Mechanism of dry slab avalanche release – a look under the hood

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Thanks to:

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Ned Bair

Joachim Heierli

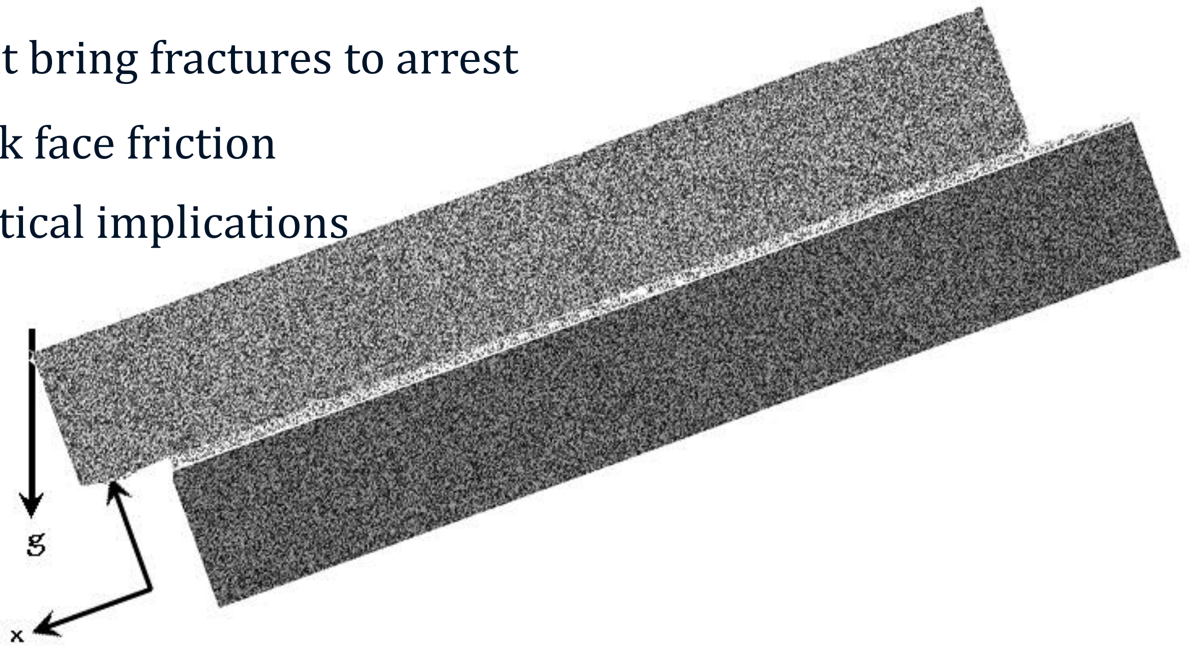
Karl Birkeland

Dry slab avalanches begin when a fracture in a weak snowpack layer undercuts a large portion of the slope

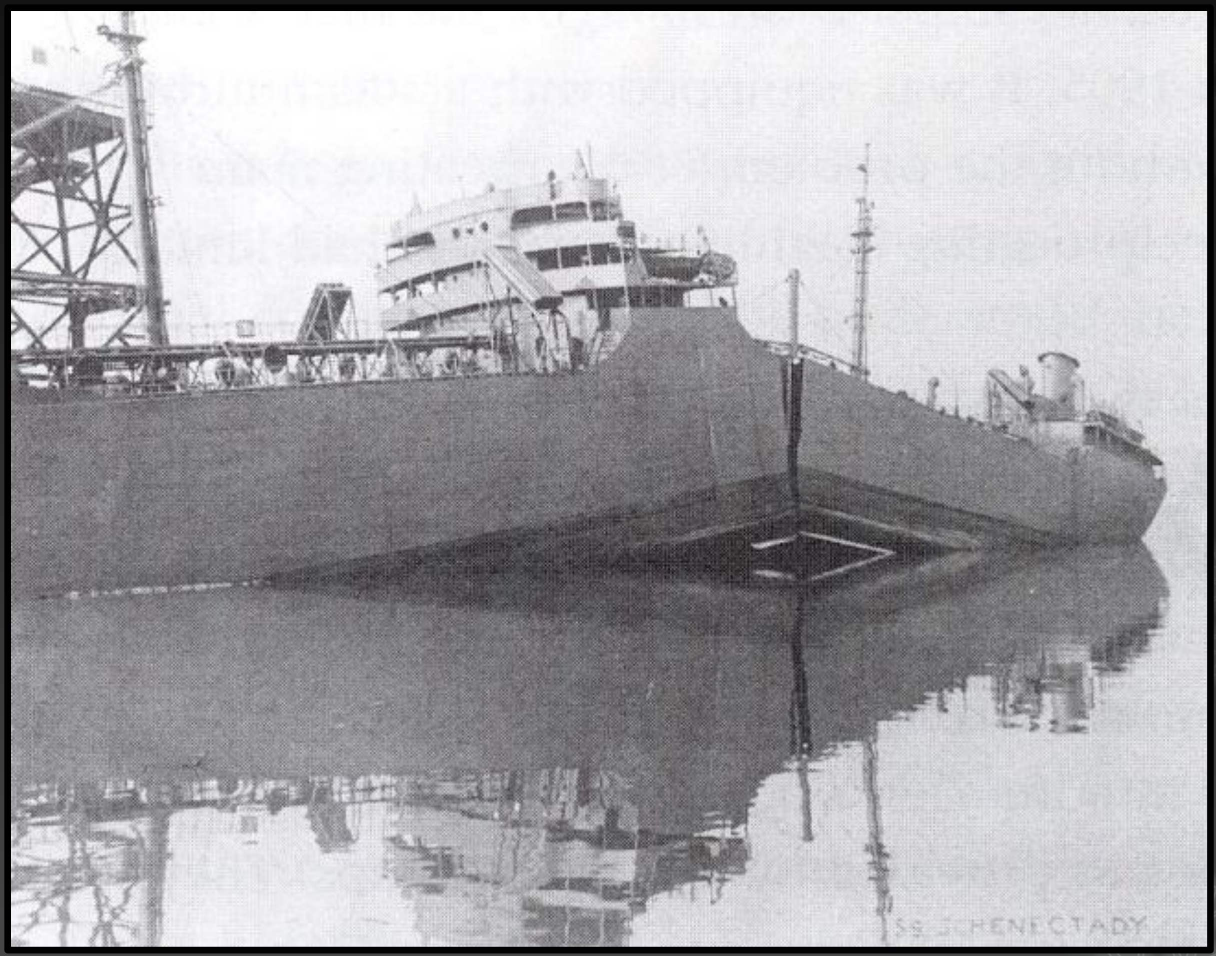
Photo: Mike Bartholow

In this presentation…

- Fracture mechanics lite (very lite)
  - Cracks
  - Energy
- The mix mode anticrack
- What bring fractures to arrest
- Crack face friction
- Practical implications

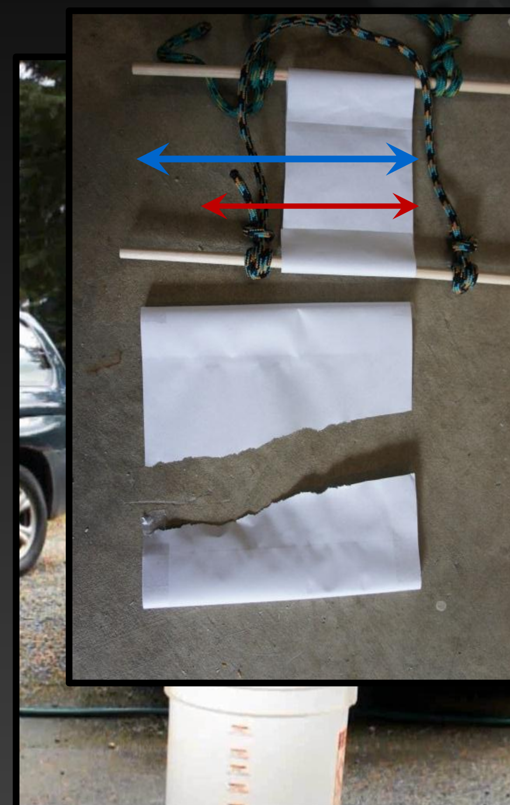


Fracture mechanics:



Cracks:

Cracks weaken the material more than you would expect from the reduction in intact cross-section.

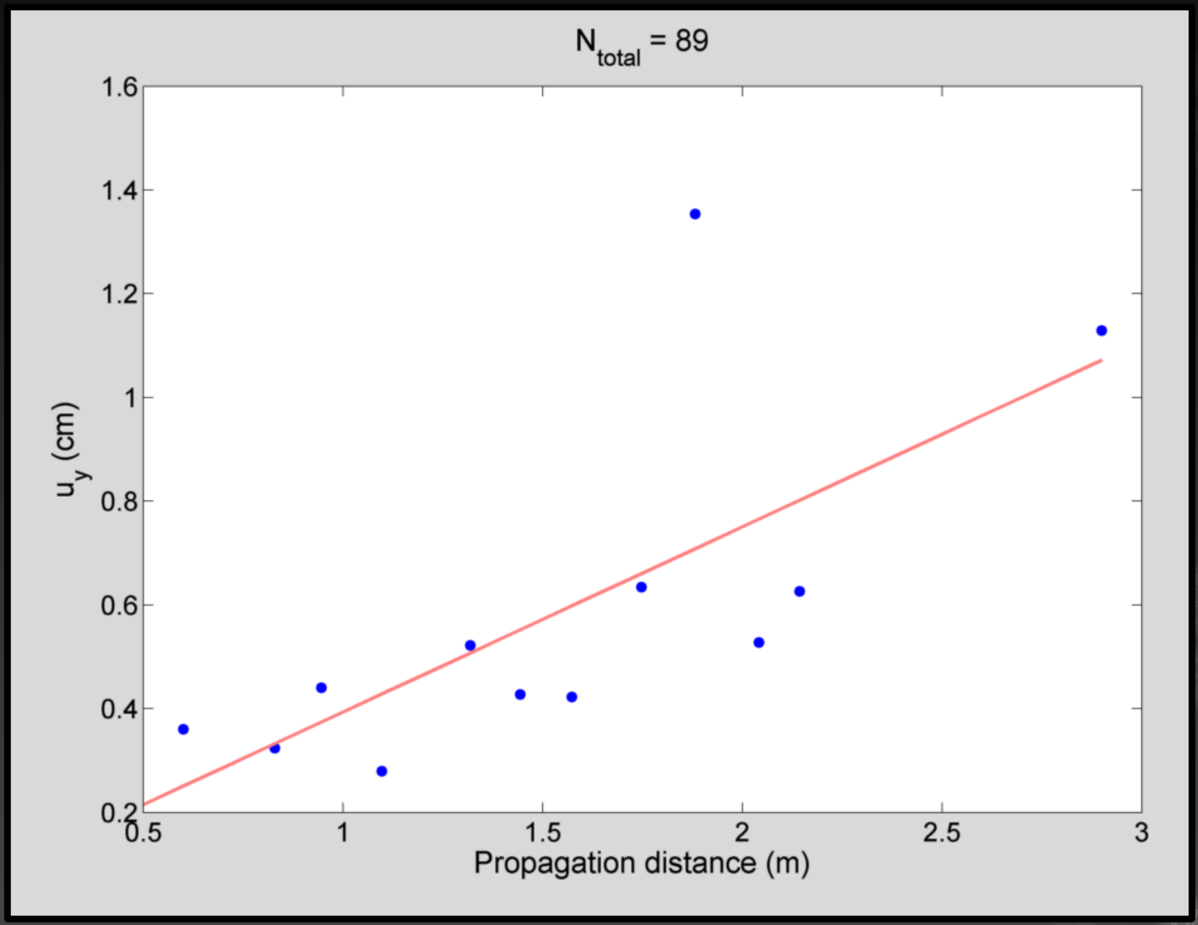


The Energy: (Equations for Wendy)

