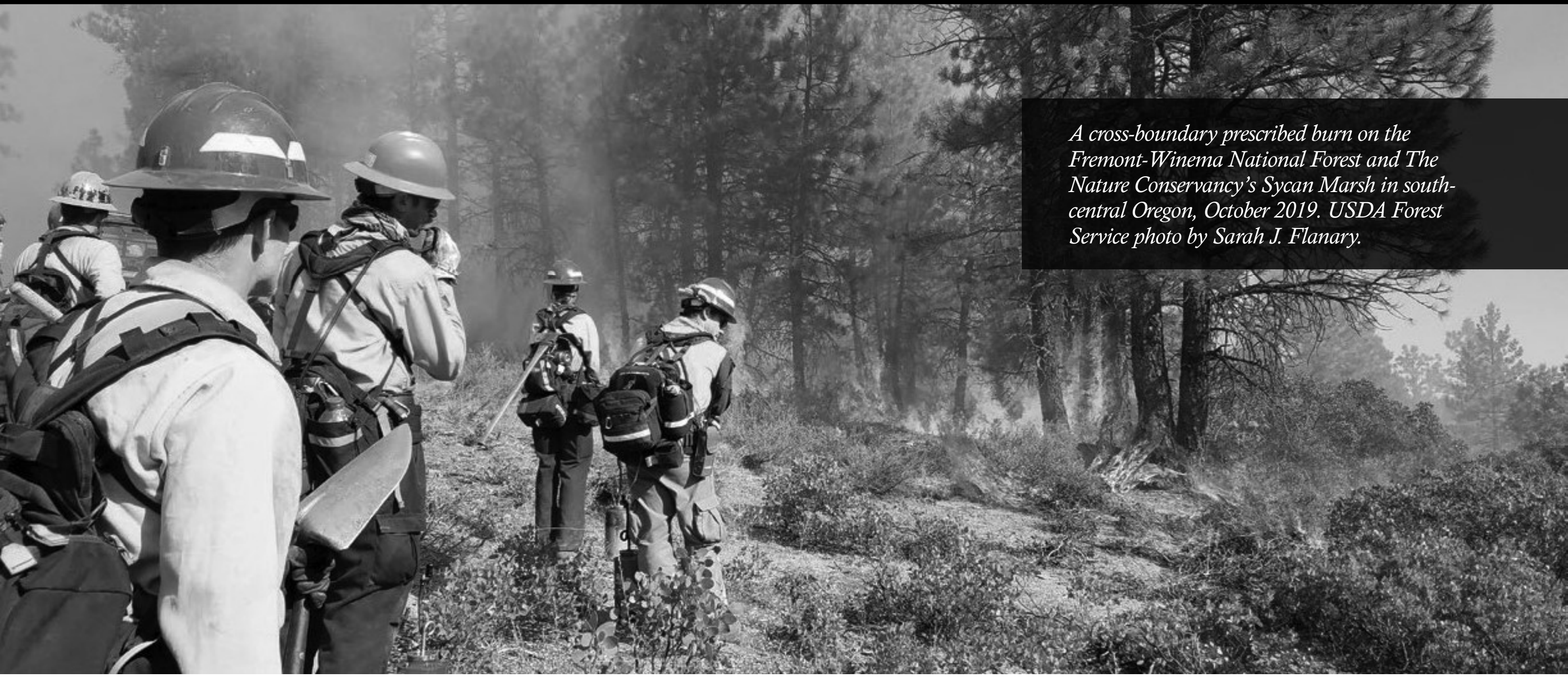

A cross-boundary prescribed burn on the Fremont-Winema National Forest and The Nature Conservancy's Sycan Marsh in south-central Oregon, October 2019. USDA Forest Service photo by Sarah J. Flanary.

Going 3D With Fuel and Fire Modeling: FastFuels and QUIC-Fire

Russ Parsons, Lucas Wells, Anthony Marcozzi, Rod Linn, Kevin Hiers, Francois Pimont, Karin Riley, Ilkay Altintas, and Sarah Flanary

Climate change, drought, insect outbreaks, and deteriorating ecosystem health have put the Nation's forests and wildlands on an increasingly unstable trajectory. Such developments are raising the stakes in—and adding uncertainty to—decision making in wildland fire and fuels management (IPCC 2022).

NEED FOR NEW MODELING

Fuel is the part of the fire behavior triangle that we can directly affect. So, we know that we need to get more proactive with fuels treatments and prescribed fire if we want to get a better handle on the fire situation. As we shift towards more prescribed fire and fuels treatments, information for fuel and fire managers also needs to shift.

