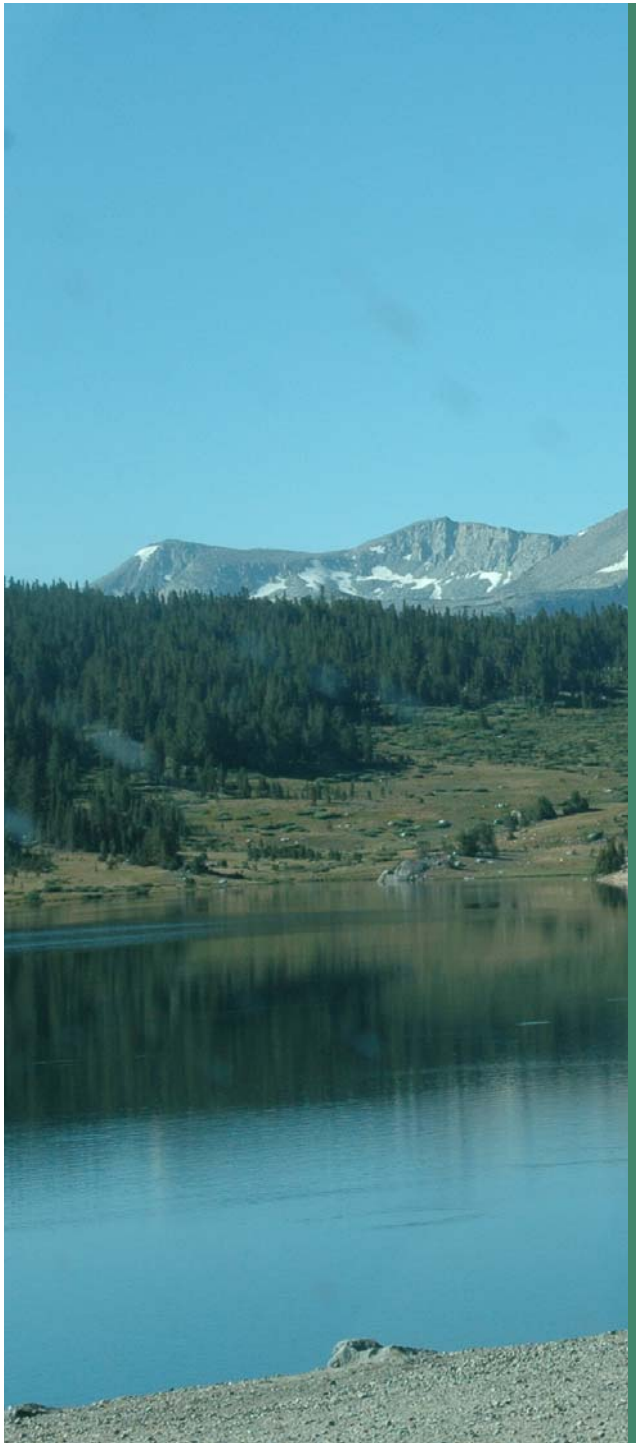
Soil Moisture and Snow: Measurements and Modeling in the Sierra Nevada

Alan Flint and Lorrie Flint

U.S. Geological Survey

Sacramento CA



Problem

- Climate and hydrologic models predict changes in climate (warmer spring) will resulting in snowmelt in the Sierra Nevada occurring earlier and with increasing spatial variability (we can see it today)
- Variability in solar radiation loading caused by topographic shading has a greater impact on the variability of snowmelt when it occurs earlier in the season
- Can we refine our simple snow melt models, which are based on air temperature, by incorporating the influence of radiation and still keep it simple?

Snowmelt in the Sierras

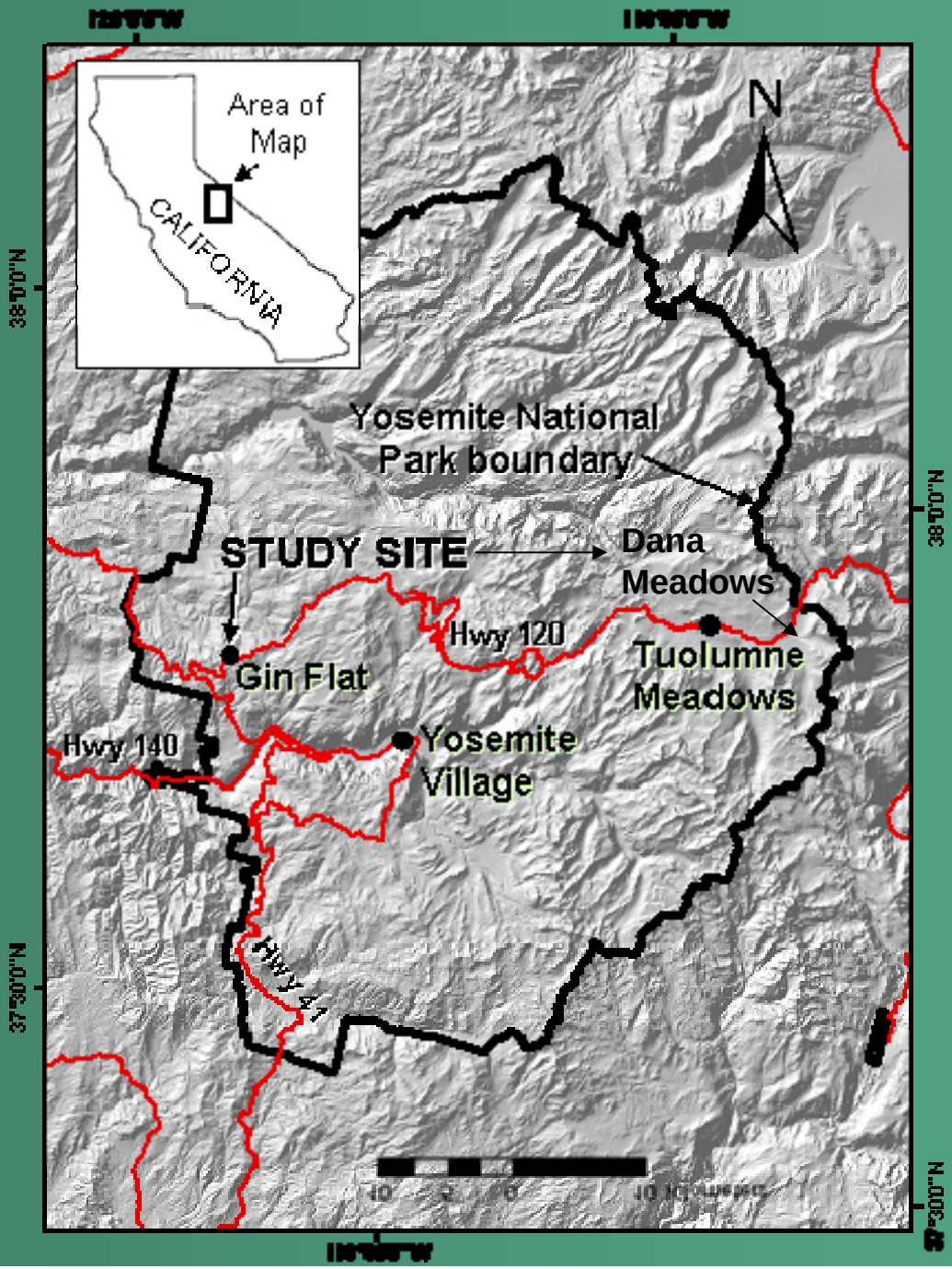
(an interesting twist)

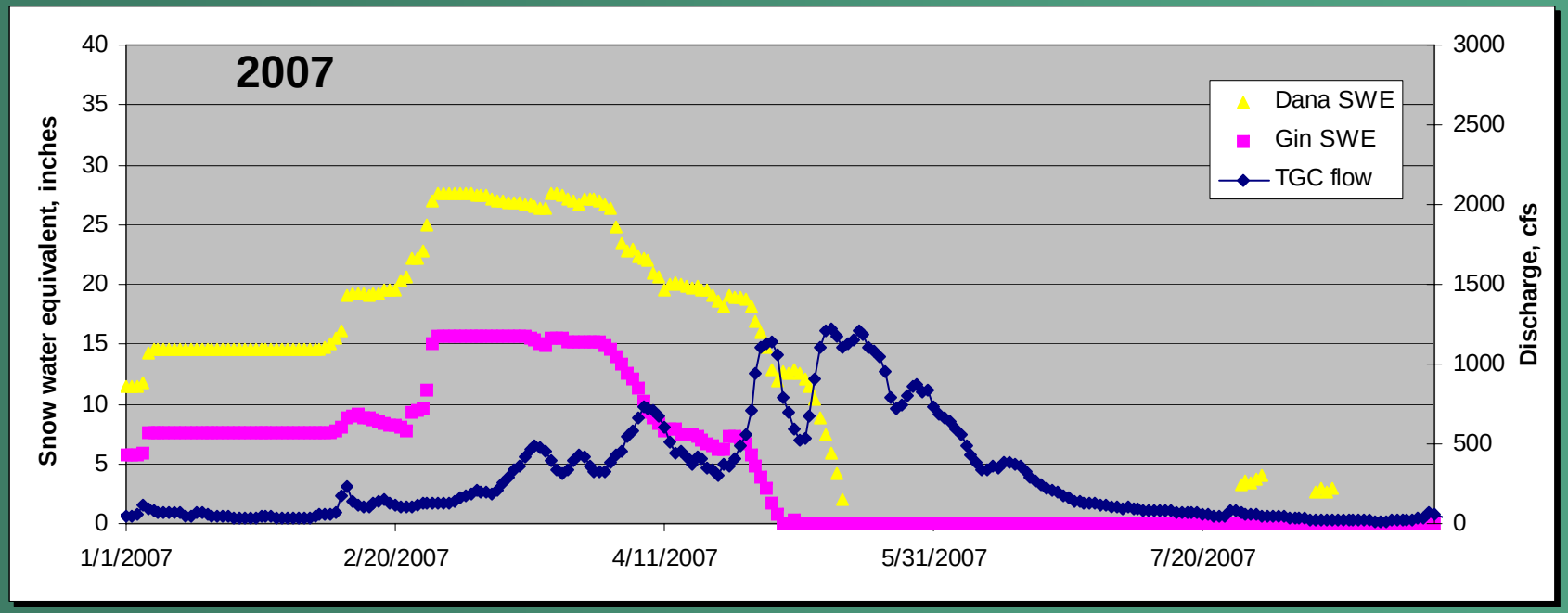
- The onset and amount of runoff from springtime snowmelt isn't just a function of snowpack
- In fall of 2007 snow fell on dry soils and the available soil water storage may have provided a delay, and even a loss to spring streamflows
- Current soil moisture monitoring and modeling may help address this issue

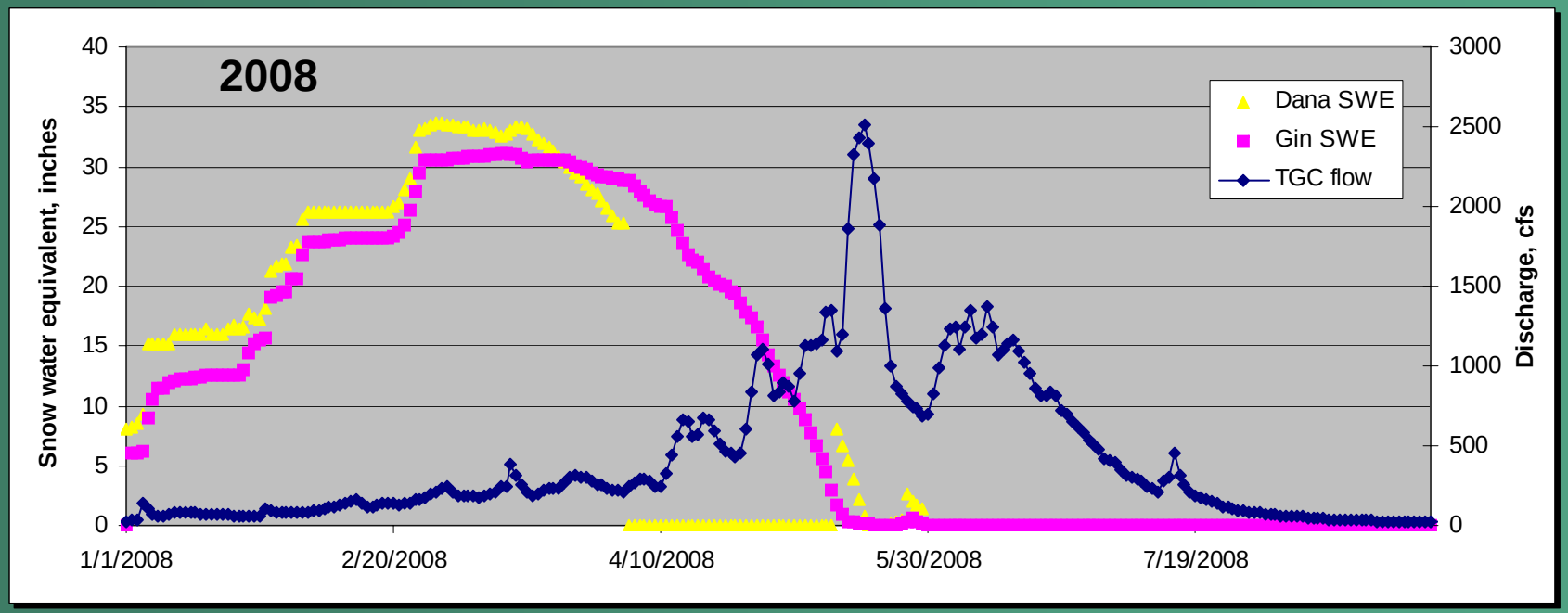
Snowmelt in the Sierras
Outline

- Soil moisture monitoring and modeling
- Snow melt monitoring and modeling
- Tripod LiDAR snow water equivalent measurements at Conway Summit
- Climate change is here: Future work

Yosemite National Park




2007
Dana SWE
Gin SWE
TGC flow
Snow water equivalent, inches
Discharge, cfs
40
35
30
25
20
15
10
5
0
3000
2500
2000
1500
1000
500
0
1/1/2007
2/20/2007
4/11/2007
5/31/2007
7/20/2007

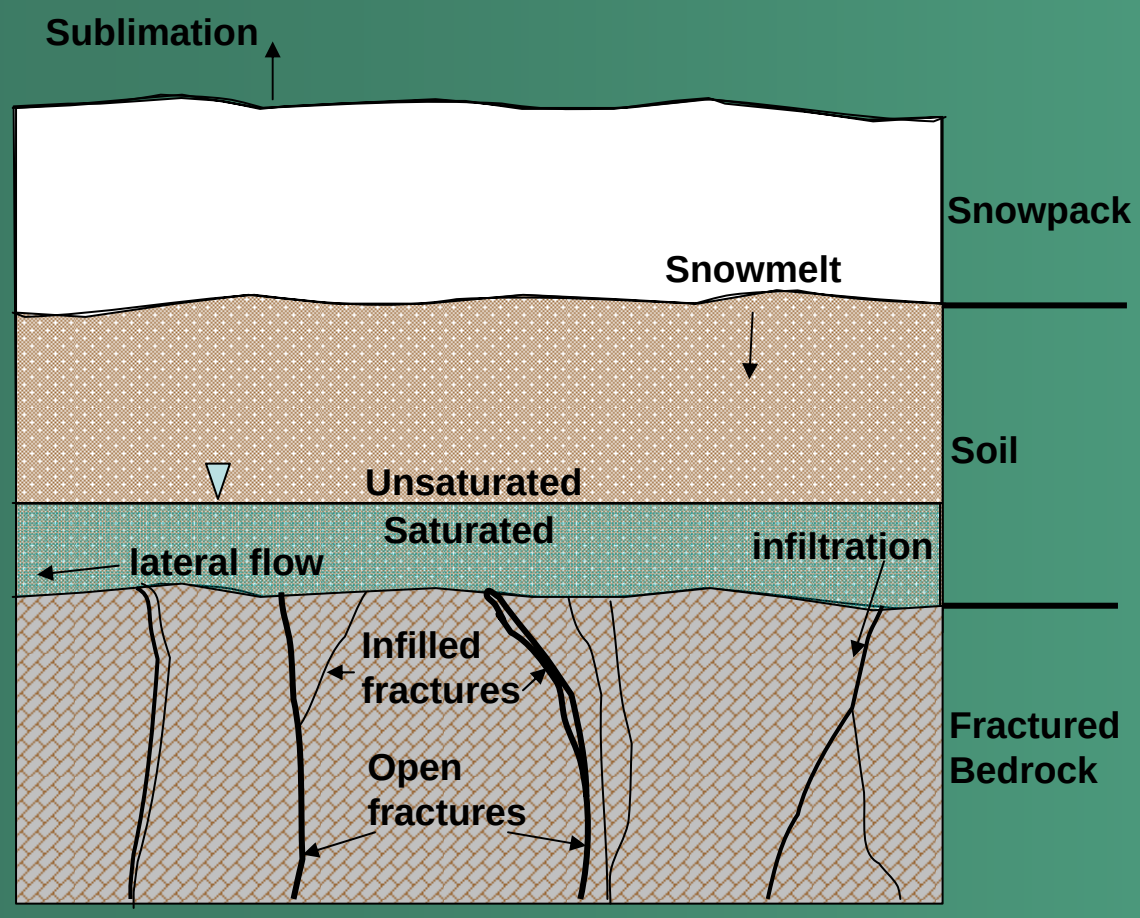

2008
Dana SWE
Gin SWE
TGC flow
Snow water equivalent, inches
Discharge, cfs
40
35
30
25
20
15
10
5
0
3000
2500
2000
1500
1000
500
0
1/1/2008
2/20/2008
4/10/2008
5/30/2008
7/19/2008

Understanding Snow Processes

Components of the Water Balance

- Precipitation
  - How much
  - Form (snow/rain)
- Snowpack
  - Sublimation
  - Melt
- Soil moisture
  - Drainage into underlying bedrock
- Flow Path
  - Key to knowing what is happening

Infiltration/Drainage into Bedrock under Snow

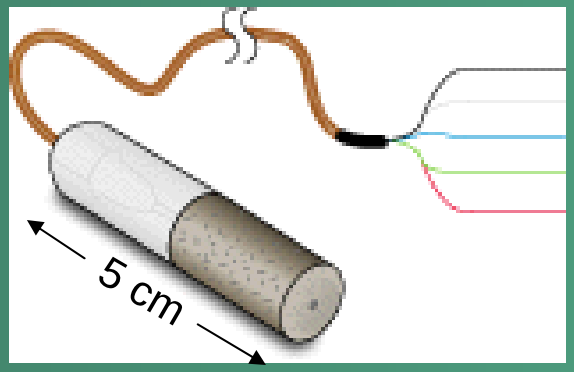


- In shallow soils under snow, infiltration into bedrock is influenced by
  - Soil storage and whether soil is frozen
  - Snowmelt rate vs. bedrock conductivity
  - Properties of fractures and fracture fill, wetting front potential of bedrock matrix
  - Under ponded conditions, drainage should equal bulk bedrock permeability

Soil Moisture Monitoring Instrumentation

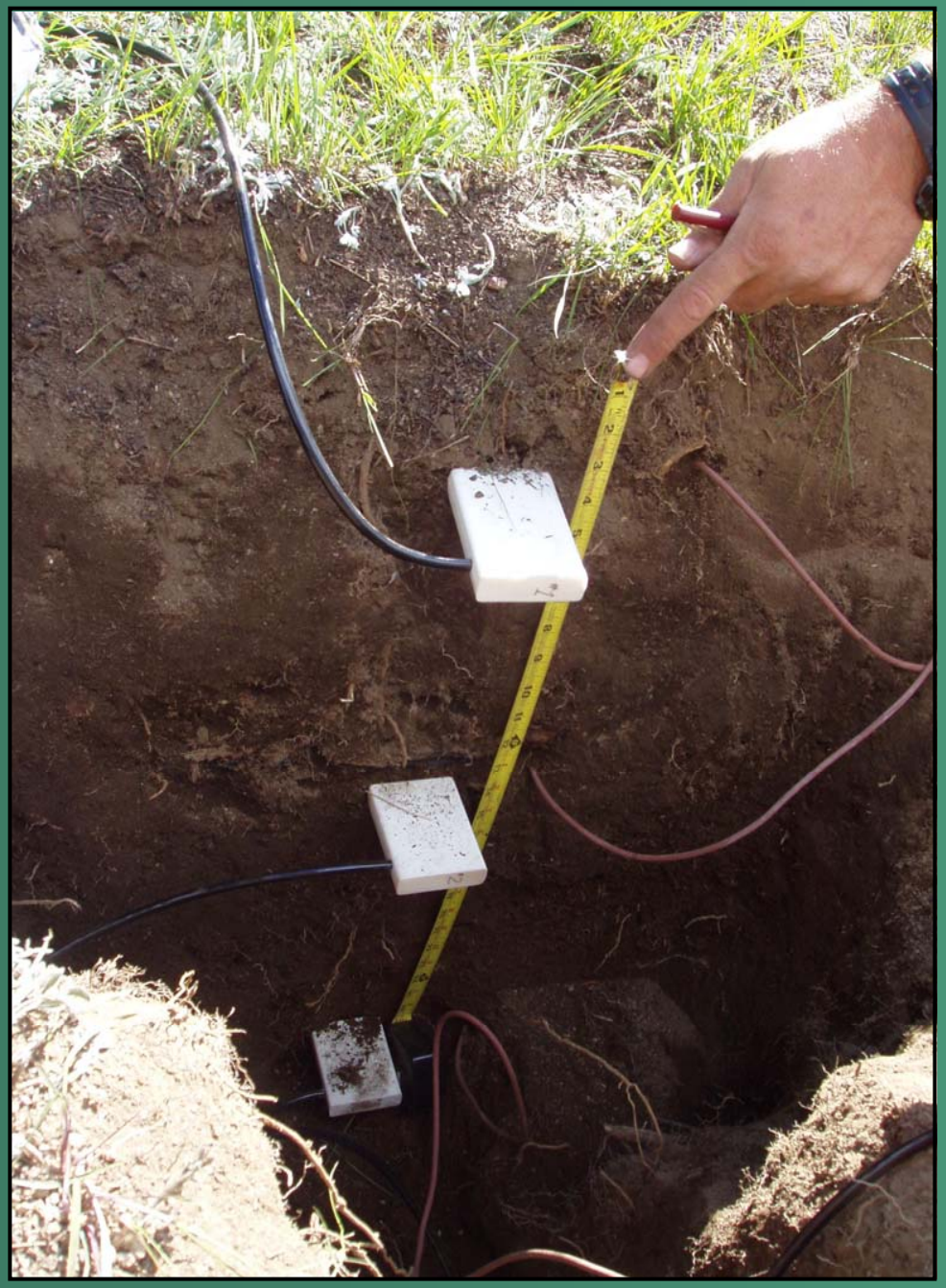
Water content:

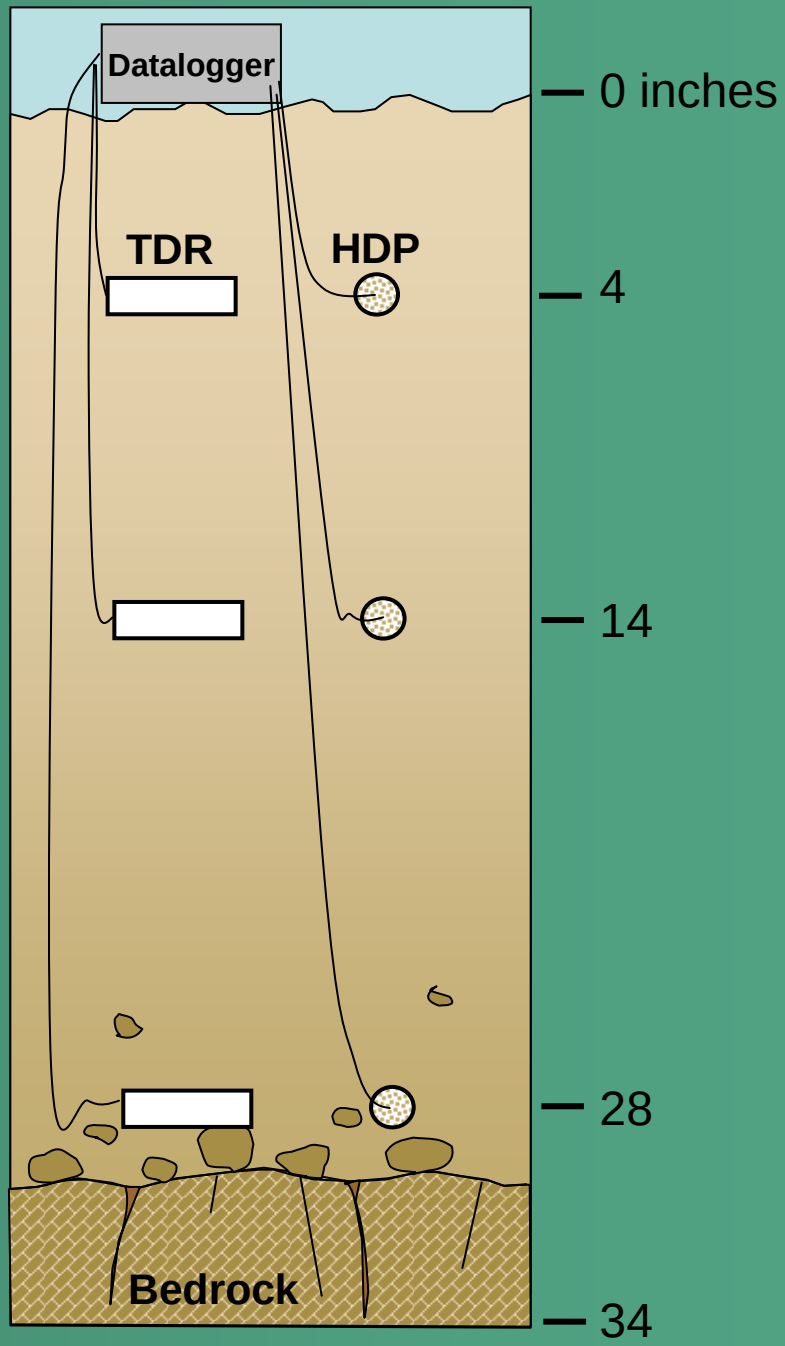
Time Domain Reflectometry (TDR)



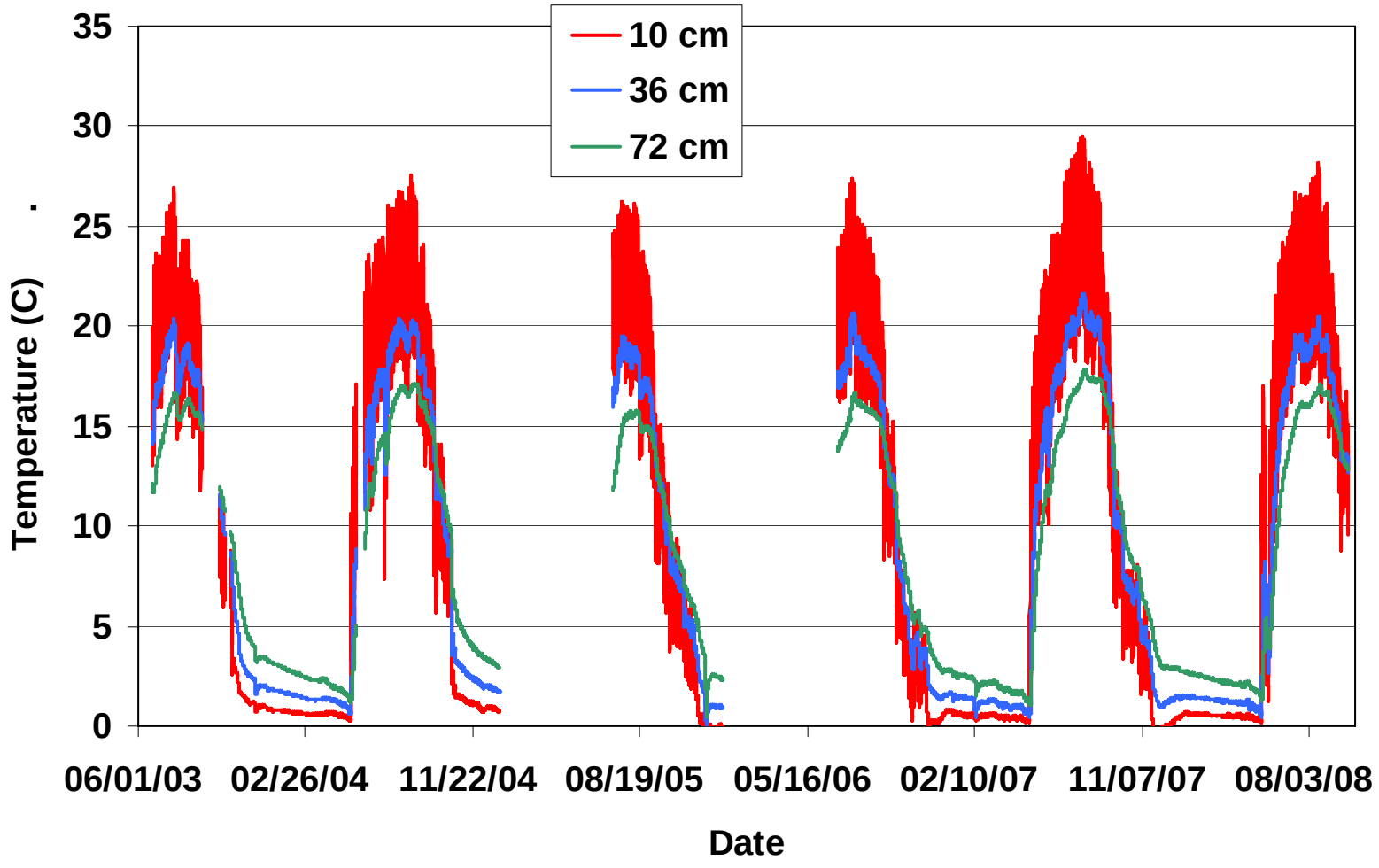
Water potential:

