Dynamical Downscaling of Western North Pacific Tropical Cyclone Genesis Using the IPRC regional Climate Model

Yuqing Wang and Ruifen Zhan

International Pacific Research Center (IPRC)
School of Ocean and Earth Science and Technology
University of Hawaii at Manoa, USA,

Introduction

- **Dynamical downscaling: Widely used for climate change assessment, seasonal predictions predictability, understanding of climate processes.**
- **Applications to TCs: The possible impact of global warming on the activity of TCs in different ocean basins (e.g., Walsh and Ryan 2000; Stowasser et al. 2007; Knutson et al. 2008; Bender et al. 2010).**
- **Knutson et al. (2007): Driven by reanalysis, ZETAC model reproduced the recent multidecadal variability of North Atlantic hurricane frequency, but hurricane count was very sensitive to how strong the large-scale nudging was used.**
- **Bender et al. (2010): The GFDL hurricane model has been applied to global warming scenario for North Atlantic and reported +10% increase in Category 4-5 hurricanes over NATL.**

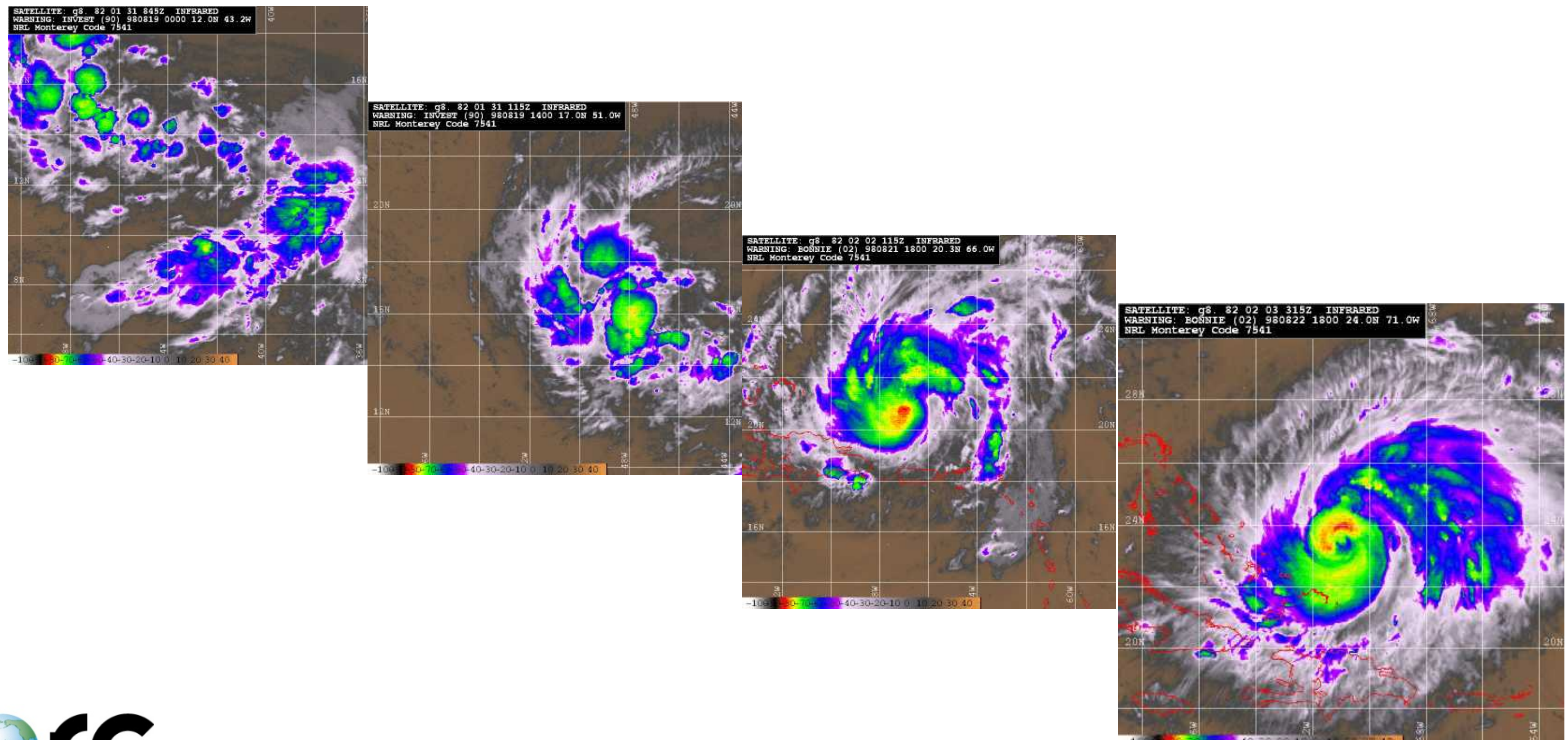
Table 2. Preliminary and auxiliary model experiments for Aug–Oct 1982 and 1995. Multiple numbers are shown where more than one ensemble member is available.

Model version	1982 tropical storm count	1995 tropical storm count
Observed	4	15
No nudging	18	25
No nudging, RAS convection	8	12, 11
2-h nudging	1	10
12-h nudging	3	10
12-h nudging—Winds only	9[a]	9[b]
48-h nudging [Model1]	6	14, 13
48-h nudging (with error corrected in nudging code)	10	21
36-h nudging (with error corrected in nudging code) [Model2]	4, 8, 8	15, 13, 12
24-h nudging (with error corrected in nudging code)	4	16

