Constructing and simulating a rain-on-snow climatology for Norway (Pall *et al.* in press, J. Clim)

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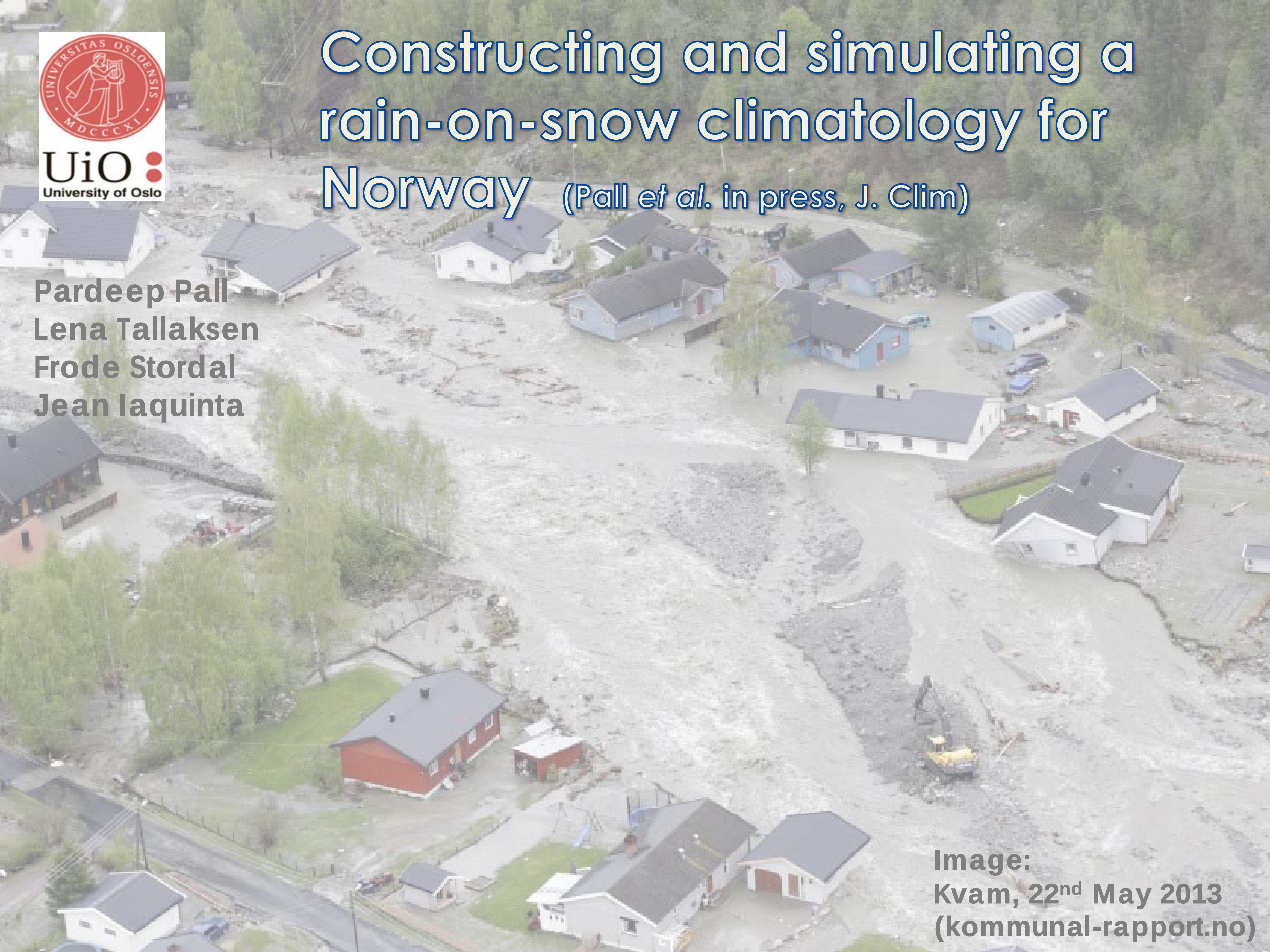


Image:
Kvam, 22nd May 2013
(kommunal-rapport.no)

