Improving capabilities in fuel treatment analysis with STANDFIRE and FuelManager

CAQSIS Meeting
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- Research Topics
- Priority Areas
- Experimental Forests & Ranges
- Partnerships
- People
- Locations
- About R&D
- National Genomics Center for Wildlife & Fish Conservation
- Urban Forest Connections Webinar

Contact Information

US Forest Service
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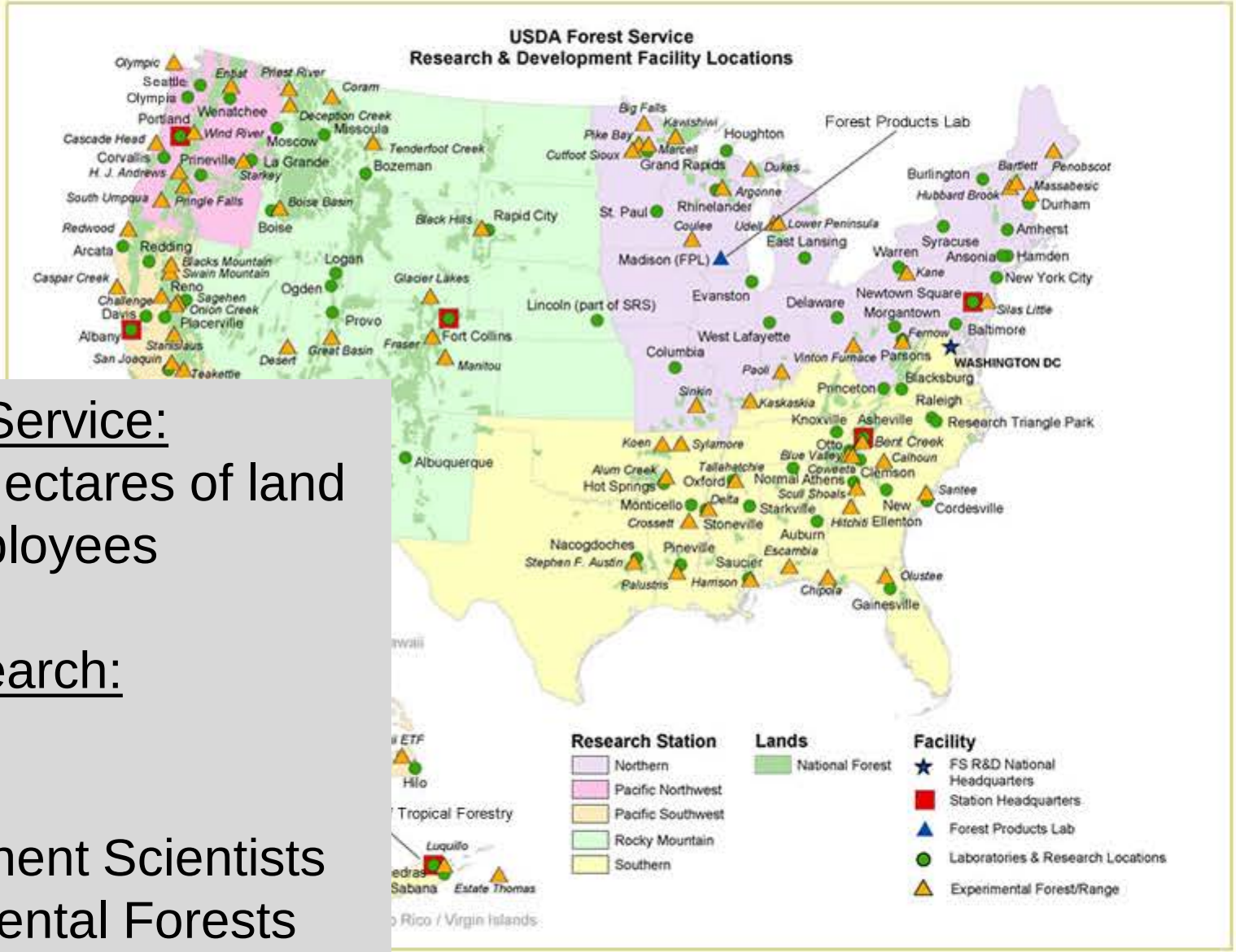
1400 Independence Ave., SW
Washington, D.C. 20250-0003
800-832-1355

To learn more about Forest Service research locations:

- use the clickable map or list below for the research stations' locations
- view the sites for Experimental Forests & Ranges

Research Stations' Locations



US Forest Service:
78 Million Hectares of land
34,250 employees

USFS Research:
5 Regions
67 Labs
550 Permanent Scientists
80 Experimental Forests

Missoula Fire Sciences Lab
Founded 1961

About 80 people total
13 permanent scientists

Burn Experiments

Wildfires in the US

~ Average of 2.51 Million Ha burned per year
~ but > 4 Million HA burned in 2015 – record year

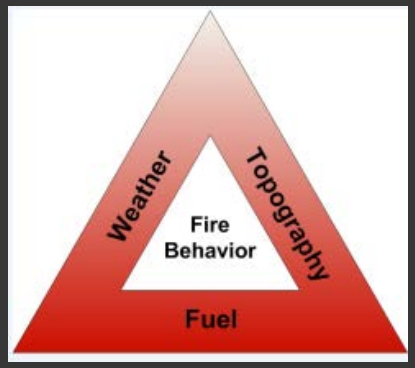
US Forest Service primary fire management agency
- ~ $2 Billion per year spent on fire fighting: **1/2 our budget**
- ~ 10,000 fire fighters: **1/3 our workforce**

Disturbing trends
- **Increasing area burned**
- **Higher fire severity**
- **Increasing population near forest**
- **Increasing costs and risks**

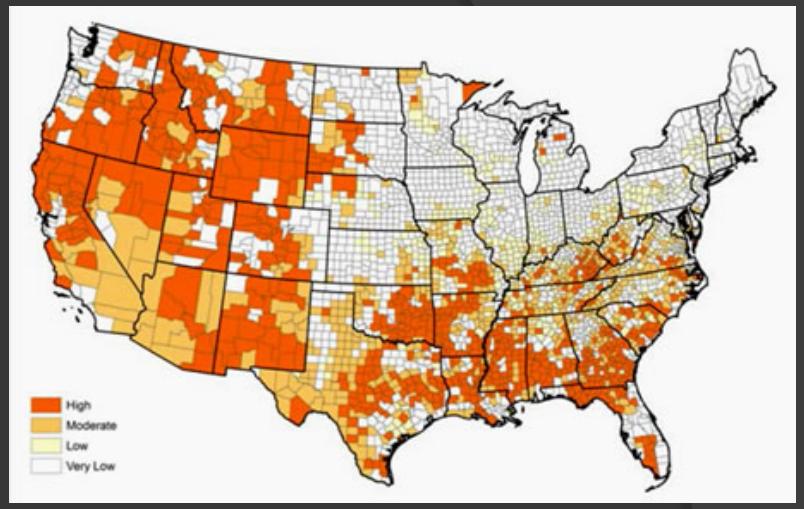
Firefighting alone cannot fix the problem: unsustainable

Fuel treatments:

A major component of current fire management strategies



Fuels – only part of fire behavior triangle we can change



Map showing where fuel treatments are needed

National, high priority issue

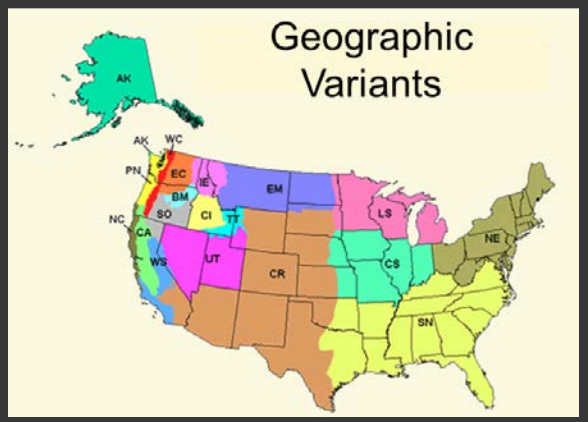
- 30 Million ha of USFS land need fuel treatments
- ~ 1 million ha treated per year on USFS land
- ~$200 million spent on per year

Decisions needed:

- How to prioritize?
- What strategies work best?
- How well will they work?

