Presentation prepared by:

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Numerical Prediction of Fire Propagation in Idealized Wildland and Urban Canopies

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Cairns International Hotel
Cairns, North Queensland
Australia

Numerical Prediction of Fire Propagation in Idealized Wildland and Urban Canopies

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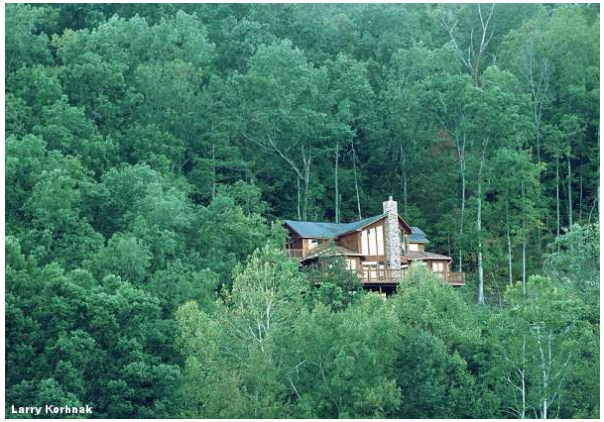
Colorado State University

Introduction

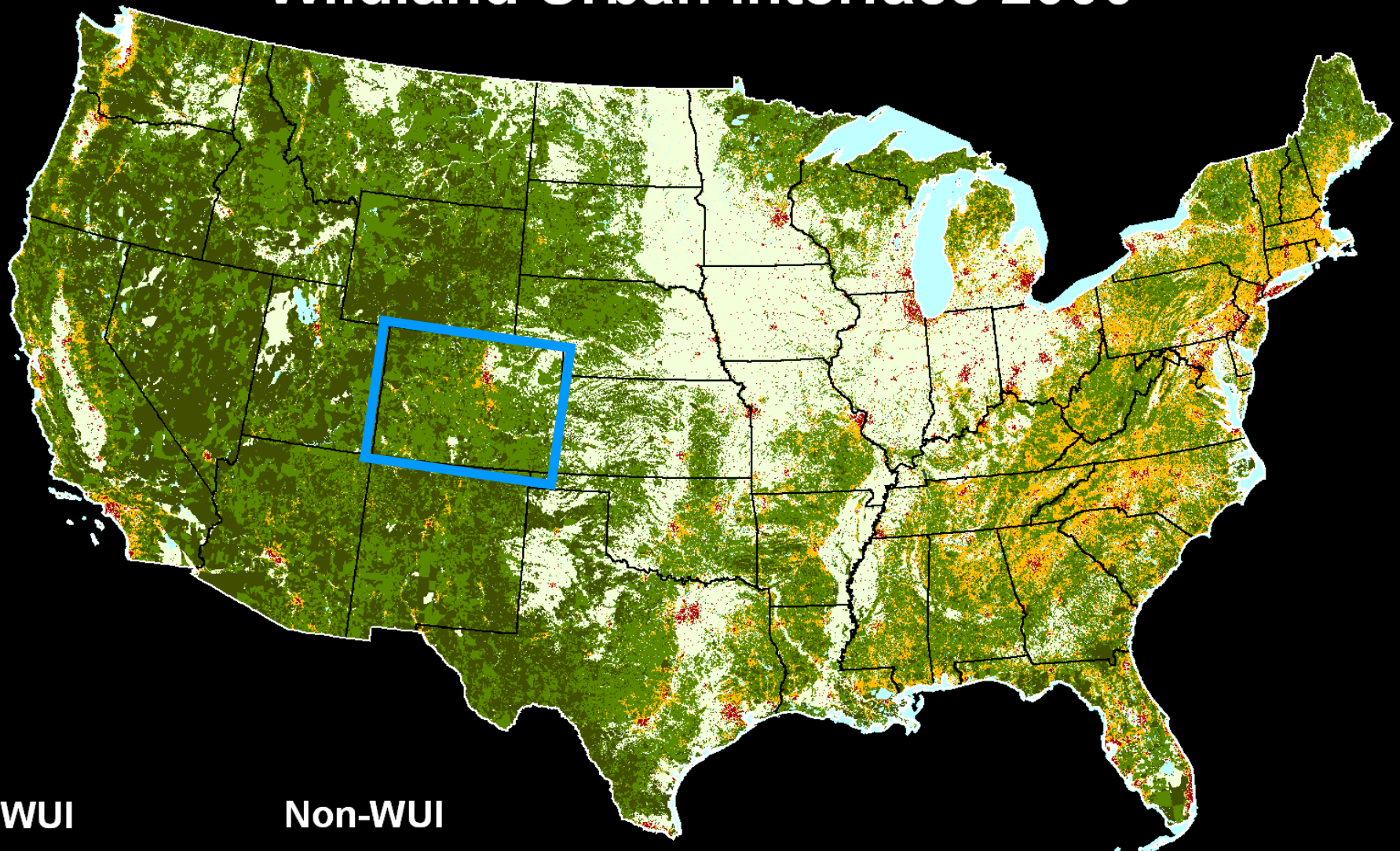
- WUI – Wildland Urban Interface
  - 9% of US land area is WUI
  - 39% of all houses are in WUI
  - up to 79% on east coast are in WUI
- Wildland/Urban Canopies
- Numerical Simulation
- CFD and Idealized Fire

Wildland-Urban Interface



- Intermix region
  - > 50 % vegetation
  - > 1 house/40 acres (16 ha)
- Interface region
  - < 50 % vegetation
  - > 1 house/40 acres (16 ha)
  - ~ 1.5 miles from region with > 75 % vegetation

Wildland Urban Interface 2000



WUI

- Intermix and interface

Non-WUI

Vegetated

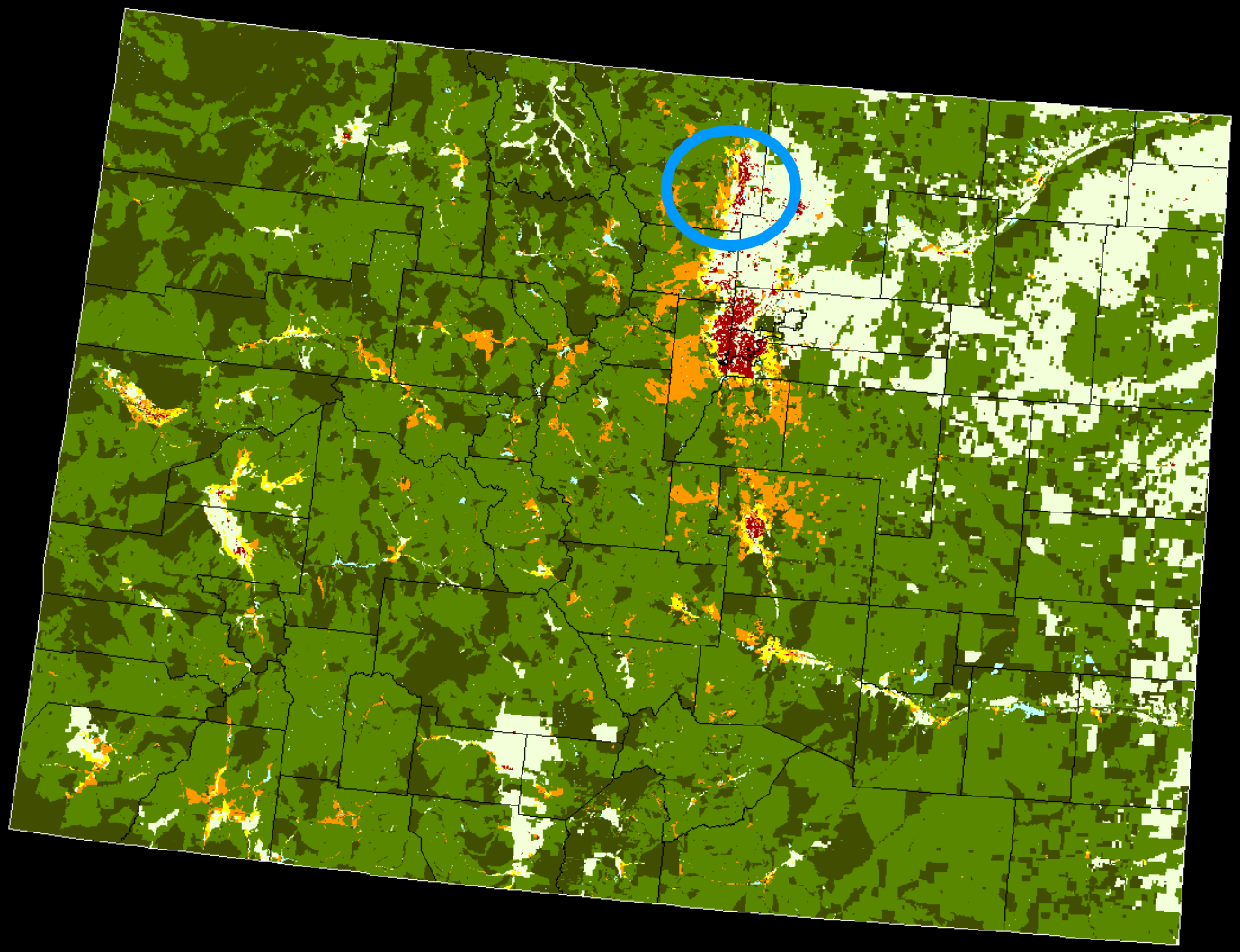
- Very low density housing
- No housing

Non-vegetated or agriculture

- High and medium density housing
- Low and very low density housing
- Water

Colorado

Wildland Urban Interface 2000



WUI

- Intermix
- Interface

Non-WUI

Vegetated

- Very Low Density Housing
- No Housing

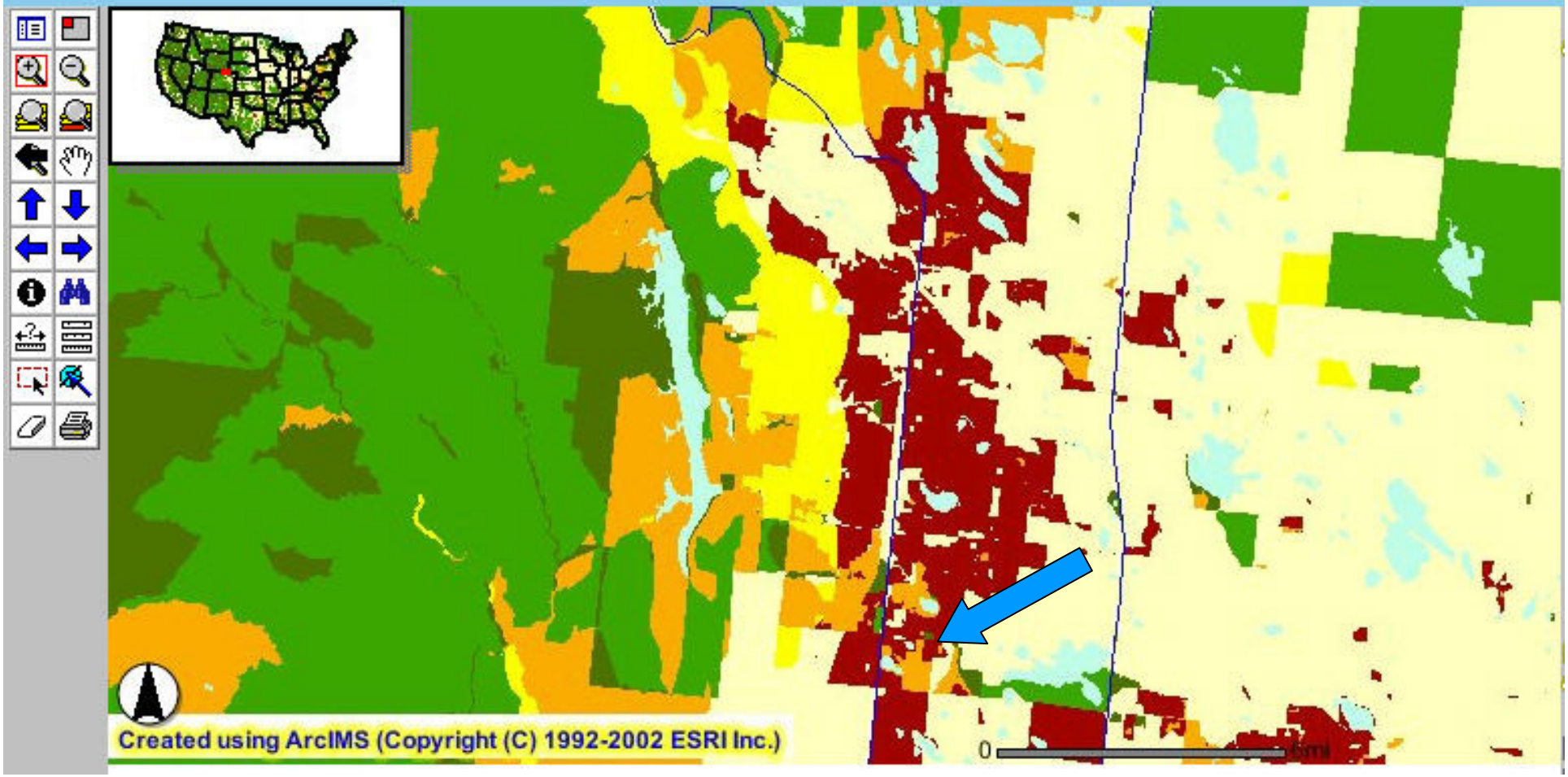
Non-Vegetated or Agriculture

- Medium and High Density Housing
- Low and Very Low Density Housing

- Water

Fort Collins, CO

Wildland Urban Interface 1990-2000



Intermix

Interface

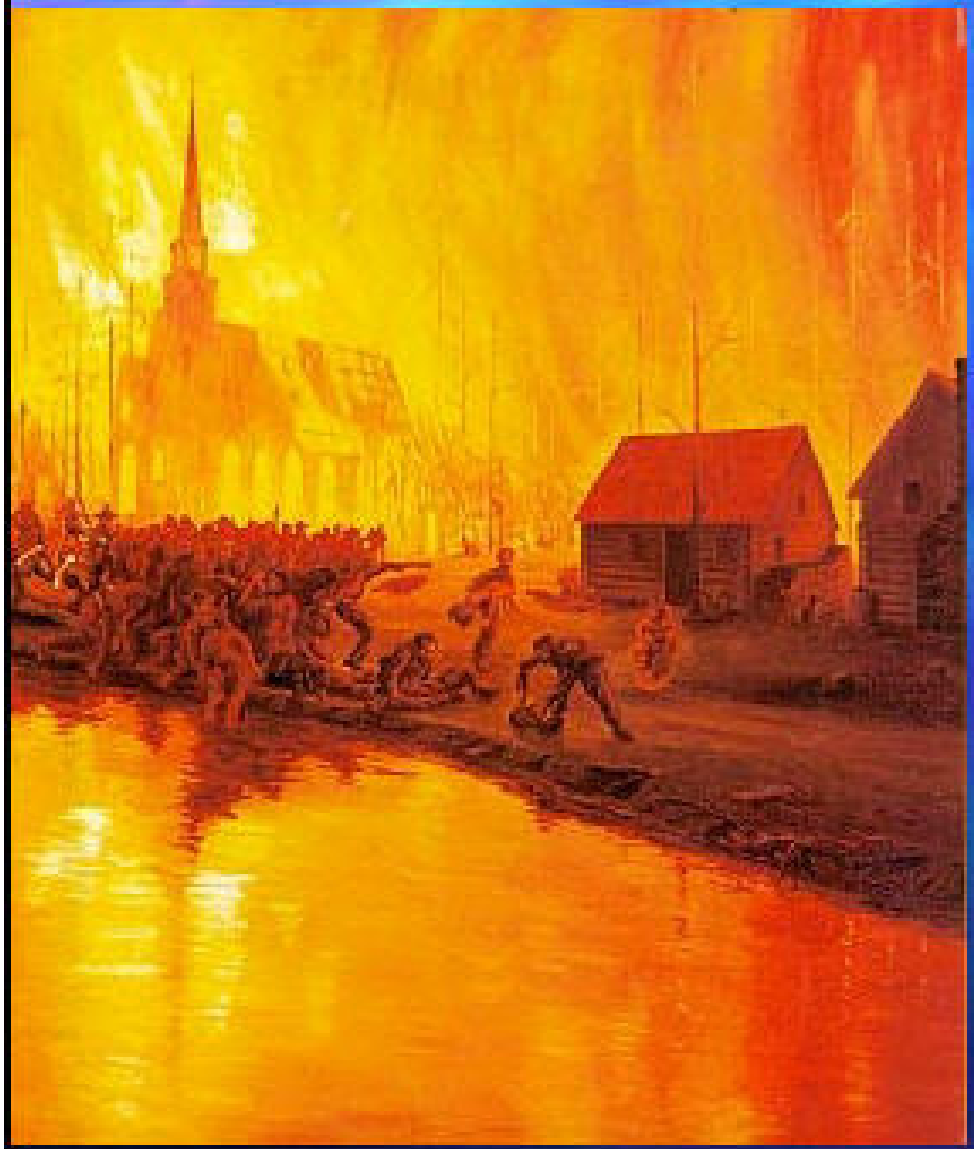
Medium to high density no vegetation

Zero to low density no vegetation

Fires in the WUI Forest /Grasslands/Urban Interface

Of the 10 largest fire loss incidents in US history, 4 occurred pre-1907 and 4 were WUI fires - all occurred within the last 15 years (NFPA).

