Current and future coupled fire-atmosphere modeling at NCAR's Research Applications Laboratory

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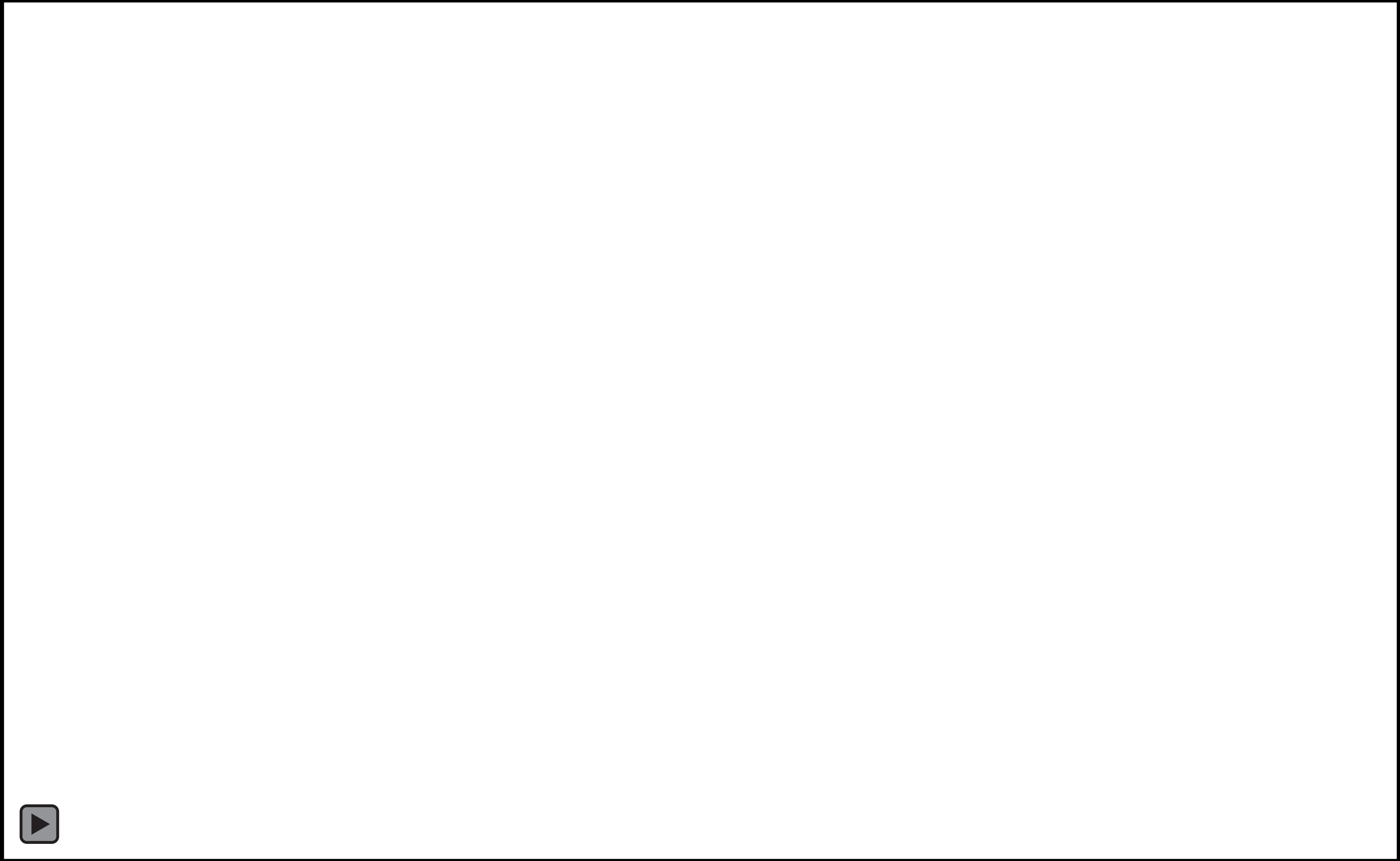
Motivation for coupled modeling

Weather affects fuel moisture, where fires start (sometimes), where and how fast fires move, and how intensely they burn

Fires heat and humidify the air, driving updrafts and turbulence, changing wind speed and direction, and creating smoke

Two-way

WRF-Fire simulation

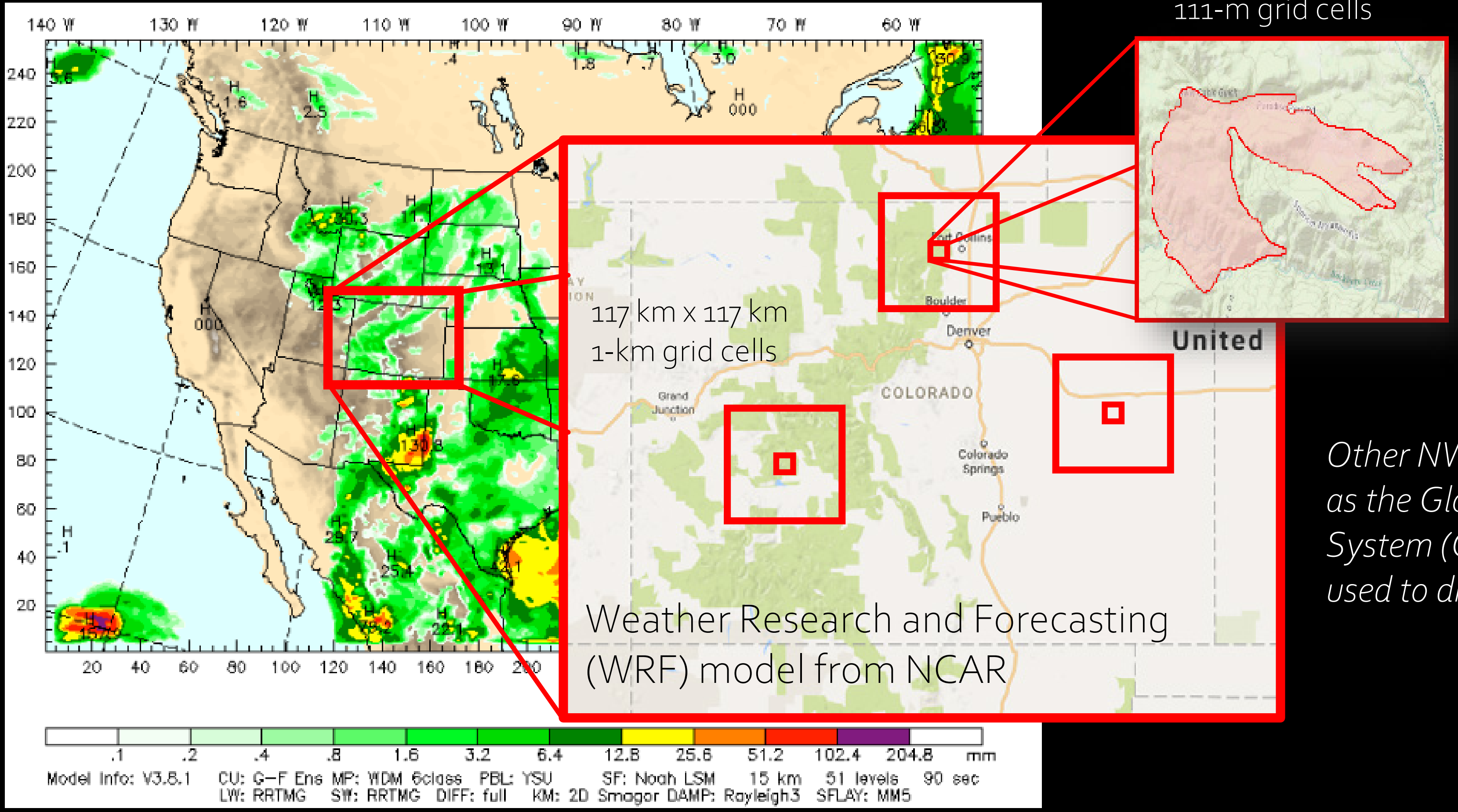


Modeling weather in WRF-Fire (CO-FPS framework)

High Resolution Rapid Refresh (HRRR) model from NOAA's National Centers for Environmental Prediction

13 km x 13 km
111-m grid cells

The Colorado Fire Prediction System (CO-FPS) was a 5-yr project sponsored by the state of Colorado



Other NWP models, such as the Global Forecasting System (GFS) can also be used to drive WRF-Fire

