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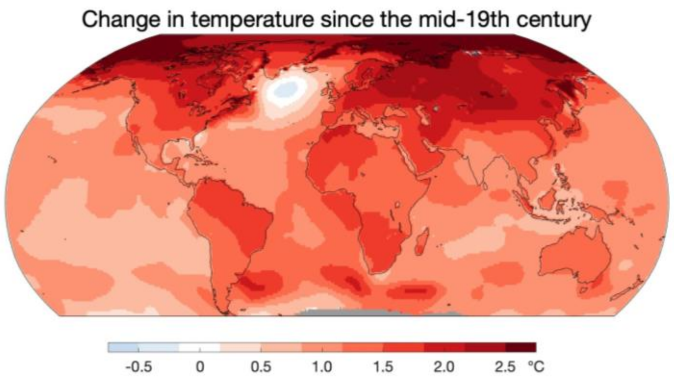
Growing Fruit IQ

Scientific and Practical Guide to Climate Change and Pome/Stone Fruit Production in South Africa

Part 2: Atlas of High-Resolution Maps for Eleven Pome and Stone Fruit Production Regions for Key Climate-Related Variables

April 2021



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1. Introduction and Aim

The year 2020 ranked with 2016 as the hottest globally since measurements began. This is extremely worrying, since the five warmest years in the period 1880-2019 have all occurred since 2015, and 9 out of the 10 hottest years since 2005. The world's climate is changing fast because of human activities causing steady increases in atmospheric concentrations of greenhouse gases such as carbon dioxide, methane and nitrous oxide. The observed (and scientifically verified) changes can no longer be denied or ignored and are set to continue over the next few decades. The questions for South African agriculture are now: what does the climate of the foreseeable future look like, what aspects of climate are changing the fastest and pose the most risk to farming, and what can farmers do about it?

Pome and stone fruit growers in South Africa are already experiencing the impacts of rising temperatures and increasingly unpredictable seasonal weather patterns. The evidence lies in more years with low rates of winter chill accumulation, a sequence of years with low fruit set in spring, high sunburn incidence in summer and poor red colour development in autumn. Shifts in rainfall patterns are observed and the severe drought of 2015-2018 had significant negative impacts on the industry. More warm spells, and sometimes record heat, cause faster soil drying and increased irrigation demand. These changes together are depressing the commercial pome and stone fruit production potential and profitability. While climatic challenges have always existed, the scientific consensus is that climate change is a 'threat multiplier', i.e. it increases the likelihood and severity of such events. Over time, unless measures are taken, climate change could threaten the sustainability of the sector.

The pome and stone fruit industries need to overcome these climatic barriers and become more resilient by adapting to the changing climate. Timeous planning can also help growers identify opportunities that climate change may offer. Effective adaptation can minimize the impacts on orchard operations, productivity and profitability; protect farm infrastructure, long-term investments and livelihoods; and help to grow the industry. This requires a good understanding of the trends and future projections of key climatic factors and their impacts on fruit production.

Although there is a large body of scientific knowledge on climate change available globally and in South Africa, this is not generally accessible to growers and technical advisors and is seldom useful for on-farm decision making. It is hoped that this Guide will become the 'go-to' source of spatial information on climate change risks, impacts and adaptation options for pome and stone fruit growers and advisors in South Africa. The aim is to provide a reliable science-based yet practical source of information to guide planning and adaptation for the next 30 years.

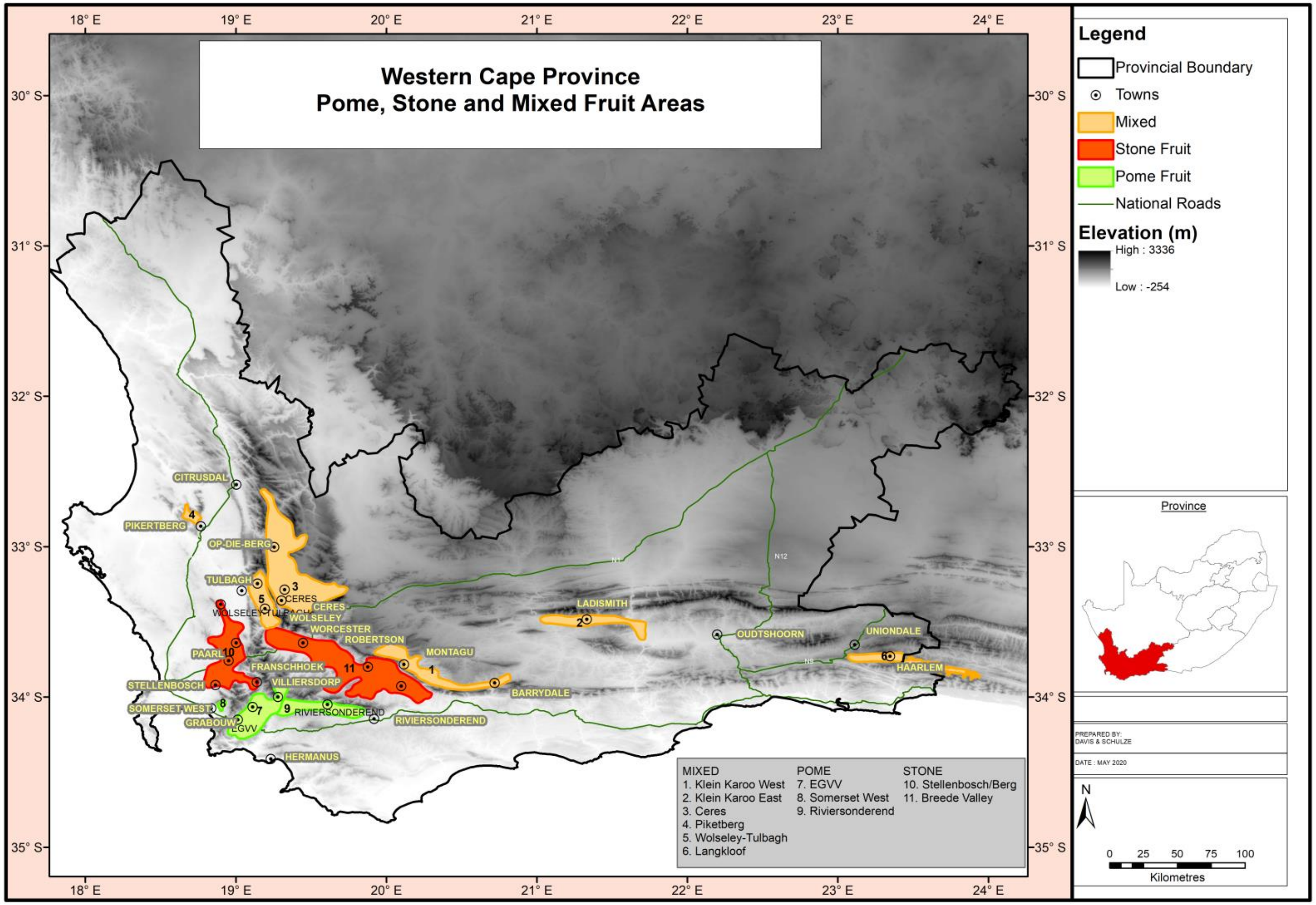


Figure 1. Pome and stone fruit production regions of the Western Cape and eastern Langkloof valley in the Eastern Cape. Based on data provided by the Western Cape Department of Agriculture (2018 fly-over database), and Google Earth (eastern Langkloof)..

2. Spatial scope

This first version of the Scientific and Practical Guide to Climate Change and Pome/Stone Fruit Production in South Africa focuses on the Western Cape Province and the whole Langkloof Valley, which includes some far western parts of the Eastern Cape Province. More than 96% of pome fruit and more than 70% of stone fruit are produced in the Western Cape - Langkloof region.

The main apple and pear production regions are shown in Figure 1 (labelled ‘pome’ and ‘mixed’). They are characterized by colder winters needed to fulfil the chilling requirements of pome fruits. Apples are grown mainly in the Koue and Warm Bokkeveld around the town of Ceres (region #3), the Elgin-Grabouw-Vyeboom-Villiersdorp (EGVV) region (#7), and the Langkloof Valley (#6). Other production regions are Piketberg (#4), Somerset West (#8), Riviersonderend (#9) and the Klein Karoo (#1). Pears are grown primarily in Ceres (#3) and the adjacent Wolseley-Tulbagh area (#5), EGVV (#7), Langkloof (#6) and the Klein Karoo (#1 and #2). Smaller production regions are Piketberg (#4), Somerset West (#8) and Riviersonderend (#9).

Stone fruit production (labelled ‘stone’ and ‘mixed’) is concentrated in the warmer and drier parts of the country and the Western Cape - Langkloof (Figure 1). A high proportion (>90%) of the country’s apricots, cling peaches, nectarines and plums are grown in the Western Cape and Langkloof. The specific regions are the Klein Karoo (#1 and #2), Ceres (#3), Piketberg (#4), Wolseley-Tulbagh (#5), Breede Valley (#11), Stellenbosch/Berg River Valley (#10), and the Langkloof Valley (#6). Of the country’s hectares planted to dessert peaches, about 70% are found in the Western Cape (Ceres - #3, Klein Karoo - #1 and #2, Piketberg - #4, Wolseley-Tulbagh - #5 and Stellenbosch-Berg - #10). Important production regions to the north (outside the scope of this guide) include the Northern, North-West, Free State and Mpumalanga Provinces. Cherry plantings have grown strongly over the past decade, and whilst 60% of hectares planted are in the Western Cape (Ceres - #3, Breede Valley - #11), significant plantings are found in the Free State, North-West, Gauteng, Mpumalanga and Northern Provinces.

3. Climate change modelling

Maps included in this Guide have been prepared at a spatial resolution of Quinary Catchments, which are relatively homogeneous agricultural and hydrological spatial units regarding climate, topography and soils. The historical climate of the Western Cape - Langkloof provides the reference, or baseline, against which projected impacts of climate change are evaluated. A comprehensive database (1950-1999) of quality-controlled daily rainfall data was used and linked to the Quinaries database. A 50-year daily rainfall record for each of the Quinaries covering the region was developed. Equally, a 50-year quality-controlled historical time series (1950-1999) was developed of daily maximum and minimum temperatures at a spatial resolution of one arc minute of latitude / longitude (~1.7 x 1.7 km). The resulting 50-year series of daily temperatures for each Quinary was then used to generate daily estimates of solar radiation and vapour pressure deficit. From these, daily values of reference potential evaporation were computed.

Future climate projections (which are NOT forecasts or predictions) are scenario-based descriptions of possible future conditions based on the current understanding of the physics of the atmosphere, on assumptions about changing greenhouse gas emissions and their atmospheric concentrations, as well as on assumptions of future technological, economic and demographic trends. The skill of the projections (i.e. their accuracy) depends strongly on how far into the future projections are made, which of a number of possible future greenhouse gas emissions pathways is considered, and on the climate variable considered (e.g. temperature projections are generally more skilful than rainfall projections). Climate projections presented in this Guide were computed using a set of Global Circulation Models (GCMs) as it is not possible to identify a 'best' model for all relevant climate variables for South Africa. The maps represent the mean or median of the outputs from this range of models.

The first set of GCMs used were derived from global scenarios produced by five IPCC (Intergovernmental Panel on Climate Change) approved GCMs for the Fourth Assessment Report of 2007. They are the so-called 'CMIP3 GCMs'. The five GCMs in this set were statistically downscaled to over 2000 climate stations in South Africa by the Climate Systems Analysis Group of the University of Cape Town. They were then further bias corrected for the topography of the Quinary Catchments. The modelling was conducted using the future scenario 'A2' from the IPCC Special Report on Emission Scenarios. Daily values of rainfall, maximum and minimum temperature, and computed daily values of solar radiation, maximum and minimum relative humidity and reference potential evaporation were generated for (i) 1971-1990 (the present) and (ii) 2046-2065 (the intermediate future).

The second set of ten GCMs used were from the World Climate Research Programme sponsored Coordinated Regional Climate Downscaling Experiment CORDEX, the so-called 'CMIP5 GCMs'. Again, the GCMs were downscaled to the Quinary Catchments and bias corrected for local topography. The modelling was conducted using the 'RCP8.5' scenario, one of the Representative Concentration Pathways of the IPCC Fifth Assessment Report of 2013. Daily values of rainfall, maximum and minimum temperature, and computed daily values of solar radiation, relative humidity and reference potential evaporation were generated for two 30-year periods: (i) 1976-2005 (the historical, or present), and (ii) 2016-2045 (the immediate future). Annual streamflows were simulated with the ACRU model using daily climate inputs from present (mid-1990s) and projected immediate future (mid-2030s) climatic conditions derived from six bias-corrected CMIP5 GCMs used in a current (as yet unpublished) Water Research Commission Project at the Centre for Water Resources Research at the University of KwaZulu-Natal.

A new set of GCMs (CMIP6) is now becoming available. Over the last two decades of model development, there has been very little change in the projections for temperature and temperature-derived variables. We thus have high confidence that the GCMs used in this study provide a reliable picture of the future that will not be altered substantially as the new GCMs begin to be used. However, for the following reasons, projections for rainfall and rainfall-derived variables remain challenging:

- First, rainfall is a derived rather than a direct output from GCMs.

- Second, complex rainfall-generating processes such as cloud formation and land surface-atmosphere interactions are not yet fully understood and resolved in climate models.
- Third, rainfall is an event based variable, and not continuous, as is temperature.

As the model developers address the weaknesses and inconsistencies in the older GCMs, the new set of GCMs can alter the picture somewhat. We have therefore decided to place annual streamflow results in an Appendix. The user is advised to be cautious when engaging with the results. We have included the results for projected annual number of dry and wet spells in the main body of the document since the science shows better agreement around increasing variability of rainfall.

For further information on methods used in this study, the uncertainties inherent in the climate change modelling outputs, and caution required when interpreting the outputs, please refer to Part 1 of the Scientific and Practical Guide to Climate Change and Pome/Stone Fruit Production in South Africa.

Local climate is a vital criterium for the selection of appropriate fruit types and cultivars for a given locality. The more detailed the knowledge, the more intelligently the land use can be planned at the farm or orchard scale. Subtle microclimatic differences on farms result from differences in elevation and aspect, and the influence of water bodies and mountains. Together with different soil types, these are used to good effect by growers when making crop and cultivar planting decisions and can provide opportunities for adapting to climate change. However, such micro scale variables are beyond the scope of this Guide. Interested readers are referred to the TerraClim tool[1].

Readers may question why agriculturally significant climatic variables such as hail, frost and strong winds are not covered in this document. Frost occurrence has been modelled for the whole Western Cape - Langkloof region and the results are presented in Part 1 of this Guide. For hail and wind, the reason for the omission is that current GCMs remain weak at modelling these variables in space and time, and the climate database for these variables is weak. Climate models are not yet sophisticated enough to model historical and future patterns of intense localized events such as hail and storms. Nevertheless, modelling conducted at national level has come to the following conclusions (DEA, 2018): “The increasing effect of the sub-tropical high-pressure systems combined with more intense inland heating will result in stronger summer south-easterly winds. Higher wind speeds combined with higher temperatures will strongly influence evaporation and evapotranspiration either resulting in drier soils and crops or increasing demand for irrigation, particularly of summer crops.” And: “Added to these summer stresses, winter storm intensity begins to increase resulting in more frequent heavy rainfall events in winter which produce flooding and related damage.”

In the following sections, key results are presented in high resolution for the pome and stone fruit regions shown in Figure 1.

[1] https://terraclim.co.za

4. Mean annual temperature

Mean annual temperature (*MAT,* in °C) represents the very broadest of indices of the environmental status of a location, and while in itself not a particularly useful statistic because it has integrated and smoothed the effects of diurnal, monthly and seasonal patterns of maximum and minimum temperatures, it is nevertheless a commonly requested statistic which is used as a general first guide to determine the suitability of a location for specific crops.

Figure 2 presents the results for the eleven pome and stone fruit regions. Under historical climatic conditions (left column), *MAT* in these regions is in the range 11-18°C. The coolest regions (11-14°C) are the Klondyke (east of Ceres), Koue Bokkeveld and Langkloof (west). Other relatively cool regions (14-16°C) include Elgin/Grabouw/Vyeboom/Elandskloof, Warm Bokkeveld, Wolseley and Koo (west of Montagu). All these regions are currently well suited to pome fruit production. The more marginal pome (mainly pear) regions have *MAT* of 16-18°C (Riviersonderend, Piketberg, Tulbagh, Langkloof east, Klein Karoo). The core stone fruit production regions generally have a *MAT* of 16-18°C and occasionally higher than 18°C e.g. Wellington.

Climate model projections for the intermediate future (mid-century) display marked increases in *MAT* (middle column). The changes from historical to intermediate future (Figure 2, right column) are of the order 2.05-2.40°C. Higher levels of warming are projected for the high-lying interior production regions e.g. Koue Bokkeveld, and for the western Langkloof and Calitzdorp regions. The EGVV region shows warming in the lower part of this range, seemingly buffered to some extent by the oceanic influence.

Annual temperatures are the integrator of both diurnal and seasonal temperature differences and serve as a very broad indicator of agricultural potential and crop suitability. It stands to reason that the anticipated increase in *MAT* becomes a major concern for pome and stone fruit growers. It will likely lead to spatial shifts in production areas and shifts in the fruit types and cultivars that are suited to specific regions. In broad terms, such shifts could see the warmer parts of EGVV and Piketberg becoming unsuited to pome fruit production, and core cooler apple regions becoming like present day core pear regions. Pear production in the Klein Karoo is likely to become more marginal, if not unsuited.

Stone fruit production should not become limited by *MAT* in the north-western high-lying regions or the Stellenbosch-southern Berg region, but could become marginal in the warmest parts of the Klein Karoo production regions, the northern Berg and parts of the Breede River valleys.

SOUTH-WESTERN COASTAL REGION (POME):

- **Historical MAT:**
  14-15°C: Grabouw
  15-16°C: Elgin, Vyeboom, Elandskloof, Somerset West
  16-17°C: Villiersdorp, Riviersonderend
  17-18°C: Greyton

- **Change in MAT:**
  2.05-2.20°C

NORTH-WESTERN HIGH-LYING REGION (POME AND STONE):

- **Historical MAT:**
  11-13°C: Klondyke, Lower Koue Bokkeveld
  13-14°C: Upper Koue Bokkeveld, Witzenberg
  14-15°C: Parts of Warm Bokkeveld
  15-16°C: Ceres, Prince Alfred Hamlet, Wolseley
  16-17°C: Piketberg
  17-18°C: Tulbagh

- **Change in MAT:**
  2.20-2.40°C (with higher values in Upper Koue Bokkeveld)

EASTERN INTERIOR REGION (POME AND STONE):

- **Historical MAT:**
  13-15°C: Langkloof (west), Koo
  15-16°C: Langkloof (central)
  16-17°C: Langkloof (east), Klein Karoo East (west) and Zoar, Barrydale
  17-18°C: Ladismith, Calitzdorp, Montagu-Poortjieskloof

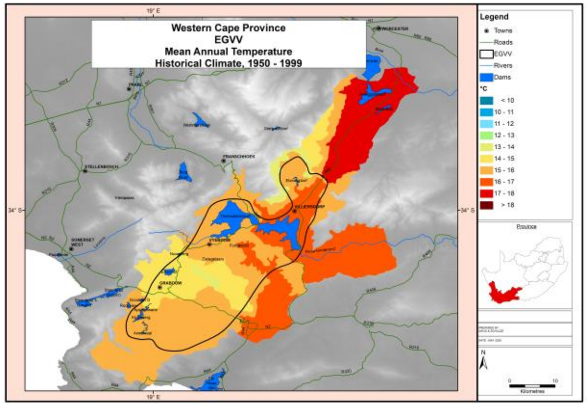
- **Change in MAT:**
  2.15-2.35°C with higher values in Langkloof (west) and Calitzdorp

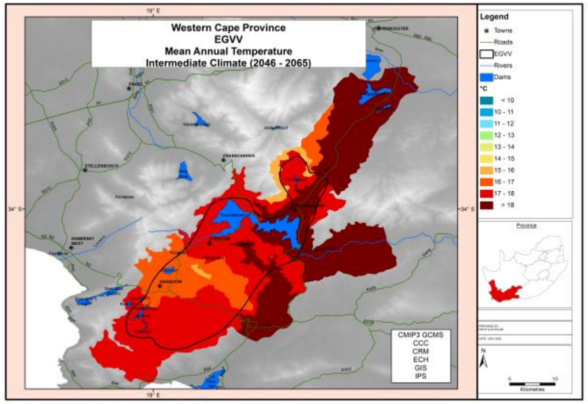
SOUTH-WESTERN RIVER VALLEYS REGION (STONE):

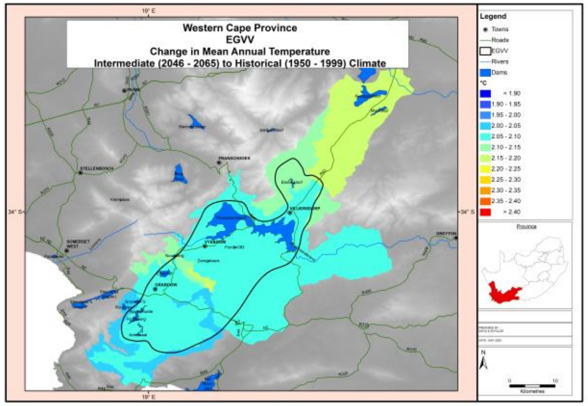
- **Historical MAT:**
  16-17°C: Franschhoek, Stellenbosch, Nuy, McGregor
  17-18°C: Simondium, Paarl, Riebeeck Kasteel, Worcester, Robertson, Bonnievale
  > 18°C: Wellington

- **Change in MAT:**
  2.10-2.30°C (with high values in Riebeeck Kasteel)

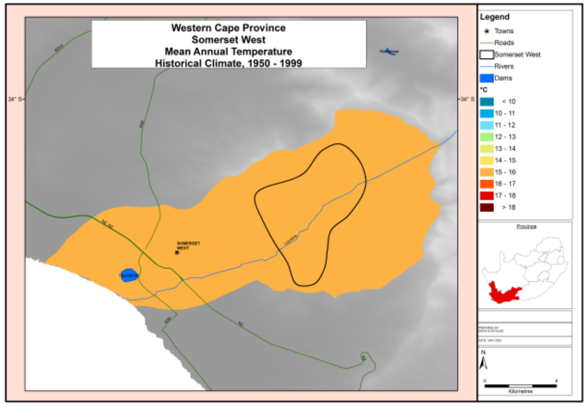
MEAN ANNUAL TEMPERATURE: EGVV

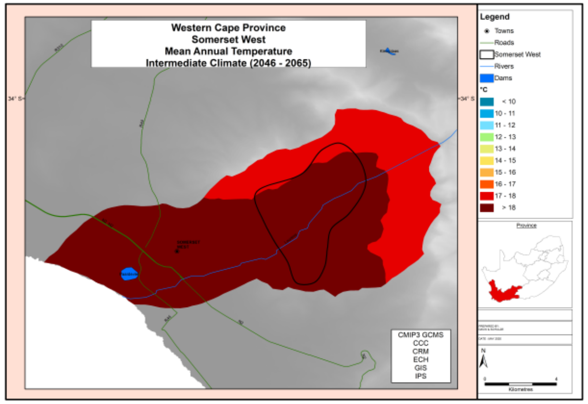


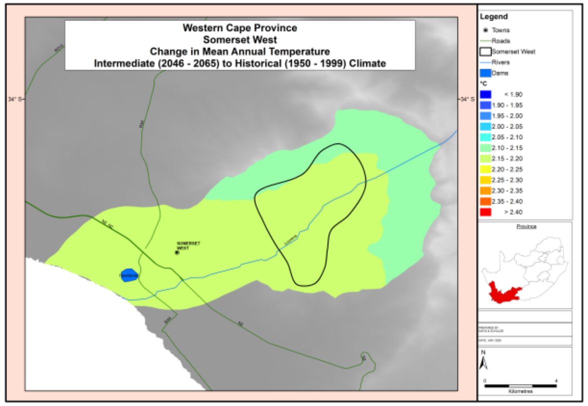




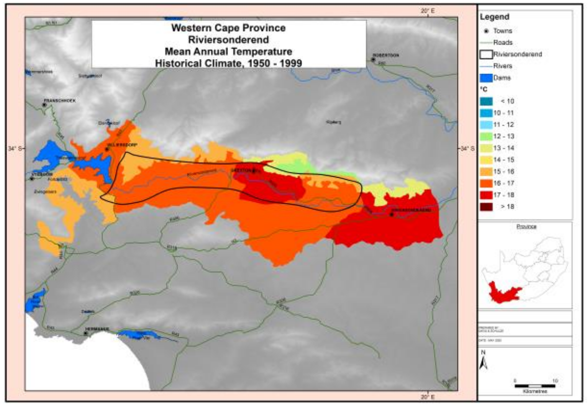
MEAN ANNUAL TEMPERATURE: SOMERSET WEST

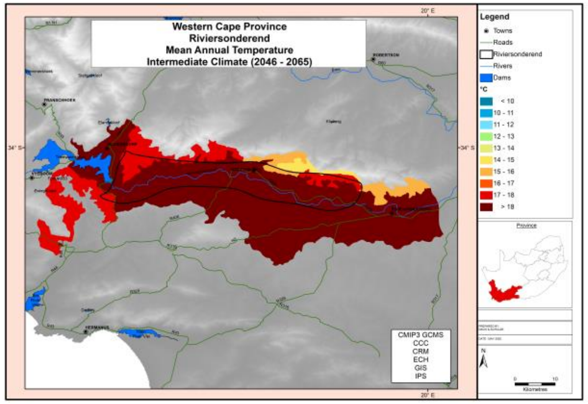


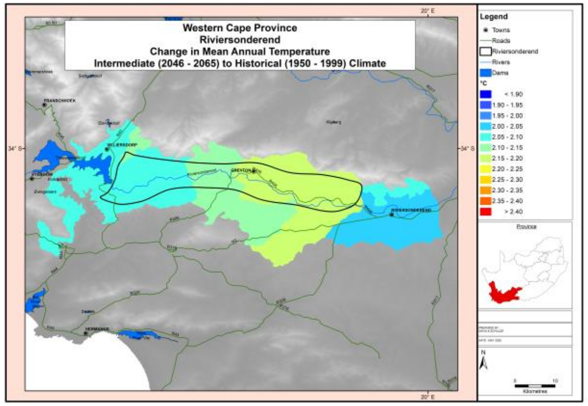




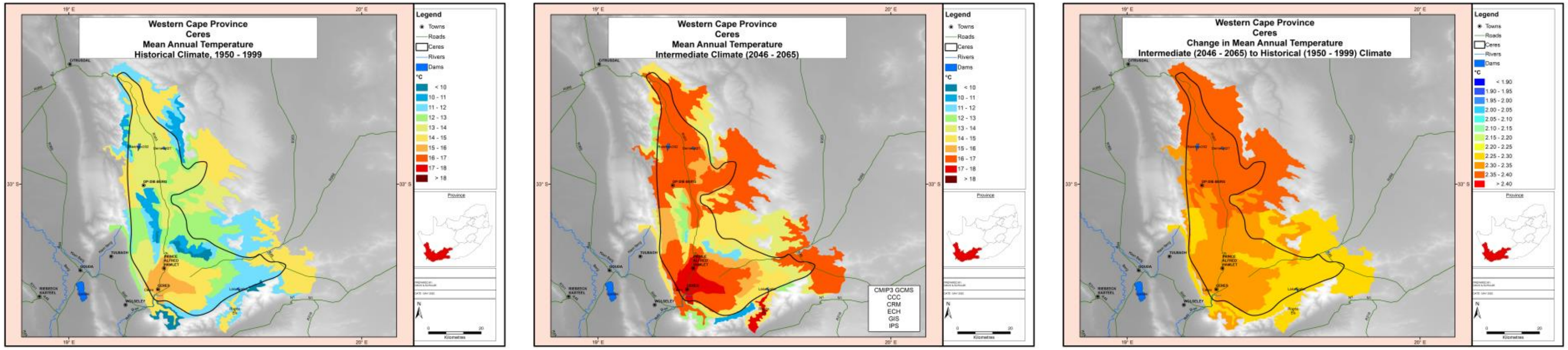
MEAN ANNUAL TEMPERATURE: RIVIERSONDEREND



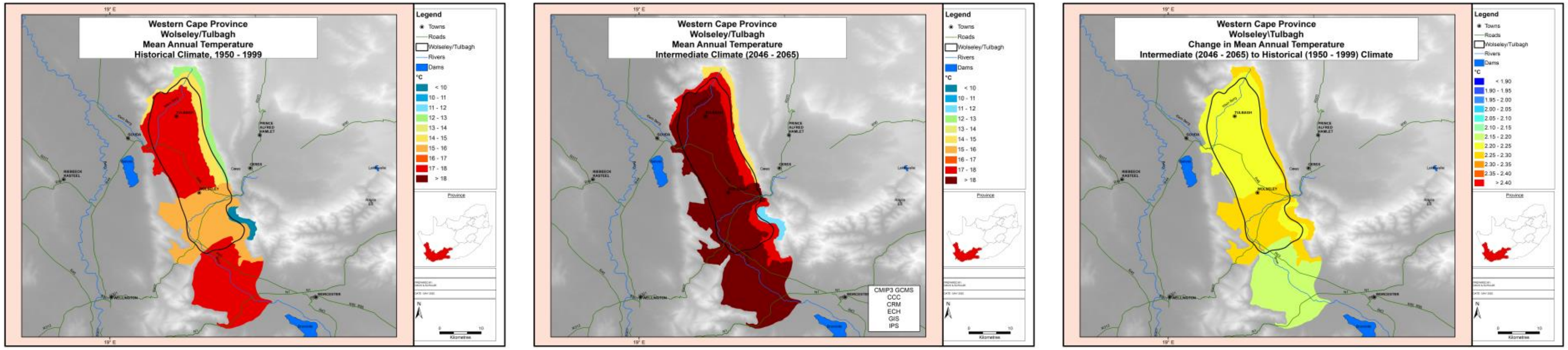




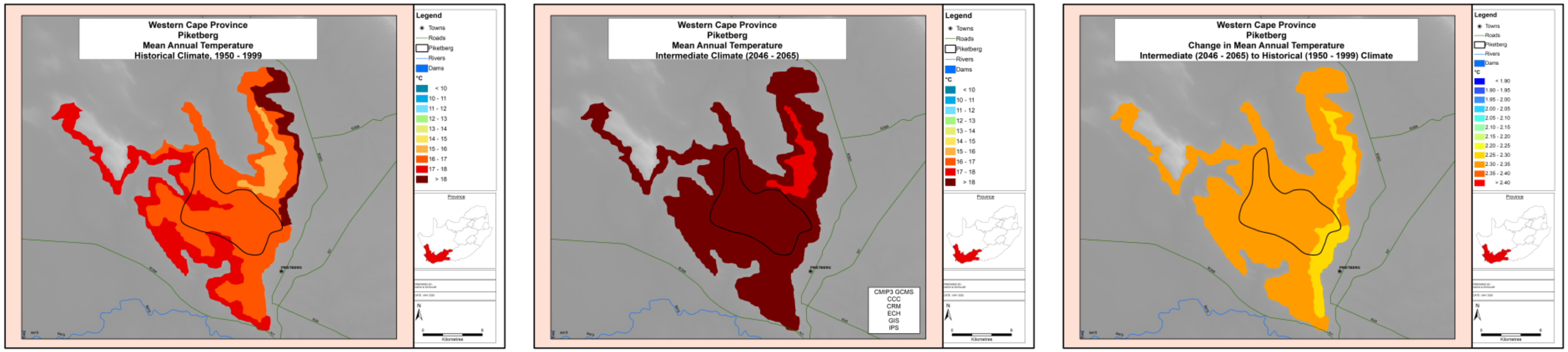
MEAN ANNUAL TEMPERATURE: CERES



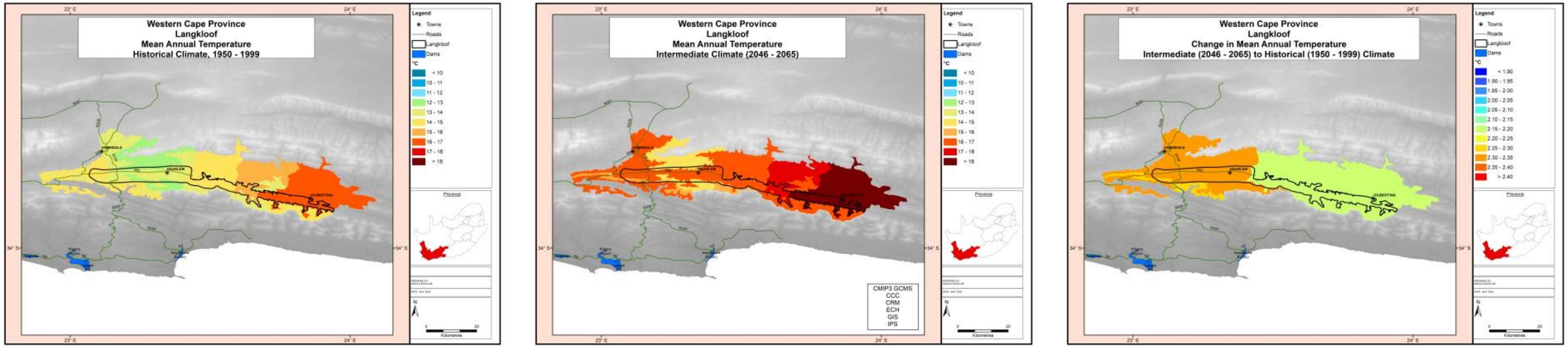
MEAN ANNUAL TEMPERATURE: WOLSELEY-TULBAGH



