Snowcover interaction with climate, topography & vegetation in mountain catchments

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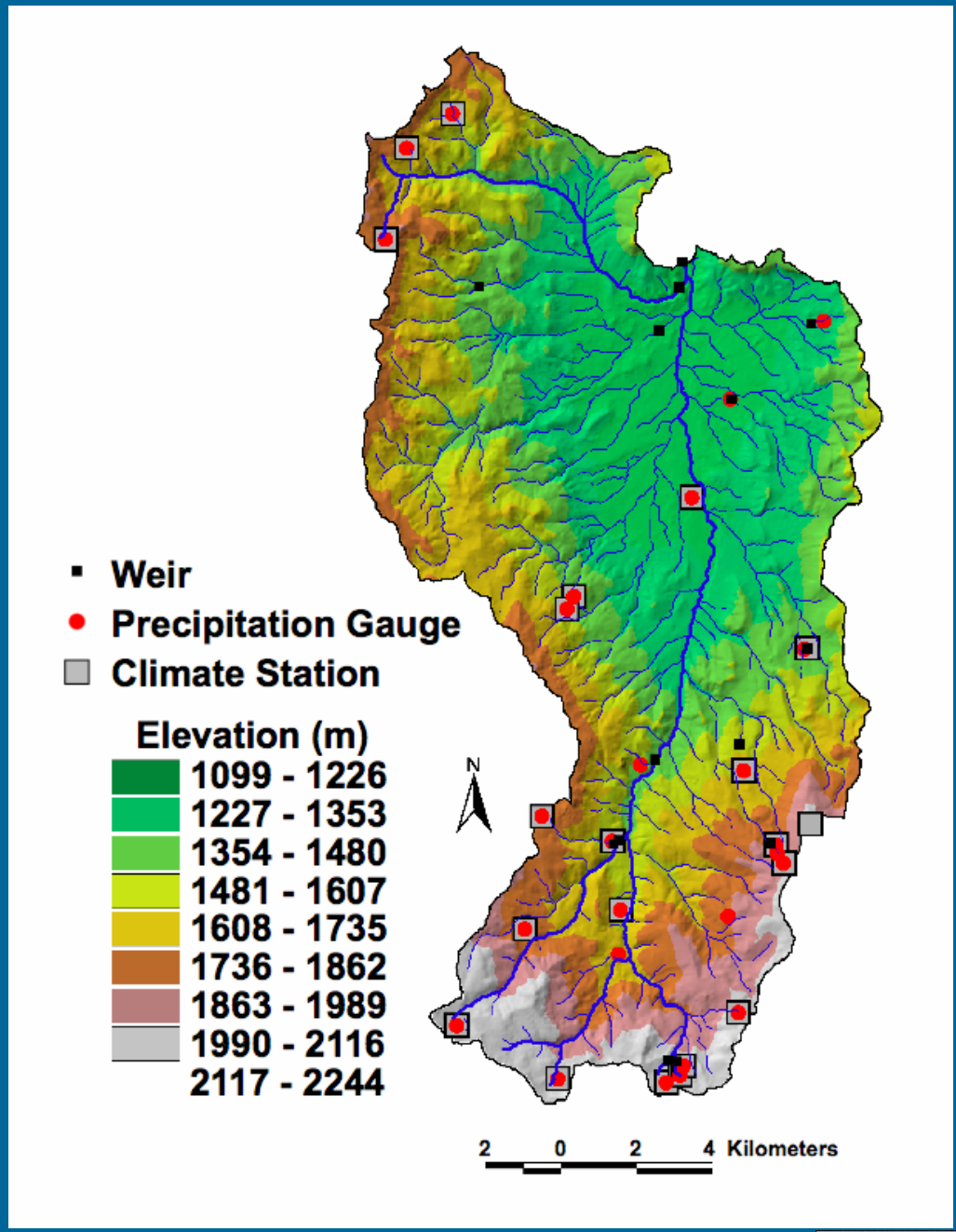
RCEW (239 km^2):

- 32 climate stations
- 36 precipitation stations
- 5 EC systems
- 14 weirs (nested)
- 6 soil microclimate stations
- 4 hill-slope hydrology sites
- 4 instrumented catchments
- 3 instrumented headwater basins:

<u>USC</u> (0.25 km^2, 186m relief) ephemeral, groundwater dominated, annual precipitation 300-500mm

<u>RME</u> (0.38 km^2, 116m relief) perennial, surface water dominated, annual precipitation 750-1000mm

<u>Johnston Draw</u> (1.8 km^2, 380m relief) ephemeral, rain-snow boundary, annual precipitation 500-600mm



Climate Trends from 45 Years of Monitoring at Reynolds Creek Experimental Watershed

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PhD project, ANURAG NAYAK
(Utah State University)

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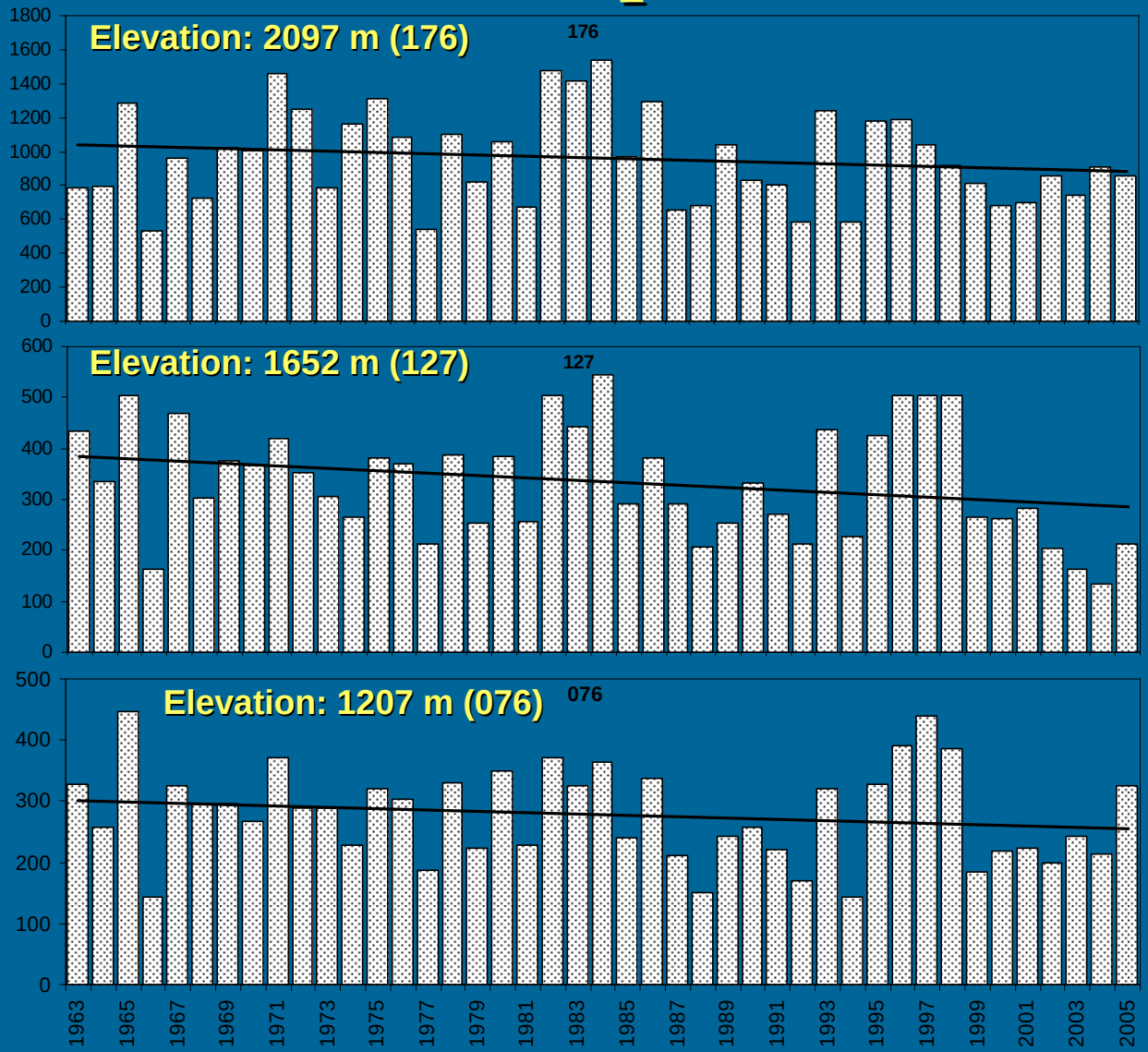
Annual Precipitation



No Significant Trend

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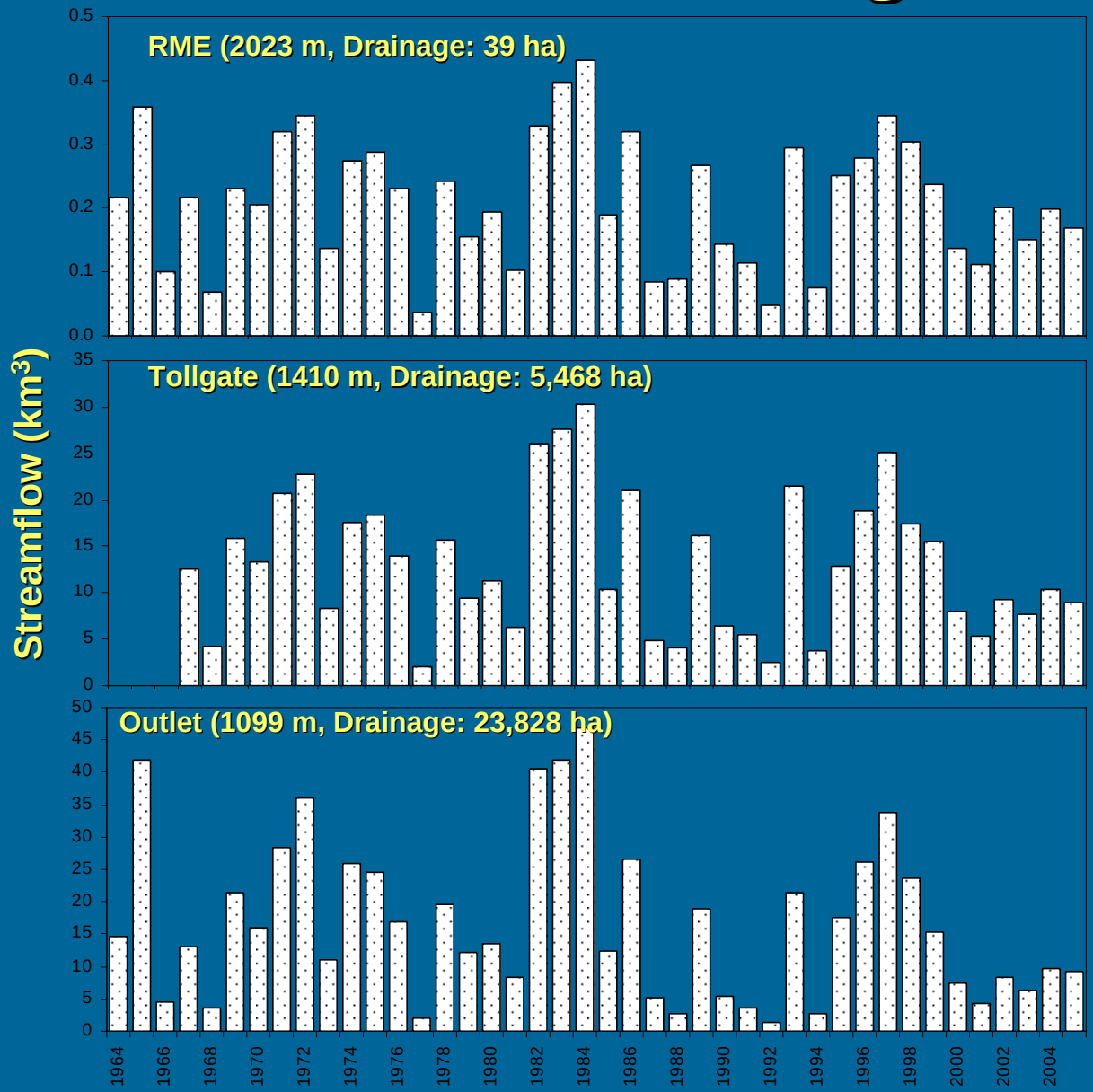
Annual Stream Discharge

No Significant Trend



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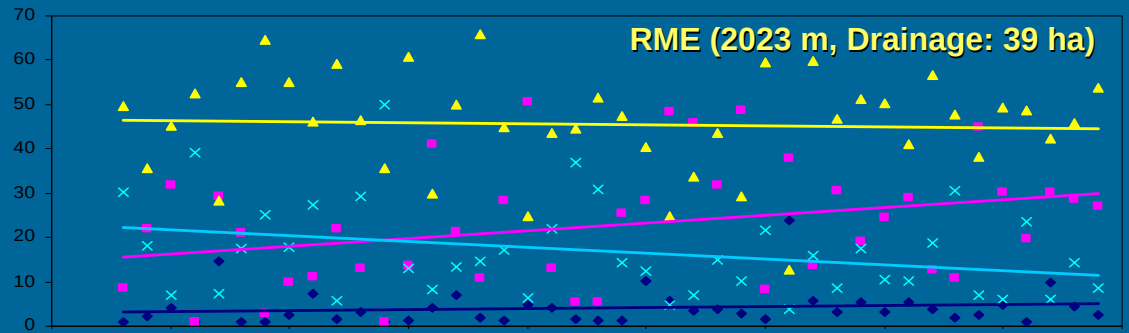
% Annual Stream Discharge, by Month

March, April, May & June (78-95% of Annual Flow)

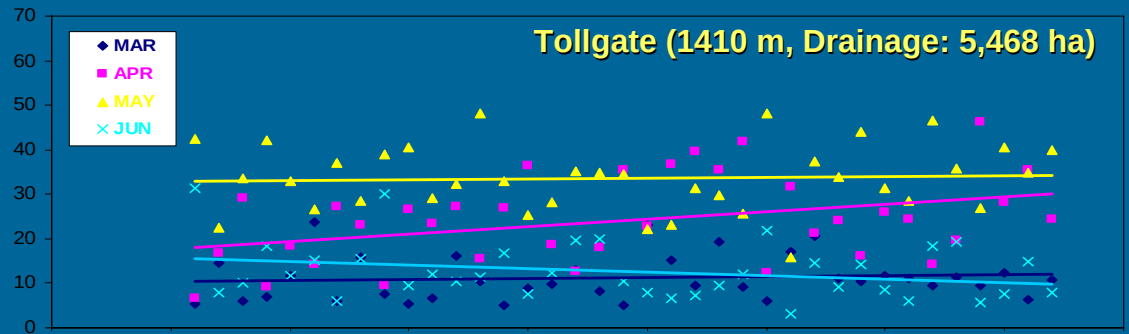
Headwater Catchment:
March +3%
April +14%
May -------
June -11%



Summer Flow: Reduced from 9% to 3%

67% Reduction

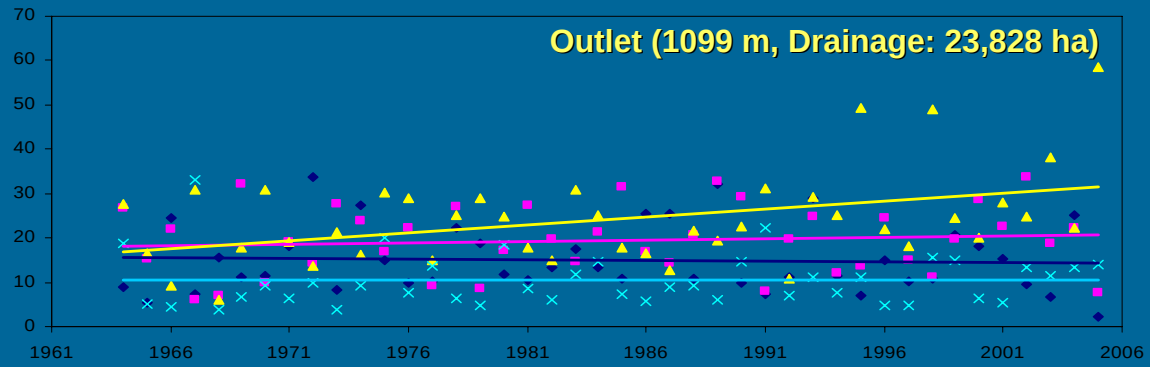
Mid-Elevation Drainage:
March +1%
April +12%
May +1%
June -5%



Summer Flow: Reduced from 21% to 10%

52% Reduction

Basin Outlet:
March -------
April +4%
May +12%
June -1%



Summer Flow: Reduced from 27% to 12%

56% Reduction

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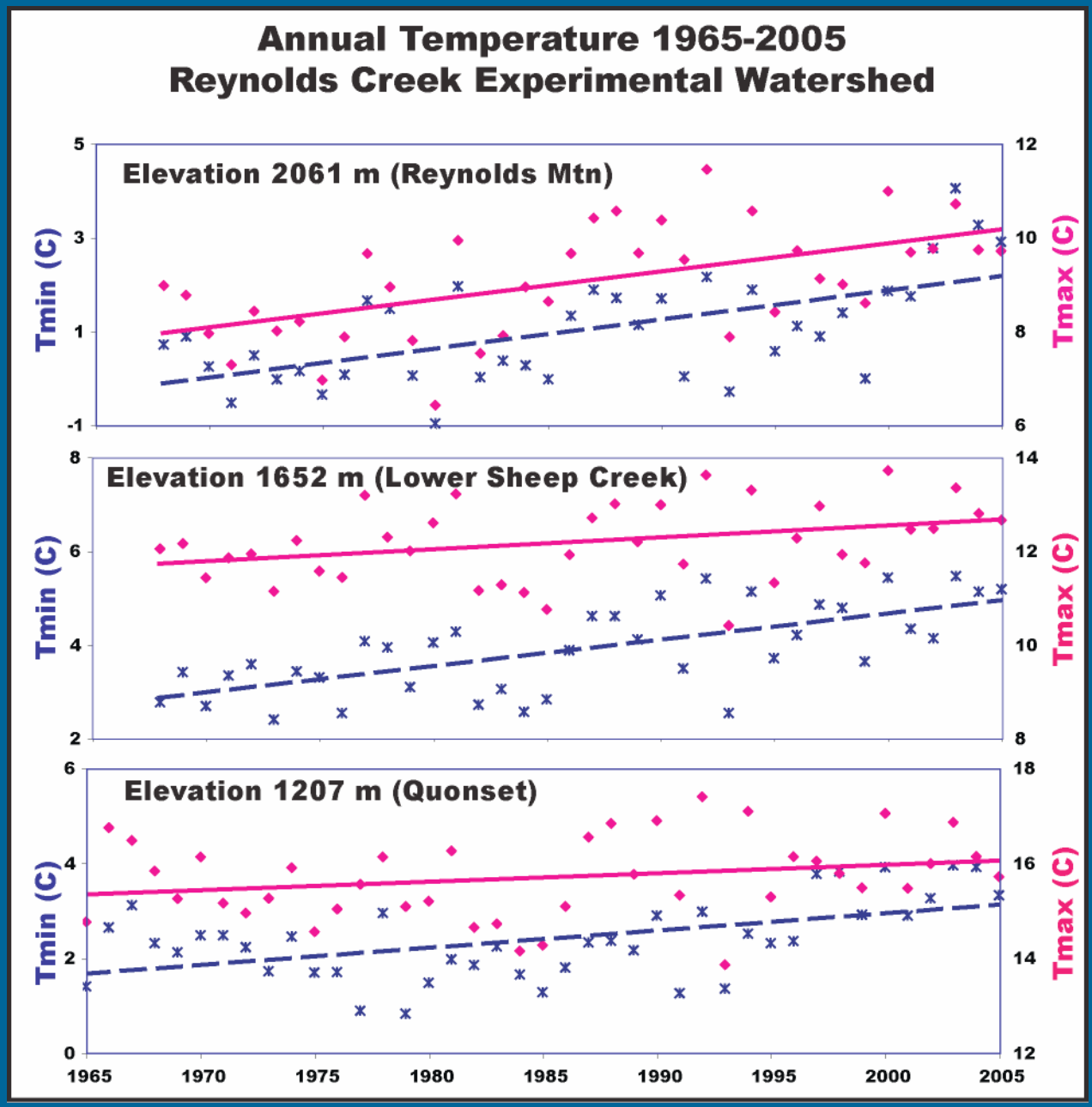

+ 2.5:
-0.6 to +1.9

+ 2.4:
+7.9 to +10.3

+ 2.7:
+2.5 to +5.2

+ 0.9:
+11.8 to +12.7

+ 1.4:
+1.7 to +3.1

+ 0.9:
15.4 to 16.3

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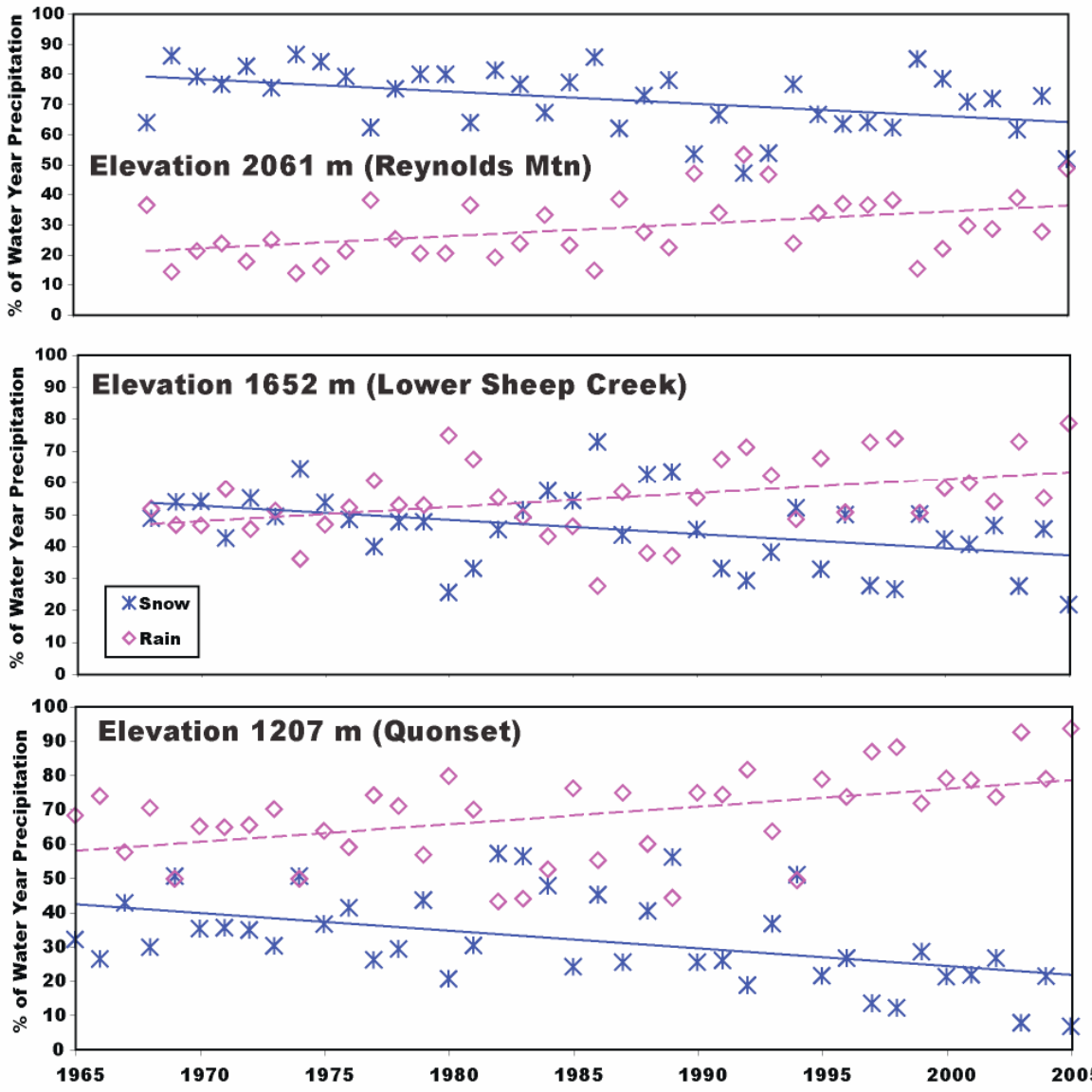
Precipitation Type - Rain vs. Snow 1965-2005
Reynolds Creek Experimental Watershed



