Challenges of representing and predicting multi-scale human – water cycle interactions in Terrestrial Systems

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Terrestrial Systems Model

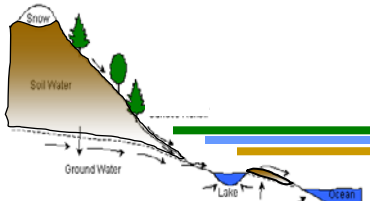
<u>White paper inspired in part by -</u>

- Famiglietti et al. 2011: "Establishing a Framework for Community Modeling in Hydrologic Science", Report from 3rd Workshop on CHyMP,
- Wood et al. 2011: "Hyperresolution global land surface modeling: Meeting a grand challenge for monitoring Earth's terrestrial water", WRR

But, focus here is slightly broader to also include water and its relationship to biogeochemical cycling as well as human influence on and vulnerabilities to changes in terrestrial water cycle

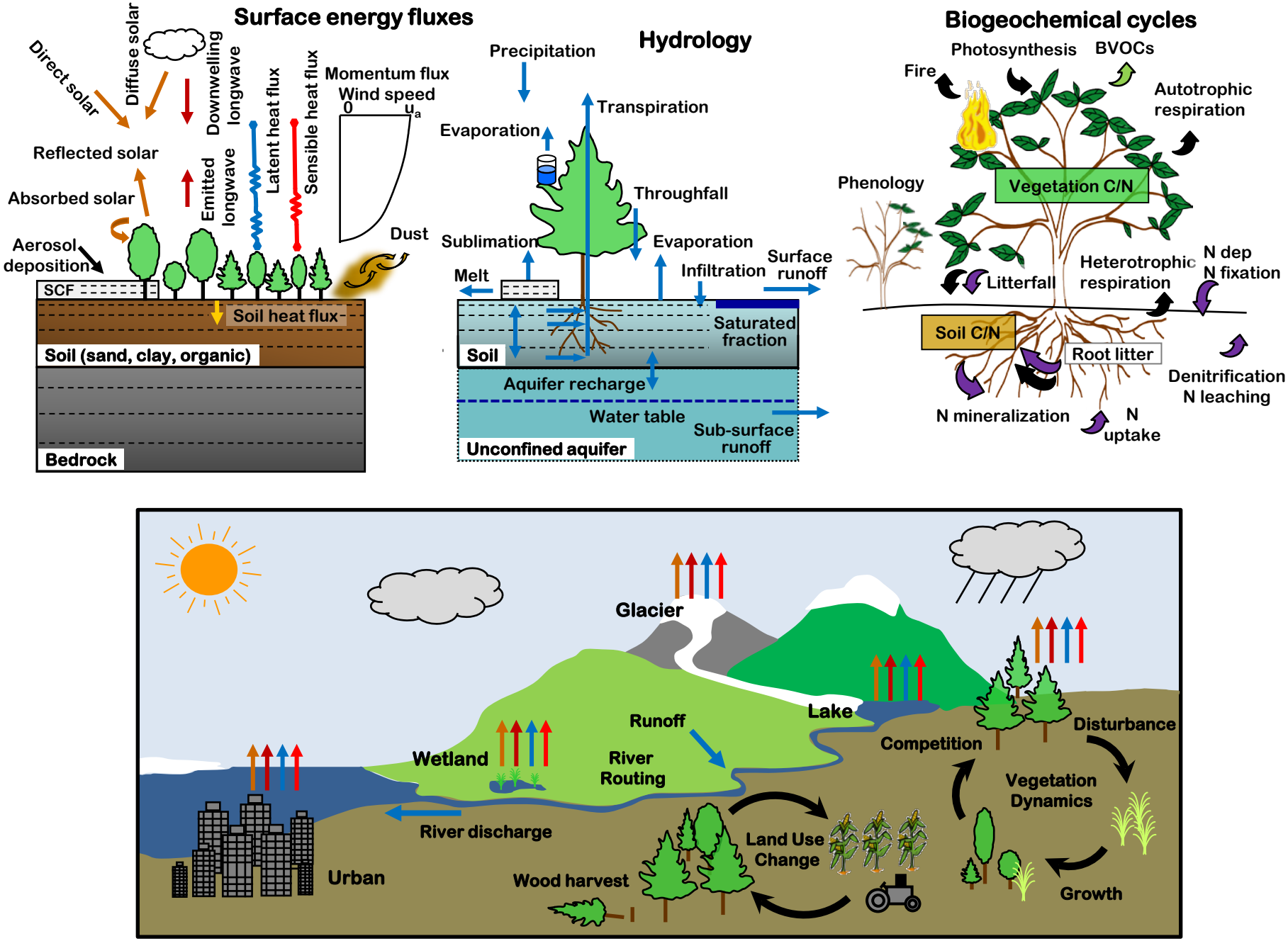
Goal is not just to improve land surface models, hydrology models, ecosystem, (or socioeconomic models) but to develop an integrated

Terrestrial Systems Model

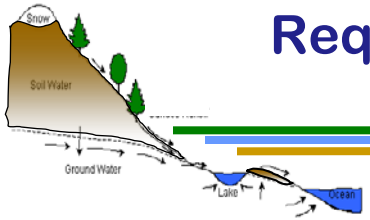


Scientific Challenges

- Emerging societal need for information about water at regional and global scales, especially with respect to understanding and predicting vulnerabilities in the water system under a changing climate
  - Requires accurate simulation of
    - terrestrial hydrology
    - land-atmosphere interactions
    - water-carbon-ecosystem interactions
    - hydrologic response to land cover change
    - human intervention in the water cycle
- Creation of a terrestrial systems model capable of simultaneously meeting all of these demands through synthesis and integration of existing knowledge manifest in hydrologic, land surface, ecosystem, and human dimensions models will require a sustained and cooperative community effort.



