Orographic Effects Assessment on Extreme Rainfall Event in Rwanda using WRF Model
*(EO AND GIS PERSPECTIVES)*

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Presentation Outline

➢ Introduction
➢ Study area description
➢ Data Collection and Methodology
➢ Results and discussions
➢ Conclusions
➢ Take-away message
1. Introduction

• Orographic effect refers to weather conditions triggered by changes to air flow when topography of land forces air upward.

• **High altitude** regions as flood prone areas due to heavy rains and
  **Low altitude** regions as drought areas due to less rains

• In this study, **WRF model** was used to **assess basic mechanisms by which high mountains affect rainfall distribution** in Rwanda
Weather Research Forecasting (WRF)-Practical Focus for Earth Observations

WRF is a mesoscale numerical weather prediction model suitable for a wide range of studies in weather simulation.

**Earth Observations Systems (Data)**
- Remotely sensed
- In Situ

**Earth System Models**
- Weather
- Atmosphere
- Climate

Benefits of a comprehensive EO => Improve our ability to:
- Monitor the earth
- Understand and predict changes to earth
Orographic precipitation mechanisms (Houze Robert Jr, 2012)

- **Upslope**
  - Daytime: Cloud layers over terrain
  - Downstream waves
  - Blocking effects
  - Deep convections

- **Overturning of convection**
- **Nighttime**
- **Seeder-Feeder**
- **Leeside convection**
- **Partial blocking**
- **Capping of deep convections**
2. Study Area

Rwanda: located in Central-East Africa

Coordinates: 1°04' -2°51'S, 28°45' -31°15'E

Area: 26,338 sq. km

Rainfall annual amount = 800 -1400 mm
3. Data Collection and Methodology

Spatial rainfall distribution using IDW method

For verification: Threat score, Bias score, Root Mean Square Error and Mean Absolute Error were used
3. Data Collection and Methodology

Model Configuration

<table>
<thead>
<tr>
<th>Model Parameters</th>
<th>Options Used</th>
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</thead>
<tbody>
<tr>
<td>Grid Resolution</td>
<td>D1:27km</td>
</tr>
<tr>
<td></td>
<td>D2:9km</td>
</tr>
<tr>
<td></td>
<td>D3:3km</td>
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<tr>
<td>Data</td>
<td>NCEP fnl (1°X1°)</td>
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<tr>
<td></td>
<td>D1 output</td>
</tr>
<tr>
<td></td>
<td>D2 output</td>
</tr>
<tr>
<td>Cumulus Parameterization Schemes (CPS)</td>
<td></td>
</tr>
<tr>
<td>1. Kain-Fritsch (KF)</td>
<td></td>
</tr>
<tr>
<td>2. Betts Miller Janjic (BMJ)</td>
<td></td>
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<td>3. Grell Devenyi (GD)</td>
<td></td>
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<tr>
<td>4. Arakawa (ARA)</td>
<td></td>
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<tr>
<td>5. Previous Kain-Fritsch (PKF)</td>
<td></td>
</tr>
<tr>
<td>Microphysics Scheme</td>
<td>WSM3-class simple scheme</td>
</tr>
<tr>
<td>PBL Scheme</td>
<td>YSU scheme (Hong et al. 2006)</td>
</tr>
<tr>
<td>Land Surface</td>
<td>Noah</td>
</tr>
<tr>
<td>Radiation Scheme</td>
<td>RRT for longwave and Dudhia for short wave radiation</td>
</tr>
</tbody>
</table>
4. Results and Discussions
   a. Sensitivity of WRF to different CPS
b. Model Skilfulness Verification

<table>
<thead>
<tr>
<th>Model</th>
<th>MAE</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kain Fritsch (KF)</td>
<td>21.47438</td>
<td>28.06659</td>
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<tr>
<td>Betts Miller Janjic (BMJ)</td>
<td>10.89266</td>
<td>15.16162</td>
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<tr>
<td>Grell Devenyi (GD)</td>
<td>29.14266</td>
<td>39.17605</td>
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<tr>
<td>Simplified Arakawa-Schubert (ARA)</td>
<td>26.17313</td>
<td>33.95771</td>
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<tr>
<td>Previous Kain Fritsch (PKF)</td>
<td>15.43283</td>
<td>18.42318</td>
</tr>
</tbody>
</table>
c. Sensitivity tests with modified topography

The WRF terrain height (AT and 4 RT experiments)

Simulated Rainfall in 24hrs (AT and RT)
d. Vertical Cross Sections Analysis
Vertical Cross Section Analysis (A-A’)

Cloud and Rain water mixing ratios at 10 UTC (12pm)  
Vertical velocity and wind vectors at 10 UTC (12 pm)
Vertical Cross Section Analysis (A-A’)

Cloud and Rain water mixing ratios at 11 UTC (1 pm)

Vertical velocity and wind vectors at 11 UTC (1 pm)
Vertical Cross Section Analysis (B-B’)

Cloud and Rain water mixing ratios at 14 UTC (4pm)

Vertical velocity and wind vectors at 14 UTC (4pm)
Vertical Cross Section Analysis (B-B’)

Cloud and Rain water mixing ratios at 17 UTC (7 p.m.)

Vertical velocity and wind vectors at 17 UTC (7 p.m.)
5. Conclusions

• The BMJ cumulus performed better than other CPS

• WRF/BMJ has high performance on low rainfall amount

• Further studies
  - Consideration of all WRF Physical schemes to find a good combination
  - Examination of Land Use effects on rainfall distribution
  - Detailed study for long period

Orographic Mechanisms observed for Rwanda on 30 November 2011
6. Take-away message

1. Global system of EO enable development of capabilities to:
   ❖ Predict natural hazards;
   ❖ Prepare for weather emergencies and other natural hazards
   ❖ Monitor air quality

2. Orographic effects/rainfall can be used as an ingredient of strategic planning:
   ❖ On water related disasters mitigation and;
   ❖ On sustainable use of water resources
THANK YOU FOR YOUR ATTENTION
References


OPW. (2002). Report of the FLOOD POLICY REVIEW GROUP.


Satellite pictures from METEOSAT-9

Nov-30-2011 00: 12 UTC
Nov-30-2011 03: 12 UTC
Nov-30-2011 06: 12 UTC
Nov-30-2011 09: 12 UTC
Nov-30-2011 12: 12 UTC
Nov-30-2011 15: 12 UTC
Nov-30-2011 18: 12 UTC
Nov-30-2011 21: 12 UTC
Dec-01-2011 00: 12 UTC
3. Data Collection and Methodology
Statistical Verification of WRF Model

1. Threat Score (TS)

\[ TS = \frac{Hits}{Hits + False\ alarms + Misses} \]

2. Bias Score (BS)

\[ BS = \frac{Hits + False\ alarms}{Hits + Misses} \]

3. Root Mean Square Error (RMSE)

\[ RMSE = \sqrt{\frac{\sum_{i=1}^{n} (S-O)^2}{N}} \]

4. Mean Absolute Error (MAE)

\[ MAE = \frac{\sum |S-O|}{N} \]