

# Remote Sensing of the Rocky Mountain Snowpack

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Geography

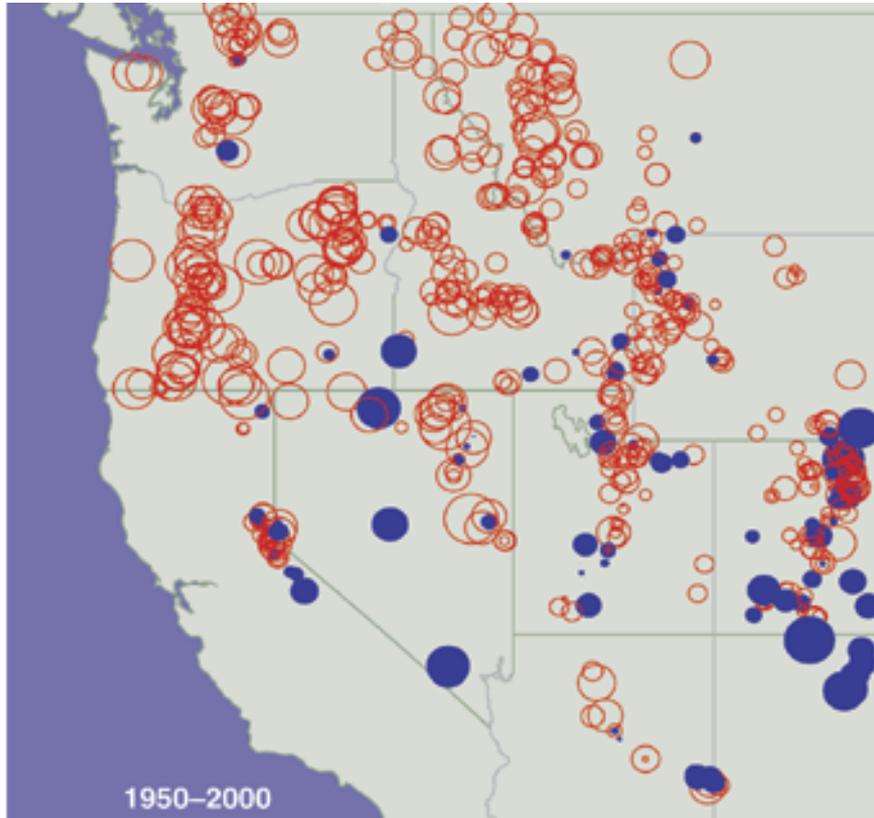
University of Colorado  
at Boulder



*Border-Water*  
6/09/2011

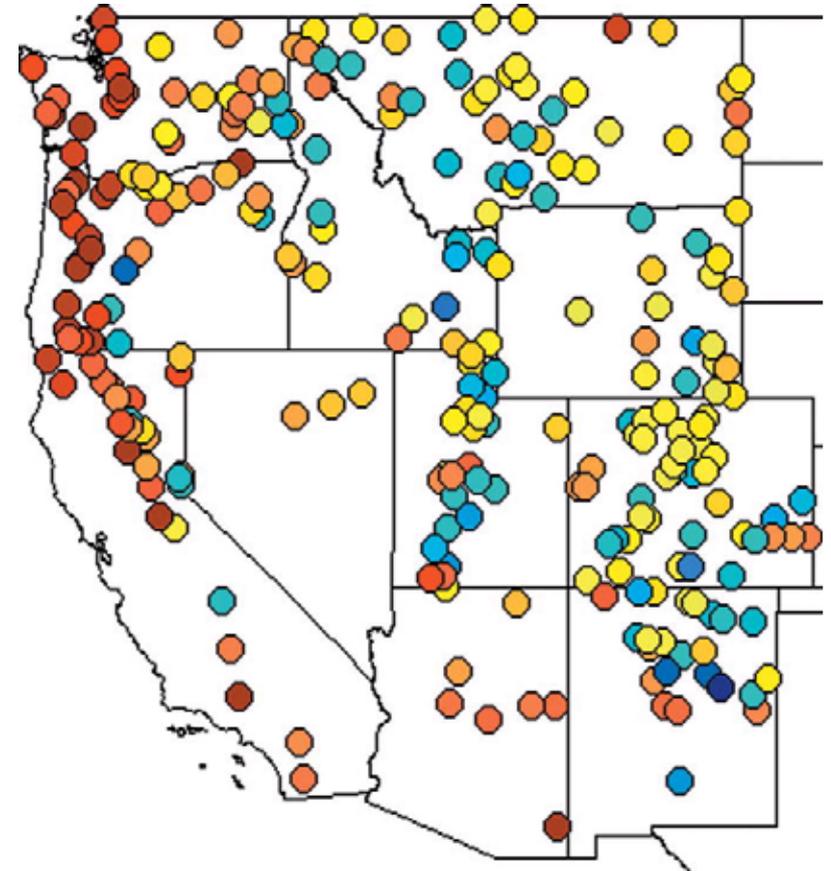
# Snowpack Trends: 1950 - 2000

Percent change in April 1  
snow water equivalent



*Service, 2004*

Percent change in  
snowfall to rainfall



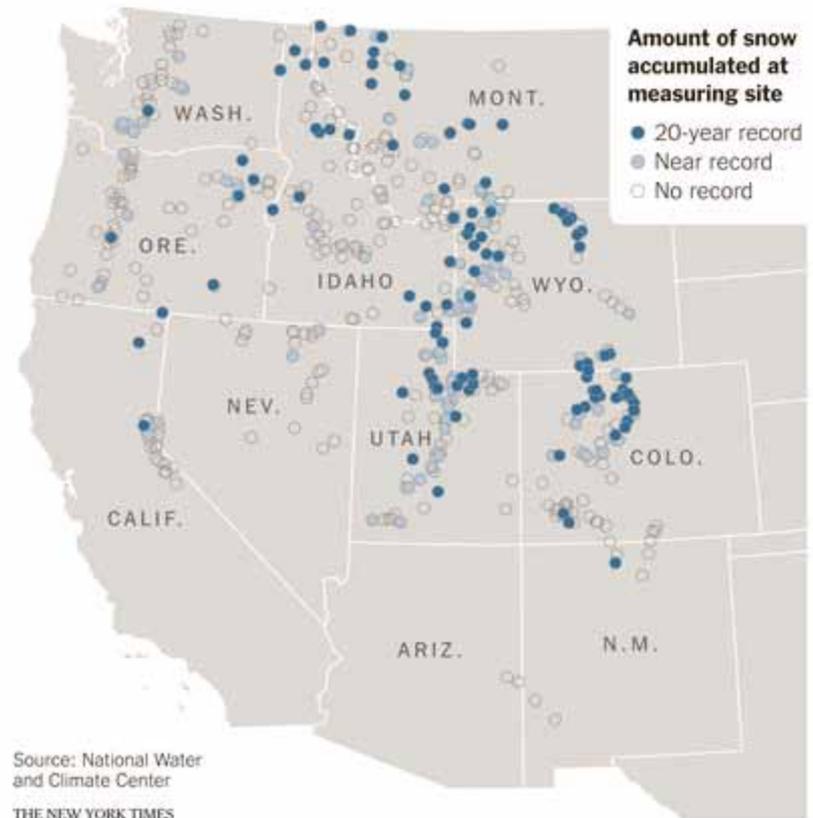
*Knowles et al., 2006*

# Current Water Year

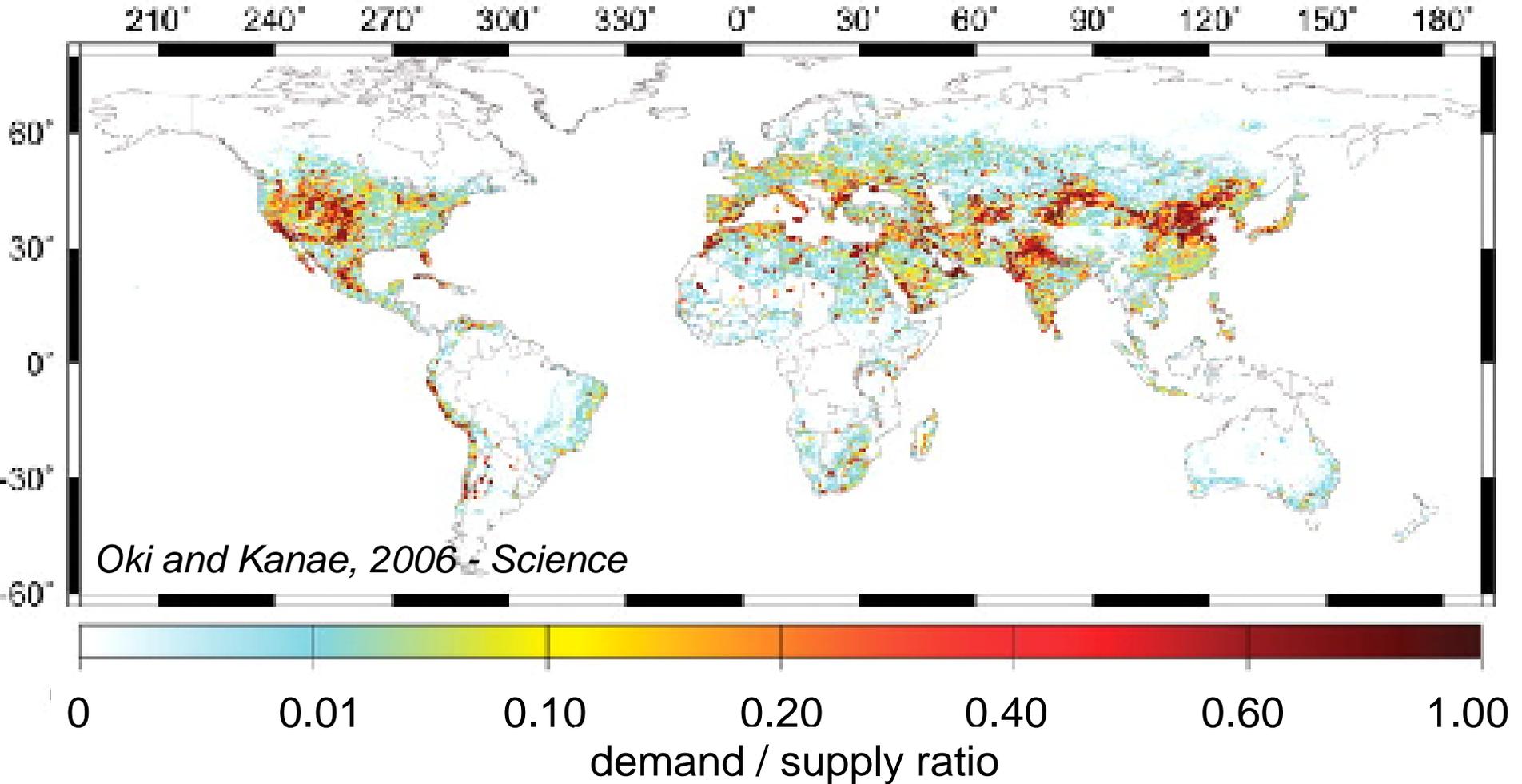
- Snowpack as driver of floods
- Rain on snow
- Spring-time weather synoptics