Lawrence et al. 2011



Required improvements and additions for comprehensive treatment of water in Terrestrial Systems Model

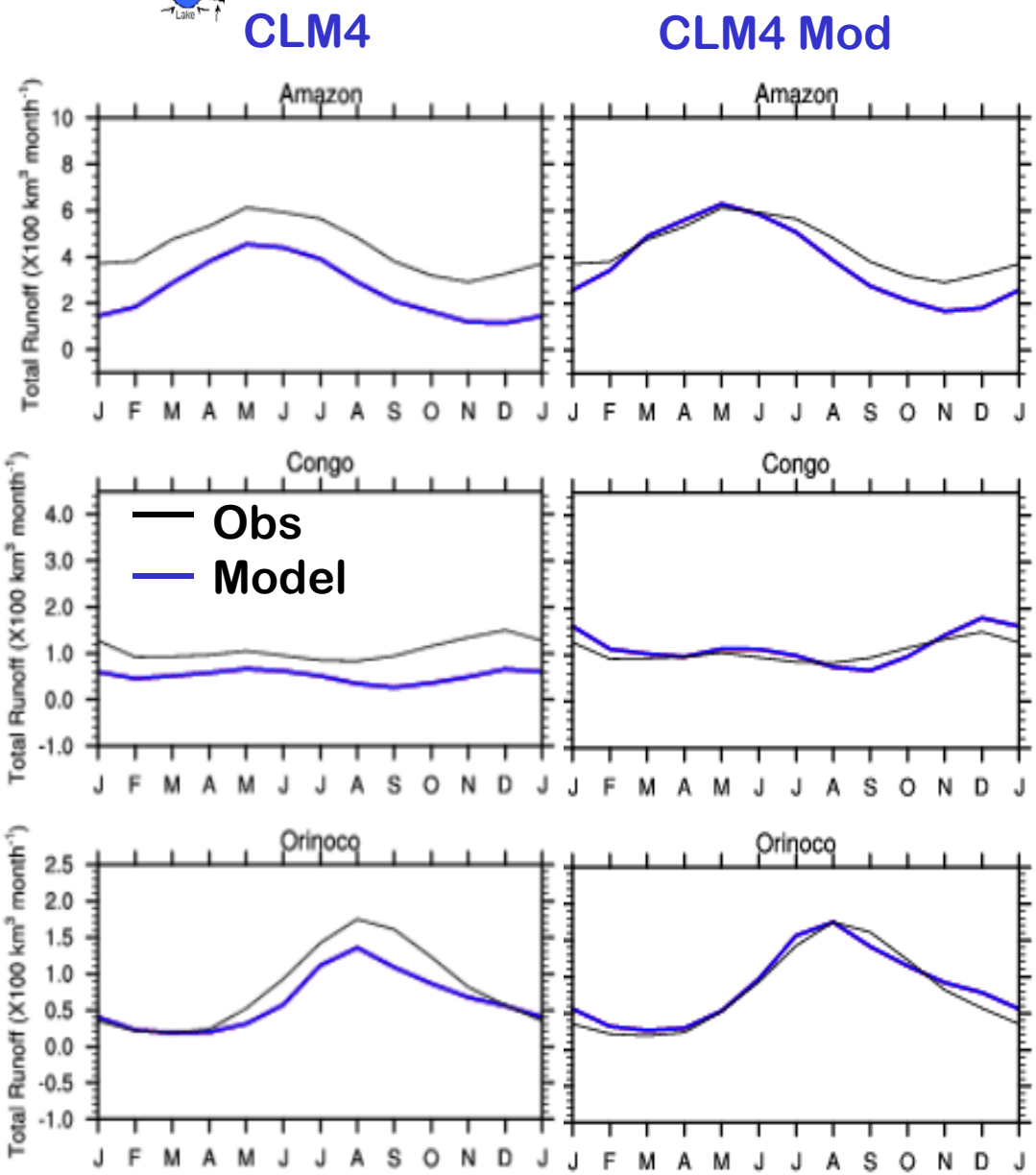
1. **Improve and augment existing parameterizations of currently modeled hydrological variables**
   - Biases in surface turbulent fluxes, soil moisture, river discharge, carbon and nutrient cycles
   - Disparity across models in strength of land-atmosphere coupling (GLASS)
   - Disparity across models of hydrologic response to land cover/use change (LUCID)

2. **Expand the representation of water to include human water management and use**

Improve existing parameterizations and structure of models to better simulate currently modeled hydrological variables

- Heterogeneity
  - What spatial resolution to get accurate soil moisture – ET relationship
  - Surface-subsurface interactions due to fine-scale topography and vegetation distribution
  - Soil vertical resolution?
- Hydrology
  - Extension to fully-integrated descriptions of terrestrial hydrology, groundwater and sub-surface lateral flow, scales of importance
  - Soil properties – datasets, parameterizations, depth
- Biological controls of ET (water-carbon interactions)
  - Within canopy and above canopy turbulence
  - Vertical canopy scaling of leaf properties
  - Dynamic roots and effect of water stress on vegetation productivity and ecosystems
  - CO_2 fertilization and interactions with nutrient dynamics

Vegetation controls on ET



Modifications to CLM4 vegetation model

- Radiative transfer
- Photosynthesis-stomatal conductance
- Canopy integration
- Updated $V_{c,max}$ from Kattge
- Multi-layer canopy (radiation, leaf N)

Bonan et al. (2011, 2012)

Improve existing parameterizations and structure of models to better simulate currently modeled hydrological variables

