California's water cycle: climate, snowpack & forest management

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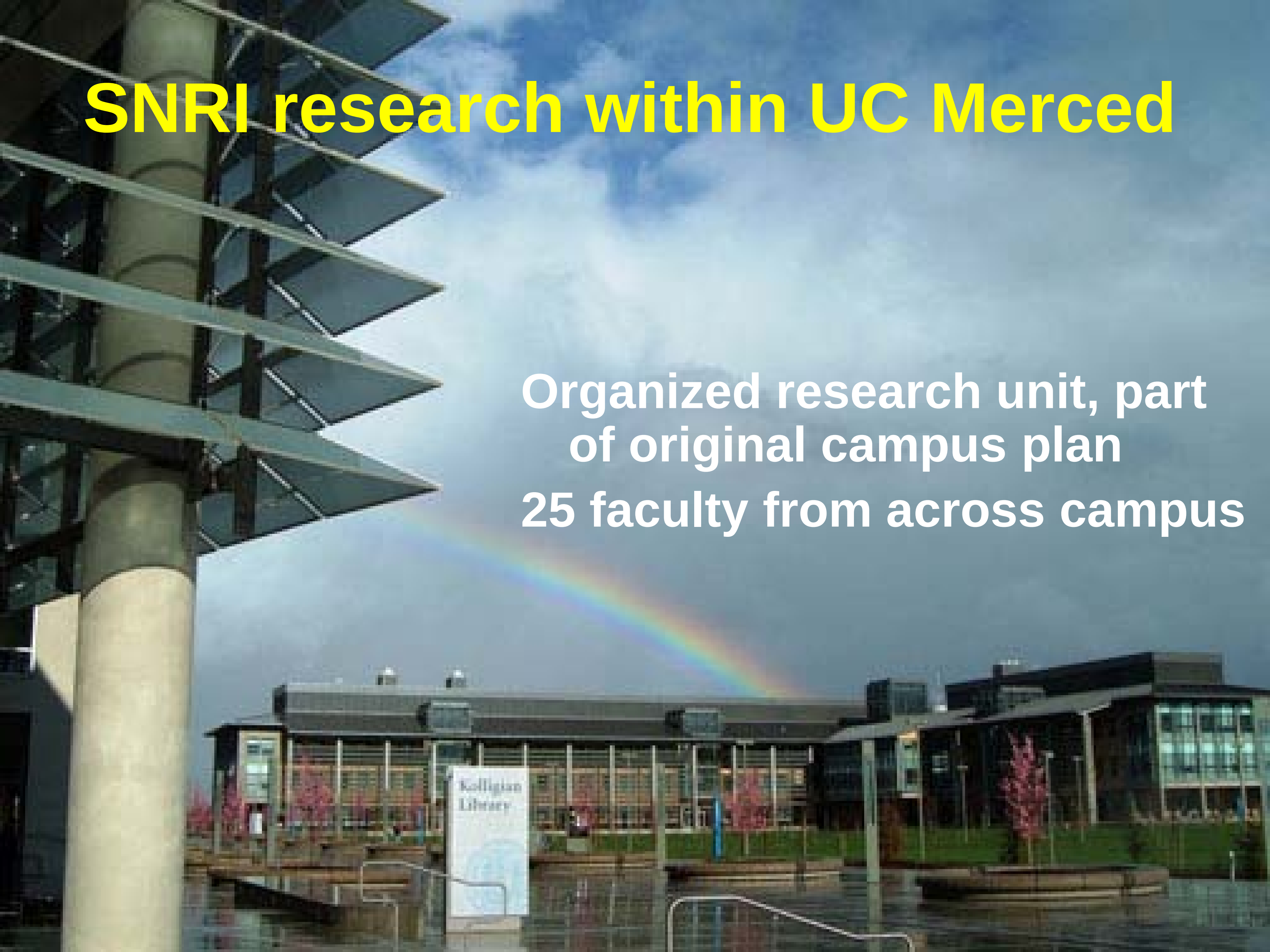
SNRI mission

- Foster interdisciplinary research in the Sierra Nevada & Central Valley eco-region
- Facilitate synergistic links between science, the arts, education & natural resource management.

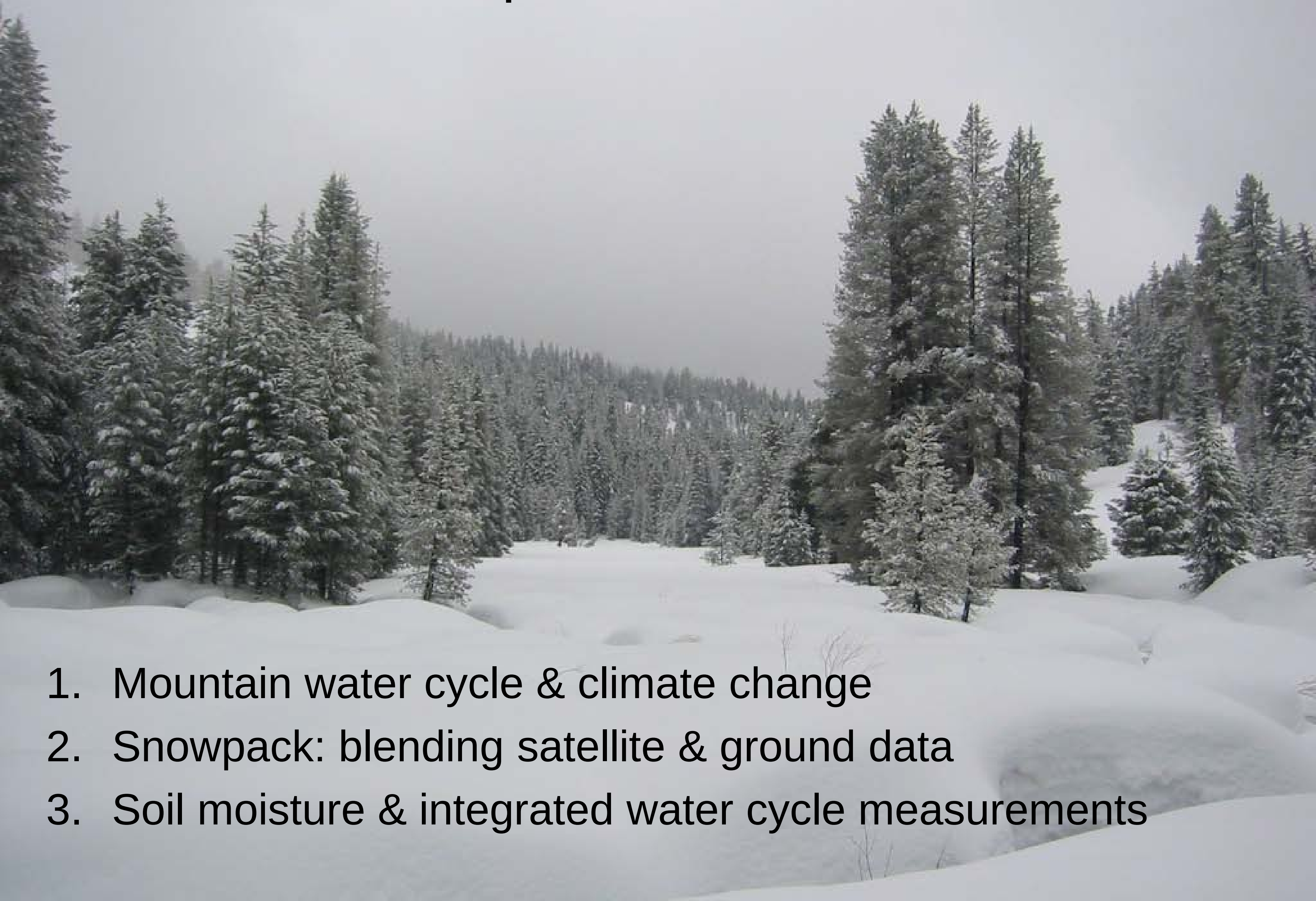
SNRI research within UC Merced

- Organized research unit, part of original campus plan
- 25 faculty from across campus



SNRI research themes

Topics in this talk



1. Mountain water cycle & climate change
2. Snowpack: blending satellite & ground data
3. Soil moisture & integrated water cycle measurements

Relevant climate basics

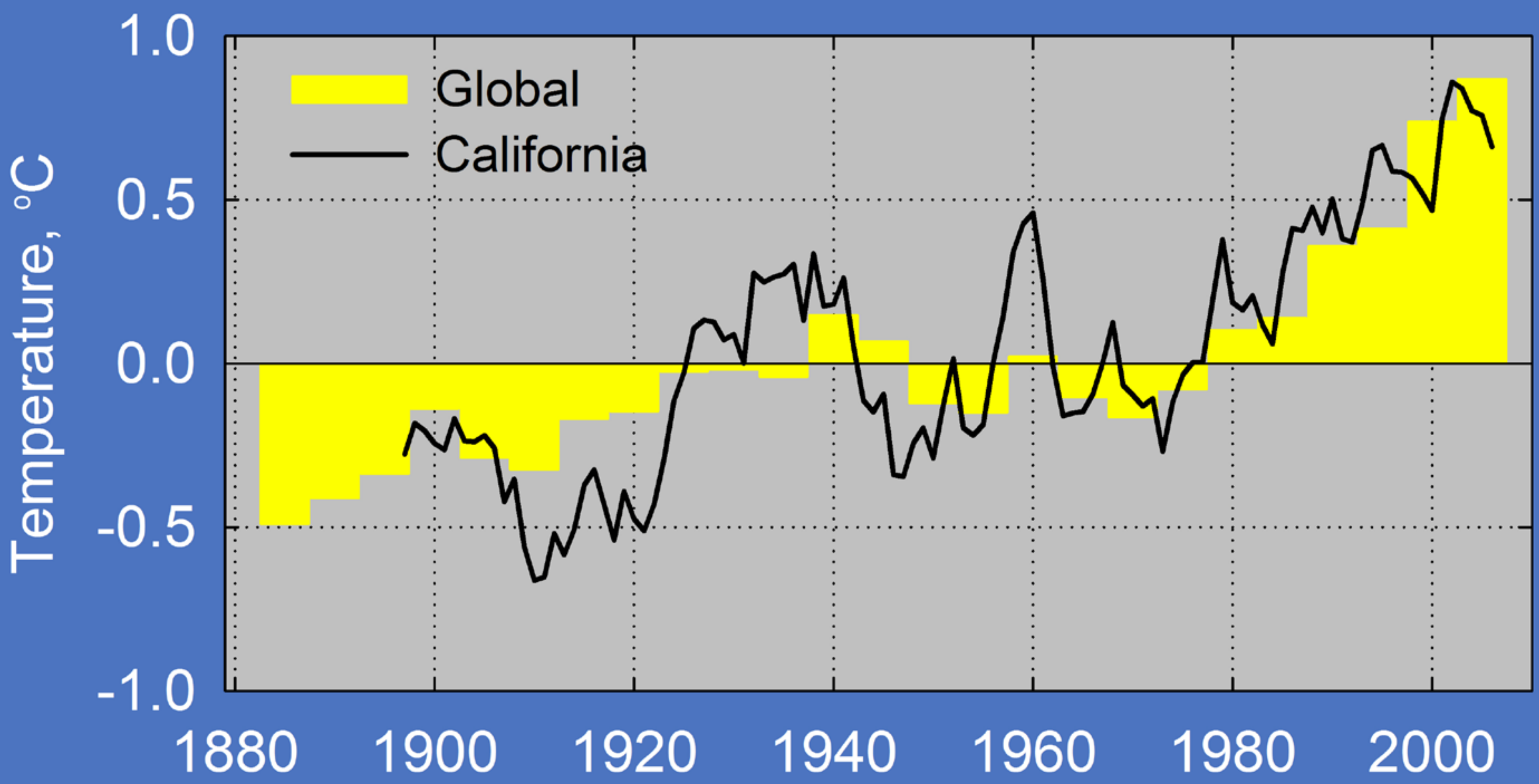
California's temperature increases are part of a global trend

Projections of future increases may be too low

The effects of temperature changes on the mountain/forest water cycle – snow vs. rain, soil moisture, evapotranspiration – go beyond historical levels

The water cycle in California's mountains is undergoing long-term shifts.

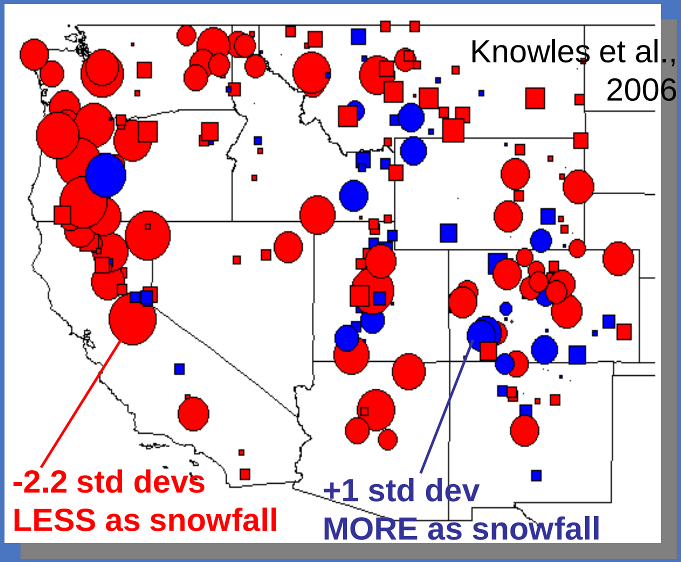
California has been warming in recent decades



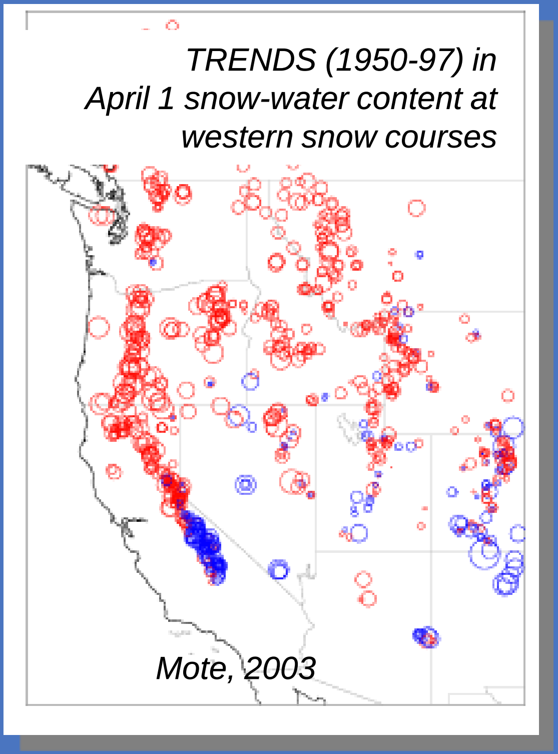
Land surface temperatures
5-yr average departure from 1901-2000 mean

