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L'eau dans la ville | Urban water

# *Impact of climate change on soil frost and future winter flooding*

## Conséquences du changement climatique sur le gel du sol et les futures inondations hivernales

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July 5, 2023

# Motivation

- Flood protection, storm- and wastewater management are essential for societies
- Urbanization and climate change are altering the water cycle and increasing flood risks
- Climate change impacts are more pronounced in the northern hemisphere



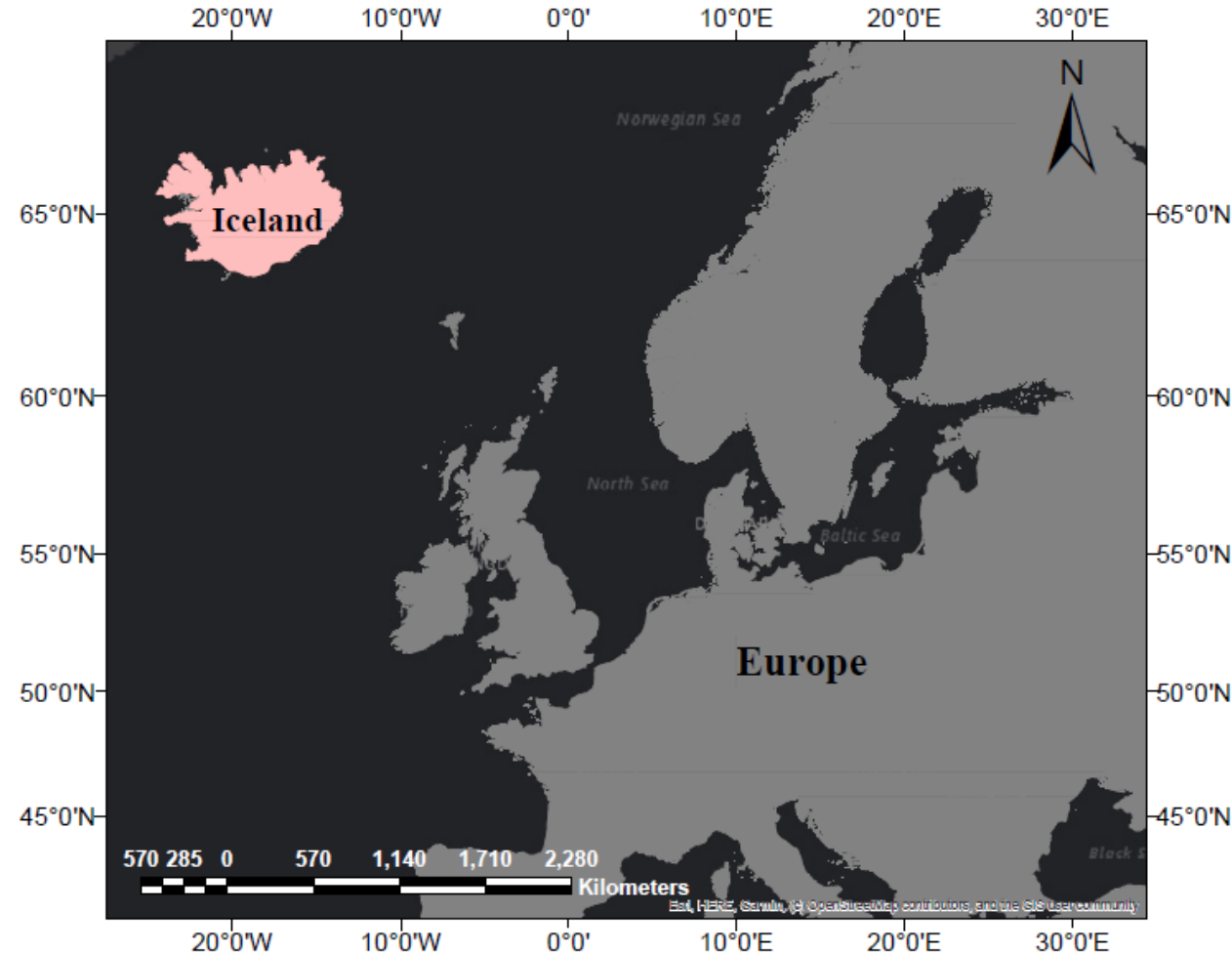
(Andradóttir et al., 2021)