- **The energy balance approach (Griffith 1920):**
- $U = U_F + U_M, U_M = U_G + U_E$

Video: Alec van Herwijnen

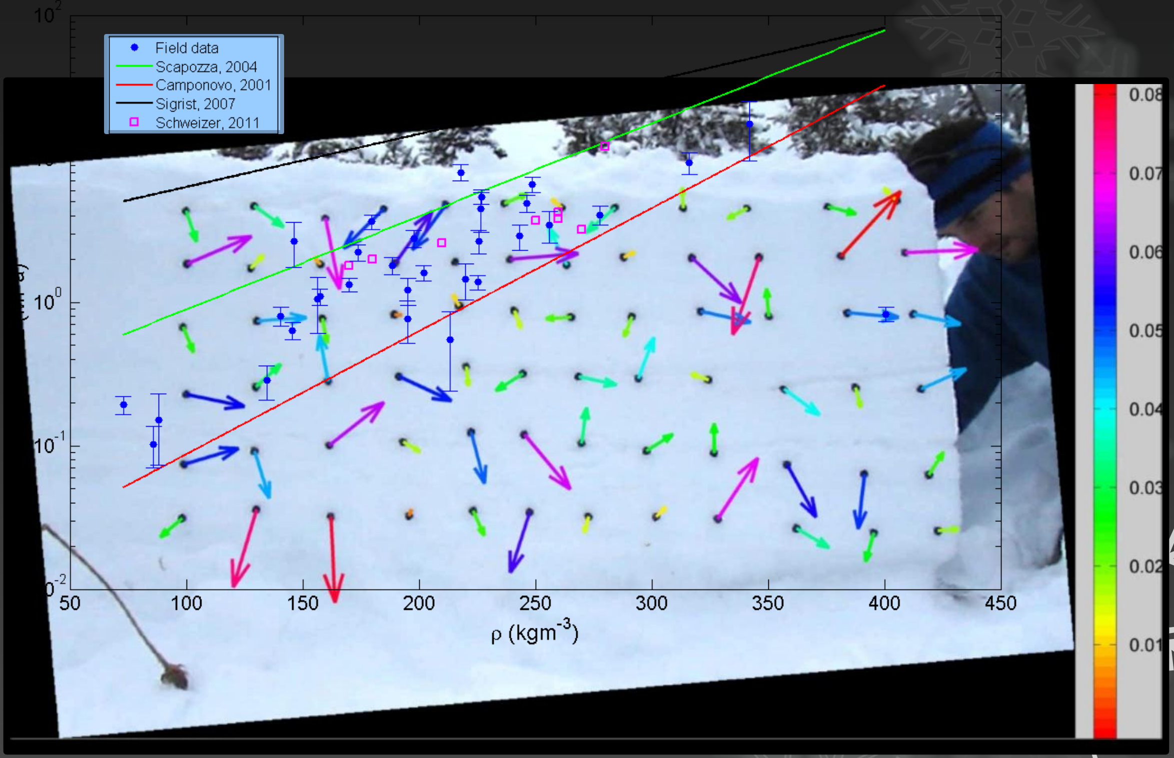
Weak layer collapse



Alec van Herwijnen

The Energy: (Equations for Wendy)

- **The energy balance approach (Griffith 1920):**
- $U = U_F + U_M, U_M = U_G + U_E = -U_E$
- $U_M(r) = C\frac{\sigma^2 r^2}{E}$

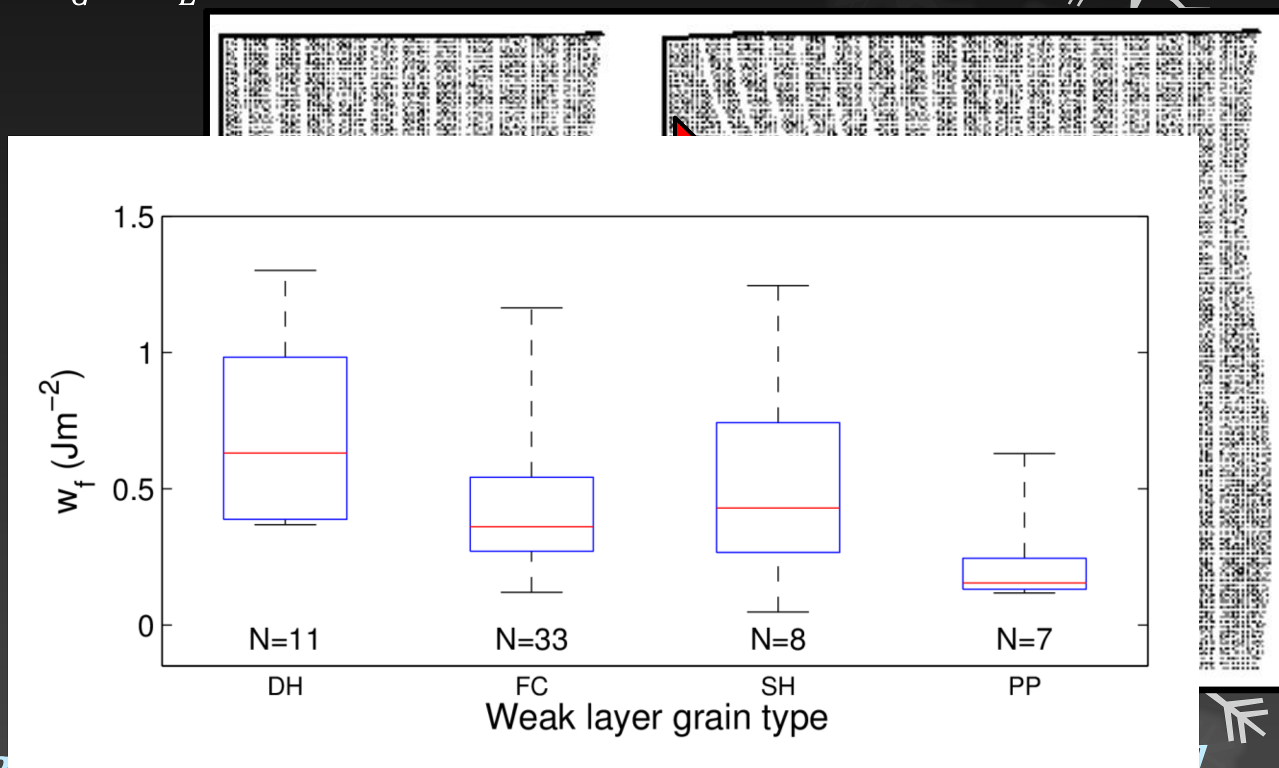


Video: Alec van Herwijnen

C – *constant,* E – elastic modulus, $E = \frac{\sigma}{h_f}$

The Energy: (Equations for Wendy)

- **The energy balance approach (Griffith 1920):**
- $U = U_F + U_M, U_M = U_G + U_E$
- $U_M(r) = C\frac{\sigma^2 r^2}{E}$
- $U_F = W_f r$

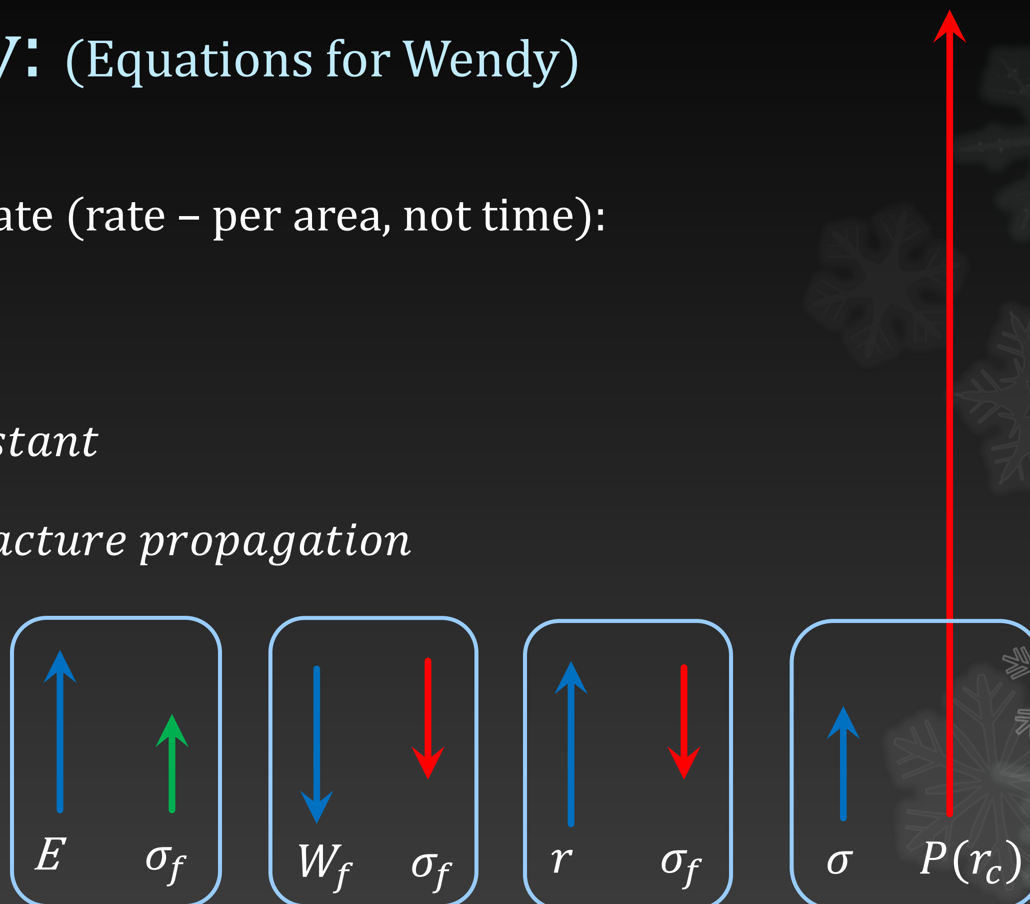


- *The elastic energ*

C – *constant,* E – elastic modulus, $E = \frac{\sigma}{h_f}$

The Energy: (Equations for Wendy)

- Energy release rate (rate – per area, not time):
- $G = \frac{dU_E}{dr} = C\frac{\sigma^2 r}{E}$
- $\frac{dU_F}{dr} = w_f = constant$
- If $G \geq W_f = fracture\ propagation$
- $\sigma_f = \sqrt{\frac{EW_f}{rC}}$



C – $constant$, E – elastic modulus, $E = \frac{\sigma}{h_f}$

In theory once a self propagation fracture starts, it can go for ever

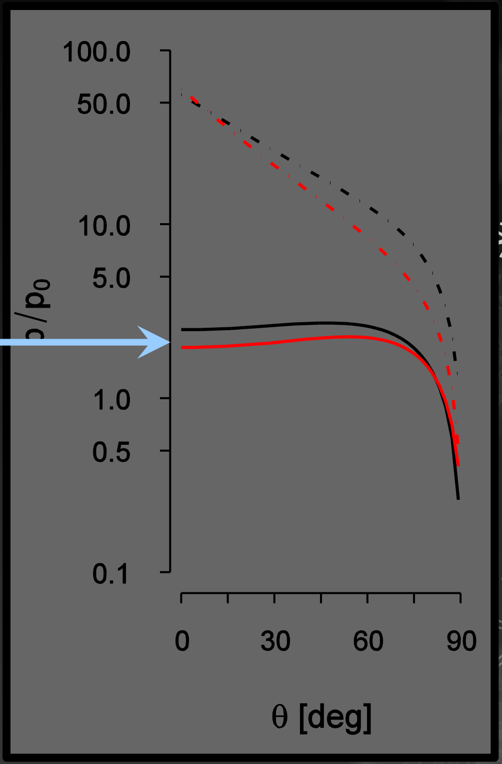
Photo: Mohan Rasiah

Take home message (fracture mechanics):

- Loading is critically important
- Soft slab avalanches are easier to trigger than hard slab
- Crack size counts.