Modeling fires in WRF-Fire

Level-set method tracks & propagates fire perimeter

6- or 18-h forecasts
30-m grid cells

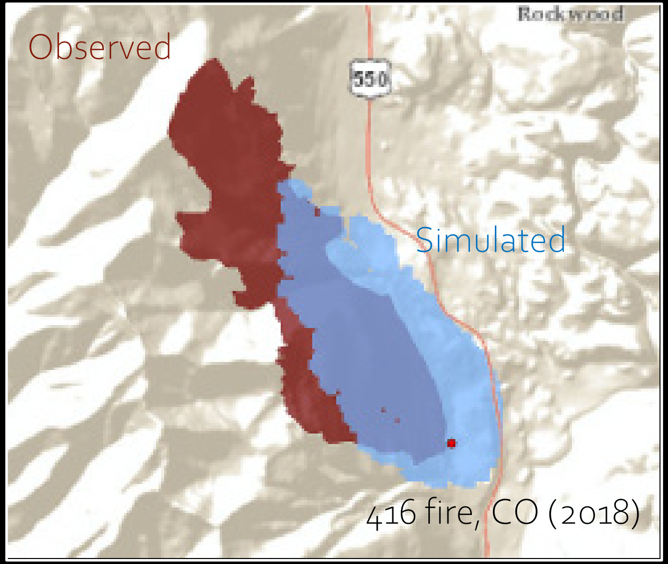
Rate of spread of flaming front is computed as function of fire-affected fuel and wind, and terrain slope using a semi-empirical method (Rothermel 1972)

Fuel burn rate is based on lab experiments (Albini et al. 1980s, 1990s)

Atmosphere is affected by fire through heat and water vapor fluxes released by burning fuel (smoke currently is passive)

