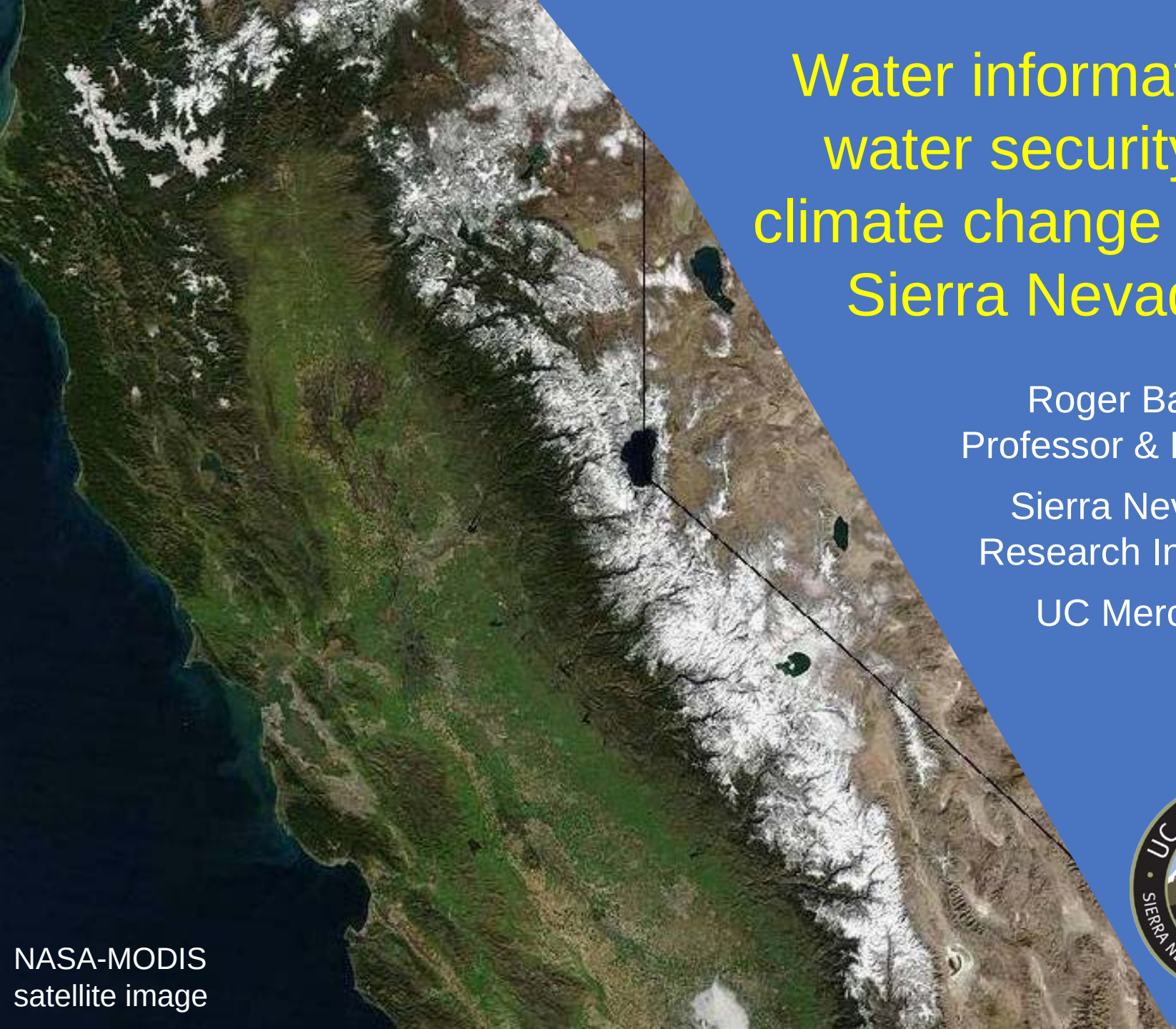


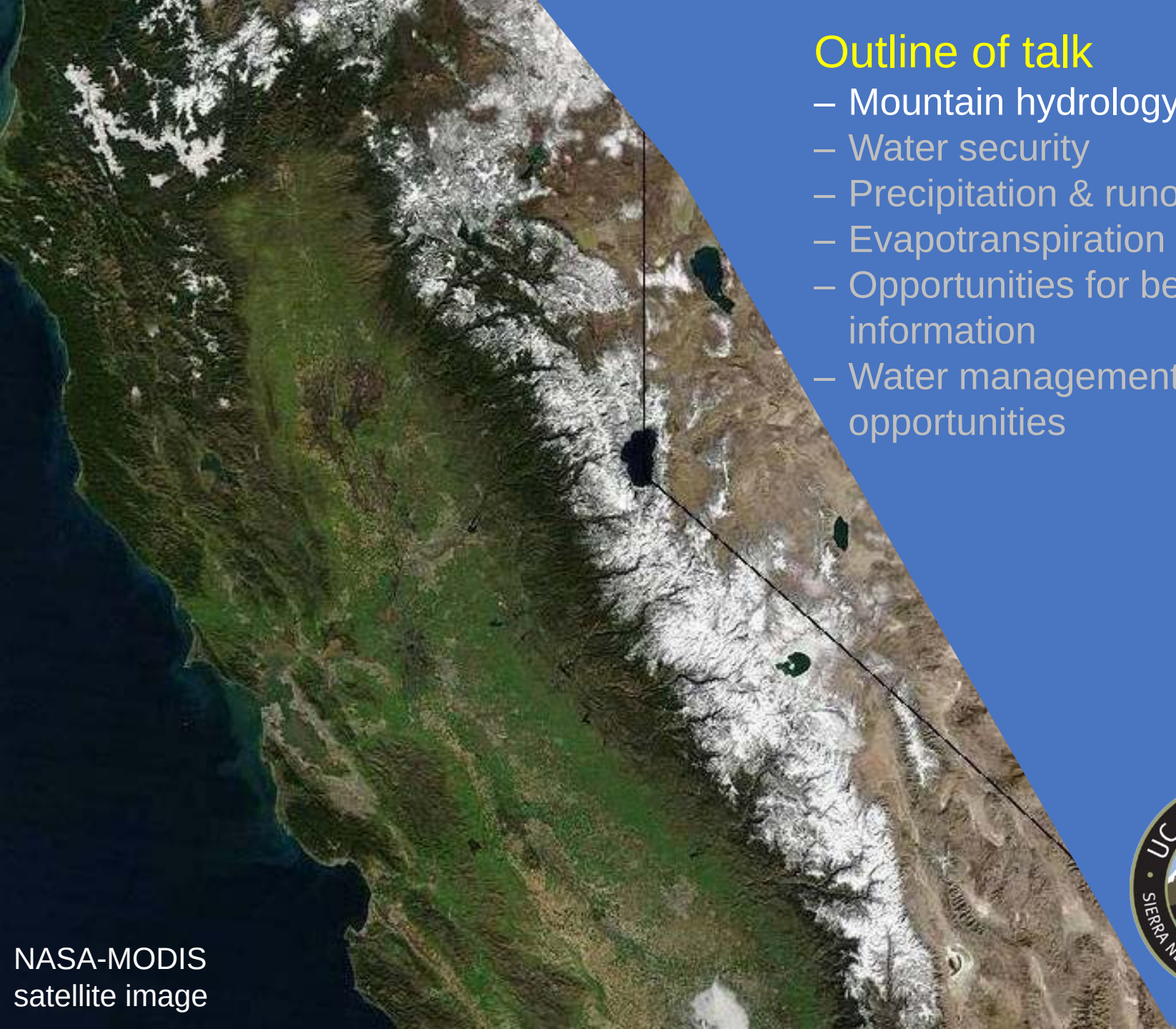
Water information, water security & climate change in the Sierra Nevada

Roger Bales
Professor & Director

Sierra Nevada Research Institute

UC Merced

NASA-MODIS satellite image



Outline of talk

- Mountain hydrology
- Water security
- Precipitation & runoff
- Evapotranspiration & runoff
- Opportunities for better water information
- Water management opportunities

NASA-MODIS satellite image

UC MERCED SNRI
SIERRA NEVADA RESEARCH INSTITUTE

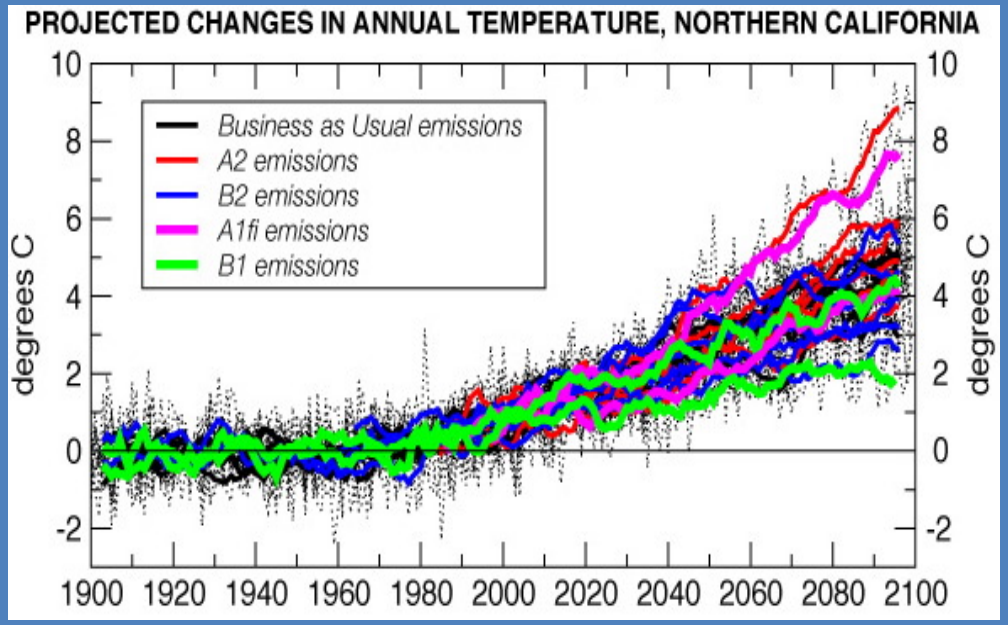
Much of the water supply for the semi-arid Western U.S. derives from mountain snowpacks

Warming by +2 to +6°C drives significant changes:

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

Precipitation changes?

Already observed (*)

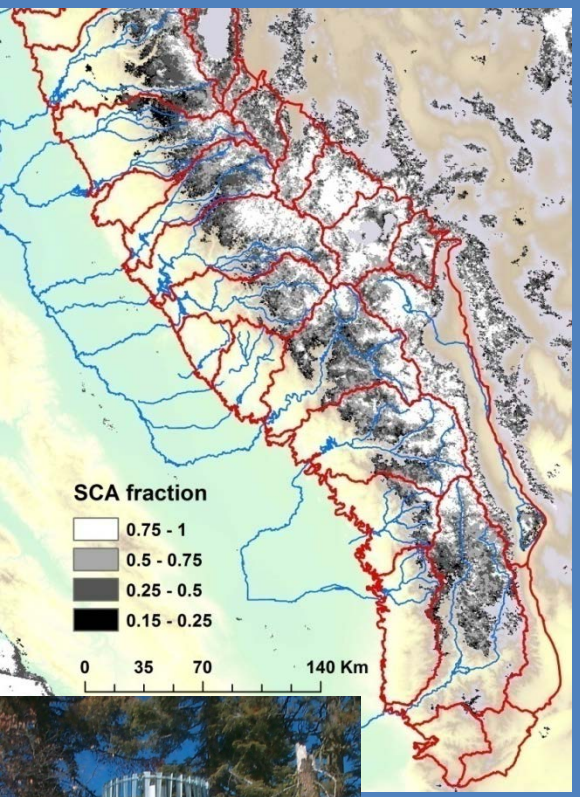


Fast facts

- About 2/3 of the precipitation that falls on the Sierra Nevada is evaporated/transpired by vegetation & 1/3 runs out in rivers
- In an average year, the Sierra Nevada receives 27% of the state's annual precipitation & provides more than 60% of the state's consumptive use of water

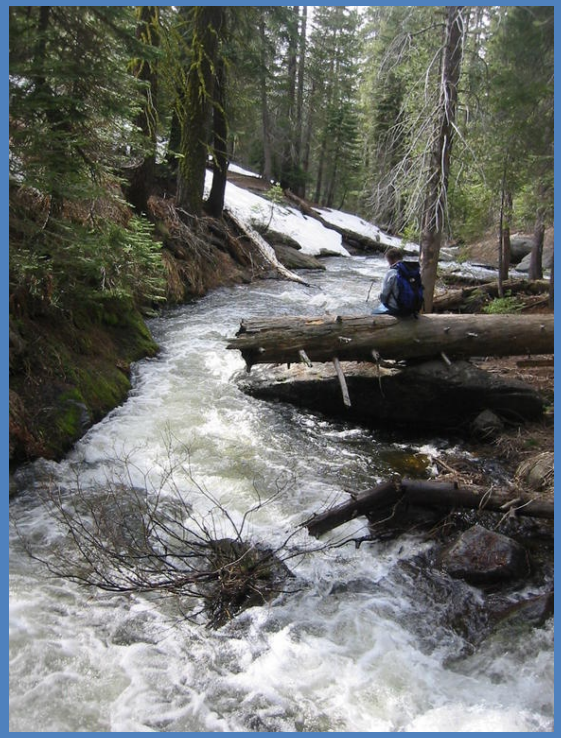
Basic water balance

Precipitation = Evapotranspiration + Runoff



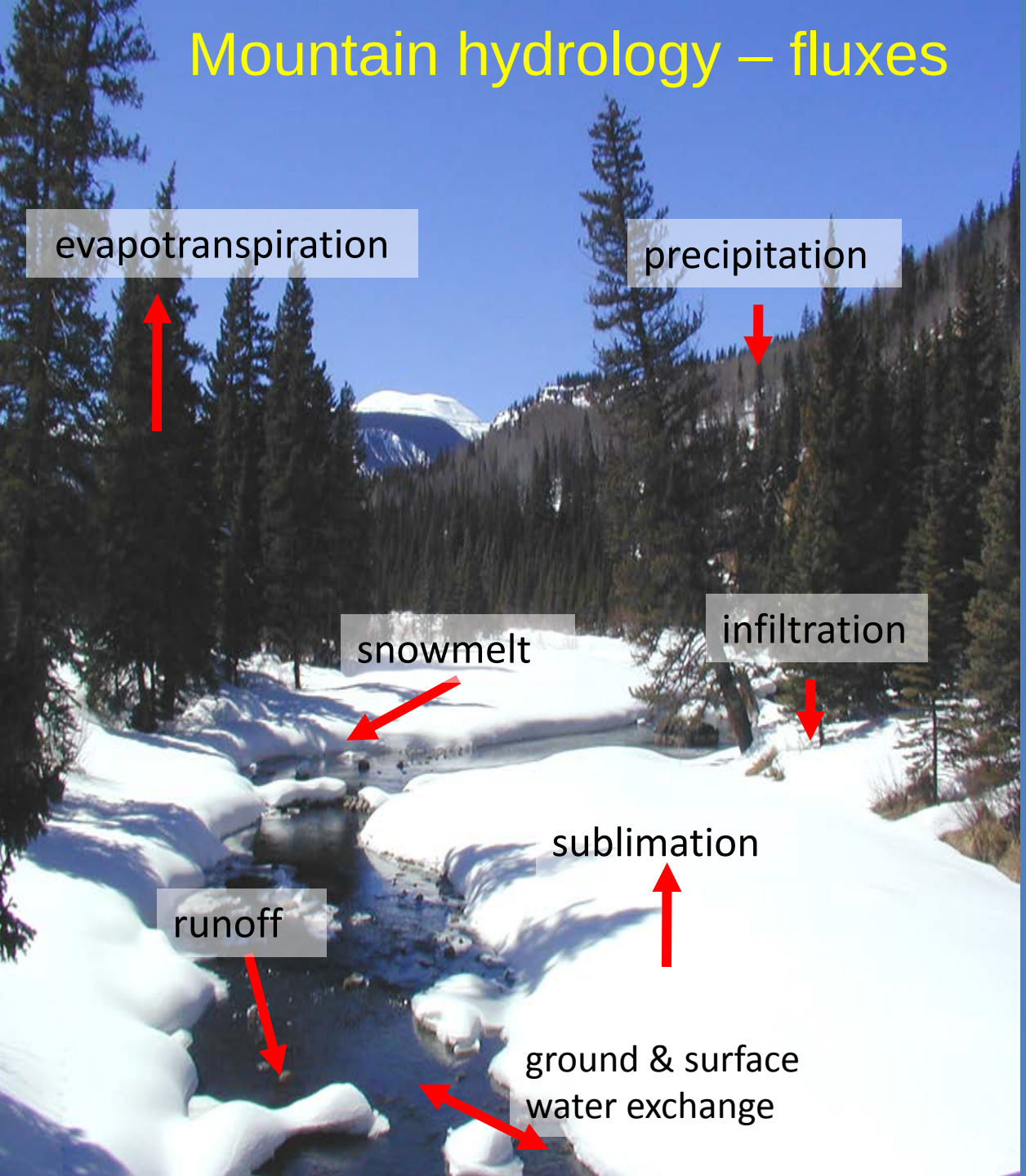
=

+



<u>Evapotranspiration</u> refers to evaporation plus water use by vegetation

Mountain hydrology – fluxes

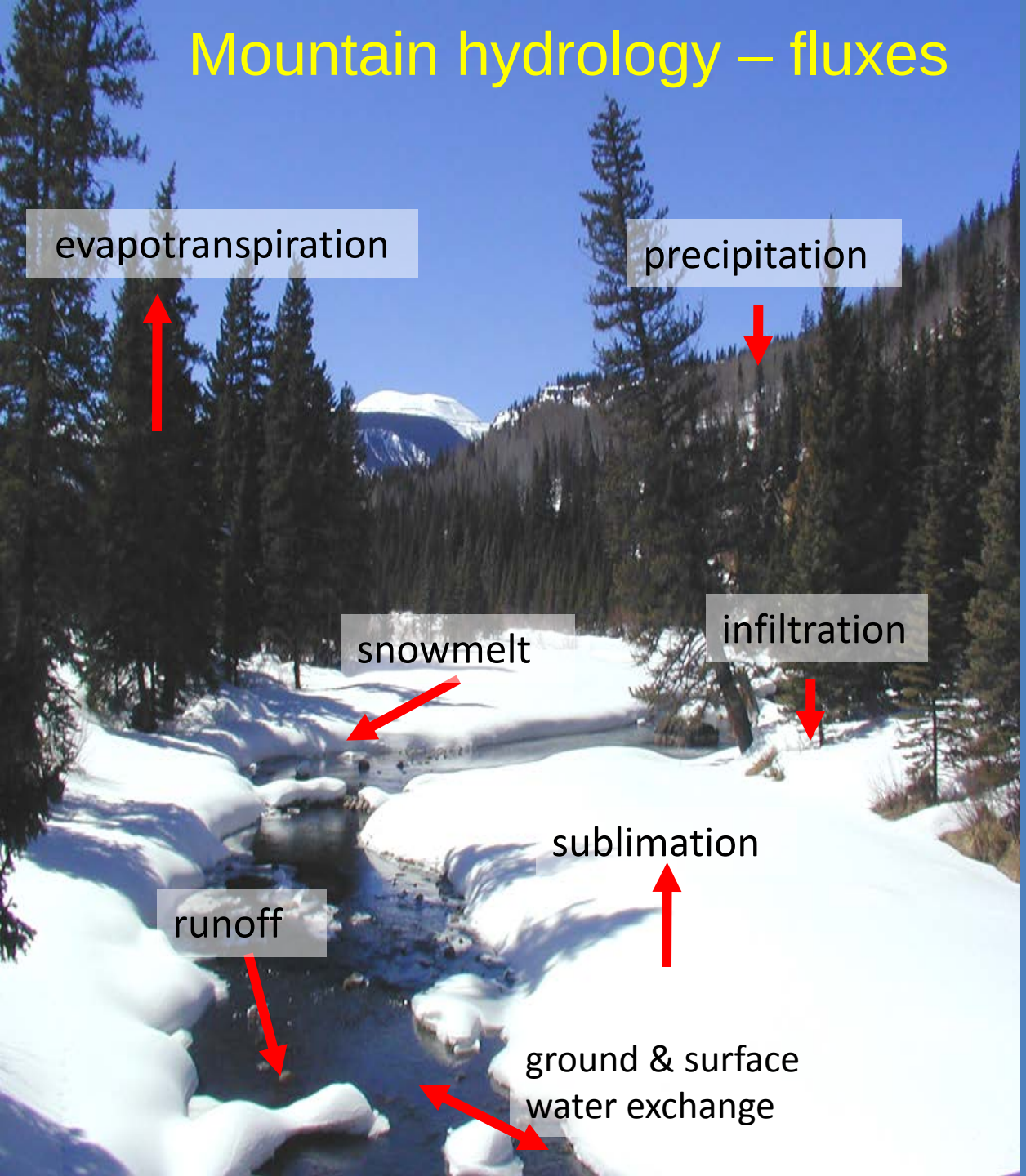


Myth:

