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Study of Martian Atmosphere Using GCM over HPC Cluster– A Survey

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ABSTRACT: General Circulation Model as the name suggests is the climate model. This model is based on the physics and mathematics that provides the general circulation study of atmosphere of planets. The equations used in this model are used to generate computer programs that simulate the atmosphere of planets. These programs can be used for prediction or forecast of weather and to understand and study the climate changes and forecasting them. These models require the integration of various chemistry, physics and biological equations.

A model is a very complex system that defines many components. These components are given as inputs to various mathematical equations. The equations are very complex and require high computation that cannot be solved using computers with simple configuration but high performance computing which does tera(10^{12}) floating points operations in a blink of an eye.

KEYWORDS: General Circulation Model, HPC cluster, Martian atmosphere

I. INTRODUCTION

General Circulation Model, GCM, are tools designed for the climate modeling. It is a challenge to complete model runs at reasonable resolution for studies of longer time scale. Coupled atmospheric/ocean simulations require enormous computational power.[4] Recently, some modelers have turned to modular model runs to produce better predictions; a strategy that magnifies resource demands. For the time scales of global climate change, coupled model run can last hundreds of simulated years (e.g. 15); for studies of the thermohaline circulation, those numbers stretch into the thousands.
To meet these needs, supercomputer manufacturers have offered a variety of solutions. Since the 1980's, parallel vector processors have been the most widely used by the GCM community.[2] However, in the 1990's cache-based massively parallel processor (MPP) machines have become increasingly prominent. These machines confront model designers to write code that runs efficiently within a single processor yet scales well for hundreds of processors. In addition, these models must be easily compliant to rapidly changing machine architectures and communication software so as to avoid time-consuming code rewrites.
The first part of the paper I. gives introduction to the GCM and atmospheric model, II. Gives introduction to the GCM and comparision of different GCMs, III. Is the related work and the technical survey of the GCMs, IV. is the introduction to HPC clusters and V. is the conclusion and future work.

II. GCM AND THEIR COMPARISION

Since the Mars missions have started there arose a need to calculate and simulate the information that was gathered. This data was calculated using many highly complex physical and mathematical equations. Therefore there was a need to develop General Circulation Model(GCM) in which the data was fed and it produced required output. These GCMs were nothing but computer programs written in Programming Language that contained atmospheric equations. Further details of the GCMs is given as following.

The study of Martian Atmosphere dates back to 1960s, when the Mars mission were initiated by NASA. The GCM developed to study the Martian Atmosphere then was called the NASA AMES. Later year after year the model progressed and new equations were added to the model. Also the MCD(Martian Climate Database) was developed which provides the information of the Martian atmosphere right from day one till date. There were many GCM developed with time. The GCM of NASA Ames, had designed and deployed many atmospheric research expidition by 1978. the climate scientists of Ames and the aircraft were successfully used to measure the cloud particles in the volcanic eruptions. The atmospheric science research of Ames expands through climatic changes produced by clouds, aerosols and greenhouse gases, stratosphere-troposphere exchange and the change in the chemical compisition of troposphere. To make observations the instruments like aircraft, unmanned aerial systems, balloons, were used. Inorder to understand the controlling mechanism models of chemistry, cloud, radiative transfer processes and dynamics were developed using the results. Even today, Ames is a leading center of NASA for atmospheric science research. Ames operates one of the world′s fastest supercomputers, Pleiades, which has a configuration of 10 petaflops of processing power.

In GFDL(Geophysical Fluid Dynamics Laboratory) the work is done over understanding the various features of weather and climate. the concentration is over the atmosphere and oceans influenced by various trace constituents. Comprehensive coupled climate model are developed to understand the air quality and climate. This too includes the study of aerosols, chemistry, clouds, biochemistry, for better understanding of carbon cycle. This includes the study of various disciplines such as, fluid dynamics, chemistry, oceanography, physics, etc.

LMDZ is a general circulation model developed since the 70s at the Laboratoire de Météorologie Dynamique(LMD) of CNRS, France[1]. It uses Fortran 77 and 90 for implementation. This specifically includes the models to understand the earth and other planets. The physical parameters addressed in this model are: Radiative heating and cooling of the atmosphere, surface thermal balance, convection, condensation of CO_2, water ice clouds, Chemistry, thermosphere etc.