Heat Dissipation Probe (HDP)

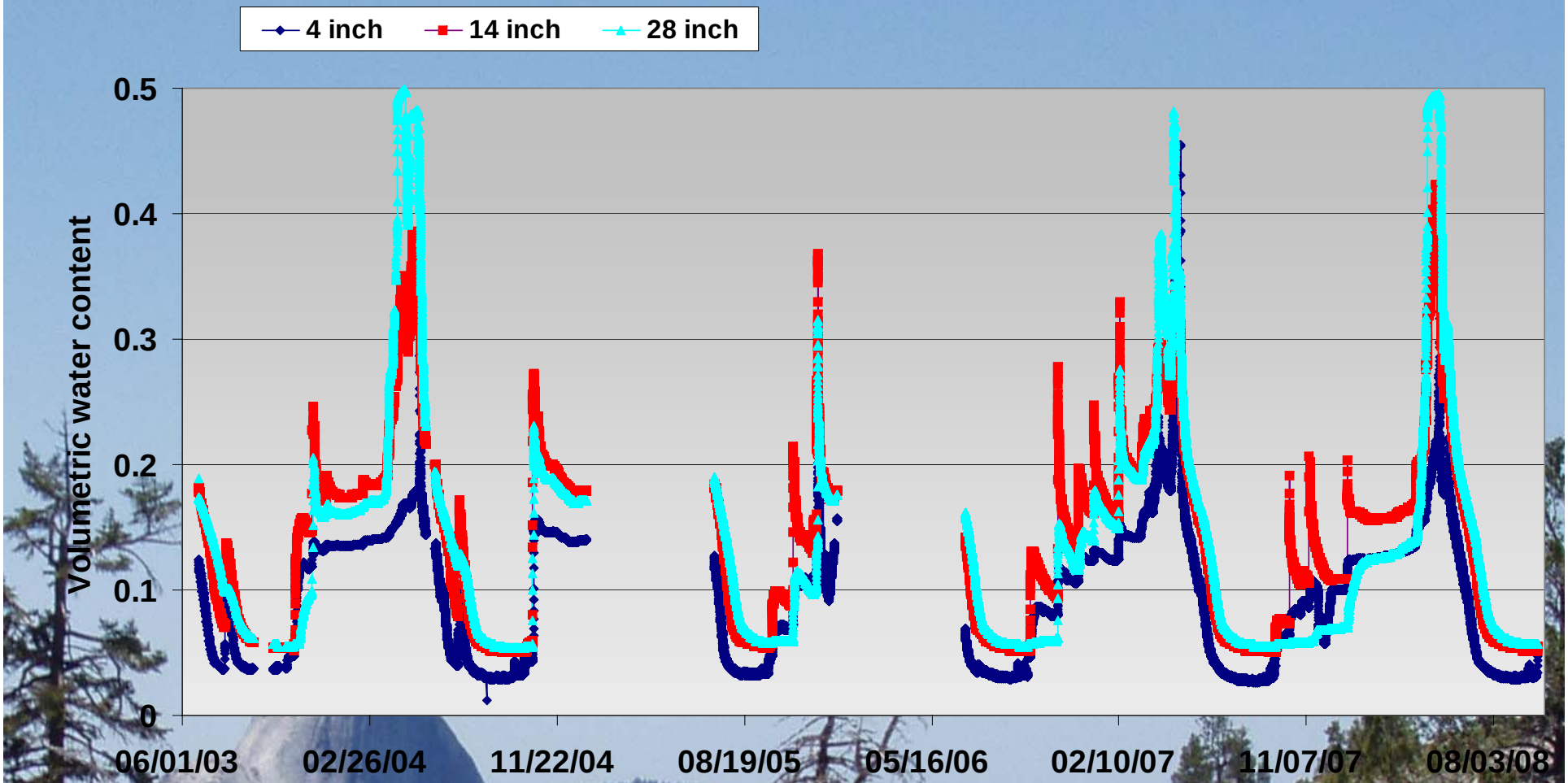



Datalogger
TDR
HDP
Bedrock
0 inches
4
14
28
34

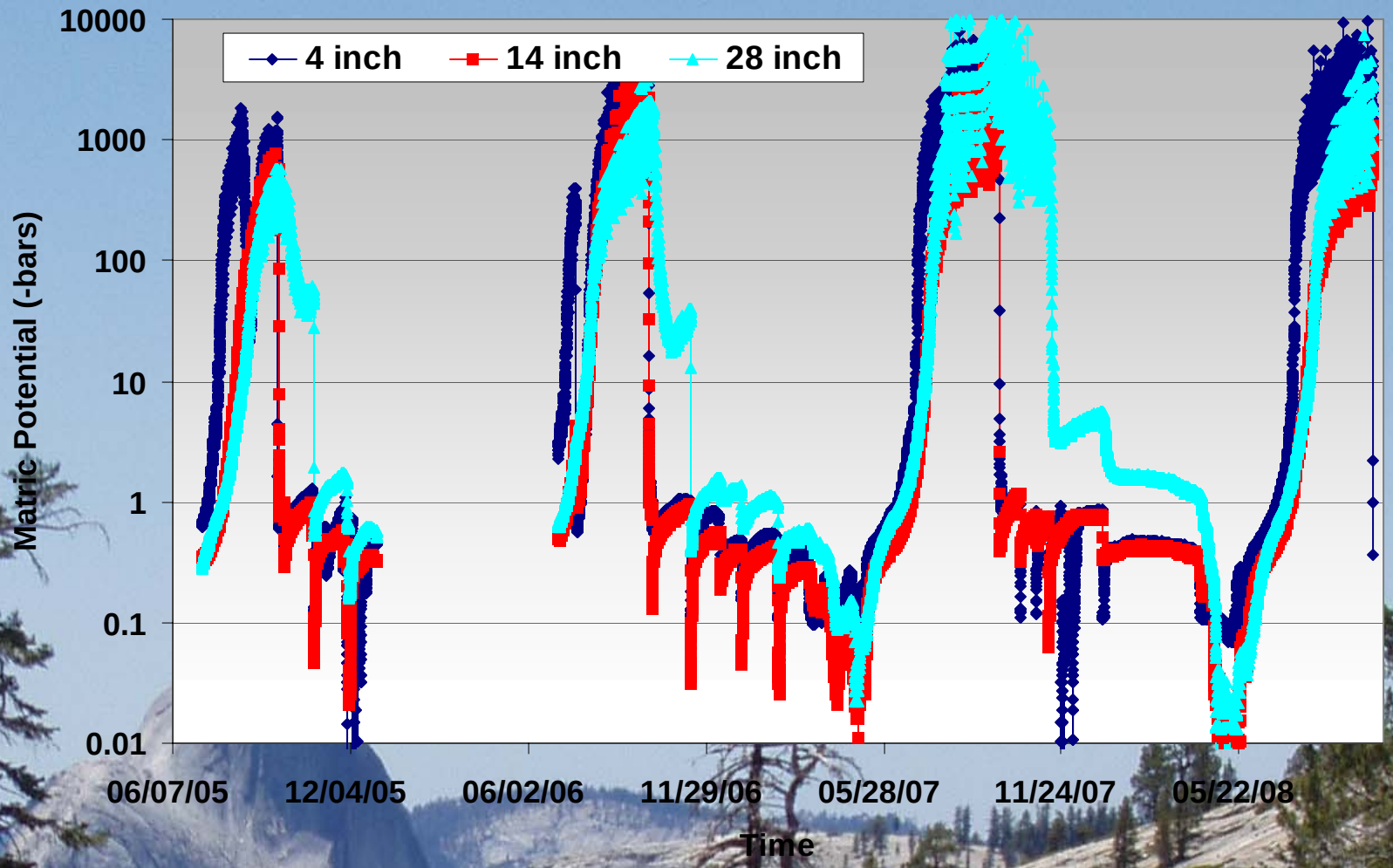
Soil Temperature - Gin Flat



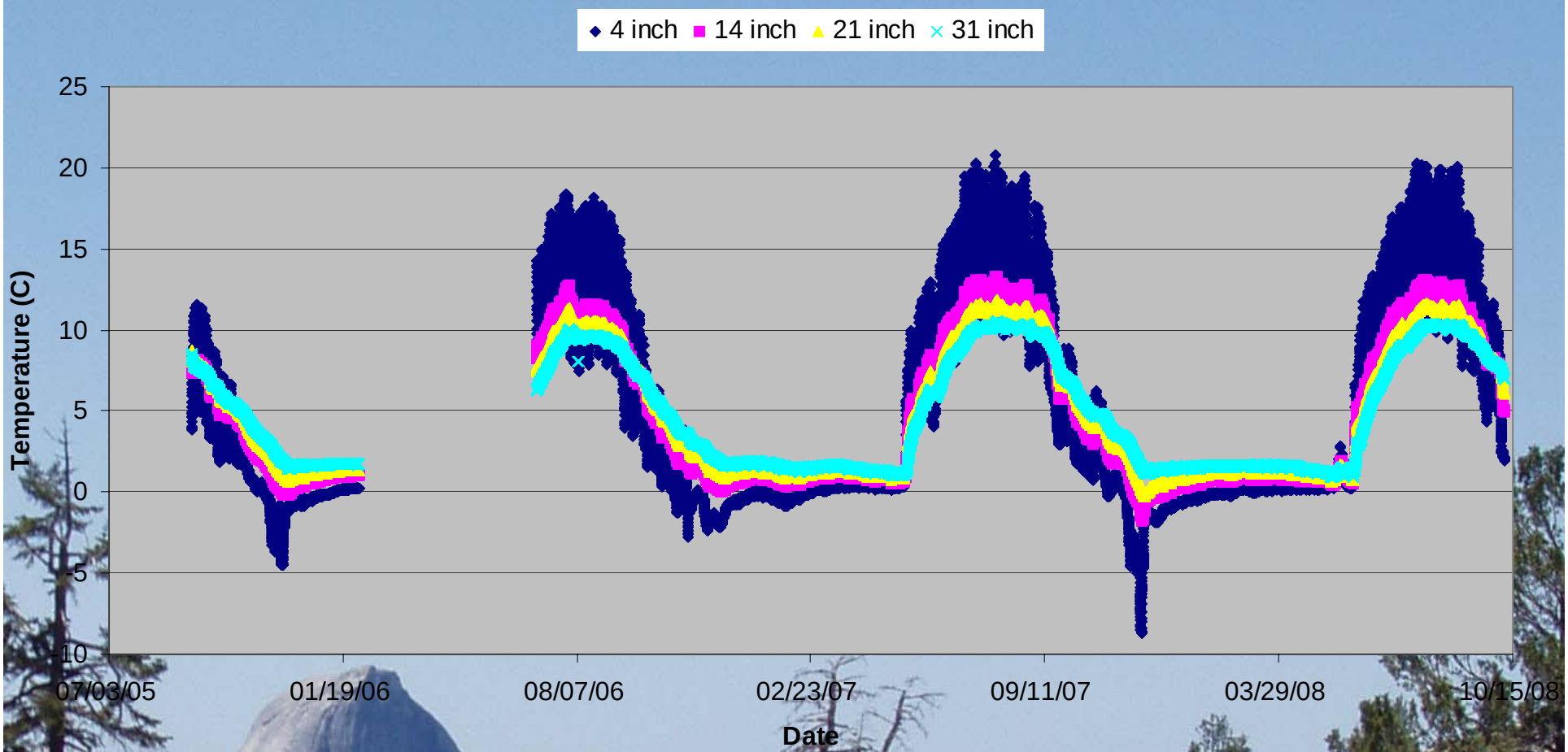
Soil Moisture – Gin Flat



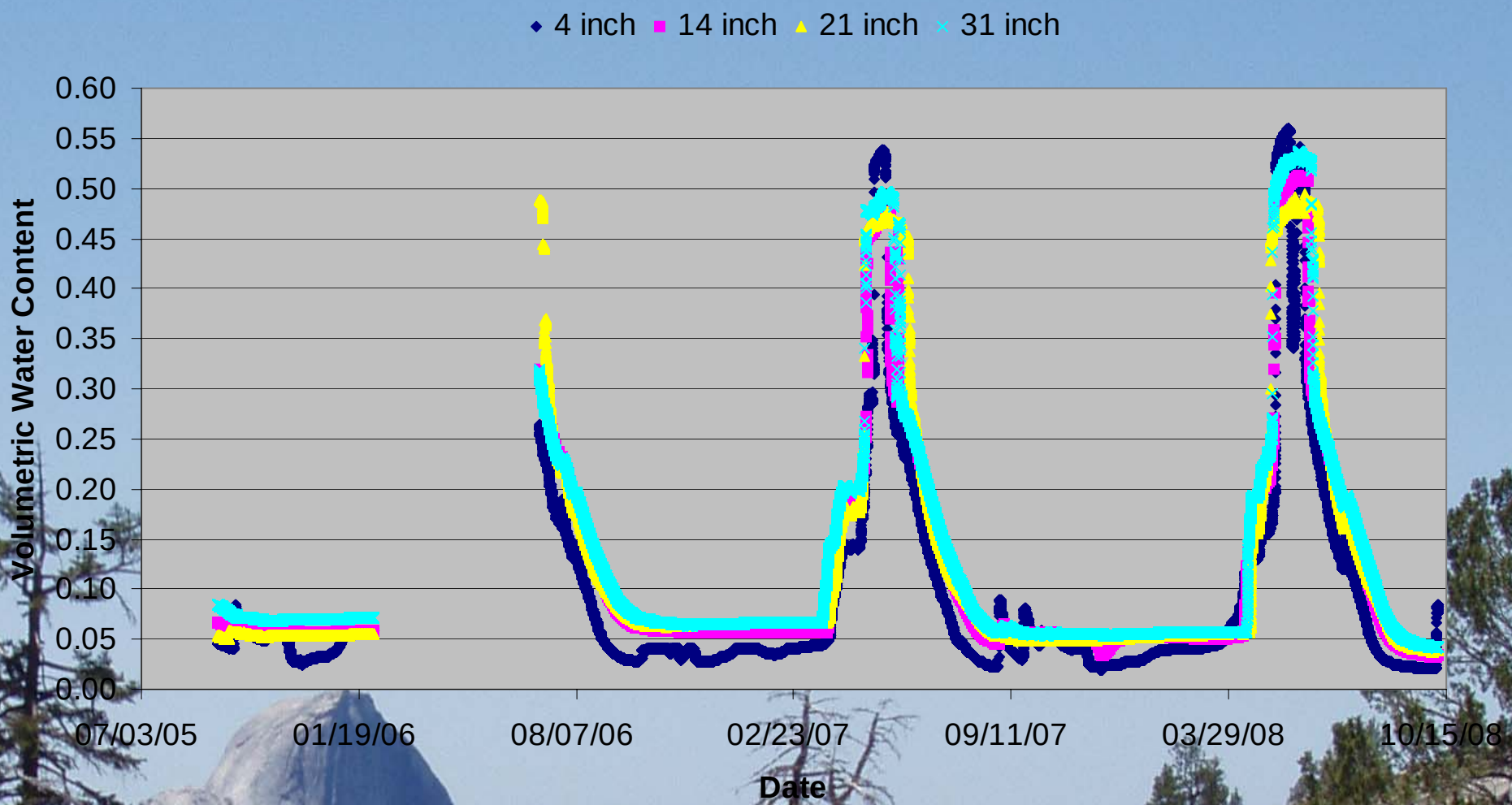
Soil Water Potential – Gin Flat



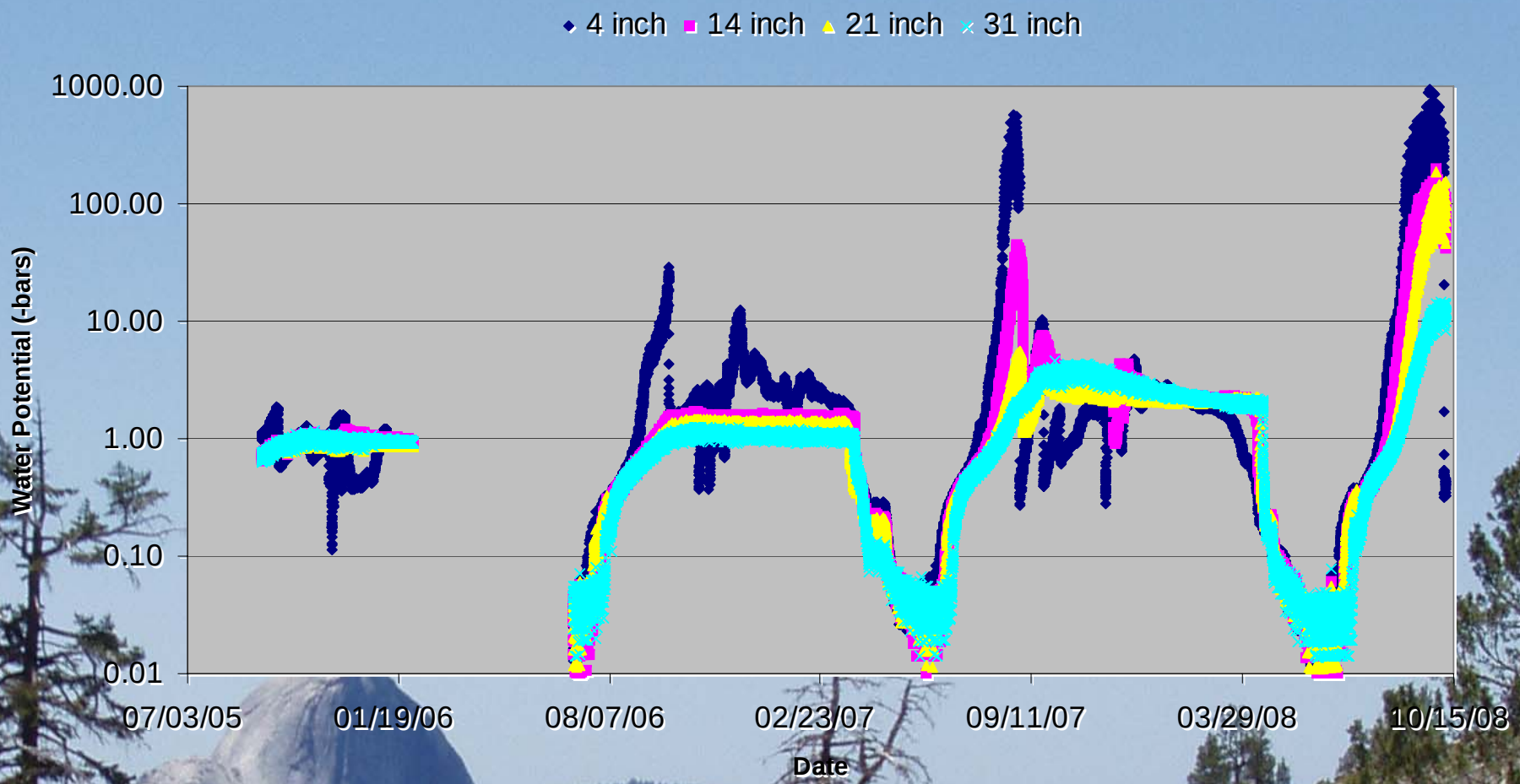
Soil Temperature

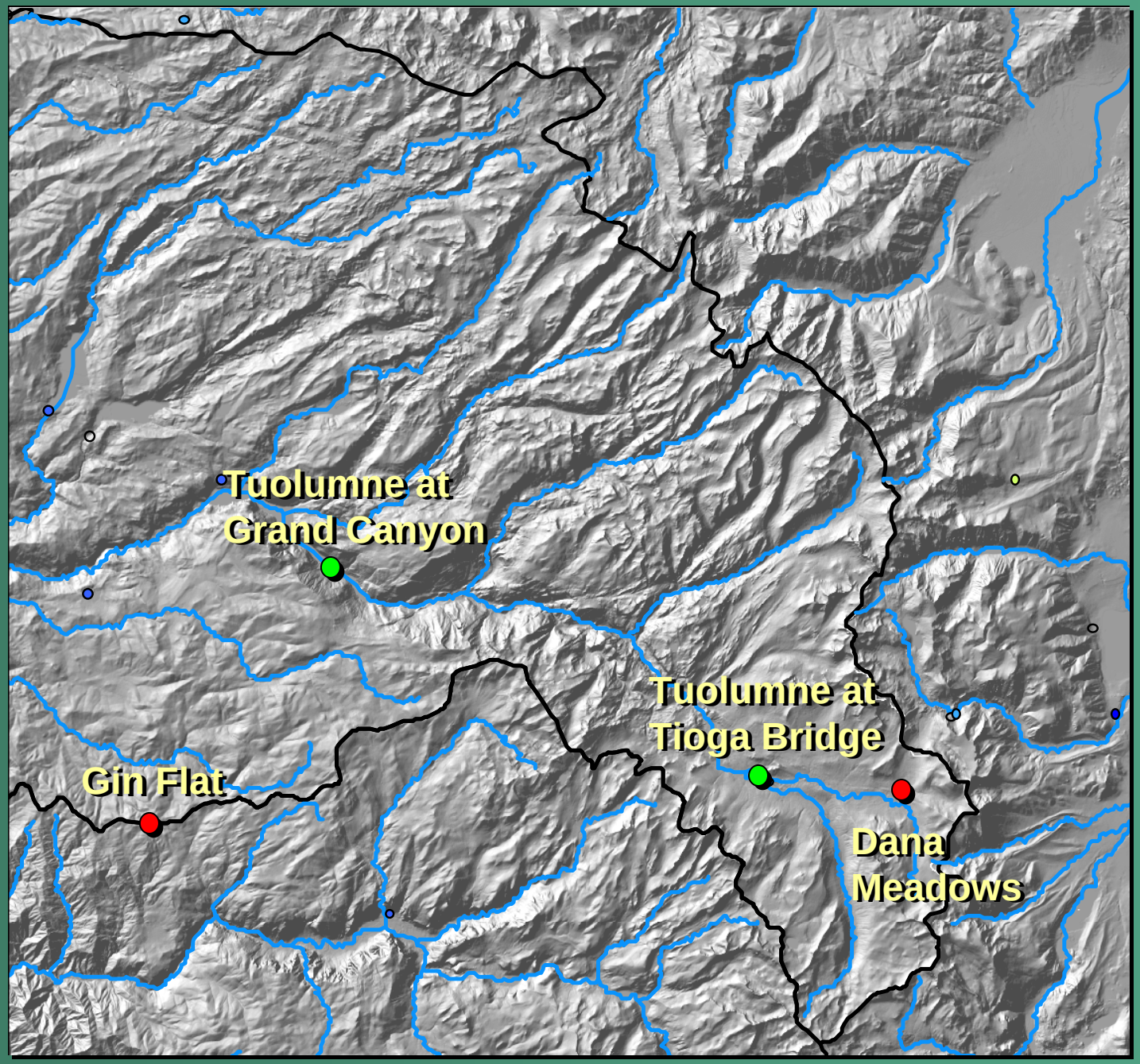


Soil Moisture

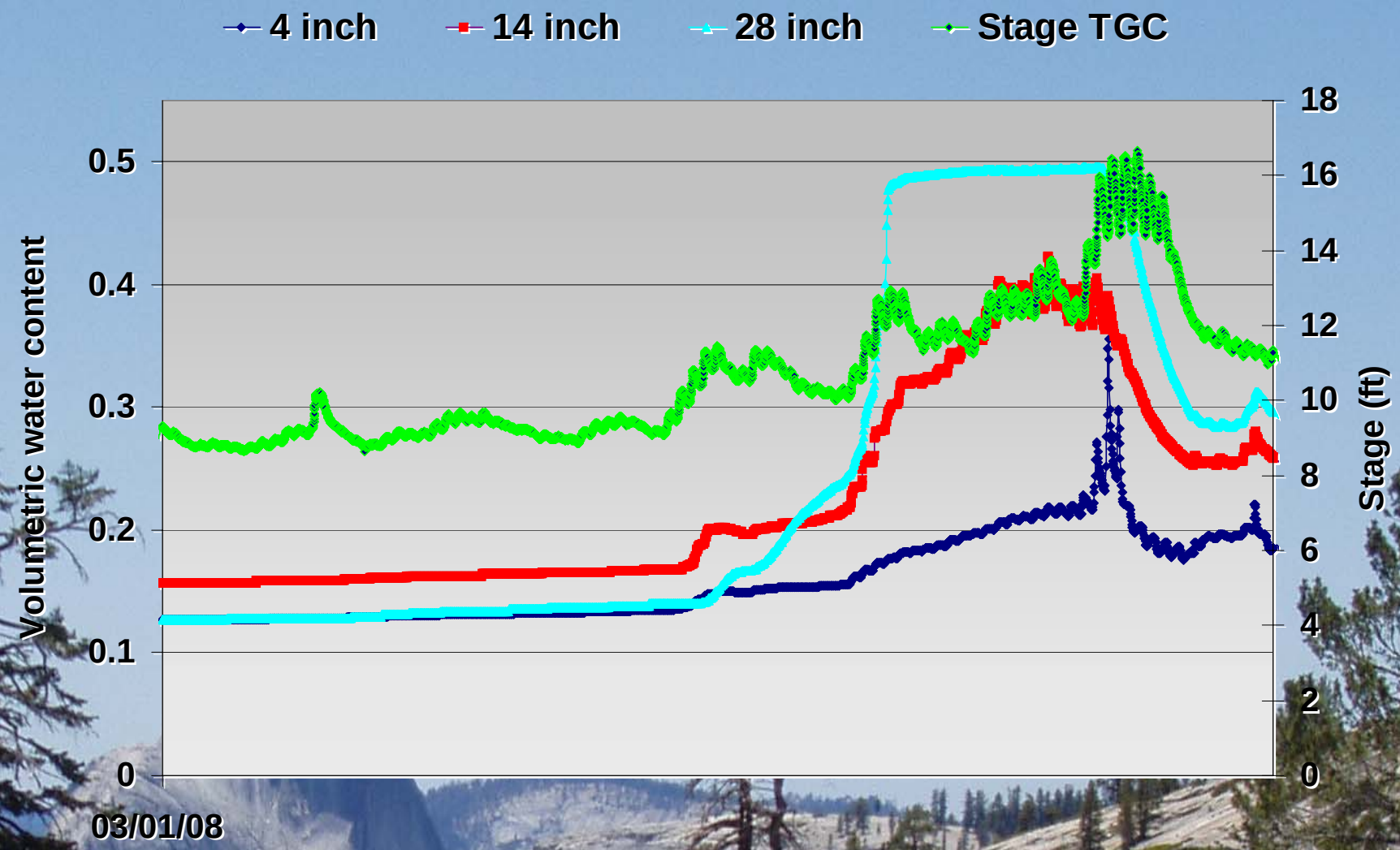


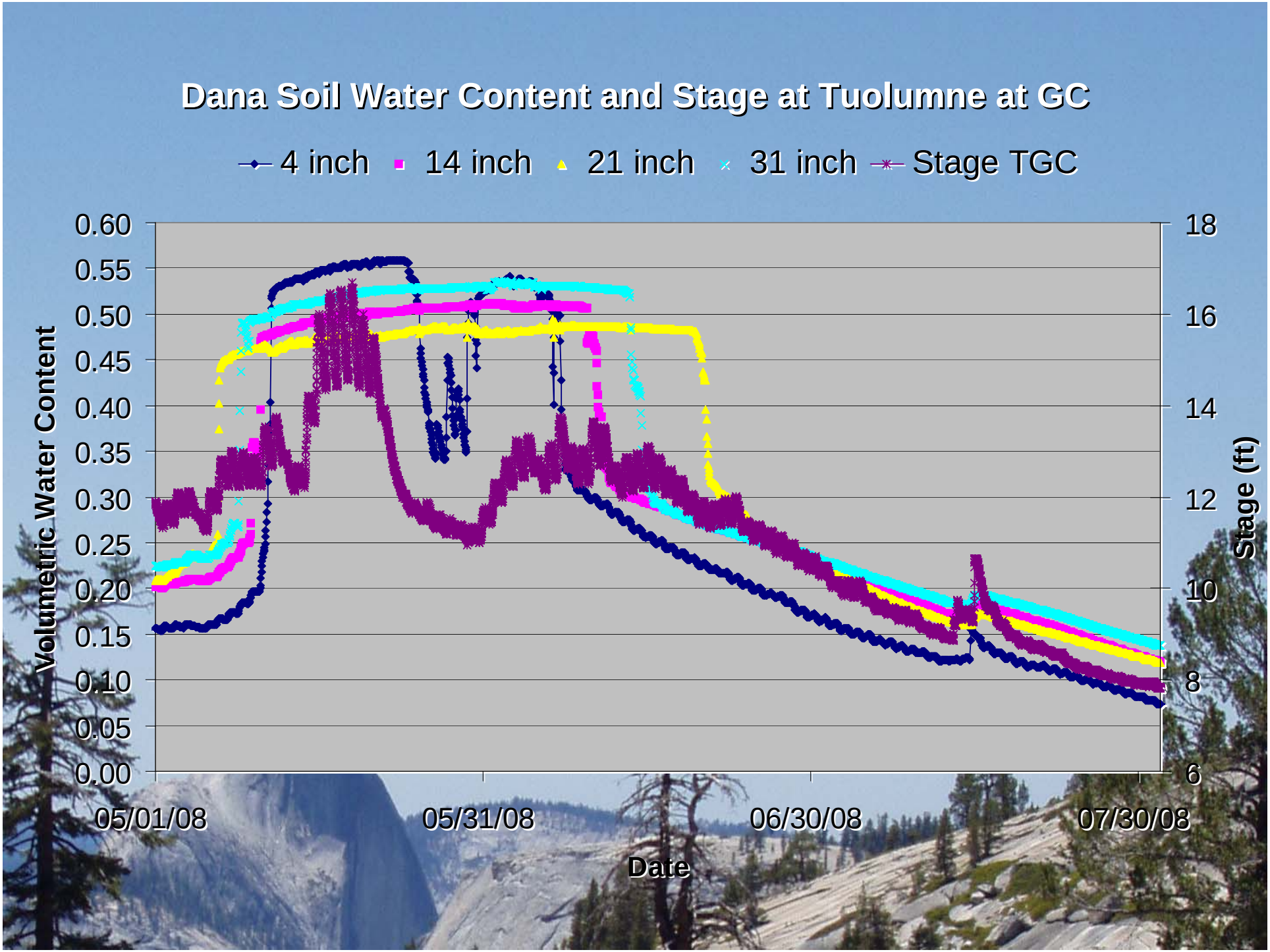
Soil Water Potential

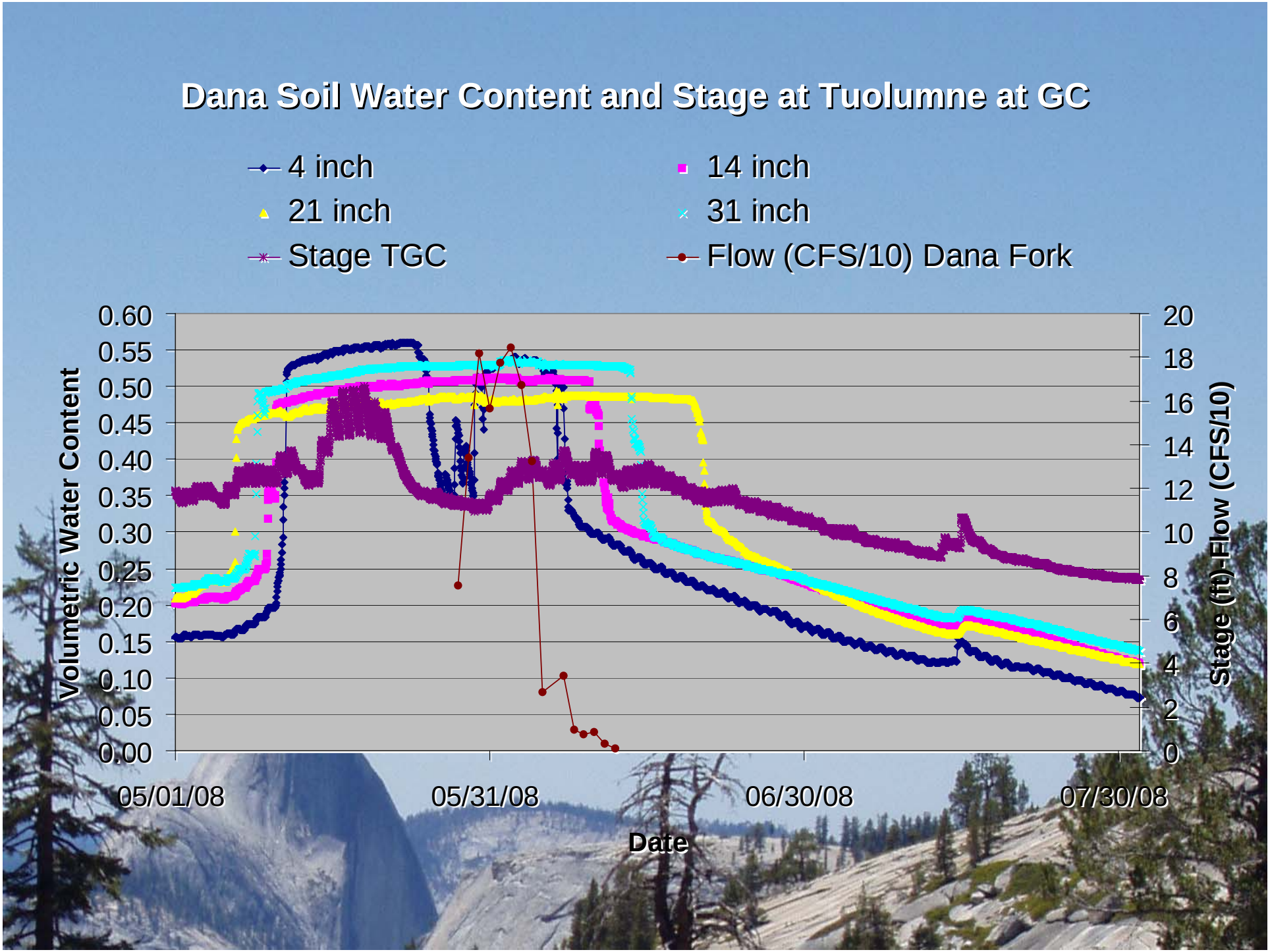



Tuolumne at
Grand Canyon
Tuolumne at
Tioga Bridge
Gin Flat
Dana
Meadows

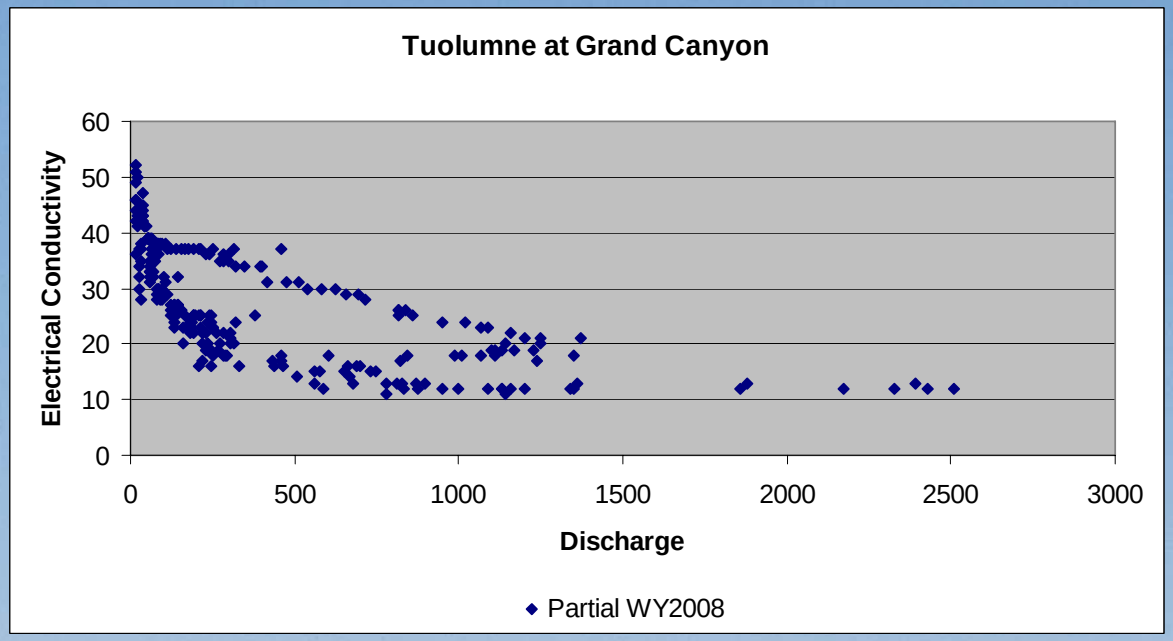
Gin Flat Soil Water Content and State at Tuolumne at GC

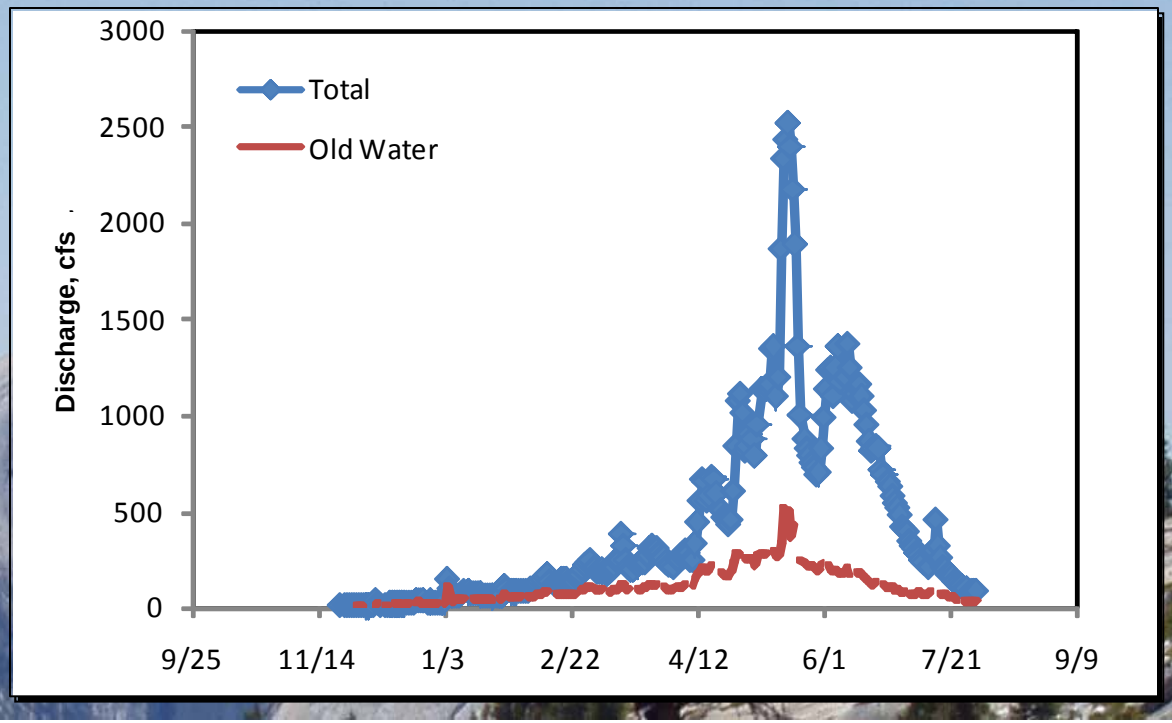


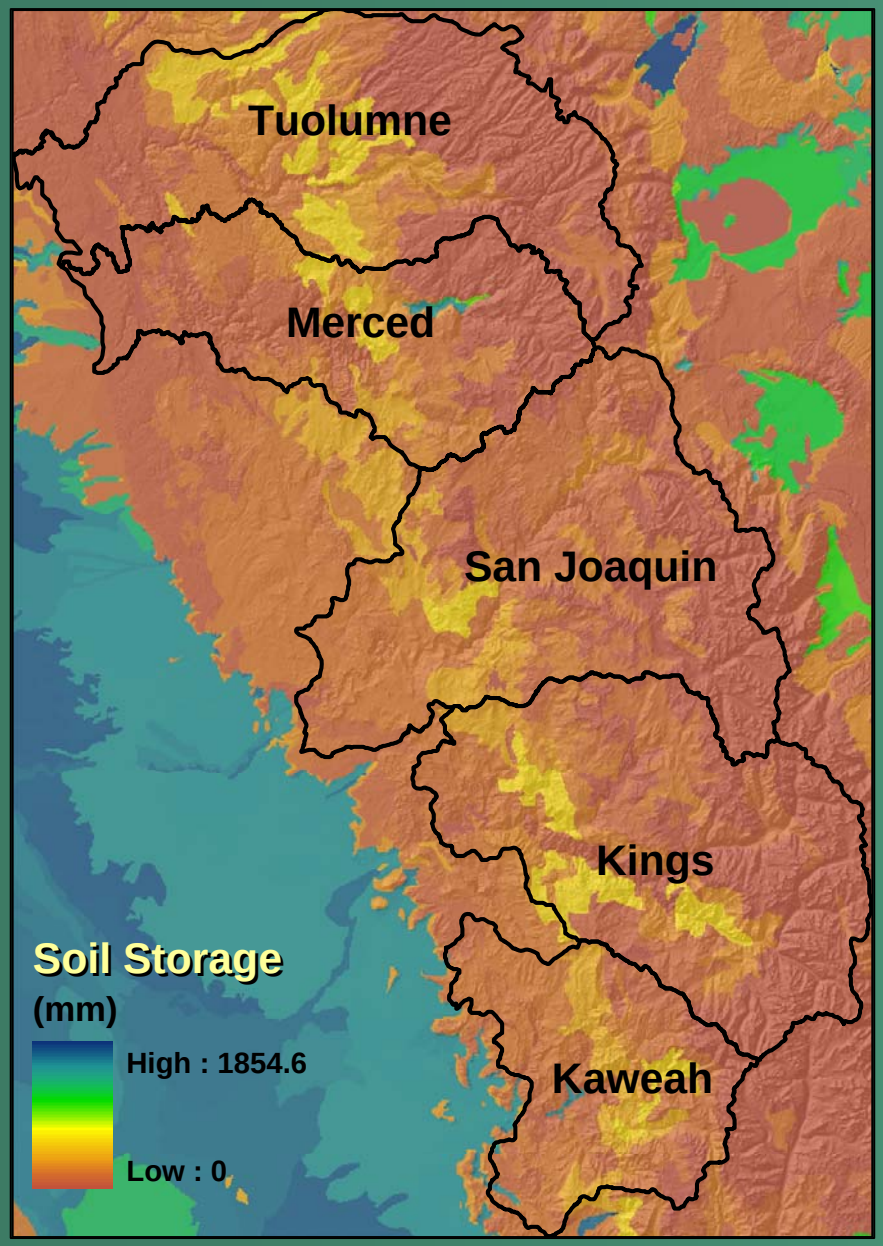

