

Model Development Towards Incorporating 3-D Subsurface Hydrologic Processes within the Community Land Surface Model (CLM): Coupling PFLOTRAN and CLM

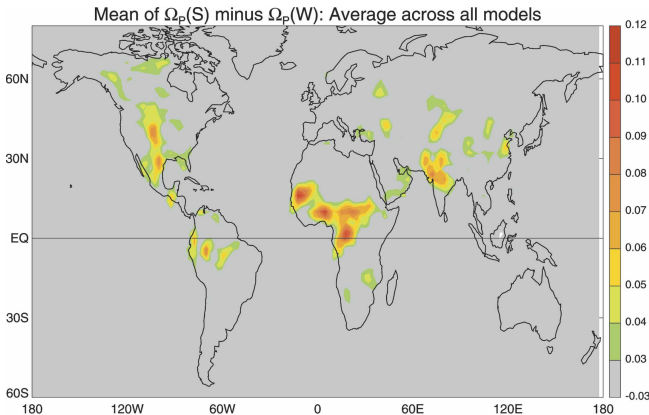
Gautam Bisht¹, Richard T. Mills¹, Forrest M. Hoffman¹, and
Peter E. Thornton¹

¹Oak Ridge National Laboratory

CCSM Land Model Working Group
15, March, 2011

Motivation

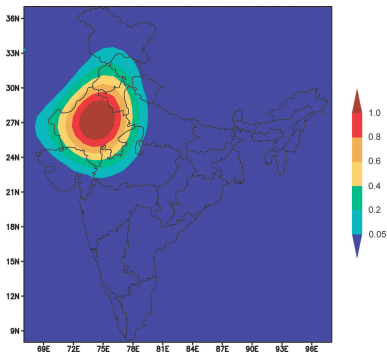
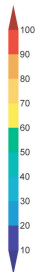
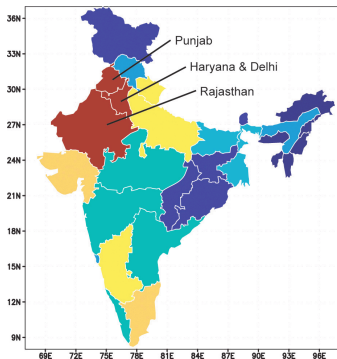
Soil moisture plays an important role in Land-Atmosphere interaction



Koster et al., 2006, J. HydroMetero.

Motivation

GRACE satellite: Groundwater depletion over India



Rodell et al. (2009), Nature

Time period: Aug, 2002 to Oct, 2008

Depletion rate: 1 m per 3 years

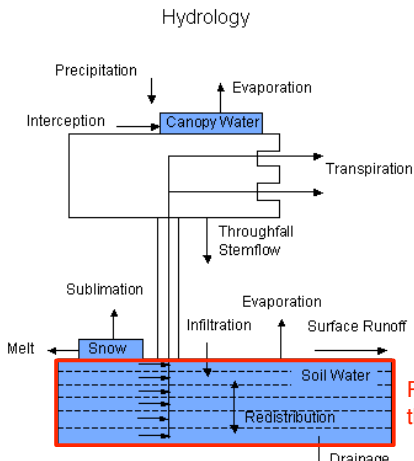
Objective

Improve subsurface hydrologic processes:

- Lateral transport of water
- Unified treatment of unsaturated and saturated zone dynamics

CLM

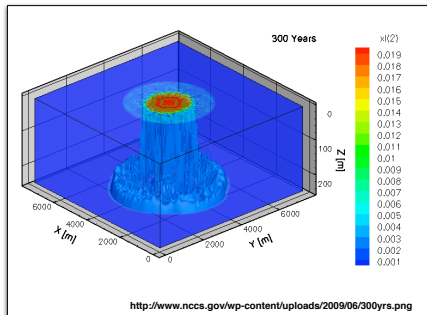
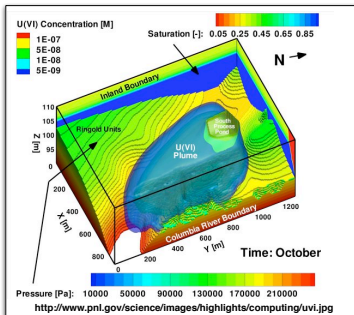
- 1) Hydrologic cycle
- 2) Biogeophysics
- 3) Biogeochemistry
- 4) Dynamic Vegetation