Background

Dynamics and physics of tropical cyclogenesis

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

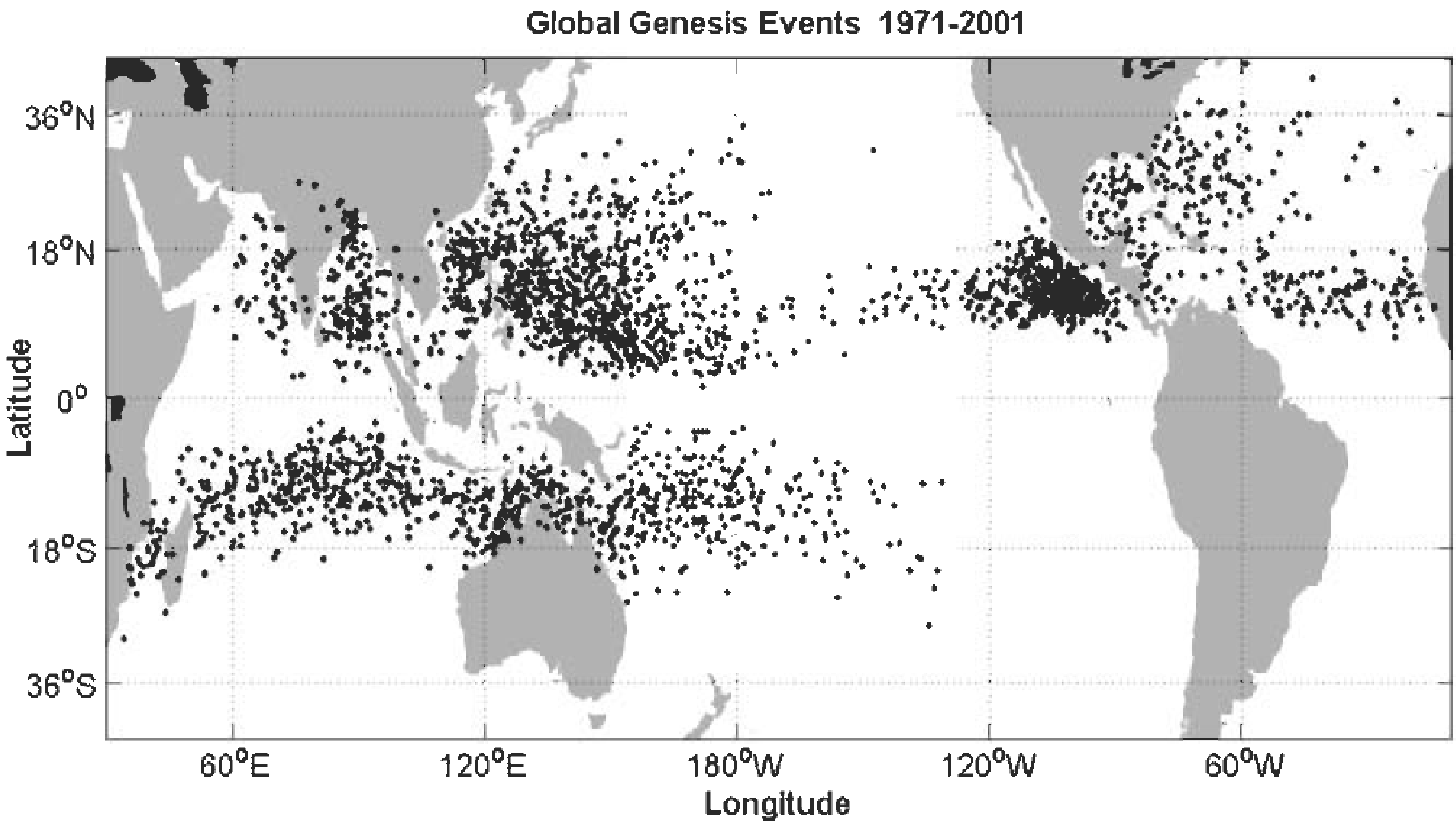


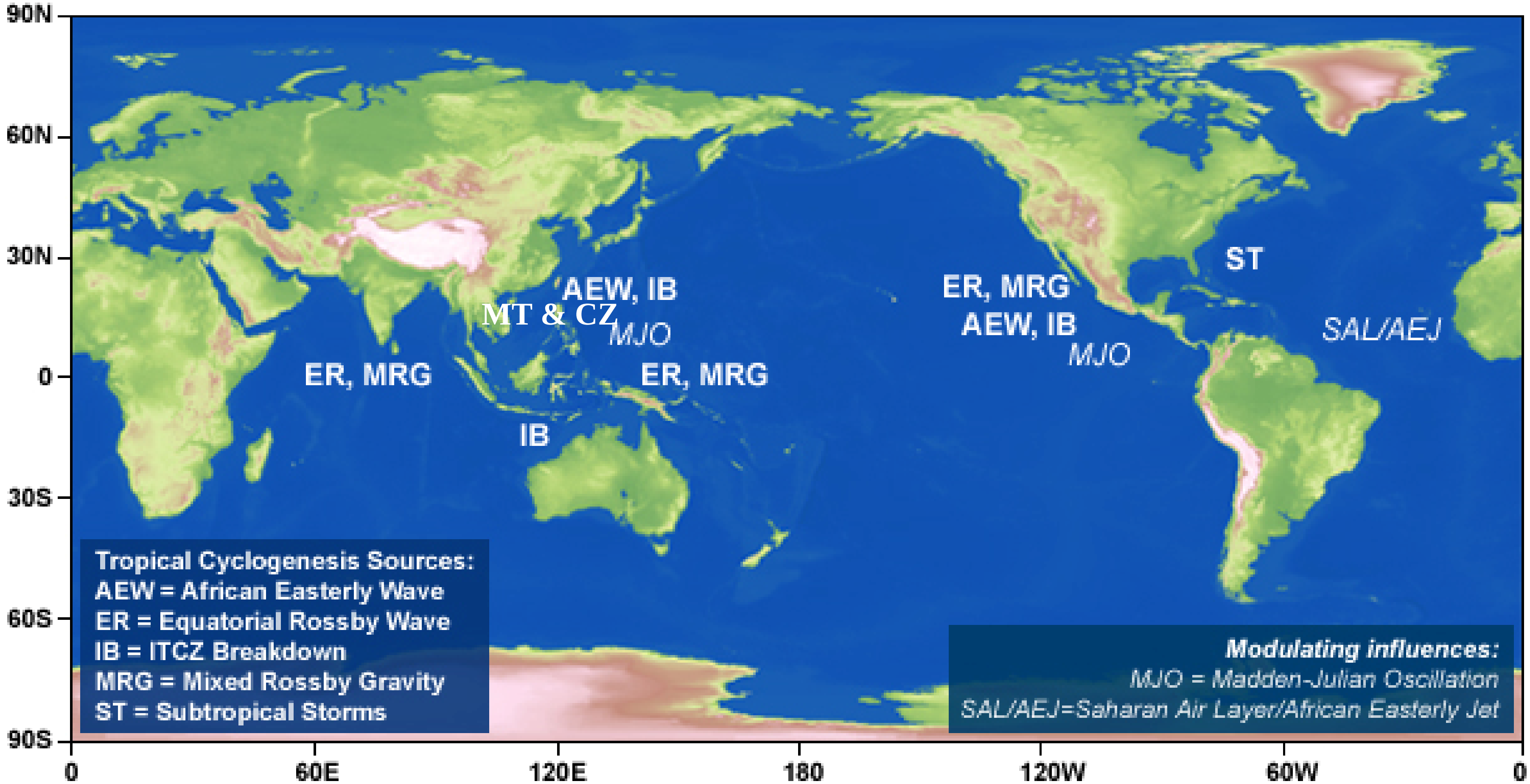
Necessary Conditions for TC Genesis

Necessary (but not sufficient) conditions for tropical cyclogenesis (Gray 1968)

- **Warm ocean, deep mixed layer**
- **Significant planetary vorticity (off the equator)**
- **Pre-existing synoptic disturbances**
- **Favorable vertical wind shear pattern**
- **Moist mid-troposphere**
- **Conditionally unstable atmosphere**

Climatology of Tropical Cyclogenesis

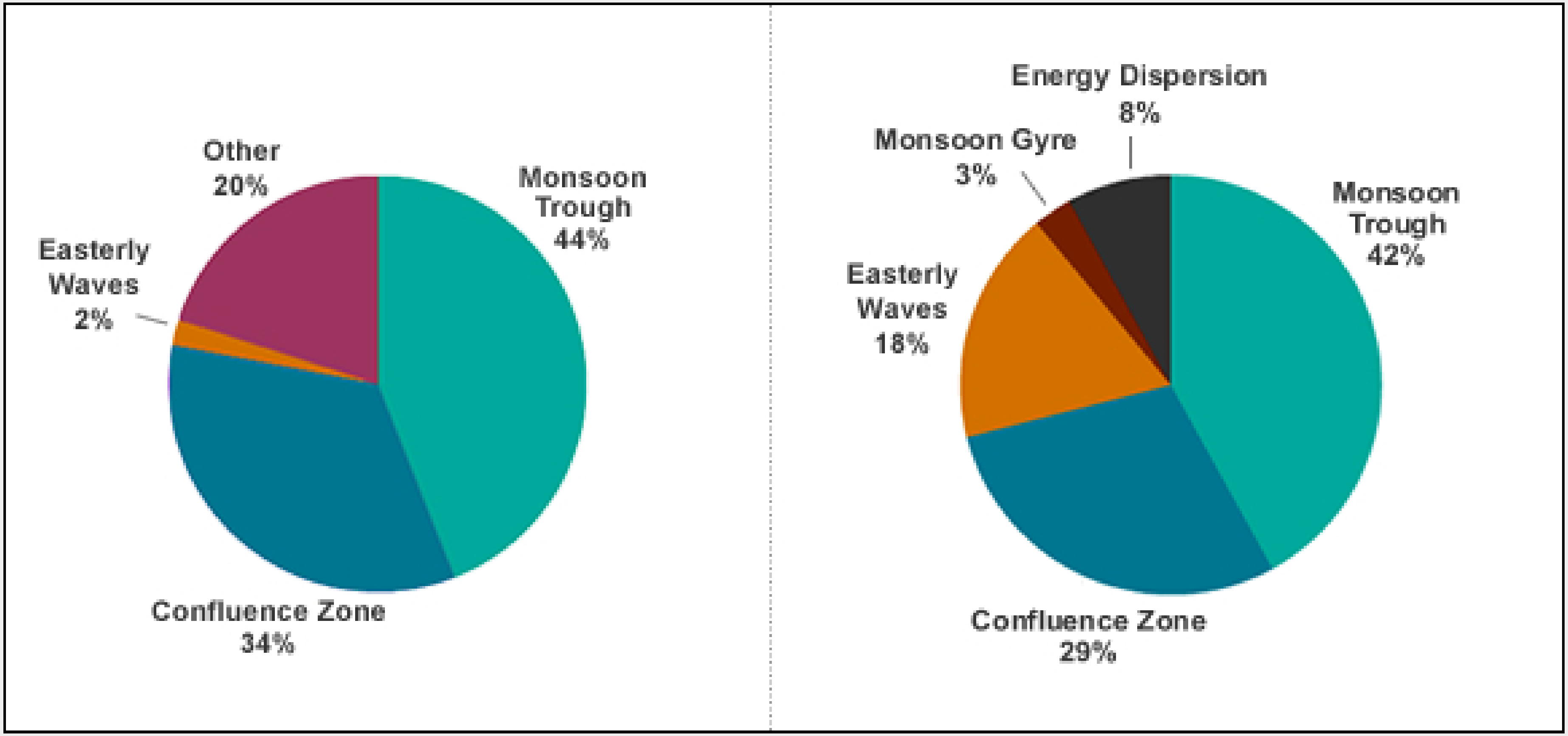




Sources of tropical cyclogenesis identified for each ocean basins

Briegel and Frank (1997) based on data 1988-1989

Ritchie and Holland (1999) based on data 984-1992 (excluding 1989)



Pie charts outlining the different pathways to tropical cyclogenesis identified by Briegel and Frank (1997) based on data in 1988-1989 and Ritchie and Holland (1999) based on data in 1984-1992 (excluding 1989).

Dynamical Downscaling of TC Genesis

Models need to be able to

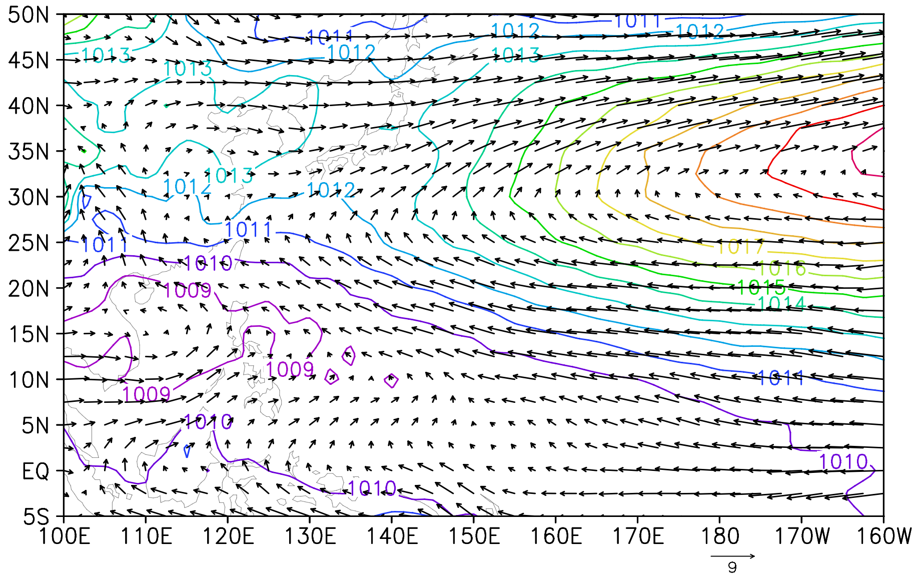
- **Reproduce large-scale climatology of TC season**
- **Reproduce the conditions for TC genesis**
- **Reproduce correctly genesis statistics**
  - **Genesis location, frequency, and seasonality, *origin – triggering mechanisms (very challenging)***
- **Reproduce the response to climate perturbations**
  - **Such as interannual variability, extreme events**

