Impacts of beetle-kill and forest fire on regional water and energy cycles in western North America

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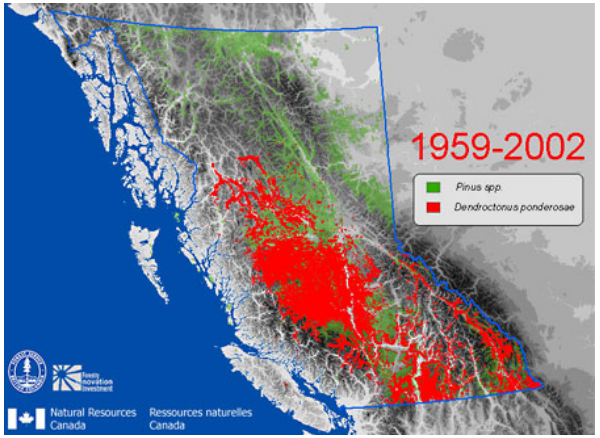
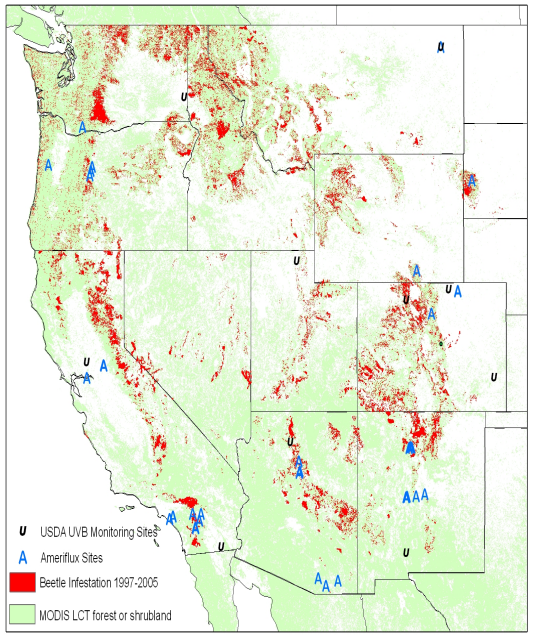
Continental-scale Natural Forest Disturbances

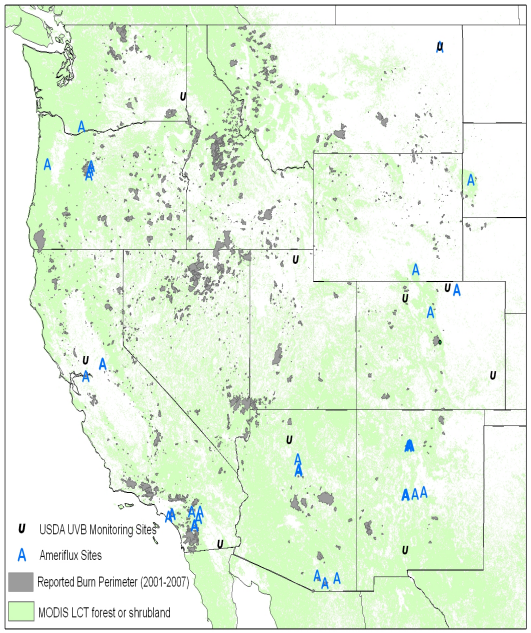
Due to warmer winter and drought

Mountain Pine Beetle



Beetle infestation Forest burned area





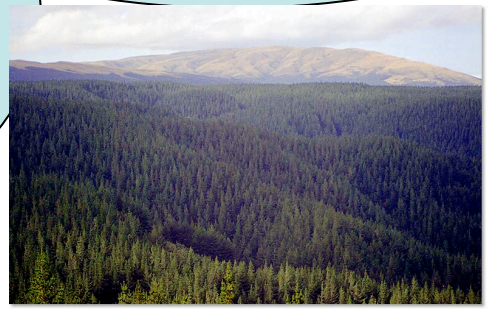
Regions of identified beetle infestation from aerial surveys from 1997-2005 (in red in the left panel) and burned area perimeters reported to the USGS from 2001-2007 (in gray in the right panel) for the western U.S

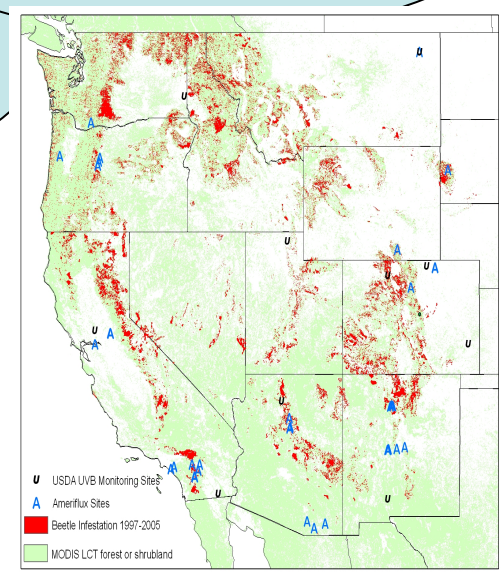
Goal of our research: Understand multi-scale interactions among biosphere, hydrosphere, and atmosphere

Regional effects:
Clouds and precipitation
Climate variability
Flood and drought

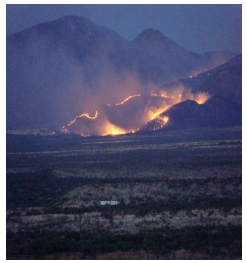
Watershed effects:
Streamflow
Water quality
Atmospheric boundary layer

Local effects:
Biological particles and VOC emissions
Latent and sensible heat
Soil moisture and snow
Carbon and nitrogen emission and deposition