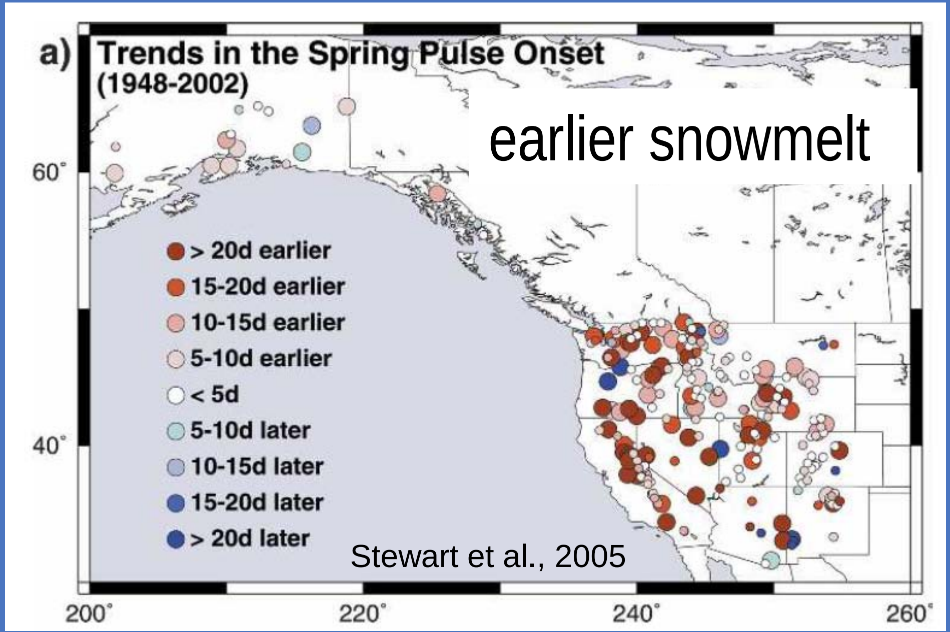
Observed changes in water cycle

less snow/more rain

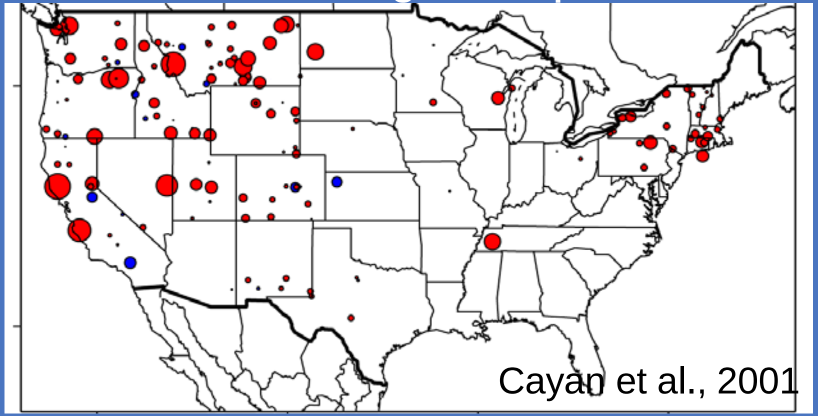


less spring snowpack

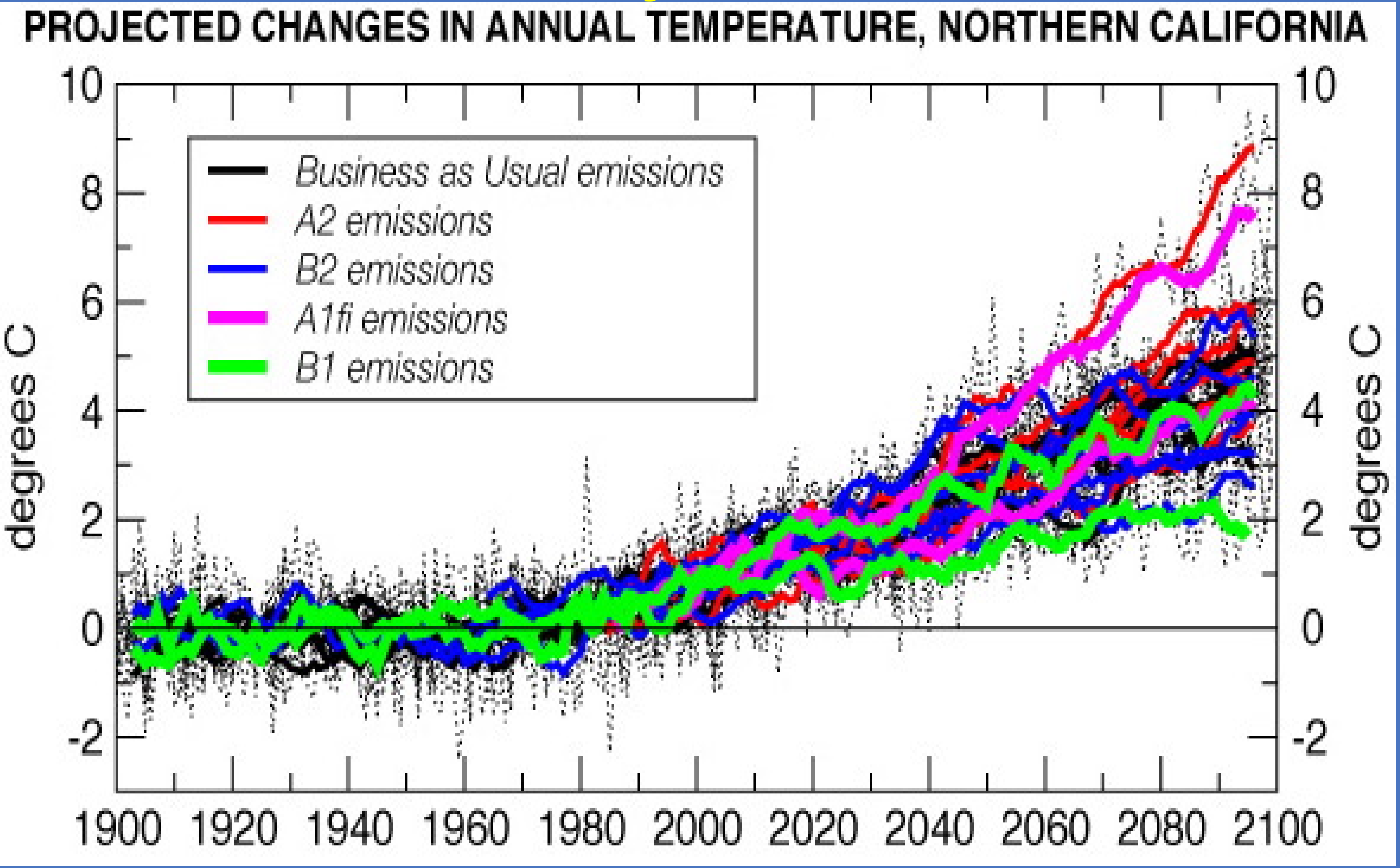




earlier greenup

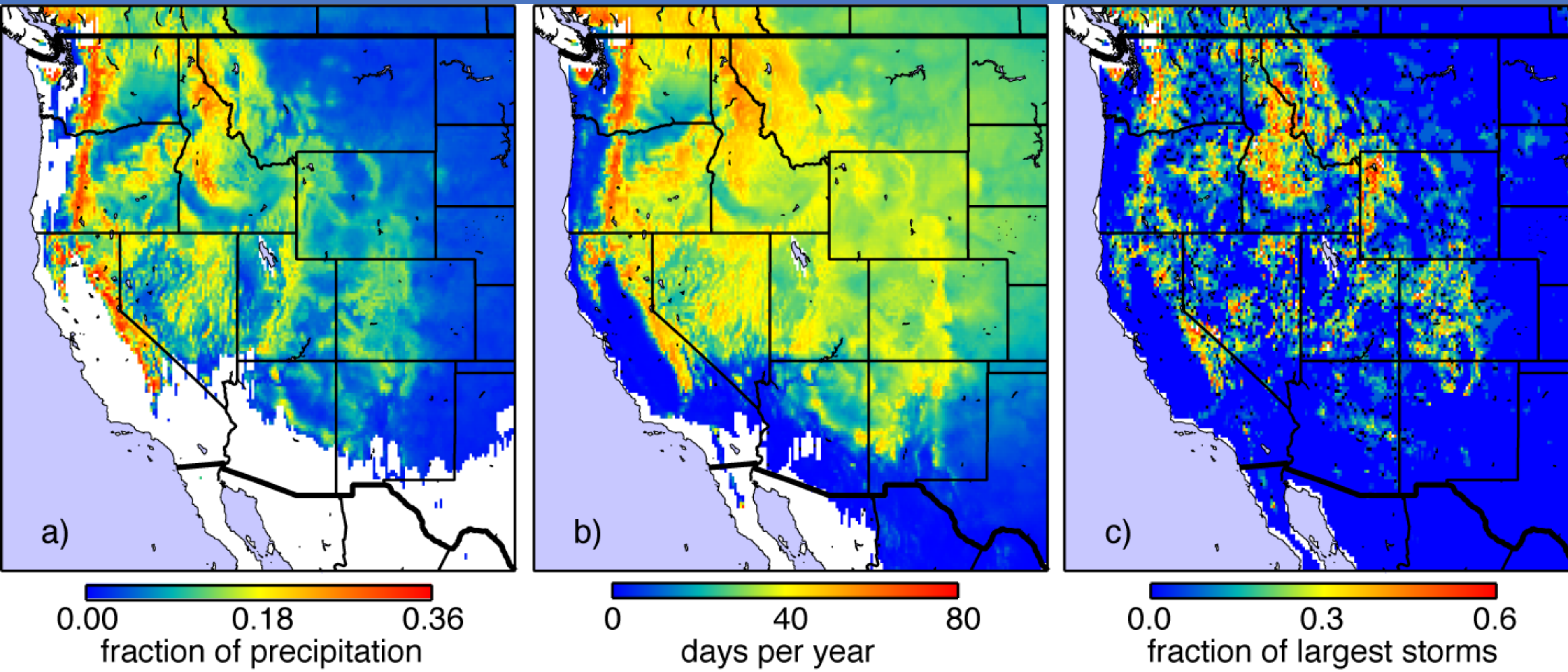


Projections & effect on water cycle



Influence of +3^{o}C on SNOW vs RAIN

More rain, less snow | Earlier snowmelt | More winter floods

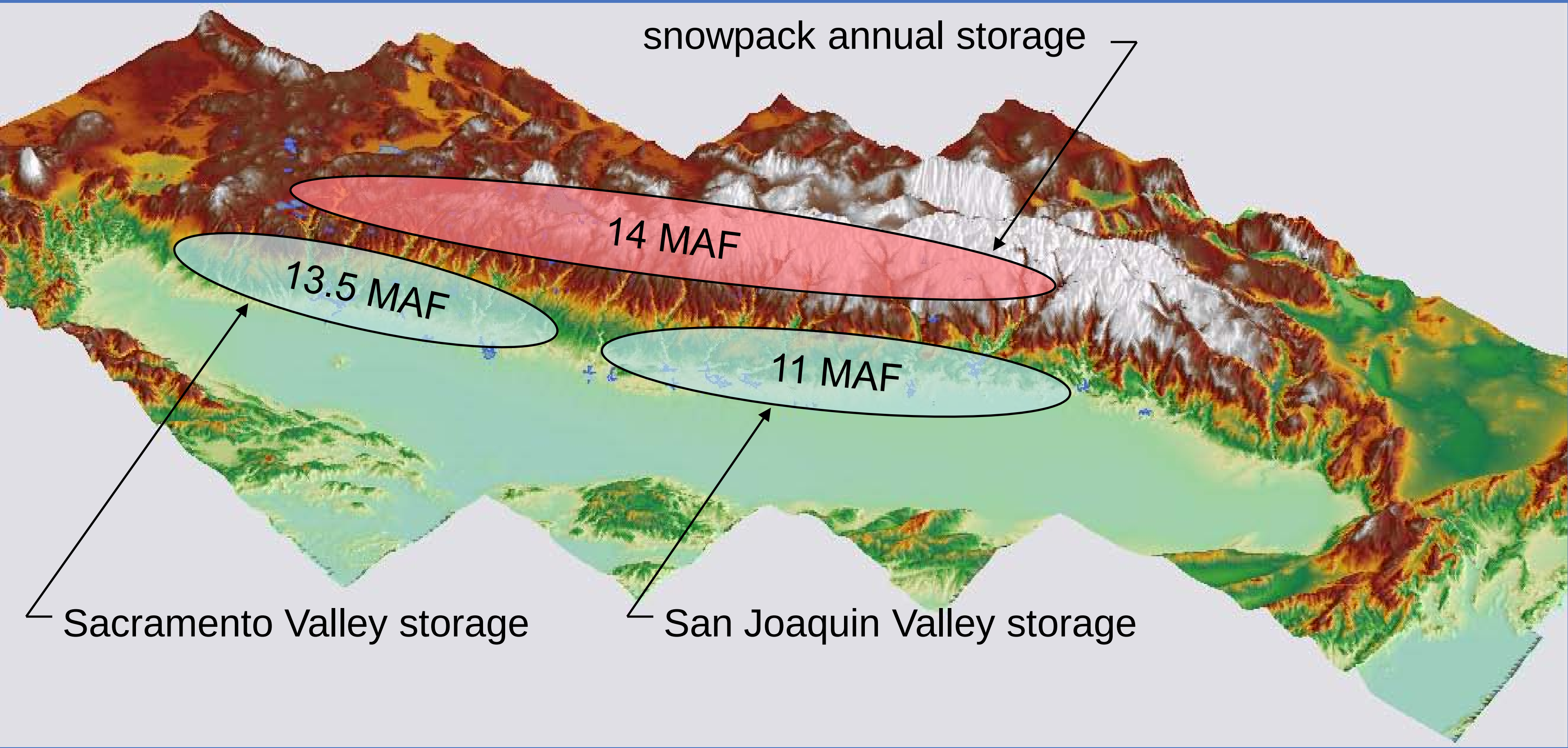


Historical, 0 to -3^{o}C

Derived from UW's VIC model daily inputs, 1950-1999

Bales et al., 2006

Snowpack loss & water storage: 30-yr horizon, or sooner?



Likely loss of ~3.5 MAF of snowpack storage in next 1-3 decades

MAF: million acre feet

Data from DWR

Three stages of response to climate change

– Is there a problem?

– What should I do?

– What are my risks and options?

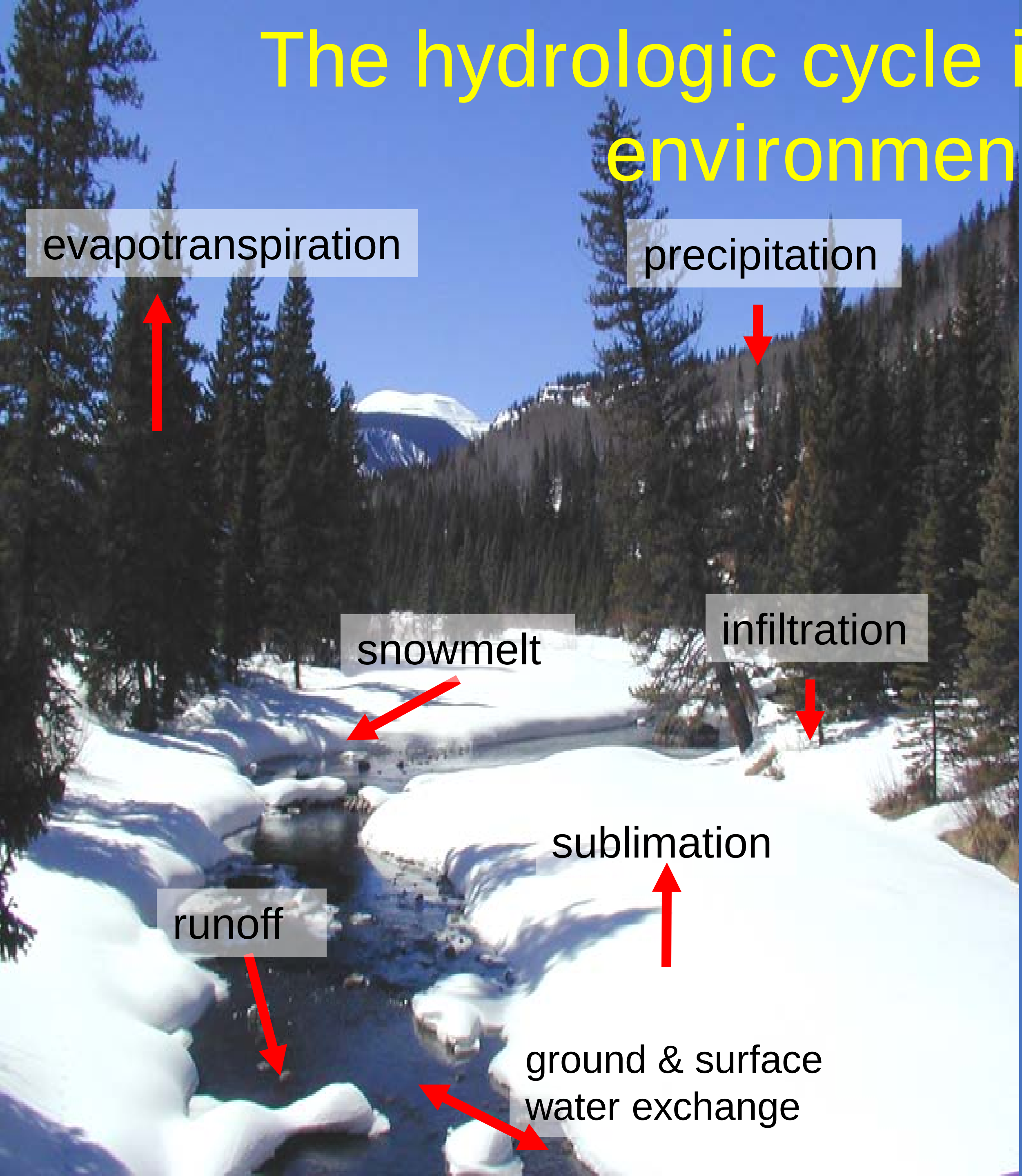
Economic & societal forces further define & constrain options for forest management in the Sierra Nevada

– How can we optimize hydropower in a changing climate?

– How do forest management actions influence water yield & runoff timing?

– How can forest managers respond to multiple objectives, including water?

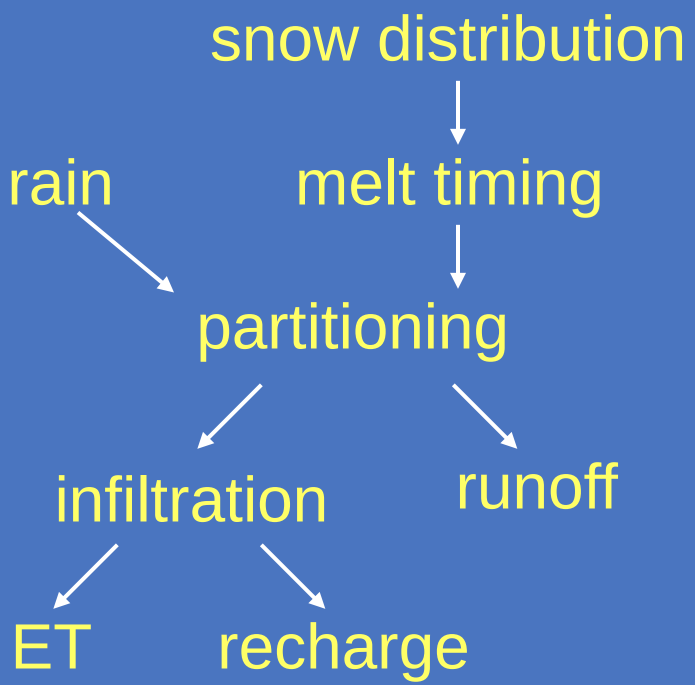
The hydrologic cycle in mountain environments



Research aimed at process understanding & predictive ability

Understanding hydrologic processes in seasonally snow-covered mountain basins: some assumptions

1. The basis for process understanding is new measurements
2. Processes are coupled & best studied together
3. Following snowmelt (plus rain) will yield process insight:

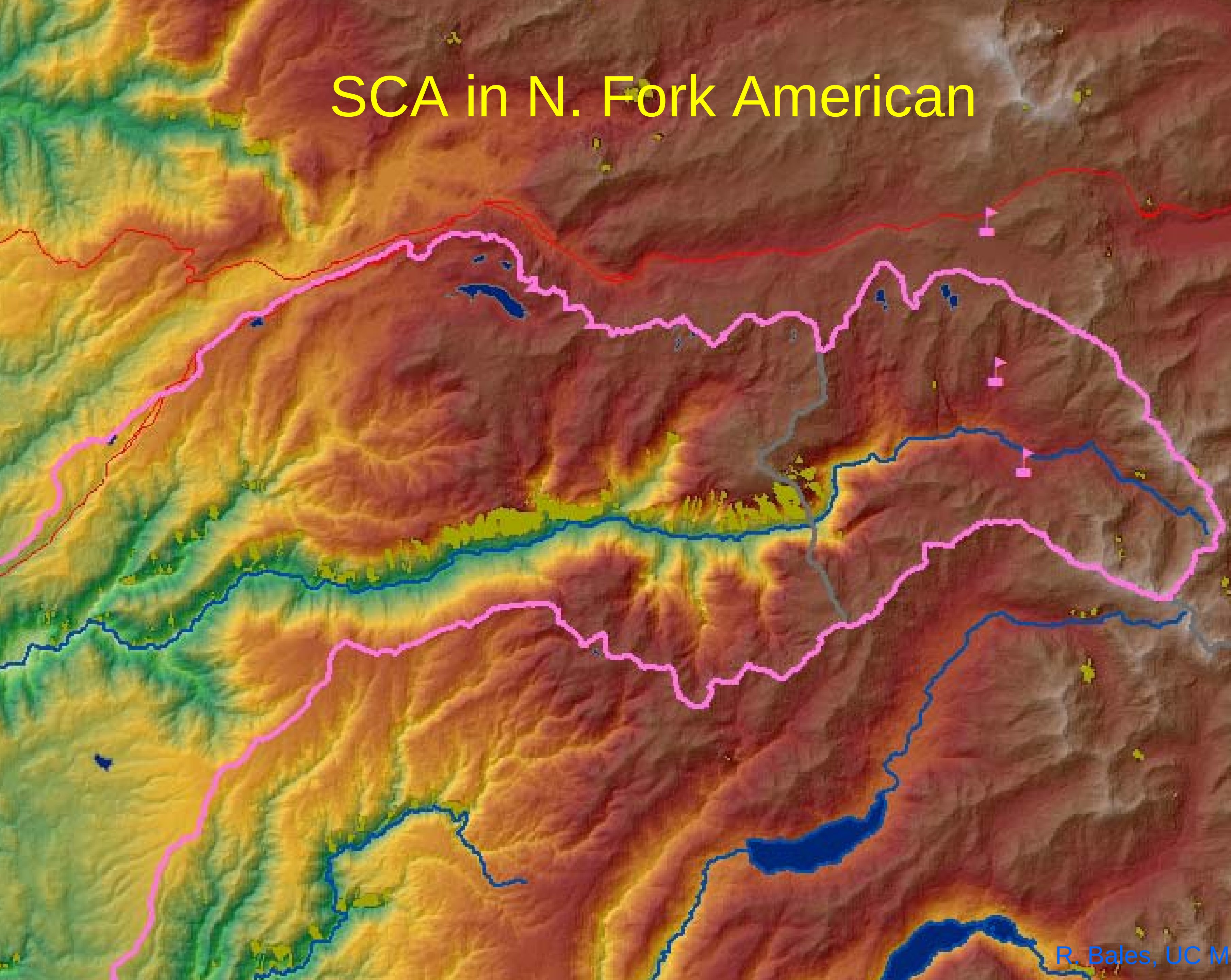


Satellite remote sensing of snowpack

Blending of low-cost ground measurements with satellite data using advanced information technology for next generation of decision-support systems

snow depth

SCA in N. Fork American



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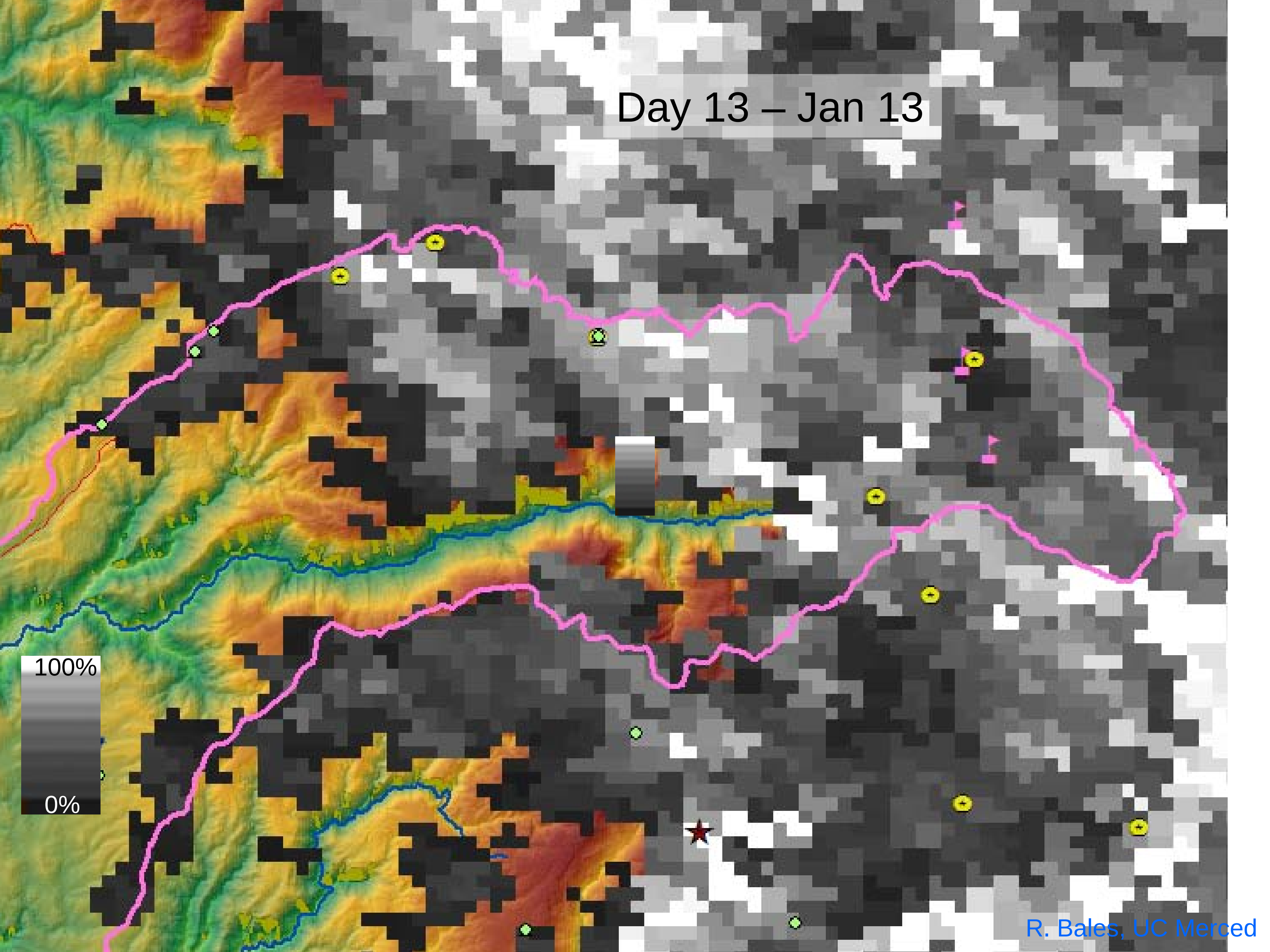
Day 13 – Jan 13
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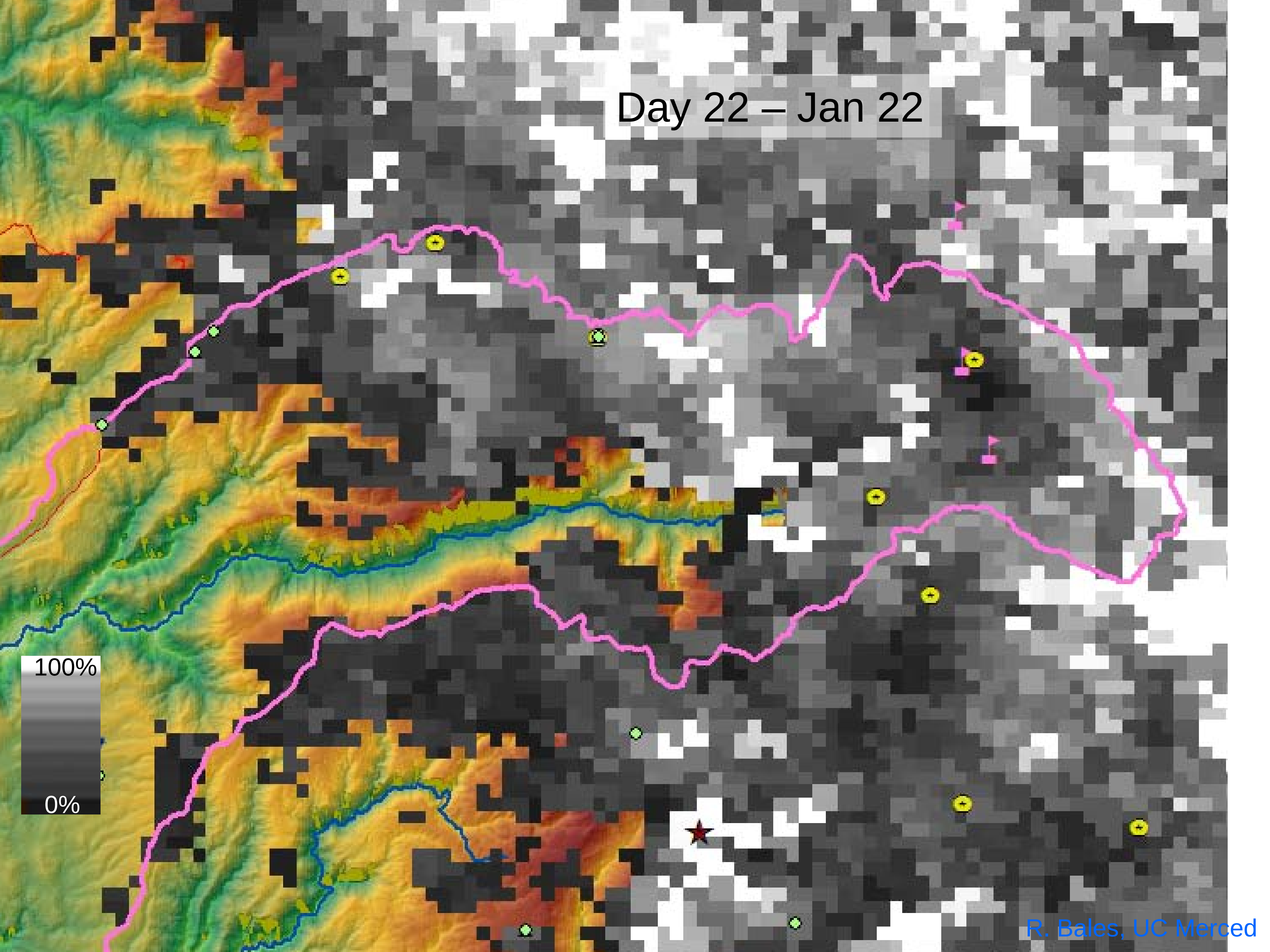