The Great Peshtigo Fire of 1871

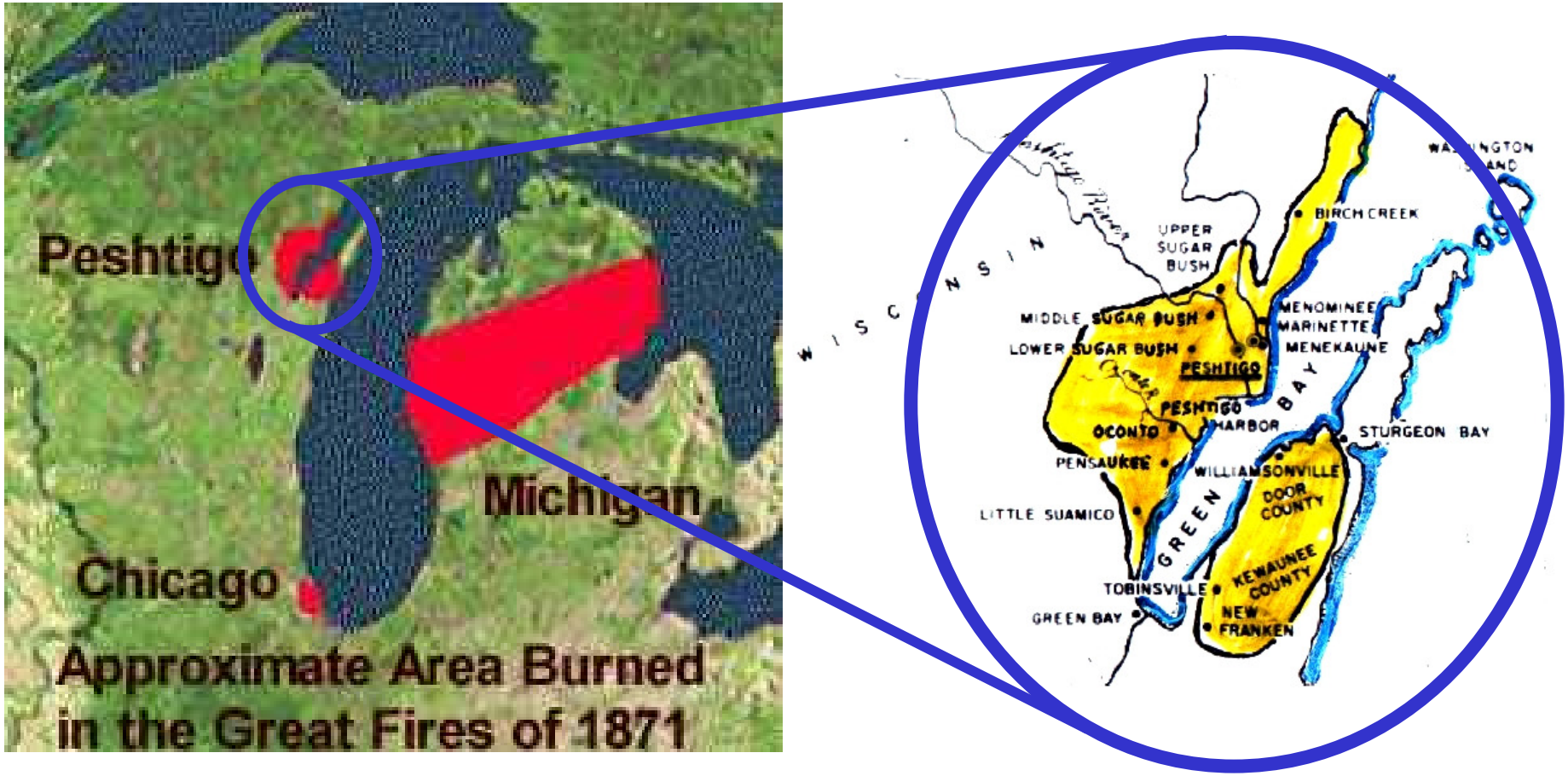


- The fire
  - Hurricane force winds
  - 60 & 50 mile swaths
  - Peshtigo river literally boils people to death

Peshtigo, Wisconsin (1871)
Deadliest Fire in American History

- The death toll was **four times higher than the famous Chicago fire**, which **ignited the same day.**
- Peshtigo, WI fire: Oct 8, 1871
  - 1,500,000 acres or 2,400 square miles
  - 3,780,000 acres or 5,900 square miles in WI & MI combined
  - Largest and deadliest in US history
- Hayman, CO fire: June 9-July3, 2002
  - 138,000 acres or 216 square miles
  - Largest in CO history

Peshtigo Fire Region (contd)

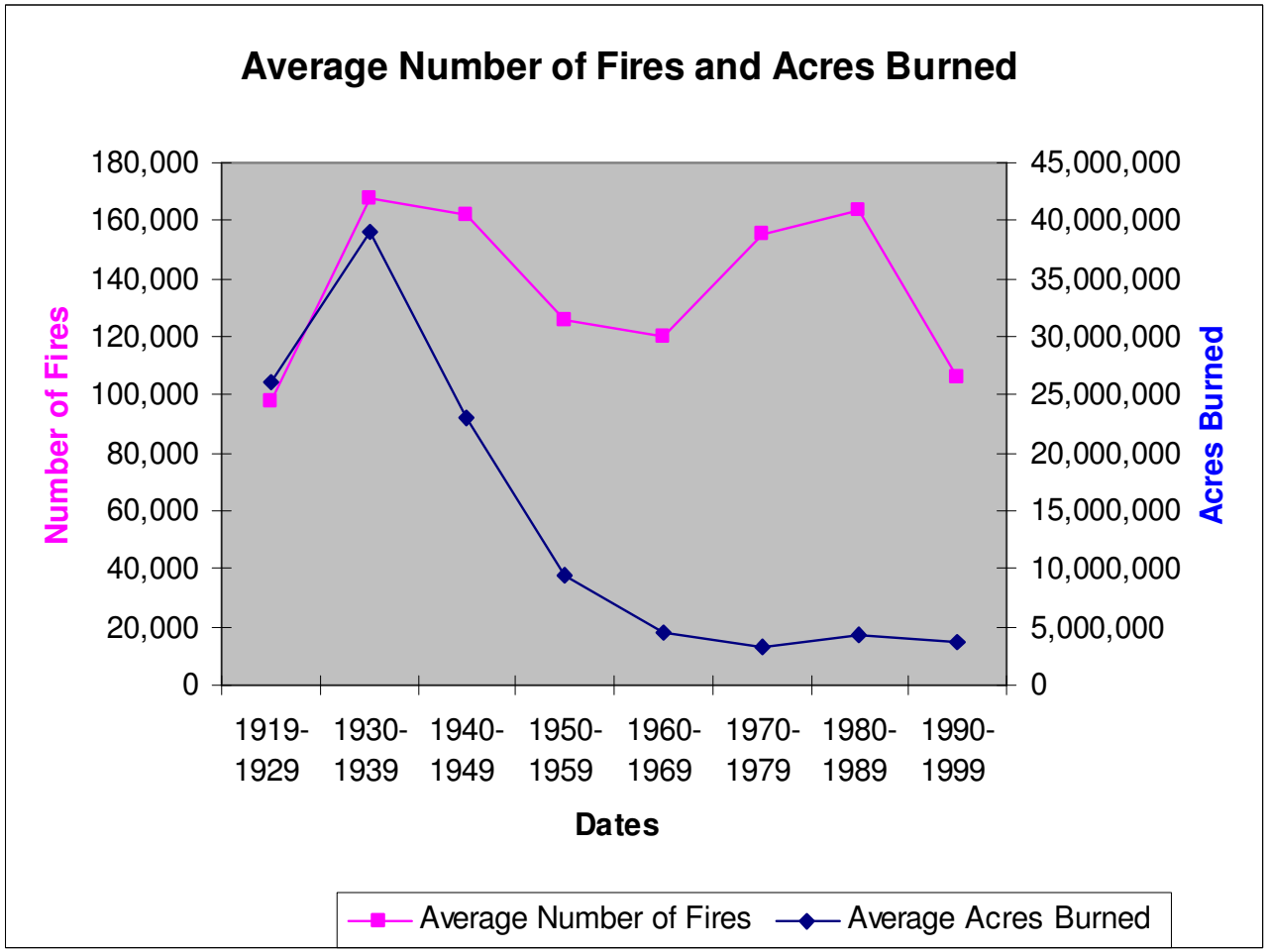


Harper's Weekly Nov 25, 1871

Society's Iconographic Collections

Artist Mel Kishner's conception of the terrorized populace fleeing down Oconto Avenue toward the protection of the river.

Wild Fire Statistics USA



Why is the problem hard to solve?

regional

community

residence fuels

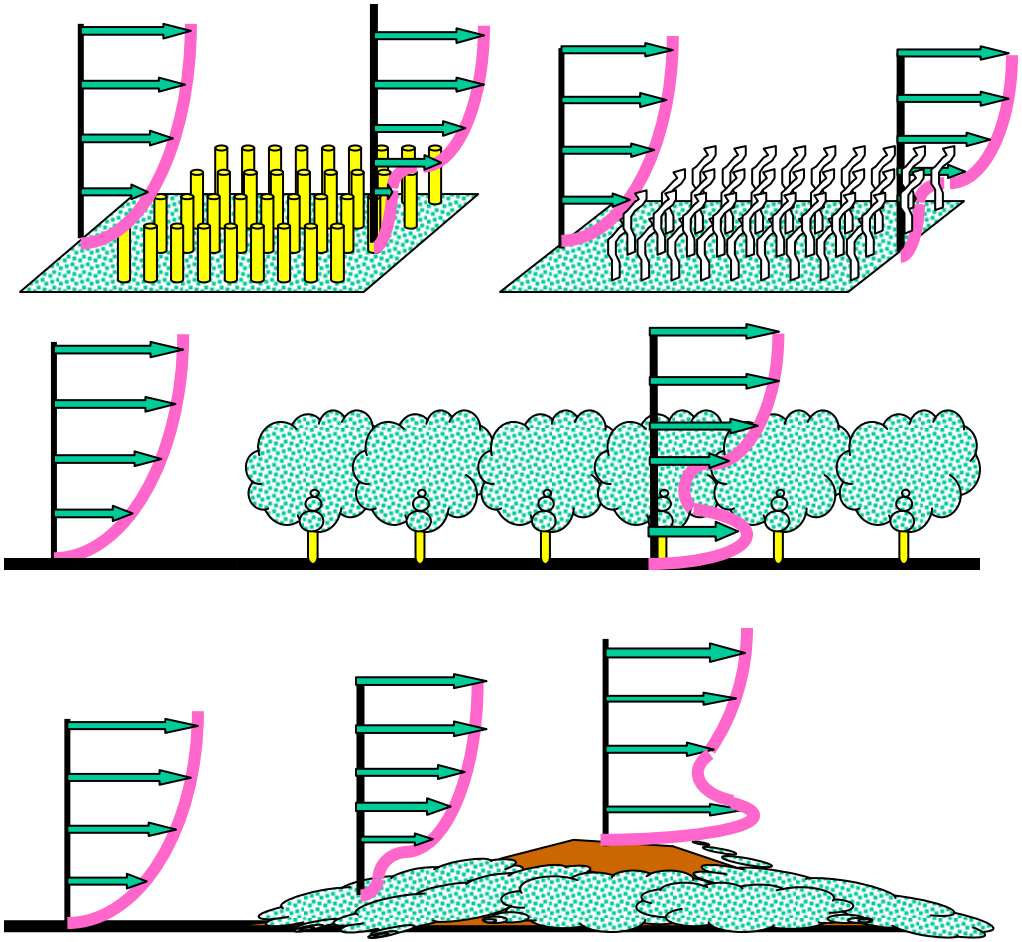
basic vegetative fuel elements

- Range of scales and multitude of driving factors

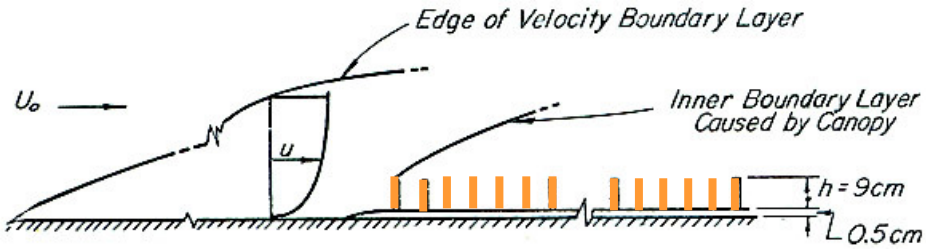
WUI Canopy Flow Fields

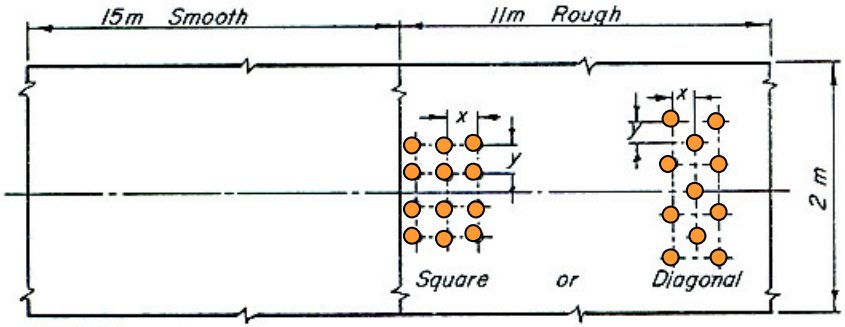
Agricultural Canopies

- Peg canopy studies
  - Velocity profiles
  - Turbulence profiles
  - Diffusion rates from point and line sources
  - Drag measurements
- Flexible strip studies
- Plastic tree studies
- Trees on hills studies



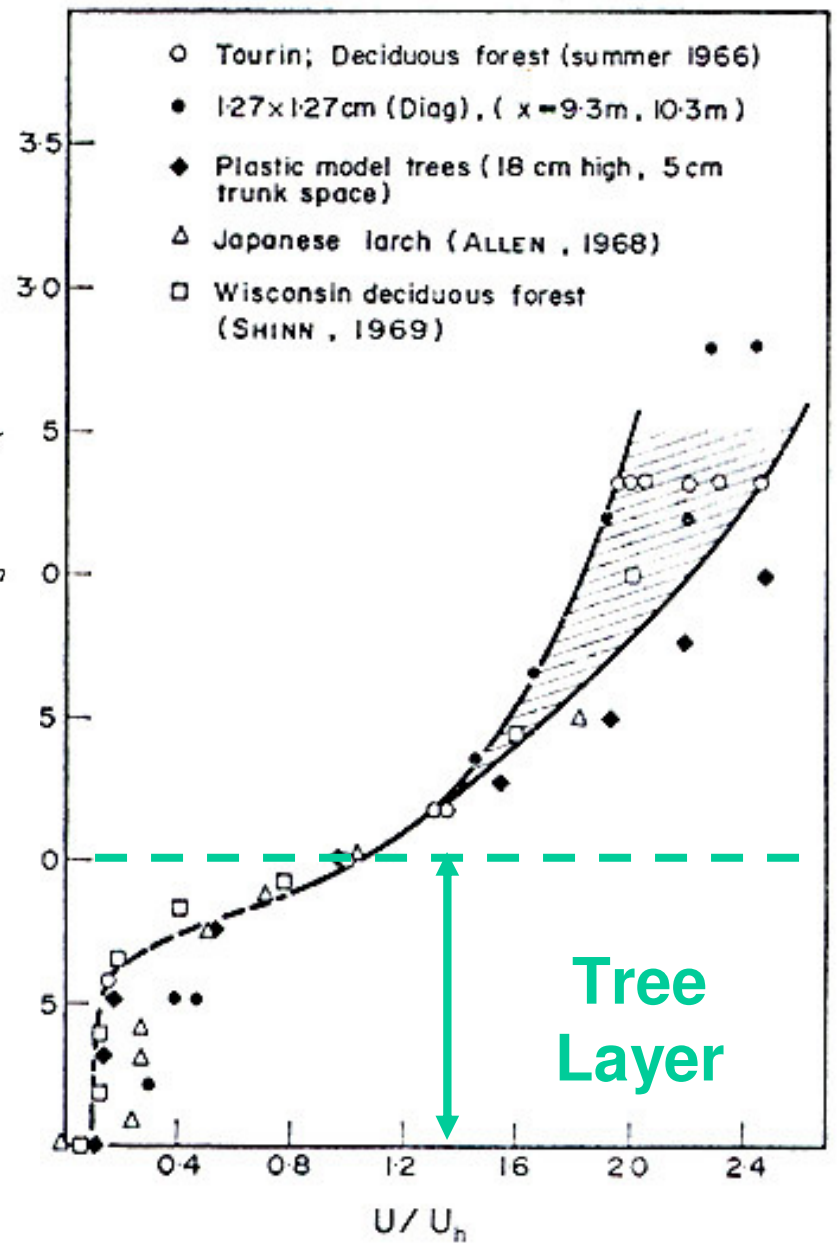
Peg Canopy Profiles



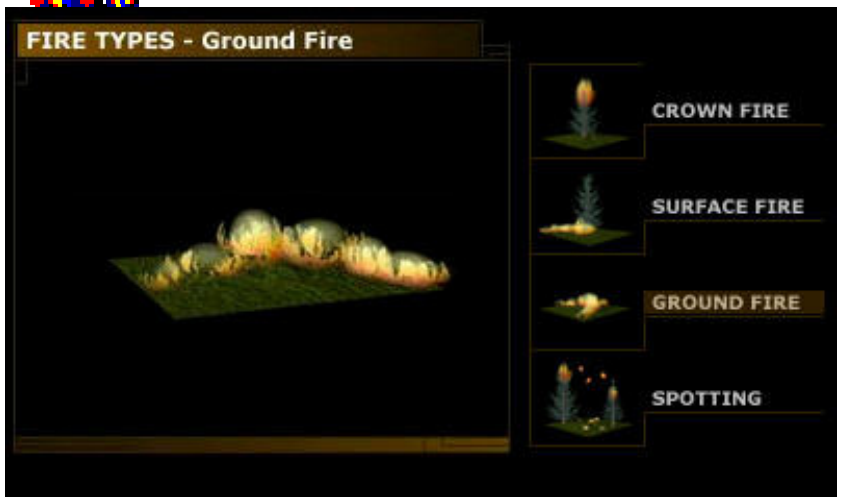


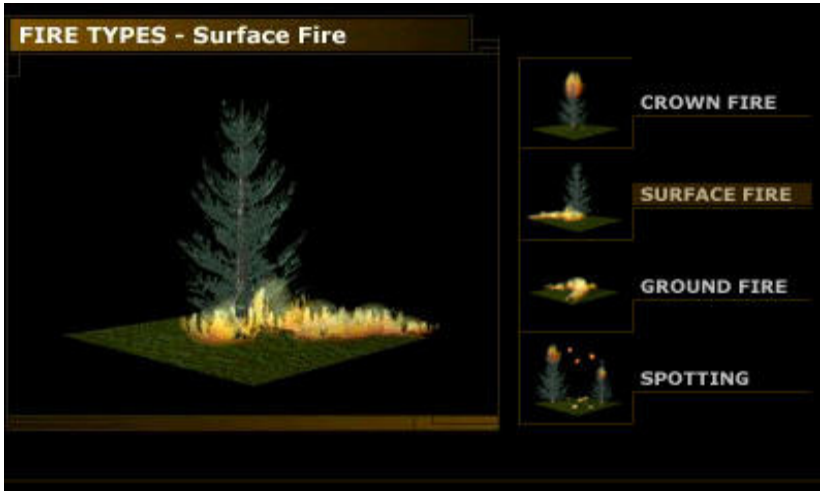
PEG ARRAYS STUDIED

x (cm)	y (cm)	ARRAY
1.27	1.27	DIAG.
2.54	2.54	SQ.
2.54	2.54	DIAG.
5.08	5.08	SQ.

