Forced and internal variability of tropical cyclone track density in the western North Pacific

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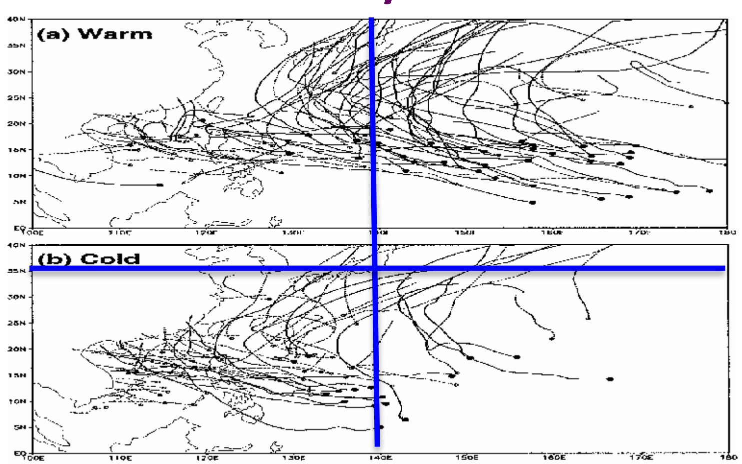
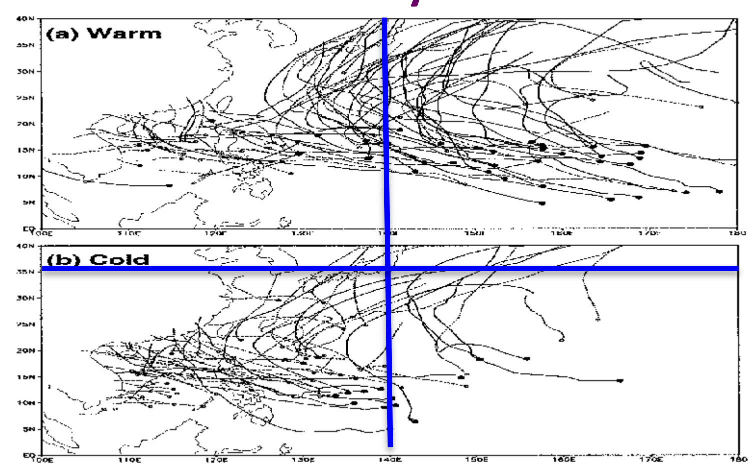
Introduction

- Western North Pacific (WNP) is the basin where tropical cyclones (TCs) are most active.
- The genesis (including both location and frequency) and tracks of WNP TCs have been shown to be modulated by various climate modes (e.g., ENSO).

El Nino years



La Nina years



(Wang & Chan 2002)

Introduction

- **Track density directly relates to the damage caused by TCs via landfall. Its variability, which integrates that in TC genesis and subsequent tracks, is also suggested to be influenced by climate variability.**
- **Previous studies are primarily based on observations which alone do not allow to establish a cause-effect relationship.**
- **Here we use high-resolution AGCM ensemble simulations to isolate the SST-forced variability and understand the internal variability. The results have important implications regarding predictability of local TC occurrence.**

Data and Methods

- **Observed and simulated TC tracks**

  Observed TC best-track data

  TC tracks from global simulations using the GFDL High-Resolution Atmospheric Model (HiRAM): 25 km horizontal resolution; forced by observed SSTs; 3 members that differ only in initial conditions; the ensemble mean is used to study SST-forced variability, and the deviation from the mean is used to study internal variability.

  (HiRAM is able to reproduce the observed climatology of various TC metrics and capture the observed variations in the annual TC number over the WNP.)