We can, with a high degree of skill, estimate or predict the magnitude of these fluxes & reservoirs of water

Reservoirs:
Snowpack storage
Soil-water storage

Mountain hydrology – fluxes



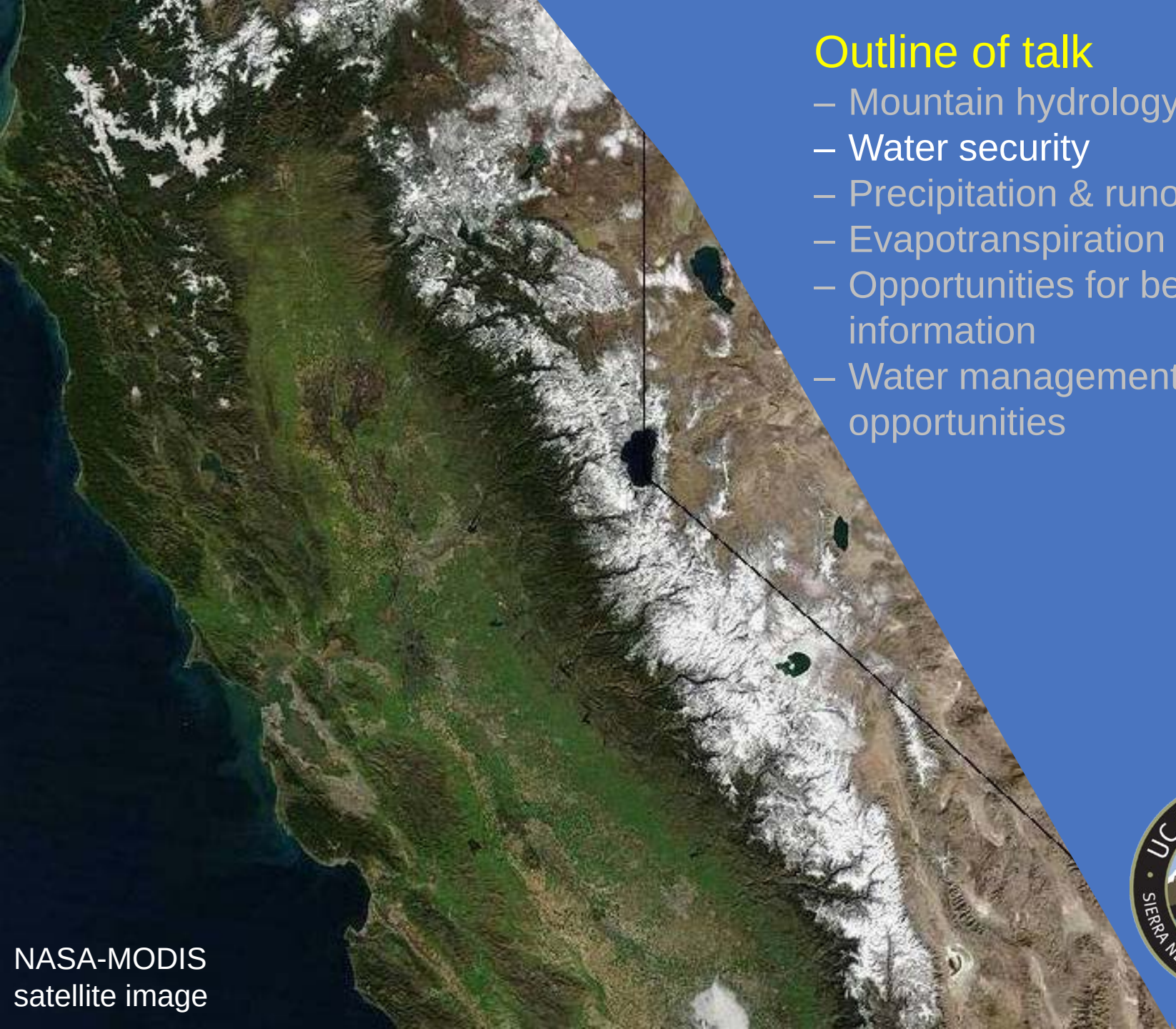
My bias:

The basis for improved predictions & better understanding is new measurements

Reservoirs:

Snowpack storage

Soil-water storage



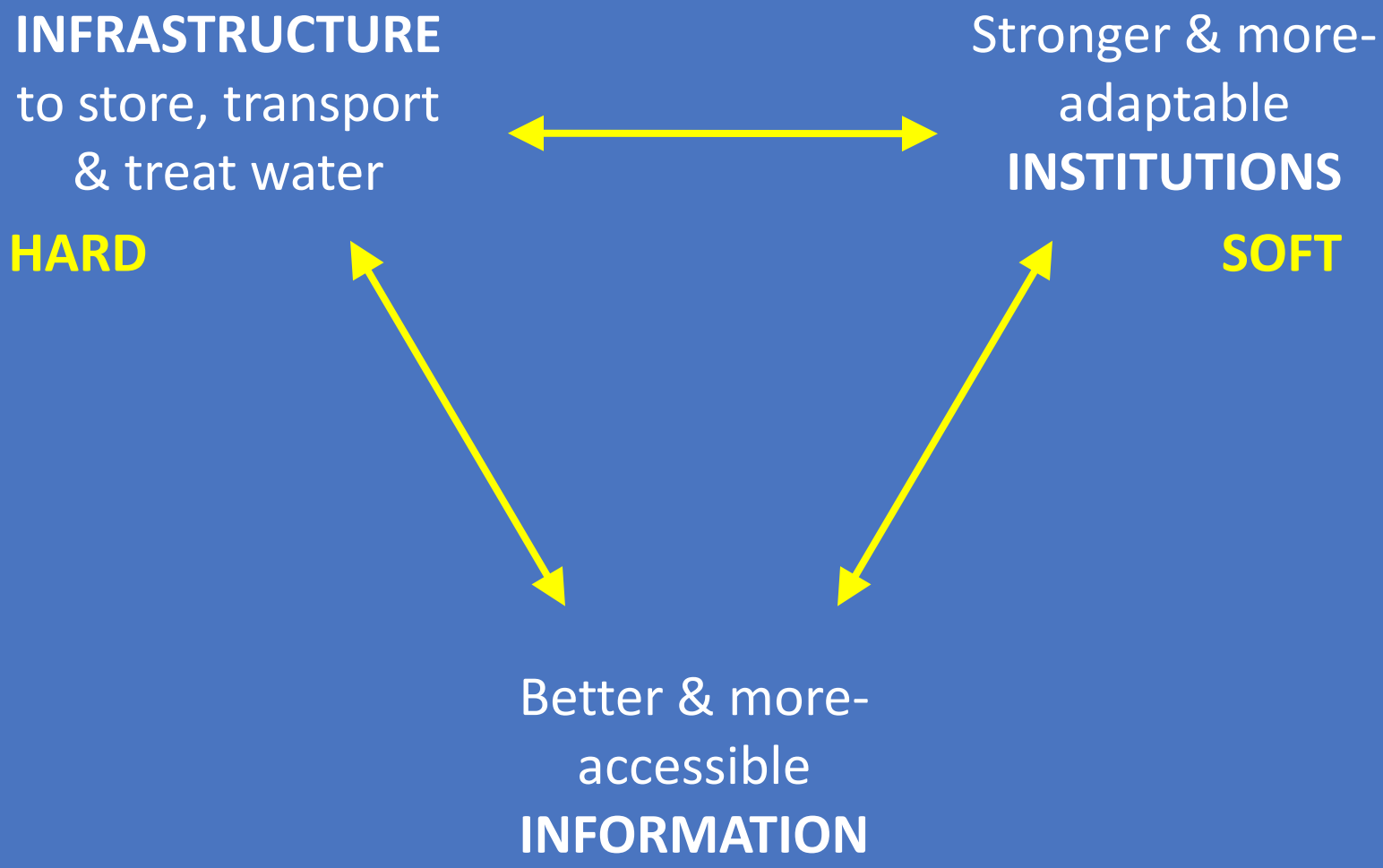
Outline of talk

- Mountain hydrology
- Water security
- Precipitation & runoff
- Evapotranspiration & runoff
- Opportunities for better water information
- Water management opportunities

NASA-MODIS
satellite image

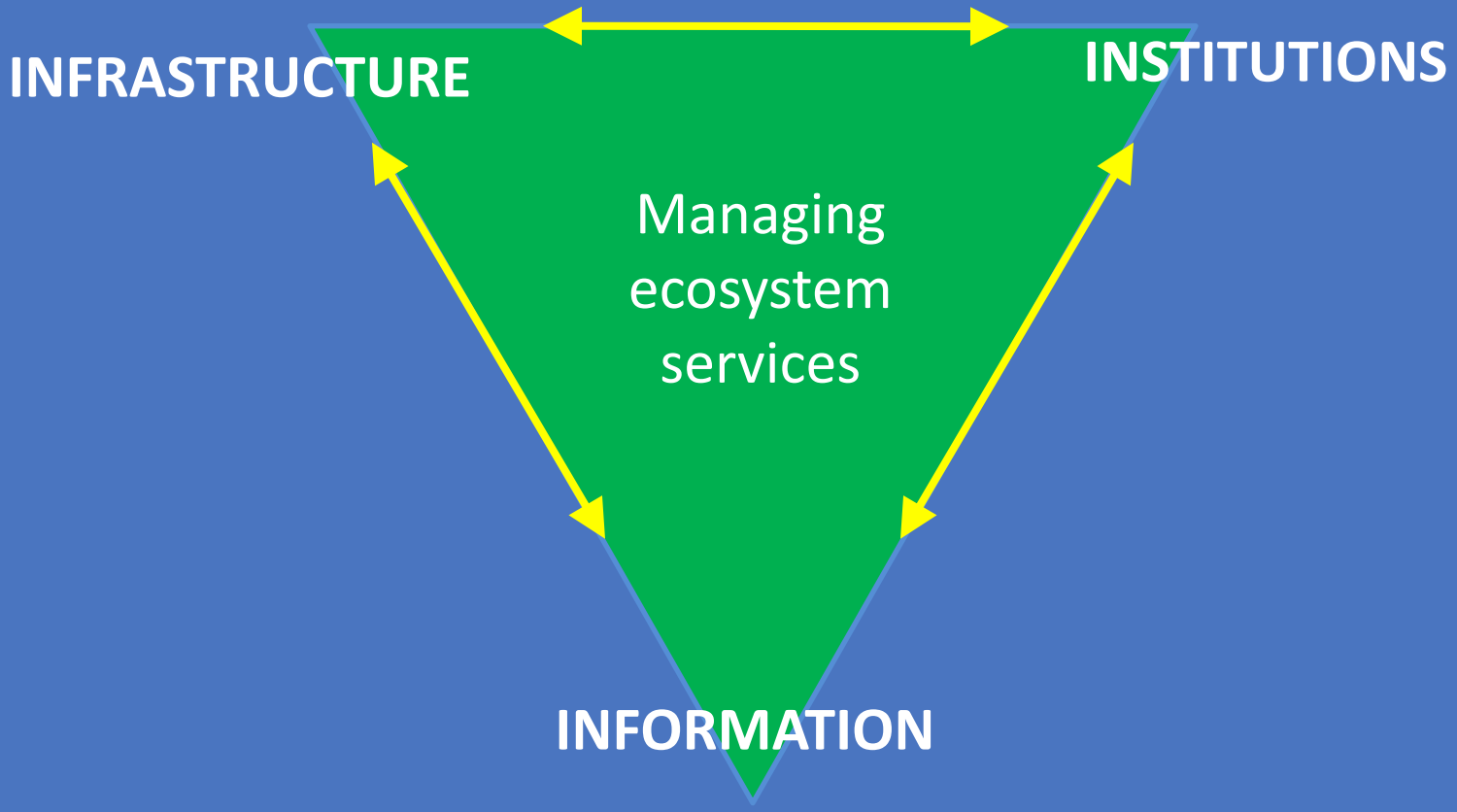
UC MERCED SNRI
SIERRA NEVADA RESEARCH INSTITUTE

Making a water-secure world – the three I's



Water security: the reliable availability of an acceptable quantity & quality of water for health, livelihoods & production, coupled w/ an acceptable level of water-related risks

Making a water-secure world – the three I's



Managing water is central to climate preparedness; and water management translates into managing ecosystem services (e.g. forest vegetation management).

Water security lies at the heart of adaptation to climate change

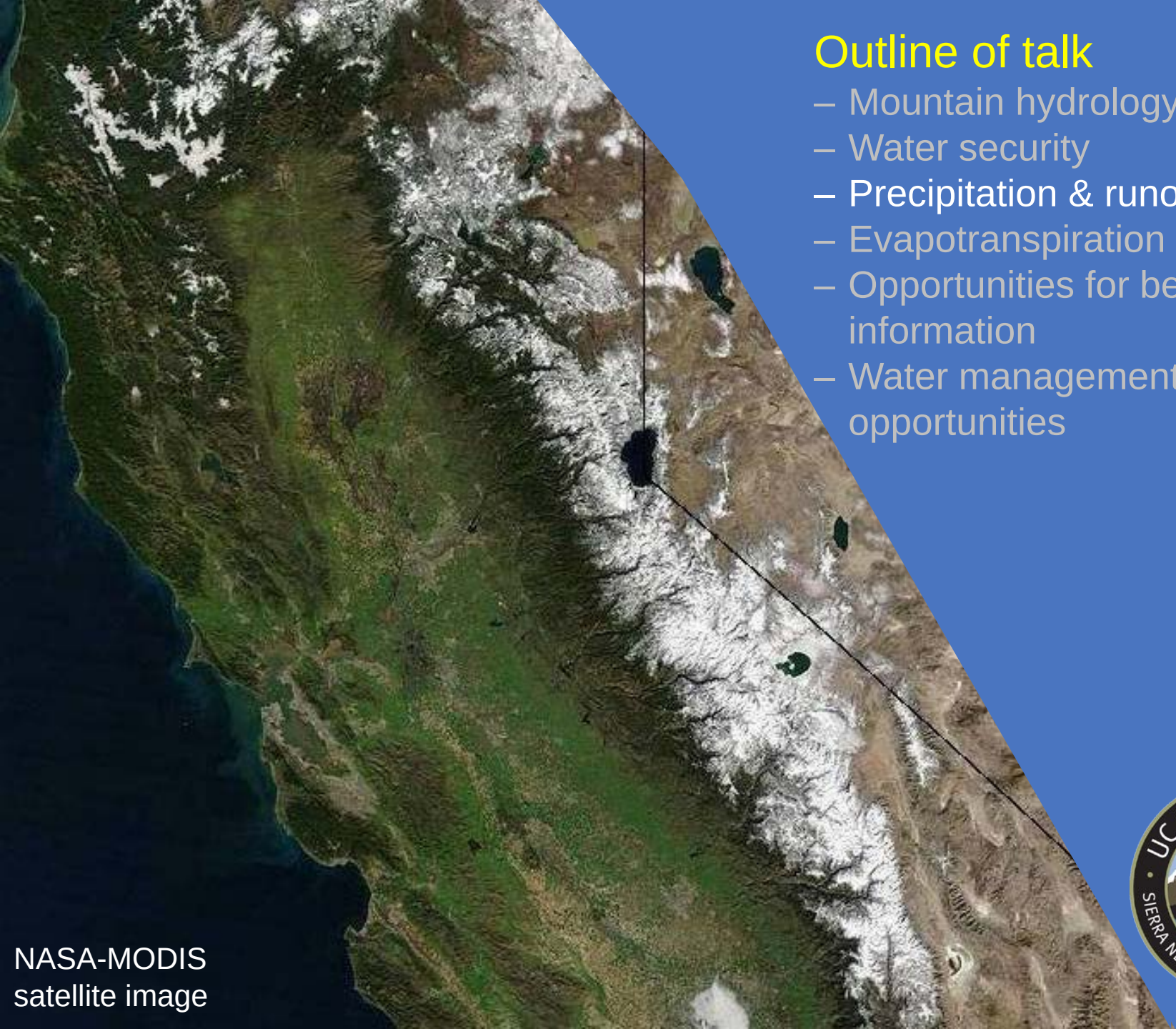
Includes both:

- 'hard' options to capture & control water
- 'soft' tools to manage demand as well as increase supply, e.g. water allocation, conservation, efficiency & land-use planning

General feeling in the water community that soft opportunities will be insufficient

What California is doing:

- Planning for infrastructure
- Collaboration & integration in planning, management
- More information-intensive decision support



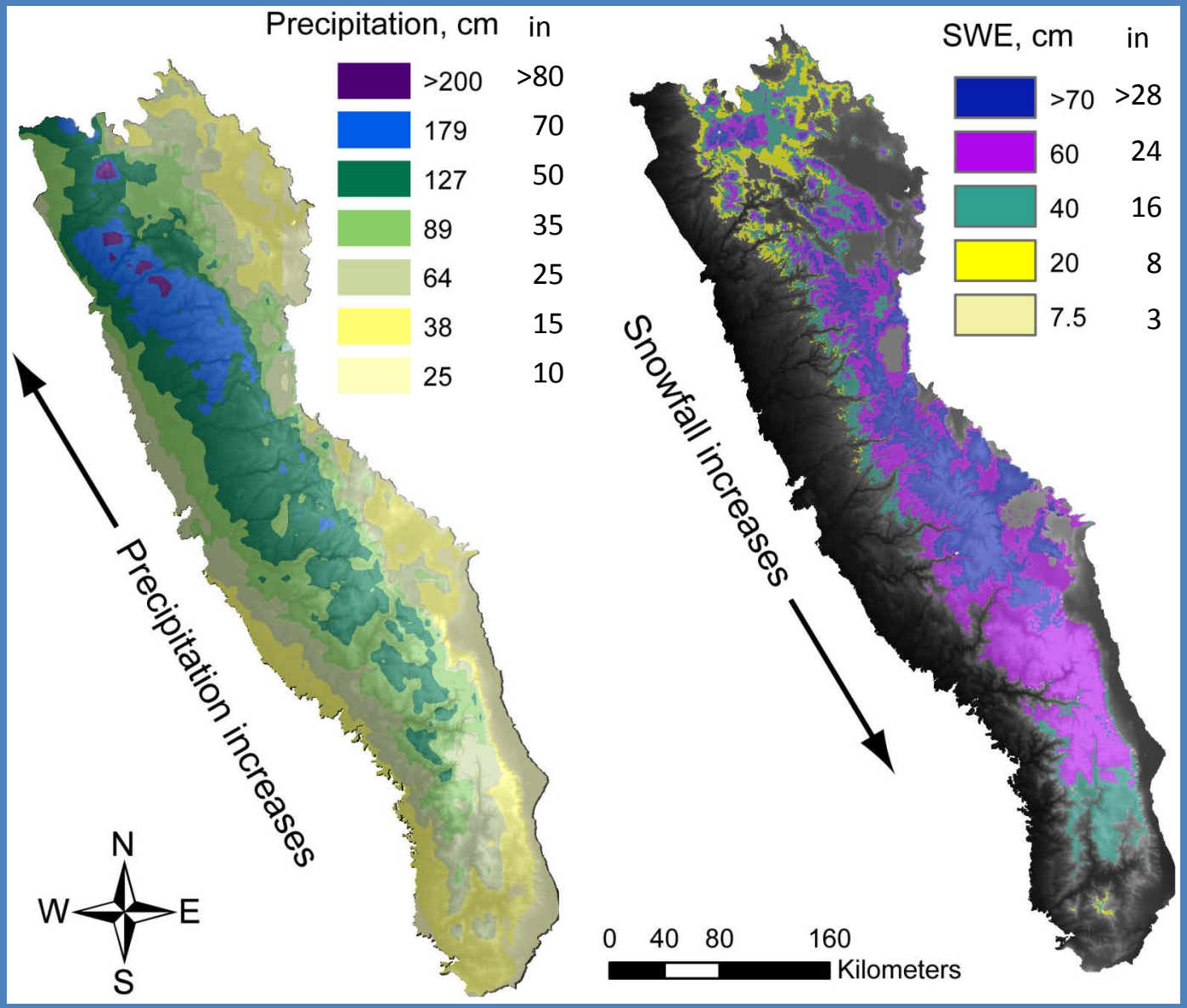
Outline of talk

- Mountain hydrology
- Water security
- Precipitation & runoff
- Evapotranspiration
- Opportunities for better water information
- Water management opportunities