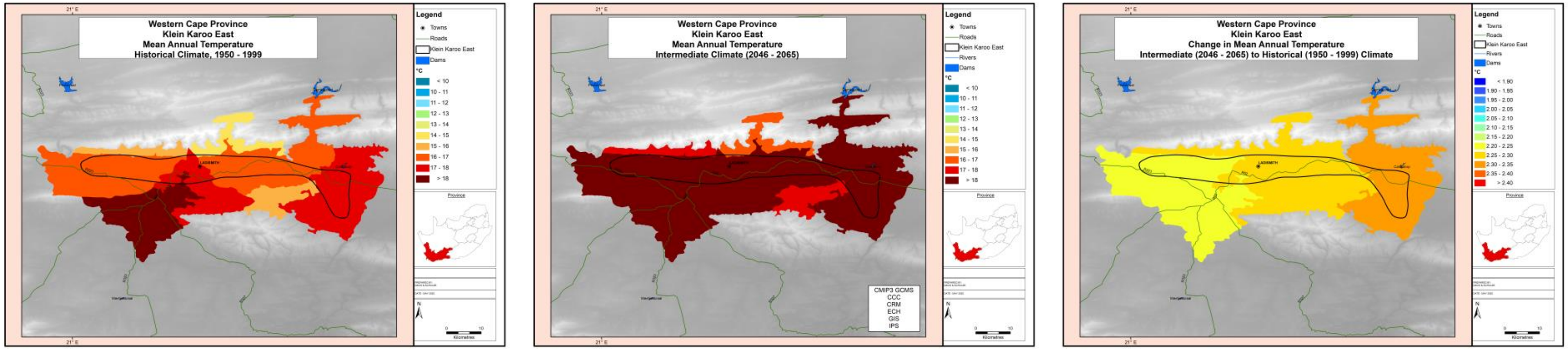
MEAN ANNUAL TEMPERATURE: PIKETBERG



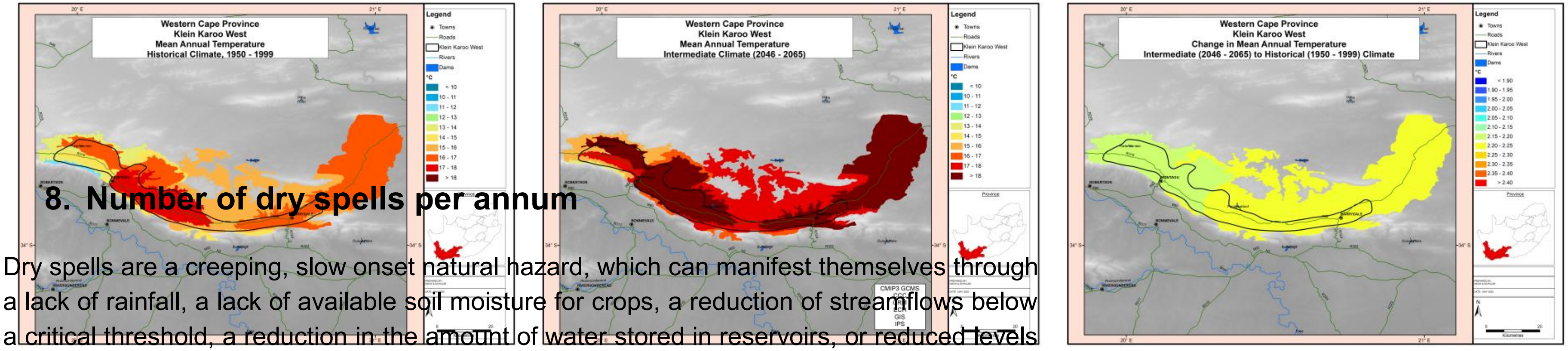
MEAN ANNUAL TEMPERATURE: LANGKLOOF



MEAN ANNUAL TEMPERATURE: KLEIN KAROO EAST



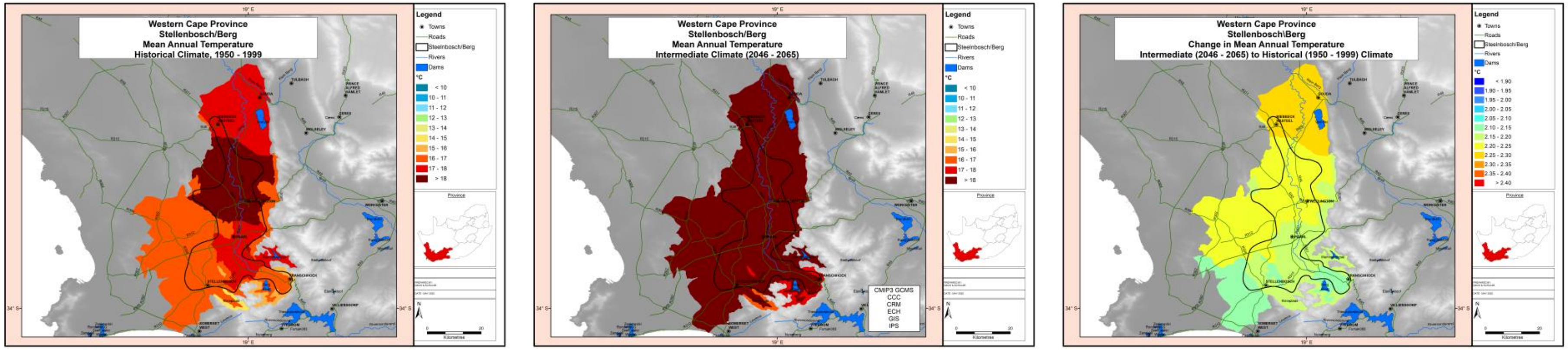
MEAN ANNUAL TEMPERATURE: KLEIN KAROO WEST



8. Number of dry spells per annum

Dry spells are a creeping, slow onset natural hazard, which can manifest themselves through a lack of rainfall, a lack of available soil moisture for crops, a reduction of streamflows below a critical threshold, a reduction in the amount of water stored in reservoirs, or reduced levels of groundwater. However, unlike aridity, which is a permanent feature of the climate in low rainfall areas, dry spells are a temporary aberration that can occur in low as well as high rainfall areas. In this section, the definition of a dry spell was a period of two consecutive months of below normal rainfall (a mild dry spell). Neither the severity nor the seasonality of the dry spells was considered, only the frequency per annum.

MEAN ANNUAL TEMPERATURE: STELLENBOSCH-BERG



MEAN ANNUAL TEMPERATURE: BREEDE

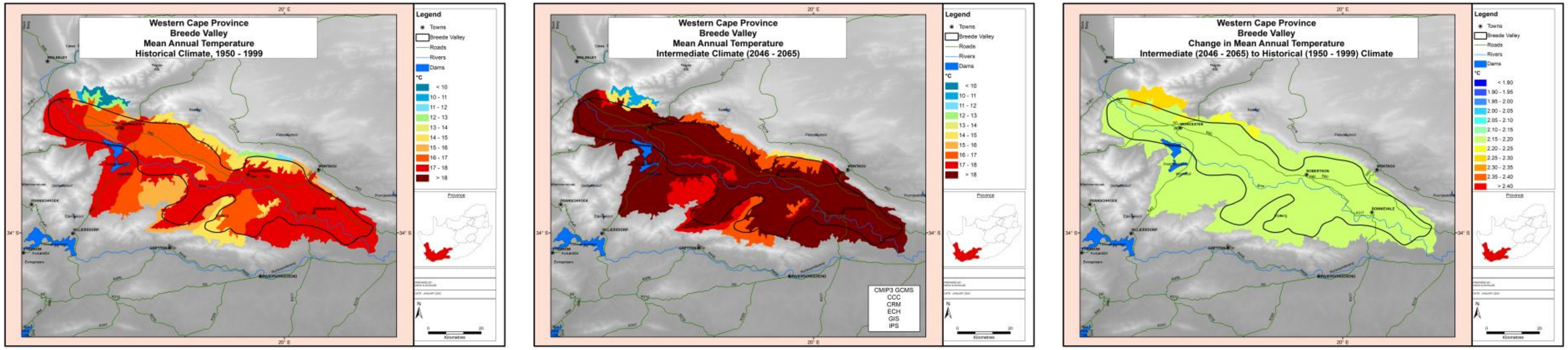


Figure 2. Mean annual temperatures (°C) under historical climatic conditions (left column), under projected climatic conditions for the intermediate future (middle column) and projected changes (in °C) from the historical climatic conditions to the intermediate future (right column) of mean annual temperatures, for each of the eleven pome and stone fruit production regions. The intermediate future maps are derived from multiple CMIP3 GCMs.

5. Mean maximum air temperature in January

During the fruit growth period, rates of physiological and growth processes generally show positive responses as temperature increases up to an optimum temperature which is often in the region of 28-30°C. As daytime temperature continues to rise, the rate of these processes begins to decrease, and this is frequently measurable above 35°C. Above 40°C, rapid decreases occur and at 45°C these processes come to a halt and damage (e.g. bleaching, sunburn) can start to occur in exposed tissues. Increasing heat, especially when experienced over several days to weeks, alters the balance between carbon gain (photosynthesis in leaves) and carbon loss (respiration in all cells, which is very sensitive to temperature increase) and thus lowers the carbon balance of the whole tree and its productive capacity. Hot mid-summer periods also increase the likelihood of sunburn and poor red colour development in susceptible cultivars.

Figure 3 presents the results for January means of daily maximum temperatures for the eleven pome and stone fruit regions. Under historical climatic conditions (left column), values vary widely in the range 22-32°C. Lower values (22-26°C) are a feature of the south-western coastal region (Elgin/Grabouw/Elandskloof), the lower Koue Bokkeveld/Witzenberg and other cooler parts of the Ceres region, and Langkloof (west and central). The higher values (28-32°C) are found in parts of Riviersonderend, around the towns of Ceres, Prince Alfred Hamlet, Wolseley, Tulbagh and the Piketberg production region, the Klein Karoo production regions (with the exception of Koo which is cooler), and the whole south-western river valleys production region (with the exception of Franschhoek which is cooler).

With projected climate change in the intermediate future (mid-century, middle column), January means of daily maximum temperature increase in the range 2.0-2.4°C (and occasionally >2.4 in the Klein Karoo) (right column). The lower end of this range (<2.1°C) is seen in EGVV production regions (Grabouw/Vyeboom), the Koo/Montagu (Klein Karoo West) and Ashton/Bonnievale (Breede Valley) regions, and Franschhoek (Berg). These regions are characterized by proximity to high mountains. Greater increases (2.25-2.4°C) are projected for the whole north-western high-lying region, whole Langkloof, most of the Klein Karoo, and the northern-most Berg production region.

The projected changes in summer mean monthly maxima will affect the pome and stone fruit sector throughout the region. However, parts of the region e.g. northern Berg River valley, Wolseley-Tulbagh and Klein Karoo, will likely experience the “double whammy” in already being hot and then having the highest projected increases in temperatures in mid-summer. Impacts will be wide-ranging, from sunburn risk to increased irrigation water demand resulting from high evapotranspiration rates.

SOUTH-WESTERN COASTAL REGION (POME):

- **Historical Jan T_{max}:**
  24-26°C: Elgin, Grabouw, Elandskloof
  26-28°C: Vyeboom, Villiersdorp, Somerset West, Riviersonderend (west)
  28-30°C: Riviersonderend (east)

- **Change in Jan T_{max}:**
  2.00-2.20°C

NORTH-WESTERN HIGH-LYING REGION (POME AND STONE):

- **Historical Jan T_{max}:**
  22-24°C: Klondyke, Lower Koue Bokkeveld
  24-26°C: Witzenberg, parts of Warm Bokkeveld
  26-28°C: Upper Koue Bokkeveld, parts of Warm Bokkeveld
  28-30°C: Ceres, Prince Alfred Hamlet, Wolseley, Piketberg
  30-32°C: Tulbagh

- **Change in Jan T_{max}:**
  2.25 - >2.40°C (higher values in Upper Koue Bokkeveld)

EASTERN INTERIOR REGION (POME AND STONE):

- **Historical Jan T_{max}:**
  24-26°C: Langkloof (west and central)
  26-28°C: Langkloof (east), Koo
  28-30°C: Klein Karoo East, Poortjieskloof, Barrydale
  30-32°C: Ladismith, Calitzdorp, Montagu

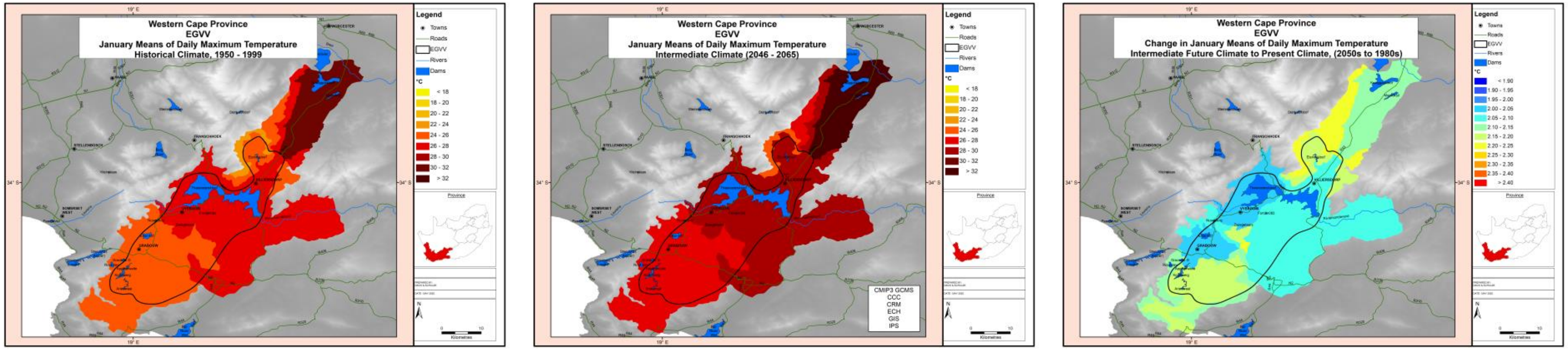
- **Change in Jan T_{max}:**
  2.05 - >2.40°C (higher values in Langkloof and parts of Klein Karoo)

SOUTH-WESTERN RIVER VALLEYS REGION (STONE):

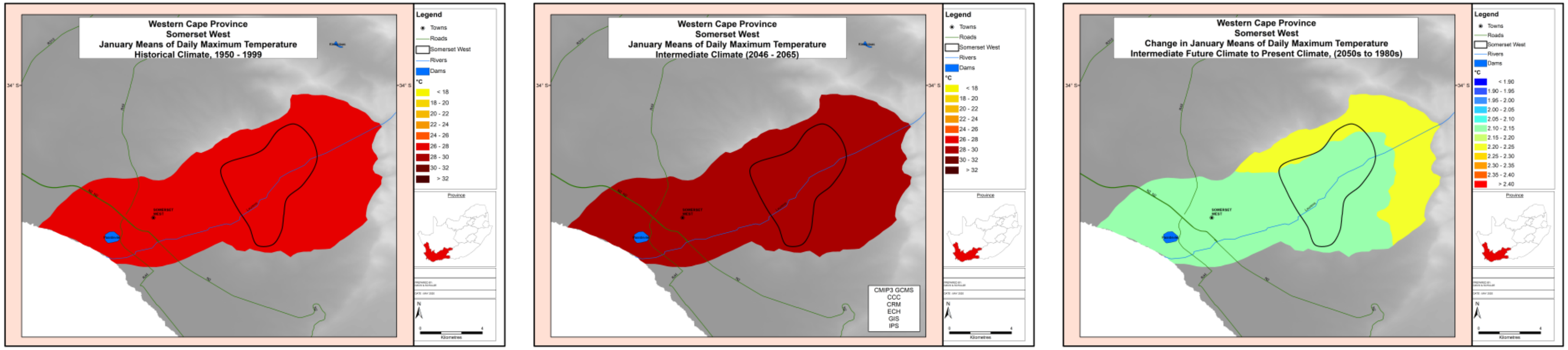
- **Historical Jan T_{max}:**
  26-28°C: Franschhoek
  28-30°C: Stellenbosch, Paarl, Riebeeck Kasteel, Slanghoek, Nuy, Bonnievale, McGregor
  30-32°C: Wellington, Worcester, Berg River valley downstream of Brandvlei Dam, Robertson, Ashton

- **Change in Jan T_{max}:**
  2.05-2.35°C

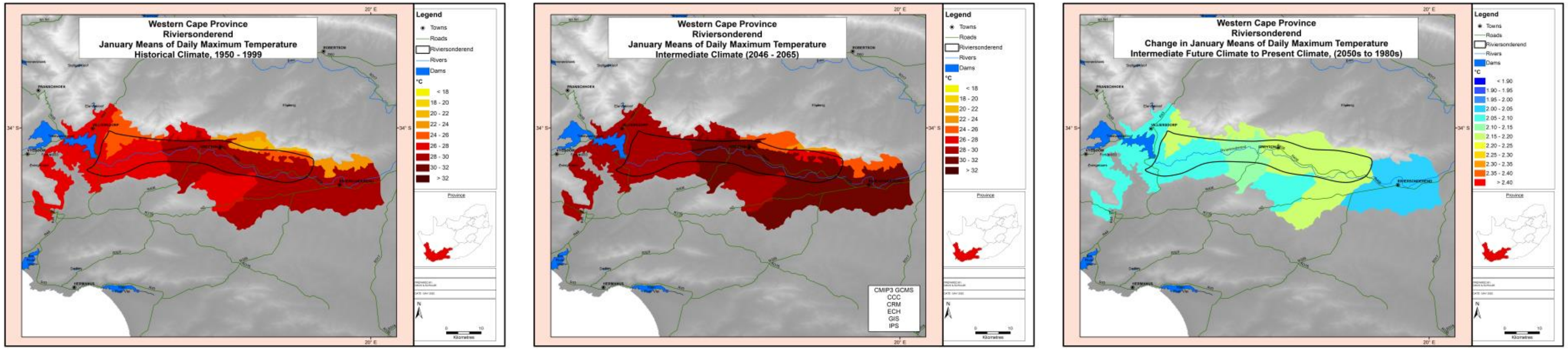
JANUARY MEANS OF DAILY MAXIMUM TEMPERATURE: EGVV



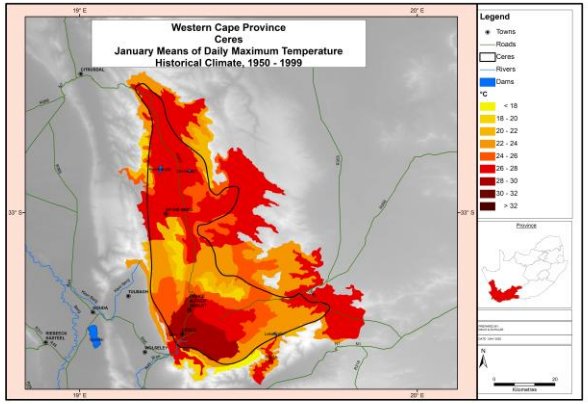
JANUARY MEANS OF DAILY MAXIMUM TEMPERATURE: SOMERSET WEST

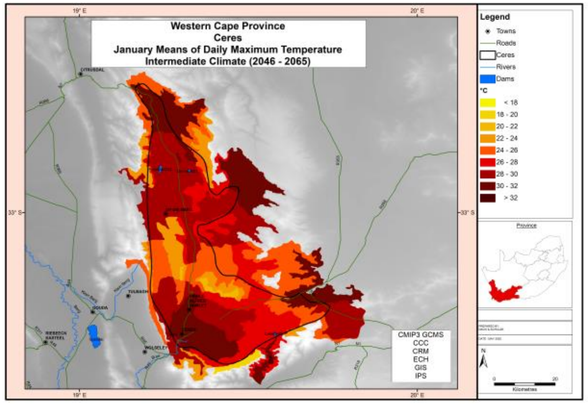


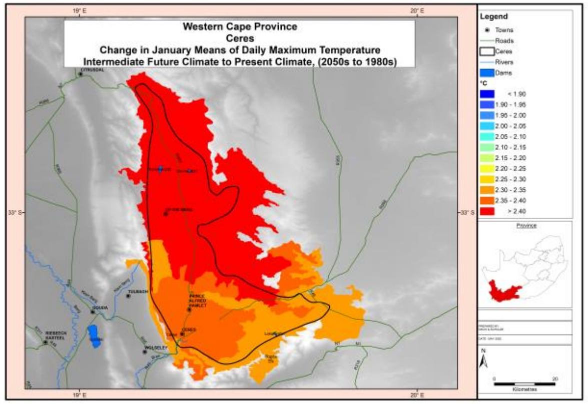
JANUARY MEANS OF DAILY MAXIMUM TEMPERATURE: RIVIERSONDEREND



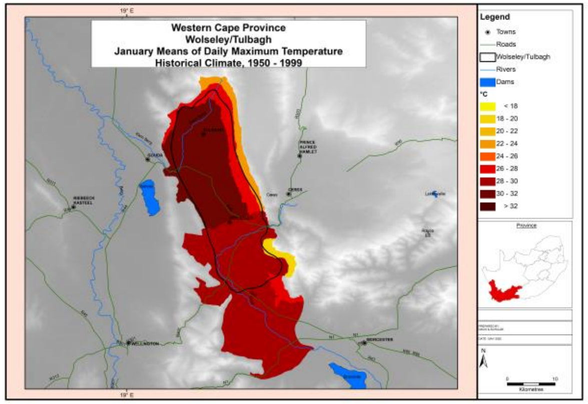
JANUARY MEANS OF DAILY MAXIMUM TEMPERATURE: CERES

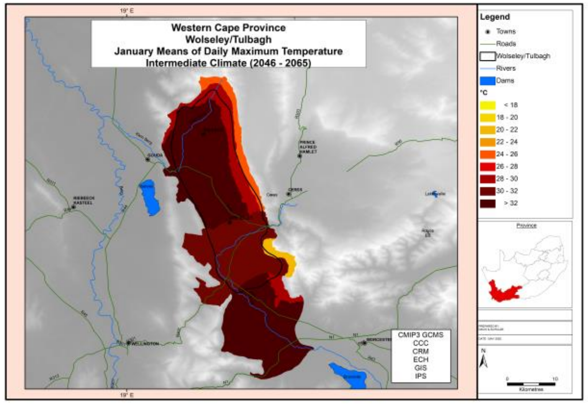


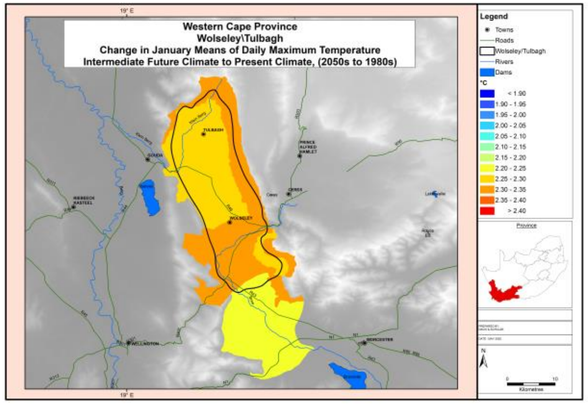




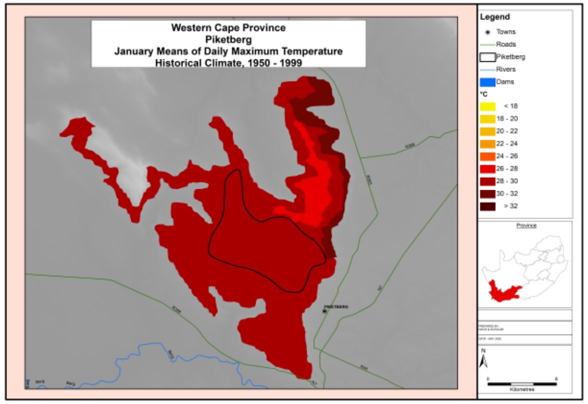
JANUARY MEANS OF DAILY MAXIMUM TEMPERATURE: WOLSELEY-TULBAGH

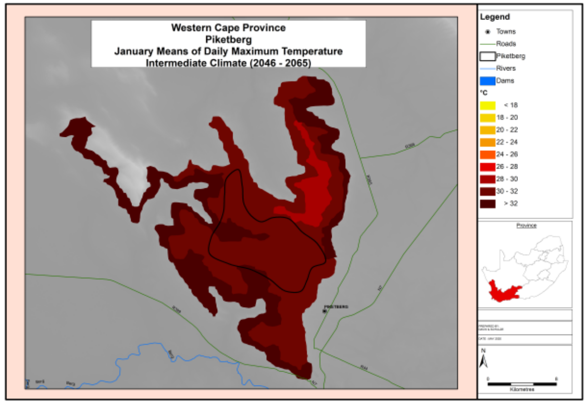


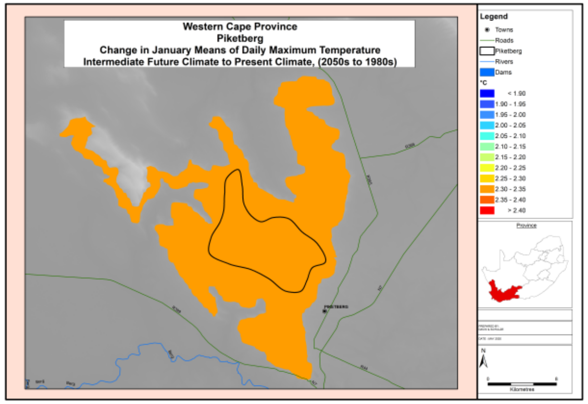




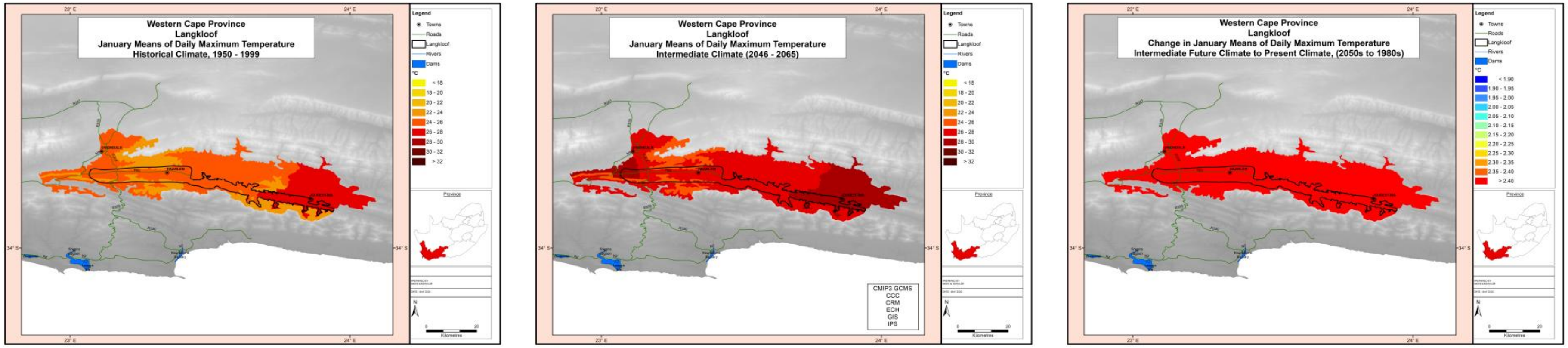
JANUARY MEANS OF DAILY MAXIMUM TEMPERATURE: PIKETBERG



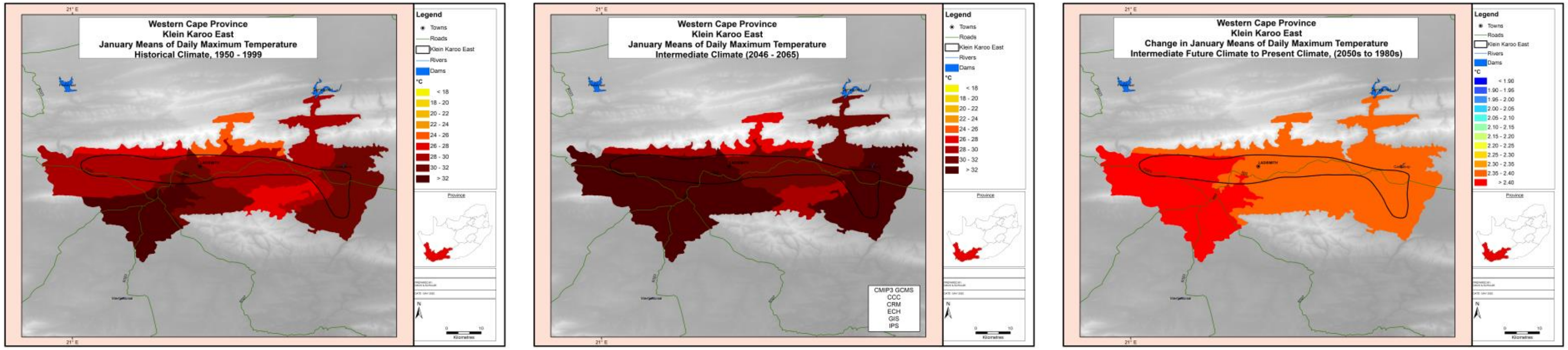




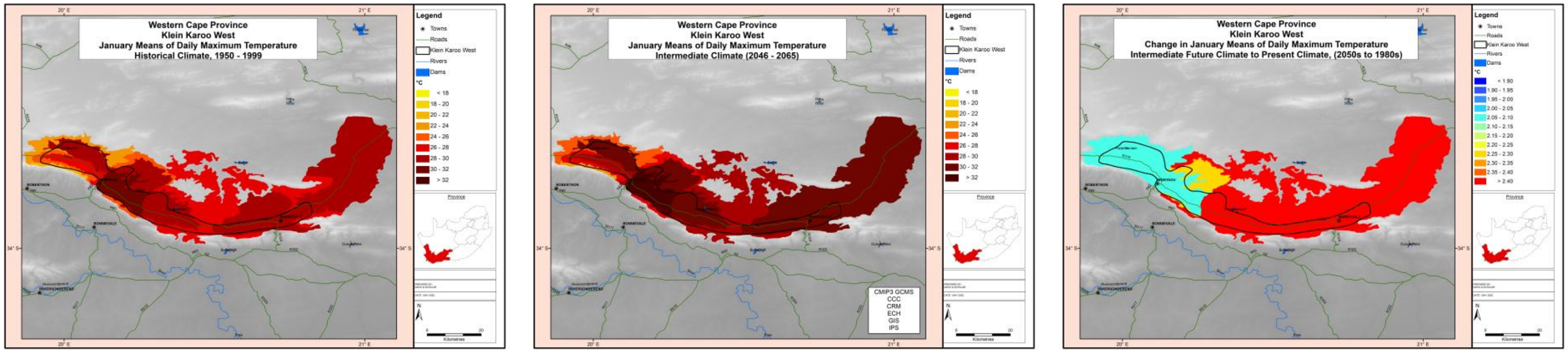
JANUARY MEANS OF DAILY MAXIMUM TEMPERATURE: LANGKLOOF



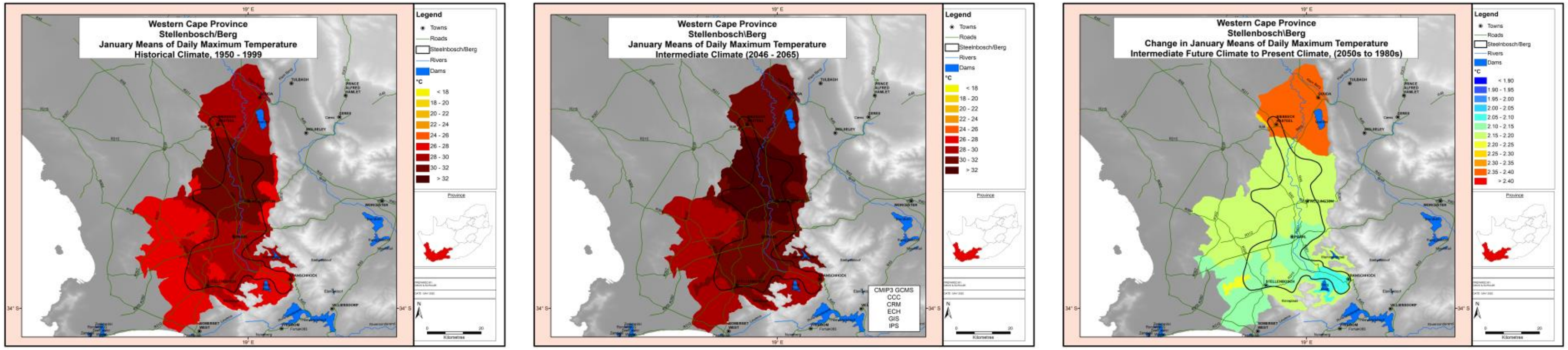
JANUARY MEANS OF DAILY MAXIMUM TEMPERATURE: KLEIN KAROO EAST



JANUARY MEANS OF DAILY MAXIMUM TEMPERATURE: KLEIN KAROO WEST



JANUARY MEANS OF DAILY MAXIMUM TEMPERATURE: STELLENBOSCH-BERG



JANUARY MEANS OF DAILY MAXIMUM TEMPERATURE: BREEDE

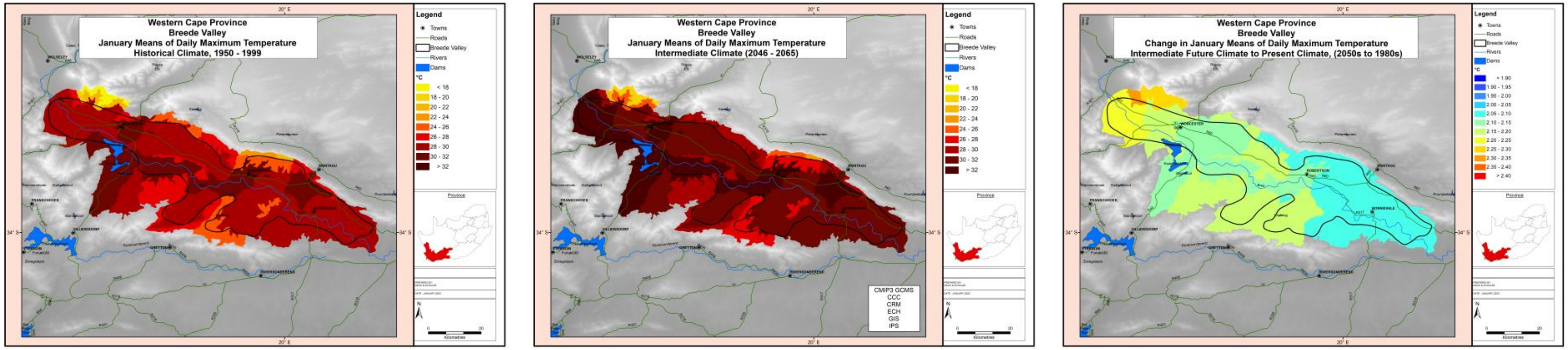


Figure 3. January means of daily maximum temperatures (°C) under historical climatic conditions (left column), under projected climatic conditions for the intermediate future (middle column), and projected changes (in °C) from the present climatic conditions to the intermediate future (right column) of January means of daily maximum temperatures, for each of the eleven pome and stone fruit production regions. The intermediate future maps are derived from multiple CMIP3 GCMs.