PFLOTRAN will be replacing this part within CLM

PFLOTRAN

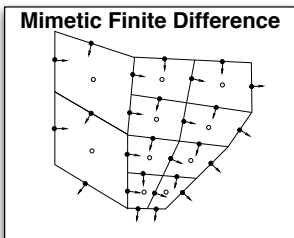
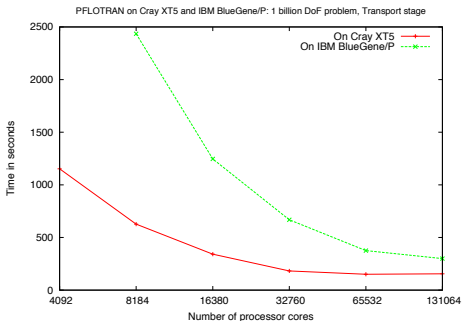
- Models Multiscale-Multiphase-Multicomponent Subsurface Reactive Flows
- Funded by SciDAC-2
- PI: Peter C. Lichtner (LANL)
- Development team: LANL, PNNL, ORNL, ANL, UIUC, Univ. of Utah



PFLOTRAN

- Various Modes:
 - Richards
 - Multiphase
 - Multiple immiscible phases
 - Two phase liquid water-gas flow
 - Thermal-Hydrologic-Chemical
 - Reactive Transport
- Written in Fortran 90, with a modular object-oriented approach
- Fully implicit time-stepping
- Uses Portable, Extensible Toolkit for Scientific Computation (PETSc)

PFLOTRAN

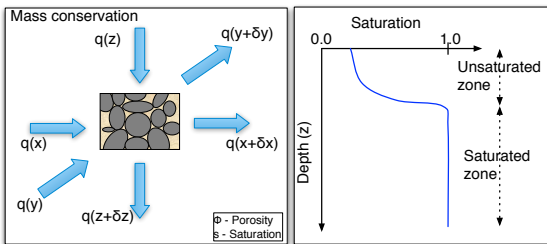


Adaptive Mesh Refinement

PFLOTRAN is one of the six Early Science Applications for OLCF-3

OLCF
DAK RIDGE LEADERSHIP COMPUTING FACILITY

Governing Equation



CLM

PFLOTRAN

$$\frac{\partial}{\partial t}(\theta) = -\nabla \cdot (\mathbf{q}) + q_w$$

$$\frac{\partial}{\partial t}(\rho\phi s) = -\nabla \cdot (\rho\mathbf{u}) + Q_w$$

$$\mathbf{q} = -K(\psi)\nabla(\psi + z)$$

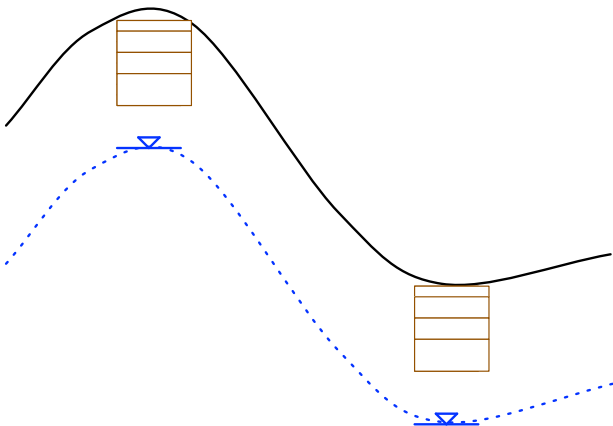
$$\mathbf{u} = -\left(\frac{\kappa\kappa_r(s)}{\mu}\right)\nabla(P + \rho gz)$$

