Accelerating Climate Models with the IBM Cell Processor

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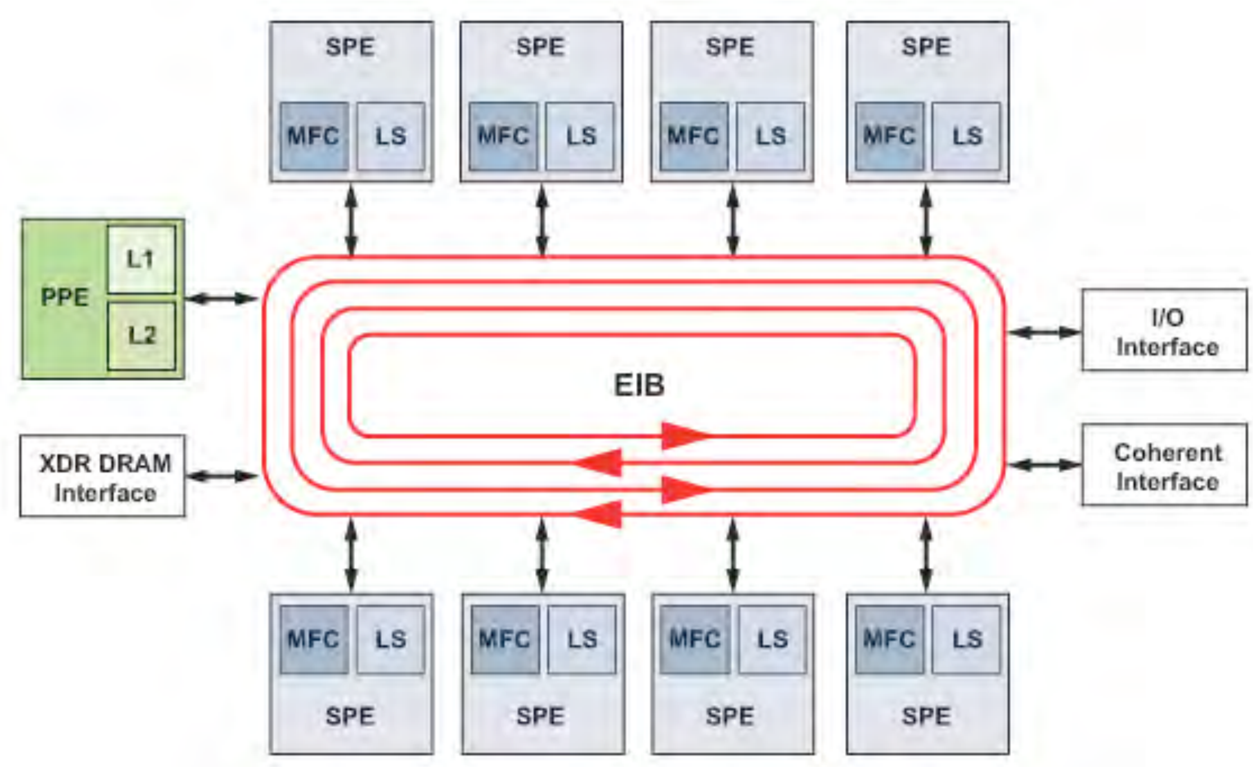
Outline

- Climate (e.g., NASA GEOS5) models
  - Column physics
    - Port the solar radiation code
  - Dynamics
    - Analyze the finite volume dynamics core
  - 4D Var data assimilation
    - Be very compute-intensive

Background

- NASA is interested in the potential performance and cost benefits of adapting some science applications to emerging nontraditional processors such as the IBM Cell
  - Motivation
    - Increase performance by one to two orders of magnitude over traditional processors.
  - Challenges
    - SPE's small local memory (256 KB)
    - A low-level communication mechanism
    - Direct memory address management

The IBM Cell Processor



- 205 single-precision GFLOPS
- High-speed data ring (EIB) with a sustained bandwidth of 205GB/s
- 25.6 GB/s processor-to-memory bandwidth
- 256KB local store at SPE

