Mountain hydrology of the semi-arid western U.S.: Research needs, opportunities & challenges

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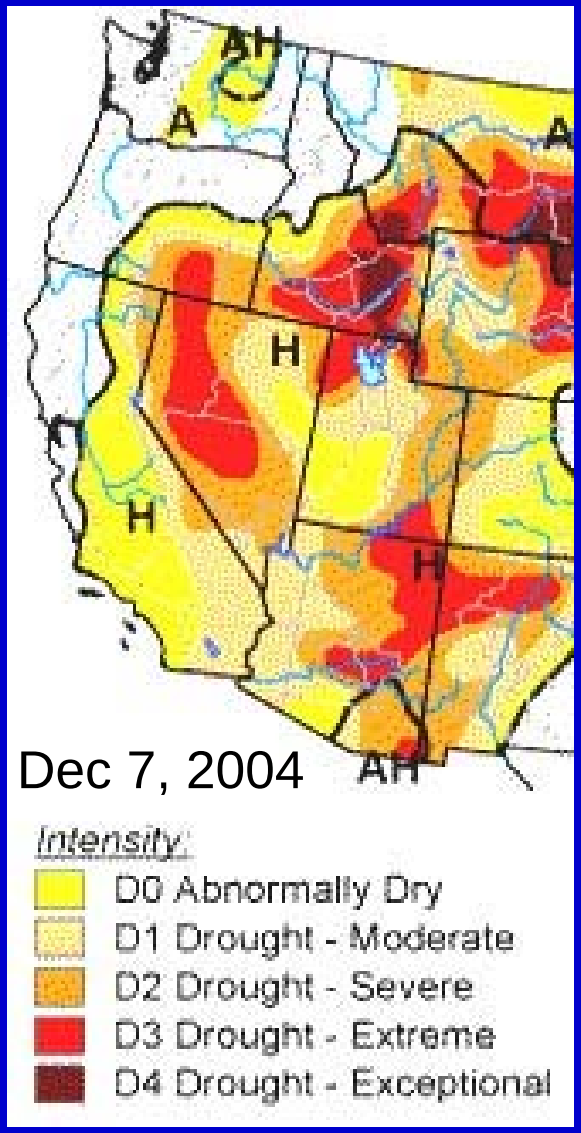
- Research needs: energy & water balance
- Opportunities: applications
- Challenges: measurement strategy

Much of the semi-arid west derives its water supply from intensively managed mountain ranges



Being in the 6th year of drought has focused attention on western water. It has made scientists & decision-makers alike push for new measurements & understanding of mountain hydrology to close critical knowledge gaps. This new understanding is needed for longer-term sustainable water management.