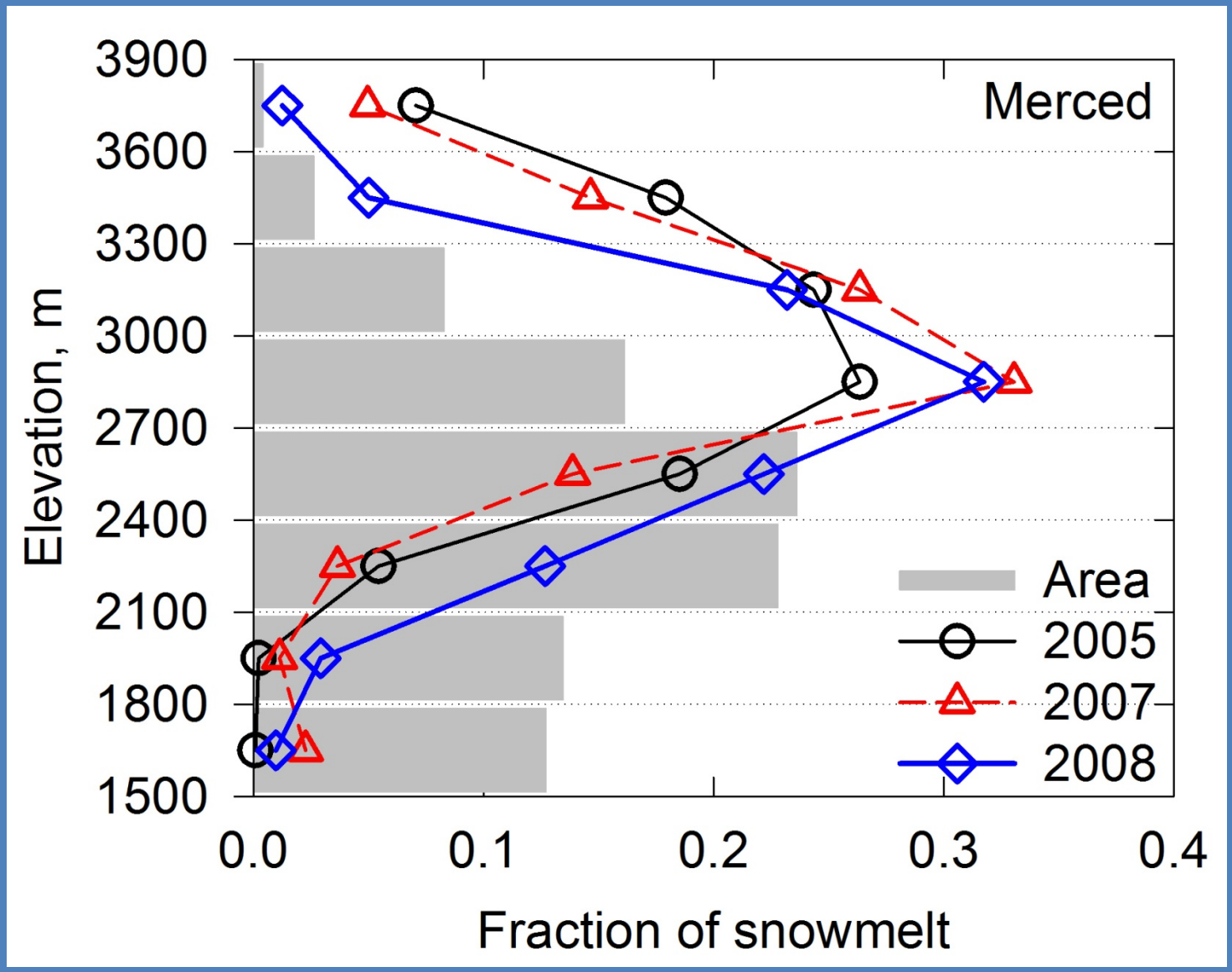
NASA-MODIS
satellite image

UC MERCED SNRI
SIERRA NEVADA RESEARCH INSTITUTE

Sierra Nevada precipitation & snow water equivalent (SWE) – climatological estimate?



What elevations provide the most snowmelt?



Based on SNRI research

Trees & snow

Trees block low-angle winter sun, retarding snowmelt …

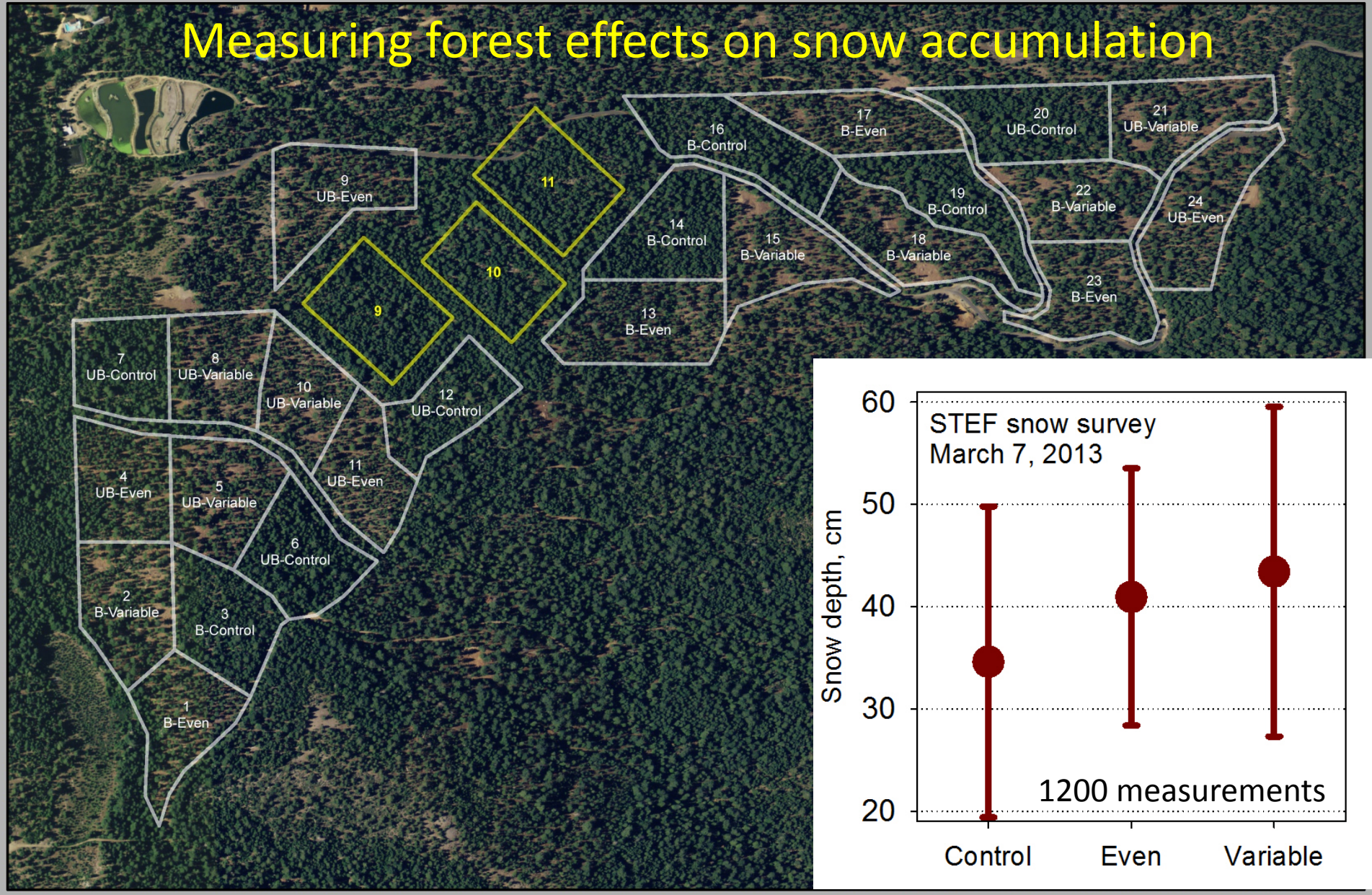
… but intercept snowfall, some of which sublimates …

… and emit longwave radiation that melts snow …

… resulting in tree wells

In dense forests less snow reaches the ground
Under-canopy snow melts earlier than snow in canopy gaps

Measuring forest effects on snow accumulation



Legend

- Variable Density Thinning Units
- 1929 Methods Of Cutting Units

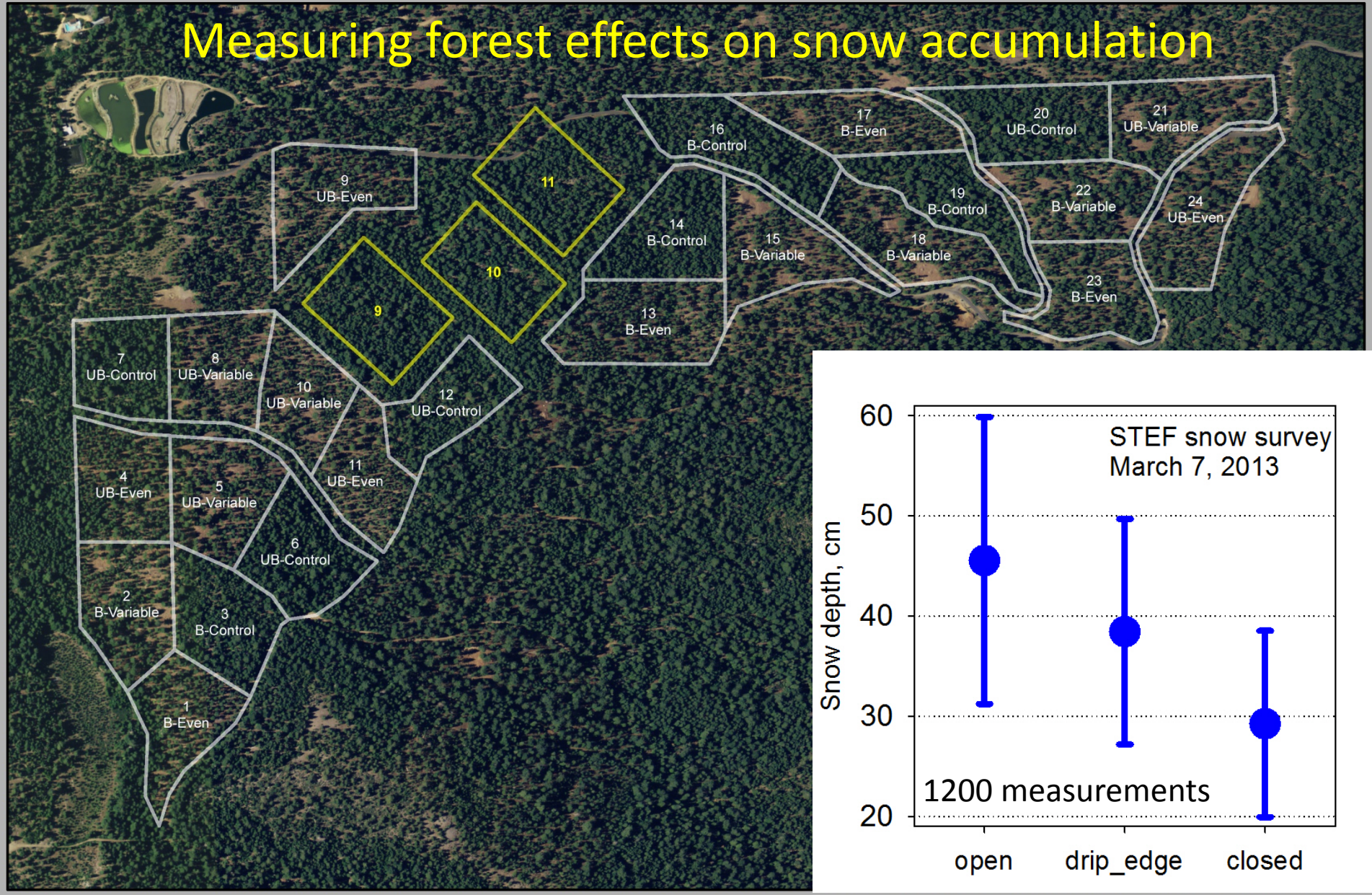
Stanislaus - Tuolumne Experimental Forest
Variable Density Thinning Study
Post-Harvest (2012)

0 50 100 200 300 400 500 Meters

N

Pacific Southwest Research Station

Measuring forest effects on snow accumulation



Legend

- Variable Density Thinning Units
- 1929 Methods Of Cutting Units

Stanislaus - Tuolumne Experimental Forest
Variable Density Thinning Study
Post-Harvest (2012)

