Photo: Turid Haugen

Trends in hydrometeorological avalanche indicators in Norway and Svalbard

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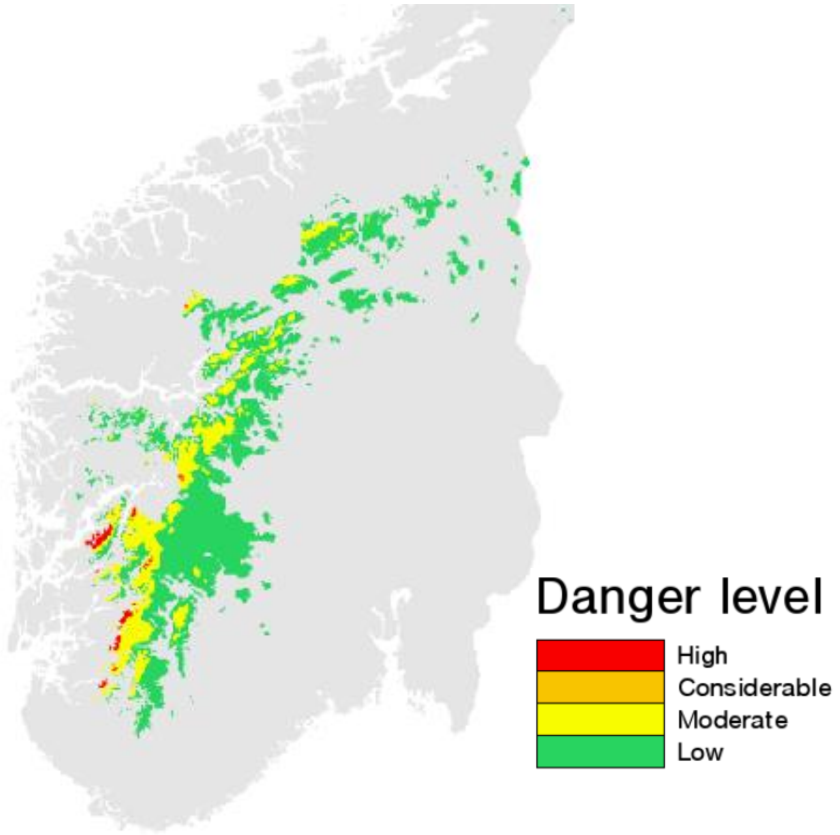
Our research focus

«How has avalanche activity changed the last 50-100 years?»

- No long time series exist of observed avalanche activity…
- … therefore we use avalanche indicators as indirect «proxy-data»



Different objective methods to estimate the daily avalanche danger

- **Indicators**
- **Large-scale weather patterns**
- **Machine learning**
- **More detailed snow models**

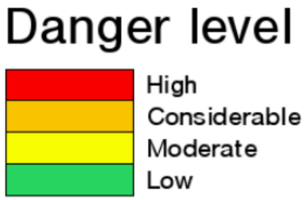
How do we do it?

- Constructing avalanche indicators for different avalanche types/problems
- Analyzing long-term trends in indicators
  - Data even back to 1957
  - Spatial resolution in mainland Norway 1 x 1 km and in Nordenskiöld Land on Svalbard 2.5 x 2.5 km
  - Next step to extend the analysis to 1970-2100 by climate model data

Avalanche indicators

- **Indicators 1 & 2:** new snowfall (NS1, NS3)
  - A lot of snowfall over 1-3 days
- **Indicator 3:** new wet snow (NWS)
  - A lot of rain/snow melt water for the first time on a snowpack
- **Indicator 4:** wind-blown snow (WBS)
  - A lot of wind over loose and dry snow surface

Threshold values divide the indicator scale into discrete classes



What is it useful for?

- In planning of costly avalanche mitigation measures (sometimes >100 mill. NOK) and land use
  - How is avalache danger changing in a future climate (cost & benefit)?
- In avalanche forecasting
  - Good avalanche indicator maps may provide useful information for the forecasters.