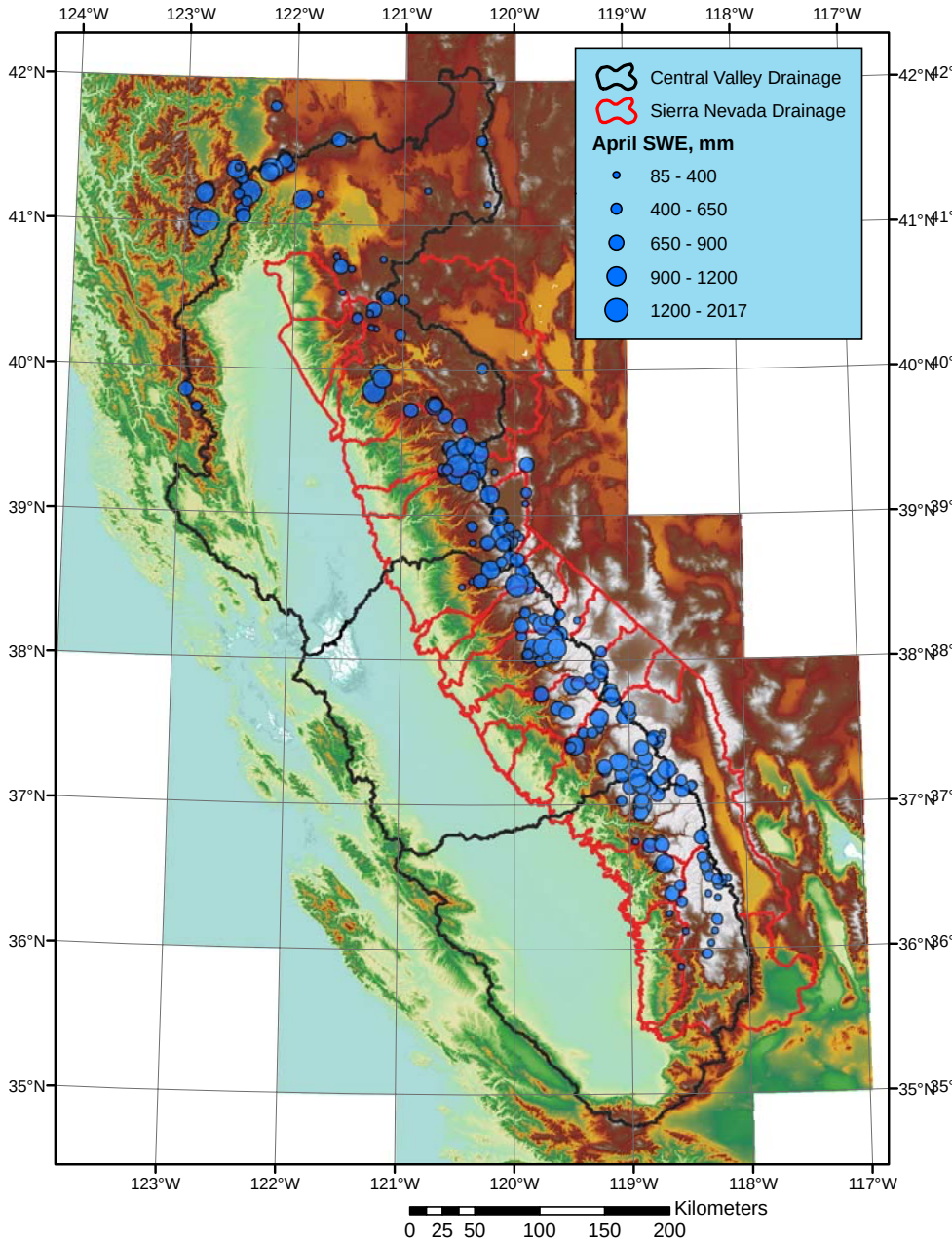
http://drought.unl.edu/dm

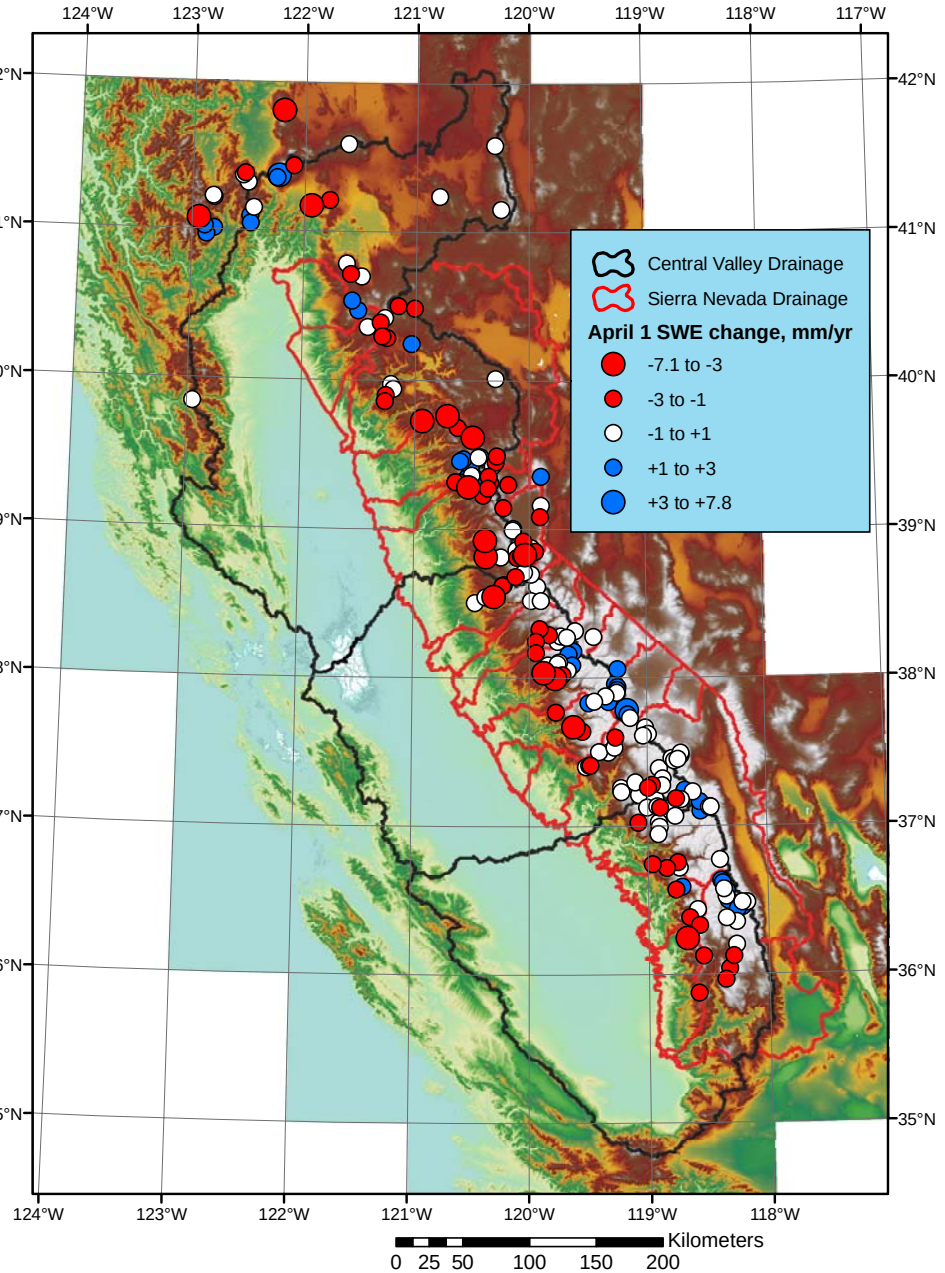
Despite the hydrologic importance of mountainous regions, the processes controlling energy & water fluxes within & out from these systems are not well understood.