## Record Snowpack

More than 90 measuring sites in the West have record snowpack totals on the ground so far this year.



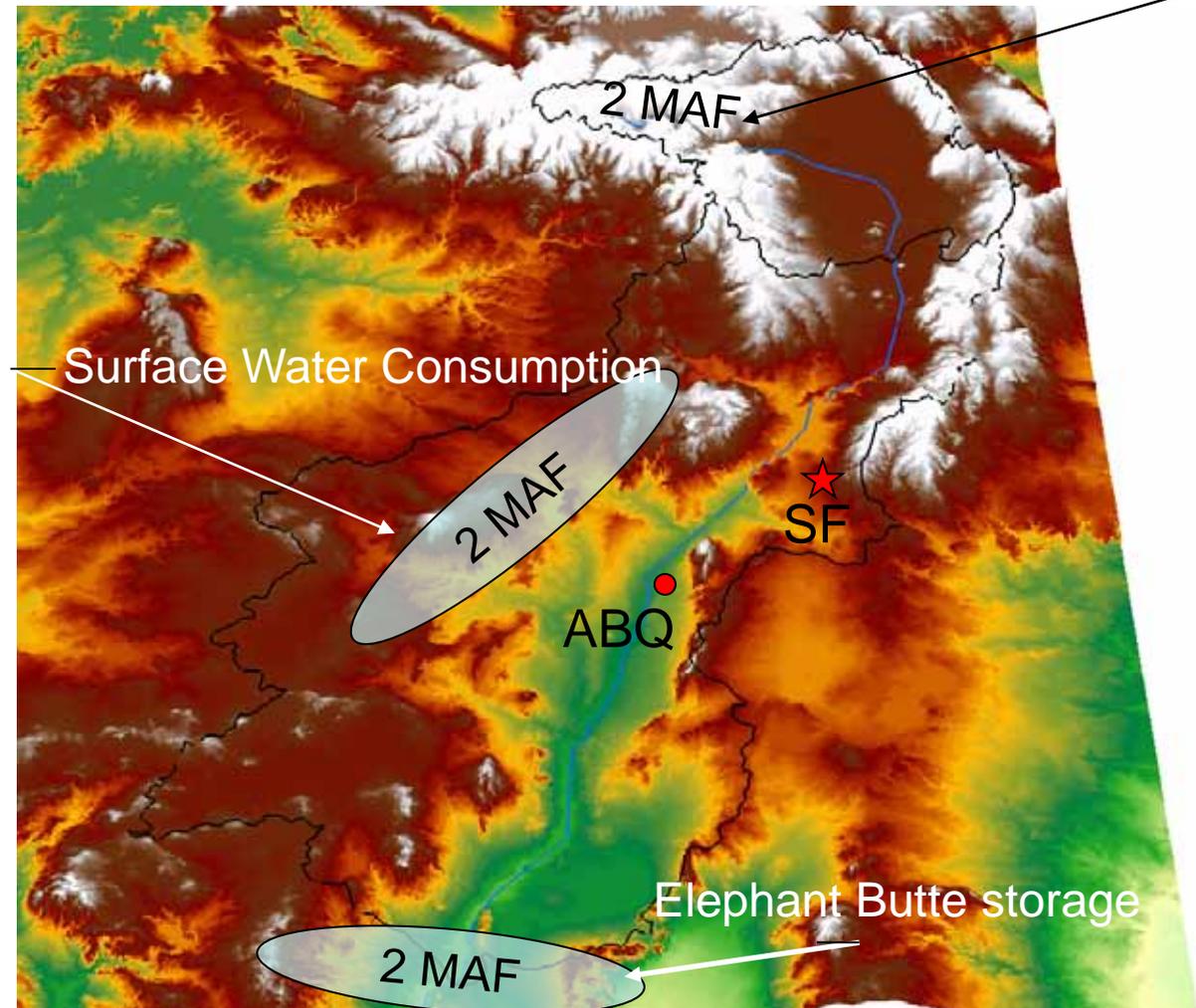
# Water demand & supply



# Snowpack loss & water storage

snowpack annual storage

- Snow is the dominant water source for the Colorado R., Rio Grande, and CA Central Valley
- Potential loss of 500,00 acre feet OR MORE of snowpack storage in coming decades

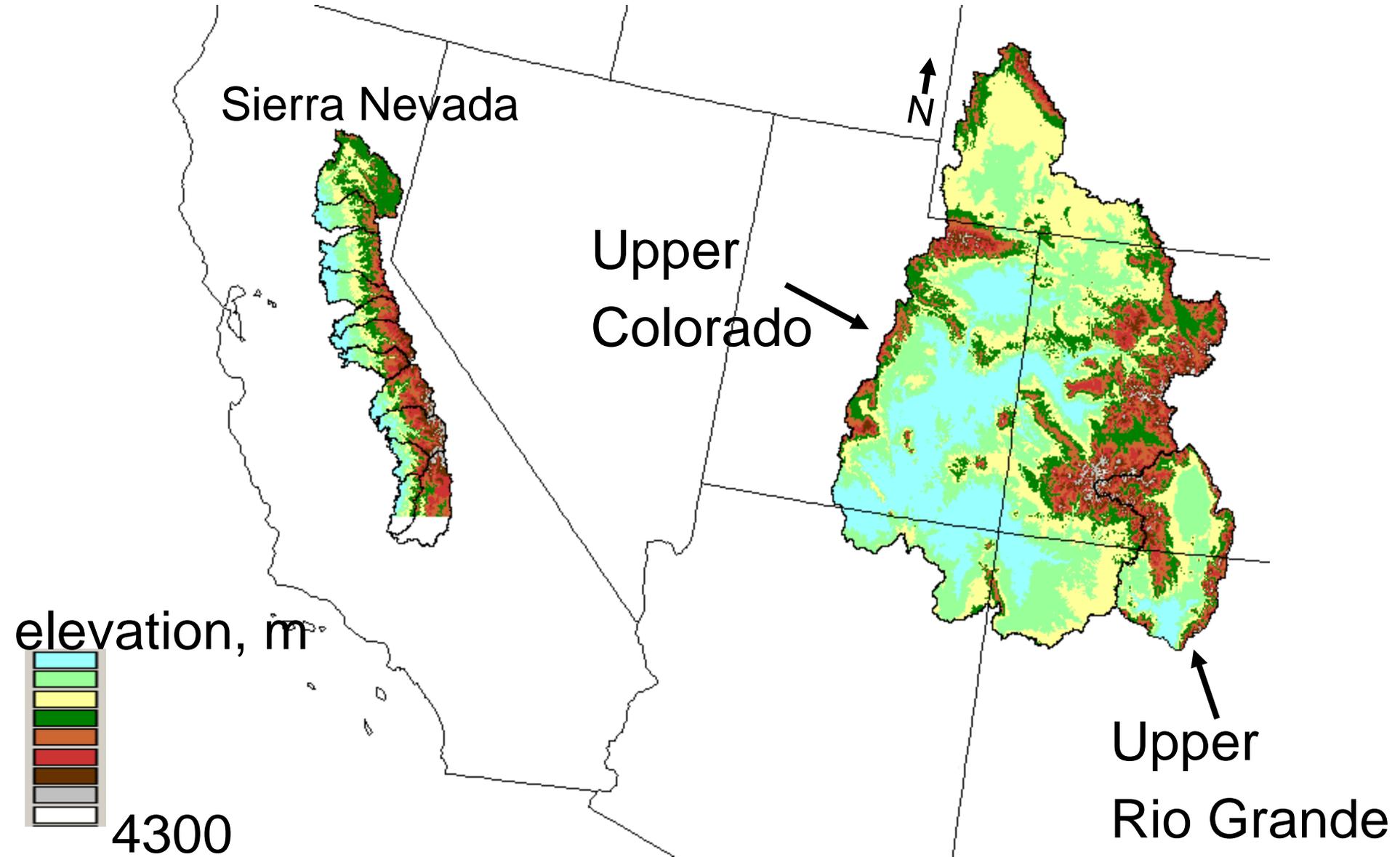


# Snowpack Remote Sensing: Wish List and Challenges

- Wish list: SWE, snow extent, grain size & albedo, impurities, organic compounds
- Snowpack is spatially heterogeneous.
- Observations are sparse and coarse.
- However, we are good at detecting snow extent

