A Comprehensive Snow Density Model for Integrating Lidar-Derived Snow Depth Data into Spatial Snow Modeling

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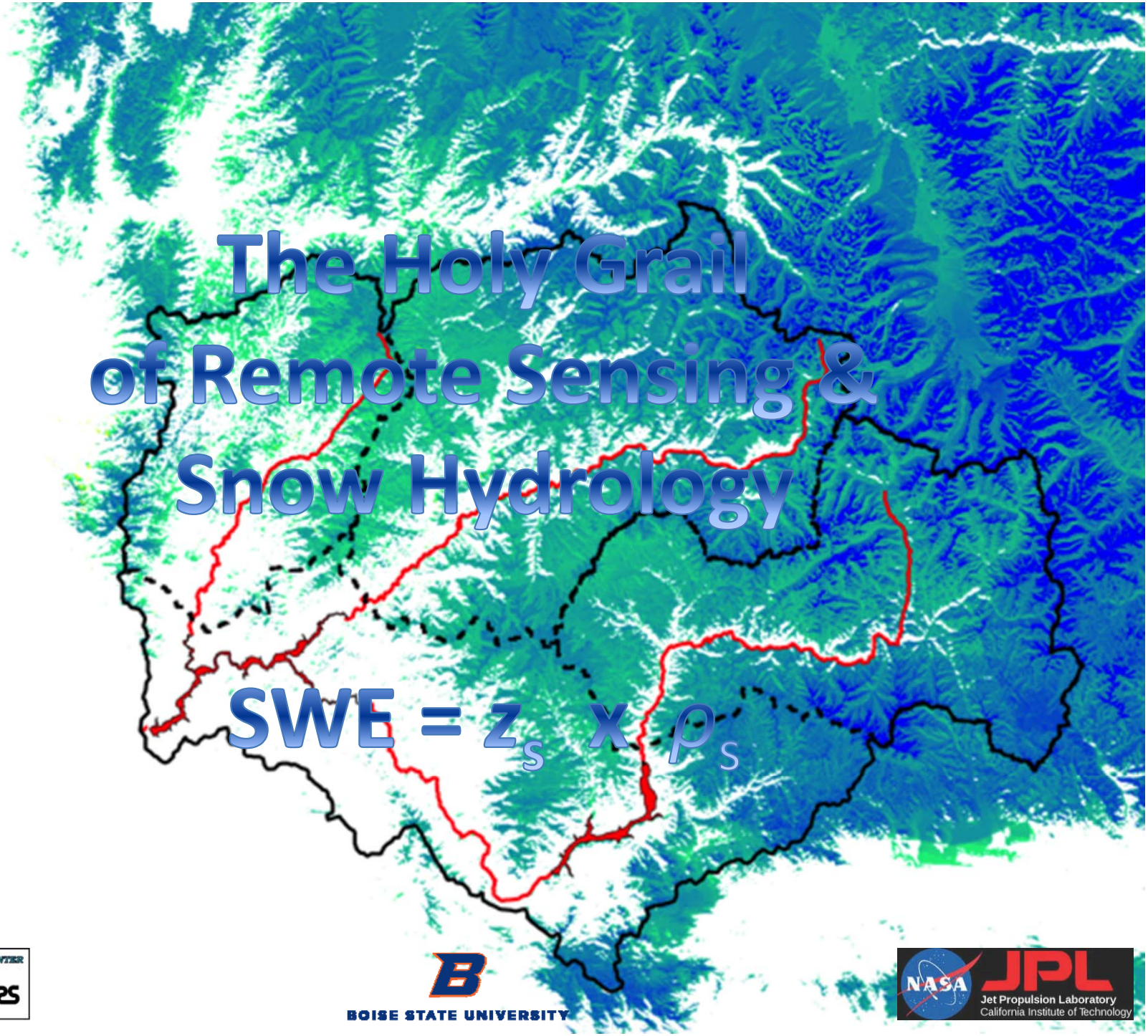

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Mechanisms that determine Snow Density:

0) Temperature and Humidity conditions during snowfall

1) Mechanical compaction due to wind)
2) Temperature aging
3) Overburden Pressure - Compaction due to Snow Load
4) Addition of Liquid Water due to Melt or Rain

Equations derived from experimental work done 50 years ago:

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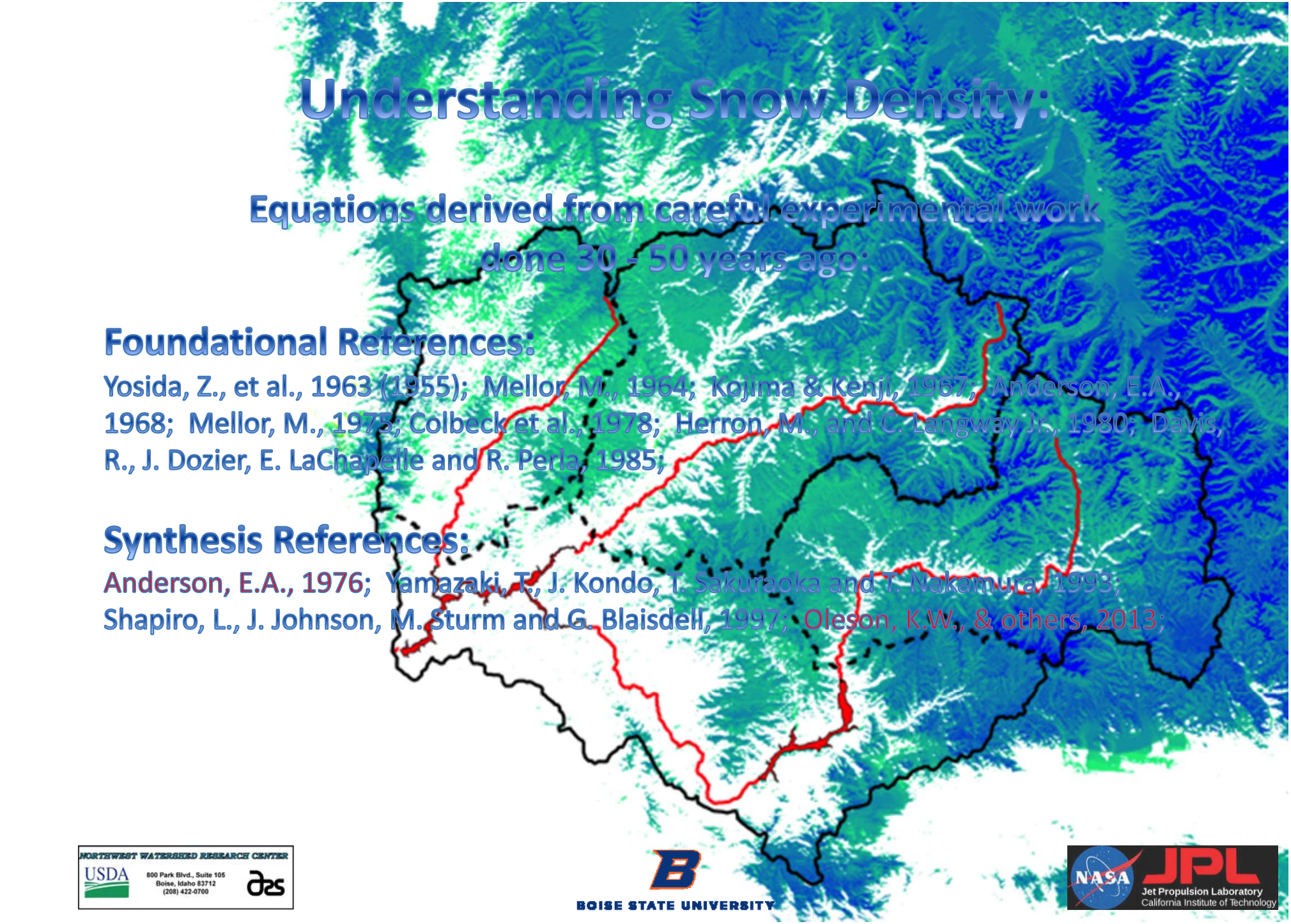

Understanding Snow Density:

Equations derived from careful experimental work done 30 - 50 years ago:

Foundational References:

Yosida, Z., et al., 1963 (1955); Mellor, M., 1964; Kojima & Kenji, 1967; Anderson, E.A., 1968; Mellor, M., 1975; Colbeck et al., 1978; Herron, M., and C. Langway, Jr., 1980; Davis, R., J. Dozier, E. LaChapelle and R. Perla, 1985;

Synthesis References:

Anderson, E.A., 1976; Yamazaki, T., J. Kondo, I. Sakuraoka and T. Nakamura, 1993; Shapiro, L., J. Johnson, M. Sturm and G. Blaisdell, 1997; Oleson, K.W., & others, 2013;

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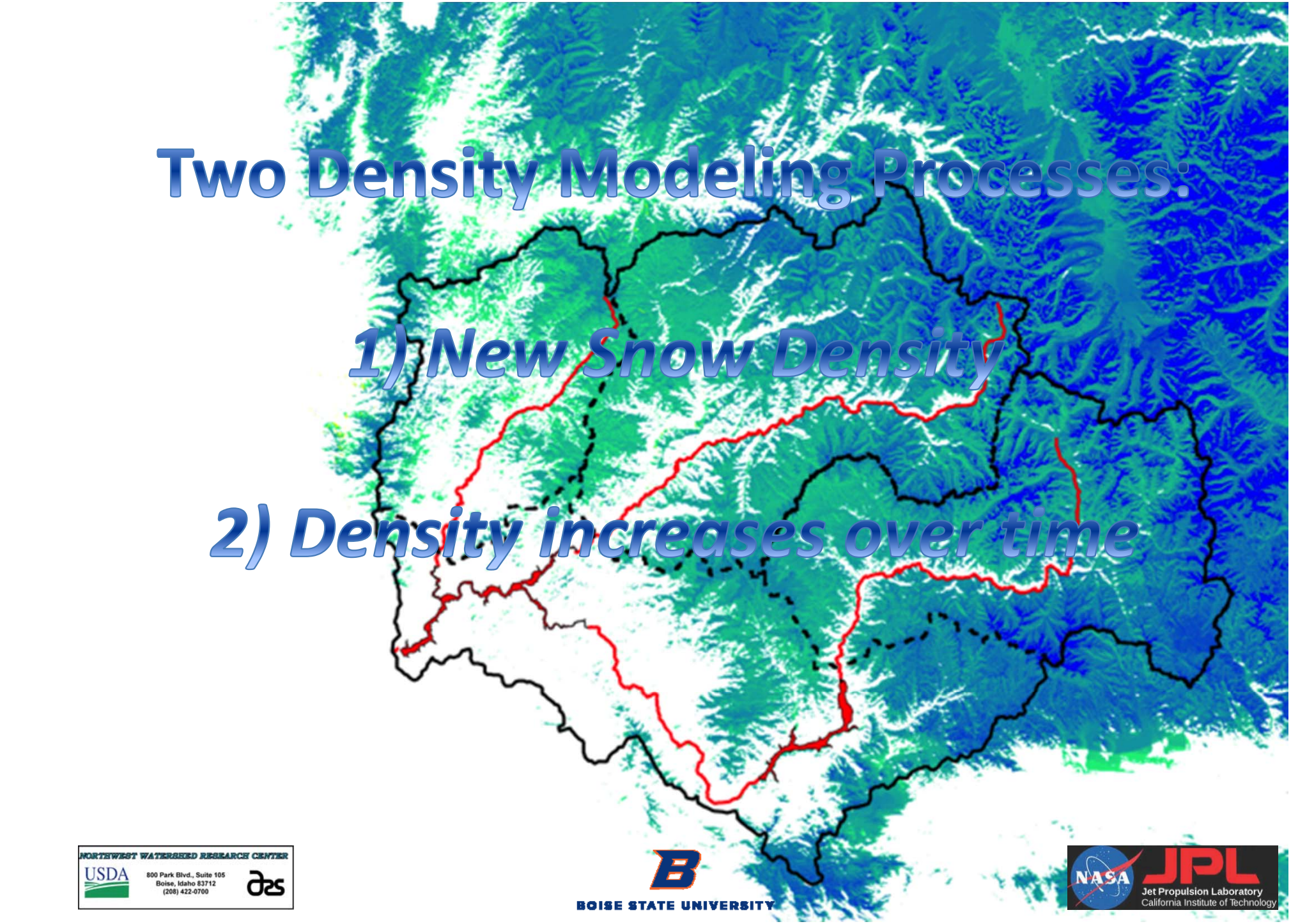