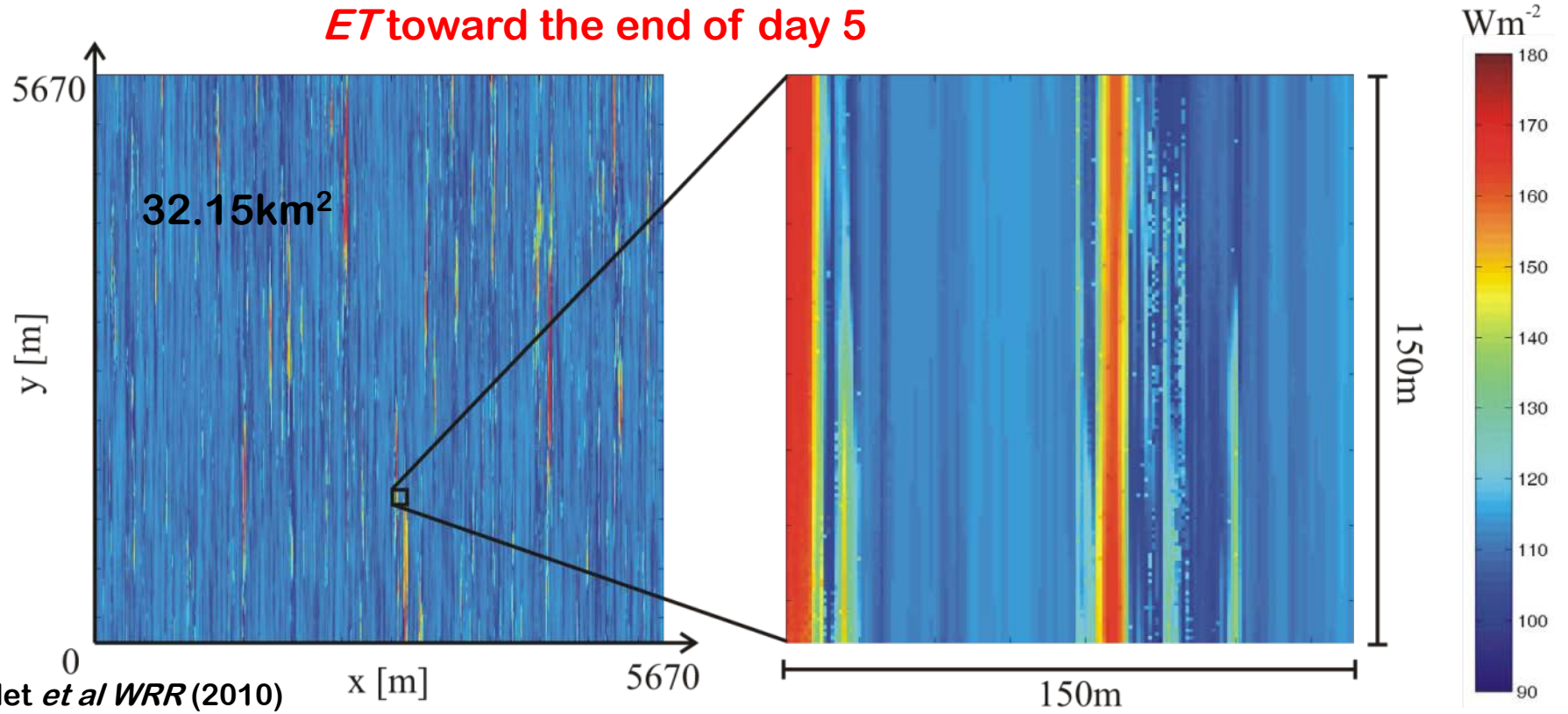
- Parameter estimation and uncertainty quantification (CSSEF)
- Pretty much everything else
  - Snow processes and snow heterogeneity
  - Streamflow models
  - …
- Scale dependence of land parameterizations?
- Resolution or sub-grid scale parameterization?

Resolution and scaling processes

Correlated Gaussian heterogeneity in K_{sat}
Grass cover
$\Delta x = \Delta y = 1m$, $\Delta z = 0.025m$

Total number of grid cells
7,962,624,000
Total number of processors
16,384

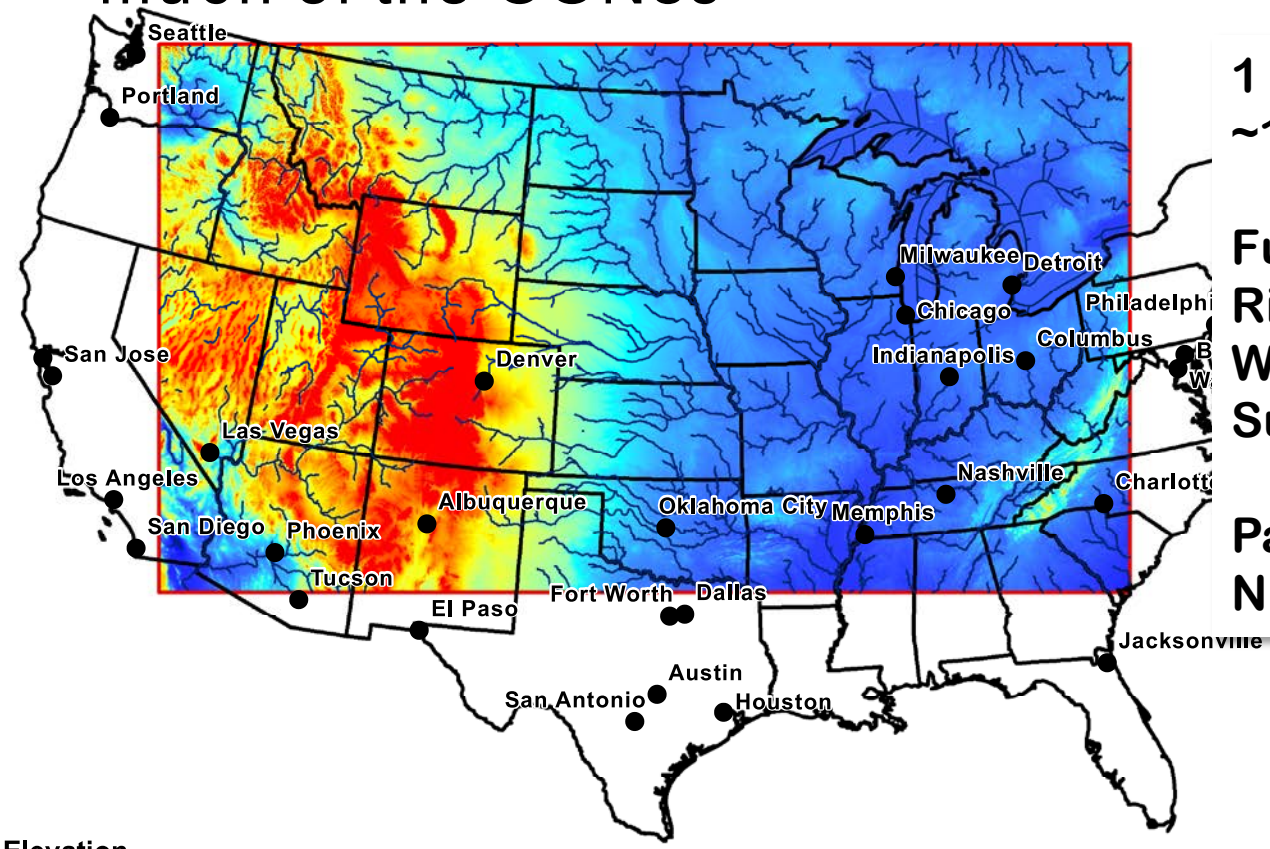
***ET* toward the end of day 5**



Kollet *et al WRR* (2010)