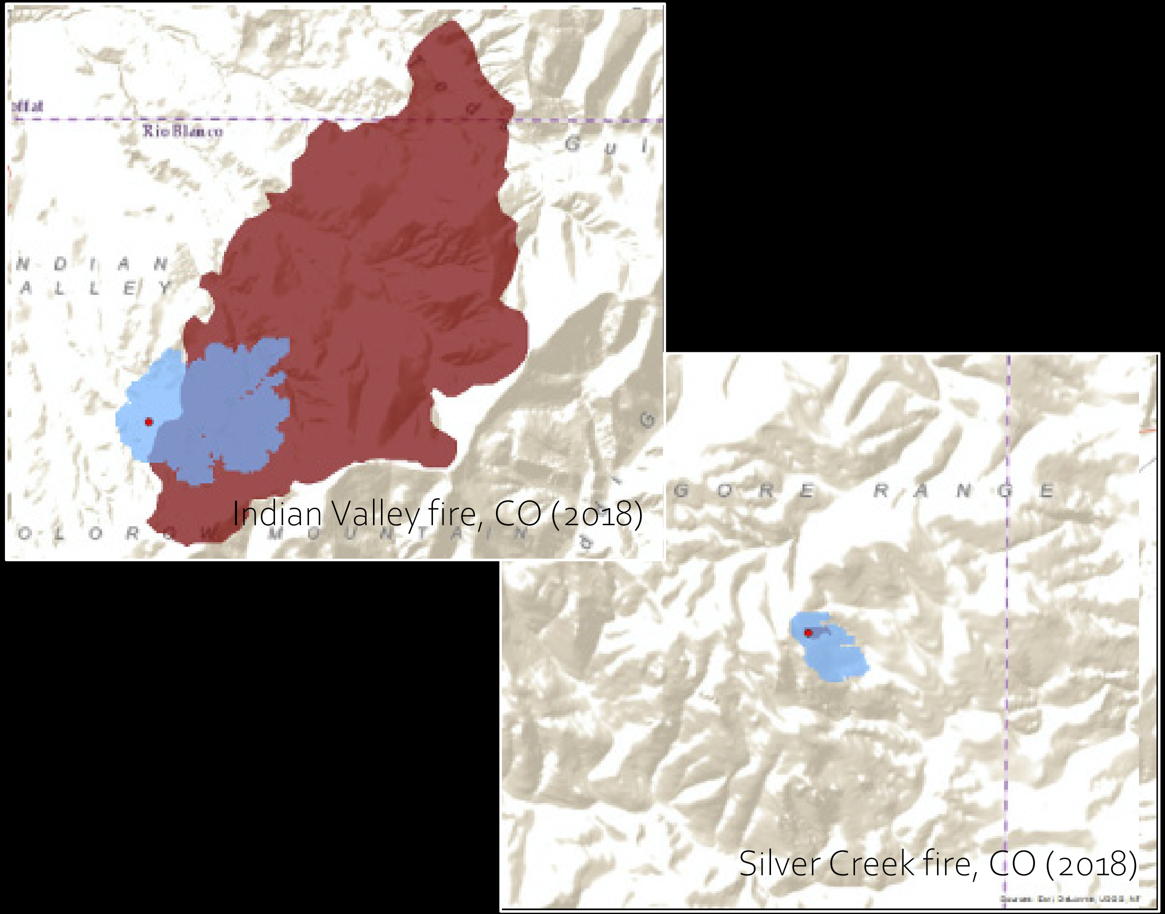
Model performance

Good simulation

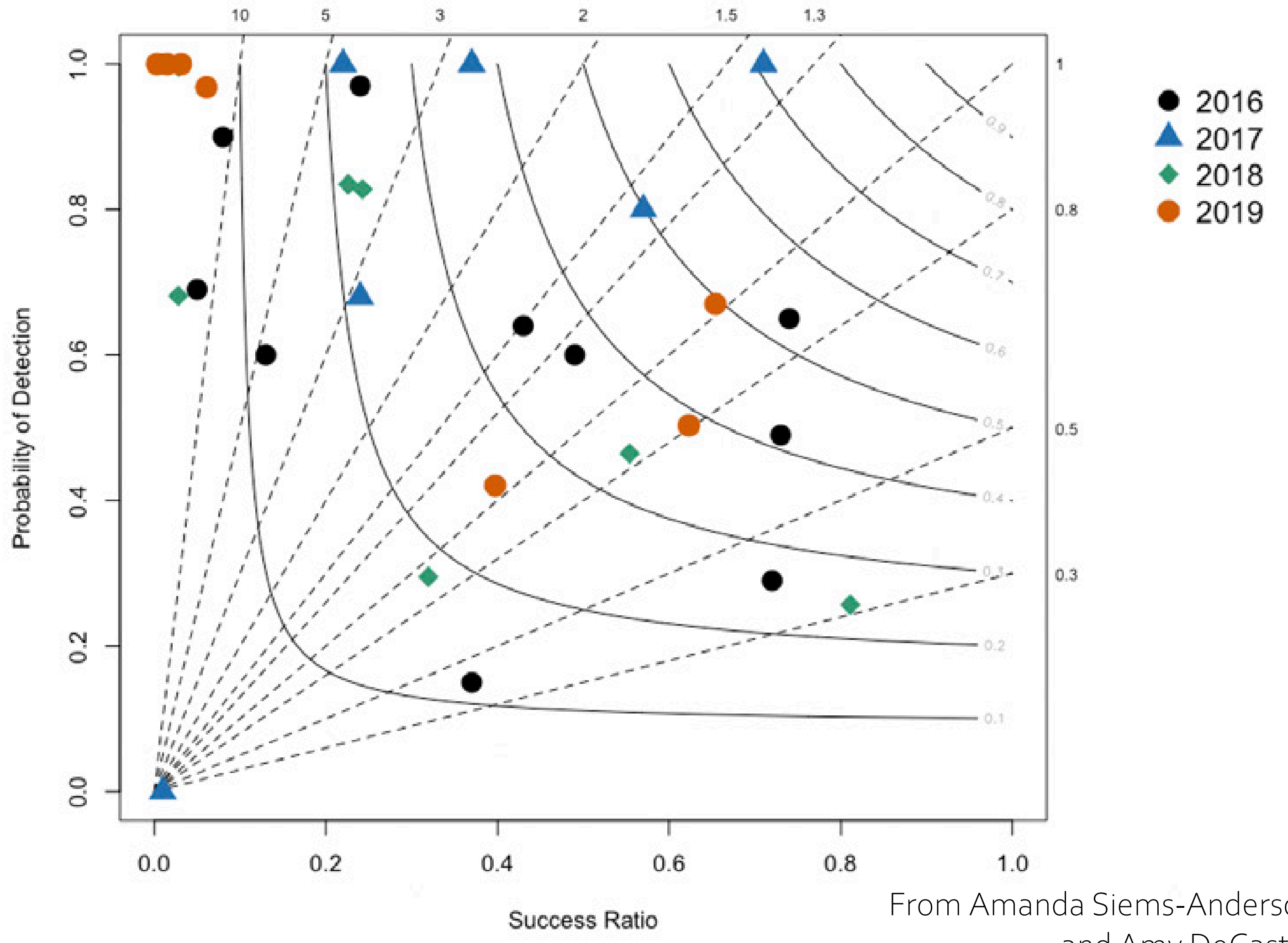


From Amanda Siems-Anderson and Amy DeCastro

Poor simulations



Model performance



From Amanda Siems-Anderson
and Amy DeCastro

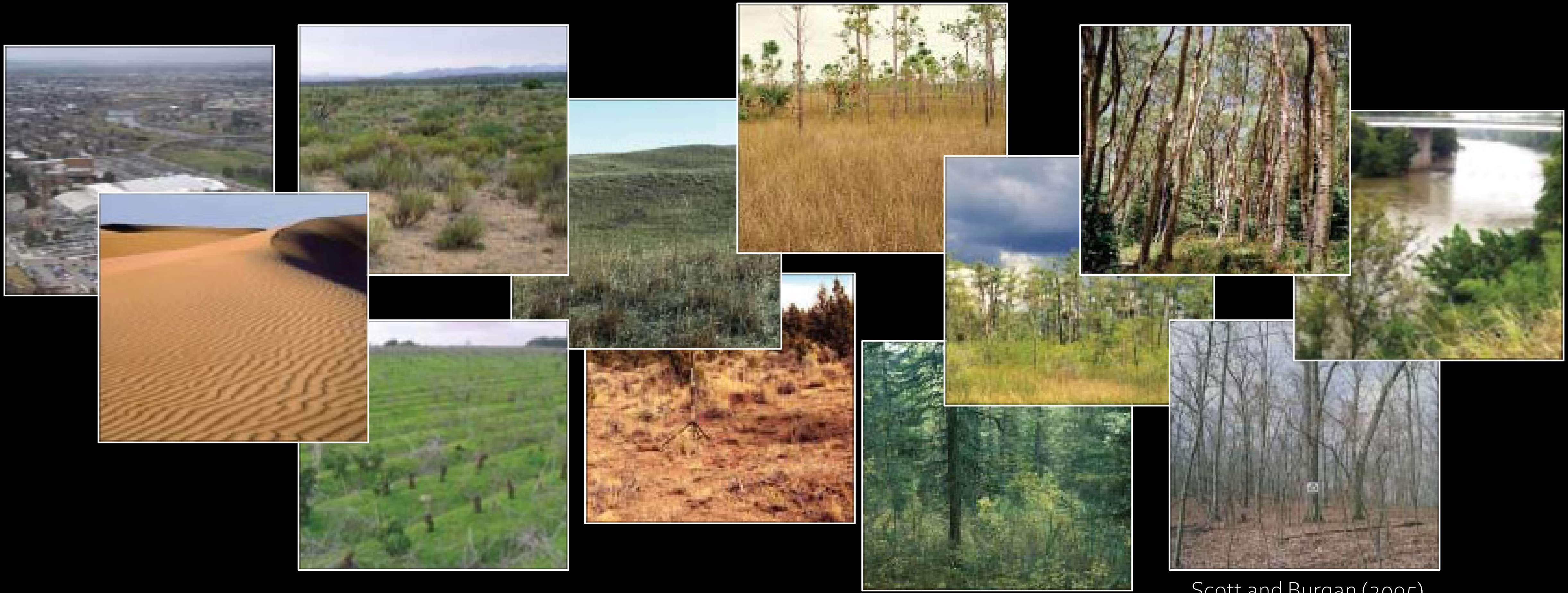
Selected sources of uncertainty in simulating fires and smoke

- Simulated weather (wind especially; also air temperature, humidity, stability, etc.)
- Fuels and fuel moisture content (urban fuels are a tremendous challenge)
- Accurate times and locations of ignitions (official reports often have large errors)
- Firebrands and spot fires (simulating and validating)
- Fire behavior models' numerics and parameterizations
- Accounting for fire suppression (challenges include getting real-time reports)
- Source terms and aerosol-radiation-cloud interactions in smoke simulations
- Simplifications due to high cost of realistic chemistry in smoke simulations

Bottom line: Uncertainty is an inevitable part of wildfire prediction

Fuel type and fuel moisture content (FMC)

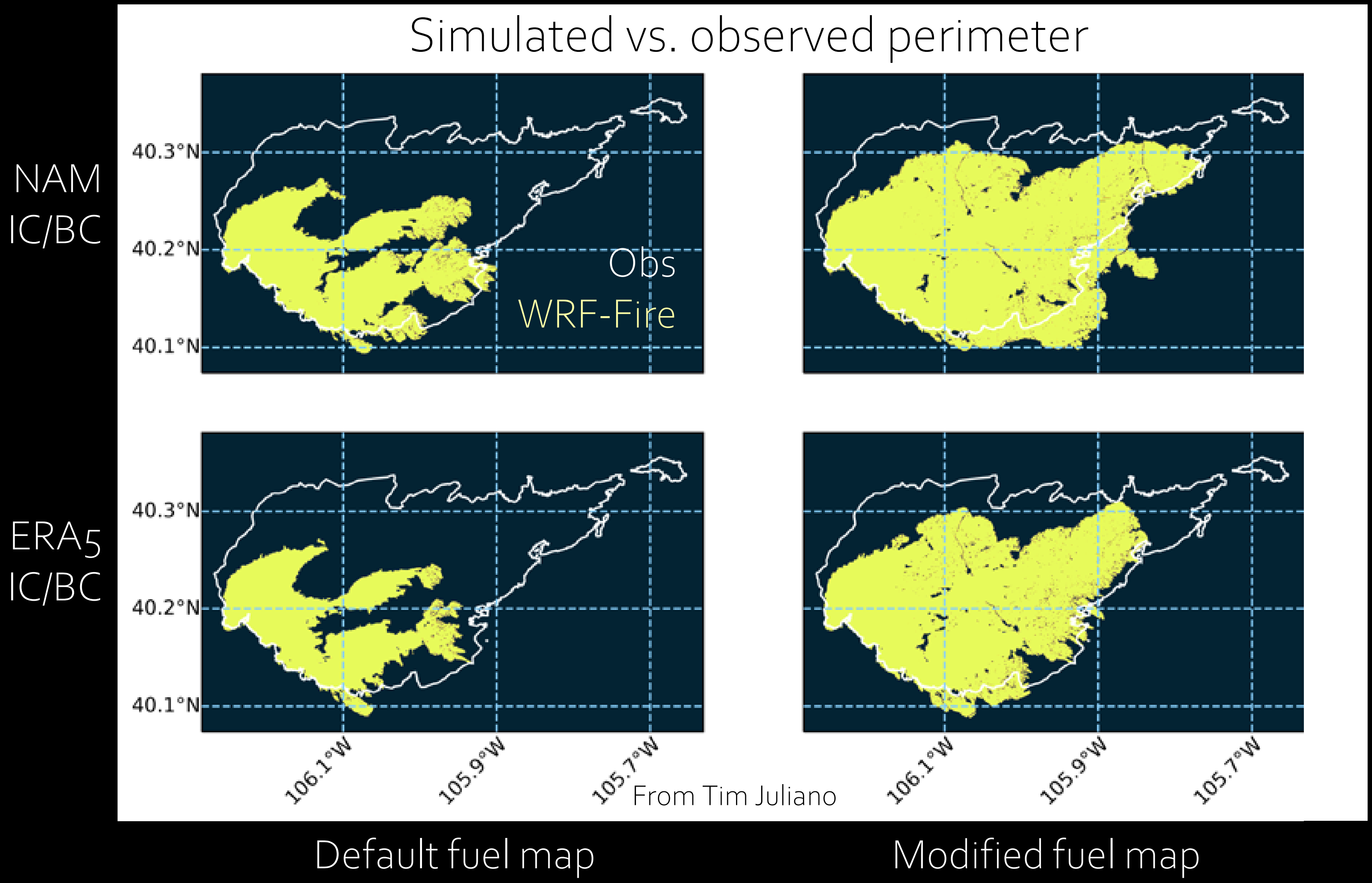
WRF-Fire uses Scott and Burgan's (2005) dynamic models for 40 fuel types