0 50 100 200 300 400 500 Meters

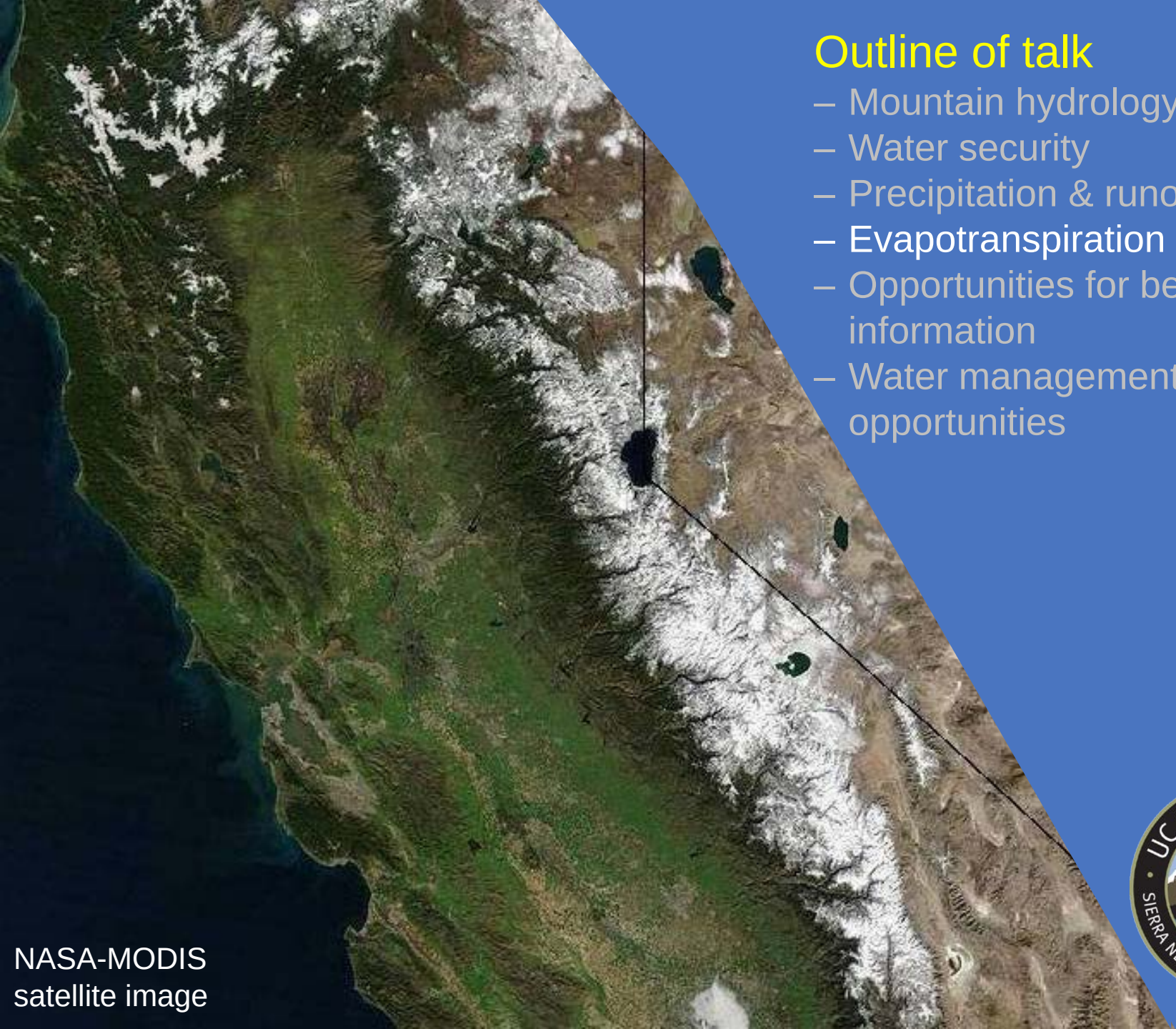
N

Pacific Southwest Research Station

Thinned unit w/ control in background

Even thinning

Variable thinning

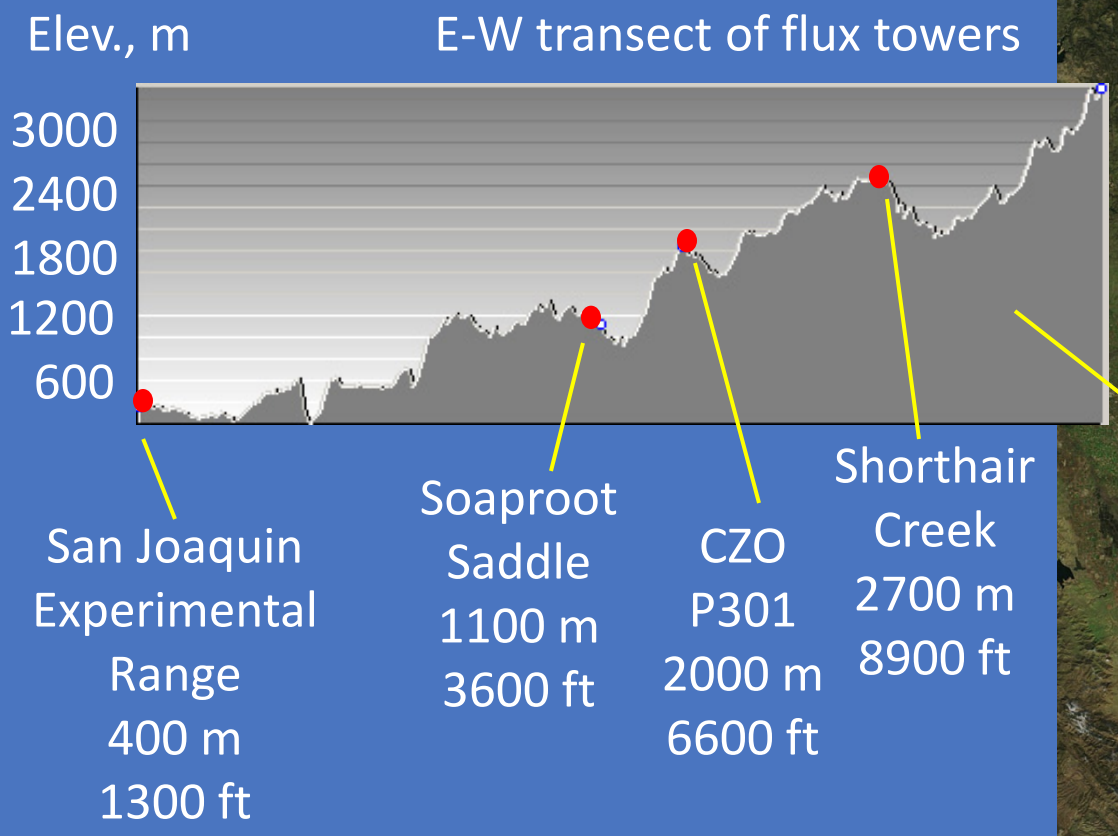


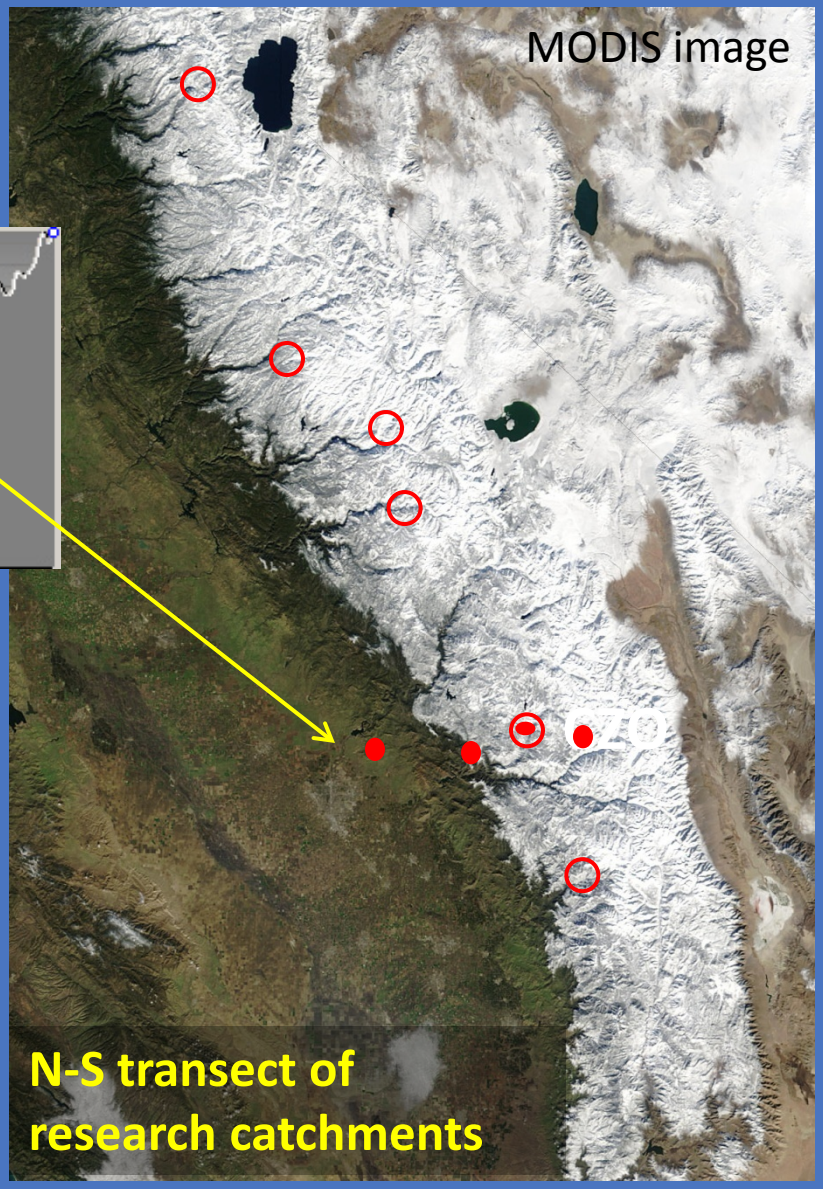
Outline of talk

- Mountain hydrology
- Water security
- Precipitation & runoff
- Evapotranspiration & runoff
- Opportunities for better water information
- Water management opportunities

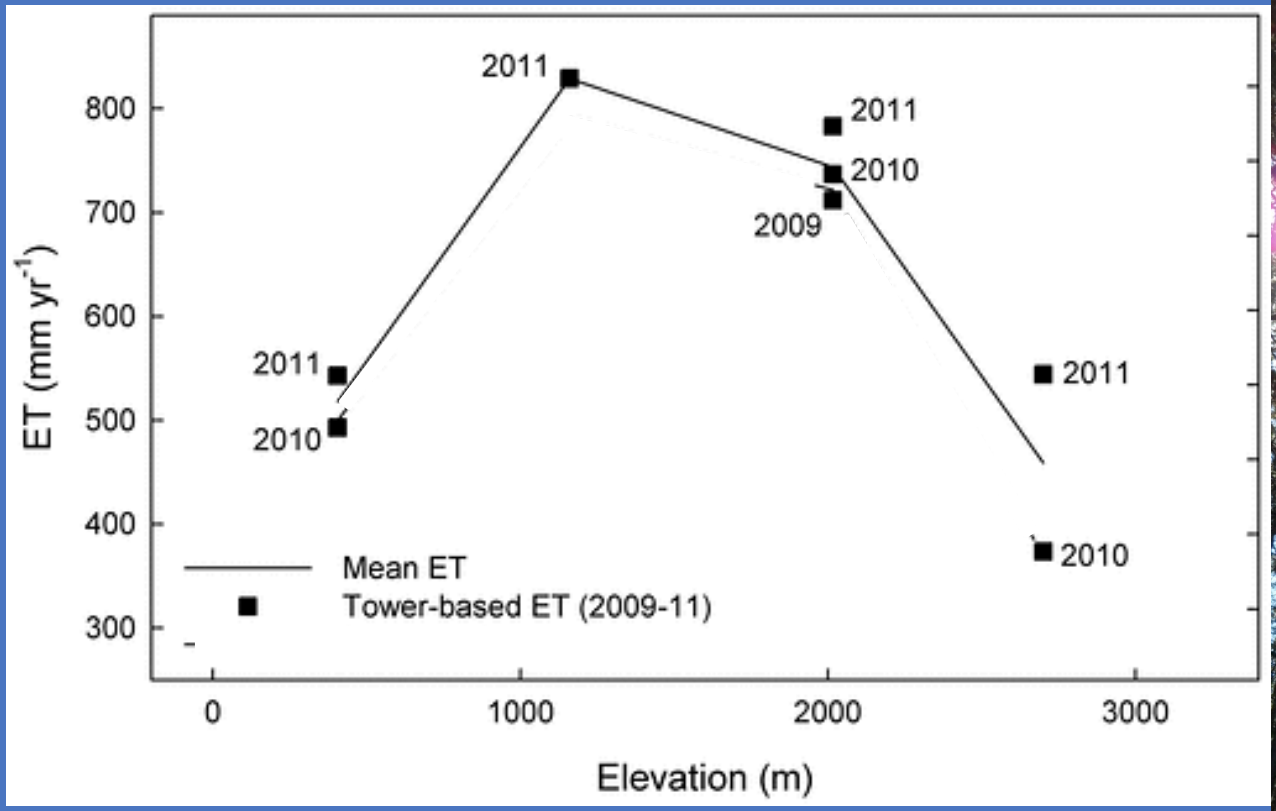
NASA-MODIS satellite image

Sierra Nevada watershed research infrastructure

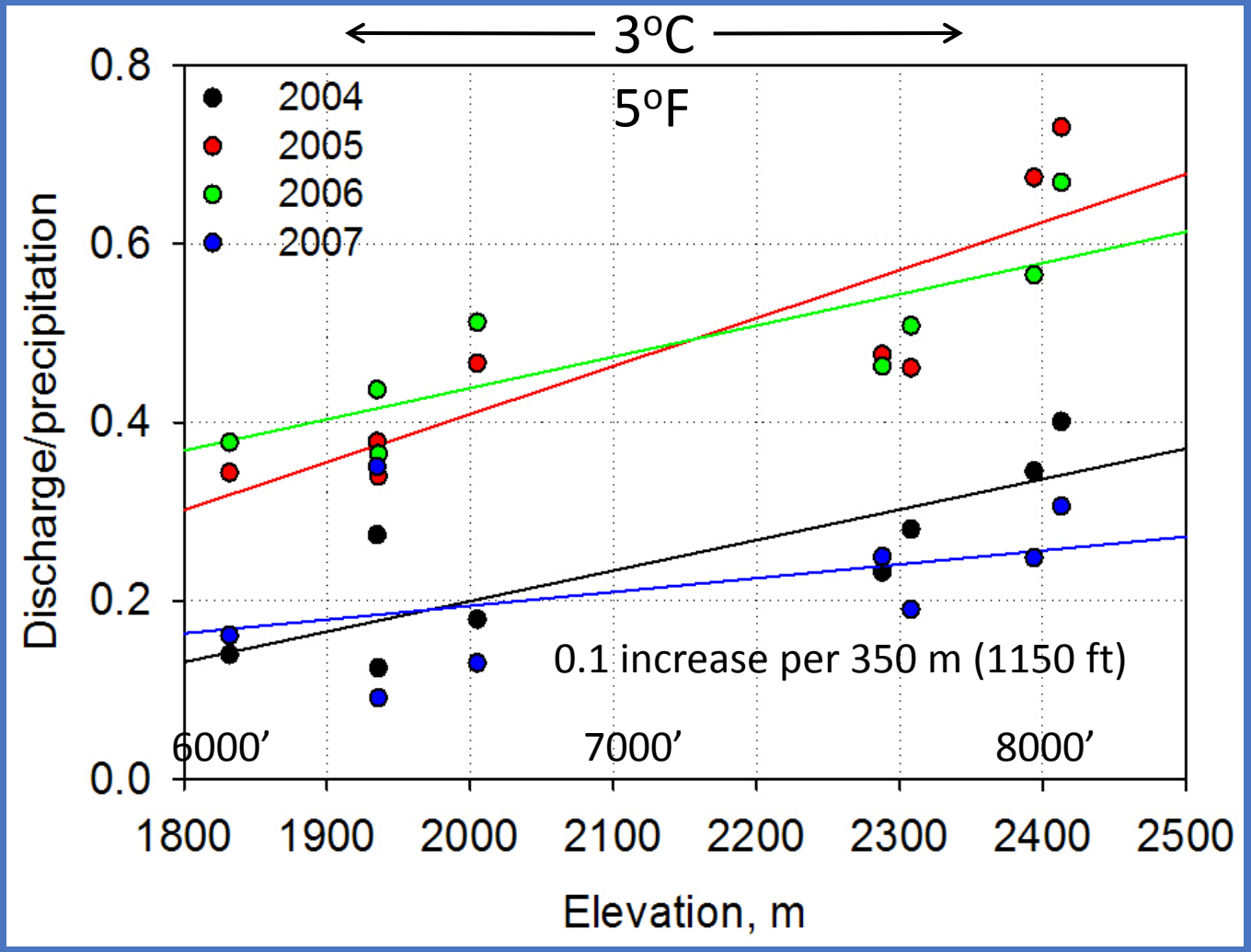




Evapotranspiration (ET) across an elevation transect



- Lower elevation is water limited
- Higher elevation is cold limited
- Highest current ET in rain to rain-snow-transition region of mixed conifer forest – year-round growth

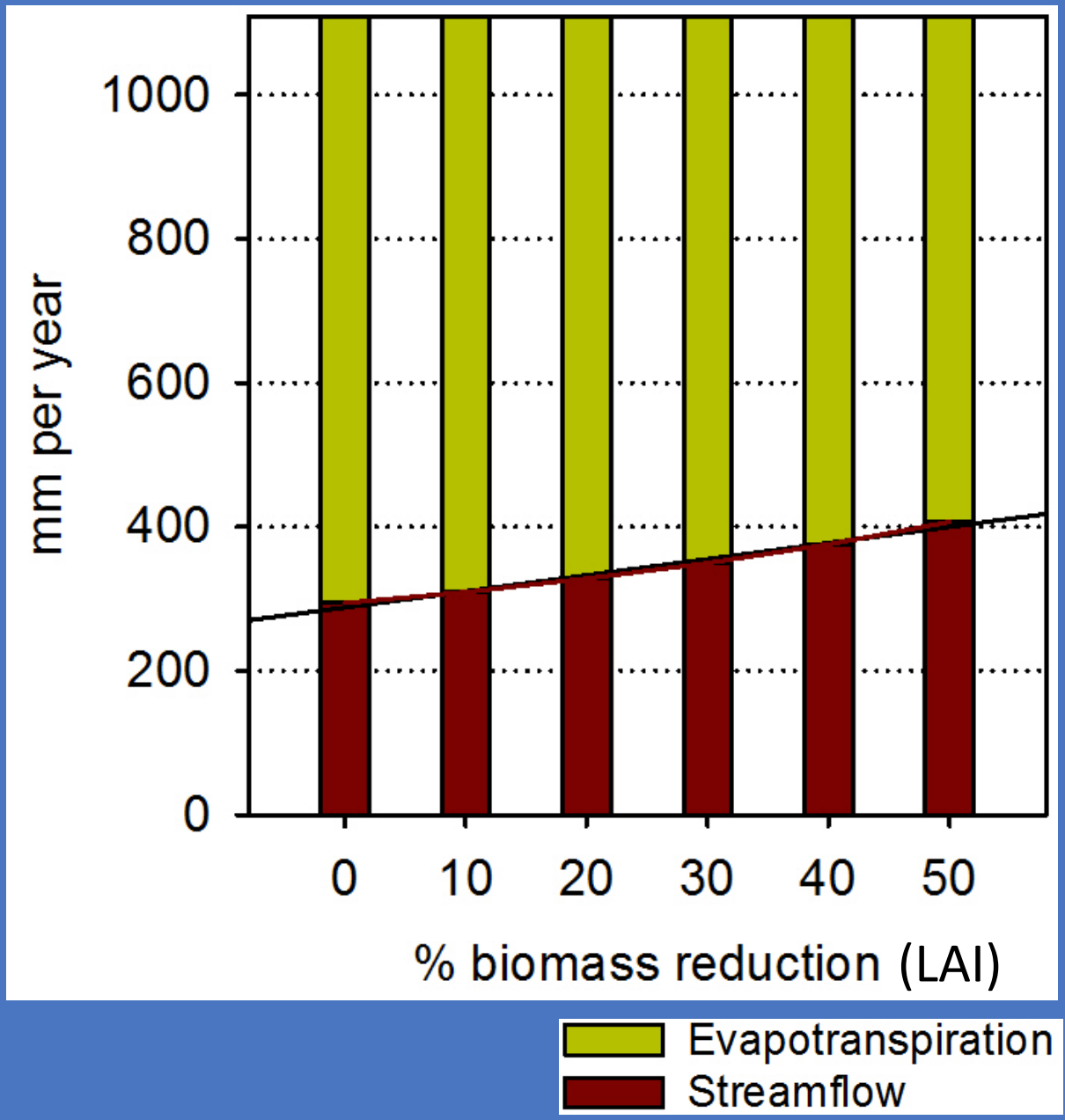


50% more runoff in snow dominated vs. mixed rain-snow catchments

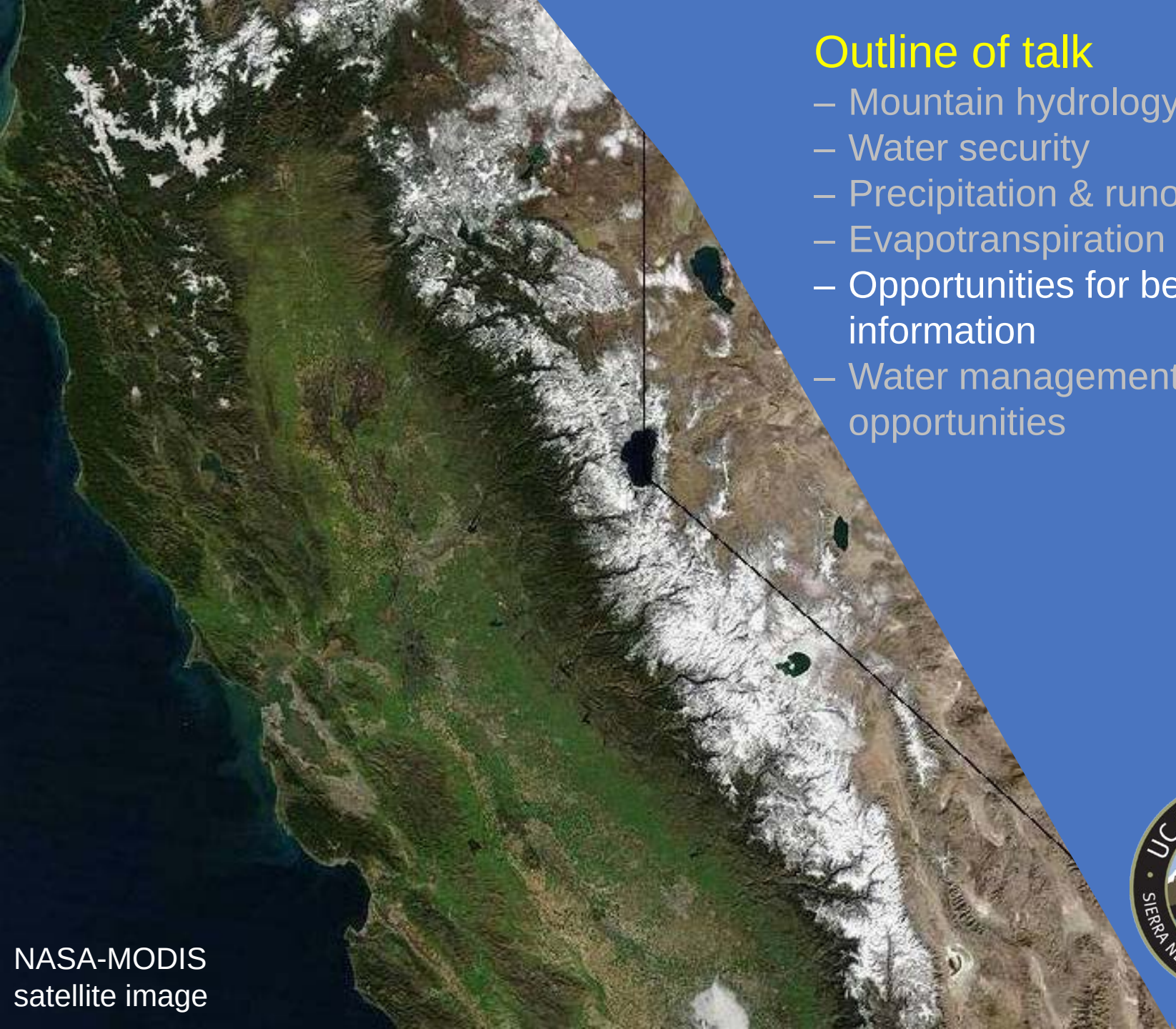
Implication for 2°C warmer climate: Reduce runoff by 10-40% in mixed conifer forest (assuming ecosystems adapt)

Decreasing temperature →
Increasing snow fraction →
Decreasing vegetation →
Coarser soils →

Impact of thinning on evapotranspiration & streamflow



- P303 headwater catchment, Southern Sierra CZO/KREW, Sierra NF
- Rain-snow transition, 2000 m elev
- Results based on very-detailed pre-treatment data & hydrologic modeling
- 5-yr average, 2004-2008
- What is the slope of this line in different forests???