Resolution and scaling processes, toward global scale

A *proof-of-concept*, 6.3M km^2 domain covering much of the CONUS



1 km lateral resolution
~158M unknowns

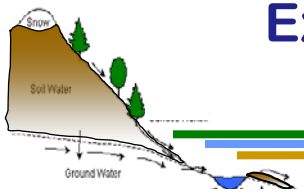
Fully integrated, 3D Richards' EQ, Shallow Water Equations, Land Surface Processes

ParFlow-CLM
NLDAS forcing

Elevation
Value
High : 4225
Low : -83

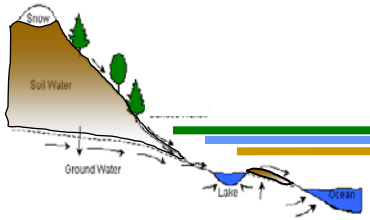
0 140 280 560 840 1,120 Miles

N



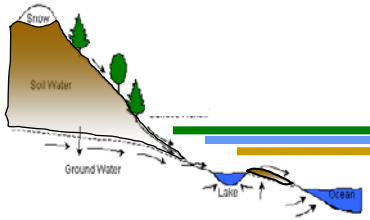
Expand the representation of water in Terrestrial Systems models to include human water management and use

- **Human alterations** (e.g., Pokhrel et al. 2012)
  - Water impoundment and reservoir operations
  - Urbanization (water demand/use and impact of impervious surfaces on local water cycle)
  - Irrigation (and crop modeling), aquifers/groundwater pumping
- **Human vulnerabilities**
  - Food production
  - Water quantity (water-related energy production and use, consumptive use)
  - Water quality (streamflow chemistry, temperature)
- **Requirements**
  - Dataset development (consumptive use, irrigation equipped areas and practices, reservoir locations and operation)
  - Integration with Integrated Assessment Modeling activities or other socioeconomic models



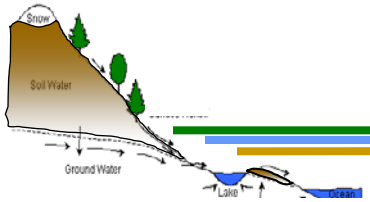
Additional Recommendations

- Maintain and expand “ease of use” for increasing range of users of models and model output
- Long term planning to address model output storage and analysis requirements, especially as resolutions increase, and data availability
- Training
- Develop extensible benchmarking and testbeds systems
- Expand collaborations and interactions across communities



Suggestions from organizing committee on key questions for Topic 3

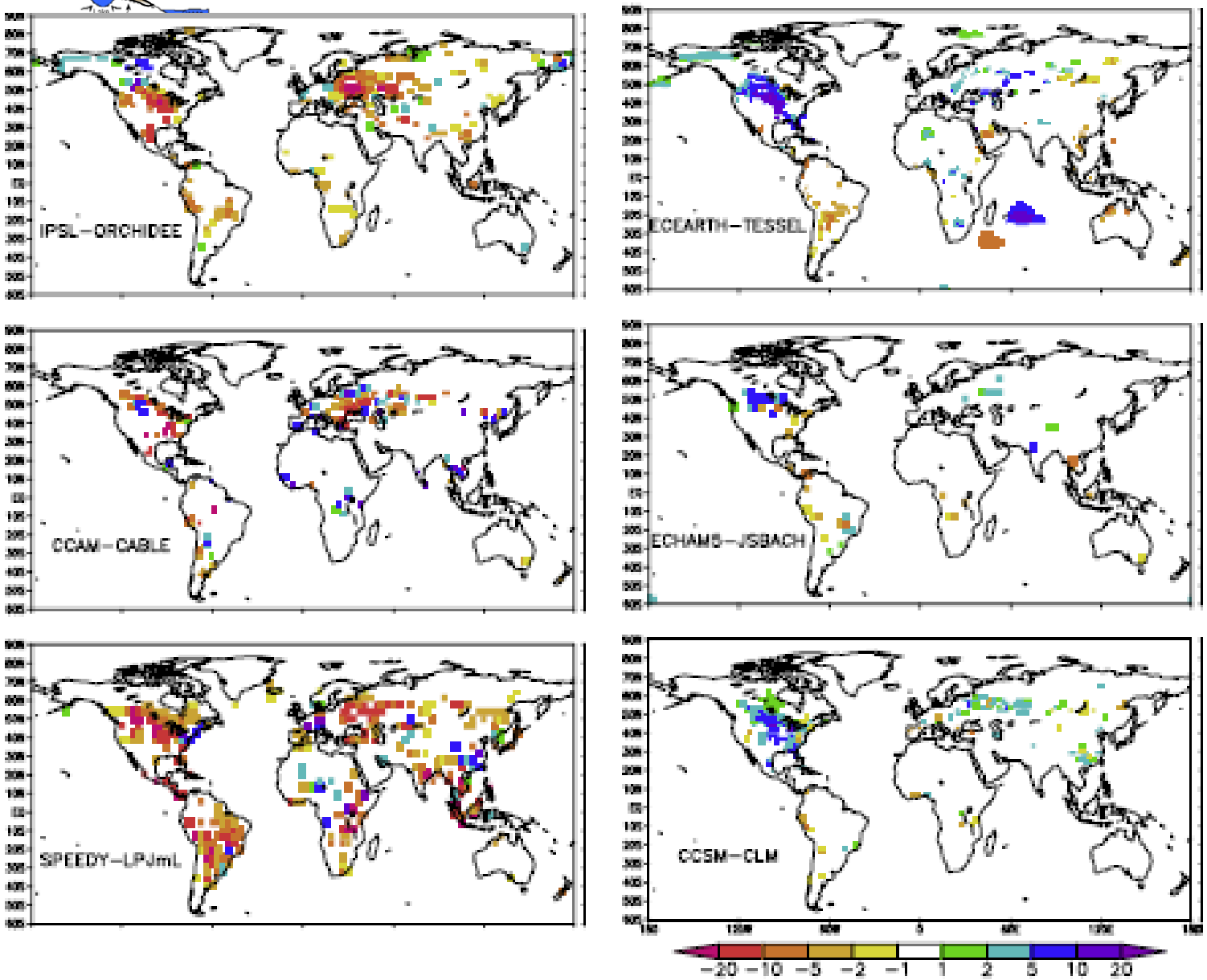
- Survey current approaches to land surface/hydrologic modeling and discuss their main differences.
- Can land surface/hydrologic modeling address the challenges discussed in (1) and (2)? If not, what are the priorities for future development?
- What are the challenges in using land surface/hydrologic models to understand and characterize the evolution of the terrestrial system in the past?
- How can modeling testbeds facilitate advances in land surface/hydrologic modeling? What are the science/technical requirements of the testbeds?