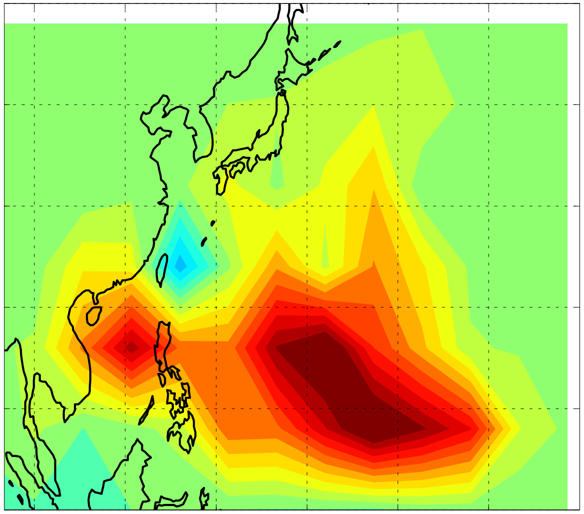
  Study period: 1979-2008

- **Calculation of track density**

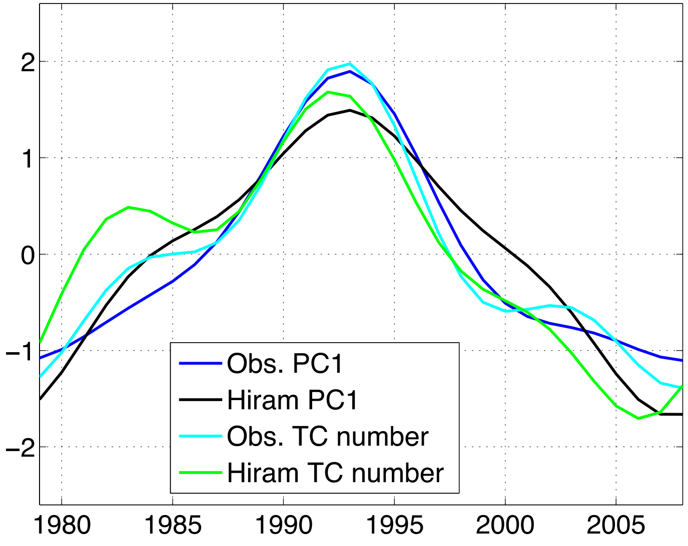
  Calculated as TC days within each 8°x8° grid box on a yearly or seasonal basis.

- **EOF and linear regression analyses**

Forced variability: low-frequency



Low-frequency variability: Mode 1



Low-frequency variability in TC track density: Mode 1

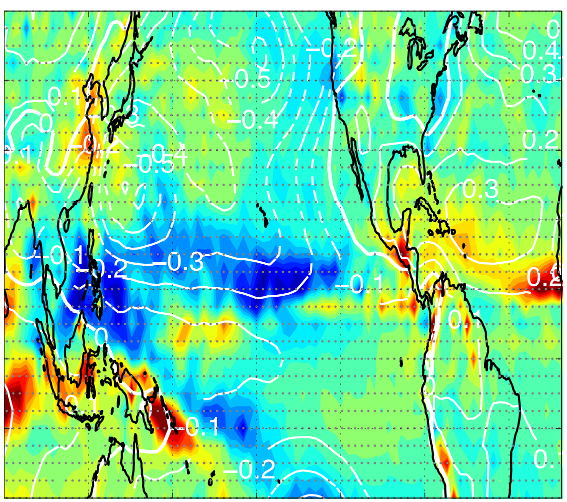
SST

Underlying SST pattern & atmospheric conditions

Vertical shear (contours) **& 850hPa vorticity** (shading)

6

SLP (contours) **& ω500** (shading)



