# EFFECT OF DIFFERENTLY INTERPOLATED GEOGRAPHICAL DATA ON WRF-ARW FORECAST

by


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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Philosophy (M. Phil.) in Mathematics


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# *DEDICATION*

*DEDICATED*

*TO*

*MY PARENTS and WIFE*

*Md. Abdus Sattar, Mrs. Aleya Begum, & Mrs.KamrunNaher*

# Declaration

This is to certify that the thesis work *"Effect of Differently Interpolated Geographical Data on WRF-ARW Forecast"* has been carried out by Md. Shahifur Rahman in the Department of Mathematics, Khulna University Engineering & Technology, Khulna, Bangladesh. The above thesis work or any part of this work has not been submitted anywhere for the award of any degree or diploma.

Signature of Supervisor

Signature of Student

# Approval

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**April, 2017**

# Abstract

With the advancement of computing power now a days Numerical Weather Forecasting (NWP) has emerged as an important tool and is playing its role for short to medium even for long range weather forecasting. Like other models theWeather Research and Forecasting (WRF) model has three components, i) Pre-processing, ii) Model running and iii) Post-processing. At the preprocessing stage one has to decide/declare the date and time, the region of interest, grid spacing (in case of nested run parent-child ratio), map projection etc. In this stage the geographical data is placed to defined grids and blended with the meteorological data. In numerical calculation/prediction the final output depends on the input. Thus it is assumed that the output has dependencies on the input values assigned at the grids. The value at the grids are depending on the interpolation technique. In this thesis we have compared the results of different predicted parameters (temperature, sea level pressure (SLP), relative humidity, cumulus accumulated precipitation and wind speed) of different events (rainfall, temperature and cyclone) calculated on the basis of different interpolation techniques. For the purpose default results are compared with the results obtained by using 4-point, 16-point and nearest neighborhood interpolation techniques. For the comparison purpose graphical/visual difference is considered. After completion of the model running GrADS(Grid Analysis and Display System) has been used for the graphing purpose. It has been found that except SLP the results of different interpolation schemes have similar pattern though the shape of the patterns are different in size. But in the case of SLP there are tremendous difference in result with respect to change of interpolation scheme.

# Publication

International conference paper

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# CHAPTER 1

## INTRODUCTION

### 1.1

Bangladesh has a peculiar geographical condition with the Himalayas in the North and the Bay of Bengal in the south. The Hilly areas are situated to the northeast in the eastern margin of the Sylhet plains, and in the southeastern part of the country in the Chittagong and Chittagong Hill Tracks regions. The world's largest mangrove forest called Sundarbans is located in the southeastern coastal zone. Bangladesh is a delta of the great river Ganges, Brahmaputra and Meghan (GBM) and most of the areas are low lying flood plains except Brained tracts and Modhupur tracts situated in the north-west and north central regions of Bangladesh respectively

Bangladesh has mild winter and hot summer. The annual statistics shows that 70.6% of the country average rainfall occurs during the southwest monsoon season and 18.9% during the pre-monsoon seasons. The winter and post monsoon accounts 1.5 and 9% of the annual rainfall respectively. There are considerable spatial variations of rainfall. The northeast part of Bangladesh experiences very high rainfall. Bangladesh enjoys generally a sub-tropical monsoon climate. There are four prominent seasons in a year namely; winter, (December - February), pre-monsoon (March - May), Monsoon (June - September), and post monsoon (October - November). Winter, which is quite pleasant begins in December and ends in February. The average annual rainfall varies from 1429 to 4338 mm. About 80% of the total rainfall of the country occurs during monsoon. The maximum rainfall is recorded in the coastal areas of Chittagong (in the south-east) and northern part of Sylhet district (in the north-east of Bangladesh) while the minimum is observed in the western and northwestern part of the country. Monsoon rainfall is very essential for agriculture. The agricultural and land use practices depends on the rainfall and water availability.

The country is prone to disasters like floods and droughts, tropical cyclones, nor westers/tornadoes. Variability of rainfall causes floods and droughts. Excess rainfall over Bangladesh and in the upper catchments causes floods in Bangladesh. It is no mentions that 92% of the catchments of Ganges, Brahmaputra and Meghan lies outside Bangladesh and the run off from these areas pass through Bangladesh which accounts for the 8% of the catchments. The severe floods cause the damage to crops, infrastructure, power supply, economic activities and overall livelihood of the affected areas. Besides, the heavy rainfall events cause flash floods and landslides. The latter is very common in Chittagong districts. The rainfall deficits for a long period causes severs draughts affecting the agricultural crops, lack of water resources for fisheries and livelihood of the people in various ways.

Normally, in the pre-monsoon season, when the warm and moist air blows from the sea to the land in the lower level and the sub topical cool air blows from the westerly direction over this moister laden hot air mass creating a situation of high instability in the troposphere for favoring the convective processes occur frequently. Due to this convection, the other disasters come from the severe thunderstorms, squall lines, nor'westers, meso-scale convective clouds and tornados which are of localize nature and are relatively short live but cause damages to lives and properties over the areas where they occur. The horizontal scale of these system is within the range 1-100 km. The Bay of Bengal is highly suitable for tropical cyclogenesis. One of the linked features of the tropical cyclone is the storm surges, which is responsible for major damages due to a tropical cyclone. The strong wind of the tropical cyclone exerts frictional force on the water surface which is proportional of the square of the wind speed. This frictional force causes high gravity waves with heights of up to 10-12meters. These waves cause water to flow island lash everything in its path. The human casualties of the cyclones of 12 November 1970, 29 April 1991 and 15 November 2007 were 300000, 128882 and 3363 respectively due to the rampages of these killer cyclones. The shock of these loses in the economy and livelihoods are respectable and takes a long time to settle the victims back to normal life.

Prediction of rainfall associated with precipitation events is challenging task for the scientist dealing in this profession. The rainfall in monsoon season are mainly associated with the activities of monsoon trough, which is an east west orientated low pressure area with axis extending from central Pakistan to the head of the bay of Bengal long the *Gangetic valley* parallel to the foot hills of Himalayas. The monsoon depressions, land depressions and meso-scales convective system generate within the monsoon trough and causes heavy rainfall. Sometimes these system originate more frequently and become unusually active to produce damaging floods.

The formation intensification and movement of the monsoon depression / land depressions and spatial temporal variability of the monsoon trough itself are very important aspects, which need to be studied. Again the formation, intensification and movement of the tropical cyclone are very also impotent aspects, which need to be studied, one of the most powerful and advance tools of such research is the Numerical weather Prediction (NWP) Model.

Initially a number of high impact events (temperature events, rainfall events and tropical cyclone events) those occurred in the recent decades were identified using observed data. The above mentioned model has been set up for predicting these impacts events. The model has been run using NCEP FNL reanalysis data ($1^0 \times 1^0$ resulation) as the initial field for different meteorological parameters.

## 1.2 Some fundamental aspects

### 1.2.1 Rainfall events

Bangladesh lies at the peak of an inverted funnel at the Bay of Bengal basin. The following figure depicts the amount of total monthly rainfall over Bangladesh (not in scale). It notices that there is a small amount of rainfall in the winter and a bit more in the pre and post monsoon season. The principal amount is accounted in the monsoon. The winter parameters of interest related to the rainfall extinction is obviously the cumulus precipitation, sea level pressure (as it has relation with good /bad weather), wind speed and temperatures are also important. Hence these four parameters should be accounted in such a study.

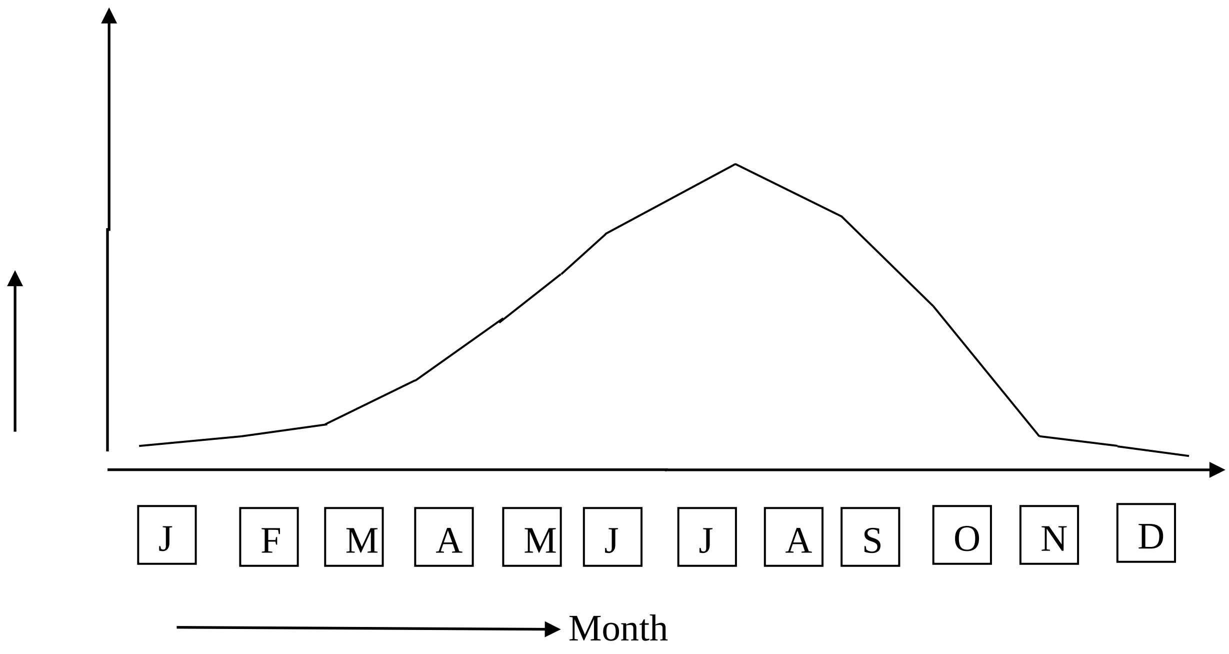



Figure-1.1: Average annual rainfall distribution pattern of Northern Hemisphere.

### 1.2.2 Tropical Cyclone

Tropical Cyclone is one of the most hazardous phenomenons faced by Bangladesh. The geographical location of this country made it cyclone prone area. The low intensity cyclones (seasonal low, depression, and deep depression) have positive impact on the basis of rainfall over the Bangladesh and they mainly occur during the monsoon season. The cyclones that come to Bangladesh in the pre and post monsoon are dangerous and devastating. The land is lucky that the frequencies of the event in pre and post monsoon are much less. The event is very rear in winter. The meteorological parameters of interest for these events are precipitation, sea level pressure, wind speed and temperature. For any study of such an event at least these parameters must be accounted.

### 1.2.3 Temperature

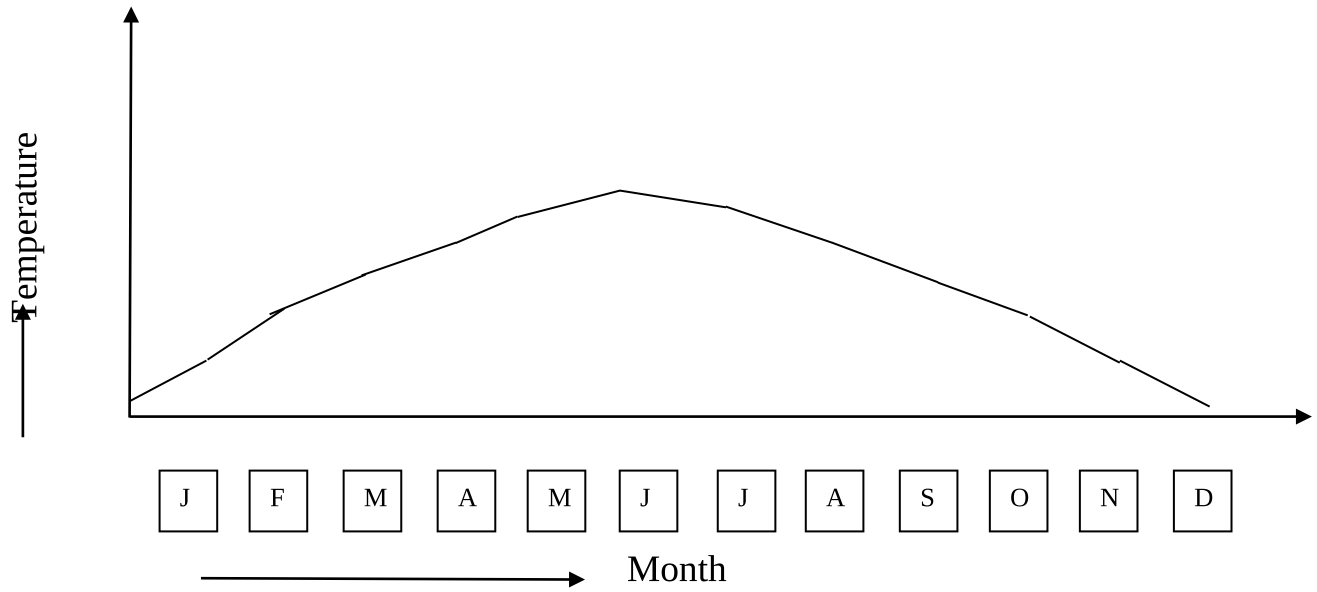



Figure-1.2: Average annual temperature distribution pattern of Northern Hemisphere.

Figure-1.2 represents average annual temperature distribution pattern of Northern Hemisphere. From the figure it is clear that at the beginning of the year (January) the average temperature is lowest. The average temperature of February and December is little bit more than the average temperature of January. These three months are under winter. The average temperature of March, April, August, September and October is moderate. The average temperature is highest in May, June and July. The highest maximum temperature is occurred at any days of these three months. So there exist a peak (highest maximum temperature) which is generally happened in June.

**Winter Minimum Temperatures:**

There are two terminologies in measuring of temperature; one is maximum temperature and another one is minimum temperature. Maximum and minimum temperature occurs once in a day. We get the reading through Maximum Minimum Thermometer. Liquid-in-glass Thermometers are accurate and inexpensive for this purpose. A liquid, usually red-colored alcohol or mercury, is free to move within a thin opening inside the glass enclosure of the thermometer. The opening is so narrow that even small temperature changes cause a relatively large change in the length of the liquid. The glass also expands and contracts as temperature changes, but its expansion and contraction is negligible compared to that of the liquid. Modified liquid-in-glass thermometers have been designed specifically for measuring daily maximum and minimum temperatures. In these special thermometers, the length of the liquid thread at either its maximum expansion or maximum contraction is preserved until the thermometer is reset. The maximum expansion is maximum temperature and the maximum contraction is minimum temperature. Generally we are aware of the minimum temperature in winter and maximum temperature in summer. In winter, generally the minimum temperature occurs at 2am-6am. But we are not interested on time when minimum temperature is recorded rather on the recorded minimum temperature itself.

Over Bangladesh the temperature is moderate, in summer it does not exceeds $45^0$C and in winter it do not fall below $5^0$C (normally). People of Bangladesh are not interested about the highest summer temperature rather they have interest in the winter minimum temperature. In this study, so, such a case is taken. The parameters of interest are obviously the temperature first and for the feelings relative humidity has a great role so far the study of temperature event relative humidity should be accounted.

## 1.2. Objectives and scope of the research work

To run any model the dependency of the output on the input is unquestionable. In sophisticated models when the data locations do not match with the location where it is to be used, interpolation is required. In the program of the model a sequence of interpolation is suggested for a type of data and finally a default is prescribed. It is generally expected that different interpolation scheme may provide different result. Thus when different interpolation scheme will be used, the input at the grid points will be different and finally, the output will be different. To verify this expectation this research is carried out. For the purpose three different high impact events are studied in which effect on the different parameters of interest (e.g. temperature, sea level pressure, wind speed, rainfall and relative humidity) are investigated.

# CHAPTER 2

## LITERATURE REVIEW

### 2.1.1 Numerical Weather Prediction (NWP) model

NWP model uses system of differential equations based on the laws of physics, fluid dynamic motion, and chemistry, and use a coordinate system which divides the planet into 3D grid. Winds, heat transfer, solar radiation, relative humidity, and surface hydrology are calculated within each grid cell, and the interactions with neighboring cells are used to calculate atmospheric properties in the future.

NWP models uses mathematical models of the atmosphere and oceans to predict the weather based on current weather conditions. Though first attempted in the 1920s, it was not until the advent of computer simulation in the 1950s that numerical weather predictions produced realistic results. A number of global and regional forecast models are run in different countries worldwide, using current weather observations relayed from radiosondes or weather satellites as inputs to the models.

Mathematical models based on some physical principals can be used to generate either short term weather forecasts or long-term climate predictions; the latter are widely applied for understanding and projecting climate change. The improvements made to regional models have allowed for significant improvements in tropical cyclone track and air quality forecasts; however, atmospheric models perform poorly at handling processes that occur in a relatively constricted area, such as wildfires.

Manipulating the vast datasets and performing the complex calculations necessary to modern numerical weather prediction require some of the most powerful supercomputers in the world. Even with increasing power of supercomputer, the forester skill of numerical weather models only extant to about six days. Factors affecting the accuracy of numerical predictions include the density and quality of observation used as input to the forecasts, along with deficiencies in the numerical models themselves Although post-processing techniques such as model output statistics (MOS) have been developed to improve the headline of errors in numerical predictions, a more fundamental problems lies in the chaotic nature of the partial differential equations used to simulate the atmosphere. It is impossible to solve these equations exactly, and small errors grow with times (doublings every five days). In addition, the partial differential equations using the model need to be supplemented with parameterization for solar radiation, moist process (cloud and precipitation), heat exchange, soil vegetation, surface water, and the effects of terrain. In effort to quantify the large amount of inherent uncertainty remaining in numeral predictions, ensemble forecasts have been used since the 1990s to help to gauge the confidence in the forecast and to obtain useful results farther into the future than otherwise possible. This approach analyzes multiple forecasts created with an individual forecast model or multiple models.

### 2.1.2 History of Numerical Weather prediction model

The history of numerical weather prediction began in the 1920s through the efforts of Lewis Fry Richardson, who used procedures originally developed by Vilhelm Bjerknes (Lynch Peter, 2008) to produce by hand a six- hour forecast for the state of the atmosphere over two points in central Europe, taking at least six weeks to do so (Lynch Peter,2006b, 2008). It was not until the advent of the computer and computer simulations that computation time was reduced to less than the forecast period itself. The ENIAC (Electronic Numerical Integrator and Computer)was used to create the first weather forecasts via computer in 1950 (Charny et al., 1950 and Cox, 2002).In 1954 Carl-Gustav Rossby's group at the Swedish meteorological and Hydrological Institute used the same model to produce the first operational forecast (i.e. routine predictions for practical use)(Harper et al. 2007). Operational numerical weather prediction in the United States began in 1955 under the Joint Numerical Weather Predication Unit (JNWPU), a joint project by the U.S. Air Force, Navy and Weather Bureau (Ame. Ins. Phy. 2008).In 1956, Norman Phillips developed a mathematical model which could realistically depict monthly and seasonal patterns in the troposphere, this became the first successful climate model (Philips, 1956; Cox, 2002). Following Phillips' work, several groups began working to create general circulation models (GCM) (Lynch Peter, 2006a). The first general model that combined both oceanic and atmospheric processes was developed in the late 1960s at the NOAA (National Oceanic and Atmospheric Administration) Geophysical Fluid Dynamics Laboratory (GFDL) (NOAA, 2008).

As computers has become more powerful, the size of the initial datasets has increased and newer atmospheric models have been developed to take advantage of the added available computing power. These newer models include more physical processes in the simplifications of the equations of motion in numerical simulations of the atmosphere (Harper et al. 2007). In 1966, West Germany and the United States began producing operational forecasts based on primitive-equation models, followed by the United Kingdom in 1972 and Australia in 1977 (Lynch Peter, 2008 and Leslie and Dietachmeyer, 1992). The development of limited area (regional) models facilitated advances in forecasting the tracks of tropical cyclones as well as air quality in the 1970s and 1980s (Shuman, 1989 and Steyn, 1991).By the early 1980s models began to include the interactions of soil and vegetation with the atmosphere, which led to more realistic forecasts (Xue and Fennessey, 1996).

The output of forecast models based on atmospheric dynamics is unable to resolve some details of the weather near the Earth's surface. As such, a statistical relationship between the output of a numerical weather model and the ensuing conditions at the ground was developed in the 1970s and 1980s, known as model output statistics (MOS) (Hugghes, 1976 and Best and Pryor, 1983). Starting in the 1990s, model ensemble forecasts have been used to help defining the forecast uncertainty and to extend the window in which numerical weather forecasting is viable farther into the future than otherwise possible (Toth and Kalnay, 1997, ECMWF, 2011 and Molteni et al. 1996).

Many research groups and agencies have developed their own global general circulation models as well as local/limited area models. Some of the better known numerical models are:

Global models

- GPS Global Forecaster System(previously AVN) – developed by NOAA
- NOGAPS - developed by the US Navy to compute with the GFS
- GEM - developed by the Meteorological Service of Canada (MSC)
- ECMWF-a model run by the European Center for Medium Range Forecast
- UKMO- developed by the UK Met Office.
- GME developed by the German Weather Service,
- FSUGSM- developed by Florida state University

Regional Models

- WRF-The Weather Research and Forecasting Model was developed cooperatively by NCEP and Meteorological Research community.
- WRF-NMM the WRF Non-hydrostatic Meso-scale Model is the primary short term weather model for US.
- ARW-Advance Research WRF developed primarily at the US National Center for Atmospheric Research(NCAR)

- ❖ AHW-Advance Hurricane WRF
  - ❖ MM5 the fifty Generation Penn State/NCAR Meso-scale Model
  - ❖ QLM-Quasi-Lagrangian Limited Model
  - ❖ NAM- North American Meso-scale Model
  - ❖ HIRLAM High Regulation Limited Area model

## 2.2 Description of WRF model

The Weather Research and Forecasting (WRF) Model is a latest generation meso-scale numerical weather forecasting community model. Its simulation capacity is very high and can simulate meteorological phenomena ranging from meters to thousands of kilometers. This section focuses on a few important feather of the Advanced Research WRF (ARW) model using NCAR Technical Note NCAR/TN -475.

Like other models WRF has three steps i) Preprocessing ii) model running and iii) post -processing. As our research is data manipulation section which is a part of prepossessing so it will be discussed in the latter section.

### 2.2.1 Introduction

The Weather Research and Forecasting (WRF) Model is a numerical weather prediction (NWP) system designed to serve both atmospheric research and operational forecasting needs. NWP refers to the simulation and prediction of the atmosphere with a computer model, and WRF is a set of software for this. WRF features two dynamical (computational) cores (or *solvers*), a data assimilation system, and a software architecture allowing for parallel computation and system extensibility. The model serves a wide range of meteorological applications across scales ranging from meters to thousands of kilometers.

The effort to develop WRF began in the latter part of the 1990s and was a collaborative partnership principally among the National Center for Atmospheric Research (NCAR), the National Oceanic and Atmospheric Administration(NOAA) (represented by the National Centers for Environmental Prediction (NCEP) and the (then) Forecast Systems Laboratory (FSL)), the Air Force Weather Agency (AFWA), the Naval Research Laboratory (NRL), the University of Oklahoma (OU), and the Federal Aviation Administration (FAA). The bulk of the work on the model has been performed or supported by NCAR, NOAA, and AFWA.

WRF allows researchers to produce simulations reflecting either real data (observations, analyses) or idealized atmospheric conditions. WRF provides operational forecasting a flexible and robust platform, while offering advances in physics, numeric, and data assimilation contributed by the many research community developers. WRF is currently in operational use at NCEP and other forecasting centers internationally including Bangladesh Metrological Department (BMD). WRF has grown to have a large worldwide community of users (over 23,000 registered users in over 150 countries), and workshops and tutorials are held each year at NCAR. WRF is used extensively for research and real-time forecasting throughout the world.

WRF offers two dynamical solvers for its computation of the atmospheric governing equations, and the variants of the model are known as WRF-ARW (Advanced Research WRF) and WRF-NMM (Nonhydrostatic Meso-scale Model). The Advanced Research WRF (ARW) is supported to the community by the NCAR Meso-scale and Microscale Meteorology Division. The WRF-NMM solver variant was based on the Eta Model, and later Nonhydrostatic Meso-scale Model, developed at NCEP. The WRF-NMM (NMM) is supported to the community by the Developmental Testbed Center (DTC).

The WRF serves as the basis for the Rapid Refresh model, an operational forecast model run regularly at NCEP.

A version of WRF-NMM tailored for hurricane forecasting, HWRF (Hurricane Weather Research and Forecasting), became operational in 2007.

In 2009, a polar optimized WRF was released through the Byrd Polar Research Center at the Ohio State University.

The principal component of the WRF Model are depicted in Figure 2.2.1. The Meso-scale and Microscale Meteorology Division of NCAR is currently maintaining and supporting a subset of the overall WRF code (Version 3) that includes:

- ❖ WRF Software Framework (WSF)
- ❖ Advanced Research WRF (ARW) dynamic solver, including one-way, two-way nesting and moving nest.
- ❖ The WRF Preprocessing System (WPS)
- ❖ WRF Data Assimilation (WRF-DA) system which currently supports 3DVAR, 4DVAR, and hybrid data assimilation capabilities
- ❖ Numerous physics packages contributed by WRF partners and the research community.
- ❖ Several graphics programs and conversion programs for other graphics tools.

There are two dynamics solvers of WSF; The Advance Research WRF (ARW) solver ("em" solver) developed primarily by NCAR and the NMM solver developed primarily by NCEP. Community support for the former is provided by the NMM Division of NCAR and that for the letter is provided by the Development trusted Center.