Particular areas for investigation

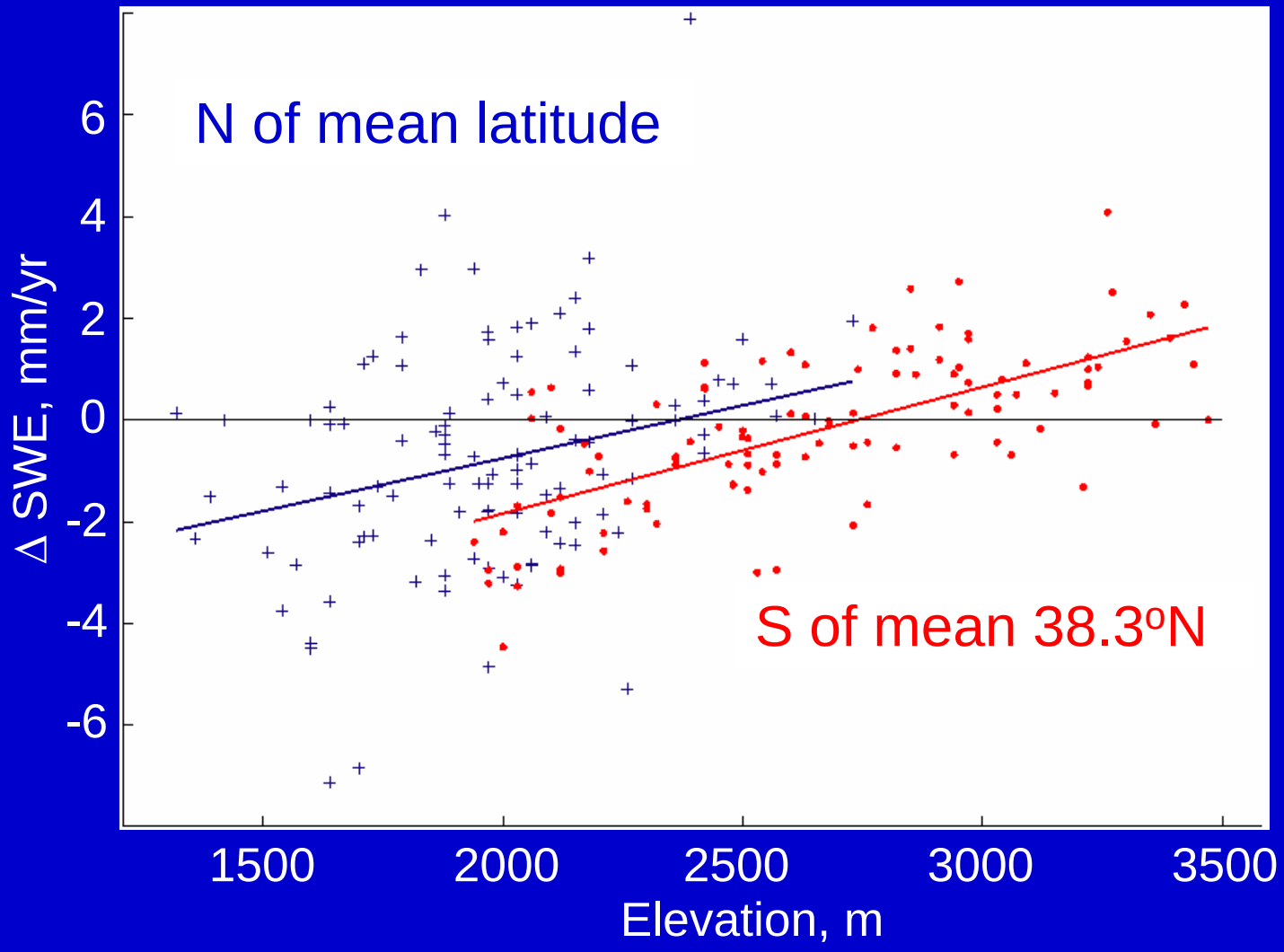
- **precipitation patterns – orographics**
- **energy balance - modeling**
- **partitioning of snowmelt & rainfall on the ground**
- **water balance – scaling point to catchment to range**

Changes in April 1 Sierra Nevada snow





Changes in April 1 Sierra Nevada snow

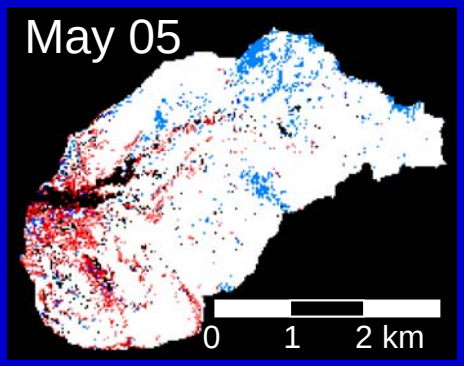


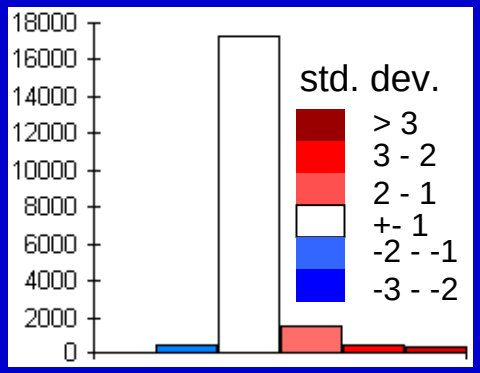
Changes in orographics?