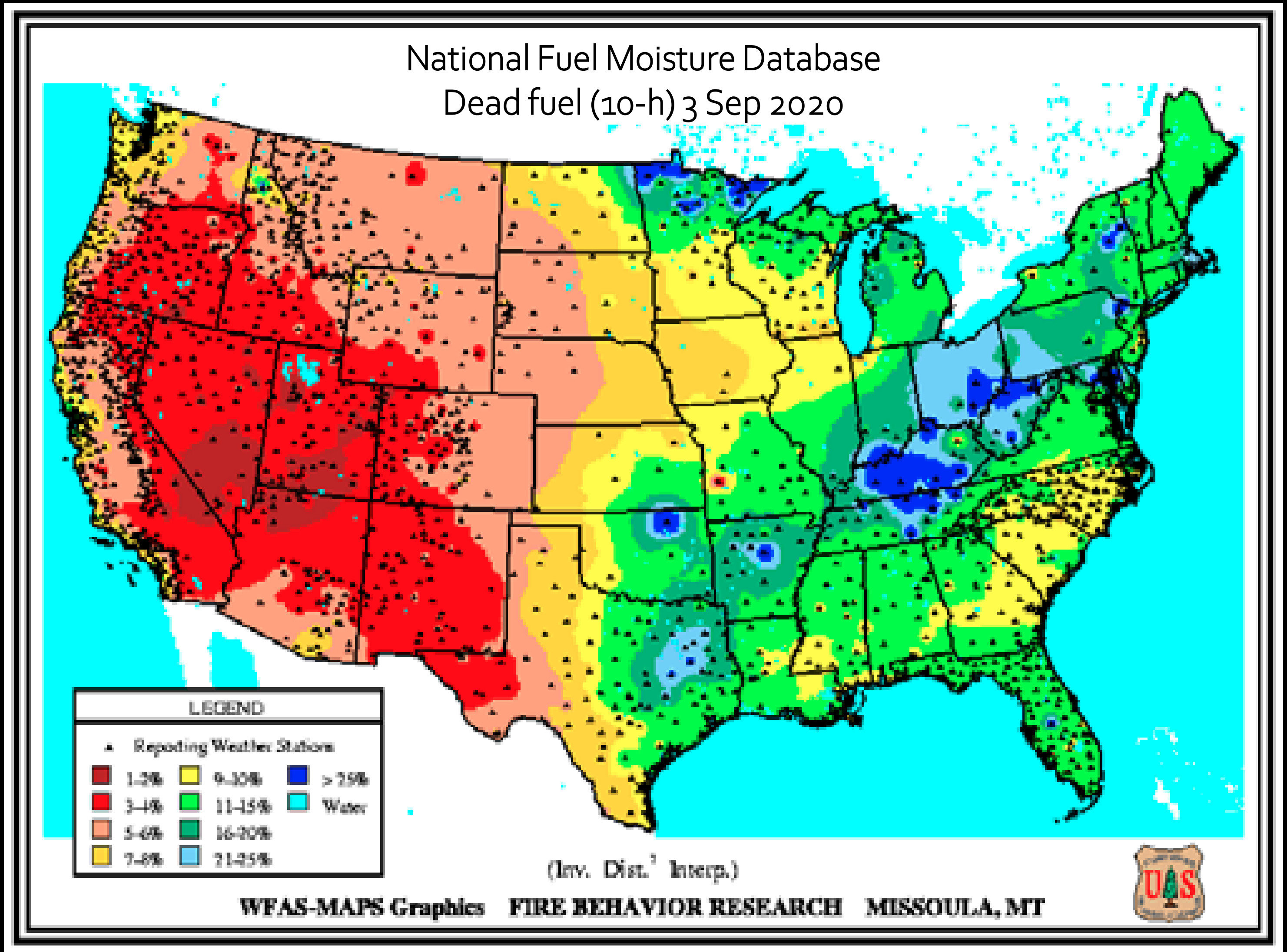
Scott and Burgan (2005)

Sources of error and uncertainty: fuel type

Sources of error and uncertainty: fuel type



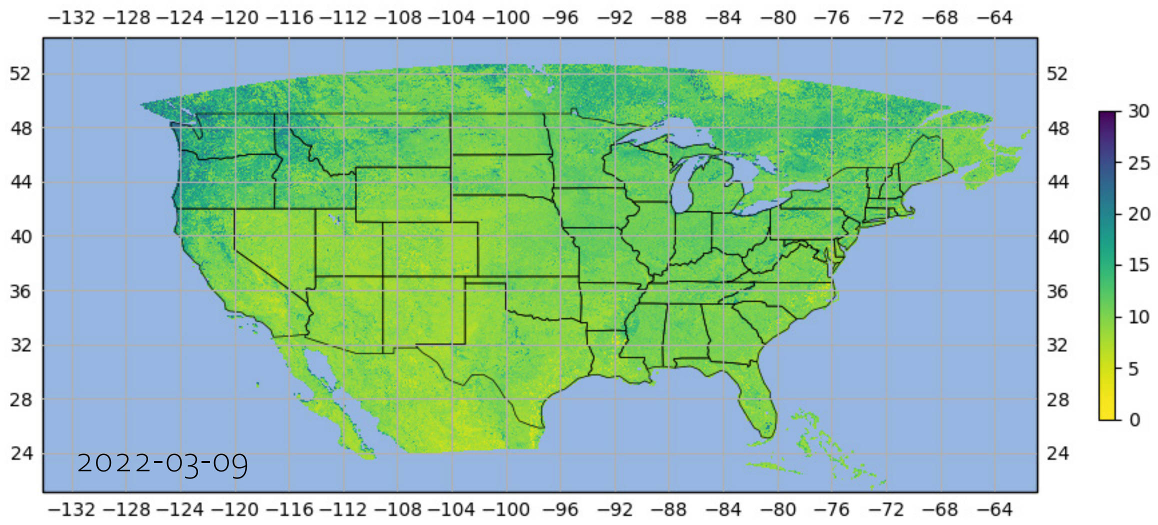
Fuels and fuel moisture content (FMC)



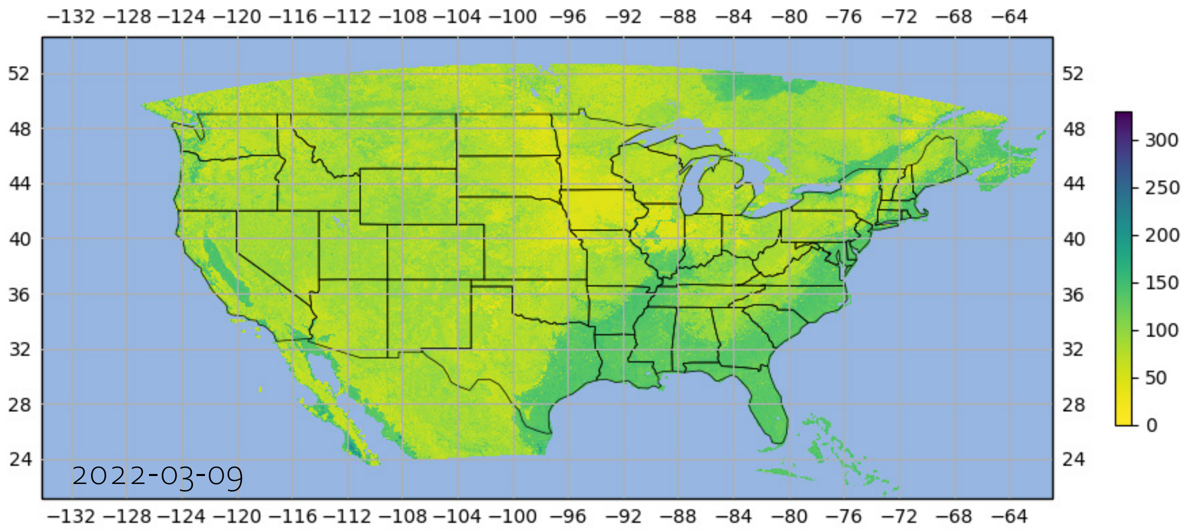
Fuels and fuel moisture content (FMC)

We use machine learning to combine spectroradiometer data from NASA's Aqua and Terra satellites, National Water Model data, and terrain data with in-situ surface observations to estimate dead and live fuel moisture content (FMC) over the conterminous US, then create daily FMC maps with 1-km pixels

Dead fuel (10-h) moisture content (%)