### 2.2.2 Advanced Research WRF (ARW)

The ARW is the ARW dynamics solver together with other components of the WRF system compatible with that solver and used in producing a simulation. Thus, is it a subset of the WRF modeling system that, in addition to the ARW solver, encompasses physics schemes, numeric /dynamics options, initialization routines, and a data assimilation package (WRF-Var). The ARW solver shares the WSF with the NMM solver and all other WRF components within the framework. Physics packages are largely shared by both the ARW and NMM solvers, although specific compatibility varies with the schemes considered. The association of a component of the WRF system with the ARW subset does not preclude it from being a component of WRF configurations involving the NMM solver. The following section highlights the major features of the ARW, Version 3, and reflects elements of WRF Version 3, which was first released in April 2008.

This technical note focuses on the scientific and algorithmic approaches in the ARW, including the solver, physics options, initialization capabilities, boundary conditions, and grid-nesting techniques.

## 2.2.3 Major Features of the ARW System, Version 3

**ARW Solver**

. **Equations**: Fully compressible, Euler nonhydrostatic with a rum- time hydrostatic option available. Conservative for scalar variables.

. **Prognostic variables**: Velocity components u and v in Cartesian coordinate, vertical velocity w, perturbation potential temperature, perturbation geopotential, and perturbation surface pressure of dry air. Optionally, turbulent kinetic energy and any number of scalars such as water vapor mixing ratio, rain\snow mixing ratio, and chemical species and tracers.

. **Vertical coordinate**: Terrain- following, dry hydrostatic-pressure, with vertical grid stretching permitted. Top of the model is a constant pressure surface.

. **Horizontal Grid**: Arakawa C-Grid staggering.

. **Integration**: Time-split integration using a $2^{nd}$- or $3^{rd}$-order Runge-Kutta scheme with smaller time step for acoustic and gravity-wave modes. Variable time step capability.

- **Spatial Discretization**: 2nd - to 6th – order advection options in horizontal and vertical.
- **Turbulent Mixing and Model Filters:** Sub- grid scale turbulence formulation in both coordinate and physical space. Divergence damping, external- mode filtering, vertically implicit acoustic step off-centering. Explicit filter option.
- **Initial Conditions**: Three dimensional for real-data, and one-, two- and three-dimensional for idealized data. Digital filtering initialization (DFI) capability available (real-data cases).
- **Lateral Boundary Conditions**: Periodic, open, symmetric, and specified options available.
- **Top Boundary Conditions**: Gravity wave absorbing (Di" union, Rayleigh damping or implicit Rayleigh damping for vertical velocity). Constant pressure level at top boundary along a material surface. Rigid lid option.
- **Bottom Boundary Conditions**: Physical or free-slip.
- **Earth's Rotation**: Full Coriolis terms included.
- **Mapping to Sphere: Four map projections are supported for real-datasimulation**: Polar stereographic, Lambert conformal, Mercator, and latitude-longitude (allowing rotated pole).Curvature terms included.

- **Nesting**: One-way interactive, two-way interactive, and moving nests. Multiple levels and integer ratios.

- **Nudging**: Grid (analysis) and observation nudging capabilities available.
- **Global Grid**: Global simulation capability using polar Fourier filter and periodic east-west conditions.
- **Model physics:**
  - **Microphysics:**
  - **Cumulus parameterizations:**
  - **Surface physics:**
  - **Planetary boundary layer physics:**
  - **Atmospheric radiation physics:**
- **WRF-Var system**

## WRF Software Framework

- Highly modular, single-source code for maintainability.
- Two-level domain decomposition for parallel and shared-memory generality.

- Portable across a range of available computing platforms.
- Support for multiple dynamics solvers and physics modules.
- Separation of scientific codes from parallelization and other architecture-specific issues.
- Input/output Application Program Interface (API) enabling various external packages to be installed with WRF, thus allowing WRF to easily support various data formats.
- Execution on a range of computing platforms (distributed and shared memory, vector and scalar types). Support for accelerators (e g., GPUs).
- Use of Earth System Modeling Framework (ESMF) and interoperable as an ESMF component.
- Model coupling API enabling WRF to be coupled with other models such as ocean, and land models using ESMF, MCT, or MCEL.

### 2.2.4 Model Physics

This subsection outlines the physics options available in the ARW. The WRF physics options fall into several categories, each containing several choices. The physics categories are

(1) Microphysics

(2) Cumulus parameterization

(3) Planetary boundary layer (PBL)

(4) land-surface model and

(5) Radiation.

The physics section is insulated from the rest of the dynamics solver by the use of physics drivers. These are between solver-dependent routines: a pre-physics preparation and post physics modifications of the tendencies. The physics preparation involves filling arrays with physics-required variables that include the temperature, pressure, heights, layer thicknesses, and other state variables in MKS units at half-level grid points and on full levels. The velocities are also de-staggered so that the physics part is independent of the dynamical solver's velocity staggering. Physics packages compute tendencies for the velocity components (un-staggered), potential temperature, and moisture fields. The solver-dependent post-physics step will restage these tendencies as necessary, couple tendencies with coordinate metrics, and convert to variables or units appropriate to the dynamics solver.

In the first Runge-Kutta step, prior to the acoustic steps, tendencies are computed for radiation, surface, PBL, and cumulus physics. These tendencies are then held fixed through the Runge-Kutta steps. Microphysics is computed after the last Runge-Kutta step in order to maintain proper saturation conditions at the end of the time-step. The initialization of the physics is called prior to the first model step. This initialization may include reading in data files for physics tables or calculating look-up tables of functions. Each physics module includes an initialization routine for this purpose. Often physics packages will have many of their own constants that should also be included in their own module, while common physical constants are passed in from the physics drivers.

### 2.2.4.1 Microphysics

Microphysics includes explicitly resolved water vapor, cloud, and precipitation processes. The model is general enough to accommodate any number of mass mixing-ratio variables, and other Quantities such as number concentrations. Four-dimensional arrays with three spatial indices and one species index are used to carry such scalars. Memory, i.e., the size of the fourth dimension in these arrays, is allocated depending on the needs of the scheme chosen, and advection of the species also applies to all those required by the microphysics option. In the current version of the ARW, microphysics is carried out at the end of the time-step as an adjustment process, and so does not provide tendencies. The rationale for this is that condensation adjustment should be at the end of the time-step to guarantee that the final saturation balance is accurate for the updated temperature and moisture. However, it is also important to have the latent heating forcing for potential temperature during the dynamical sub-steps, and this is done by saving the microphysical heating as an approximation for the next time-step

Currently, the sedimentation process is accounted for inside the individual microphysics modules, and, to prevent instability in the calculation of the vertical flux of precipitation, a smaller time step is allowed. The saturation adjustment is also included inside the microphysics. In the future, however, it might be separated into an individual subroutine to enable the remaining microphysics to be called less frequently than the model's advection step for efficiency.

Different scheme of microphysics options available in ARW are discuss as follows

a) Kessler scheme: A warn-rain (i,e no ice) scheme use commonly in idealize cloud modeling studies

b) Purdue Lin:

c) WSM3:

d) WSM5:

e) WSM6:

f) Eta GCP:

g) Thompson:

h) Goddard:

i) Morrison 2-Moment:

#### 2.2.4.2 Cumulus parameterization

These schemes are responsible for the sub-grid-scale effects of convective and/or shallow clouds. The schemes are intended to represent vertical fluxes due to unresolved updrafts and downdrafts and compensating motion outside the clouds. They operate only on individual columns where the scheme is triggered and provide vertical heating and moistening profiles. Some schemes additionally provide cloud and precipitation field tendencies in the column, and future schemes may provide momentum tendencies due to convective transport of momentum. The schemes all provide the convective component of surface rainfall. Cumulus parameterizations are theoretically only valid for coarser grid sizes, (e.g., greater than 10 km), where they are necessary to properly release latent heat on a realistic time scale in the convective columns. While the assumptions about the convective eddies being entirely sub-grid-scale break down for finer grid sizes, sometimes these schemes have been found to be helpful in triggering convection in 5–10 km grid applications. Generally, they should not be used when the model can resolve the convective eddies itself (e.g., ≤ 5 km grid).

The available Cumulus parameterization options in ARW are as follows

a) Kain-Fritsch:

b) Betts-Miller-Janjic:

c) Grell-Devenyi:

d) Grell-3:

e) Old Kain-Fritsch:

#### 2.2.4.3 Surface Layer

The surface layer schemes calculate friction velocities and exchange coefficients that enable the calculation of surface heat and moisture fluxes by the land-surface models and surface stress in the planetary boundary layer scheme. Over water surfaces, the surface fluxes and surface diagnostic fields are computed in the surface layer scheme itself. The schemes provide no tendencies, only the stability-dependent information about the surface layer for the land-surface and PBL schemes. Currently, each surface layer option is tied to particular boundary-layer options, but in the future more interchangeability and options may become available. Note that some boundary layer schemes (YSU and MRF) require the thickness of the surface layer in the model to be representative of the actual surface layer (e.g. 50-100 meters).

**Similarity Theory:**

a) MM5 Similarity

b) Eta Similarity

c) Pleim-Xiu (PX) Similarity

#### 2.2.4.4 Land- Surface Model (LSM)

The land-surface models (LSMs) use atmospheric information from the surface layer scheme, radiative forcing from the radiation scheme, and precipitation forcing from the microphysics and convective schemes, together with internal information on the land's state variables and land-surface properties, to provide heat and moisture fluxes over land points and sea-ice points. These fluxes provide a lower boundary condition for the vertical transport done in the PBL schemes (or the vertical diffusion scheme in the case where a PBL scheme is not run, such as in large-eddy mode). [Note that large-eddy mode with interactive surface fluxes is not yet available in the ARW, but is planned for the near future.] The land-surface models have various degrees of sophistication in dealing with thermal and moisture fluxes in multiple layers of the soil and also may handle vegetation, root, and canopy effects and surface snow-cover prediction. The land surface model provides no tendencies, but does update the land's state variables which include the ground (skin) temperature, soil temperature profile, soil moisture profile, snow cover, and possibly canopy properties. There is no horizontal interaction between neighboring points in the LSM, so it can be regarded as a one-dimensional column model for each WRF land grid-point, and many LSMs can be run in a stand-alone mode.

The different land surface scheme options available in ARW are as followings:

a. 5-layer thermal diffusion: Soil temperature only 5 scheme using five layers.

b. Noah LSM: Unified NCEP/NCAR/AFWA scheme with soil temperature and moisture in four layers fractional snow cover frozen soil physics

c. Urban canopy model: 3 category UCM option. This can be run as an option with the Noah LSM

d. Rapid Update Cycle (RUC) LSM: RUC operational sceame with soil temperature and moisture in 6 layers, multi-layer snow cover frozen soil physics

e. Pleim-Xiu LSM (PX): Two layers scheme with vegetation and sub-grid tiling

### 2.2.4.5 Planetary Boundary Layer

The planetary boundary layer (PBL) is responsible for vertical sub-grid-scale fluxes due to eddy transports in the whole atmospheric column, not just the boundary layer. Thus, when a PBL scheme is activated, explicit vertical diffusion is de-activated with the assumption that the PBL scheme will handle this process. The most appropriate horizontal diffusion choices are those based on horizontal deformation or constant Kh values where horizontal and vertical mixing are treated independently. The surface fluxes are provided by the surface layer and land-surface schemes. The PBL schemes determine the flux profiles within the well-mixed boundary layer and the stable layer, and thus provide atmospheric tendencies of temperature, moisture (including clouds), and horizontal momentum in the entire atmospheric column. Most PBL schemes consider dry mixing, but can also include saturation effects in the vertical stability that determines the mixing. The schemes are one-dimensional, and assume that there is a clear scale separation between sub-grid eddies and resolved eddies. This assumption will become less clear at grid sizes below a few hundred meters, where boundary layer eddies may start to be resolved, and in these situations the scheme should be replaced by a fully three-dimensional local sub-grid turbulence scheme such as the TKE diffusion scheme.

PBL scheme options available in ARW model are as followings:

a. Medium Range Forecast Model (MRF) PBL:
b. Yonsei University (YSU) PBL:
c. Mellor-Yamada-Janjic (MYJ) PBL:
d. Asymmetrical Convective Model version 2 (ACM2) PBL:

### 2.2.4.6 Atmospheric Radiation

The radiation schemes provide atmospheric heating due to radiative flux divergence and surface downward longwave and shortwave radiation for the ground heat budget. Longwave radiation includes infrared or thermal radiation absorbed and emitted by gases and surfaces. Upward longwave radiative flux from the ground is determined by the surface emissivity that in turn depends upon land-use type, as well as the ground (skin) temperature. Shortwave radiation includes visible and surrounding wavelengths that make up the solar spectrum. Hence, the only source is the Sun, but processes include absorption, reflection, and scattering in the atmosphere and at surfaces. For shortwave radiation, the upward flux is the reflection due to surface albedo. Within the atmosphere the radiation responds to model-predicted cloud and water vapor distributions, as well as specified carbon dioxide, ozone, and (optionally) trace gas concentrations. All the radiation schemes in WRF currently are column (one-dimensional) schemes, so each column is treated independently, and the fluxes correspond to those in infinite horizontally uniform planes, which is a good approximation if the vertical thickness of the model layers is much less than the horizontal grid length. This assumption would become less accurate at high horizontal resolution.

At present the following long wave and short wave radiation options are available in ARW model:

**Longwave Radiation**

a) Rapid Radiative Transfer Model (RRTM) Longwave:

b) Eta Geophysical Fluid Dynamics Laboratory (GFDL) Longwave:

c) CAM 3 Longwave:

**Shortwave Radiation**

a) MM5 (Dudhia) Shortwave:

b) Goddard Shortwave:

c) Eta Geophysical Fluid Dynamics Laboratory (GFDL) Shortwave:

d) CAM3 Longwave:

### 2.2.5 Post-Processing Utilities

There are a number of visualization tools available to display WRF-ARW model data. Model data in netCDF (Newark Common Data Format) format can essentially be displayed using any tool capable of displaying this data format.

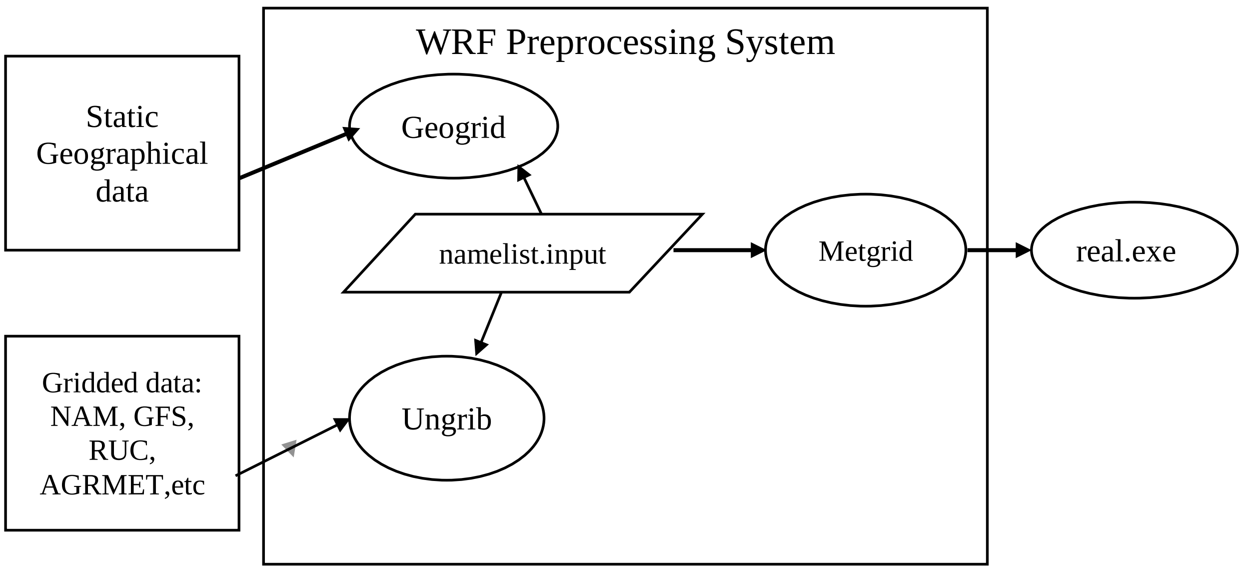
Currently the following post-processing utilities are supported: NCL, RIP4, ARWpost (converter to GrADS), UPP, and VAPOR.

NCL, RIP4, ARWpost and VAPOR can currently only read data in netCDF format, while UPP can read data in netCDF and binary format.

## 2.3 WRF Preprocessing System

The WRF Preprocessing System (WPS) is a set of three programs whose collective role is to prepare input to the real program for real-data simulations. Each of the programs performs one stage of the preparation: geogrid defines model domains and interpolates static geographical data to the grids; ungrib extracts meteorological fields from GRIBformatted files; and metgrid horizontally interpolates the meteorological fields extracted by ungrib to the model grids defined by geogrid. The work of vertically interpolating meteorological fields to WRF eta levels is performed within the real program (while the model is run).

The data flow between the programs of the WPS is shown in the following figure. Each of the WPS programs reads parameters from a common namelist file, as shown in the figure. This namelist file has separate namelist records for each of the programs and a shared namelist record, which defines parameters that are used by more than one WPS program. Not shown in the figure are additional table files that are used by individual programs. These tables provide additional control over the programs' operations, though they generally do not need to be changed by the user.




**Schematic Diagram of WPS**

**Function of Each WPS Program**

The WPS consists of three independent programs: geogrid, ungrib, and metgrid. A brief description of each of the three main programs is given below, with further details presented in subsequent sections.

**Program geogrid**

The purpose of geogrid is to define the simulation domains, and interpolate various terrestrial data sets to the model grids. The simulation domains are defined using information specified by the user in the “geogrid” namelist record of the WPS namelist file, namelist.wps. In addition to computing the latitude, longitude, and map scale factors at every grid point, geogrid will interpolate soil categories, land use category, terrain height, annual mean deep soil temperature, monthly vegetation fraction, monthly albedo, maximum snow albedo, and slope category to the model grids by default. Global data sets for each of these fields are provided through the WRF download page, and, because these data are time-invariant, they only need to be downloaded once. Several of the data sets are available in only one resolution, but others are made available in resolutions of 30", 2', 5', and 10'; Besides interpolating the default terrestrial fields, the geogrid program is general enough to be able to interpolate most continuous and categorical fields to the simulation domains. New or additional data sets may be interpolated to the simulation domain through the use of the table file, GEOGRID.TBL. The GEOGRID.TBL file defines each of the fields that will be produced by geogrid; it describes the interpolation methods to be used for a field, as well as the location on the file system where the data set for that field is located.

**Program ungrib**

The ungrib program reads GRIB files, "degribs" the data, and writes the data in a simple format called the intermediate format. The GRIB files contain time-varying meteorological fields and are typically from another regional or global model, such as NCEP's NAM or GFS models. The ungrib program can read GRIB Edition 1 and, if compiled with a "GRIB2" option, GRIB Edition 2 files.

GRIB files typically contain more fields than are needed to initialize WRF. Both versions of the GRIB format use various codes to identify the variables and levels in the GRIB file. Ungrib uses tables of these codes – called Vtables, for "variable tables" – to define which fields to extract from the GRIB file and write to the intermediate format..Vtables for common GRIB model output files are provided with the ungrib software.

**Program metgrid**

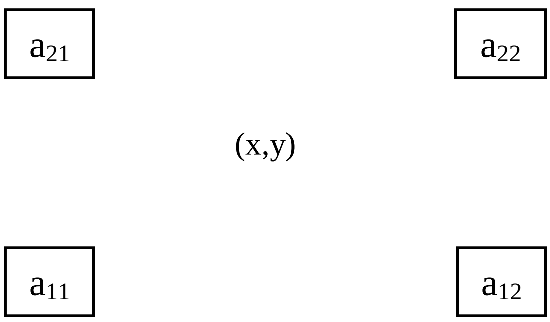
The metgrid program horizontally interpolates the intermediate-format meteorological data that are extracted by the ungrib program onto the simulation domains defined by the geogrid program. The interpolated metgrid output can then be ingested by the WRF real program. The range of dates that will be interpolated by metgrid are defined in the “share” namelist record of the WPS namelist file, and date ranges must be specified individually in the namelist for each simulation domain. Since the work of the metgrid program, like that of the ungrib program, is time-dependent, metgrid is run every time a new simulation is initialized.

Control over how each meteorological field is interpolated is provided by the METGRID.TBL file. The METGRID.TBL file provides one section for each field, and within a section, it is possible to specify options such as the interpolation methods to be used for the field, the field that acts as the mask for masked interpolations, and the grid staggering (e.g., U, V in ARW; H, V in NMM) to which a field is interpolated.

## 2.4 Available Interpolation Options in Geogrid and Metgrid

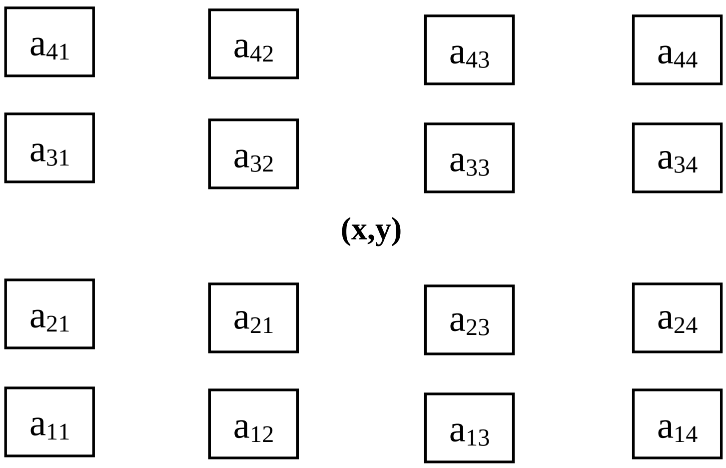
Through the GEOGRID.TBL and METGRID.TBL files, the user can control the method by which source data – either static fields in the case of geogrid or meteorological fields in the case of metgrid – are interpolated. In fact, a list of interpolation methods may be given, in which case, if it is not possible to employ the i-th method in the list, the (i+1)-st method will be employed, until either some method can be used or there are no methods left to try in the list. For example, to use a four-point bi-linear interpolation scheme for a field, we could specify interp_option=four_pt. However, if the field had areas of missing values, which could prevent the four_pt option from being used, we could request that a simple four-point average be tried if the four_pt method couldn't be used by specifying interp_option=four_pt+average_4pt instead. Below, each of the available interpolation options in the WPS are described conceptually;

### 1. 4-Point: Four-point bi-linear interpolation




The four-point bi-linear interpolation method requires four valid source points $a_{ij}$, $1\leq i,j \leq$, 2surrounding the point (x, y), to which geogrid or metgrid must interpolate, as illustrated in the figure above. Intuitively, the method works by linearly interpolating to the x-coordinate of the point (x, y) between $a_{11}$and$a_{12}$, and between $a_{21}$and $a_{22}$, and then linearly interpolating to the y-coordinate using these two interpolated values.

**2. 16-Point: Sixteen-point overlapping parabolic interpolation**




The sixteen_pt overlapping parabolic interpolation method requires sixteen valid source points surrounding the point (x,y), as illustrated in the figure above. The method works by fitting one parabola to the points$a_{i1}$,$a_{i2}$, and $a_{i3}$, and another parabola to the points $a_{i2}$, $a_{i3}$, and $a_{i4}$, for row i, $1 \leq i \leq 4$ ; then, an intermediate interpolated value pi within row i at the x-coordinate of the point is computed by taking an average of the values of the two parabolas evaluated at x, with the average being weighted linearly by the distance of x from $a_{i2}$ and $a_{i3}$. Finally, the interpolated value at (x, y) is found by performing the same operations as for a row of points, but for the column of interpolated values pi to the y-coordinate of (x, y).

**3. average_4pt: Simple four-point average interpolation**

The four-point average interpolation method requires at least one valid source data point from the four source points surrounding the point (x,y). The interpolated value is simply the average value of all valid values among these four points.

**4. wt_average_4pt : Weighted four-point average interpolation**

The weighted four-point average interpolation method can handle missing or masked source data points, and the interpolated value is given as the weighted average of all valid values, with the weight $w_{ij}$ for the source point aij, $1 \leq i, \ j \leq, 2$, given by

$$w_{ij} = \max\left\{0, 1 - \sqrt{(x - x_i)^2 + (y - y_i)^2}\right\}.$$

Here, $x_i$ is the x-coordinate of $a_{ij}$ and $y_j$ is the y-coordinate of $a_{ij}$.

**5. average_16pt: Simple sixteen-point average interpolation**

The sixteen-point average interpolation method works in an identical way to the four point average, but considers the sixteen points surrounding the point (x,y).

**6. wt_average_16pt: Weighted sixteen-point average interpolation**

The weighted sixteen-point average interpolation method works like the weighted four point average, but considers the sixteen points surrounding (x,y); the weights in this method are given by

$$w_{ij} = \max\left\{0, 2 - \sqrt{(x - x_i)^2 + (y - y_i)^2}\right\}$$

Where $x_i$ and $y_j$ are as defined for the weighted four-point method, and 1≤i, j≤.4

**7. nearest_neighbor: Nearest neighbor interpolation**

The nearest neighbor interpolation method simply sets the interpolated value at (x,y) to the value of the nearest source data point, regardless of whether this nearest source point is valid, missing, or masked.

**8. search: Breadth-first search interpolation**

The breadth-first search option works by treating the source data array as a 2-d grid graph, where each source data point, whether valid or not, is represented by a vertex. Then, the value assigned to the point (x,y) is found by beginning a breadth-first search at the vertex corresponding to the nearest neighbor of (x,y), and stopping once a vertex representing a valid (i.e., not masked or missing) source data point is found. In effect, this method can be thought of as "nearest valid neighbor".

**9. average_gcell: Model grid-cell average**

The grid-cell average interpolator may be used when the resolution of the source data is higher than the resolution of the model grid. For a model grid cell Γ, the method takes a simple average of the values of all source data points that are nearer to the center of Γ than to the center of any other grid cell.

