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A Comparative Study of high Resolution Weather Model WRF & ReGCM Weather Model

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Abstract: The science of numerical weather forecasting [1] is as old as the advent of ENIAC . Earth System Models or atmospheric models are built on the basis of interdependence among the prognostic variables and their effect on the atmosphere. These models have succeeded in predicting the future weather conditions provided initial weather inputs are fed to the system. A remarkable progress has been seen in this field for the past 50 years, giving a clear understanding of climate change which is increasing daily with the invention of advanced complex prediction methodologies . These models have found applications in a variety of fields including climate prediction, data assimilation, case studies, theoretical & sensitivity studies. In this presentation, a survey study is made regarding the 2 mostly used weather models: WRF and RegCM, their evolution followed by architectures, applications and advantages .

Keywords*:* Numerical Weather Forecasting, Atmospheric Models, WRF , RegCM.

I. INTRODUCTION

Population in economically developing nations like India depend extensively on climate for their welfare (e.g., agriculture, water resources, power generation, industry) and likewise are vulnerable to variability in the climate system. Weather forecasting deals with the methodologies providing timely and expected weather forecasts which is highly crucial for agriculture based countries. Its origin took place in about 19th century, when the great American meteorologist Cleveland Abbe concluded from his experiments that meteorology is essentially the application of hydrodynamics and thermodynamics to the atmosphere'' [3]. Climate models, both global and regional, are the primary tools that aid in our understanding of the many processes that govern the climate system. These models [2] use differential equations ,conservation laws(Fig 2),formulated based on the factors governing the physical behavior of the atmosphere ,dividing the Earth into a 3D grid coordinate system(Fig 1). The interaction among these variables (wind components , surface pressure, temperature, mixture of cloud water , ice ,snow etc) with the adjacent grid cells help in calculation of future atmospheric conditions.

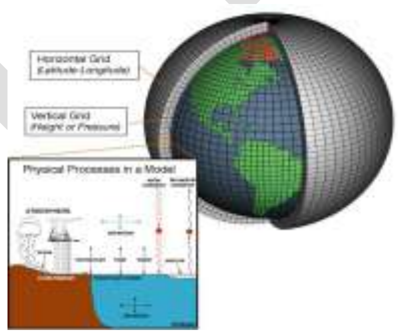

Fig 1: Atmospheric model schematic

A. *Model Types*

1. Cloud-Resolving Models (CRMs)
2. Mesoscale Models
3. Numerical Weather Prediction (NWP) Models
4. Regional Climate Models (RCMs)
5. Global Circulation Models (GCMs)

The seasonal predictions made by these Earth models are generally computed by the use of High Performance Computing architectures. Scientific simulations[12] are typically compute intensive in nature. It takes week or days to obtain result if ordinary single processor system is used. For example, in predicting weather the amount of computation is so large that it could take ordinary computer weeks if not months. To make a simulation more feasible the use of High Performance Computing (HPC) is essential. HPC is the use of supercomputers and complex algorithms to do parallel computing i.e. to divide large problems into smaller ones, distribute them among computers so as to solve them simultaneously.

B. Important Issues to be Considered While Building Models

1. *Purpose:* The model should be able to reflect its purpose for Eg: Whether it is build for NWP or climate simulation, climate and weather case and process studies etc.
2. *Efficiency vs. Accuracy:* These 2 factors play a major role in prediction purpose so,the model should utilize the available resources well to produce better results.
3. *Domain and Resolution*: The area of interest (Domain) must be large enough to protect the main region of our study from boundary effects and resolution denotes the scale of features which can be simulated with the model.Generally Regional models presents higher resolution over smaller domains than global ones.

$$\frac{\partial \overline{V}}{\partial t} + \overline{V}\cdot\nabla\overline{V} = -\frac{\nabla p}{\rho} - 2\overline{\Omega}\times\overline{V} + \overline{g} + \overline{F}_{\overline{V}}$$ Conservation of Momentum

$$C_p\left(\frac{\partial T}{\partial t} + \overline{V}\cdot\nabla T\right) = \frac{1}{\rho}\frac{dp}{dt} + Q + F_T$$ Conservation of Energy

$$\frac{\partial \rho}{\partial t} + \overline{V}\cdot\nabla\rho = -\rho\nabla\cdot\overline{V}$$ Conservation of Mass

$$\frac{\partial q}{\partial t} + \overline{V}\cdot\nabla q = \frac{S_q}{\rho} + F_q$$ Conservation of Water

$$p = \rho R T$$ Equation of State

Fig 2:Climate Model Equations.

