Data Organization and I/O in a Parallel Ocean Circulation Model

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Ocean General Circulation Models

- Modular Ocean Model (MOM)
- Parallel Ocean Model (POP)
- Miami Isopycnic Coordinate Ocean Model (MICOM)
- Semi-spectral Primitive Equation Model (SPEM)
- Several other models

Grand Challenges

- Fine resolution
  - ~ 0.1^o resolution -> 3600x1200x100 grid
- Long time scale (decades, century)
- Many physical processes
- Topography
  - ~ Load balance due to bottom and land

Modular Ocean Model (MOM3)

- Community model, free download from Internet
- Developed and supported by GFDL, Bryan-Cox-Semtner.
- Large number of physical parametrizations.
- Widely used in ocean flow/circulation simulations (350 users)
- Adopted by NCAR (NCOM), LANL(POP), and many others for further developments.

MOM3

- 3D Large scale general ocean circulation
- Navier-Stokes + hydrostatic, Boussinesq approx.
- Finite difference
- Dynamics split into barotropic, baroclinic modes
- Barotropic: depth-averaged column velocities, 2D variables
- Baroclinic: deviations from barotropic modes, 3D variables
- Tracers: temperature and salinity, etc. 3D variables
- Free surface, Killworth et al, explicit method
- Free surface, Dukowicz et al, implicit method.

Some Observations of MOM3 Codes

- Memory window (out-of-core)
- Many options (*.F --> *.f)
- 80,000 lines of Fortran in 367 subroutines.
- I/O uses netCDF
- 1D decomposition (latitudes)

FLow Chart of Simulation Process

Read topography, initial condition, etc

Time step through all subtask:

