Report on the
Brain Storming Seminar on the

High Performance Computing for Weather and Climate Modeling

held at IIT Delhi
on March 2 - 4, 2005

S. K. Dash

Centre for Atmospheric Sciences
Indian Institute of Technology Delhi
Hauz Khas, New Delhi 110016

Special Geographical Position of India

- India has a special geographical location in the tropics with vast wide land to the north and ocean to the south giving rise to large differential heating.
- There are a large number of mountain ranges with numerous peaks and complex terrain heights across the country.
- Weather and climate of India are basically dominated by the southwest monsoon circulation which gives rise to rainfall of large spatial and temporal variations.
- India has a long coastline affected by severe cyclones. India in general is full of glaciers, ecosystems and biodiversity which are vulnerable to global warming.
- Today it is very important to examine the impact of climate studies in the regional scales.
- Considering the complexity if India's terrain and the associated weather and climate it is absolutely essential to use very high resolution (1-5 km) regional model nested to global model.
- Such modeling studies warrant HPC platforms.

HPC Initiatives by DST, Government of India

- **Parallelisation of the operational weather forecasting model of the National Centre for Medium Range Weather Forecasting (NCMRWF) has been successfully done by many leading centres of the country on their indigenously built parallel computers such as PARAM, FLOSOLVER, ANUPAM and C-DOT High Performance Parallel Processing System (CHIPPS).**

- **It may be noted that PARAM, FLOSOLVER and ANUPAM have been designed and fabricated by the Centre for Development of Advanced Computing (C-DAC), the National Aerospace Laboratories (NAL), and the Bhaba Atomic Research Centre (BARC) respectively.**

- **These parallel computers along with ANURAG of Defence Research & Development Organization (DRDO) have been extensively used for many other computer intensive applications in computational fluid dynamics, scientific visualisation and molecular dynamics.**

Belief

- With the existing knowledge of our monsoon phenomenon, it is possible to improve our forecasting skill by certain percentage using state-of-the-art computers; of course with more observed data.

- It does not underscore the need for better understanding of the atmospheric processes.

- It only emphasizes the need to churn more out of the existing knowledge by using the technology to the maximum extent possible.

The Seminar

➢ ***The objectives of the seminar were to:***

- **review the current international and national status on HPC in meteorological applications,**
- **review the existing computing resources available with the premier institutions concerned with weather and climate in the country,**
- **debate on using state-of-the-art computers available in the country for operational weather forecasting with high resolution numerical models and**
- **prepare a report on the future requirements of computing resources.**

➢ **The seminar was inaugurated by Prof. V. S. Ramamurthy, Secretary, DST in the Senate Room of IITD on March 2, 2005 at 9:30am.**

The Seminar (Contd…)

- **Representatives of various organizations engaged in the field such as NCMRWF, IMD, Indian Institute of Tropical Meteorology (IITM), Indian Institute of Science (IISc), Space Applications Centre (SAC), IITD, C-DAC, NAL, Centre for Mathematical Modeling and Computer Simulation (C-MMACS) and BARC presented:**

(1) current HPC and modeling activities in weather and climate in their institutions along with the existing computing facilities and

(2) research plan and the requirements of HPC facilities till 2010 in the first phase and till 2020 in the second phase.

- **Besides the above institutions there were also short presentations from IIT Kharagpur, Cochin University of Science and Technology (CUSAT), Jadavpur University, Air Head Quarters and Snow and Avalanche Studies Establishment (SASE).**

The Seminar (Contd…)

- **Representatives of reputed computer organizations such as Intel, IBM, CRAY, Silicon Graphics and HP also presented**

(1) the state-of-the-art HPC power available with them and

(2) their roadmap up to 2010 in the first phase and 2020 in the second phase. These computing organizations were represented by Dr. David Barkai (Intel), Mr. David Blaskovitch (IBM), Mr. Per Nyberg (CRAY), Mr. Andrew Wyatt (SGI) and Dr. Enda W. O' Brein (HP).