# CHAPTER 3

## METHODOLOGY

For this study purpose WRF-ARW is used. This model includes a preprocessing system in which data are assigned to the grid points. If the input file data location don’t match with the grid location interpolating schemes take their role to calculate the value of the par the desired location. For the purpose different interpolation scheme are incorporated in the model, in this purpose a sequence is suggested for calculating a particular per and a default is also suggested.

The target of this research is to check the effect of interpolation technique on the output. For this purpose, three different types high impact weather phenomenon have been chosen for the study; one stormy weather, are temperature related event and one monsoon rain event. The study is coined through visualizing the impact of different interpolation scheme on different parameter of interest in different events. For rain and stormy weather rainfall, sea level pressure, temperature and wind speed are taken. For the temperature case, temperature, sea level pressuresand relative humidity are studied. Out of different interpolation schemes, the default (Which was declared when the model was collected from NCAR site) is kept to run the model. Then 4-point, 16-point and nearest neighborhood interpolation has been considered to interpolates the data and the model is run. The result of this three techniques along with the default are presented and analyzed.

# CHAPTER 4

## Results and Discussions

In this research three different types of meteorological phenomenon has been selected; one rain related, one cyclone related and one temperature. It is generally supposed that to study any rain event one should take a look cumulus precipitation along with the sea level pressure, wind speed and temperature. For anycyclonic event study the same parameter to be account ted. For any temperature event relative humidity will need to be taken in alone with the temperature itself.

In this study we have tried to compare the effect of different interpolation scheme. For the purpose other than 'default' (whichwas suggested in the down loaded model) we have chosen 4-point, 16-point and nearest neighborhood method for comparison (a brief description of the methods has been presented earlier), comparison among the methods are done with the parameters of interest. The phenomenon are presented in the following section. It may be noted here that at the initial time no precipitation/rainfall can be made.

## 4.1 Effect on Rainfall prediction (01 July -2008)

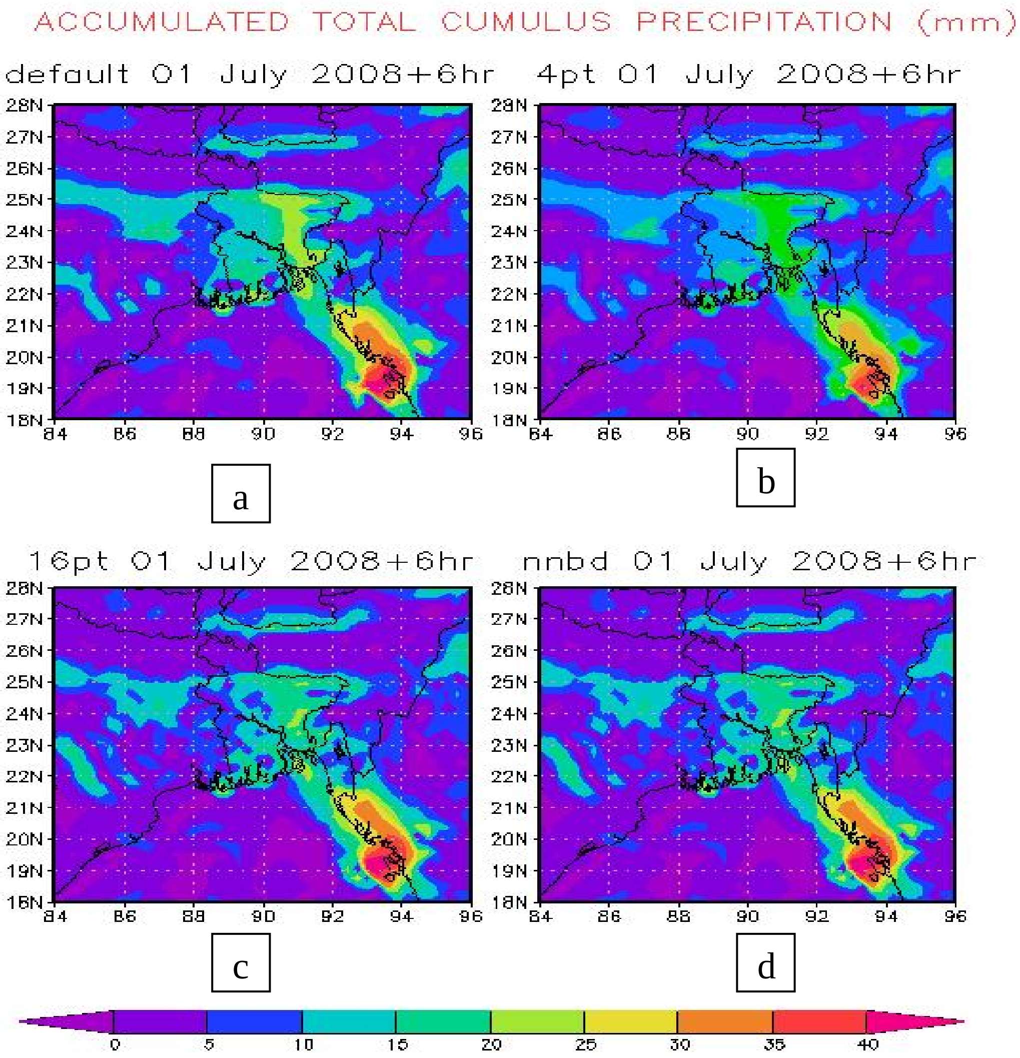



Figure 4.1.1Accumulated total cumulus precipitation of 01 July 2008 after 6 hours

Figure 4.1.1 indicates that the upper two images are same but the lower two images are different from upper. Because upper two images are used four point interpolation technique. We used sixteen point and nearest neighborhood interpolation technique and got some changes. Look at carefully the adjacent area of $23^0$ N, $25^0$ N, $85^0$ Eand have some changes. In the central part of our domain is absolutely different of each interpolation.

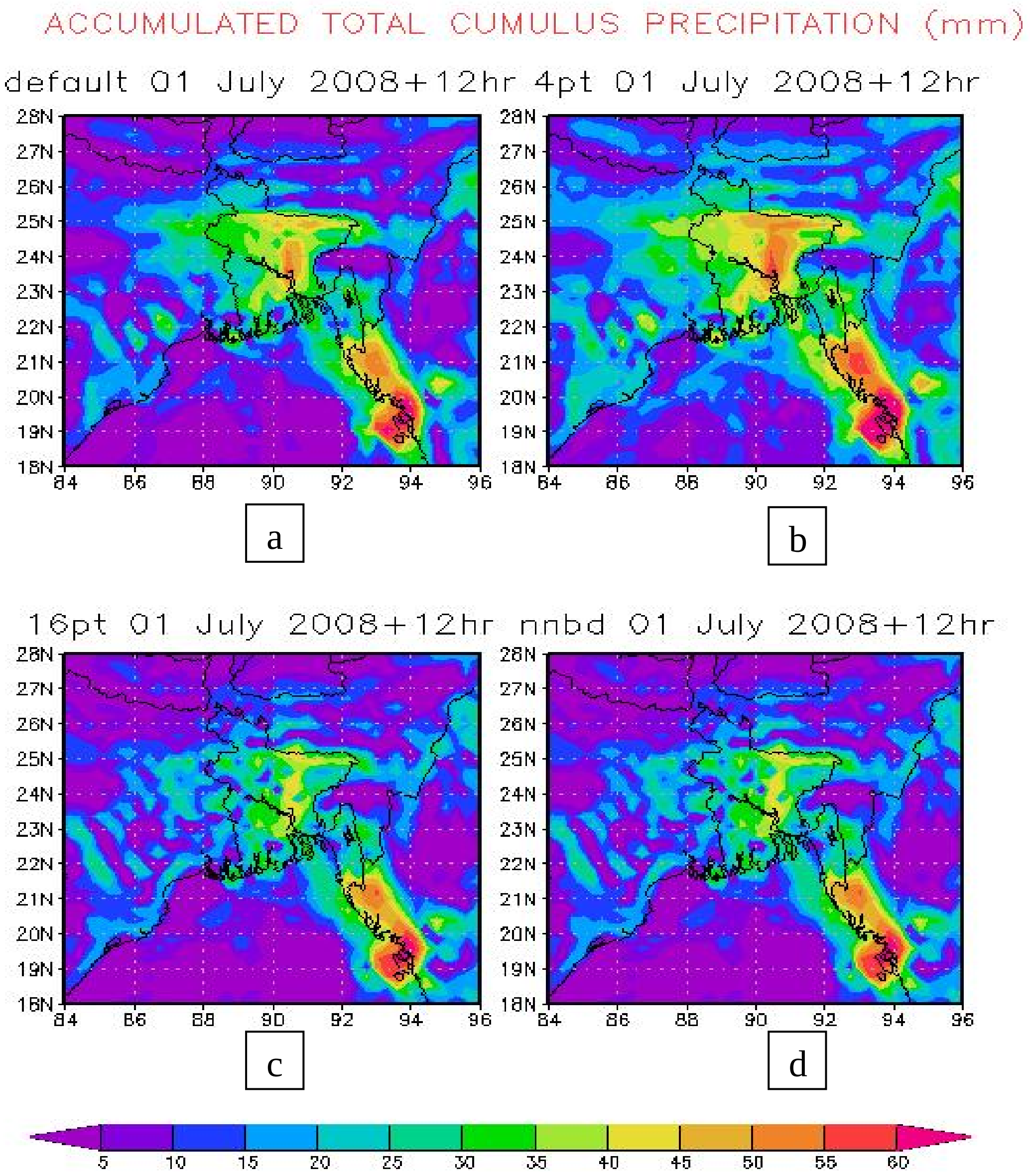



Figure 4.1.2Accumulated total cumulus precipitation of 01 July 2008 after 12 hours

Figure 4.1.2 also indicates that the upper two images are same but the lower two images are different from upper. Because default and four point interpolation technique are same. We used sixteen point and nearest neighborhood interpolation technique and got some changes. Look at carefully the adjacent area of $23^0$ N, $25^0$ N, $85^0$ E and have some changes. In the central part of our domain is absolutely different of each interpolation.

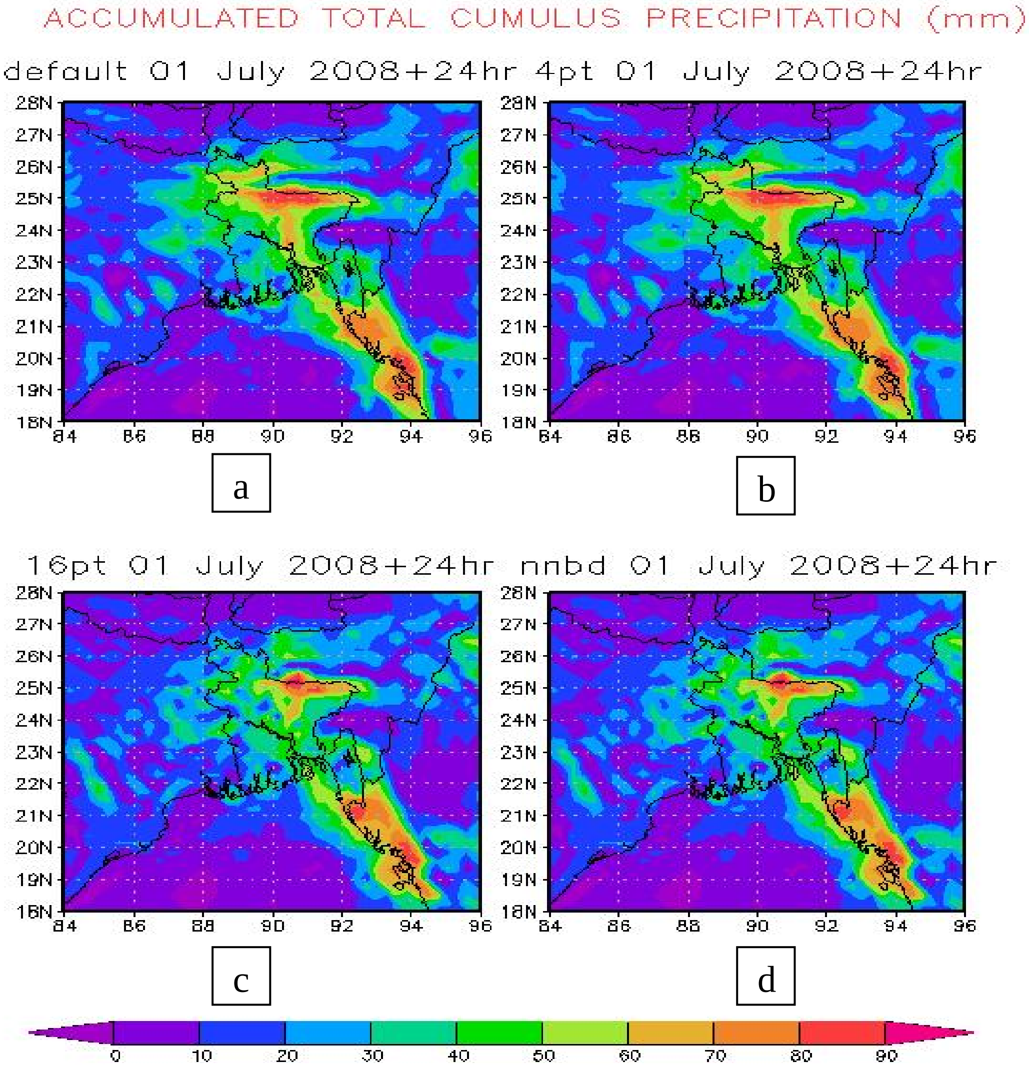



Figure 4.1.3Accumulated total cumulus precipitation of 01 July 2008 after 24 hours

Figure 4.1.3 indicates that after 24 hours the scenario having changed from last 24 hours.The upper two images are same but the lower two images are different from upper. Because Becausedefault and four point interpolation technique are same. We used sixteen point and nearest neighborhood interpolation technique and got some changes. Look at carefully the adjacent area of $22^0$ N, $25^0$ N, and $90^0$ E and have some changes. In the central part of our domain is absolutely different of each interpolation.

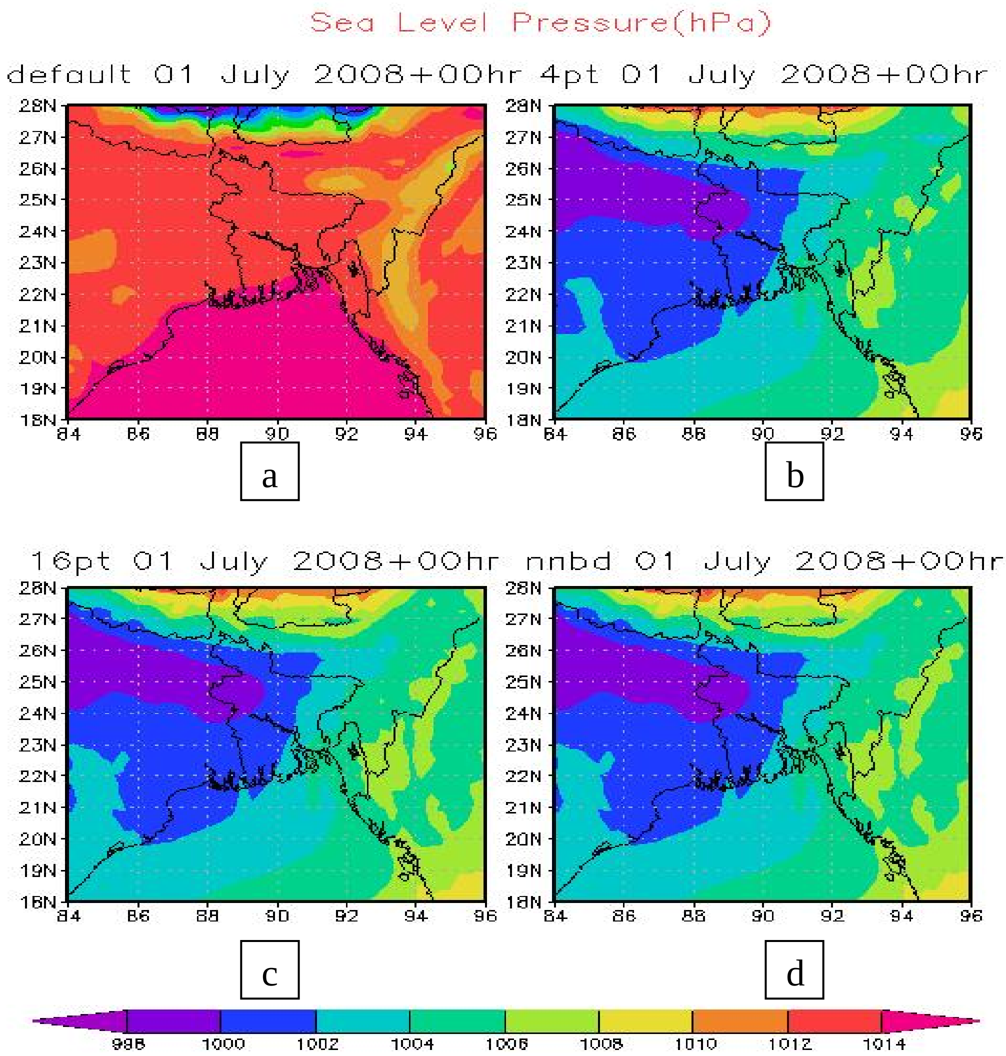



Figure 4.1.4Sea Level Pressure (hPa) of 01 July 2008 at 00 hour

Figure 4.1.4 represents sea level pressure (SLP) of that domain. In the area $23^0$N, $24^0$N and $85^0$E SLP is 1010 hPa but for the same area the SLP is not the same with respect to other interpolation technique. In the 4pt interpolationSLP is 1000 hPa in $21^0$N,$22^0$Nand $85^0$E.In the sixteen point and nearest neighborhood interpolation technique this area is $21^0$ N, $22^0$ N and $84.1^0$E. In the default interpolation technique SLP of the upper middle portion and the others interpolation technique the upper middle portion are not same. Same as the lower right corner.

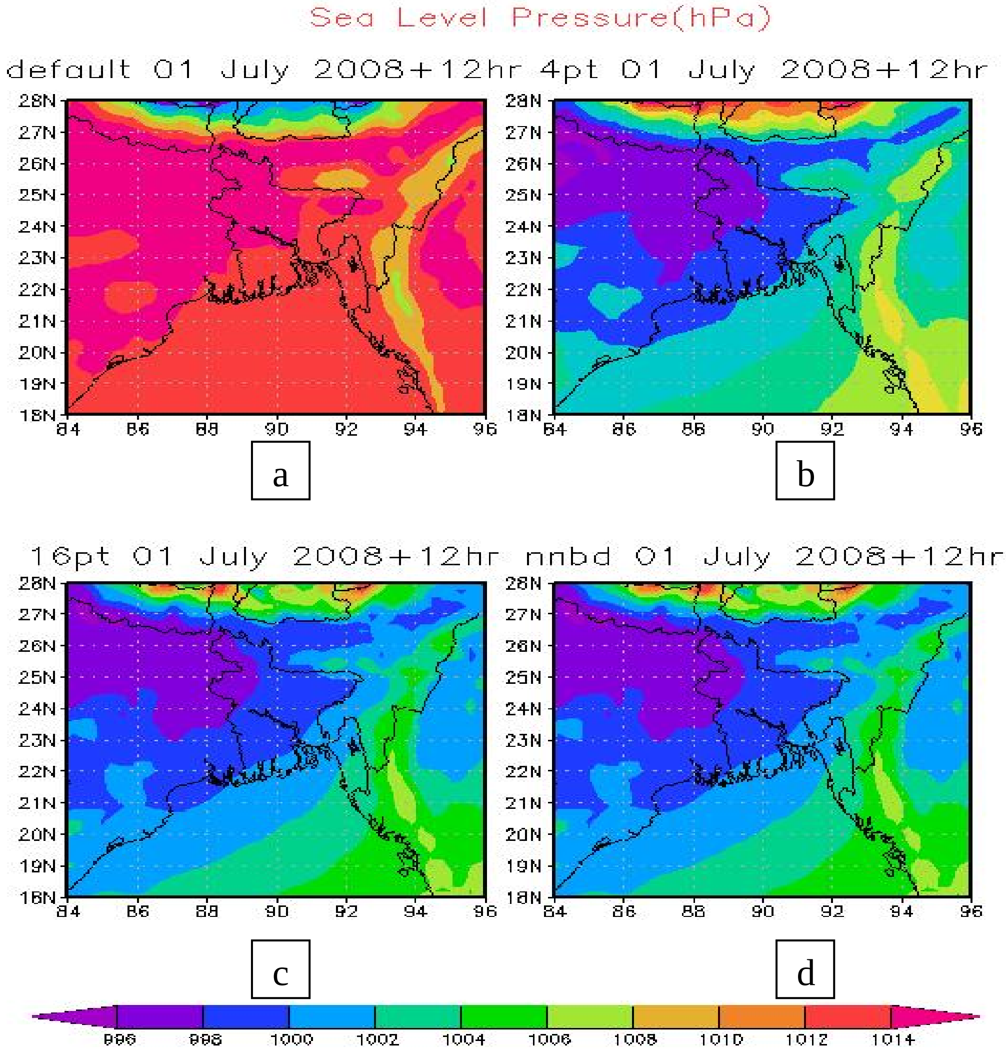



Figure 4.1.5Sea Level Pressure (slp) of 01 July 2008 after 12 hours

Figure 4.1.5represents sea level pressure (SLP) after 12 hours of that domain. In the area $23^0$N,and $90^0$E SLP is 1012hPa but the same area the SLP is not that with respect to other interpolation technique. In the 4pt interpolation SLP is 996hPa in $21^0$ N, $22^0$ N, $23^0$ Nand $84^0$E, $85^0$E, $86^0$E, In the sixteen point and nearest neighborhood interpolation technique this area is $21^0$ N, $22^0$ N and $84.1^0$E. In the default interpolation technique SLP of the left middle portion and the others interpolation technique the left middle portion are not same. Same as the lower right corner.

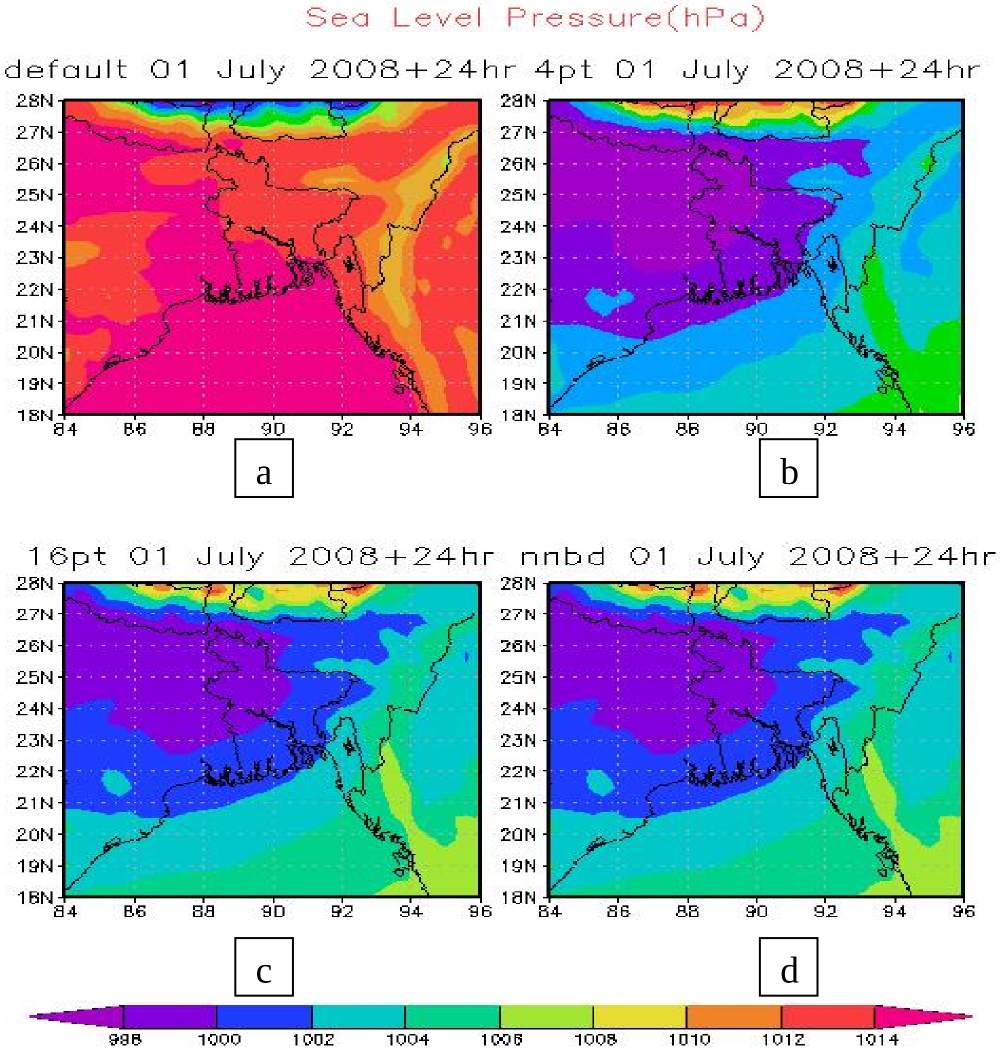



Figure 4.1.6Sea Level Pressure (slp) of 01 July 2008 after 24 hours

Figure 4.1.6represents sea level pressure (SLP) after 24 hours of that domain. In the area $23^0$N, and $90^0$E SLP is 1012 hPa but the same area the SLP is not that with respect to other interpolation technique. In the 4pt interpolation SLP is 996 hPa in $21^0$ N, $22^0$ N, $23^0$ N and $84^0$E, $85^0$E, $86^0$E, In the sixteen point and nearest neighborhood interpolation technique this area is $21^0$ N, $22^0$ N and $84.1^0$E. In the default interpolation technique SLP of the upper left portion and the others interpolation technique the upper left portion are not same. The scenario of the lower right corners are fully different of each interpolation techniques.

