The role of precision in meteorological computing:

A study using the NMITLI Varsha GCM

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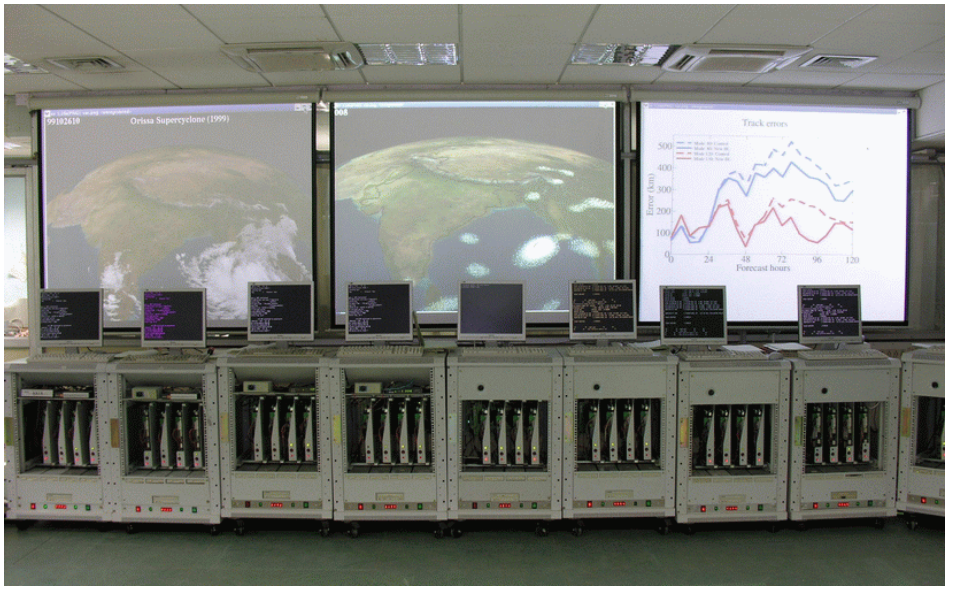
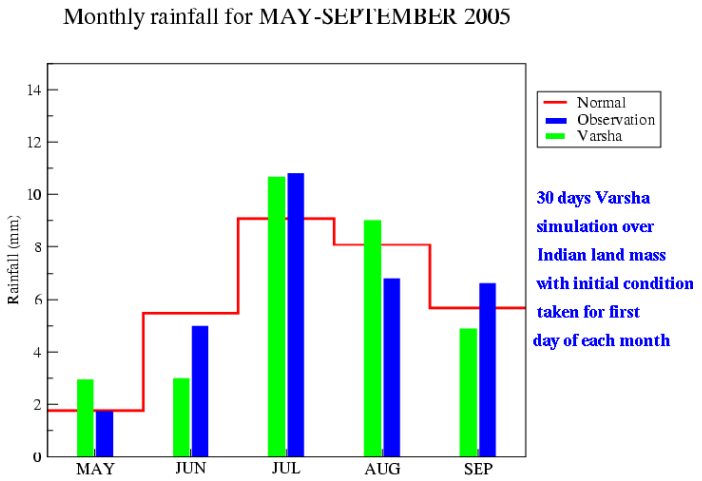
Motivation / Outline

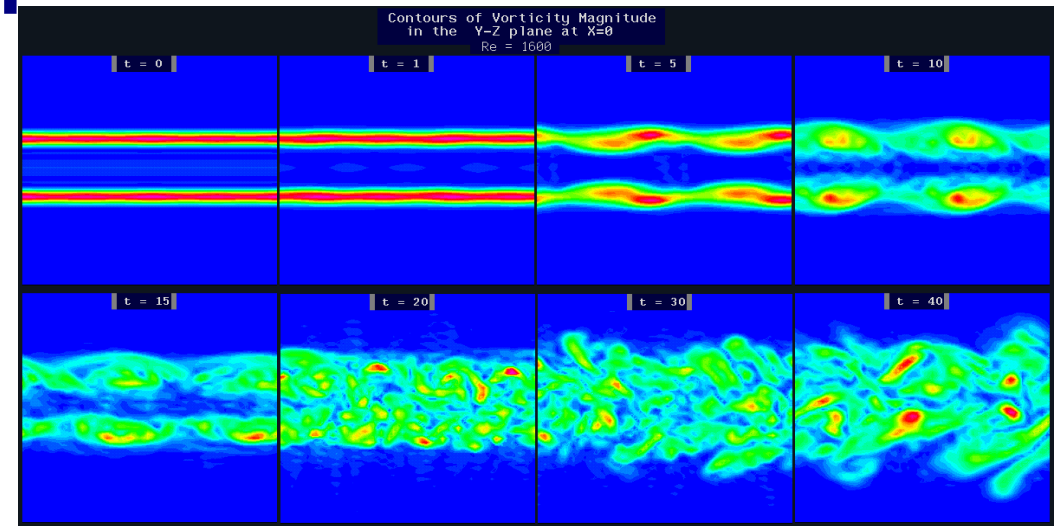
- NAL/ Flosolver
- Varsha GCM
  - NMITLI project
- One Month forecasts of the monsoon rainfall
- Round-off errors
  - Reproducibility/ Accuracy
- Remedy
  - Compute with a higher number of digits





National Aerospace Laboratories

- Founded in 1959
  - Part of the CSIR chain of laboratories
- Premier civilian research laboratory in aerospace
- Multiple disciplines
- Pioneers in CFD and parallel computing in India

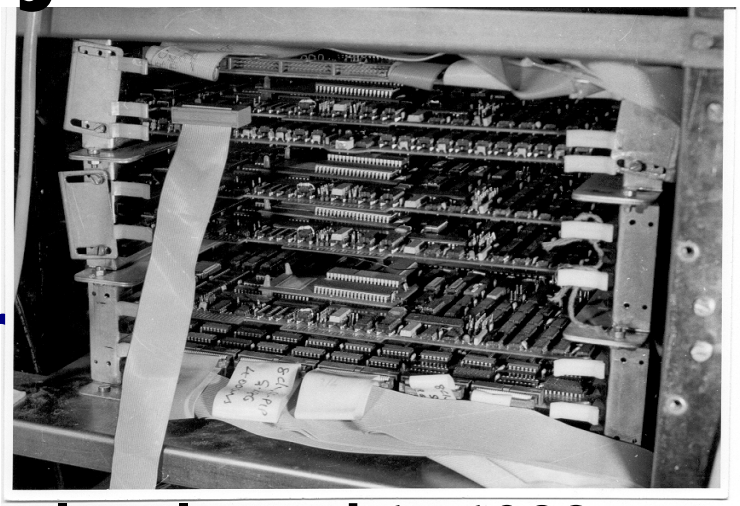


DNS of a jet

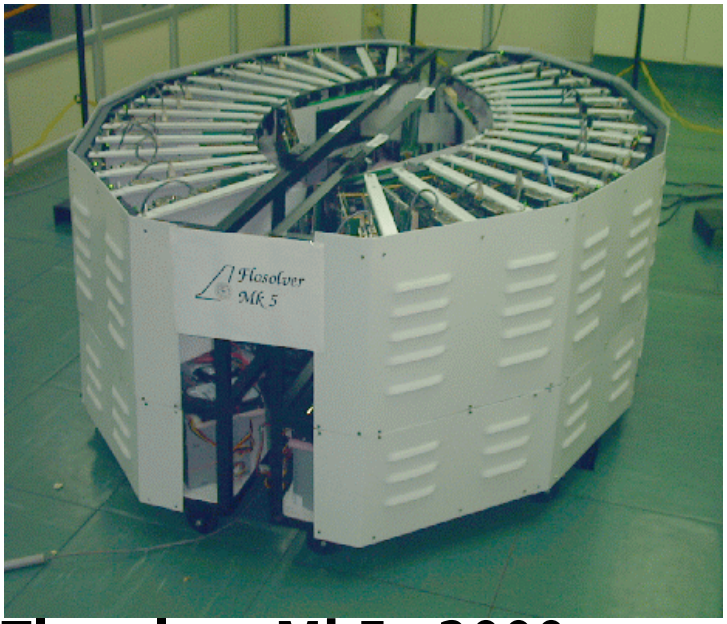
Flosolver Project

- Started in 1986
  - CFD requirements of NAL
- First Indian parallel computer

  Sinha *et al*, Super Computer, 1988
- Six generations since then
- Focus: Fluid dynamics, Meteorology
- NAL FloSwitch
  - 9th ECMWF Workshop, 2000
- NAL FloOptiLink



Flosolver Mk1 : 1986



Flosolver Mk5 : 2000

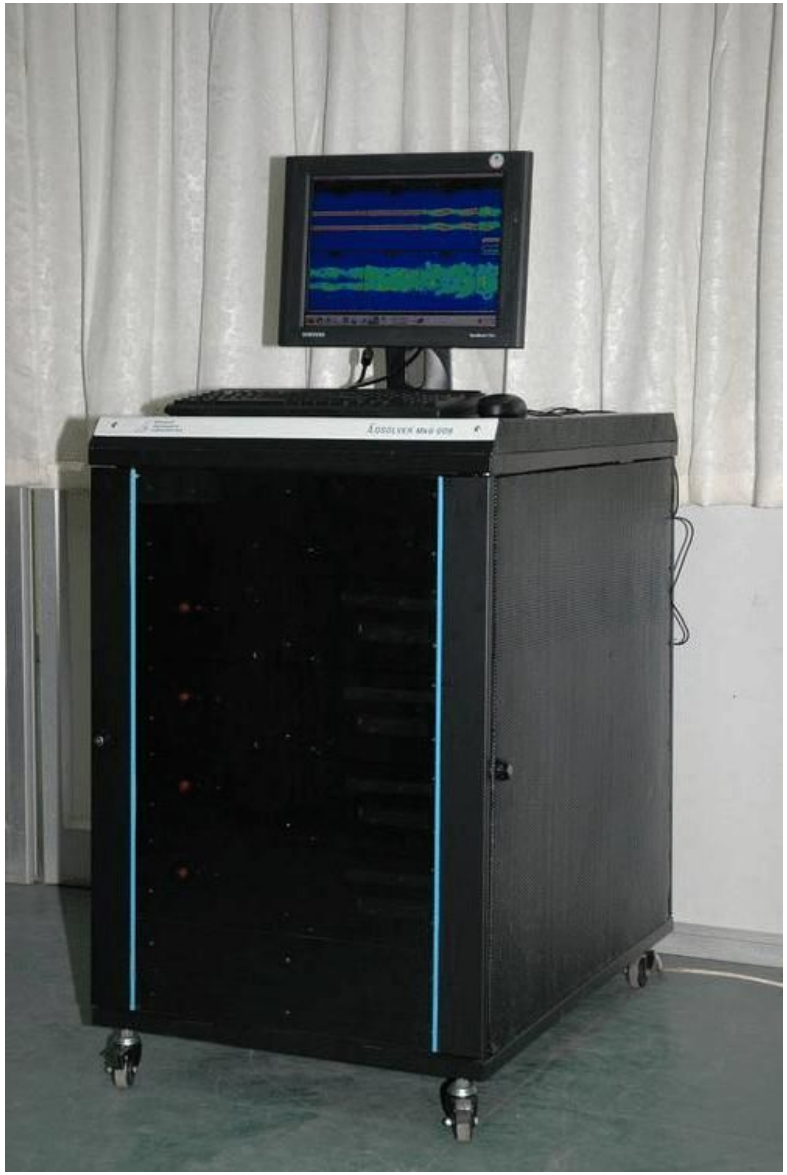
NMITLI project

- Government of India project
- Support for new, unconventional ideas
- Focus: technology development
- "Mesoscale modelling for monsoon related predictions"
  - 2001 – 2006
  - Flosolver Mk 6
  - Varsha GCM

Flosolver Mk 6

Current / planned hardware

- 10 Tflops
- Processors
  - Intel Xeon
  - Opteron ?
- Improved versions of FloSwitch/ FloOptiLink



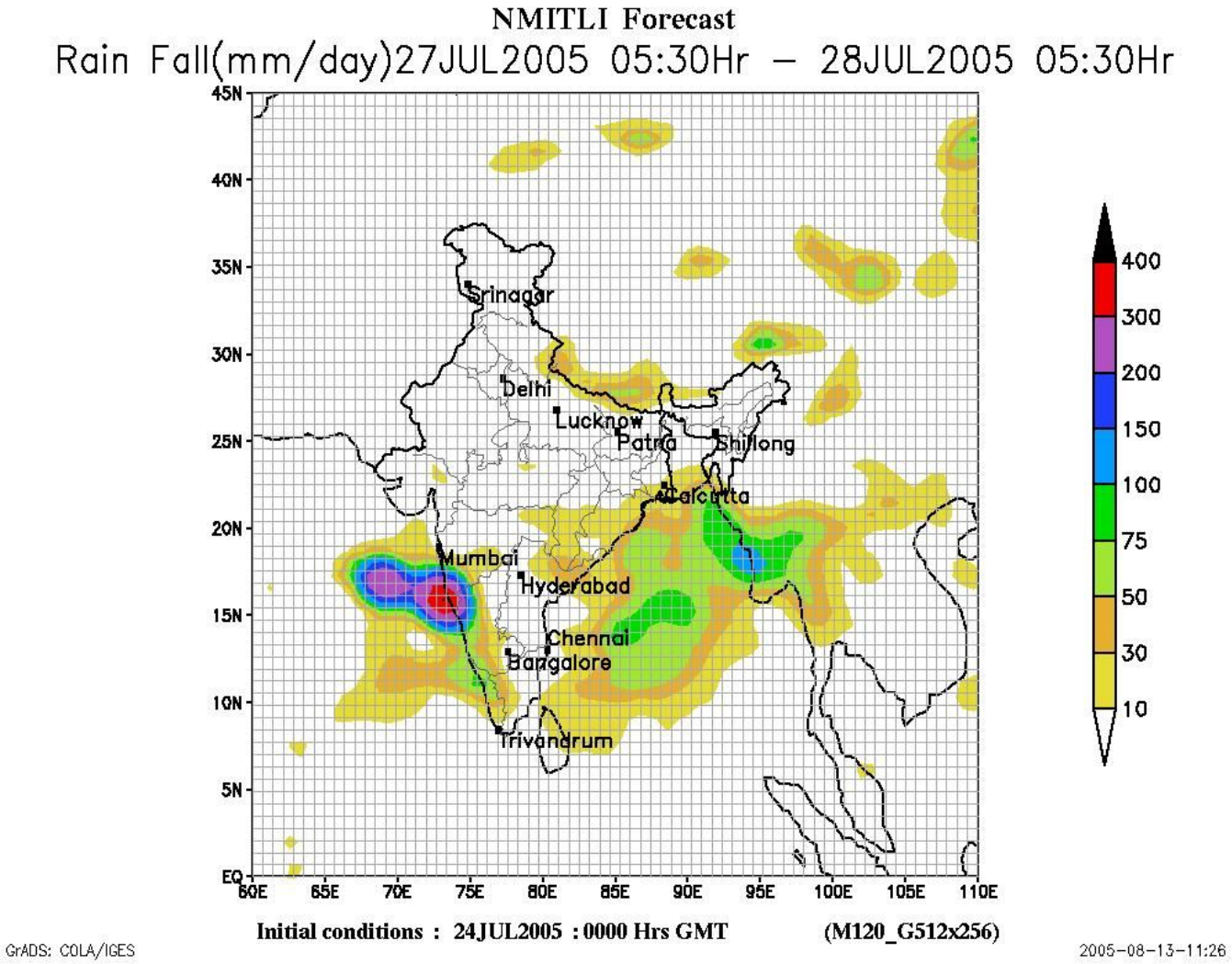
Varsha GCM: History

- Spectral, hydrostatic GCM
- Origin : GCM T-80 of NCEP, NCMRWF
- Porting from CRAY code, Parallelization on Flosolver Mk3 (Sinha et al, *Current Science* 1994)
- Rewritten in Fortran 90: Nanjundiah and Sinha, *Current Science* 1998
- New features: BL module, radiation module, time stepping. Rao & Narasimha *JFM* 2006, Venkatesh et al *Mausam* 2006 (Varsha 1.0)
- Rewritten in C: 2005 - 2006 (Varsha2C)
- Multi-precision version: 2006 (Varsha2C-MP)

