TRADITIONS AFFECTED BY CLIMATE CHANGE

Miwatari, Sake Brewing and Miso Production in the Suwa Region of Nagano

The Miwatari Haikanshiki, a Shinto ritual performed after Miwatari has been confirmed. Featured is Kiyoshi Miyasaka, the current chief priest of Yatsurugi Shrine (2018)

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Executive Summary

Lake Suwa's most recently recorded *Miwatari* occurred in 2018, marking an eight-year consecutive absence of this ancient winter phenomenon. *Miwatari*, an ice ridge historically believed to be a trail left by a deity, and formally observed by Yatsurugi Shrine, has for centuries been a very important sacred event. Its absence in recent years signals a major shift in the lake's winter conditions, with effects on other climate-dependent cultural practices in the region.

This briefing paper combines Yatsurugi Shrine records (1444-2025) with Japan Meteorological Agency (JMA) temperature data (1945-2025) to quantify how winters at Lake Suwa have changed over time. Although the Yatsurugi Shrine records begin in December 1443, these observations are attributed to the winter of 1444; accordingly, the analysis spans the period 1444-2025. Key findings include:

Delayed *Miwatari*: The seasonality of *Miwatari* has been delayed by +0.190 days per year (≈ +19 days per century) during the period 1925-2025, with a historically remarkable shift in timing from December-January to January-February (Figure 6).

Warming Winters: Since 1945, mean winter temperatures have increased at a rate of +0.023°C per year (≈ +2.3°C per century, Figure 7), while the annual number of sub-zero days (below 0°C) has declined by −0.325 days per year (≈ −33 days per century, Figure 8). The cumulative winter-severity indicator, Accumulated Freezing Degree Days (AFDD), shows a significant decline over time (slope −0.843/year), indicating a reduced capacity for the lake to sustain the freezing conditions required for full ice formation.

Impacts on Fermentation: During the sake production window of October to March (noting that December to March is the peak cold-brewing season), days exceeding ideal thermal brewing thresholds of 10°C and 15°C are increasing at a rate of +21 and +17 days per century, respectively. For miso, days with maximum temperatures of ≥30°C have increased by 29 days per century. Recent years (2023 and 2025) have broken records, seeing more than 60 days above that threshold (Figure 10).

Broader Implications

Rising winter temperatures driven by anthropogenic climate change have made the complete freezing of Lake Suwa increasingly rare. Analysis by 25-year intervals since 1900 shows that freeze-over frequency has declined from 96% in the early twentieth century to 48% in the past 25 years. As winter conditions change, the *Miwatari* and its associated Shinto ritual, which has continued for almost 600 years, is disappearing.

The climate of the Suwa region has historically fostered a fermentation industry, particularly in sake and miso production: the distinctive flavour profiles of both are the result of unique microbial activities that have evolved over centuries, modulated by local ambient temperatures. Recent warming trends are disrupting these temperature-sensitive processes and are threatening to compromise the quality of the product itself.

Climate change is not only increasing the risks of torrential rainfall, flooding, and heatwaves, but it is also changing the cultural landscapes of Japan. Previous investigations by Greenpeace Japan have documented delayed leaf colouration in maple and gingko trees and the warming by 1.47°C per century at the summit of Mount Fuji.[1,2] Research into climate-cultural topics, including traditional fermentation, remains insufficient. However, beyond adaptation strategies, it is imperative to mitigate climate change to avert increased warming and further cultural loss.

Introduction

Miwatari

Omiwatari (henceforth *Miwatari*) is a rare ice phenomenon observed most notably on Lake Suwa, Nagano prefecture (~200 km West of Tokyo). It is characterised by the formation of a cracked ice ridge across the lake's surface after it has frozen over.

Figure 1: Location of Lake Suwa

The term *Omiwatari* **御神渡り** (**御** honorific; **神** god; **渡り**crossing) or *Miwatari* (excluding the honorific)[3] reflects the belief that the ridge is a trail left by a deity. Each winter, the chief priest and representatives of Yatsurugi Shrine monitor Lake Suwa for signs of *Miwatari*. Once the phenomenon has been confirmed, a Shinto ritual is performed to honour and celebrate the event (Figure 3). The *Miwatari's* position, shape and direction were used to predict the coming summer climate and harvest season[4]. The association of *Miwatari* with religious rites and its perceived forecasting value has ensured the survival of records dating back to 1443. This 600-year archive is one of the longest continuous human observational records of ice phenology in the world.

[1] Greenpeace Japan, 紅葉時期にみる気候変動の影響について (2023)
[2] Greenpeace Japan, Signs of Climate Change at Mount Fuji (2025)
[3] Although widely known as 'Omiwatari', the current chief priest of Yatsurugi shrine uses the term 'Miwatari', citing its use in the original written archive
[4] Records exist because the state of ice was reported to the government every year, as stated by S. Fujiwhara, Notes on the Climatic Variations Concluded from the Dates of the First Complete Freezing of Lake Suwa in Japan, *Geografiska Annaler* 3:4, 358-361, doi: 10.1080/20014422.1921.11880920

Figure 2 (left): Miwatari across Lake Suwa
Figure 3 (right): The Miwatari Haikanshiki, a Shinto ritual performed after Miwatari has been confirmed. Featured is Kiyoshi Miyasaka, the current chief priest of Yatsurugi Shrine (2018)

