# The Sensitivity of Mountain Snowcovers to Temperature, Humidity, and Phase Change

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**USA**

# Phase Change:

## The True Impact of Climate Warming!

# Rain/Snow Transition Elevation

## What is it?

- **Elevation at which – during a storm – phase changes from rain to snow**
- **Includes a transition zone with mixed phase**

## Why do we care?

- **Hydrologic response is very different**
- **Increasing elevation will decrease SWE volume, even as snow depth increases…**

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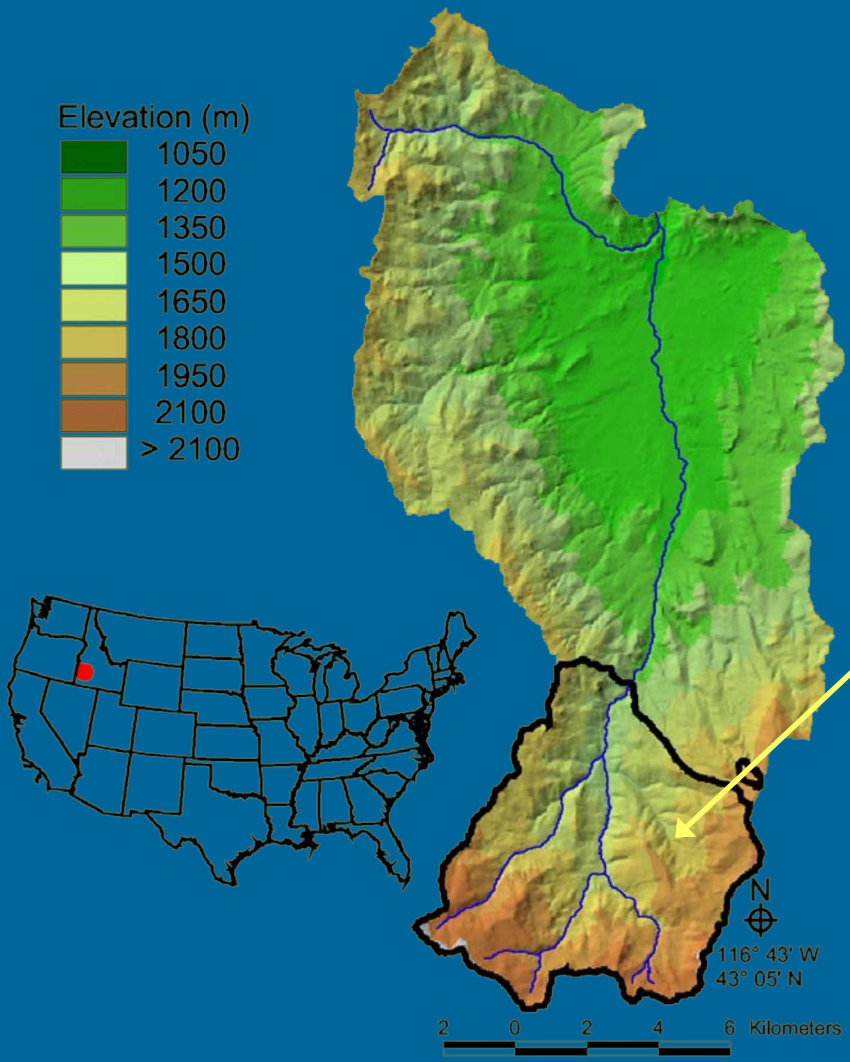
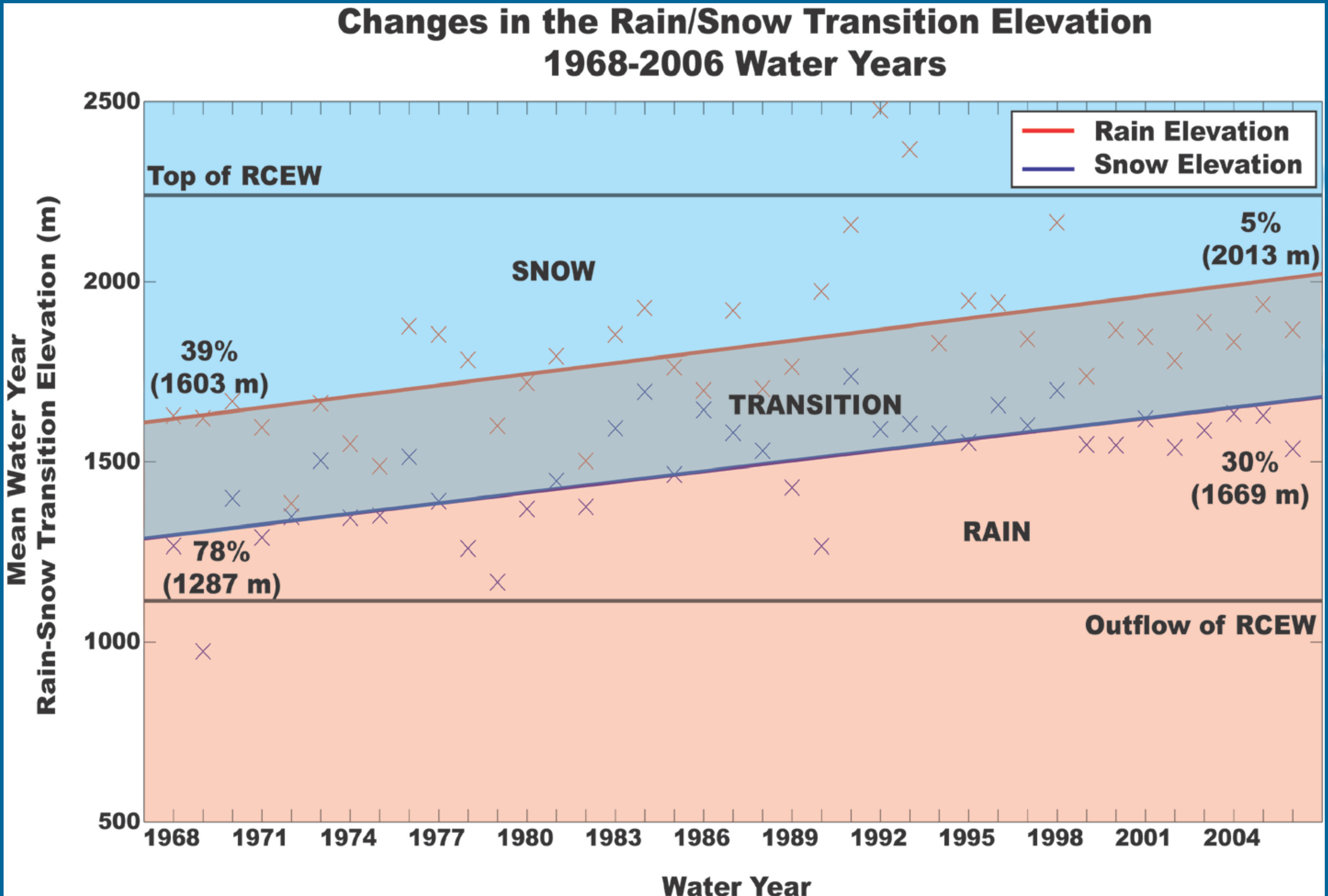
# Reynolds Creek Experimental Watershed