6. Mean minimum air temperature in July

Both low and high night-time minimum temperatures in winter can limit fruit crop productive potential. Since deciduous fruit trees experience a period of dormancy in winter, they are in this phase well protected from chilling injury even at very low temperatures. However, this is only true for the endo-dormancy phase and before the buds start to become active at the end of winter. In South Africa, pome fruit generally start to flower towards the end of September, while some stone fruit cultivars already start to flower in July. Extended cold weather in this sensitive reproductive period can be detrimental to fruit set and yield, especially where this comes with the risk of frost. An extended period of very warm winter nights, on the other hand, can interfere with the normal accumulation of chill units and result in trees not reaching the dormant state before spring, as well as triggering early flowering. Once trees become physiologically active (as for some early apricot and peach cultivars in July already), hot nights can accelerate and potentially damage processes occurring during pollination and can lead to low fruit set. High night-time temperatures will also increase respiration rates of emerging leaves and small fruit and create a carbon deficit in this early growth stage.

Figure 4 presents the results for July means of daily minimum temperatures for the eleven pome and stone fruit regions. Historically, the range of values is 2-7°C and occasionally >7°C (left column). The whole Bokkeveld region and western Langkloof show values of 2-4°C. Warmer night-time July temperatures (>6°C) are experienced in some parts of the south-western coastal region, Tulbagh, Piketberg, Ladismith, Poortjieskloof (east of Montagu), the central and eastern Langkloof, the whole Stellenbosch-Berg region (except Franschhoek which is colder), and the Upper Breede valley (Slanghoek/Worcester).

Projected July means of daily minimum temperature by mid-century (middle column) increase by less than 2.05°C in all the regions except the western Langkloof (increase up to 2.1°C) and Klein Karoo West (increase up to 2.2°C) (right column). Overall, the climate modelling conducted for this study indicates lower, more benign, mid-winter minimum temperature increases than the projected increases of mid-summer maxima.

The increase in winter mean monthly minima holds both positives and negatives. Less frost damage could be one outcome. However, dormancy could be disrupted, with trees beginning to flower earlier, which may even increase the risk of frost during the early season. Insufficient accumulated chilling would have significant impacts on pome (and some stone) fruit production in already warmer production regions. Many pests and diseases would be able to over-winter in the warmer conditions, thus changing the timing and severity of early season impacts on orchards.

SOUTH-WESTERN COASTAL REGION (POME):

- **Historical Jul T_{min}:**
  4-5°C: Grabouw
  5-6°C: Elgin, Vyeboom
  6-7°C: Elandskloof, Somerset West, Riviersonderend
  >7°C: Villiersdorp

- **Change in Jul T_{min}:**
  <2.05°C

NORTH-WESTERN HIGH-LYING REGION (POME AND STONE):

- **Historical Jul T_{min}:**
  2-3°C: Klondyke, Lower Koue Bokkeveld, Op-die-Berg
  3-4°C: Upper Koue Bokkeveld, Witzenberg, Warm Bokkeveld, Prince Alfred Hamlet, Ceres
  4-5°C: Wolseley
  6-7°C: Tulbagh, Piketberg

- **Change in Jul T_{min}:**
  1.90-2.05°C

EASTERN INTERIOR REGION (POME AND STONE):

- **Historical Jul T_{min}:**
  3-4°C: Langkloof (west)
  4-5°C: Calitzdorp, Koo, Barrydale
  5-6°C: Langkloof (central), Klein Karoo East (west) and Zoar, Montagu
  6-7°C: Langkloof (east), Ladismith, Poortjieskloof

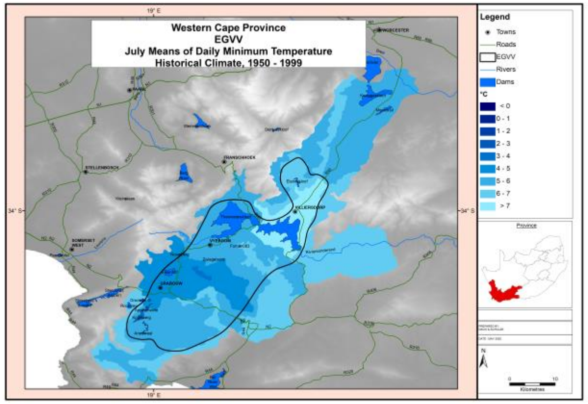
- **Change in Jul T_{min}:**
  1.90-2.20°C

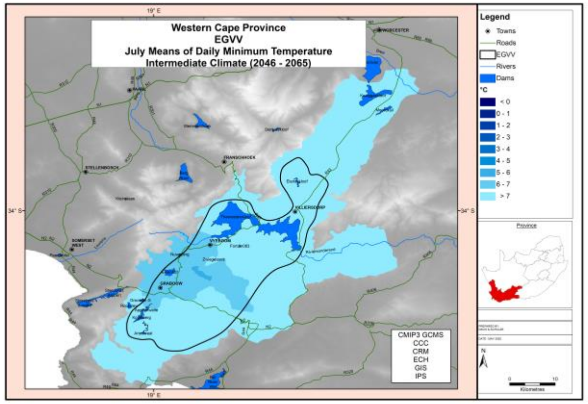
SOUTH-WESTERN RIVER VALLEYS REGION (STONE):

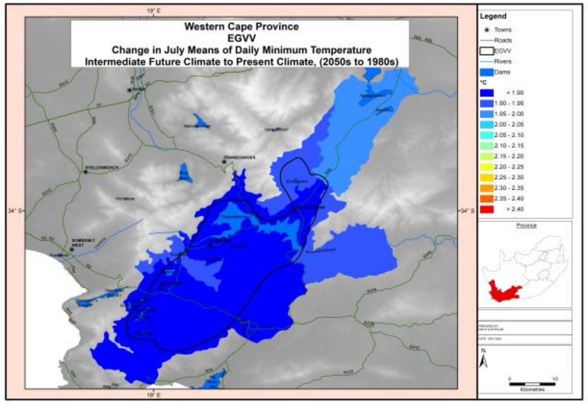
- **Historical Jul T_{min}:**
  4-5°C: Ashton, McGregor
  5-6°C: Franschhoek, Nuy, Robertson, Bonnievale
  6-7°C: Stellenbosch, Paarl, Wellington, Slanghoek, Worcester
  >7°C: Riebeeck Kasteel

- **Change in Jul T_{min}:**
  1.90-2.05°C

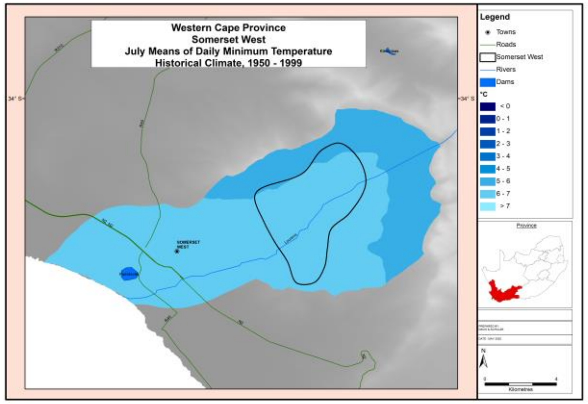
JULY MEANS OF DAILY MINIMUM TEMPERATURE: EGVV

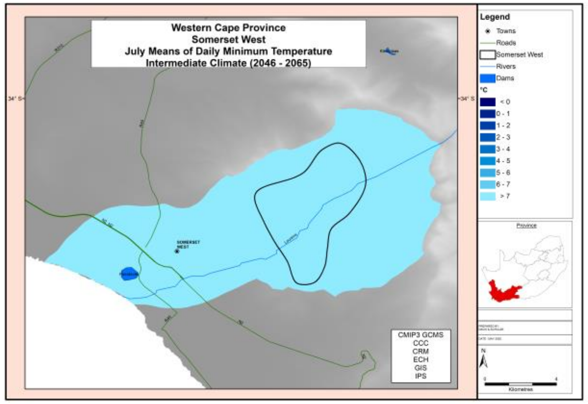


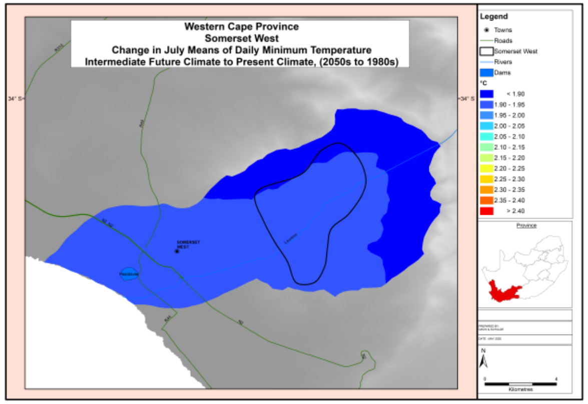




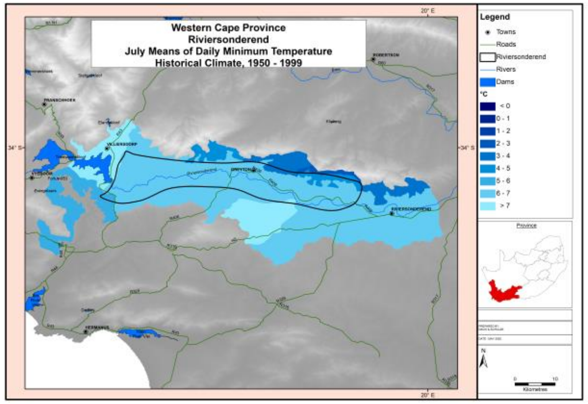
JULY MEANS OF DAILY MINIMUM TEMPERATURE: SOMERSET WEST

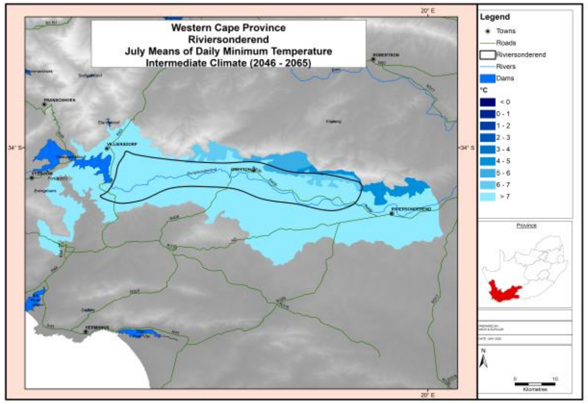


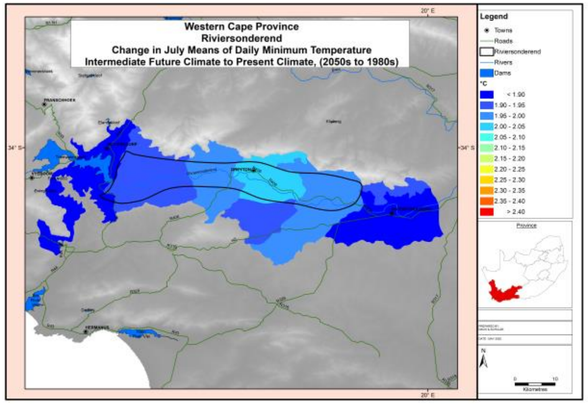




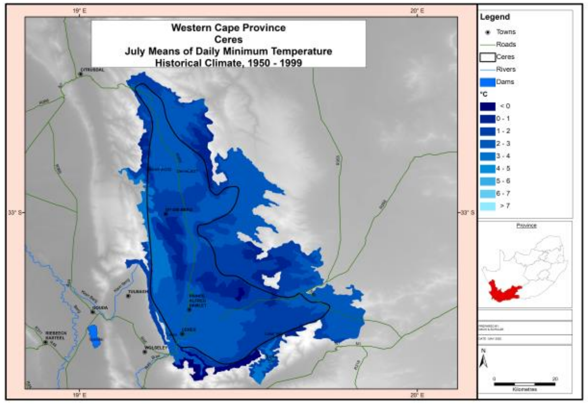
JULY MEANS OF DAILY MINIMUM TEMPERATURE: RIVIERSONDEREND

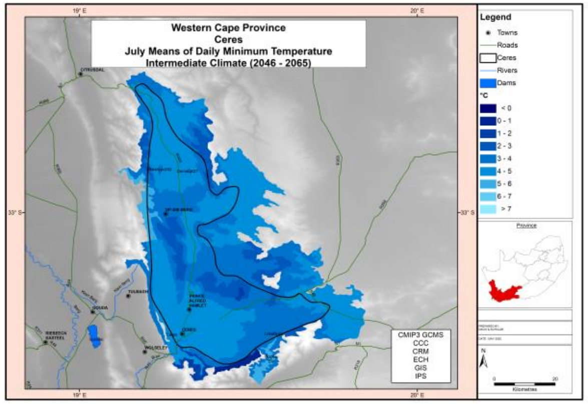


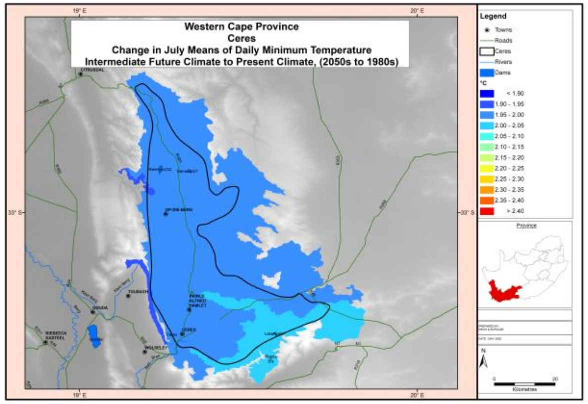




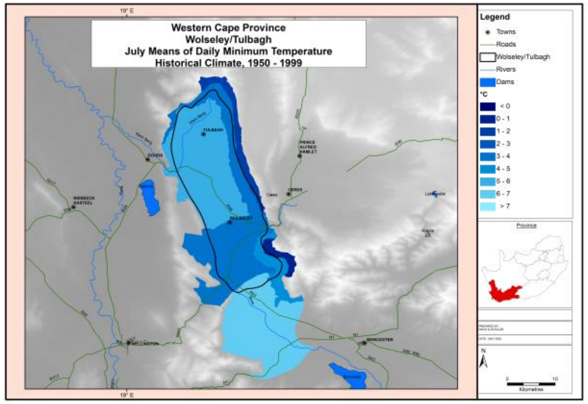
JULY MEANS OF DAILY MINIMUM TEMPERATURE: CERES

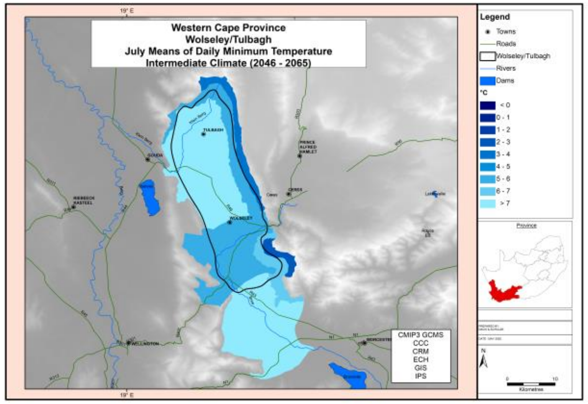


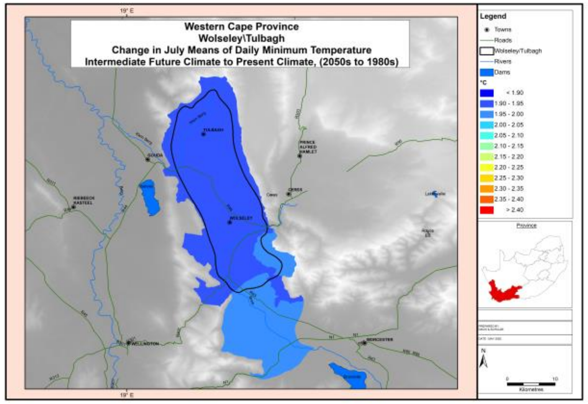




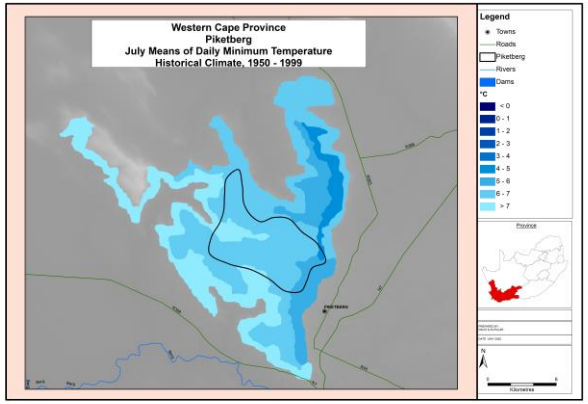
JULY MEANS OF DAILY MINIMUM TEMPERATURE: WOLSELEY-TULBAGH

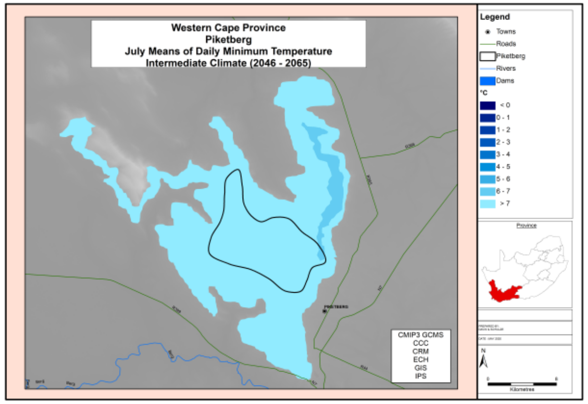


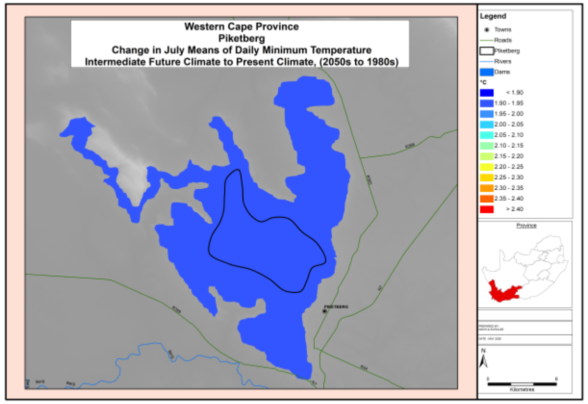




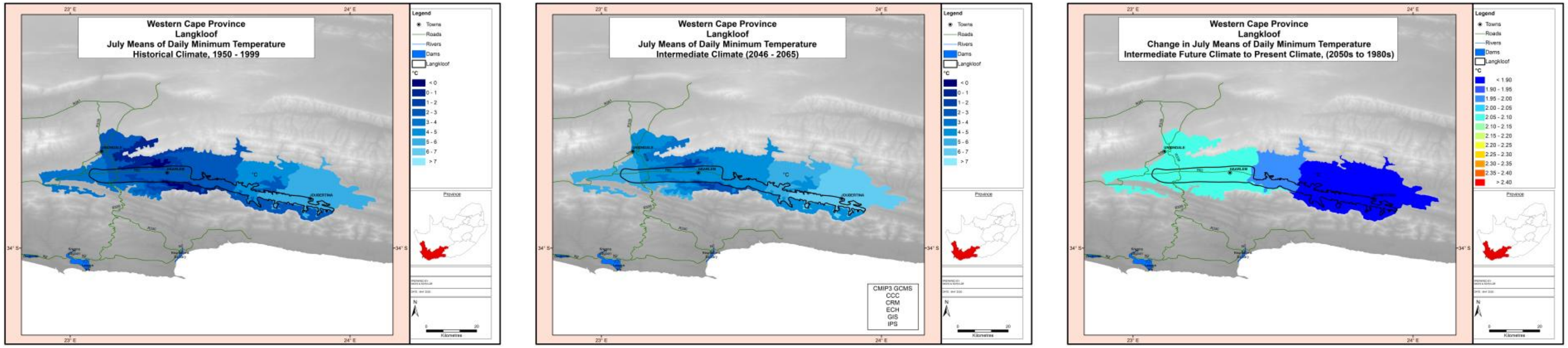
JULY MEANS OF DAILY MINIMUM TEMPERATURE: PIKETBERG



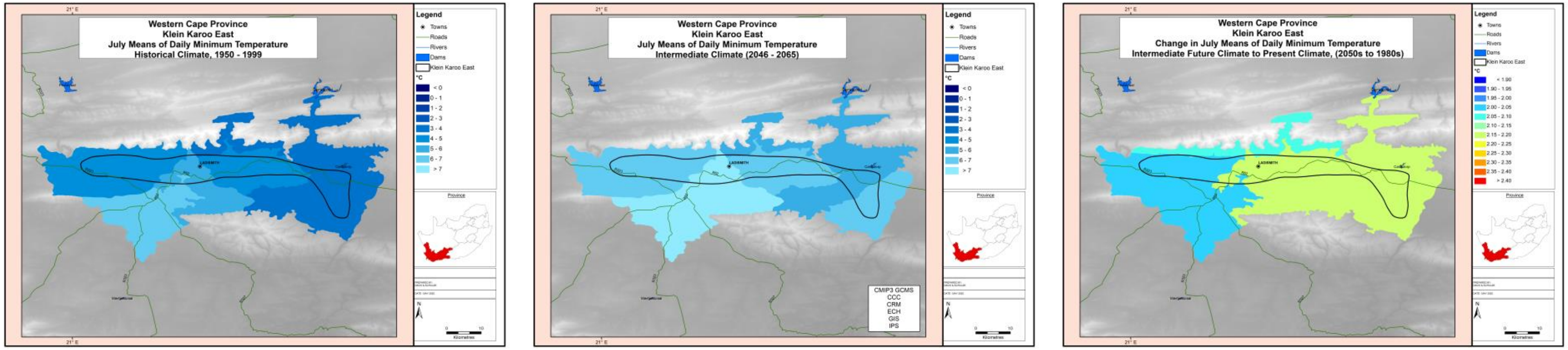




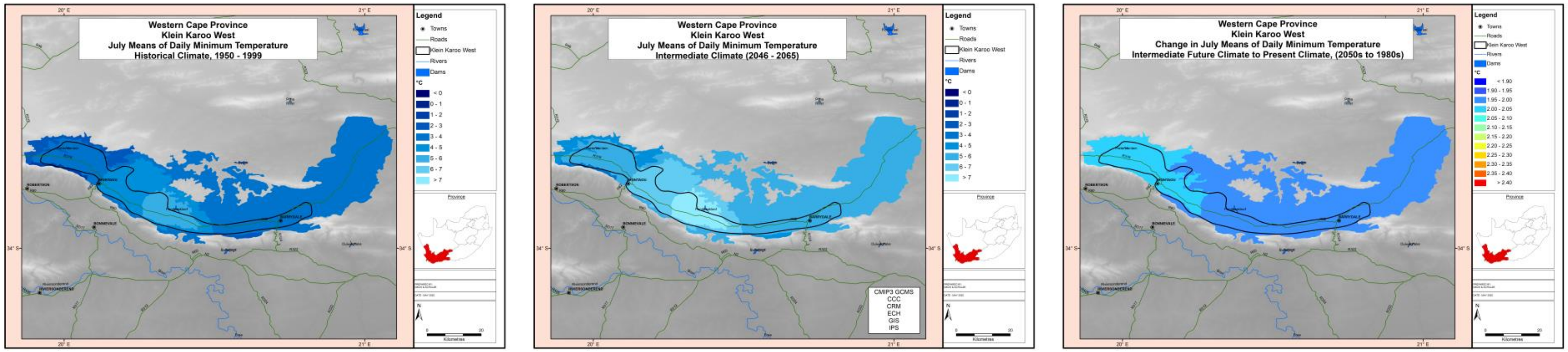
JULY MEANS OF DAILY MINIMUM TEMPERATURE: LANGKLOOF



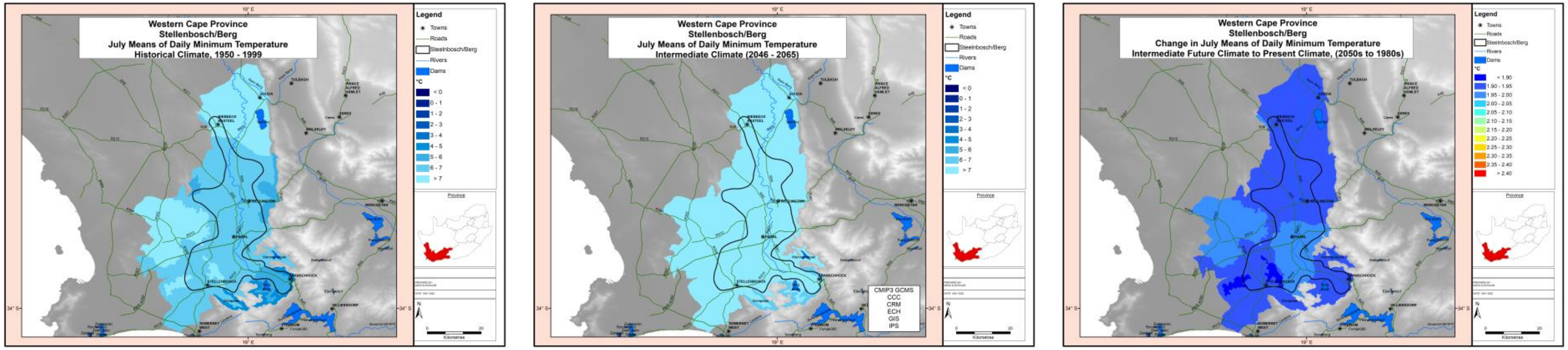
JULY MEANS OF DAILY MINIMUM TEMPERATURE: KLEIN KAROO EAST



JULY MEANS OF DAILY MINIMUM TEMPERATURE: KLEIN KAROO WEST



JULY MEANS OF DAILY MINIMUM TEMPERATURE: STELLENBOSCH-BERG



JULY MEANS OF DAILY MINIMUM TEMPERATURE: BREEDE

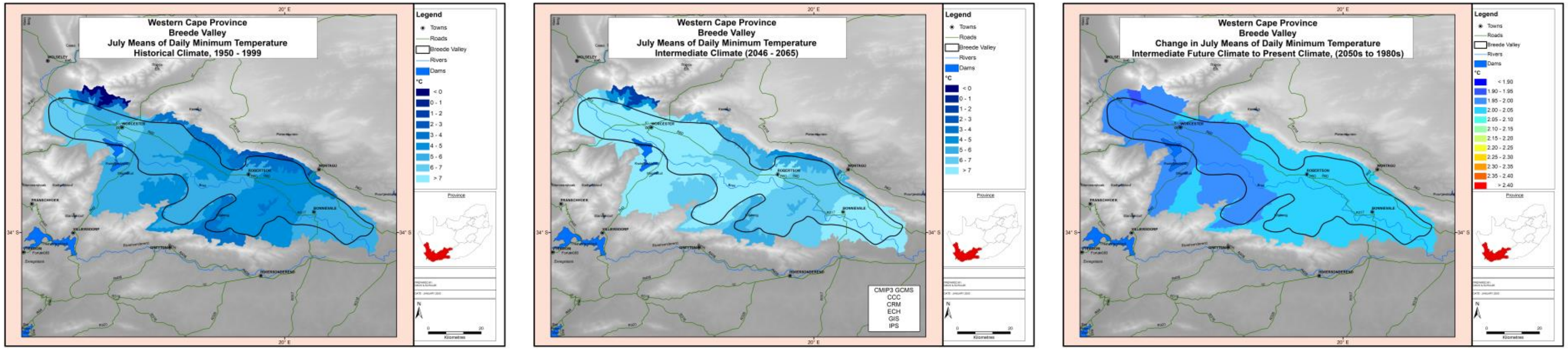


Figure 4. July means of daily minimum temperatures (°C) under historical climatic conditions (left column), under projected climatic conditions for the intermediate future (middle column), and projected changes (in °C) from the present climatic conditions to the intermediate future (right column) of July means of daily minimum temperatures, for each of the eleven pome and stone fruit production regions. The intermediate future maps are derived from multiple CMIP3 GCMs.

7. Annual number of days >35°C per annum

Crops have critical upper temperature thresholds which, when they are exceeded even for a short time, can affect yield or the quality of the crop. The thresholds differ from crop to crop and even between cultivars, with different penalties regarding yields or quality, depending on which threshold is exceeded. One example is presented here, namely, the number of days per annum when the maximum temperature exceeds 35°C. Plant physiological processes (e.g. stomatal opening and thus photosynthesis) often decline above 35°C, certain metabolites (e.g. red pigment) begin to be destroyed, and tissue damage can result at temperatures approaching 40°C when oxidative processes become toxic. In related analyses and mapping, the potential risks of future high temperatures on sunburn and poor red colour development in susceptible cultivars are presented, based on known thresholds.

Figure 5 presents the results for days per annum of daily maximum temperatures exceeding 35°C for the eleven pome and stone fruit regions. For the historical period (left column), the values range from fewer than 4 days (EGVV, Somerset West, most of Ceres, western Langkloof) to more than 12 days (Tulbagh, Montagu, south of Calitzdorp, Wellington, Ashton).

Under the projections for the 2050s (Figure 5, middle column), an additional 2-8 days above 35°C is seen for most of the south-western coastal region, Koue Bokkeveld, Piketberg, Langkloof, Koo/Montagu and Franschhoek (right column). At the other end of the spectrum, 16-18 additional hot days are projected for the area around Wellington, and more than 18 additional hot days are projected for Tulbagh and Calitzdorp, so that by mid-century the areas around these towns could experience between 34 and 42 such hot days annually.

The significant projected increases in hot days in the intermediate future (~ 30 years hence) does not bode well for pome and stone fruit growers in regions that today are already hot. Heat stress will affect fruit trees and humans working outside in many ways. Such conditions also result in high evaporative water losses from soil and water bodies and through transpiration. Irrigation demand will thus increase.

SOUTH-WESTERN COASTAL REGION (POME):

- **Historical Days >35°C:**
  Number of days per annum is generally up to 4 days across most of the region.
  The central part of the Riviersonderend region (Greyton) can experience up to 8 days per annum.

- **Change in Days >35°C:**
  An increase of 2-6 days per annum across most of the region.
  A greater increase, up to 14 days per annum is possible for the eastern part of the Riviersonderend region.

NORTH-WESTERN HIGH-LYING REGION (POME AND STONE):

- **Historical Days >35°C:**
  Number of days per annum is generally up to 2 days in the cooler areas of the Koue Bokkeveld.
  In the Warm Bokkeveld and Piketberg the number is up to 6 days per annum.
  The highest number of very hot days is experienced in Wolseley (6-8) and Tulbagh (12-14).

- **Change in Days >35°C:**
  An increase of up to 6 days per annum in the Koue Bokkeveld and Piketberg, but 6-10 days in the Warm Bokkeveld.
  A greater increase of 10-12 days (Wolseley) and 18-20 days (Tulbagh). Wolseley and Tulbagh could experience up to 20 or 34 hot days, respectively, in future.

EASTERN INTERIOR REGION (POME AND STONE):

- **Historical Days >35°C:**
  Number of days per annum is generally up to 4 days in Langkloof (west) and Koo, and 4-8 days in Langkloof (east), Klein Karoo East (Zoar) and Klein Karoo West (Poortjieskloof).
  The highest number of very hot days per annum are experienced in Ladismith, Calitzdorp and Barrydale (8-12) and Montagu and south of Calitzdorp (14-18).