- **There were 88 registered participants** including e**xperts in weather and climate, technocrats, software engineers, policy makers, young researchers attended and participated in the seminar.**

- **Based on deliberations on the first two days, a panel discussion was held on the third day to arrive at a number of recommendations.**

India Meteorological Department

NUMERICAL MODELS

1. LIMITED AREA ANALYSIS AND FORECAST MODEL

   Horizontal Resolution: 0.75x0.75 lat/long

2. QUASI-LAGRANGIAN MODEL

   Resolution : 400x400 lat/long 40 KM, 16 SIGMA LEVELS

3. FLORIDA STATE UNIVERSITY REGIONAL SPECTRAL MODEL

   Resolution: 0.68x0.75 lat/long with 16 sigma vertical

4. STORM SURGE MODEL

COMPUTER SYSTEMS at IMD

- **SGI ALTIX 350**

  (2 CPU Intel Itanium 1.4 GHz Processor, 2GB RAM)

- **SGI ORIGIN 200**

- **Power Edge 1600SC DELL (Xeon Processor)**

PLAN FOR URGRADING IMD COMPUTERS

- **CPU: Sustained performance of 100 Gflops upgradable to 500 Gflops.**
- **MAIN MEMORY : 128 GB or more with a provision for upgradation to 1 TB.**
- **Processors bandwidth - 100 GB/sec or more.**
- **Hard disk - 1 TB scalable to 10 TB or more.**

Models at NCMRWF

- **Global Atmospheric Models**
  - T80/L18 at 150 km resolution
  - T170/L28 at 75 km resolution
- **Mesoscale Atmospheric Models**
  - MM5 (Nested 90, 30, 10 km)
  - Eta at 48 & 22 km resolutions
  - Regional Spectral Model (50 km)
- **Ocean Wave Model**
  - WAVEWATCH-III at 1 Deg for Global Oceans
- **Crop-Weather models**
  - CERES model for cereals
  - CROPGRO model for legumes

COMPUTER SYSTEMS at NCMRWF

CRAY SV1: 24 processor vector system performance of 3-4 Gflops.

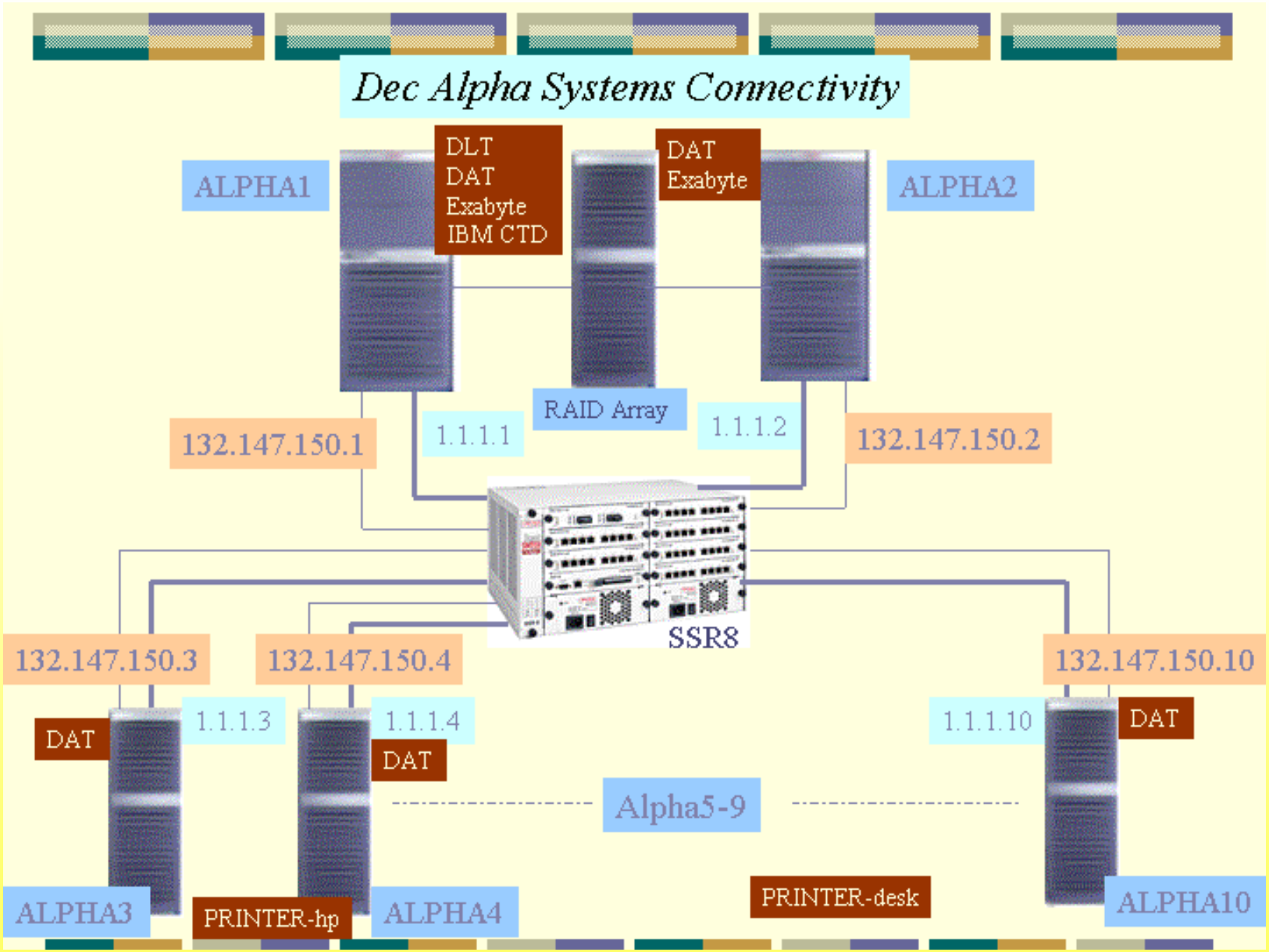
ANUPAM-ALPHA System (Developed by BARC)