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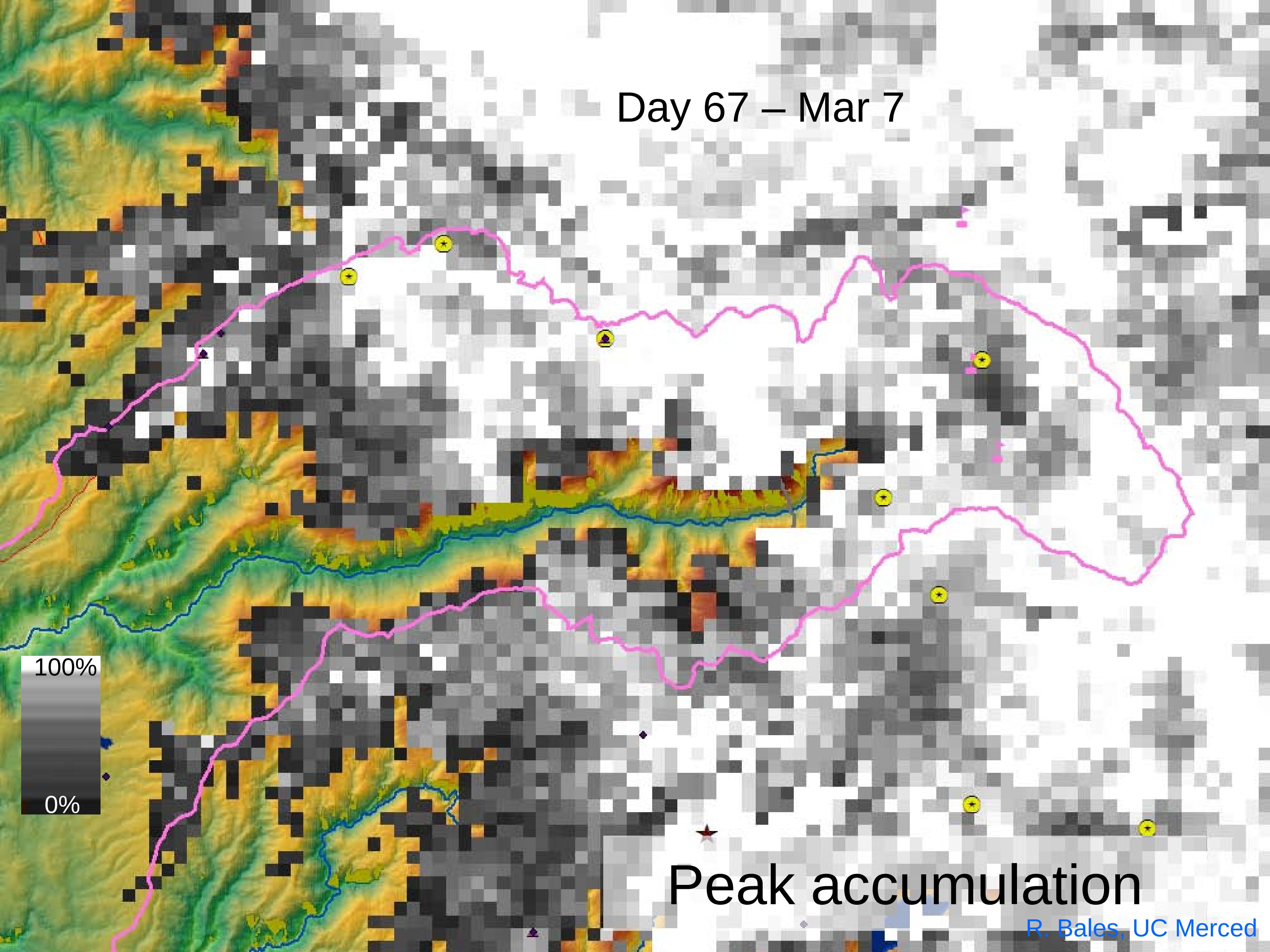

Day 67 – Mar 7
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Peak accumulation
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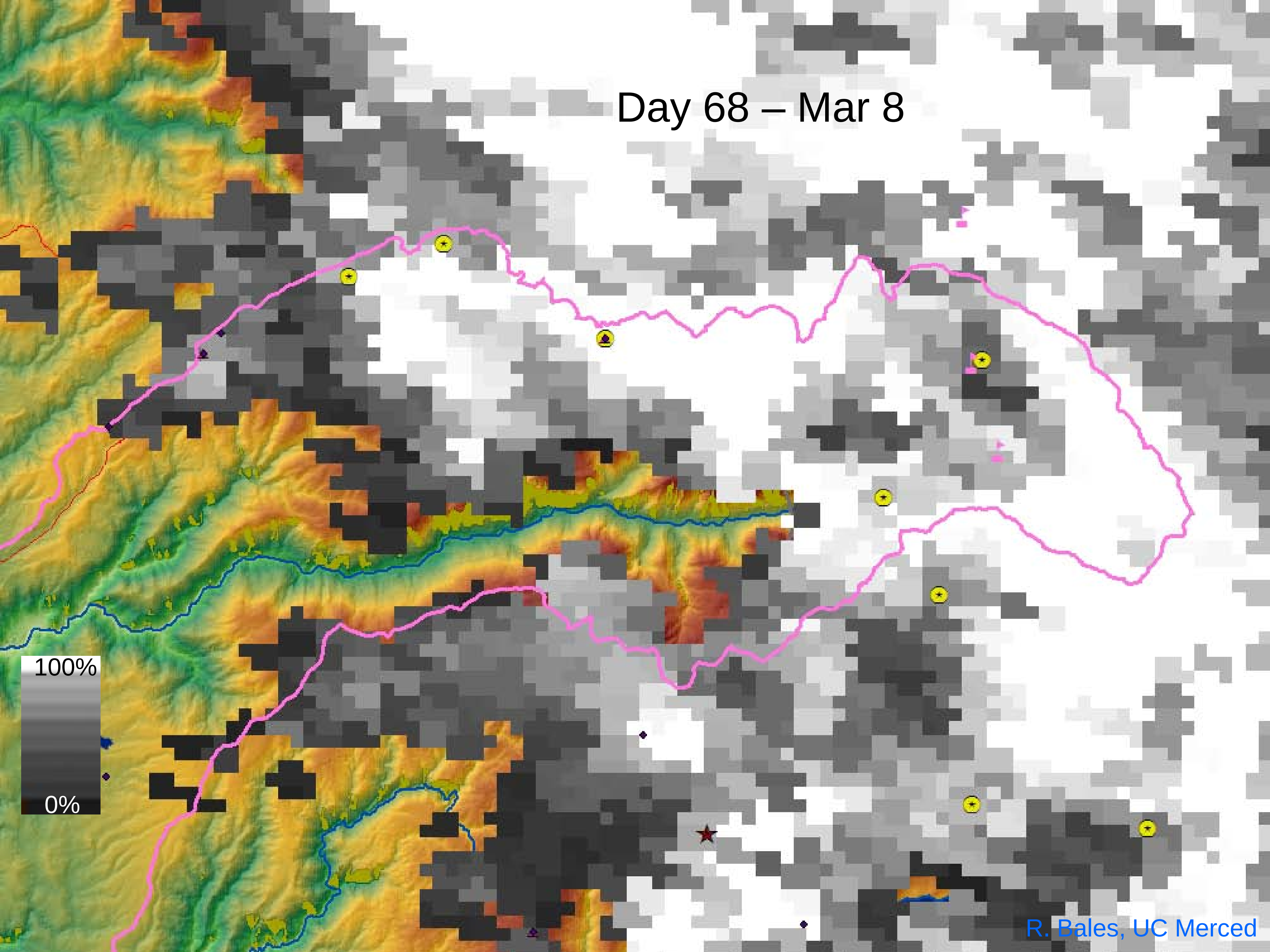

Day 68 – Mar 8
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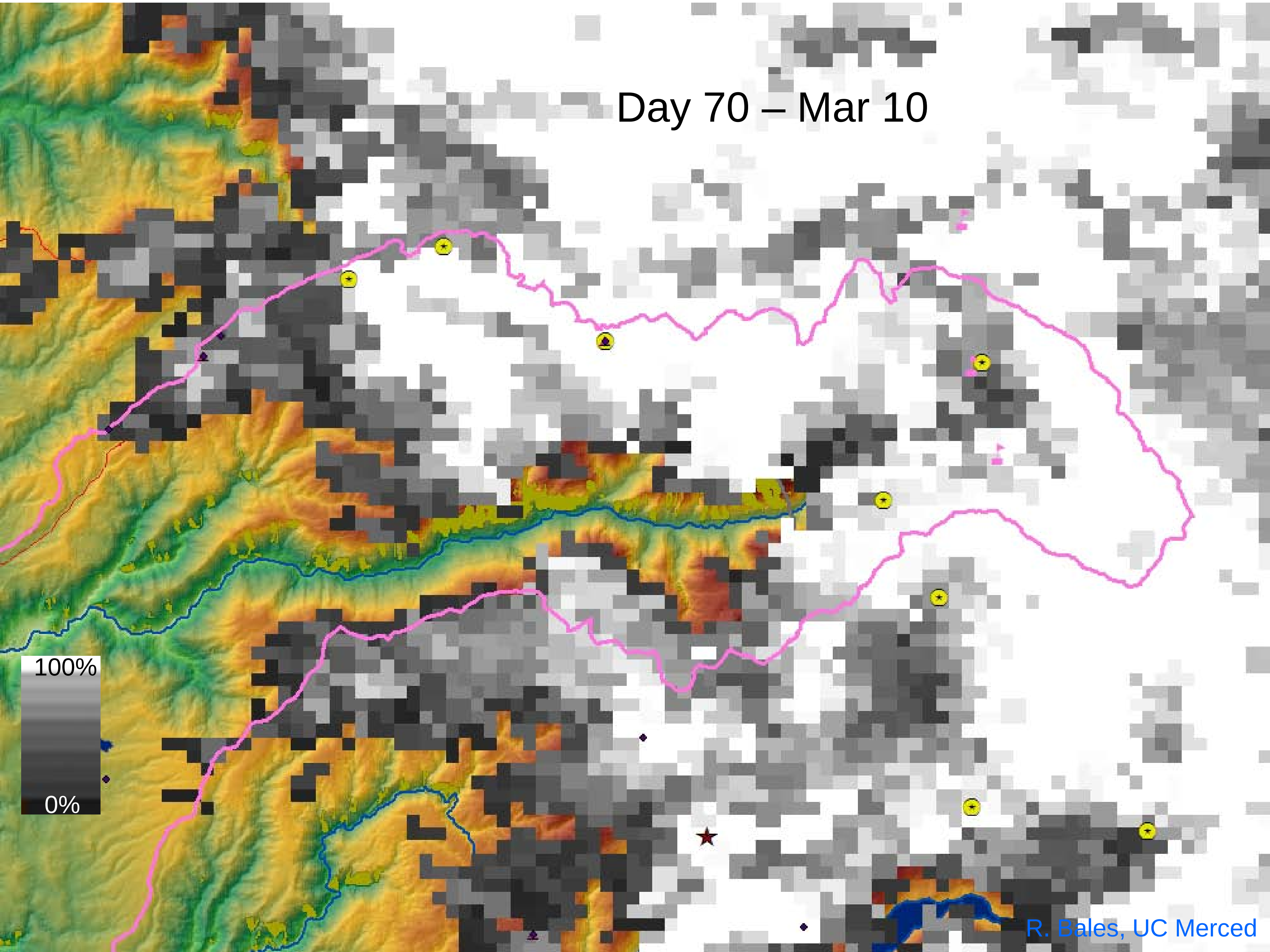
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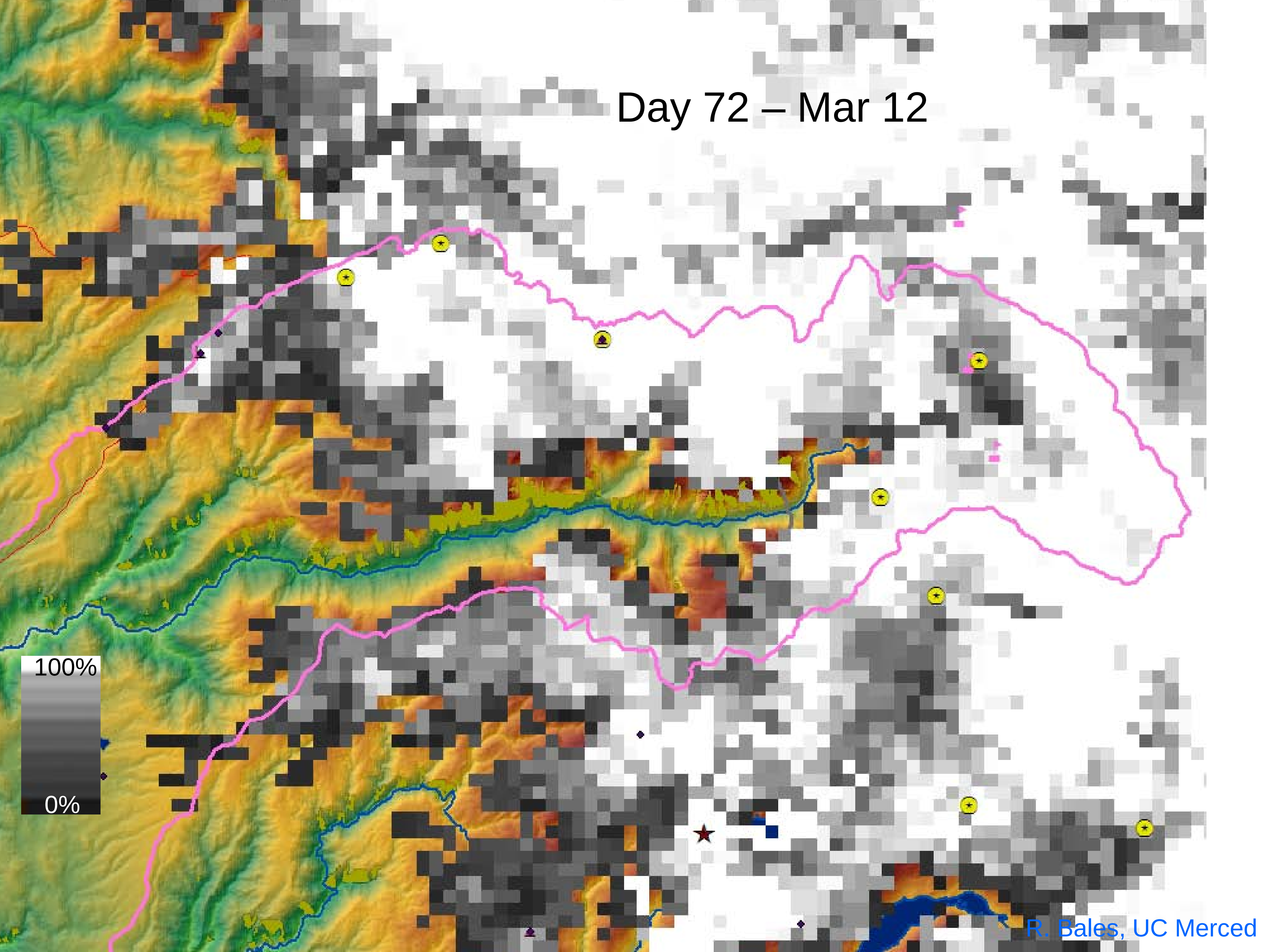
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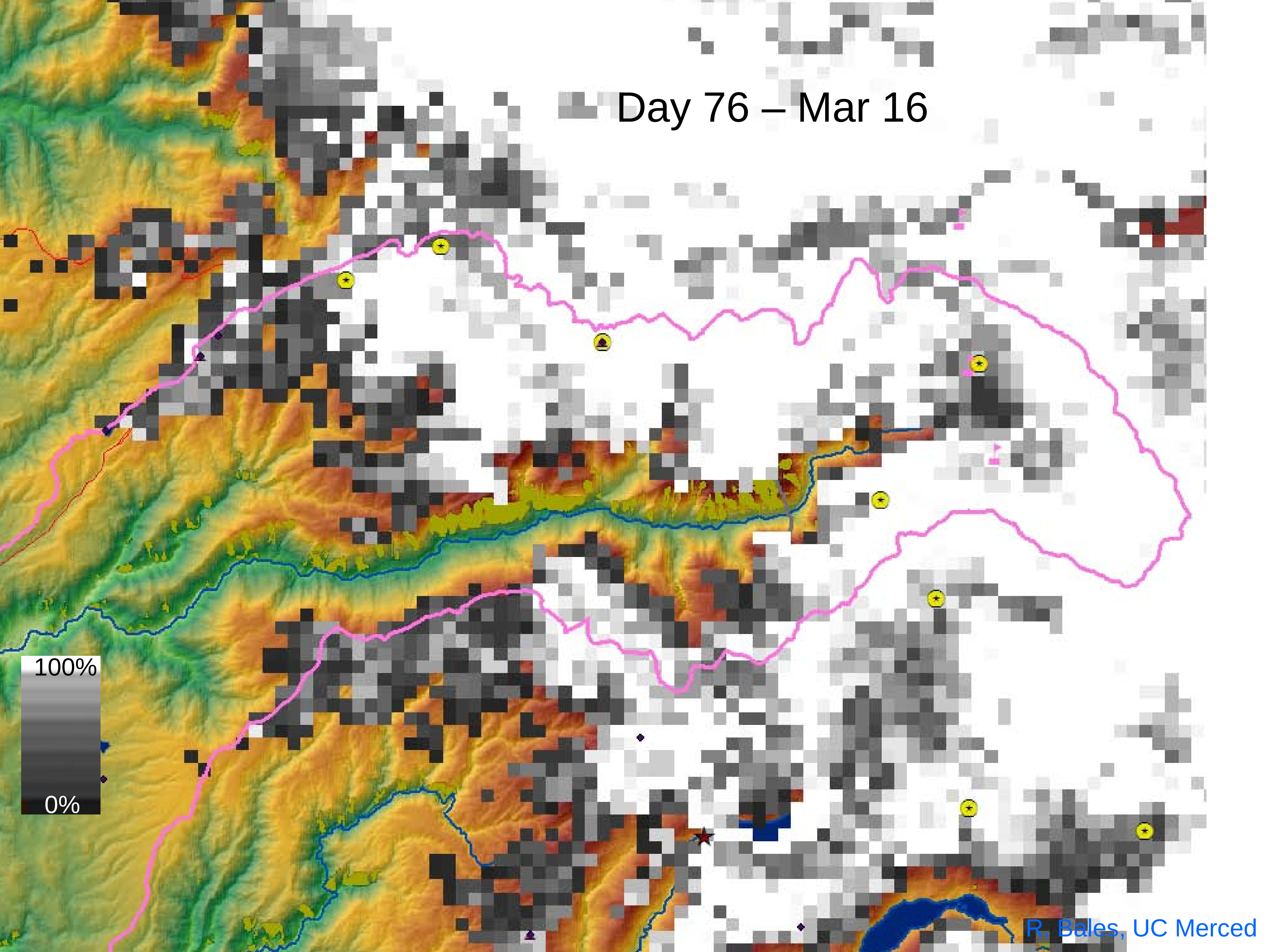
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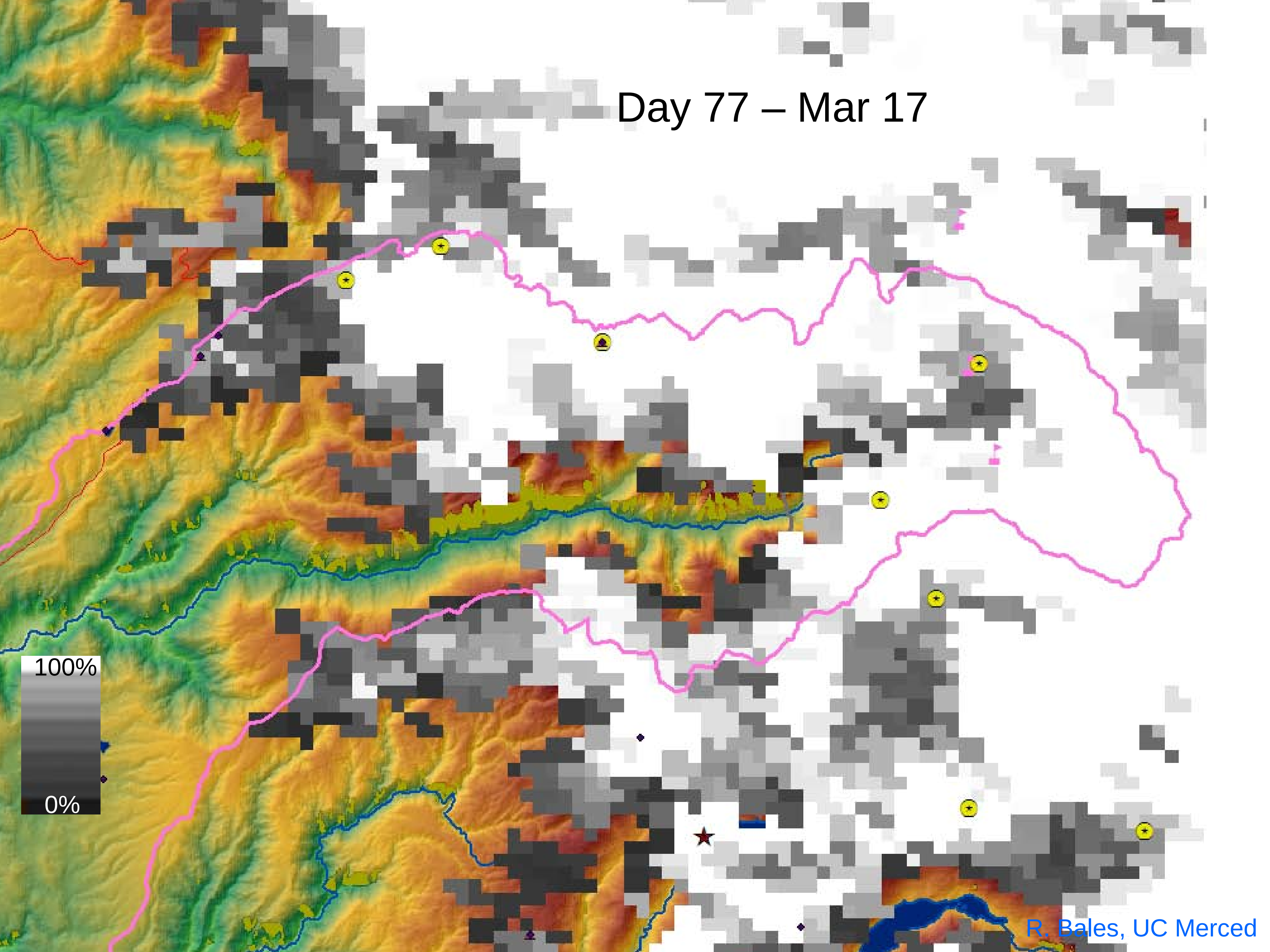
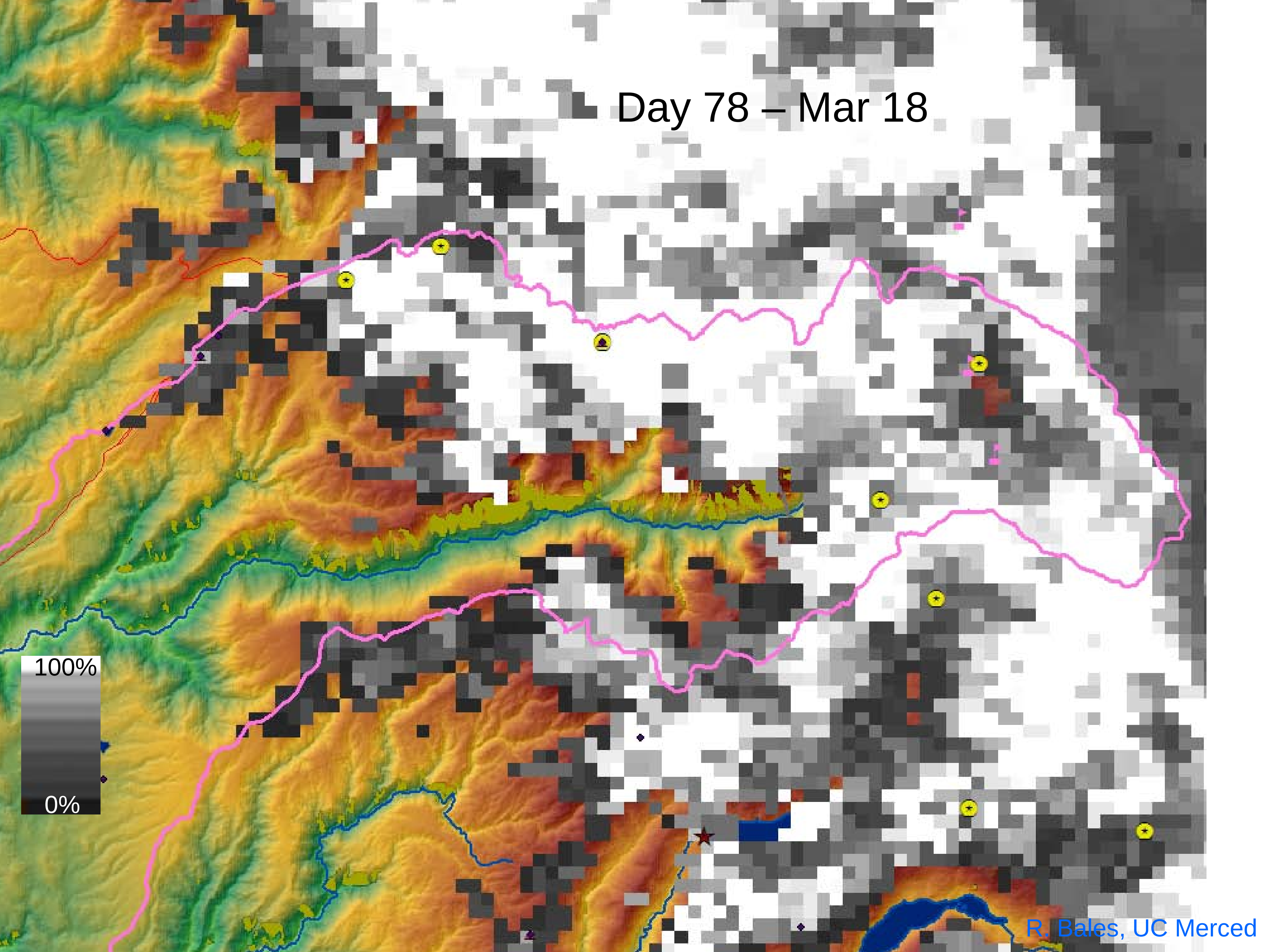
Day 77 – Mar 17