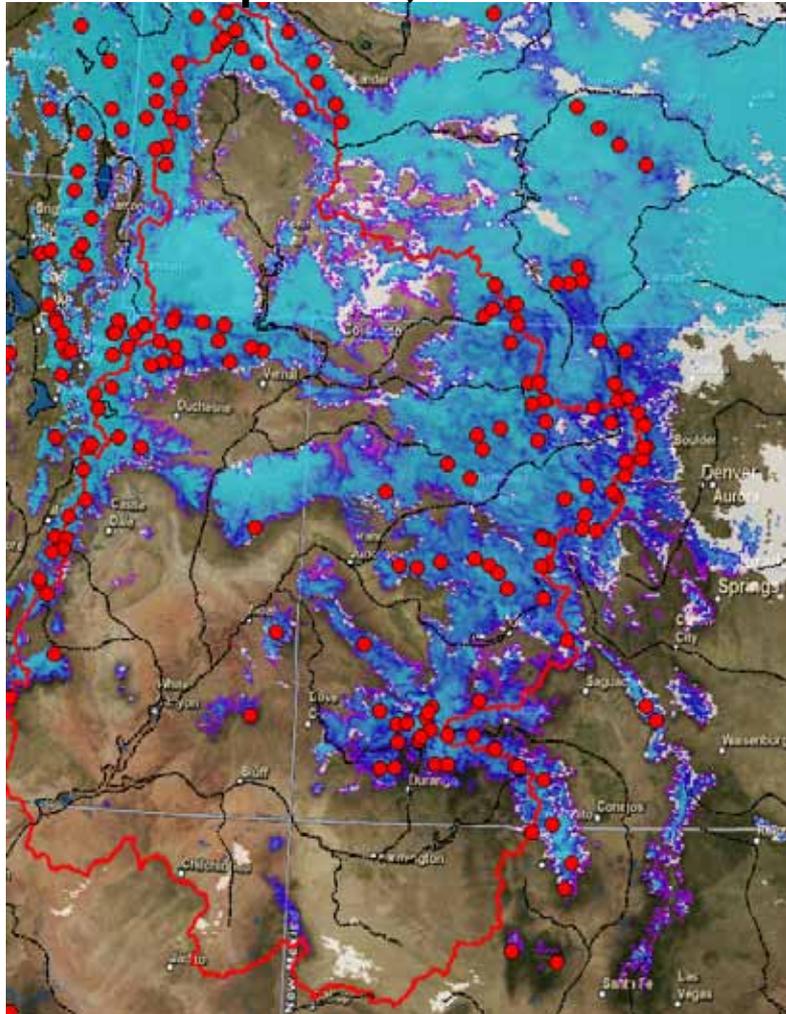


# Study Regions

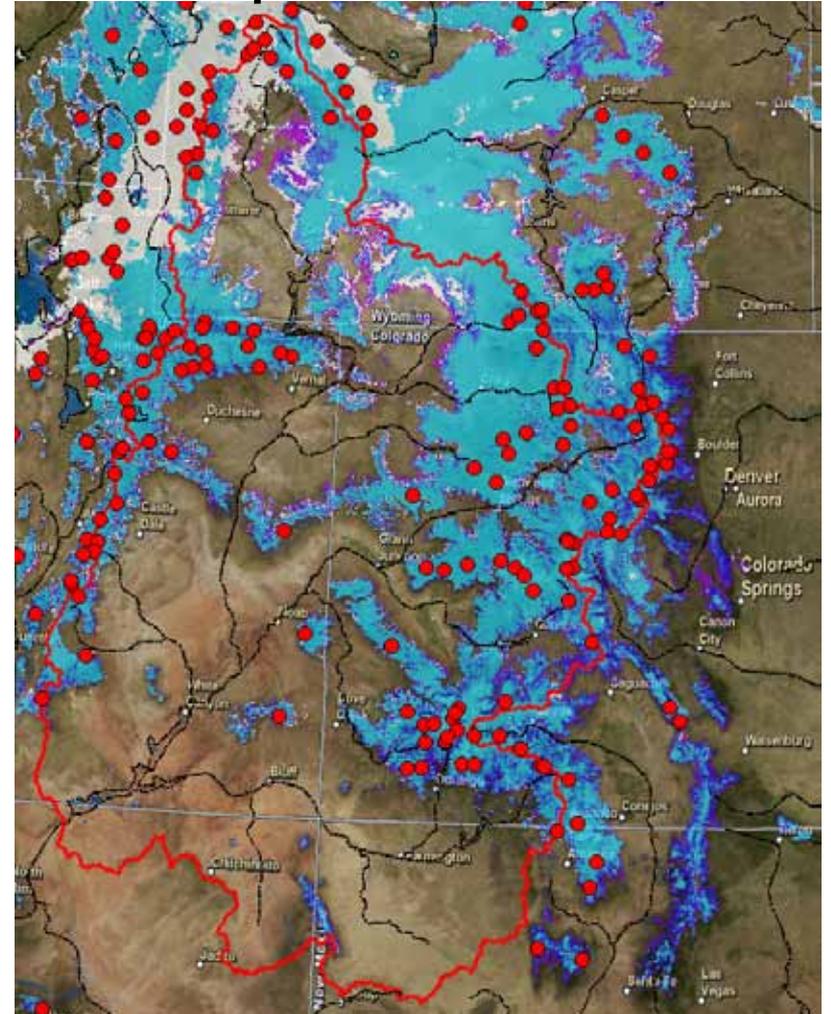


# Snow Extent in the Colorado River Basin from MODIS

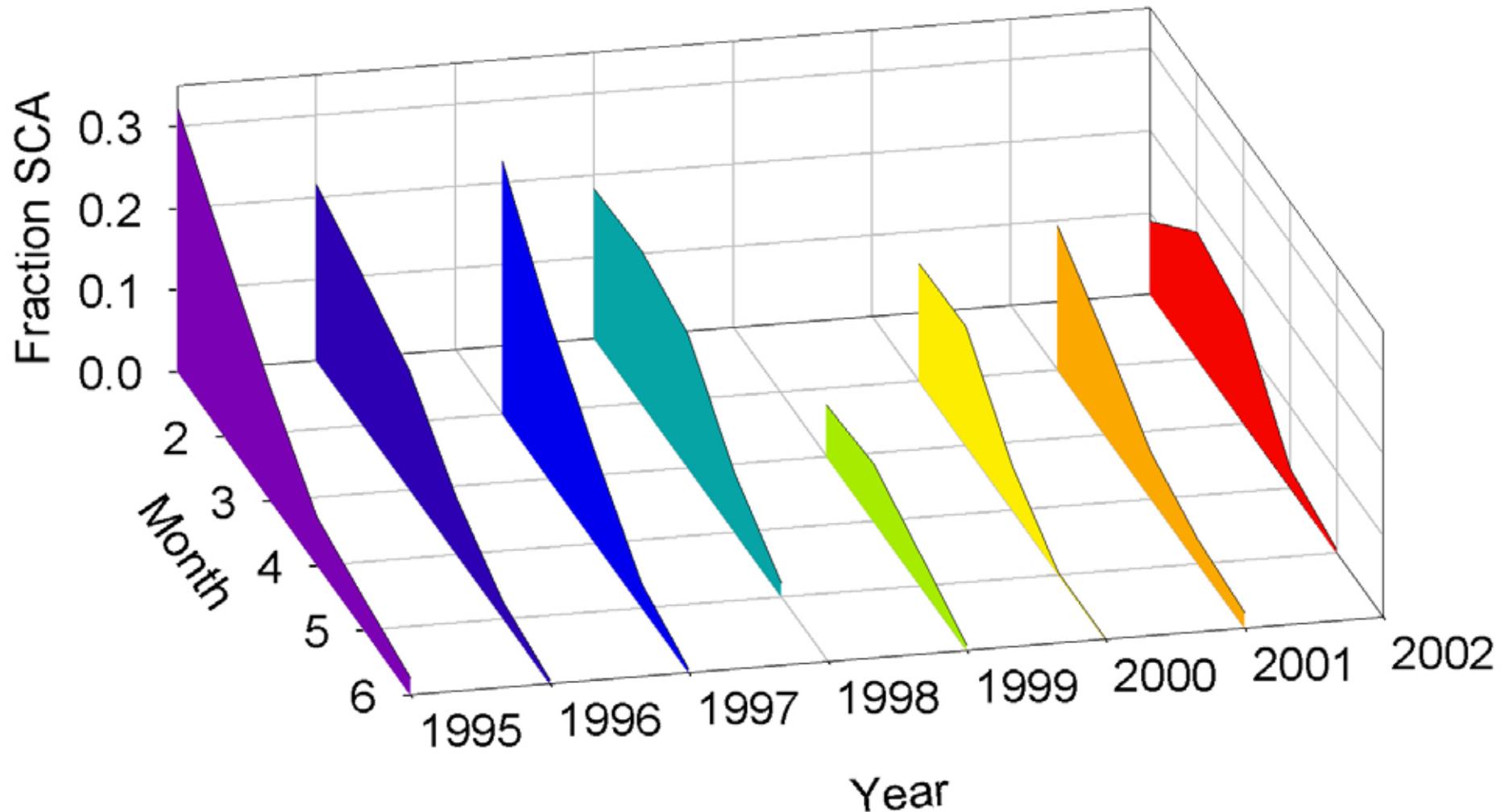
April 6, 2009



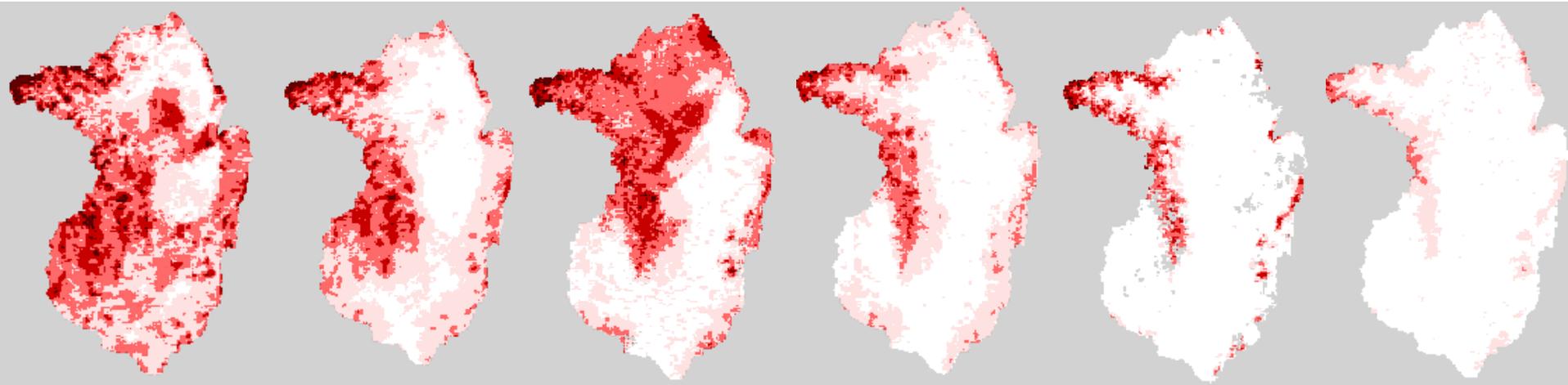
April 8, 2010



# Upper Colorado River SCA from AVHRR



# 1995 Upper Rio Grande SCA



Jan