2 Nos. DEC-ALPHA Servers AS4100 @600MHz each with Memory of 1GB each.

9 Nos. DEC-ALPHA Work Stations @600MHz each with Memory of 512MB each.

Inter-Node communication: Gigabit Ethernet Smart Switch Router.

ANUPAM-Alpha system



INDIAN INSTITUTE OF TROPICAL METEOROLOGY

Numerical Models:

- **Atmospheric Global spectral**
  T30 GCM (~ 3.75^{o} x 3.75^{o} and 18 sigma levels)
- **Atmospheric Global Grid -point model (3.75^{o} x 2.5^{o} and 18 levels**
- **POP Ocean General Circulation Models (OGCM)**
  (1.875^{o} x 1.4^{o} horizontal resolution and 32 vertical levels)

- **Regional Climate Models: Downscaling GCM**
- **Land-climate-Water Modeling: Integrated Biosphere simulator**
- **Mesoscale Modeling:**
  MM5; RAMS: Regional Atmospheric Mesoscale System ARPS: Advanced Regional Prediction System
- **Regional Land Ocean Coupled Models**
- **Global Chemistry-Transport model: MOZART**
- **Regional Atmospheric pollution Model: REMO-CHEM**
- **Chemistry-Climate GCM for Upper Atmosphere: HAMMONIA**
- **Modeling of tropical clouds**

Computing Resources at IITM

Existing facilities :

High End Workstations- 18
Pentium PCs- 150

Configuration	Present Need	5-10 Years Down
64 bit Processing Capacity	1 TeraFLOPS (64/128 processor)	5 TeraFLOPS (≥256 processor)
Memory	500 Gigabytes	1 Terabyte
Storage	40 Terabytes	150 Terabytes
Mass Storage Device	SDLT /Tape Library with 4 drives	Robotic Tape Library with 15 drives
Estimated Investment	Rs. 15 Crores	Rs. 50-60 Crores

Centre for Atmospheric Sciences, IIT Delhi

Numerical Models

Model Name	Data Assimilation 3 D-VAR of MM5 system	MM5	COAMPS	ARPS	RCM
Purpose	Improved analysis for initial and boundary condition	Simulation of Mesoscale phenomena	Study large scale features through coupling of ocean and atmosphere	Air-Sea interaction, boundary layer study	Regional Climate predication
Area	IMR	Indian region	Orissa	over Indian Ocean	South East Asian monsoon
Resolution	60 km & 20 km	30 km (as reqd basis)	27 km	25 km	90 km
Future plan	Meso-Scale Analysis for ARMEX	Couple MM5 with Ocean Model MOM.	Sensitivity Studies on different Parameterization Schemes.	Sensitivity Studies on different PBL Parameterization Schemes.	To study the impact of satellite derived surface parameters.

