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Discussions and interventions

2024 ice jams and spring flooding across Ostrobothnia: observations and prospects

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Abstract

Seasonal snow and ice play a key role in the hydrological regimes of Arctic and sub-Arctic river catchments that differentiate them from their lower latitude counterparts. Against a backdrop of assumed reduced spring flooding due to ongoing Arctic warming resulting in shorter winters with less snowfall, we examine the prevailing conditions that led to spring-melt flooding, its impact and mitigation management strategies across Northern Ostrobothnia in April, 2024. We find that sustained freezing temperatures in early 2024, combined with thicker than average snowpack in March, preconditioned the region's catchments to two episodes of flooding driven by abrupt warm events and widespread snowmelt in early March and April. Due to their predominantly shallow, east to west long-profiles, the region's rivers received large fluxes of snowmelt runoff simultaneously along their entire courses, responding rapidly with rising levels and discharge. Thick river ice formed during the colder than average winter, causing ice jams at constricting pinch-points including bridges, dams and where rivers naturally shallowed or narrowed, leading to backup and flooding. Numerous effective civil interventions - including the release of discharge into managed agricultural areas – prevented extensive flood damage and major disruption to infrastructure other than temporary closure of some roads. We conclude that the event was pragmatically managed, precluding significant material damage and disruption. However, projected long-term climate scenarios indicating increased temperature fluctuations and extreme precipitation – including snowfall - events associated intense warm air intrusions, coupled with potential meter-scale relative sea- and base-level rise could act in consort to increase the region's winter and spring flood risk, rather than mitigate it.

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Key Points

- At the turn of March and April 2024 – earlier than average – severe floods occurred in the Northern Ostrobothnia River basins; flooding was greatest on the Kalajoki River.
- The floods were associated with intensive thawing of snow cover and ice crumbling, and was accompanied by ice phenomena, including ice jams.
- Civil intervention and rescue operations, with early anticipation of the situation, meant that the floods were effectively managed with no significant material loss or disruption.

Introduction

The hydrological regimes of Arctic and sub-Arctic River catchments modulated by seasonal freezing and interceded by abrupt thawing and snowmelt, contrast markedly with their lower latitude counterparts. The onset of warmer spring temperatures kickstarts these hydrological systems after sustained sub-zero temperatures throughout winter. Such extreme meteorological conditions co-determine the timing and magnitude of potential spring snowmelt river flooding, which remains the primary factor responsible for natural hazards and related infrastructure and other material losses (e.g. Grigorieva & Livenets, 2022). Major sub-Arctic Siberian rivers – the Ob, Yenisei, Lena – and their tributaries are typically associated with high magnitude, seasonal snowmelt floods. These rivers are of considerable length with a strong meridional profile that traverses numerous climatic zones. As a result, the spring thaw typically migrates northwards from southern latitudes, causing the formation of snowmelt floods in the upper (southern) reaches of rivers, which subsequently encounter ice barriers within the still-frozen riverbeds downstream to the north (Myglan & Vaganov 2011; Kichigina, 2020). In Siberia, such ice jams result in high magnitude flood waves that are amplified by specific drainage basin configurations and catchment hypsometries where initially, snowmelt and subsequent thawing ground across extensive areas within their southern (upper) zones, act to overwhelm the system and the resulting flood hydrograph (Shiklomanov *et al.*, 2007).

In northern Europe, the scale of the river systems and the associated spring floods are considerably smaller. Floods across Scandinavia, particularly Finland, are a frequent and well-documented phenomenon. Despite this, spring floods remain difficult to forecast due to variable meteorological conditions and difficult-to-determine water storage accumulated in heterogeneous snow distributions with contrasting density and thermal profiles. The ice situation on rivers is also a key factor, itself determined by the magnitude, duration and consistency of winter cold-spells, and the associated formation of ice jams that impede river discharge.