Load Memory Window data from disk/ramdisk

Advection velocities

Isopycnal mixing, vertical mixing, horizontal mixing

Vertical boundary condition

tracer equations

Baroclinic equations

Write Memory Window data to disk/ramdisk ← **Communication**

Barotropic equation (free surface) ← **Communication**

Diagnostics

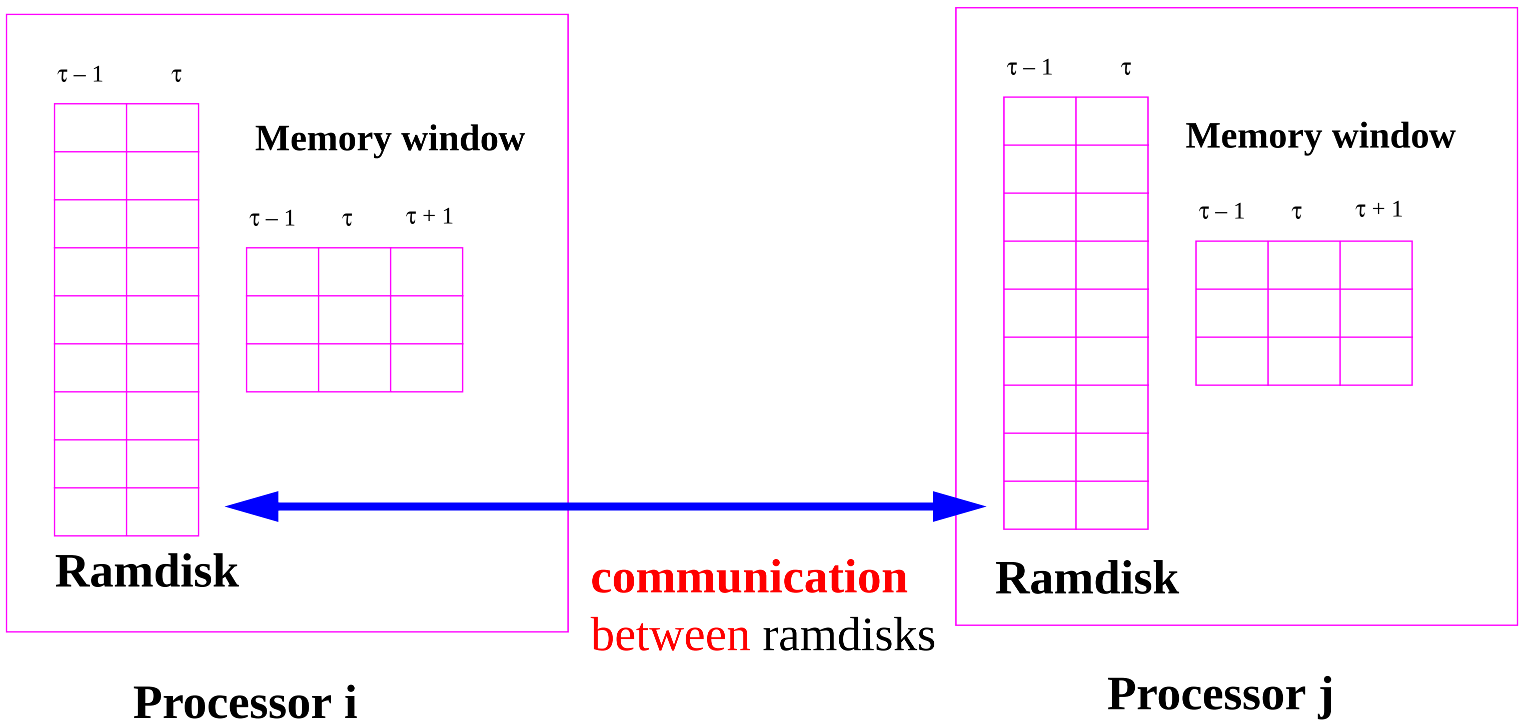
Data Organization

Three different data indexings:

- In memory: A(i , k , j , uv , ts)
- In disk file: A(i , j , k , uv , ts)
- In ramdisk: A(i , k , uv , ts , j)

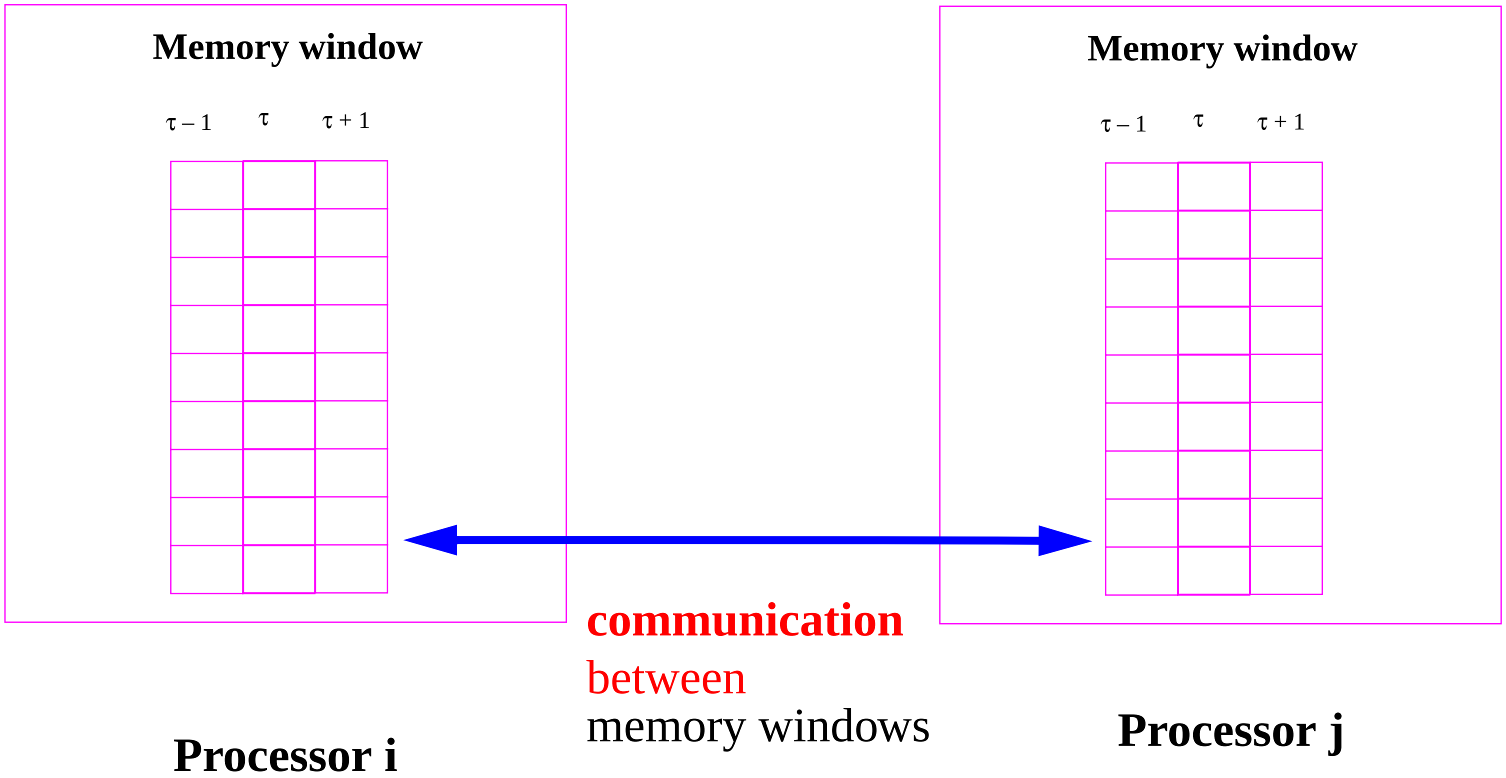
uv=1,2 for velocities
ts=1,2,..., for temp, salinity, etc