Computer Resources at CAS ,IITD

Workstation/ Server/Make	Model	Number of Processors	Speed	RAM	HDD
IRIX/ORIGIN 300	SGI	Two	500 MHz	1 GB	90 GB
SUN-ULTRA 10	SUN	Single	266 MHz	128 MB	4 GB
DIGITAL COMPAQ ALPHA	ALPHA	Single	500 MHz	256 MB	108 GB
IBM	IBM P570	Four	1.9 GHz	8 GB	876 GB

Computer Resources at CAS ,IITD

(continued…….)

Workstation/ Server/Make	Model	Number of Processors	Speed	RAM	HDD
IRIX/ORIGIN 2100	SGI	Two	500 MHz	512MB	18 GB
SUNFIRE 280R	SUN	Single	900 MHz	4GB	144 GB
ALPHA COMPAQ	ALPHA	Single	667 MHz	1GB	140 GB
ALPHA COMPAQ	ALPHA	Single	350 MHz	512MB	54 GB
COMPAQ DEC-ALPHA	ALPHA	Single	500 MHz	256MB	108 GB

Centre for Atmospheric and Oceanic Sciences, Indian Institute of Science, Bangalore

- **Atmospheric Model**
  - Horizontal Resolution: T-42 2.85 x 2.85 (latitude x longitude) resolution.
  - Eulerian Spectral Model with Semi-Lagrangian Moisture Advection.
  - Cloud simulation (cumulus parameterization) Scheme of Zhang and McFarlane (1995).
  - Shortwave radiation using the Delta-Eddington Scheme of Briegleb (1992).
  - Longwave Calculations using the Absorptivity-Emissivity method of Ramanathan and Dewey (1996).
  - Boundary Layer computations using Monin-Obhukov theory.
  - Winds, temperature, humidity, rainfall are the major products from the atmospheric model.

- **Ocean Model**
  - 1x1 Global Ocean model on Arakawa C-Grid.
  - Primitive Equation model with free surface conditions.
  - Ocean currents, salinity, sea-surface height, sea surface temperature are the major products from the ocean model.

Space Applications Centre, Ahmedabad

Numerical Models

- Extended Range Monsoon Prediction (ERMP)
- Mesoscale Model (MM5)
- Climate Model for Global Change (CCM)
- Global Ocean Model for Ocean State Forecast (MOM)

  Horizontal Resolution: Variable nested grid (862 x 458 points)

  Vertical Resolution: 35 levels with 15 levels in top 150m.

Ocean Wave Model (WAM , SWAN)

WAM: Grid resolution : 1^o x 1^o
SWAN: Grid resolution : 0.08 x0.08

Radiative Transfer Model (RTTOV7)

Computer Systems at SAC

- 2 Itanium-II 4 cpu machines
- Clock Speed ~ 1 GHz
- OS – Linux
- Intel compiler
- Disk space ~ 280 GB each
- RAM – 8 GB

Centre for Mathematical Modelling and Computer Simulation

Atmosphere and Climate

Long-range Forecasting of Monsoon
4D- Variational Data Assimilation
Long-lead Forecasting of cyclone