- **Many questions still unanswered**

The Forest Vegetation Simulator (FVS)



Strengths

- Primary vegetation modeling tool in US
- Individual-tree, distance-independent, growth and yield model
- Original model: Prognosis (Stage 1973)
- Empirical model, calibrated by geographic region
- Large user base (> 500 +)
- Several extensions – disturbances, insect attacks, fire, carbon, economics, climate change

Limitations

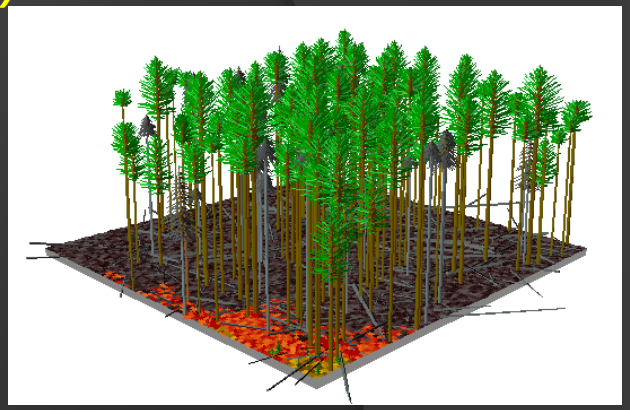
- Old architecture – monolithic
- Overly integrated -- not modular
- → Limited capability to improve
- Recent, open source developments

Assessing fuel treatments at stand scales

Primary tool: FFE-FVS

Forest Vegetation Simulator (FVS)

- How stands grow over time
- Response to treatments
- Numerous forest processes
- Higher detail data critical to ecology, habitat, silviculture

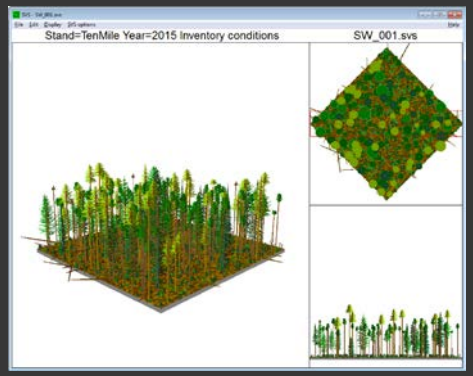


Stand Visualization System (SVS)

FFE: Fire & Fuels Extension

- Adds biomass / fuel quantities
- Simple fire modeling
- Fire effects

Mismatched detail: fuels vs. fire



- Fuels information in FFE-FVS is more detailed than what the fire models can use.
- fully attributed tree list → 4 single values
- litter, duff, CWD, shrub, herb → Single FBFM

Fuels

Fire

- **Relatively low sensitivity**
- **Fire modeling is a bottleneck**

- Difficult to represent real/measured fuels
- Hard to assess how fuel changes translate to fire behavior changes

- For many purposes, **<u>we need more detail</u>**

STANDFIRE: Providing an alternative approach for examining fire at stand scales

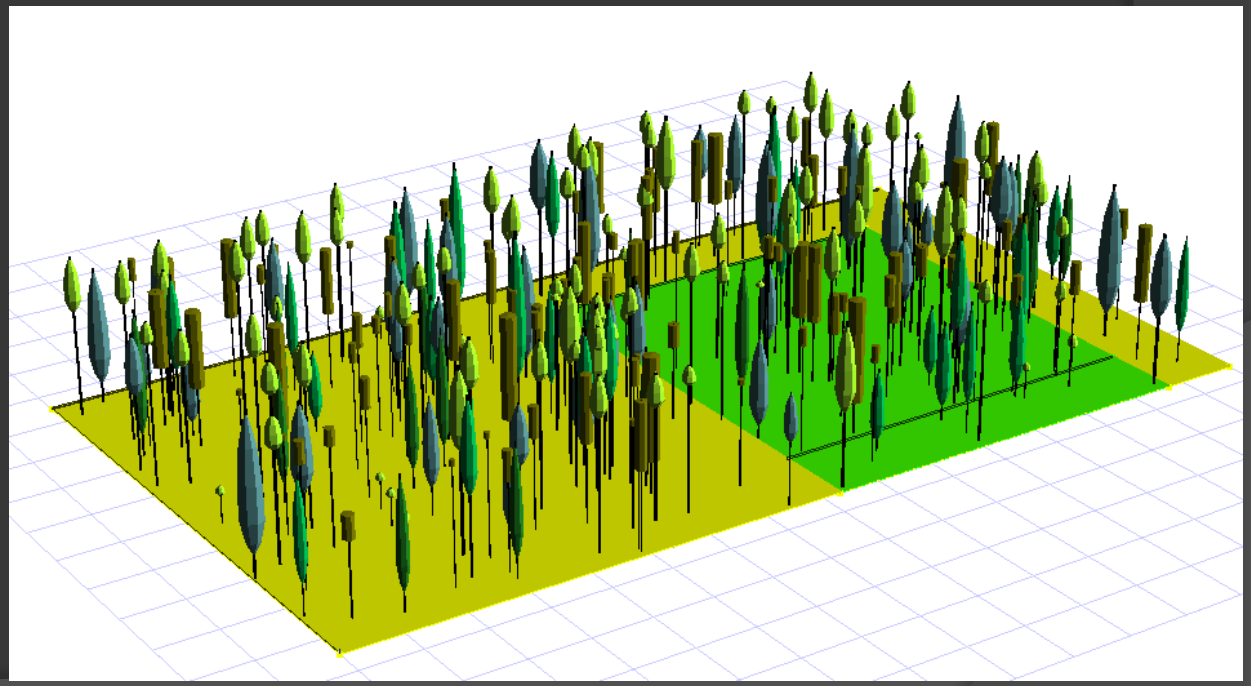
CAPSIS FireLib

http://www.inra.fr/capsis

Interface → Python process → FFE –FVS, SVS → CAPSIS/ FireLib → Run Fire Simulation → Post process WFDS output

In STANDFIRE, CAPSIS Firelib provides:

- Visualization, analysis and I/O capabilities
- 3D geometry calculations for biomass allocation to voxels
- Capability to develop complex, spatially explicit treatments



STANDFIRE CAPSIS Interactive 3D viewer

Fire library

- It is one of the shared libraries

- biomechanics (P. Ancelin)
- castanea (H. Davi)
- crobas (A. Makela, R. Schneider)
- delaunay, math, nelderoptimization (A. Piboule)
- economics / 2 (C. Orazio, O. Pain, G. Ligot)
- emerge (T. Bronner)
- fire (F. Pimont)
- forenerchips (N. Bilot)
- forestgales (B. Gardiner, C. Meredieu, T. Labbé)
- genetics (I. Seynave et al.)
- ifnutil (J.L. Cousin, M.D. Van Damme)
- johnsondistribution (T. Fonseca)
- lerfobutil (F. Mothe)
- numerics (A. Franc)
- organon (N. Osborne)
- quest (A. Achim, E. Duchateau)
- regeneration (P. Balandier, N. Donès)
- samsaralight (B. Courbaud, N. Donès, G. Ligot, M. Jonard)
- spatial (F. Goreaud)
- volume (G. Lagarrigues)

