Synergistic Observations and Hydrologic Modeling over a Snow-Dominated Mountain Basin

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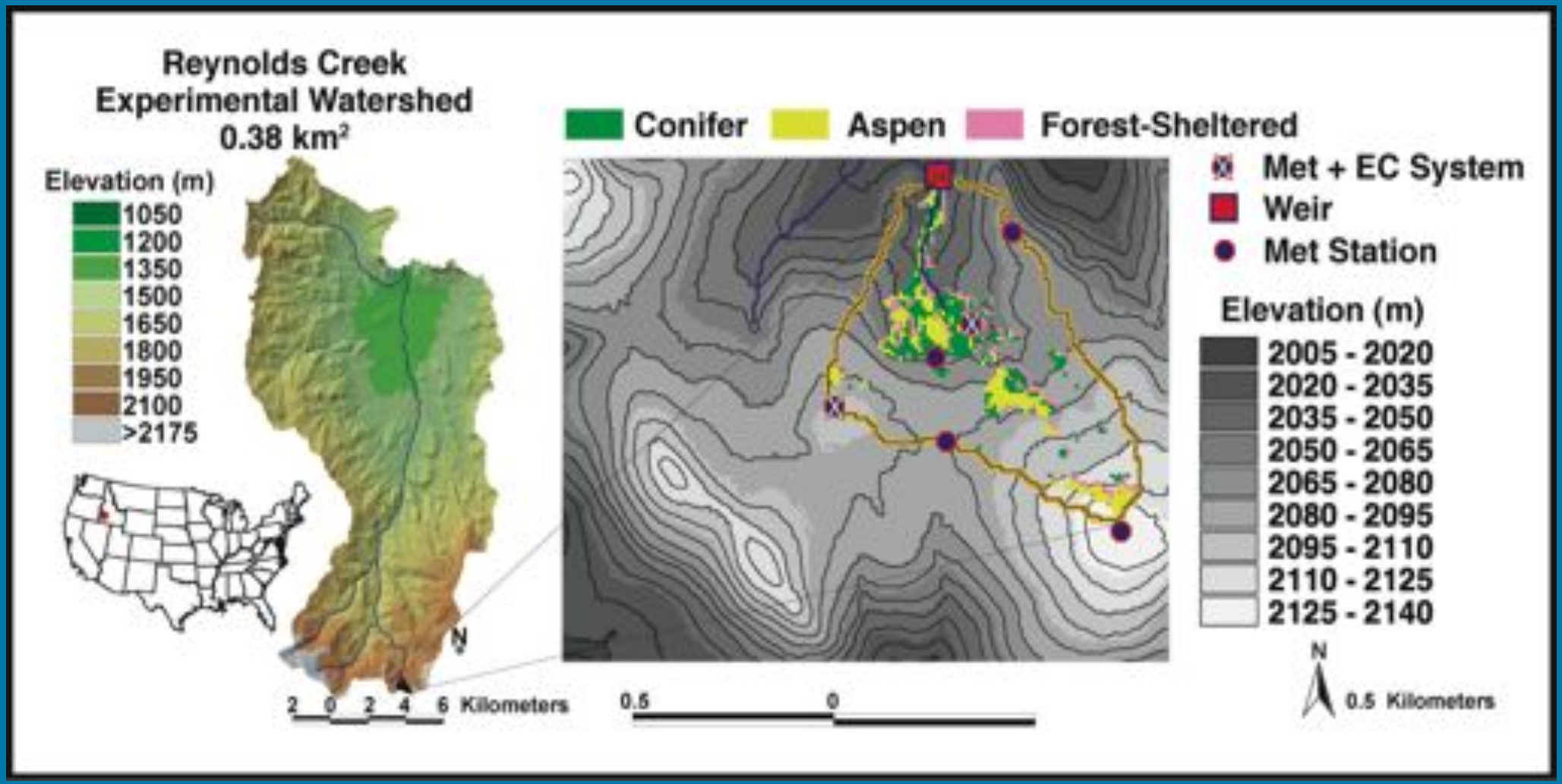
Reynolds Mountain East Study Catchment (0.38 km^2, 118 m relief)



- 4 soil micro-climate sites
- 3 precipitation measurement sites
- 4 deep ground water wells
- 2-3 detailed snow surveys

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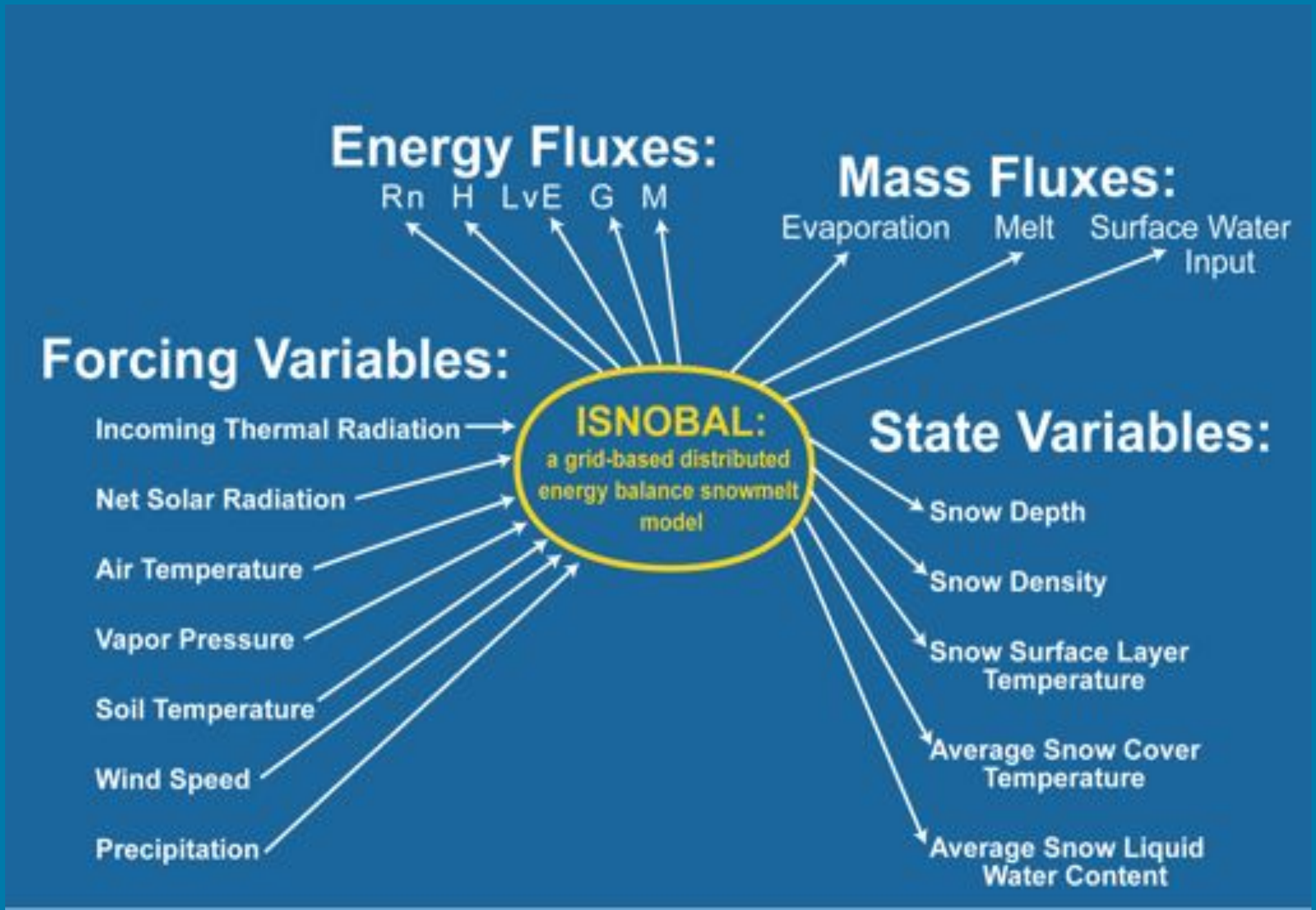

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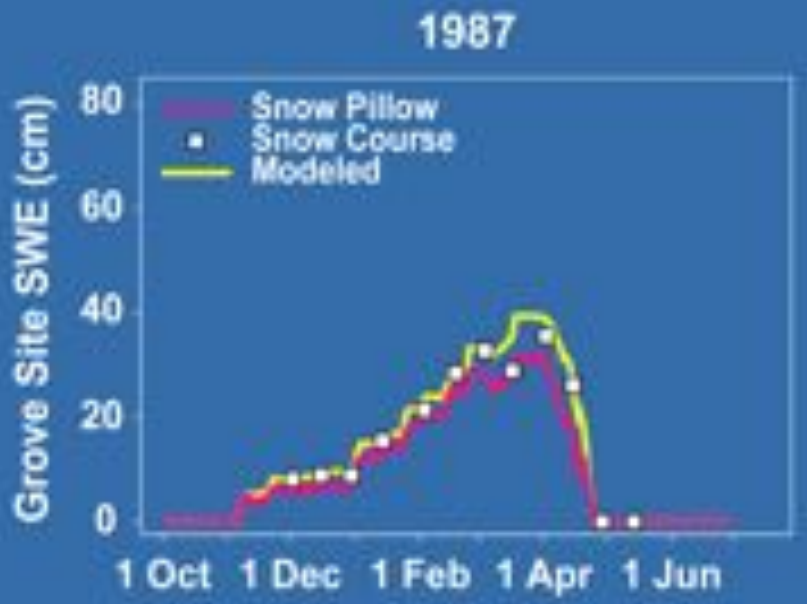
Validation: Modeled and Observed SWE

(Point Comparison)