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Natures Gift to Science:

Oroville Dam Spillway, March 3, 2017

Shasta Lake, 2014 & 2015

Upper San Joaquin, March 17, 2017

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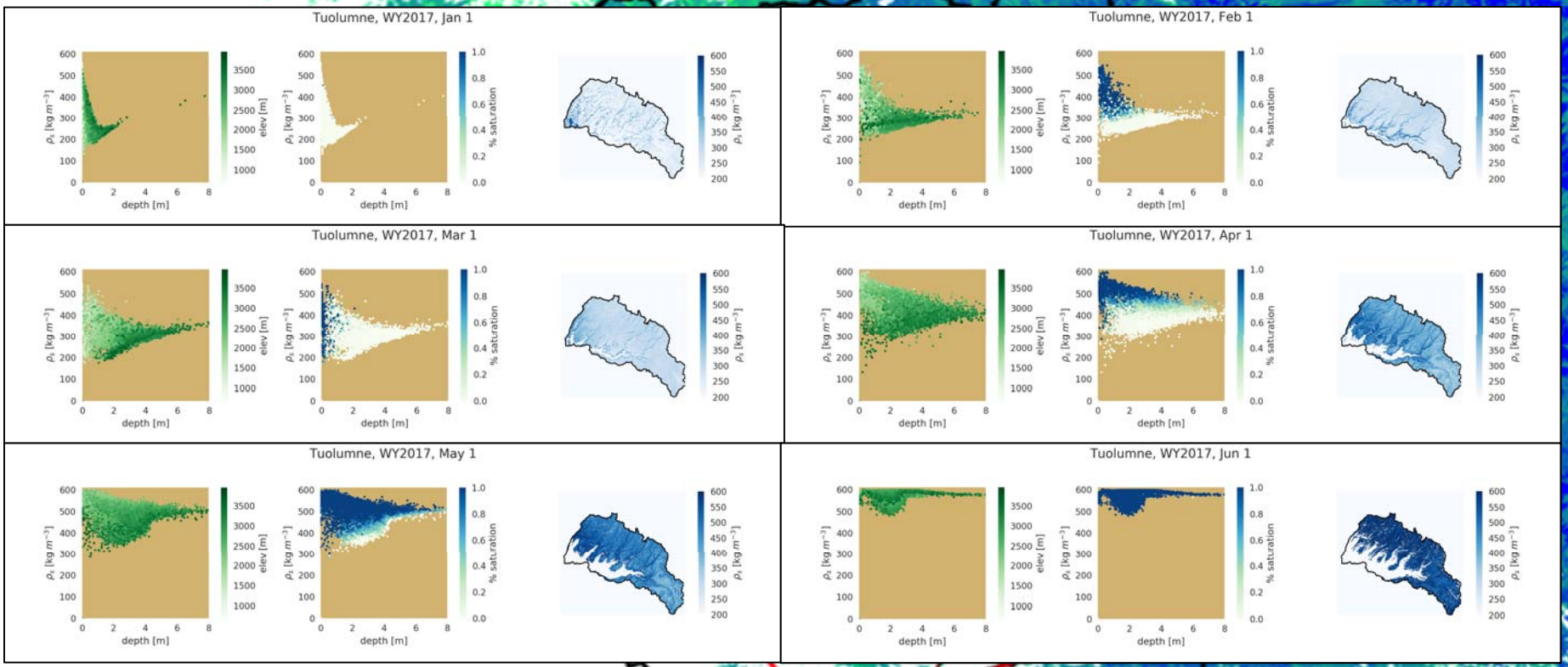
Model Behavior:
Tuolumne River Basin, 50m Resolution, 2017 Snow Season

ρ_s vs z_s & Elevation | ρ_s vs z_s & Liquid Water | Basin ρ_s Distribution | ρ_s vs z_s & Elevation | ρ_s vs z_s & Liquid Water | Basin ρ_s Distribution