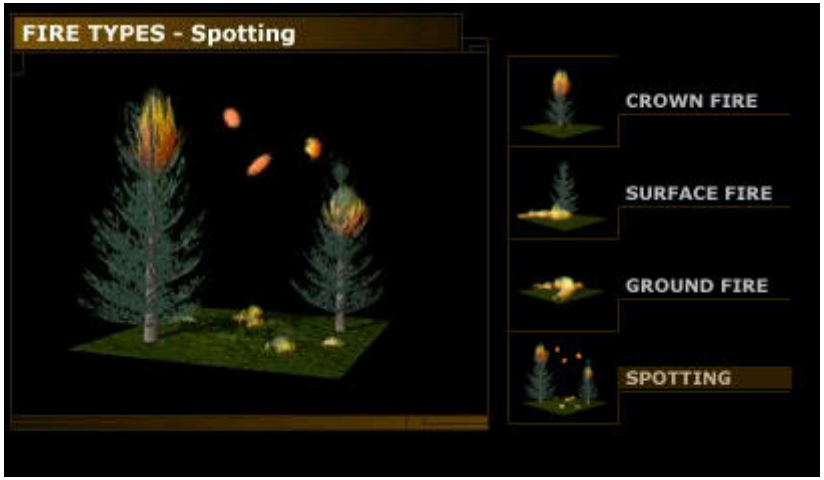


Fire Types

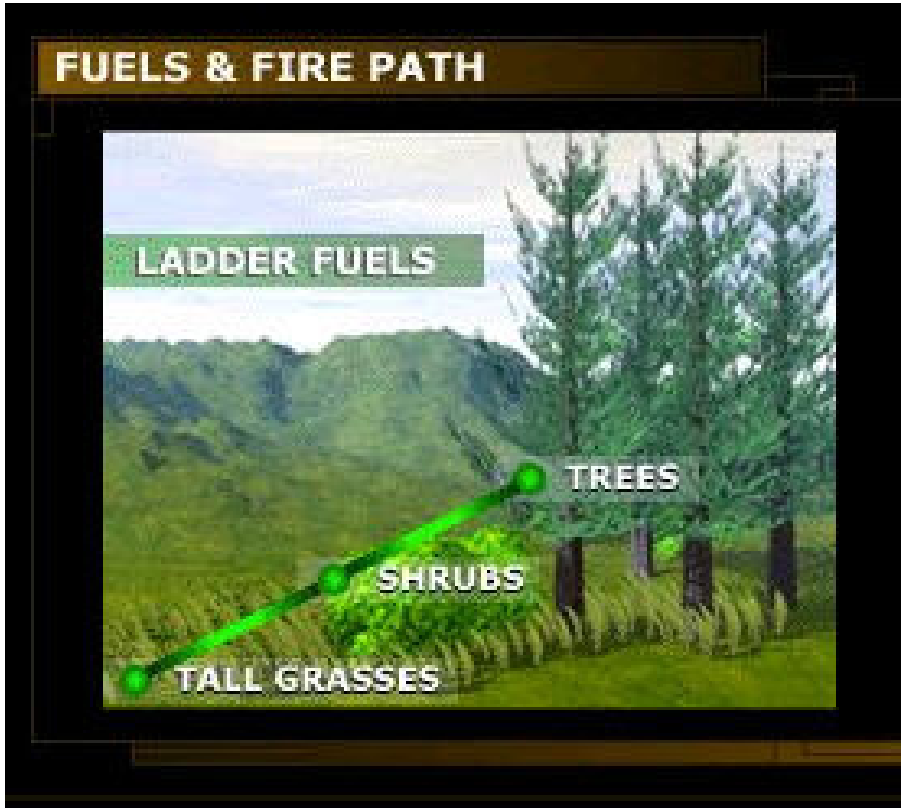

FIRE TYPES - Ground Fire
CROWN FIRE
SURFACE FIRE
GROUND FIRE
SPOTTING


FIRE TYPES - Surface Fire
CROWN FIRE
SURFACE FIRE
GROUND FIRE
SPOTTING


FIRE TYPES - Crown Fire
CROWN FIRE
SURFACE FIRE
GROUND FIRE
SPOTTING


FIRE TYPES - Spotting
CROWN FIRE
SURFACE FIRE
GROUND FIRE
SPOTTING

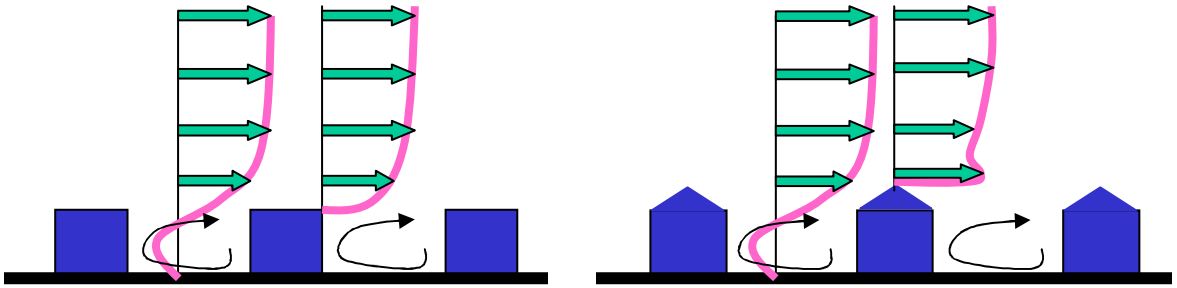
Fuels & Fire Path

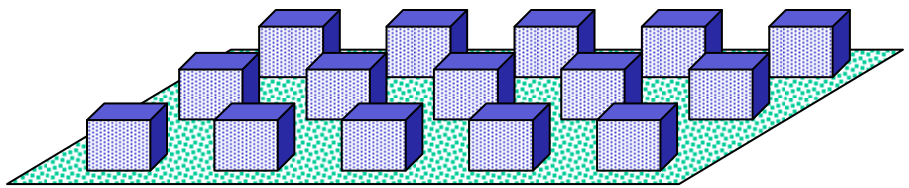


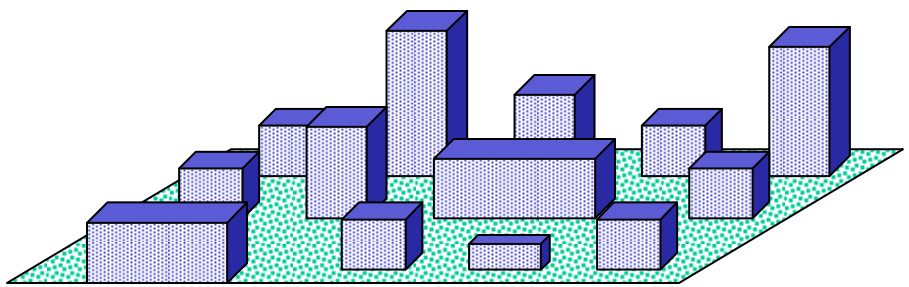

WIND

Urban Canopies

- 2-D models
  - Flat roofs
  - Slanted roofs
- 3-D model
  - Equal height
    - Blocks
    - Rectangular prisms
  - Variable height
- 3-D specific sites





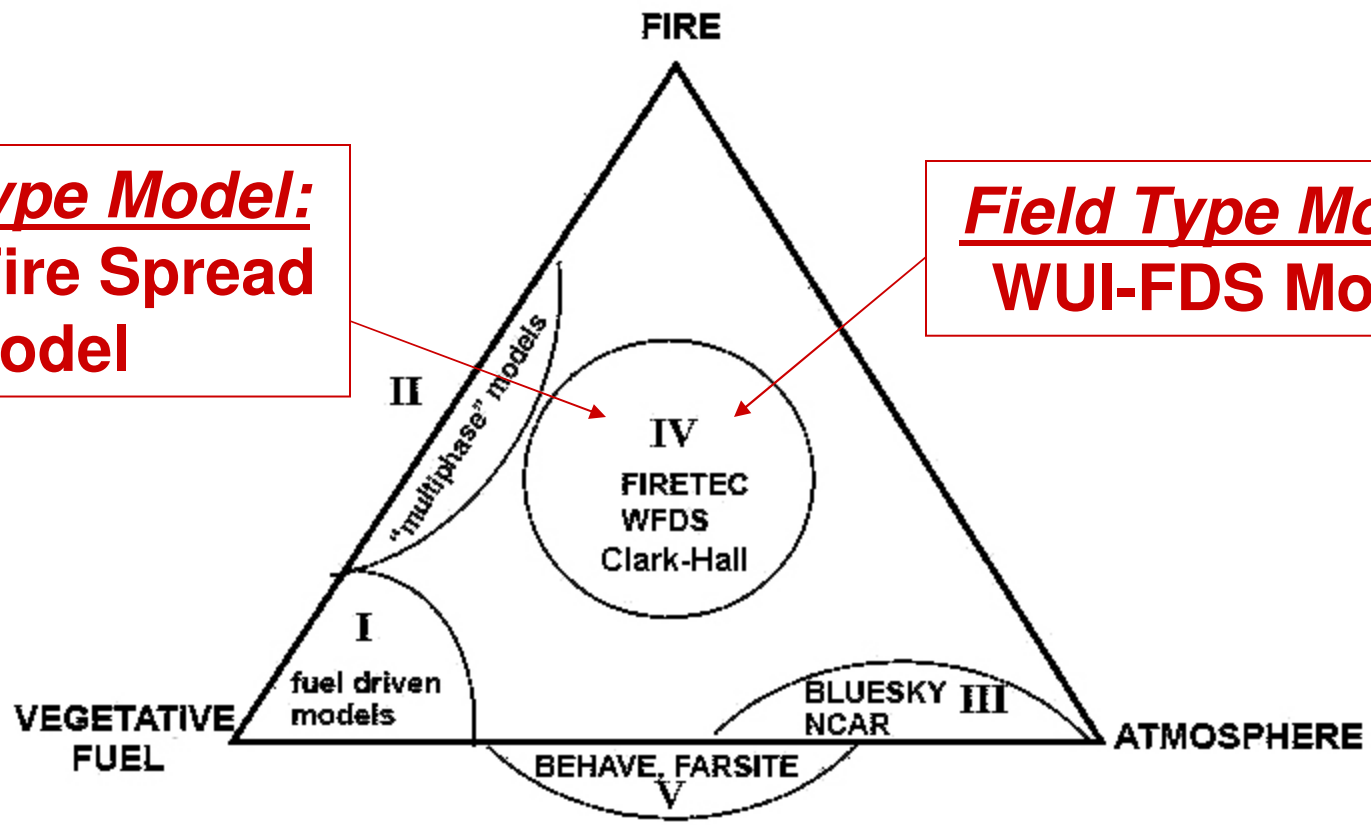


CFD Simulation of Fluid Motions in WUI Canopies

Wildland Fire Model Triangle

Zone Type Model:
Urban Fire Spread Model

Field Type Model:
WUI-FDS Model



Zonal Model for Urban Fires

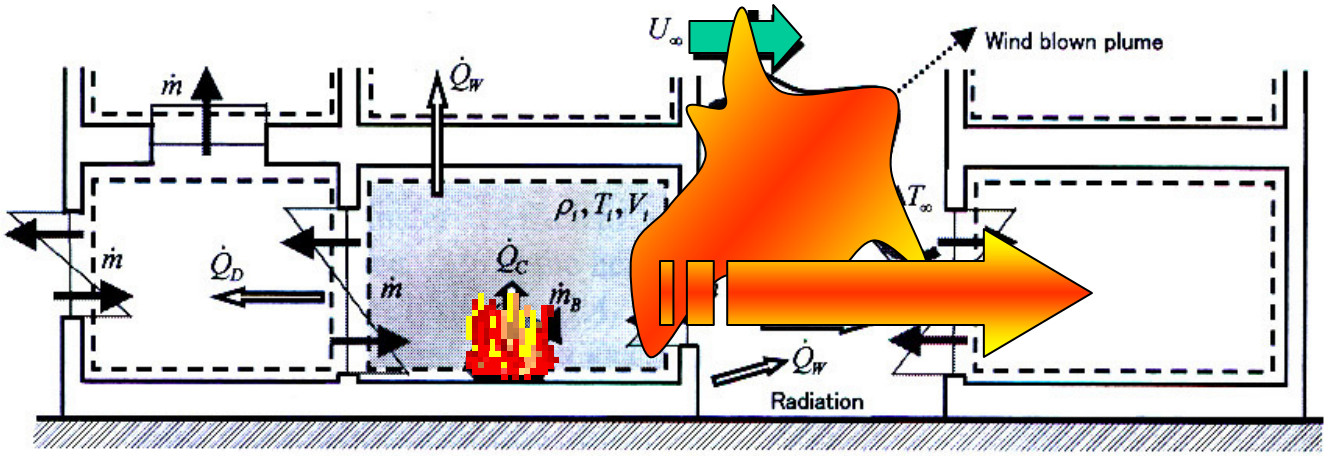
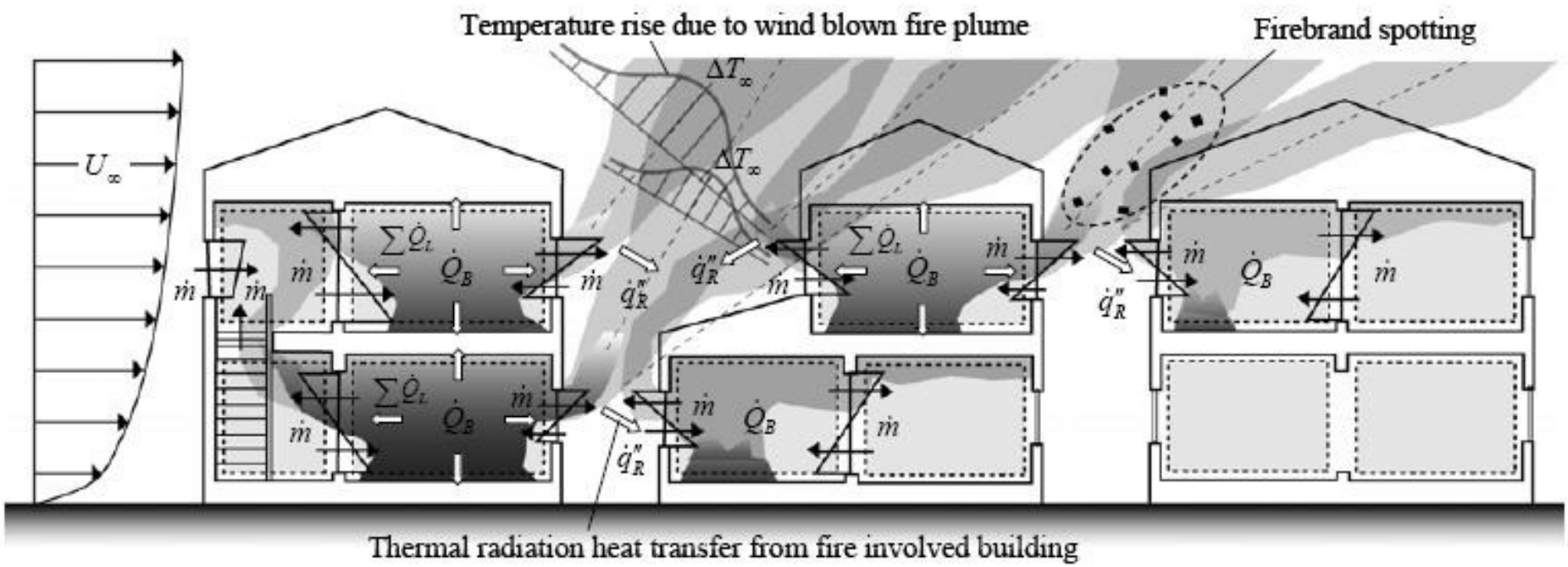
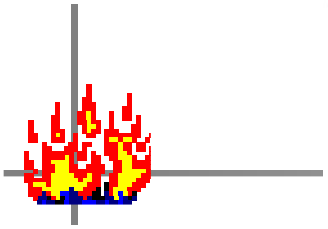


