

Parallel MODFLOW 6

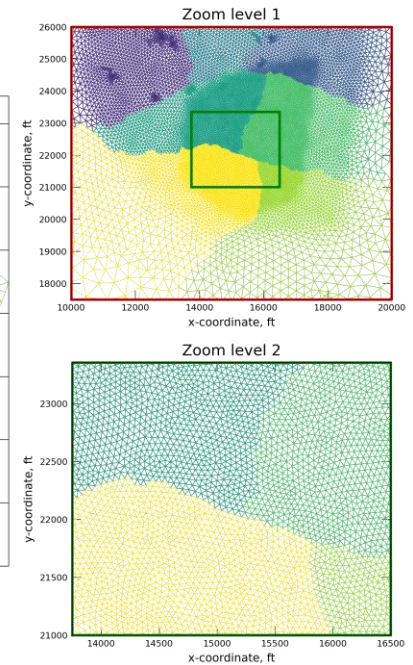
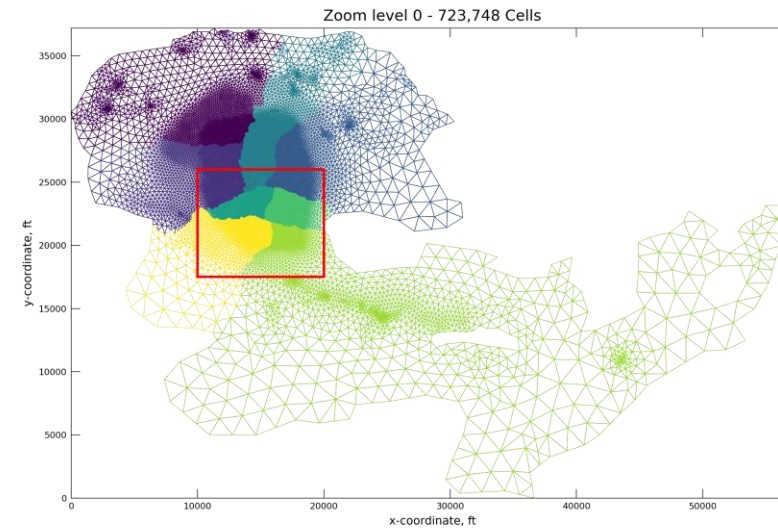
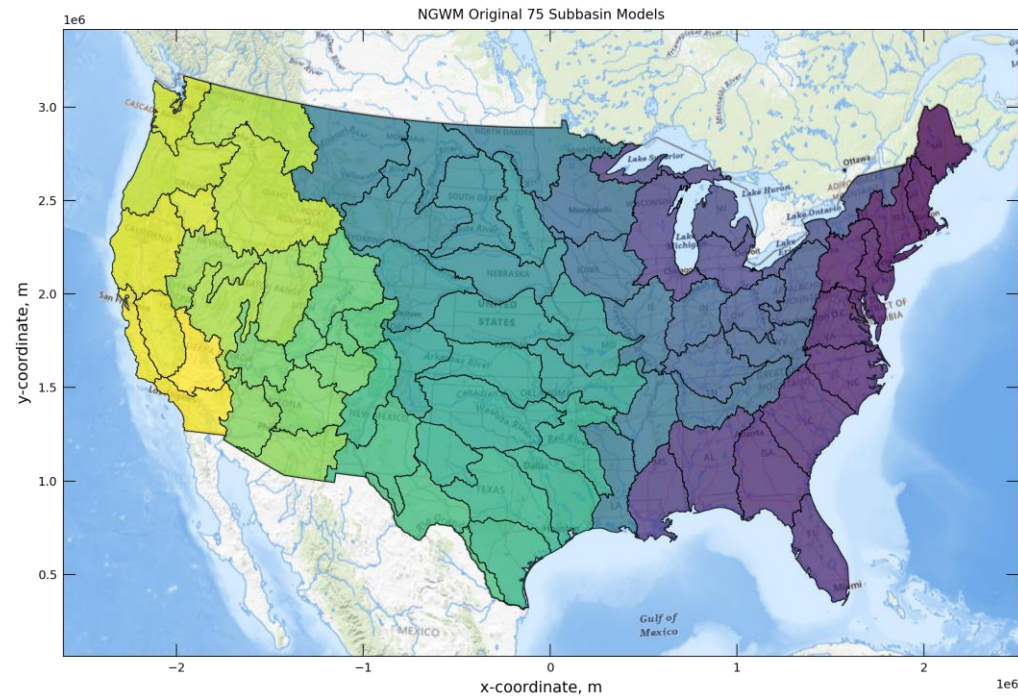
By the MODFLOW Development Team