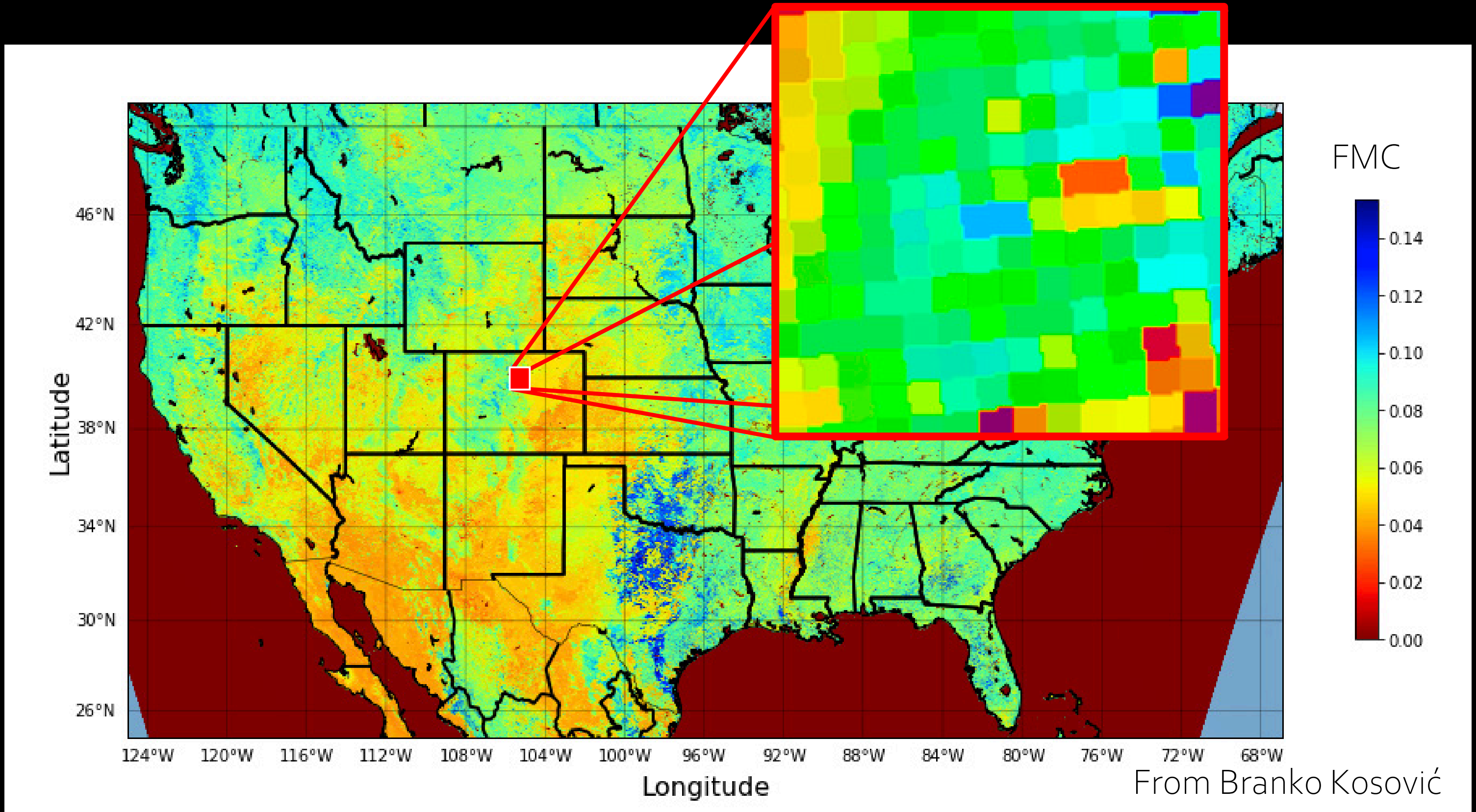
Live fuel moisture content (%)



Daily dead and live FMC data are served through:
https://ral.ucar.edu/solutions/products/fuel-moisture-for-wildland-fire-spread-prediction
Data are archived at NCAR's DASH:
https://data.ucar.edu/dataset/fuel-moisture-content-live-and-dead-over-the-conterminous-united-states

Fuels and fuel moisture content (FMC)

9 July 2016   Day of Cold Springs fire, CO



From Branko Kosović

NCAR's daily national map of 1-km gridded FMC (%)

Fuels and fuel moisture content (FMC)

New project to generate hourly FMC

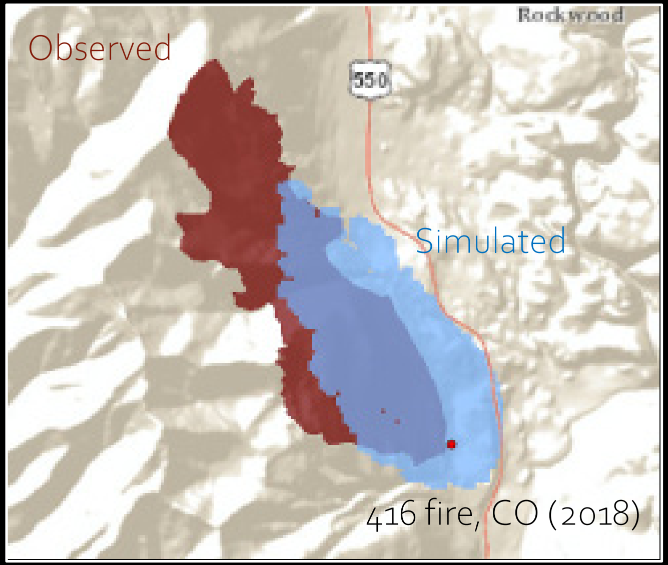
Sponsor: Joint Polar Satellite System (JPSS) Program Office
PIs: Pedro Jimenez (NCAR) and Eric James (NOAA / CIRES)

Objective: Adapt NCAR's machine-learning algorithms to use reflectances and other products from the Advanced Baseline Imager (ABI) and Visible Infrared Imaging Radiometer Suite (VIIRS) instruments

- GOES and VIIRS will be blended to provide 375-m FMC retrievals over CONUS with 1-h frequency
- VIIRS-based estimations of FMC for Alaska with diurnal updates