In Finland's Ostrobothnia and Lapland regions, complex yet shallow gradient river network systems and their associated hydrological regimes can result in severe spring snowmelt flooding. The main rivers flowing into the Gulf of Bothnia run longitudinally from east to west, and the spring thaw, which generally progresses northwards from southerly latitudes, in contrast to Siberian systems, impacts river networks along their entire lengths over just several days. This also distinguishes these river systems from those in southern Finland, where large floods can occur at any time of the year and are most often driven by intense rainfall in the summer.

In this paper, we briefly describe the flood events in Ostrobothnia during the spring of 2024 and present the hydrological causes and impacts of the specific river systems flowing into the Gulf of Bothnia. We utilise data collected by the Finnish Meteorological Institute and their joint hydrological monitoring network with, for example, Kemijoki Oy and draw on information from a summary published by the Finnish Environment Agency, ELY information centres, the Finnish Meteorological Institute and the Flood Centre. We further illustrate our study with observations from the Kalajoki River valley in April and May 2024.

Conditions of flooding

Finland's river systems can be hydrologically characterised and grouped by area into three primary regimes: 1) catchments of the lake regions of Southern and Central Finland with high retention capacities and low flow variability, 2) small river catchments in the coastal areas of the Gulf of Finland and the Gulf of Bothnia with high flow variability and, 3) large rivers of Northern Ostrobothnia and Lapland with efficient, seasonal flow regimes (Mustonen, 1986). It is notable that all of Finland's largest rivers are regulated, at least in their lower catchments through dams and storage structures primarily purposed for harnessing hydropower, but as a by-line regulating discharge. The large latitudinal gradient and the influence of variable air masses with very different meteorological conditions mean that thermal-pluvial conditions are diverse across Finland, particularly in winter (Veijalainen *et al.* 2010). Over the 1971–2000 reference period, the mean annual temperature across Finland varied between 5°C and −2°C, and the mean precipitation rate between 450 mm and 700 mm per year (Drebs *et al.*, 2002). The thermal winter defined by daily mean sub-zero temperatures, lasts in northern Finland 100 days longer on average compared to southern Finland, and terrestrial snow-cover persists on average for 150–190 days per year.

In northern Finland, just over 95% of the annual peak river discharge events occur in spring, coinciding with the onset of abrupt snowmelt, which contrasts with southern Finland where such floods occur year-round (Korhonen & Kuusisto 2010; Veijalainen *et al.*, 2010). Ostrobothnian rivers are particularly sensitive to spring floods, mainly in April and May. These rivers drain low-lying areas with only a few shallow lakes able to alleviate the flood wave and buffer the flood hydrograph (Figure 1). The highest daily discharge recorded instrumentally in Finland was 4824 $m^3 s^{-1}$ at Isohaara on the Kemijoki River in Lapland in May 1973, compared to a mean annual maximum discharge at this location of just ~2900 $m^3 s^{-1}$ (Albrecht, 2023). In Northern Ostrobothnia, floods occurred in 1977, 1982, 1987, 1997, 1998, 2000 and 2002, and on the Kalajoki River, the largest flood recorded was on 25 April 2000 when a discharge of 384 $m^3 s^{-1}$ was recorded in the town of Ylivieska (Räsänen, 2021).

Not only are the long profiles of these rivers very shallow, but they also flow east to west, which favours snow and river ice melt along their length simultaneously, leading to abrupt increases in discharge and water levels over a relatively short period of a few days. They mainly drain agricultural areas with a moderate population density across rural Finland, though these rivers also flow through some major towns and cities with high population density. Due to the behaviour of river ice, a number of natural or man-made obstructions to flow along river courses become critical foci during spring floods, where there is channel narrowing, shallowing across rapids and low bridge profiles, dams and other structures. It is the low-lying agricultural or built-upon land areas around these constricted channel zones - pinch-points - that are susceptible to flooding.