Dana Soil Water Content and Stage at Tuolumne at GC
4 inch
14 inch
21 inch
31 inch
Stage TGC
Volumetric Water Content
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Stage (ft)
18
16
14
12
10
8
6
05/01/08
05/31/08
06/30/08
07/30/08
Date

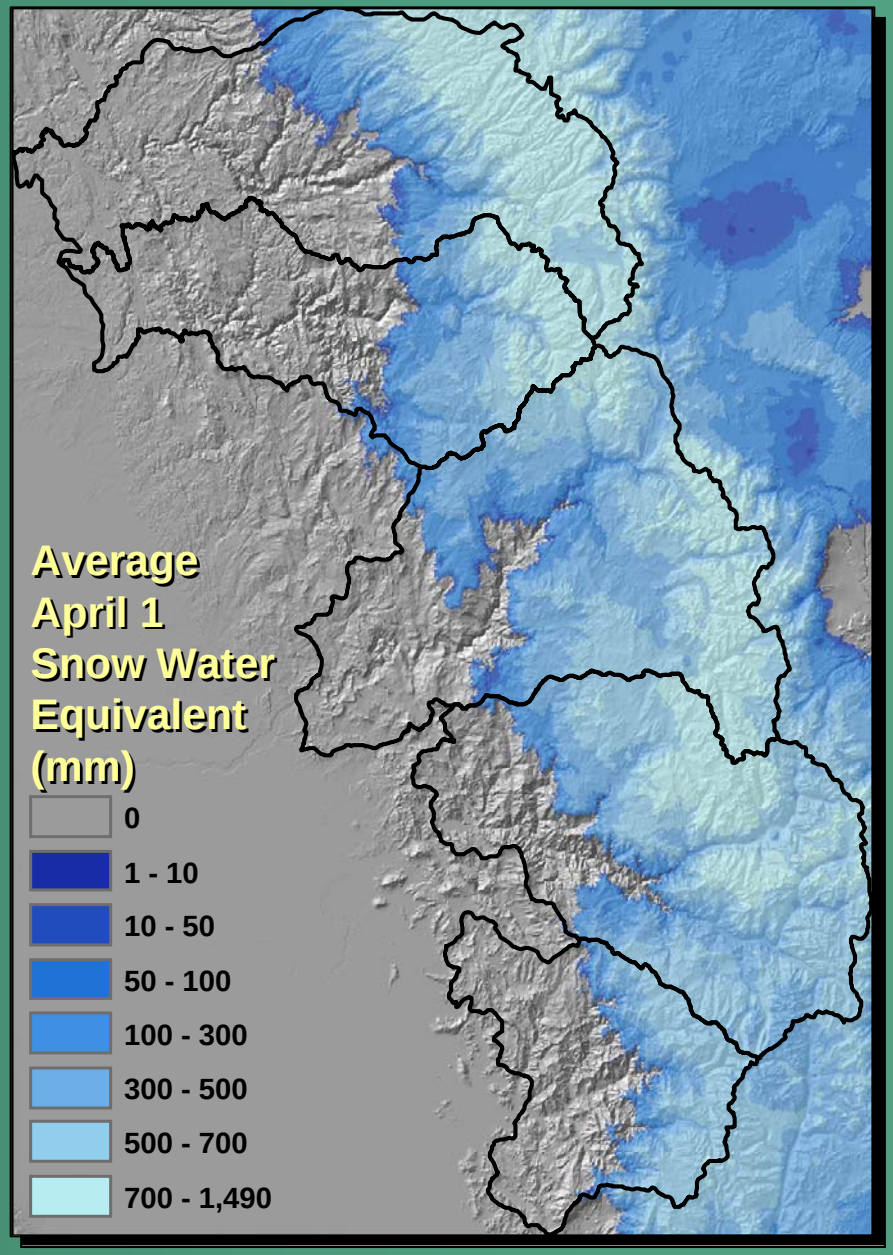

Dana Soil Water Content and Stage at Tuolumne at GC
4 inch
14 inch
21 inch
31 inch
Stage TGC
Flow (CFS/10) Dana Fork
Volumetric Water Content
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Stage (ft)-Flow (CFS/10)
20
18
16
14
12
10
8
6
4
2
0
05/01/08
05/31/08
06/30/08
07/30/08
Date

Electrical Conductivity and Discharge

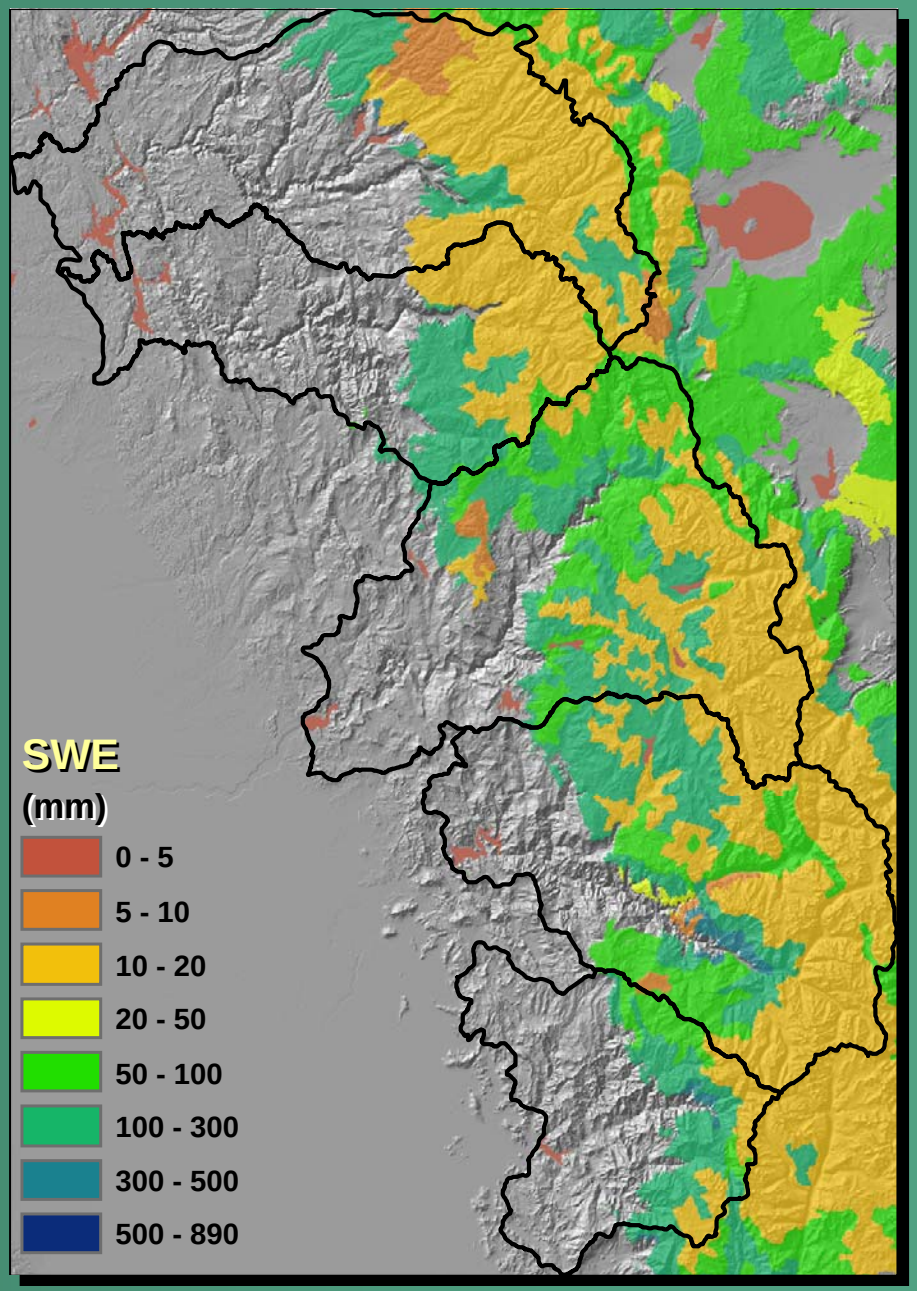





Tuolumne
Merced
San Joaquin
Kings
Kaweah
Soil Storage
(mm)
High : 1854.6
Low : 0

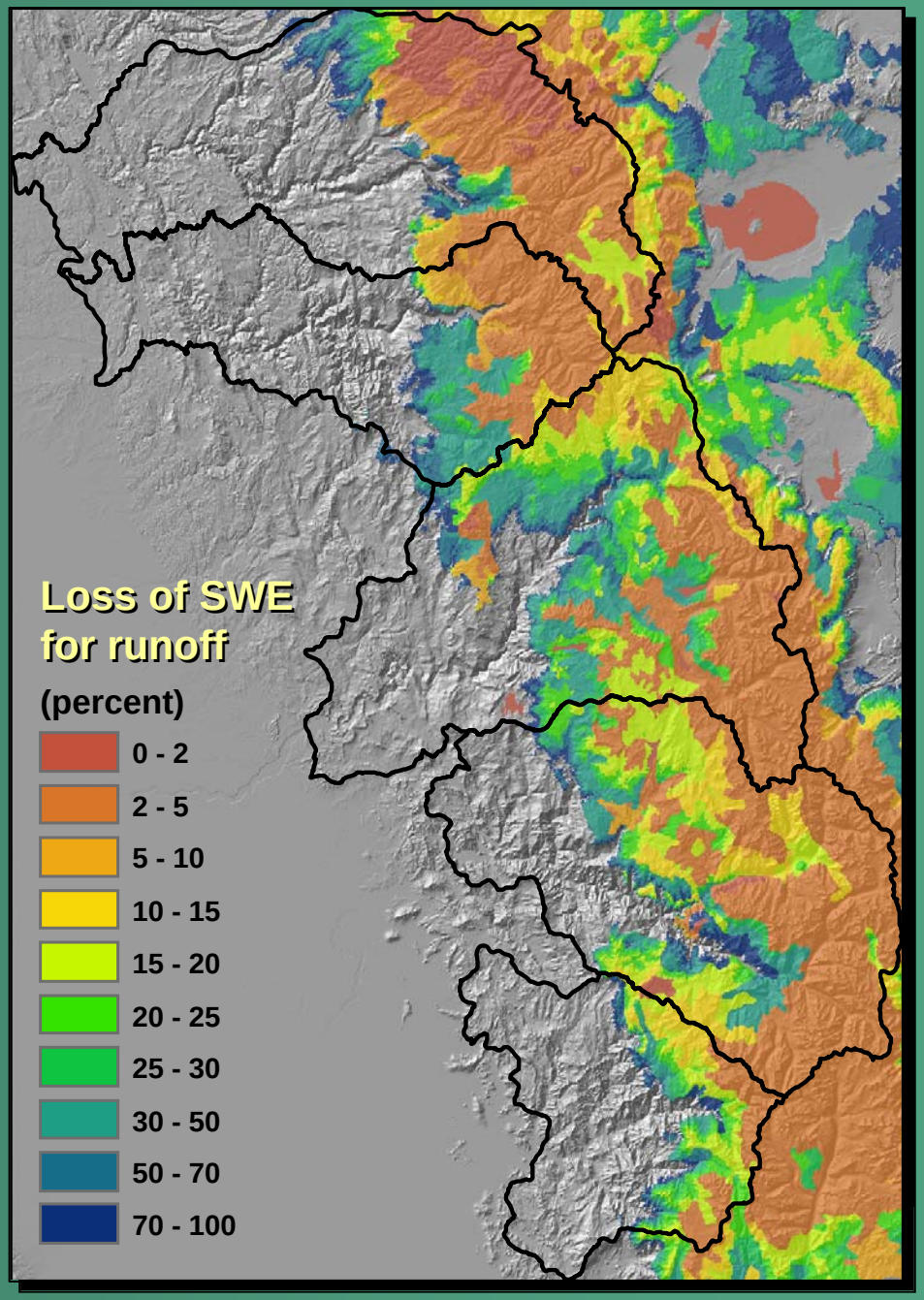

Average
April 1
Snow Water
Equivalent
(mm)
0
1 - 10
10 - 50
50 - 100
100 - 300
300 - 500
500 - 700
700 - 1,490