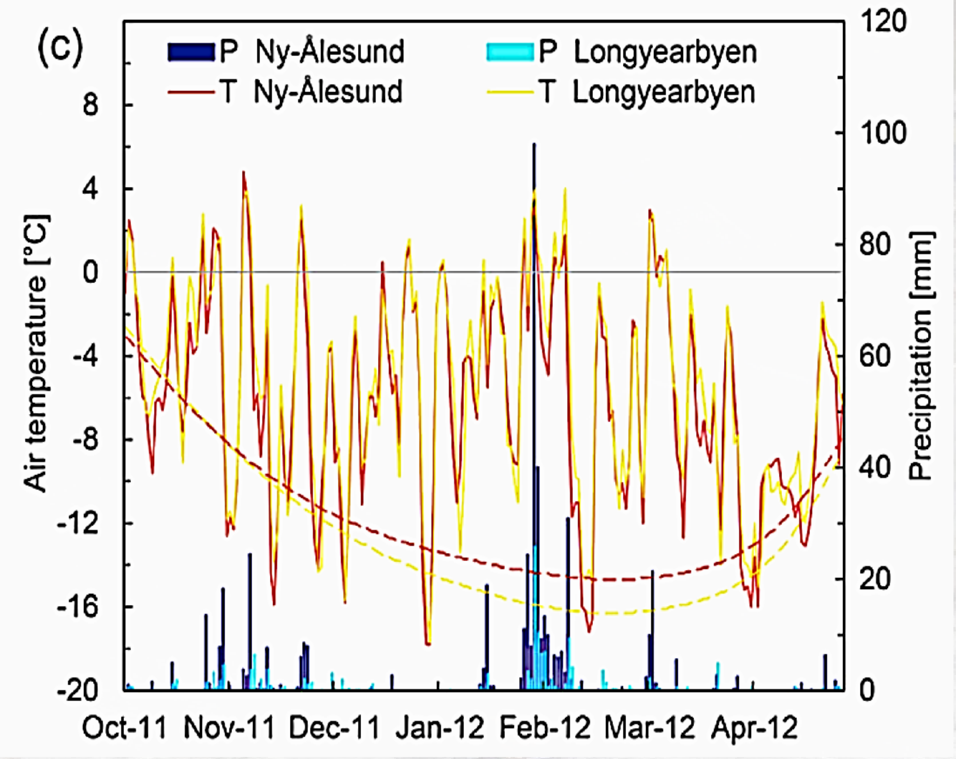
Intro: Rain-on-snow events

- ROS events are multivariate, hydrometeorological phenomenon

- Occur mainly at high-latitudes and mountainous areas

- Require a sufficient combination of:
  - Rainfall
  - Snowpack
  - Snow Coverage

… all underpinned by Temperature (so time lags are important)



A winter 2011-12 ROS event in Svalbard, characterised in terms of daily precipitation and temperature (Hansen et al. 2014)

Intro: Rain-on-snow impacts

- ROS has significant impacts

- Immediate term

  Floods, landslides, avalanches

- Longer term (from ice formation)

  Animal / vegetation decline,
  permafrost thermal budget

- Lower intensity events: rain freezes on or within snow, forming 'locked pastures' of ice layers, preventing foraging (e.g. caribou, musk oxen)

- Higher intensity events: basal ice formation imparts substantial latent heat, affecting the thermal budget of soils and permafrost

Not even a Ferrari escapes damage due to floods in Kvam, May 2013 (Roald, 2013)