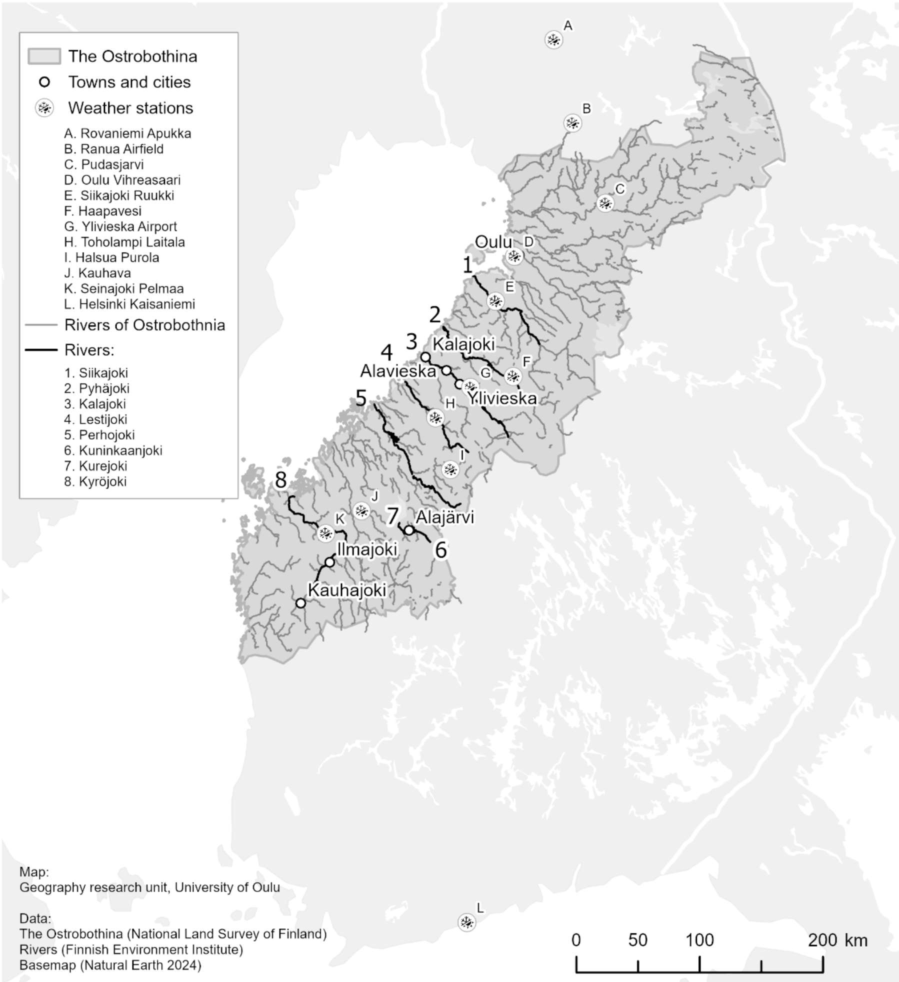

Figure 1. Study area of Ostrobothnia – main rivers and catchments discussed.

Flood in spring 2024

Towards the end of March 2024, snow accumulation across Ostrobothnia was well above average. Snowpack thickness in the upper parts of individual catchments was 100 to 130 mm w.e., and up to 150 mm w.e. in some areas (https://www.vesi.fi/en/karttapalvelu/). The ice cover on rivers was also thicker than the long-term average after winter temperatures well below -15°C sustained over long periods. The spring snowmelt occurred in several stages. The first warm period occurred in mid-March (Figure 2), and melting impacted mainly the southernmost reservoirs. Stronger warming and accompanying rainfall occurred over the Easter period; for example, in Kauhajoki (Suupohjan seutukunta), which received ~22 mm of rain. More intensive snowmelt occurred on 8 April when air temperatures rose to 5°C accompanied by rainfall of 15 – 25 mm. This warm spell led to a situation that favoured river flooding, and which abated in mid-April with the re-establishment of sub-zero temperatures for ~10 days.