Ocean Modelling

Ocean Chemistry and Marine Productivity
Global Ocean Circulation
Carbon cycle

Computing

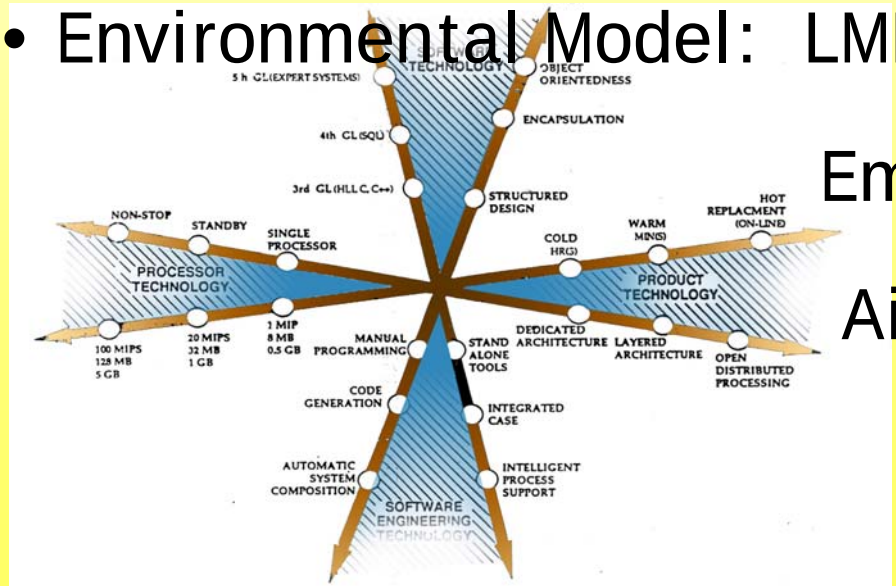
- **High resolution with multi model interface**
- **Parallel computing in a multi-tasking (ensemble simulation) environment**
- **Storage, Pre processor memory, stack size for very high I/O Computing**
- **User-oriented, productive benchmarking**

Centre for Development of Advanced Computing

- Weather Forecast Model: T80, T126,T170, WRF, MM5
- Ocean Model: MOM4
- Climate Model: CCSM
- Environmental Model: LMD Chemistry

  Emission Inventory

  Air Quality Model



C-DAC's Terascale Supercomputing System

1 Teraflop peak performance

248 Nos. of Power 4 RISC Processors

AIX / LINUX Operating System

PARAMNet-II System Area Network @2.5 Gbits/Sec Full Duplex

C-DAC HPCC Tools based programming environment

www.cdacindia.com

IGrid Infrastructure

- **10TF of Computing Power in the Grid**
- **At least 100TB of storage (possibly a Petabyte)**
- **Backbone connectivity evolving to several Mbits/sec.**
- **Visualization Infrastructure with high resolution displays**
- **Application drivers :** *Bioinformatics, Weather Forecasting, Seismic Data Processing*

Computing Resources at NAL

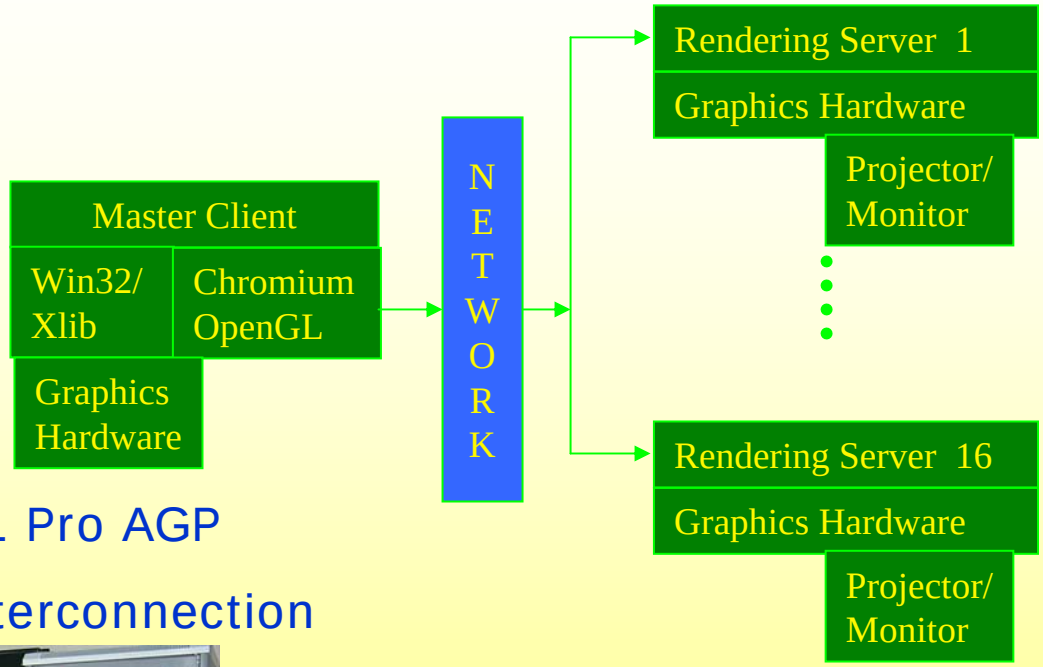
- Developed as part of the NMITLI project
- Flosolver Series: Mk1, Mk2, Mk3, Mk4 SCSI Switch, Mk5 32 Nodes
- Mk6
  - 8-processor independent units with FloSwitch interconnect
  - FloSwitch is custom built for met applications
  - Four 8 node machines interconnected with Flo-Opti-Link switch
- MoU with TCS
- Target hardware: 128 processor machine

