



MUSLOC 2019, UPC

Landslide activity in Norway due to intense rainfall and snow melt

*Håkon Heyerdahl, José Cepeda, Bjørn
Kalsnes, Kjersti Gislås, Øyvind Høydal,
Frode Sandersen
(NGI / Klima 2050)*





Introduction

- Climatic change
- Some landslide events
- An instrumented slope
- Plans for pilot projects in the “Klima 2050” project

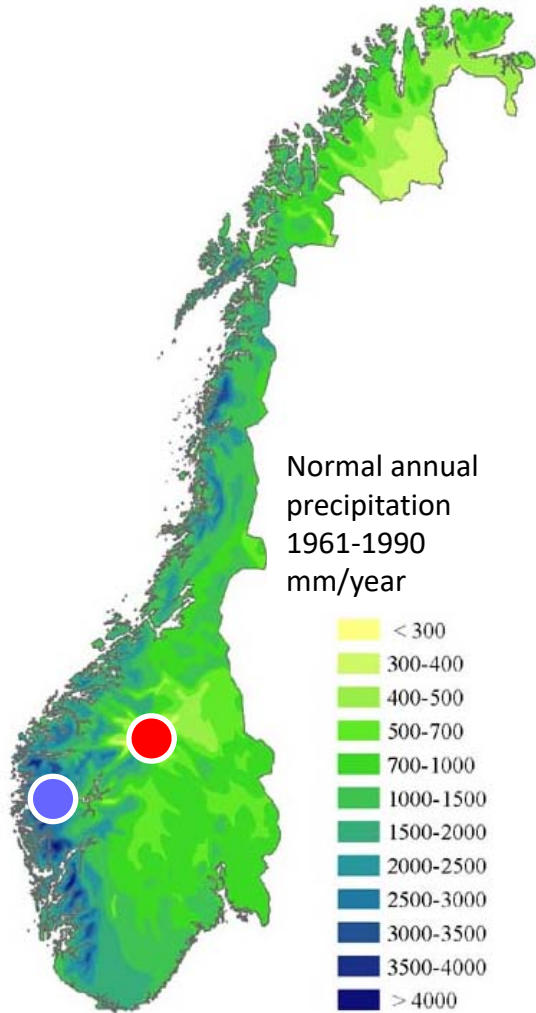


1 Climate change in Norway

- Warmer – shorter winters, less snow
- Wetter – more intense rainfall scours
- Wilder - more wind
- **We already see these effects!**

Normal annual precipitation

(www.met.no)



- Wet on the Atlantic coast (West)
- «Rain shadow» behind central mountain; orographic rainfall (East)

Driest

Øygarden, Skjåk (Gudbrandsdalen)

-> 278 mm/year

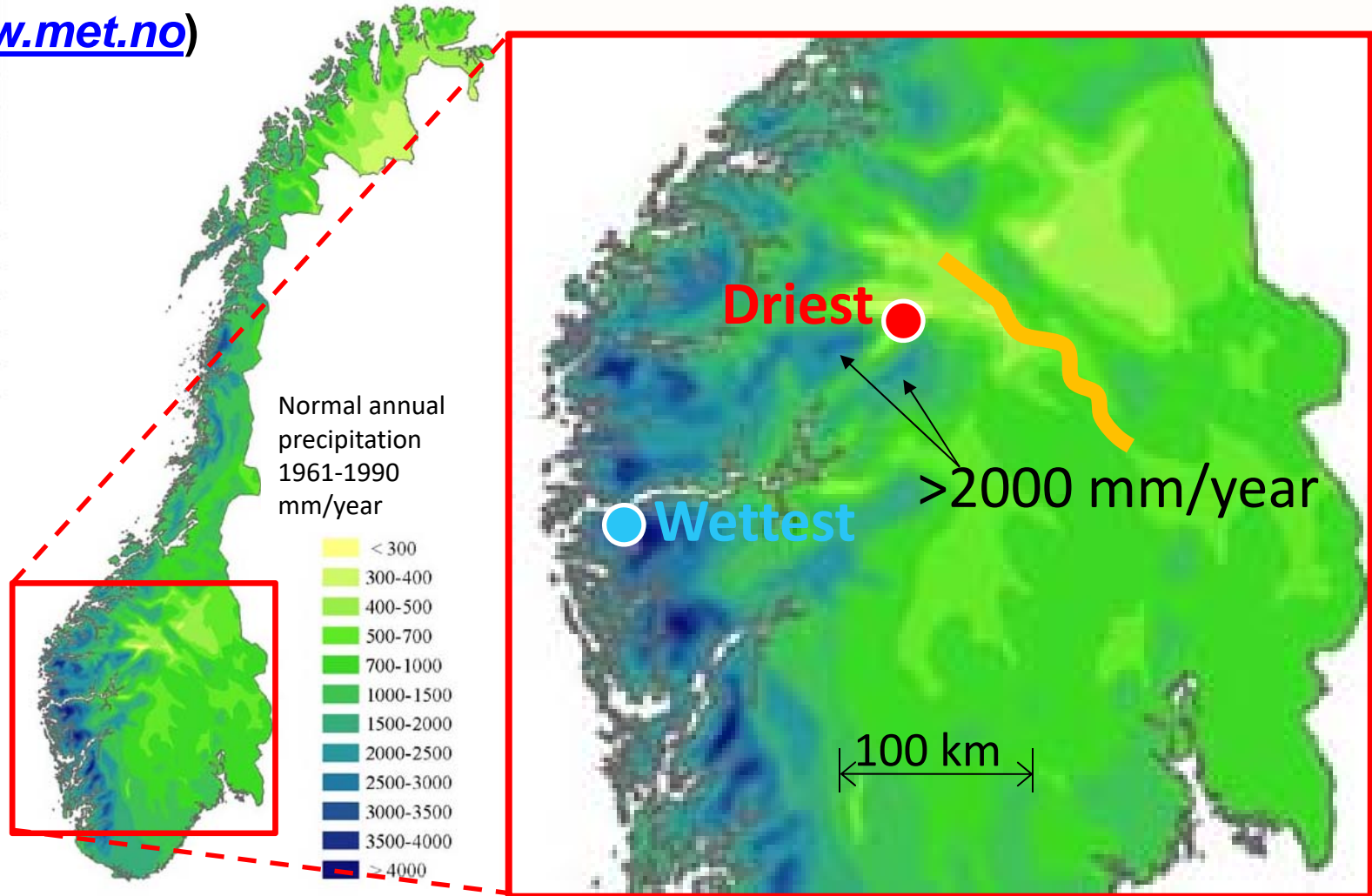
Wettest

Brekke, Sognefjorden:

-> 3575 mm/year (5596 mm in 1990)

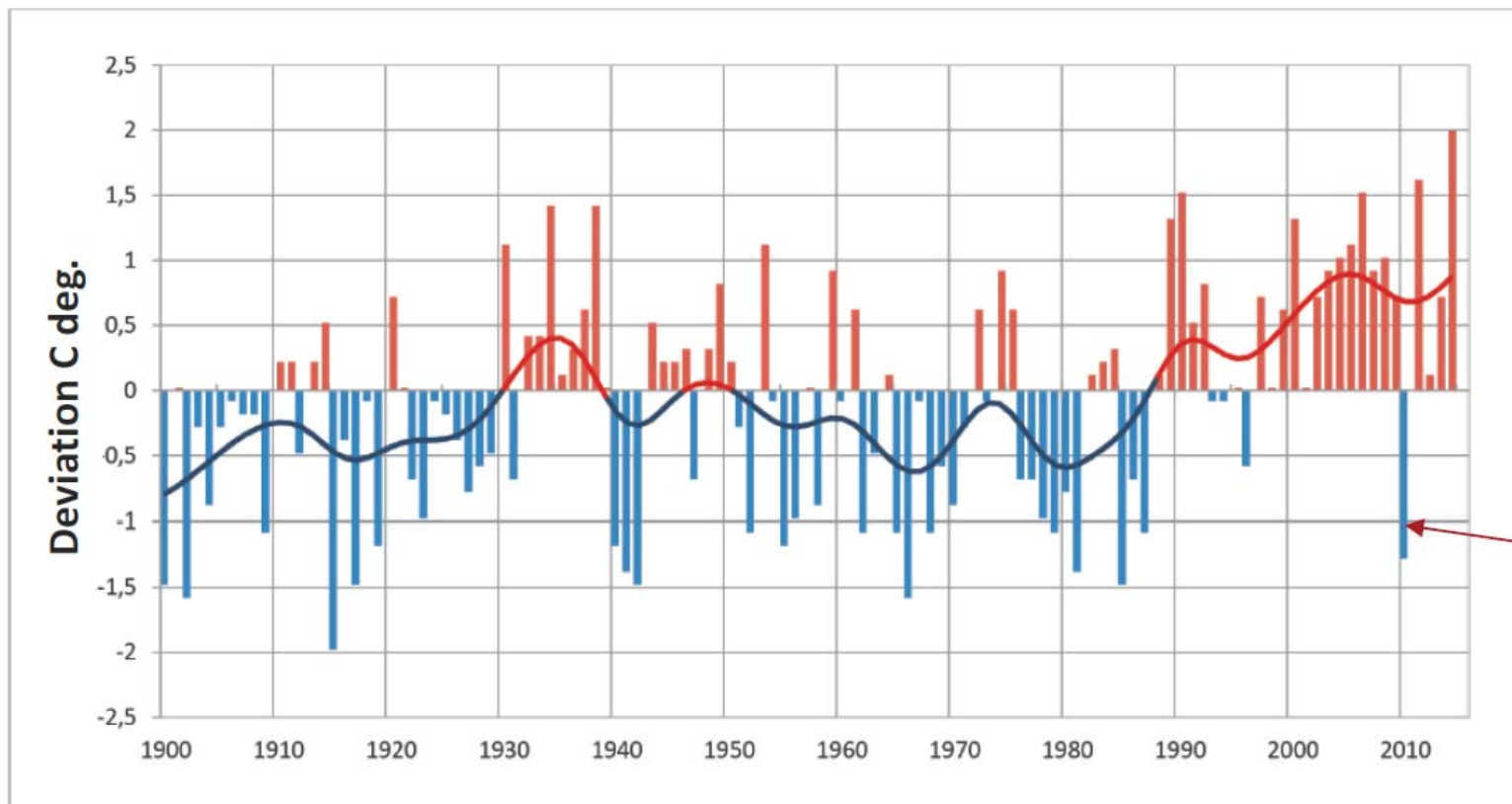
Normal annual precipitation

(www.met.no)