Set-up in mainland Norway

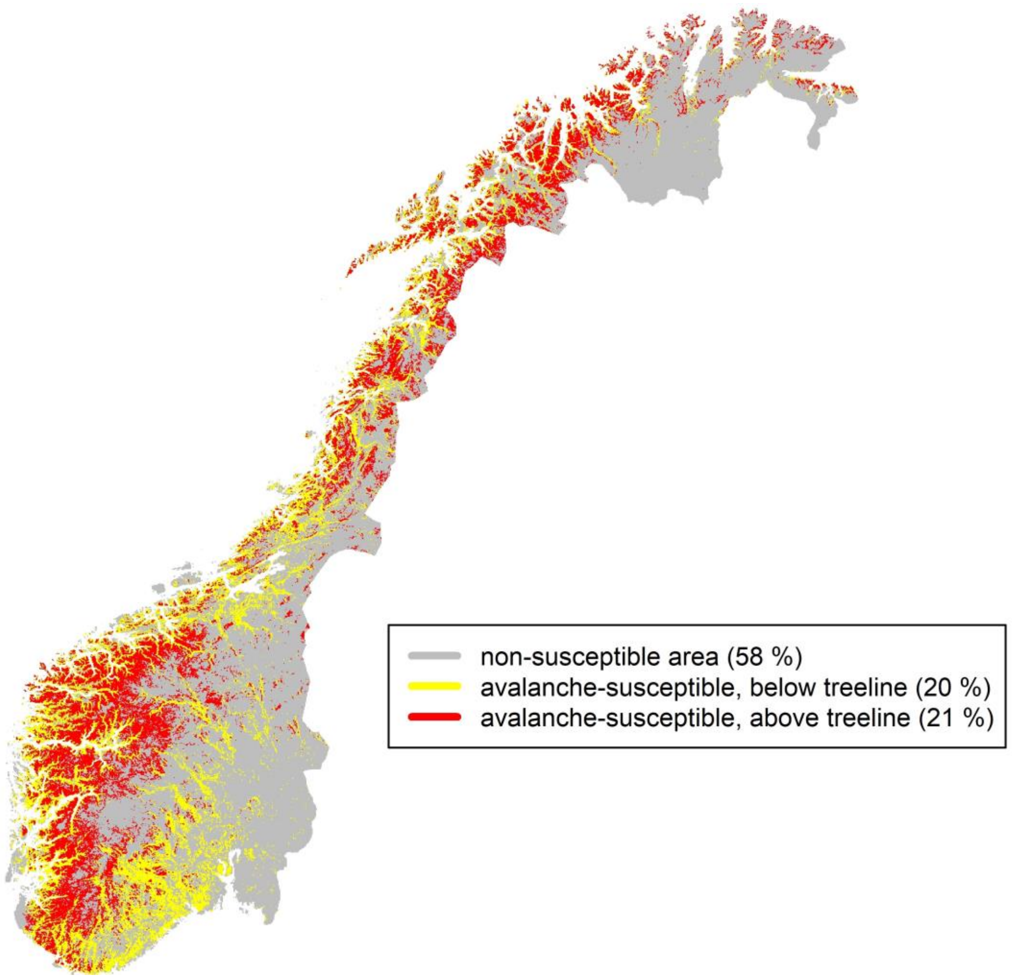
Two seasons: winter (dec-feb) and spring (mar-may)

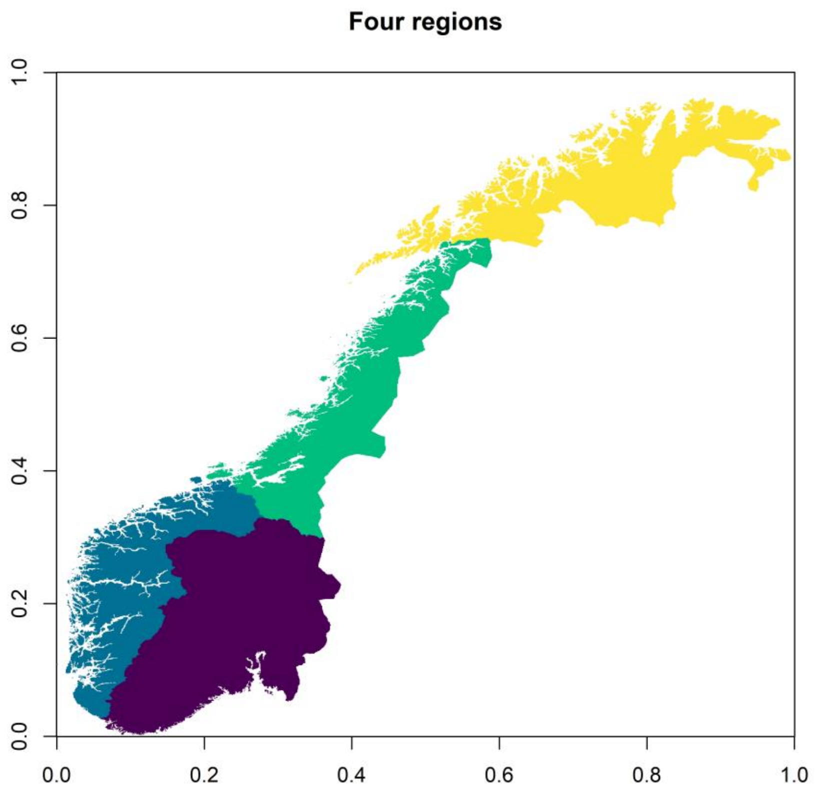
Two elevation zones: over/under treeline in avalanche terrain