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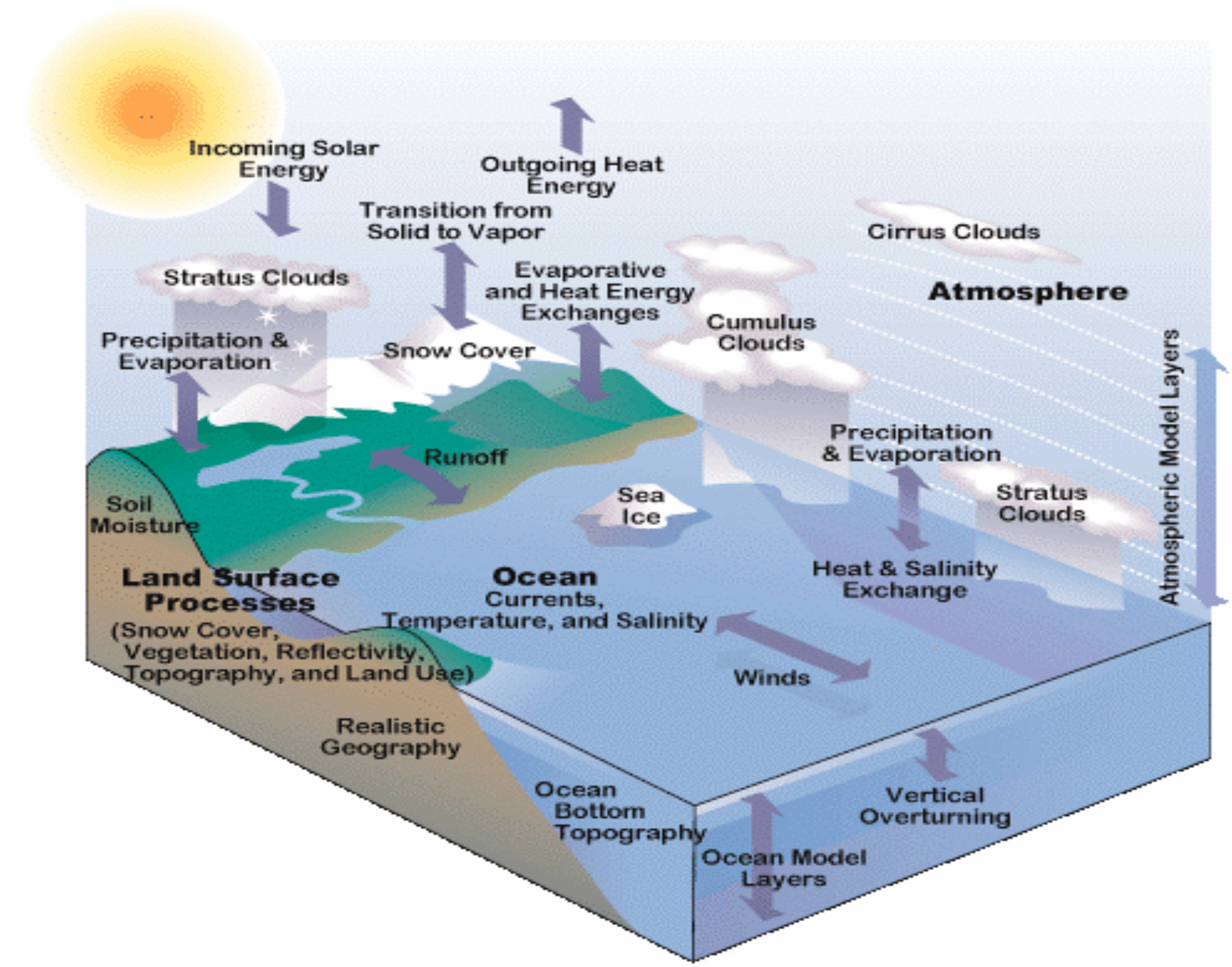