Dynamical Downscaling of the WNP TCs by IRAM

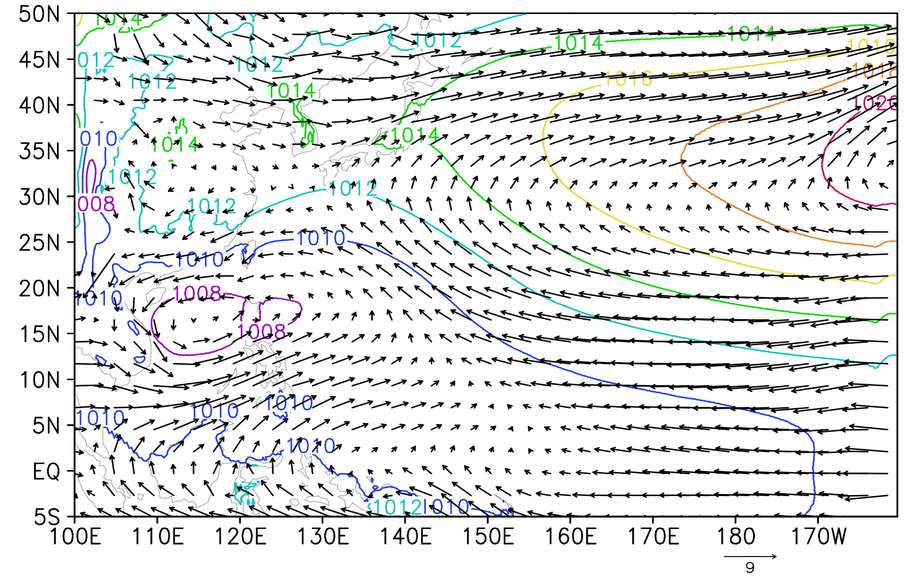
- **The IPRC Regional Climate Model (iRAM) (Wang et al. 2003)**
- **Simulation period：1990-2006，May 25-November 30**
- **Domain：100^{o}E-159.6^{o}W, 15^{o}S-56.7^{o}N**
- **Horizontal resolution：0.3^{o}**
- **Grids: East-west 333，North-south 240**

Sea level pressure and wind at 850 hPa

(a) Reanalysis



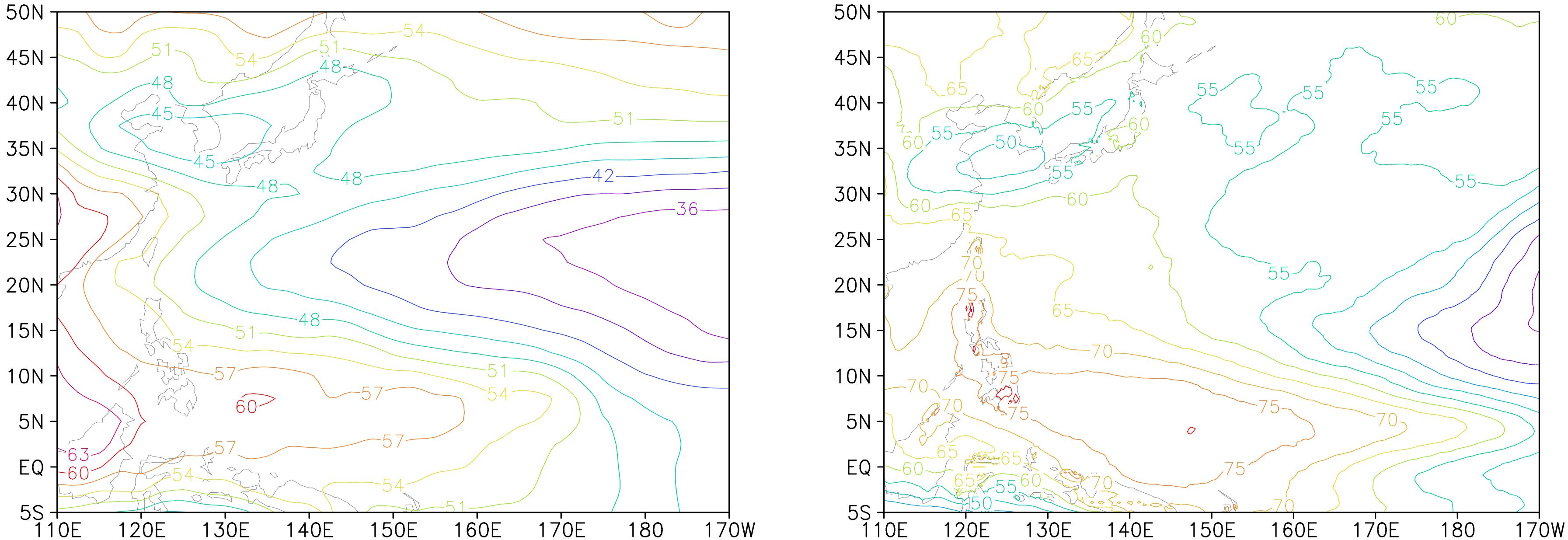
(b) model



Mean sea level pressure (hPa) and wind field (ms^{-1}) at 850-hPa level average over June-November for (a) NCEP data, (b) model experiment

Relative humidity

(a) Reanalysis (b) model

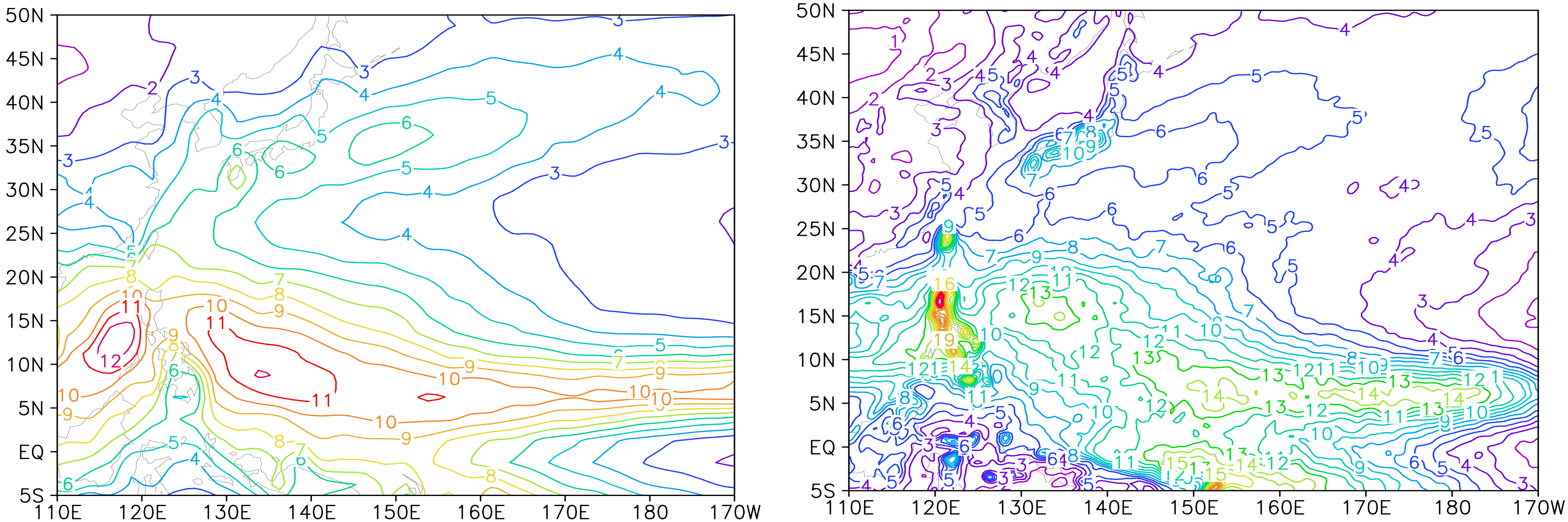


Mean 500-700-hPa relative humidity (%) over June-November for (a) NCEP data, (b) model experiment