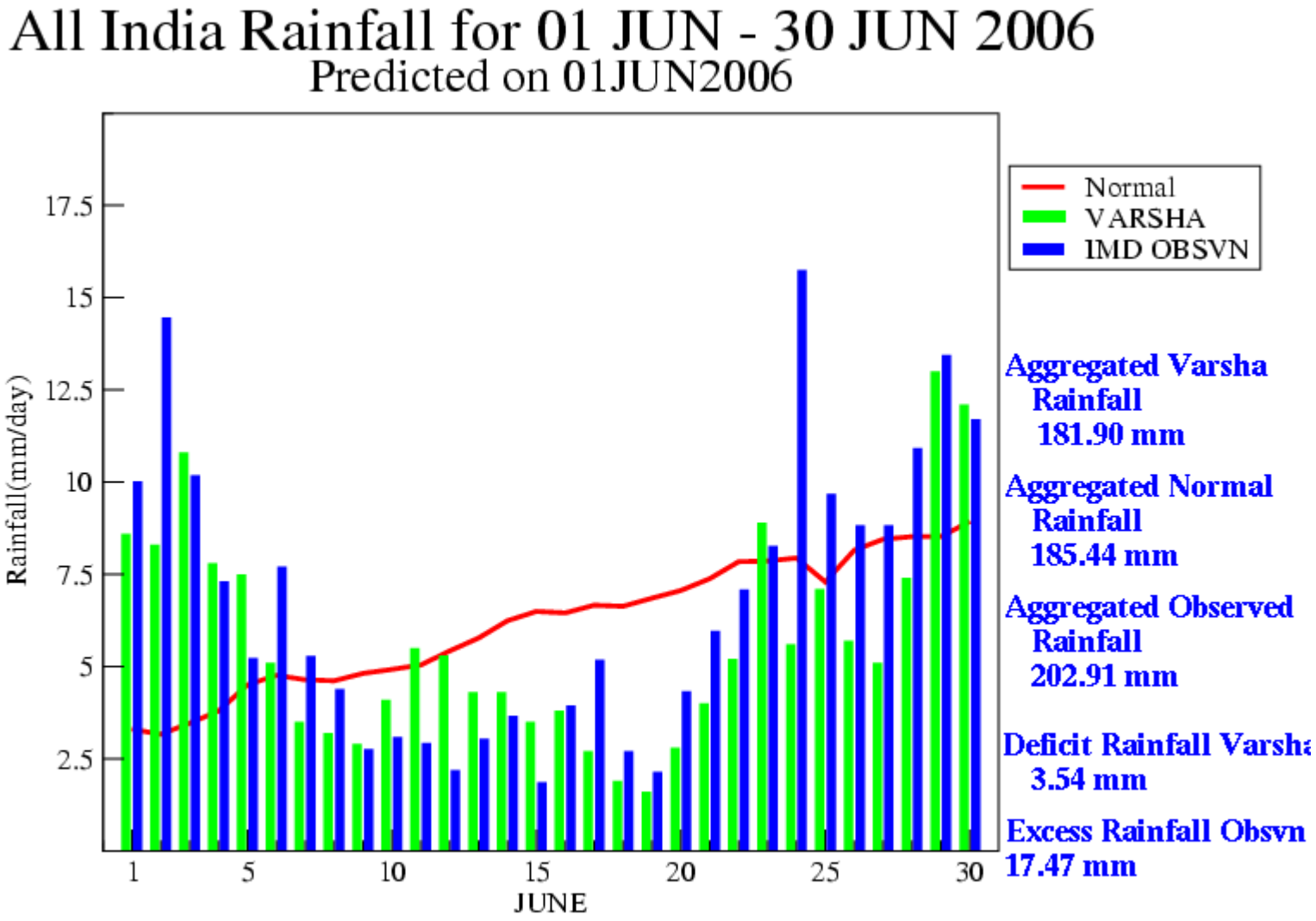
Varsha GCM

- Mainly used for research
- Regular five day simulations/forecasts
  - Since May 2005
  - Initial conditions: NCEP FNL dataset
  - For validation
  - Resolution: 120, 512x256
- One month simulations/forecasts
  - Monsoon rainfall
  - 1986 – 2005: Reasonably good
  - 2006 forecasts: Being assessed

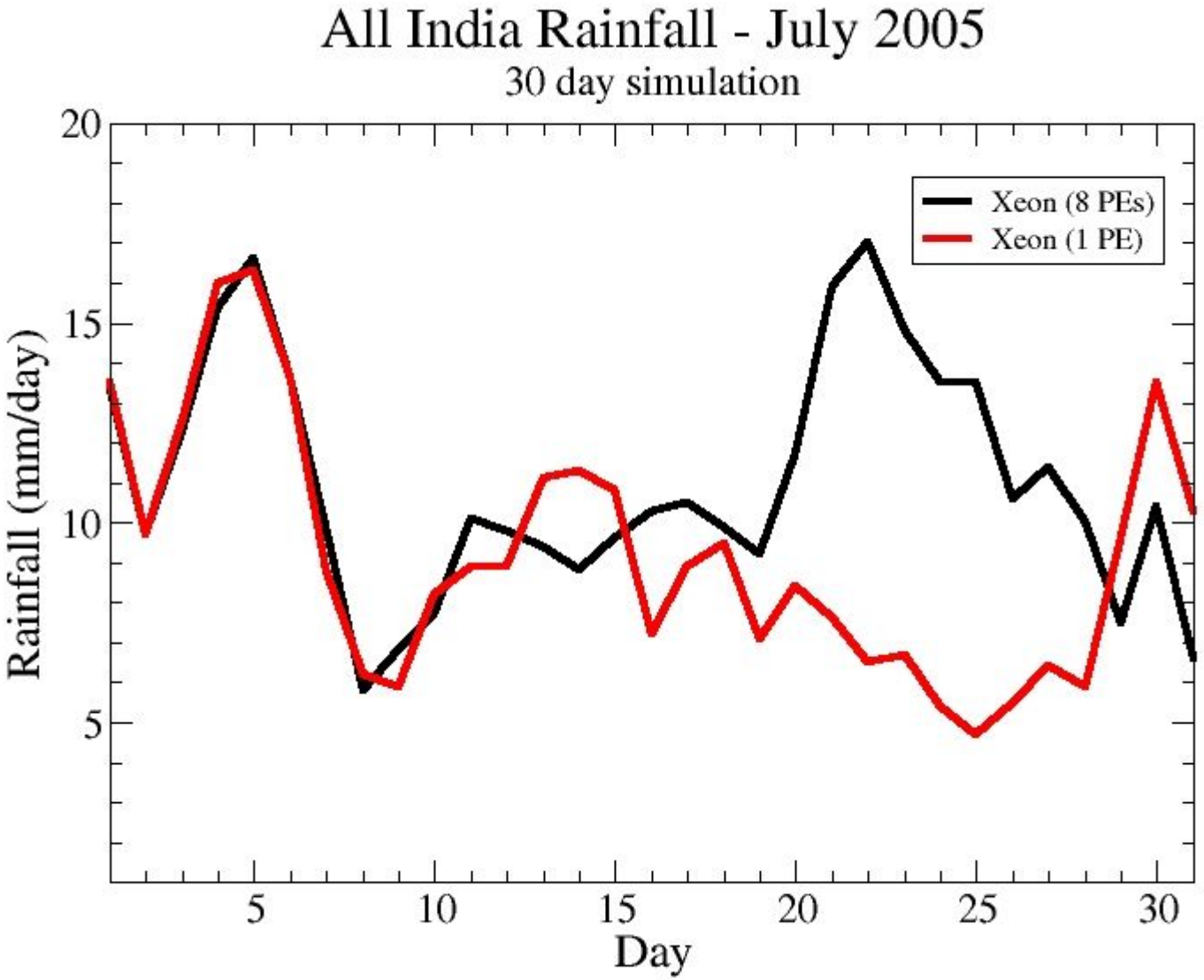
All India Rainfall: AIR



Importance of AIR



Repeatability of results: Number of processors



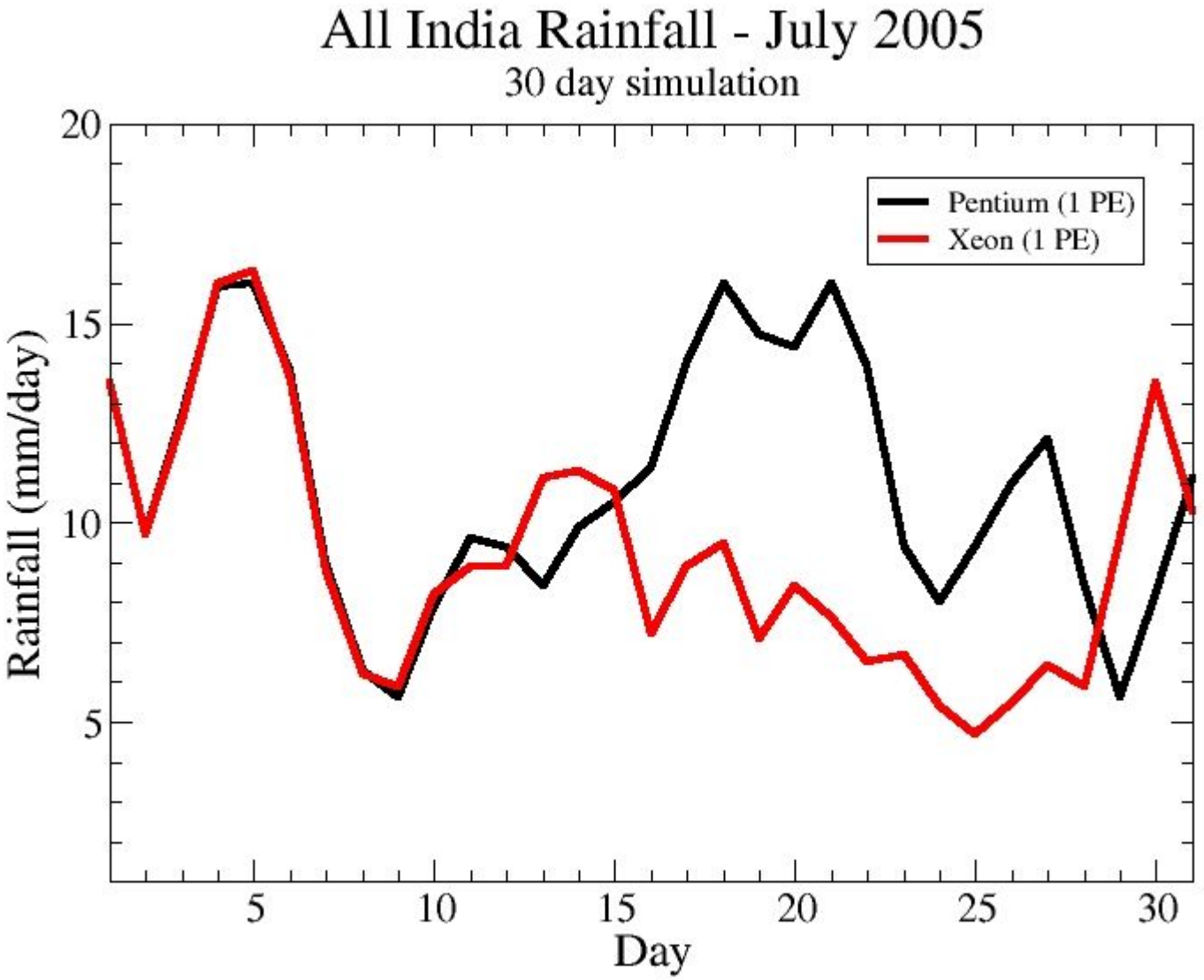
Possible reasons

- **Global sums**
  - **One dimensional decomposition over latitudes in the parallel code**
  - **Round off errors while adding up the partial sums**
    - **((A+B)+C)+D *not equal* to (A+B) + (C+D) in floating point computer arithmetic**
- **Random numbers used in the cloud calculations ?**

Round off errors: literature

- He and Ding : (ECMWF 2000)
  - Global sums prone to round off errors
  - Double-double precision
  - Multi-precision (too hard)
- Bailey
  - Vortex sheet role up simulations
  - Multi-precision required