Meteorological & climatic controls on precipitation in mountains: spatially, interannually?

Energy balance: spatial variability of snow surface albedo above treeline

Albedo measured from AVRIS

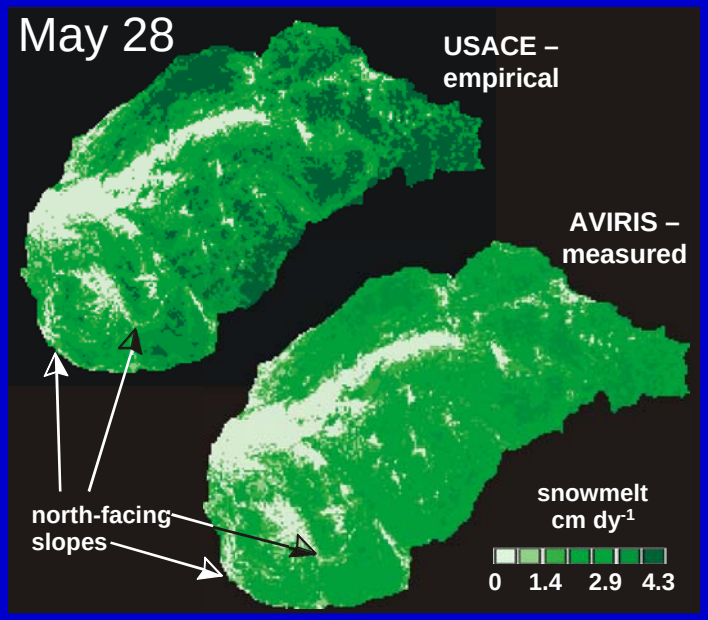




α_{mean} = 0.664

age = 11 dy

Measured albedo can be quite different from empirical estimates



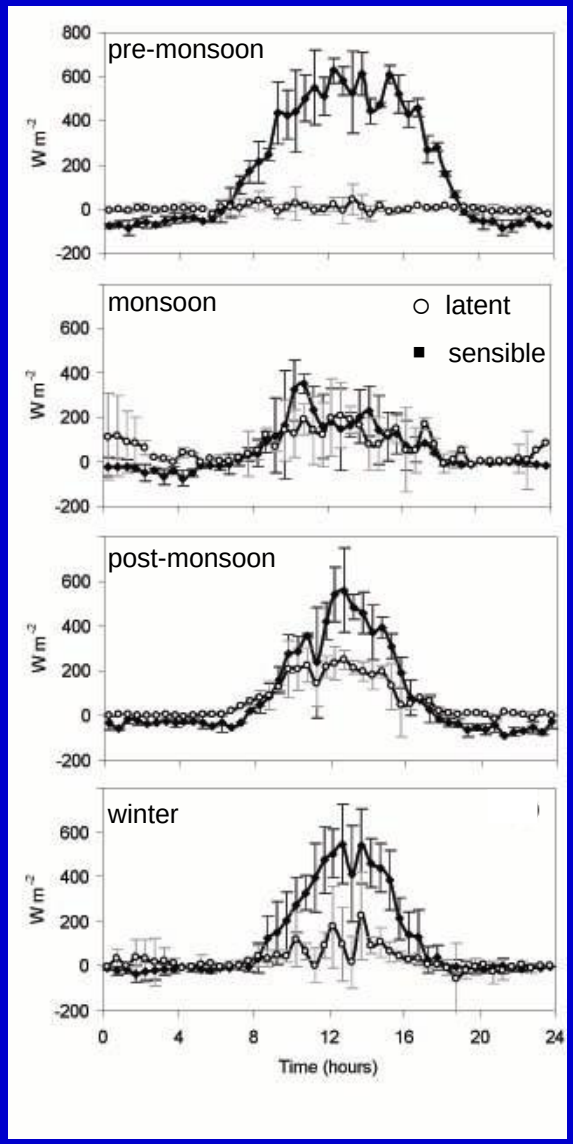
Modeled snowmelt is very sensitive to albedo on slopes where solar radiation dominates

Small spatial variation in albedo measured by AVRIS — but large changes with grain size as snow ages — depends on elevation, latitude, orientation, wind exposure, dust deposition

Test basins for radiation balance & remote sensing needed across range of variability in mountains

