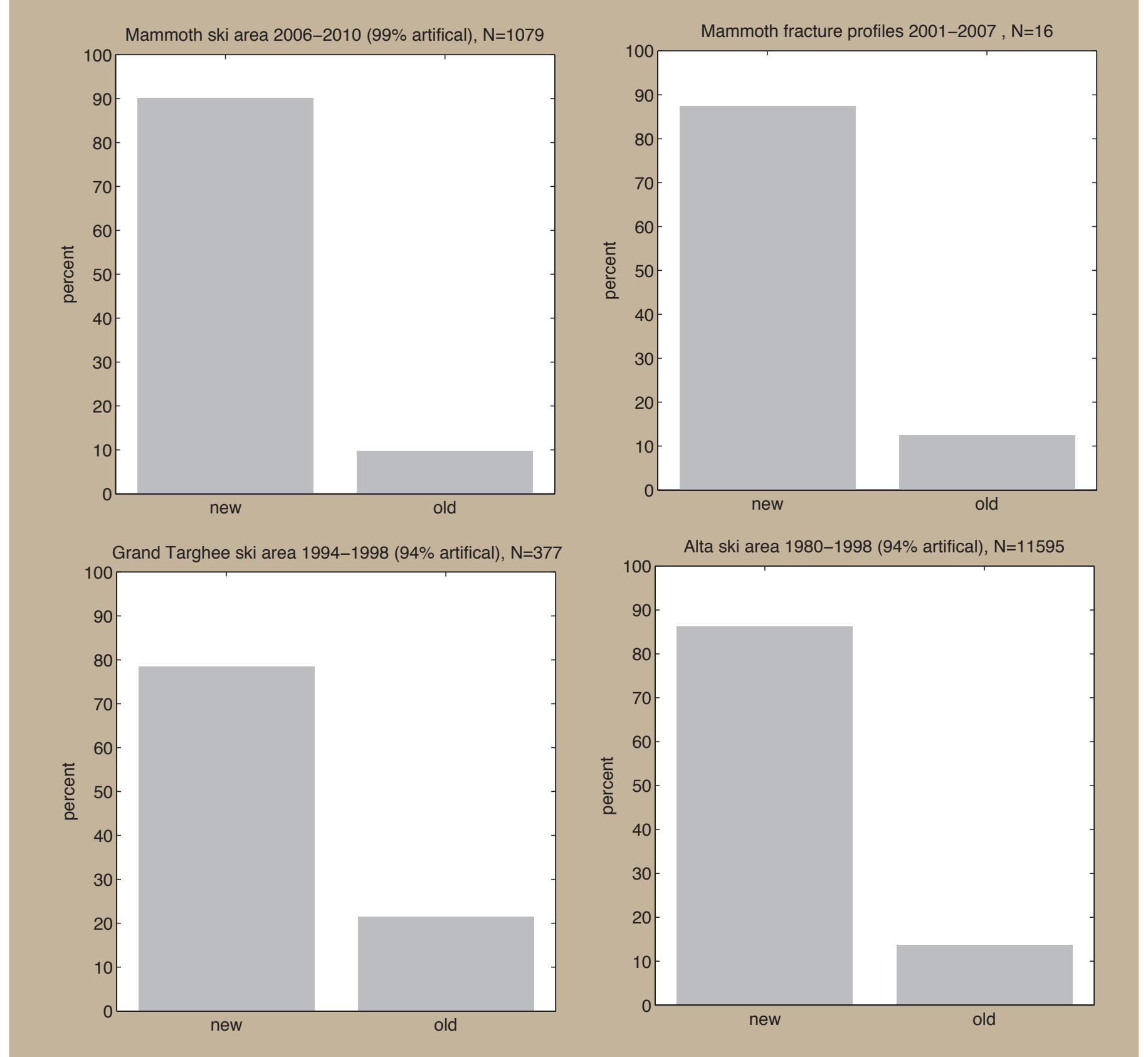
Using near infrared photography to link spatial patterns in stratigraphy with stability

Edward Bair
Donald Bren School of Environental Science and Management, Univeristy of California - Santa Barbara
US Army Corps of Engineers Cold Regions Research and Engineering Laboratory

This work is supported by: NSF Hydrological Sciences award#1015057, a US Army Corps of Engineers CRREL/ORAU student fellowship, and the following organizations:

Percentages of slabs with old snow

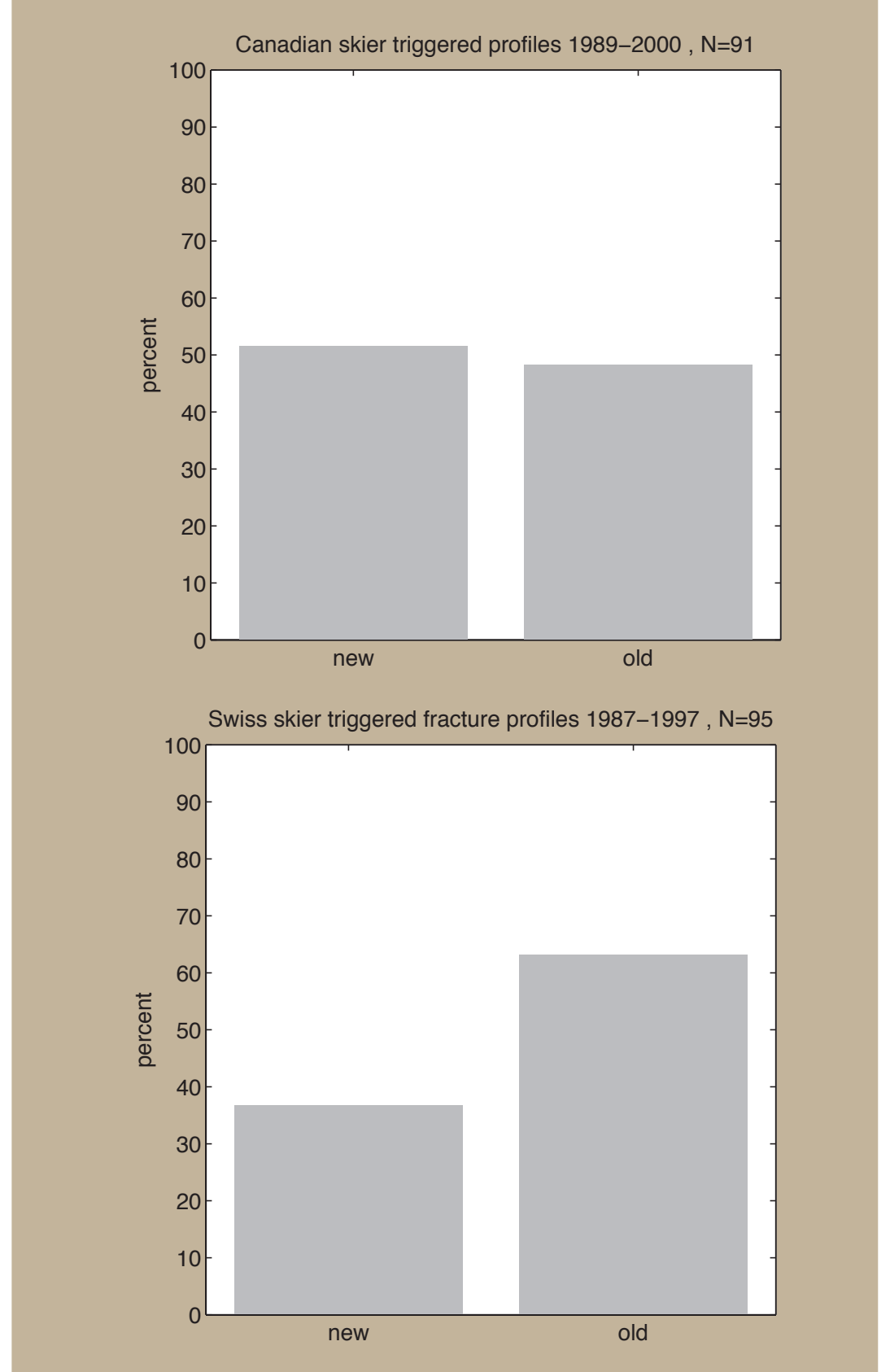
Ski areas (≥ Class 2)
(94-99 percent new snow)