Norway: Development of annual mean temperature 1900-2014

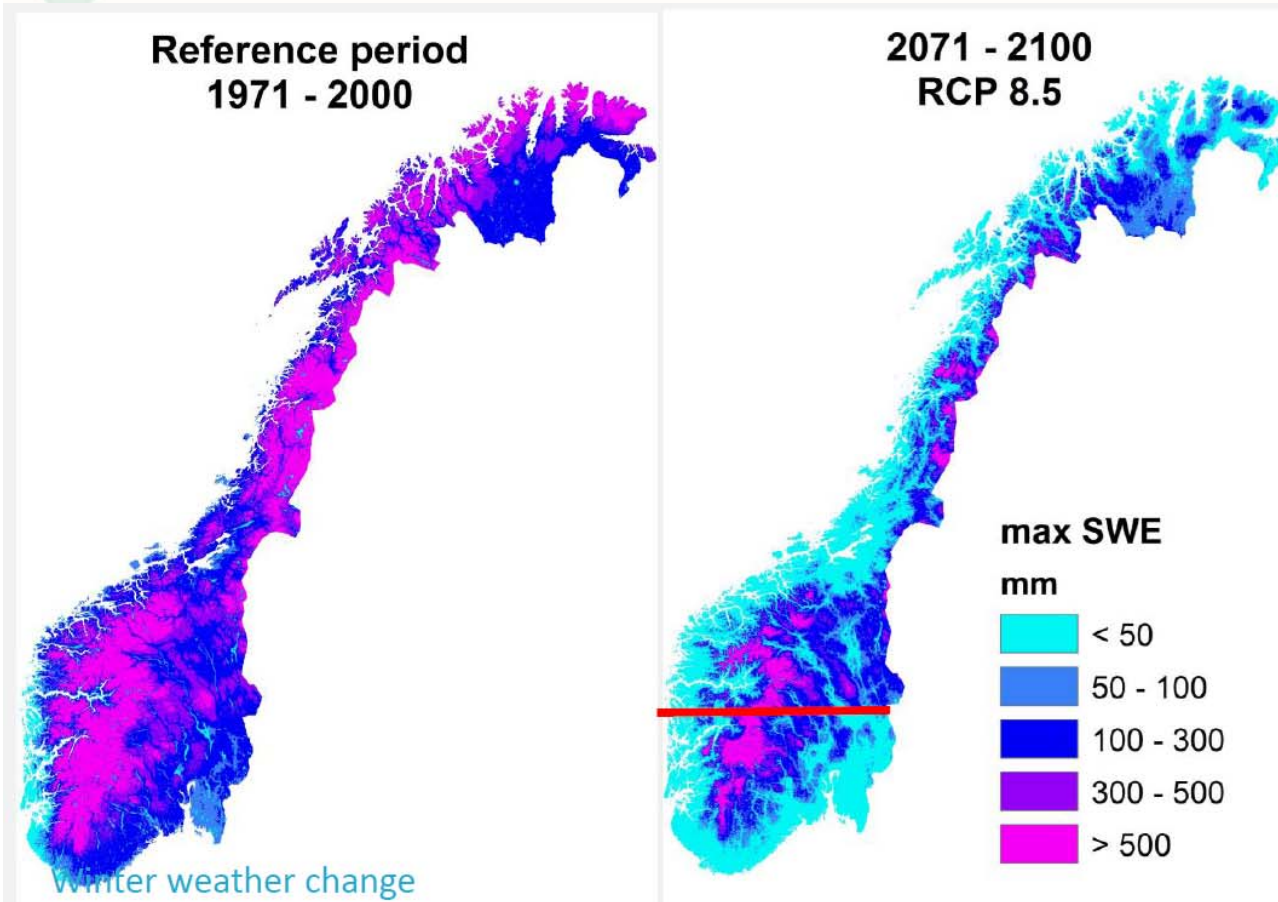


Do not forget this in future climat

Source: K. Isaksen, MET



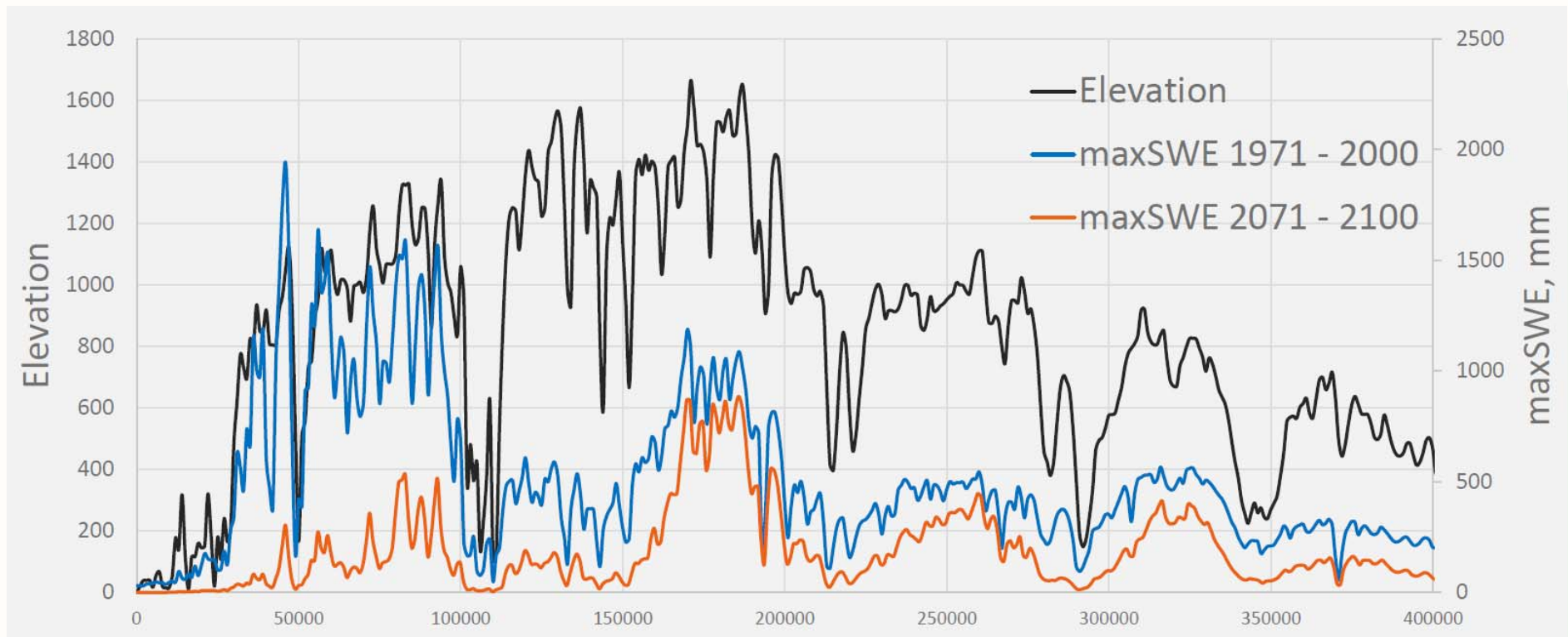
Reduced max snow amount



In high mountain:
Increased precip.,
while most areas will
have an reduction.