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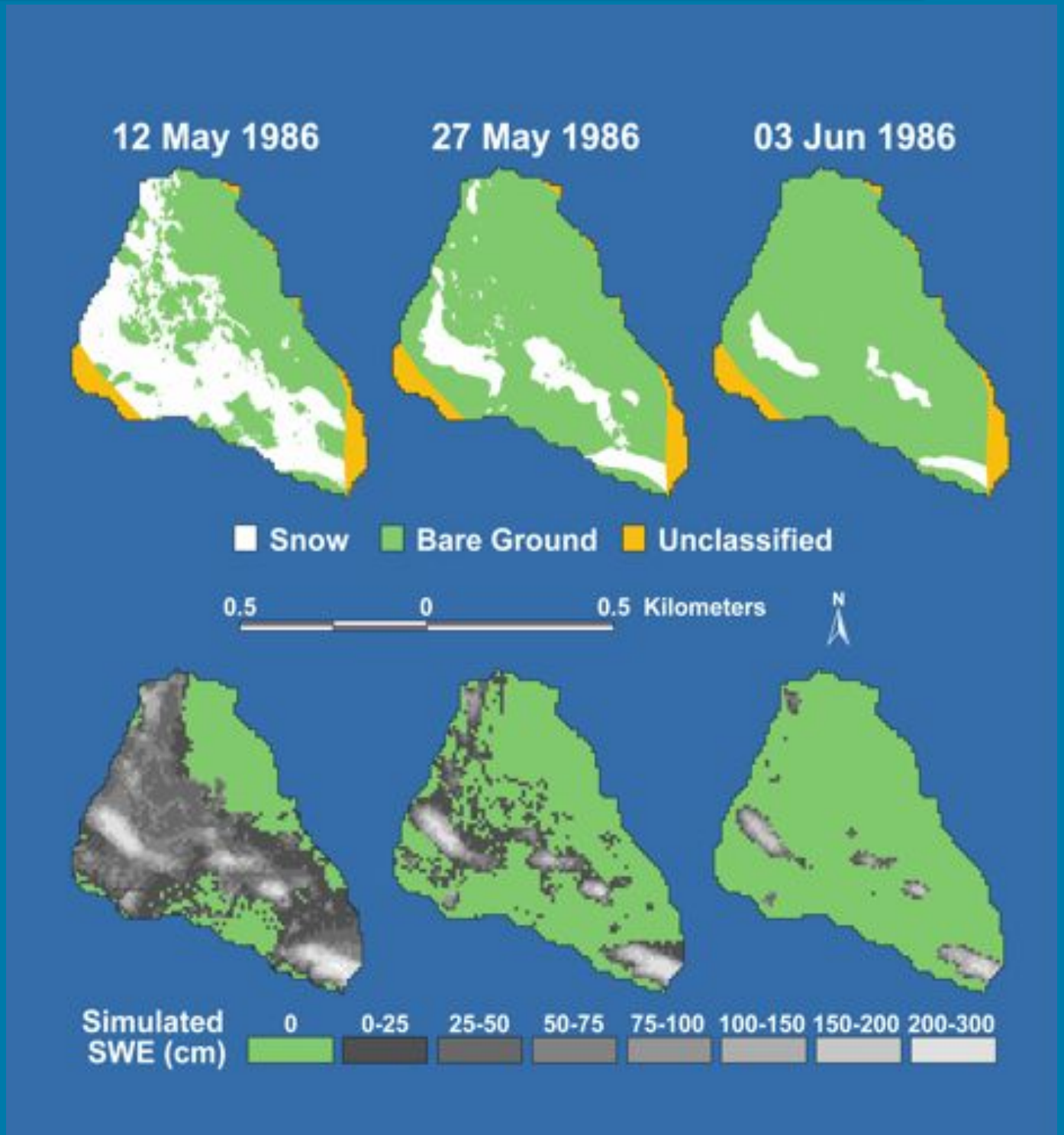
1986 Simulated Snow Distribution

Aerial Photos

Modeled SWE



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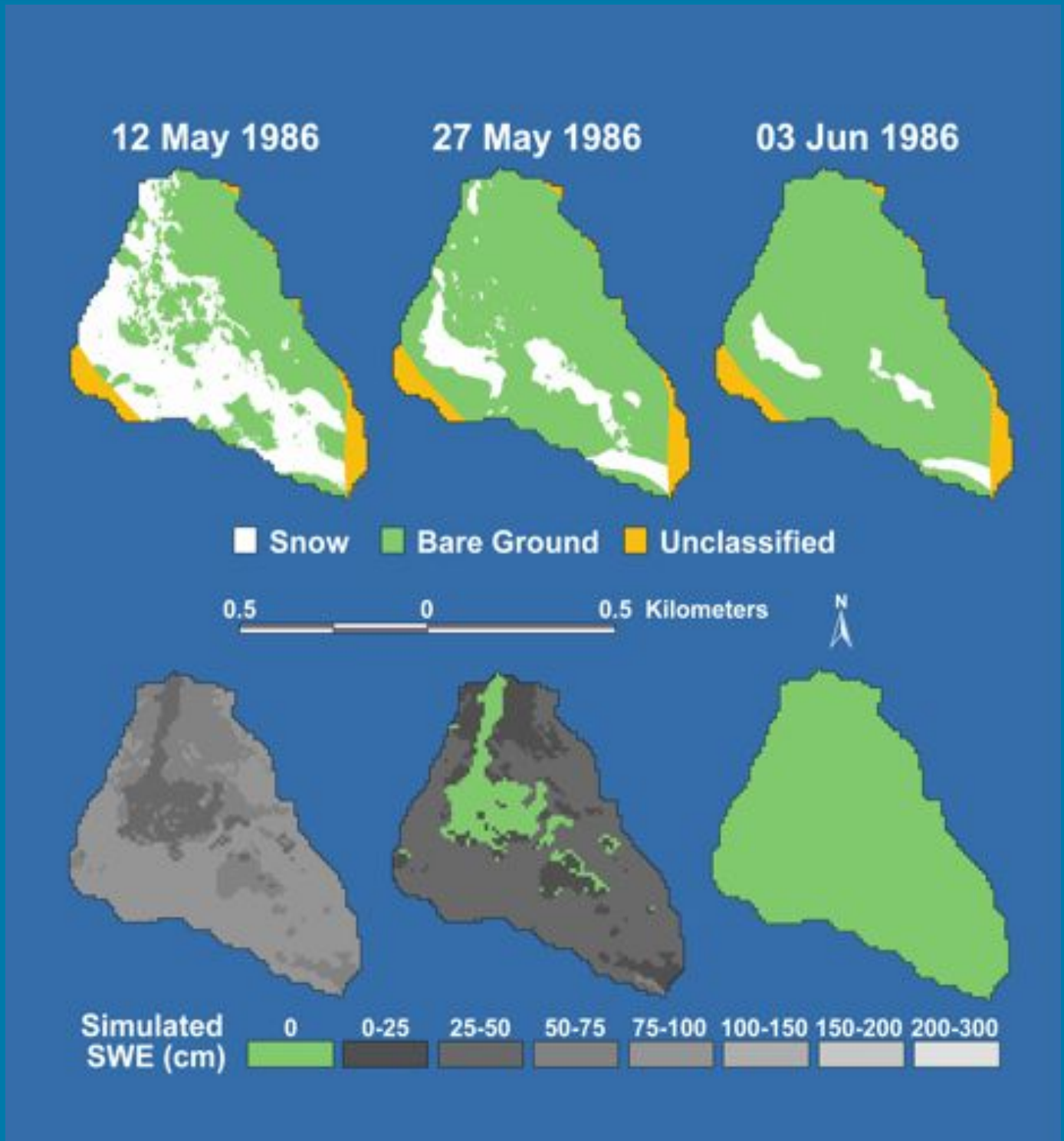
1986 Simulated Snow Distribution

Aerial Photos

Modeled SWE:

spatially constant wind and precipitation inputs



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Four Snow Seasons Selected for Climate Change Scenario Simulation

1984: cold & wet (1221mm P_{cp}, 826mm SWE)

1987: warm & dry (652mm P_{cp}, 263mm SWE)

2001: cool & dry (685mm P_{cp}, 362mm SWE)

2006: warm & wet (1148mm P_{cp}, 622mm SWE)

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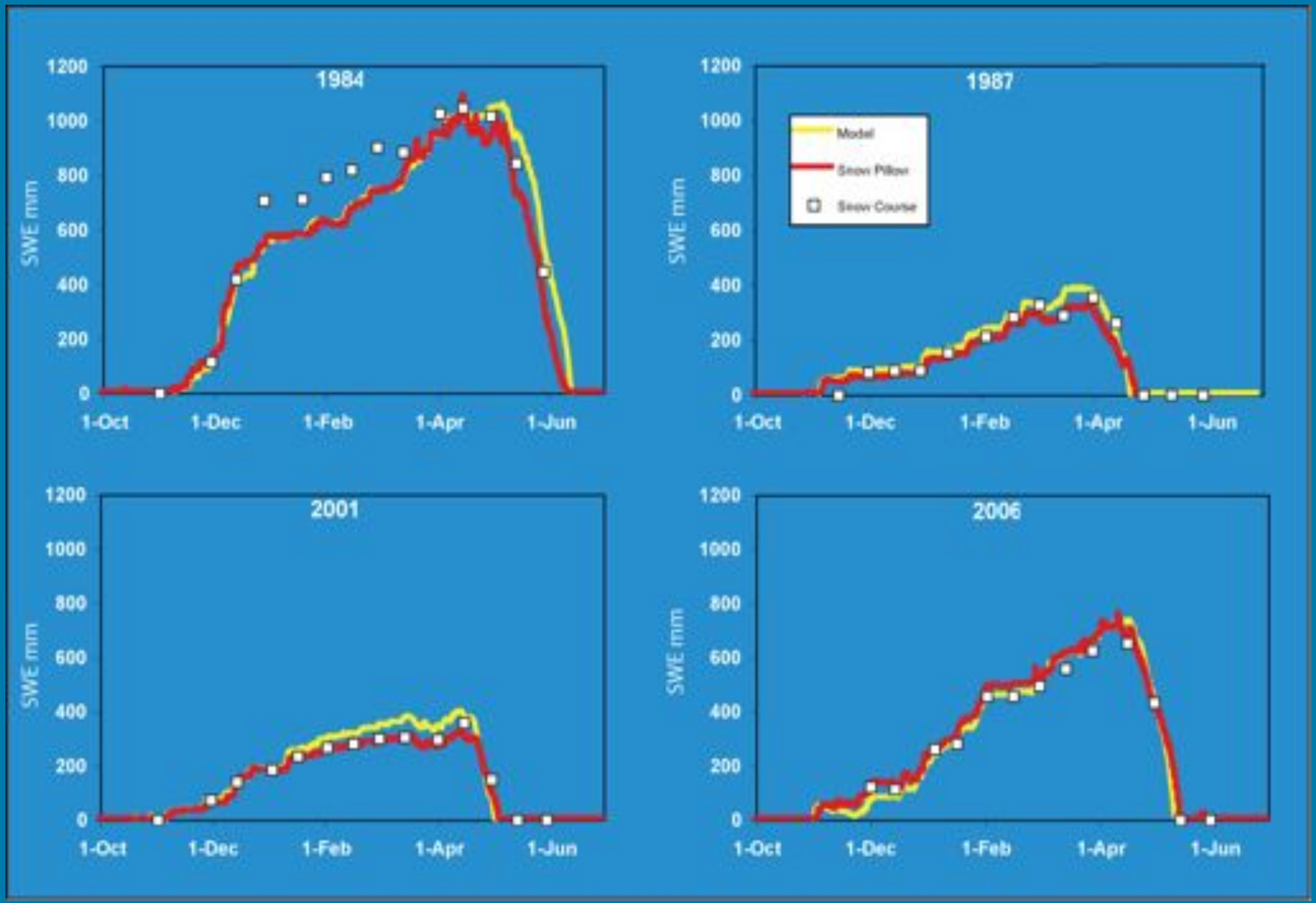
Validation: Modeled and Observed SWE (Point Comparison)



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If we put this snow model into a coherent, physics-based hydrology model would it Improve our understanding of mountain hydrology?