Regions: 4 large regions (eastern, western, middle, northern Norway)

Historical grid data: seNorge (v2018) weather and snow; Klinogrid wind

Study regions





Set-up in Svalbard

Two seasons: winter (dec-feb) and spring (mar-may)

Two elevation zones: above/below 500 m asl.

Region: Nordenskiöld Land avalanche forecast region

Historical grid data: *CARRA* (1991-2020)

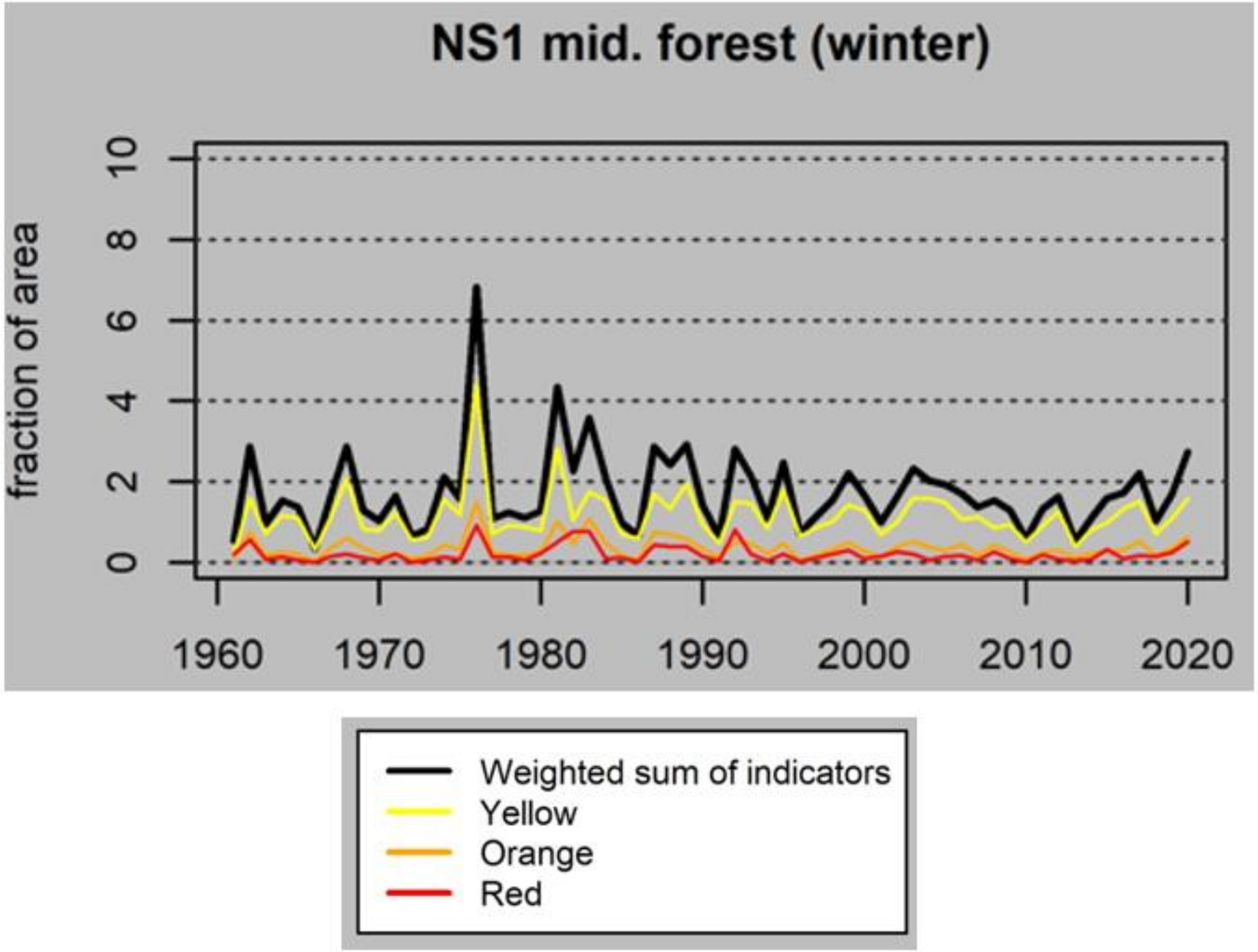
Results (prelim.)