$$\theta = \phi s$$

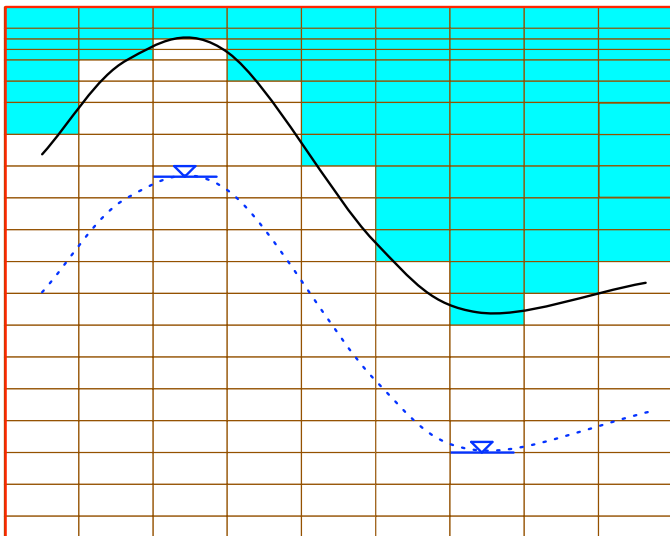
$$K = \frac{\rho g \kappa}{\mu}$$

$$P = \rho g \psi$$

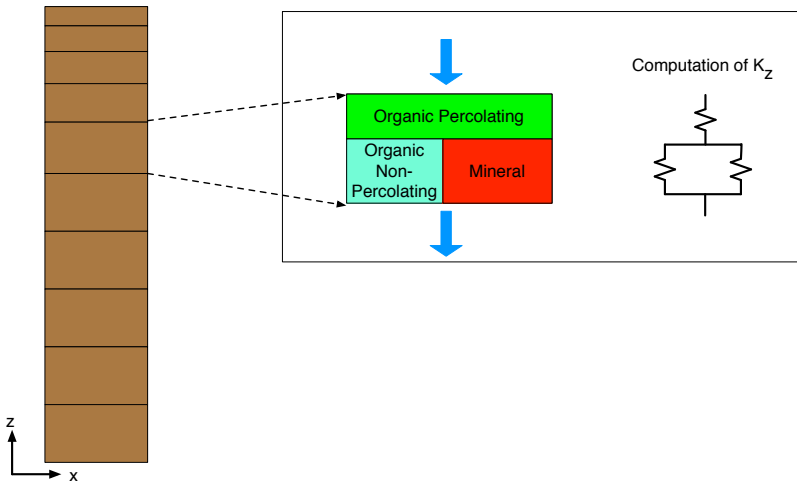
CLM : Conceptual Domain



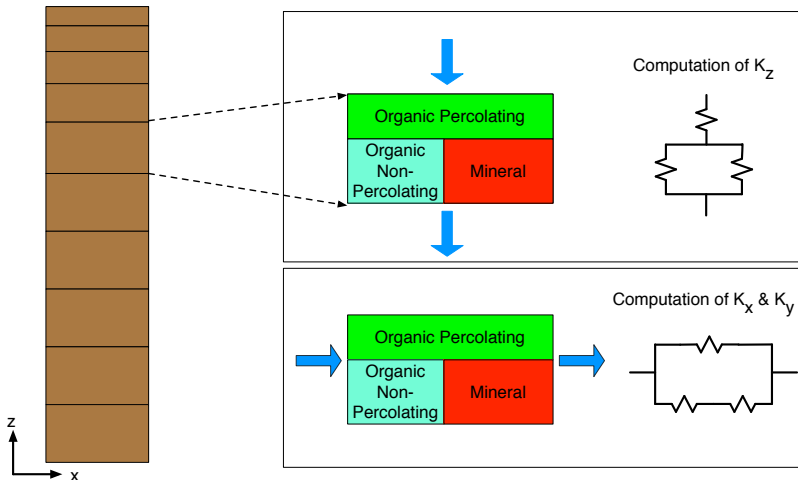
PFLOTRAN - CLM: Conceptual Domain



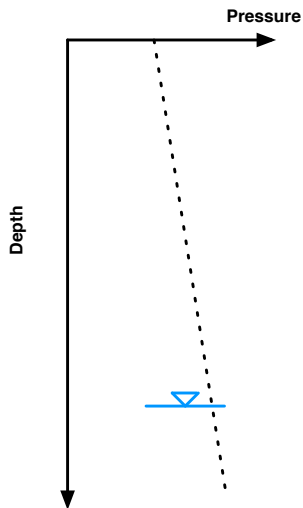
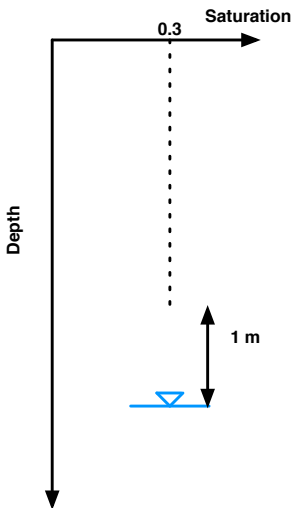
PFLOTRAN - CLM: Soil properties initialized by CLM



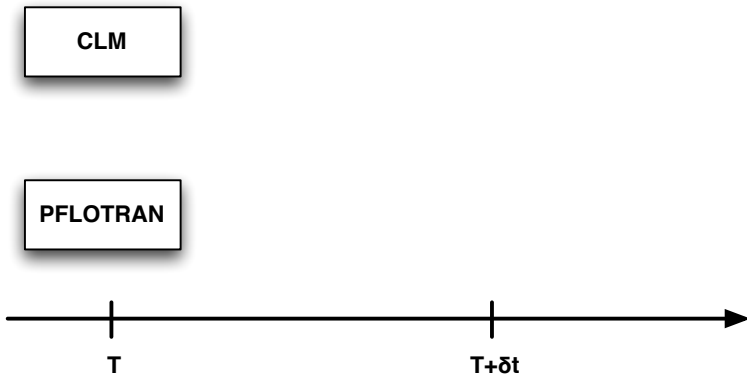
PFLOTRAN - CLM: Soil properties initialized by CLM