Snow: -16%:
80% to 62%

Still Snow Dominated

Snow: -17%:
55% to 38%

Now Rain Dominated

Snow: -22%:
41% to 19%

Almost Never Snows

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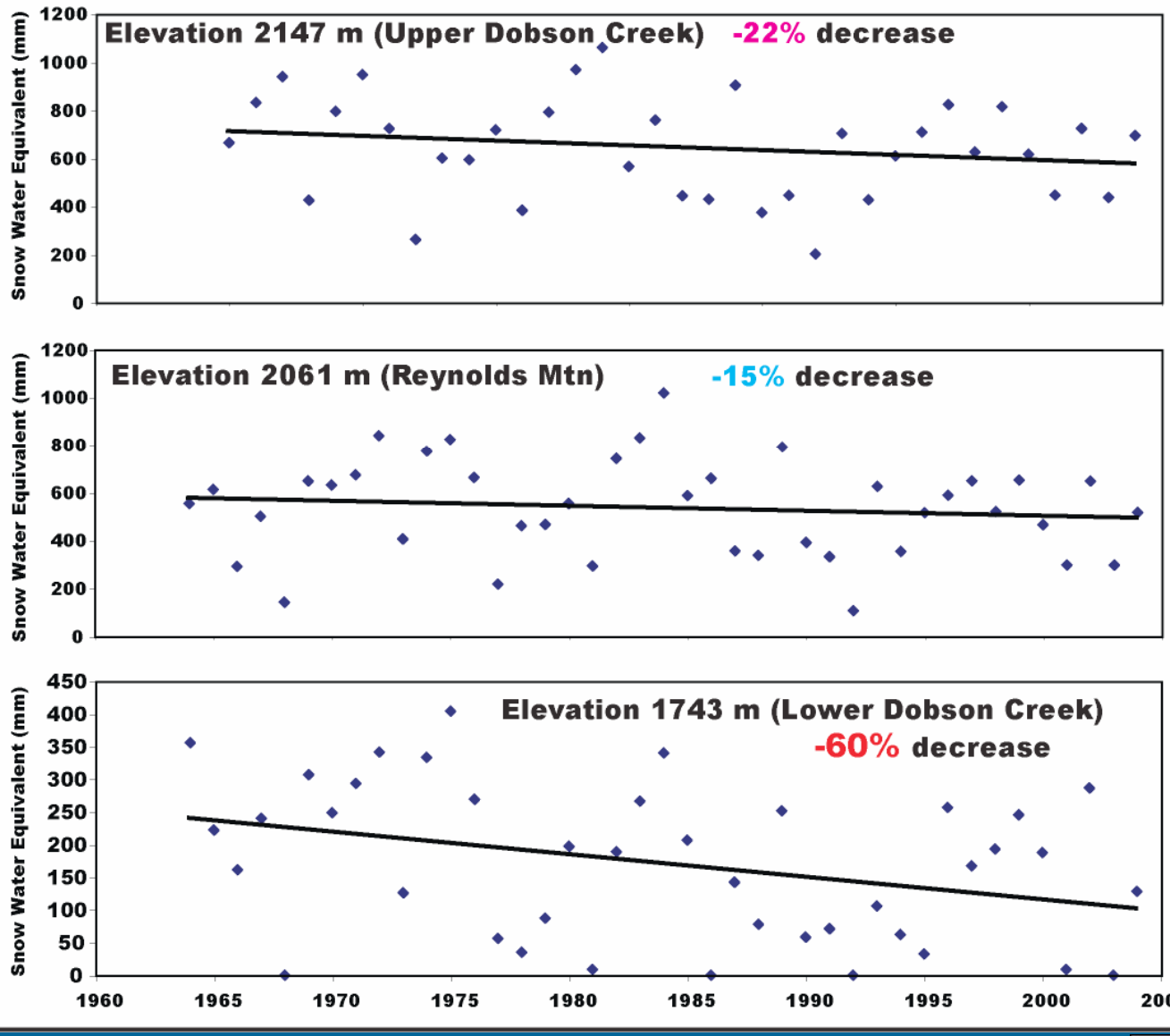
April 1 Snow Water Equivalent - 1960-2005
Reynolds Creek Experimental Watershed



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- **Annual precipitation & discharge are unchanged**
  - However, early spring flows are increased
  - Summer flows are significantly reduced
- **Climate is warming**
  - All temperatures have increased
  - Minimum temperatures increased the most
- **More precipitation falls as rain**
  - Smaller change at high elevation
  - Large change at low elevation
- **Strong elevation effect**
  - Effects availability of water in summer
  - More area at lower elevation
  - Increase in winter ROS events

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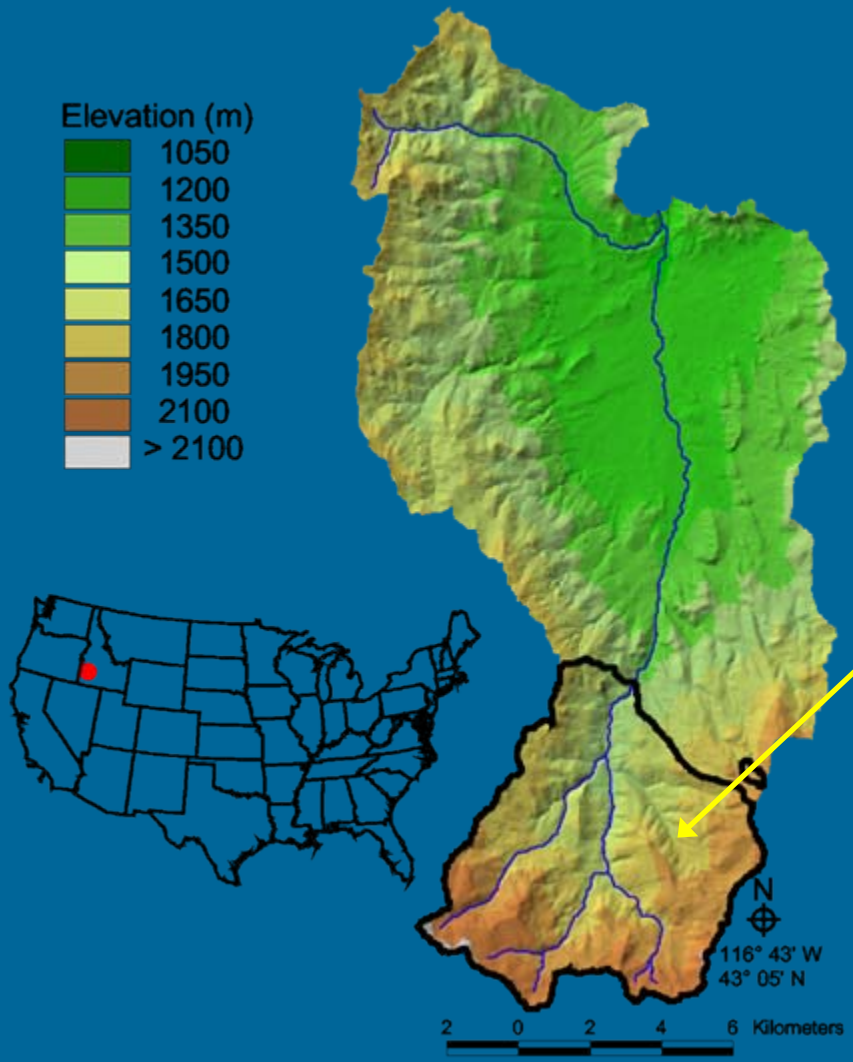
Reynolds Creek Experimental Watershed



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

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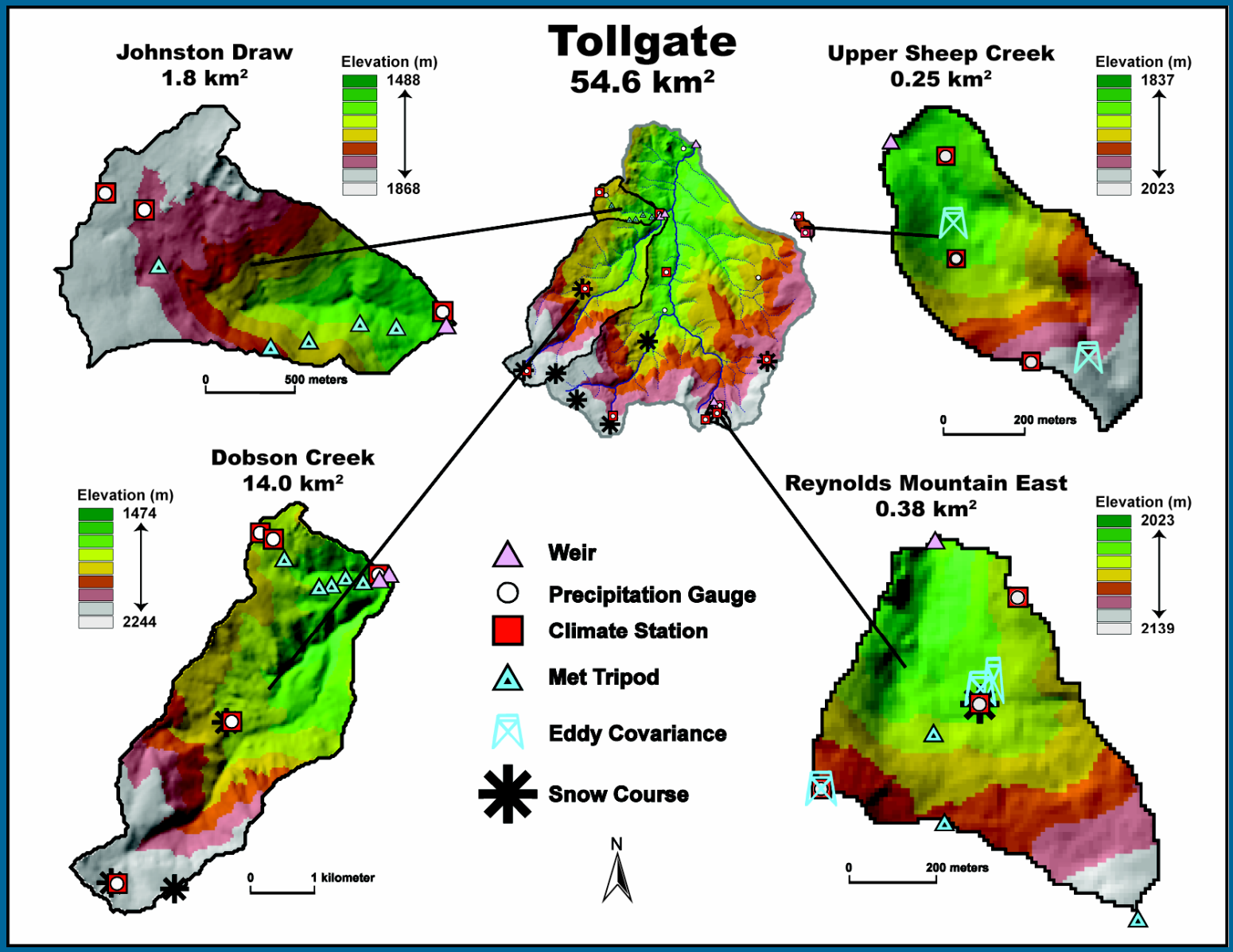
Scaling up to Tollgate



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Snow & Hydrologic Modeling:

Simulation of terrain and forest shelter effects on wind fields, patterns of snow redistribution, snowmelt and runoff

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PhD project, ADAM WINSTRAL
(University of Reading, UK)

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Snow Redistribution and Drifting

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Drifts and Forest Cover, RCEW

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Forest Canopy- Snowcover Interaction

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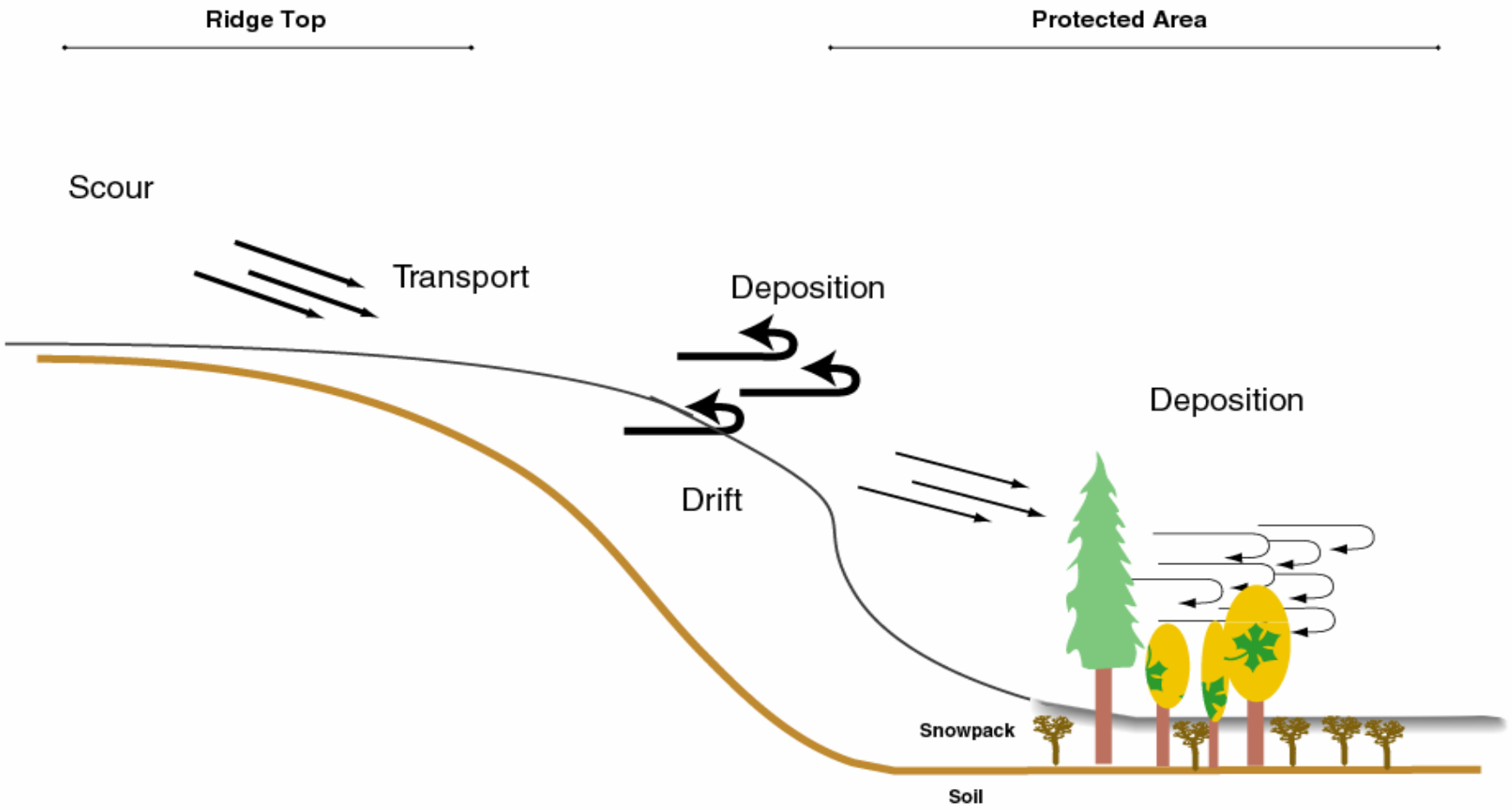
Conceptual Diagram of Topographic and Vegetation Effects



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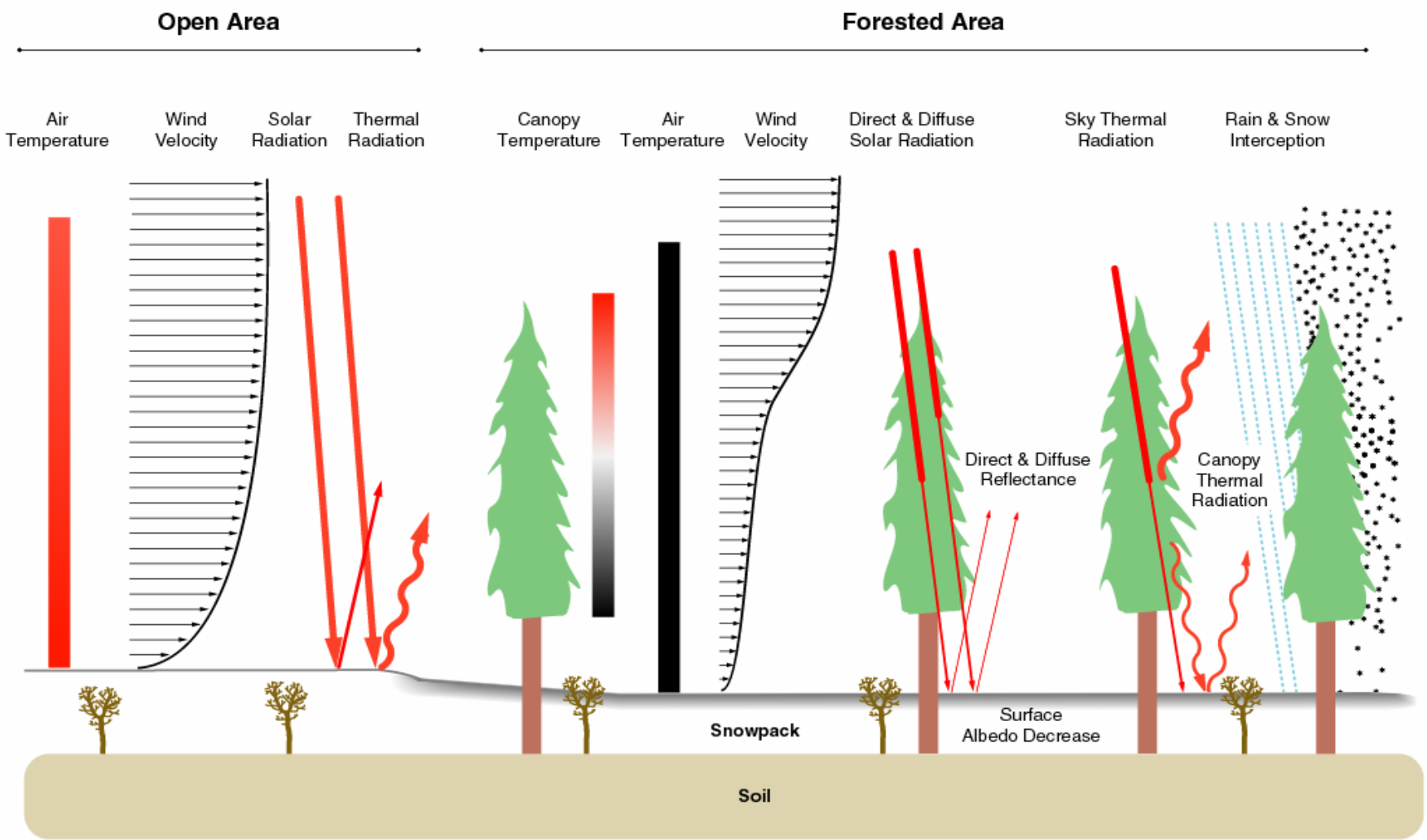
Conceptual Diagram of Canopy Effects



Canopy_filter(e)
Timothy Link
1/15/98

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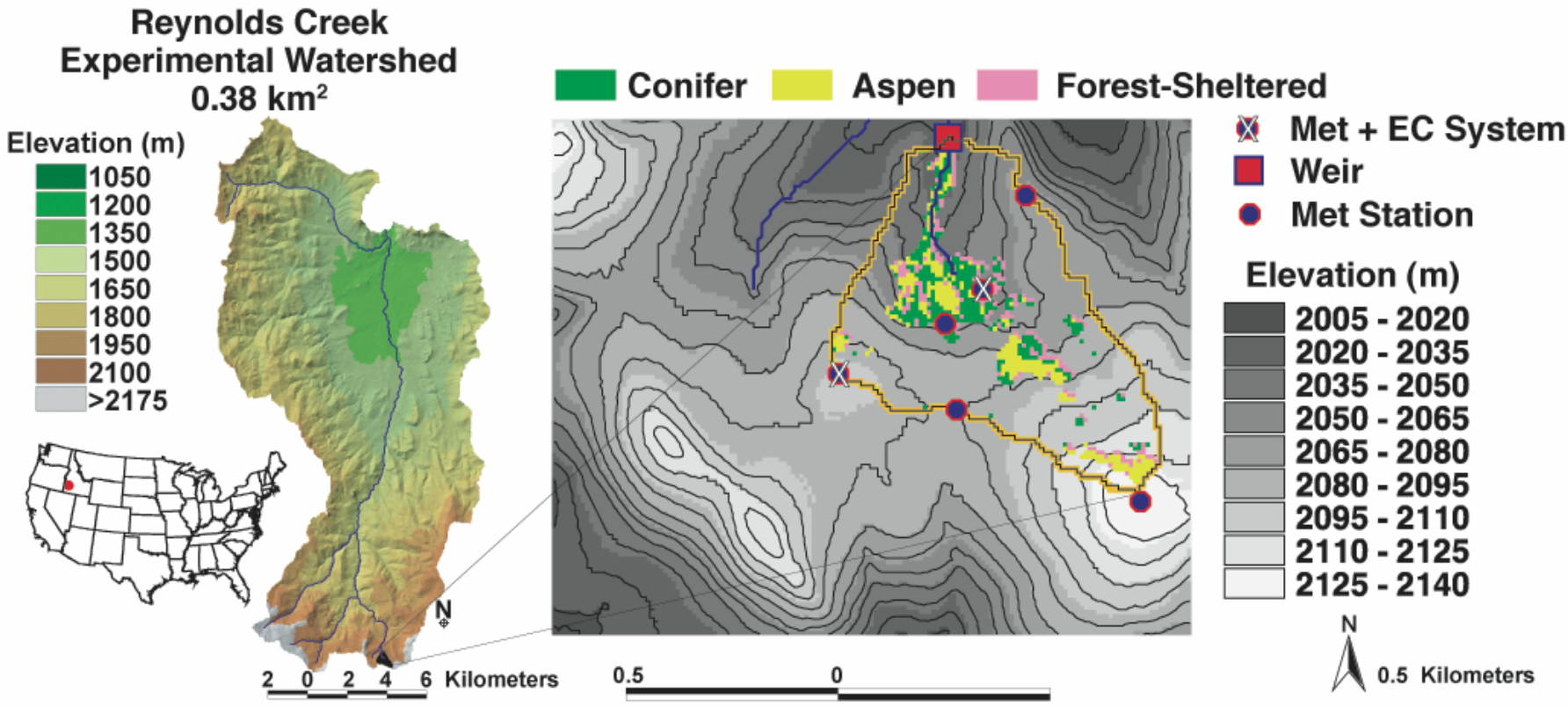
Reynolds Mountain East Study Catchment (0.38 km², 118 m relief)



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The Ridge Site

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The Grove Site

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The Grove Site

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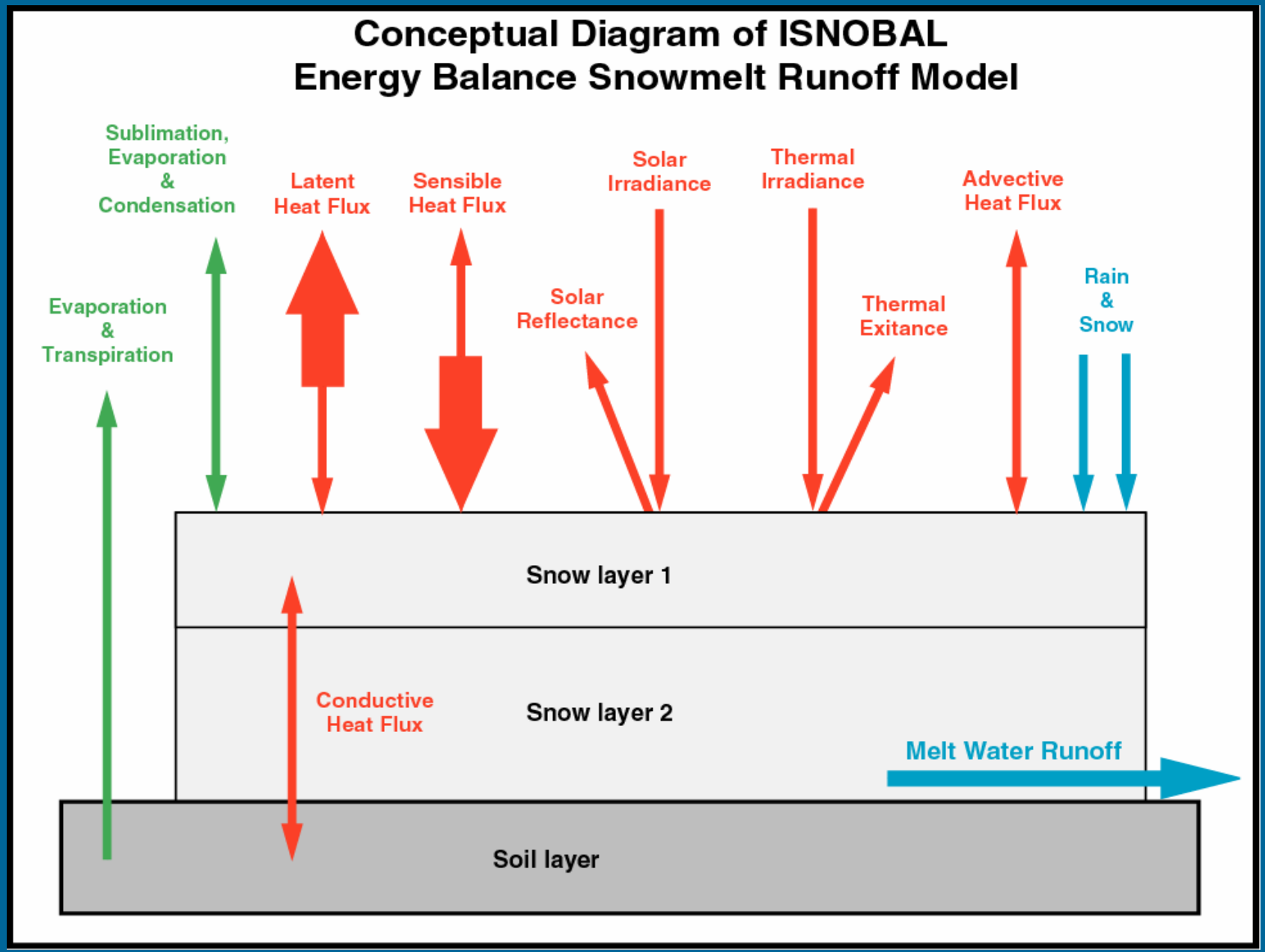
Conceptual Diagram of ISNOBAL Energy Balance Snowmelt Runoff Model



