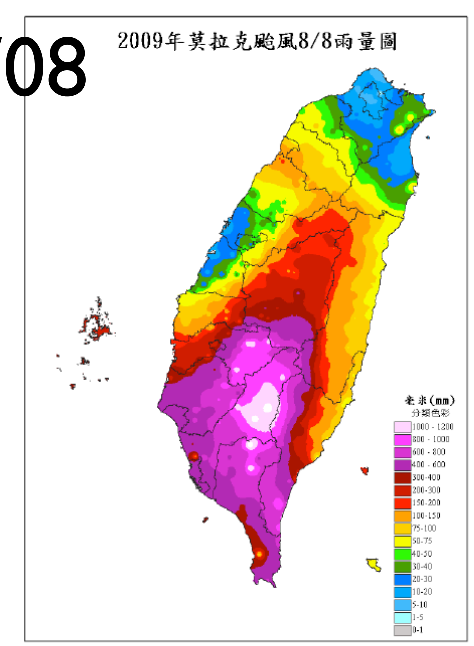


08/09

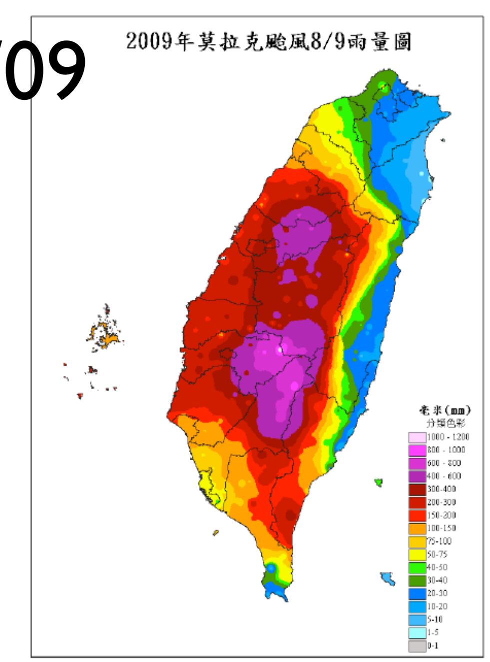


Rain gauge
daily rainfall

08/08



08/09



Concluding Remarks

- MRI and CAM5 high-resolution model can produce intense TCs. But often overestimate the number of intense TCs.
- MRI 20km mesh AGCM simulate better climatological TC track density over NW Pacific while CAM5 has better simulation over N Atlantic.
- Model simulation of seasonal evolution of TC activities are reasonable. The model biases can be link to the error in large-scale TC genesis condition.
- MRI model better capture the trend and interannual variability of basin-scale TC activities.
- Relative to peak TC intensity, TCs in the MRI model tends to stay more time in developing and mature stage, while TCs in the CAM5 model have longer lifetime.
- Both MRI and CAM5 produce more rain near the center of TC as compared to TRMM observation estimate. But dynamical range of TRMM rainfall retrieval might not be good for the heavy rainfall associated with TC.