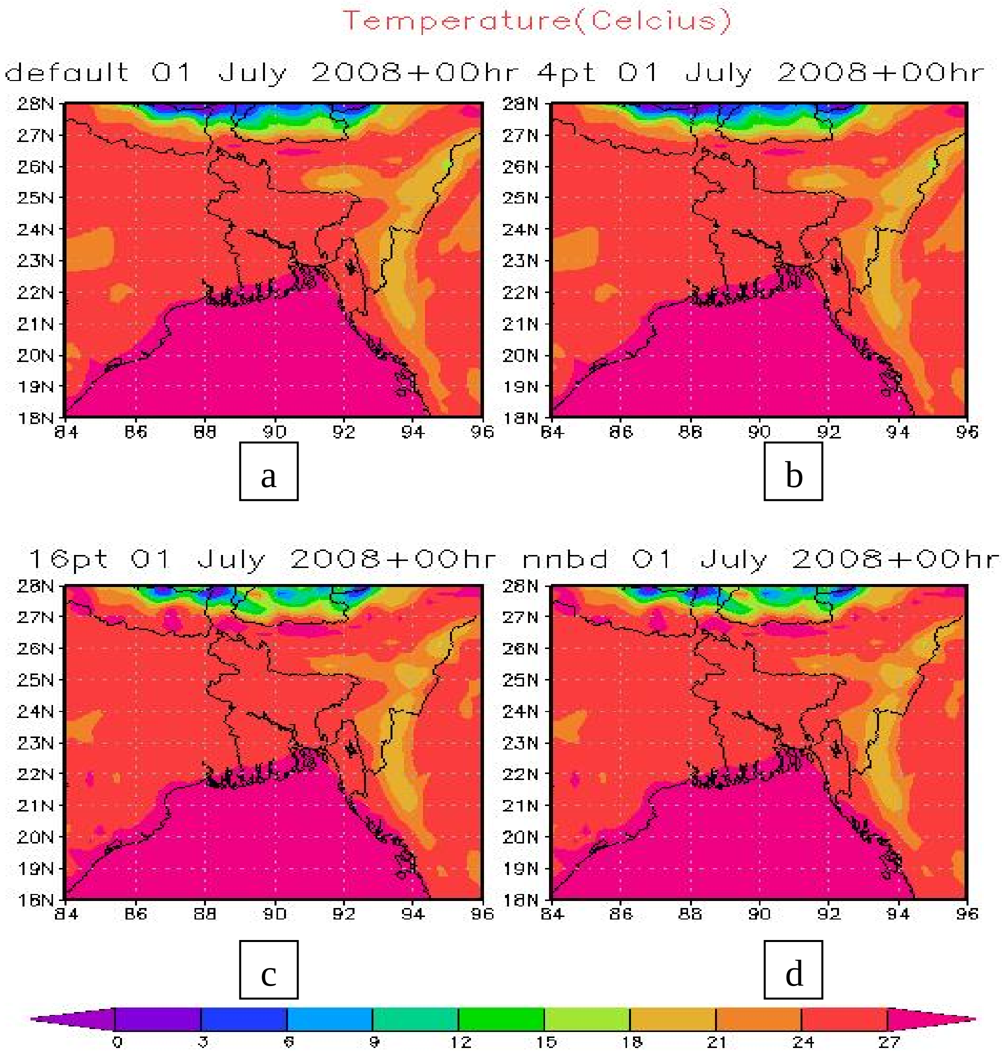



Figure 4.1.7Temperature (Celsius)of 01 July 2008 at00 hours

Figure 4.1.7indicates temperature in Celsius. Image no's a and b are same but c and d are different.Temperature 21$^0$ Celsius in the area 23$^0$ N and 24$^0$ N and 85.6$^0$E in image no's a and b. whereas Temperature 21$^0$ Celsius in the area 23$^0$ N and 24$^0$ N and 85$^0$E in image no's c and d. Upper middle area are change in four different interpolation techniques.

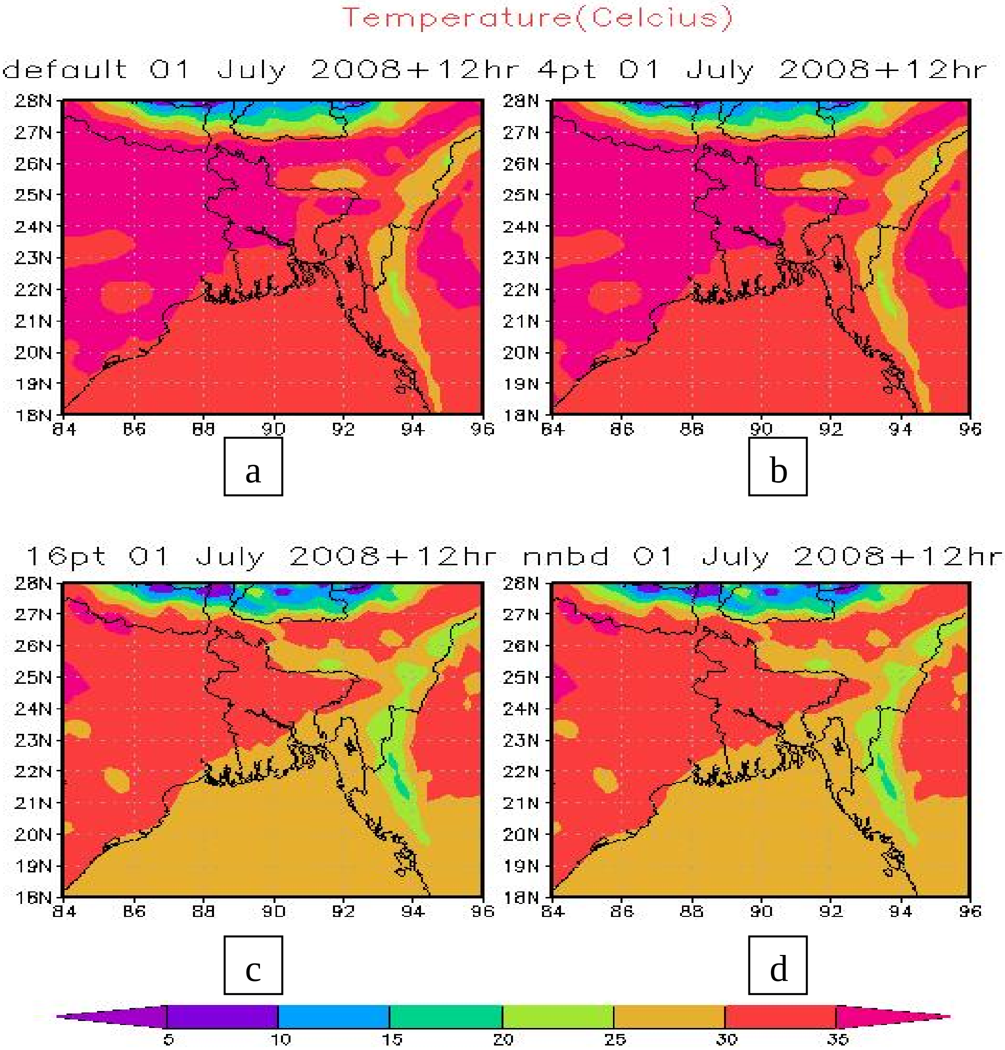



Figure 4.1.8Temperature (Celsius) of 01 July 2008 after 12 hours

Figure 4.1.8indicates temperature in Celsius. Image no's a and b are same but c and d are different. Temperature $21^0$ Celsius in the area $23^0$ N and $24^0$ N and $85.6^0$E in image no's a and b. whereas Temperature $21^0$ Celsius in the area $22^0$ N and $23^0$ N and $85^0$E in image no's c and d. Upper middle area change in four different interpolation techniques.

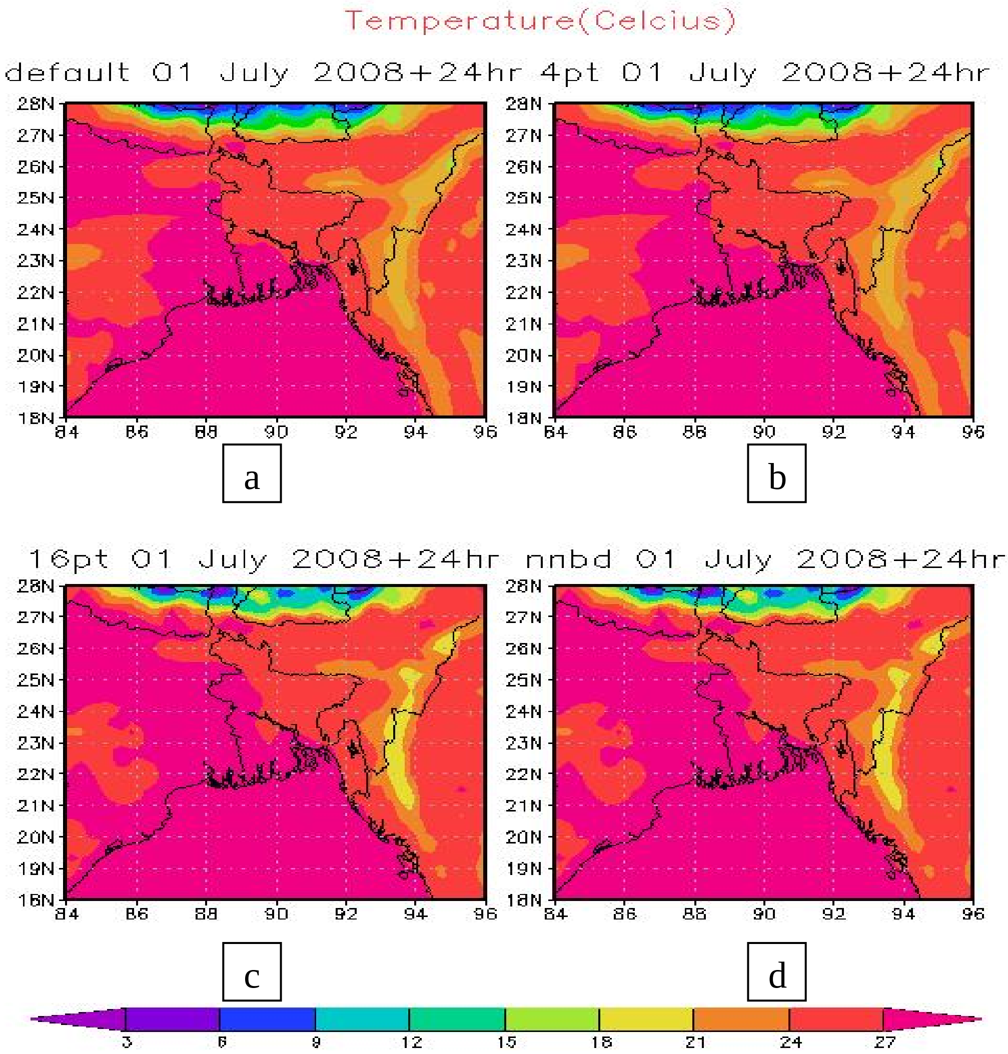



Figure 4.1.9Temperature (Celsius) of 01 July 2008 after 24 hours

Figure 4.1.9 represents temperature scenario. This picture indicates that the upper two images are same but the lower two images are different from upper. Because upper two images are used four point interpolation technique. We use sixteen point and nearest neighborhood interpolation technique and got some changes. If anybody observe the locations $23^0$, $24^0$N, $84^0$,$85^0$ E, and $23.5^0$,$24^0$ N and $96^0$E .S/he must agree with me that there are some changes with respect to others interpolation technique.

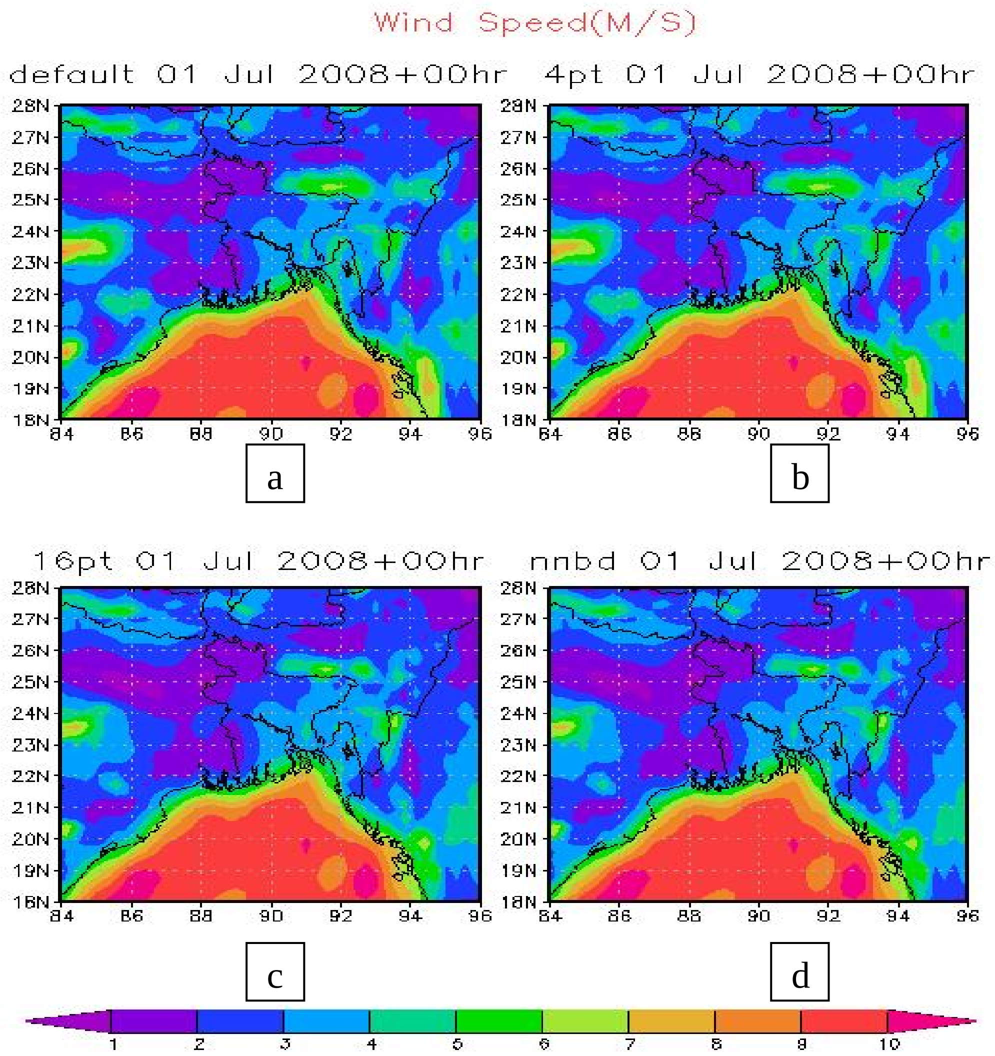



Figure 4.1.10wind Speed ($ms^{-1}$) of 01 July 2008 at 00 hours

Figure 4.1.10 represents wind speed scenario. This picture indicates that the imagesa and b are same but the images c and d are different from upper. Because imagesa and b are used four point interpolation technique. We use sixteen point and nearest neighborhood interpolation technique and having some changes. If someone observe the locations $21^0$,and $85^0$E. S/he must agree with me that there are some changes with respect to others interpolation technique. Specially left middle change in different interpolation techniques.

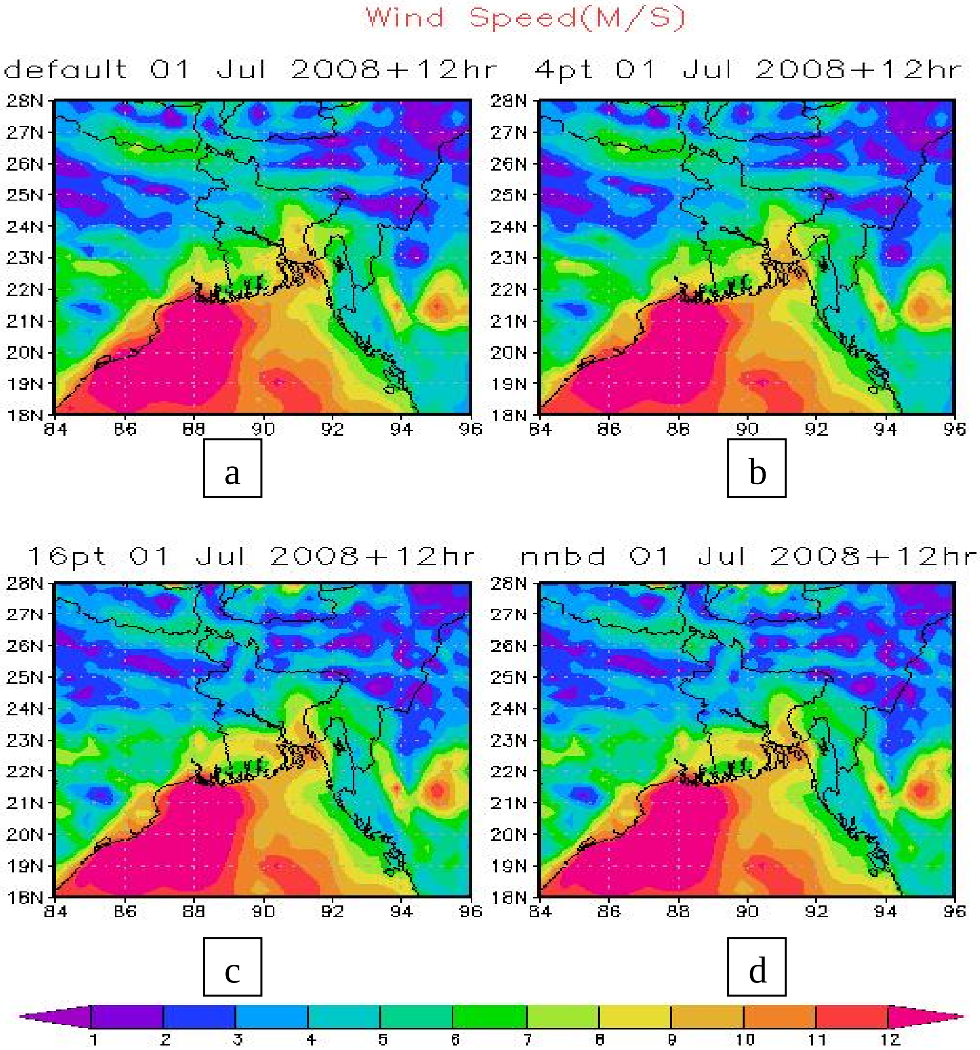



Figure 4.1.11wind Speed ($ms^{-1}$) of 01 July 2008 after 12 hours

Figure 4.1.1represents wind speed scenario. This picture indicates that the images a and b are same but the images c and d are different from upper. Because images a and b are used four point interpolation technique. We use sixteen point and nearest neighborhood interpolation technique and having some changes. If someone observe the locations $25^0$, and $85^0$E. S/he must agree with me that there are some changes with respect to others interpolation technique. Besides the pictures of the upper right corners are different with respect to different interpolation techniques.

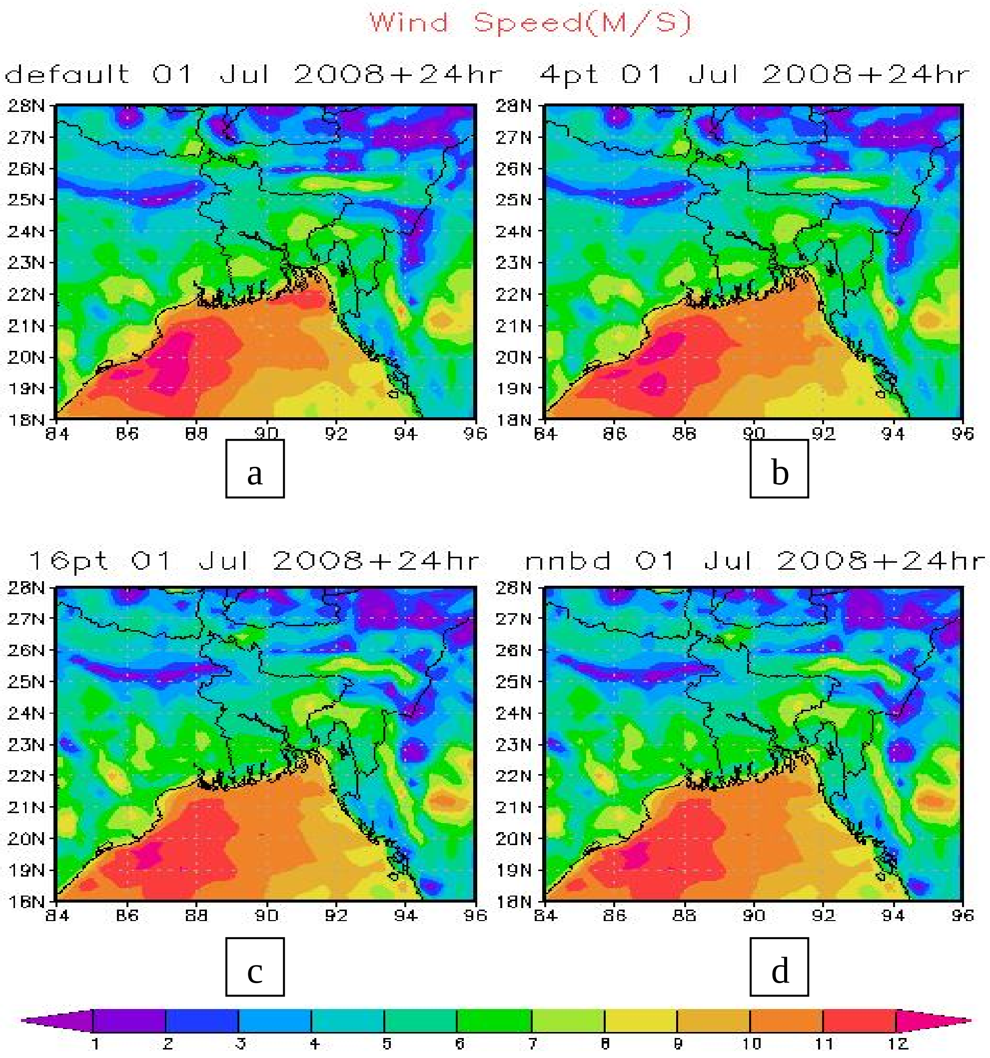



Figure 4.1.12wind Speed ($ms^{-1}$) of 01 July 2008 after 24 hours

Figure 4.1.12 represents wind speed scenario. This picture indicates that the images a and b are same but the images c and d are different from upper. Because images a and b are used four point interpolation technique. We use sixteen point and nearest neighborhood interpolation technique and having some changes. If someone observe the locations $25^0$, and $85^0$E. S/he must agree with me that there are some changes with respect to others interpolation technique. Besides the pictures of the upper right corners are different with respect to different interpolation techniques. Upper right corner change of interpolation techniques.

## 4.2 Effect on Tropical Cyclone prediction (TC) (Aila-23 may -2009)

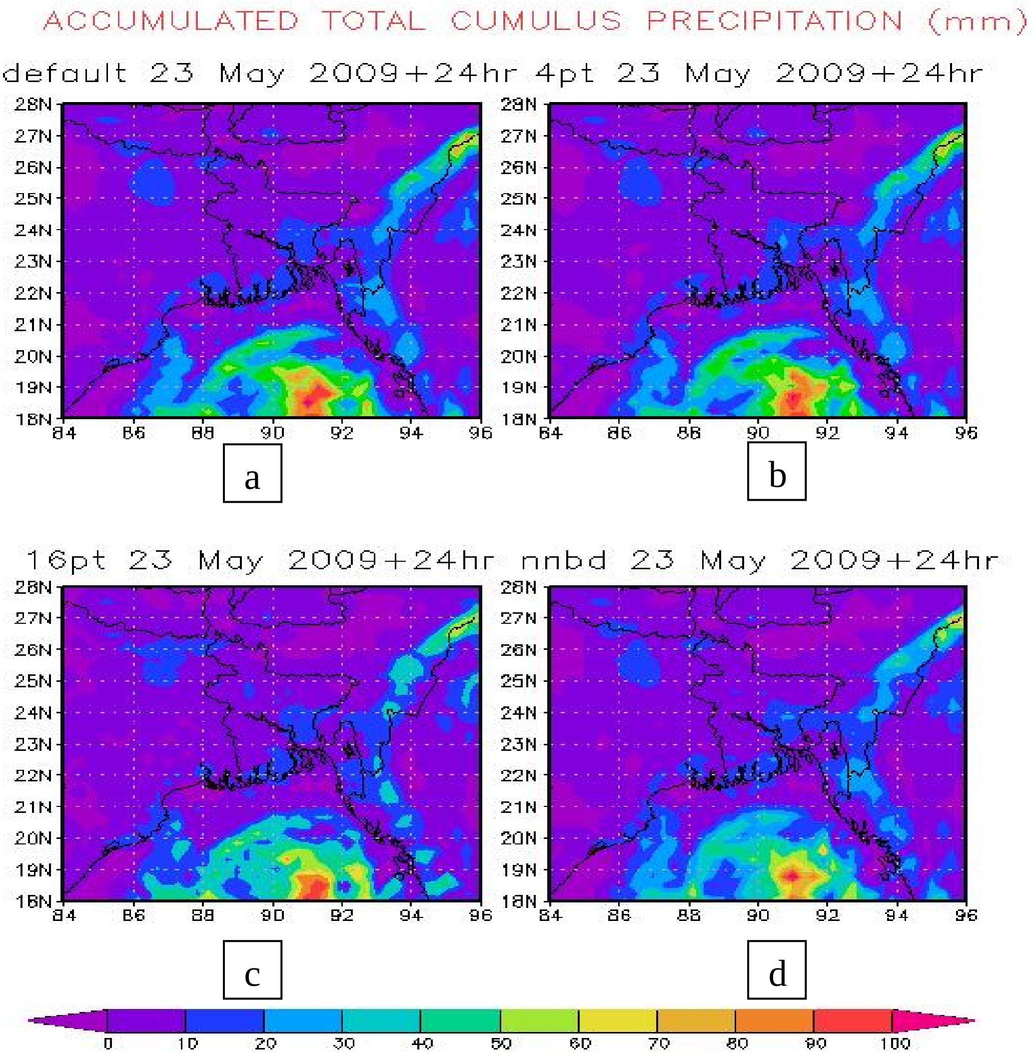



Figure 4.2.1 Accumulated total cumulus precipitation of 23 May 2009 after 24 hours

Figure 4.2.1indicates theaccumulated total cumulus precipitation of 23 May 2009 after 24 hours.The imagesa and b are same but the images c and d are different from a and b. Because upper two images are used four point interpolation technique. We used sixteen point and nearest neighborhood interpolation technique and got some changes. Look at carefully the adjacent area of $18^0$ N, $19^0$ N, $91^0$ E and have some changes. In the lower middle part and right part of our domain is absolutely different for each different interpolation techniques.