Insect outbreaks

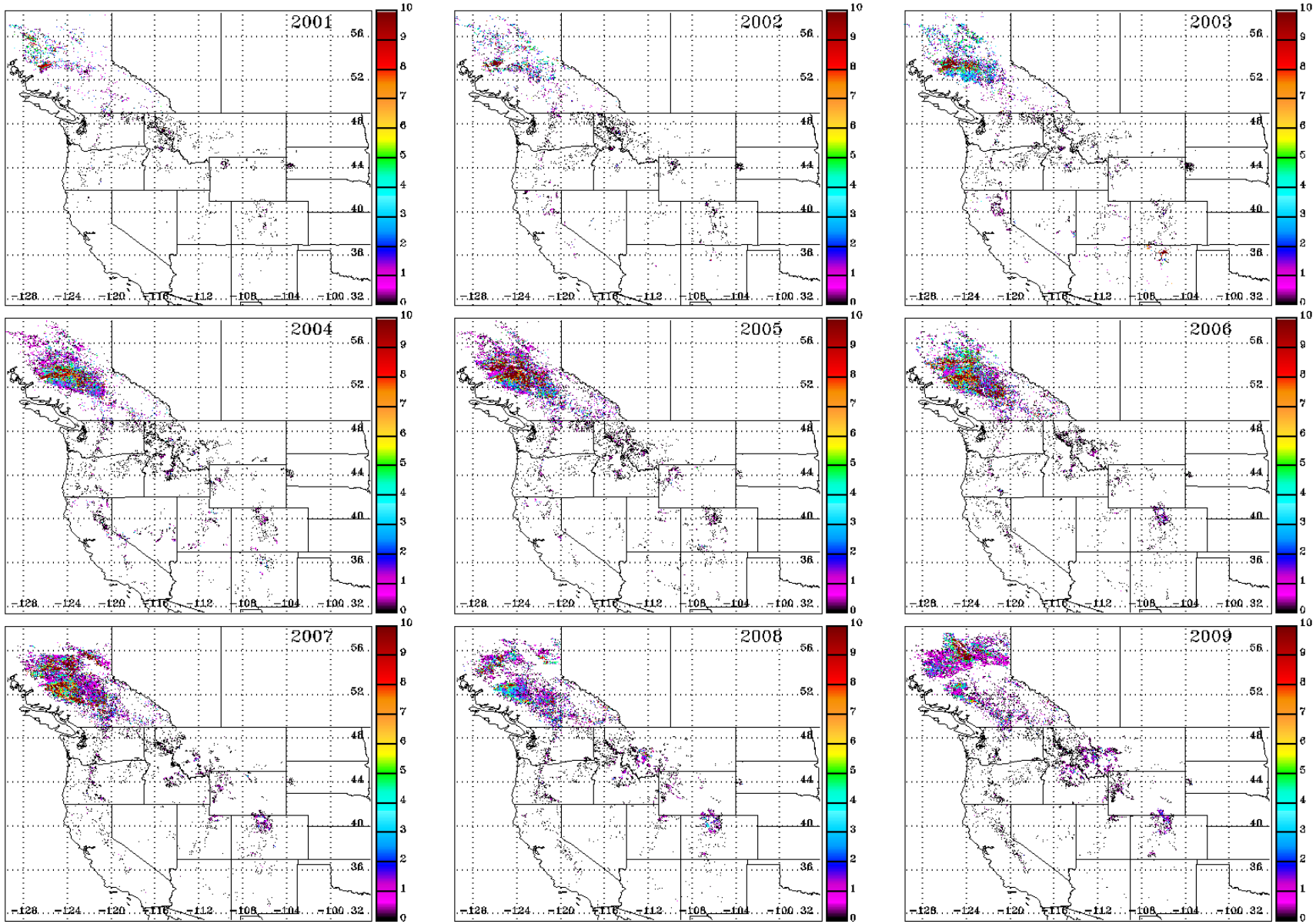


Fire

Our approach

- Data development:
  - Consolidate in-situ, ADS (aerial detection survey), MTBS (Monitoring Trends in Burn Severity) product, NASA MODIS data to construct trajectories of MPB and fire outbreak, changes in physical properties (LAI, vegetation fraction, albedo, emissivity)
- Modeling:
  - Improve the Noah LSM to represent the outbreak
  - 10-year (2000-2010) reanalysis of surface fluxes, soil moisture, snow, runoff using 1-km HRLDAS
  - High-resolution WRF/Noah regional climate simulations
- Observation:
  - Surface and intensive boundary-layer sounding over disturbed forests

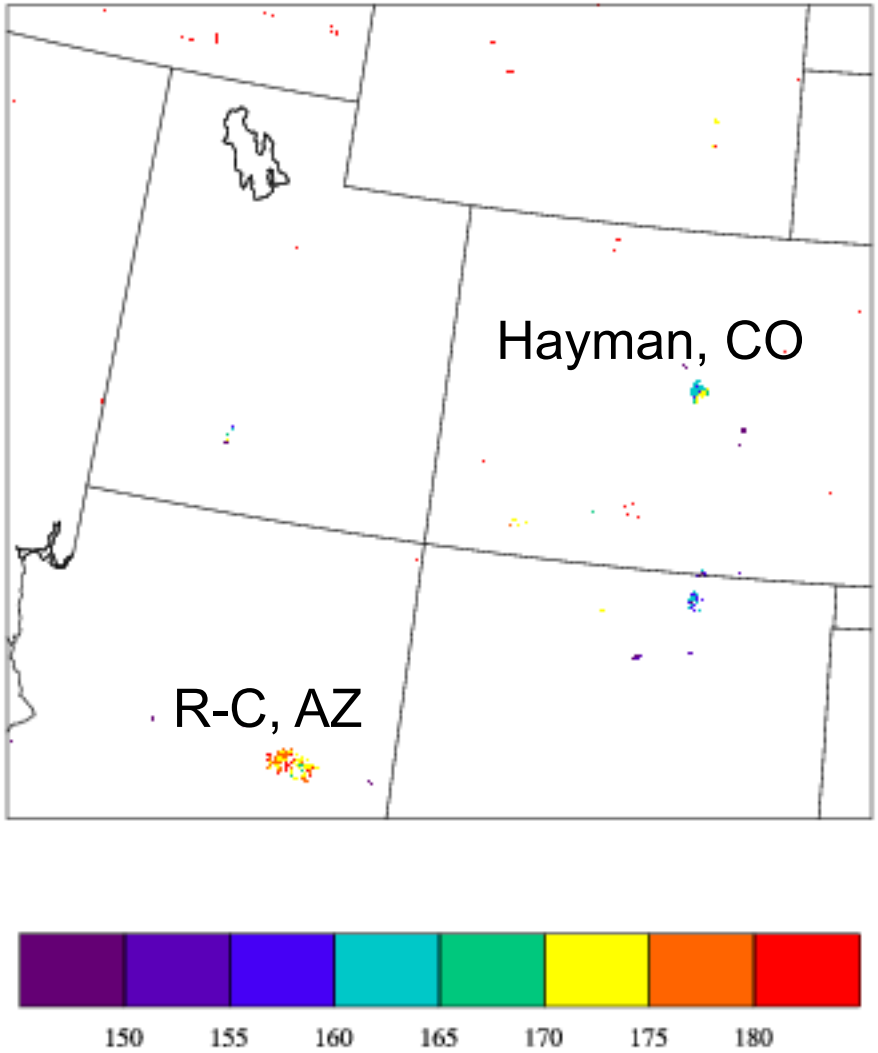
Constructing beetle-kill trajectory (2000-2009)

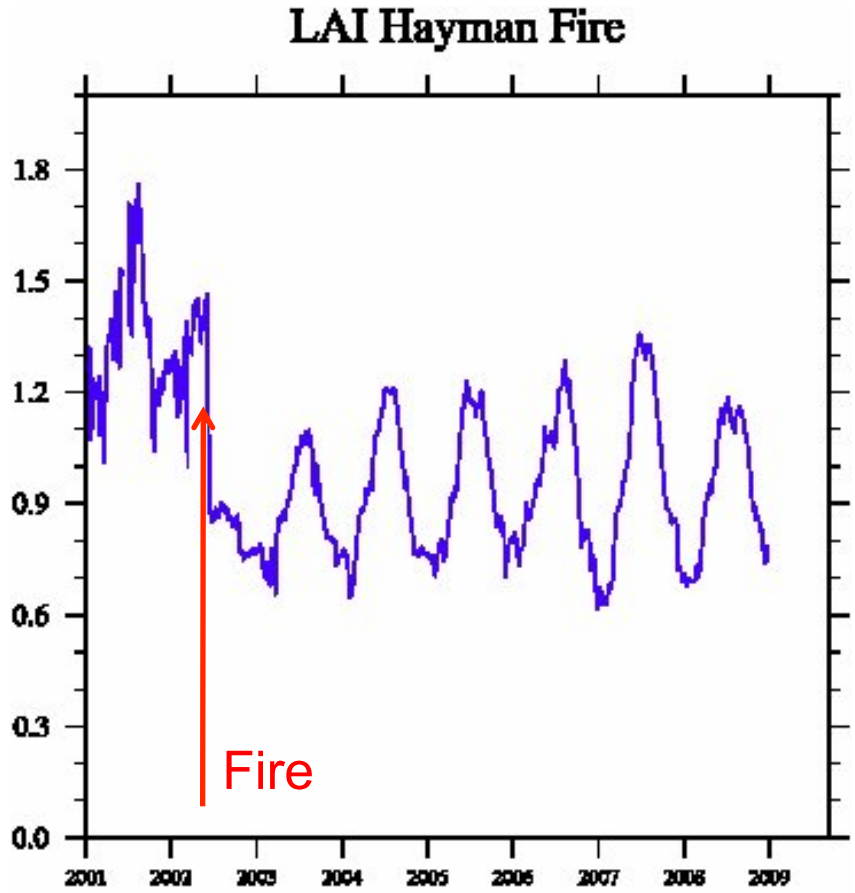


Mortality area (ha) per gridcell. gridcell = 100ha (or 1km^2)

Utilize MODIS 500-m data in WRF: Colorado Hayman - started 8 Jun, controlled 18 Jul. Arizona Rodeo-Chediski - started 18 Jun, controlled 7 Jul.

