Tropical cyclones simulated by very high resolution global climate models

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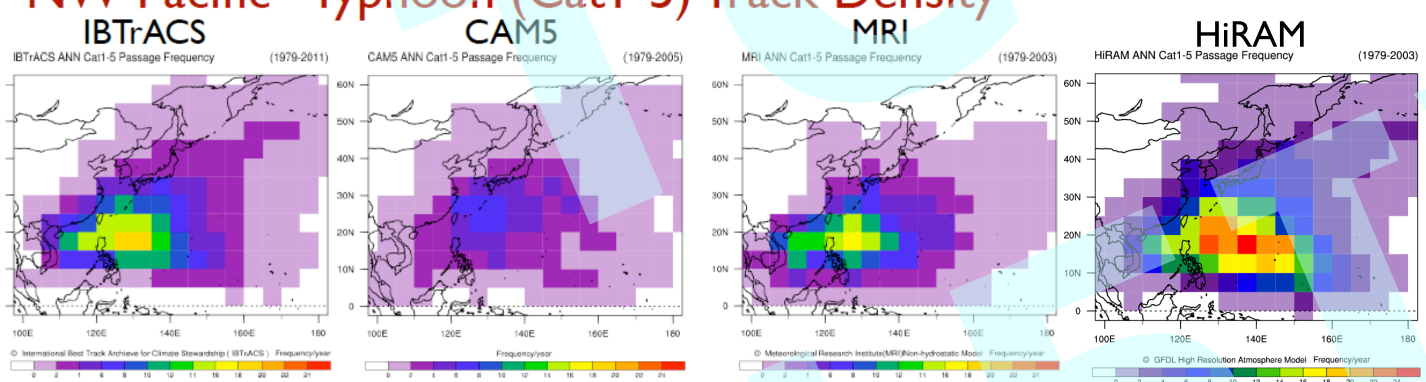
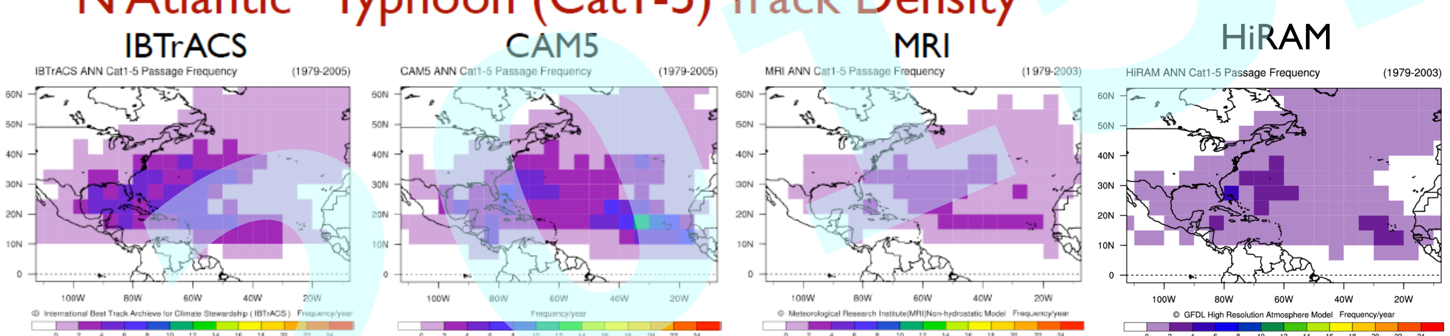
NW Pacific Typhoon (Cat1-5) Track Density



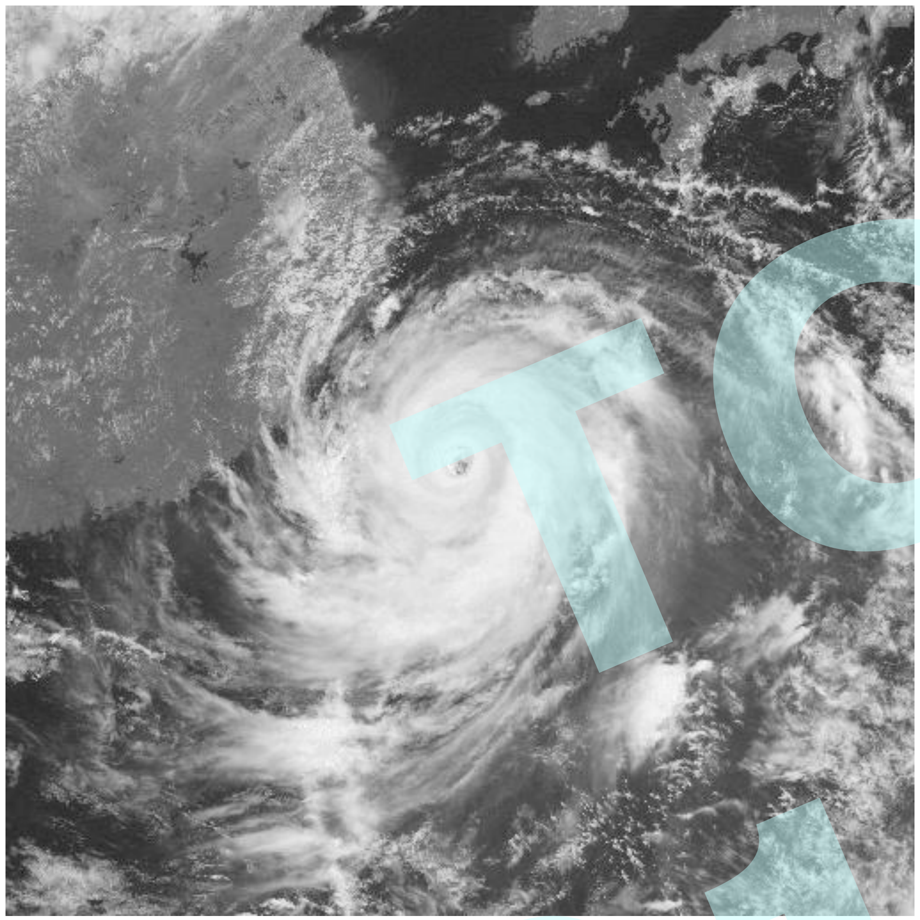
N Atlantic Typhoon (Cat1-5) Track Density

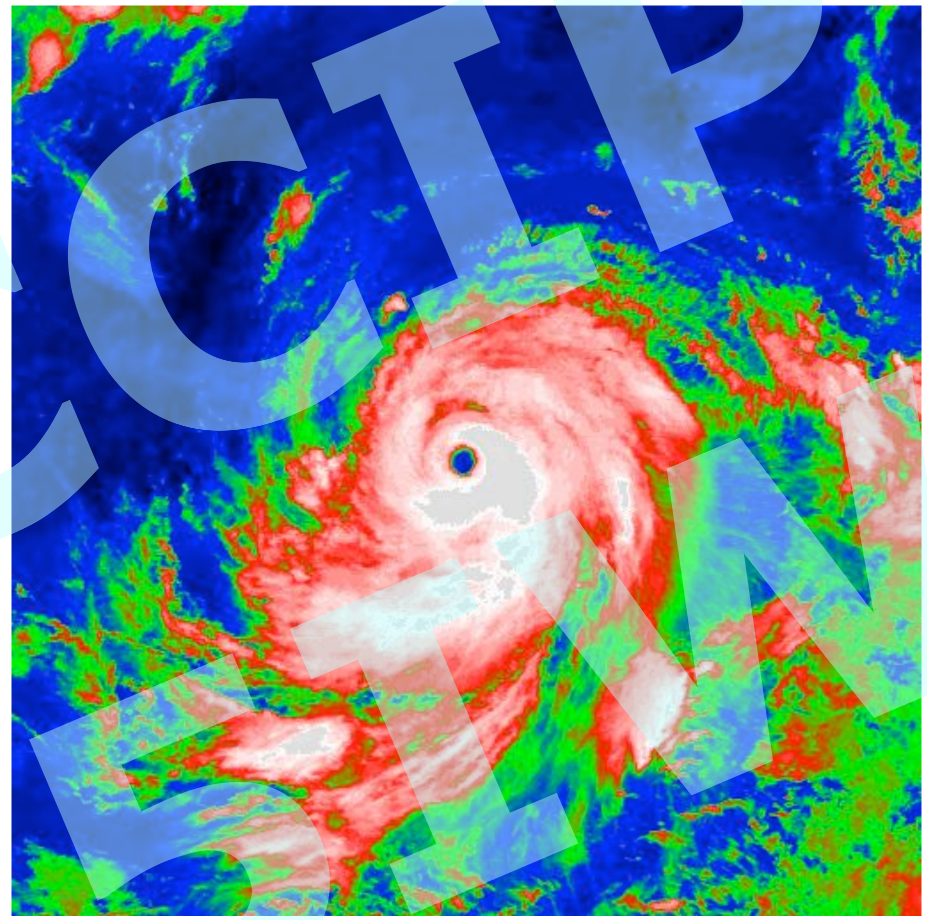


- Long-term high resolution models are required to properly simulate tropical cyclone (TC) intensity and climate-TC interactions
- Model validation and comparison:
  - Mean characteristics and structure
  - Seasonal cycle, interannual variability, and long-term trend
  - Rainfall associated TC

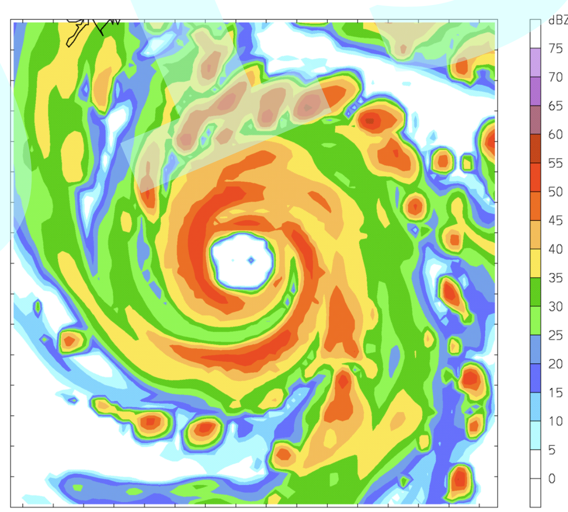
Workshop on High-Resolution Climate Simulation, Projection, and Application, 2015/01/19-20

High resolution model is needed to properly simulate tropical cyclone (intensity and precipitation)





Typhoon Herb



WRF simulation at 4 km resolution

High-resolution AGCM Time Slice Experiments

Present-day climate experiment (1979 - early 2000s MRI, CAM, HiRAM)
observed sea surface temperature (SST) and sea-ice concentration

MRI AGCM 3.2

- Based on operational JMA-GSM
- Resolution: TL959(20km) with
- 64 vertical levels (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

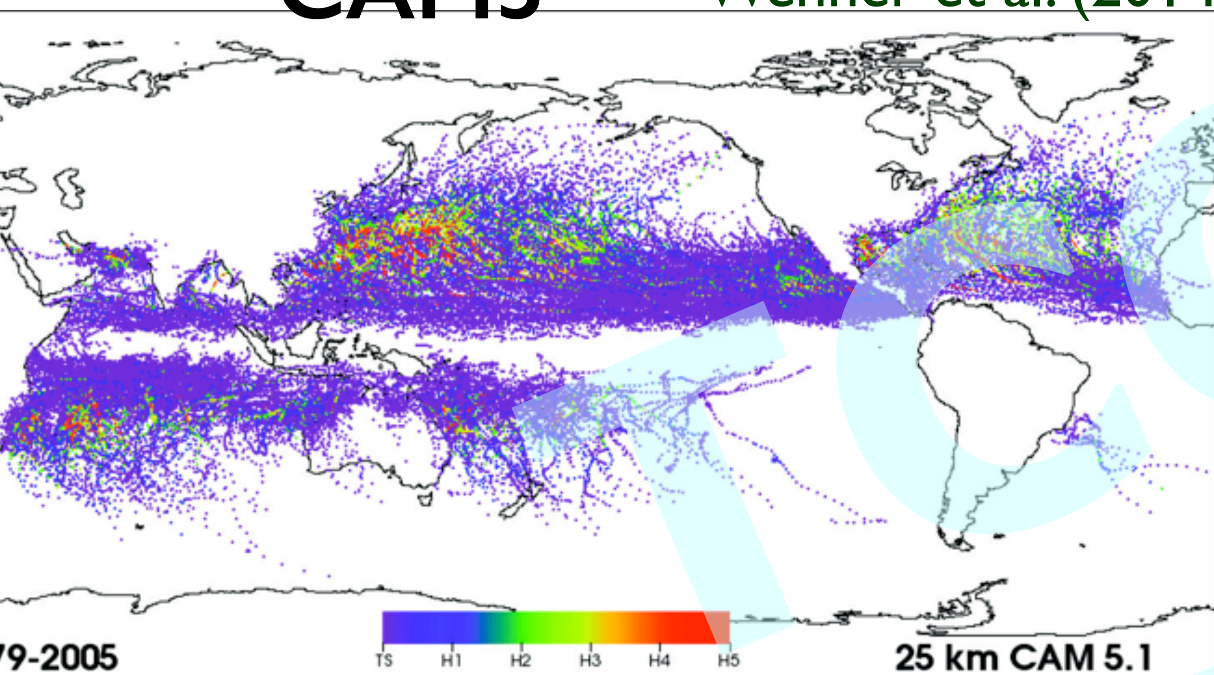
- Standard release version 5.1 with time dependent prescribed aerosol forcing. No further tuning.
- Observed ozone, CO2, solar forcing
- Resolution: 0.23 x 0.31
- 30 vertical levels (top 2 hPa)
- Physics
  - Deep convection: Zhang and McFarlane (1995)
  - Shallow convection: Park and Bretheerton (2009)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

HiRAM

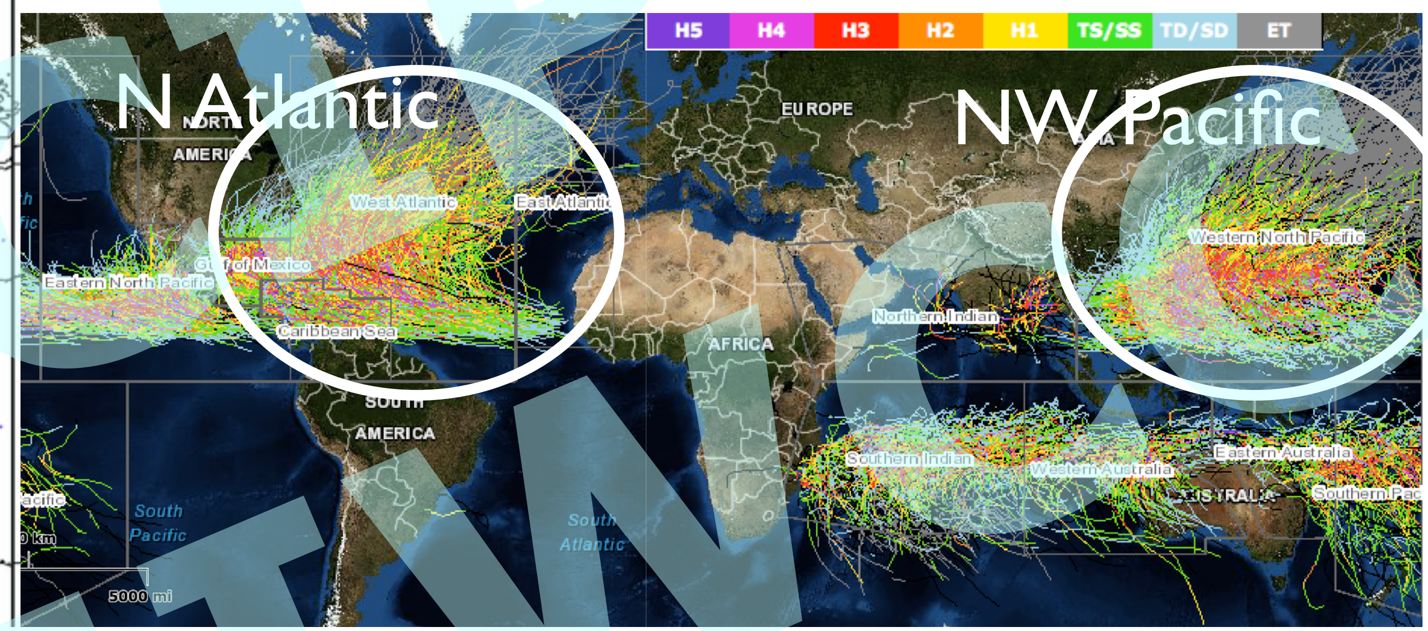
- Sharing the codes with GFDL AM2/AM3 except running with Non-hydrostatic Cubed-sphere Finite-Volume dynamical code
- Resolution: C384 (~23km)
- 32 vertical levels (top 1 hPa)
- Physics
  - Non precipitating shallow convection scheme (Bretherton et al. 2004)
  - 6-category single-moment bulk cloud microphysics with time implicit treatment of microphysics processes
  - Surface fluxes modified for high-wind situation over ocean (Moon et al. 2007)

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

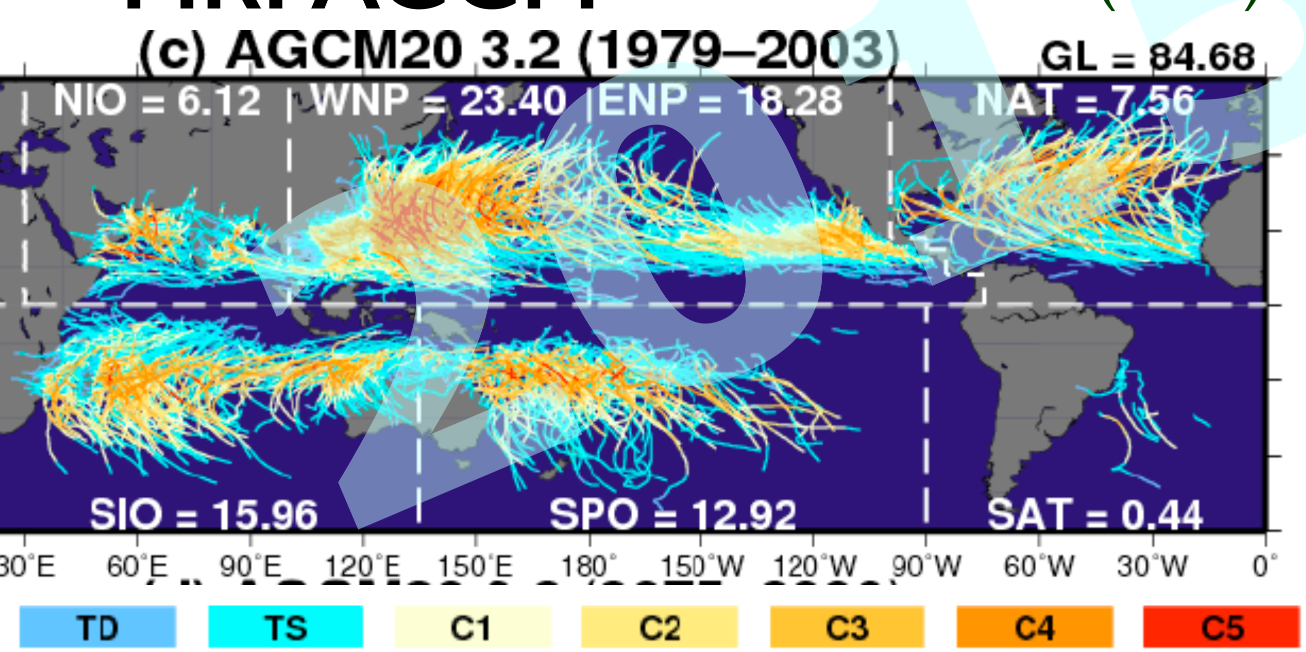
CAM5 Wehner et al. (2014)



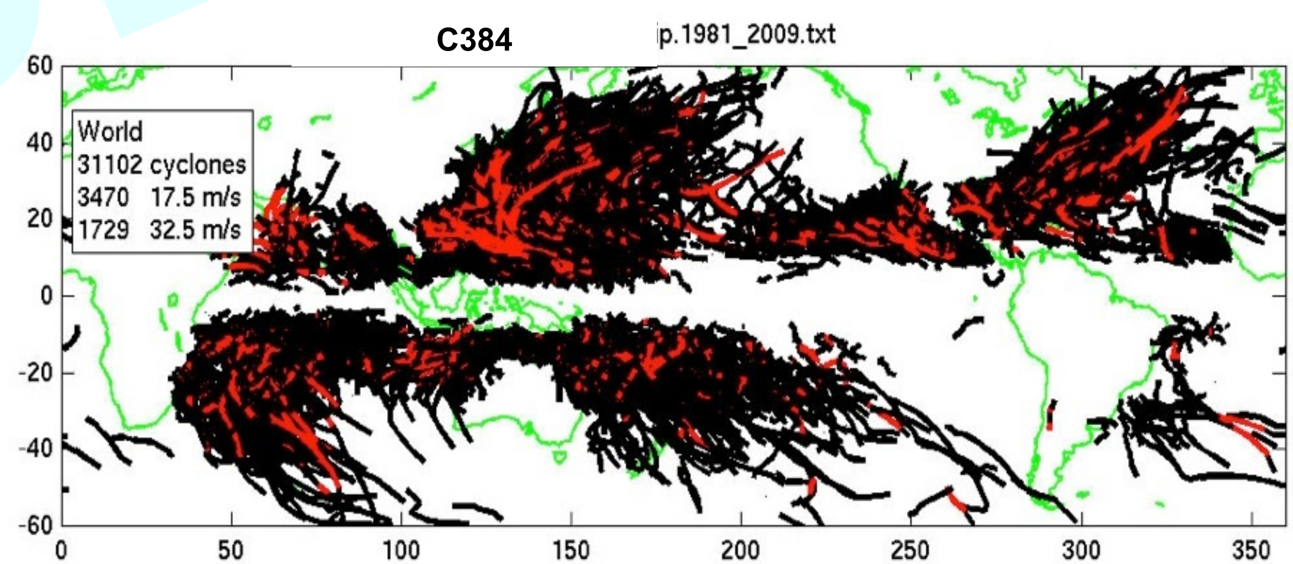
OBS **IBTrACS v3r4**



MRI AGCM Murakami et al. (2012)



HiRAM



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

CAM5 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 at least 2 days (not necessarily consecutive)

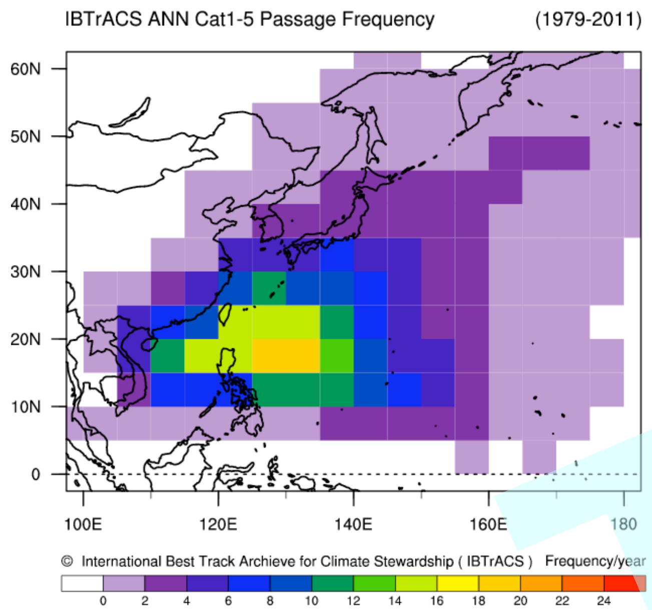
MRI Tropical Cyclone Detection and Tracking Scheme

(Murakami et al., 2012)