In recent decades, however, this once-annual occurrence has become increasingly rare. At the time of writing (2026), the most recent *Miwatari* was recorded in 2018. This eight year absence marks one of the longest gaps since record-keeping began, on par with only an eight year absence during 1508-1515, although the reliability of this specific record has been questioned.[5,6,7]

While the precise climatic variables required for *Miwatari* remain a subject of study, the relationship between warming temperatures and lake ice loss is well established globally, especially in the Northern Hemisphere.[8,9] As *Miwatari* requires a complete freeze-over of the lake, changes in local climate conditions offer an important context for understanding its recent absence. Years in which *Miwatari* fail to occur are known as *Akenoumi* (**明けの海** open sea).[10]

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[5] The gap recorded for 1508-1515 (winters commencing in 1507-1514), as compared to estimated winter temperatures during this time, has been challenged as 'statistically unlikely' (6) and its existence has been disputed by Arakawa (7)
[6] Minoru Tanaka and Masatoshi M. Yoshino, "RE-EXAMINATION of the CLIMATIC CHANGE in CENTRAL JAPAN BASED on FREEZING DATES of LAKE SUWA." *Weather* 37, no. 9 (1982): 252–59, doi: 10.1002/j.1477-8696.1982.tb03626.x
[7] H. Arakawa, 16世紀の気候と"当社神幸記"に現われたる明海の記事 (1963), https://www.metsoc.jp/tenki/pdf/1963/1963_03_0082.pdf
[8] Alessandro Filazzola et al., "Climate Change Drives Increases in Extreme Events for Lake Ice in the Northern Hemisphere," *Geophysical Research Letters* 47, no. 18 (2020), doi: 10.1029/2020gl089608.
[9] R. Iestyn Woolway et al., "Global Lake Responses to Climate Change," *Nature Reviews Earth & Environment* 1, no. 8 (2020): 388–403, doi: 10.1038/s43017-020-0067-5.
[10] Note that some scholars define *Akenoumi* as years in which the lake did not freeze. Here we refer to non-omiwatari years, regardless of freeze-over

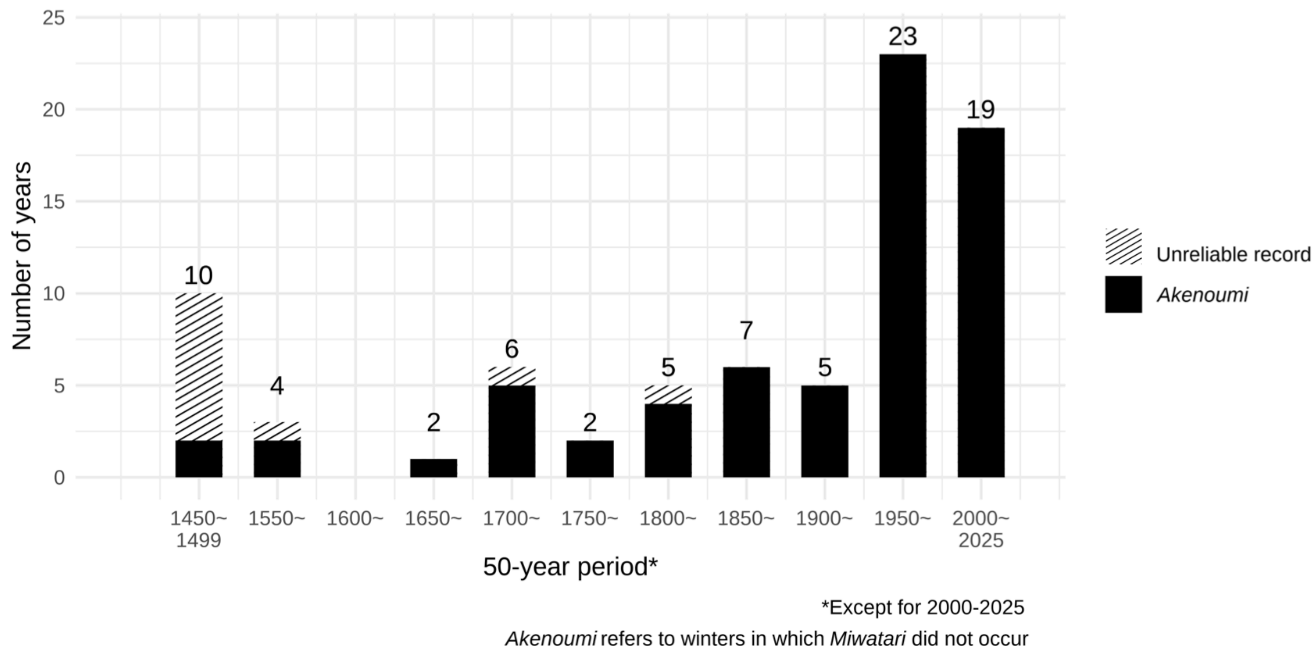

Figure 4: Occurrence of Akenoumi (years without Miwatari) in 50-year periods since record-keeping began. 'Unreliable record' refers to the contested 1508-1515 gap[7] and years marked in Arakawa[11]