(Rosenzweig et al., 2018)

# Maritime Climate Characteristics

- Many coastal regions have mild maritime climate influenced by the Gulf Stream
  - Narrow range in annual temperature
    - e.g. 2.0 to 5.7 °C in Southern Iceland
  - Mild winters with frequent freeze thaw cycles
  - Frequent, and rather low intensity precipitation in the form of rainfall throughout the year
    - Largest volumes produced during rain-on-snow, that can occur in peak winter months (December, January, February)




# Our Previous Research Highlights

## RESEARCH ARTICLE

- Rain-on-snow (RoS) events coinciding with soil frost
  - Responsible for the largest flooding events in the capital region of Iceland
  - Have become more voluminous in the past 7 decades with climate change
- While soil frost is decreasing, the likelihood of RoS to coincide with soil frost remains high
- RoS and soil frost negatively affect the performance or sustainable urban drainage systems

## Rain on snow induced urban floods in cold maritime climate: Risk, indicators and trends

Hrund Ólöf Andradóttir  | Anna Rut Arnardóttir | Tarek Zaqout



Contents lists available at [ScienceDirect](#)

Journal of Hydrology

journal homepage: [www.elsevier.com/locate/jhydrol](http://www.elsevier.com/locate/jhydrol)



### Research papers

Trends in soil frost formation in a warming maritime climate and the impacts on urban flood risk



Tarek Zaqout <sup>a,\*</sup>, Hrund Ólöf Andradóttir <sup>a</sup>, Johanna Sörensen <sup>b</sup>



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### Research papers

Hydrologic performance of grass swales in cold maritime climates: Impacts of frost, rain-on-snow and snow cover on flow and volume reduction



Tarek Zaqout <sup>\*</sup>, Hrund Ólöf Andradóttir

# Research Goal

- The overarching goal of this research was to study the regional variations in winter flood mechanisms in the maritime cold climate of Iceland
  - Long term trends in soil temperature and soil frost
  - Long term trends in rain-on-snow events' intensity
  - The joint probability and frequency of rain-on-snow events co-occurring with soil frost