- Bed-rock to Boundary Layer ETRS strategy:
  - Atmospheric, Vegetation & Snow processes
- Atmospheric, Vegetation & Snow Processes
- Sub-Surface Processes:
  - Unsaturated-zone (soil moisture)
  - Ground-water recharge & extraction
- Flow routing & streamflow prediction

We used the Penn St Integrated Hydrology model (PIHM) to investigate some of these questions

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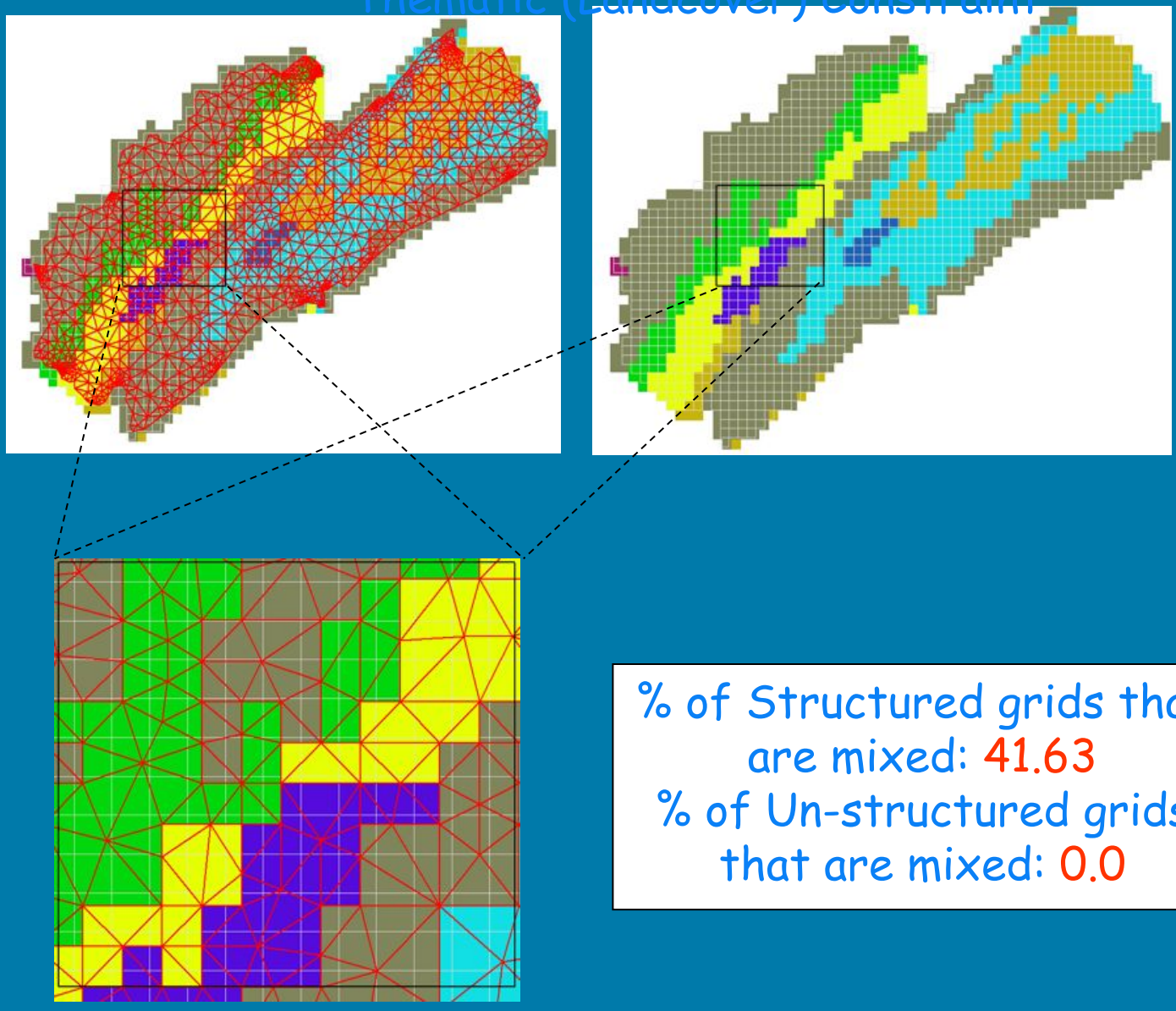
Constrained Unstructured Mesh Decomposition Provides Additional Accuracy and Flexibility

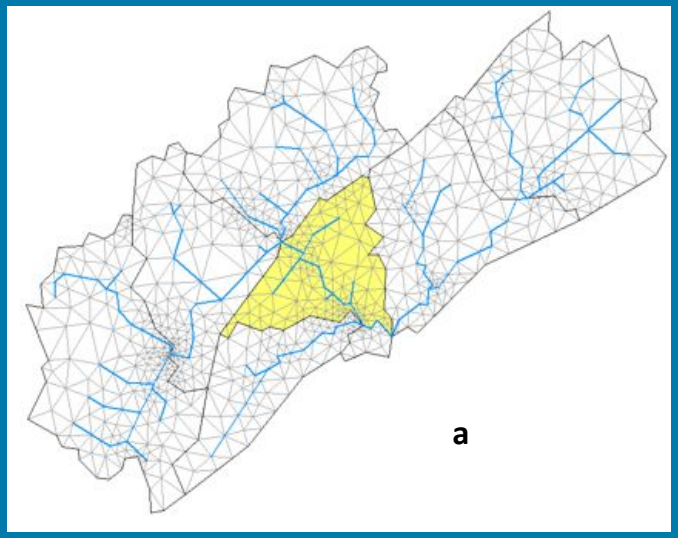
Thematic (Landcover) Constraint

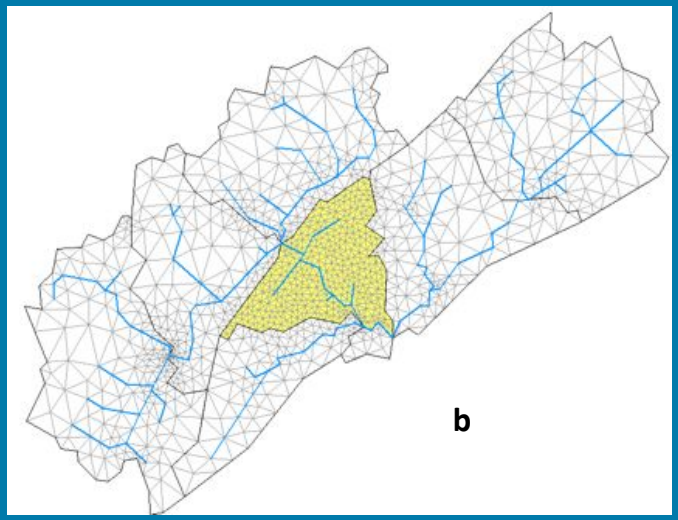


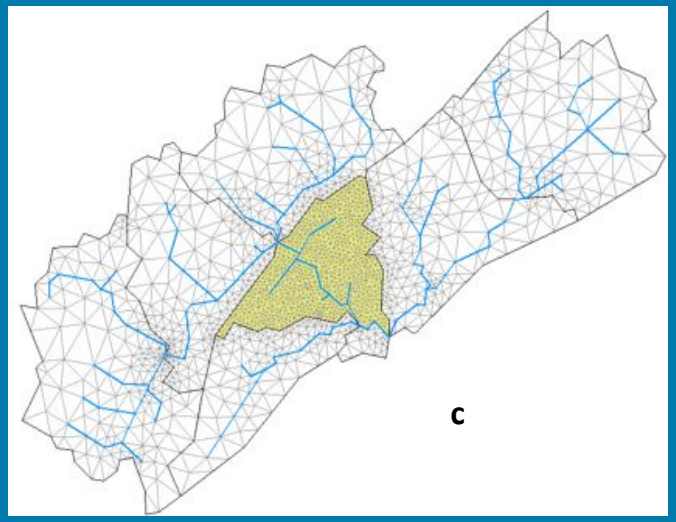
% of Structured grids that are mixed: 41.63
% of Un-structured grids that are mixed: 0.0

This leads to **non-introduction of any additional data uncertainty** arising from subgrid variability

Constrained Unstructured Mesh Decomposition Provides Additional Accuracy and Flexibility







Maximum area of triangle in targeted nested zone in **(a)** : 2 sq. km

Maximum area of triangle in targeted nested zone in **(b)** : 0.2 sq km

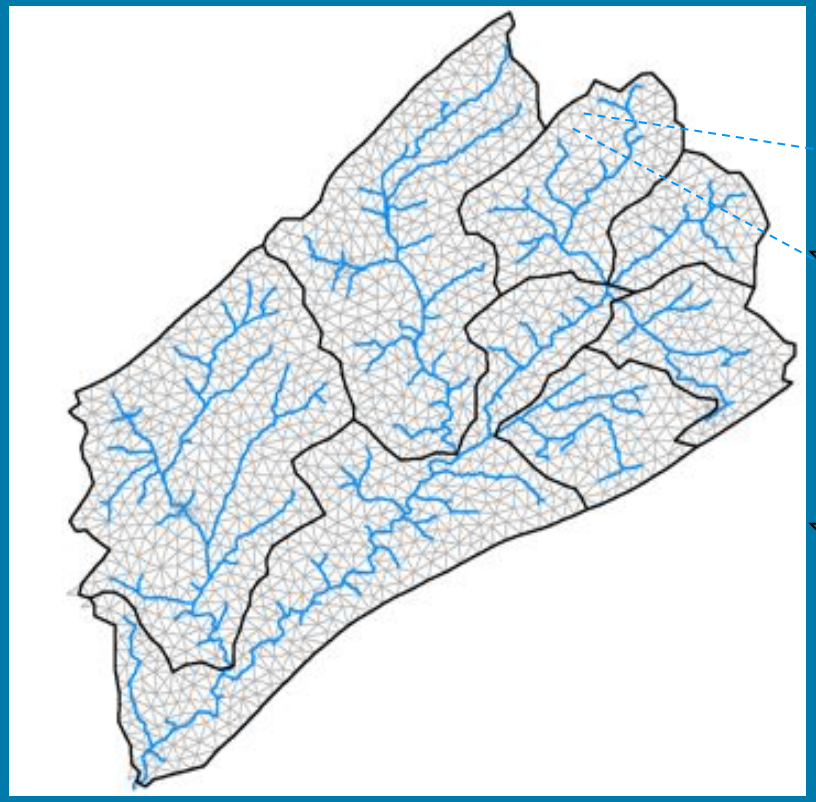
Maximum area of triangle in targeted nested zone in **(c)** : 0.01 sq km

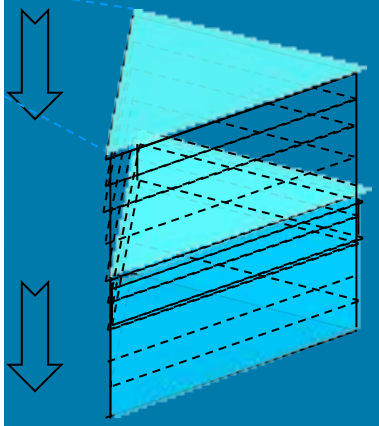
Nested Decomposition

Semi-Discrete Finite Volume Formulation of Conservation Equations

$$\frac{\partial \phi}{\partial t} = \nabla.(\phi U) + \nabla.(\Gamma \nabla \phi) + Q_{ss}$$

where $f \circ \{y_o, y_g\}$ correspond to overland and subsurface head





control volume
i V_i

Finite Volume Method ensures MASS BALANCE locally (in each control volume) and globally