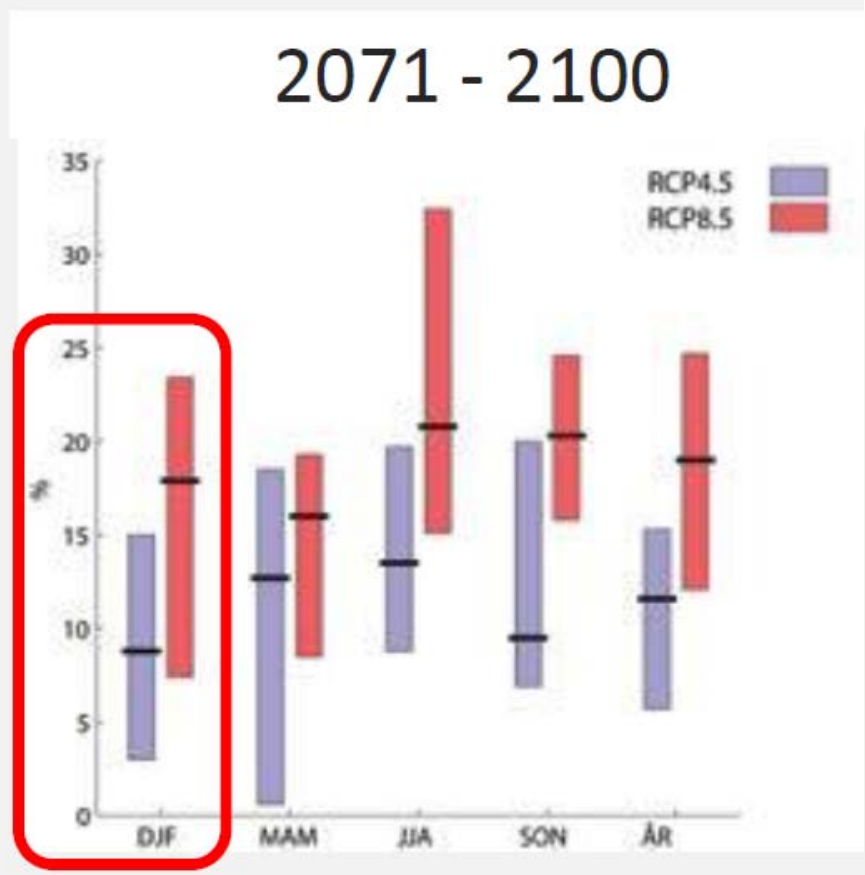
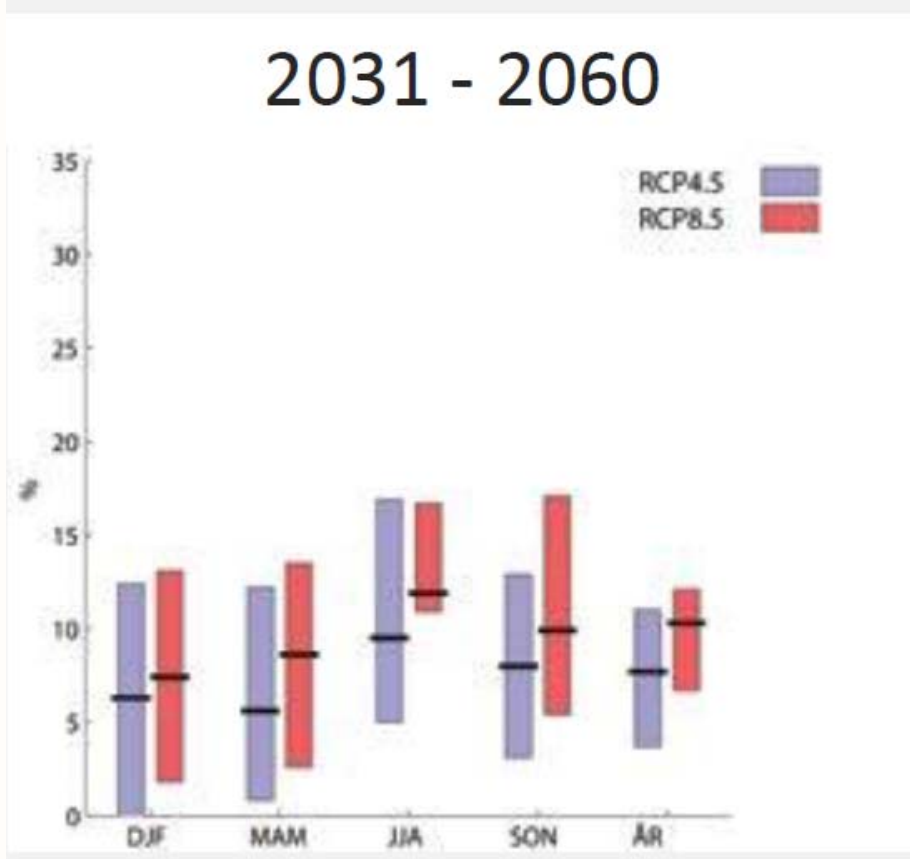


Large reduction in maximum snow amount due to warmer climate





Heavy rainfall: Relative change in precipitation intensity



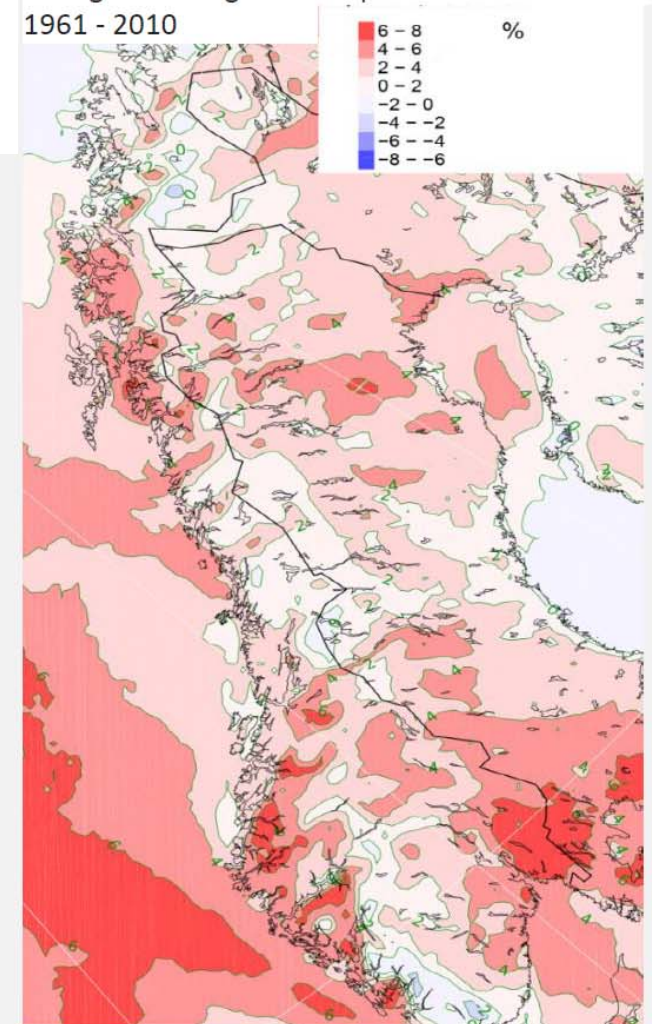


More intense wind

- 1961 – 2010: The strongest wind have increased 6-8% on the west coast
- Future: likely increase in strong wind during winter, but high uncertainty

Change (%) in 99-percentile 2071 - 2100		RCP 4.5	RCP 8.5
Year		-0,8	-0,9
Winter	<i>DJF</i>	1,2	1,2
Spring	<i>MAM</i>	-1,5	-2
Summer	<i>JJA</i>	-1,9	-2,7
Fall	<i>SON</i>	-0,3	0,1

Change in strong wind 99-percentile linear trend
1961 - 2010





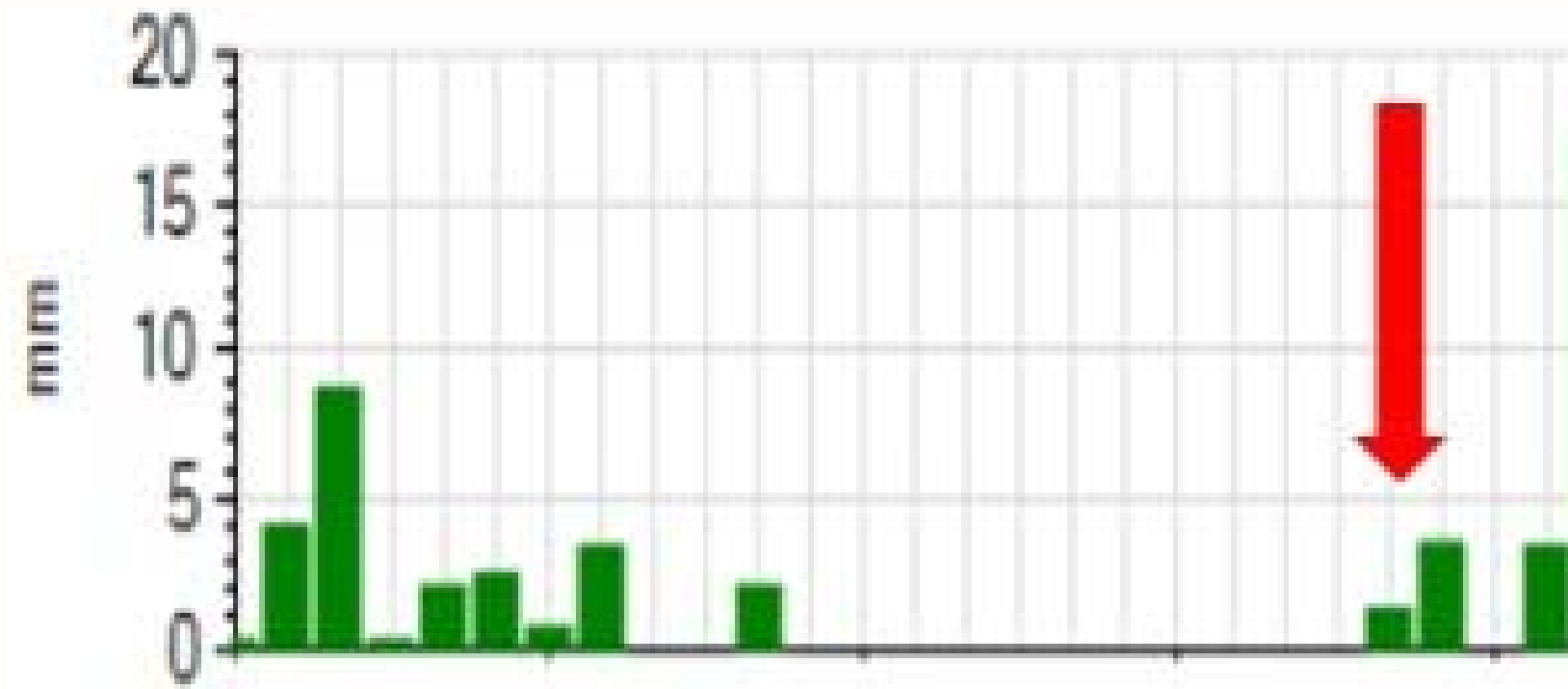
2 Some landslides following hydro-metrological events

Otta, Norway, 29-30 April 2008





Rainfall before landslide



On the day of the landslide: No rainfall, no snow in the area, sunshine.....

www.senorge.no



On the day of the rainfall...

