Orographic Effects Assessment on Extreme Rainfall Event in Rwanda using WRF Model
(E0 AND GIS PERSPECTIVES)

Mrs. Gretta Muhimpundu

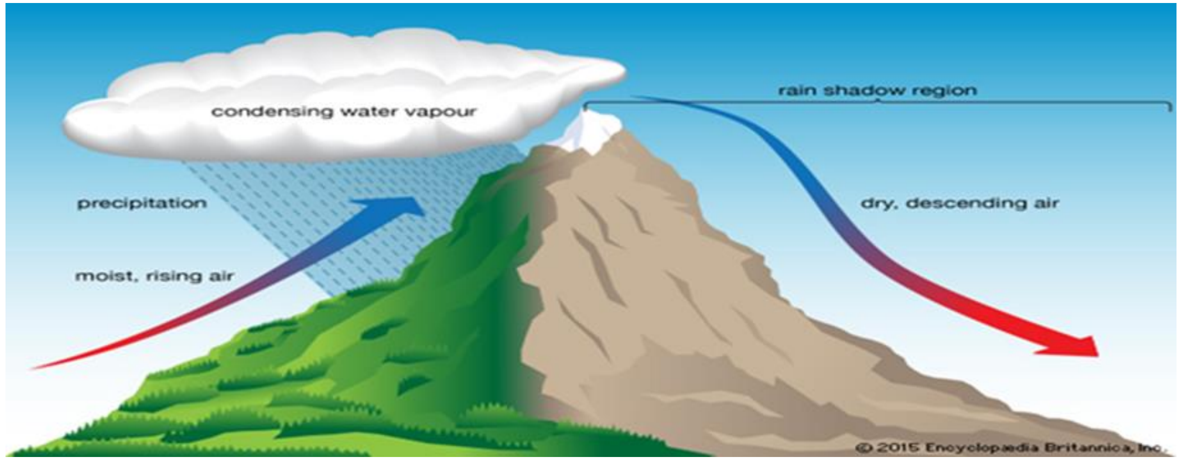
AFRICAGIS 2019 CONFERENCE
November 19, 2019
Kigali-Rwanda

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

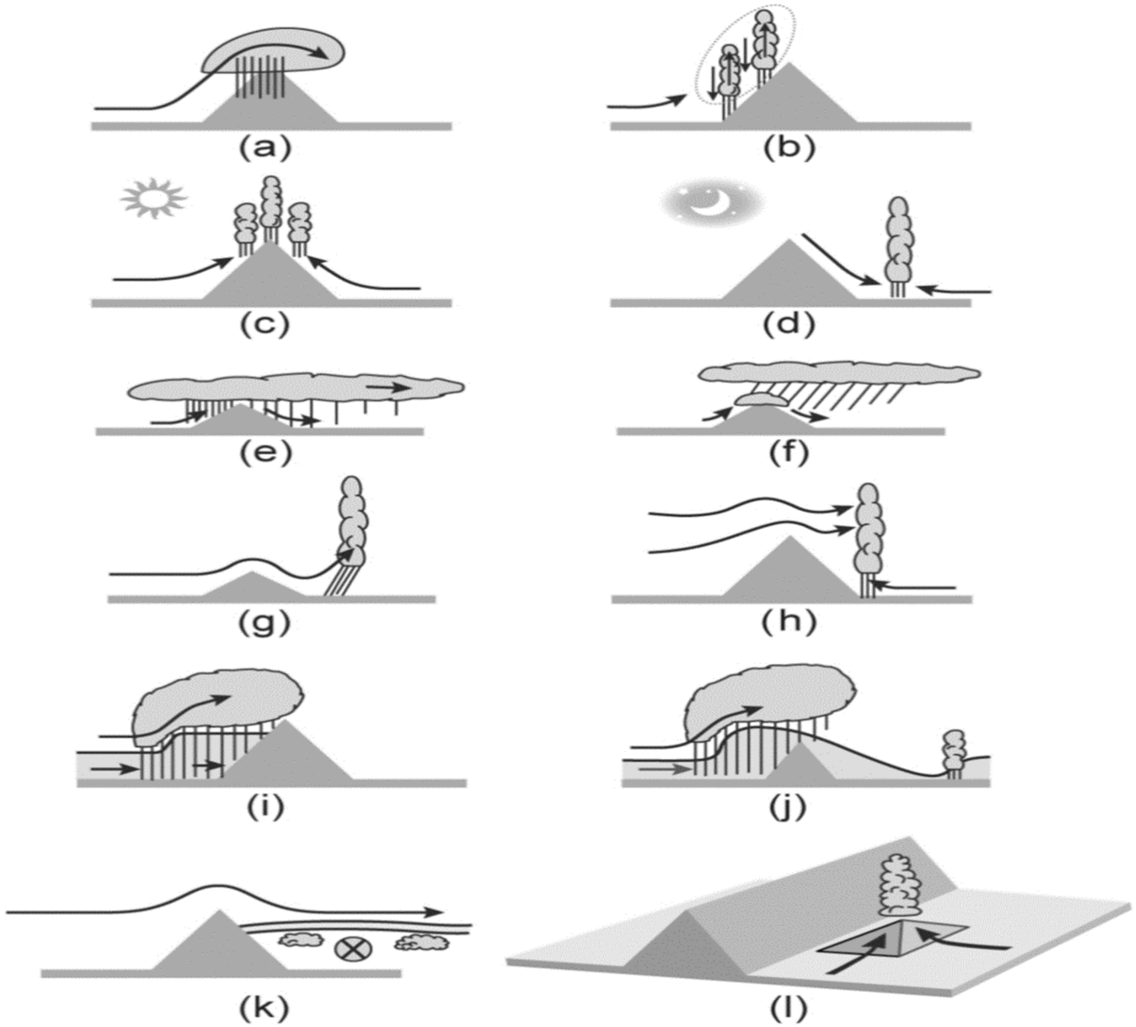
Earth Observations Systems (Data)
- Remotely sensed
- In Situ