Molotch et al., GRL, 2004

Energy balance in mountain forest

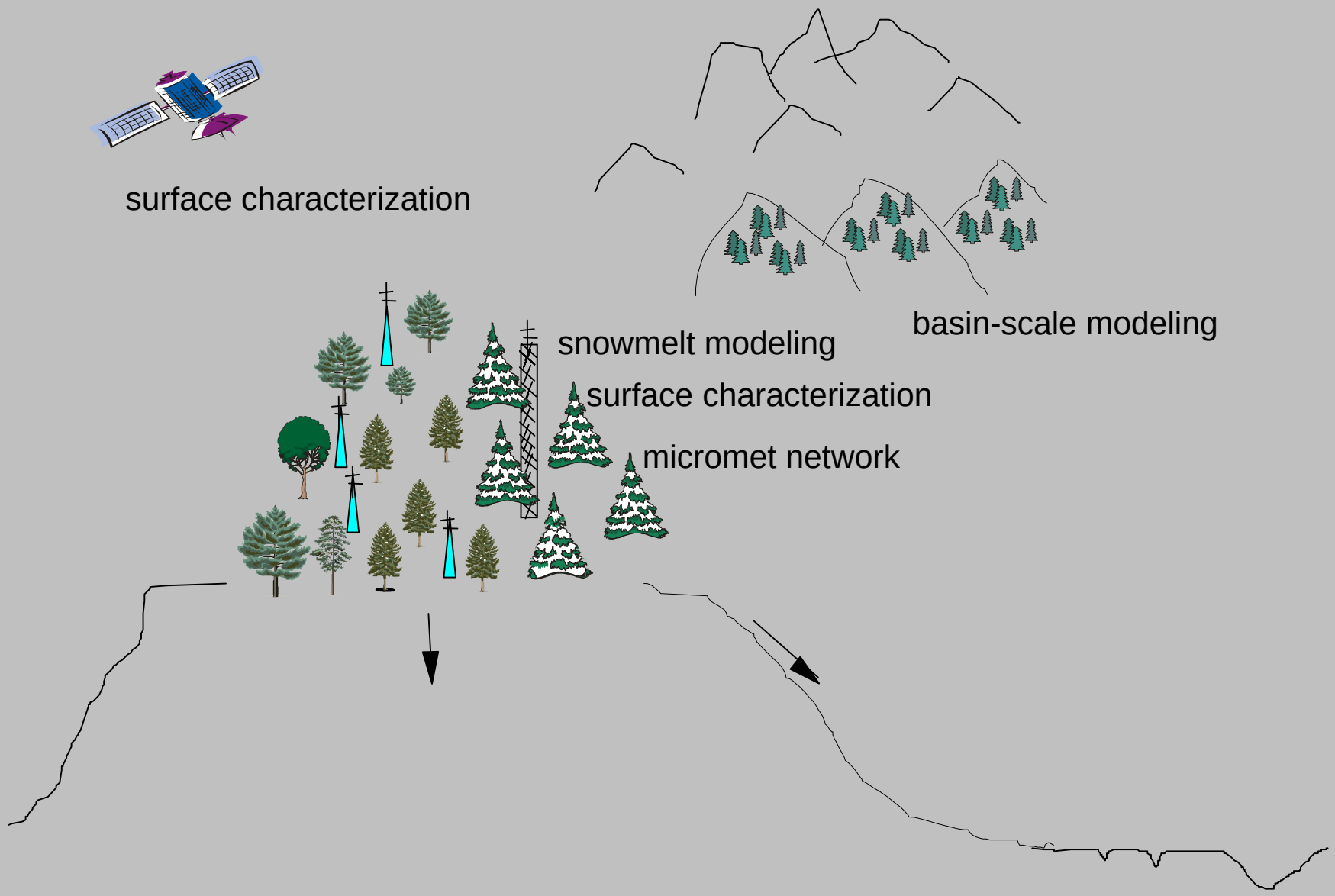


Issues & research needs are somewhat different — turbulent fluxes, vegetation control on heterogeneity

Daily cycles of turbulent fluxes at Mt Bigelow, AZ. 2400 m elevation, 2nd growth Ponderosa Pine-Douglas Fir forest