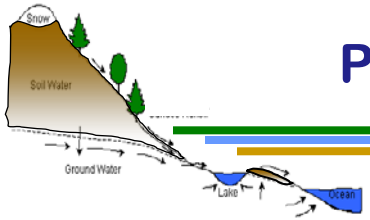


Model history (required? If so, needs work)

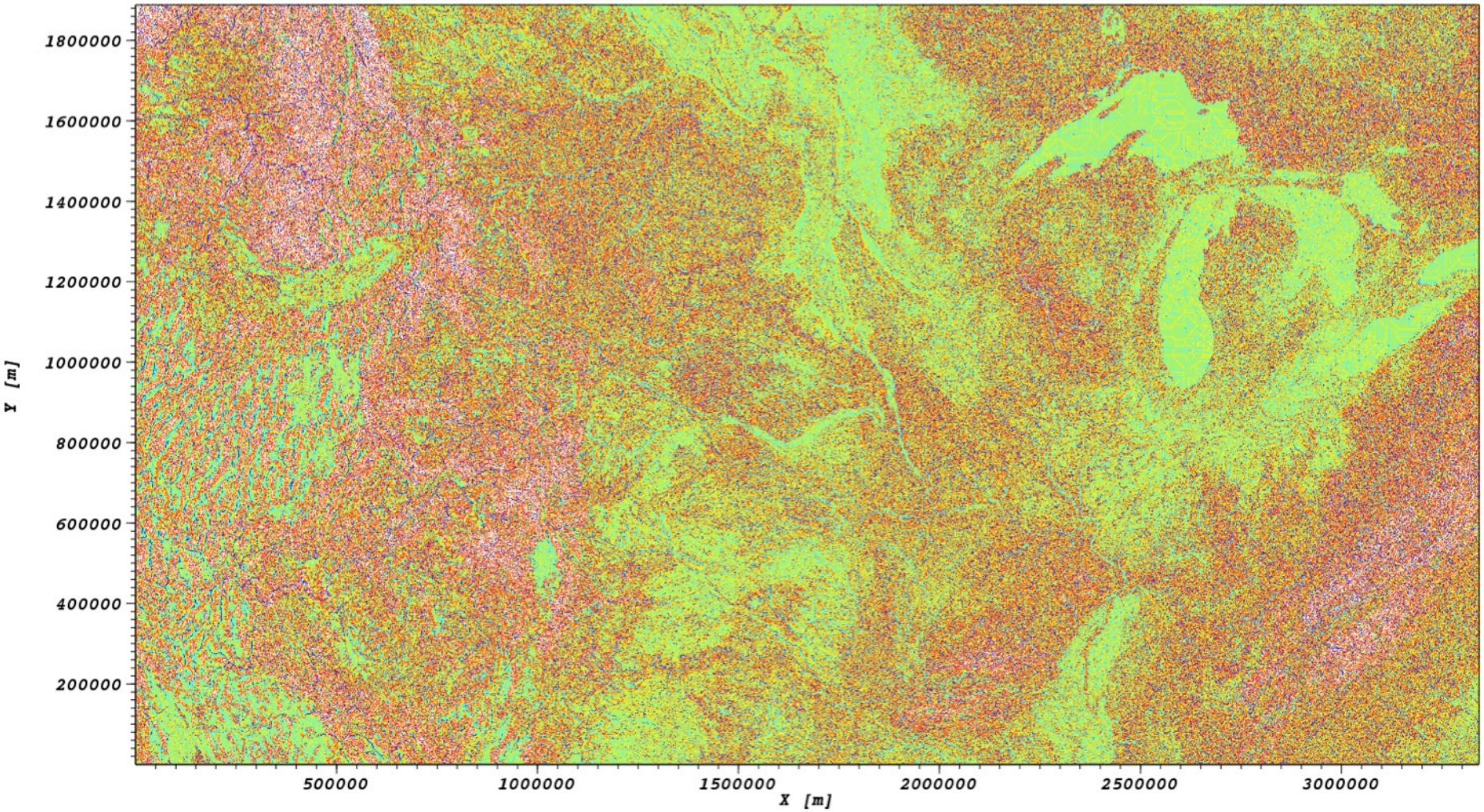
- biosphere has on the modulation of evapotranspiration, subsequent generations of land surface models incorporated dynamic vegetation controls
- land models have begun to integrate groundwater modules (Liang et al., 2003; Maxwell and Miller, 2005; Fan et al 2007) and efforts to extend these models to include fully-integrated descriptions of terrestrial hydrology
- On the whole, the current generation of land models are quite comprehensive (e.g., Lawrence et al. 2011), and as a result of decades of model development these models can perform many of the tasks of traditional stand-alone hydrologic models.