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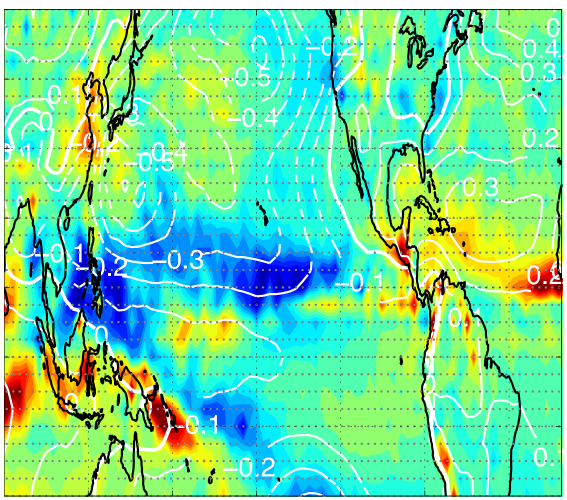
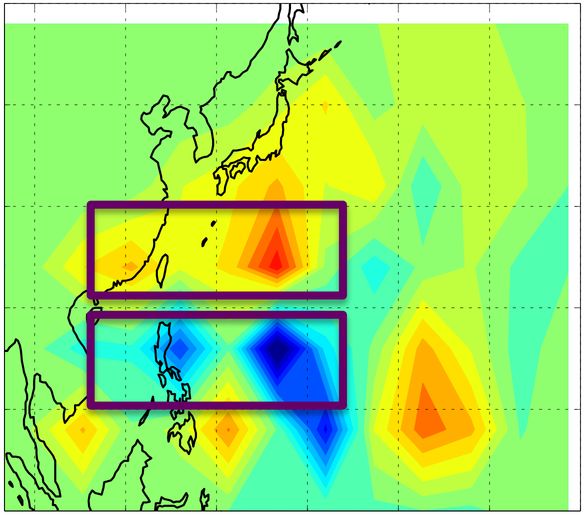
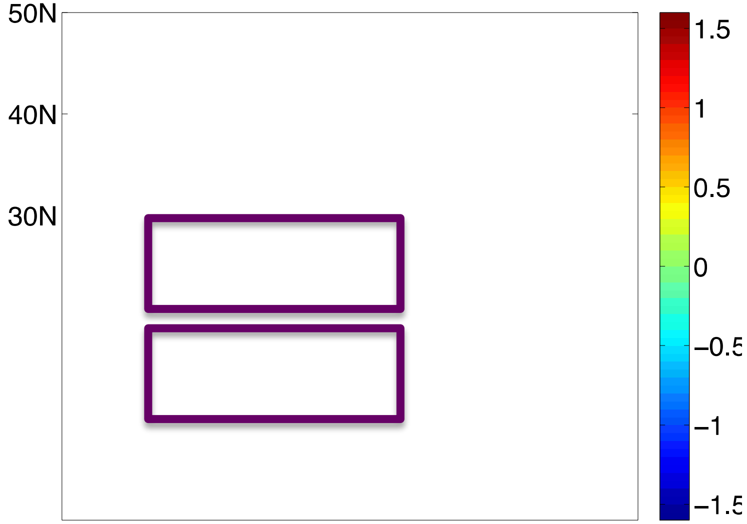




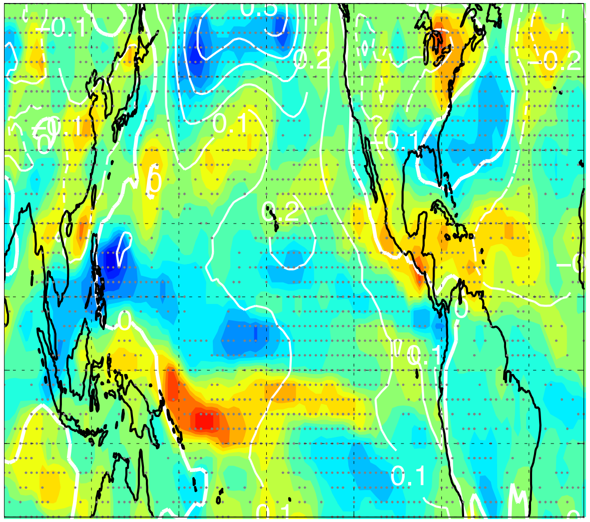
Low-frequency variability: Mode 2



Underlying SST pattern & atmospheric conditions

SST

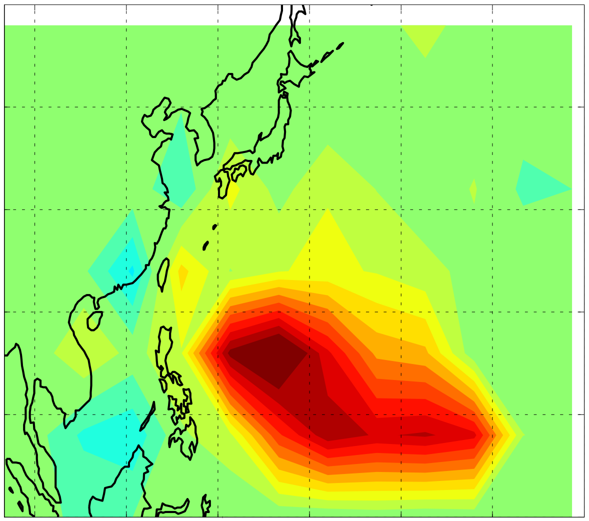
SLP (contours) **&**
850hPa vorticity (shading)



