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.

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

Global Genesis Events 1971-2001
Sources of tropical cyclogenesis identified for each ocean basins
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°E-159.6°W, 15°S-56.7°N
- Horizontal resolution: 0.3°
- Grids: East-west 333, North-south 240
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
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
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

<table>
<thead>
<tr>
<th>June-November of the years</th>
<th>Annual Mean TC Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1970-2001 (CMA)</td>
<td>21.2</td>
</tr>
<tr>
<td>1990-2006 (CMA)</td>
<td>21.7</td>
</tr>
<tr>
<td>1990-2006 (iRAM)</td>
<td>20.7</td>
</tr>
</tbody>
</table>
First position of tropical storms

From CMA data (1971-2000)  
Model results (1990-2006)

The units are numbers per 5° square box per 6-month (JJASON) period
Occurrence of tropical storms


The units are number per 2.5° square box per 6-month (JJASON) period
Interannual variation of TC number

correlation: 0.85
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


Summer SSTA in the EIO could explain about 50% of the total variance of TS genesis frequency over the WNP

R = -0.69
Genesis location and frequency in cold and warm years

Cold cases  Total=12

Warm cases  Total=79

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
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°lat*0.5°lon
- Domain: 15°S-56.5°N, 70°E-160°W
- Time integration: 00 UTC 27 May– 18 UTC 30 Oct
- Control Run: Default setting, observed Weekly SST
- Sensitivity Run1 (WSR): +1°C SST in EIO (10°S-22.5°N, 80°-100°E)
- Sensitivity Run2 (CSR): −1°C SST in EIO
### Selected cases

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

<table>
<thead>
<tr>
<th>Year</th>
<th>OBS frequency</th>
<th>Warm EIO SSTA</th>
<th>Cold EIO SSTA</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1998</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1994</td>
<td>33</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climatology</td>
<td>20</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Genesis frequency of WNP TSs in 2004 Typhoon Season

OBS

TS_Fr=22

CTRL

TS_Fr=22

WSR

TS_Fr=15

Less

CSR

TS_Fr=31

More
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

**OBS**
- TC_Fr=10

**CTRL**
- TC_Fr=9
- Climatology: 20

**CSR-CTRL**
- Climatology: 20

**CSR**
- TC_Fr=17
Genesis frequency of WNP TSs in 1994 Typhoon Season

OBS

TC_Fr=33

CTRL

TC_Fr=31
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!