Summary of UND training project:

Application of numerical model on extreme weather and environmental studies

Research Center for Environmental Changes, Academia Sinica, Taiwan

Chuan-Yao Lin

Deeper Understanding Natural Disaster Mitigation Training Program, 19, April, 2021
Regional Climate Changes

Outline

urbanization

Temperature
precipitation
Air pollution
Summary of examples of cases studies

- Typhoon and TD: Sri Lanka (2019); Philippines (Haiyan, 2013); Macau (Hato, 2017); Taiwan (Morako, 2009);
- Thunderstorm:
  a. Urban Flash flooding case in Taiwan
  b. Lightning simulation
- Regional climate changes
  Dynamic downscaling and applications - Heat waves; precipitation
- Environmental research issues:
  a. Long-range transport of Asian Dust
  b. River dust events impact on air quality of western Taiwan
  c. Long-range transport of Biomass Burning products to Taiwan and East Asia
Cross scale modeling system: From regional to urban scale (WRF-UCM)

Regional scale

Local scale

Urban scale

Urban Canopy Effects

Dynamic Effects

- turbulence production
- canopy heating & cooling
- anthropogenic heating
- radiation trapping
- radiation attenuation
- drag

Thermal effects
The graphic depicts some of the physical processes and parameters that are typically parameterized, both because they cannot be explicitly predicted in full detail in model forecast equations.

- Initial conditions, boundary conditions, emission, parameterization of physical and chemical processes (how details)
- Resolution
Observation

426 stations of rain gauge

Air quality monitoring stations
Questions

Hypothesis

Design your modeling work

- Resolution (domains)
- Physical and chemical schemes
- How many observation data you have?

Validation

Understanding the physical and chemical processes (mechanisms)

Disaster Mitigation Implications, and strategies proposed

How many observation data you have?
I: Extreme weather: Cases study (TD, Typhoon)
Effects of horizontal resolution and air–sea flux parameterization on the intensity and structure of simulated Typhoon Haiyan (2013)

Mien-Tze Kueh¹, Wen-Mei Chen¹, Yang-Fan Sheng¹, Simon C. Lin², Tso-Ren Wu³, Eric Yen⁴, Yu-Lin Tsai³, and Chuan-Yao Lin¹

Duration: Nov.3-11
Peak: 230 km/h (145 mph) (10min)
Intensity: 895 hpa
Why can not well capture minimum central pressure?

(Mori et al. 2014, GRL) WRF-1km Cress-4 km
the positive effect of surface flux formulas cannot be effectively enhanced unless the grid spacing is properly reduced to efficiently yield intense and contracted eyewall structure.
Numerical Analysis of the Mesoscale Dynamics of an Extreme Rainfall and Flood Event in Sri Lanka in May 2016
Observed development of the low pressure system / later tropical cyclone ‘Roanu’ over the Bay of Bengal (14-22 May 2016)

<table>
<thead>
<tr>
<th>Date</th>
<th>Synoptics</th>
</tr>
</thead>
<tbody>
<tr>
<td>14th May 2016</td>
<td>Meteorology Department issued a severe weather advisory for twelve hours commencing 11:30 am (local). Low pressure area developed over southwest Bay of Bengal</td>
</tr>
<tr>
<td>15th May 2016</td>
<td>Nearly 100mm of rainfall was reported in many areas in western &amp; southern Sri Lanka. Several parts of the capital Colombo were flooded</td>
</tr>
<tr>
<td>16th May 2016</td>
<td>The system paralleled the east coast of Sri Lanka &amp; developed into a depression (D) Water levels on the major rivers rising and the flooding</td>
</tr>
<tr>
<td>17th May 2016</td>
<td>By the morning the system is already passed Northern part of the island. Several landslides in central part of the country</td>
</tr>
<tr>
<td>18th May 2016</td>
<td>Intensified into a deep depression (DD) 0300 UTC Water levels on the Kelani River rose rapidly, Flooding continued</td>
</tr>
<tr>
<td>19th May 2016</td>
<td>Further drifted North &amp; intensified into a cyclonic storm (CS) 0000 UTC</td>
</tr>
<tr>
<td>21th May 2016</td>
<td>Landfall into Bangladesh coast north of Chittagong, Bangladesh 1000 UTC Gradually weakened into a DD over Mizoram 1800 UTC</td>
</tr>
<tr>
<td>22th May 2016</td>
<td>Gradually weakened into a D near Myanmar and adjoining Manipur - 0000 UTC well marked low pressure area over Myanmar - 0300 UTC</td>
</tr>
</tbody>
</table>

Source: India Meteorological Department, 2016
Questions

• What was the main cause for the heavy rainfall and flooding in western part of Sri Lanka?
  — Main cause for the heavy rainfall was just a low pressure system.

• Why May 15 & 16 received the maximum rainfall over western part of Sri Lanka?