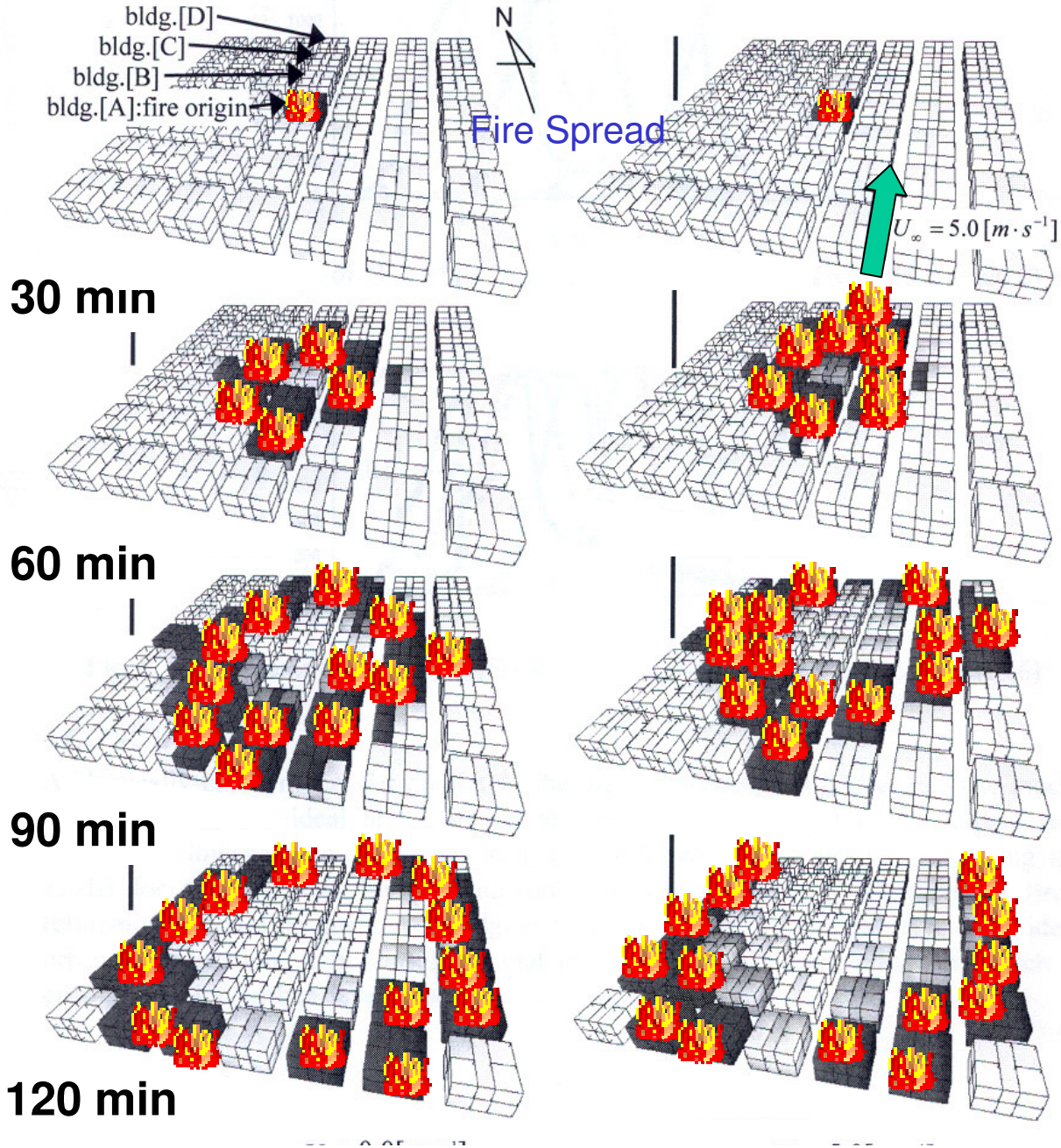
Fig. 1: Urban fire spread model

- Himoto & Tanaka (2002), 7th Int. Symp. On Fire Safety Science.
- Ensemble of single compartment zones with radiation and heat exchange to initiate ignition.
- Urban fire spread predicted by integrating simulation of individual fires.

Urban Fire Spread Model



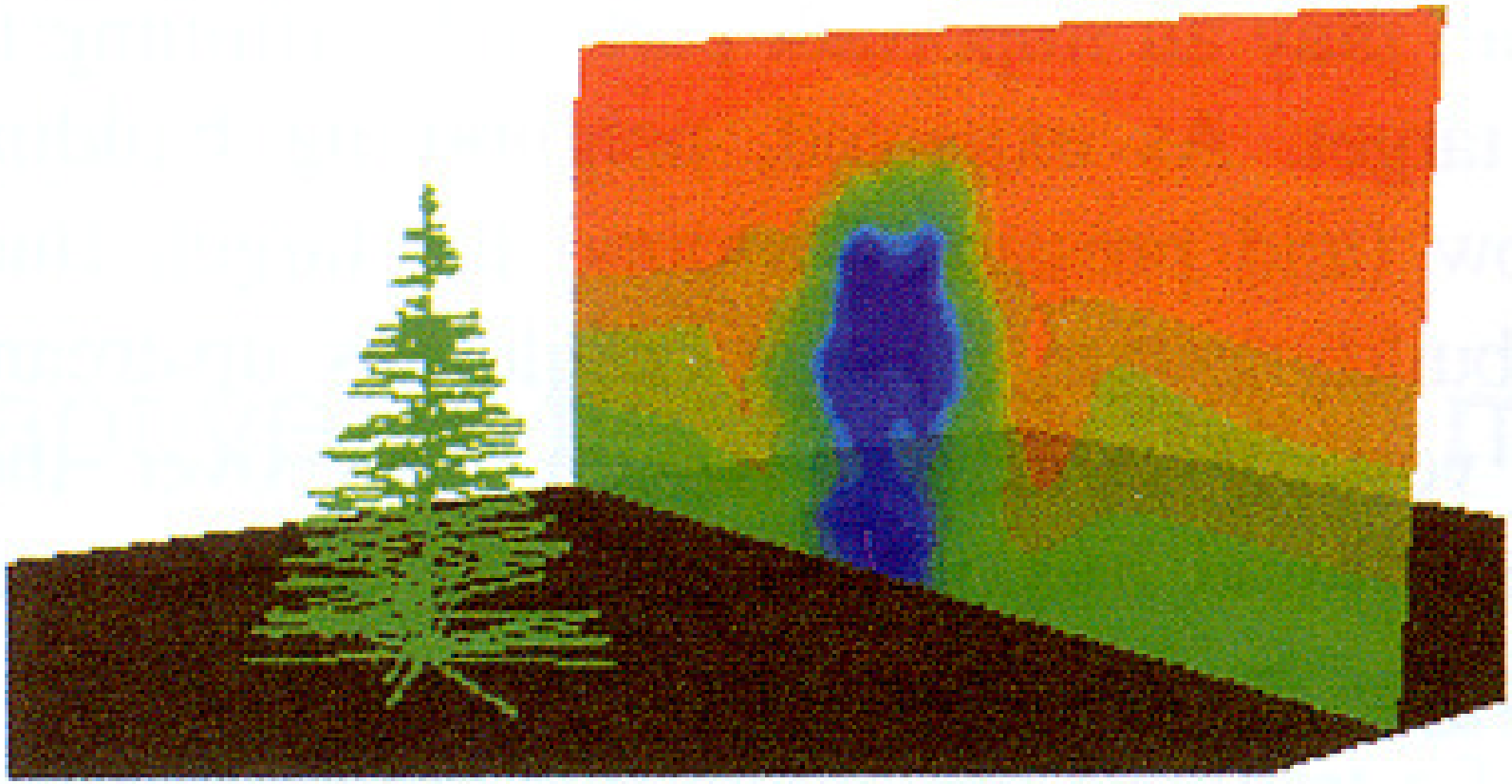


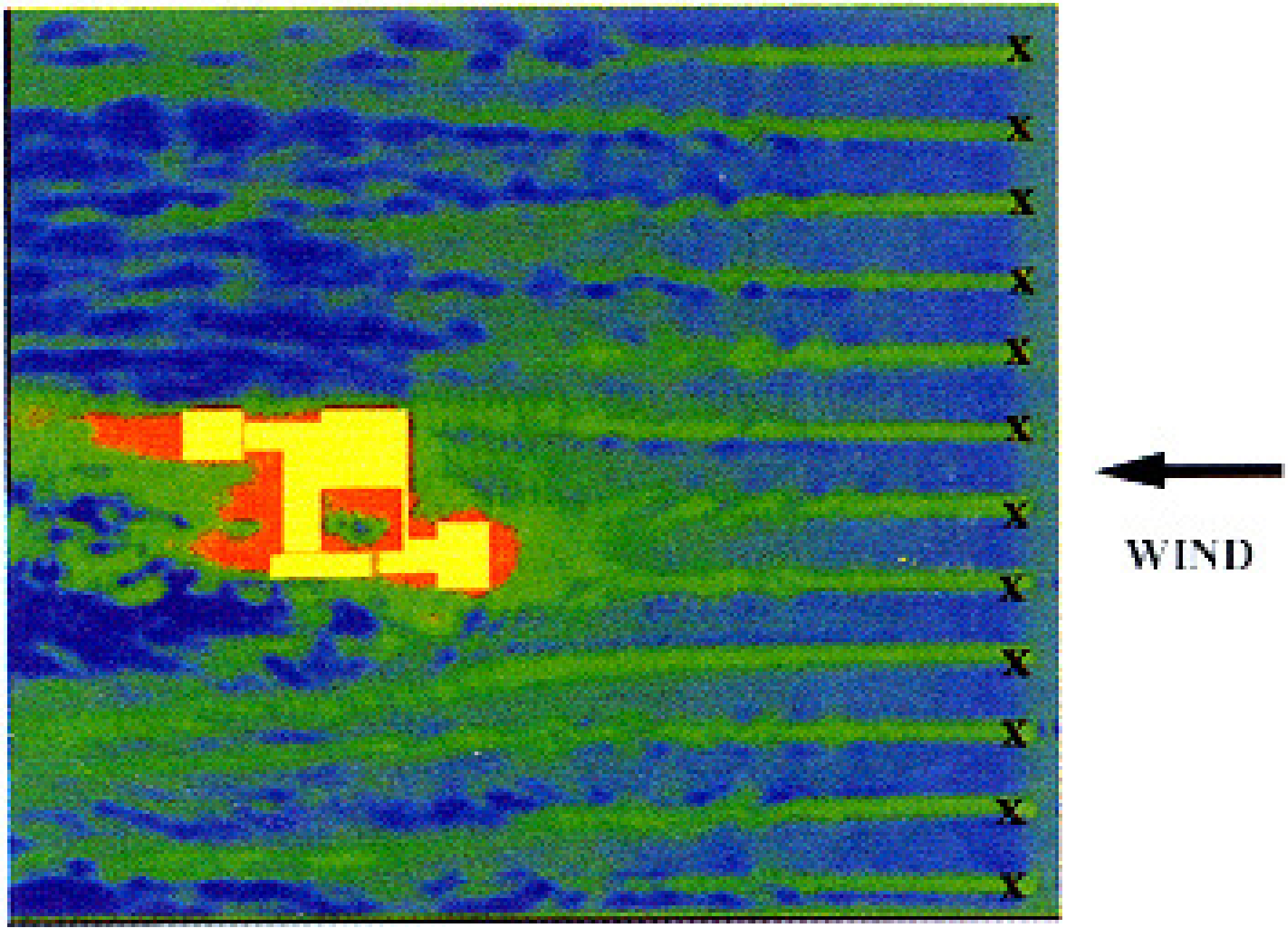

bldg.[D]
bldg.[C]
bldg.[B]
bldg.[A]:fire origin
N
Fire Spread
$U_\infty = 5.0\,[m \cdot s^{-1}]$
30 min
60 min
90 min
120 min

U = 0 (m/s)

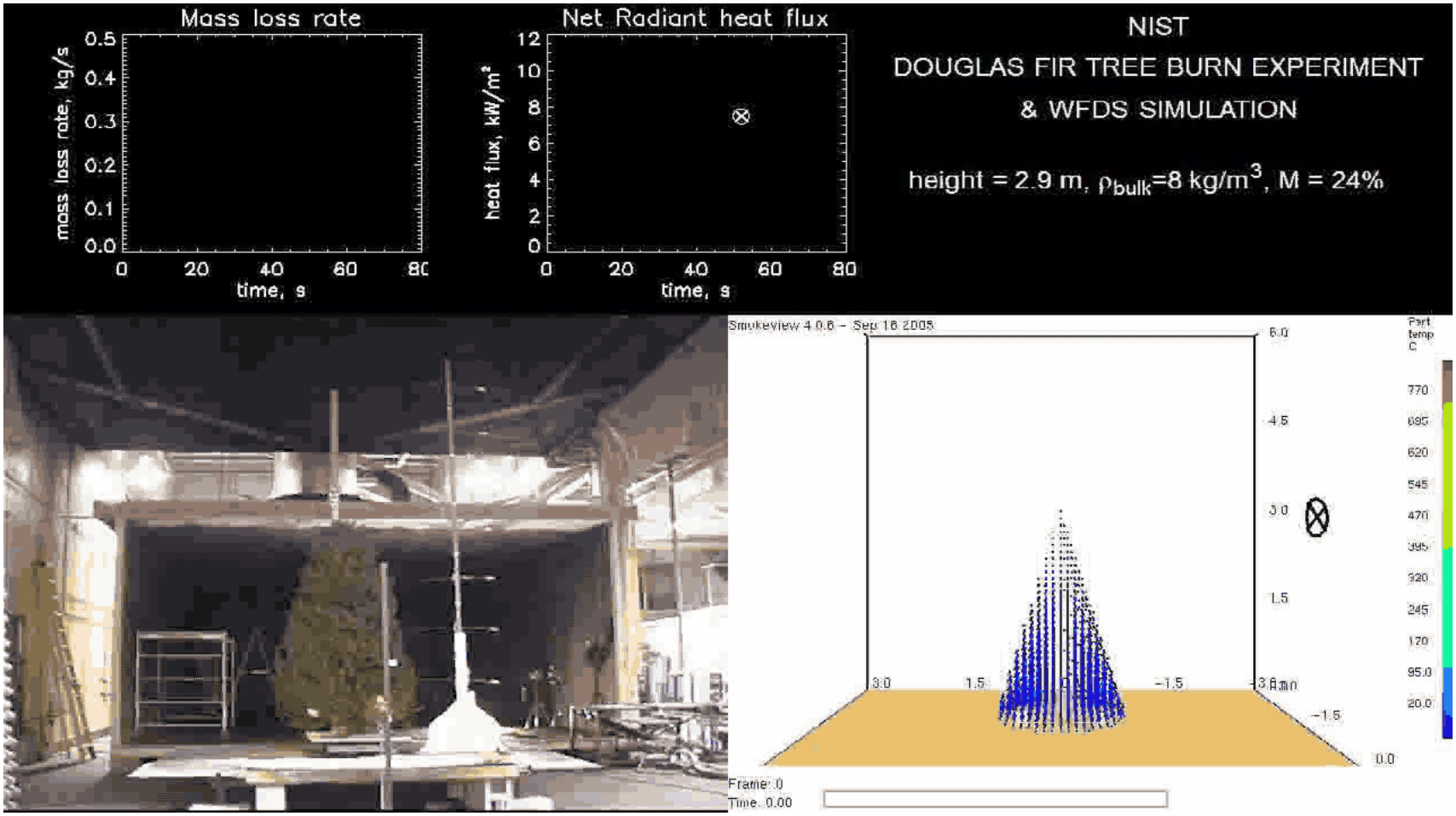
U = 5 (m/s)