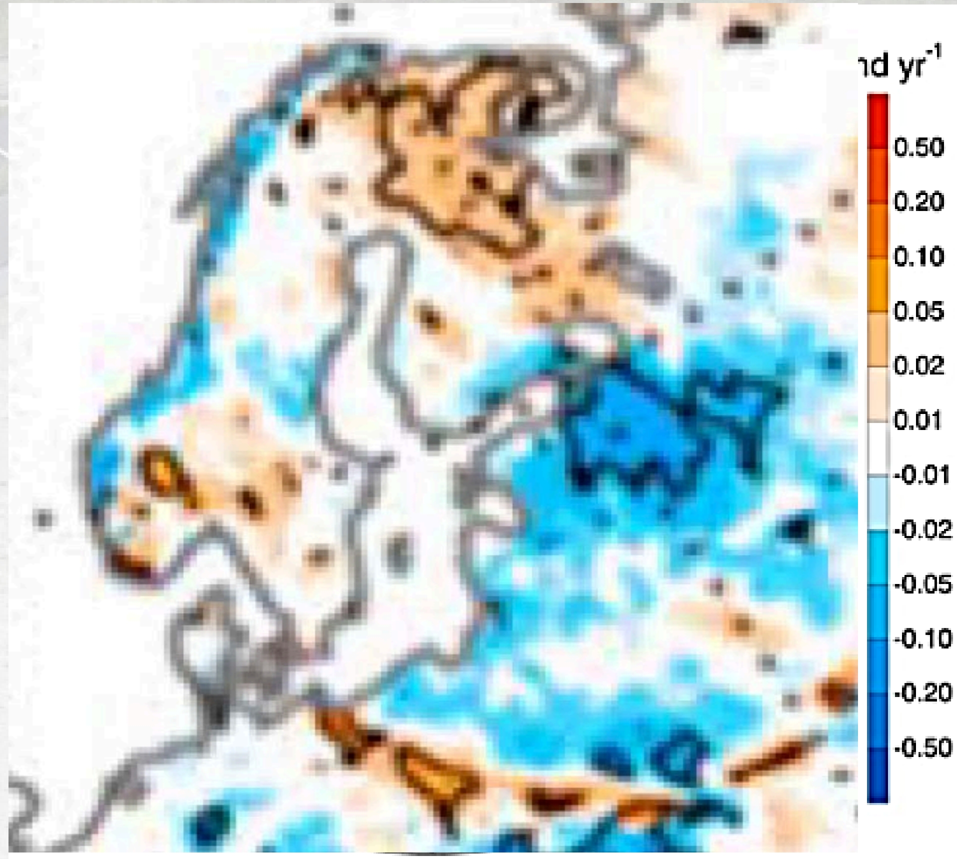
A wild female reindeer struggles to find food on the ice-encapsulated tundra in Reindalen, one week after a warm spell and ROS event (Hansen et al. 2014)

Intro: Rain-on-snow climatology

- ROS events are hard to quantify:
- sparse observational network
- mixture of rain- and snowfall
- spatial scale mismatch between re-analysis (~25-100km) and local event (~10-1km)

> Limited good-resolution studies at continental & regional scales

> Varying definitions of ROS events from field studies and local case studies



Winter (DJF) trend (days/yr) in ROS events from MERRA re-analysis (0.5°×0.66°),1979-2013 (Cohen et al. 2015).

[Daily rain threshold = 1cm; snow cover = 0.5]

Data: seNorge

- We search for ROS events using the seNorge data set (v1, 1957-2016)

- Gridded high-resolution (1km)
- Interpolated Temp, Precip
  + snow module for SWE, snow cover

- We use 4 'macro regions' (Rizzi et al. 17)

M = 'Mountain' (>1000 m a.s.l., alpine)

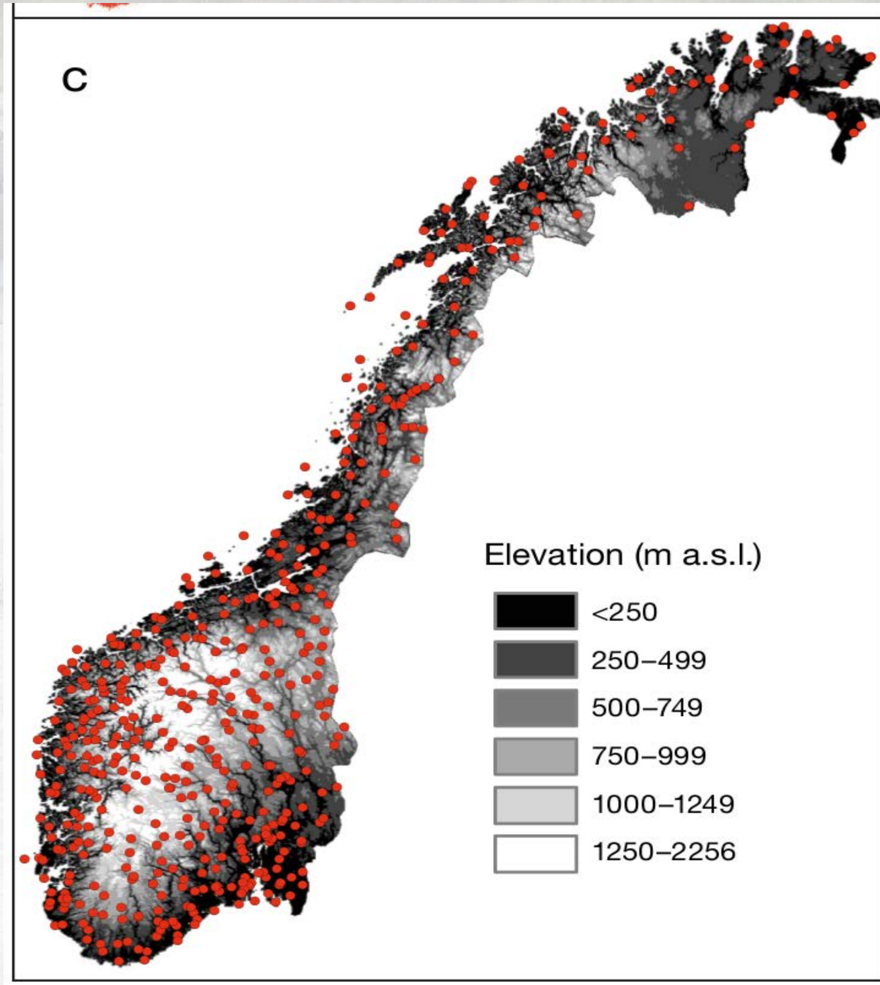
N = 'North' (mainly Arctic)