104 + 32 change and trend estimates

Mainland Norway: 4+3 indicators/input, 4 regions, 2 seasons, 2 elevation zones

Svalbard, Nordenskiöld Land: 4+4 indicators/input, 2 seasons, 2 elevation zones

Long-term trends from 1961-90 to 1991-2020



Results: Nordenskiöld Land, Svalbard

Relative change (%) from 1991-2005 to 2006-2020

	Dec-Feb, > 500 m asl.	Dec-Feb, ≤ 500 m asl.	March-May, > 500 m asl.	March-May, ≤ 500 m asl.
NS1	47 %	33 %	27 %	43 %
NS3	29 %	17 %	25 %	49 %
NWS	-49 %	79 %	N/A	68 %
WBS	-17 %	-25 % (*)	-30 %	-31 %
Q_{rs}	N/A	314 %	N/A	307 % (*)
SWE	1 %	3 %	2 %	3 %
$U_{>9}$	-16 %	-19 %	-25 % (**)	-27 % (**)
T0	97 %	93 % (*)	31 % (*)	68 % (*)

Results: mainland Norway (prelim.)

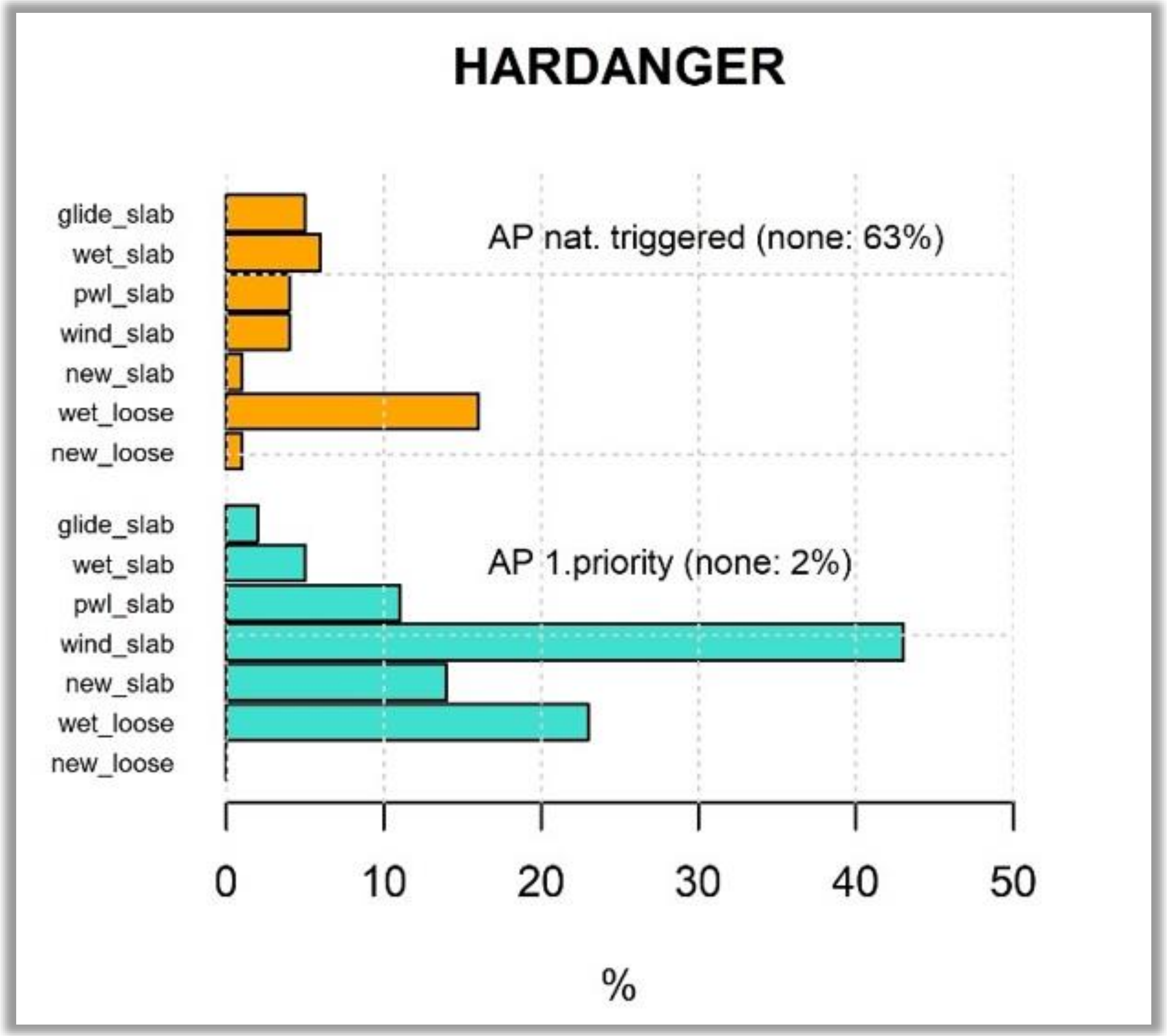
- The number of days with high wind speeds and runoff from the snow pack (due to rain and snow melt) have generally increased, while the average snow amounts have decreased from 1961-1990 to 1991-2020.
- In the period from 1961-1990 to 1991-2020 the avalanche indicators generally indicate
  - a reduced avalanche danger level below the tree line in the spring season (except in northern Norway);
  - an increased avalanche danger level above the tree line.
- The indicators' year-to-year variability is large and only a few of the avalanche indicator trends are found statistically significant.