• Why only western part of Sri Lanka received relatively maximum rainfall and why not the eastern part of Sri Lanka?
## WRF Model parametrization & configuration

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal Resolution</td>
<td>3 km (170 X 135 grids) / 9km</td>
</tr>
<tr>
<td>Time interval ((\Delta t))</td>
<td>60 mins</td>
</tr>
<tr>
<td>Run time</td>
<td>4 days (96 hours)</td>
</tr>
<tr>
<td>Vertical Levels</td>
<td>38</td>
</tr>
<tr>
<td>Feedback</td>
<td>Off</td>
</tr>
<tr>
<td>Radiation</td>
<td>LW: RRTM; SW: Dudhia</td>
</tr>
<tr>
<td>Surface Layer</td>
<td>Revised MM5 Monin-Obukhov scheme</td>
</tr>
<tr>
<td>Land Surface Model</td>
<td>unified Noah land-surface model</td>
</tr>
<tr>
<td>Boundary Layer</td>
<td>YSU</td>
</tr>
<tr>
<td>Cumulus</td>
<td>Kain-Fritsch (new Eta) scheme</td>
</tr>
<tr>
<td>Microphysics</td>
<td>Lin et al. scheme</td>
</tr>
<tr>
<td>Nudging</td>
<td>Grid nudging, Initial conditions 6hrs</td>
</tr>
<tr>
<td>SSTs</td>
<td>SST update</td>
</tr>
</tbody>
</table>
Model Evaluation

![Model Evaluation Diagram](image-url)
Extreme weather: Flash flood case
Taipei Flash flood case
14 June, 2015


(from Jou et al.2016)
Taipei Flash flood case (14 June, 2015)
Model domains and configures

Version WRF 3.9
Met. IC, BC: ERA5 dataset
Microphysics : WSM 5-class scheme
Long-wave radiation : RRTM
Short-wave radiation : RRTM
Surface layer : Revised MM5 Monin-Obukhov scheme (Jimenez, renamed in v3.6)
Land-surface model : Unified Noah LSM
Boundary layer scheme : YSU scheme
Cumulus : Grell-Freitas ensemble scheme (only Do1 and D02)
Urban canopy model: 2D

D01: 6 km, 211x211;
D02: 2 km, 211x253;
D03: 666m, 241x166
WRF/Urban Canopy Model

- **Single layer** Urban-Canopy Model (UCM, Kusaka et al., 2004)
- **UCM** treats man-made surfaces
  - urban geometry (orientation, diurnal cycle of solar azimuth), symmetrical street canyons with infinite length
  - Shadowing from buildings and reflection of radiation
  - Anthropogenic heating
  - Multi-layer roof (HR), wall (HW) and road (HG) models

Defined and implemented urban canopy parameterizations such as height-to-width ratios and sky view factors into model formulations.
Model evaluation
Observation

666 m

2 KM

6 KM
Regional climate changes
Future warming in Taiwan simulated by WRF nested with ECHAM5/MPIOM (A1B scenario)

ECHAM5: domain:192x96 $\Delta x=1.875$ degree
WRF:
  Domain1 : 301x301 $\Delta x,y=15$km FDDA
  Domain2 : 382x400 $\Delta x,y=5$km, vertical 45 levels

75 years simulation:
1979-2003; 2015-2039; 2075-2099
Dynamical downscaling

- Existing Global climate models (GCMs) typically run at a scale of 200 km which is too coarse for application regional or local.
- Especially for variables that depend on regional topographic, such as precipitation, surface wind and temperature.
- Dynamical downscaling with regional climate model is an essential component to fill the gap between GCMs and regional application.

(Lin et al. 2015)
The projected warming trend shows altitudinal variations with more significant temperature increase in mountain areas (altitude > 1000 m) than in plain areas (altitude < 500 m) and greater increase in the distant future 2075-2099.

During winter, the projected warming trend shows latitudinal variations with more significant temperature increase in northern Taiwan than in southern Taiwan.
WBGT estimation from Observation and ECHAM5-WRF during summer (JA)

2003-2012 WBGT >31°C:
Taipei: 10.74%
Taichung: 4.22%
Kaohsiung: 11.28%

(Lin et al. 2017; Climatic Changes)
II Environmental studies
Sources of air pollutants

- Ozone
- Secondary aerosols

Primary pollutants:
- CO
- CO₂
- SO₂
- NO
- NO₂

Secondary pollutants:
- SO₃
- H₂SO₄
- HNO₃
- O₃
- H₂O₂

Natural and Human-Generated Emissions

Transport and Chemical Reactions

Winds

Deposition

Haze

Biological Effects on Natural Resources

https://www.nps.gov/subjects/air/sources.htm
WRF-Chem

- Chemistry is online, completely embedded within WRF model
- Consistent: all transport done by meteorological model
  - Same vertical and horizontal coordinates
  - Same physical parameterization for subgrid scale transport
  - No interpolation in time
Long-range transport: Asian Dust