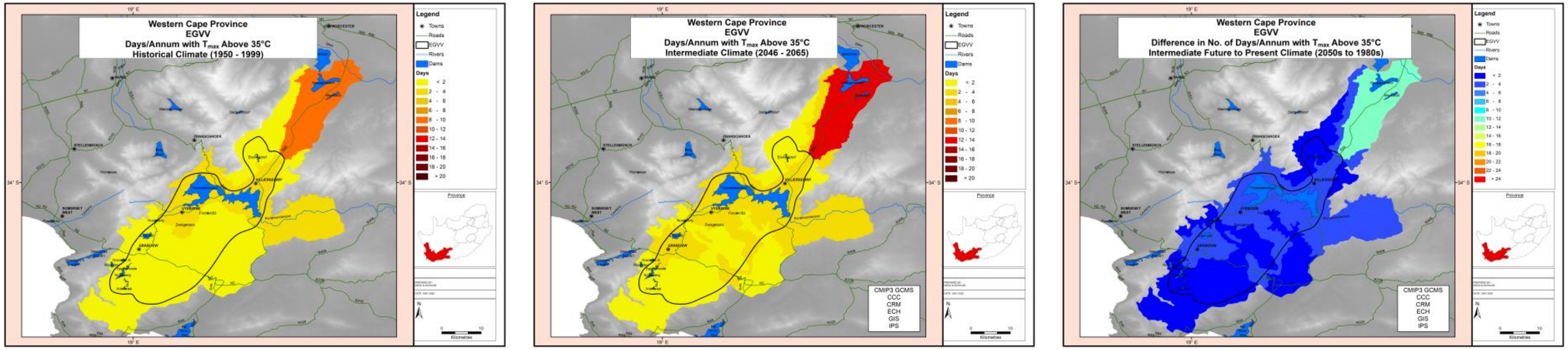
- **Change in Days >35°C:**
  An increase of 4-8 days per annum in Langkloof, Koo and Montagu.
  A greater increase of 6-18 days in Ladismith-Zoar, Poortjieskloof and Barrydale.
  A very large increase of 20-24 days in Calitzdorp. This could bring the future annual number of very hot days in Calitzdorp to 42.

SOUTH-WESTERN RIVER VALLEYS REGION (STONE):

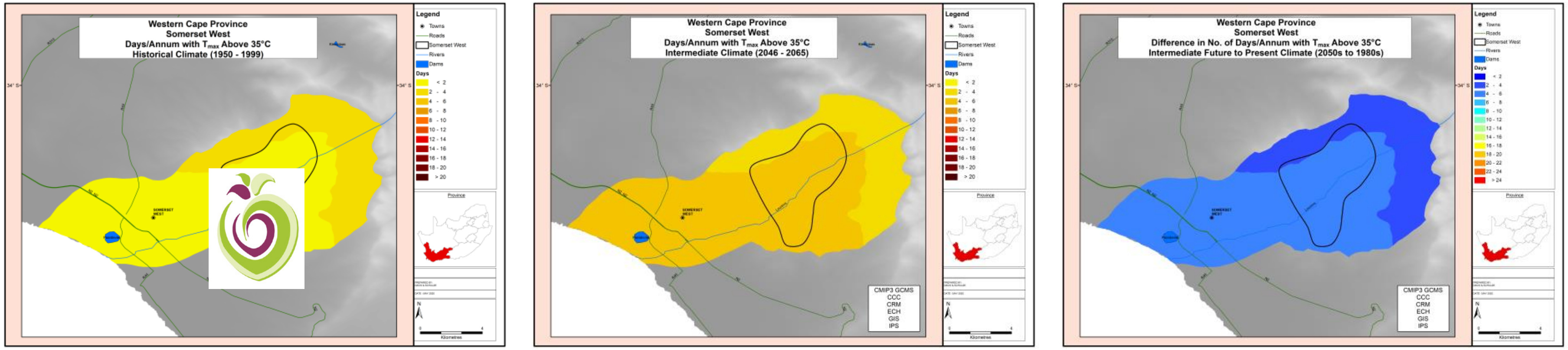
- **Historical Days >35°C:**
  Number of days per annum is generally up to 8 days in Franschhoek, Stellenbosch, Riebeeck Kasteel, Slanghoek, Nuy, McGregor, Bonnievale.
  Pniel-Paarl, Worcester and Robertson experience 8-12 very hot days per annum.
  The highest number of very hot days per annum (14-18) is experienced in Wellington and Ashton.

- **Change in Days >35°C:**
  An increase of 2-8 days in Franschhoek, Simonsberg, Windmeul, Ashton.
  A greater increase of 8-12 days in Stellenbosch, Riebeeck Kasteel, Slanghoek, Nuy, Robertson, Bonnievale, McGregor.
  A very large increase of 12-18 days in Pniel-Paarl, Wellington, Worcester.
  Wellington could experience up to 36 very hot days per annum in future.

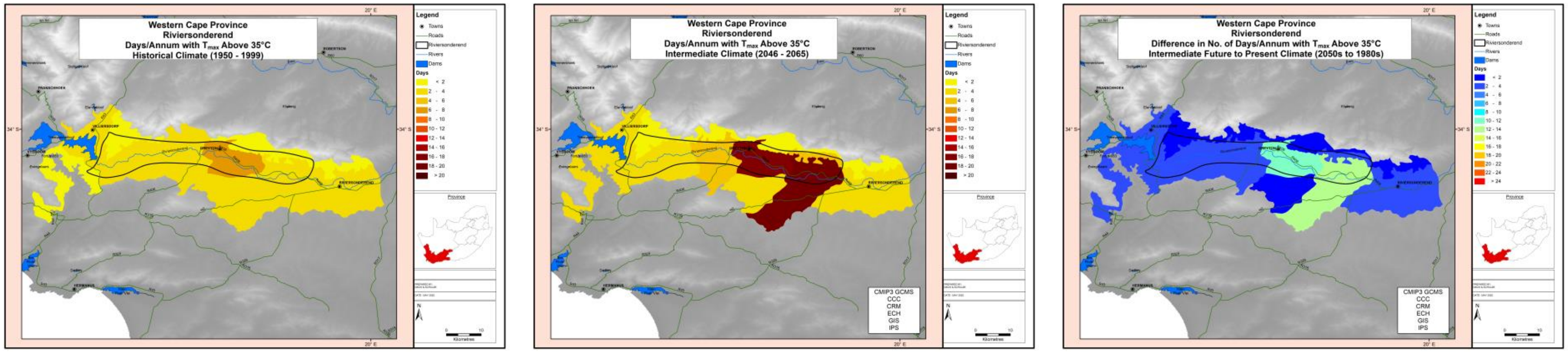
DAYS PER ANNUM TMAX >35°C: EGVV



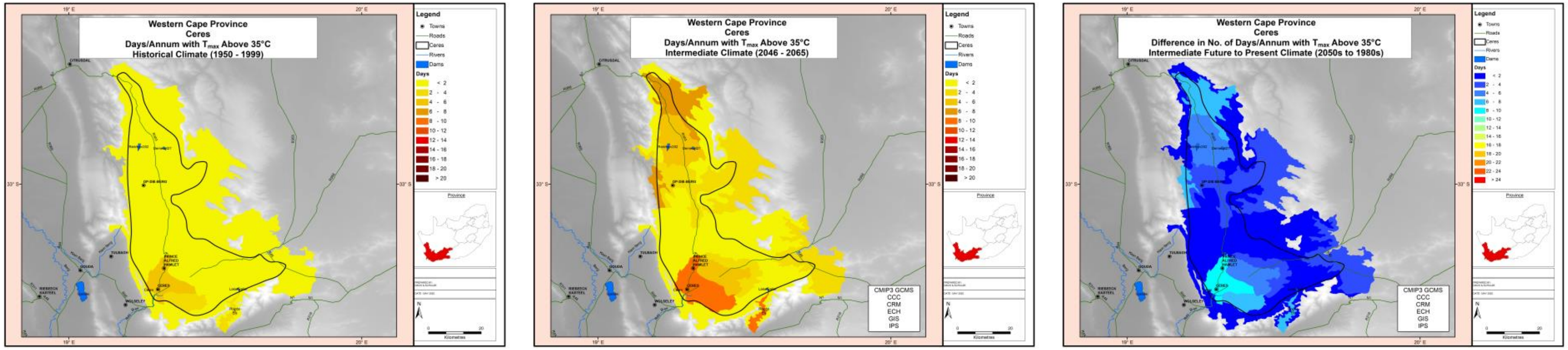
DAYS PER ANNUM TMAX >35°C: SOMERSET WEST



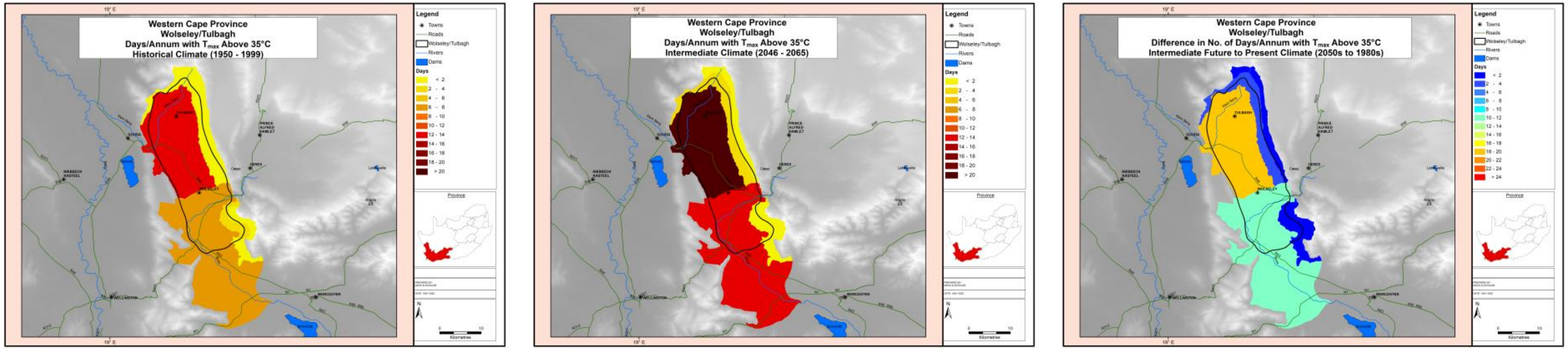
DAYS PER ANNUM TMAX >35°C: RIVIERSONDEREND



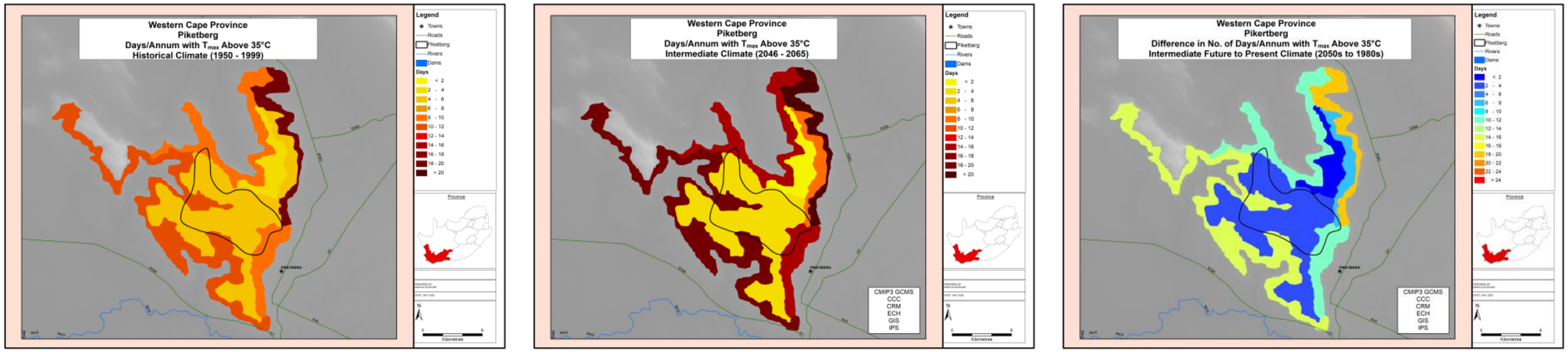
DAYS PER ANNUM TMAX >35°C: CERES



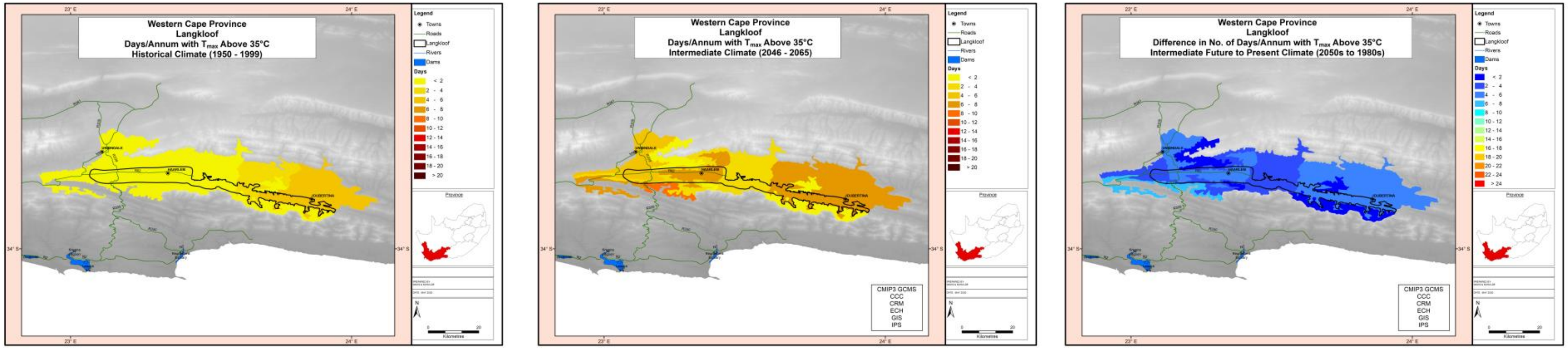
DAYS PER ANNUM TMAX >35°C: WOLSELEY-TULBAGH



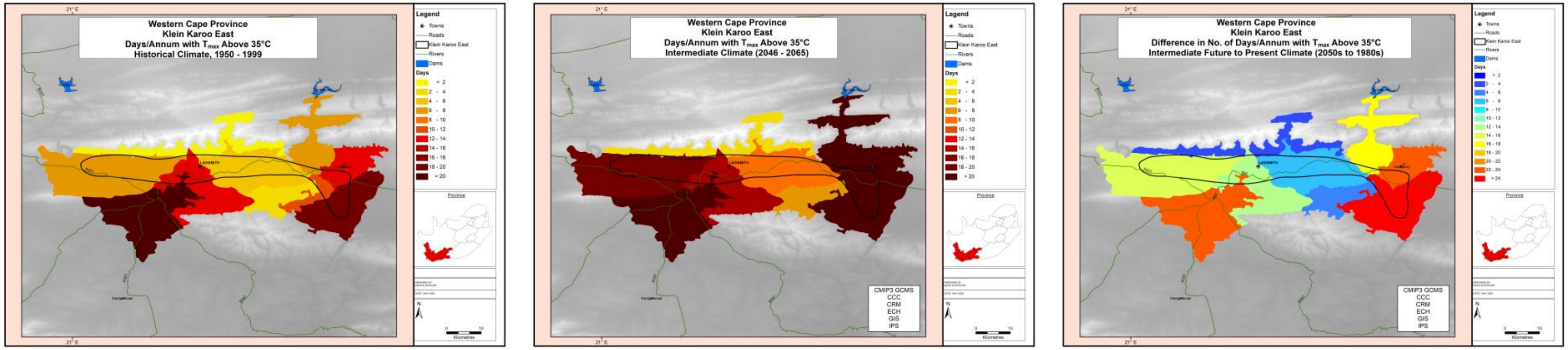
DAYS PER ANNUM TMAX >35°C: PIKETBERG



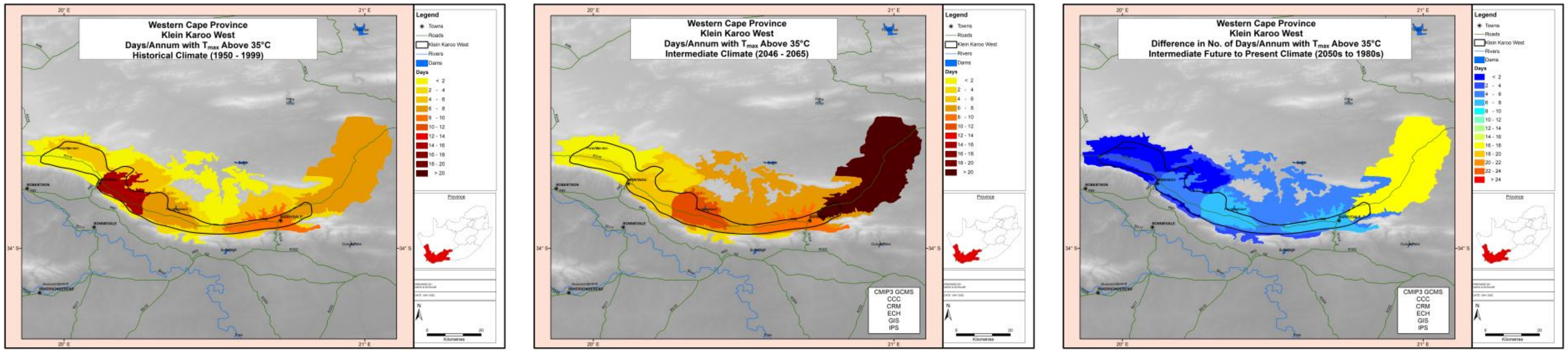
DAYS PER ANNUM TMAX >35°C: LANGKLOOF



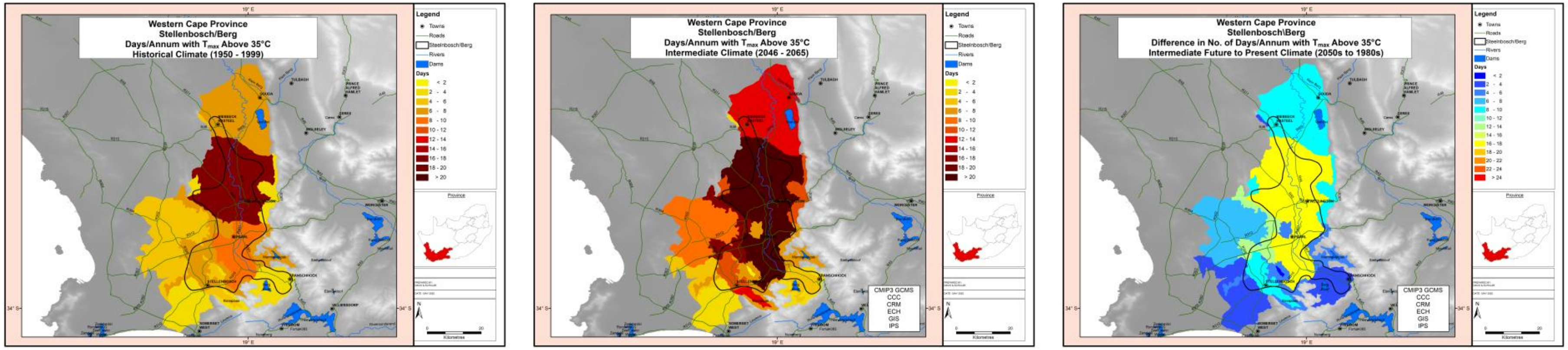
DAYS PER ANNUM TMAX >35°C: KLEIN KAROO EAST



DAYS PER ANNUM TMAX >35°C: KLEIN KAROO WEST



DAYS PER ANNUM TMAX >35°C: STELLENBOSCH-BERG



DAYS PER ANNUM TMAX >35°C: BREEDE

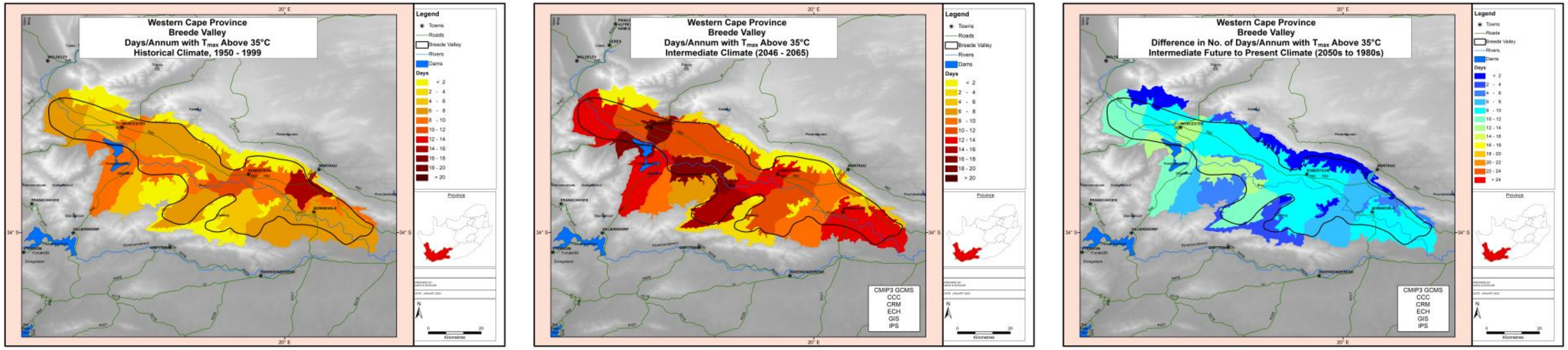


Figure 5. Average days per annum on which daily maximum temperatures exceed 35°C under historical climatic conditions (left column), under projected climatic conditions for the intermediate future (middle column), and projected changes from the present climatic conditions to the intermediate future of average days per annum on which daily maximum temperatures exceed 35°C (right column), for each of the eleven pome and stone fruit production regions. The intermediate future maps are derived from multiple CMIP3 GCMs.

8. Number of dry spells per annum

Dry spells are a creeping, slow onset natural hazard, which can manifest themselves through a lack of rainfall, a lack of available soil moisture for crops, a reduction of streamflows below a critical threshold, a reduction in the amount of water stored in reservoirs, or reduced levels of groundwater. However, unlike aridity, which is a permanent feature of the climate in low rainfall areas, dry spells are a temporary aberration that can occur in low as well as high rainfall areas. In this section, the definition of a dry spell was a period of two consecutive months of below normal rainfall (a mild dry spell). Neither the severity nor the seasonality of the dry spells was considered, only the frequency per annum.

Figure 6 presents the results for the average number of two-month dry spells per annum for the eleven pome and stone fruit regions. Under historical climatic conditions (left column), mild dry spells occur between 2.6 and 3.4 times per year across all regions, with differences within each region. Dry spells are historically least common in parts of the western Langkloof, parts of Riviersonderend and Klein Karoo East, and the area around Nuy in the Breede valley. The highest risk of mild dry spells is found in most of the south-western coastal region, the far western and the eastern parts of the Langkloof, Koo, Barrydale, and several parts of the Breede valley.

Overall, climate model projections for the 2050s (Figure 6, middle column) show increases in mild dry spells into the immediate future (until the 2030s) across all regions (with one exception around Bonnievale). One or more additional occurrences per year (values above 1.0) are seen in Elgin-Grabouw, Franschhoek-Pniel-Paarl, Riebeeck Kasteel, and the Breede River valley downstream of the Brandvlei Dam (right column).

Dry spells of short and medium duration are a concern to water resource managers as they imply increases in irrigation water requirements and reductions in runoff. The projections of more dry spells per annum of two consecutive months' duration over the next 10-20 years would thus constitute a further concern to region's irrigators and water resource managers.

SOUTH-WESTERN COASTAL REGION (POME):

- **Historical 2-Month Dry Spell:**
  2.6-2.8: Riviersonderend (Greyton)
  2.8-3.0: Vyeboom, Riviersonderend (east)
  3.2-3.4: Elgin, Grabouw, Villiersdorp, Elandskloof, Somerset West, Riviersonderend (Helderstroom)

- **Change in 2-Month Dry Spell:**
  0.0-0.2: Vyeboom, Villiersdorp, Elandskloof, Riviersonderend (Helderstroom, east)
  0.2-0.4: Riviersonderend (Greyton)
  0.8-1.0: Somerset West
  1.2-1.4: Elgin
  1.4-1.6: Grabouw

NORTH-WESTERN HIGH-LYING REGION (POME AND STONE):

- **Historical 2-Month Dry Spell:**
  2.8-3.0: Warm Bokkeveld, Tulbagh, Piketberg
  3.0-3.2: Koue Bokkeveld, Witzenberg, Ceres, Prince Alfred Hamlet, Wolseley

- **Change in 2-Month Dry Spell:**
  0.0-0.4: southern Warm Bokkeveld, Klondyke, Wolseley
  0.4-0.6: Koue Bokkeveld, Witzenberg, Ceres, Prince Alfred Hamlet, Tulbagh
  0.6-1.0: Lower Koue Bokkeveld, Piketberg

EASTERN INTERIOR REGION (POME AND STONE):

- **Historical 2-Month Dry Spell:**
  <2.6: Parts of Langkloof (west), Klein Karoo East (central)
  2.6-2.8: Langkloof (central), Calitzdorp), Montagu, Poortjieskloof
  2.8-3.0: Langkloof (east)
  3.0-3.4: Langkloof (far west), Koo, Barrydale

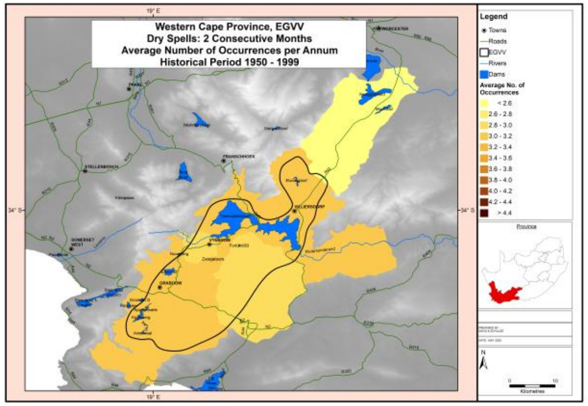
- **Change in 2-Month Dry Spell:**
  0.0-0.2: Barrydale
  0.2-0.4: Langkloof (far west), Koo
  0.4-0.6: Langkloof (far west), Langkloof East, Montagu, Poortjieskloof
  0.6-0.8: Langkloof (west)
  0.8-1.0: Langkloof (central and east)

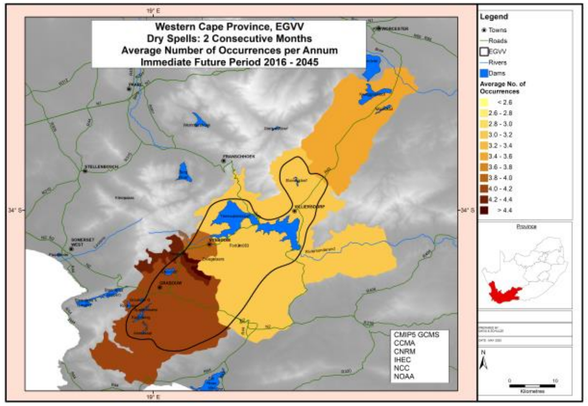
SOUTH-WESTERN RIVER VALLEYS REGION (STONE):

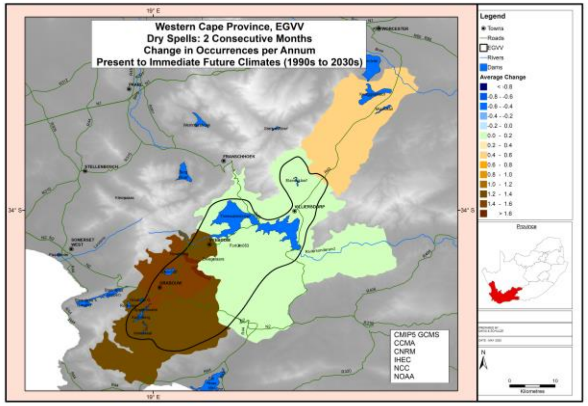
- **Historical 2-Month Dry Spell:**
  2.6-2.8: Nuy
  2.8-3.0: whole Stellenbosch-Berg region, Slanghoek, Robertson
  3.0-3.4: Worcester, Ashton, McGregor, Bonnievale

- **Change in 2-Month Dry Spell:**
  -0.2-0.0: Bonnievale, Ashton
  0.2-0.6: Slanghoek, Nuy, Robertson
  0.6-1.2: Stellenbosch, Wellington, Worcester, Breede River downstream of Brandvlei Dam
  1.2-1.6: Franschhoek-Pniel-Paarl, Riebeeck Kasteel