Semi-Discrete Finite Volume Formulation of Conservation Equations

$$\frac{\partial \phi}{\partial t} = \nabla.(\phi U) + \nabla.(\Gamma \nabla \phi) + Q_{ss}$$

where $f \circ \{y_o, y_g\}$ correspond to overland and subsurface head

⇓ Integrating over control volume V_i

$$\int_{V_i} \frac{\partial \phi}{\partial t} dV = \int_{V_i} \nabla.(\phi U) dV + \int_{V_i} \nabla.(\Gamma \nabla \phi) dV + \int_{V_i} Q_{ss} dV$$

⇓ Applying Gauss's Theorem

$$\frac{\partial}{\partial t} \int_{V_i} \phi dV = \int_{A_{ij}} \vec{n}.(\phi U) dA + \int_{A_{ij}} \vec{n}.(\Gamma \nabla \phi) dA + \int_{V_i} Q_{ss} dV$$

⇓ Semi-Discrete form

$$A_i \frac{d\overline{\psi}}{dt} = \sum_j \vec{n}.\vec{C} A_{ij} + \sum_k \vec{n}.\vec{D} A_{ik} + \overline{Q}_{ss} V_i$$

Volumetric Conservative Scalar $\overline{\psi} \equiv \{\overline{\psi}_o, \overline{\psi}_g\}$

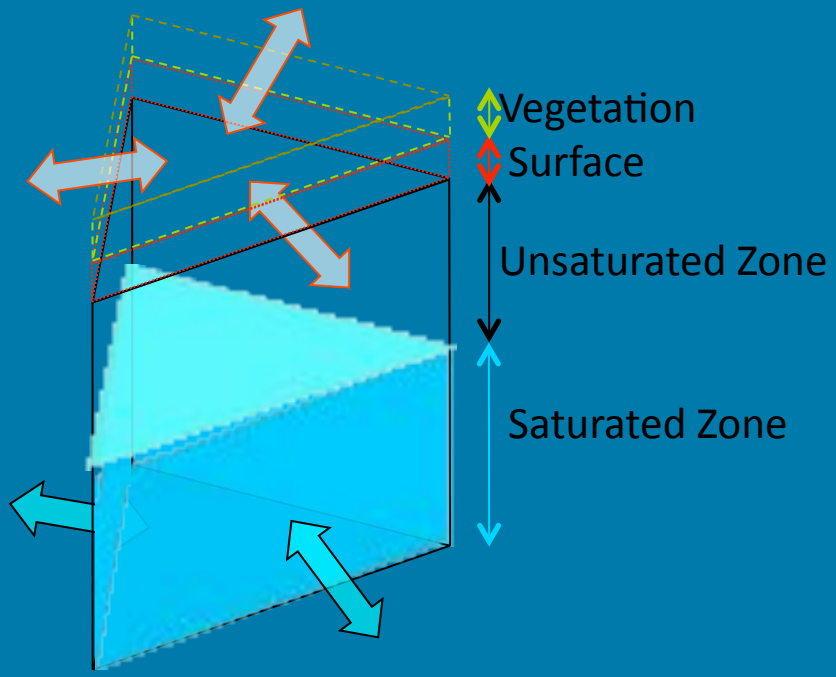
Normalized Convective and Diffusive Flux through control volume faces

Source/Sink Flux per unit volume

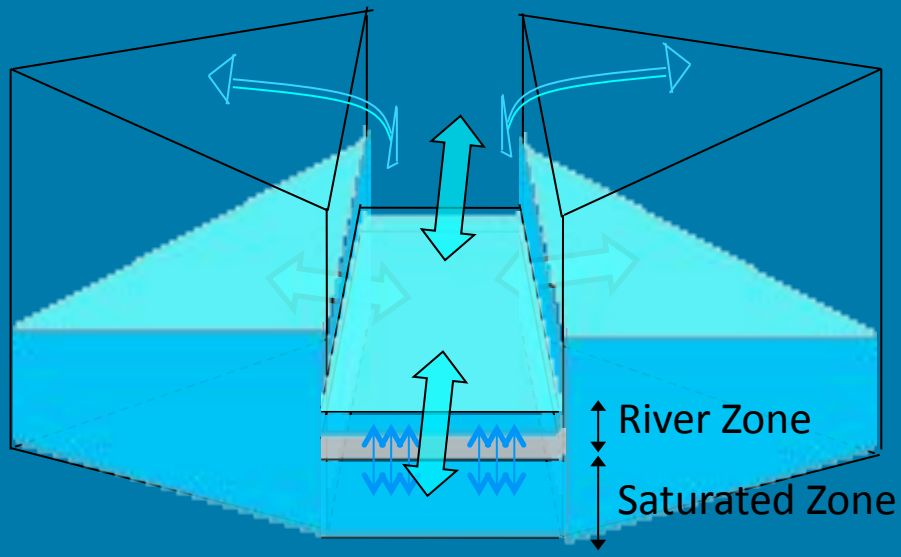
Finite Volume Method ensures MASS BALANCE locally (in each control volume) and globally

Large Scale Model Application Formulation

Control Volumes (Kernels) in PIHM



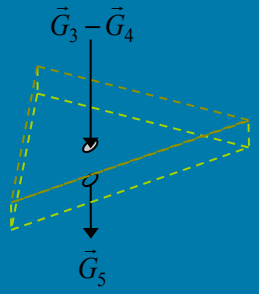
Prismatic Kernel



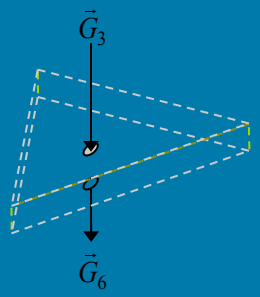
Linear Kernel

Large Scale Model Application Formulation

Interception



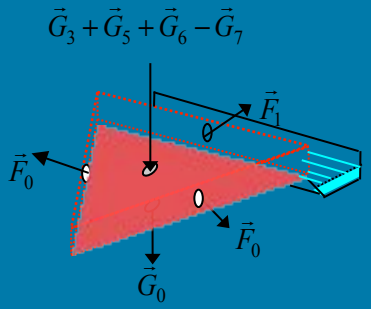
$$\frac{d\psi_0}{dt} = \vec{G}_3 - \vec{G}_4 - \vec{G}_5$$



$$\frac{d\psi_1}{dt} = \vec{G}_3 - \vec{G}_6$$

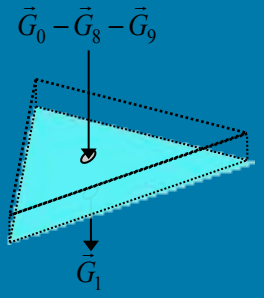
Snow Melt

Overland Flow



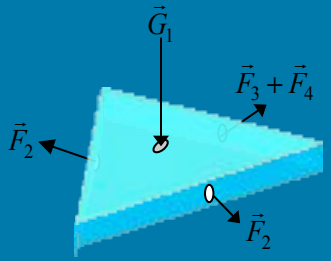
$$\frac{d\psi_2}{dt} = \vec{G}_3 + \vec{G}_5 + \vec{G}_6 + \vec{G}_7 - \vec{G}_0 + \vec{F}_0 + \left\|\vec{F}_1\right\|$$

Unsaturated Zone

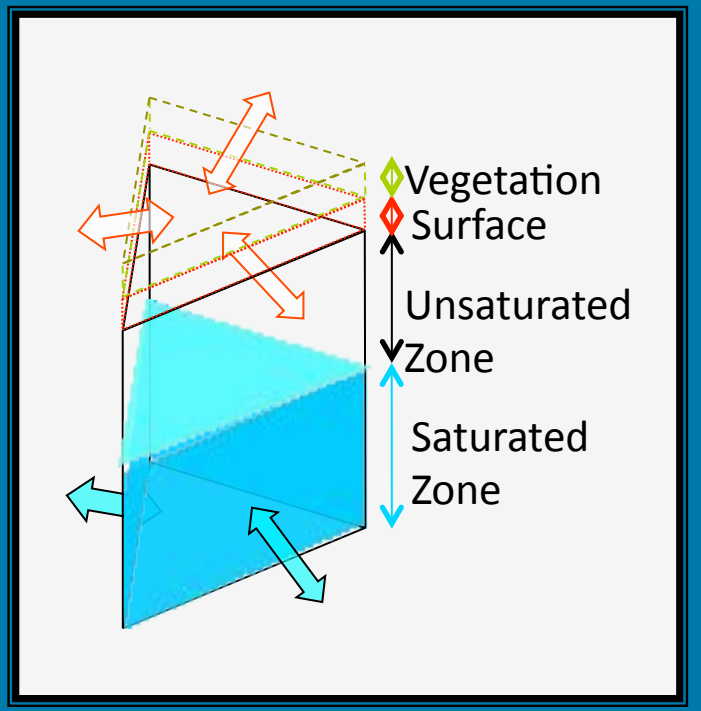


$$\frac{d\psi_3}{dt} = \vec{G}_0 - \vec{G}_1 - \vec{G}_8 - \vec{G}_9$$

Saturated Zone



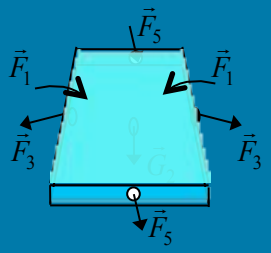
$$\frac{d\psi_4}{dt} = \vec{G}_1 + \vec{F}_2 + \left\|\vec{F}_3\right\| + \left\|\vec{F}_4\right\|$$



Prismatic Kernel

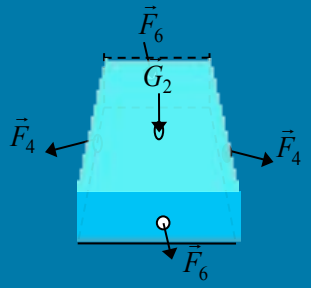
Control Volumes (Kernels) in PIHM

Channel

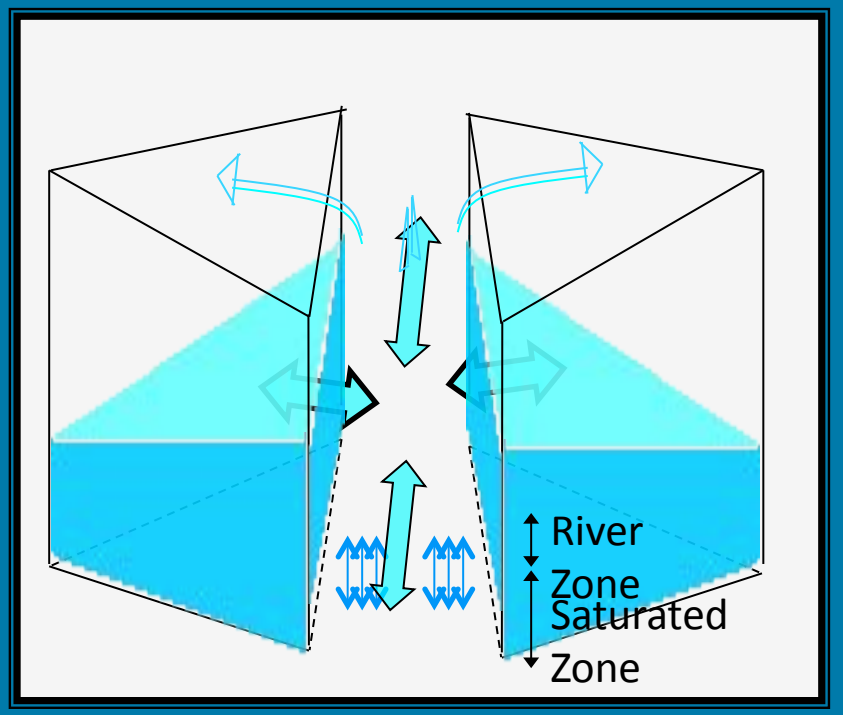


$$\frac{d\psi_5}{dt} = \vec{G}_3 - \vec{G}_2 - \vec{G}_7 + \vec{F}_1 + \vec{F}_5 + \left\|\vec{F}_3\right\|$$