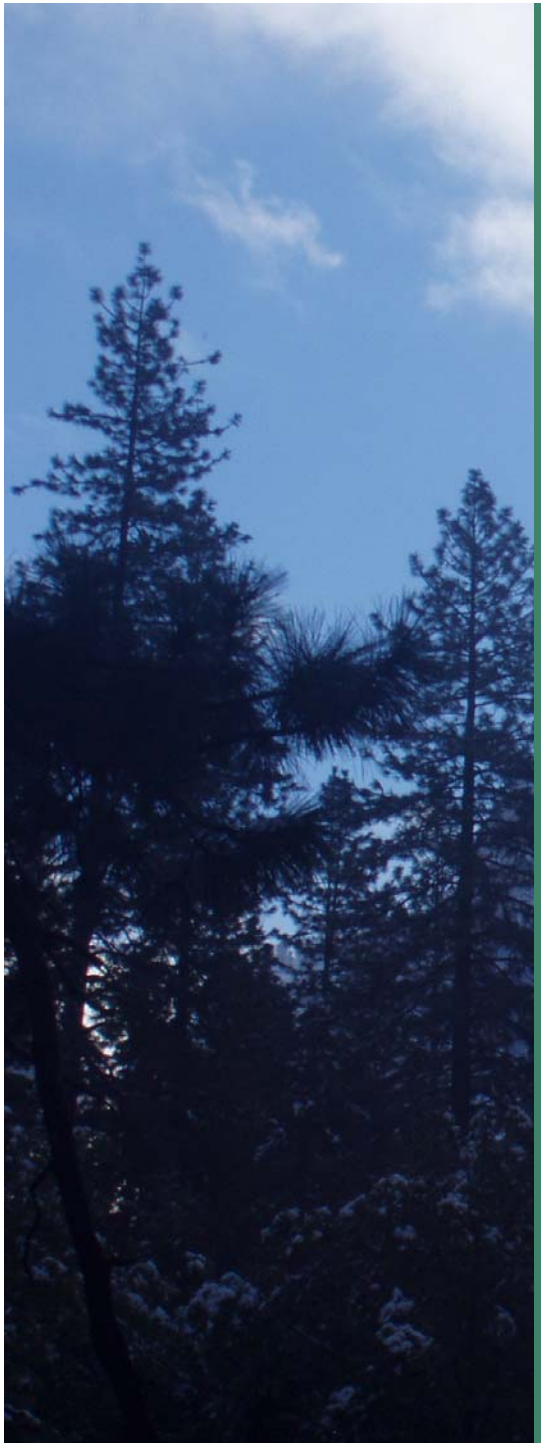
Snow melt water available for stream flow after rewetting (to field capacity) completely dry soil during snowmelt



Percentage of SWE lost to soil storage during snowmelt in a year with dry preceding fall

Tuolumne	7%
Merced	12%
San Joaquin	13%
Kings	12%
Kaweah	19%



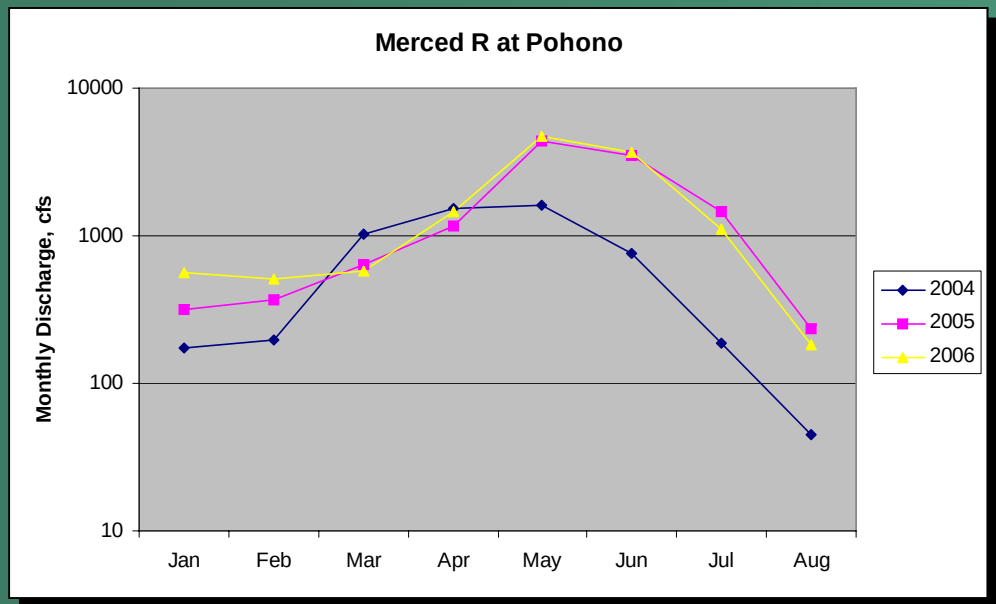


Soil water summary

- Active hydrologic processes occurring above and below snow pack
- There are very similar processes happening at very different locations
- Knowing soil moisture status prior to melt may be important for time and amount of streamflow

Variable Onset of Spring Snowmelt

Merced Basin



Tuolumne Basin

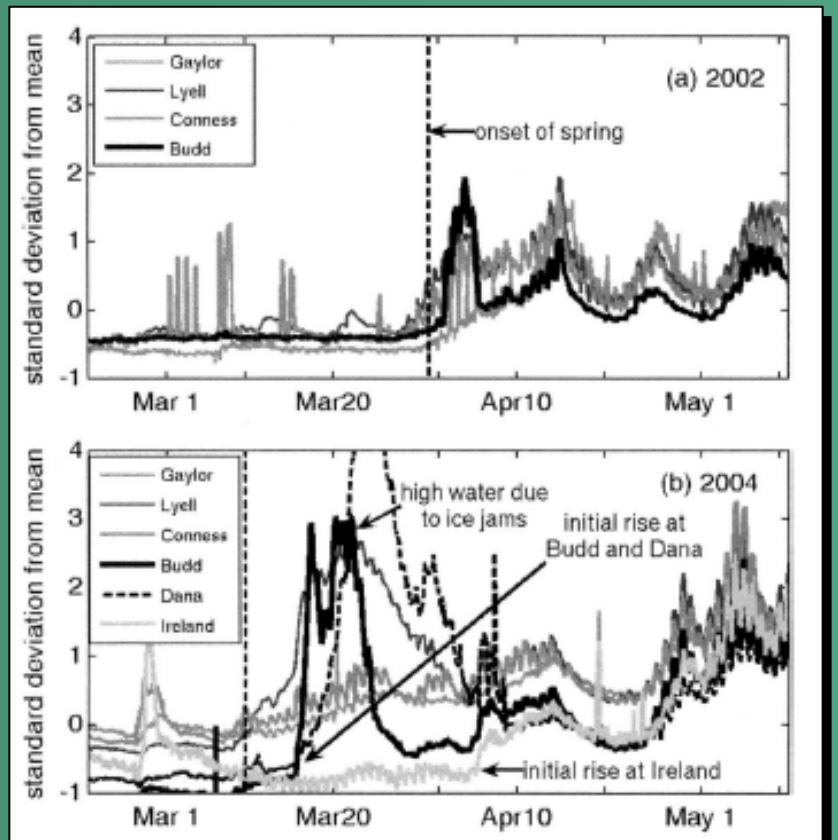
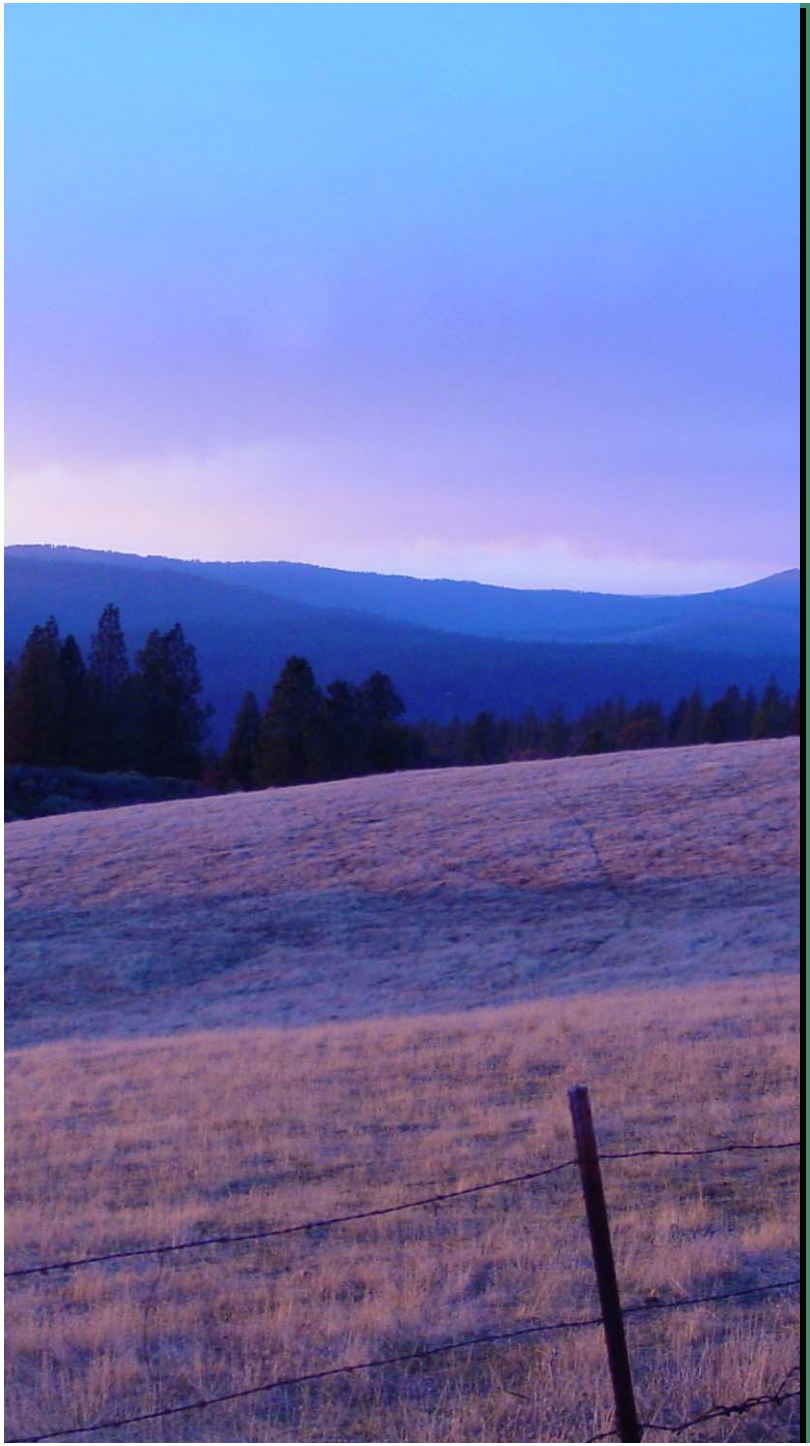


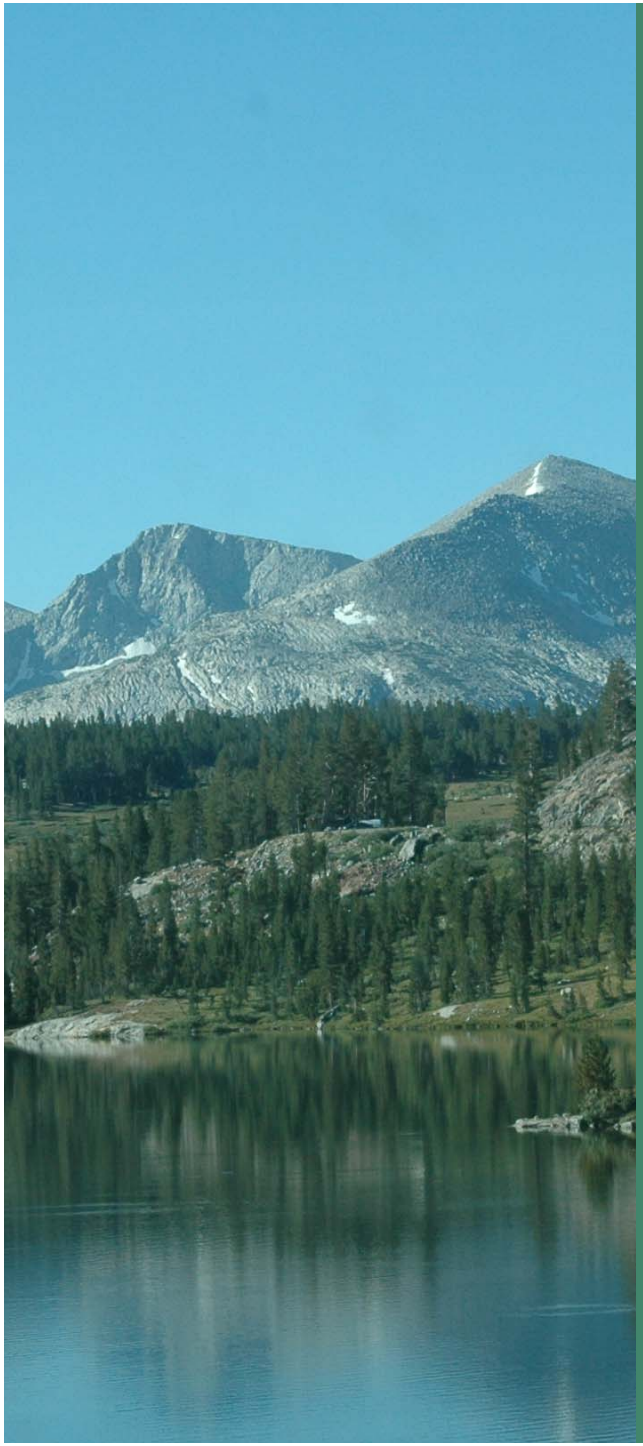
FIG. 6. Spring onset as measured by standard deviations from the mean stage at a subset of Tuolumne River subbasins for (a) 2002 and (b) 2004. In 2002, spring onset was synchronous at all gauged locations. In 2004, most streams began rising on or before 8 March. Budd Creek and the Dana Fork above Gaylor Creek began rising 16 March, and Ireland Creek began flowing 5 April. Depths more than two std devs above the mean immediately following the spring onset are associated with ice dams and do not represent actual discharge amounts.

From Lundquist and Flint, 2006



Objective

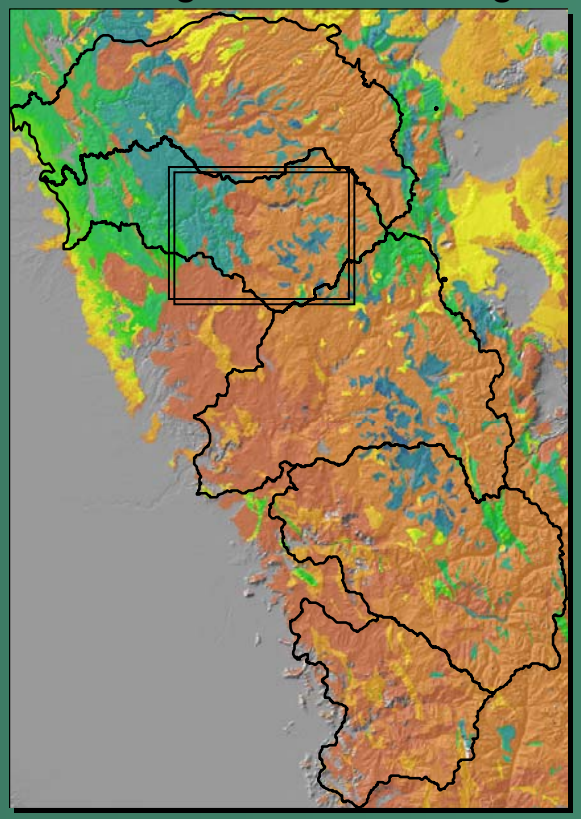
- Downscale a regional water balance model to southern Sierra basins
  - Incorporate processes at a scale that allows for the more detailed influence of topographic shading and changes in solar radiation load (270m to 90m or 30m) for current climate
  - Monthly to daily (with hourly radiation)
- Refine model to correct streamflow predictions to account for radiation
  - Simple as Snow-17 but with the added radiation term (as air temperature enhancement)

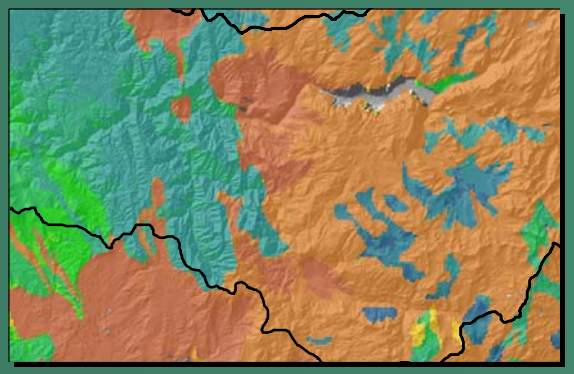


Recharge and Runoff

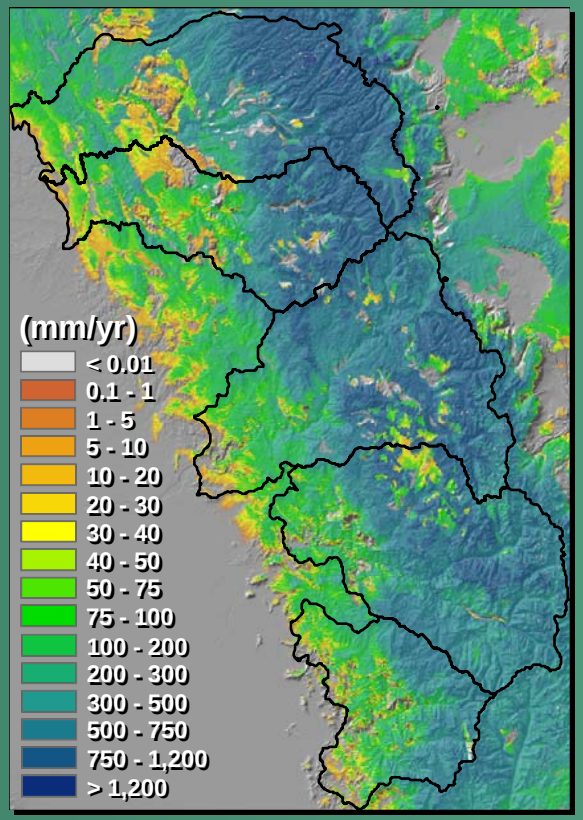
- Basin Characterization Model (BCM)
  - run in FORTRAN
  - uses grid-based data
  - calculates in-place recharge or generated runoff
- Potential evapotranspiration (Priestley-Taylor)
  - hourly solar radiation modeled using topographic shading and cloudiness
  - vegetation density
- Snow accumulation and melt based on NWS Snow-17 Model
- Soils (STATSGO): hydraulic properties and depth determine soil storage
- Geology is used to estimate bedrock permeability
- Precipitation and air temperature is available using PRISM datasets or spatially

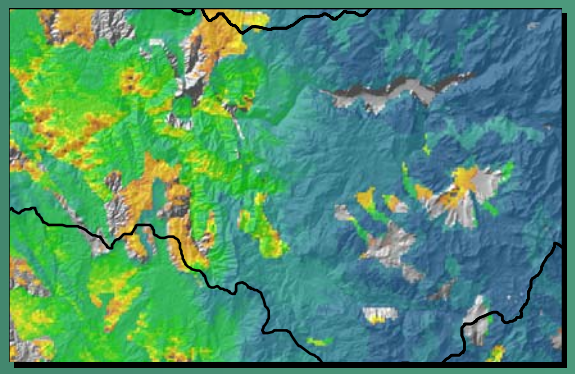
Average Annual Recharge



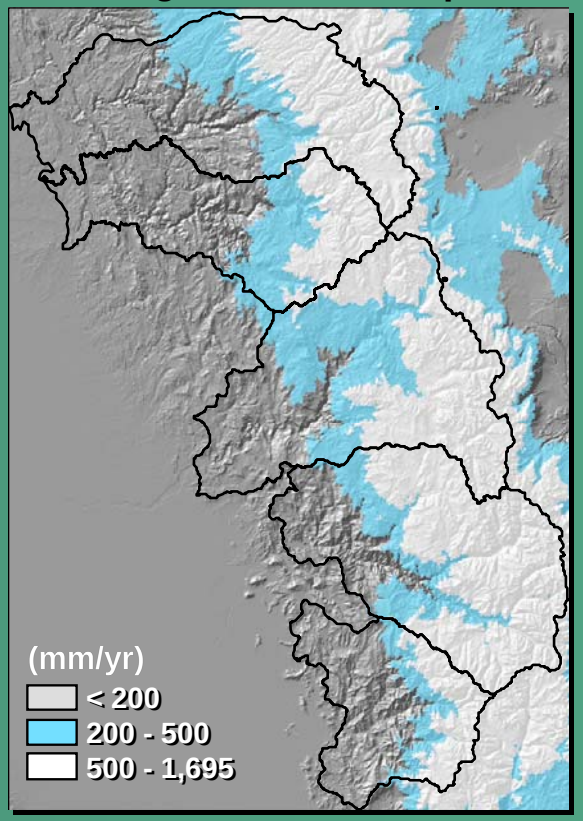


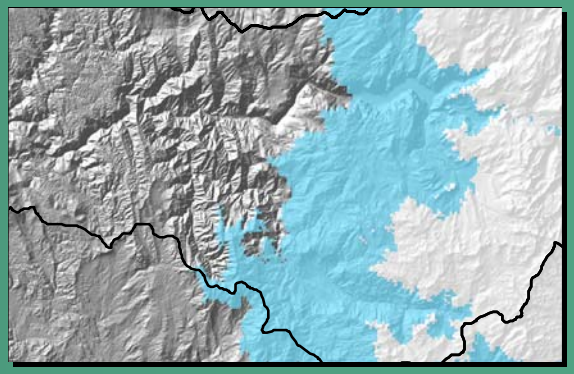
Average Annual Runoff





Average Annual Snowpack





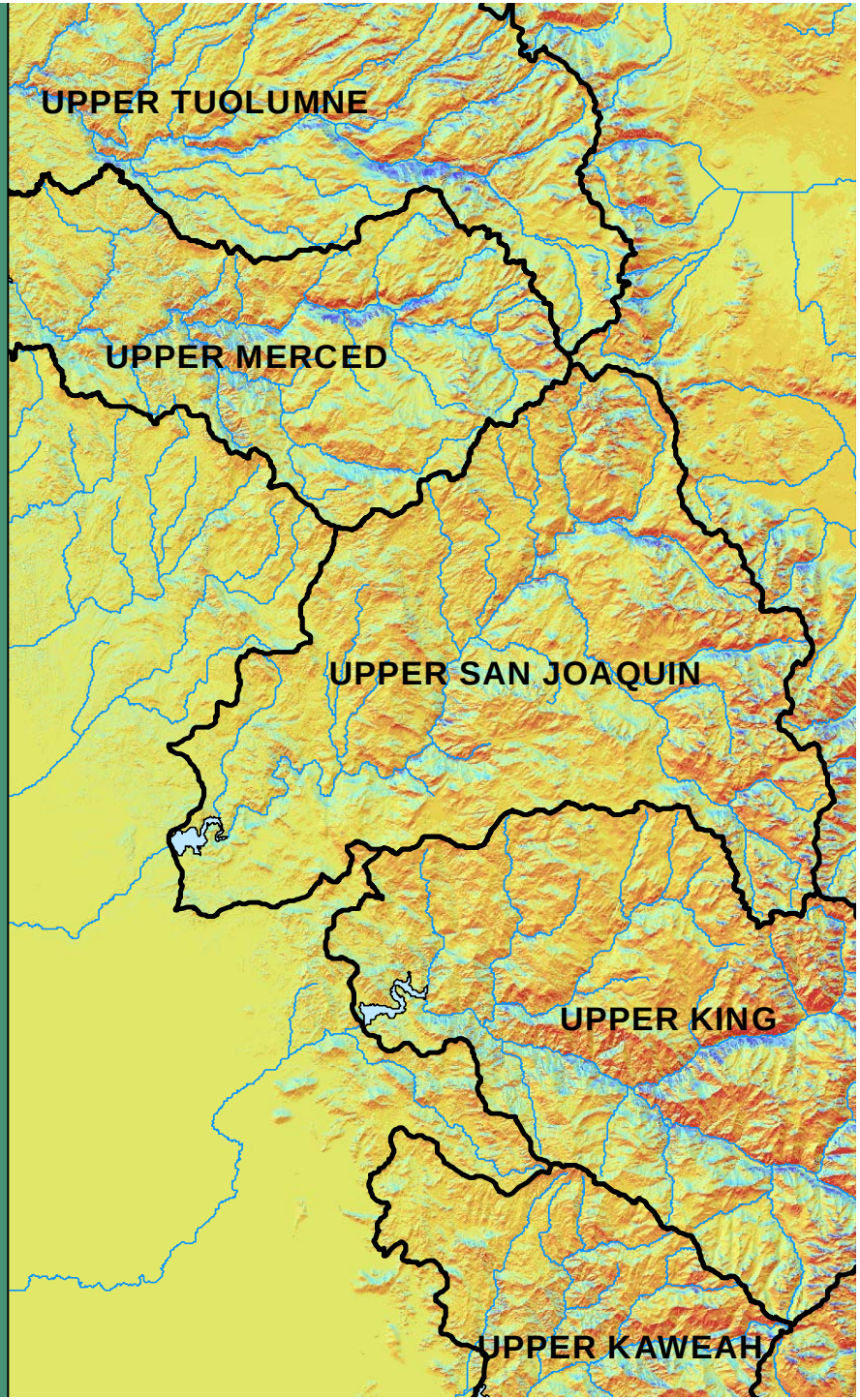
Solar Radiation
(March 1 – April 1)

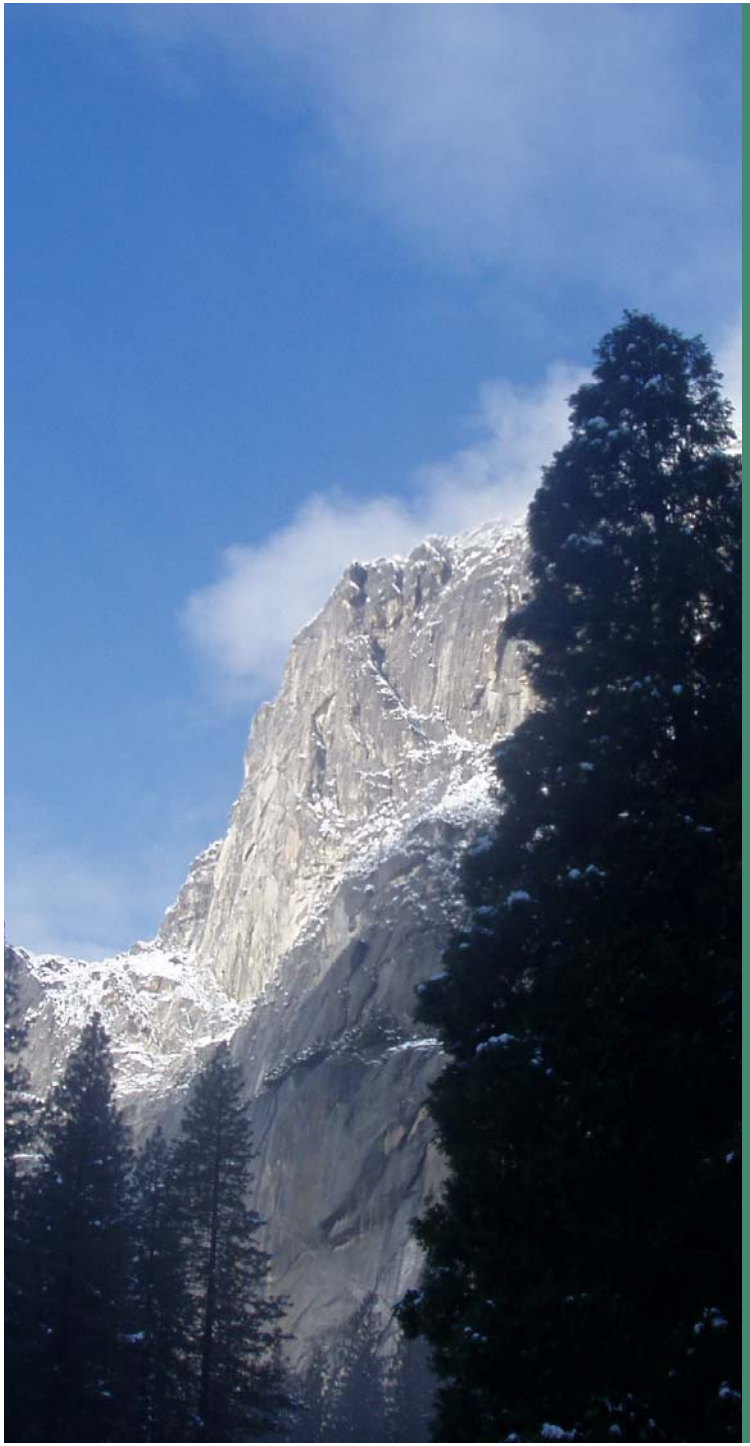
- Steep north-facing slopes show an increase in radiation of up to 95 percent
- Most slopes have a 25-50 percent increase in radiation
- Steep south-facing slopes have a reduction in radiation