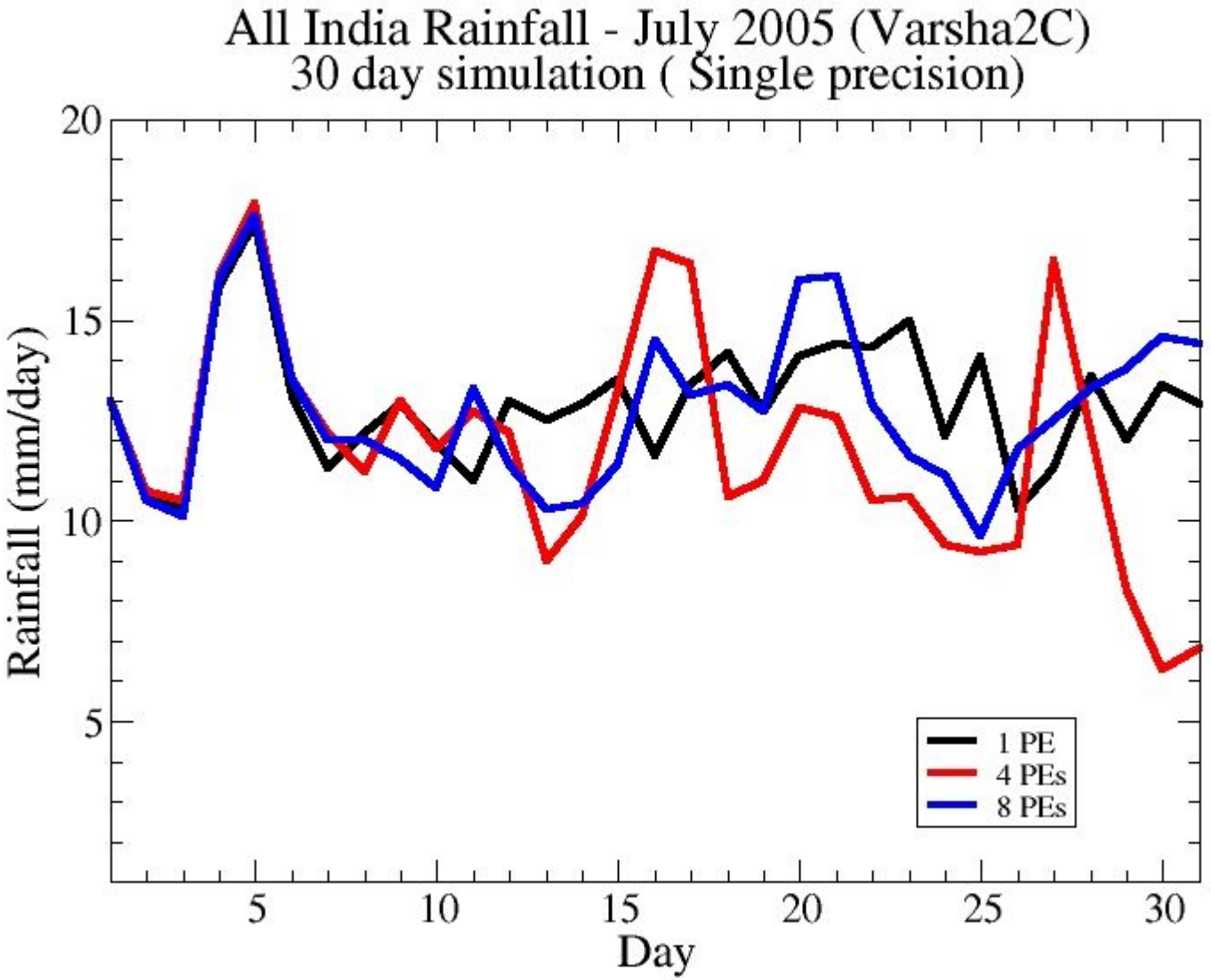
Repeatability of results: Different processors



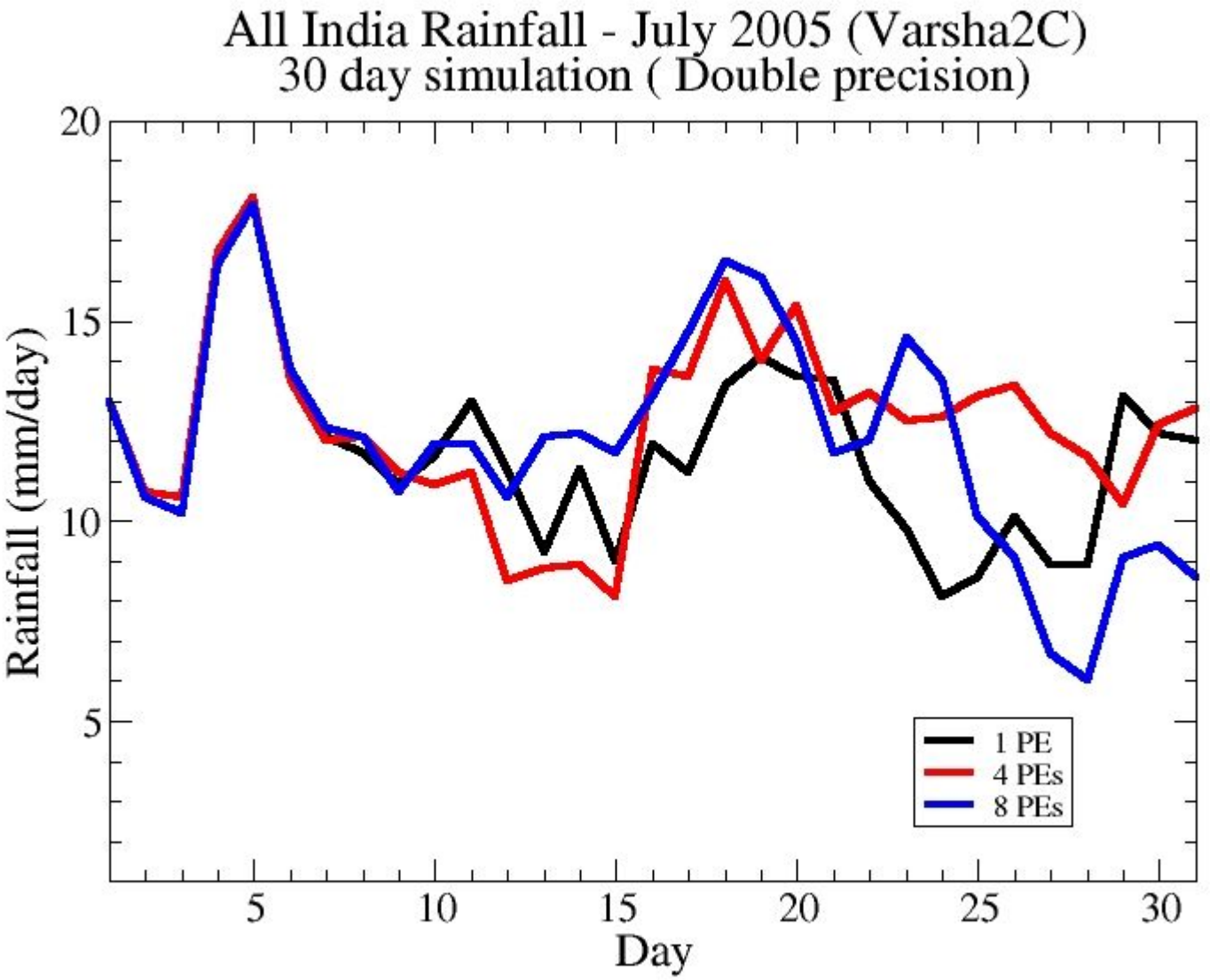
Varsha2C

- **VarshaC (C version)**
  - **Passing of variables: Arguments / structures**
  - **Type: real**
  - **Changes in dynamics (time integration part)**
  - **Better scalability**
  - **Completed: June 2006 (7 Man months)**
  - **Single/Double precision**
    - **Time for code modification: ~ 1 week**

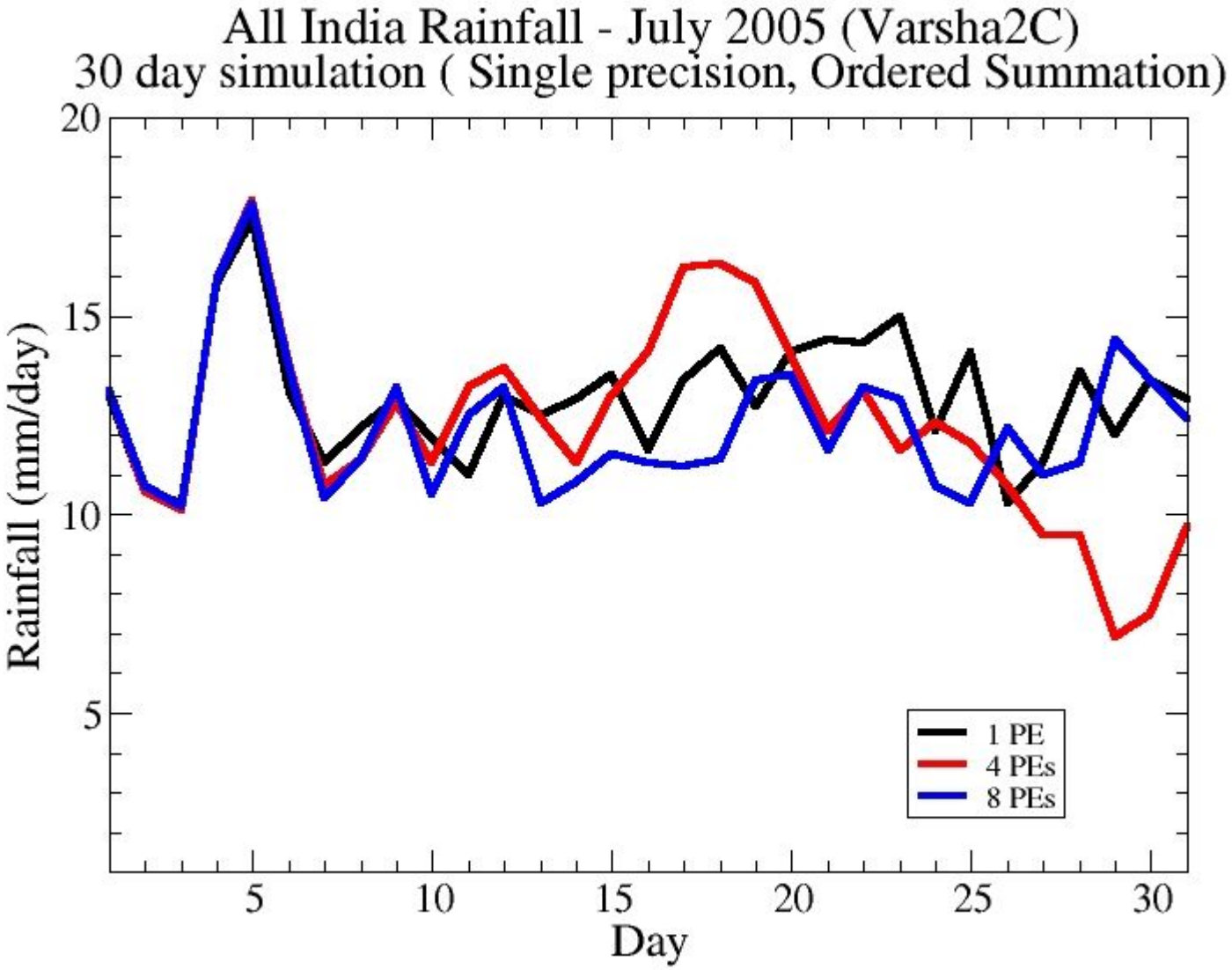
Single precision



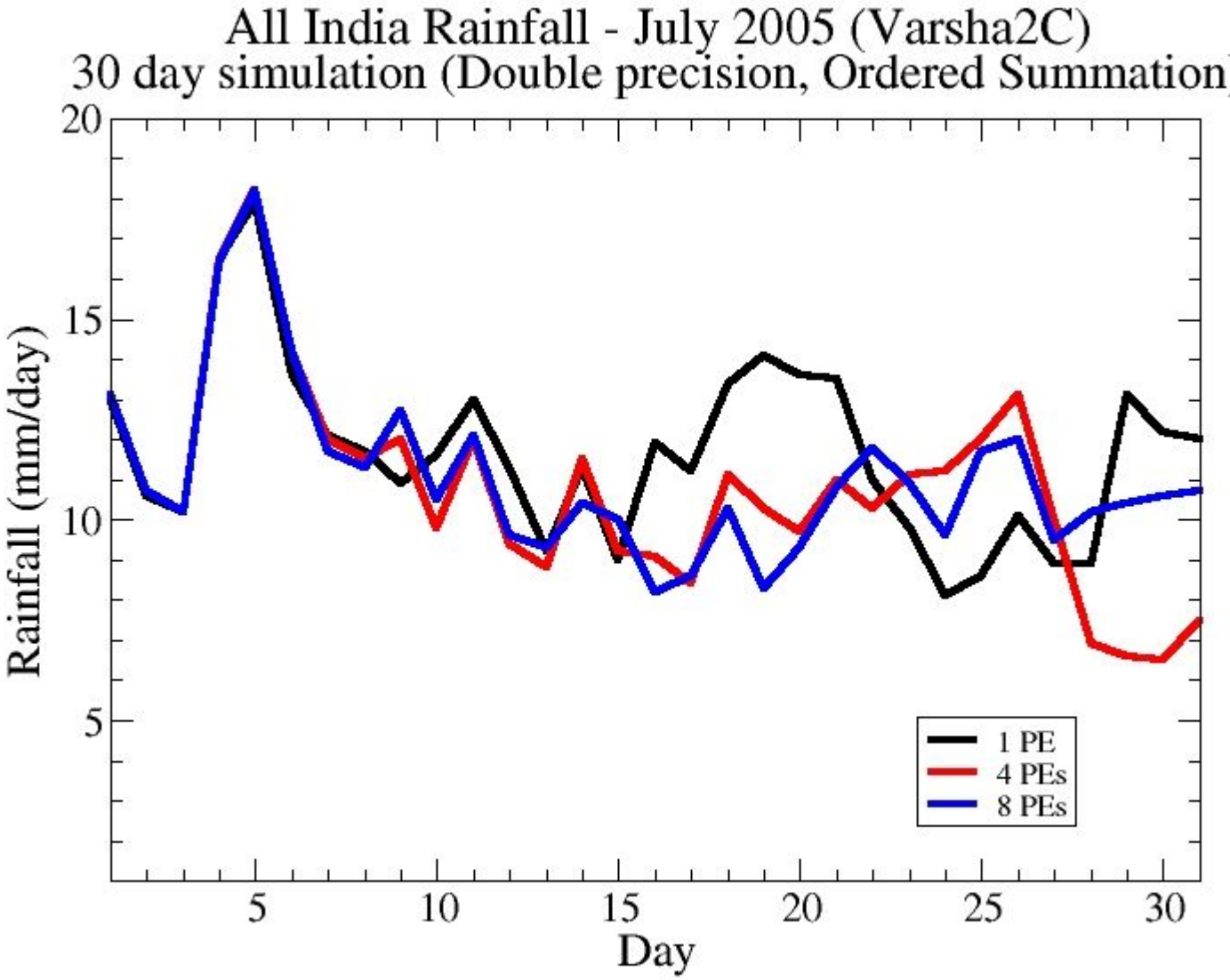
Double precision



Single : order of summation



Double : order of summation



VarshaMP

- **Multi-precision version**
  - **Code change: ~ 45 days**
- **C / C++**
  - **C++ compiler required**
- **Uses the ARPREC library**
  - **New datatype mp_real**
  - **All arithmetic operations, math functions overloaded**

Multi-precision libraries

- **MPFUN90**
- **ARPREC**
- **HFLOAT**
- **GNUMP**

3.14159265358979323846264338327950288419
71693993751058209749445923078164062
86208998628034825342117067982148086513
28230664709384460955058223172535940
81284811174502841027019385211055964
46229489549303819644288109756659334
61284756482337867831652712019091456
48566923460348610454326648213393607
26024914127372458700660631558817488152
09209628292540917153643678925903600
11330530548820466521384146951941511
6094...