Potential applications:

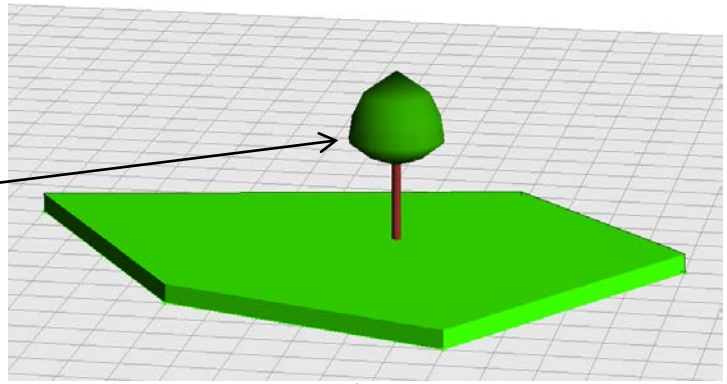
• To give a 3D voxelized representation of foliage/fine woody elements for physics-based computations :

- Fire simulations
- Windflow with LES codes
- Radiative transfer in heterogeneous canopies
- Etc.

• Can be applied to *spatialized trees* (should heritate from *FiPlant*) or vegetation layers (should heritate from *FiLayerSet*)

http://capsis.cirad.fr/capsis/help_en/firelib

Fire lib: fuel items



***FiPlants* = individual description**

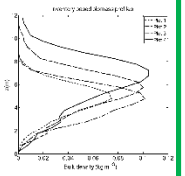
Species, Position, DBH
Dimensions: H, CBH, CD
Geometry, Color

Mass [*Particle1*]
Mass profile[*Particle1*]

Mass[*Particle2*]
Mass profile[*Particle2*]

...

Mass[*ParticleN*]
Mass profile[*ParticleN*]



Fire and Severity parameters *(if any)*

***FiLayerSets* = coarse description (understorey)**

Prism defined by a polygonal base, H, BH

n Layers

Layer 1

Name
H, BH
C, L, SpatialGroup

BulkDensities[*Particles*]

...

Layer n

Name
H, BH
C, L, SpatialGroup

BulkDensities[*Particles*]

Clumps

Particles: leaves, needles, thin twigs

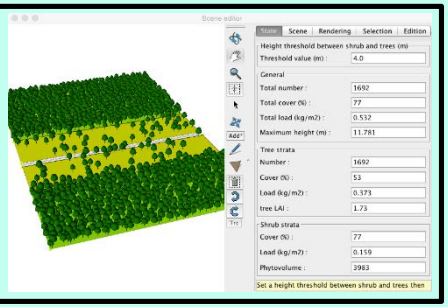
MVR, SVR, MC

Fire library and physics-based fire models

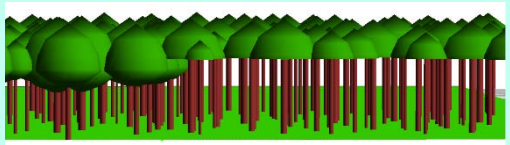
Fire Library

3D fuels Scene
Plants, LayerSets

Calculate **fuel properties and Visualization**

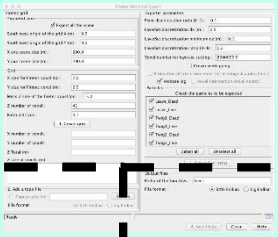


Apply **fuel treatments**
Thinning, Pruning
Clearing, Prescribed burning



Model **fire behavior**

Compute **detailed fuel structure**

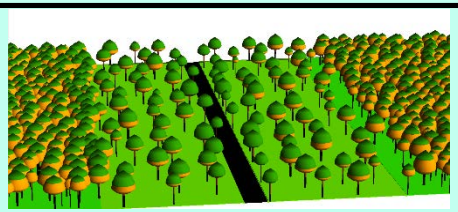


Export to

Import outputs to

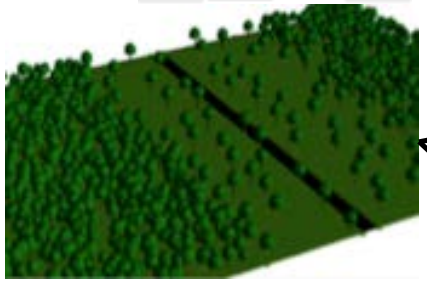
FIRETEC, WFDS

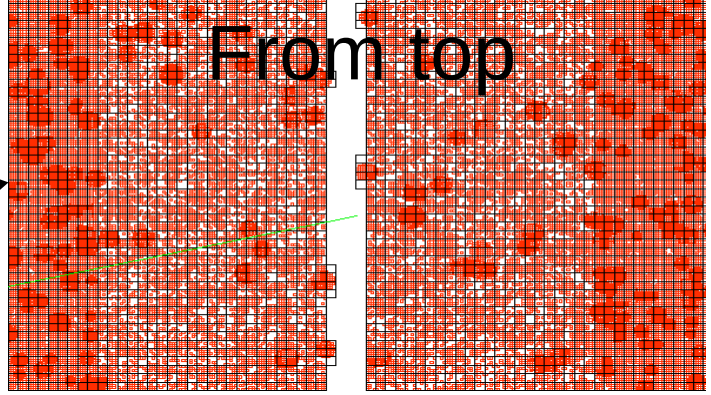
Model **fire effects**

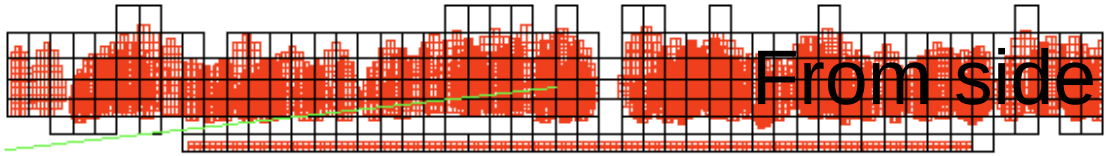


Physics-based fire models

FireLib: Export to FIRETEC







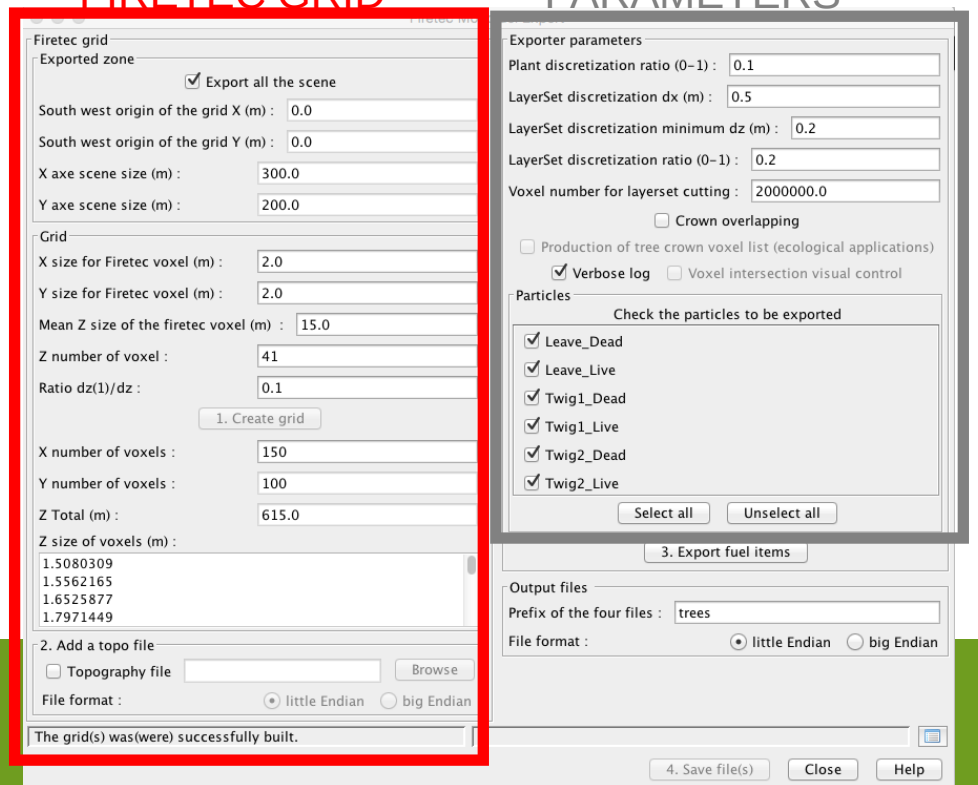
In red: voxelized 3D structures (FuelMatrix) of *Plants* and *LayerSets*