-95 - -73
-73 - -60
-60 - -50
-50 - -43
-43 - -37
-37 - -32
-32 - -28
-28 - -25
-25 - -22
-22 - -17
-17 - -12
-12 - 28

Solar radiation

(Percent change)





Work in Progress

- Refining BCM to a daily time step and adding radiation function to snowmelt module
- Calibrate daily model to snow cover and SWE from MODIS and from Tripod LiDAR
- Calibrate daily model to high country runoff measurements and total basin discharge into 5 reservoirs
- Incorporate soil moisture model and daily evapotranspiration
- Downscaling future climate scenarios to BCM scale (270-m is complete for GFDL-A2, 3 to go at this scale for US)

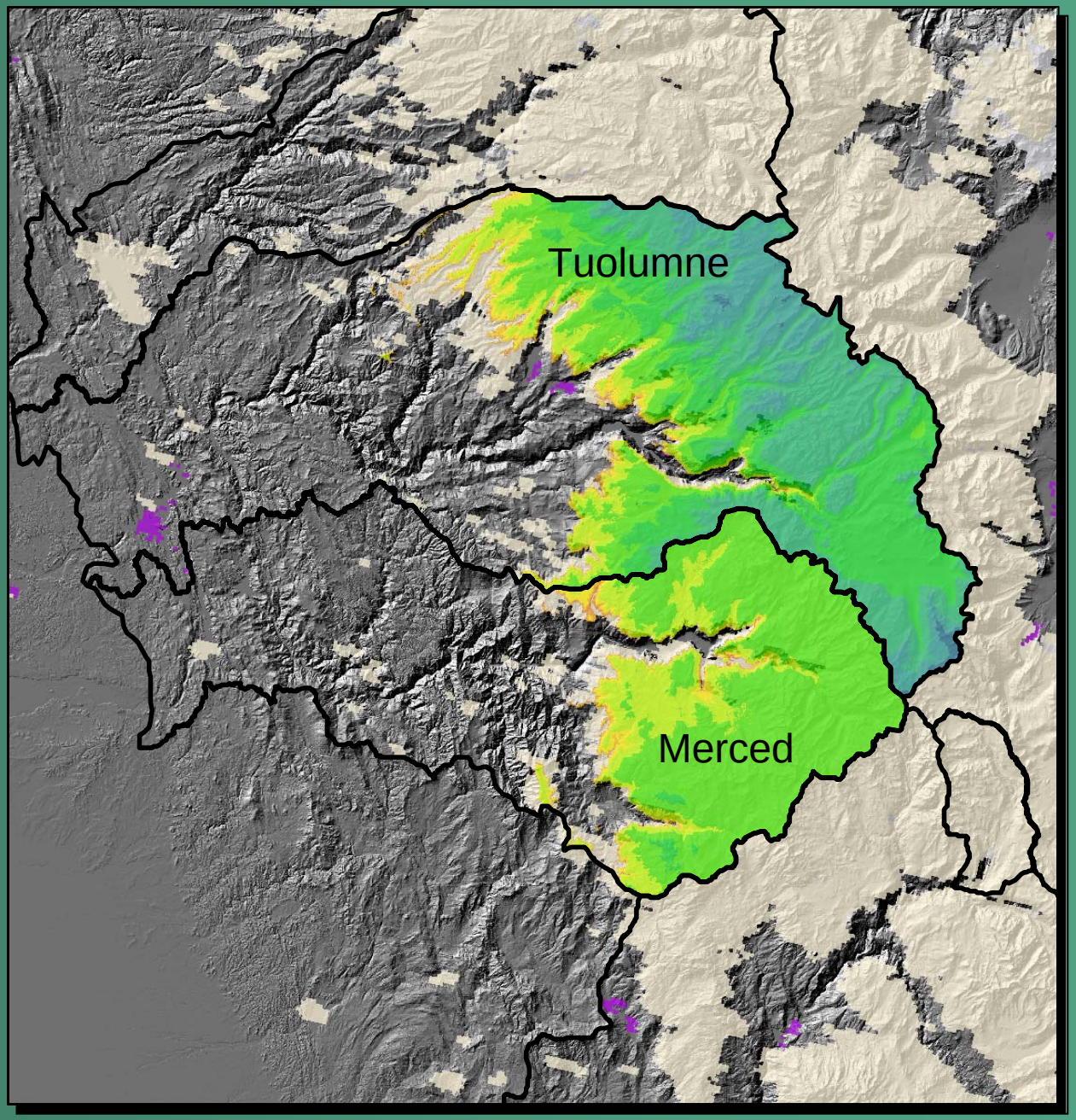
Preliminary Snow Modeling Daily

MODIS snow cover

Snowpack Depth

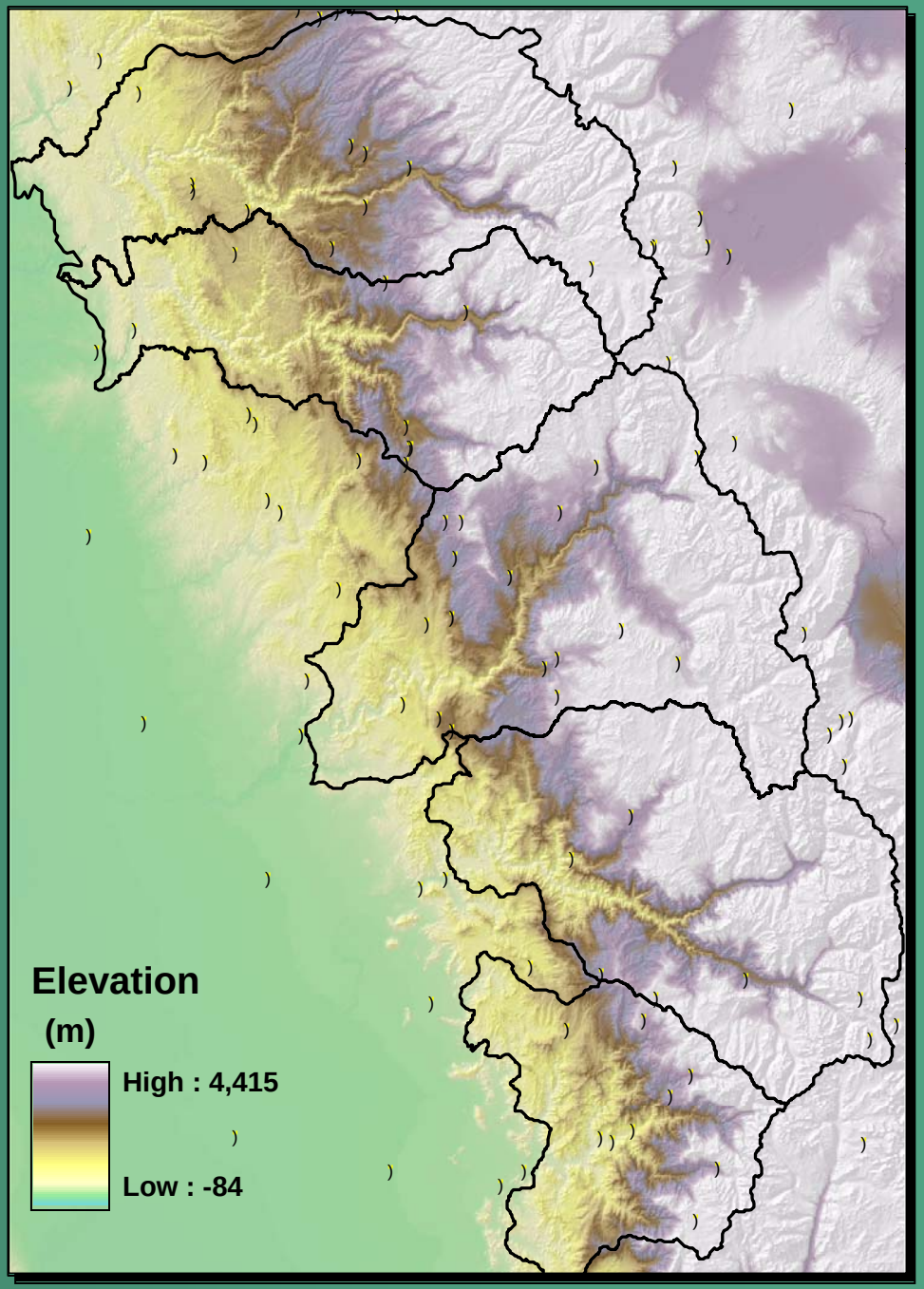
(mm)

- 0 - 1
- 1 - 10
- 10 - 25
- 25 - 50
- 50 - 100
- 100 - 250
- 250 - 500
- 500 - 750
- 750 - 900
- 900 - 1,000
- 1,000 - 1,150
- 1,150 - 1,250



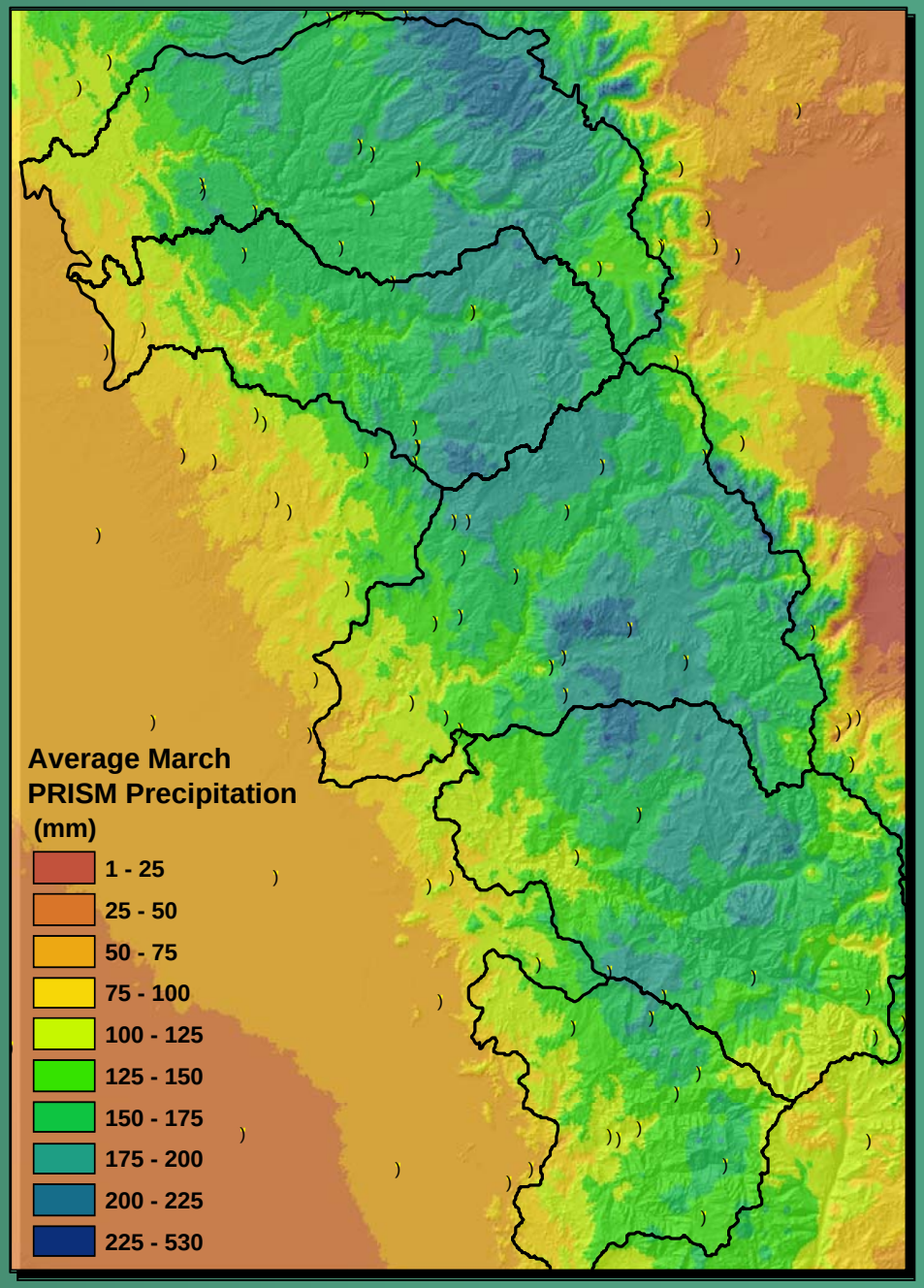
Spatial Distribution of Station Data

- Correlating deterministic data to elevation improves the spatial distribution of sparse data such as air temperature and precipitation
- Gradient-inverse-distance-squared regression technique develops equations for every day with all available data using station data, elevation, location (distance between stations)

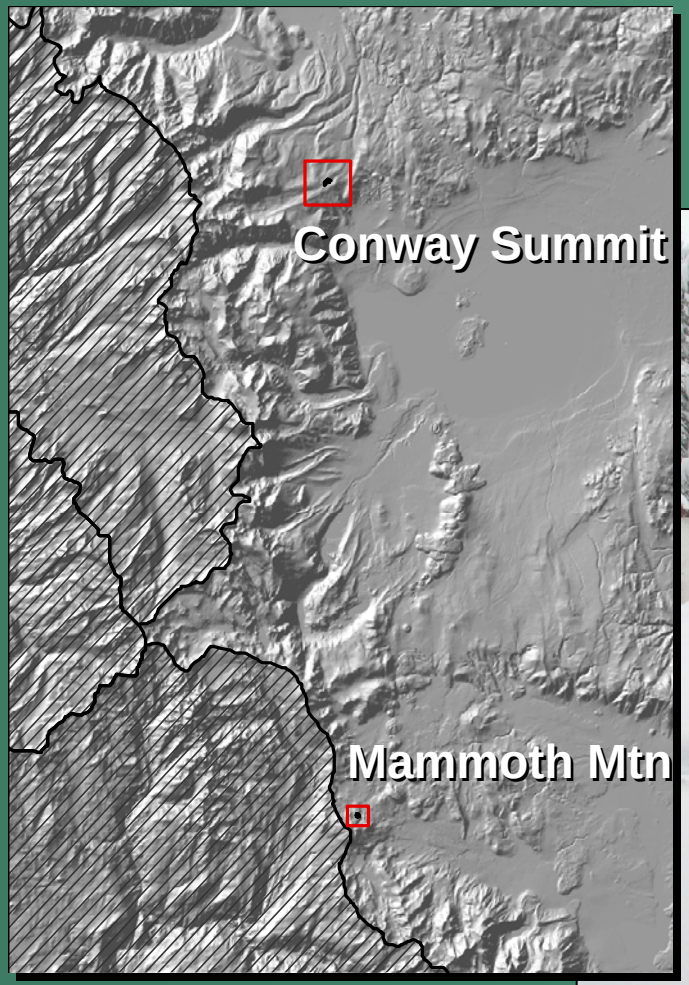


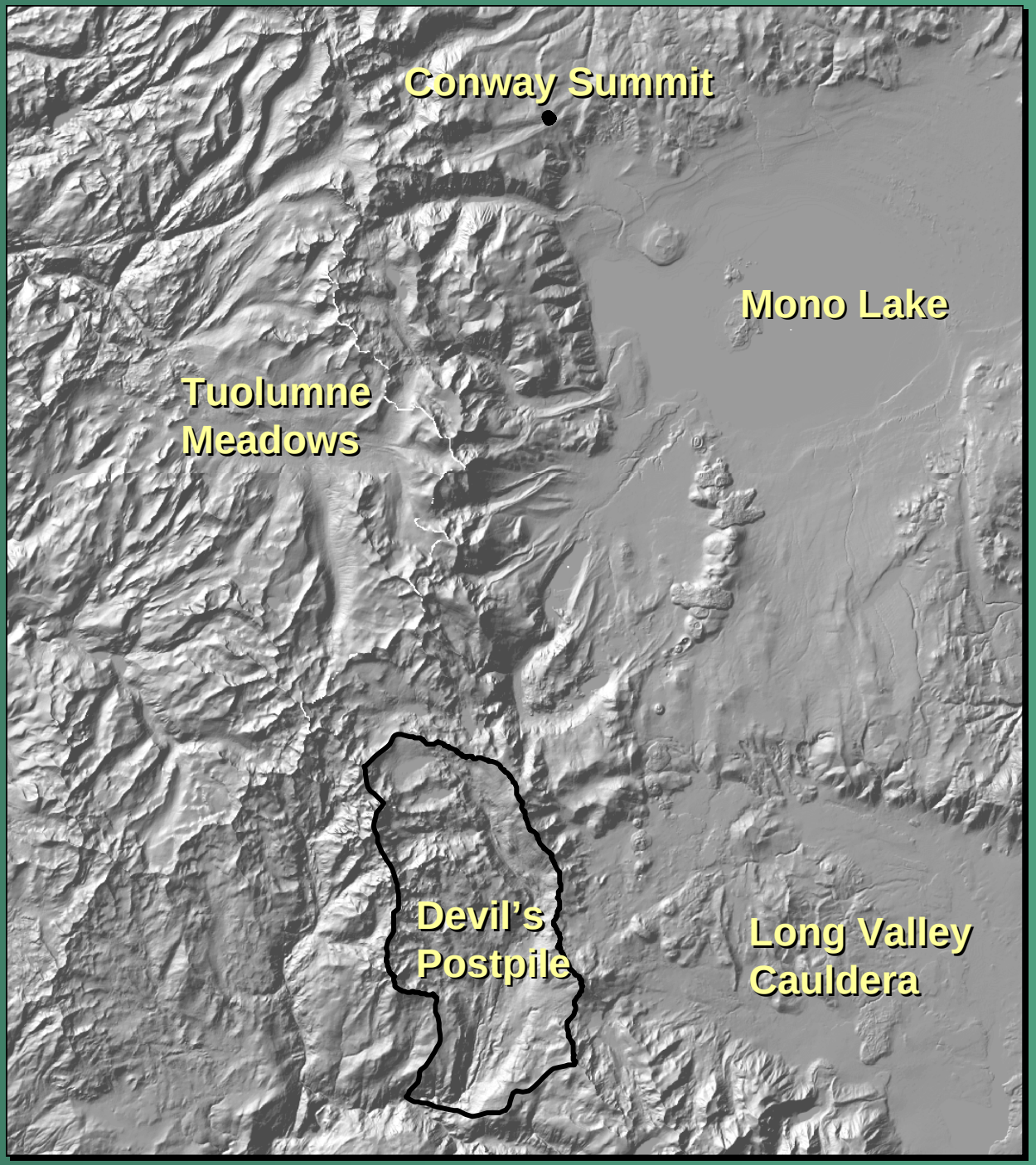
Spatial Distribution of Precipitation

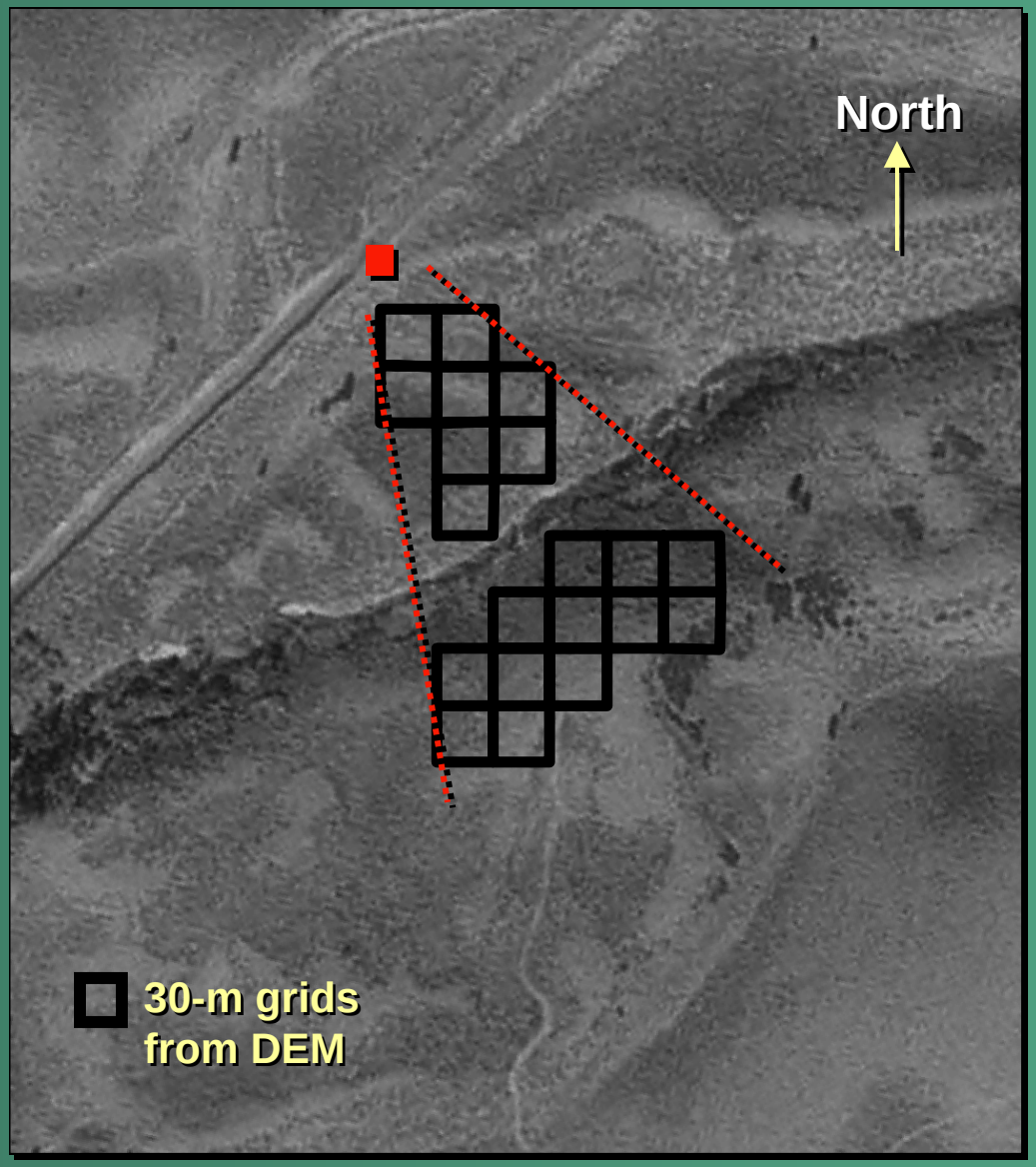
- Daily gradient-inverse-distance-squared regressions are conditioned by monthly PRISM data to provide more information on spatial structure of precipitation between stations
- Models that accumulate snow correctly and as important as models that melt snow
- Both precipitation and air temperature distribution necessary (radiation is predictable)