MODFLOW 6 and FloPy: Take Your Modeling to the Next Level

Princeton, New Jersey, USA

Friday, May 31 – June 1, 2024

Motivation



Model of a Regional Groundwater Basin in Southern California, Tetra Tech 2023

- Large national/continental scale models
- High resolution, regional models

Moore's Law

Cramming More Components onto Integrated Circuits

GORDON E. MOORE, LIFE FELLOW, IEEE

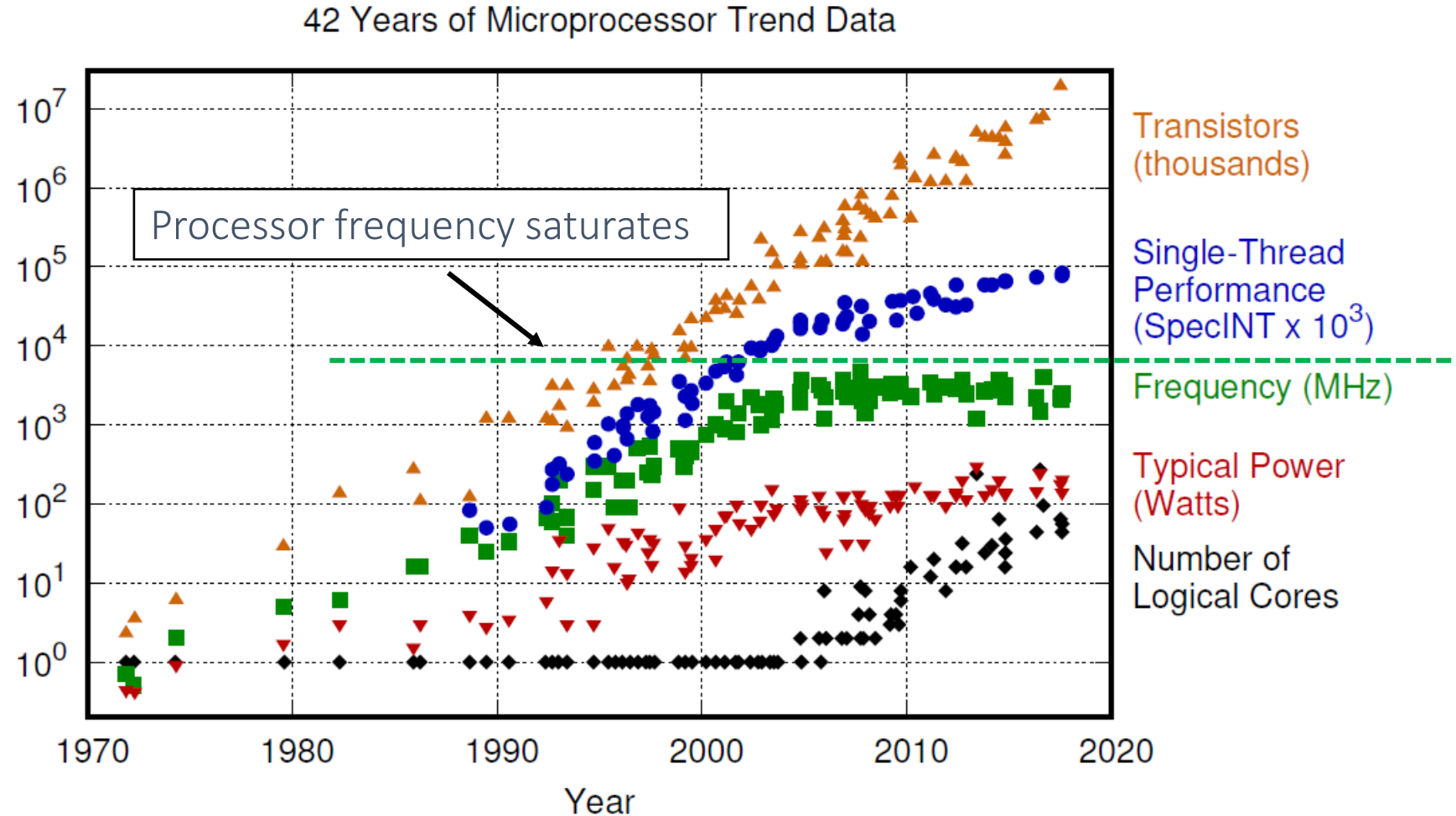
Integrated circuits will lead to such wonders as home computers—or at least terminals connected to a central computer—automatic controls for automobiles, and personal portable communications equipment. The electronic wristwatch needs only a display to be feasible today.