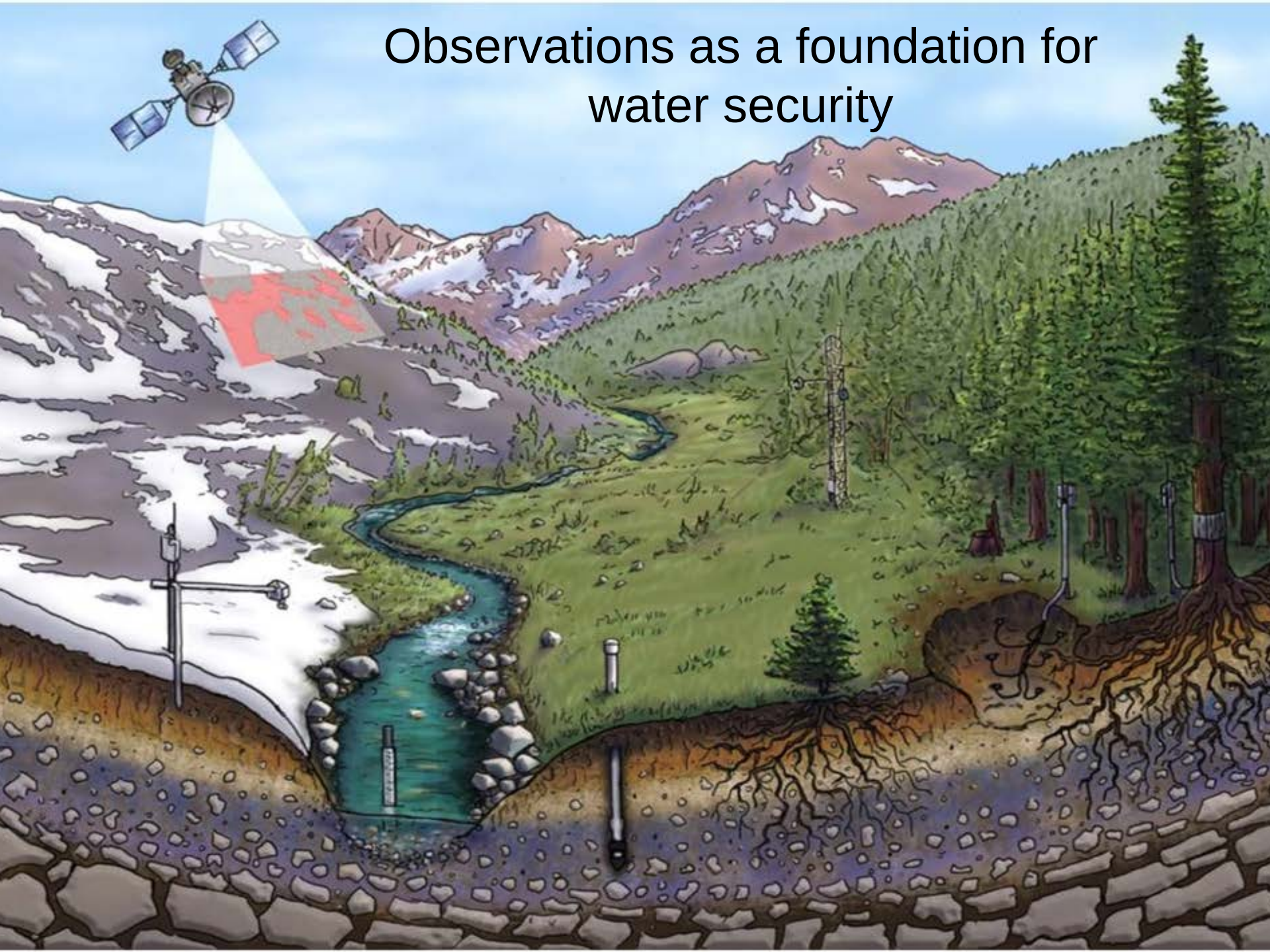
Outline of talk

- Mountain hydrology
- Water security
- Precipitation & runoff
- Evapotranspiration & runoff
- Opportunities for better water information
- Water management opportunities

NASA-MODIS satellite image

UC MERCED SNRI
SIERRA NEVADA RESEARCH INSTITUTE

Observations as a foundation for water security

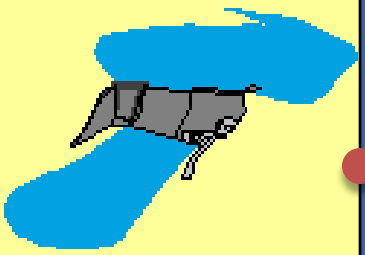


Seasonal runoff forecasts are based on historical observations & have some skill in a stationary climate

Precipitation forecast

Ground data

Empirical & regression methods



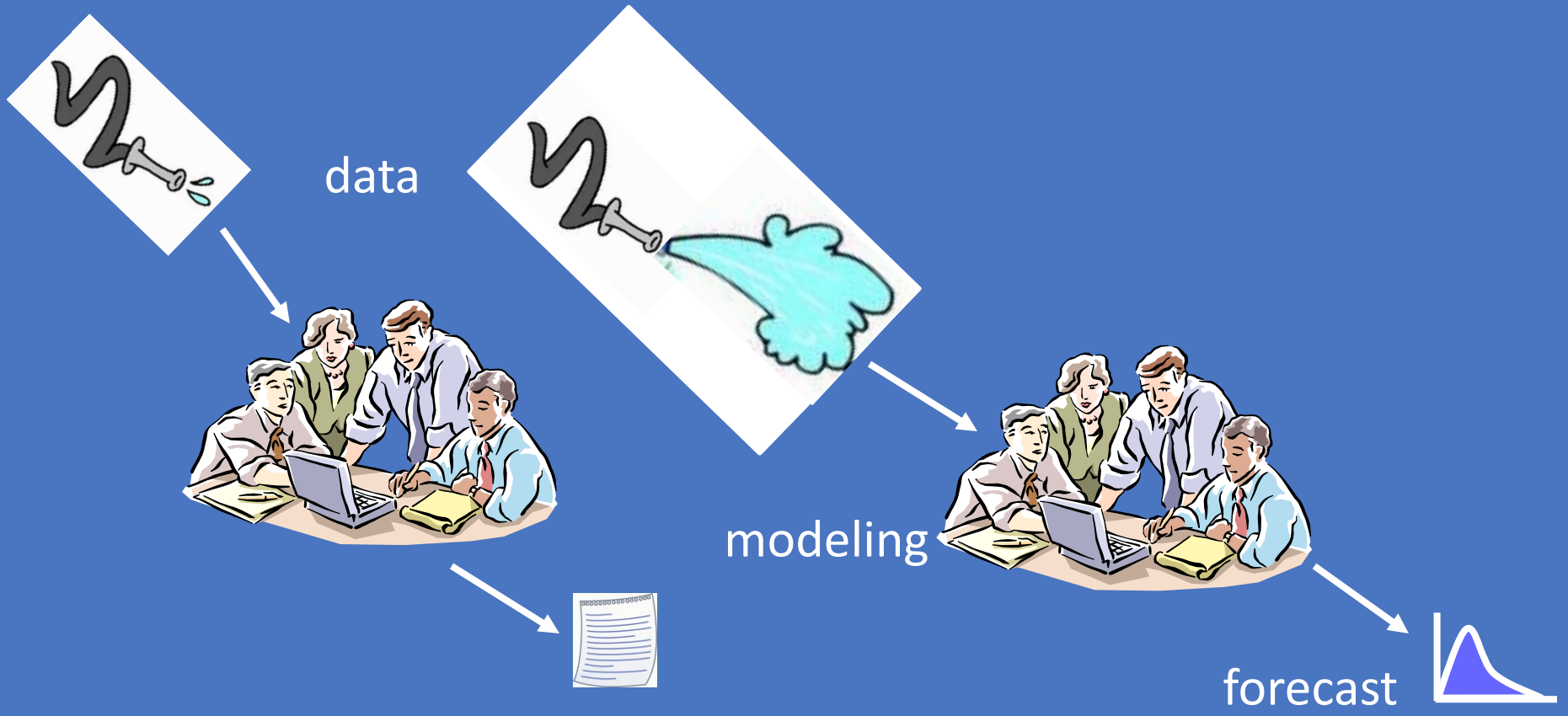
Volume forecasts

Decision making

Forecasts use a few point measurements as indices of snow accumulation R. Bales

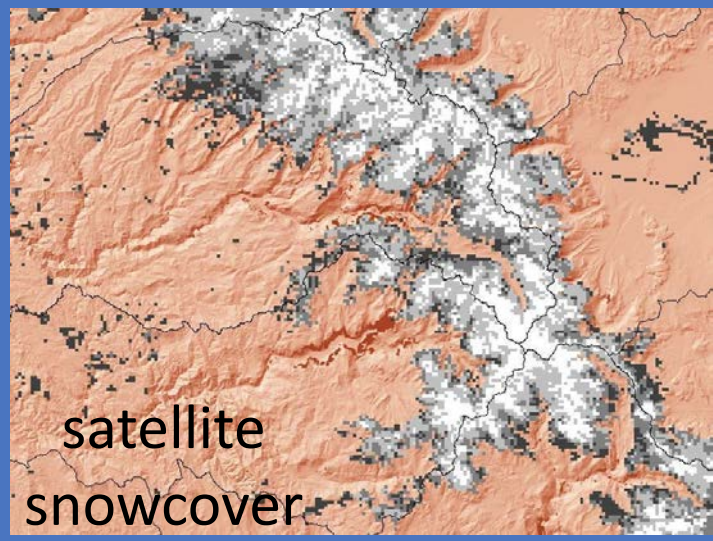
Some additional points re water supply context

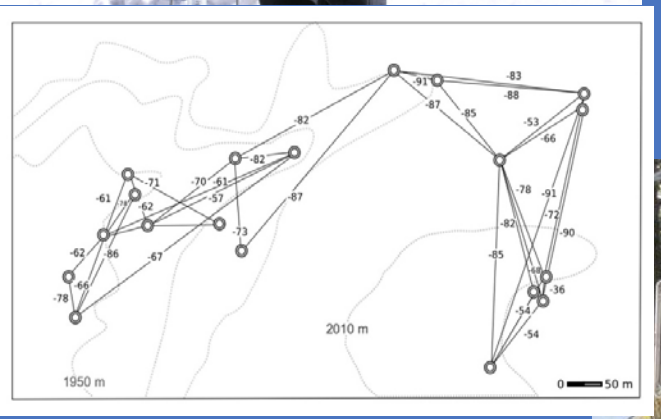
1. We cannot model our way out of this uncertainty
2. Improvements in forecast skill require new observations
3. The technology to support new observations is available
4. This technology has matured over the past 5-10 years

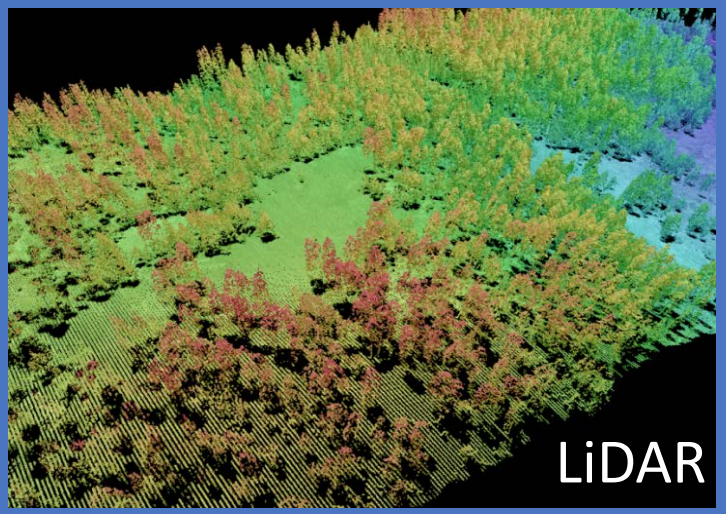


Measurement technology – verification & forecasts

Available now: blending data from satellites, aircraft, wireless sensor networks, advanced modeling tools