**Tollgate Basin**
**Area: 54.6 $km^2$**
**Elev: 1410 - 2241 m**

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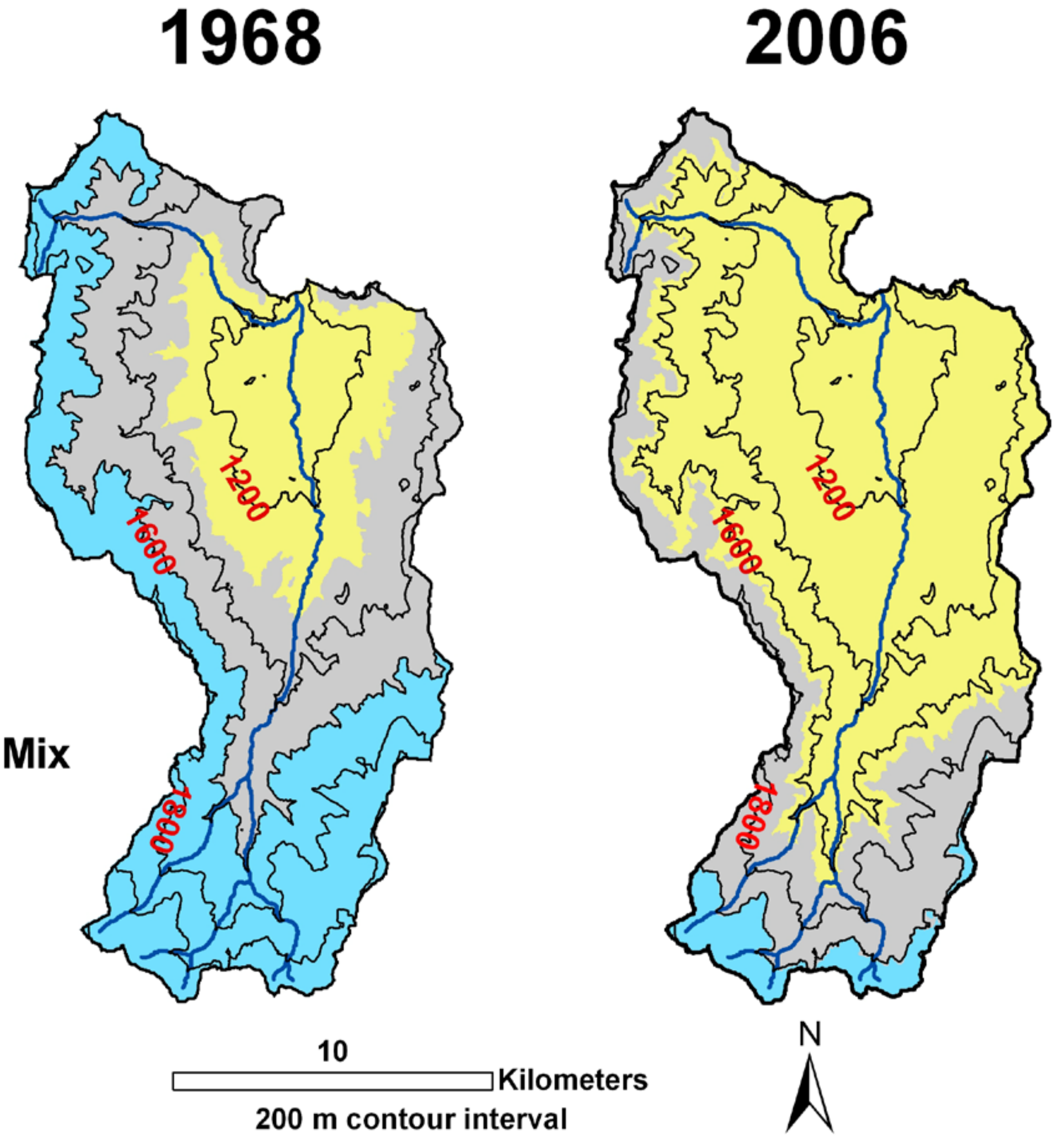
# Reynolds Creek Experimental Watershed Idaho, USA




**Dominant Precipitation Type**

- Snow
- Rain/Snow Mix
- Rain

# The 1996 NW ROS Flood

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# Condensation/Evaporation vs. Advection

$\lambda_v E$ is typically 50-1000 greater than M

$$M = c_{pp} \rho_{pp} z_{pp} (T_{pp} - T_s)$$

$$\lambda_v E = \lambda_v * E$$

$$melt = \lambda_v E / \lambda_f \text{ -or- } M / \lambda_f$$

where:

$c_{pp}$ = specific heat of precipitation: (4218-4116 J kg$^{-1}$ K$^{-1}$ (0-40 °C))

$\lambda_v$ = latent heat of vaporization: (2.501 x 10$^6$ J kg$^{-1}$ (0° C))

$\lambda_f$ = latent heat of fusion: (0.334 x 10$^6$ J kg$^{-1}$ (0° C))

$\rho_{pp}$ = precipitation density: (kg m$^{-3}$)

$z_{pp}$ = depth of precipitation (m)

$T_{pp}$ = average precipitation temperature (K)

$T_s$ = average snowcover temperature (K)

E = evaporation (1 kg $H_2O$ = 1 mm $H_2O$ / m$^2$)

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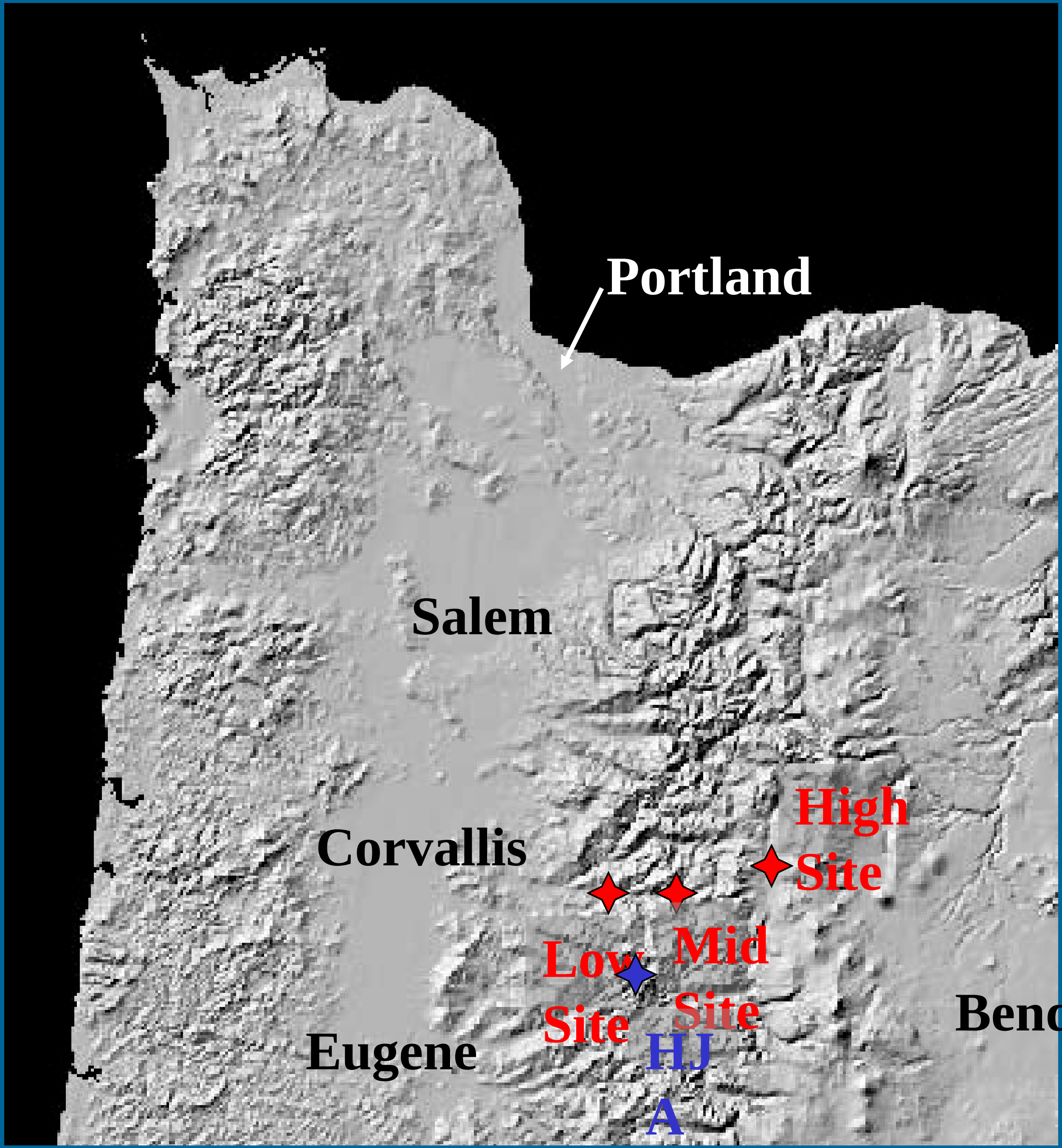
# Cascade Site Locations

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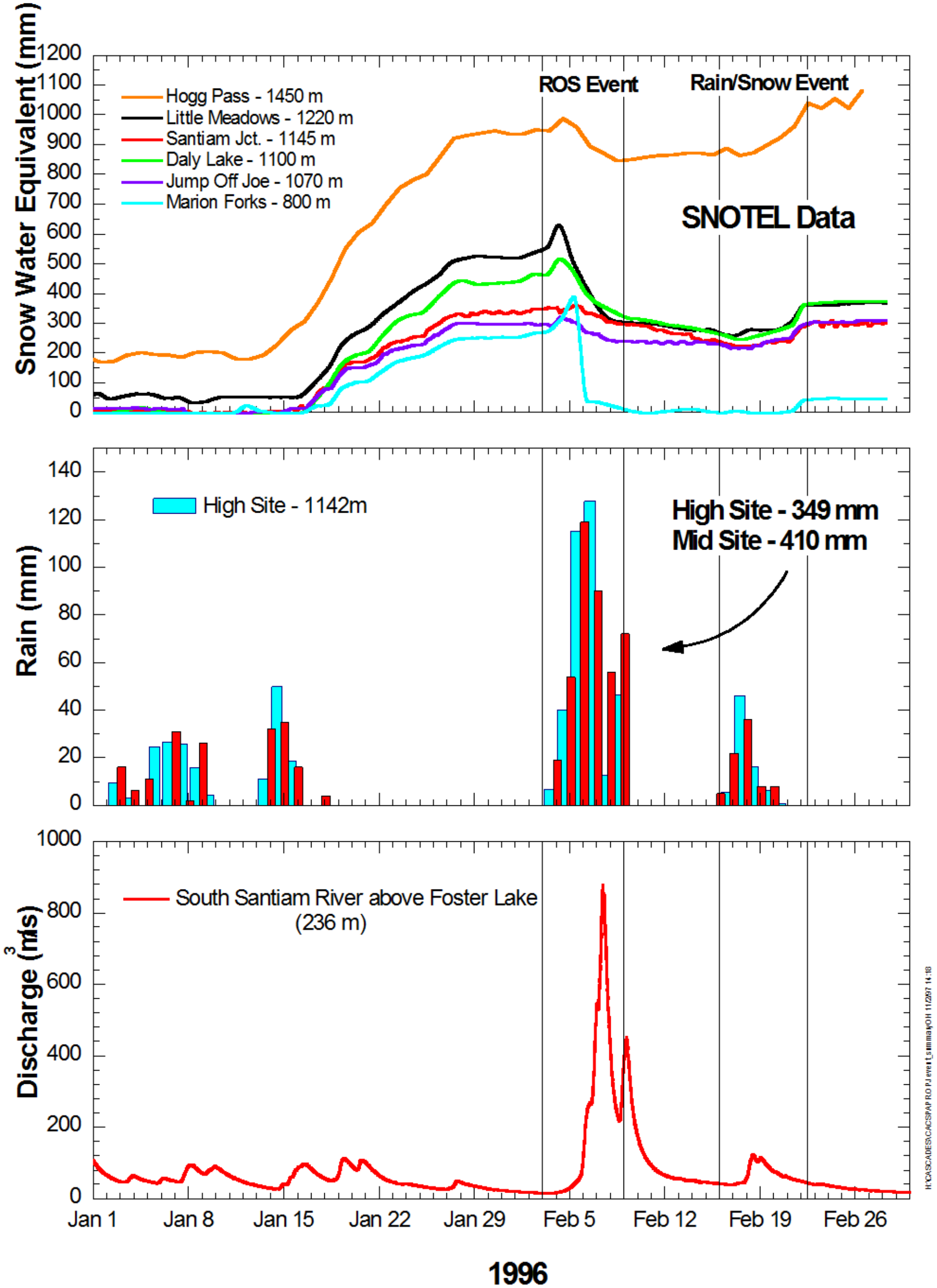
# Central Cascade Rain-on-Snow Event