Developed primarily for computing fundamental constants like Pi, etc.

main.c

```
#include <stdio.h>
#include <stdlib.h>
#include "mpi.h"
#ifdef MULTI_PRECISION
  #include "mp_real.h"
#endif

void agcm(int *,int *);
int main(int argc, char *argv[])
{
  int numprocs,myid;

  MPI_Init(&argc,&argv);
  MPI_Comm_size(MPI_COMM_WORLD,&numprocs);
  MPI_Comm_rank(MPI_COMM_WORLD,&myid);

#ifdef MULTI_PRECISION
  mp::mp_init(128);
#endif
  agcm(&numprocs,&myid);
#ifdef MULTI_PRECISION
  MPI_Barrier(MPI_COMM_WORLD);
  mp::mp_finalize();
#endif
  MPI_Barrier(MPI_COMM_WORLD);
  MPI_Finalize();
  return 0;
}
```

cprec.h

```
//  precision is controlled here
#ifdef MULTI_PRECISION
    #include "mp_real.h"

    typedef mp_real real;
#else
  #ifdef DOUBLE_PRECISION
    typedef double real;
  #else
    typedef float real;
  #endif
#endif
```

Number of digits

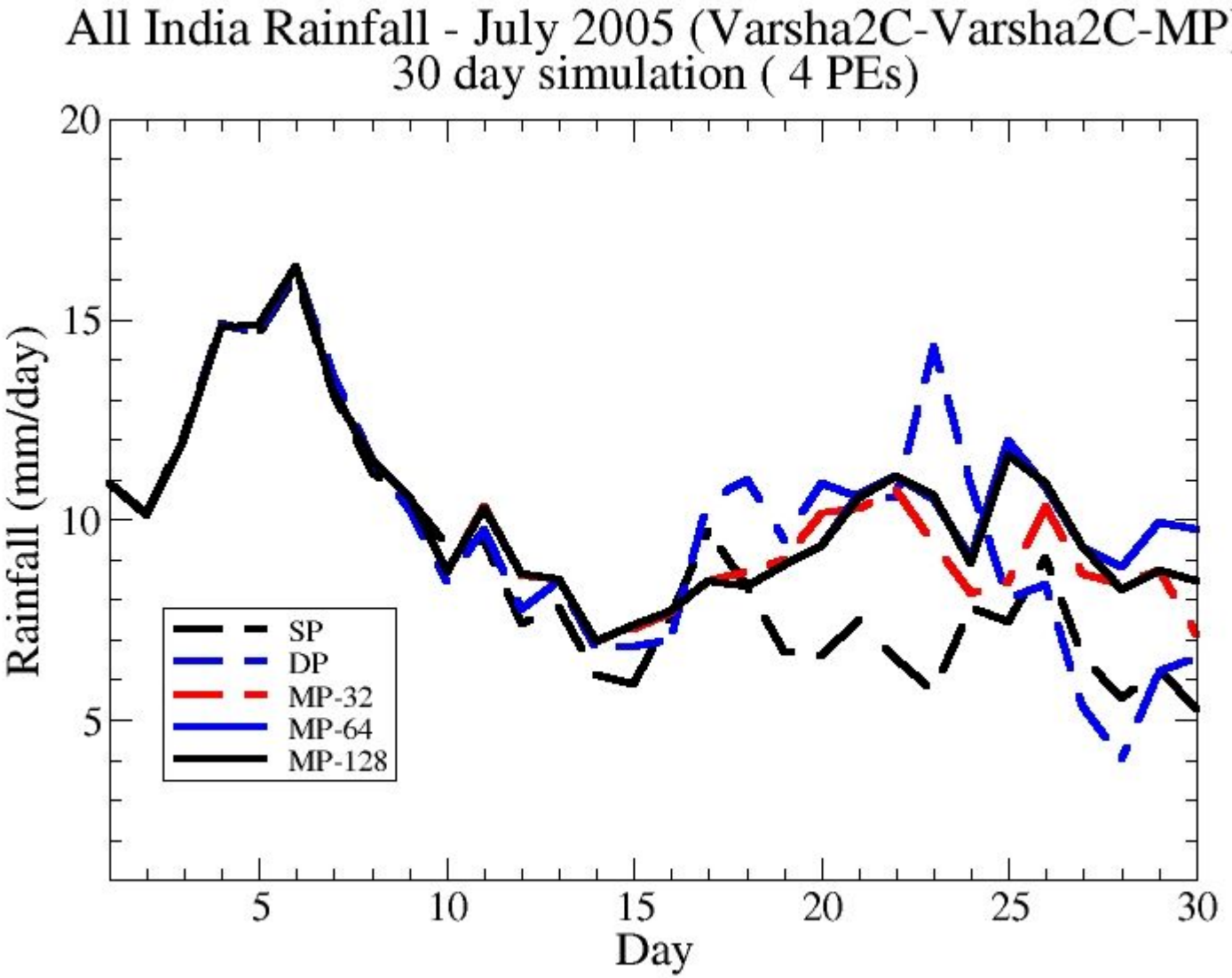
Issues

- Input data : single precision
- Compiler issues
- Memory requirements
- Parallelization
- Debugging
- Run-times
- Restart

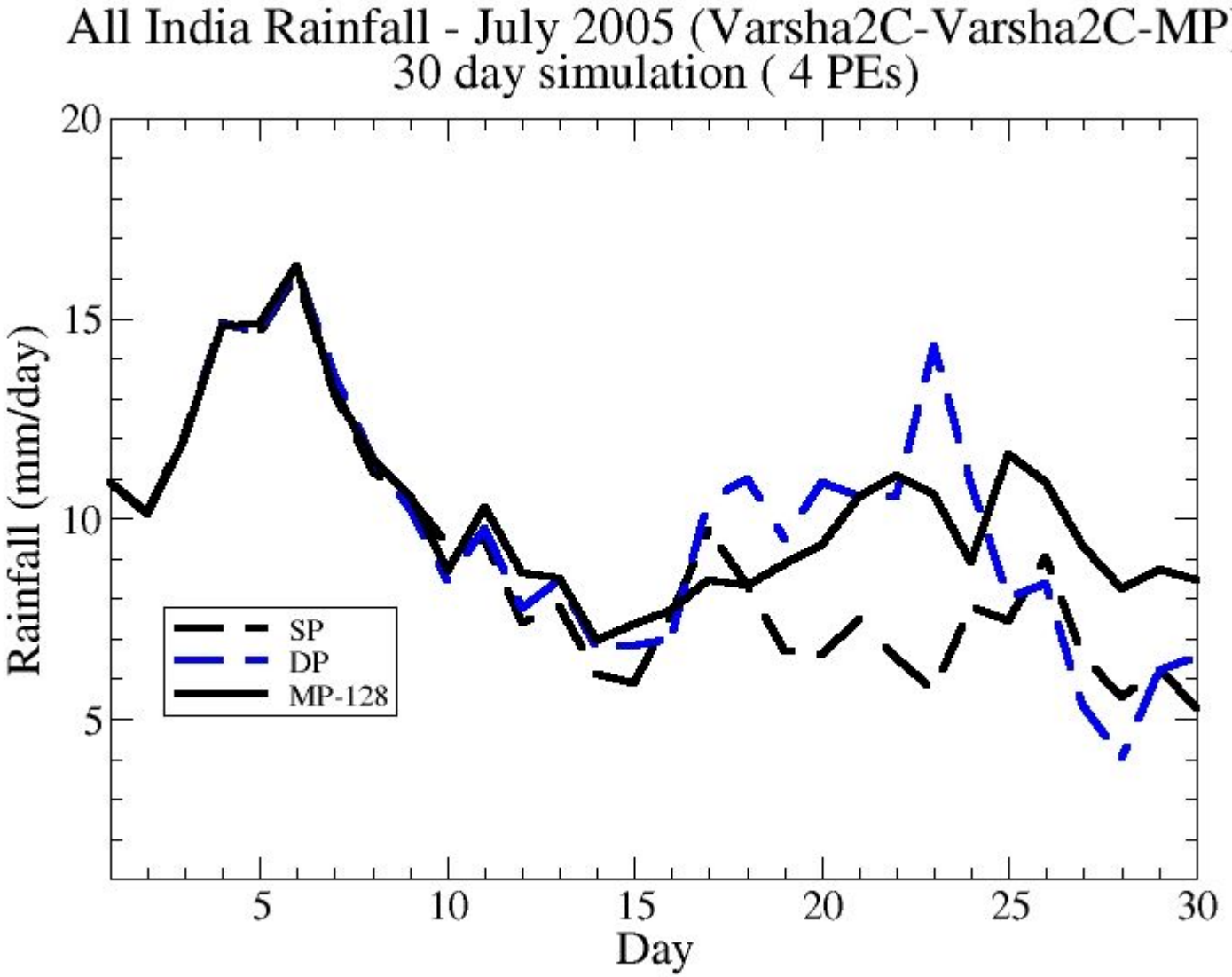
RESULTS

- **VarshaC, VarshaMP:**
  - **All India Rainfall**
  - **30 Day integrations**
  - **Lower model resolution (T- 60)**
- **Lorenz system (1963 JAS)**
  - **MPFUN90**