from *Electronics*, pp. 114–117, April 19, 1965



Gordon Moore (1929-2023)

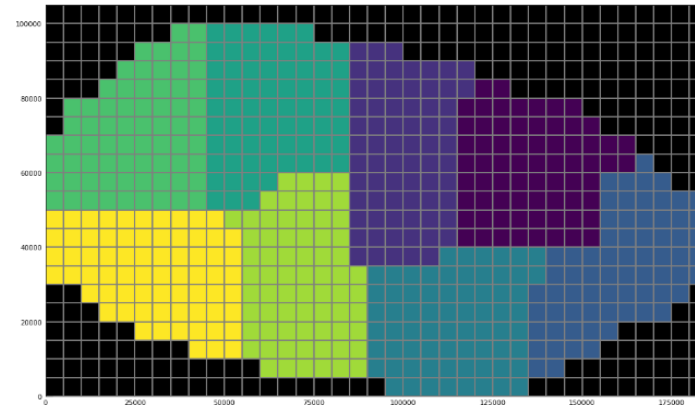
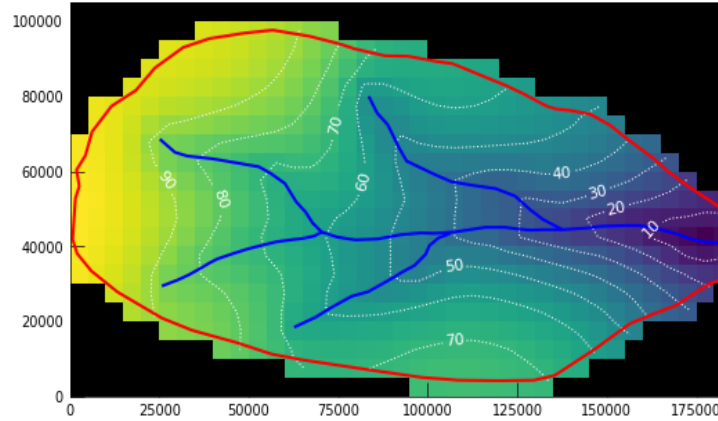
Moore's Law: the end of it...



Original data up to the year 2010 collected and plotted by M. Horowitz, F. Labonte, O. Shacham, K. Olukotun, L. Hammond, and C. Batten
New plot and data collected for 2010-2017 by K. Rupp

Strategy: Domain Decomposition

- Instead of running a model on 1 processor core ...
- ... distribute over many cores
- Exchange of data at the domain interface
- Efficiency affected by
 - Amount of communication between domains
 - Load imbalance: solution of multiple domains proceeds in lock step...