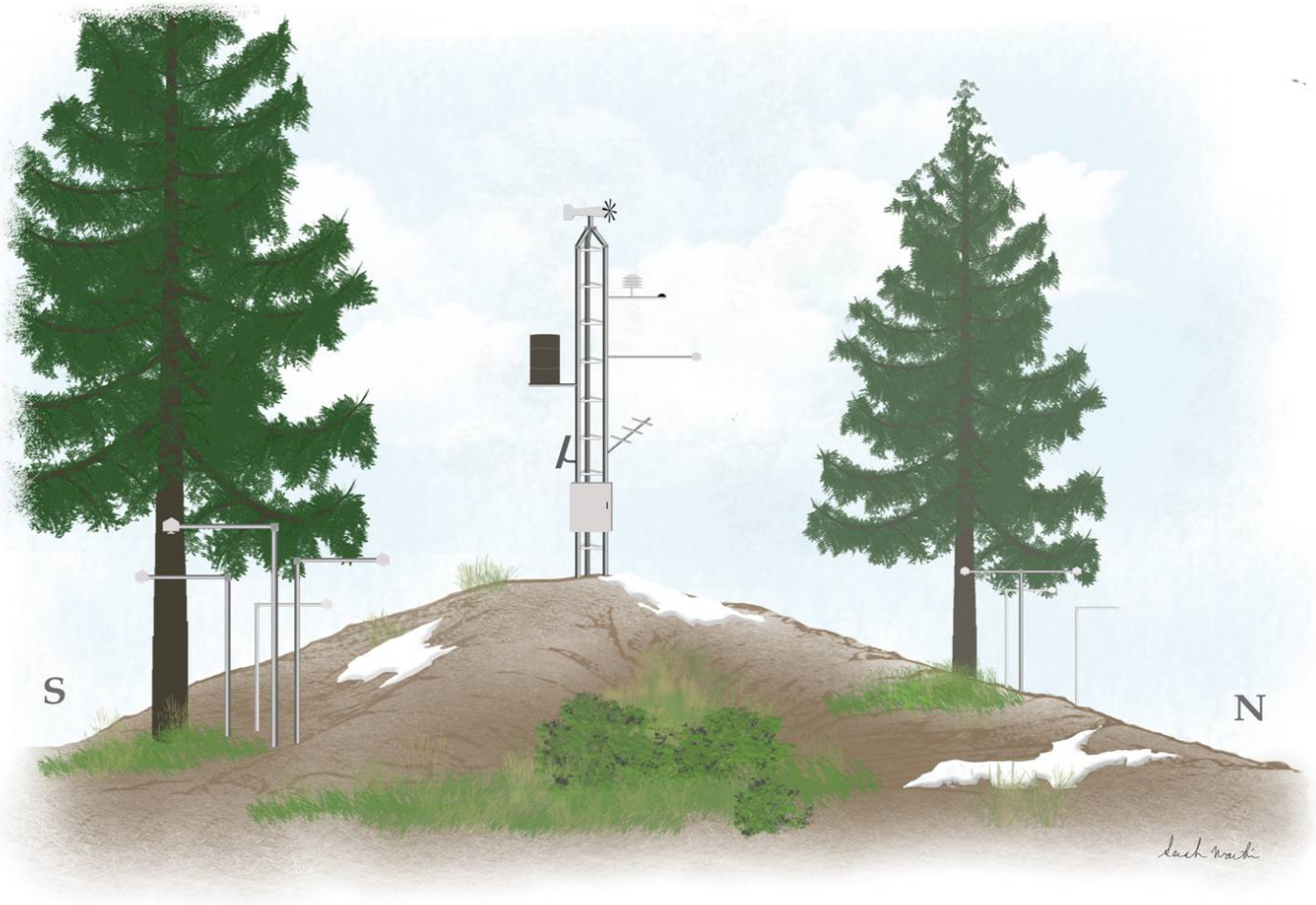






Together these add up to Big Data challenges

Sensor networks: 5-10 yr ago, wired sensor networks



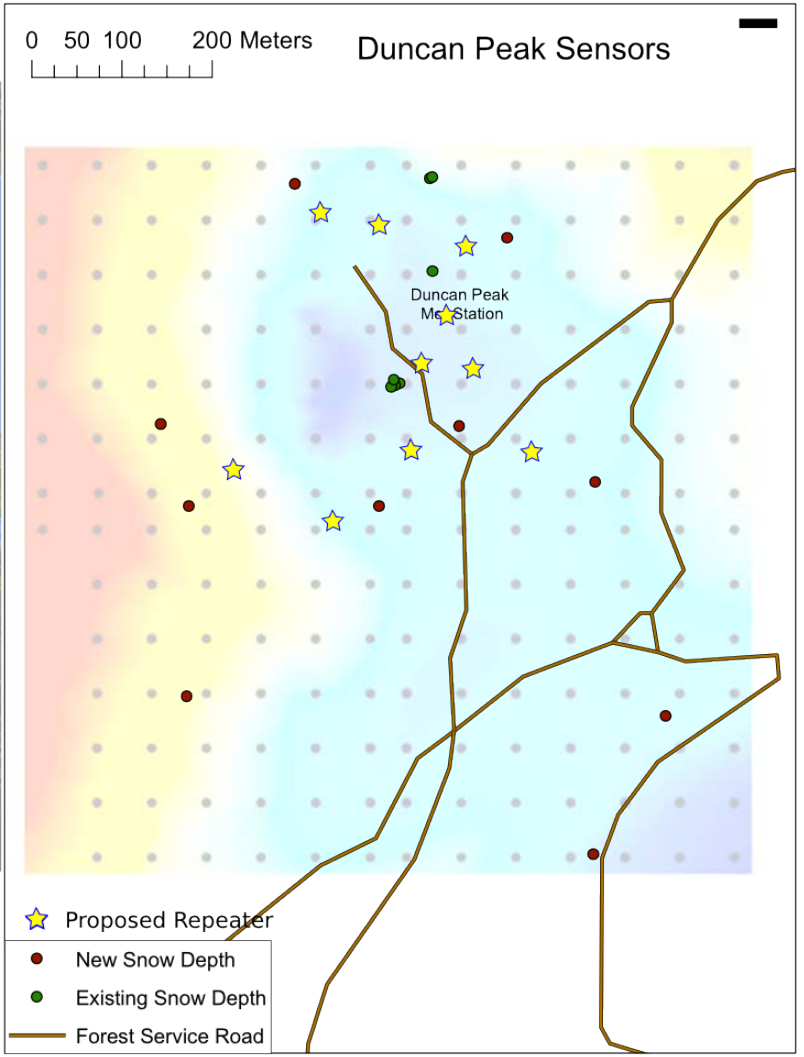
Met station

North, south facing sensor nodes; <45 m wire lengths

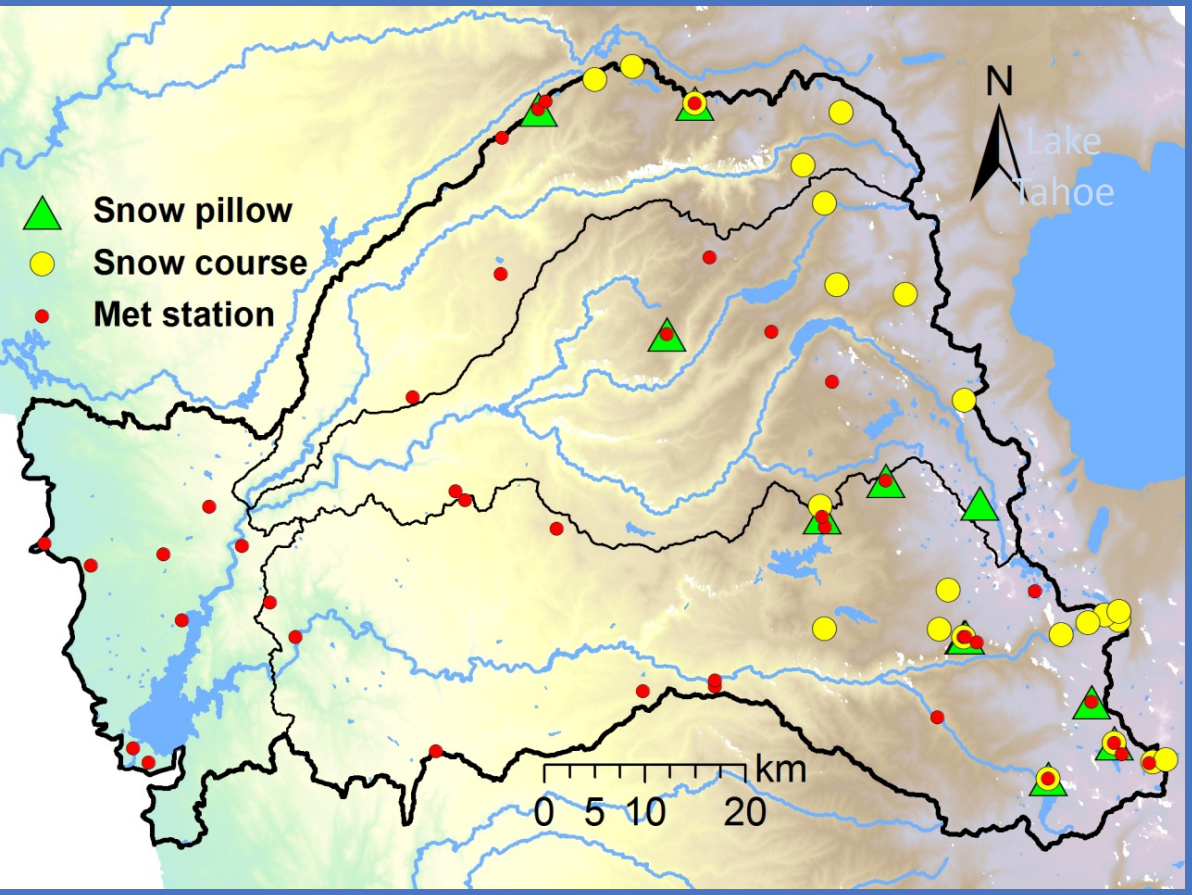
- snow depth, temp, soil moisture

Current setup: *wireless* nodes

Improved representation of the landscape: topography & vegetation

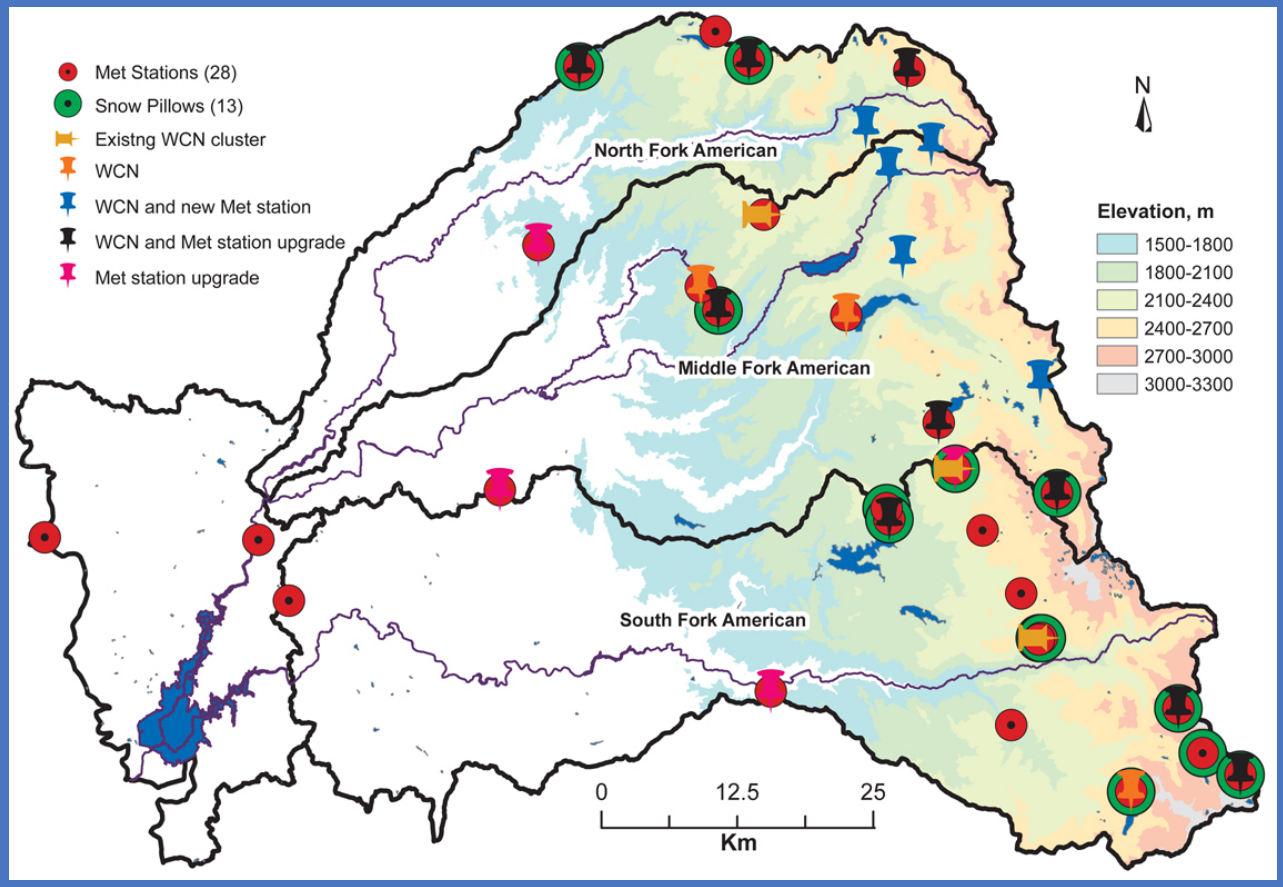


American River basin – current hydrologic measurements



- 2 snow pillows in N. Fork, 1 in Middle Fork, 8 in S. Fork
- Non-representative network
- Stations are on flat ground, in clearings, at mid elevations

Basin-wide deployment of hydrologic instrument clusters – American R. basin



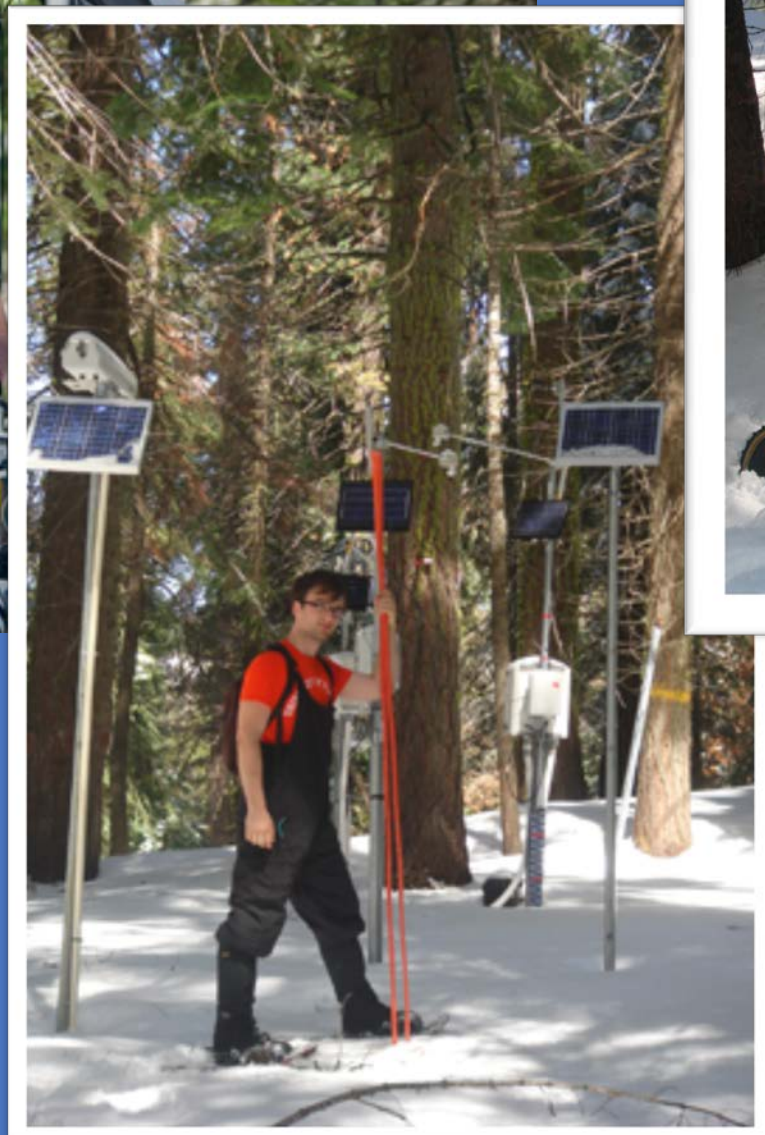
Strategically place low-cost sensors to get spatial estimates of snowcover, soil moisture & other water-balance components

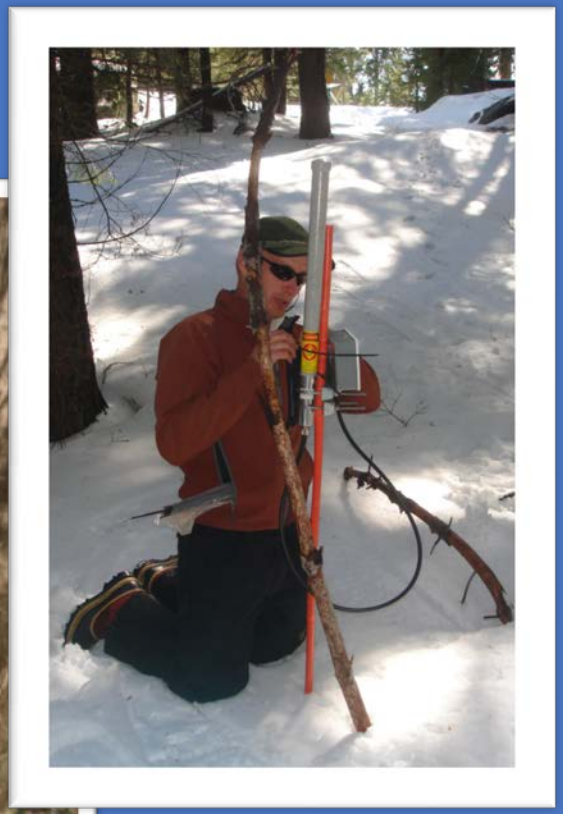
Network & integrate these sensors into a single spatial instrument for water-balance measurements.

Node construction at Alpha site

Wireless embedded sensor network nodes

Sensor node





Hopper node

Meteorological stations

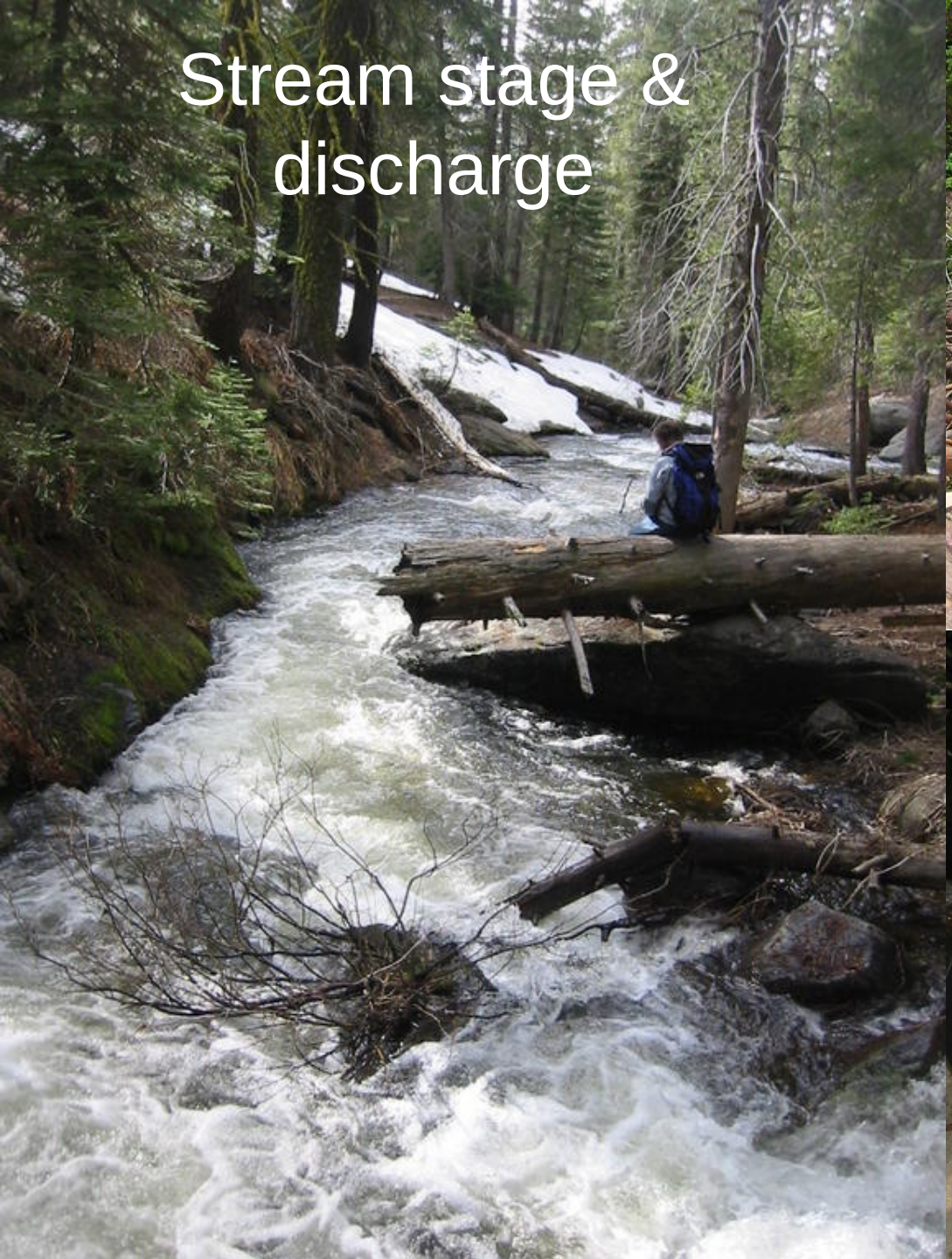
- In cooperation w/ CA-DWR
- Data available on CDEC

Snow depth sensors


Wireless motes


Soil moisture

Stream stage & discharge



Satellite snowcover data plus spatial energy-balance data provide:

- Historical & real-time estimates of daily & seasonal snowmelt
- Historical estimates of snowpack water storage
- Projections of seasonal snowmelt & snowpack water storage