In Black: FIRETEC voxels

GUI of the export to FIRETEC

FIRETEC GRID

PARAMETERS



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journal homepage: www.elsevier.com/locate/envsoft

Modeling fuels and fire effects in 3D: Model description and applications

François Pimont [a, *], Russell Parsons [b], Eric Rigolot [a], François de Coligny [c], Jean-Luc Dupuy [a], Philippe Dreyfus [e], Rodman R. Linn [d]

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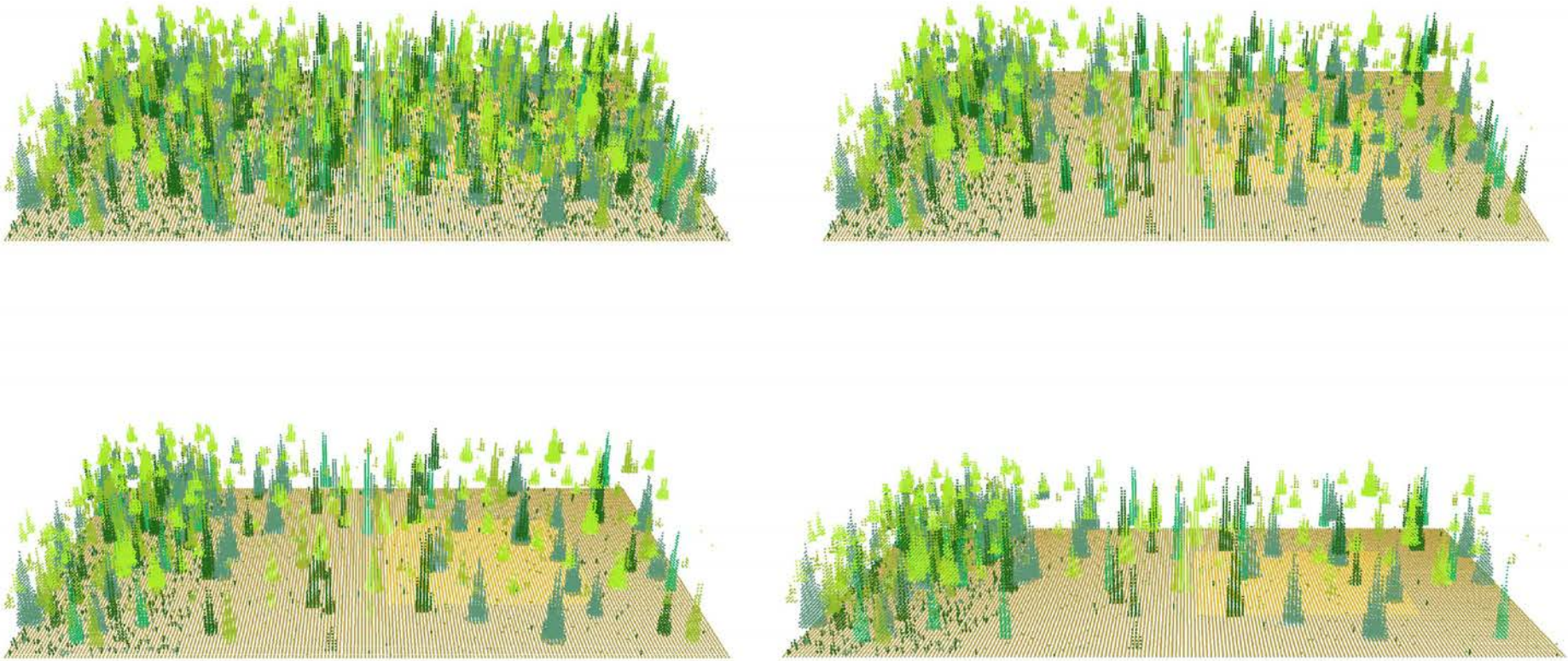
[e] RDI, ONF, 84000, Avignon, France

Recent paper describes FuelManager -- CAPSIS FireLib implements many FuelManager core modeling capabilities

Animation: four fire simulations -- Swan Valley Site



UL: control, UR: 1.5 m crown space, LL 3m, LR, 4.5m

Post processing fire model output

Interface

Python

Canopy Fuel Consumed: 63%

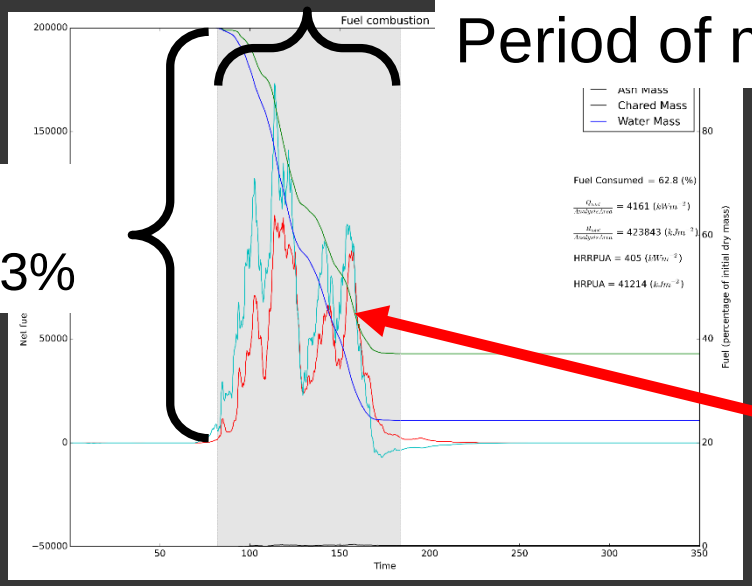
FFE –FVS, SVS

CAPSIS/ FireLib

Run Fire Simulation

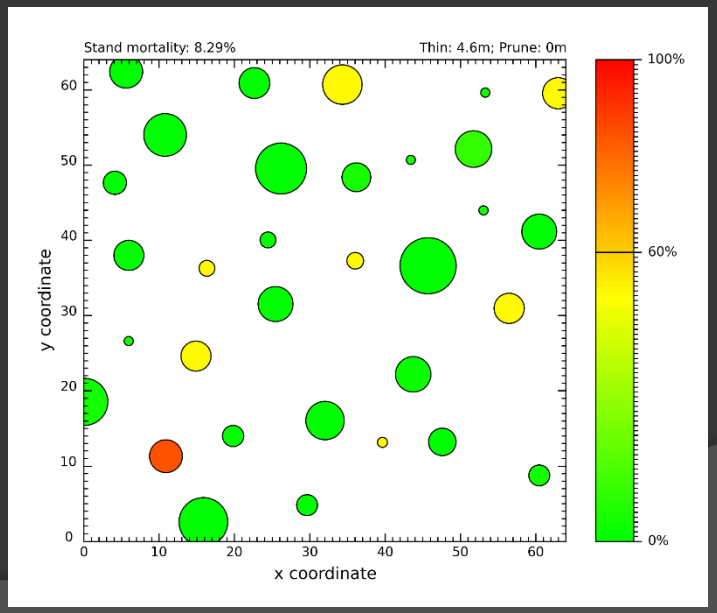
Post process WFDS output

Period of main burning



Detailed output characterizing fire behavior

Heat transfer and fuel consumption over time



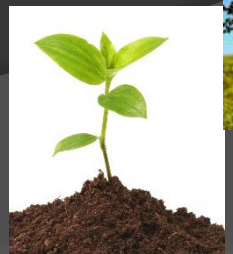
Fire effects: Probability of mortality by tree

