A wildland fire modeling and visualization environment

Jan Mandel, University of Colorado, Denver, CO; and J. D. Beezley, A. Kochanski, V. Y. Kondratenko, L. Zhang, E. Anderson, J. Daniels II, C. T. Silva, and C. Johnson

Acknowledgements

- Janice Coen, Ned Patton, John Michalakes, NCAR
- Eric Jorgensen, Bigyan Muherjee, Mavin Martin, Paul Rosen, University of Utah
- Craig Clements, San Jose State University
- Bedrich Sousedik, now at Univ. of Southern California
- Nina Dobrinkova, Georgi Jordanov, Bulgarian Academy of Sciences
- Barry Lynn and Guy Kelman, Weather-It-Is, LTD
- NSF grant ATM-0835579
- NIST Fire Research Grants Program 60NANB7D6144
- NSF grant CNS-0821794 (Janus supercomputer)

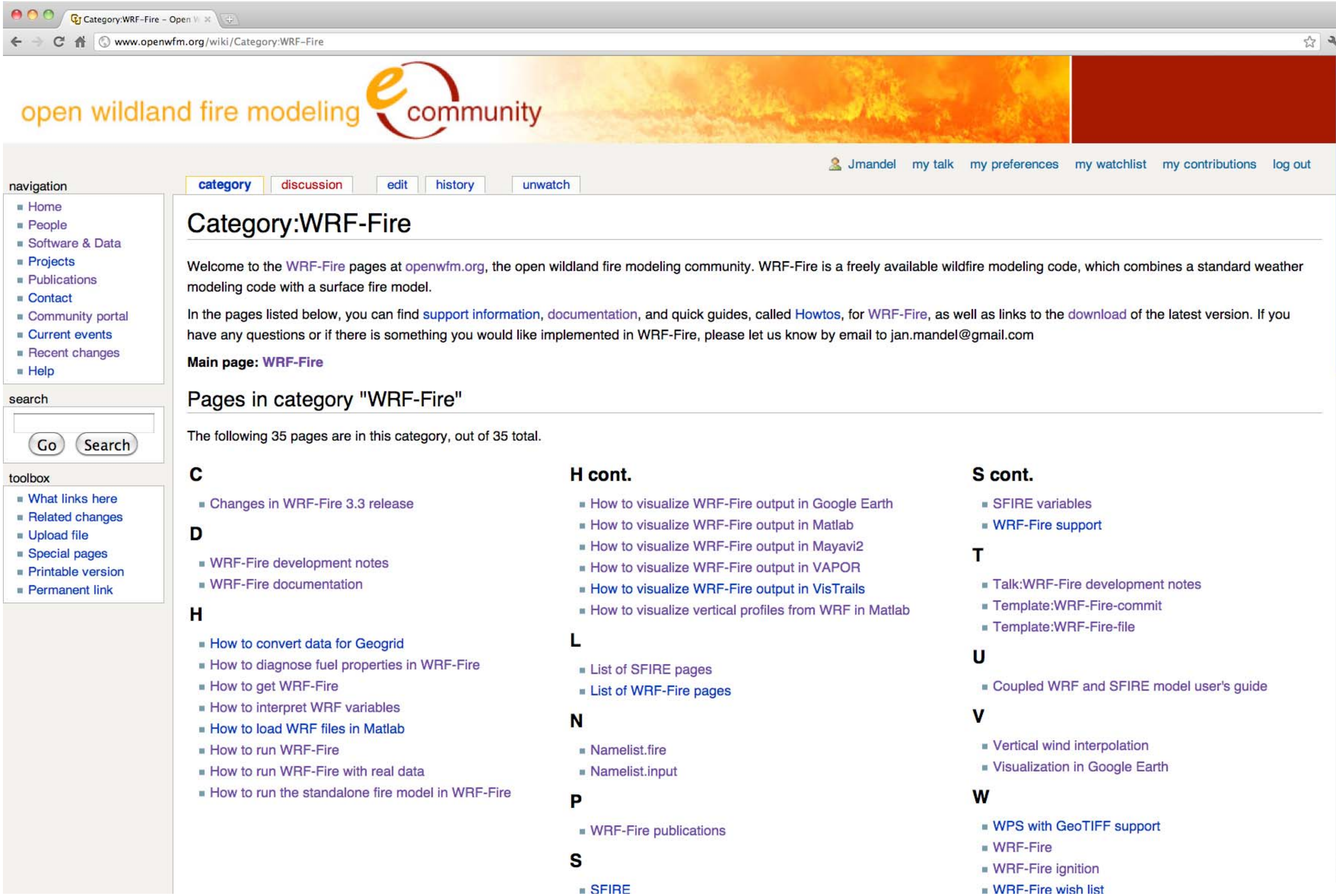
OpenWFM.org components

- 2D fire spread model coupled with WRF
  - A code with a subset of features is distributed with WRF release as WRF-Fire.
  - The current development version available on openwfm.org as WRF coupled with SFIRE.
- Extended WRF Preprocessing System (WPS)
- Wiki: guides, links to software repositories
- Utilities
  – Visualization, Data preprocessing, Diagnostics
- Web interfaces, data assimilation (future)

Objectives and design limitations

- Model faster than real time
  - Fast enough for forecasting at 100m atmosphere and 10m fire scale
  - Fire parameterization to capture essential fire behavior and feedback on the atmosphere
- Open source, collaborative development
  - Public read access to source code repositories
  - Invite collaborations
- Subject to WRF programming conventions for WRF release
  - Affects the choice of algorithms
- Data assimilation
  - Modify the state (atmosphere, fire position,…) and parameters (fuels, spread rate,…) of the running coupled model in response to data
  - This is the overall goal but we had to have a suitable model first.

http://www.openwfm.org/wiki/List_of_SFIRE_pages



Origins

- USDA Forest Service wildfire modeling system: BEHAVE - fire properties at one point, FARSITE - surface fire spread

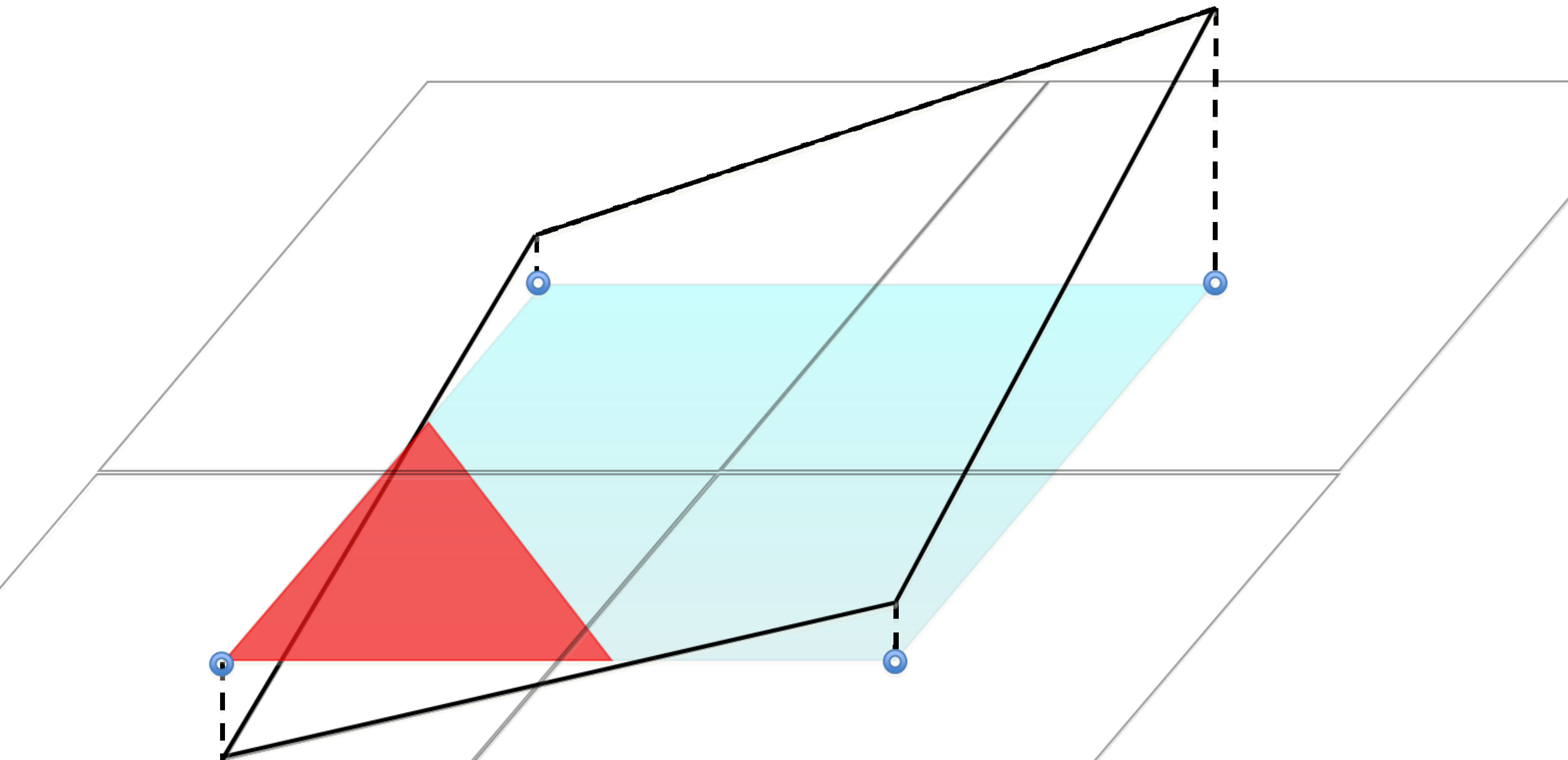
- NCAR's Coupled Atmosphere-Wildland Fire Enviroment (CAWFE), based on the Clark-Hall research weather code, fire propagation by tracers

- The Weather Research and Forecasting model (WRF)
  - A standard, well structured, extensible, massively parallel, and evolving
  - **Supported**, community code
  - Preprocessing for standard meteorological data
  - Built-in export/import of state – essential for data assimilation!