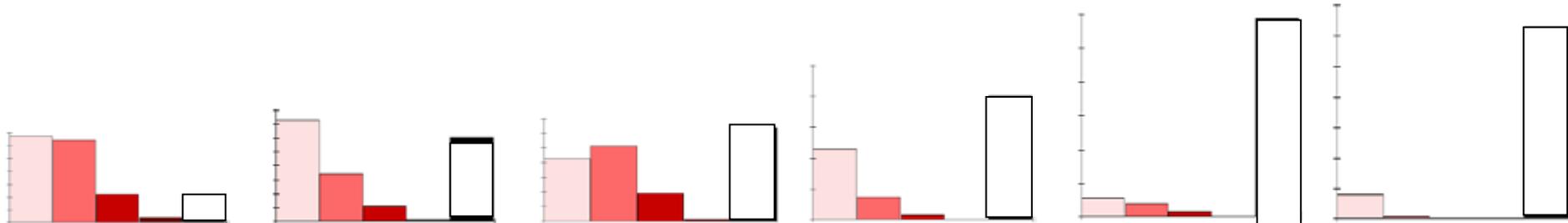
Feb

Mar

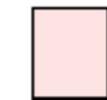
Apr

May

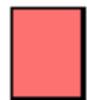
Jun



percent SCA



1-25



26-50



51-75



76-100

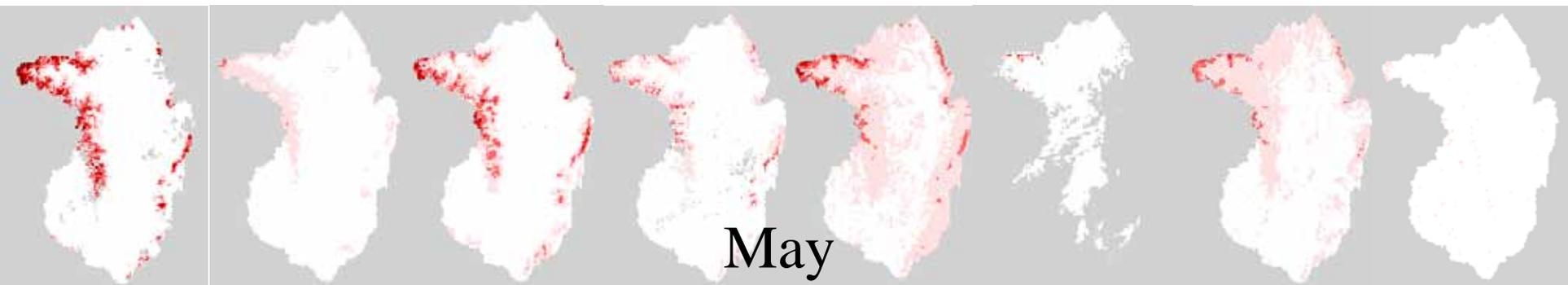
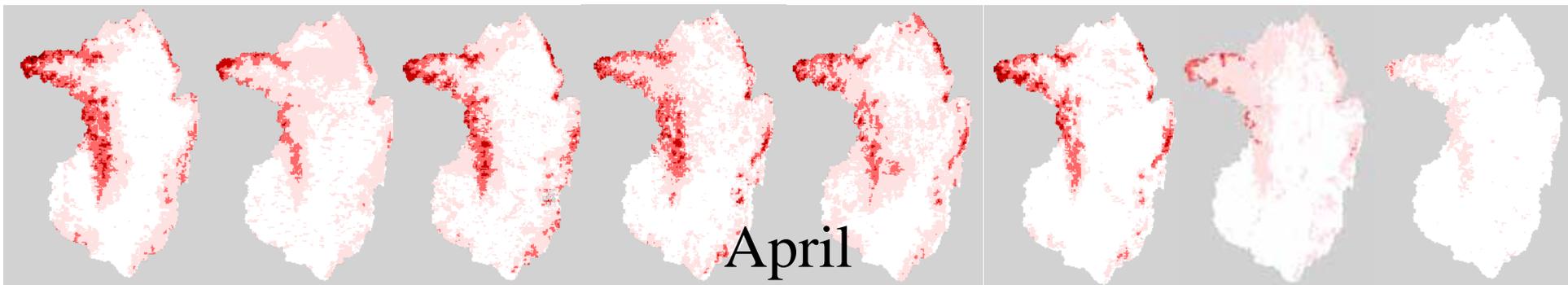