Forced variability: high-frequency

HiRAM simulations

Observations



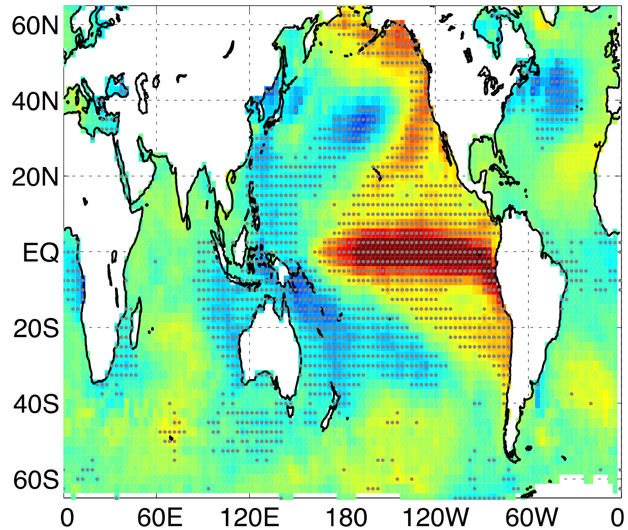
Only one physically meaningful mode exists in observations, and this mode can be considered as a mixture of the two modes of HiRAM simulations.

Underlying SST pattern

HiRAM mode 1

HiRAM mode 3

Obs. mode 1



Seasonal evolution of ENSO effect on TC track density

Seasonal evolution of ENSO effect on TC track density

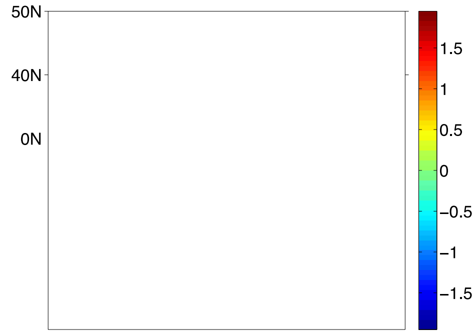
- **Method: a joint EOF analysis of TC track density over five consecutive seasons from AMJ of the current year [AMJ(0)] through AMJ of the following year [AMJ(1)].**
- **Physical basis: the persistence of ENSO signals which span AMJ(0) to AMJ(1).**

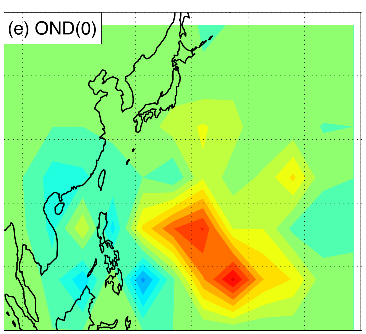
Seasonal evolution of ENSO effect on TC track density: Observations

Modes 1 & 2 in observations

Mode 1
AMJ(0)--OND(0)

Mode 2
AMJ(0)--OND(0)