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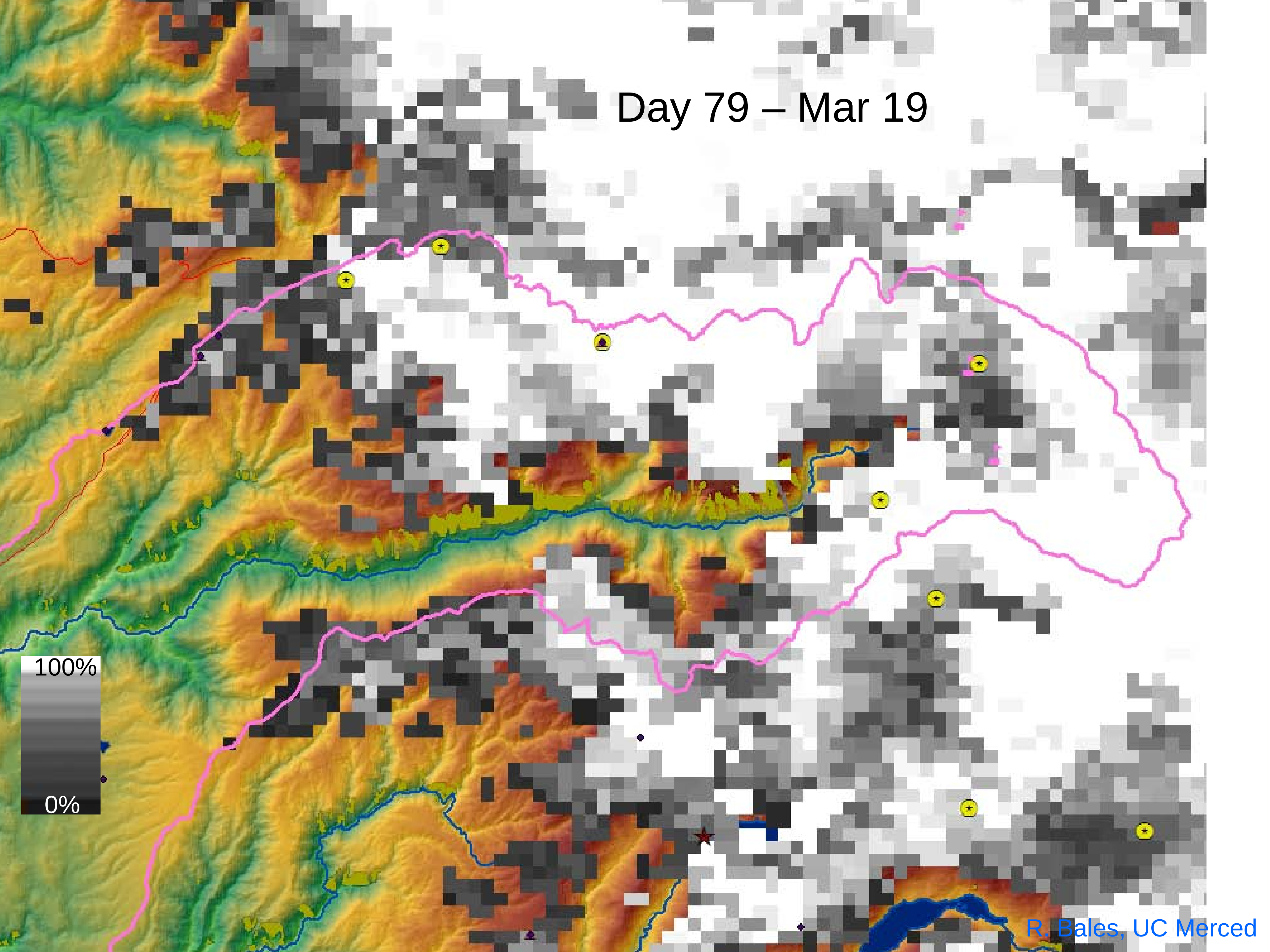
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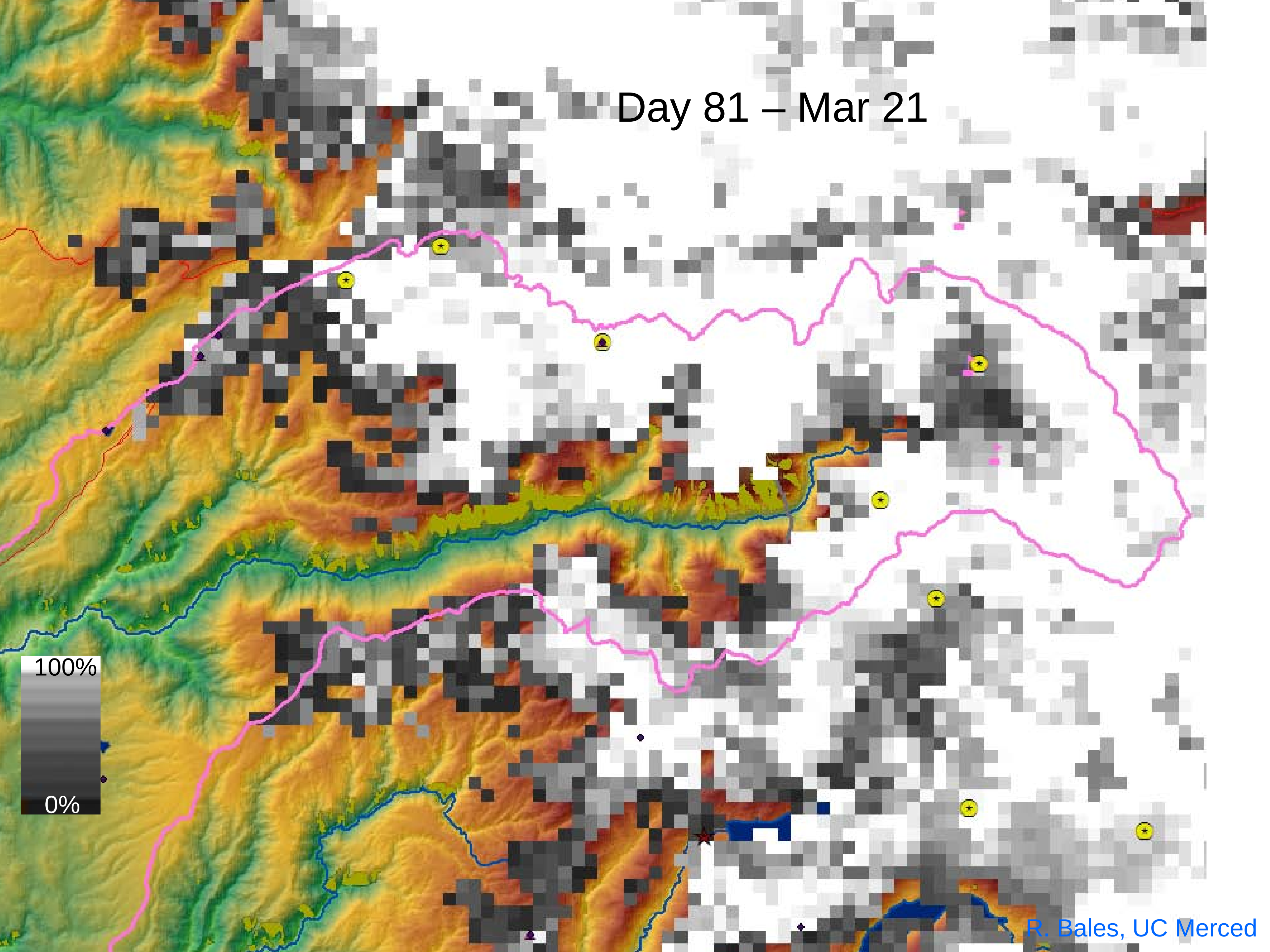
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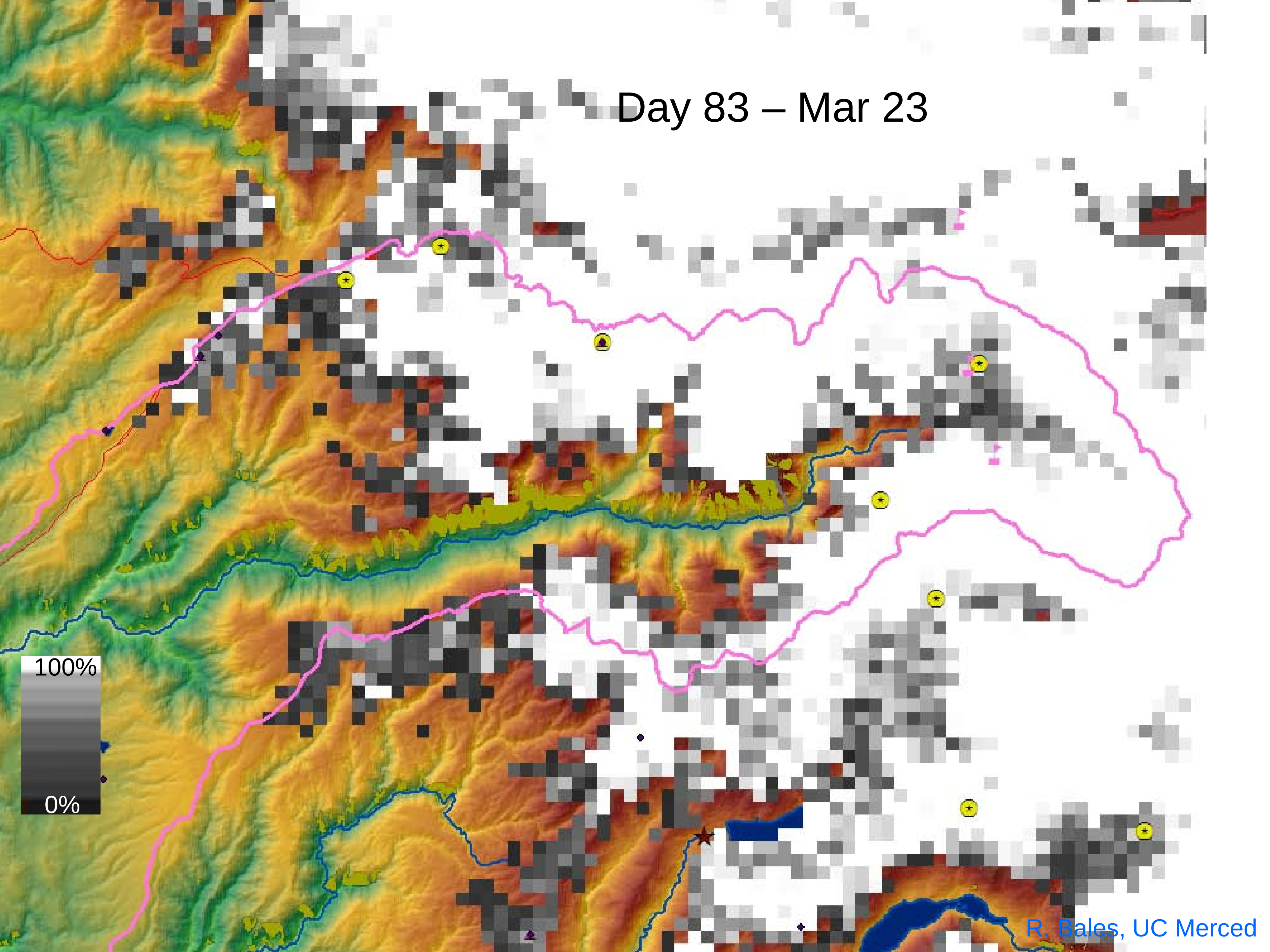
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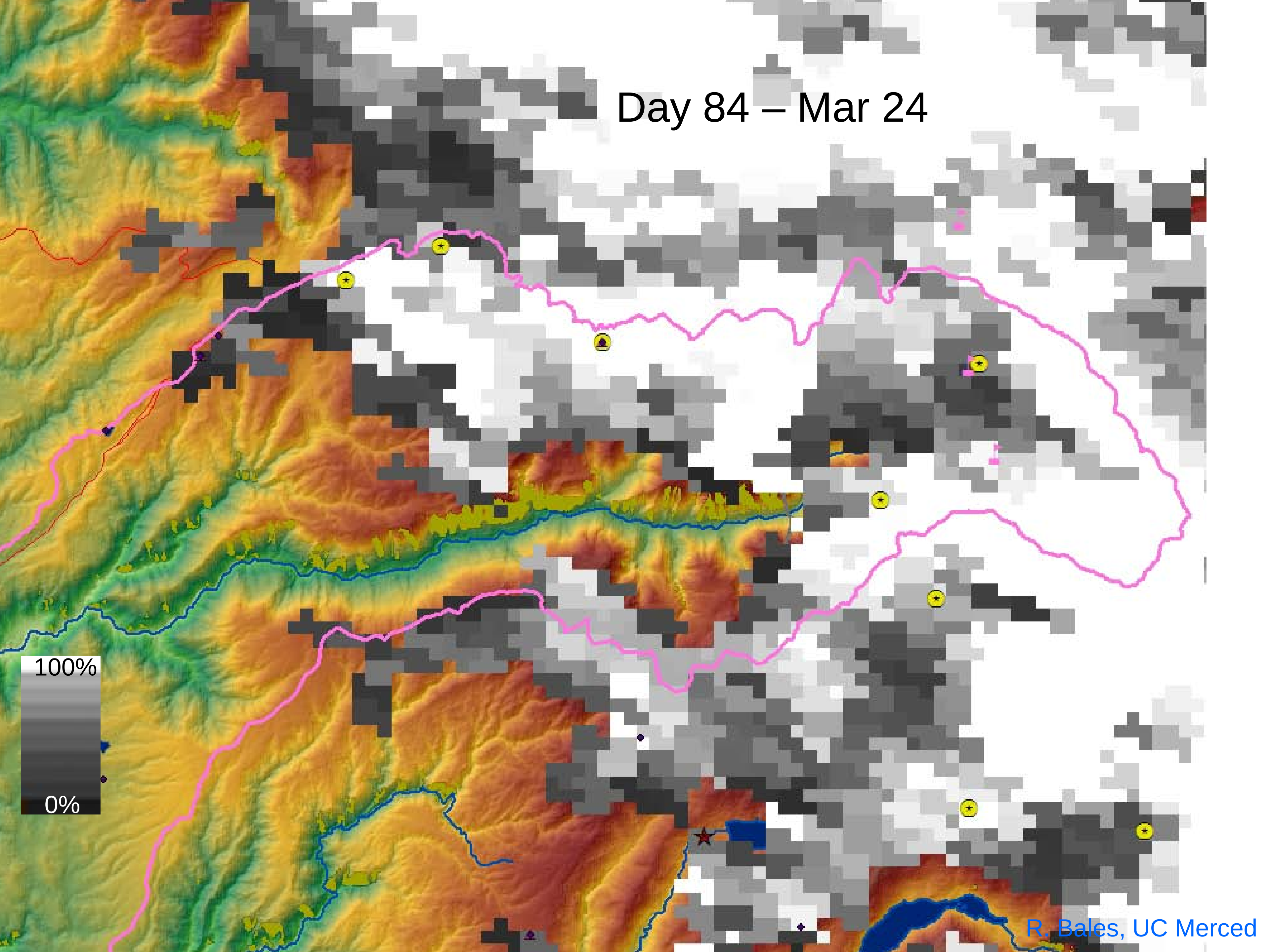
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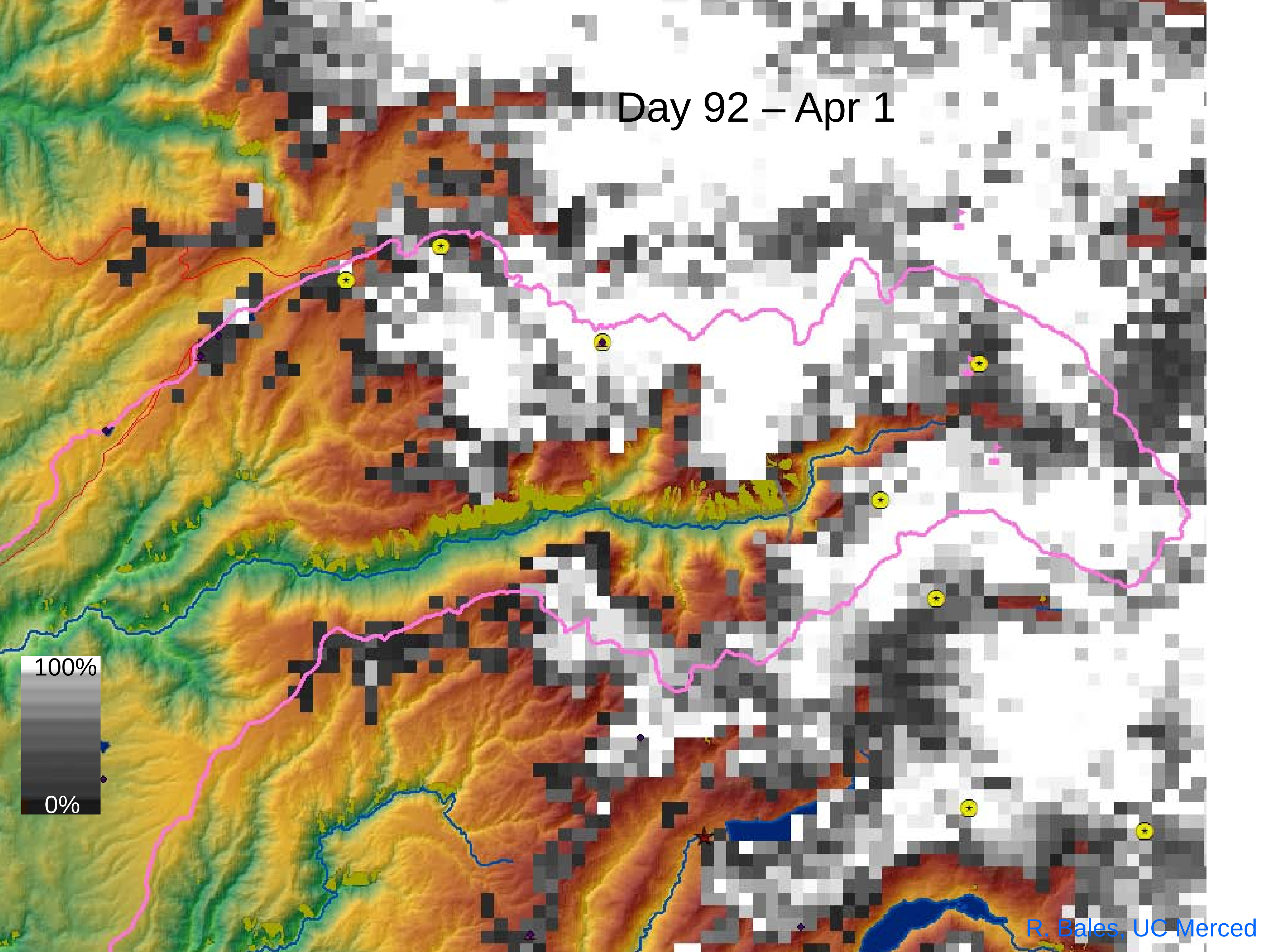
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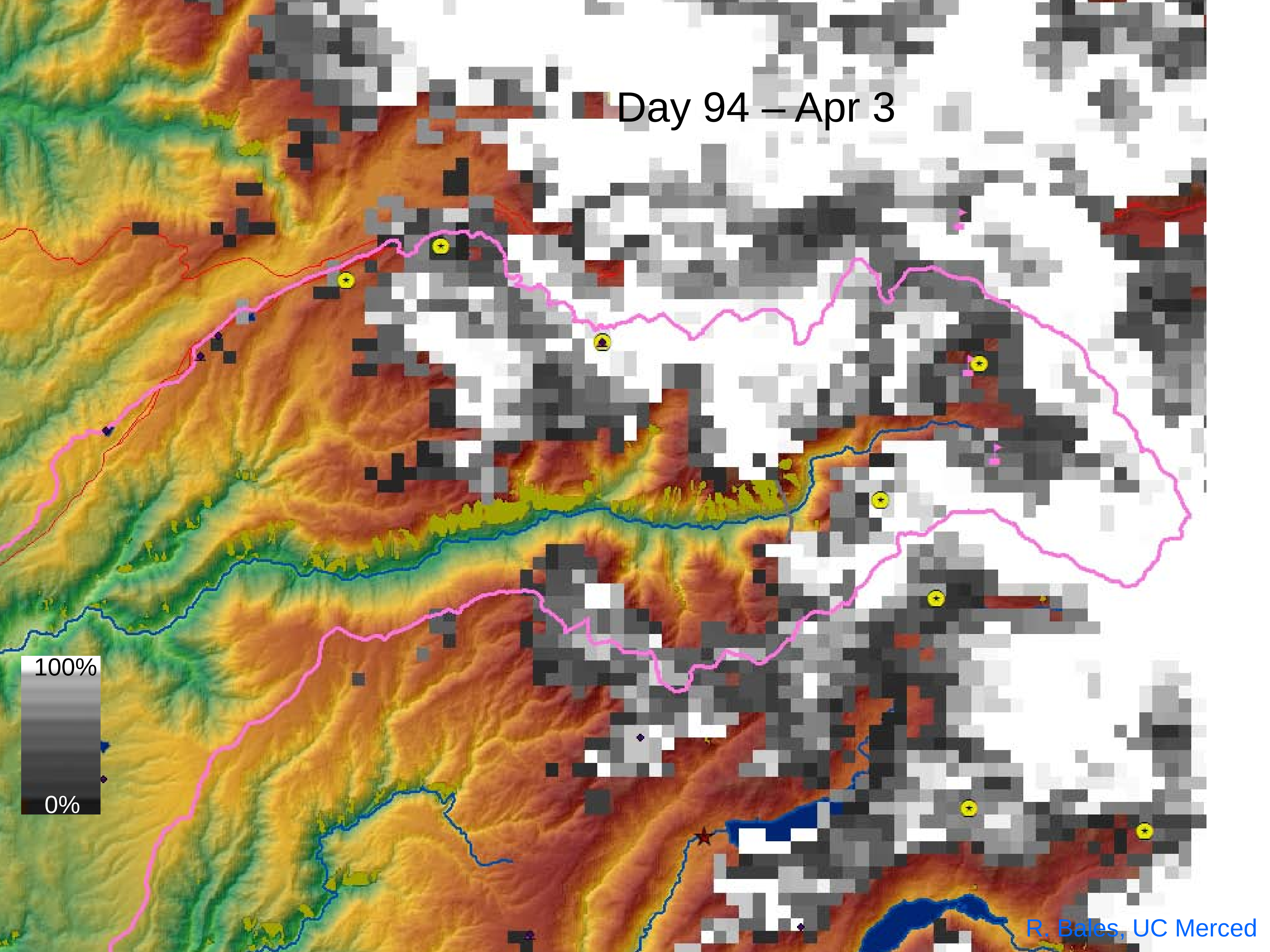
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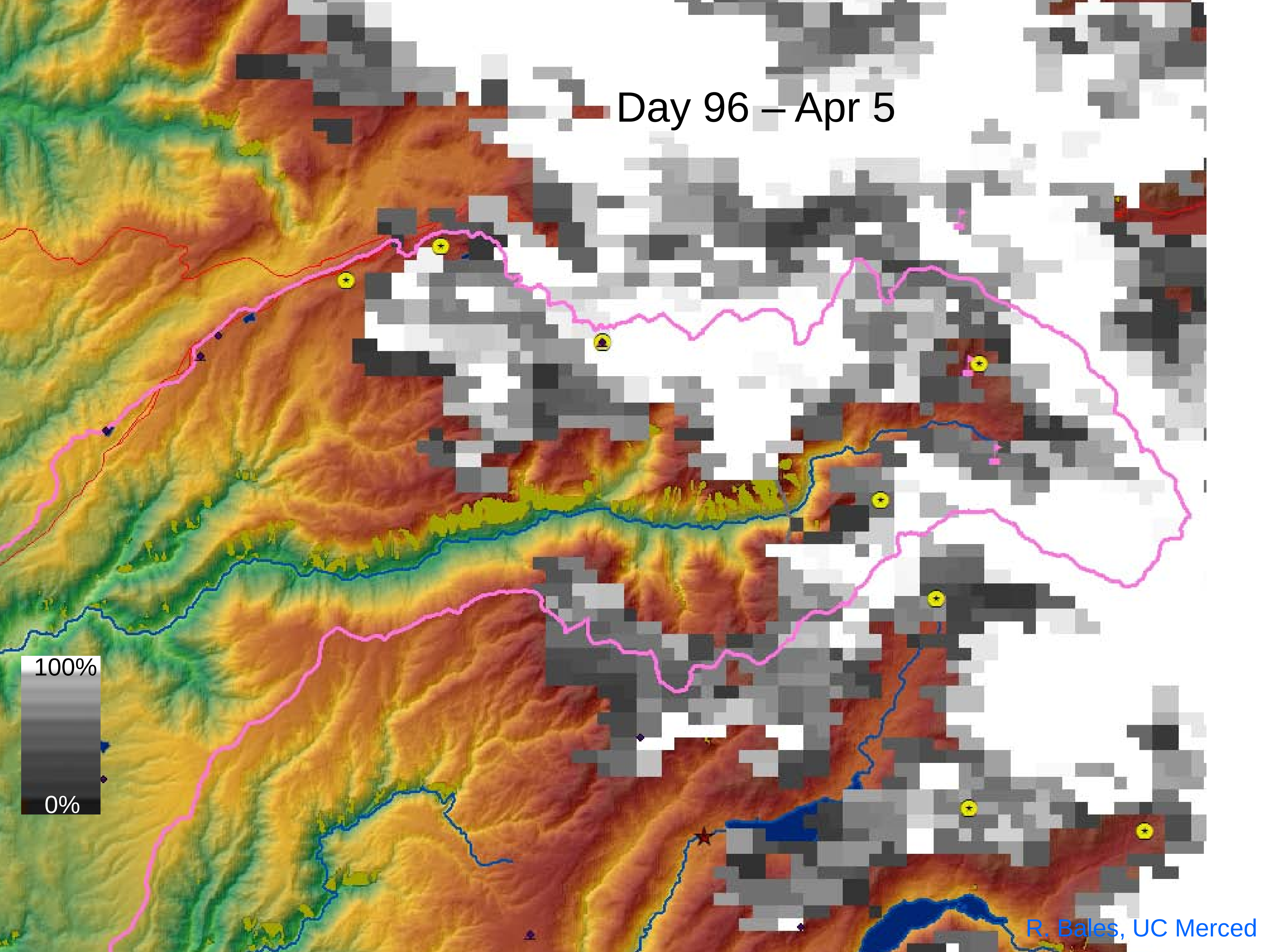
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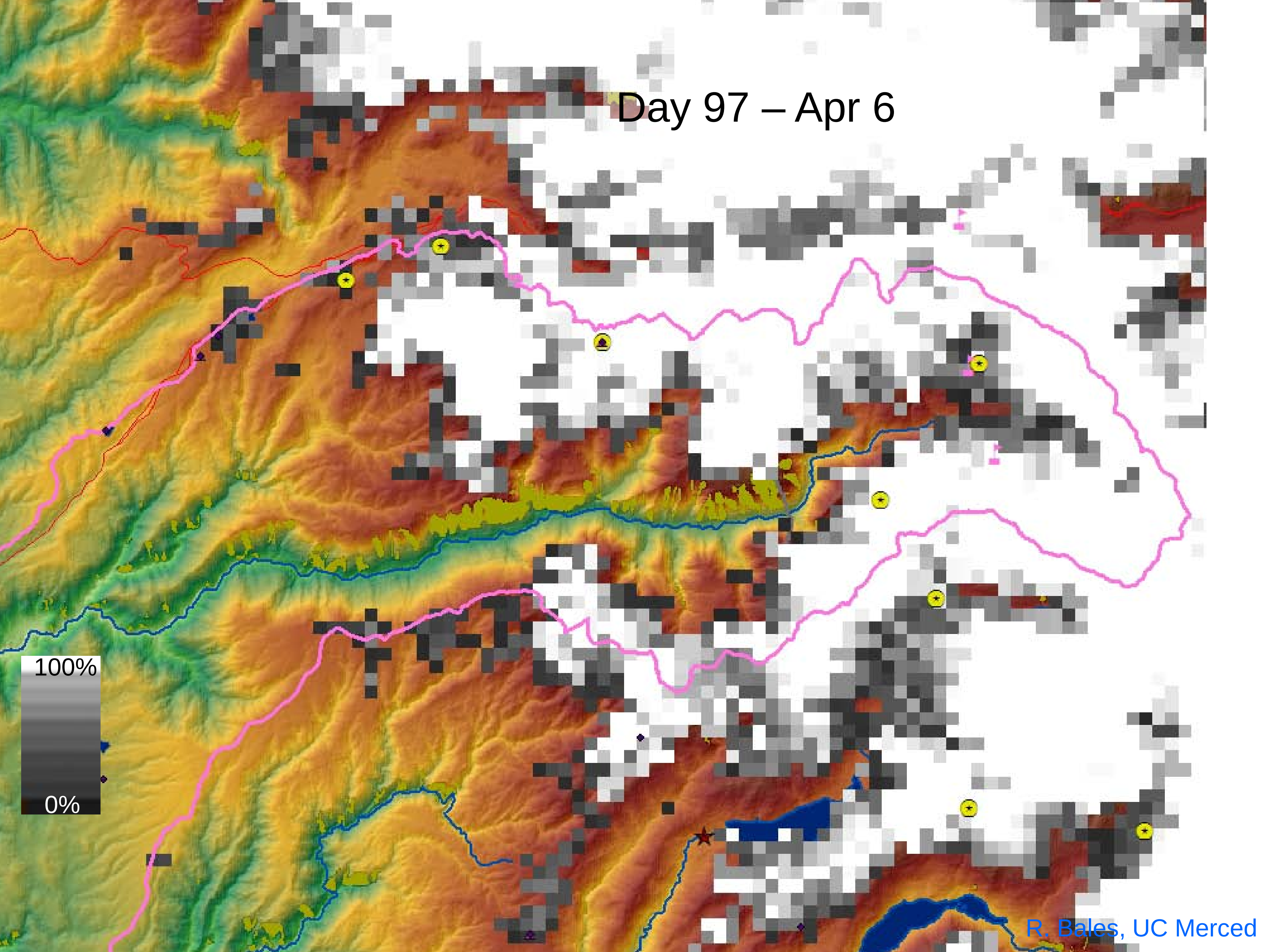
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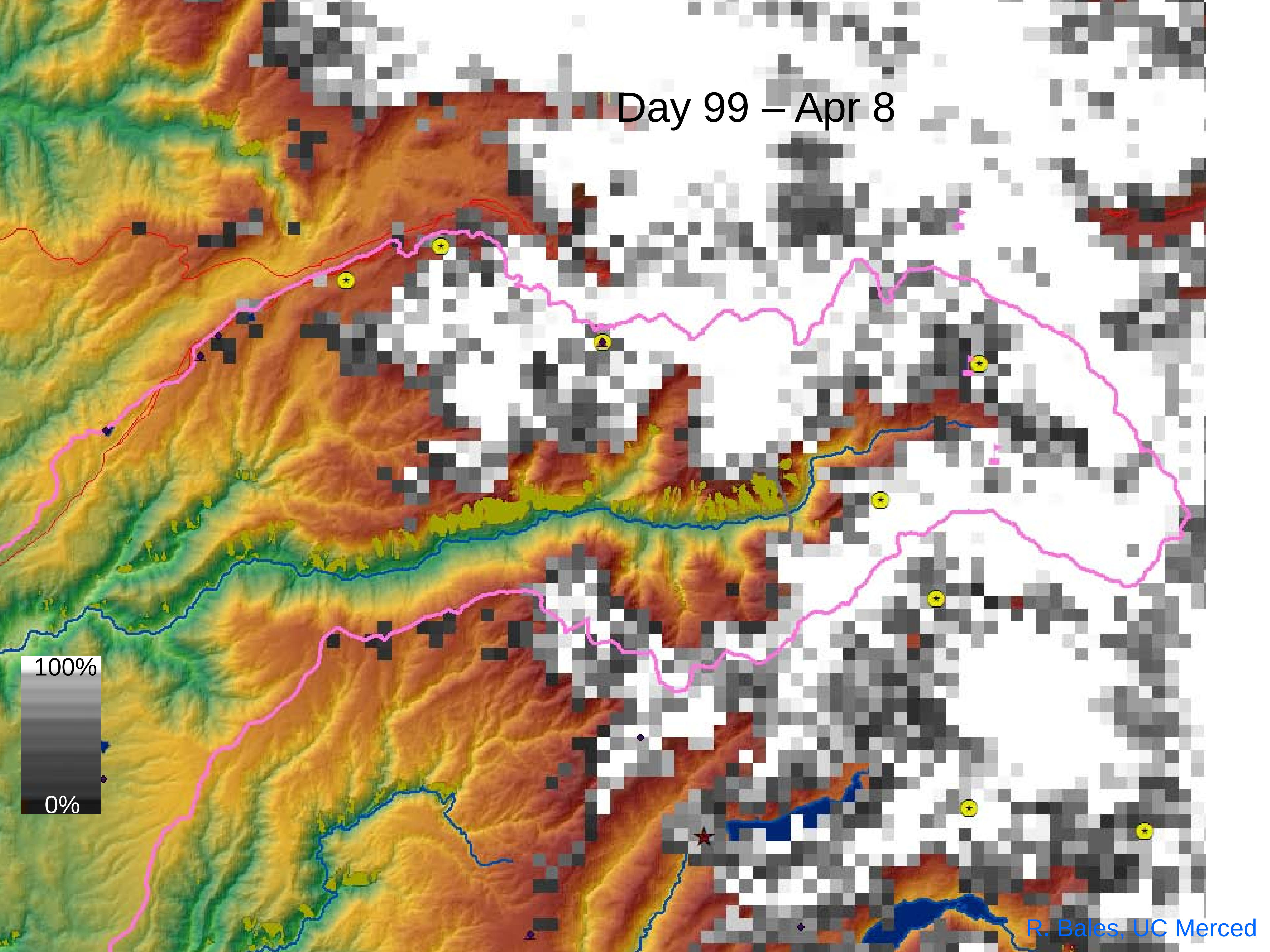