SW = 'Southwest' (wet maritime)

SE = 'Southeast' (maritime/continental)

- We define a gridbox daily ROS event as:
  1) rainfall ≥ 5mm
  2) SWE ≥ 3mm
  3) Snow cover ≥ 25%

(results not sensitive to harsher thresholds)



Stations and 1km resolution topography in the SeNorge dataset (Dyrrdal et al. 2012)

Results: 1961-90 climatology

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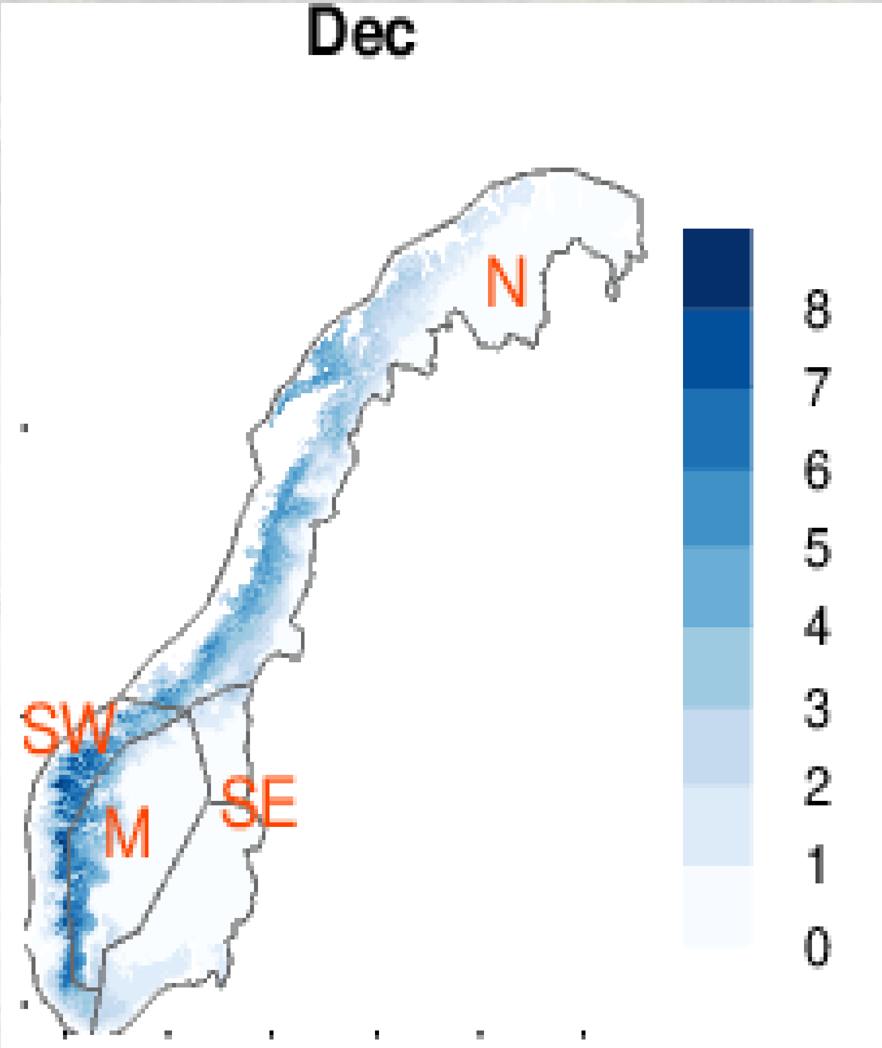