Full Physics WFDS Model
Joint Forest & Building Canopy

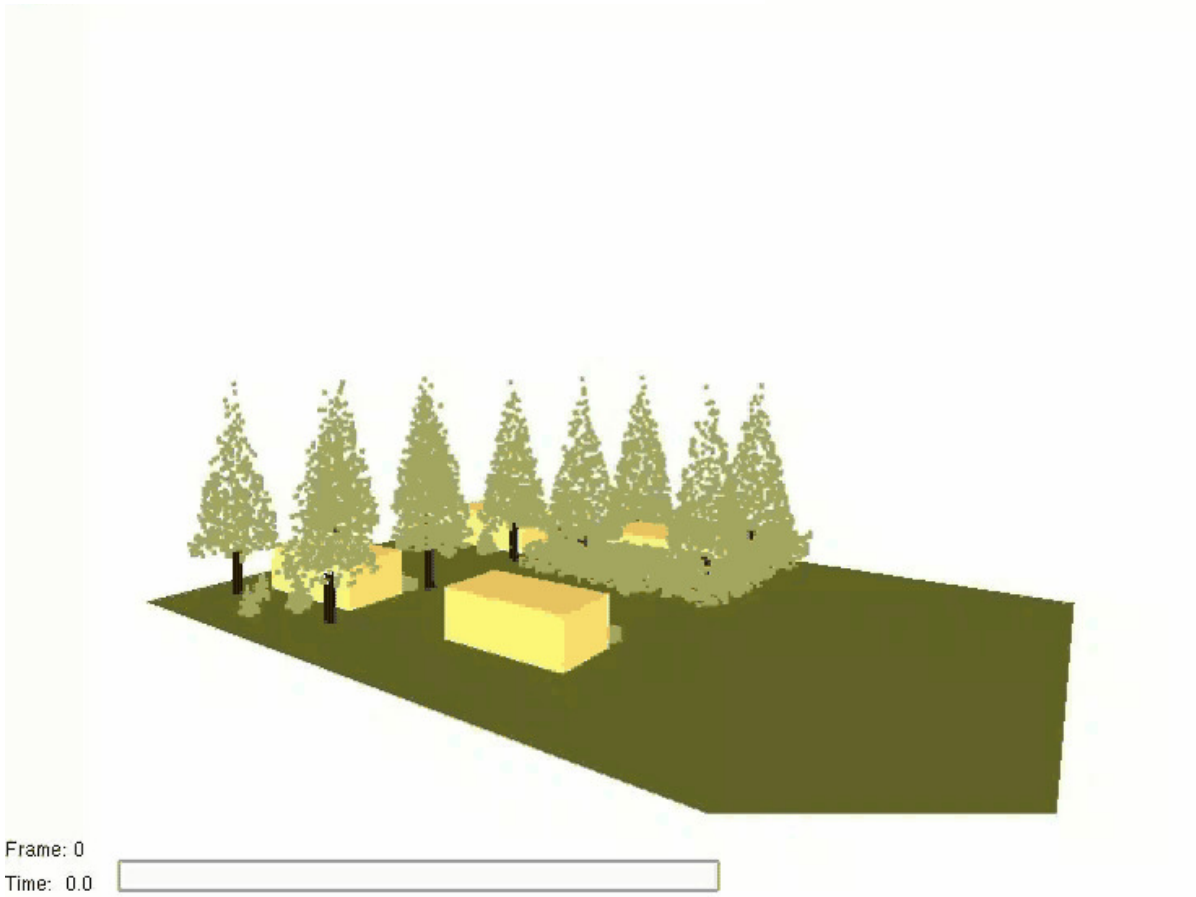



WIND

WFDS Simulation of Burning Douglas Fir Experiment

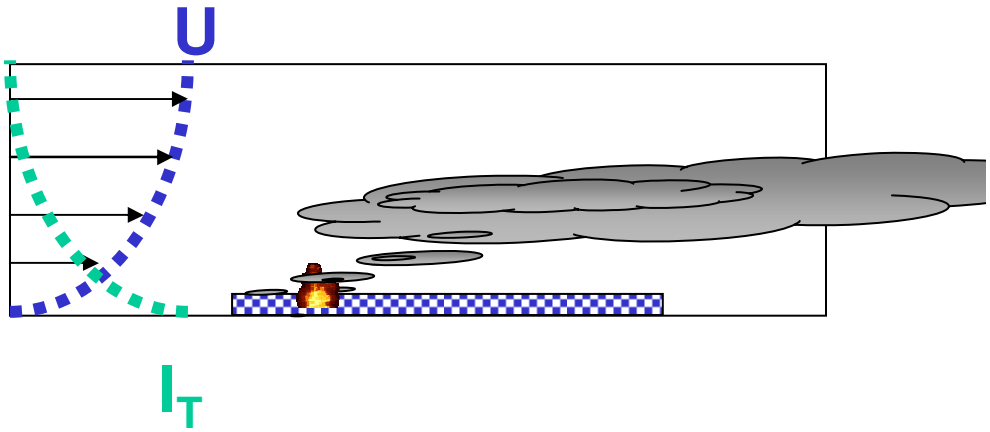


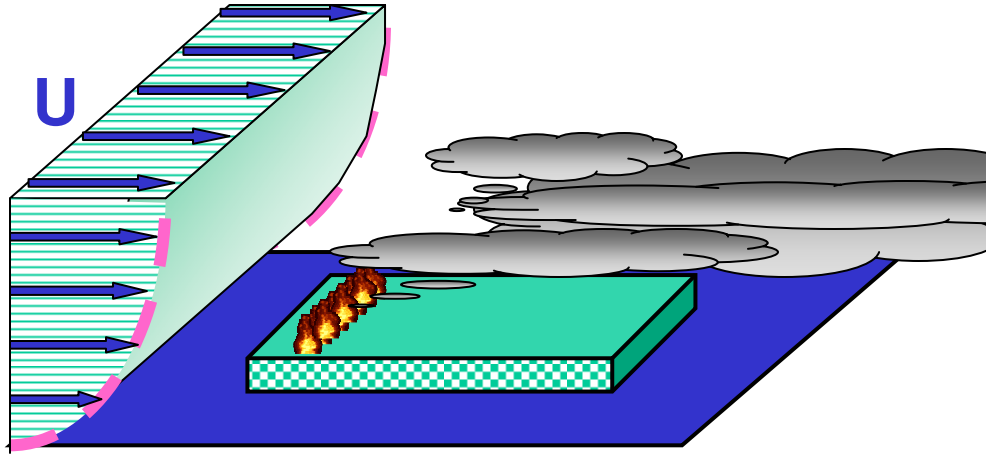
WFDS Simulation of WUI Situation



CFD Simulation of Fire in Idealized Canopies

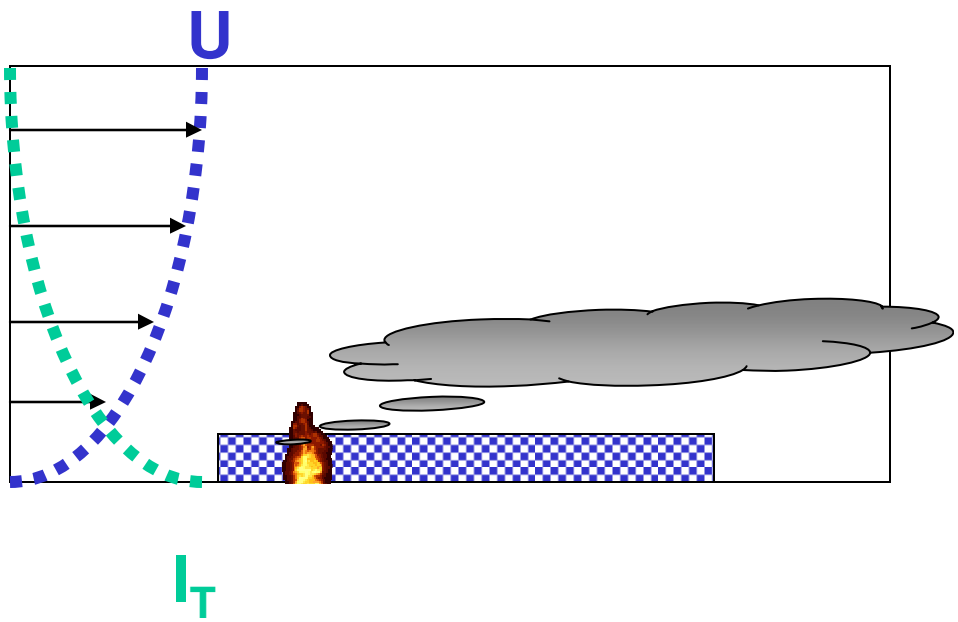
- Limit study to buoyancy and mass burning rate scaling.
- Canopy simulated as porous fluid zone.
- Initially look only for gross behaviors.
- CFD vehicle will be FLUENT 6.1.22

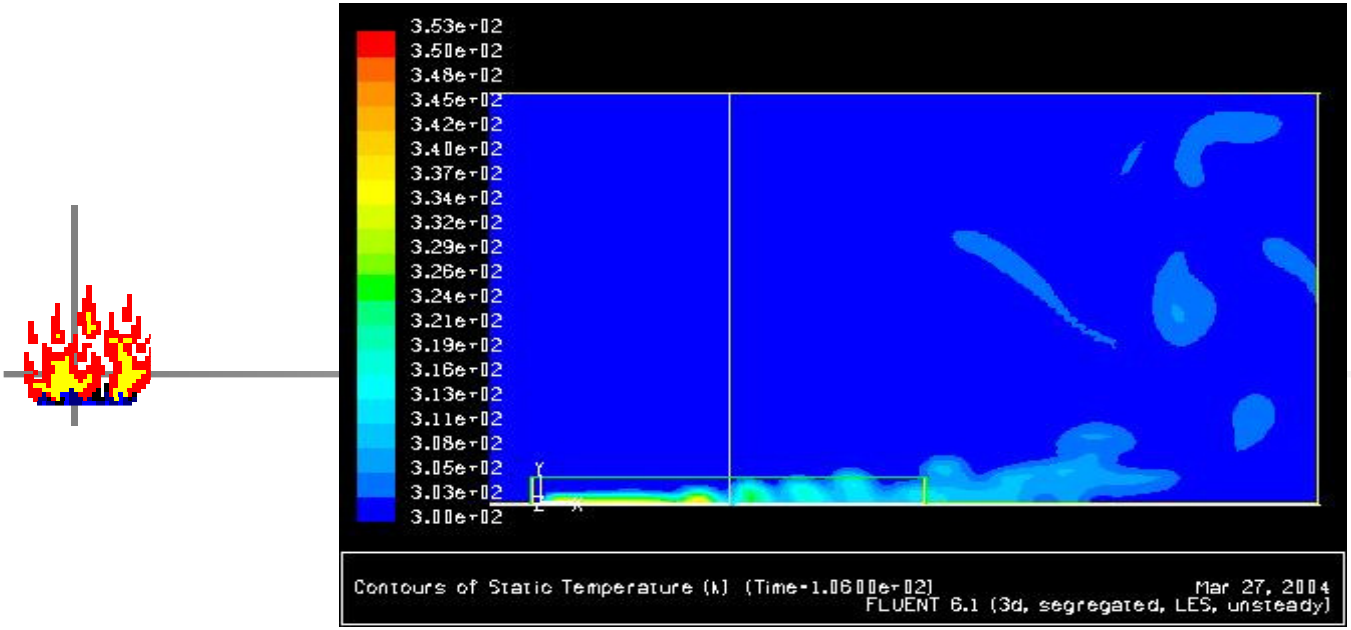




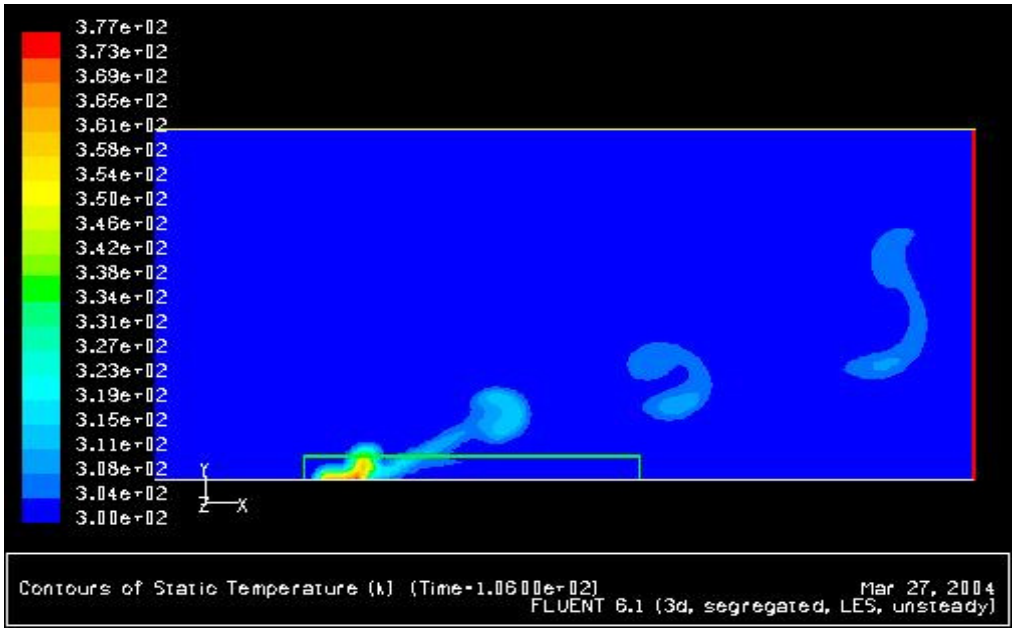
2-d Fires in Porous Zones

- **Domain:**
  - **300 x 60 m**
- **Porous zone:**
  - **100 x 6 m**
- **Heat source:**
  - **2 x 4 m; 100kW/m^3**
- **SKE & LES turbulence models**
- **Power law profile**
  - **p = 0.14, $U_{10\,m}$ = 1 m/s**
- **Turbulence inlet**
  - **I_T = 10%**