The sequence of the process starting from the observations obtained from radar, sattelites till the outcome of fine predicted or simulated results is a long way when all the things are put together illustrated by the diagram (Fig 2)

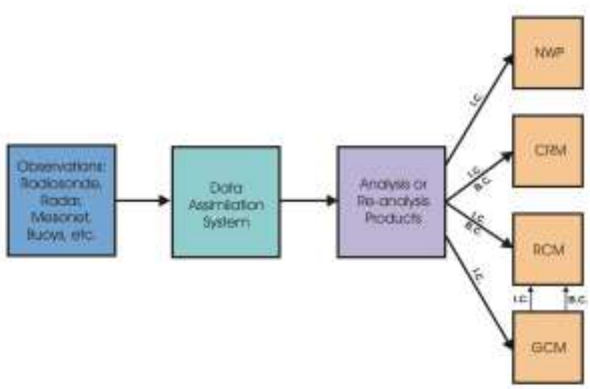

Fig 3 From observations to model simulation/prediction

II. WRF MODEL

A. Definition.

TheWeather Research and Forecasting(WRF) model is a mesoscale community model[15] developed jointly by National Centre for Atmospheric Research(NCAR) Advanced Research WRF(ARW) , National Centers for Environmental Predictions'(NCEP) Non-hydrostatic Mesoscale Model(NMM) .This dynamic model inherits all the enhanced features and dynamical cores of the above communities , making it a full fledged end-to-end forecasting system .WRF software has been designed for real time simulation of the atmosphere, air quality modeling, wildfire simulation and advanced hurricane and tropical storm prediction, intensifying the bond between research and operational forecasting communities .

B. *Model Software Architecture*

Software development and maintenance costs adds a lot to the total cost of a large numerical simulation code. Moreover cost for computational resources is greatly reduced with a code able to run on multiple high-performance computing platforms. The modular and hierarchical architecture(Fig 4) of WRF facilitates grouping of multiple dynamic cores and plug-compatible physics in a single code over a diverse parallel platforms thus providing performance portability, extensibility, usability, run-time configurability, interoperability, among different Earth models. It is neutral with respect to external packages for I/O and makes effective use of computer aided software engineering (CASE) tools.

The WRF model is presented in a three-level hierarchy (Figure 2) structure.

1. The highest levels correspond to the *driver layer* holding the responsibilities of top-level control of initialization, time-stepping, I/O, instantiating domains, maintaining the nesting between domain type instances , decomposition,parallelism and processor topologies.
2. The *model layer* correspond to the lowest layer containing the subroutines required for actual model computations.
3. The mediation layer acts as the interface between the model and driver layers encapsulating the unwanted information . It encompasses the features of inheritance along with encapsulating details that are of no concern to other layers .

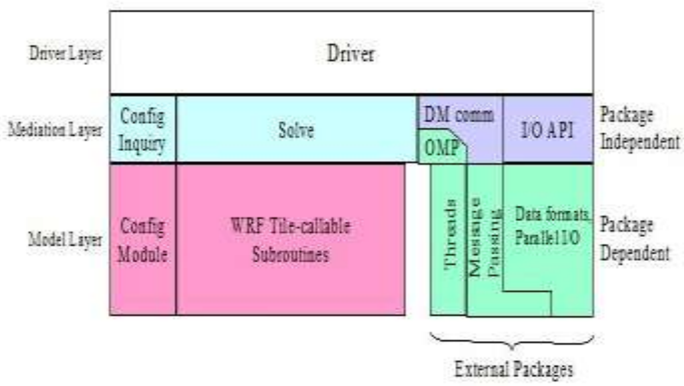

Fig 4: WRF 3-Hierarchy Stucrure.

C. *WRF System Model*

The following fig(5) depicts the system architecture of a WRF model with a brief description of its components .