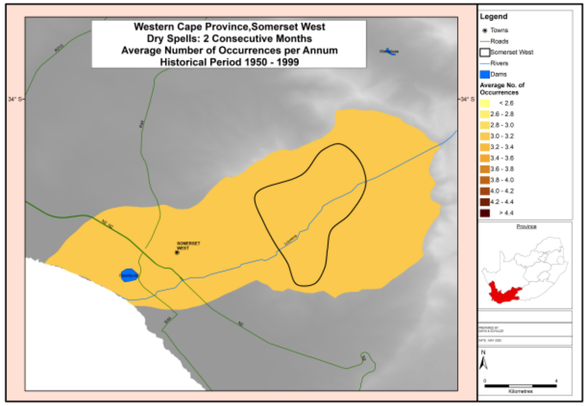
DRY SPELLS 2-MONTH: EGVV

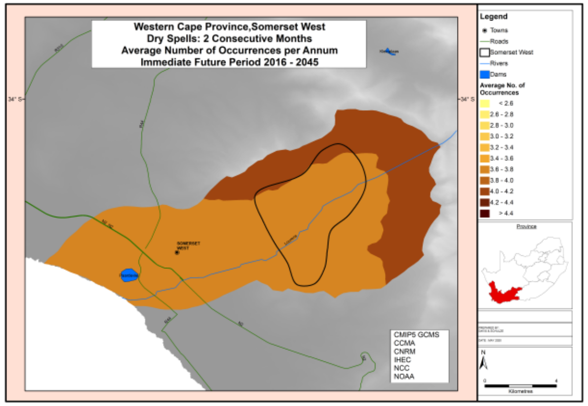


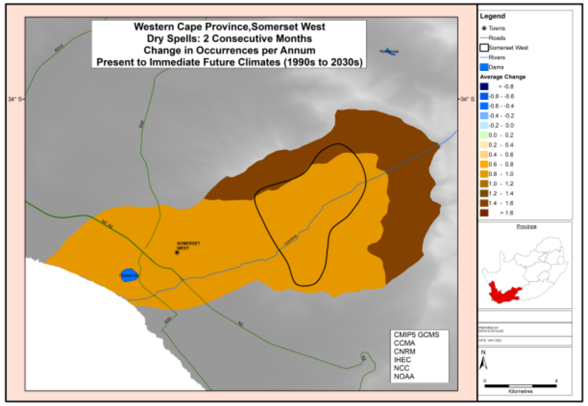




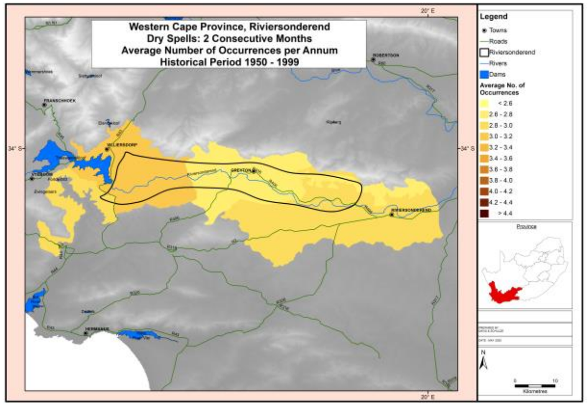
DRY SPELLS 2-MONTH: SOMERSET WEST

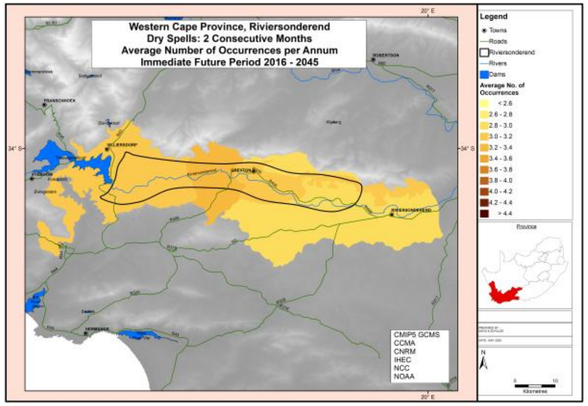


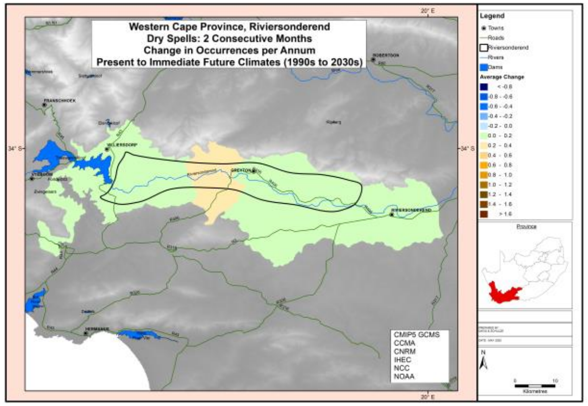




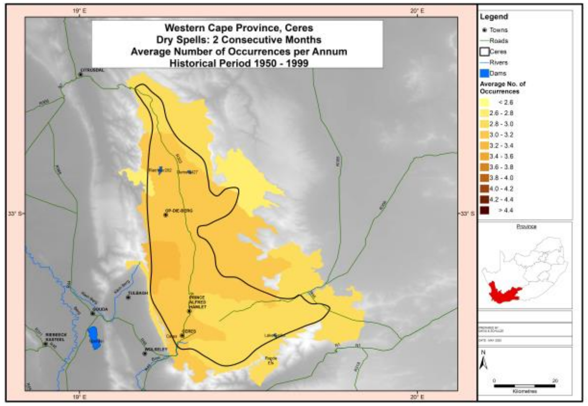
DRY SPELLS 2-MONTH: RIVIERSONDEREND

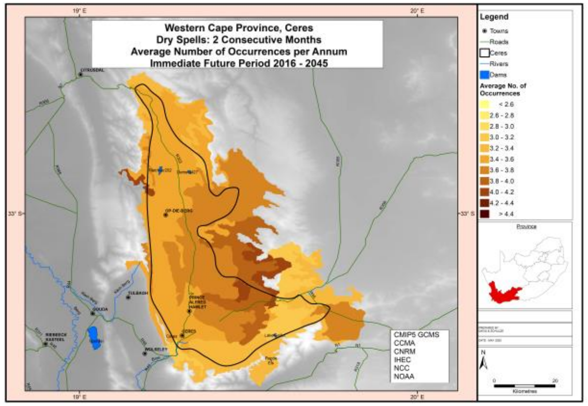


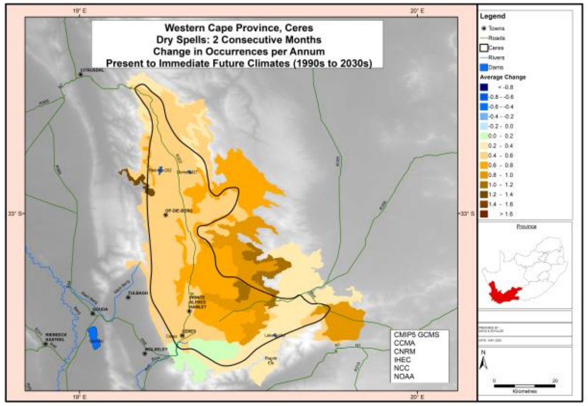




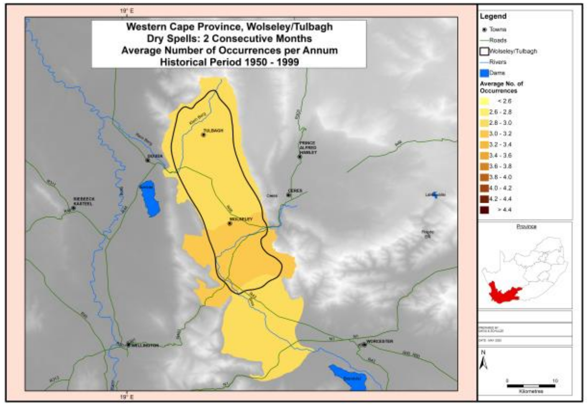
DRY SPELLS 2-MONTH: CERES

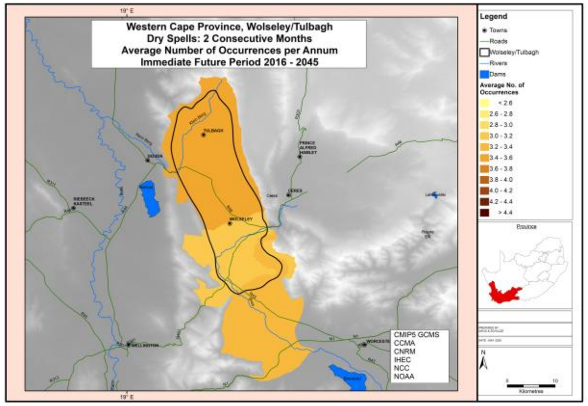


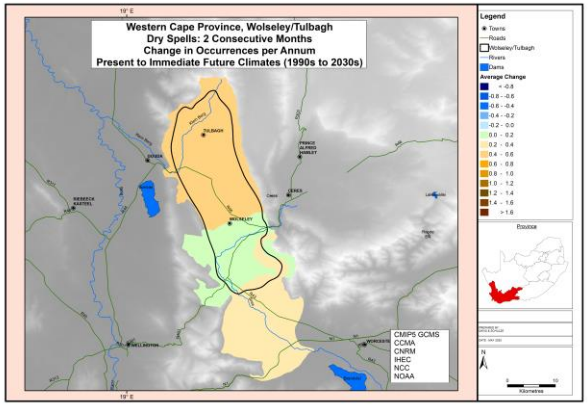




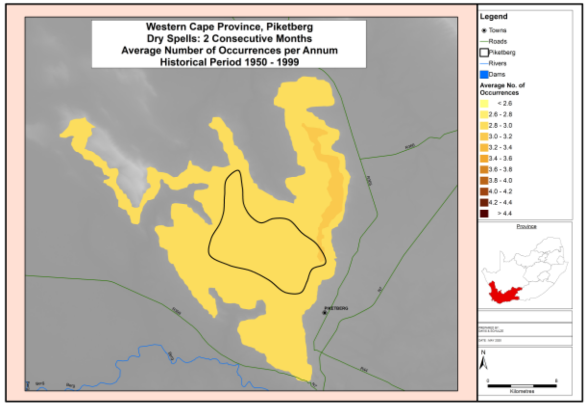
DRY SPELLS 2-MONTH: WOLSELEY-TULBAGH

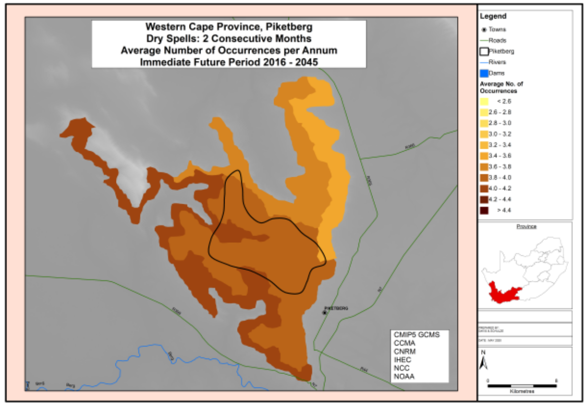


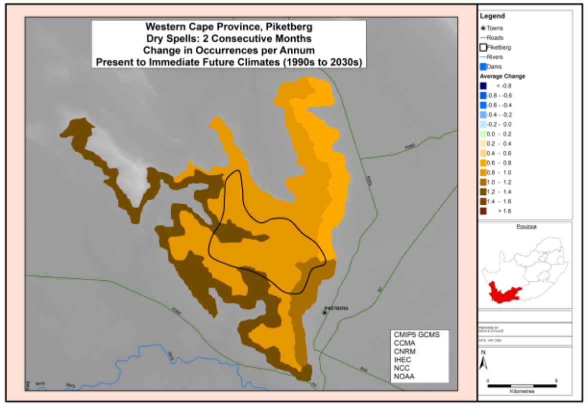




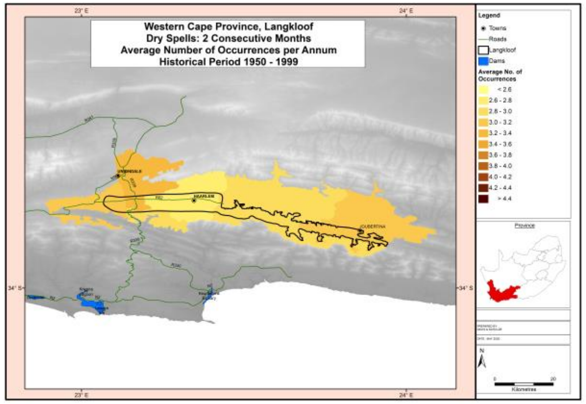
DRY SPELLS 2-MONTH: PIKETBERG

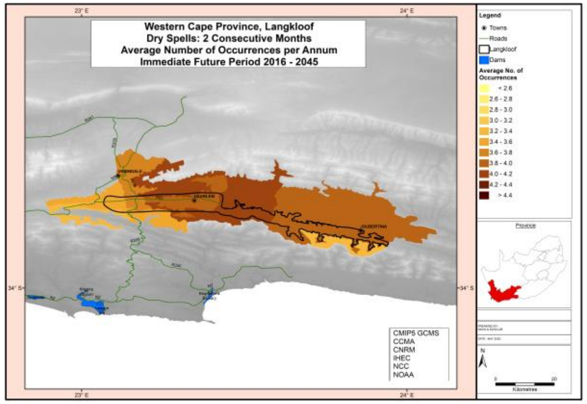


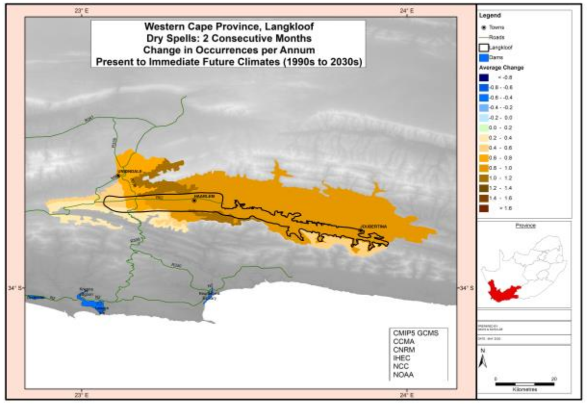




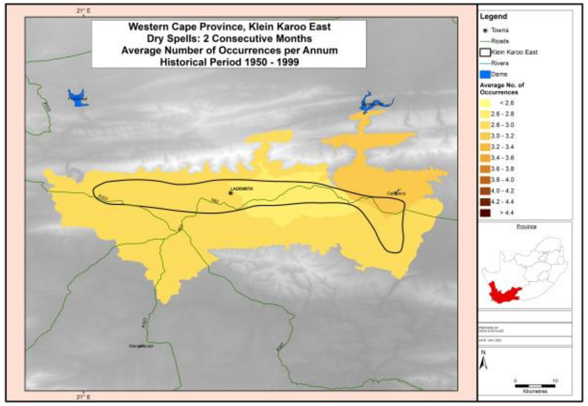
DRY SPELLS 2-MONTH: LANGKLOOF

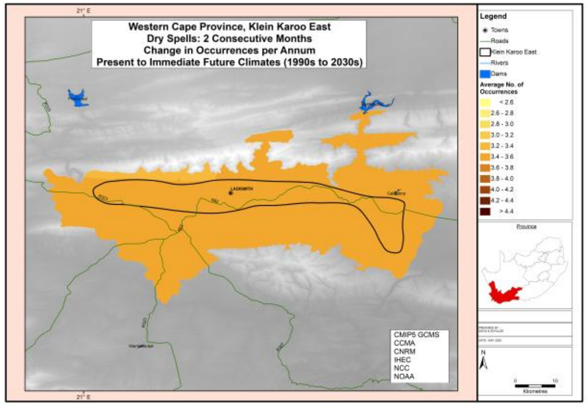


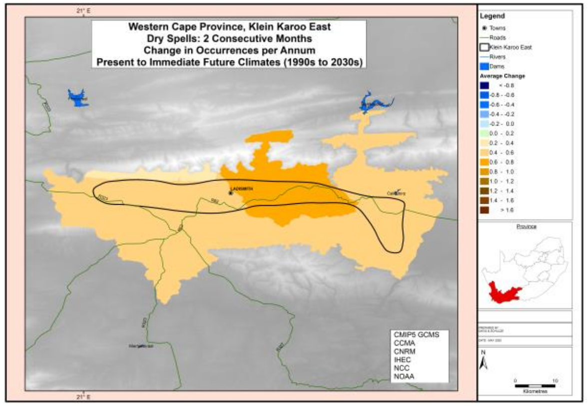




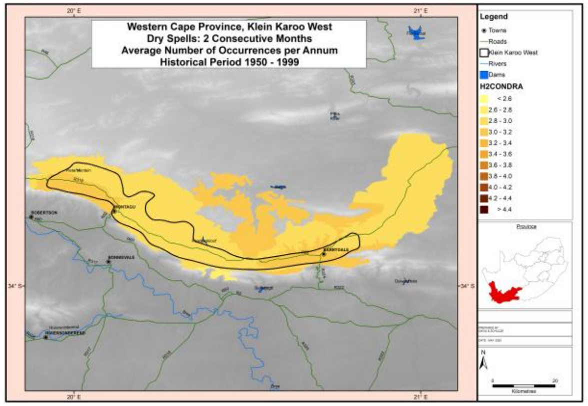
DRY SPELLS 2-MONTH: KLEIN KAROO EAST

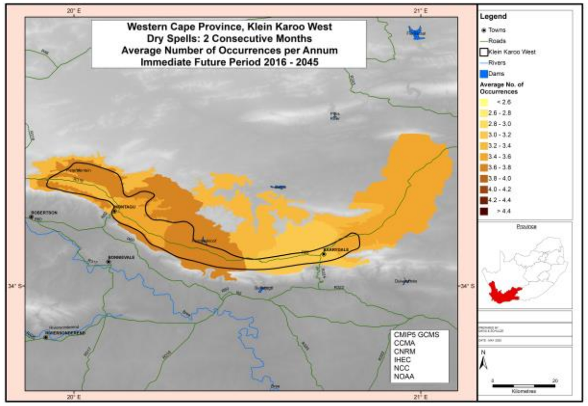


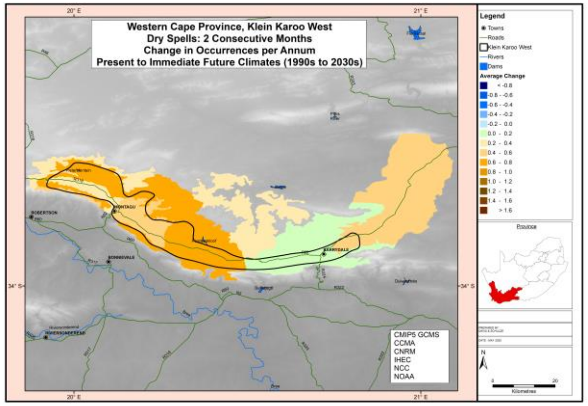




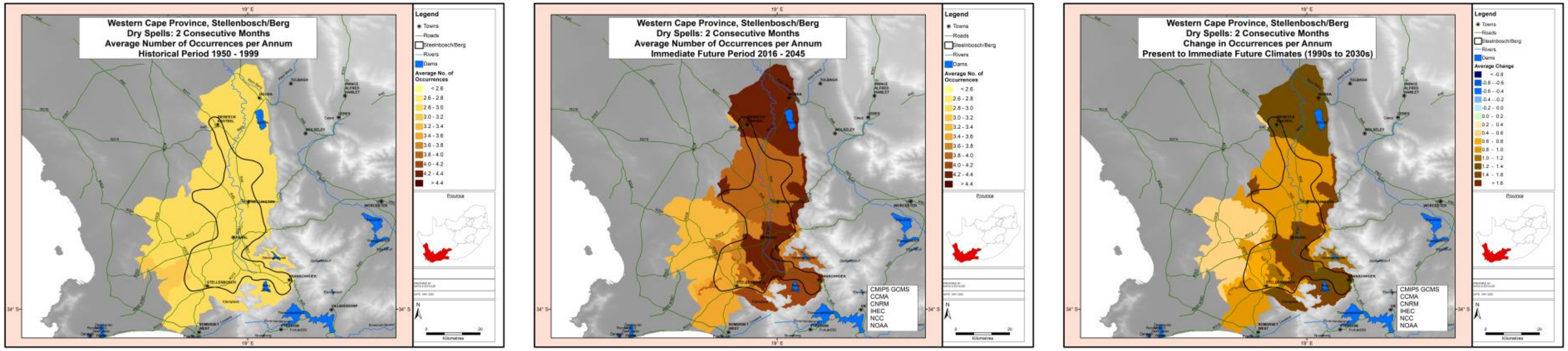
DRY SPELLS 2-MONTH: KLEIN KAROO WEST







DRY SPELLS 2-MONTH: STELLENBOSCH-BERG



DRY SPELLS 2-MONTH: BREEDE

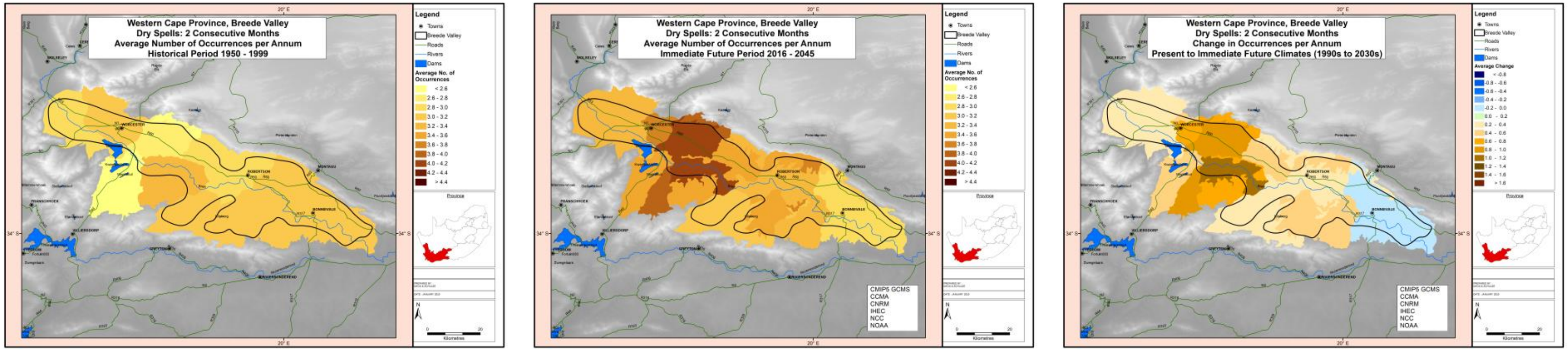


Figure 6. Two month dry spells for the eleven pome and stone fruit regions at high spatial resolution under historical climatic conditions (left column), under projected climatic conditions for the immediate future (middle column), and projected changes from the present climatic conditions to the immediate future of two month dry spells (right column), for each of the eleven pome and stone fruit production regions. The immediate future maps are derived from multiple CMIP5 GCMs.

9. Number of wet spells per annum

Wet spells in this analysis are the inverse of dry spells, with a two-month duration of above normal rainfall considered here (10% or more above the median). The number of wet spells of two months duration in the years being assessed were summed and then divided by the number of years to obtain probabilities of wet spells per year.

Figure 7 presents the results for the average number of two-month wet spells for the eleven pome and stone fruit regions. The values for historical climatic conditions are shown in the left column. Wet spells generally occur around three times per year, with slightly higher probabilities in the Koue Bokkeveld, Wolseley, far western parts of the Langkloof, Koo and parts of the Breede River valley.

The projected average number of two-month wet spells for the immediate future (Figure 7, middle column) and the changes between these periods (right column) point to generally fewer wet spells of two-month duration. The regions at greatest risk are the western Langkloof, Poortjieskloof, Paarl, Riebeeck Kasteel and the area around Worcester, where on average just less than one fewer wet spell per year could be experienced.

When considering both dry spells and wet spells, arguably the most significant finding is the ’double whammy’ effect of simultaneous projections for increases in dry spells of two-month duration and of decreases in wet spells of the same duration. This analysis clearly illustrates that one needs to go well beyond merely assessing impacts of climate change on an annual or even a seasonal basis. This ’double whammy’, while not showing *when* the dry or wet spells occur over a year, could signify important impacts such as reduced irrigation water availability in dams.

SOUTH-WESTERN COASTAL REGION (POME):

- **Historical 2-Month Wet Spell:**
  Generally around 3 per year or slightly lower

- **Change in 2-Month Wet Spell (occurrences per annum):**
  0 to -0.2: Riviersonderend (east)
  -0.2 to -0.4: Villiersdorp, Elandskloof, Somerset West, Riviersonderend (west)
  -0.4 to -0.6: Elgin, Grabouw, Vyeboom

NORTH-WESTERN HIGH-LYING REGION (POME AND STONE):

- **Historical 2-Month Wet Spell:**
  Generally around 3 per year, but slightly higher in the Koue Bokkeveld and Wolseley

- **Change in 2-Month Wet Spell:**
  0 to 0.2: Klondyke
  -0.2 to -0.4: southern Bokkeveld, Wolseley
  -0.4 to -0.6: Bokkeveld north of Ceres, Tulbagh, Piketberg

EASTERN INTERIOR REGION (POME AND STONE):

- **Historical 2-Month Wet Spell:**
  Generally around 3 per year, but slightly higher in the far western Langkloof and Koo

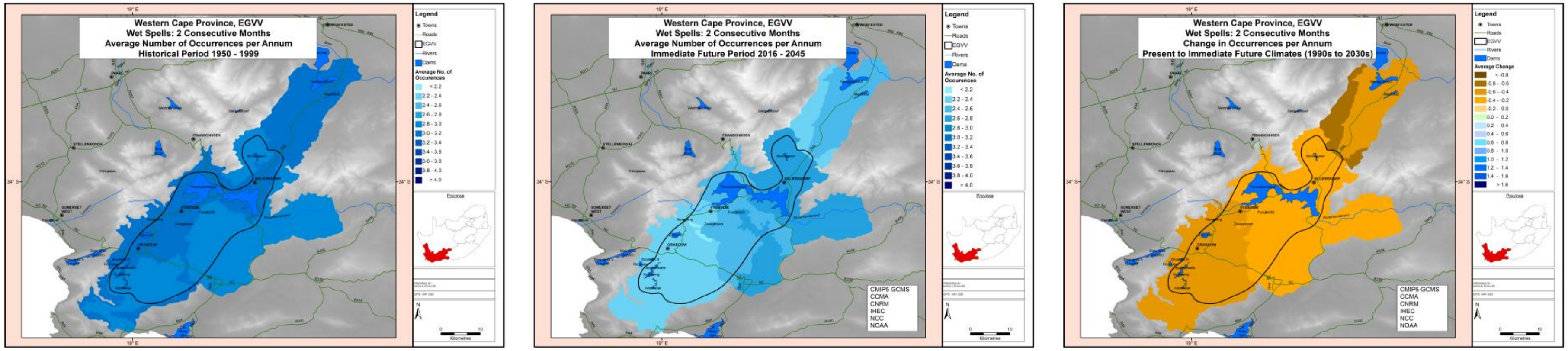
- **Change in 2-Month Wet Spell:**
  -0.2 to -0.4: east of Ladismith, Barrydale
  -0.4 to -0.6: Langkloof (east), west of Ladismith, Montagu
  -0.6 to -0.8: Langkloof (west)
  <0.8: Poortjieskloof

SOUTH-WESTERN RIVER VALLEYS REGION (STONE):

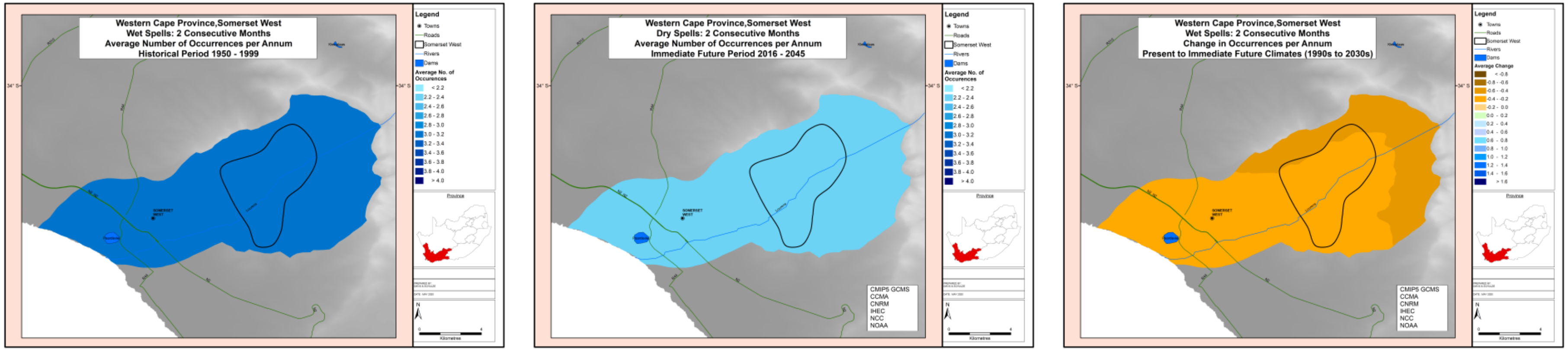
- **Historical 2-Month Wet Spell:**
  Generally around 3 per year, but slightly higher in the Breede than the Berg River Valley

- **Change in 2-Month Wet Spell:**
  -0.2 to -0.4: Stellenbosch, Windmeul, Slanghoek, Nuy, Robertson, Bonnievale
  -0.4 to -0.6: Franschhoek, Wellington, Worcester, McGregor
  -0.6 to -0.8: Paarl, Riebeeck Kasteel, east/south-east of Worcester