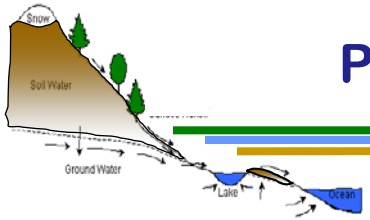
Impact of land cover change on Latent Heat Flux
LUCID (Pitman et al. 2009)





Preliminary Results Show Cross-Scale Behavior





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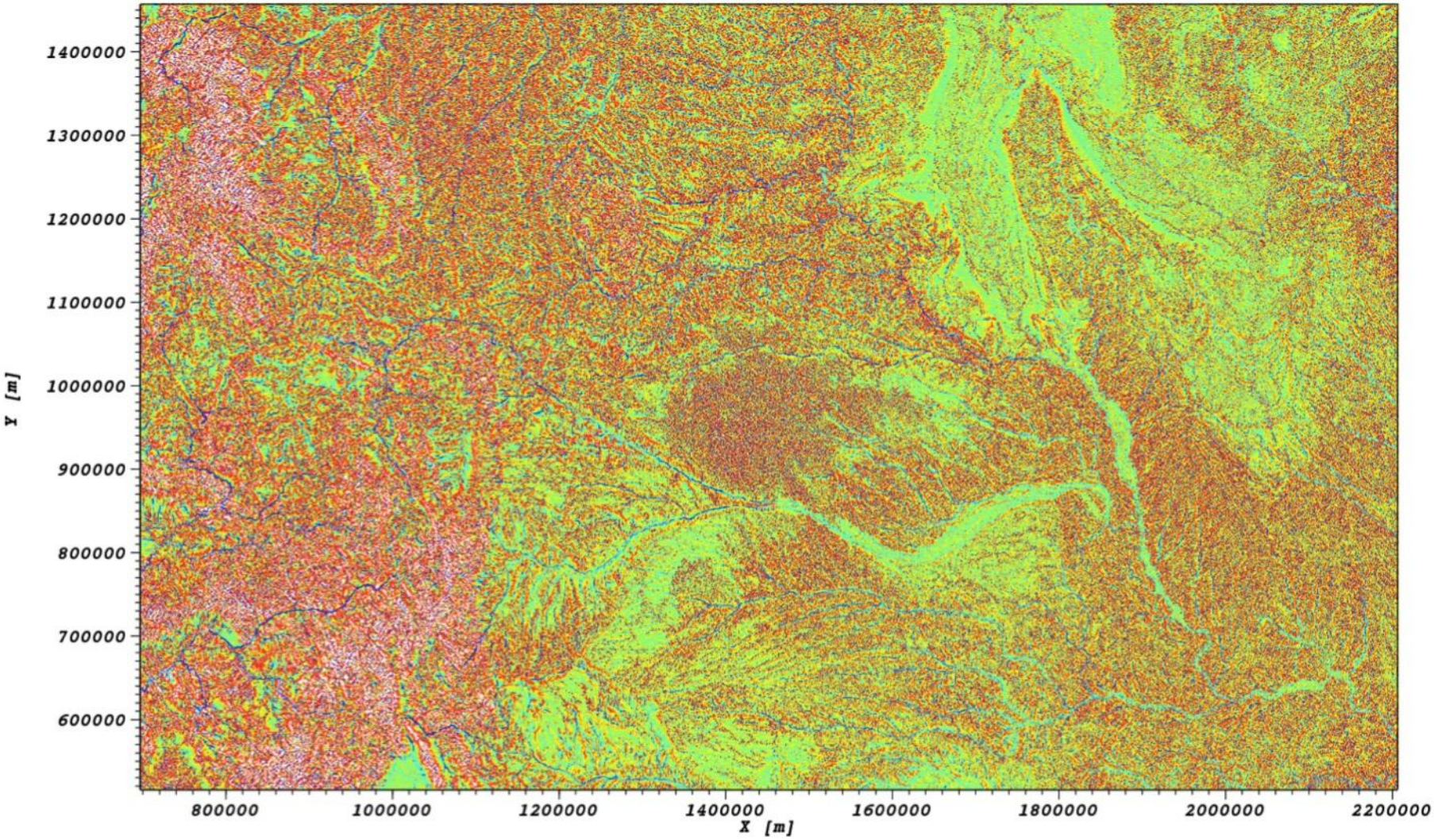