Out-of-Core Mode



* Requires extra memory copy

In-Core Mode



* Speedup Computation
* Prepare for parallel I/O

Input/Output, netCDF

MOM uses netCDF (POP, CSM, Impact)

- netCDF is self-describing, portable, flexible.
- main problem is efficiency

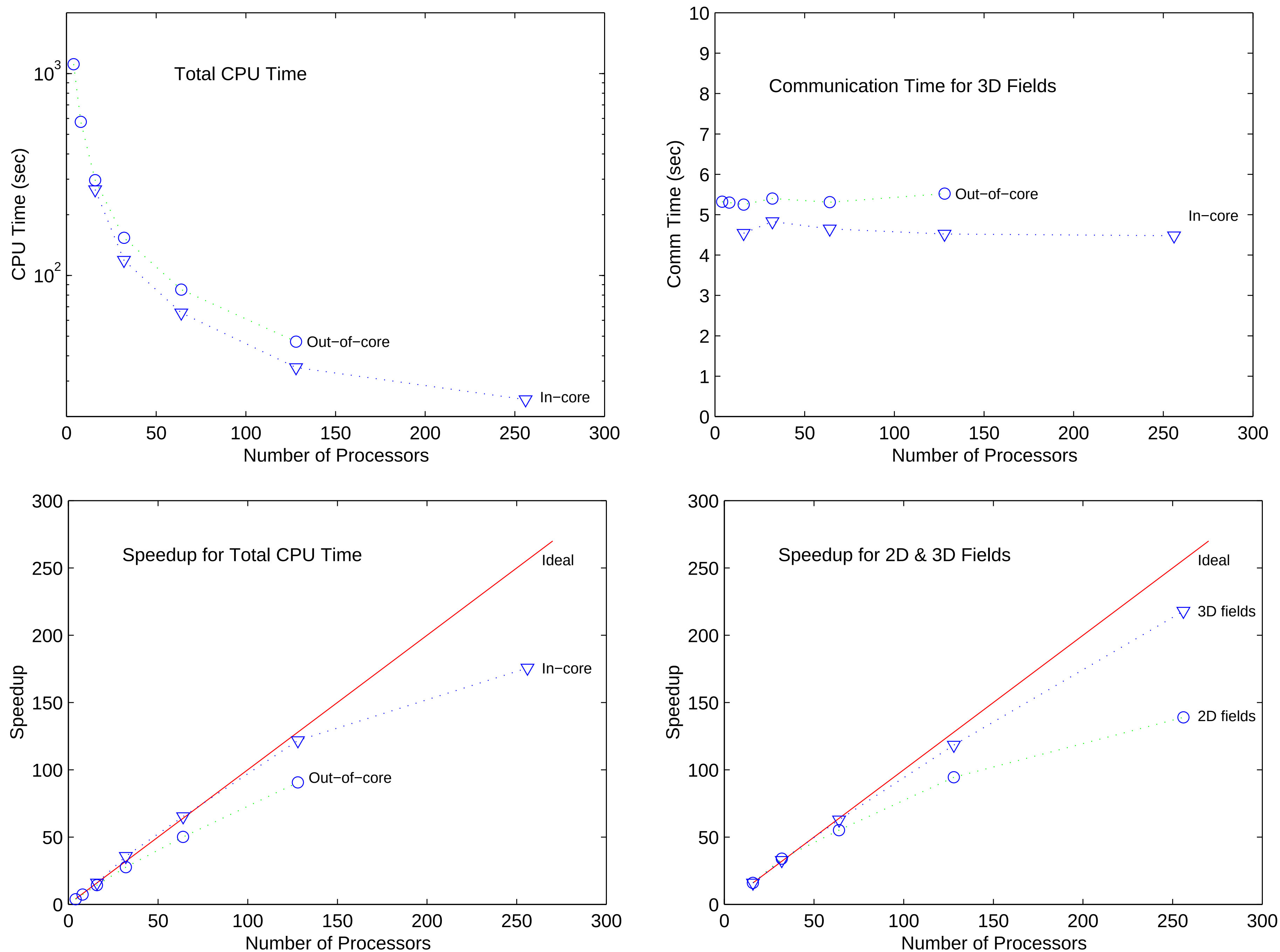
NERSC resolved critical issues of netCDF in parallel T3E environment (Owen, Anand, Luzmoor, Davis)

- Unlimited dimension
- **Assign** I/O control environment ($NETCDF_FFIOSPEC)
- subset of PEs open a global file

netCDF rates are reasonable

- 17 MByte/sec on 1PE.

