Sensitivity of Microphysics and Planetary Boundary Layer Configurations for Extreme Rain Forecast over the Western Nepal using WRF-ARW Model.

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A Dissertation

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As a partial fulfillment for the
Master's Degree in Hydrology and Meteorology

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Declaration

I, *Kumar Rana*, hereby declare that the dissertation entitled **"Sensitivity of Microphysics and Planetary Boundary Layer Configurations for Extreme Rain Forecast over the Western Nepal using WRF-ARW Model,"** presented herein is genuine work, done by myself, and has not been published or submitted elsewhere for the award of any degree. All sources of information have been specifically acknowledged to the author(s) or institution(s) and listed in the references.

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This is to recommend that the dissertation entitled **"Sensitivity of Microphysics and Planetary Boundary Layer Configurations for Extreme Rain Forecast over the Western Nepal using WRF-ARW Model"** has been carried out by Mr. Kumar Rana for the partial fulfillment of Master's Degree of Science in Hydrology and Meteorology. This is the original work and has been carried out under my supervision. To the best of my knowledge, this thesis work has not been submitted for any other degree in any institutions.

Therefore, I recommend this dissertation for approval and acceptance.

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The dissertation entitled **“Sensitivity of Microphysics and Planetary Boundary Layer Configurations for Extreme Rain Forecast over the Western Nepal using WRF-ARW Model”** by **Mr. Kumar Rana** has been accepted as a work for partial fulfillment of the requirements for the Master’s Degree of Science in Hydrology and Meteorology.

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Certification

This dissertation submitted by **Mr. Kumar Rana** entitled, **"Sensitivity of Microphysics and Planetary Boundary Layer Configurations for Extreme Rain Forecast over the Western Nepal using WRF-ARW Model"** to the Central Department of Hydrology and Meteorology as a partial fulfillment of the requirements for the award of Master's Degree of Science in Hydrology and Meteorology under Tribhuvan University has been accepted and approved by,

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Abstract

The occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable is known as extreme, in many cases, a weather or climate event with high impact is also known as extreme. Even though extreme events do not occur often, they can be harmful, can cause great devastation to infrastructures, can affect our economy, and can even cause the loss of life. Monsoon season is a one of the crucial seasons for the precipitating extreme rainfall. Every monsoon affects the environment as well as life style of all living things, causing landslide, floods and affect socioeconomic sector. If the monsoon event could be predicted ahead of event days, we can minimize the loss of property or life. Study of past rainy days shows that all the extreme event were on monsoon season (data taken from 2010 to 2018). In this study WRF (v4.0.3) was used to simulate extreme events to test the sensitivity of the combination of planetary boundary layer physics and microphysics scheme, using initial and boundary condition data from NCEP FNL with 1^0x1^0spatial resolution and 6 hourly temporal resolutions. From this study no single scheme combination performs best for all rainfall category. In this study two methods were depicted to overcome a conclusion. Continuous verification shows Thompson-Mynn is best, with result value of RMSE value 68.86. From categorical verification, Skill score test statistics 'Probability of Detection' showed Thompson-Mrf, Wdm6-Mynn, and Lin-Mynn best for low, moderate and heavy rainfall category with value 0.671, 0.436, 0.419. 'Proportion Correct' showed Morrision-Mynn, Thompson-Mrf and Wdm6-Mynnwas best for low, moderate and heavy rainfall category with the score value 0.336, 0.255, 0.264. 'False Alarm Ratio' showed Morrision-Mynn, Morrision-Mrfand Wdm6-Mynn best for low, moderate and heavy rainfall category with value 0.566, 0.559, 0.433. It comes to the point that there must be a different physical combination for different rain category.

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Abbreviation

NWP	Numerical Weather Prediction
WRF	Weather Research and Forecasting Model
WMO	World Meteorological Organization
MODIS	Moderate Resolution Imaging Spectroradiometer
NCEP	National Centers for Environmental Prediction
PBL	Planetary Boundary Layer
RRTM	Rapid Radiative Transfer Model
ARW	Advanced Research WRF
DHM	Department of Hydrology and Meteorology
FNL	Final Operational Global Analysis data
GFS	Global Forecast System
WPS	WRF Pre-Processing System
Cu	Cumulus
AWS	Automatic Weather Station
GRIB	Gridded Binary
MSLP	Mean Sea Level Pressure
JMA	Japan Meteorological Agency
AWS	Automatic Weather Station
NCL	NCAR Command Language
IMD	India Meteorological Department
POD (H)	Probability of Detection / Hit
POFD	Probability of False Detection / True Negative
FAR	False Alarm Ratio
TS	Threat Score
PC	Proportion Correct
HSS	Hidke Skill Score

Introduction

Background

Precipitation is defined as water in liquid or solid forms falling to the earth. It is deposition of atmospheric moisture and is perhaps the most important phase of the hydrological cycle (Lal, 2014). Rain, hail, sleet and, snow etc. are the general forms of precipitation. However, precipitation does not mean some other forms of condensed moisture for example fog, dew and frost. The first step in precipitation processes is condensation. The process of condensation starts from a change from water vapor to liquid, while the process of precipitation involves the falling out of that water as rain, snow, hail or some other hydrometer from the upper atmosphere. The most surprising factor, is the fact that there are more periods of cloudiness without the occurrence of precipitation. Sometimes snowflakes or raindrops are formed from cloud droplets or ice crystals and, at other times. It may be informed that there are different processes to occurrence of rainfall from the cloud. But at the same time, it is true that not all condensation, even in the ascending currents of air, is followed immediately by precipitation. Even though all clouds contain water, some produce precipitation while other can't produce. In some cases, all precipitated moisture does fall from the clouds, but it gets evaporated in the atmosphere before actually reaching the earth's surface. Only when the cloud droplets, ice pellets or ice crystals grow to such a large size as to exceeds the normal buoyancy and updrafts in the atmosphere then precipitation starts to fall. It means that some special processes must operate in a cloud from which precipitation falls.

For the study of atmospheric phenomena there must be a data. In Nepal DHM maintain the hydrological and meteorological station to observe the activities of atmosphere. It cannot produce the station as well as it required. There is insufficient in-situ data over most of the hilly region because of inhomogeneous topography, leads to difficult in studies of extreme meteorological event(Tiwari et al., 2018a). Therefore, the remote sensing data and model simulated rainfall data are good alternative for studying the extreme processes in complex topographic regions (Navale et al., 2020a). To forecast future based on present situations, the mathematical coupled models of the atmosphere as well as oceans is used in Numerical Weather Prediction (NWP) model because it has wide range of application and produces realistic results. Most of the models rely on various type of observed data i.e., initial and boundary condition, in-situ or remote sensing or proxy data. The Advanced Research Weather research and foresting (WRF-ARW) is a regional popular model broadly used for both research and forecasting purposes of high-impact meteorological events, like atmospheric event such as extreme rainfall, tropical cyclones and thunderstorms, lightening, hydrology and atmospheric Chemistry etc. (Chawla et al., 2018a).

Depending on the impacts of extreme meteorological events to each country, the definition of the extreme events could be different. For example, on the basis of soil type, vegetation, slope of terrain, and drainage systems etc. in each country and region, the threshold for the low, moderate to heavy or extreme rainfall may differ from place to place, for example IMD defined a heavy rainfall, amount greater than 35.6 mm while DHM greater than 50 mm. These extreme rainfalls are source of landslide and flood that plagues the country every year. Extreme precipitation has its source in Bay of Bengal during Indian Summer Monsoon. The west-east expansion of Himalaya blocks the monsoon wind, causing heavy rainfall on the south-facing slopes, acting as a barrier for the south west monsoon winds and controlling freezing and dry winds from the polar region to Indian subcontinent region (Karki et al, 2017)**.** Due to highly varied physiographical and topographical regions of altitudinal differences; geology, topography and climatic conditions in these regions differ and response to the extreme weather events also differ from region to region. Further affecting the brittle environment, in turn leading to susceptibility to hazard and disaster due to unreasonable inclines, rivers produce energetic runoff (Chawla et al., 2018b). Hence, it is difficult to obtained good result of these extreme events and reason behind such events. Therefore, it is very essential to predict extreme events accurately to potential loss of lives and livelihoods.

The Weather Research and Forecasting (WRF) Model is a next-generation mesoscale numerical modeling system designed for both atmospheric research and operational forecasting purposes. It features two dynamical cores. The model gives a wide range of meteorological applications across scales from tens of meters to thousands of kilometers. The WRF model began to develop in the latter 1990's. WRF was a collaborative partnership of the National Center for Atmospheric Research (NCAR), the National Oceanic and Atmospheric Administration (represented by the National Centers for Environmental Prediction (NCEP) and the Earth System Research

Laboratory), the U.S. Air Force, the Naval Research Laboratory, the University of Oklahoma, and the Federal Aviation Administration (FAA).

For enthusiastic, WRF can produce simulations based on actual atmospheric conditions (i.e., from observations and analyses, initial and boundary condition) or idealized conditions. WRF offers operational forecasting as well and flexible, computationally-efficient platform, while all this was succeeded because of recent advances in physics, numeric, and data assimilation contributed by developers from the expansive research community worldwide. WRF is currently in operational use at NCEP and other national meteorological centers as well as in real-time forecasting configurations at laboratories, universities, and companies has a large worldwide community of registered users (a cumulative total of over 48,000 in over 160 countries) ("WRF | NMM," n.d.). The WRF system contains two dynamical solvers, referred to as the ARW (Advanced Research WRF) core and the NMM (Nonhydrostatic Mesoscale Model) core.

In this study, WRF-ARW model of version 4.0.3 using within domains of 9km×9km and 3km×3kmspatial resolution. It has been used for the numerical simulation of the past extreme rainfall events based on 99 percentile values. In Nepal, a handful of attempt was done to simulate the extreme rainfall event using WRF model (Dasari and Salgado, 2015). Individual sensitivity test was done for predicating extreme rainfall in the same study.

1.1.1 Rationale of Study

The following study was carried out with the aim of evaluating a sensitivity of physics scheme combination of WRF-ARW model. Where eight competitive forecasters switching the two PBL physics combination with four Micro Physics (MP) were tested. Such study helps in selecting the appropriate physics scheme for WRF-ARW model to use administratively as well as research purposes. Which can minimize the socioeconomic impacts of such extreme weather event.

1.1.2 Research Questions

- Which physics scheme gives a more accurate representation of an event in western Nepal?
- Which configuration simulates rain category better?

1.1.3 Objective of the study

The main objective of the study is to conduct the sensitivity test of all the combination of micro-physics scheme and Planetary Boundary layer physics.

The secondary objective of the study is to:

- Find out which combination is best in simulating extreme rainfall events in the Western Nepal.
- Identify the best combination for low, moderate and heavy rainfall events.