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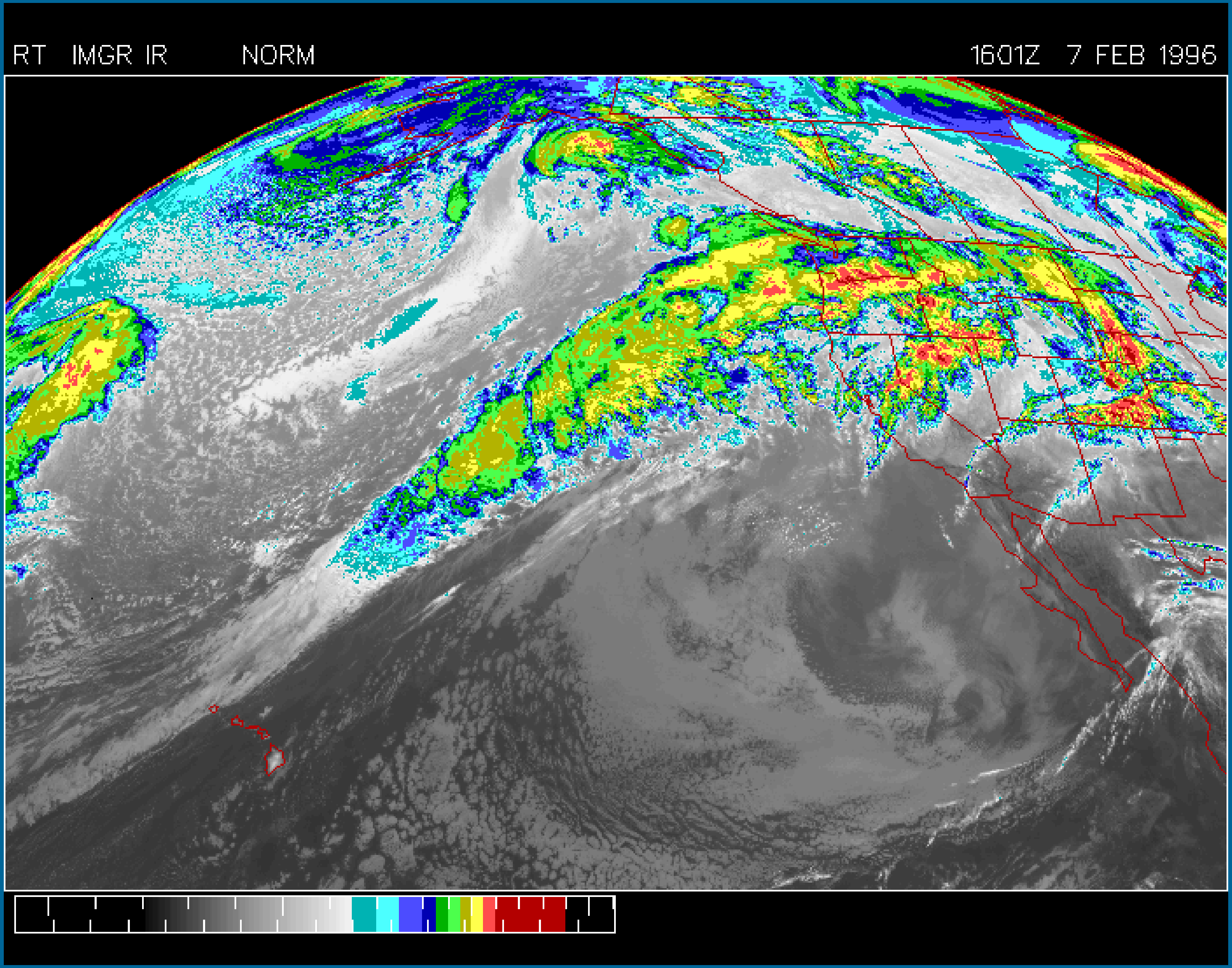
# 1996 Snowpack
# Pre-Flood

# February 1996 Rain-on-Snow Event

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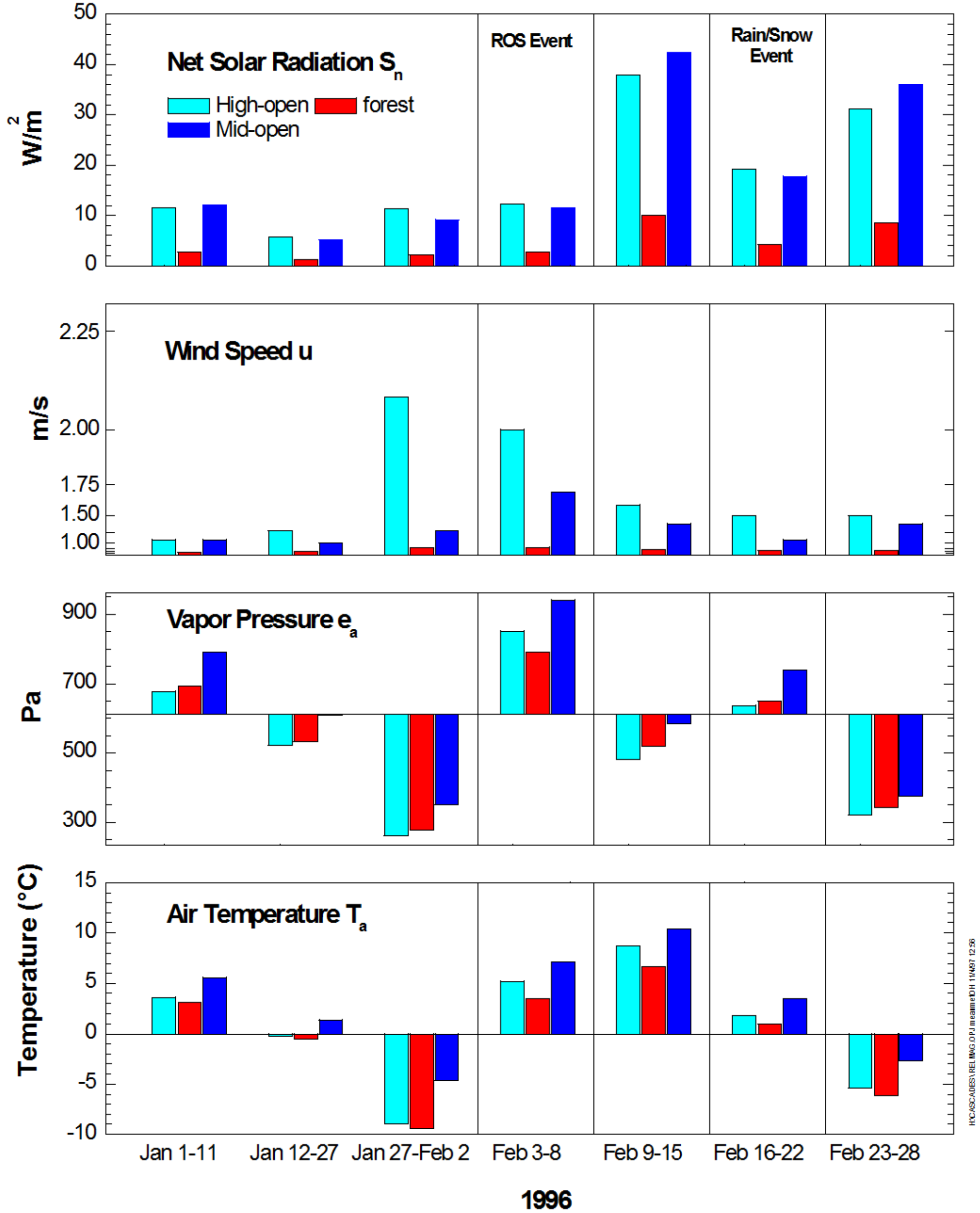
# Blue River ~9,000 cfs