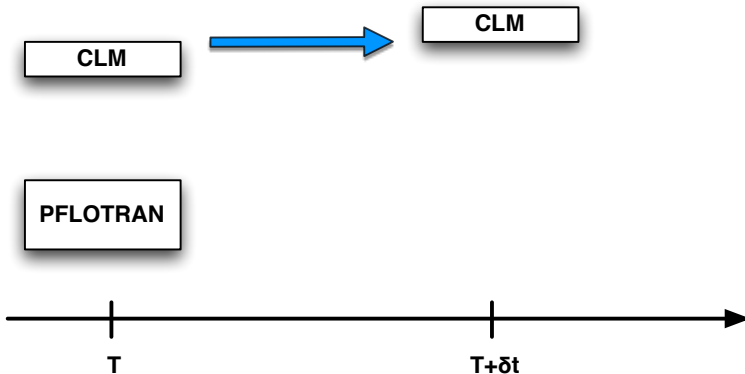
PFLOTRAN - CLM: Initial conditions



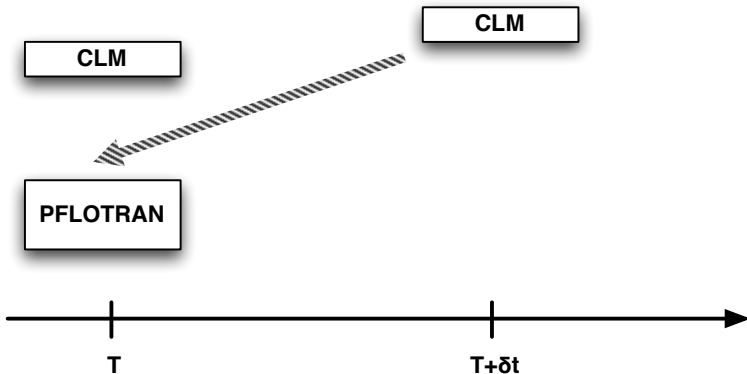
PFLOTRAN - CLM: Time-stepping



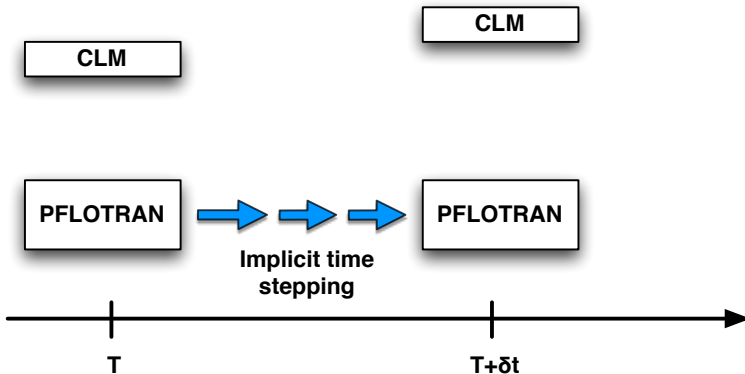
PFLOTRAN - CLM: Time-stepping



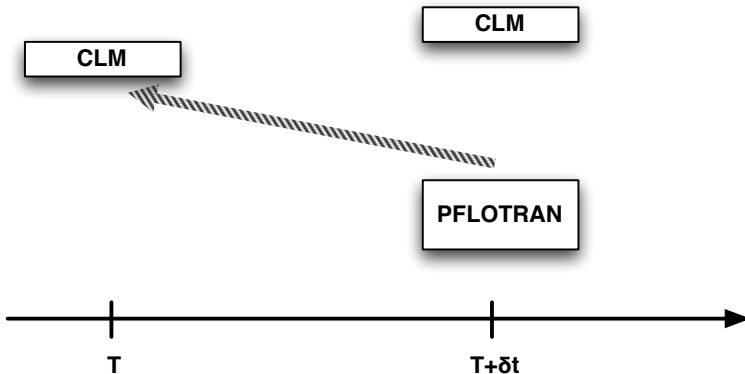