Literature Review

The occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable is known as extreme, in many cases, a weather or climate event with high impact is also known as extreme event (TT-DEWCE, 2016). As the criteria of heavy and extreme rainfall events vary among the countries, Meteorological Department of Nepal (DHM) also classifies rain in basis of one-day rainfall, as light, moderate, heavy, very heavy and extremely heavy category. Even though extreme events do not occur often, they can be harmful, can cause great devastation to infrastructures, can affect our economy, and can even cause the loss of life (IPCC 2012). It is therefore necessary for Meteorological communities to improve the understanding and characterization of extreme weather, climate events. It is also necessary of monitoring of such extreme event with spatial and temporal variation and consistent methodologies for their definition and for the computation of their thresholds. So that efficient systems for monitoring and forecasting of these extreme events can be applied as part of building resilient societies coping with extreme events. The occurrence of heavy precipitation events is a major hazard that has often led to floods, landslides, as well as the loss of human lives and major economic losses such as infrastructure. In many regions of the world, it is likely that there have been statistically significant increases in the number of extreme precipitation events although it is not uniform in all regions (IPCC 2013). Floods and landslides are the most frequently occurring natural hazards in Nepal (Gaire et al., 2015; Shrestha et al., 2008). These hazards occur primarily during the monsoon season, accounting for nearly half of the country's recorded disaster events. In recent years, erratic and unpredictable monsoon rainfall patterns and increased climate variability have led to severe and frequent flood disasters in the country (Dangal, 2015; Delalay et al., 2018; Khanal and Watanabe, 2006). The intensification of extreme precipitation events across western Nepal during the recent decades are increasing (Bohlinger et al., 2017; Karki et al., 2017; Nayava, 2004). The decadal distribution of these extreme one-day rainfalls shows that there is a considerable increasing or decreasing throughout the year and year (Nandargi and Dhar, 2011). It is also reported that for arrange of emission scenarios, the projections until the end of the 21stcentury indicate that it is likely that return period of events of annual maximum 24-hour precipitation is decreasing (IPCC, 2012). Heavy precipitation events frequently occur during the monsoon season over the southern slopes of the Himalayas. The West-East expansion of Himalaya blocks the monsoon wind, causing heavy rainfall on the south-facing slopes which act as a barrier (west-east Himalayas) for the South West Monsoon winds and also restricts frigid and dry winds from the polar region to blow south into the Indian subcontinent. Extreme rainfall events that often occur in Nepal during monsoon season are influenced by variations of climate due to its physical topography, monsoonal winds and ocean influences (Indian Ocean). The monsoon is characterized by moist southeasterly monsoonal winds coming from the Bay of Bengal (summer monsoon) and occasionally from the Arabian Sea with widespread precipitation (winter monsoon). Precipitation over Nepal is received by two major weather systems; the Southwest monsoon greatly impacts the southeastern parts of the country during the monsoon season while the Western disturbances predominantly affect the northwestern high mountainous parts during the winter season(Karki et al., 2017). Complex topography and scarcity of observed data over the Himalayan region is a major challenges for the modelling community to simulate and to investigate the weather and climate over Himalayan region (Tiwari et al., 2018b). Because, the coverage of rain gauge network and meteorological radars is sparse in the Himalayan region. Therefore, the remote sensing data and model simulated rainfall data proves to be the only reliable options for studying and research of the precipitation processes in complex topographic regions like the Himalaya (Navale et al., 2020b). Numerical weather prediction uses mathematical equations of the atmosphere and oceans to predict the weather based on present weather conditions (initial and boundary conditions). It produces realistic results. In the context of climate change, it is pertinent to ascertain whether the characteristics of summer monsoon are also changing. The summer monsoon (June–September) rainfall is very crucial for the economic development, disaster management, hydrological planning of the country. Its impacts on overall socioeconomic aspect. More extreme cases of disaster become very critical to the human being as well as ecosystem. Though summer monsoon is a dominant feature over Nepal, there is a large spatial variation of its effectiveness due to differences in location and its topography. The ongoing changing climate with its associated global warming had been observed to have impacted and will continue to affect the rainfall pattern of different parts of the world (Adebayo, 1999; Bello, 1998). The impact will be increase, decrease or total shift in rainfall characteristics (Odjugo, 2000; Olaniran, 2002). Therefore, forecast of such events helps to reduce from excessive damage. And helps the National Meteorological and Hydrological Service Centers to decide the threat and monitor it for proper advisory or warning actions as determined in their particular countries.

WRF is widely used for both studying as well as forecasting a variety of high-impact meteorological events, such as rainfall events, tropical cyclones and thunderstorms etc. And selection of microphysics scheme influence the spatial pattern of rainfall, while the choice of PBL and cumulus parameterization, influence the magnitude of rainfall in the model simulation, therefore selection of appropriate scheme is very important in meteorological modeling(Chawla et al., 2018b). In the past research many researchers have been tested performance of the WRF model configured with different parameterization schemes.. Morrison parameterization reproduced the system with observation in simulation two convective rainfall events over the central Andes of Peru in WRF-ARW(Martínez-Castro et al., 2019a). Thompson scheme followed by the Morrison scheme able to capture location of extreme rainfall in Chennai, India (Mohan et al., 2018). Mynn (Mellor–Yamada Nakanishi Niino) schemes show better results over India (Gunwani and Mohan, 2017). Mynn performed better for both variables rainfall and temperature in during a West African monsoon regime (Gbode et al., 2019)..Non local PBL scheme was fundamental to correctly simulate the heavy precipitation in southern Italy (Avolio and Federico, 2018). Thompson scheme followed by the Morrison scheme able to capture location of extreme rainfall in Chennai, India (Mohan et al., 2018).PBL scheme affect the all-surface variable(Chawla et al., 2018b; Srinivas et al., 2018).Climate change projection indicating an increasing trend of the frequency of such event. Precipitation is very sensible to PBL scheme (Shin and Hong, 2011).The choice of PBL scheme has a significant effect on precipitation (QUE et al., 2016). The selection of MP scheme influences the spatial pattern of rainfall, while the choice of PBL and cumulus parameterization, influence the magnitude of rainfall in the model simulation.

Therefore, selection of appropriate scheme is very important in meteorological modeling(Chawla et al., 2018b). Betts Miller Janjic (BMJ) cumulus scheme is found to give better result for the simulation of heavy rainfall events as compared to other cumulus schemes for the Indian monsoon region using WRF model(Kumar et al., 2014). In Nepal, a handful of attempts was done to simulate the heavy rainfall event using WRF model(Collier and Immerzeel, 2015; Karki et al., 2018, 2017; Regmi and

Maharjan, 2015; Shrestha et al., 2017a). In which the sensitivity test of different physics option for prediction of extreme events were used that could cause enormous destructions of lives, property, roads, community etc. Langtang basin, Central Himalayas, Morrison Scheme was found to reproduce the monsoonal precipitation distribution over a 10 days period (Orr et al., 2017). Similar result was detected over convective precipitation event on pre-monsoon in Kathmandu valley (Shrestha et al., 2017a). Therefore, it is important to monitor closely the rainfall variation across the country on daily time scale. In Nepal, Meteorological Forecasting Division (MFD), Department of Hydrology and Meteorology (DHM), has started to use global model (NWP) products are mostly applied in operational forecast. DHM uses the models Weather Research and Forecasting (WRF-ARW) model from the National Center for Atmospheric Research (NCAR). Despite the predictability of these models in some certain cases, they may fail to predict extreme events because of several reasons. Three main factors causing uncertainties in NWP are the initial conditions, the imperfection of the models, and the chaos of the atmosphere (Lorenz, 1969). While the initial condition problem for NWP can be reduced by data assimilation methods, the imperfection of models, which relates to many sub grids processes, can be alleviated by using proper physical parameterizations. For regional weather forecasting centers with limited capabilities in data assimilation and resource computation to provide the cloud resolved resolution forecast, choosing correct physical parameterization schemes still plays the most important role in downscaling the processes in regional NWP models(Pérez-Bello et al., 2019).

Despite these past many experiments using different parameterization schemes to evaluate the performance of the WRF model, the simulation event has generally one event. This study focuses on the choice sensitivity test of combination from PBL scheme *Mrf* and *Mynn* and microphysics scheme *Lin, Thomson, Morrison* and *Wdm6* and for Cumulus scheme (Bmj).

Data and Methodologies

3.1 Study Area

Nepal is a south east Asian landlocked country. Its topography varies from 59 meters to 8848 meters. And situated within $80^{0}4$” E to $88^{0}12$” E and $26^{0}22$” N $30^{0}27$” N. Study area was set with two nested domains. Outer domain, blue color with grid resolution 9km**x**9km and inner domain, red color with 3km**x**3km.

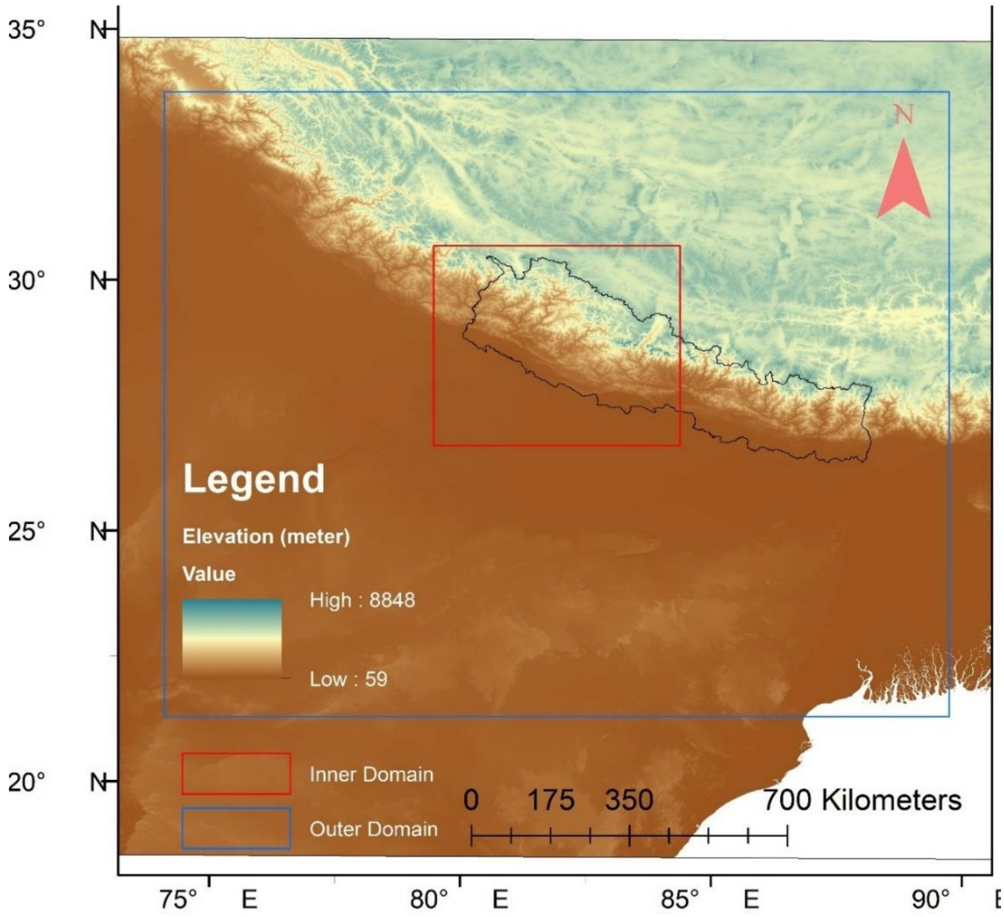

Figure 1 Study Area

3.2 Data

This research work is done using the daily accumulated rainfall data from 2010 to 2018 provided by meteorological stations from Department of Hydrology and Meteorology. Figure (2) shows the station location that are used for study. Where black circle stations were used for selection of event and both black circle and blue star stations were used for verification purposes. The global six hourly datasets from National Centers for Environmental Prediction (NCEP) Global Forecast System (GFS) have been used to provide the initial and lateral boundary conditions for WRF model at $1^0 \times 1^0$ grid spatial resolutions and temporal resolution of 6 hours. Downloaded from National Center for Atmospheric Research (NCAR) website *(https://rda.ucar.edu/datasets/ds083.2/)*

3.3 Event

For the selection of event data was taken from the 17 districts (Baitadi', 'Dadeldhura', 'Kanchanpur', 'Darchula', 'Bajhang', 'Doti', 'Kaliali', 'Bajura', 'Achham', 'Surkhet', 'Banke', 'Bardiya', 'Jajarkot', 'Dailekh', 'Dang', 'Salyan', 'Rukum') having daily rainfall data from 2010 to 2019 having complete 9 years. From those districts these station with index number [101, 103, 104, 105, 106, 107, 108,116, 119, 121, 201, 205, 209, 224, 227, 230, 234, 235, 241, 243, 244, 302, 304, 309, 314, 318, 320, 322, 324, 326, 331, 406, 409, 411, 412, 415, 418, 420, 422, 423, 424, 425, 426, 433, 434, 435, 436, 437, 438, 510, 511, 513, 515, 518, 520, 535, 538, 539]has complete 9 years daily record,[total 58 station] and taken for selection of event. Then the value of rainfall for event was selected based on the 99 percentile values from rainy days [Threshold from IMD, rainy days >=2.5 mm]. And those given values which is equal or greater than 99 percentile was grouped by the date. That event values were recorded at least at two districts on that event days. In this way 22 event days was selected for the study. For the verification purposes 98 station were selected. For verification those 98 stations with station index no [101, 103, 104, 105, 106, 107, 108, 109, 115, 116, 117, 118, 119, 121, 122, 123, 201, 205, 208, 209, 215, 224, 227, 230, 234, 235, 239, 240, 241, 243, 244, 302, 303, 304, 308, 309, 312, 314, 317, 318, 319, 320, 322, 324, 326, 329, 331, 332, 401, 402, 406, 409, 410, 411, 412, 414, 415, 416, 417, 418, 420, 422, 423, 424, 425, 426, 428, 430, 432, 433, 434, 435, 436, 437, 438, 440, 501, 507, 510, 511, 512, 513, 515, 517, 518, 520, 521, 527, 529, 530, 532, 533, 534, 535, 536, 537, 538, 539] and have record for all 22 event days. All station detail can be found here *http://dhm.gov.np/meteorological-station/*. In figure (2) black circle station were used for selection of event and both station red star and black circle were used for verification. Figure (3) shows the flow chart of event selection processes.