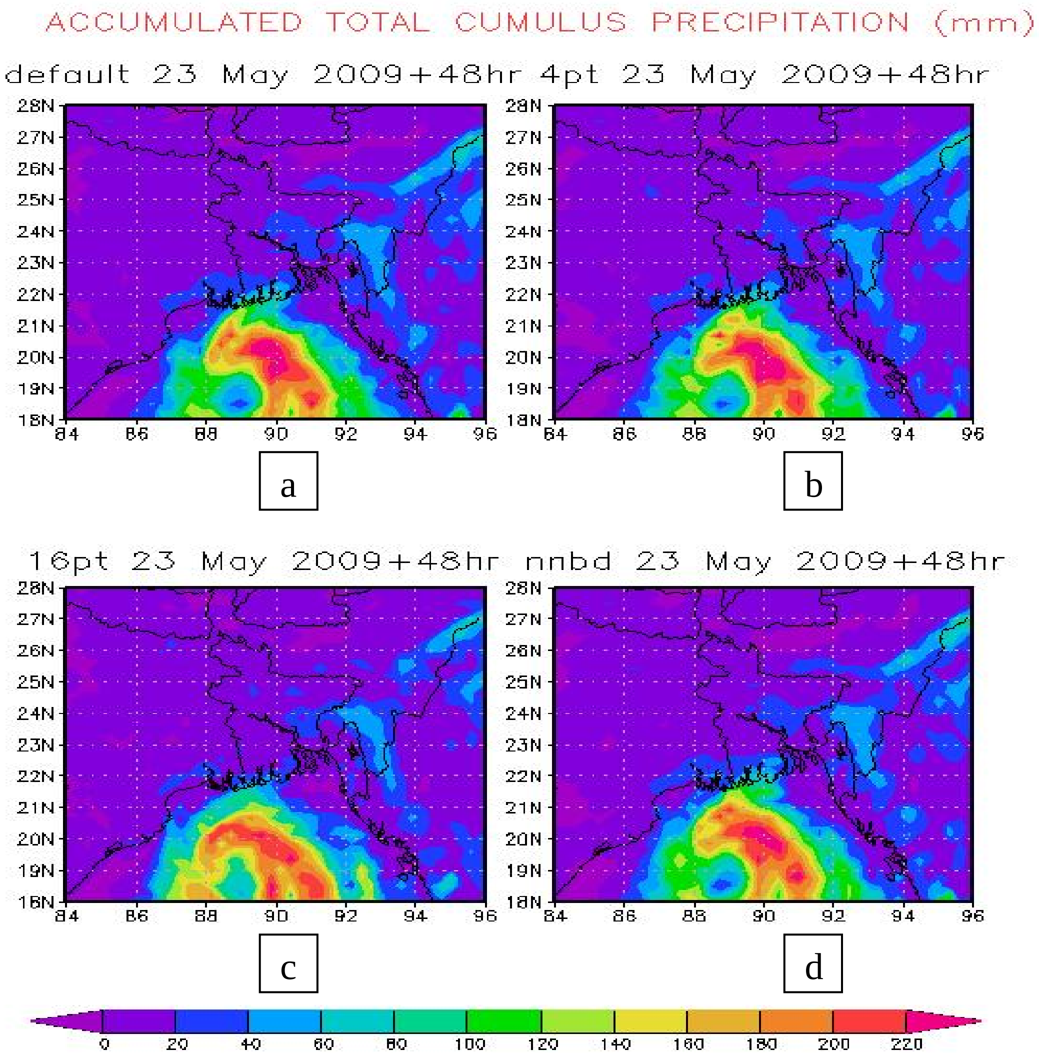



Figure 4.2.2Accumulated total cumulus precipitation of 23 May 200 after 48 hours

Figure 4.2.2 indicates that theaccumulated total cumulus precipitation of 23 May 2009 after 48 hours. The images a and b are same but the images c and d are different from a and b. Because upper two images are used four point interpolation technique. We used sixteen point and nearest neighborhood interpolation technique and got some changes. Look at carefully the adjacent area of latitude $18^0$ N, $19^0$ N, $20^0$ Nand longitude from$88^0$E-$92^0$ E and clearly changed. In the lower middle part of our domain is absolutely different for each different interpolation techniques.

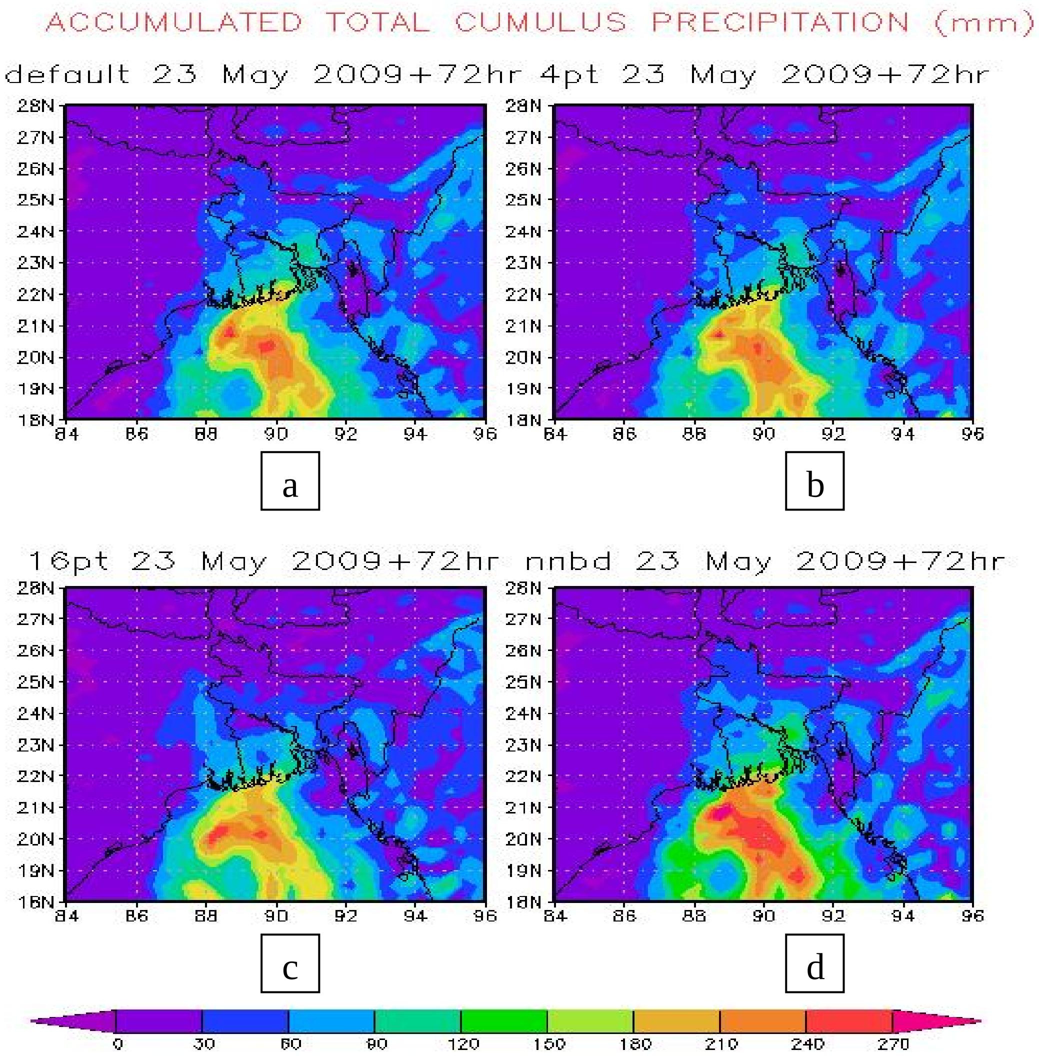



Figure 4.2.3 Accumulated total cumulus precipitation of 23 May 200 after 72 hours

Figure 4.2.3 indicates that theaccumulated total cumulus precipitation of 23 May 2009 after 48 hours. The images a and b are same but the images c and d are different from a and b. Because upper two images are used four point interpolation technique. We used sixteen point and nearest neighborhood interpolation technique and got some changes. Look at carefully the adjacent area of latitude $18^0$ N, $19^0$ N, $20^0$ N, $21^0$ N and longitude from $88^0$E-$92^0$ E andclearly changed. In the lower middle part and right part of our domain is absolutely different for each different interpolation techniques.

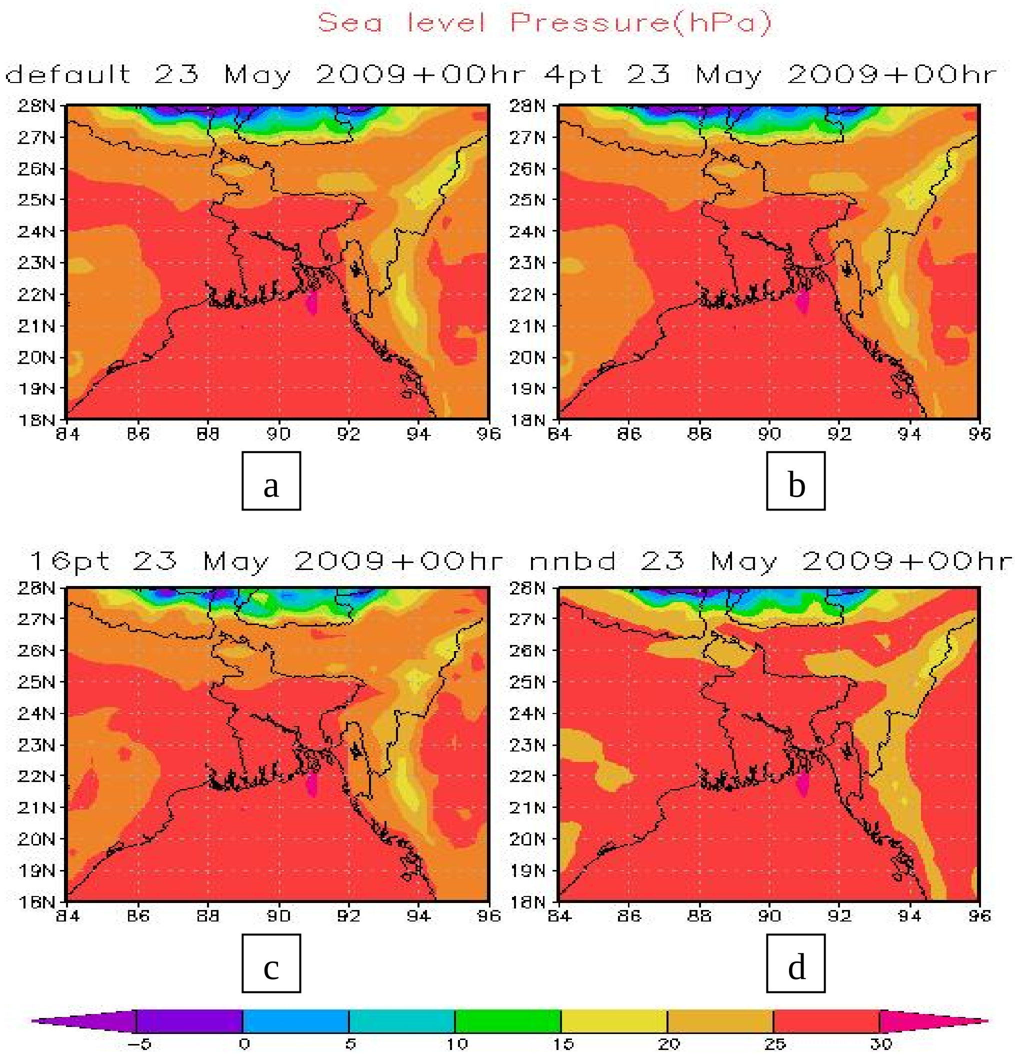



Figure 4.2.4Sea Level Pressure (hPa)of 23 May 2009at 00 hour

Figure 4.2.4 represents sea level pressure (SLP) 00 hours of that domain. In the area $23^0$N, and $90^0$E SLP is 1012 hPa but the same area the SLP is not that with respect to other interpolation technique. In the 4pt interpolation SLP is 996 hPa in $19^0$ N, $20^0$ N, $23^0$ N and $84^0$E, $85^0$E, $86^0$E, In the sixteen point and nearest neighborhood interpolation technique this area is $21^0$ N, $22^0$ N and $84.1^0$E. In the default interpolation technique SLP of the upper left portion and the others interpolation technique the upper left portion are not same. The scenario of the lower right corners are fully different of each interpolation techniques.

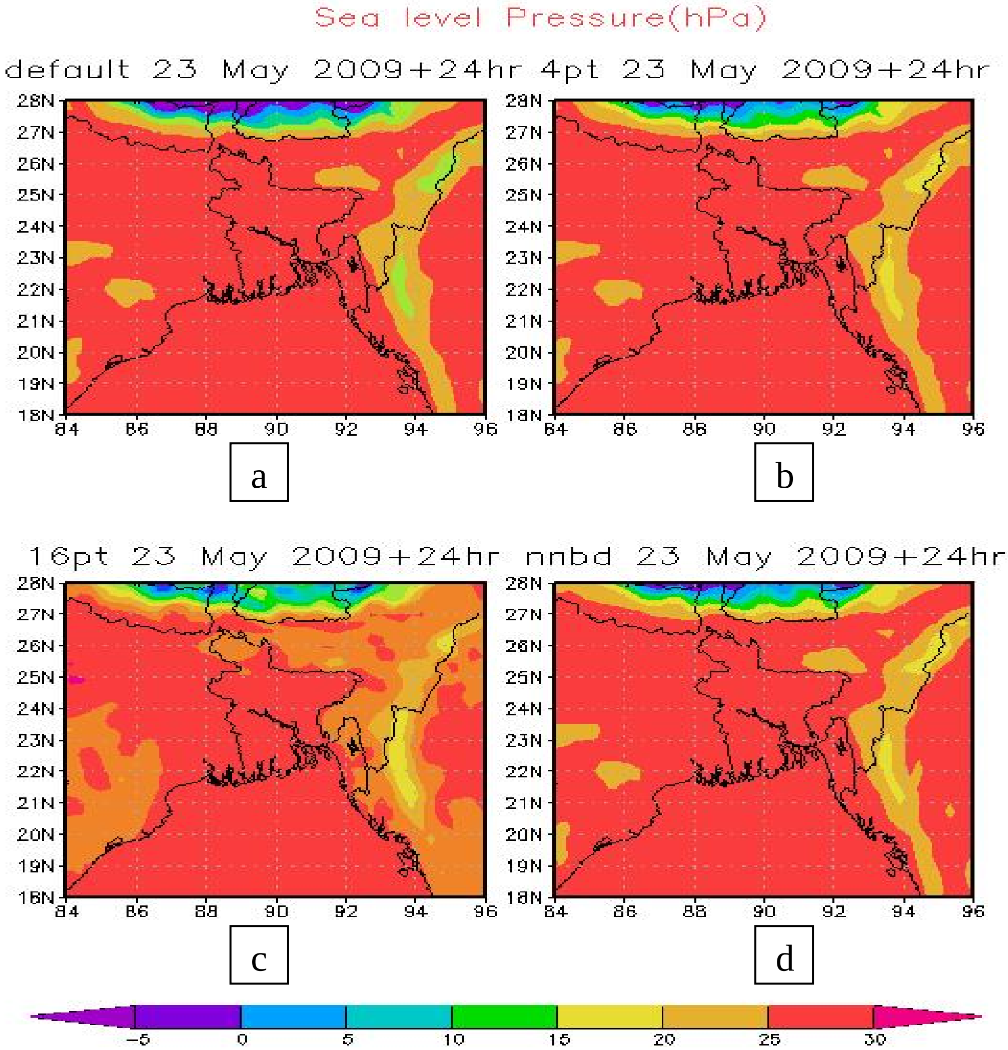



Figure 4.2.5Sea Level Pressure (hPa) of 23 May 200 after 24 hours

Figure 4.2.5 represents sea level pressure (SLP) after 24 hours of that domain. In the area $23^{0}$N, and $90^{0}$E SLP is 20hPa but the same area the SLP is not that with respect to other interpolation technique. In the 4pt interpolation SLP is 25hPa in $21^{0}$ N, $22^{0}$ N, $23^{0}$ N and $84^{0}$E, $85^{0}$E, $86^{0}$E, In the sixteen point and nearest neighborhood interpolation technique this area is $21^{0}$ N, $22^{0}$ N and $84.1^{0}$E. In the default interpolation technique SLP of the upper left portion and the others interpolation technique the upper left portion are not same. The scenario of the right are fully different of each interpolation techniques.

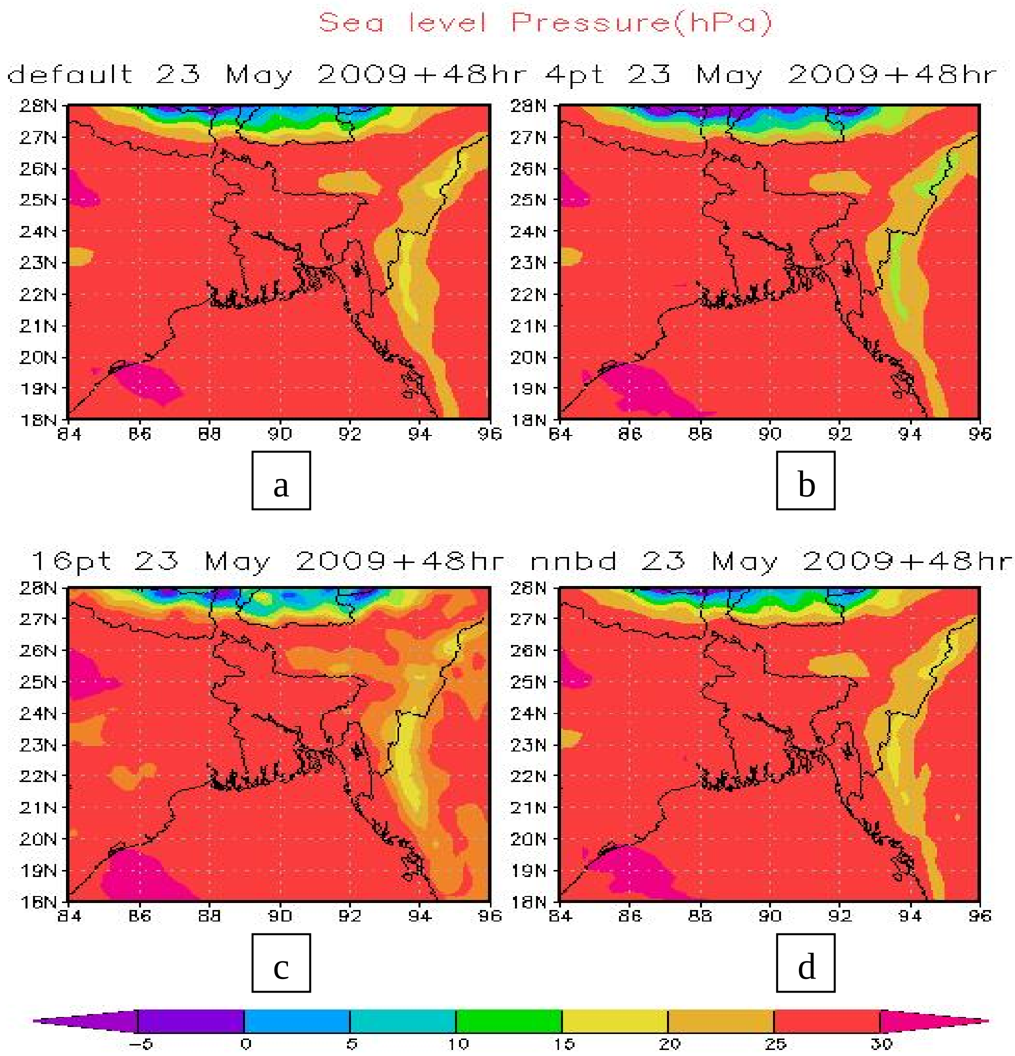



Figure 4.2.6Sea Level Pressure (hPa) of 23 May 2009 after 48 hours

Figure 4.2.6 represents sea level pressure (SLP) after 48 hours of that domain. In the default interpolation technique SLP of a and b and the others interpolation technique the upper left portion are not same. The scenario of the upper and right corners are fully different of each interpolation techniques. There are also changes in position $18^0$, $19^0$, $20^0$N and $2086^0$ E to $88^0$ E.

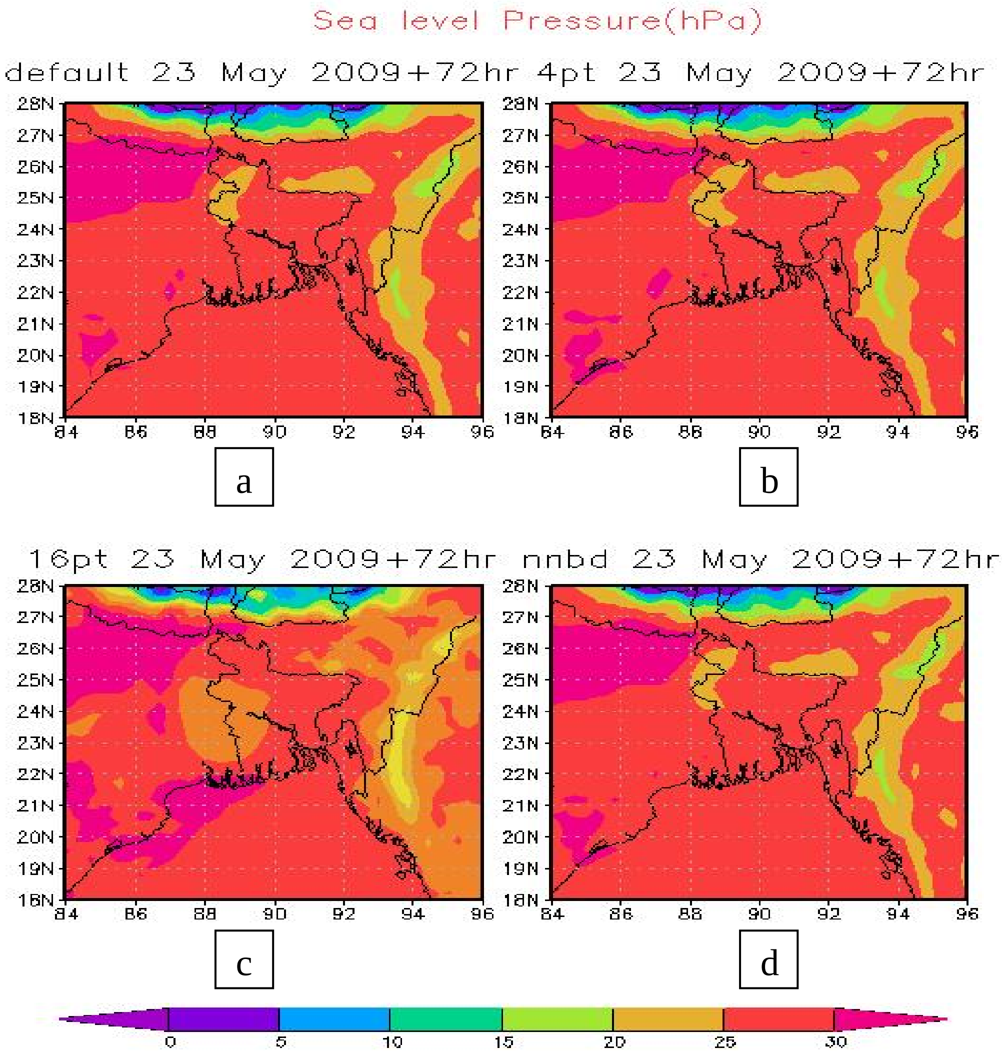



Figure No 4.2.7 Sea Level Pressure (hPa) of 23 May 200 after 72 hours

Figure 4.2.7 represents sea level pressure (SLP) after 72 hours of that domain. The scenario of the right portions are fully different of each different interpolation techniques.