One clear difference is that the time scale for asking questions becomes less immediate, allowing more time for identifying and quantifying differences between alternatives. In this context, we need more detailed information about fuels. In many cases, the options for how we treat (or burn) depend a lot on the fuels we have. Given a particular stand structure, composition, and condition, what could be done? How will a treatment alter fuel loads now and in the future? How will such changes alter fire behavior? Under what conditions? The greater detail needed to answer these questions adds complexity but also offers more tangible pathways to solutions.

With respect to prescribed fire, how we lay out the ignition over time and space has a profound impact on both the fire behavior and fire effects as well as how much smoke is produced and where it goes. Numerous factors affect fire intensity and plume dynamics in prescribed burns, so modeling should ideally help untangle complexity and expose risk-based tradeoffs in treating fuels and planning prescribed fires.

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At present, however, operational decision support systems in the United States are built on well-known but simple fire models primarily oriented towards suppression (Rothermel 1972). Though fast, the models do not account for a fire's physical processes and plume dynamics, and they operate at coarser detail with respect to fuels and fire behavior than is needed for prescribed fire and fuels treatment analysis (Hoffman and others; Parsons and others 2018).

Advanced-research, "full-physics," coupled-fire-atmospheric fire models (such as FIRETEC (Linn and others 2002) and the Wildland Urban Interface Fire Dynamics Simulator (WFDS) (Mell and others 2007, 2009)) address fire physical processes, fuel/fire interactions, and plume dynamics in sophisticated mechanistic detail, but their high computational demands make operational use difficult (Mell and Linn 2017). Recent developments of "reduced fire physics" models such as QUIC-Fire (Linn and others 2020) and the level-set formulation of WFDS (Bova and others 2016) enable faster-than-real-time calculations but still capture key aspects of plume dynamics, fire behavior, and smoke transport over much larger and more operationally relevant extents (Gallagher and others 2021). Although such models offer remarkable new possibilities, their application and use have so far been greatly limited by a lack of three-dimensional (3D) input data.

For several years, our research team has worked to close the gap between data and models. We started at the scale of individual trees and groups of trees (Caraglio and others 2007; Parsons and others 2011), then moved on to stand scales (Pimont and others 2016; Parsons and others 2018). The data needs of 3D fire models are substantial, and sophisticated methods are needed to translate trees into "voxels"—volumes that contain data, like pixels in an image. This translation process can work with a variety of formats; it typically uses modeling to extend data in different ways, either from a limited set of observations (such as a plot) to a larger modeled set (such as a stand) or to impute key attributes that were not directly measured (Pimont and others 2016; Parsons and others 2018).

In 2018, our team developed a stand-scale platform called STANDFIRE (Parsons and others 2018), designed to make it easier to use 3D fire models at stand scales. STANDFIRE is a 3D fuel and fire modeling system that expanded on key developments in FuelManager (Pimont and others 2016) by linking the Forest Vegetation Simulator (Crookston and Dixon 2005), an empirical forest growth model, to both WFDS and FIRETEC. This linkage between forest fuel and fire models enables 3D fuel modeling and stand-level fire analysis for all major forest species in the United States using commonly available forest inventory data.

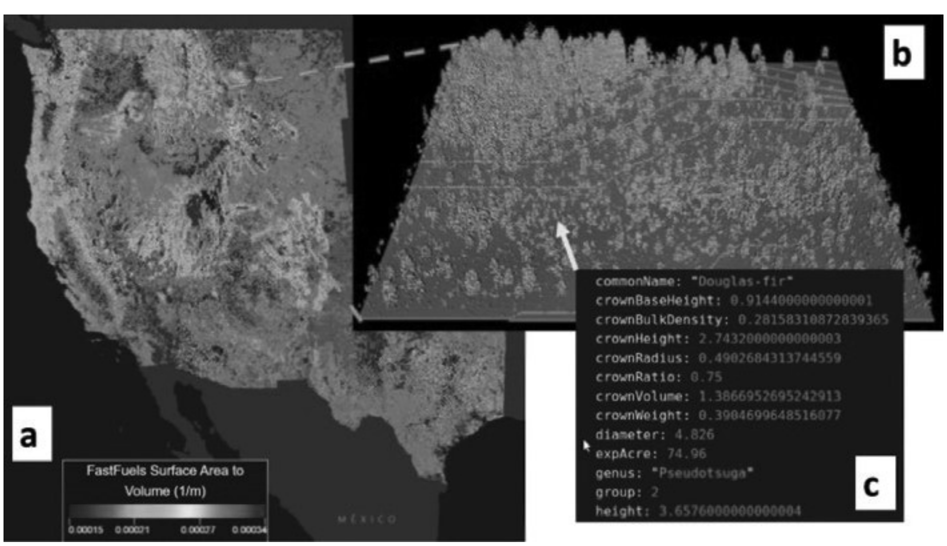

Figure 1—*FastFuels provides seamless fuels data for physics-based fire models as high-detail 3D arrays over vast areas, opening the door for operational use of advanced fire models to support fuels treatment and prescribed fire planning and implementation. Prototype data have been developed for the continental United States (a) and can be viewed interactively as 3D voxels (b). Voxel data are driven by underlying tree-list-level data (c).*

However, forest inventory data is by nature drawn from plots, so it is not "wall to wall" (continuous) over larger areas. The stand-scale focus in STANDFIRE was useful for fuels treatment analysis, but the lack of "wall-to-wall" data over larger areas limited the use of advanced fire models. To build capacity to use these models to their full potential, we needed to close this gap.