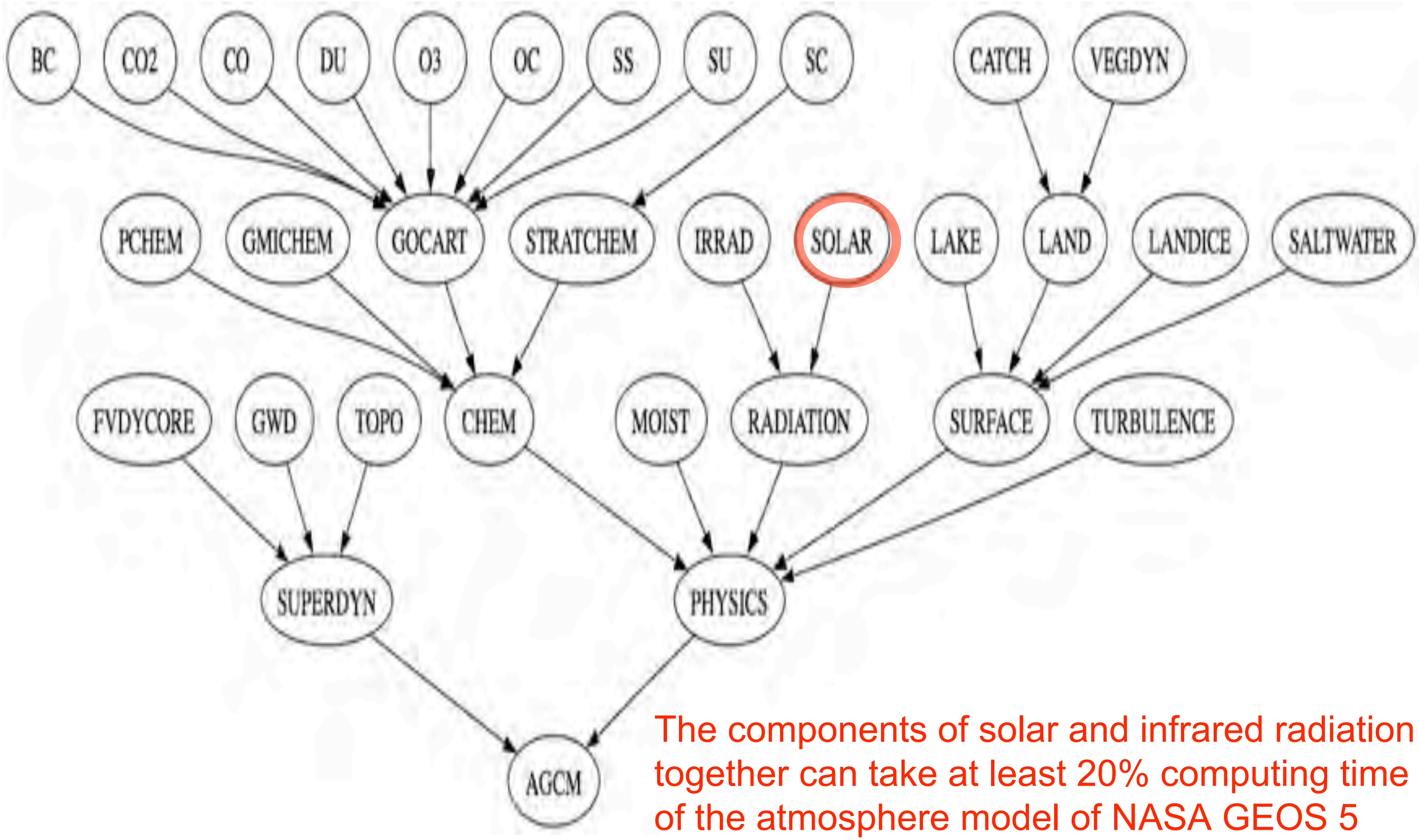
Processes in a Climate Model