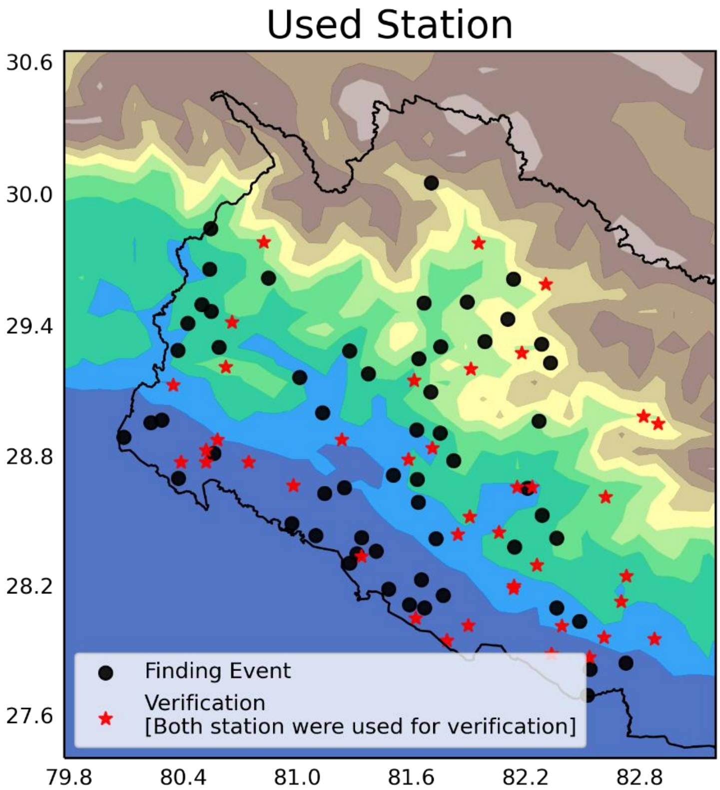

Figure 2 Station Location from DHM

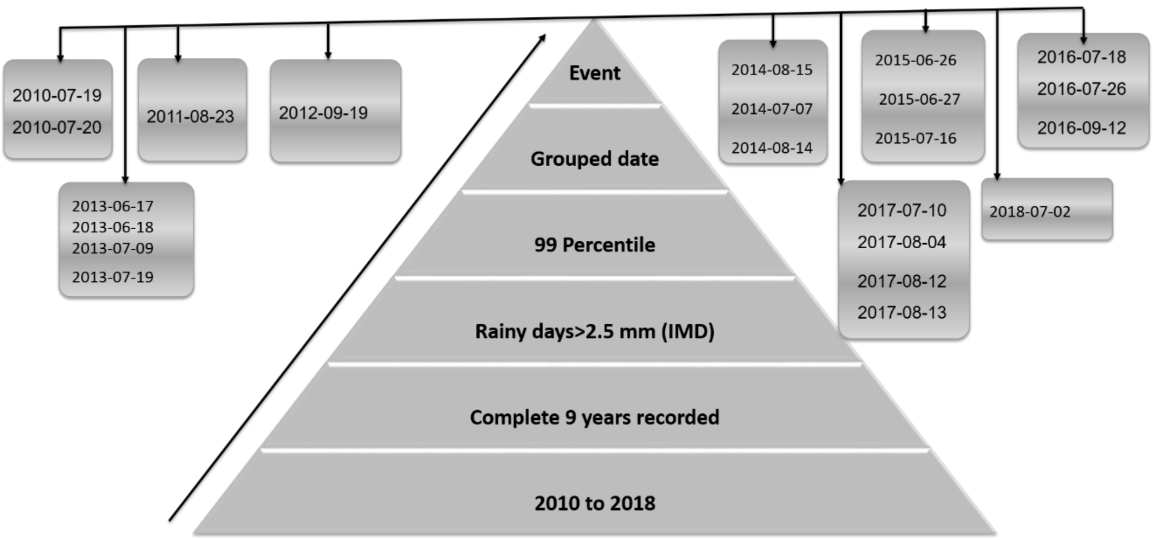

Figure 3 Flow chart for Event Selection

3.4 Model Description

Weather Research and Forecasting Model

For this studies Advanced Research Weather Research and Forecasting (WRF-ARW), model version 4.0.3 was used. Sensitivities of combination of Microphysics and Planetary Boundary Layer (PBL) schemes was evaluated in this research work. The Weather Research and Forecasting (WRF) is state-of-the-art atmospheric simulation system, a fully compressible, three-dimensional (3D), Eulerian, nonhydrostatic, primitive-equation regional atmospheric model with multiple nesting abilities. It is usable for broad range of applications across scales ranging from meters to thousands of kilometers. This is available with several advanced physics and numerical schemes, designed for better prediction of atmospheric processes and operational forecasting. In academic purpose Advanced Research Weather Research and Forecasting (WRF-ARW) core is widely used for various reasons like it is community model, open source and has wide range of application from few km to thousands of km. This model can be run on Linux, Unix operating system and suitable on high processing supercomputer. A comprehensive description of the model is given in (Skamarock et al., 2019). WRF processes can be divided into three processes, such as Preprocessing (WPS), WRF and Post Processing which is shown in the flow chart on figure (4).

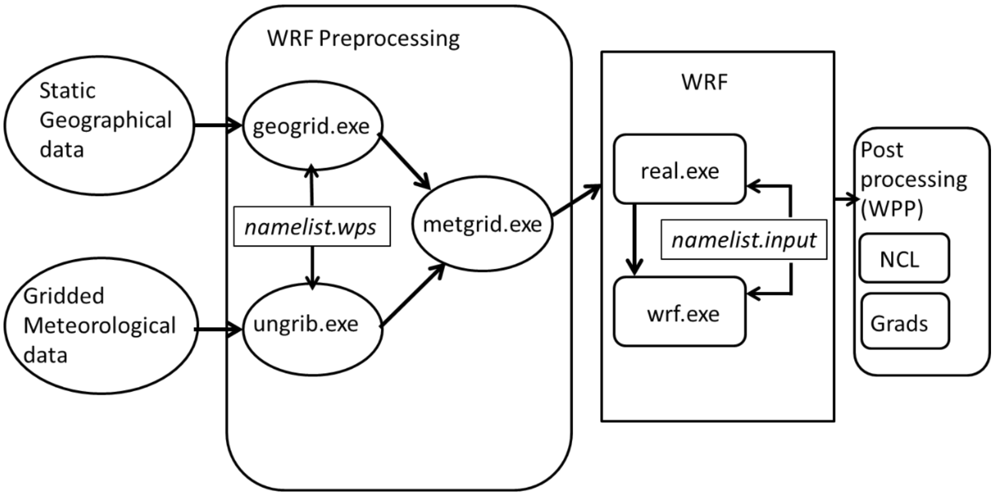

Figure 4 WRF Flow Chart

WRF preprocessing

The WPS is a program used for real data simulation which comes from initial boundary condition data. This module is to prepare input data for wrf and real module. It has three sets of programs (geogrid.exe, ungrib.exe, and metgrid.exe) which are briefly described below:

Geogrid.exe: The main function of this program is to define the simulation domain and interpolates the various static datasets such as soil categories, land use category, terrain height, vegetation cover, albedo, etc.to the simulation model domain. These datasets are interpolated to the model grids. Besides interpolating the default terrestrial fields, it can also able to interpolate various continuous and categorical fields to the simulation domains.

Ungrib.exe: The GRIB files are used in ungrib program which degribs the data and save these data in the intermediate format, which can then use in the metgrid program. It includes numerous meteorological fields such as temperature, precipitation u-, v-, w winds components, sea level pressure, surface pressure etc. which are from different global to regional model like NCEP GFS. The ungrib program reads GRIB1 and GRIB2 data types. Here, in this study, we used GRIB2 files which use various codes to identify the variables and levels.

Metgrid.exe: The metgrid program interpolates meteorological fields that are obtained from geogrid and ungrib programs to the selected simulation domains. This interpolated metgrid output can then be taken by the real.exe program of WRF. The work of the metgrid program is time-dependent and run every time a new simulation is initialized like ungrib program. The detailed description of these programs can see on this link also*http://homepages.see.leeds.ac.uk/~lecrrb/wrf/aRWUsersGuide.pdf*

WRF Run

After WPS ran successfully, the WRF model is ready to run and the model contains different initialization module real.exe and a numerical integration module wrf.exe. The initial and boundary condition for the wrf.exe module generated by real.exe module of the program that are derived from the output files provided by the WRF Preprocessing System (WPS). The real.exe program completes following work:

- Read data from the namelist of WPS and allocate space
- Initialize rest of variables
- Read input data from the WRF Preprocessing System (WPS)
- Prepare soil fields for use in model (usually, vertical interpolation to the requested levels)
- Checks to verify soil categories, land use, land mask, soil temperature, sea surface temperature is all consistent with each other
- Generate the initial and lateral boundary conditions files

After running the real.exe module, the numerical integration modulei.e. wrf.exe can able to run which is used to provide prediction/forecast over specific duration. For this it takes the initial and boundary condition provided by the WPS, these will be directly used by the WRF model. The setting in the namelist.input file should be same as namelist.wps file for the configuration of the WRF model. The detailed description of these programs can be seen on following address.

http://homepages.see.leeds.ac.uk/~lecrrb/wrf/aRWUsersGuide.pdf

Post Processing

After successfully running WRF module. The output data file can be analyze and visualize with help of post processing tool such as NCL (NCAR Command Language, wrf-python etc.) according to your feasibility.

Used Experimental Physics Scheme

Linscheme (MP)(Lin et al., 1983)**:** Lin scheme contain six classes of hydrometeors such as water vapor, cloud water, rain, cloud ice, snow and graupel (ALAM, 2014) and is one of the worldly wise microphysics schemes in WRF model. In Nepal this scheme uses for operational purposes and it is also most suitable for research studies.

Thompsonscheme (MP):(Thompson et al., 2008) It is widely used with WRF model and other model and well known double moment bulk microphysical scheme. The Thompson scheme explicitly predicts the hydrometeor mixing ratios of cloud water, rain, cloud ice, snow, and graupel and the number concentration (only for rain and cloud ice hydrometeors). Snow shape is considered non spherical, with bulk density varying inversely with diameter as in observations (Alam, 2014), and its size distribution depends on both ice water content and temperature and is represented as a sum of exponential and gamma distributions.

Morrison 6-class double-moment scheme (MP): Morrison is a double-moment more complicated microphysics scheme because it includes estimating number concentrations and mixing ratios of four hydrometeor species such as cloud water, cloud ice, rainwater, and snow and the number concentrations are also predicted for ice, snow, rain and graupel. It also finds out rain size distribution and different rates of rain evaporation in stratiform and convective regions. The cloud number concentration is diagnosed and the development of graupel in generation of precipitation is also included in this scheme. The Morrison parameterization scheme has options to optimize simulations by accommodating the selection of ice nucleation method and CCN spectra (Alam, 2014).

WDM6(MP): A new double-moment bulk cloud microphysics scheme, the Weather Research and Forecasting (WRF). Double-Moment 6-class (WDM6) Microphysics scheme, which is based on the WRF Single-Moment 6-class (WSM6) Microphysics scheme. In addition to the prediction for the mixing ratios of six water species (water vapor, cloud droplets, cloud ice, snow, rain, and graupel) in the WSM6 scheme, the number concentrations for cloud and rainwater are also predicted in the WDM6 scheme, together with a prognostic variable of cloud condensation nuclei (CCN) number concentration. The strength of this new microphysics scheme is its ability to allow flexibility in variable raindrop size distribution by predicting the number concentrations of clouds and rain, coupled with the explicit CCN distribution, at a reasonable computational cost.(Lim and Hong, 2010)

MRF (PBL):(Hong and Pan, 1996)it is a nonlocal First-order closure; follows (Troen and Mahrt, 1986)concept of incorporating a counter gradient correction term into downgradient diffusion expressed solely by locale mixing.