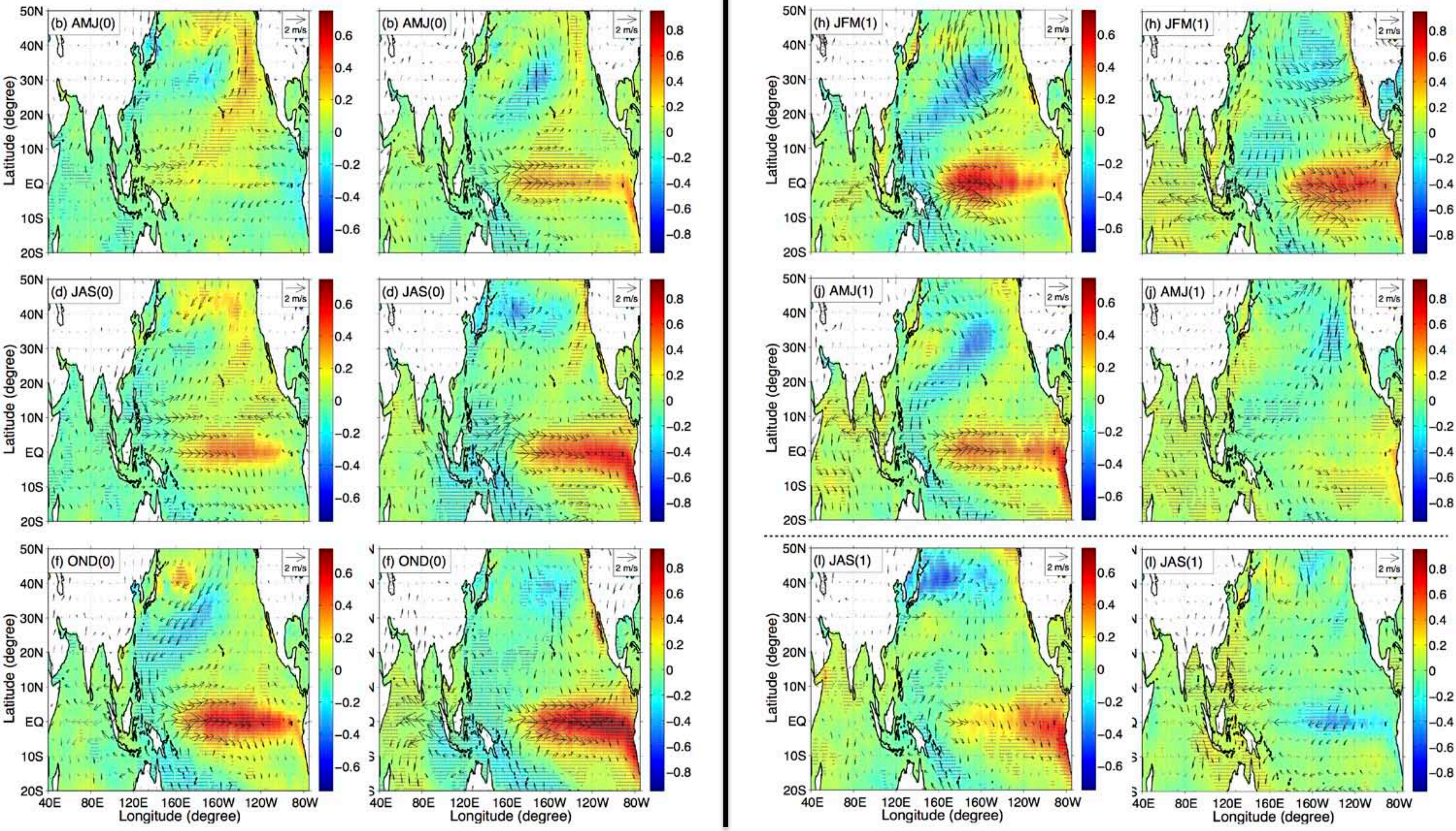


Mode 1
JFM(1)—JAS(1)

Mode 2
JFM(1)—JAS(1)

Underlying SST pattern & atmospheric conditions

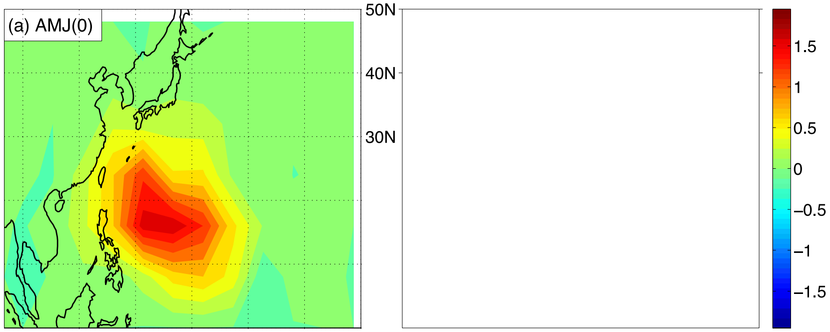
Mode 1	Mode 2	Mode 1	Mode 2
AMJ(0)--OND(0)	AMJ(0)--OND(0)	JFM(1)—JAS(1)	JFM(1)—JAS(1)



Modes 1 & 2 in HiRAM simulations

Mode 1
AMJ(0)--OND(0)

Mode 2
AMJ(0)--OND(0)