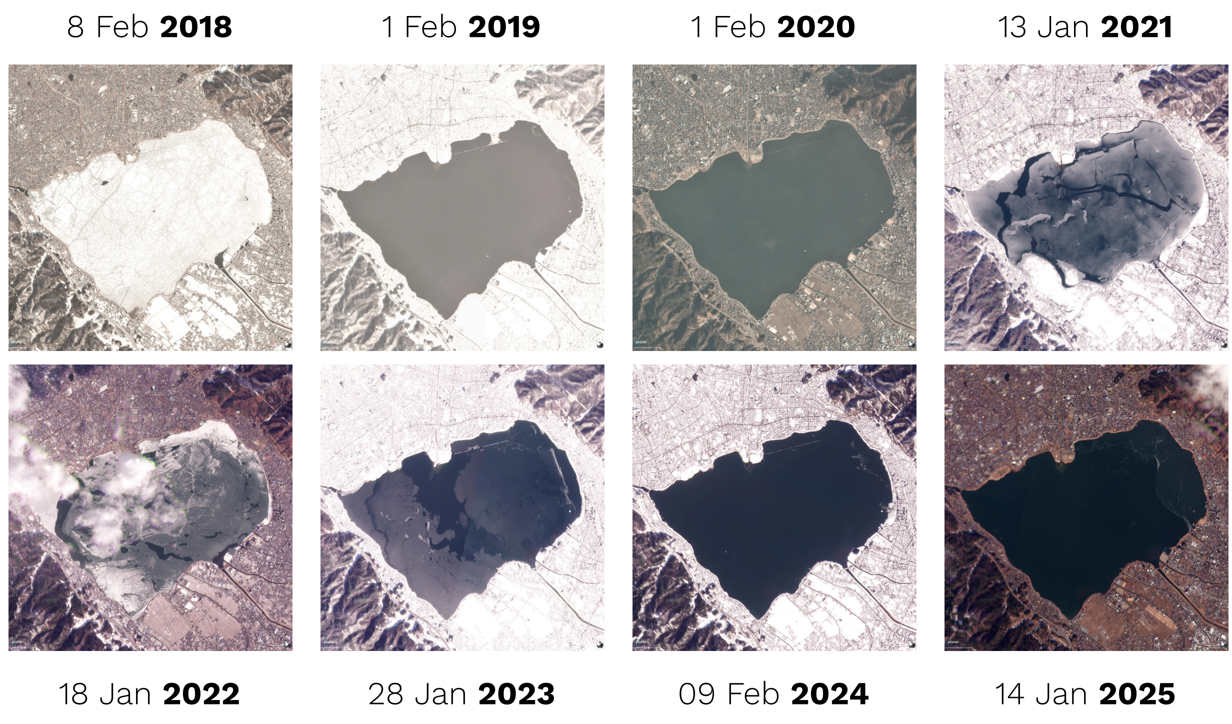

Figure 5: Satellite imagery of Lake Suwa, showing days with observed peak ice cover (for years with ice, filtered for cloud-free days) © 2025 Planet Labs PBC

[11] Arakawa's record (16) marks *Akenoumi* years as "open" but some years are annotated as "open?"

Figure 5 displays satellite imagery of Lake Suwa in winter from 2018 to 2025. Despite snow and partial freezing of the lake, the conditions required for *Miwatari* were not met after 2018. For the shrine priests and local community, increasing *Akenoumi* represents the fading of a cross-generational tradition. The cultural significance of the disappearing *Miwatari* has also been documented in the short film *MIWATARI*.[12]

Fermentation

Nagano Prefecture's high-altitude geography and harsh winters fostered a tradition of fermentation techniques, such as miso (a paste made from fermented soybeans) and sake (an alcohol brewed from fermented rice). The diet of fermented staples is credited with the region's high life expectancy. However, rising temperatures and shifting seasonal cycles now threaten the feasibility of sustaining these traditional food systems.

Nagano ranks second in Japan as a major sake producer, with 9 out of more than 80 breweries in the Suwa region.[13] While the cold climate and availability of high-quality water historically favoured brewing, a 2024 Greenpeace panel with a long-established sake brewery (founded in the 17th century) noted that brewers now struggle to source quality rice and to maintain the low temperatures essential for the fermentation process. According to a testimonial from a local brewery, brewing standard sake in Suwa requires temperature caps of 15°C, and *Daiginjo* (premium-ranked sake) requires 10°C, thresholds becoming increasingly difficult to maintain as temperatures rise.

Shinshu miso (miso from Nagano) accounts for 50% of Japan's miso consumption, with 20 of Nagano's 85 storehouses located in Suwa.[14] According to a local company, miso production relies on distinct seasons and temperatures close to 30°C, but prolonged exposure to temperatures above 30°C accelerates fermentation and maturation, causing miso to darken and lose its flavour. Like sake brewers, miso producers report increasing difficulty in managing thermal thresholds in a warming climate.

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[12] 御渡り / MIWATARI, directed by Ono Yusuke, sponsored by Greenpeace Japan, uploaded November 30, 2023, https://youtu.be/1JXT_U40ttk
[13] Nagano Prefecture Sake Brewers Association (n.d.) https://www.nagano-sake.or.jp/intro/
[14] Nagano Prefecture Miso Industry Cooperative Federation (n.d.) https://shinshu-miso.or.jp/aboutus/

Methodology

Data Sources All temperature data presented in this report are retrieved from the Japan Meteorological Agency (JMA) ‘Past Weather’ public database from 1945-2025[15]. The Suwa Weather Observatory is located at 36°0’2.7” N 138°06’5” E.