Though the local discharge primarily reflected prevailing weather conditions, the key importance lay in the flow control of numerous water-storing structures. The Lapväärtinjoki, in Southern Ostrobothnia region, received its highest discharge on 12 April. Earlier, on 10 April, high water levels were recorded in the neighbouring upper reaches of the Kyrönjoki. Here, the impending flood wave was flattened by the managed diversion of ~12.5 million m^3 of water into natural overspill areas, predominantly composed of agricultural areas where a floodplain of 1,900 ha was formed. This affirmative action was carried out to protect the city of Ilmajoki. Similar management and active flood prevention measures were also carried out on the Lapuajoki, with the resulting peak flow of its lower sections occurring on 13 April, with high water levels sustained from the end of March through to mid-May. Within the Ähtäväjoki catchment, particularly high floodwater discharges were observed on the Kuninkaanjoki, which flows into Alajärvi, and also the Savonjoki, which flows into Lappajärvi, with peak discharge from these reservoirs recorded at ~50 m^3 s^{-1}. Ice dams also appeared, causing a flood hazard for the recreational cabins and other infrastructure on and near the riverbanks. Ice dams also posed a hazard on the Perhonjoki River, when its peak flow was recorded on 14 April.

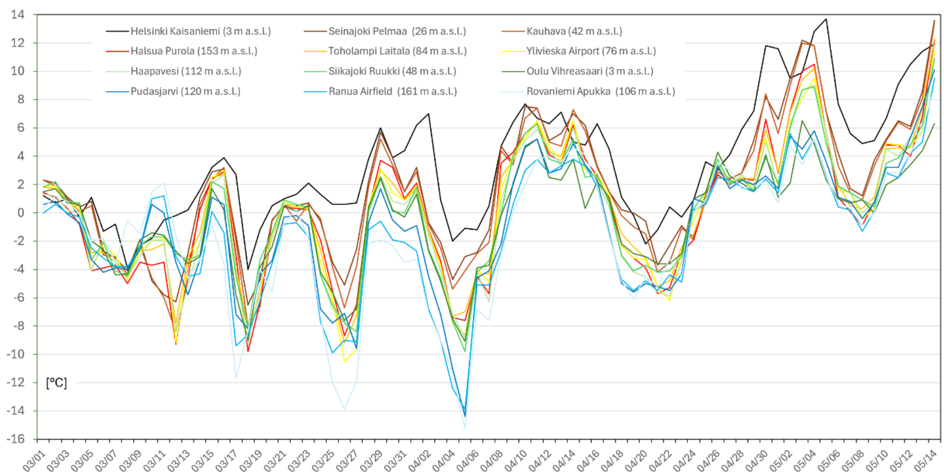

Figure 2. Daily air temperatures across Finland in spring 2024 (data source: Finnish Meteorological Institute).

The spring melt and associated flood events drew significant media attention. The Finnish news services focused on the Lestijoki and Kalajoki river valleys further north. At Lestijoki, the observed hydrograph reveals three distinct peaks (Figure 3) with the Saarenpää gauge indicating a marked increase in daily discharge from 30 March onwards. On 3 April, the flow attained 29 $m^3 s^{-1}$ and subsequently started to decrease. The next major event began on 8 April, with the subsequent flood peaks occurring on 14 and 15 April, with corresponding discharges of 152.6 and 153.1 $m^3 s^{-1}$, respectively. The third peak was on 1 May with a moderate discharge of 64 $m^3 s^{-1}$, after which the discharge tailed off to its mean base-flow rate of 13 $m^3 s^{-1}$ on 22 May. The main discharge peaks and high-water flows were accompanied by major ice jams, resulting in a critical situation that threatened the bridge in Saarenpää on the border of the municipalities of Kannus and Himanka.