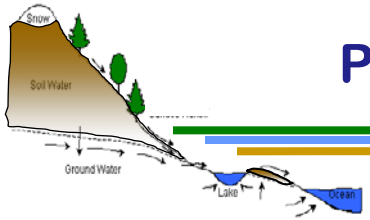

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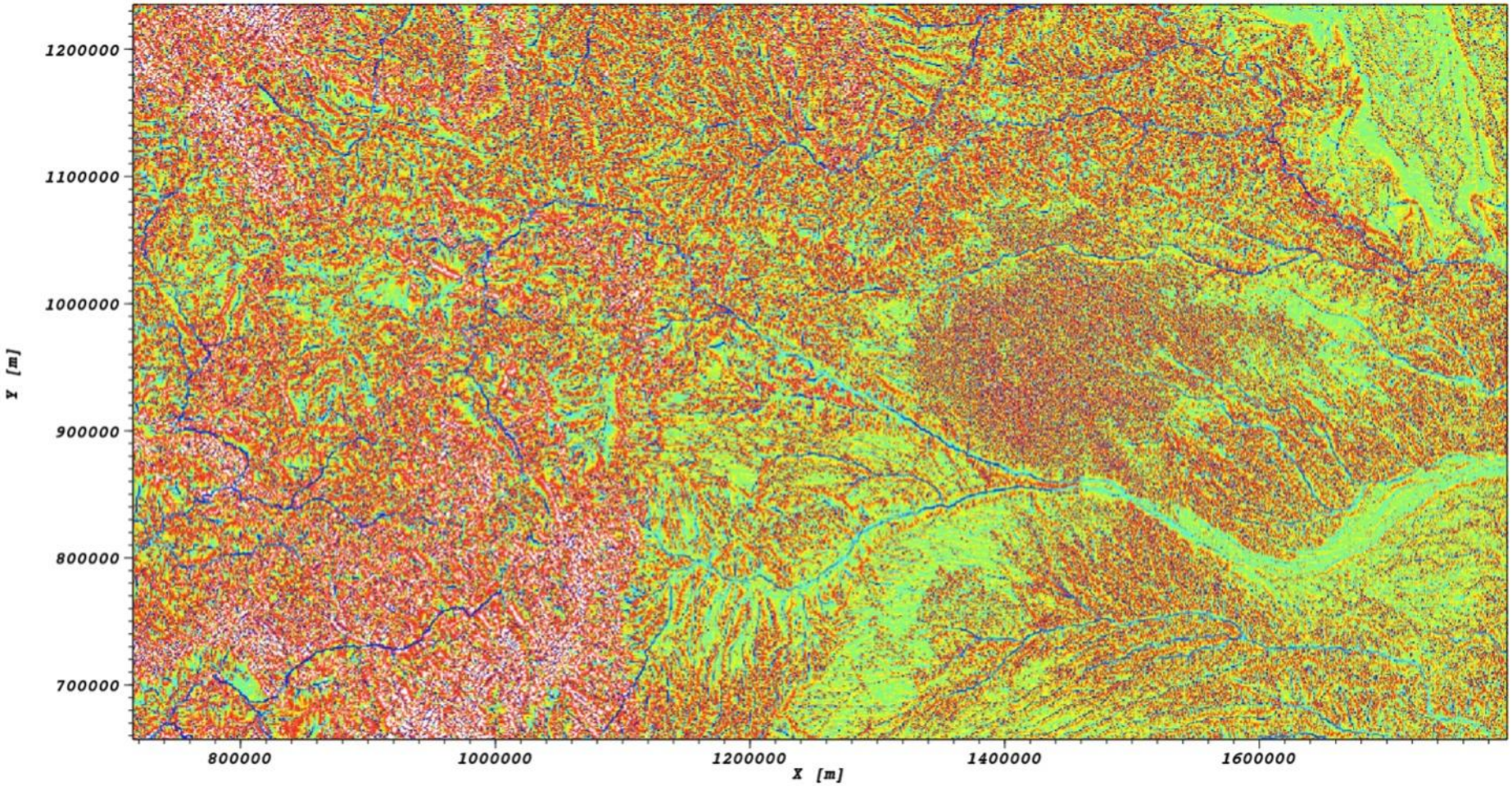