MYNN (PBL):(Nakanishi and Niino, 2006) it is a local scheme. Both 1.5- (MYNN2) and second-order (MYNN3) closure schemes; compared to the Mellor–Yamada PBL scheme (Mellor and Yamada, 1982), expressions of stability and mixing length are based on the results of large eddy simulations rather than on observations, while the expressions of mixing length are more applicable to a variety of static stability regimes.

BMJ (CU): Based on Betts-Miller convective scheme(Betts, 1986; Betts and Miller, 1986); primary modification was made by (Janjić, 2000, 1994, 1990) including the introduction of “cloud efficiency” to provide an additional degree of freedom in determining target profiles of heat and moisture. Shallow convective adjustment is an important part of the parameterization.

3.5 Model Setup

Two nested domain was set, as mentioned in figure (5) outer domain of 9km^{x}9km with blue box, named D01 and inner domain of 3km^{x}3km with red box, named D02. Output data was taken from inner domain for verification and Cumulus option was turned off for inner domain. For spin up time period 3hr was taken. And details of namelist.input can be seen on the table (1).

Model setup Description was given on the table.

Table 1 WRF namlist.input

Selected Model Setup descriptions

Description	**Configuration**
Model	WRF-ARW 4.0.3
Horizontal resolution	9km, 3km
E_WE	173, 163
E_SN	156, 151
Interval Seconds	3600
Time Steps	36
History interval	60, 30
Vertical levels	35
E_vert	35
P_top_requested	50 hpa
Downscaling Ratio	1:3
Projection system	Mercater
Nesting	Two-way nesting
Ra_lw_physics, ra_sw_physics	CAM
Sf_sfclay_physics	Revised MM5 Monin-Obukhov scheme

Sf_surface_physics	Noah-MP land-surface model
Cu_physics	BMJ, 0
Microphysics	***Lin, Morrision, Thompson, Wdm6***
PBL scheme	***Mrf, Mynn***

Taking other parameter same, this study only focuses on combination of given four Microphysics (MP) and two PBL schemes, given in italic and bold faces on table.

3.6 R Verification Package

R is an open-source platform, where its user-friendly interface helps us to code and interpret our results. It has huge library packages easy to use, and there are different library packages for different field of study. As this study required, R verification package is a library tool written in R language by NCAR-Research Application Laboratory, and maintained by *Eric Gilleland*. Useful for verification purpose in different forecast sector, such as verifying discrete, continuous and probabilistic forecast and forecasts pressed as parametric distribution etc. Version 1.42(Laboratory, 2015).

3.7 Rainfall Category:

Depending on the impacts of 24 hour accumulated rainfall each country, could have different rainfall category such as trace, low, moderate, heavy, very heavy and extreme etc. For example, on the basis of type of soil, vegetation, terrain slope and aspect, and drainage systems etc. in each country and region, the threshold for the low, moderate to heavy or extreme rainfall may differ place to place, that is the same amount of precipitation has devastating impacts on one country/region such as loss of life and property through lead to flood and landslides but the same amount of precipitation has less effect to other country/region. In the context of Nepal DHM classify the rainfall category on the basis of rainfall amount, which is given in the table (2).

Table 2 Rainfall Category

Rainfall amount based on total accumulated rainfall during 24 hrs	Light Rain	Less than 10 mm
	Moderate Rain	Greater than 10 mm less than 50 mm
	Heavy Rain	Greater than 50 mm

(Source:"Department of Hydrology and meteorology, Babarmahal Kathmandu Nepal," n.d.)

3.8 Test Statistics

Continuous verification:

Verifying forecasts of continuous variables measures how the values of the forecasts differ from the values of the observations(Wilks, 2011). The attributes of continuous verification methods and statistics will be demonstrated on a following.

Mean Error:

It indicates the average forecast error. It is called the (additive) bias. Does not measure the magnitude of the errors. Does not measure the correspondence between forecasts and observations, i.e., it is possible to get a perfect score for a bad forecast if there are compensating errors. *(https://www.cawcr.gov.au/projects/verification/)*

$$Mean\ Error = \frac{1}{N}\sum_{i=1}^{N}(Fi - Oi)$$

Where N=Number if observation

F_i=Forecast

O_i=Observation

Its value ranges from -ꝏ to ꝏ. And perfect value is 0.

Multicategory Verification:

Contingency Table:

It is a statistical tool. And known as two-way frequency table depend upon yes, no observation and forecast values. It is a tabular representation with at least two rows and two columns used in statistics to represent categorical data in terms of frequency counts.

Table 3 $3^{x}3$ Contingency Table

<table>
<tr><td></td><td colspan="4">Observation</td></tr>
<tr><td rowspan="4">Forecast</td><td></td><td>Light</td><td>Moderate</td><td>Heavy</td></tr>
<tr><td>Light</td><td>m</td><td>n</td><td>o</td></tr>
<tr><td>Moderate</td><td>p</td><td>q</td><td>r</td></tr>
<tr><td>Heavy</td><td>s</td><td>t</td><td>U</td></tr>
<tr><td colspan="5"></td></tr>
<tr><td>Light
a=m
b=n+o
c=p+s
d=q+r+t+u</td><td>Moderate
a=q
b=p+r
c=n+t
d=m+o+s+u</td><td colspan="3">Heavy
a=u
b=s+t
c=o+r
d=m+n+p+q</td></tr>
</table>

Table 4 $2^{x}2$ Contingency Table

<table>
<tr><td rowspan="5">Forecast</td><td colspan="4">Observation</td><td rowspan="5">Marginal total for Forecast</td></tr>
<tr><td></td><td>Yes</td><td>No</td><td></td></tr>
<tr><td>Yes</td><td>a</td><td>b</td><td>a+b</td></tr>
<tr><td>No</td><td>c</td><td>d</td><td>c+d</td></tr>
<tr><td></td><td>a+c</td><td>b+d</td><td>a+b+c+d</td></tr>
<tr><td colspan="5">Marginal total for Observations</td><td>Sample Size (n)</td></tr>
</table>

a= Hits b=False Alarm c=Miss d=Correct Negative

Scalar Attributes of Contingency Table:

Forecast verification is a process of comparing the quality of competitor forecasts. Forecast verification techniques allow comparison of the relative best score of competing forecasters or forecasting systems, here combination of MP physics and PBL physics. Analysis of verification statistics and their components can also help in the determining of specific strengths and weaknesses of forecasters. From contingency table wide variety of these scalar attributes have been designed and used to distinguish forecaster's performance.Wide variety of these scalar attributes have been designed and used to characterize forecasters performance, over the long history of the verification of forecasts of this type. The forecast performance information contained in the contingency are given below.

Accuracy:

It is defined as average correspondence between pairs of forecasts and the event they are meant to predict.(Wilks, 2011)

Proportion Correct (PC) = a+d/n

Its value ranges from 0 to 1 and perfect value is 1

Answer the question: overall, what fraction of the forecast were correct?

Threat Score (TS)

It is an alternative to the proportion correct that is particularly useful when the event to be forecast (as 'yes' event) occurs substantially less frequent than the nonoccurrence (the 'no' event).(Wilks, 2011)

TS= a/(a+b+c)

Its value ranges from 0 to 1 and perfect value 1

Answer the question: How well did the forecast 'Yes' events correspond to the observed 'Yes' event?

Bias:

comparison of average forecast with the average observation, usually represents as a ratio for verification of contingency table; measures the correspondence between the average forecast and average observed value of the predictand.(Wilks, 2011)

B= (a+b)/(a+c)

Its value ranges from -1 to 1 and perfect value =1, under-forecast value<1, over-forecast value>1

Answer the question: How did the forecast frequency of 'Yes' events compare to the observed frequency of 'Yes' events forecast?

Reliability and Resolution:

Reliability pertains to the relationship of the forecast to the distribution of observation, for specific values of (i.e., condition on) the forecast resolution. Resolution is the degree to which the forecast sorts the observed event into group that are different from each other. The fraction of 'Yes' forecast that turn out to be wrong, or that proportion of the forecast events that fail to materialize.(Wilks, 2011)

FAR = b/(a+b)

Its value ranges from 0 to 1 and perfect value is 0.

Answer the question: what fraction of the observed 'Yes' event did not occur?

Discrimination:

It is converse of resolution. It pertains to differences between the conditional distribution of the forecast for different values of the observation. The discrimination attribute reflects the ability of the forecasting system to produce different forecast for those occasions having different realized outcomes of the predictand.(Wilks, 2011)

Probability of detection (POD or H) = a/(a+c)

Fraction of those occasion when the forecast event occurred on which it was also forecast. (True positive fraction)(Wilks, 2011)

Its value ranges from 0 to 1 and its perfect value is1

Answer the question: what fraction of the observed ‘Yes’ event were correctly forecast?

Probability of false detection (POFD or F) = b/(b+d)

Condition relative frequency of a wrong forecast given that event does not occur. (False positive fraction)(Wilks, 2011)

its value ranges from 0 to 1 and its perfect value is 0

Answer the question: what fraction of the observed ‘no’ events were incorrectly forecast as ‘Yes’.

Results

Continuous Verification:

From continuous verification over all physical combination of forecasts is over estimated for low rain forecast and underestimated for the medium and heavy rainfall event. Which is clearly shown in the figure (5) and figure (7). Mynn has less ME value than Mrf. From the mean error value Lin-Mynn shows the best result for the continuous category in figure (7).

