Climate Analogues

Horizons Region, New Zealand

Climate Change Projections from CCAM-Downscaled CMIP6 Simulations

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For

Horizons Regional Council

Report:	Climate Analogues Report
Baseline:	1986–2005
Scenarios:	SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5

September 17, 2026

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1 Executive Summary

Climate analogues provide an intuitive way of communicating how the climate of a particular location may change in the future. Rather than describing projected changes solely in terms of changes in the magnitude of individual climate variables, such as an increase in mean temperature or a decrease in annual rainfall, a climate analogue identifies a location whose climatology (i.e. the baseline climate that we are used to operating under) resembles the projected future climate of the location of interest. Essentially it answers the question: given my current location, where is the location nearest to me that, over the climatological period, experienced the climate conditions that I am projected to experience in year X?

Climate analogues can be particularly useful for translating climate projections into information that is meaningful for adaptation planning. Existing conditions at the analogue location provide tangible examples of the types of agricultural systems, vegetation, water-management practices, and environmental pressures that may be compatible with the projected climate. They can therefore help stakeholders visualise climatic changes that may otherwise be difficult to interpret from maps or numerical projections alone. Analogue locations can also provide useful starting points for investigating potential adaptation options and identifying experience that may be transferable between regions.

Climate analogues should, however, be interpreted carefully. No location provides a perfect analogue for another. Similarity in selected climate variables does not imply similarity in all aspects of climate, particularly extremes, drought characteristics, storm occurrence, or the sequencing of weather events. Climate risks are a function of the hazard, exposure and vulnerability and, in that context, locations may differ substantially in soils, topography, hydrology, ecosystems, land use, infrastructure, and socioeconomic conditions. Furthermore, the most appropriate analogue depends on which climate variables are included in the comparison and how differences between them are weighted. Climate analogues are therefore best regarded as a complementary tool rather than a substitute for quantitative climate projections. Their principal value lies in providing an accessible, spatially explicit representation of projected change and helping connect climate information with practical experience of conditions that already occur elsewhere.

2 Selection of scenarios

In the generation of these climate analogues, projections of changes under four Shared Socioeconomic Pathway (SSP) emissions scenarios have been considered:

1. ***SSP1-2.6:*** A low-emissions pathway consistent with strong global mitigation efforts and relatively limited future climate warming.
2. ***SSP2-4.5:*** An intermediate pathway representing moderate emissions reductions and moderate climate warming.
3. ***SSP3-7.0:*** A medium-to-high emissions pathway associated with substantial future climate warming.
4. ***SSP5-8.5:*** A high-emissions pathway characterised by continued growth in greenhouse gas (GHG) emissions and significant climate warming.

It must be emphasised that climate scenarios are not predictions of the future, but tools for exploring uncertainty and assessing risk. While the likelihood of these four scenarios occurring is not equal, governments, regional councils, investors, and insurers must allocate capital effectively. Treating all scenarios as equally likely leads to poor planning, either under-preparing for most likely outcomes and potential risks or over-insuring against highly improbable realisations.

Given the current trajectory of international actions on GHG emissions mitigation, the SSP1-2.6 scenario has become inconsistent with observed trends during the 2020–2030 period and it is therefore implausible that the global future climate will follow the SSP1-2.6 scenario. In contrast, the GHG emissions reduction actions

that have been achieved to date increasingly rule out the SSP5-8.5 scenario, i.e. the SSP5-8.5 scenario has become implausible based on trends in the costs of renewables, the emergence of climate policy, and recent emission trends [1]. This is not to say that these two scenarios do not have their uses: SSP1-2.6 shows us what could have been achieved had earlier climate projection pledges been realised, while the SSP5-8.5 scenario shows the world that has been avoided by actions to date. The SSP5-8.5 scenario, representing a severe tail-risk envelope, would also be a valid scenario for stress-testing financial institutions. For planning purposes, however, more weight should be assigned to the SSP2-4.5 and SSP3-7.0 scenarios.

3 Selection of future periods

Projections were considered over three periods: the near-future (2021-2040), mid-century (2041-2060), and end of the century (2080-2099), all relative to a 1986-2005 baseline climatology. Although the radiative forcing (the rate at which energy is being added to the climate system compared to the pre-industrial baseline) increases to 2.6 W m^{-2} under SSP1-2.6 by 2100, to 4.5 W m^{-2} under SSP2-4.5 by 2100, to 7.0 W m^{-2} under SSP3-7.0 by 2100, and to 8.5 W m^{-2} under SSP5-8.5 by 2100, one should not expect that there will always be a consistent (monotonic) increase or decrease in some climate variable from SSP1-2.6 to SSP2-4.5 to SSP3-7.0 to SSP5-8.5 under any of these future periods since the pathways to that 2100 end point can be very different, and over the near-term to mid-century, natural variability can dominate the climate signal; often the climate signal emerges only later in the century. This is demonstrated in Figure 1. It is clear from this figure that both over the

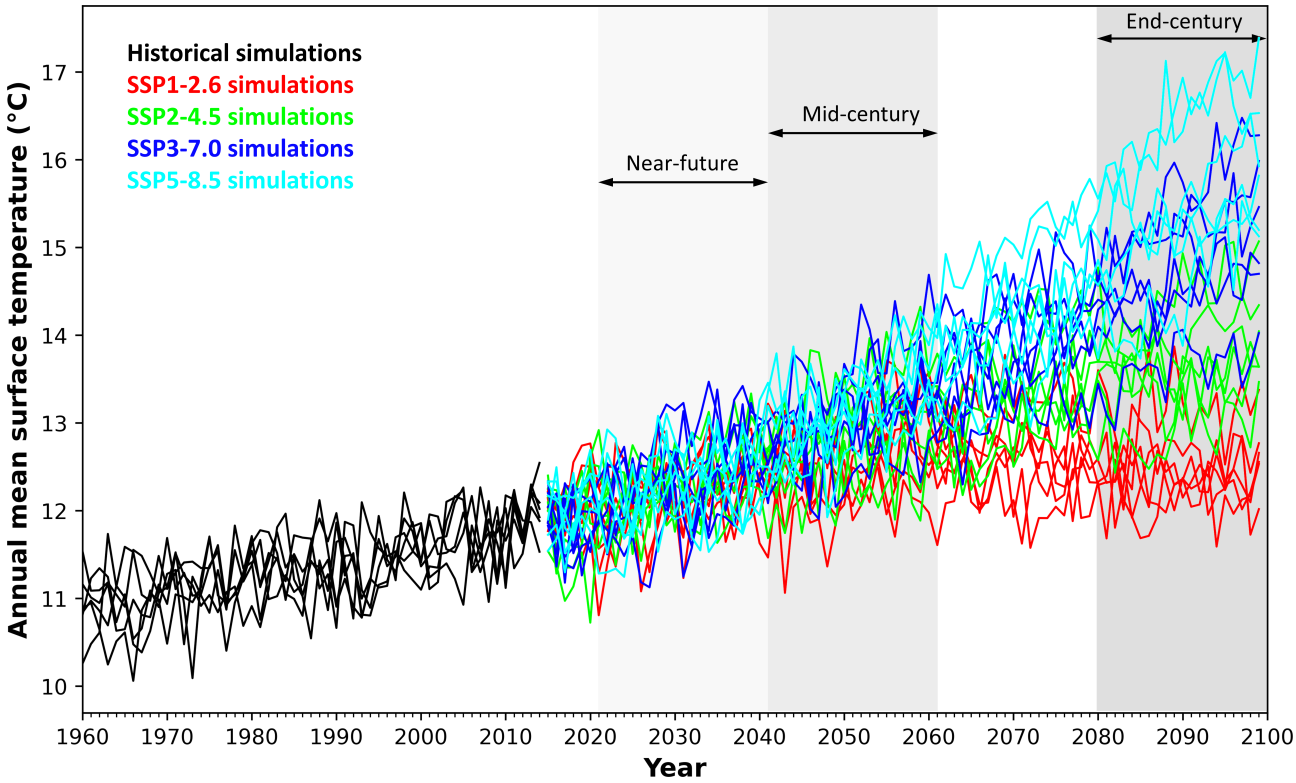


Figure 1: Annual mean surface temperature time series extracted from the six different model simulations, for the Horizons Region, for the historical baseline (black traces) and for the four different SSP scenarios (SSP1-2.6 in red; SSP2-4.5 in green, SSP3-7.0 in blue and SSP5-8.5 in cyan). Also shown are the three different analysis periods considered in this report. The original of this figure can be downloaded here.

near-future and mid-century, the year-to-year variability (unforced climate variability) and inter-model spread obscure any statistically significant separation of the projections under the four different SSPs.

[1] Hausfather, Z. and Peters, G.P., Emissions – the 'business as usual' story is misleading, Nature, doi:10.1038/d41586-020-00177-3, 2020

4 Selection of climate variables

The following climate variables were selected for climate analogues analysis:

Annual mean daily mean temperature: Average daily air temperature (T_{mean}) is a foundational climate variable, intricately linked to ecosystem function, societal wellbeing, agricultural productivity, and infrastructure resilience. In the Horizons region, T_{mean} shapes seasonal cycles, influences growing seasons, determines frost risk, and impacts both terrestrial and aquatic systems. Its projected changes are therefore essential to regional planning and adaptation.

Annual total precipitation: Total rainfall (PR) is a foundational climate variable shaping ecosystem viability, water resource sustainability, agricultural productivity, and natural hazard risk in the Horizons Region. Its seasonal and spatial variability underpins socio-economic resilience, influencing water storage, crop yields, flood and drought frequency, and ecosystem health. Climate change is expected to intensify hydrological extremes, redistribute precipitation patterns, and amplify variability, elevating overall risk exposure.

Annual number of frost days: The number of frost days (FD, defined as the number of days per year with minimum temperatures below 0°C) is a key climate variable with direct implications for agriculture, horticulture, ecosystem function, and infrastructure vulnerability in the Horizons Region. Frost events influence crop selection, the timing of planting and harvest, pest cycles, and the overwintering of both cultivated and native species. Pronounced changes in the frequency or timing of frost days can substantially alter growing season length, risk management for frost-sensitive industries, and the competitive balance between desirable and invasive species.

Annual potential evapotranspiration deficit: Potential evapotranspiration deficit (PED) is a crucial climate variable for the Horizons Region, reflecting the difference between atmospheric moisture demand and available water supply at the land surface. It is a direct indicator of soil moisture stress, drought risk, and potential impacts on agriculture, natural ecosystems, and water resource management. Analysing modelled projections of PED provides essential insights into how regional water budgets may change in the future due to climate change.

Annual number of growing degree days over a 5°C threshold: Growing degree days (GDD5, base 5°C) is a key agroclimatic variable, widely used for estimating and optimising crop development and maturity, agricultural scheduling, and ecological modelling. Increased GDD5 generally signals a longer and warmer growing season, enabling more rapid plant development but also potentially altering pest dynamics, water use, and crop selection.

Annual number of growing degree days over a 10°C threshold: Similar to GDD5, growing degree days (base 10°C; GDD10) is a critical indicator for understanding heat accumulation relevant to agriculture, horticulture, forestry, and ecosystems. GDD10 quantifies cumulative thermal energy above a 10°C baseline temperature, acting as an integrative measure of season length and intensity for plant growth, phenology, and pest development.

Annual number of hot days (>25°C): The number of hot days exceeding 25°C (TX25) is a critical climate variable linked to human health, animal health, agriculture, energy demand, biodiversity, and various infrastructure risks. TX25 is particularly relevant to the Horizons Region, as it signals the intensity and duration of extreme summertime heat and can be used to assess heat stress on dairy cattle. A commonly used cattle heat-stress metric is the Temperature–Humidity Index (THI), calculated from air temperature and relative humidity as follows:

$$\text{THI} = (1.8 \times T + 32) - (0.55 - 0.0055 \times RH)(1.8 \times T - 26) \quad (1)$$

where T is the temperature in °C and RH is the relative humidity in percent. THI values for a range of temperatures and humidities are shown in Figure 2. As is clear from Figure 2, for typical summer-time late afternoon humidities in the upper 50s or lower 60s (%), THI values of around 72 or 73 can be expected, i.e., the onset

Temperature (°C) \ Humidity (%)	50	55	60	65	70	75	80	85	90	95
18	62.6	62.8	63.0	63.2	63.3	63.5	63.7	63.9	64.0	64.2
19	63.9	64.2	64.4	64.6	64.8	65.1	65.3	65.5	65.7	66.0
20	65.3	65.5	65.8	66.1	66.4	66.6	66.9	67.2	67.5	67.7
21	66.6	66.9	67.2	67.5	67.9	68.2	68.5	68.8	69.2	69.5
22	67.9	68.2	68.6	69.0	69.4	69.7	70.1	70.5	70.9	71.2
23	69.2	69.6	70.0	70.4	70.9	71.3	71.7	72.1	72.6	73.0
24	70.5	70.9	71.4	71.9	72.4	72.8	73.3	73.8	74.3	74.7
25	71.8	72.3	72.8	73.3	73.9	74.4	74.9	75.4	76.0	76.5
26	73.1	73.7	74.2	74.8	75.4	75.9	76.5	77.1	77.7	78.2
27	74.4	75.0	75.6	76.2	76.9	77.5	78.1	78.7	79.4	80.0
28	75.7	76.4	77.0	77.7	78.4	79.0	79.7	80.4	81.1	81.7
29	77.0	77.7	78.4	79.2	79.9	80.6	81.3	82.0	82.8	83.5
30	78.3	79.1	79.8	80.6	81.4	82.2	82.9	83.7	84.5	85.2
31	79.6	80.4	81.2	82.1	82.9	83.7	84.5	85.3	86.2	87.0
32	80.9	81.8	82.6	83.5	84.4	85.3	86.1	87.0	87.9	88.7

Figure 2: Temperature-humidity (THI) values for a range of temperatures and humidities. A typical interpretation for dairy cattle is approximately that a THI of less than 68 implies little or no heat stress, THI values between 68 and 71 imply mild stress, THI values between 72 and 79 imply moderate stress, values between 80 and 89 imply severe stress, and values higher than 90 imply very severe/emergency conditions.

of moderate heat stress in dairy cattle, whenever the temperature exceeds 25°C. Given that projected trends in humidity over the Horizons Region are negligible, trends in THI will be driven almost entirely by trends in temperature and that the number of exceedances of temperature above 25°C is therefore a useful indicator for heat stress on dairy cattle.

5 Methodology

Below, we use TX25 (number of very hot days >25°C in each year), under the SSP2-4.5 scenario, as an example, with Palmerston North (40.355°S, 175.612°E) as the target location. The process is shown in Figure 3 where the multi-model mean data have been used (noting that in the analysis below, each of the six models is considered individually). The process described in this figure is applied to every grid cell over the Horizons Region to create Figure 4. There are already three locations in the map shown in Figure 4 that by 2021-2040 will experience TX25 values unprecedented anywhere in New Zealand in the climatological record (as per the multi-model mean).

To avoid the plethora of arrows shown in Figure 4, we consider climate analogues for each of the Horizons sub-regions as a whole, i.e., the sub-regions shown in Figure 5. Averaging the vectors shown in Figure 4 does not produce meaningful results as divergence between vectors can result in their average pointing to a location in the ocean or somewhere with a value quite different to the climate analogue target. Therefore, for each region, the end points of the vectors across all six model simulations are collected. The largest few clusters of end points are then identified (between 1 and 3 clusters), i.e., common locations pointed to from multiple cells in each region. Where these end points are tightly clustered and pointed to by a large majority of the cells within the region, these are considered to be high confidence climate analogues and the vectors connecting the centroid (the sub-region's geographic centre) of each sub-region to the medoid of each cluster (the site within the cluster with the minimum total distance to all other sites) are coloured black. In contrast, vectors pointing to diffuse clusters of end points from only a few cells within the sub-region are considered low confidence and are coloured white. Grey-scale colours on vectors show intermediate confidence levels; the darker the vector the greater the confidence. A small black circle is shown at the centroid of each region. In many cases it is not possible to identify a valid climate analogue either because there are no well-clustered sets of end points (the Hierarchical Density-Based Spatial Clustering of Applications with Noise (HDBSCAN) algorithm identifies many of the end points as 'noise') or because too few cells within the region have climate analogues in the historical

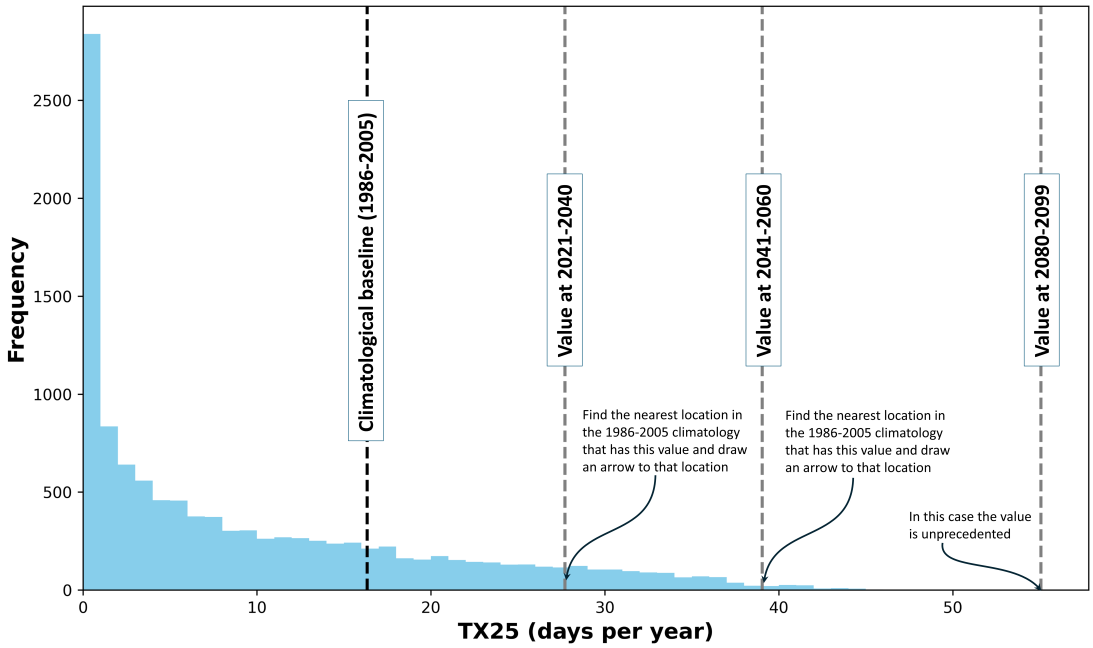


Figure 3: A histogram of the TX25 values (i.e. the number of days in each year when the daily maximum surface temperature exceeds 25°C) for the whole country is shown in blue. The climatological TX25 value (16.325 days/year) for Palmerston North is shown with a vertical black dashed line. Under SSP2-4.5 that increases to 27.7 days per year by 2021-2040 as shown by the leftmost vertical dashed grey line. To find the climate analogue, the location nearest to Palmerston North that has a TX25 value of at least 27.7 days/year is found and an arrow is drawn from Palmerston North to that location. A similar process is used to find the climate analogue for 2041-2060. By 2080-2099, the TX25 value exceeds any value found anywhere in New Zealand between 1986 and 2005, i.e. the climatological baseline. As such this 2080-2099 value is unprecedented in the historical record anywhere in New Zealand. In the figures below, such locations are shown with a small purple cross as no climate analogue vector can be defined.

record. In this case the vectors and their centroid dot are omitted; we follow the edict that it is better to say nothing than to say something that is highly uncertain. An example of one such figure is shown in Figure 6.

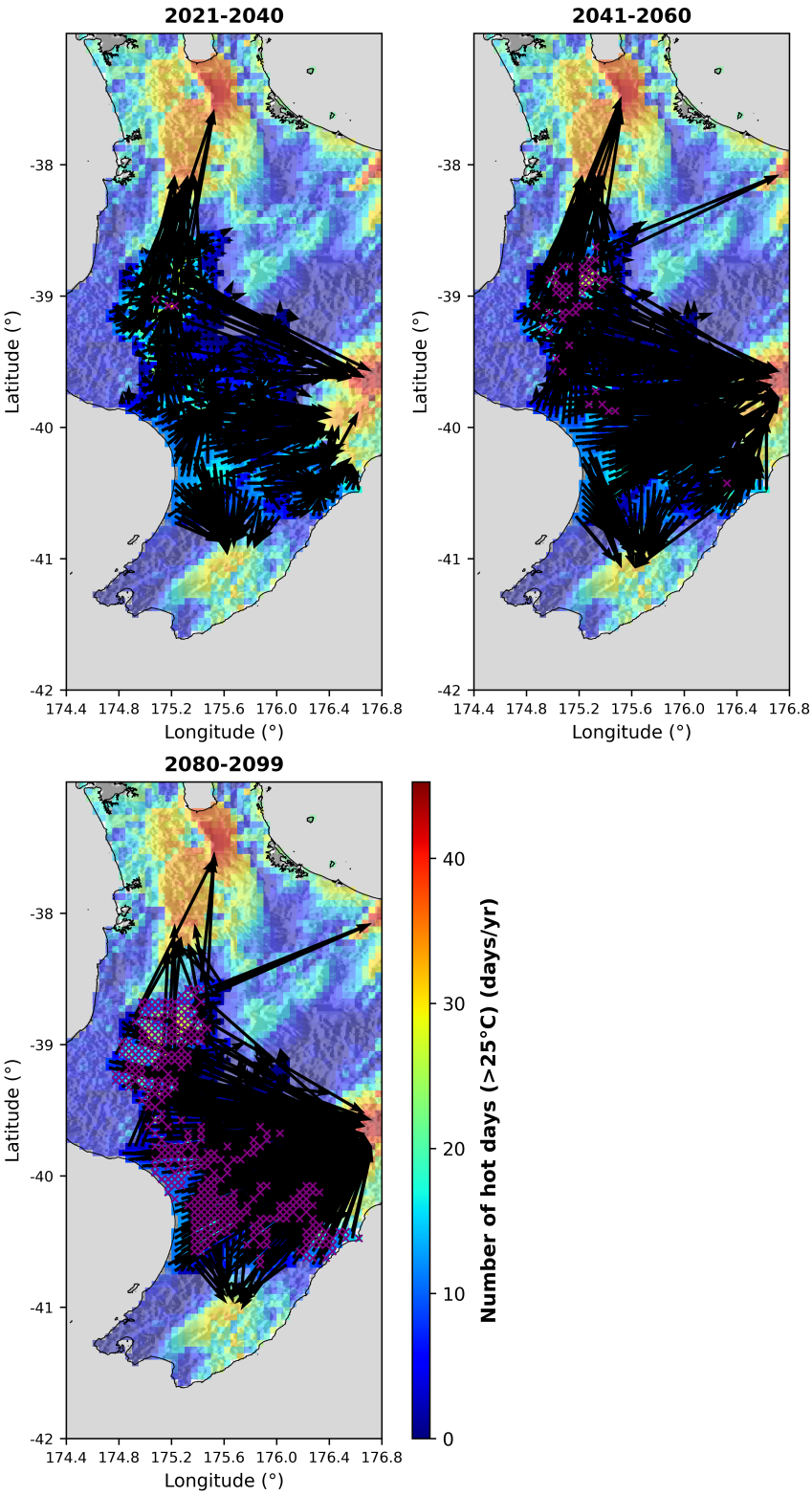


Figure 4: Climate analogues for every grid cell in the Horizons Region over the three future periods, under the SSP2-4.5 scenario. These results were derived from the multi-model mean baseline and projected changes. The background field in each panel shows the 1986-2005 baseline TX25 climatological field. Arrows point to the climate analogue locations for each grid cell. Cells marked with a small purple x denote locations for which the future value is unprecedented anywhere in New Zealand in the 1986-2005 historical record.