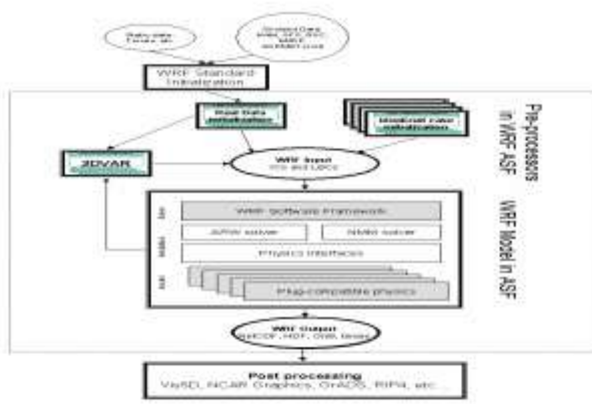

Fig 5:WRF System Model

i *Model Components* :Preprocessors for producing initial and lateral boundary conditions for idealized, real-data, and one-way nested forecasts.Postprocessors for meant for analysis and visualization purpose.A three-dimensional variational data assimilation (3DVAR) program for obtaining three dimensional input data. Each of the preprocessors and 3DVAR are parallel programs implemented using the WRF Advanced Software Framework (ASF). Data streams between the programs are input and output through the ASF's I/O and Model Coupling API. The WRF Model (large box in figure) contains two dynamical cores(ARW and NMM) providing flexibility and initialization programs for real and (for ARW) idealized data (real.exe/ideal.exe) in applications.

D. Working of WRF Model.

Some of the details for running WRF are architecture dependent. For distributed memory runs, it is usually necessary to use some form of the mpirun command; for example: mpirun -np 4 wrf.exe In general, however, for single-processor or shared memory parallel runs, the command is ./wrf.exe. It can be specified by either tile aspect ratio through the WRF namelist.input file. To run WRF it is necessary to first generate a set of initial conditions which will be read in from the file wrfinput. We need to set the io form option in the namelist.input file to '1' and the other options such as grid dimensions, dx, dt, etc. and then type ./ideal.exe in the run directory. This will generate the file wrf input. As long as the basic grid specifications are not changed in the namelist. input file, you can continue to reuse the wrf input file for multiple runs of the wrf.exe code.After that we need to edit the namelist.input file to set such run-specific items as number of time steps, output frequency, etc. and then run the wrf.exe code using the procedure for your system . WRF will input the namelist.input file and also the wrfinput file of initial conditions. As it runs it will output to the file wrf output file.

However during the run of WRF model one of its component ie.WRF Pre-processing System (WPS) plays a major role.Its main function is to interpolate the Real-data while dealing with numerical prediction cases along with adding more aobervations for analysis.The diagram(Fig 6) depicts the workflow co-ordination among WPS and WRF .

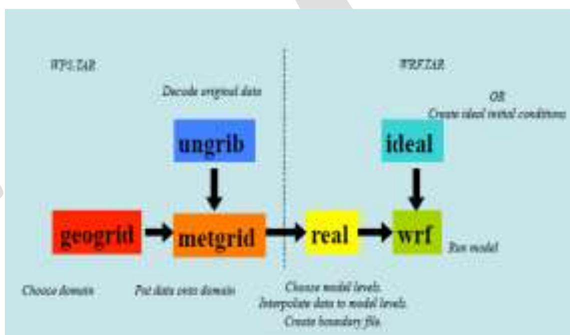

Fig 6: WPS AND WRF Program Workflow

E. Basic Software Requirement

i. Fortran 90/95 compiler-- Code uses standard f90 (portable).
ii. C compiler- Registry"-based automatic Fortran code generation (for argument lists, declarations , nesting functions, I/O routines).
iii. Perl-- configure/compile scripts.
iv. Netcdf library-- for I/O operations and machine independent feature.
v. MPI if distributed memory is used.

F. Merits and Demerits of WRF Model

The table(1) below gives an overview of the merits and demerits of a WRF model.