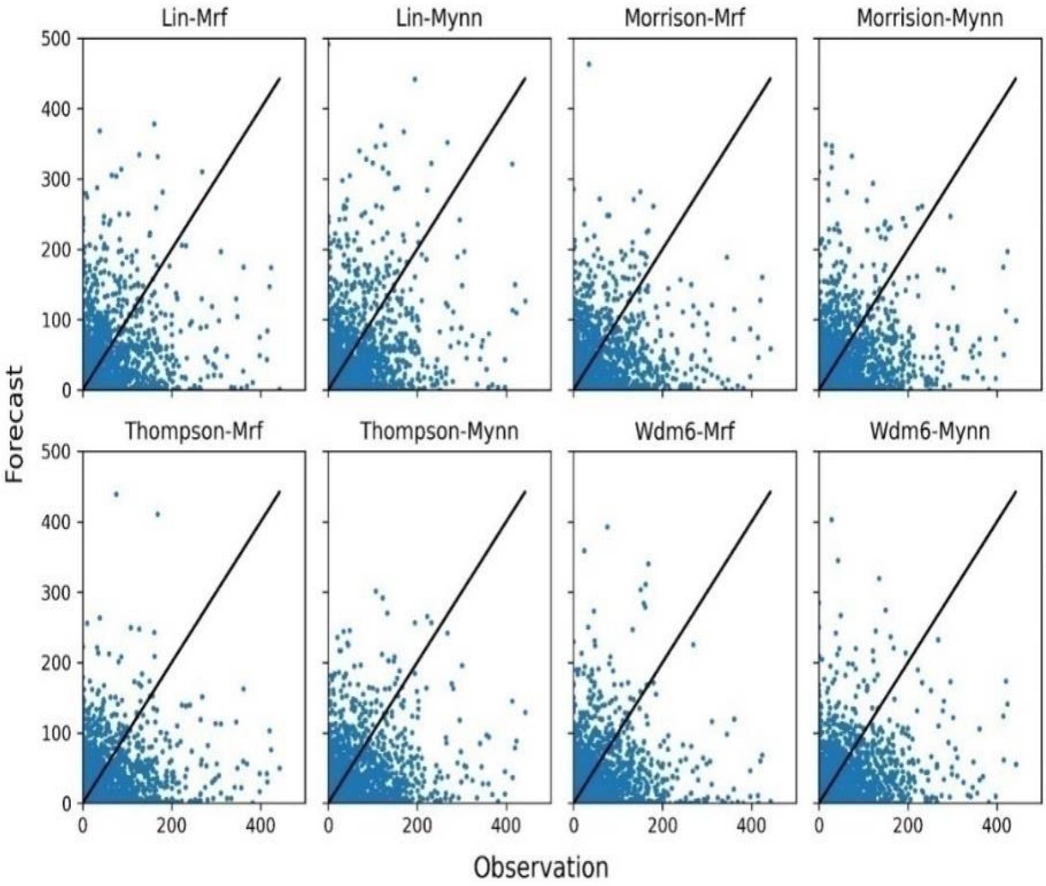

Figure 5 Scatter plot of Forecast vs Observation

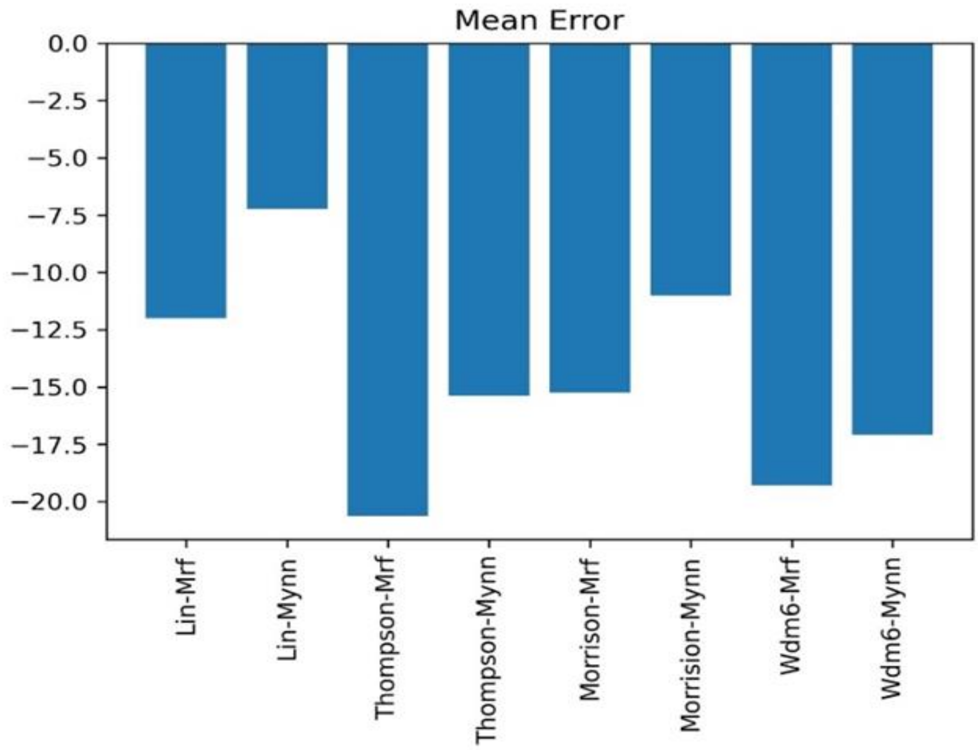

Figure 6 Mean error for continuous verification

<u>Multicategory Verification:</u>

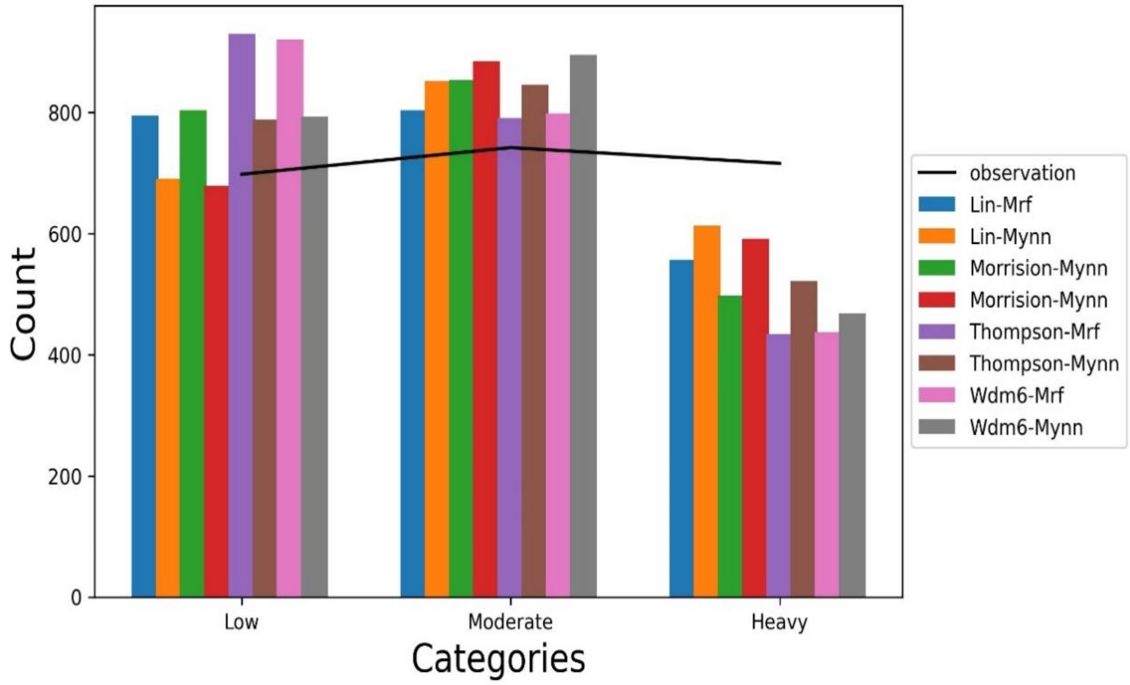

Figure 7 Histogram Chart of Categorical Verification

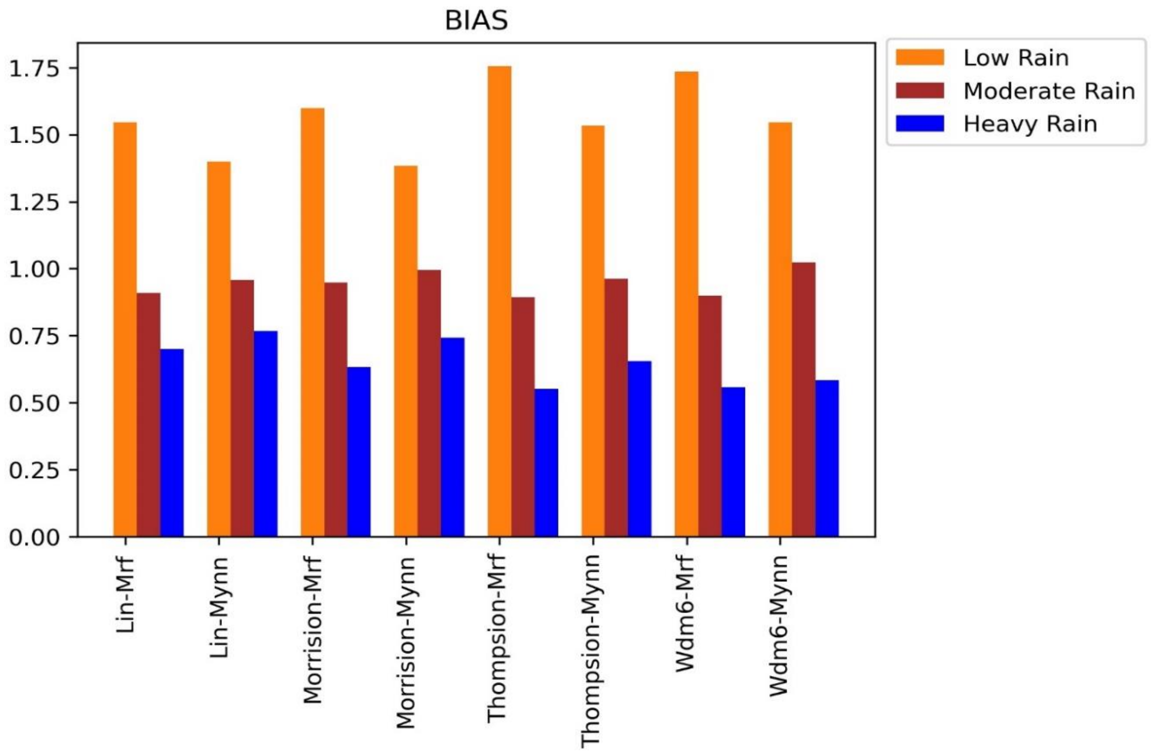

Figure 8 Bias Score

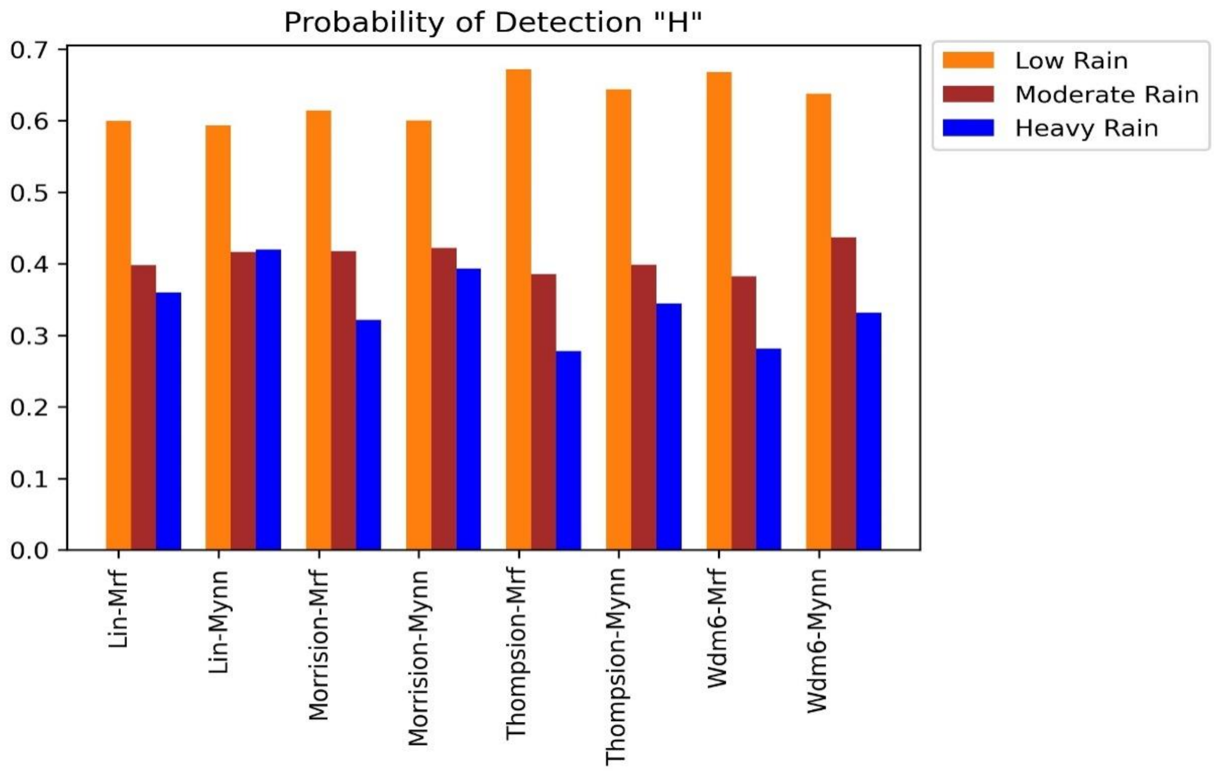

Figure 9 Probability of Detection (POD or H)