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

Overturning of convection

Daytime

Nighttime

Cloud layers over terrain

Seeder-Feeder

Downstream waves

Leeside convection

Blocking effects

Partial blocking

Deep convections

Capping of deep convections

2. Study Area

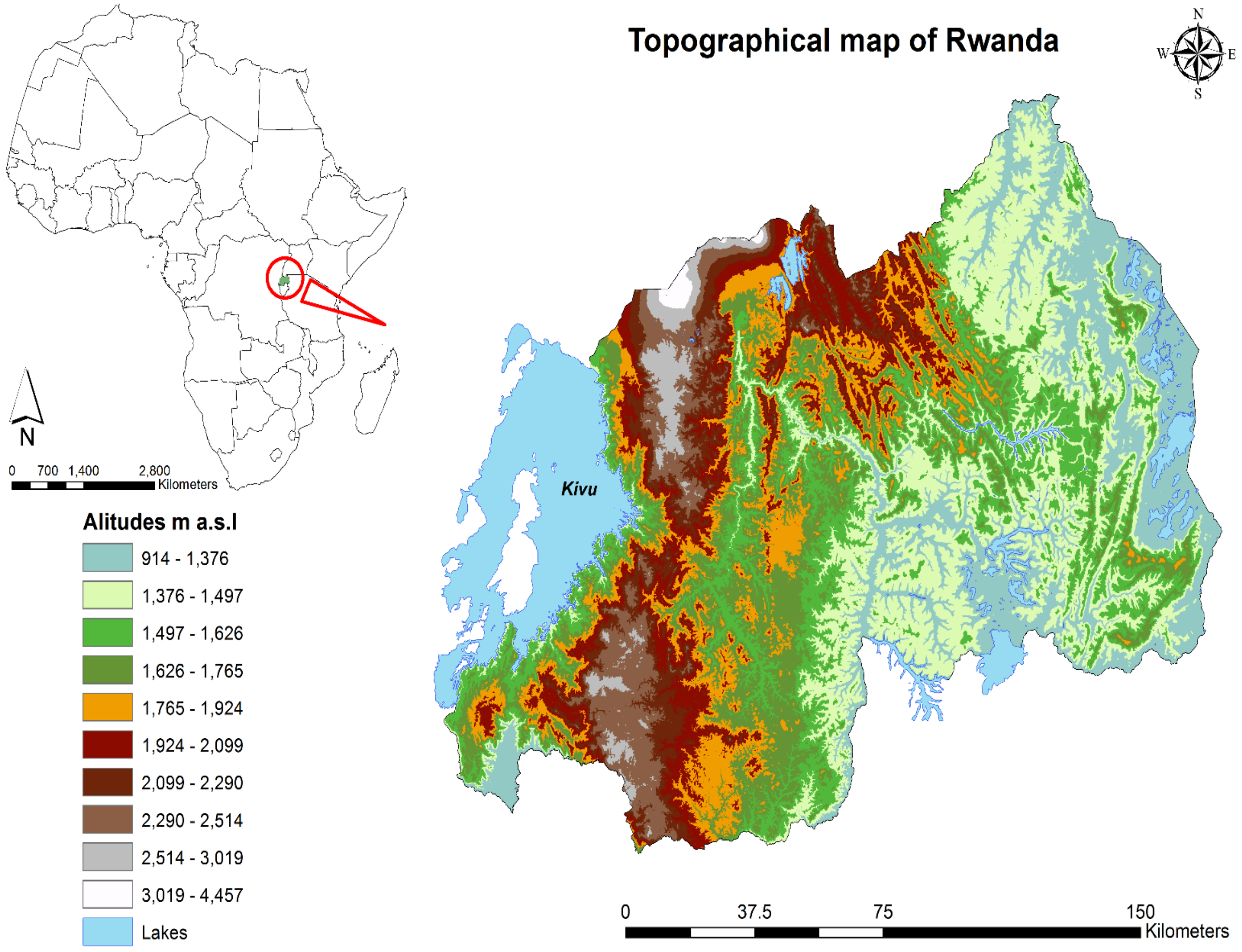
Rwanda: located in Central-East Africa

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

Area: 26,338 sq. km

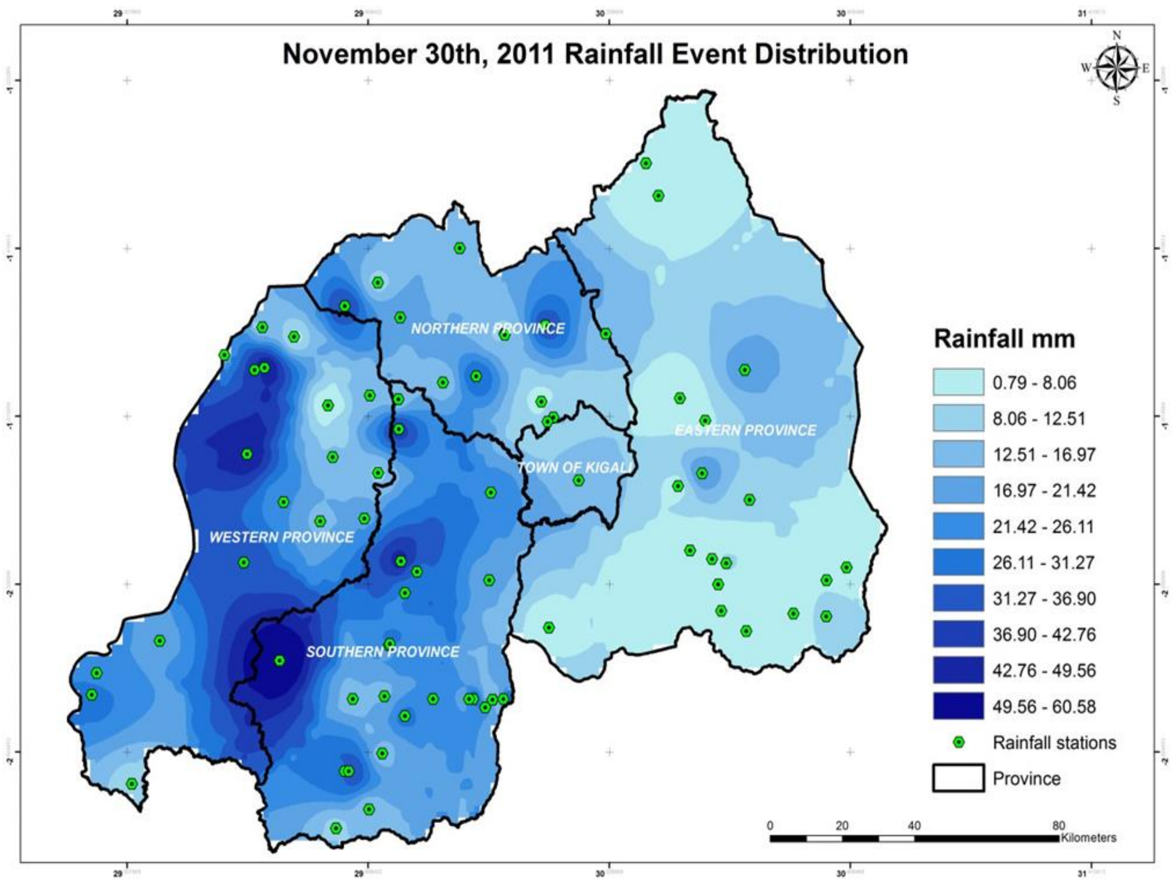
Rainfall annual amount =

800 -1400 mm

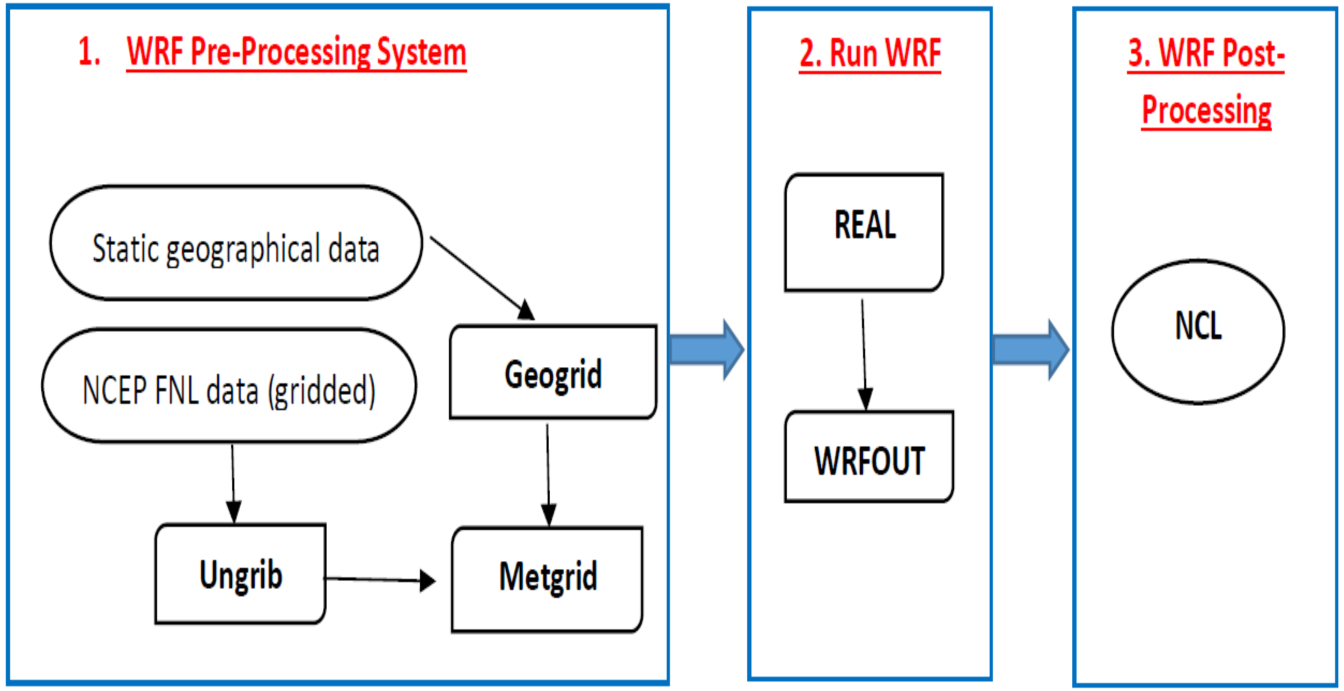


3. Data Collection and Methodology

Spatial rainfall distribution using IDW method



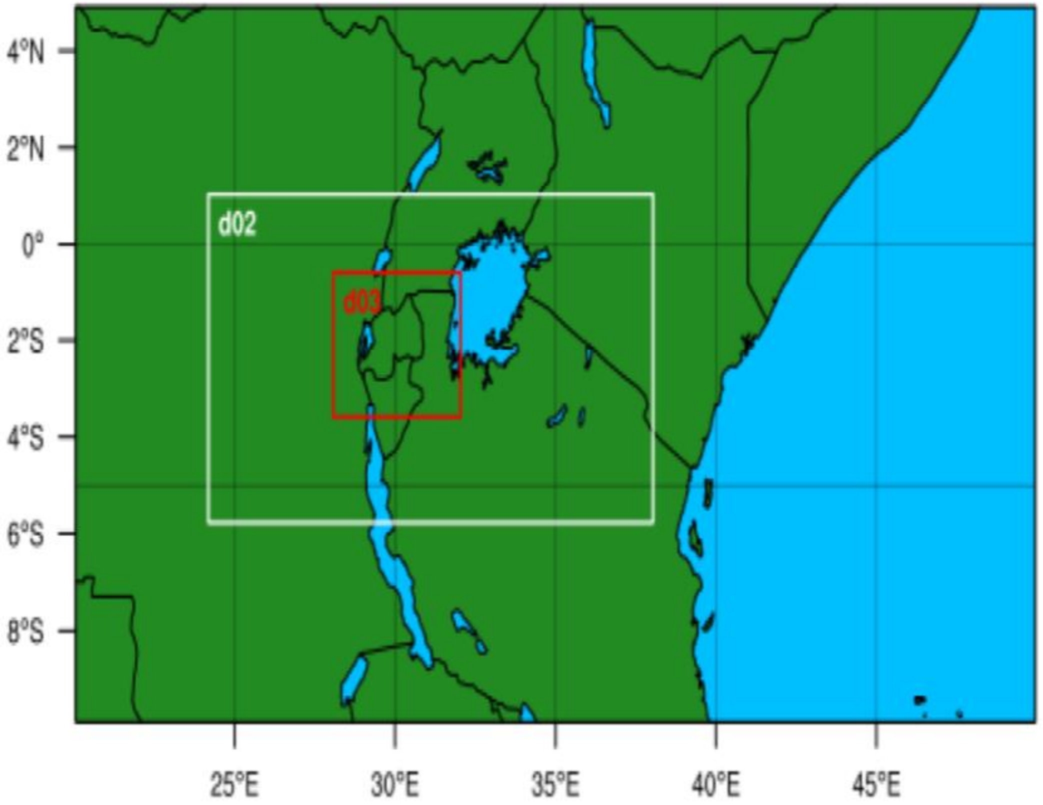
WRF Modeling system flow chart



For verification: Threat score, Bias score, Root Mean Square Error and Mean Absolute Error were used