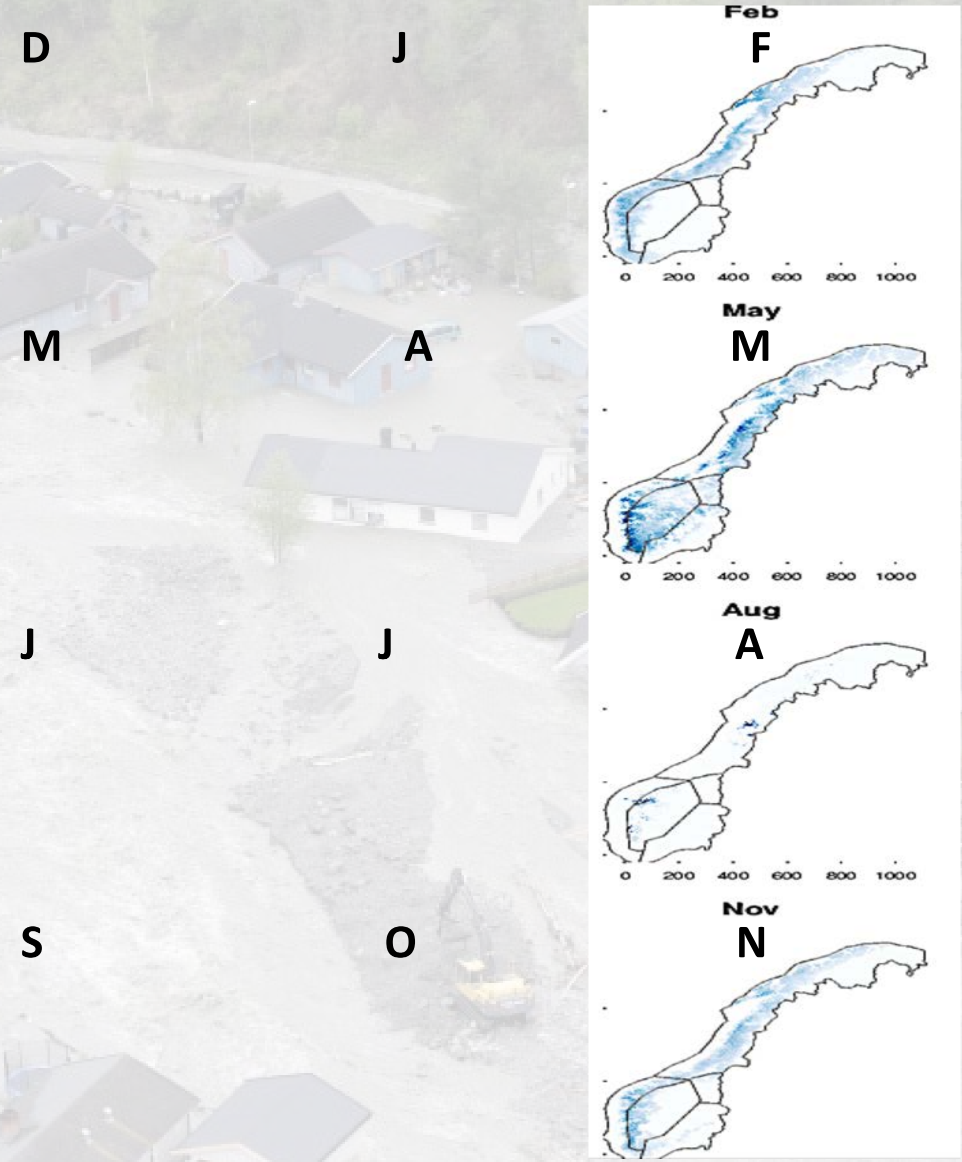


Average December ROS count for 1961-90, (with 4 macro regions in Rizzi et al. 2017)

Results: 1961-90 climatology

- The Southwest winter-spring has the largest counts
  - at foothill elevations
  - on western Mountain flank
  - consistent with westerlies bringing rain on winter snow
  - activity decreases as snow declines into the spring