http://www.ucar.edu/communications/CCSM/overview.html

NASA GEOS 5 Code Structure



The components of solar and infrared radiation together can take at least 20% computing time of the atmosphere model of NASA GEOS 5

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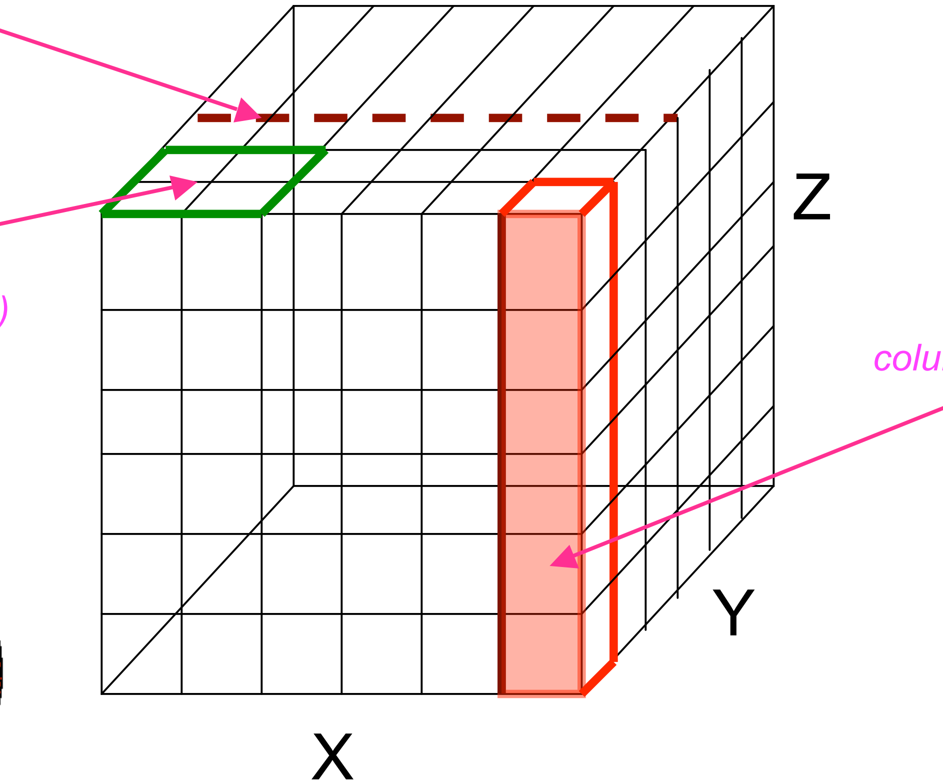
Climate and Weather Models

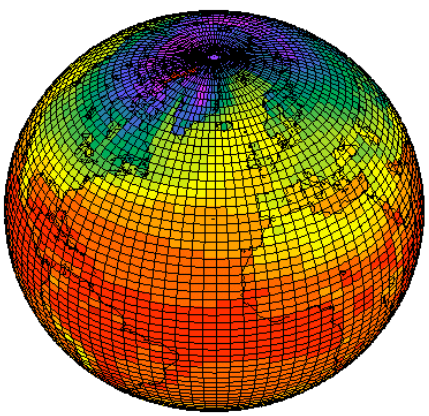
- Constraints
  - A few hundred thousand lines of code written in Fortran over 20+ years
    - Some modularity in F90/95
    - Still evolving
  - Production requirement
    - Cannot rewrite completely
    - Minimal intrusion
    - Good ratio of performance to cost
- Solutions
  - Select the computationally intensive model components
    - I/O is smaller compared to computation
    - The number of lines of code is manageable

Porting Strategies for A Cell Processor

- To simplify porting, put the calculations involving dependency into one SPE
  - Take in extra data to make it self-contained
    - The communication cost for extra data should be smaller than its calculation cost
- Minimize the intrusion to the original code as much as possible

Data Decomposition for Cell Streaming Model: Climate and Weather Applications





Climate model predicts global warming

Weather forecasts

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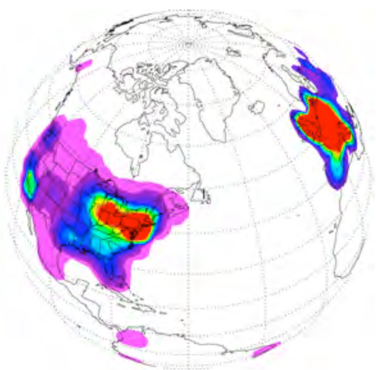
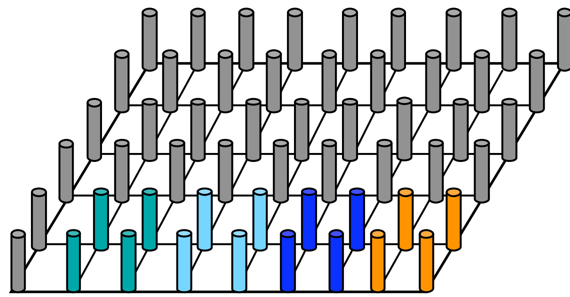
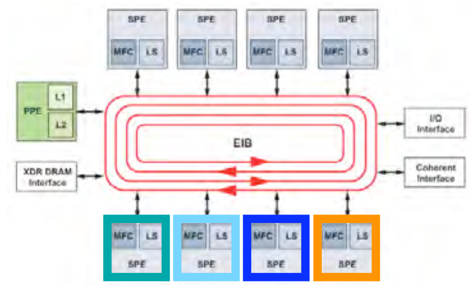
Port the Solar Radiation Code to IBM Cell Processor