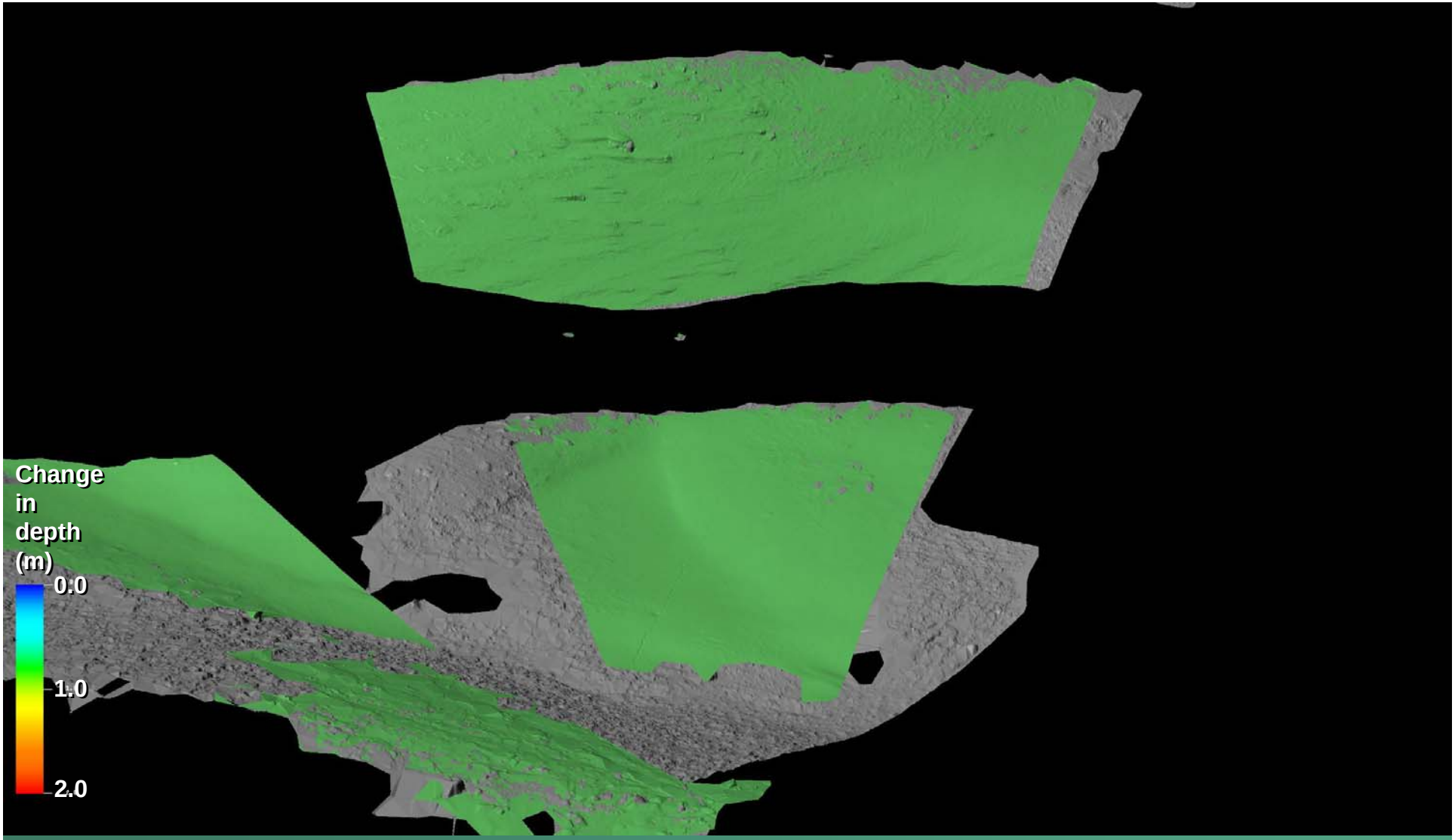


Tripod-LiDAR investigations of snow volume and snow water equivalent

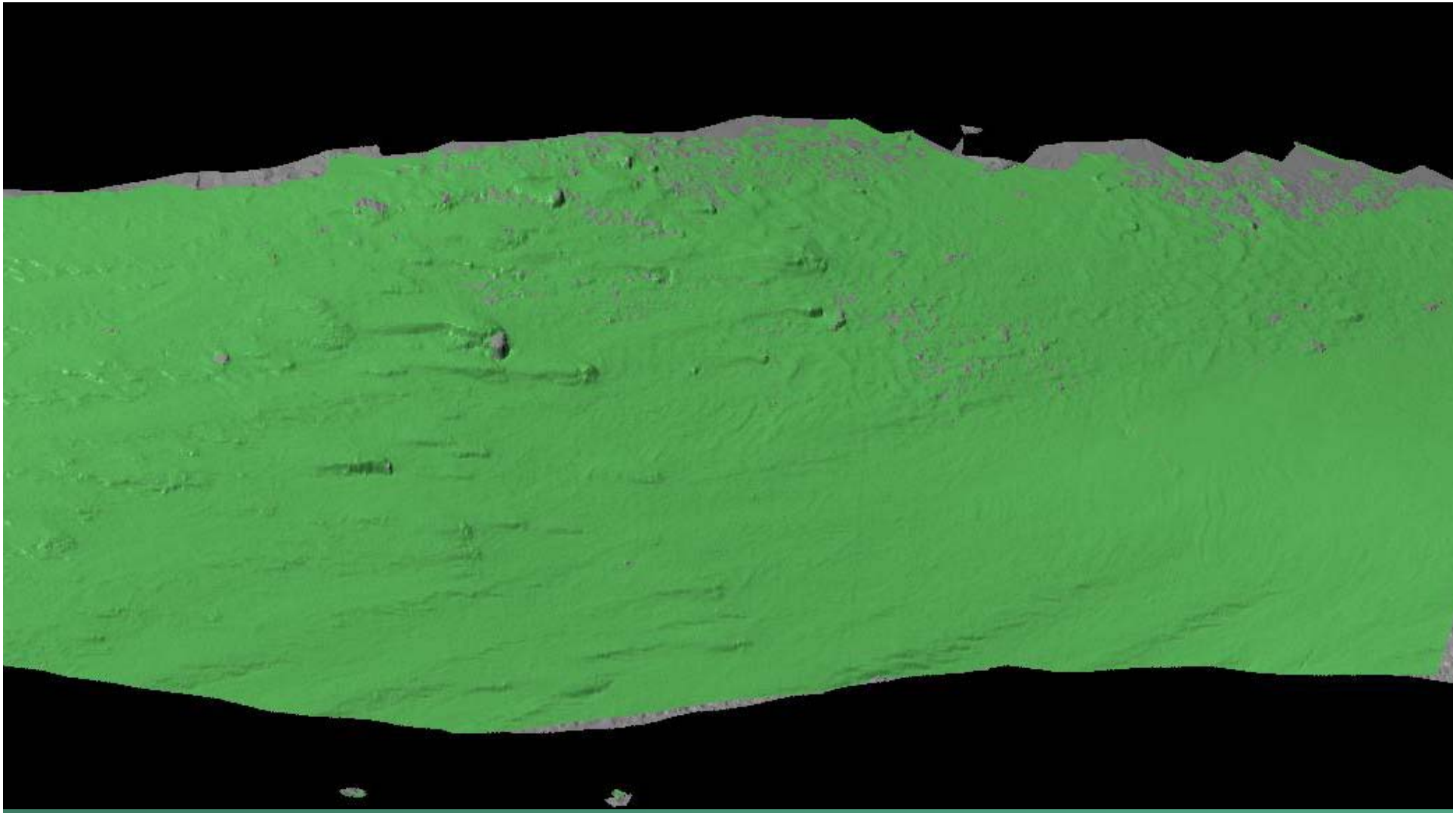



Conway Summit
Mono Lake
Tuolumne
Meadows
Devil's
Postpile
Long Valley
Cauldera

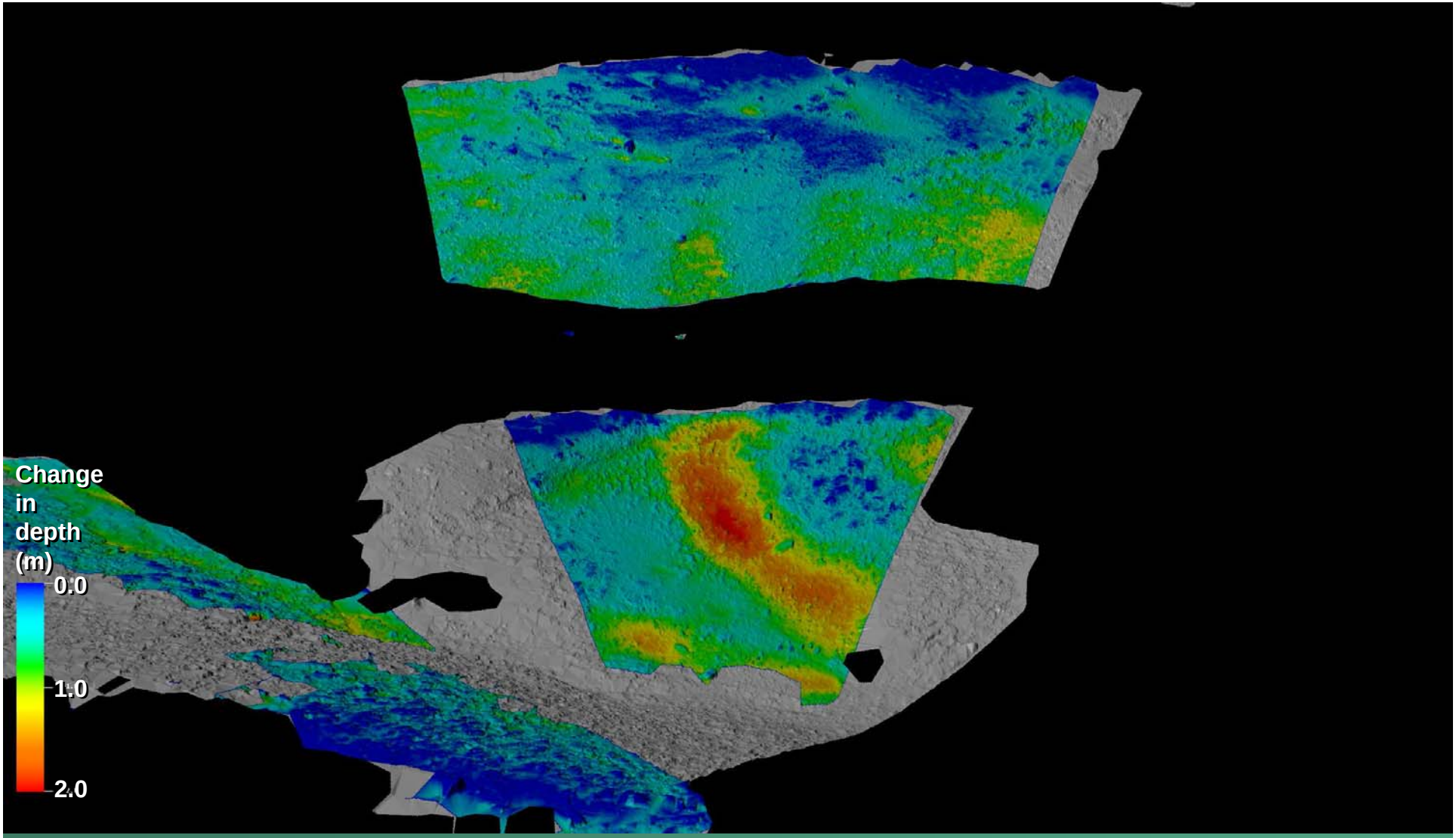

North
30-m grids
from DEM



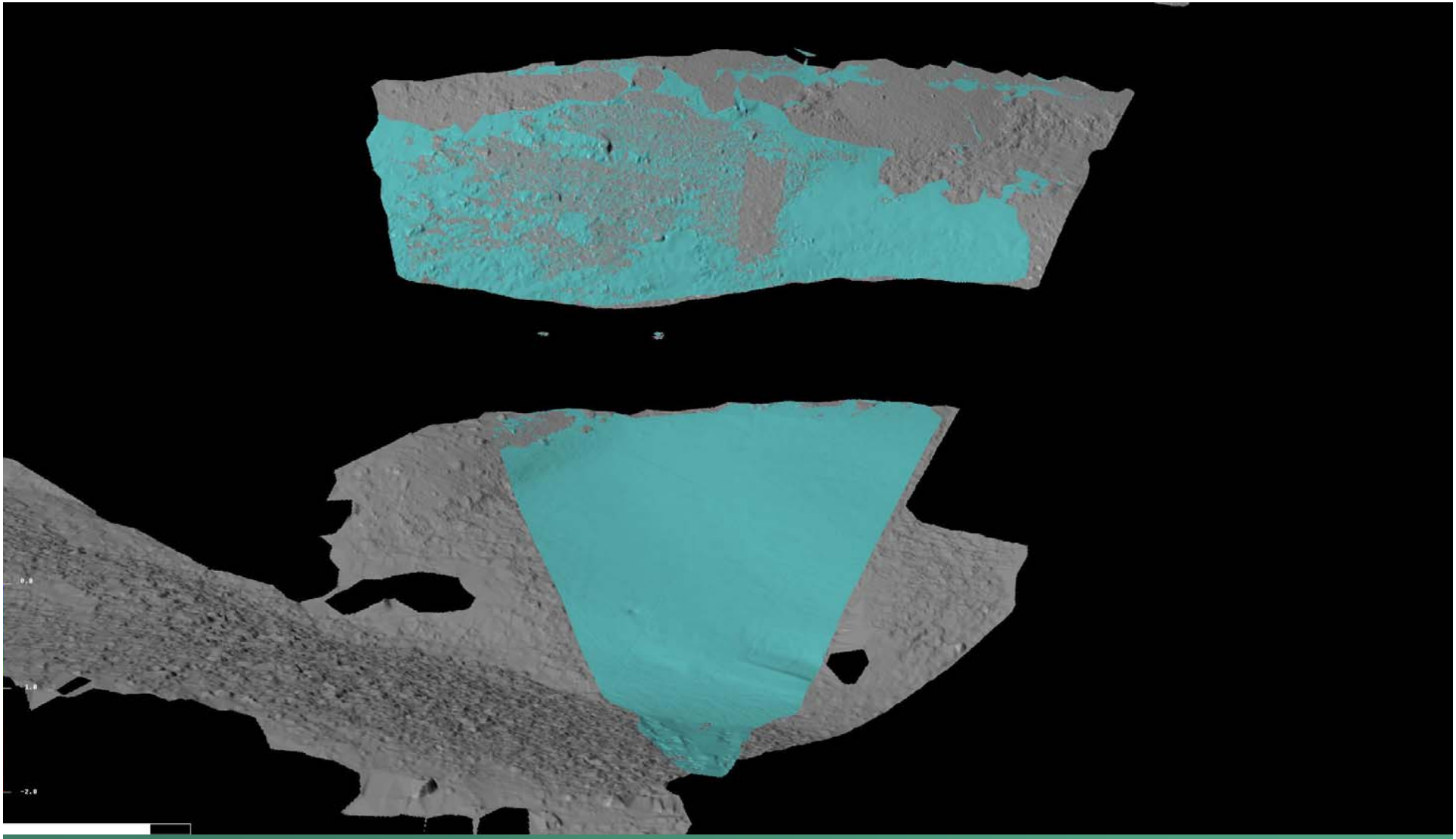
January 10, 2008 **Snow Elevation**



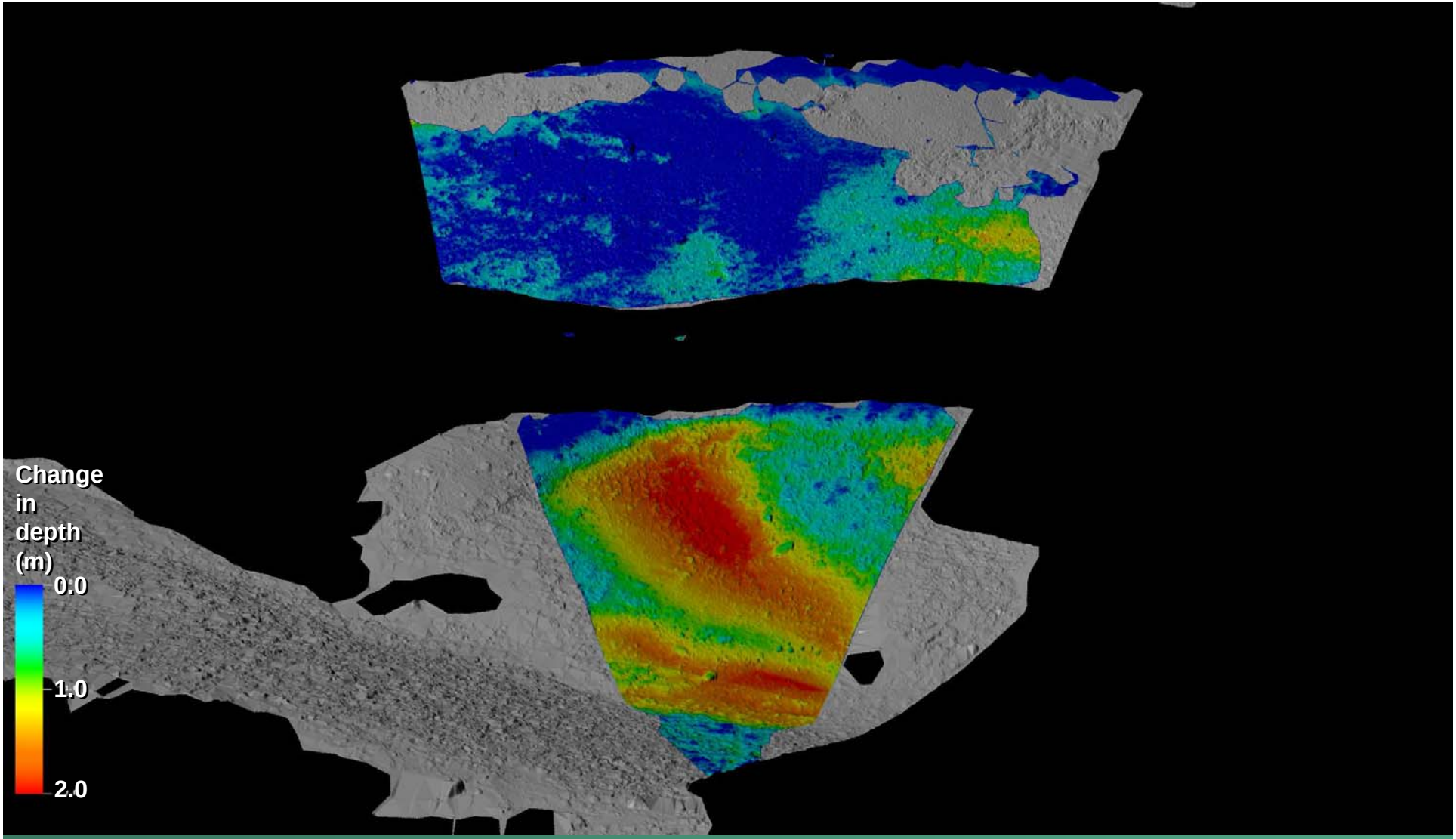
January 10, 2008 **Snow Elevation**



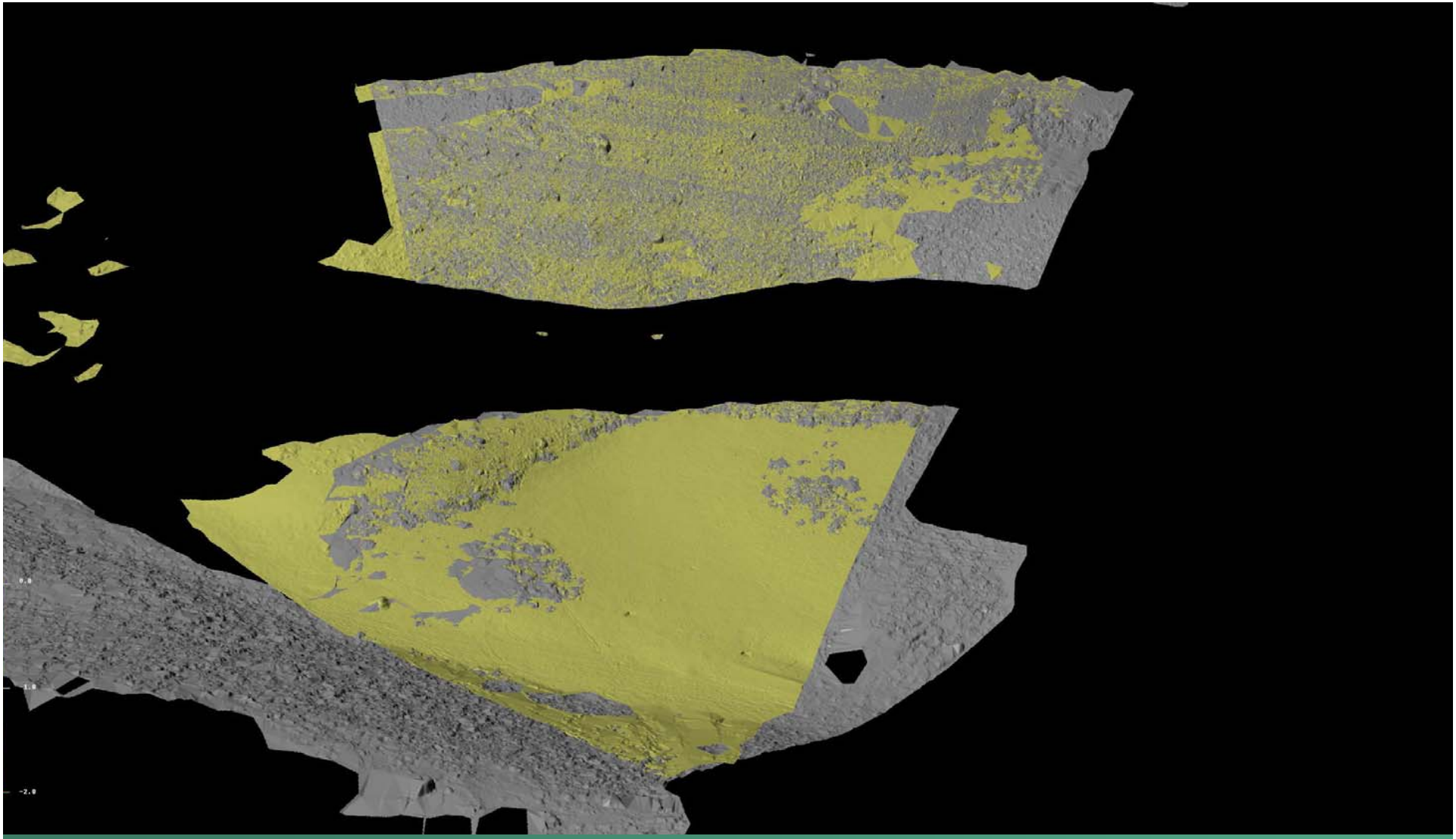
January 10, 2008 **Snow Depth**



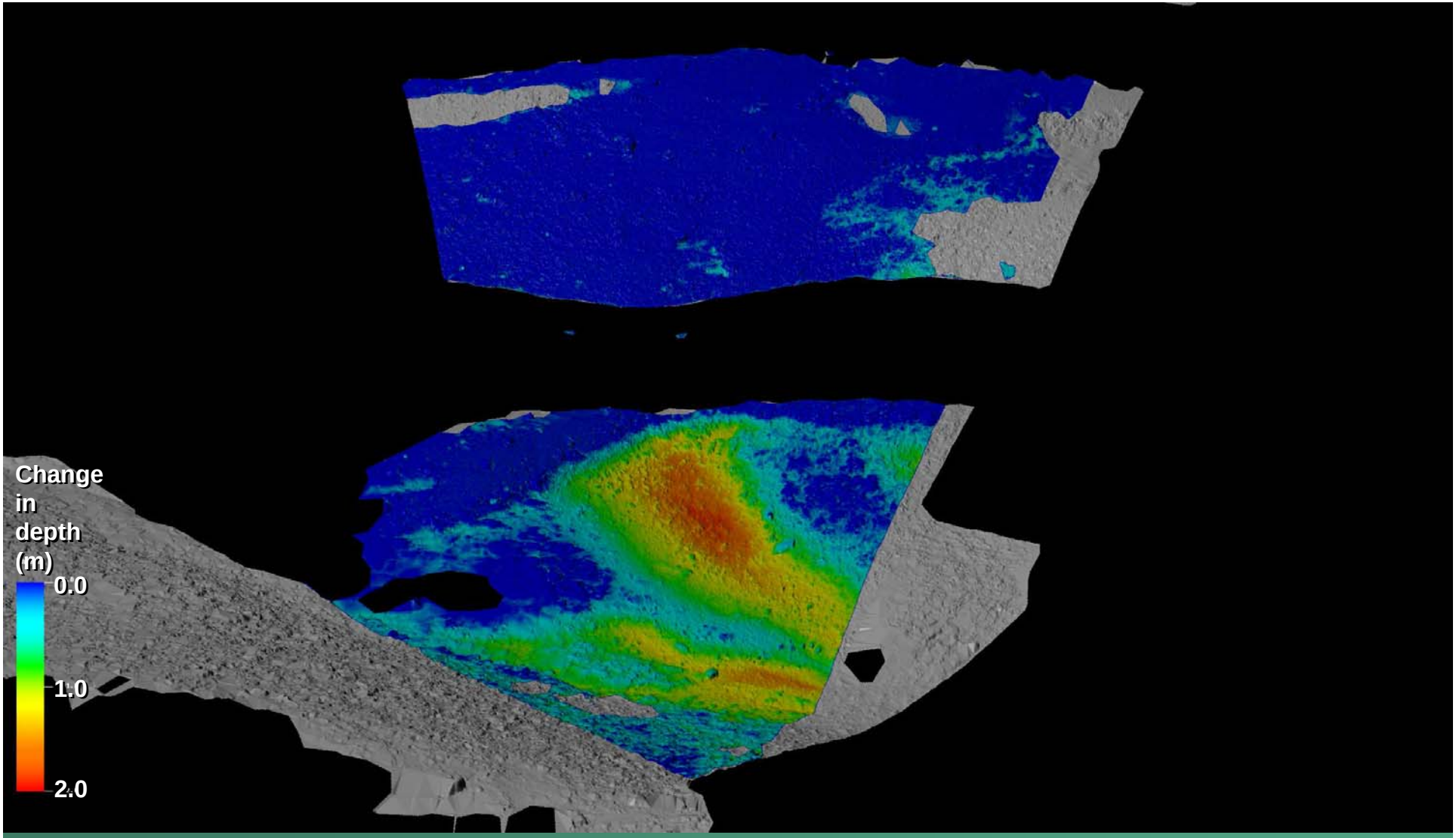
March 31, 2008 Snow Elevation



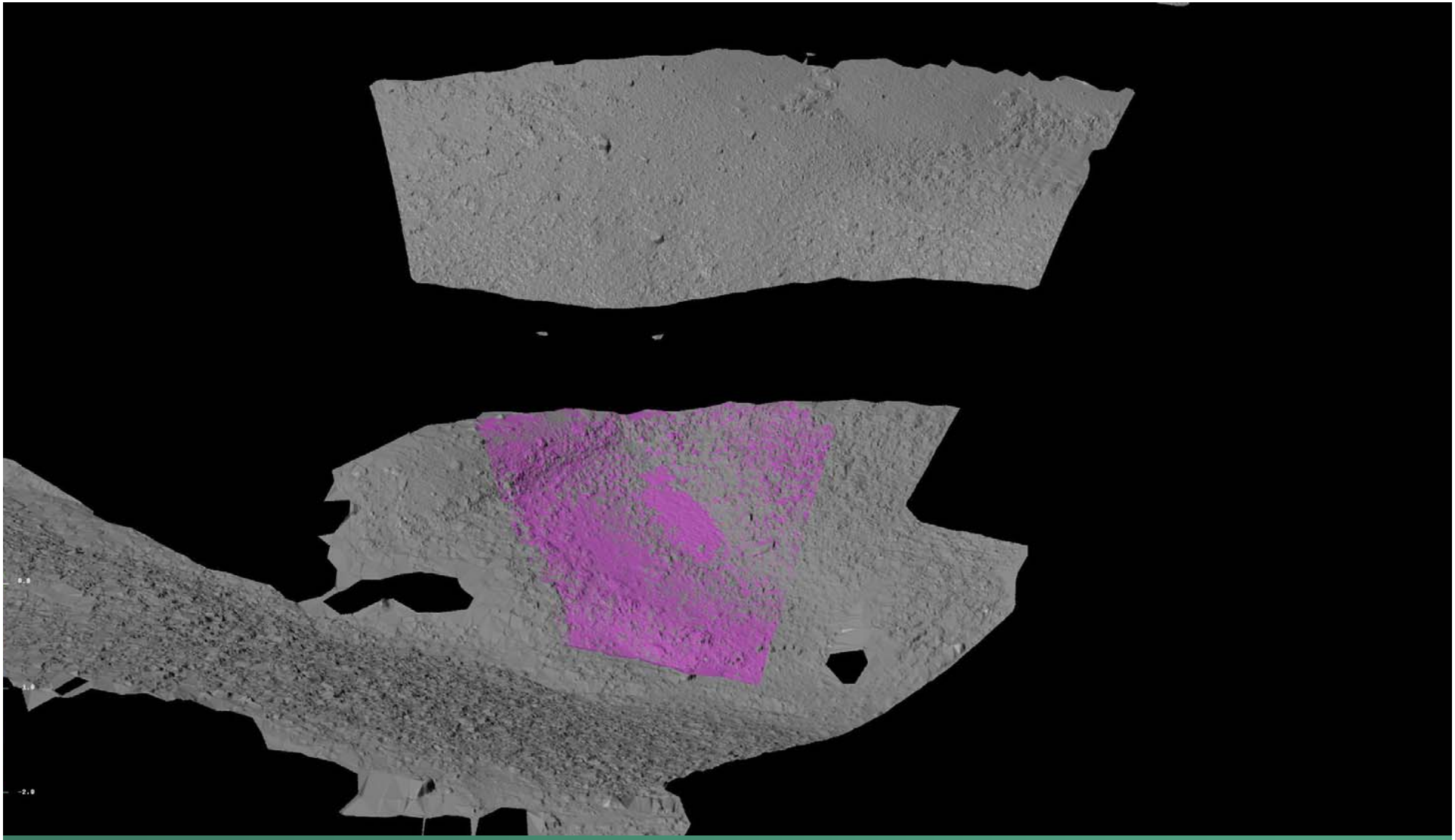
March 31, 2008 **Snow Depth**



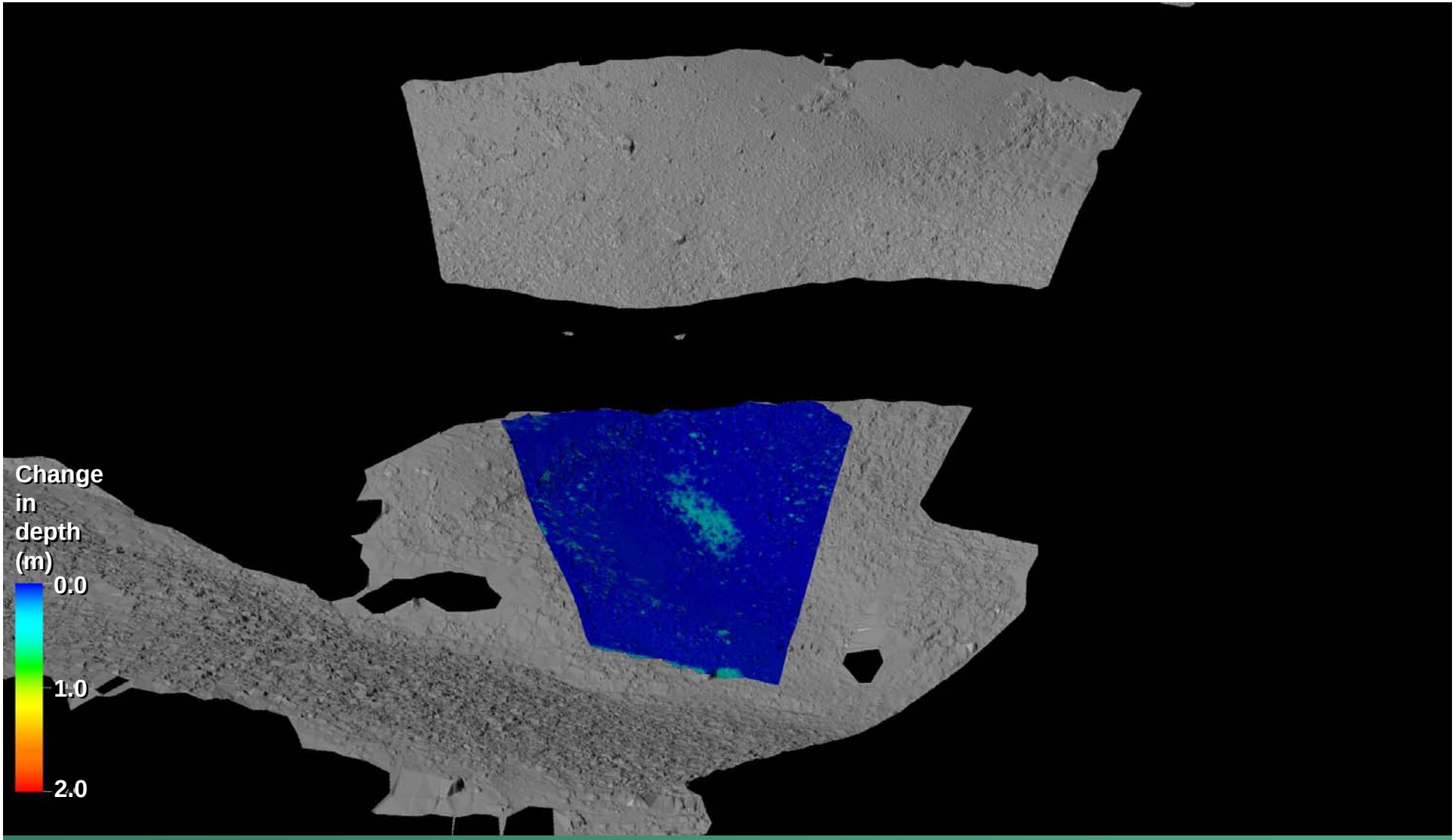
April 21, 2008 **Snow Elevation**



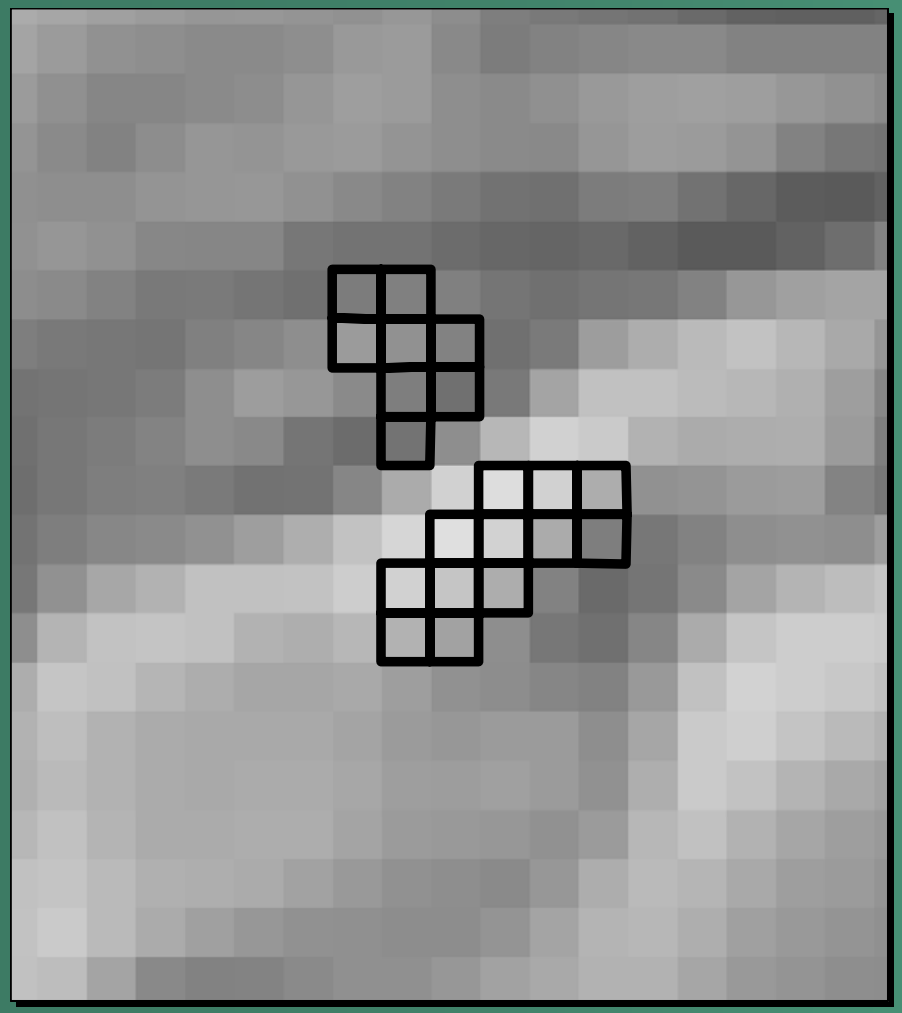
April 21, 2008 **Snow Depth**