Freeze records and *Miwatari* dates before 1945 are sourced from Arakawa[16] based on Yatsurugi Shrine records; dates from 1945-1978 are taken from Tanaka & Yoshino[17] based on data from the local meteorological observatory. Freeze records from 1982 to 2020 are sourced from the Global Lake and River Ice Phenology database[18]. 2020-2025 freeze records and *Miwatari* dates after 1982 were compiled from records such as newspaper reports. Although the reliability of the *Miwatari* record may be questioned and interpreted cautiously, they remain valuable as qualitative indicators of long-term environmental change.

Analytical scope and limitations The reliability of *Miwatari* date records between 1683 and 1923 has been questioned by Arakawa[9] and Tanaka & Yoshino[10] due to potential inconsistencies in documentation and interpretation. Since the effects of anthropogenic climate change became prominent after the industrial age, quantitative trend analysis focuses on data from 1925 onward, corresponding to the consistent post-1923 records. Linear models were used to estimate changes in Miwatari dates from both 1444-2025 and 1925-2025. Results from the post-1925 period are emphasised in quantitative interpretation, while earlier estimates are presented to illustrate long-term directional patterns.

Definition of winter variables Accumulated Freezing Degree Days (AFDD) were calculated as a proxy for winter severity using daily mean air temperatures from December 1 to February 3, allowing for a one-month cooling period before the *Miwatari* observation window, which spans from the beginning of January to around February 4. AFDD reflects how intense cold conditions persist during winter, calculated as the sum of mean daily degrees below 0°C. Winter variables (sub-zero days, AFDD, and mean winter temperature) were assigned ‘cold seasons’ to capture a continuous year across each winter. Each cold season spans August of the previous year to July of the following year; for example, the 2025 mean

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[15] Japan Meteorological Agency (JMA), 諏訪, 過去の気象データ検索, https://www.data.jma.go.jp/stats/etrn/index.php?prec_no=48&block_no=47620&year=&month=&day=&view=

[16] H. Arakawa, “Fujiwhara on Five Centuries of Freezing Dates of Lake Suwa in the Central Japan.” Archiv Für Meteorologie, *Geophysik Und Bioklimatologie Serie* B 6, no. 1-2 (1954): 152–66, doi: 10.1007/bf02246747.

[17] Tanaka and Yoshino, “RE-EXAMINATION OF...LAKE SUWA”

[18] National Snow & Ice Data Center, Global Lake and River Ice Phenology, https://nsidc.org/data/lake_river_ice/freezethaw.html

winter temperature was averaged across December 2024, January 2025 and February 2025.

Results

1. Seasonality of Lake Suwa (delay of *Miwatari*)

As well as declining in frequency, *Miwatari* is occurring progressively later in the winter season. To quantify this, *Miwatari* dates were expressed as the number of days relative to January 1st (treated as Day 0). Figure 6 shows the gradual delay in *Miwatari* dates relative to January 1st. Missing intervals represent years with no reported *Miwatari* (1508-1515) or a gap in the record (1873-1892).