2010/03/21 dust storm

(Lin et al. 2012 ACP)
Long-range transport: Indochina Biomass burning

ATSR-WFA Hot Spots (2012 March)

(Lin et al. 2009; 2014)
Seasonal variation of CO, O3 and PM10 at LuLin Mountain station (2006-2009)
Models long-range transport of Southeast Asia biomass-burning aerosols to Taiwan and their radiative forcings over East Asia

WRF/chem configures

- Radiaton: RRTMG
- PBL: Mellor Yamada Janjic (MYJ)
- Chemistry driver: RADM2
- Aerosol driver: MADE/SORGAM
- Biomass mass burning emission: FINN1
- Domain: resolution 15 km, vertical 35 levels.
- Spin up time: 5 days (3/10~3/14).

Fig. 6. Backward trajectory analysis results obtained using HYSPLIT model starting at 00:00 UTC (08:00LST) on 18 March 2008 at altitude 3000 m at Banciao station in northern Taiwan. Distribution of active fires detected by MODIS from 15 (green dots) to 16 (blue dots) March 2008.
Model evaluation: AOD

Fig. 8. Average AOD at 550 nm observed by AERONET and simulated using WRF-Chem with and without biomass-burning emission (Sim-bb and Sim-nobb) and simulation started from 09 March (Sim-Fd9) at various ground stations from 15 to 18 March, 2008.
Ozone sounding and transport of Ozone

20080318
Temperature (°C)

Ozone sounding and transport of Ozone

Ozone (ppbv)

Relative Humidity (%)
Average reduction in shortwave radiation fluxes at ground surface simulated with and without biomass-burning emission during 15-18 March, 2008 (unit W m$^{-2}$).

(Lin et al. 2014)
Identification of IndoChina biomass burning products to Taiwan

HALO Modeling

OC at 06 UTC

Org.

Tainan

Westcoast

Taiwan 20.03.18 Flight 906
Figure 7.1: Overview of forcing and feedback pathways involving greenhouse gases, aerosols and clouds. Forcing agents are in the green and dark blue boxes, with forcing mechanisms indicated by the straight green and dark blue arrows. The forcing is modified by rapid adjustments whose pathways are independent of changes in the globally averaged surface temperature and are denoted by brown dashed arrows. Feedback loops, which are ultimately rooted in changes ensuing from changes in the surface temperature, are represented by curving arrows (blue denotes cloud feedbacks; green denotes aerosol feedbacks; and orange denotes other feedback loops such as those involving the lapse rate, water vapour and surface albedo). The final temperature response depends on the effective radiative forcing (ERF) that is felt by the system, i.e., after accounting for rapid adjustments, and the feedbacks.
### Challenges

#### Radiative forcing of climate between 1750 and 2011

<table>
<thead>
<tr>
<th>Forcing agent</th>
<th>Radiative Forcing (W m⁻²)</th>
<th>Confidence Level</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Well Mixed Greenhouse Gases</strong></td>
<td></td>
<td><strong>Very High</strong></td>
</tr>
<tr>
<td></td>
<td>CO₂</td>
<td>Halo carbons</td>
</tr>
<tr>
<td></td>
<td>Other WMGHG</td>
<td>CH₄, N₂O</td>
</tr>
<tr>
<td><strong>Ozone</strong></td>
<td></td>
<td><strong>High</strong></td>
</tr>
<tr>
<td></td>
<td>Stratospheric</td>
<td>Tropospheric</td>
</tr>
<tr>
<td><strong>Surface Albedo</strong></td>
<td></td>
<td><strong>High/Low</strong></td>
</tr>
<tr>
<td></td>
<td>Land Use</td>
<td>Black carbon on snow</td>
</tr>
<tr>
<td><strong>Contrails</strong></td>
<td></td>
<td><strong>Medium</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Contrail induced cirrus</td>
</tr>
<tr>
<td><strong>Aerosol-Radiation Interac.</strong></td>
<td></td>
<td><strong>Low</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>AR4 estimates</td>
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<tr>
<td><strong>Aerosol-Cloud Interac.</strong></td>
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<tr>
<td><strong>Total anthropogenic</strong></td>
<td></td>
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</tr>
</tbody>
</table>

- **Heating factors**
- **Cooling factors**
- **Large uncertainty**
- **Heating effect but with significant uncertainties**
https://acp.copernicus.org/preprints/acp-2021-204/

https://doi.org/10.1038/s41598-020-76181-4

Hsieh, C.-Y., C.-R. Jung, Chuan-Yao Lin*, Bing-Fang Hwang*, 2020, Combined exposure to heavy metals in PM2.5 and pediatric asthma, *The Journal of Allergy and Clinical Immunology.*

https://doi.org/10.5194/nhess-19-1509-2019

(https://doi.org/10.2151/jmsj.2019-046)

https://doi.org/10.1007/s10584-017-2091-0


(*Corresponding author)


Thank you !!!