Sub-Channel Aquifer



$$\frac{d\psi_6}{dt} = \vec{G}_2 + \vec{F}_4$$



River Kernel

1st Attempt:
2006 Water Year - Soft-coupling between Isnobal & PIHM

- Mix of raster and unstructured grids
- 1st detailed evaluation of ground-water data…
- No solid validation on soil moisture and groundwater
- Some validation on ET

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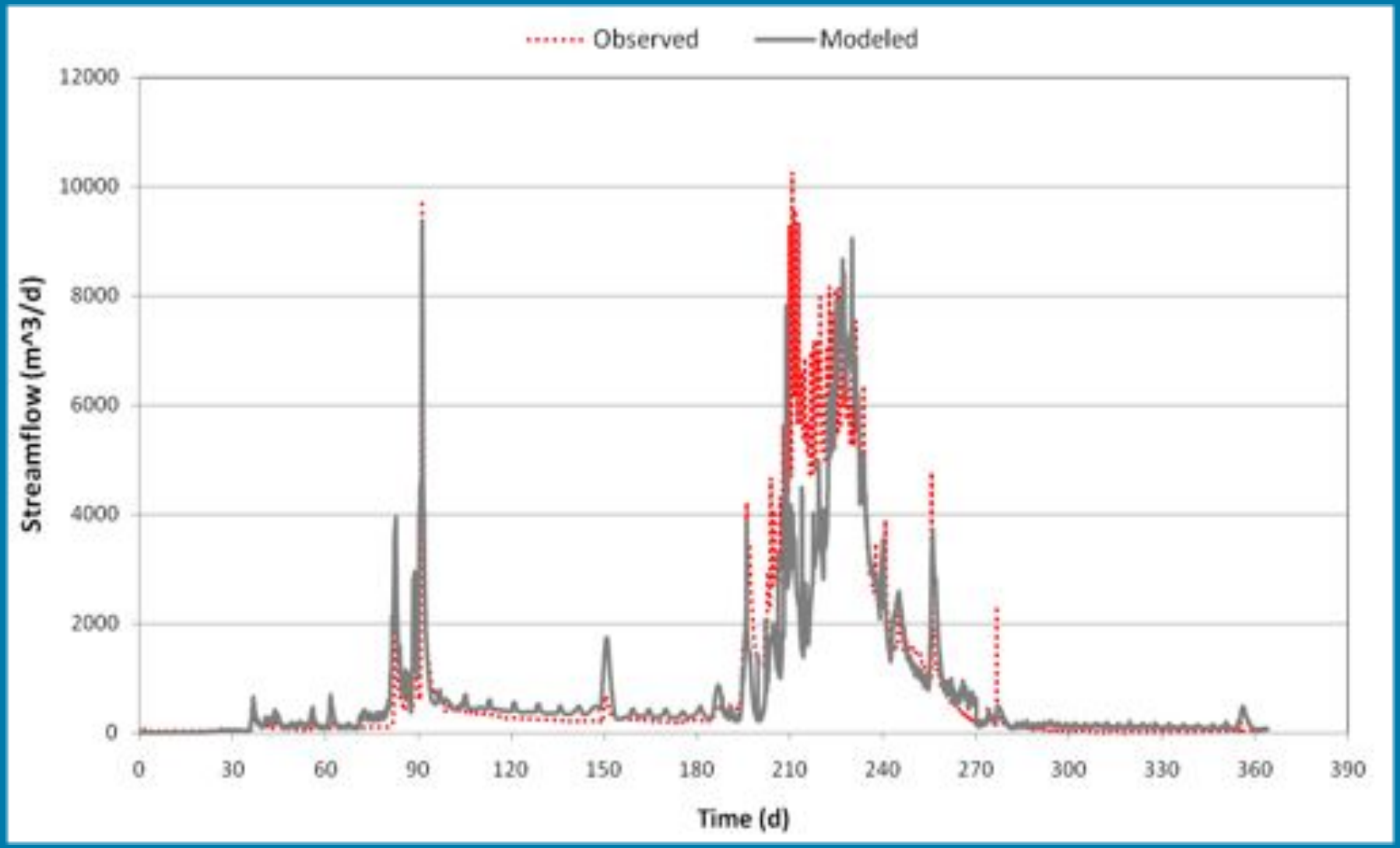
Simulated and Measured Streamflow: 2006 Water Year



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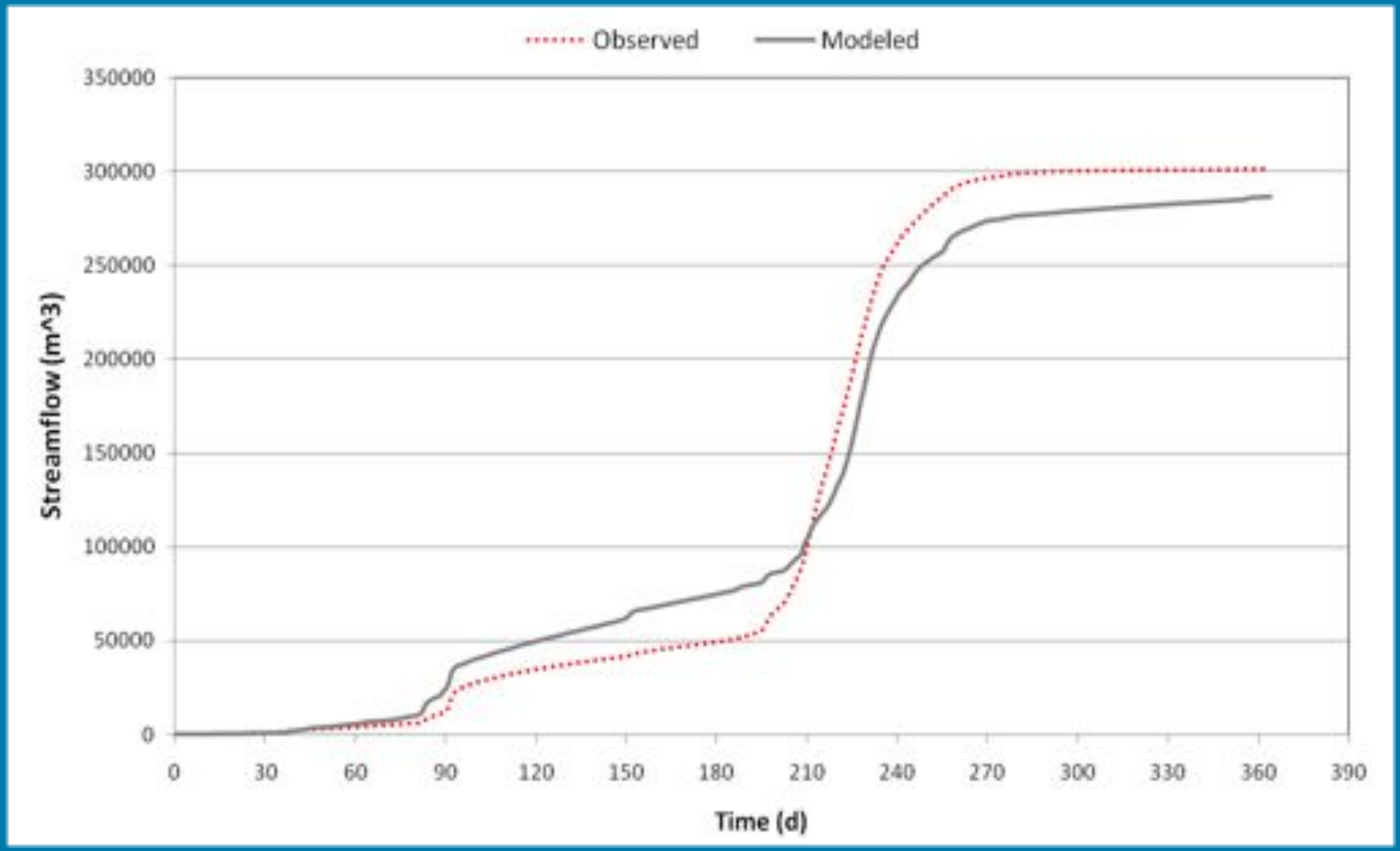
Cumulative Simulated and Measured Streamflow: 2006 Water Year