All 2002 burn areas



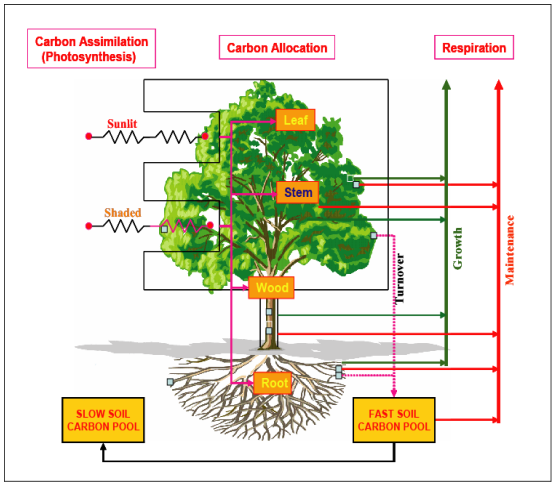


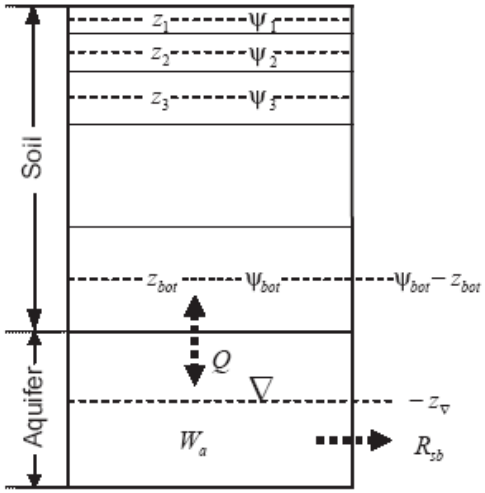
1-km MODIS averaged for 353 km^2

Noah Model Development

A new prototype: Noah Multi-Physics (Noah-MP)

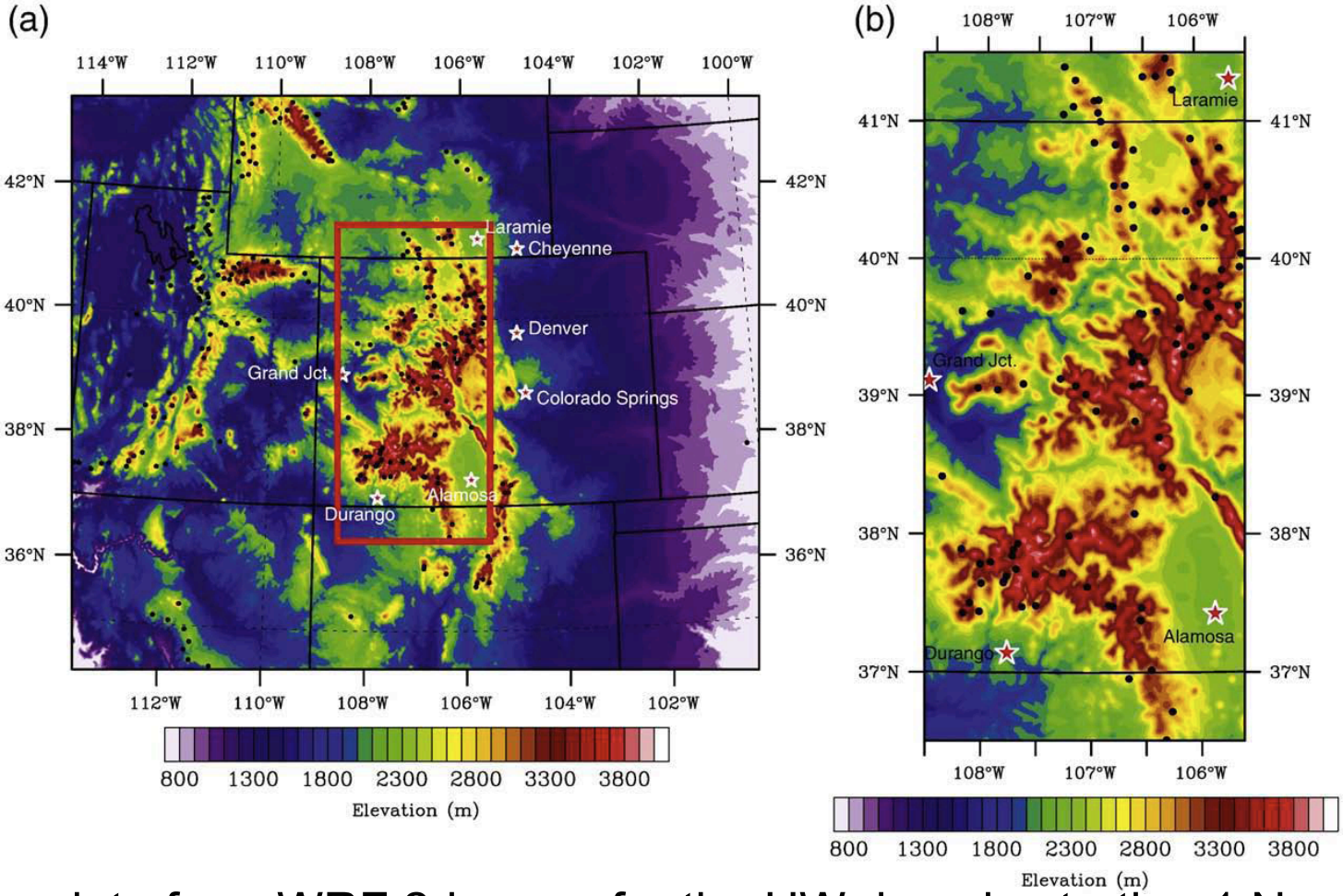
- Multi-layer snowpack model
- Dynamic vegetation, multi-layer vegetation canopy, two-stream radiation transfer
- Groundwater model
- 2-D high-res explicit routing
- Ball-Berry canopy resistance
- Irrigation treatment
- van Genuchten soil hydraulics, spatially varying soil layer thickness
- New frozen soil scheme





Niu, Liang, Mitchell, Chen, Ek, et al., 2011a,b, *JGR*.