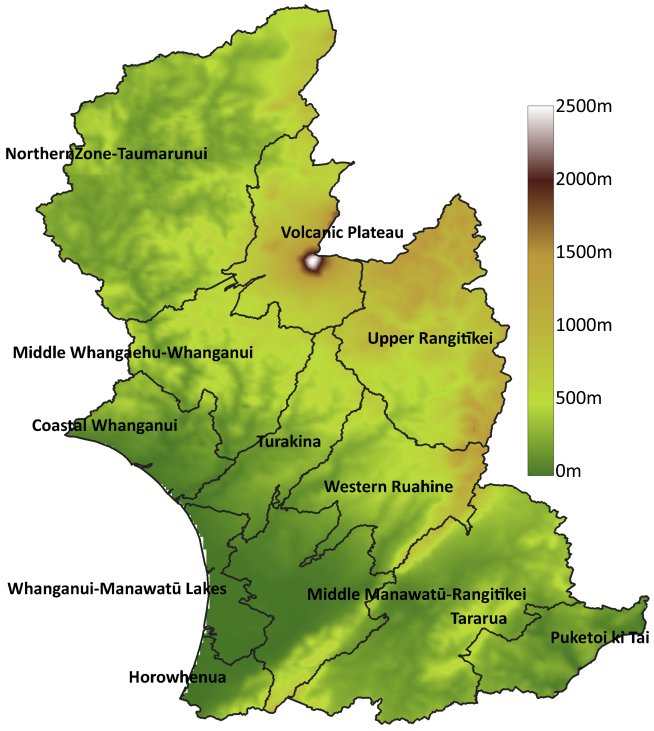


Figure 5: The 12 sub-regions over which the climate analogues are considered together with a map of the elevation (in metres) across the whole Horizons Region.

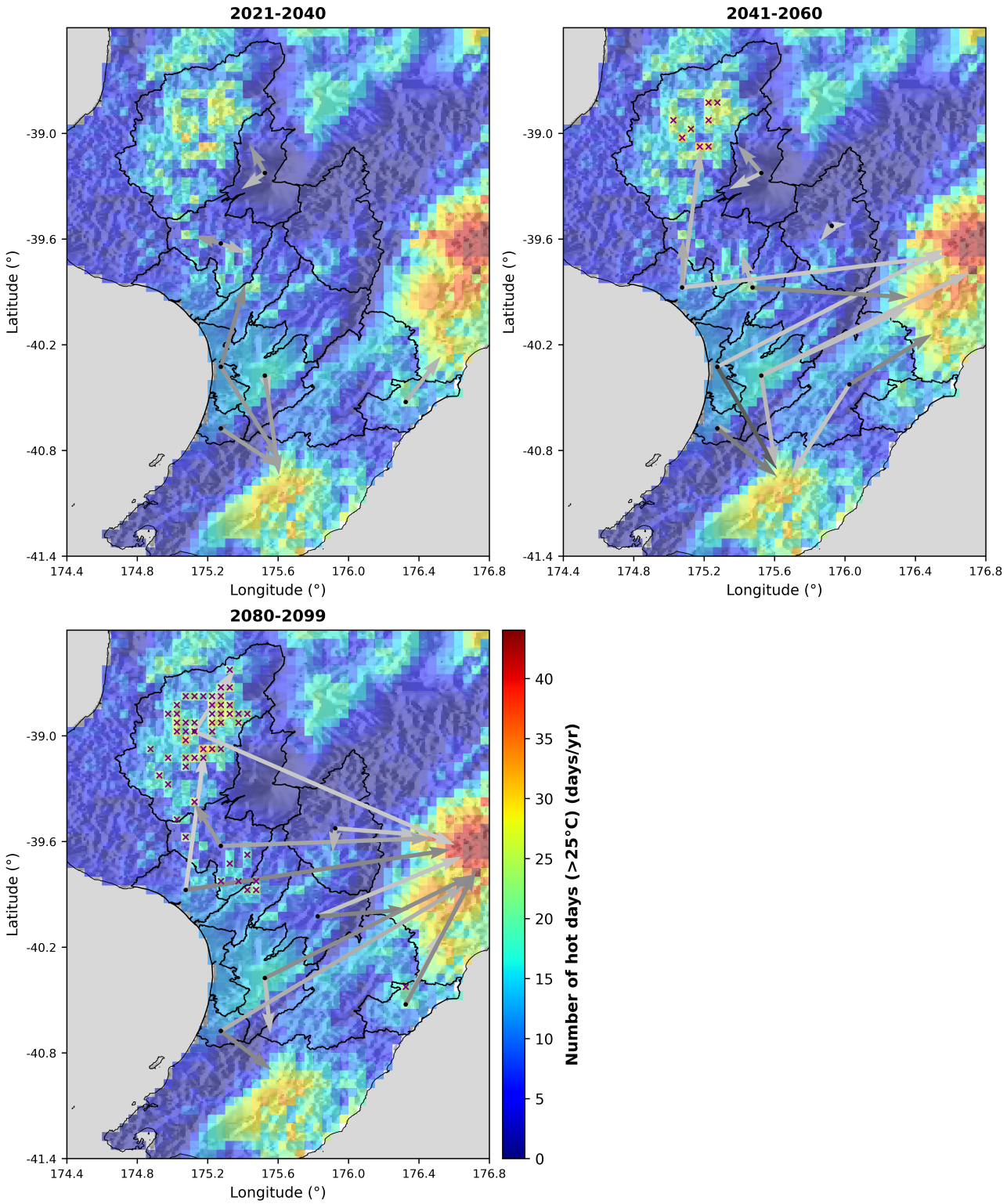


Figure 6: Climate analogues for each of the 12 sub-regions under the SSP2-4.5 scenario. The background field shows the multi-model mean 1986-2005 baseline TX25 field. Arrows point to the centres of one or more clusters of climate analogue vector end points. Note that these clusters are drawn from across all six models; where models are consistent, clusters will be tight, confidence in the vector will be high, and the vector will be coloured black. Low confidence vectors are coloured white with greyscales showing intermediate levels of confidence. In this case, only when all six models cannot find a valid climate analogue in the historical record for a given cell is the cell marked with a purple x. Such locations can be seen in the 2041-2060 and 2080-2099 panels.

6 Daily mean temperature

Climate analogues for daily mean temperature (T) under the SSP1-2.6 greenhouse gas (GHG) emissions scenario are shown in Figure 7. The results indicate that in the near-future, although projected changes in T are

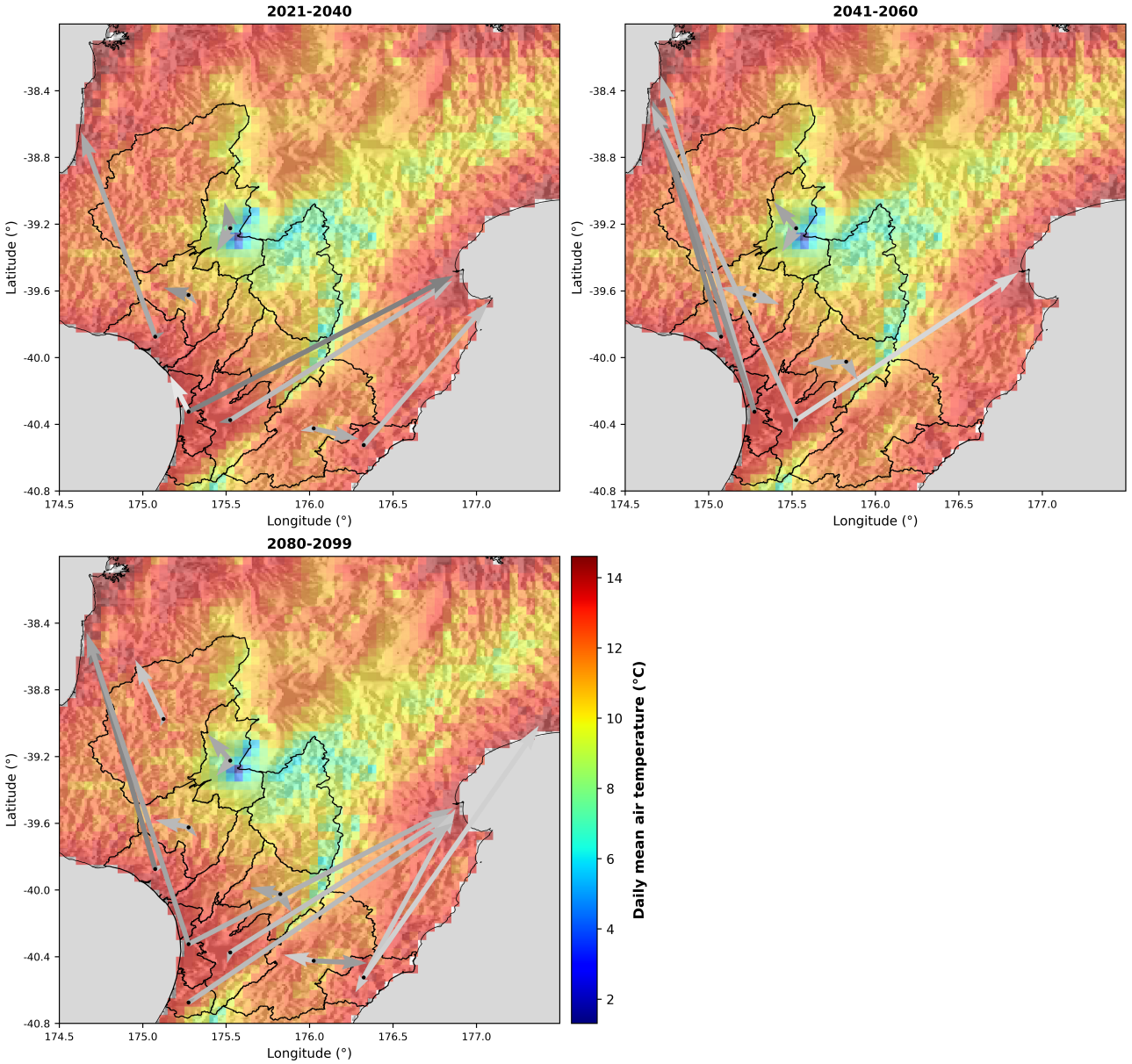


Figure 7: Climate analogues calculated for each of the 12 sub-regions. The background field shows the 1986-2005 baseline daily mean temperature field. Arrows point to the climate analogue locations for each region under the SSP1-2.6 GHG emissions scenario for the near-future (2021-2040), mid-century (2041-2060) and end of the century (2080-2099). The darker the arrow the greater the confidence in the detected climate analogue. The original of this figure can be downloaded here.

small, there is some indication that locations within Coastal Whanganui need to look to the coast north of New Plymouth for their near-future climate analogues. Locations within Volcanic Plateau and Middle Whangaehu-Whanganui need to look within their regions but to sites at lower elevations for their climate analogues. Regions with historically elevated temperatures (Whanganui-Manawatū Lakes, Middle Manawatū-Rangitīkei, and Puketoi ki Tai) all need to look to the north-east to the coastal regions of Napier to find their climate analogues. Tararua, in turn, looks to Puketoi ki Tai. By mid-century, with larger changes in T projected, climate analogues need to be located further afield. Again Coastal Whanganui looks to the coast north of New Plymouth but now too does Whanganui-Manawatū Lakes and Middle Manawatū-Rangitīkei (but also to locations along the coast north of Napier). As before, locations within Volcanic Plateau and Middle Whangaehu-Whanganui look within

their regions but to sites at lower elevations for their climate analogues; this is now also true for sites in Western Ruahine. By the end of the century, under this SSP1-2.6 scenario, 10 of the 12 sub-regions have robustly identified climate analogues. NorthernZone-Taumarunui now needs to look just outside the region to the north-west to find its climate analogues. Locations within Volcanic Plateau, Middle Whangaehu-Whanganui, and Western Ruahine need to look to even lower elevation locations within their regions for their climate analogues. The historically warmer regions of Coastal Whanganui, Whanganui-Manawatū Lakes, Middle Manawatū-Rangitīkei, Horowhenua, and Puketoi ki Tai need to look either to the coast up the North Taranaki Bight, or the coastal regions around Napier or even further north up around Hawke's Bay. Sites in Tararua either need to look to Puketoi ki Tai, or to the warmer parts to the west of the region. No locations in the Horizons Region failed to find analogues elsewhere in New Zealand, i.e., no crosses in any of the grid cells in Figure 7.

The climate analogues for T under the SSP2-4.5 GHG emissions scenario are shown in Figure 8. Similar to the SSP1-2.6 scenario, for the near-future, Coastal Whanganui again needs to look to the coast north of New Plymouth to find its climate analogues but now so too does Whanganui-Manawatū Lakes (though there is a weaker indication that some locations in Whanganui-Manawatū Lakes may need to look to regions around Napier, as does Middle Manawatū-Rangitīkei). Locations within Volcanic Plateau, Middle Whangaehu-Whanganui and Western Ruahine need to look within their regions but to sites at lower elevations for their climate analogues. Turakina needs to look south-west towards the coast while locations in Tararua either need to look to warmer western parts of the region or to Puketoi ki Tai for their climate analogues. Puketoi ki Tai in turn needs to look north-east to the coast south of Napier. Locations in Horowhenua need to look up and along the coast for climate analogues. By mid-century this changes, with the warmer regions needing to look further afield to find their climate analogues. Half of the sub-regions (Coastal Whanganui, Whanganui-Manawatū Lakes, Horowhenua, Middle Manawatū-Rangitīkei, Turakina, and Puketoi ki Tai) now need to look to the northern coast of the North Taranaki Bight. Locations within Volcanic Plateau, Middle Whangaehu-Whanganui and Western Ruahine still need to look within their sub-regions but to sites at lower elevations for their climate analogues. By century's end, further shifts north are required with some of the warmer regions needing to look as far north as Auckland. Locations in Tararua need to look to the coast around Napier or to just inside Puketoi ki Tai. Locations in NorthernZone-Taumarunui need to look north-west to just outside the region.

The climate analogues for T under the SSP3-7.0 GHG emissions scenario are shown in Figure 9. In the near-future, locations in Coastal Whanganui and Whanganui-Manawatū Lakes need to look to the coast along the North Taranaki Bight, though there is also a weaker indication that sites in Whanganui-Manawatū Lakes will need to look to areas around Napier (as do Horowhenua, Puketoi ki Tai and Middle Manawatū-Rangitīkei). As before, locations within Volcanic Plateau, Middle Whangaehu-Whanganui and Western Ruahine (and now also Turakina) need to look within their regions but to sites at lower elevations for their climate analogues. By mid-century greater shifts are required. Several of the warmer sub-regions now need to look further north along the coast of the North Taranaki Bight, or even to as far north as Auckland (for Coastal Whanganui and Whanganui-Manawatū Lakes) for their climate analogues. The two most easterly sub-regions (Puketoi ki Tai and Tararua) need to look north-east to the coast around Napier or further north, although the stronger indications are for Puketoi ki Tai to look to the North Taranaki Bight coast and for Tararua to look to Puketoi ki Tai. By the end of the century there is a much clearer signal of a northward shift. Coastal Whanganui, Whanganui-Manawatū Lakes, Middle Manawatū-Rangitīkei, and Puketoi ki Tai now need to look as far north as Northland and/or to areas around Auckland to find their climate analogues. Locations in NorthernZone-Taumarunui now need to look north-west towards the coast while locations in Volcanic Plateau need to look to NorthernZone-Taumarunui.

The climate analogues for T under the SSP5-8.5 GHG emissions scenario are shown in Figure 10. Under this very high GHG emissions scenario, over the near-future warmer regions along the south-west coast of the Horizons Region (Whanganui-Manawatū Lakes, Coastal Whanganui) need to look to coastal regions to the north-west (along the North Taranaki Bight) for their climate analogues. Locations within Volcanic Plateau, Middle Whangaehu-Whanganui and Western Ruahine need to look within their regions but to sites at lower elevations for their climate analogues. Locations in Whanganui-Manawatū Lakes, Middle Manawatū-Rangitīkei and Puketoi ki Tai need to look to regions around Napier. By mid-century this pattern becomes even more ro-

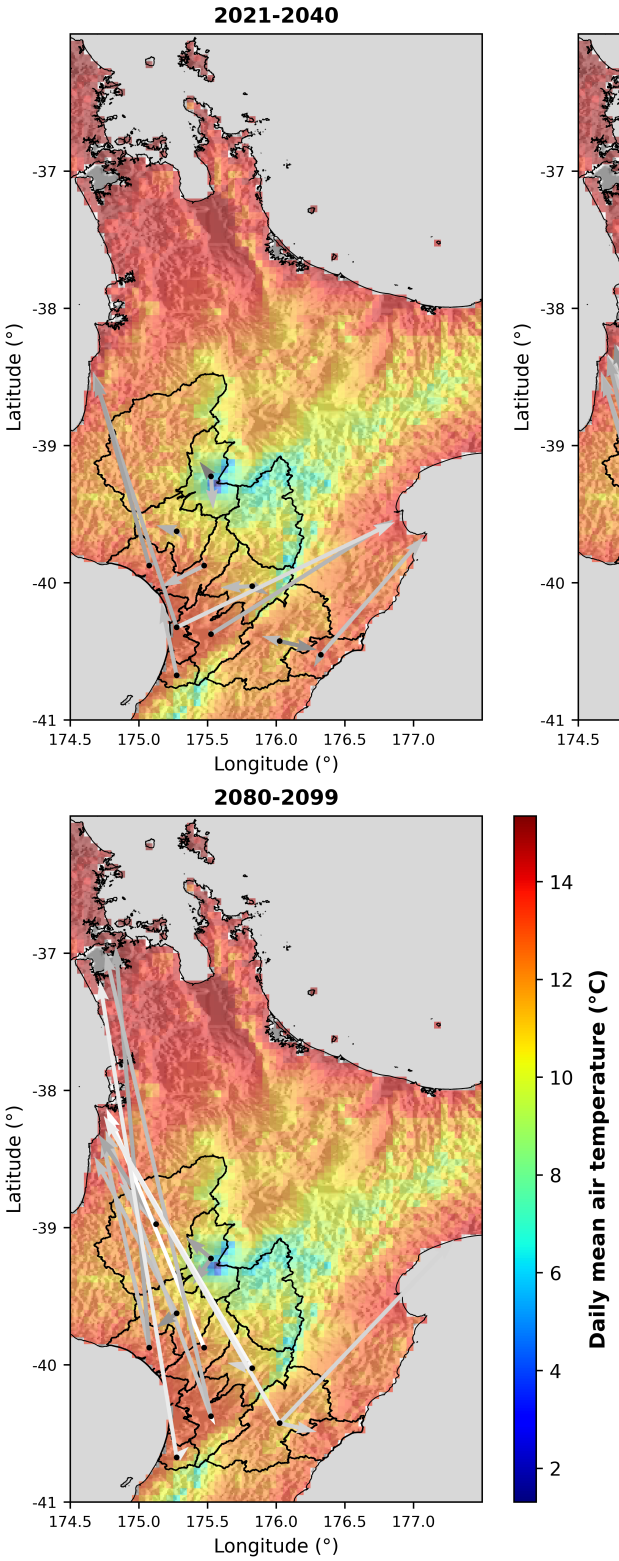


Figure 8: Climate analogues calculated for each of the 12 sub-regions. The background field shows the 1986-2005 baseline daily mean temperature field. Arrows point to the climate analogue locations for each region under the SSP2-4.5 GHG emissions scenario for the near-future (2021-2040), mid-century (2041-2060) and end of the century (2080-2099). The darker the arrow the greater the confidence in the detected climate analogue. The original of this figure can be downloaded here.