Non-persistent weak layers dominate

Source: Westwide Avalanche Network and Mammoth Mountain Ski Patrol

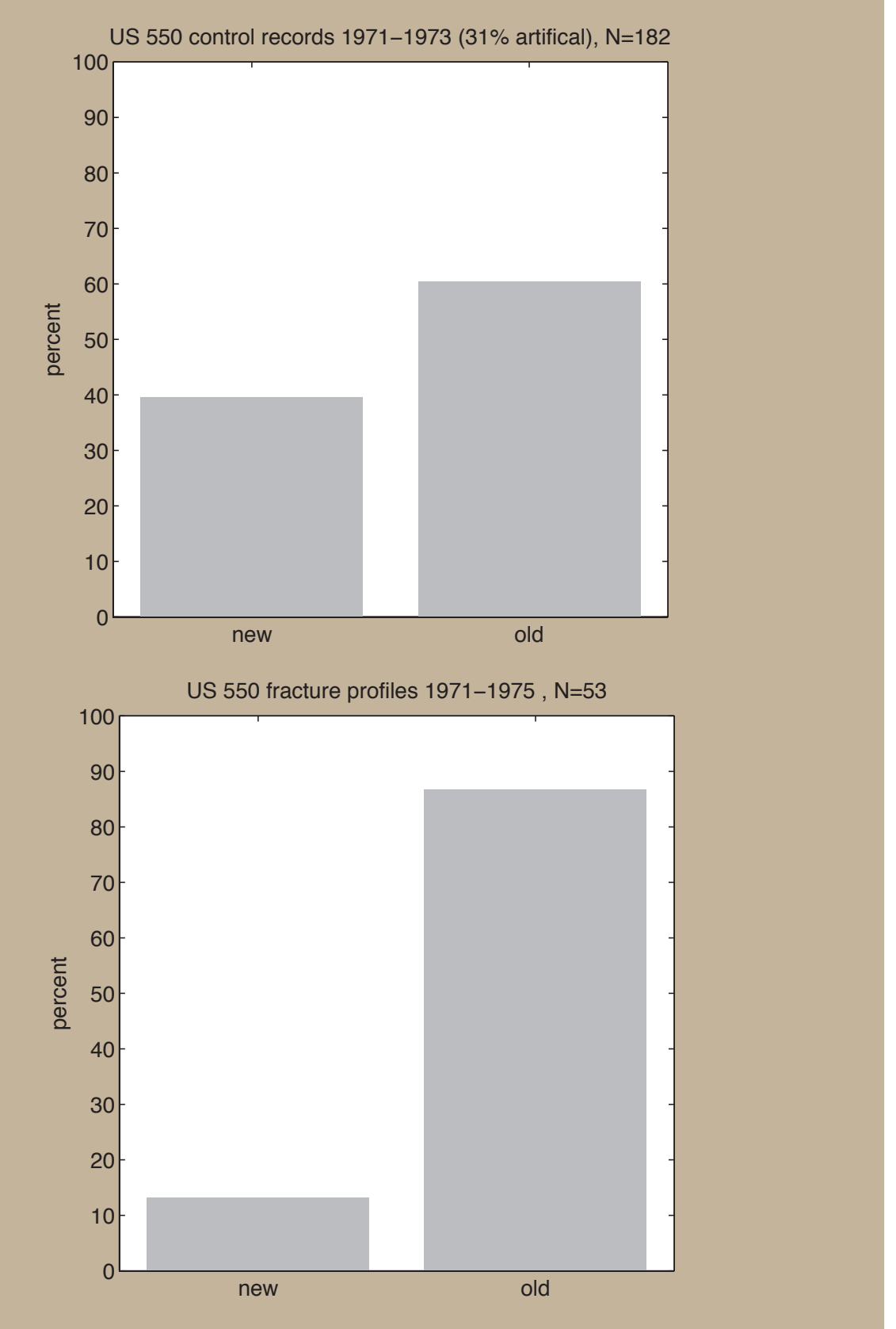
Skier triggered accidents
(37-52 percent new snow)



Mix of persistent and non-persistent weak layers

Source: Schweizer and Jamieson (2000)

A continental highway pass (≥ Class 2)
(13-40 percent new snow)