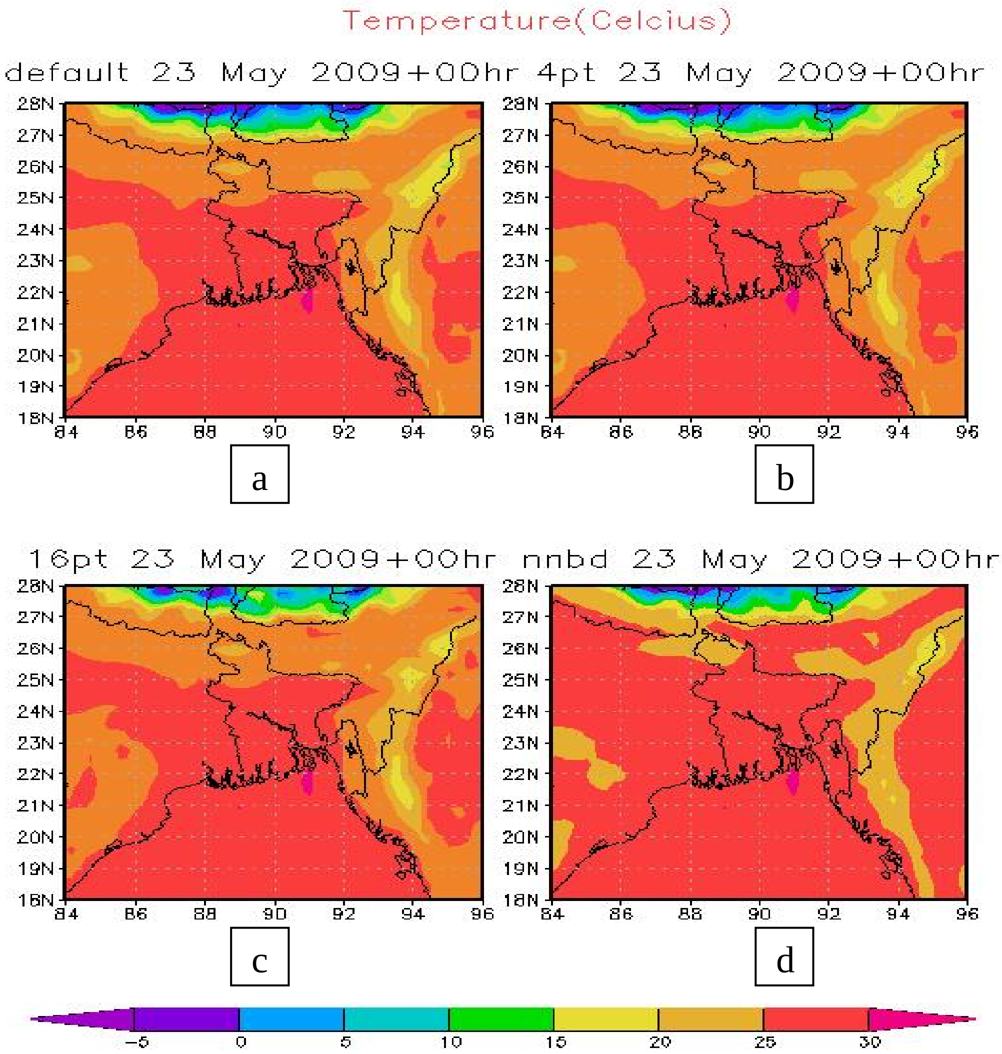



Figure 4.2.8 Temperature (Celcius) of 23 May 2009 at 00 hour

Figure 4.2.8 indicates that temperature in Celsius. Image no’s a and b are same but c and d are different. Temperature $21^0$ Celsius in the area $23^0$ N and $24^0$ N and $85.6^0$E in image no’s a and b. whereas Temperature $21^0$ Celsius in the area $23^0$ N and $24^0$ N and $85^0$E in image no’s c and d. Upper middle area are change in four different interpolation techniques.

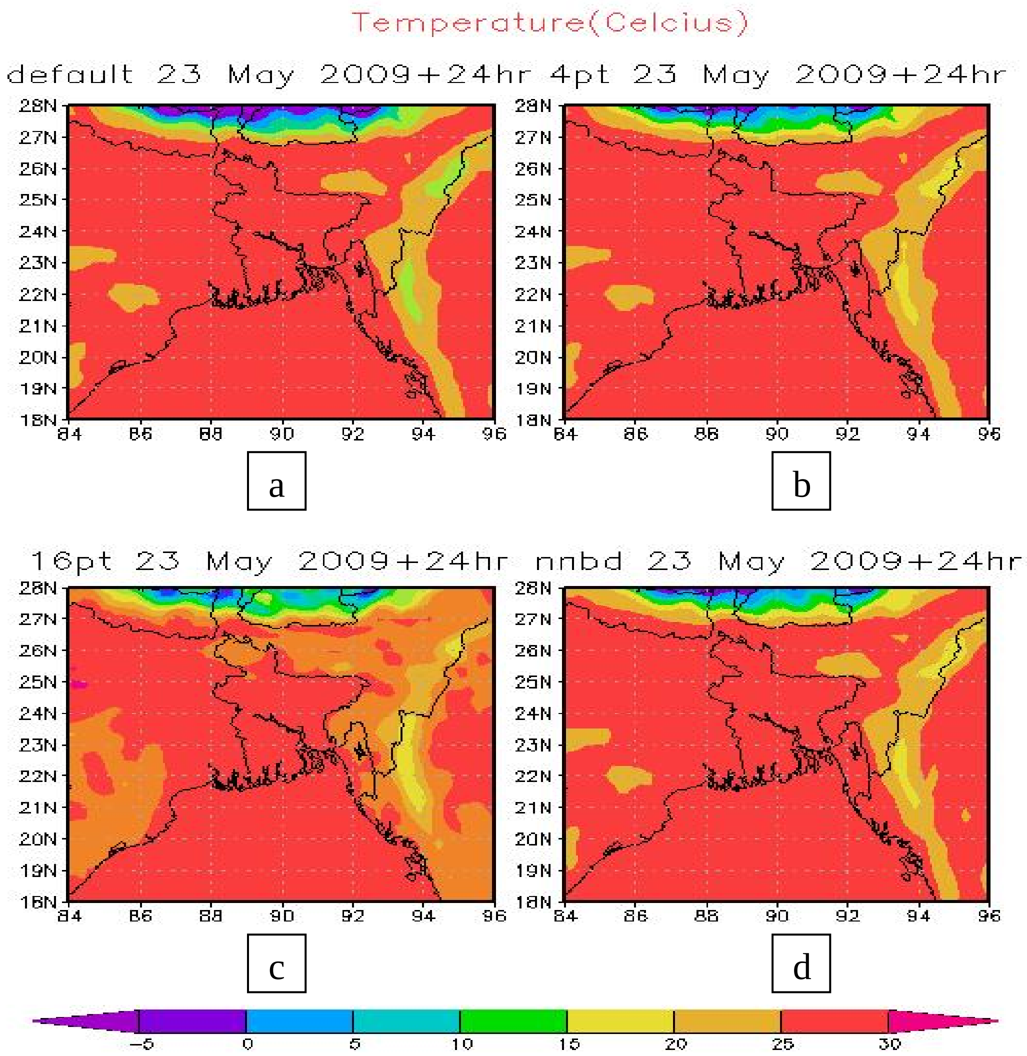



Figure 4.2.9Temperature (Celcius) of 23 May 2009 after 24 hours

Figure 4.2.9 indicates temperature in Celsius. Image a and b are same but c and d are different. Temperature $21^0$ Celsius in the area $23^0$ N and $24^0$ N and $85.6^0$E in image no's a and b. whereas Temperature $21^0$ Celsius in the area $23^0$ N and $24^0$ N and $85^0$E in image no's c and d. Upper middle and right parts change in four different interpolation techniques.

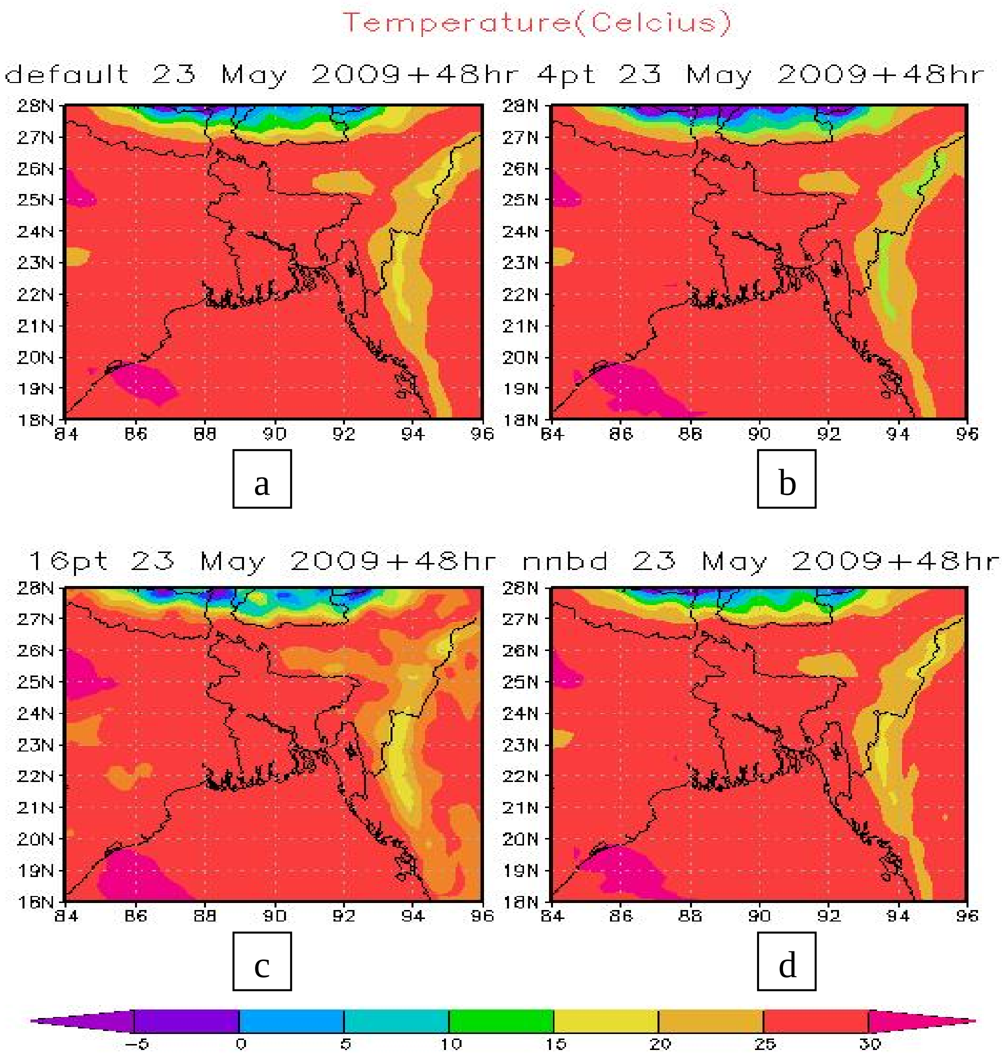



Figure 4.2.10Temperature (Celcius) of 23 May 2009 after 48 hours

Figure 4.2.10 indicates temperature in Celsius. Image no's a and b are same but c and d are different. Temperature $21^0$ Celsius in the area $23^0$ N and $24^0$ N and $85.6^0$E in image no's a and b. whereas Temperature $21^0$ Celsius in the area $23^0$ N and $24^0$ N and $85^0$E in image no's c and d. Right part of our domain change in four different interpolation techniques.

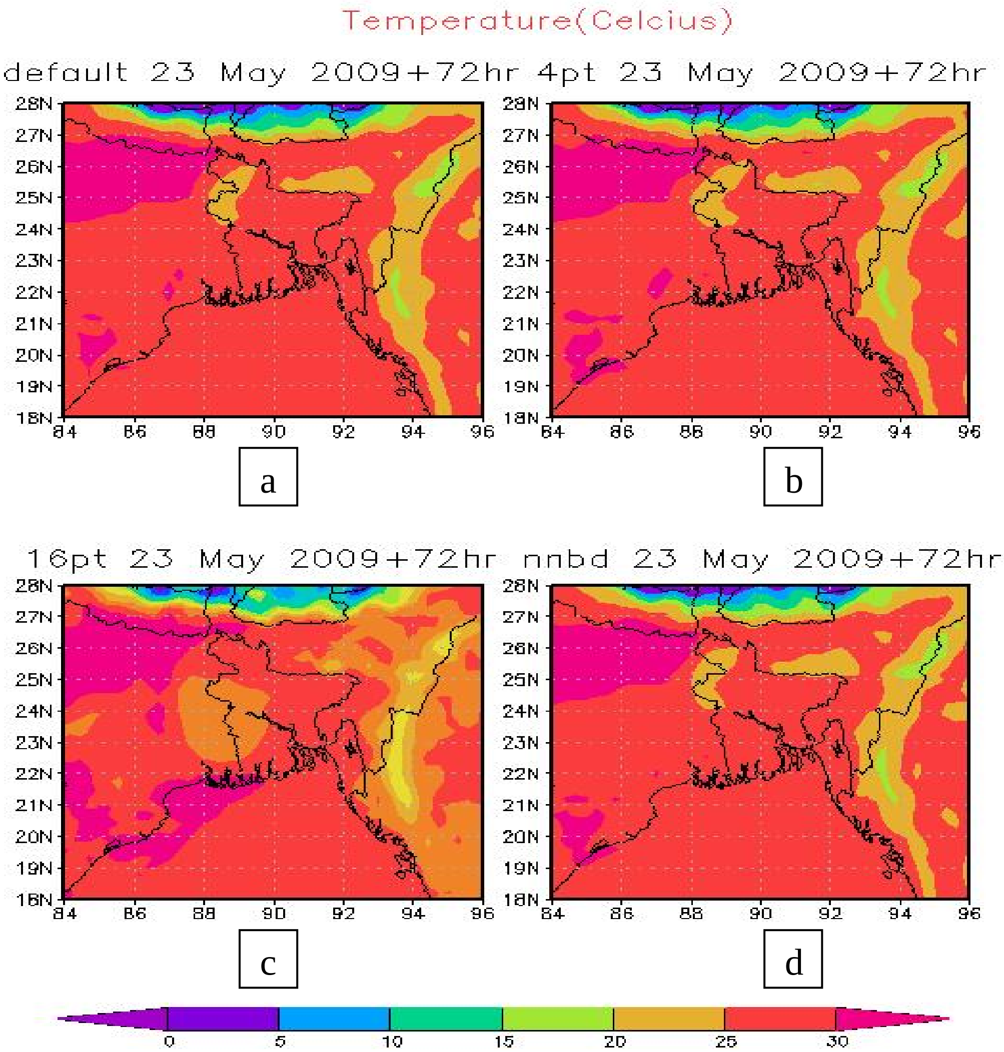



Figure 4.2.11Temperature (Celsius) of 23 May 2009 after 72 hours

Figure 4.2.11 indicates that temperature in Celsius. Image no's a and b are same but c and d are different. Temperature $21^0$ Celsius in the area $23^0$ N and $24^0$ N and $85.6^0$E in image no's a and b. whereas Temperature $21^0$ Celsius in the area $23^0$ N and $24^0$ N and $85^0$E in image no's c and d. Right part of our domain change in four different interpolation techniques.

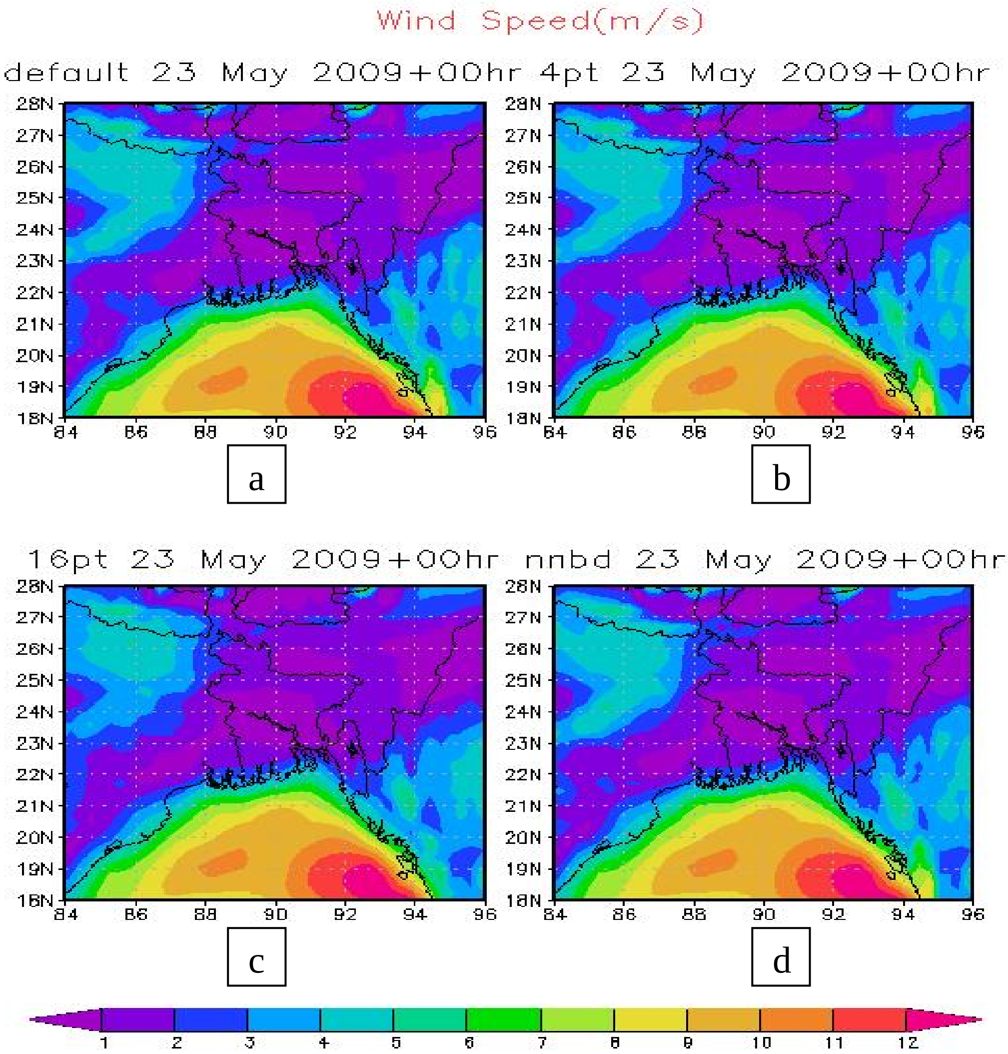



Figure 4.2.12 Wind Speed (ms$^{-1}$) of 23 May 2009 at00 hours

Figure 4.2.12 represents wind speed scenario. This picture indicates that the images a and b are same but the images c and d are different from upper. Because images a and b are used four point interpolation technique. We use sixteen point and nearest neighborhood interpolation technique and having some changes. If someone observe the locations 25$^0$, and 85$^0$E . S/he must agree with me that there are some changes with respect to others interpolation technique. Besides the pictures of the upper right corners are different with respect to different interpolation techniques.

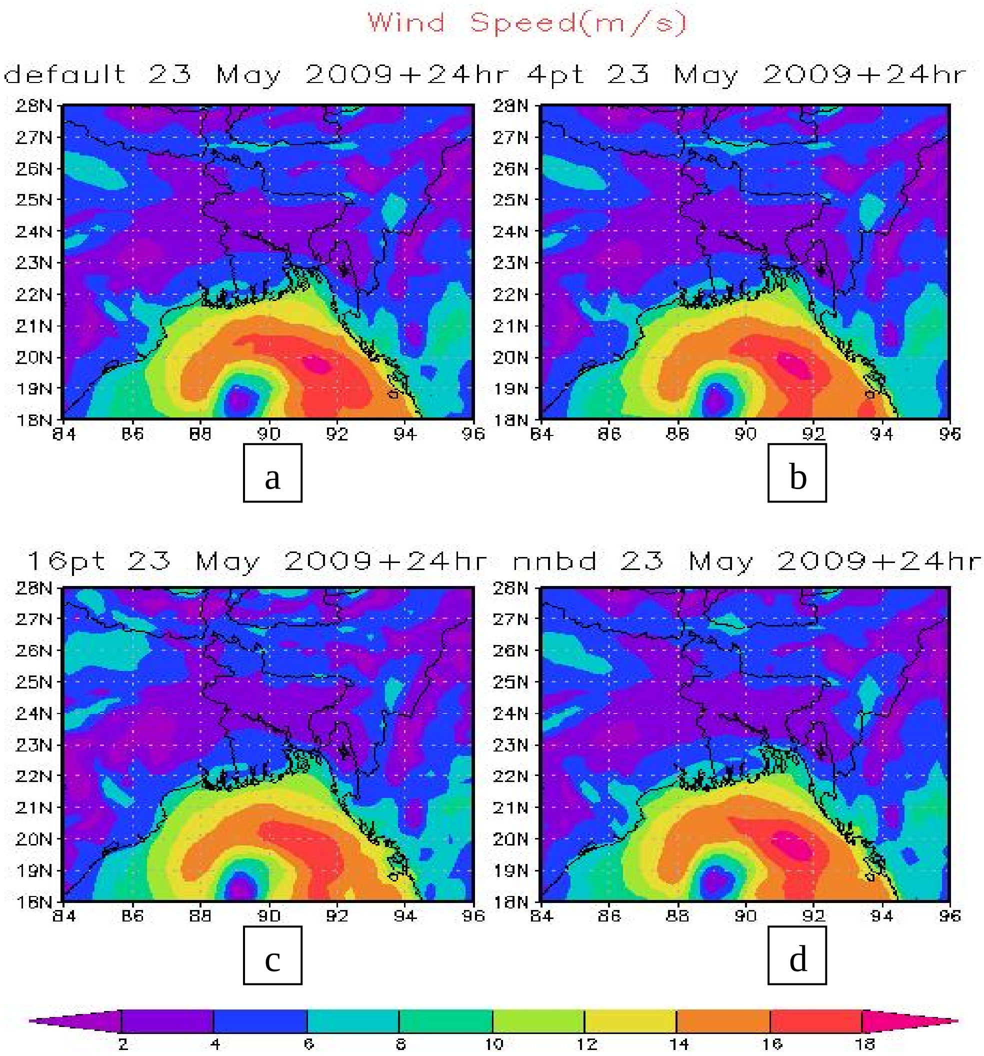



Figure 4.2.13 Wind Speed ($ms^{-1}$) of 23 May 2009 at 24 hours

Figure 4.2.13 represents wind speed scenario. This picture indicates that the images a and b are same but the images c and d are different from upper. Because images a and b are used four point interpolation technique. We use sixteen point and nearest neighborhood interpolation technique and having some changes. If someone observe the locations $25^0$, and $85^0$E . S/he must agree with me that there are some changes with respect to others interpolation technique. Besides the pictures of the upper right corners are different with respect to different interpolation techniques.

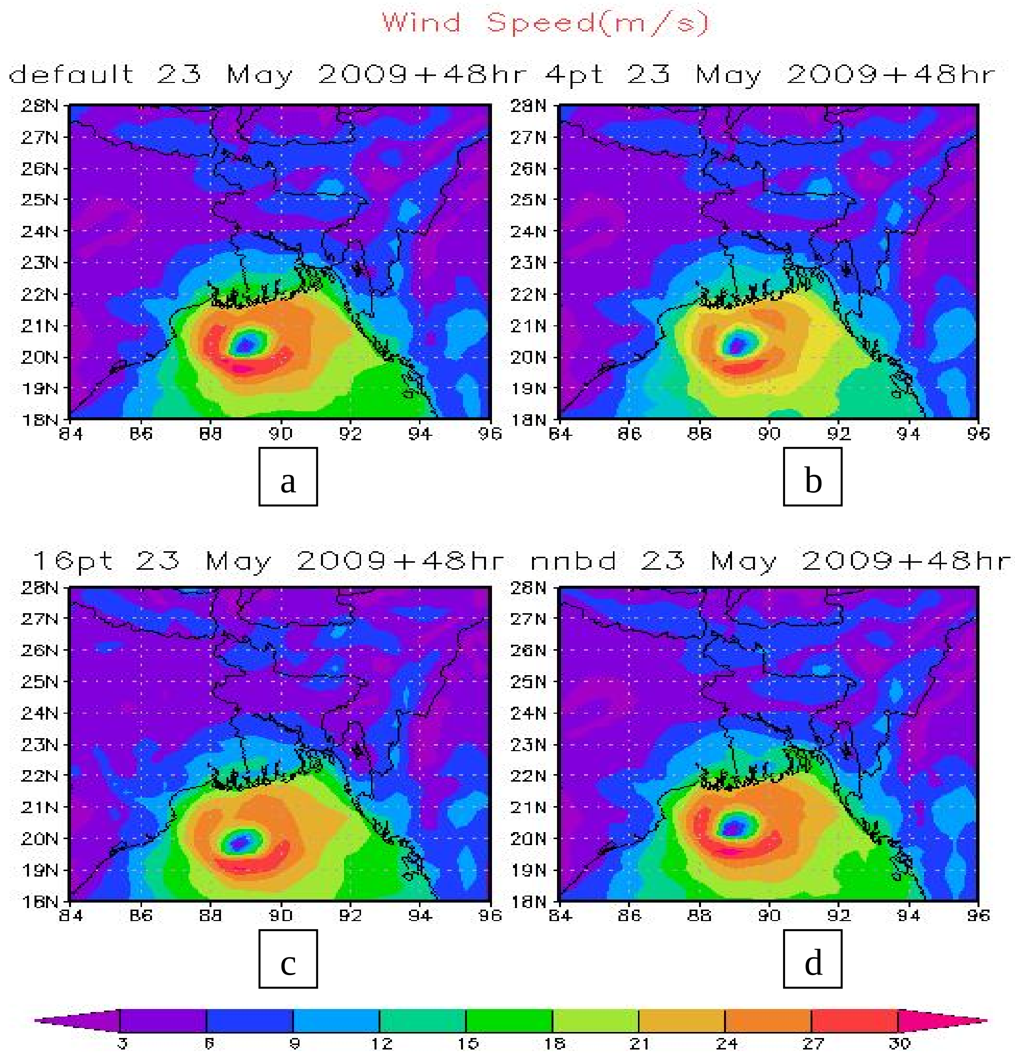



Figure 4.2.14 Wind Speed ($ms^{-1}$) of 23 May 2009 at 48 hours

Figure 4.2.14 represents wind speed scenario. This picture indicates that the images a and b are same but the images c and d are different from upper. Because images a and b are used four point interpolation technique. We use sixteen point and nearest neighborhood interpolation technique and having some changes. If someone observe the locations $25^0$, and $85^0$E . S/he must agree with me that there are some changes with respect to others interpolation technique. Besides the pictures of the upper right corners are different with respect to different interpolation techniques.