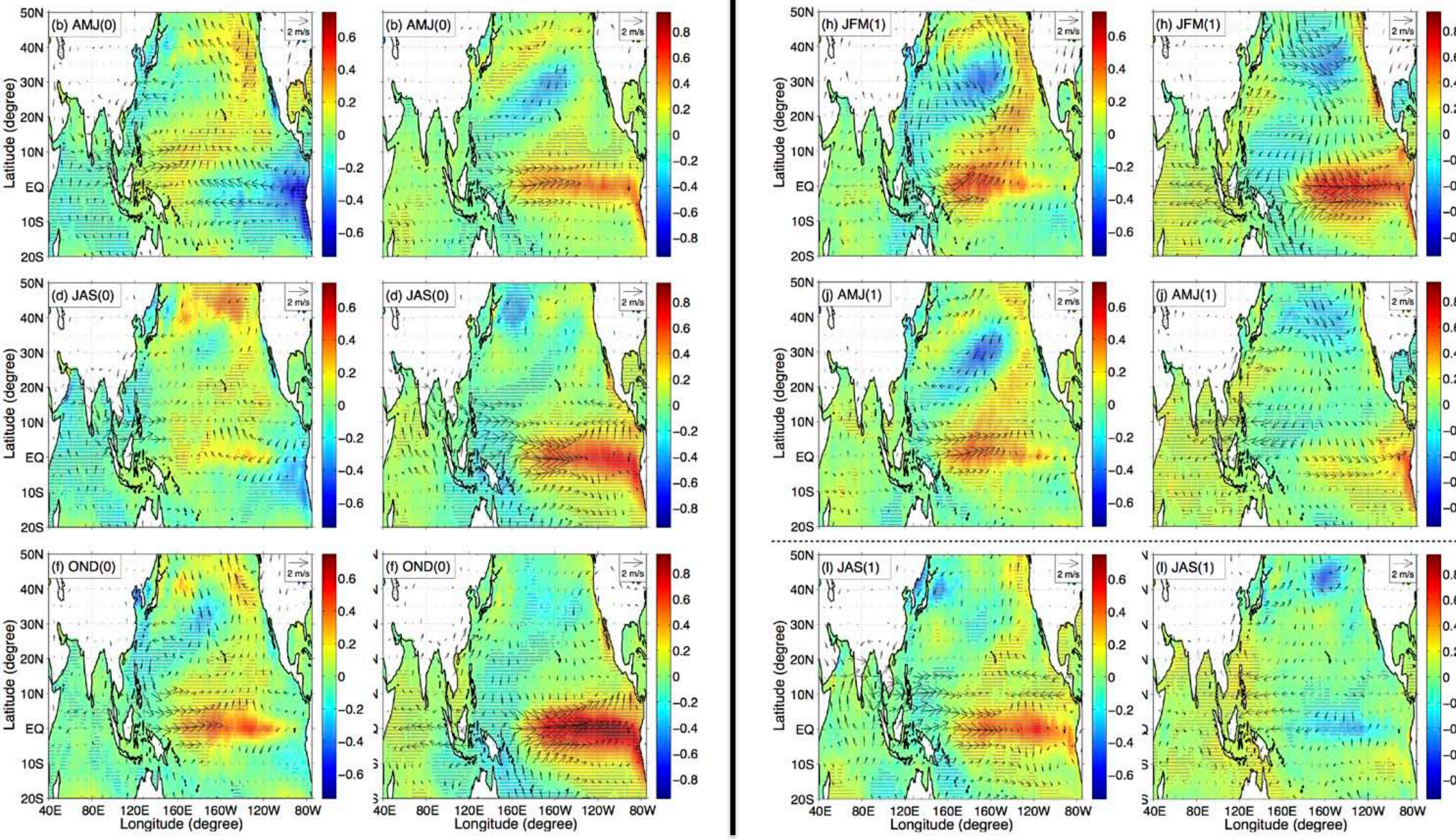


Mode 1
JFM(1)—JAS(1)

Mode 2
JFM(1)—JAS(1)

Underlying SST pattern & atmospheric conditions

Mode 1 AMJ(0)--OND(0) | **Mode 2** AMJ(0)--OND(0) | **Mode 1** JFM(1)—JAS(1) | **Mode 2** JFM(1)—JAS(1)



Internal variability

Definition

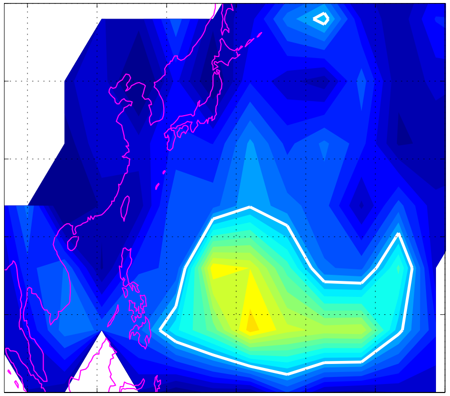
- The track density at each grid in each simulation can be partitioned into two components: an ensemble mean approximating the forced response, and the departures from that mean.
- The internal variability is measured as the signal-to-noise ratio:

$$R = \frac{\sigma_F}{\sigma_I}$$

where σ_F is the standard deviation of the ensemble mean component, and σ_I, representing the internal variability, is the standard deviation of the departures from the mean in all three ensemble members. A large value of R indicates that the internal variability is not as important as the forced response, and hence high predictability.