NCEP reanalysis has a dry bias compared to EC40 over the ocean

Precipitation

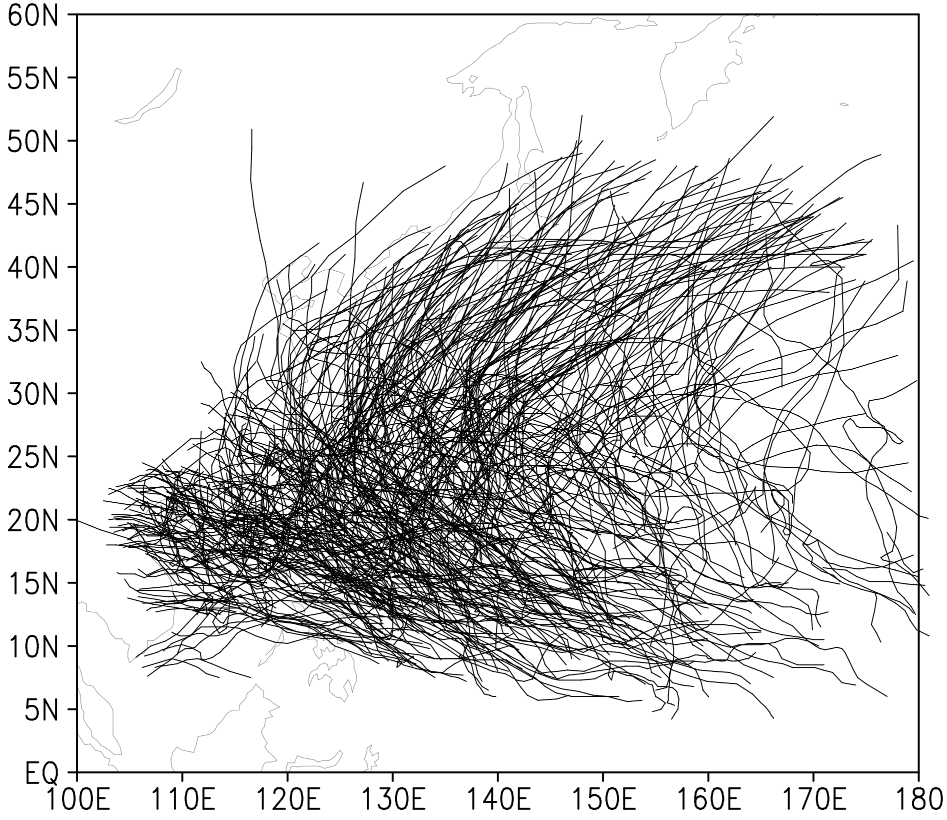
（a）CMAP　　　　　　　　(b) model



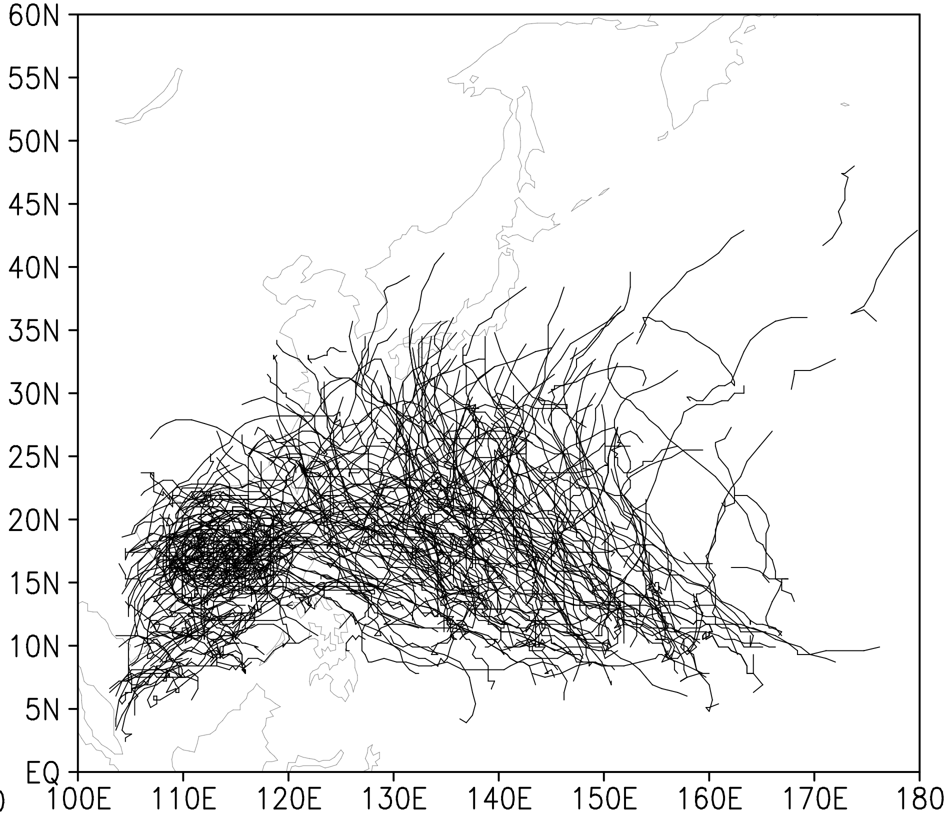
Mean precipitation in mm day^{-1} for June-November (a) CMAP data , (b) model

TC Tracks

Observed TC tracks from CMA-STI
1990-2006



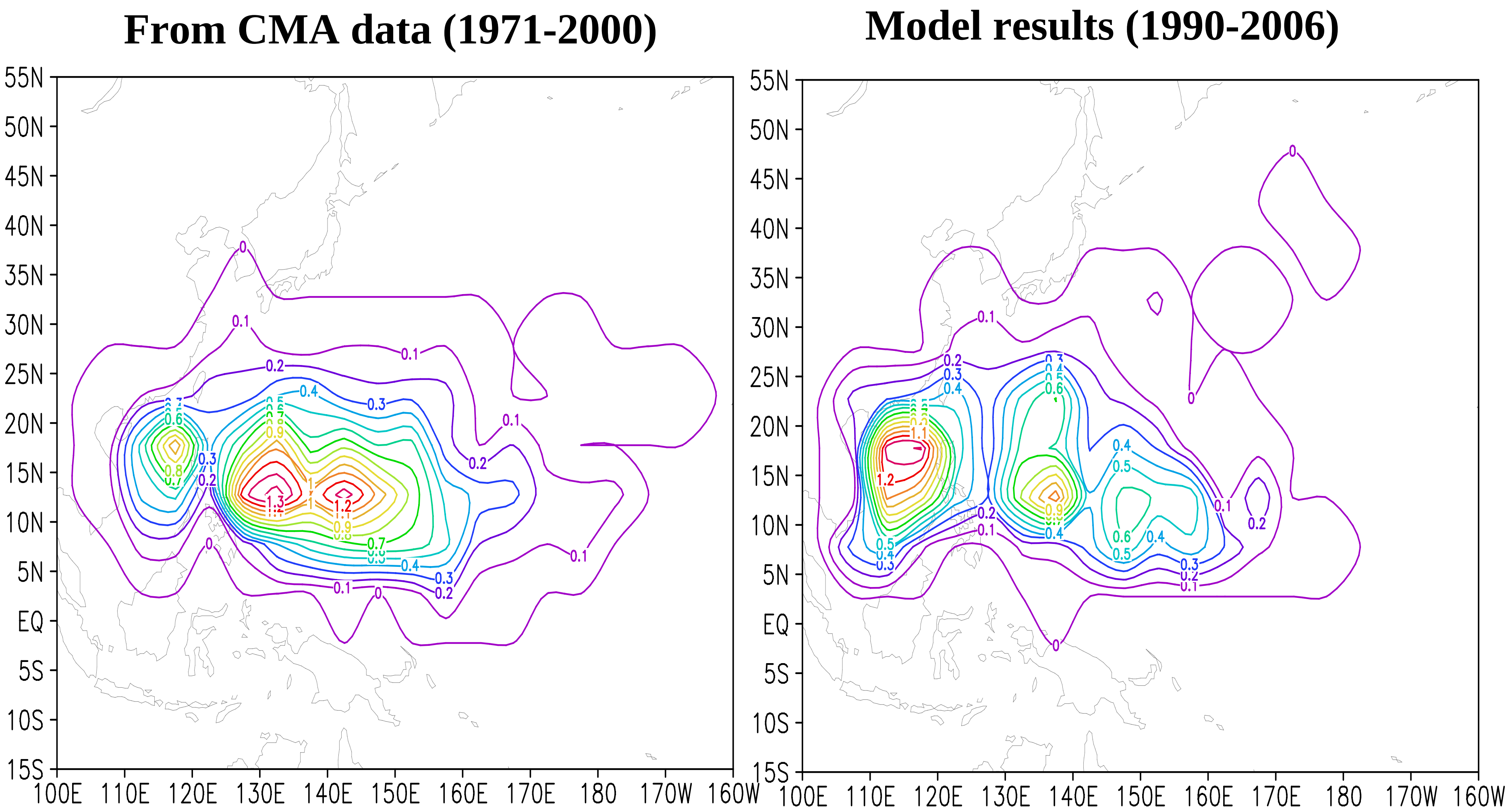
Detected TC tracks from model
1990-2006



Climatology

June-November of the years	Annual Mean TC Numbers
1970-2001 (CMA)	21.2
1990-2006 (CMA)	21.7
1990-2006 (iRAM)	20.7