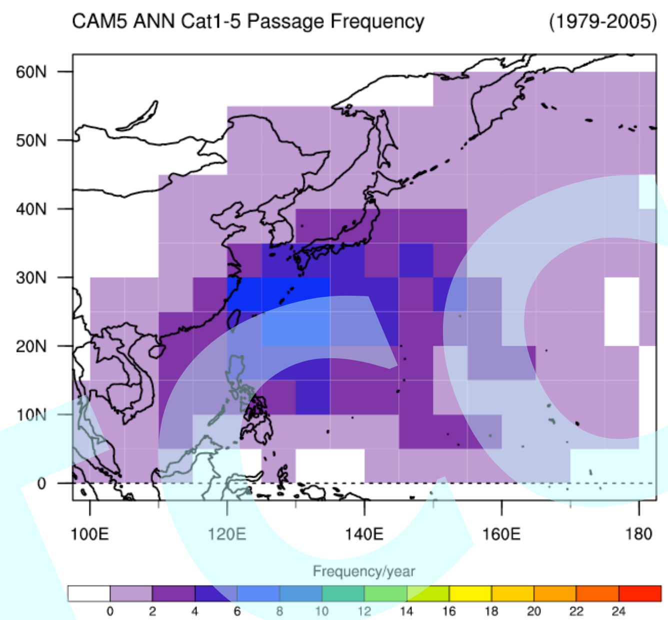
- Local relative vorticity maximum at 850hPa > $2.0 \times 10^{-4}\ s^{-1}$.
- The maximum wind speed at 850 hPa exceeds 17 m/s.
- There is an evident warm core aloft. Namely, the sum of the temperature deviations at 300, 500, and 700 hPa exceeds 2K. The temperature deviation for each level is computed 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