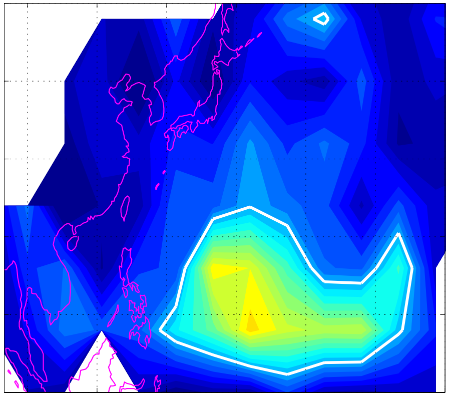
Signal-to-noise ratio of TC track density

Whole year



Signal-to-noise ratio of TC track density

Whole year



Early TC season (AMJ)

Peak TC season (JAS)

Late TC season (OND)

Signal-to-noise ratio of basin-integrated metrics

	Early TC season (Apr-Jun)	Peak TC season (Jul-Sep)	Late TC season (Oct-Dec)	Whole year (Jan-Dec)
Total days	1.65	0.98	1.35	1.68
Total numbers	1.62	1.06	1.53	1.71

Basin-integrated metrics is more predictable than local TC occurrence.
The predictability is highest in the early TC season and lowest in the peak TC season.

Summary

- The decadal variability is dominated by two modes: a nearly-basin-wide mode, and a dipole mode between the subtropics and lower latitudes. The former mode links to variations in TC numbers and is attributable to variations in SSTs over the northern off-equatorial tropical central Pacific, whereas the latter might be associated with the Atlantic Multidecadal Oscillation.
- The interannual variability is also controlled by two modes: a basin-wide mode driven by SST anomalies in the tropical central Pacific, and a southeast-northwest dipole mode connected to the conventional eastern Pacific ENSO.
- The seasonal evolution of anomalous pattern in TC track density is modulated by two types of ENSO: a hybrid CP and EP ENSO, and a conventional EP ENSO.
- TC track density exhibits prominent internal variability with strong spatial and seasonal dependencies. And basin-integrated metrics (e.g., total TC number and TC days) are more predictable.

Thank you for your attention!

Model performance

Observed & simulated TC genesis and tracks

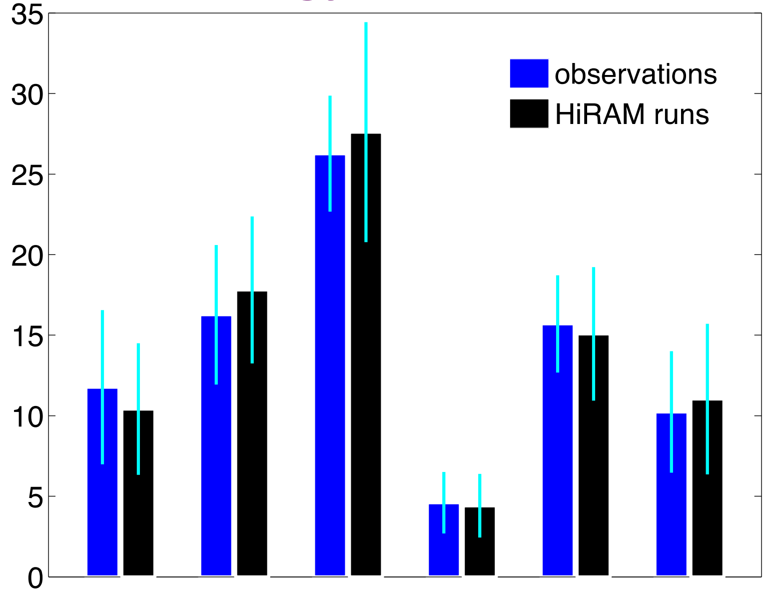
(b) HiRAM run 1

Latitude (degree)

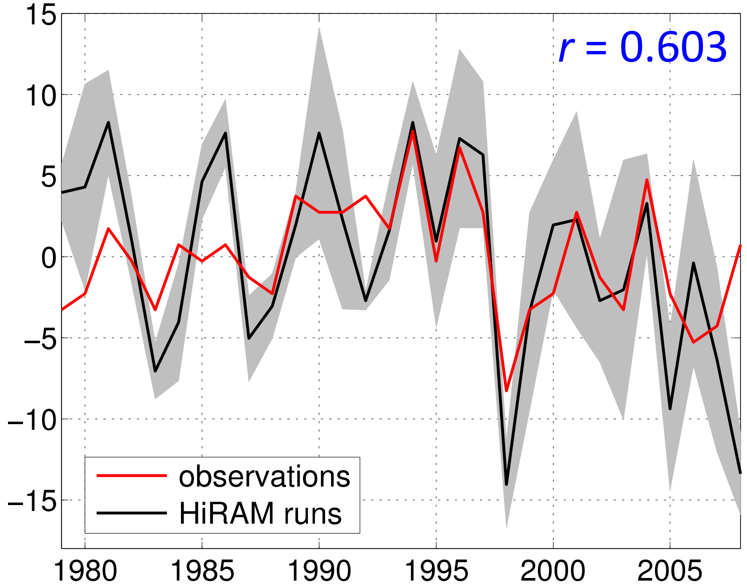
e (degree)