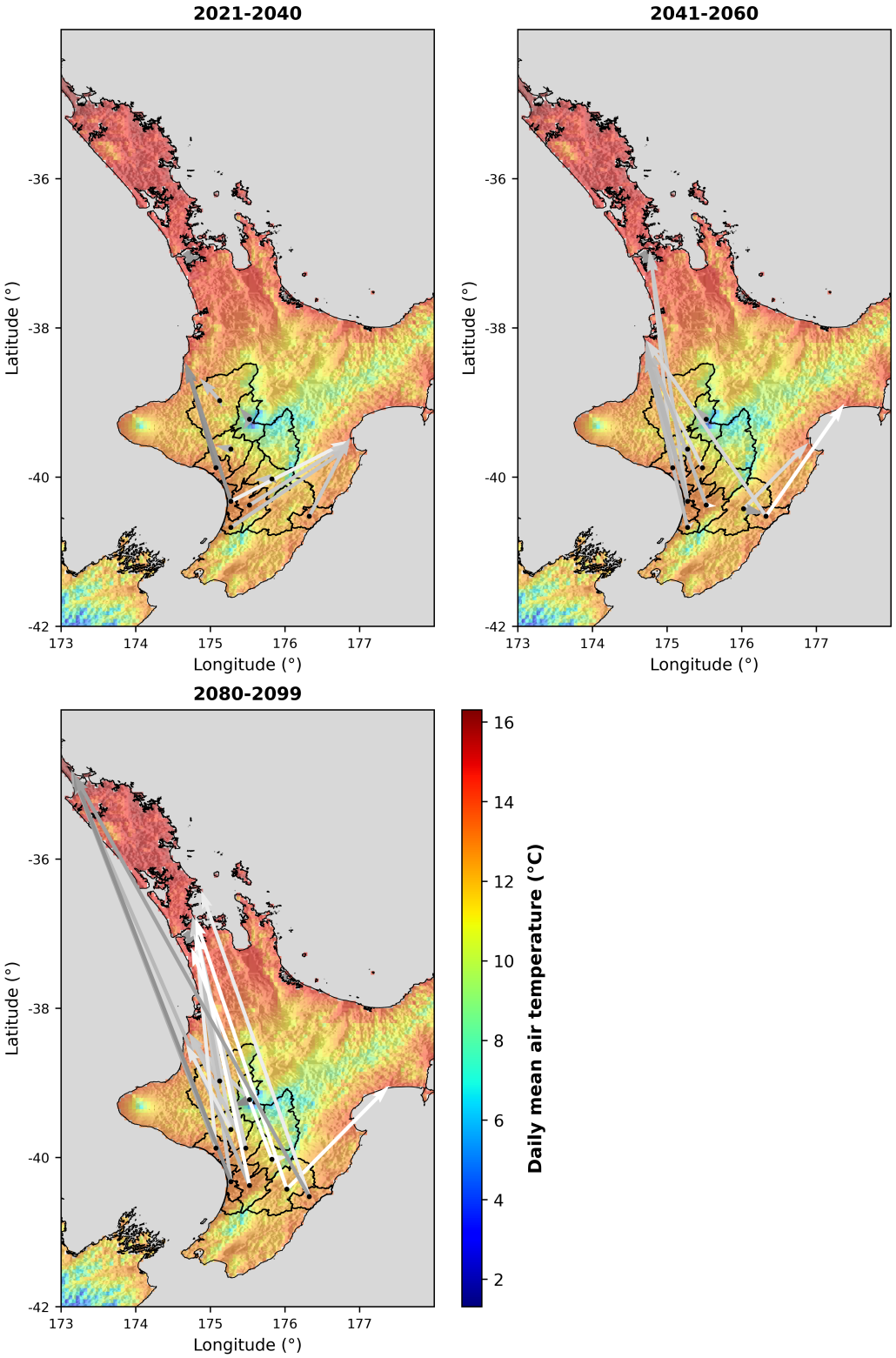


Figure 9: Climate analogues calculated for each of the 12 sub-regions. The background field shows the 1986-2005 baseline daily mean temperature field. Arrows point to the climate analogue locations for each region under the SSP3-7.0 GHG emissions scenario for the near-future (2021-2040), mid-century (2041-2060) and end of the century (2080-2099). The darker the arrow the greater the confidence in the detected climate analogue. The original of this figure can be downloaded here.

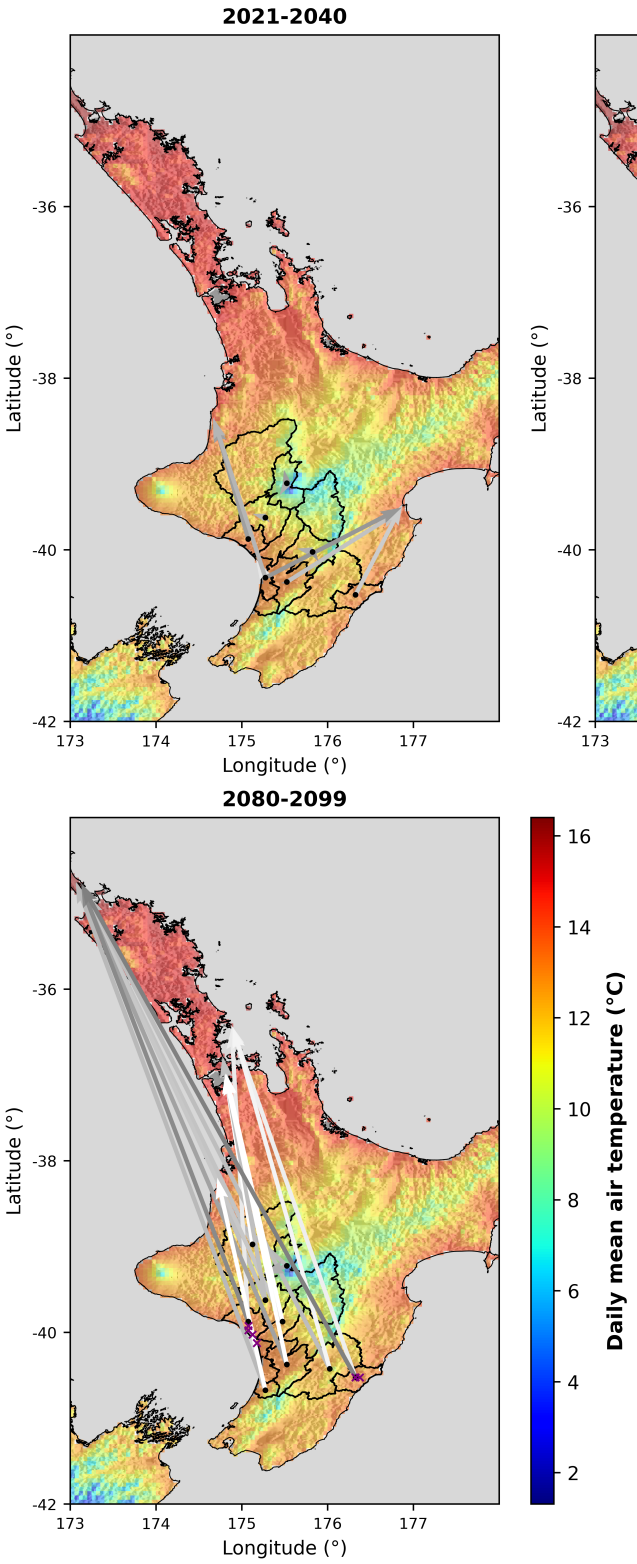


Figure 10: Climate analogues calculated for each of the 12 sub-regions. The background field shows the 1986-2005 baseline daily mean temperature field. Arrows point to the climate analogue locations for each region under the SSP5-8.5 GHG emissions scenario for the near-future (2021-2040), mid-century (2041-2060) and end of the century (2080-2099). The darker the arrow the greater the confidence in the detected climate analogue. Cells marked with a small purple x denote locations for which the future value is unprecedented anywhere in New Zealand in the 1986-2005 historical record. The original of this figure can be downloaded here.

bust. All three south-west coast regions (Coastal Whanganui, Whanganui-Manawatū Lakes, and Horowhenua) need to look further north along the coast of the North Taranaki Bight (as do Middle Manawatū-Rangitīkei and Turakina), although there are also weaker indications that sites in Coastal Whanganui and Whanganui-Manawatū Lakes may need to look as far north as Auckland. Tararua needs to look either to Puketoi ki Tai or, with less likelihood, to Napier, while Puketoi ki Tai itself needs to look either further north along the coast of the North Taranaki Bight or, with less likelihood, to Gisborne for its climate analogues. By the end of the century, in addition to seven of the sub-regions (Coastal Whanganui, Horowhenua, Middle Manawatū-Rangitīkei, Tararua, Puketoi ki Tai, Middle Whangaehu-Whanganui, and NorthernZone-Taumarunui) showing clearly the need to look north of Auckland for their climate analogues, there are now initial indications that locations in Coastal Whanganui, Whanganui-Manawatū Lakes, and Puketoi ki Tai are projected by all six models to experience temperatures unprecedented anywhere in New Zealand in the historical record. Climate analogues would then need to be sought outside of New Zealand, e.g., along the eastern seaboard of Australia for these locations. There is also weaker evidence that for some sub-regions, climate analogues may be found further north along the coast of the North Taranaki Bight (e.g., for Horowhenua) or around Auckland.

7 Annual total precipitation

Changes in annual total precipitation (PR) are provided as percentage changes and these were converted to absolute changes before calculating the climate analogues. These analogues under the SSP1-2.6 GHG emissions scenario are shown in Figure 11. Given the small projected changes in annual total precipitation under the SSP1-2.6 scenario, it is not surprising that in the near-future reliable climate analogues can only be identified for 8 of the 12 sub-regions and, in all cases, the analogues can be located within the region. This remains largely true by mid-century, although there is some indication that some sites in Middle Manawatū-Rangitīkei may need to look to Whanganui-Manawatū Lakes. Little change occurs by the end of the century.

Climate analogues for annual total precipitation under the SSP2-4.5 GHG emissions scenario are shown in Figure 12. Again, the changes in precipitation are small with high uncertainty. Results are essentially unchanged from the SSP1-2.6 scenario.

Climate analogues for annual total precipitation under the SSP3-7.0 GHG emissions scenario are shown in Figure 13. The situation is largely the same as for SSP2-4.5 indicating that for the Horizons Region, consideration of sub-regional climate analogues is not a useful way to assess and plan for changes in precipitation. There is some weak evidence that locations in Middle Manawatū-Rangitīkei may need to look to the northern parts of Whanganui-Manawatū Lakes for their precipitation climate analogues.

Climate analogues for annual total precipitation under the SSP5-8.5 GHG emissions scenario are shown in Figure 14. The situation remains largely unchanged with no indication that one would need to look outside any region to find climate analogues for any of the projection time horizons.

8 Frost days

Climate analogues for the annual number of frost days (FD) under the SSP1-2.6 GHG emissions scenario are shown in Figure 15. Given the projected warming across the region, it is not surprising that, in general, climate analogues are found by looking to regions with fewer frost days each year. In the near-future, under SSP1-2.6, this means regions such as Volcanic Plateau look to lower elevation, warmer, locations for their climate analogues. Most other regions do not need to look beyond the border of the region to find climate analogues in the near-term. The climatological warm region of Coastal Whanganui needs to look to the south-western slopes of Mt. Taranaki. This signal becomes more robust by mid-century, with indications now that Horowhenua needs to look either to Whanganui-Manawatū Lakes or the Kāpiti Coast to find regions with the requisite fewer frost

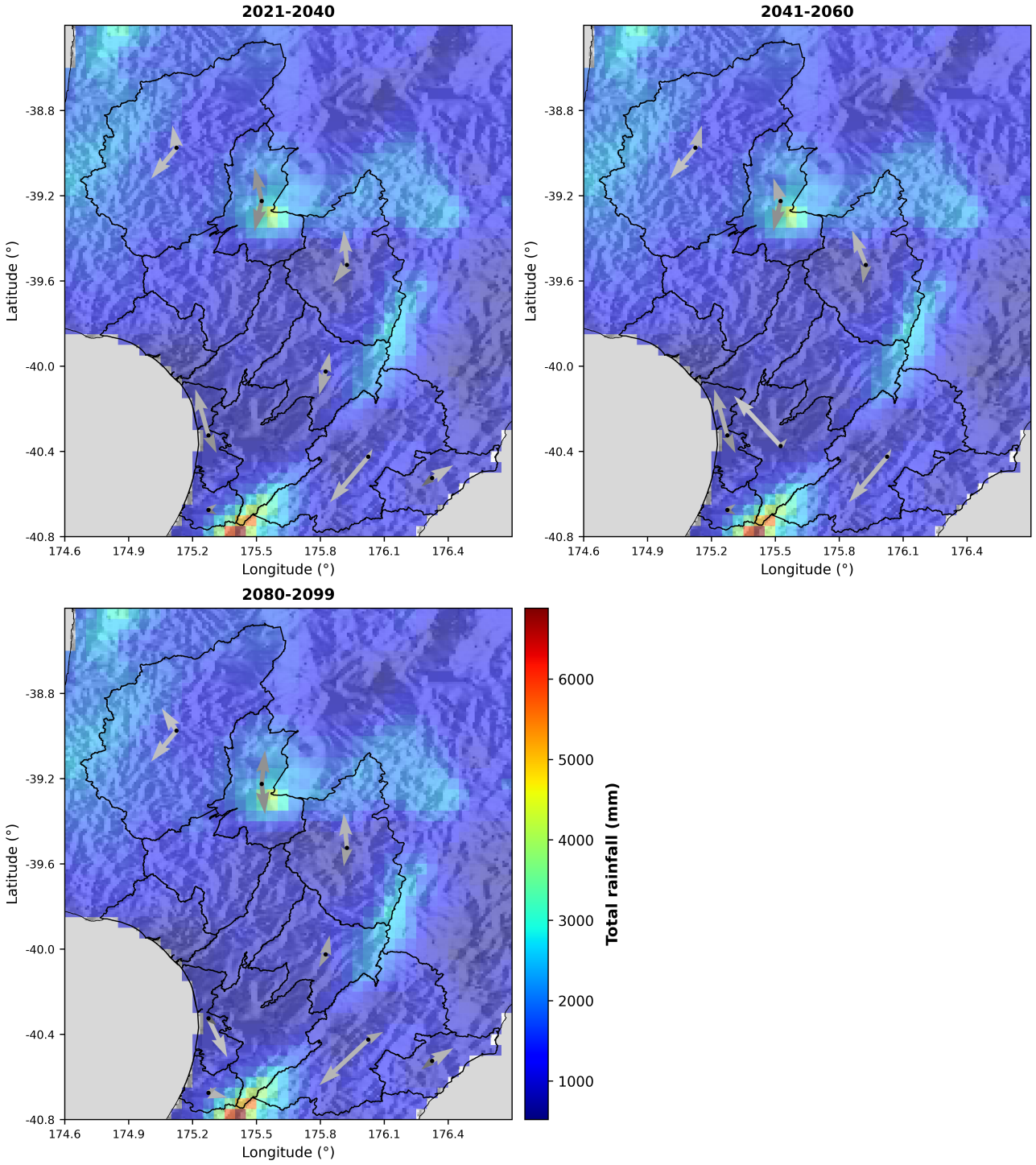


Figure 11: Climate analogues calculated for each of the 12 sub-regions. The background field shows the 1986-2005 baseline annual total precipitation field. Arrows point to the climate analogue locations for each region under the SSP1-2.6 GHG emissions scenario for the near-future (2021-2040), mid-century (2041-2060) and end of the century (2080-2099). The darker the arrow the greater the confidence in the detected climate analogue. The original of this figure can be downloaded here.

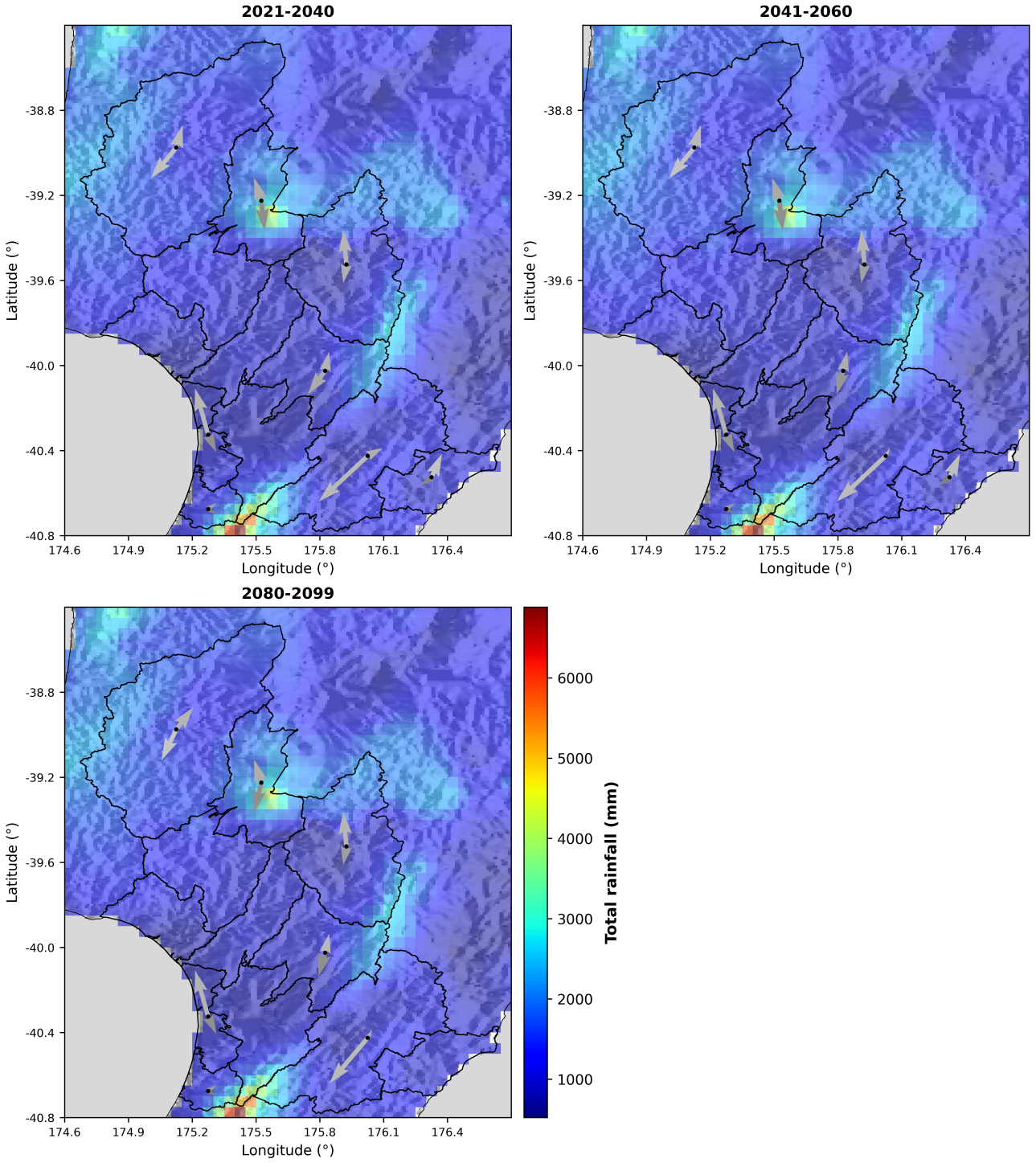


Figure 12: Climate analogues calculated for each of the 12 sub-regions. The background field shows the 1986-2005 baseline annual total precipitation field. Arrows point to the climate analogue locations for each region under the SSP2-4.5 GHG emissions scenario for the near-future (2021-2040), mid-century (2041-2060) and end of the century (2080-2099). The darker the arrow the greater the confidence in the detected climate analogue. The original of this figure can be downloaded here.

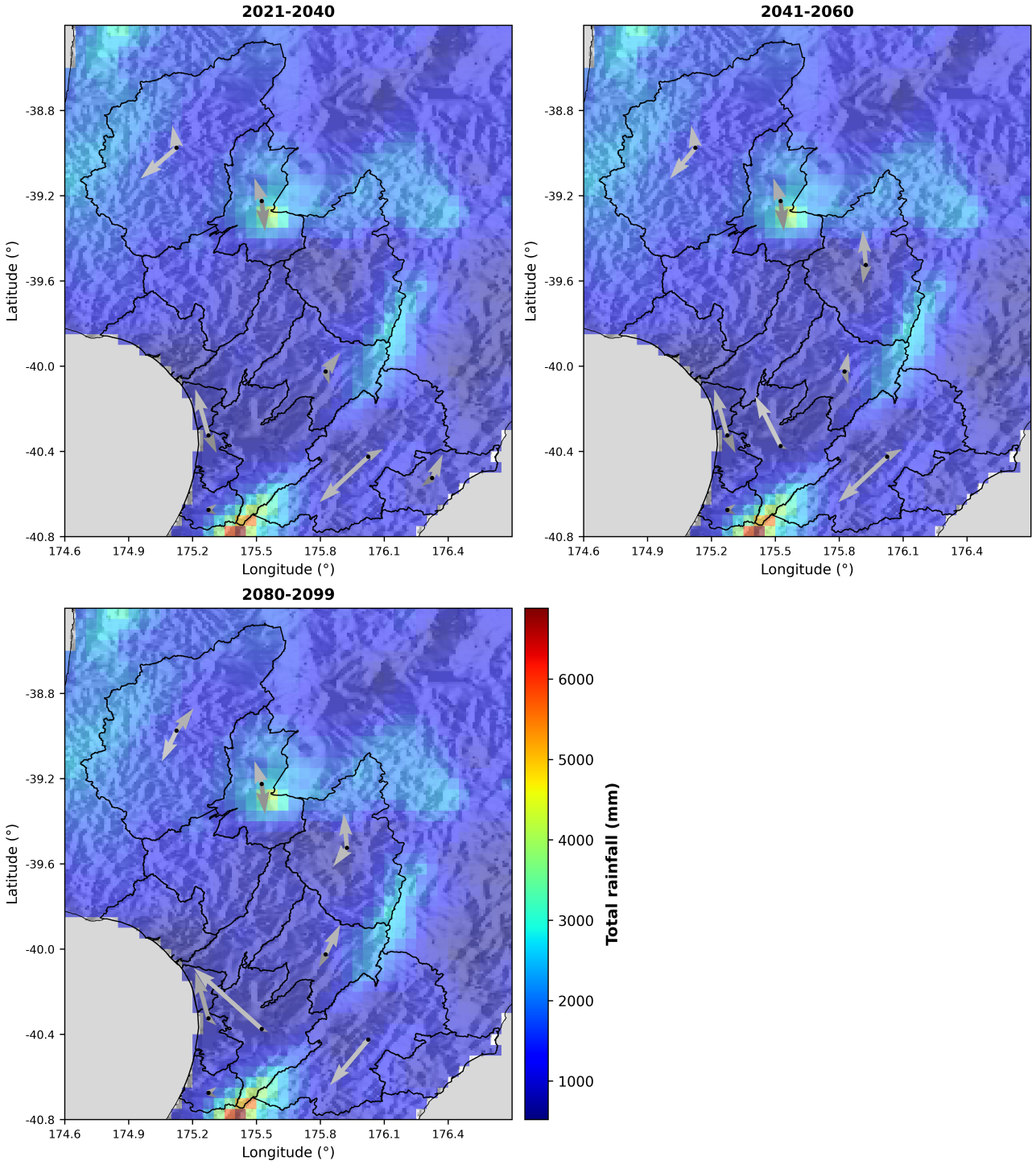


Figure 13: Climate analogues calculated for each of the 12 sub-regions. The background field shows the 1986-2005 baseline annual total precipitation field. Arrows point to the climate analogue locations for each region under the SSP3-7.0 GHG emissions scenario for the near-future (2021-2040), mid-century (2041-2060) and end of the century (2080-2099). The darker the arrow the greater the confidence in the detected climate analogue. The original of this figure can be downloaded here.