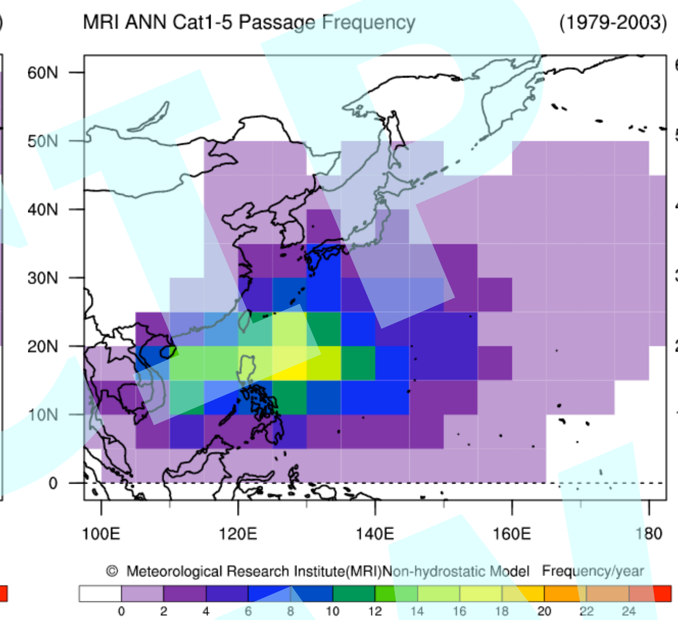
IBTrACS



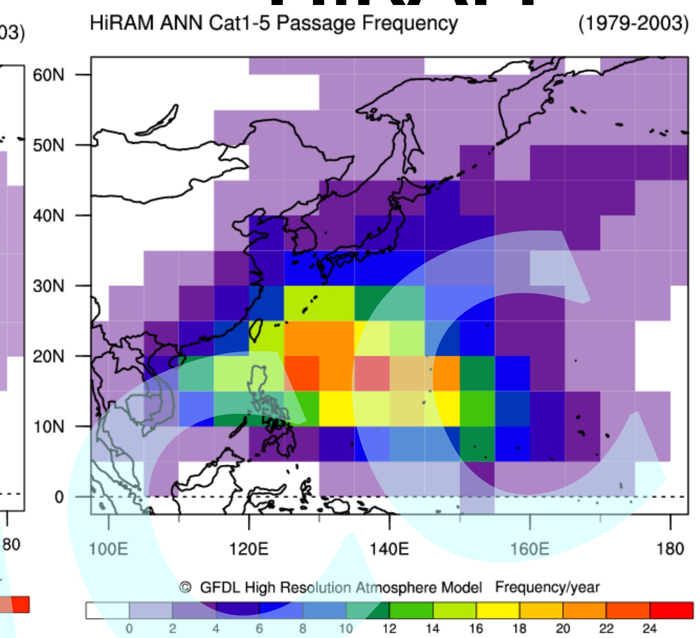
CAM5.1



MRI AGCM

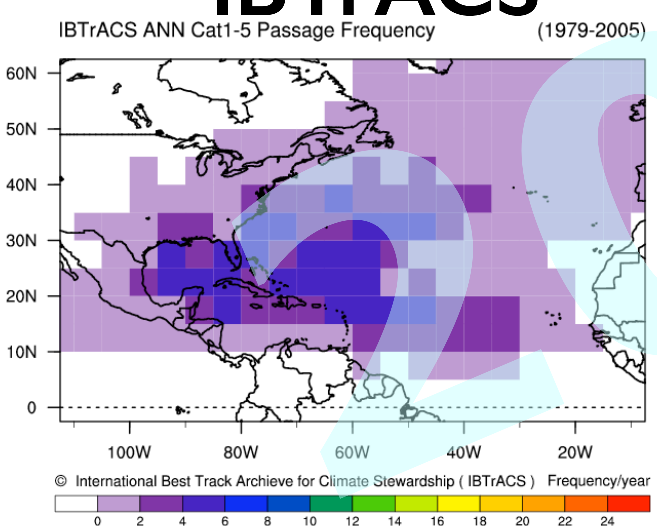


HiRAM

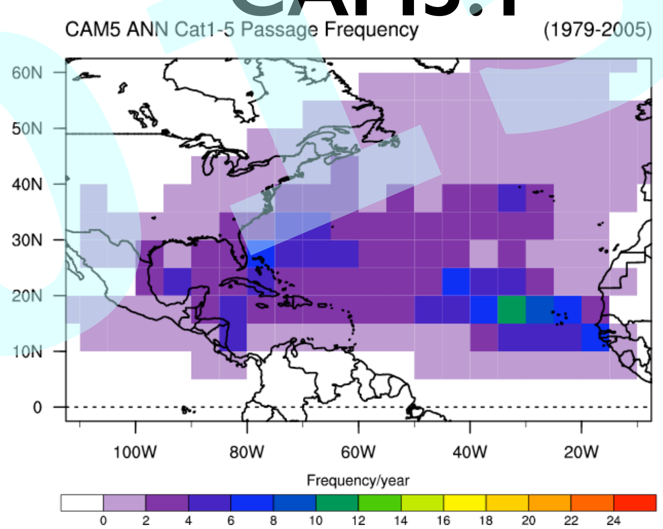


N Atlantic Typhoon (Cat1-5) Track Density

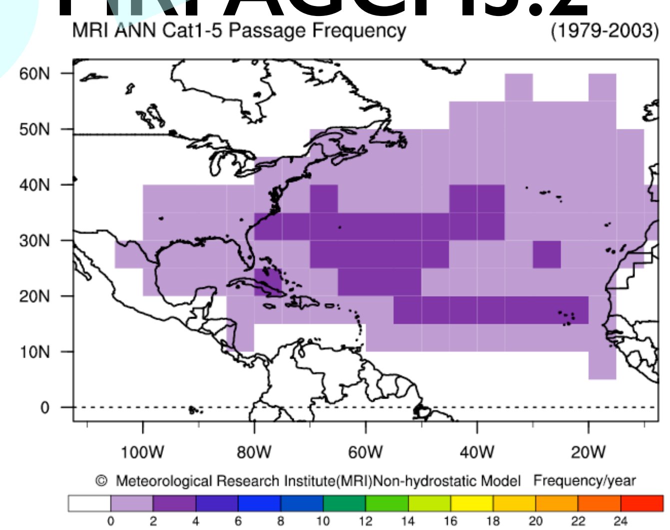
IBTrACS



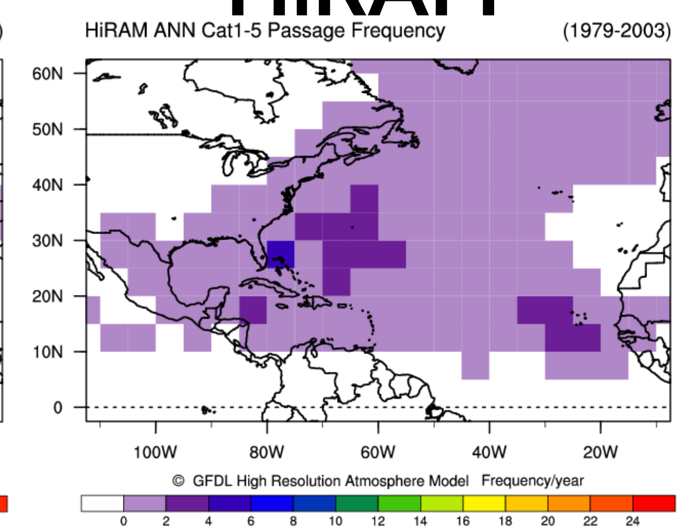
CAM5.1



MRI AGCM3.2

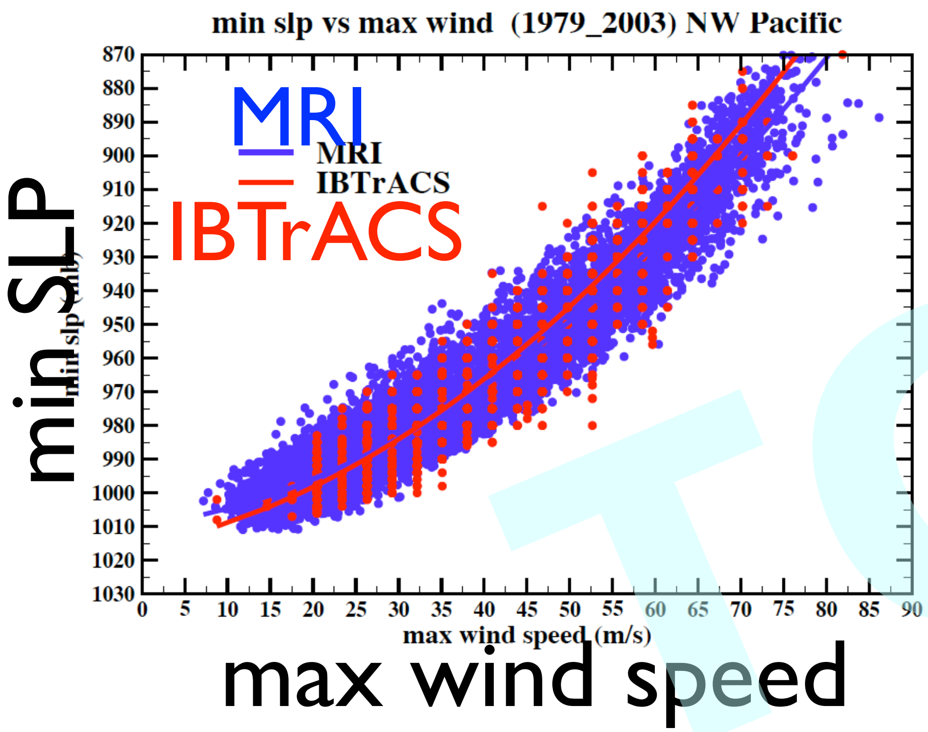


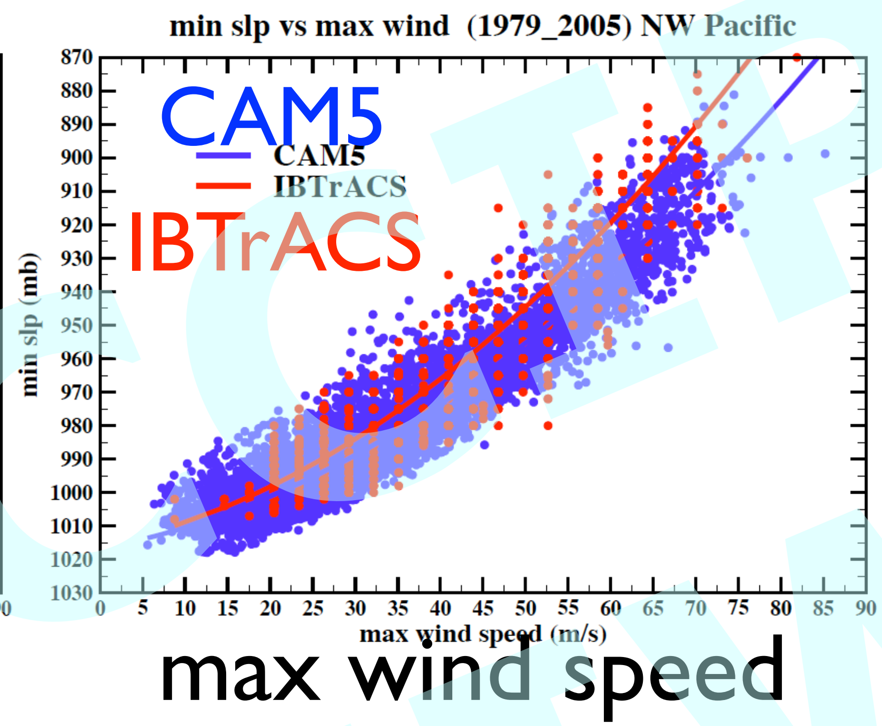
HiRAM

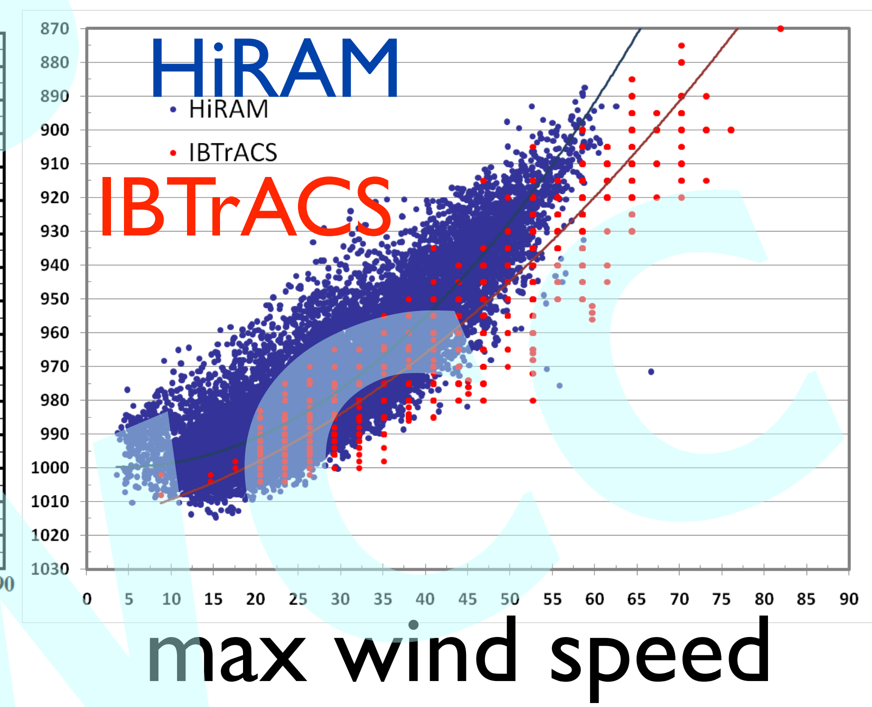


Minimum Sea Level Pressure vs. Maximum wind speed

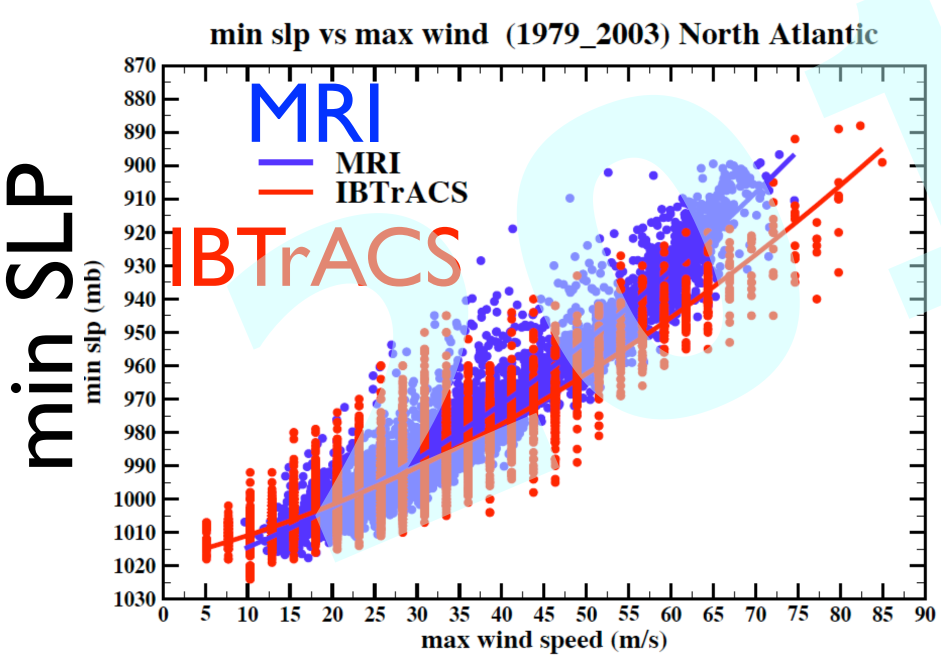
NW Pacific

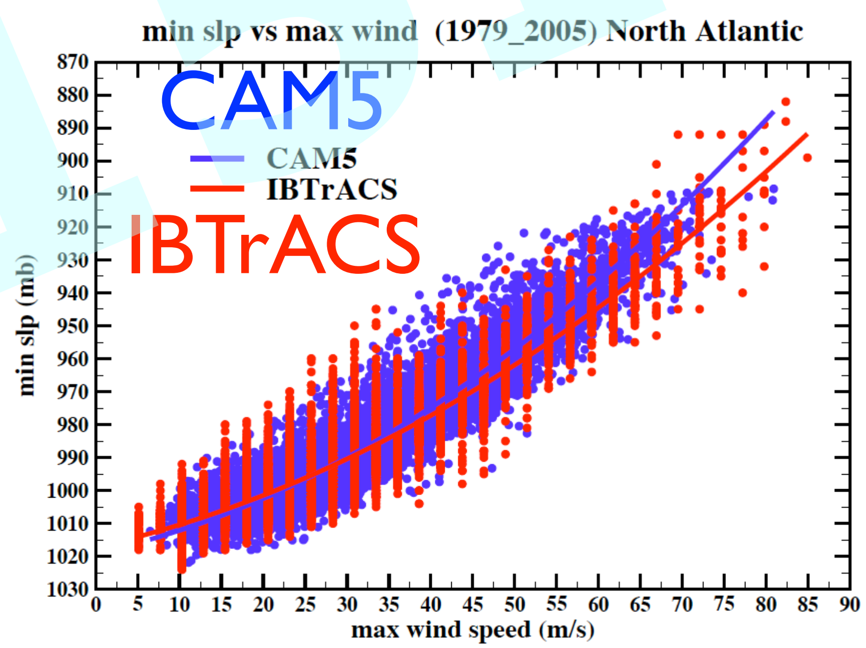


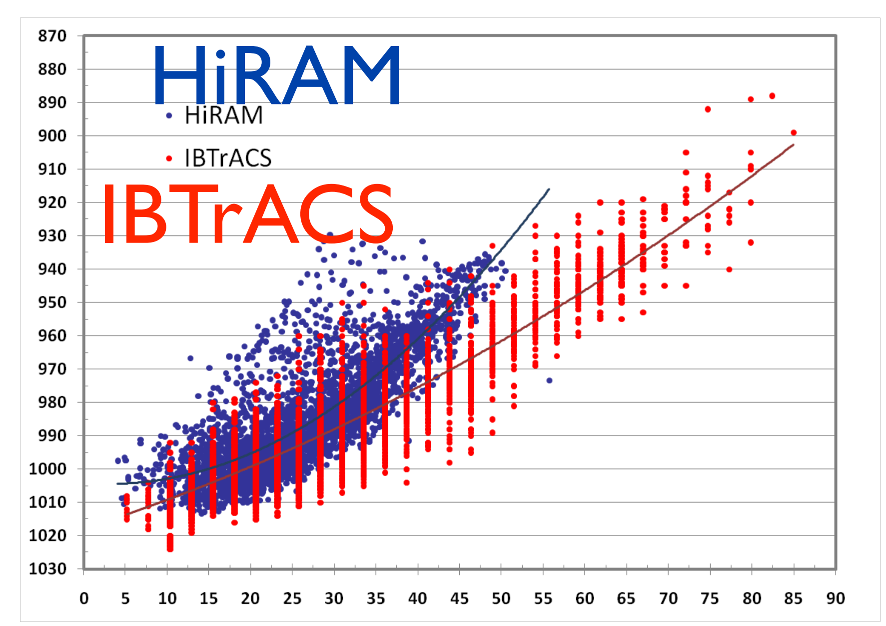




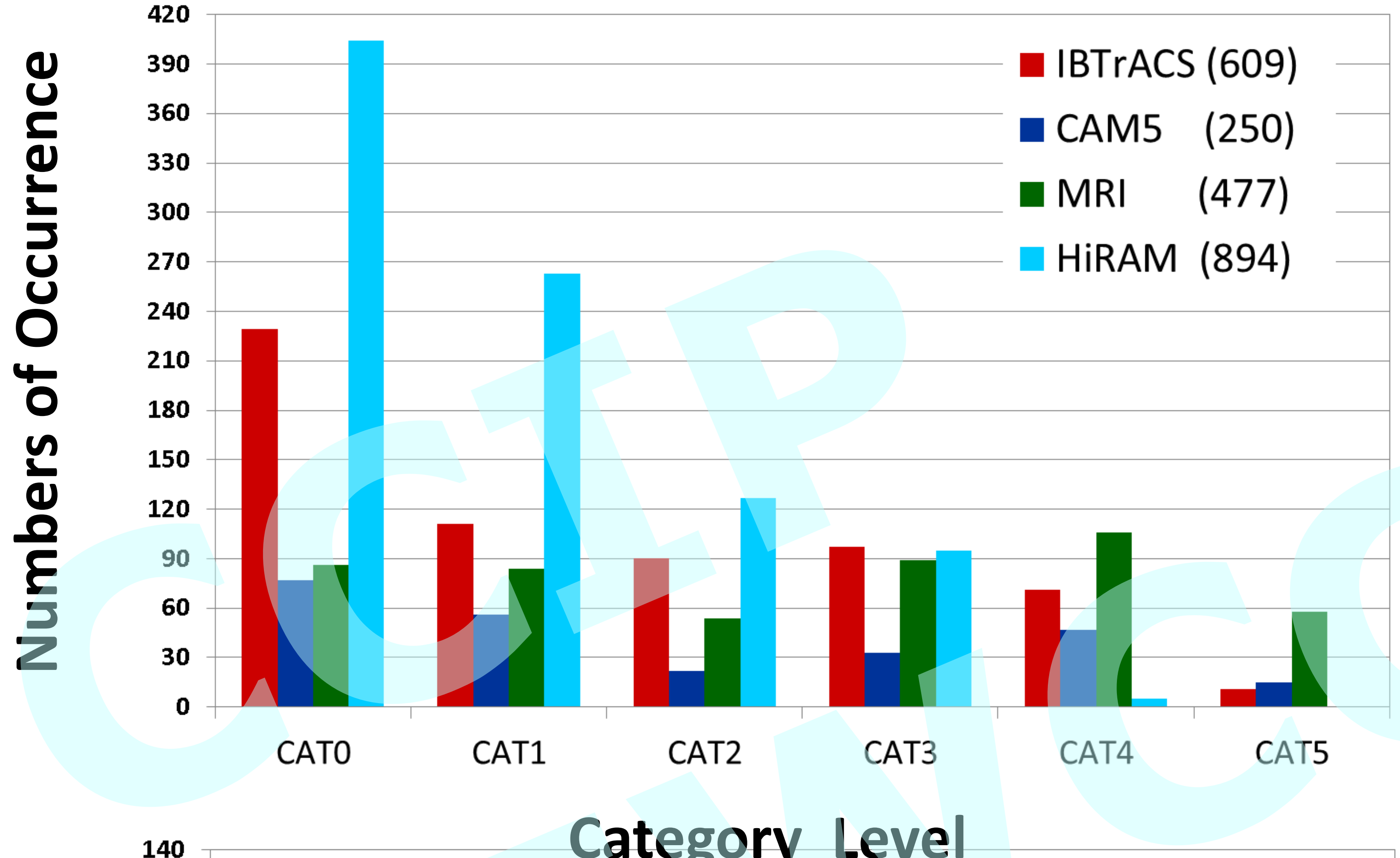
North Atlantic



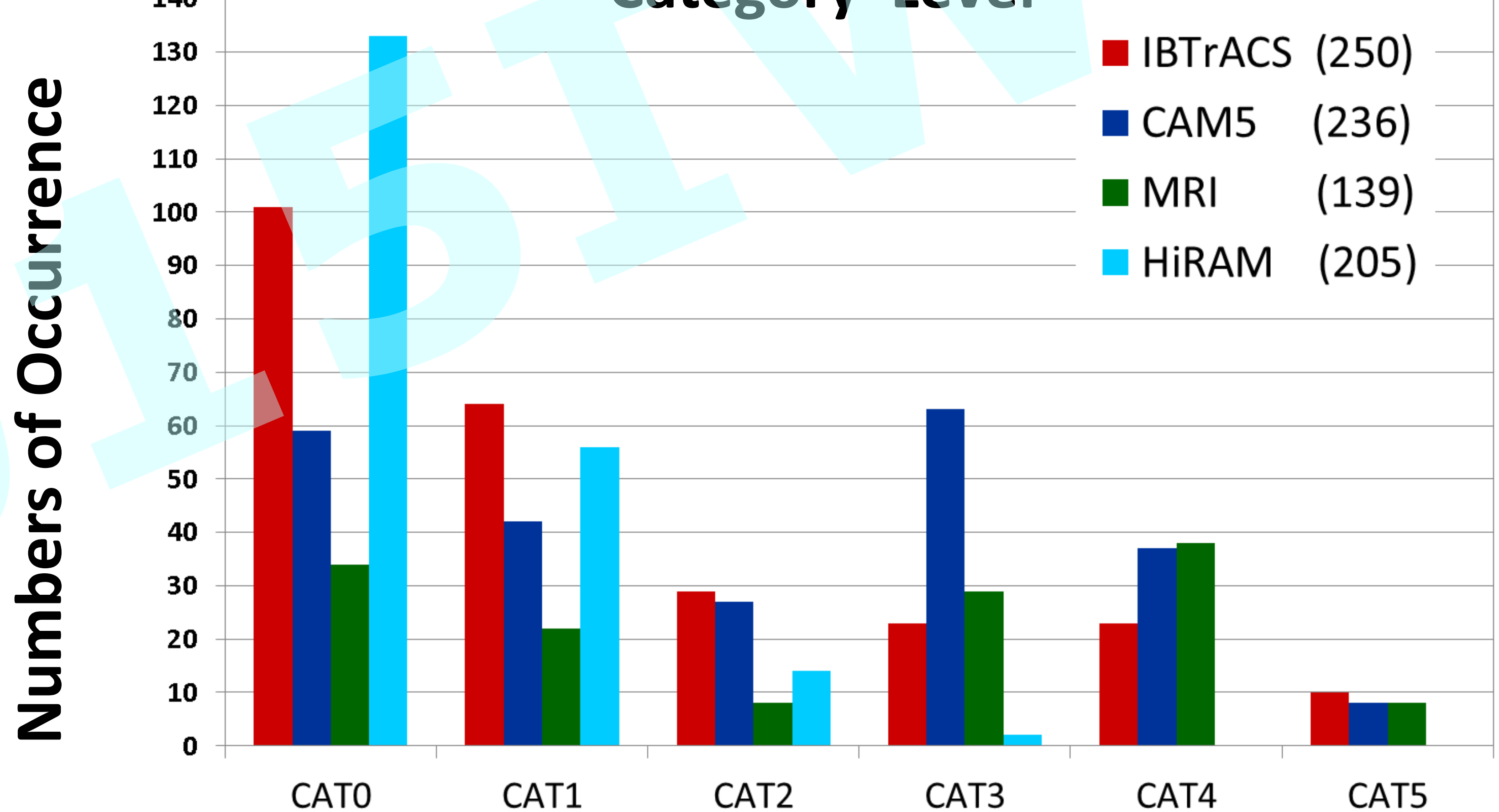




NW Pacific
(1979-2003)

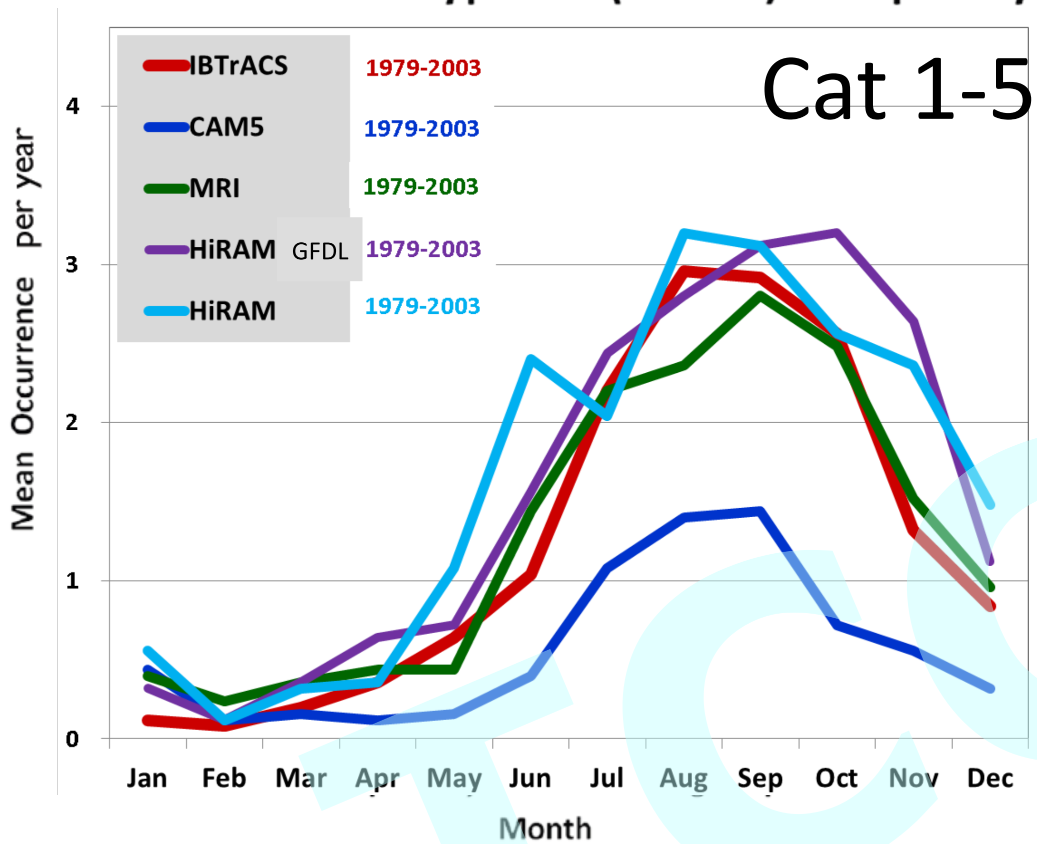


N Atlantic
(1979-2003)

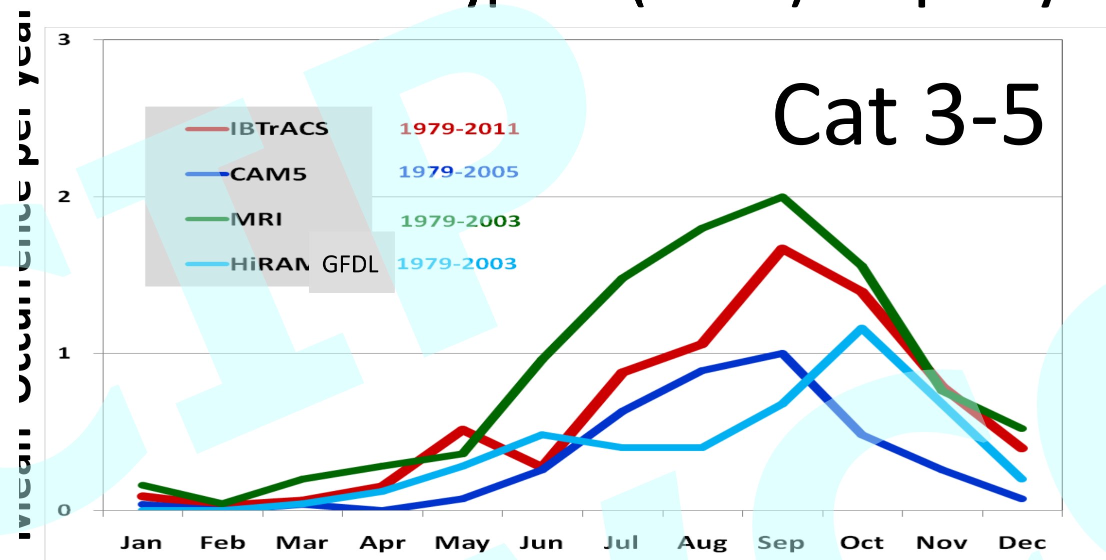


NW Pacific

WP Seasonal Typhoon(Cat1-5) Frequency

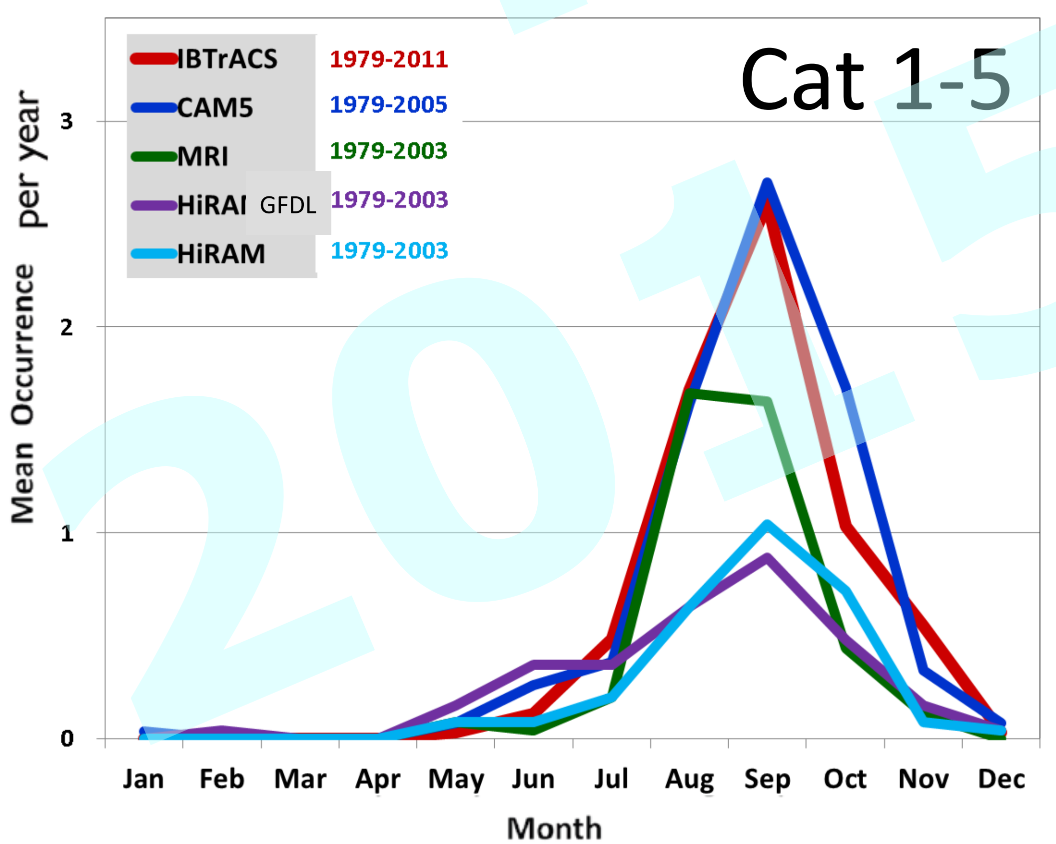


WP Seasonal Typhoon(Cat3-5) Frequency

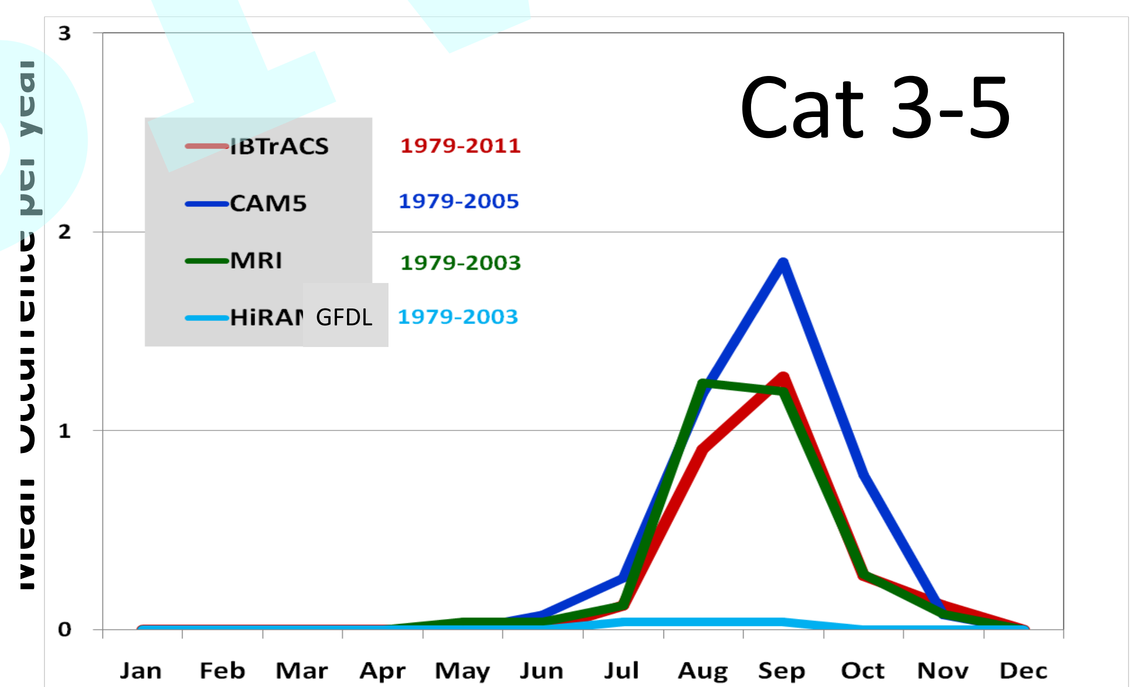


N Atlantic

NA Seasonal Hurricane(Cat1-5) Frequency



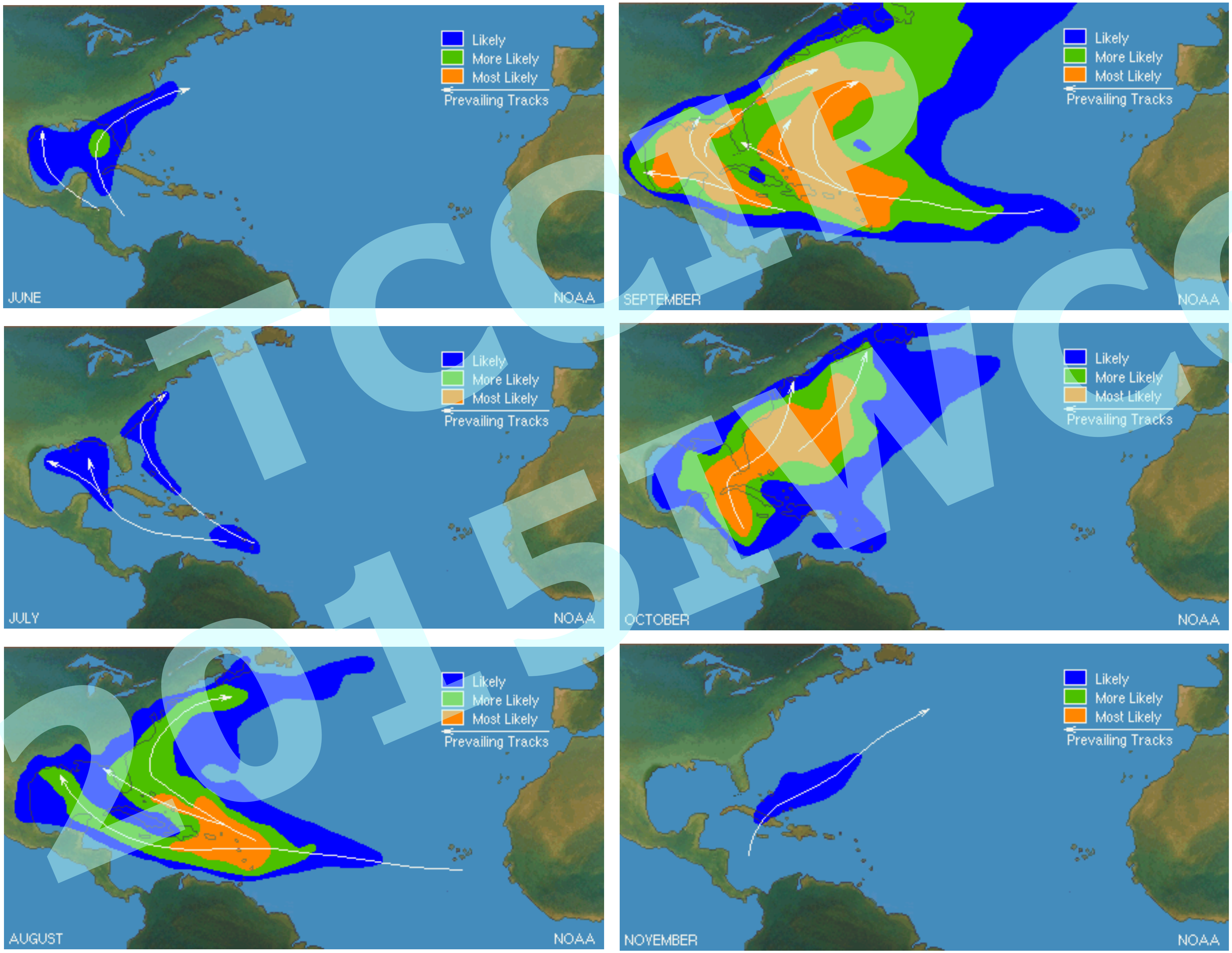
NA Seasonal Typhoon(Cat3-5) Frequency



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

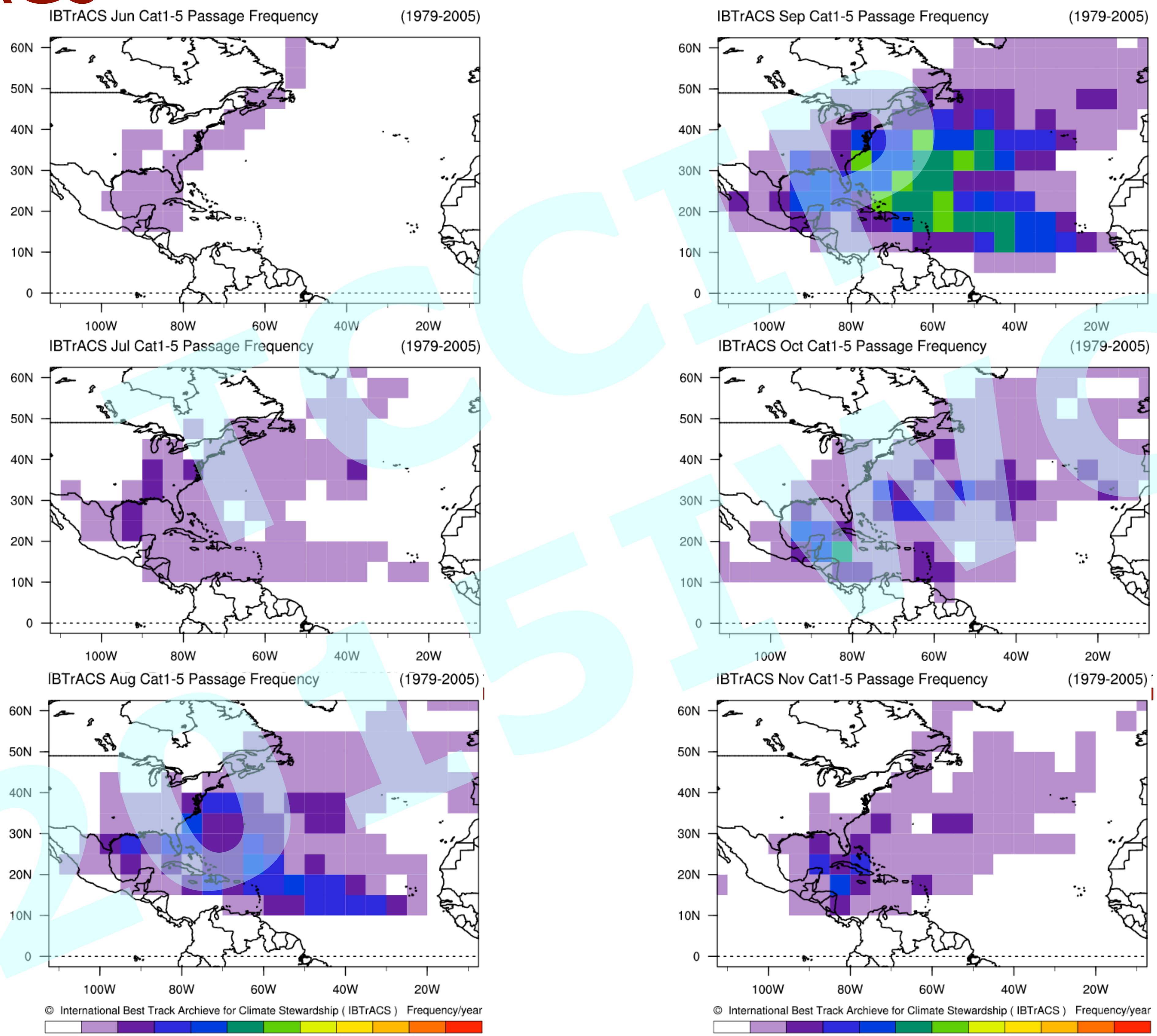
Sep.

July

Oct.

Aug.

Nov.



Climatological Hurricane (Cat1-5) Track density by Month

CAM5

Atlantic

June

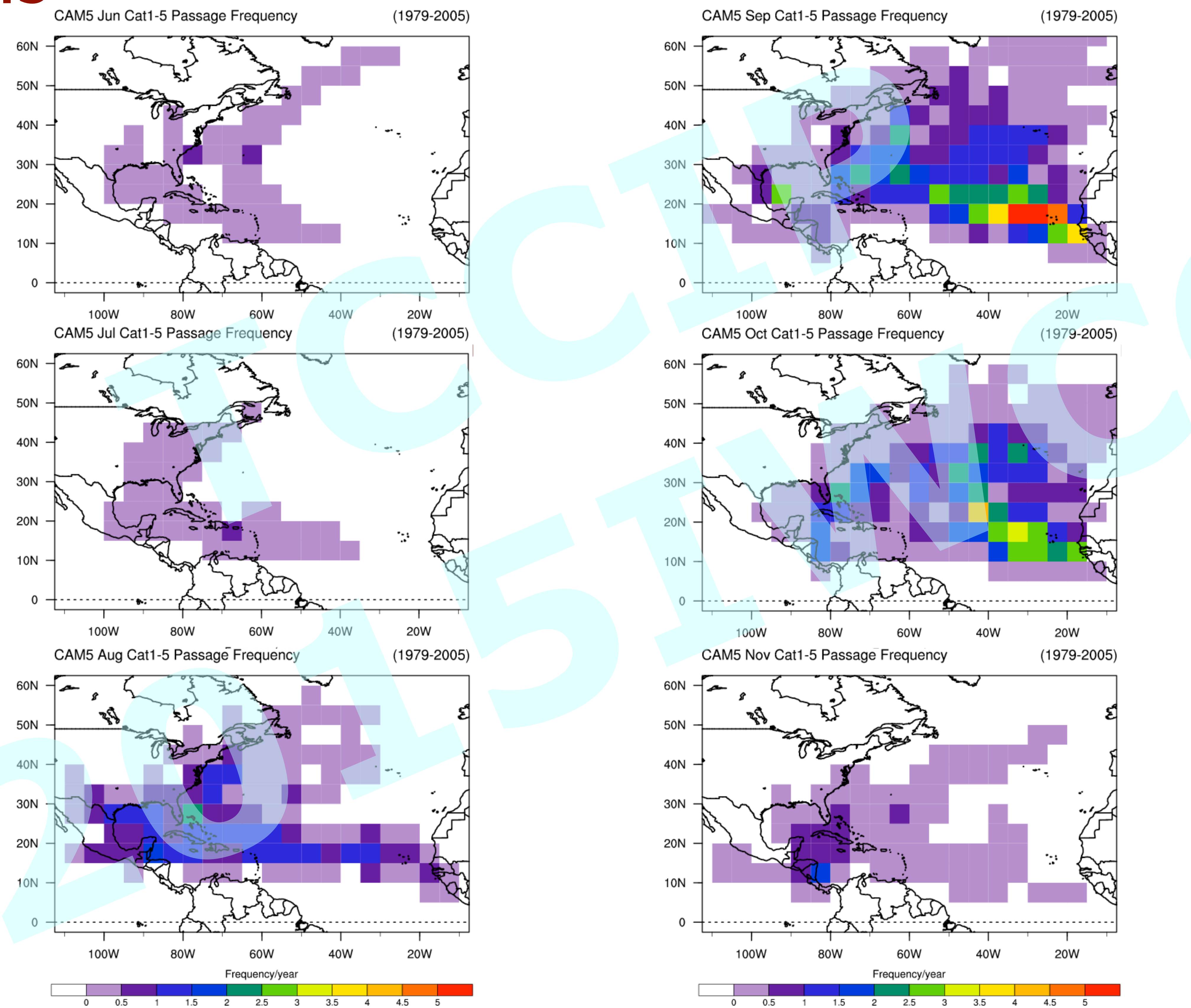
July

Aug.