Mix Mode Anticrack:

Mix Mode Anticrack has both compression and shear components in it.

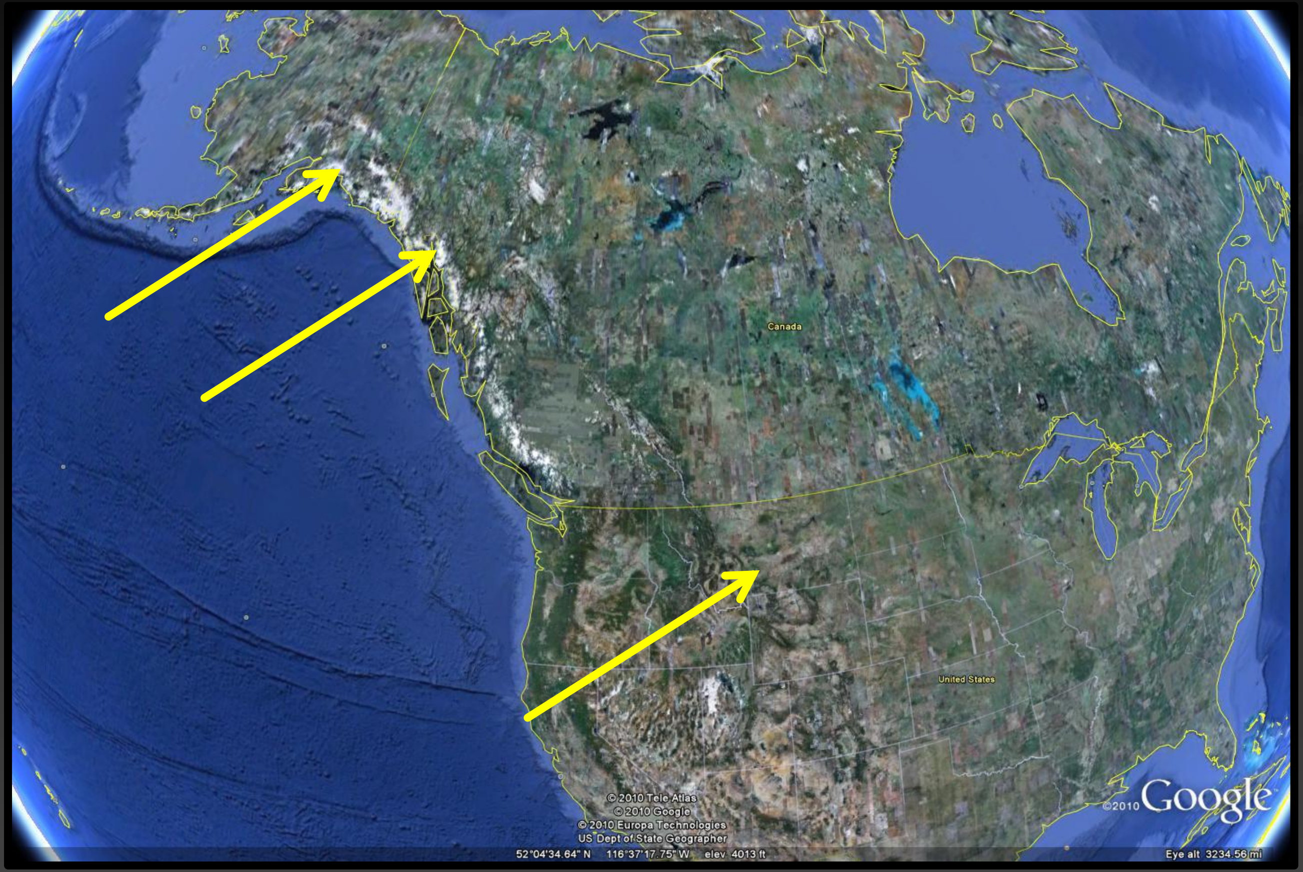


$$U_M(r) = \frac{\pi \gamma r^2}{4E_{slab}}(\sigma^2 + \tau^2) - \frac{r^3}{6E_{slab}D}[\lambda_{\tau\tau}\tau\tau^2 + \lambda_{\sigma\tau}\sigma\tau + \lambda_{\sigma\sigma}\sigma^2]$$

Joachim Heierli 2008

How does slope angle affect ECT results?

Field areas



Canada
United States
© 2010 Tele Atlas
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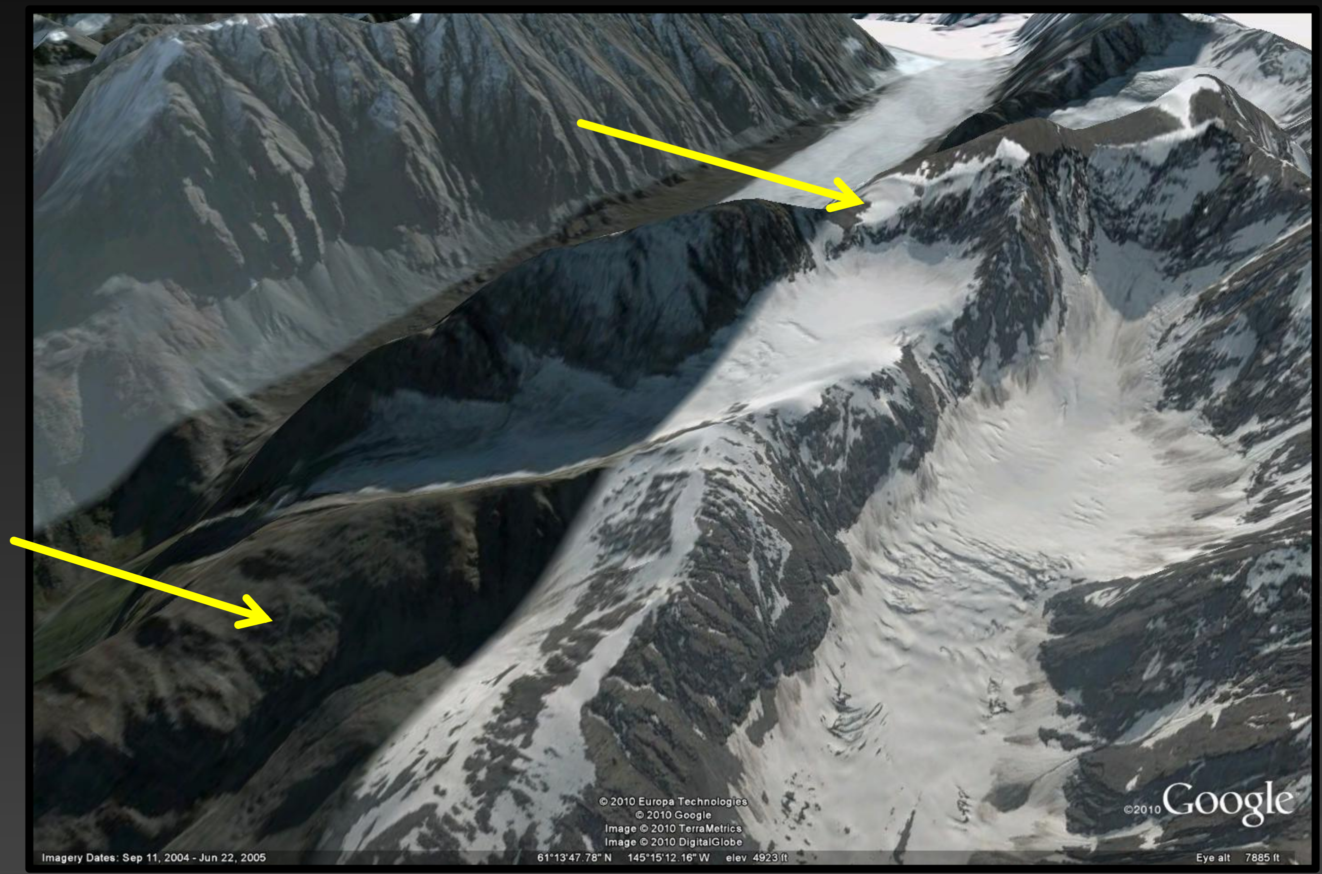
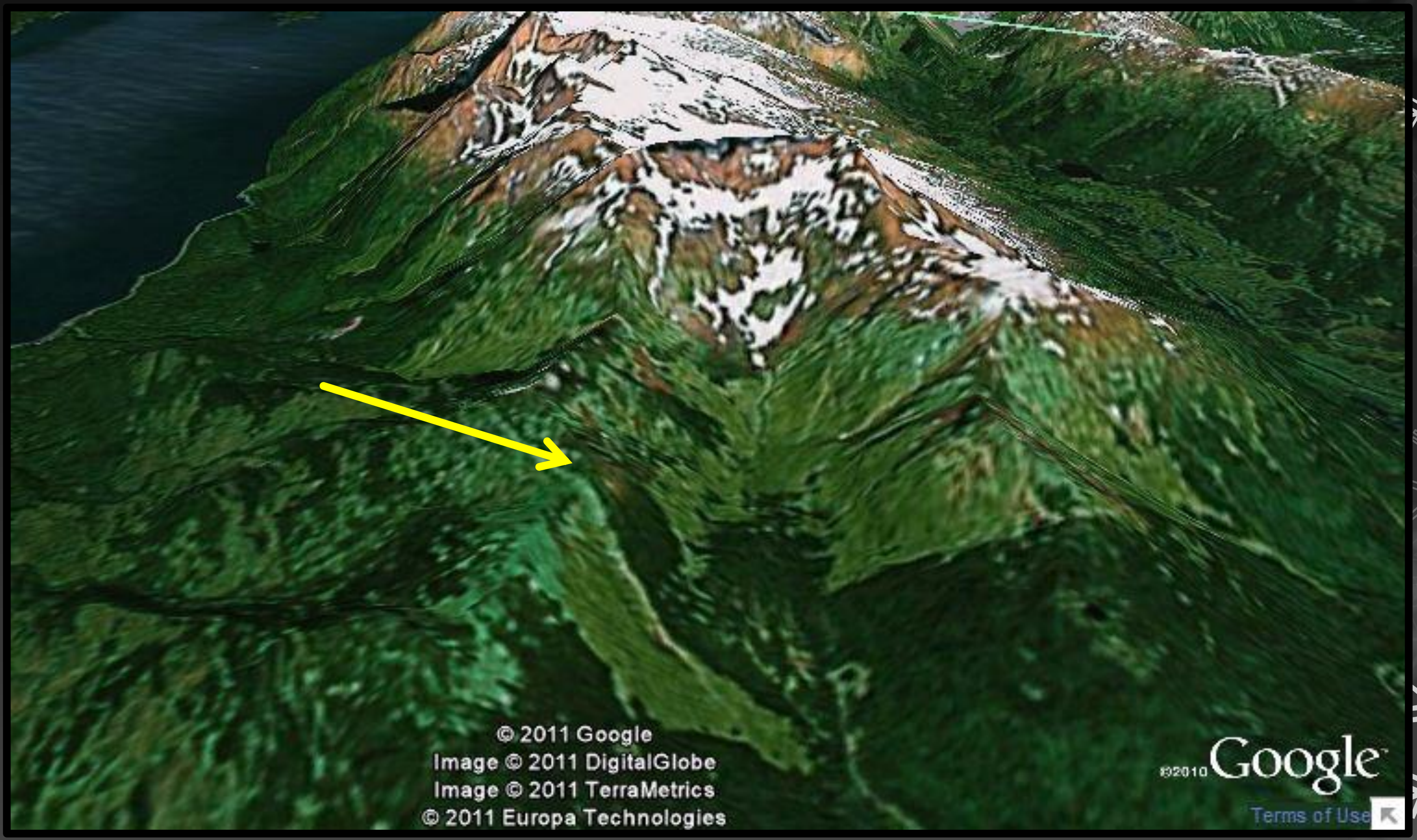
US Dept of State Geographer
©2010 Google
52°04'34.64" N 116°37'17.75" W elev 4013 ft
Eye alt 3234.56 mi