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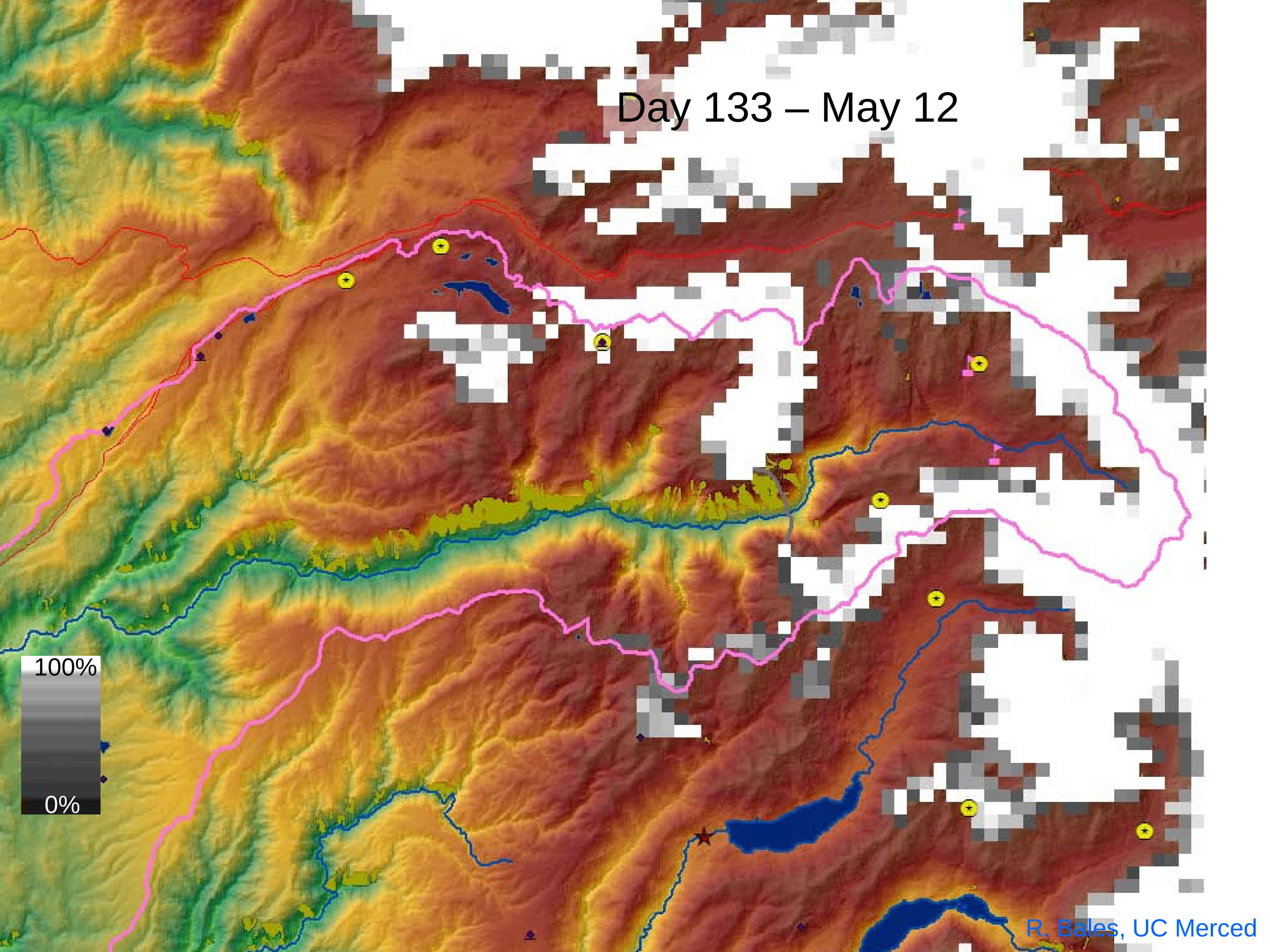
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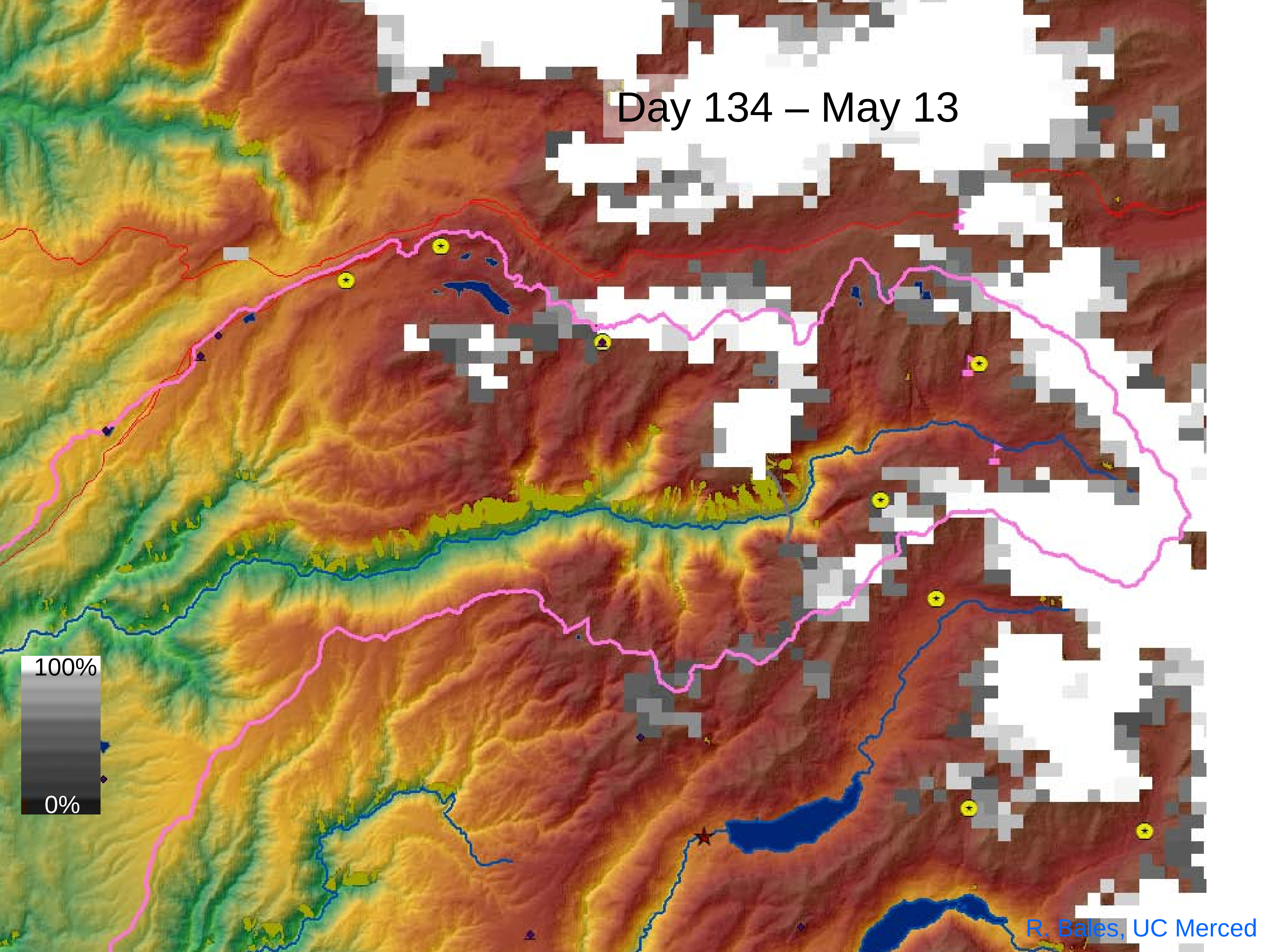
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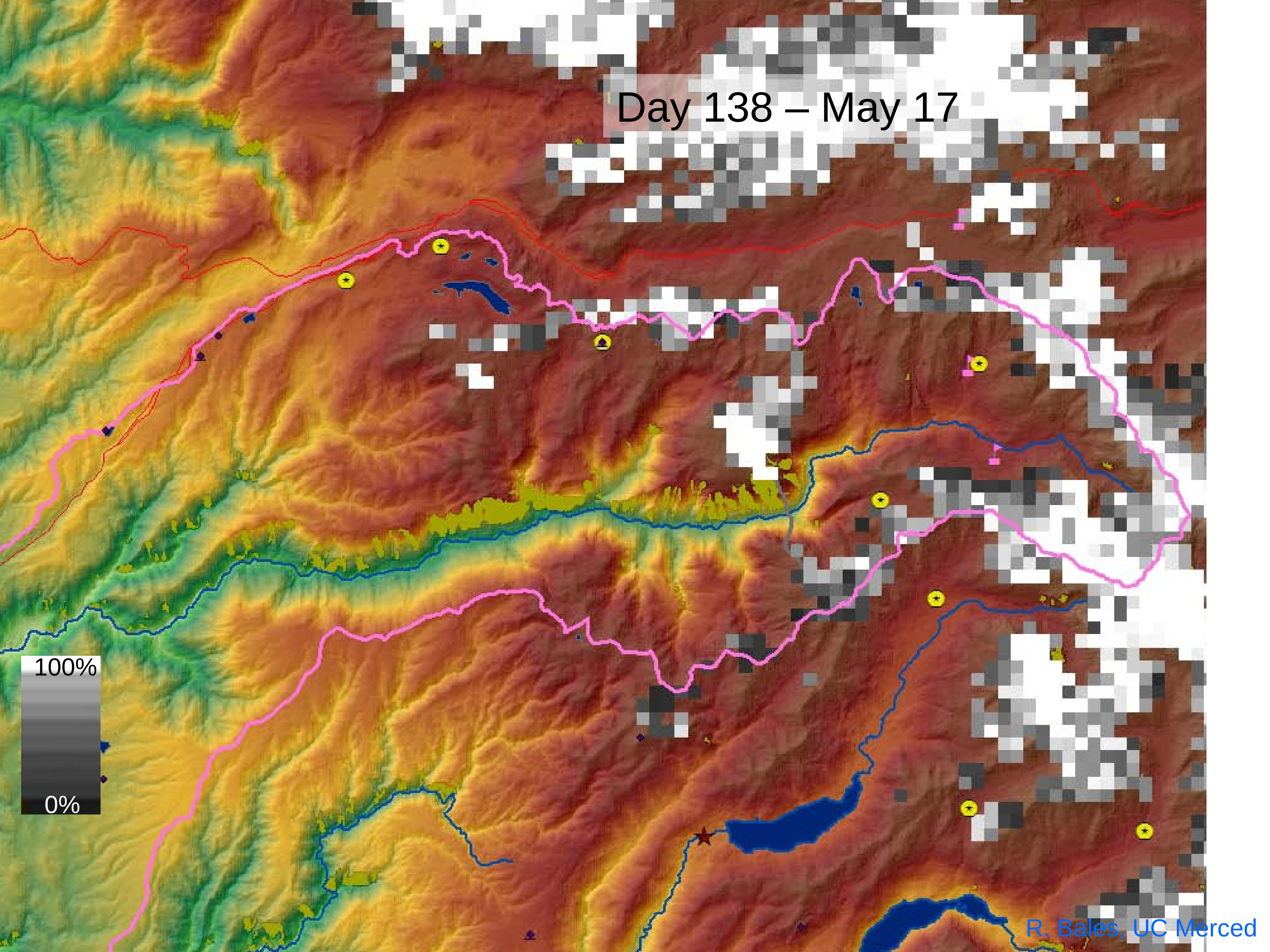
Day 138 – May 17
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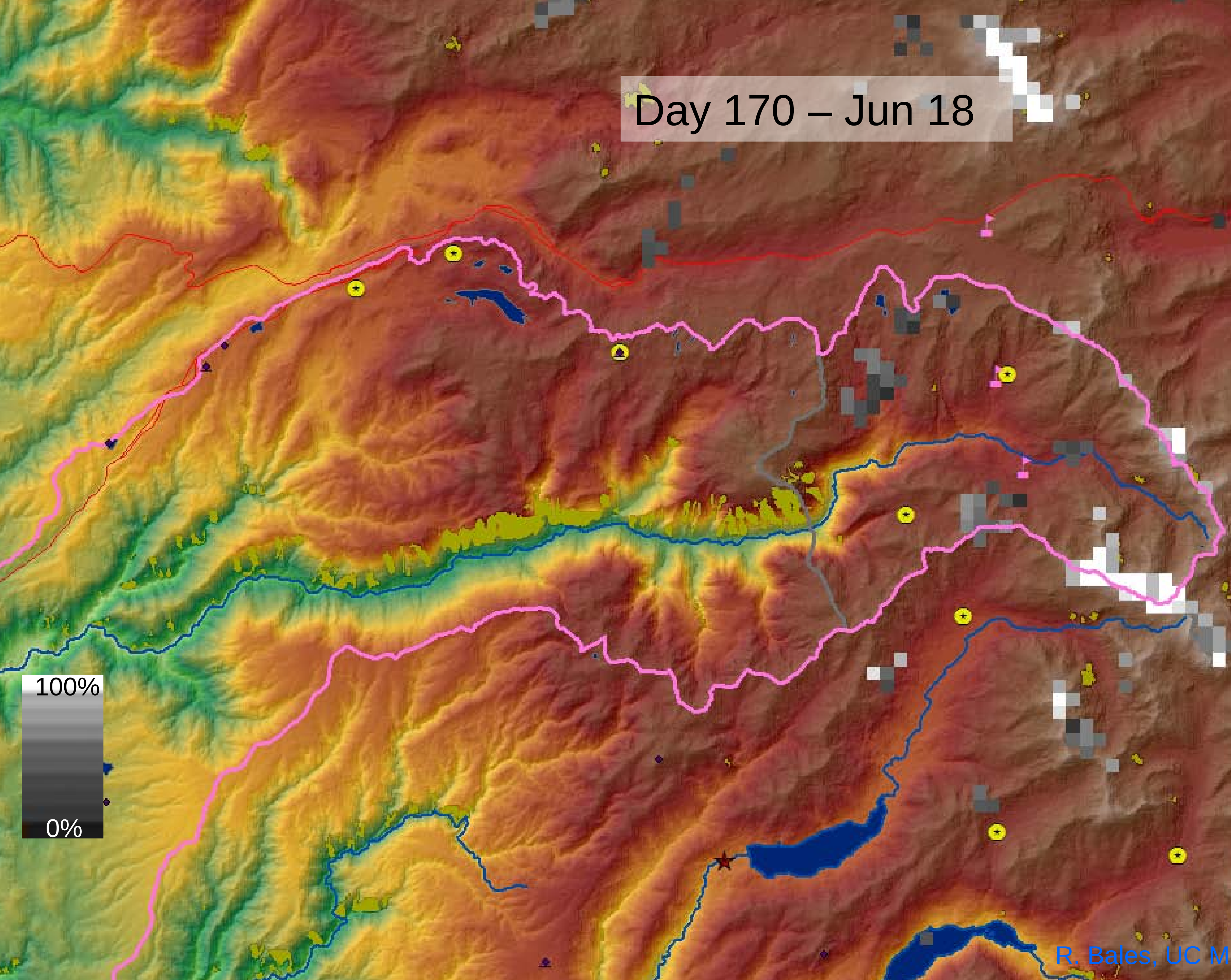
Day 170 – Jun 18
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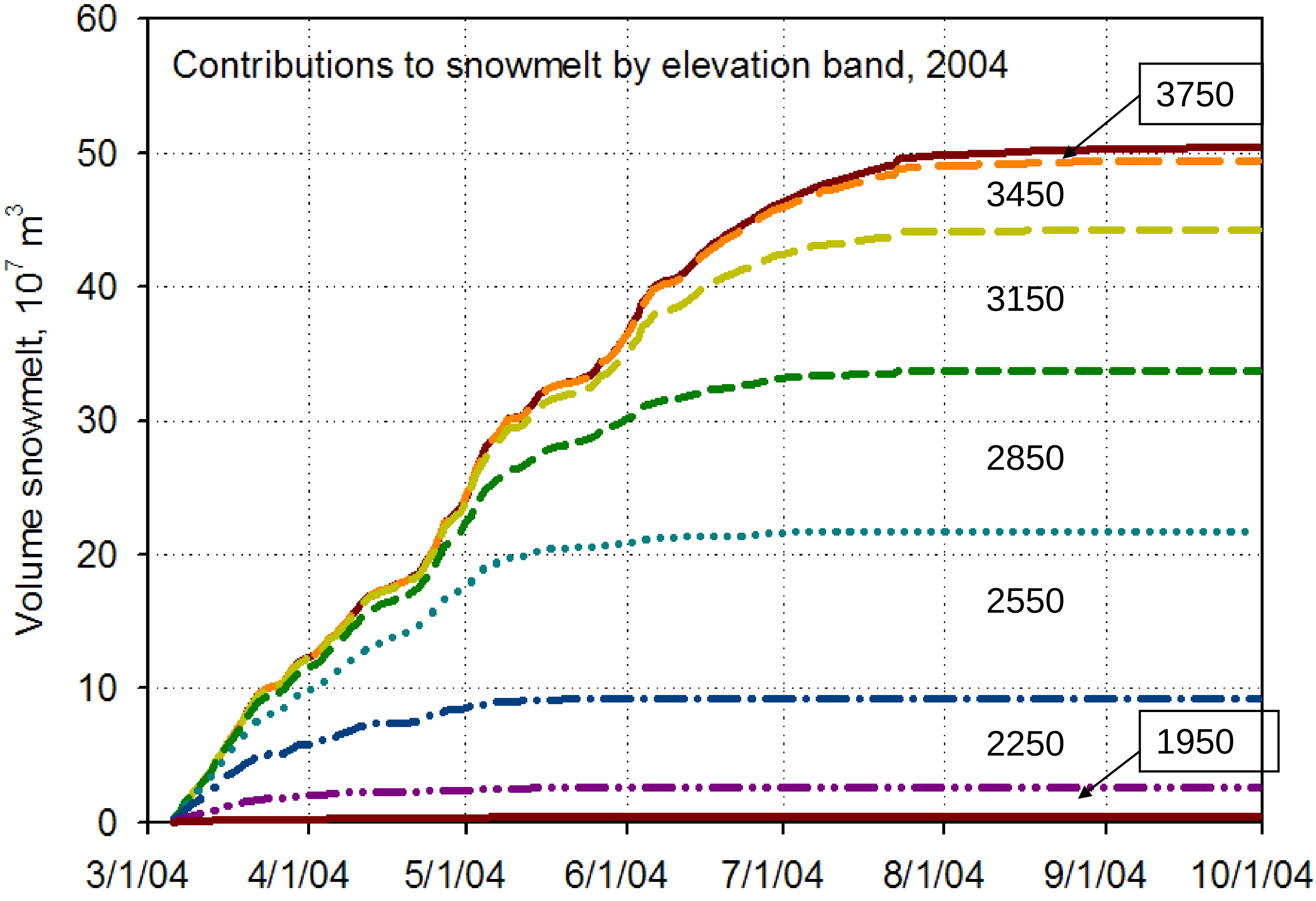
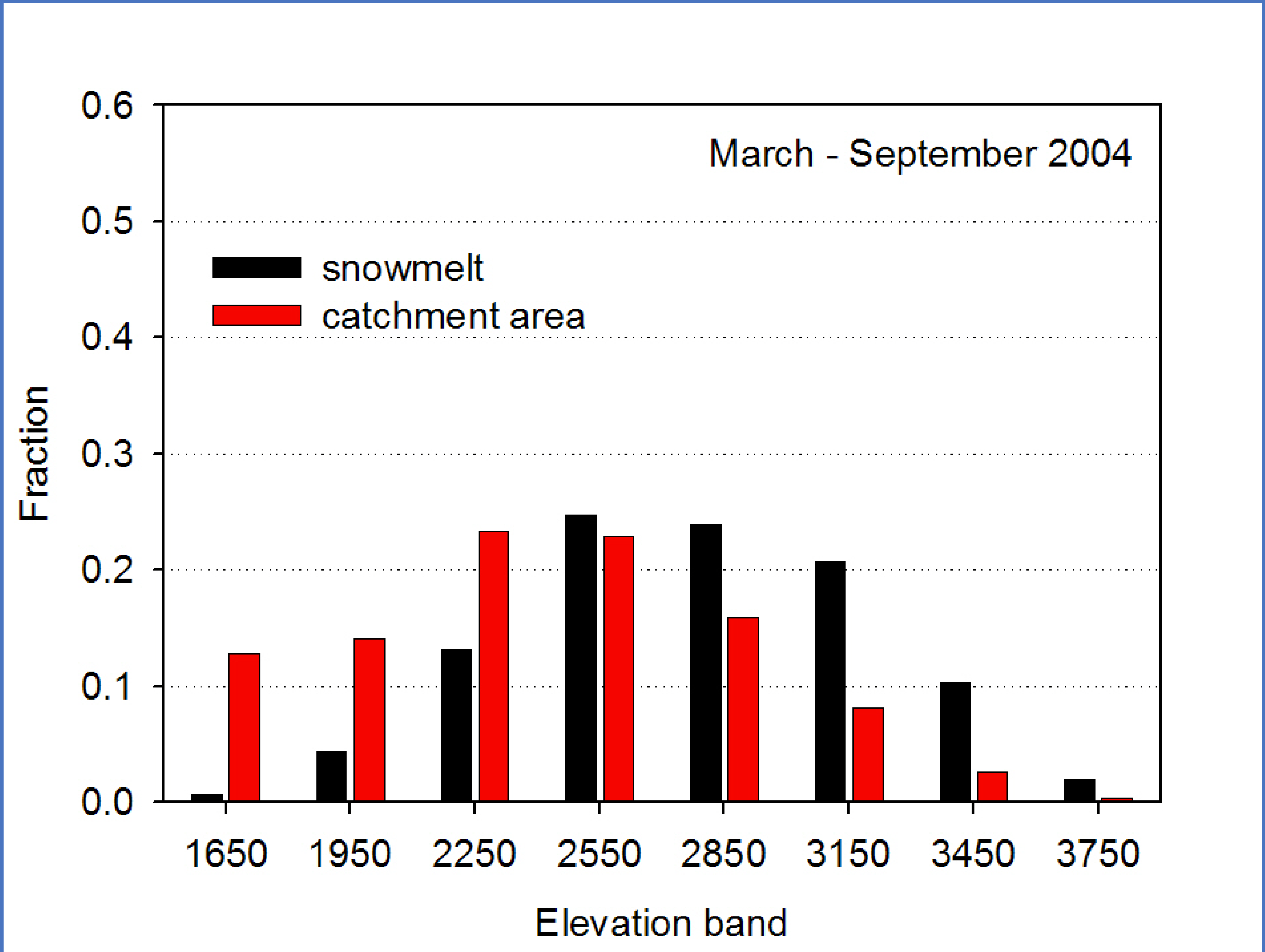
Contributions to snowmelt by elevation