0



no data

# March, April & May R. Grande SCA



1995

1996

1997

1998

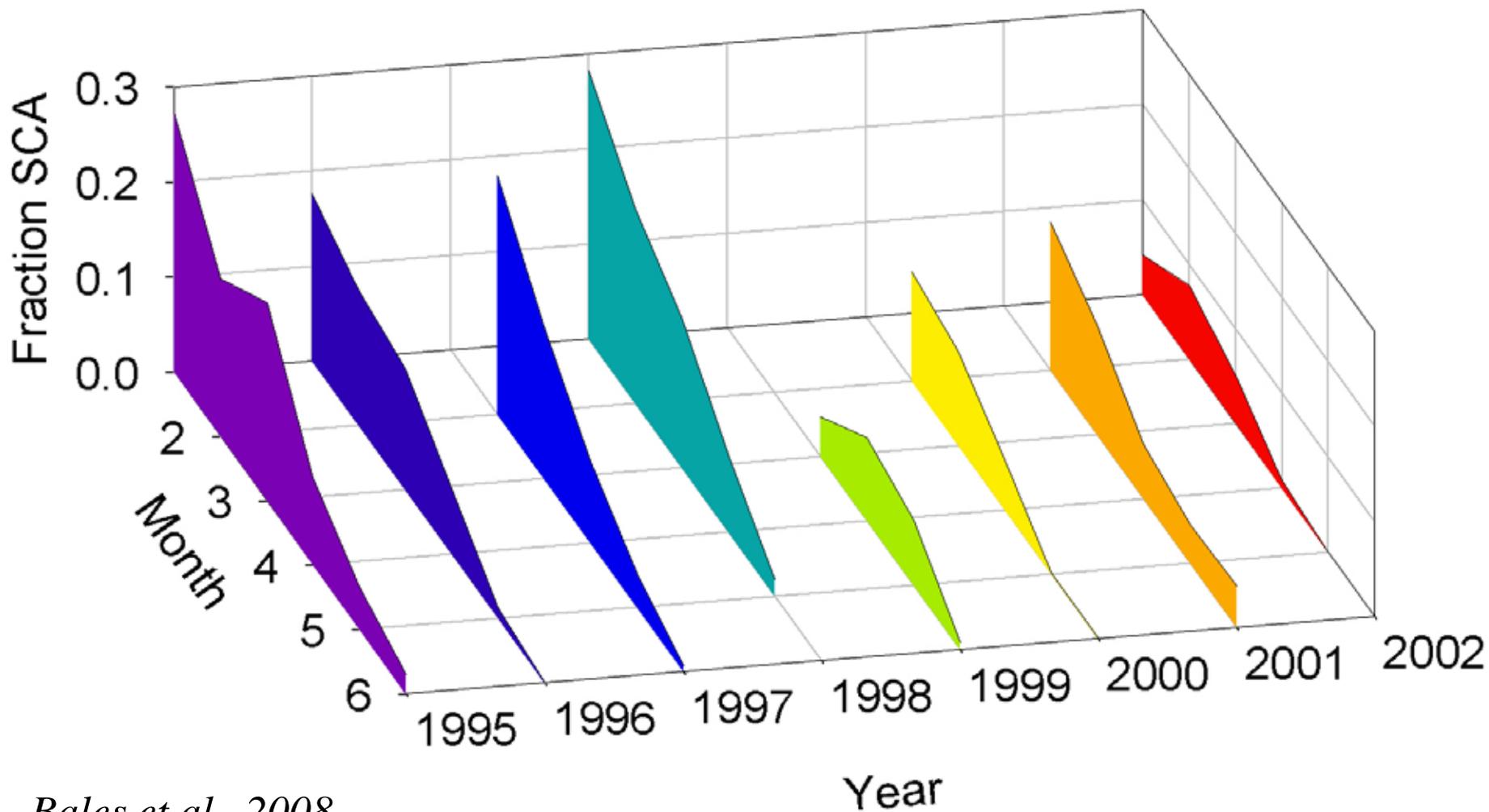
1999

2000

2001

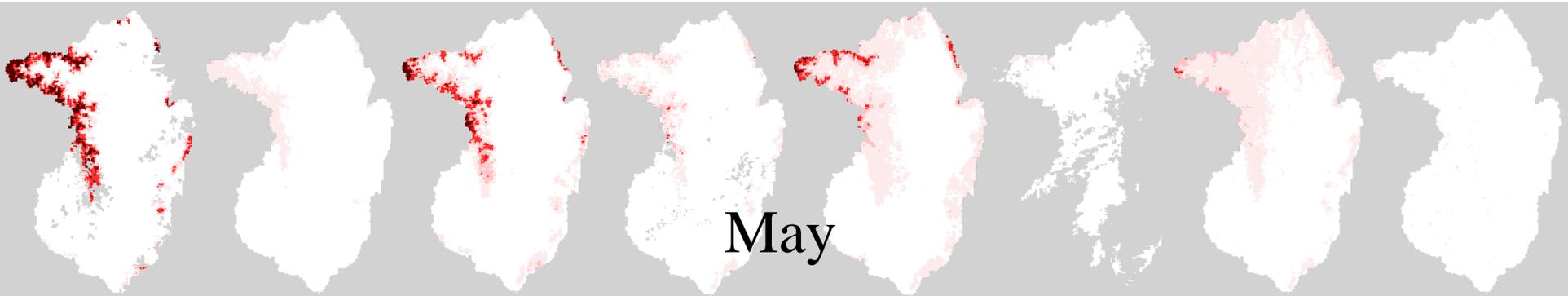
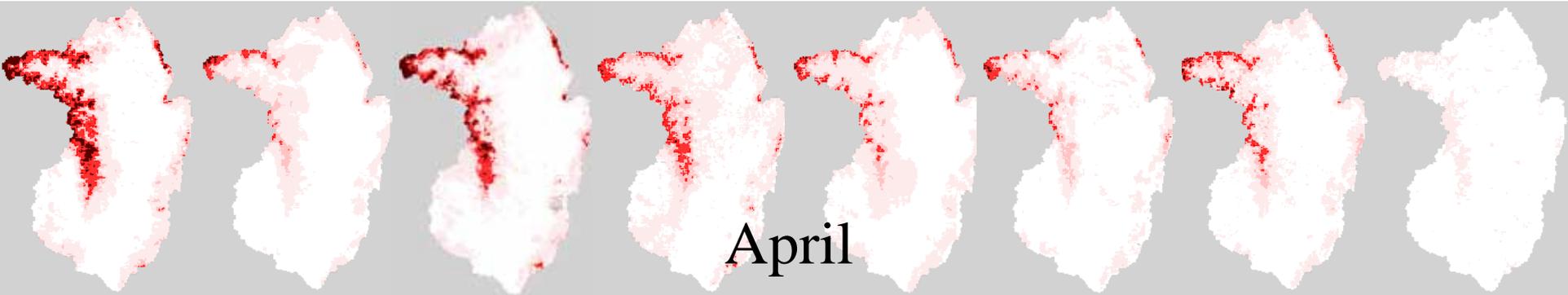
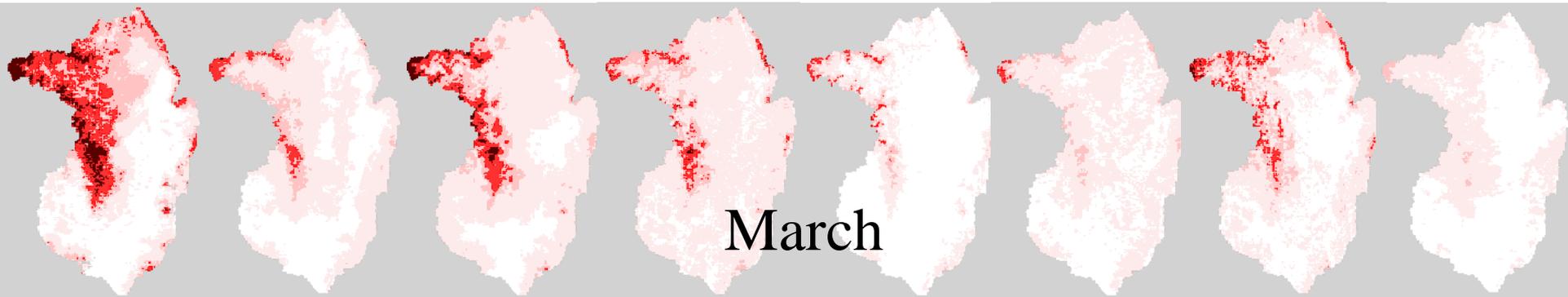
2002