Colorado HW offline snow simulations



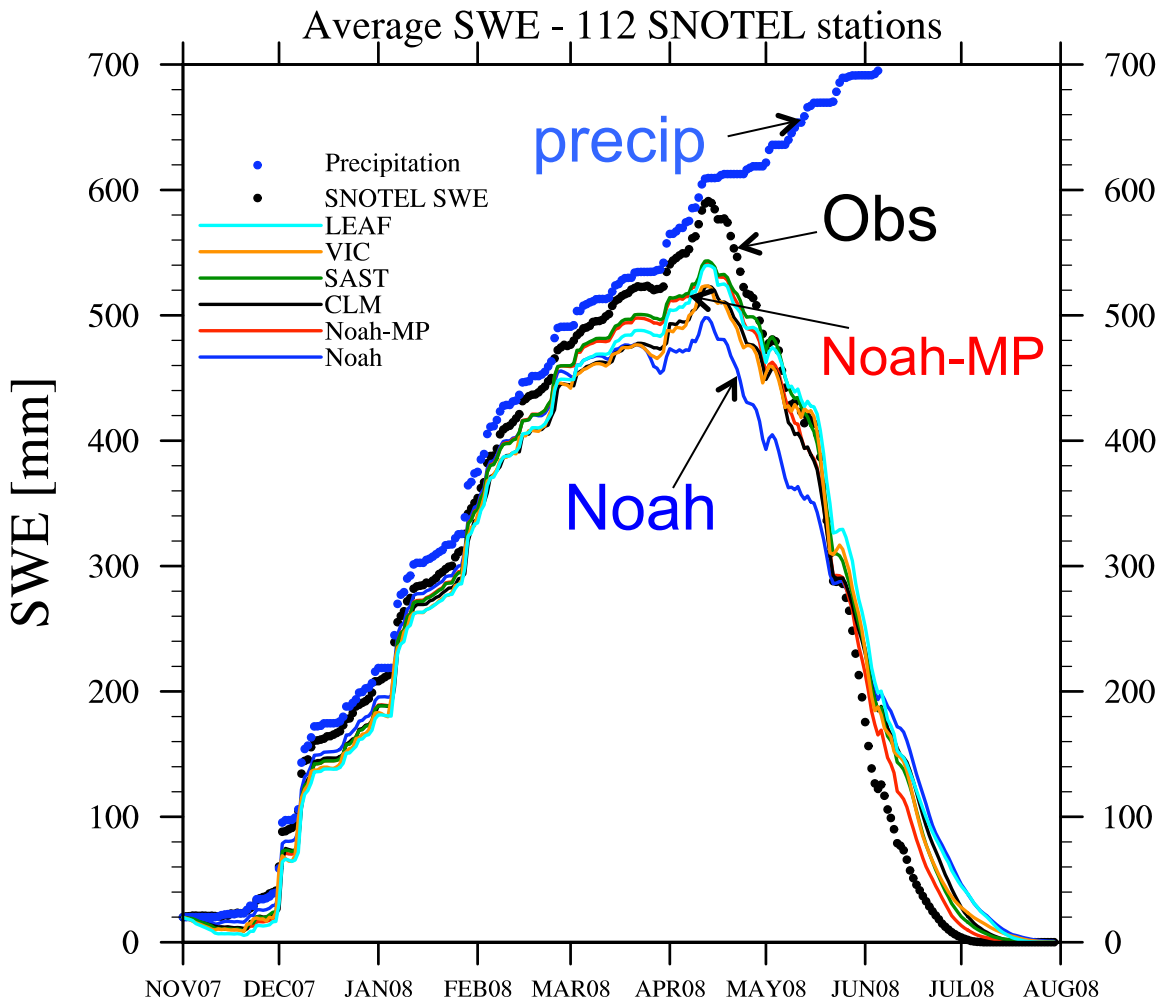
- Forcing data from WRF 2-km run for the HW domain starting 1 Nov 2007 for 2007-2008 winter season
- Replace WRF solar downward radiation with hourly 0.5-degree GOES-derived radiation

Community effort to inter-compare snow models for the Colorado HW regions

We focus on six physically-based models

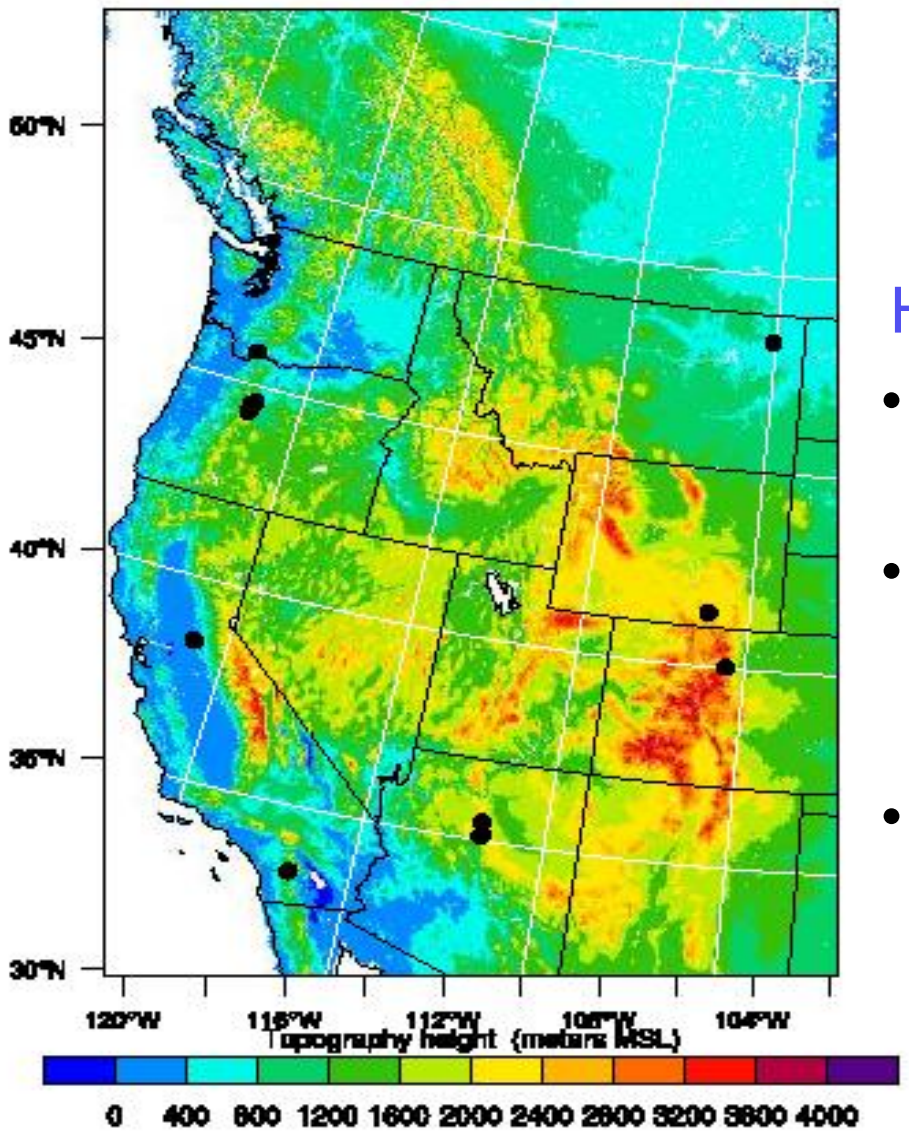
- Noah (WRF): Tewari, Barlage, Chen (NCAR)
- CLM (CCSM): Wen, Jin (Utah State)
- LEAF-2 (RAMS): Miguez-Macho (U.de Santiago de Compostela, Spain
- Noah-MP: Noah Multi-Physics. Niu (U. Arizona) and Yang (U. Texas-Austin), Tewari, Barlage, Chen (NCAR)
- SAST (Snow–Atmosphere–Soil Transfer Model): Jin (Utah State)
- VIC: Livneh, Lin, and Lettenmaier (U. Washington)

Comparing SWE simulated by six models



- Understand key processes controlling evolution of snowpack in Colorado HW region through comparing snow models
- Improve snowpack modeling in climate models

10-year land-surface reanalysis domain
using High-resolution land data assimilation (HRLDAS)



Terrain height (m)
Dots are AmeriFlux sites

HRLDAS forcing conditions

- NARR 32-km: t, q, u/v, p, longwave radiation.
- National LDAS (NLDAS): precipitation, 1/8 degree, hourly.
- U. Maryland/NOAA GOES 0.5-deg hourly solar downward radiation.

Beetle Test-Simulation Summary

- Simulation period: 1 Jan 2004 – 1 Aug 2005 (first 8 months for spin-up)
- Beetle simulation: based on preliminary ADS survey, 225,000 ENF grids are affected at some level by beetles. As first simulation, entire grid is assumed affected at same level.