Persistent weak layers dominate

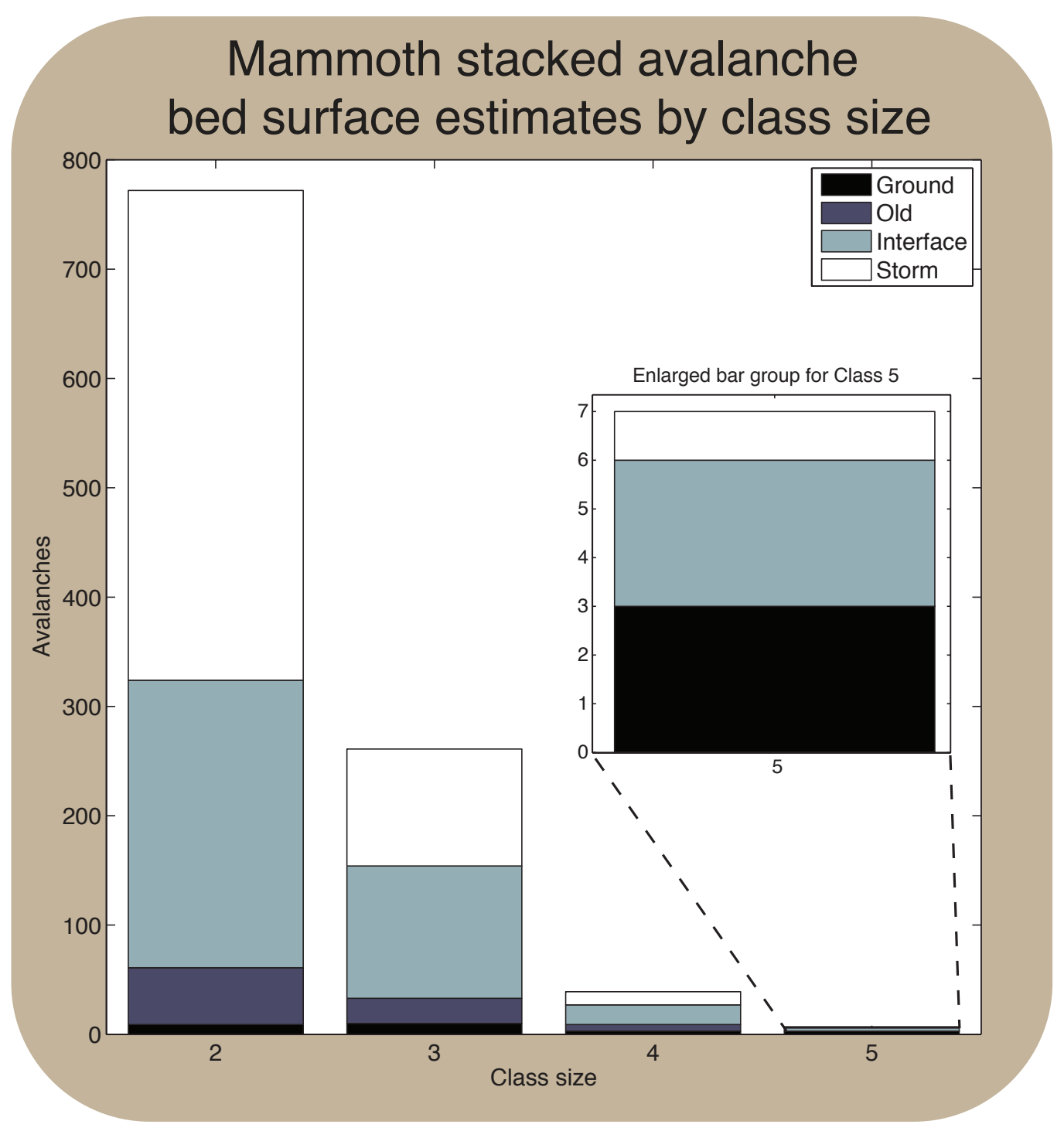
Source: Armstrong and Ives (1976)

Limited research on non-persistent weak layers

A majority of avalanche research has focused on persistent layers. In comparison, we know very little about non-persistent weak layers despite their prevlance in ski areas and other areas with predominantly artificial triggers. One study (Brown and Jamieson 2006) finds that failure layers in new snow are less dense and composed of larger crystals than adjacent strata, while another (Stethem and Perla 1980) finds failure layers in new snow are denser than the slab, but that crystal types are often the same. Micropenetrometer studies of new snow (Pietzch 2009; Peilmier 2003) and observations of atmospheric forms (Casson et al. 2008) show that new snow is highly stratified, especially in wind exposed areas like avalanche starting zones. Fist hardness new snow, classified as a uniform layer by traditional methods, can actually vary in hardness by an order of magnitude over 10cm (Pietzch 2009).