0.5^o x 0.5^o Global Ocean (722x258x40)



Snapshot I/O in MOM

Old:

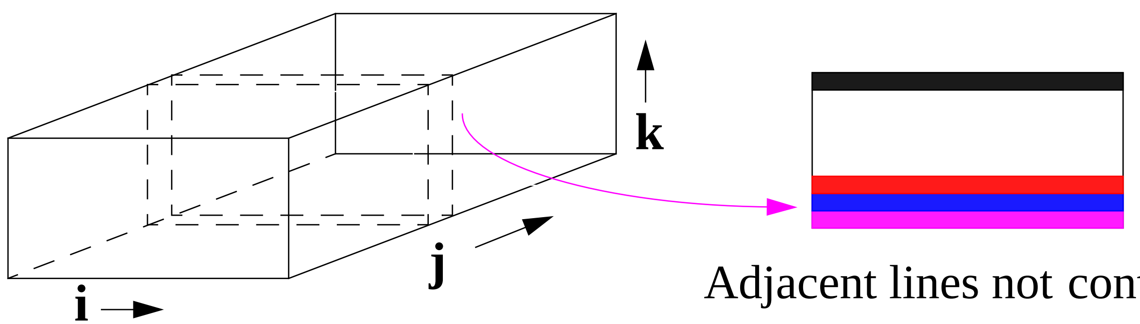
- Load from Ramdrive to Memory Window
- Write out data one latitude slice at a time.

New:

- Do index switch in memory.
- Write all latitudes in one shot.

Reduce I/O time by a factor of 50 !

A(i, k, j)
in memory



A(i, j, k)
in data files

Adjacent lines not contiguous in file space

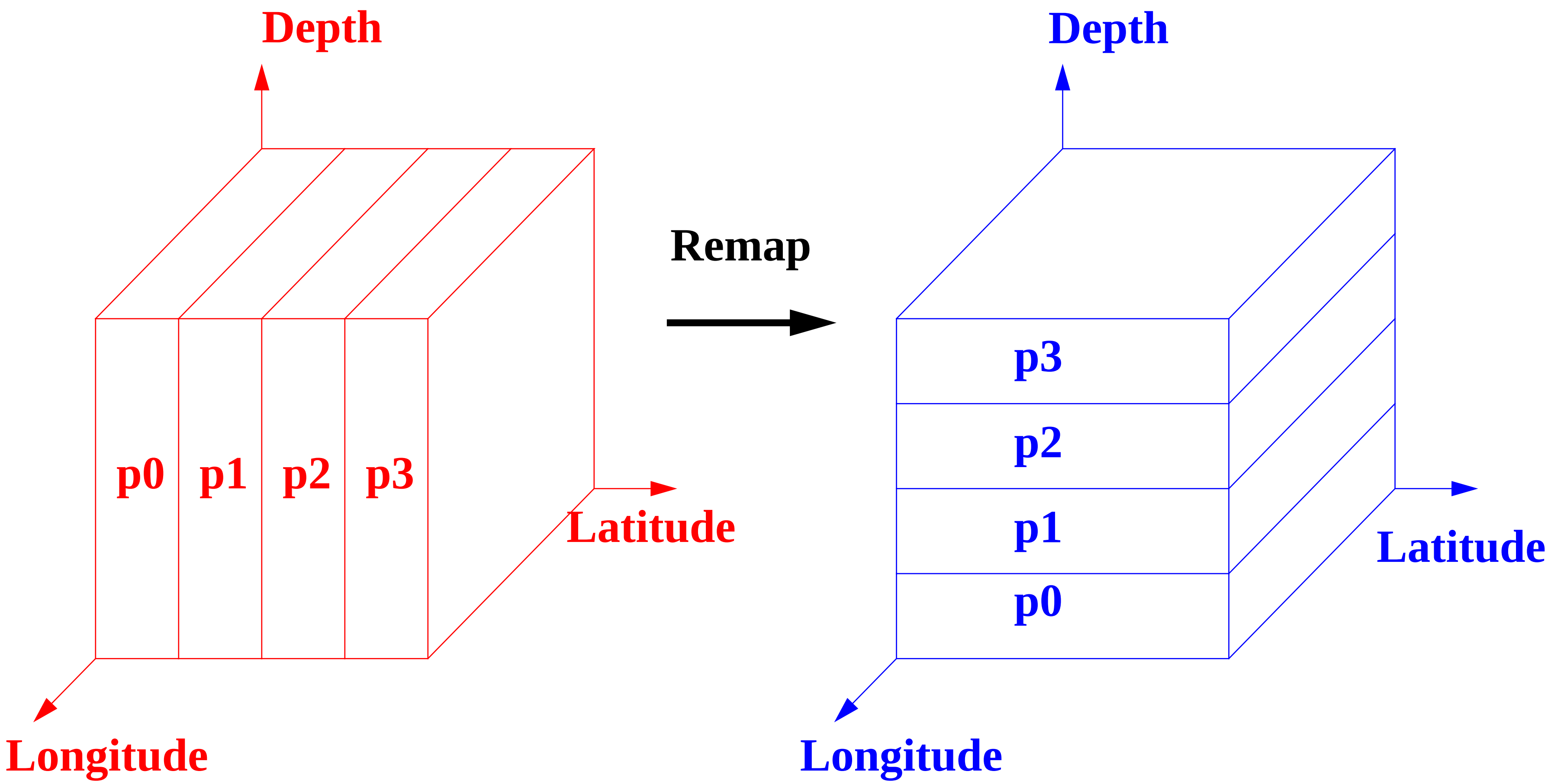
Memory Window (Out-of-core)