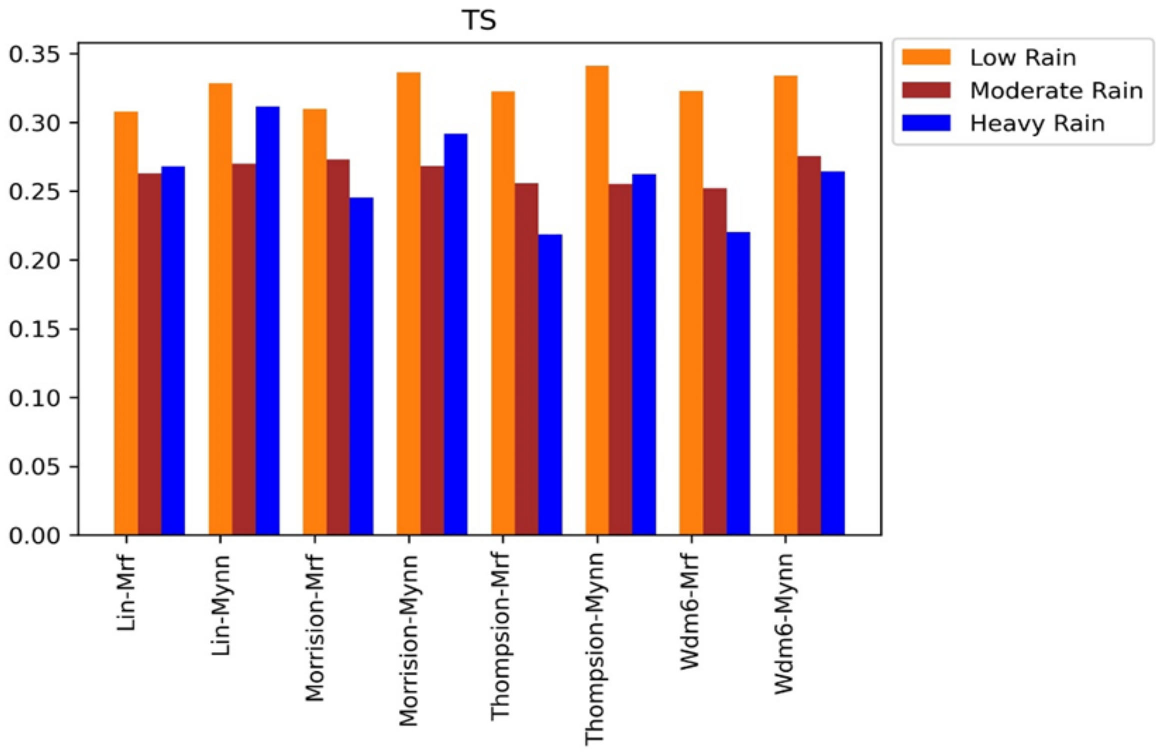

Figure 10 Threat Score

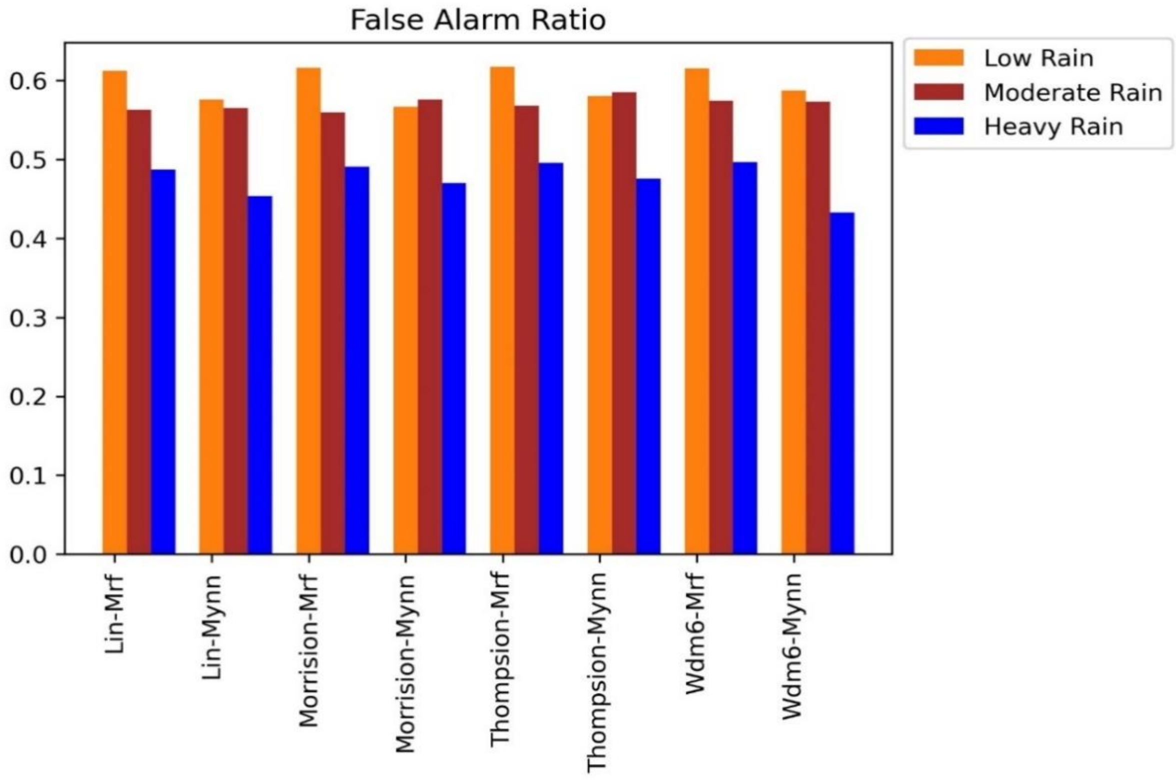

Figure 11 False Alarm Ratio

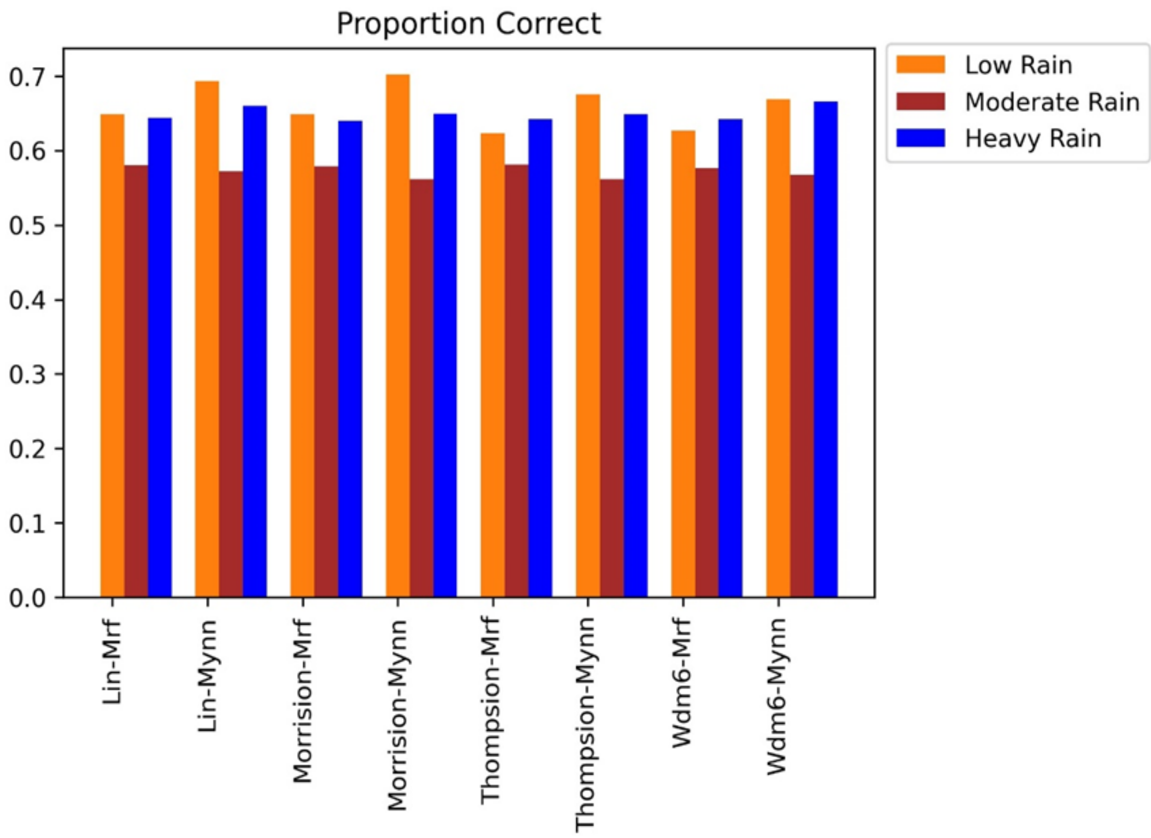

Figure 12 Proportion Correct

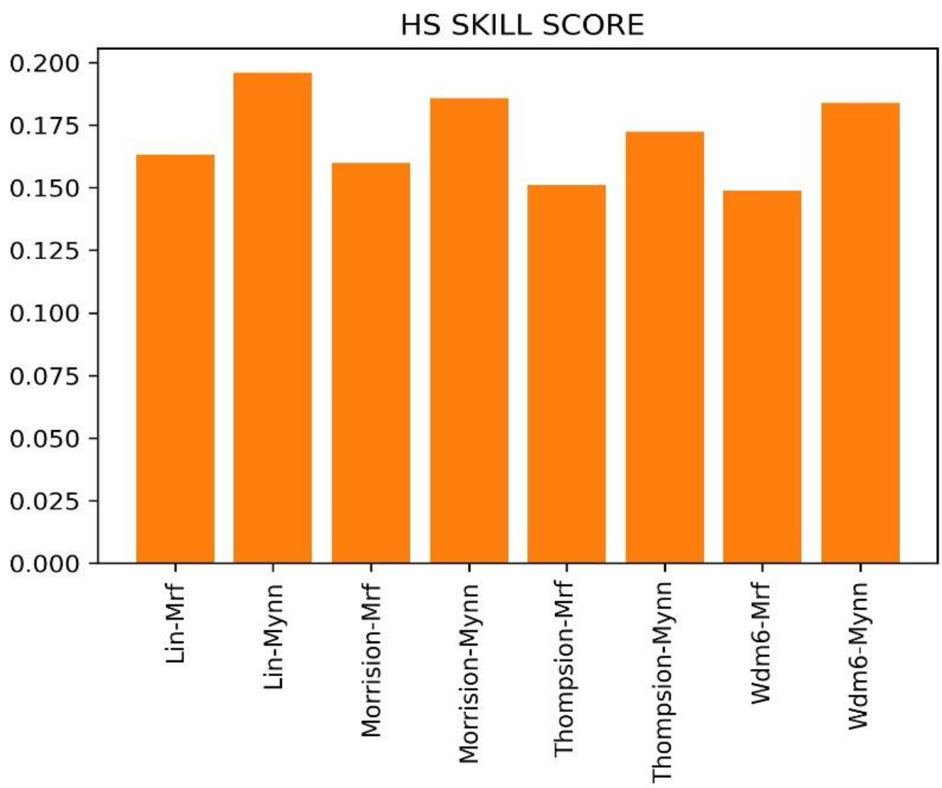

Figure 13 Hidke Skill Score

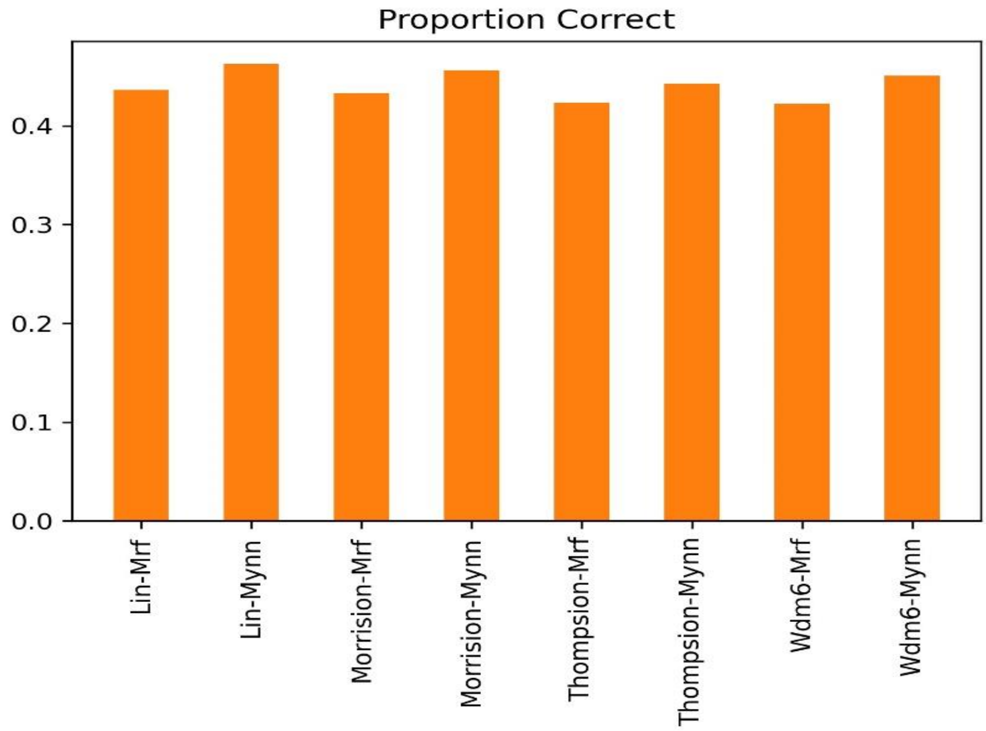

Figure 14 Overall Proportion Correct

The histogram charts figure (7) shows the number of observation or forecast that occurred at given study area for selected rainfall category. We divided rainfall into three main category/bins on the basis of rainfall value of DHM (0-10 mm, 10-50 mm, >50 mm). It is clear from figure (7) Lin-Mynn and Morrision-Mynn physics combination shows underestimation of observe event and all other combination overestimate the observe event for low rain category. For moderate rain category all combination overestimates the observe event. And for heavy rainfall category all combination underestimates the observe event.