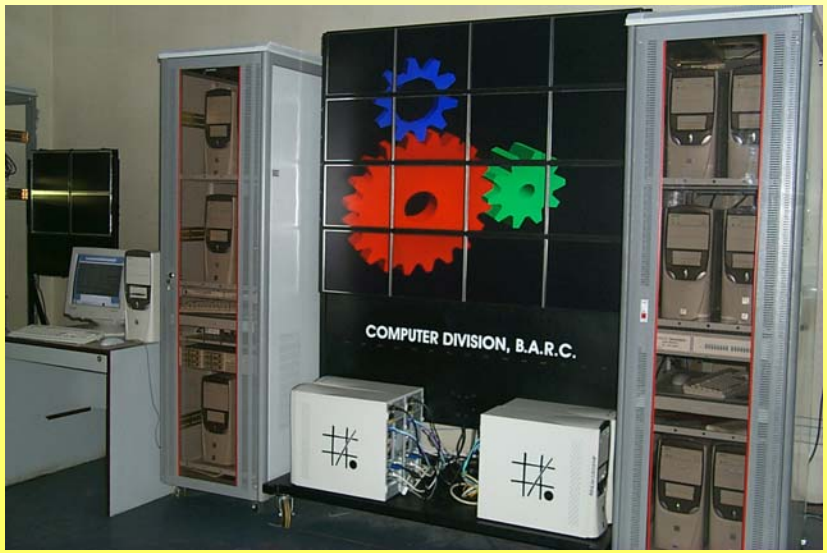
Computer Division, BARC, Mumbai
Rendering Cluster & High Resolution Display

Rendering Cluster

- 1 Master Client
- 16 Graphics Servers
- 1.7 Ghz P-IV Processors
- 512 MB RAM per PC
- Graphics Cards

  64 MB 3DlabsOxygenGVX1 Pro AGP
- Fast / Gigabit Ethernet Interconnection





High Resolution Display

- Tiled 4x4 LCD Panels
- 5120 x 4096 total resolution

  1280 x 1024 per LCD

Computing Grid at BARC

- *Computing Grid system has been set up as a Test-Bed using existing Grid Technology Components*

100 Mbps fiber Grid Enable Visual Area Network

2

1 HPC

Grid Enable

4

Web Service

AFS

PBS

Globus

Fabric

Clusters

3

Visual Data server

Grid Enable

Recommendations

1) More trained manpower and many fold enhanced computing resources

- **In spite of the fact that India as a nation needs to focus more on weather related research, the manpower and infrastructure available for cutting-edge research are very less compared to other developed countries.**

- **Estimate indicates that India has about one tenth of the manpower and one thousandth of the computing power available at a similar reputed organization engaged in weather and climate research in a developed country.**

- **Thus there is no second opinion to the fact that India as a nation has to generate more trained manpower and create many fold enhanced computing resources for research and operational weather forecasting at all time scales.**