Modifying Noah-MP parameters (zero order effects of MPB)

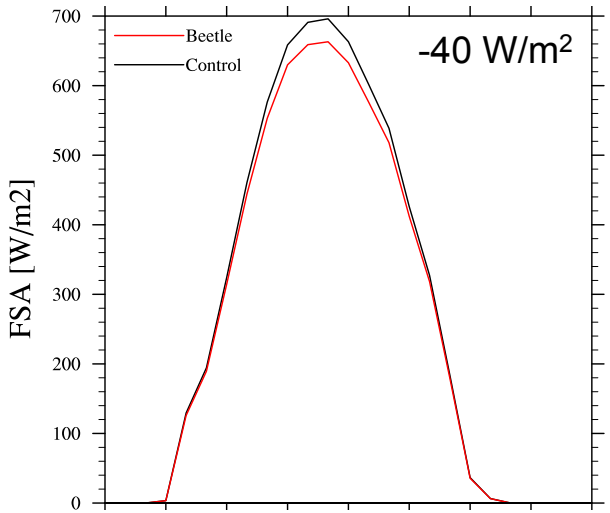
	Control	Beetle
Roughness Length	1.09 m	0.5 m
LAI	2.0 – 5.5	1.0
α_{vis}, α_{NIR}	0.07, 0.35	0.10, 0.45
Carboxylation max	50 μ mol CO_2 $m^{-2}s^{-1}$	5 μ mol CO_2 $m^{-2}s^{-1}$

June-Averaged diurnal-cycle of Surface Energy Budget

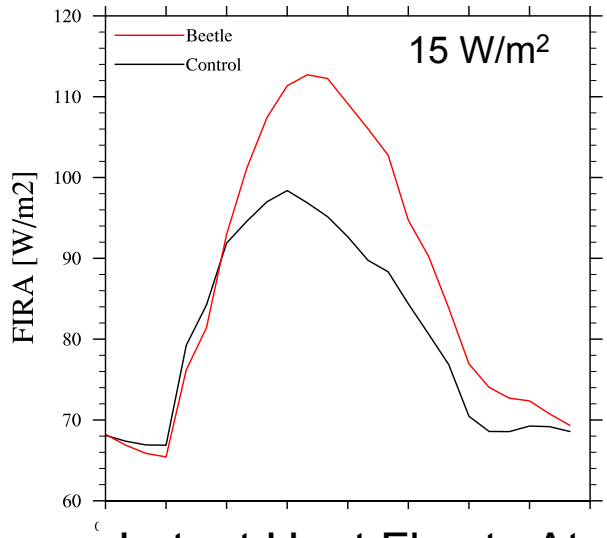
Average of 100 points affected by beetles spatially spread across domain