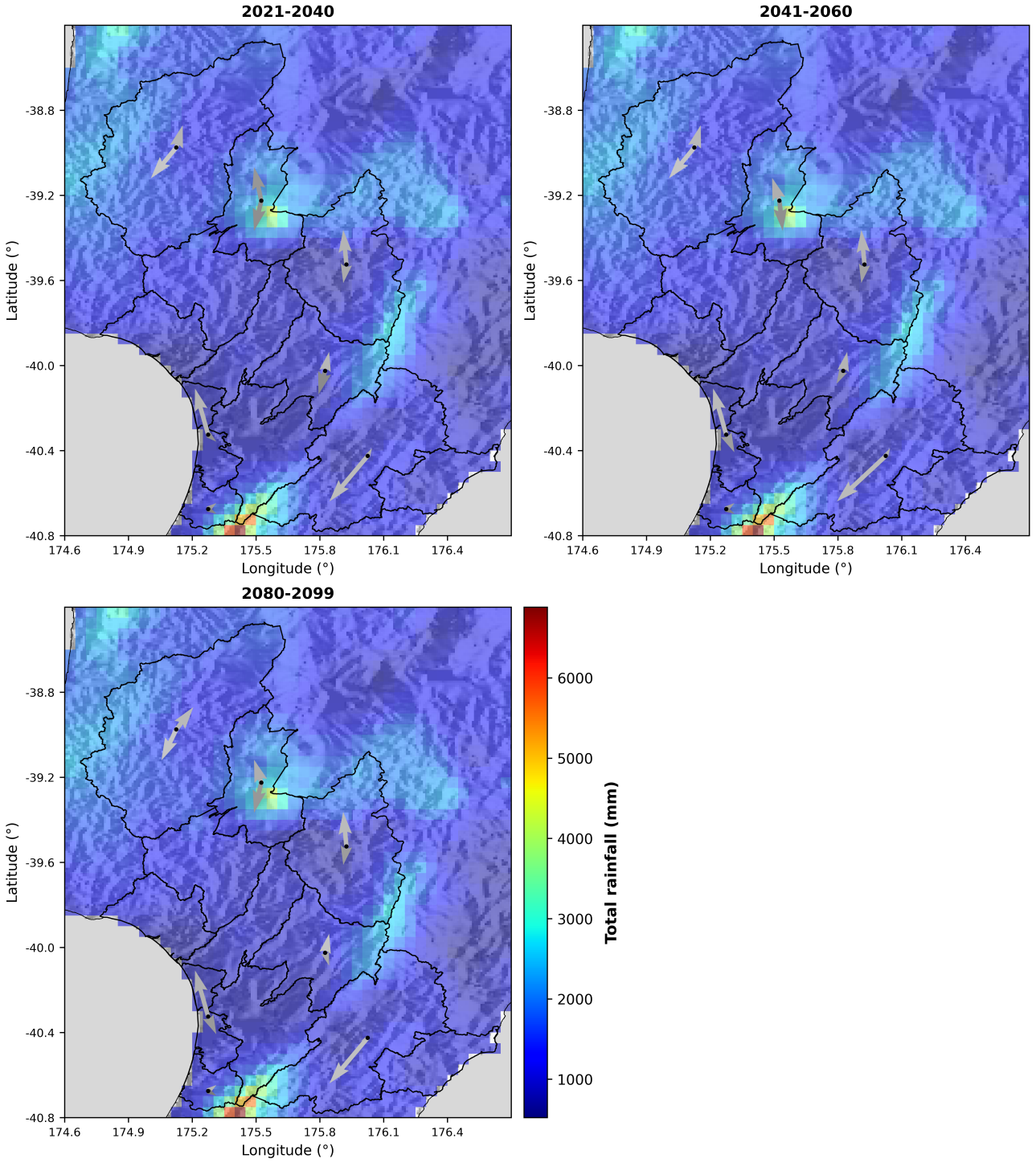


Figure 14: Climate analogues calculated for each of the 12 sub-regions. The background field shows the 1986-2005 baseline annual total precipitation field. Arrows point to the climate analogue locations for each region under the SSP5-8.5 GHG emissions scenario for the near-future (2021-2040), mid-century (2041-2060) and end of the century (2080-2099). The darker the arrow the greater the confidence in the detected climate analogue. The original of this figure can be downloaded here.

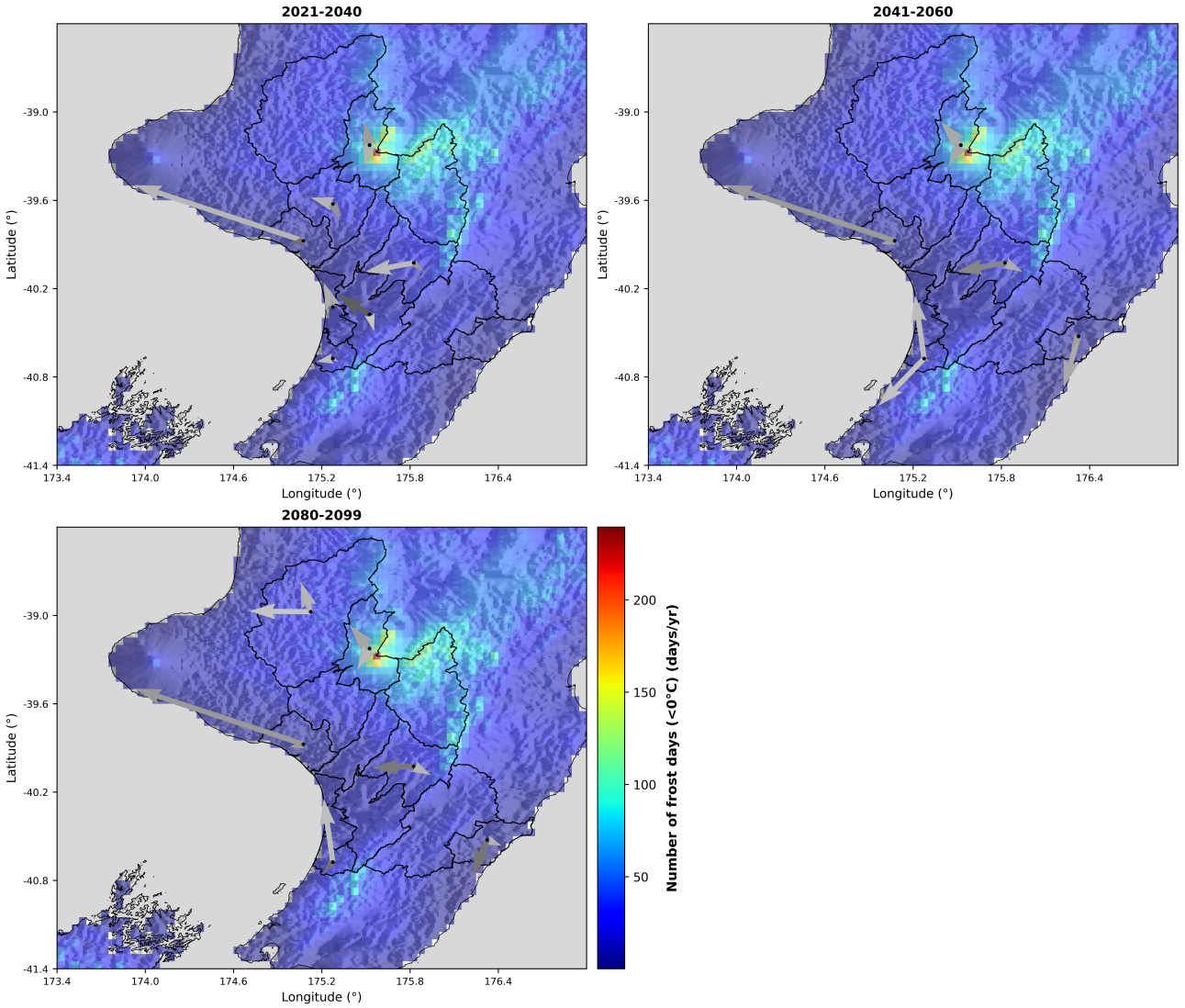


Figure 15: Climate analogues calculated for each of the 12 sub-regions. The background field shows the 1986-2005 baseline annual number of frost days. Arrows point to the climate analogue locations for each region under the SSP1-2.6 GHG emissions scenario for the near-future (2021-2040), mid-century (2041-2060) and end of the century (2080-2099). The darker the arrow the greater the confidence in the detected climate analogue. The original of this figure can be downloaded here.

days. Puketoi ki Tai needs to look to coastal regions around Castlepoint. Because of the strong GHG emissions reductions under this scenario, by the end of the century these geographical shifts weaken somewhat.

Climate analogues for FD under the SSP2-4.5 GHG emissions scenario are shown in Figure 16. In the near-

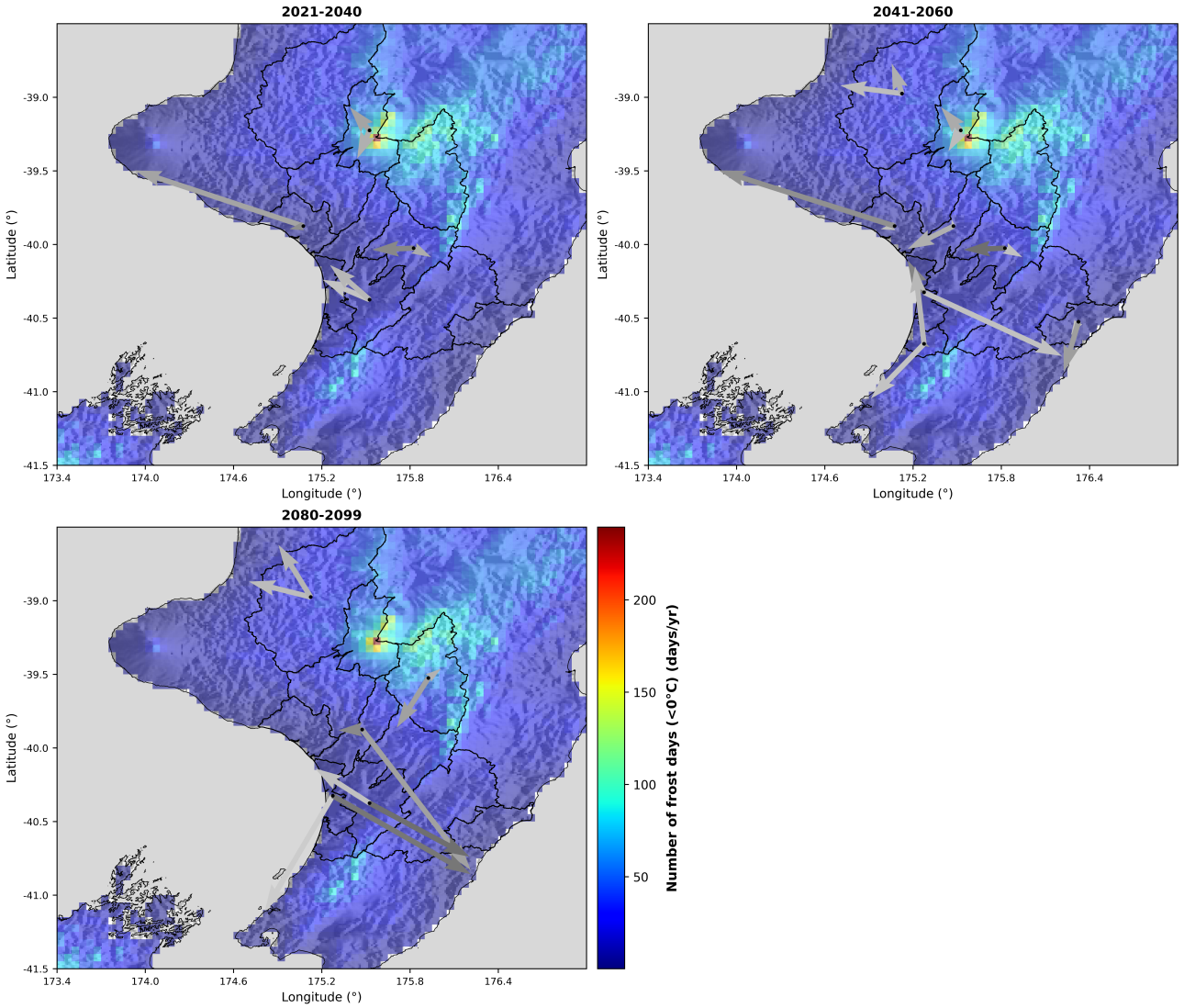


Figure 16: Climate analogues calculated for each of the 12 sub-regions. The background field shows the 1986-2005 baseline annual number of frost days. Arrows point to the climate analogue locations for each region under the SSP2-4.5 GHG emissions scenario for the near-future (2021-2040), mid-century (2041-2060) and end of the century (2080-2099). The darker the arrow the greater the confidence in the detected climate analogue. The original of this figure can be downloaded here.

future, under this GHG emissions scenario, robust climate analogues can only be identified for 4 of the 12 sub-regions. As before, locations in Volcanic Plateau look to lower elevation, warmer, locations for their climate analogues. Locations in Coastal Whanganui again need to look to the south-western slopes of Mt. Taranaki while locations in Middle Manawatū-Rangitīkei need to look to Whanganui-Manawatū Lakes. By mid-century, a clearer climate signal emerges, with NorthernZone-Taumarunui now needing to look north-west outside the region for its climate analogues. Whanganui-Manawatū Lakes needs to look across to the other side of the North Island and Puketoi ki Tai needs to look south to areas around Castlepoint. As before, Horowhenua needs to look either to Whanganui-Manawatū Lakes or the Kāpiti Coast to find regions with fewer frost days. By century's end there are indications that locations in Upper Rangitīkei need to look to Western Ruahine for their climate analogues, while Turakina, Middle Manawatū-Rangitīkei, and Whanganui-Manawatū Lakes all need to look to coastal areas around Castlepoint or, with weaker signals, to the coast to the west.

Climate analogues for FD under the SSP3-7.0 GHG emissions scenario are shown in Figure 17. In the near-

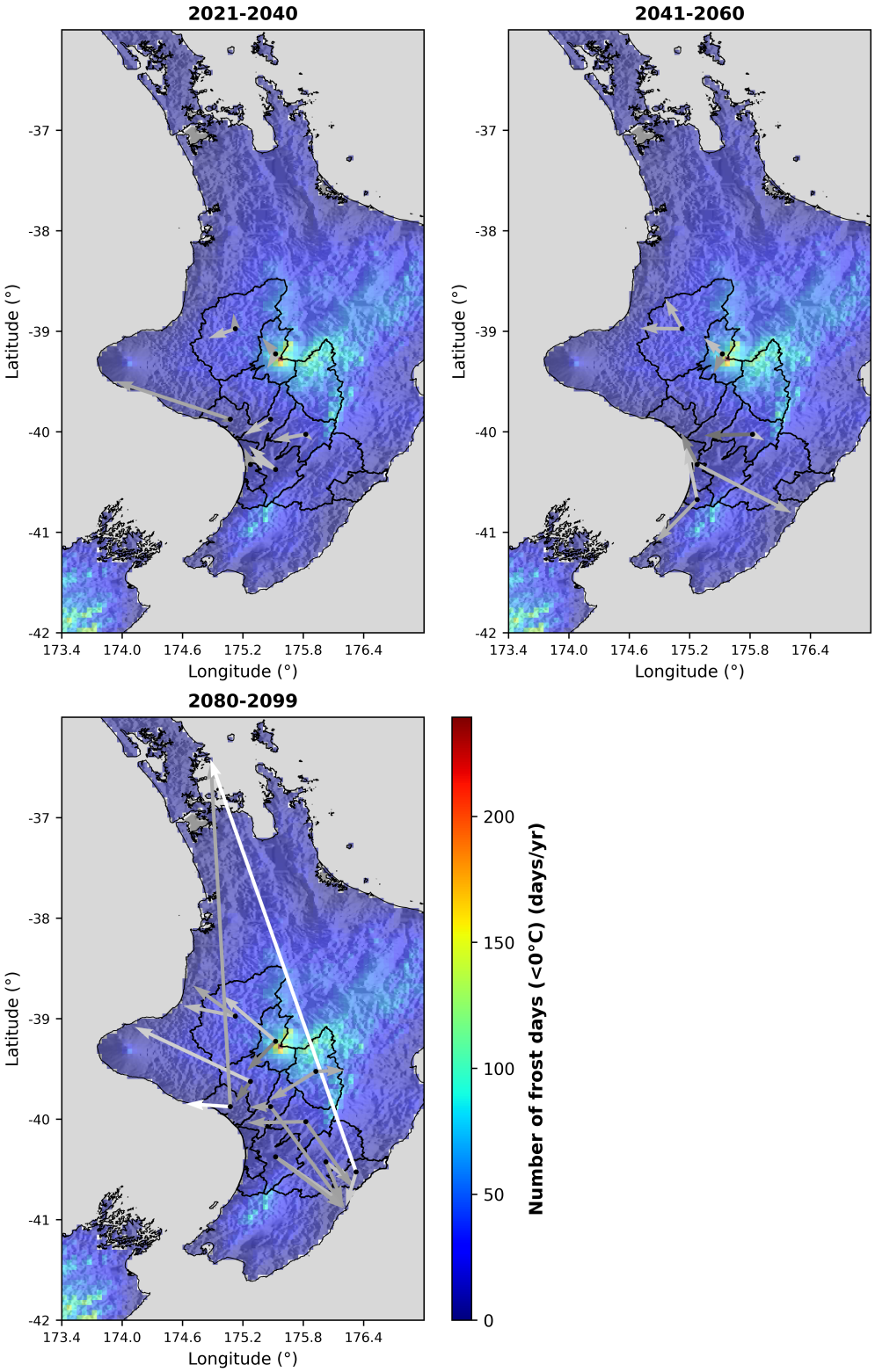


Figure 17: Climate analogues calculated for each of the 12 sub-regions. The background field shows the 1986-2005 baseline annual number of frost days. Arrows point to the climate analogue locations for each region under the SSP3-7.0 GHG emissions scenario for the near-future (2021-2040), mid-century (2041-2060) and end of the century (2080-2099). The darker the arrow the greater the confidence in the detected climate analogue. The original of this figure can be downloaded here.

future and mid-century, the situation under this GHG emissions scenario is largely similar to that under the SSP2-4.5 scenario. By century's end, however, more dramatic shifts are observed. Coastal Whanganui and, to a lesser extent, Puketoi ki Tai, now need to look to areas around Kawau Island for their climate analogues. Middle Whangaehu-Whanganui looks to Coastal Whanganui or to the coast around New Plymouth, while NorthernZone-Taumarunui looks to locations along the coast to the west. Locations in Volcanic Plateau need to look either to NorthernZone-Taumarunui or to Middle Whangaehu-Whanganui. Upper Rangitīkei looks to Turakina while Middle Manawatū-Rangitīkei, Tararua, Turakina, Western Ruahine and Puketoi ki Tai all look to coastal areas around Castlepoint.

Climate analogues for the annual number of frost days (FD) under the SSP5-8.5 GHG emissions scenario are shown in Figure 18. Over the near-future, climate analogues can largely be found within each region although, as before, locations in Coastal Whanganui need to look to the south-western slopes of Mt. Taranaki for their FD climate analogues and locations in Middle Manawatū-Rangitīkei need to look to Whanganui-Manawatū Lakes. By mid-century, locations in Coastal Whanganui again need to look to coastal regions south-west and north-west of Mt. Taranaki. Locations in Middle Manawatū-Rangitīkei need to look to Whanganui-Manawatū Lakes, while Whanganui-Manawatū Lakes and Turakina need to look to regions around Castlepoint. Horowhenua needs to look south-west to areas around Porirua Harbour. By the end of the century many sub-regions (Coastal Whanganui, Whanganui-Manawatū Lakes, Horowhenua, Middle Manawatū-Rangitīkei, Turakina, Upper Rangitīkei and Puketoi ki Tai) need to look to regions around the western perimeter of the Hauraki Gulf. Volcanic Plateau needs to look north-west beyond NorthernZone-Taumarunui or south-west to Middle Whangaehu-Whanganui. Four regions (Horowhenua, Middle Manawatū-Rangitīkei, Puketoi ki Tai, and Turakina) can also look to regions around the coast close to Castlepoint. Again Horowhenua can look to regions around Porirua Harbour. Middle Whangaehu-Whanganui looks to coastal regions north of Mt. Taranaki or to Coastal Whanganui.

