

Parallelization Framework for the Integrated Surface and Subsurface Flow and Transport Simulator: Parallelization of HydroGeoSphere

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UNIVERSITY OF
Waterloo



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Environmental and Engineering Services Worldwide

Outline

4/10/2011

- ❖ **Parallel targets for improving computational efficiency**
 - Hot spots of computation

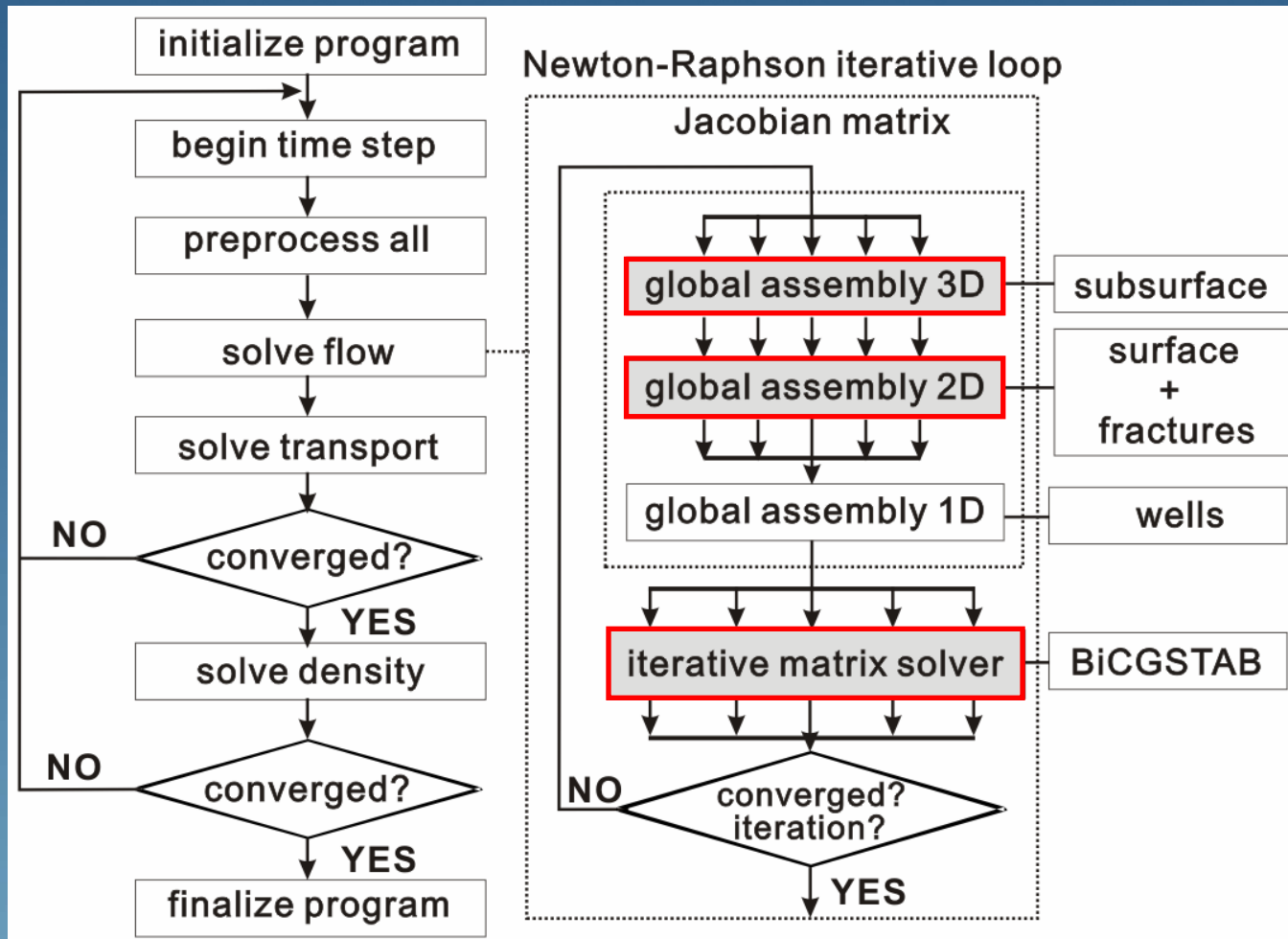
- ❖ **Parallel strategies for HydroGeoSphere**
 - Node reordering scheme
 - Parameter privatization

- ❖ **Evaluation of parallel efficiency**
 - Conceptual models
 - Large scale models

Computing Flow and Time of Serial HGS

4/10/2011

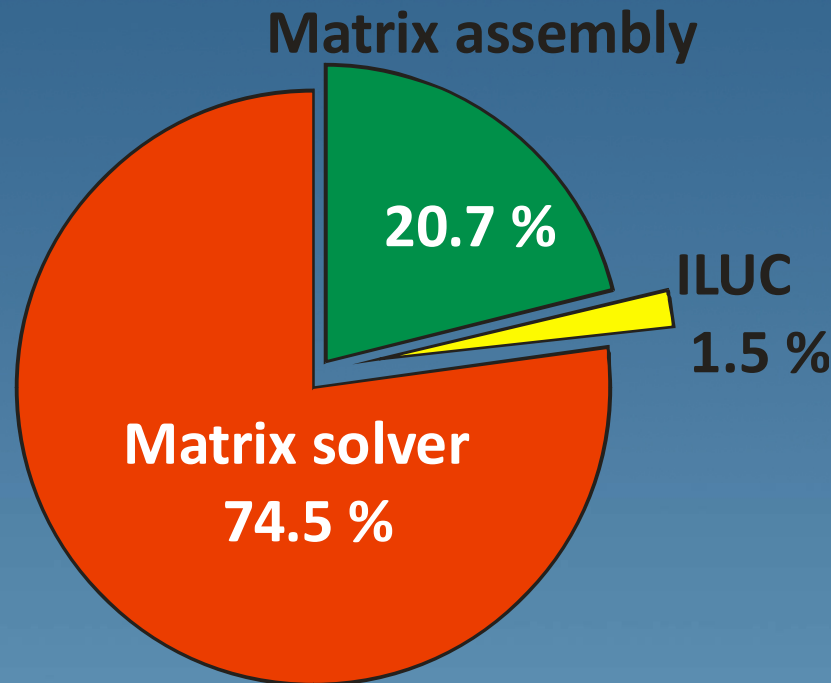
- Targets of parallelization are matrix assembly and iterative matrix solver