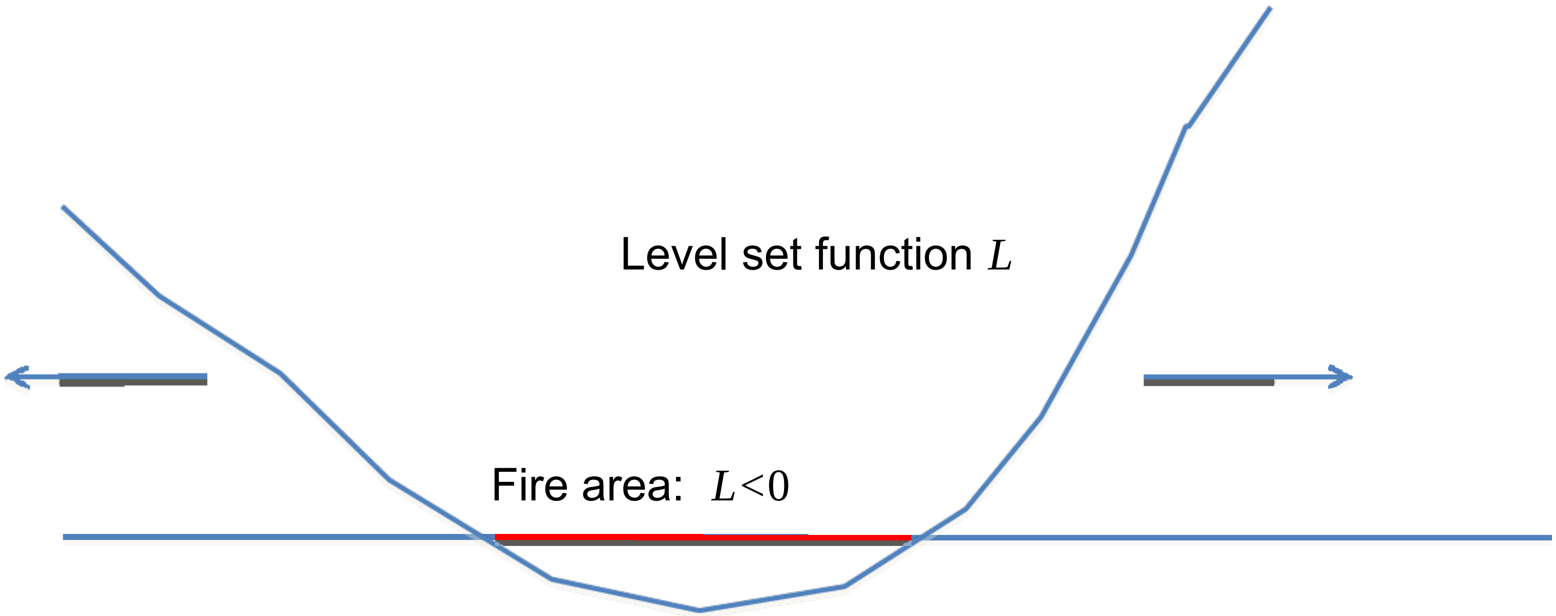
- Fire spread model by the level set method
  - Supports BEHAVE fire spread formulas
  - Flexible for easy implementation of various features
  - The fire location can be **changed by a modifying gridded array** – no tracers
  - Better suited for **data assimilation**

Representation of the fire area by a level set function

- The level set function is given on center nodes of the fire mesh
- Interpolated linearly, parallel to the mesh lines
- Fireline connects the points where the interpolated values are zero



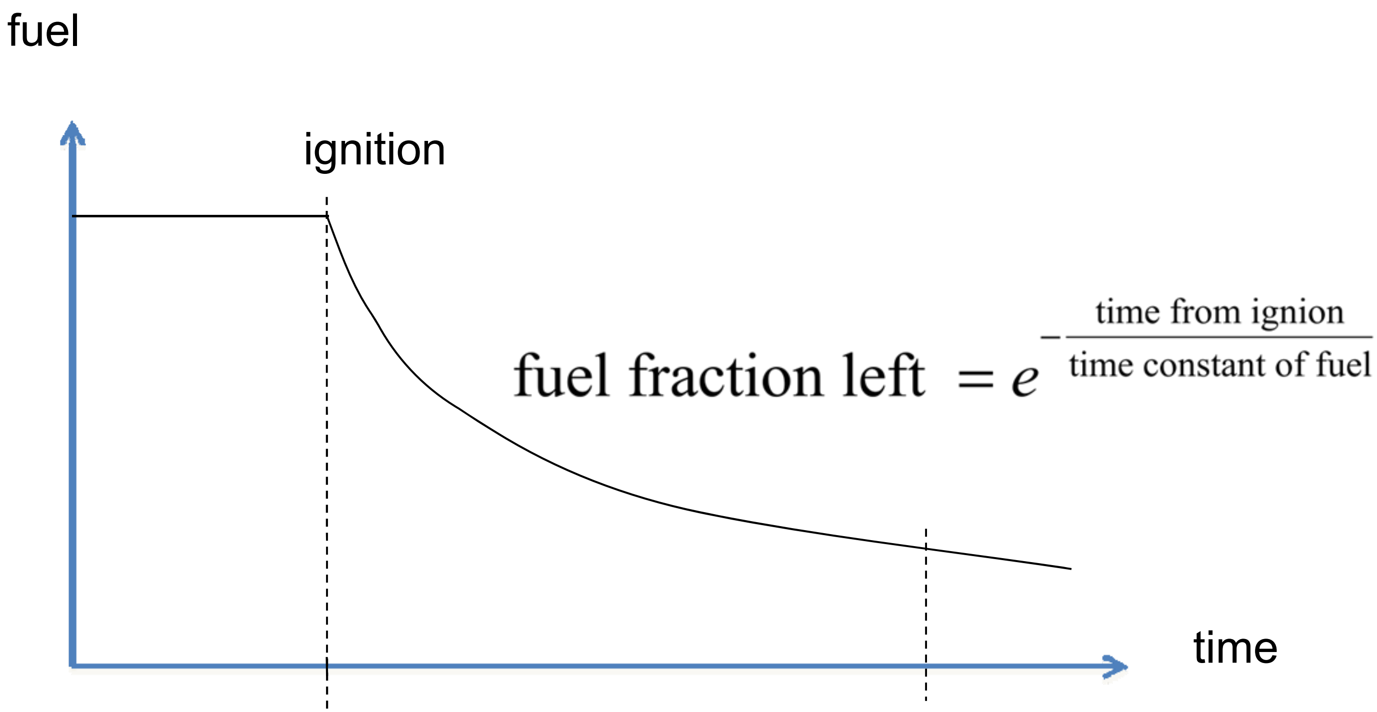
Evolving the fireline by the level set method



Level set equation $$\frac{\partial L}{\partial t} = -R \,||\, \nabla L \,||$$

Right-hand side < 0 → Level set function goes down → fire area grows

The fire model: fuel consumption



$$\text{fuel fraction left} = e^{-\frac{\text{time from ignion}}{\text{time constant of fuel}}}$$

Time constant of fuel:

30 sec - Grass burns quickly
1000 sec – Dead & down branches(~40% decrease in mass over 10 min)

Coupling with WRF-ARW

- WRF-ARW is explicit in time – **short time step needed**
- Fire is a physics package, called only in the last Runge-Kutta substep
- Fire module inputs wind, outputs heat and vapor flux