Fraction of snowmelt from various elevations

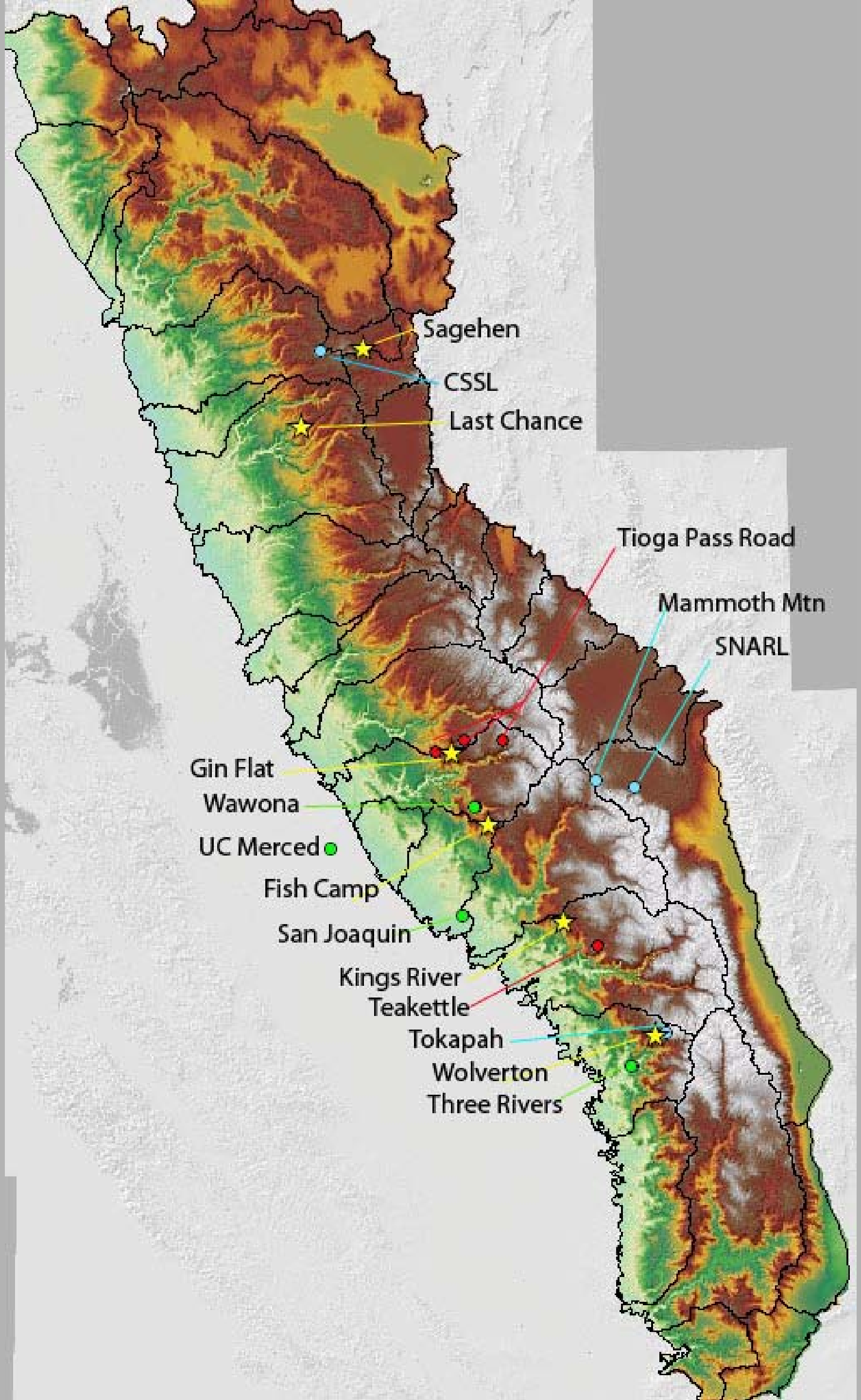


Merced R. basin data shown

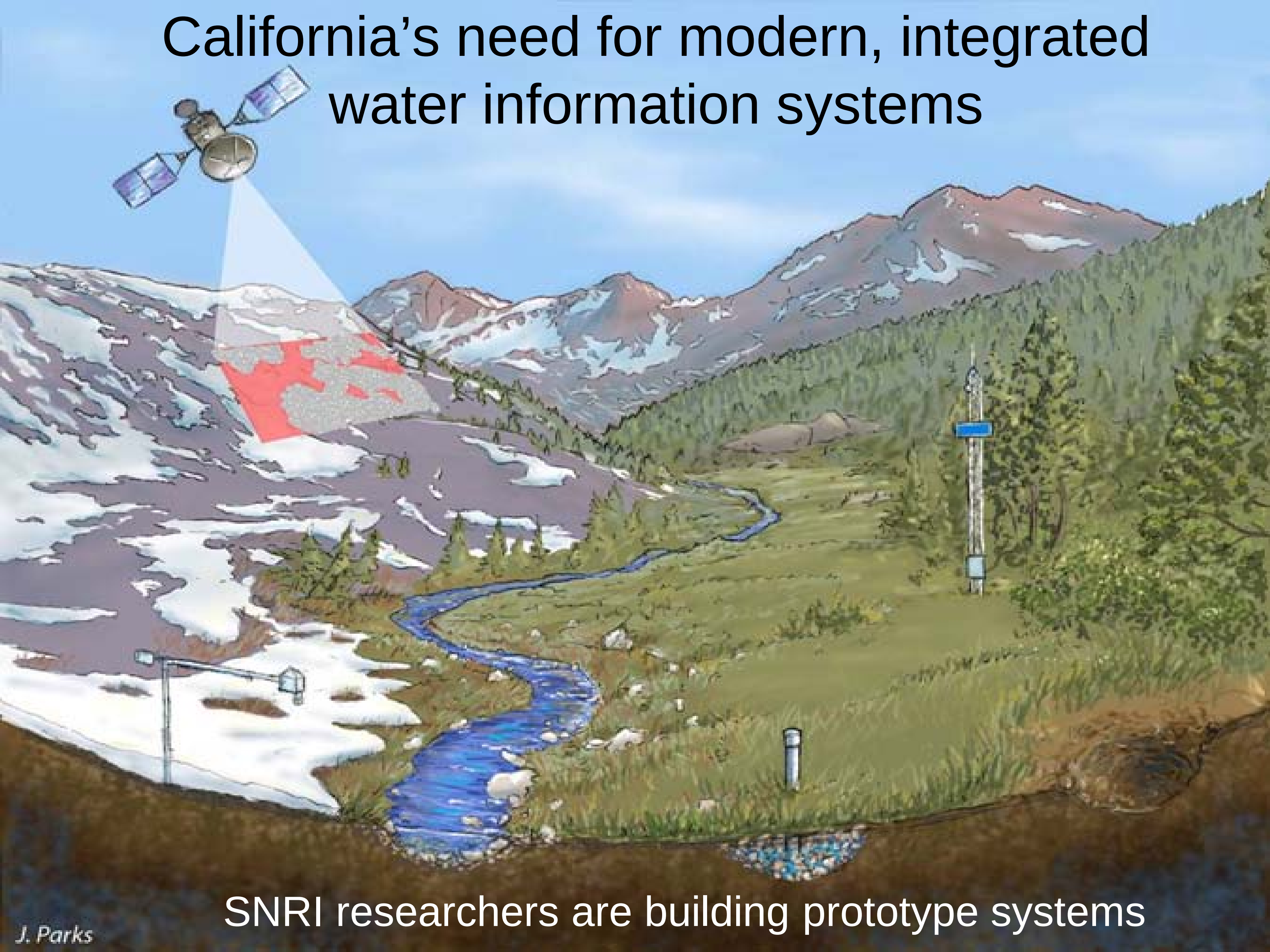
Similar patterns in other basins & years

Integrated measurements

Sierra Nevada field stations & instrument clusters with hydrologic & ecosystem research. Additional sites are planned. Single instrument locations, e.g. single meteorological stations or stream gages, are not shown.



California’s need for modern, integrated water information systems

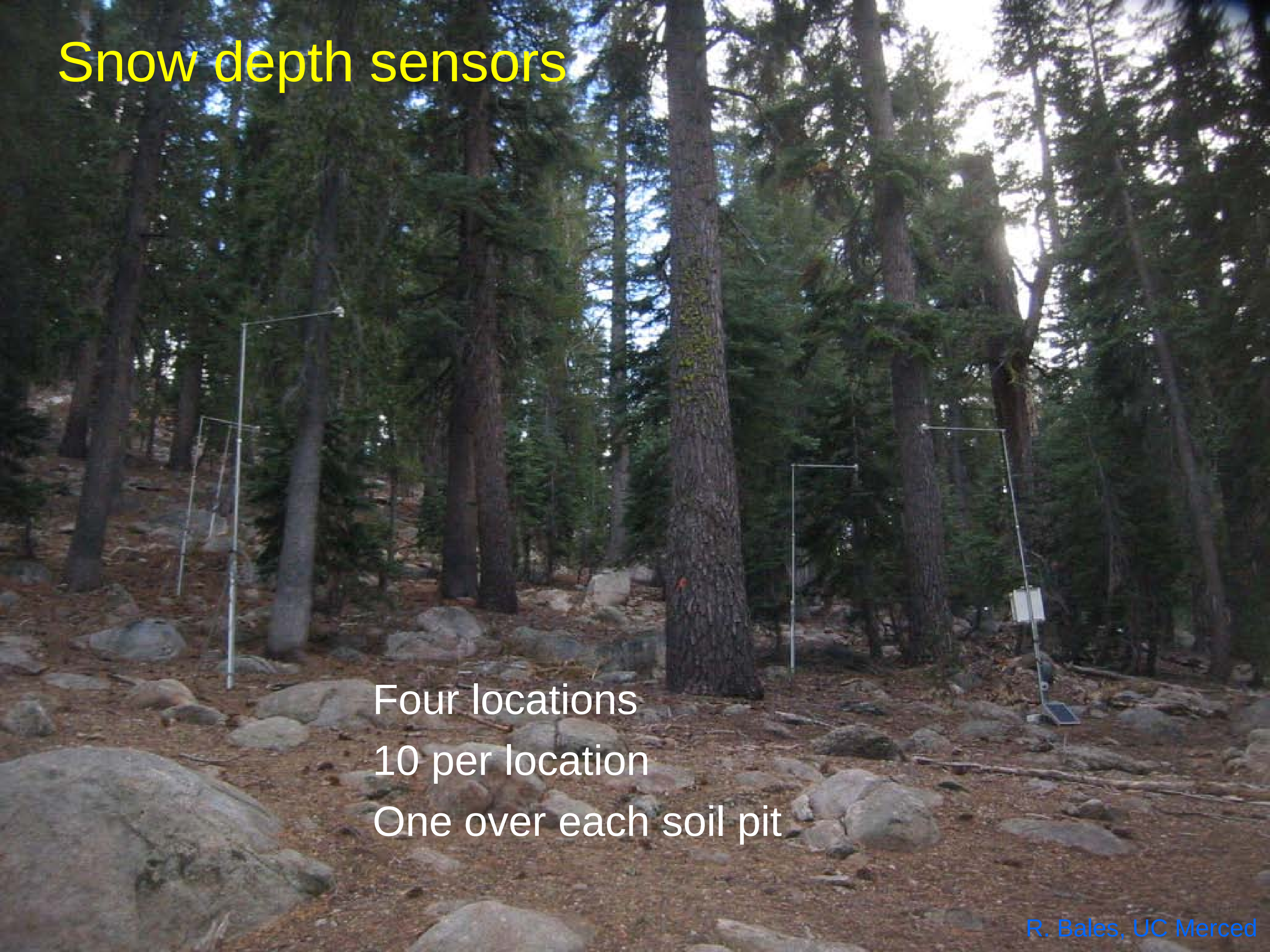


SNRI researchers are building prototype systems

Meteorological stations

- In cooperation w/ CA-DWR
- Data available on CDEC

Snow depth sensors



Four locations

10 per location

One over each soil pit

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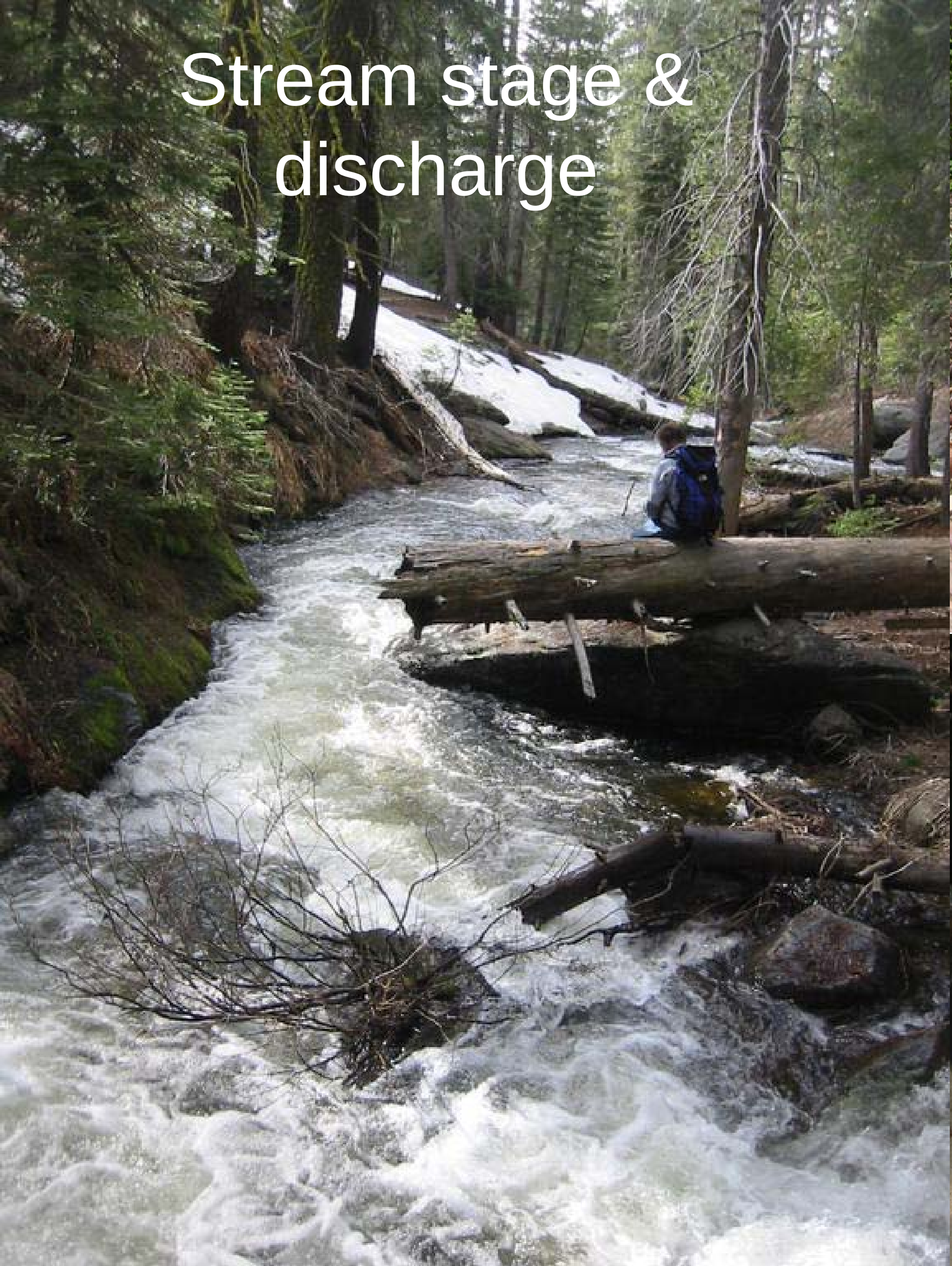
Soil moisture