9 Potential evapotranspiration deficit

Climate analogues for the annual potential evapotranspiration deficit (PED) under the SSP1-2.6 GHG emissions scenario are shown in Figure 19. Over the near-future, climate analogues for most of the 8 sub-regions for which climate analogue vectors could be robustly defined can be found within the region. There is some indication that Middle Manawatū-Rangitīkei needs to look to northern Whanganui-Manawatū Lakes for its climate analogues. By mid-century there is a greater sense that locations in Middle Whangaehu-Whanganui, Turakina, Middle Manawatū-Rangitīkei, and Whanganui-Manawatū Lakes need to look to south-west coastal areas. This is also true for Puketoi ki Tai where climate analogues are likely to be found closer to its eastern coast. The situation by the end of the century is largely similar which is not surprising given the stabilising nature of the low emissions SSP1-2.6 scenario.

The climate analogues for PED under the SSP2-4.5 GHG emissions scenario are shown in Figure 20. Over the near-future it appears that climate analogues can primarily be found within each region though locations in Turakina need to look south-west or north-west (into Upper Rangitīkei). Middle Manawatū-Rangitīkei needs to look to the northern parts of Whanganui-Manawatū Lakes. By mid-century the situation is largely unchanged with the statistics for climate analogues being rather weak. This is also true around century's end, though there is now an indication that locations in NorthernZone-Taumarunui need to look towards the north-east to drier inland regions. Puketoi ki Tai needs to look to its drier coast.

Under SSP3-7.0 (see Figure 21) the PED climate analogues indicate a need to look further afield. Although over the near-future climate analogues can be found within each region, by mid-century locations in Middle Whangaehu-Whanganui need to look to Coastal Whanganui, locations in Middle Manawatū-Rangitīkei need to look to Whanganui-Manawatū Lakes, and locations in Tararua need to look to Puketoi ki Tai. By century's end there is a much larger change. Locations in Volcanic Plateau again need to look north-east to outside the region, while locations in Middle Whangaehu-Whanganui need to look to Coastal Whanganui. Upper Rangitīkei,

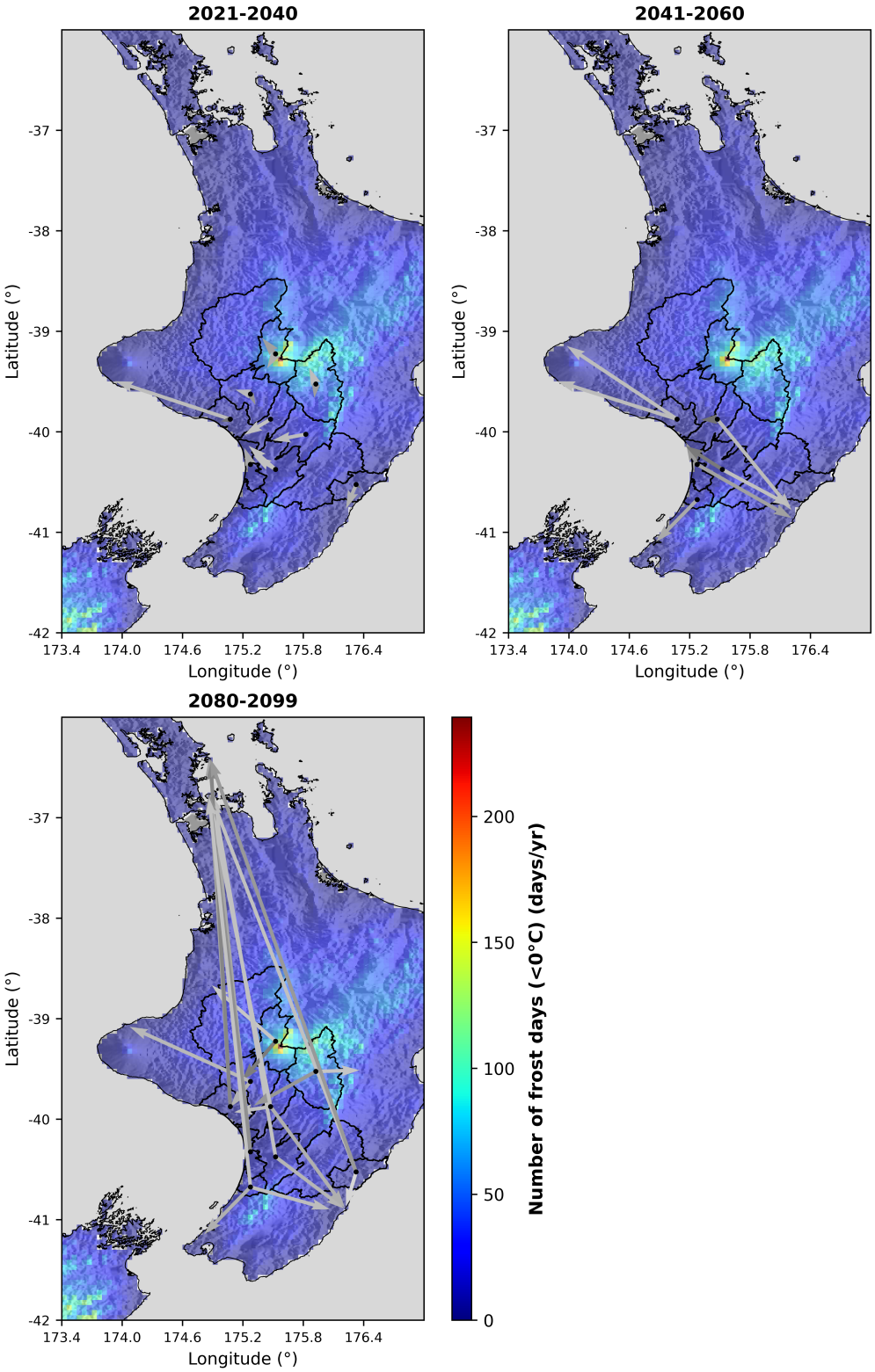


Figure 18: Climate analogues calculated for each of the 12 sub-regions. The background field shows the 1986-2005 baseline annual number of frost days. Arrows point to the climate analogue locations for each region under the SSP5-8.5 GHG emissions scenario for the near-future (2021-2040), mid-century (2041-2060) and end of the century (2080-2099). The darker the arrow the greater the confidence in the detected climate analogue. The original of this figure can be downloaded here.

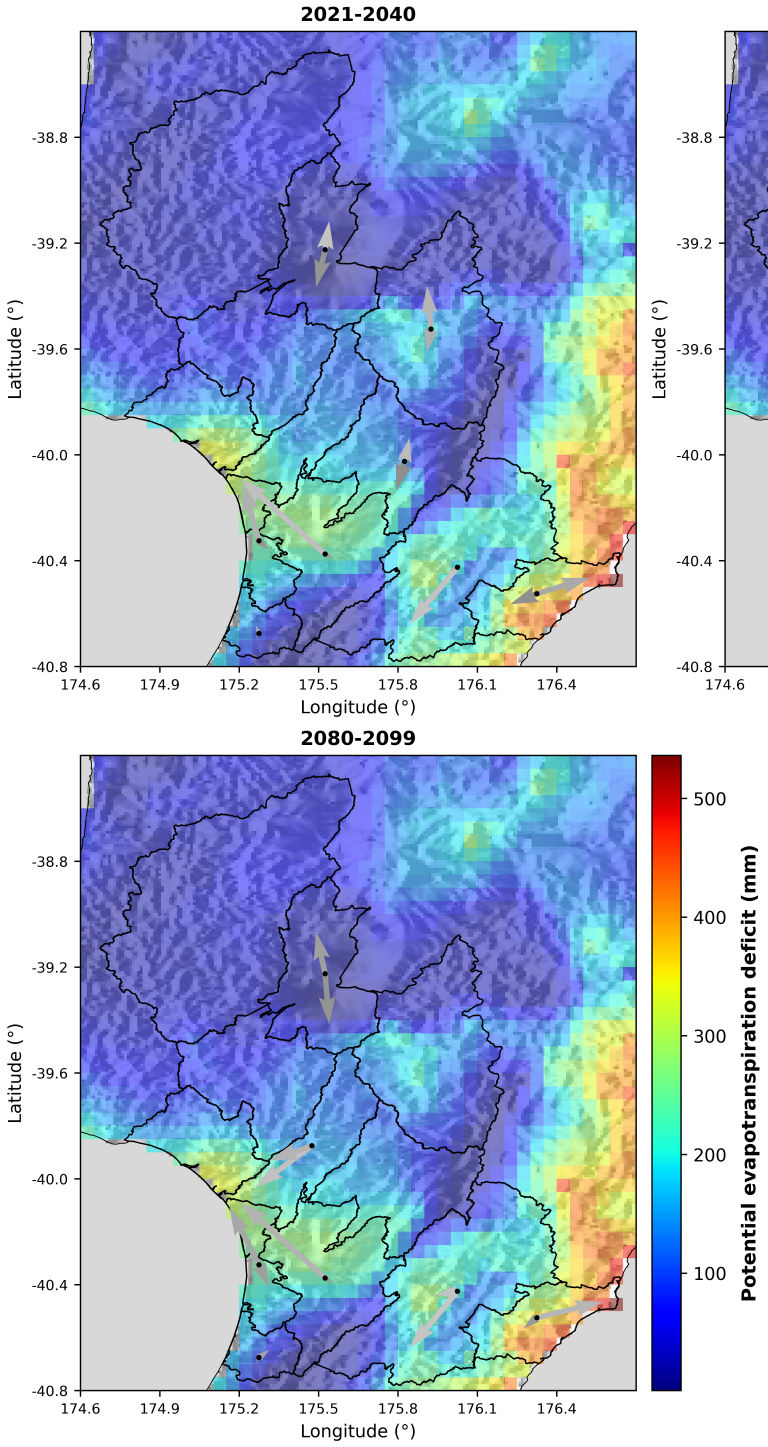


Figure 19: Climate analogues calculated for each of the 12 sub-regions. The background field shows the 1986-2005 baseline potential evapotranspiration deficit. Arrows point to the climate analogue locations for each region under the SSP1-2.6 GHG emissions scenario for the near-future (2021-2040), mid-century (2041-2060) and end of the century (2080-2099). The darker the arrow the greater the confidence in the detected climate analogue. The original of this figure can be downloaded here.

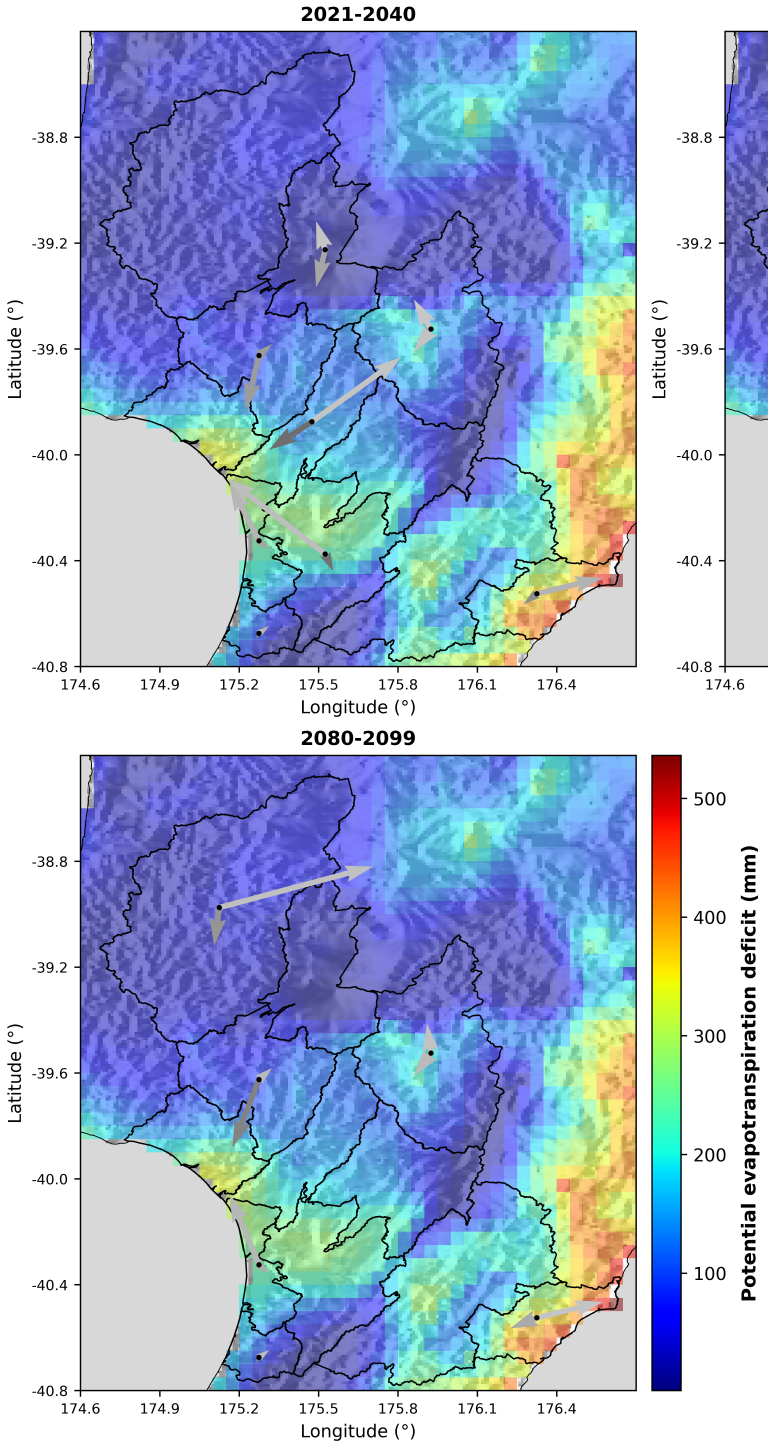


Figure 20: Climate analogues calculated for each of the 12 sub-regions. The background field shows the 1986-2005 baseline potential evapotranspiration deficit. Arrows point to the climate analogue locations for each region under the SSP2-4.5 GHG emissions scenario for the near-future (2021-2040), mid-century (2041-2060) and end of the century (2080-2099). The darker the arrow the greater the confidence in the detected climate analogue. The original of this figure can be downloaded here.

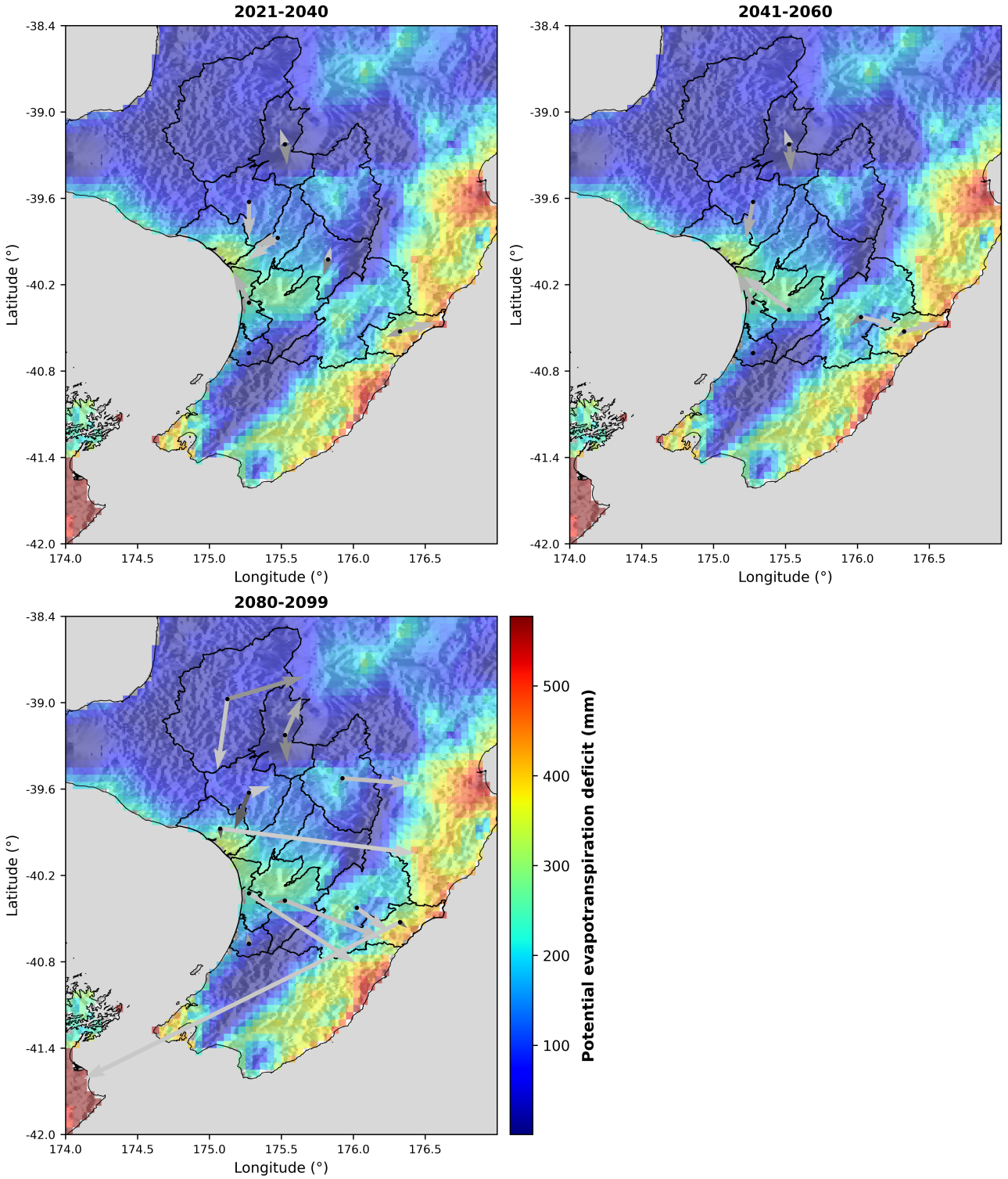


Figure 21: Climate analogues calculated for each of the 12 sub-regions. The background field shows the 1986-2005 baseline potential evapotranspiration deficit. Arrows point to the climate analogue locations for each region under the SSP3-7.0 GHG emissions scenario for the near-future (2021-2040), mid-century (2041-2060) and end of the century (2080-2099). The darker the arrow the greater the confidence in the detected climate analogue. The original of this figure can be downloaded here.

Coastal Whanganui, Whanganui-Manawatū Lakes, Middle Manawatū-Rangitīkei, and Tararua all need to look to drier regions to the east. Locations in the historical dry region of Puketoi ki Tai now need to look across Cook Strait to regions around Blenheim for their climate analogues.

Climate analogues for the annual PED under the SSP5-8.5 GHG emissions scenario are shown in Figure 22. The situation is quite similar to that for SSP3-7.0, although by mid-century there is already a suggestion that locations in NorthernZone-Taumarunui need to look north-east to drier regions. By century's end, Turakina and Western Ruahine join Coastal Whanganui in needing to look east for their climate analogues. Again Whanganui-Manawatū Lakes, Middle Manawatū-Rangitīkei and Tararua look to drier regions to the south-east. Locations in Puketoi ki Tai must look across Cook Strait to find their climate analogues.

10 Growing degree days over a 5°C threshold

Climate analogues for the annual number of growing degree days over a 5°C threshold (GDD5) under the SSP1-2.6 GHG emissions scenario are shown in Figure 23. Given the warming projected for the Horizons Region, it is not surprising that even in the near-future, locations in the warmer regions of Coastal Whanganui, Whanganui-Manawatū Lakes, Middle Manawatū-Rangitīkei, Tararua and Puketoi ki Tai will need to look elsewhere for climate analogues. Coastal Whanganui needs to look to the coast along the North Taranaki Bight, Whanganui-Manawatū Lakes and Middle Manawatū-Rangitīkei need to look to the coast around Napier, Tararua looks to Puketoi ki Tai, and Puketoi ki Tai looks to coastal regions south of Napier. By mid-century Horowhenua also needs to look to Napier as does Middle Manawatū-Rangitīkei. The other three dry sub-regions need to look to the coast up the North Taranaki Bight. This remains true at century's end but now with locations in Puketoi ki Tai needing to look further along the coast north of Napier. Locations in Tararua need to look to Puketoi ki Tai.

Climate analogues for the GDD5 under the SSP2-4.5 GHG emissions scenario are shown in Figure 24. Over the near-future the situation is largely the same as for SSP1-2.6 but now with locations in Horowhenua needing to look north-west further along the coast. By mid-century, however, the warmer regions of Coastal Whanganui, Whanganui-Manawatū Lakes, Horowhenua, Turakina, Middle Manawatū-Rangitīkei, and Puketoi ki Tai need to look to the northern coast of the North Taranaki Bight for their climate analogues. Locations in Volcanic Plateau need to look to warmer locations at lower elevations. By century's end, many sub-regions need to be looking to the northern coast of the North Taranaki Bight or to Auckland for their climate analogues. Some locations in Tararua will need to look along the coast north of Napier or to Puketoi ki Tai.

Climate analogues for GDD5 under the SSP3-7.0 GHG emissions scenario are shown in Figure 25. As before, over the near-future, locations in Coastal Whanganui and Whanganui-Manawatū Lakes need to look to the coast along the North Taranaki Bight. Horowhenua, Middle Manawatū-Rangitīkei, and Puketoi ki Tai (and to a lesser extent Whanganui-Manawatū Lakes) need to look to coastal regions around Napier. Locations in Volcanic Plateau need to look to warmer locations at lower elevations. By mid-century Coastal Whanganui and Whanganui-Manawatū Lakes need to look to regions around Auckland, or to locations further along the coast of the North Taranaki Bight (as do Middle Whangaehu-Whanganui, Turakina and Puketoi ki Tai). Locations in Tararua need to look either to Puketoi ki Tai or Napier, while locations in Puketoi ki Tai could also look to the Hawke's Bay coast. By century's end, the climate analogues are characterised by shifts to the coast of the North Taranaki Bight, regions around Auckland, or regions in Northland.