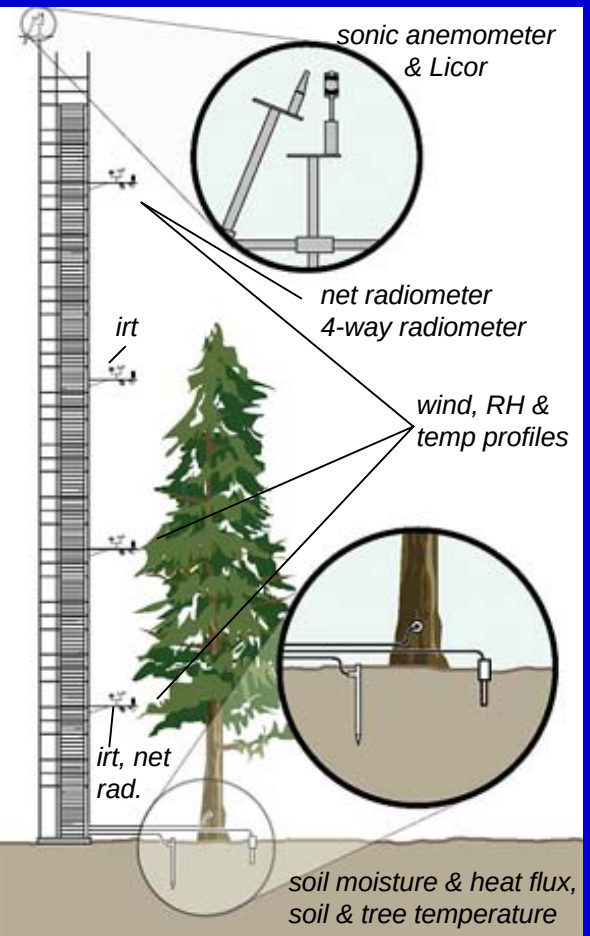
Brown-Mitic et al., in press

Scaling from point to basin

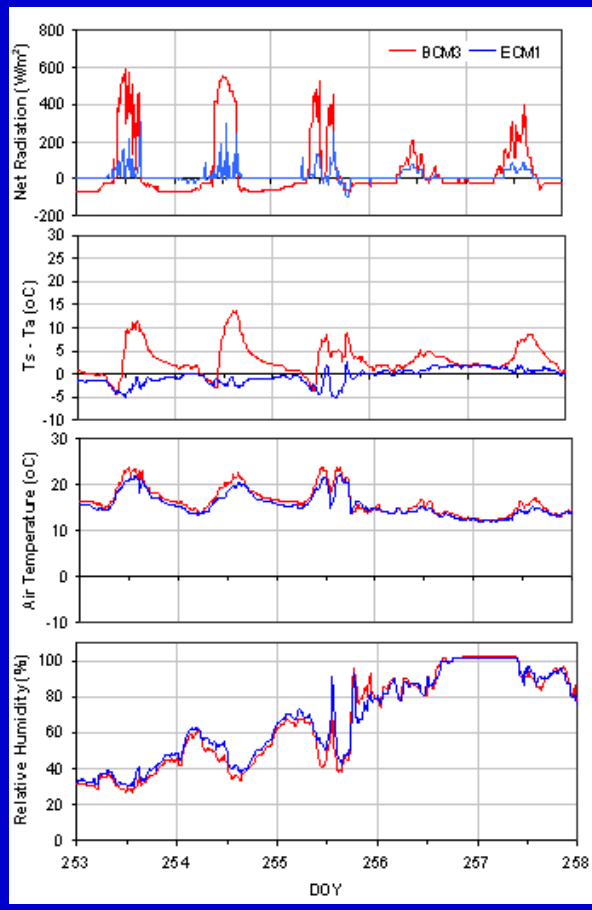


Measurement clusters: flux towers & water-balance instrumentation arrays

Pilot deployments over past 4 yr to develop concept



Co-locate soil moisture with snow measurements?



Similarity in T_{air} & RH — differences in net radiation (reflected in surface temperature) & potential for heat transfer

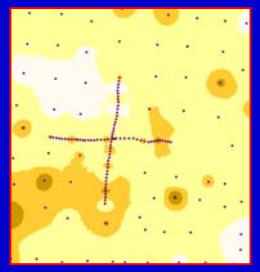
Scaling mountain water balance

snow distribution
↓
melt timing
↓
partitioning
↙ ↘
infiltration runoff
↙ ↘
ET recharge

How to blend measurements from multiple scales, with integrated modeling schemes?