Evaluation of indicators

Evaluation of indicators vs. daily forecast data in 2017-2022 (NAWS-data)

	Avalanche problem for mon	Mon	Tue	Wed
Nordenskiöld Land		2	2	2
Finnmarkskysten		1	1	1
Vest-Finnmark		1	1	2
Nord-Troms		2	2	2
Lyngen		2	2	3

NAWS-data


HARDANGER
glide_slab
wet_slab
pwl_slab
wind_slab
new_slab
wet_loose
new_loose
AP nat. triggered (none: 63%)
glide_slab
wet_slab
pwl_slab
wind_slab
new_slab
wet_loose
new_loose
AP 1.priority (none: 2%)
0
10
20
30
40
50
%

Severe avalanche days

Danger level 3 - Considerable

«Observed» avalanche situation (NAWS-data)

- severity index = trigger sensitivity · frequency · size
- severity index > 0.05 means «*severe avalanche day*»

Avalanche indicators

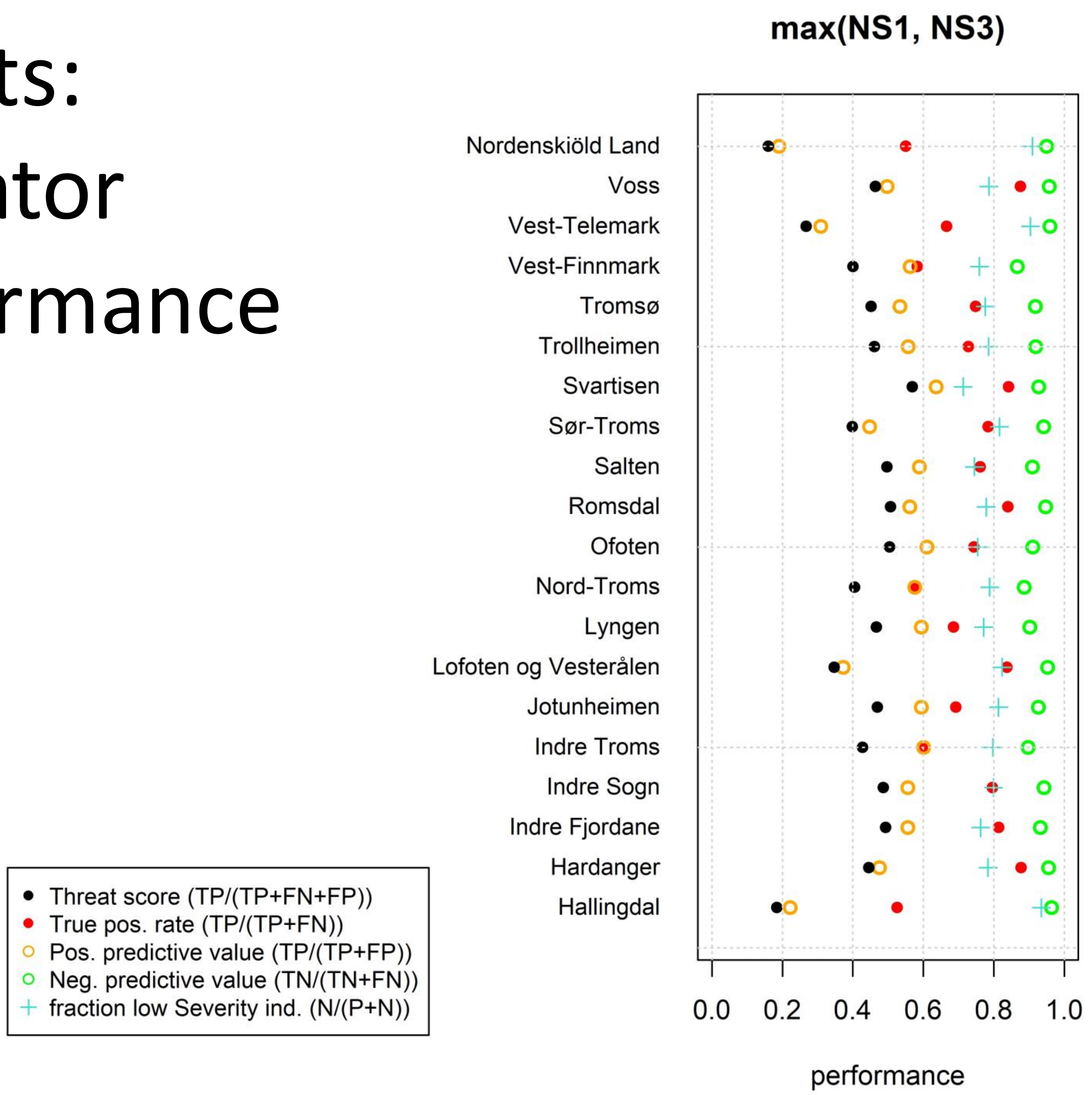
- weighing areas with yellow, orange and red indicator levels
- enough indicator area means «*severe avalanche day*» (optimized tresholds)

Statistics (binary classifiers)

Ind. severe \ Obs. severe	*No*	*Yes*
Yes	FP	TP
No	TN	FN

- ● Threat score (TP/(TP+FN+FP))
- ● True pos. rate (TP/(TP+FN))
- ○ Pos. predictive value (TP/(TP+FP))
- ○ Neg. predictive value (TN/(TN+FN))