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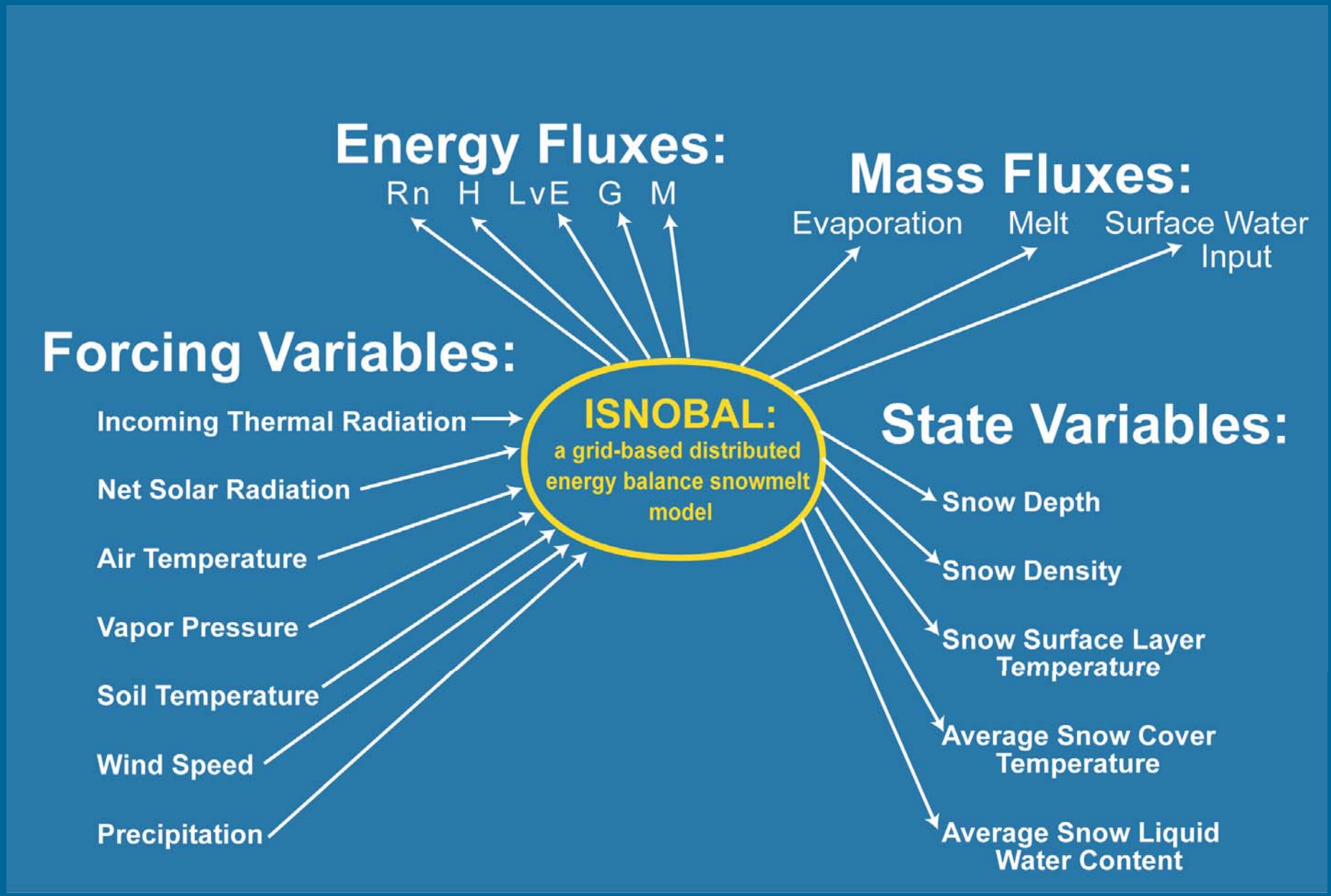

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Four Snow Seasons Selected for Simulation

1986, 1987, 1989 for SCA Data

1997 for ROS Event

I. Verify Simulated Snow Distributions

* Time-series AP

II. Evaluate Terrain & Vegetation Shelter Effects on

* Simulated Snow Cover Energy Balance

* Snow Melt

* Runoff

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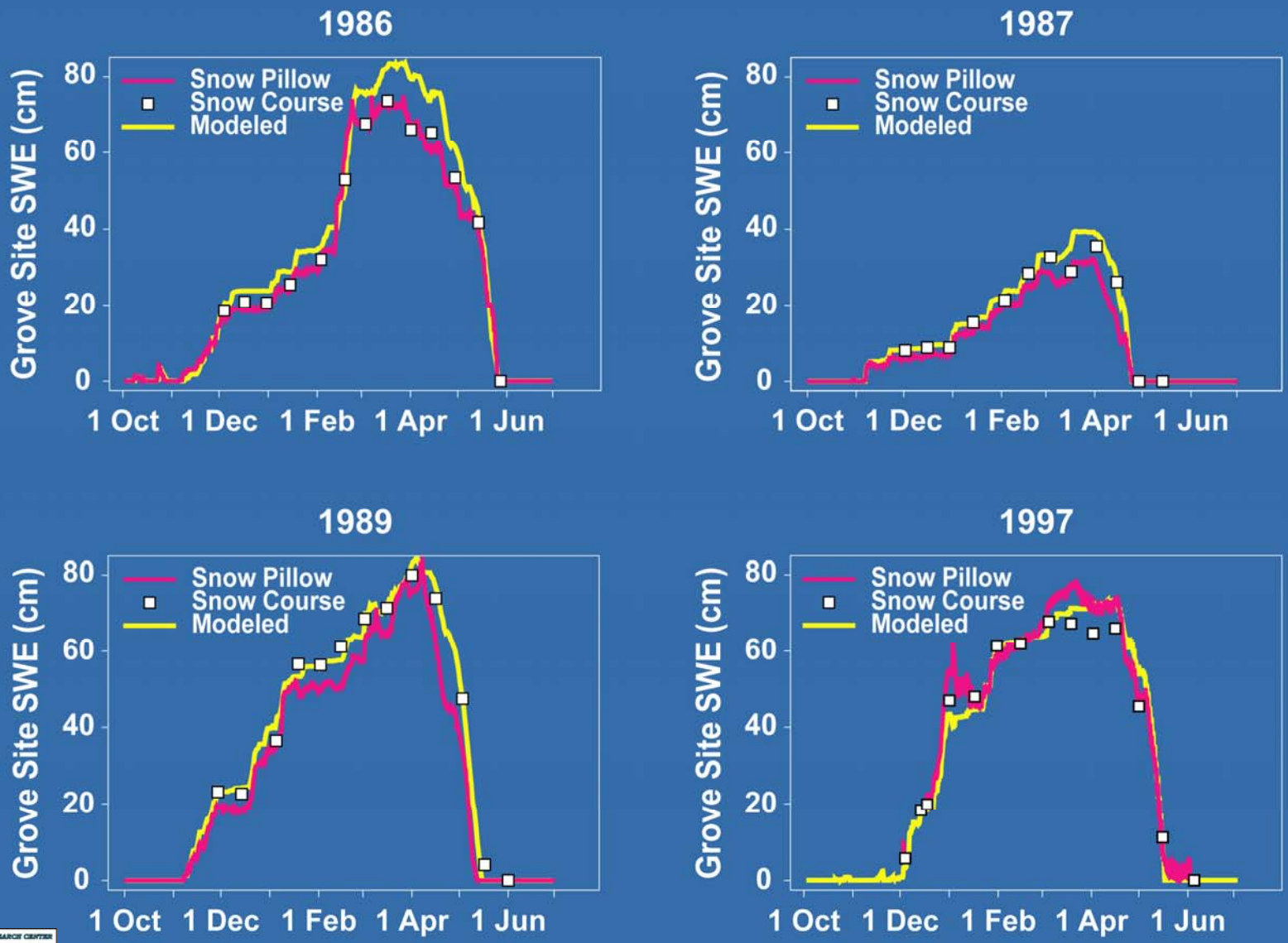
Modeled and Observed SWE (Point Comparison)



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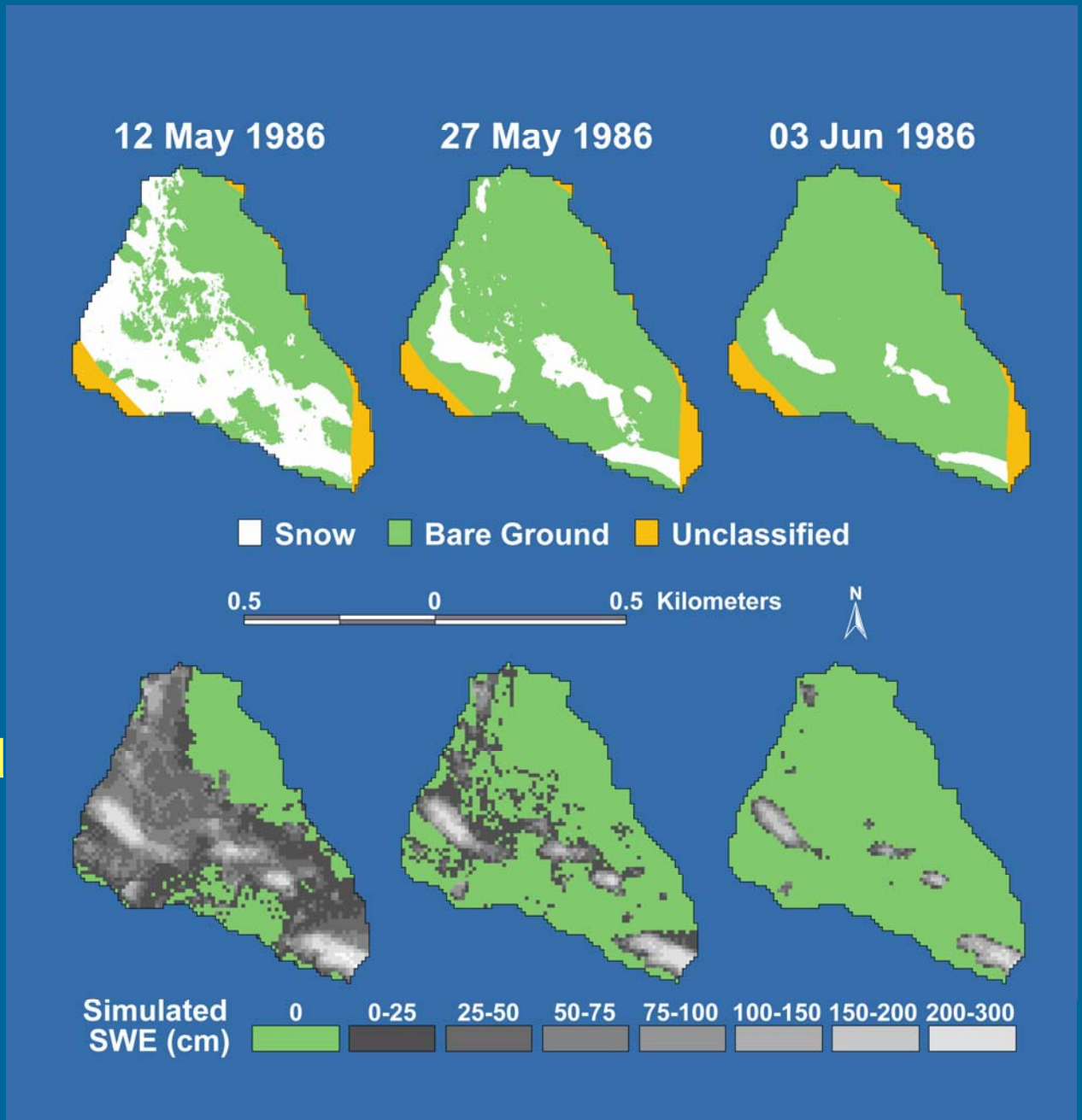
1986 Simulated Snow Distribution

Aerial Photos

Modeled SWE



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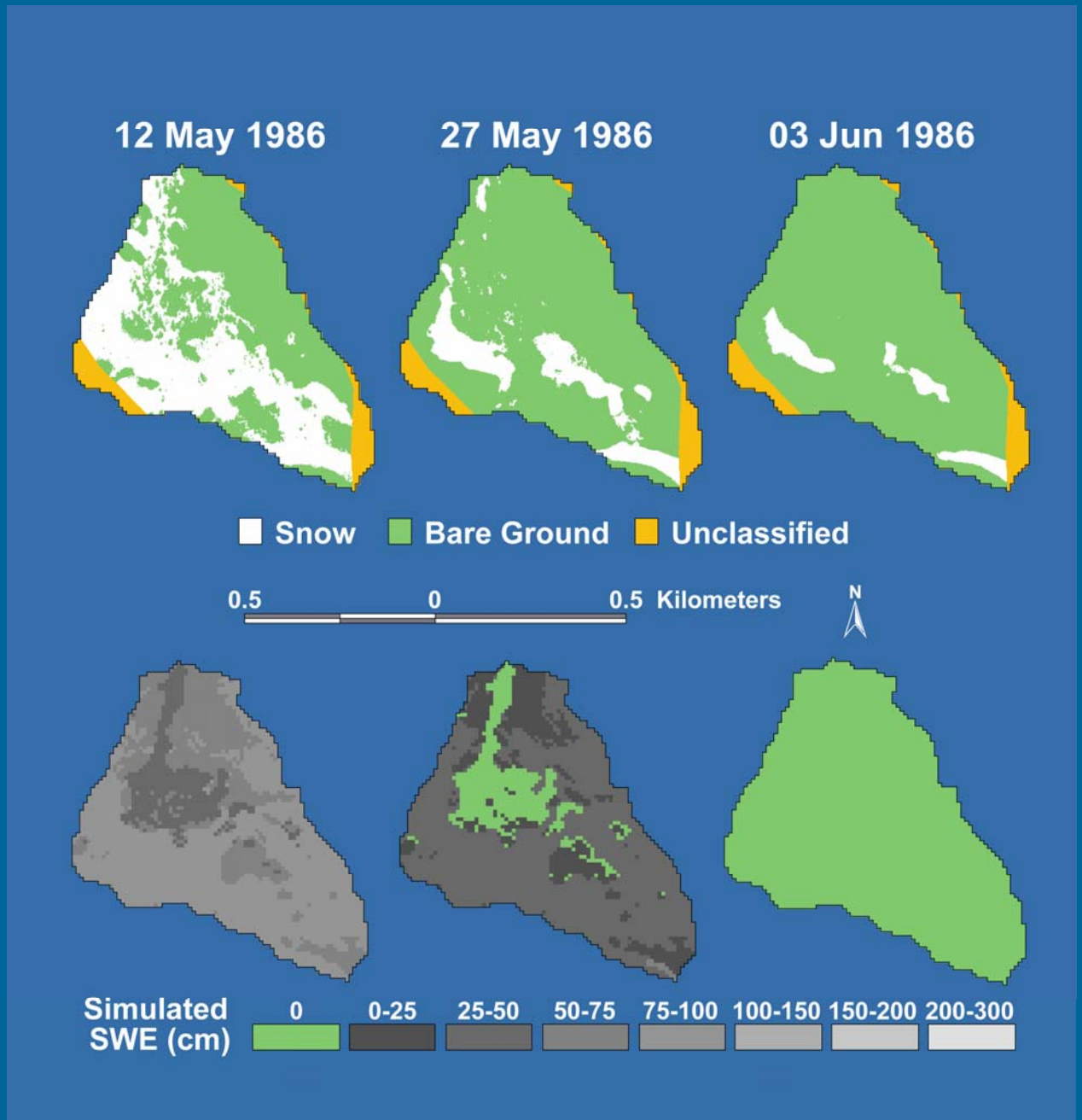
1986 Simulated Snow Distribution

Aerial Photos

Modeled SWE:

spatially constant wind and precipitation inputs



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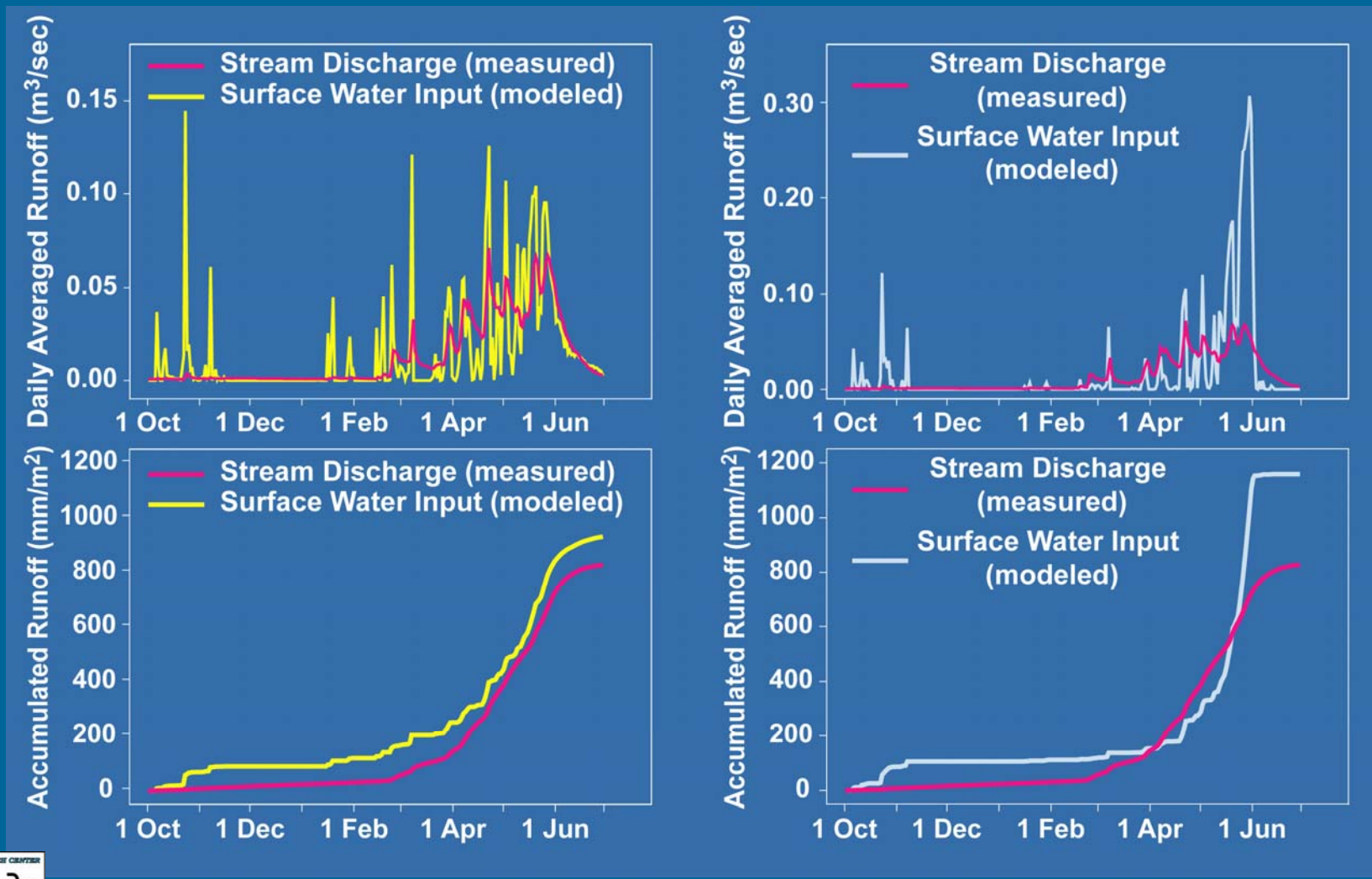
1986 Simulated Surface Water Inputs

Spatially Distributed Wind and Precipitation Inputs

Spatially Constant Wind and Precipitation Inputs



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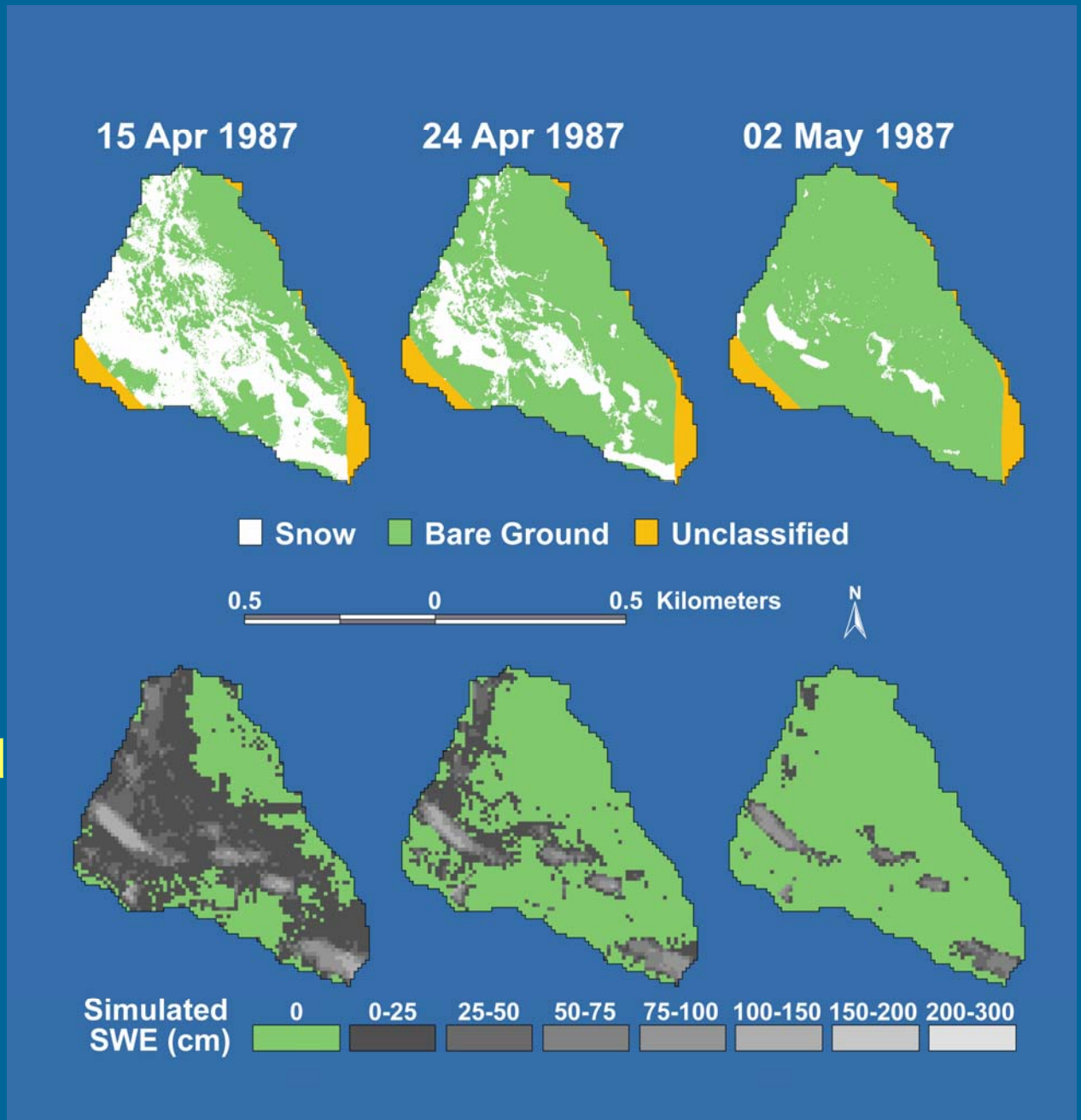
1987 Simulated Snow Distribution

Aerial Photos

Modeled SWE



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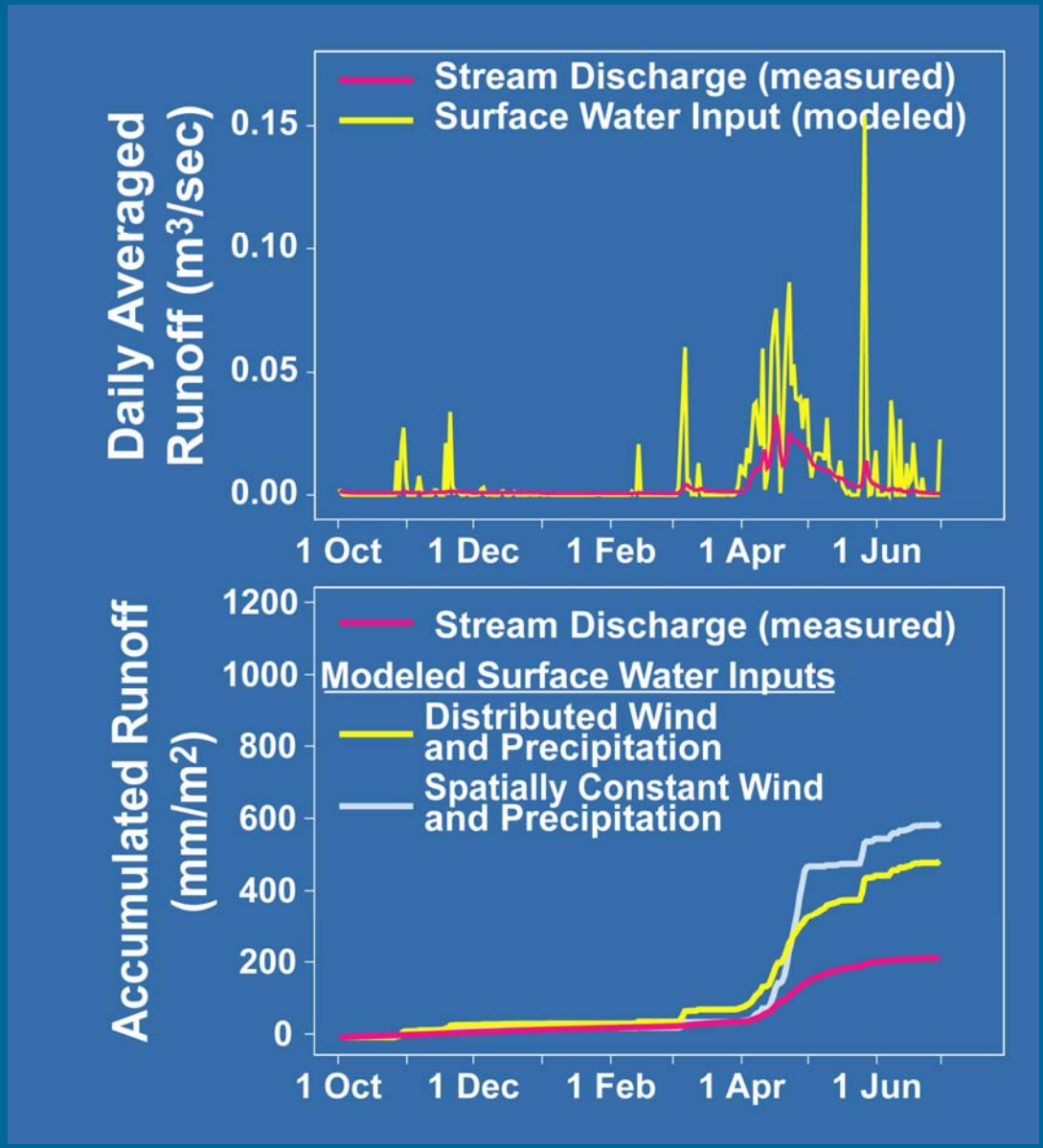
1987 Simulated Surface Water Inputs