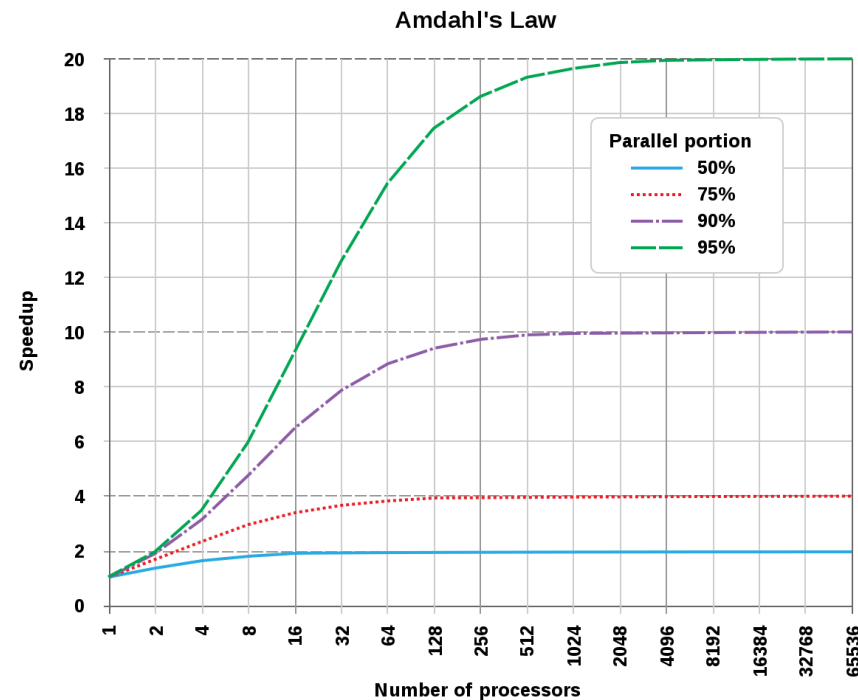
Limit on Speedup

- Further division of the work (i.e. smaller domains, increase in processor cores) increases communication overhead
- Put differently: how large can you make your model?!

- Amdahl's law:

$$\text{Speedup} \leq \frac{1}{1 - p}$$

with p = parallel portion



Parallel Solution

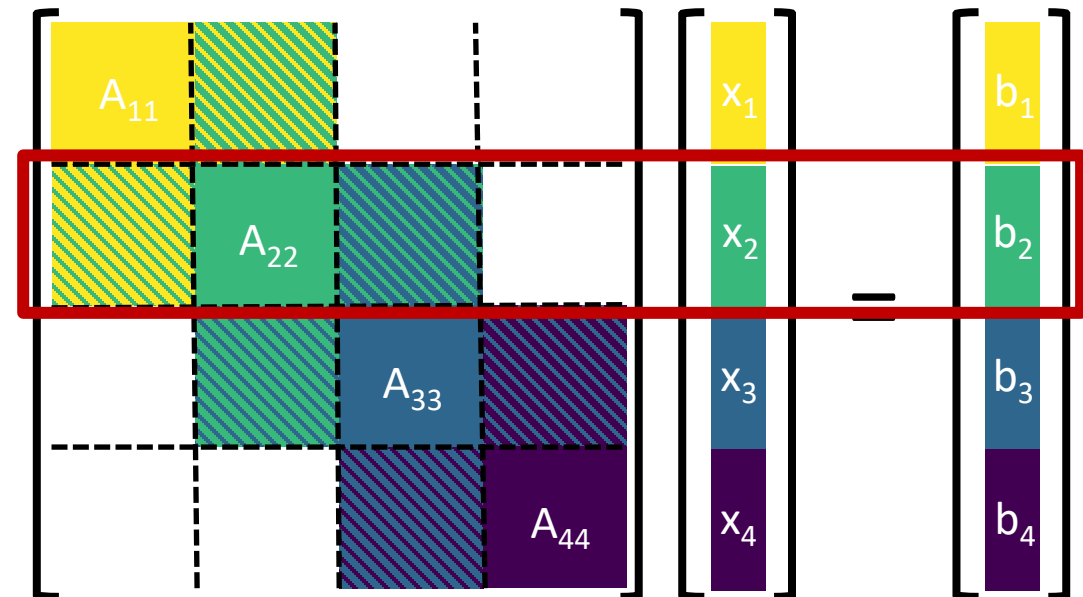
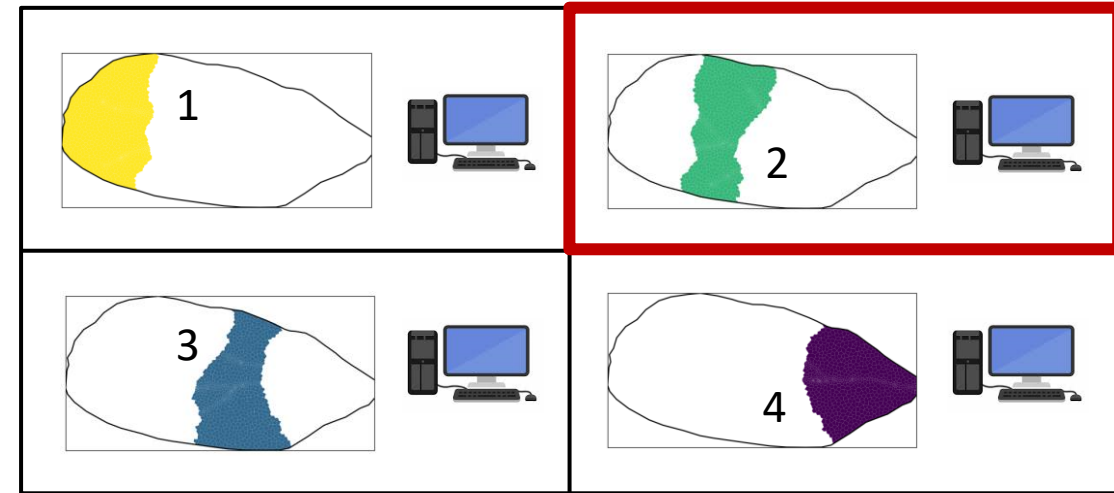
- Example: solve the groundwater flow equation ($Ax = b$) over 4 domains
- Dependent variable \mathbf{x} (head) and right-hand side \mathbf{b} are distributed
- Each process now manages a contiguous set of rows of the system matrix