The spring flooding of 2024 had a moderate impact on residents of the municipalities along the Kalajoki River (Figures 4 and 5) that were well documented. At the Hamari gauge in Ylivieska, above-average discharge of 21.2 $m^3 s^{-1}$ was measured on 2 April, followed by a significant increase in the river's water level from 8 April. This spring flood wave culminated with a discharge of 276 $m^3 s^{-1}$ on 15 April, after which it subsided. However, two weeks later, the river level rose again on 1 May with a corresponding discharge of 155 $m^3 s^{-1}$, which was sustained through until 21 May.

River ice and ice-related phenomena accompanied and compounded the 2024 spring snowmelt floods. An ice-dam formed in the centre of Alavieska on 11 April, which lasted for two days until it disintegrated on 13 April. The loose, flowing ice then subsequently accumulated at the village of Tynkä. The excess backed-up discharge overtopped the river banks and flowed extensively across the natural floodplain zones between the towns of Ylivieska and Alivieska, with the flooded area up to 2 to 4 km wide in the village of Niemelänkylä. This village is one of the three key flood risk areas identified in Northern Ostrobothnia, and accordingly, local rescue services anticipated that its 140 inhabitants would need to be evacuated. Ultimately, only four people needed direct assistance from the municipality. Rescue and mitigation efforts were mainly concerned with pumping water from basements and securing low-lying houses against flooding, as well as providing advice on property protection and safety. There were, though some knock-on, indirect issues particularly concerned with floodwater interference with the sewage system and disposal.

On 13 April, rescue operations focused on Ylivieska, where significant ice-jams dammed and raised the river level, resulting in moderate local flooding that inundated several roads. On the evening of 14 April, all traffic was closed on roads Ämmäntie and Letontie in Kalajoki, Sievinmäentie (between Koivuoja and Markkula) in Sievi, Kiveläntie (Junno and Mönkö) in Nivala and Hamarintie in Ylivieska due to this extensive flooding. Earlier, the road to Väätintie (Akanneva and Väätti) in Alavieska was also partially flooded. Water levels were also anticipated to rise on rivers further north. An ice-dam formed in the municipality of Pyhäjoki, backing-up the discharge and raising the river-level along the Pyhäjoki, resulting in floodwater that inundated several local roads. The cold-snap and return to sub-zero temperatures from mid-April for 10 days thereafter acted to suppress the risk of further flooding across Ostrobothnia.

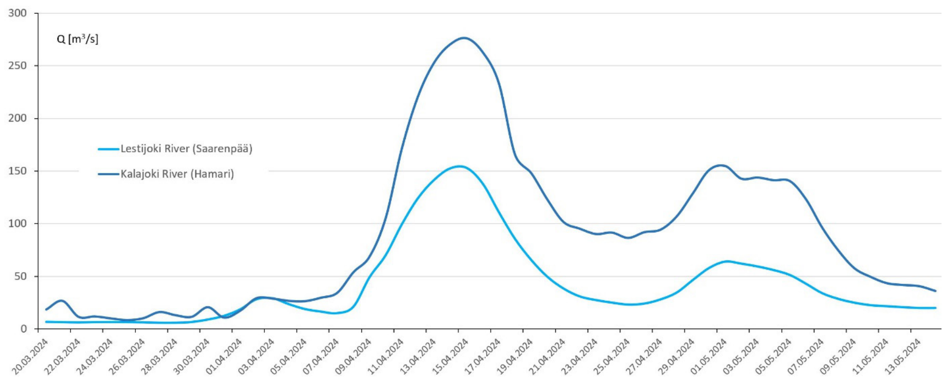

Figure 3. Average daily discharge for the Lestijoki and Kalajoki rivers in spring 2024 (data source: vesi.fi).