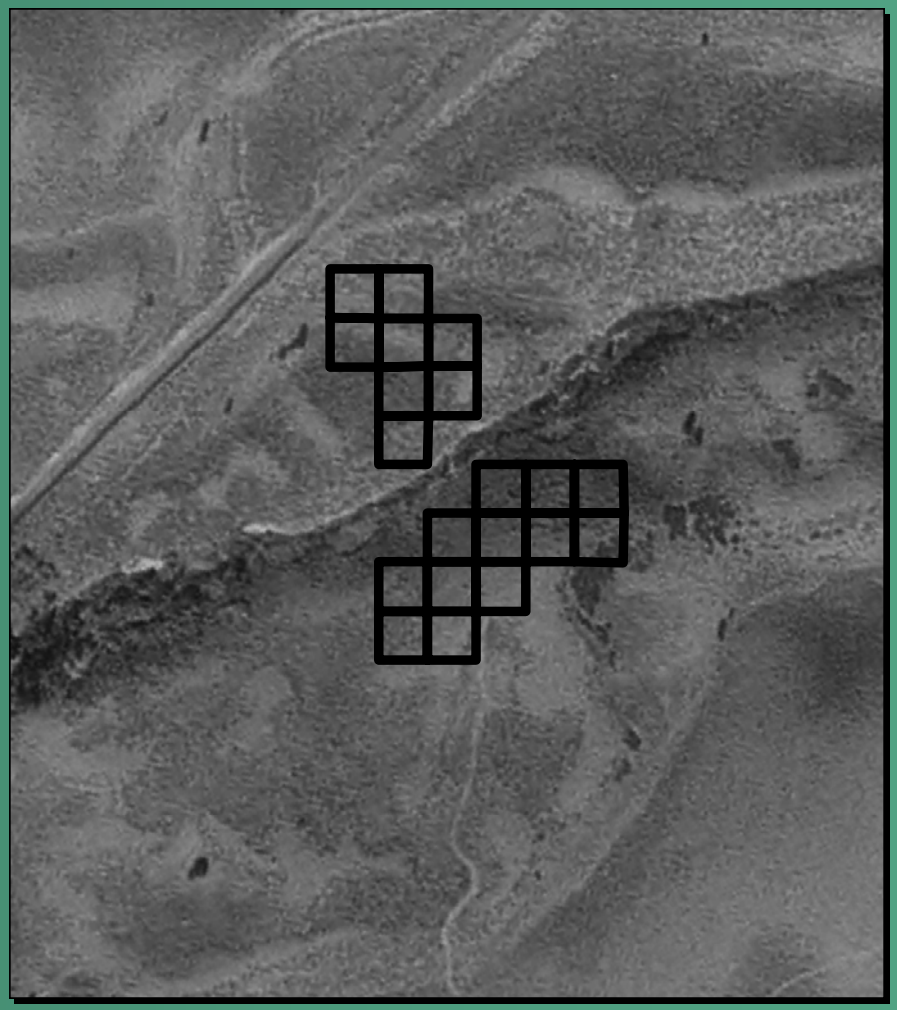
May 20, 2008 **Snow Elevation**



May 20, 2008 **Snow Depth**

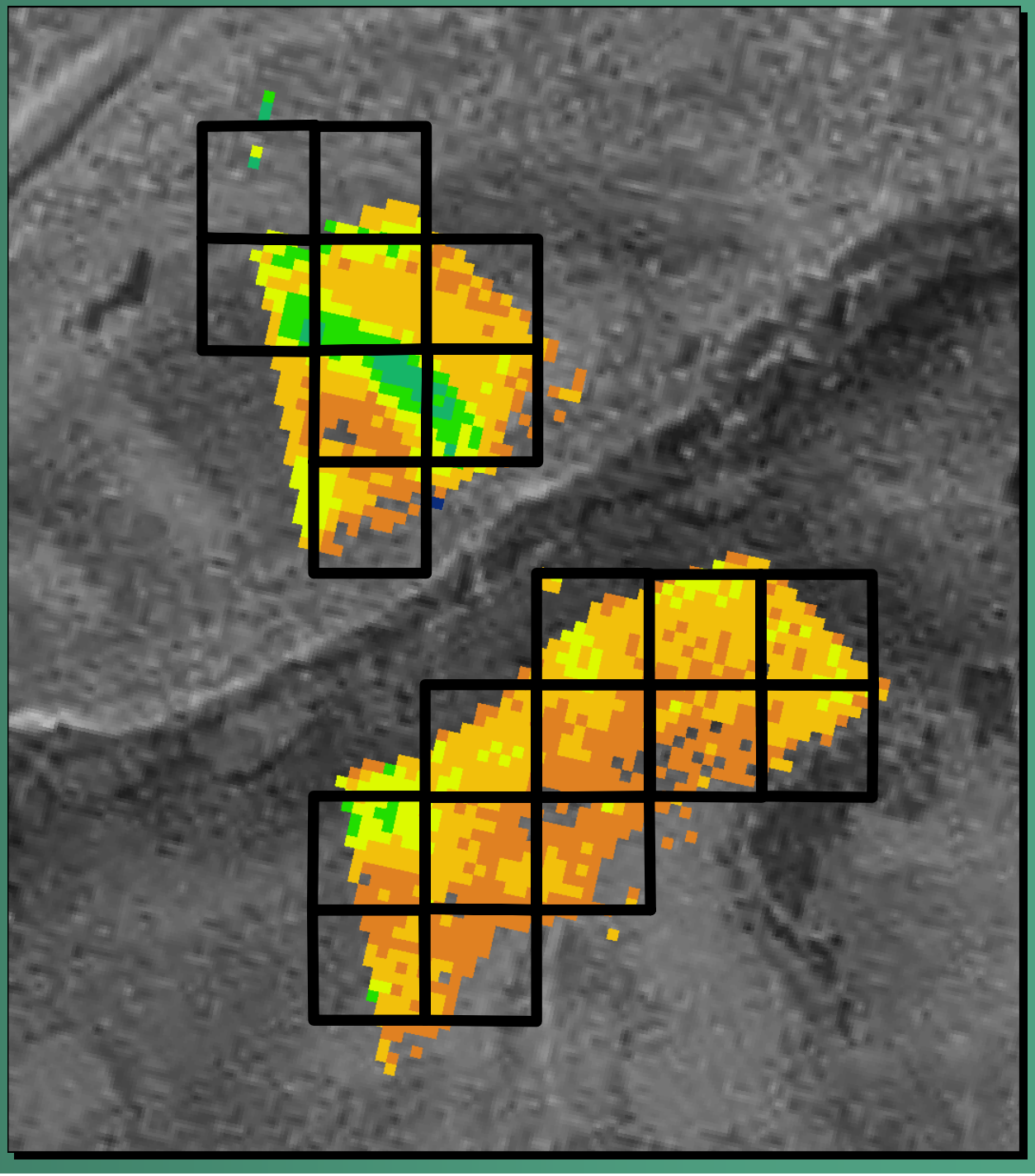


30-m DEM



Orthophotoquad

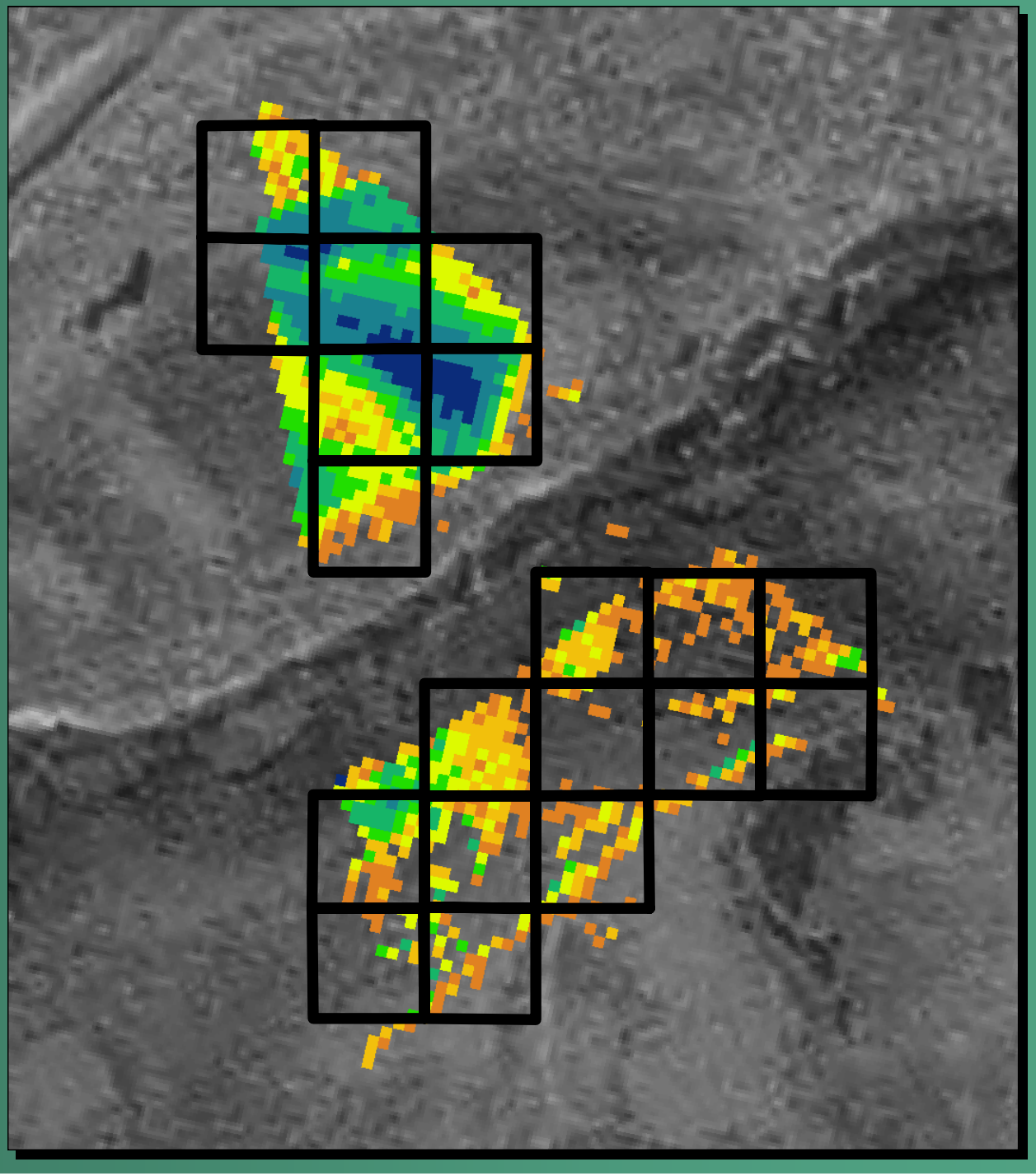
Jan. 10, 2008



Snow Water Equivalent (mm)

- 0 - 20
- 20 - 100
- 100 - 200
- 200 - 300
- 300 - 400
- 400 - 600
- 600 - 800
- 800 - 1,060

March 31, 2008



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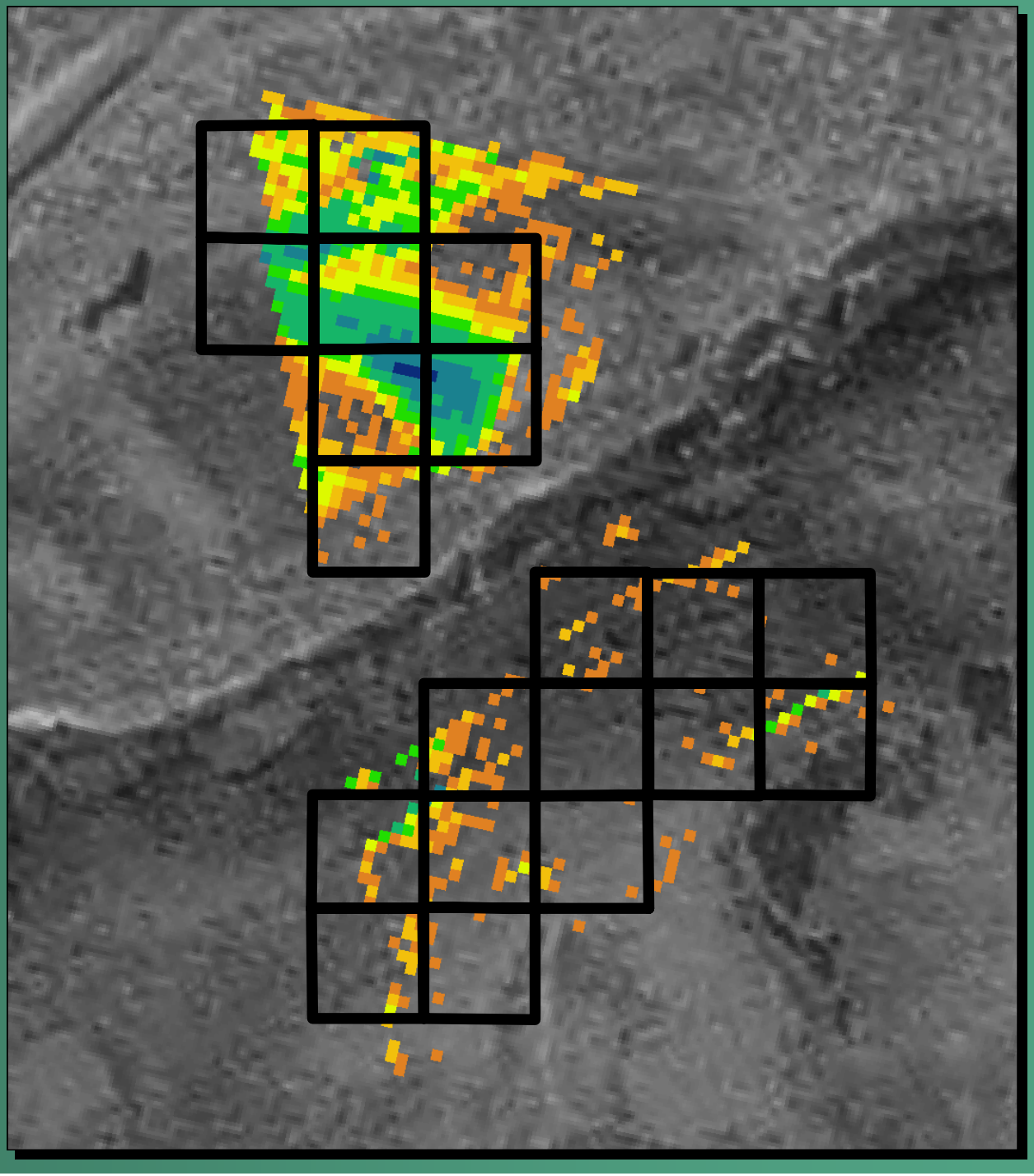
April 21, 2008



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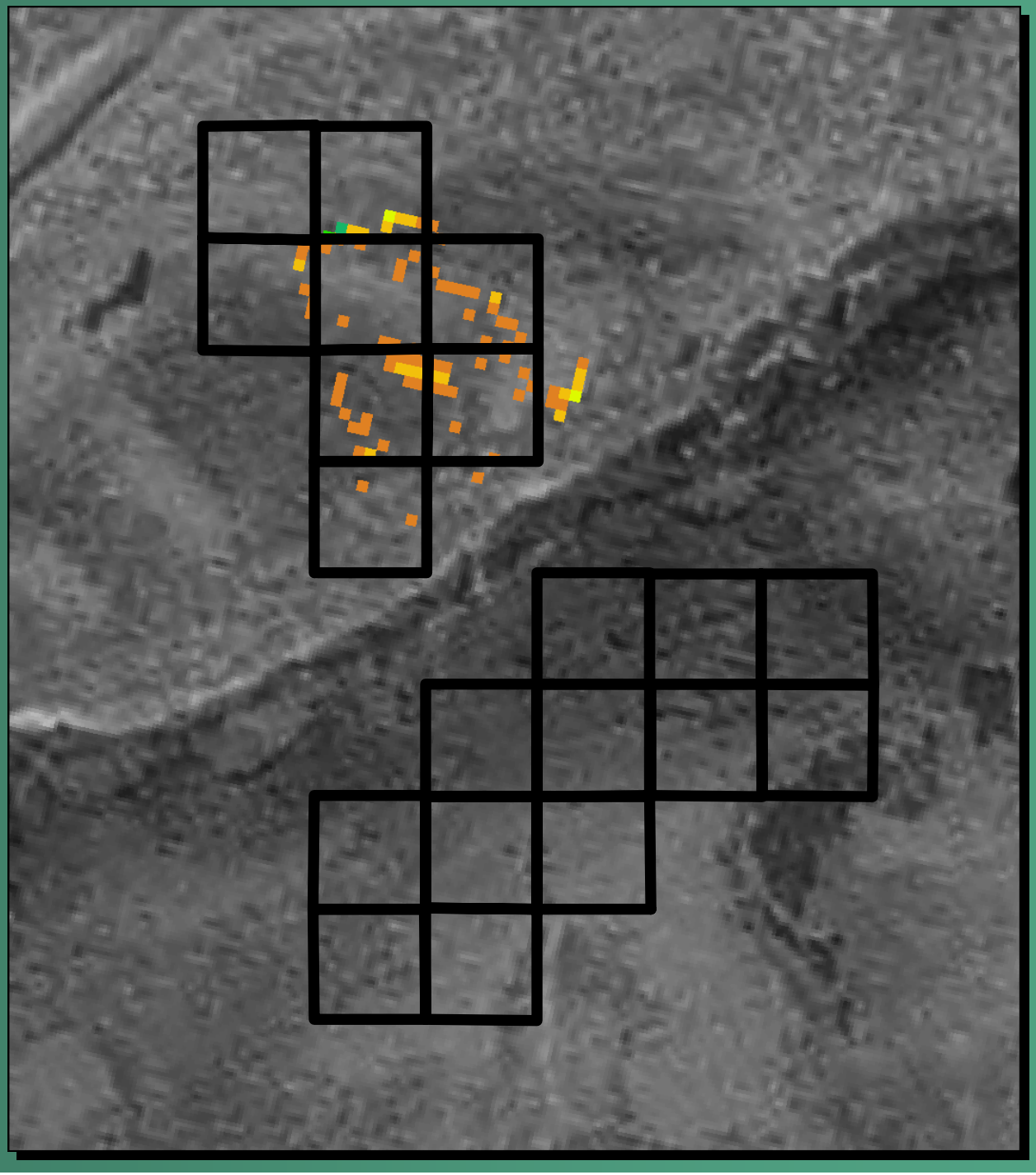
May 20, 2008



Snow Water Equivalent
(mm)

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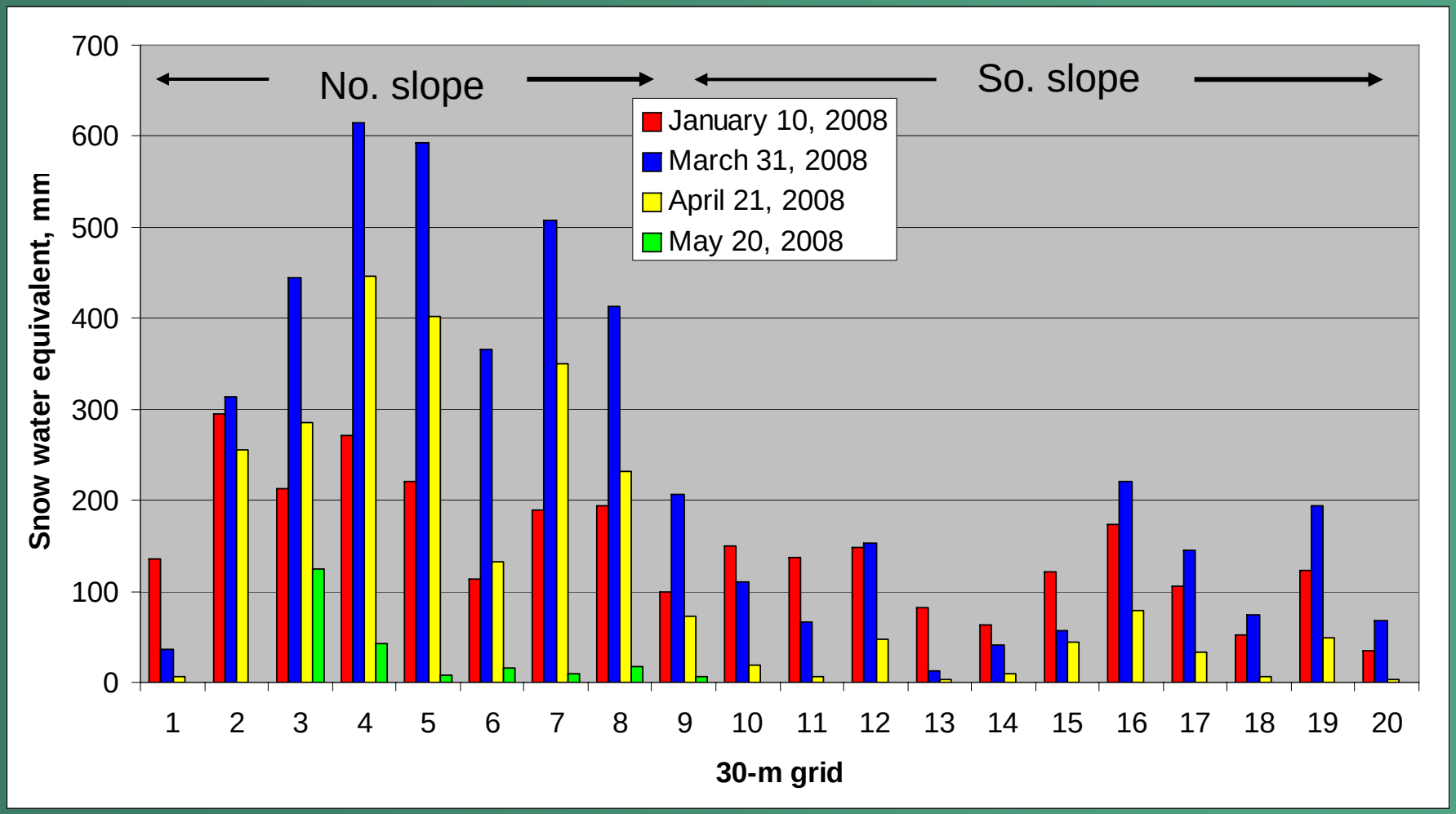
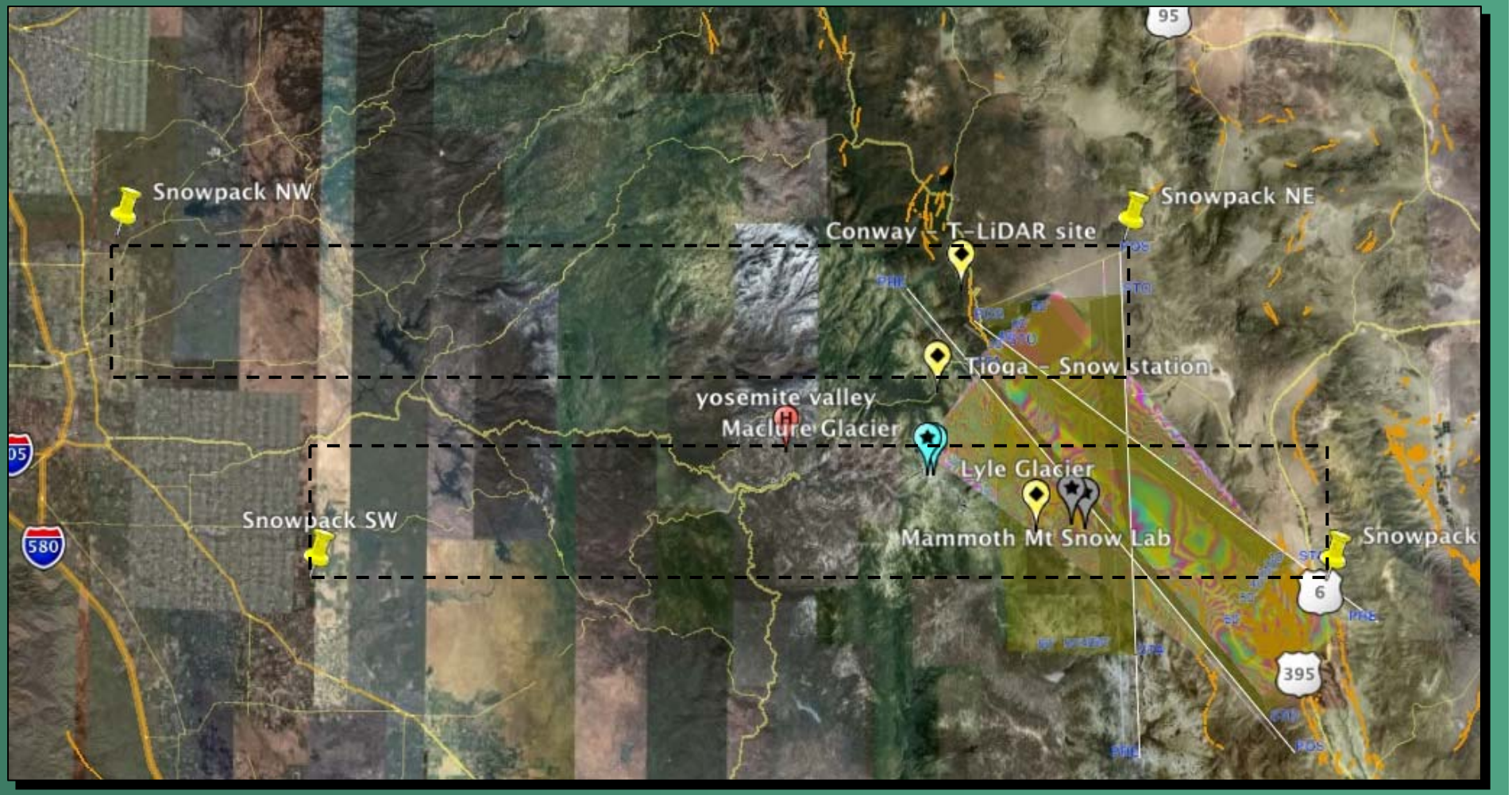
- 20 - 100
- 100 - 200
- 200 - 300
- 300 - 400
- 400 - 600
- 600 - 800
- 800 - 1,060