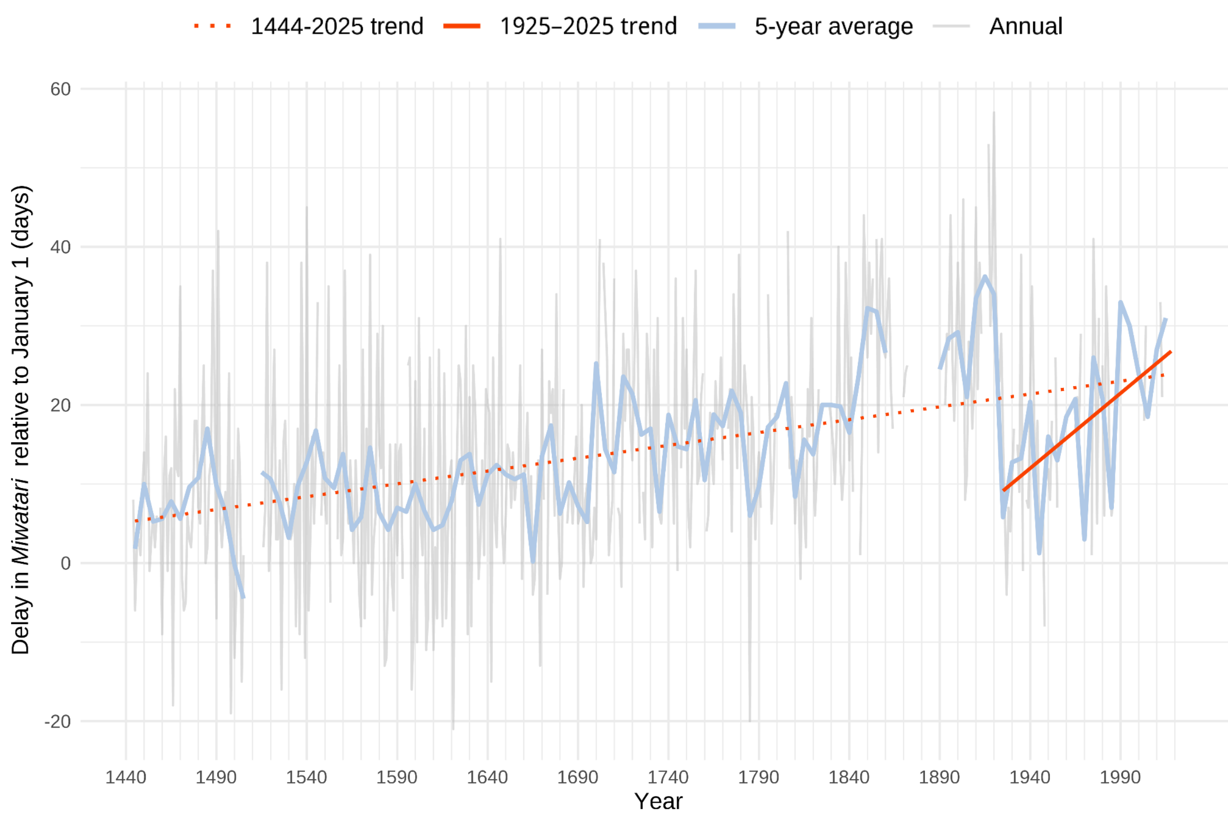

Figure 6: Delay in Miwatari dates relative to January 1st (1444-2025) with annual date of Miwatari; averages for every 5 years; linear regression fitted to 1925-2025 (slope = 0.190 days/year).

While *Miwatari* was typically observed across December and January before the late 17th century, occurrences after this period have generally shifted to January and mid-February. Although the full dataset provides a long-term baseline, changes during the modern observational period (1925–2025) are substantially more pronounced, with dates shifting by approximately +1.9 days per decade.

These patterns are consistent with broader trends in freeze-over phenology, although complete freeze-over may also be influenced by local factors such as *onsen* (hot spring) development[19]. A study on freeze-over dates at Lake Suwa calculates a delay of 46 days per 100 years (+4.6 days per decade for the period 1923-2014), which is deeply concerning.[20] In a global context, a review of 19 Northern Hemisphere lakes found that the mean delay rate of ice formation (1855-2019) is +11.6 days per century.[21]

2. Annual Mean Winter Temperature, Suwa City

Figures 7 and 8 combine thermal data (Japan Meteorological Agency) with event data (*Miwatari* and freeze-over years) for 1945-2025.

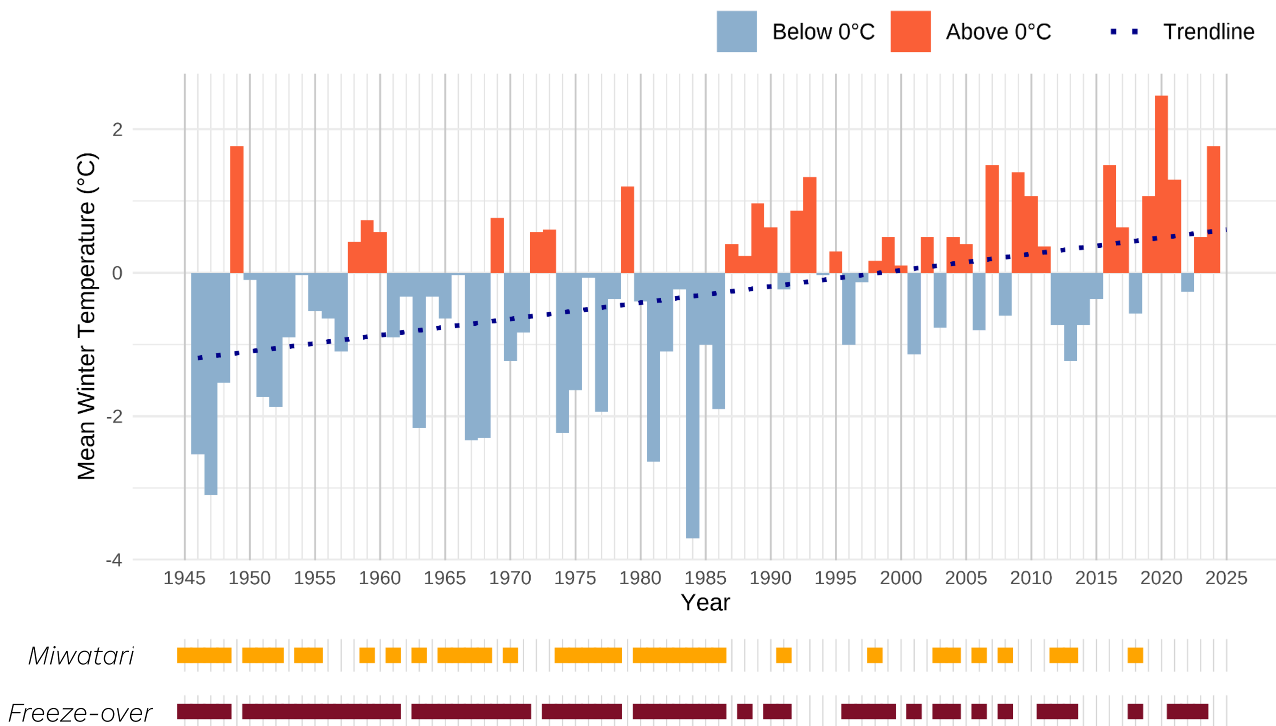

Figure 7: Annual Mean Winter Temperature, 1945-2025, with fitted trendline (slope = 0.023°C/year); Miwatari (yellow) and Freeze-over (maroon) years

Miwatari and freeze-over events are occurring less frequently. After 1986, consecutive annual series are rarer and shorter. There are some years in which *Miwatari* did not occur despite successful freeze-over, which Tanaka & Yoshino have attributed to "the lack of a subsequent cold wave necessary for deformation and cracking of the ice."[22]