# Upper Rio Grande SCA



*Bales et al., 2008*

# March, April & May R. Grande SWE



1995

1996

1997

1998

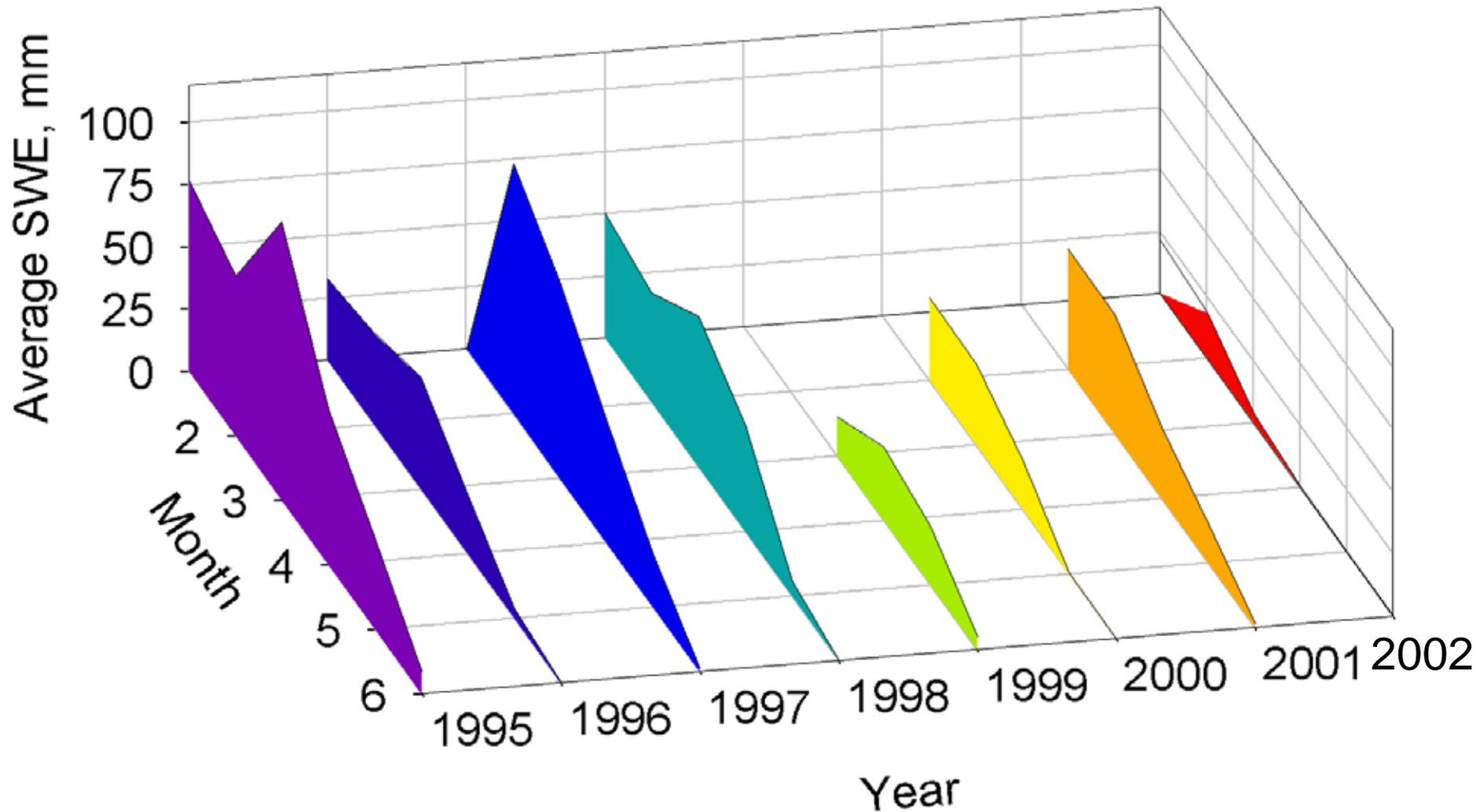
1999

2000

2001

2002

# Upper Rio Grande SWE



# Sierra Nevada SWE from MODIS

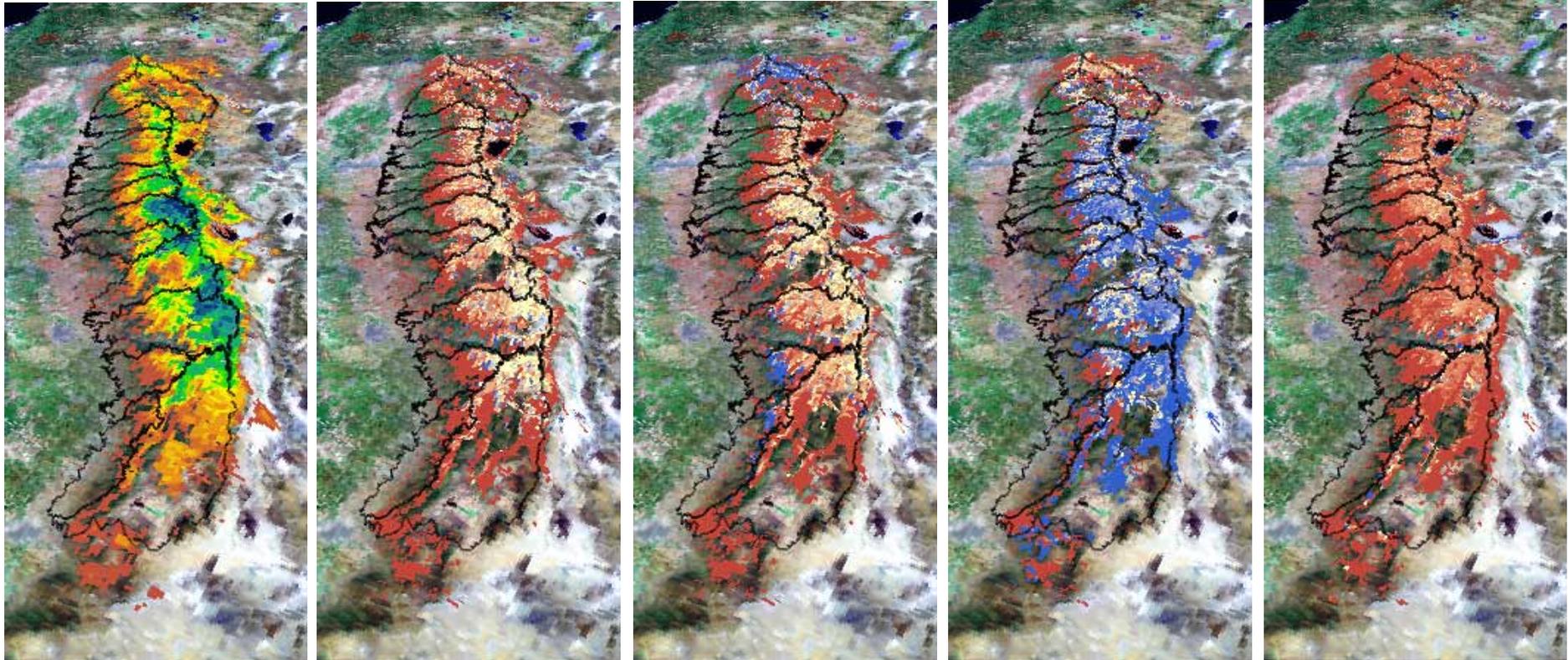
2001 – 2007  
Average

2002

2004

2005

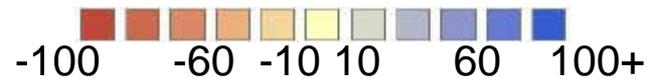
2007



avg. SWE, cm



SWE anomaly, %

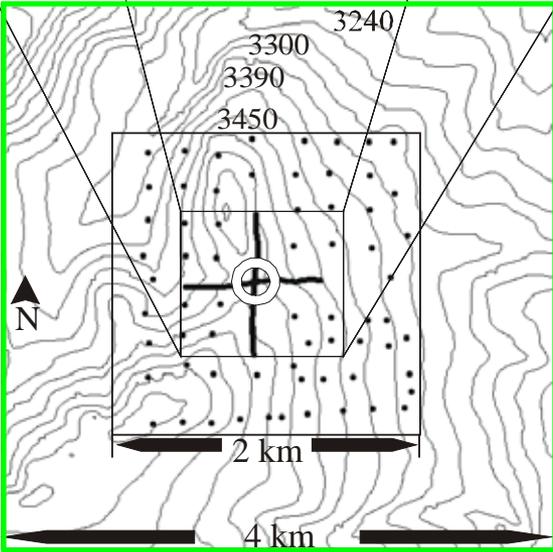
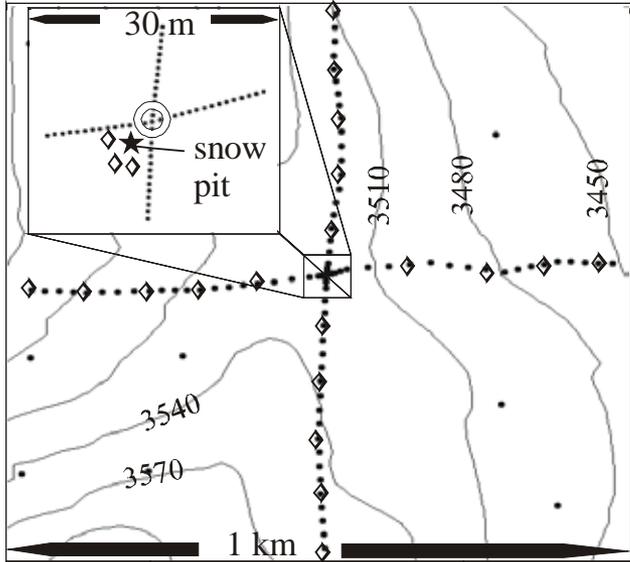