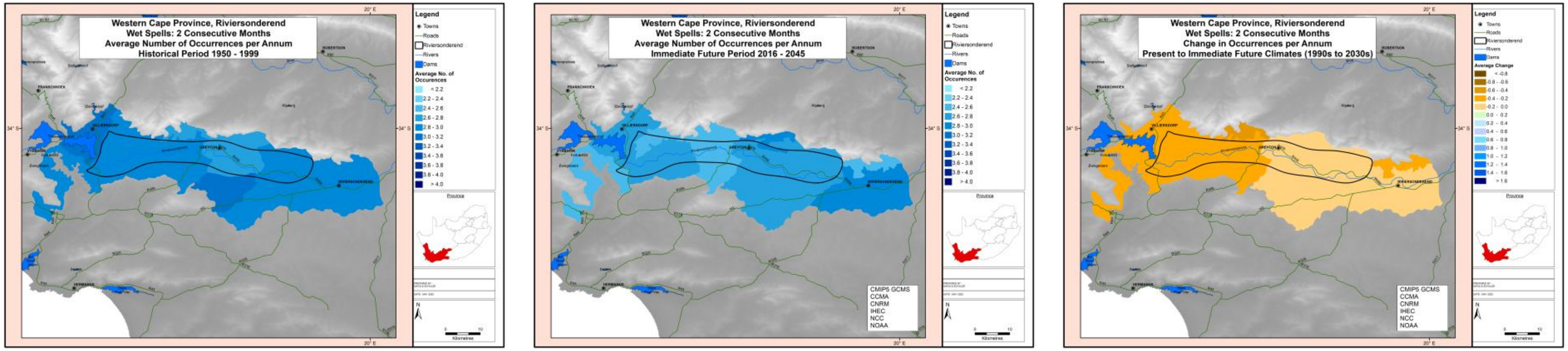
WET SPELLS 2-MONTH: EGVV



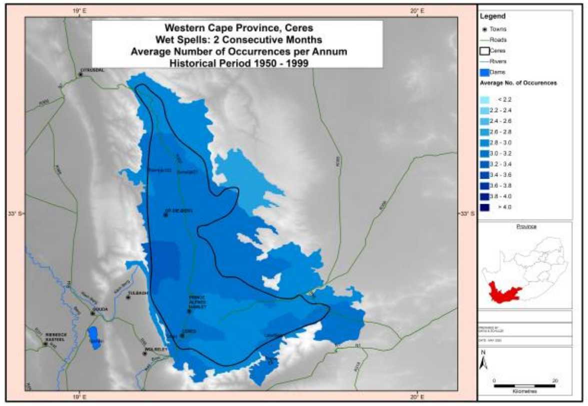
WET SPELLS 2-MONTH: SOMERSET WEST

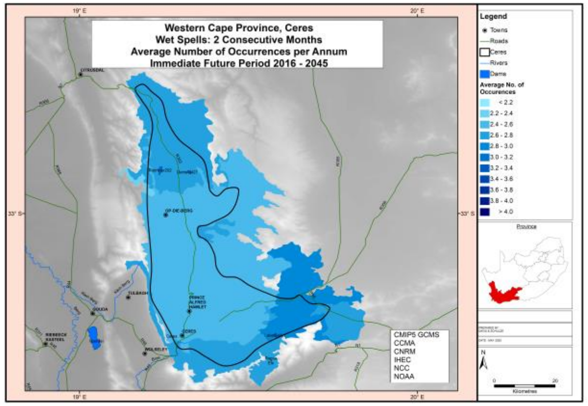


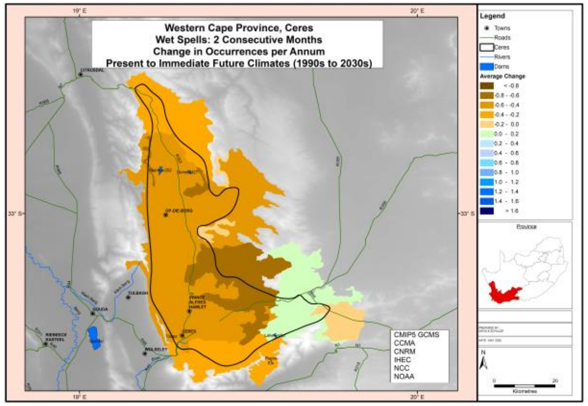
WET SPELLS 2-MONTH: RIVIERSONDEREND



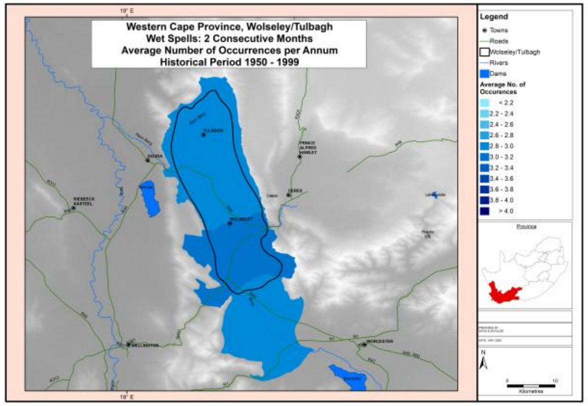
WET SPELLS 2-MONTH: CERES

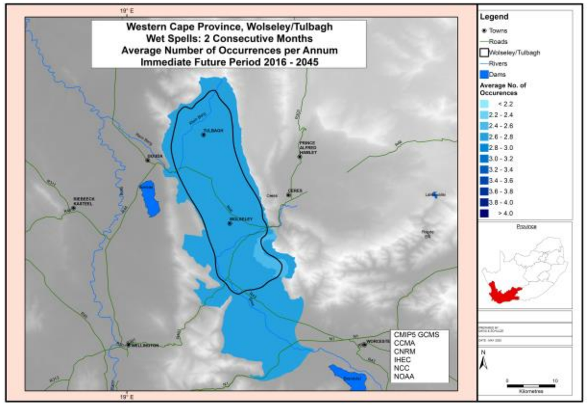


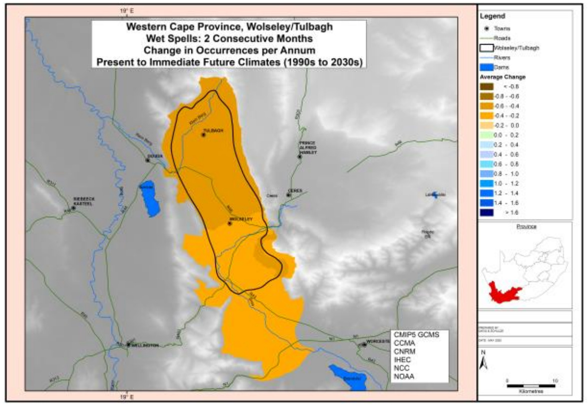




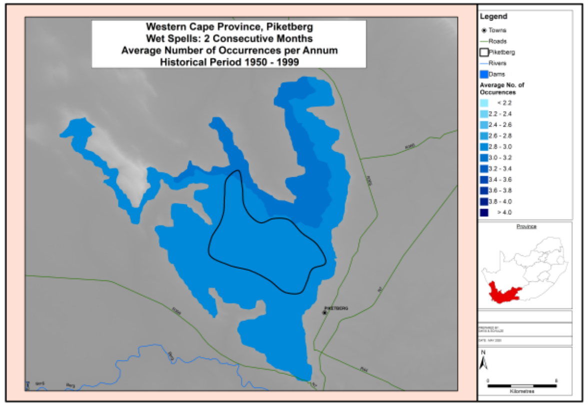
WET SPELLS 2-MONTH: WOLSELEY-TULBAGH

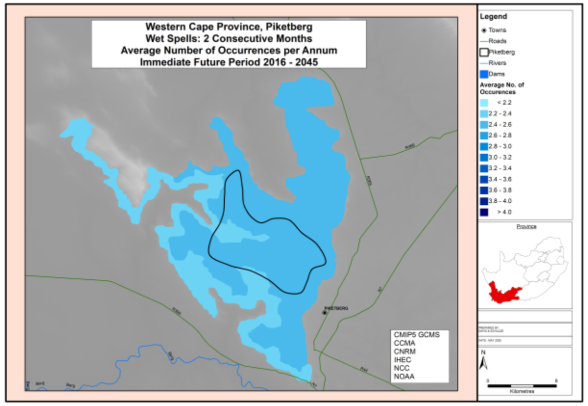


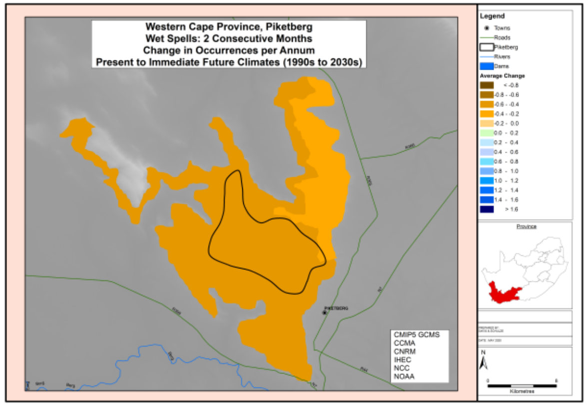




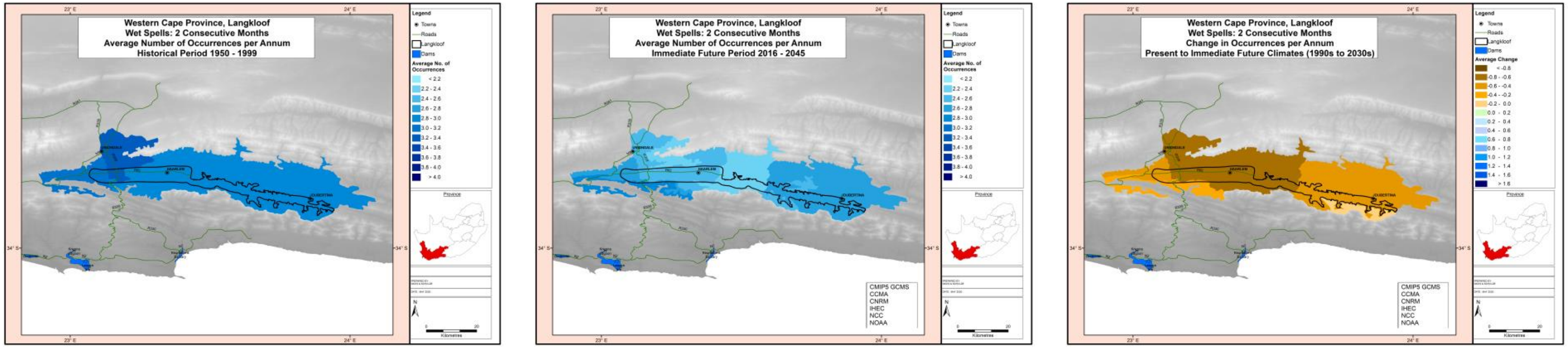
WET SPELLS 2-MONTH: PIKETBERG



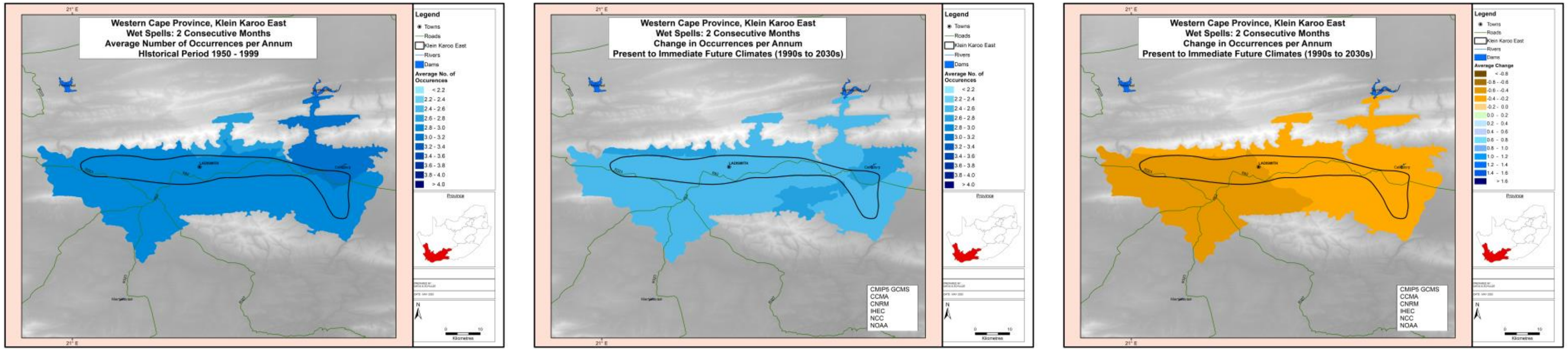




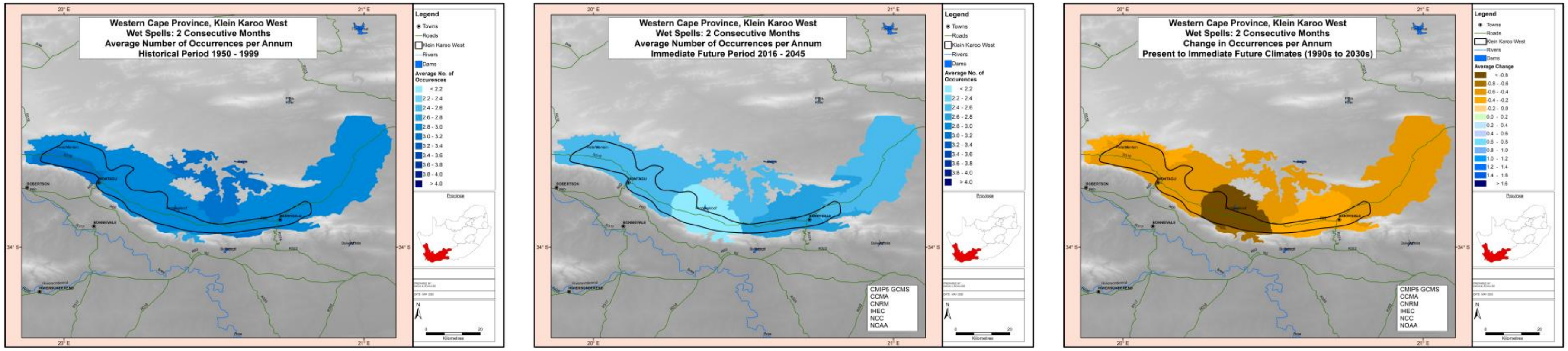
WET SPELLS 2-MONTH: LANGKLOOF



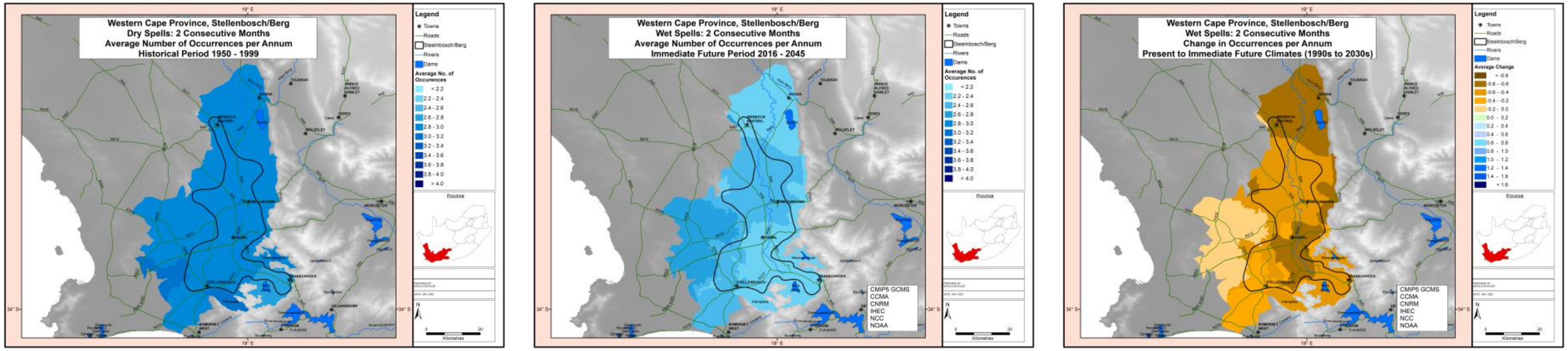
WET SPELLS 2-MONTH: KLEIN KAROO EAST



WET SPELLS 2-MONTH: KLEIN KAROO WEST



WET SPELLS 2-MONTH: STELLENBOSCH-BERG



WET SPELLS 2-MONTH: BREEDE

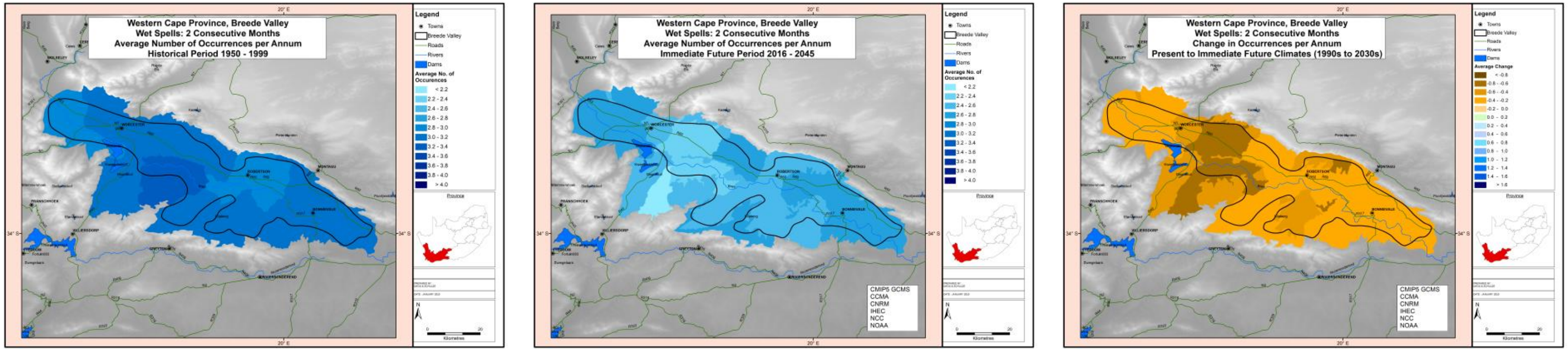


Figure 7. Two month wet spells for the eleven pome and stone fruit regions at high spatial resolution under historical climatic conditions (left column), under projected climatic conditions for the immediate future (middle column), and projected changes from the present climatic conditions to the immediate future of two month wet spells (right column), for each of the eleven pome and stone fruit production regions. The immediate future maps are derived from multiple CMIP5 GCMs.

10. Potential evaporation: annual and seasonal

The accurate estimation of evaporation from natural vegetation or agricultural crops is vital. Evaporation is the driving force of the total amount of water which can be 'consumed' by a plant system through evaporation and transpiration processes (together termed 'evapotranspiration'). Similarly, evaporation from storage reservoirs, wetlands and rivers can constitute a major loss of water to water resource managers, irrigators, and downstream users. Evaporation is controlled by the capacity of air to take up water vapour, the amount of energy available for the process of evaporation (provided mainly by solar radiation), and the degree of turbulence (related to wind) in the lower atmosphere. These three factors create an atmospheric demand. All three these factors change with climate change.

The Penman-Monteith method of estimating evaporation is used as the point of departure in computations. Values were converted to A-pan equivalent reference potential evaporation since the expression of water use of crops in South Africa is still largely based on an A-pan equivalent.

Figure 8 presents the results for annual A-pan equivalent reference potential evaporation for the eleven pome and stone fruit regions. Thereafter, Figures 9-12 present the respective results for spring, summer, autumn, and winter.

Under historical climatic conditions in the pome and stone fruit production regions, mean annual A-pan equivalent reference potential evaporation values are in the range 1200-1900 mm (Figure 8, left column), and the projected annual increases in the immediate future are in the range 70-120 mm (right column). At the higher end of these increases (>100 mm per annum) are Elgin, most of the north-western high-lying regions, the eastern Langkloof, Koo-Montagu, Calitzdorp, most of the Stellenbosch-Berg region, and the upper Breede region.

Reference potential evaporation is a highly seasonal phenomenon. Historically, values are in the range of 350-550 mm in spring (Figure 9, left column), 450-700 mm in summer (Figure 10, left column), dropping to 250-400 mm in autumn (Figure 11, left column), and 150-300 in winter (Figure 12, left column). Mountainous and south-eastern areas generally display the lowest values and the Karoo and hot river valley regions display the highest values.

Projected changes into the immediate future of the 2030s, shown in the right-hand columns of Figures 9-12, display the largest increases in spring and summer at 30-40 mm. The projected increases are 10-30 mm in autumn and only 10-20 mm in winter.

Historical annual reference potential evaporation is already high in the region at up to around 2 000 mm, and projected increases into the 2030s of up to 120 mm, mostly in spring and summer, will impact on water availability. Higher potential evaporation from dams, wetlands and riparian zones will constitute an unavoidable loss to the region's water, ecology, and agriculture sectors. Additionally, all else remaining the same, soils are anticipated to dry out more rapidly in future, leading to potential negative implications for runoff production. Irrigation water demands will be higher than at present, leading to both increased abstractions from dams and reduction in river flows where irrigation is from run-of-river.

SOUTH-WESTERN COASTAL REGION (POME):

- **Historical Annual Evaporation:**
  1300-1400mm: Elgin, Grabouw, Vyeboom, Somerset West
  1400-1500mm: Villiersdorp, Elandskloof
  1500-1600mm: Riviersonderend
  1600-1700mm: Riviersonderend (Greyton)

- **Change in Annual Evaporation:**
  80-90mm: Elandskloof
  90-100mm: Grabouw, Vyeboom, Villiersdorp, Somerset West, Riviersonderend
  100-110mm: Elgin

NORTH-WESTERN HIGH-LYING REGION (POME AND STONE):

- **Historical Annual Evaporation:**
  1200-1400mm: Klondyke, Lower Koue Bokkeveld
  1400-1500mm: Witzenberg, Upper Koue Bokkeveld, Piketberg
  1500-1700mm: Ceres, Prince Alfred Hamlet, Piketberg, Wolseley
  1700-1800mm: Tulbagh

- **Change in Annual Evaporation:**
  90-100mm: Klondyke
  100-110mm: Koue Bokkeveld, Witzenberg, Central Warm Bokkeveld, Wolseley, Piketberg
  110-120mm: Ceres, Prince Alfred Hamlet, Tulbagh

EASTERN INTERIOR REGION (POME AND STONE):

- **Historical Annual Evaporation:**
  1300-1400mm: Langkloof (west)
  1400-1500mm: Langkloof (east), Koo, Akkerboom (between Montagu and Barrydale)
  1500-1700mm: east of Ladismith (Zoar), Barrydale
  1700-1800mm: Calitzdorp, west of Ladismith, Poortjieskloof
  1800-1900mm: Montagu, Calitzdorp-south

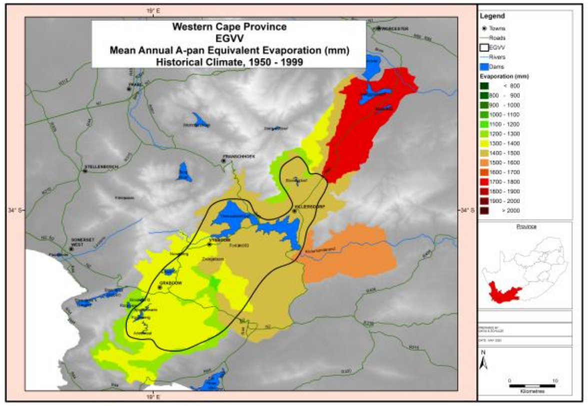
- **Change in Annual Evaporation:**
  70-80mm: Akkerboom
  80-90mm: Langkloof (far west), Barrydale
  90-100mm: Langkloof (west), Klein Karoo East, Poortjieskloof
  100-110mm: Montagu, Koo
  110-120mm: Langkloof (east), Calitzdorp

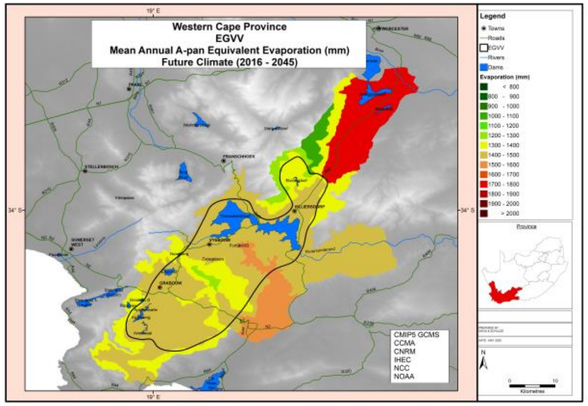
SOUTH-WESTERN RIVER VALLEYS REGION (STONE):

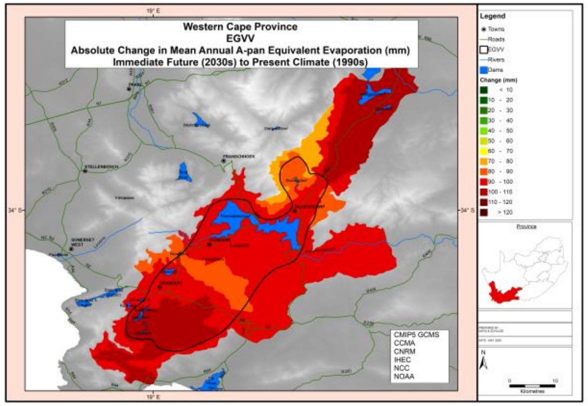
- **Historical Annual Evaporation:**
  1400-1500mm: Franschhoek
  1500-1600mm: Stellenbosch
  1600-1700mm: Pniel-Paarl, Riebeeck Kasteel, Slanghoek, Nuy, McGregor, Bonnievale
  1700-1800mm: Wellington, Worcester, Robertson
  1800-1900mm: Ashton

- **Change in Annual Evaporation:**
  90-100mm: Simonsberg, Windmeul, Robertson, McGregor, Bonnievale
  100-110mm: Franschhoek, Stellenbosch, Paarl, Slanghoek, Worcester, Nuy
  110-120mm: Wellington, Riebeeck Kasteel

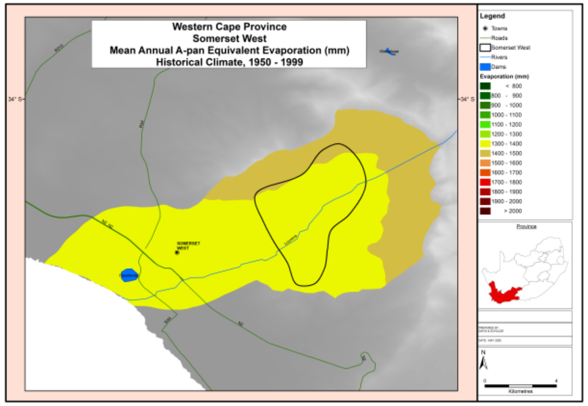
MEAN ANNUAL A-PAN EQUIVALENT EVAPORATION: EGVV

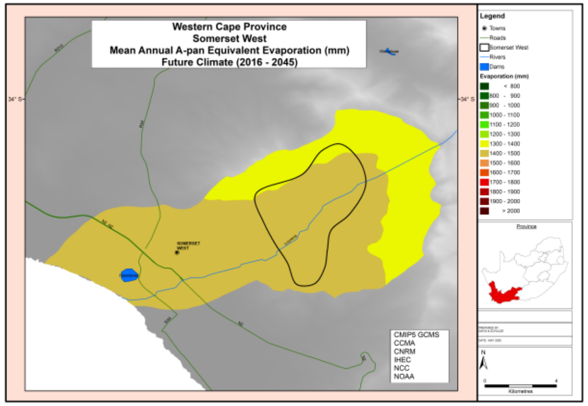


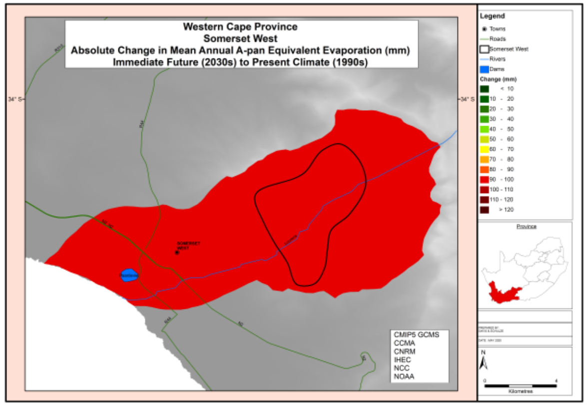




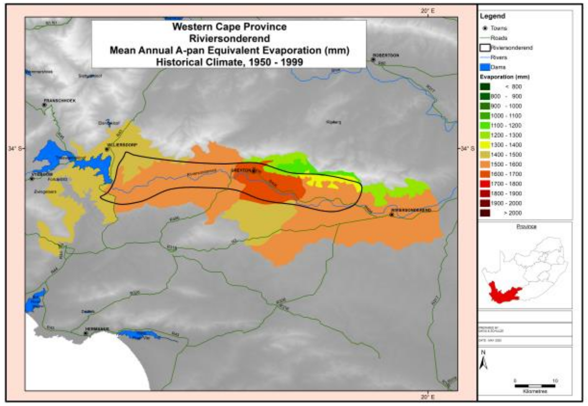
MEAN ANNUAL A-PAN EQUIVALENT EVAPORATION: SOMERSET WEST

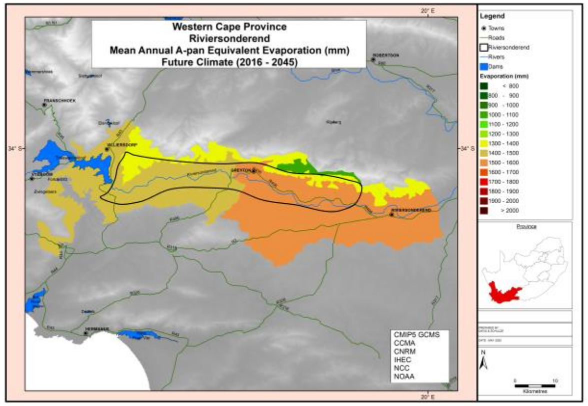


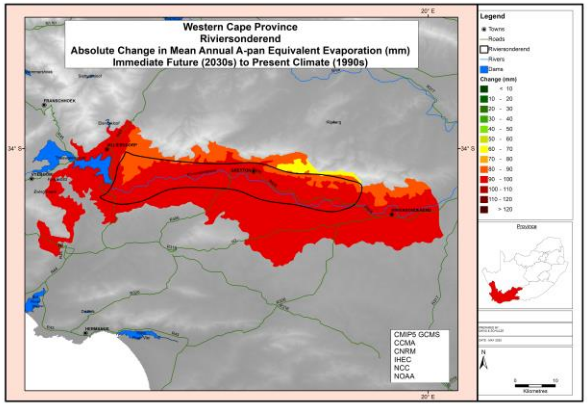




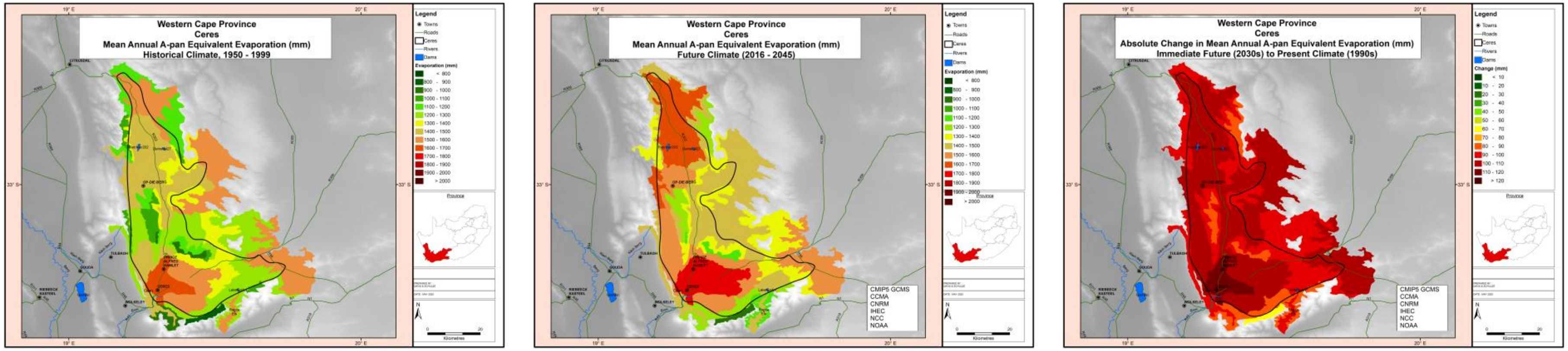
MEAN ANNUAL A-PAN EQUIVALENT EVAPORATION: RIVIERSONDEREND



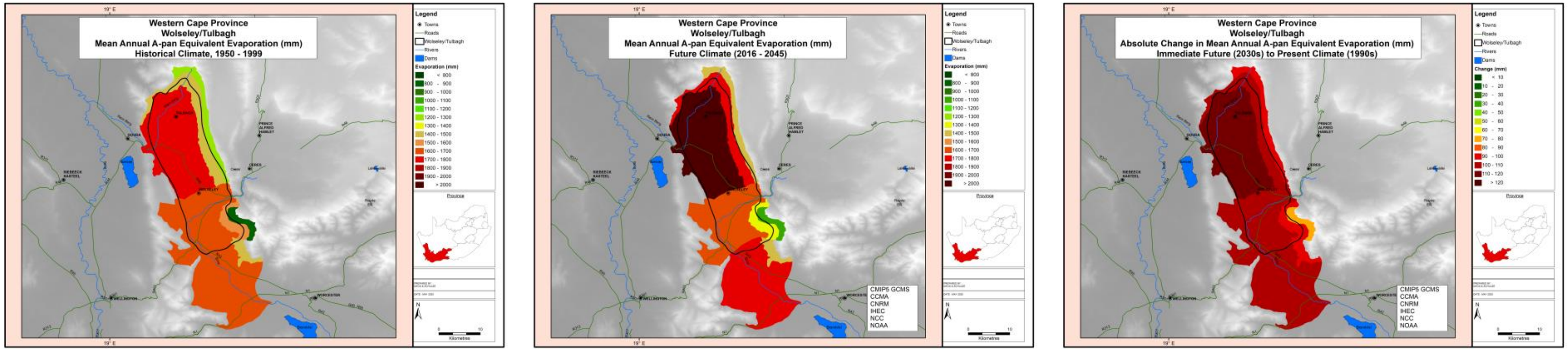




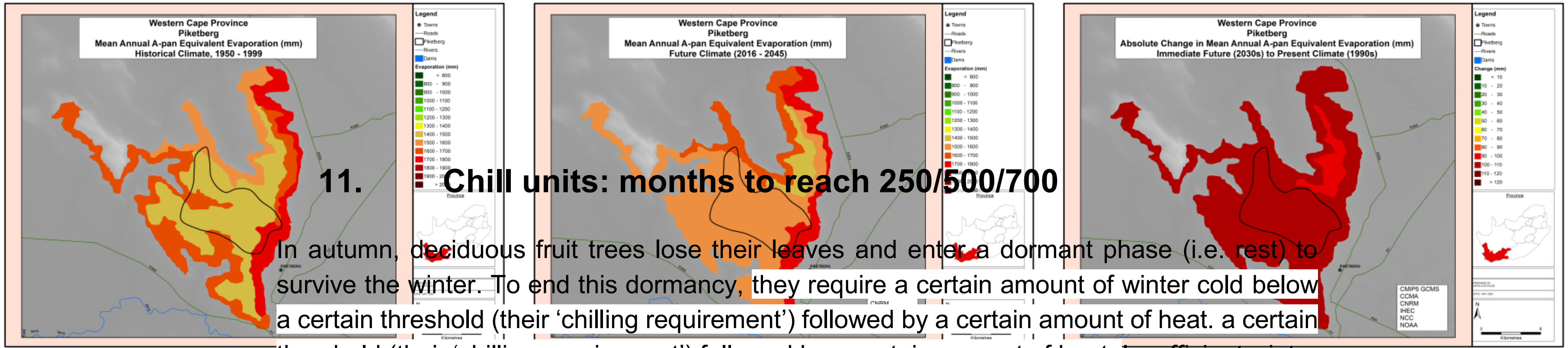
MEAN ANNUAL A-PAN EQUIVALENT EVAPORATION: CERES



MEAN ANNUAL A-PAN EQUIVALENT EVAPORATION: WOLSELEY-TULBAGH



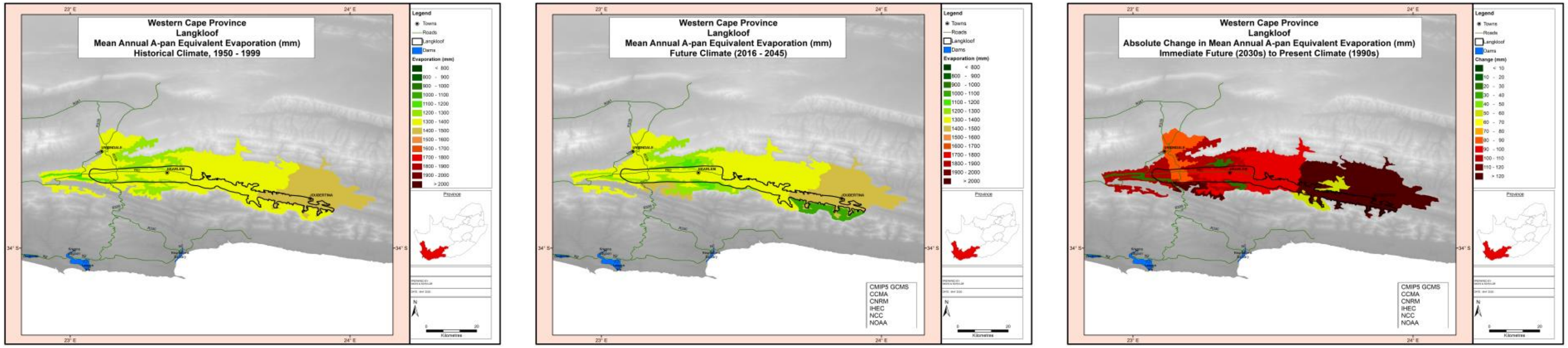
MEAN ANNUAL A-PAN EQUIVALENT EVAPORATION: PIKETBERG



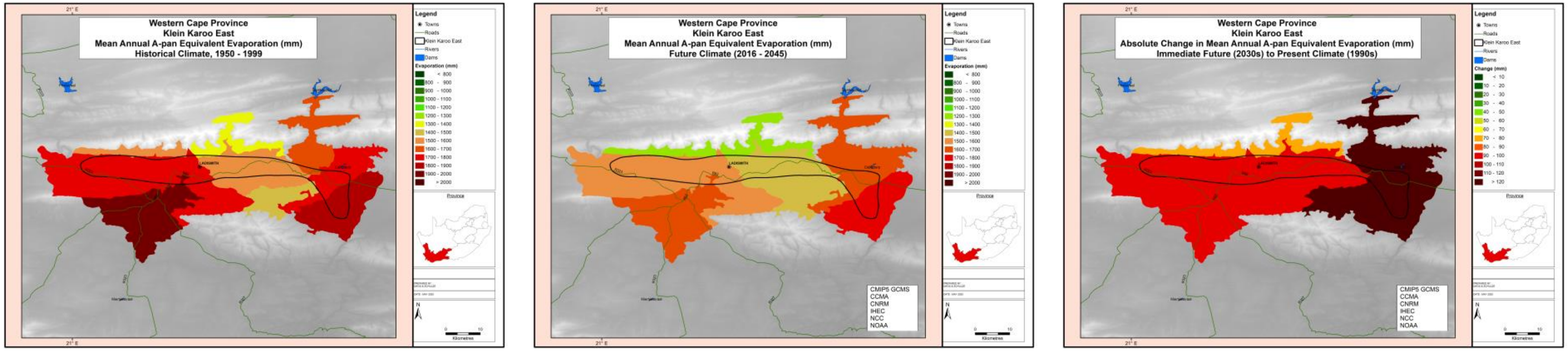
11. Chill units: months to reach 250/500/700

In autumn, deciduous fruit trees lose their leaves and enter a dormant phase (i.e. rest) to survive the winter. To end this dormancy, they require a certain amount of winter cold below a certain threshold (their ‘chilling requirement’) followed by a certain amount of heat. a certain threshold (their ‘chilling requirement’) followed by a certain amount of heat. Insufficient winter chilling may result in delayed foliation, reduced fruit set, and reduced fruit quality. The required amount of chilling for completion of the rest period varies between species and cultivars. Many chill accumulation models have been formulated, most of them requiring observed or estimated hourly temperatures. For this study, the Utah Chill Unit model, with its South African