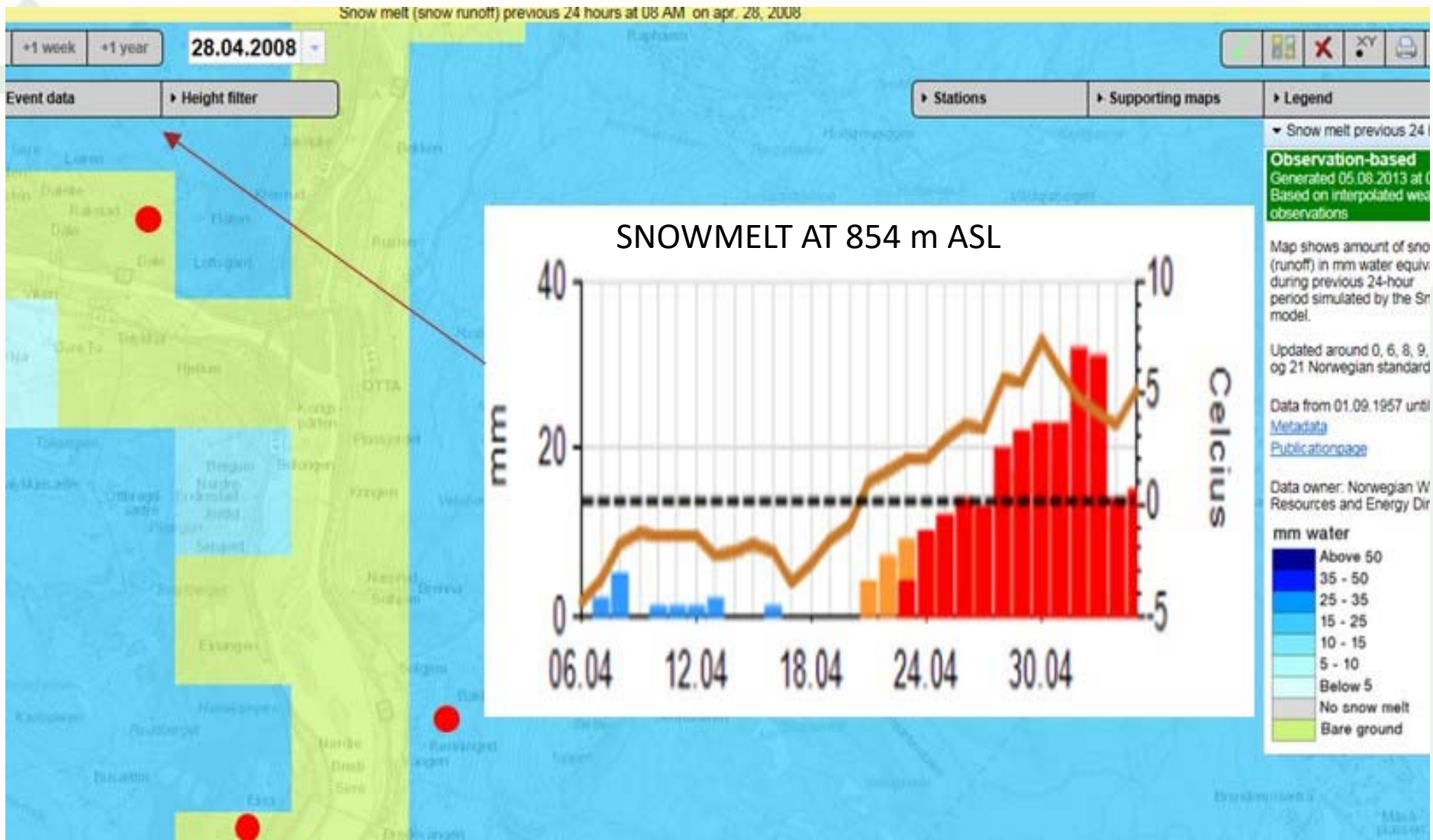
- ↪ No rainfall
- ↪ Sunshine
- ↪ No snow in the landslide area

➔ **Thirsty from thinking:
What may be the reason for this slide...**



Photo: H. Heyerdahl, NGI

Snow cover and snow melt in the mountains



www.senorge.no



Landslide events in Jølster, 2019

- Report for landslide hazard mapping in Jølster delivered spring 2019
 - NGI on behalf of NVE
- In July 2019 an extreme event occurred
 - Rainfall stopped in the Jølster area
 - Extreme local rainfall (exact values not known)
 - Debris flows on open slopes and along rivers

Photos from Jølster: Øyvind Høydal/Frode Sandersen, NGI

Jølster, 2019 – Landslides



Photo: Øyvind Høydal/Frode Sandersen, NGI

Jølster, 2019 – Debris flows scraping off soil to bedrock





Jølster, 2019 – Runout towards farm





Jølster 2019 – What is the effect of vegetation



➔ Jølster, 2019 – Shed hit by runout



➔ Jølster, 2019 – Vassenden, debris flow along river



➔ Jølster, 2019 – Vassenden, debris flow along river



Jølster 2019 – Car hit by slide



Driver not found



How to deal with such events?

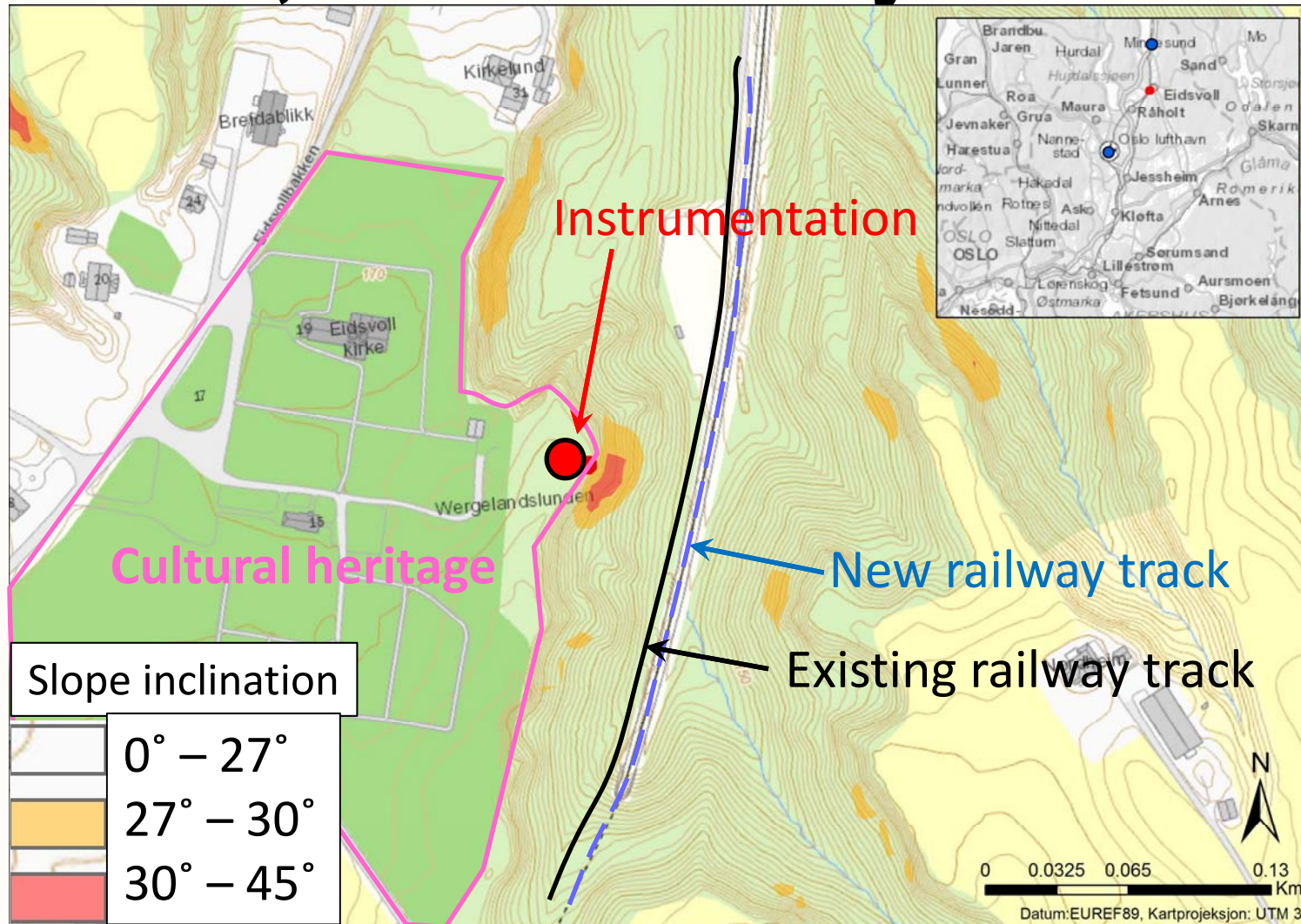
- Virtually all soil slopes (and down slope areas) in region potentially exposed during extreme conditions
- Can we secure such areas? To what level?
 - Linear infrastructure
 - Dwellings?
- Can they be predicted / warned prior to occurring?
- General societal risk in critical situation:
 - Mobile network was down
 - Power supply was down
 - Roads in/out of area were blocked
 - Water supply affected locally