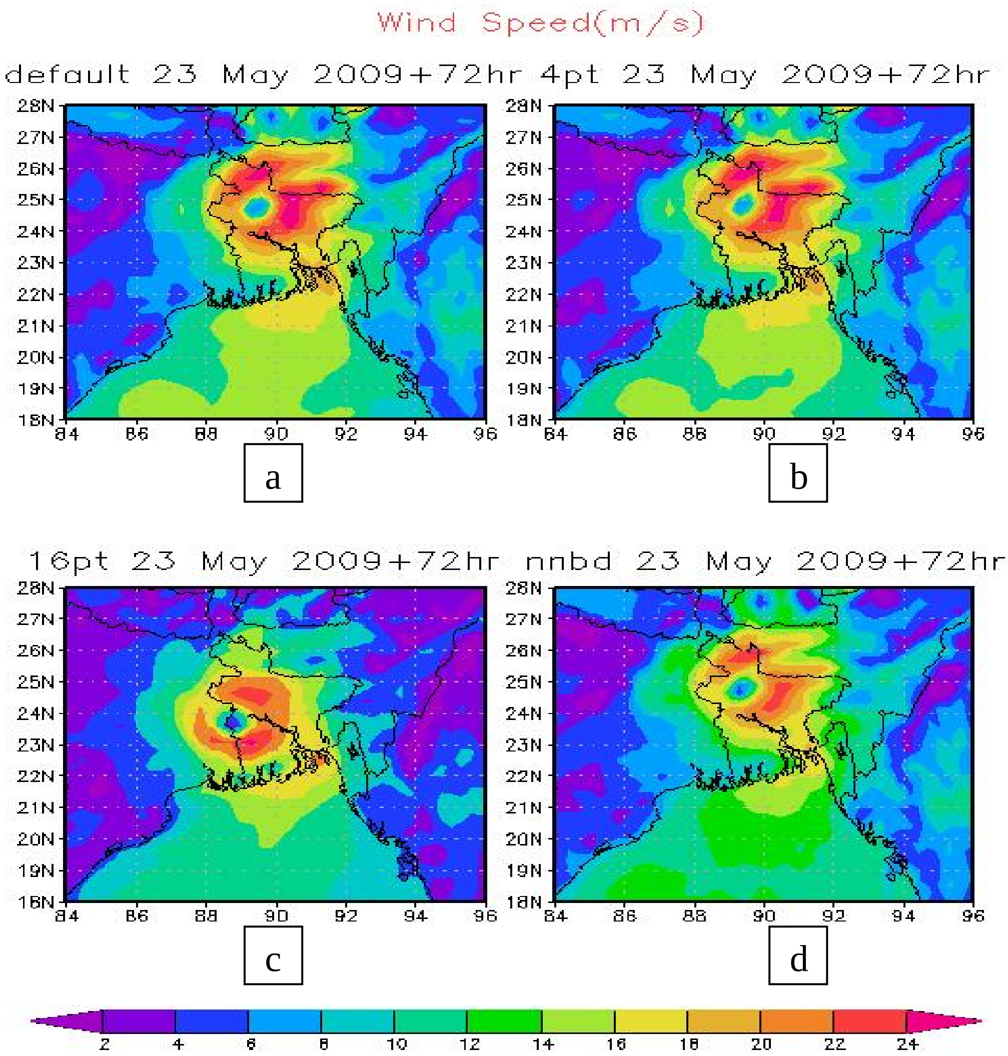



Figure 4.2.15 Wind Speed ($ms^{-1}$) of 23 May 2009 after 72 hours

Figure 4.2.15 represents wind speed scenario. This picture indicates that the images a and b are same but the images c and d are different from upper. Because images a and b are used four point interpolation technique. We use sixteen point and nearest neighborhood interpolation technique and having some changes. If someone observe the locations $25^0$, and $85^0$E. S/he must agree with me that there are some changes with respect to others interpolation technique. Besides the pictures of the upper right corners are different with respect to different interpolation techniques.

## 4.3 Effect on Tropical Temperature prediction (23 January -2016)

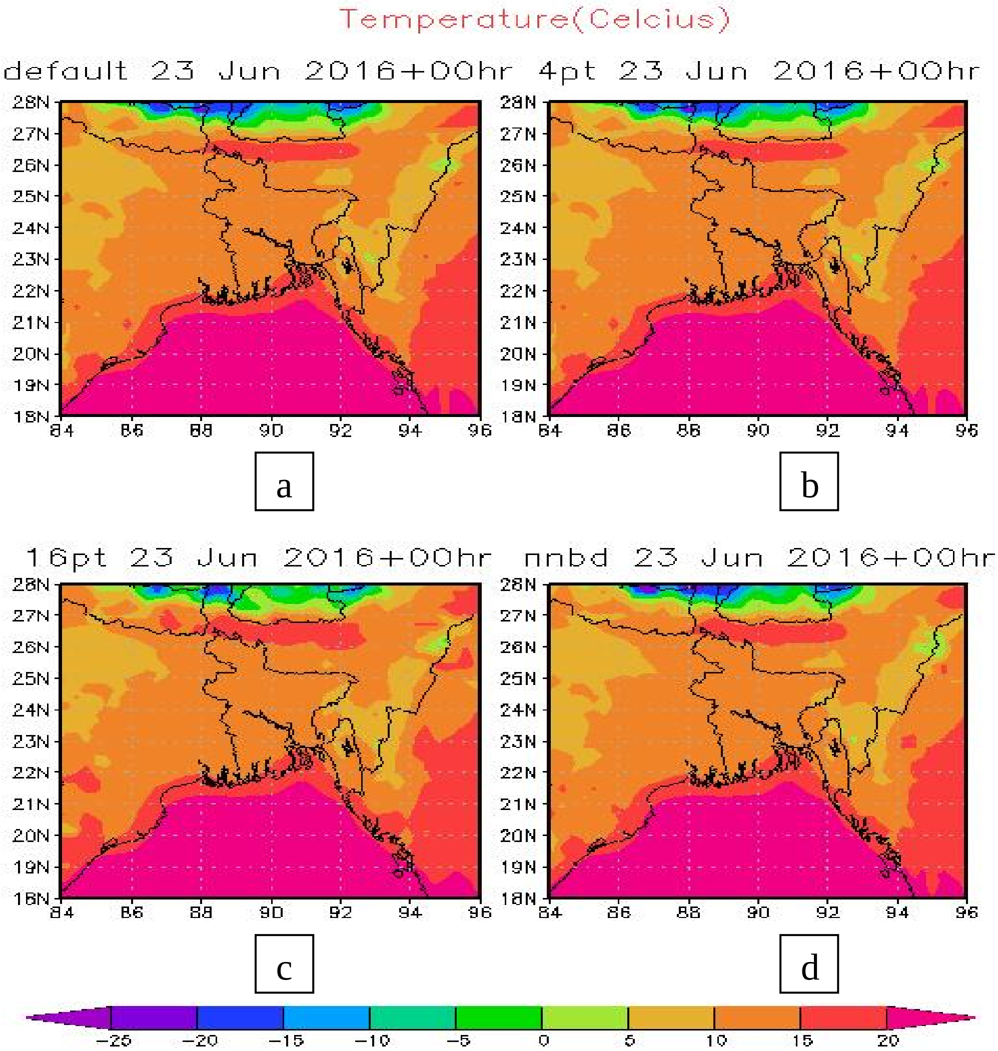



Figure 4.3.1 Temperature (Celsius) of 23 January 2016 at 00 hour

Figure 4.3.1 indicates temperature in Celsius. Image no's a and b are same but c and d are different. Temperature $21^0$ Celsius in the area $23^0$ N and $24^0$ N and $85.6^0$E in image no's a and b. whereas Temperature $21^0$ Celsius in the area $23^0$ N and $24^0$ N and $85^0$E in image no's c and d. Upper middle area are change in four different interpolation techniques.

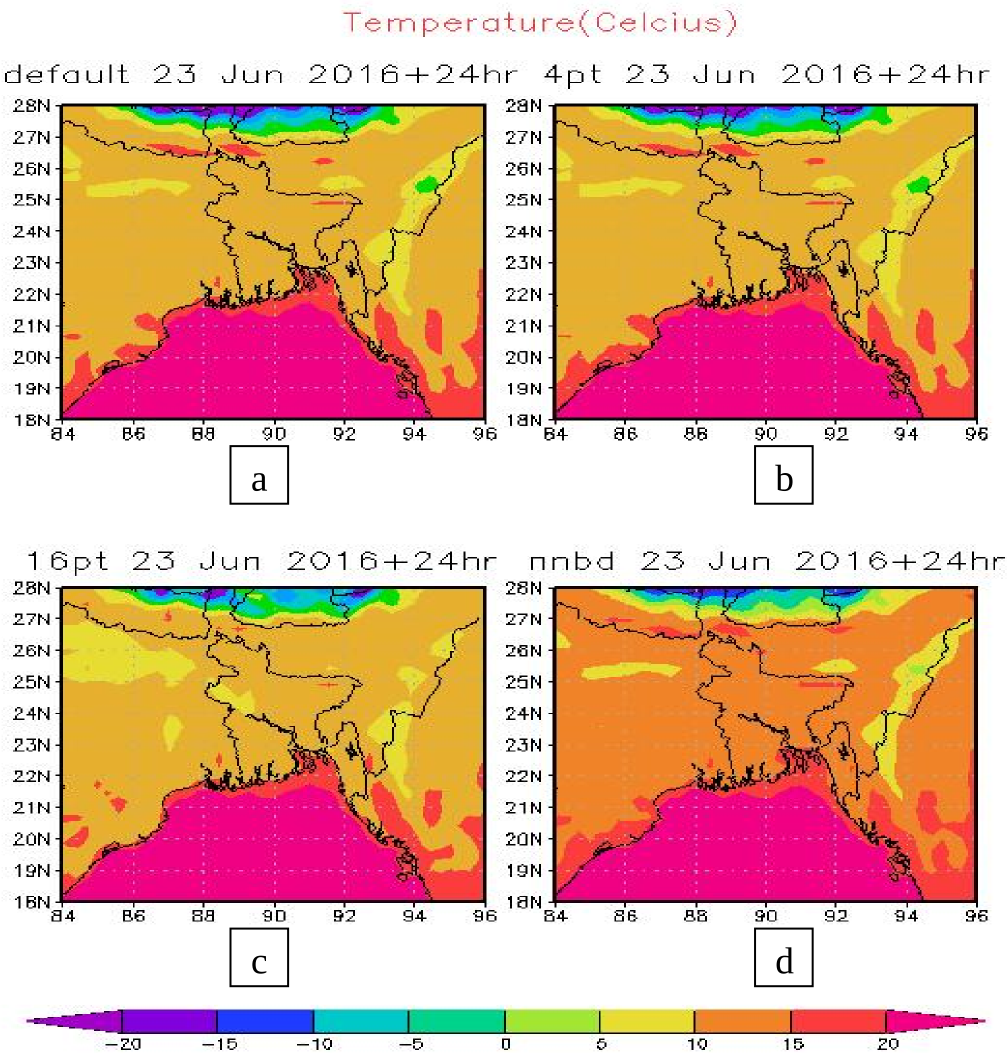



Figure 4.3.2Temperature (Celsius) of 23 January 2016 after 24 hours

Figure 4.3.2 indicates temperature in Celsius. Image no's a and b are same but c and d are different. Temperature $21^0$ Celsius in the area $23^0$ N and $24^0$ N and $85.6^0$E in image no's a and b. whereas Temperature $21^0$ Celsius in the area $23^0$ N and $24^0$ N and $85^0$E in image no's c and d. Upper middle area are change in four different interpolation techniques.

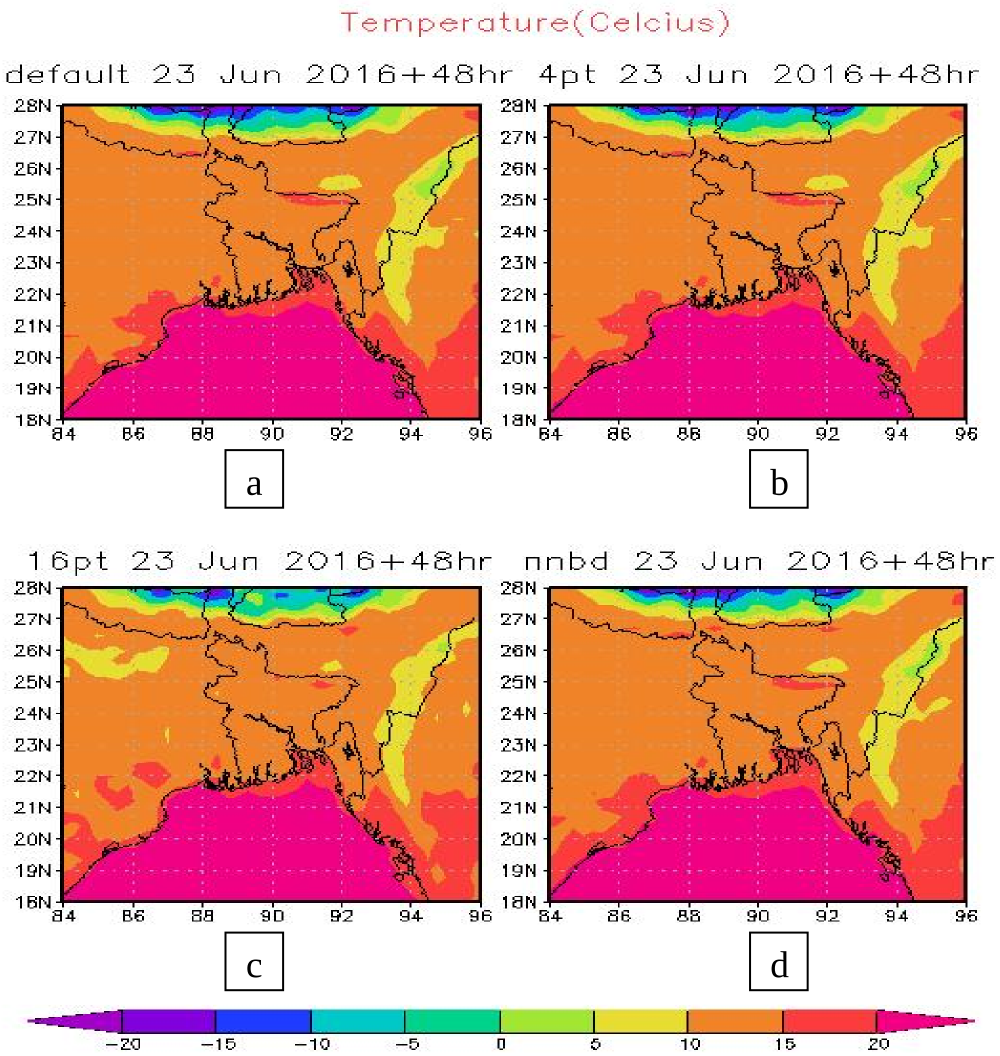



Figure 4.3.3 Temperature (Celsius) of 23 January 2016 after 48 hours

Figure 4.3.3 indicates that temperature in Celsius. Image no's a and b are same but c and d are different. Temperature $21^0$ Celsius in the area $23^0$ N and $24^0$ N and $85.6^0$E in image no's a and b. whereas Temperature $21^0$ Celsius in the area $23^0$ N and $24^0$ N and $85^0$E in image no's c and d. Upper middle area are change in four different interpolation techniques.

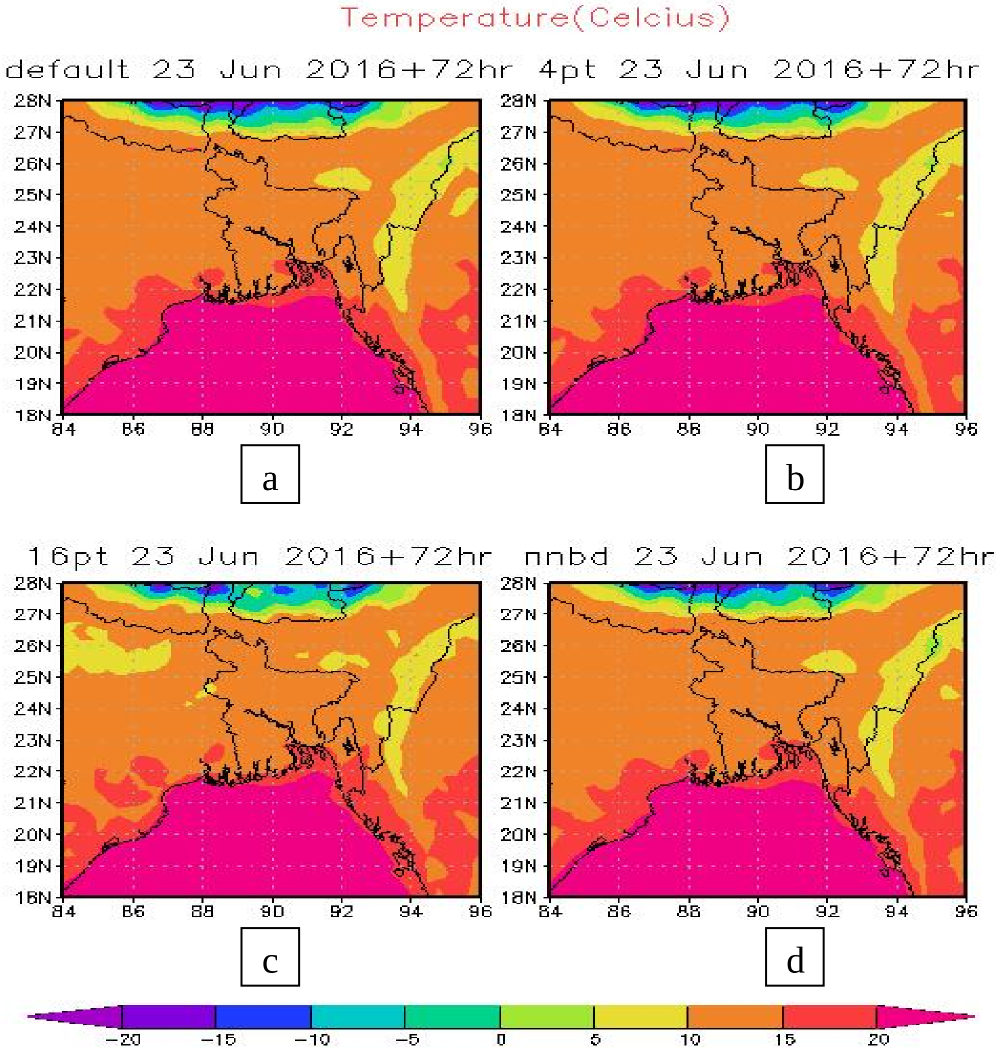



Figure 4.3.4Temperature (Celsius) of 23 January 2016 after 72 hours

Figure 4.3.4 indicates that temperature in Celsius. Image no's a and b are same but c and d are different. Temperature $21^0$ Celsius in the area $23^0$ N and $24^0$ N and $85.6^0$E in image no's a and b. whereas Temperature $21^0$ Celsius in the area $23^0$ N and $24^0$ N and $85^0$E in image no's c and d. Upper middle area are change in four different interpolation techniques.

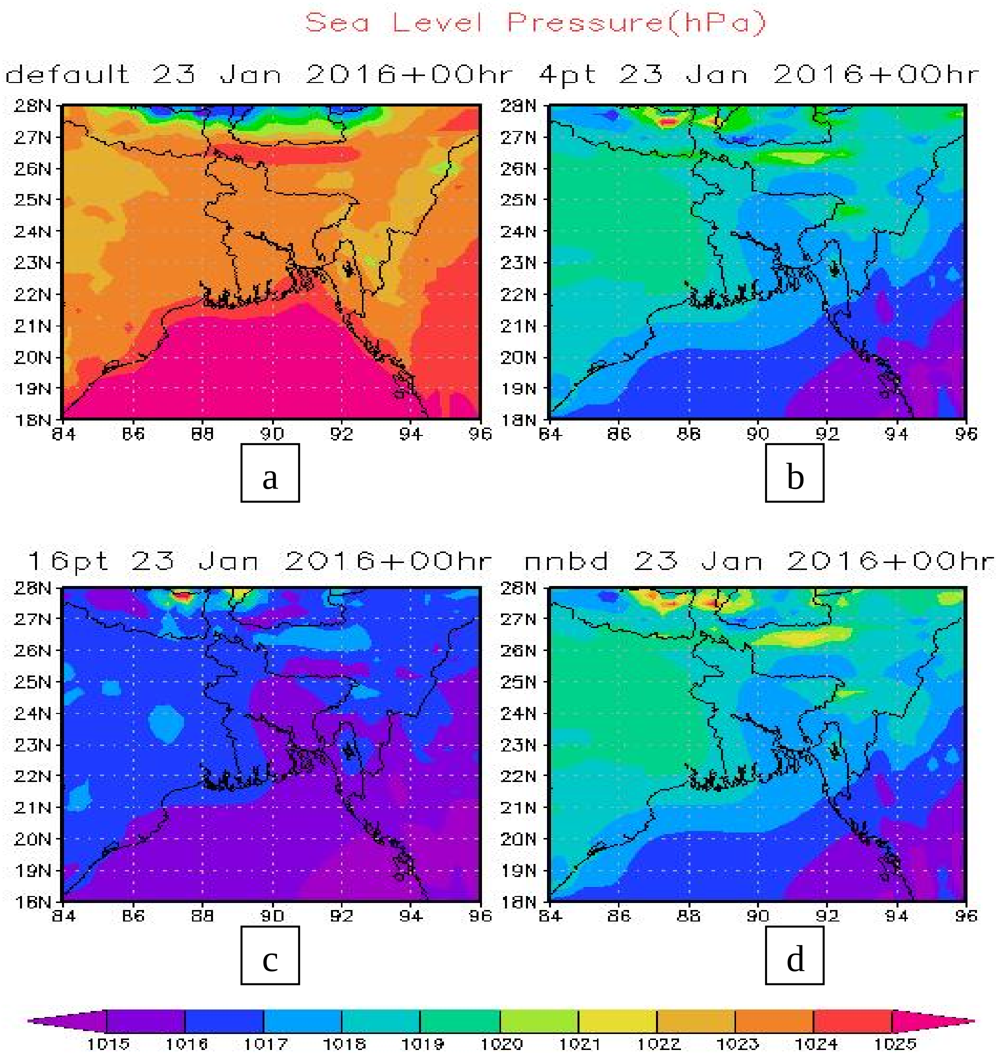



Figure 4.3.5 Sea Level Pressure (slp) 23 January 2016 at 00 hours

Figure 4.3.5 represents Sea Level Pressure (slp). This picture indicates that the images a and b are same but the images c and d are different from upper. Because images a and b are used four point interpolation technique. We use sixteen point and nearest neighborhood interpolation technique and having some changes. If someone observe the locations $25^0$, and $85^0$E. S/he must agree with me that there are some changes with respect to others interpolation technique. Besides the pictures of the upper right corners are different with respect to different interpolation techniques.

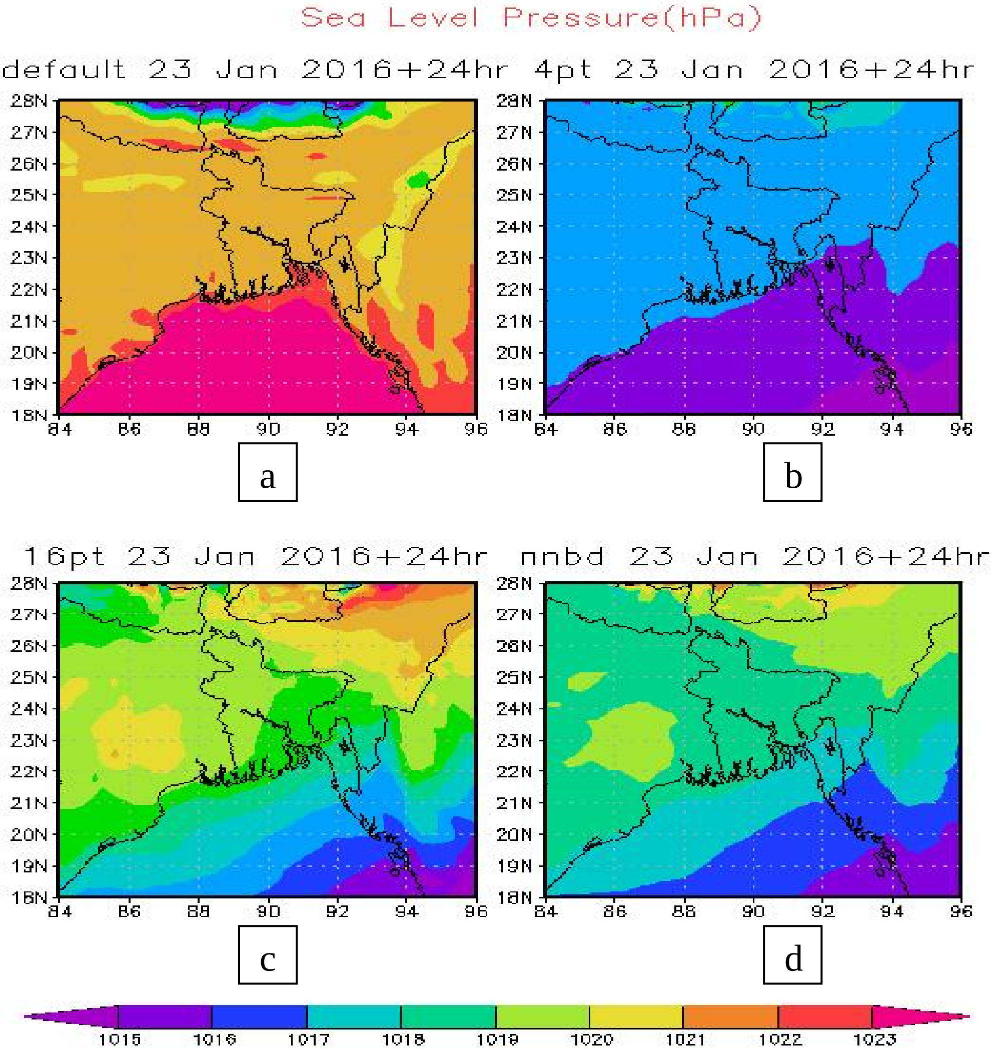



Figure 4.3.6 Sea Level Pressure (slp) 23 January 2016 at 24 hours

Figure 4.3.6 represents Sea Level Pressure (slp). This picture indicates that the images a and b are same but the images c and d are different from upper. Because images a and b are used four point interpolation technique. We use sixteen point and nearest neighborhood interpolation technique and having some changes. If someone observe the locations $25^0$, and $85^0$E . S/he must agree with me that there are some changes with respect to others interpolation technique. Besides the pictures of the upper right corners are different with respect to different interpolation techniques.