MEAN ANNUAL A-PAN EQUIVALENT EVAPORATION: LANGKLOOF



MEAN ANNUAL A-PAN EQUIVALENT EVAPORATION: KLEIN KAROO EAST



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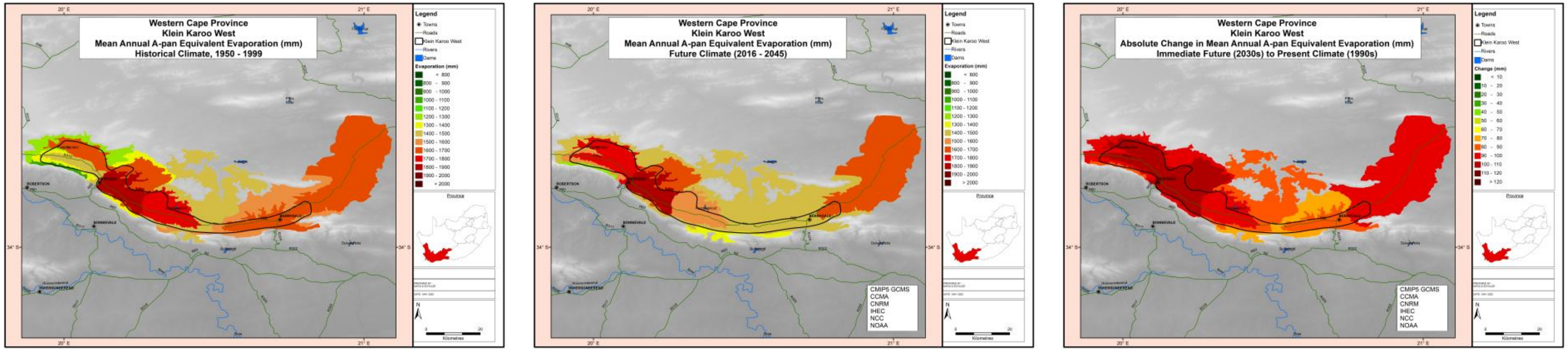
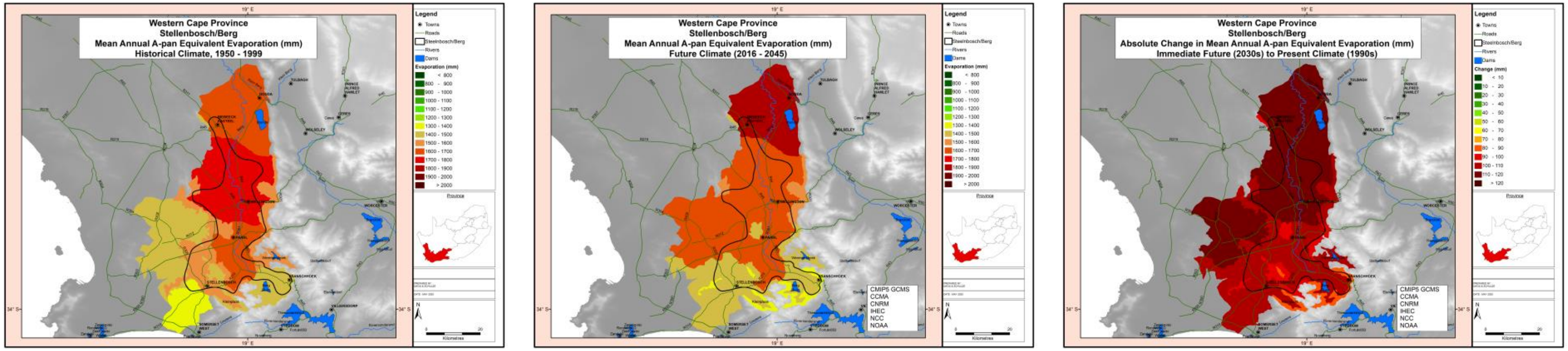


MEAN ANNUAL A-PAN EQUIVALENT EVAPORATION: STELLENBOSCH-BERG



MEAN ANNUAL A-PAN EQUIVALENT EVAPORATION: BREEDE

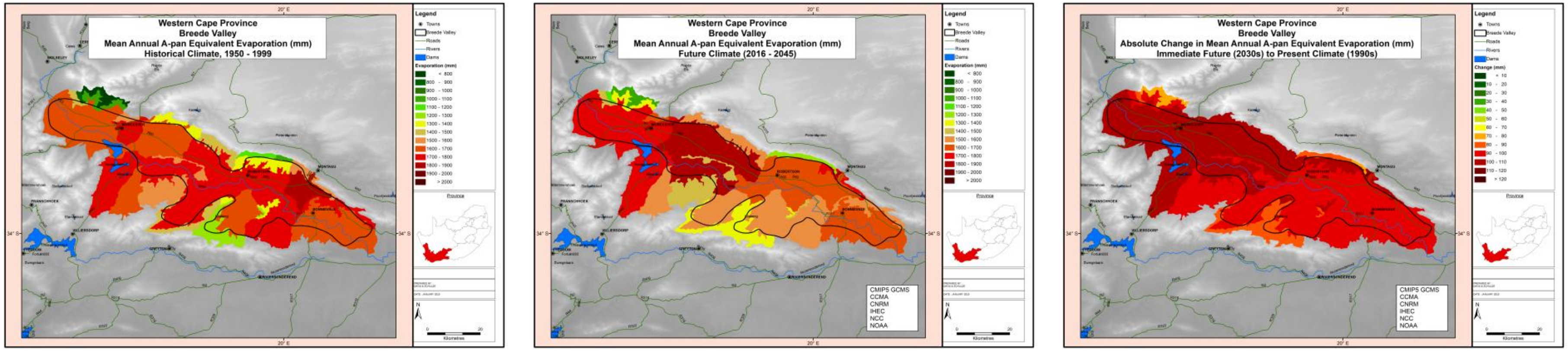
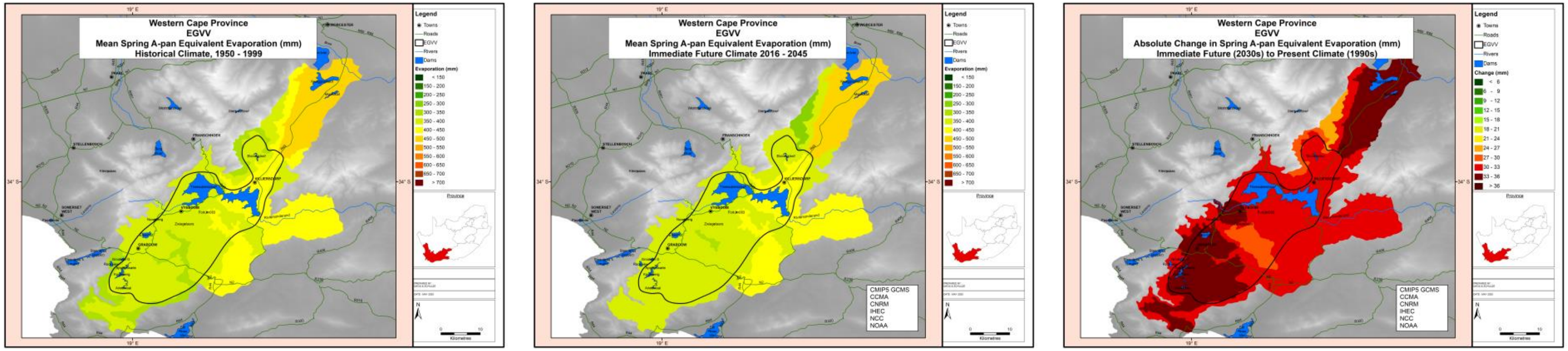


Figure 8. Mean ANNUAL A-pan equivalent reference potential evaporation (in mm) under historical climatic conditions (left), under projected climatic conditions for the immediate future (middle column), and projected increases (in mm) from the present to immediate future climates (right) for each of the eleven pome and stone fruit production regions. The immediate future maps are derived from multiple CMIP5 GCMs.

MEAN SPRING A-PAN EQUIVALENT EVAPORATION: EGVV



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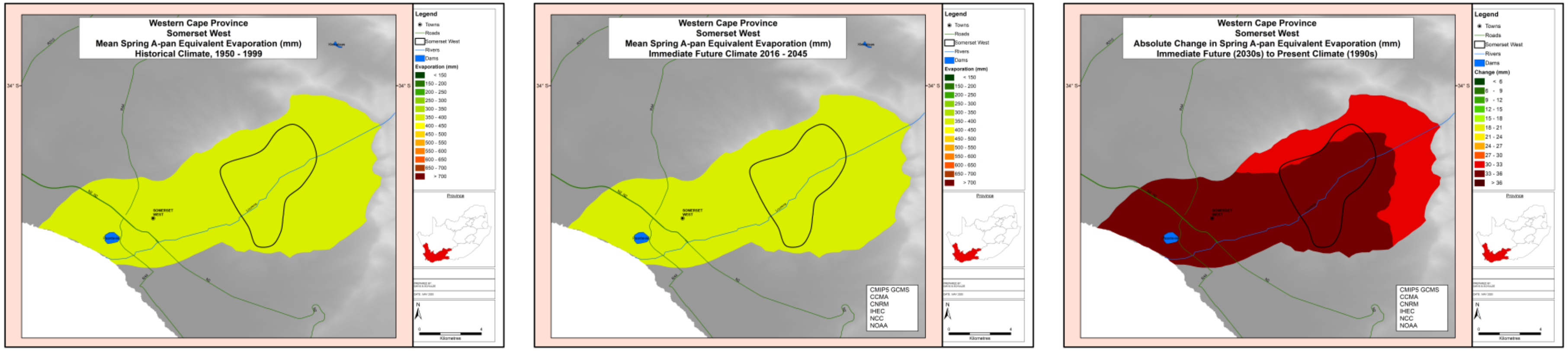

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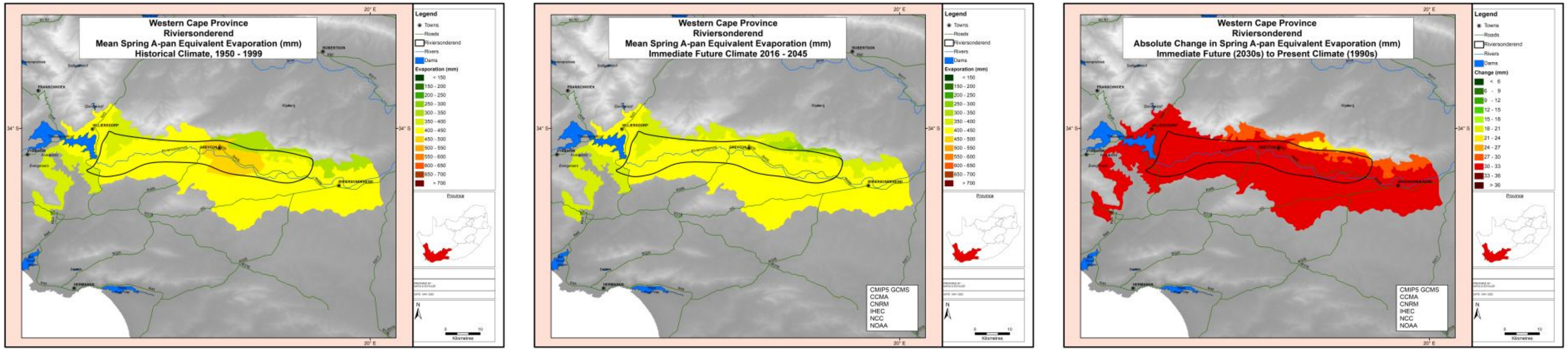
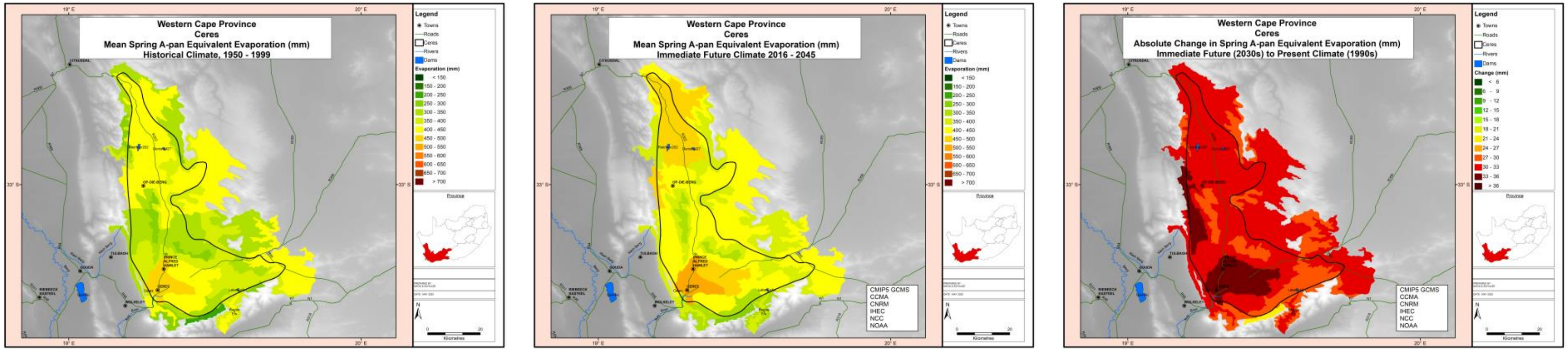
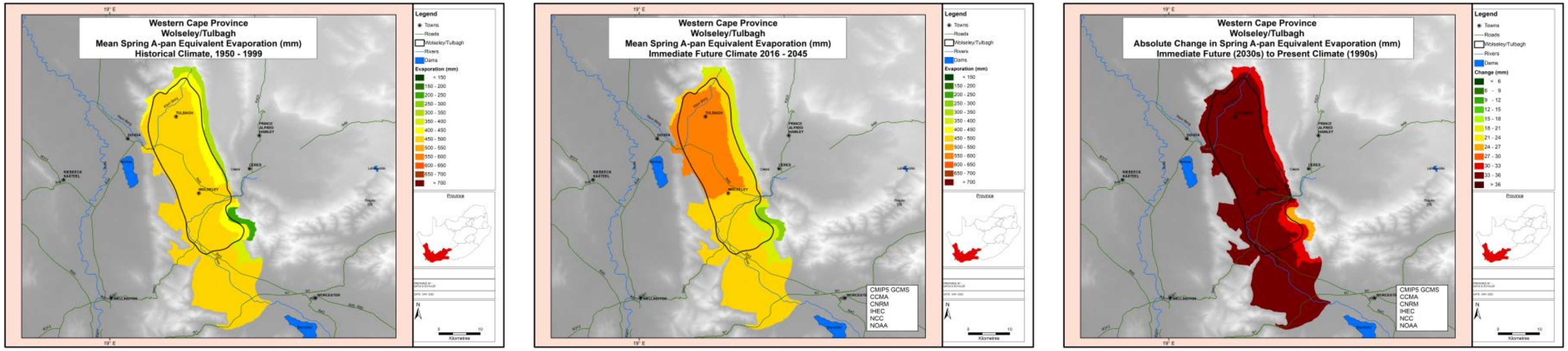


MEAN SPRING A-PAN EQUIVALENT EVAPORATION: CERES



MEAN SPRING A-PAN EQUIVALENT EVAPORATION: WOLSELEY-TULBAGH



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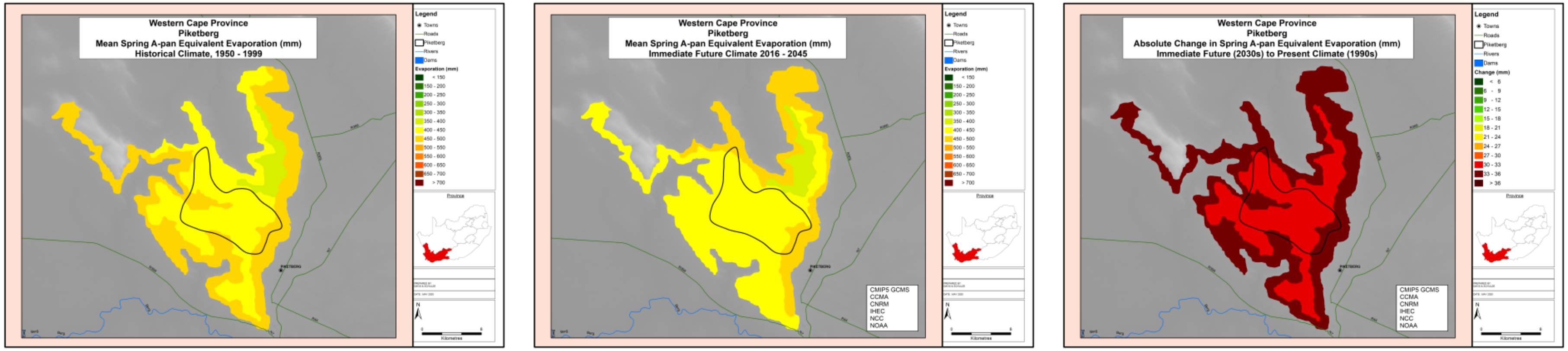
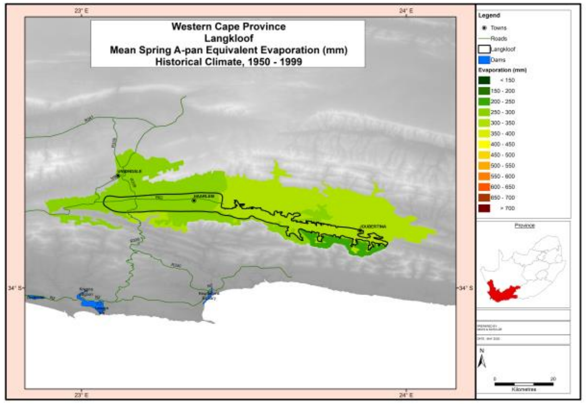
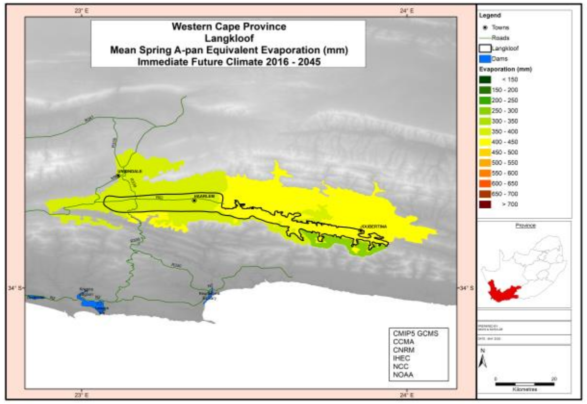
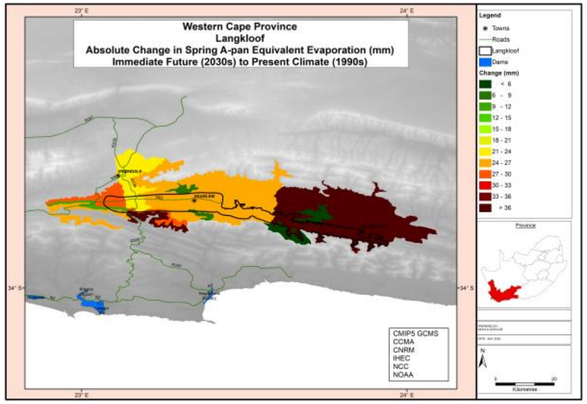


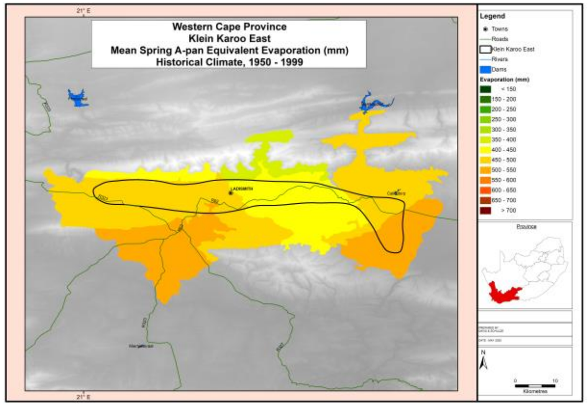
MEAN SPRING A-PAN EQUIVALENT EVAPORATION: LANGKLOOF

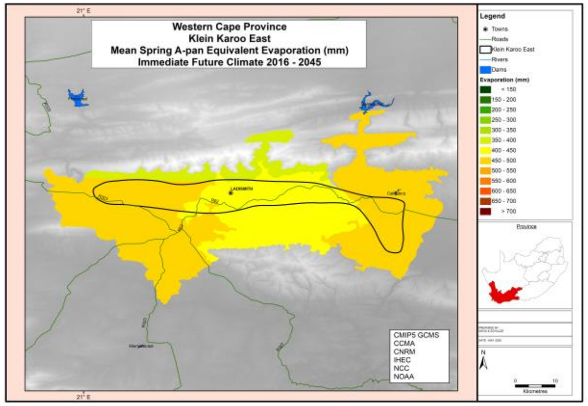


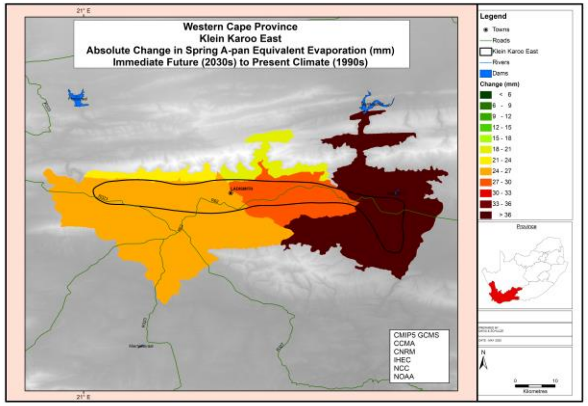




MEAN SPRING A-PAN EQUIVALENT EVAPORATION: KLEIN KAROO EAST







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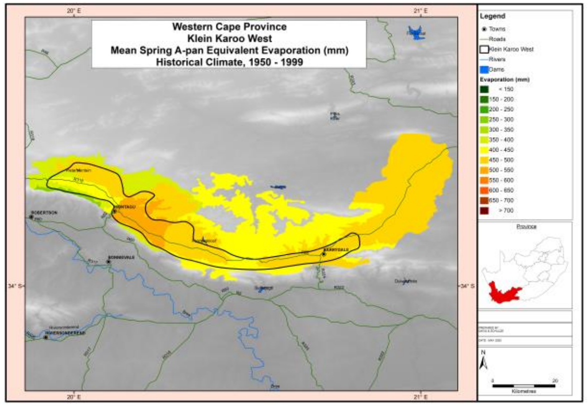
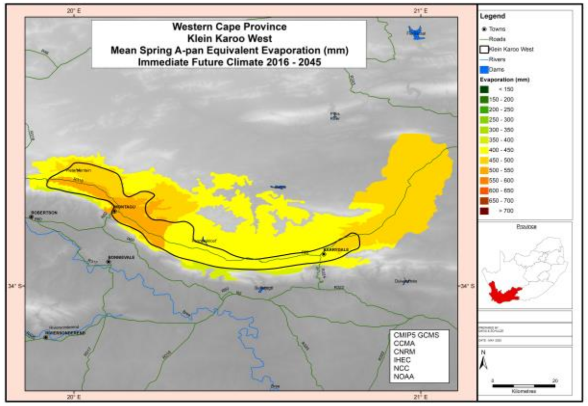
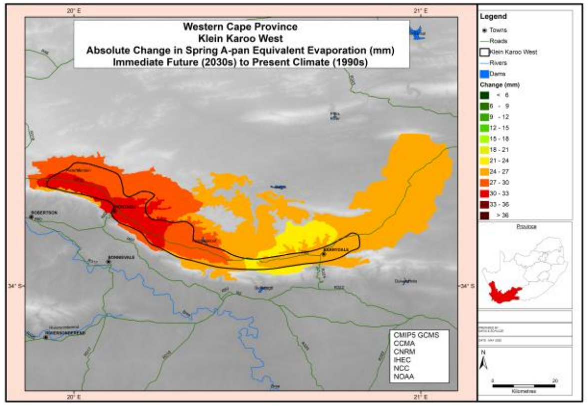
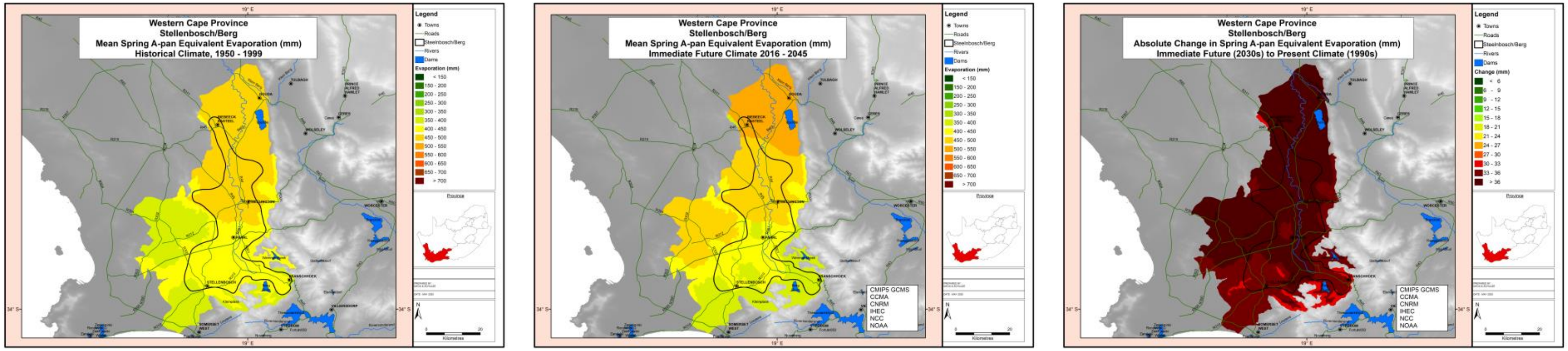






MEAN SPRING A-PAN EQUIVALENT EVAPORATION: STELLENBOSCH-BERG



MEAN SPRING A-PAN EQUIVALENT EVAPORATION: BREEDE

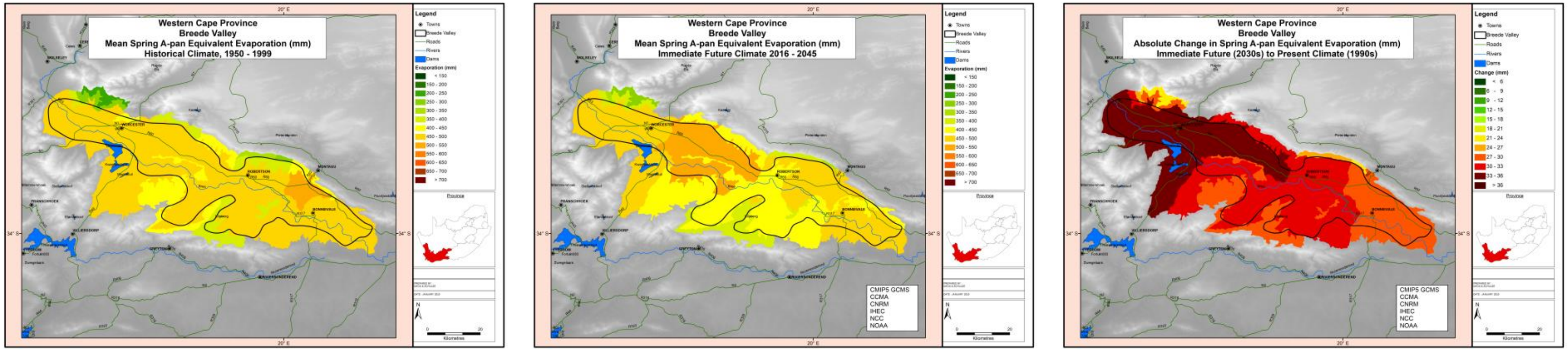
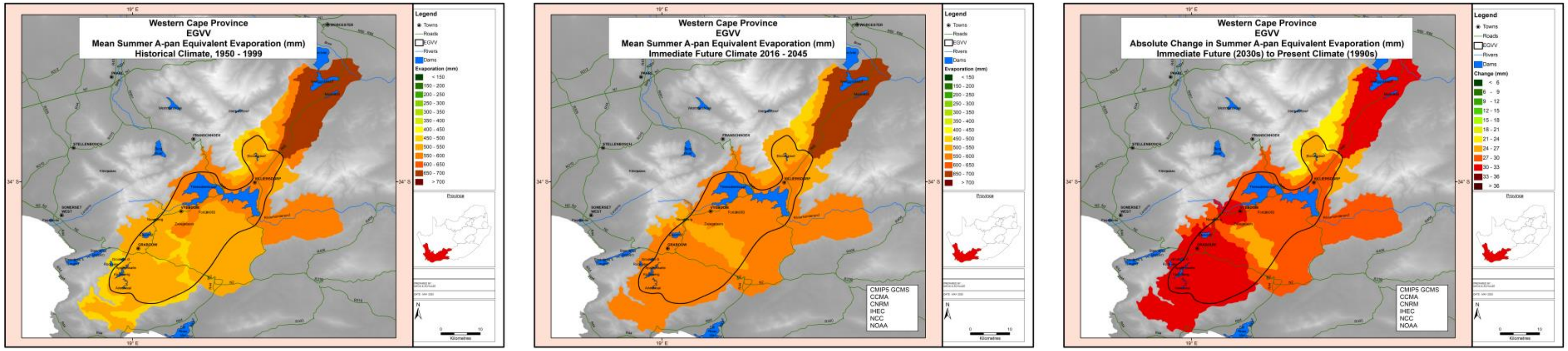
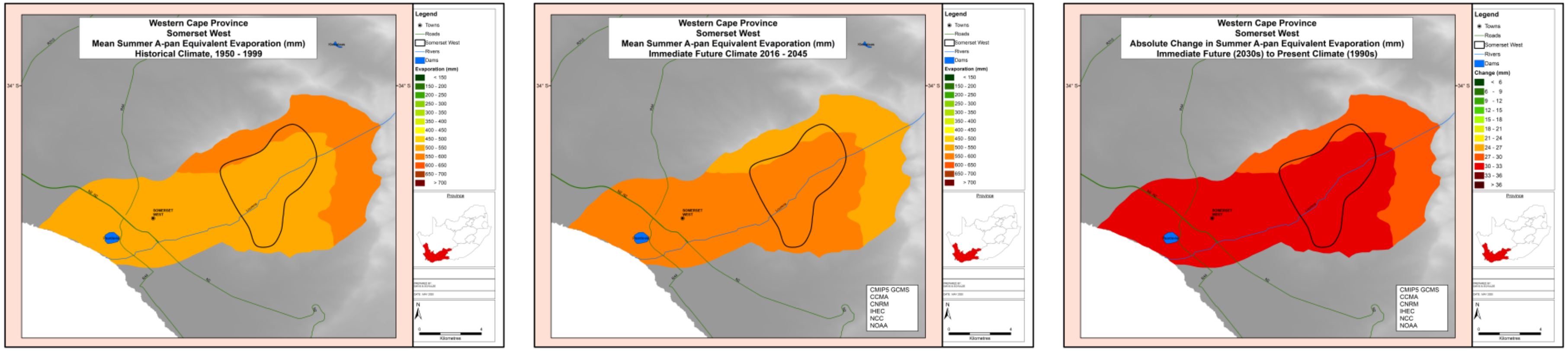


Figure 9. Mean A-pan equivalent reference potential evaporation (in mm) for SPRING under historical climatic conditions (left column),under projected climatic conditions for the immediate future (middle column), and projected increases (in mm) from the present to immediate future climates (right column) for each of the eleven pome and stone fruit production regions. The immediate future maps are derived from multiple CMIP5 GCMs.