To solve this system:

- choose $A = M - N$
- $M \approx A$ and M_{ij}
- $M_{ij} = 0$ for $i \neq j$ (Block-Jacobi), we use the iterative scheme:

$$\mathbf{x}_i^{k+1} = M_{ii}^{-1} (\sum_j N_{ij} \mathbf{x}_j^k + \mathbf{b}_i)$$

- Does not depend on \mathbf{x}_j^{k+1} , hence parallel

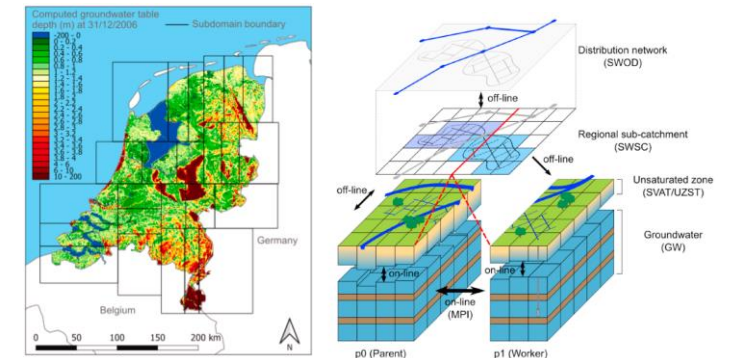


Earlier Work

- Good results for national-scale model
- Global groundwater with MODFLOW 6 prototype

More work needed: a **framework** solution

- Current and future model types
- Feature complete: XT3D, BUY, TVD, MVR, ...
- Possible to add or modify hydrologic concepts without expert knowledge on parallelization
- MODFLOW remains available in its core set of functionality
- FloPy support for pre- and post-processing



Distributed memory parallel groundwater modeling for the Netherlands Hydrological Instrument

J. Verkaik^{a,b,*}, J.D. Hughes^c, P.E.V. van Walsum^d, G.H.P. Oude Essink^{a,b}, H.X. Lin^{e,f}, M.F. P. Bierkens^{b,a}

^a Unit Subsurface and Groundwater Systems, Delft, the Netherlands

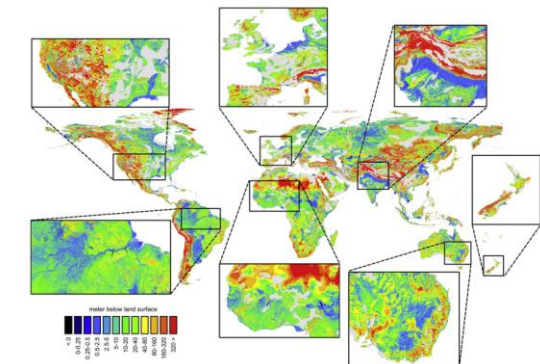
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^f Institute of Environmental Sciences, Leiden University, Leiden, the Netherlands



GLOBGM v1.0: a parallel implementation of a 30 arcsec PCR-GLOBWB-MODFLOW global-scale groundwater model

Jarno Verkaik^{1,2}, Edwin H. Sutanudjaja², Gualbert H. P. Oude Essink^{1,2}, Hai Xiang Lin^{3,4}, and Marc F. P. Bierkens^{2,1}