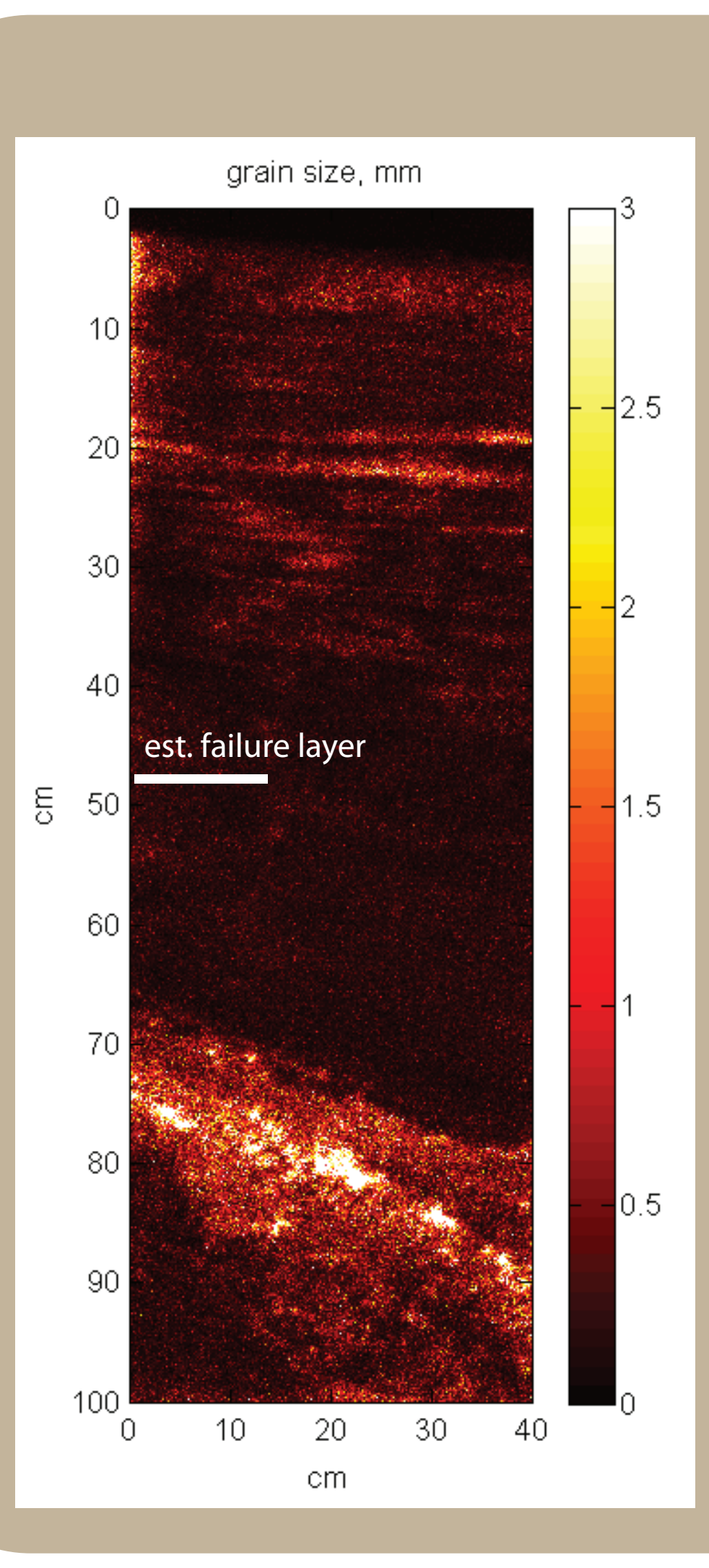
The competing effects of stress and compaction from overburden cause substantial changes within hours (Birkeland et al. 2006). The dyanimic nature of the position and strength of new snow requires a new approach to stability modeling. Stability models that assume the weak layer exists in a static location are not correct. For new snow avalanches, preliminary results suggest failure layers are often not substantially different optically than the slab. Because of the high proportion of avalanches that fail at the interface or in storm snow, we propose a spatially distributed stability index model that examines stability at all depths to predict small to large avalanches for ski areas.