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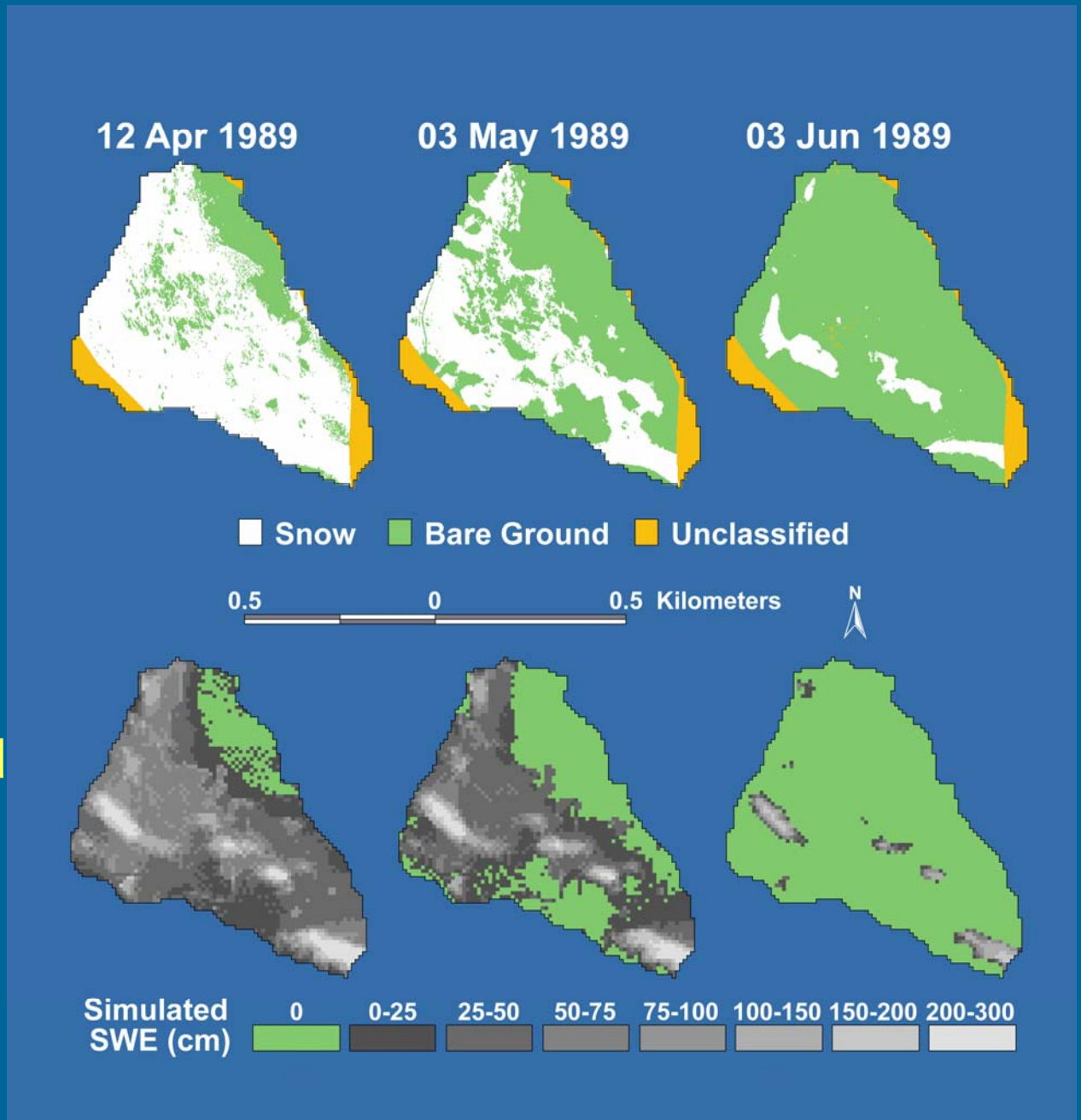
1989 Simulated Snow Distribution

Aerial Photos

Modeled SWE



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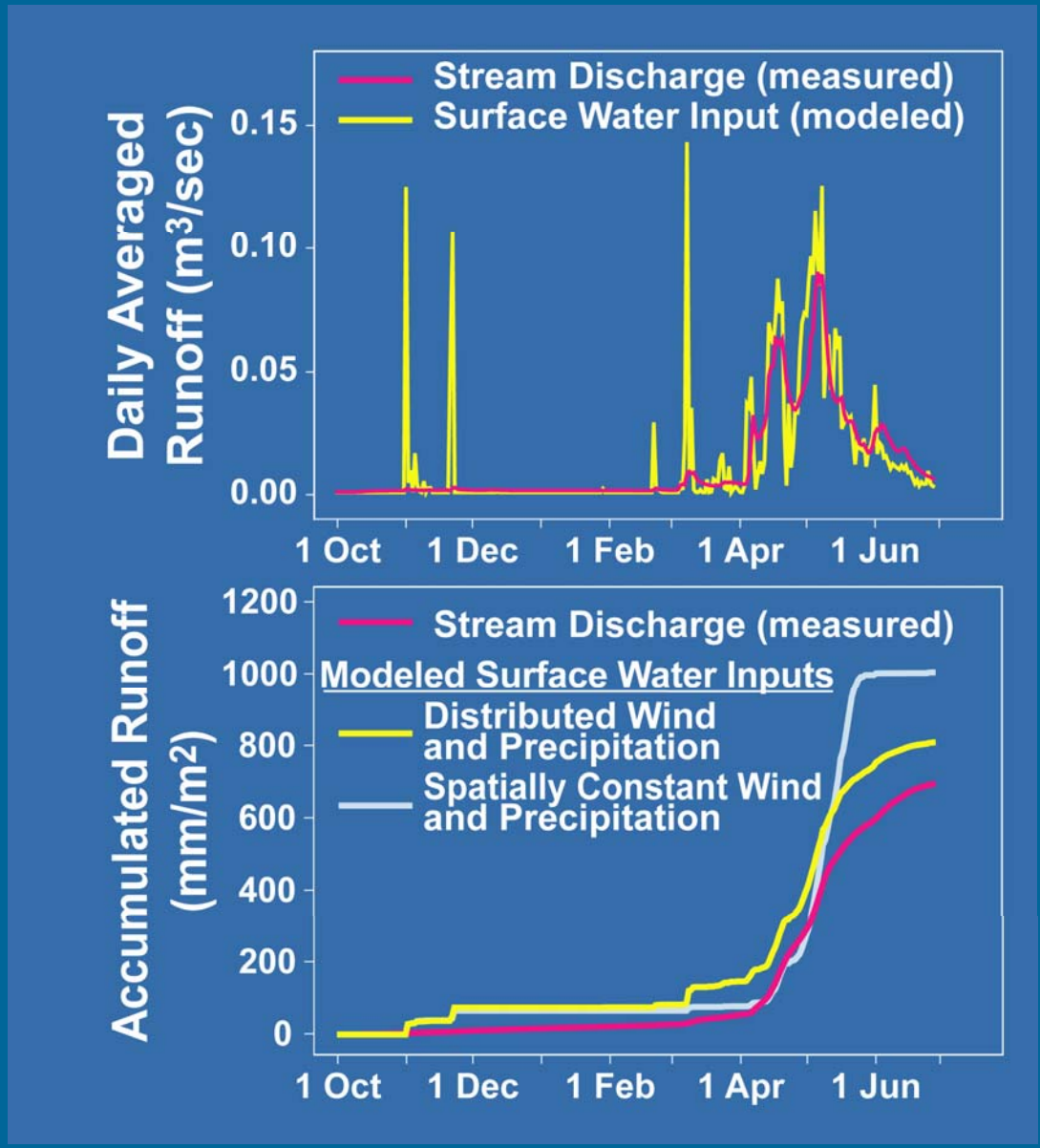
1989 Simulated Surface Water Inputs



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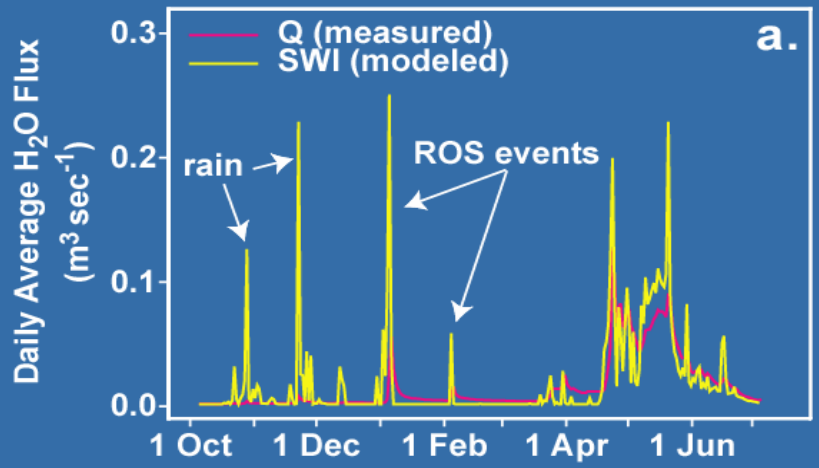
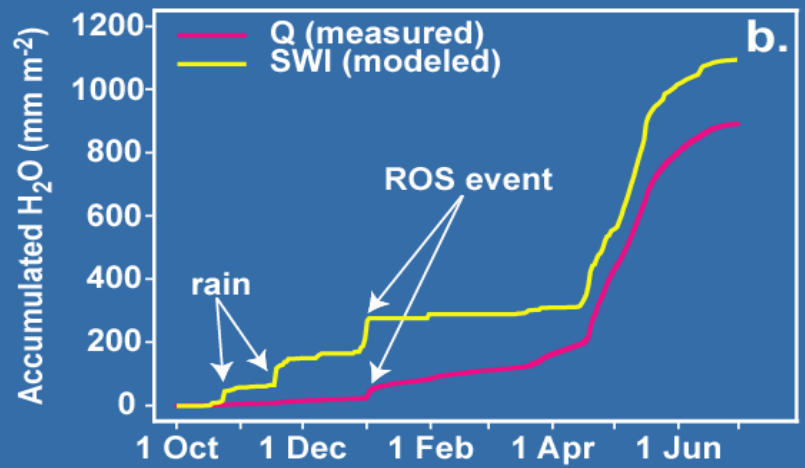
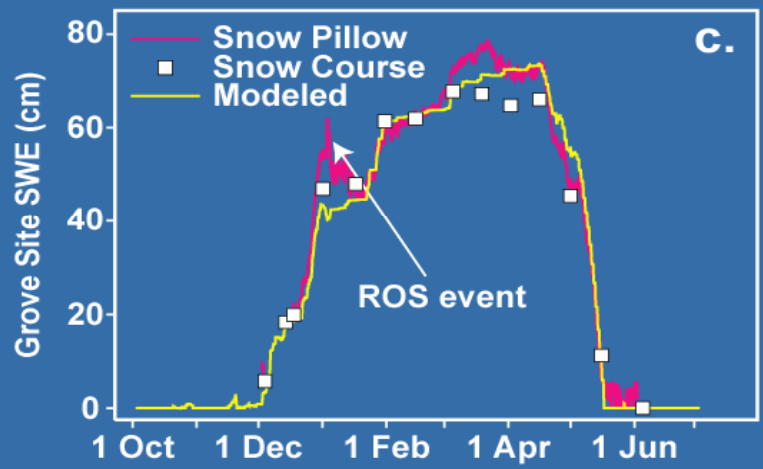
1997 Simulated Surface Water Inputs and SWE







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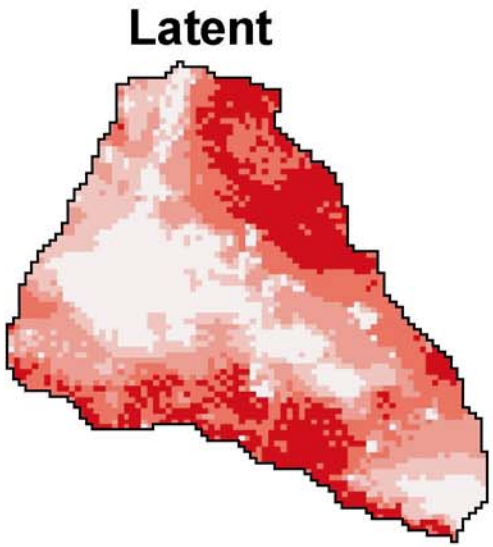
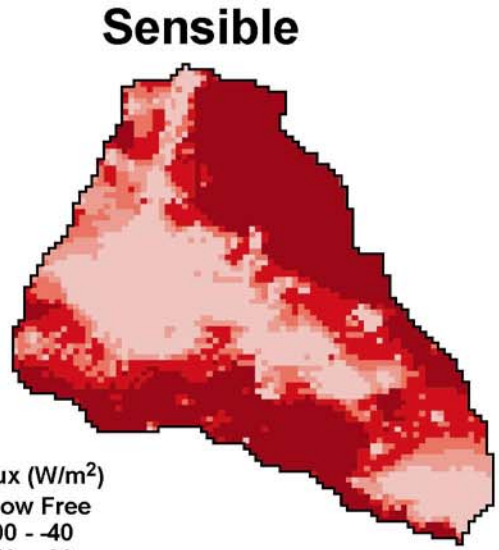
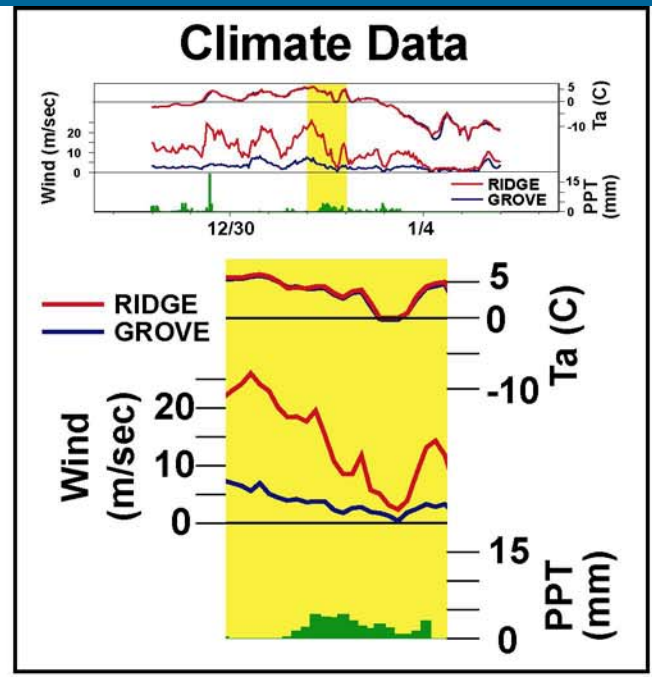
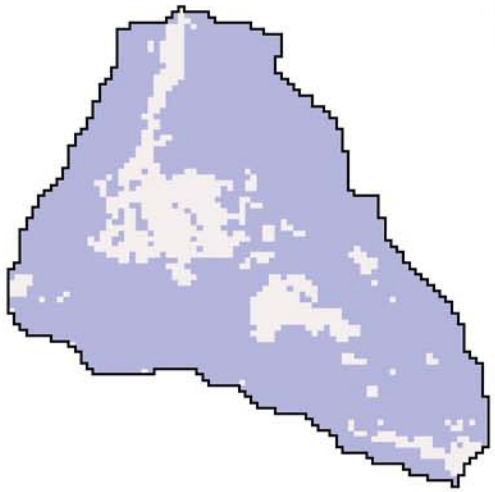
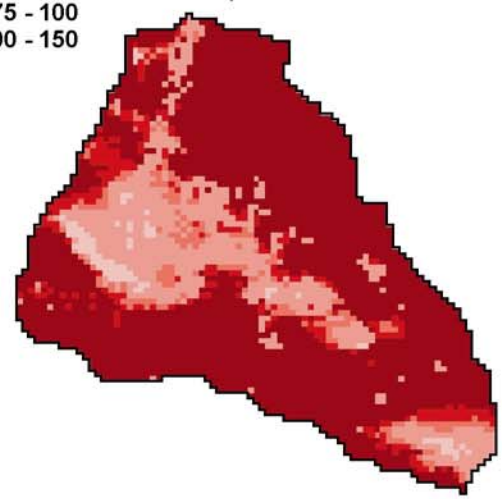




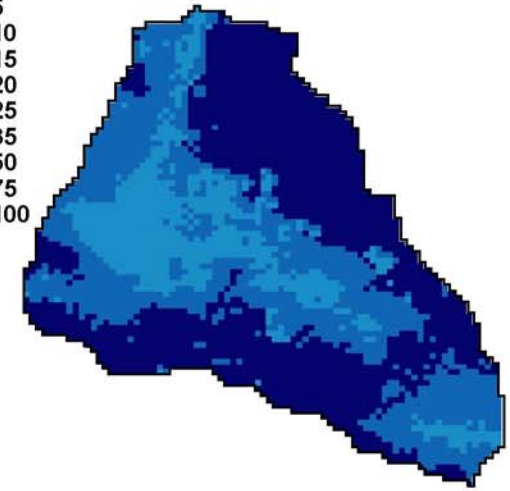
Heat Flux (W/m^2)
Snow Free
-200 - -40
-40 - -20
-20 - 0
0 - 20
20 - 40
40 - 60
60 - 75
75 - 100
100 - 150







SWI (mm)
0
0 - 5
5 - 10
10 - 15
15 - 20
20 - 25
25 - 35
35 - 50
50 - 75
75 - 100



01 Jan 1997

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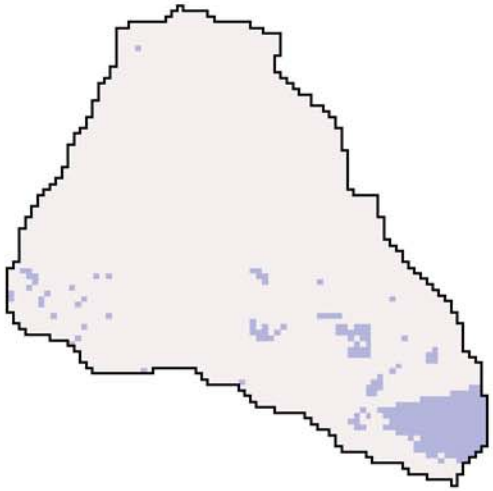
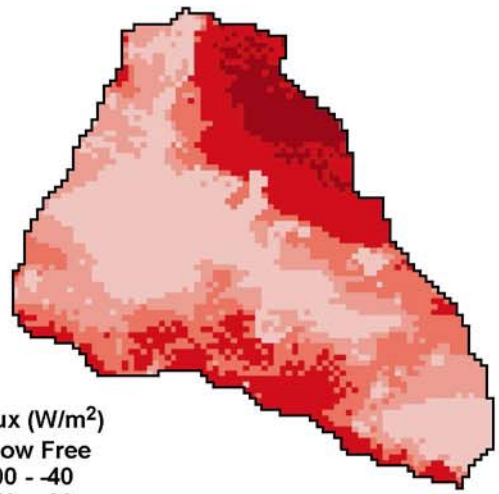
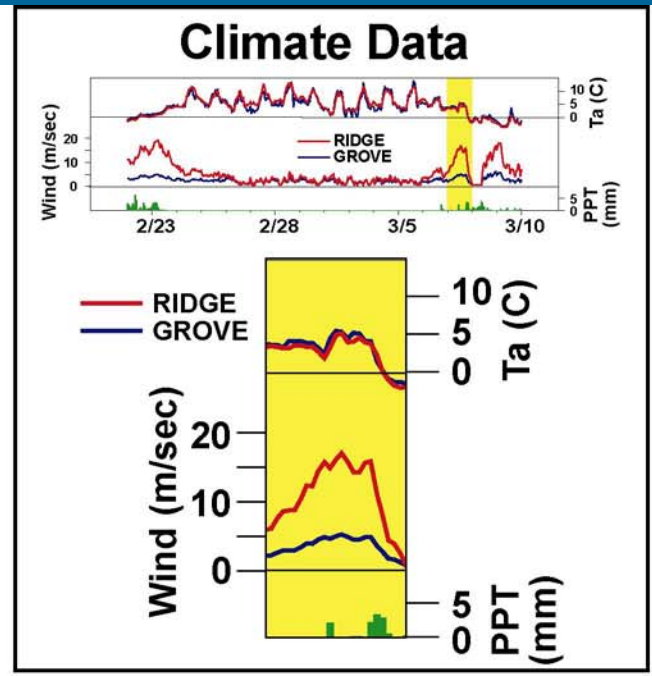
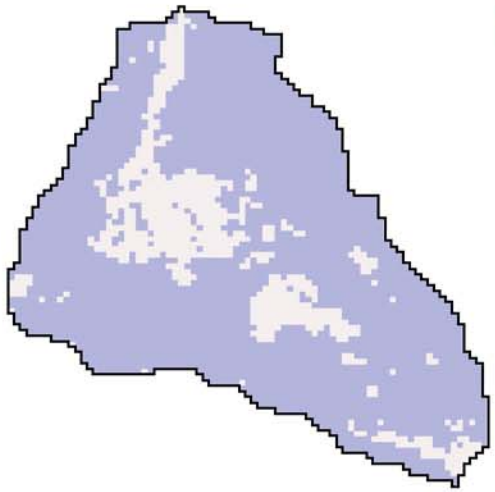
Mid-winter ROS: *Sensible* + *Latent Heat* dominated

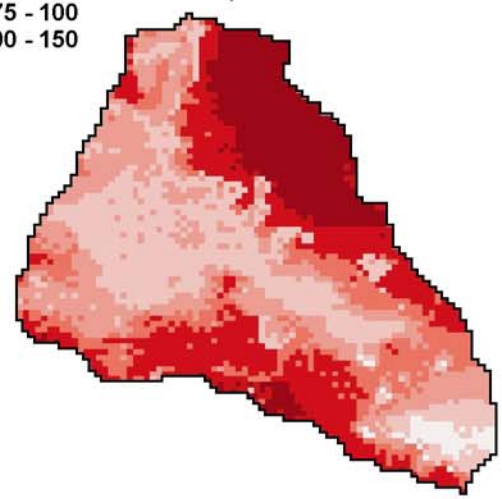




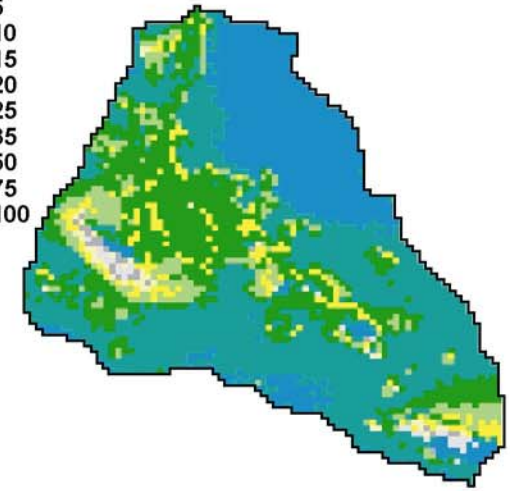
Heat Flux (W/m^2)
Snow Free
-200 - -40
-40 - -20
-20 - 0
0 - 20
20 - 40
40 - 60
60 - 75
75 - 100
100 - 150







SWI (mm)
0
0 - 5
5 - 10
10 - 15
15 - 20
20 - 25
25 - 35
35 - 50
50 - 75
75 - 100



07 Mar 1986

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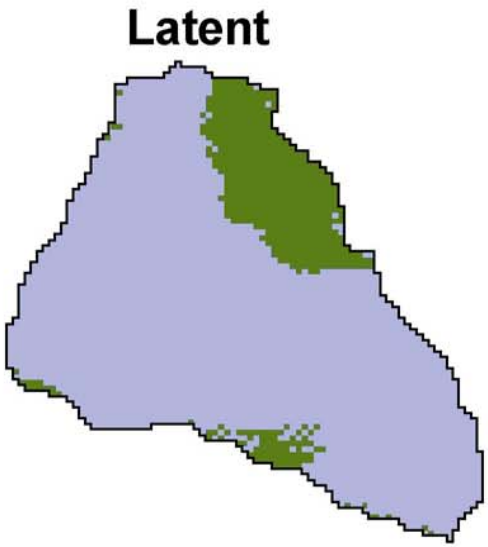
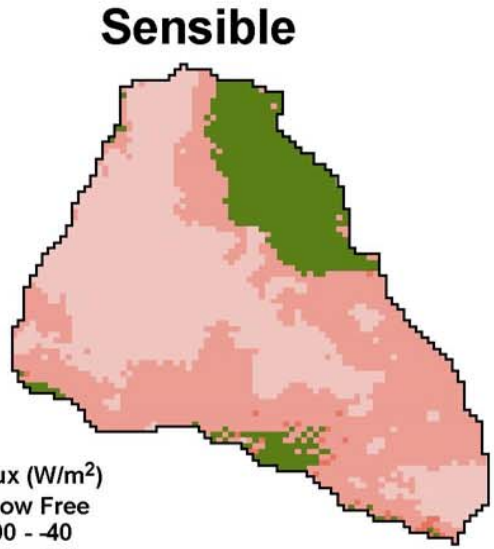
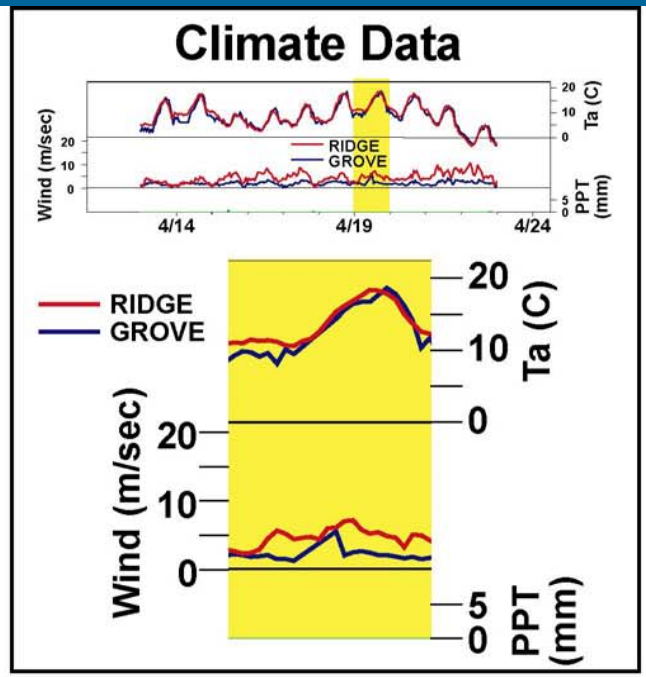
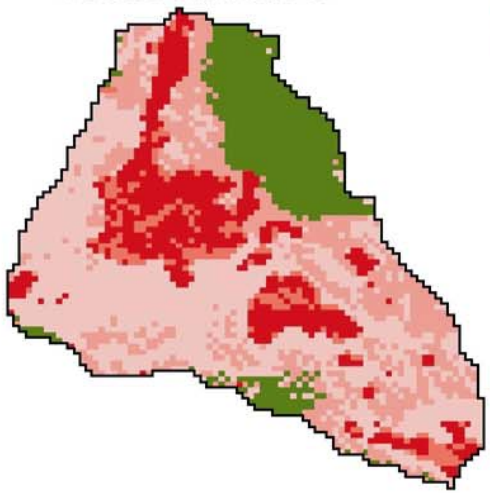
Early spring wind event: *Sensible Heat* dominated