# Model Validation: San Juan and Rio Grande

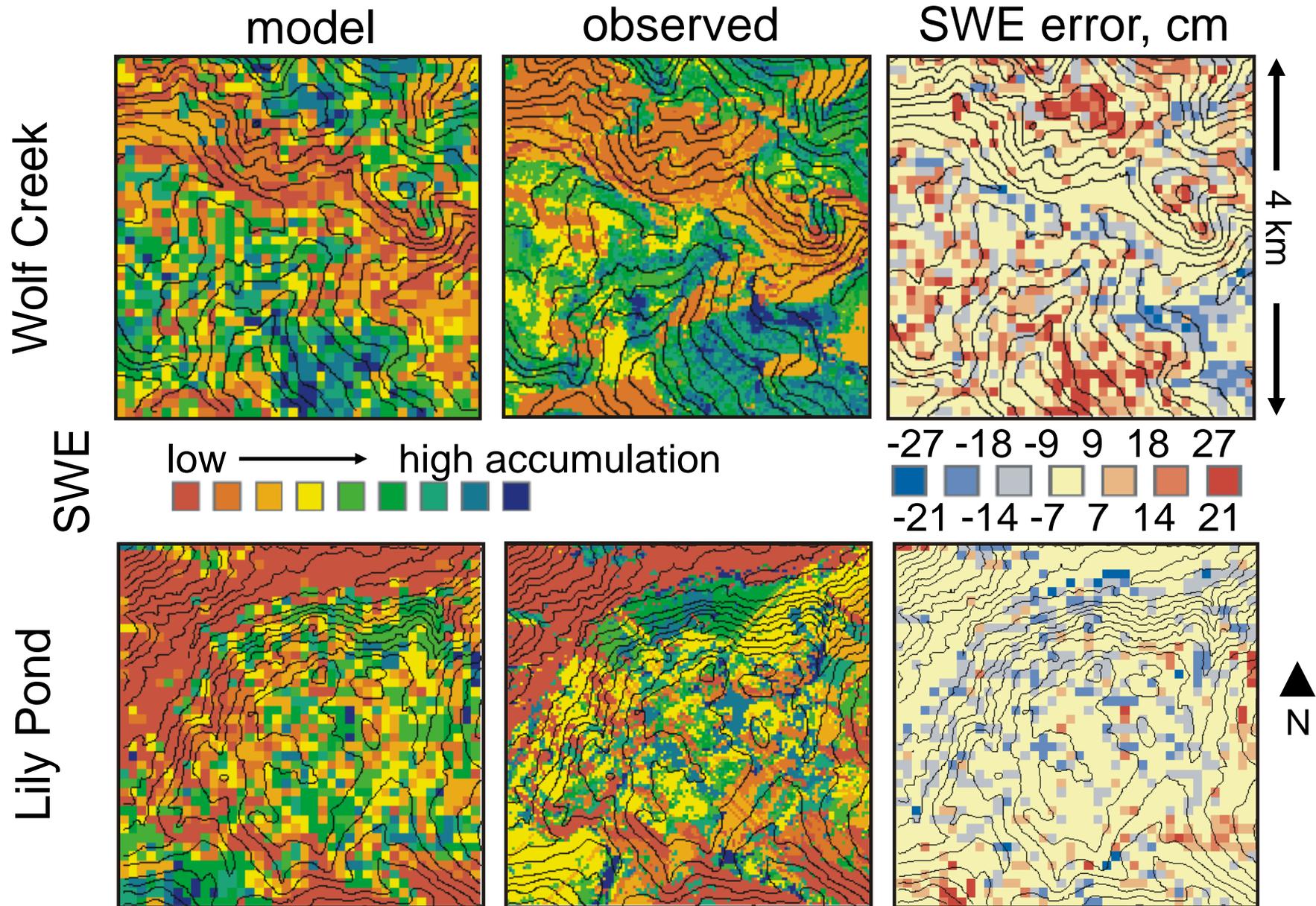
1000+ depth measurements



6 people  
8 days

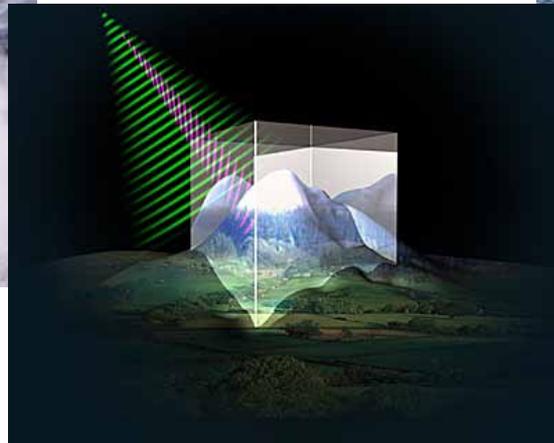


# Model Validation: Landsat ETM+



# Future: Direct Measurement of SWE

- Direct SWE measurement from radar instrument (Ku and X-band radars).
- High spatial resolution ( $< 100$  m).
- Penetrates deep snowpack ( $> 1$  m).
- Algorithm in development -> launch 2016 – 2020?



# Conclusions

- **Snow cover depletion record contains useful information regarding snow accumulation.**
- **Spatial estimates of SWE are unparalleled in terms of accuracy and spatial resolution.**
- **Future focus on research-operations and direct retrieval methods from radar.**

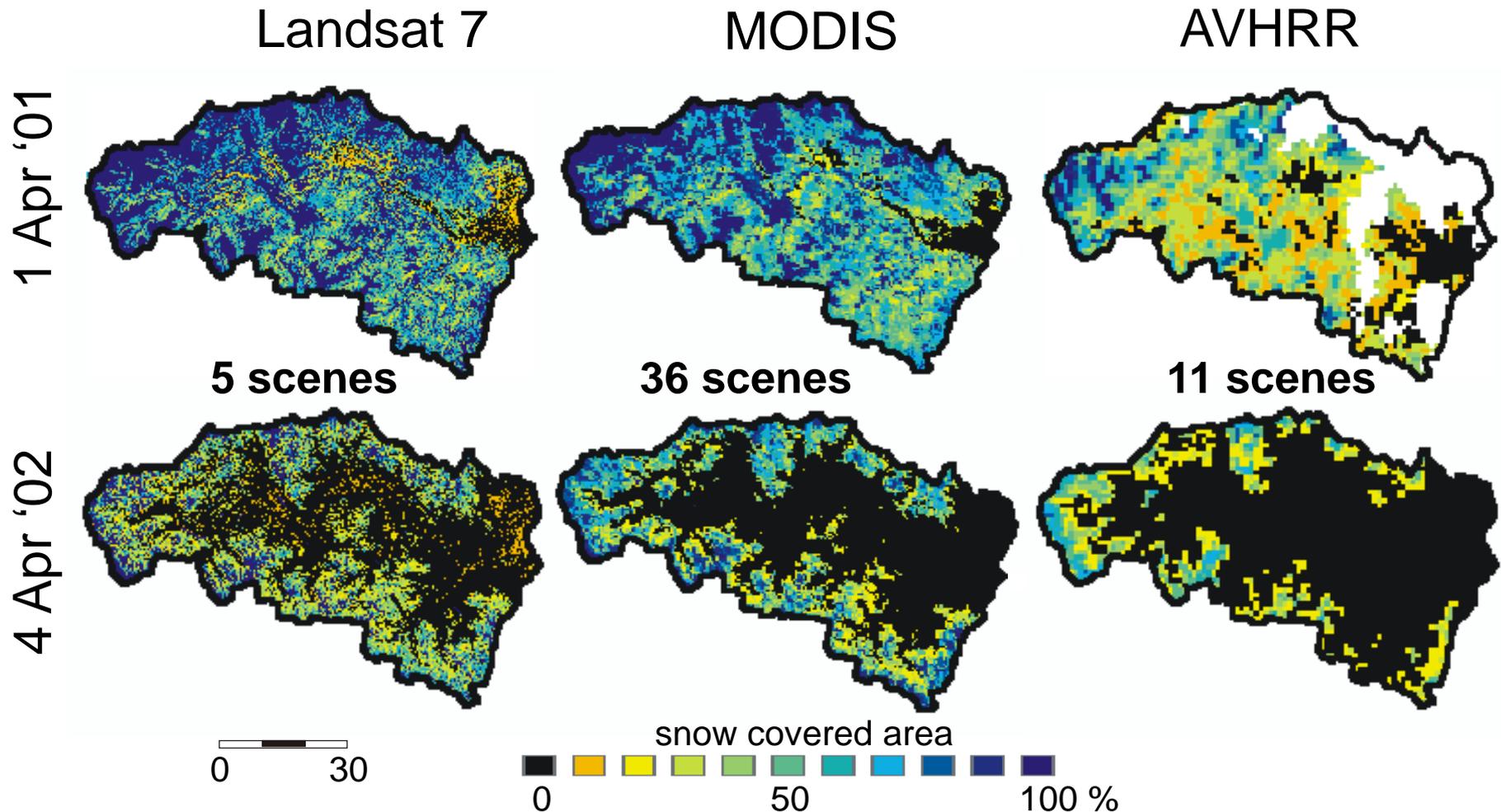
# Acknowledgements

- NSF: Hydrological Sciences; STC for the Sustainability of semi-Arid Hydrology and Riparian Areas (SAHRA)
- NASA: Terrestrial Hydrology
- NOAA: Innovative Research Program; Office of Hydrologic Development.