Red: beetle effects; Black: unaffected forests

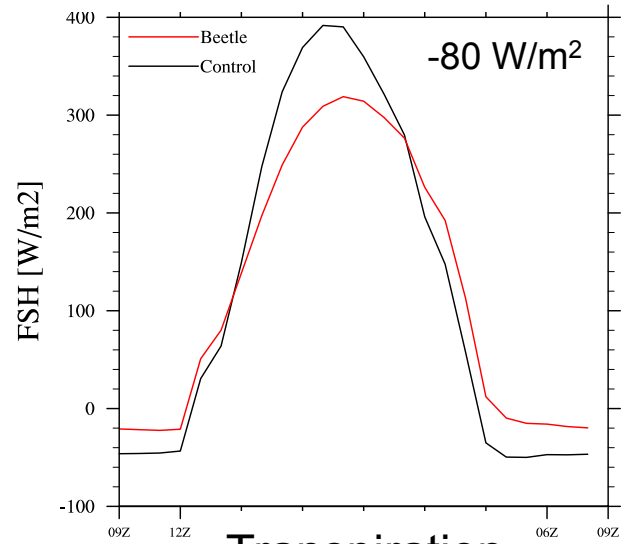
Absorbed Solar Radiation



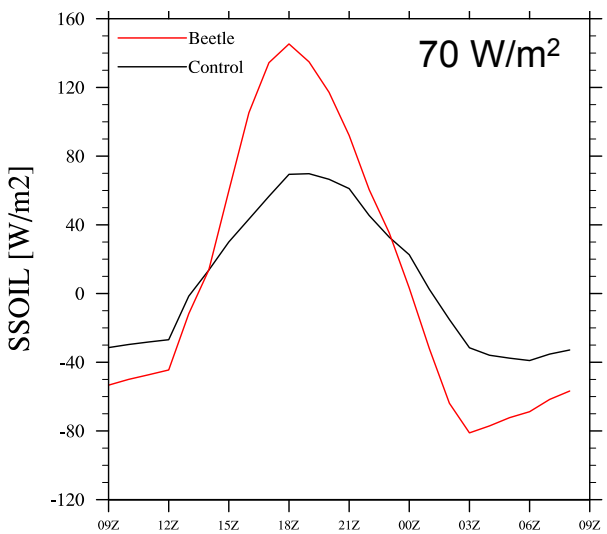
Net LW to Atmosphere



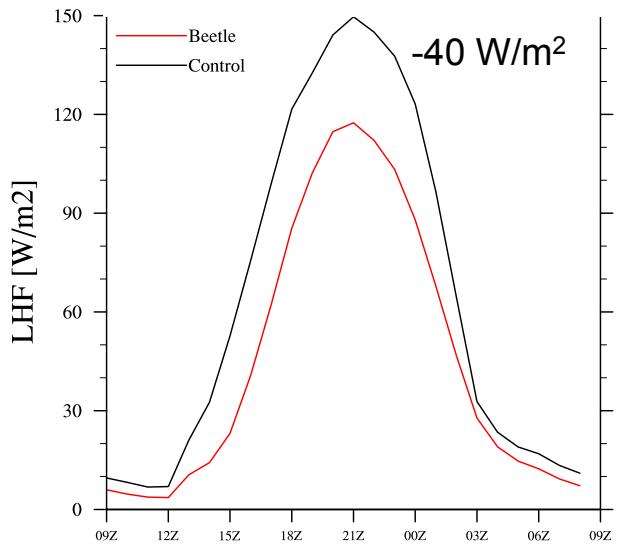
Sensible Heat Flux to Atm



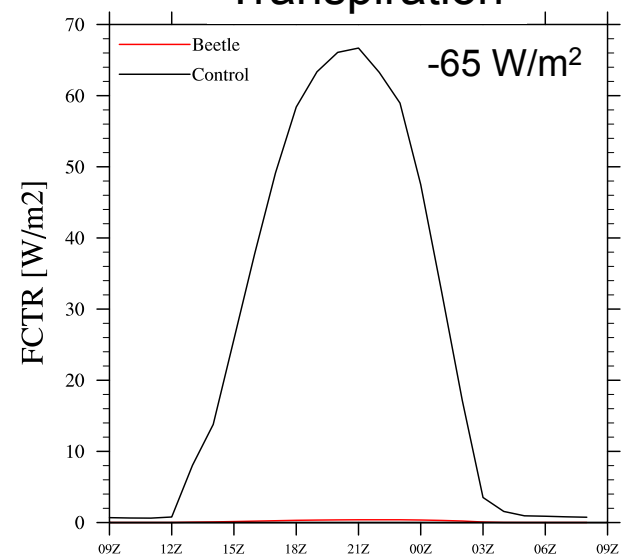
Downward Soil Heat Flux



Latent Heat Flux to Atm



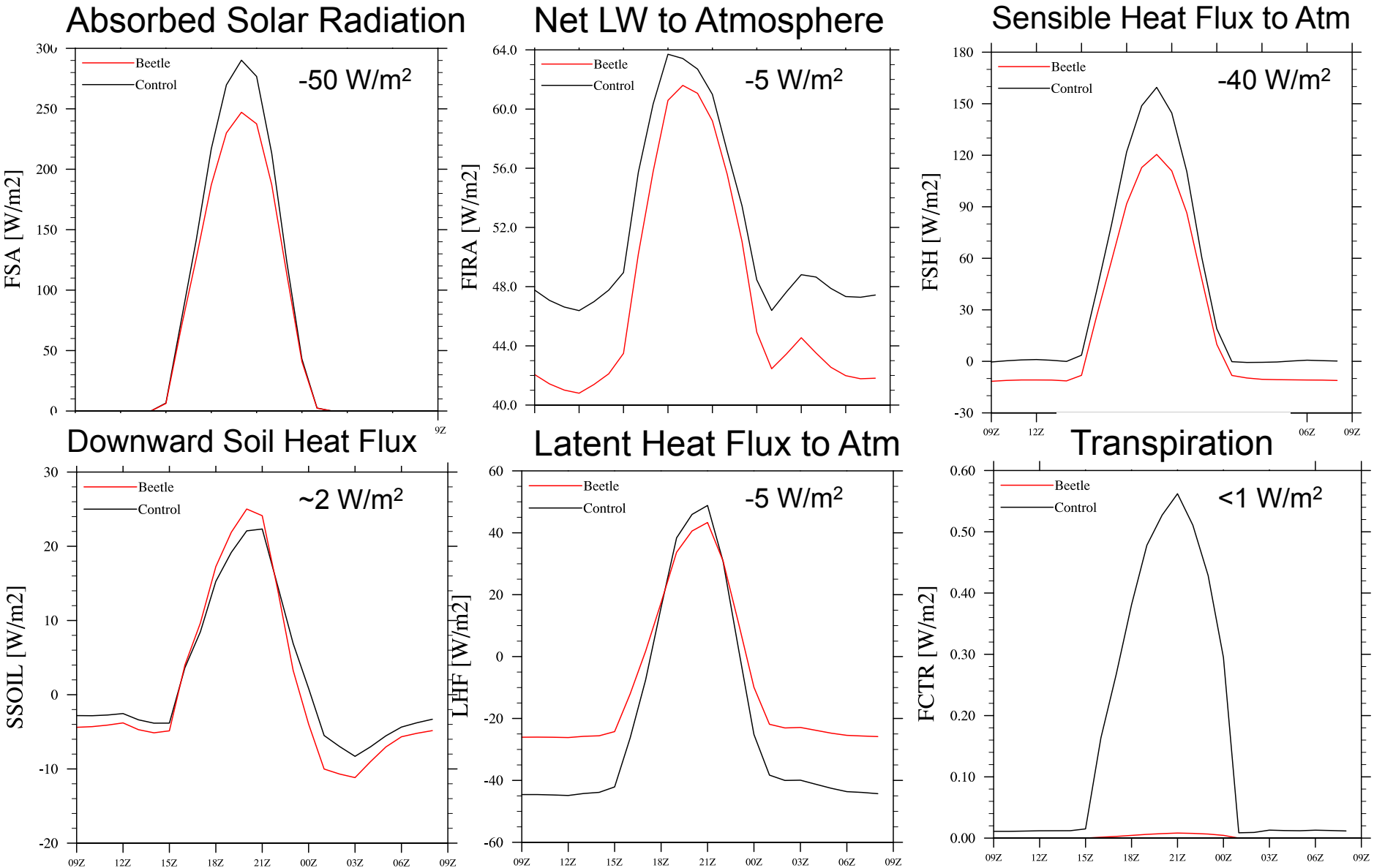
Transpiration



January-averaged diurnal-cycle Surface Energy Budget

Average of 100 points affected by beetles spatially spread across domain

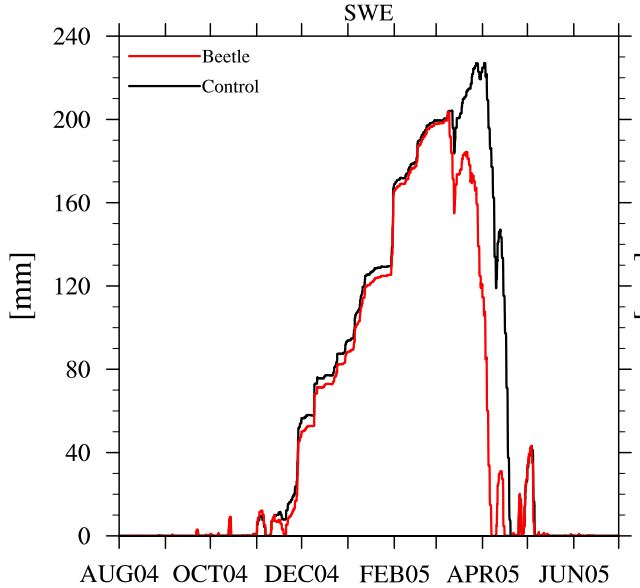
Red: beetle effects; Black: unaffected forests

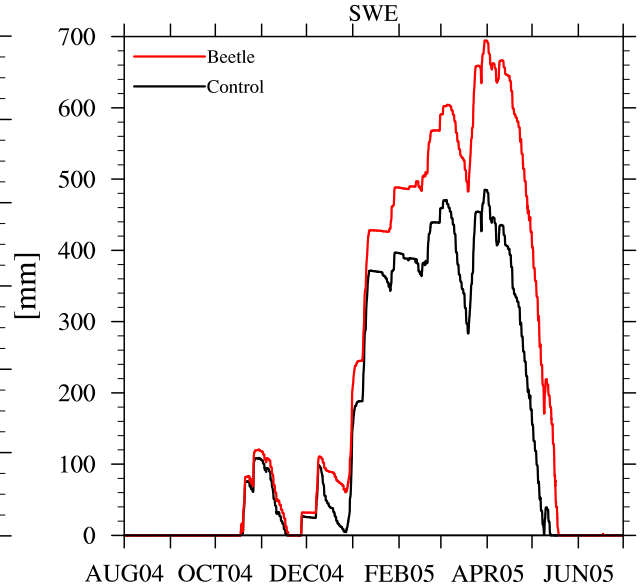


Effects on Seasonal Surface Water Budget

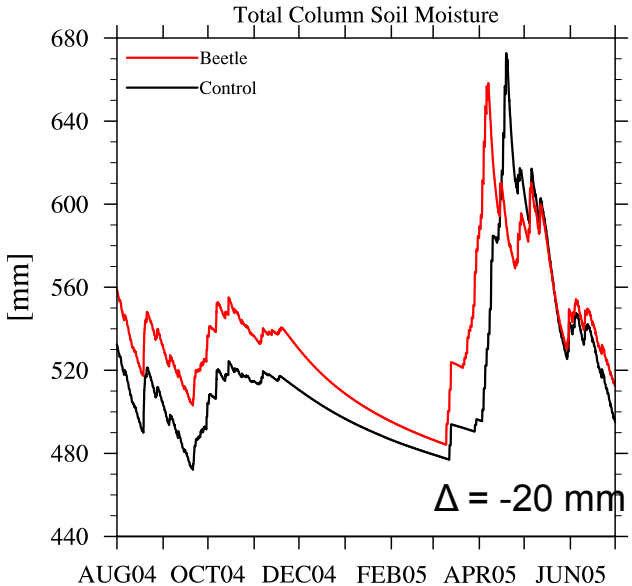
Single point near Niwot Ridge, CO

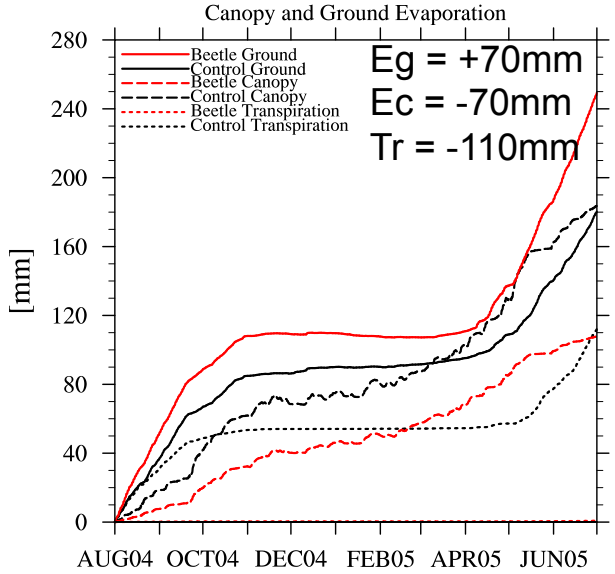
Red: beetle effects; Black: unaffected forest