Landslide hazard mapping in Jølster

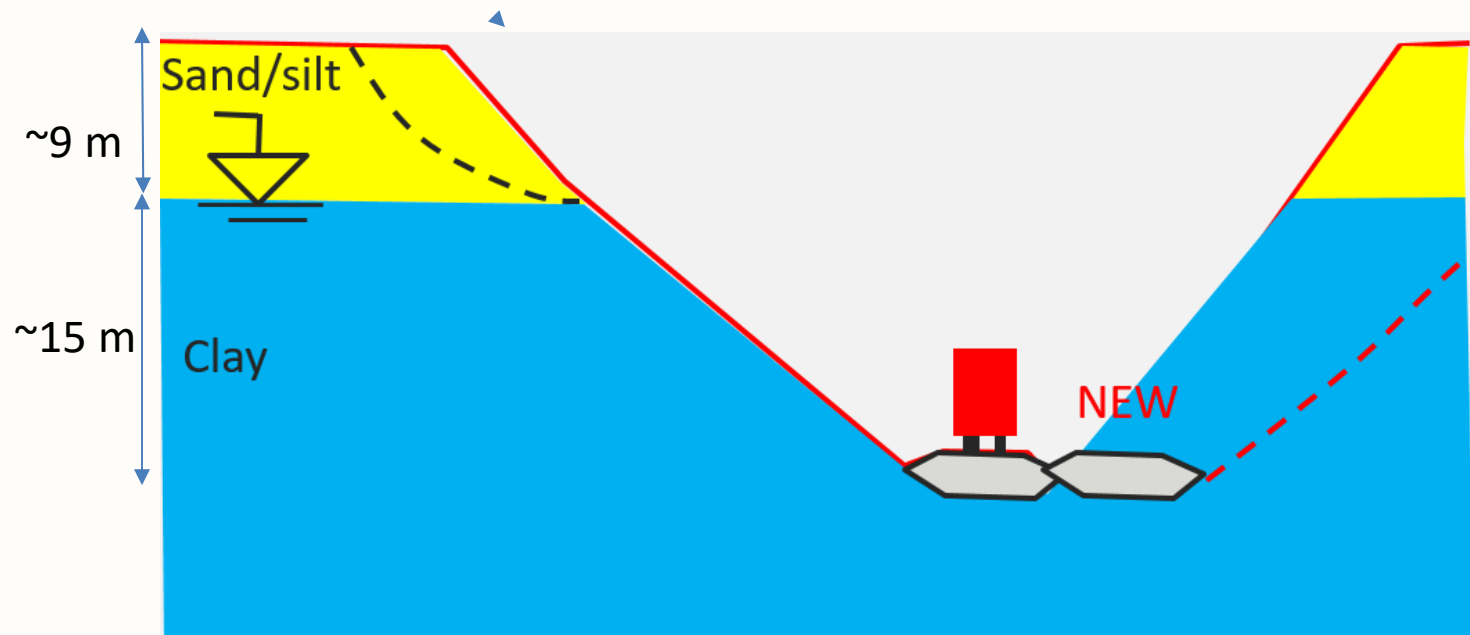
- Fair correspondence with events
- However:
 - Extreme events – what is the «return period»?
 - Where will they occur?
 - Intensity of debris flows difficult to assess prior to event
- NGI will do a research project on the event

3 An instrumented railway slope at Eidsvoll, Eastern Norway



Design criteria for slope stability

- Eurocode 7: $\gamma_m \geq 1.25$ for drained conditions.
- Railway owner requires even higher safety level
- New track activates slope safety requirement for the left slope!
- Preservation of the left slope desirable (cultural heritage)

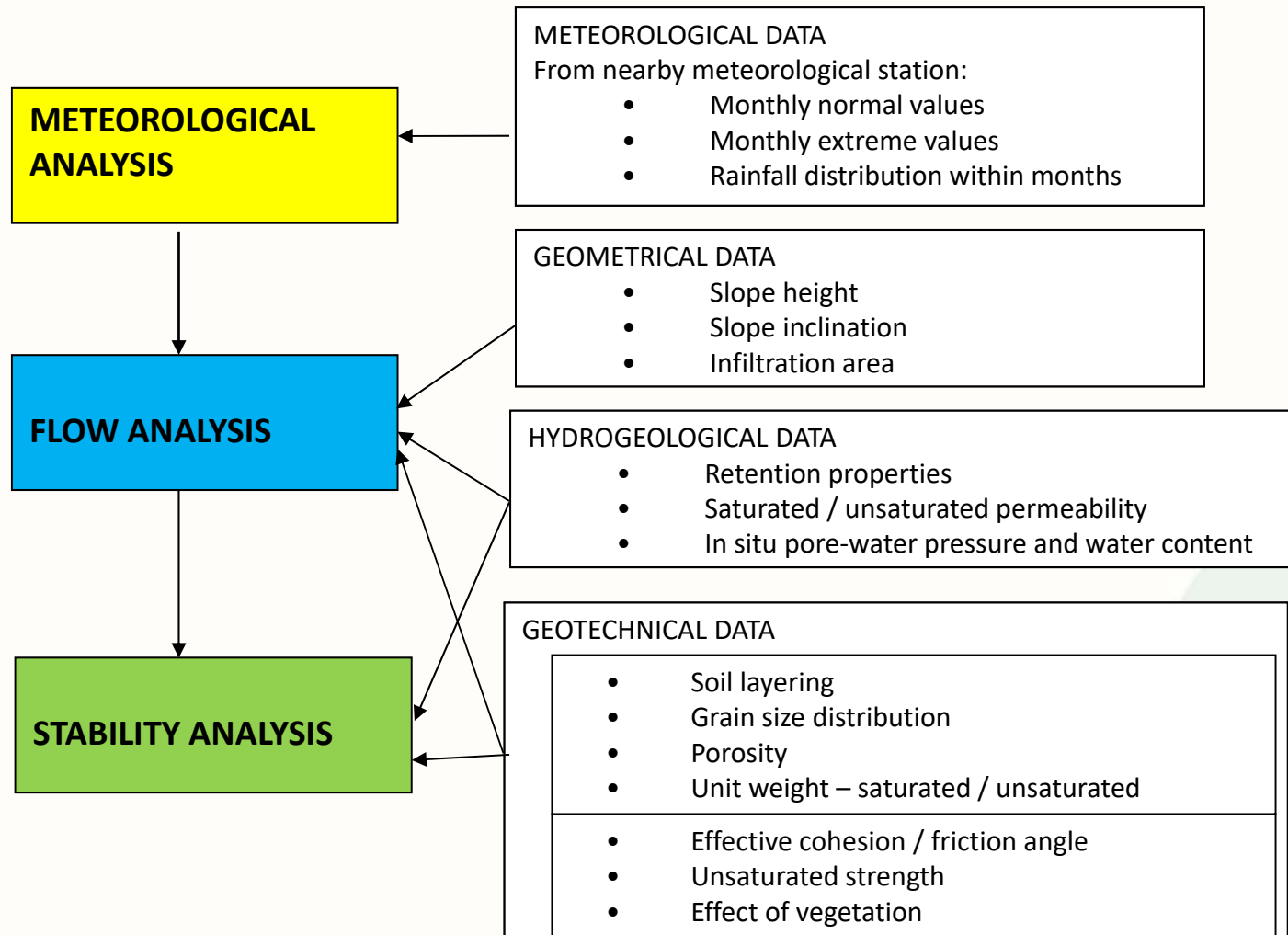




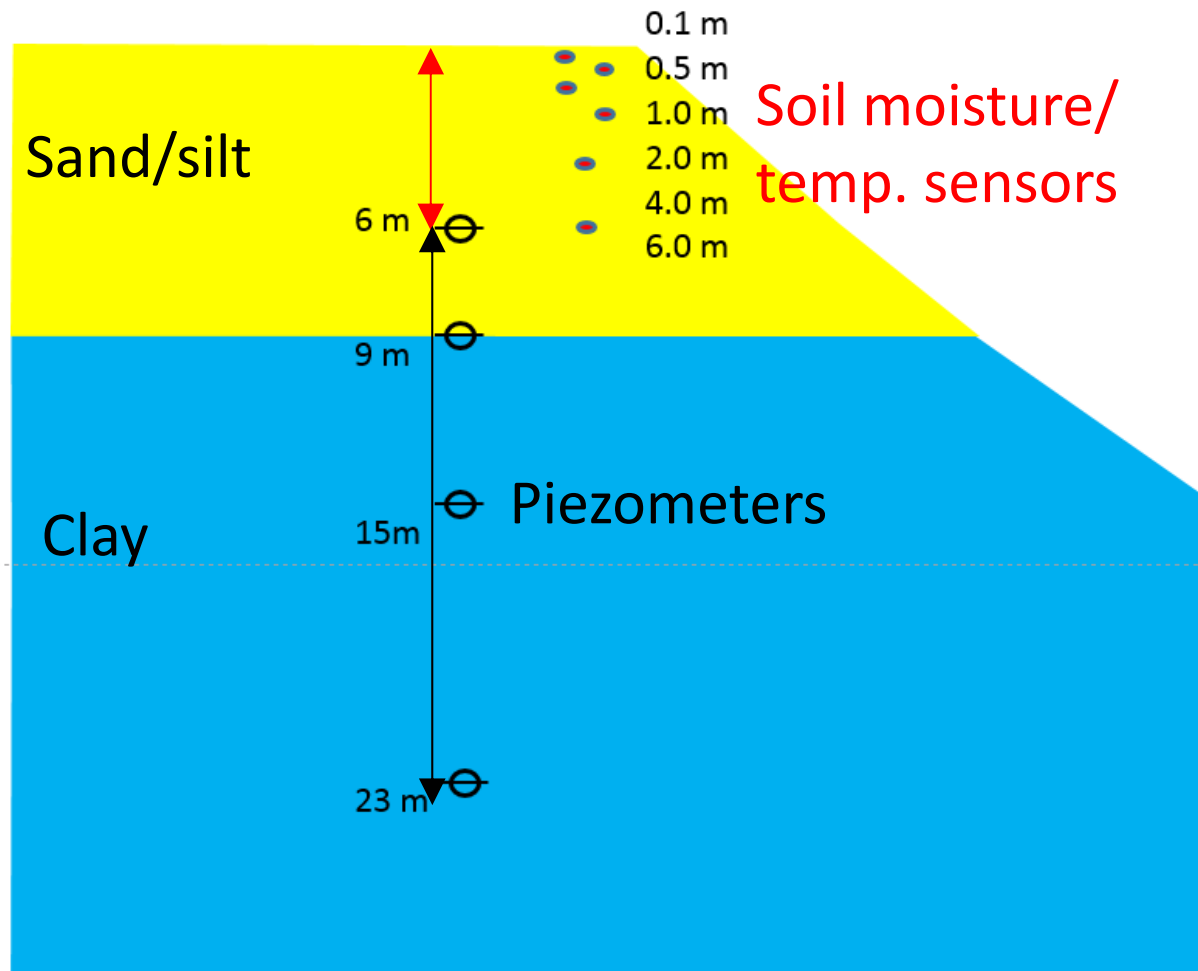
Alternative approach possible?