PFLOTRAN - CLM: Time-stepping



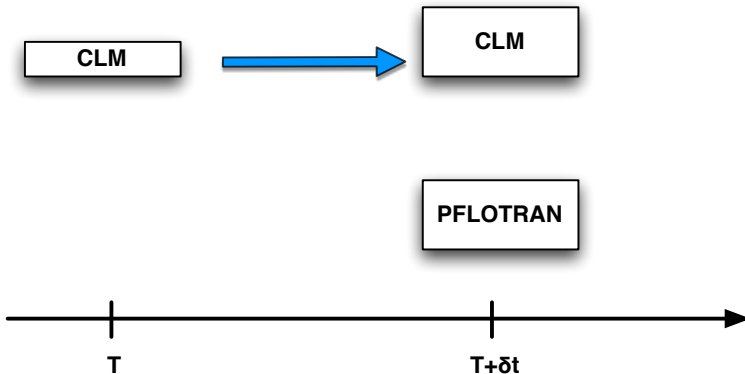
PFLOTRAN - CLM: Time-stepping



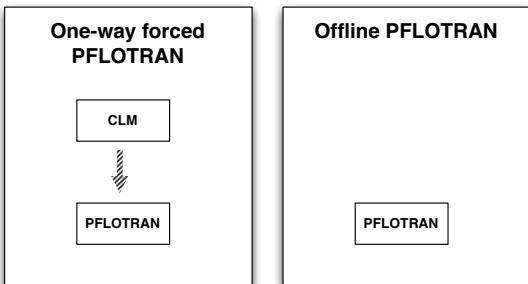
PFLOTRAN - CLM: Time-stepping



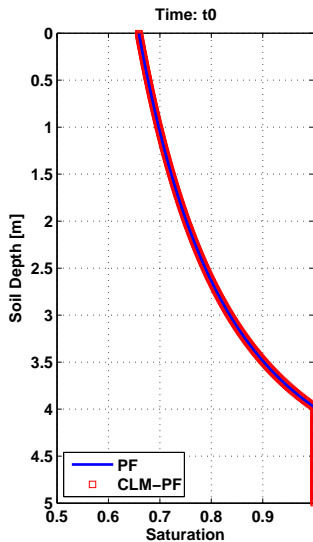
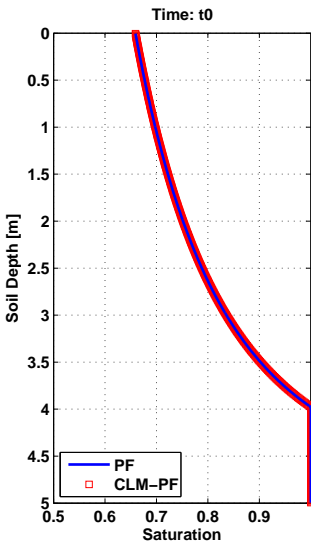
PFLOTRAN - CLM: Time-stepping