Figure (8) shows the bias score at different bin category overall estimation is quite similar by all combination foreach bin category. For low rain category, Bias score 1.38 >1 is best score given by Morrision-Mynn which clearly indicate that there is overestimation of rainfall event, Mynn shows a less bias than Mrf for all MP physics for low rain category while seeing on MP Lin gives low bias on overall but bias score of Morision-Mynn is 1.38 less than that of Lin-Mynn, 1.39.For moderate rain category Morrision-Mynn gives its best with Bias score 0.99 <1, which indicate that there is underestimation of event.Mynn gives higher bias than Mrf but both gives less than 1. MP scheme Lin gives less bias on overall but Thomson-Mrf is least bias with score 0.89. But Wdm6-Mynn shows a bias of 1.02 >1, shows the overestimation. For the heavy rain category Lin-Mynn gives its best Bias score is 0.76<1, which is also an indication of underestimation. Mynn gives higher than that of Mrf but both are less than 1. Lin MP physics gives highest bias while Thompson gives least, both less than 1.

Figure (9) shows the Probability of Detection (POD or H) score, which describe about, was observed yes event correctly forecasted. For low rain category Thompson-Mrf combination gives best with the score value 0.67 and worst value by Lin-Mynn with score value 0.59. Mynn has less score than the Mrf, it means Mrf shows a better performance from POD. MP physics Lin gives the less POD value as compared to other MP.For moderate rain category Wdm6-Mynn give best with score 0.63 and worst value is scored by Wdm6-Mrf with value 0.38.Mrf gives less value than Mynn. Thompson scheme gives less value than others. Depending upon the PBL scheme Wdm6 mp has higest as well as lowest POD value for this category. For heavy rain category Lin-Mynn gives best score with value 0.59 and Thompson-Mrf gives its worst value with score 0.28. Mynn give higher valu than that of Mrf. Lin MP has higher value than other MP. Combination with PBL has different value for different scheme.

Figure (10) shows Threat Score (TS). For low rain category Thompson-Mynn gives best result with value 0.34, and worst value of 0.30 by Lin-Mrf combinations. Mynn gives higher value than that of Mrf. Lin MP gives lowest TS value while Thompson gives highest value with Mynn than Mrf.Wdm6-Mynn is best for moderate rain category with value 0.27 and worst by Wdm6-Mrf with value of 0.25. With Lin and Wdm6 MP physics Mynn gives greater value and with Thompson and Morrision MP,Mrf gives higher value. Lin-Mynn is best for heavy rain category with score value 0.31 and worst value by the physical combination Thompson-Mrf with score 0.21. Mynn gives higher value than Mrf for this category. Lin MP has higher value than other MP physics

Figure (11) shows False Alarm Ratio (FAR), Morrision-Mynn gives the best score with value 0.56, and Thompson-Mrf gives worst value 0.61 for low rain category. Mynn gives lesser value than Mrf. Mrf PBL scheme gives nearly same value for all MP physics while Mynn has different. Wdm6-Mynn has value of 0.58 while Morrision-Mynn 0.56. Morrison-Mrf gives best score with value 0.55and Thompson-Mynn gives worst value 0.58, for moderate rain category Mynn has lower value than Mrf for Wdm6 MP physics but for all MP physics Mynn has higher value. For Lin MP Mrf and Mynn shows nearly same result for this category. Wdm6-Mynn gives best result for heavy rain category with value 0.43 and worst value by Wdm6-Mrf and Thompson-Mrf both combinations score the same value of 0.49. Mynn has lesser value than that of Mrf. Lin MP has lower value than other MP physics but Wdm6 with Mynn has lowest.

Figure (12) shows the Proportion Correct (PC), for low rain category, from PC Morrision-Mynn is best with score value 0.70 and worst value by Thompson-Mrf with value 0.62, Mynn has higher value than Mrf. For the moderate category Thompson-Mrf is best with score value 0.58 and worst value by Morrision-Mynn with score 0.56. Mynn has lower value than Mrf. For heavy rainfall category Wdm6-Mynn is best with value 0.66 and worst is Morrision-Mrf with score 0.63. Mynn has higher value than Mrf. Lin MP gives better than Morrision MP but worse than Wdm6 MP.

Figure (13) show the value of Hidke Skill Score, measures accuracy of the forecast relative to that of random chance, it does not compare the categorical value but overall values, from these Hidke Skill Score the best combination is Lin-Mynn with the highest value of 0.19. From figure it is seen that Mynn has higher value than Mrf. And Lin MP has highest value than another MP scheme. From figure (14) overall proportion correct were measure, from that Lin-Mynn gives the best result with value 0.46 .

Values

Table 5 Value of Continuous Verification

NAME	ME	MAE	MSE	RMSE	BIAS
Lin-Mrf	-12.0083	47.57758	5536.514	74.40776	0.755965
Lin-Mynn	-7.22625	46.28302	5275.002	72.62921	0.755965
Thompson-Mrf	-20.6088	45.01852	5143.479	71.71805	0.755965
Thompson-Mynn	-15.3932	43.54609	4743.044	68.86976	0.755965
Morrision-Mrf	-15.2342	45.90601	5188.289	72.02978	0.755965
Morrision-Mynn	-11.0109	45.33344	5141.003	71.70079	0.755965
Wdm6-Mrf	-19.2868	46.25976	5511.736	74.24107	0.755965
Wdm6-Mynn	-17.0791	43.45391	4819.529	69.42283	0.755965

Table 6 Value for Low Rainfall Category

	BIAS	TS	HSS	PC	POD(H)	POFD(F)	FAR
Lin-Mrf	1.5467	0.3077	0.1633	0.6484	0.5992	0.3342	0.6126
Lin-Mynn	1.3988	0.3285	0.1958	0.6930	0.5931	0.2732	0.5760
Morrision-Mrf	1.5984	0.3096	0.1598	0.6485	0.6143	0.3397	0.6157
Morrision-Mynn	1.3837	0.3364	0.1858	0.7020	0.6000	0.2637	0.5664
Thompson-Mrf	1.7547	0.3225	0.1509	0.6236	0.6717	0.3940	0.6172
Thompson-Mynn	1.5331	0.3409	0.1723	0.6753	0.6440	0.3137	0.5799
Wdm6-Mrf	1.7358	0.3230	0.1487	0.6266	0.6679	0.3885	0.6152
Wdm6-Mynn	1.5458	0.3340	0.1840	0.6690	0.6374	0.3198	0.5876

Table 7 Value for Moderate Rainfall Category

	BIAS	TS	HSS	PC	POD(H)	POFD(F)	FAR
Lin-Mrf	0.9097	0.2629	0.1633	0.5804	0.3976	0.3092	0.5630
Lin-Mynn	0.9582	0.2701	0.1958	0.5720	0.4164	0.3325	0.5654
Morrision-Mrf	0.9488	0.2729	0.1598	0.5786	0.4178	0.3235	0.5597
Morrision-Mynn	0.9946	0.2682	0.1858	0.5612	0.4218	0.3530	0.5759
Thompson-Mrf	0.8922	0.2558	0.1509	0.5813	0.3854	0.3020	0.5680
Thompson-Mynn	0.9623	0.2552	0.1723	0.5616	0.3989	0.3401	0.5854
Wdm6-Mrf	0.9003	0.2522	0.1487	0.5762	0.3827	0.3084	0.5749
Wdm6-Mynn	1.0229	0.2753	0.1840	0.5670	0.4367	0.3542	0.5731

Table 8 Value for Heavy Rainfall Category

	BIAS	TS	HSS	PC	POD(H)	POFD(F)	FAR
Lin-Mrf	0.7007	0.2680	0.1633	0.6438	0.3594	0.1943	0.4870
Lin-Mynn	0.7678	0.3112	0.1958	0.6597	0.4196	0.2015	0.4536
Morrision-Mrf	0.6322	0.2455	0.1598	0.6393	0.3217	0.1783	0.4912
Morrision-Mynn	0.7423	0.2918	0.1858	0.6495	0.3936	0.2021	0.4698
Thompson-Mrf	0.5524	0.2184	0.1509	0.6417	0.2783	0.1541	0.4962
Thompson-Mynn	0.6559	0.2623	0.1723	0.6489	0.3441	0.1775	0.4755
Wdm6-Mrf	0.5580	0.2202	0.1487	0.6417	0.2811	0.1557	0.4962
Wdm6-Mynn	0.5846	0.2645	0.1840	0.6655	0.3315	0.1442	0.4330

Discussion and Conclusions

In this study among the eight competitive forecasters no single combination gives the best for all three categories. For low rain category Morrision and Thompson microphysics are much better than other. This works are similar with past works(Karki et al., 2018; Martínez-Castro et al., 2019b; Mohan et al., 2018; Rajeevan et al., 2010; Shrestha et al., 2017b). And for Moderate rainfall category Morrision, Thompson and Wdm6 physics comes better which supports works with (Douluri and Chakraborty, 2021; Karki et al., 2018; Martínez-Castro et al., 2019b; Mohan et al., 2018; Rajeevan et al., 2010; Shrestha et al., 2017b). While investigating heavy rainfall category Lin and Wdm6 MP physiscs find its best value which is similar with works by (Chakraborty et al., 2021; Efstathiou et al., 2013; Lv et al., 2020; Nasrollahi et al., 2012; Patel et al., 2019). But in the case of PBL scheme, Mynn is the best scheme than other, this is also supports the works by (Comin et al., 2021; Gbode et al., 2019a; Zeyaeyan et al., 2017, Gunwani and Mohan, 2017).

For testing the sensitivity of physical schemes in the WRF-ARW model on the simulation heavy rainfall forecast for western Nepal, 8 different model configurations have been established by switching two PBL parameterization schemes and four cloud microphysics schemes. The 22 event days was simulated with eight different physics combination for heavy rainfall occurring in western Nepal, using initial and boundary condition data from the NCEP FNL from GFS model. Having two nested domains of 9km×9km outer domains and 3km×3km inner domain. For outer domain BMJ Cumulus Physics scheme was used while it is turned off for inner domain. Simulated data was taken for competitive forecasters from inner domain of grid resolution 3km×3km.

Overall value was quite similar. From different skill score different combination gives the its best result for different rain category. From continuous verification Lin-Mynn gives its best result. From the POD and TS skill score Wdm6-Mynn and Lin-Mynn gives its best result for moderate and heavy rainfall category, but for low rain Thompson-Mynnand Morrision-Mynn gives its best from the TS skill score and Thompson-Mrf from the POD skill score. From other skill score FAR and PC Morrision-Mynn gives its best for low rain category and Thompson-Mrf for moderate category and Wdm6-Mynn for the heavy rain category.

Limitation

For selection of event, event days selection was based on those rainfall days, when at least two districts have rainfall record on that day.

For perfection of skill score, there is no any threshold value.