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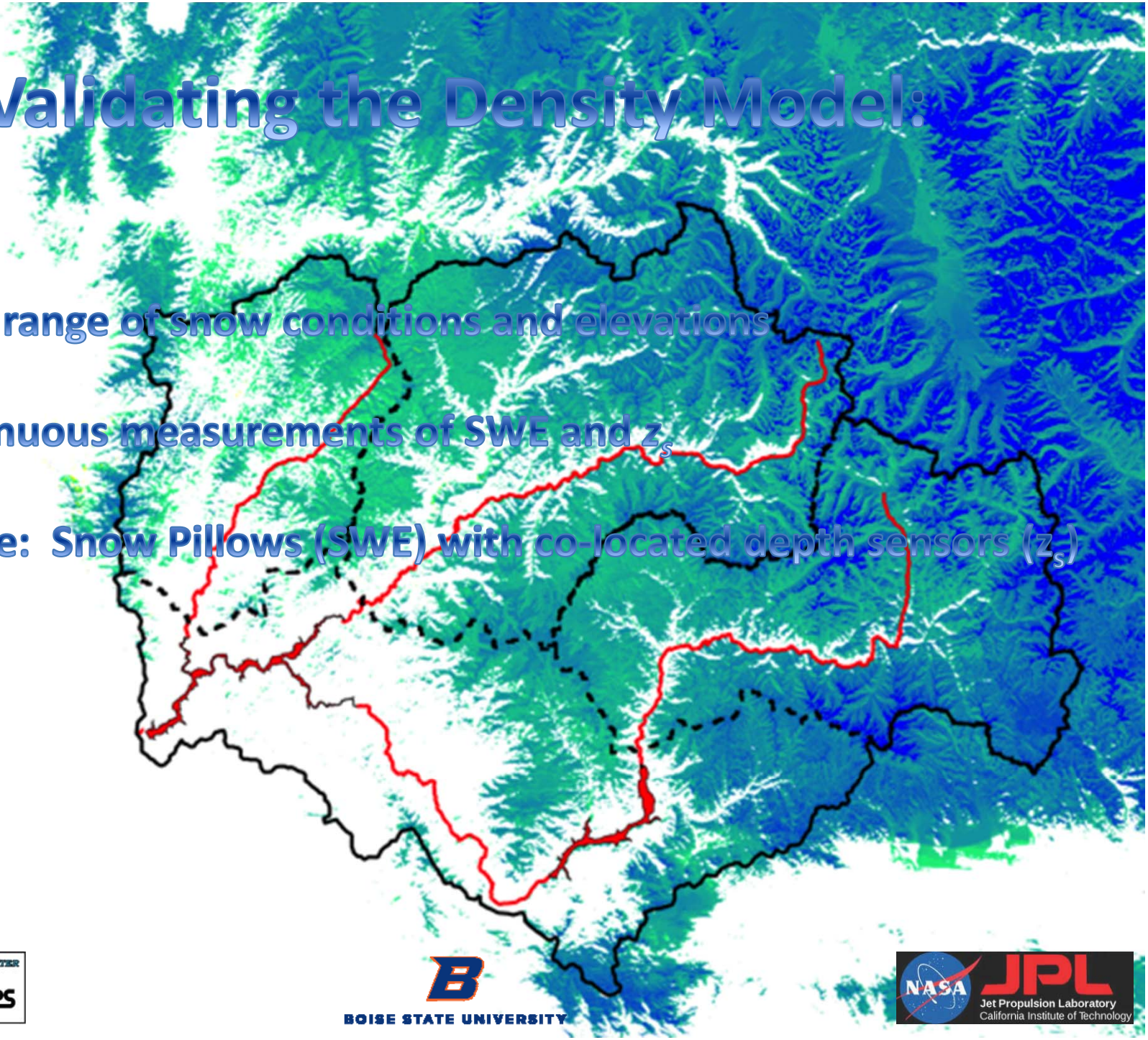
Validating the Density Model:

1) Need range of snow conditions and elevations

2) Continuous measurements of SWE and z_s

Desirable: Snow Pillows (SWE) with co-located depth sensors (z_s)



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Reynolds Creek Experimental Watershed, Idaho:

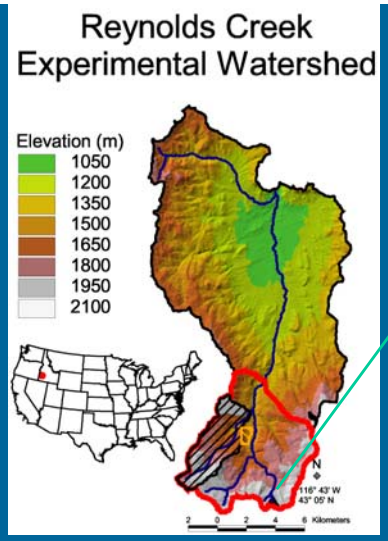
1 Pillow site, (2067 m) WY2009

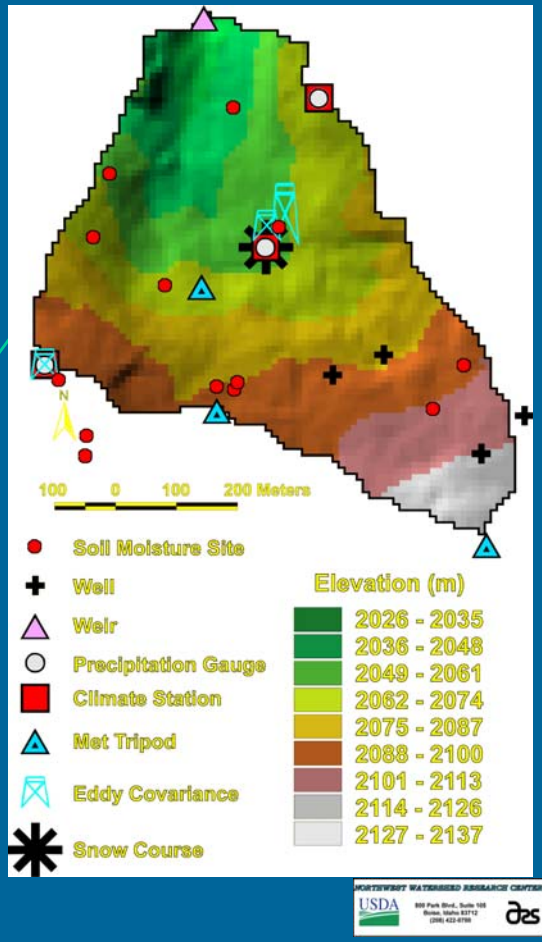
Coordinated Lidar, Radar, field survey & snow course