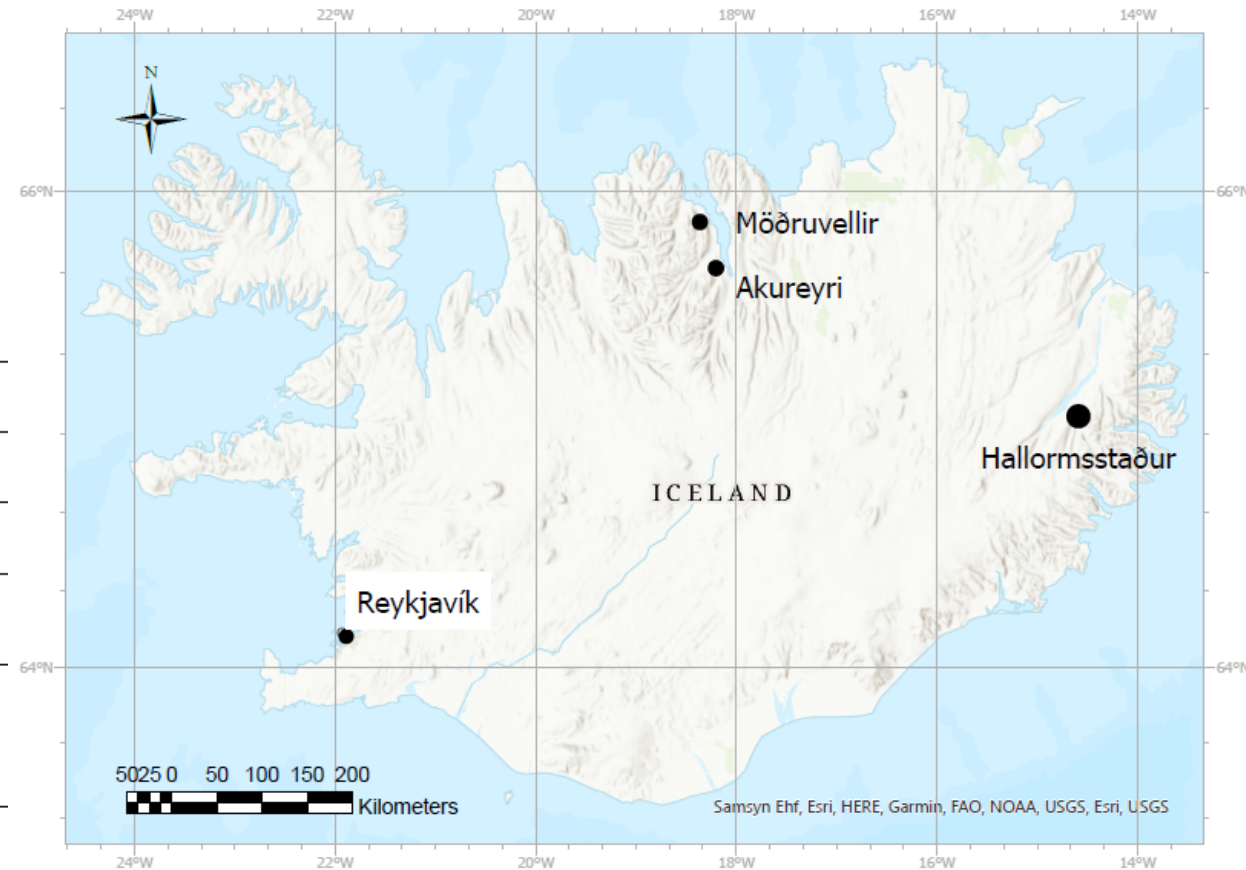
# Outline

- Background and Motivation
- Methods
- Results and Discussion
- Conclusions and Future Perspectives

# Study Sites and Data Availability

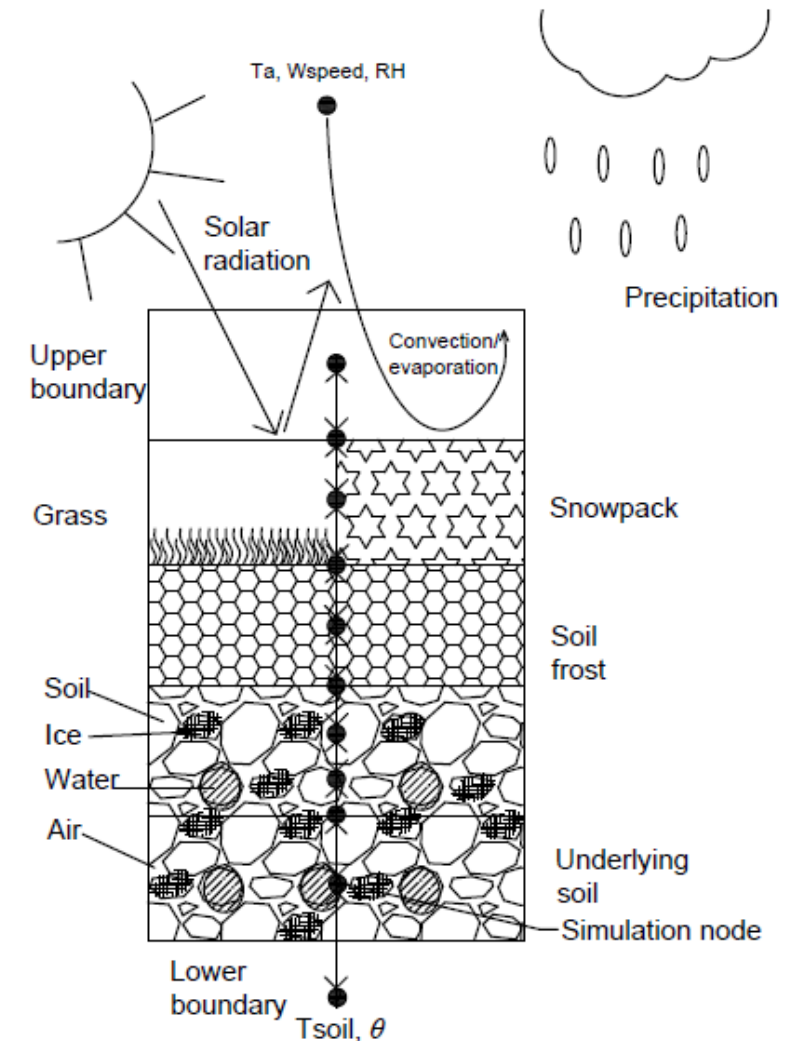
- Three regions were chosen as study sites
- Availability of historical records varied