¹Unit Subsurface and Groundwater Systems, Delft, the Netherlands

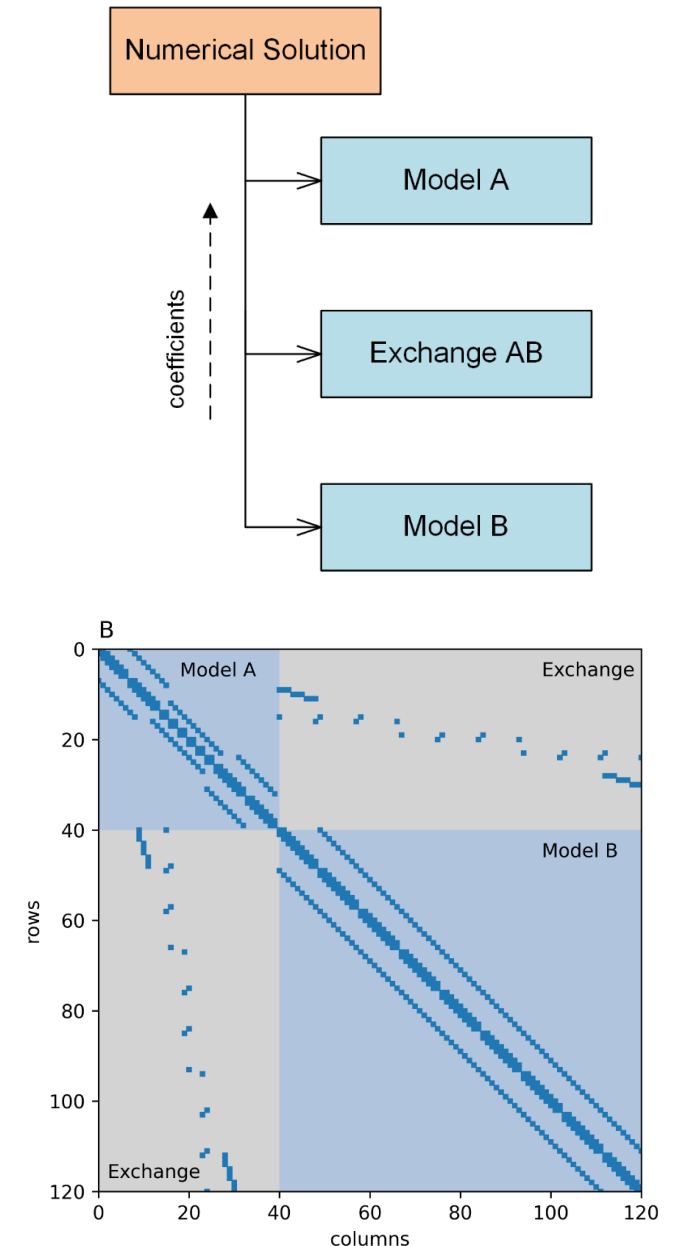
²Department of Physical Geography, Faculty of Geosciences, Utrecht University, Utrecht, the Netherlands

³Department of Applied Mathematical Analysis, Faculty of Electrical Engineering, Mathematics and Computer Science, Delft University of Technology, Delft, the Netherlands

⁴Institute of Environmental Sciences, Faculty of Science, Leiden University, Leiden, the Netherlands

Framework Solution

- MODFLOW 6 has conceptualized a hydrologic process model into a “Numerical Model”
- Multiple models can be connected with Exchanges to be solved in a single Numerical Solution



Framework Solution

Building Blocks:

1. Generalized coupling of Models based on the Exchanges
2. Virtualization of Data with synchronization: MPI
3. Parallel solution: PETSc



```
# File generated by Flopy ...
BEGIN options
PRINT_INPUT
END options


BEGIN dimensions
NEXG 36
END dimensions

BEGIN exchangedata
1 3 2 1 1 1 1 50.00000000 16.66666667 33.33333333
1 3 2 1 2 1 1 50.00000000 16.66666667 33.33333333
...
END exchangedata
```

A diagram showing a grid of cells. A portion of the grid on the left is colored blue, and a portion on the right is colored orange. A point 'n' is located within the blue region, and a point 'm' is located within the orange region. A horizontal dashed line segment labeled L_n extends from point 'n' to the boundary between the blue and orange regions. A vertical dashed line segment labeled L_m extends from point 'm' to the same boundary. A vertical double-headed arrow labeled Δw indicates the width of the orange region.

The cover image shows a modern, multi-story building with a curved facade and large windows, illuminated at night. The building is situated next to a body of water, and the lights from the building reflect on the water's surface.