Reynolds Mountain East:

0.38 km^2, 118m relief

- Primary Snow Research Basin
- HEAVILY! Instrumented
  - 7 climate & EB, 3 precipitation stations
  - 6 GW wells, 12 SM sites, 3 soil profile sites
  - 3 EC systems
- Intensive Snow Surveys 2000 - 2007
- Model Testing and Development Site





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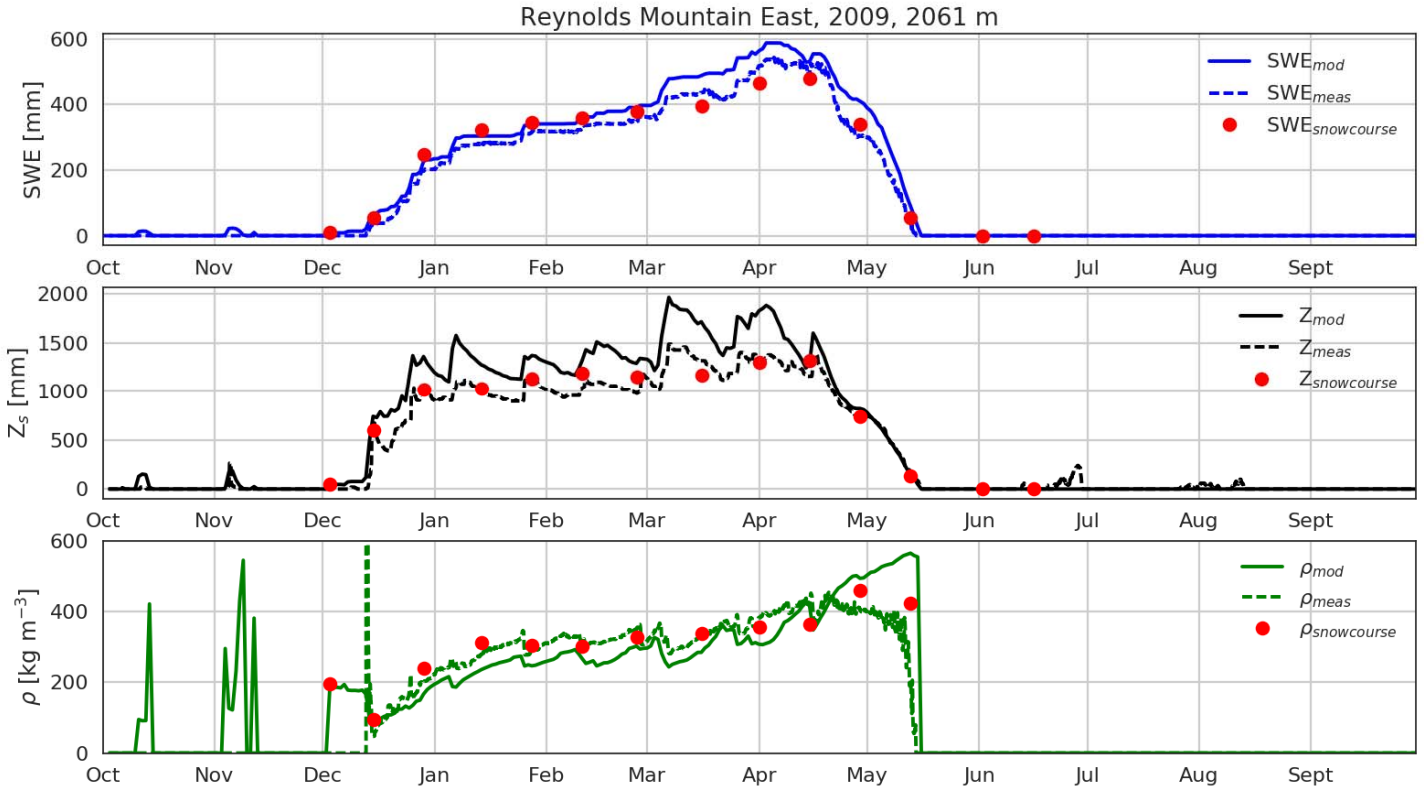
Reynolds Mtn East, 2009 Snow Season:

measured & modeled depth, SWE, density, temperature and liquid water



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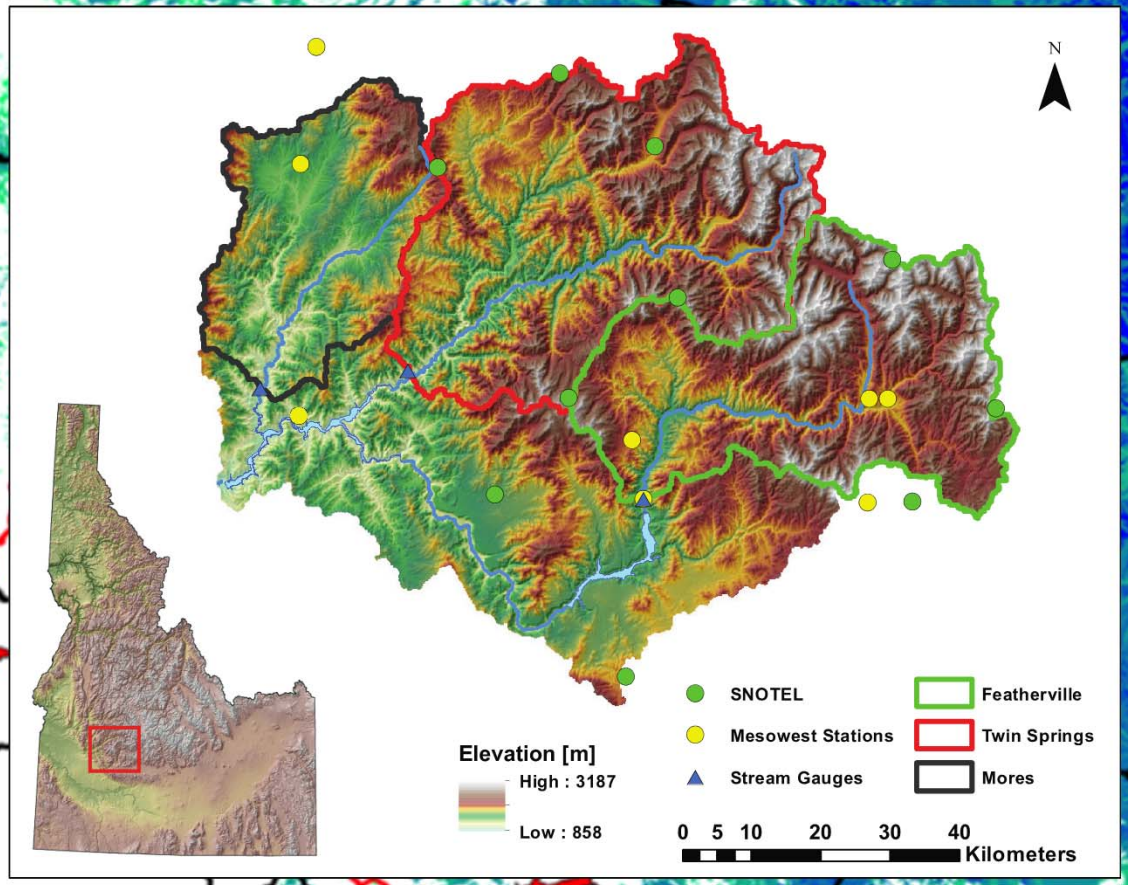
Boise River Basin (7,000 km^2), Idaho:

14 SNOTEL sites,
WY2017
1400 – 2600m

co-located pillow and depth sensor



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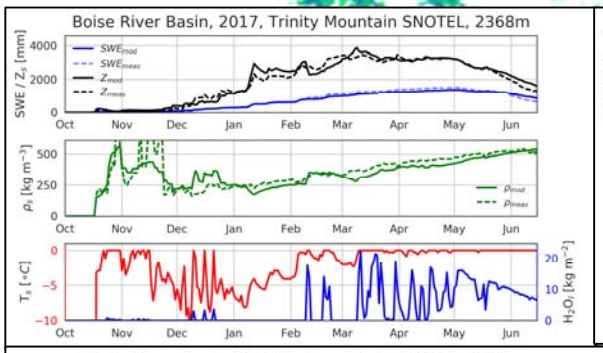
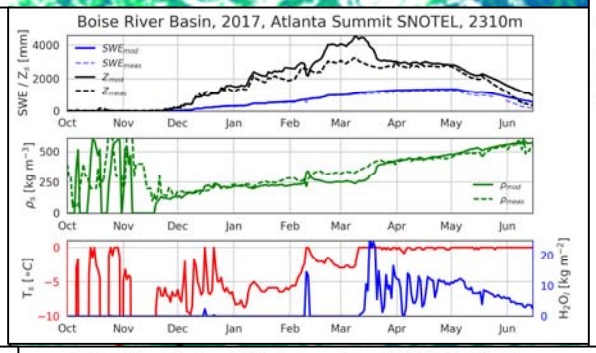
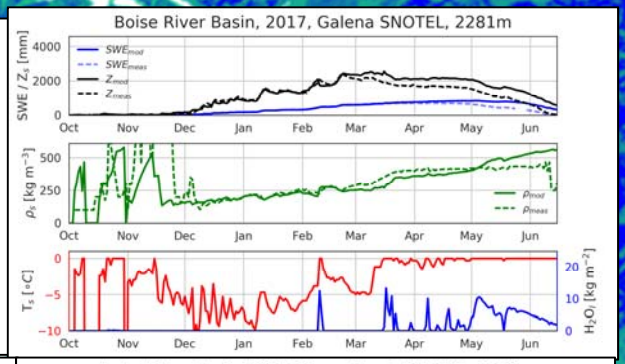
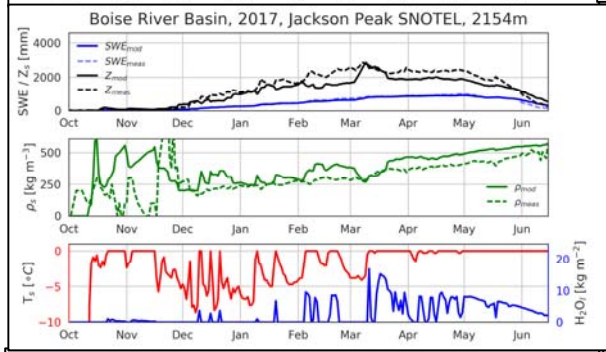
Boise River Basin, 2017 Snow Season:

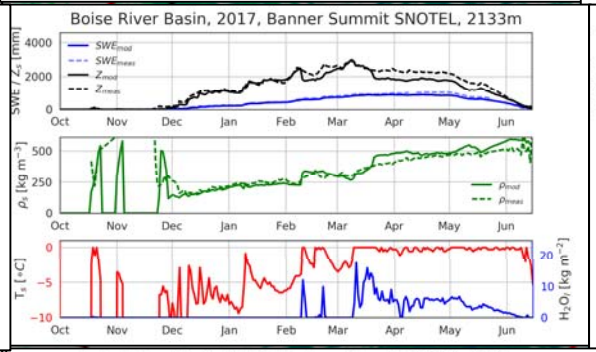
measured & modeled depth, SWE, density, temperature and liquid water