Study Site	Reykjavík	Möðruvellir/Akureyri	Hallormsstaður
Daily weather data	1949–2018	1949–2022	1950–1990
Hourly weather data	2007–2018	1996–2022	2008–2021
Daily snow data	1949–2018	1964–2022	1950–1990
Hourly soil data	2007–2018	1996–2016	1996–2021
Measured at 10, 20, 50, and 100 cm			



# Soil Temperature and Frost Modeling

- The Simultaneous Heat and Water (SHAW) model was used to simulate soil temperature, moisture, and frost
- Frost formation processes are complex: involving the interaction of atmosphere-surface-soil-water + ice
- Outputs: soil temperature, soil moisture content, soil ice content, frost depth





- **Trend analysis**

- The long-term trends at the three studied sites were determined using the non-parametric Mann-Kendall test and the significant slopes using the Theil-Sen method

- **Bivariate frequency analysis**

- The frequency and joint probability of two winter events occurring simultaneously were determined using the Copula method by estimating a joint distribution

$$C(Fx(x), Fy(y)) = C(u1, u2)$$

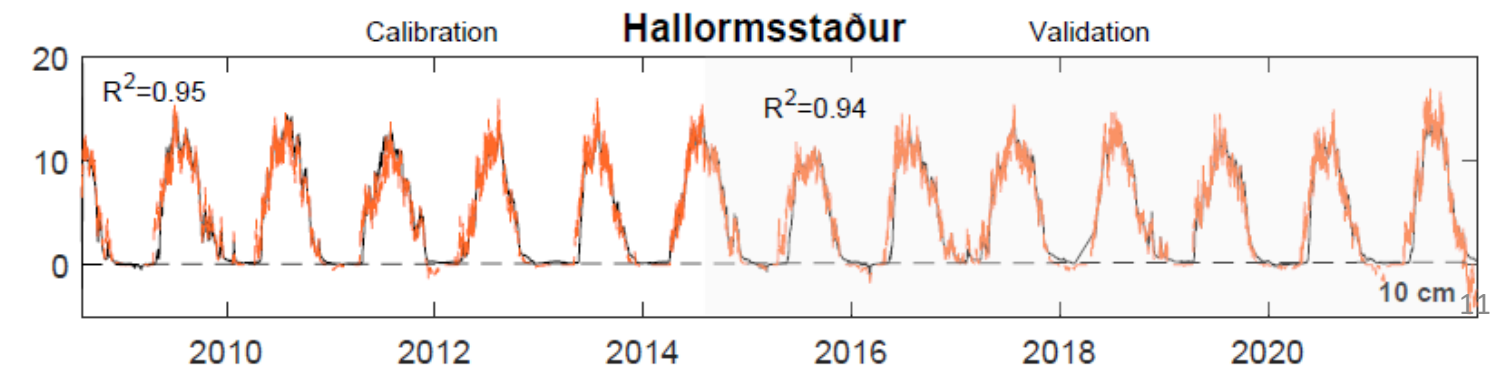
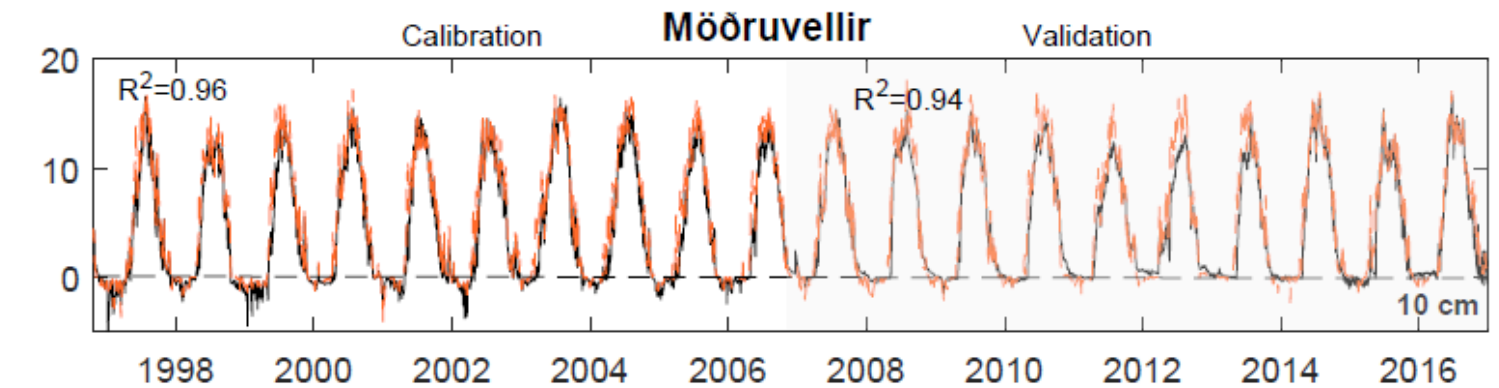
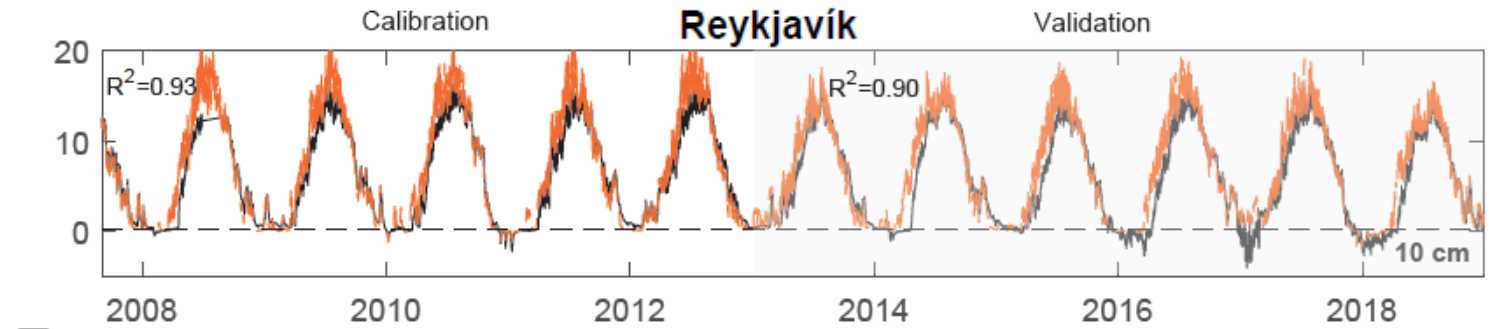
- Bivariate joint return periods for the annual maxima were derived as the inverse of the probability of two events