Computing Flow and Time of Serial HGS

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Distribution of Computing time



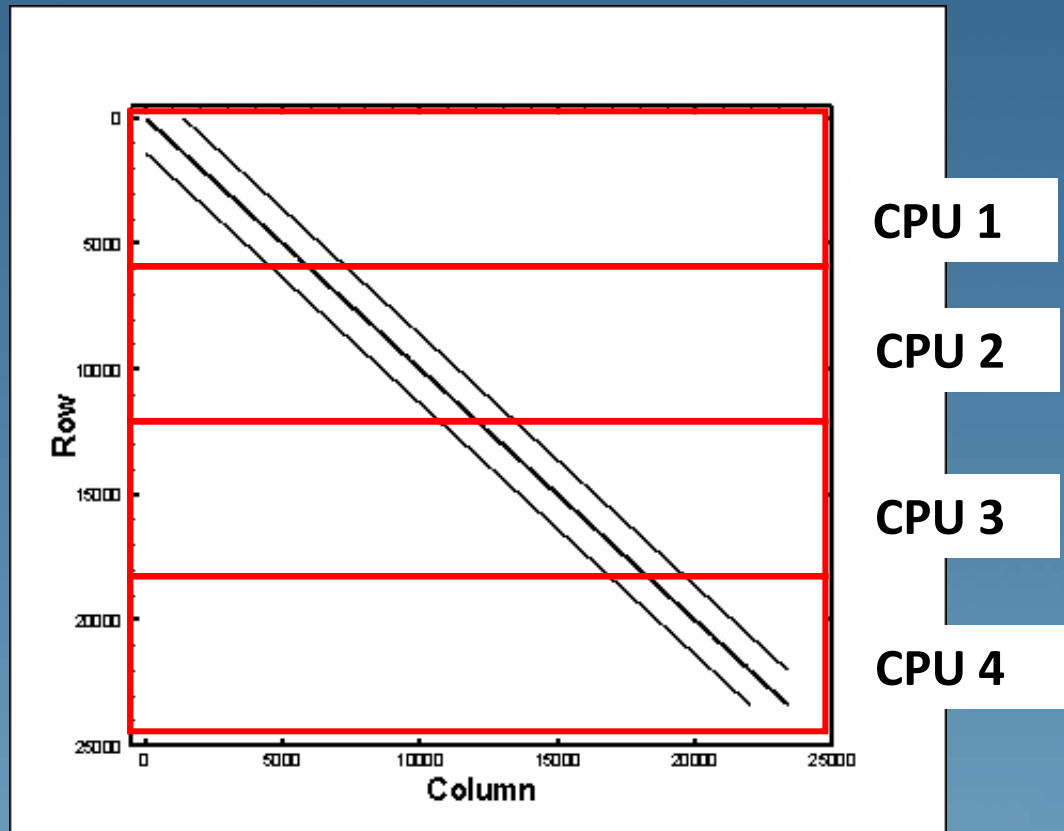
(Global) **Matrix composition** and **solver iteration** take more than 90% of total computing time!

Parallel Schemes Applied to HGS

a. Matrix composition

- Coarse grain parallelism

Assembling Matrix is highly independent so coarse grain parallelism is applied which leads to high parallel efficiency