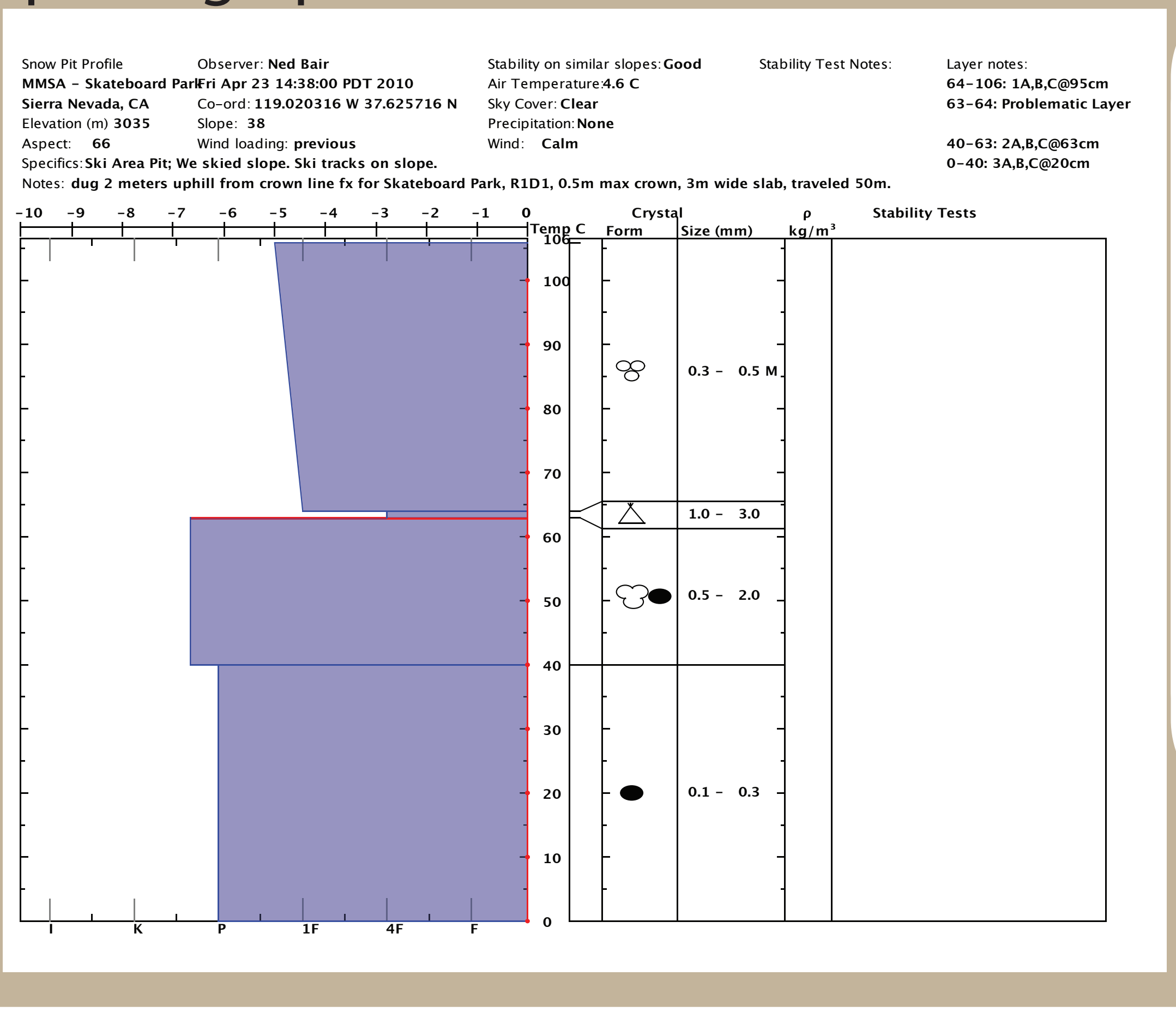
Mammoth stacked avalanche bed surface estimates by class size



nIR measurements at two crown faces that failed in the storm layer

4/23/2010 @ 7:30 Skateboard Park
photographed on 4/23/2010 @ 14:00




Snow Pit Profile
MMSA - Skateboard Park
Sierra Nevada, CA
Elevation (m) **3035**
Aspect: **66**
Observer: **Ned Bair**
Fri Apr 23 14:38:00 PDT 2010
Co-ord: **119.020316 W 37.625716 N**
Slope: **38**
Wind loading: **previous**
Stability on similar slopes: **Good**
Air Temperature: **4.6 C**
Sky Cover: **Clear**
Precipitation: **None**
Wind: **Calm**
Stability Test Notes:
Layer notes:
64-106: 1A,B,C@95cm
63-64: Problematic Layer
40-63: 2A,B,C@63cm
0-40: 3A,B,C@20cm
Specifics: **Ski Area Pit; We skied slope. Ski tracks on slope.**
Notes: **dug 2 meters uphill from crown line fx for Skateboard Park, R1D1, 0.5m max crown, 3m wide slab, traveled 50m.**