Summary: STANDFIRE

- STANDFIRE uses CAPSIS FireLib to extend FFE-FVS providing:
  - Detailed fuel modeling capabilities that better represent real world fuels
  - 3D physics-based fire modeling platform
  - Opportunity for spatially explicit treatments
- STANDFIRE is a prototype
  - Will continue to be in active development
  - Lots of work to be done!
  - Interested in collaboration
- Next steps
  - LiDAR forest data read in
  - Topography
  - GTR and paper later this year

Expanding our collaboration

- Looking ahead, forestry faces steep challenges
  - Climate change, drought, die-off
  - Insects and diseases
  - Fire
  - Policy? ☺
- Many reasons to work more closely together
- Common themes
  - Fire science
  - Forest growth and management
  - Disturbance interactions
  - Field studies in wilderness landscapes
  - Mapping / remote sensing / LiDAR



Thanks!

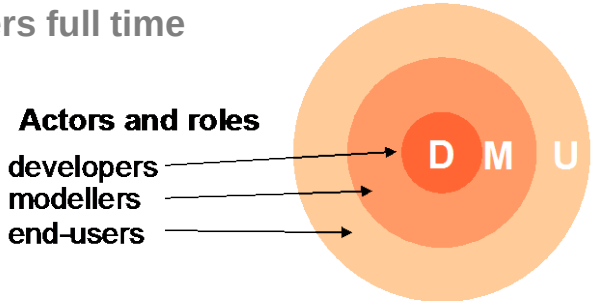
For more information, contact Russ Parsons
(406) 329-4872, rparsons@fs.fed.us

Auxiliary Slides

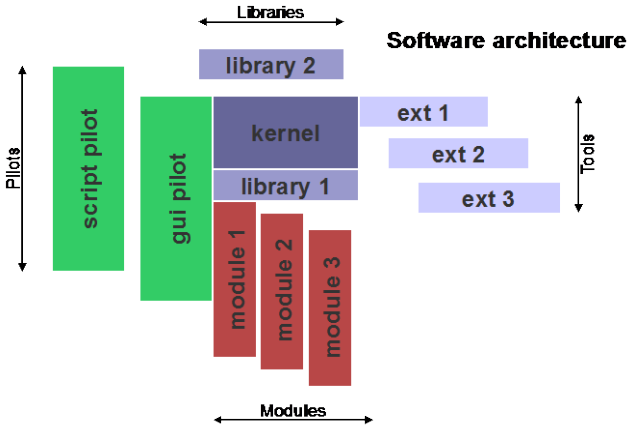
CAPSIS: World Class modeling

http://www.inra.fr/capsis

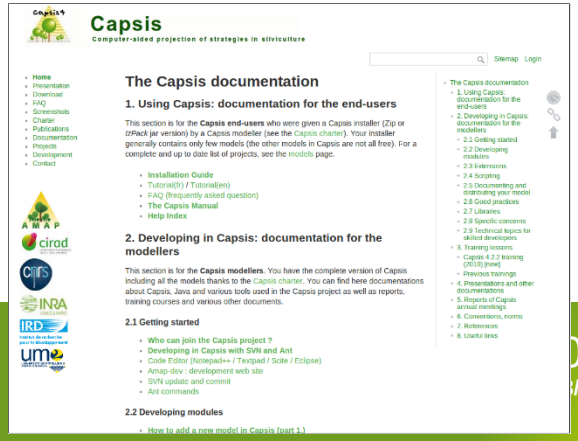
- Our modeling is implemented in CAPSIS, a generic software platform for forestry modeling, developed at INRA since 1994:
  - A world-wide community of modelers
  - 1 or 2 developers full time



- Clear participation rules (charter):
  - Common parts = free software (LGPL)
  - Modules freely accessible to members



- Benefits:
  - Common architecture: efficient, versatile, collaborative
  - Access to common libraries, features, documentation
  - Diffusion: repository, website, documentation



Dufour-Kowalski S., Courbaud B., Dreyfus P., Meredieu C., de Coligny F., 2012. Capsis: an open software framework and community for forest growth modelling. **Annals of Forest Science** (2012) 69:221-233

Plant Models parameterization

Modeling initial step

- *Plants*:
  - *Detailed inventory*
  - *Observed distribution*
  - *Modelled distribution*
  - *+ Plant models*
- *LayerSets*:
  - *Set of Observed Layers*
  - *Predefined undestorey*
  - *Succession model*

Plant models are implemented in text files, using a list of predefined functions

```
#Name   Genus   Trait   Tax. Level  Info    SLA Color (RGB) CrownGeometry
Picea mariana           Picea   Resineous   1   ICFME   6.5 0,102,51    {(0,10);(50,100);(100,10)}
Picea mariana dead      Picea   Resineous   1   ICFME   0   0,102,51    {(0,10);(50,100);(100,10)}
Pinus banksiana         Pinus   Resineous   1   ICFME   6.5 0,102,51    {(0,10);(10,60);(25,99);(50,93);(75,69);(100,5)}
Pinus banksiana dead    Pinus   Resineous   1   ICFME   0   0,102,51    {(0,10);(10,60);(25,99);(50,93);(75,69);(100,5)}
[...]
#ParticleType   Status  SpeciesName     MVR(kg/m3)      SVR(m2/m3)      Moisture(%) source
Leave   Live    Picea mariana   500 4000    100 Unknown
Twig1   Live    Picea mariana   500 1600    100 Unknown
Twig2   Live    Picea mariana   500  533    100 Unknown
Twig1   Dead    Picea mariana   500 1600    10  Unknown
Twig2   Dead    Picea mariana   500  533    10  Unknown
[...]
#Mass crown profile (z in m, H in m): vertical and horizontal
Leave   Live    Pinus banksiana Vertical    aover1plusExpbminusc1minusHRELFromGround(0.996;2.403;13.086)    ICFME
Twig1   Live    Pinus banksiana Vertical    aover1plusExpbminusc1minusHRELFromGround(0.996;2.936;14.112)    ICFME
Twig2   Live    Pinus banksiana Vertical    aover1plusExpbminusc1minusHRELFromGround(0.997;2.538;13.46) ICFME
[...]
#Plant dimension equations
H   Picea mariana   aDBHplusb(0.9477;0.7108)    ICFME
H   Picea mariana dead  aDBHplusb(0.9477;0.7108)    ICFME
CD  Pinus banksiana aH(0.1322)  ICFME
CD  Pinus banksiana dead    aH(0.1322)  ICFME
CBH Pinus banksiana aH(0.2;0;10000) ICFME
CBH Pinus banksiana dead    aH(0.2;0;10000) ICFME
[...]
# Model for biomass
Leave   Live    Pinus banksiana aDBHpowb(0.00672; 2.25699)  ICFME
Twig1   Live    Pinus banksiana aDBHpowb(0.00478; 2.0889)   ICFME
Twig2   Live    Pinus banksiana aDBHpowb(0.00105; 2.43234)  ICFME
Twig1   Dead    Pinus banksiana aDBHpowb(0.00824; 1.88877)  ICFME
Twig2   Dead    Pinus banksiana aDBHpowb(0.00161; 2.30592)  ICFME
[...]
```