CPU 1

CPU 2

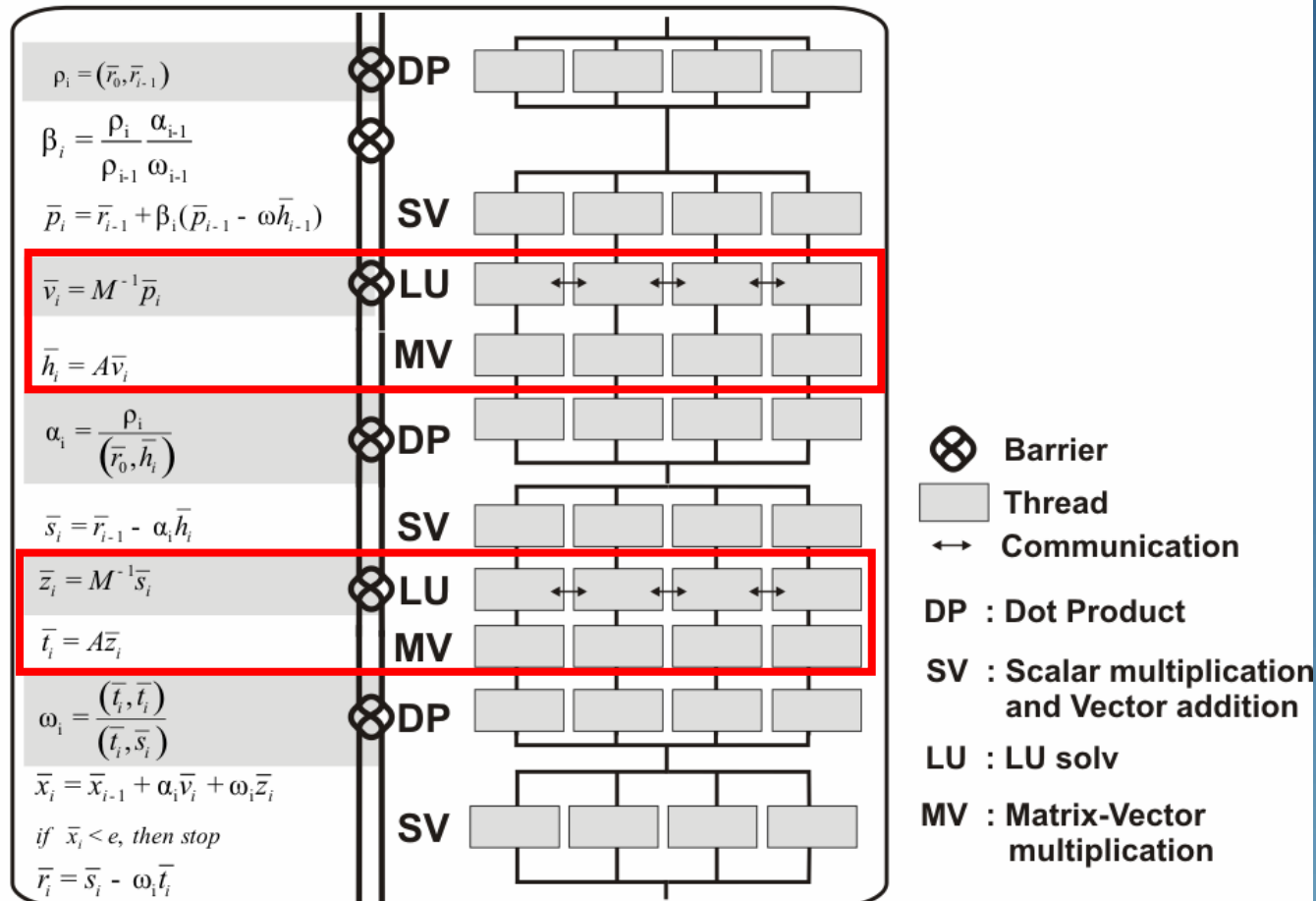
CPU 3

CPU 4

Parallel Schemes Applied to HGS

$$\bar{r}_0 = \bar{b} - A\bar{x}_0; A\bar{v}_0 = \bar{p}_0 = 0; w_0 = 1; b_0 = a_0 = 1$$

For $i = 1, 2, \dots$



b. Solver iteration

Algorithm of BiCGSTAB

Parallel Schemes Applied to HGS

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❖ Floating-point operation (Chin and Forsyth, 1993)

b. Solver iteration

	LU	MV	DP	SV
Floating-point operation	2nzp	2nz	4n	6n
3D, level 0-ILU	12n	12n	4n	6n

> 70%

❖ Computing time using Scalasca

	LU	MV	DP	SV
Computing time per iteration (%)	55.8	37.4	2.4	0.02

> 93 %

❖ LU and MV are hot spots for parallelization

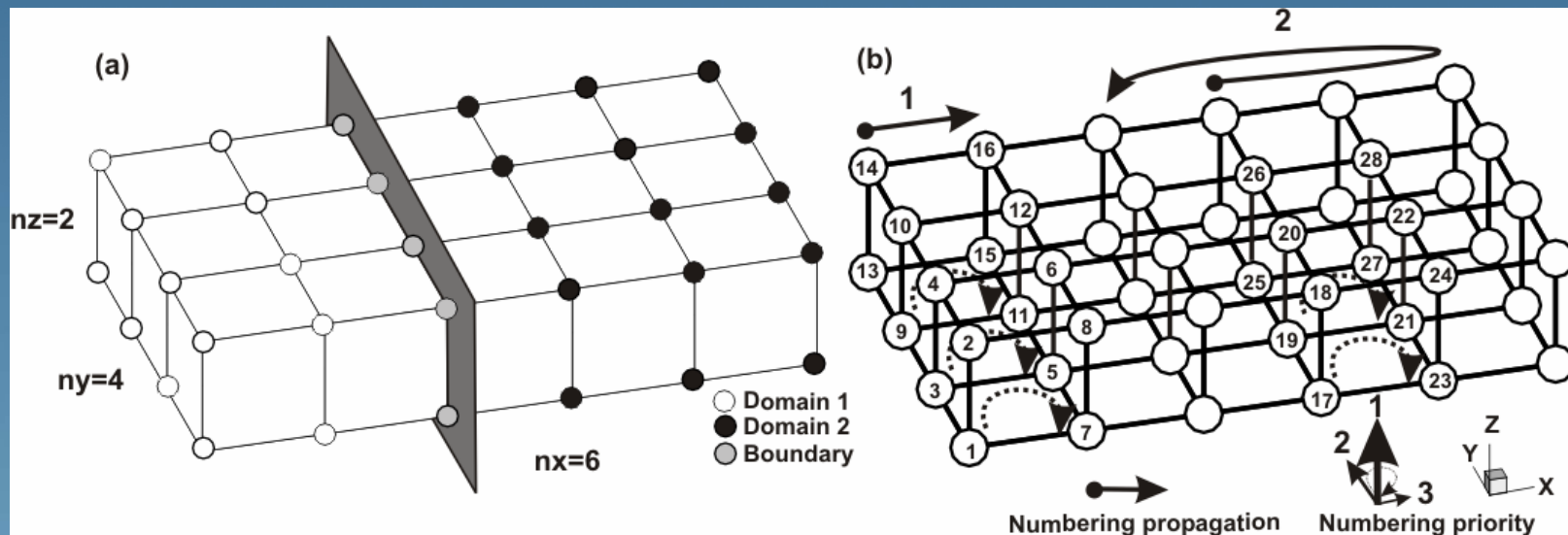
- MV is independent computation, so easy to parallelized
- LU needs information on neighboring nodes, so parallel methods are necessary

Parallel Schemes Applied to HGS

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b.1 Parallelization of LU solve

- Domain partitioning and node reordering
 - Domain partitioning scheme is applied to make independent sub-matrix
 - Node reordering is performed to make band width of matrix narrower



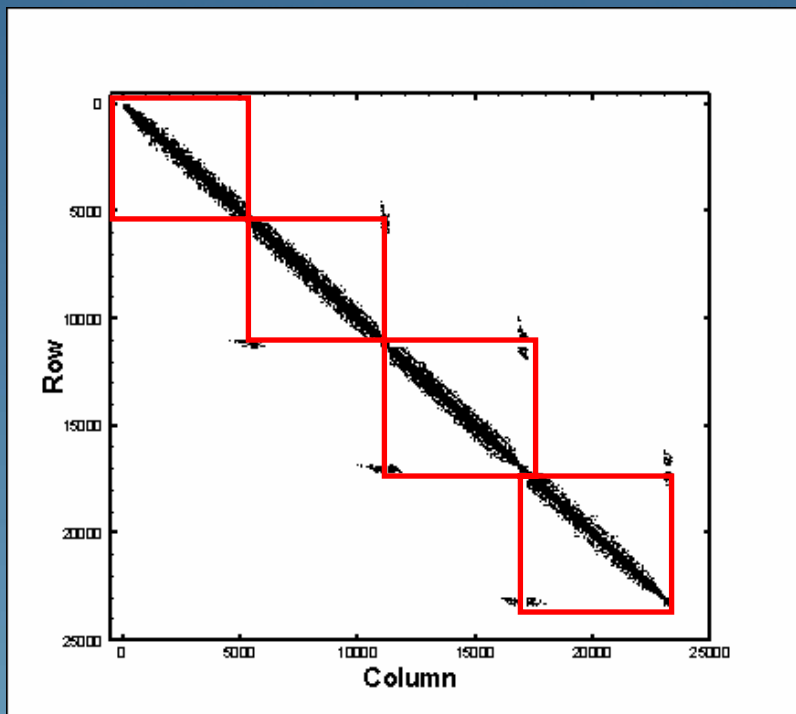
Schematic of a) domain partitioning method and b) Numbering scheme