# Debris Flow: HJ Andrews Experimental Forest

# Central Cascade Rain-on-Snow Event

## Mean Meteorological Parameters

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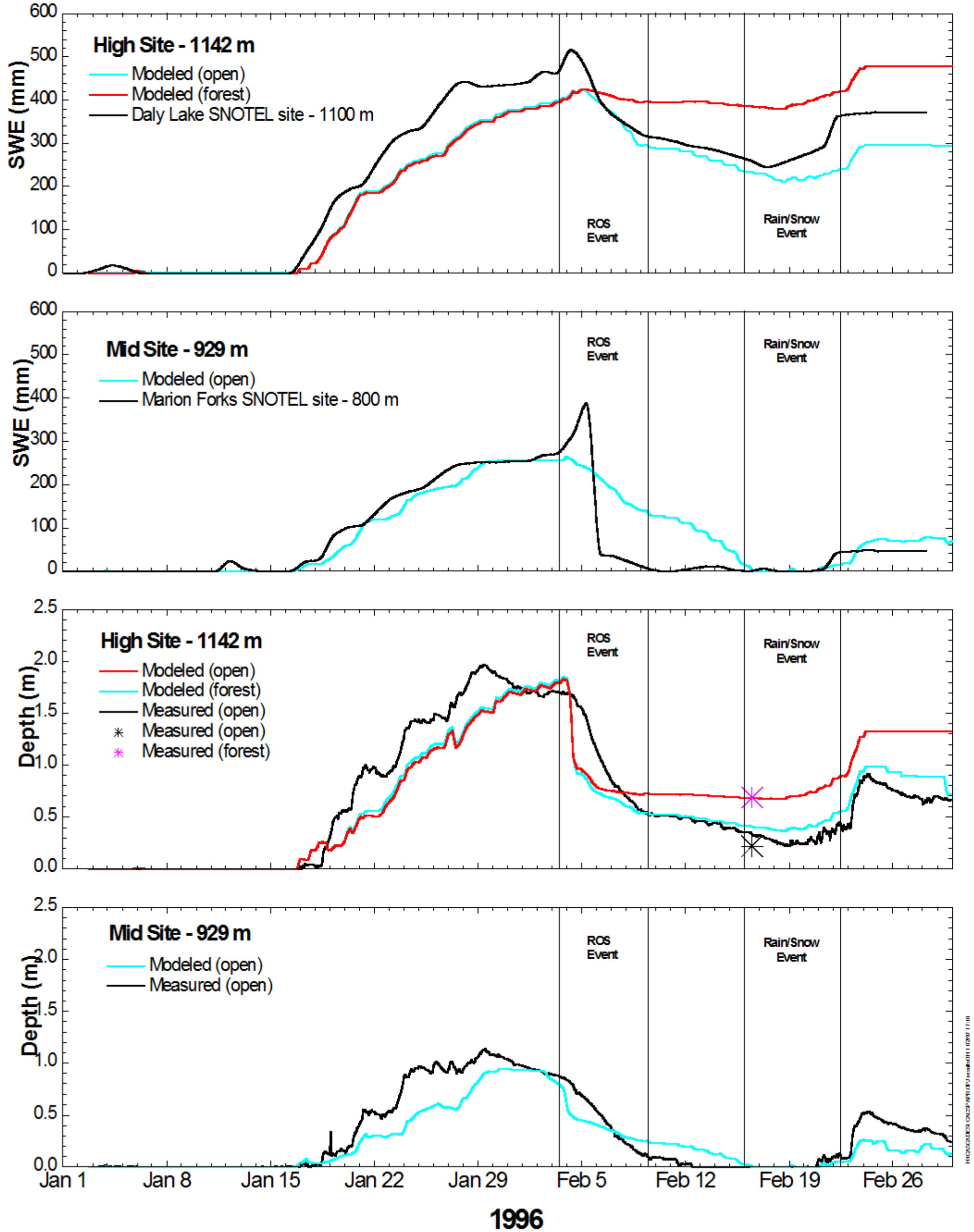
# Modeled and Measured Snowpack

## High and Mid Sites

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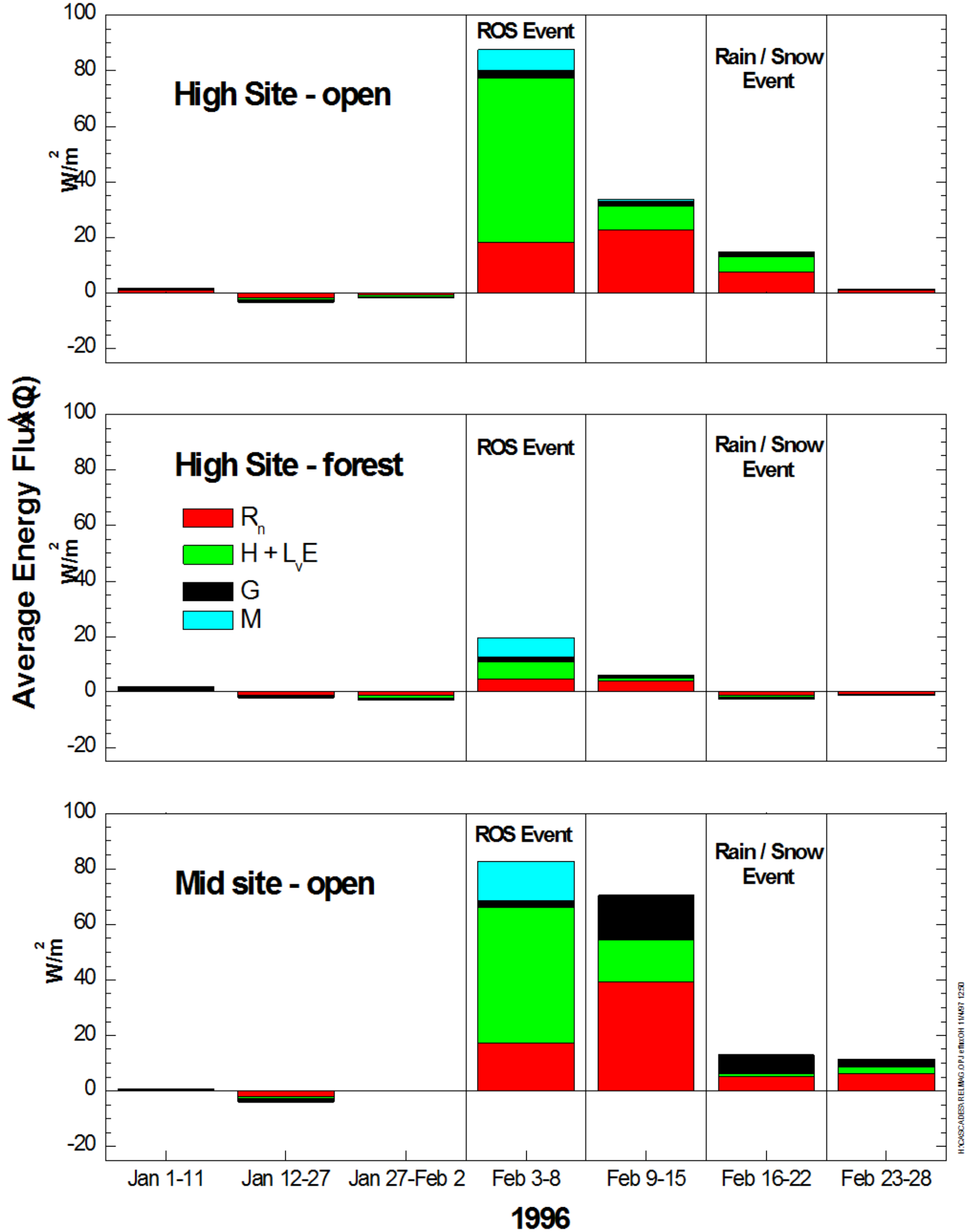
# Central Cascade Rain-on-Snow Event

## Relative Snowpack Energy Fluxes





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# Condensation vs. Advection

## 2 Examples: advection of rain, $\rho_{pp} = 1.0$

| $z_{pp}$ | $T_{pp}$ | $c_{pp}$ | M (J $m^{-2}$) | $\lambda_v E$ | Melt (mm) |
|---|---|---|---|---|---|
| 10 | 1 | 4215 | 42,152 | | 0.12 |
| 10 | 10 | 4192 | 419,220 | | 1.26 |
| 10 | 0 | | | 25,010,000 | 74.88 |
| 70 | 4 | 4208 | 1,178,100 | | 3.53 |
| 3 | 0 | | | 7,503,000 | 22.46 |

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# Testing a Spatial Snow Model During ROS:

# RCEW – January, 1997

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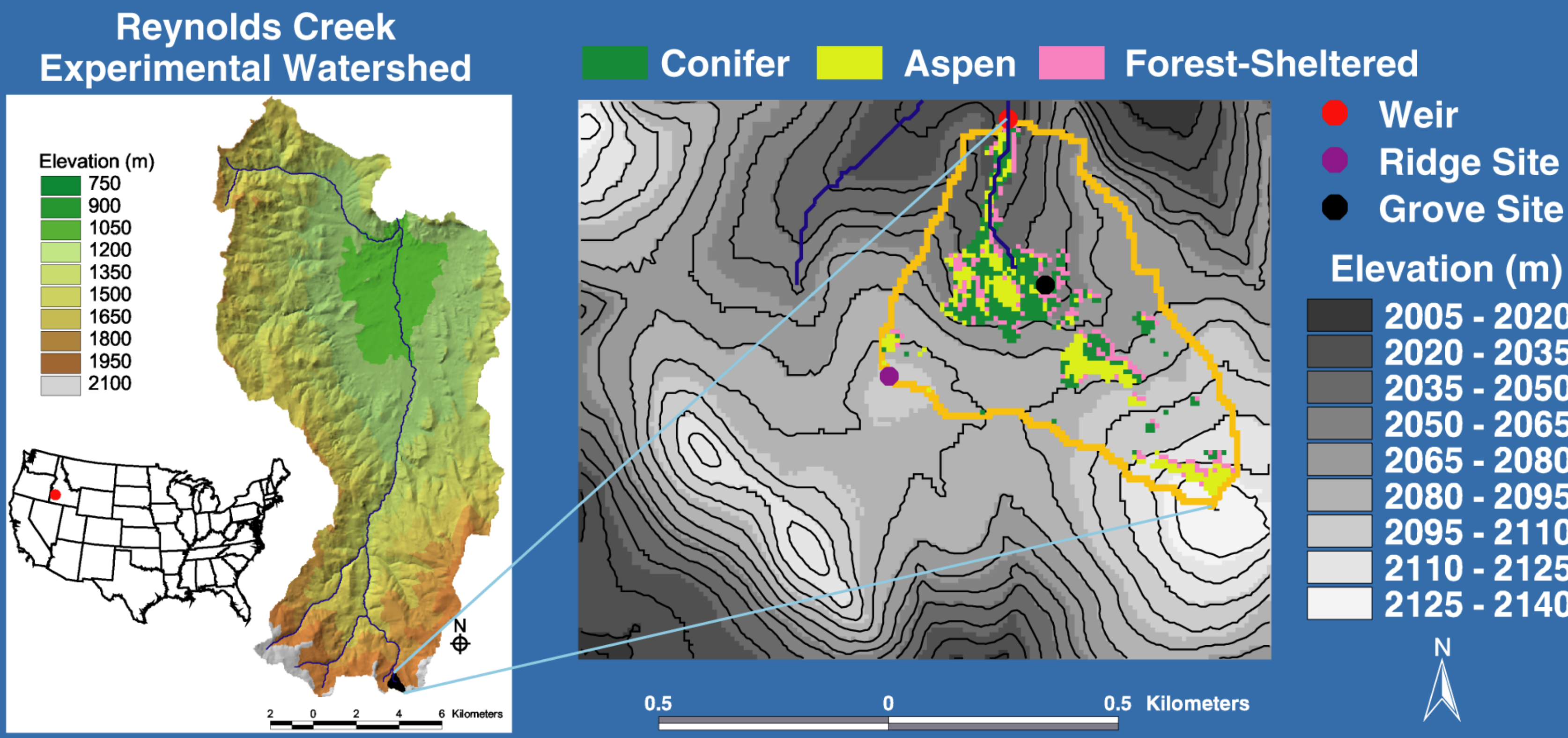
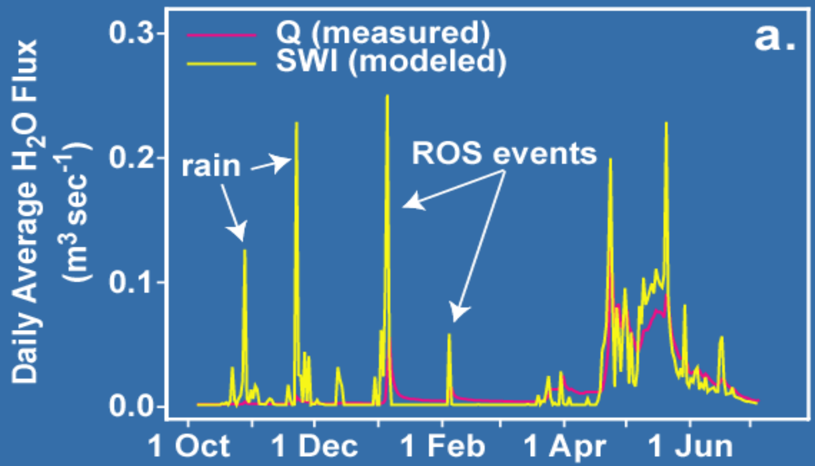
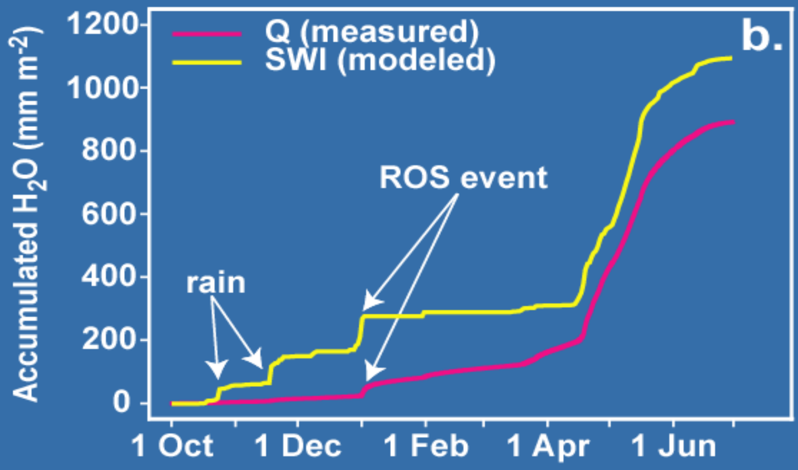
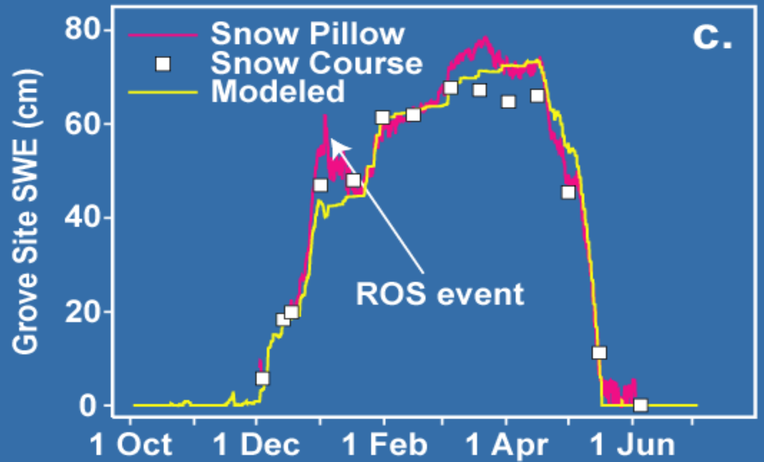
# Reynolds Mountain East Study Basin



# January 1997 ROS Event

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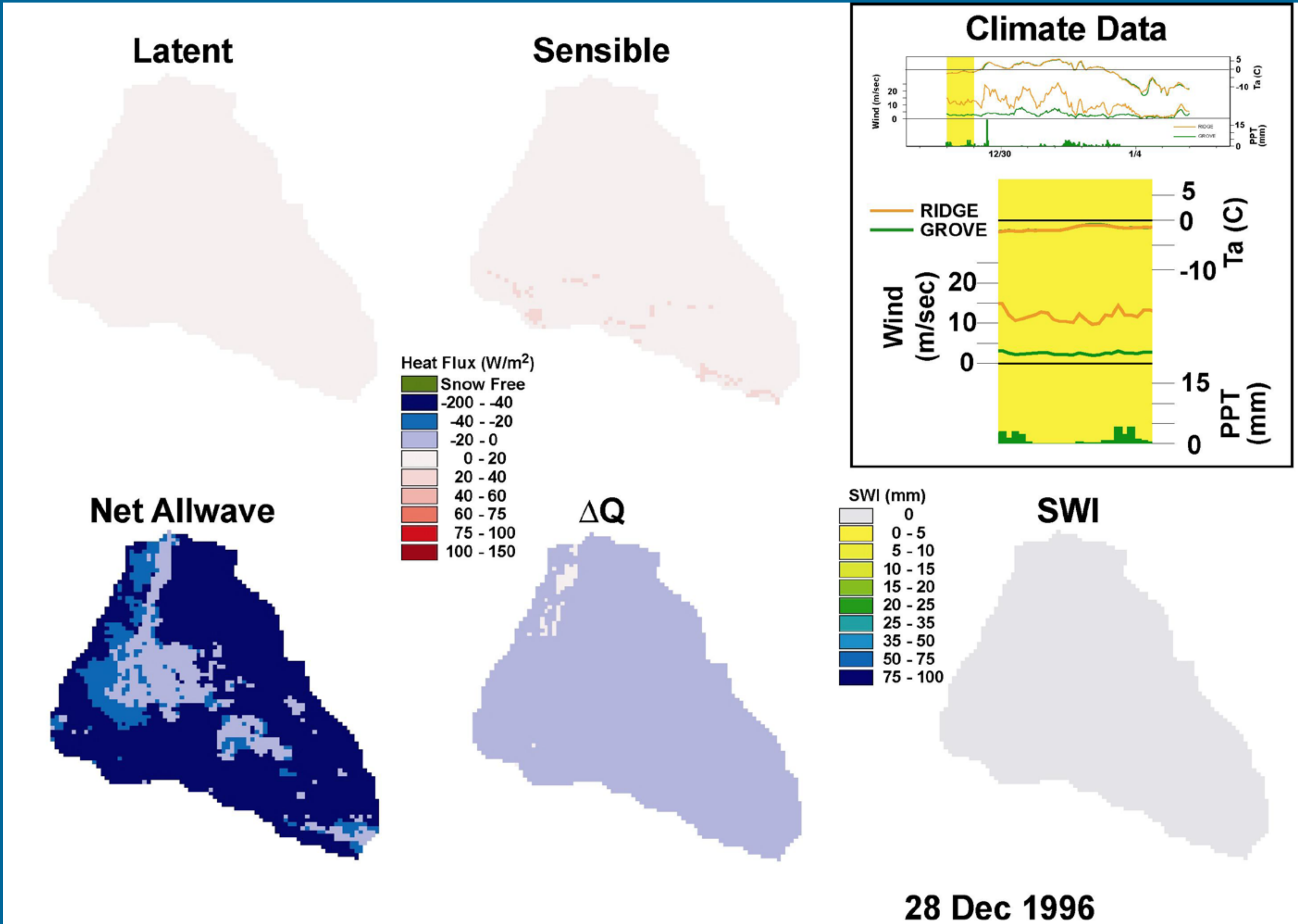


