Building a Complex Surface to Simulate America's Dry West

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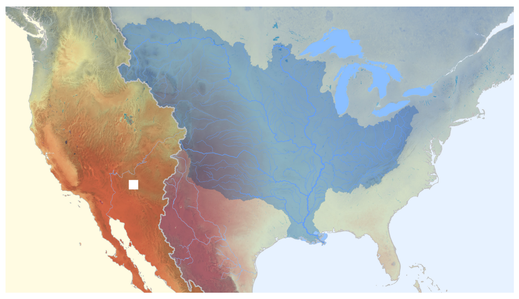


Direction Solar Radiation Contributing to Evaporation with Mississippi Basin Overlay with White Square to Show the Location of 10 km² Study Area (not to scale)

Rising high above the great plains, the Rocky Mountains split the United States into the dry west and wet east. To cross the continental divide from the east is to reach the end of the fertile rivers of the Mississippi basin. Replacing the plains and prairies are shrublands, dry lakes, and expansive pine forests, which burn.

Our analysis focused on 10 km2 west of downtown Flagstaff, Arizona. Data gathered from various national datasets was prepared in ESRI's ArcMap software (see workflow below). The final surface is computed using Dyer's Water Balance Toolbox (v. 2.2) and merges monthly precipitation, radiation, temperature,

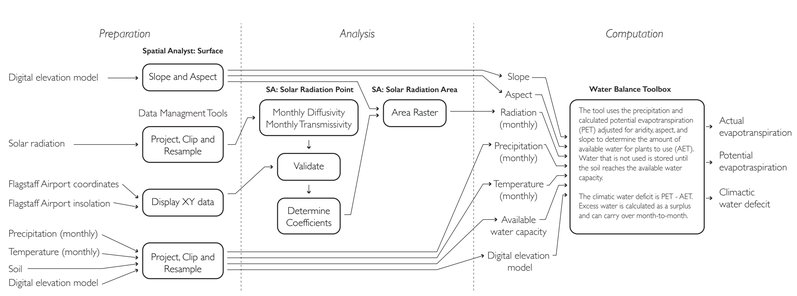
Stock-and-flow systems dynamics model of the interactions between soil, grass, forest and fire within the simiulation study area.

As populations continue to settle in these forests, how might we visualize the complex relationship between climate, habitat, and the primordial catalyst, fire? Might dynamic landscape visualization motivate biomass reduction efforts along different constituents?

This project uses climatic, topographic, and soil data to create a new, time dependent surface. This surface, a monthly climatic water deficit, is a visual representation of the relationship between solar radiation and water availability. It shows how plants sense their environment and how wildfire might thrive on it. On the Colorado Plateau, the growing season is short because of the episodic precipitation, high evaporation rates, and moderate temperatures. One bolt of dry lightning and the vegetation may ignite.

"The primary effects of climate on plants are determined by the interactions of energy and water"[3]

and soil water capacity over topographic features such as elevation, slope, and aspect. The spatial sensitivity is represented in the two- and three-dimensional surface grids to the right. Here, the spatial analysis capabilities of GIS algorithmically combine the variables into monthly surfaces from which rules regarding direct and indirect time-dependent effects may be simulated.



Simplified ArcMap workflow for preparing various geo-spatial datasets for integration into simulation surface.

Data Sources

LANDFIRE, 2008, Existing Vegetation Cover Layer, LANDFIRE 1.1.0, U.S. Department of the Interior, Geological Survey. Accessed Dec 2016 at http://landfire.cr.usgs.gov/viewer/.

National Solar Radiation Data Base, Typical Meteorological Year (TMY3) data, 723755 Flagstaff Pulliam Airport, http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3, accessed Dec 2016.

PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, accessed Dec 2016.

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at http://websoilsurvey.nrcs.usda.gov, Accessed Dec 2016.