Parallel Schemes Applied to HGS

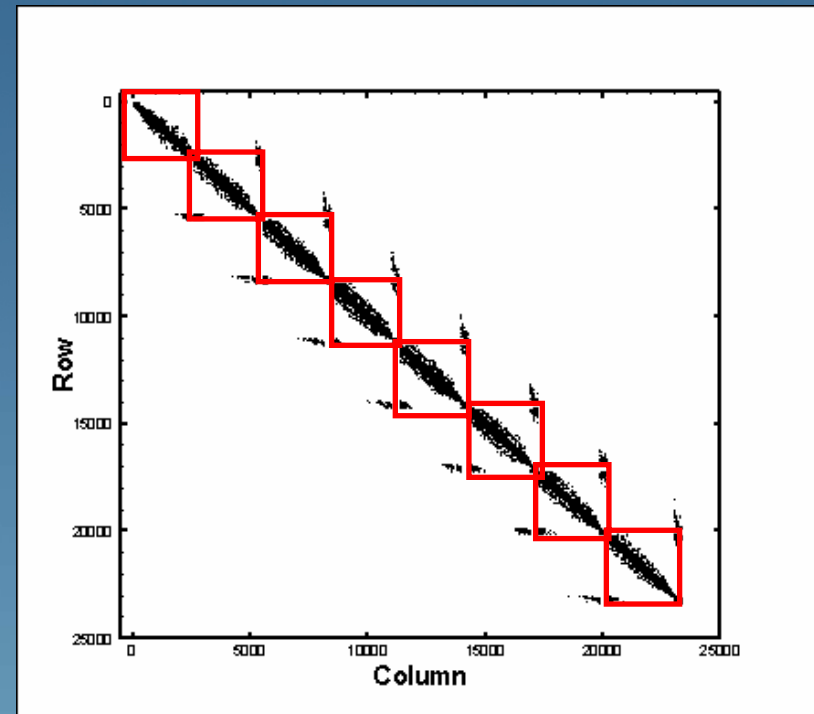
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b.1 Parallelization of LU solve

- Results of domain partitioning and node reordering



4 Threads

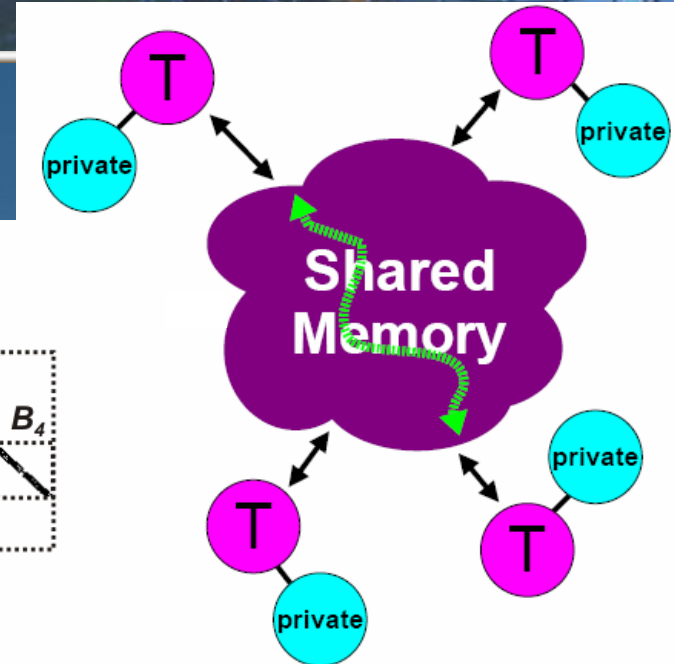
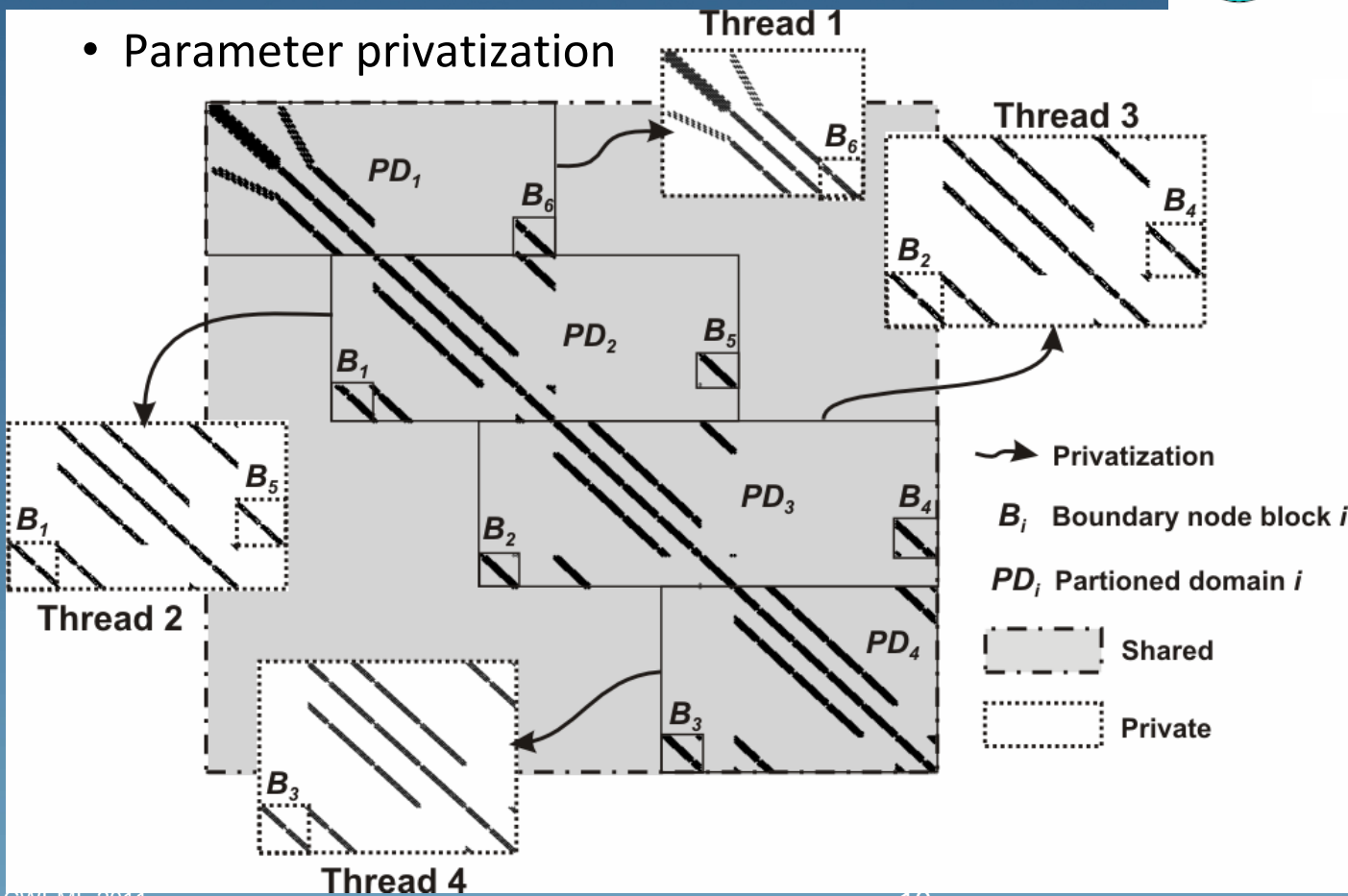