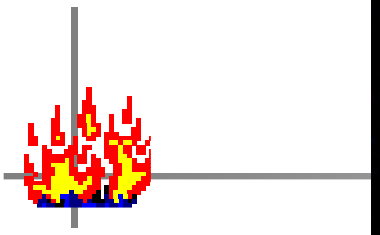


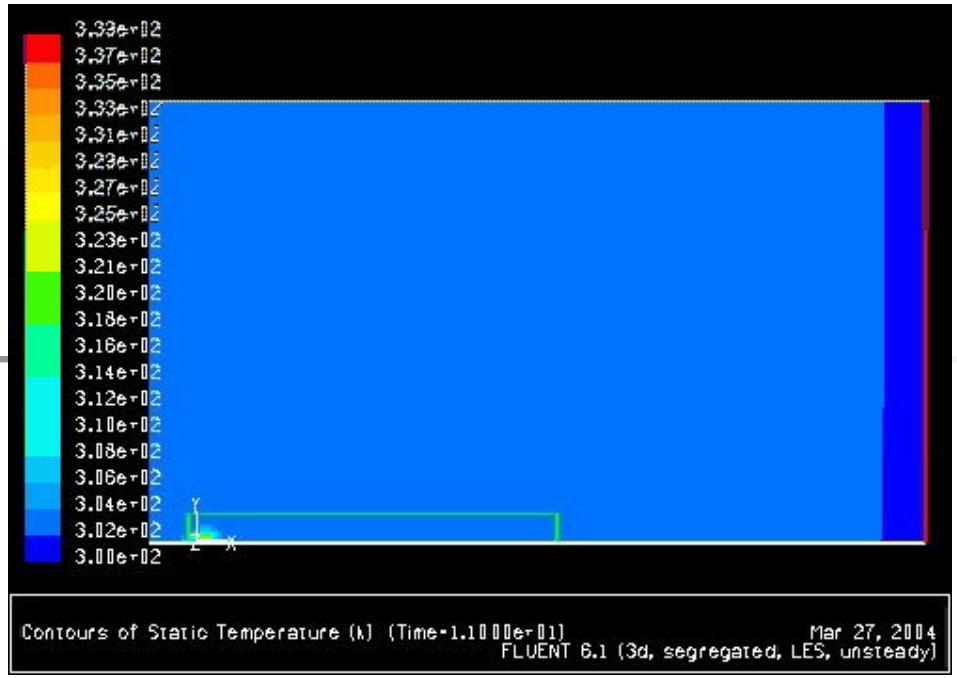


Temperature – No canopy

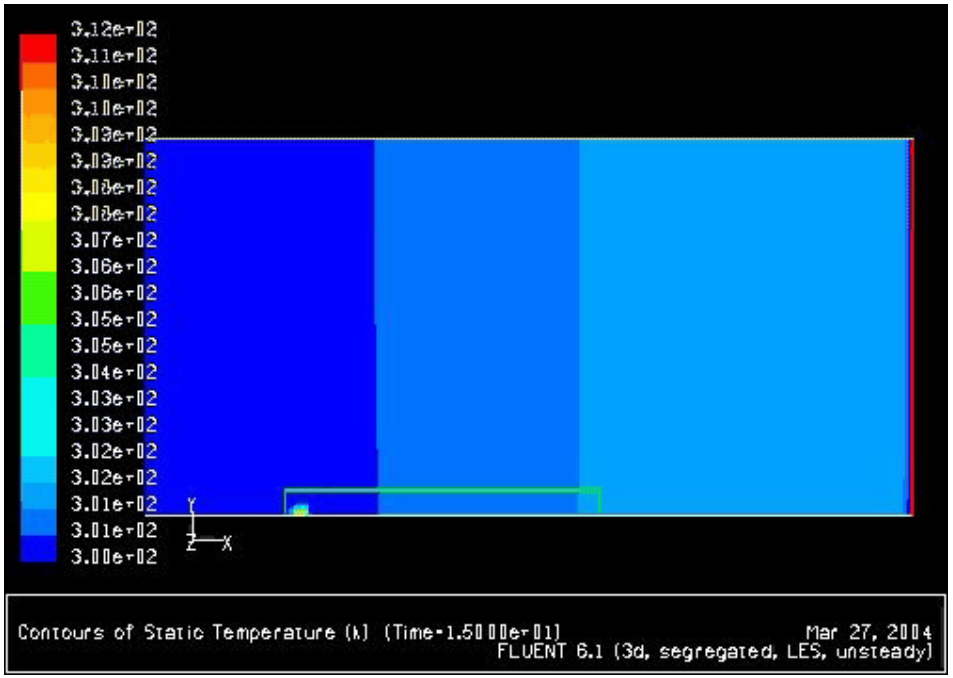


Temperature – Porous canopy





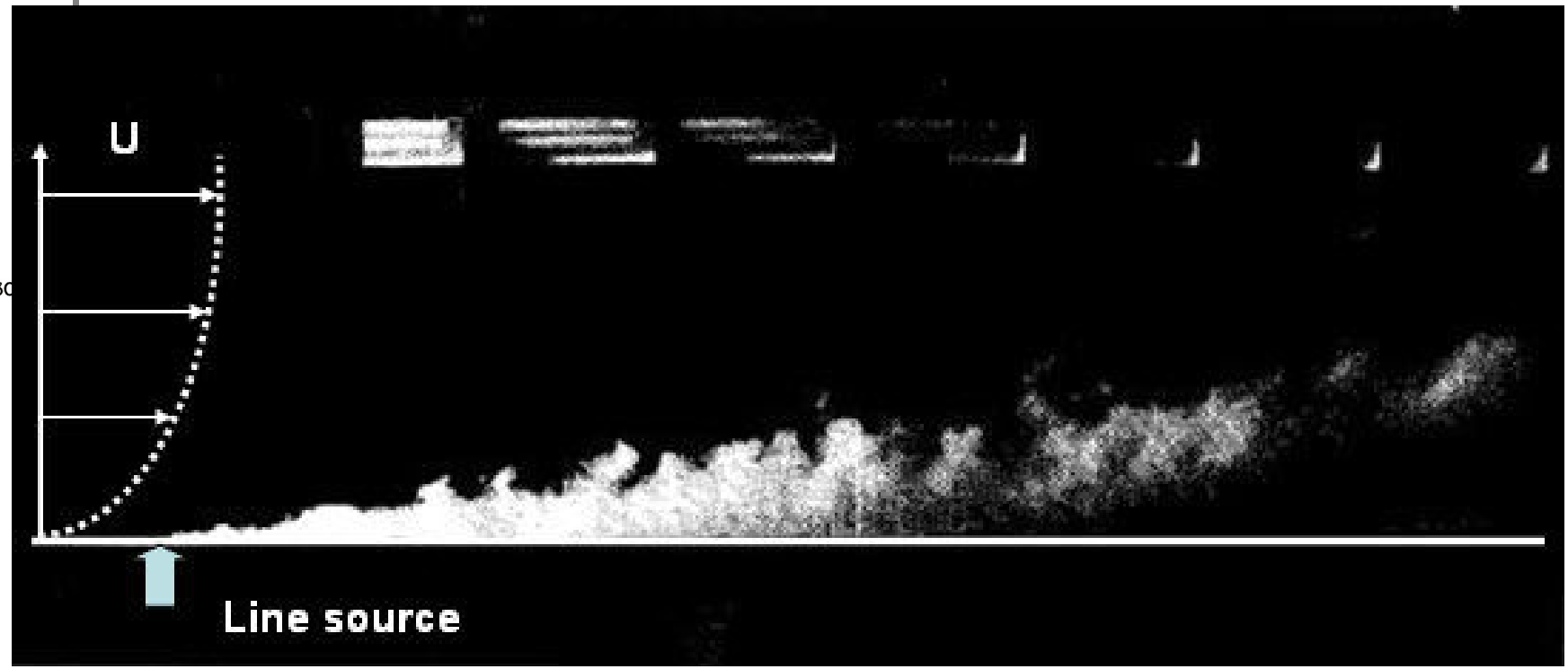
No porous canopy



Porous canopy

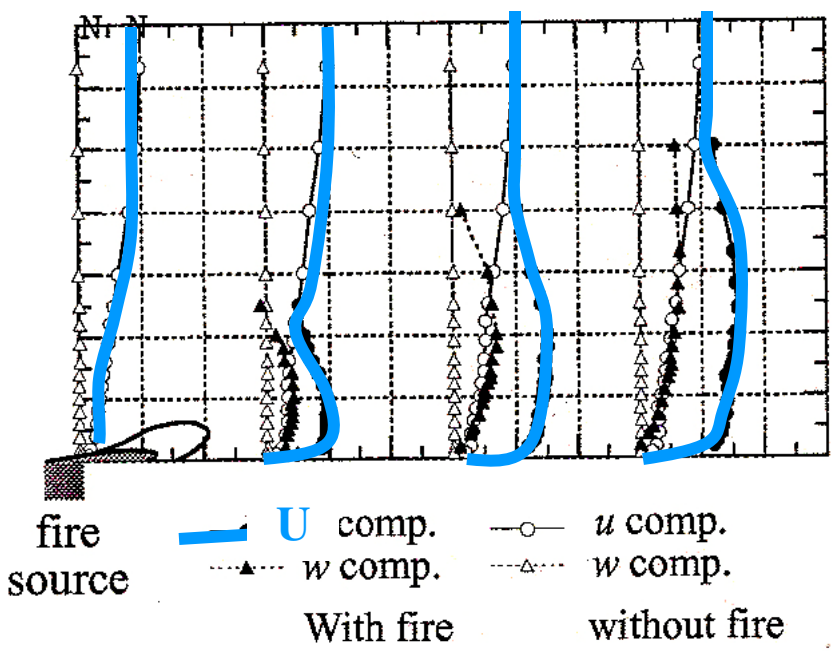
Buoyant Plumes in Turbulent BL

Meroney (1979)

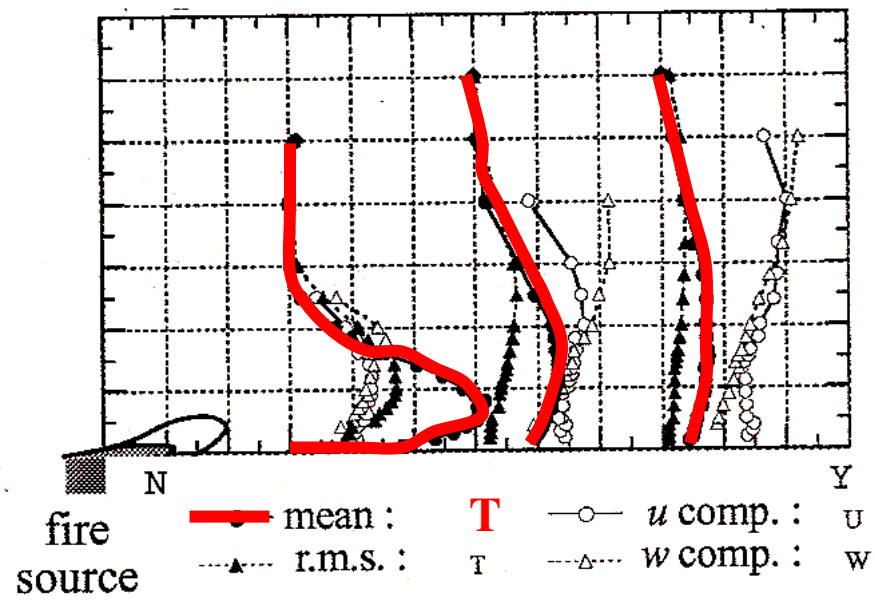


Flames in Boundary Layers

Maruyama and Tanaka (2002)



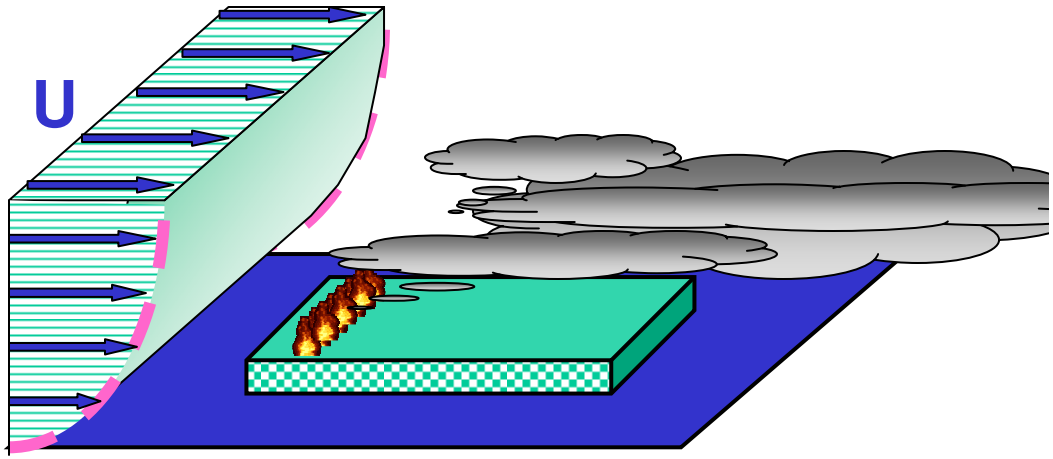
a. Variation of the mean velocity profiles



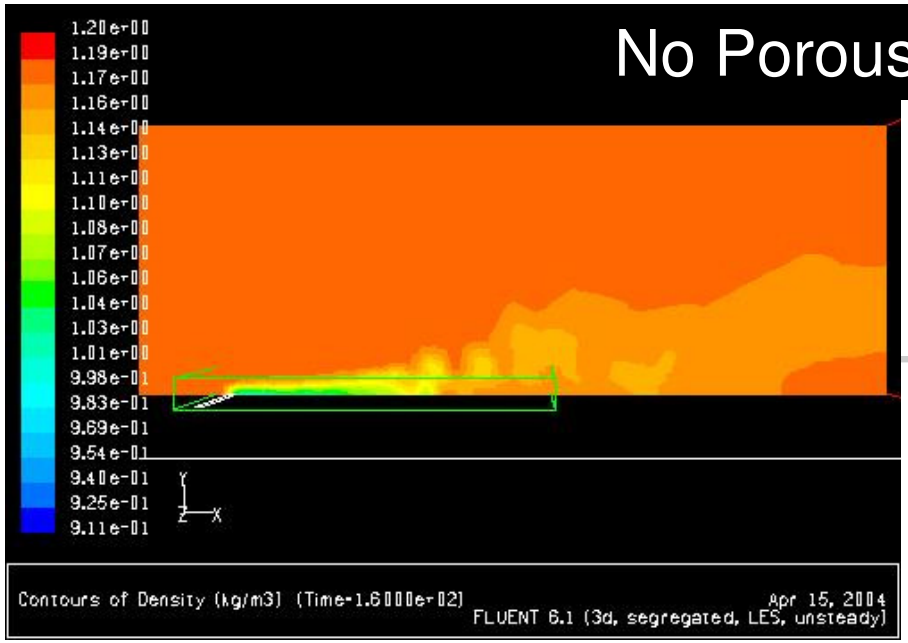
b. Variation of the temperature and the velocity fluctuation with fire.

3-d Fires in Porous Zones

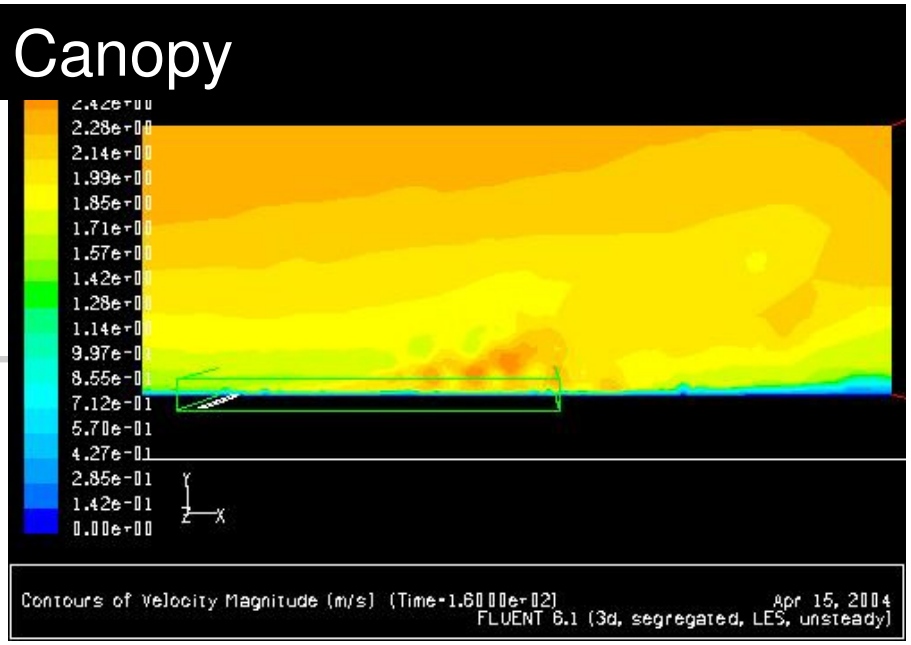
- **Domain:**
  - **300 x 300 x 60 m**
- **Porous zone:**
  - **100 x 100 x 6 m**
- **Heat source:**
  - **2 x 4 x 90 m; 100kW/m^3**
- **SKE & LES turbulence models**
- **Power law profile**
  - **p = 0.14, $U_{10\,m}$ = 1 m/s**
- **Turbulence inlet**
  - **I_T = 10%**