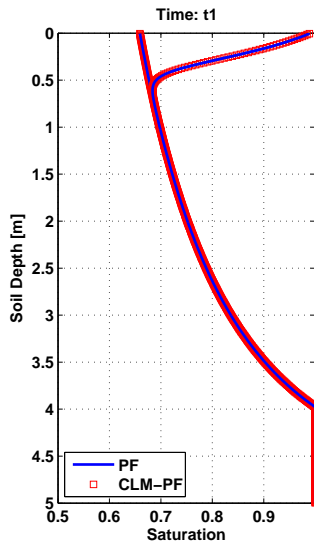
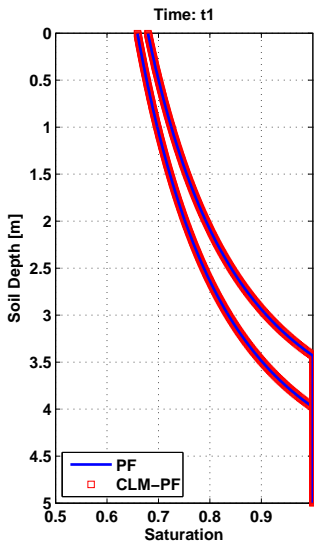
Experiment-1: Sanity check of coupling



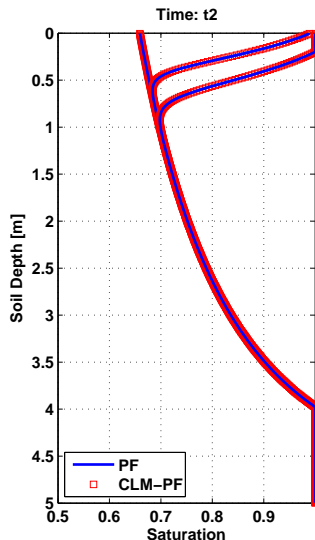
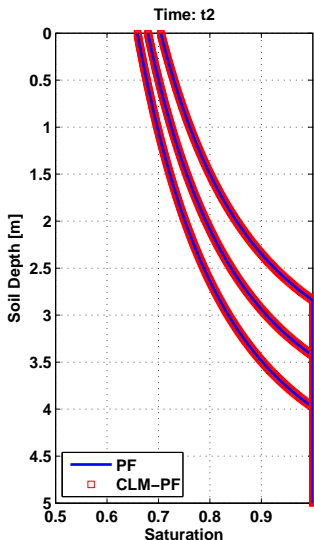
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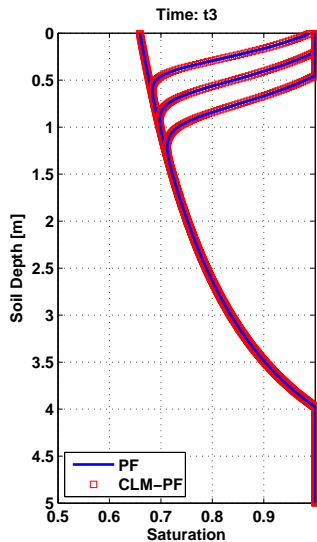
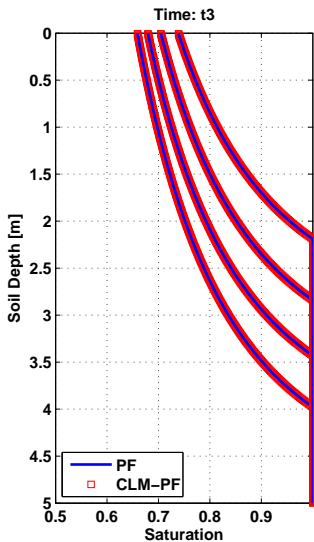
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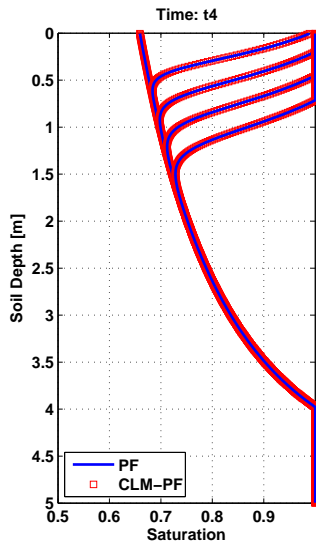
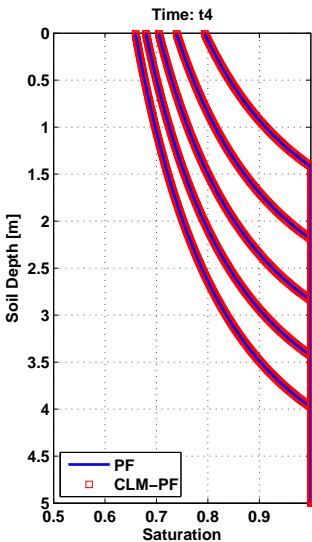
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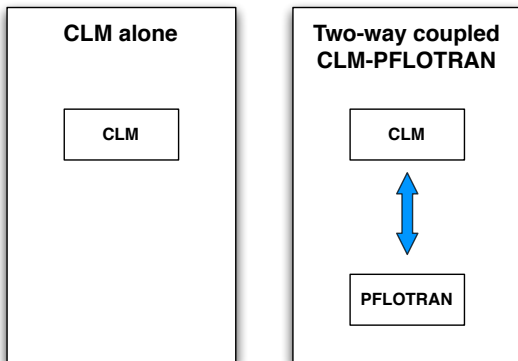
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Experiment-1: Sanity check of coupling