8 Threads

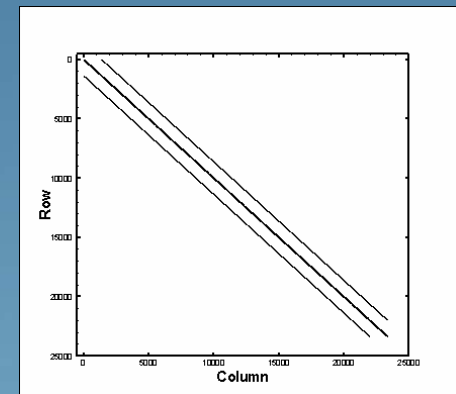
Parallel Schemes Applied to HGS

b.1 Parallelization of LU solve

- Parameter privatization



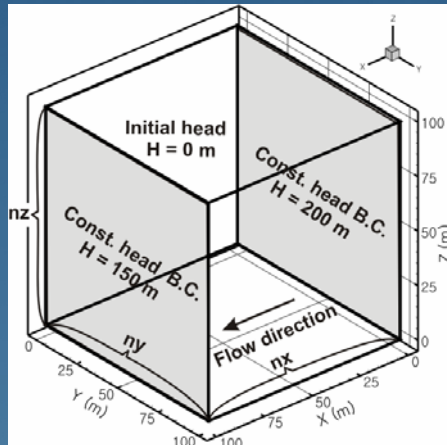
(After Ruud van der Pas, 2009)



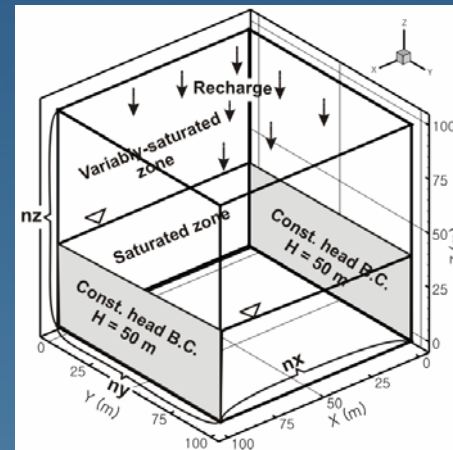
Scalability Tests of Parallel HGS

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a. Conceptual models



Saturated flow



Variably-saturated flow

no	Nx	ny	nz	Simulation type	Heterogeneity (m/day)		Test machine
					Mean ln(K)	Var ln(K)	
1	100	33	10	S ¹⁾ , VS ²⁾	-4.6	10.6	GPC ³⁾
2	330	330	10	S, VS	-4.6	10.6	GPC
3	330	330	10	VS	-4.6	10.6	TCS ⁴⁾

S¹⁾ : Saturated flow; VS²⁾ : Variably-saturated flow

GPC³⁾ : General Purpose Cluster (GPC) at Scinet/University of Toronto

TCS⁴⁾ : Tightly Coupled System (TCS) at Scinet/University of Toronto

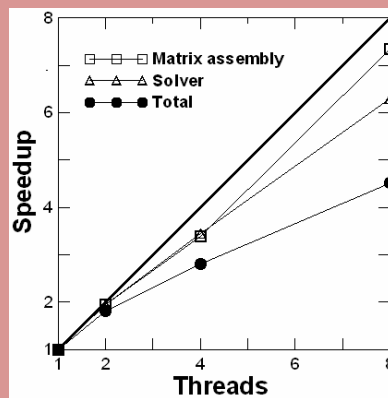
❖ Parallel HydroGeoSphere (PHGS), is compiled by Intel® FORTRAN compiler 10.1 for GPC and IBM xlf compiler for TCS