[19] As discussed in Tanaka and Yoshino, "RE-EXAMINATION OF...LAKE SUWA", p.252
[20] Sapna Sharma et al., "Direct Observations of Ice Seasonality Reveal Changes in Climate over the Past 320–570 Years," *Scientific Reports* 6, no. 1 (2016): 25061–61, doi: 10.1038/srep25061.
[21] R. Iestyn Woolway et al., "Global lake responses to climate change"
[22] Tanaka and Yoshino, "RE-EXAMINATION OF...LAKE SUWA", p.252

Figure 7 shows a critical shift to above-zero temperatures across winter months (December, January and February). Winter temperatures are rising at a rate of 2.3°C per century, which serves as the broader context for ice-free years. While winters during 1945-1986 were predominantly below 0°C, winters after 1986 have been predominantly above 0°C. The 1986 turning point coincides with when consecutive *Miwatari* and freeze-overs become rarer. Sharma et al. calculated that for the ice-free threshold for Lake Suwa (-1.7°C) and future climate projections, Lake Suwa "may permanently lose ice cover within this generation".[23]

3. Freezing trends, Suwa City

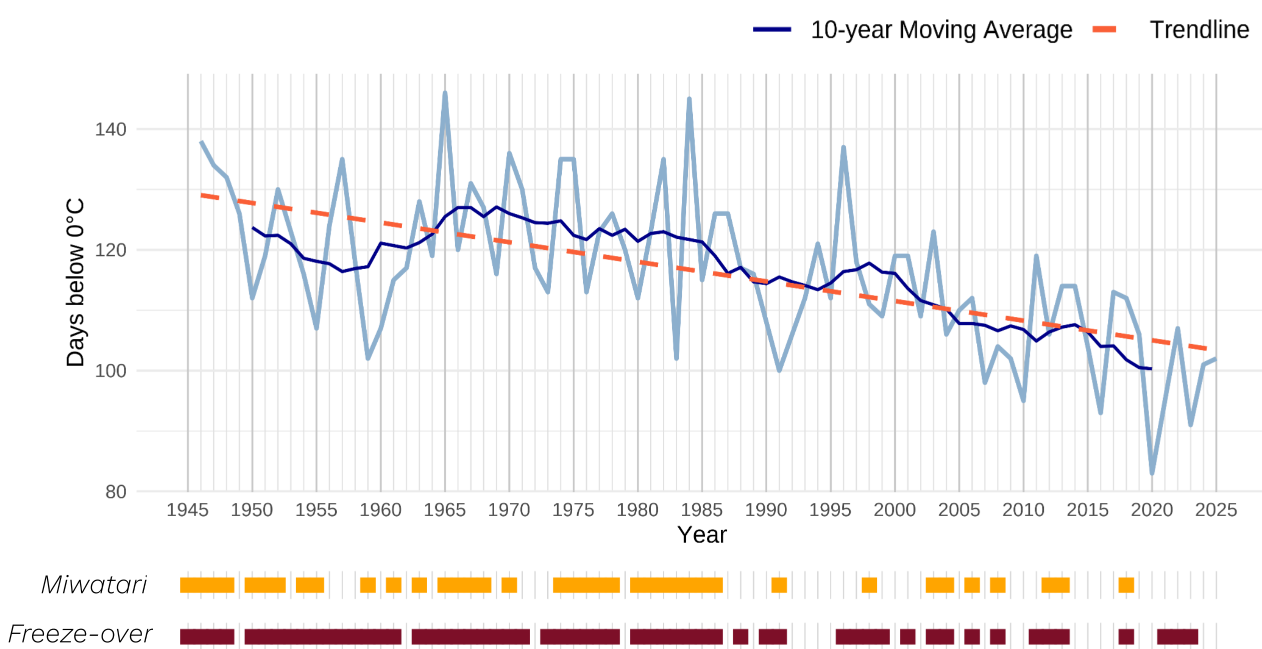

Figure 8: Annual number of days with minimum temperature below 0°C, with a 10-year centred moving average and fitted trendline (slope =-0.325 days/year); Miwatari (yellow) and Freeze-over (maroon) years

Sub-zero days (days in which the minimum temperature dropped below 0°C) are decreasing by more than a month per century (-33 days/100 years), suggesting the declining prevalence of freezing conditions. 2020 saw a record-low of only 83 sub-zero days, complemented by the record winter mean temperature shown in Figure 7.

According to Yatsurugi Shrine's chief priest, Lake Suwa freeze-over can be expected when temperatures drop below -10°C for 3 consecutive days. While this

[23] Sapna Sharma et al., "Forecasting the Permanent Loss of Lake Ice in the Northern Hemisphere within the 21st Century," *Geophysical Research Letters* 48, no. 1 (2021) https://doi.org/10.1029/2020gl091108.

used to be a common occurrence, days reaching -10°C are also in rapid decline. As with *Akenoumi* (years without *Miwatari*), the wider record spanning from 1444 to the present reveals that ice-free years were very rare. Examination of the recent record reveals that freeze-over failed in only one year during 1901-25, two years in both 1926-1950 and 1951-75, eight years during 1976-2000, and thirteen years in the past 25 years. In percentage terms, freeze-over occurred in 96% of years in 1901–1925, compared with 48% of years in 2001-2025.