Stream stage & discharge



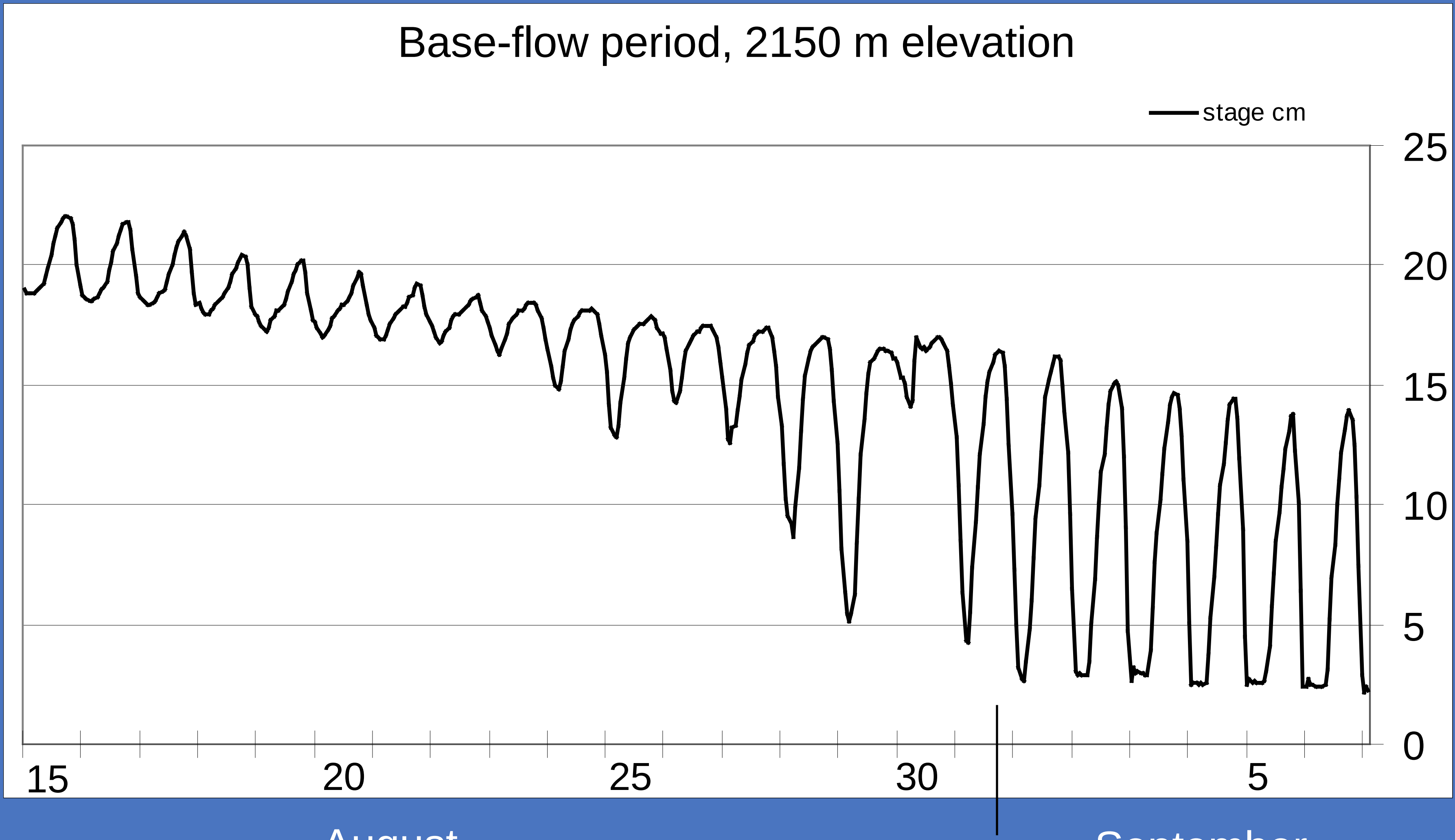
Meadow piezometers & wells


Stream instrumentation

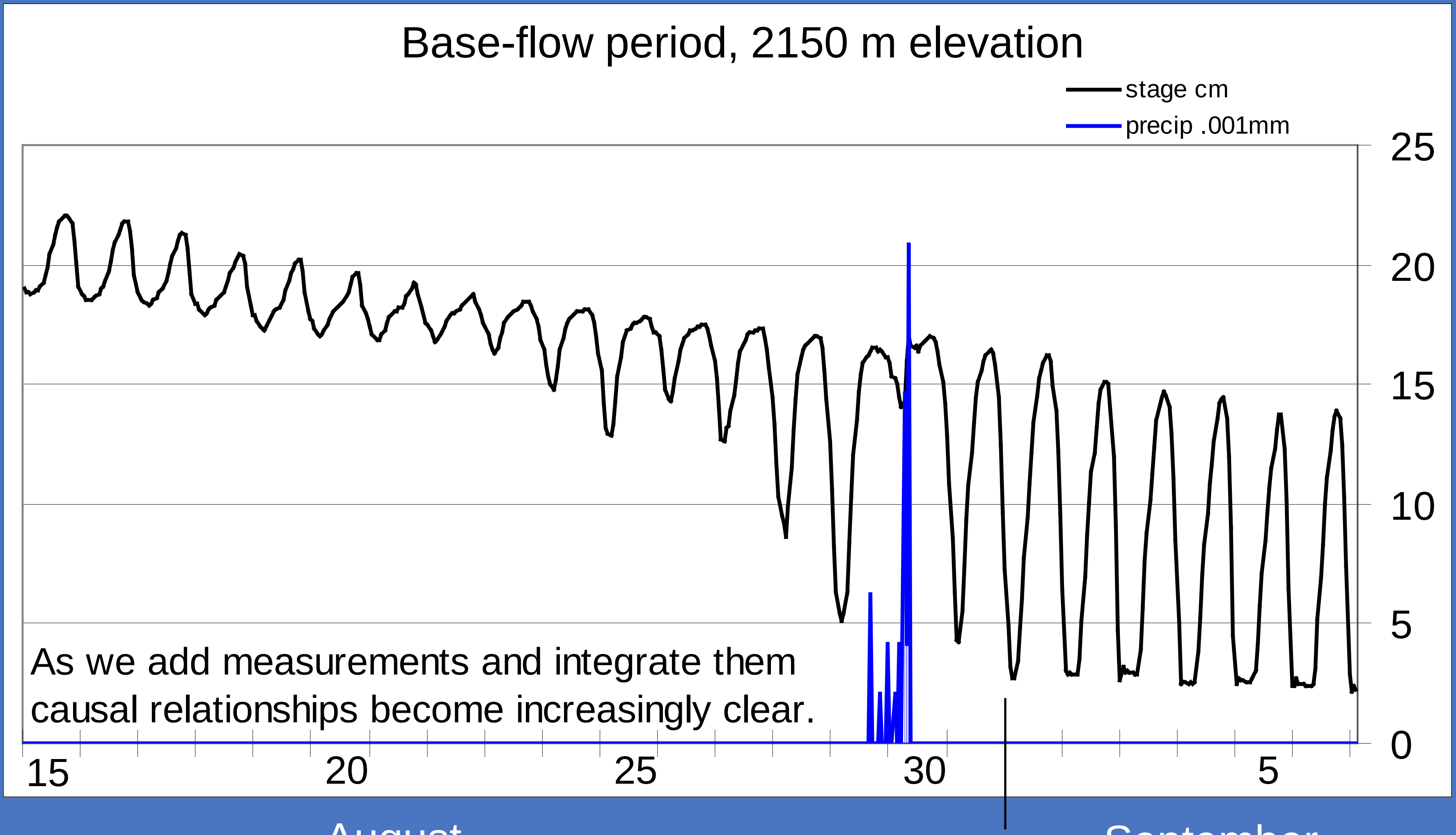

Sap flow


Flux tower

Wolverton Creek, Sequoia NP: stream stage

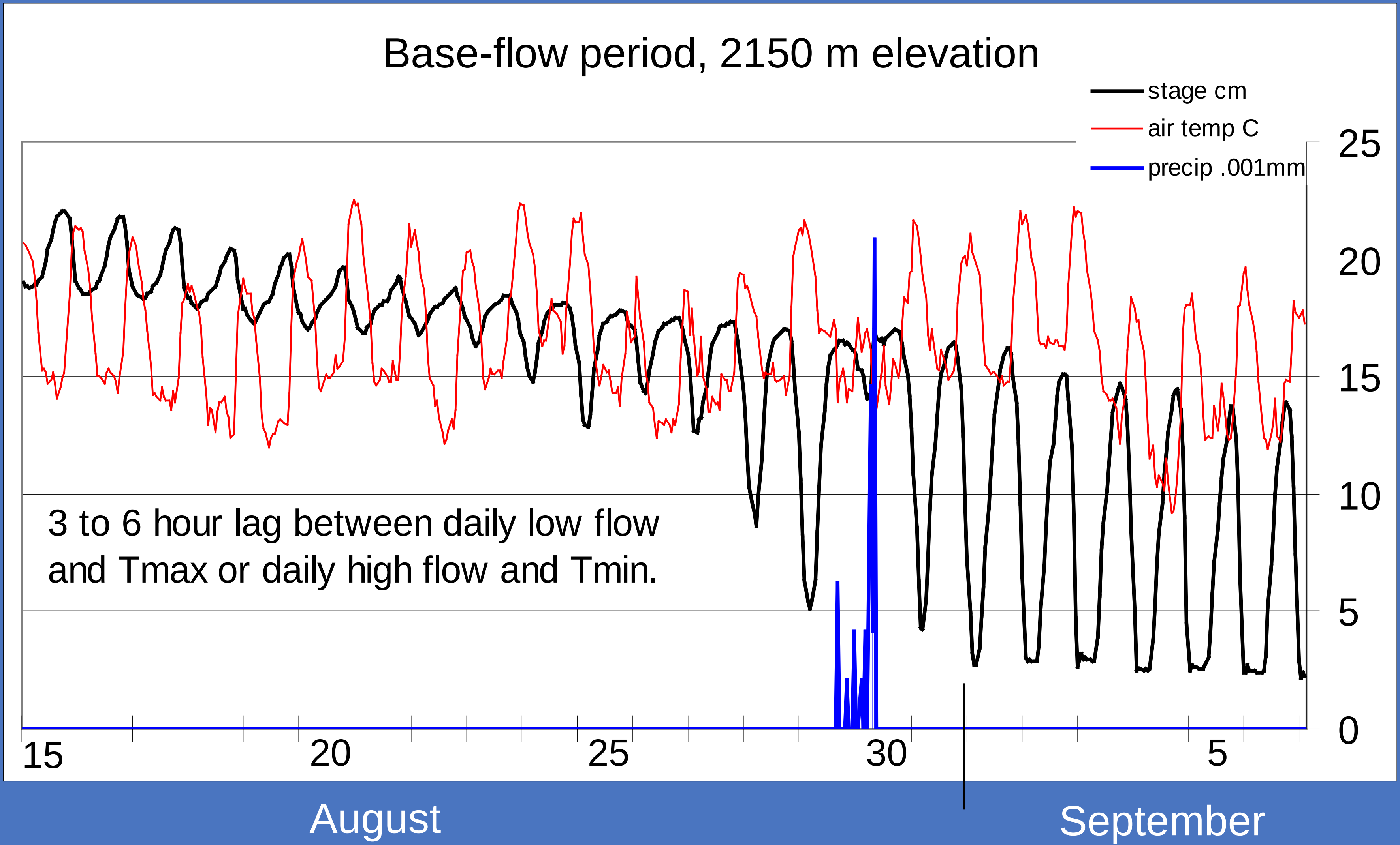


Wolverton Creek, Sequoia NP: stage & precipitation

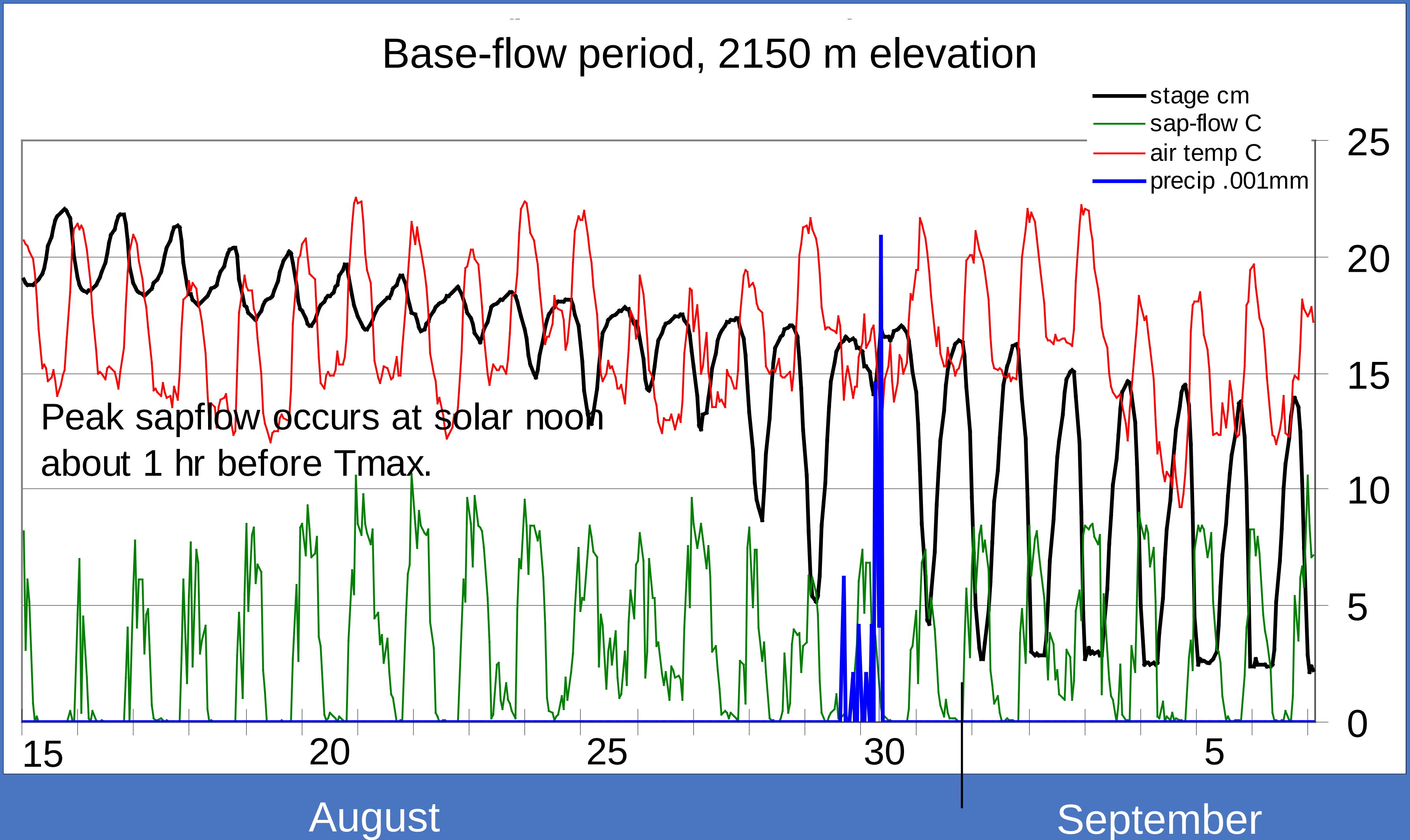


As we add measurements and integrate them causal relationships become increasingly clear.

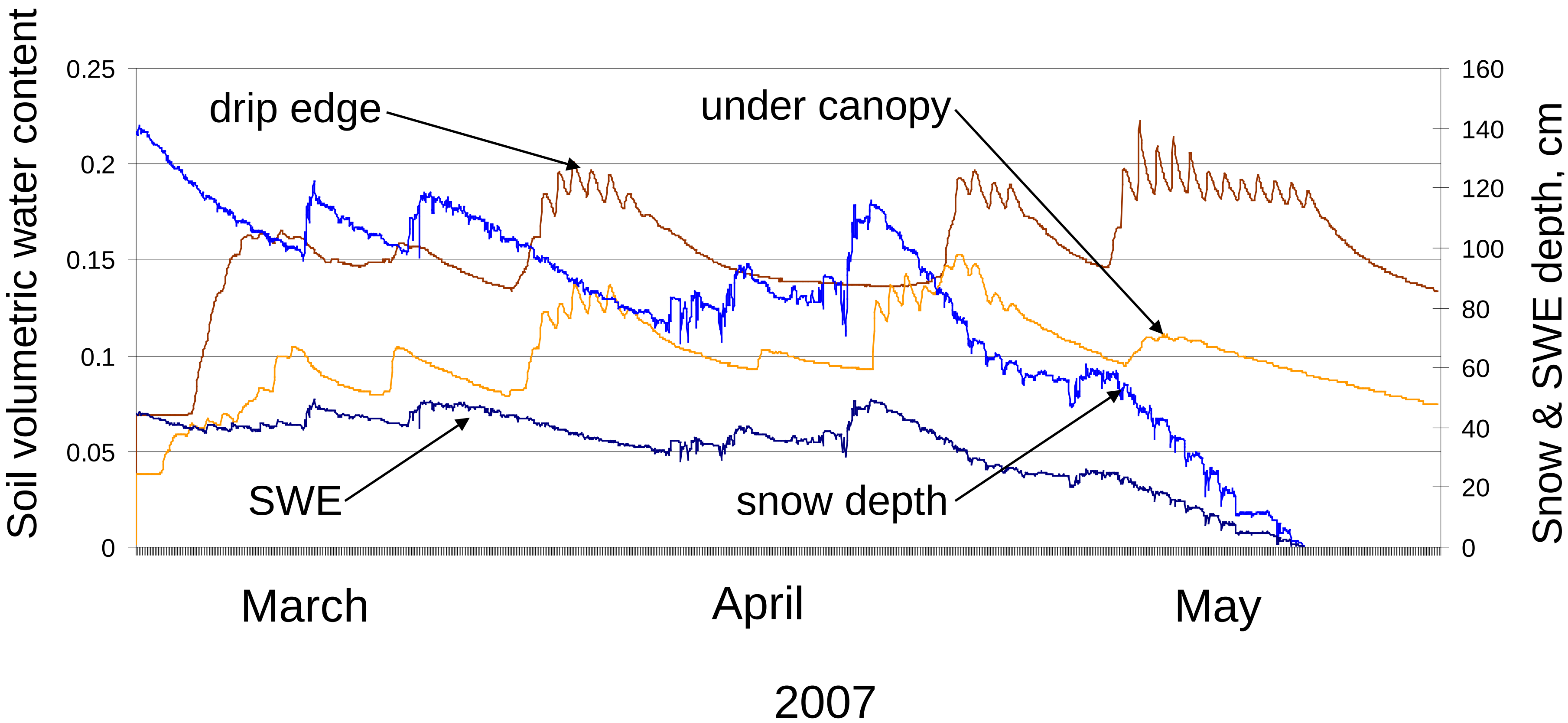
Wolverton Creek, Sequoia NP: stage, precip & air temperature



Wolverton Creek, Sequoia NP: stage, precip, air temp & sap flow

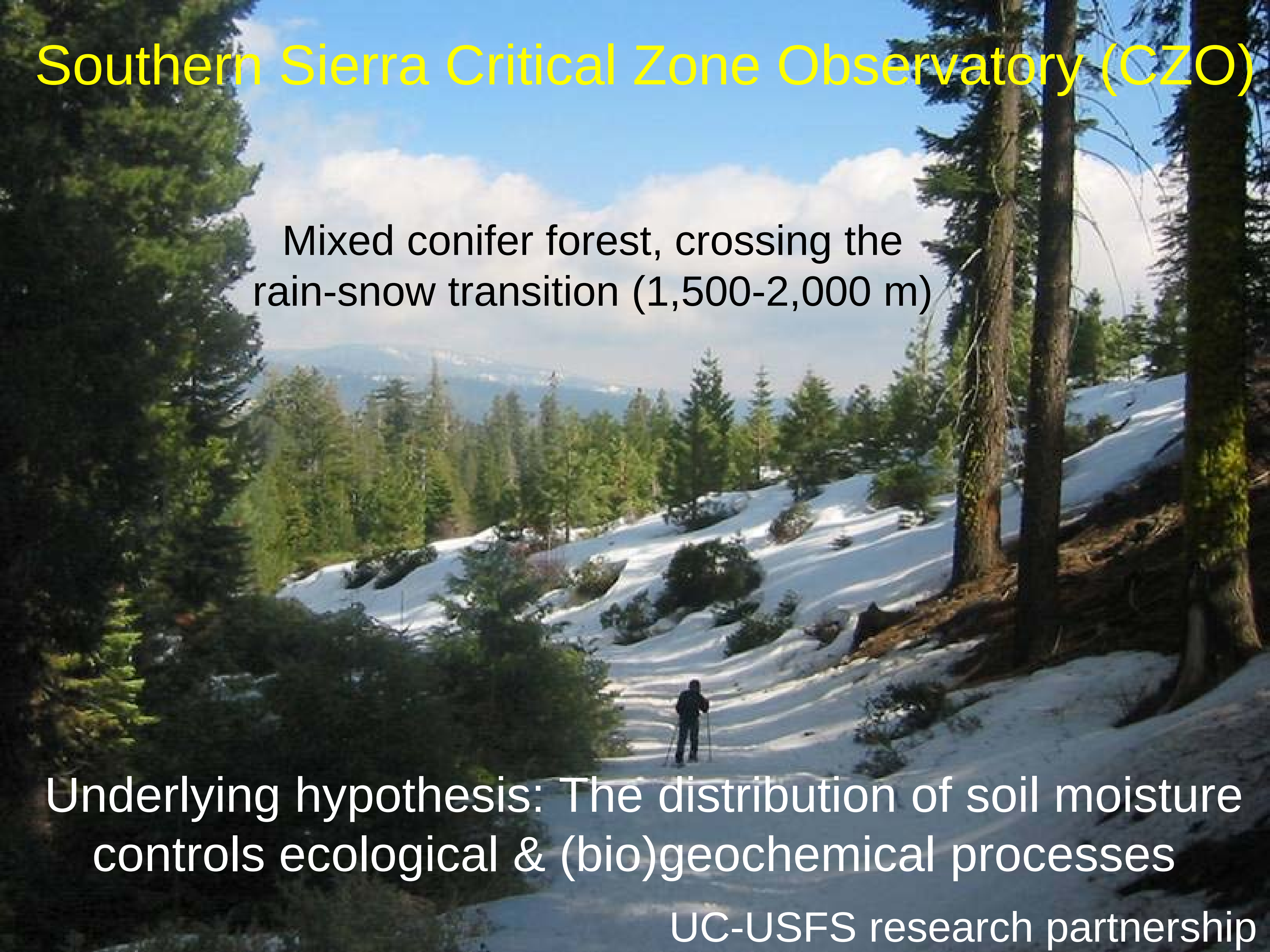


Soil volumetric water content response to snowmelt: Wolverton basin



Snow depth from acoustic sensors over each pit
Snow density from Panther Meadow snow course