Field area - Montana

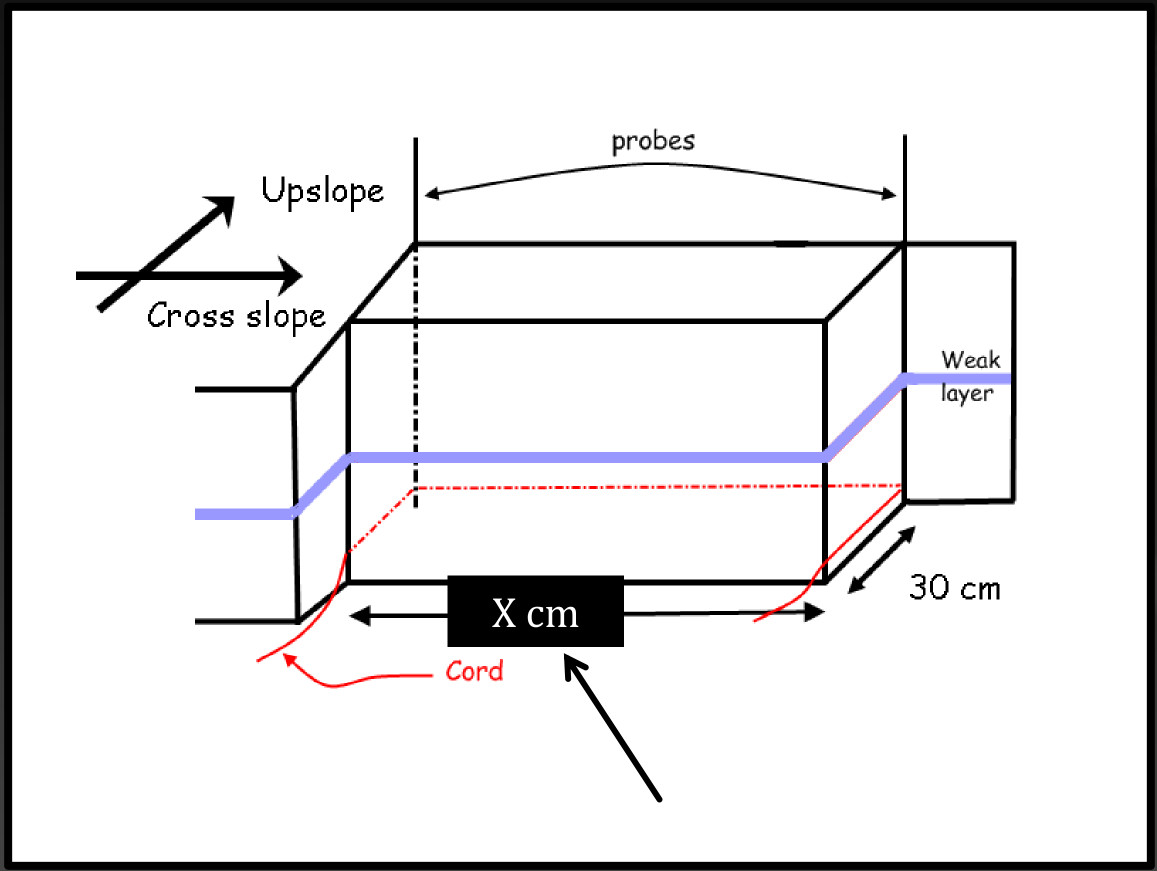
Field area – Chugach Alaska



Field area – SE Alaska



Slightly modified ECT



> 2(slab depth) + shovel width

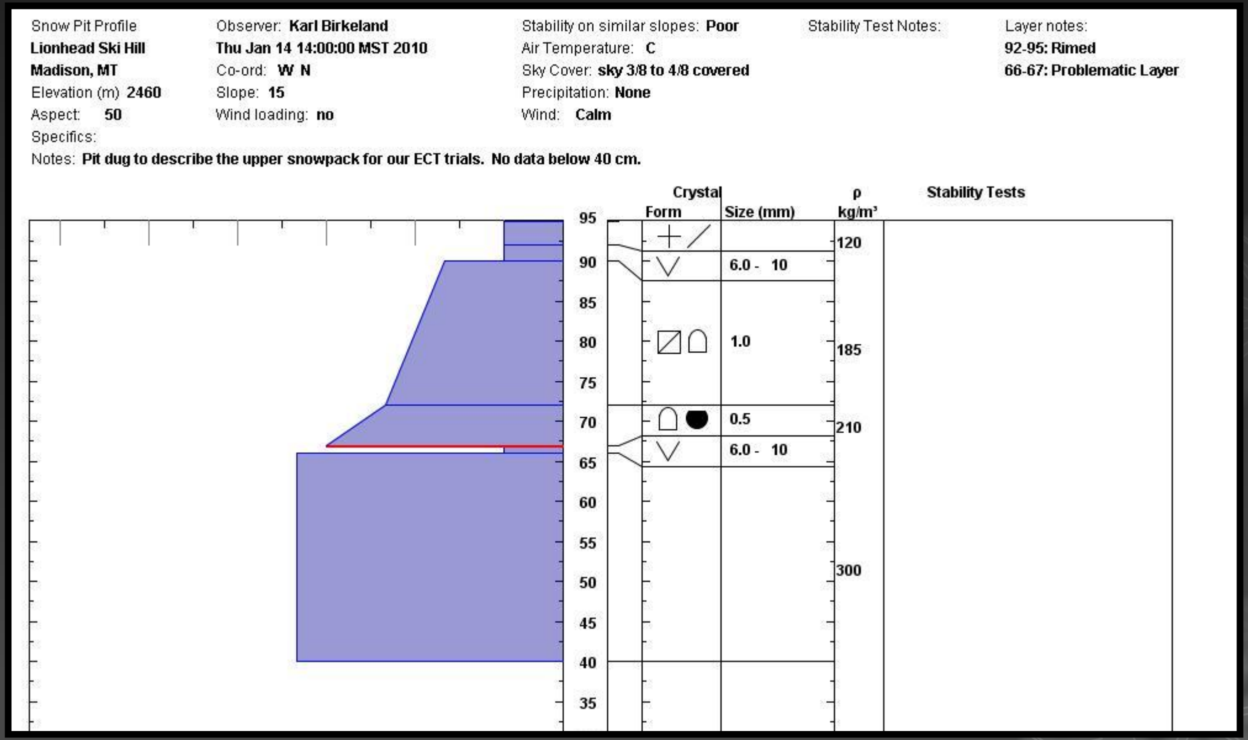
Only considered ECTPs

Other data

- Slope angle measured by looking upslope with a Suunto clinometer (+/- 1°)
- Weak layer depth at each test
- One manual profile/day

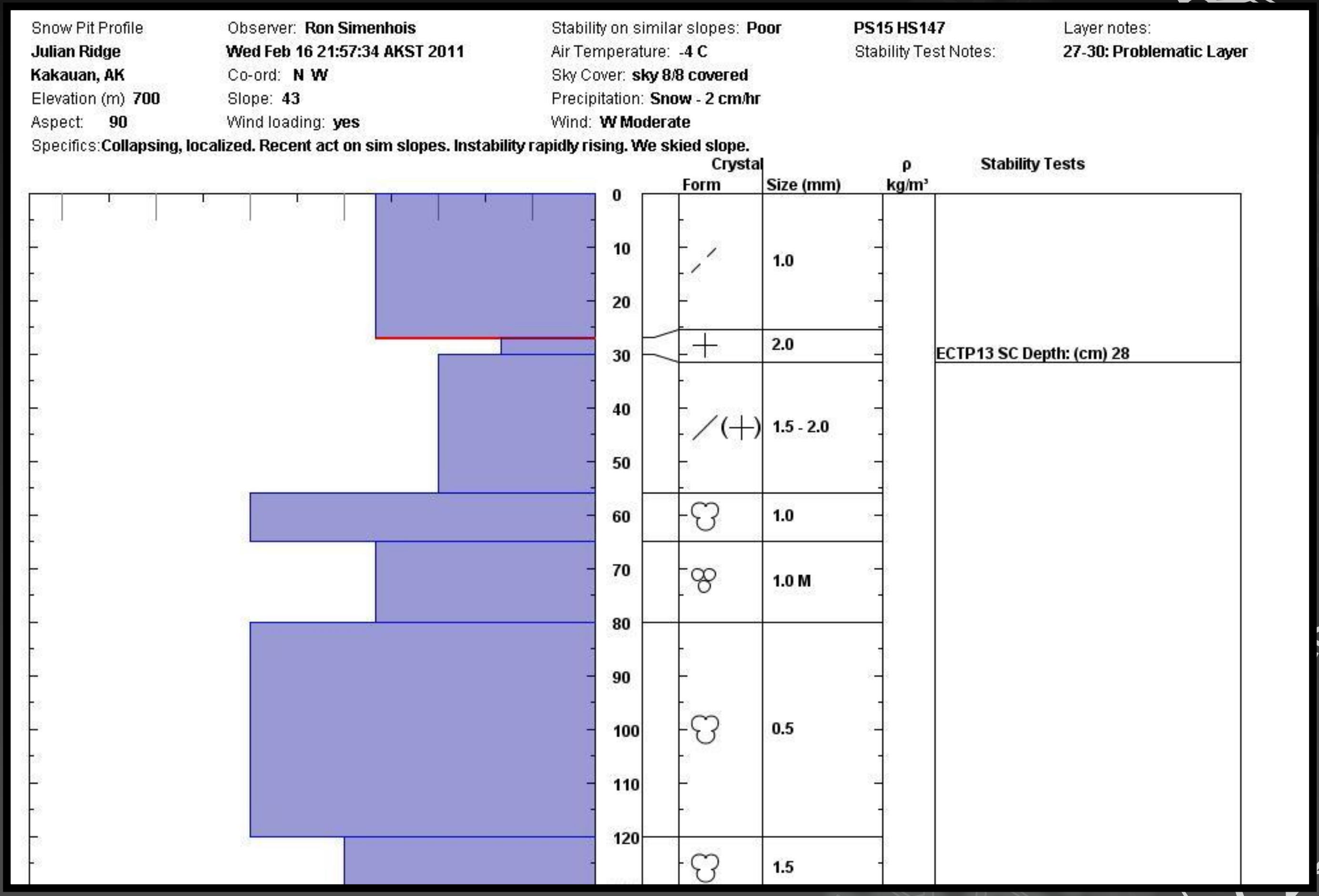
Snowpack structure

- Surface hoar weak layer for all four datasets (4 to 10 mm xtals)
- Mean slab depths from 24 to 30 cm (sd = 1-4)
- Mean slab densities from 160 to 180 kg/m^3