Global Circulation Model Main Memory Data Transfer via DMA Local Store







The solar radiation component of NASA's Goddard Earth Observing System Model, Version 5 (GEOS-5) was chosen to evaluate the Cell's programming paradigm due to these factors:

- One of the most computationally intensive parts of GEOS-5, at least 20% (including infrared radiation)
- The time required for I/O is much smaller than for numeric computation
- The independent vertical column calculation greatly simplifies parallel programming

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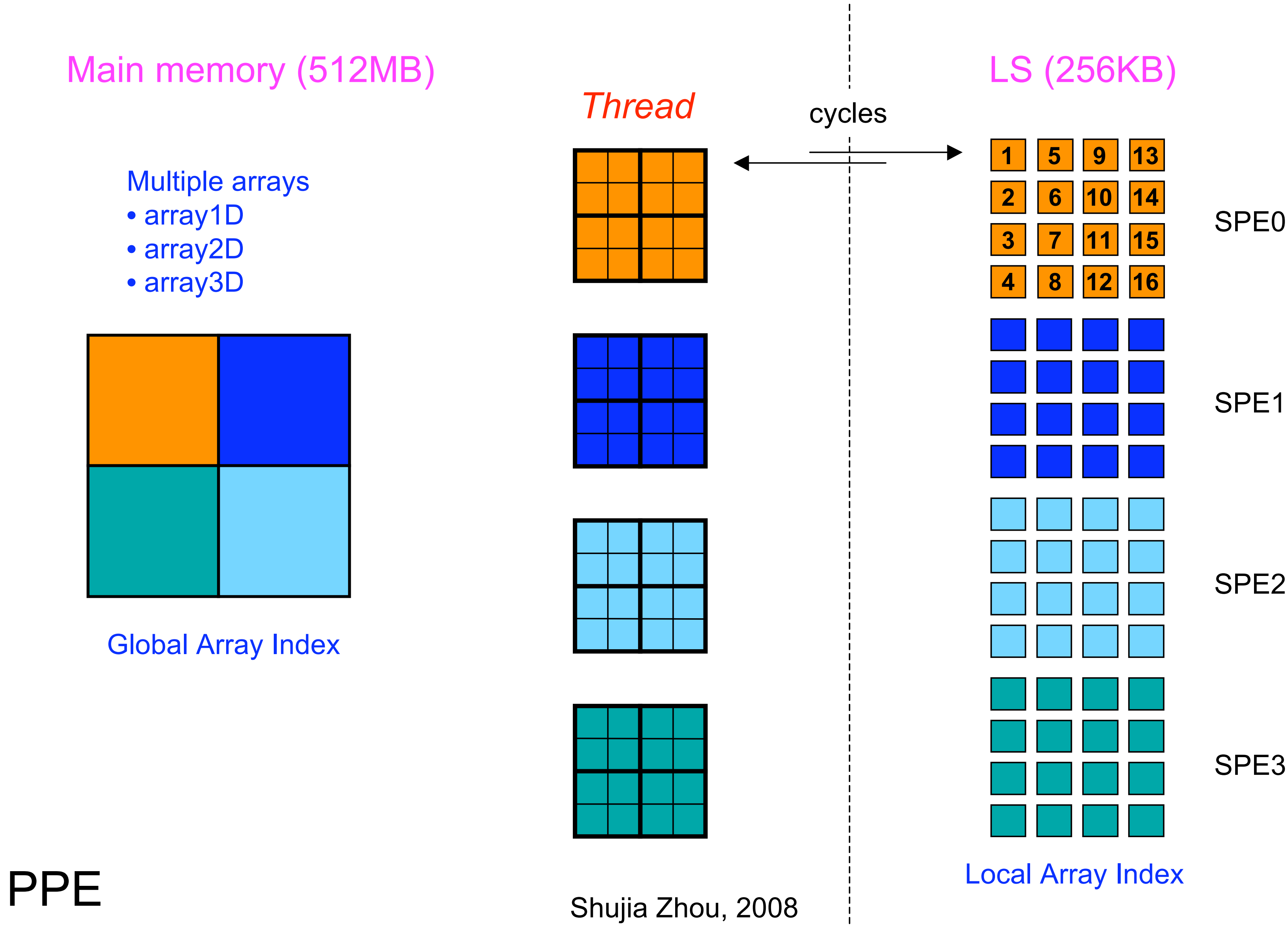
Flow Diagram of Data Transfer via DMA (4 SPEs)