Deltares

 **USGS**
science for a changing world

Parallel Computing with MODFLOW 6

Martijn Russcher
Joe Hughes, Chris Langevin,
Alden Provost, Jarno Verkaik,
Wesley Bonelli, Joshua Larsen,
Eric Morway, Michael Reno

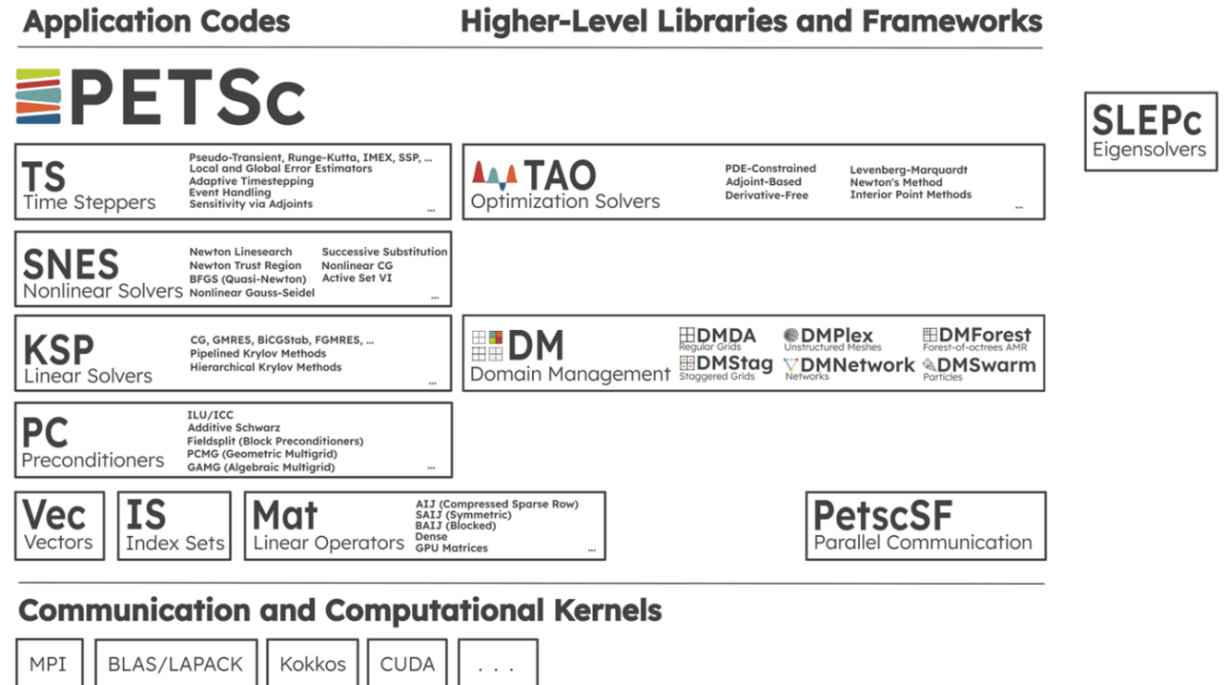
MODFLOW and More @ Princeton, NJ
June 3rd, 2024

The logo for "enabling delta life" features a stylized circular icon with a wave-like pattern, followed by the text "enabling delta life" in a lowercase, sans-serif font.

More on this: Monday, 15:20

Parallel Solver: PETSc

- The Portable, Extensible Toolkit for Scientific Computation
- Suite of data structures and routines developed and maintained by ANL
- Scalable (parallel) solution of scientific applications modeled by partial differential equations
- Robust, Efficient, Portable
- Fortran bindings
- And: PETSc solver configured from IMS settings, including MILU(T)



How to get it?

Windows:

- Download 'win64par.zip'
- Install through FloPy:

```
get-modflow --repo modflow6 --ostag win64par :python
```

Linux/Mac

- Instructions in the parallel user guide:

<https://github.com/MODFLOW-USGS/modflow6/wiki/Parallel-MODFLOW-User-Guide>

MODFLOW 6.5.0

Latest









This is the approved USGS MODFLOW 6.5.0 release.