- What is the probability of a slide from the upper layer?
- Which annual probability (or risk) is acceptable?
- How to perform such an evaluation?

Input required for analysis



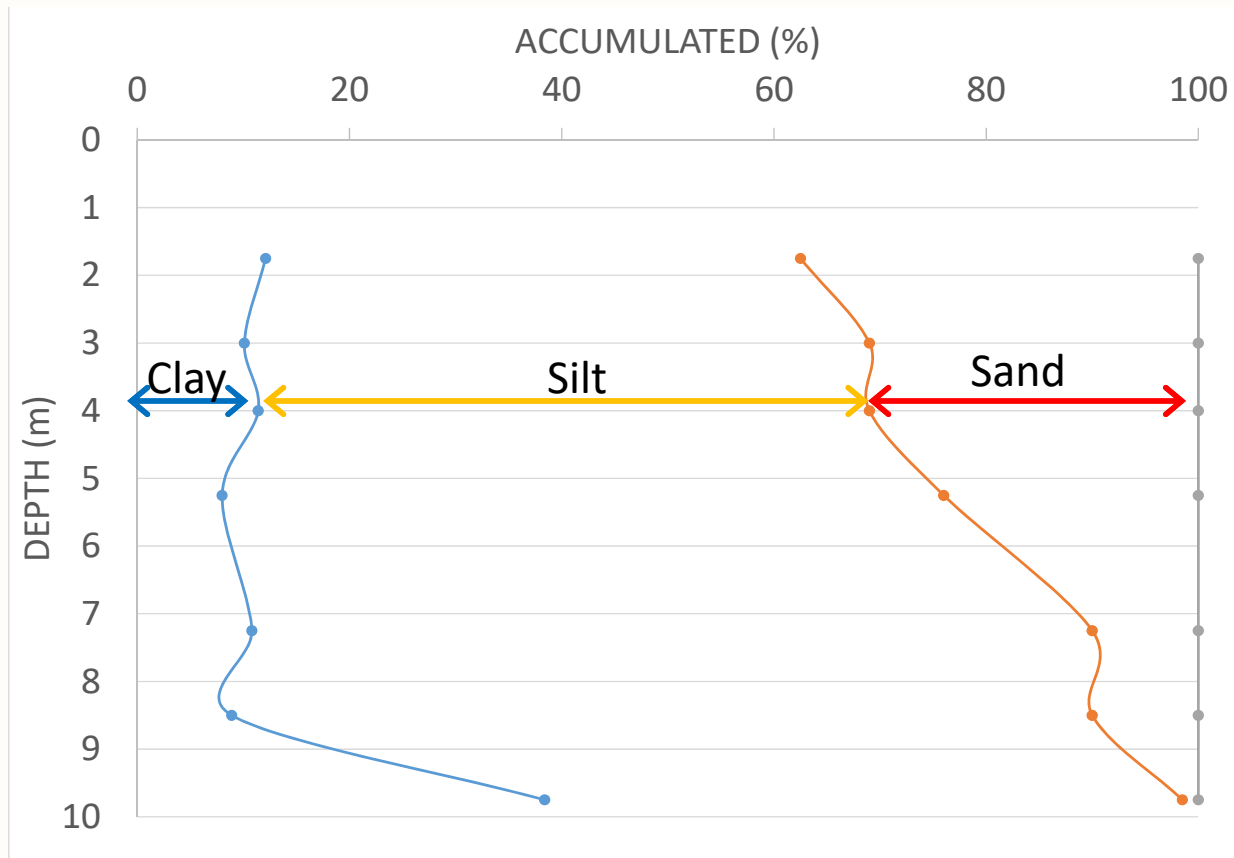
In situ slope instrumentation



Installation holes for sensors