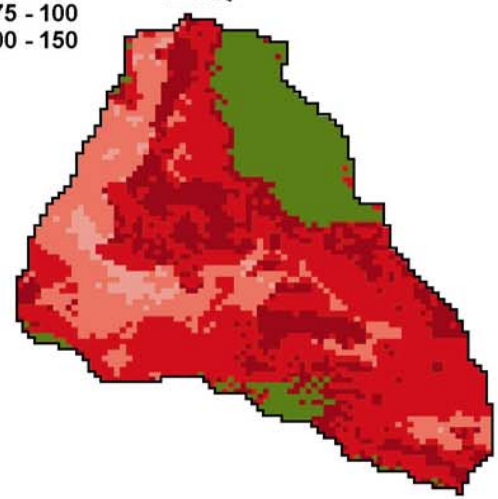




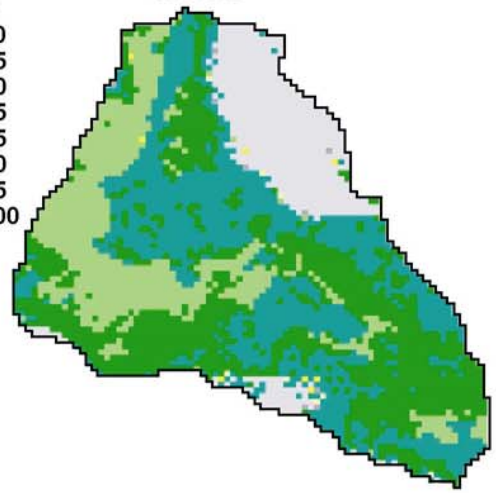
Heat Flux (W/m^2)
Snow Free
-200 - -40
-40 - -20
-20 - 0
0 - 20
20 - 40
40 - 60
60 - 75
75 - 100
100 - 150







SWI (mm)
0
0 - 5
5 - 10
10 - 15
15 - 20
20 - 25
25 - 35
35 - 50
50 - 75
75 - 100



19 Apr 1989

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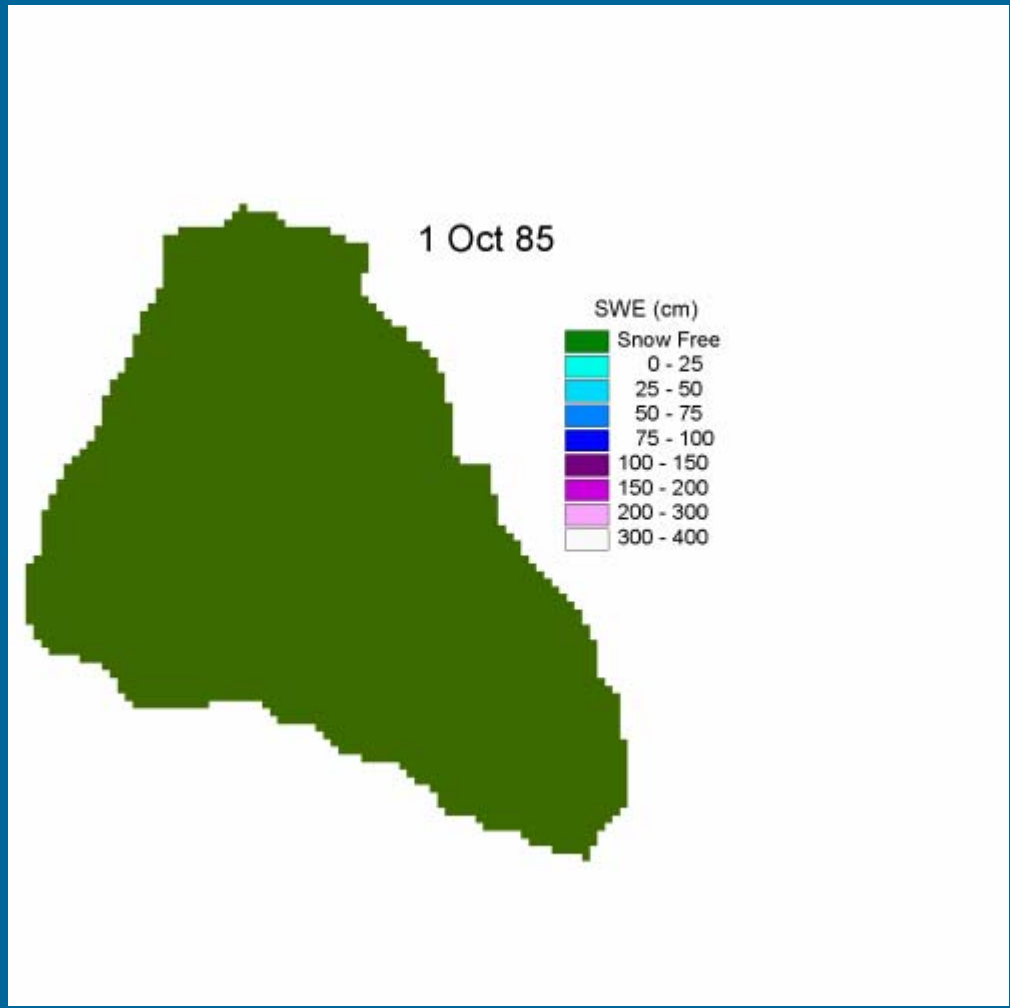
Typical spring melt event: *Radiation* dominated

Simulated Daily SWE

1986 Snow Season



View movie at http://www.usask.ca/ip3/download/presentations/swe_movie.avi

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Boise River Basin (2150 km^2) 1998 Water Year

DANNY MARKS and DAVID GAREN*

*** National Water and Climate Center**
USDA-Natural Resources Conservation Service
Portland, Oregon, USA

- **Large Area Climate Data Distribution**
- **Canopy Corrections**
- **Satellite Derived Snow Covered Area for Verification**
- **Streamflow Simulation**

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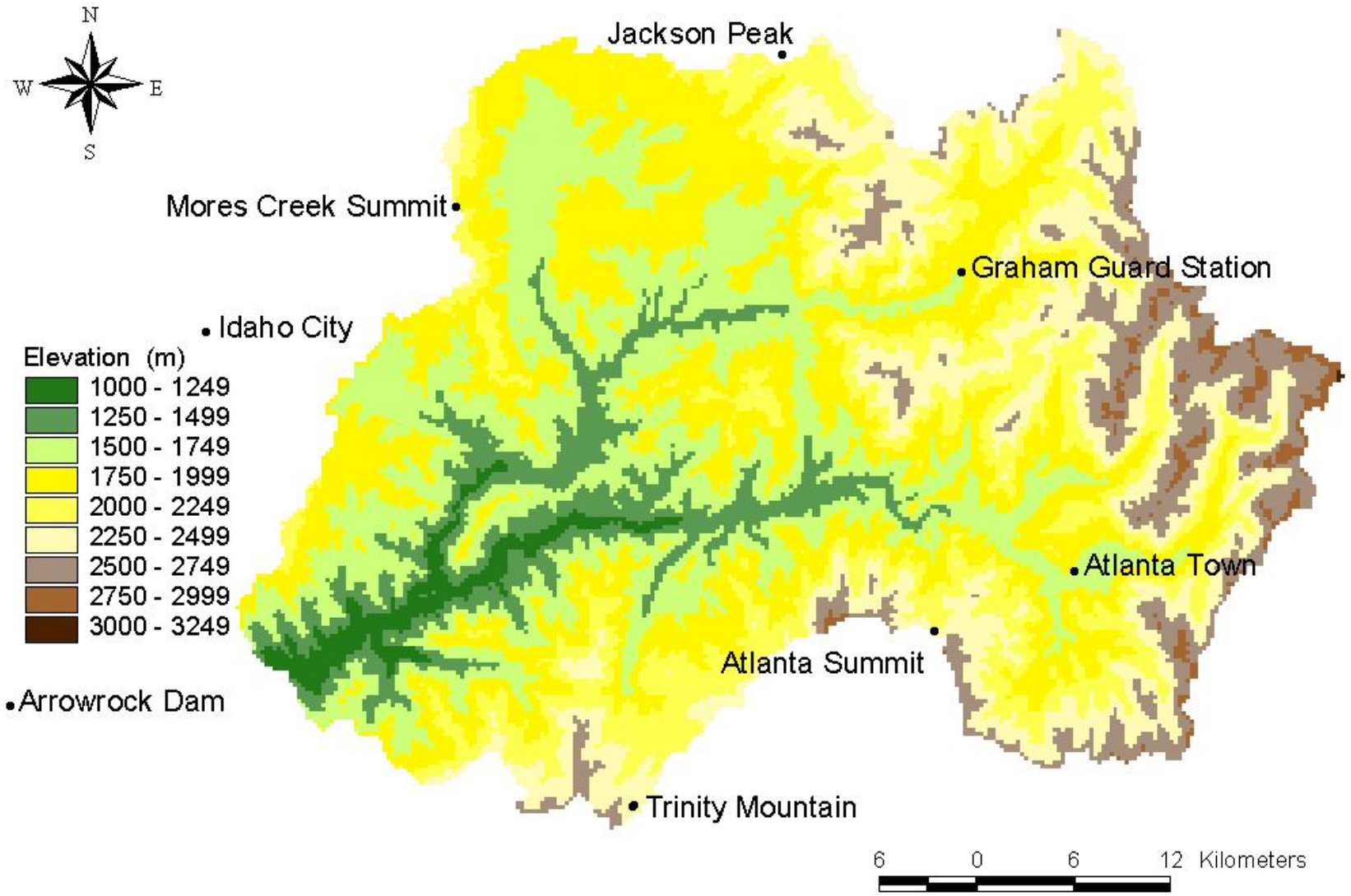
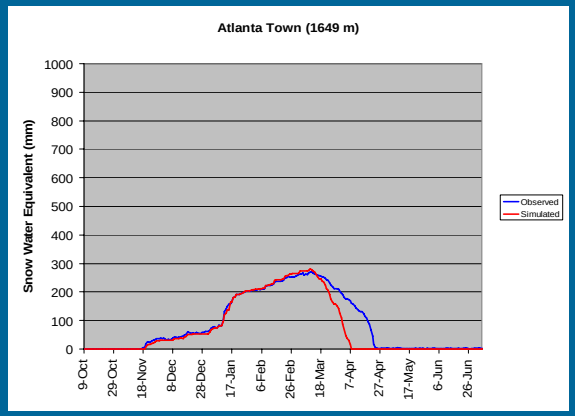
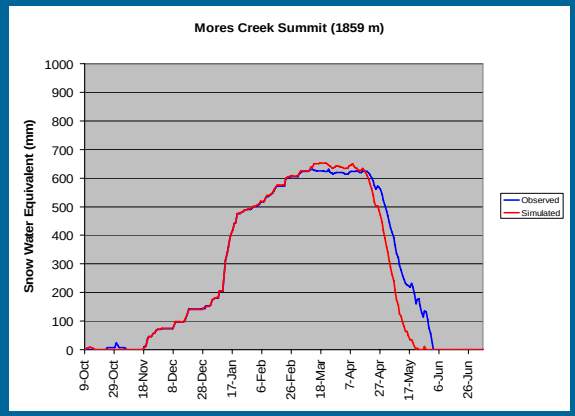
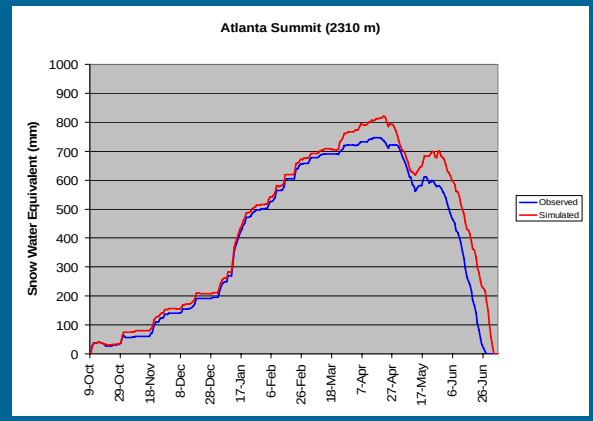
Boise River Elevation and Data Site Locations

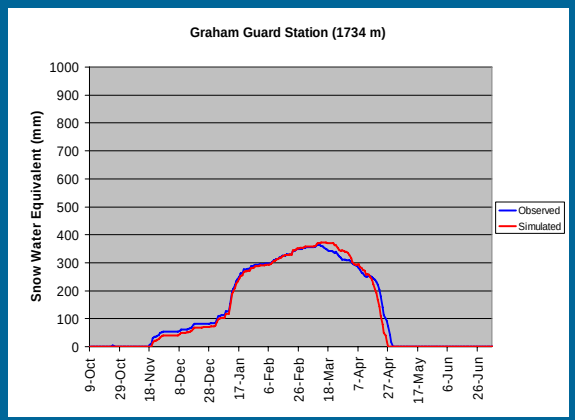


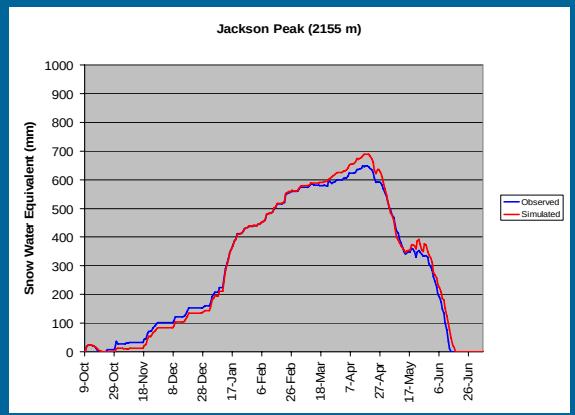
Boise River Snow Water Equivalent
Water Year 1998

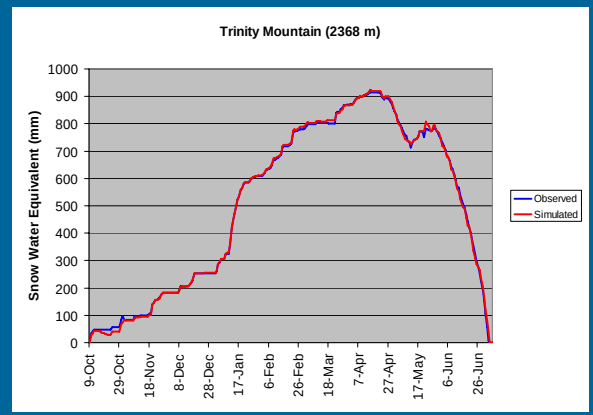












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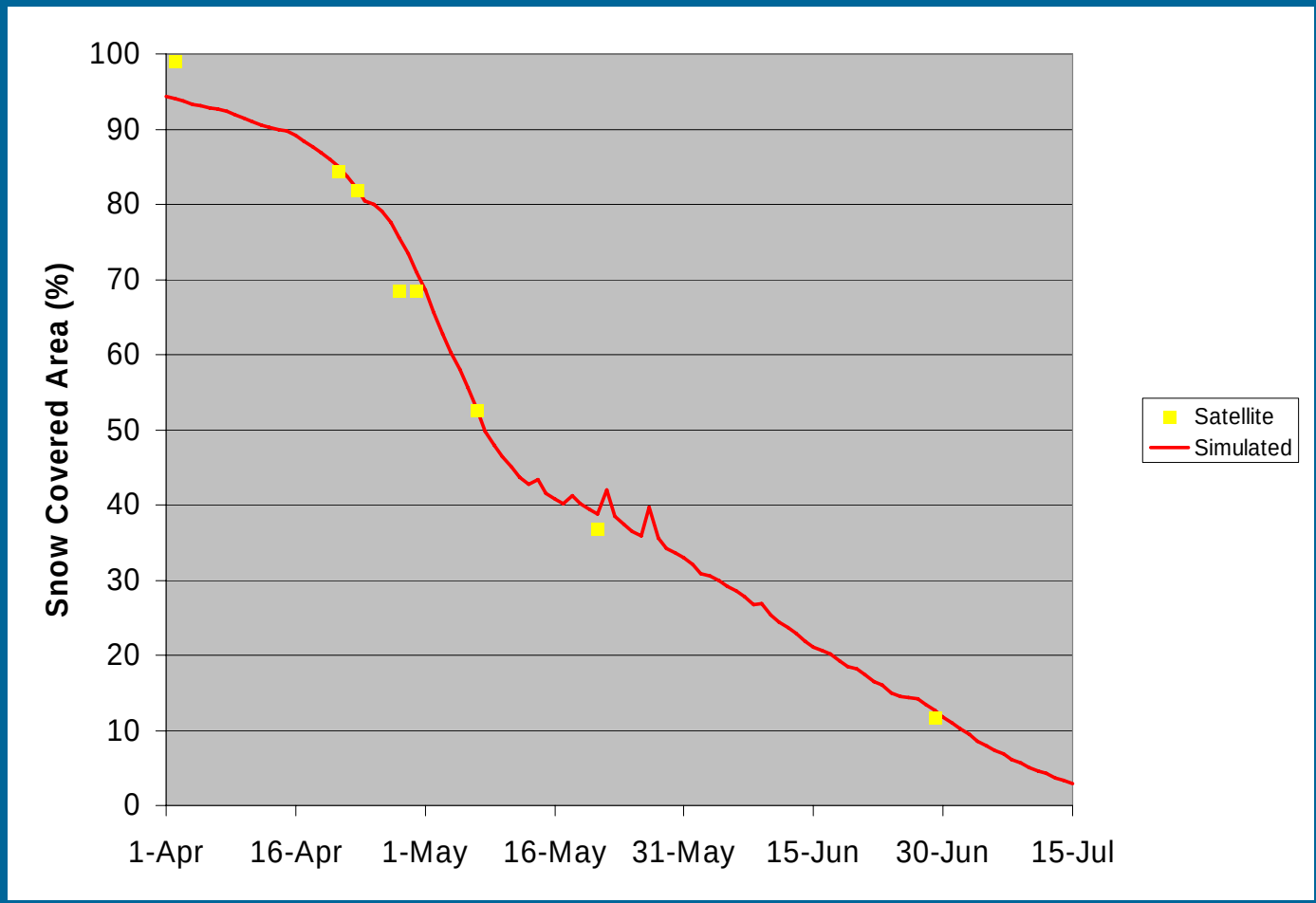
Simulated and Satellite Snow Covered Area (SCA) Boise River Basin, Water Year 1998



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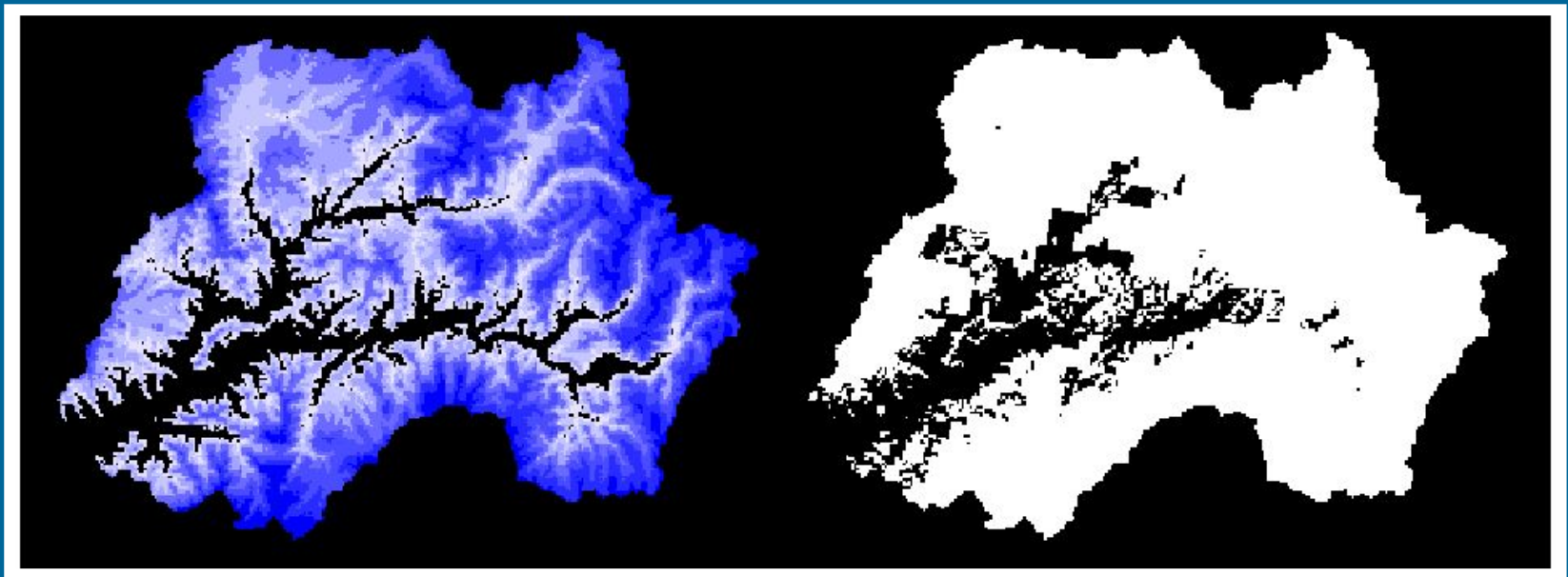
Boise River Simulated Snow Water Equivalent and Satellite Snow Covered Area (SCA) 21 April 1998



Snow Water Equivalent (mm)
- 1 - 150
- 151 - 300
- 301 - 450
- 451 - 600
- 601 - 750
- 751 - 900
- 901 - 1050
- 1051 - 1200
- 1201 - 1350
- 1351 - 1500
- 0

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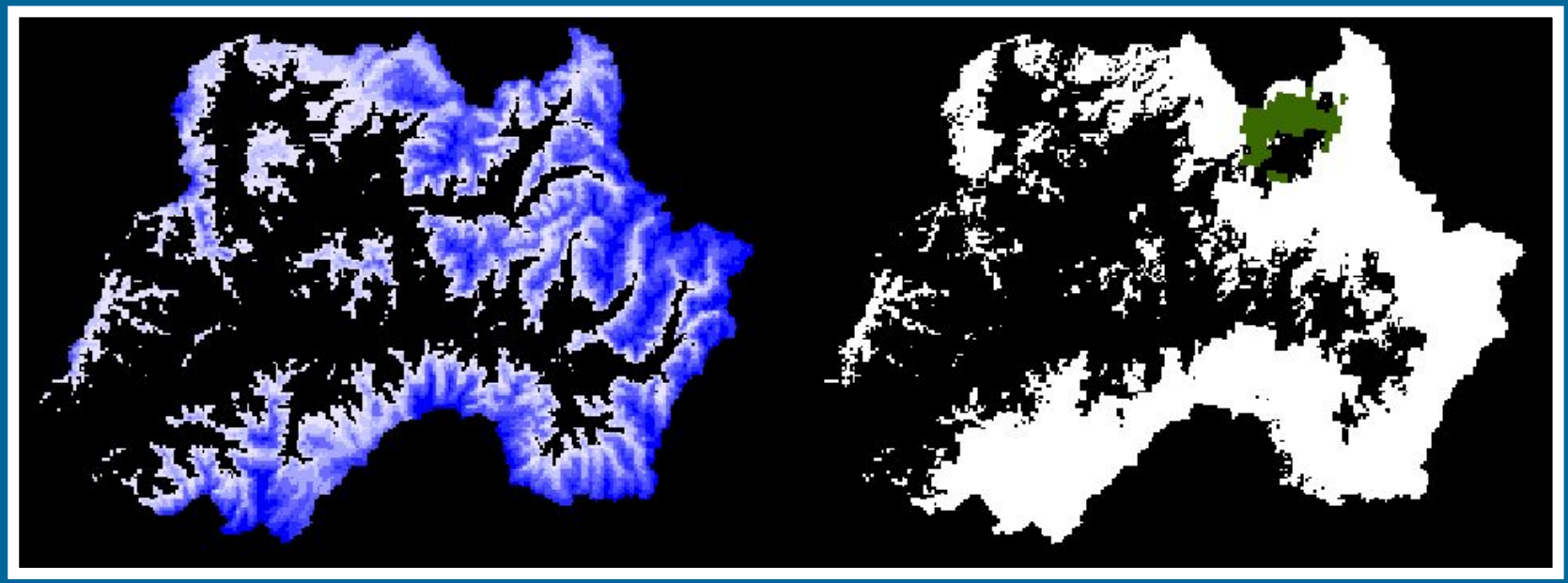
Boise River Simulated Snow Water Equivalent and Satellite Snow Covered Area (SCA) 7 May 1998



Snow Water Equivalent (mm)
- 1 - 150
- 151 - 300
- 301 - 450
- 451 - 600
- 601 - 750
- 751 - 900
- 901 - 1050
- 1051 - 1200
- 1201 - 1350
- 1351 - 1500
- 0