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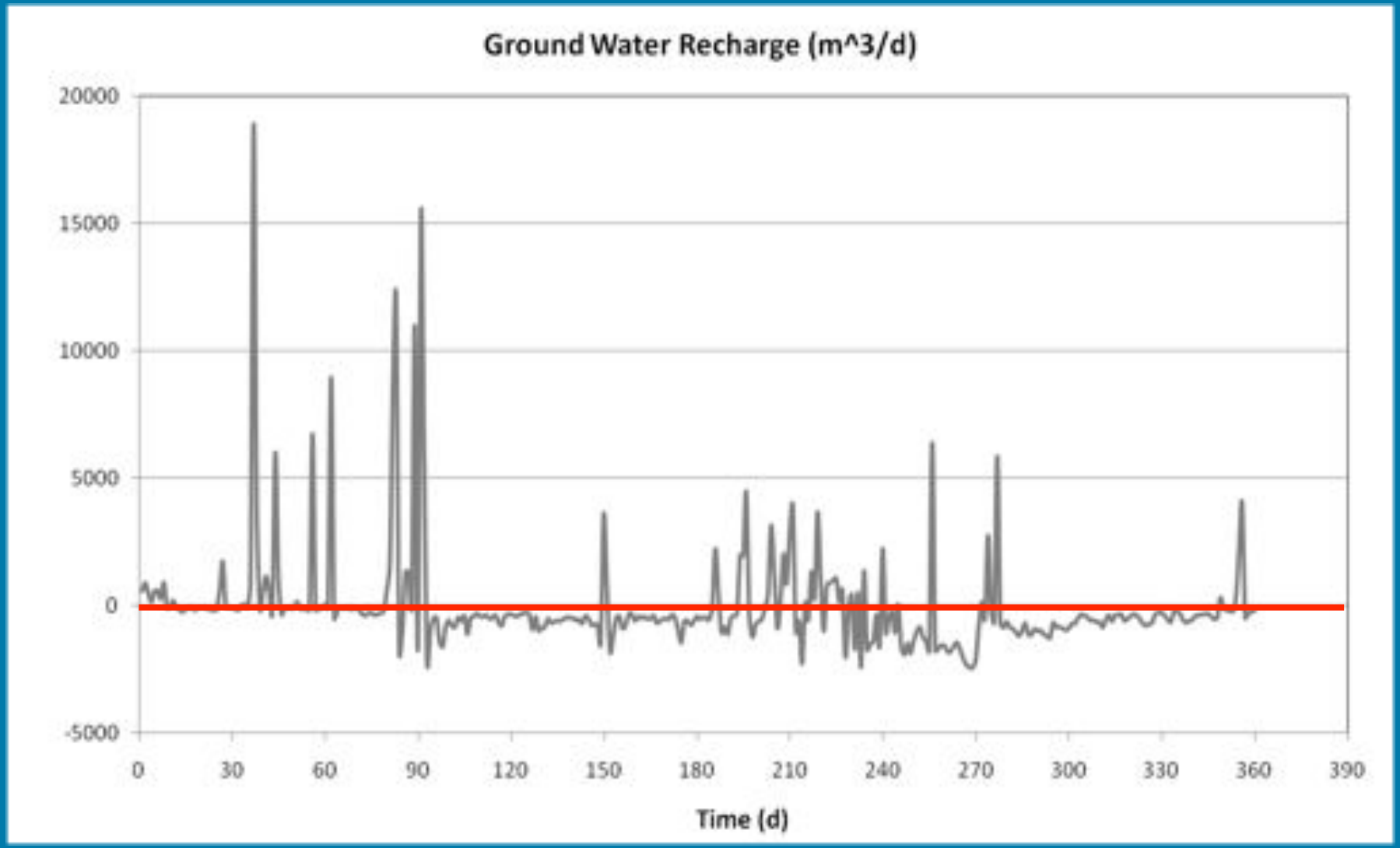
Groundwater Recharge and Use
2006 Water Year



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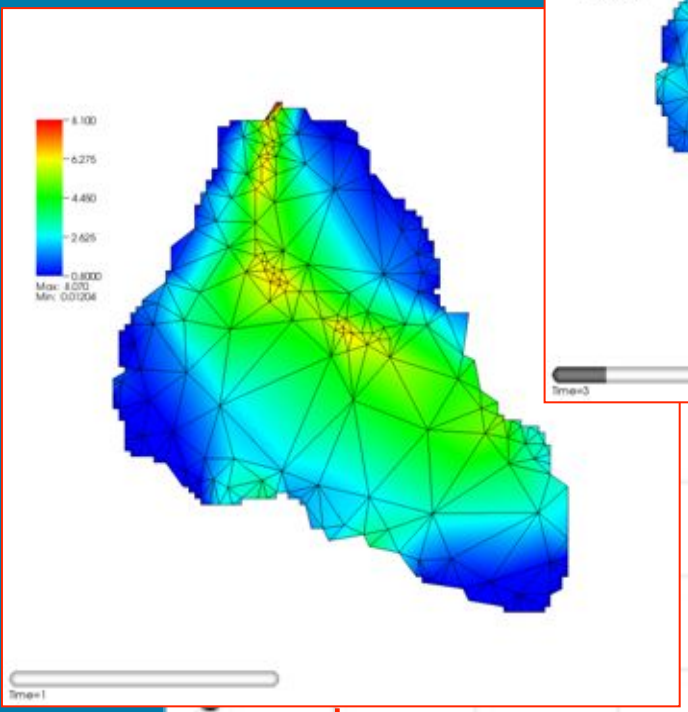
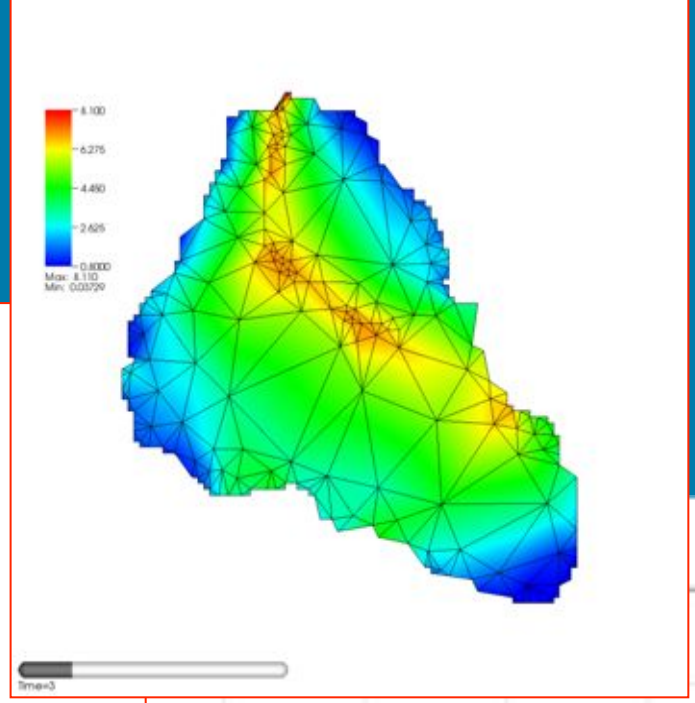
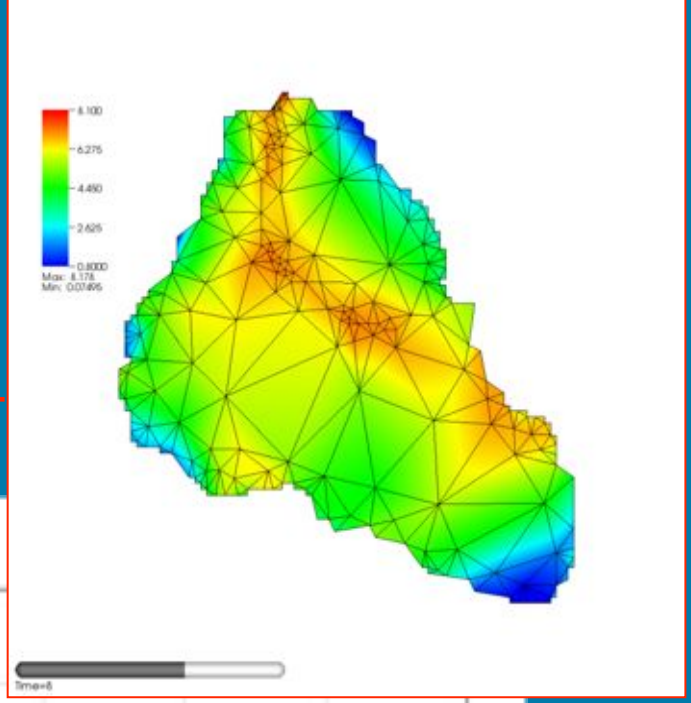
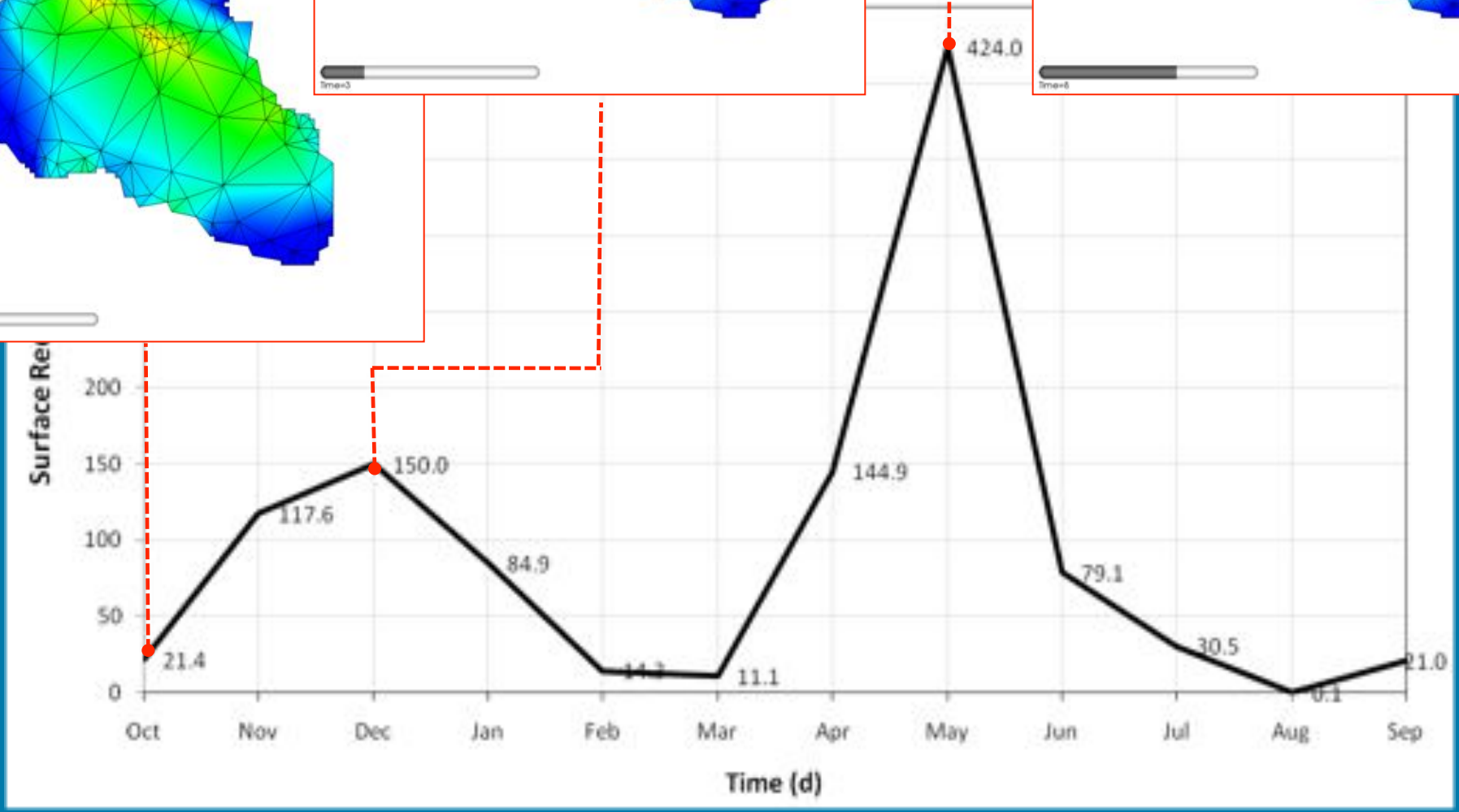
Groundwater Head:

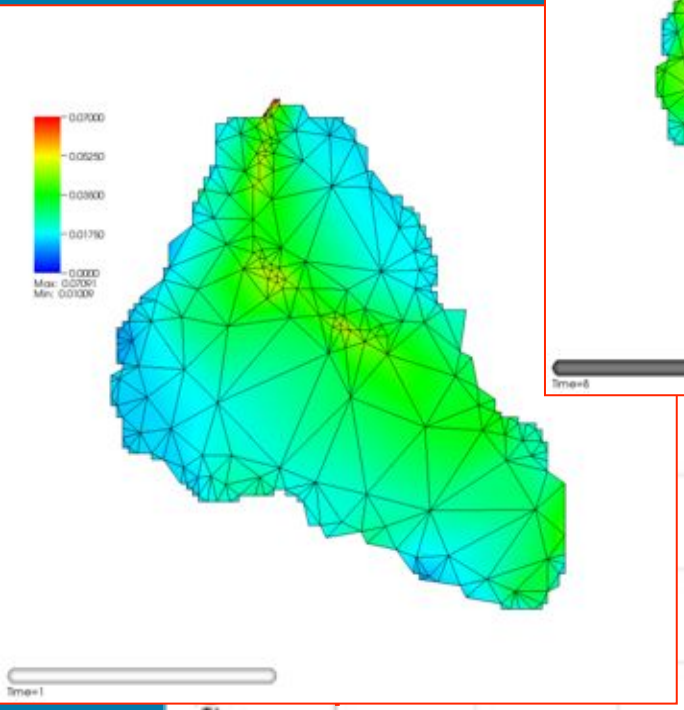


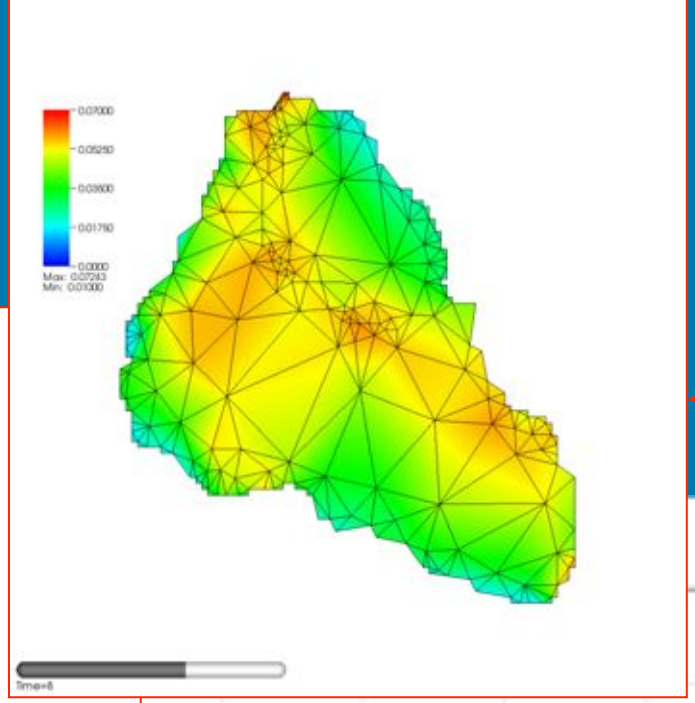


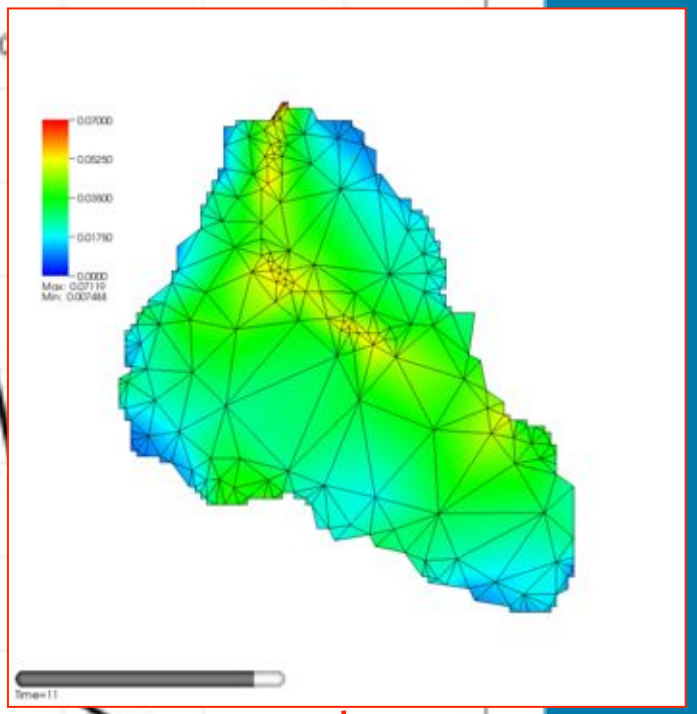




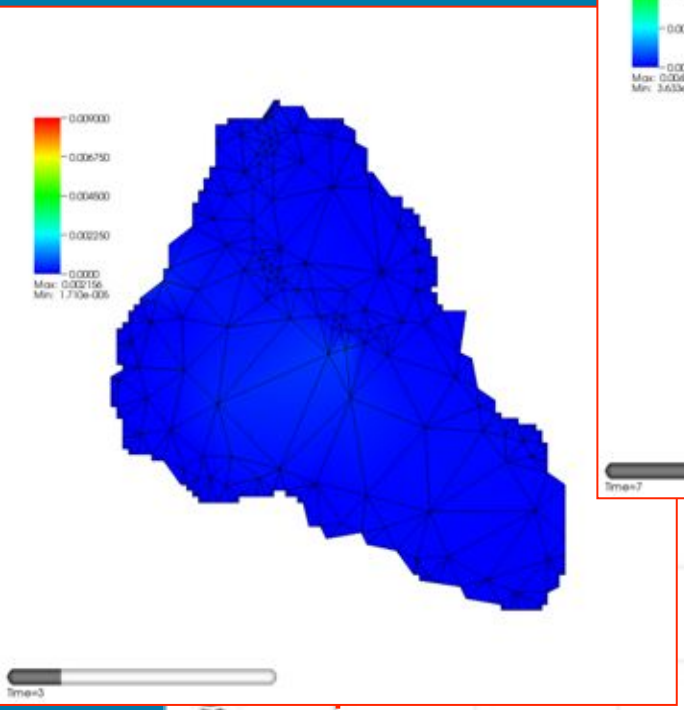
Soil Moisture: 2006 Water Year

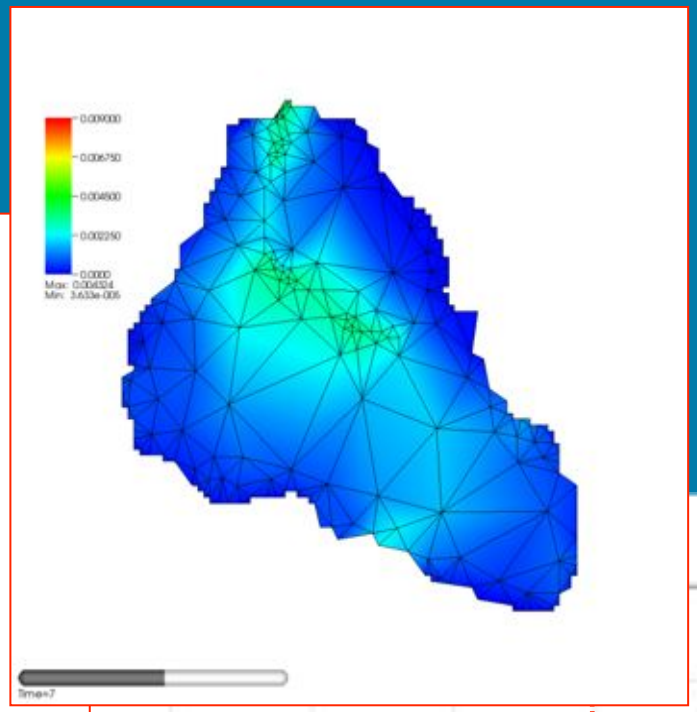


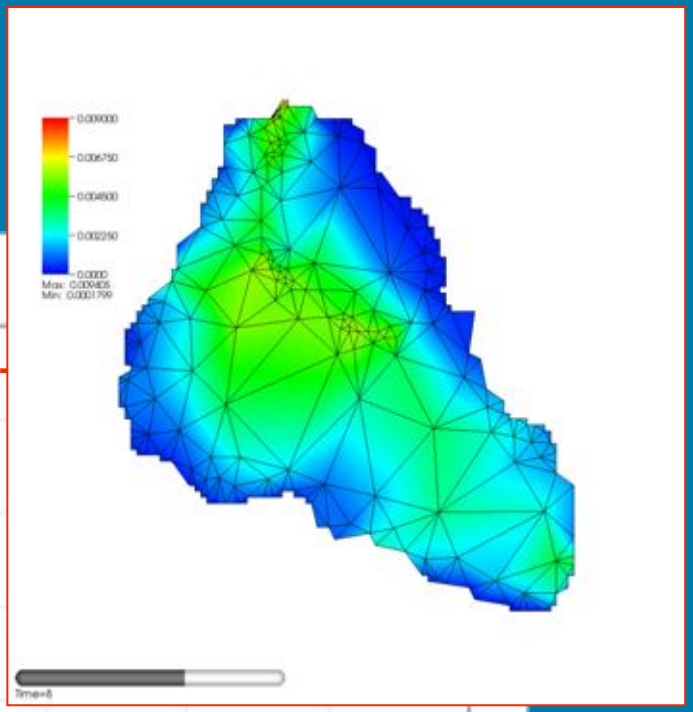


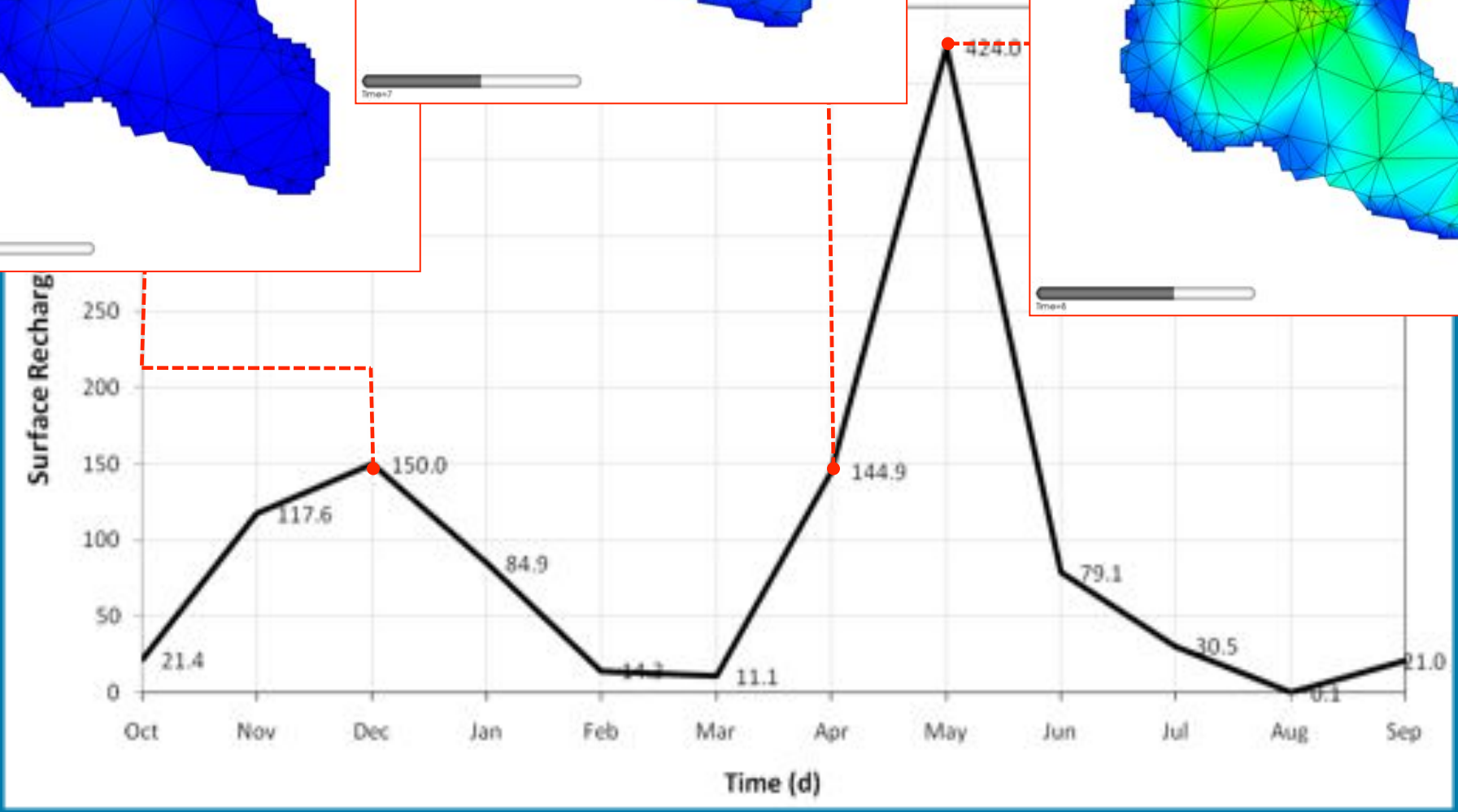


Direct Evaporation

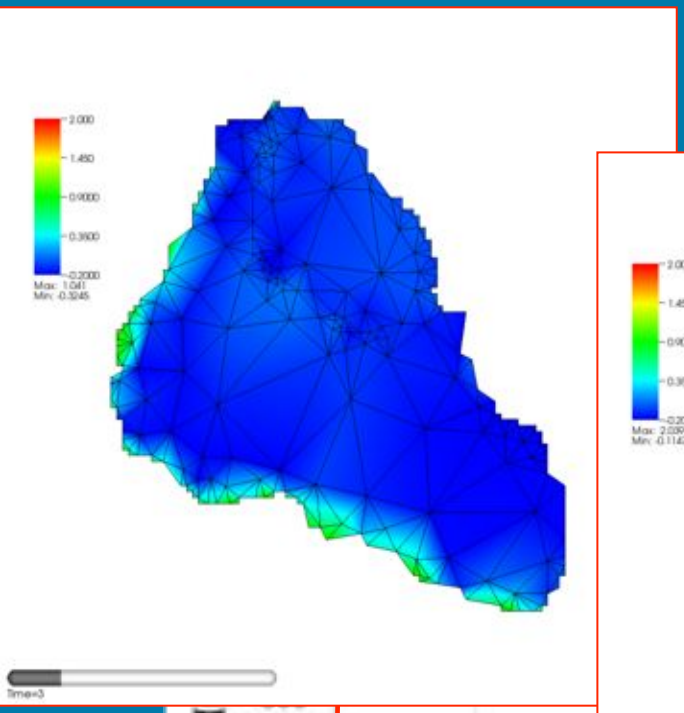


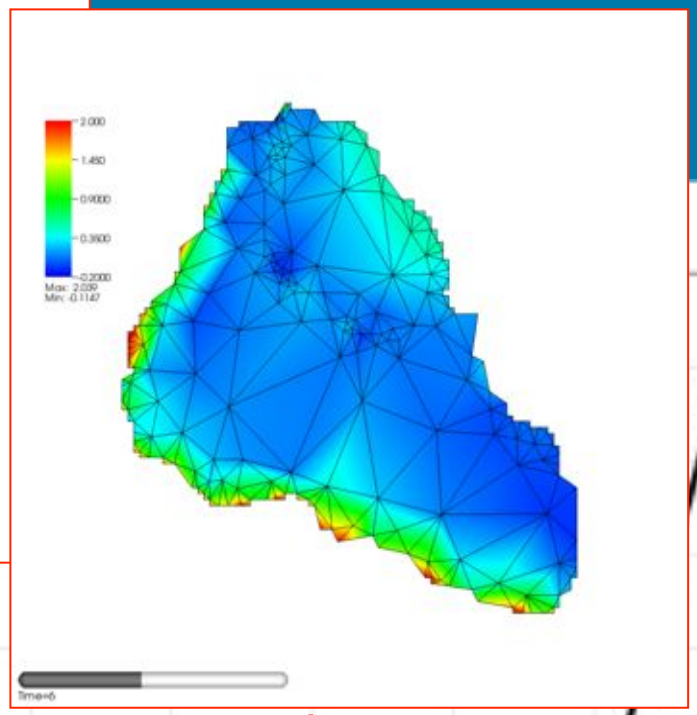


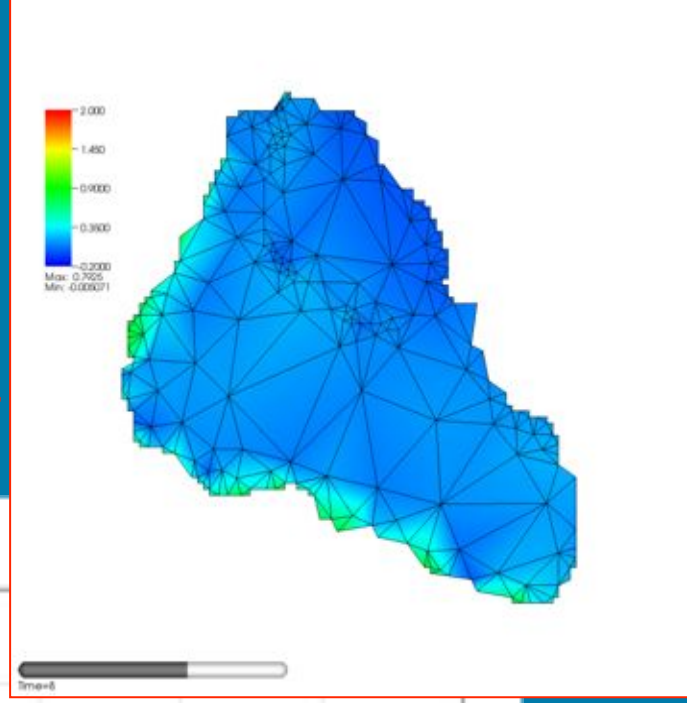