Scalability Tests of Parallel HGS

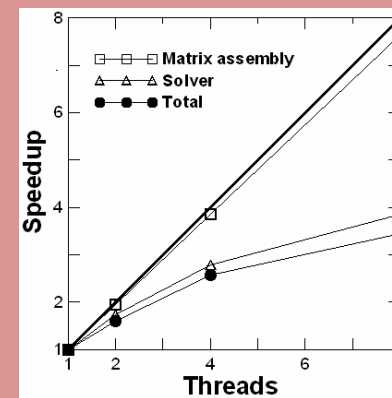
simulation #1,
GPC, 10^5 nodes

Saturated
flow

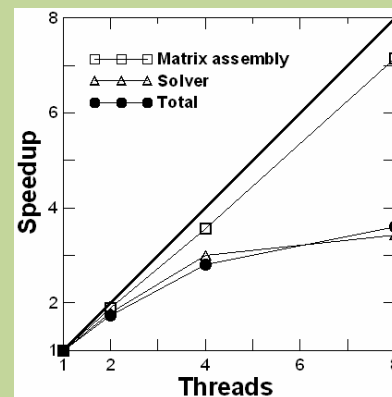
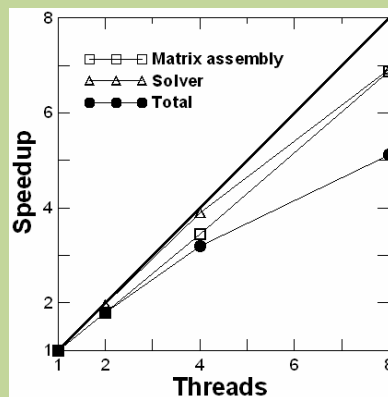
Privatization