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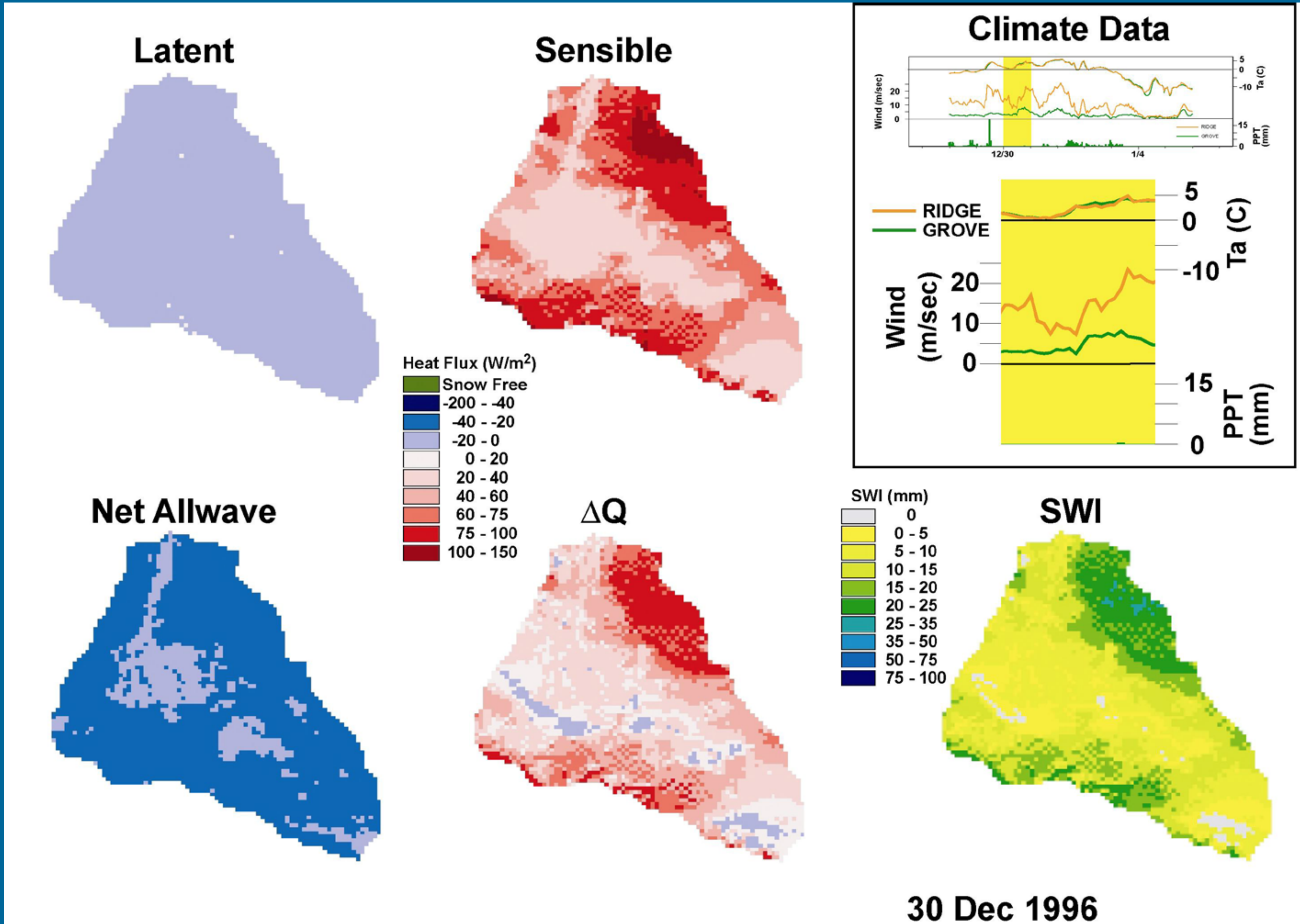