3. Data Collection and Methodology

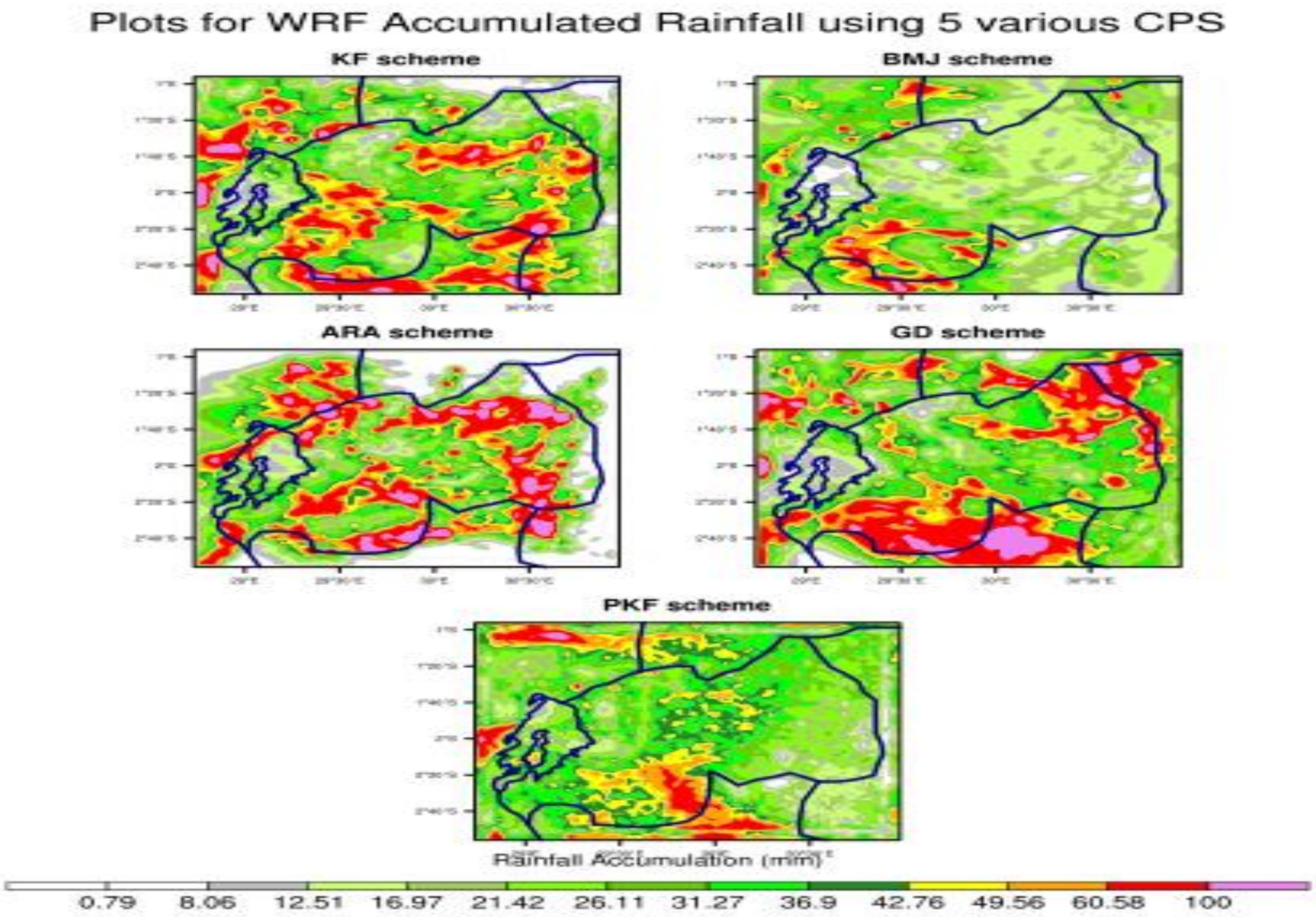
Model Configuration



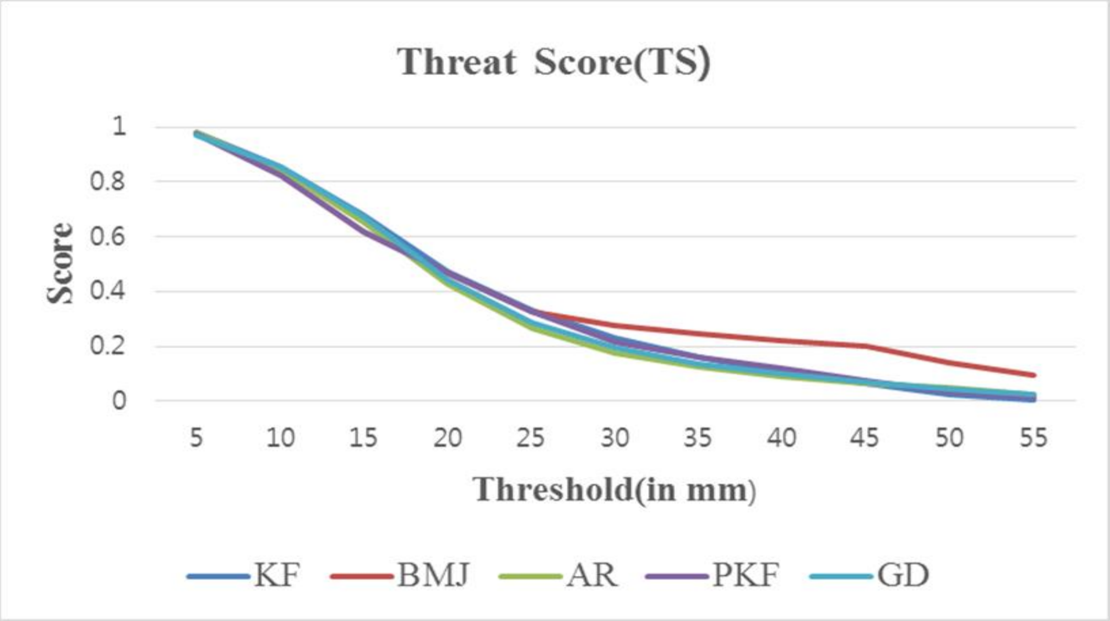
Model Parameters	Options Used		
Grid Resolution	D1:27km	D2:9km	D3:3km
Data	NCEP fnl (1°X1°)	D1 output	D2 output
Cumulus Parameterization Schemes (CPS)	1. Kain-Fritsch (KF)		
	2. Betts Miller Janjic (BMJ)		
	3. Grell Devenyi (GD)		
	4. Arakawa (ARA)		
	5. Previous Kain- Fritsch (PKF)		
Microphysics Scheme	WSM3-class simple scheme		
PBL Scheme	YSU scheme (Hong et al. 2006)		
Land Surface	Noah		
Radiation Scheme	RRT for longwave and Dudhia for short wave radiation		