Model performance

Good simulation



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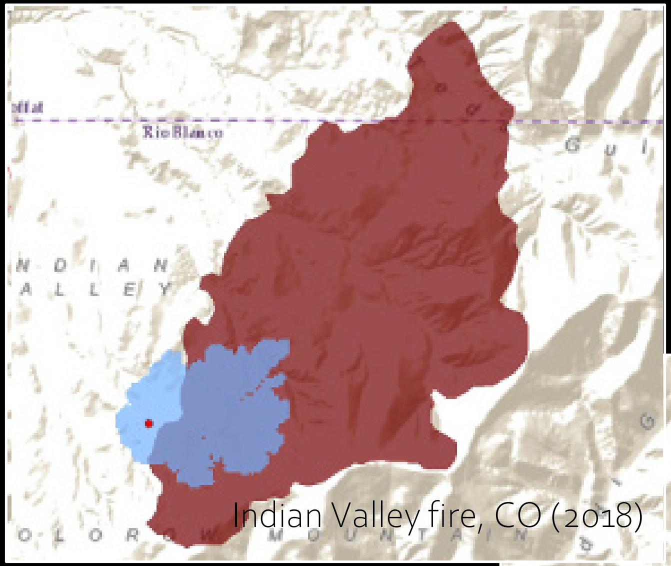
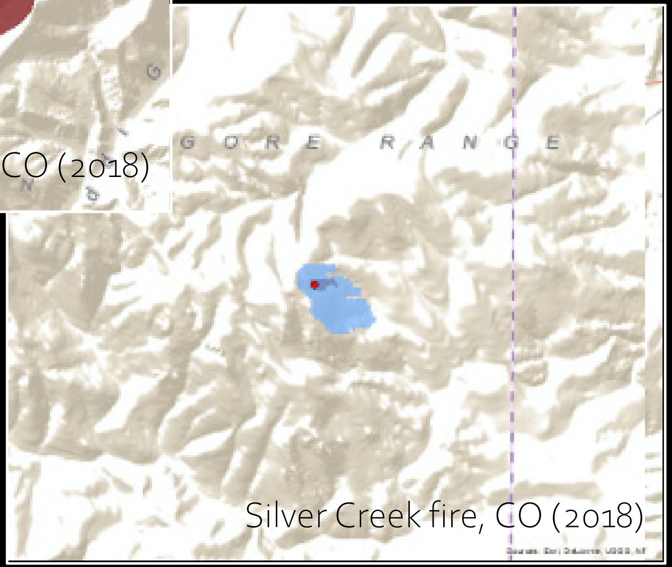
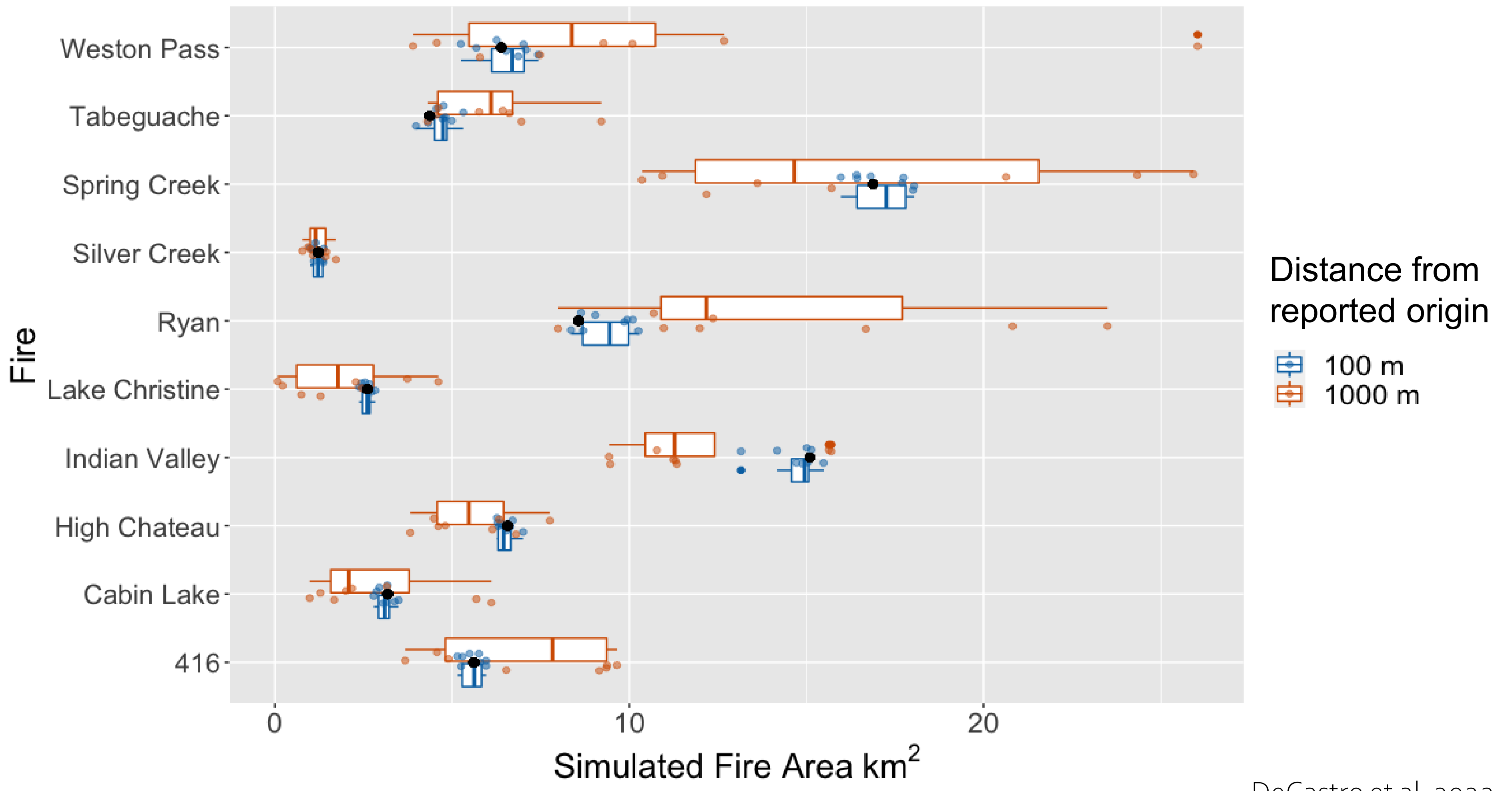
Poor simulations





Sources of error and uncertainty: reported ignition



DeCastro et al. 2022

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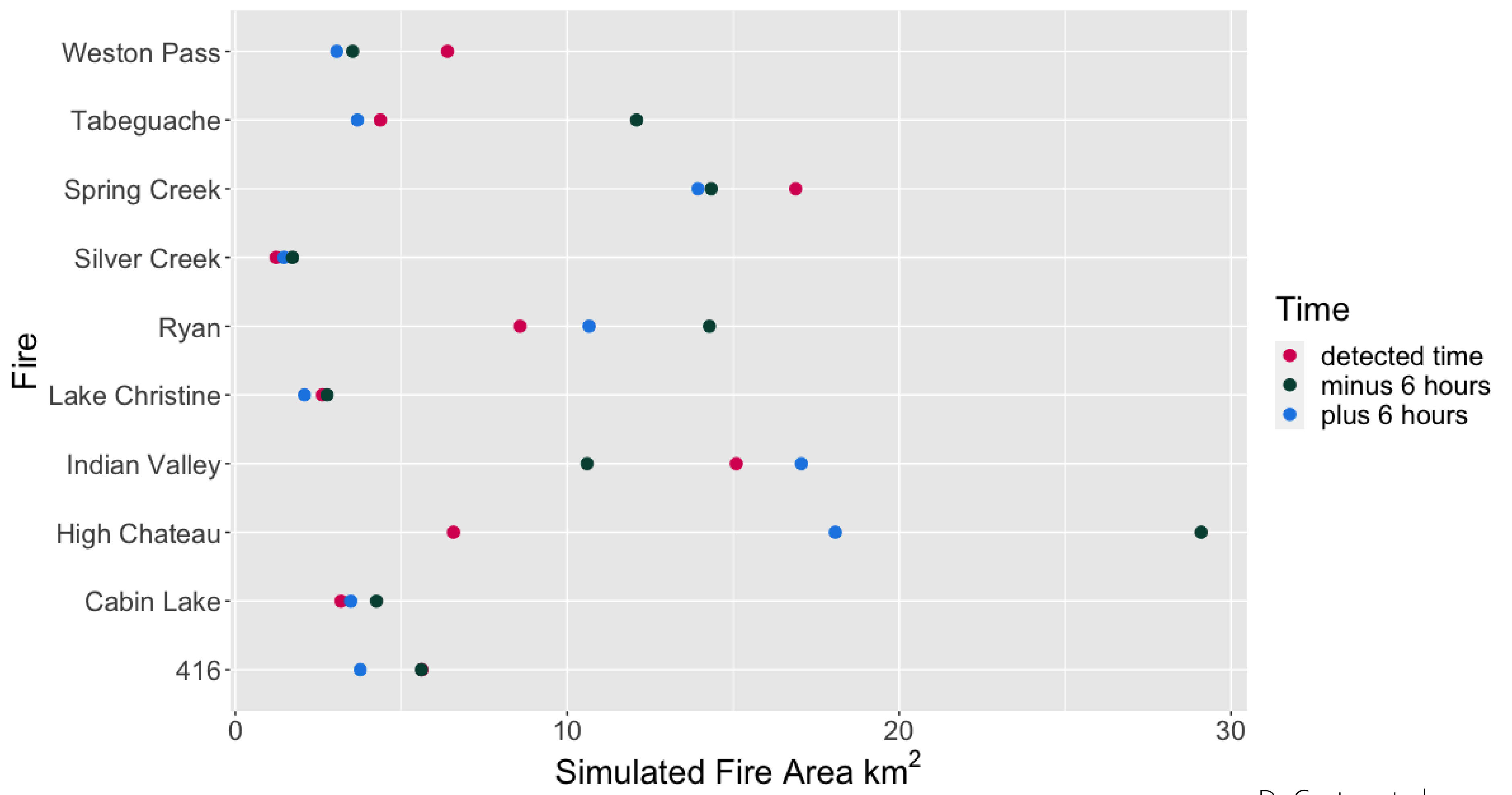
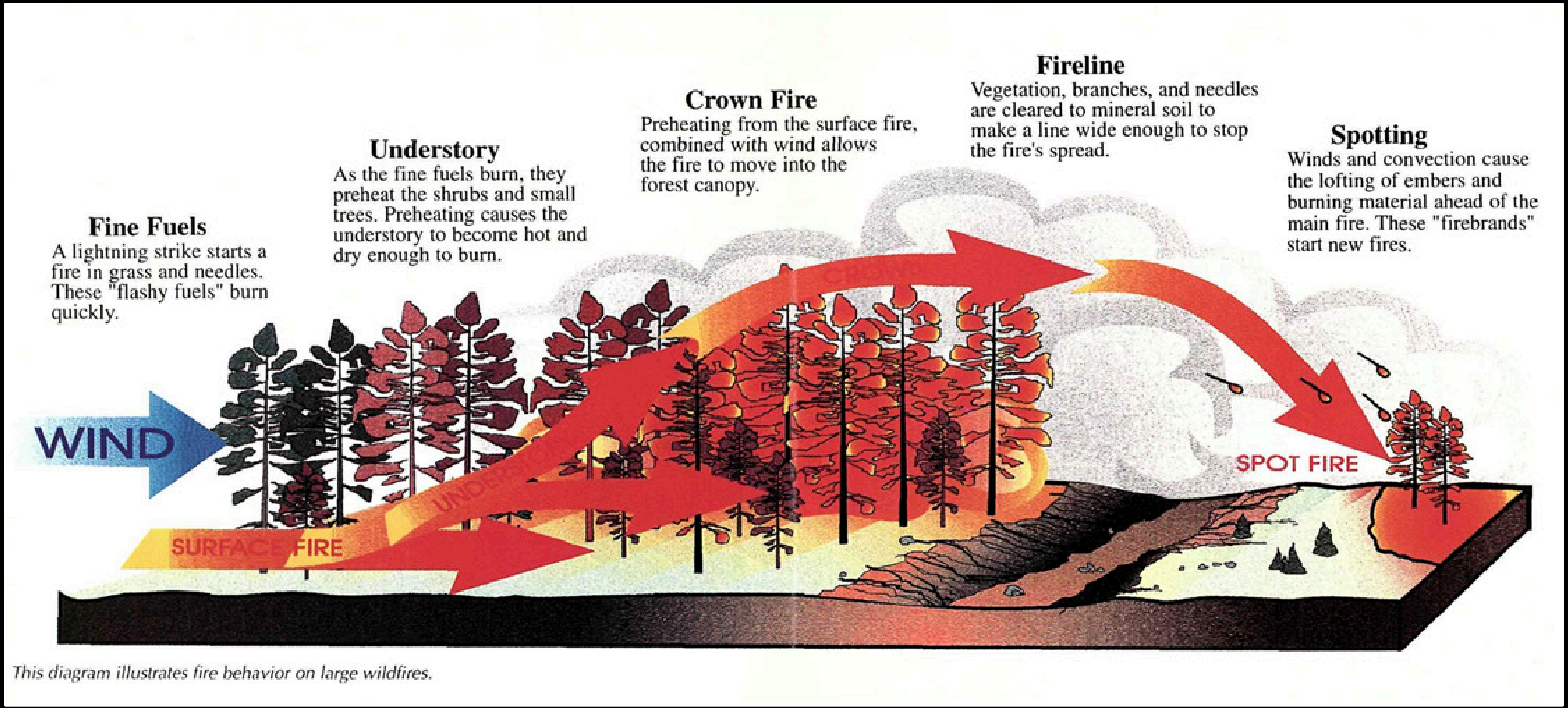


