Characterizing rain-on-snow events in the Southern Sierra Nevada

Tessa Maurer
PhD Candidate, UC Berkeley

California Extreme Precipitation Symposium
June 30, 2020
Topics

Introduction & study sites
Rain-on-snow events
Random Forest model
Rain-on-snow in the Sierra Nevada

- Regular phenomenon in the Sierra Nevada
- Difficult to model: snowpack can increase water available for runoff, but also delay peak runoff
- Effect of vegetation & small-scale processes on snowpack energy balance is an ongoing knowledge gap
Rain-on-snow in the Sierra Nevada

$$\Delta Q = R_n + H + L_v E + G + M$$

- Net radiation, $R_n$
- Sensible heat flux, $H$
- Latent heat flux, $L_v E$
- Advective heat flux (rain), $M$
- Ground heat flux, $G$

Snowpack

4
Rain-on-snow in the Sierra Nevada

\[ \Delta Q = R_n + H + L_v E + G + M \]

- Shortwave radiation
- Sensible heat flux, $H$
- Latent heat flux, $L_v E$
- Longwave radiation
- Snowpack
- Advective heat flux (rain), $M$
- Ground heat flux, $G$
Total of 74 sensing locations ("nodes") spanning ~1700 to 2600 m
Wireless sensor networks
Goals

1. Characterize ROS events in the Southern Sierra Nevada
2. Assess the capacity of a data-driven model for predicting snow depth change during ROS events
3. Identify potential drivers of snow depth change during ROS events
1. Characterize ROS events in the Southern Sierra Nevada
2. Assess the capacity of a data-driven model for predicting snow depth change during ROS events
3. Identify potential drivers of snow depth change during ROS events
1. Characterize ROS events in the Southern Sierra Nevada
2. Assess the capacity of a data-driven model for predicting snow depth change during ROS events
3. Identify potential drivers of snow depth change during ROS events
Introduction & study sites
Rain-on-snow events
Random Forest model
Event identification

Rain-on-snow events:
- Identified individually at each node

Goal → identify ROS events, including mixed-phase periods
Event identification

Rain-on-snow events:
  • Identified individually at each node
  • Hourly criteria
    • $P > 0$ mm
    • Dewpoint $T > 0$ °C
    • Snow depth $> 10$ cm

Goal $\rightarrow$ identify ROS events, including mixed-phase periods
Rain-on-snow events:
• Identified individually at each node
• Hourly criteria
  • $P > 0 \text{ mm}$
  • Dewpoint $T > 0 \degree\text{C}$
  • Snow depth > 10 cm
• Event criteria
  • Total $P > 10 \text{ mm}$
  • Length $\geq 8 \text{ hrs}$
  • Mixed events: $0.9*P \geq 0.1*\Delta HS$

Goal → identify ROS events, including mixed-phase periods
Rain-on-snow events:
• Identified individually at each node
• Hourly criteria
  • $P > 0$ mm
  • Dewpoint $T > 0$ °C
  • Snow depth $> 10$ cm
• Event criteria
  • Total $P > 10$ mm
  • Length $\geq 8$ hrs
  • Mixed events: $0.9*P \geq 0.1*\Delta HS$
• End of event: 4 non-ROS hrs

Goal → identify ROS events, including mixed-phase periods
<table>
<thead>
<tr>
<th>Network</th>
<th>Average elevation, m</th>
<th>Water year record</th>
<th>Number of ROS events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Met (LOM)</td>
<td>1735</td>
<td>2008-2017</td>
<td>166</td>
</tr>
<tr>
<td>Upper Met (UPM)</td>
<td>1979</td>
<td>2008-2017</td>
<td>163</td>
</tr>
<tr>
<td>P301 network (P301)</td>
<td>1997</td>
<td>2010-2016</td>
<td>41</td>
</tr>
<tr>
<td>SEKI 1 (SK1)</td>
<td>2226</td>
<td>2008-2016</td>
<td>27</td>
</tr>
<tr>
<td>SEKI 2 (SK2)</td>
<td>2261</td>
<td>2008-2016</td>
<td>52</td>
</tr>
<tr>
<td>SEKI 3 (SK3)</td>
<td>2596</td>
<td>2008-2016</td>
<td>22</td>
</tr>
<tr>
<td>SEKI 4 (SK4)</td>
<td>2639</td>
<td>2008-2016</td>
<td>25</td>
</tr>
</tbody>
</table>