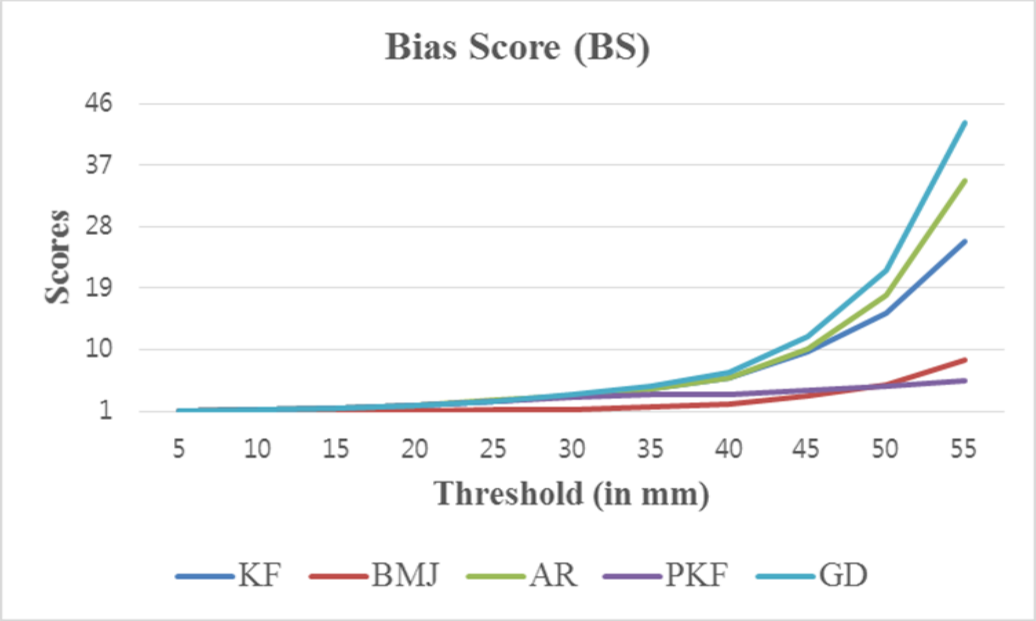
4. Results and Discussions

a. Sensitivity of WRF to different CPS



b. Model Skilfulness Verification

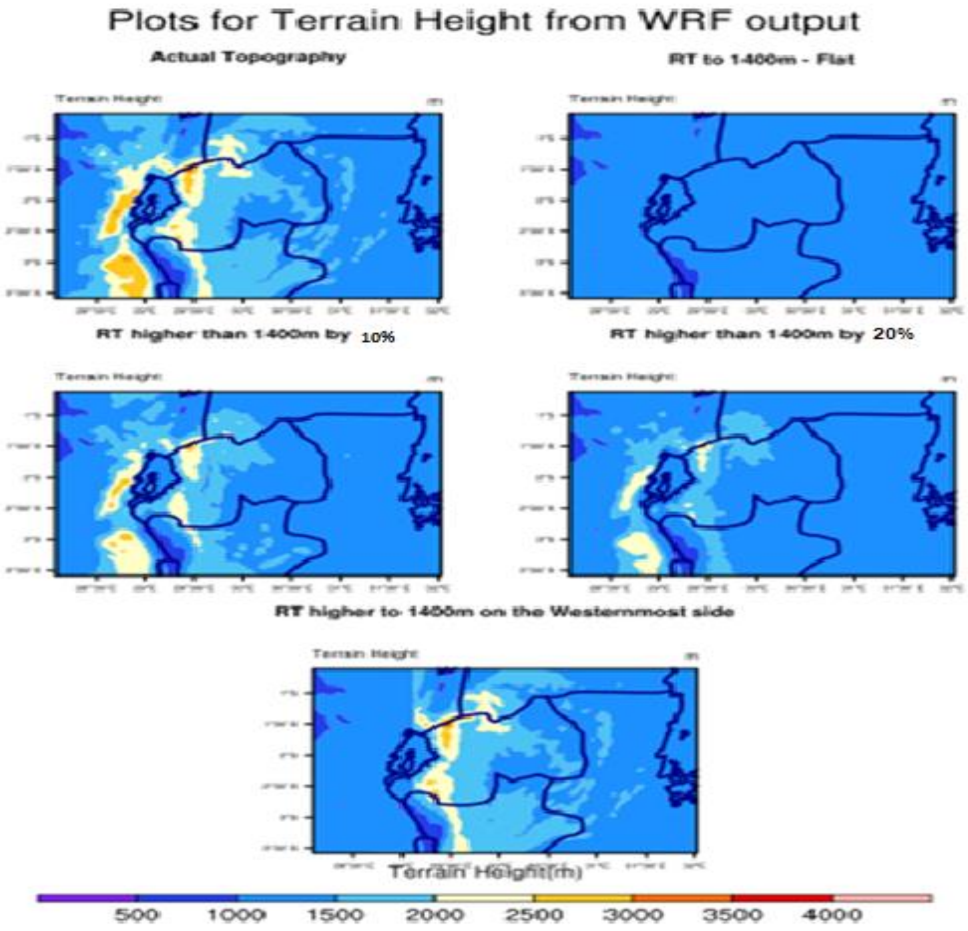




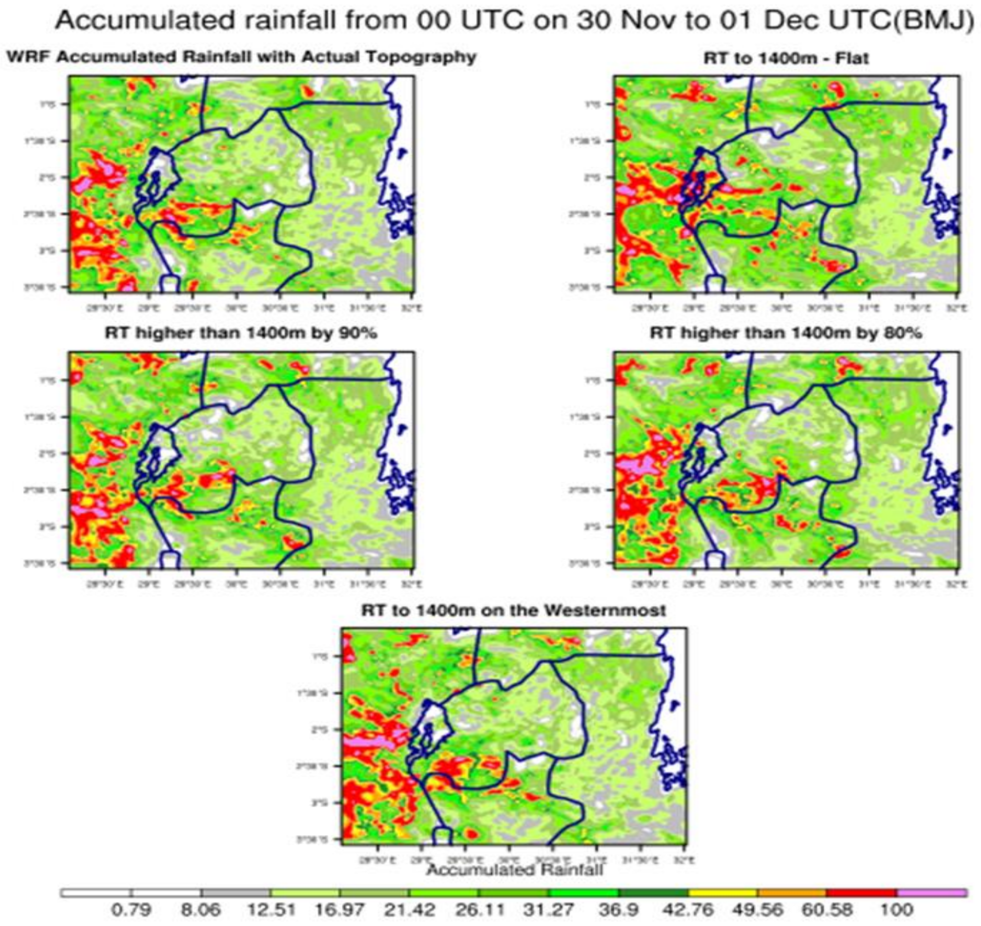
CPS	MAE	RMSE
Kain Fritsch (KF)	21.47438	28.06659
Betts Miller Janjic(BMJ)	10.89266	15.16162
Grell Devenyi (GD)	29.14266	39.17605
Simplied Arakawa-Schubert(ARA)	26.17313	33.95771
Previous Kain Fritsch (PKF)	15.43283	18.42318