Sep.

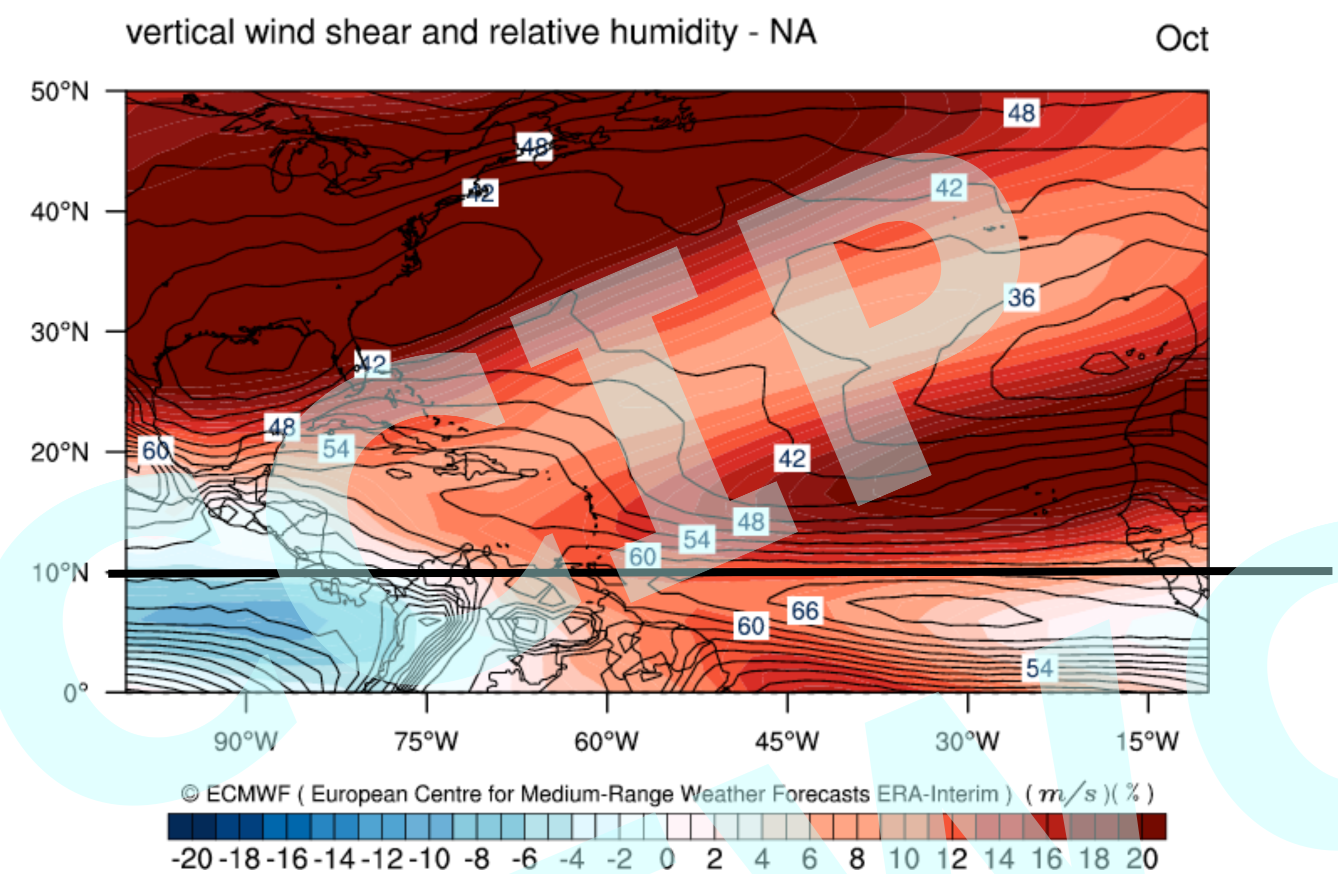
Oct.

Nov.

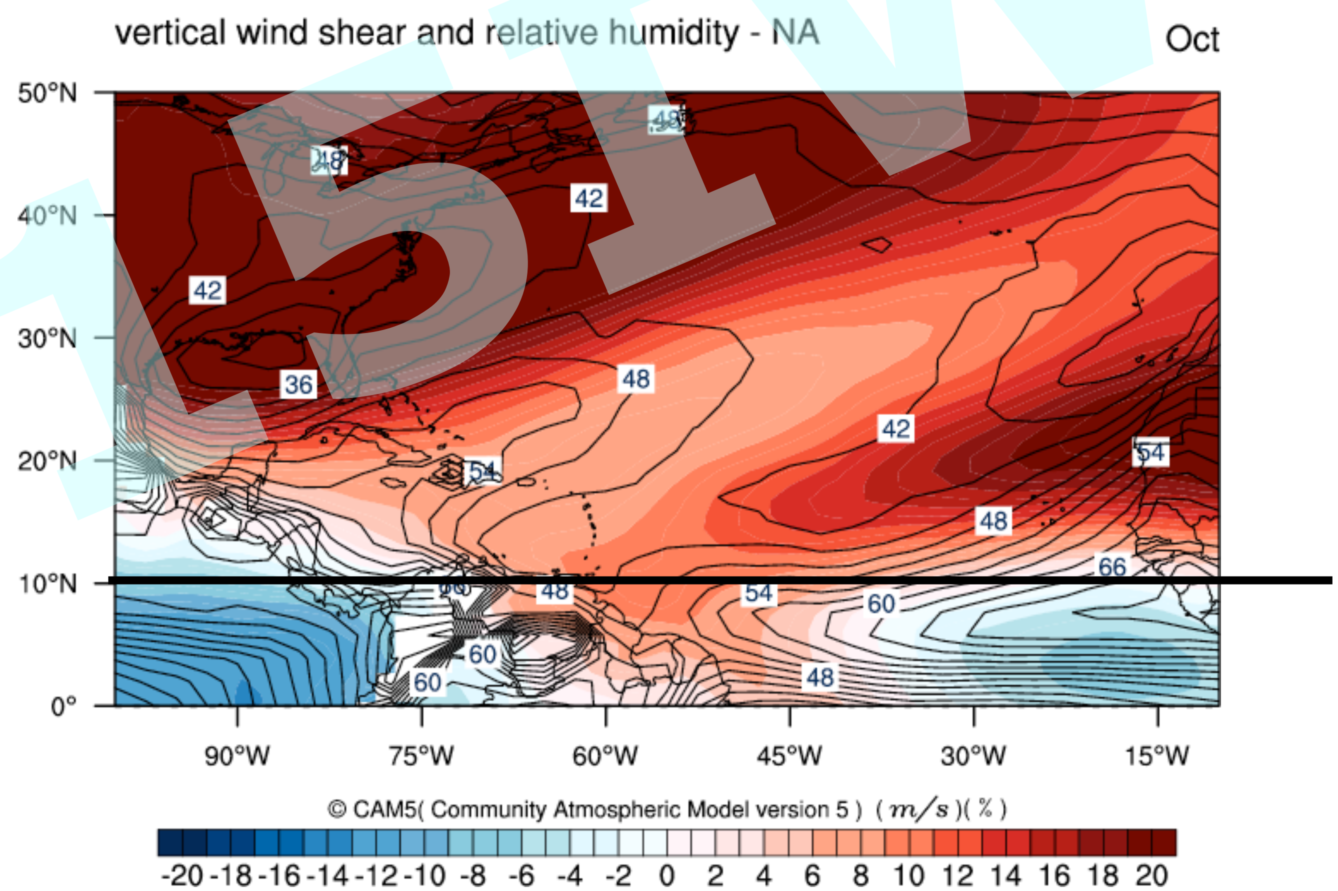


October zonal wind shear (shading) and RH (contour)

ERA interim



CAM5



Climatological Hurricane (Cat1-5) Track density by Month

MRI

Atlantic

June

Sep.

July

Oct.

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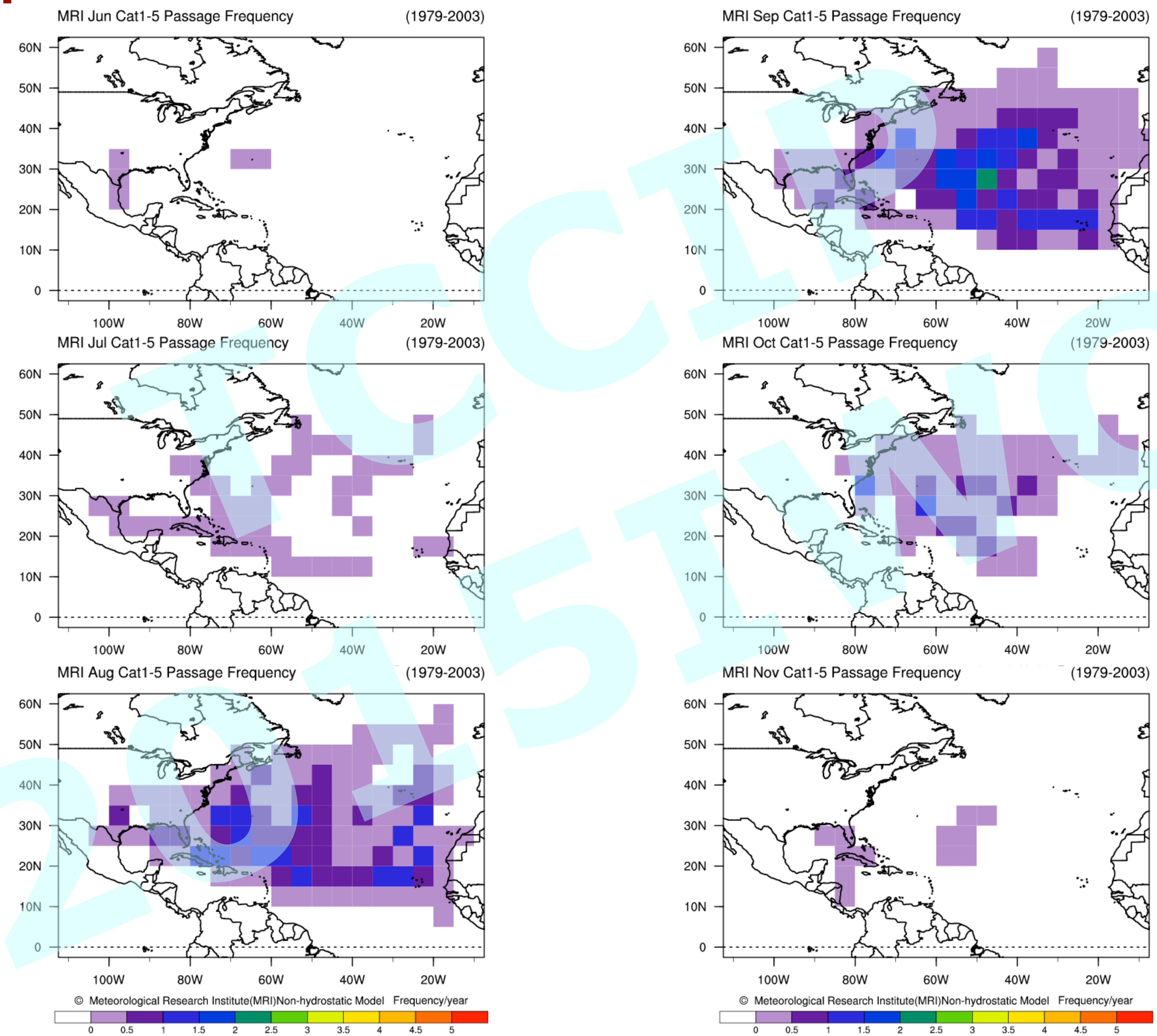
Nov.



Climatological Hurricane (Cat1-5) Track density by Month

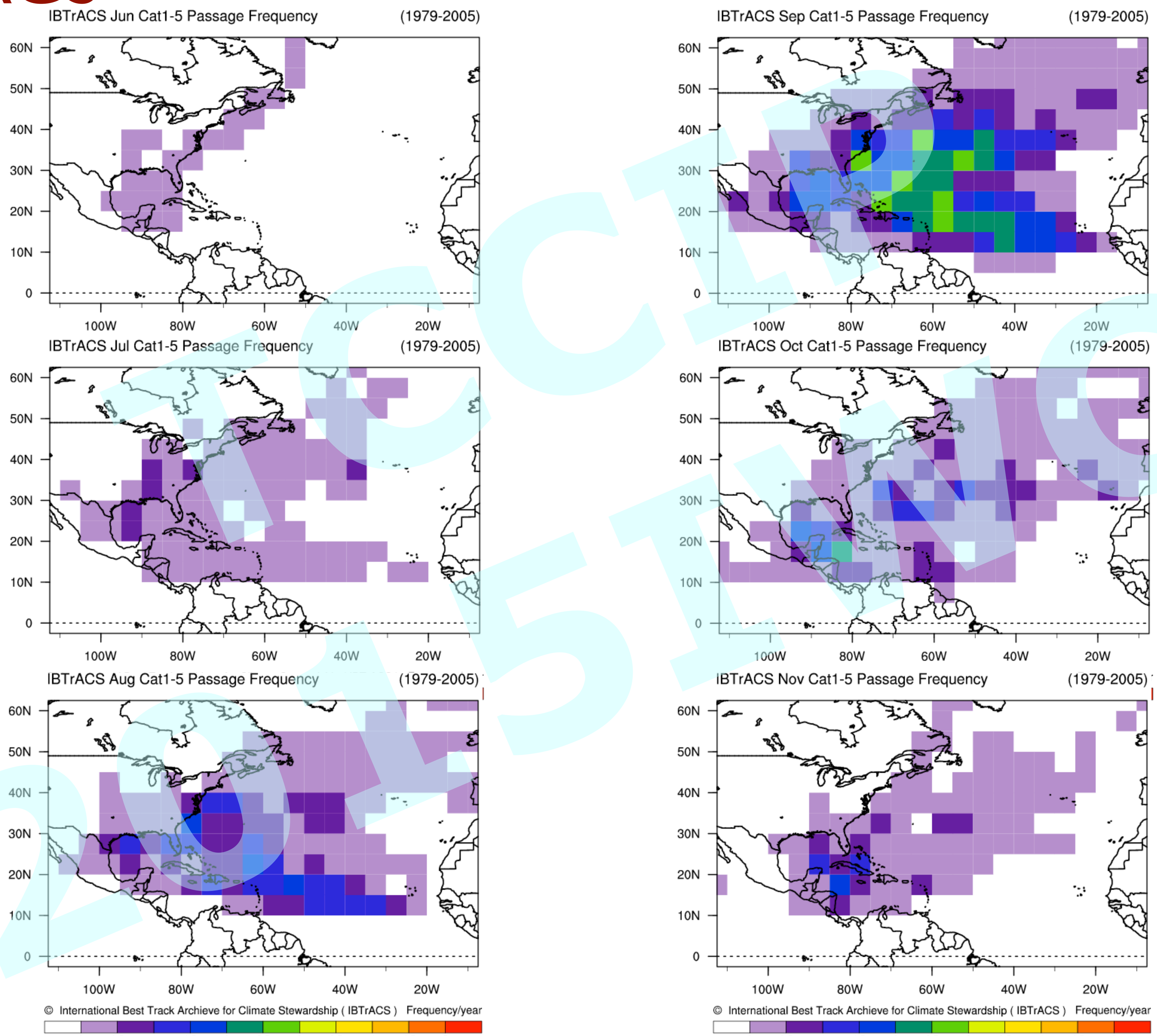
IBTrACS

Atlantic

June

July

Aug.



Sep.

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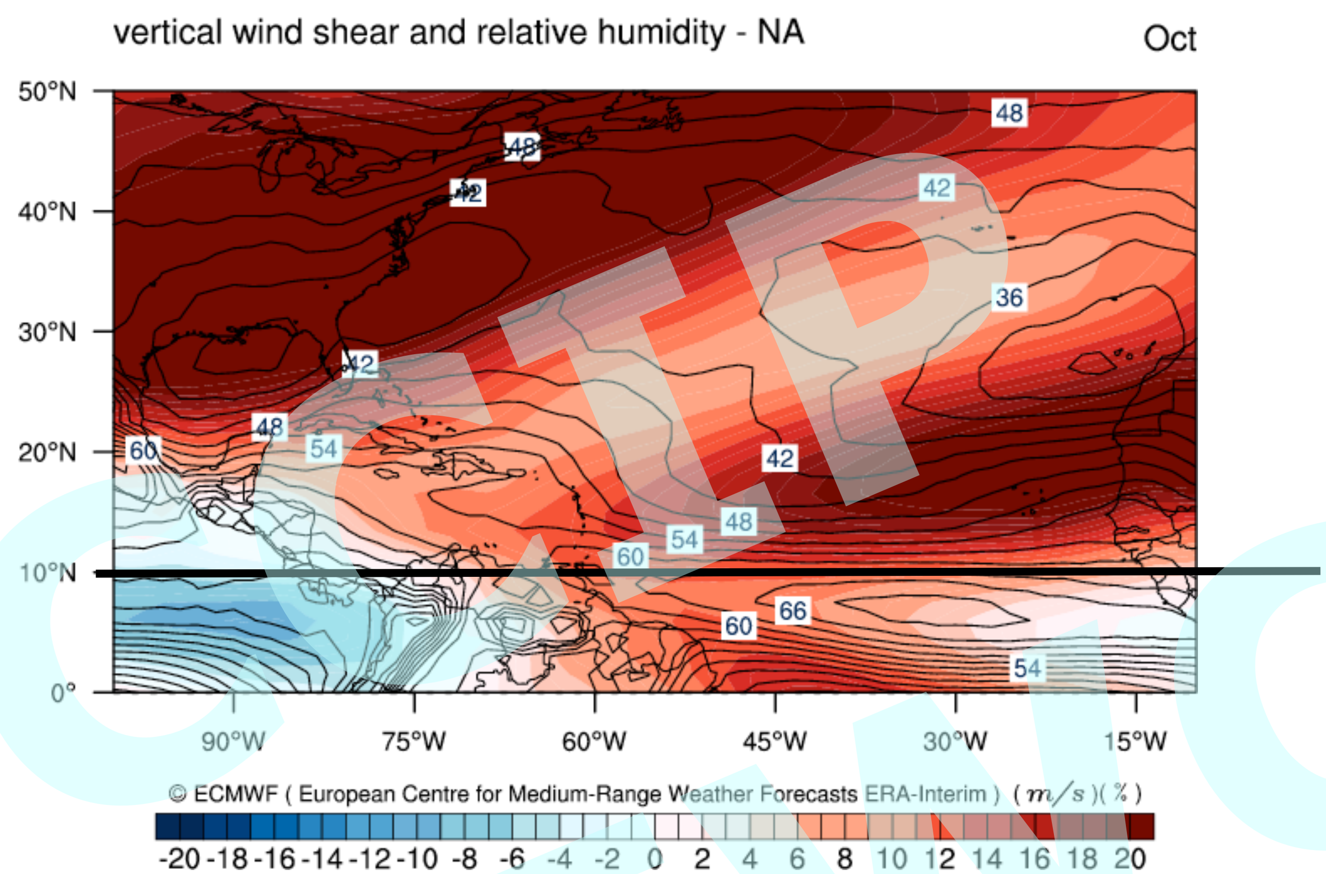
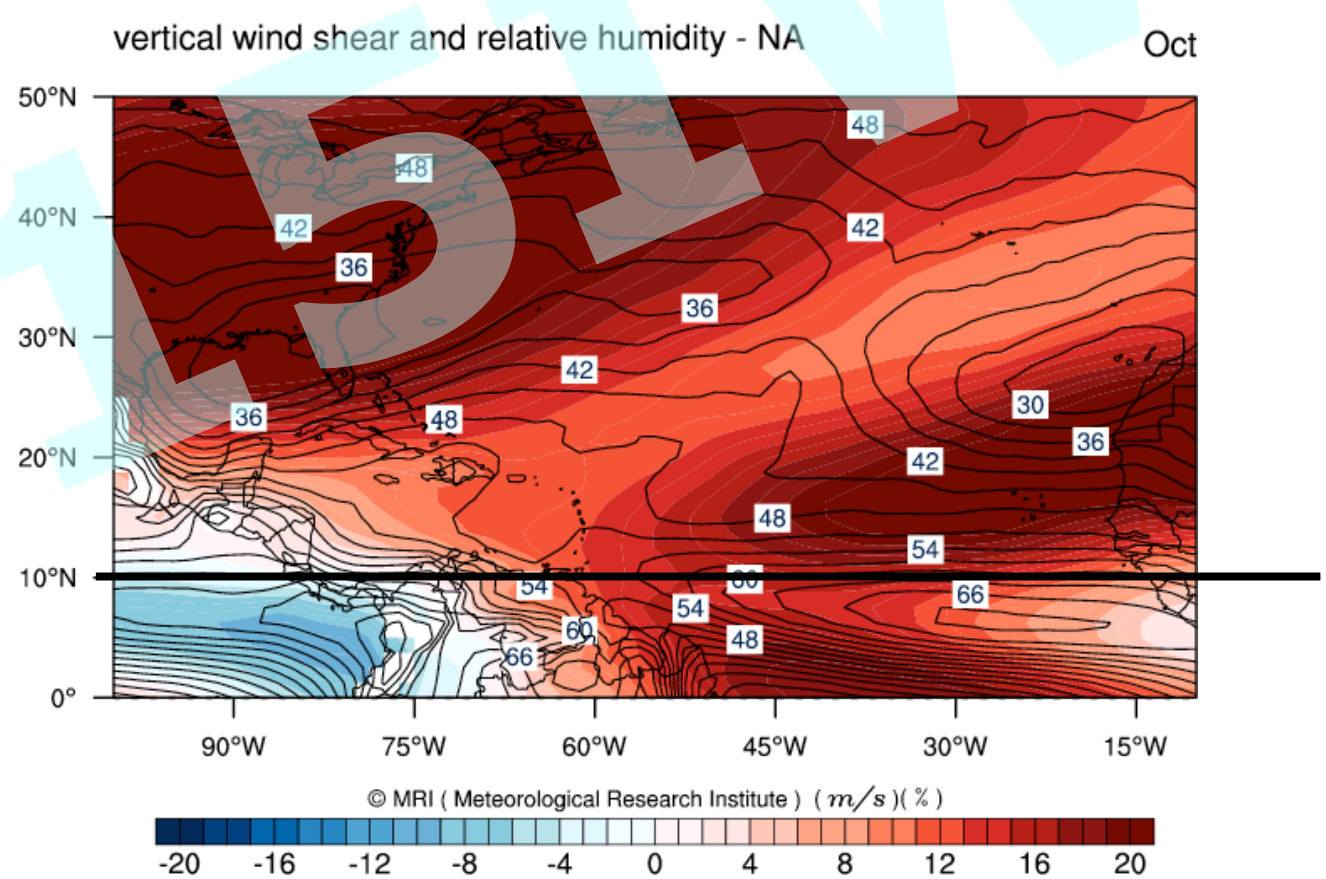