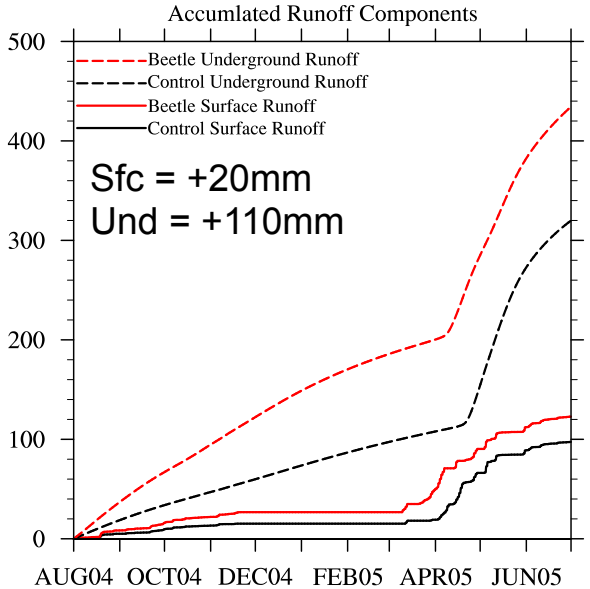




Left: SWE at Niwot Ridge
Right: SWE at 38.5N,120.1W (Sierra Nevada, N California)

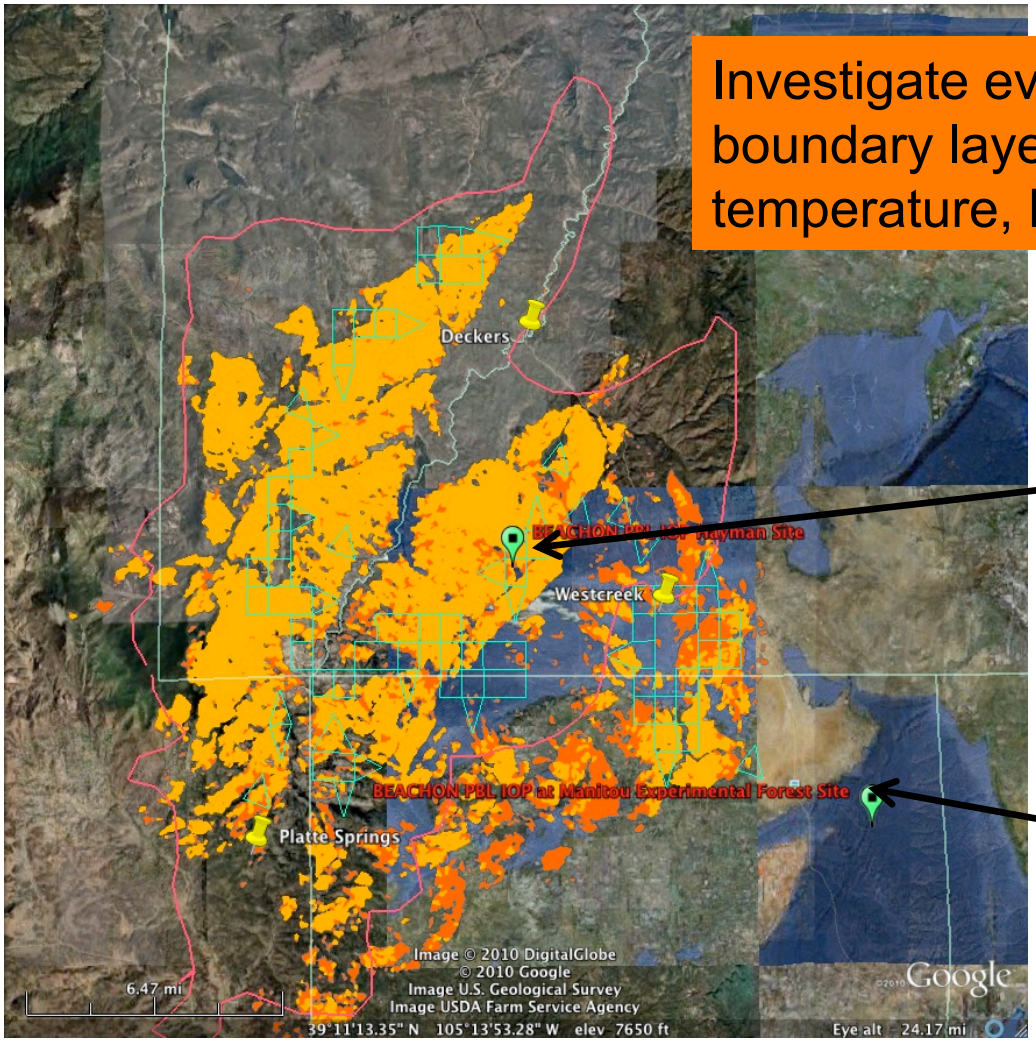






2010 August BEACHON Boundary Layer Intensive Field Campaign

Using NCAR GPS Advanced Upper-Air Sounding System (GAUS)



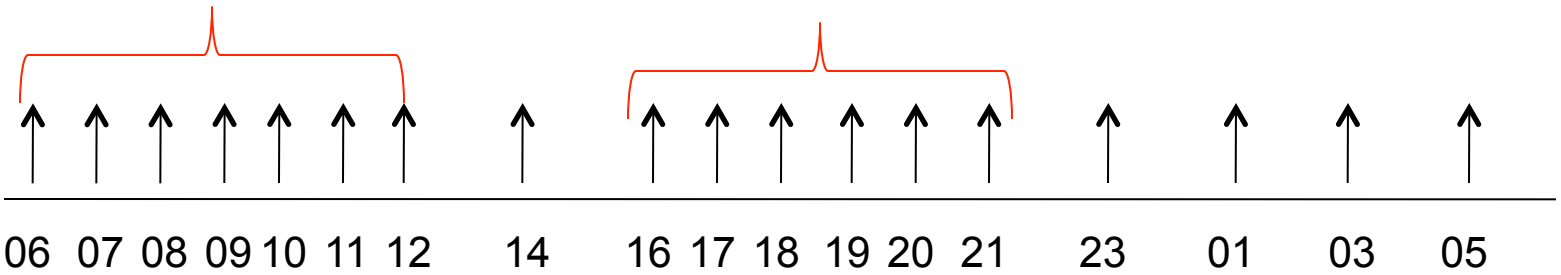
Investigate evolution of boundary layer (wind, temperature, humidity)

Hayman fire-burn site

Manitou Experimental Forest site: natural ponderosa pine
Long-term NCAR BEACHON site

NCAR GPS Advanced Upper-Air Sounding System (GAUS)

- Two sites, synchronized launch (local time)