- Only small portions of data stored in computer memory. Swap data between memory and disk.
- Enable MOM to run on from workstations to C90
- Complicates code design, parallelization
- 50% slowdown on cache-based processors

Table 1: Timing for Different Memory Usage Modes

Time	Total	Baroclinic	Barotropic
Memory Window Only	256	202	35.3
MW + Ramdrive	354	297	35.4

Remapping 3D Array for Efficient I/O



Latitude-Split
A(i, k, j)

Depth-Split
A(i, j, k)

Parallel I/O Basic Design

- Data file written as in sequential environments
  - ~ Portable to other platforms
  - ~ Output file directly used in any other platforms (visualization) without extra file convertion
  - ~ Restart/checkpointing simplified
  - ~ Adaptable to changing environment: run on different # of processors at different times.

- Use a few designated I/O processors
  - ~ Relieves memory limitations of a single processor
  - ~ Increasing available I/O channels, thus bandwidth

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- Low-level I/O modules
  - ~ Most existing I/O interface intact

Parallel I/O Basic Design (con't)

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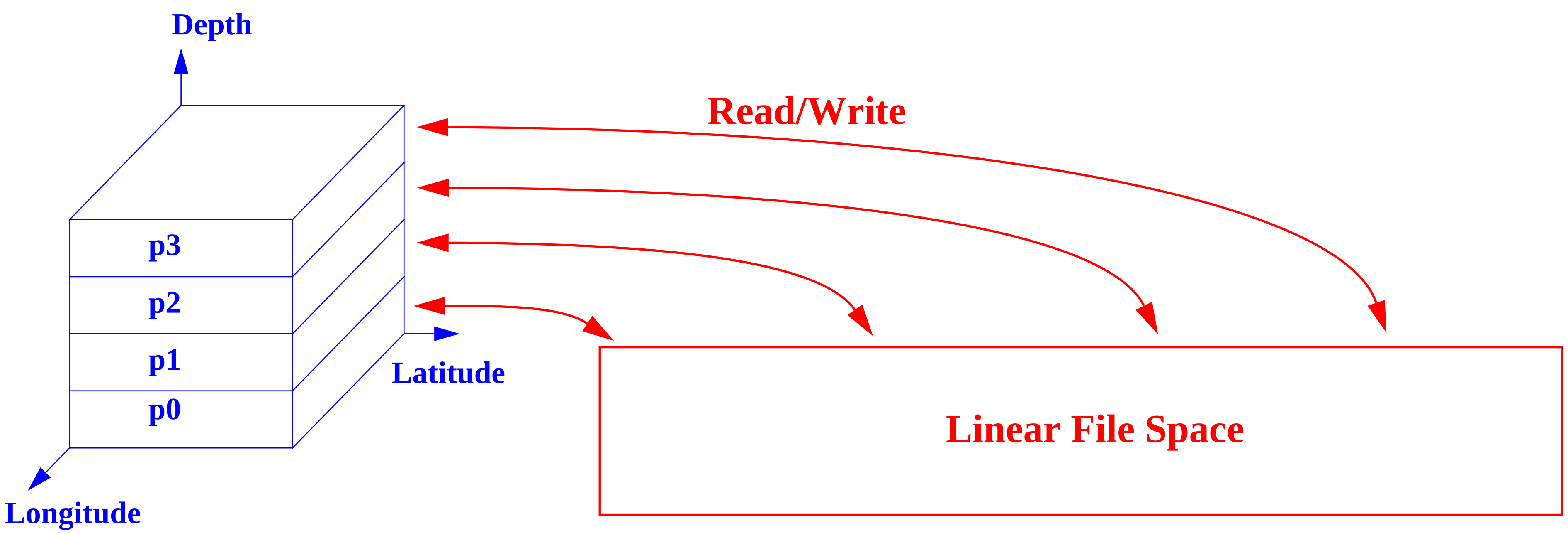
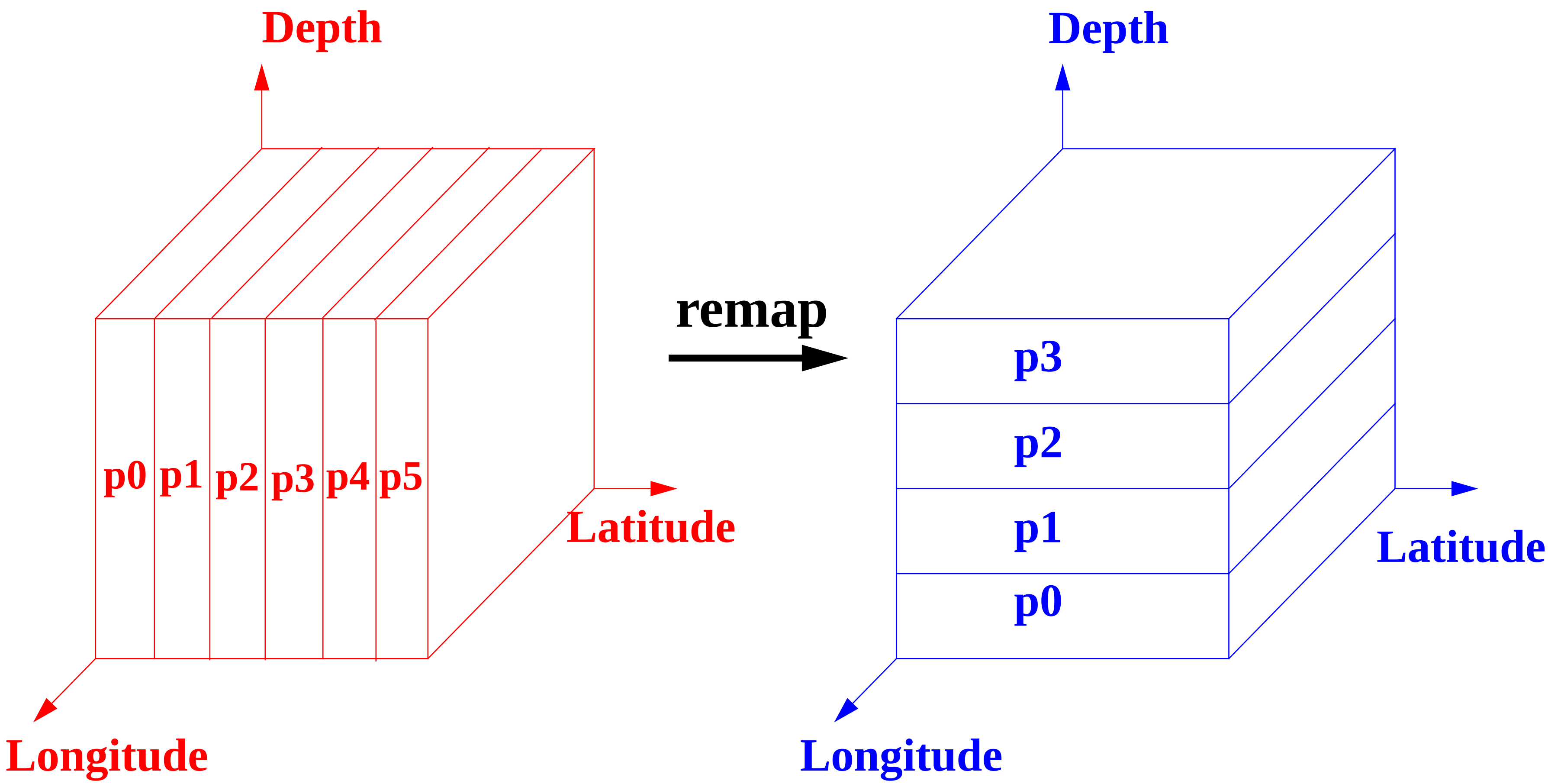


Depth-Split Decomp

Parallel I/O Implementation

- Start with In-Core mode (everything in memory)
- Do 3D arrays, one after another, one at a time.
- Remapping 3D array to depth-split distribution on ioPEs.
  - (# of ioPEs <= # of levels)
  - use in-place remapping algorithm
- Each ioPE write/read the partial 3D array in one shot.
  - Treated as contiguous block in 1D array.
  - Requires only collective I/O for 1D array.
- 2D arrays are done similarly.