plot/hillslope

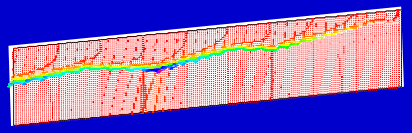
soil moisture



snow distribution

micromet

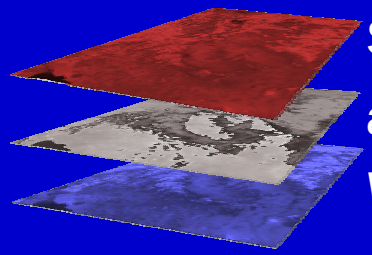
fluxes



infiltration & recharge

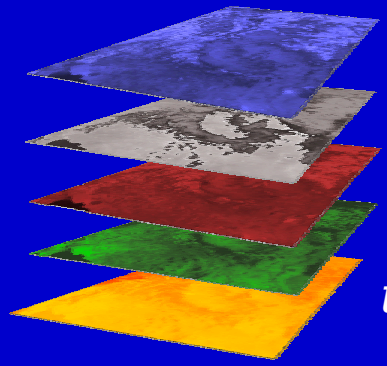
basin

remote sensing



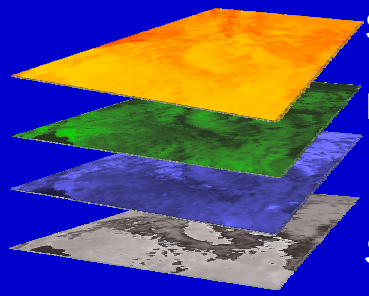
SCA
albedo
vegetation

ground/RS



SWE
precip
radiation
EB
topography

ground



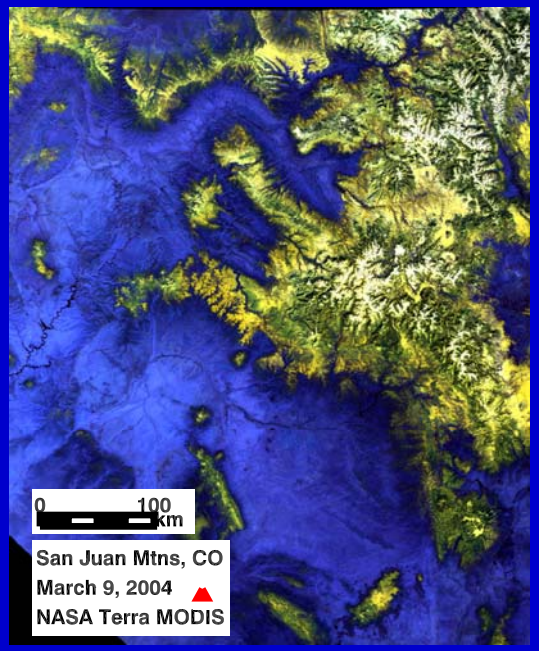
soil moisture
micromet
bedrock
soils

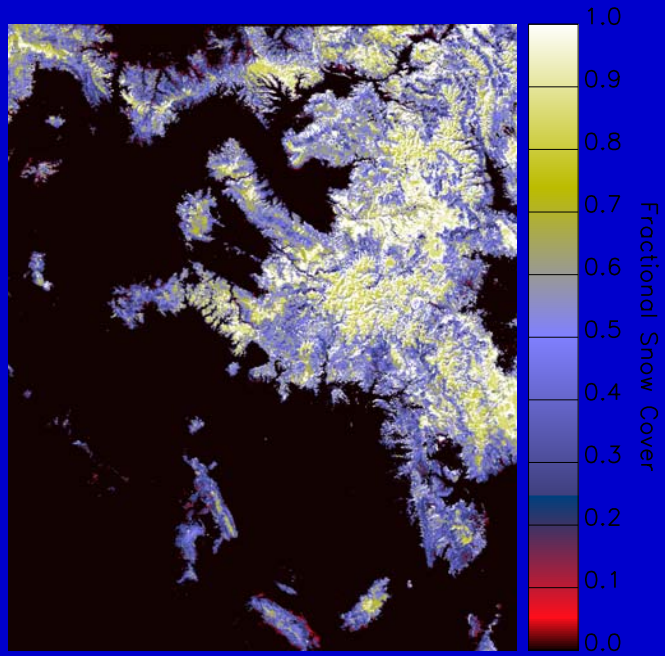
Lack of integrated measurement strategies & data/information systems for mountain hydrologic data hamper improvements to understanding the aforementioned processes

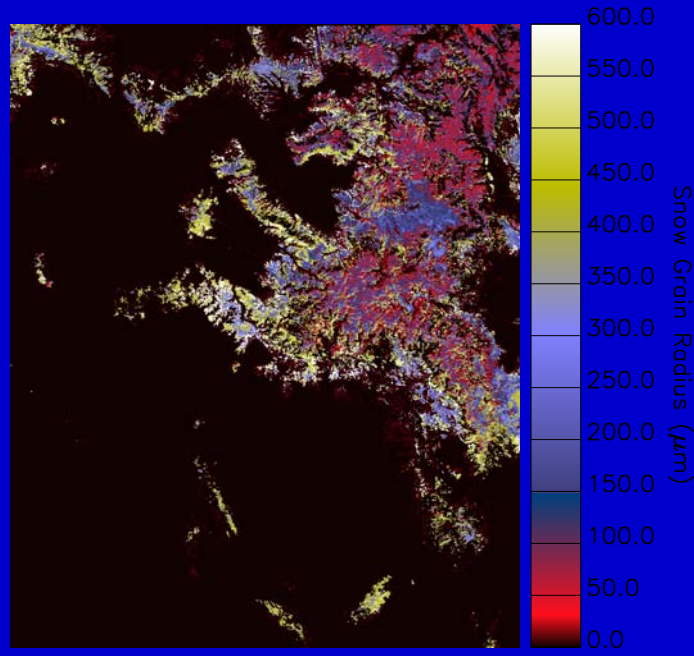
<u>Topics</u>:

- **precipitation & snowcover — blend of remote sensing & ground-based measurements**
- **integrated water balance measurement strategies: measurements as a research area**

MODIS fractional SCA & grain size







MODIS has sufficient spectral sampling to estimate grain size & thus albedo, as well as fractional SCA, within a 500 m pixel

Mountain snowcover is generally not continuous at the 500-m scale — binary snowcover models consistently overestimate basin-wide SCA & albedo

Snow under trees remains a challenge — ground truth needed for research

The question remains: how best to use knowledge of snowcover from remote sensing as part of an integrated measurement & modeling strategy

Painter and Davis, in preparation

Mountain precipitation

Research needs cover most aspects of the problem:

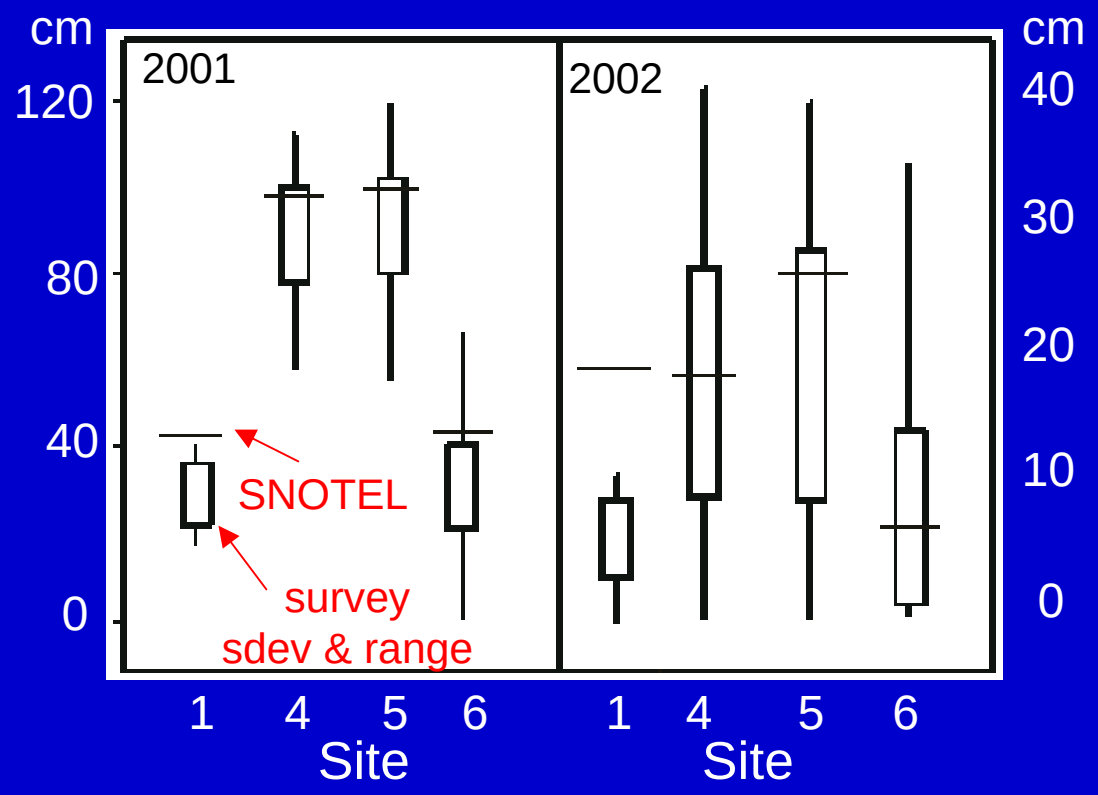
- Measurement at a point
- Ground-based network design
- Integration of remotely sensed & ground-based measurements