Crown profile

species

Cumulative function is a/(1+Exp(b-c(1-z/H))

Biomass distributions

aDBHplusb: H(DBH)=a*DBH+b

Plant dimension equations

Biomass equations

Source for allometric equations: ICFME (Alexander et al. 2004)

CAPSIS FireLib: fuel Modeling

Individual tree crowns

- crown biomass from FFE-FVS
- Crown profile geometry
- Distribution of biomass within crown volume

Can be parameterized

Fuel heterogeneity

- Fuels as discrete/ grouped elements
- Multiple fuel sets, characteristics
- Patchy / discontinuous fuels

Fuel Treatments

- Wide range of thinning, pruning capabilities
- Spatially explicit treatment and visualization
- Calculation of fuel changes, fire behavior and effects

Advances in fire modeling open new possibilities

Topic	"Regular" models	Physics based fire models
Surface fuels	Homogeneous, continuous, contiguous single fuel model (for 30m + pixel)	Heterogeneous, discontinuous, multiple fuels; multiple fuels interact
Canopy fuels	4 variables: CBD, HT, CBH, % cover (for 30m + pixel)	Full tree list with x,y,z Full vertical and horizontal distribution
Surface fire	Rothermel 1972	**All fire spread is emergent outcome of all interactions (fuel, fire, atmosphere, topography)**
Transition to crown fire	Van Wagner	
Crown fire spread	Rothermel 1991	
Veg/wind interaction	Single wind adj. factor	Indiv . tree crown drag, full windfield interaction
Veg/fire interaction	None, but some thresholds	Highly sensitive to fuel structure, arrangement

Then: (1972)

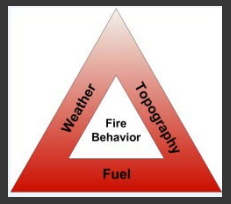
Small scale lab burns used to develop Rothermel model

Now: (2017: 45 years later)

3D physics-based fire simulation with FIRETEC

Fuel treatments:

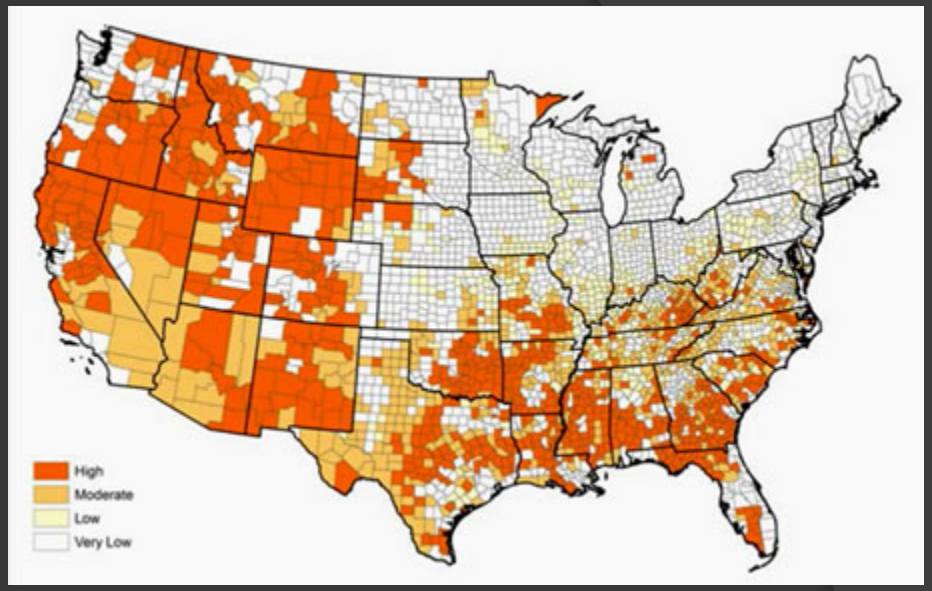
A major component of current fire management strategies



Fuels – only part of fire behavior triangle we can change

National, high priority issue

- 2013 – 65-82 Million acres of USFS land estimated to need fuel treatments
- 2-3 Million acres treated per year on USFS land
- ~$200 M. spent on hazard fuels in 2014 alone
- 27.6 Million acres treated between 2001 and 2011



National map for priority of broad scale fuels management

Decisions needed:

- National / regional / Forest / Project – allocation of $
- What strategies work best?
- **Many questions still unanswered**

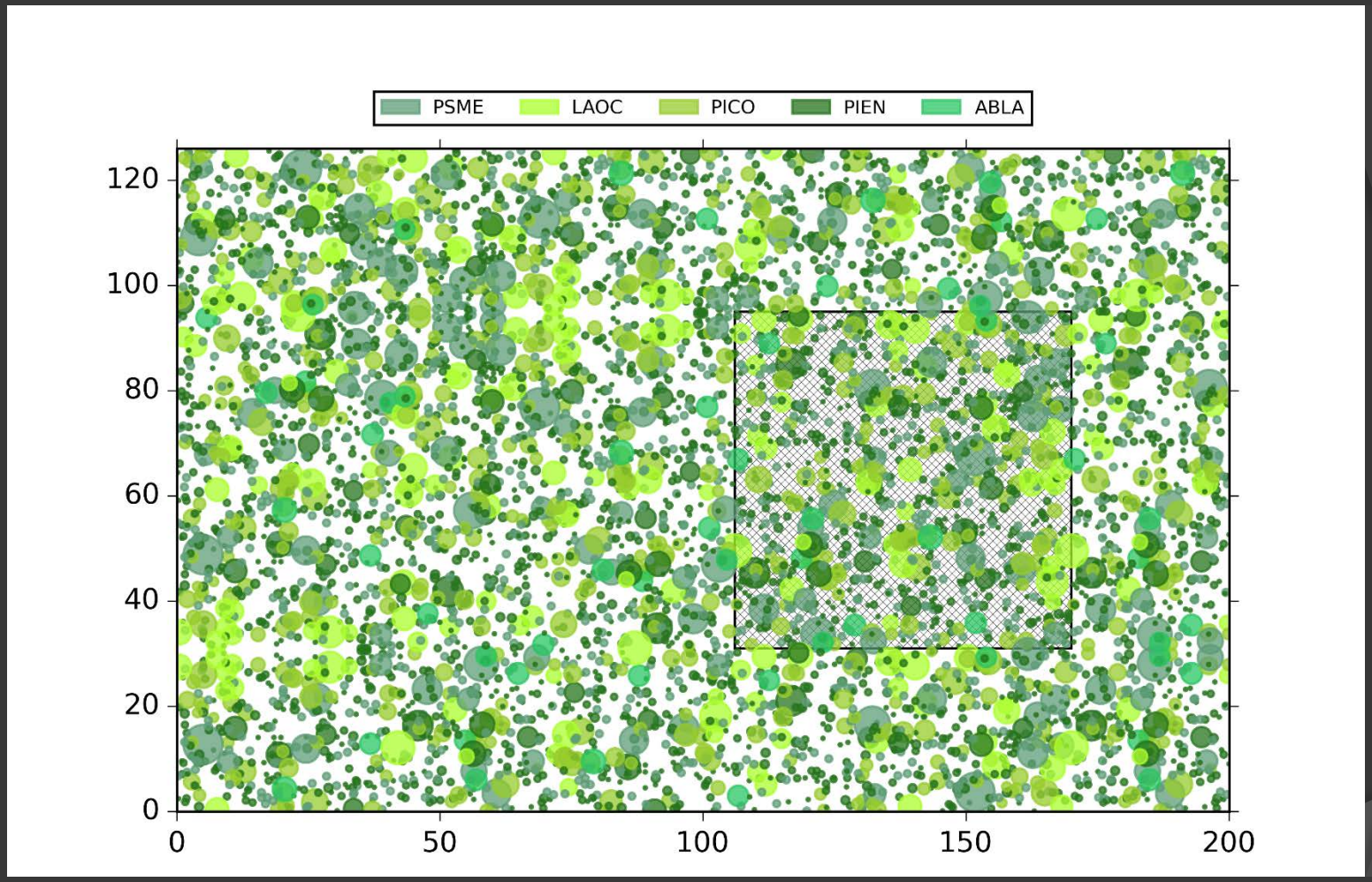
Increasingly complex constraints in a rapidly changing landscape