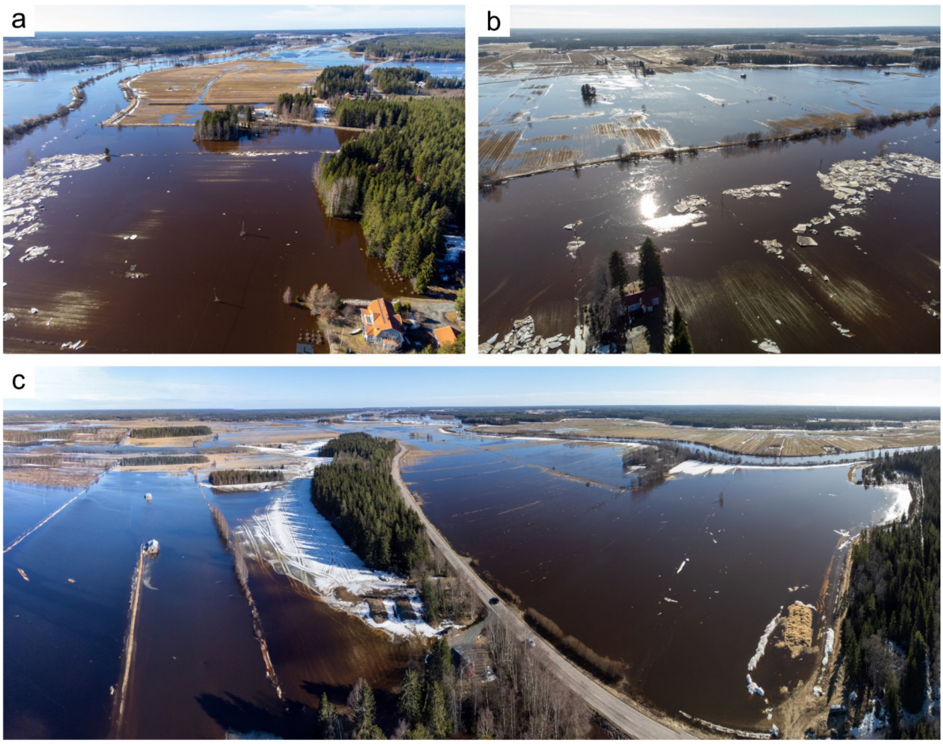

Figure 4. Flood of the Kalajoki river (April 14, 2024): a–c – inundation on the Niemelänkylä–Korteperä section (photographs M. Kasprzak).

Discussion

During the events of April 2024, the rescue services in Northern Ostrobothnia were called on and performed over 80 flood-related tasks. Press reports reveal that the response services were highly effective in their flood control activities, as had been previously reported for specific rivers in spate – such as Kemijoki – in the last few years (Räsänen 2021; Albrecht 2023). Although it was reported that the Kalajoki flood was exceptionally large, events of a similar magnitude have occurred in recent decades that neither caused major damage, material losses or threatened the population. Its course and floodwater extent was well within the scenarios assumed in the planning documents for flood risk management (Kettunen *et al.*, 2015; Parjanne *et al.*, 2018).

Our observations along the Kalajoki river catchment confirm that the region is well prepared and protected for flood risks. This has been achieved through completed flood control measures in the formation of riverbeds, the construction of flood embankments and levees, and the raising of road surfaces. It would be unrealistic and exceptionally expensive to attempt to entirely preclude excess water from the river's natural floodplain areas. Hence, the designation of specific flood areas combined with public dissemination are equally important in long-term mitigation strategies. Despite the direct flood threat to some low-lying buildings, along with additional risk from fast-flowing ice, the inhabitants of the region were well prepared for the events and there was no panic or undue emergency. One notable consequence of the build-up of river ice and subsequent jams in 2024, was the direct impact on river bank erosion. Large blocks of river ice, once released and packed tightly can exert large mechanical forces on the river channel in numerous places, resulting in selective, but significant bed and bank erosion, impacting on the rivers sediment load and downstream water quality.