CLOSING THE GAP

To provide data for use with advanced fire models over large areas, our team is currently developing a prototype fuel modeling platform called FastFuels, which substantially reduces the "data-to-models gap." FastFuels links STANDFIRE architecture to forest plot data from the Forest Service's Forest Inventory and Analysis (FIA) program, leveraging "wall-to-wall" TreeMap data built on statistical imputation and machine learning (Riley and others 2021) and other spatial data, essentially providing plot-level data details but at landscape scales.

Designed to work via high-performance computing or cloud servers with an automated "data-on-demand" model (focusing on a specific spatial area), FastFuels provides detailed 3D fuels inputs suitable for advanced fire models such as QUIC-Fire. Expanding our capabilities through partnership in a recent National Science Foundation project called the WiFIRE Commons, the team used our FastFuels architecture to build 3D voxelized fuels at 1 m3 resolution for the entire conterminous United States (fig. 1). The data can also be viewed interactively (*to use the interactive viewer, turn on the Forest Service FastFuels data in the menu in the upper right, navigate to a forested area, and click on the map*).

FastFuels is envisioned as a 3D fuels "superhighway," accelerating the use of 3D fire models by leveraging FIA databases and other available spatial data and then combining the data with cutting-edge modeling to enable the use of 3D fire models at landscape scales. In addition to providing voxelized (3D raster) data for 3D fire models, FastFuels retains individual tree attribute data, facilitating in-depth fuels treatment analysis and paving the way for stronger fire behavior/fire effects interactions. Similarly, FastFuels also seeks to facilitate use of data from new sources (such as lidar and unmanned aerial systems) and new techniques emerging in the fields of remote sensing and wildland fuels science. Along these lines, a series of specialized "on-ramps" are envisioned to enable rapid incorporation of detailed data for specific areas.

This team is currently working on on-ramps for both airborne lidar data (airborne laser scanning) and terrestrial lidar scanning data. The on-ramps concept enables us to update our baseline FastFuels data with more local and specific data. In this case, these on-ramps enable us to incorporate highly detailed fuels data over large areas (often tens of thousands of acres or larger) or extremely high detail for small areas (usually less than an acre), capturing both landscape and plot scales. These data on-ramps provide a means by which fuels maps can be more rapidly updated, and they also enable the use of existing lidar data to better effect in fuels and fire management.

FastFuels is currently configured to produce 3D fuels inputs for the fast-running 3D fire model QUIC-Fire (fig. 2). However, FastFuels is intended to support many modeling tools; it will be expanded to provide inputs for a larger set of fire models. An additional benefit of going 3D is that 3D fuels and fire behavior simulation outputs can be represented dynamically in videos or interactively with virtual reality. These capabilities will help in developing advanced firefighter training environments (fig. 3).