No Privatization

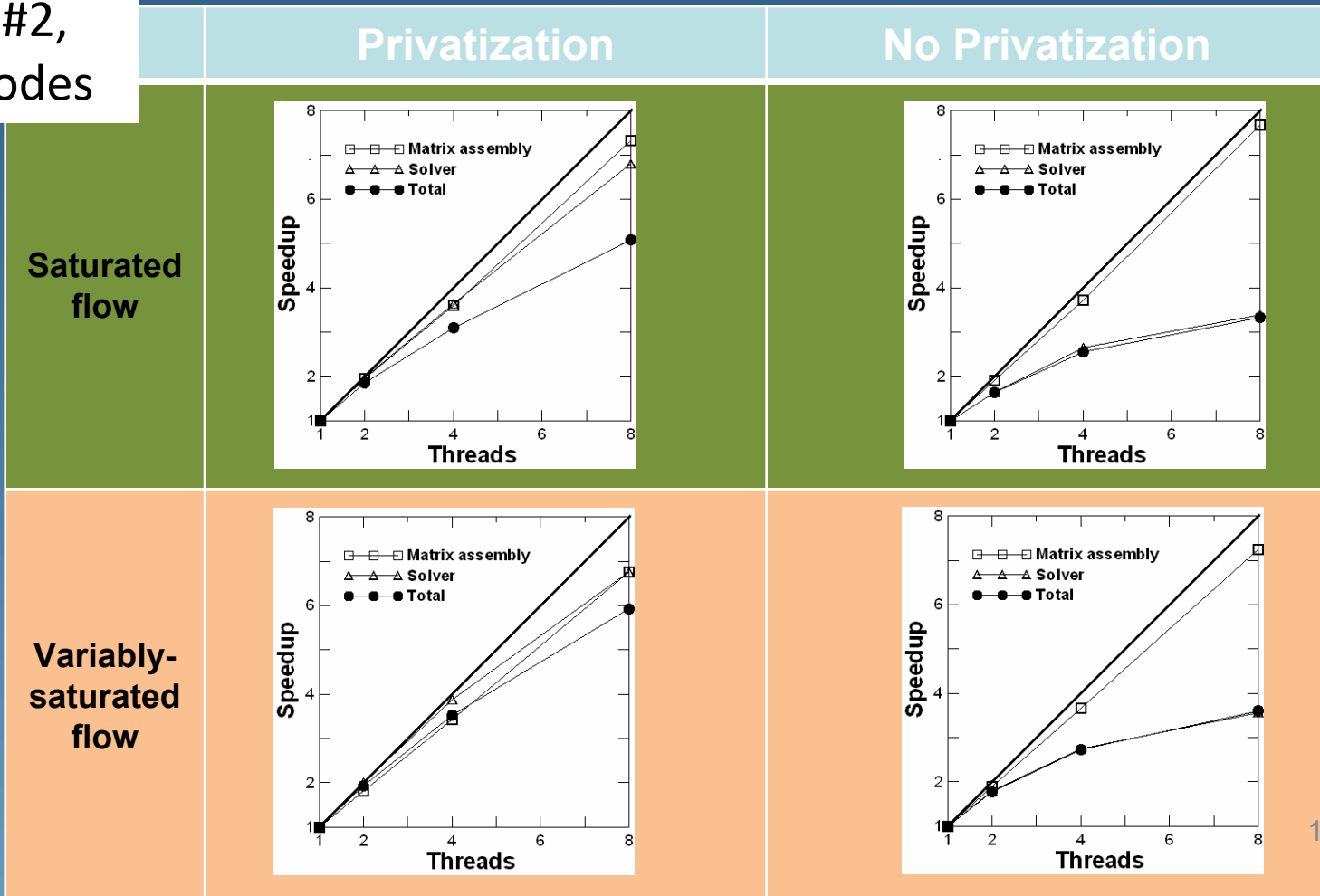


Variably-
saturated
flow



Scalability Tests of Parallel HGS

simulation #2,
GPC, 10^6 nodes

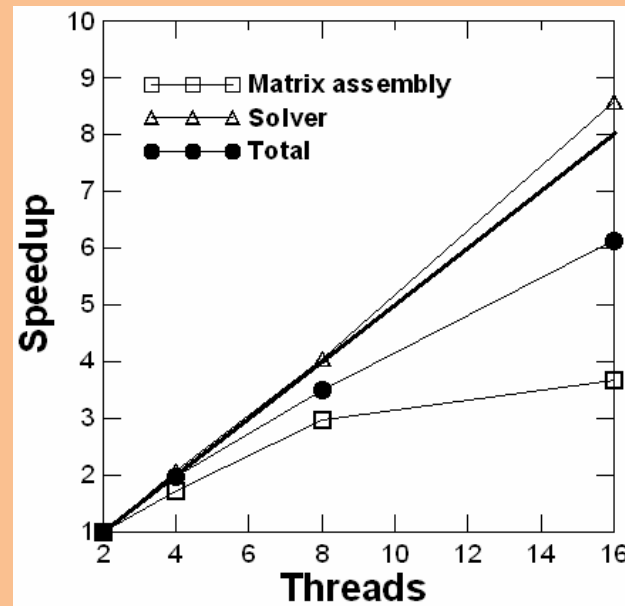


Scalability Tests of Parallel HGS

simulation #3,
TCS, 10^6 nodes

Privatization

Variably-saturated
flow



Summary of Scalability Tests

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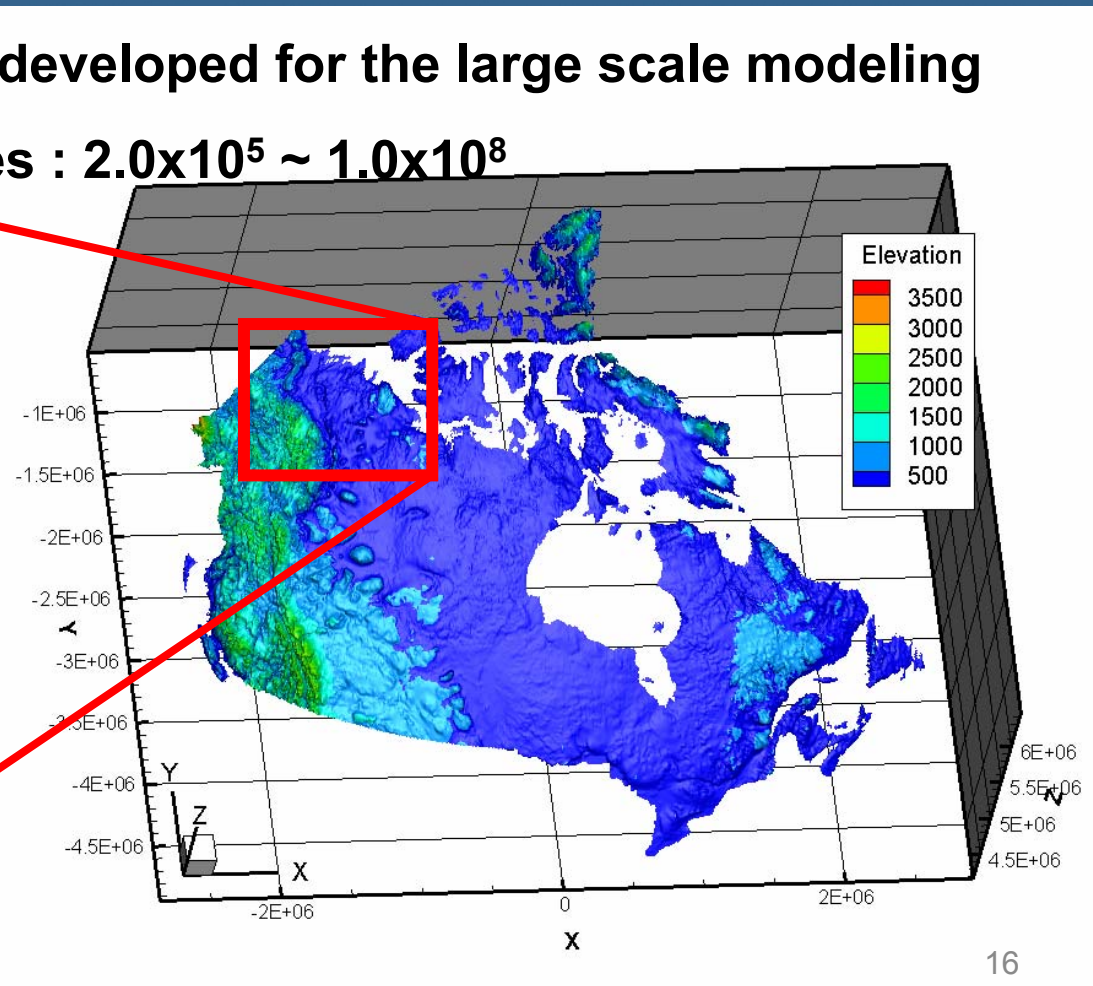
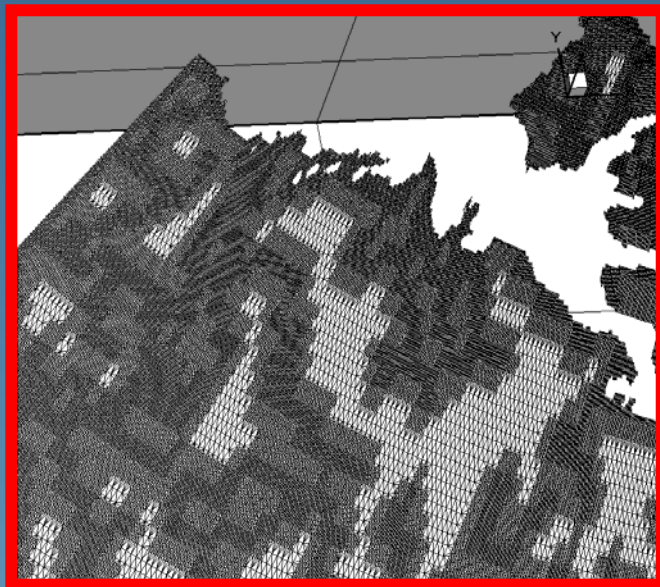
- ❖ **Computing time for global matrix assembly and that for its solving are more than 90 % of the total computing time.**
- ❖ **For BiCGSTAB solver parallelization, over 95 % of parallel efficiency can be obtained if two and four threads are applied for GPC and TCS, respectively.**
- ❖ **Domain partitioning and privatization schemes are effective to increase parallel efficiency.**
- ❖ **The maximum speedups achieved are 6.0 for GPC using eight threads, which is 75 % of parallel efficiency, and 6.2 for TCS using 16 threads, for which the speedup is based on the performance of two threads.**