Remapping a 3D array from 6 processors to 4 designated I/O processors



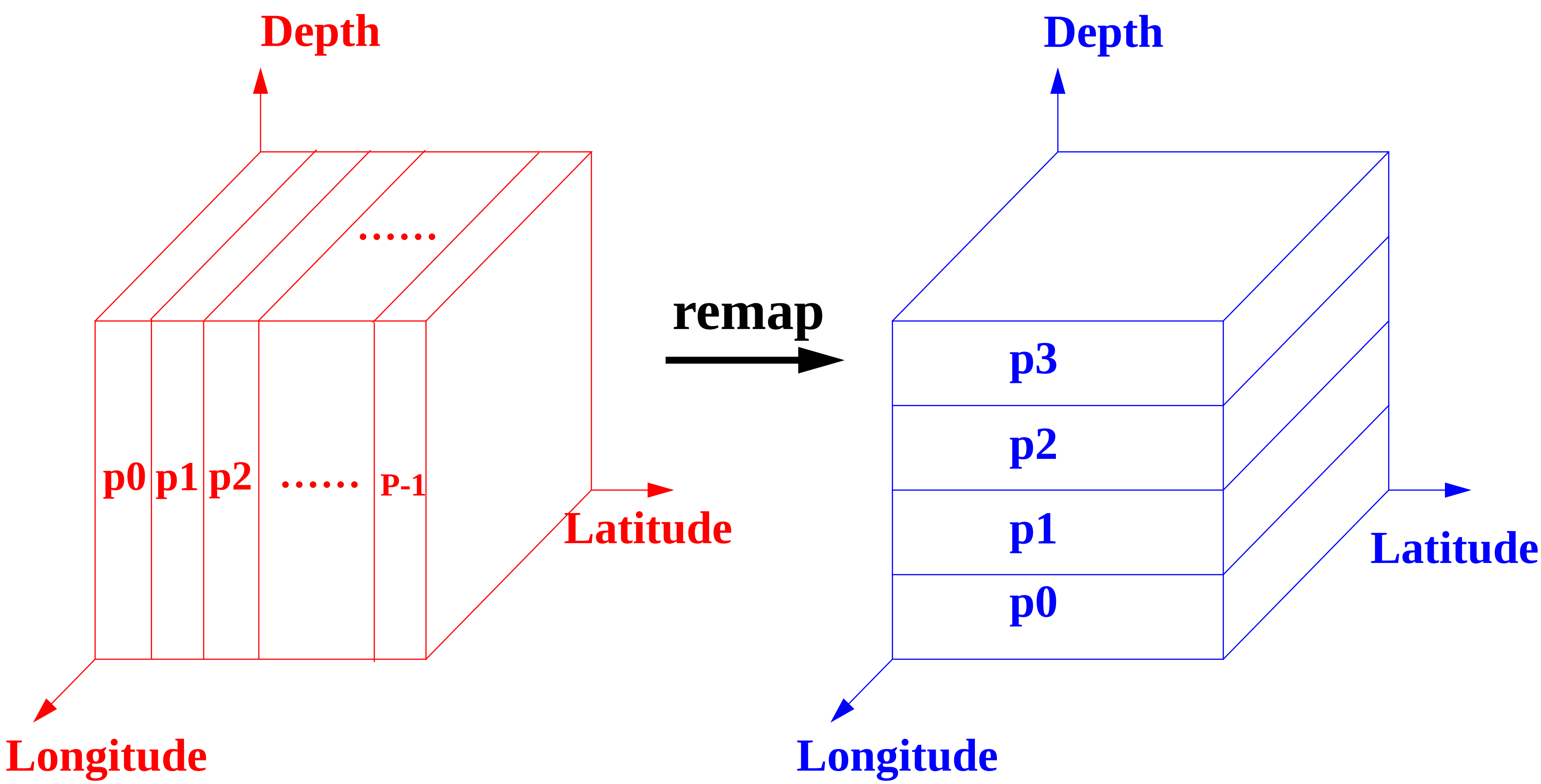
Latitude-Split

A(i, k, j)

Depth-Split

A(i, j, k)

