Sierra Nevada snow & Central Valley water: connections & climate change

Roger Bales, UC Merced

- Snowcover in the Western U.S.
- Snowcover & climate change
- Measuring snowcover
- Outlook
Snow cover in the Western U.S.

- exhibits considerable interannual variability
- occurs on only a small fraction of the landscape
- yet it sustains the streamflow & groundwater recharge of much of the west
Snowcover variability

% snow covered area (SCA) from AVHRR
Most runoff & recharge comes from snowmelt

Serreze et al., 1999
Much of the semi-arid west derives its water supply from intensively managed mountain ranges.

**News Focus**

In a region already prone to water shortages, researchers now forecast that rising temperatures threaten the American West's hidden reservoir: mountain snow.

**As the West Goes Dry**
Being in a 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.
Snow cover & climate change

– Western snowpacks hold less water than 50 years ago
– They are also melting earlier
– Result is earlier runoff & drier summer soil
– These trends should continue as climate warms further
Climate change

There are 3 important points on which the science community agrees:

– global warming is occurring
– the primary cause is fossil fuel consumption
– if we fail to act now to reduce greenhouse gases it will get worse

Melting glaciers threaten Peru, BBC News Oct 2003
Melting glaciers may make billions thirsty, CNN Dec 2003
A Melting Glacier in Tibet Serves as an Example and a Warning, NY Times, Nov 2004
Melting Glaciers Said Threatening Everest, AP Nov 2004
Northern Hemisphere temperature

Mann et al., 1999
Global surface temperature

Variability

www.gcrio.org/ipcc/qa/cover.html (modified)
1900 - 94 TEMPERATURE TRENDS

TREND / 100 YEARS

Neg.  Pos.

〇  1°
〇  2°
〇  3°

Source: Karl et al. 1996
April 1 snow water equivalent (SWE) in Pacific NW has declined up to 60% since 1950

Mote, GRL 2003
Estimating influence of possible +6°C on SNOW vs RAIN

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

"Great things are done when men and mountains meet.” --William Blake

Dettinger, unpublished
Estimating influence of possible +6°C on SNOW-SEASON LENGTH

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

Dettinger, unpublished
Estimating influence of possible +6°C on RAIN-FLOOD STORMS

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

Dettinger, unpublished
Measuring the snowpack

– Every spring primary questions asked by water managers are “How much snow is out there & how much runoff will it produce?”
– Their estimates are often off by 20-30%

– Ground-based measurements
– Snow from space
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
Mountain precipitation

- Precipitation gauges severely undercatch snow
- The accuracy provided by existing networks simply is not adequate
Sierra Nevada snowcover & Kings River runoff

1998 snow-covered area

Red: clouds
Black: no snow
Greyscale: SCA

R. Davis, CRREL
Snow cover mapping process

Scene evaluation:
- degree of cloud cover
- Coverage over study basins

Build Cloud Masks using several spectral-based tests

AVHRR bands

Composite cloud mask

Execute sub-pixel snow cover algorithm: AVTREE using bands 1,2,3 (reflectance) as input

Build thermal mask

Execute atmospheric corrections, conversion to engineering units using AVREF

Application of cloud, thermal & geographic masks to raw AVTREE output

GEOREG script

Ground measured snow water equivalent

Topography

Interpolate using hypsometric method

Combine sub-pixel SCA and ground-based interpolated SWE to produce total basin water maps

Total snow water equivalent map
Remote sensing gives accurate SCA estimates; SWE remains a future challenge

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Resolution</th>
<th>Domain</th>
<th>Purpose</th>
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<td>MODIS</td>
<td>moderate</td>
<td>full</td>
<td>snow cover</td>
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<tr>
<td>AVHRR</td>
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<td></td>
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Radarsat

5.3 GHz
HH polarization
SWE distribution: field methods

- Snow depth: 6 people, 8 days, 400+ measurements
- Snow density: 11 measurements

Depth measurement
Gin Flat snow studies
Gin Flat data 2003/04

December 8, 2003-April 27, 2004

February 26

Temp (°C)

Depth (cm)

SWE (cm)

Accumulation rate
Melt rate

Sensor 1 to Sensor 10
Outlook

- Developing El Niño?
- Not a dry winter?
Developing El Niño?

Figure 1. Mean (top) and anomalous (bottom) SSTs for October 2004. The SST anomalies are computed with respect to the 1971-2000 base period means (Smith and Reynolds, 1998, J. Climate, 11, 3320-3323).
Climate Outlook

The key below is used to interpret each of the color versions of the Climate Outlook products. In areas where confidence in predictive skill has been established, the probabilities of the above normal, near normal or below normal categories are measured accordingly above the Climatology level of 1/3 (33.3%) for each category. These probabilities are represented using colors as depicted in the key below.

In those areas where the skill of our present prediction tools is not sufficient, the default is equal chances (white color). The probabilities of experiencing each of the three categories (above normal, near normal or below normal) remain equally likely (1/3) in the white areas on attached maps.

<table>
<thead>
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<th>Probability of Occurrence</th>
<th>Most likely category</th>
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<td>60.0%-80.0%</td>
<td>16.7%-48.7%</td>
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</tr>
<tr>
<td>Near</td>
<td>40.0%-60.0%</td>
<td>33.3%-33.3%</td>
<td>Above</td>
</tr>
<tr>
<td>Below</td>
<td>00.0%-20.0%</td>
<td>03.3%-33.3%</td>
<td>Above</td>
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<tr>
<td>Above</td>
<td>80.0%-100.0%</td>
<td>48.7%-66.7%</td>
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<tr>
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<tr>
<td>Below</td>
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TEMPERATURE OUTLOOK
1.5 MO LL SEASONAL
VALID: JFM 2005
MADE: 18 NOV 2004

EC MEANS EQUAL CHANCES FOR A, N, B
A MEANS ABOVE
N MEANS NORMAL
B MEANS BELOW
Climate Outlook

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NCEPPRODUCTS
EC MEANS EQUAL CHANCES FOR A, B OR C
A MEANS ABOVE
B MEANS NORMAL
C MEANS BELOW

PRECIPITATION OUTLOOK
1.5 MO LL SEASONAL
VALID: JFM 2005
MADE: 18 NOV 2004