First position of tropical storms

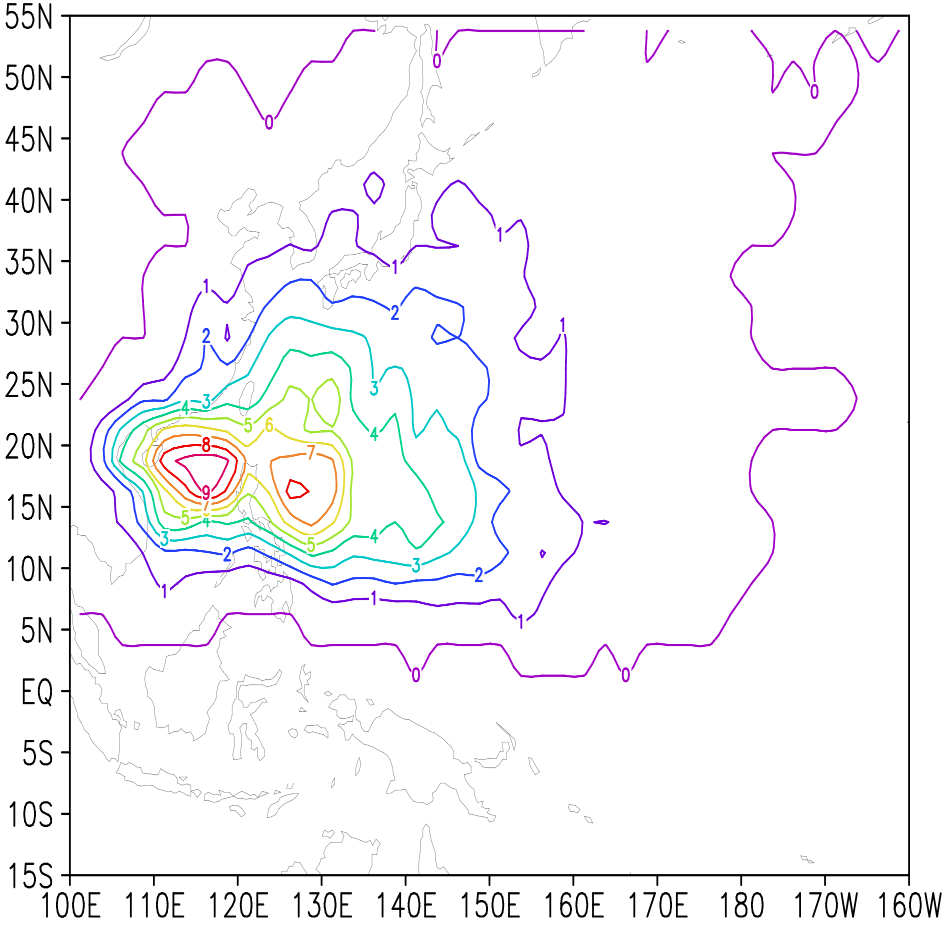


The units are numbers per 5^0 square box per 6-month (JJASON) period

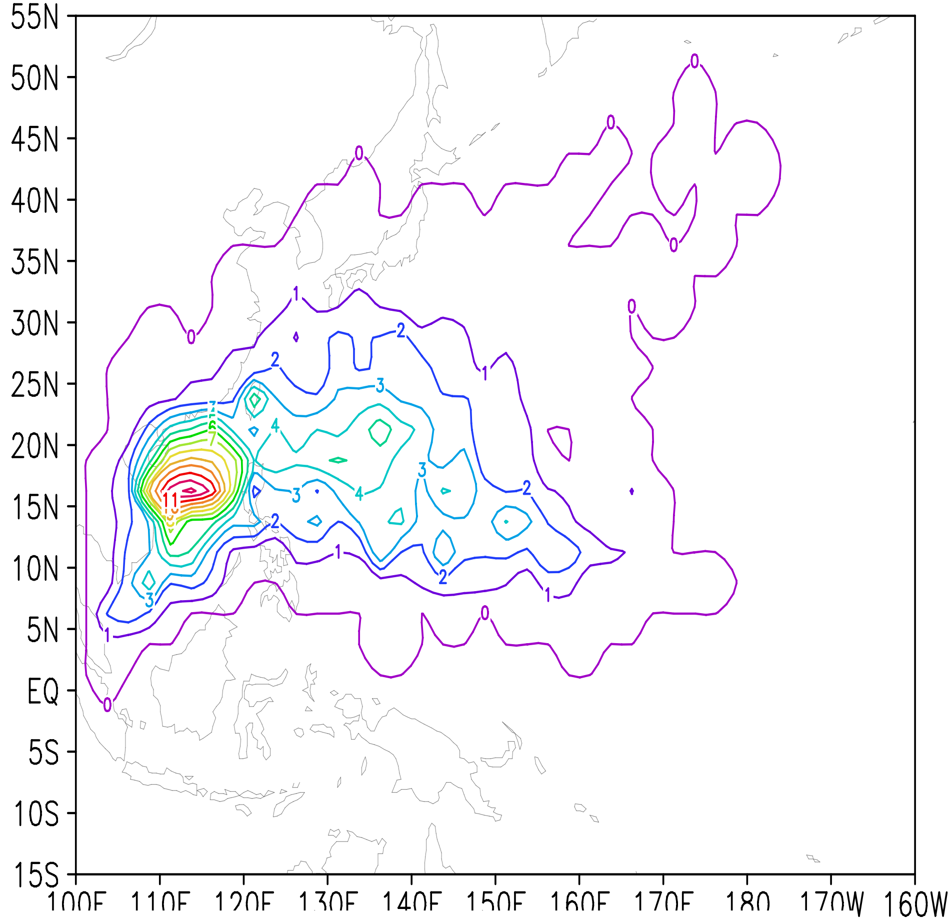
INTERNATIONAL PACIFIC RESEARCH CENTER
SOEST, University of Hawaii

Occurrence of tropical storms

From CMA-STI data (1971-2000)

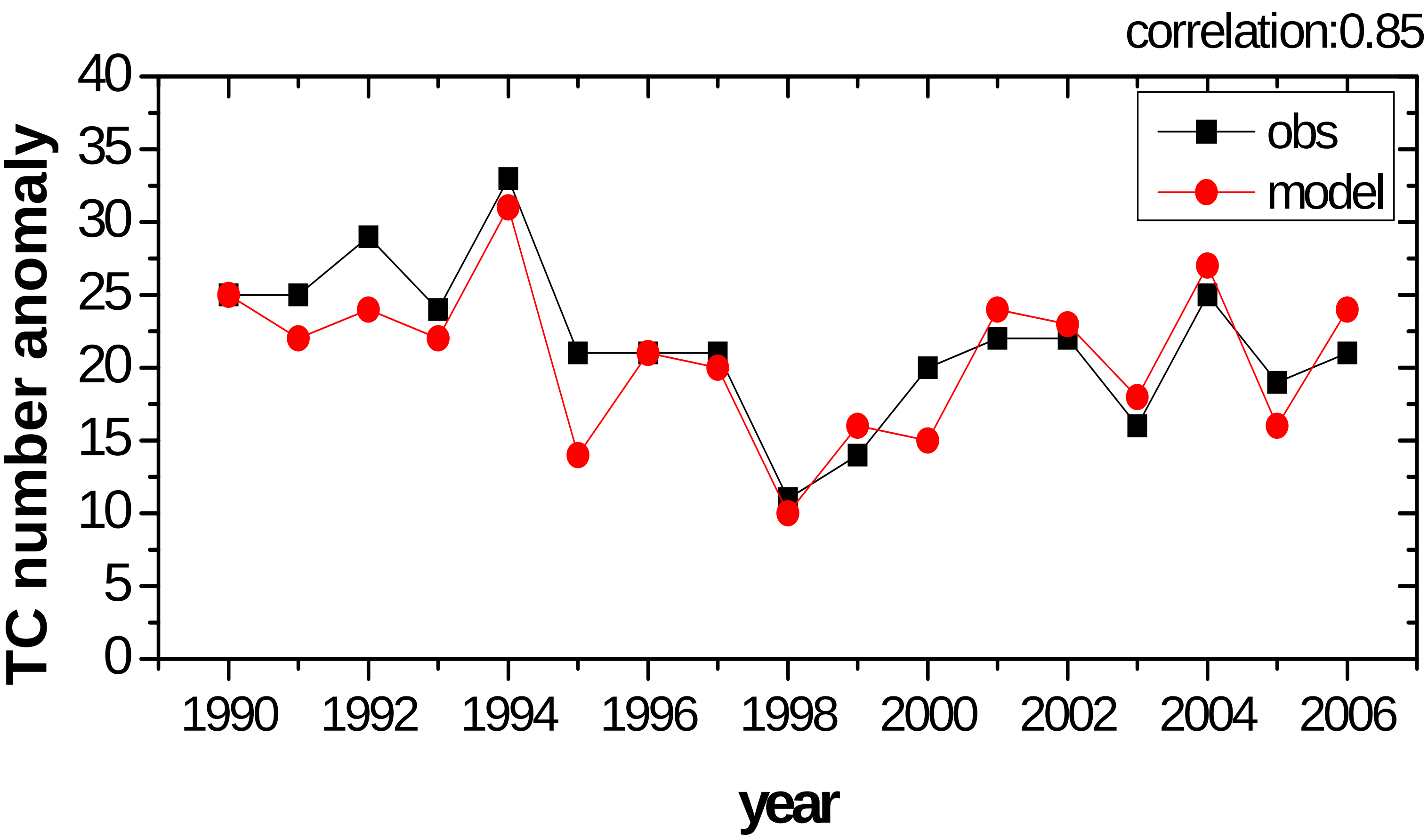


Model results (1990-2006)