# Outline

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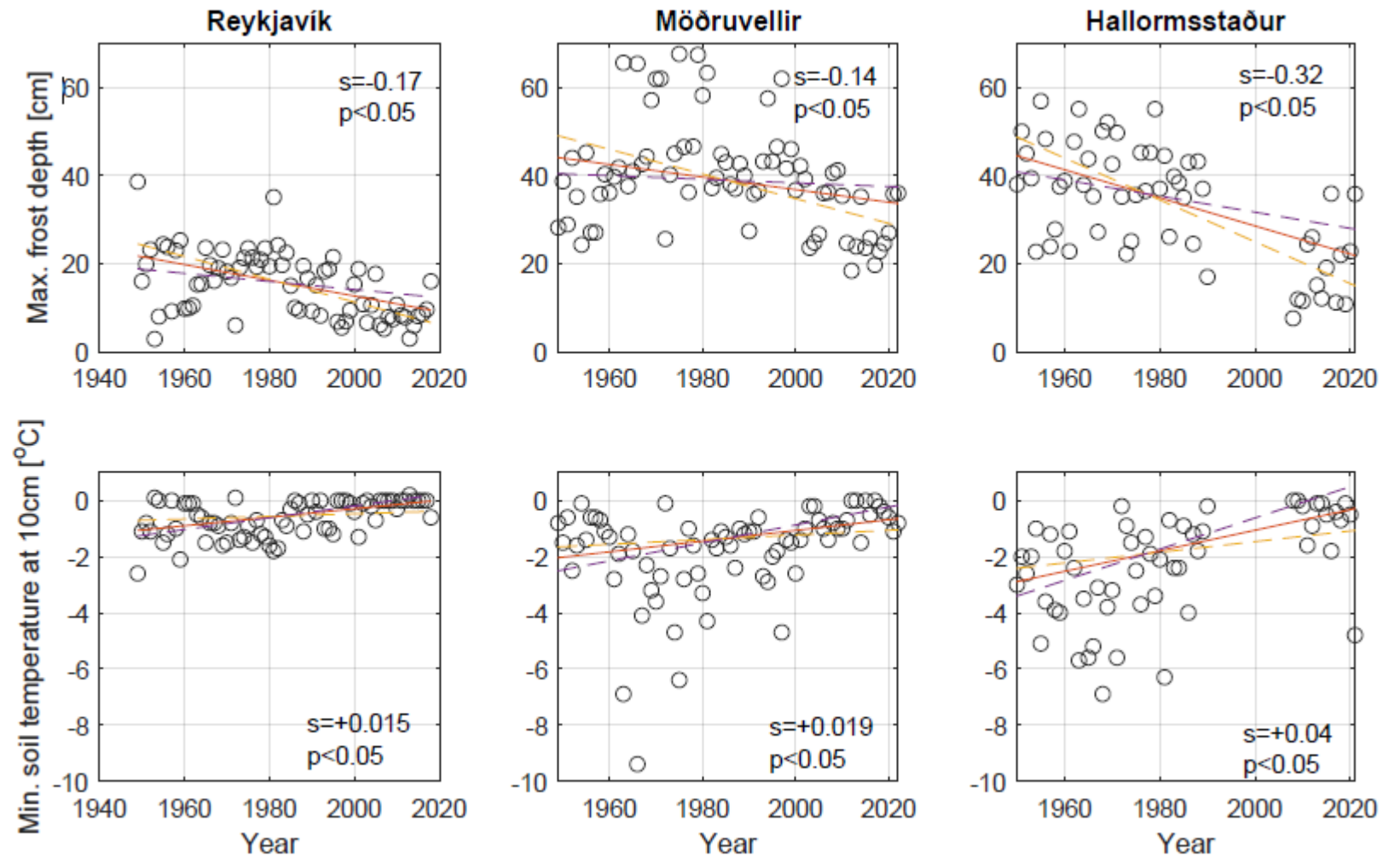
# Soil Temperature Prediction

- The model performed well in all sites for both calibration and validation
  - Reykjavík (RMSE=1.47–2.83 °C)
  - Möðruvellir (RMSE=1.02–1.93 °C)
  - Hallormsstaður (RMSE=0.82–1.17 °C)
- Lower performance during the freezing period