- + fraction low Severity ind. (N/(P+N))

Results: indicator performance



Results: mean indicator performance (2017-2022)

- Our four hydrometeorological avalanche “proxy” indicators show a modest performance in mainland Norway, where they in 43 - 52 % of cases correctly indicate a (human-forecasted) significant avalanche danger level and in 89 - 93 % of cases correctly indicate a low avalanche danger level.

Next steps

- Evaluation of indicator performance against satellite data
- Try out a persistent weak layer (PWL) indicator
- Adjust and optimize indicator tresholds
- Publish results (early 2024)

Thank you!

Results: indicator performance (2017-2022)

Mainland Norway

	TPR (%)	*PPV (%)*	*NPV (%)*	*TSc (%)*	*FP:FN*	*low Severity index (%)*
max(NS1, NS3)	74	52	93	43	2.7	79
NWS	38	44	92	25	0.8	88
WBS	47	43	89	28	1.1	84

Nordenskiöld Land, Svalbard

	TPR (%)	*PPV (%)*	*NPV (%)*	*TSc (%)*	*FP:FN*	*low Severity index (%)*
max(NS1, NS3)	55	19	95	16	5.1	91
*NWS**	25	25	93	14	0.9	99
WBS	53	8	90	7	13.5	91

** the threshold values for NWS indicator for Svalbard were modified from those used for the mainland Norway (see Sect. 2.5)*