MERITS	DEMERITS
1. Better numeric , less diffusive ,allows real and idealized simulations in same framework by granting longer time steps . 2. Better handling of topography with plug-in architecture and nesting feature. 3. Use of Fortran 90 ,NetCDF ,GRADS,MPI(for shared memory operations).	1. Smaller range of physics choices . 2. Software design is unintuitive for physical scientists as NetCDF files can be huge sometimes. 3. Comparatively slower and take hours to compile.

TABLE 1: MERITS and DEMERITS of WRF MODEL.

In 2004 a WRF benchmark (Fig 7) was developed in order to demonstrate computational performance and scaling of this model on different architectures.It was run on multiple platforms ,changing the number of processes and their performance in terms of simulated seconds was noted.

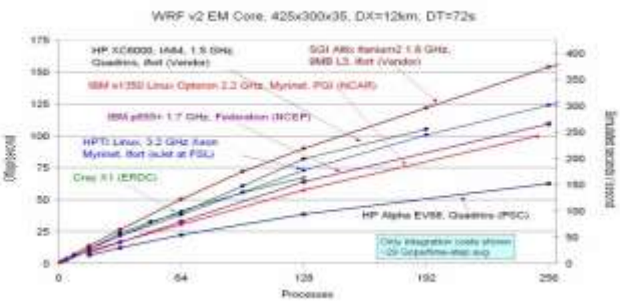

Fig 7: WRF Benchmark (2004)

III. REGCM MODEL

RegCM is an open source Regional Climate Model(Limited Area Model), originally developed by Giorgi et al. [8,9] and then modified, improved and discussed by Giorgi and Mearns [10] . It uses the *Downscaling*[11] method for getting a clear high-resolution (Fig 8)weather information (for Eg giving a better representation of the underlying topography at a scale of 50 km or even less) compared to that relatively coarse-resolution information by global climate models (GCMs).

However, the RCM is susceptible to any systematic errors in the driving fields provided by the GCM. High frequency, i.e. 12 or 6 hourly, time-dependent GCM fields are required to provide the boundary conditions for the RCM. Table 2 lists the various dynamical and physical packages of successive versions of the RegCM system.

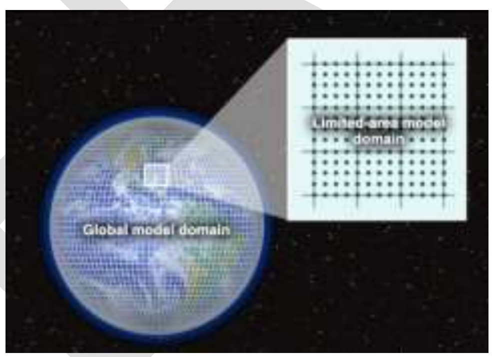

Fig 8: Snapshot of RegCM Resolution

	RegCM1	RegCM2	RegCM2.5	RegCM3
Primary references	Dickinson et al. (1989) Giorgi and Bates (1989)	Giorgi et al. (1993a,b)	Giorgi and Shields (1999) Pal et al. (2000)	
Dynamics	MM4 Anthes et al. (1987)	MM5 (hydrostatic) Grell et al. (1994)	MM5 (hydrostatic) Grell et al. (1994)	MM5 (hydrostatic) Grell et al. (1994)
Radiative transfer	CCM1 Kiehl et al. (1987)	CCM2 Briegleb (1992)	CCM3 Kiehl et al. (1996)	CCM3 Kiehl et al. (1996)
Boundary layer	Local Deardorff (1972)	Nonlocal, counter-gradient Holtslag et al. (1990)	Nonlocal, counter gradient Holtslag et al. (1990)	Nonlocal, counter gradient Holtslag et al. (1990)
Land surface	BATS 1a Dickinson et al. (1986)	BATS 1e Dickinson et al. (1993)	BATS 1e Dickinson et al. (1993)	SUBBATS Giorgi et al. (2003a)
Convective precipitation	Anthes–Kuo Anthes (1977)	Grell (1993) Anthes (1977)	Zhang and MacFarlane (1995) Grell (1993)	MIT (Emanuel 1991) Anthes–Kuo, Grell (1993)
Resolvable precipitation	Implicit Giorgi and Bates (1989)	Explicit Hsie et al. (1984)	SIMEX Giorgi and Shields (1999)	SUBEX Pal et al. (2000)
Aerosols and chemistry	Not available	Not available	Qian and Giorgi (1999) (no dusts)	Solmon et al. (2006) Zakey et al. (2006)

TABLE2: DESCRIPTION of the PROGRESSION of the VERSIONS of the REGCM SYSTEM

A. *RegCM Model Description*

The different types of global data needed in order to localize the REGCM model is given by the following diagram (Fig 9) followed by the typical REGCM architecture(Fig 10) and its components description.