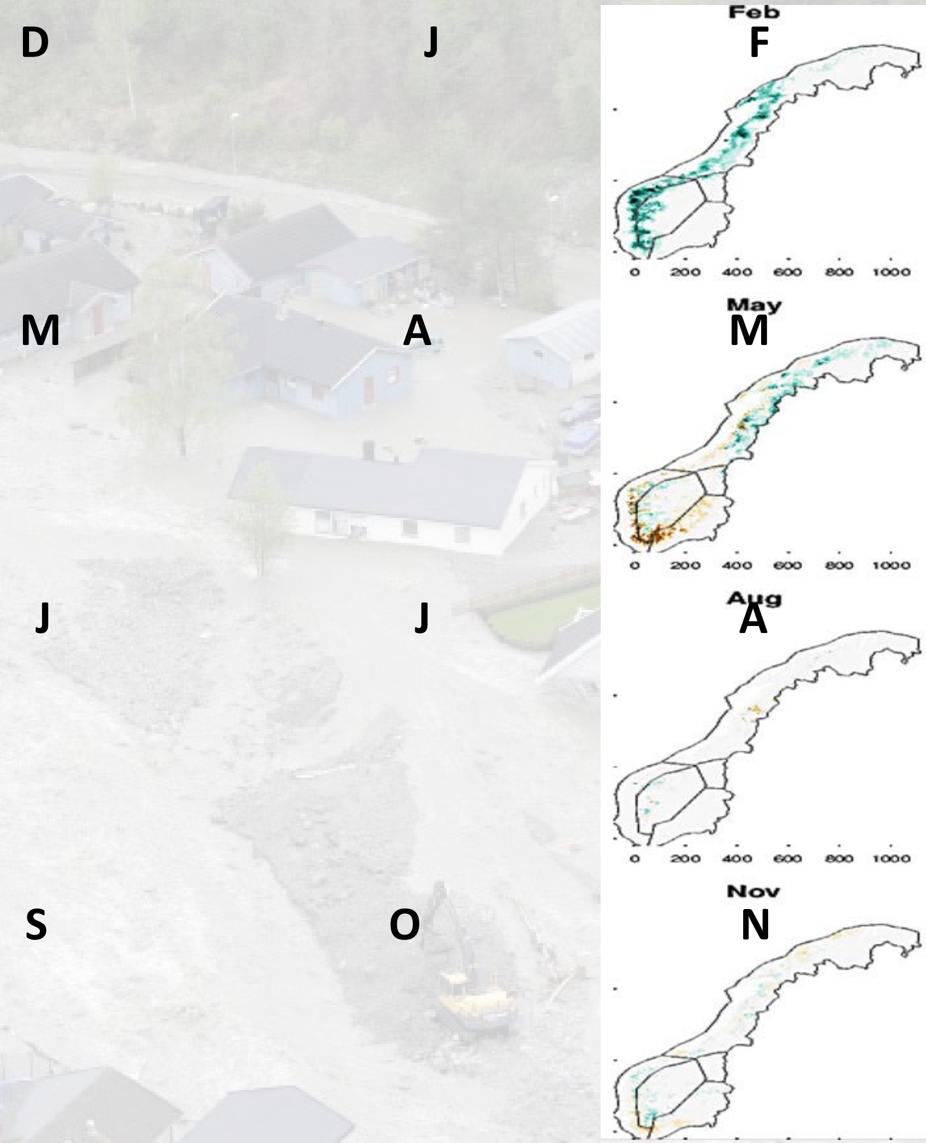
- The Mountain region spring-summer has the largest counts
  - snow persists at altitude
  - snow falls as rain in warmer months



Average monthly ROS count for 1961-90

Results: change 1981-10 vs. 1961-90

- Southwest winter-spring has the largest changes
  - coastal counts decrease due to less snow under warming
  - high-elevation counts increase as snow persists under warming but more precipitation falls as rain
- Southeast decreases in spring again due to less snow under warming (+ no precip change)
- North decreases in summer again due to less snow under warming (+ ROS events in preceding months)