Climate analogues for GDD5 under the SSP5-8.5 GHG emissions scenario are shown in Figure 26. Over the near-future and mid-century the situation is very similar to that under SSP3-7.0. By mid-century, however, there is greater certainty that locations in the three warmer south-west coastal sub-regions will need to look along the coast of the North Taranaki Bight. By century's end locations with GDD5 values unprecedented in the historical record, across all six models, begin to appear. Climate analogues for remaining sites are characterised by shifts to regions around Northland, Auckland (to a lesser extent), or to the coast of the North Taranaki Bight (to a lesser extent still).

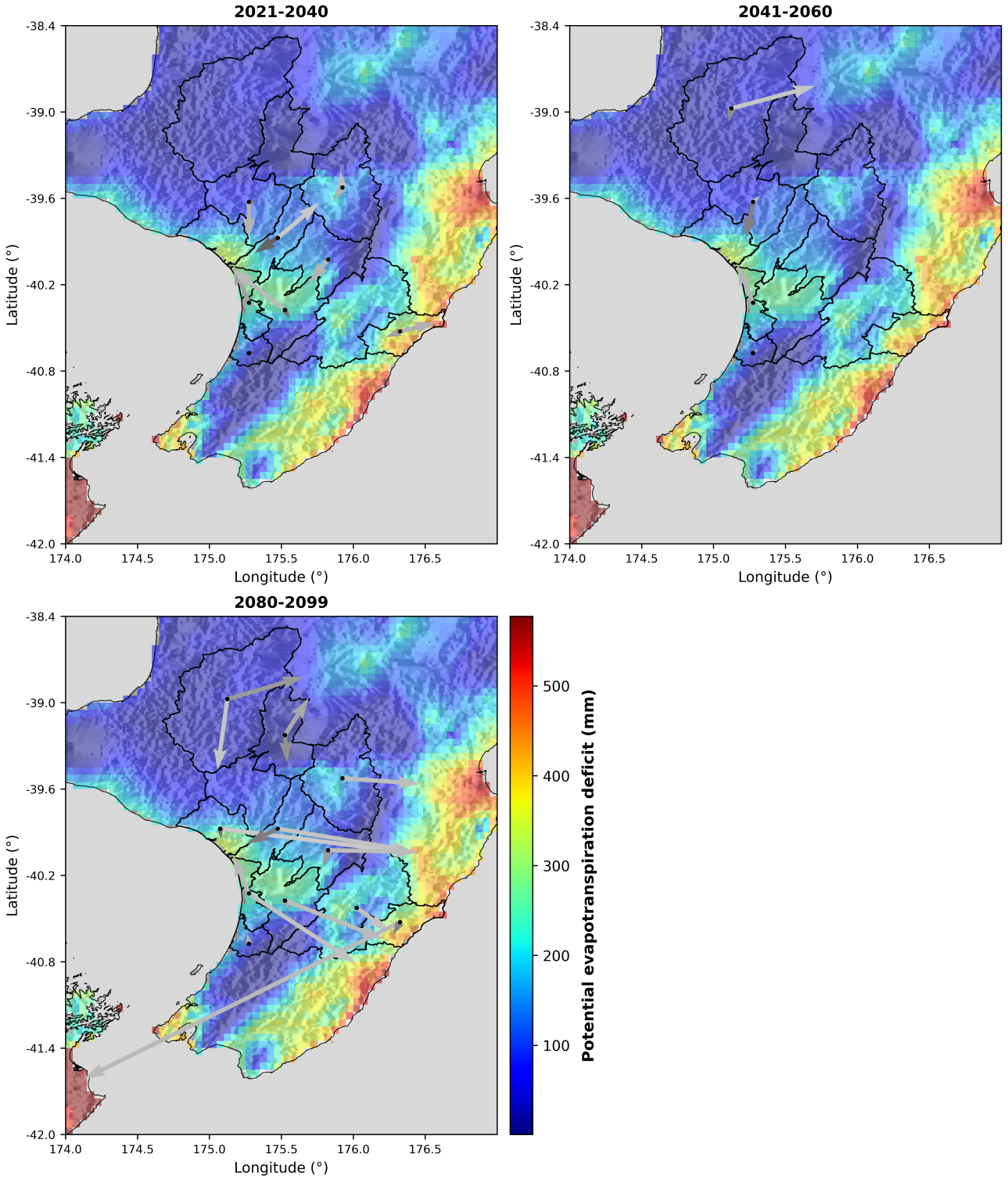


Figure 22: Climate analogues calculated for each of the 12 sub-regions. The background field shows the 1986-2005 baseline potential evapotranspiration deficit. Arrows point to the climate analogue locations for each region under the SSP5-8.5 GHG emissions scenario for the near-future (2021-2040), mid-century (2041-2060) and end of the century (2080-2099). The darker the arrow the greater the confidence in the detected climate analogue. The original of this figure can be downloaded here.

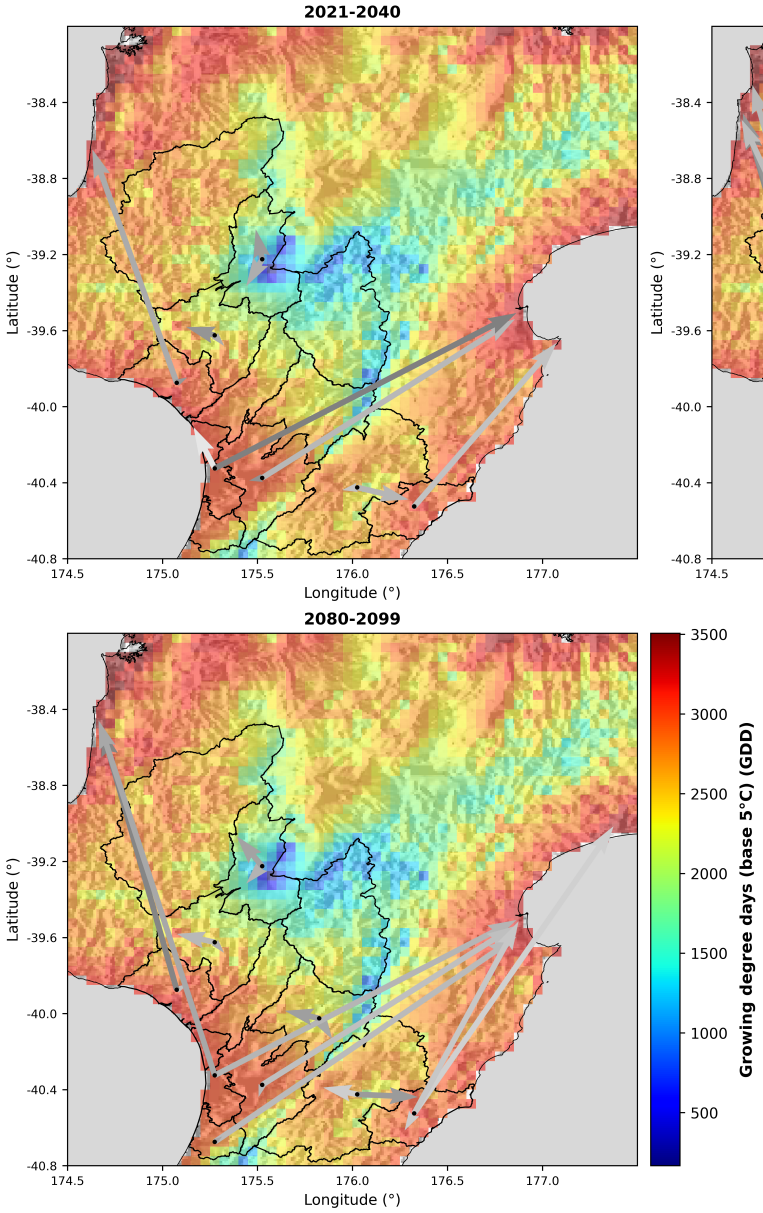


Figure 23: Climate analogues calculated for each of the 12 sub-regions. The background field shows the 1986-2005 baseline annual number of growing degree days over a 5°C threshold. Arrows point to the climate analogue locations for each region under the SSP1-2.6 GHG emissions scenario for the near-future (2021-2040), mid-century (2041-2060) and end of the century (2080-2099). The darker the arrow the greater the confidence in the detected climate analogue. The original of this figure can be downloaded here.

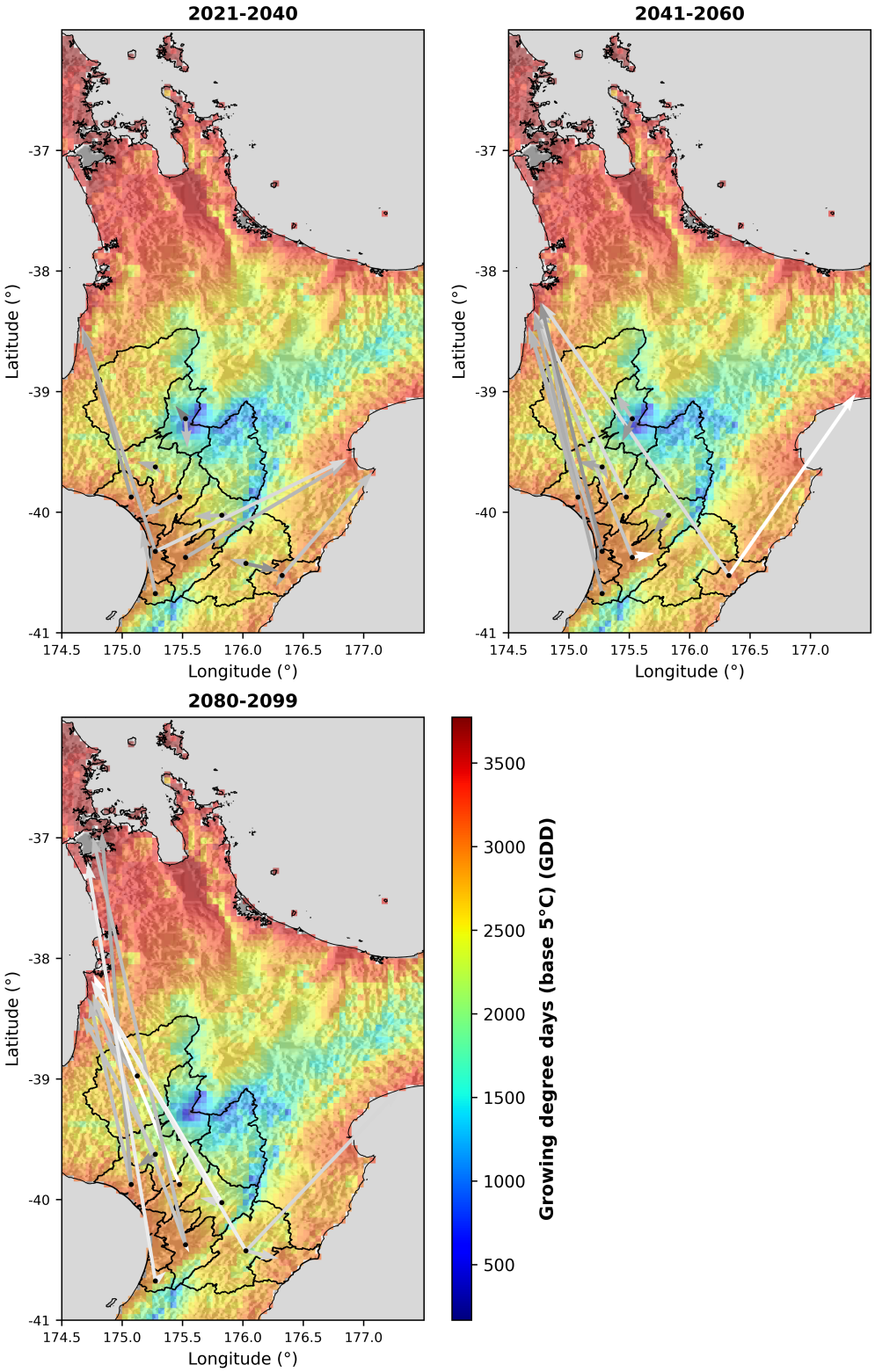


Figure 24: Climate analogues calculated for each of the 12 sub-regions. The background field shows the 1986-2005 baseline annual number of growing degree days over a 5°C threshold. Arrows point to the climate analogue locations for each region under the SSP2-4.5 GHG emissions scenario for the near-future (2021-2040), mid-century (2041-2060) and end of the century (2080-2099). The darker the arrow the greater the confidence in the detected climate analogue. The original of this figure can be downloaded here.

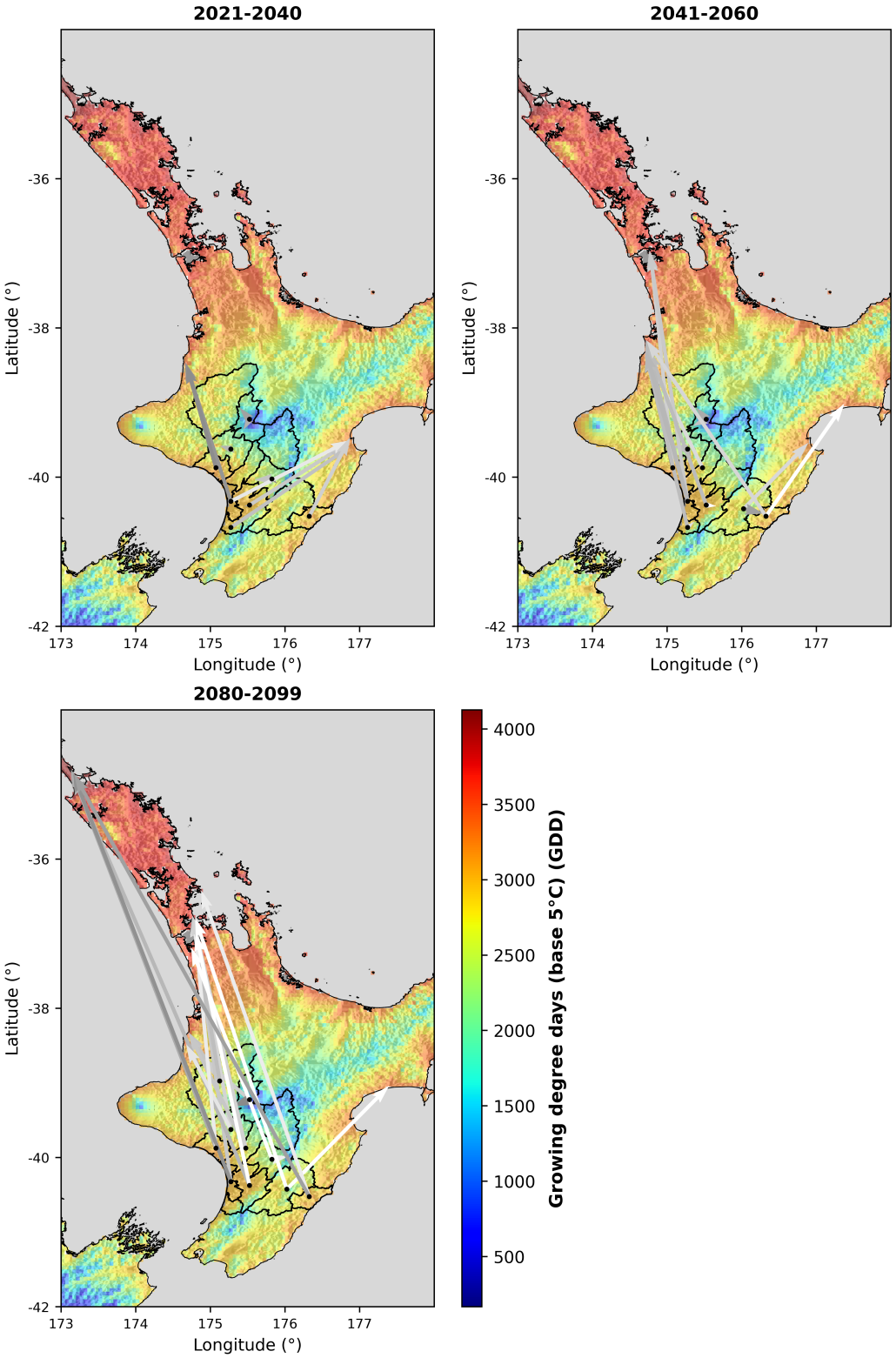


Figure 25: Climate analogues calculated for each of the 12 sub-regions. The background field shows the 1986-2005 baseline annual number of growing degree days over a 5°C threshold. Arrows point to the climate analogue locations for each region under the SSP3-7.0 GHG emissions scenario for the near-future (2021-2040), mid-century (2041-2060) and end of the century (2080-2099). The darker the arrow the greater the confidence in the detected climate analogue. The original of this figure can be downloaded here.

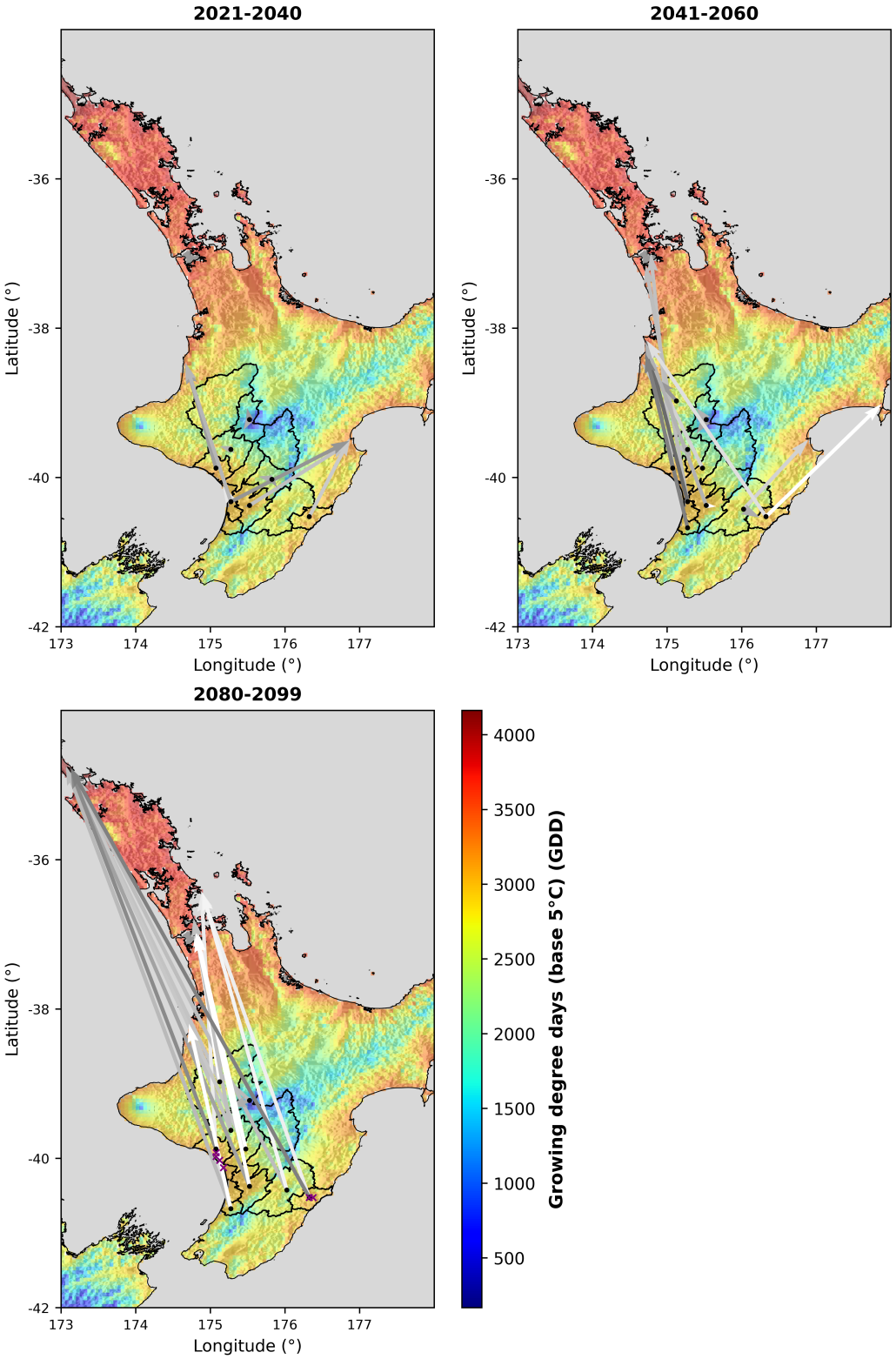


Figure 26: Climate analogues calculated for each of the 12 sub-regions. The background field shows the 1986-2005 baseline annual number of growing degree days over a 5°C threshold. Arrows point to the climate analogue locations for each region under the SSP5-8.5 GHG emissions scenario for the near-future (2021-2040), mid-century (2041-2060) and end of the century (2080-2099). The darker the arrow the greater the confidence in the detected climate analogue. Cells marked with a small purple x denote locations for which the future value is unprecedented anywhere in New Zealand in the 1986-2005 historical record. The original of this figure can be downloaded here.