2) Three types of Weather & Climate related Organizations

- **Major government organizations like IMD, NCMRWF, SAC and Indian Air Force (Met. Branch) who have to deliver operational products and hence need committed/dedicated HPC resources. They are able to get their resources from their internal budgetary mechanism and project their future needs too.**

- **The second type of organizations include BARC, NAL, C-MMACS and C-DAC who have also mechanism to project and meet their HPC requirements.**

- **The third type of organisations are autonomous research centers, IITs and Universities. They have huge capabilities in modelling and are trying to keep abreast with the latest R&D. However, their computing resources are sub-critical and need to be urgently addressed if they have to remain in the forefront of research in atmospheric sciences. Their needs could be met most efficiently by establishing at least two HPC centers in the country.**

3) Requirements of Operational Organizations

- **Requirements of operational agencies are different from those of academic and research organizations. They work on real time data and forecasts have tremendous societal consequences.**

- **These agencies such as IMD and NCMRWF need the most powerful computers for operational forecasting.**

- **Such operational agencies should have their own group of software scientists devoted to the continuous maintenance and growth of the operational numerical models. These scientists will exclusively be responsible for efficient running of numerical models in the HPC environment and conduct research on getting maximum throughput on any available platform.**

4) Needs of Research Organizations

- **Each research organization needs a critical level of manpower and computing resources to deliver results.**
- **It may be difficult to create and sustain high computing resources optimally for several such research institutions. Hence, sharing of resources through the grid computing is a possible solution.**
- **High bandwidth machines such as vector machines are considered to be ideal for operational agencies where performance is the key. On the other hand, scalar machines have shown dramatically improved performance in recent times and are cost-effective so far as research activities are concerned.**
- **Augmentation of internet bandwidth adequately and internal network to Gigabit Ethernet with a fiber-optics backbone should also be an integral part of the proposed supercomputer facilities.**

5) Computing resources for Universities

- **Universities are the primary source of scientific manpower.**

- **Computing consists of major chunk of research in weather & climate and thus it is appropriate to develop the curriculum in such a way that the existing Masters students in the country get maximum exposure to the use of computers in modeling of the atmosphere-ocean system.**

- **Such trained young scientists will become assets in the future and also they will be more interested to build career in this challenging field.**

- **For teaching and research activities, a large number of low-end computing resources should be provided to all the academic institutions and Universities in the country.**

6) HPC Research in India

- **India has demonstrated the capability of developing HPC platforms based on off-the-shelf components. This effort should be continued at a faster pace with the objective of having teraflop or petaflop machines soon.**

- **India need research in issues related to hardware design as well as in the development of software engineered to operate efficiently on the developed hardware.**

- **Data mining is also an important issue.**

- **There should be balanced effort to build successful computing groups strong in hardware as well as in software.**

- **The organizations like C-DAC, NAL and BARC have demonstrated capabilities to do work in the field of providing HPC solutions and their infrastructure should be upgraded to compete with internationally computing environment.**

7) Future Need of Computing Power

➢**Future requirements based on sustained speed are given below:**

Time scale	Short Term (Two Years)	Medium Term (by 2010)	Long Term (by 2020)
Sustained speed	1 Tflops	100 Tflops	1Pflop
Model resolution	40 km (T319L60)	25 km (T511L60)	10 km

➢ **However, for the effective solution of a multi-dimensional problem such as weather and climate, one should consider sustainable interconnect speeds, storage speeds, memory and visualization capabilities, ability to be upgraded etc. as benchmark criteria in addition to the sustained speed.**

8) Availability of continuous financial sources

- **While creating two centralized HPC centres emphasis should be given on the sustenance of state-of-the-art technology.**
- **In order to keep up with the cutting-edge research one has to keep up with the latest technology also.**
- **Hence, there should be inbuilt mechanism to upgrade the HPC systems from time to time.**
- **There should be continuous financial sources available to upgrade the machines to state-of-the-art computers.**

9) Regular Interactions

- **Interaction between weather and climate scientists on one hand and computer scientists on the other is very essential for the growth of NWP and climate studies.**
- **More interactive seminars to be held regularly.**


Thank You