4. Accumulated Freezing Degree Days (AFDD)

As emphasised by Fujiwhara[24], lake freeze-over is the result of accumulated cold in preceding weeks. Accumulated Freezing Degree Days (AFDD), a proxy for winter severity, is the sum of daily mean temperatures below 0°C. The AFDD for each winter (not graphed) exhibited a downward trend (*slope* = -0.843, $p < 0.001$), despite considerable interannual variability. This decline in degree-day accumulation indicates a long-term reduction in the cumulative freezing energy available for ice formation, consistent with the increased frequency of *Akenoumi* observed recently.

Mean winter temperature, sub-zero days, and AFDD can be used in conjunction to understand *Miwatari* occurrence, although a precise model would require other factors such as wind, radiation and snowfall. For example, in 1959, despite fewer sub-zero days and an above-zero winter mean, Lake Suwa achieved freeze-over and *Miwatari*. Its above-average AFDD value and 3 consecutive days of -10°C minimum temperatures suggest it was a severe winter; some winters are more 'efficient,' with cold concentrated enough to drive ice formation despite warmer overall conditions. Conversely, recent winters (2021-2023) experienced freezing conditions but did not produce *Miwatari*; these winters had low AFDD values, indicating that the cold intensity was insufficient. The results drawn from Sections 2-4 complement the broader trend of milder winters and suggest that the thermal threshold required for *Miwatari* is becoming increasingly difficult to reach.

5. Thermal Thresholds in Sake Brewing (10°C and 15°C)

According to results of a 2024 survey conducted by the Shinshu Climate Change Adaptation Centre (covering 20 sake breweries across Nagano), 70% of respondents stated that their manufacturing process is being affected by climate change. When asked whether they are currently implementing, or have previously implemented, adaptation measures in response to climate change, 75% of respondents said 'Yes'.[25]

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[24] S. Fujiwhara, "Notes on the Climatic Variations...", p.358
[25] 信州気候変動適応センター (Shinshu Climate Change Adaptation Centre), 令和5年度国民参加による気候変動情報　収集・分析委託事業（2年目）成果報告会 (2024), Courtesy of Takashi Hamada, Nagano Environmental Conservation Research Institute.

The number of days in which temperatures exceeded 10°C and 15°C was investigated (not graphed): the number of days above 10°C is increasing at a rate of ~21 days per century, driven by increasingly warmer days in November and March. The number of days above 15°C is increasing at a rate of ~17 days per century, driven by increasingly warmer days in October and March.

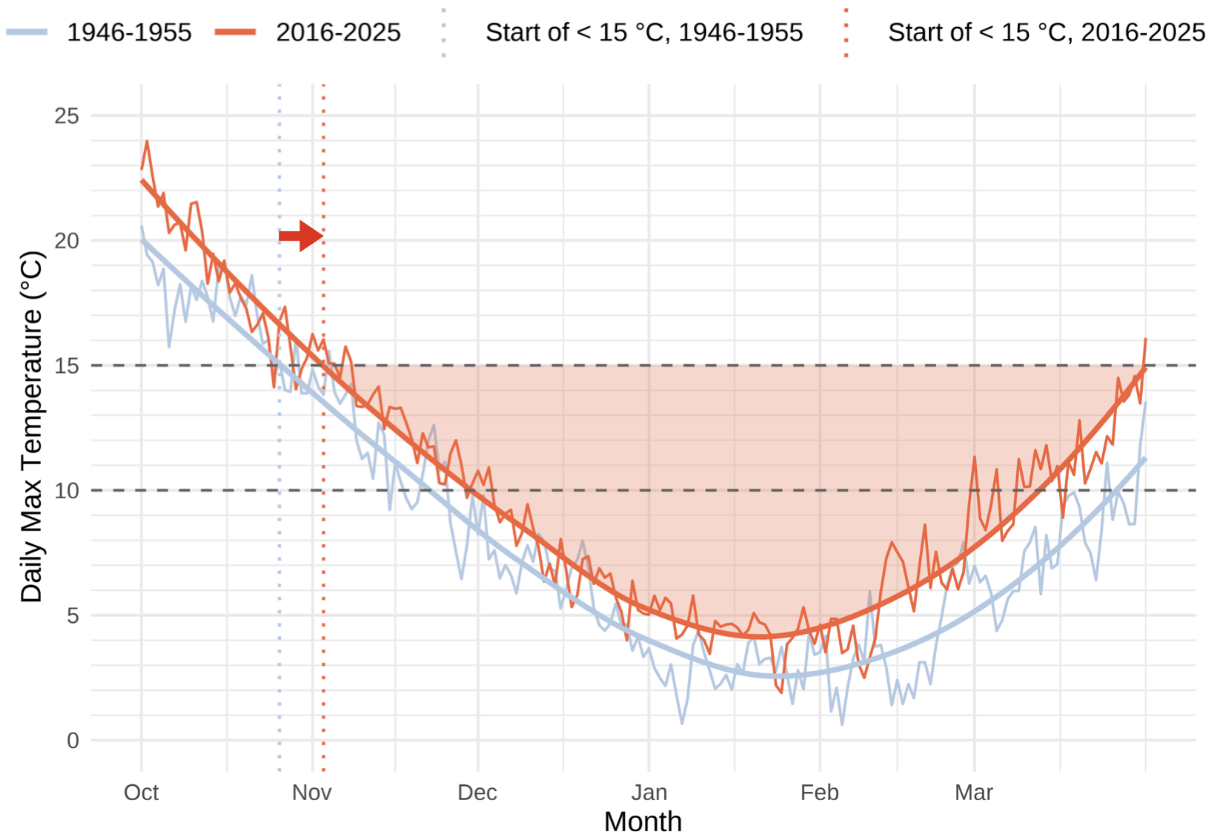

Figure 9: Daily maximum temperatures, averaged across decades 1946-1955 and 2015-2025, with dotted lines showing the start of < 15°C temperatures and shaded region representing the approximate thermally suitable window for sake brewing in 2016-2025