11 Growing degree days over a 10°C threshold

Climate analogues for the annual number of growing degree days over a 10°C threshold (GDD10) under the SSP1-2.6 GHG emissions scenario are shown in Figure 27. Again, given the warming projected for the Hori-

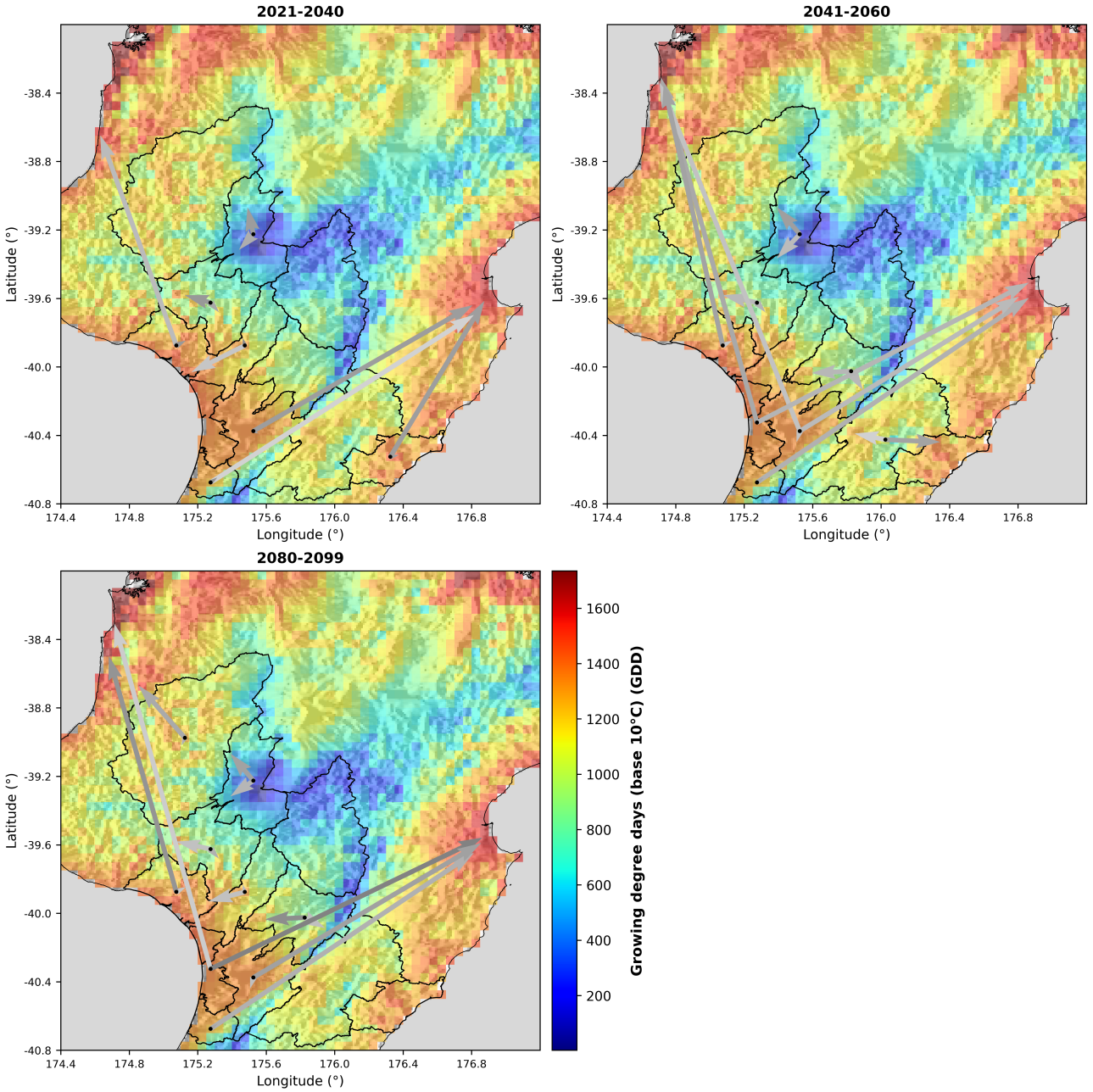


Figure 27: Climate analogues calculated for each of the 12 sub-regions. The background field shows the 1986-2005 baseline annual number of growing degree days over a 10°C threshold. Arrows point to the climate analogue locations for each region under the SSP1-2.6 GHG emissions scenario for the near-future (2021-2040), mid-century (2041-2060) and end of the century (2080-2099). The darker the arrow the greater the confidence in the detected climate analogue. The original of this figure can be downloaded here.

zons Region, it is not surprising that even in the near-future, locations in the warmer regions of Horowhenua, Middle Manawatū-Rangitīkei, and Puketoi ki Tai will need to look to areas inland of Napier for their climate analogues. Turakina needs to look to Coastal Whanganui while Coastal Whanganui itself needs to look to the coast of the North Taranaki Bight. Locations in Volcanic Plateau and Middle Whangaehu-Whanganui can find climate analogues within their regions at lower elevations. By mid-century the situation is similar but now with Coastal Whanganui needing to look further north along the coast of the North Taranaki Bight, as do Whanganui-Manawatū Lakes and Middle Manawatū-Rangitīkei (both of which can also look to areas around

Napier). Locations in Horowhenua can also look to areas around Napier. Tararua looks to Puketoi ki Tai. Locations in Volcanic Plateau, Middle Whangaehu-Whanganui and Western Ruahine can find climate analogues within their regions at lower elevations. The situation is similar around the end of the century but now with locations in NorthernZone-Taumarunui needing to look north-west, outside the region, to find their climate analogues.

Climate analogues for GDD10 under the SSP2-4.5 GHG emissions scenario are shown in Figure 28. Over the

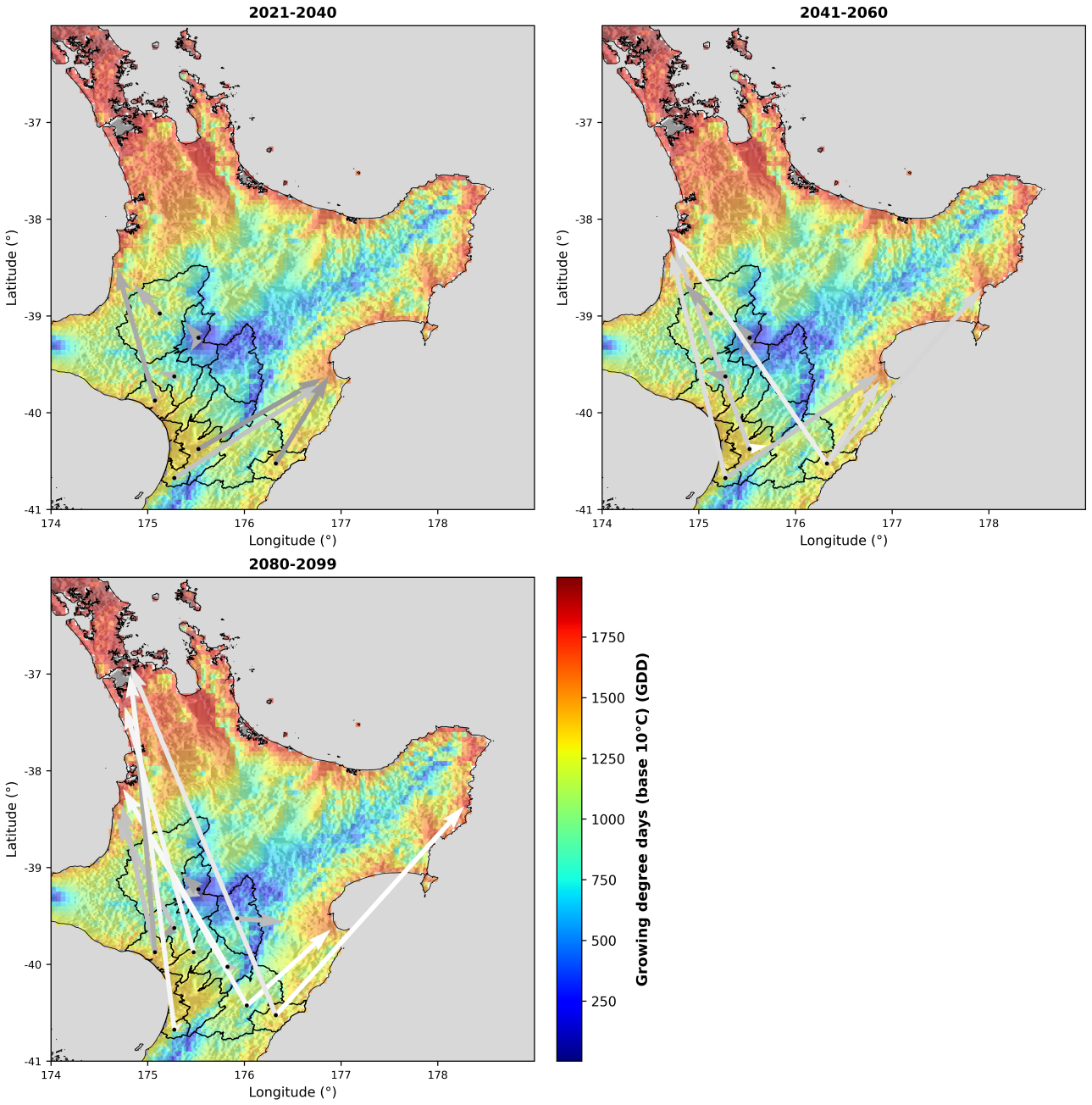


Figure 28: Climate analogues calculated for each of the 12 sub-regions. The background field shows the 1986-2005 baseline annual number of growing degree days over a 10°C threshold. Arrows point to the climate analogue locations for each region under the SSP2-4.5 GHG emissions scenario for the near-future (2021-2040), mid-century (2041-2060) and end of the century (2080-2099). The darker the arrow the greater the confidence in the detected climate analogue. The original of this figure can be downloaded here.

near-future, the situation is largely the same as for SSP1-2.6, but now with an indication that locations in NorthernZone-Taumarunui can look to areas just outside the region to the north-west for their climate analogues. By mid-century locations in Volcanic Plateau and Middle Whangaehu-Whanganui can look within their regions to lower elevations. Horowhenua, Middle Manawatū-Rangitīkei and Puketoi ki Tai need to look either

to the north coast of the North Taranaki Bight or to coastal regions of Napier or even to Tairāwhiti for their climate analogues. By the end of the century, Coastal Whanganui, Middle Whangaehu-Whanganui, and Tararua need to look to the north coast of the North Taranaki Bight. Coastal Whanganui can also look to regions around Auckland as can Turakina, Horowhenua, and Puketoi ki Tai. The warm eastern regions can look to Napier or to the Tairāwhiti coast. Locations in Upper Rangitīkei need to look outside the region to warmer areas to the east.

Climate analogues for GDD10 under the SSP3-7.0 GHG emissions scenario are shown in Figure 29. As before, over the near-future, locations in Coastal Whanganui and Whanganui-Manawatū Lakes need to look to the coast along the North Taranaki Bight; Whanganui-Manawatū Lakes can also look to the coast around Napier. Horowhenua, Middle Manawatū-Rangitīkei, and Puketoi ki Tai can also look to areas just inland of Napier. Other sub-regions can generally look to locations within the region at lower elevations for their climate analogues. By mid-century far larger shifts are projected. Warmer sub-regions along the south-west coast need to look to the north coast of the North Taranaki Bight, or even as far north as Auckland. The easternmost sub-regions (Tararua and Puketoi ki Tai) need to look either to Napier or further north-east up the Hawke's Bay coast. By century's end, the climate analogues are characterised by shifts to the coast of the North Taranaki Bight, regions around Auckland, or regions in Northland.

Climate analogues for GDD10 under the SSP5-8.5 GHG emissions scenario are shown in Figure 30. Over the near-future and mid-century the situation is very similar to that under SSP3-7.0. By century's end, several locations in Coastal Whanganui, Whanganui-Manawatū Lakes and Puketoi ki Tai are projected, by all six models, to experience GDD10 values unprecedented anywhere in New Zealand in the historical record. Climate analogues for other locations are characterised by shifts to regions around Northland, Auckland (to a lesser extent), or to the coast of the North Taranaki Bight (to a lesser extent still).

12 Number of hot days (>25°C)

Climate analogues for the annual number of hot days with daily maximum temperature exceeding 25°C (TX25) under the SSP1-2.6 GHG emissions scenario are shown in Figure 31. Over the near-future, climate analogues for Volcanic Plateau, Middle Whangaehu-Whanganui and Coastal Whanganui can generally be found within each region. Locations in Whanganui-Manawatū Lakes either need to look north-east to warmer parts of Turakina, or south of the Horizons Region to the northern parts of the Wairarapa Valley. Horowhenua and Middle Manawatū-Rangitīkei also need to look to the northern parts of the Wairarapa valley. Locations in Puketoi ki Tai need to look north-east outside the region. By mid-century there is a much clearer signal that many sub-regions either need to look to warmer locations in the southern areas of the Hawke's Bay Region (Turakina, Western Ruahine, Middle Manawatū-Rangitīkei, Tararua, and Puketoi ki Tai) or to warmer locations in the north of the Wairarapa Valley (Horowhenua, Whanganui-Manawatū Lakes, Middle Manawatū-Rangitīkei, and Tararua). The situation is largely similar by century's end; not surprising given the stabilising nature of the low emissions SSP1-2.6 scenario.

Climate analogues for TX25 under the SSP2-4.5 GHG emissions scenario are shown in Figure 32. In the near-future, under this GHG emissions scenario, sites in Volcanic Plateau and Middle Whangaehu-Whanganui can find their climate analogues within their regions. Whanganui-Manawatū Lakes needs to look either north-east to Turakina or south-east to warmer parts of the northern Wairarapa Valley. This is also the climate analogue target for Middle Manawatū-Rangitīkei and Horowhenua. Locations in Puketoi ki Tai need to look north-east to the warmer parts of the southern Hawke's Bay Region. By mid-century, TX25 values unprecedented in the historical record start to appear in NorthernZone-Taumarunui. Climate analogues for Volcanic Plateau and Upper Rangitīkei can generally be found within these regions. There is now stronger evidence that several of the sub-regions need to look to the warmer parts of the southern Hawke's Bay Region (Coastal Whanganui, Whanganui-Manawatū Lakes, Turakina, Middle Manawatū-Rangitīkei, and Tararua) or to the warmer parts of the northern Wairarapa Valley (Horowhenua, Whanganui-Manawatū Lakes, Middle Manawatū-Rangitīkei, and

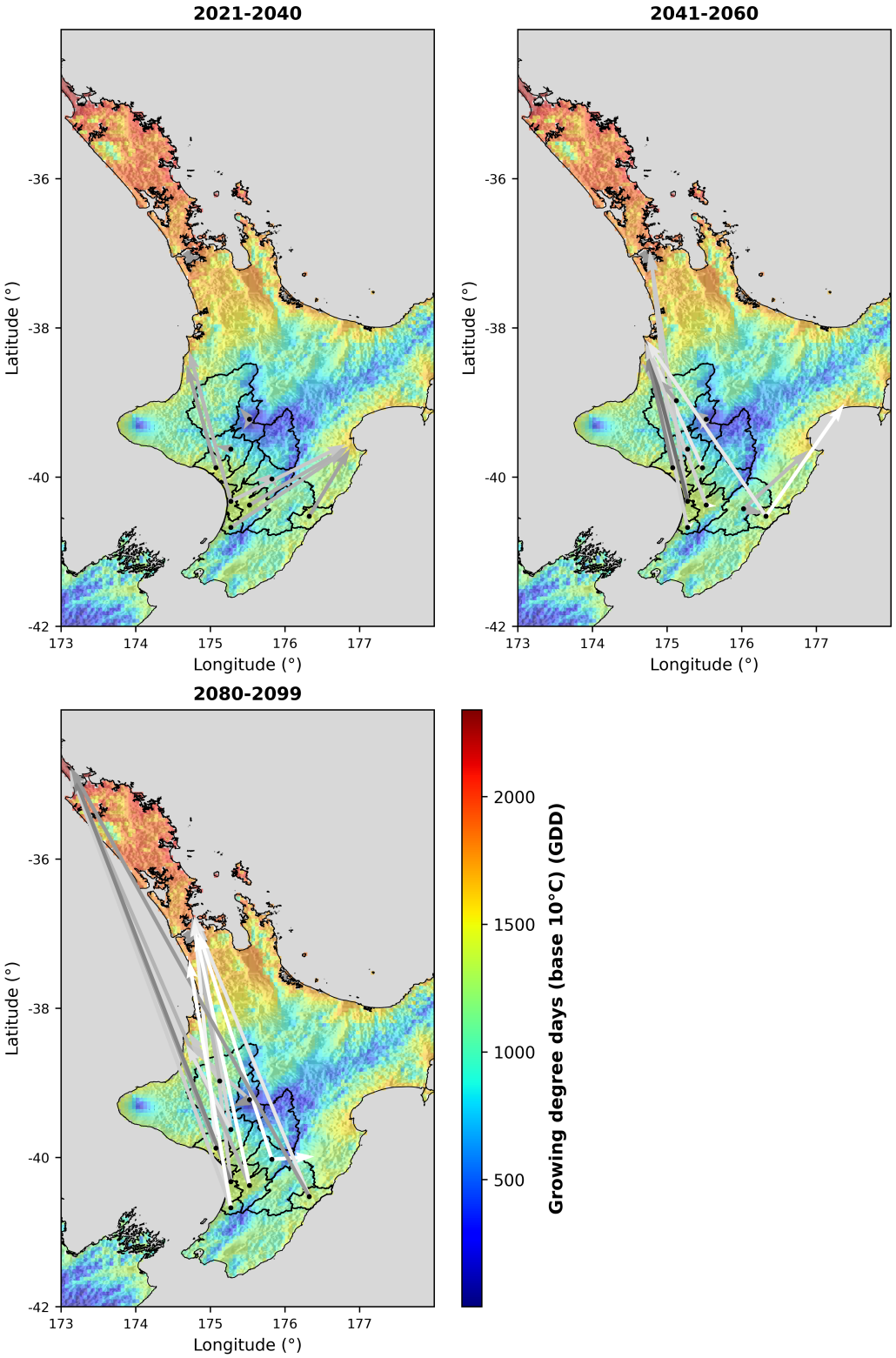


Figure 29: Climate analogues calculated for each of the 12 sub-regions. The background field shows the 1986-2005 baseline annual number of growing degree days over a 10°C threshold. Arrows point to the climate analogue locations for each region under the SSP3-7.0 GHG emissions scenario for the near-future (2021-2040), mid-century (2041-2060) and end of the century (2080-2099). The darker the arrow the greater the confidence in the detected climate analogue. The original of this figure can be downloaded here.

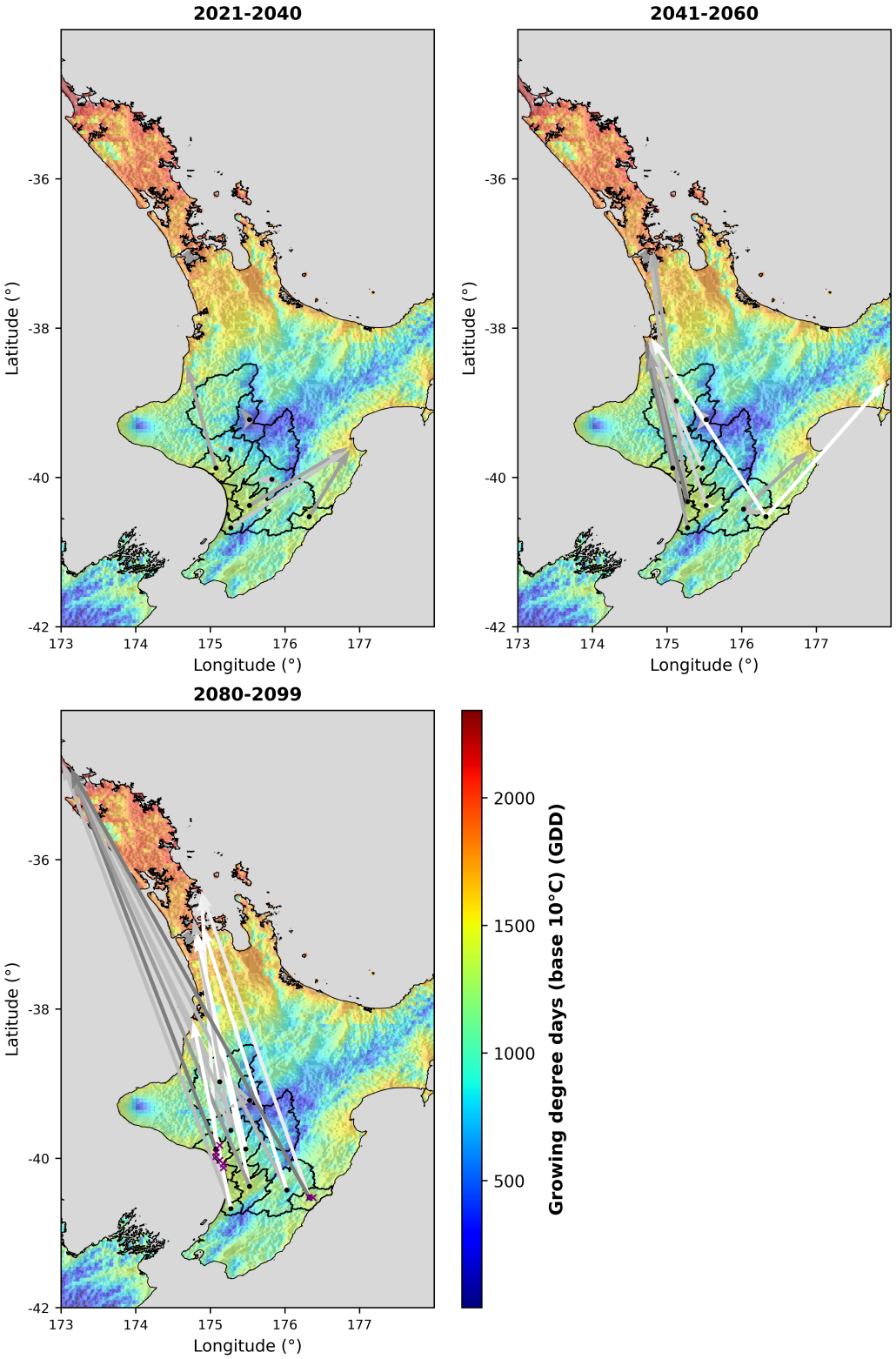


Figure 30: Climate analogues calculated for each of the 12 sub-regions. The background field shows the 1986-2005 baseline annual number of growing degree days over a 10°C threshold. Arrows point to the climate analogue locations for each region under the SSP5-8.5 GHG emissions scenario for the near-future (2021-2040), mid-century (2041-2060) and end of the century (2080-2099). The darker the arrow the greater the confidence in the detected climate analogue. Cells marked with a small purple x denote locations for which the future value is unprecedented anywhere in New Zealand in the 1986-2005 historical record. The original of this figure can be downloaded here.