MRI



Climatological Hurricane (Cat1-5) Track density by Month

IBTrACS

Atlantic

June

July

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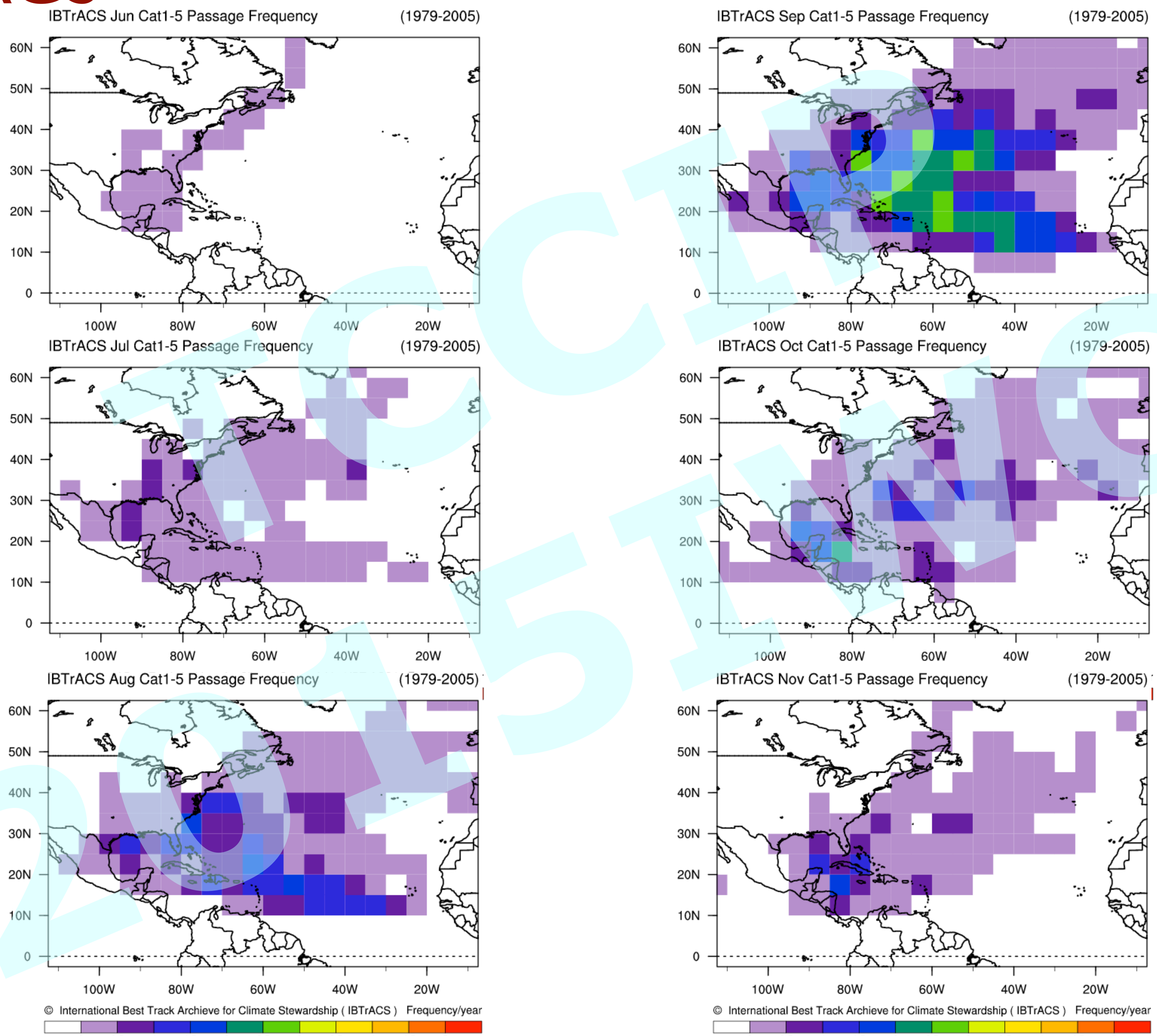

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Climatological Hurricane (Cat1-5) Track density by Month

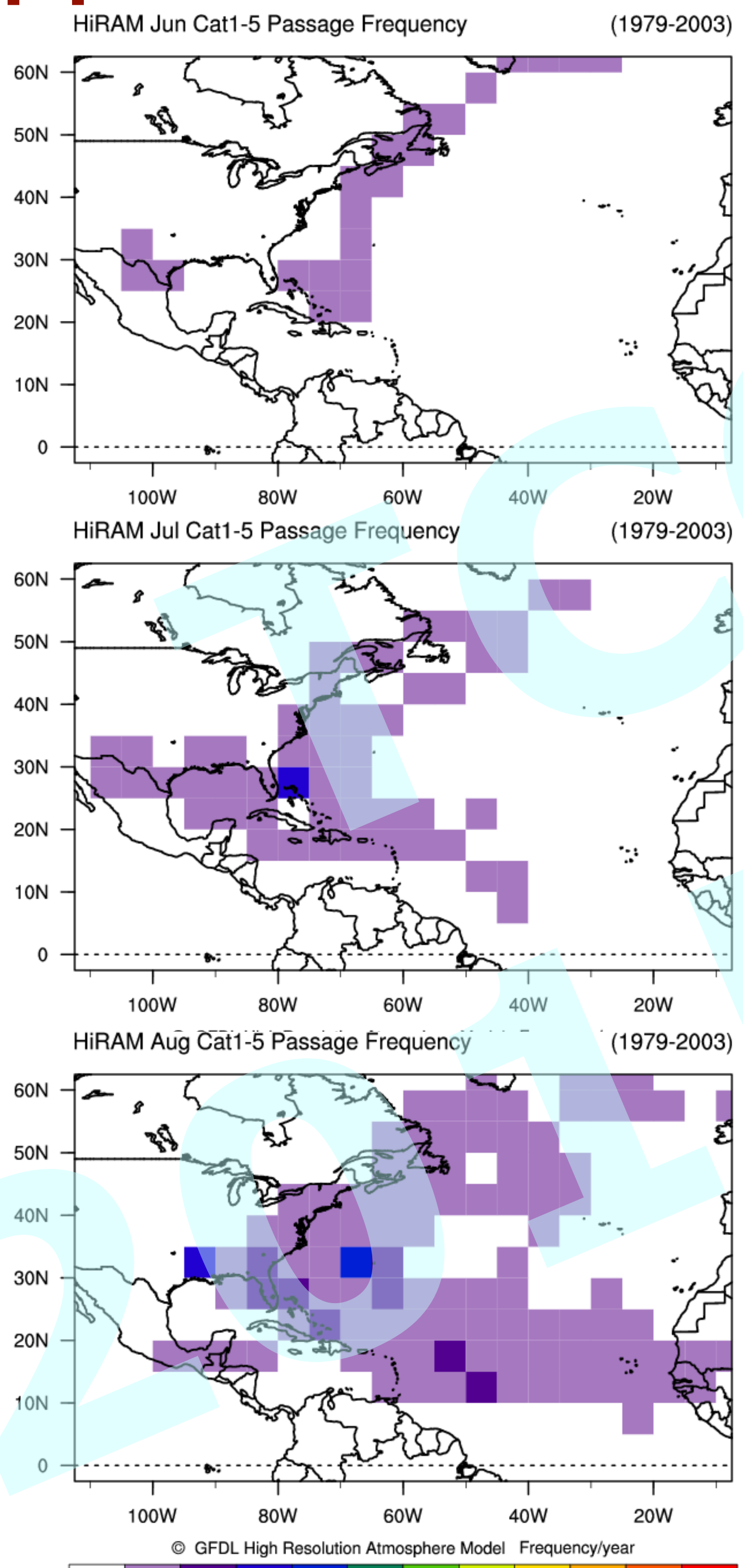
HiRAM

Atlantic

June

July

Aug.



Sep.

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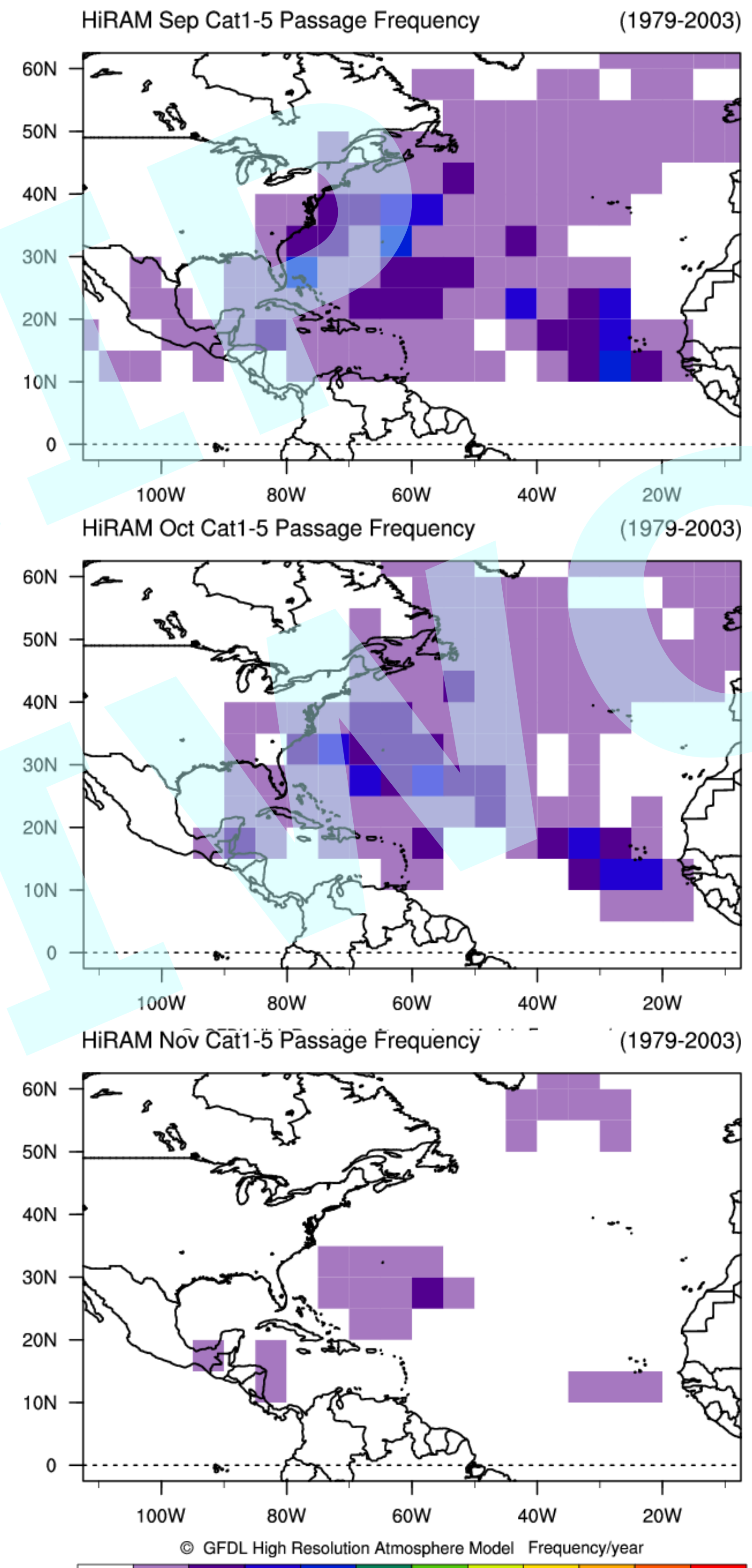


For NW Pacific, monthly mean genesis position are closely associated with the position and movement of the mean monsoon trough from June to November.

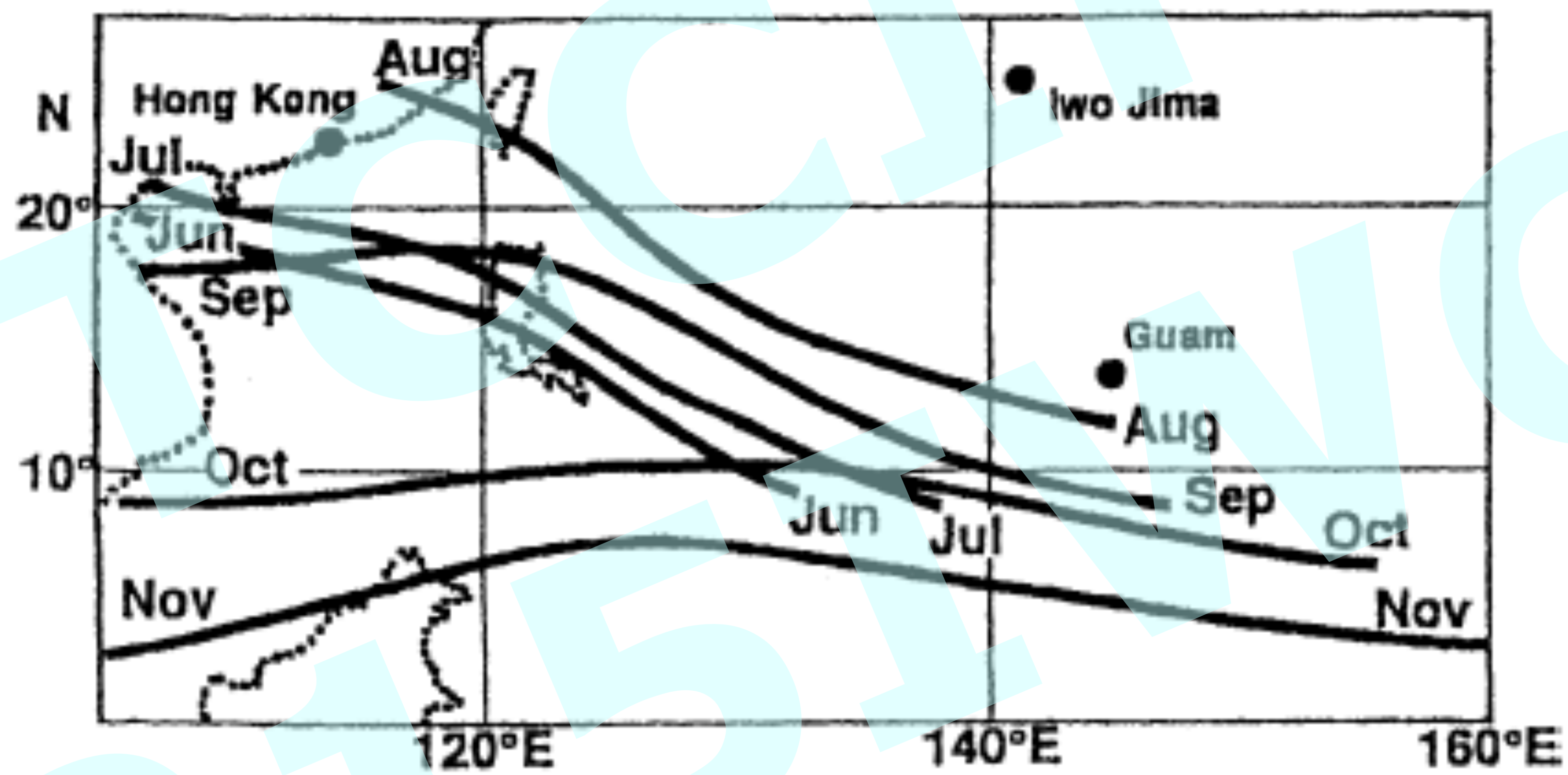


FIG. 3. Typical migration of the axis of the monsoon trough indicated by its mean monthly positions during Jun–Nov (after Atkinson 1971).

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

Climatological Typhoon (Cat1-5) Genesis by Month

IBTrACS

NW Pacific

June

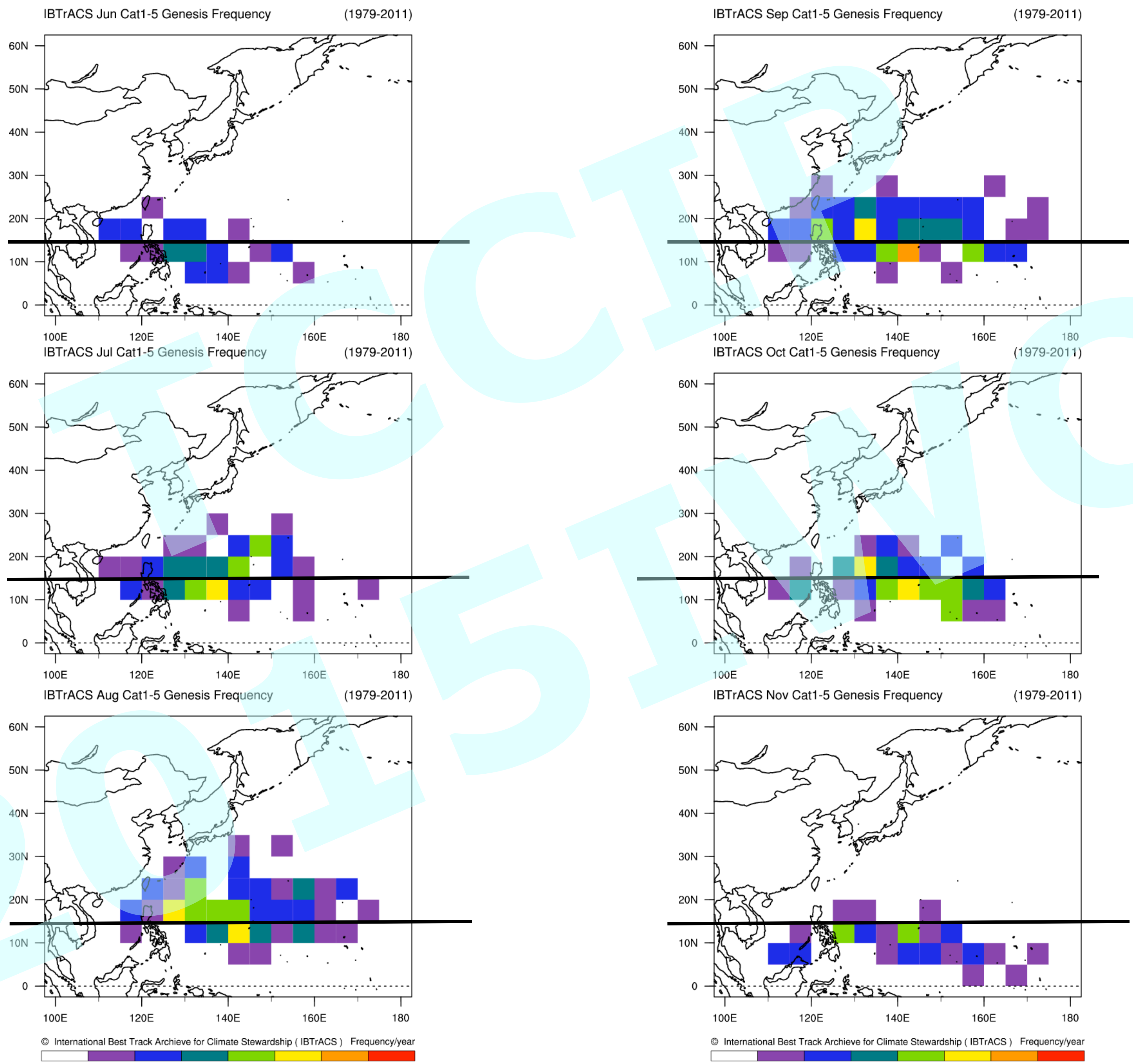
July

Aug.

Sep.

Oct.

Nov.



Climatological Typhoon (Cat1-5) Genesis by Month

MRI

NW Pacific

June

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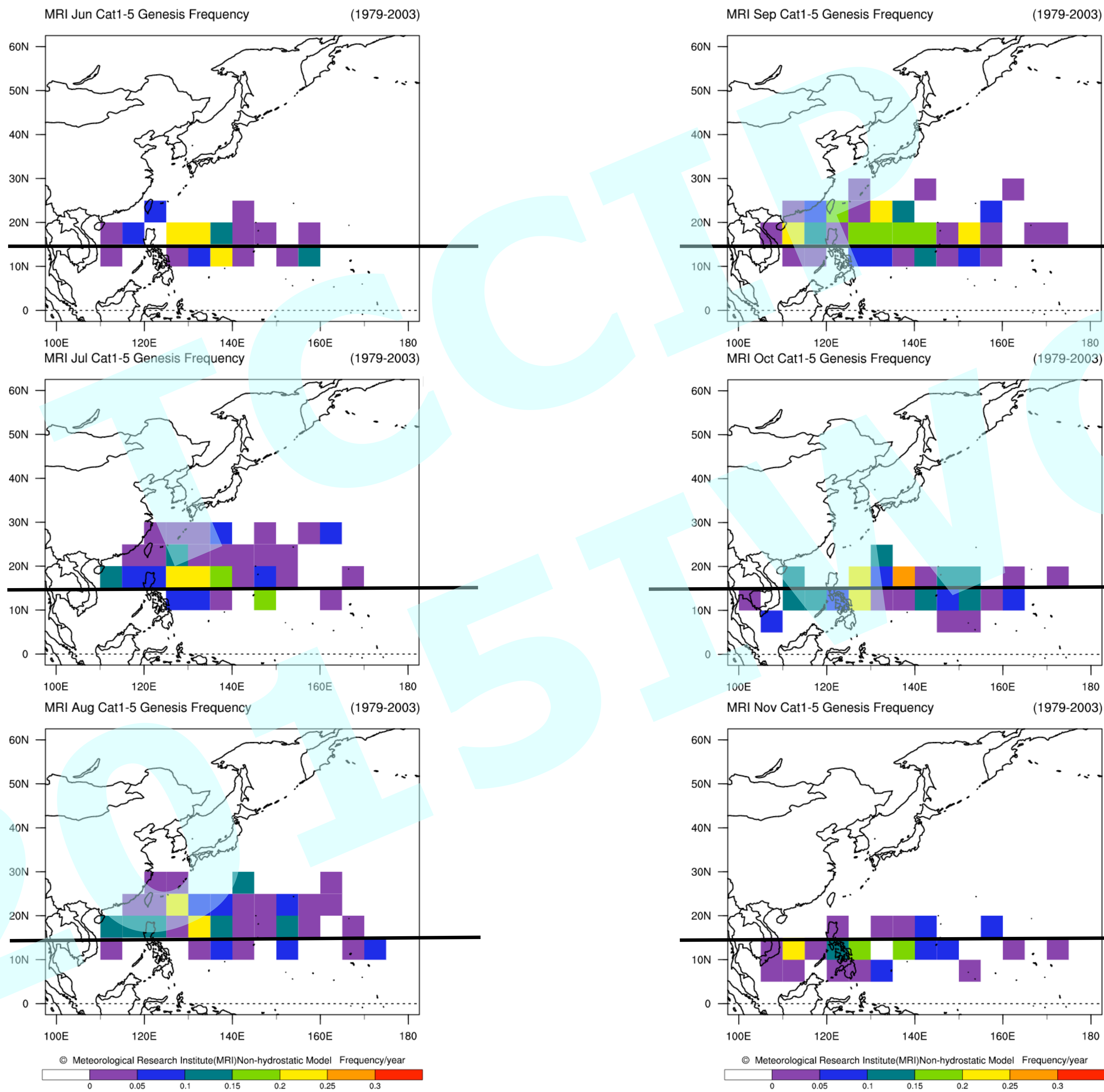

Climatological Typhoon (Cat1-5) Genesis by Month

CAM5

NW Pacific

June

July

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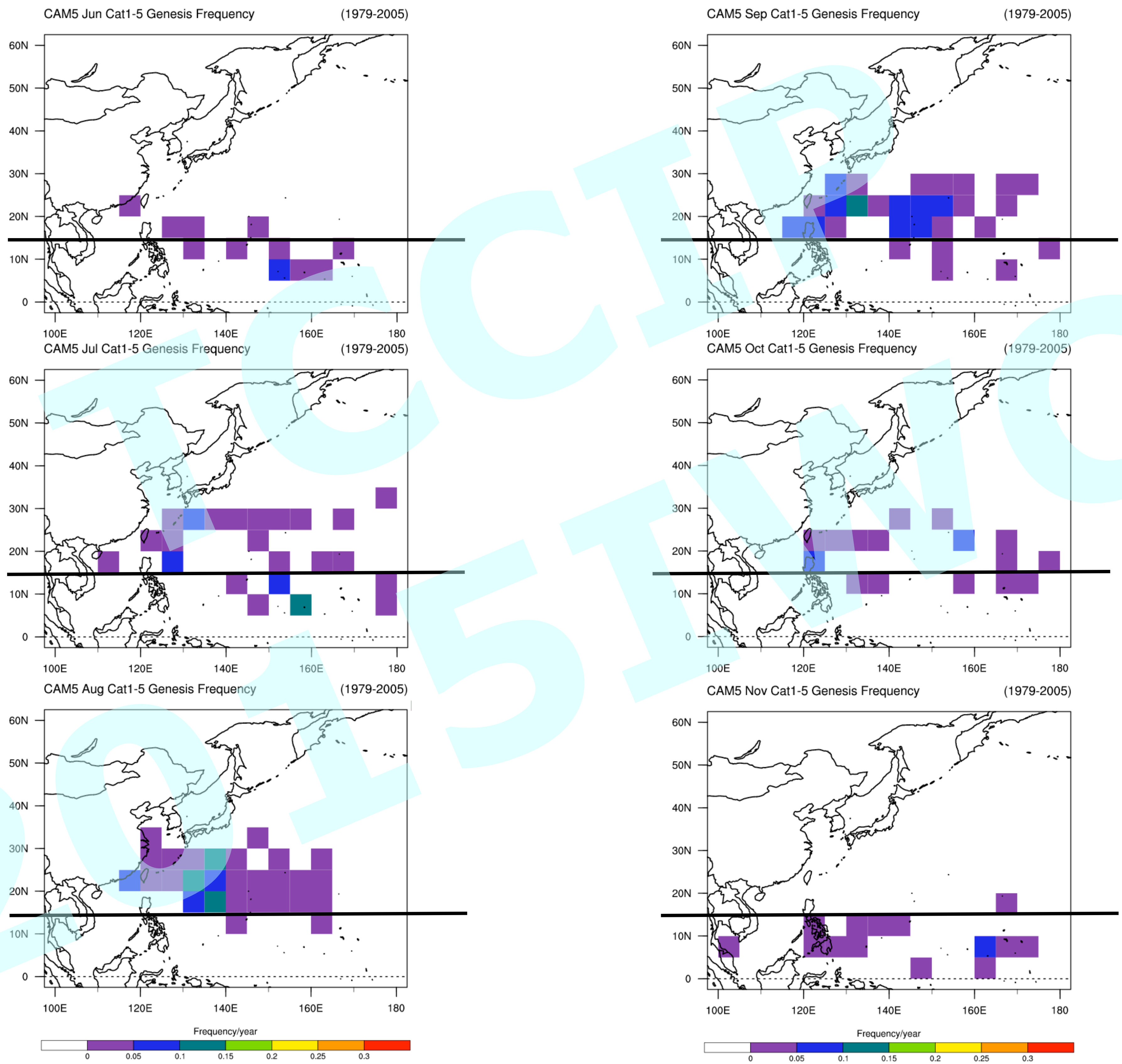
Oct.