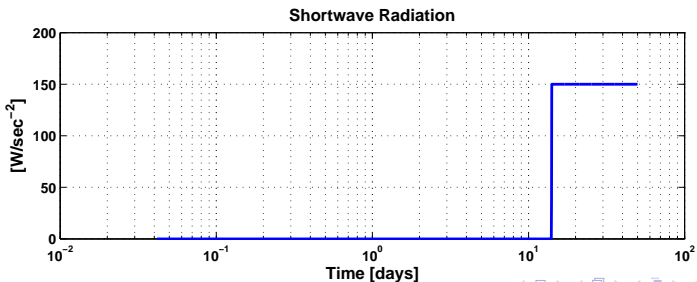
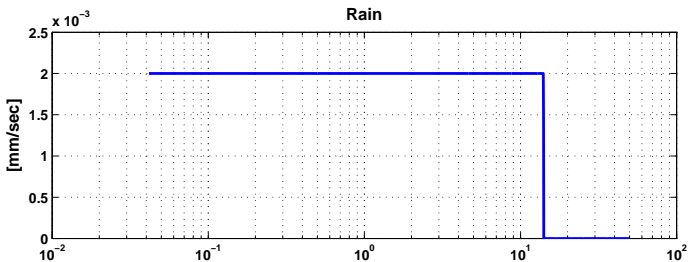


Experiment-2: Single soil column simulation

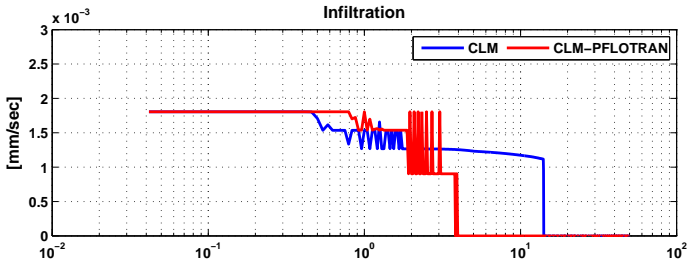
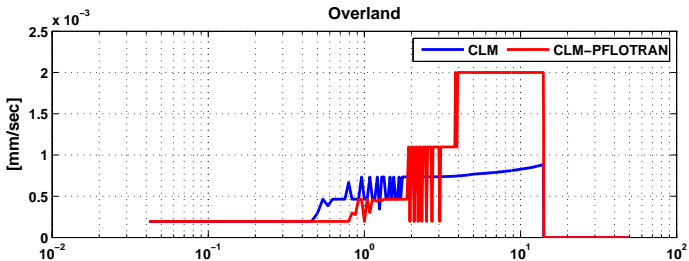