c. Sensitivity tests with modified topography

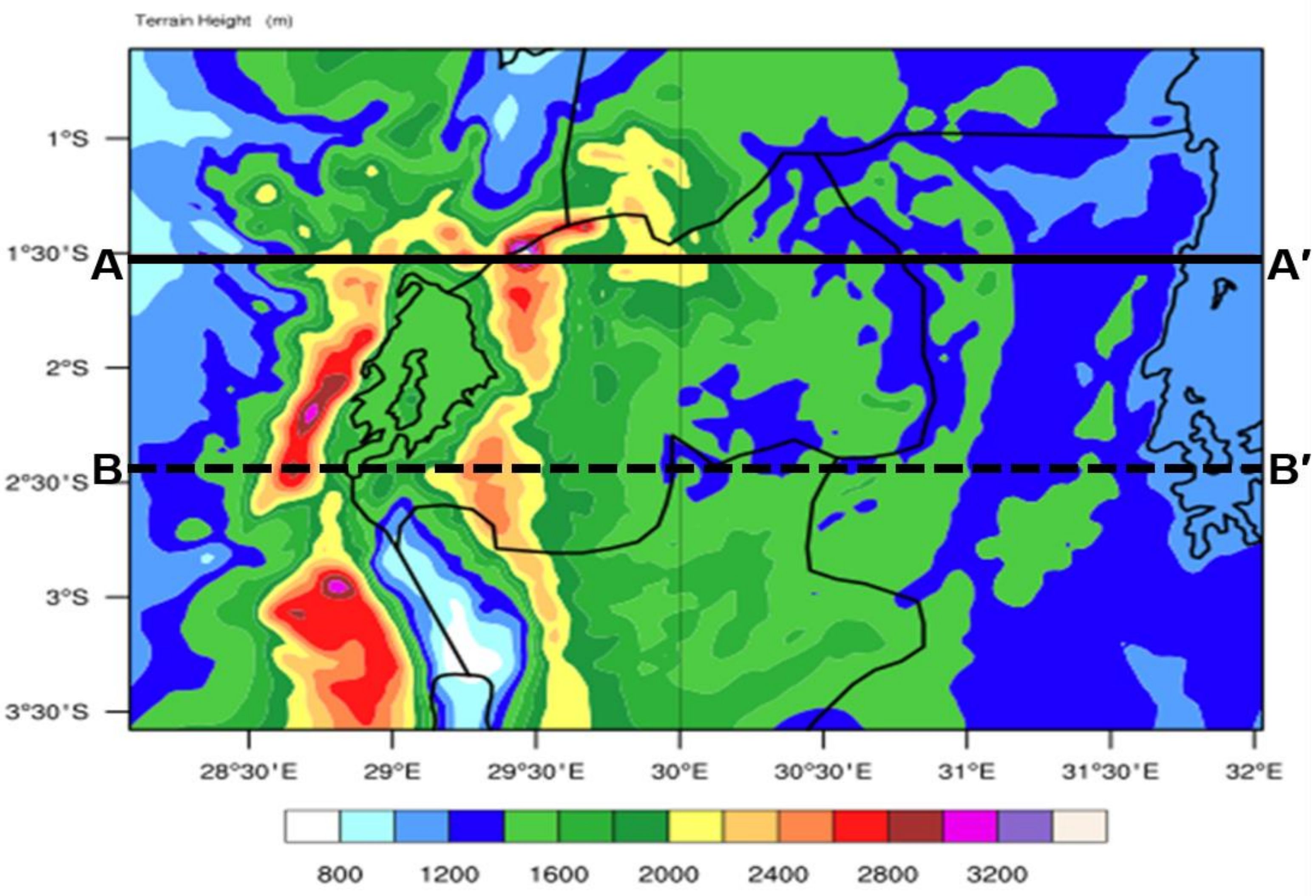
The WRF terrain height (AT and 4 RT experiments)



Simulated Rainfall in 24hrs (AT and RT)

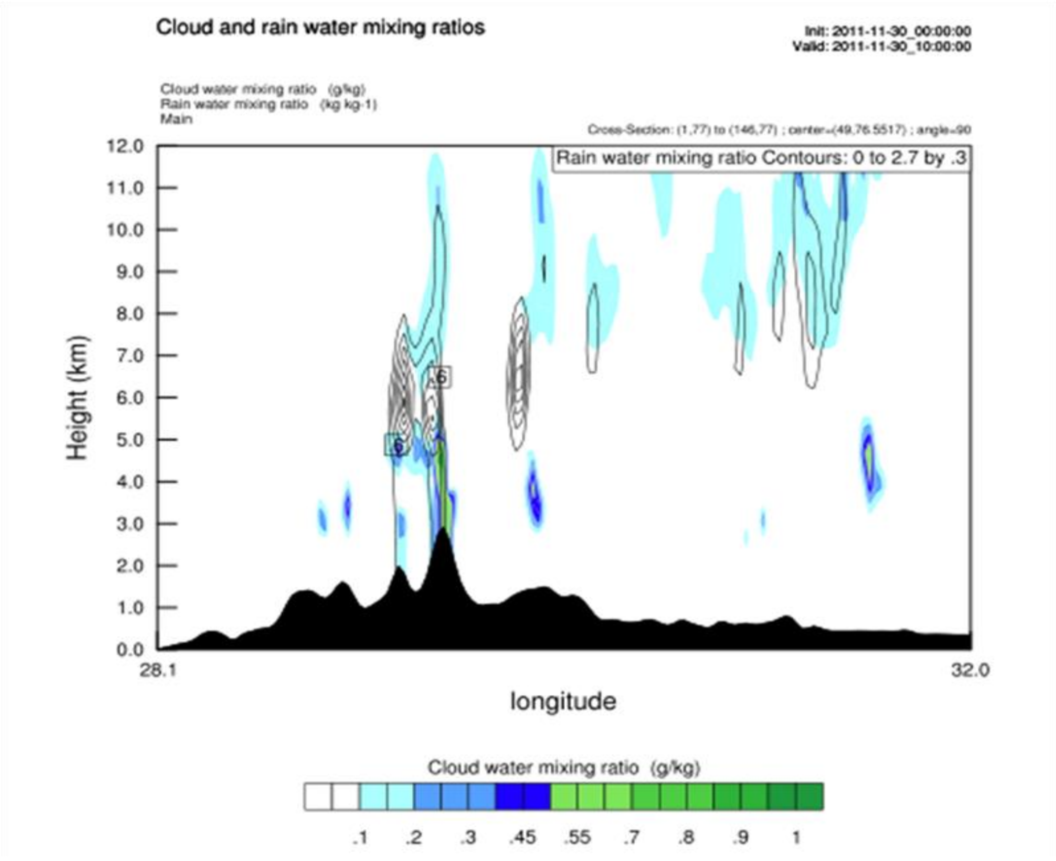


d. Vertical Cross Sections Analysis

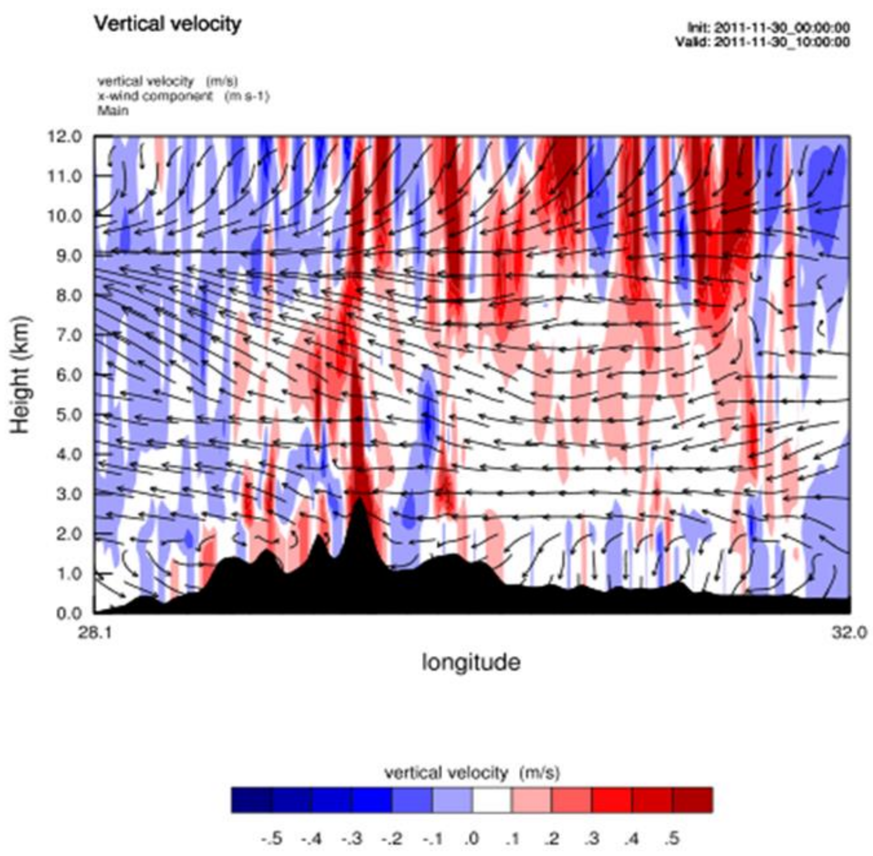


Vertical Cross Section Analysis(A-A')

Cloud and Rain water mixing ratios at 10 UTC (12pm)