Nov.



Climatological Typhoon (Cat1-5) Genesis by Month

IBTrACS

NW Pacific

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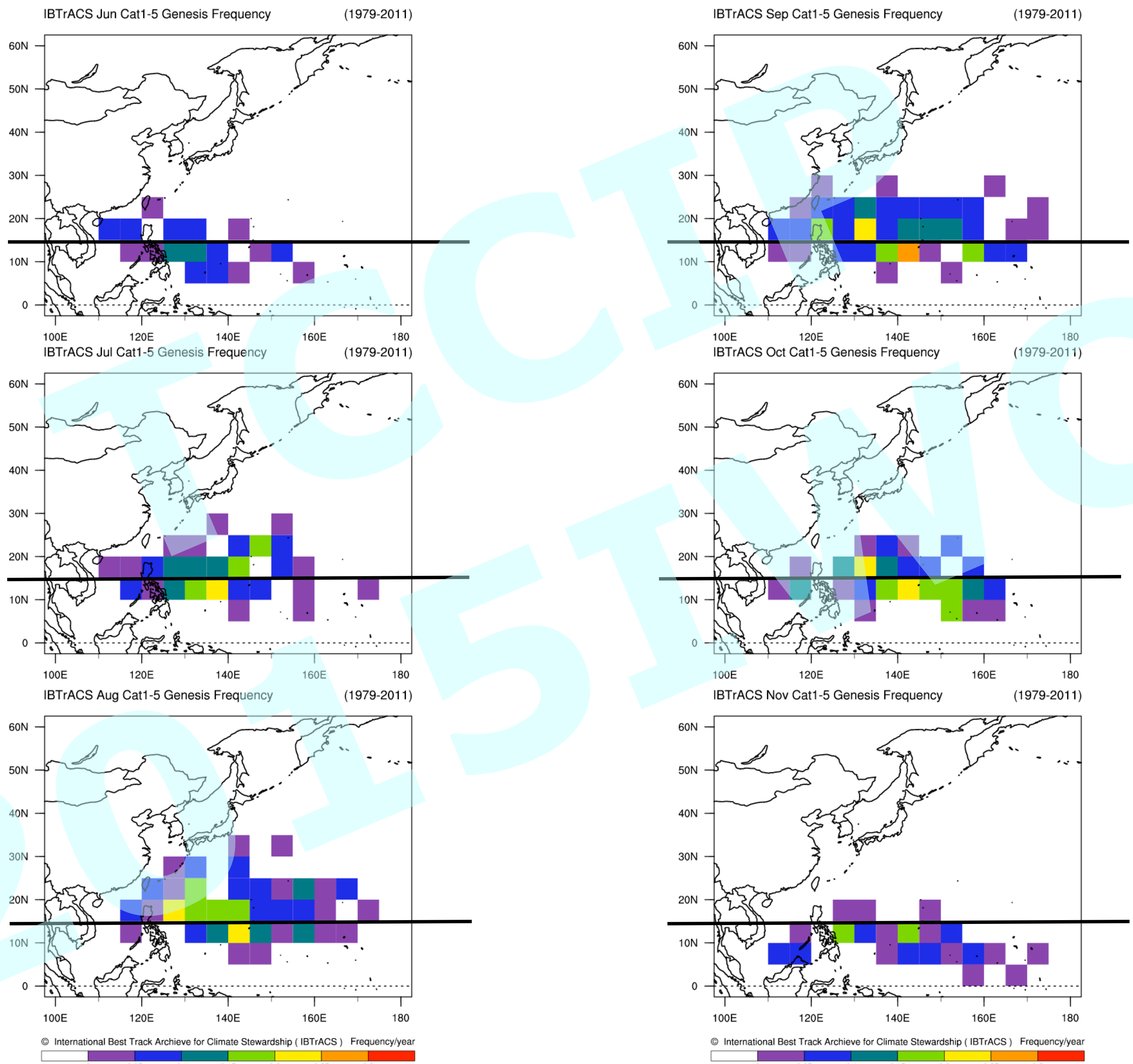
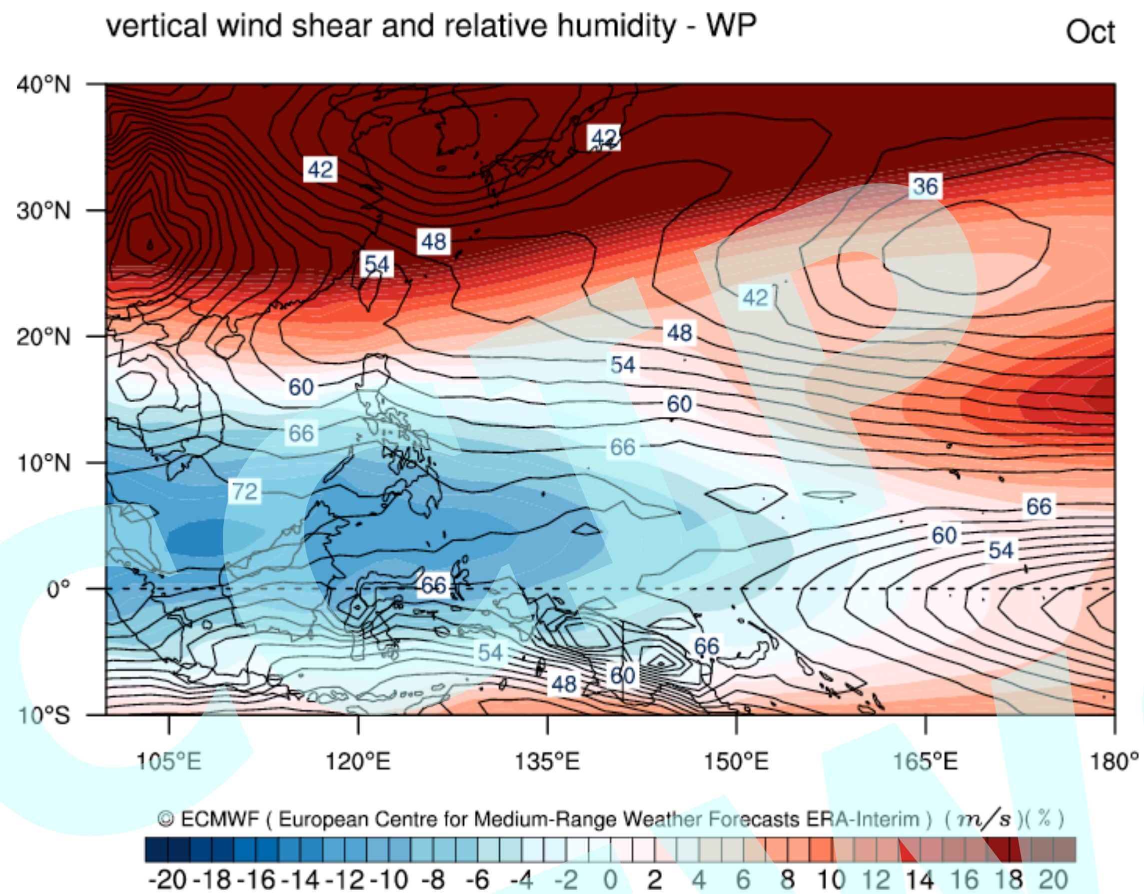
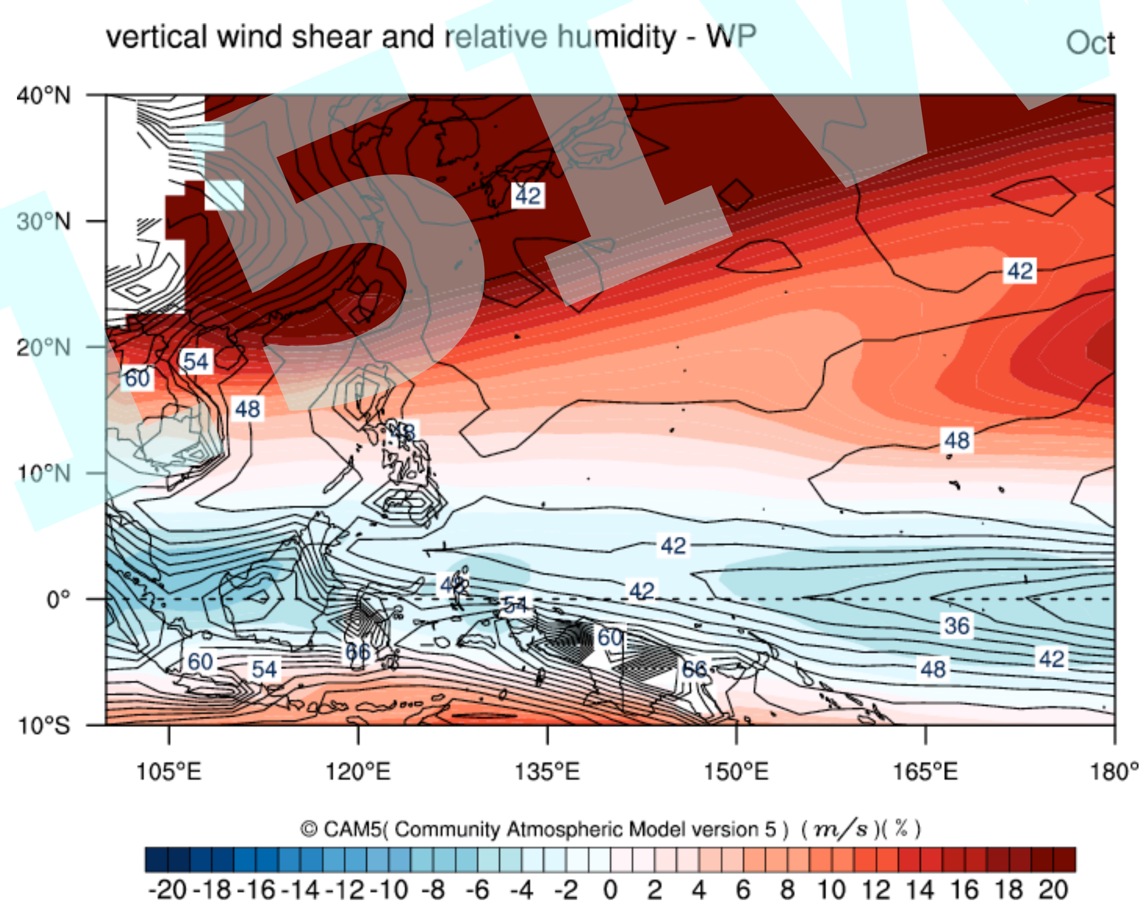


October zonal wind shear (shading) and RH (contour)

ERA interim



CAM5



Climatological Typhoon (Cat1-5) Genesis by Month

IBTrACS

NW Pacific

June

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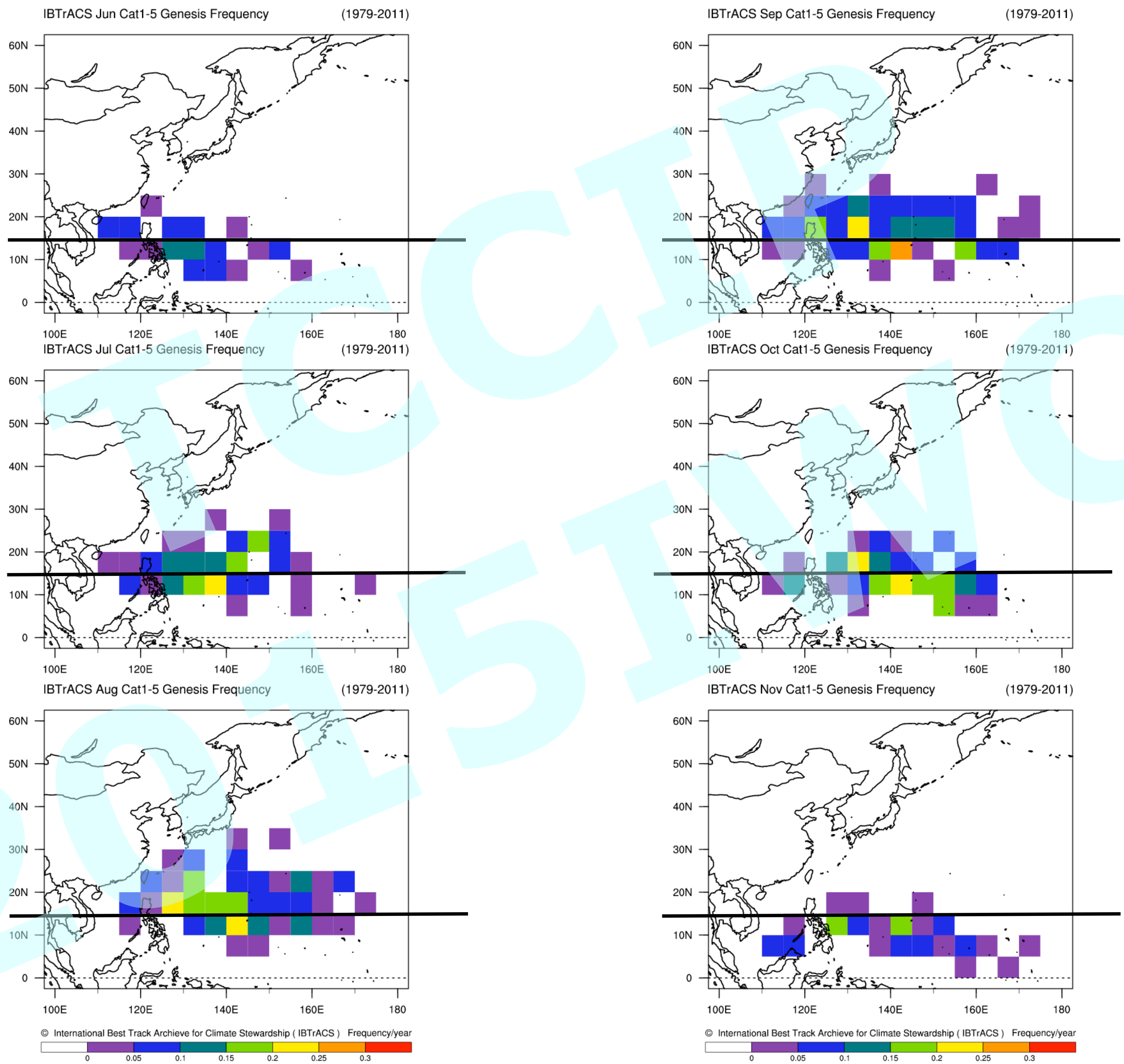


Climatological Typhoon (Cat1-5) Genesis by Month

HiRAM

NW Pacific

June

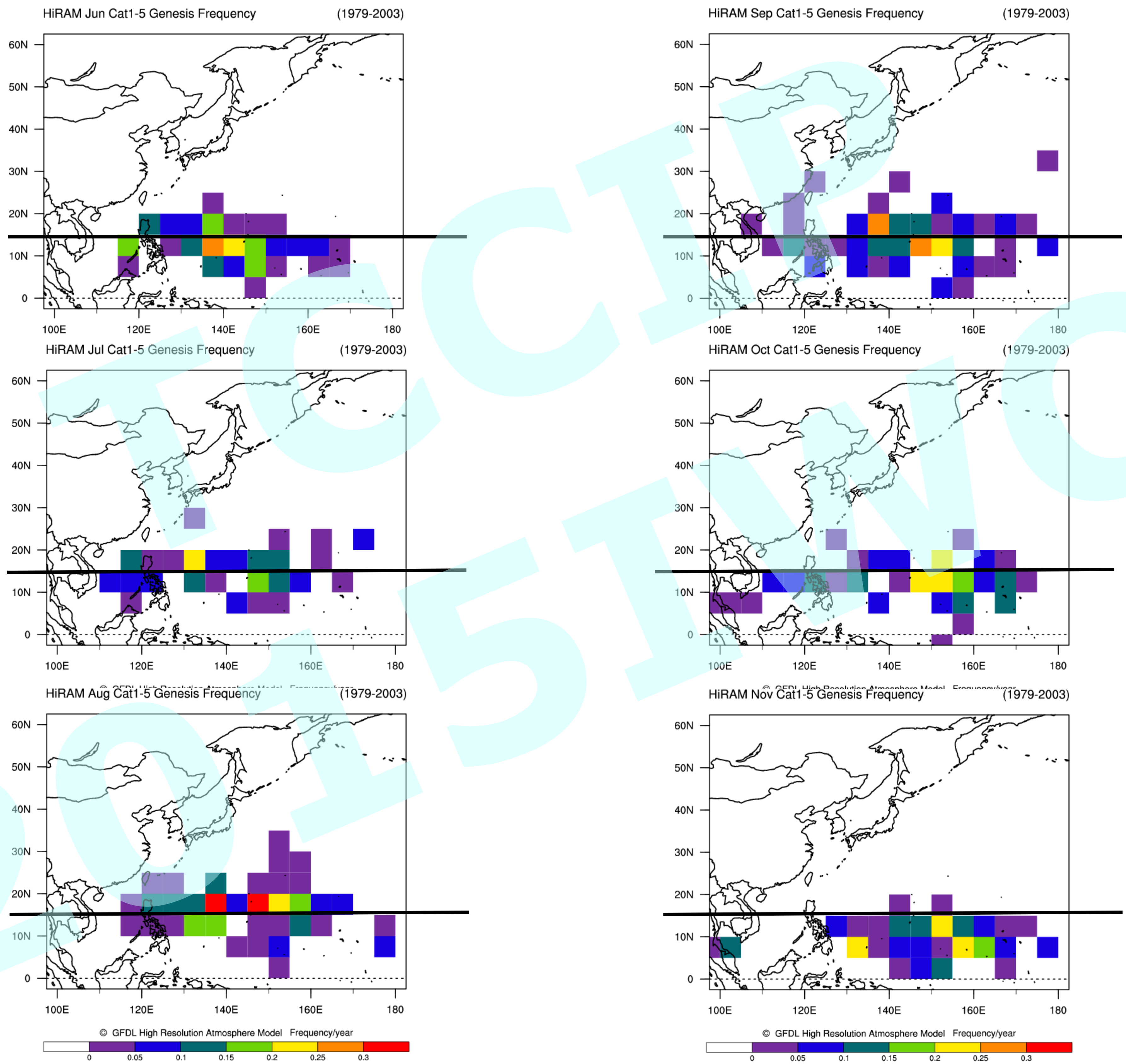
Sep.

July

Oct.

Aug.

Nov.