The accuracy provided by existing networks simply is not adequate

Snow course & snow telemetry sites

- Point measurements of SWE — not quantitative measures of basin-scale SWE
- Established as index sites to estimate seasonal runoff using statistical models — located at sites with persistent snowcover
- Emerging water resources decision support systems & hydrologic models are based on mass balance — quantitative SWE estimates are a top priority

April SWE bias at 4 Colorado sites

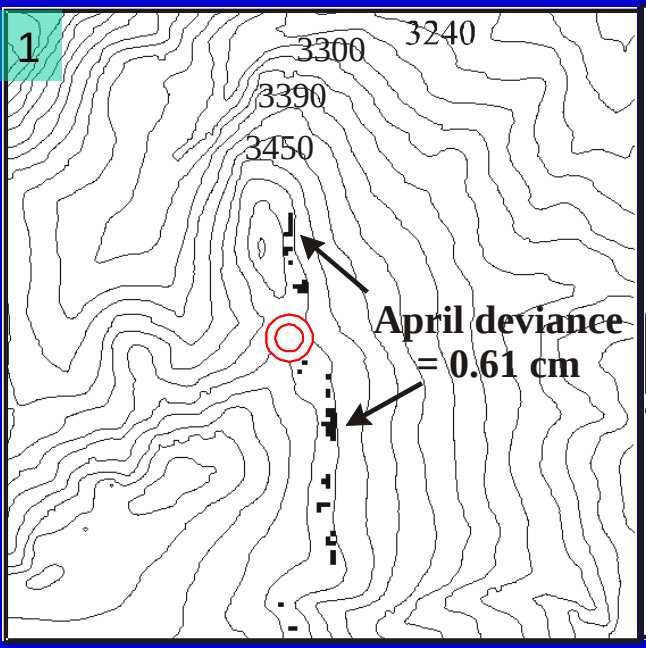


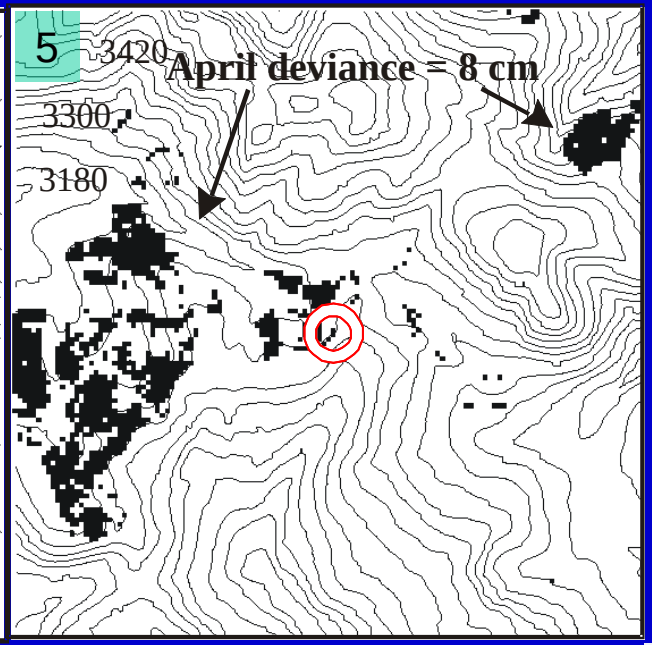
SNOTEL site generally has much more snow than does surrounding area

How to design representative network?

Molotch et al., in preparation

Optimal locations for measuring mean SWE





- Based on topography, vegetation, energy balance factors, it is possible to design a network to minimize the error in spatial estimates
- Existing sites generally do not fall within that area
- Network design is still a research issue
- New technology must also be used to extend point measurements — lower cost, less intrusive

Molotch et al., in preparation

Concluding thoughts

- Current ability to quantitatively estimate water fluxes & reservoirs in mountains is woefully inadequate (also ecological & biogeochemical linkages)
- Economic value of & societal demand for new knowledge & tools for mountain hydrology is very large
- Advances will require sustained investments in new measurements & infrastructure, including data & information systems (plus research)
- Measurement strategies will rely heavily on remote sensing — need complimentary ground-based systems