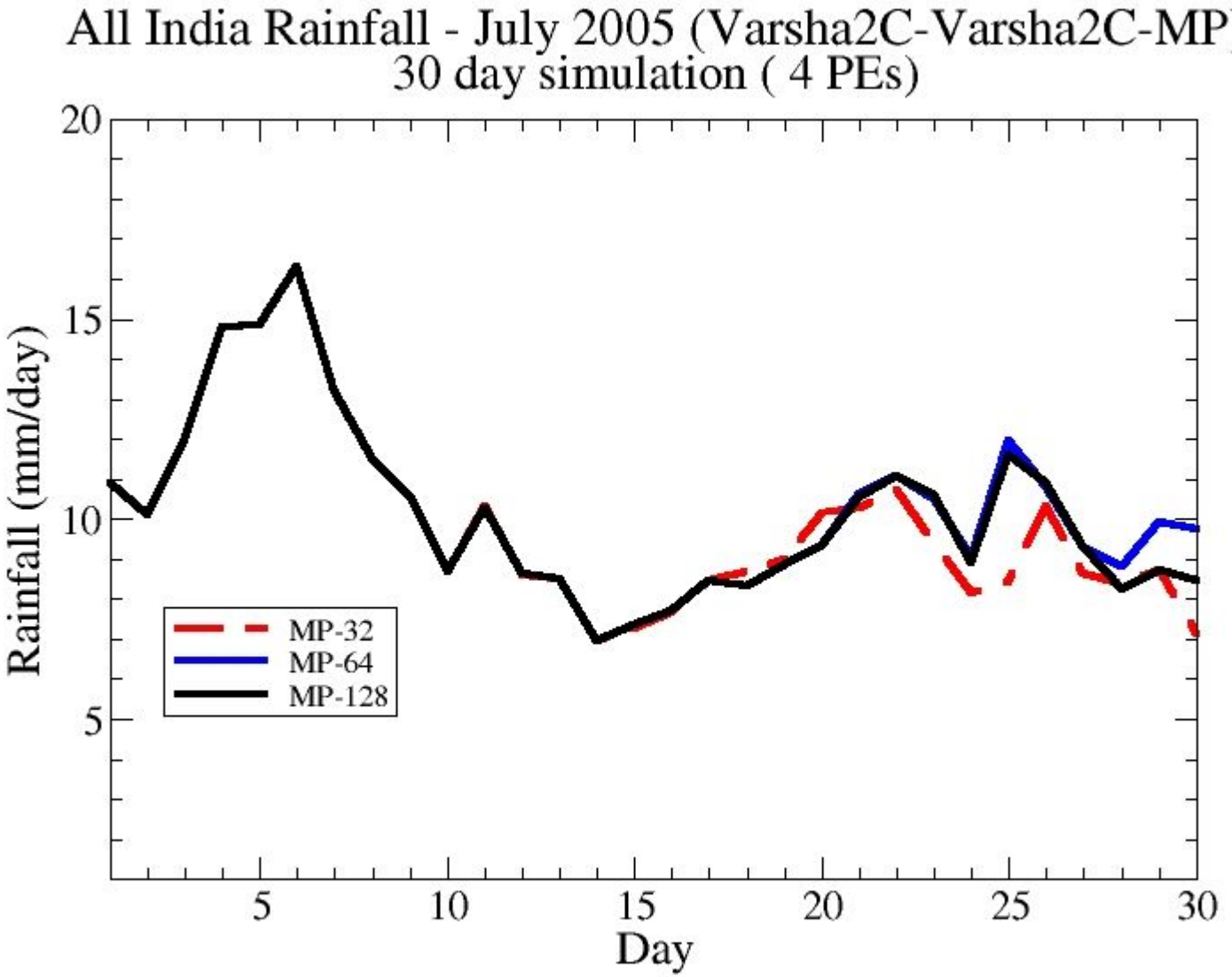
Single, double, multi-precision



Comparison- 2

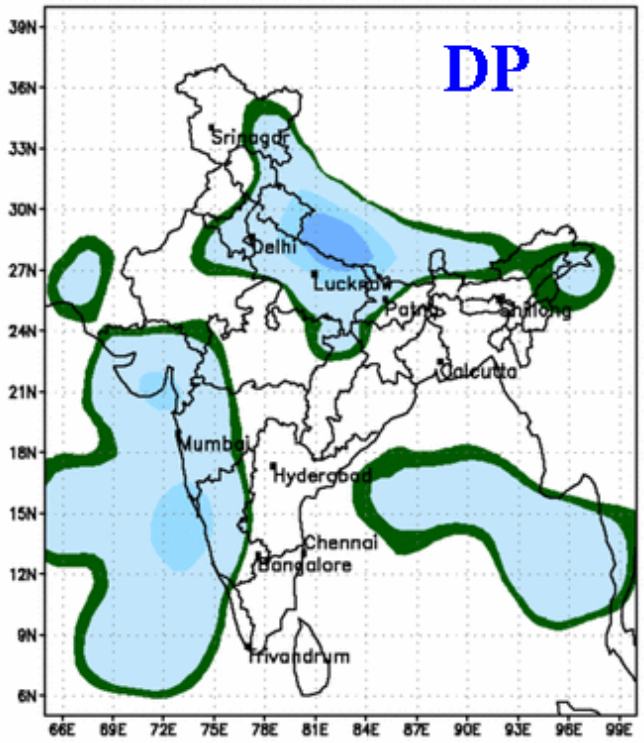


Computation with 32, 64, 128 Digits



Spatial patterns

Day 05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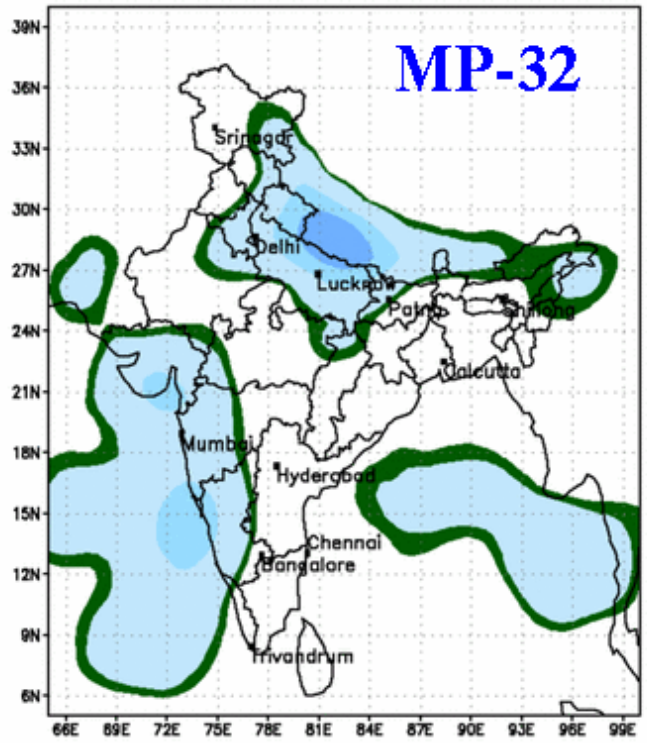
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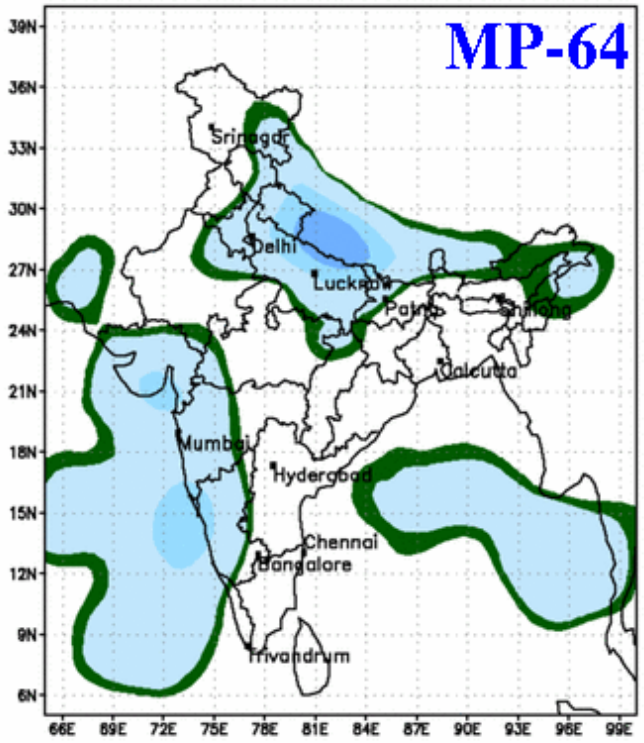
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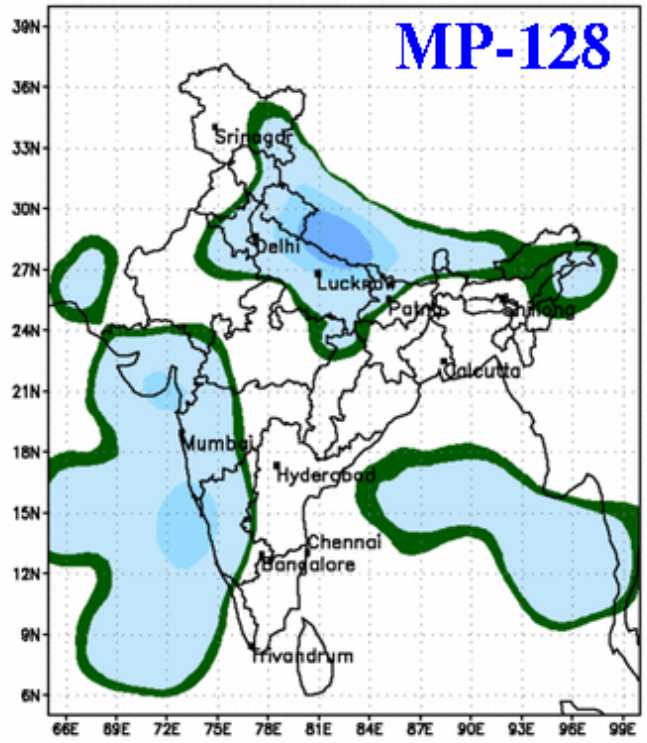
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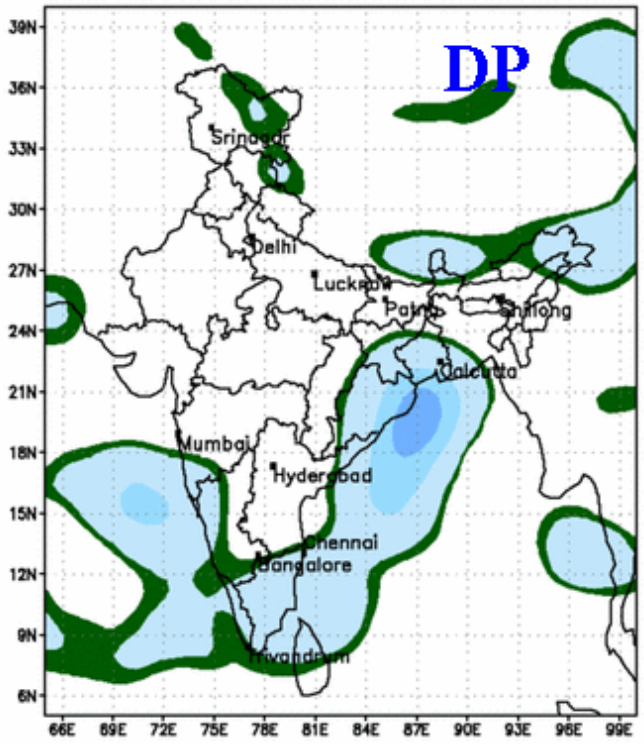
Day 10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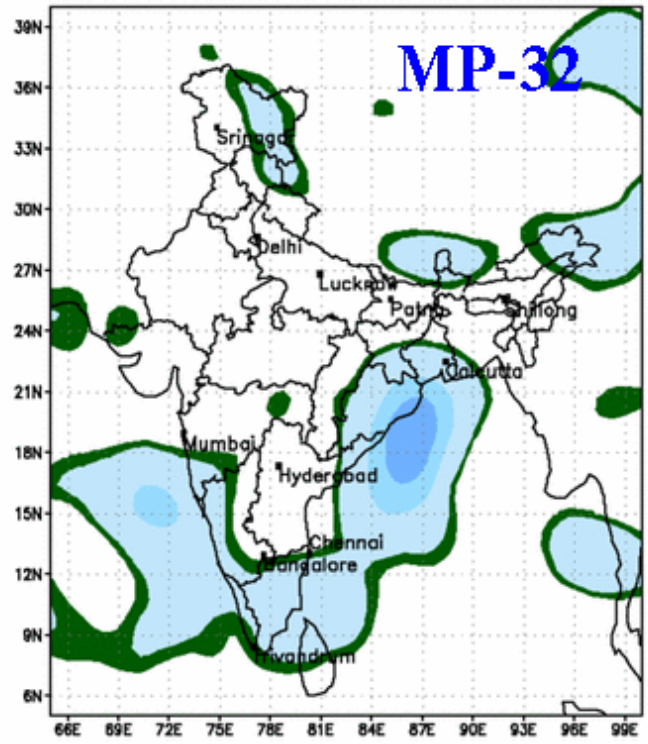
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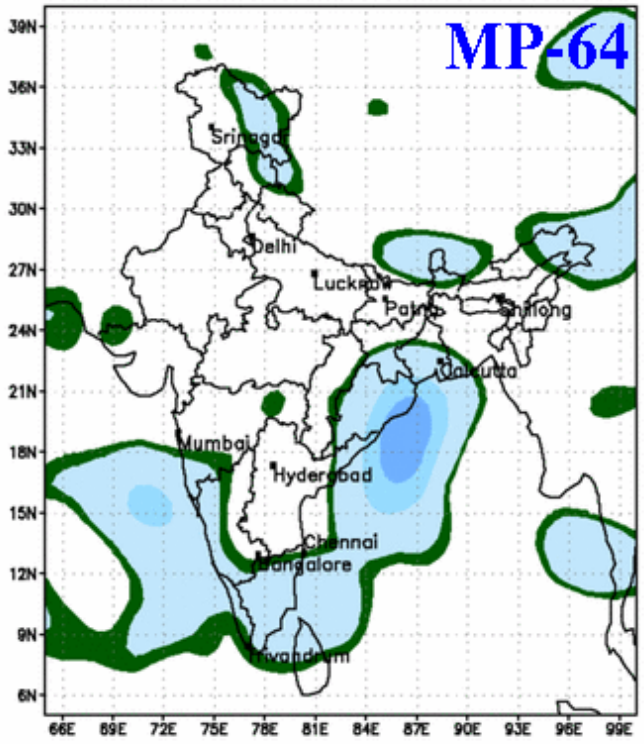
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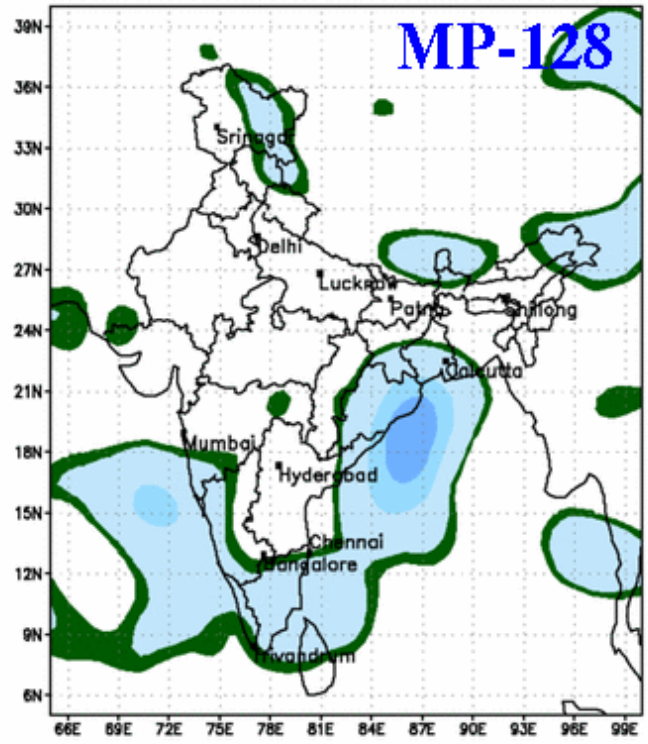
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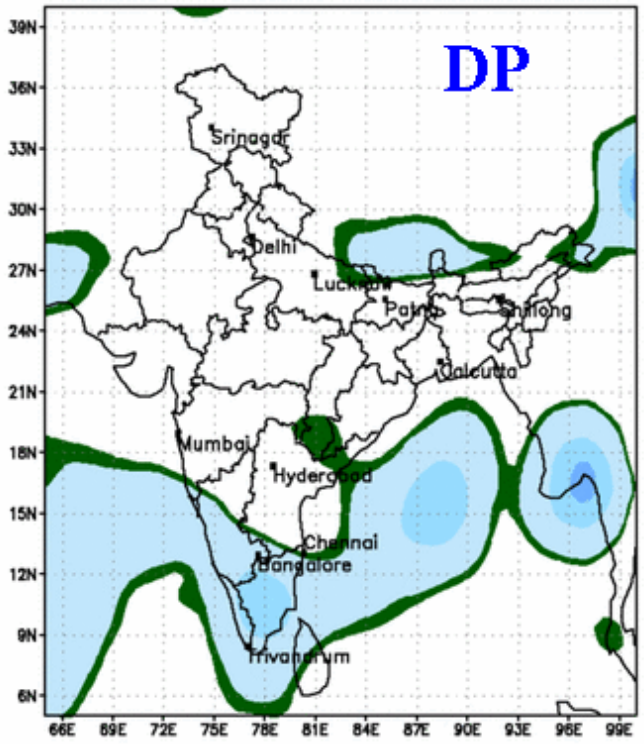
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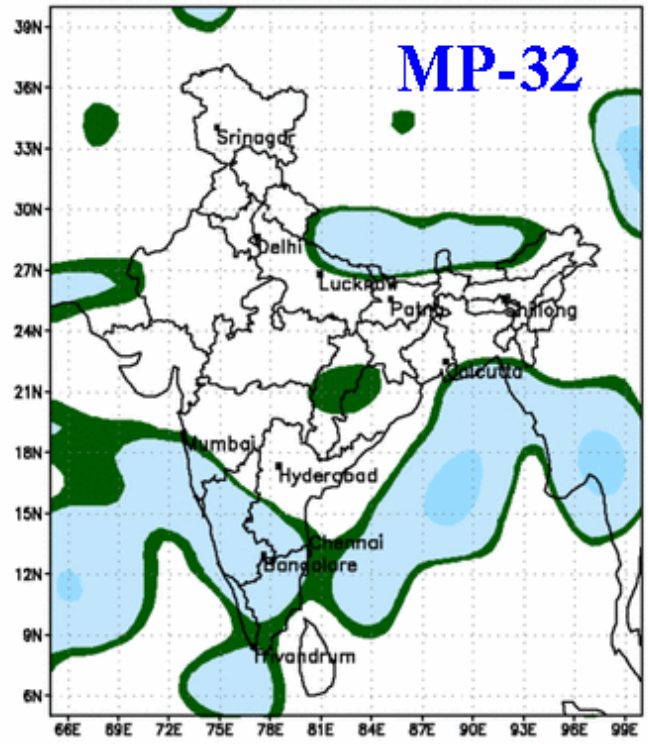
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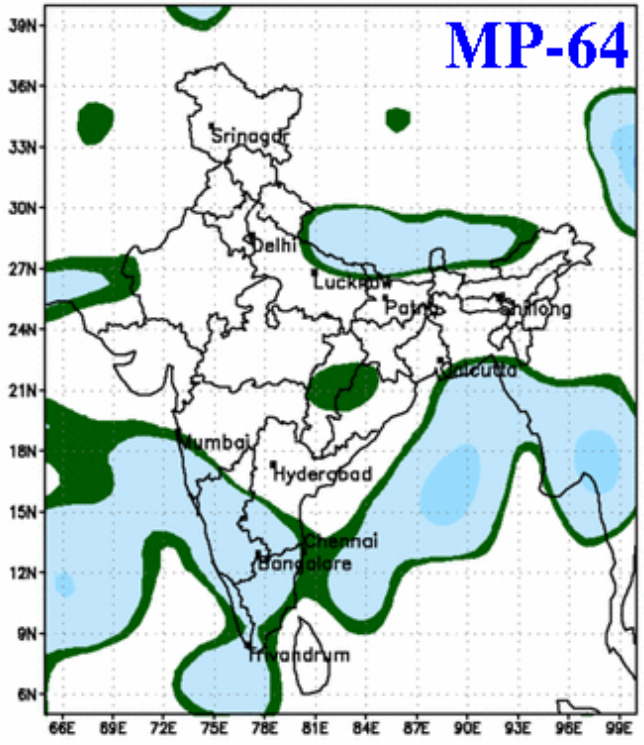