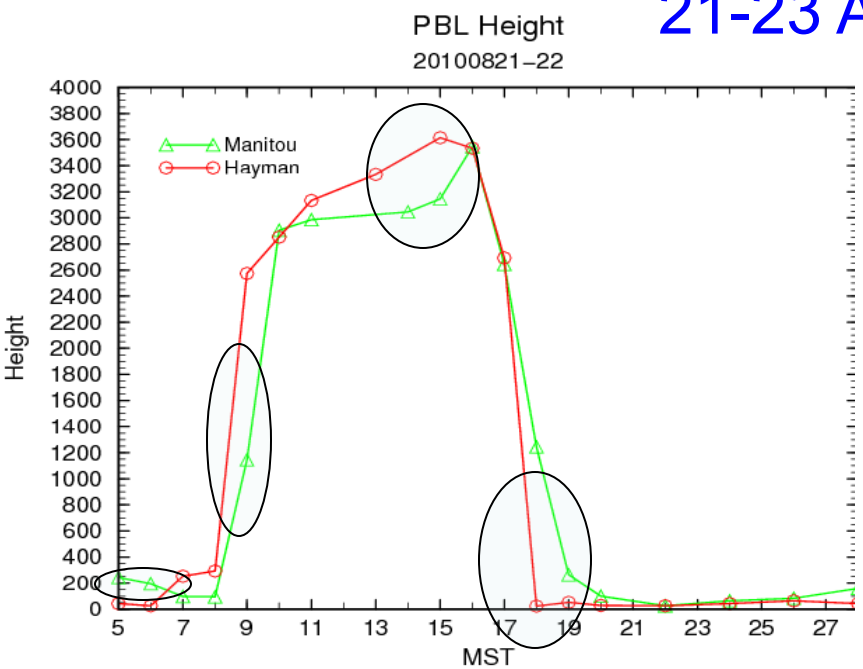


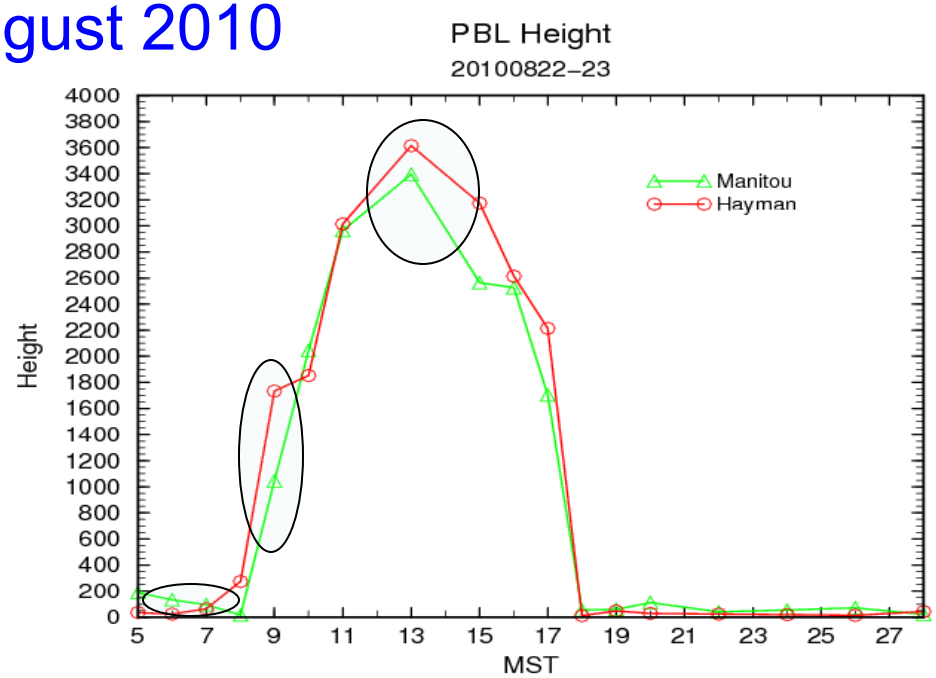
- 18 sondes/day. Intensive for PBL transition
- Two IOPS:
  - Two day for wet soil (13-14 Aug 2010): 72 sondes
  - Two day in dry spell (21-22 Aug 2010): 72 sondes
- Additional measurements at burned sites
  - Surface met stations (2-m)
  - VOC samplers (2-m or above canopy)

Diurnal cycle of PBL height at Hayman and Manitou

determined by θv and wind speed profile

21-23 August 2010

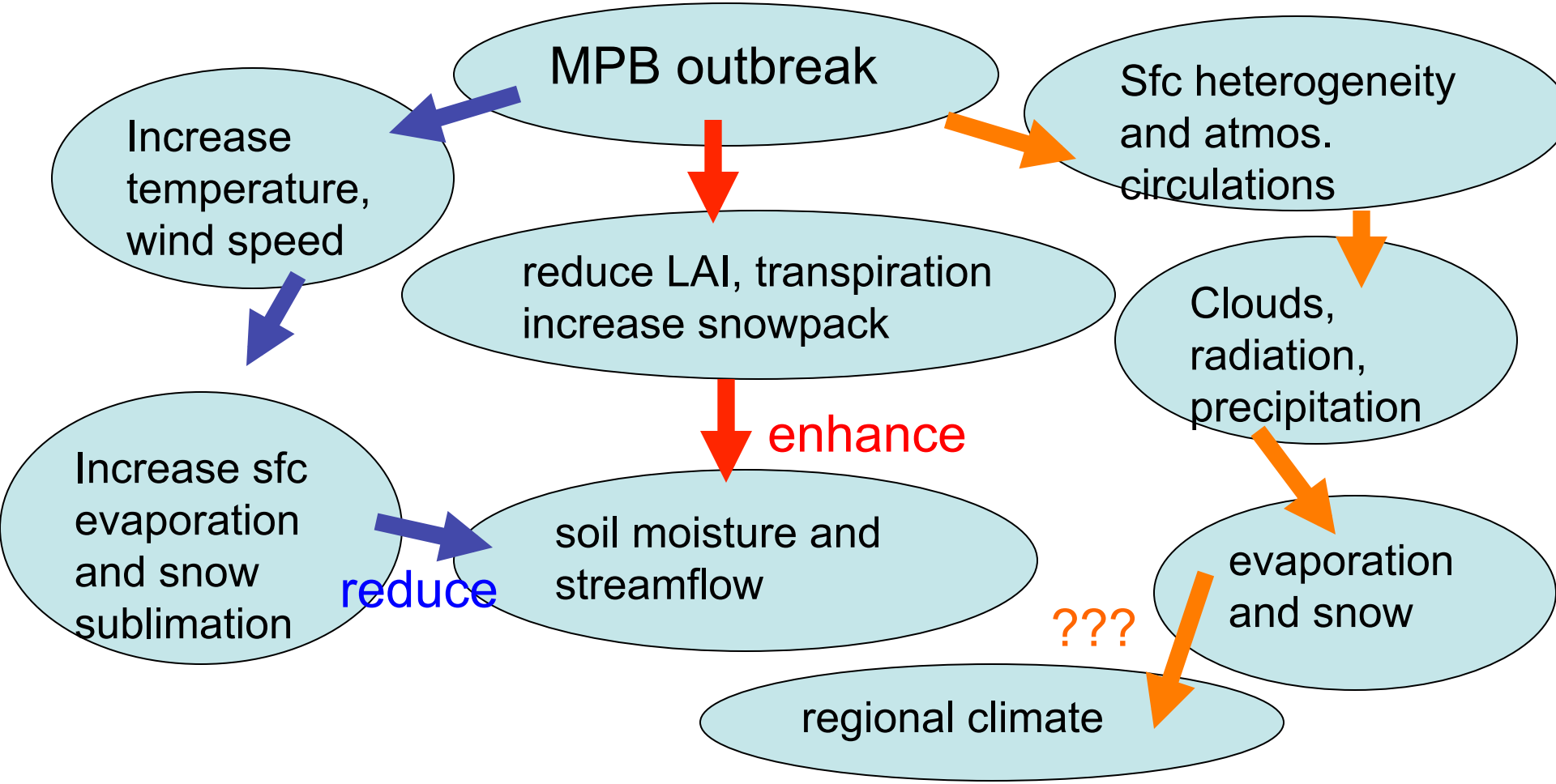




Hayman (burned site):

- stronger nocturnal stable layer near the surface
- stronger early-morning mixing and quicker transition to convective (about one hour earlier)
- mixed layer depth at both sites exceed 3 km AGL, deeper at Hayman
- PBL collapse earlier at 7 pm at Hayman site

Final Remark



Need integrated observation and modeling study