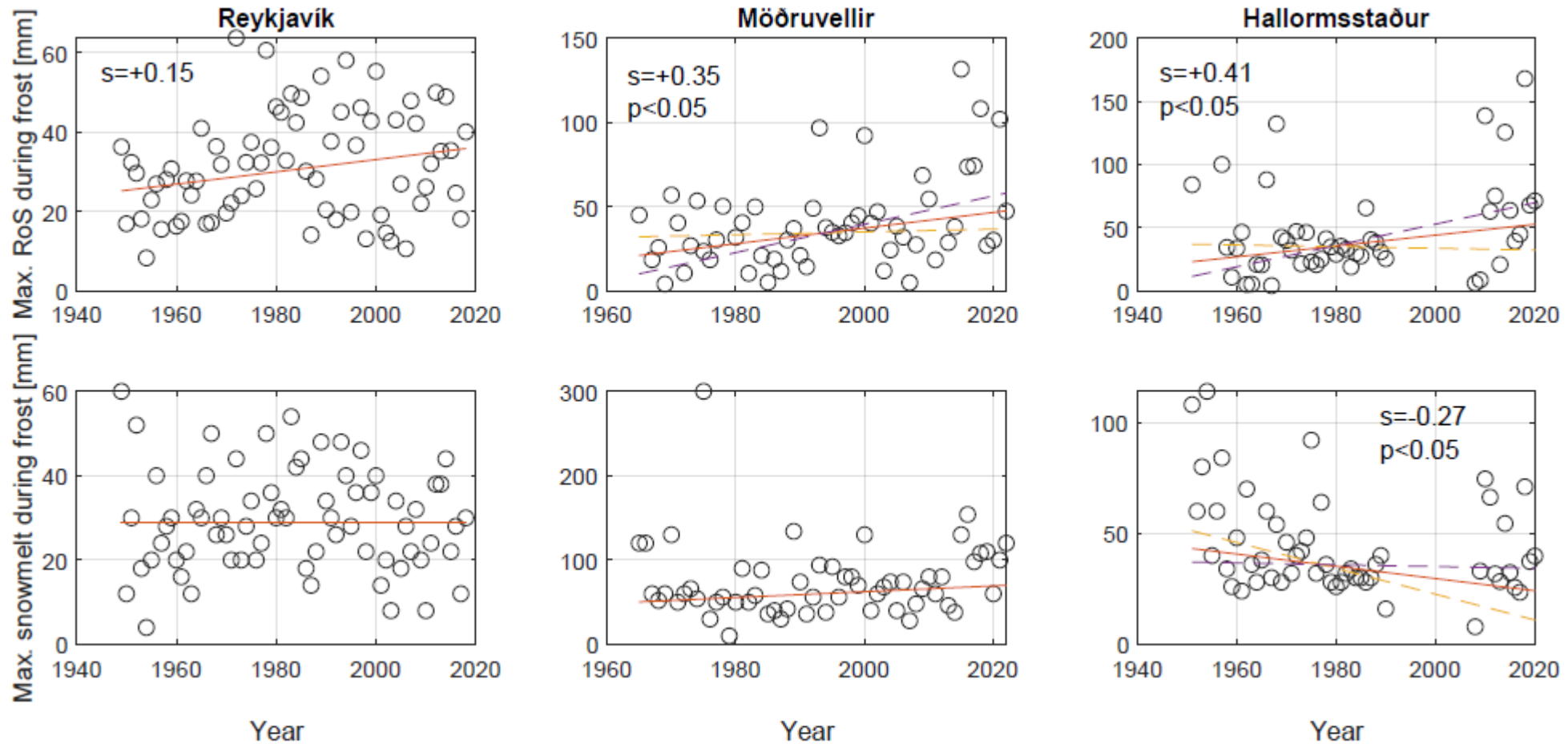


# Spatial Variations and Trends

- Max. frost depth decreased in all three locations
- Soil temperature at 10 cm depth warmed significantly
- The higher latitudes were more affected than Reykjavík