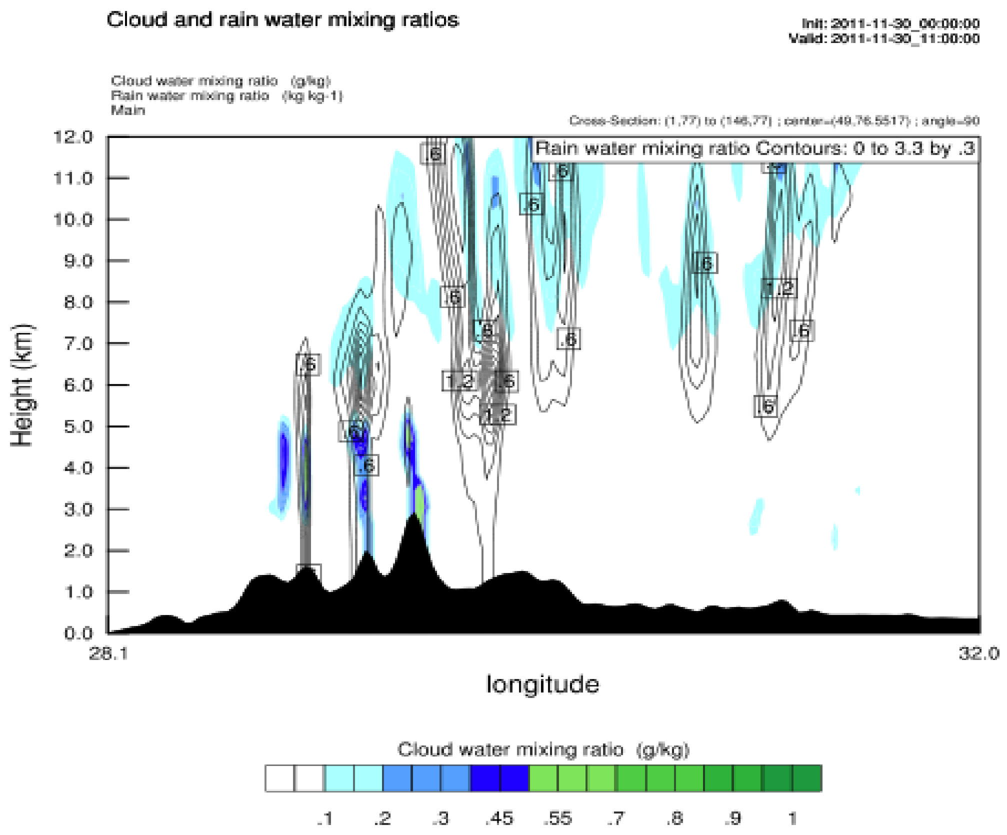


Vertical velocity and wind vectors at 10 UTC (12 pm)

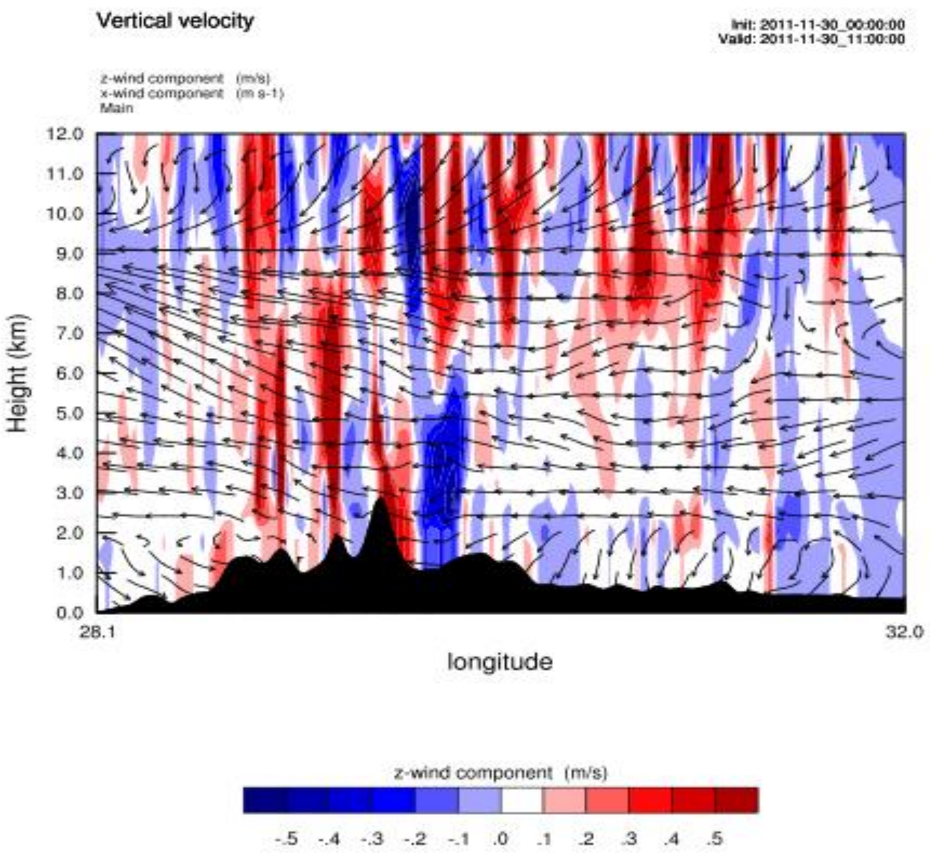


Vertical Cross Section Analysis (A-A')

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

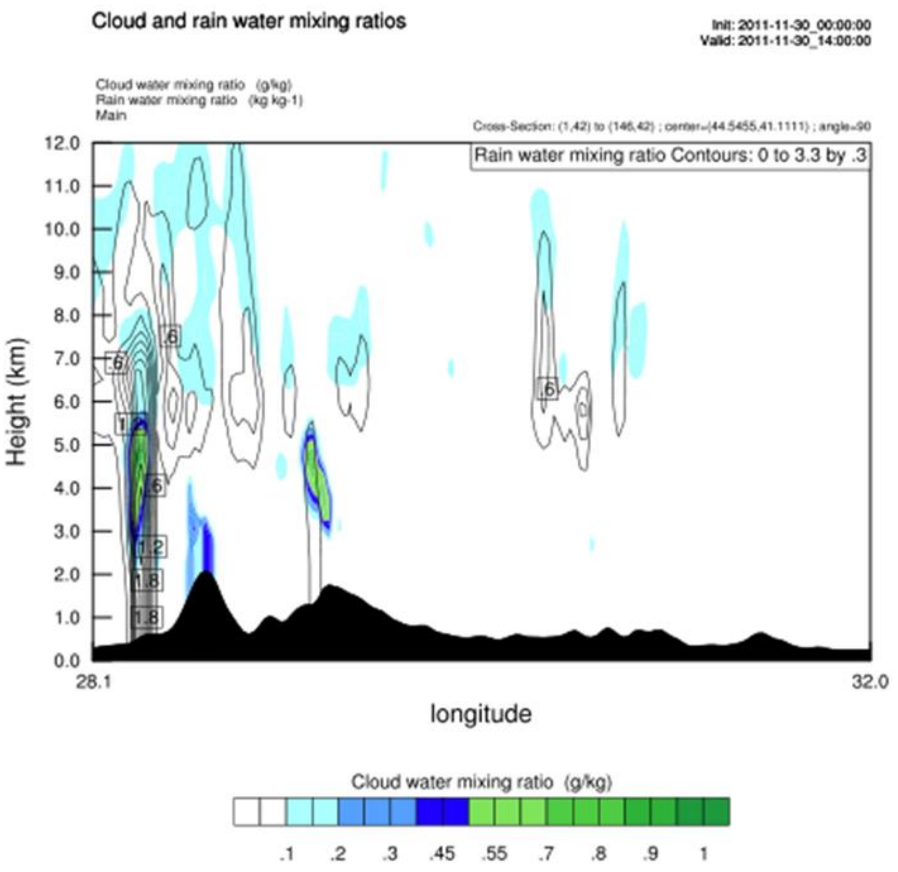


Vertical velocity and wind vectors at 11 UTC (1 pm)

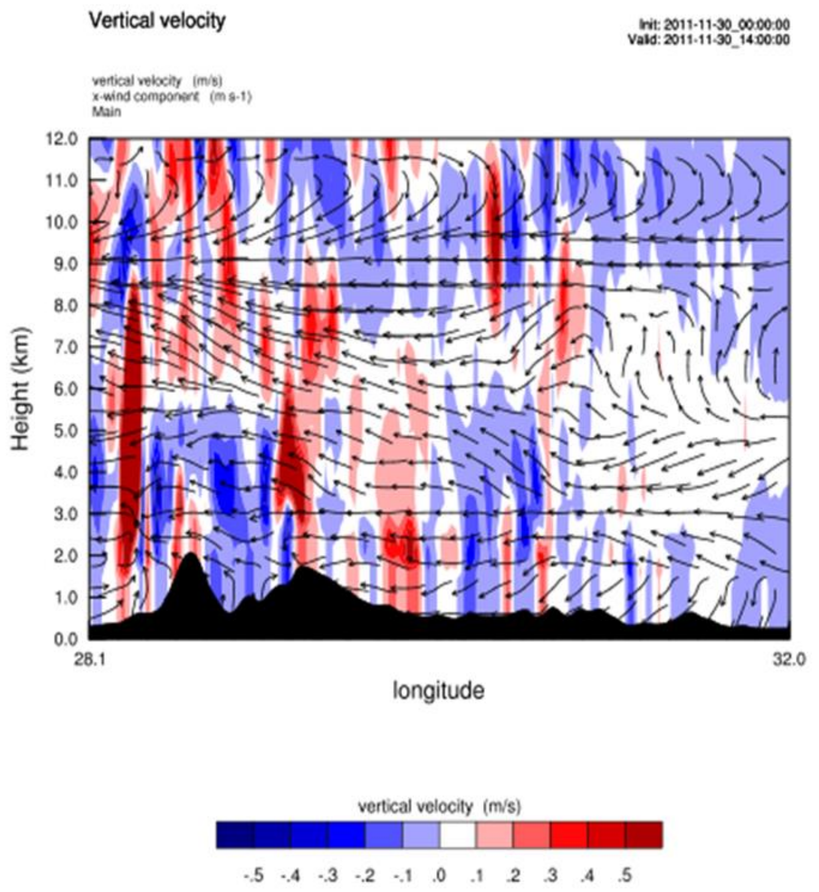


Vertical Cross Section Analysis (B-B’)