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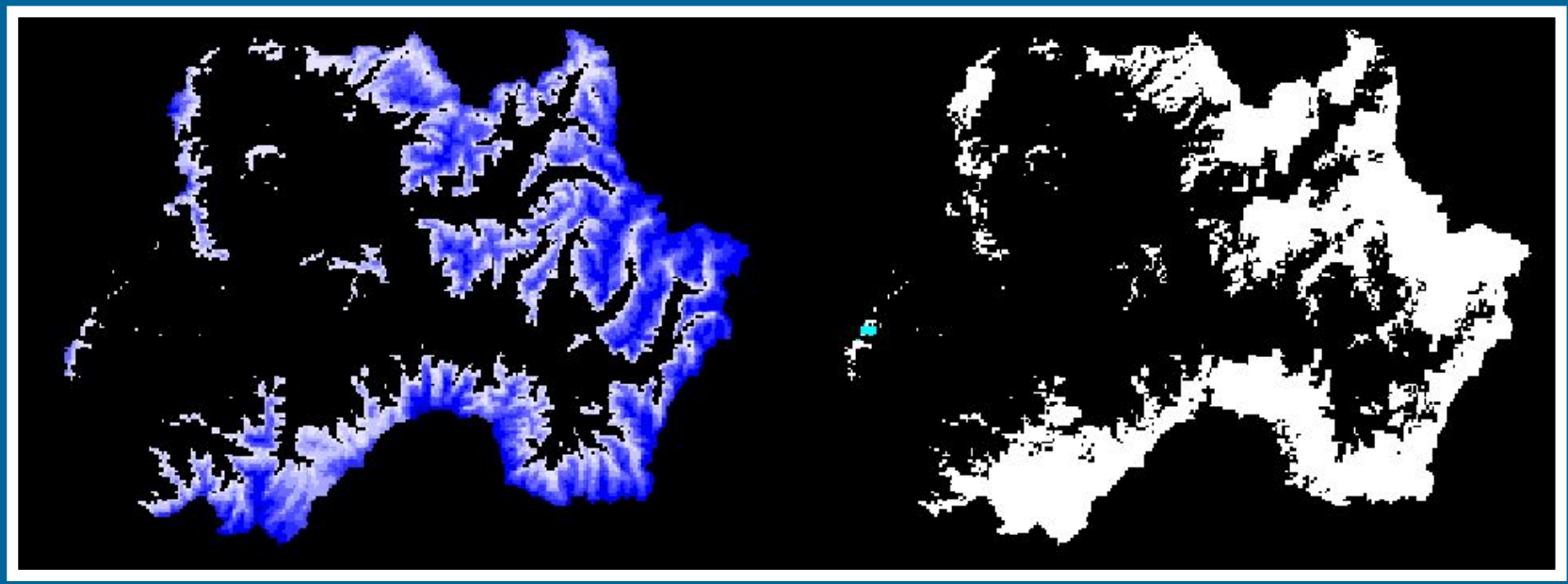
Boise River Simulated Snow Water Equivalent and Satellite Snow Covered Area (SCA) 21 May 1998



Snow Water Equivalent (mm)
- 1 - 150
- 151 - 300
- 301 - 450
- 451 - 600
- 601 - 750
- 751 - 900
- 901 - 1050
- 1051 - 1200
- 1201 - 1350
- 1351 - 1500
- 0

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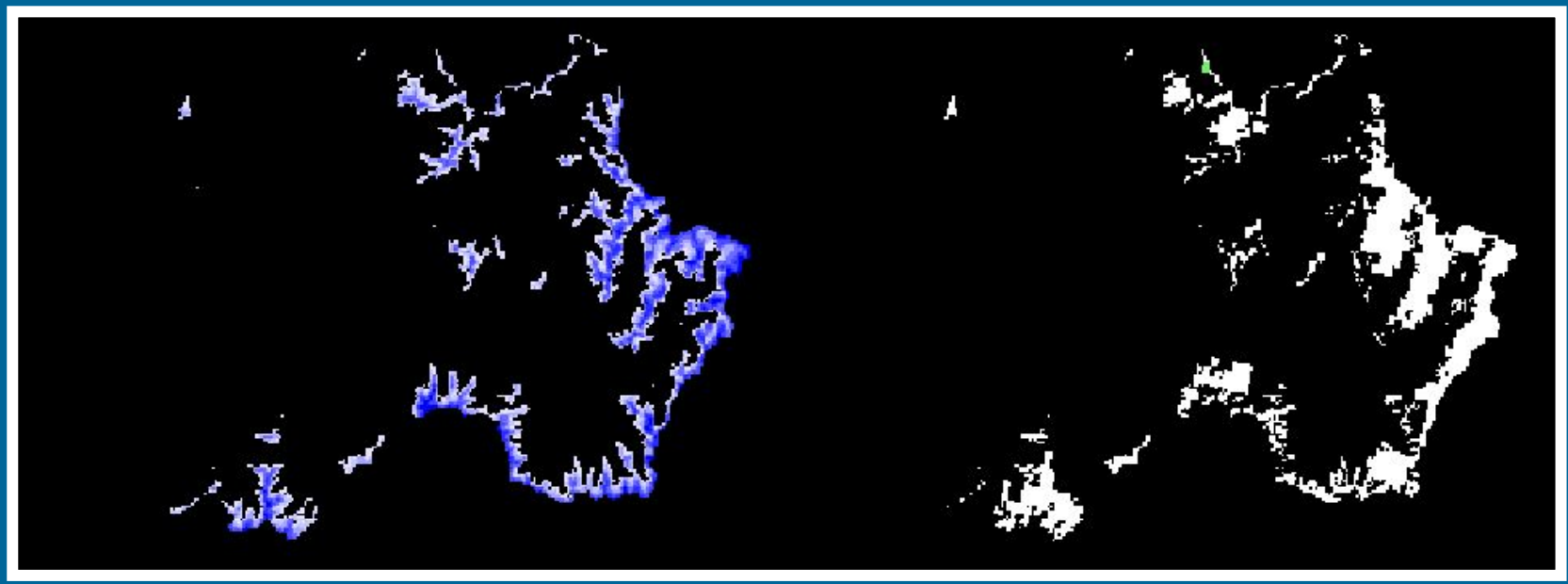
Boise River Simulated Snow Water Equivalent and Satellite Snow Covered Area (SCA) 29 June 1998



Snow Water Equivalent (mm)
- 1 - 150
- 151 - 300
- 301 - 450
- 451 - 600
- 601 - 750
- 751 - 900
- 901 - 1050
- 1051 - 1200
- 1201 - 1350
- 1351 - 1500
- 0

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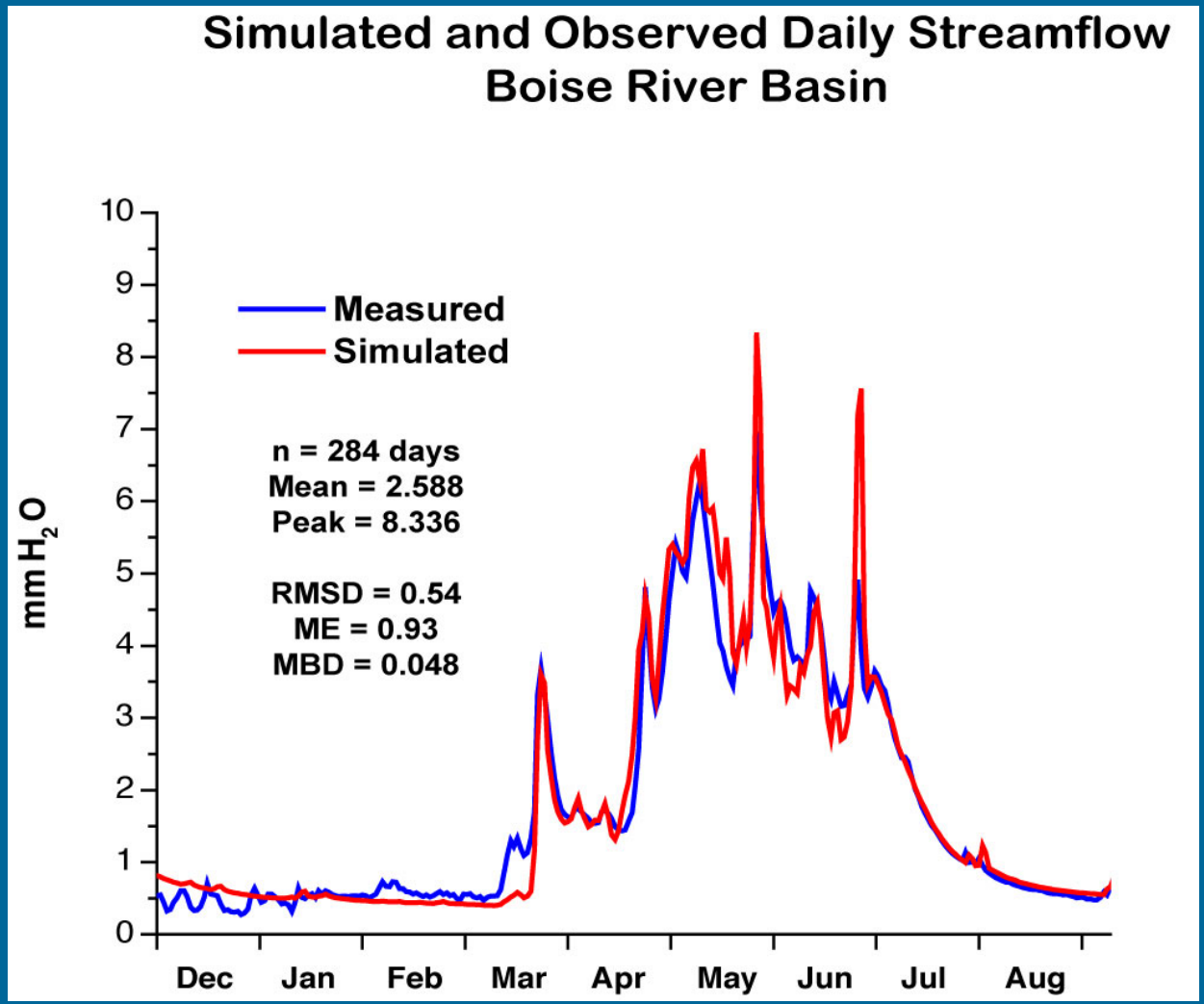
Boise River Streamflow Simulation
Water Year 1998



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Comparing sensible and latent heat fluxes over snow along a North American Cordilleran Transect

DANNY MARKS & John Pomeroy

Students:

Michele Reba (U of I)

Warren Helgason (U of S)

Dan Bewley (U of Wales)

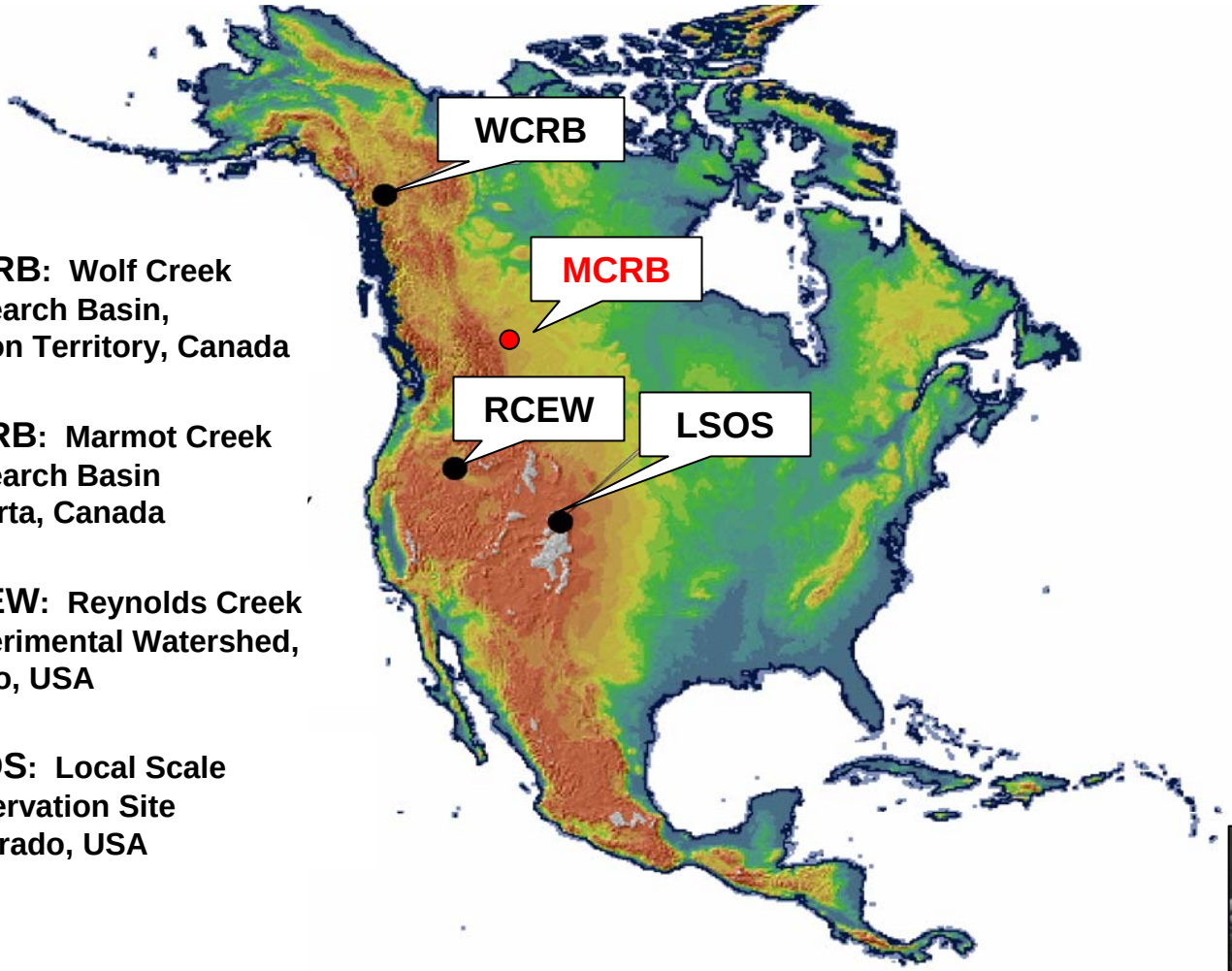
Northwest Watershed Research Center

USDA-Agricultural Research Service

Boise, Idaho

USA

GAPP North American Cordilleran Transect

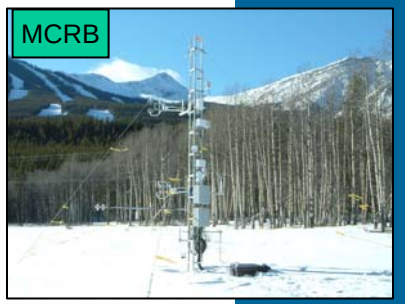


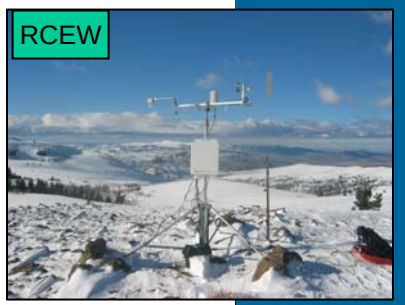
WCRB: Wolf Creek Research Basin, Yukon Territory, Canada

MCRB: Marmot Creek Research Basin Alberta, Canada

RCEW: Reynolds Creek Experimental Watershed, Idaho, USA

LSOS: Local Scale Observation Site Colorado, USA





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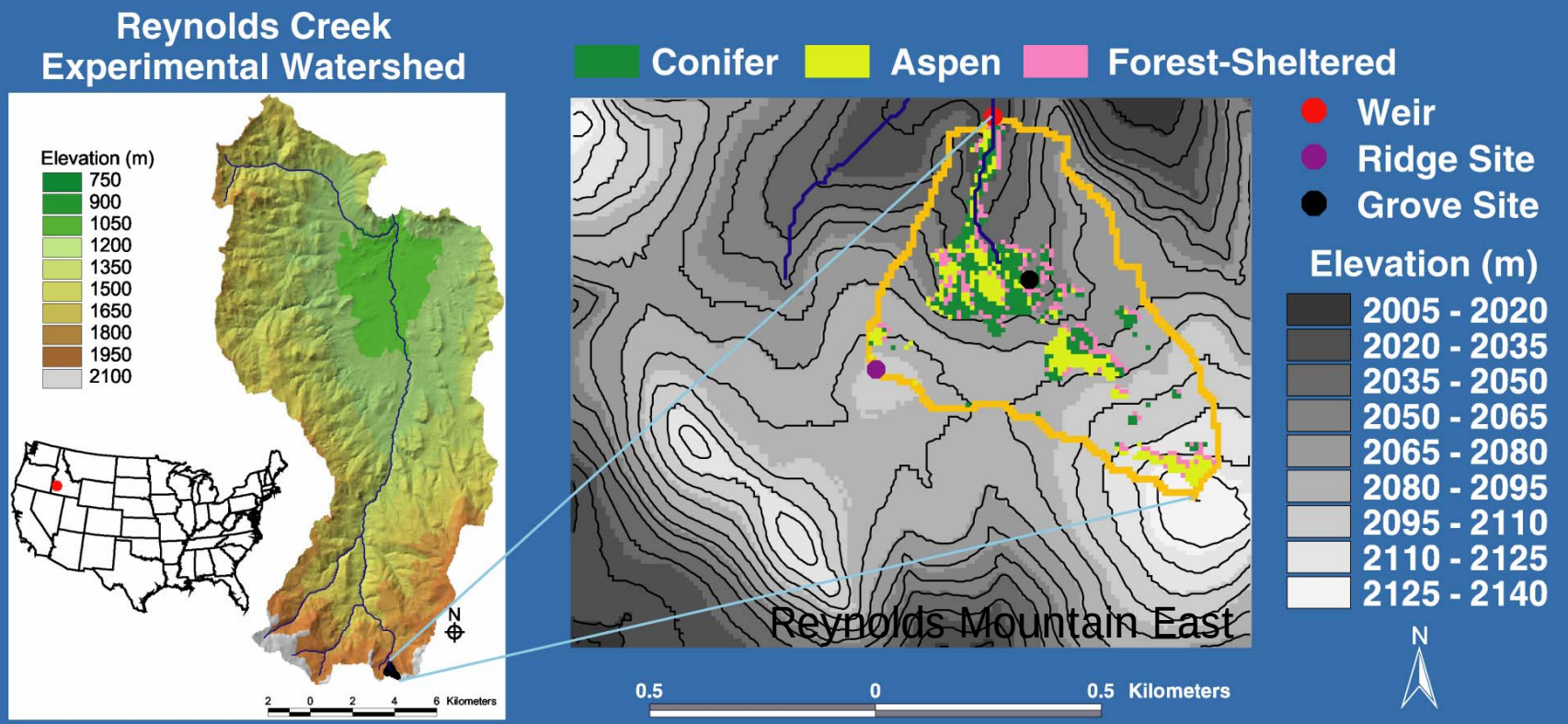
RME Study Site



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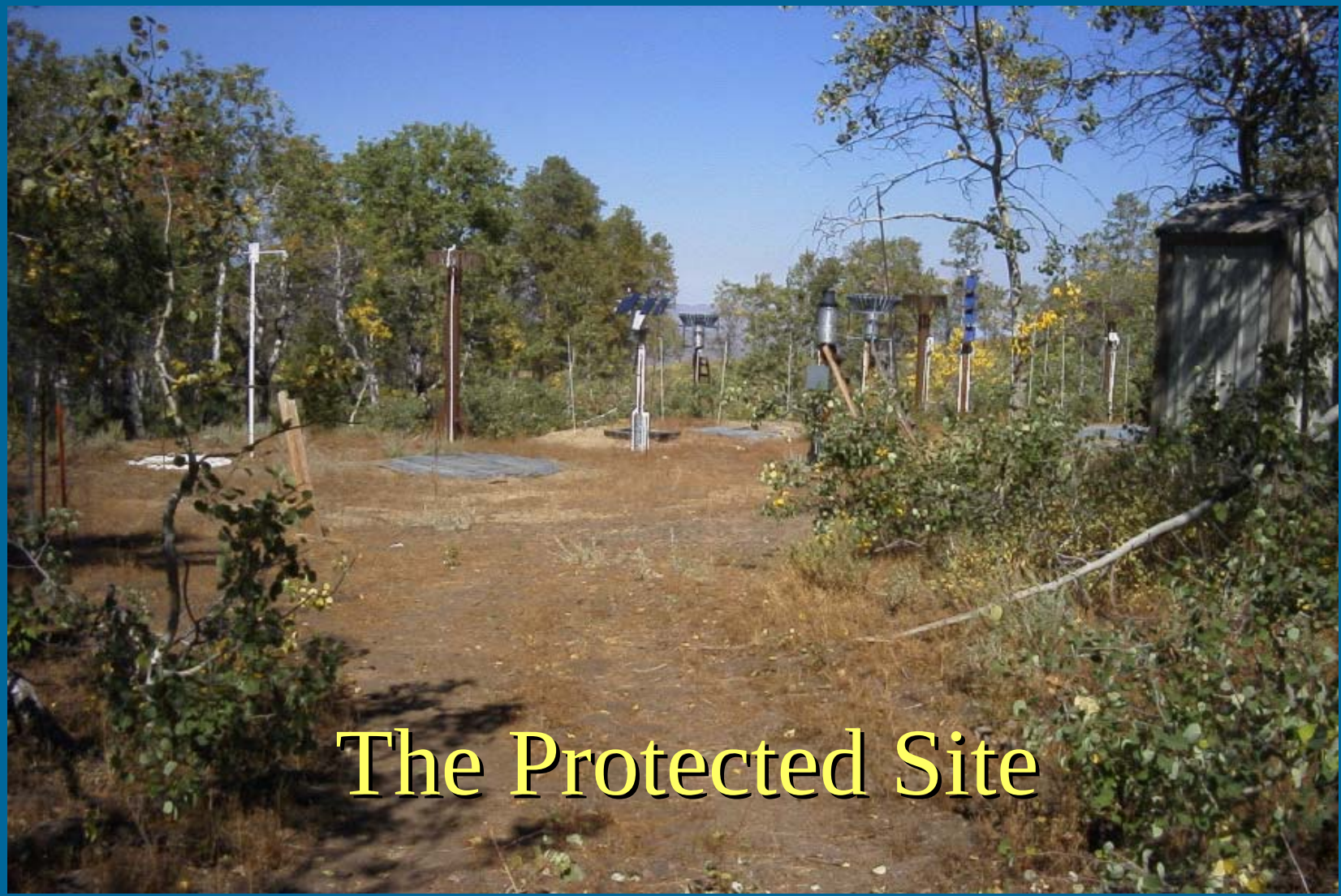
The Grove



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The Ridge

The Exposed Site

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Exposed Site

Protected Site

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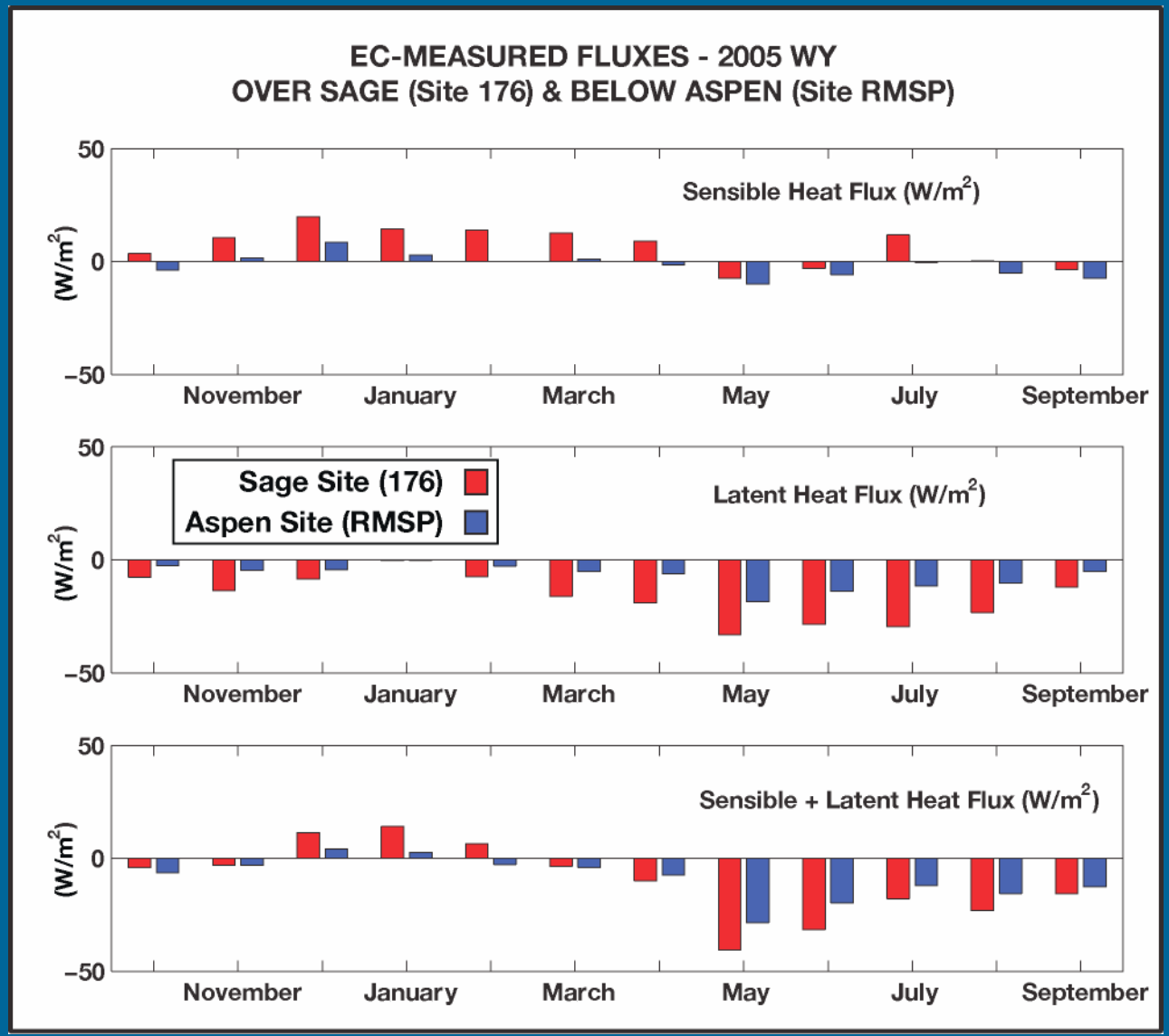
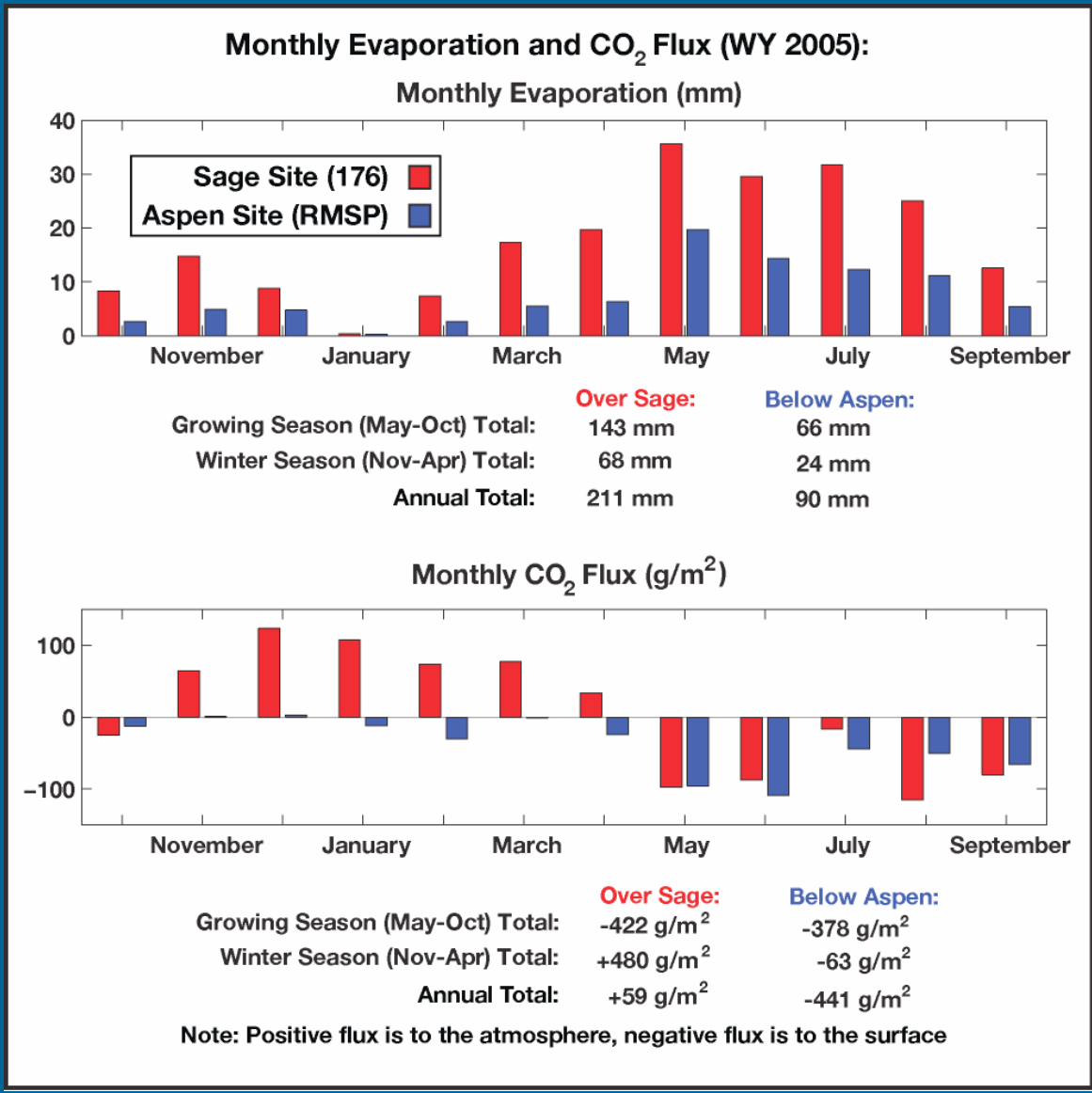
WY 2005 Monthly EC-Measured H & L_vE Over Sage and Below Aspen:



WY 2005 Monthly EC-Measured CO_2 & ET Over Sage and Below Aspen:



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Preliminary Conclusions

- First full-year measurements of evaporation/transpiration
  - ~33% (211 mm) of 2005 deposition (630 mm) lost to ET over sage
  - ~10% (90 mm) of 2005 deposition (879 mm) lost to ET below aspen

- First measurements of Carbon flux
  - Sage site close to balance, but lost carbon to atmosphere
  - Below aspen site took carbon from the atmosphere
  - Critical to get Above Aspen Data

- Data only for 2005 water year; add 2004 & 2006 data

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Scale effects on snowcover accumulation and melt modelling:

Determining the minimum complexity required to capture essential features of snowmelt over large regions with complex terrain

DANNY MARKS

PhD project, ADAM WINSTRAL
(University of Reading, UK)

Northwest Watershed Research Center
USDA-Agricultural Research Service
Boise, Idaho
USA

Scaling Issues

- Distributing Forcing Data Over Large Areas
  - Orography (Pacific NW & BC - ROS events)
    - Mixed phase precipitation events: Rain vs Snow
    - Dew point temperature as an indicator of phase
  - Terrain & canopy-induced variability
- Linkages between forcing & energy state
- Measurement & Validation

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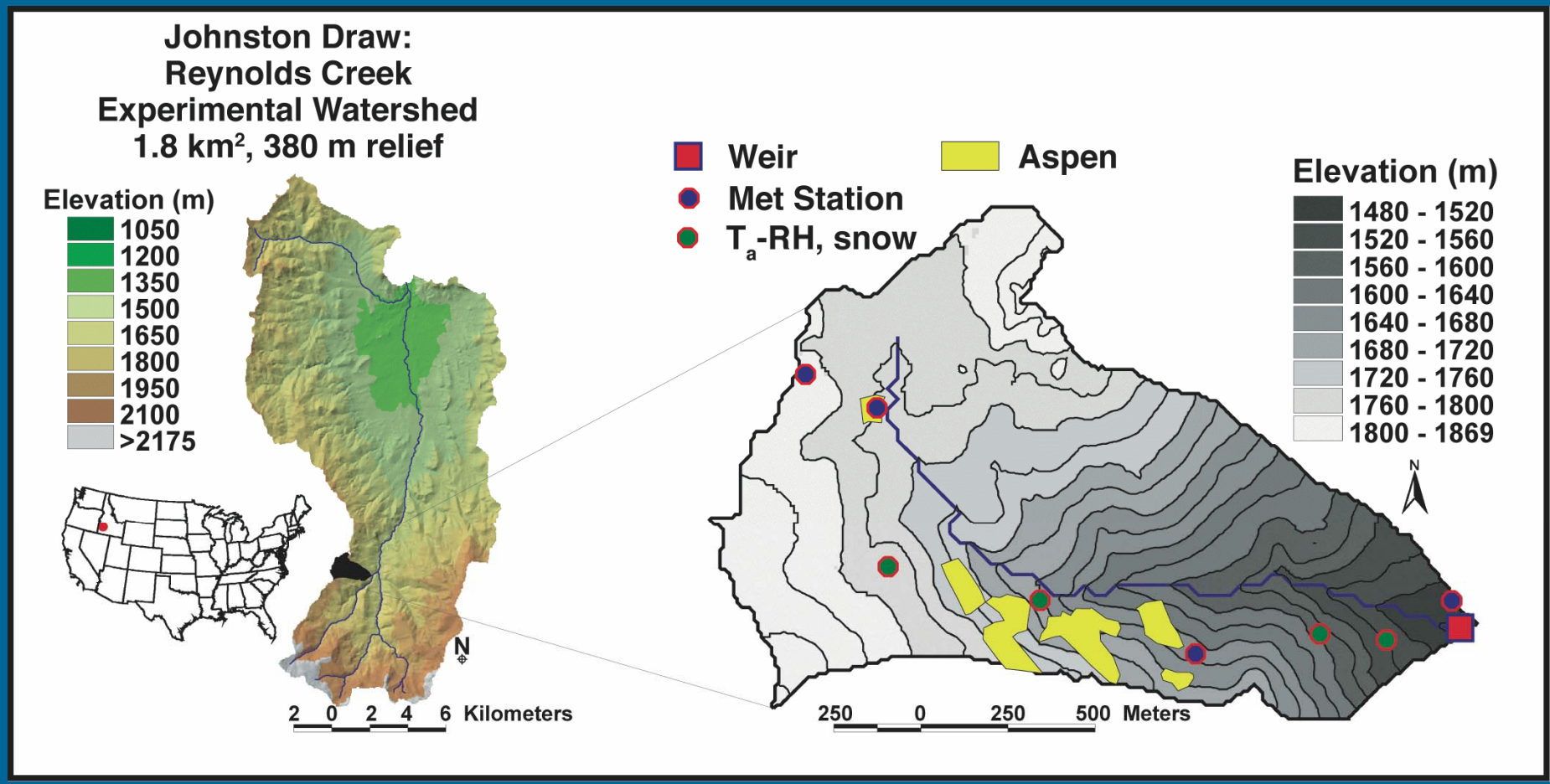
Johnston Draw Study Catchment
(1.8 km^2 , 380 m relief)



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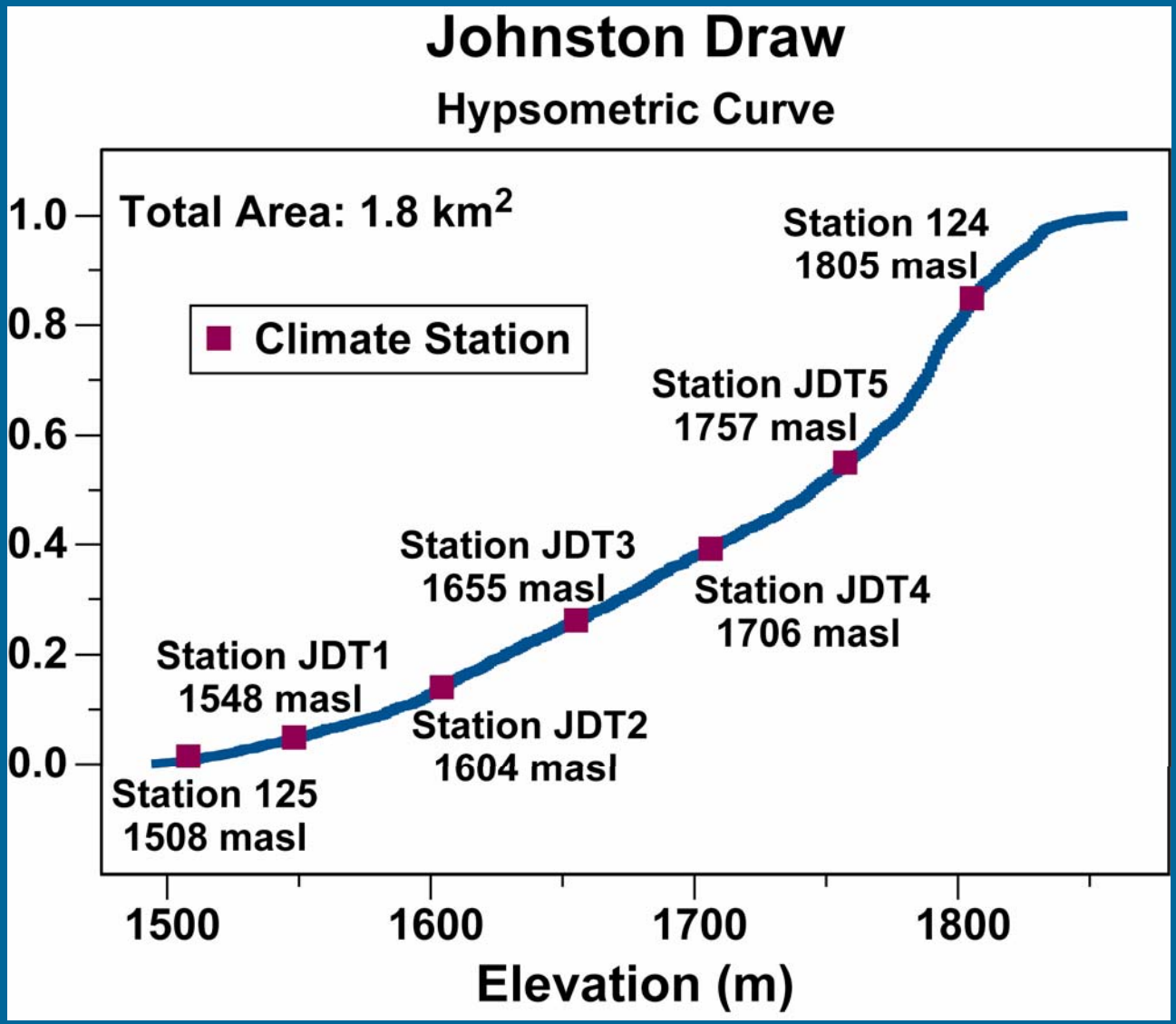

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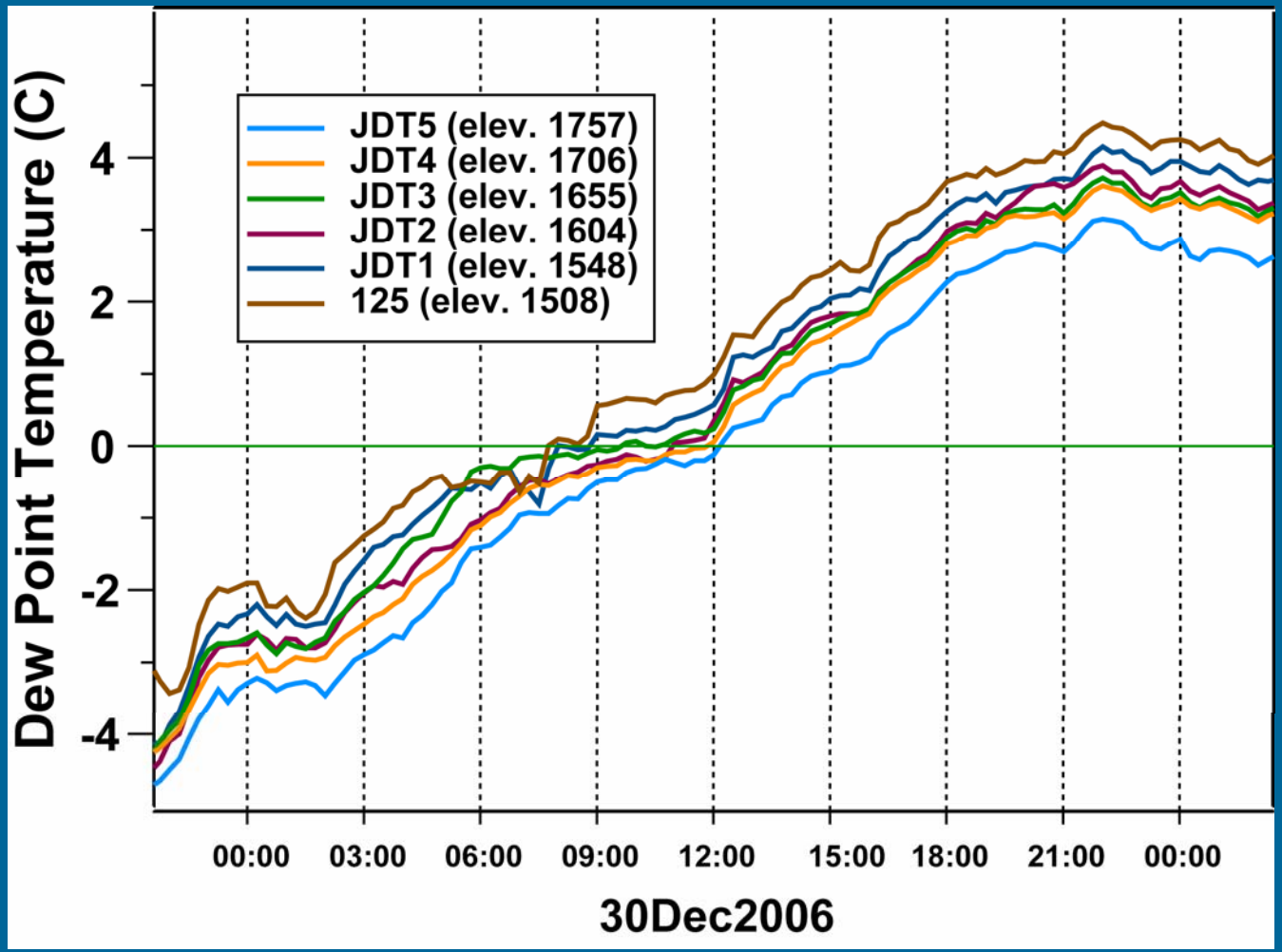

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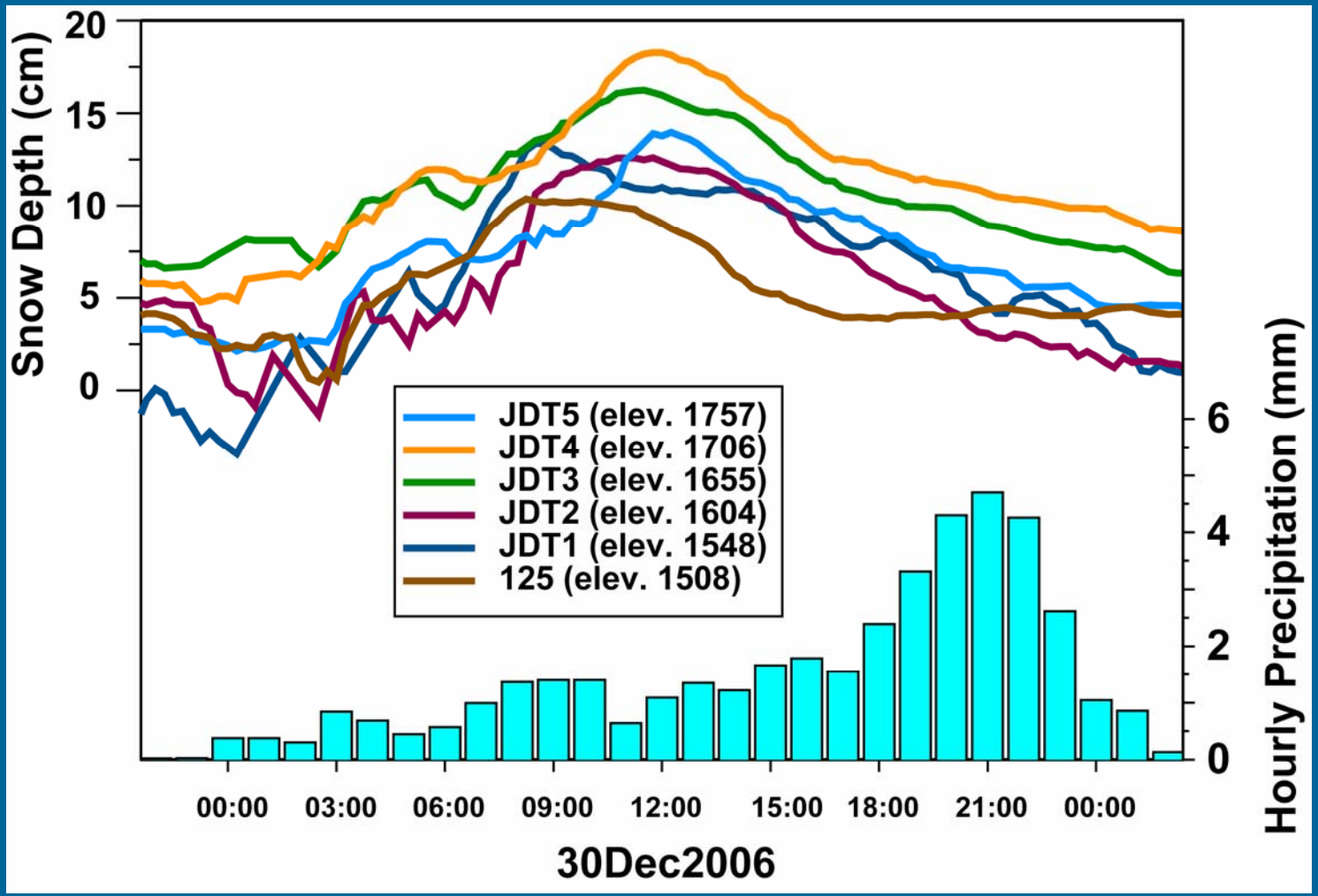

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Preliminary Conclusions

- Dew Point Temperature is a reliable predictor of precipitation phase.
- Need second year of data, and additional events for validation
- Need data from additional sites (Klamath River basin, Oregon; BC?)
- Summer Precipitation (Kananaskis, Wolf Creek)

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A Scalable Shading Model for Radiation at the Forest Floor, using LiDAR-derived Canopy Parameters

Richard Essery

(University of Wales, Aberystwyth)

Danny Marks

(USDA-ARS Northwest Watershed Research Center)

See: Essery, Bunting, Hardy, Link, Marks, Melloh, Pomeroy, Rowlands and Rutter, 2007, in review, *Journal of Hydrometeorology;*

Pomeroy, Rowlands, Hardy, Link, Marks, Essery, Sicart and Ellis,

2007, in review, *Journal of Hydrometeorology*

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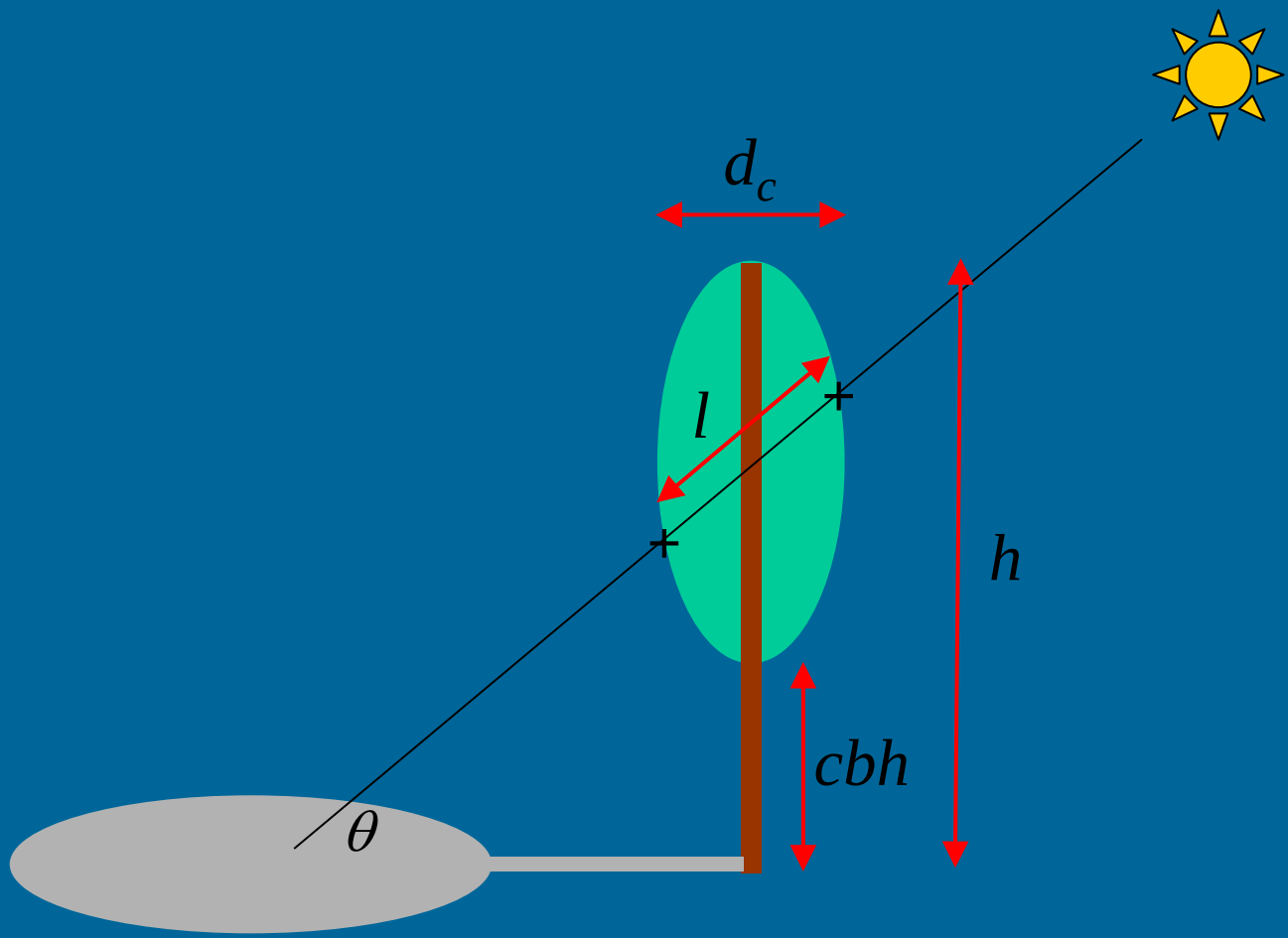
Geometric shading model



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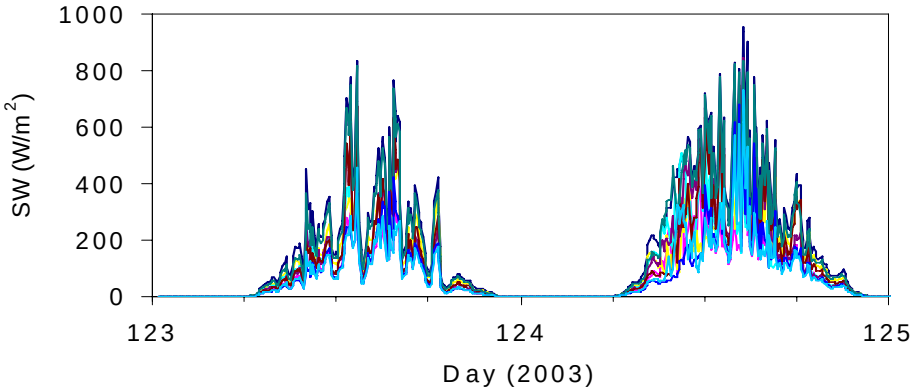
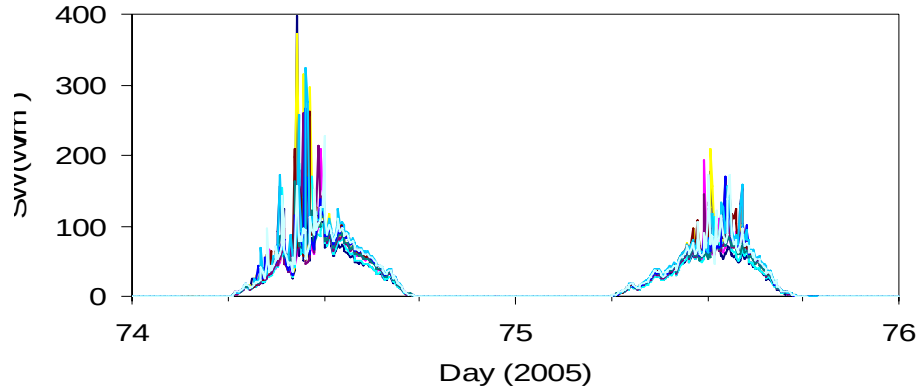
Solar Radiation to Snow beneath Shrubs and Trees