DeCastro et al. 2022

Predicting the likelihood of spot fires

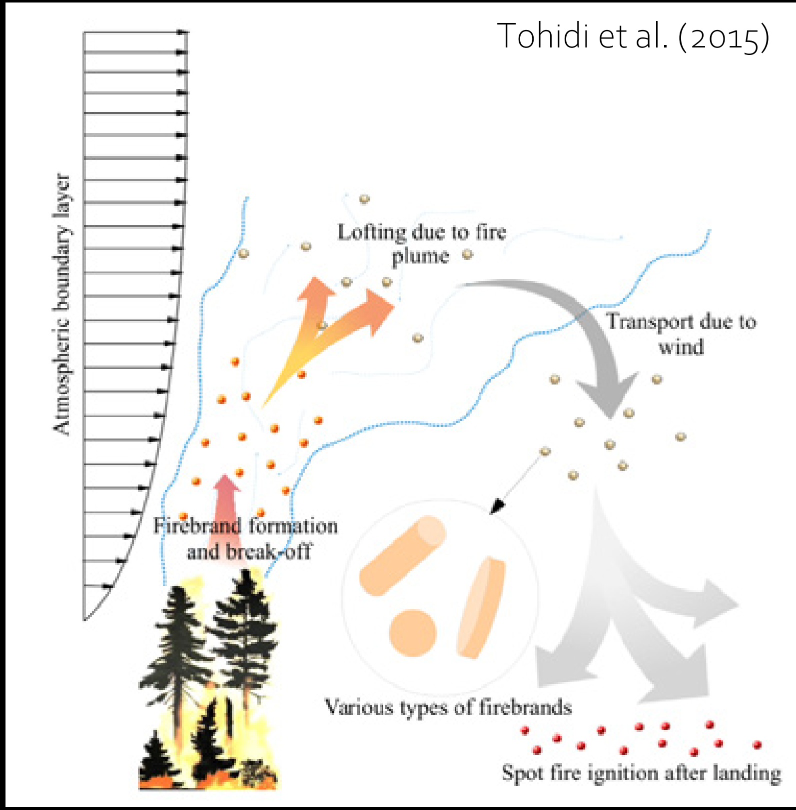


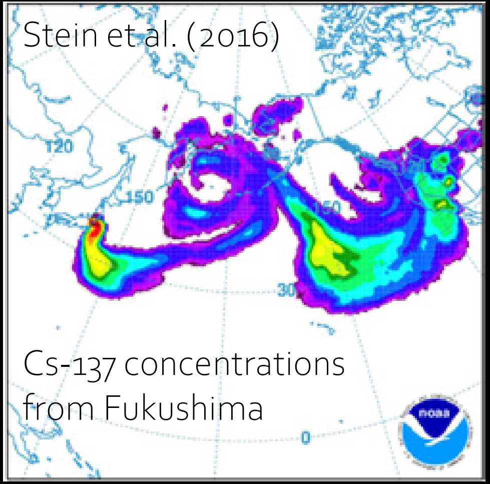
US Forest Service (1996)

Embers can ignite spot fires 10s of km downwind from the flaming front

Predicting the likelihood of spot fires

Our approach is based on Lagrangian particle modeling of the kind used to model transport and dispersion of airborne pollutants