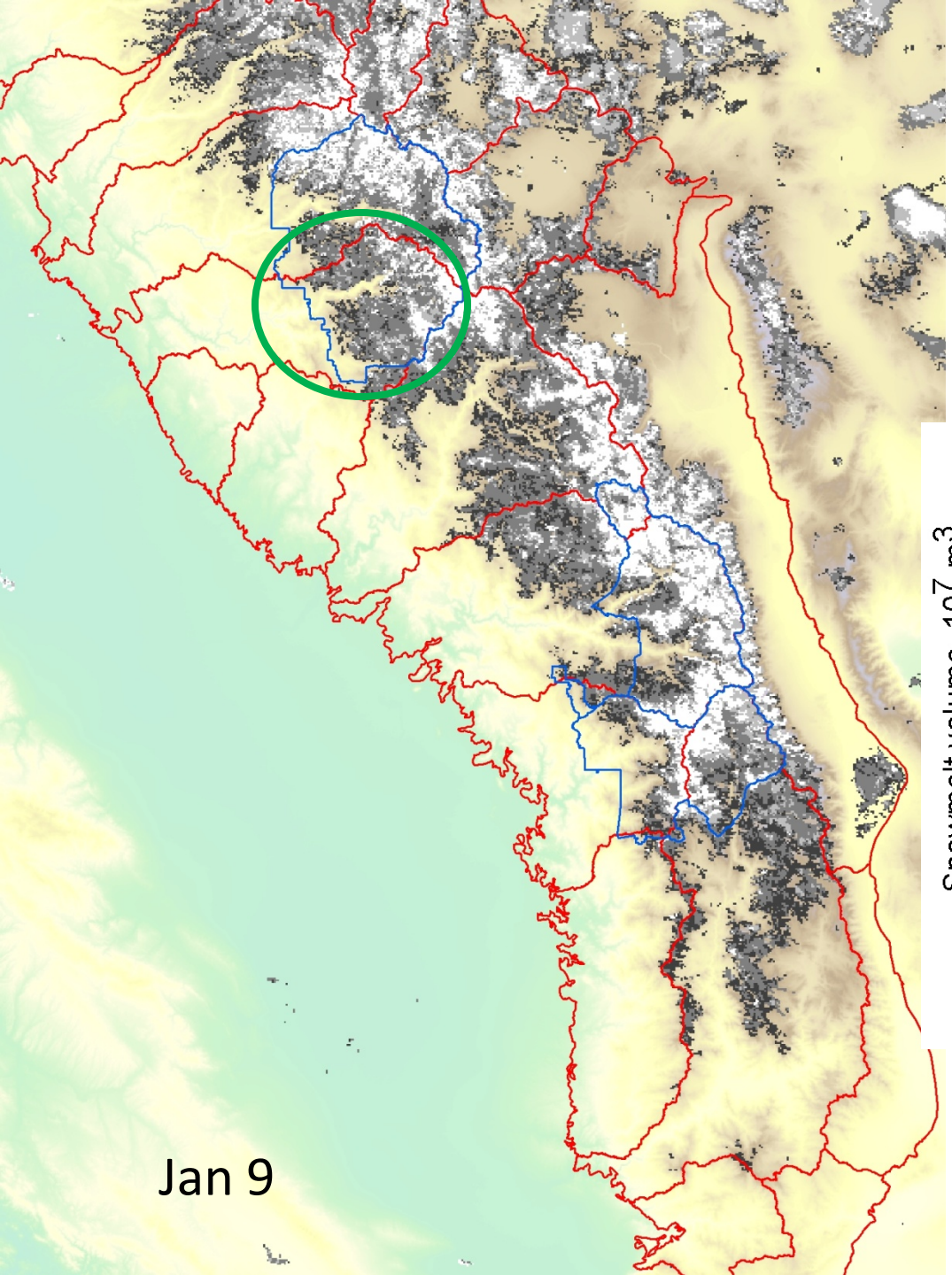
Fractional snow covered area from MODIS

White is most snowcover, black least

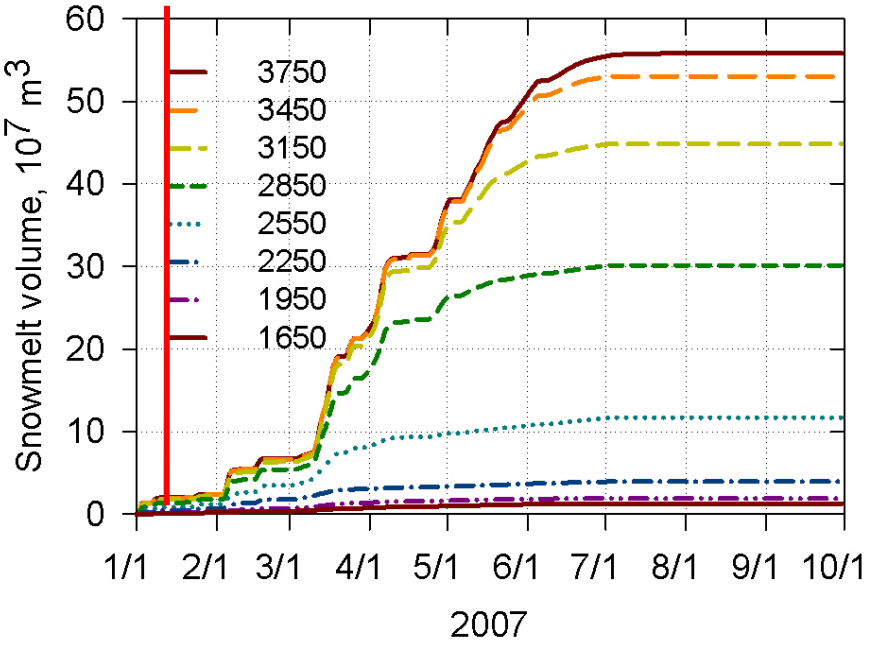
Pixel size: 500 m

Available 2000-present

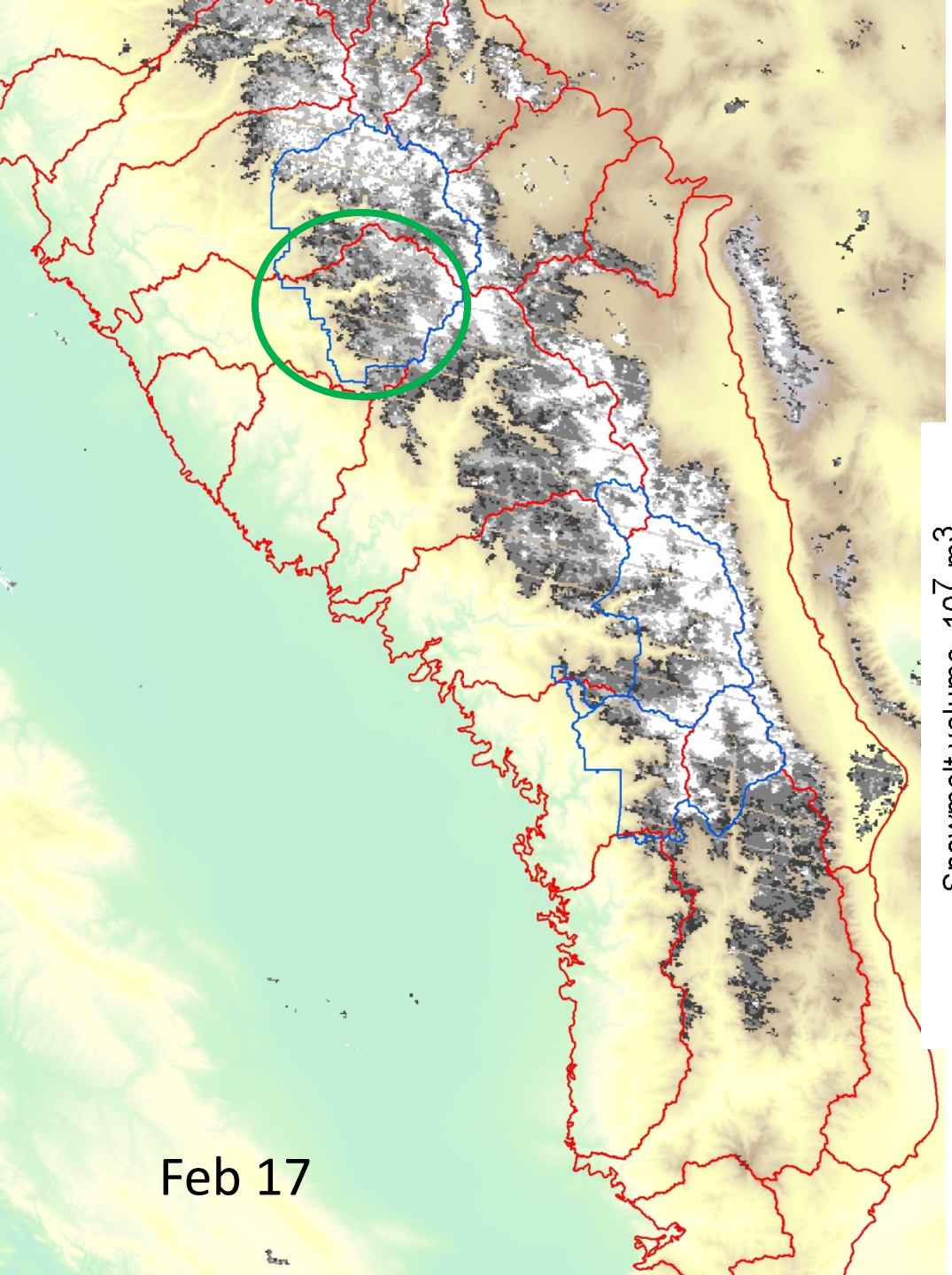
Merced basin SCA & snowmelt volume – 2007



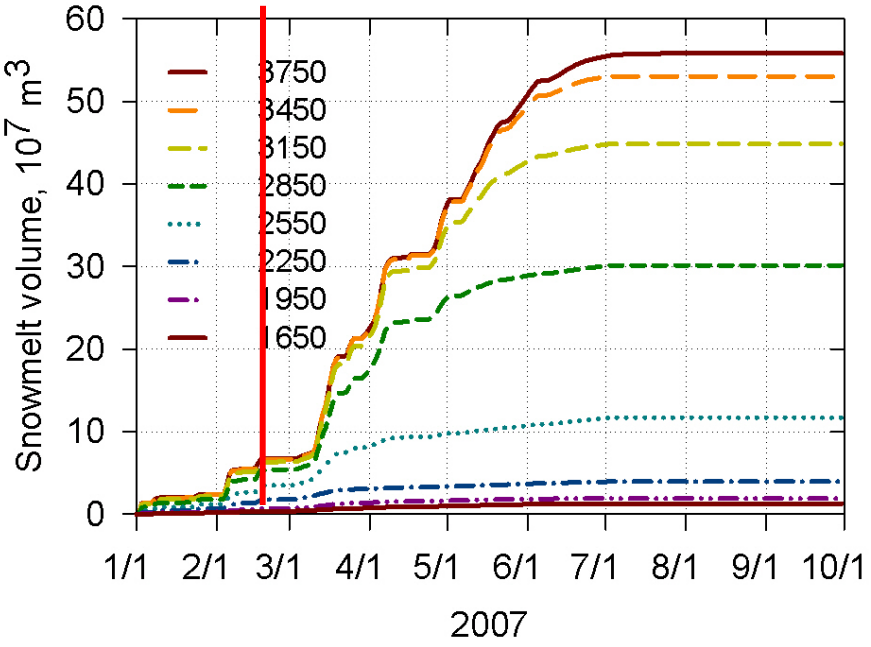
Cumulative snowmelt by elevation band



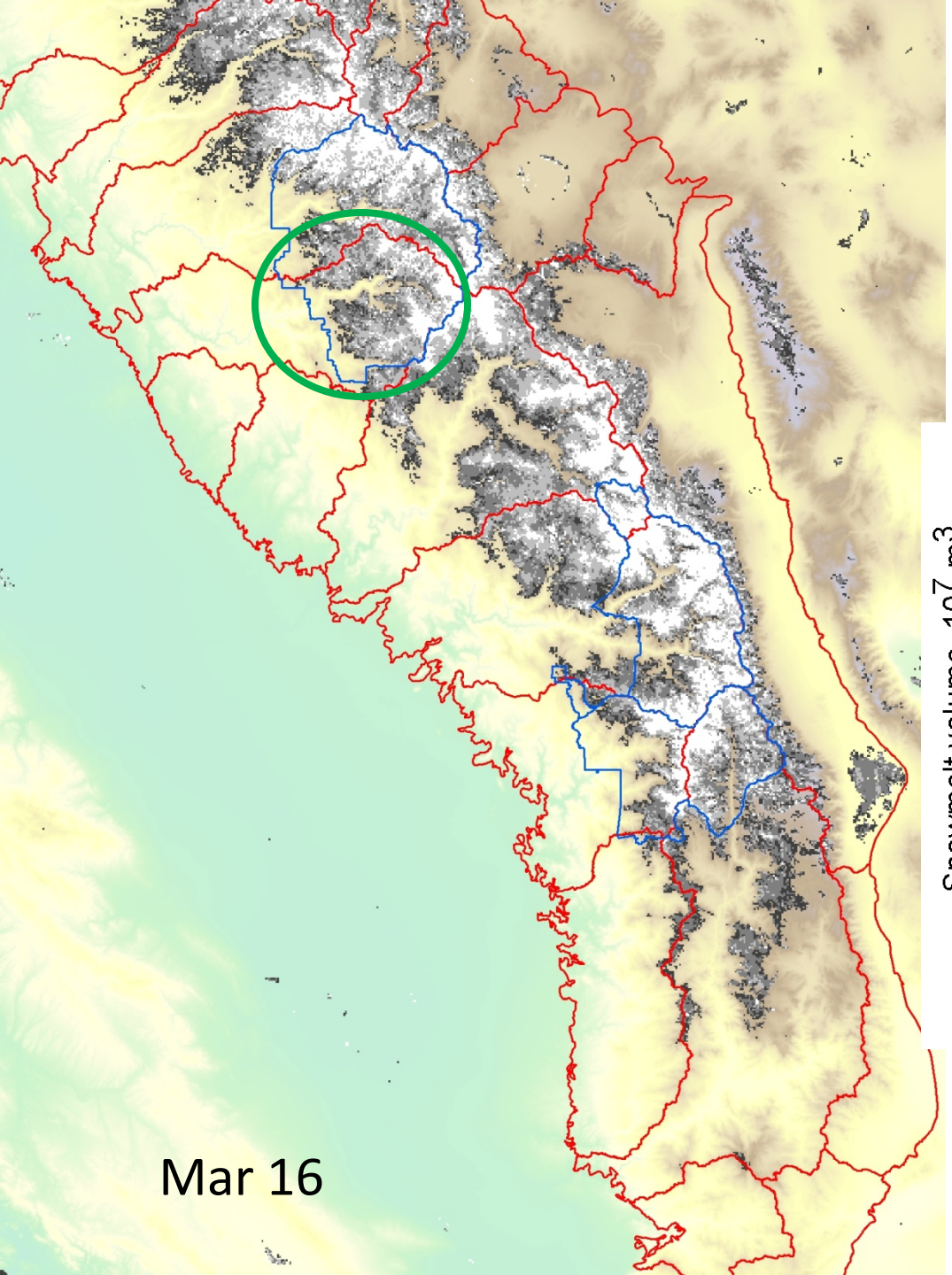
Merced basin SCA & snowmelt volume – 2007



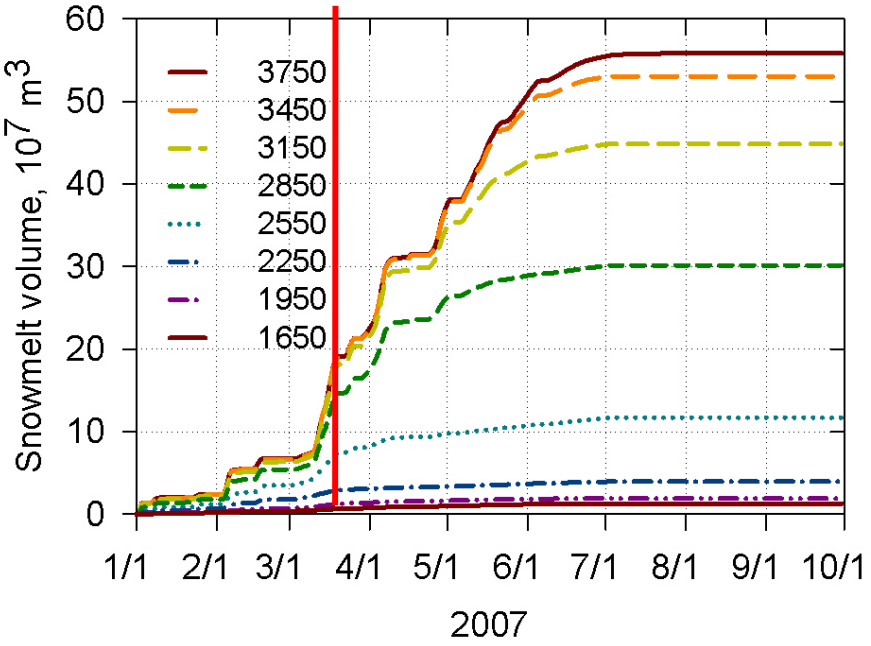
Cumulative snowmelt by elevation band



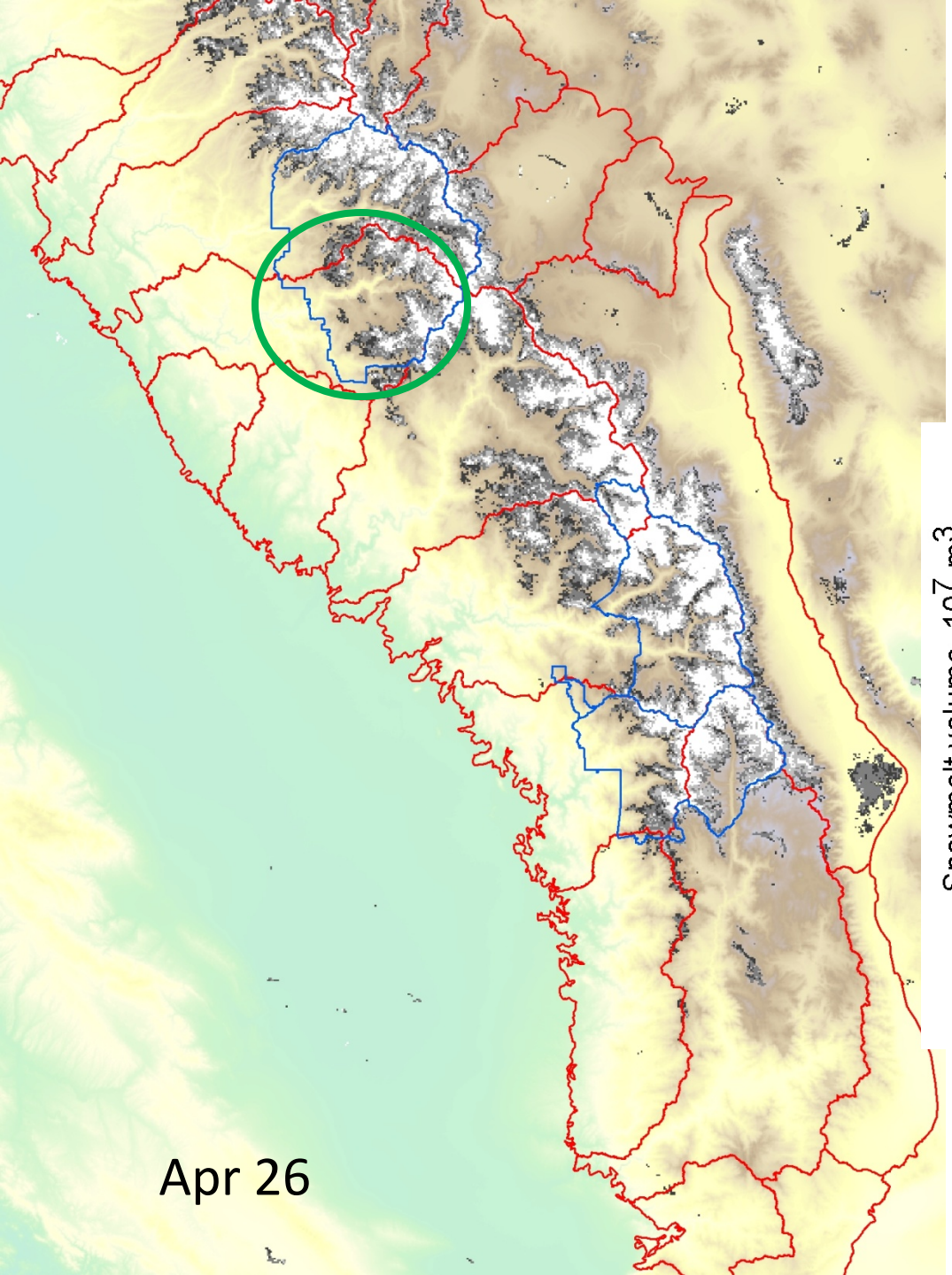
Merced basin SCA & snowmelt volume – 2007