Work is ongoing to improve flood prediction in high-latitude regions, where snow accumulation and its subsequent spring melt play a key role in the hydrological regime of complex river systems. Veijalainen *et al.* (2010) argued that snowmelt floods will be less frequent in Finland with ongoing increasing temperatures and climate warming. Similar forecasts were recently summarised by Parjanne *et al.* (2021), with the reduction in the scale of spring floods expected to mainly impact southern and central Finland. In the rivers of the north of the country, this trend may not be noticeable in the short term or may even be contrary, due to an observed increase in precipitation and particularly extreme snowfall (Bailey *et al.*, 2021; Bailey & Hubbard, 2025) despite generally milder temperatures and a shortened winter season. This is against the general backdrop of a predicted increase in flood frequency observed across Europe due to a corresponding increase in high-magnitude rainfall events (Fang *et al.*, 2024).

In the case of Ostrobothnia, future flood scenarios should also consider accounting for eustatic sea level rise, which may well exceed the long-term glacio-isostatic uplift response over the next decades (Rosqvist *et al.* 2013; Pellikka *et al.* 2018; Watson Hubbard & Hubbard, 2025). Around the Gulf of Bothnia, where the mitigating isostatic rebound response to the deglaciation of the Fennoscandia at around 15ka BP (Patton *et al.*, 2016) remains strong, current eustatic sea-level rise of ~4.5 mm a^{-1} is largely offset, resulting in only a minor incremental increase or even a lowering in relative sea-level. However, such conducive conditions are unlikely to sustain even under current greenhouse gas emission scenarios, not to mention faster-than-forecast mass loss from the Greenland and Antarctic ice sheets (e.g. Box *et al.*, 2022), that could potentially drive meter-scale eustatic sea-level rise. Considering the most recent round of IPCC projections (AR6, 2021), the incremental sea-level rise in the Gulf of Bothnia

Figure 5. Ice jams and other phenomena on the Kalajoki river (April 14, 2024): a, b – ice floe beyond the riverbed in the town of Ylivieska; c, d – ice floe in front of local barriers on the Niemelänkylä–Korteperä section; e – ice jam near the village of Tynkä; f, g – traces of flood in the vicinity of the Vetenoja village (photographs M. Kasprzak).

occurs even under best-case scenarios (Watson Hubbard & Hubbard, 2025). Under worst-case scenarios, multi-meter elevation of river catchment base levels will occur, compounding local and upstream flood risk.

One indirect and somewhat unexpected consequence is that Spring floods have resulted in a new phenomenon dubbed "flood tourism" in the press. While curiosity regarding natural processes and observations of ice jams and raised water levels is understandable, the deliberate driving of vehicles through flooded areas is an undesirable and somewhat counter-productive consequence, further complicating, and occasionally leading to new rescue operations. General interest regarding the new phenomena of "flood tourism" led the Kotimaisten kielten keskus (Institute for the Languages of Finland) to announce it as its "word of the year" for 2024.

In conclusion, we find that existing hydrological scenarios related to climate change cannot assume a decreased flood risk across Ostrobothnia despite warmer and shorter winters. With increasing global temperatures, particularly across the Arctic, spring floods may occur earlier or otherwise become more vigorous as more frequent warm-air incursions, occurring throughout winter as well as spring, will become the norm. As a result, river ice regimes will continue to change – generally becoming shorter but also potentially undergoing multiple ice formation/breakout cycles each season (Yang *et al.*, 2020). Our observations of the spring snowmelt floods in 2024 appear to confirm this. It must not be ruled out that floods caused by rainfall and storm events in other seasons will also occur with increased intensity and frequency, and may be further compounded by such intense rain falling on impermeable frozen ground, with high runoff potential and significant flash-flood potential. Despite Finland's rapid and pragmatic civil response to managing increasing flood-risks, as evidenced by the minimal infrastructure damage, disruption and cost of the April 2024 floods we observe here, there is no room for complacency as baseline climatological, meteorological and hydrological system parameters will continue to change over the next decades. Forecasting of catchment runoff and flooding scenarios, coupled with the changing river ice situation through improved hydraulic modelling based on future synoptic-scale climate scenarios, will be critical. Moreover, a pragmatic strategy might also consider observations from recent events and closely monitor and learn how system's forcing and response is changing in real-time.

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