Experiment setup similar to Maxwell and Miller (2005, J. of HydroMeterology) : Rain for 14 days

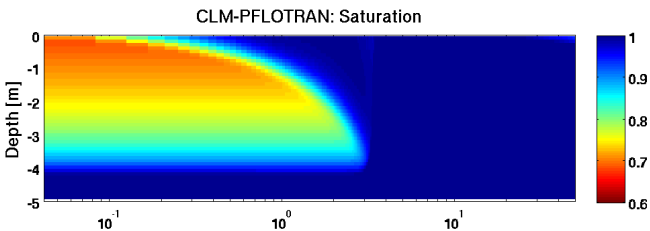
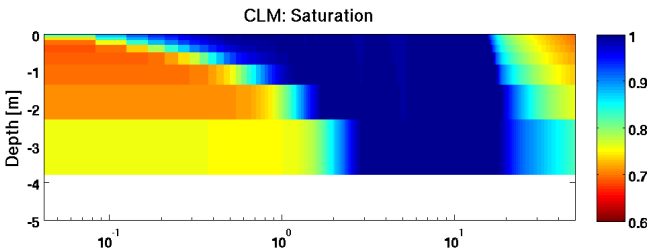
Experiment-2: Single soil column simulation



Experiment-2: Single soil column simulation



Experiment-2: Single soil column simulation



Development of coupling with HPC in mind

CLM domain

0	6	12	18
1	7	13	19
2	8	14	20
3	9	15	21
4	10	16	22
5	11	17	23

PFLOTRAN domain

44	45	46	47
40	41	42	43
36	37	38	39
32	33	34	35
28	29	30	31
24	25	26	27
20	21	22	23
16	17	18	19
12	13	14	15
8	9	10	11
4	5	6	7
0	1	2	3

Development of coupling with HPC in mind

CLM domain

0	6	12	18
1	7	13	19
2	8	14	20
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Processor - 0

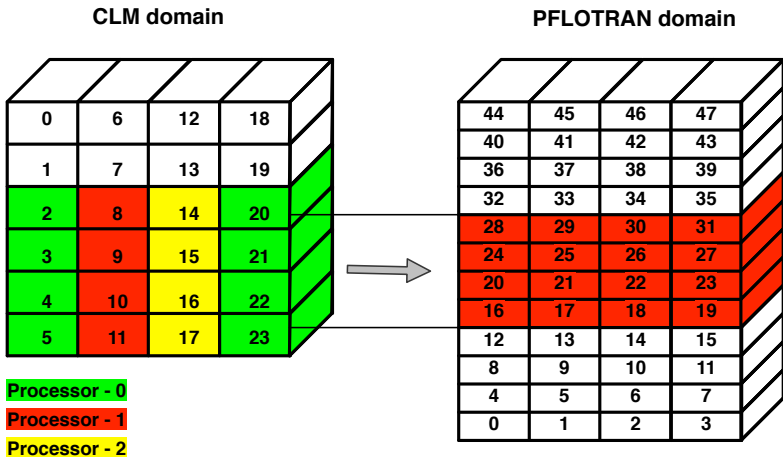
Processor - 1

Processor - 2

PFLOTRAN domain

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12	13	14	15
8	9	10	11
4	5	6	7
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Development of coupling with HPC in mind



Next steps

- Restart capability
- Map projection
- Application of the coupled model to a study site
- Nutrient transport
- Thermal Hydrologic transport

Acknowledgements

- DOE ASCR
- PFLOTRAN team
- Daniel Ricciuto

Questions?

Gautam Bisht : bishtg@ornl.gov

Richard Mills : rmills@climatemodeling.org

Forrest Hoffman : forest@climatemodeling.org

Peter Thornton : thorntonpe@ornl.gov