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

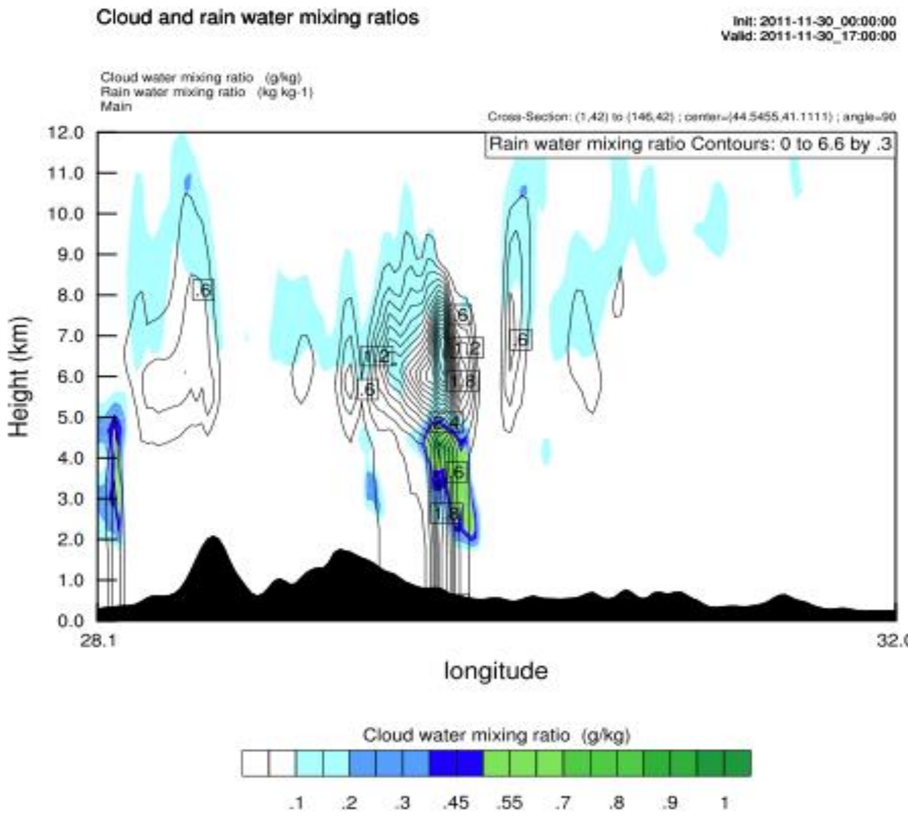


Vertical velocity and wind vectors at 14 UTC (4pm)

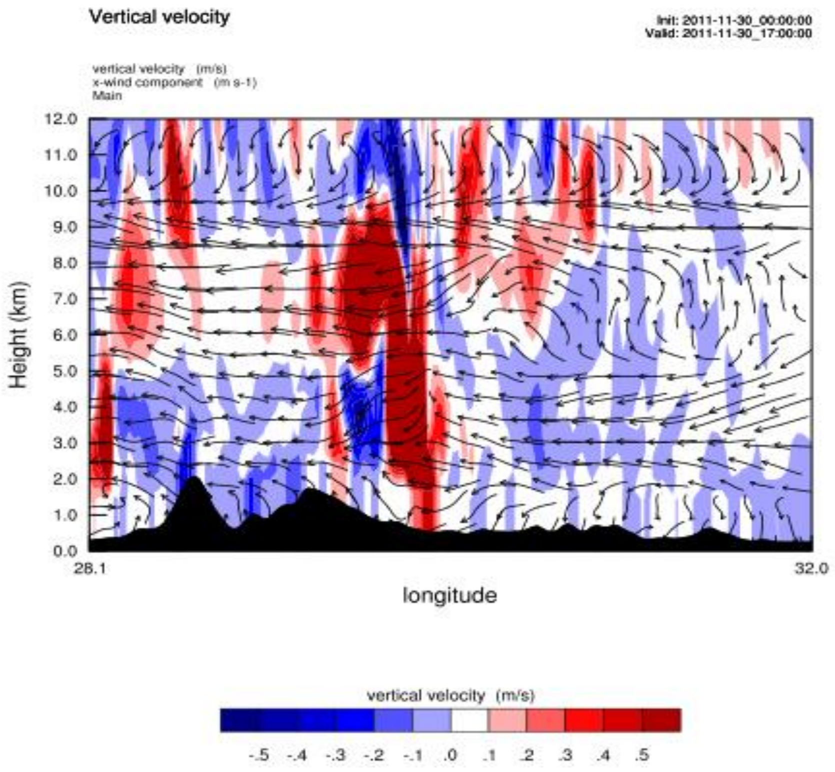


Vertical Cross Section Analysis (B-B’)

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



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

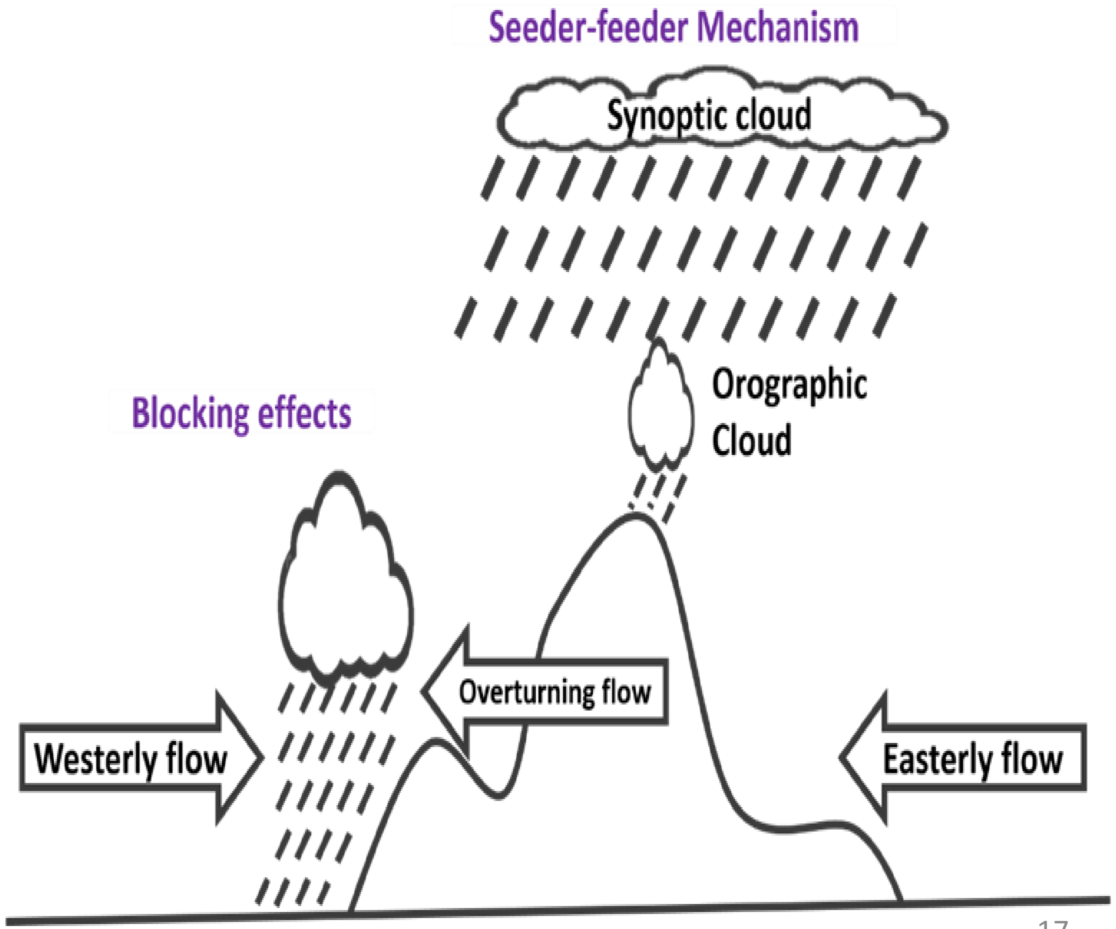


5. Conclusions

- The BMJ cumulus performed better than other CPS
- WRF/BMJ has high performance on low rainfall amount
- <u>Further studies</u>

- 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

Argent, R., Sun, X., Semazzi, F., Xie, L., & Liu, B. (2015). The development of a customization framework for the WRF model over the lake Victoria basin, eastern Africa on seasonal timescales. *Advances in Meteorology*, *2015*. https://doi.org/10.1155/2015/653473

Dell, M., Jones, B. F., & Olken, B. A. (2014). What Do We Learn from the Weather ? The New Climate–Economy Literature. *Journal of Economic Literature*, *52*(3), 740–798. https://doi.org/10.3386/w19578

Felix, N. J. (2015). CHARACTERISTICS OF EXTREME RAINFALL EVENTS, (August).