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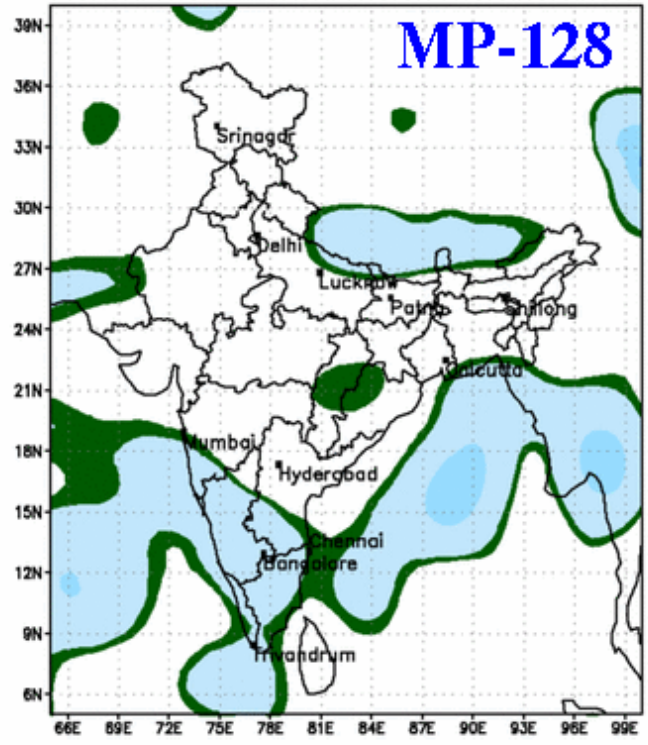
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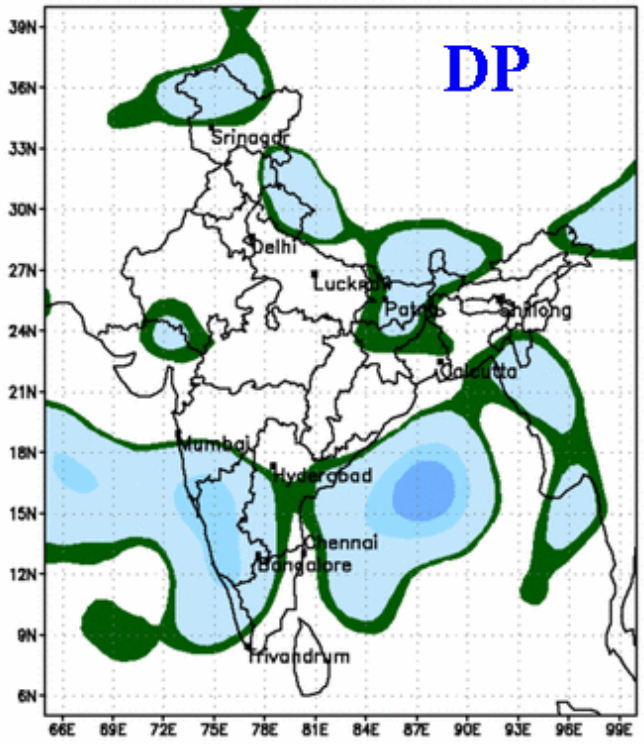
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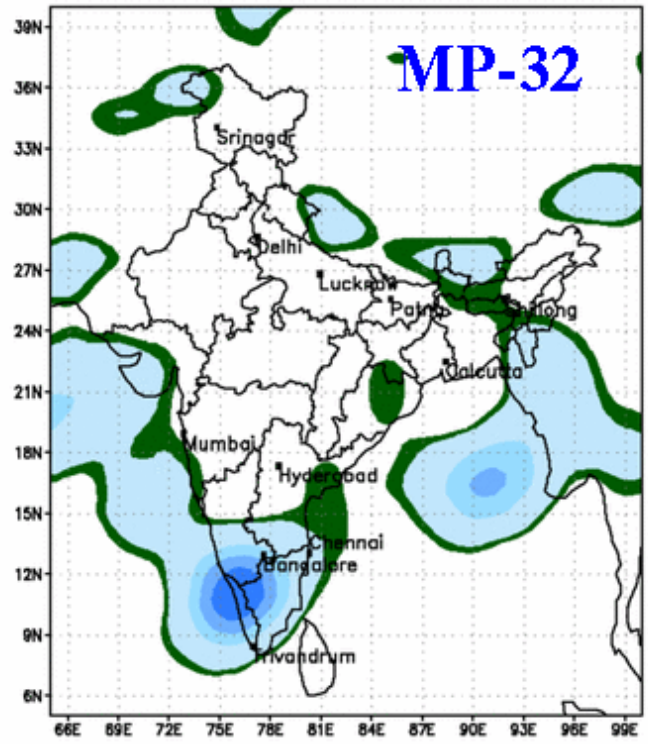
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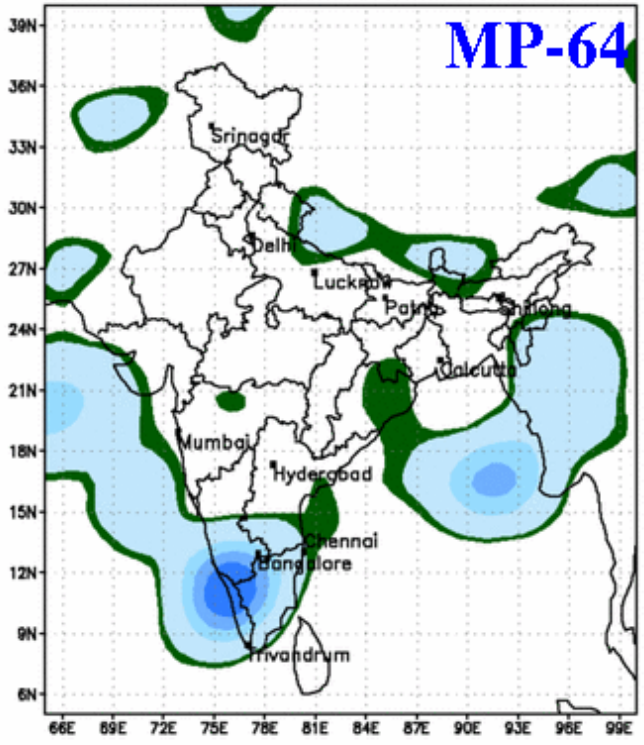
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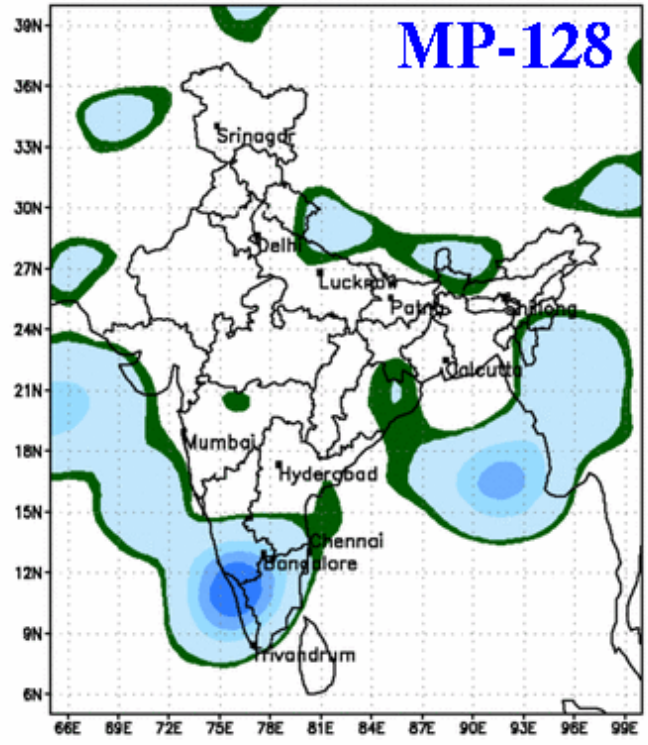
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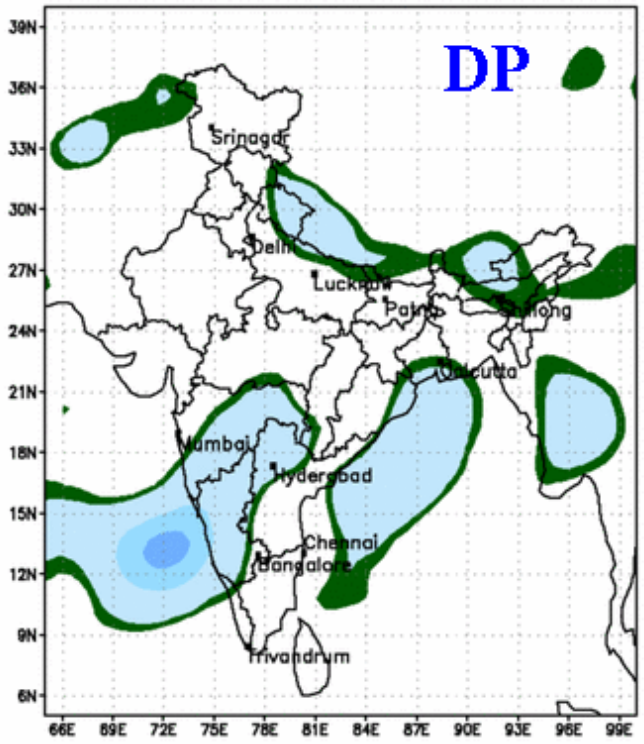
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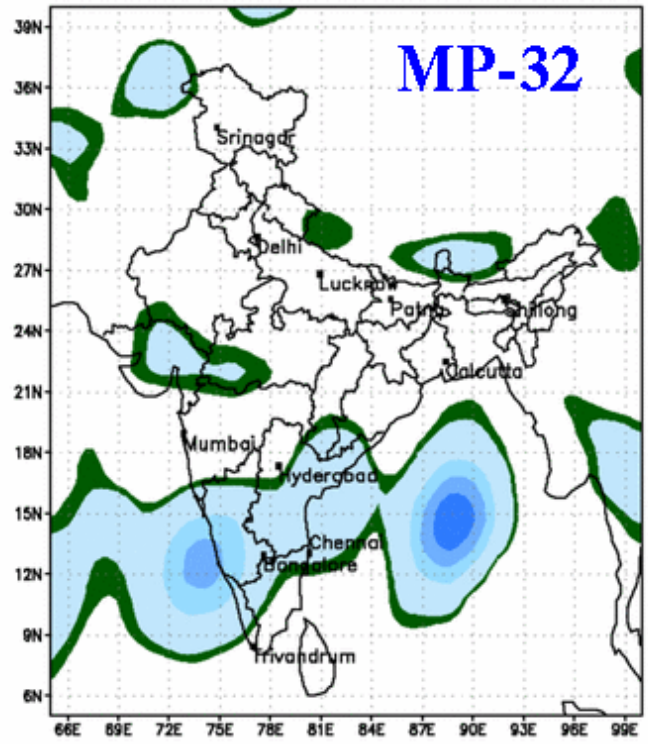
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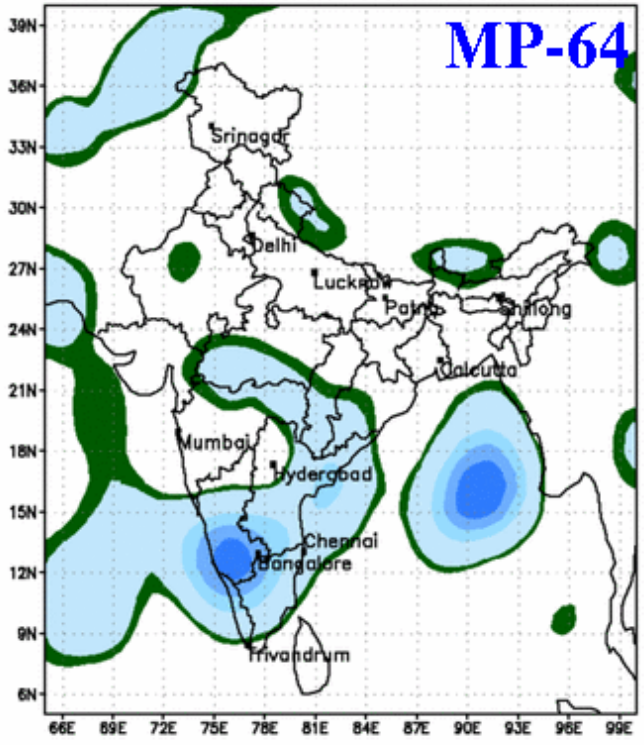
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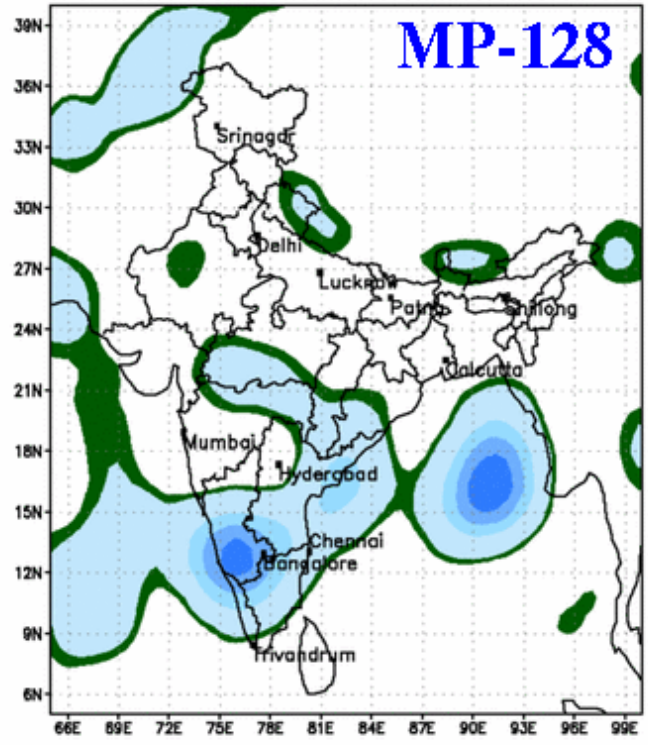
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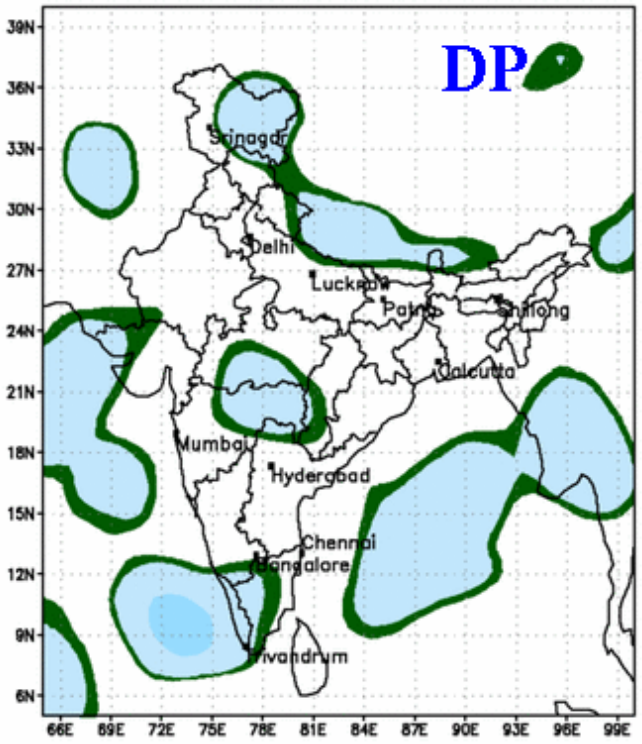
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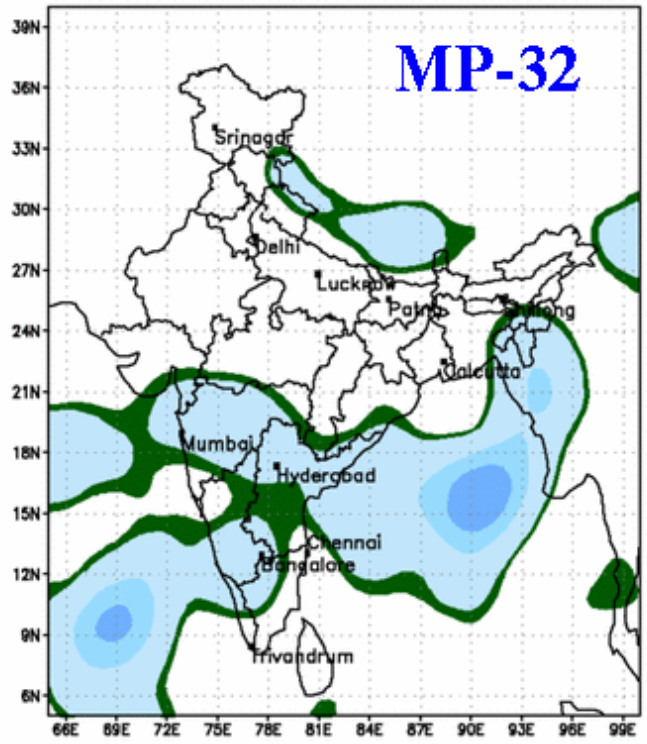
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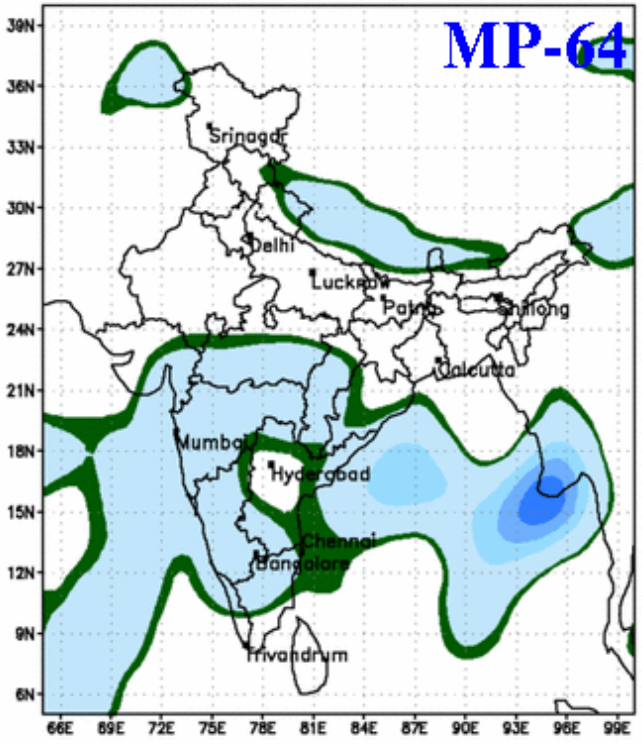
Calcutta
Mumbai
Hydergoad
Chennai
Bangalore
Trivandrum