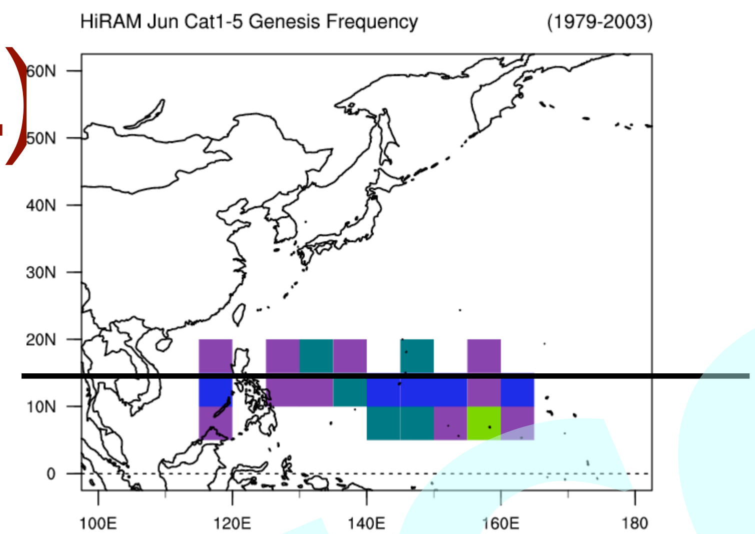


Climatological Typhoon (Cat1-5) Genesis by Month

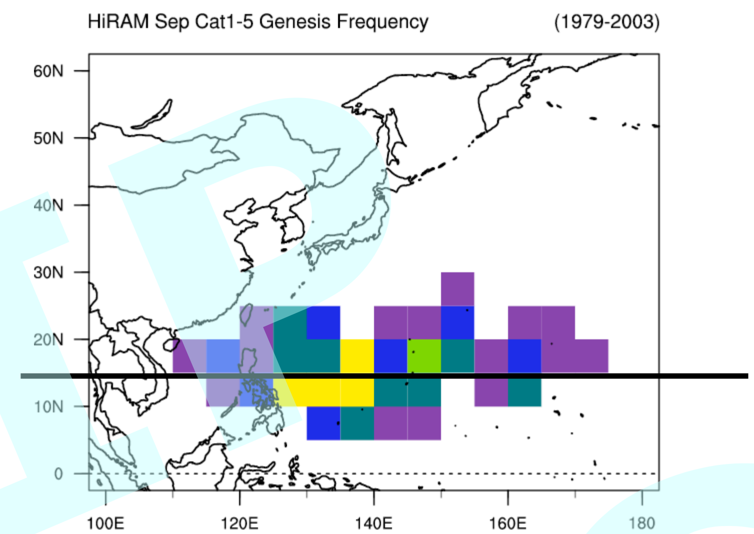
HiRAM (GFDL)

NW Pacific

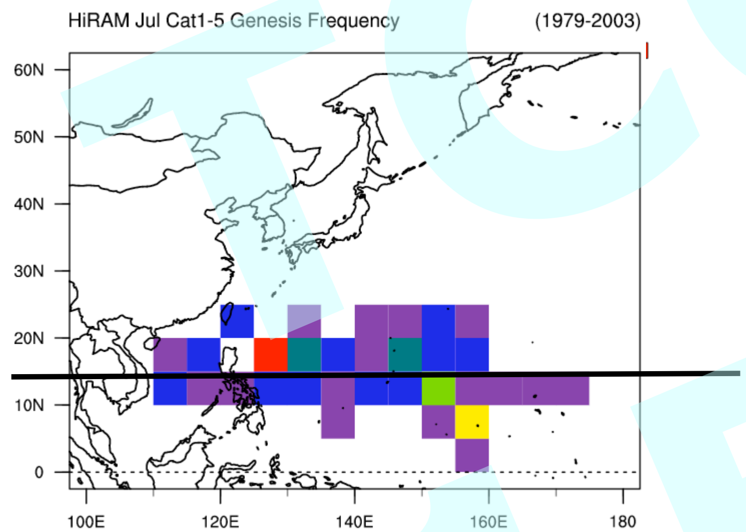
June



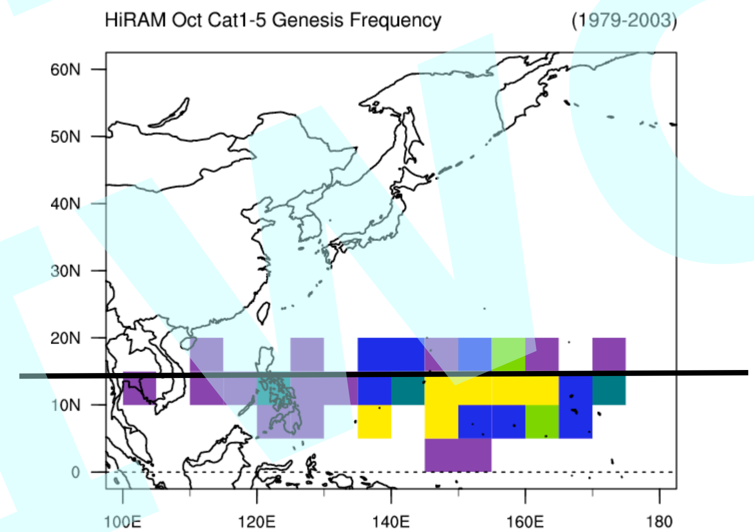
Sep.



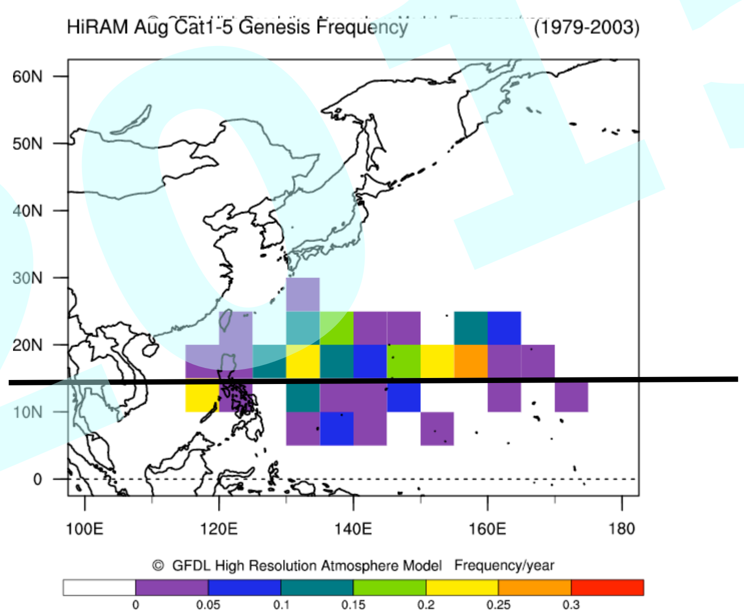
July



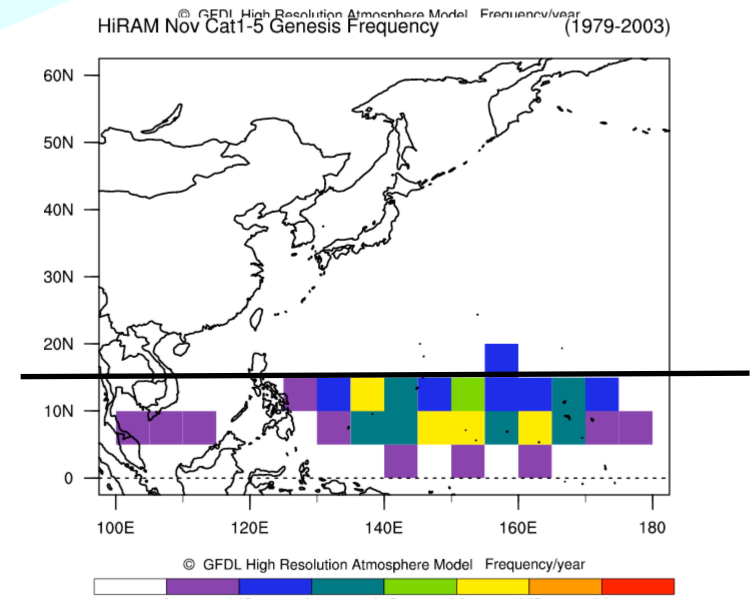
Oct.



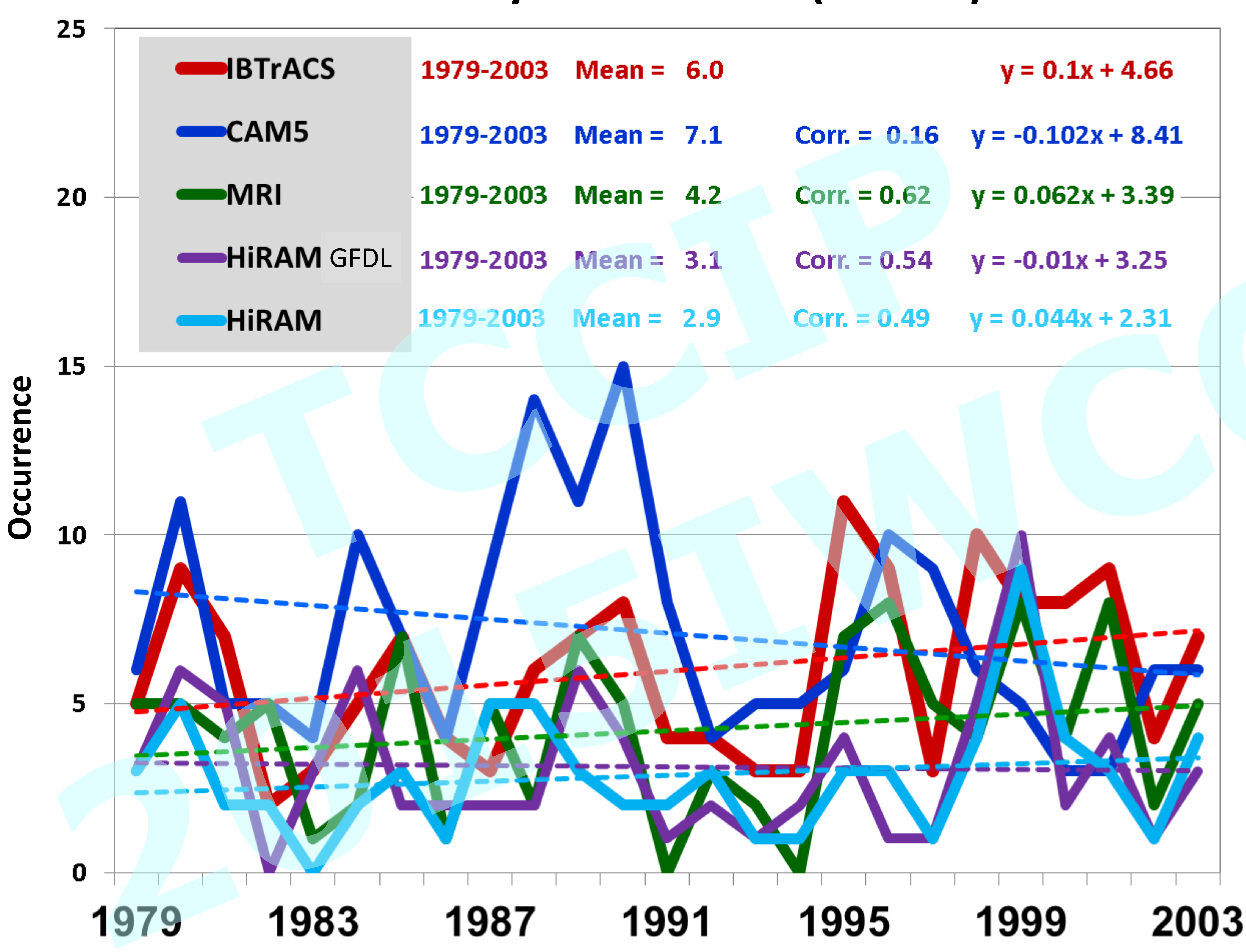
Aug.



Nov.



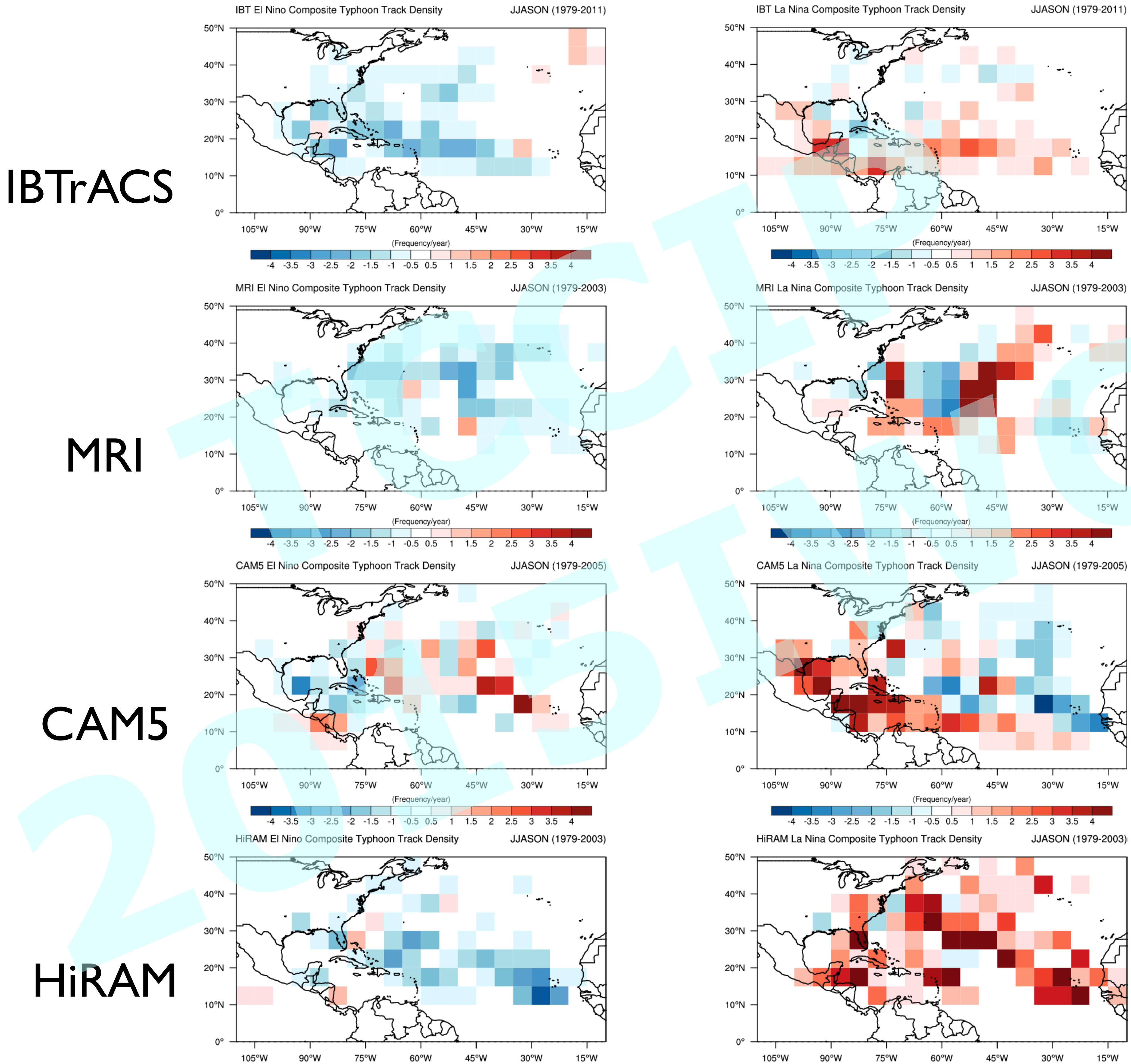
Interannual Variability of Hurricane (Cat 1-5) N Atlantic



