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 are modulated by various climate modes (e.g., ENSO).

(Wang & Chan 2002)
Introduction

• The variability in TC track density integrates variations in TC genesis and tracks, and thus is expected to be influenced by climate variability as well.

• We use high-resolution AGCM ensemble simulations to isolate SST-forced variability and understand internal variability.

• The results have important implications for predictability of local TC occurrence.
Data and Methods

- **Observed and simulated TC tracks**
  - Observed TC best-track data
  - GFDL High-Resolution Atmospheric Model (HiRAM):
    - 25 km horizontal resolution;
    - forced by observed SSTs;
    - 3 members that differ only in initial conditions;
    - ensemble mean = SST-forced variability; and the deviation from the ensemble mean = internal variability.

- **Study period**: 1979-2008

- **Calculation of track density**
  Calculated as TC days within each 8°x8° grid box on a yearly basis.
Observed & simulated TC genesis and tracks

Observations

HiRAM run 1

Zhao et al. (2009)
Forced variability: 
low-frequency (≥ 10 years)
Low-frequency variability in TC track density: Mode 1
Low-frequency variability in TC track density: Mode 1

Low-frequency variability: Mode 1

Figure 3: (a) Spatial pattern of the first leading mode of the low-pass-filtered annual TC track density (denoted as mode L1; unit: days per year) in the WNP from observations. (b) As in (a), but for HiRAM-simulated track density. (c) Normalized time series of the corresponding principal component (PC) from observations (blue) and HiRAM simulations (black). Also shown are normalized anomalies of low-pass-filtered annual TC numbers in observations (cyan) and HiRAM simulations (green), and NAO index of the preceding winter (red).
Low-frequency variability in TC track density: Mode 2

Low-frequency variability: Mode 2

Figure 5: As in Fig. 3, but for the second leading mode (denoted as mode L2) of the low-pass-filterers annual TC track density.
Low-frequency variability in TC track density: Mode 2

Figure 5: As in Fig. 3, but for the second leading mode (denoted as mode L2) of the low-pass-filterers annual TC track density.
Forced variability:
high-frequency (< 10 years)
Modes of high-frequency variability in TC track density: HiRAM simulations

Mode 1
High-frequency variability in TC track density: HiRAM simulations

HiRAM simulations

Mode 1

Mode 3
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

Central Pac El Nino

HiRAM mode 3

Eastern Pac El Nino

Obs. mode 1

Hybrid El Nino
Internal variability
Internal variability

Definition

- Track density = forced response (ensemble mean) + internal variability (departures from the ensemble mean).

- The internal variability is measured as the signal-to-noise ratio:

\[ R = \frac{\sigma_F}{\sigma_I} = \frac{\text{forced response}}{\text{internal variability}} \]

A large value of \( R \) indicates that the internal variability is not as important as the forced response, and hence high predictability.
Internal variability

Signal-to-noise ratio of annual TC track density

- Large over the main development region, and small over the South China Sea and along the coast of East Asia.

Landfall is hard to predict.

- The local maximum value is ~1.4.
- In contrast, the signal-to-noise ratio of total TC numbers/days is ~1.7.

Basin-integrated metrics are more predictable.
Internal variability

Signal-to-noise ratio of seasonal TC track density

- Peak season is high in internal noise.
- Landfall is hard to predict.
Summary

• Modes dominating on **decadal** timescales:
  • a nearly-*basin-wide* mode, linked to variations in SSTs over the northern off-equatorial tropical central Pacific;
  • a *dipole* mode between the subtropics and lower latitudes, associated with the Atlantic Multidecadal Oscillation.

• Modes dominating on **interannual** timescales:
  • a *basin-wide* mode, driven by central Pacific ENSO;
  • a southeast-northwest *dipole* mode, connected to eastern Pacific ENSO.

• TC track density is **less predictable** in peak season and over the South China Sea and along the coast of East Asia. Total TC **number/days are more predictable** than local TC occurrence, particularly the landfall.
Thank you for your attention!