Observed & simulated TC numbers

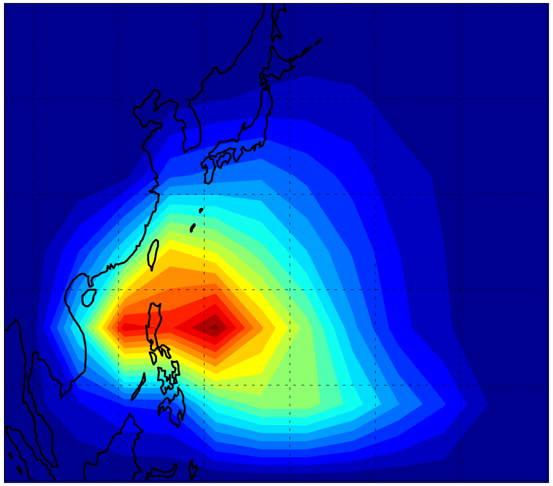
Climatology in various basins



Variations in WNP

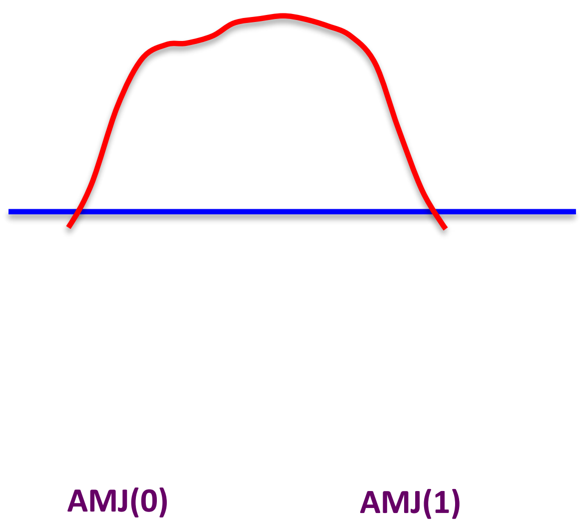


Climatological distribution of track density



Generally, both HiRAM and iRAM reproduce the observed large-scale pattern and magnitude of TC track density, despite some biases over the South China Sea.

- **Method: a joint EOF analysis of TC track density over five consecutive seasons from AMJ of the current year [AMJ(0)] through AMJ of the following year [AMJ(1)].**
- **Physical basis: the persistence of ENSO signals which span AMJ(0) to AMJ(1).**



(Du et al. 2009)

Summary

- **Forced interannual-to-decadal variability of annual TC track density is studied using TC tracks from observations and simulations by a 25-km-resolution version of the GFDL HiRAM that is forced by observed SSTs.**
- **The decadal variability is dominated by two modes: a nearly-basin-wide mode, and a dipole mode between the subtropics and lower latitudes. The former mode links to variations in TC numbers and is attributable to variations in SSTs over the northern off-equatorial tropical central Pacific, whereas the latter might be associated with the Atlantic Multidecadal Oscillation.**
- **The interannual variability is also controlled by two modes: a basin-wide mode driven by SST anomalies of opposite signs located respectively in the tropical central Pacific and eastern Indian Ocean, and a southeast-northwest dipole mode connected to the conventional eastern Pacific ENSO.**

Summary

- **We further explored the seasonal evolution of the ENSO effect on TC activity via a joint EOF analysis using TC track density of consecutive seasons. The seasonal evolution of anomalous pattern in TC track density is modulated by two types of ENSO: a hybrid CP and EP ENSO, and a conventional EP ENSO.**
- **The TC track density also exhibits prominent internal variability with strong spatial and seasonal dependencies. The internal variability is largest during the TC peak season, and is particularly strong in the South China Sea and along the coast of East Asia, making an accurate prediction and projection of TC landfall extremely challenging. In contrast, basin-integrated metrics (e.g., total TC number and TC days) are more predictable.**