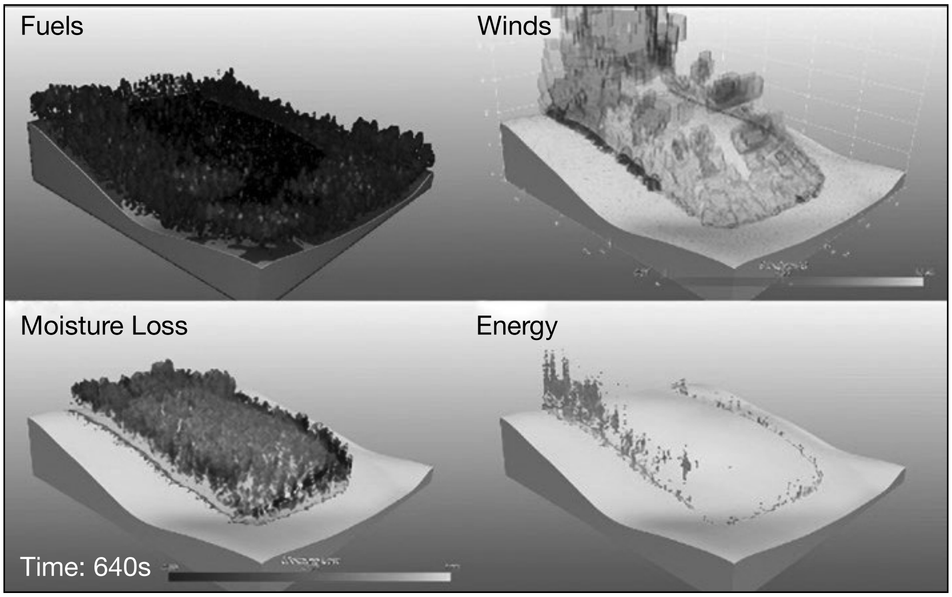

Figure 2—*Example of a 3D fire simulation with QUIC-Fire using FastFuels data. Panels show different aspects of the same simulation, including topography and fuel consumption (upper left), moisture loss (lower left), vertical energy to the atmosphere (lower right), and 3D plume and surface winds (upper right). Simulations are dynamic in space and time and can be viewed as videos. A link enables the user to view the FastFuels-QuicFire Demo video.*

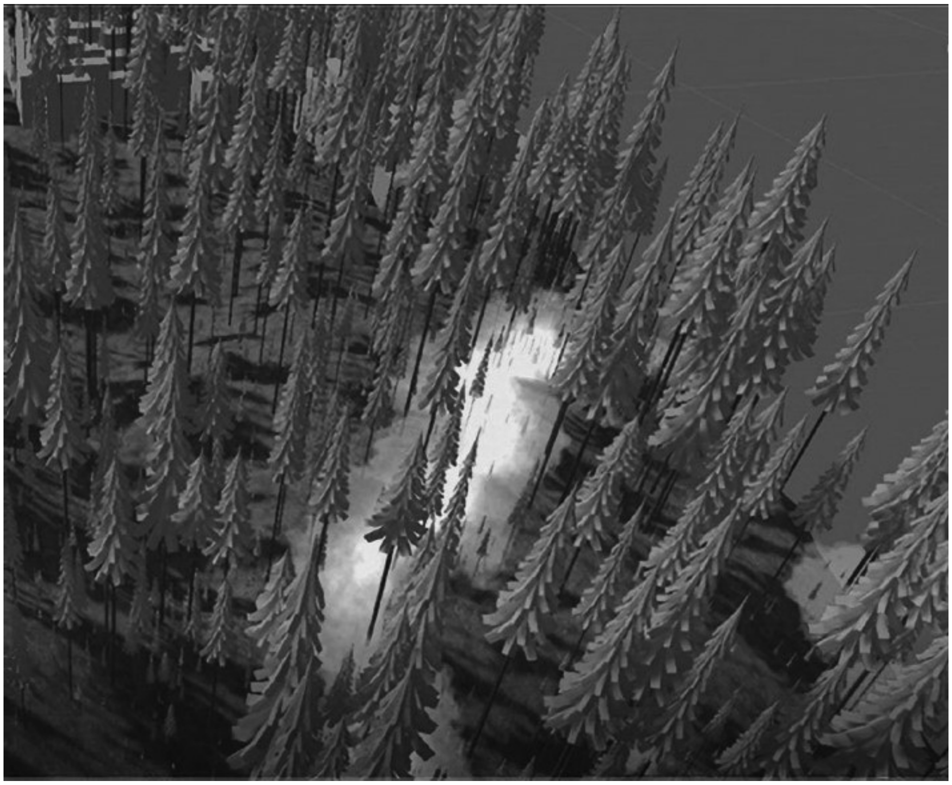

Figure 3—*3D immersive visualization in virtual reality, illustrating the connection between FastFuels data, dynamic 3D fire behavior, and virtual reality visualization using the Unity platform.*

NEXT STEPS

FastFuels is still in active development, and the development team is very excited about its potential. The team is currently creating tools to enable silvicultural detailed fuels treatments with FastFuels data, on-ramps to incorporate lidar data, and tools to enable detailed ignitions over space and time. We hope that these developments will accelerate innovation in—and the application of—advanced fire modeling.

FastFuels and QUIC-Fire are not intended to replace current systems but rather to complement and expand the existing toolbox for fuel and fire managers. The development team hopes to integrate these new tools into existing tool suites, such as IFTDSS (the Interagency Fuel Treatment Decision Support System). We also hope that having more interactive 3D visualizations of fuels and fire behavior will help improve firefighter training and communication with stakeholders making fuels management decisions.

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Erratum

Fire Management Today volume 80(1), in the article "COVID 'Shots: Hotshot Superintendents Reflect on the COVID Fire Year of 2020" by Emily Haire, showed an incorrect caption for the photo at right; the corrected caption follows.

Wyoming Interagency Hotshot Crew members cooking jerk chicken on the 2020 Lost Creek Fire in Oregon. The crew took to heart the challenge of becoming self-sufficient for meals through the use of a kitchen trailer, resulting in increased camaraderie and cohesion. USDA Forest Service photo by Kyle Miller.