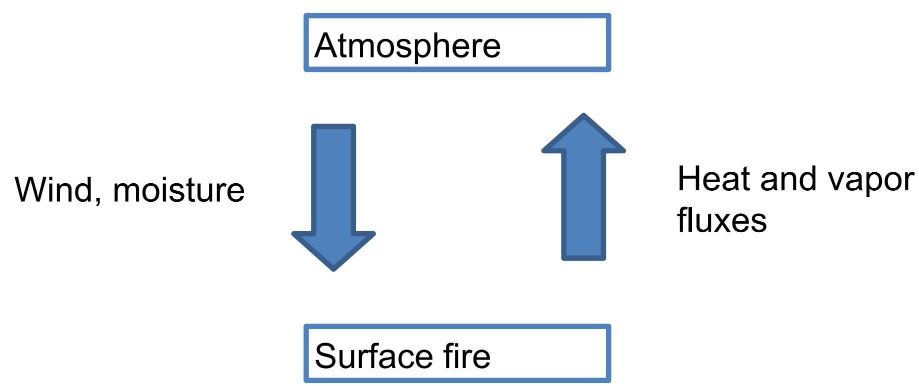
$$\frac{\partial \Phi}{\partial t} = R(\Phi)$$

$$\Phi^{*} = \Phi^{t} + \frac{\Delta t}{3} R\left(\Phi^{t}\right)$$

$$\Phi^{**} = \Phi^{t} + \frac{\Delta t}{2} R\left(\Phi^{*}\right)$$

$$\Phi^{t+\Delta t} = \Phi^{t} + \Delta t R\left(\Phi^{**}\right)$$

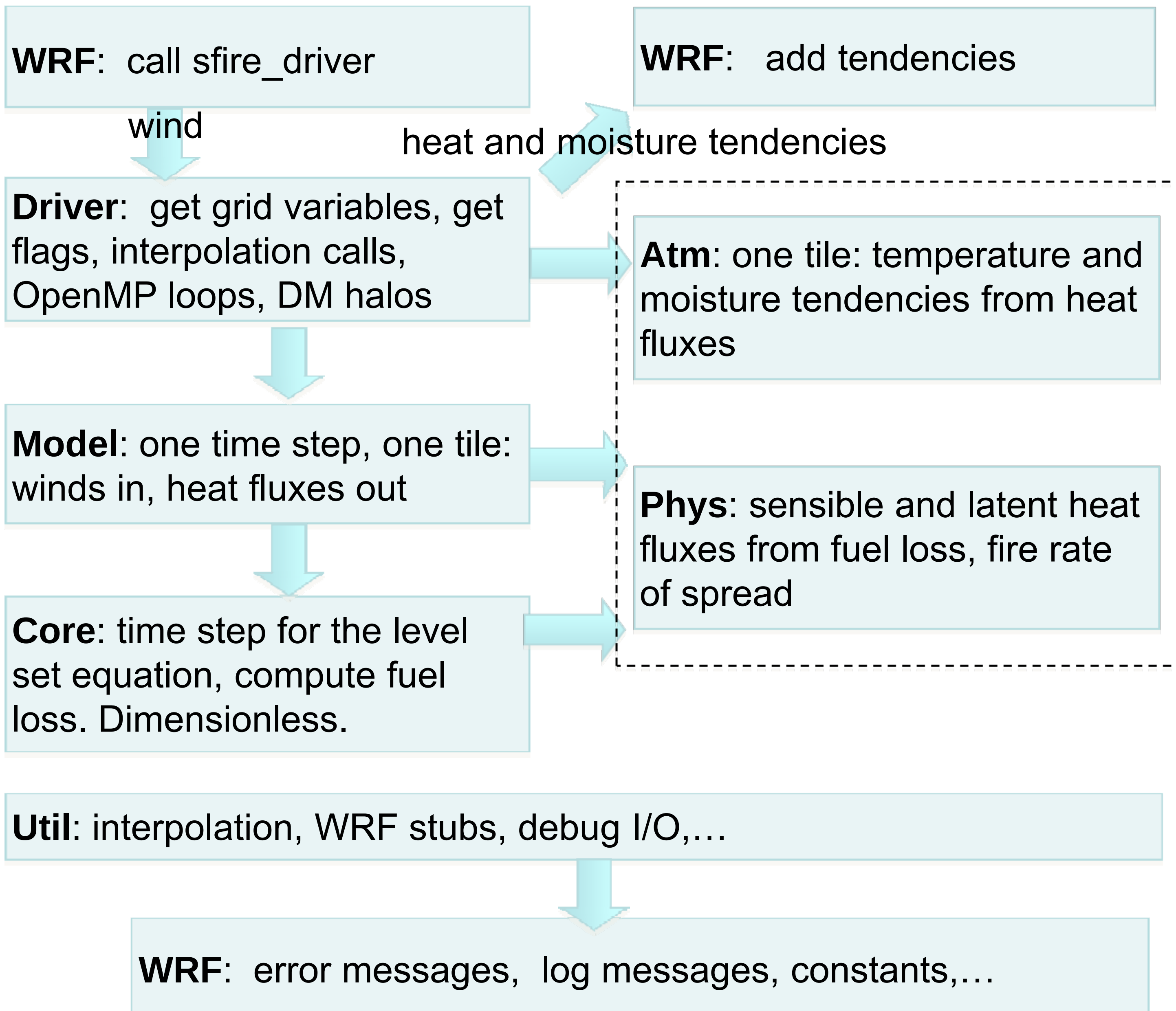
Runge-Kutta order 3 integration in time



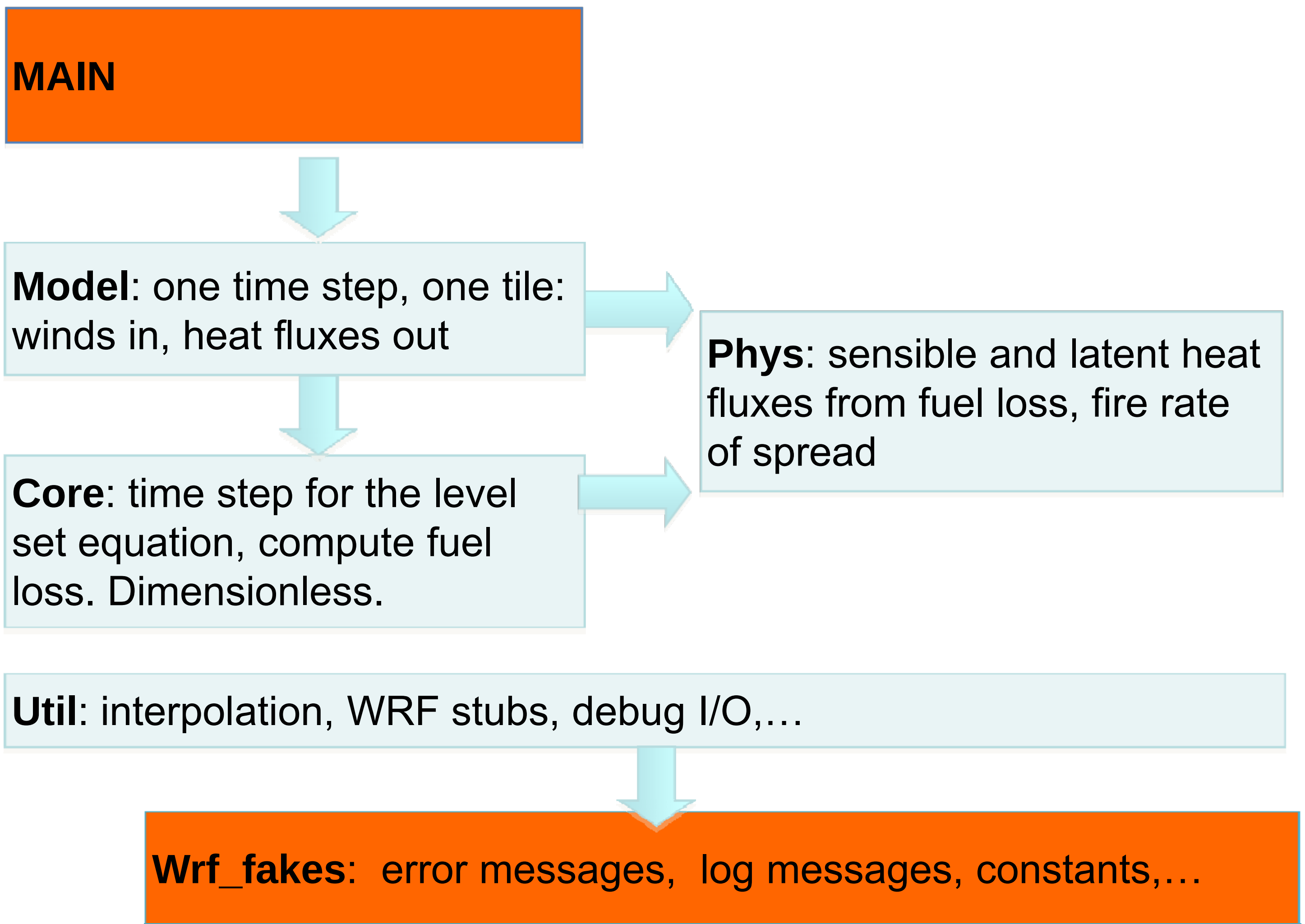
Wind interpolation

- Spread rates for different fuels depend on **wind at different heights**
- Interpolation to 6m from ideal logarithmic profile, then apply BEHAVE wind reduction factors to fuel-dependent heights.
  - But this throws away information if there are WRF levels under 6m.
- Better: Interpolate the horizontal wind to the appropriate heights from the WRF mesh directly
  - Exact if the wind profile is exactly logarithmic (just like piecewise linear interpolation is exact for linear functions)
  - If there are no WRF nodes under 6m, mathematically equivalent to the reduction factors
  - Tricky
    - The heights of the nodes are computed from the geopotential, a part of the solution
    - The geopotential varies a lot above the fire
    - The atmospheric and fire mesh have different resolutions
    - The result depends on the roughness length.
    - Take the roughness length from LANDUSE or fuels?