Beetle attacks

Invasive species

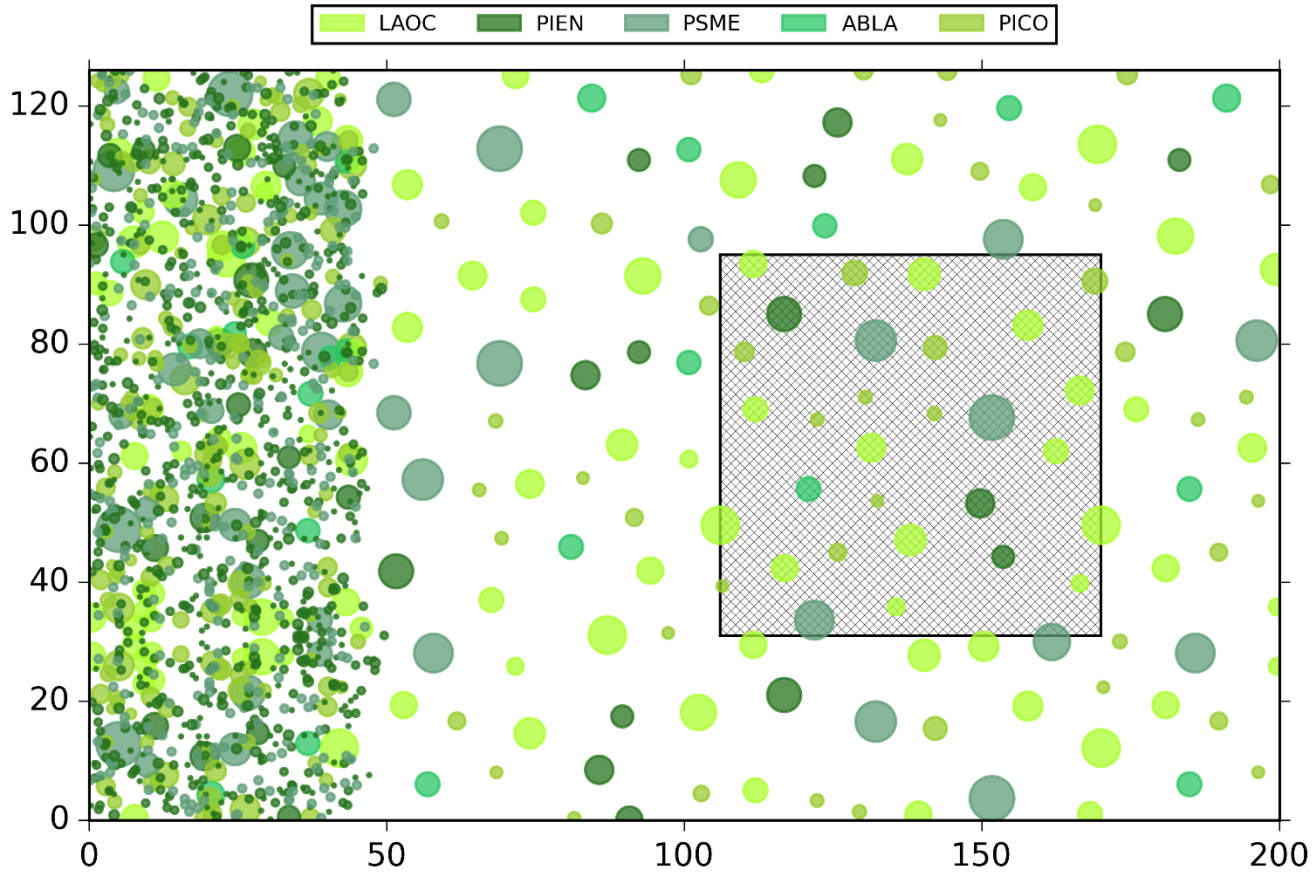
Drought stress

CAPSIS FireLib statistically extends the SVS stand to a larger simulation area specified by the user, using simulated annealing (optimization approach)



This larger area provides a context for the 3D fire simulation such that:

- the dynamic windfield can adjust to the canopy
- the fire can burn into the stand
- The SVS square serves as a focal point for analysis



Same stand after spatially explicit, crown-space thinning

An Overview of STANDFIRE

What does STANDFIRE do?

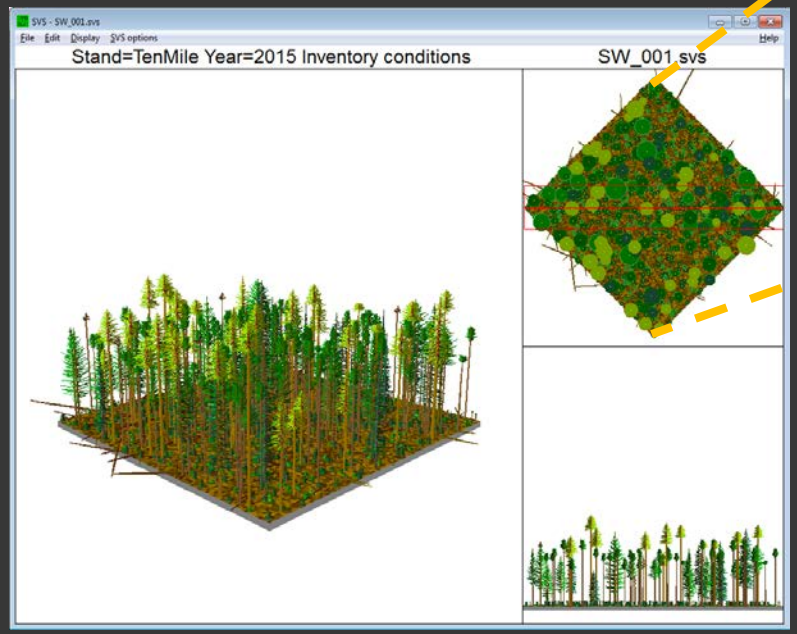
- Extends FFE-FVS with alternative, high-detail fire modeling
- Accesses fuels data from FFE-FVS using pyFVS
- Builds off SVS treelist file or real world spatial forest data
- Growth over time comes from FVS
- Relies on CAPSIS and FireLib for spatial fuel modeling
  - Extend data statistically to larger areas
  - Quantification of fuels in voxels
- Opens door for more in-depth assessments of fuel treatments or other fuel changes

