Modeling Ecohydrologic Impacts of Mountain Pine Beetle Infestation

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Motivation

- Most land surface models (LSMs)/parameterizations or catchment hydrology models have not been developed or adapted to this disturbance, limits predictability

- Science/modeling questions relating to ‘Model sensitivity to infestation’:
  - What is the sensitivity of model structure (1-d vertical and 3-d) catchment-scale energy and water fluxes to infestation in terms of loss of plant conductance and loss of canopy (e.g. leaf/needle area and roughness)?
  - How does the ‘patchy’ nature of infestation impact system responses? Thresholds?
  - Can infestation be properly parameterized through existing parameter adjustments or are more fundamental conceptual developments necessary?
  - Can we develop a reliable multi-model framework for scenario development?
Ecohydrologic Impacts of Mountain Pine Beetle Infestation: Observational Facilities

Due to the nature of aerial surveys, the data on this map will only provide rough estimates of location, intensity and the resulting trend information for agents detectable from the air. Many of the most destructive diseases are not represented on this map because these agents are not detectable from aerial surveys. The data presented on this map should only be used as a partial indicator of insect and disease activity, and should be validated on the ground for actual location and extent of disease. Shaded areas show locations where tree mortality or defoliation were apparent from the air. Intensity of damage is variable and not all trees in shaded areas are dead or defoliated.
Variability in Outbreak Conditions

- Severity and duration
- Treatment of dead standing snags
  - Harvest & immediate transfer of snags
  - Snag fall rate and delay period
Model Sensitivity Studies to Hypothetical (Typical?) Infestation

Chimney Park LAI Data

Leaf Area Index (m² m⁻²)

- Hit-2007
- Hit-2008
- Hit-2009
- Regeneration
- Unthinned
- Clearcut

Courtesy: Ewers, Reed, Pendall, Harpold, Whitehouse
Model Sensitivity Studies to Hypothetical Infestation Prescription

• Prescribed Evolution:
  – Assume staged and ‘steady-state’ response to infestation
  – Perturb 3 physiological and structural parameters (stomatal resistance, LAI and roughness length)

  • Transpiration shut-down due to blue-stain fungus: \( rs = 125.0 \rightarrow 1000 \text{ s/m} \)
  • Loss of needles: LAI=2.75-3.25 \( \rightarrow \) 15\%, 40\% (LAI)
  • Tree fall: \( z_0 = \sim 0.5\text{m} \rightarrow 25\%(z_0) \)

  – Caveat: No understory response
Hypothetical Tower Footprint Analysis:

- Clear Cut: 30%
- Infested 2008, late-red: 7%
- Uninfested: 14%
- Infested 2007, grey: 11%
- Infested 2010, green: 10%
- Infested 2009, green: 20%
- Infested 2009, grey: 8%
- Infested 2008, late-red: 7%
- FLUX Tower
- Uninfested: 14%

Mean wind
Water Budget Changes under Hypothetical Infestation Perturbations

The diagram illustrates the percent difference in various water budget components under different perturbations. The perturbations include changes in root strength (rs), leaf area index (LAI), and roughness length (z0).

Key components and their changes:
- **Dew**: Shows minimal change across perturbations.
- **ETAkin**: Slight decrease in some scenarios.
- **Edir**: Generally low changes, with slight increases in some cases.
- **Trans**: Moderate changes in response to perturbations.
- **Canevap**: Significant increase in one scenario.
- **Esnow**: Small changes, mostly negligible.
- **Sfrnff**: Moderate decrease in one scenario.
- **Ugrnff**: Significant increase in one scenario.
- **SM** and **SNOM**: Small changes, with slight increases in some cases.

The legend provides a color code for each perturbation condition:
- **rs = 1000**
- **rs, LAI -15%**
- **rs, LAI - 40%**
- **rs, LAI - 40%, z0 - 25%**
- **Tower Footprint Decomp.**
**1-D Noah Model Validation: Niwot Ridge**

- **Mid-summer fluxes** appear reasonable
- **Major problems** with winter/spring fluxes
  - LE-H partitioning is wrong in Noah
  - Note large difference in winter/spring Ground Heat Flux
1-D Noah Model Validation: Niwot Ridge

- Positive ET Bias and weak correlation (0.43)
- Poor snowpack dynamics appears to be leading issue
Multi-model assessment: Noah vs. RHESSys

RHESSys (1d & 3d)  Noah (1d & 3d)
Multi-model assessment: Noah vs. RHESSyS

• Differing snowpack dynamics:
  • RHESSyS showing better storage properties during 2010

• Differing ET characteristics:
  • RHESSyS less biased but also less correlated
Conclusions:

• Initial Sensitivity Tests: ‘Early conceptual model holds…’
  – Loss of transpirative function yields large, positive response in soil moisture and, less so, runoff
  – Changes due to LAI reduction modestly impact soil hydrology
  – Decrease in canopy roughness also enhances soil moisture, runoff, and dewfall, while decreasing canevap, snomelt and sublimation
  – Aggregation mitigates extreme responses from individual class

• Caveats to initial tests: ‘Understory response is missing…’
  – No understory response in Noah
  – No transience in vegetation
  – More work to do on aggregation

• However!: ‘Suite of models currently inadequate…’
  – Validation for an inclusive range of state AND flux variables across all seasons is proving difficult at Niwot site
  – Inter-model differences appear to be complicated
  – Much more work is needed to make these models applicable…
Modifications to CLM-CN

- **Stem C & N**
- **Coarse Root C & N**
- **Leaf C & N**
- **Fine Root C & N**

**Snag (m\textsuperscript{th} year)**

**CWD C & N**

**Dead Foliage (n\textsuperscript{th} year)**

**Litter C & N**

**Green Attack**
**Fading**
**Red Attack**
**Gray Attack**
**Snagfall**
**Recovery**
Simulated Soil N Dynamics Play a Key Role in C Fluxes and Recovery

Point simulation in Idaho: 95% mortality over 3 years