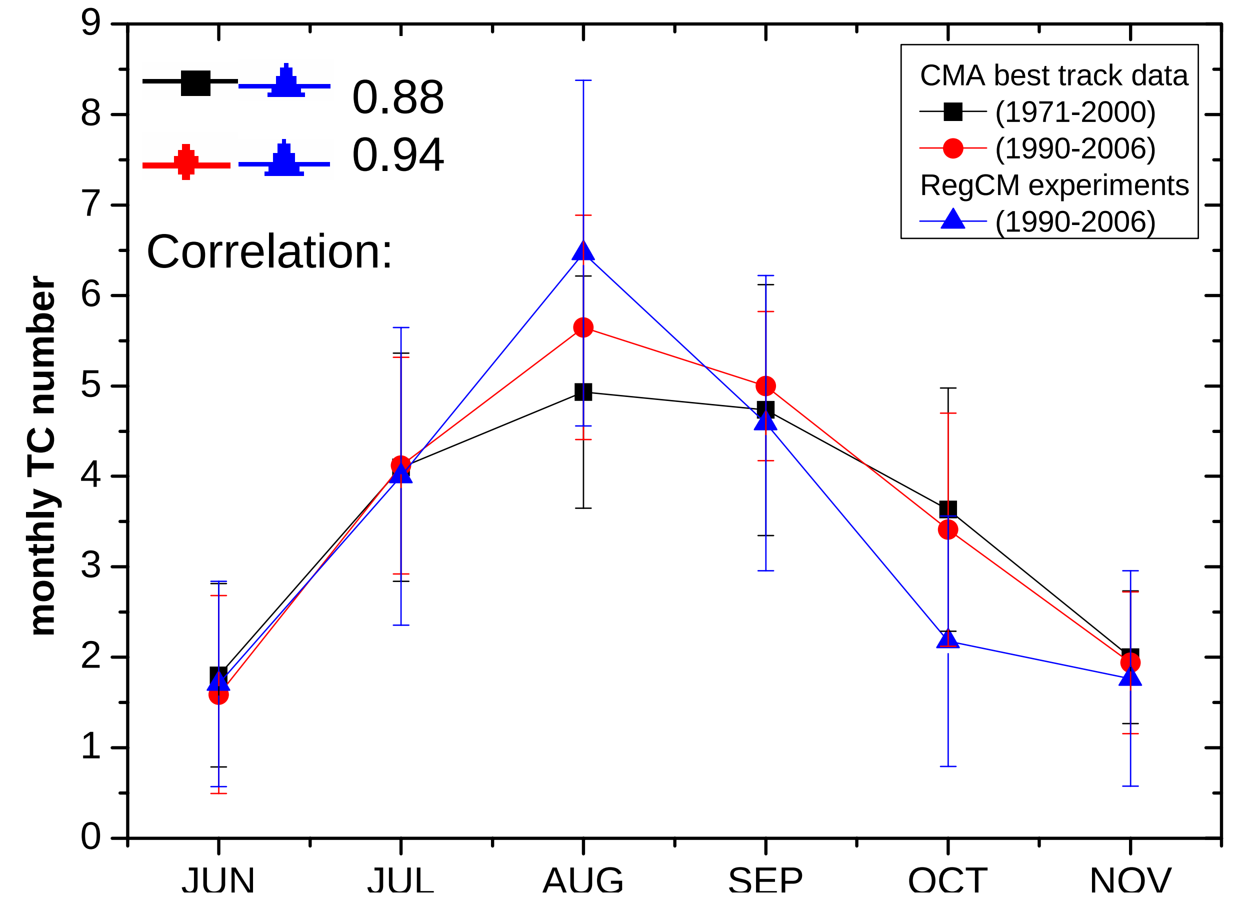


The units are number per 2.5^{o} square box per 6-month (JJASON) period

Interannual variation of TC number



Seasonality



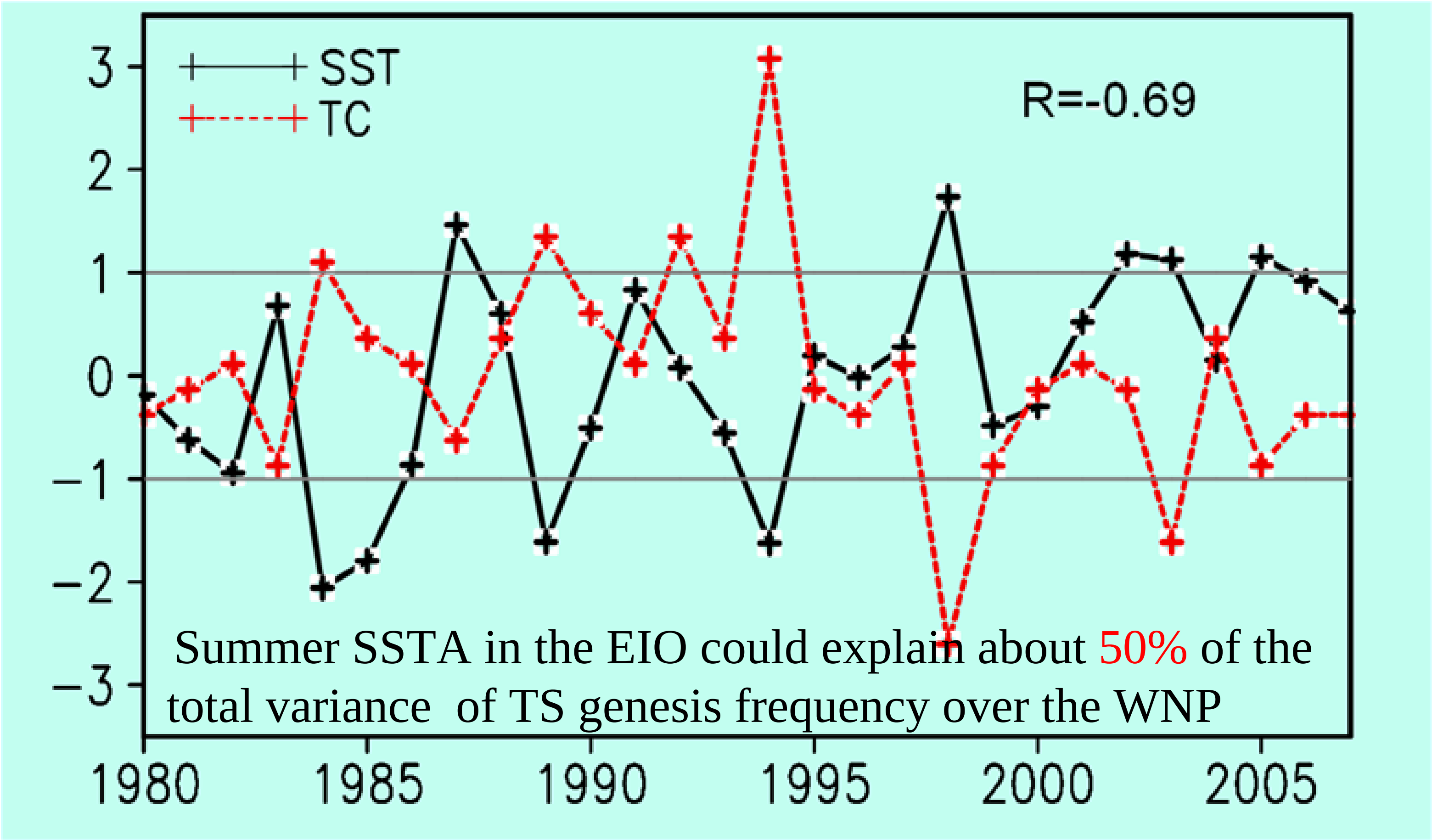
Long-term (1971-2000 and 1990-2006) monthly mean number of tropical storms in the WNP for JJASON obtained from CMA compared to results from the iRAM

Climate sensitivity and extreme events

- A critical test for the suitability of the model to be used for evaluation of impact study of climate change

- An example for the response of WNP TC activity to East Indian Ocean SSTA

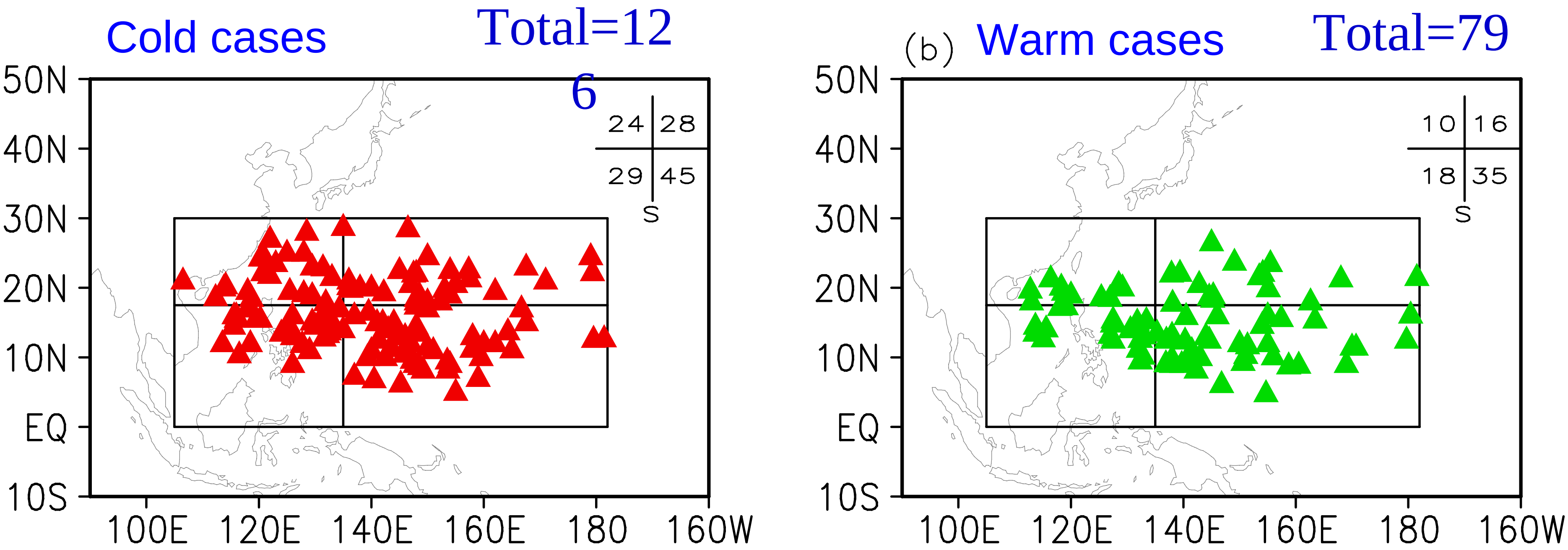
Summer (June-August) SSTA in East Indian Ocean (EIO) and WNP TS genesis frequency



Warm years: 1987, 1998, 2002, 2003, 2005

Cold years: 1982, 1984, 1985, 1989, 1994

Genesis location and frequency in cold and warm years



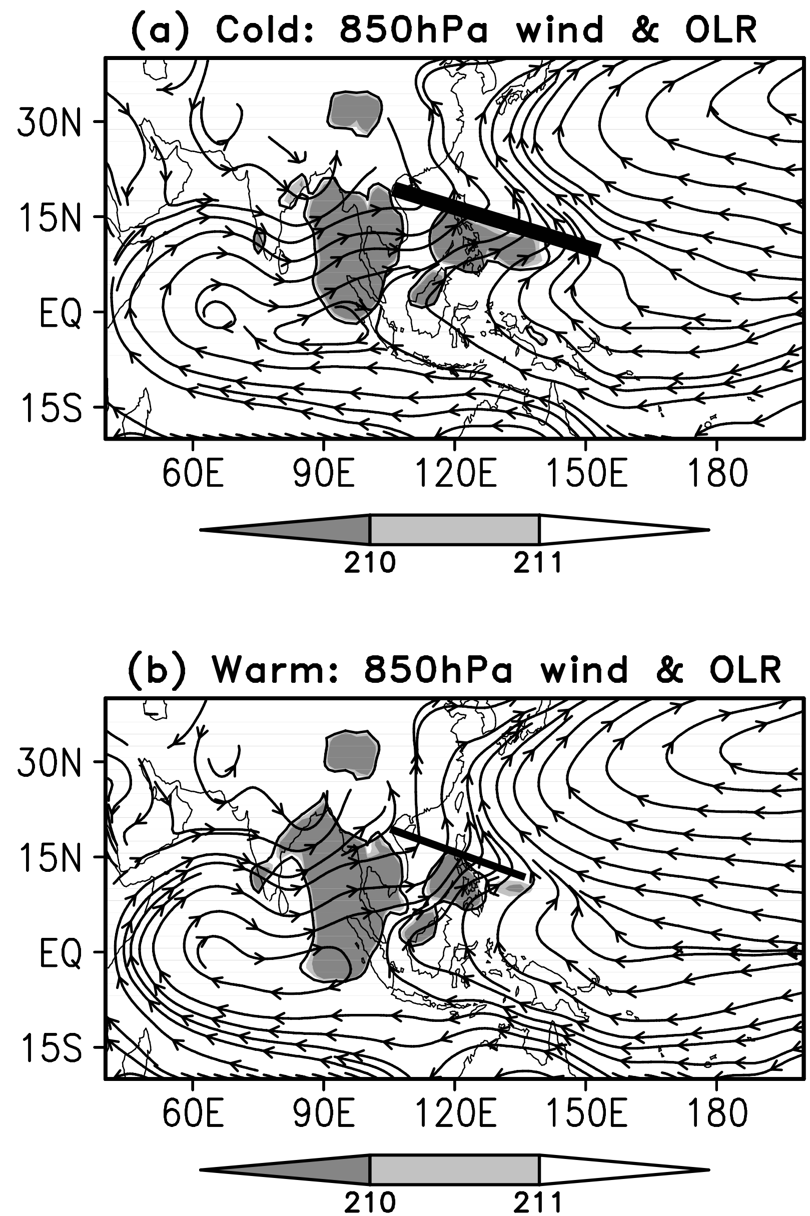
T-test: significant at the 99% confidence level