Occurrence record estimate:
Type: Soft slab
Trigger: 1 kg handcharge by author
Class : R1D1
Bed surface: in new snow

3m wide
ran 50m
50 cm max crown

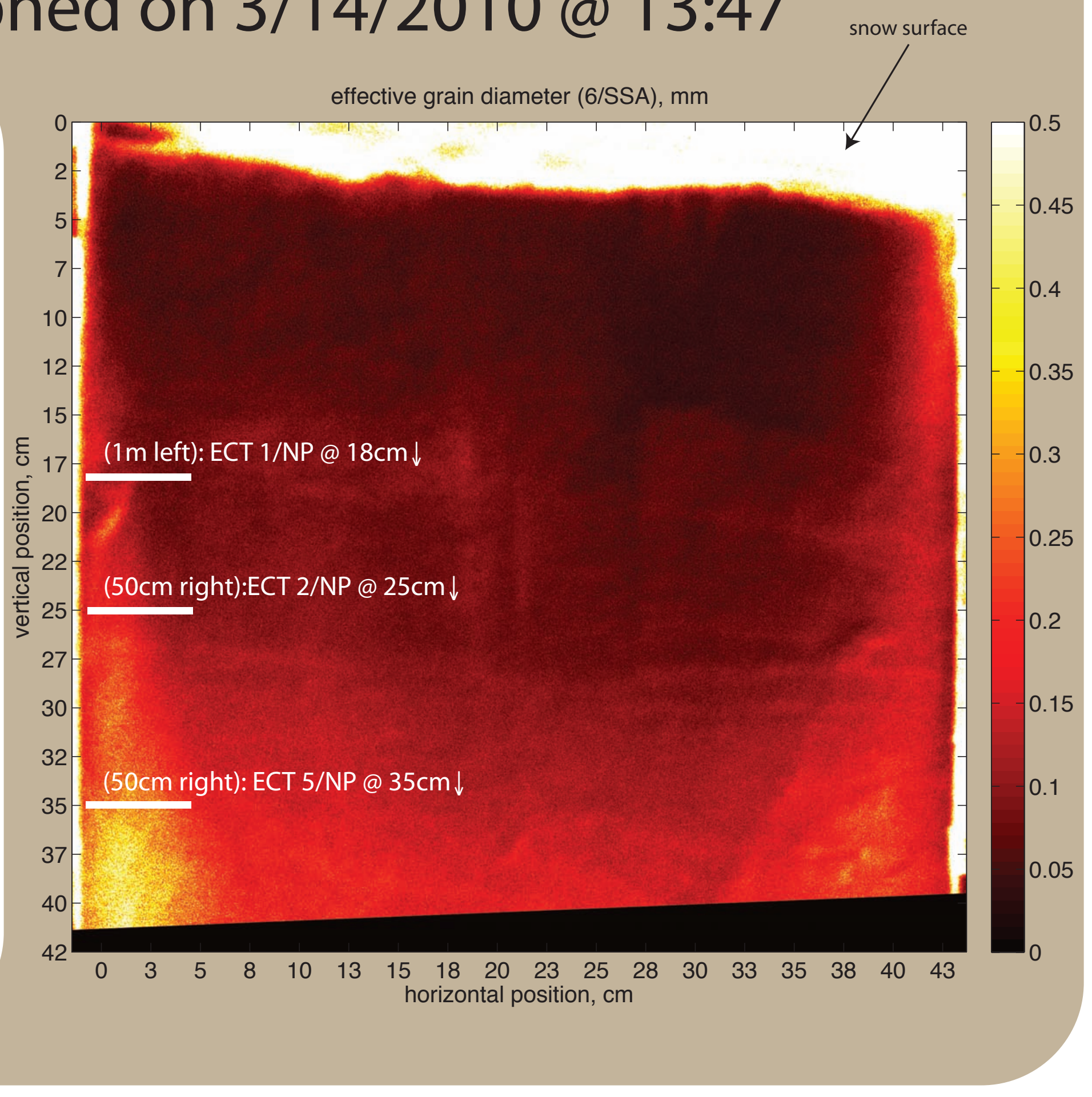
notes: the failure did not occur at the obvious melt-freeze crust or on the graupel layer on top of it

3/13/2010 @ 6:25 Comeback Cliffs 5
photographed on 3/14/2010 @ 13:47

Occurrence record estimate:
Type: Soft slab
Trigger: ski cut
Class : R2D1
Bed surface: old/new snow interface

7m wide
ran 35m
30 cm max crown estimate

new wind blown snow made it difficult to find the bed surface during examination, but I concluded it was in the storm layer because of the lack of significant change in grain size.