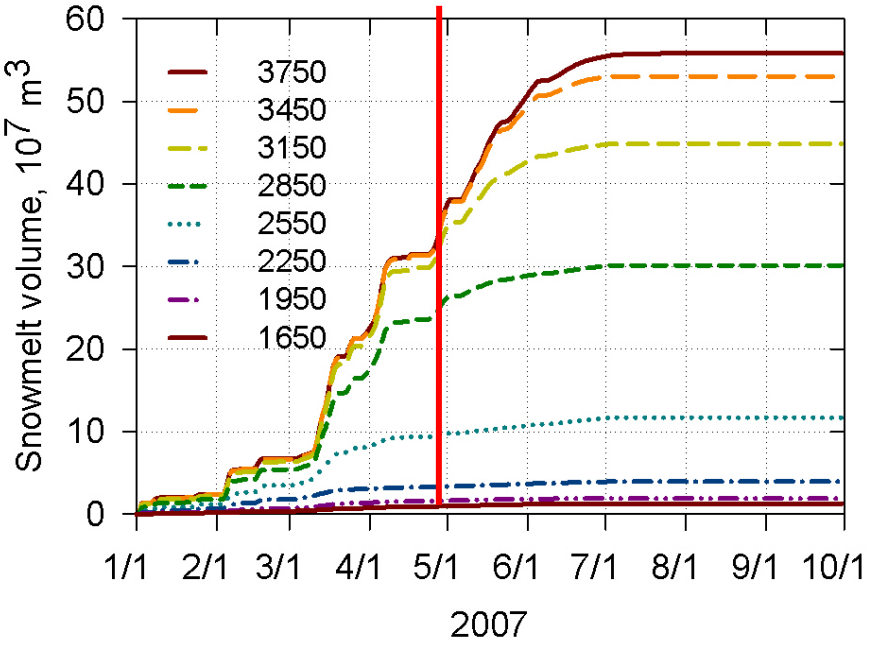
Cumulative snowmelt by elevation band



Merced basin SCA & snowmelt volume – 2007



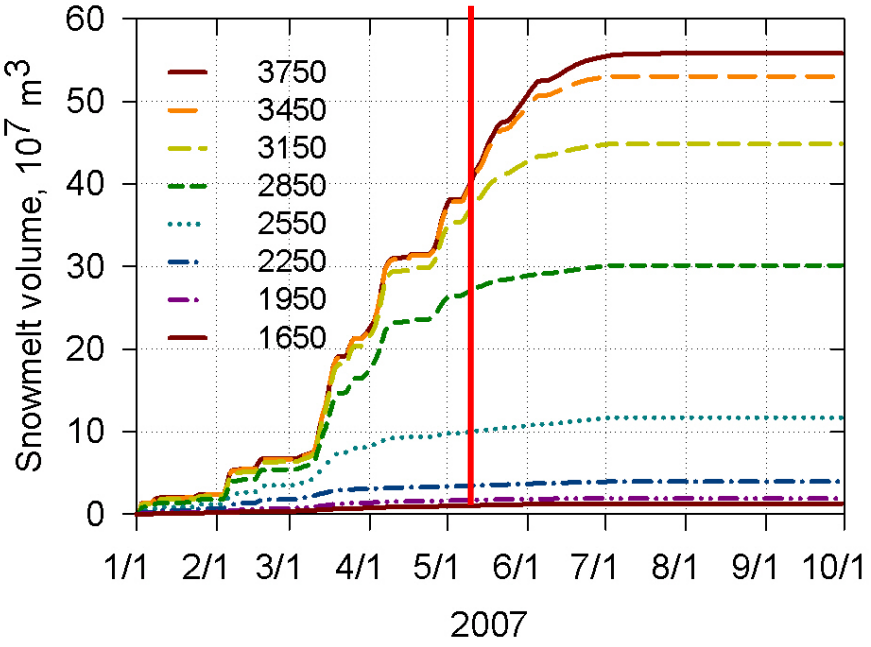
Cumulative snowmelt by elevation band



Merced basin SCA & snowmelt volume – 2007

May 7

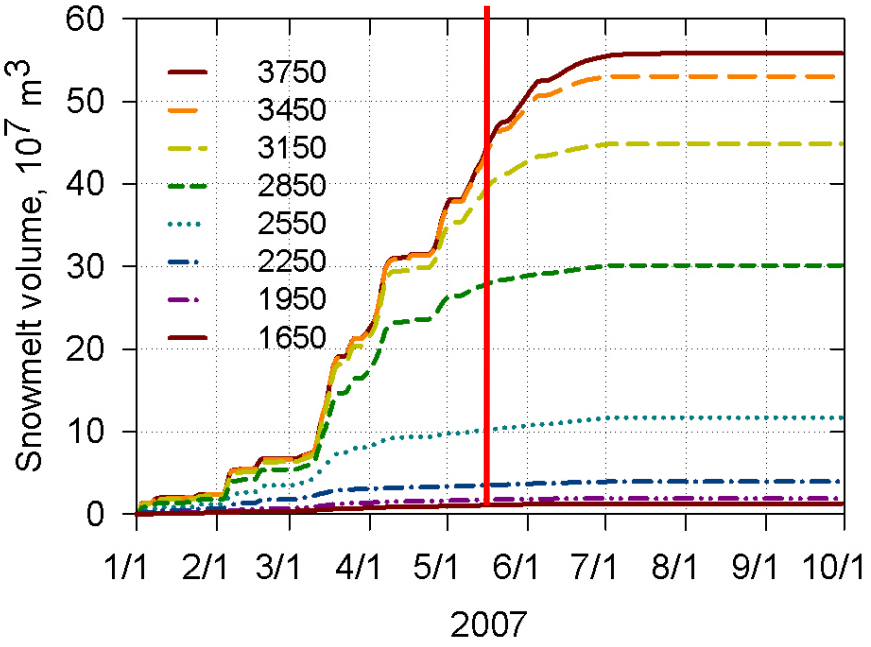
Cumulative snowmelt by elevation band



Merced basin SCA & snowmelt volume – 2007

May 14

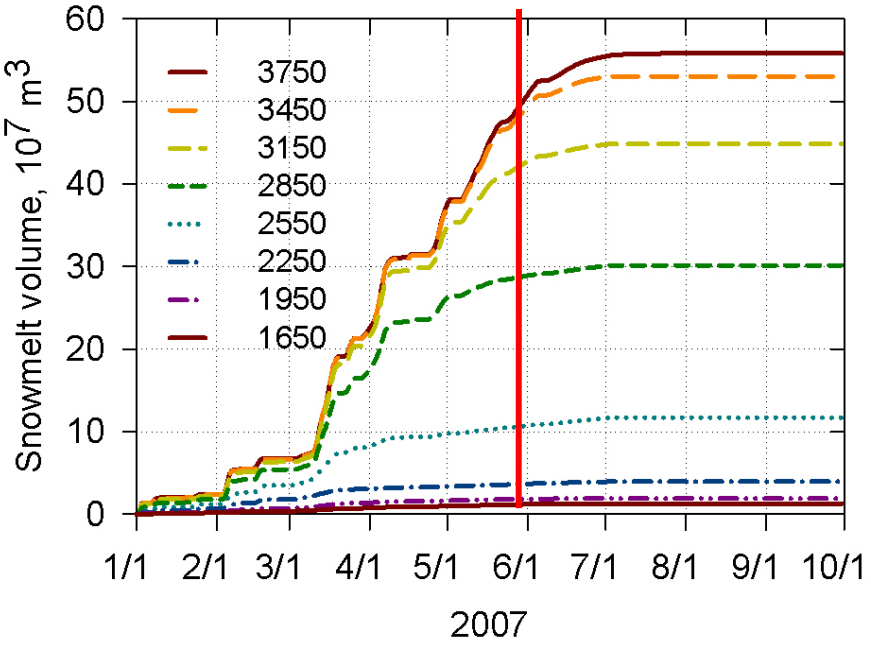
Cumulative snowmelt by elevation band



Merced basin SCA & snowmelt volume – 2007

May 28

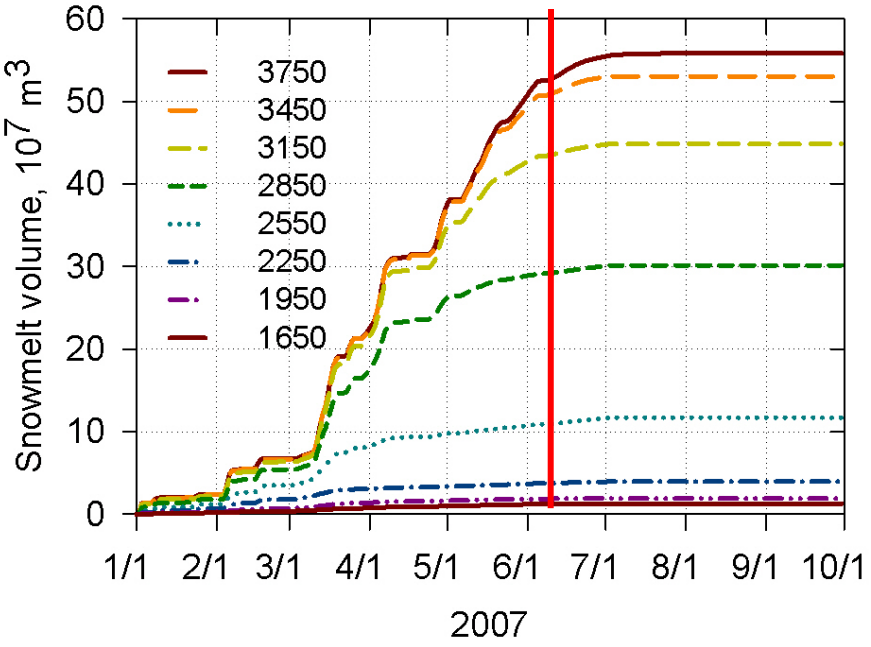
Cumulative snowmelt by elevation band



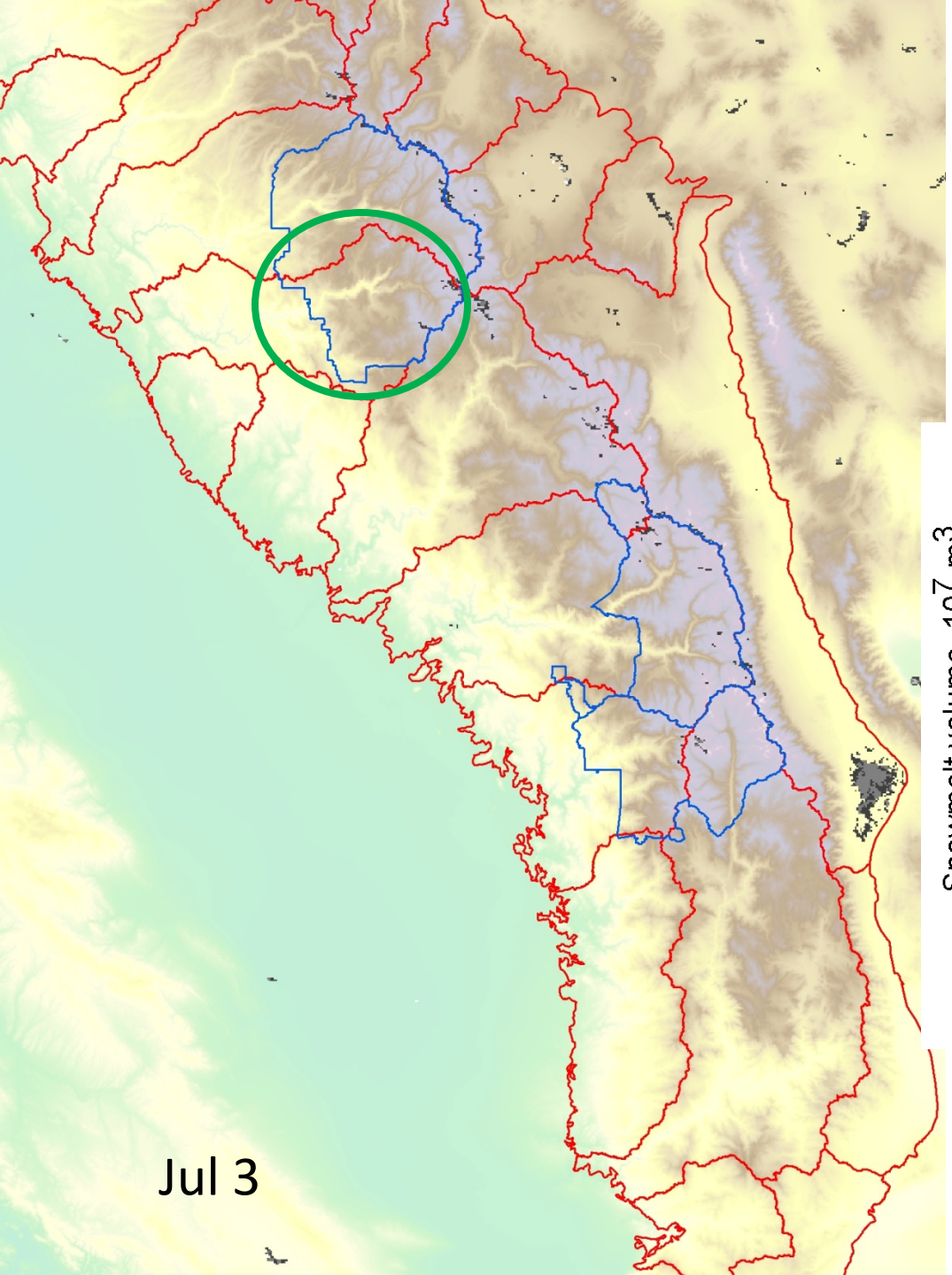
Merced basin SCA & snowmelt volume – 2007

Jun 9

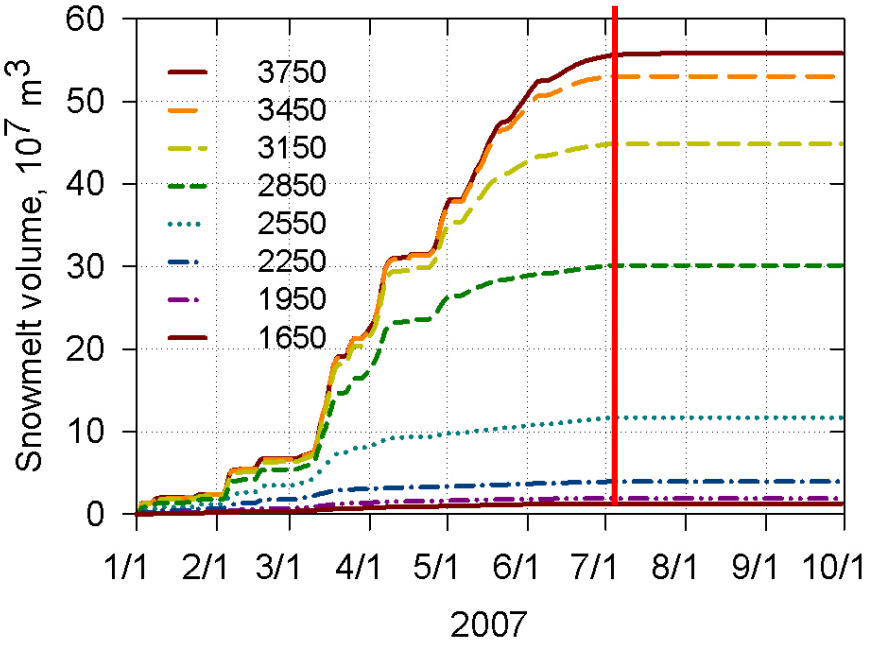
Cumulative snowmelt by elevation band

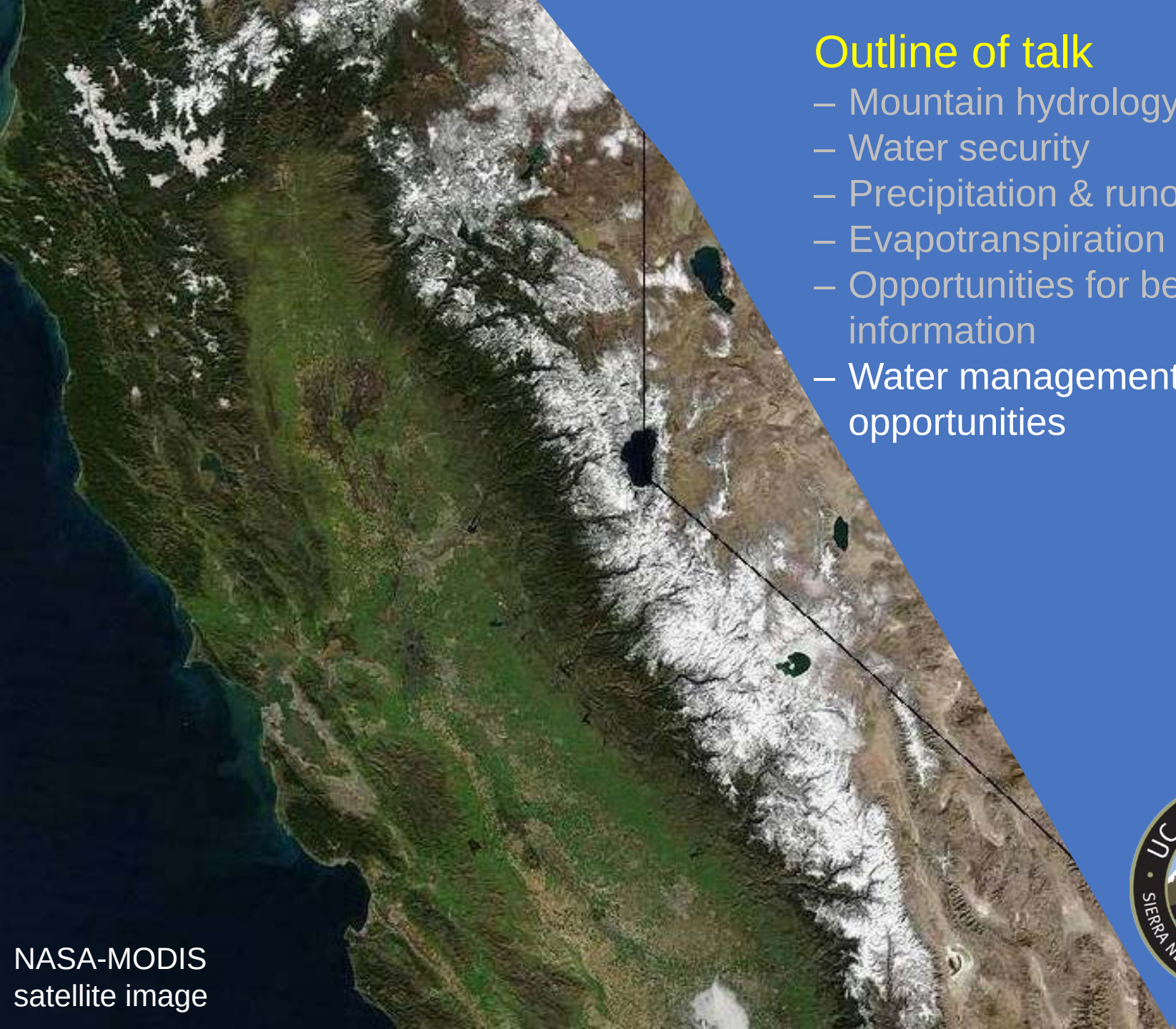


Merced basin SCA & snowmelt volume – 2007



Cumulative snowmelt by elevation band





Outline of talk

- Mountain hydrology
- Water security
- Precipitation & runoff
- Evapotranspiration & runoff
- Opportunities for better water information
- Water management opportunities

NASA-MODIS satellite image

UC MERCED SNRI
SIERRA NEVADA RESEARCH INSTITUTE

Concluding points

Forecasting water supply using spatial data & appropriate modeling could reduce key uncertainties by ~50%

Even a few % improvement in operating high-elevation hydropower ($1.5 billion per yr) would provide significant gains

Better information is a critical foundation for water security

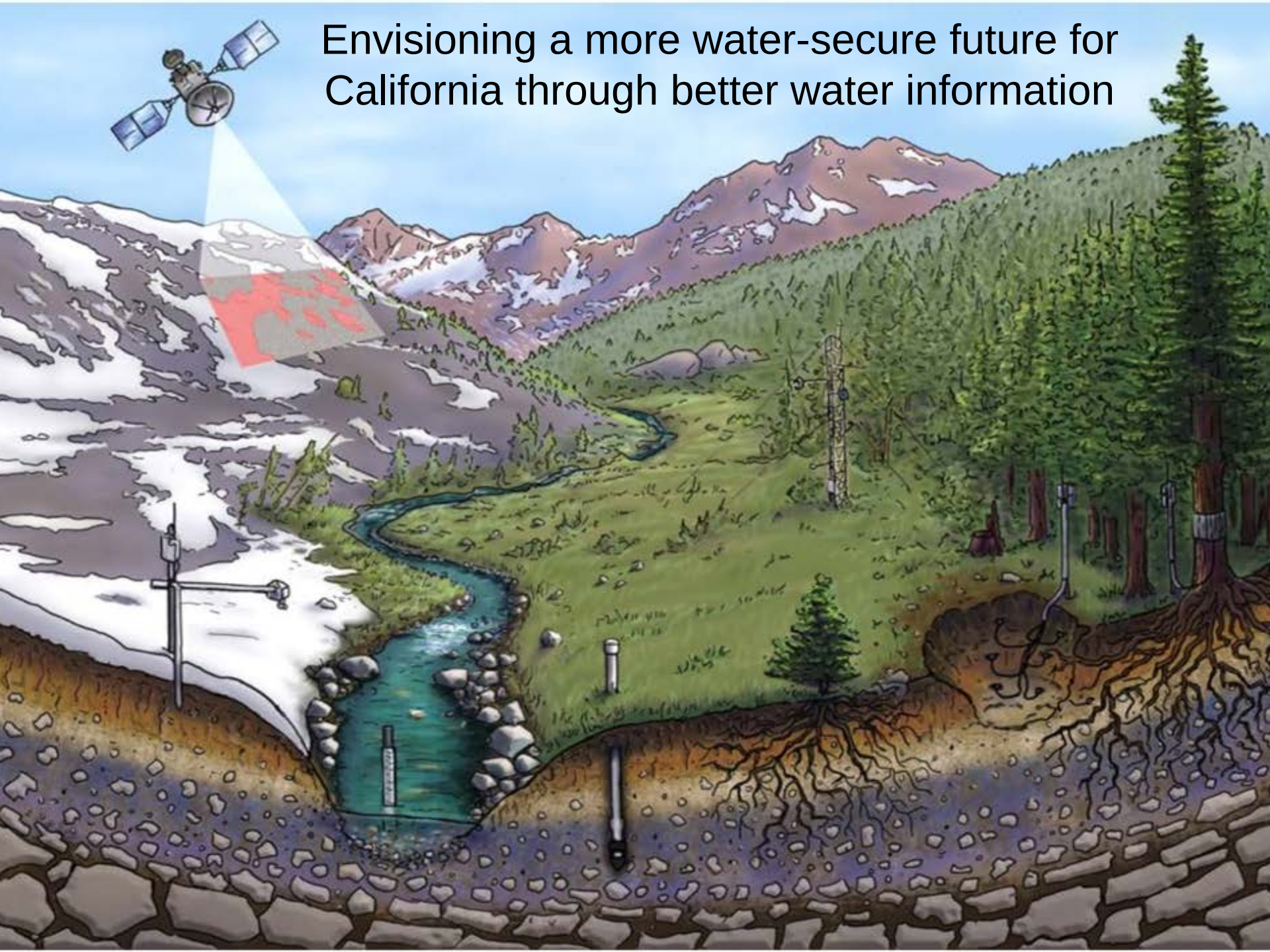
Concluding points (cont.)

Timing & amount of runoff are sensitive to small changes in temperature

Forest management is important for water yield & the timing of snowmelt runoff

Downstream beneficiaries have a stake in upstream watershed management

Envisioning a more water-secure future for California through better water information



Acknowledgements

Research support: NSF Critical Zone Observatory (CZO) program, NASA REASoN, California DWR, U.S. Forest Service, CITRIS
Collaborators: M. Conklin, S. Glaser, M. Goulden, C. Tague, C. Hunsaker, J. Dozier, T. Painter, R. Rice
Students & postdocs: B. Kerkez, S. Welch, P. Kirchner, P. Saksa, R. Ray
Research staff: X. Meng, M. Meadows, P. Womble, M. Pickard

For bibliography of research presented contact rbales@ucmerced.edu