Software Structure

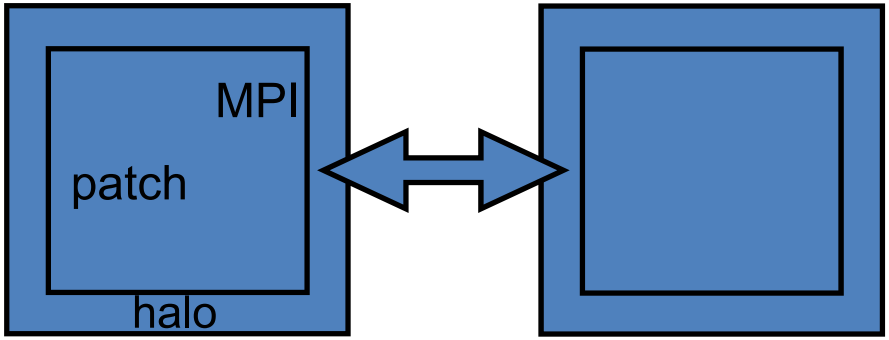


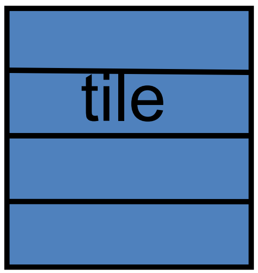
Standalone fire code



WRF parallel infrastructure

- Distributed memory (DM): **halo exchanges** between grid **patches**: each patch runs in one MPI process; programmer only lists the variables to exchange
- Shared memory (SM): **OpenMP loops** over **tiles** within the patch
- Computational routines are **tile callable**. They can read from a **layer of cells** beyond the tile but must avoid race conditions: no writing into an array that another tile may read a boundary layer from



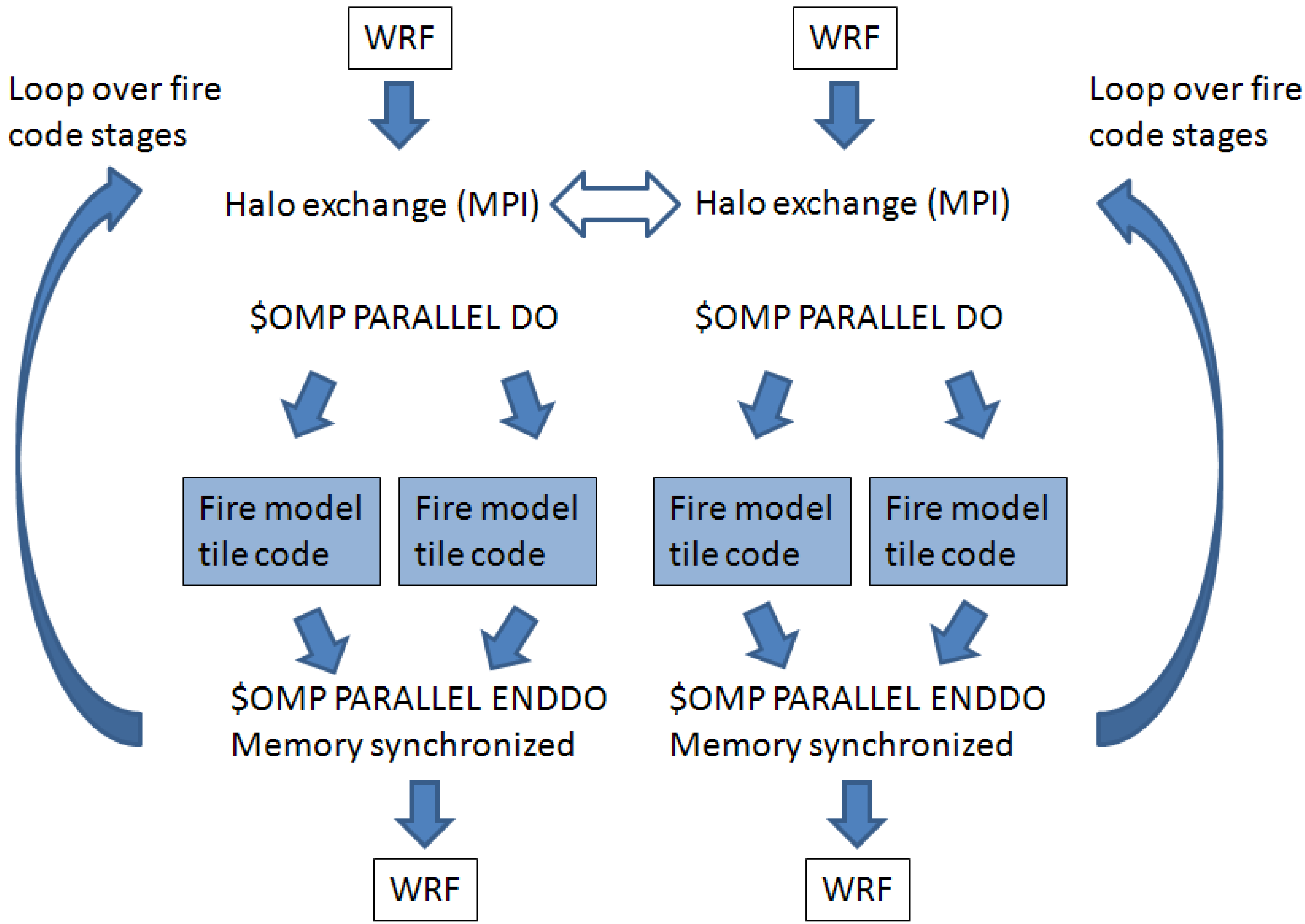


OpenMP threads, multicore

Example: 2 MPI processes 4 threads each

Compliance affects the choice of numerical algorithms!

Parallelism in WRF-Fire: implementing a PDE solver in the WRF physics layer, meant for pointwise calculations

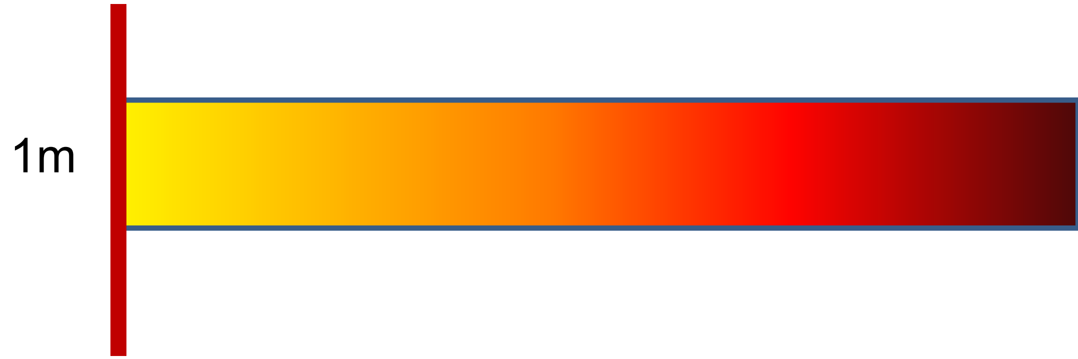


Diagnostic outputs

- Heat flux (reaction intensity) ($J/m^2/s$)
- Rate of spread (m/s)
- Fireline intensity
  - Byram(J/m/s)
  - **new fireline intensity ($J/m/s^2$)**
- For the actual fire modeled: at the fireline only
- For a **fire danger rating**: everywhere, with the rate of spread taken as the maximum rate in any direction.