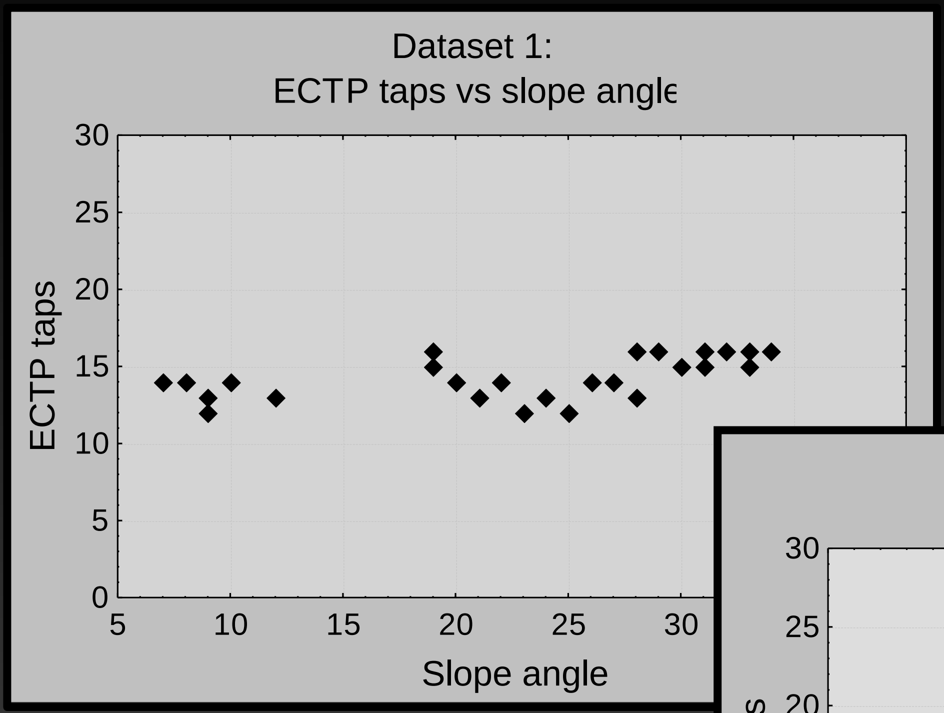


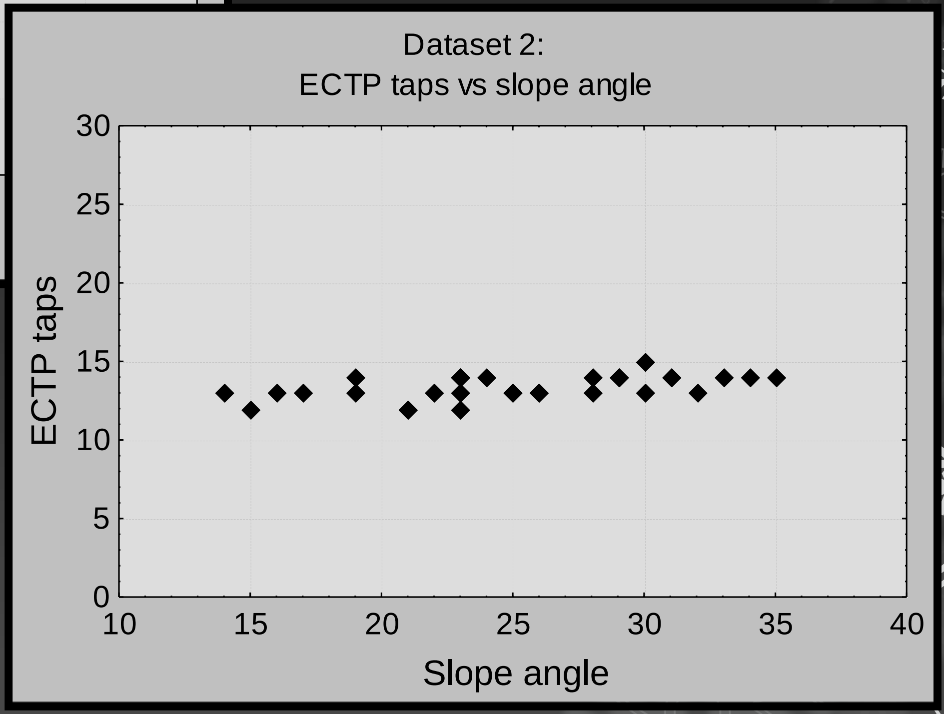
Snowpack structure (SE AK)

- SS over 4F- PP ~28cm deep.

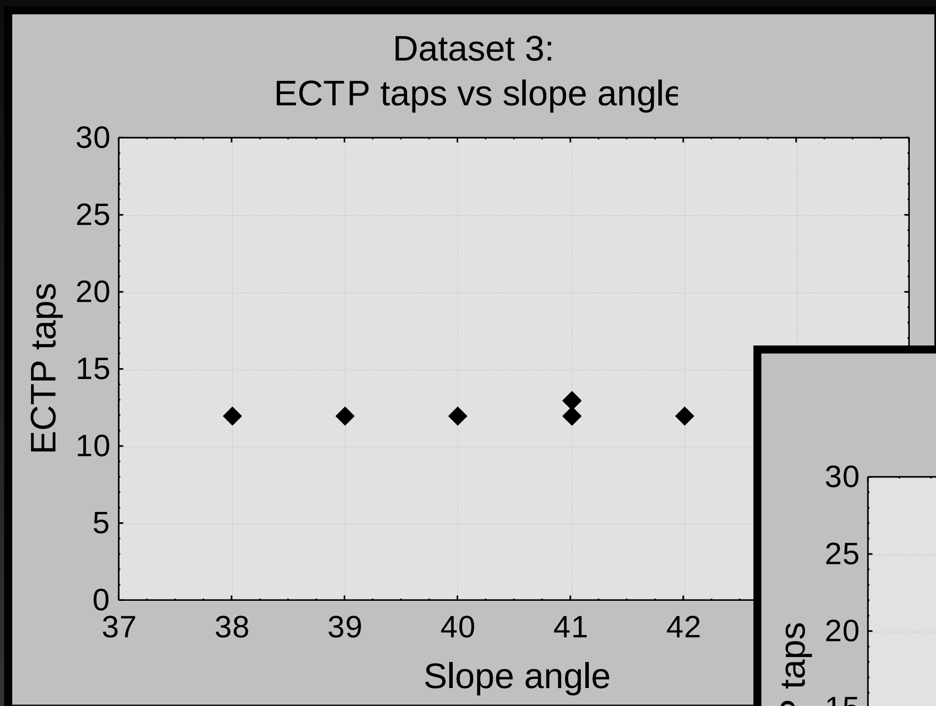


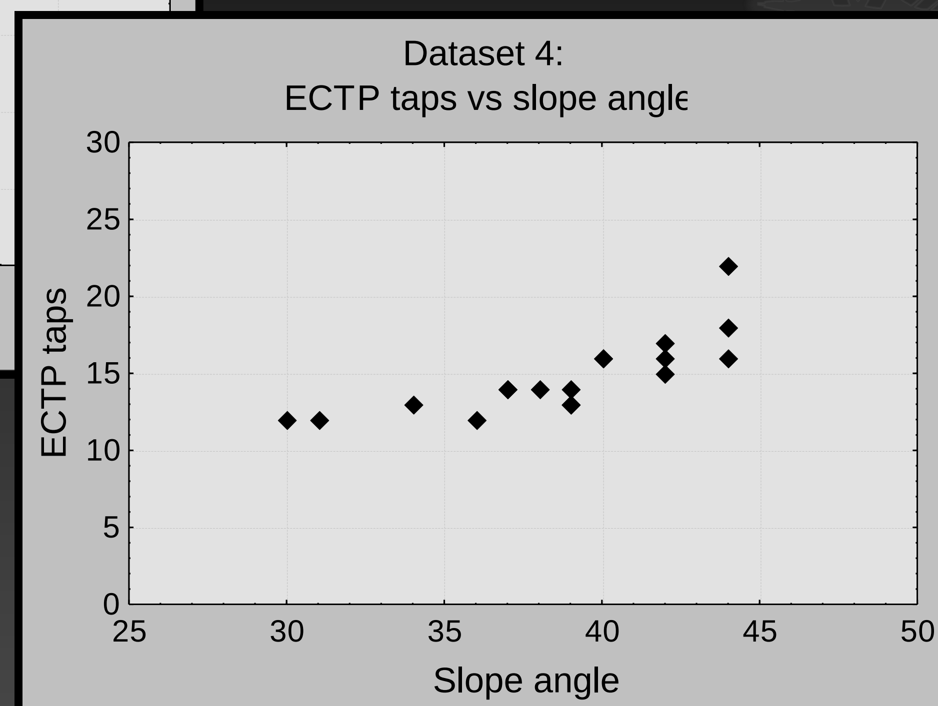
Results – Montana:



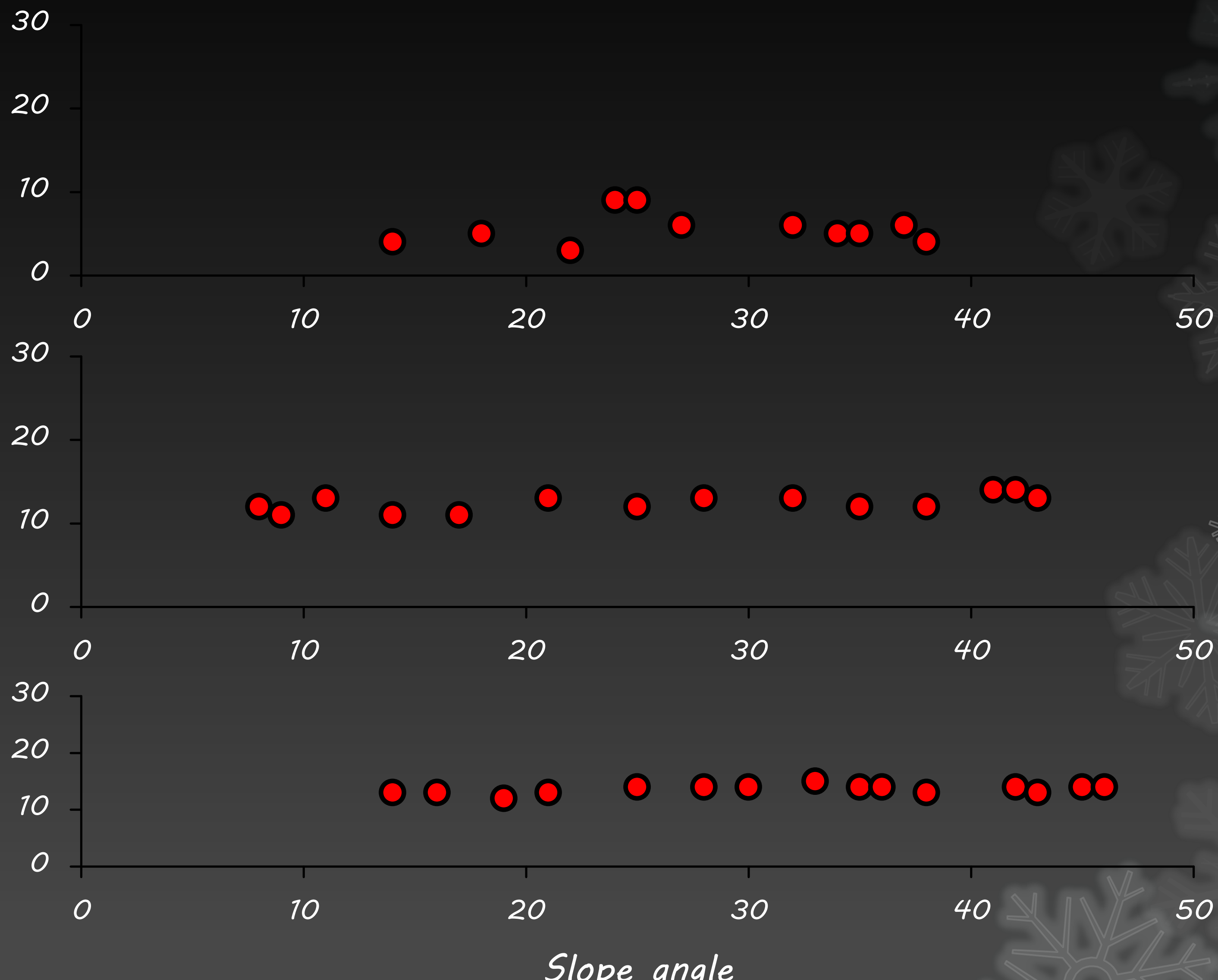


Results – Chugach Alaska:





Results – Southeast Alaska:



Take home message (Mix mode anticrack):

- If the snow conditions are reasonably similar, observers can conduct tests on low angle slopes before committing to steeper terrain

Fracture arrest:

In theory it shouldn't happen, but in reality it happens often. Why?