Station Detail

Table 9 Table Station Detail

S. N	IndexNo.	Station	District	Measuring	Lon	Lat	Elevate-ion (m)
1	108	Satbanjh	Baltadi	Precipitation	80.4974	29.4973	1881
2	106	BelauriSantipur	Kanchanpur	Precipitation	80.3754	28.6986	164
3	105	Mahendra Nagar	Kanchanpur	Agrometeorology	80.2305	28.9548	197
4	123	BICHAWA	KANCHANPUR	PRECIPITATION	80.5185	28.7733	176
5	121	DODHARA	KANCHANPUR	PRECIPITATION	80.0883	28.8882	175
6	119	HANMANNAGAR	KANCHANPUR	PRECIPITATION	80.2862	28.9664	213
7	122	PARSIA	KANCHANPUR	PRECIPITATION	80.3882	28.7737	170
8	115	DAINSILI	BAITADI	Climatology	80.656	29.4165	2083
9	104	Dadeldhura	Dadeldhura	Synoptic	80.5878	29.3014	1879
10	107	Darchula	Darchula	Climatology	80.5454	29.845	945
11	109	LUMPTHI	DARCHULA	PRECIPITATION	80.8222	29.7826	1653
12	118	JOGBUGHA	DADELDHURA	PRECIPITATION	80.3474	29.1279	379
13	116	RUPAL	DADELDHURA	PRECIPITATION	80.373	29.2884	1458
14	117	SAHUKHARKA	DADELDHURA	PRECIPITATION	80.6239	29.2114	2092
15	101	Kakerpakha	Baitadi	Precipitation	80.5382	29.6583	783

16	103	Patan (West)	Baitadi	Climatology	80.5458	29.4671	1292
17	239	MALAKHETI	KAILALI	PRECIPITA TION	80.5191	28.8281	185
18	240	CHAUMALA	KAILALI	PRECIPITA TION	80.7429	28.7742	171
19	241	GOGANEPANI	KAILALI	PRECIPITA TION	81.2459	28.6563	1070
20	243	BALIYA	KAILALI	PRECIPITA TION	81.1428	28.6283	167
21	244	BHAJANI	KAILALI	PRECIPITA TION	80.9695	28.4898	132
22	230	GOPGHAT (GOLAGHAT)	ACHHAM	PRECIPITA TION	81.2748	29.285	1548
23	235	SUGALI	ACHHAM	PRECIPITA TION	81.3729	29.1798	1668
24	201	Pipalkot	Bajhang	Precipitation	80.8479	29.6188	1455
25	234	DUMRAKOT	DOTI	PRECIPITA TION	81.0118	29.1634	1042
26	209	Dhangadhi(Attariya)	Kaliali	Synoptic	80.56	28.8127	184
27	205	Katai	Doti	Precipitation	81.1333	29	1388
28	208	Sandepani	Kailali	Precipitation	80.9785	28.6642	159
29	215	Godavari(West)	Kailali	Climatology	80.5792	28.8762	280
30	224	OIRANO	BAJURA	PRECIPITA TION	80.4234	29.411	1116
31	227	KOLTI	BAJURA	Precipitation	81.6662	29.5035	1411
32	318	BAU KHOLA (BAM)	MUGU	PRECIPITA TION	82.1349	29.6139	2821
33	319	MANGRI	MUGU	PRECIPITA TION	82.3058	29.589	2257

34	320	GAMTHA	MUGU	PRECIPITA TION	81.8927	29.5087	1848
35	302	Thirpu	Kalikot	Precipitation	81.7519	29.3032	1017
36	308	Nagma	Kalikot	Climatology	81.9106	29.2006	2017
37	309	Bijayapur (Raskot)	Kalikot	Precipitation	81.6391	29.2495	1822
38	332	JUPHAL	DOLPA	PRECIPITA TION	82.8207	28.9836	2475
39	322	CHAUTHA	JUMLA	PRECIPITA TION	82.1074	29.4311	2785
40	324	RUDU(NARAKOT)	JUMLA	PRECIPITA TION	81.9863	29.3277	2364
41	326	JAMNA (Dillichaur)	JUMLA	PRECIPITA TION	82.2833	29.3167	2438
42	303	Jumla	Jumla	Synoptic	82.1796	29.2747	2363
43	304	GuthiChaur	Jumla	Precipitation	82.3304	29.2309	2727
44	312	Dunai	Dolpa	Climatology	82.896	28.9507	2098
45	329	MANMA	KALIKOT	Climatology	81.6135	29.1488	1729
46	331	GELA	KALIKOT	PRECIPITA TION	81.7005	29.0964	1732
47	314	KIRMI	HUMLA	PRECIPITA TION	81.7028	30.0518	2859
48	317	GOTHI	HUMLA	PRECIPITA TION	81.9526	29.7783	1680
49	426	BADHICHAUR	SURKHET	PRECIPITA TION	81.5056	28.713	535
50	430	KHANIKHOLA	SURKHET	PRECIPITA TION	81.9063	28.5219	1335
51	432	MEHALKUNA	SURKHET	Climatology	81.8431	28.4389	540
52	433	KALIDAMAR	SURKHET	PRECIPITA TION	81.7294	28.4209	635

53	409	Khajura (Nepalganj)	Banke	Agrometeorology	81.5903	28.1137	129
54	412	Naubasta	Banke	Precipitation	81.6527	28.2302	161
55	414	Baijapur	Banke	Precipitation	81.8985	28.0184	150
56	416	Nepalgunj(Reg.Off.)	Banke	Climatology	81.6228	28.052	141
57	420	Nepalgunj Airport	Banke	Aeronautical	81.6682	28.1006	165
58	402	Dailekh	Dailekh	Climatology	81.7085	28.8381	1394
59	410	Bale Budha (TalloDhungeshwor)	Dailekh	Precipitation	81.5843	28.7844	590
60	411	Rajapur	Bardiya	Precipitation	81.0976	28.434	133
61	415	Bargadaha	Bardiya	Precipitation	81.338	28.4259	166
62	417	Rani Jaruwa Nursery	Bardiya	Climatology	81.3378	28.3374	145
63	438	DHAKERI	BANKE	PRECIPITATION	81.7661	28.1572	153
64	440	BHAGAWANPUR	BANKE	PRECIPITATION	81.7857	27.9475	137
65	428	JAGATIPUR	JAJARKOT	PRECIPITATION	82.1564	28.6572	1386
66	422	GWATI	DAILEKH	PRECIPITATION	81.7502	28.9071	1472
67	423	RANIMATTA	DAILEKH	PRECIPITATION	81.6288	28.6944	2157
68	424	DADIMADI	DAILEKH	PRECIPITATION	81.6261	28.922	1281
69	425	KATTI	DAILEKH	PRECIPITATION	81.8214	28.7802	1224

70	418	MainaGaun (D.Bas)	Jajarkot	Precipitation	82.2689	28.9613	1913
71	401	Pusma Camp	Surkhet	Climatology	81.2327	28.8755	953
72	406	Surkhet (Birendra Nagar)	Surkhet	Synoptic	81.6352	28.5879	720
73	434	KUMALGAUN	BARDIYA	PRECIPITA TION	81.3121	28.3495	144
74	435	TARATAL	BARDIYA	PRECIPITA TION	81.2759	28.3078	141
75	436	RAMBHAPUR	BARDIYA	PRECIPITA TION	81.4143	28.3635	150
76	437	MANPUR	BARDIYA	PRECIPITA TION	81.4801	28.1856	132
77	529	PADHAMPUR	DANG	PRECIPITA TION	82.1355	28.1885	656
78	532	SUKHABARE	DANG	PRECIPITA TION	82.3908	28.0159	586
79	533	RATAMATA	DANG	PRECIPITA TION	82.6121	27.9628	517
80	535	RAMPUR (Beljhundi)	DANG	PRECIPITA TION	82.3637	28.1003	649
81	536	GANGADI	DANG	PRECIPITA TION	82.3351	27.8849	216
82	537	LAMAHI	DANG	PRECIPITA TION	82.5367	27.8706	243
83	538	LALMATIYA	DANG	PRECIPITA TION	82.7261	27.8424	287
84	539	GADHAWA	DANG	PRECIPITA TION	82.5388	27.8156	231
85	501	Rukumkot	Rukum	Precipitation	82.6207	28.6128	1568
86	513	Chaurjhari Tar	Rukum	Climatology	82.2103	28.654	863

87	520	KEUR GAUN	ROLPA	PRECIPITA TION	82.3628	28.4229	2145
88	527	SULICHOUR(SARI CHOUR)	ROLPA	PRECIPITA TION	82.7292	28.2472	845
89	507	Nayabasti (Dang)	Dang	Precipitation	82.1394	28.2013	685
90	510	Koilabas	Dang	Precipitation	82.5251	27.6923	200
91	515	Ghorai (Dang)	Dang	Synoptic	82.4842	28.0372	663
92	530	SWARGDWARI	PYUTHAN	PRECIPITA TION	82.7013	28.1284	1232
93	534	HANSPUR	PYUTHAN	PRECIPITA TION	82.8788	27.9543	742
94	518	KABRENETA	SALLYAN	PRECIPITA TION	82.2876	28.5289	1143
95	521	PAKHAPANI	SALLYAN	PRECIPITA TION	82.0604	28.4488	846
96	517	KOTJHARI	RUKUM	PRECIPITA TION	82.2341	28.6584	1142
97	511	Salyan Bazar	Salyan	Climatology	82.1423	28.3821	1557
98	512	Luwamjula Bazar	Salyan	Precipitation	82.258	28.2968	895

Namelist.wps

&share

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max_dom = 2,

start_date = #start_date, #start_date,

end_date   = #end_date, #end_date,

interval_seconds = 3600,

io_form_geogrid = 2,

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debug_level = 0,

/

&geogrid

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parent_grid_ratio = 1,3,

i_parent_start    = 1,60,

j_parent_start    = 1,66,

e_we          = 173,163,

e_sn          = 156,151,

geog_data_res = 'default','default',

dx = 9000,

dy = 9000,

map_proj=  'mercator',

ref_lat   = 27.695,

ref_lon   = 81.929,

truelat1  = 27.695,

truelat2  = 0,

stand_lon = 81.929,

geog_data_path = '/NWP/kumar/resolution_4/WPS_GEOG',

opt_geogrid_tbl_path = '#path',

ref_x = 86.5,

ref_y = 78.0,

/
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&ungrib

out_format = 'WPS',

prefix = 'FILE',

/

&metgrid

fg_name = 'FILE',

io_form_metgrid = 2,

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/

&mod_levs

press_pa = 201300 , 200100 , 100000 , 95000 , 90000 , 85000 , 80000 , 75000 , 70000 ,

65000 , 60000 , 55000 , 50000 , 45000 , 40000 , 35000 , 30000 ,25000 , 20000 , 15000 , 10000 , 5000 , 1000

/

&plotfmt

ix = 100

jx = 100

ioff = 30

joff = 30

/

Namelist.input

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start_month         = #start_month,    #start_month,
start_day           = #start_day,    #start_day,
start_hour          = #start_hour,    #start_hour,
start_minute        = 00,    00,
start_second        = 00,    00,
end_year            = #end_year,   #end_year,
end_month           = #end_month,    #end_month,
end_day             = #end_day,    #end_day,
end_hour            = #end_hour,    #end_hour,
end_minute          = 00,    00,
end_second          = 00,    00,
interval_seconds    = 3600,
input_from_file     = .true.,  .true.,  ,
history_interval    = 60,    30,
frames_per_outfile   = 1000,   1000,
restart             = #restart,
restart_interval     = #rst_interval,
io_form_history      = 2,
io_form_restart      = 2,
io_form_input        = 2,
io_form_boundary      = 2,
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debug_level             = 0,
/
&domains
time_step               = 36,
time_step_fract_num     = 0,
time_step_fract_den     = 1,
max_dom                 = 2,
e_we                    = 173,     163,
e_sn                    = 156,     151,
e_vert                  = 35,      35,
p_top_requested         = 5000,
num_metgrid_levels      = 27,
num_metgrid_soil_levels = 4,
dx                      = 9000,    3000,
dy                      = 9000,    3000,
grid_id                 = 1,       2,
parent_id               = 1,       1,
i_parent_start          = 1,       60,
j_parent_start          = 1,       66,
parent_grid_ratio       = 1,       3,
parent_time_step_ratio  = 1,       3,
feedback                = 1,
smooth_option           = 0,
/
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&physics
mp_physics              = 2/8/10/16,        2/8/10/16,
ra_lw_physics           = 3,        3,
ra_sw_physics           = 3,        3,
radt                    = 5,        5,
sf_sfclay_physics       = 1,        1,
sf_surface_physics      = 4,        4,
bl_pbl_physics          = 5/99,     5/99,
bldt                    = 0,        0,
cu_physics              = 2,        0,
cudt                    = 0,        0,
isfflx                  = 1,
ifsnow                  = 0,
icloud                  = 1,
surface_input_source    = 1,
num_soil_layers         = 4,
sf_urban_physics        = 0,        0,
maxiens                 = 1,
maxens                  = 3,
maxens2                 = 3,
maxens3                 = 16,
ensdim                  = 144,
/
&fdda
```

```
/
&dynamics
w_damping              = 0,
diff_opt               = 1,
km_opt                 = 4,
diff_6th_opt           = 0,      0,
diff_6th_factor        = 0.12,   0.12,
base_temp              = 290.,
damp_opt               = 0,
zdamp                  = 5000.,  5000.,
dampcoef               = 0.2,    0.2,
khdif                  = 0,      0,
kvdif                  = 0,      0,
non_hydrostatic= .true.,   .true.,
moist_adv_opt          = 1,      1,
scalar_adv_opt         = 1,      1,
/

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spec_bdy_width         = 5,
spec_zone              = 1,
relax_zone             = 4,
specified              = .true.,  .false.,
nested                 = .false.,   .true.,
```

```
/
&grib2
/
&namelist_quilt
nio_tasks_per_group      = 0,
nio_groups               = 1,
/
```

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