Future Study

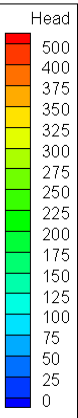
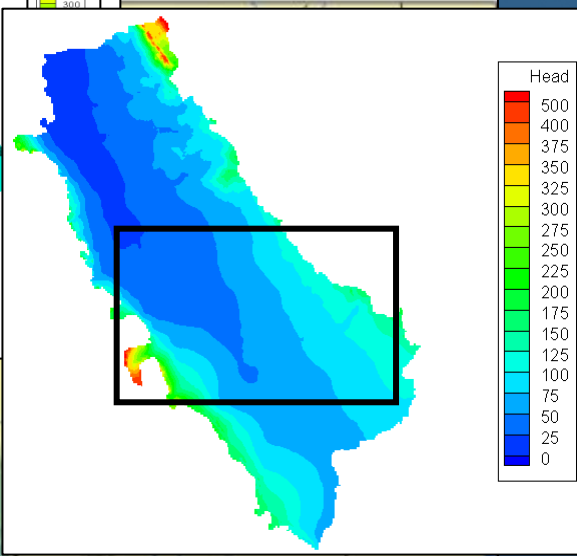
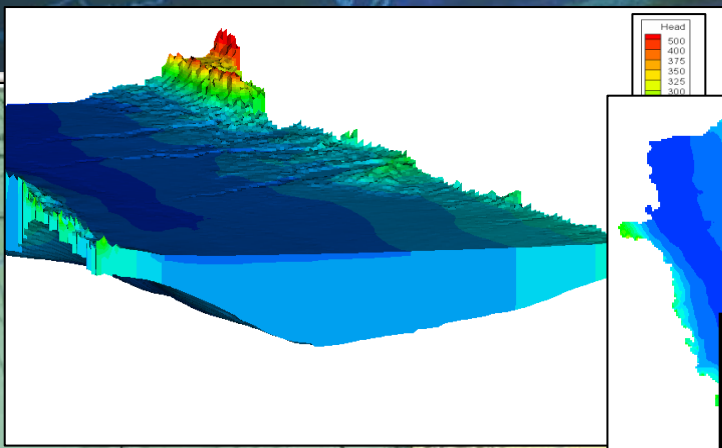
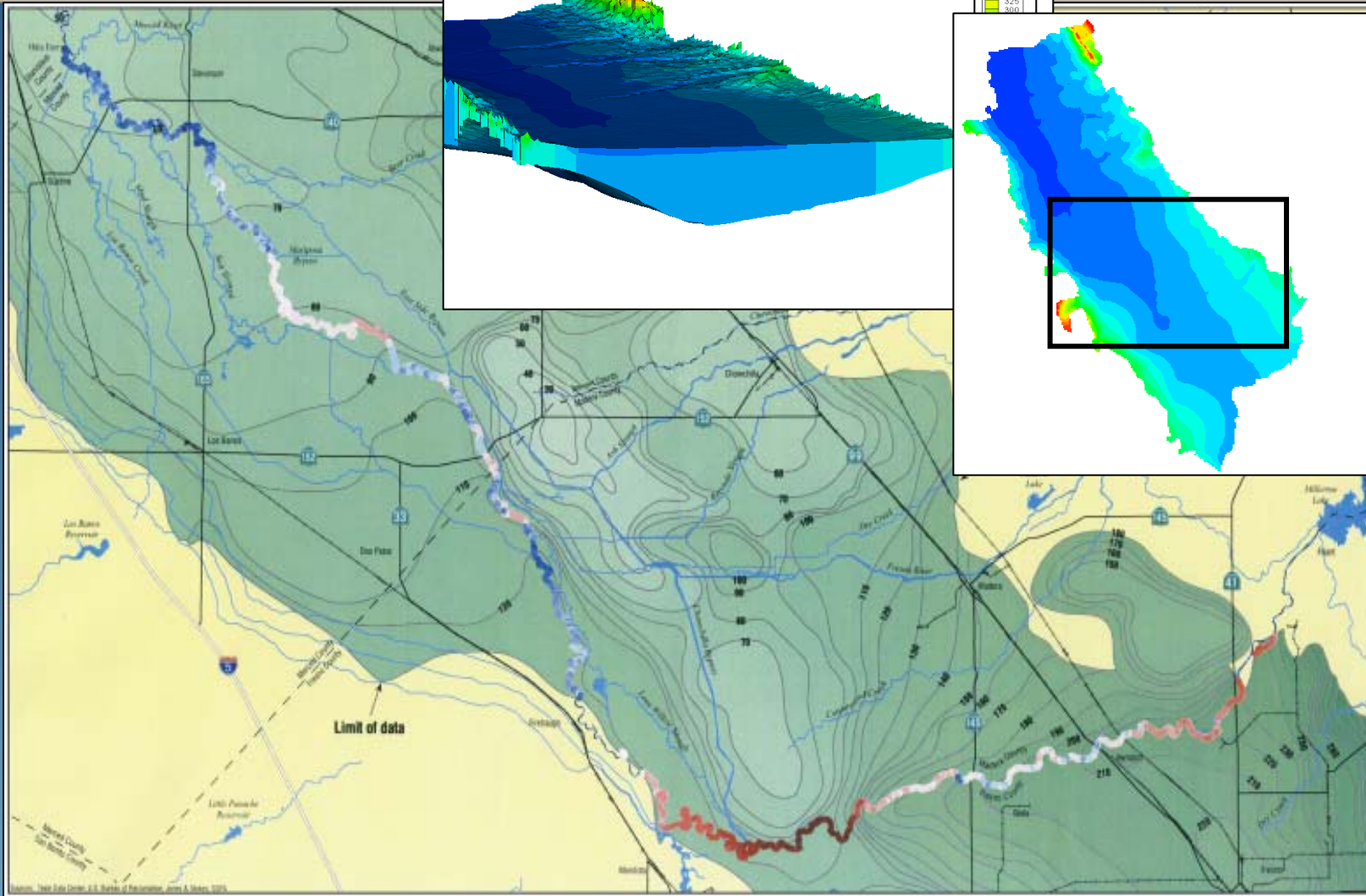
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❖ Large scale simulation

- Mesh generator is newly developed for the large scale modeling
- Various numbers of nodes : $2.0 \times 10^5 \sim 1.0 \times 10^8$



Future Study



Acknowledgements

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