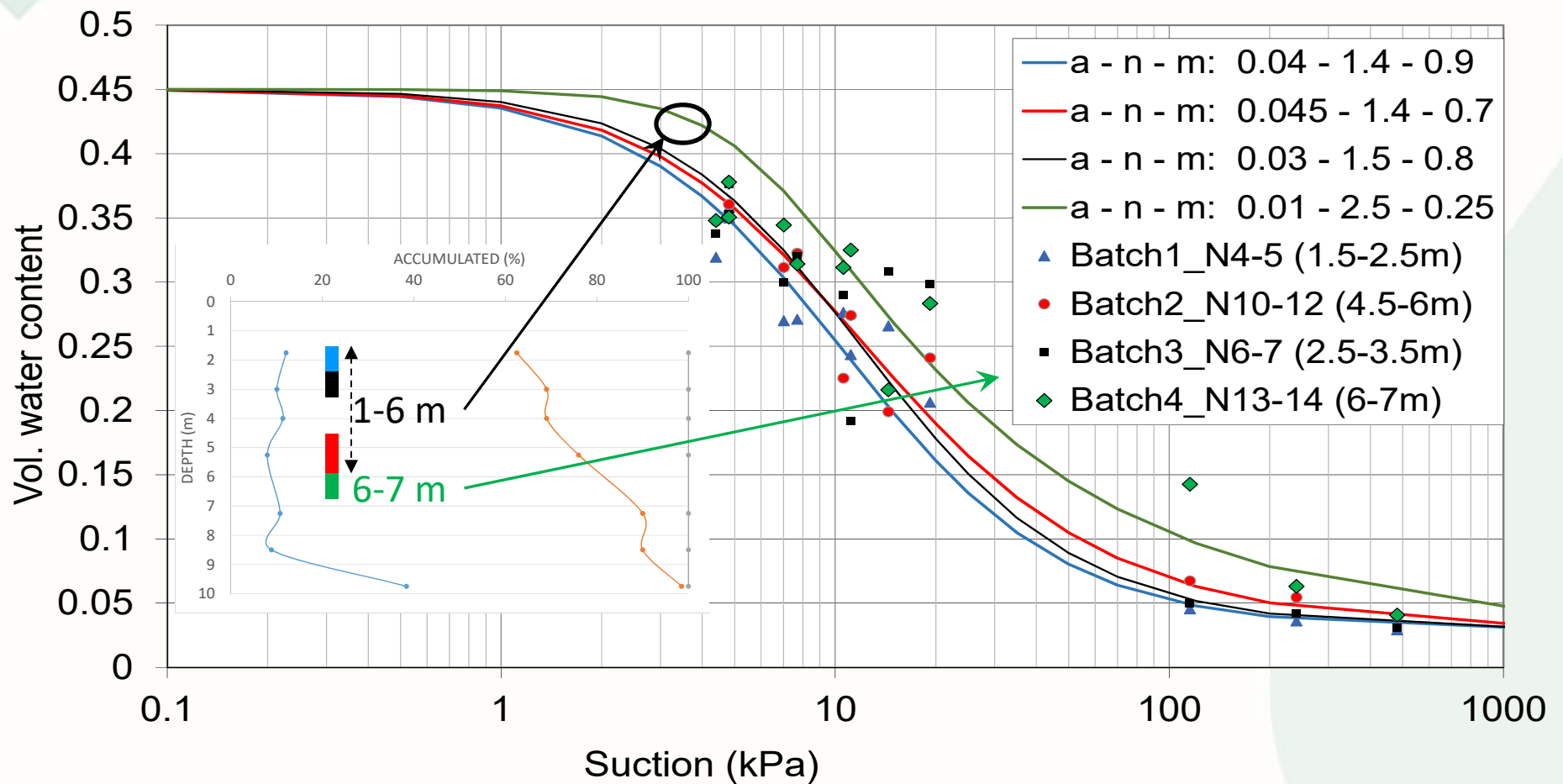


Variation in GSD with depth

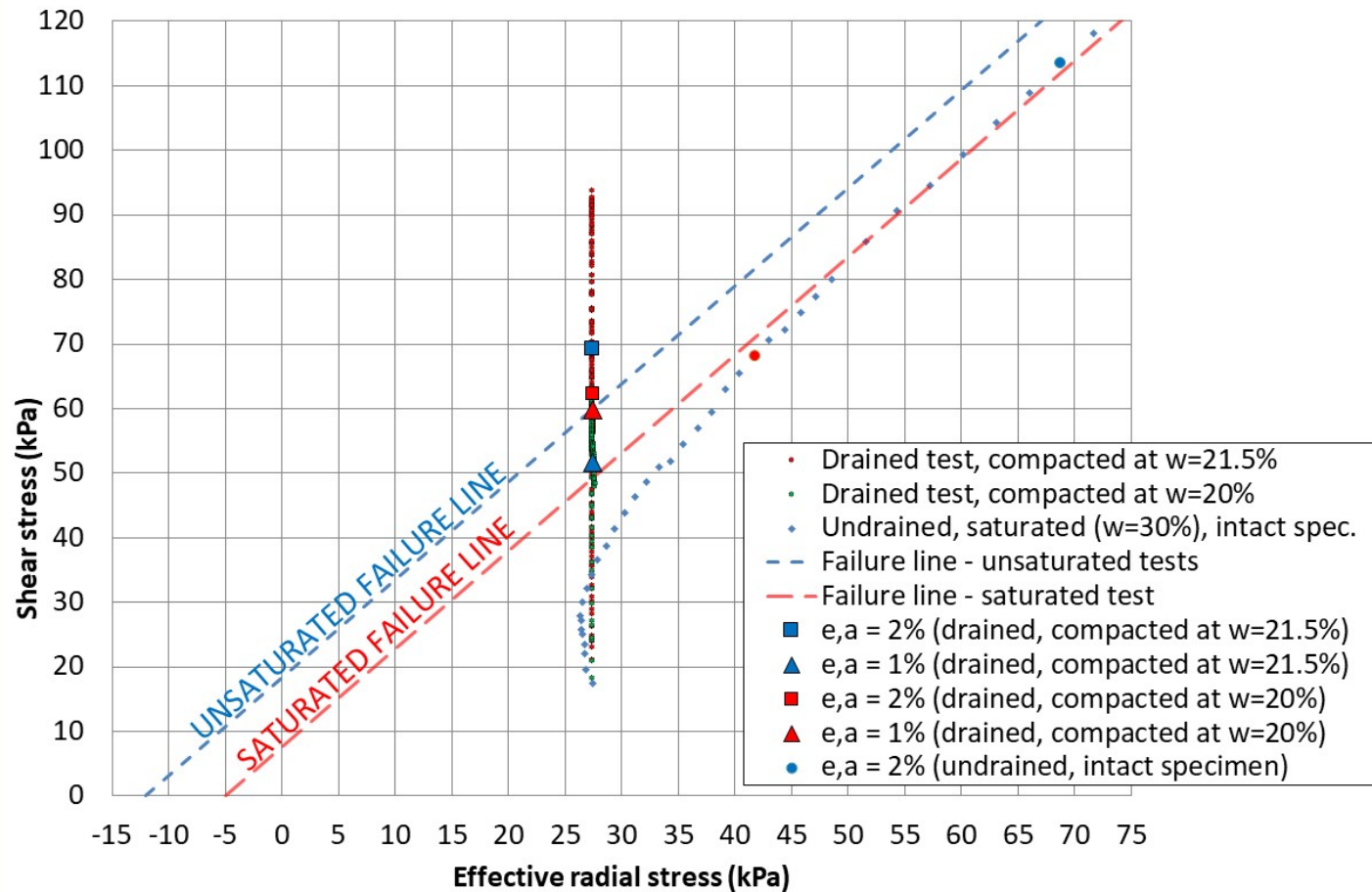


Continuous change in grain size distribution. How can we approach this

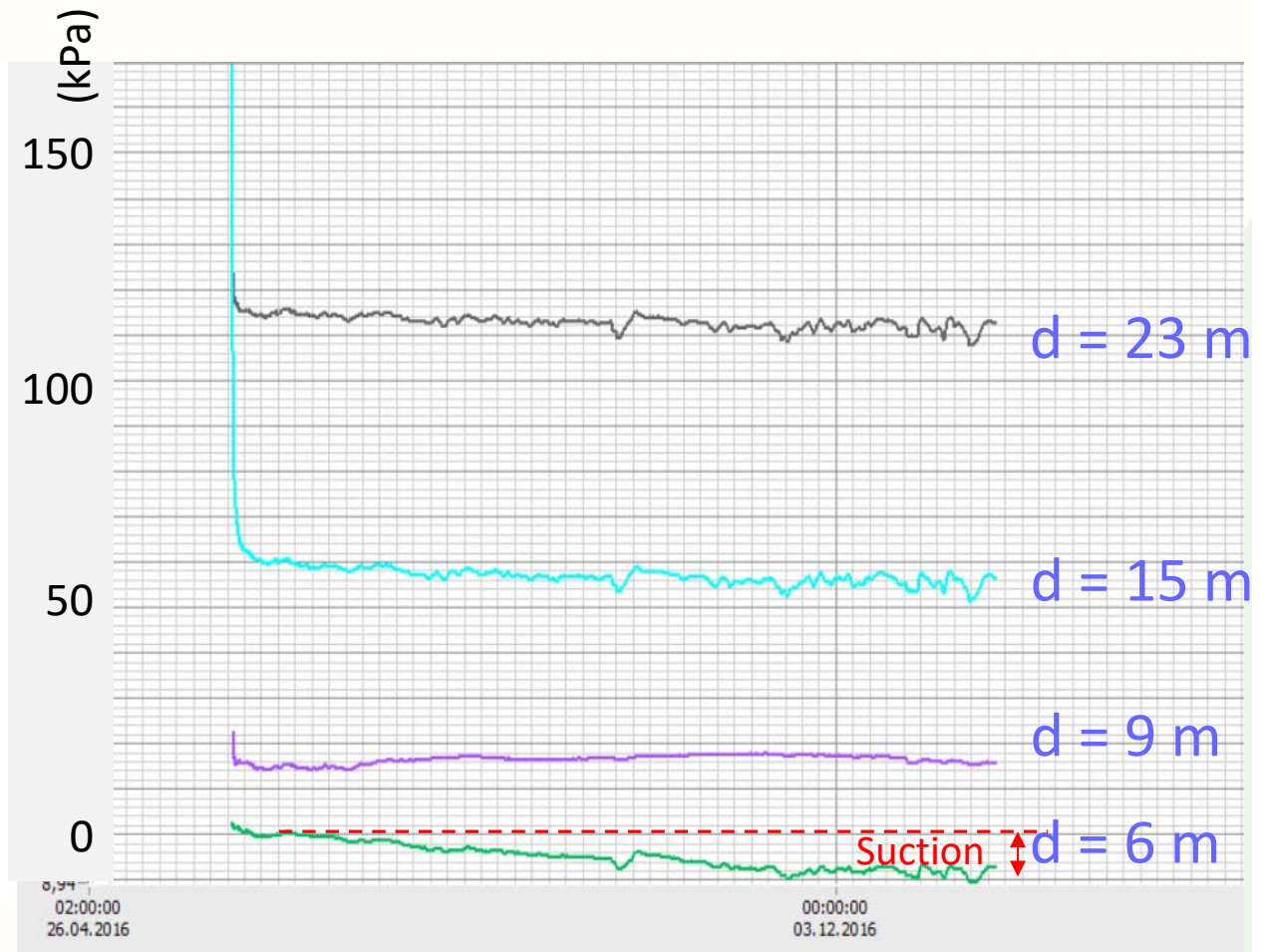
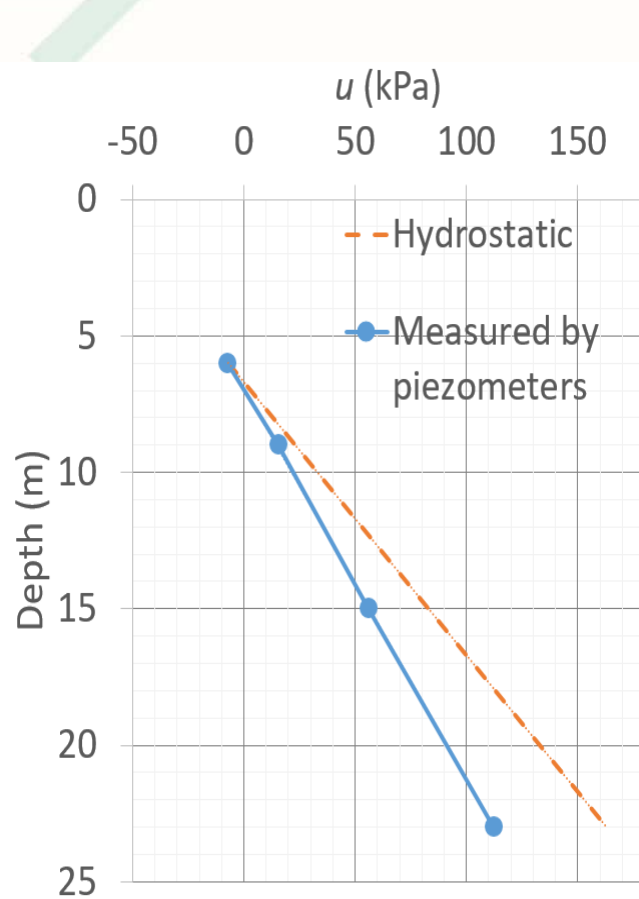
Retention curves and GSD