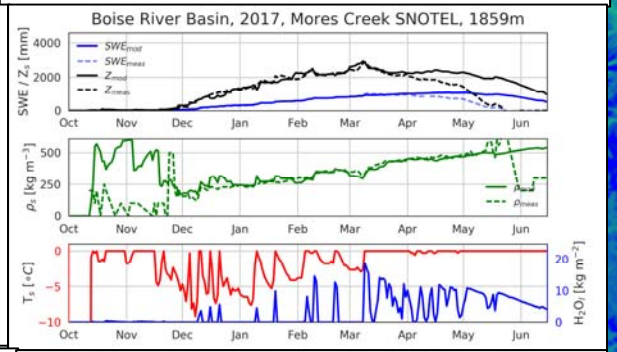


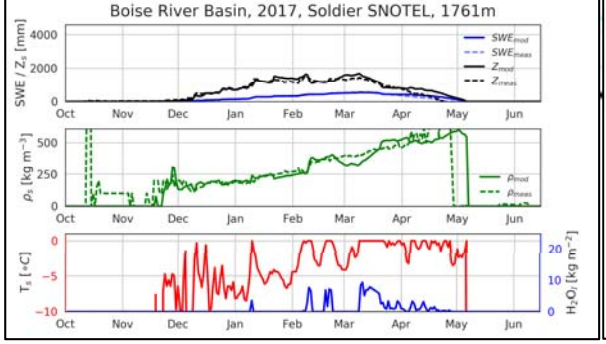


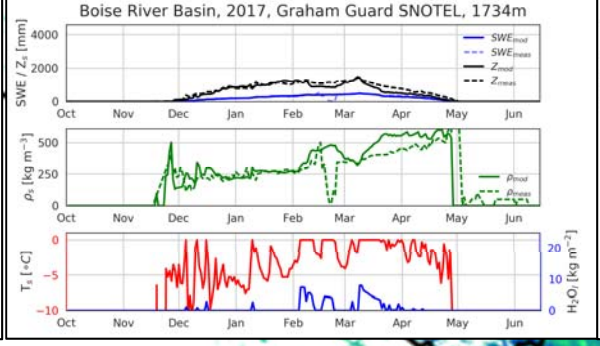


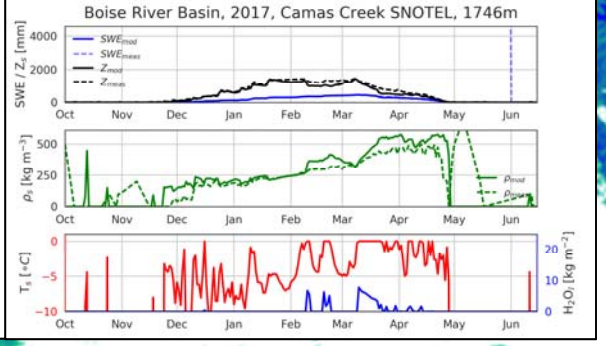












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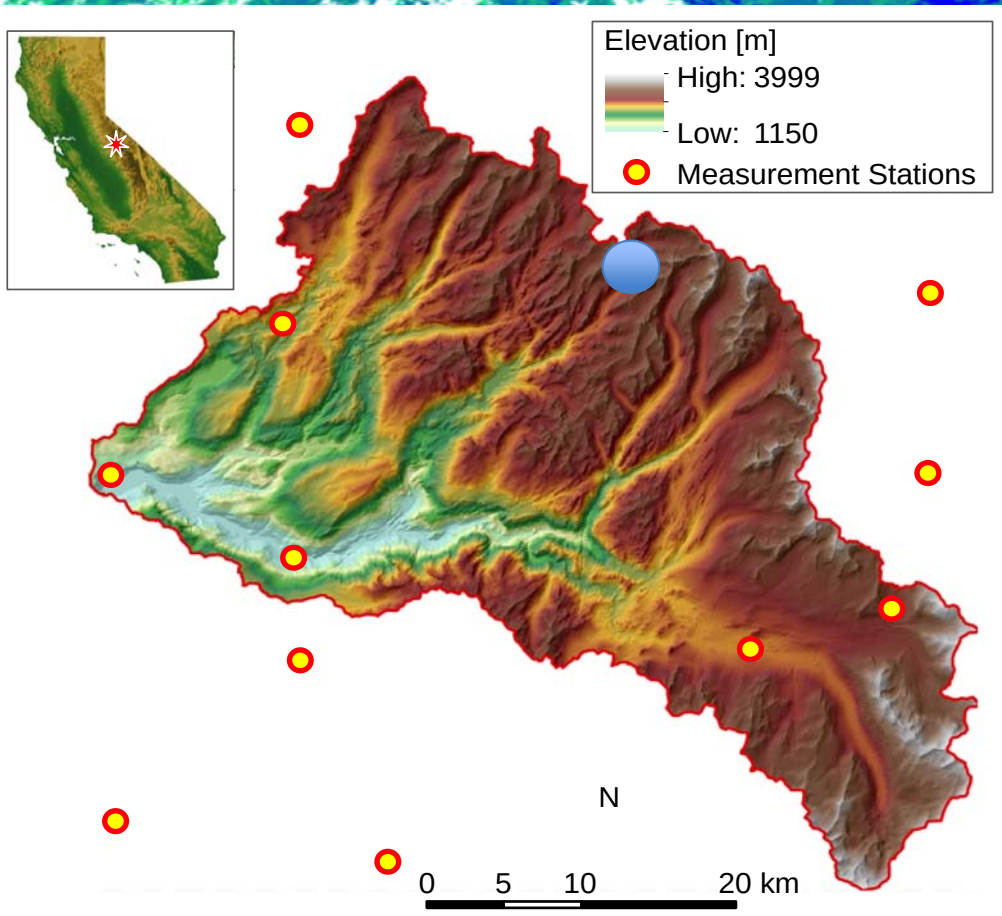
Tuolumne River Basin (1184 km^2), Southern Sierra Nevada, California, USA