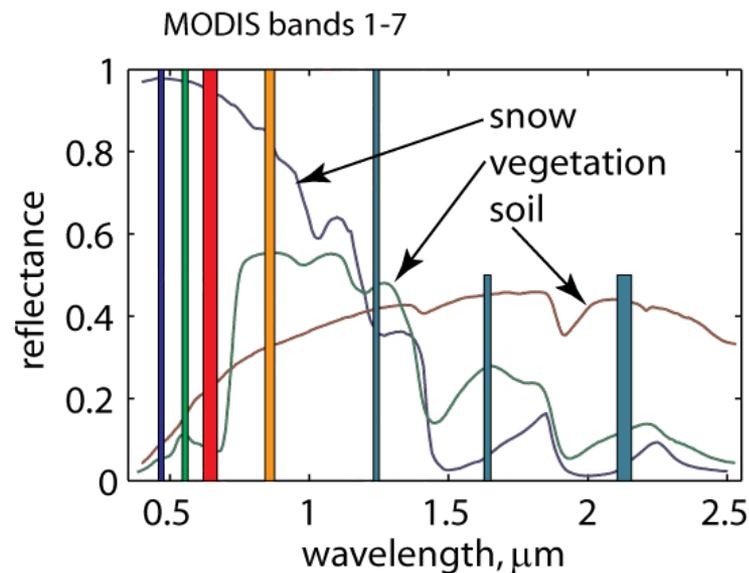
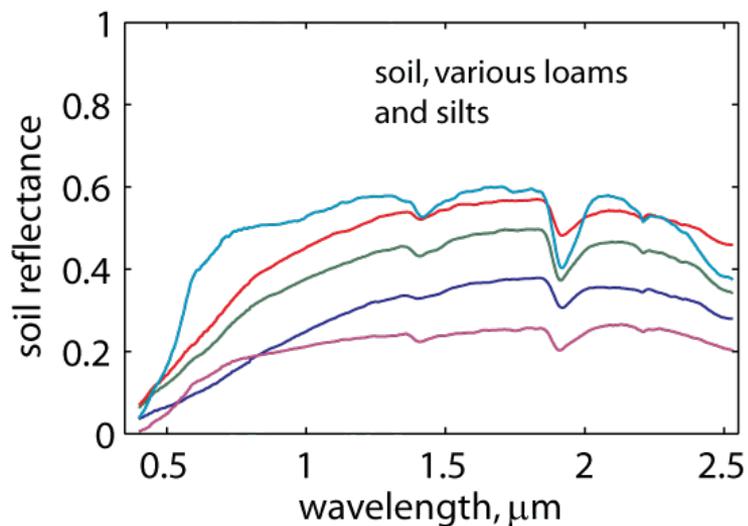
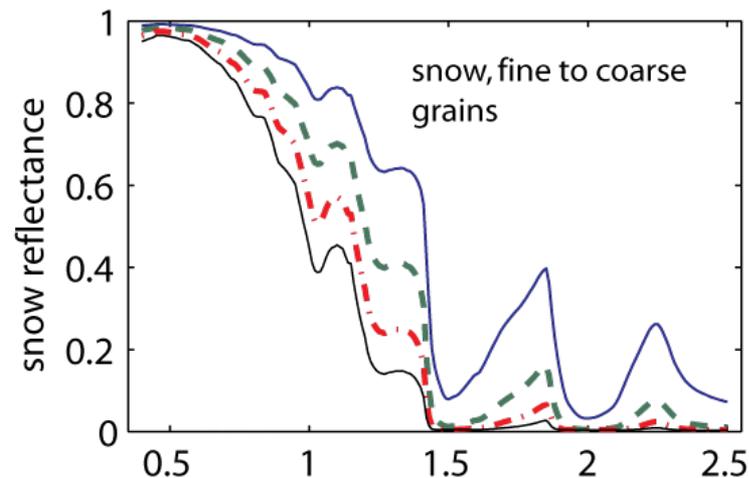
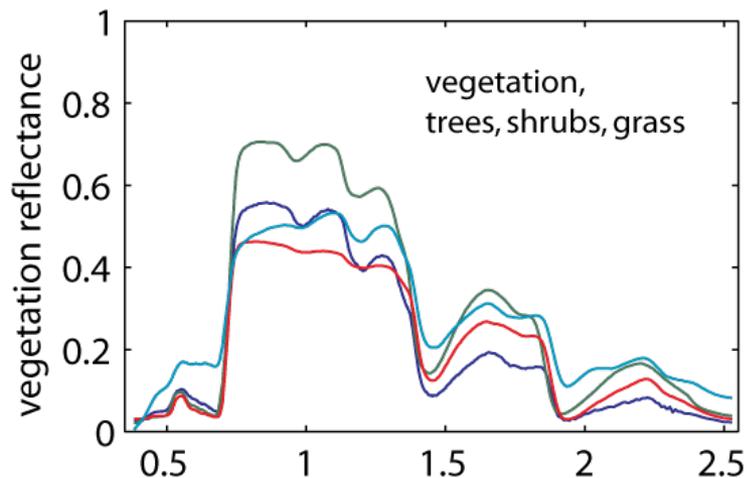


•B. Imam, R. Bales, J. Dozier, T. Painter, L. Lestak, B. Guan

# Remotely sensed snow covered area



# Spectra with MODIS "land" bands



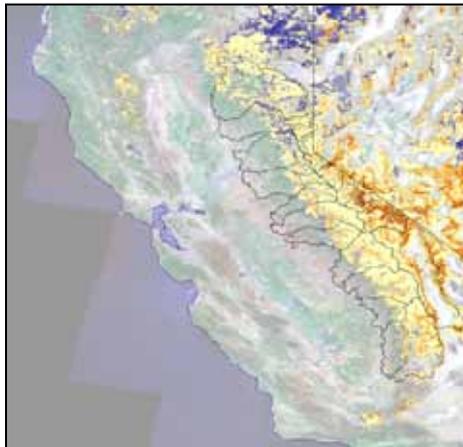
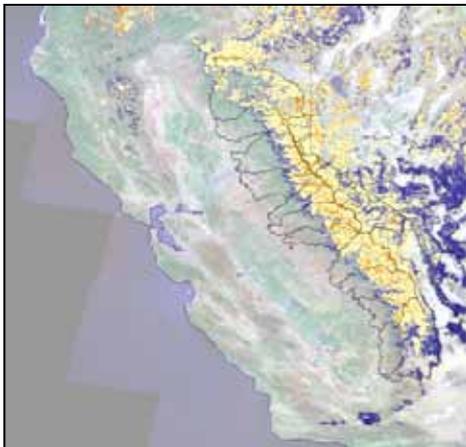
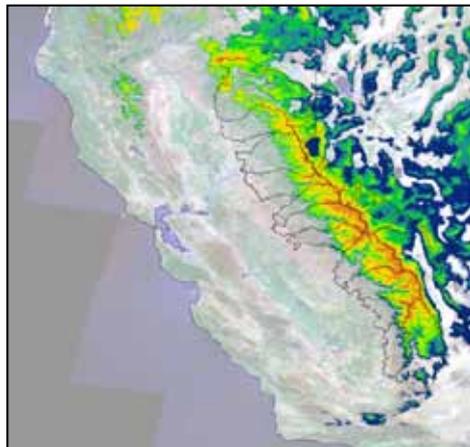
# Sierra Nevada Snow Cover from MODIS

2001 – 2007 Average

2001

2002

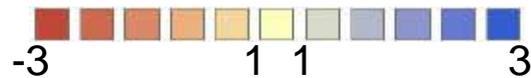
2003



avg. persistence, months



anomaly, months

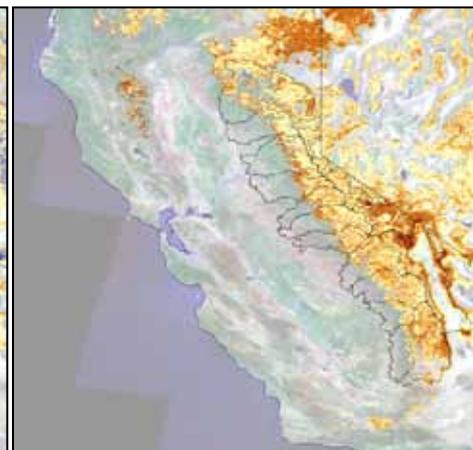
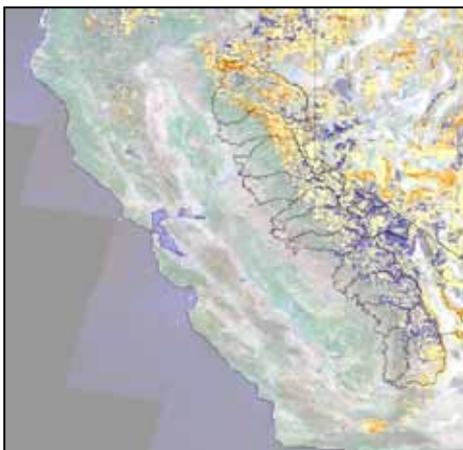
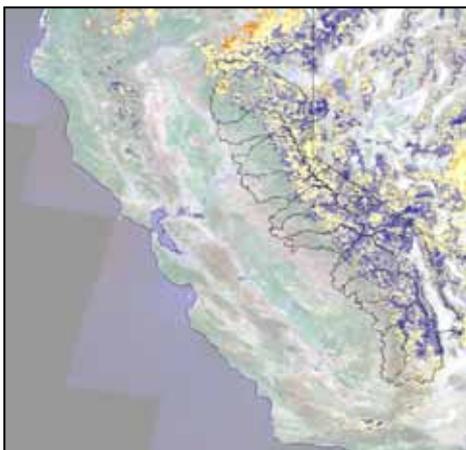
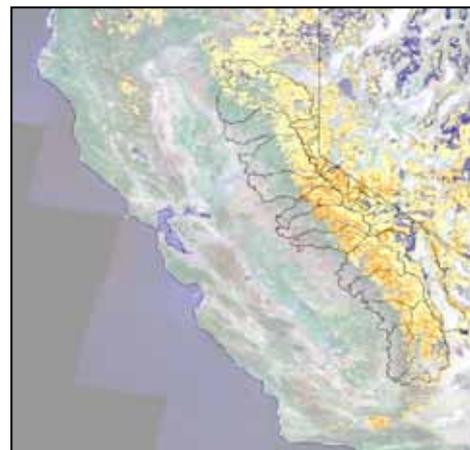


2004

2005

2006

2007



# SWE Reconstruction model

$$SWE_n = SWE_0 - \sum_{j=1}^n \dot{a} M_j$$

when  $SWE_n = 0$ ,

$$SWE_0 = \sum_{j=1}^n \dot{a} M_j$$

snow covered area



daily snowmelt, cm