Langevin, C.D., Hughes, J.D., Provost, A.M., Russcher, M.J., Morway, E.D., Reno, M.J., Bonelli, W.P., Panday, Sorab, Merrick, Damian, Niswonger, R.G., Boyce, S.E., and Banta, E.R., 2024, MODFLOW 6 Modular Hydrologic Model version 6.5.0: U.S. Geological Survey Software Release, 23 May 2024, <https://doi.org/10.5066/P13COJIM>

Visit the USGS "MODFLOW and Related Programs" site for information on MODFLOW 6 and related software: <https://doi.org/10.5066/F76Q1VQV>

Assets

8

 mf6.5.0_linux.zip		
 mf6.5.0_mac.zip		
 mf6.5.0_macarm.zip	104 MB	3 days ago
 mf6.5.0_win64.zip	105 MB	3 days ago
 mf6.5.0_win64par.zip	255 MB	3 days ago
 release.pdf	2.18 MB	3 days ago
 Source code (zip)		3 days ago
 Source code (tar.gz)		3 days ago

1 person reacted

Parallel MODFLOW User Guide

mjr-deltares edited this page 3 days ago · 10 revisions

Introduction

This guide describes the parallel capabilities in MODFLOW. Because these capabilities have recently been developed, this will be a living document for now.

When to use

The parallelization of MODFLOW is based on decomposition of the simulation domain and distributed memory computing with the message passing interface (MPI). The parallel run mode can be used to speed up a simulation run over a large spatial domain. The size and that the ratio between below 25000 nodes per single processor. This

under development

Parallel MODFLOW has been designed as a generic component that is targeted to be used for all hydrologic models in the MODFLOW 6 simulator. It is (near) feature complete: every package and formulation in the serial simulation is available in a parallel setup. The few exceptions to this rule will be documented here. The currently supported process models are GWF.

Pages

Find a page...

Home

MODFLOW Development Plans

Parallel MODFLOW User Guide

Introduction

When to use

Parallel GWF

Parallel GWT

Parallel GWE

Installation

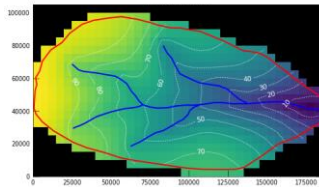
Windows

Linux, MacOS

Cloning MODFLOW

How to run it?

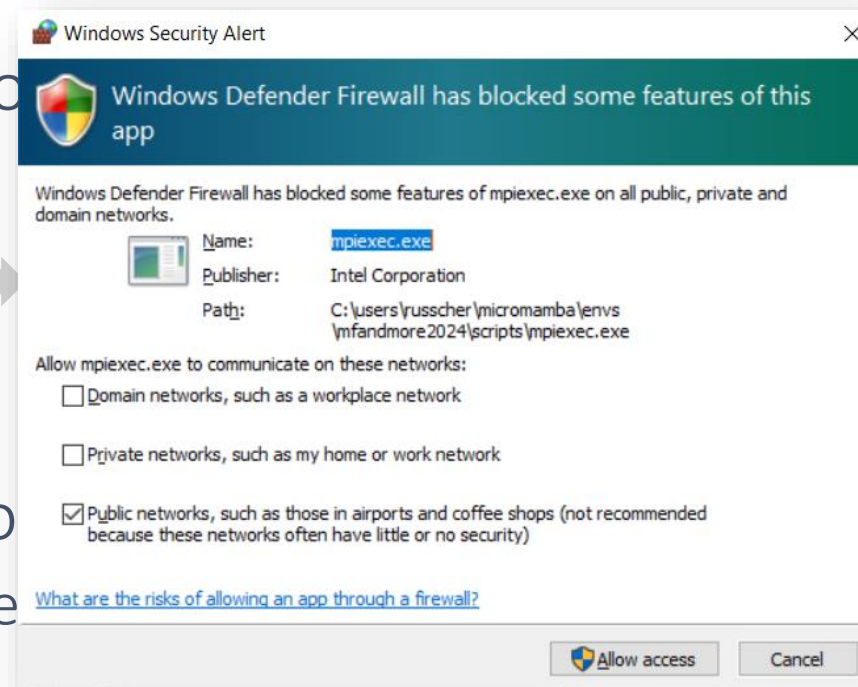
- Partitioning with Flopy



- Assign models to cores
 - Better load balance
 - optional

- Run parallel simulation:

```
D:\> mpiexec.exe -np 8 mf6.exe -p
```



```
ing base simulation
utils.Mf6Splitter(base_sim)
ng mask for the nr. of domains
t.optimize_splitting_mask(nparts=nr_domains)
el
it.split_model(split_array)
```

sim.hpc:

```
# File generated by Flopy
BEGIN options
END options

BEGIN partitions
  model_0 0
  model_1 1
  model_2 2
  model_3 3
  model_4 4
  model_5 5
  model_6 6
  model_7 7
END partitions
```


Notebook