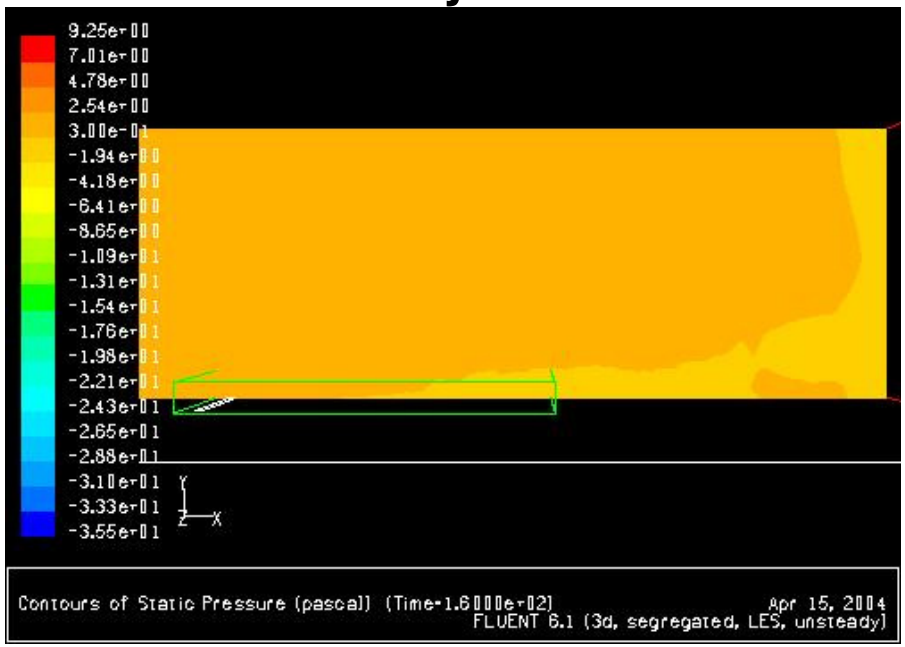
No Porous Canopy



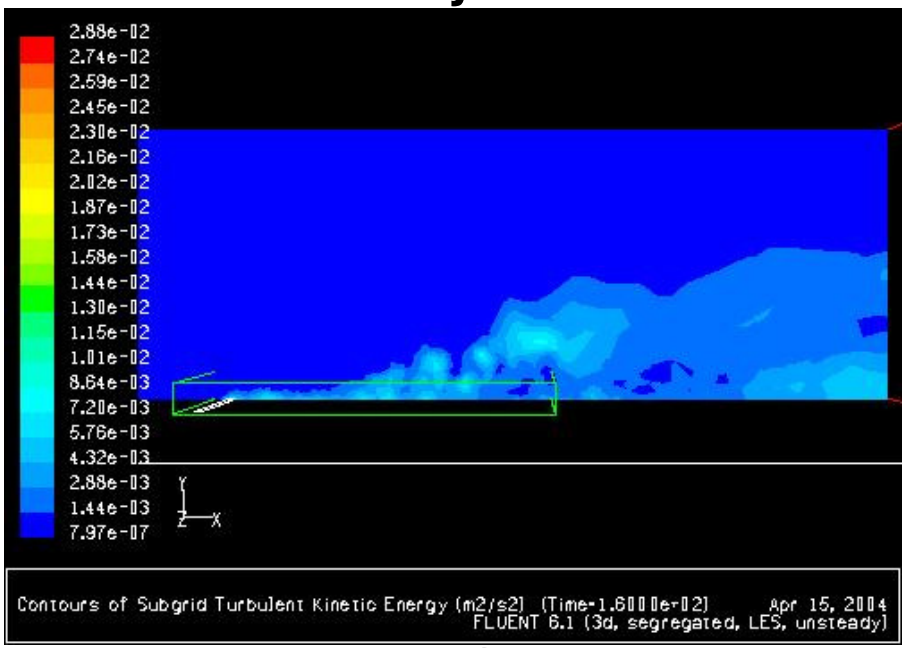
Density Contours



Velocity Contours

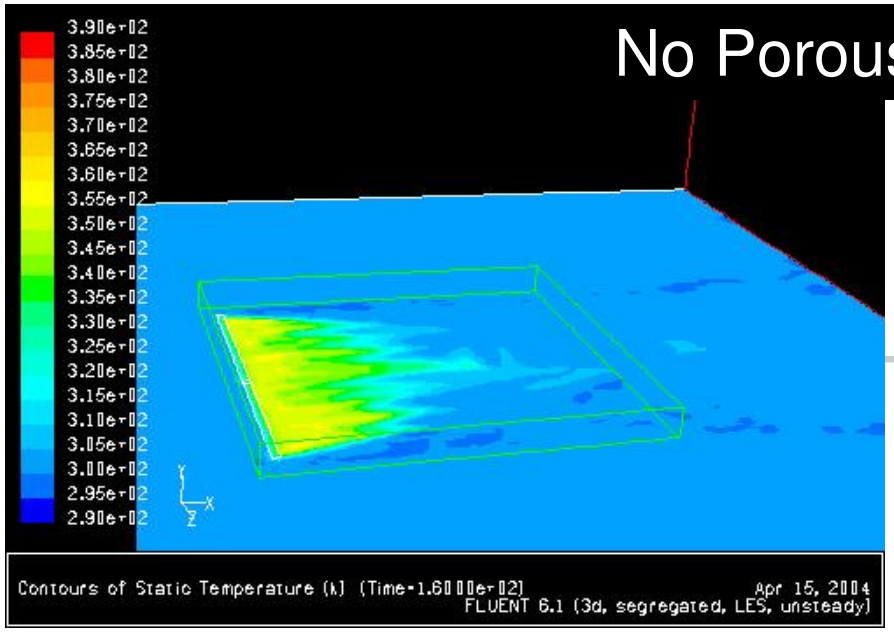


Pressure Contours

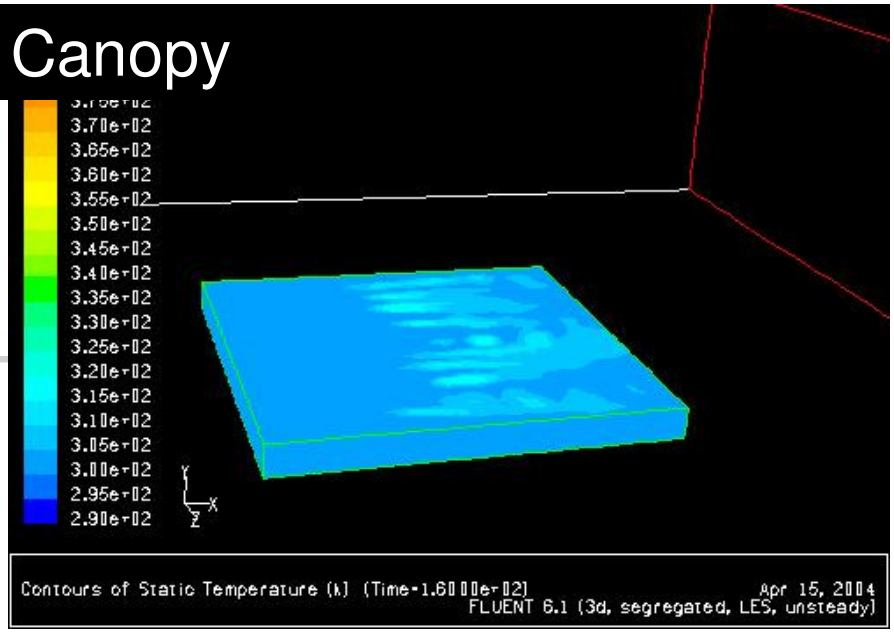


TKE Contours

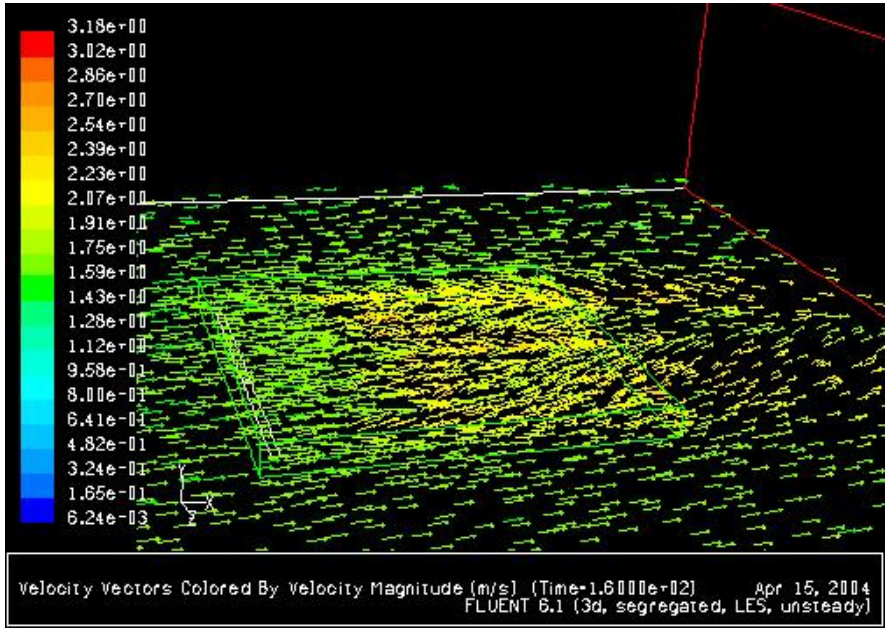
No Porous Canopy



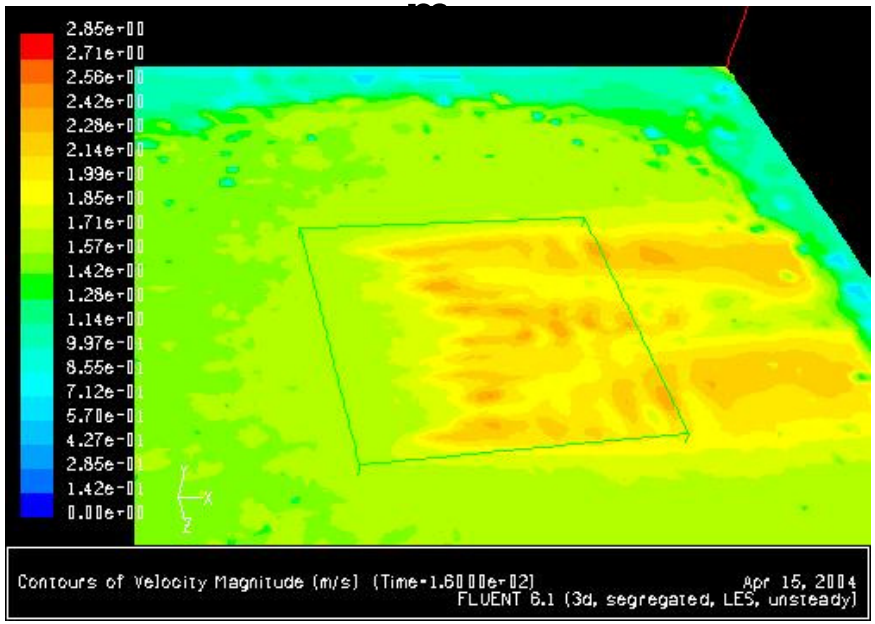
Temperature Contours



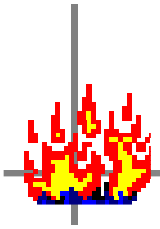
Temperature Contours, Y = 6 m

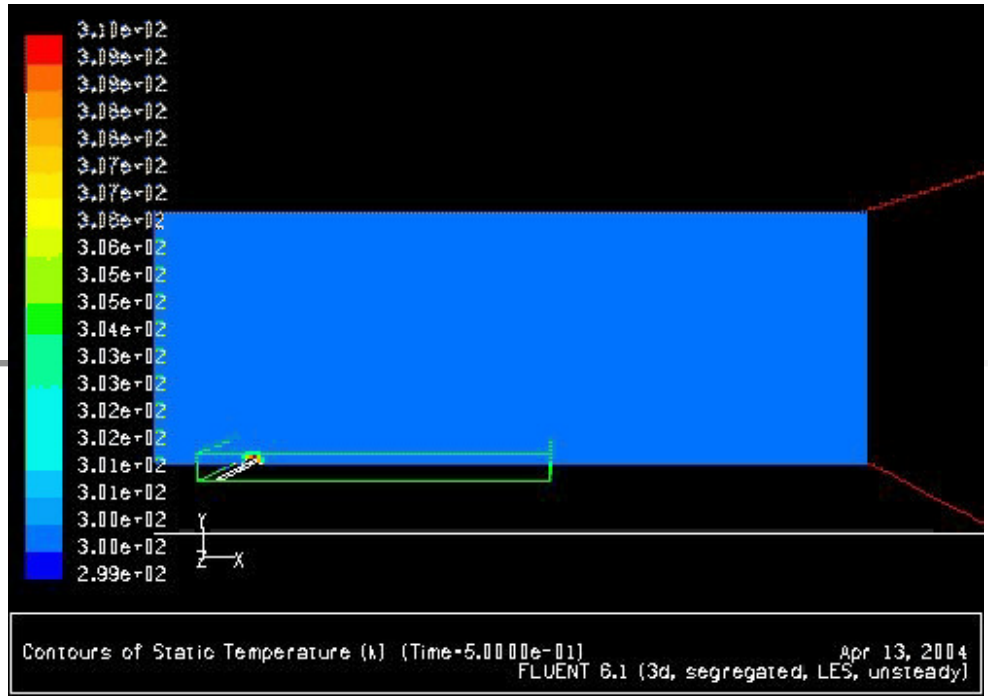


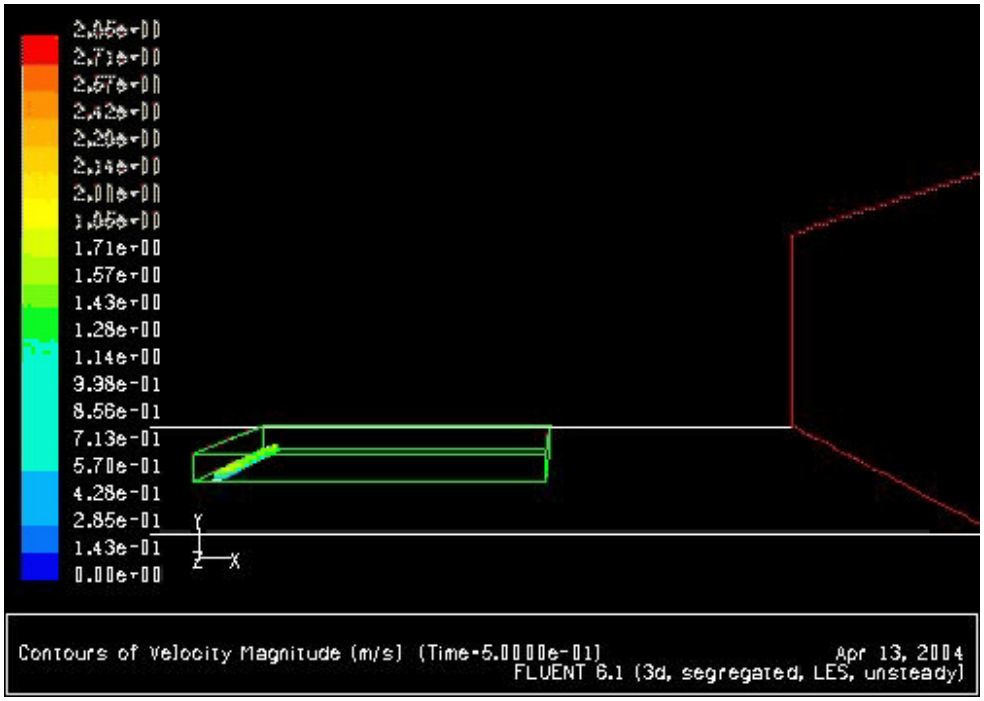
Velocity Vectors, Y = 2 m



Velocity Contours, Y = 2 m



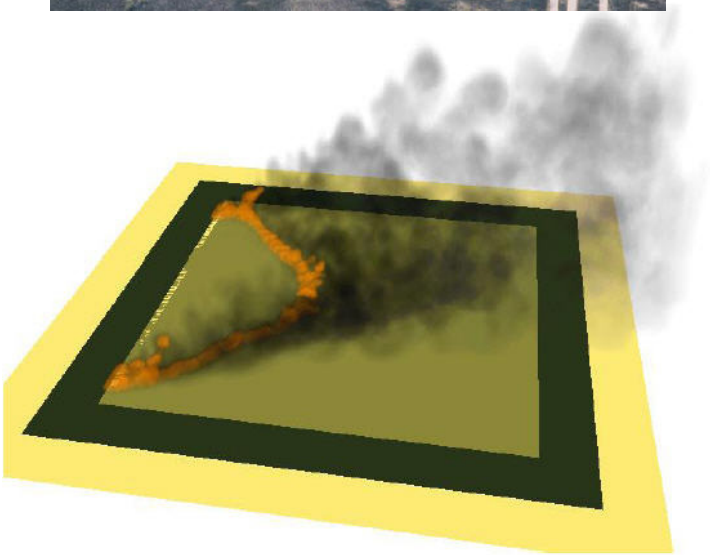




No Porous Canopy

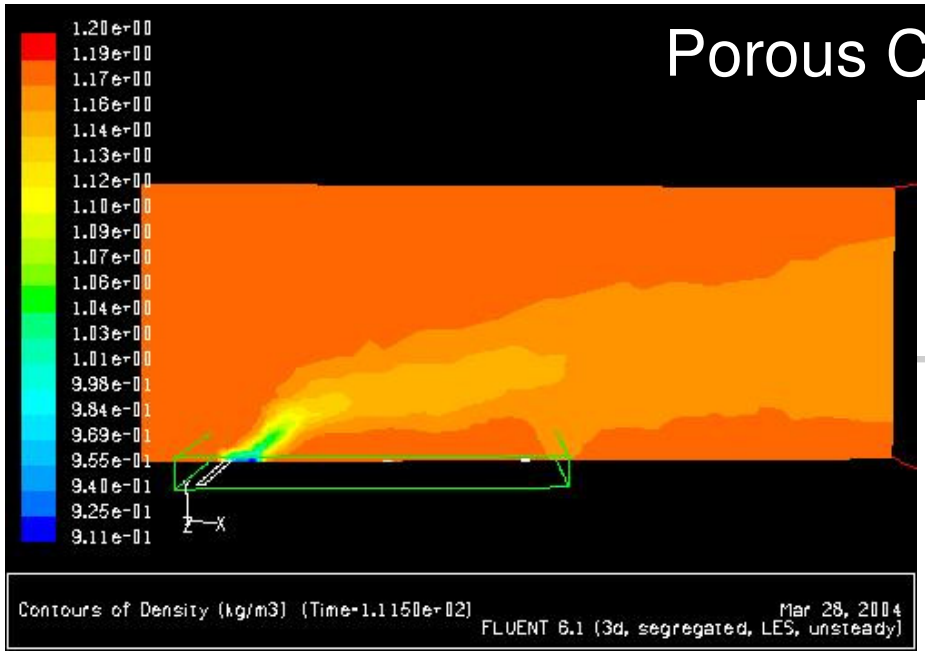
WFDS Simulation of Australian Grassland Experiment

Mell et al. (2006)

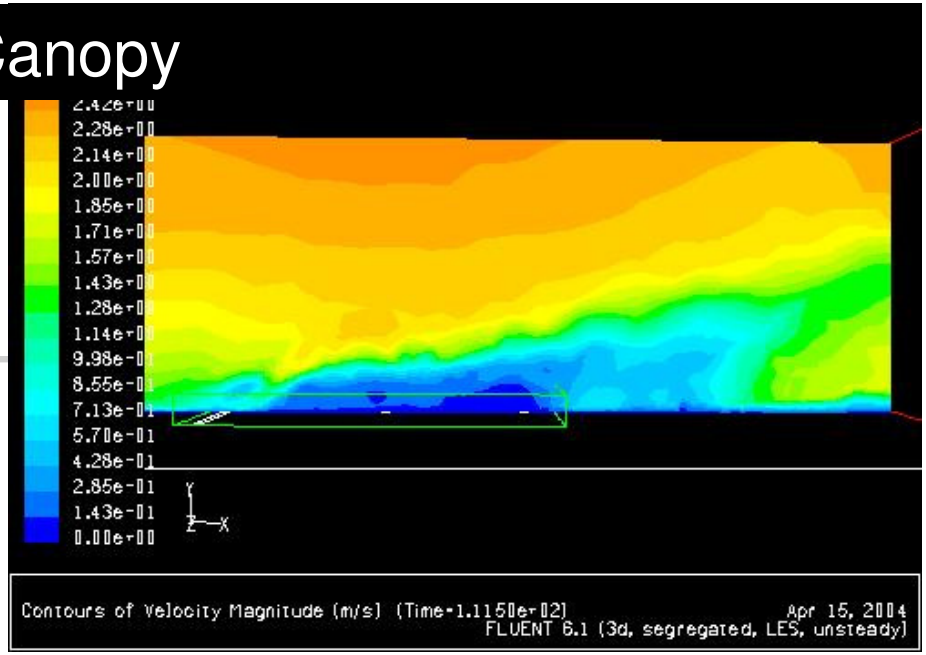


- Cheney et al. (1993, 1995) Northern Territory, AU.
- Natural grass ,200 m x 200 m plot; 5 m/s wind left to right Ignition length 175m, t = 56 sec.
- WFDS simulation, t = 56 sec .