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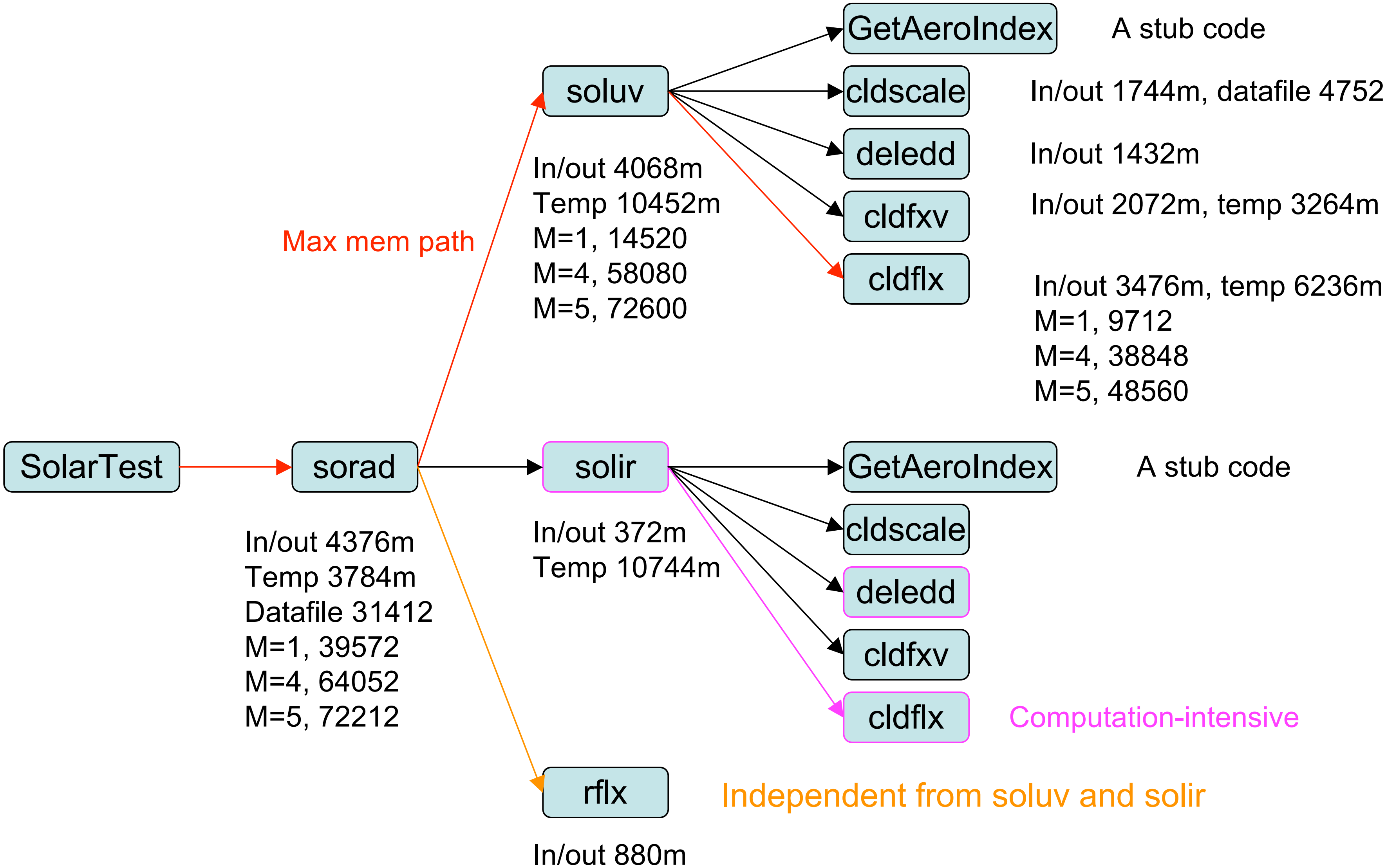
Detailed Memory Analysis