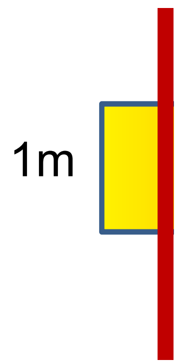
Fireline intensity

Byram's: heat per unit length of the fireline from all available fuel burning in 1s, regardless how far, does not depend on the speed of burning (J/m/s)



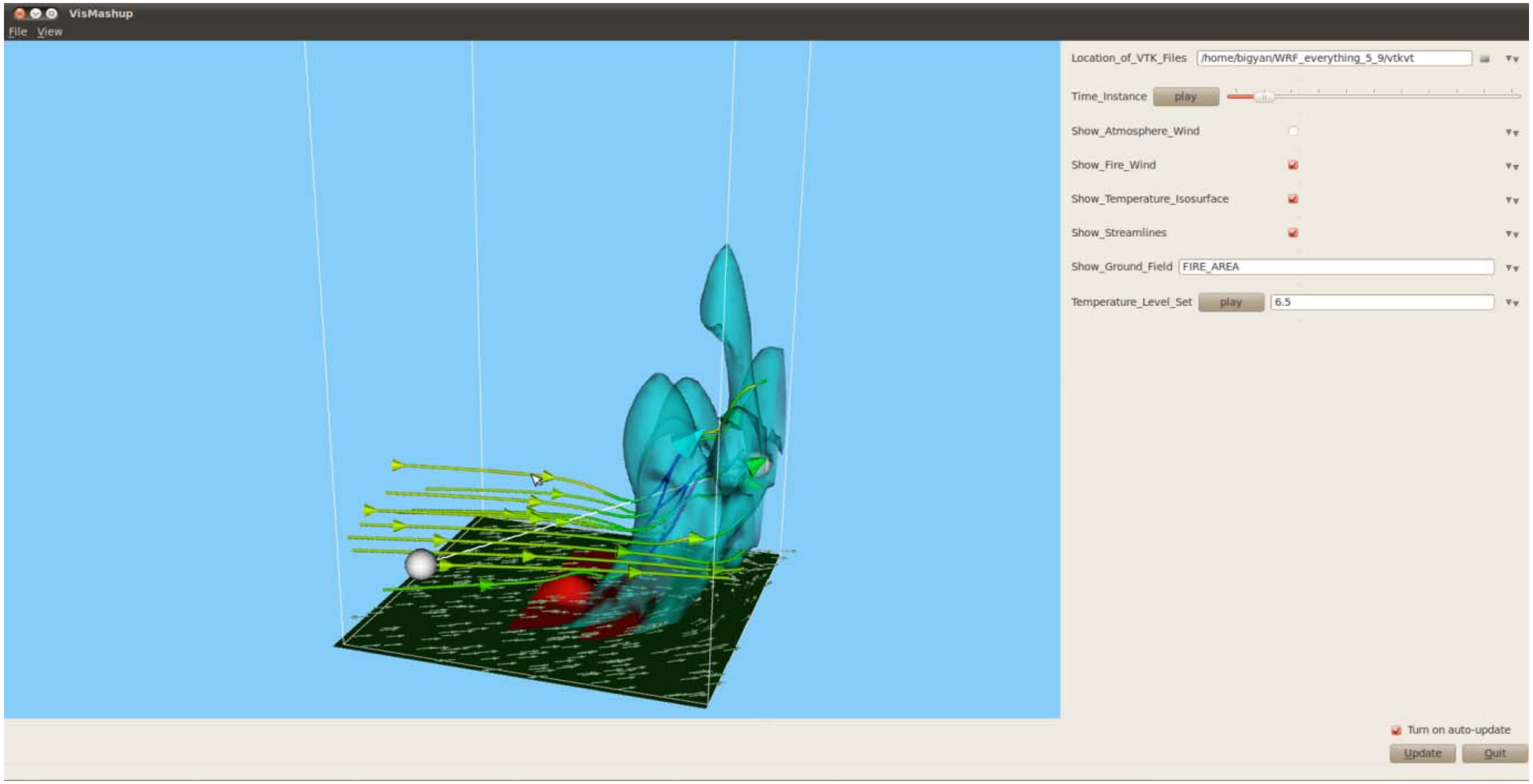
$$\text{spread rate (m / s)} * \text{heat contents of fuel (J/kg)} * \text{available fuel (kg/m}^2\text{)}$$

New: heat per unit length of the fireline from the **newly burning fuel only** the fireline moves over in a small unit of time (**J/m/s²**)



$$\frac{1}{2}\frac{\text{spread rate (m / s)} * \text{heat contents of fuel (J/kg)} * \text{available fuel (kg/m}^2\text{)}}{\text{burn time (s)}}$$

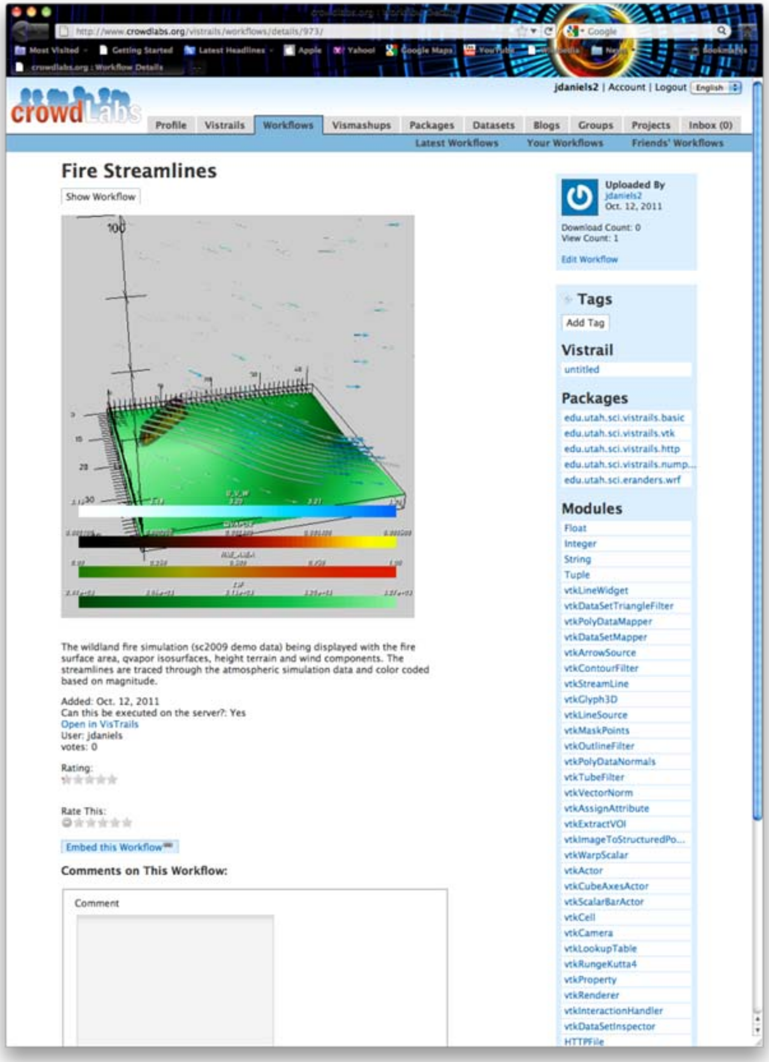
Walk-through desktop client: VisTrails/VisMashups

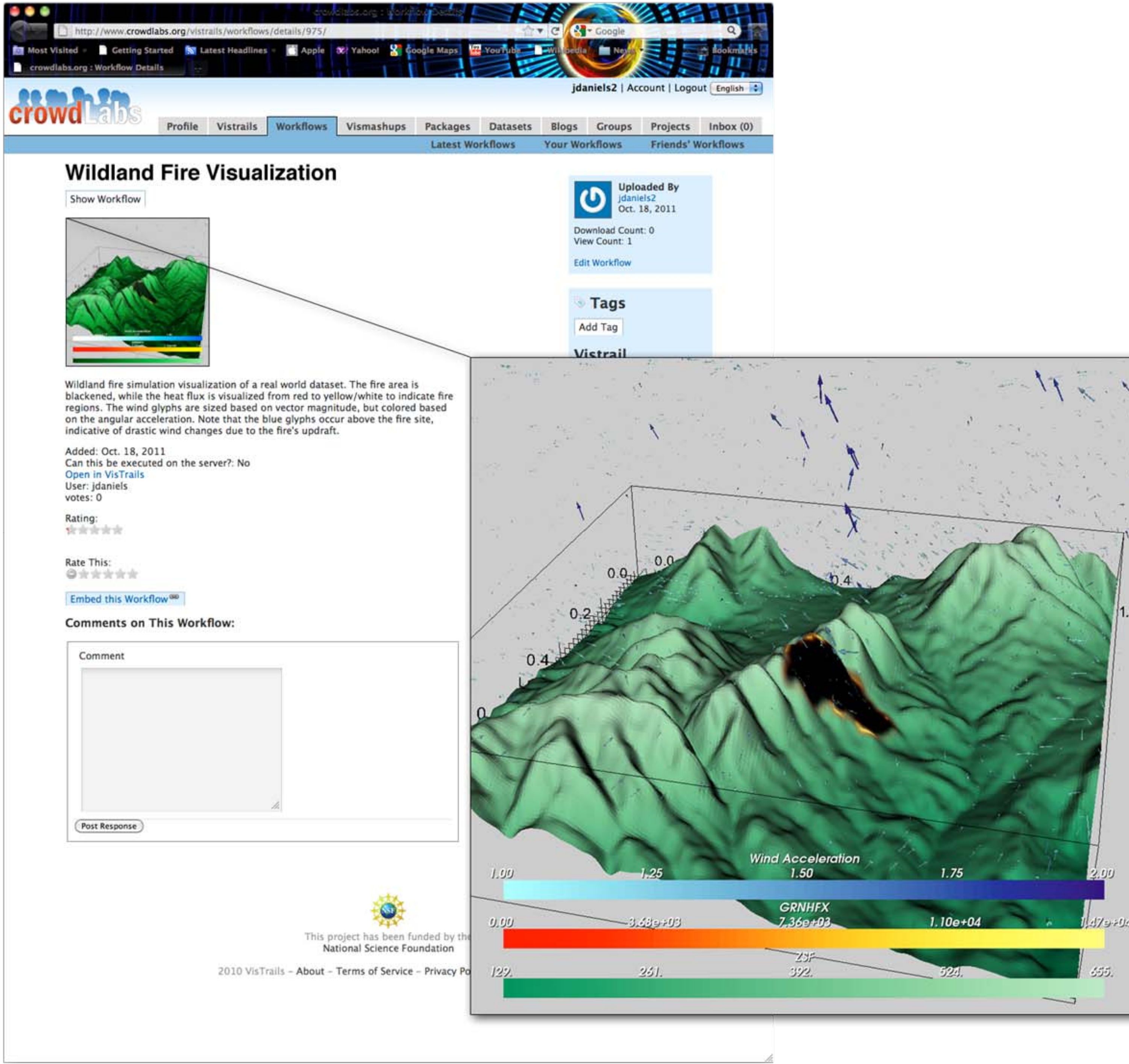


- Simplified development of user interfaces inVisTrails
- save simulation, data, process, and **user settings** as a **workflow**