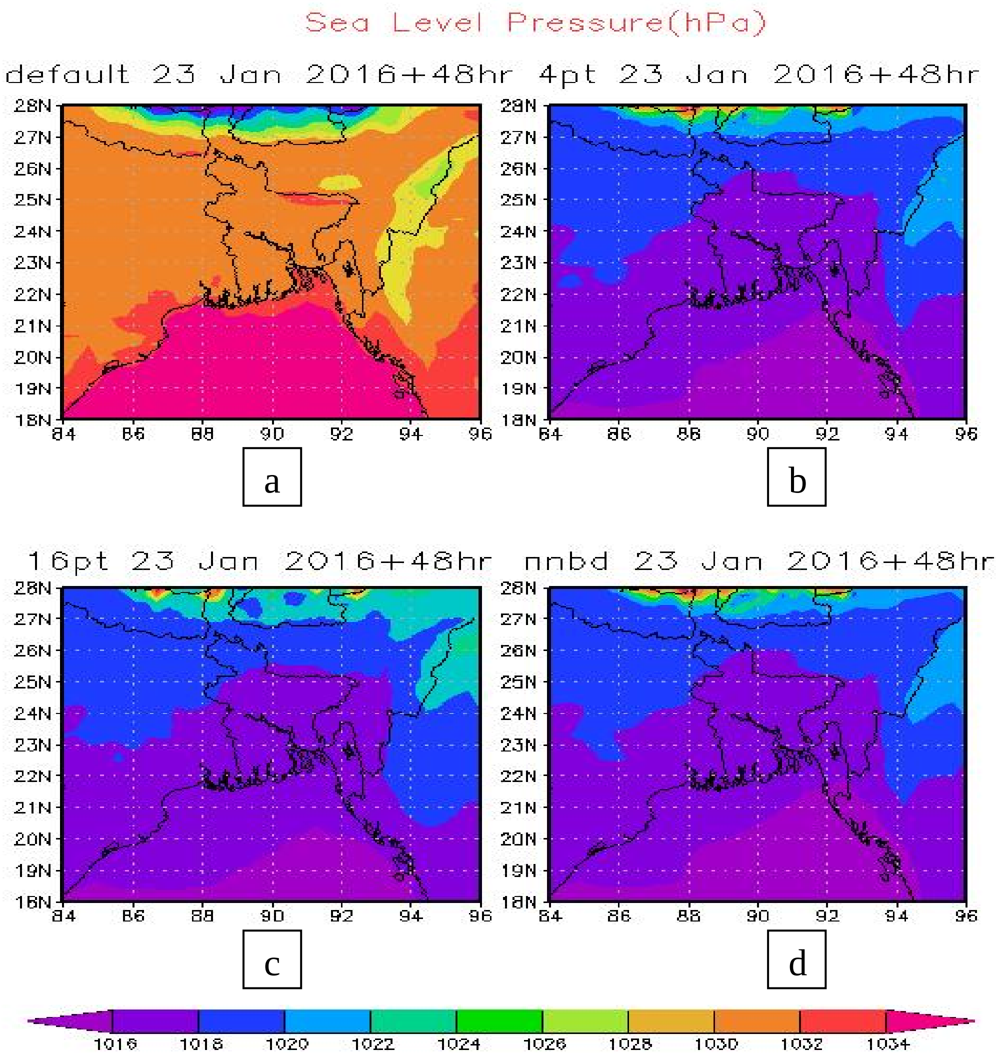



Figure 4.3.7 Sea Level Pressure (slp) 23 January 2016 at 48 hours

Figure 4.3.7 represents Sea Level Pressure (slp). This picture indicates that the images a and b are same but the images c and d are different from upper. Because images a and b are used four point interpolation technique. We use sixteen point and nearest neighborhood interpolation technique and having some changes. If someone observe the locations $25^0$, and $85^0$E . S/he must agree with me that there are some changes with respect to others interpolation technique. Besides the pictures of the upper right corners are different with respect to different interpolation techniques.

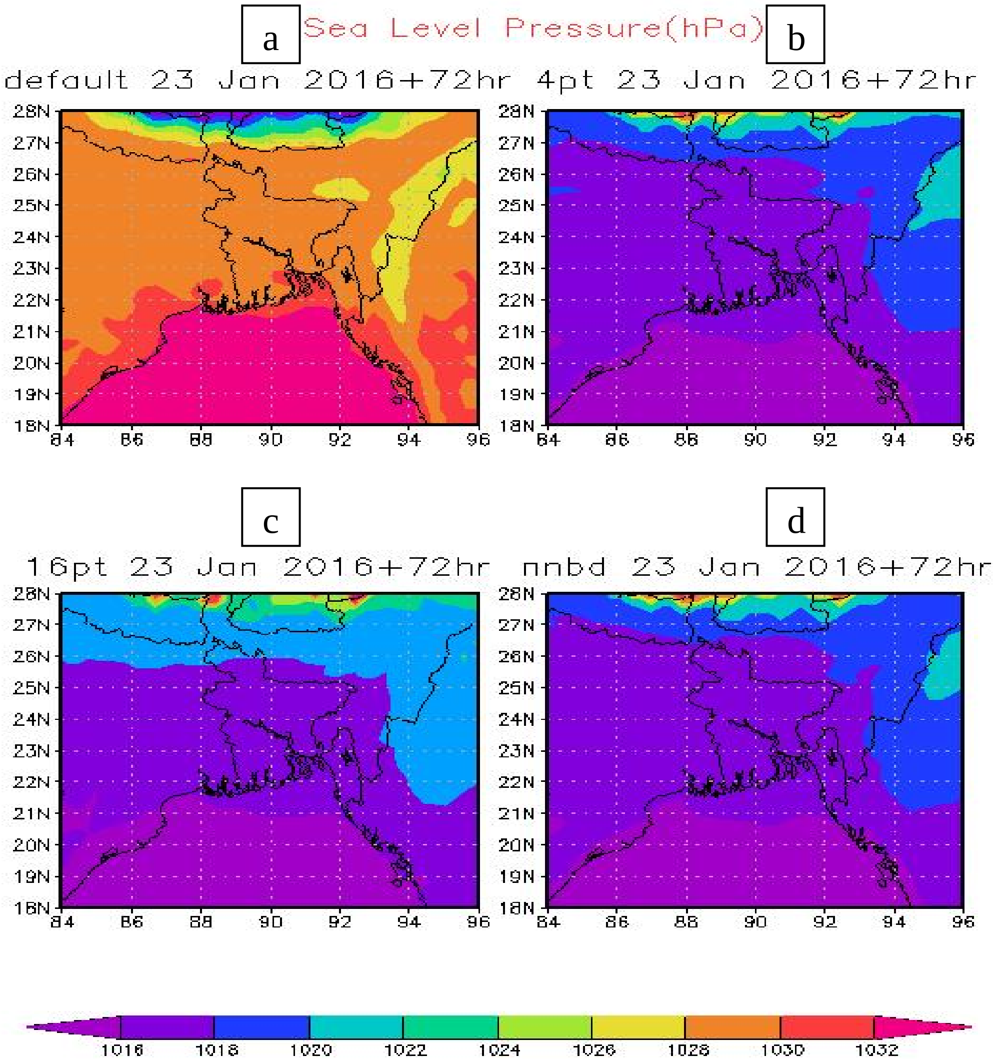



Figure 4.3.8 Sea Level Pressure (slp)of 23 January 2016 at 72 hours

Figure 4.3.8 represents Sea Level Pressure (slp). This picture indicates that the images a and b are same but the images c and d are different from upper. Because images a and b are used four point interpolation technique. We use sixteen point and nearest neighborhood interpolation technique and having some changes. If someone observe the locations $25^0$, and $85^0$ E. S/he must agree with me that there are some changes with respect to others interpolation technique. Besides the pictures of the upper right corners are different with respect to different interpolation techniques.

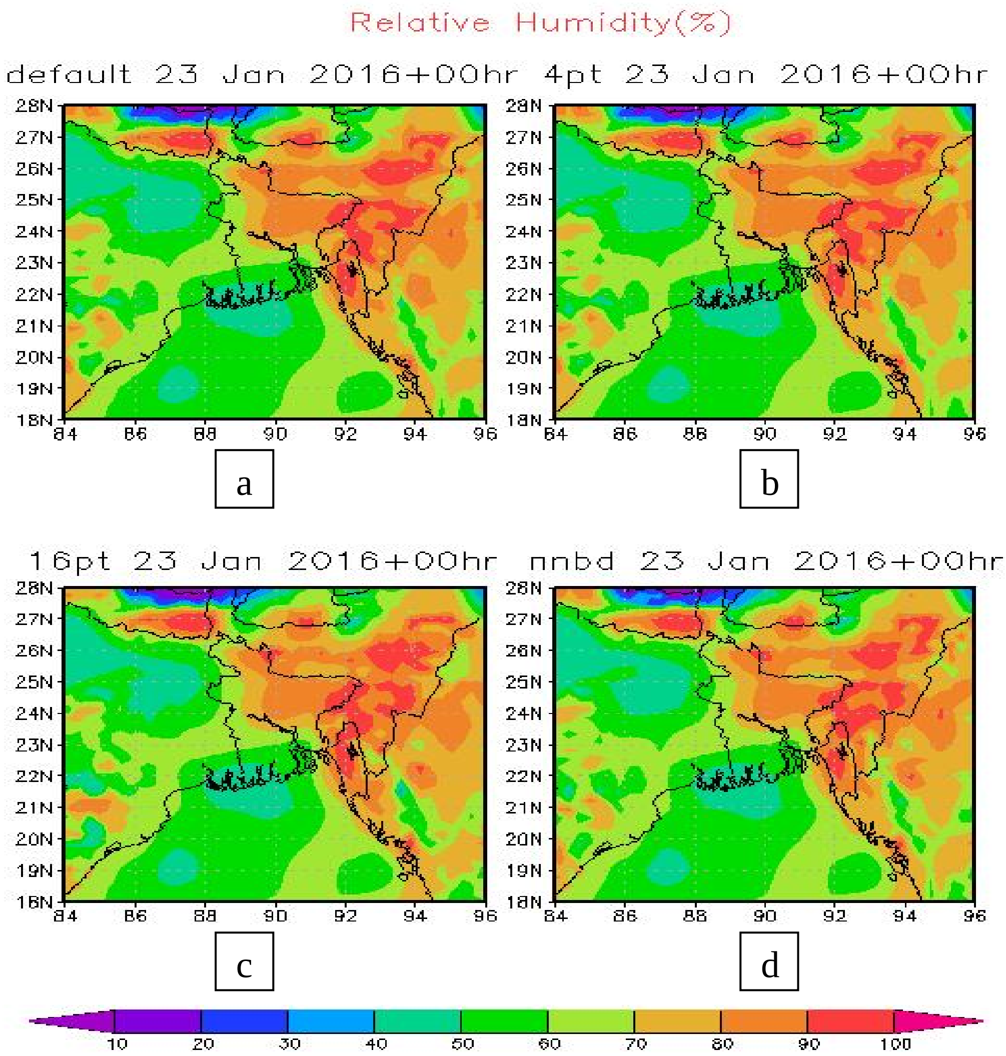



Figure 4.3.9 Relative humidity(rh) of 23 January 2016 at 00 hours

Figure 4.3.9 represents relative humidity scenario. This picture indicates that the images a and b are same but the images c and d are different from upper. Because images a and b are used four point interpolation technique. We use sixteen point and nearest neighborhood interpolation technique and having some changes. If someone observe the locations $25^0$, and $85^0$E . S/he must agree with me that there are some changes with respect to others interpolation technique. Besides the pictures of the upper right corners are different with respect to different interpolation techniques.

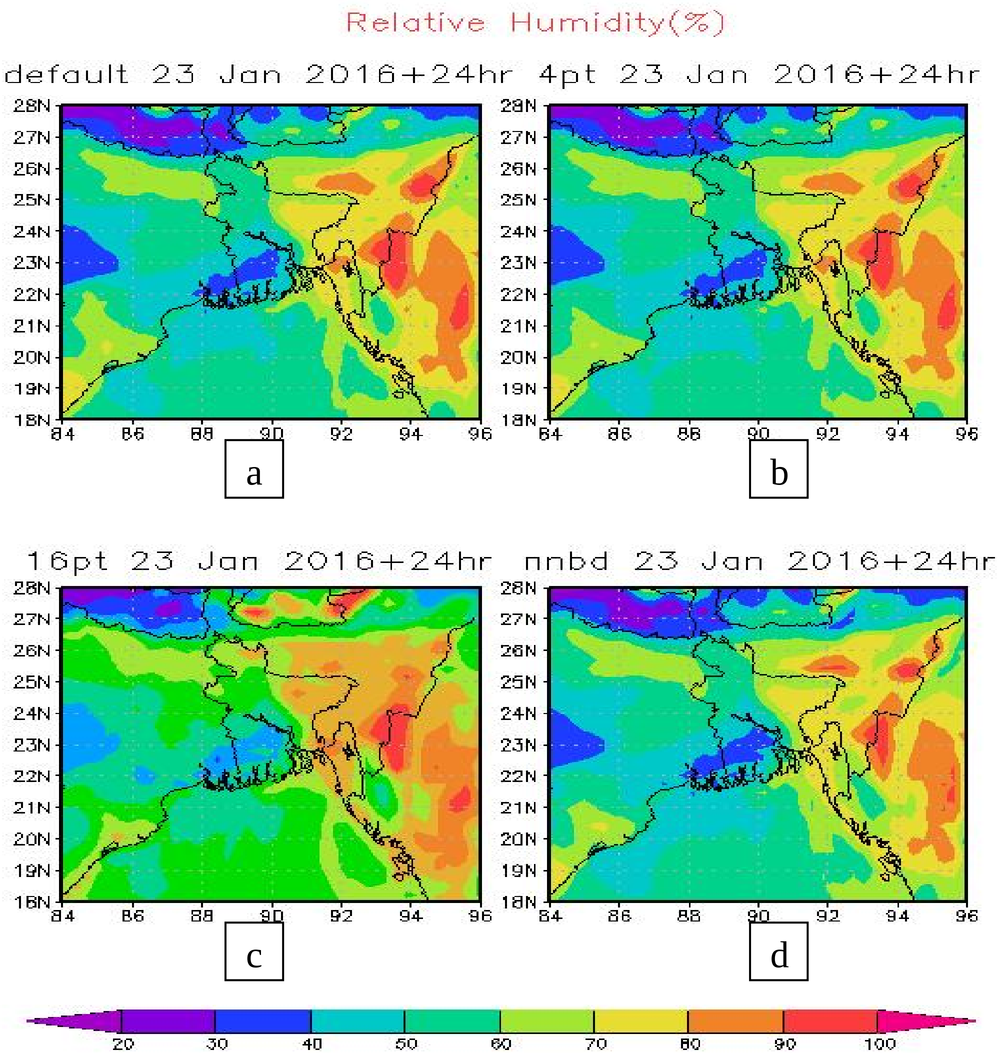



Figure 4.3.10 Relative humidity(rh) of 23 January 2016 after 24 hours

Figure 4.3.10 represents relative humidity scenario. This picture indicates that the images a and b are same but the images c and d are different from upper. Because images a and b are used four point interpolation technique. We use sixteen point and nearest neighborhood interpolation technique and having some changes. If someone observe the locations $25^0$, and $85^0$E . S/he must agree with me that there are some changes with respect to others interpolation technique. Besides the pictures of the upper right corners are different with respect to different interpolation techniques.

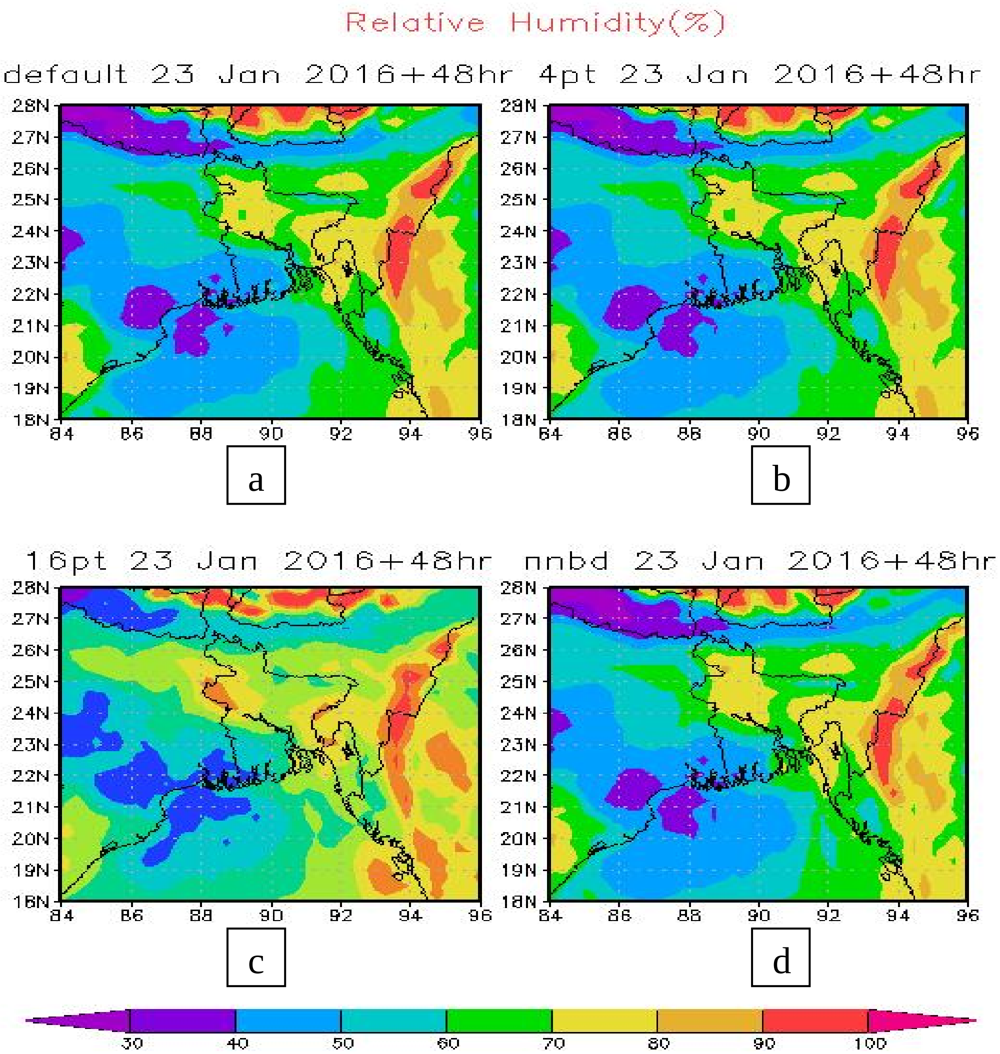



Figure 4.3.11 Relative humidity(rh) of 23 January 2016 after 48 hours

Figure 4.3.11 represents relative humidity scenario. This picture indicates that the images a and b are same but the images c and d are different from upper. Because images a and b are used four point interpolation technique. We use sixteen point and nearest neighborhood interpolation technique and having some changes. If someone observe the locations $25^0$, and $85^0$E . S/he must agree with me that there are some changes with respect to others interpolation technique. Besides the pictures of the upper right corners are different with respect to different interpolation techniques.

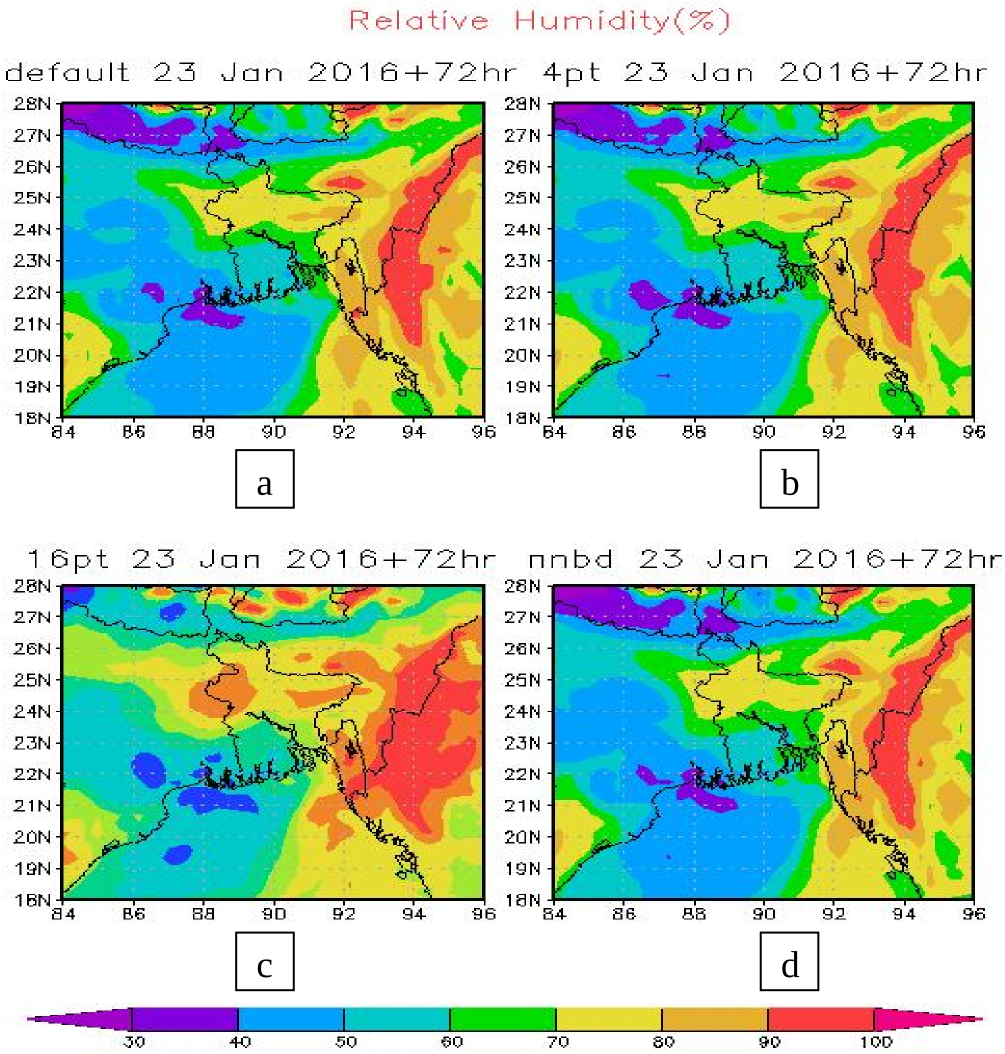



Figure 4.3.12 Relative humidity(rh) of 23 January 2016 after 72 hours

Figure 4.3.12 represents relative humidity scenario. This picture indicates that the images a and b are same but the images c and d are different from upper. Because images a and b are used four point interpolation technique. We use sixteen point and nearest neighborhood interpolation technique and having some changes. If someone observe the locations $25^0$, and $85^0$ E. S/he must agree with me that there are some changes with respect to others interpolation technique. Besides the pictures of the upper right corners are different with respect to different interpolation techniques.

# Chapter 5

# Conclusions

In this research work, primarily it was assumed that if change is made on the interpolation technique, the output might be changed.For the verification purpose of this assumption, three different phenomenon has been studied on which attention has been given to the parameters temperature, sea level pressure, wind speed, cumulus precipitation and relative humidity. Onthe basis of the results it can be concluded that

- In case of temperature prediction an insignificant difference between the default and 4 pt interpolation outputs are observed. The outputs on the basis of 16 point and nearest neighborhood interpolation are quite different.
- In case of relative humidity predictiondefault and 4 pt. interpolation are similar, though with the advance of time a little discrepancy isobserved.
- In case of accumulated total cumulus precipitationprediction 4 point interpolation are similar to default. Nearest neighborhood has less deviation than 16 pt.with respect to default.
- In case ofwind speed the effect of different interpolation schemes are like precipitation estimation. 4 point is similar to default then with respect to deviation nearest neighborhood and then 16 point.
- For the prediction of the sea level pressure none of the cases are comparable in terms of time.

Finally, it is suggested that rigorous study should be done to identify the case of the tremendous effect of interpolationscheme on the prediction of sea level pressure.

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