Flesch, T. K., & Reuter, G. W. (2012). WRF model simulation of two Alberta flooding events and the impact of topography. *Journal of Hydrometeorology*, *13*(2009), 695–708. https://doi.org/10.1175/JHM-D-11-035.1

Georgakakos, K. P., & Hudlow, M. D. (1984). Quantitative Precipitation Forecast Techniques for Use in Hydrologic Forecasting. *Bulletin of the American Meteorological Society*. https://doi.org/10.1175/1520-0477(1984)065<1186:QPFTFU>2.0.CO;2

Jr, R. A. H. (2012). OROGRAPHIC EFFECTS ON PRECIPITATING CLOUDS, (2011), 1–47. https://doi.org/10.1029/2011RG000365.1.INTRODUCTION

Kizza, M., Westerberg, I., Ntale, H. k., & Rodhne, A. (2009). Estimating Areal Rainfall over the Lake Victoria and its basin uing ground-based and satellite data.

Li, L., Schmid, W., & Joss, J. (1995). Nowcasting of Motion and Growth of Precipitation with Radar over a Complex Orography. *Journal of Applied Meteorology*. https://doi.org/10.1175/1520-0450(1995)034<1286:NOMAGO>2.0.CO;2

MIDIMAR. (2012). Republic of Rwanda, Ministry of Disasters Management and Refugee Affairs, identification of disaster higher risk zones on floods and landslides, (March), 1–33.

Ntwali, D., Ogwang, B. A., & Ongoma, V. (2016). The impacts of topography on spatial and temporal rainfall distribution over Rwanda based on a model. *Atmospheric and Climate Sciences*, *6*(April), 145–157. https://doi.org/10.4236/acs.2016.62013

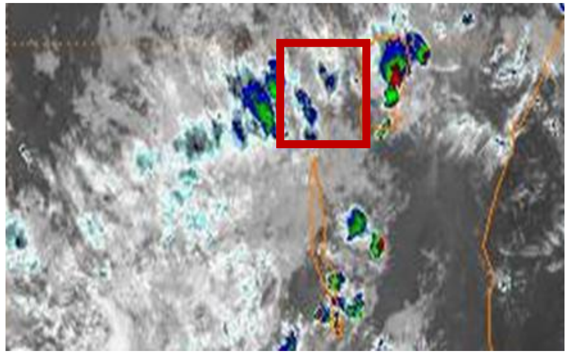
OPW. (2002). Report of the FLOOD POLICY REVIEW GROUP.

Pohl, B., Crétat, J., & Camberlin, P. (2011). Testing WRF capability in simulating the atmospheric water cycle over Equatorial East Africa. *Climate Dynamics*, *37*(7–8), 1357–1379. https://doi.org/10.1007/s00382-011-1024-2

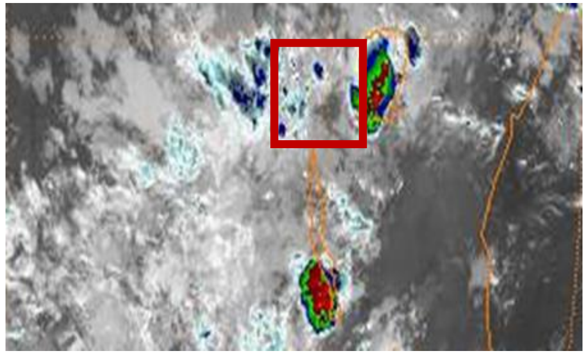
Powers, J. G., Klemp, J. B., Skamarock, W. C., Davis, C. A., Dudhia, J., Gill, D. O., … Duda, M. G. (2017). The Weather Research and Forecasting (WRF) Model: Overview, System Efforts, and Future Directions. *Bulletin of the American*

Satellite pictures from METEOSAT-9

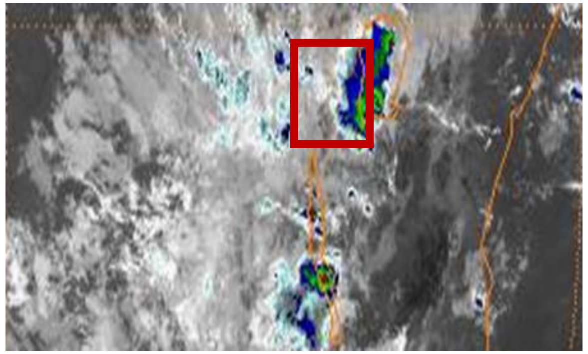
Nov-30-2011 00: 12 UTC



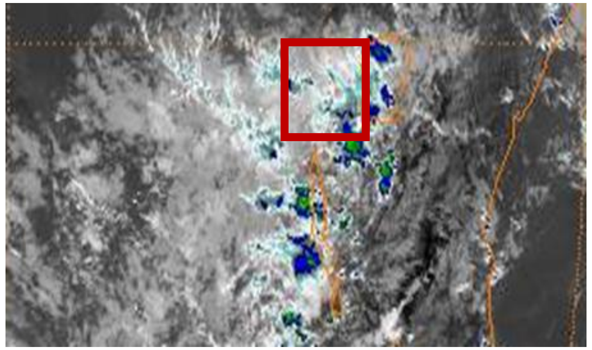
Nov-30-2011 03: 12 UTC



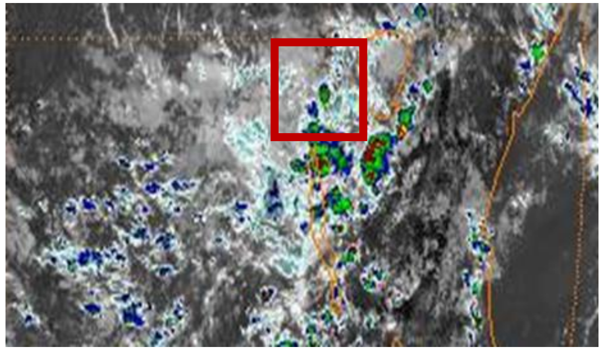
Nov-30-2011 06: 12 UTC



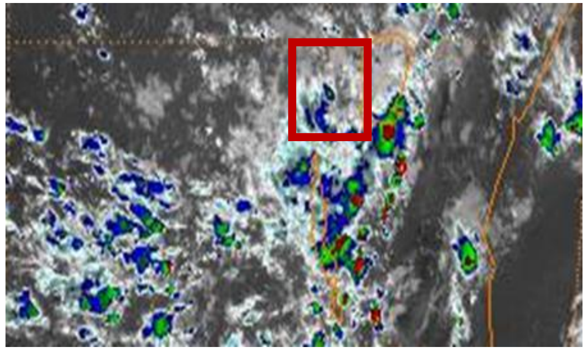
Nov-30-2011 09: 12 UTC



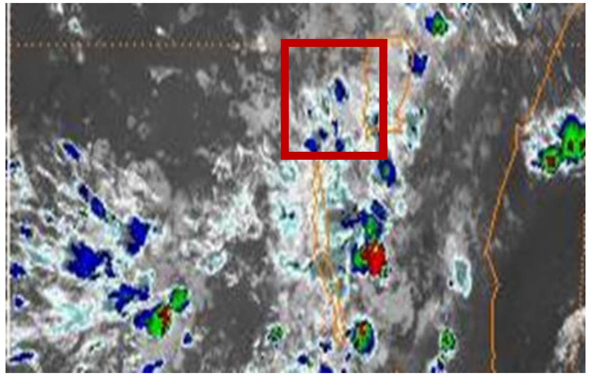
Nov-30-2011 12: 12 UTC



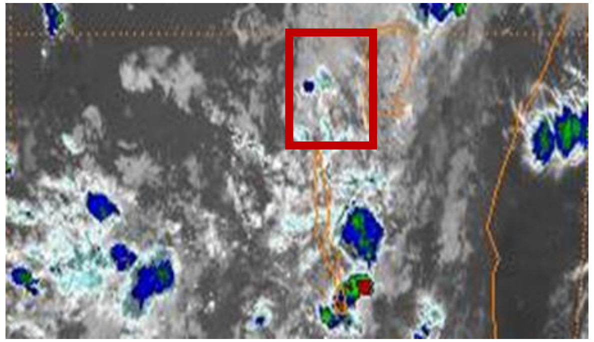
Nov-30-2011 15: 12 UTC



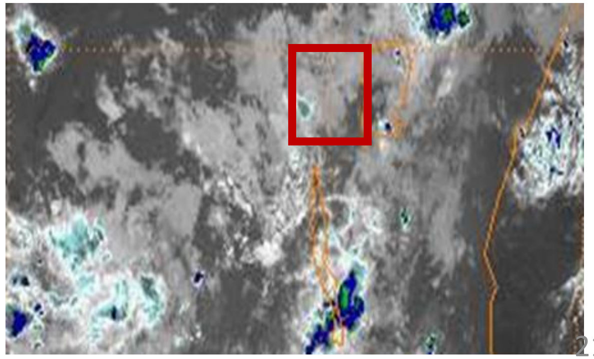
Nov-30-2011 18: 12 UTC



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)

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

4. Mean Absolute Error (MAE)

$$MAE = \sum / \frac{S-0}{N} /$$