Tall Shrubs, Wolf Creek

Marmot Creek level forest

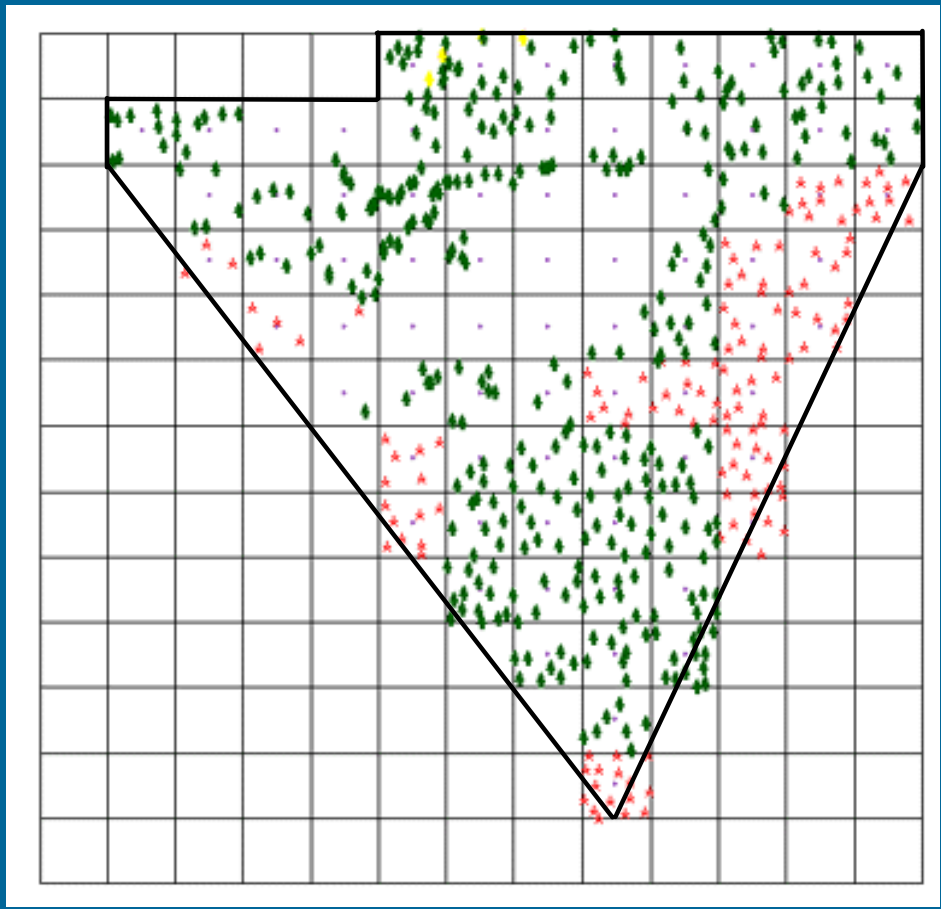




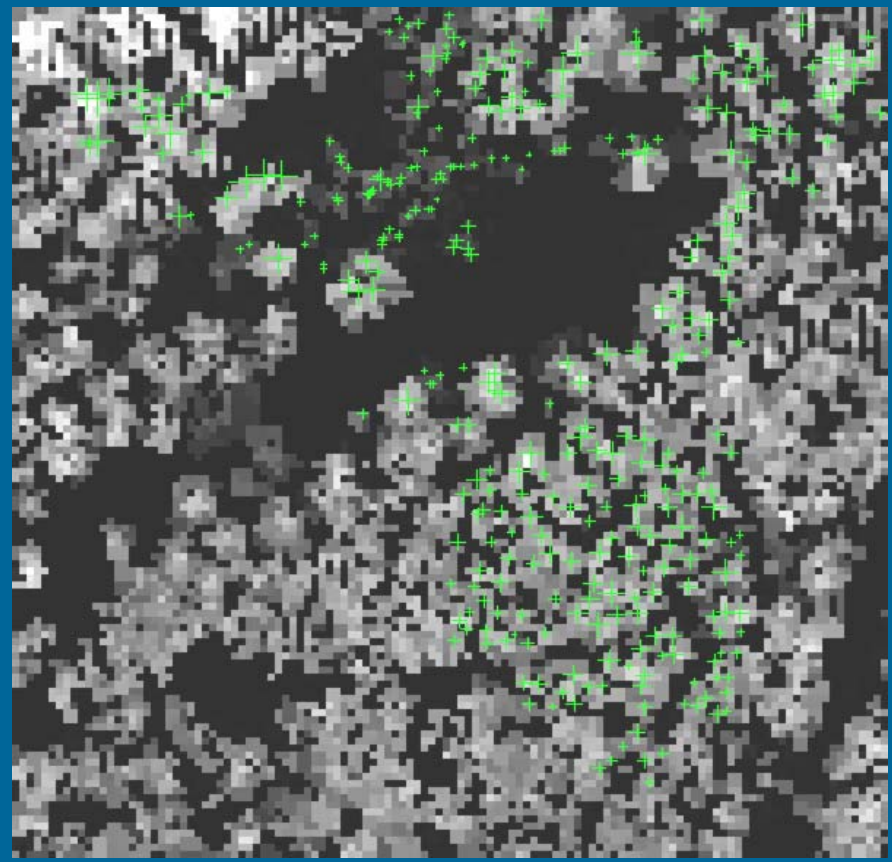
See: Pomeroy, *et al.*, in review, 2007, *Journal of Hydrometeorology;*
Bewley *et al.*, 2007, in press, *Arctic, Antarctic and Alpine Research;*

Link, Marks and Hardy, 2004, *Hydrological Processes*

Inventory map



LiDAR + tree map



100 m

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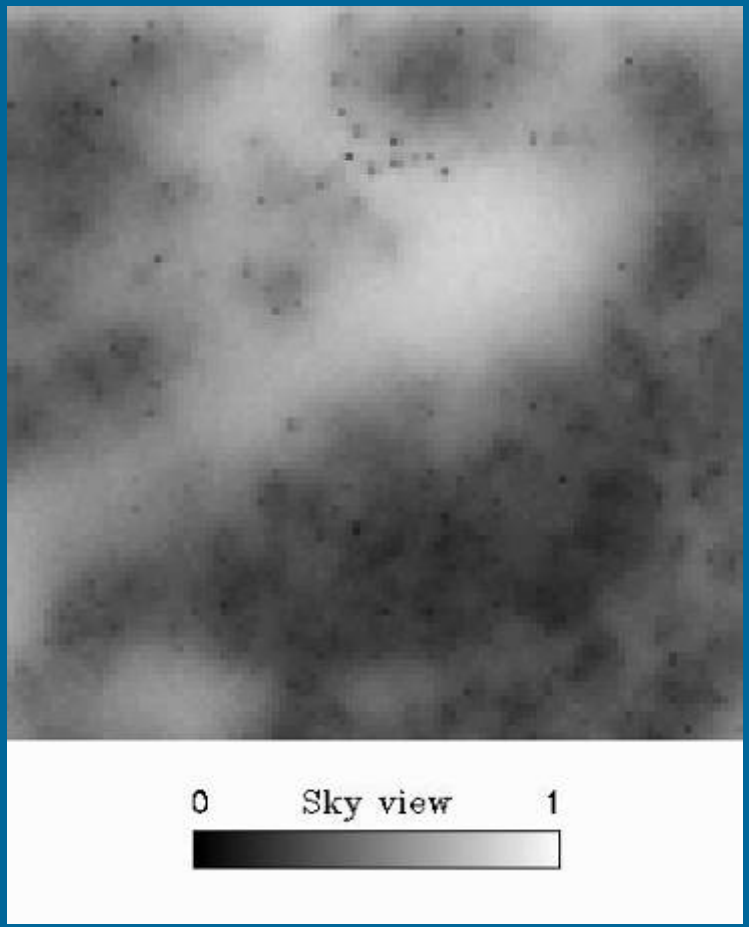
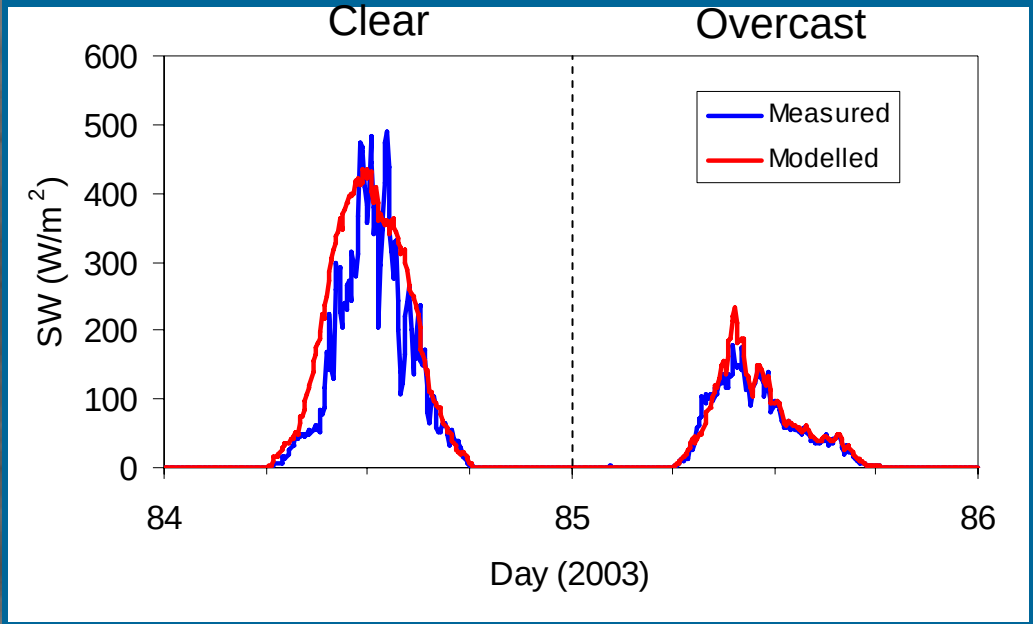
Stand Scale Modelling of Solar Radiation

Simulated sky view

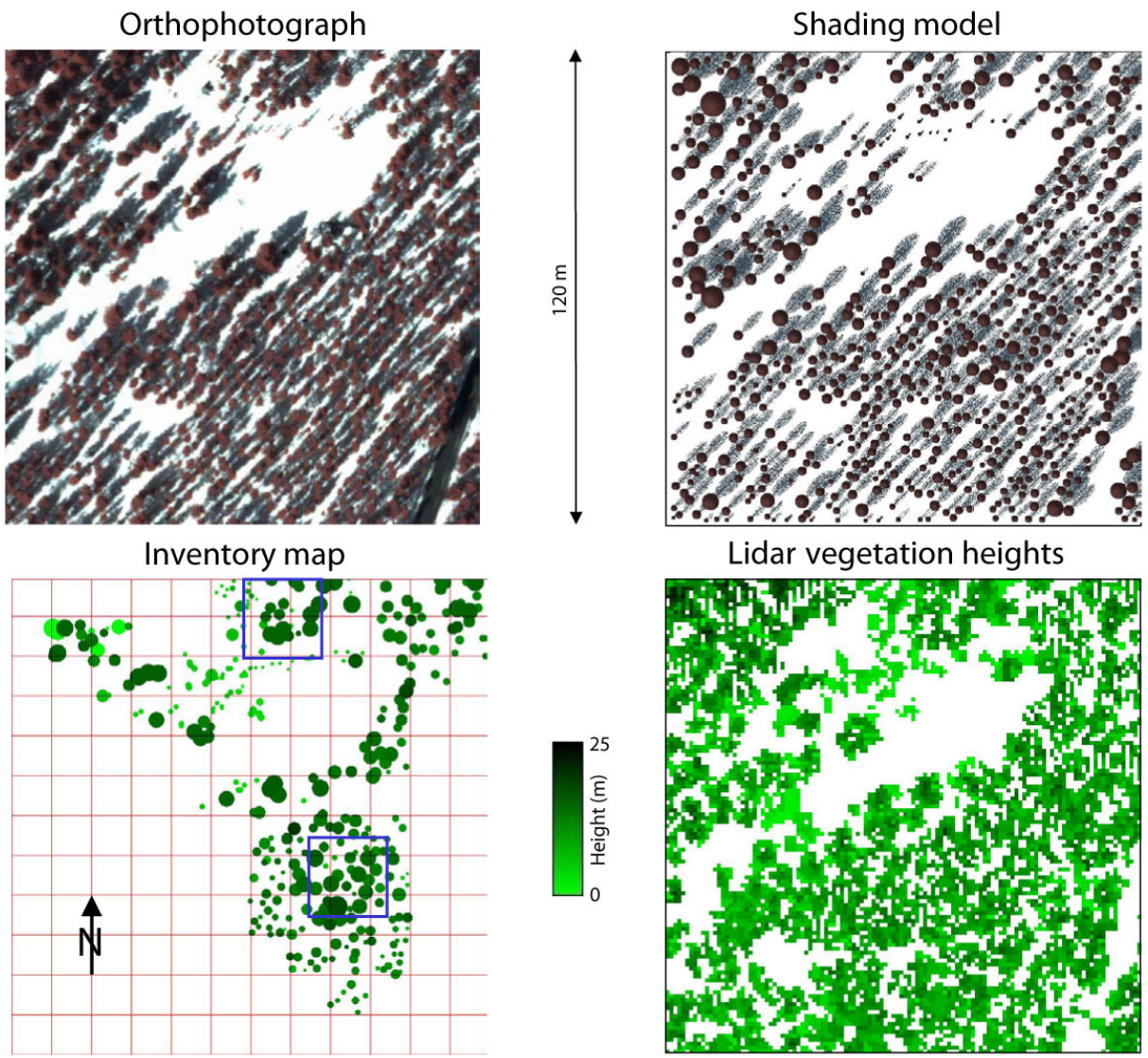


Simulated sky view



Essery *et al.* (2007). In review for *Journal of Hydrometeorology*.

Fine Scale Modelling of Sub-alpine Solar Radiation



Essery *et al.* (2007). In review for *Journal of Hydrometeorology*.

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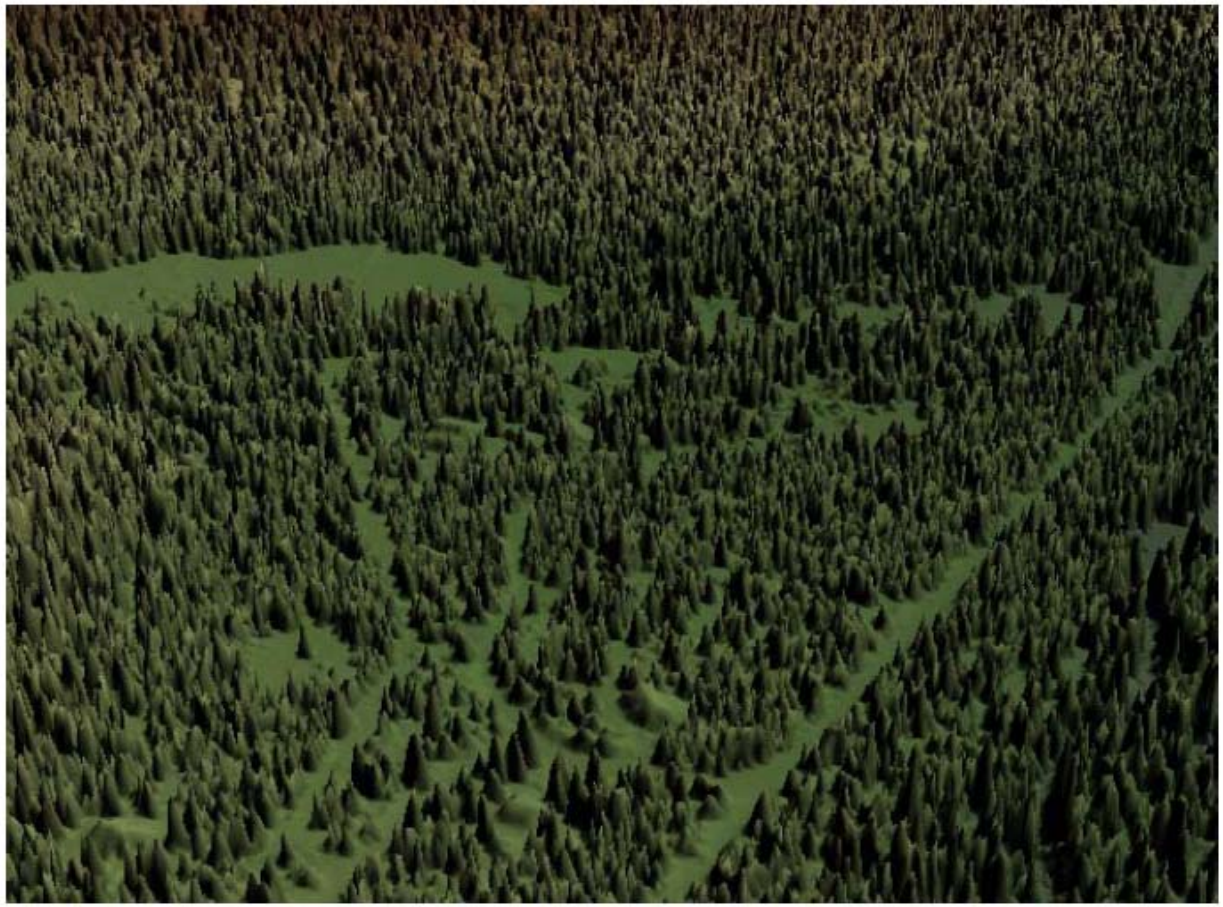
LiDAR Forest CSM & DEM Characterization



Pomeroy, *et al.*, in review, 2007, *Journal of Hydrometeorology;*
Essery *et al.* (2007). In review for *Journal of Hydrometeorology*

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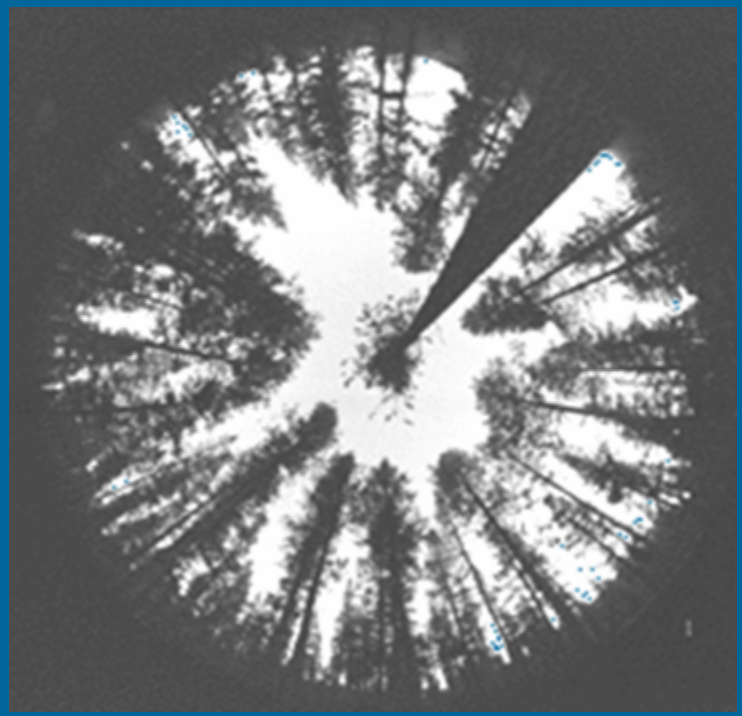
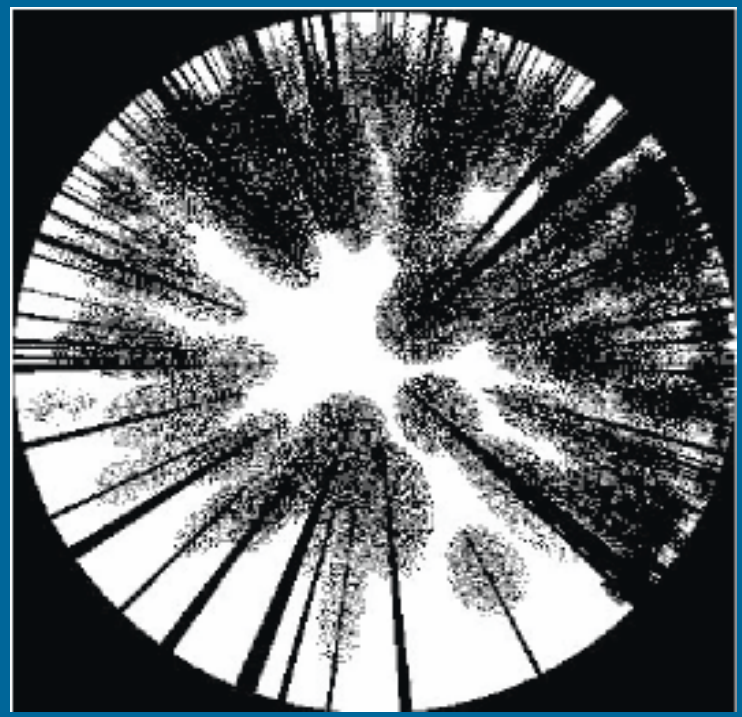
Sky view

From hemispherical photographs



From LiDAR shading model



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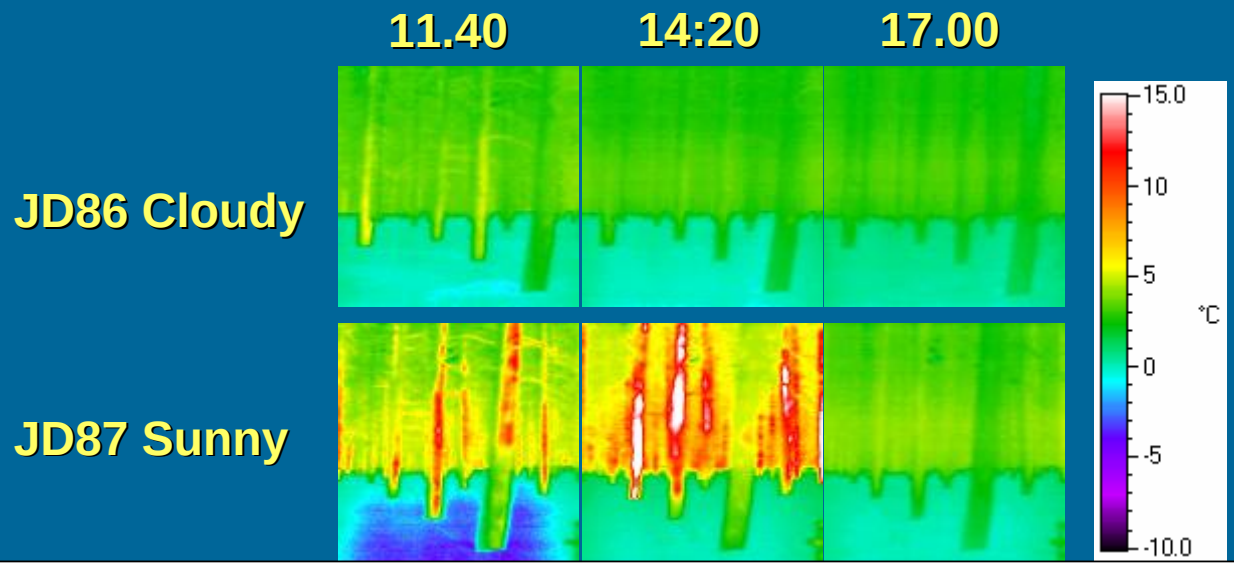
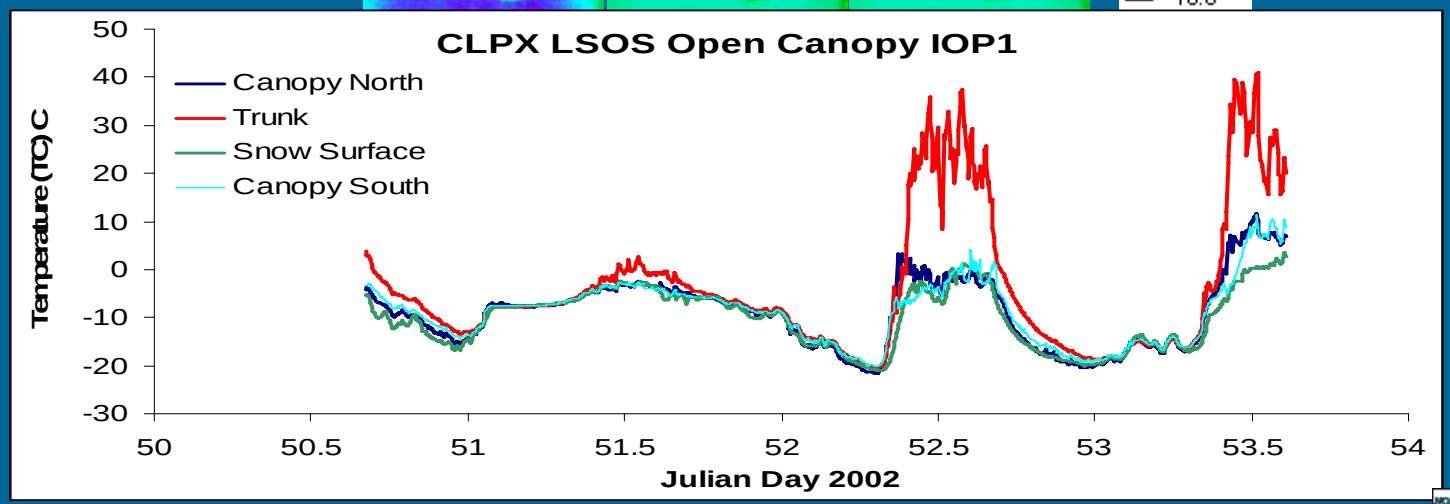
The Longwave Radiation Problem:

Hot Canopy and Trunks Increase Forest Longwave Radiation





Pomeroy, Marks, Ellis, *et al.*, 2007, in prep, *Hydrological Processes*

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