1 Pillow site:
Slide Mtn (2804)
WY2017

Only functional site with co-located pillow & depth sensor



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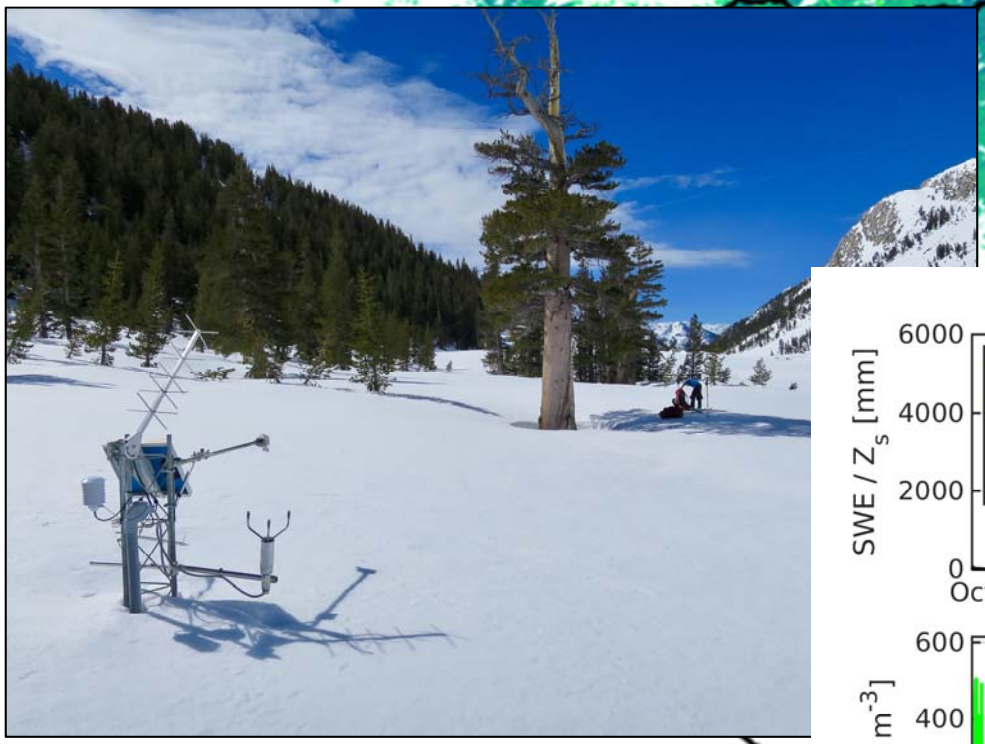
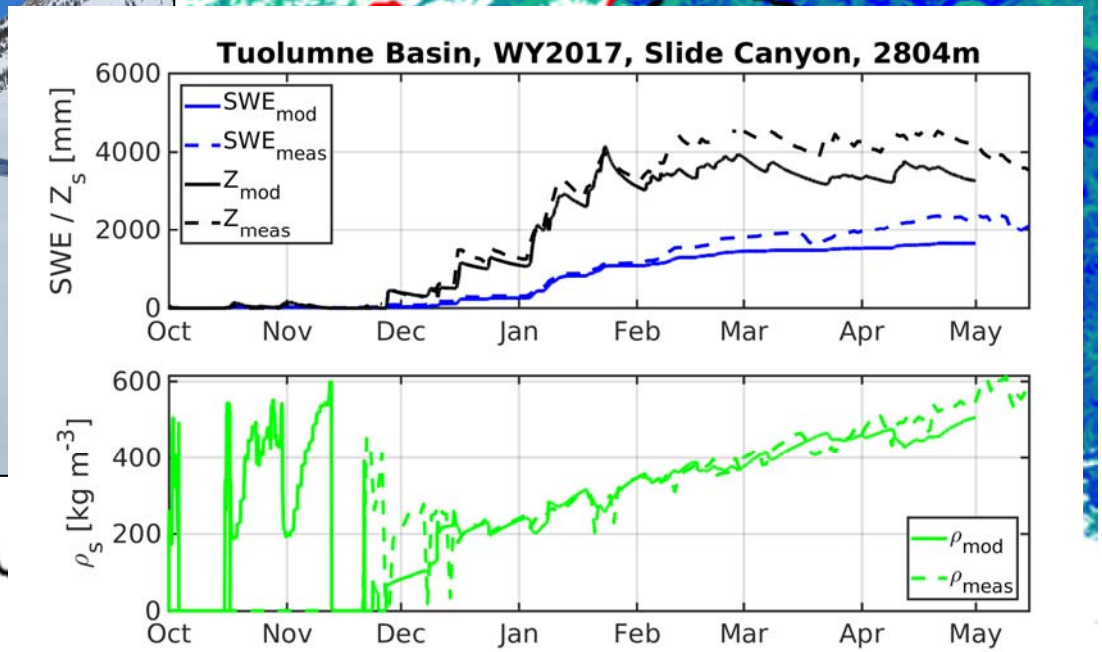
Tuolumne, Slide Canyon Site, 2017 Snow Season:

measured & modeled depth, SWE, density





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