Mean SWE per 30-m grid cell



NASA JPL Plane-based InSAR

Proposed Pathlines for NASA UAVSAR Flights

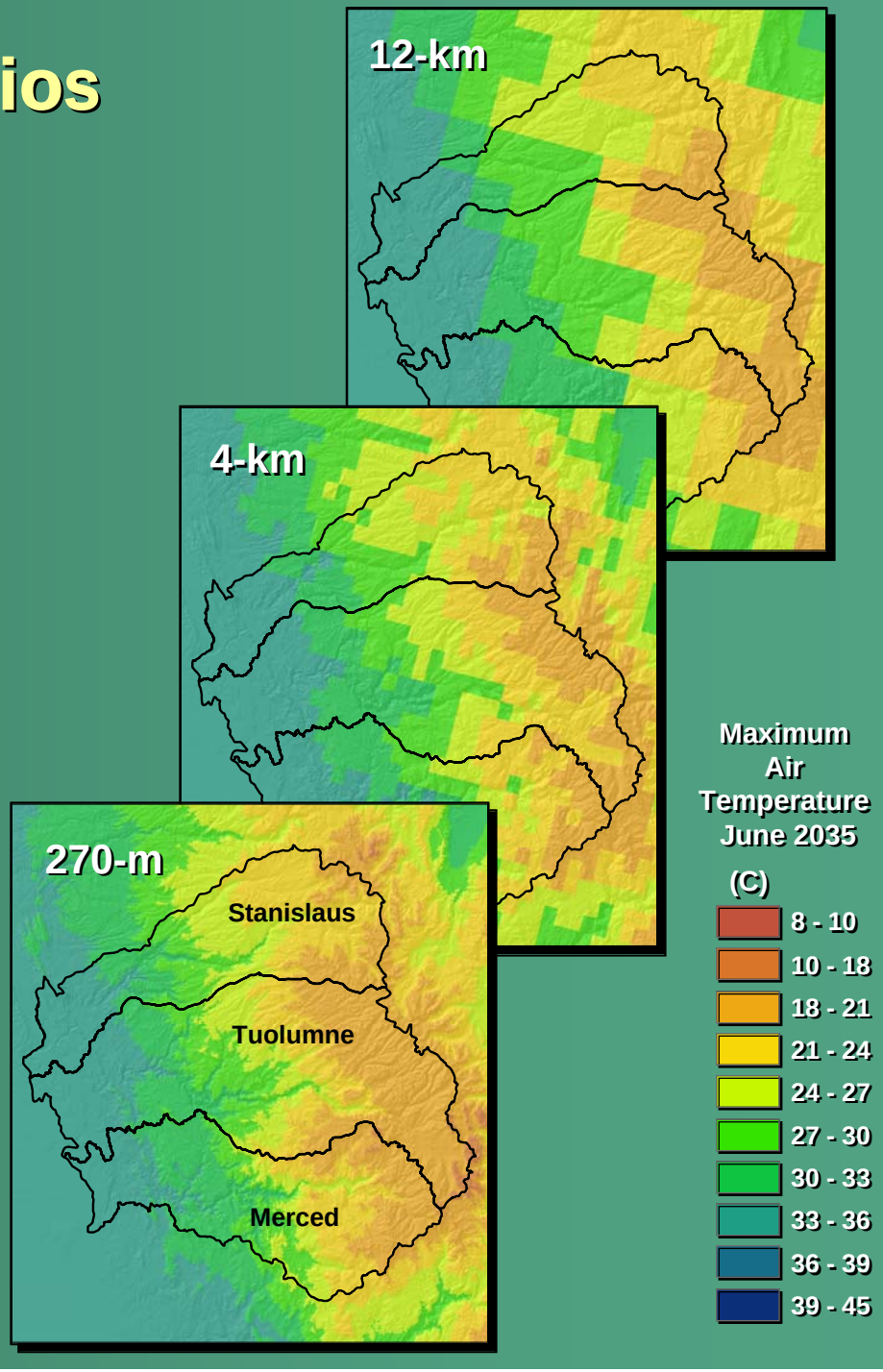


Testing the Soil/Snowmelt model using Climate Change Scenarios

- State of California is using four “families” of emission scenarios to investigate possible future climate changes
- IPCC Fourth climate assessment provides recent model simulations
- Geophysical Fluid Dynamics Lab (GFDL), and NCAR’s Parallel Climate Model (PCM)
  - A2: medium-high emissions
  - B1: low emissions

Climate Change Scenarios

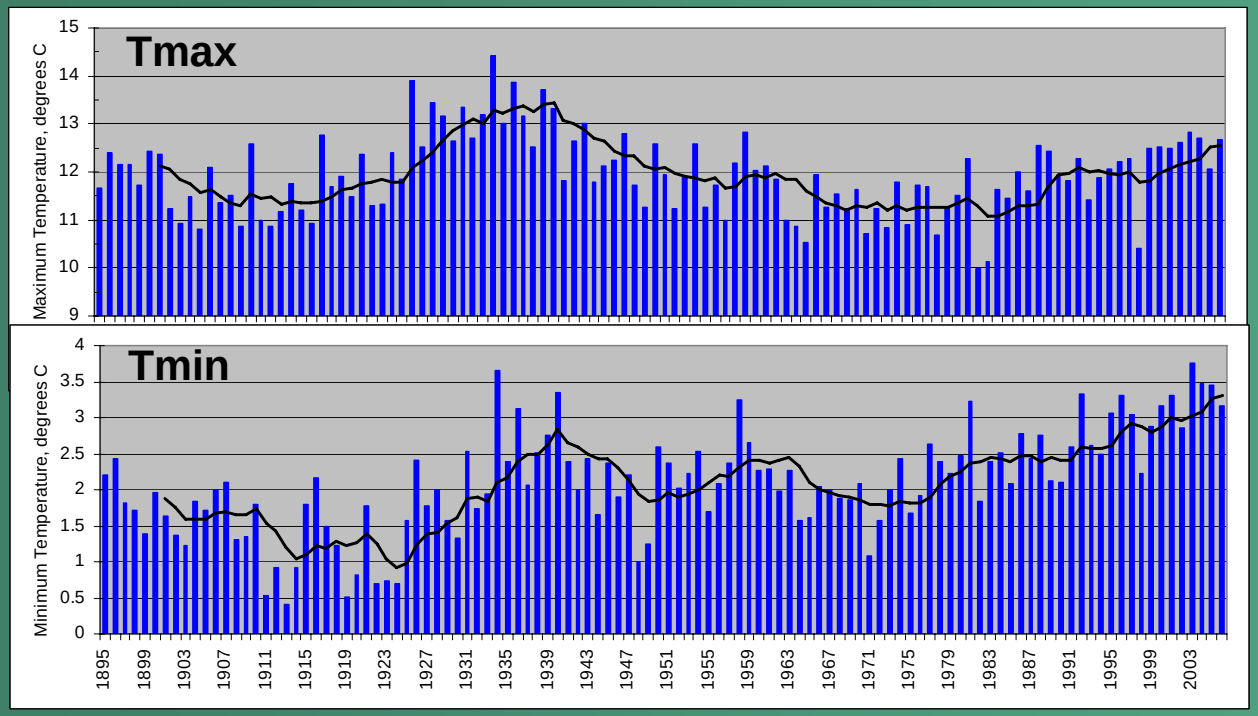
- Climate model data at 2.5 degree resolution were downscaled to 1/8 degree, 12-km using a constructed analogues method by Hidalgo et al. (2007)
- These data were further downscaled to 4-km using a gradient-inverse-distance-squared (GIDS) method
- Statistical transformation was used to ensure that the climate model and historical data have similar statistical properties: the mean and standard deviation of the measured1970-2000 period were used for corrections compared to the 1950-2000 modern climate model
- Data was further downscaled to 270-m using GIDS for model application



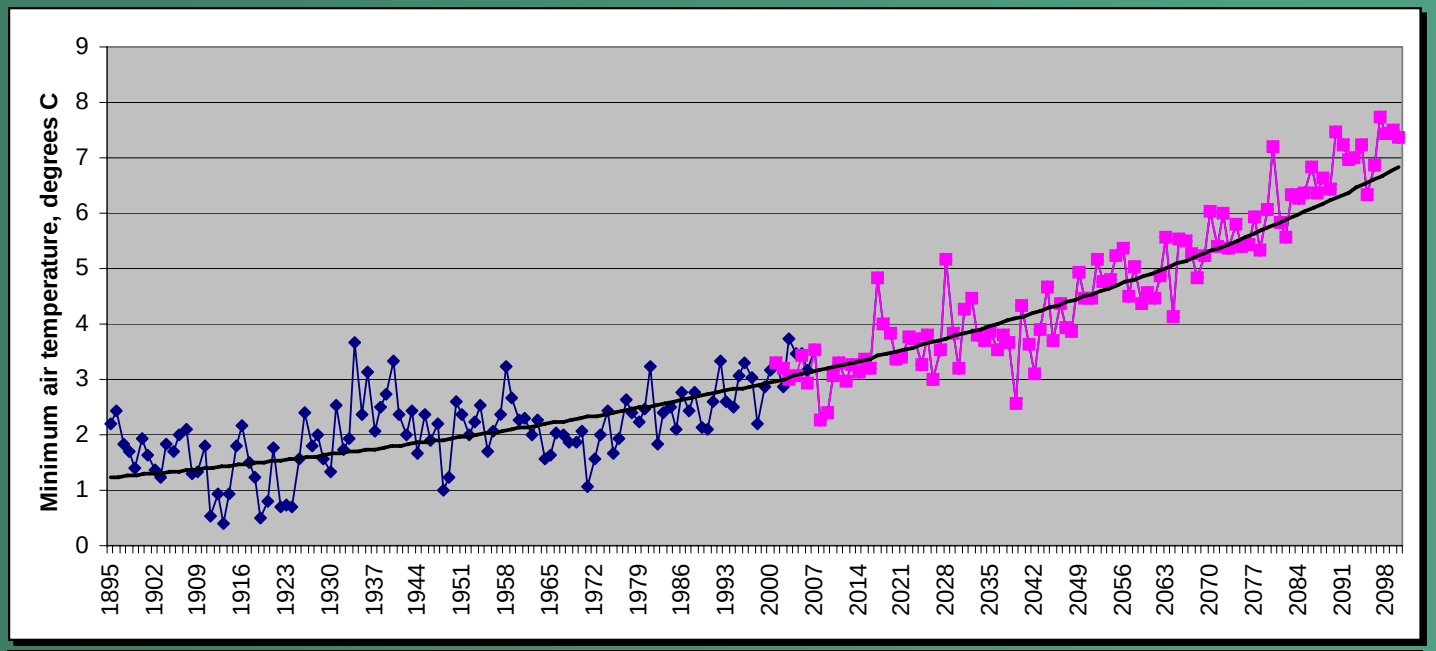
Climate Change Scenarios

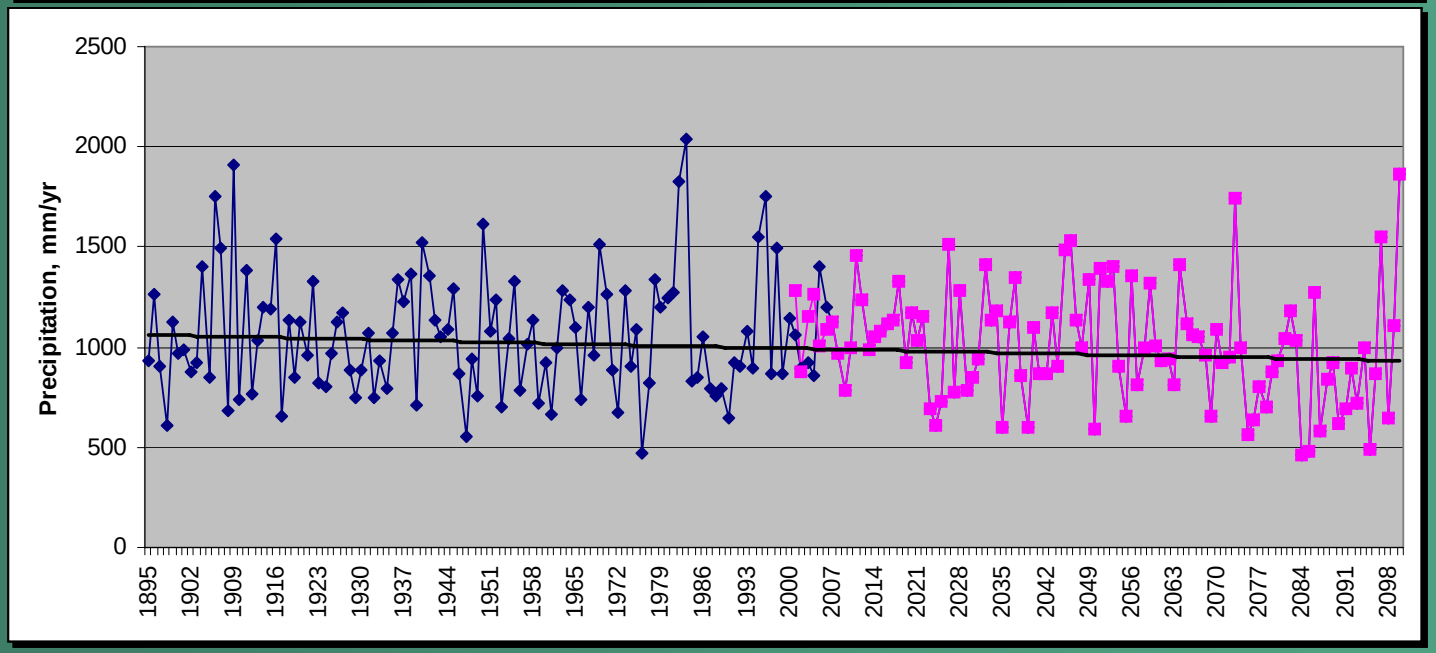
- Apply the daily downscaled maps of precipitation, minimum and maximum air temperature to the Sierra Nevada
  - Look for early spring snow melt
  - Look for increase spatial variability of snowmelt
  - Look for the occurrence of snow on dry soils
- Are the other significant issues that arise as a consequence of climate change that would cause us to re-evaluate our soil moisture/snow melt modeling?

Upper Tuolumne Basin

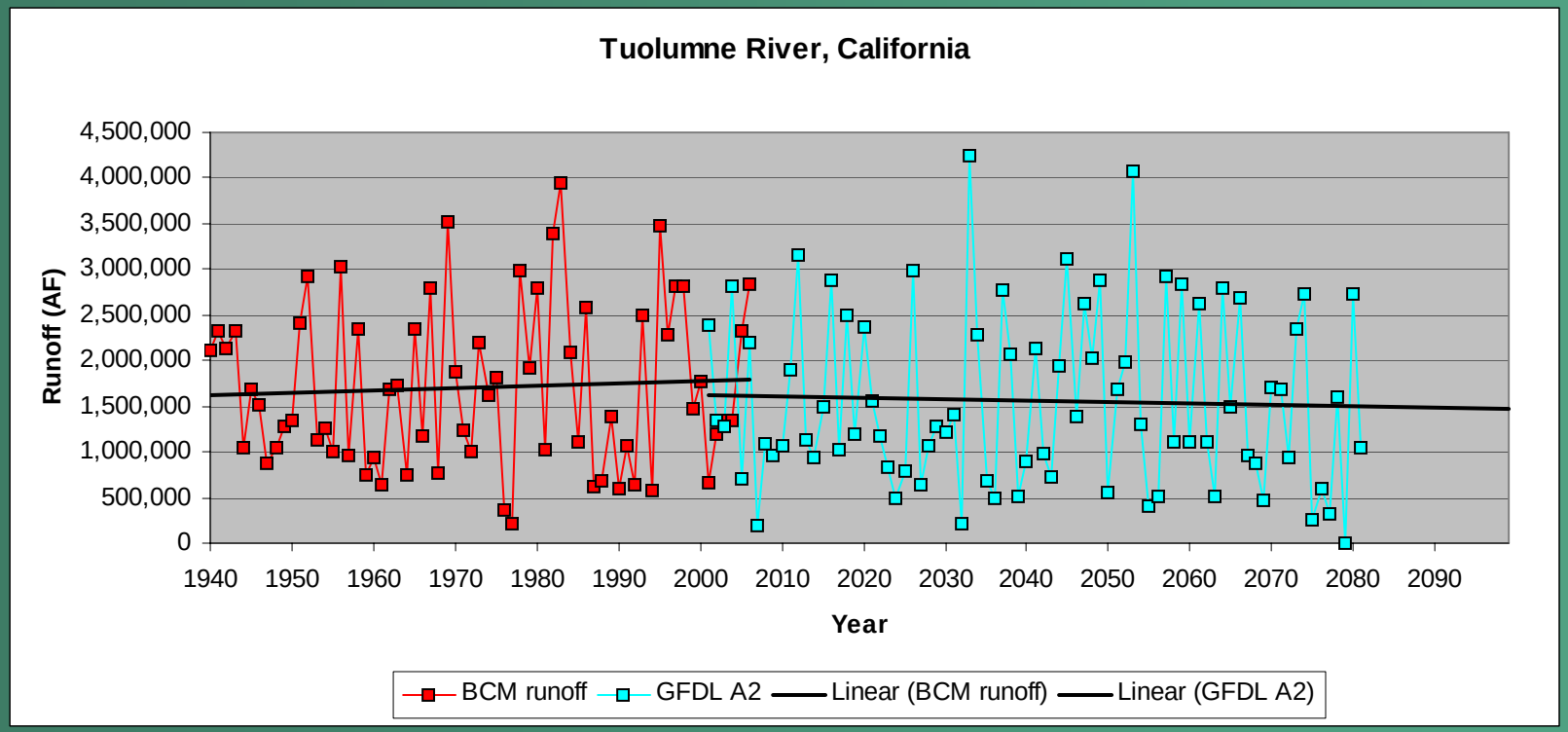


Upper Tuolumne Basin GFDL A2



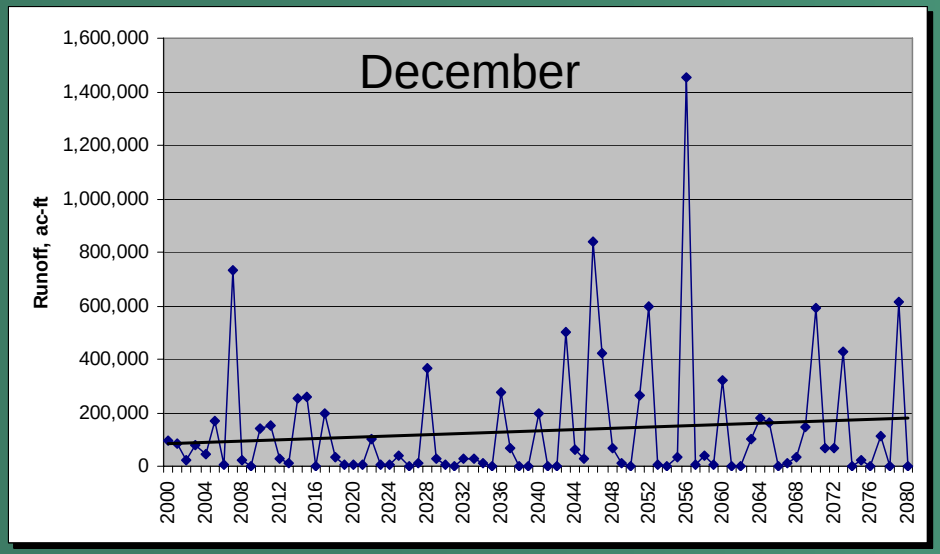


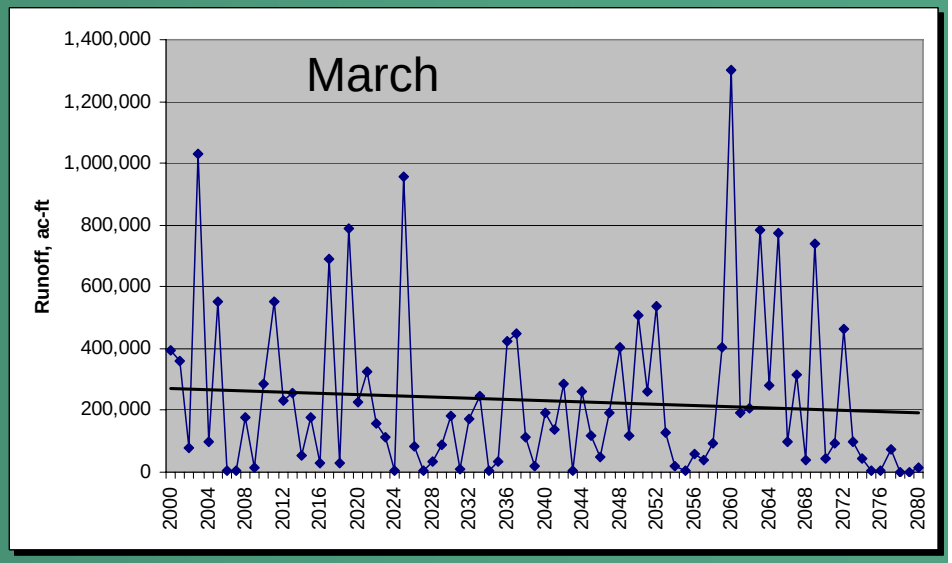
Upper Tuolumne Basin GFDL A2

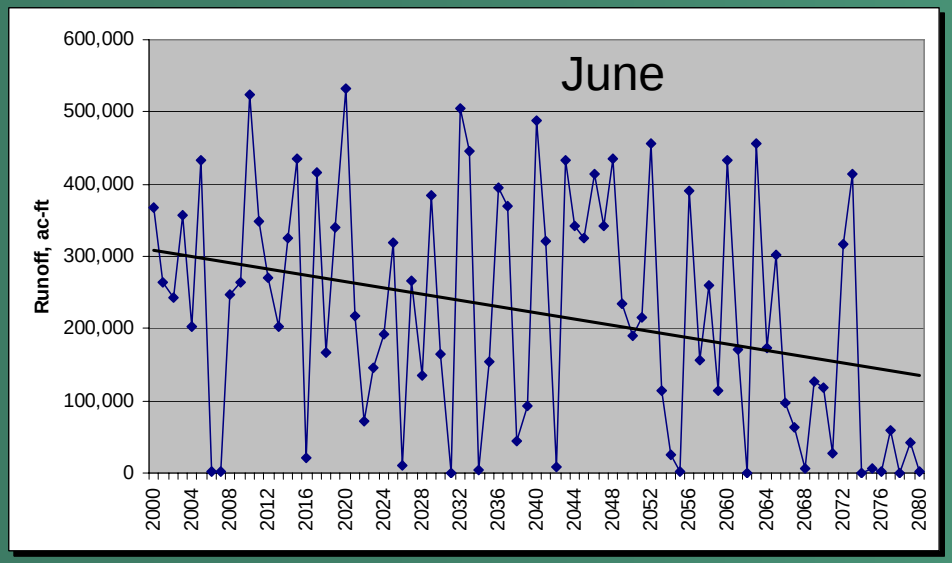


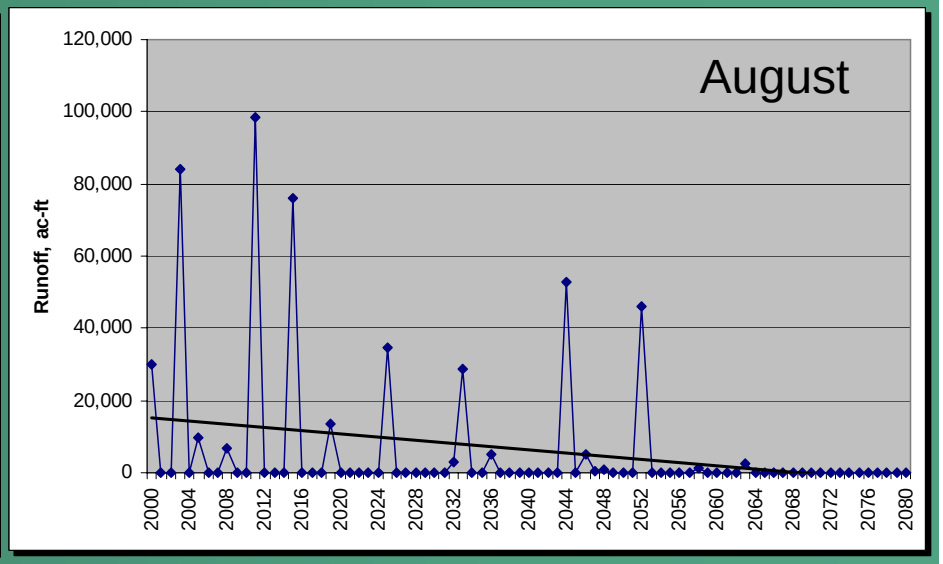
9% reduction in total runoff (not baseflow) between 2000-2040 and 2040-2080

Upper Tuolumne Basin









Summary

- Antecedent soil moisture may have a role in predicting spring runoff
  - Future climate model would suggest late fall rain rather than snow due to increased warming may reduce the significance of this issue
- Increased warming may lead to early snow melt making variable radiation loads contribute more to variable snow melt
- TLidar and UVASAR may provide a new way to do detailed snow melt surveys and high elevation/remote surveys
- Future climate change is here and testing our model and the hydrologic system will provide us insight and scenarios for management evaluation