Figure 9 analyses daily maximum temperature trends for the six-month window October to March, highlighting 10°C (*Daiginjo*) and 15°C (standard sake) thresholds. The recent decade averages (highlighted in red, 2016 to 2025) exceed the earliest-recorded decade averages (highlighted in blue, 1946 to 1955) for almost every day, indicating an upward trend in autumn and winter maximum temperatures over the period of 80 years. The window of suitable temperatures for standard sake brewing (<15°C) has (1) been delayed by approximately a week, as indicated by the arrow, and (2) become narrower, recently moving beyond the 15°C threshold by March with the early onset of spring.

6. Thermal thresholds in Miso Production (30°C)

According to the results of the same survey by Shinshu Climate Change Adaptation Centre (covering 12 miso producers across Nagano), 100% of respondents stated that their manufacturing process is being affected by climate change, with 58.3% describing the impact as 'significant'. When asked whether they are currently implementing or have previously implemented adaptation measures in response to climate change, 83.3% of respondents said 'Yes'.[26] Respondents described how climate change has shifted the fermentation window to earlier and has affected the product colour-flavour balance.

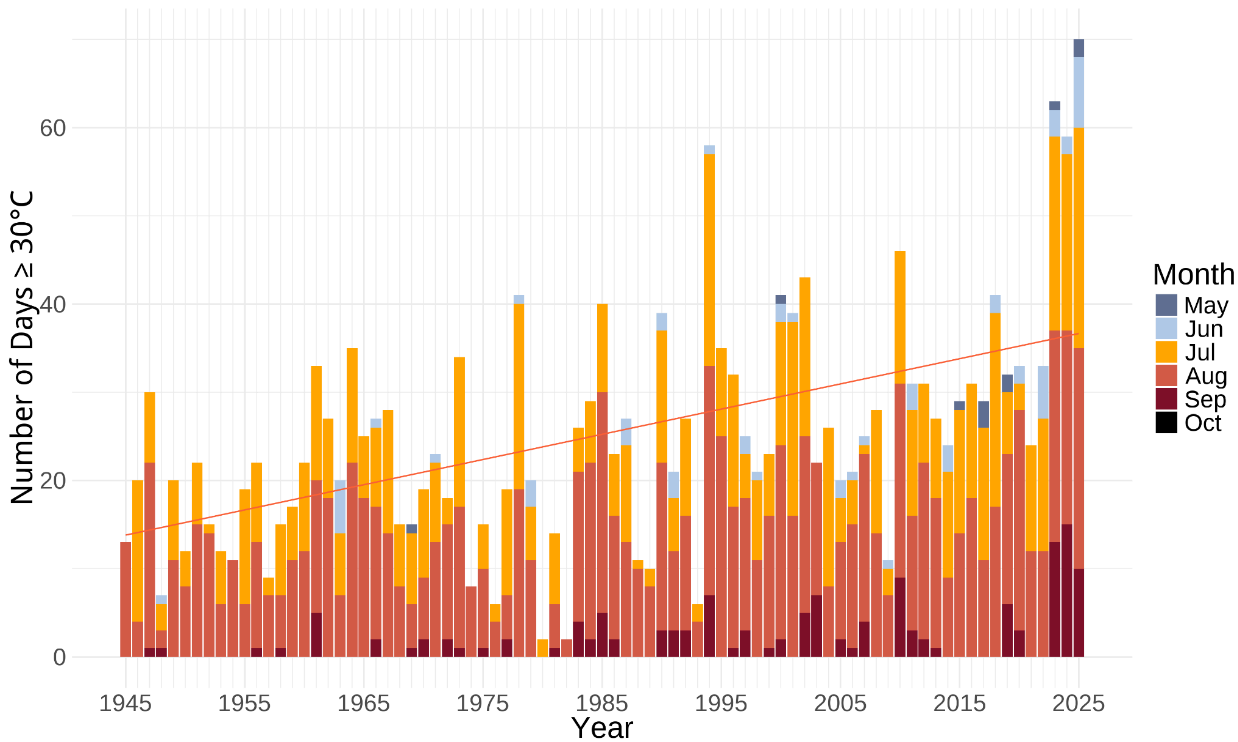

Figure 10: Days where maximum temperatures exceeded 30°C (1945-2025) grouped by months May to October (slope = 0.286 days/year)

Figure 10 shows the number of days exceeding 30°C (the ideal thermal threshold for miso fermentation in Suwa) during May to October. As indicated by the trendline, days above 30°C are increasing by approximately 29 days per century. The years 2023 and 2025 have seen a surge of more than 60 days per year, the most seen in recorded history at Suwa. This is mostly driven by an increase in days exceeding the threshold during July and August. In the last 3 years in particular, September has also seen more days above 30°C. These results indicate that summers are becoming both hotter and longer.

[26] 信州気候変動適応センター (Shinshu Climate Change Adaptation Centre)