- *Not heavily researched*
- *Dynamic system*
  - $G < W_f \neq fracture\ arrest$
- *Spatial variability is to blame, but…*

Fracture arrest:

Two main reasons:

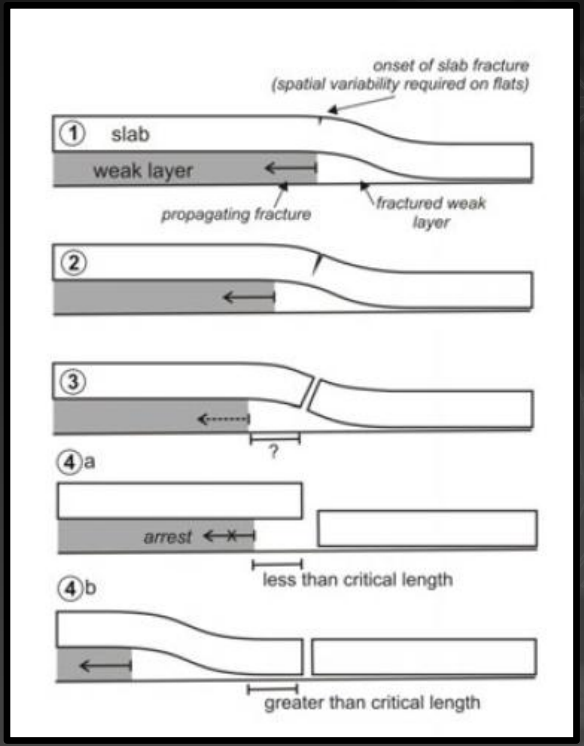
- Increase in W_f
- Decrease in U_M
    - Slab fracture
    - Decrease in wave length
    - Decrease in slab thickness
    - Decrease in collapse magnitude.

Photo: ASARC

Fracture arrest:

Slab Fracture

- "The race"
- Transition from SS to HS can create similar effect

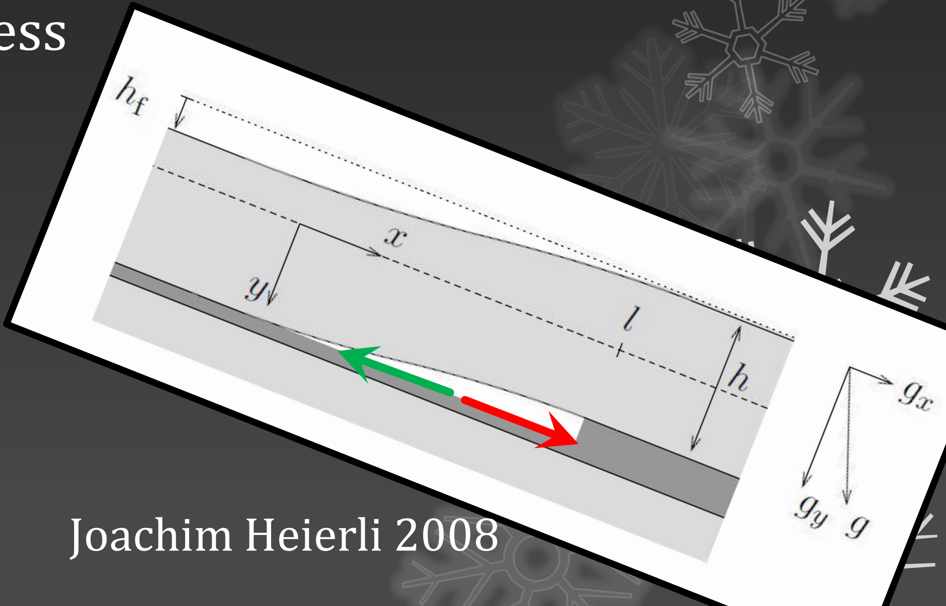


Gauthier & Jamieson 2010

Fracture arrest:

Decrease in wave length:

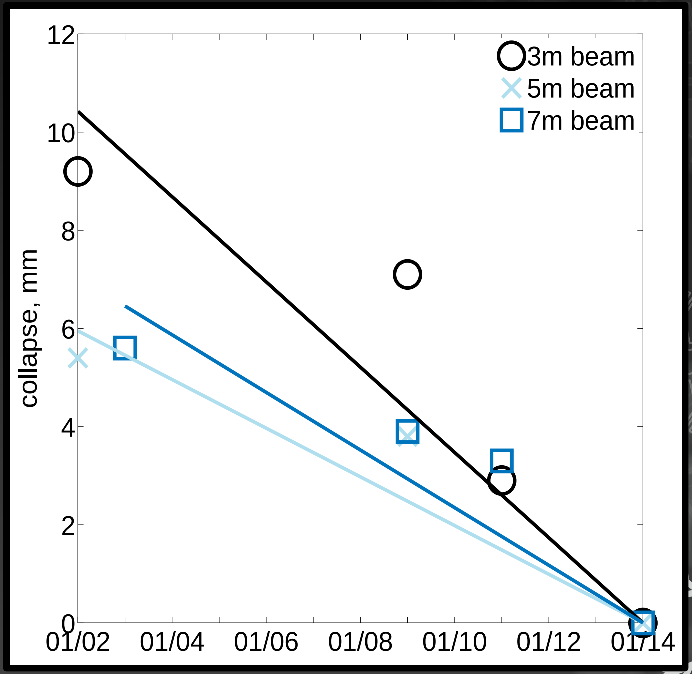
- Crack size is limited ($2r \approx l$)
- Effective wave length ($l > 2r_c$)
  - Decrease in elastic modulus
  - Decrease in slab thickness



Joachim Heierli 2008

Fracture arrest:

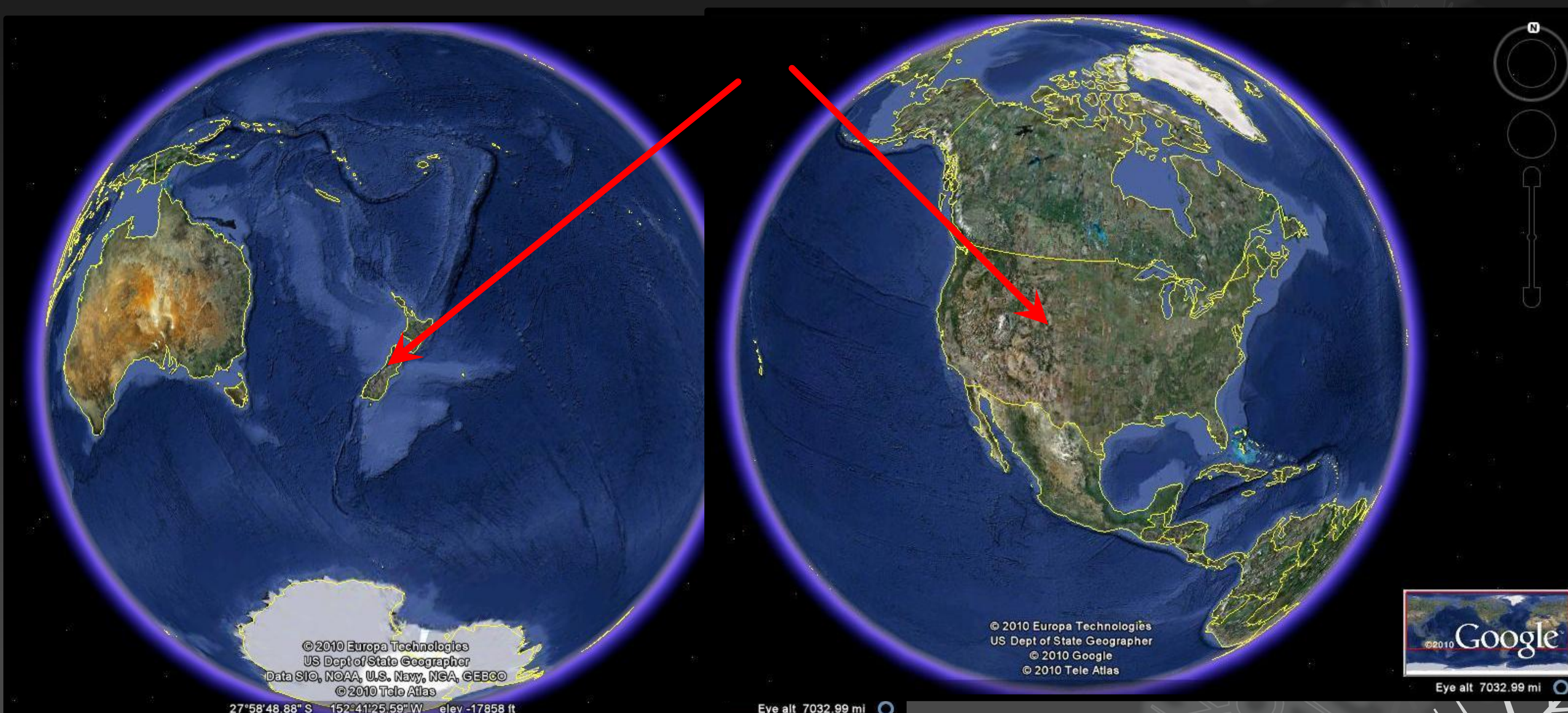
Decrease in gravitational energy (or load)



Ned Bair

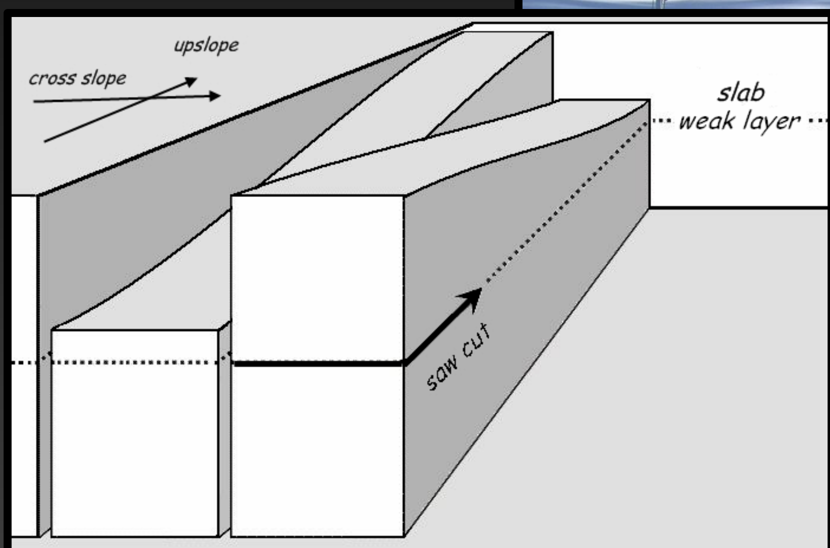
The effect of changes in slab thickness:

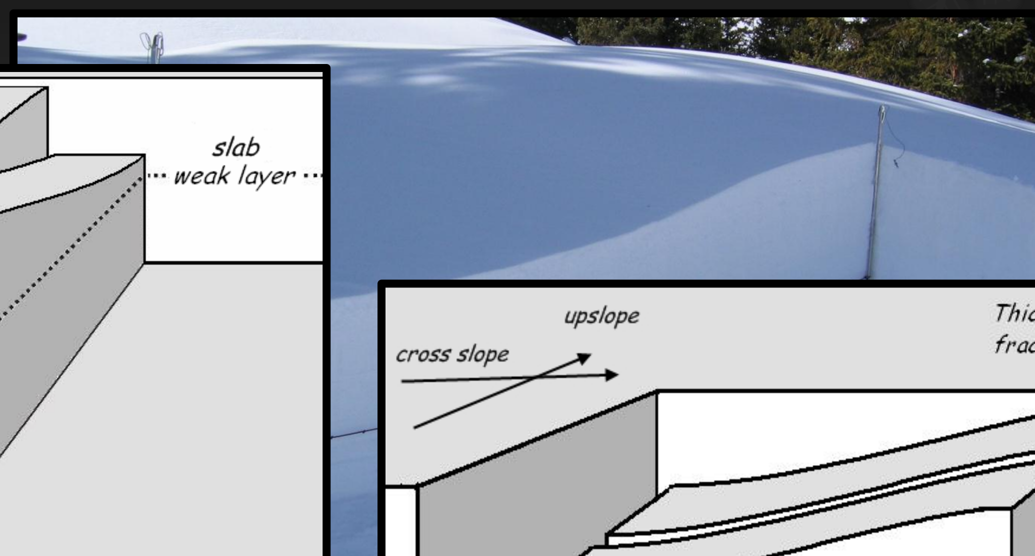
- In 2007/2008 winter in Colorado and winter of 2008 in New Zealand we collected data on fractures along weak snowpack layers.

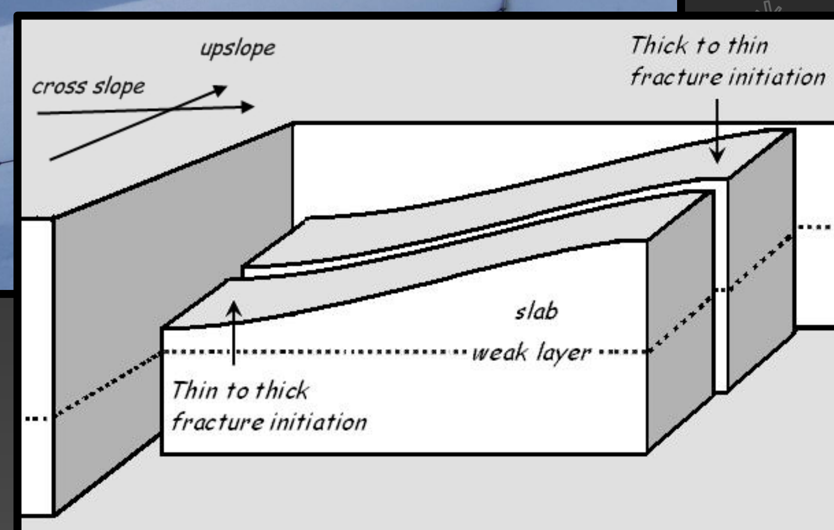


Methods:

- ECT length was between 200 – 300cm to capture slab thickness variations.
- In some of the pits we modified the slab thickness with a snow saw







Results:

- In all 116 side by-side tests from 52 pits:

Results:

- In all 116 side by-side tests from 52 pits:

Take home message (fracture arrest):

- Hard slab avalanches likely to be larger than soft slab avalanches
- Fractures are more likely to propagate from areas of thin slab to areas of thick slab than the other way around. ⇒ Wise route selection / escape route

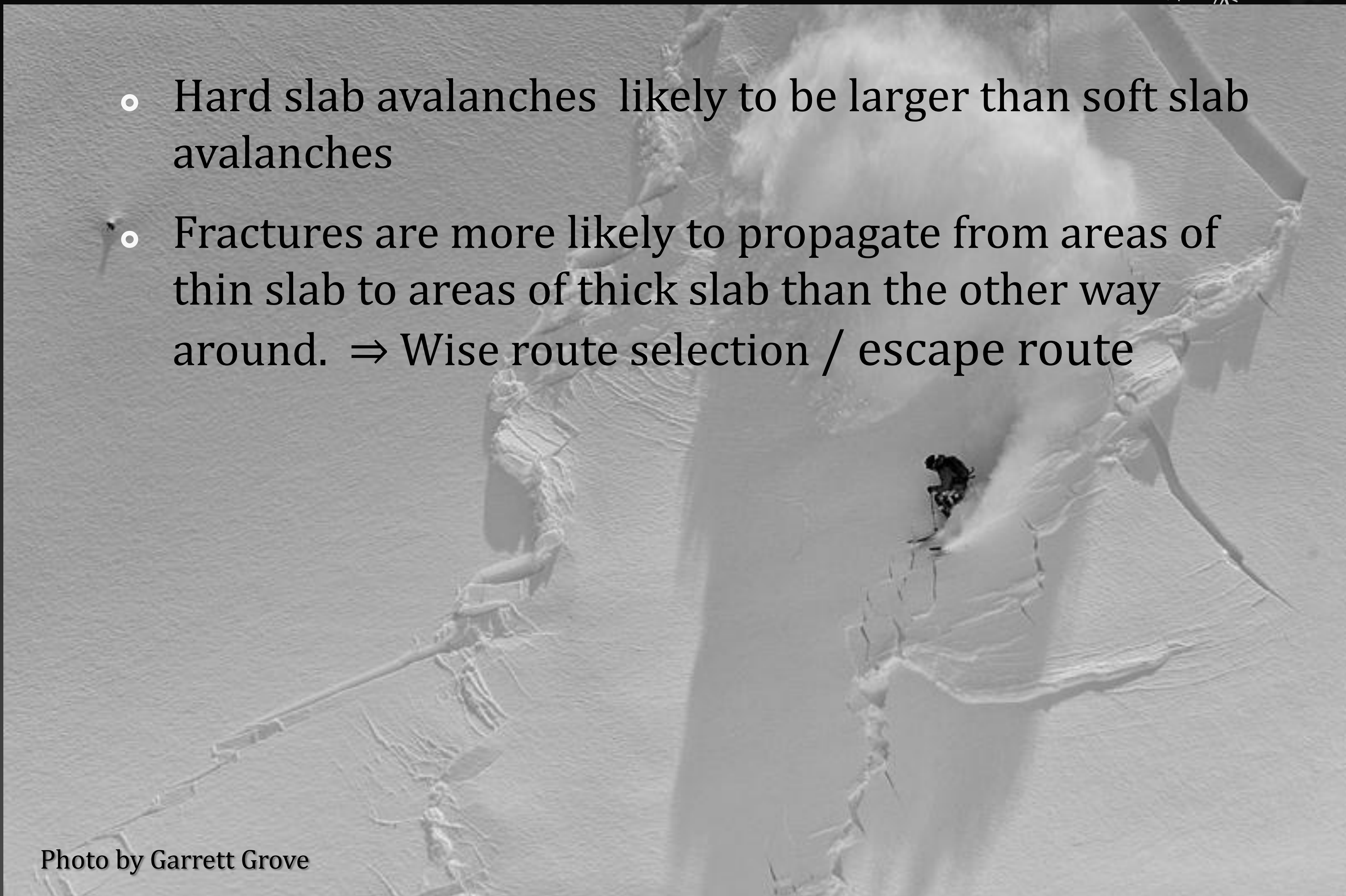
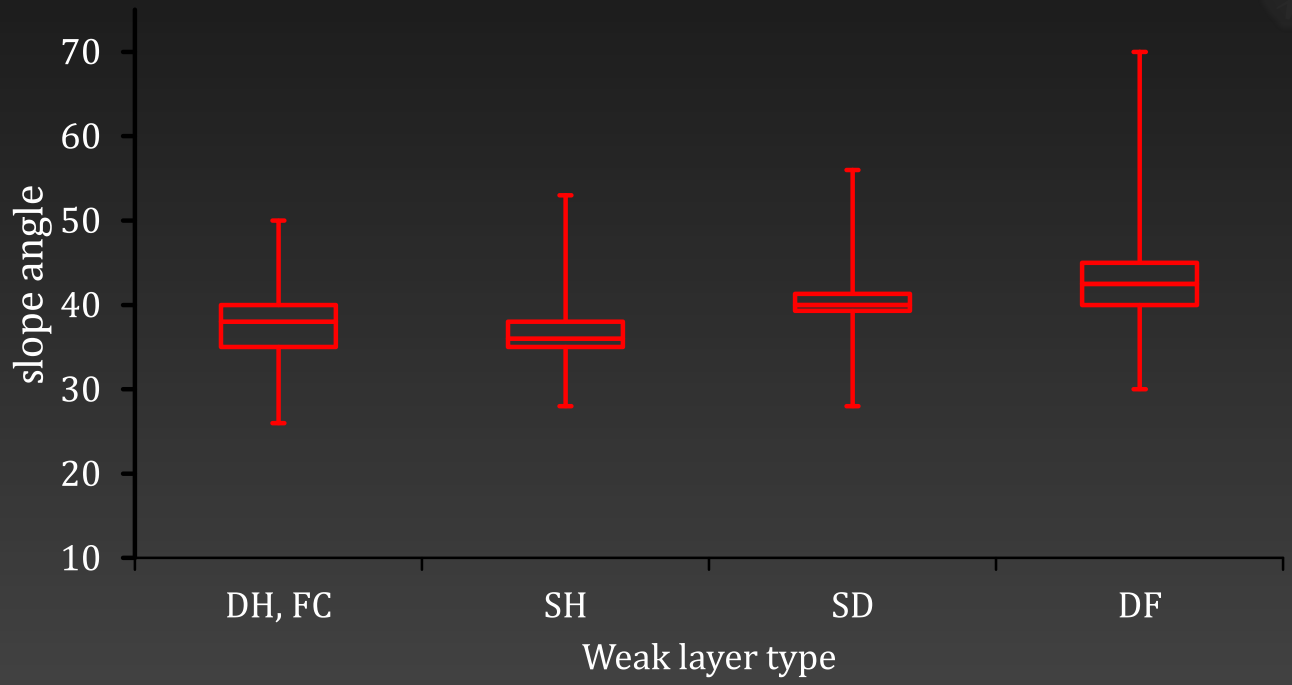


Photo by Garrett Grove

Downslope motion…

- Different types of weak layers have different “preferred" avalanche release angles



From McCammon I., 2009 (TAR *Vol. 27, NO 4)*

Methods (Friction coefficient measurements):

Procedure field work:

Methods (Friction coefficient measurements):