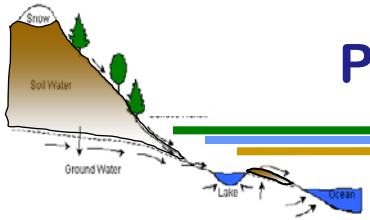

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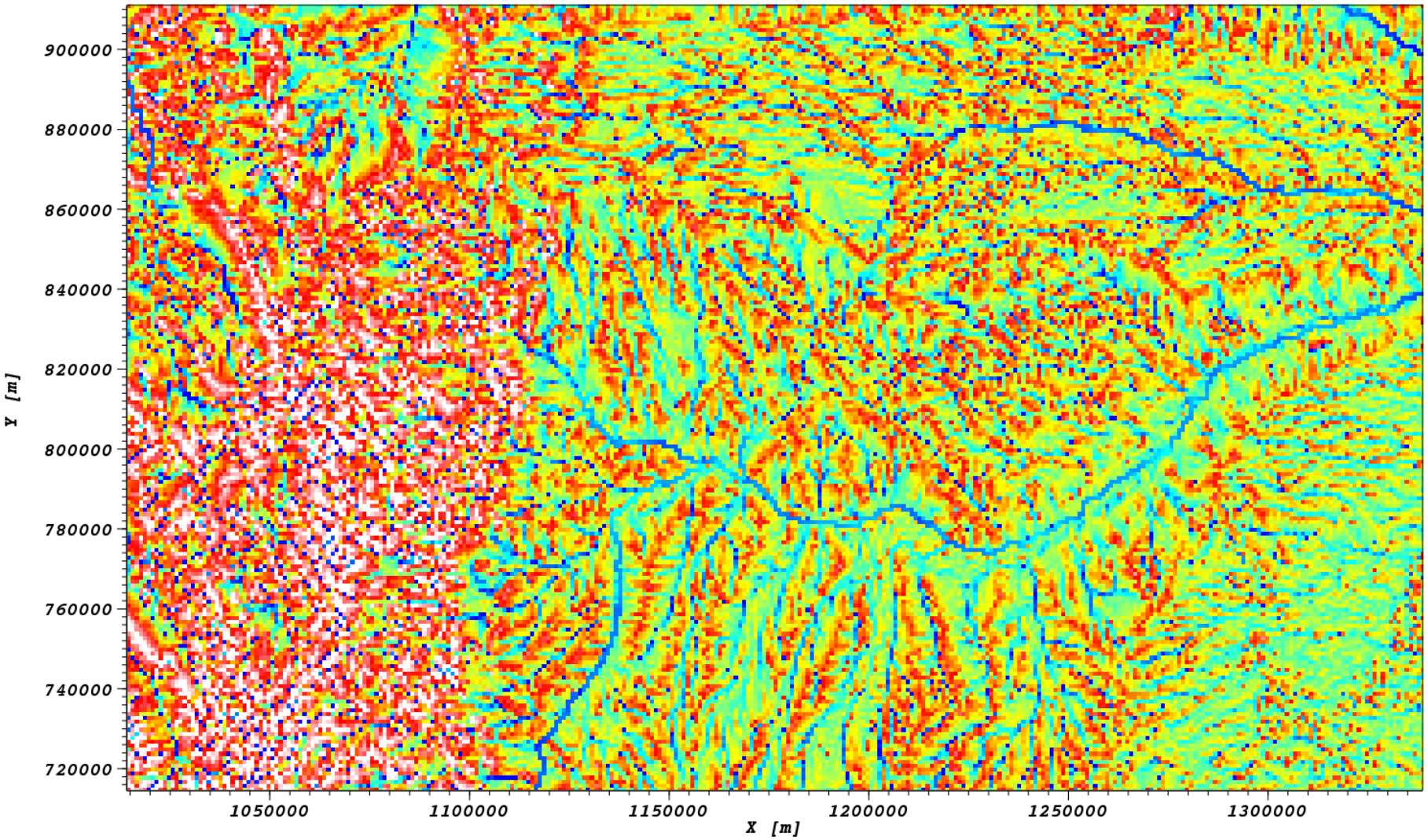
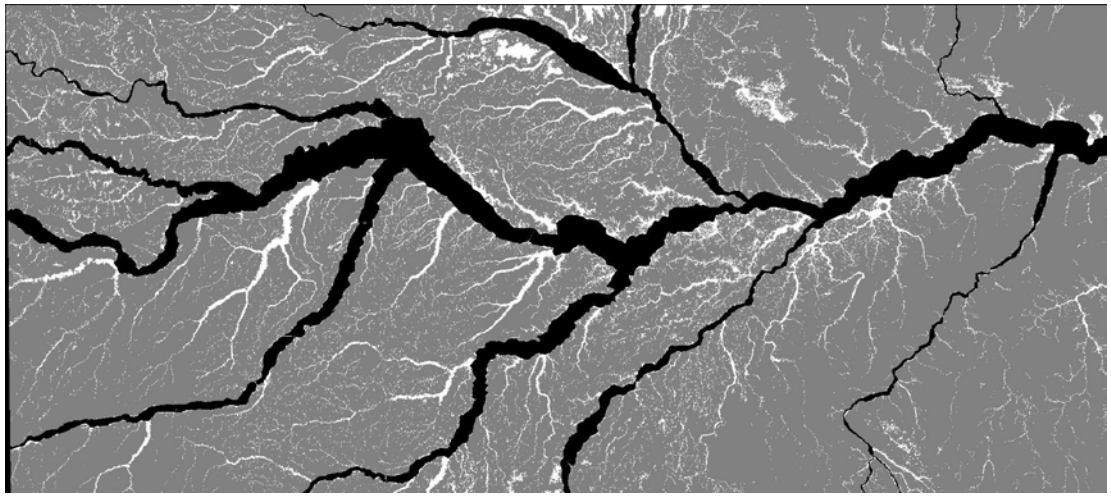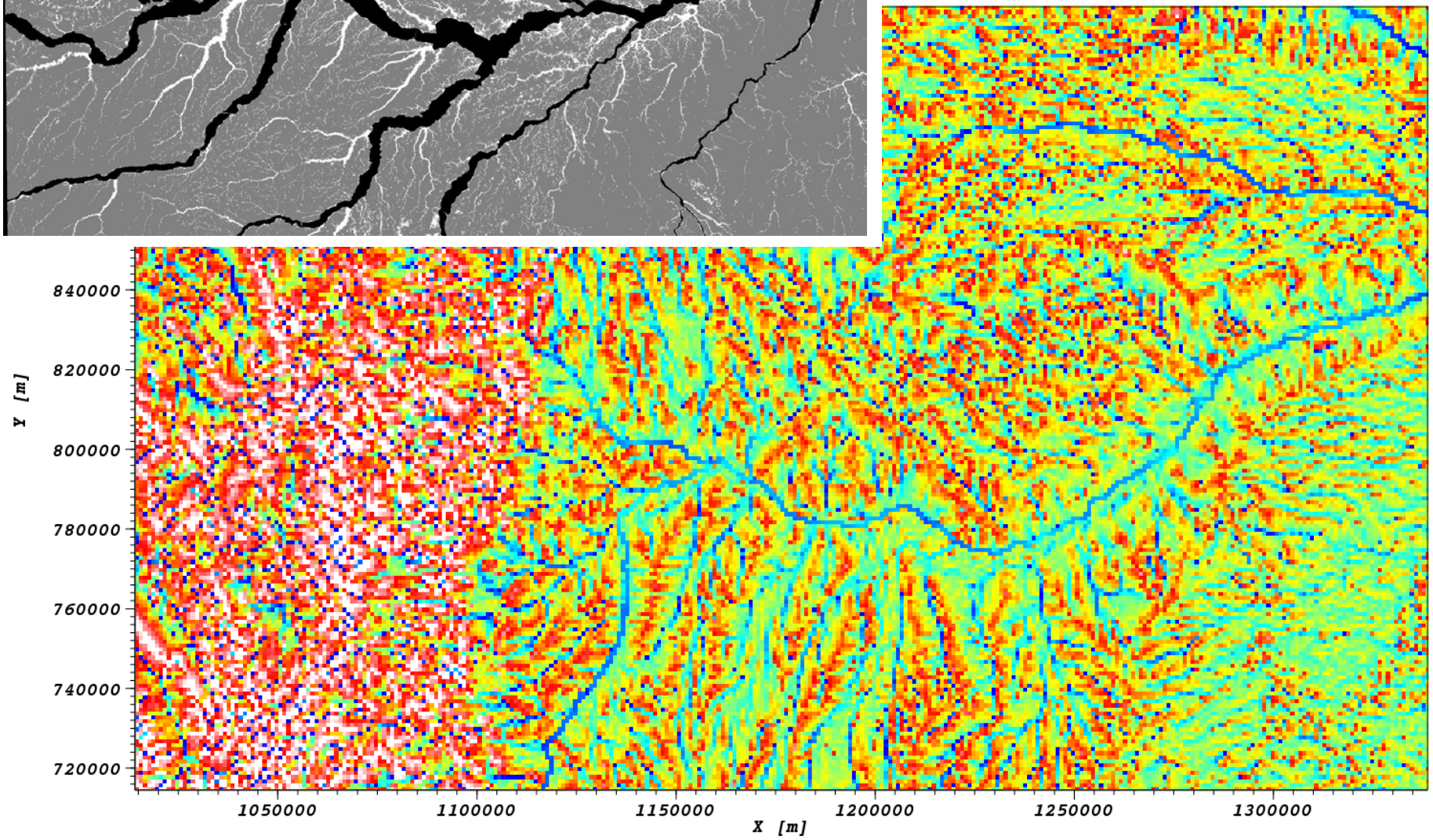
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