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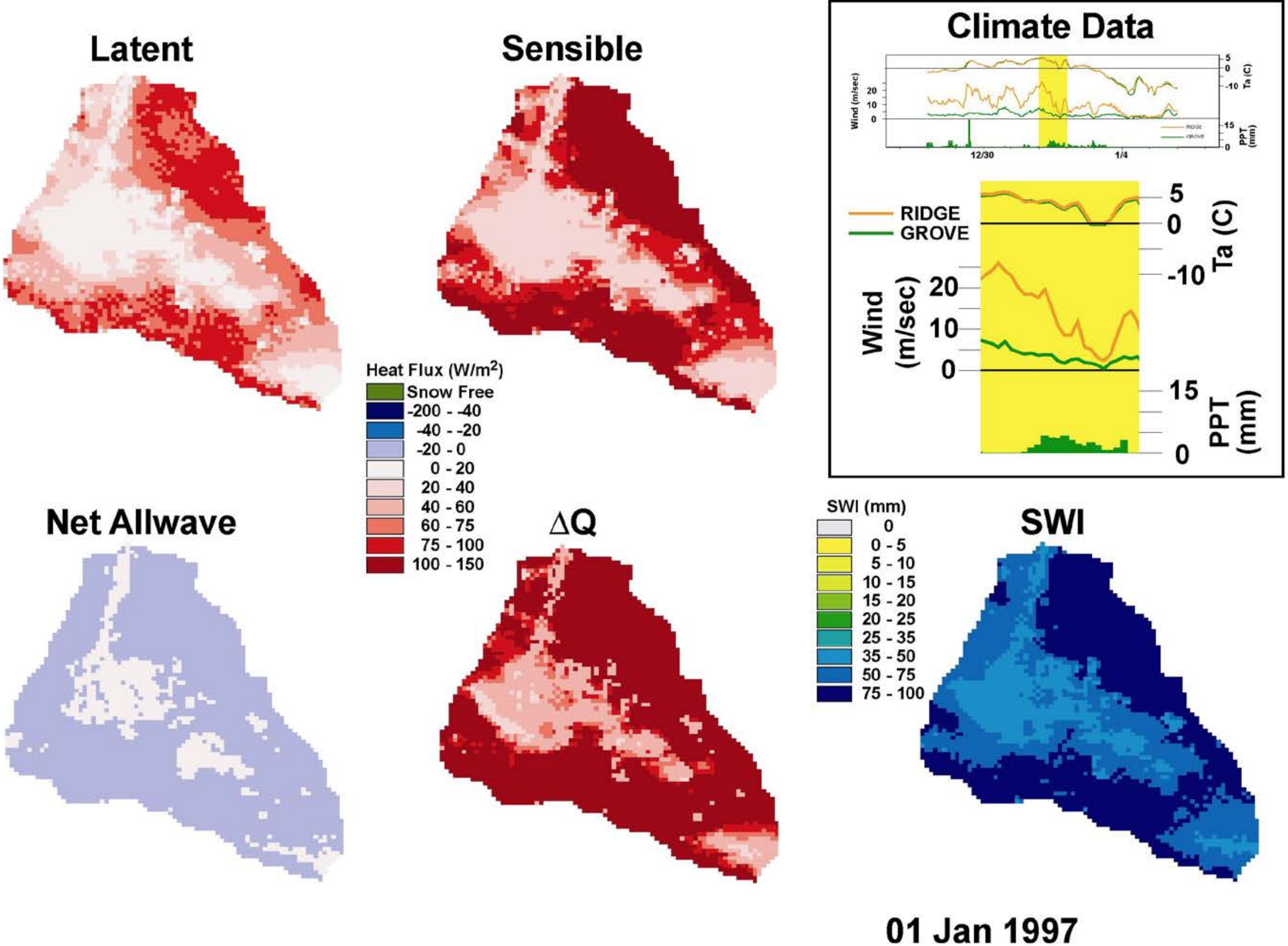
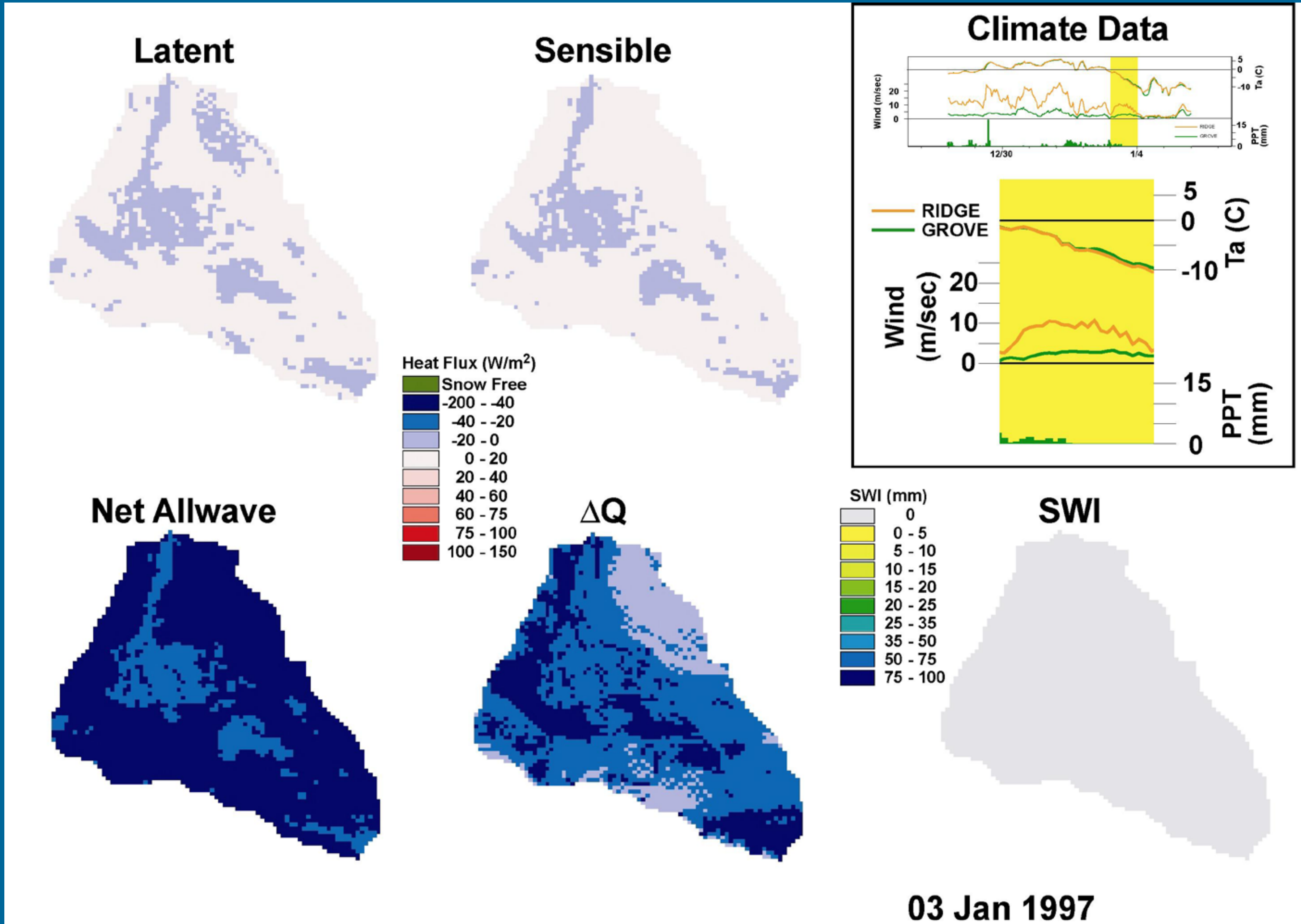


Latent
Sensible
Climate Data
Wind (m/sec)
Ta (C)
PPT (mm)
12/30
1/4
RIDGE
GROVE
5
0
-10
20
10
0
15
0
Heat Flux (W/m2)
Snow Free
-200 - -40
-40 - -20
-20 - 0
0 - 20
20 - 40
40 - 60
60 - 75
75 - 100
100 - 150
Net Allwave
ΔQ
SWI (mm)
0
0 - 5
5 - 10
10 - 15
15 - 20
20 - 25
25 - 35
35 - 50
50 - 75
75 - 100
SWI
01 Jan 1997

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# Simulating the Dynamic Nature of the Rain/Snow Transition:

# RCEW – Dobson Creek:

# 2005 Christmas Flood

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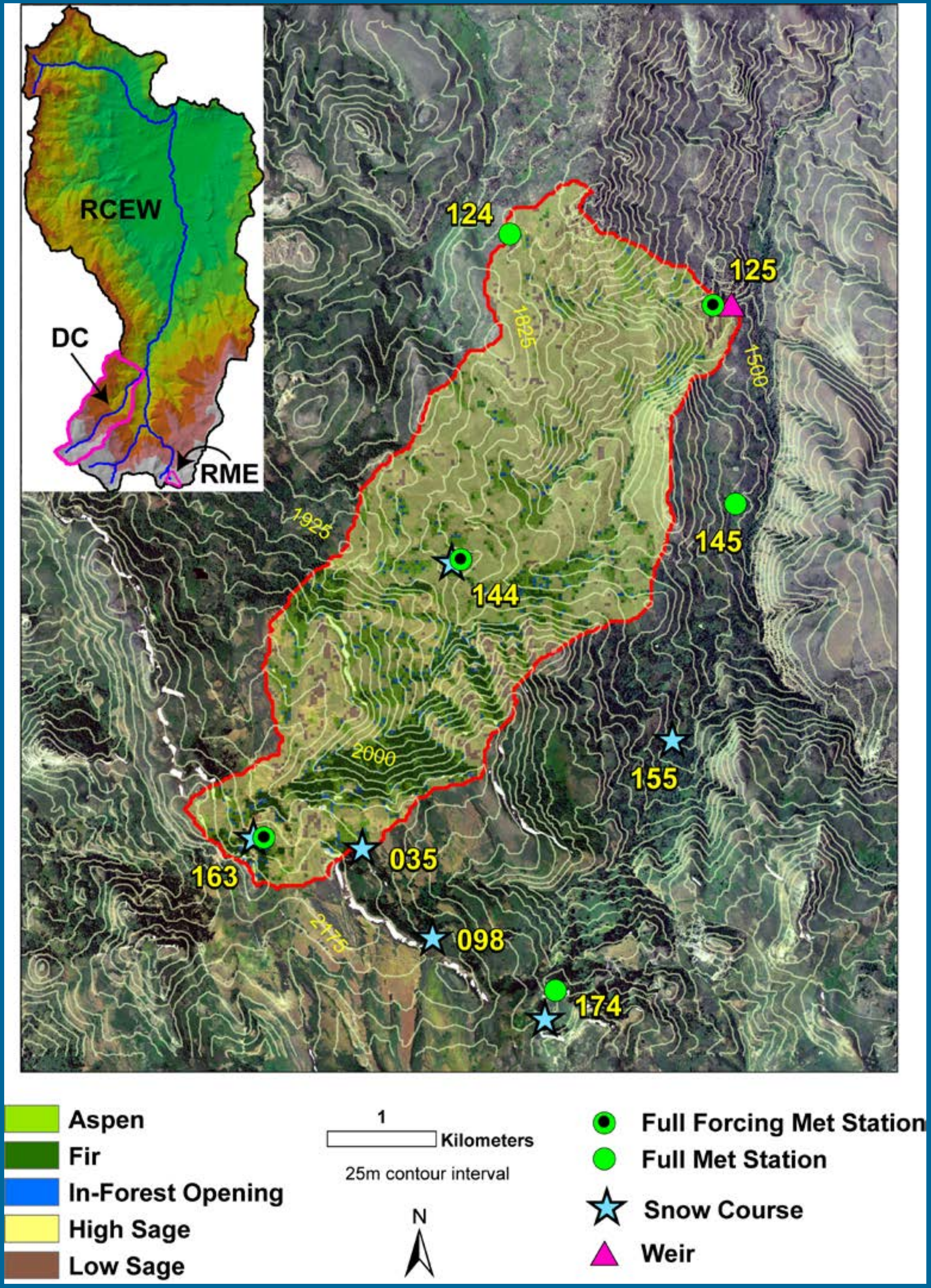