Fig 9: RegCM Global Data

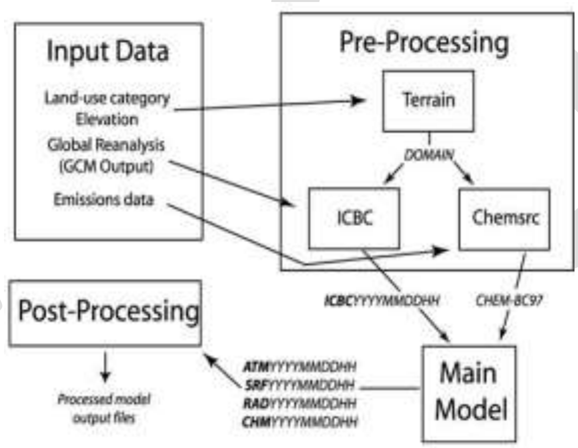

Fig 10: RegCM Architecture Model

1. *Model Components:* The Terrain file is used for creating the domain file consisting localized topography and projection information. The SST for the model is created using sst program containing the sea surface temperature to be used in generating the icbc for the model and lastly the ICBC files created using icbc program, contains surface pressure, temperature, horizontal wind components and time resolution for the input file.

After successfully running the model it generates 4 files in the output directory.

i. ATM –Contains atmosphere status of the model.
ii. SRF-Contains surface diagnostic variables.
iii. RAD –Contains radiation information.

B. *Software Requirements.*

i. Unix or Linux OS.
ii. FORTRAN 90/95 compiler, python language interpreter.
iii. Make utility (GNUmake).
iv. NetCDF library.
v. MPI (for parallel shared memory).
vi. Graphics (GrADS, FERRET, NCL,) for visualization.

C. *Applications of Regional Climate Modeling*

i. Model development and validation with a high resolution for smaller areas.

ii. Used in process studies such as topographic effects, regional hydrolic budgets.
iii. Climate change studies
iv. Paleoclimate studies(Climate effects of aerosols).
v. Seasonal prediction
vi. Impact studies

D. Advantages and Disadvantages of RCM Modelling

MERITS	DEMERITS
1. Physical and comprehensive based downscaling climate modeling system. 2. Wide variety of applications such as process studies ,Climate change and Seasonal prediction. 3. High resolution through multiple nesting (currently 10-50 km grid interval)	1. Only one-way nesting so no regional-to-global feedbacks. 2. Not intended to correct systematic errors in the large scale forcing fields

TABLE 3:MERITS and DEMERITS of RCM MODELLING

E. Basic Issues in RCM Modeling

Ratio of forcing fields resolution to model resolution should not exceed 6-8. For a successful RCM simulation it is thus critical that the driving large scale boundary conditions be of good quality.Model physics if happens to be same in both in the nested RCM and driving GCM then better interpretation of model results is obtained. The model resolution should be sufficient to capture relevant forcings and to provide useful information for given applications.

IV. IMPORTANCE OF RCM OVER GCM.

Global Climate Models (GCMs) are mainly used for simulating global climate system ,providing estimates of climate variables [6]. The GCM owing to its coarse resolution and lack of fine features their accuracy normally decreases for a small area. To overcome the limitations of GCM, dynamical downscaling using high-resolution Regional Climate Models (RCMs) nested(Fig 12) in GCMs are used. These RCMs lead to better estimations of future climate conditions since their horizontal resolutions are much finer than the GCMs [5].Fig 11 gives a practical view of the distortion made by GCM over a limited area compared to RCM.