Total events: 496

Goal → identify ROS periods, including mixed-phase periods
Event characterization

- Average air temperature, °C
- Precipitation, cm
- Storm length, hrs
- Average dewpoint temperature, °C
- Average wind speed, m/s
- Change in snow depth, cm
• 55% of identified events saw an overall increase in snow depth
• For the most part, the same storm resulted uniformly in decreases (or increases) across a site, but not always
• Micro-scale effects can be seen in patterns of snow depth change during a storm:
Topics

Introduction & study sites
Rain-on-snow events
Random Forest model
- Algorithm combines decision trees with stochastic decision-making
- Allows for nonlinear regression
- Relatively interpretable

Example schematic of decision tree
• Algorithm combines decision trees with stochastic decision-making
• Allows for nonlinear regression
• Relatively interpretable

Schematic of decision tree

Features
- Climate (e.g. dewpoint temperature, precipitation, wind)
- Physiographic (topography and vegetation)
- Timing (e.g. day of water year)
Performance

R² = 0.87
RMSE = 3.91 cm
Bias = 2.97 cm
Kling-Gupta Efficiency = 0.72
Feature importance

Average dewpoint T
Total precipitation
DOWY
Average wind speed
Standard deviation of dewpoint T
Storm length
Change of T over storm
Initial snow depth
CV of dewpoint T
Hours of stable dewpoint T
Autocorrelation of dewpoint T
Elevation (1 m)
Atmospheric river
Storm start time
Slope (1 m)
Aspect (10 m)
Canopy height (1 m)
LAI (10 m)
Open fraction (1 m)
Open fraction (10 m)
Aspect (1 m)
Previous ROS events
Canopy height (10 m)
Sheltering coefficient
Feature importance

- Average dewpoint T
- Total precipitation
- DOWY
- Average wind speed
- Standard deviation of dewpoint T
- Storm length
- Change of T over storm
- Initial snow depth
- CV of dewpoint T
- Hours of stable dewpoint T
- Autocorrelation of dewpoint T
- Elevation (1 m)
- Atmospheric river
- Storm start time
- Slope (1 m)
- Aspect (10 m)
- Canopy height (1 m)
- LAI (10 m)
- Open fraction (1 m)
- Open fraction (10 m)
- Aspect (1 m)
- Previous ROS events
- Canopy height (10 m)
- Sheltering coefficient

Importance score
Effects of precipitation phase

Kolmogorov-Smirnov test:

$p$ (snow-first vs rain-first) = $2.34^{-5}$

$p$ (snow-first vs all rain) = $0.0265$

$p$ (rain-first vs all rain) = $0.00877$
Effects of Leaf Area Index

Model performance by quintile range of LAI

- More open
- More closed
Effects of Leaf Area Index

Model performance by quintile range of LAI

Values:
- Performance metric, cm
- Quintile (LAI range)
- Q1: (0.08, 0.56)
- Q2: (0.56, 0.86)
- Q3: (0.86, 2.05)
- Q4: (2.05, 2.43)
- Q5: (2.43, 3.95)

Legend:
- Absolute bias
- RMSE

More open ↔
More closed →
Effects of Leaf Area Index

Model performance by quintile range of LAI

- "Open"
- "Intermediate"
- "Closed"

More open → More closed
Effects of Leaf Area Index

Kolmogorov-Smirnov test:

- $p$ (open vs intermediate) = 0.078
- $p$ (closed vs intermediate) = 0.053
- $p$ (open vs closed) = 0.47
Conclusions and next steps

Conclusions
• ROS events in the Southern Sierra Nevada often include or are part of longer mixed-phase events
• Snowpack response is statistically different in rain-first, snow-first, and all-rain events
• Snowpack response is statistically different at “intermediate” LAIs than at open or closed sites

Next steps
• What can we learn from soil moisture data?
• Possible inclusion of physical model to investigate effect of LAI
Collaborators: Francesco Avanzi, Safeeq Khan, Steve Glaser, Roger Bales, Martha Conklin

Thank you!