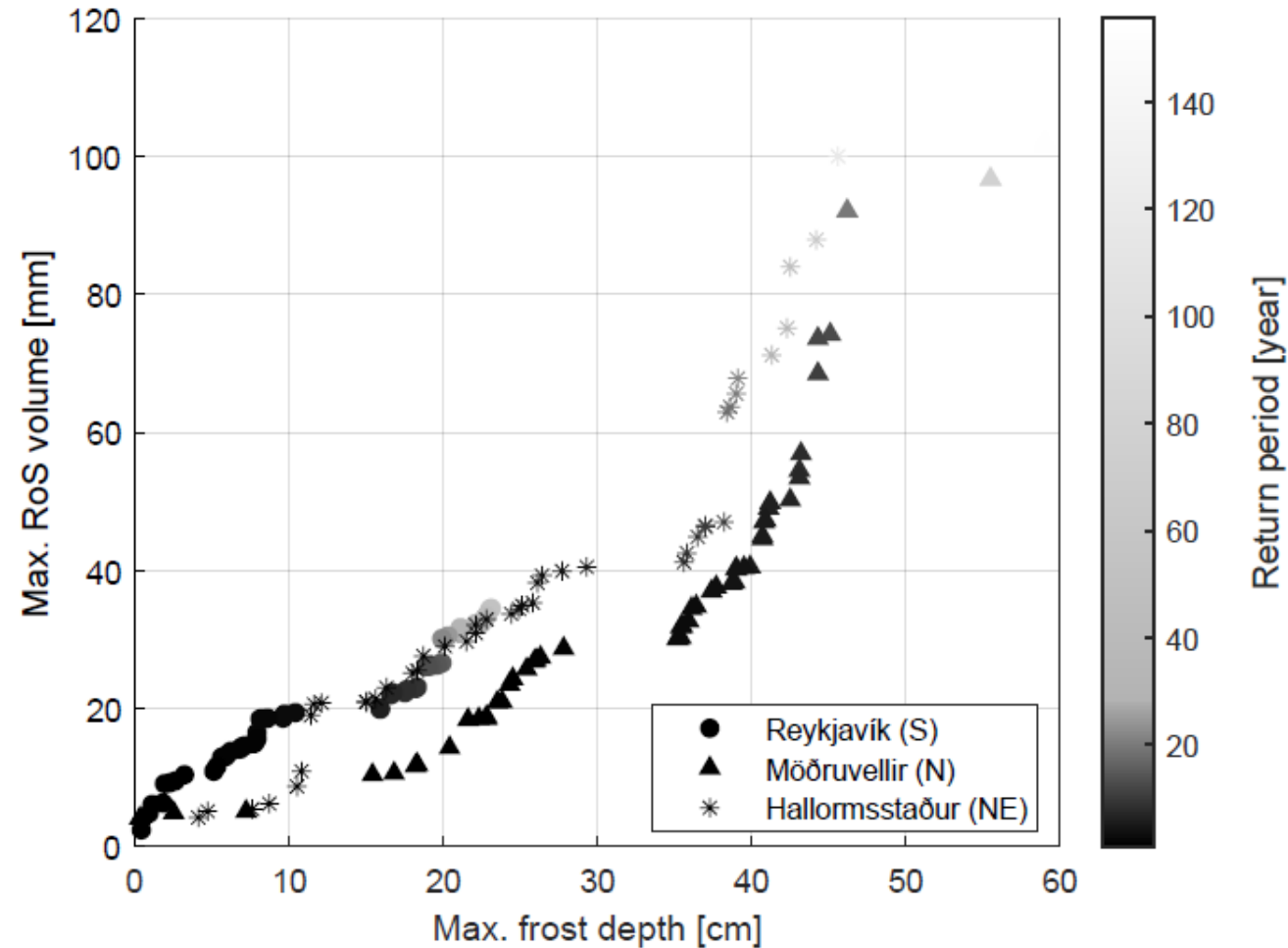
# Trends in Winter Rain and/or Snowmelt during Frost



- RoS events during frost increased in the last decades
- Snowmelt either did not change or decreased

# Co-probability of RoS and Frost

- Is considerable at all studied sites!
- The volume of RoS during frost and severity of frost varies by sites
- For example, RoS event with frost with return period of 4 years
  - **North:** RoS > 35 mm w/ frost > 33 cm
  - **Northeast:** RoS > 38 mm, frost > 26 cm
  - **South:** RoS > 20 mm, frost > 11 cm



# Conclusions and Next Steps

- Soil frost depth and temperature varied substantially between the studied regions
- RoS events increased in all studied regions and pose an increasing flood risk
- The frequency of RoS and frost occurring simultaneously differed by region and needs to be taken into account for flood mitigation
- RoS and frost will be analyzed for future climate scenarios to assess potential increase in winter flood risk

# Acknowledgements

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• If you are interested in learning more about our research:

- Zaqout, T., Andradóttir, H. Ó., & Sörensen, J. (2023). Trends in soil frost formation in a warming maritime climate and the impacts on urban flood risk. *Journal of Hydrology*, 617, 128978. <https://doi.org/10.1016/j.jhydrol.2022.128978>
- Zaqout, T., Andradóttir, H. Ó., & Arnalds, Ó. (2022). Infiltration capacity in urban areas undergoing frequent snow and freeze-thaw cycles: Implications on Sustainable Urban Drainage Systems. *Journal of Hydrology*, 607, 127495. <https://doi.org/10.1016/j.jhydrol.2022.127495>
- Zaqout, T., & Andradóttir, H. Ó. (2021). Hydrologic performance of grass swales in cold maritime climate on-snow and snow cover on flow and volume reduction. *Journal of Hydrology*, 597, 126159. <https://doi.org/10.1016/j.jhydrol.2021.126159>
- Andradóttir, H. Ó., Arnardóttir, A. R., & Zaqout, T. (2021). Rain on snow induced urban floods in cold indicators and trends. *Hydrological Processes*, 35(9), e14298. <https://doi.org/10.1002/hyp.14298>