Remapping a 3D array from P processors to 4 designated I/O processors



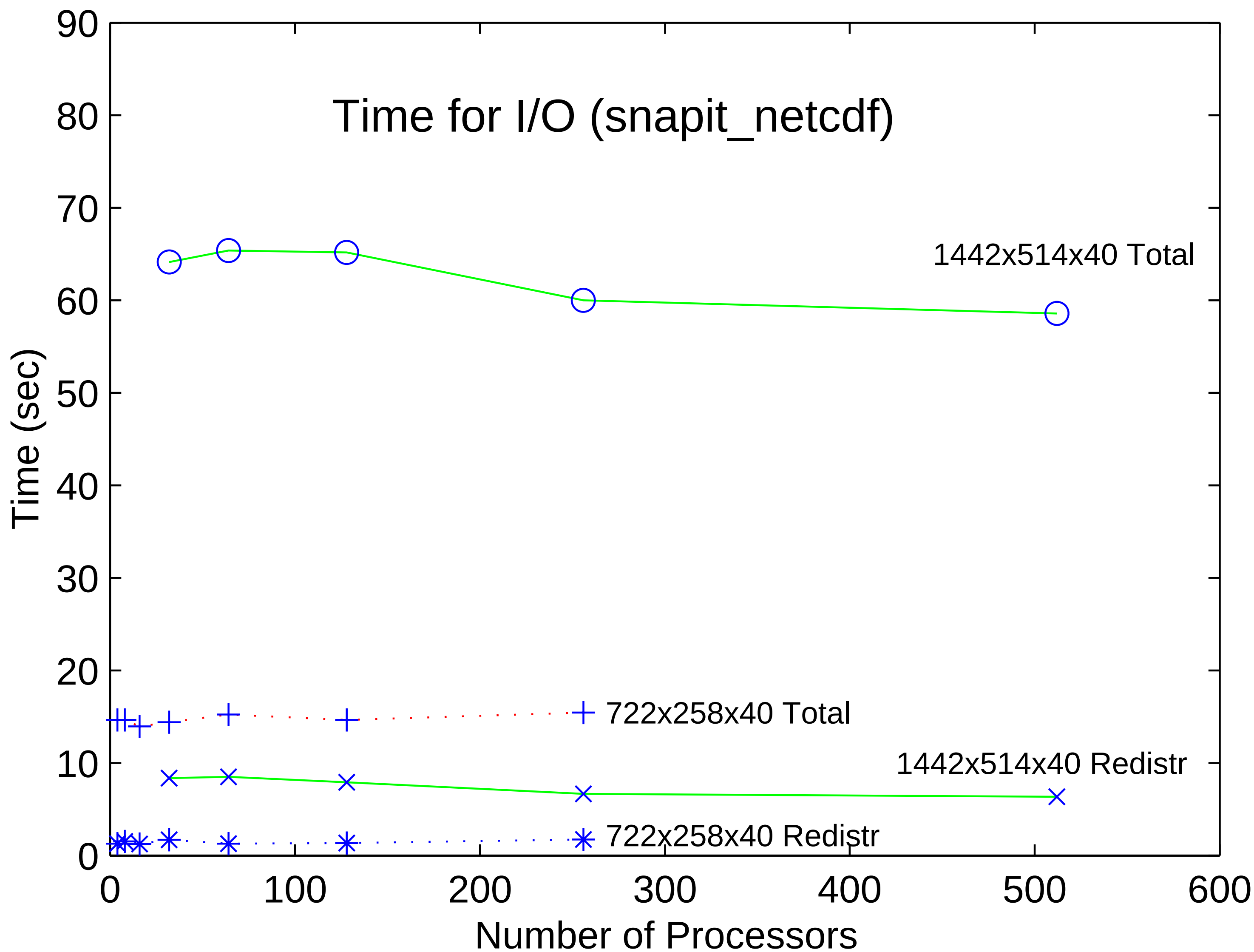
Latitude-Split

A(i, k, j)

Depth-Split

A(i, j, k)

Timing of the Parallel Snapshot I/O for 0.5^{o} and 0.25^{o} Resolutions on T3E with netCDF.



Optimization : Diagnose

- Diag() scales very poorly to large # of processors
- Reason: getunit() is called each time step. It's very time consuming.
- Modified diag() such that it calls getunit() once a simulated day, or a pre-specified interval. This speeds up diag() by a factor of 32!
- Similar modifications are made for relunit().

Summary and Conclusions

- Analysis of data organization and I/O in MOM3
- Out-of-core memory usage mode not suitable
- In-core memory usage mode speedup computing and facilitate I/O
- Sequential netCDF I/O is speedup by 50-fold
- Parallel I/O design and implementation scales well
- An inplace 3D array remapping algorithm developed
- 2D barotropic explicit free surface not scales well.