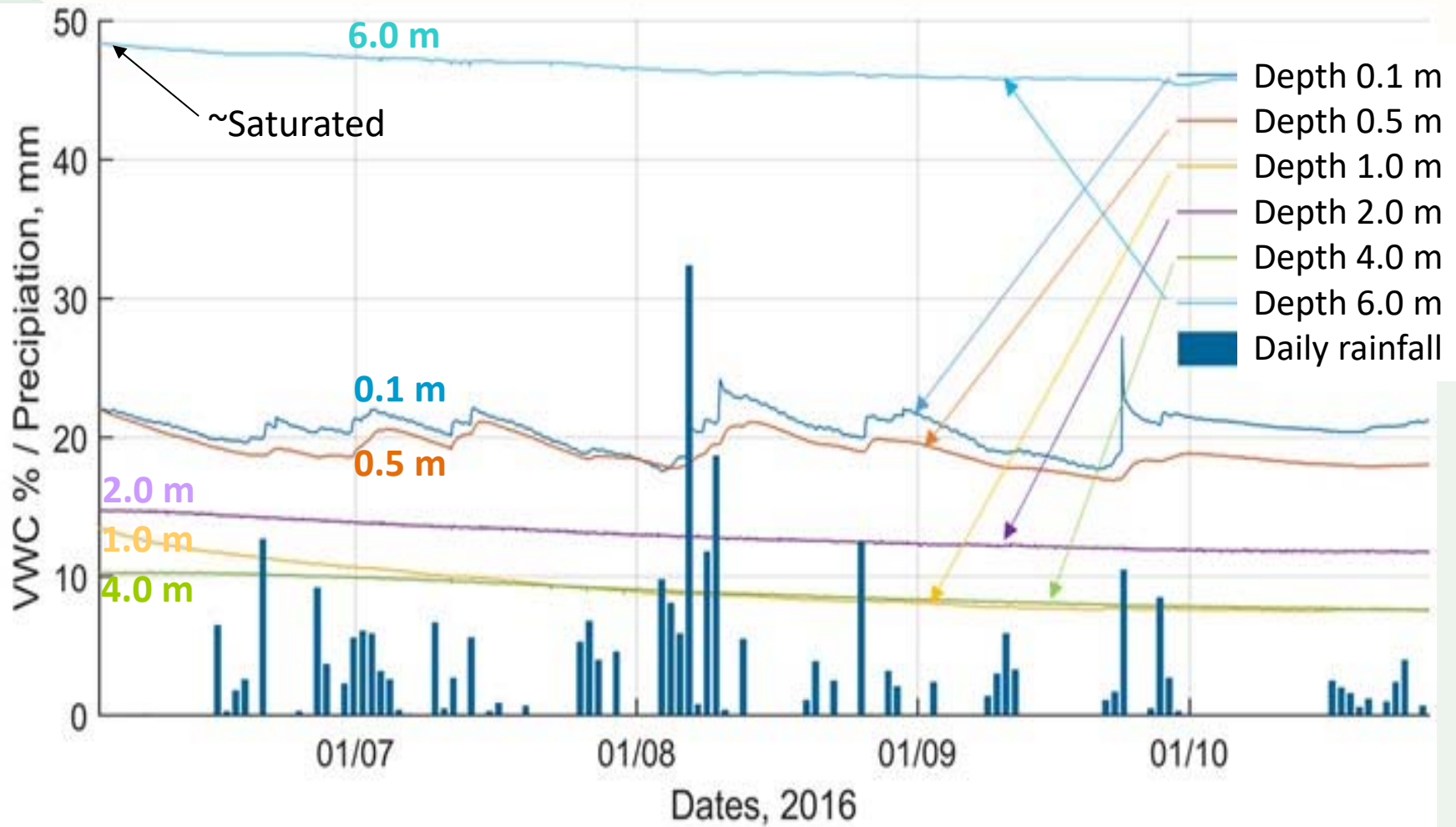
Triaxial tests – intact/compacted (saturated/constant water content)



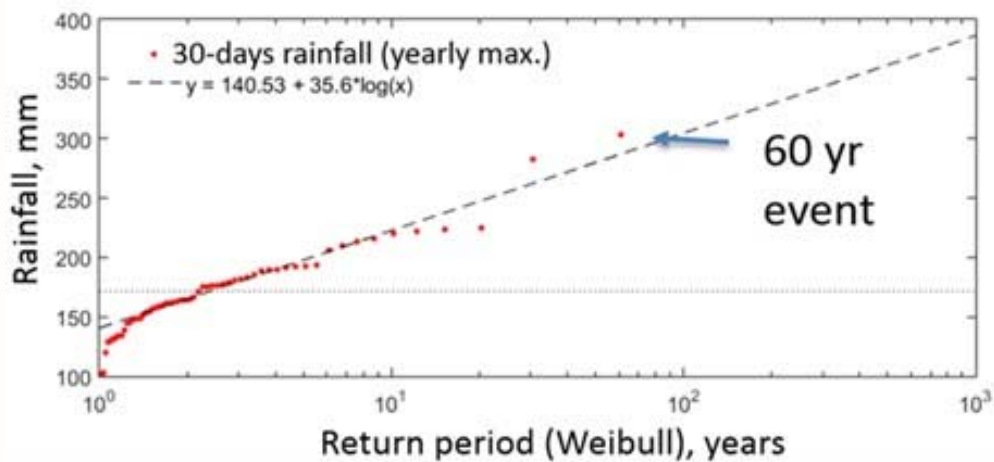
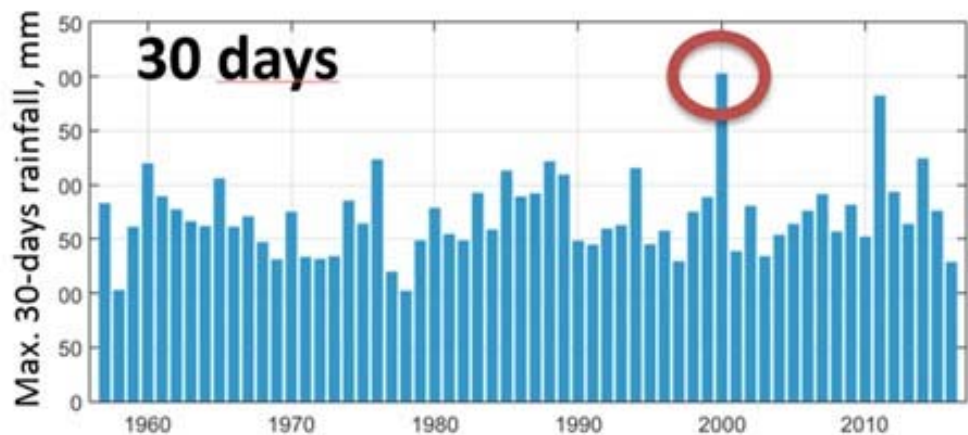
Field data: Pore-water pressure



In situ water content and daily rainfall

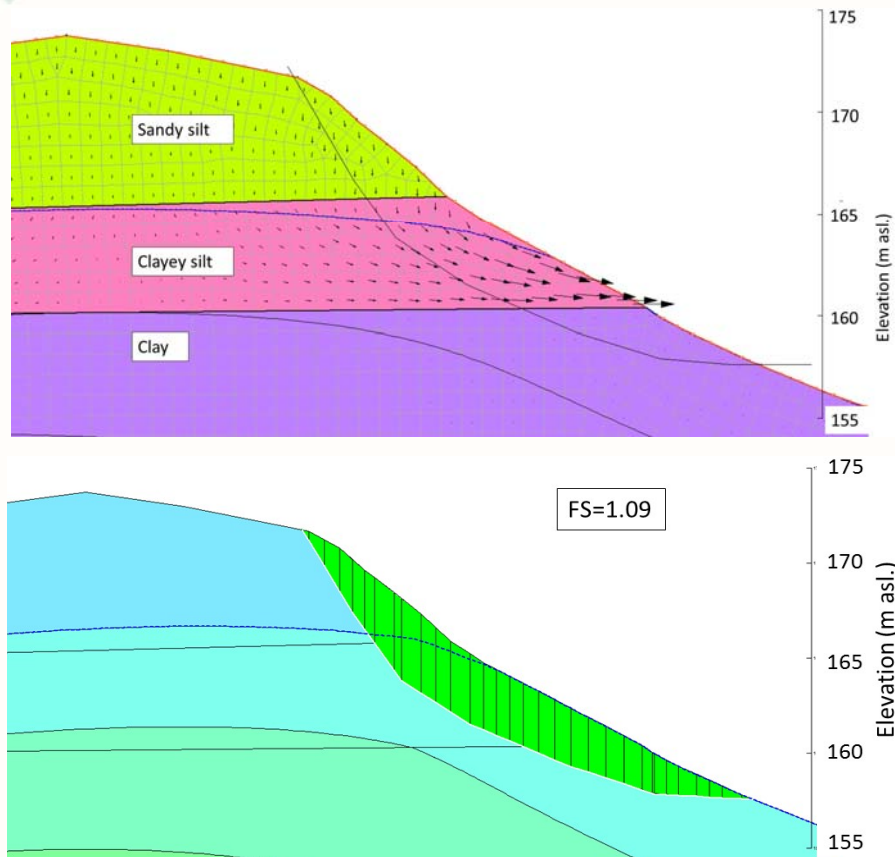


Design rainfall and return period



Date	mm
27-11-2000	303.1
06-09-2011	282.4
03-11-2014	224.6
13-11-1976	223.5
11-09-1988	221.8
27-07-1960	219.9
12-09-1994	215.6
05-09-1985	213.2
25-08-1989	209.6

Stability during autumn of year 2000



Day no.	Safety factor (same surface)
0 (1 Aug)	1,09
73 (12 Oct)	1,05
115 (24 Nov)	0,96
134 (14 Dec)	0,97

Note: No failure in year 2000!



Conclusion for slope safety

- Combined in situ instrumentation, laboratory testing and numerical analyses gave increased understanding of slope respons.
- Stabilizing measures in the upper part of the slope were avoided, assuming $P(\text{failure}) < 1/100$ pr. year is acceptable.
- Review of evaluations to be continued in future pilot study

Acknowledgments

- Bane NOR SF
- Norwegian Research Council (RCN)



4 Pilot study 1 (Eidsvoll site)

- ↪ Continue measurements
- ↪ Local rainfall station
- ↪ Update hardware to web-cast data
- ↪ Apply ML for infiltration data
- ↪ Automize stability evaluations
- ↪ Use this for local warning for the railway
- ↪ Cooperating with the railway company

Pilot study 2: Bodø site

- ↗ 500 m long clay slope along railway
- ↗ Seasonal movement along much of the slope in wet periods
- ↗ Want to test various types of mitigation and also monitoring
- ↗ Many ideas from this workshop!
- ↗ Cooperation can be possible