The radiative transfer problem from a snow pit wall can be solved by considering that snow acts as a collection of equivalent sized spheres (Warren and Wiscombe 1980). My nIR profiles suggest that these spheres are the same size in failure layers and adjacent strata for non-persistent weak layers. Since density does not affect albedo (Bohren 1975), it's possible that these grains are the same size, but packed differently. Packing differences could be caused by different atmospheric forms and the influence of wind. I propose that packing differences are largely responsible for formation of non-persistent weak layers.

To investigate and model non-persistent weak layers, I will:

1) make measurements of failure layers at crown faces and at protected study plots using an nIR camera, a snow micro-penetrometer, and traditional snow pit observations such as detailed temperatures and densities.

2) investigate a snow camera which photographs flakes as they fall to determine how atmospheric form affects packing.

3) develop a continuum stability model which models the dynamic vertical evolution of non-persistent weak layers.

4) investigate development of a spatially distributed stability index that uses a wind model, SnowTran-3D (Liston et al. 2007), driven by a high-resolution (1m^2) DEM, 7-8 anemometers, and 2 precipitation stations over Mammoth Mountain (1600 hectares).

Research plan:

Measurements:

Stability tests to identify weak layer depth:
- Extended column
- Tilt-board

Instruments to measure strength and stratigraphy:
- Snow micropenetrometer
- nIR camera
- disdrometer (snowflake camera)
- traditional methods
(i.e. hand lens, 250cc density cutter)

Models:

- Geostatistical model to examine spatial variation in weak layer location
- Continuum stability index model to examine fractures within storm layer
- Spatially distributed stability index driven by a wind model

Software:

- Develop open source (MATLAB) package to process and calibrate near infrared digital images, possibly eliminating frame and flat-field correction requirements

Research questions:

1) Do non-persistent weak layers form at different depths throughout the course of a storm?

2) For microstructure, how does variability within a storm slab compare to the differences between a failure layer and a slab?

Armstrong, R. L., and Ives, J. D. (1976), Avalanche release and snow characteristics, San Juan Mountains, Colorado.
Bair, E. H. (2010), Mammoth Mountain Ski Patrol avalanche and weather database, http://snow.ucsb.edu/cues/.
Birkeland, K. W., Kronholm, K., Logan, S., and Schweizer, J. (2006), Field measurements of sintering after fracture of snowpack weak layers, Geophysical Research Letters, 33: L03501, doi: 10.1029/2005GL025104.
Bohren, C. F., and Beschta, R. L. (1979), Snowpack albedo and snow density, Cold Regions Science and Technology, 1(1): 47-50, doi: 10.1016/0165-232X(79)90018-1.
Brown, C., and Jamierson, B. (2006), Evolving shear strength , stability, and snowpack properties in storm snow, International Snow Science Workshop, Telluride, CO., pp. 15-21.
Casson, J. (2008), Evaluating the importance of crystal-type on new snow instability : a strength versus stress approach using the SNOSS model, Proceedings of the 2008 International Snow Science Workshop, Whistler, B.C., pp.
Liston, G. E., Haehnel, R. B., Sturm, M., Hiemstra, C. A., Berezovskaya, S., and Tabler, R. D. (2007), Instruments and Methods Simulating complex snow distributions in windy environments using SnowTran-3D, Journal of Glaciology, 53: 241-256, doi: 10.3189/172756507782202865.
Peitzsch, E. H. (2009), Water movement in a stratified and inclined snowpack: Implications for wet slab avalanches, Department of Earth Sciences, Montana State University, Bozeman, MT, 162 pp.
Pielmeier, C. (2003), Textural and mechanical variablity of mountain snowpacks, University of Bern, Bern, Switzerland, 126 pp.
Schweizer, J., and Jamieson, J. B. (2000), Field observations of skier-triggered avalanches, Proceedings International Snow Science Workshop, Big Sky, Montana, USA.
Stethem, C., and Perla, R. (1980), Snow-slab studies at Whistler Mountain, British Columbia, Canada, Journal of Glaciology, 26(94): 85-91.
Warren, S., and Wiscombe, W. (1980), A model for the spectral albedo of snow, I, Pure snow, Journal of the Atmospheric Sciences, 37(12): 2712-2733.
WAN (1998), Westwide Avalanche Network: Avalanche observations.