MP-64
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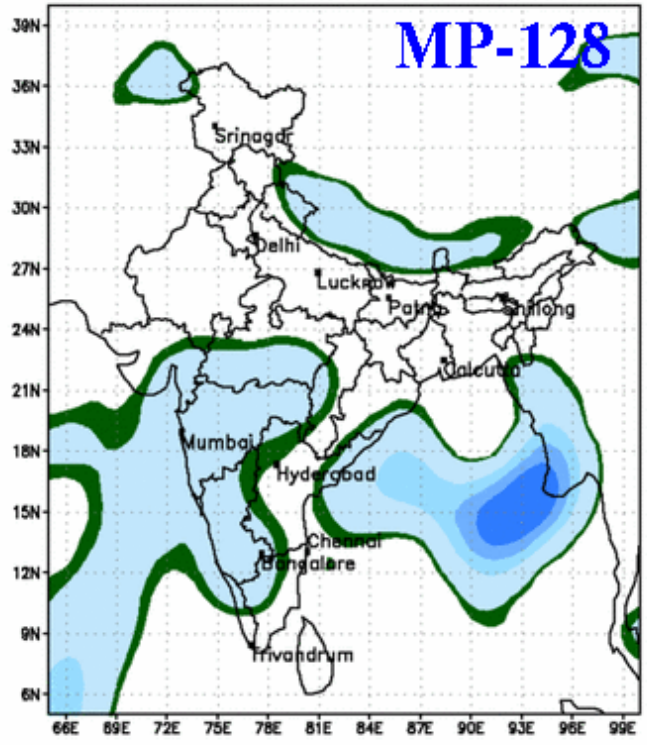
Lucknow
Patna
Shillong
Calcutta
Mumbai
Hydergoad
Chennai
Bangalore
Trivandrum


MP-128
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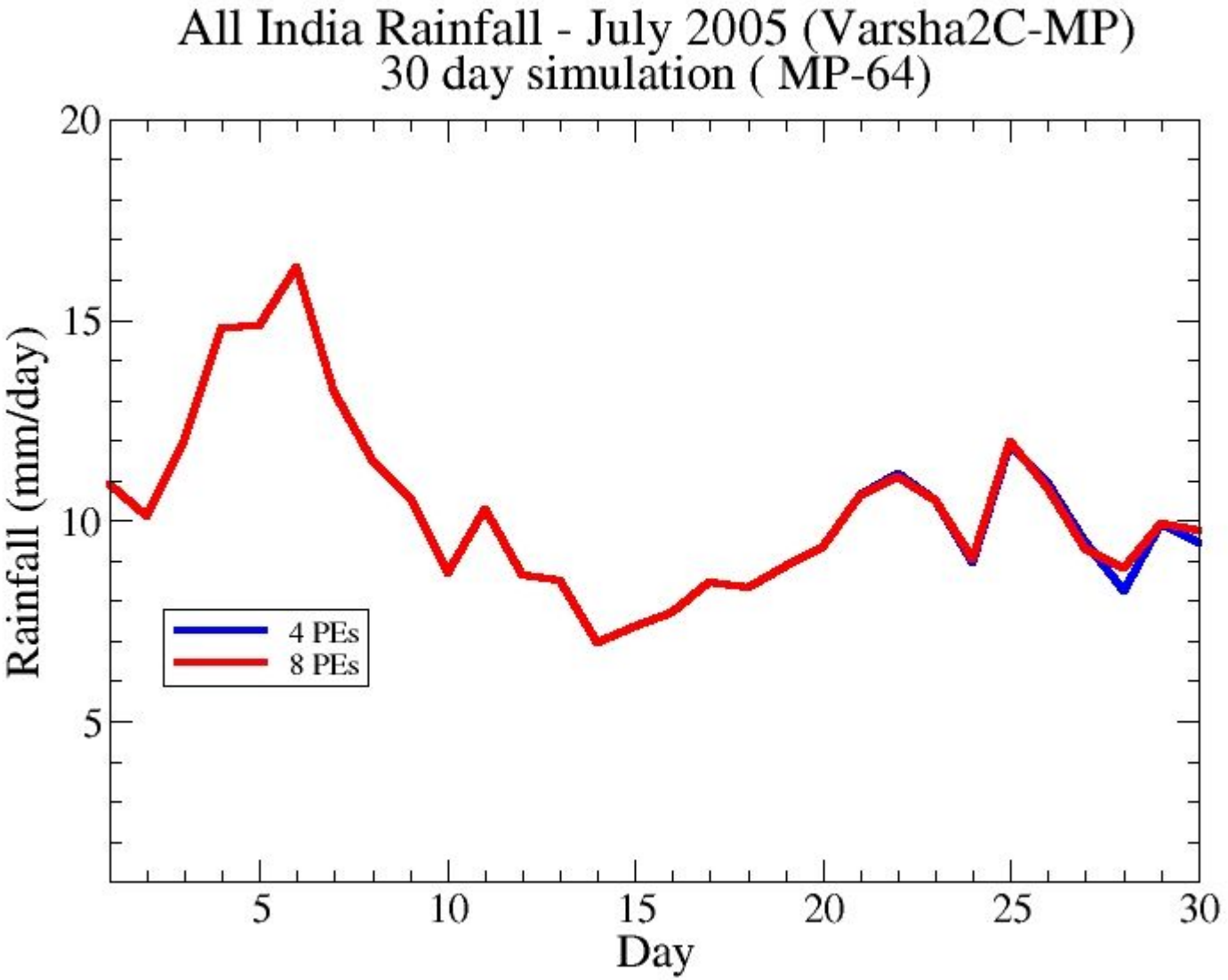
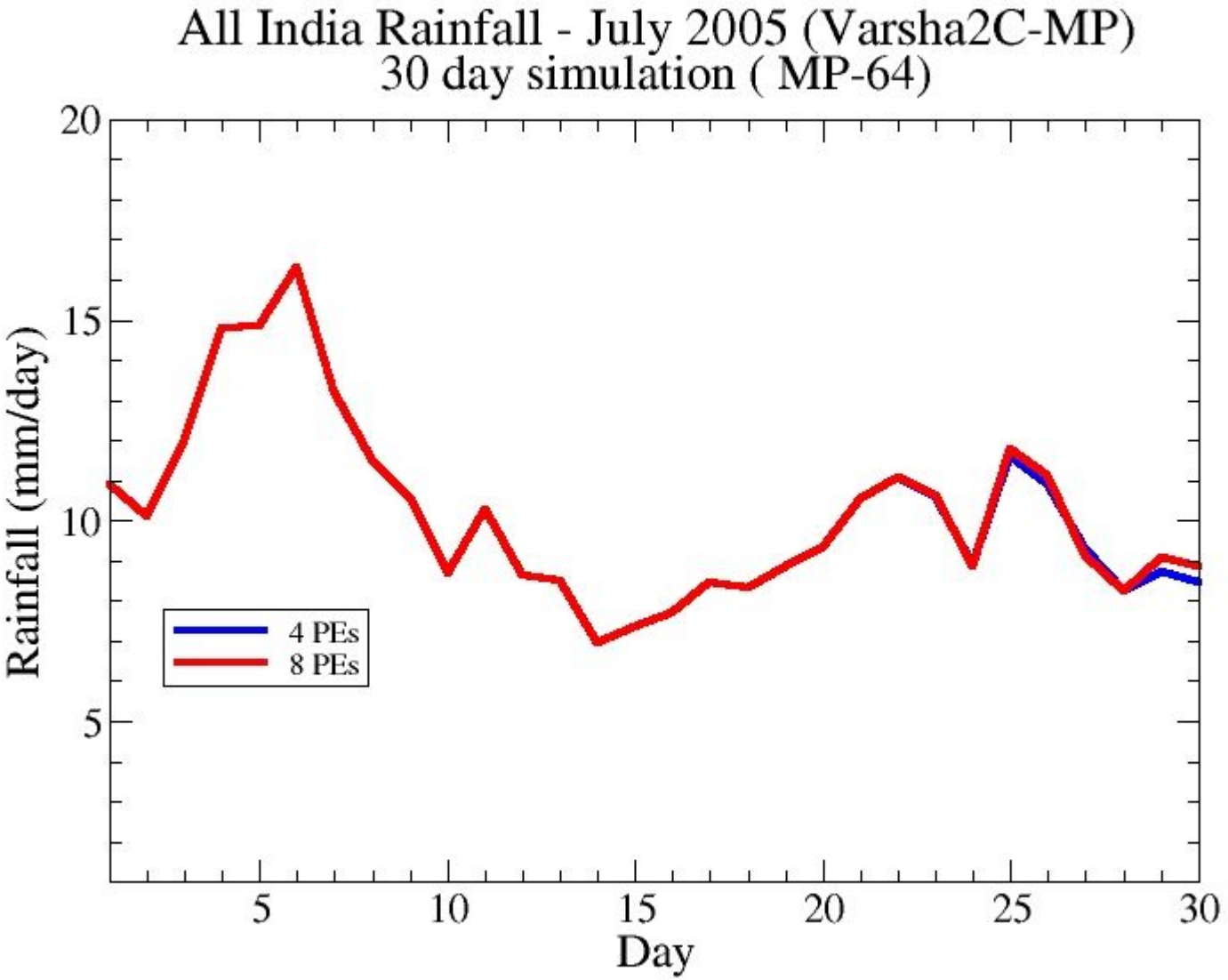
Lucknow
Patna
Shillong
Calcutta
Mumbai
Hydergoad
Chennai
Bangalore
Trivandrum