U.S. Geological Survey, 2013, USGS NED n36w112 1/3 arc-second 2013 1 x 1 degree ArcGrid: U.S. Geological Survey.

References

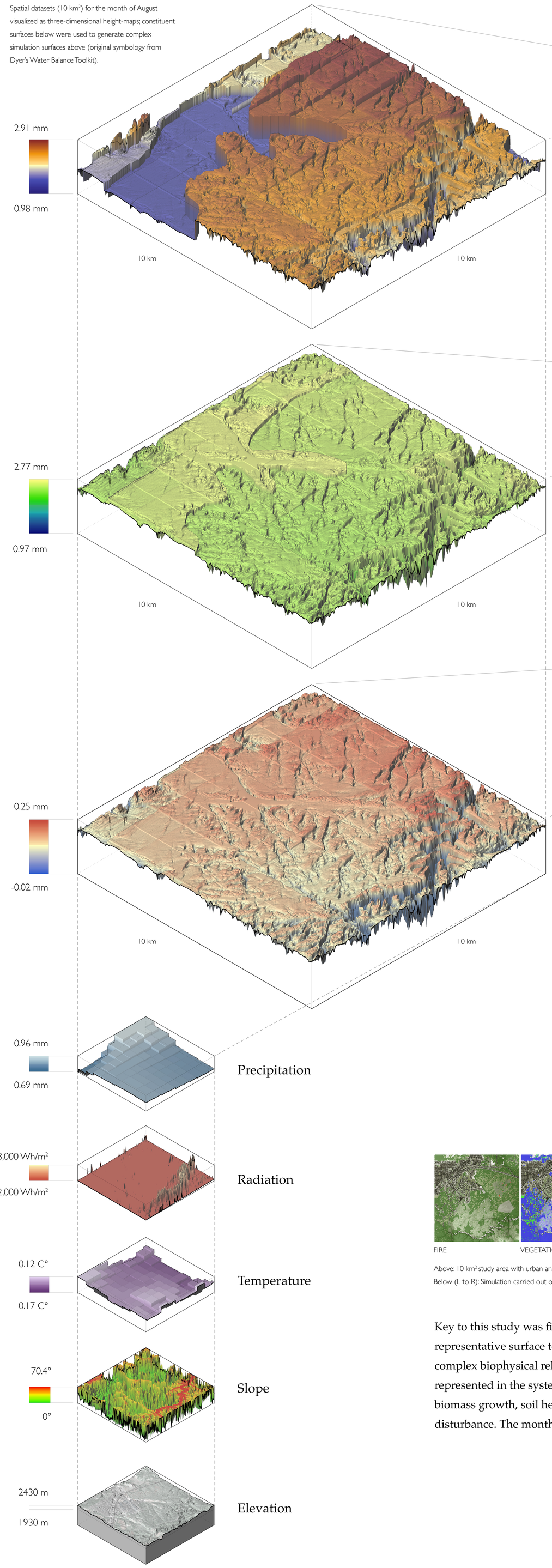
1. Achtemeier, Gary L. "Field validation of a free-agent cellular automata model of fire spread with fire–atmosphere coupling" International Journal of Wildland Fire 2013, 22, 148–156.

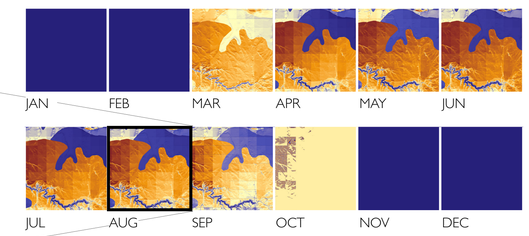
2. Perryman, Holly A . "A cellular automata model to link surface fires to firebrand lift-off and dispersal" International Journal of Wildland Fire 2013, 22, 428–439.

3. Stephenson, Nathan L. "Actual Evapotranspiration and Deficit: Biologically Meaningful Correlates of Vegetation Distribution Across Spatial Scales" (1998).