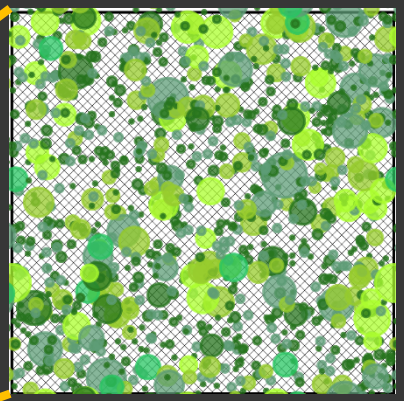
Architecture

- Python: pyFVS (open source interface to FVS model)
- Java: CAPSIS + FireLib (implements FuelManager concepts)
- Modular design enables testing of new components

Getting fuels data into 3D

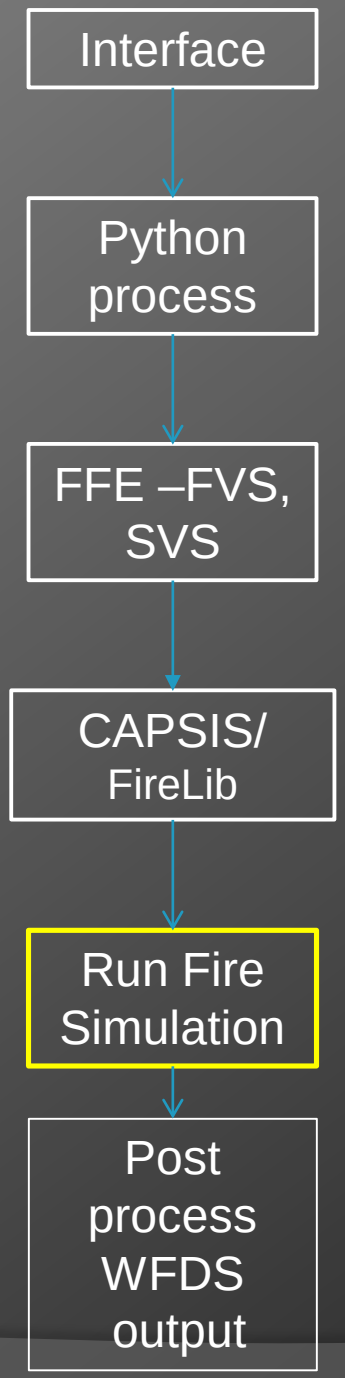
- We need trees with coordinates for 3D modeling
- Stem mapped stand data is still rare, so STANDFIRE builds upon the SVS stand.
- Currently developing LiDAR stem map input process.



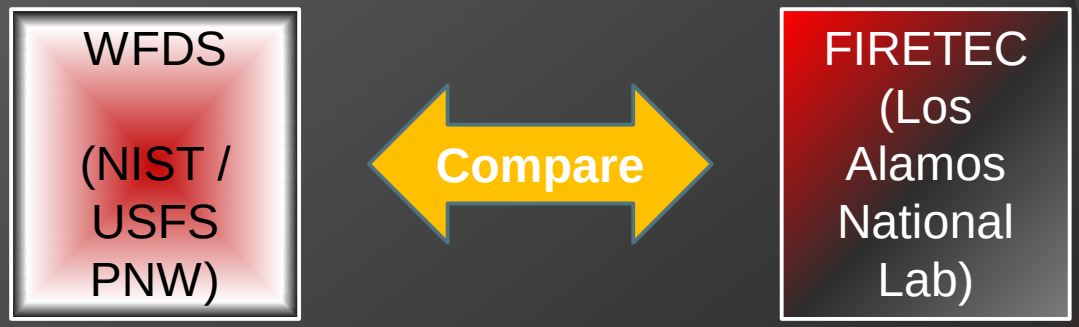


SVS view of a stand

Running 3D fire models



STANDFIRE produces input files for two distinct and independent physics-based fire models



About physics-based fire models

Driven by first principles

Hydrodynamics (CFD) modeling

- Solve Navier-Stokes equations
- Emergent behaviors
  - Flow of wind around trees and topography
  - Fire spread

Computationally intensive

- Multiprocessor computers
- Slower than real time

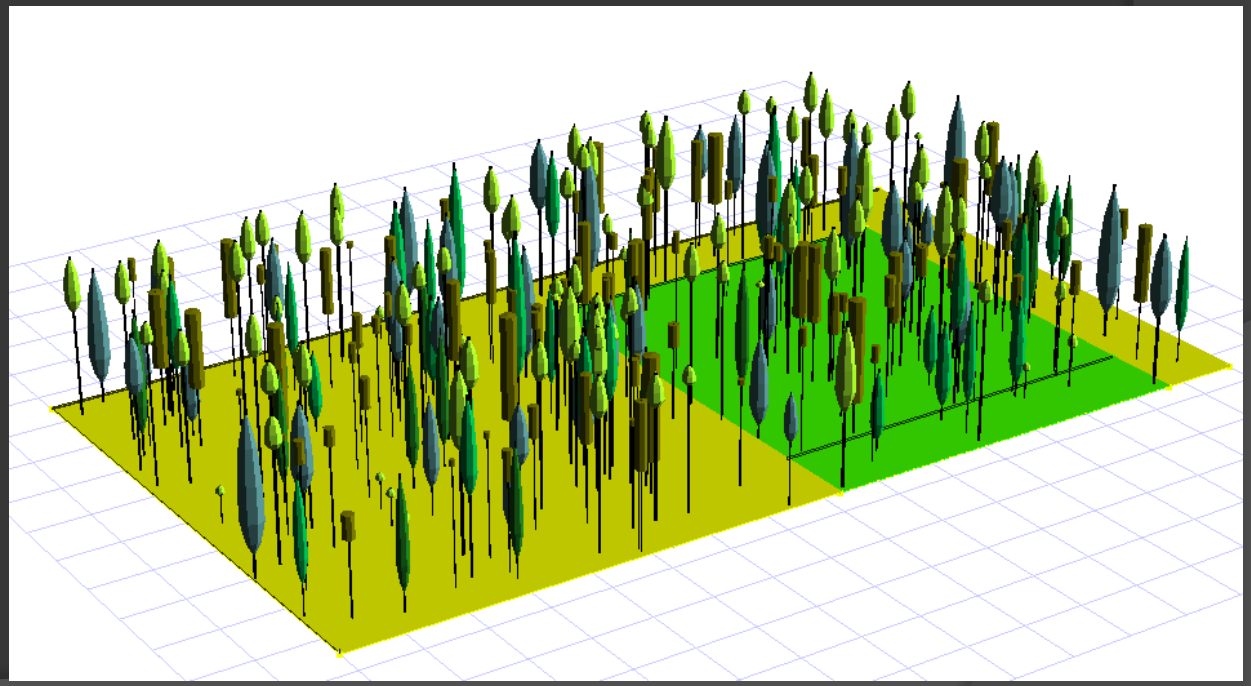
CAPSIS FireLib

http://www.inra.fr/capsis

Interface → Python process → FFE –FVS, SVS → CAPSIS/ FireLib → Run Fire Simulation → Post process WFDS output

CAPSIS – Computer Aided Projections of Strategies in Silviculture

- Open software forestry modeling platform (INRA, France)
  - Modular framework, common architecture
  - Facilitates connections between models
  - FuelManager and STANDFIRE both use FireLib
- In STANDFIRE, CAPSIS Firelib provides:
  - Visualization, analysis and I/O capabilities
  - 3D geometry calculations for biomass allocation to voxels
  - Capability to develop complex, spatially explicit treatments



STANDFIRE CAPSIS Interactive 3D viewer