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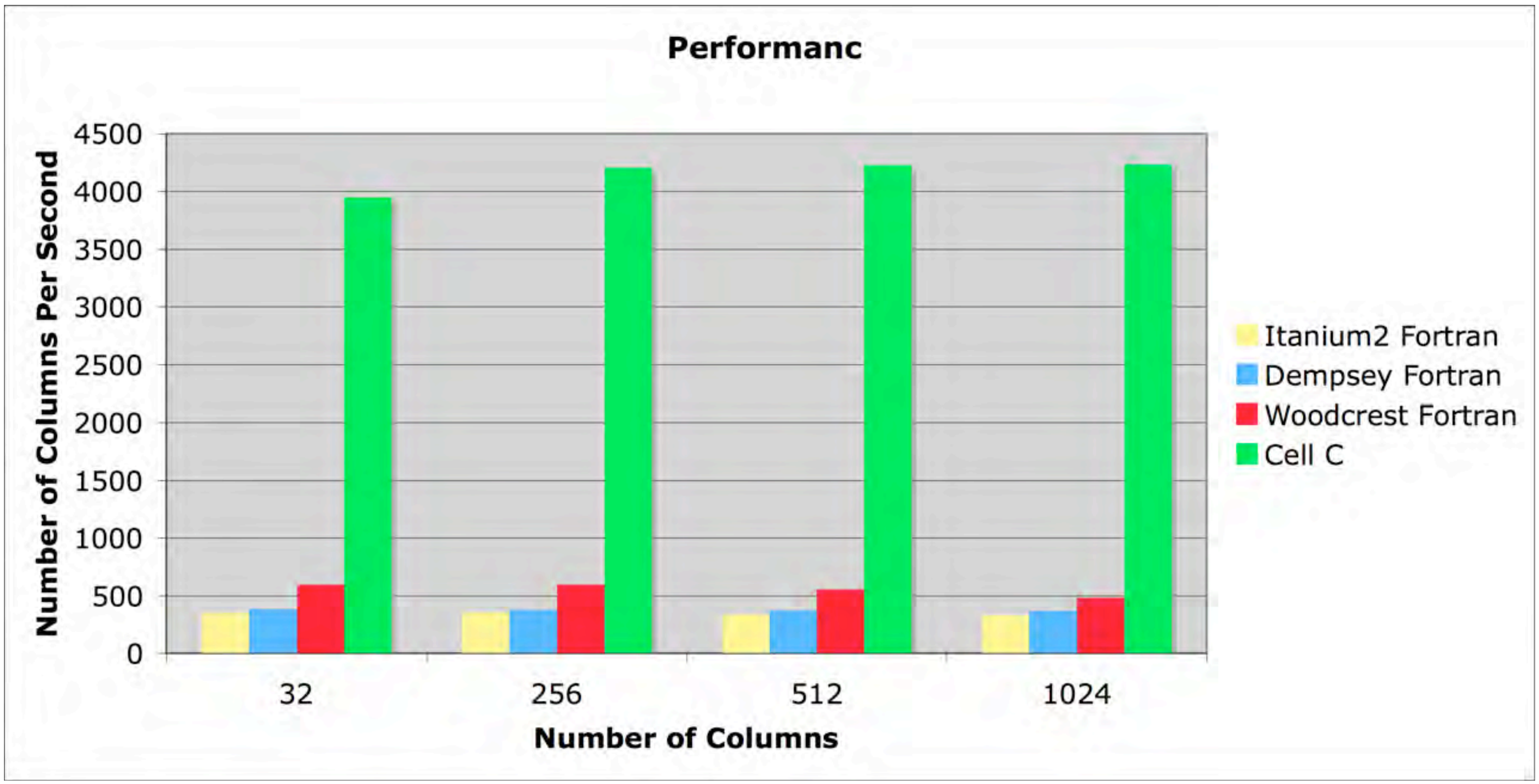
Profile of The Cell-Version Solar Radiation Code