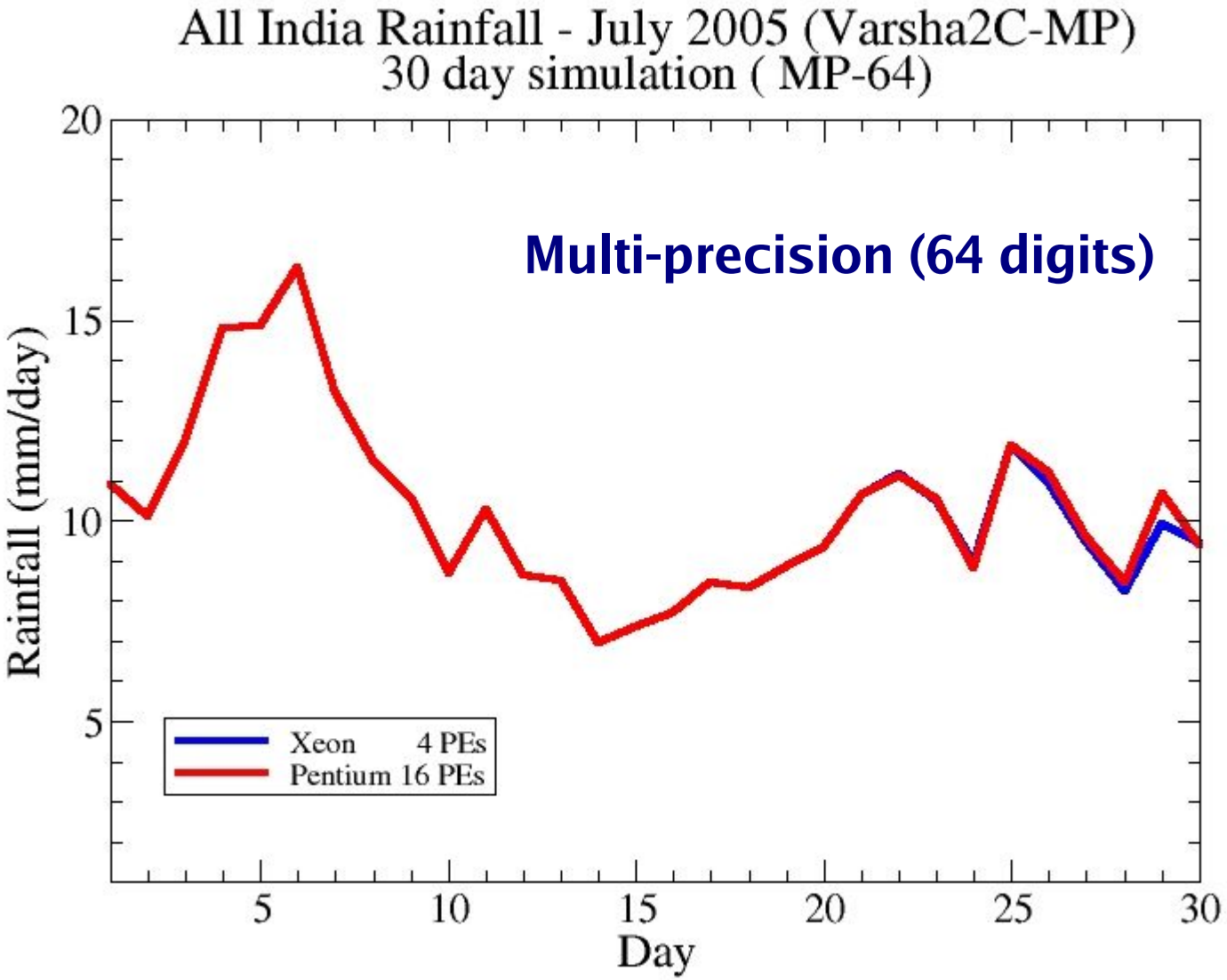
64 digits: Different no. of PEs



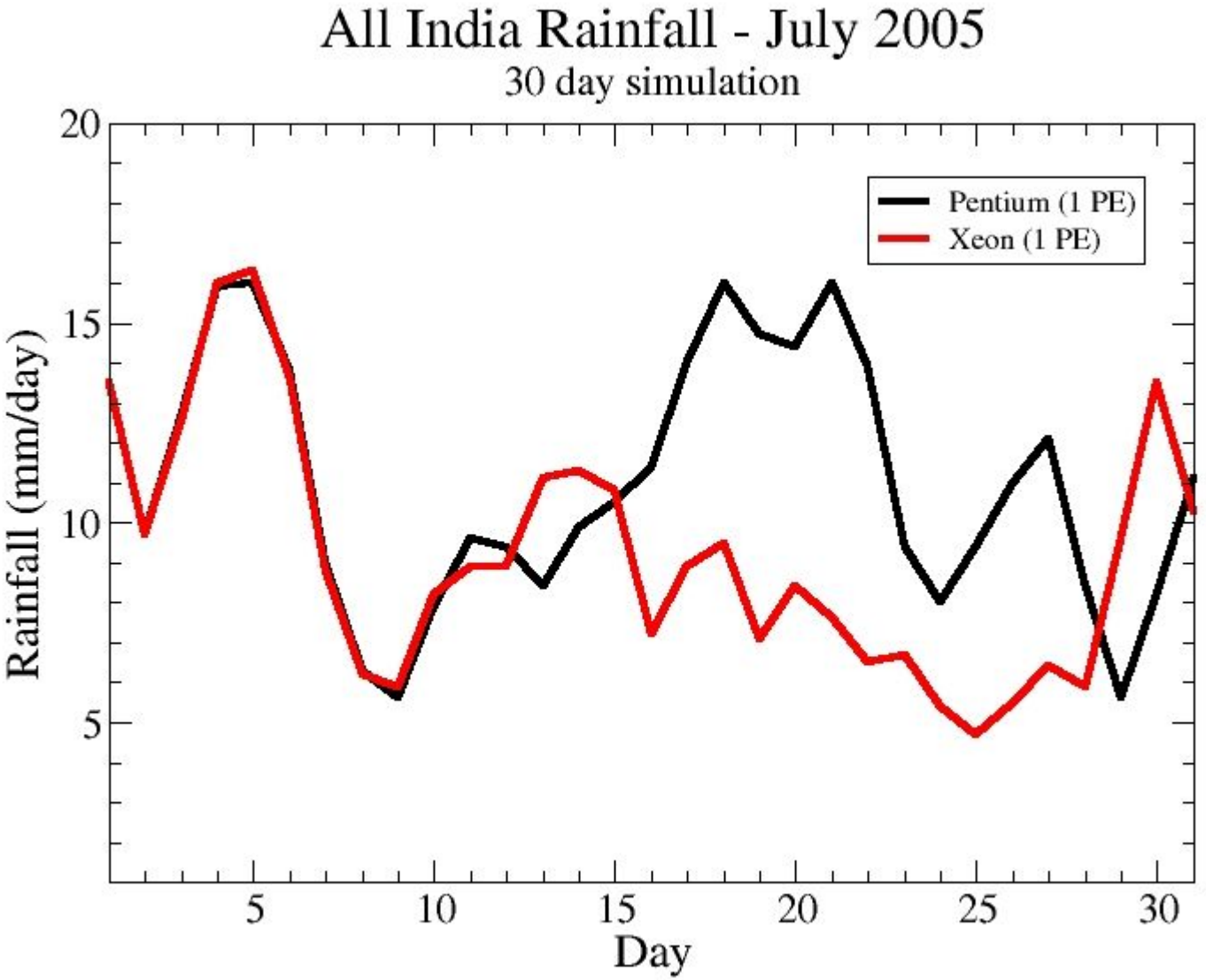
128 digits: Different no. of PEs



Different platforms/ no. of processors



Repeatability of results: Single precision



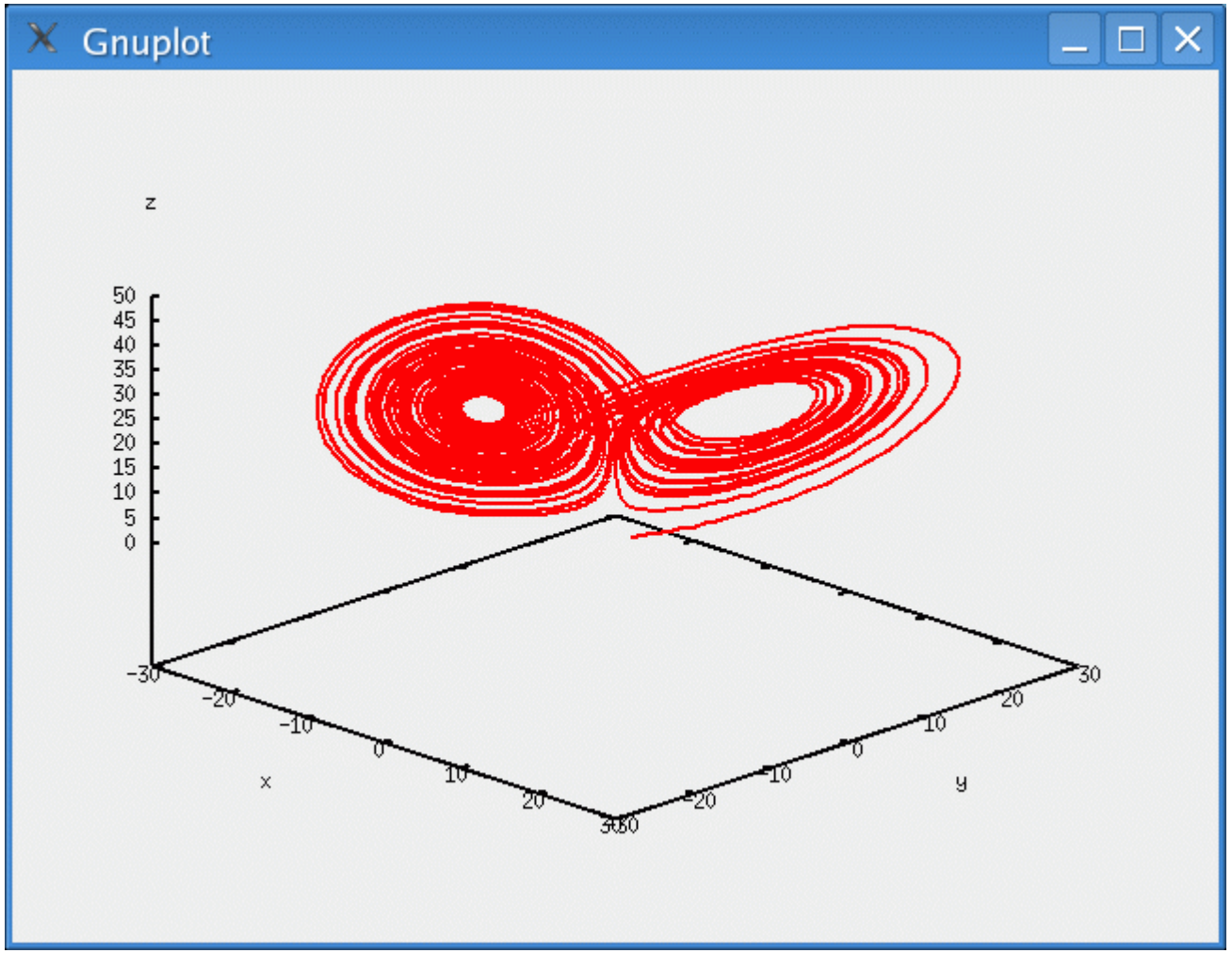
Significance to Chaos

- Lorenz system (1963) computed with the multi-precision
  - Fortran version
  - MPFUN90 library used
  - RK4 time stepping

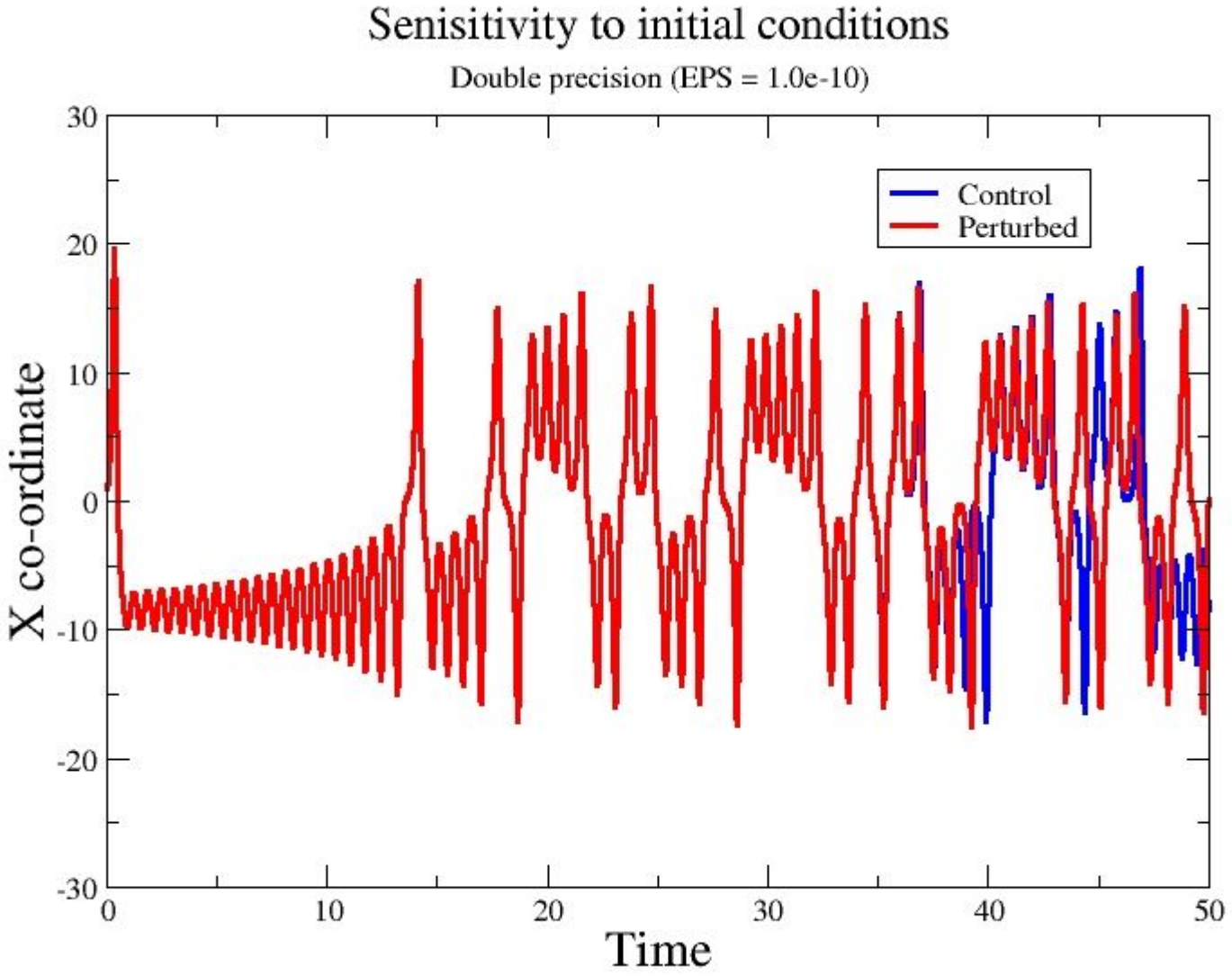
$$\begin{aligned} \dot{x} &= \mathbf{s}(y - x) \\ \dot{y} &= \mathbf{r}x - y - xz \\ \dot{z} &= xy - \mathbf{b}z \end{aligned}$$

- Computation with upto 2048 digits
- No significant change in the nature of solutions

Standard trajectory



Growth of perturbations



Nature of solutions

Time at which two trajectories diverge beyond 0.01 (initial difference is 1.0e-10)

DP	31.89
MP-16	31.89
MP-32	31.89
MP-64	31.89
MP-128	31.89
MP-512	31.89
MP-1024	31.89
MP-2048	31.89

Role of precision

	20.000	30.000
DP	13.4729057433 3027	9.86686 0933476248
MP-16	13.47290574339619	9.866859443550 267
MP-32	13.47290574339619	9.86685944355 0123
MP-64	13.47290574339619	9.86685944355 0123
MP-128	13.47290574339619	9.86685944355 0123
MP-512	13.47290574339619	9.86685944355 0123
MP-1024	13.47290574339619	9.86685944355 0123
MP-2048	13.47290574339619	9.86685944355 0123

Role of precision

	40.000	49.000
DP	-8.743318752850055	-5.74396101251091
MP-16	-8.5345964 63420804	8.6908 95354052055
MP-32	-8.534596443596334	8.690908640180727
MP-64	-8.534596443596334	8.690908640180727
MP-128	-8.534596443596334	8.690908640180727
MP-512	-8.534596443596334	8.690908640180727
MP-1024	-8.534596443596334	8.690908640180727
MP-2048	-8.534596443596334	8.690908640180727

Conclusions

- **Multi-precision calculations done with a complete GCM (*VarshaC-MP*)**
  - **(32, 64, 128 digits) ARPREC library**
- **Round off errors do play a significant role in long-term integrations**
- **Can get repeatable results across different processors and different number of processors if number of digits is greater than 64**

Conclusions...

- Could have implications for ensemble runs
- Distinction between round-off errors and chaos should be made
- Multi-precision calculations: computing power/time required is very large
  - Can use all the new supercomputer power which is going to be available
- Promising field of study

Thank you