Web-based interface: CrowdLabs

- VisMashups on the web
- Integrates social web site and scalable evironment to collaboratively analyze and visualize data
- For now, from stored simulations
- Future: communicate with a supercomputing server to run simulations

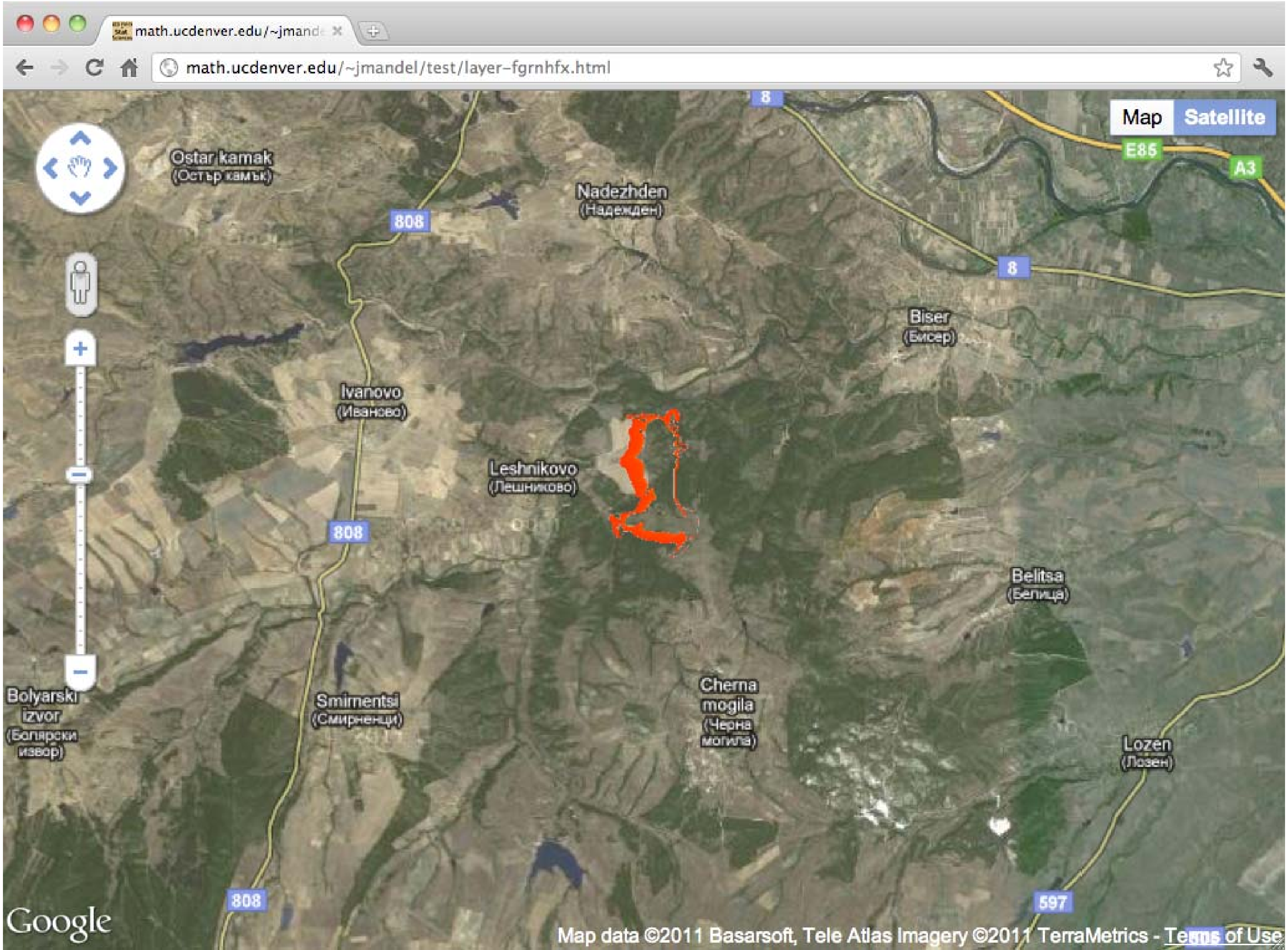



http://www.crowdlabs.org/vistrails/workflows/details/975/
jdaniels2 | Account | Logout
crowdLabs
Profile
Vistrails
Workflows
Vismashups
Packages
Datasets
Blogs
Groups
Projects
Inbox (0)
Latest Workflows
Your Workflows
Friends' Workflows
Wildland Fire Visualization
Show Workflow
Uploaded By
jdaniels2
Oct. 18, 2011
Download Count: 0
View Count: 1
Edit Workflow
Tags
Add Tag
Wildland fire simulation visualization of a real world dataset. The fire area is blackened, while the heat flux is visualized from red to yellow/white to indicate fire regions. The wind glyphs are sized based on vector magnitude, but colored based on the angular acceleration. Note that the blue glyphs occur above the fire site, indicative of drastic wind changes due to the fire's updraft.
Added: Oct. 18, 2011
Can this be executed on the server?: No
Open in VisTrails
User: jdaniels
votes: 0
Rating:
Rate This:
Embed this Workflow
Comments on This Workflow:
Comment
Post Response
This project has been funded by the
National Science Foundation
2010 VisTrails - About - Terms of Service
Wind Acceleration
1.00
1.25
1.50
1.75
2.00
GRNHFX
0.00
3.68e+03
7.36e+03
1.10e+04
1.47e+04
ZSF
129.
261.
392.
524.
655.

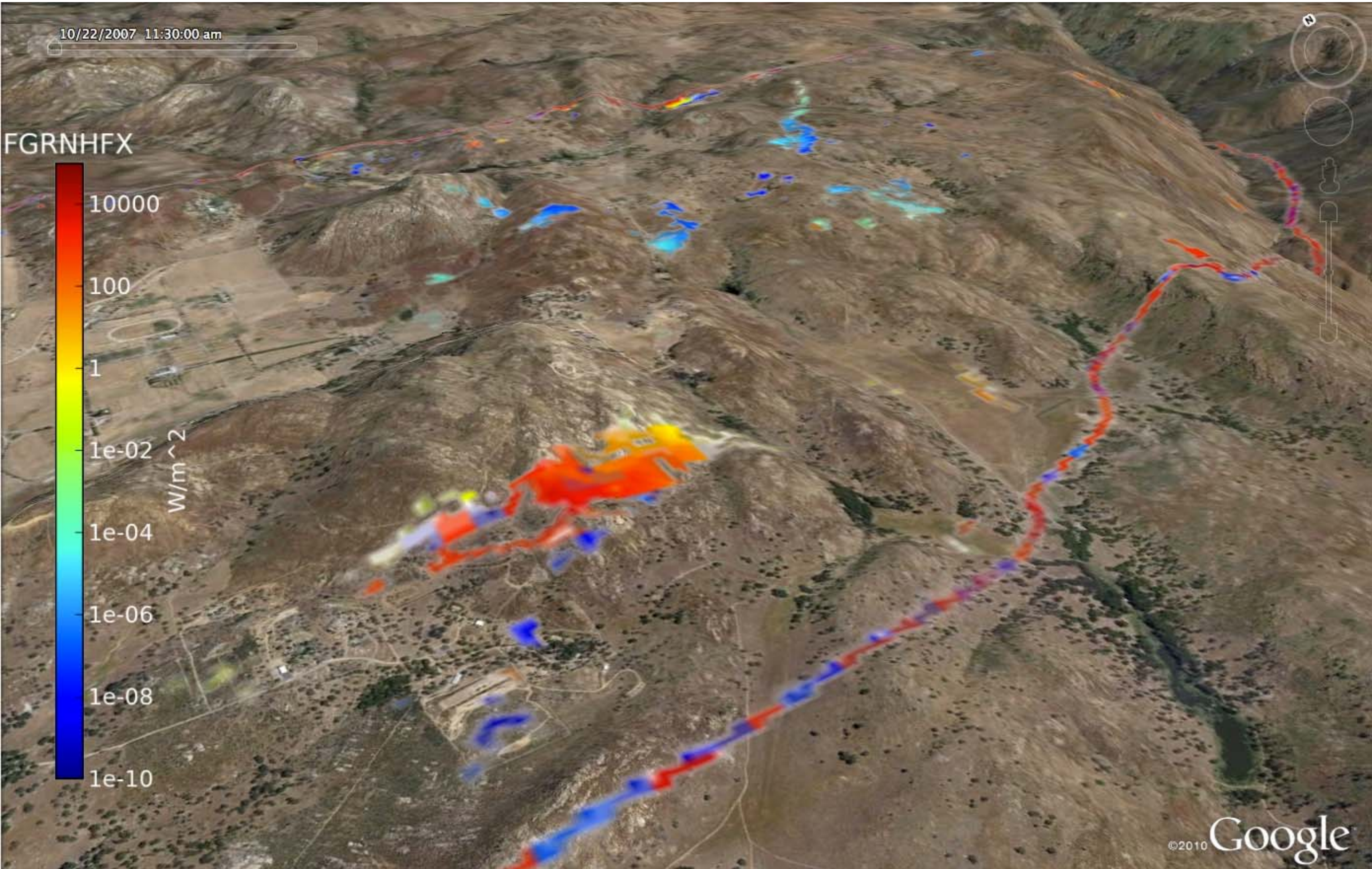
Web-based interface: Google Earth and Google Maps