Function call	DMA get		soluv	solir	cldscale	deledd	cldflx
Time (usec)	40		25186	143308	77	99	4551
iteration	1	soluv	1		1	20 = 5x4	5
		solir		1	3	120= 3x10x4	30= 3x10
		total	1	1	4	140	35

8 SPEs, 1024 columns, single precision of deledd(), no vectorization

Performance

IBM BladeCenter QS20	Itanium 2	Xeon	
single precision, vectorization and unrolling of deledd() and cldflx()	single precision	single precision	
1 PPE + 8 SPEs PPE: 64-bit PowerPC, 3.2GHz SPE: 128-bit SIMD, 3.2 GHz	1 core of Intel Itanium2, 1.5 GHz, with 4MB Cache	1 core of Intel Xeon (dempsey), 3.2 GHz, with 4 MB cache (2MB per core)	1 core of Intel Xeon (woodcrest), 2.66 GHz, with 4 MB cache (2MB per core)



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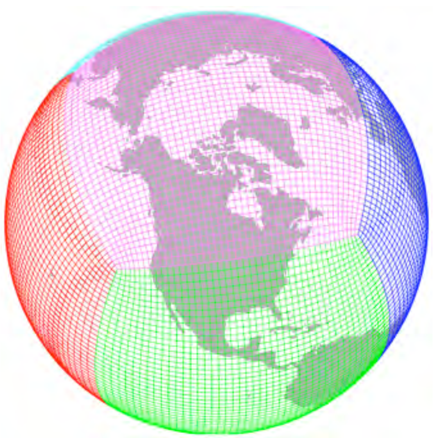
Performance

- For 1024 columns, latest results show that the Cell ran the C-version code 8.8, 11.6, 12.8 times faster than a core on Intel's Woodcrest, Dempsey, and Itanium2 processors for the baseline code (Fortran, single-precision), respectively, with
  - Vectorization
  - Unrolling (~11% improvement)
  - IBM XL SPU C compiler (~20% improvement over gcc)

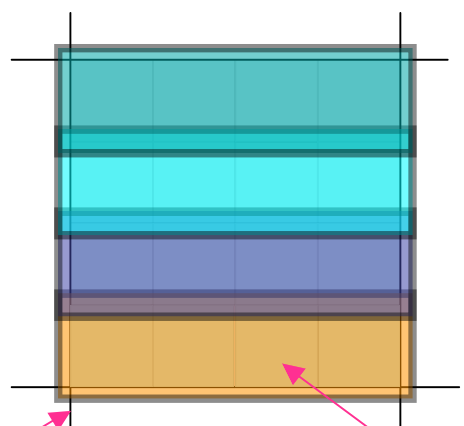
Accelerate
The Key Climate and Weather Community Component
Cubed-Sphere Finite Volume Dynamics (CSFVD)

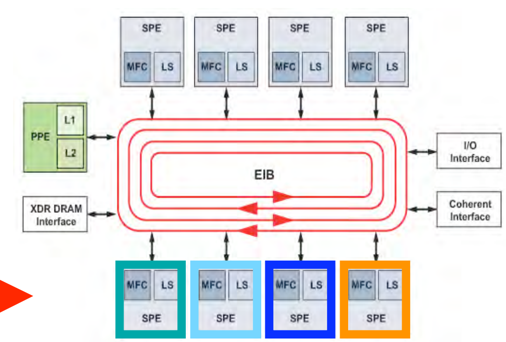
- CSFVD becomes next-generation climate models and weather forecast systems of NASA GMAO, NOAA GFDL, and NSF NCAR
- CSFVD takes at least 25% of total computing time
- Our analysis indicates that CSFVD can use Cell's streaming programming model to accelerate

Cubed-sphere grid



Data decomposition





Data domain for MPI process

Data patch for SPE

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Computing Requirement for 4D-Var

- The 4D Var data assimilation system better utilize satellite observations and consequently improve forecasting skill
  - Typically request hundreds of iterations of the linearized forecast model and its adjoint for each forecast run.
  - Require significantly shorten the execution time of the model to satisfy the operational requirement.

Summary

- We have demonstrated that IBM Cell technology can dramatically accelerate the physics components of climate and weather applications
- Our analysis shows that the dynamics component should be amenable to accelerate
- Data assimilation is extremely compute-intensive, which desires extraordinary acceleration

Acknowledgements

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