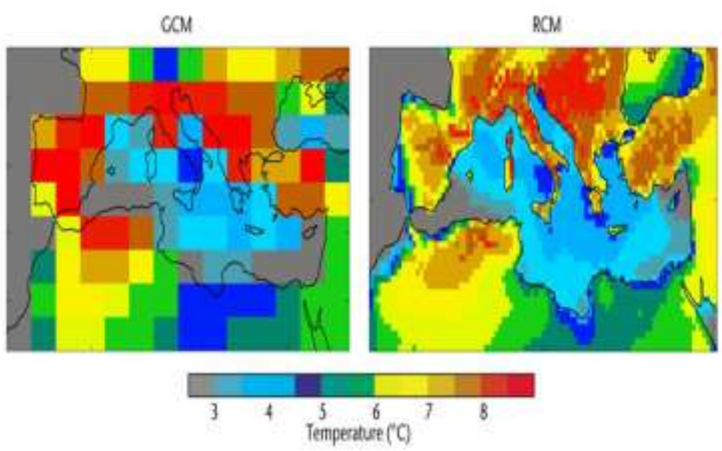

Fig 11: GCM and RCM Resolution View Over a Small Region.

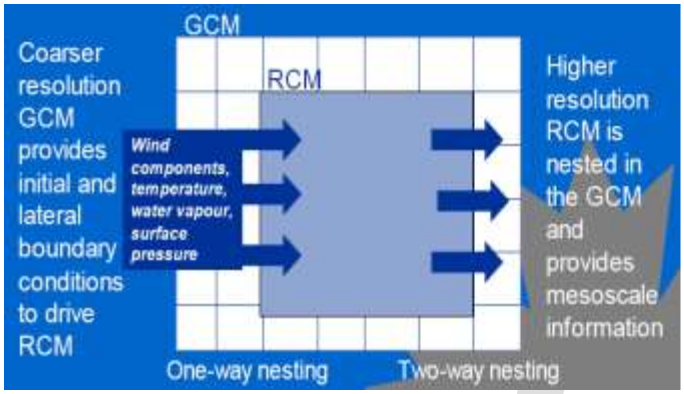

Fig 12:Nesting

A. *Comparison of the Two Models.*

The Figure (TABLE 4) below gives some points differentiating the two models with respect to their use and behavior.

GCM	RCM
1. Due to their relatively coarse resolution, GCMs are unable to include the effects of regional features. 2. GCM provide minimum of 200 km grid spacing. 3. GCMs are used for simulation of global climate system.	1. RCM are meant for relatively fine resolution for regional or small areas. 2. RCM can provide to at least 20-60 km of grid spacing. 3. RCMs are used for simulation of regional climate system.

TABLE 4: COMPARISON of RCM AND GCM

Here we have included a Fig(TABLE 5) giving a brief inter comparison of all the related features of the different available climate models.

	MC2	GEM	CRCM	CCCma GCMIII
Regional/ Global	Regional	Global	Regional	Global
Physics Package	RPN	RPN	CCCma GCMIII	CCCma GCMIII
Hydrostatic	N	Y	N	Y
Spatial Discretization	Finite-Differencing	Variable Grid Spacing, 3-D Finite Element	Finite-Differencing	Spectral, finite-element in vertical
Timestepping	SISL	SL, 2-level implicit	SISL	SI
Vertical Coord	Terrain-Following (Gal-Chen)	Terrain-Following (Eta)	Terrain-Following (Gal-Chen)	Terrain-Following (Eta)
Applications	Cloud-scale and mesoscale modelling, regional forecast	NWP, Data Assimilation, Research	Regional climate simulation and prediction, regional climate change scenarios	Global Climate prediction and simulation, climate change scenarios

TABLE 5: INTER-COMPARISON of DIFFERENT MODELS

V. CONCLUSION

Thus we have got a clear cut idea about these two models in our discussion made so far regarding their history, applications, working of the models, software requirements and a brief comparison of them .GCMs and RCM s have increased our level of understanding about the on-going atmospheric processes and the prediction of the same after a long period.Though climate modeling has made sufficient improvements in the last decades still researchers are undergoing experiments in different aspects regarding the increase in scale and lowering the cost,how to make finer resolutions feasible,coupling of RCMs with other climate models,more extensive comparative studies and last but not the least development of a two-way nesting mechanism.These areas hold a great work as future scope to be made yet in climate system modeling.

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