III. RELATED WORK

The Ames Mars model is development of NASA. The key improvements in the model since 1980s is as following. In 1980s-1990s, they considered that plays a significant role in the Martian atmosphere. Many algorithms were implemented and the model was tested by increasing the number of layers up to 13. By 2000s their research turned towards the simulations of tracer transportation. Also their research was concerned with the microphysics and dust lifting schemes. Photochemistry was added later 2010 onwards to study the impact of trace gas transport.

The code and data files used in Ames Mars GCM are setup to run on standard little-endian (x86, x86_64) Linux computers that uses the GFORTRAN compiler. The code requires the GFORTRAN version 4.3 or later to work properly. This is the information of the radiative transfer code used in the NASA Ames Mars GCM(v23, September 2010).

The code for GFDL model is written in the FORTRAN language. It would run on any unix platform that has perl version 5 installed. This is because the tool that would construct the makefile is written in perl5. The recent publication version of the code is 4.12.

LMDZ gives a terrestrial model of earth and other planets. Around 1990s-2000s LMDZ developed various models for different planets such as Earth, Mars, Venus, Titan respectively. Around 2008 a generic GCM was developed to study the Early Earth and Early Mars conditions. Since 2011 work is done to gather the all versions into one main framework. LMDZ model is efficient enough to simulate the behavior of the atmosphere appropriately.

Initially Leovy and Mintz(1969) attempted to create a Mars GCM by successfully adapting the terrestrial GCM of University of California, Los Angeles.[11] Later they worked over adapting French Laboratoire de Météorologie

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Dynamique (LMD)to Martian conditions. A successful simulation was carried out of a full Martian year and was published(Hourdin et al 1993,1995).[11] Alongwith the Reading University a Mars GCM, which was a simple dynamical model, was then developed at Oxford in early 1990s(Collins and James 1995).[11] Later the work is going on to extend a single model to upper atmosphere(Angelats i Coll et al. 2003).[11]

IV. HPC CLUSTER

HPC clusters are a collection of High Performing Computer nodes that are connected together to solve large computing tasks. These give a Single System Image(SSI) to the end user. The user submits a job to the master node and the master node further distributes the job to the nodes. Heavy computing tasks that would take days while running on the simple computer can be done within few minutes or few hours using the HPC cluster. HPC clusters are used in many systems namely medical, imaging, commerce, oil and gas expiration, to bioscience, climate and atmospheric research, data warehousing, data security, and many more. HPC allows scientists, researchers and engineers to solve complex problems related to science, engineering and business problems using applications that require features like high bandwidth, low latency networking, and very high computing capabilities.

Nowadays most of the supercomputers use the Linux Operating System, but the manufacturers as per their requirement have their own specific Linux-derivative therefore there is no existing industry standard. This is because the different hardware architecture, require optimization of the operating system for each hardware design. For intercommunication in the cluster nodes, loosely connected clusters PVM and MPI are used while for tightly connected clusters OpenMP is used.

The performance of supercomputers is measured and benchmarked in "FLOPS"(FLoating point Operations Per Second), and are prefixed as tera-1012(TeraFLOPS), peta-1015(PetaFLOPS), Exascale-1018(ExaFLOPS)[12].

HPC clusters play a major role in research of atmospheric sciences. The data that is extracted is very huge, and takes hours for calculation in super computers. the equations used in the climate and atmospheric studies are very complex. they require high computing.

Current GCMs solves many issues as i. The general Dynamics of Mars, ii. Physical processes in the Atmosphere, iii. Chemical processes in the atmosphere. Our interest is to concentrate over the Chemical processes, in particular Ozone formation and destruction in the Martian atmosphere.

V. CONCLUSION AND FUTURE WORK

This paper is a survey that gives the concise information and comparison of GCMs and their use for implementing and studying the atmospheric science. GCM models are highly authenticated and verified models used for weather forecasting and prediction of the behavior of various gases and particles present in the planet's atmosphere. In the course of time many GCMs are introduced and developed by various organizations. These GCMs are: NASA Ames which was developed in 1970s, photochemistry was added to the project in 2010 to study the effect of tracers in the atmosphere; GCM by Geophysical Fluid Dynamic Laboratory; LMDZ by Laboratoir de Meteorology, France; Oxford's GCM model, which is based on the LMDZ model; and many others. These models are executed over the HPC clusters. The further study of Martian atmosphere by getting the recent data of Mars and adding them into the GCM as per our requirement is possible.

The future work includes further simulation and study of the photochemistry with different parameters. Few such parameters are scavenging of dust particles by condensing clouds, Thermal structure of mesosphere, behavior of the radiatively active clouds, the cloud structure prediction. Addressing these issues will help us study the Martian atmosphere more accurately.

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