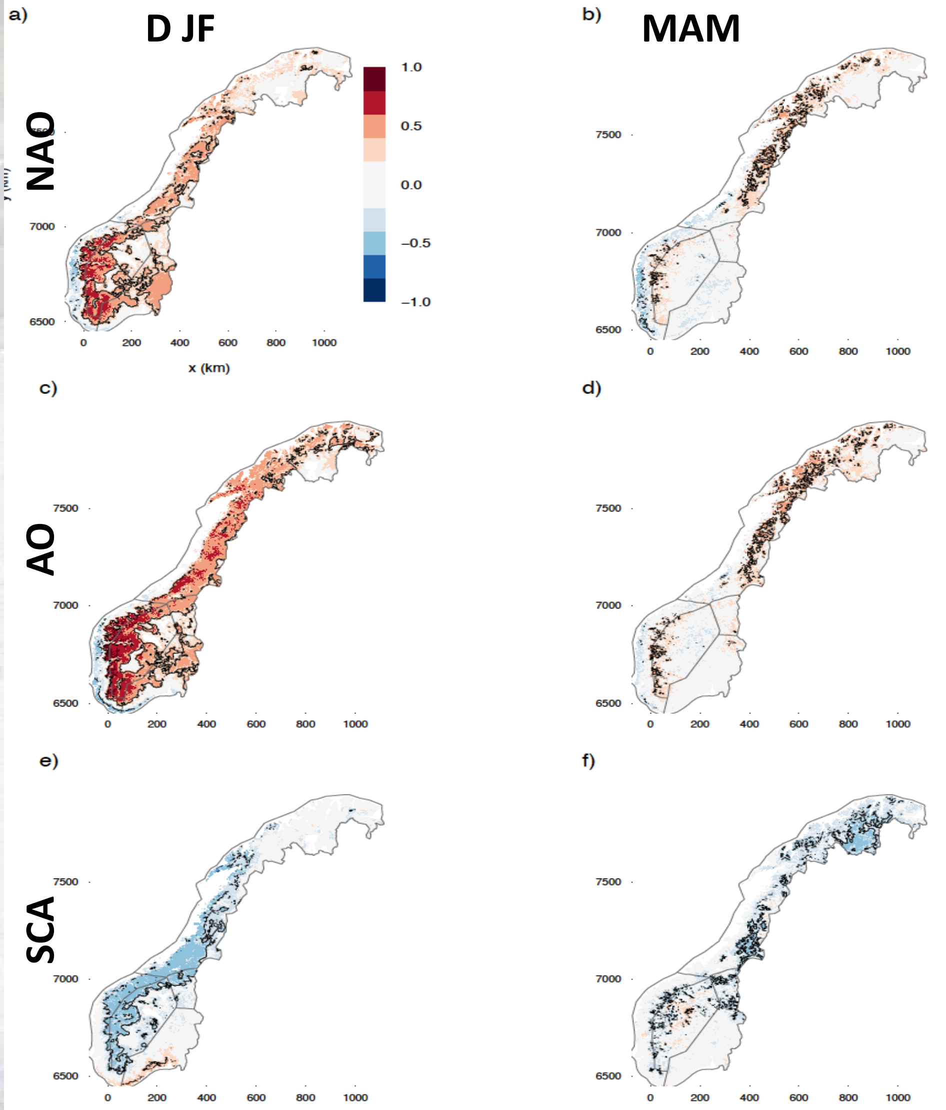


Change in average monthly ROS count from 1961-90 to 1981-2010

Results: large-scale circulation

- We also looked for relation of ROS counts to large-scale circulation, via correlation with the:
  - North Atlantic Oscillation (NAO)
  - Arctic Oscillation (AO)
  - Scandinavia Pattern (SCA)

- Highest correlations are in winter western Norway with the AO
- Again, the signal straddles the South West and Mountain regions
- Correlations move northward in spring as winter ROS counts diminish
- AO correlations extend further north due to more Arctic nature of the index
- SCA correlations strongest in spring



Correlation between daily ROS count and circulation indices for Sep 1957 – Nov 2016

Conclusions

- Rain-on-snow (ROS) events are multivariate hydrometeorological phenomena
- Require a combination of rain and snowpack (underpinned by temp)
- Conventional resolution datasets (~100s – 10s km) too coarse to capture detailed (topographic-influenced) climates in Norway
- We look for ROS days using 1 km resolution SeNorge data set
- 1961-1990 climatology dominated by winter-spring signal in western areas
- 1981-2010 climatology shows coastal decreases (less snow under warming) and higher-elevation increase (more precipitation under warming)
- Winter-spring ROS patterns broadly correlate with the Arctic Oscillation

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Paper in press (J. Clim): **journals.ametsoc.org/doi/10.1175/JCLI-D-18-0529.1**
See also: **LATICE & EMERALD projects on UiO webpages**