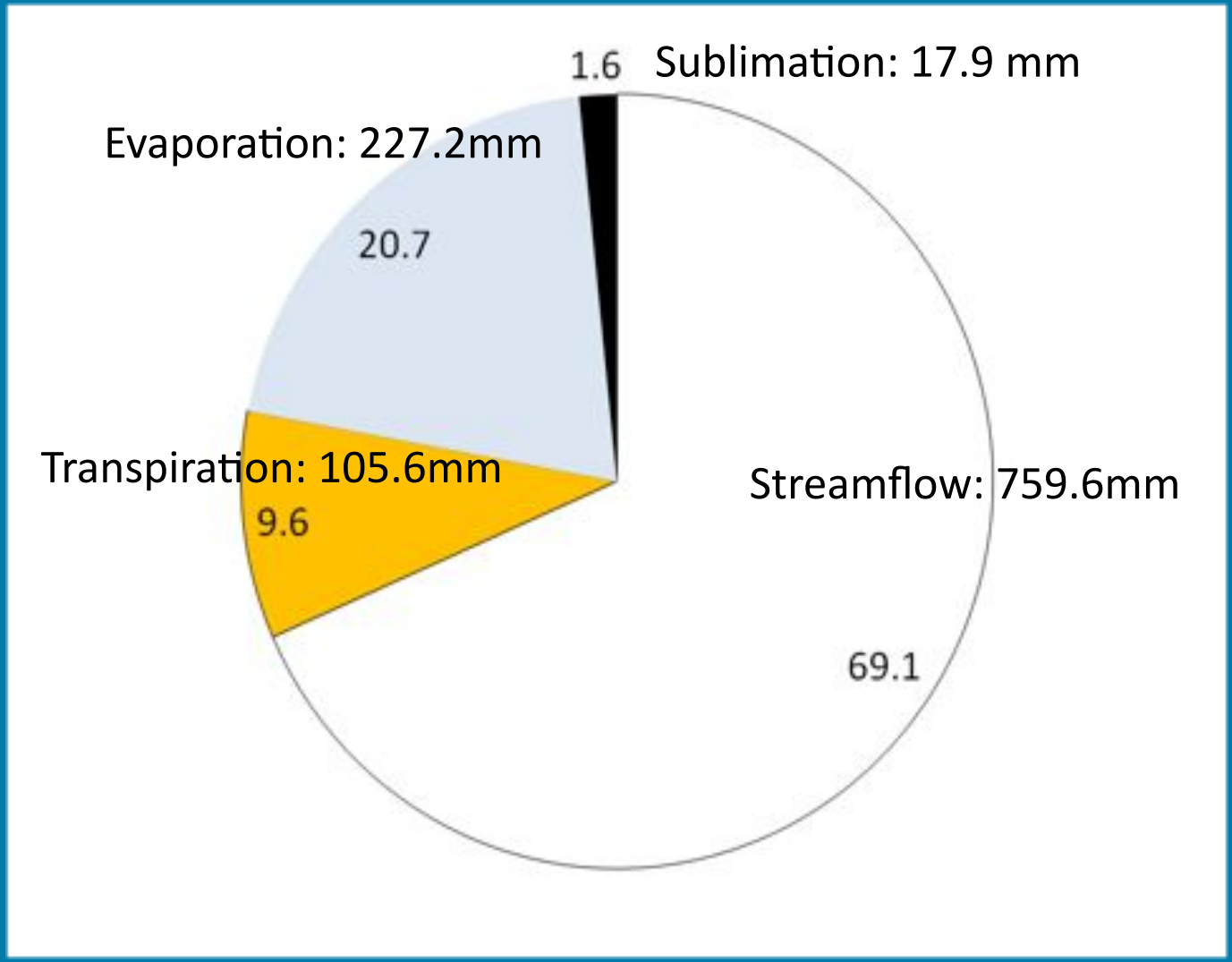
Sublimation







Water Balance: 2006 Water Year
1,148 mm precipitation



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- Not perfect, but a good start
- Just beginning to learn about below ground processes
- Need to sort out groundwater data & need multi-year simulations for storage
- Use the model to locate optimum measurement sites
- Need to work on numerical issues for fine-scale simulations

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