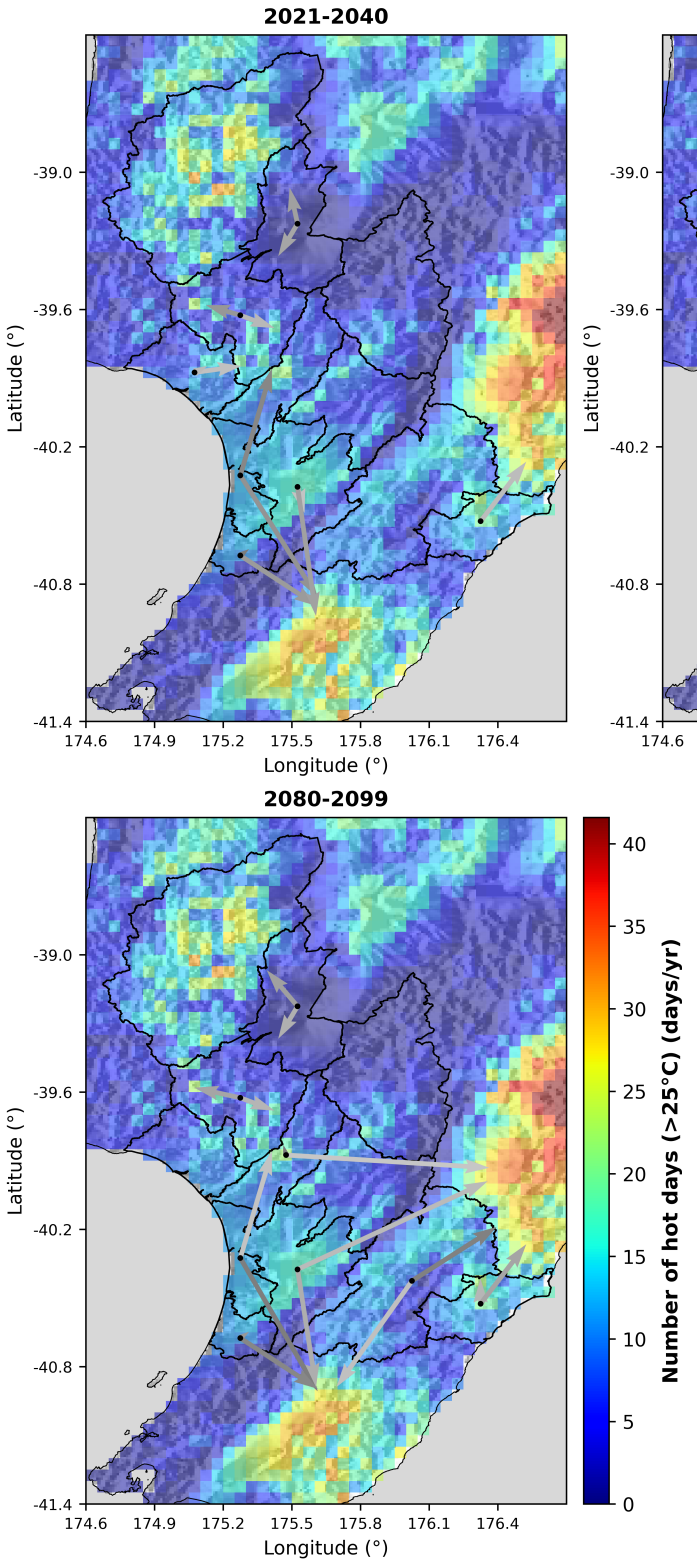


Figure 31: Climate analogues calculated for each of the 12 sub-regions. The background field shows the 1986-2005 baseline annual number of hot days, i.e., days with a daily maximum temperature exceeding 25°C. Arrows point to the climate analogue locations for each region under the SSP1-2.6 GHG emissions scenario for the near-future (2021-2040), mid-century (2041-2060) and end of the century (2080-2099). The darker the arrow the greater the confidence in the detected climate analogue. The original of this figure can be downloaded here.

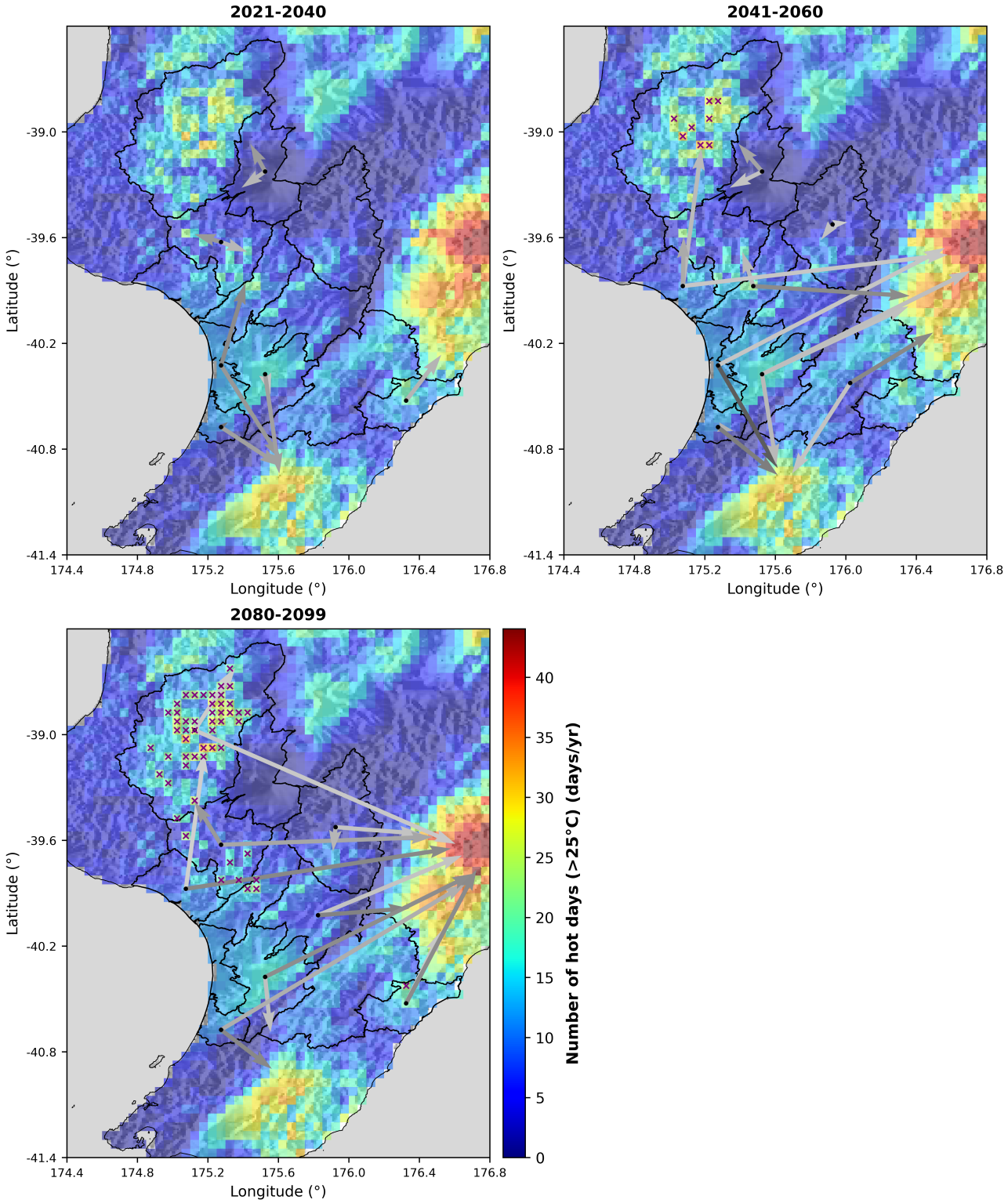


Figure 32: Climate analogues calculated for each of the 12 sub-regions. The background field shows the 1986-2005 baseline annual number of hot days, i.e., days with a daily maximum temperature exceeding 25°C. Arrows point to the climate analogue locations for each region under the SSP2-4.5 GHG emissions scenario for the near-future (2021-2040), mid-century (2041-2060) and end of the century (2080-2099). The darker the arrow the greater the confidence in the detected climate analogue. Cells marked with a small purple x denote locations for which the future value is unprecedented anywhere in New Zealand in the 1986-2005 historical record. The original of this figure can be downloaded here.

Tararua). By the end of the century there is a far larger number of locations in NorthernZone-Taumarunui, Middle Whangaehu-Whanganui, Turakina and Puketoi ki Tai with TX25 values projected to be unprecedented in the historical record. For most sub-regions it is now necessary to look to areas around Hastings to find climate analogues, or, in the case of Horowhenua, to the north Wairarapa Valley.

Climate analogues for TX25 under the SSP3-7.0 GHG emissions scenario are shown in Figure 33. In the near-future, Volcanic Plateau and Middle Whangaehu-Whanganui can again find their climate analogues within their regions. Sub-regions towards the north-east of the Horizons Region (Turakina, Western Ruahine, Middle Manawatū-Rangitīkei, Tararua, and Puketoi ki Tai) need to look to the warmer regions around Hastings, while the four sub-regions to the south-west of the Horizons Region (Horowhenua, Whanganui-Manawatū Lakes, Middle Manawatū-Rangitīkei, and Tararua) need to look to the warmer areas of the north Wairarapa Valley. Whanganui-Manawatū Lakes can also look to Turakina for climate analogues. By mid-century again we start to see unprecedented TX25 values projected by all six models for several locations in NorthernZone-Taumarunui, and one cell in Middle Whangaehu-Whanganui. There is now stronger evidence for six of the sub-regions needing to look to the area around Hastings (now including NorthernZone-Taumarunui). The three sub-regions to the south-west still need to look to the northern parts of the Wairarapa Valley. By century's end, under this SSP3-7.0 emissions scenario, many locations across the Horizons Region are projected to experience TX25 values unprecedented in the historical record. For remaining locations, climate analogues are likely to be found in the southern parts of the Hawke's Bay Region, or, for NorthernZone-Taumarunui, north of the region, and for Middle Manawatū-Rangitīkei south of the region.

Climate analogues for TX25 under the SSP5-8.5 GHG emissions scenario are shown in Figure 34. In the near future Volcanic Plateau and Middle Whangaehu-Whanganui can again find their climate analogues within their regions. Whanganui-Manawatū Lakes needs to look to Turakina while Puketoi ki Tai needs to look just north of the region. The four other sub-regions to the south of the Horizons Region (Horowhenua, Whanganui-Manawatū Lakes, Middle Manawatū-Rangitīkei, and Tararua) need to look to the warmer areas of the north Wairarapa Valley. By mid-century again unprecedented TX25 values start appearing in NorthernZone-Taumarunui, Middle Whangaehu-Whanganui, and Turakina. There is now stronger evidence for six of the sub-regions (NorthernZone-Taumarunui, Coastal Whanganui, Turakina, Whanganui-Manawatū Lakes, Middle Manawatū-Rangitīkei, and Tararua) needing to look to the area around Hastings for their climate analogues. Horowhenua and, to a lesser extent, Whanganui-Manawatū Lakes, can look south to the Wairarapa Valley. By century's end, under this extreme GHG emissions scenario, nearly every location is projected to experience TX25 values unprecedented in the historical record. Only for Volcanic Plateau can valid climate analogues be determined and these are either just to the west (in NorthernZone-Taumarunui) or further to the east to the inland south of the Hawke's Bay Region.

13 Conclusions

This report assesses climate analogues for the Horizons Region using six CCAM-downscaled CMIP6 climate simulations, a 1986–2005 baseline, three future periods, and four GHG emissions scenarios. A climate analogue is defined as a location whose historical climatology resembles the projected future climate of a location or sub-region. The approach provides an intuitive, spatially explicit way of translating climate projections into conditions already experienced elsewhere, while recognising that analogue locations may differ substantially in non-climatic characteristics and should therefore complement, rather than replace, quantitative projections.

Climate analogues are calculated separately for 12 Horizons sub-regions and for each of the six climate models, allowing both the direction and magnitude of geographical shifts and model agreement to be assessed. The analysis considers daily mean temperature, annual precipitation, the annual number of frost days, potential evapotranspiration deficit, growing degree days above 5°C and 10°C, and the number of days in each year where the daily maximum temperature exceeds 25°C.

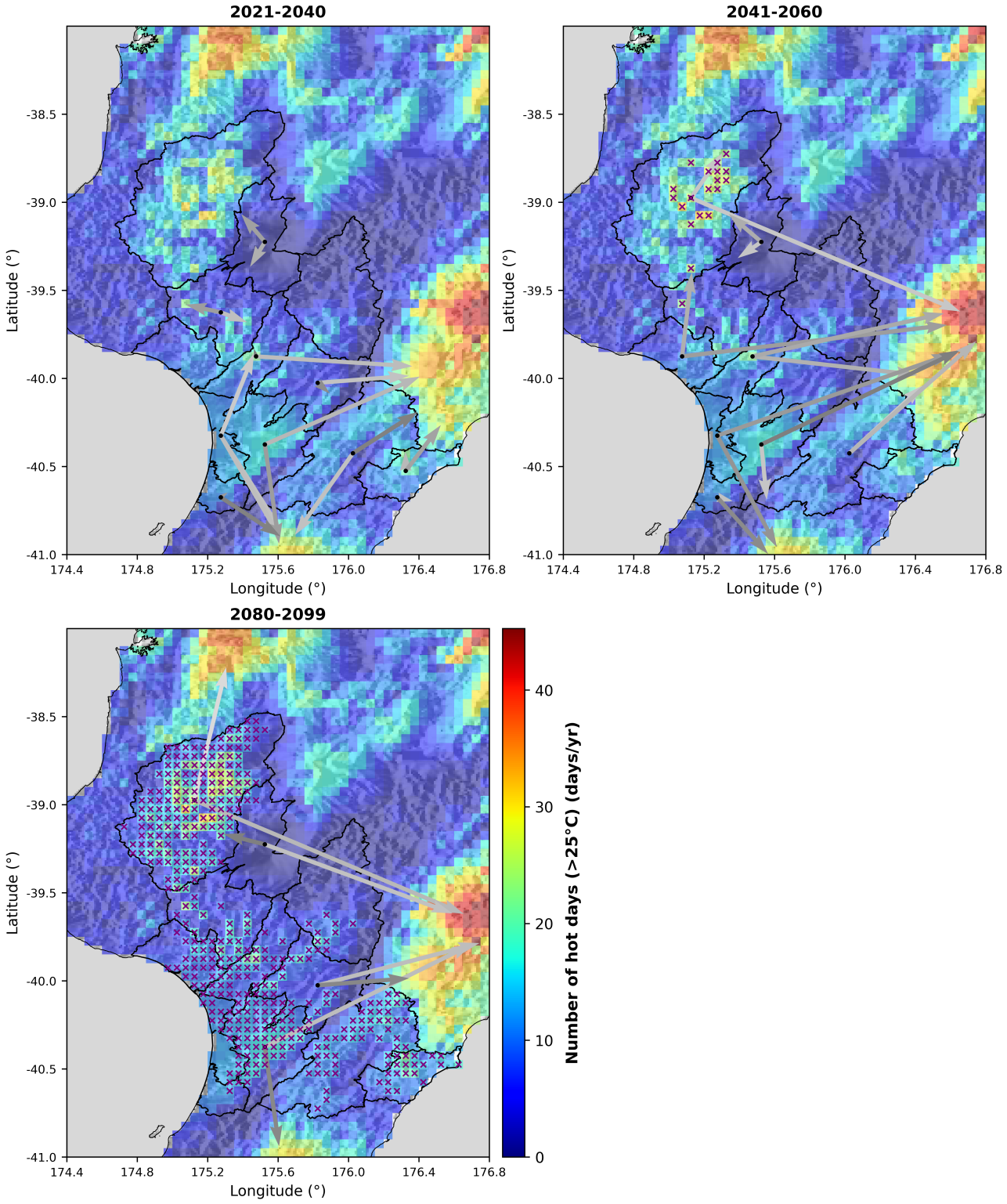


Figure 33: Climate analogues calculated for each of the 12 sub-regions. The background field shows the 1986-2005 baseline annual number of hot days, i.e., days with a day maximum temperature exceeding 25°C. Arrows point to the climate analogue locations for each region under the SSP3-7.0 GHG emissions scenario for the near-future (2021-2040), mid-century (2041-2060) and end of the century (2080-2099). The darker the arrow the greater the confidence in the detected climate analogue. Cells marked with a small purple x denote locations for which the future value is unprecedented anywhere in New Zealand in the 1986-2005 historical record. The original of this figure can be downloaded here.

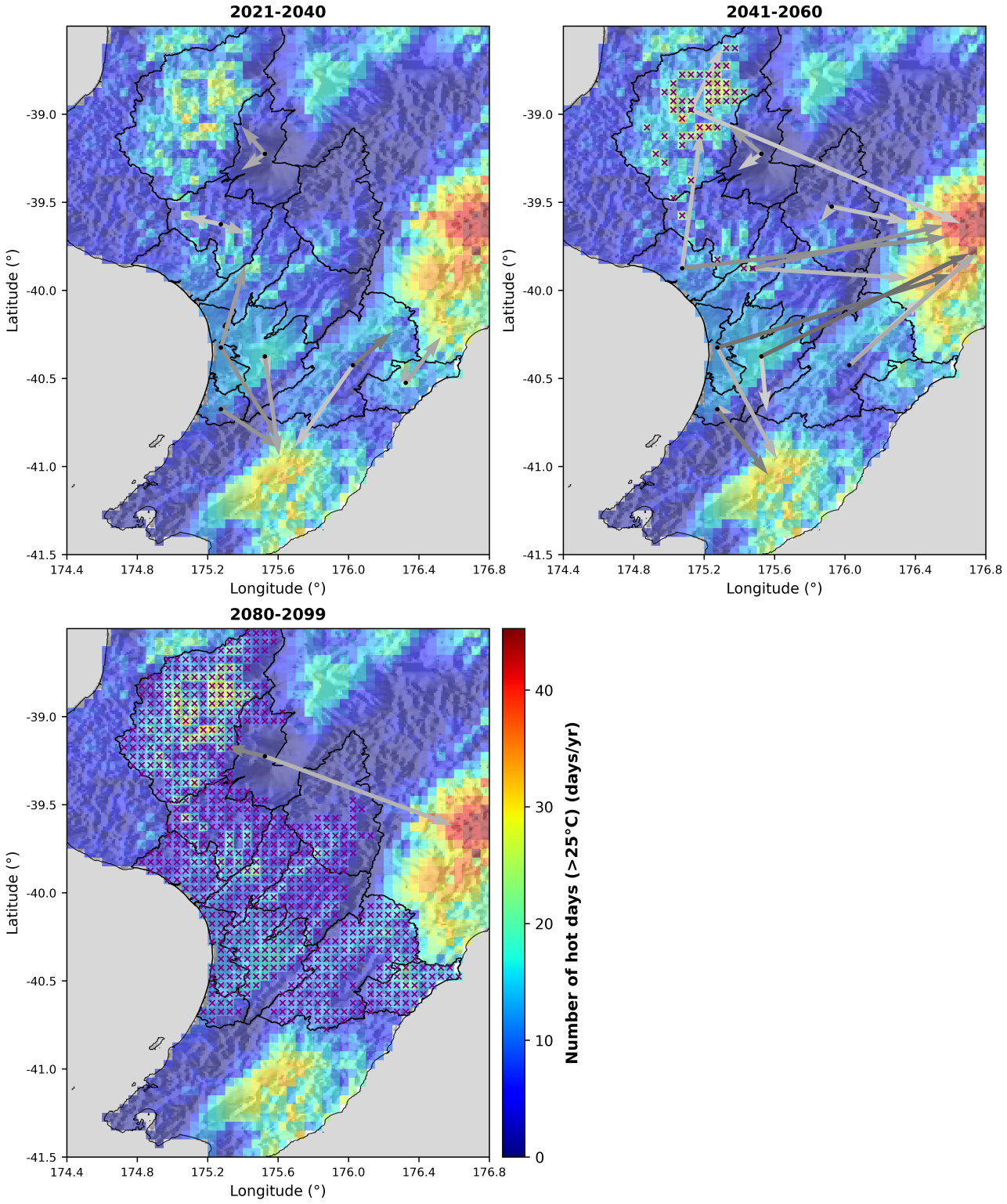


Figure 34: Climate analogues calculated for each of the 12 sub-regions. The background field shows the 1986-2005 baseline annual number of hot days, i.e., days with a daily maximum temperature exceeding 25°C. Arrows point to the climate analogue locations for each region under the SSP5-8.5 GHG emissions scenario for the near-future (2021-2040), mid-century (2041-2060) and end of the century (2080-2099). The darker the arrow the greater the confidence in the detected climate analogue. Cells marked with a small purple x denote locations for which the future value is unprecedented anywhere in New Zealand in the 1986-2005 historical record. The original of this figure can be downloaded here.

The clearest overall signal is a progressive displacement towards historically warmer, lower-elevation and, for PED, drier locations as warming increases. For temperature and growing-degree-day metrics, analogues increasingly occur northward, particularly along the North Taranaki Bight, Hawke's Bay coast, Auckland and Northland. Under higher-emissions scenarios late in the century, projected conditions increasingly exceed anything observed anywhere in New Zealand during 1986–2005. Frost-day analogues similarly shift towards warmer coastal and lower-elevation areas, with all regions requiring distant analogues by century's end under SSP5-8.5. PED analogues increasingly favour drier areas, especially under SSP3-7.0 and SSP5-8.5. In contrast, changes in annual precipitation are sufficiently small and uncertain that sub-regional climate analogues provide little useful differentiation.

Overall, these climate analogues demonstrate how increasingly large geographical shifts, and ultimately unprecedented climatic conditions, emerge as emissions and time horizons increase.