- The same KML files display in both
- **A de-facto standard for wildland fire information**
- Simulation layer combines with other information (perimeter, images,…)
  - Animation in Google Maps
  - Manually advanced frames and a fly-through in Google Earth
- Near future: start and control simulation on a supercomputing server, use automatically retrieved fuel, topography, and meteorological data

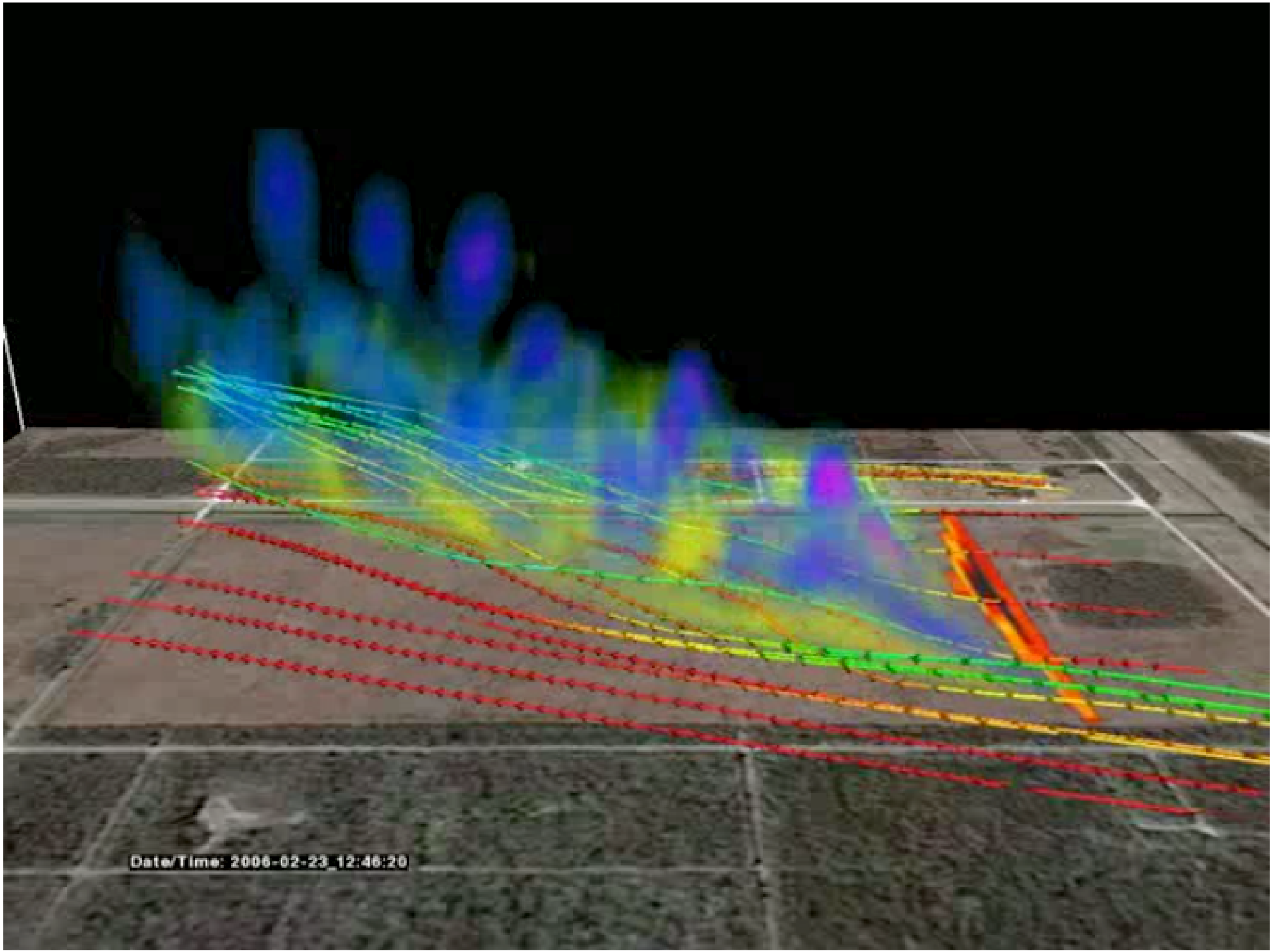
Web-based interface: Google Maps



Fire heat flux in Google Earth



Simulation of the FireFlux experiment (Clements et al. 2007)



2007 Witch fire Model Setup

- Atmospheric domains:

D01 120x96 32km resolution

D02 121x97 10.6km resolution

D03 126x103 3.5km resolution

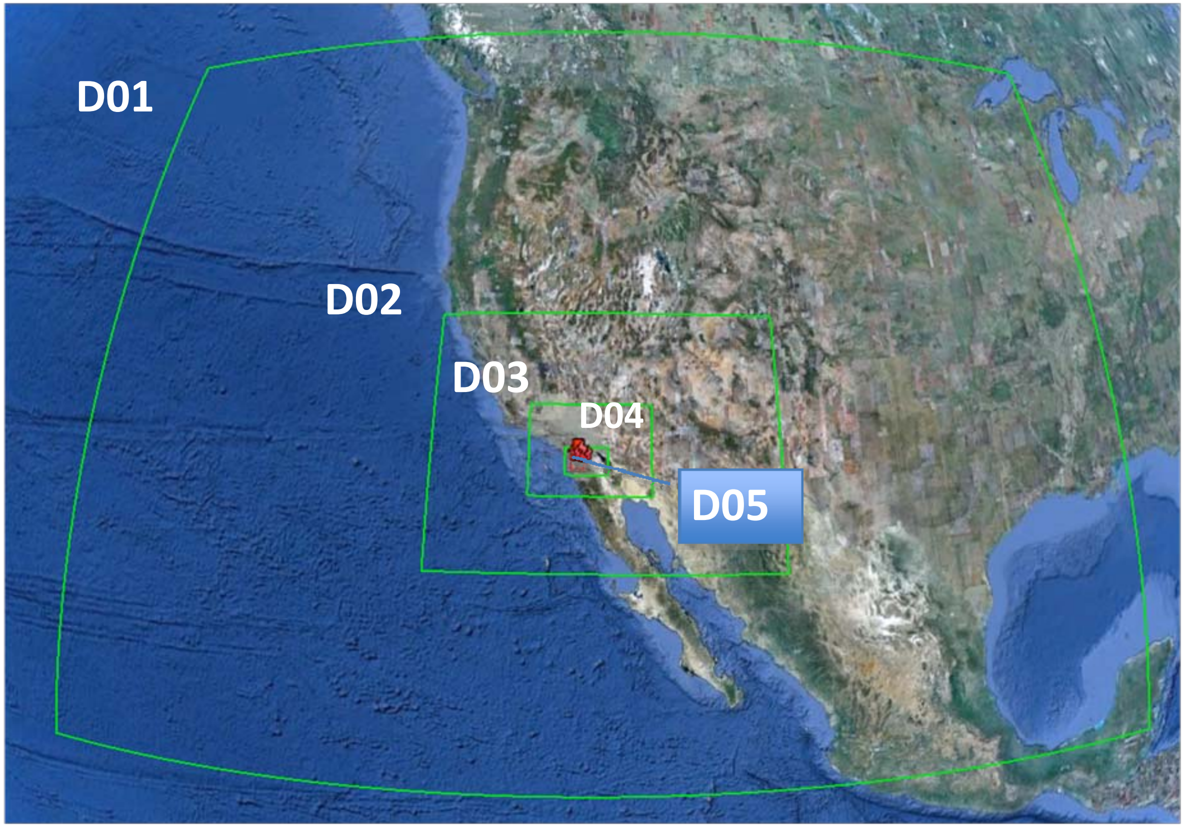
D04 135x94 1.18km resolution

D05 155x118 390m resolution

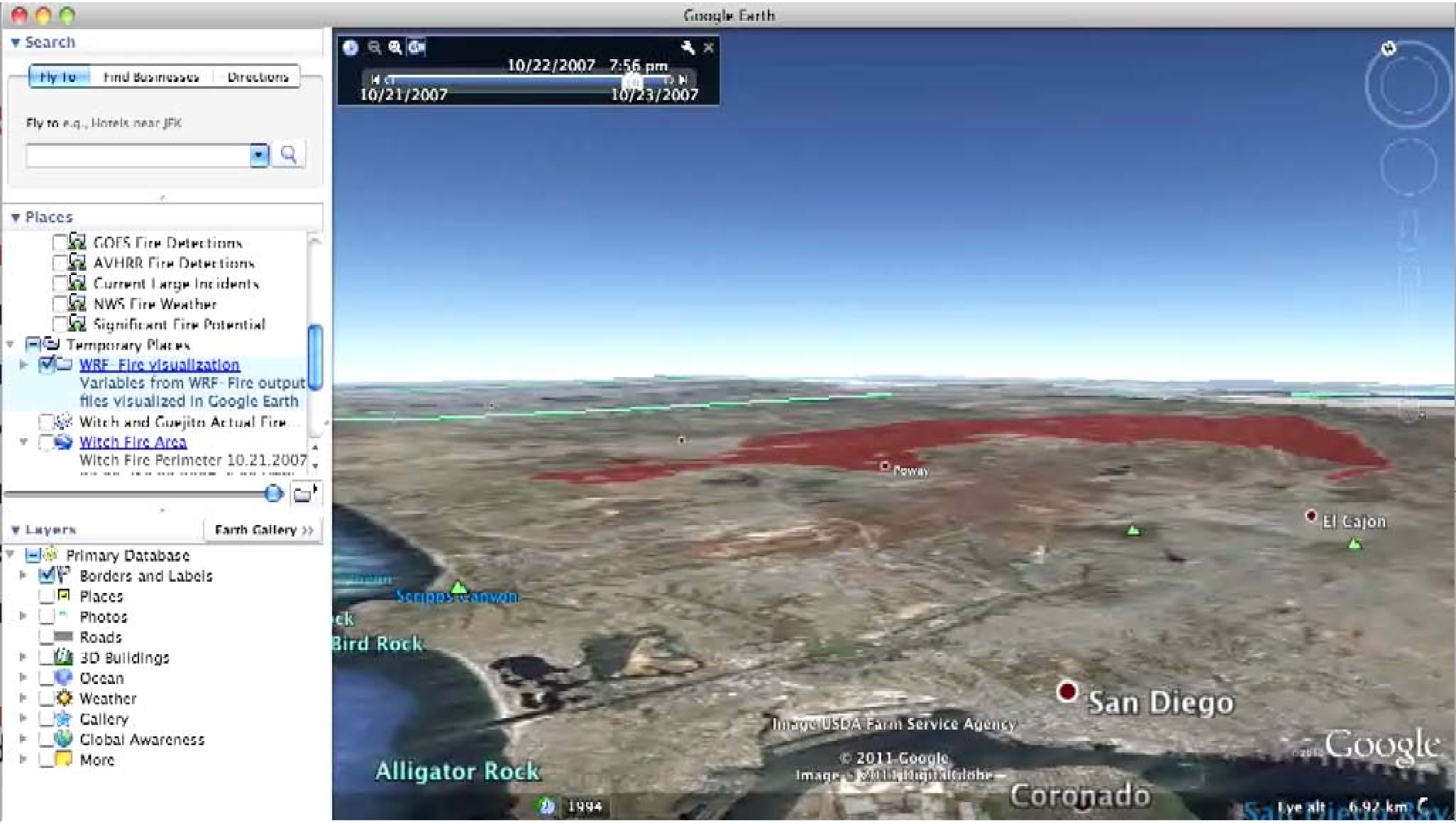
- **Fire model**

Nested in D05

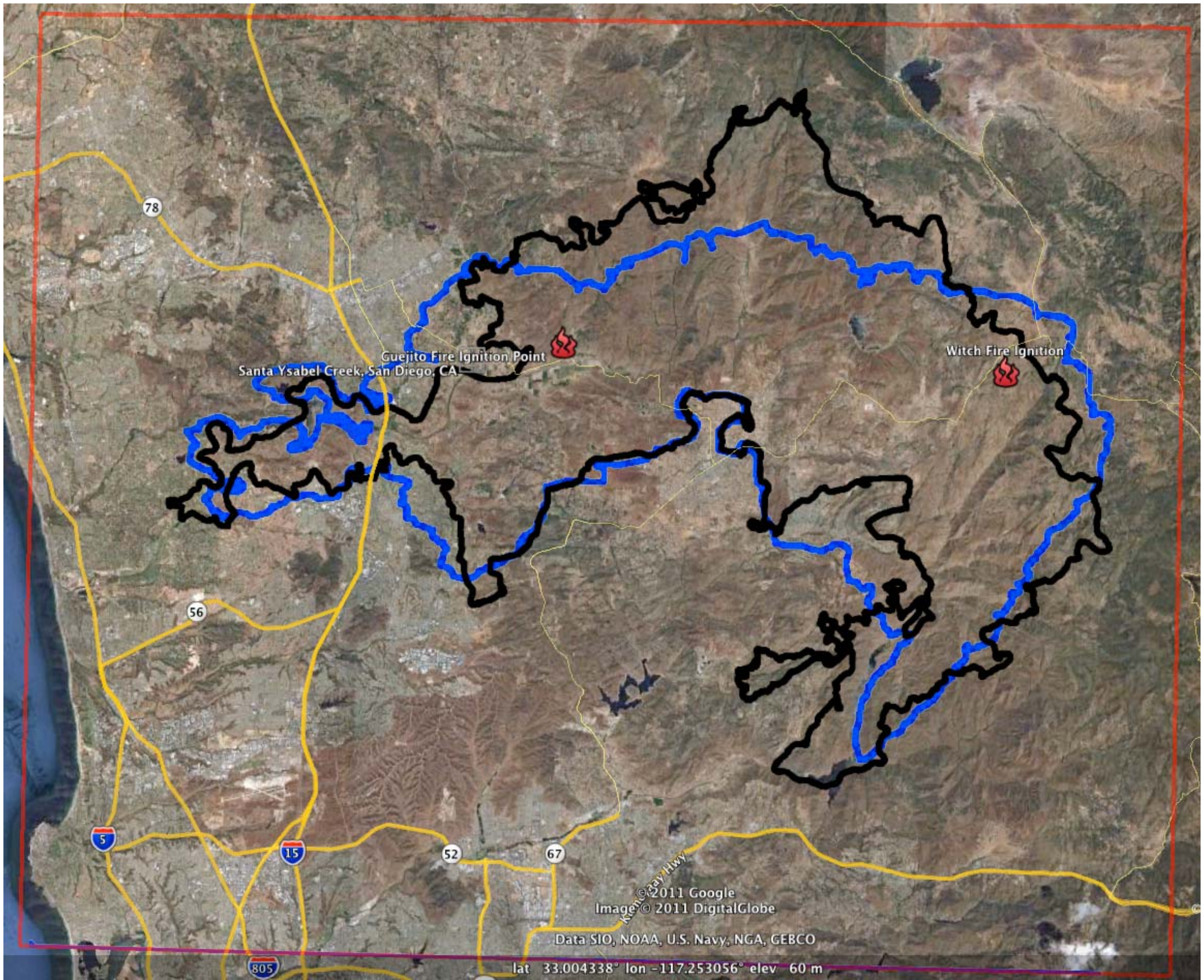
3100x2360, 19.5m resolution



2007 Witch fire burned area



2007 Witch fire
WRF Fire perimeter (blue)
observed fire perimeter (black)



Current and future directions

- Web-based interfaces to run simulations
- Data assimilation
- Case studies, validation
- Fire code improvements
- Rothermel/BEHAVE calibrated spread rates include the feedback from the atmosphere; ours should not
- Scale dependence, role of the feedback on the atmosphere,…

References

- Jan Mandel, Jonathan D. Beezley, and Adam K. Kochanski, Coupled atmosphere-wildland fire modeling with WRF 3.3 and SFIRE 2011, Geoscientific Model Development 4, 591-610, 2011
- Jan Mandel, Jonathan D. Beezley, Janice L. Coen, and Minjeong Kim, Data Assimilation for Wildland Fires: Ensemble Kalman filters in coupled atmosphere-surface models, IEEE Control Systems Magazine 29, Issue 3, June 2009, 47-65
- P. Mates, E. Santos, J. Freire and C. Silva. CrowdLabs: Social Analysis and Visualization for the Sciences In proceedings of the 23rd International Conference on Scientific and Statistical Database Management (SSDBM), LNCS 6809/2011, pp. 555-564, 2011.
- E. Santos, Lins, L Ahrens, J.P., Freire, J, and Silva, C. T., VisMashup: Streamlining the Creation of Custom Visualization Applications, IEEE Transactions on Visualization and Computer Graphics 15 (6) 1539-1546, 2009