# Dobson Creek Basin:

**1474 – 2244 m (770m)**

**Fir: 11%**
**Aspen: 17%**
**Sage: 72%**

**6 snow courses**
**6 precip – met stations**

**2 weirs**
**(Johnston Draw included)**

# The Event:

**From Dec 25, 2005, to Jan 1, 2006**
**(8 days, 192 hrs)**

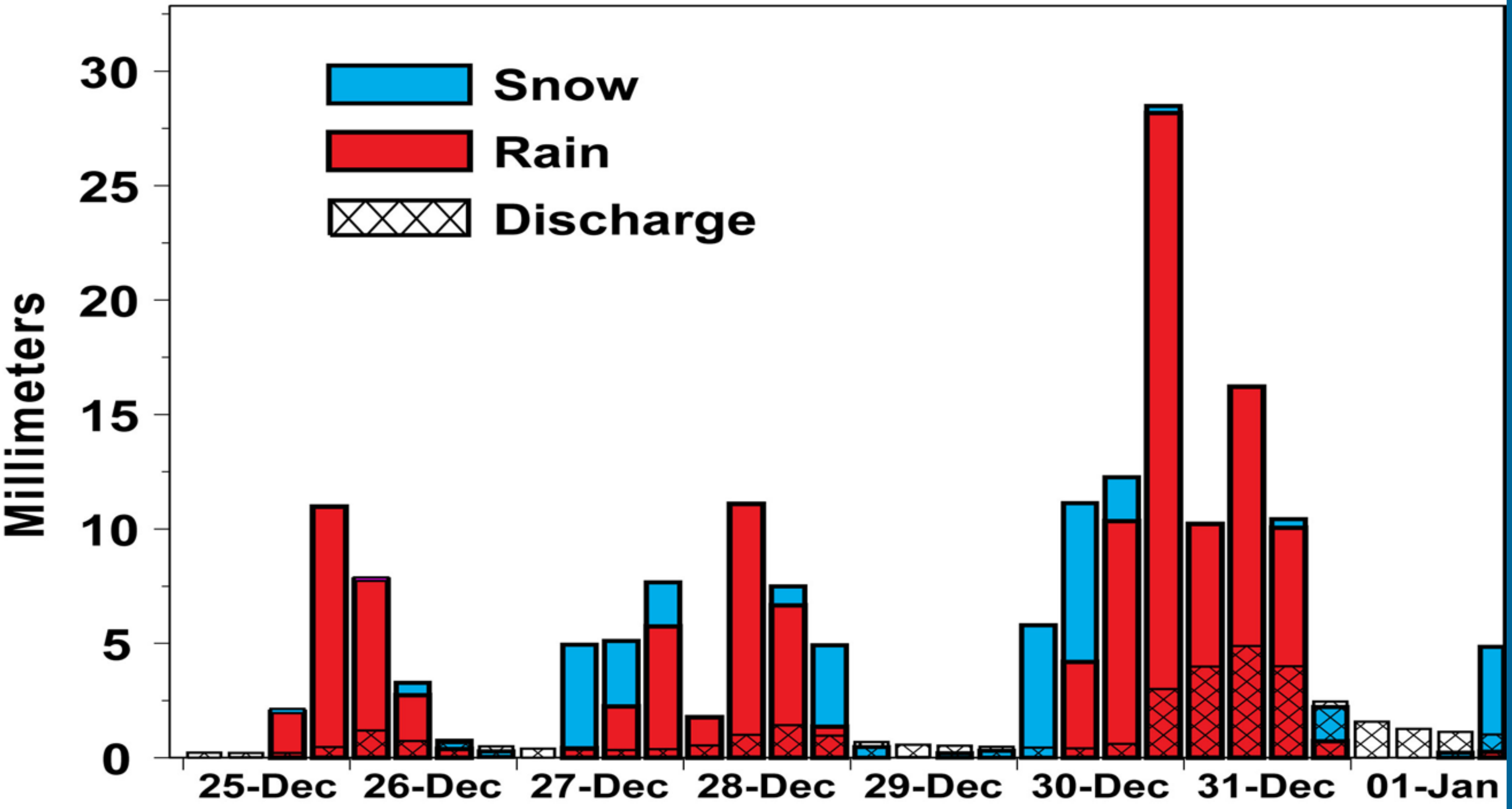
**Mixed Rain/Snow Storm Event**
**38 mm snow, 136 mm rain**

**174 mm precipitation**
**(~20% total WY precipitation!)**

**Multiple Transitions between Rain & Snow**

**Different Transition times with Elevation**

# Mixed Rain/Snow Event
# Dobson Creek Drainage (14.05 km²)
# 6 hour totals
# 12/25/05 - 1/1/06 (192 hrs)



# Dobson Creek Weir

$Q_{max}$ = ~4.0 $m^3\ s^{-1}$ (200 cfs)

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# Dobson Creek Weir, Jan 30, 2003

$Q = \sim 1.8\ m^3\ s^{-1}$

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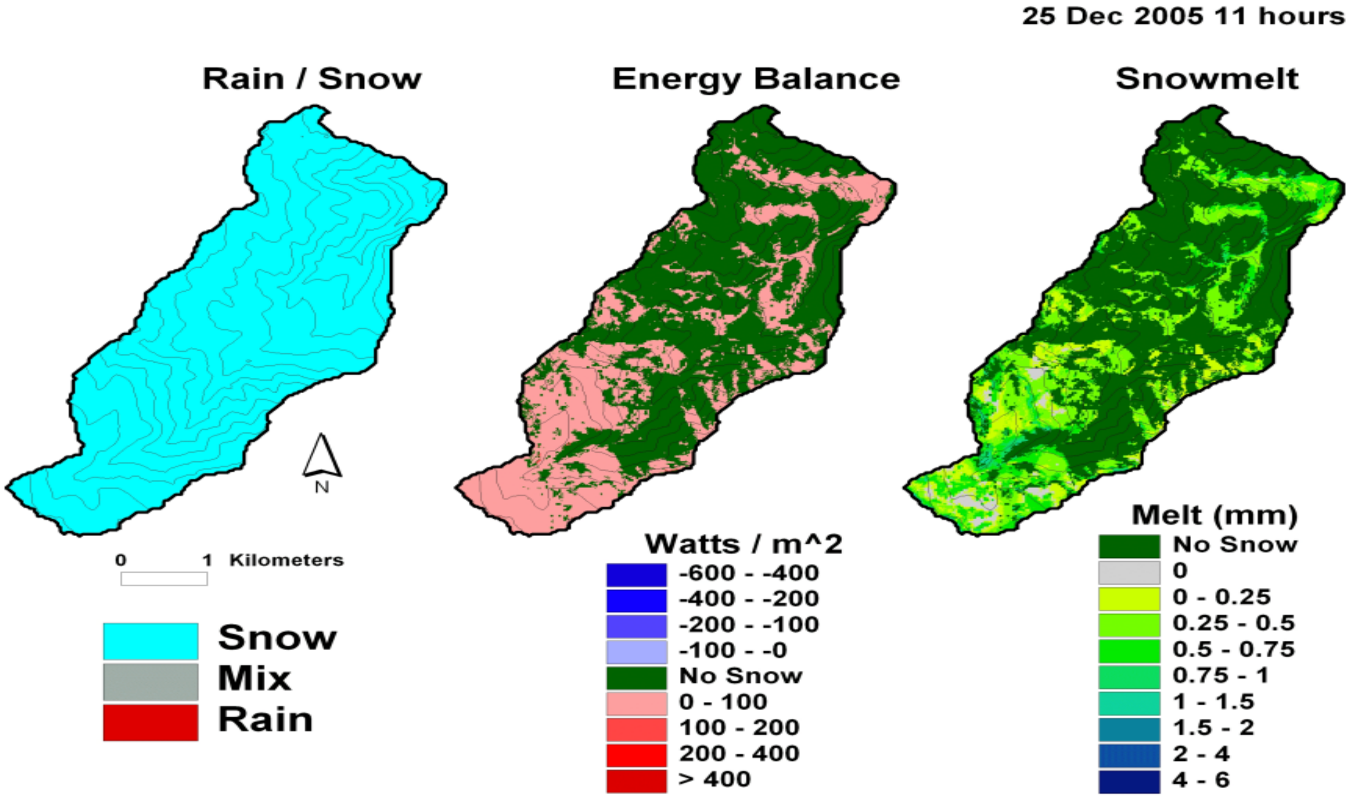


# RCEW: Dobson Creek ($14.0\ km^2$)

**1474 – 2244m: 770 m relief**

## 7-day Mixed Rain/Snow Event: 12/25 – 31/2005

**136 mm rain + 60 mm melt**

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|---|---|---|---|---|---|
| 10 | 1 | 4215 | 42,152 | | 0.12 |
| 10 | 10 | 4192 | 419,220 | | 1.26 |
| 10 | 0 | | | 25,010,000 | 74.88 |
| 170 | 4 | 4208 | 2,861,440 | | 8.57 |
| 8 | 0 | | | 20,008,000 | 59.89 |

# Summary

<u>**Conditions Producing Major ROS Flood:**</u>

- **Extended period of cold, wet weather**
  - **Deep snowpack**
  - **Low-elevation snowpack**
- **"Pineapple Express"- type Storm**
  - **High air temperature**
  - **High humidity**
  - **Very high wind speeds**
  - **Intense, sustained frontal precipitation**
    - **Enhanced by orographic uplift**

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# Conclusions

- The 1996, 1997 and 2006 ROS floods:
  - Intense, sustained rainfall
  - Driven by convection/condensation
- Exacerbated by high winds in open areas
- Surface water input determined by many factors:
  - Size and position of watershed
  - Degree of topographic exposure
  - Vegetation canopy characteristics
  - Position of Rain – Snow Transition Elevation

# Are the Trends in the Reduction of the Rain – Snow Transition Elevation Extended to other Areas of the West?

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