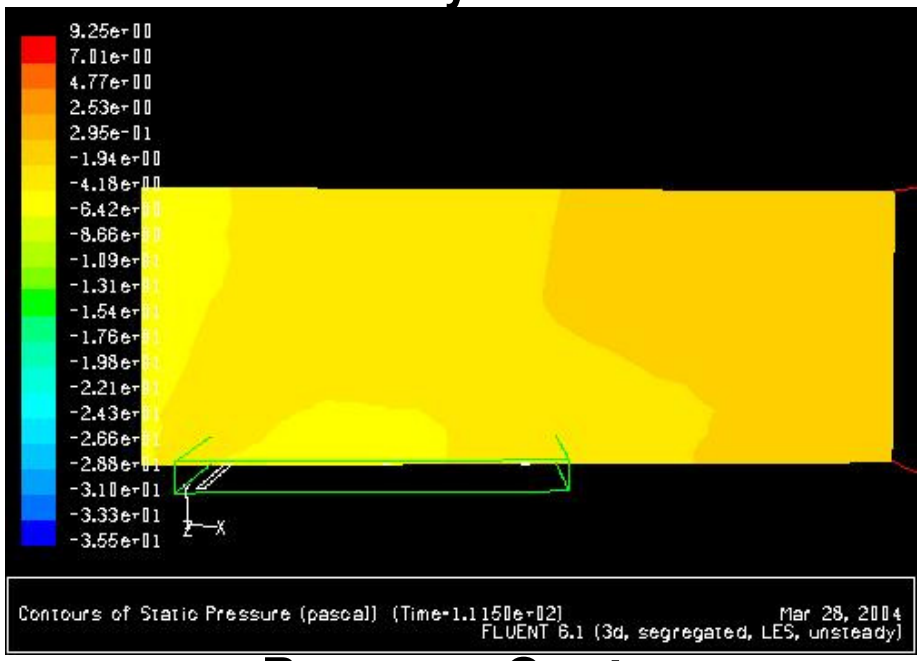
Porous Canopy



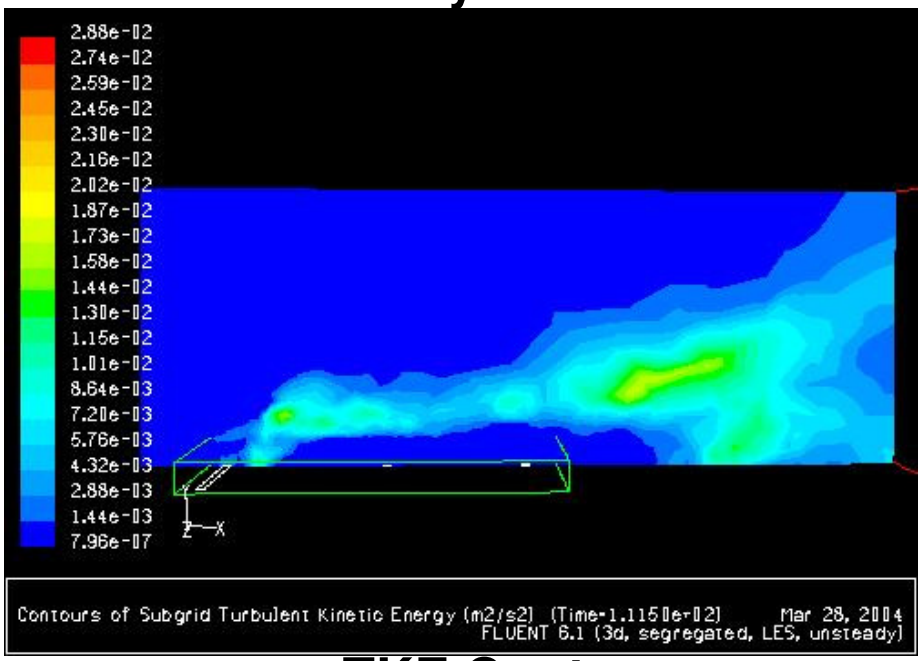
Density Contours



Velocity Contours

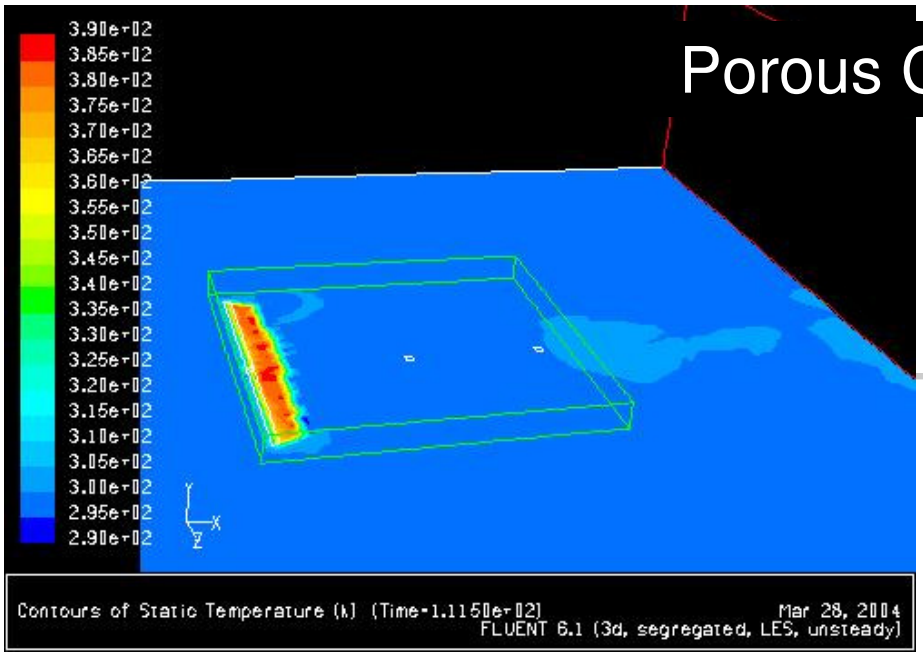


Pressure Contours

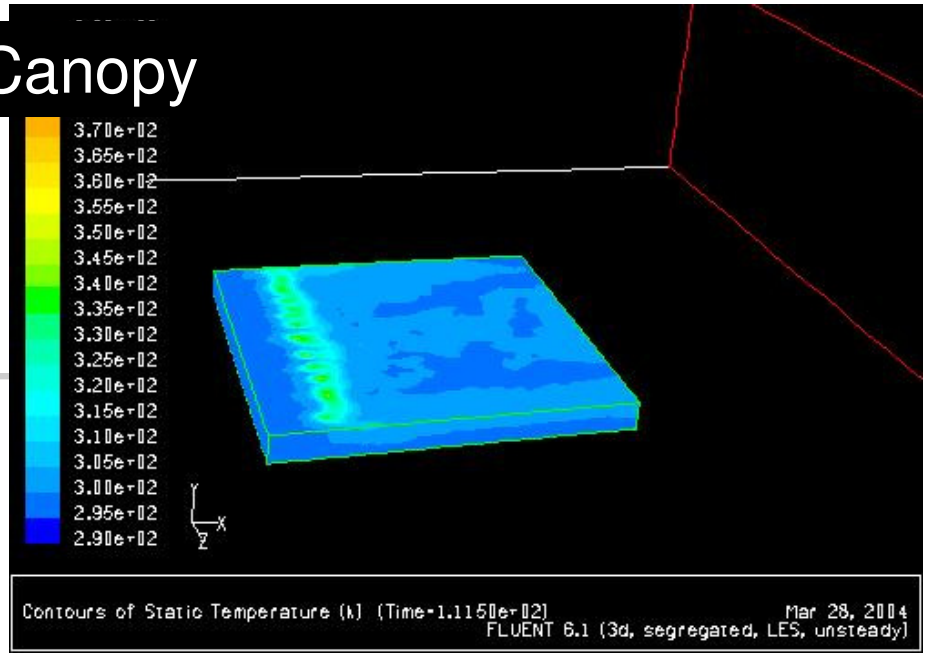


TKE Contours

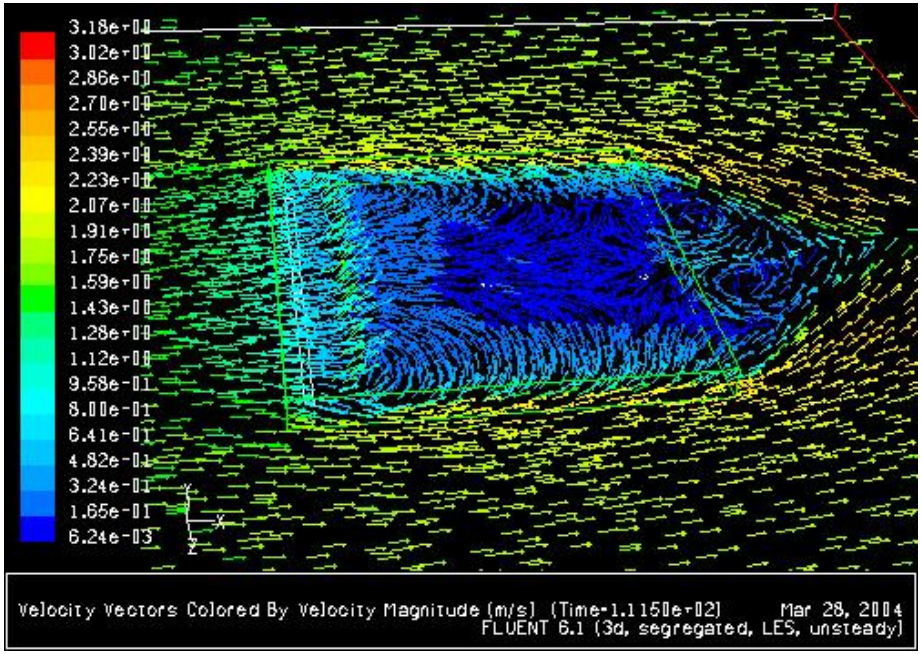
Porous Canopy



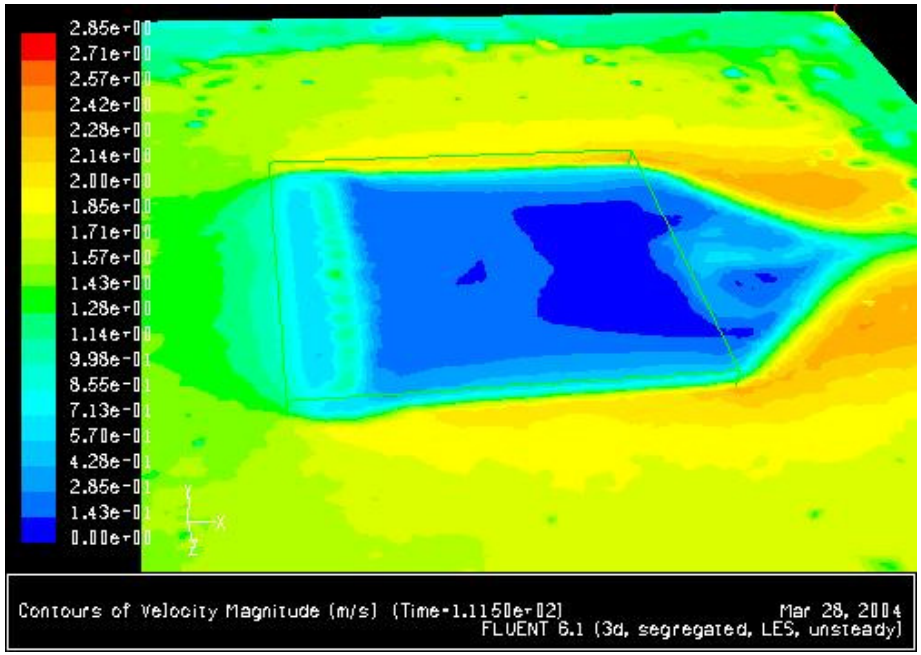
Temperature Contours



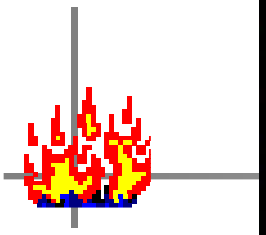
Temperature Contours, Y = 6 m

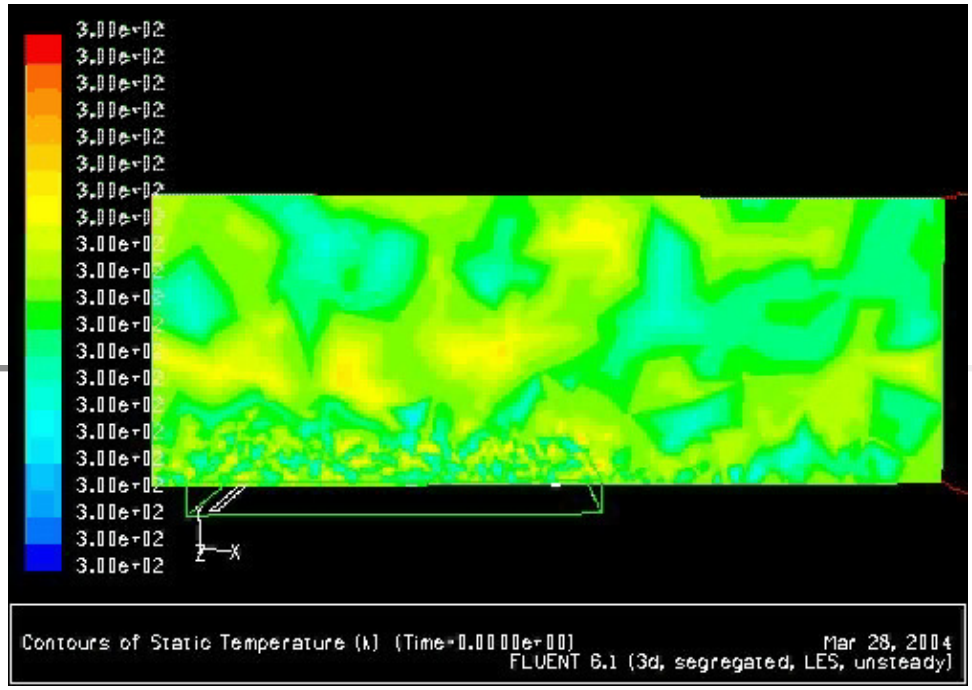


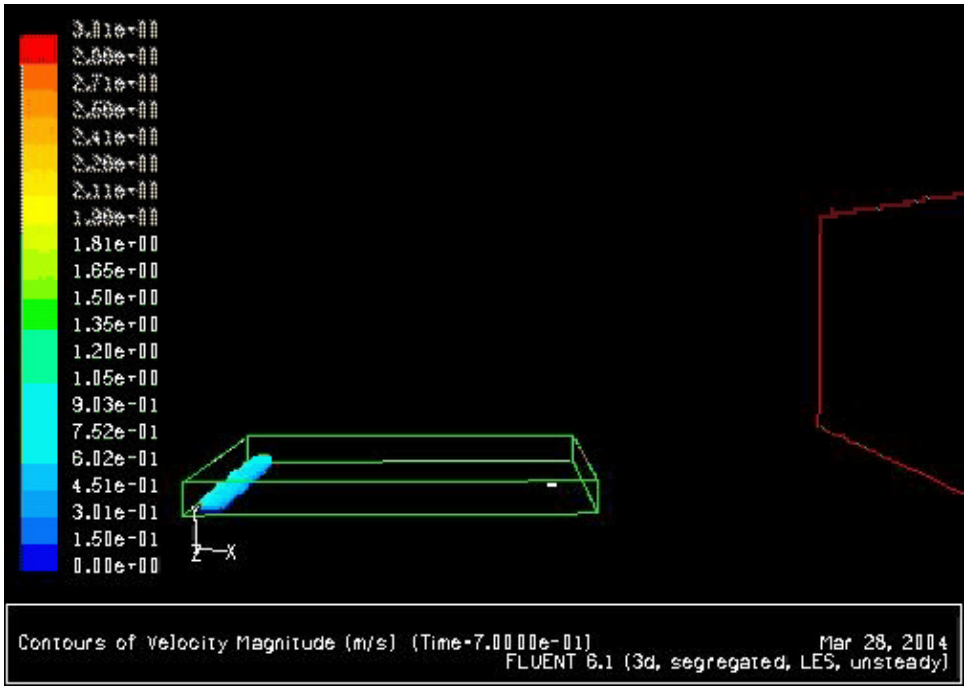
Velocity Vectors, Y = 2 m



Velocity Contours, Y = 2 m







Porous canopy

Diagnosis by the Wind Doctor

- Smoke and fire generated in forest and urban canopies is a major modern hazard.
- Fire spread is significantly influenced by the porous nature of the canopies.
- Understanding of the phenomena requires joint consideration of fluid flow in porous media, combustion, and radiation.
- CFD provides a valuable way to analyze the fire mechanics, predict fire spread, and evaluate mitigation strategies.

Fire Rainbow

HIS IS A FIRE RAINBOW - THE RAREST OF ALL NATURALLY OCCURRING ATMOSPHERIC PHENOMENA. THE PICTURE WAS CAPTURED ON THE IDAHO/WASHINGTON BORDER. THE EVENT LASTED ABOUT 1 HOUR. March 22, 2007 CLOUDS HAVE TO BE CIRRUS, AT LEAST 20K FEET IN THE AIR, WITH JUST THE RIGHT AMOUNT OF ICE CRYSTALS AND THE SUN HAS TO HIT THE CLOUDS AT PRECISELY 58 DEGREES.