- Frequency in cold years is 1.6 times that in warm years
- The increase in cold years occurs in the whole region

Composite 850hPa wind and OLR for C/W cases

Cold

Warm



- For the cold years the monsoon trough deepens and extends eastward and northward, favoring TC genesis!

Experimental design

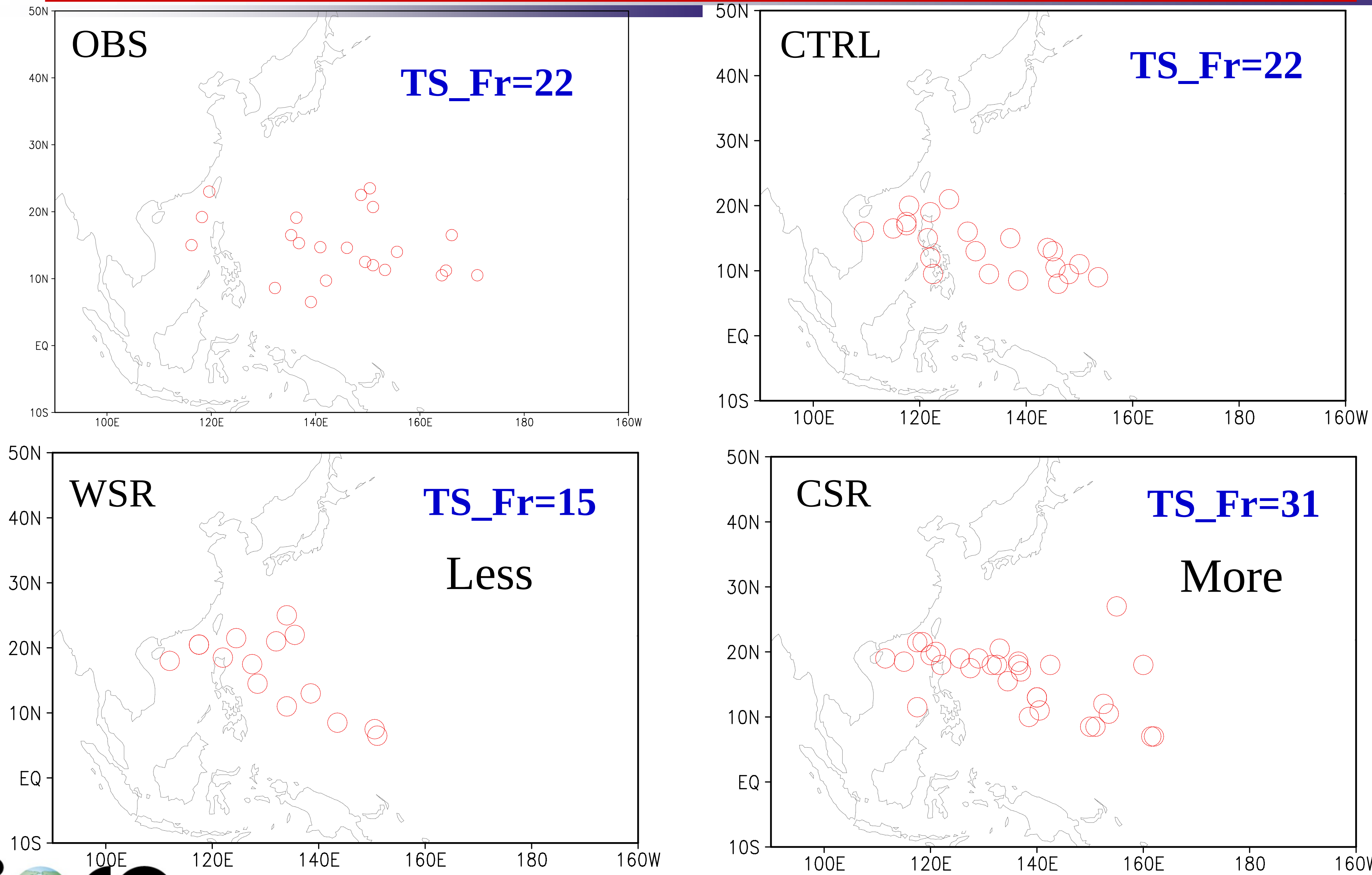
- IPRC-regional atmospheric model (IRAM)
- Resolution: 0.5^{o}lat*0.5^{o}lon
- Domain: 15^{o}S-56.5^{o}N, 70^{o}E-160^{o}W
- Time integration: 00 UTC 27 May– 18 UTC 30 Oct
- Control Run: Default setting, observed Weekly SST
- Sensitivity Run1 (WSR): +1^{o}C SST in EIO (10^{o}S-22.5^{o}N, 80^{o}-100^{o}E)
- Sensitivity Run2 (CSR): –1^{o}C SST in EIO

Selected cases

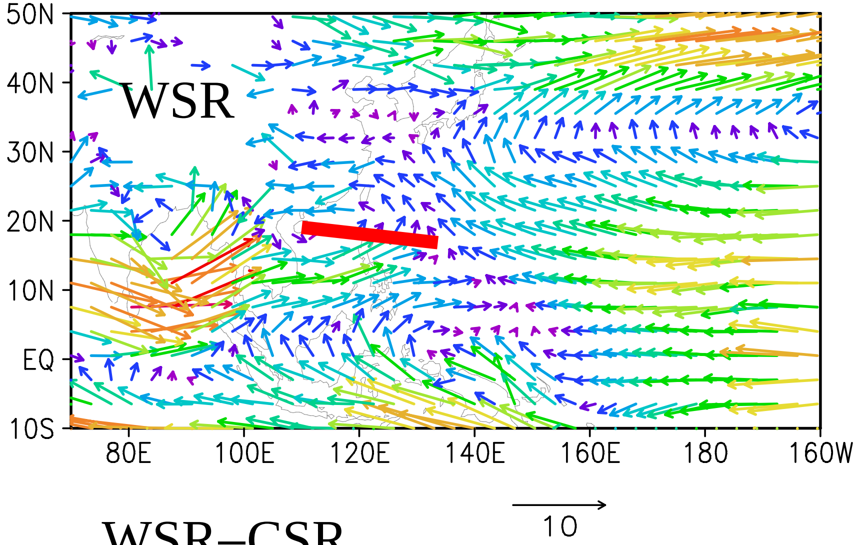
- **Normal year: 2004**
- **Well above normal year: 1994**
- **Well below normal year: 1998**

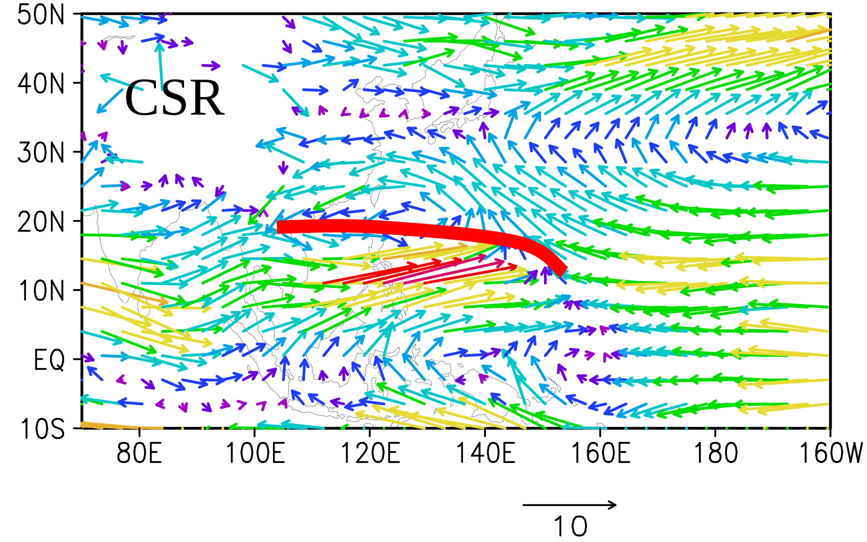
Year	OBS frequency	
2004	22	
1998	10	Warm EIO SSTA
1994	33	Cold EIO SSTA
Climatology	20	