Southern Sierra Critical Zone Observatory (CZO)



Mixed conifer forest, crossing the rain-snow transition (1,500-2,000 m)

Underlying hypothesis: The distribution of soil moisture controls ecological & (bio)geochemical processes

UC-USFS research partnership

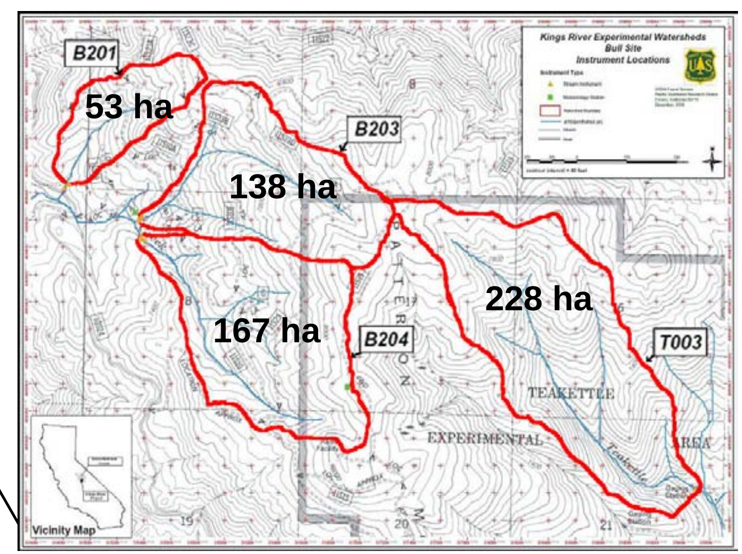
Kings River Experimental Watersheds

99 ha

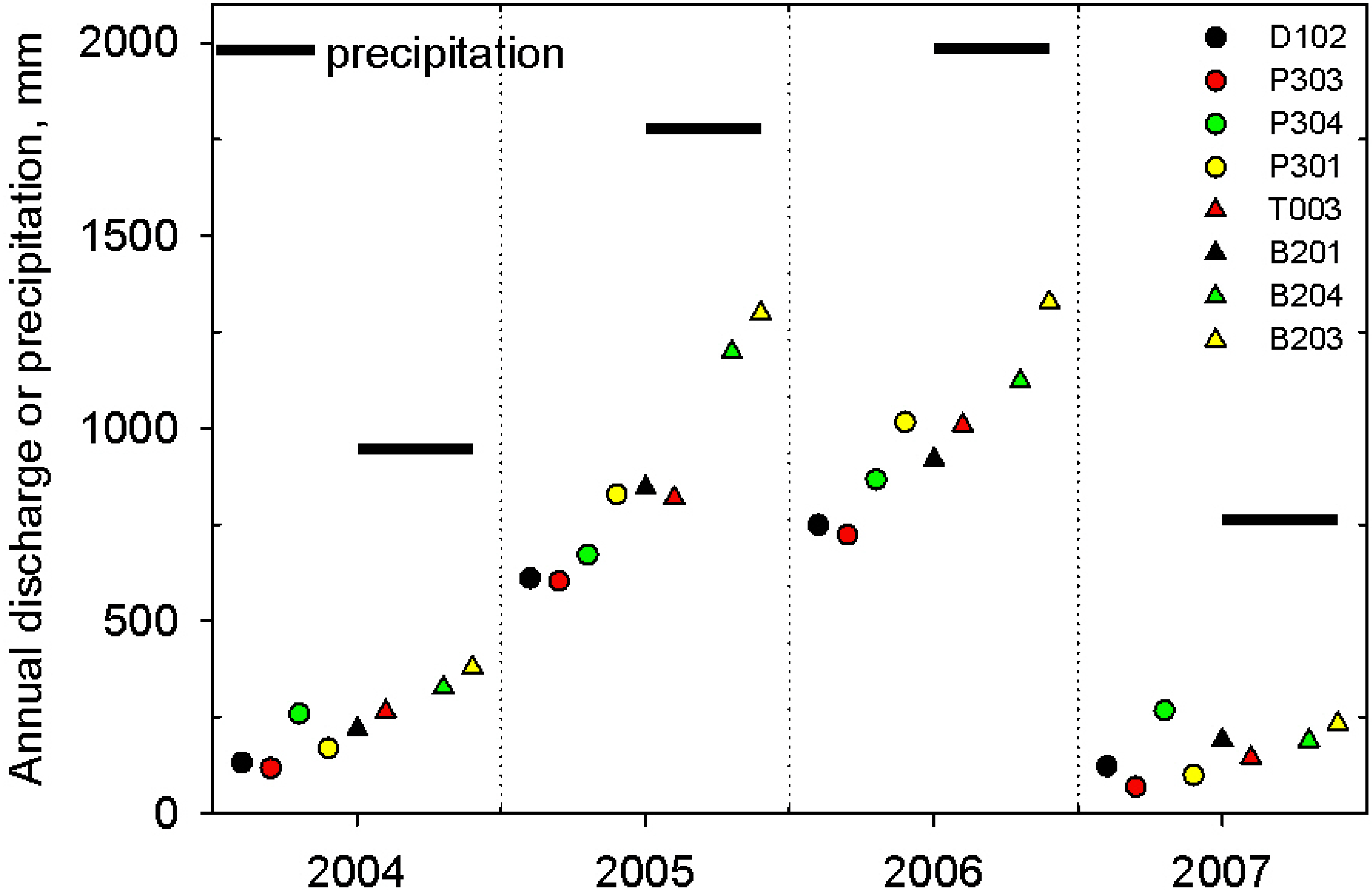
132 ha

49 ha

121 ha

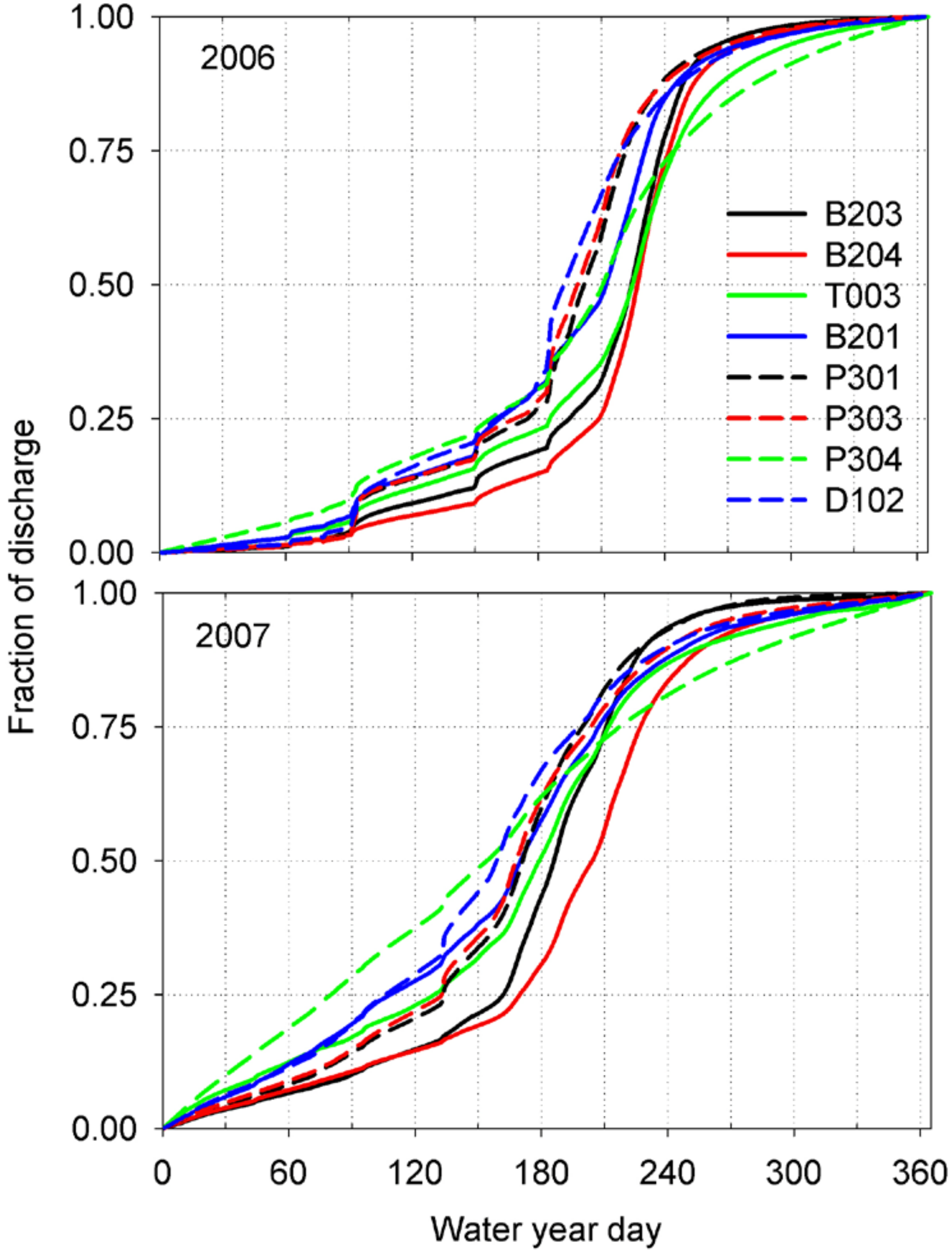


Annual stream discharge & water yield increased with elevation

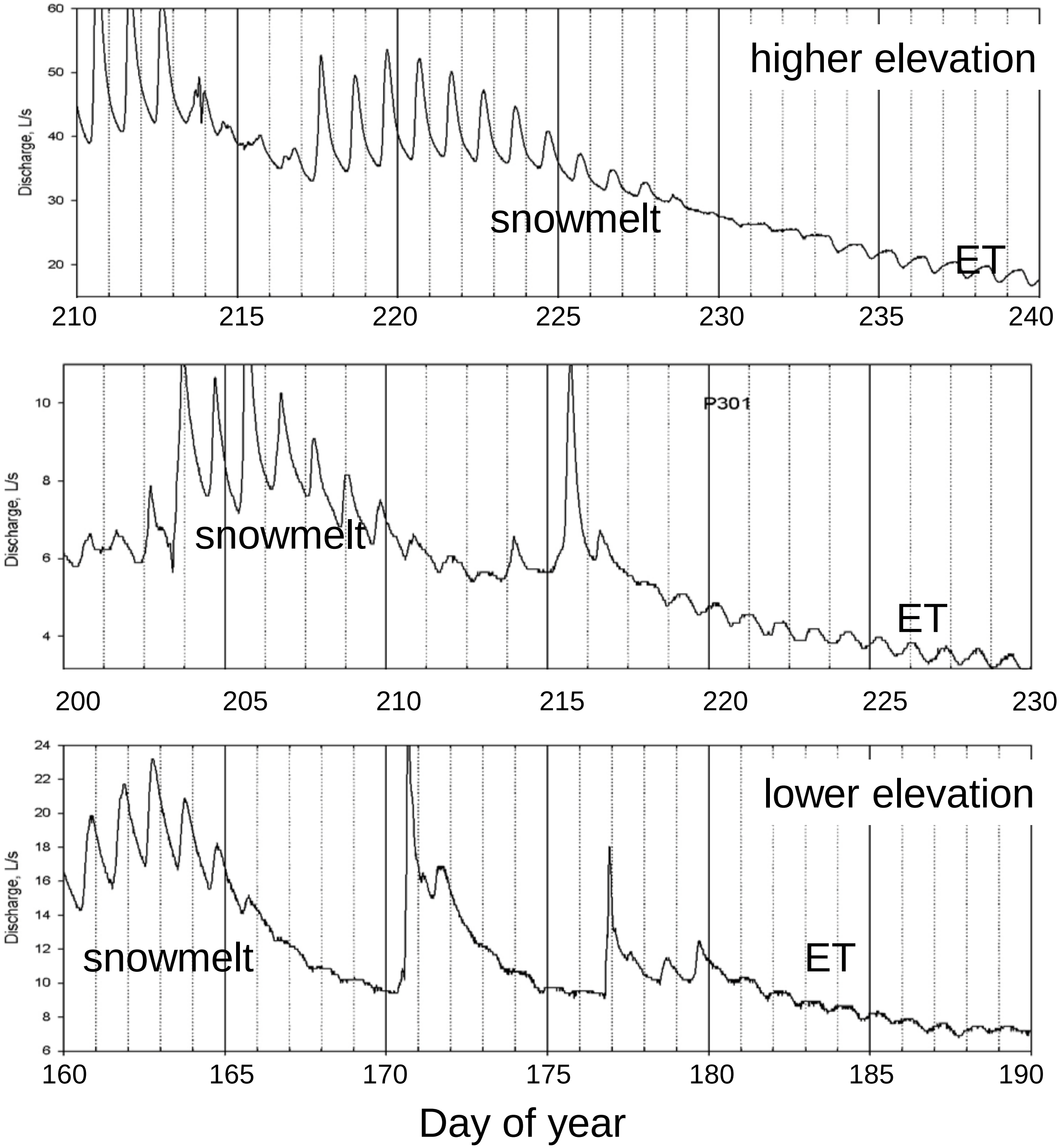


C. Hunsaker et al., in preparation

About 1 month lag in runoff across elevation gradient

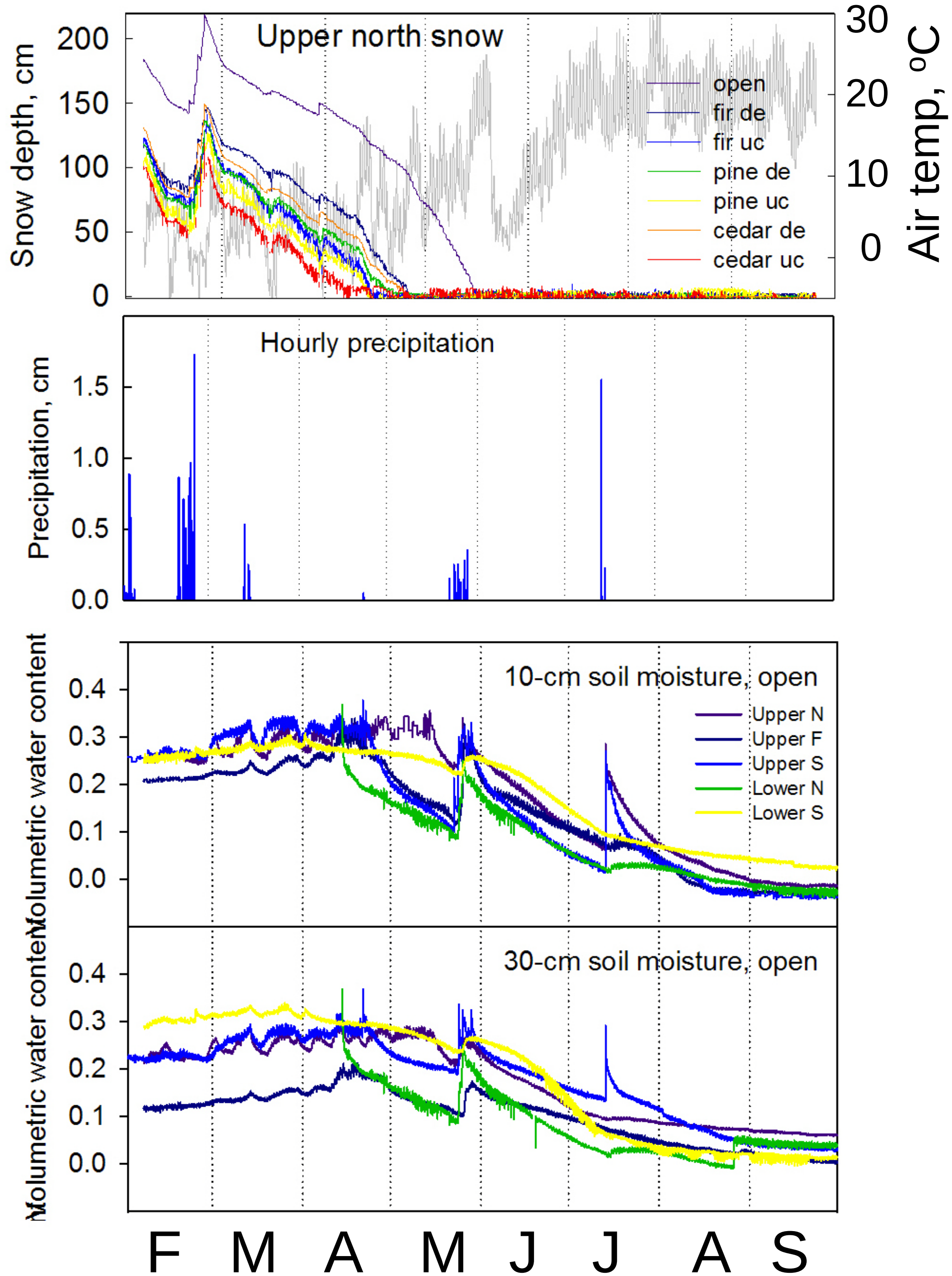


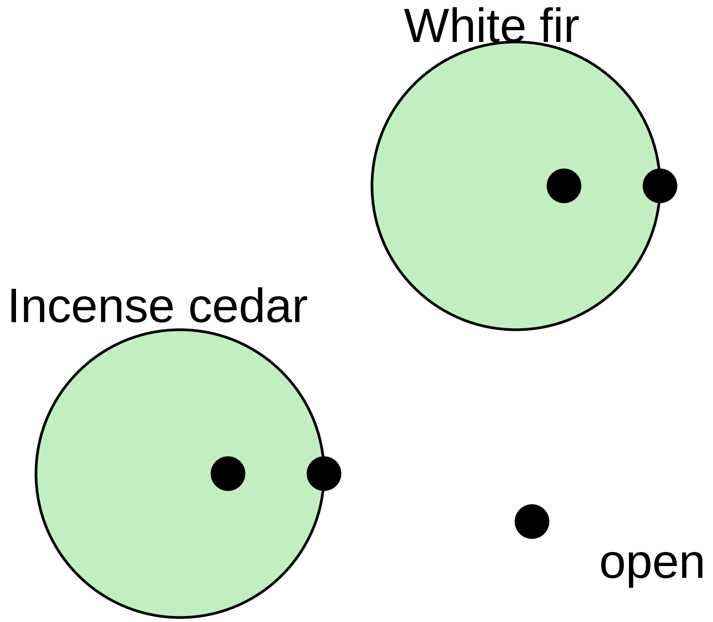
- Transition from rain–snow mix to snow dominated
- Can forest management manipulate energy balance to slow snowmelt



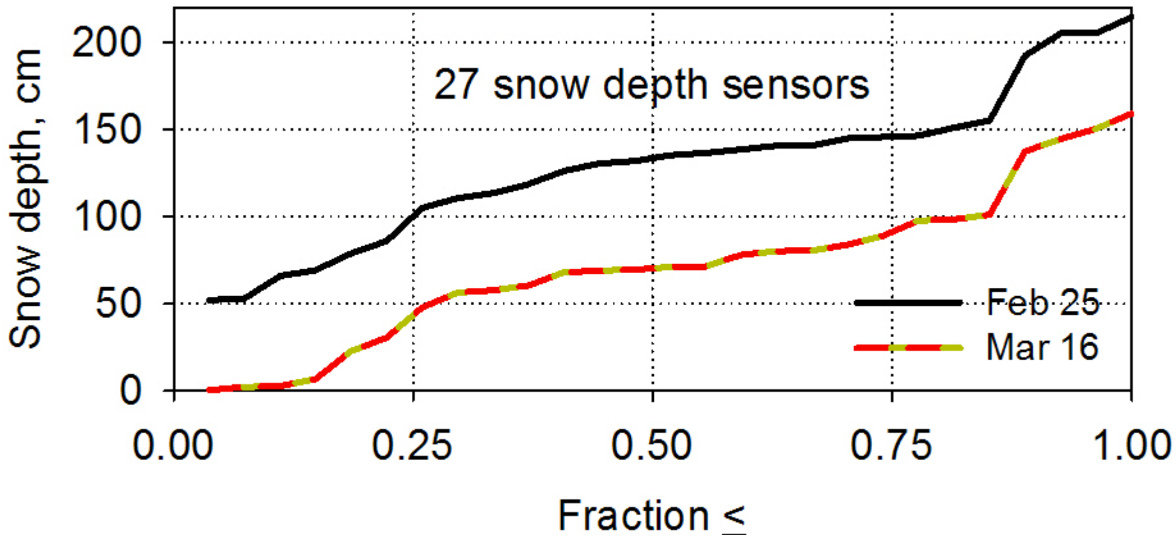
Transition from snowmelt to ET control in rain vs snow dominated stream

Soil moisture response to snowmelt & rain

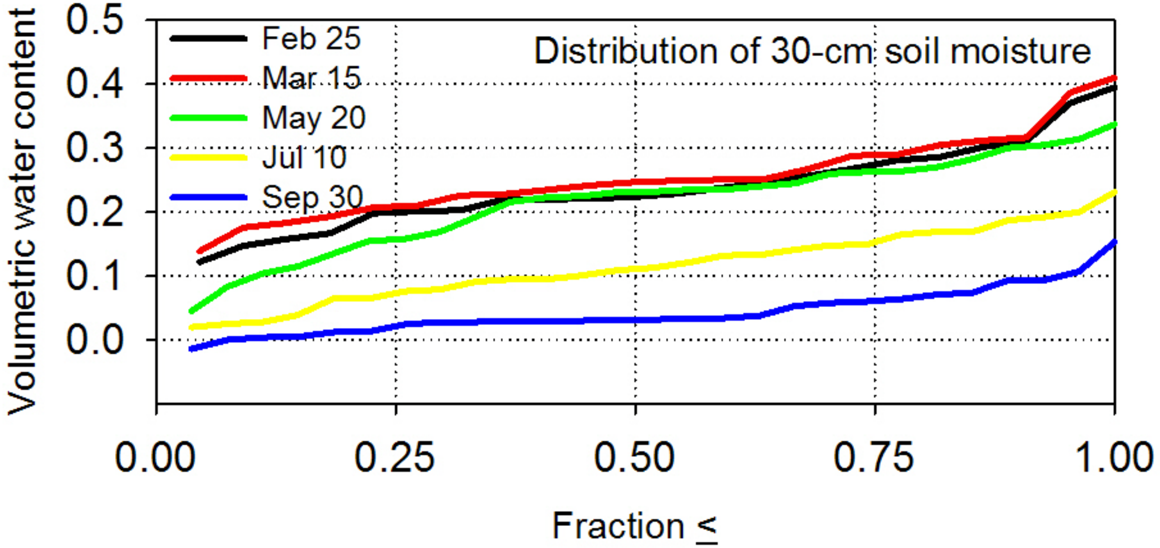




Linking snow & soil moisture



Peak snow depth occurred on Feb 25; 3 weeks later over 1/3 of the snow had melted



Soil became wetter as snowmelt progressed, then dried across all sites.

Summary re water cycle & climate change

Warming by +2 to +6ºC

Uncertain precipitation changes, possibly decline

Significant changes just in response to temperatures

– rain-vs-snow storms *
– snowpack amounts *
– snowmelt timing *
– flood risk
– streamflow timing *
– low baseflows
– growing seasons *
– recharge?
– drier soil in summer

Already observed (*)

Remote sensing work supported by NASA

Acknowledgements: Jeff Dozier (UCSB) & Tom Painter (U. Utah)

Ground-based work supported by NSF & State of California

SNRI Mountain Hydrology Group: Martha Conklin, Bob Rice, Xiande Meng, Sarah Martin, Peter Kirchner, Ryan Lucas, Phil Saksa, Matt Meadows

Ostrander, YNP