4. Water Balance Toolbox for ArcGIS and User Manual version 2 from Dyer, J.M. 2009. Assessing topographic patterns in moisture use and stress using a water balance approach, Landscape Ecology 24: 391–403.

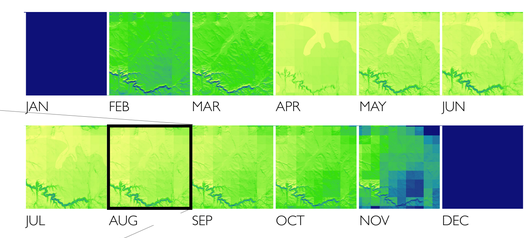
Spatial datasets (10 km²) for the month of August visualized as three-dimensional height-maps; constituent surfaces below were used to generate complex simulation surfaces above (original symbology from Dyer's Water Balance Toolkit).





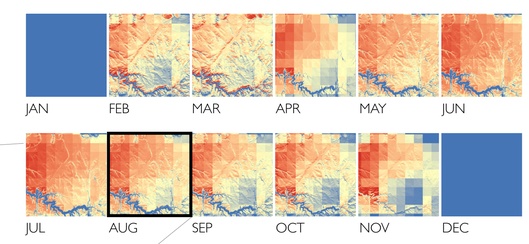
Climactic Water Deficit (PET - AET)

"Deficit refers to evaporative demand not met by available water, or the difference between potential and actual evapotranspiration."[4] The deficit can also contribute to patterns of vegetation distribution, decay rates, and post-fire recovery or succession.[3]



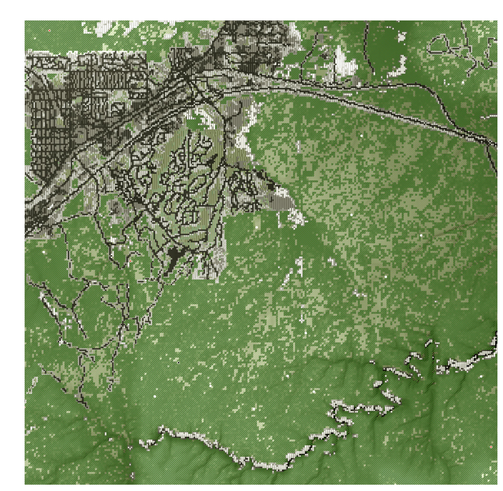
Actual Evapotranspiration (AET)

"Actual evapotranspiration refers to water loss from a vegetated surface given water availability, and is equal to available water or potential evapotranspiration, whichever is less."[4]

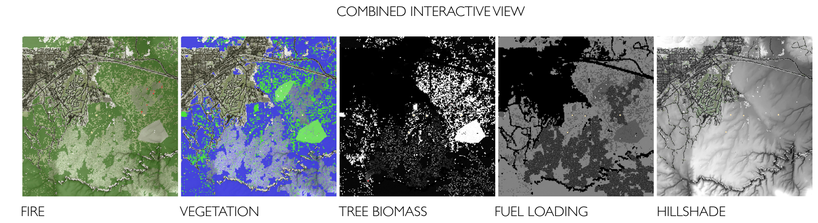


Potential Evapotranspiration (PET)

"Potential evapotranspiration is the evaporative water loss from a vegetated surface in which water is not a limiting factor; it depends mainly on heat and radiation."[4]



COMBINED INTERACTIVE VIEW



Above: 10 km² study area with urban and vegetation land cover, as visualized from within simulation

Below (L to R): Simulation carried out over complex surface, which informed behavior and disposition of various elements of the model.

Key to this study was finding a representative surface to explore the complex biophysical relationships represented in the system dynamics of biomass growth, soil health, and fire disturbance. The monthly deficit surfaces are then exported as grids and used as the computational layer for a Processing (Java) simulation. Existing land cover was overlaid and land management interventions were visually modeled in real-time.

Acknowledgments

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