Genesis frequency of WNP TSs in 2004 Typhoon Season

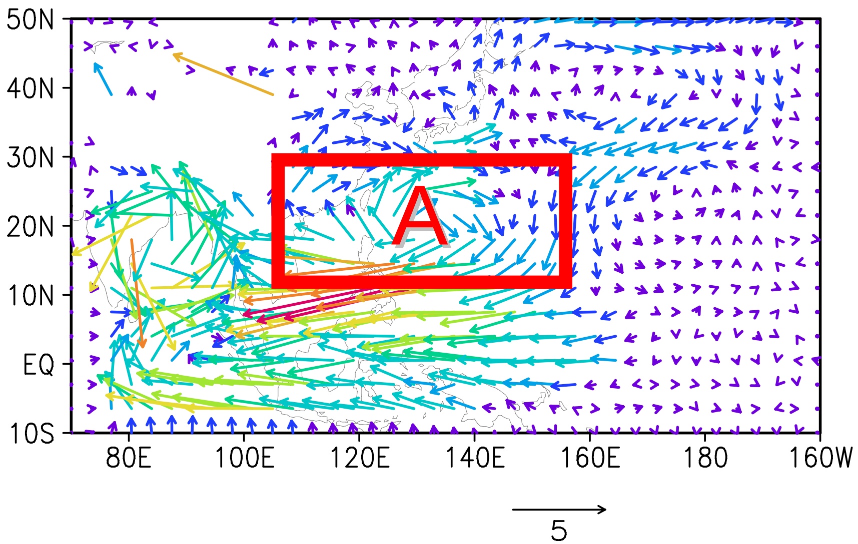


850hPa wind averaged June-October in 2004





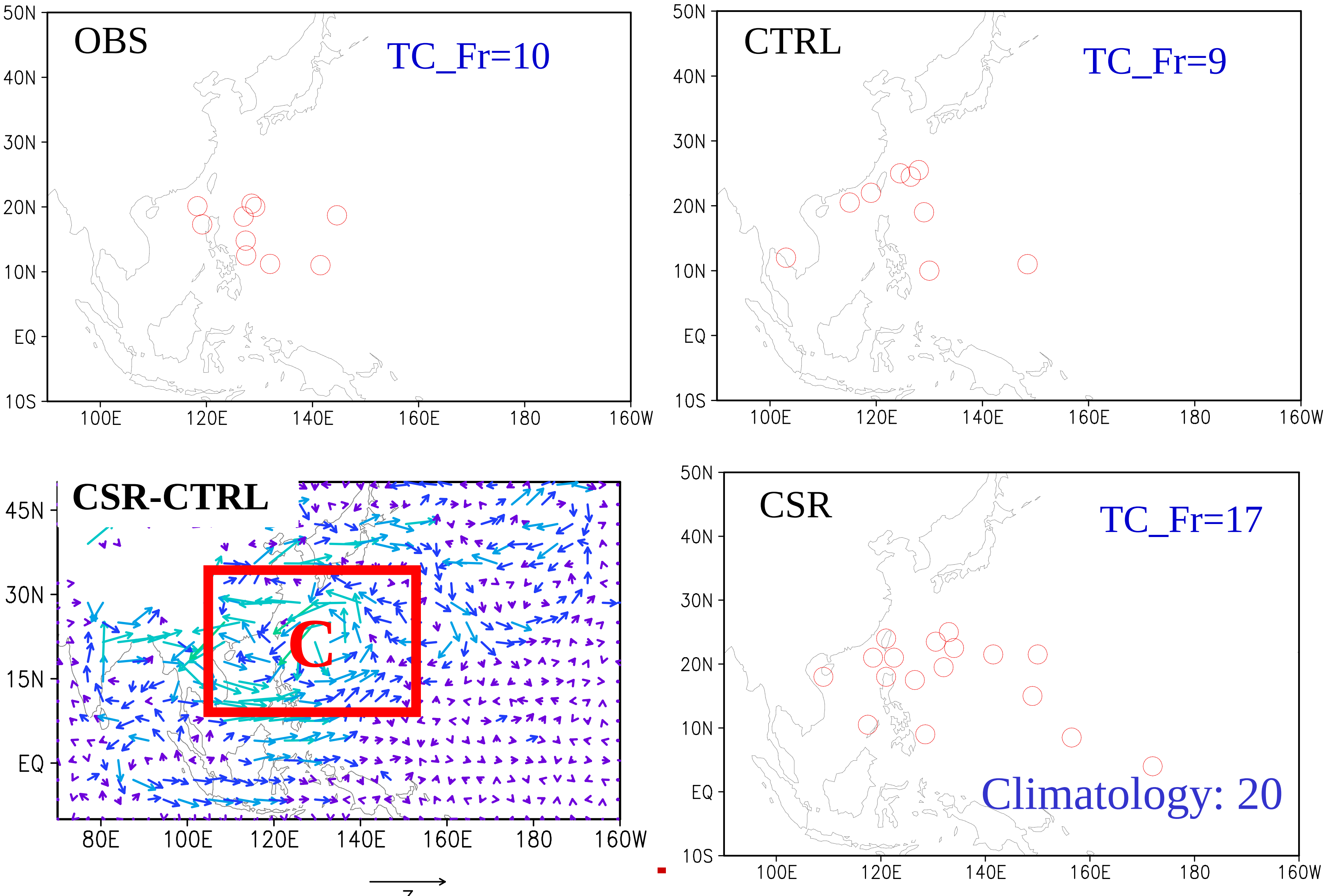
WSR–CSR



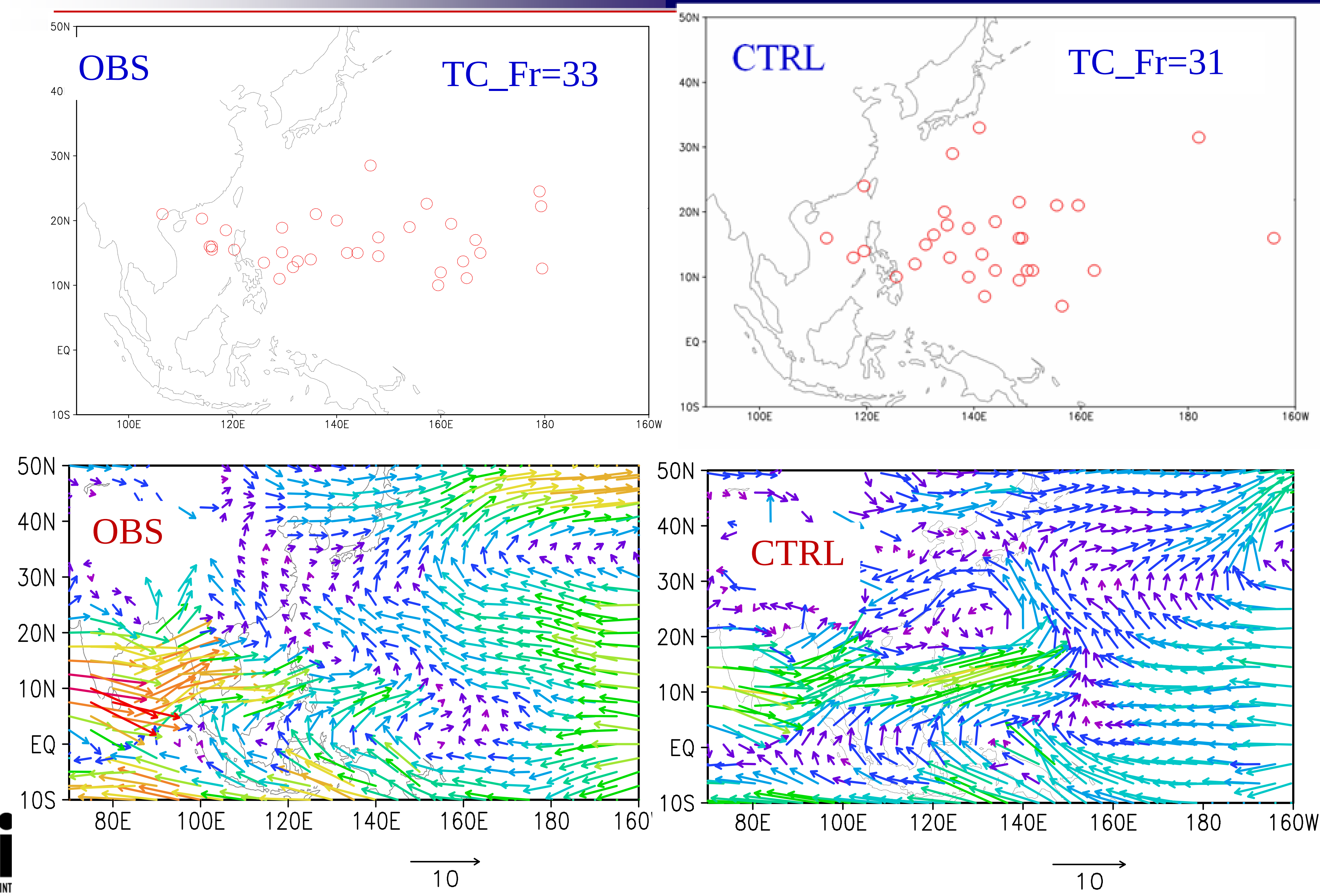
In cold case, monsoon trough deepens and extends eastward

Warm SST in EIO excites an anomalous anticyclone in the region of WNP TC genesis

Genesis frequency of WNP TCs in 1998 Typhoon Season



Genesis frequency of WNP TSs in 1994 Typhoon Season



Summary

•The IRAM reproduced the climatology, interannual, and seasonal variations reasonably well driven by the good quality reanalysis without the use of any large-scale nudging;

•The model simulated not only the annual frequency of the WNP but also the geographical distribution of TC locations and frequency of occurrence reasonably well;

•The model reproduces observed sensitivity to SSTA over the East Indian Ocean and the extreme events in 1994 and 1998;

•Results are very encouraging for experimental seasonal predictions of the WNP TCs and assessment of global warming effect on TC activities over the WNP.

Issues on Dynamical Downscaling of TC Genesis

Models need to be able to

- **reproduce large-scale climatology of TC season**
- **reproduce the conditions for TC genesis**
- **reproduce correctly genesis statistics**
  - **Genesis location, frequency, and seasonality,**
    origin – triggering mechanisms (very challenging)
- **reproduce the response to climate perturbations**
  - **Such as interannual variability, extreme events**

Three critical issues

- **Model and the quality of lateral forcing**
- **Sensitivity to the location of lateral boundary**
- **Internal variability, initial value problem also**

Thank for your attention!