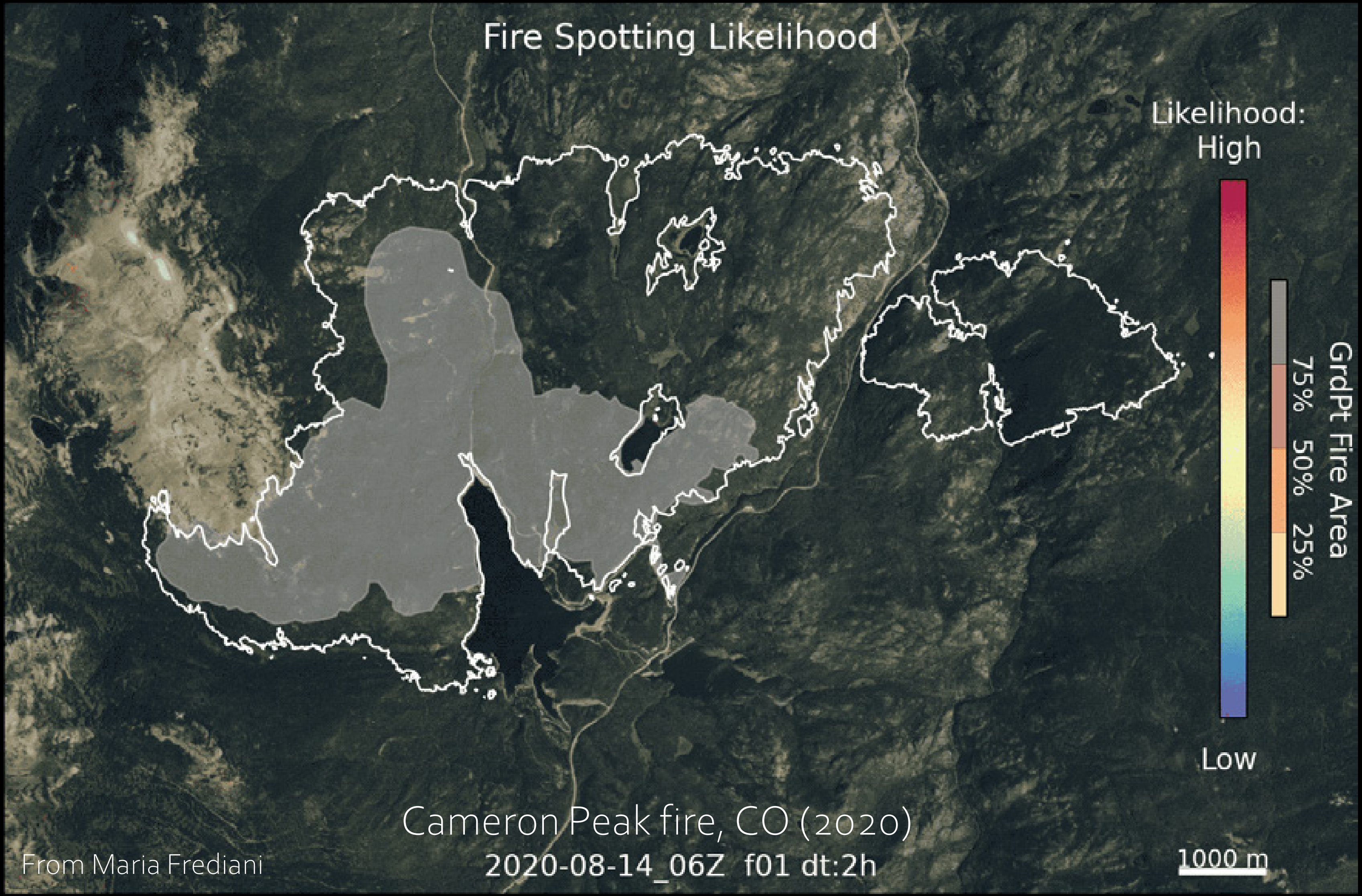




Processes being modeled

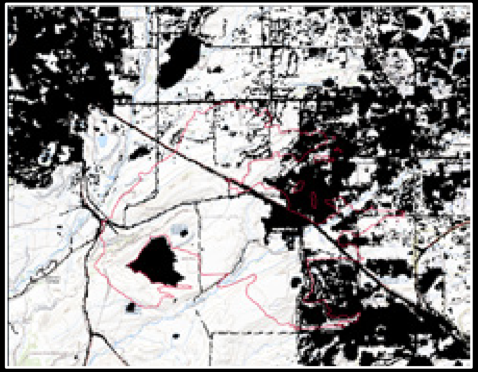
1) Release of firebrands (embers) by main fire
2) Transport through the air
3) Burnout
4) Settling and deposition onto fuel on ground

Predicting the likelihood of spot fires

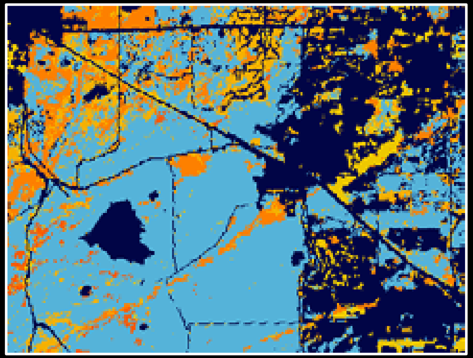


Marshall fire, CO (2021)

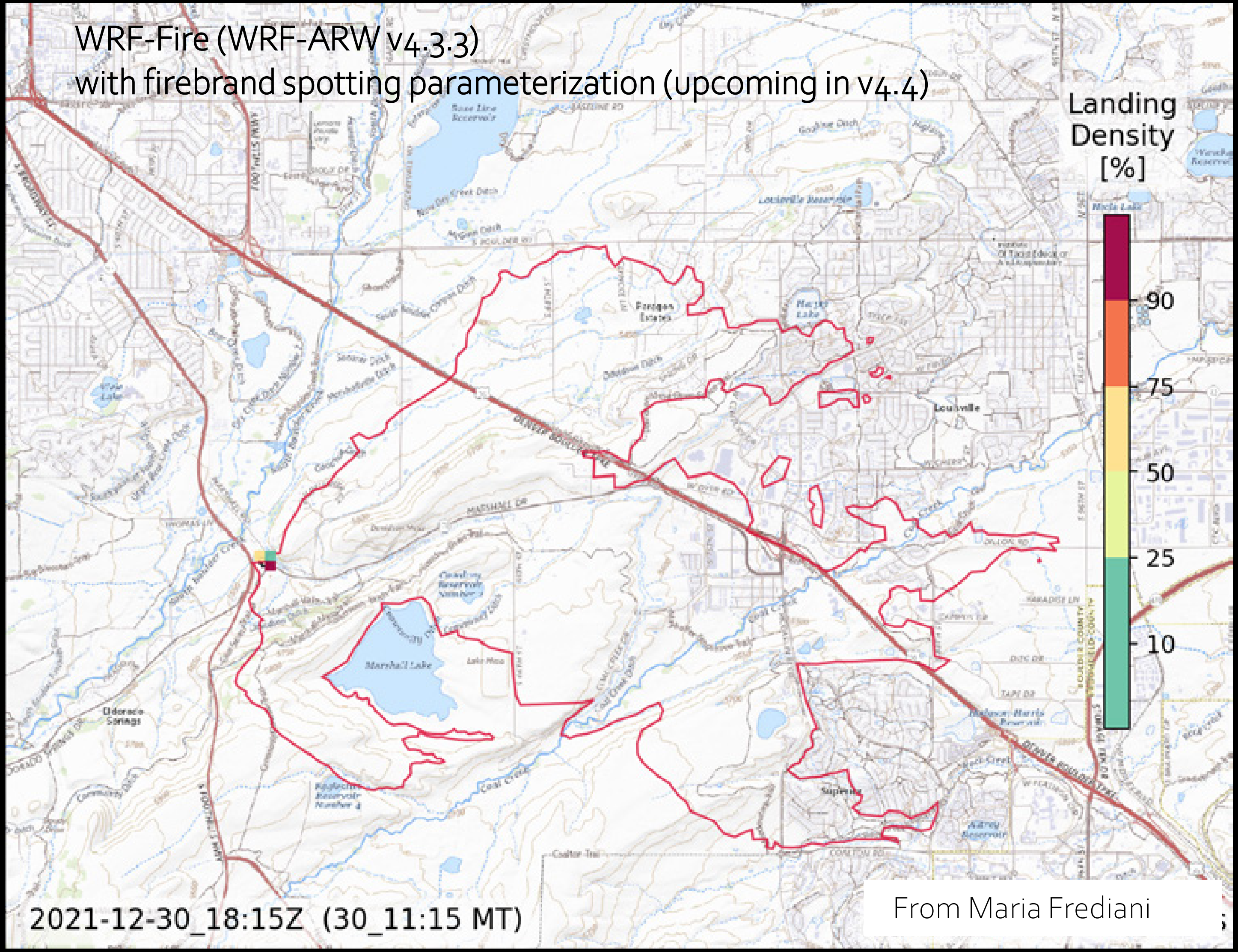
FMC = 8% or 0%



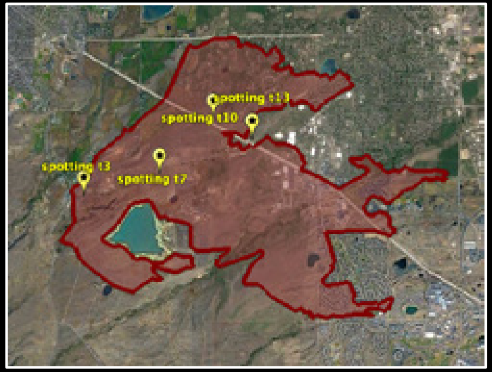
LANDFIRE fuel load



0.0 (kg m3) 3.5



Burned area



Challenges and goals

- Reliable, well distributed observations of local weather and fire in real time
- Fast, skillful forecasts with assimilation of relevant data at appropriate scales
- Accurate, frequently updated databases of fuel and fuel moisture content
- Understanding urban fuels and other influences of the built environment
- Ensembles (dynamical, statistical, AI) with probabilistic output (and *training*)
- Accounting for fire suppression (challenges include getting good reports)
- Smoke and plume height predictions (smoke affects far more people than fires)
- Simulating pyrocumuli (connecting biomass smoke to microphysics)
- Predicting longer-term effects (e.g., flooding, poor water quality, new land cover)
- *Integration into stakeholder workflows (cannot be overemphasized)*

Roles for inter-agency collaboration

- Sustained funding at meaningful levels for interdisciplinary research and development involving lasting, two-way strategic partnerships with stakeholders
- Realistic allocations of staff time and resources to work on interdisciplinary teams, such as a rapid-response unit with deployable sensors
- Testbeds, workshops, multi-agency working groups, and demonstration exercises (NOAA is building a fire weather testbed)
- Collaboratively developed products, workflows, and methods of validation that include decisions and outcomes — more than just model validation
- Comprehensive, vetted, curated database of selected fires (pre-fire conditions, fire behavior, air quality, emergency response, impact on people and infrastructure, recovery of the ecosystem, etc.)
- More coordinated research on connections among scales (climate to turbulence)

Thank you for your attention.

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