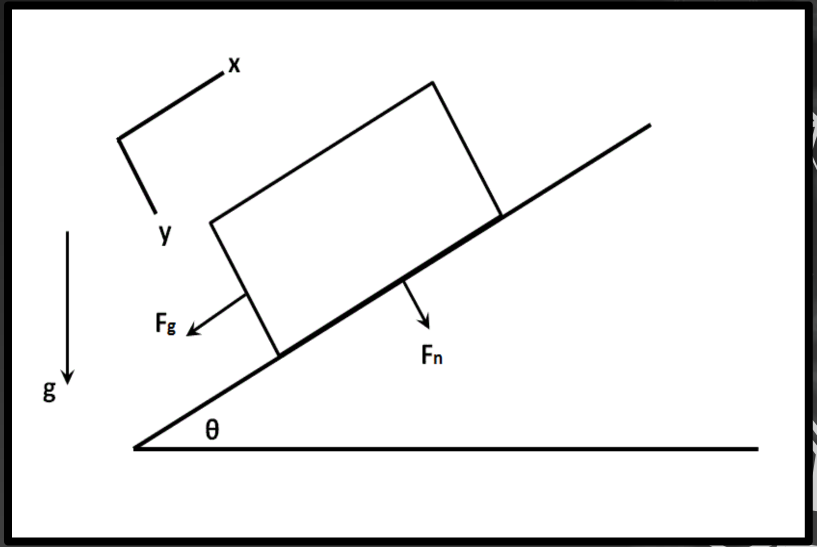
Procedure: Deriving the friction coefficient

For every frame in the video {

- $(u_x(t), u_y(t))$
- $(v_x(t), v_y(t))$
- $v(t) = v_0(t) + at$
- $a = \frac{v(t) - v_0(t)}{t}$
- $aM = F = \frac{(Fg - \mu Fn)}{M}$, (Newton's 2nd)
- $a = \frac{1}{M(Fg - \mu Fn)} = g(sin\theta - \mu cos\theta)$
- $\mu = tan\theta - \frac{a}{gcos\theta}, \theta \neq 0$

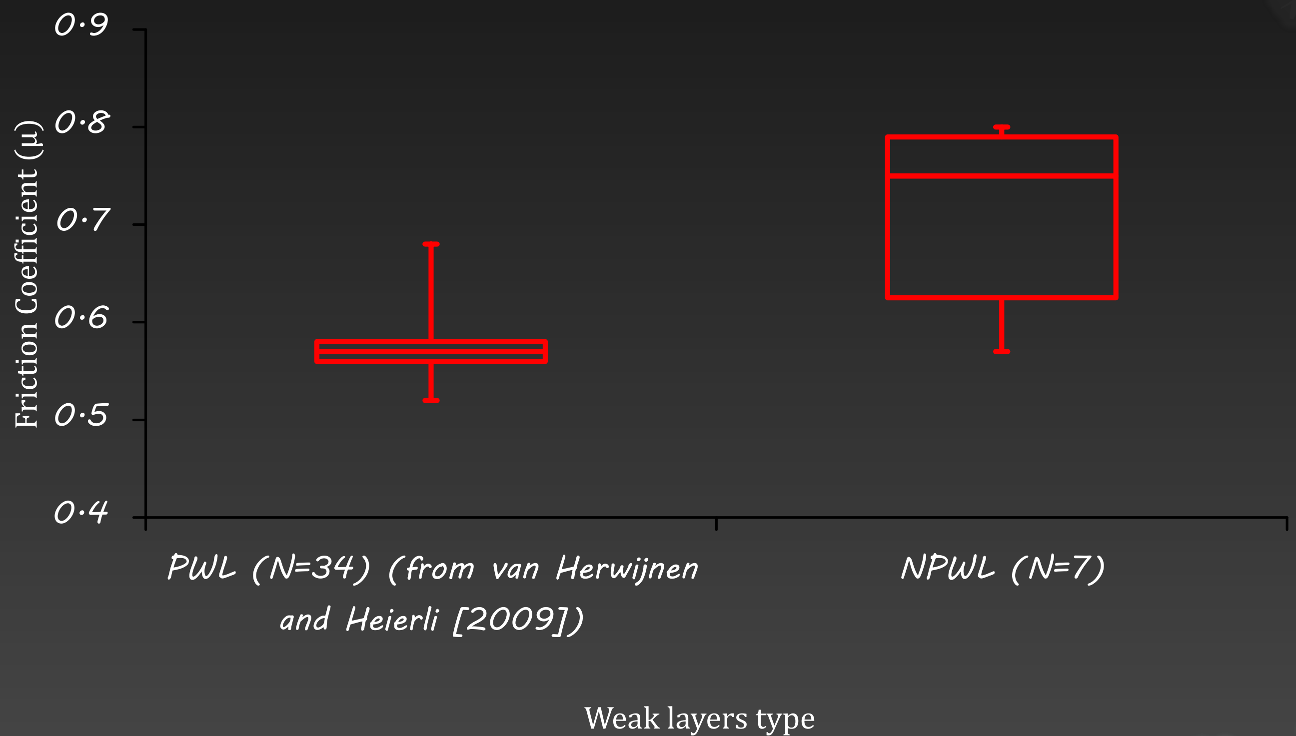
}

- *Get average μ*

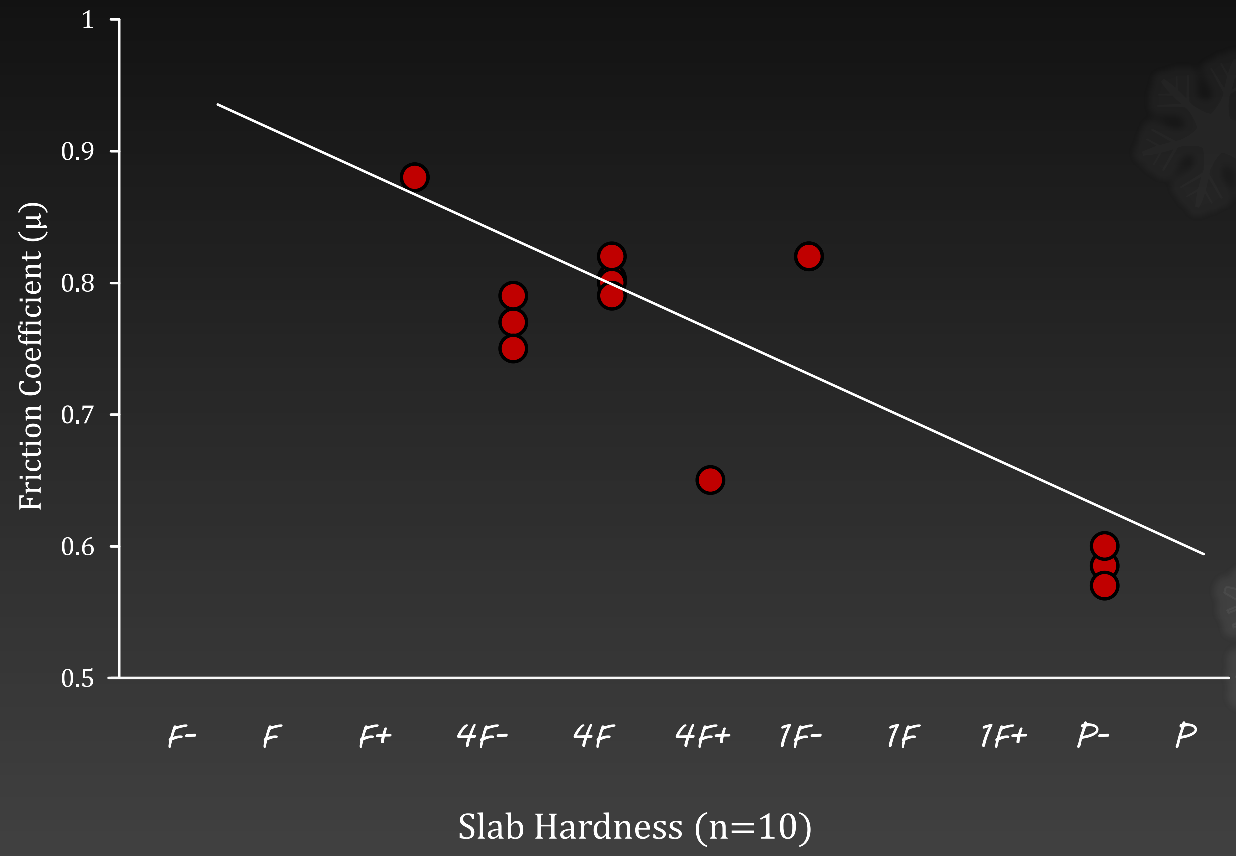


Results (Friction coefficient measurements):

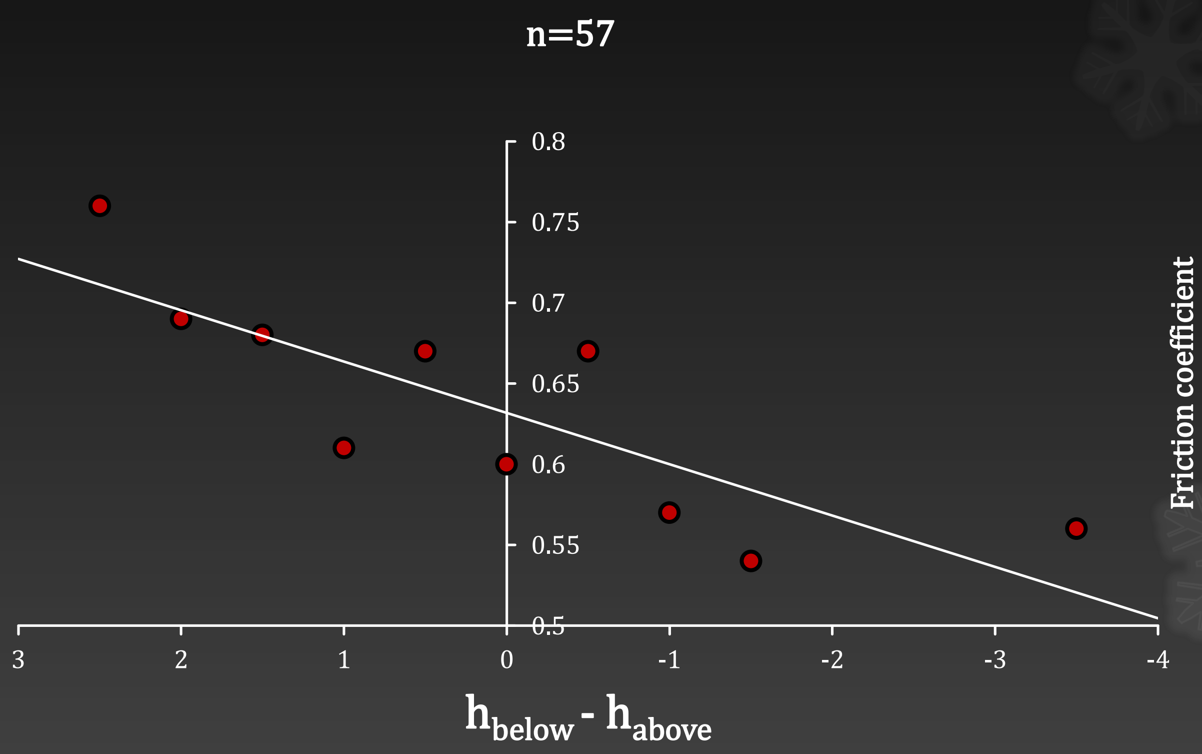
PWL vs. NPWL:



Results (Friction coefficient measurements):



Results (Friction coefficient measurements):



Take home message (friction):

- Avalanches releasing on non-persistent weak layers tend to release on steeper slopes mainly due to crack face friction
- Ski cutting newly fallen soft snow can be deceptive if not carried to the steeper part of the slope
- Hard slab avalanche are more likely to “pull” into flatter areas.
- Relying on crack face friction for stability evaluation is impractical.

Take home message (important):

- The fundamentals of avalanche forecasting shouldn’t change.
- The snowpack doesn't care how much you know
  - Use your knowledge to understand why you need to maintain margins of error rather than narrowing them down.


Thanks!