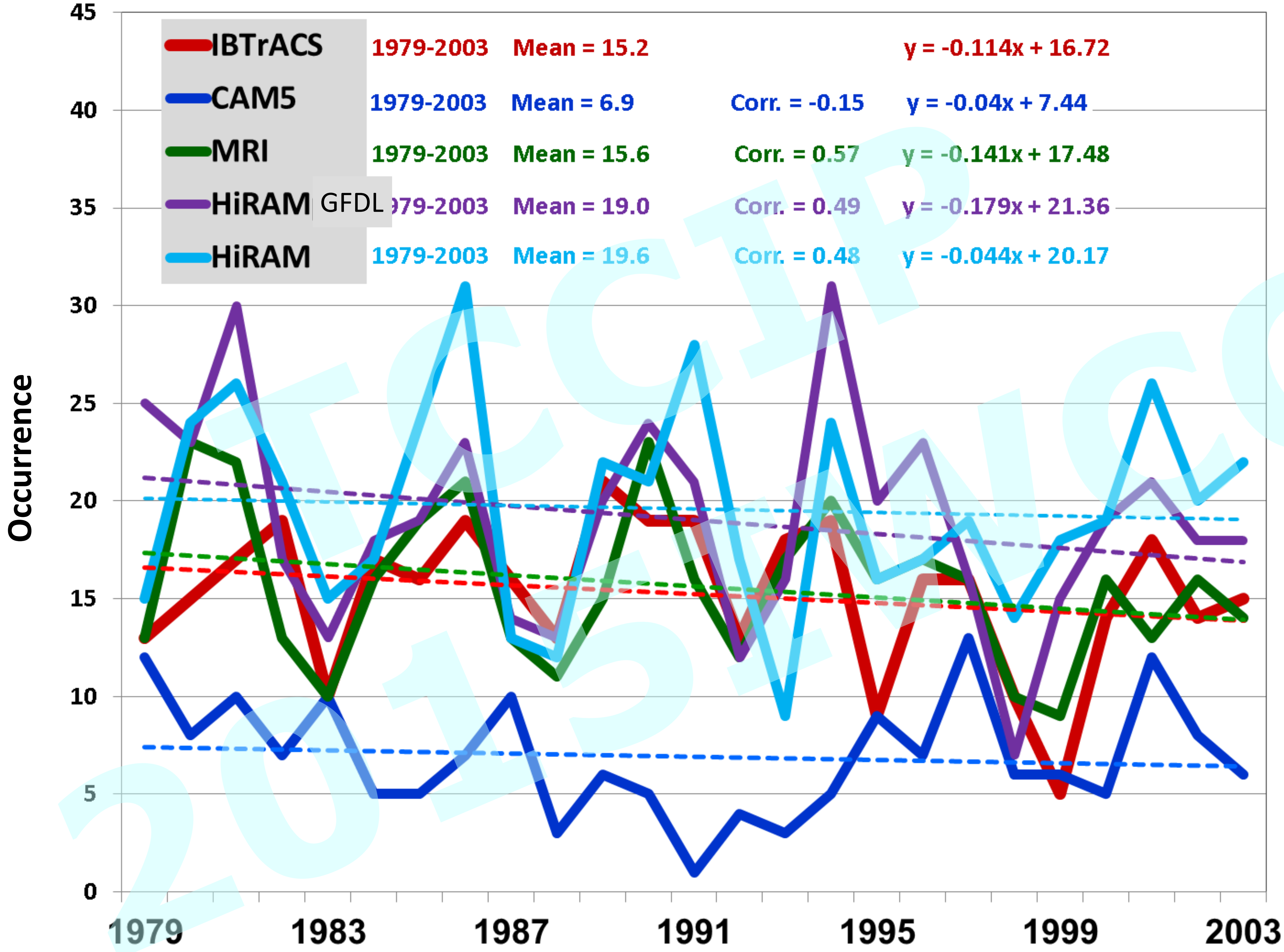
N Atlantic

El Nino

La Nina



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



NW Pacific

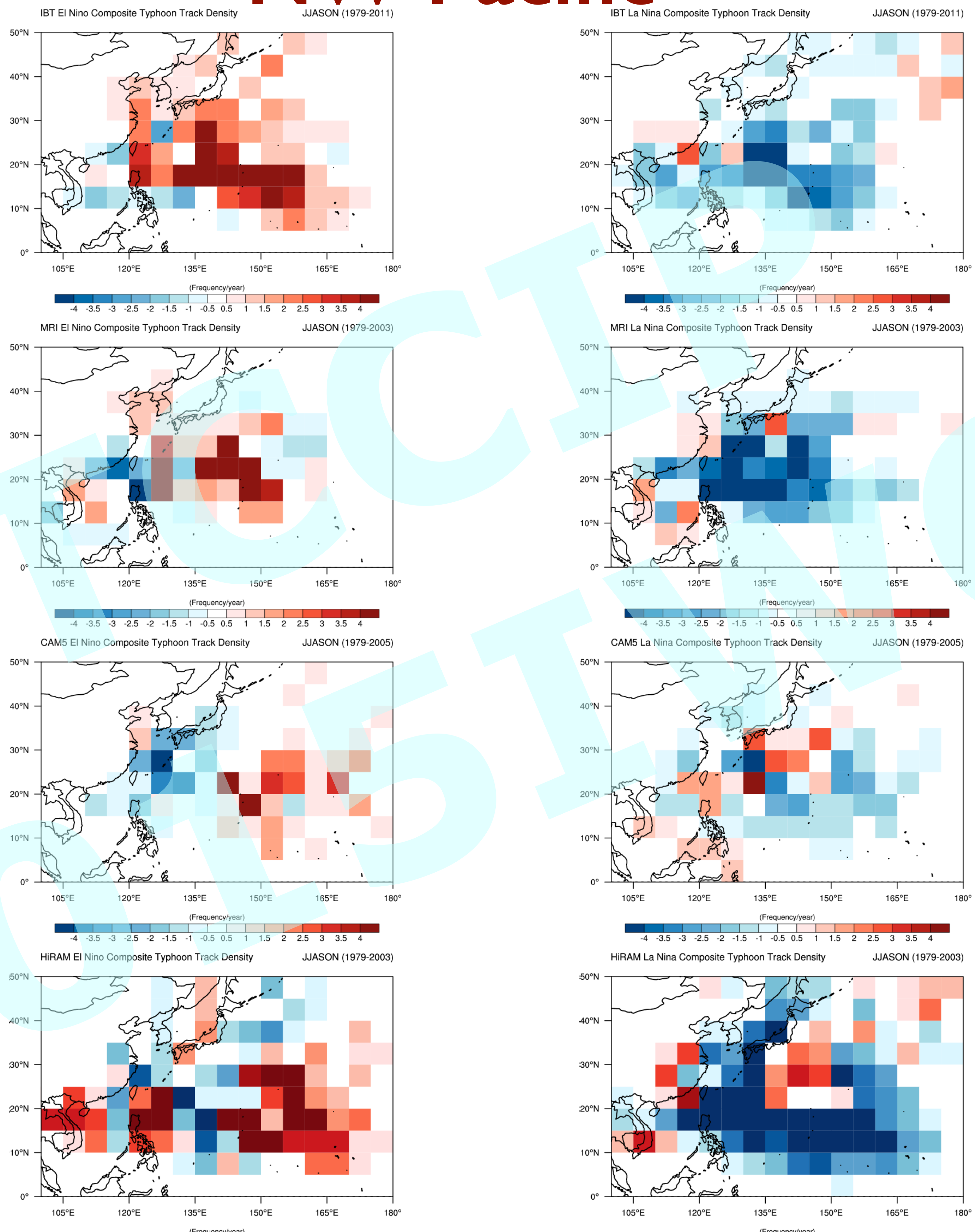
El Nino | La Nina

IBTrACS | IBTrACS

MRI | MRI

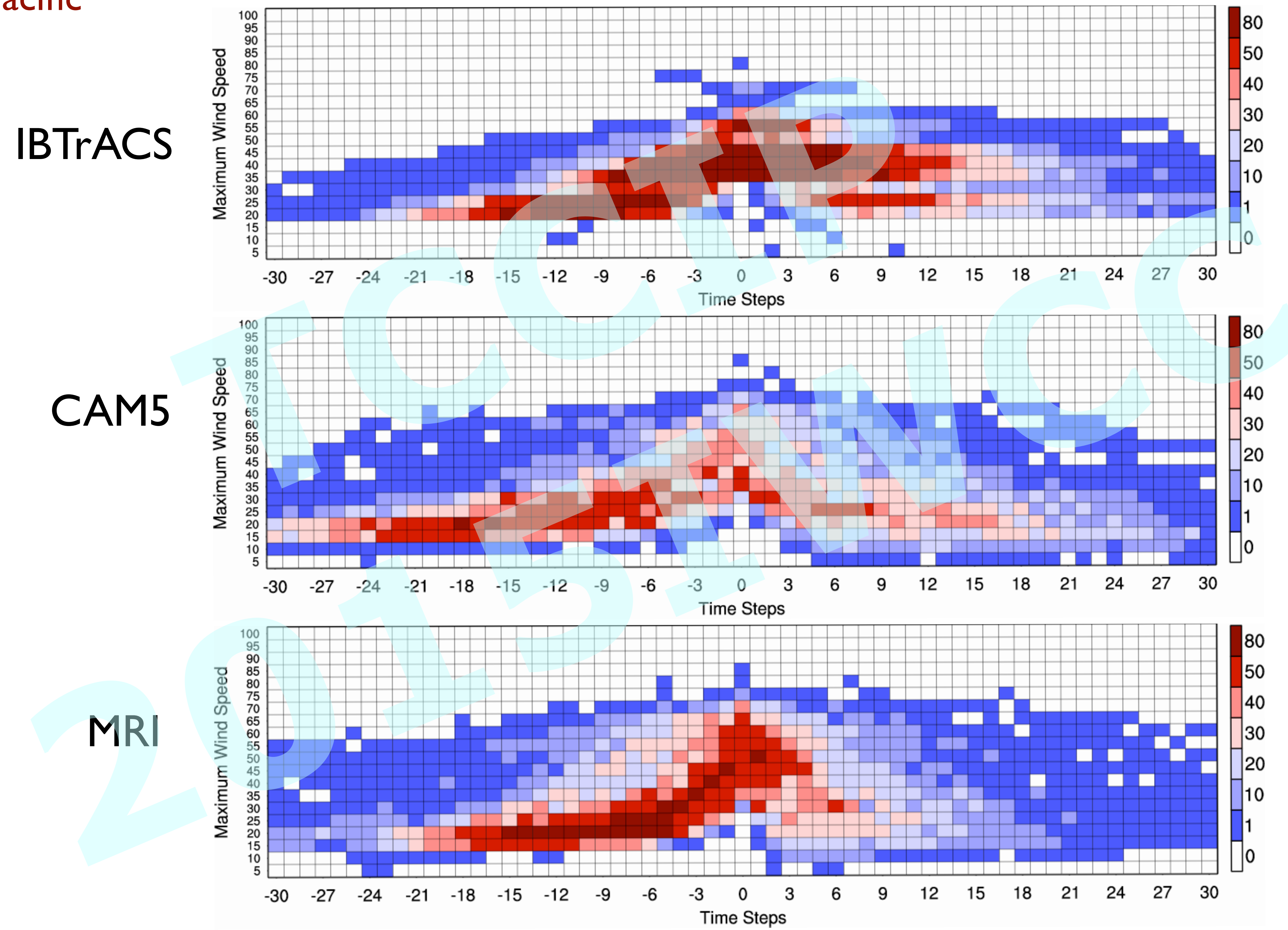
CAM5 | CAM5

HiRAM | HiRAM



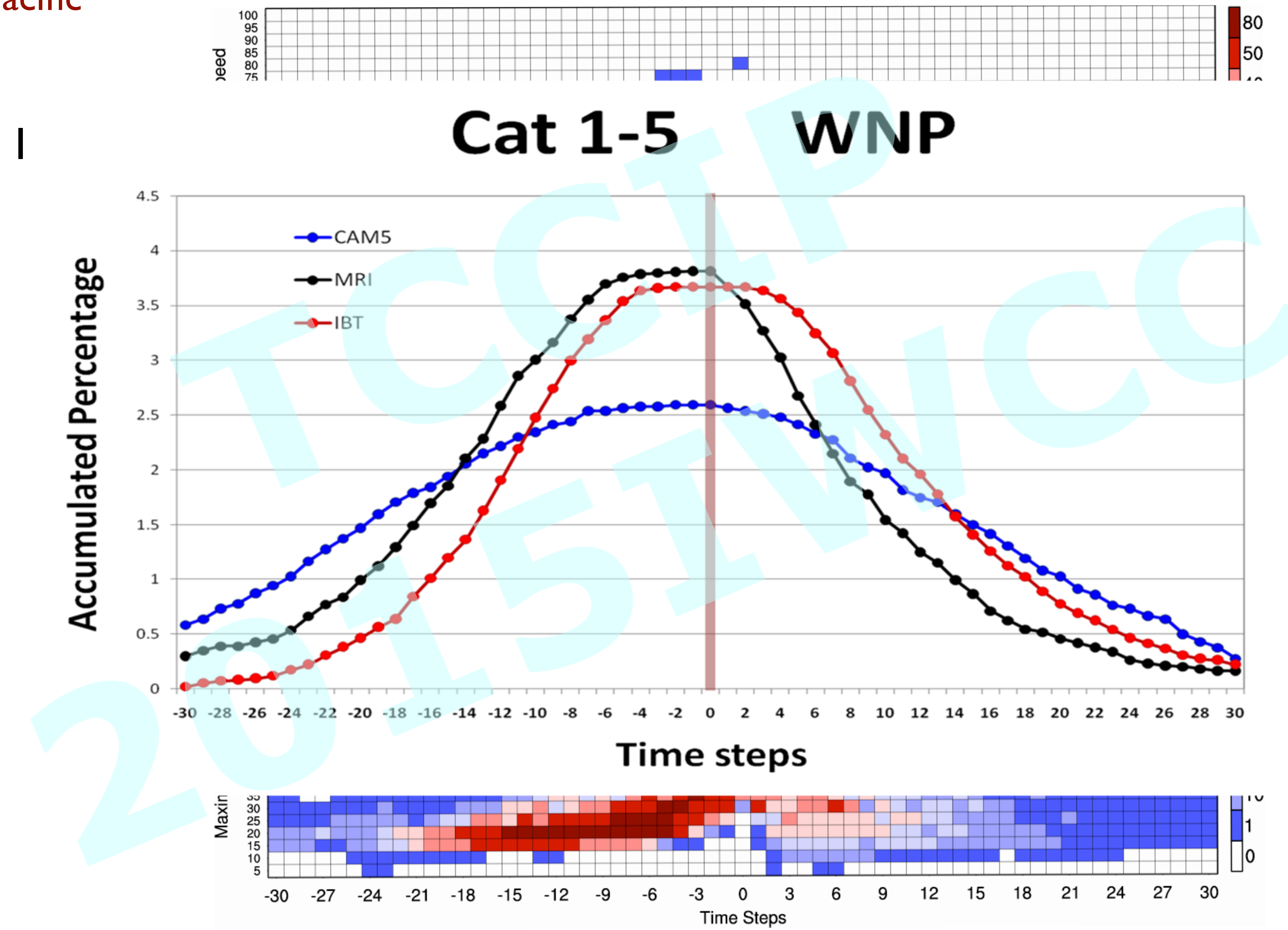
Normalized 2D Frequency Distribution of Max Wind and Time Relative to Peak Intensity

W Pacific

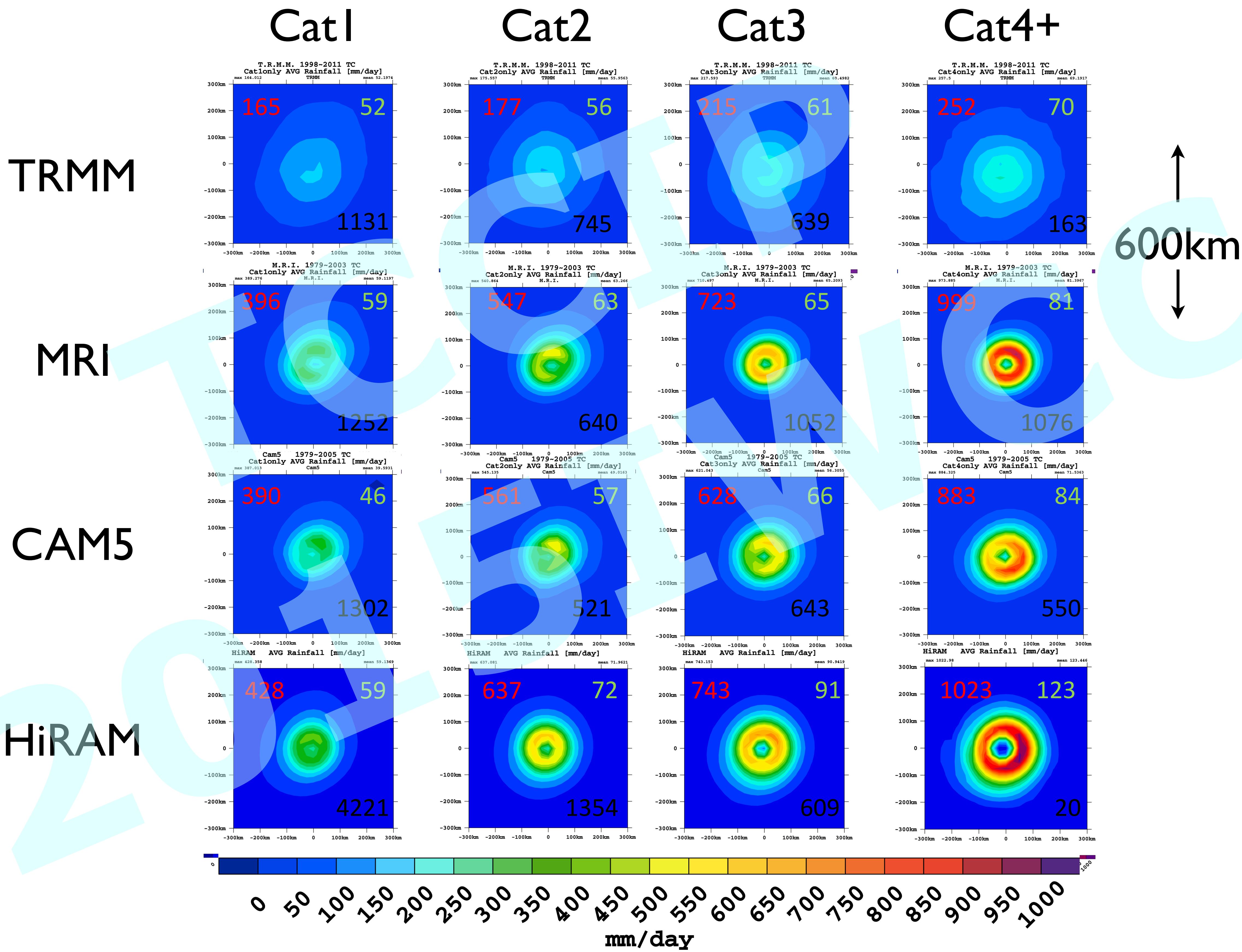


Normalized 2D Frequency Distribution of Max Wind and Time Relative to Peak Intensity

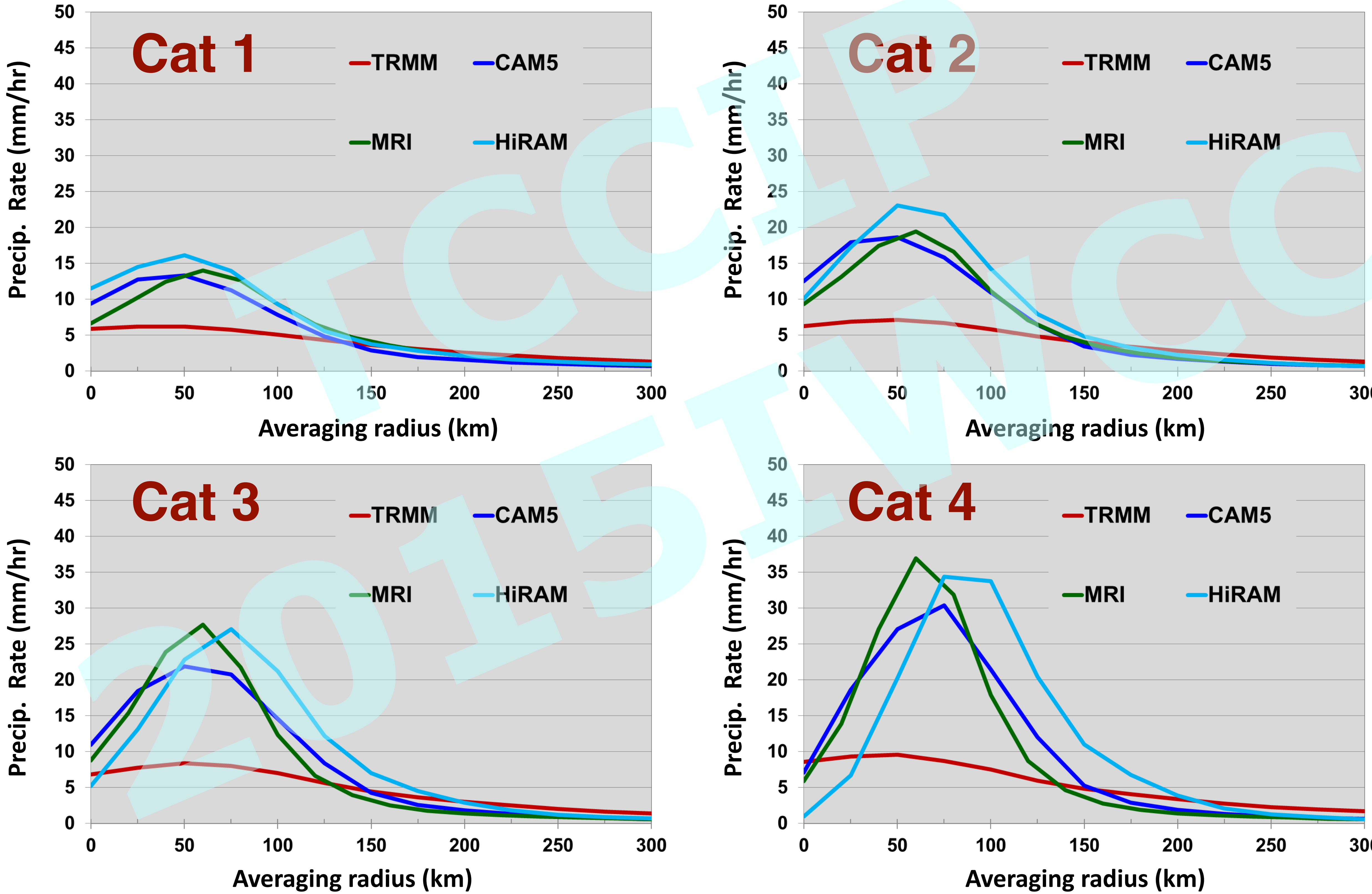
W Pacific



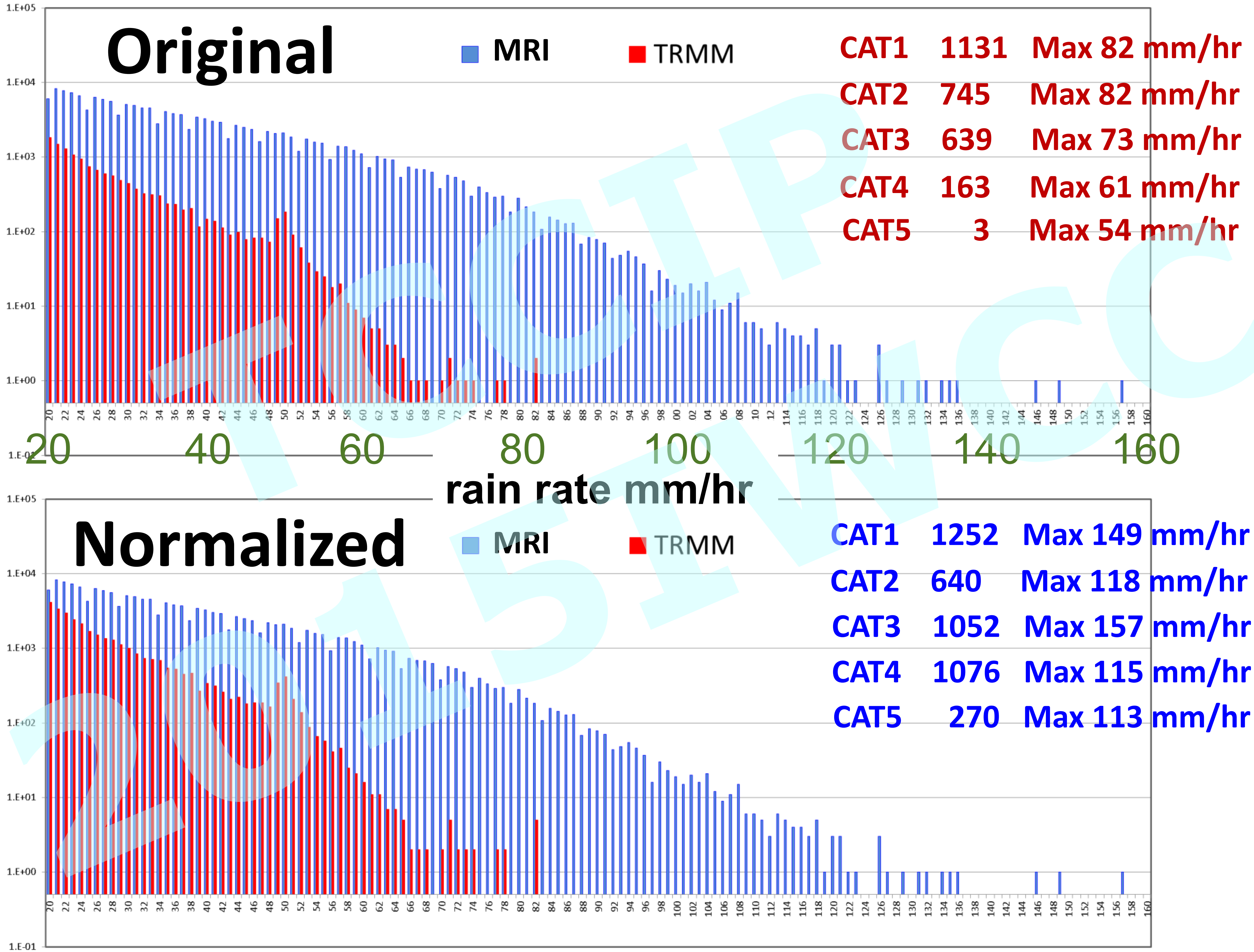
Composite of rainfall associated with tropical cyclone during different intensity stages



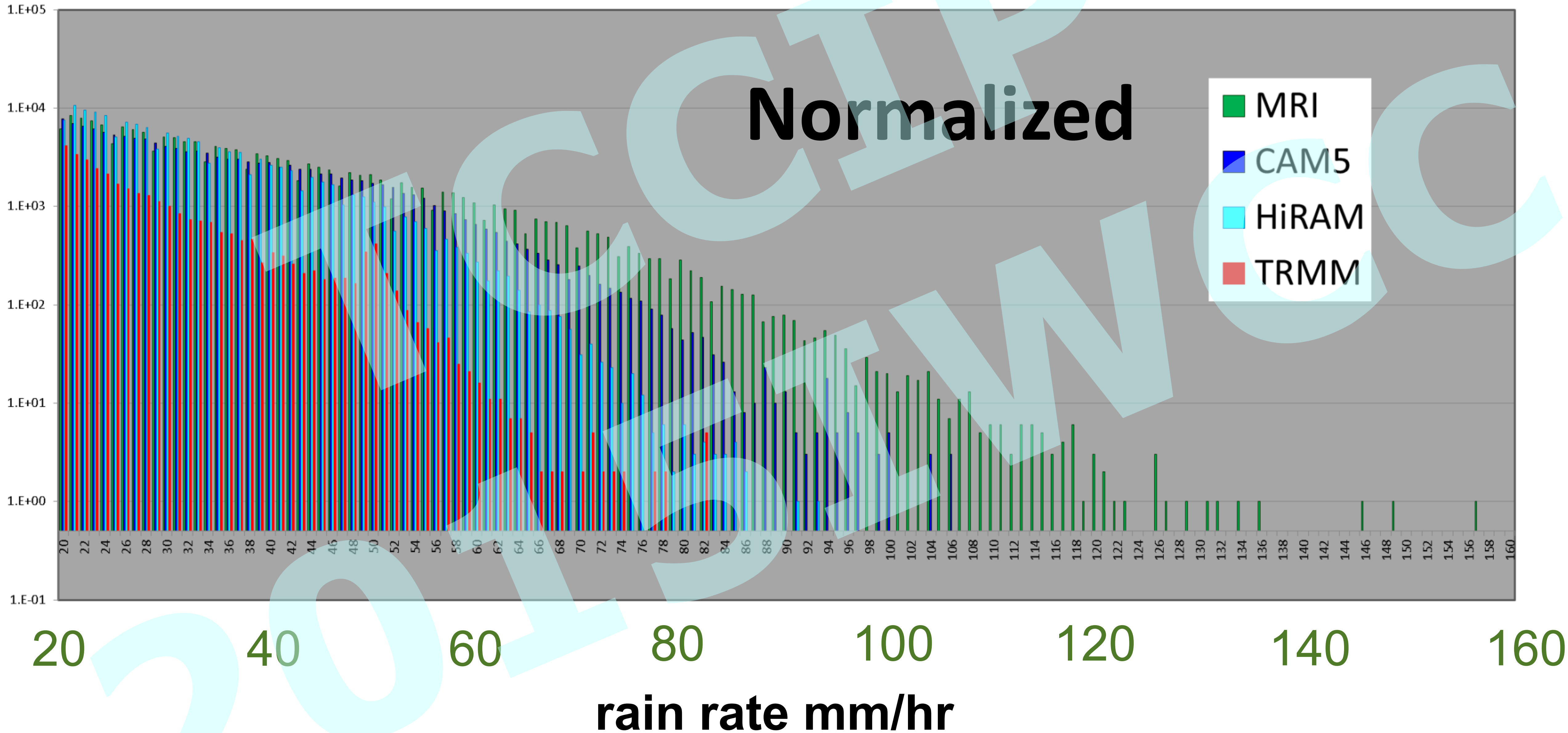
Composite of rainfall associated with tropical cyclone during different intensity stages



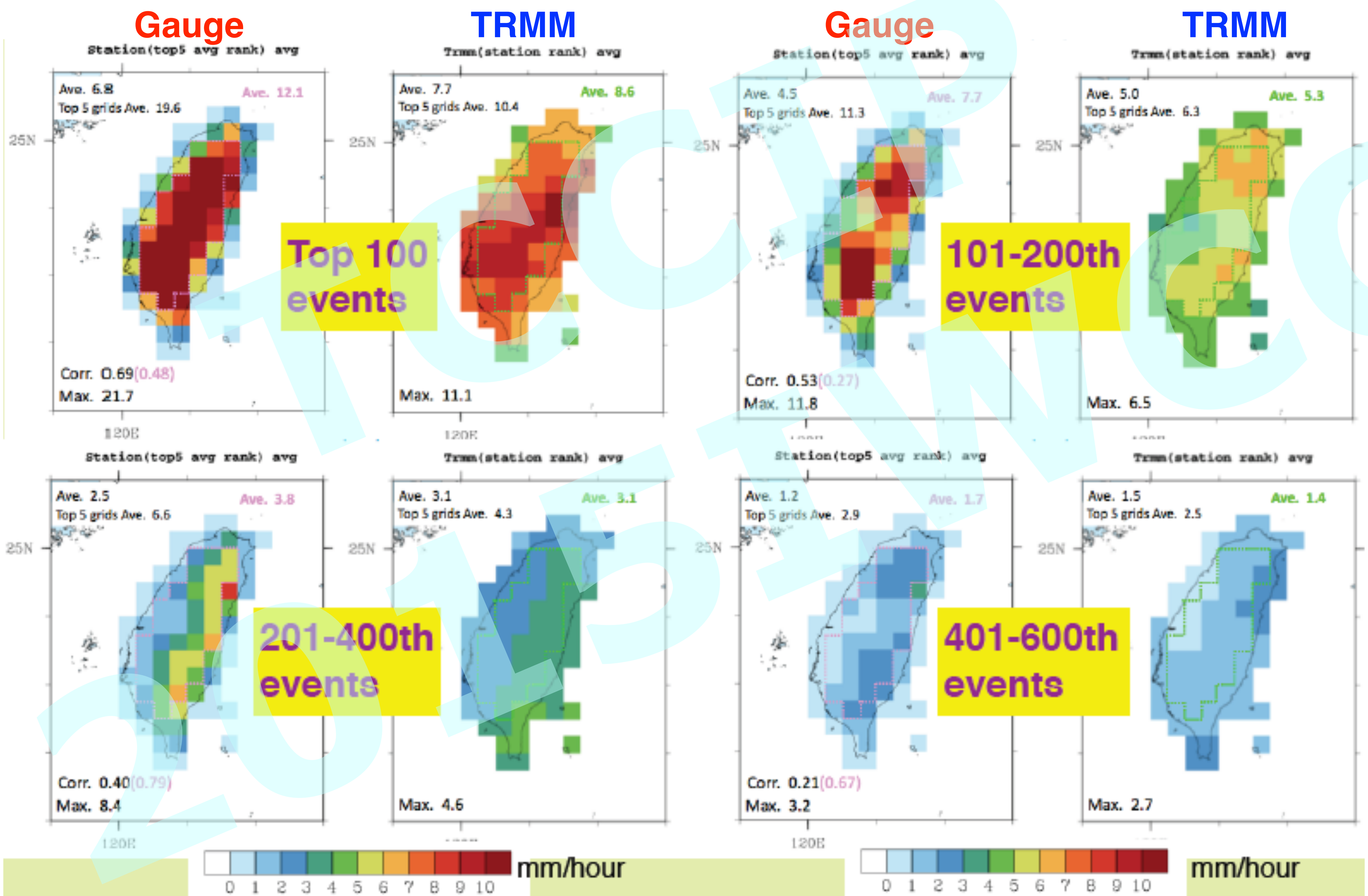
PDF of grid rainfall extremes associated with TCs



PDF of grid rainfall extremes associated with TCs



Comparison of Surface and TRMM rainfall analyses for period when typhoon within 300km from Taiwan



Concluding Remarks

- MRI and CAM5 high-resolution models can produce intense TCs. But often overestimate the number of intense TCs.
- MRI 20km mesh AGCM and HiRAM simulate better climatological TC track density over NW Pacific while CAM5 has better simulation over North 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 conditions.
- MRI and HiRAM models better capture the trend and interannual variability of basin-scale TC activities.
- All high-resolution climate models (MRI, CAM5, and HiRAM) studied 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 as shown in the comparison with surface observation.