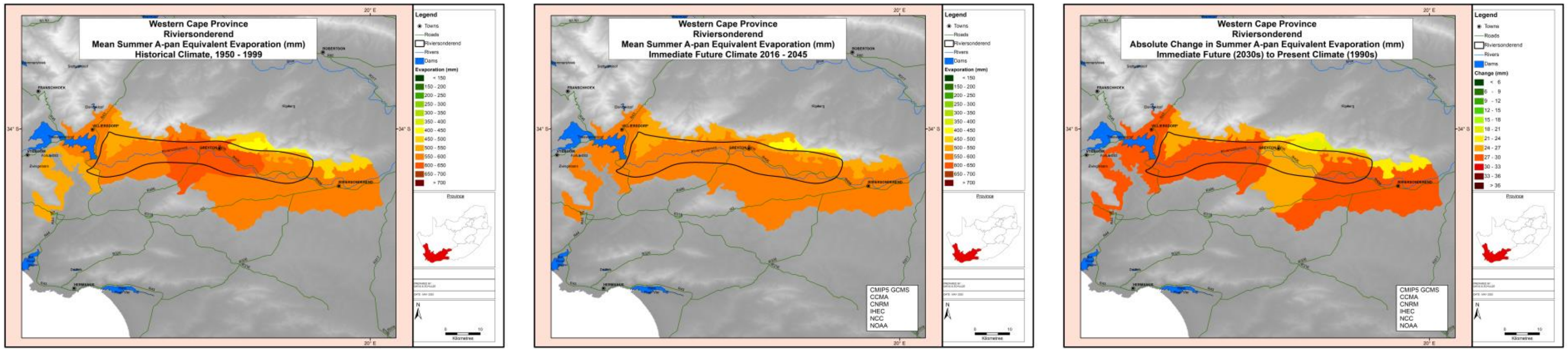
MEAN SUMMER A-PAN EQUIVALENT EVAPORATION: EGVV



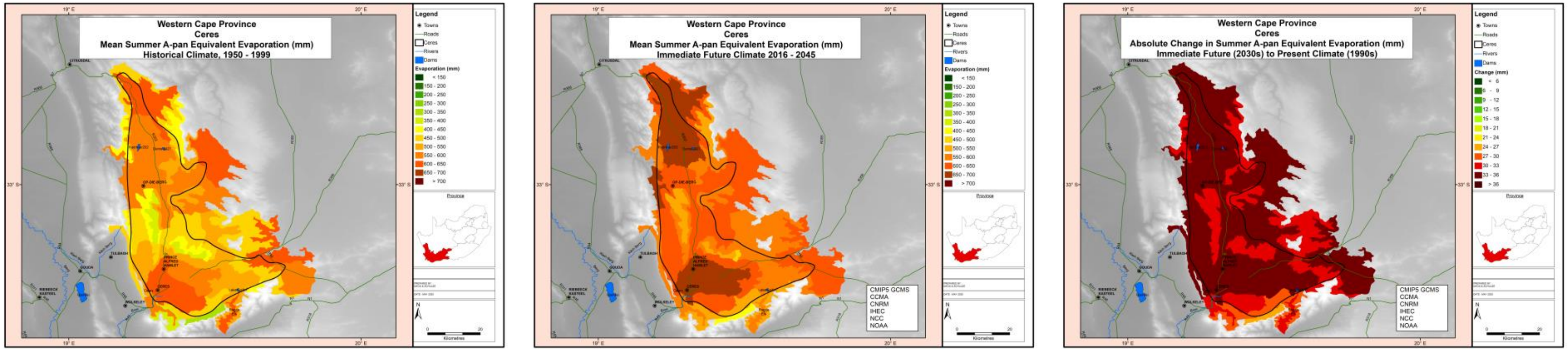
MEAN SUMMER A-PAN EQUIVALENT EVAPORATION: SOMERSET WEST



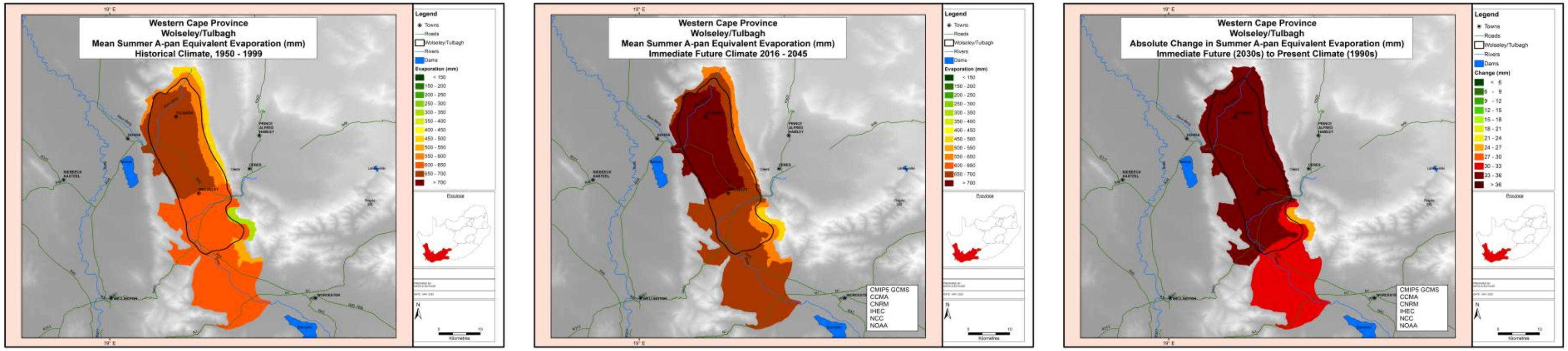
MEAN SUMMER A-PAN EQUIVALENT EVAPORATION: RIVIERSONDEREND



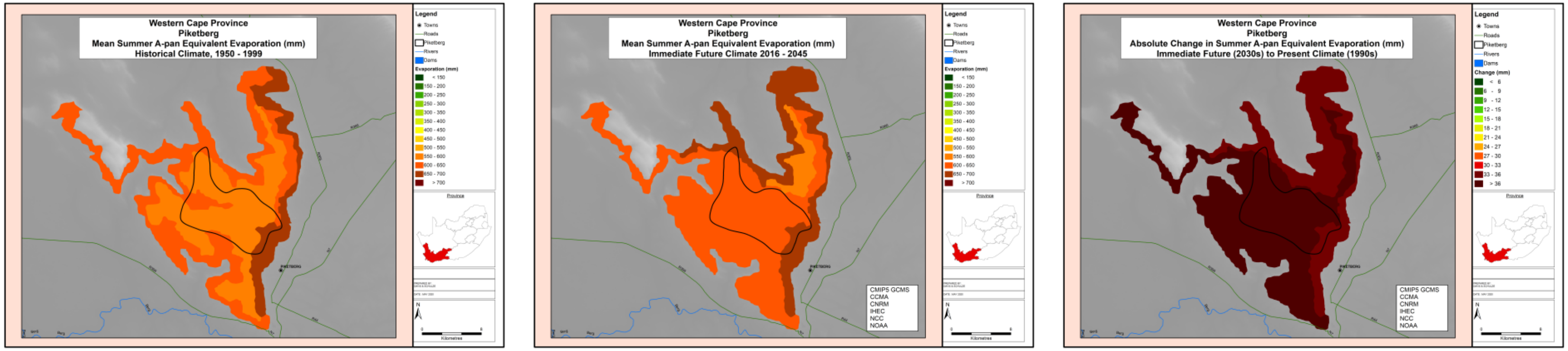
MEAN SUMMER A-PAN EQUIVALENT EVAPORATION: CERES



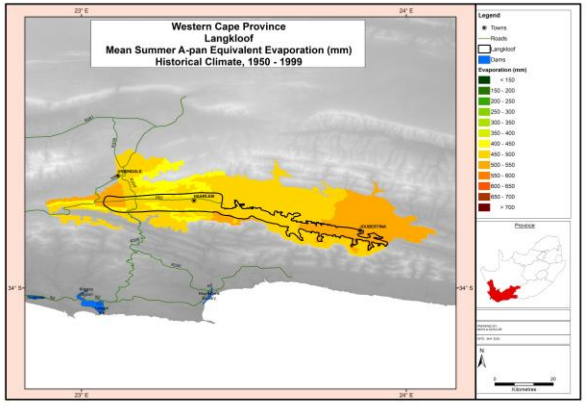
MEAN SUMMER A-PAN EQUIVALENT EVAPORATION: WOLSELEY-TULBAGH

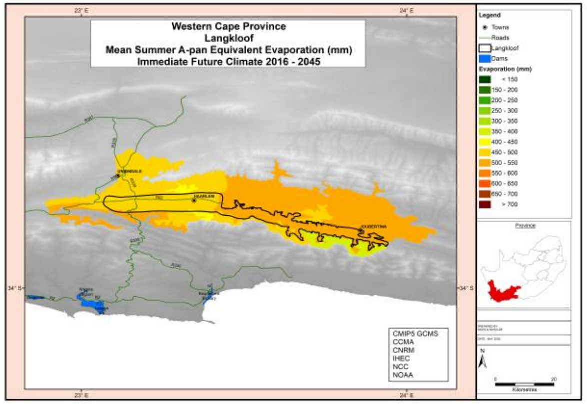


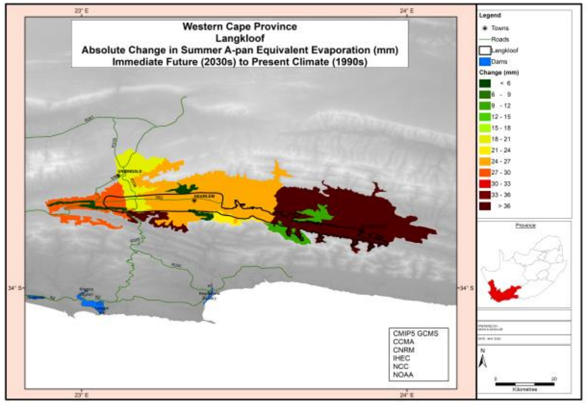
MEAN SUMMER A-PAN EQUIVALENT EVAPORATION: PIKETBERG



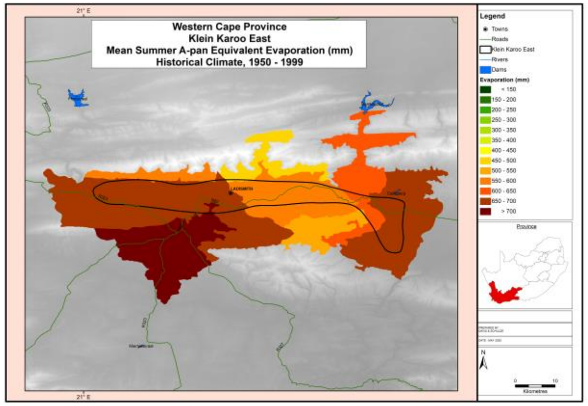
MEAN SUMMER A-PAN EQUIVALENT EVAPORATION: LANGKLOOF

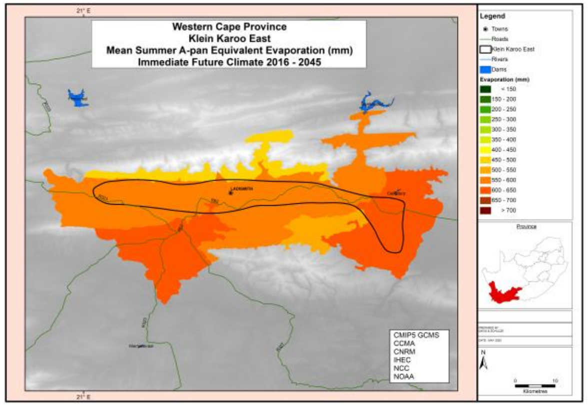


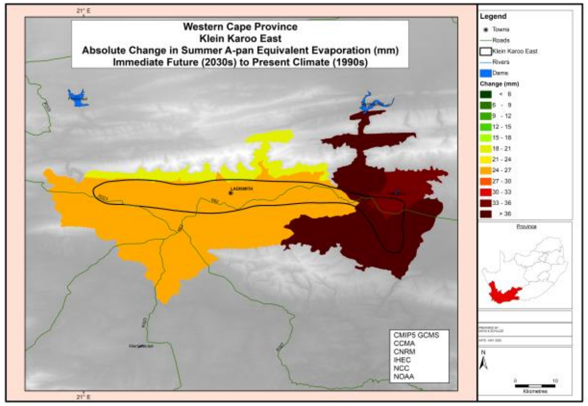




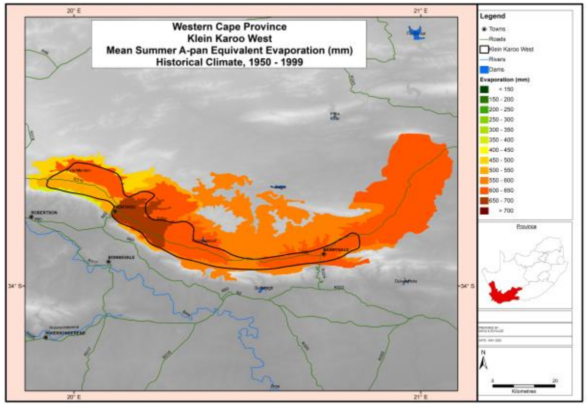
MEAN SUMMER A-PAN EQUIVALENT EVAPORATION: KLEIN KAROO EAST

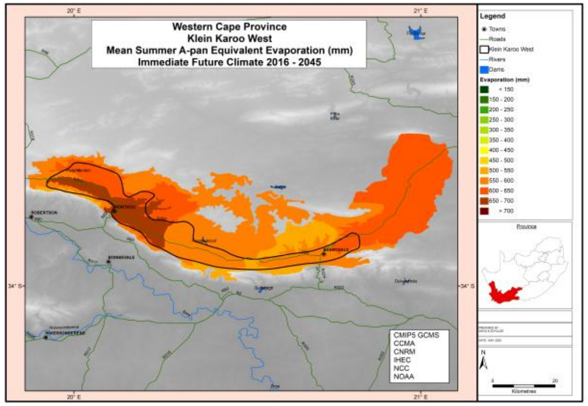


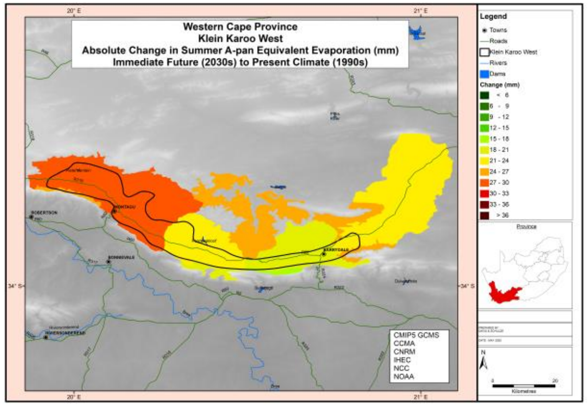




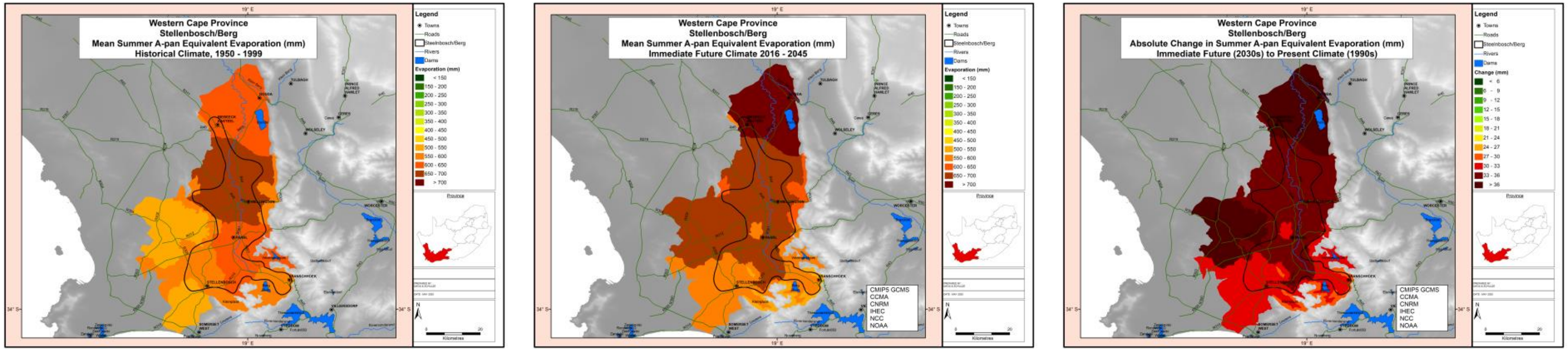
MEAN SUMMER A-PAN EQUIVALENT EVAPORATION: KLEIN KAROO WEST







MEAN SUMMER A-PAN EQUIVALENT EVAPORATION: STELLENBOSCH-BERG



MEAN SUMMER A-PAN EQUIVALENT EVAPORATION: BREEDE

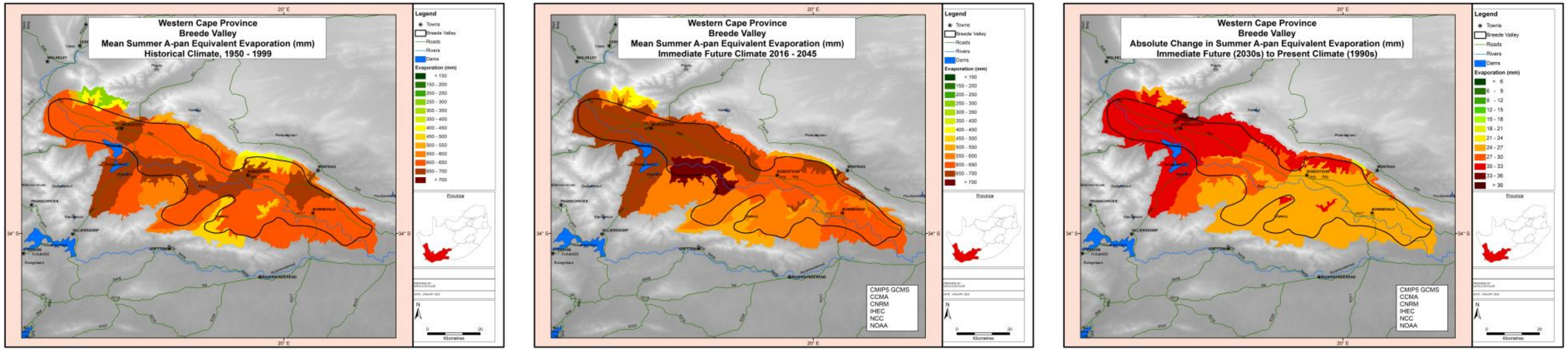
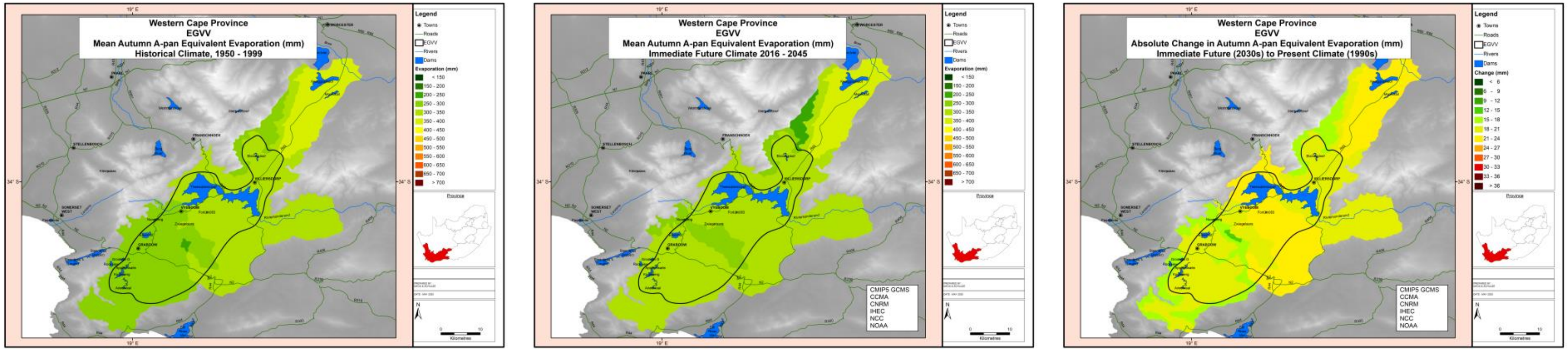
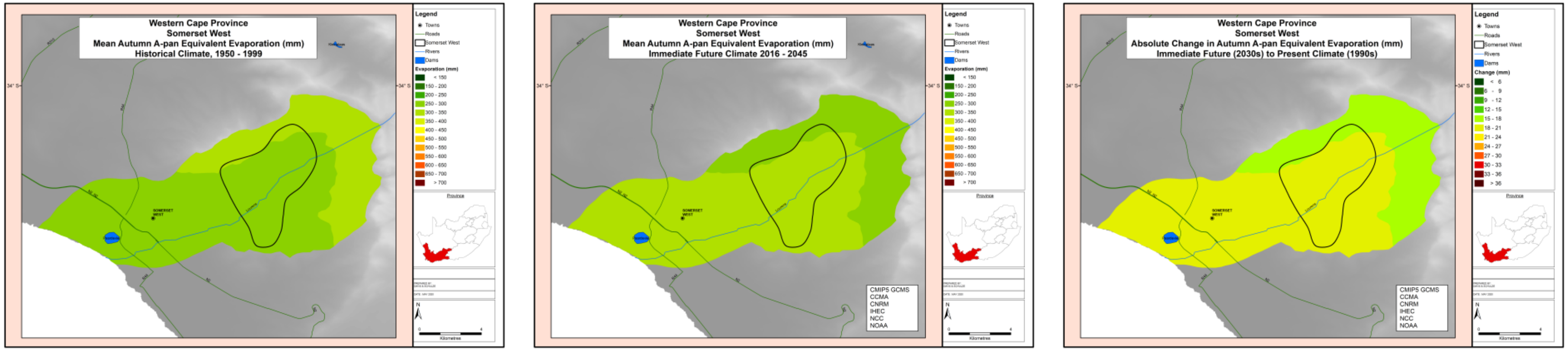


Figure 10. Mean A-pan equivalent reference potential evaporation (in mm) for SUMMER under historical climatic conditions (left column), under projected climatic conditions of the immediate future (middle column), and projected increases (in mm) from the present to immediate future climates (right column) for each of the eleven pome and stone fruit production regions. The immediate future maps are derived from multiple CMIP5 GCMs.

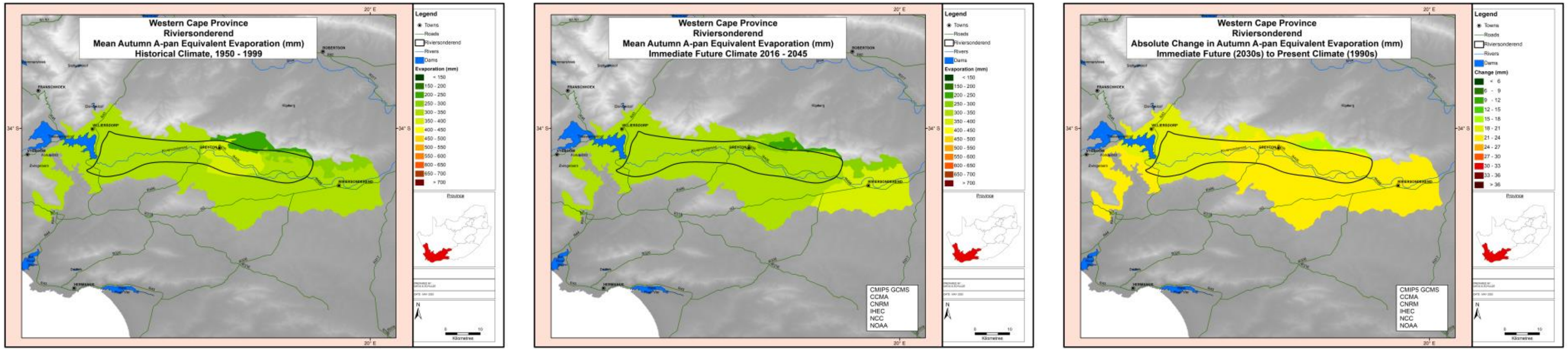
MEAN AUTUMN A-PAN EQUIVALENT EVAPORATION: EGVV



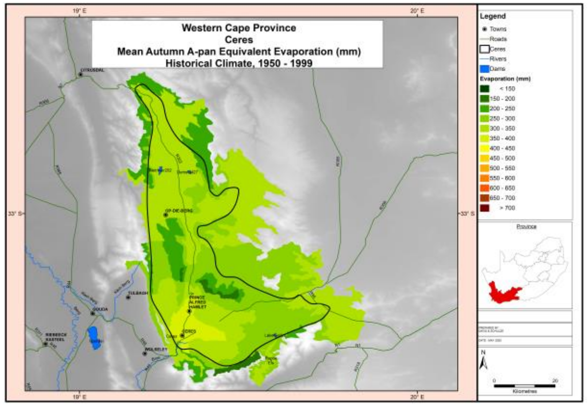
MEAN AUTUMN A-PAN EQUIVALENT EVAPORATION: SOMERSET WEST

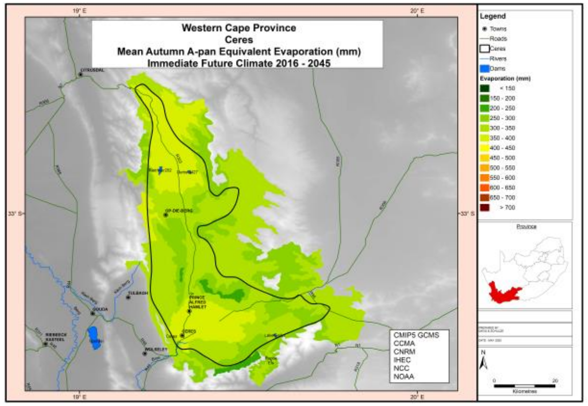


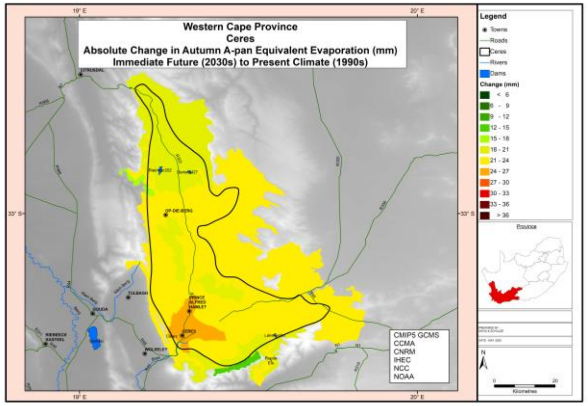
MEAN AUTUMN A-PAN EQUIVALENT EVAPORATION: RIVIERSONDEREND



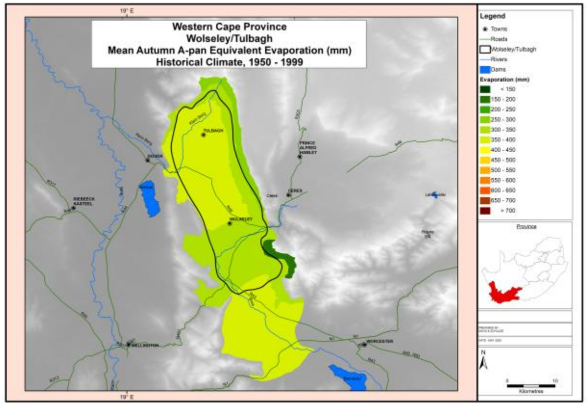
MEAN AUTUMN A-PAN EQUIVALENT EVAPORATION: CERES

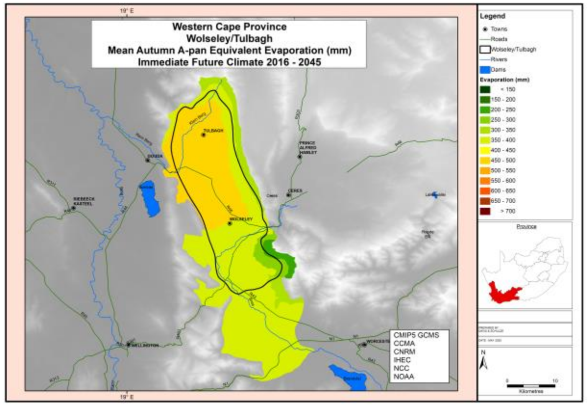


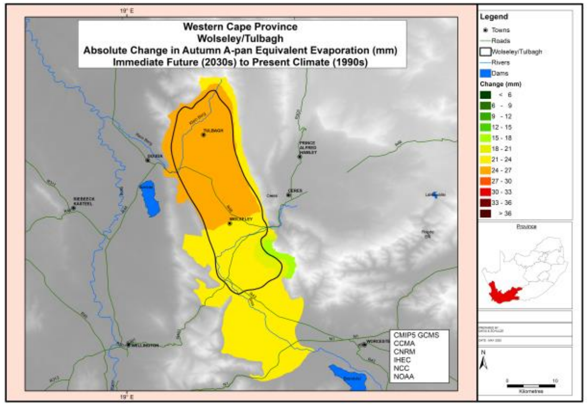




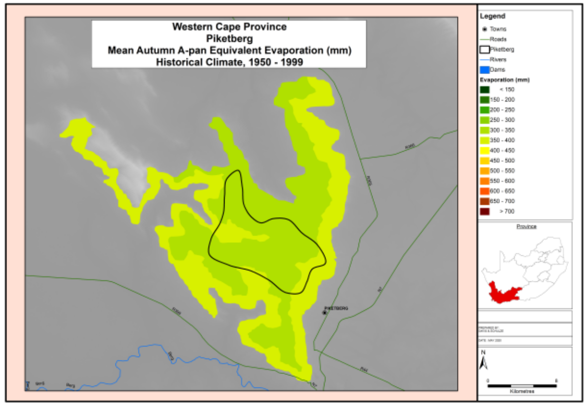
MEAN AUTUMN A-PAN EQUIVALENT EVAPORATION: WOLSELEY-TULBAGH

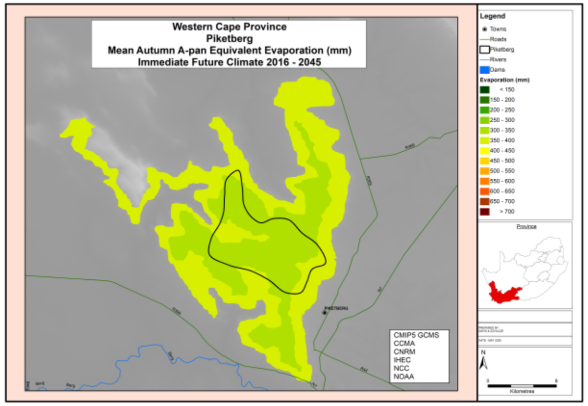


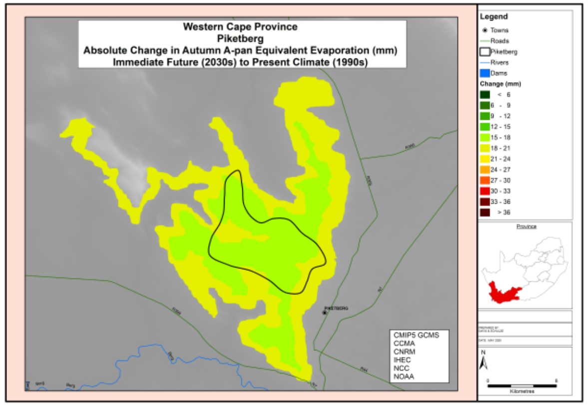




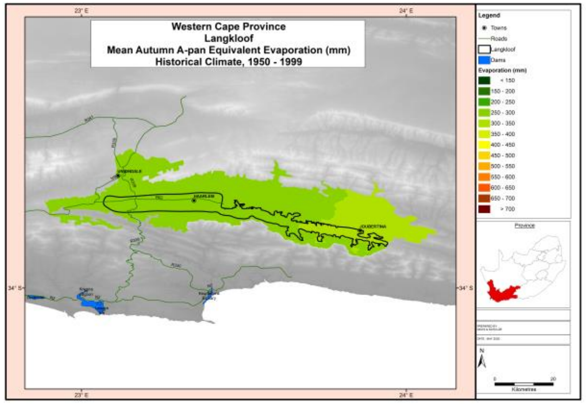
MEAN AUTUMN A-PAN EQUIVALENT EVAPORATION: PIKETBERG

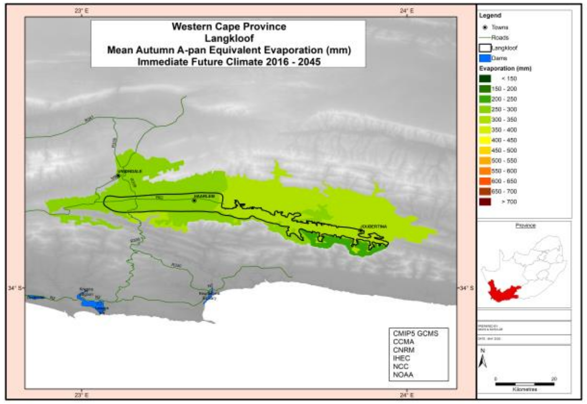


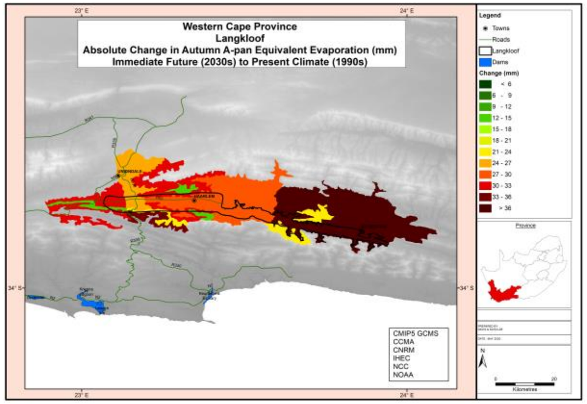




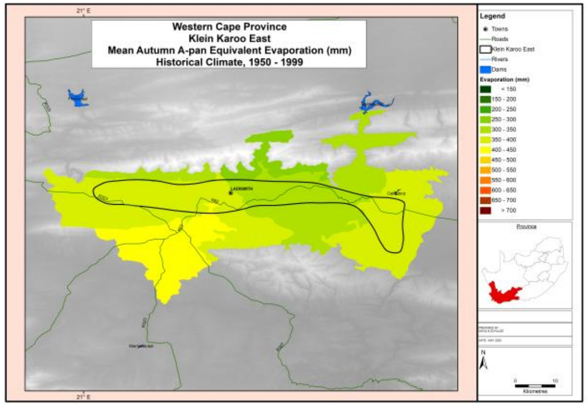
MEAN AUTUMN A-PAN EQUIVALENT EVAPORATION: LANGKLOOF

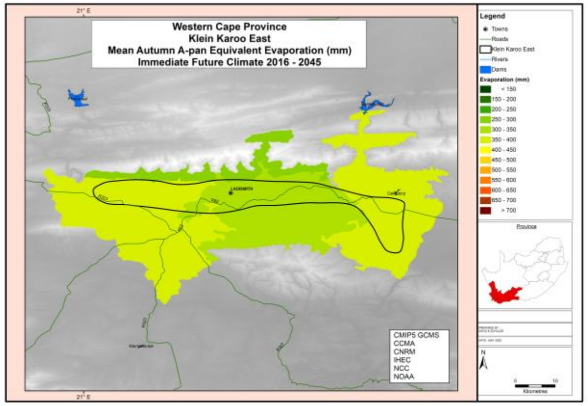


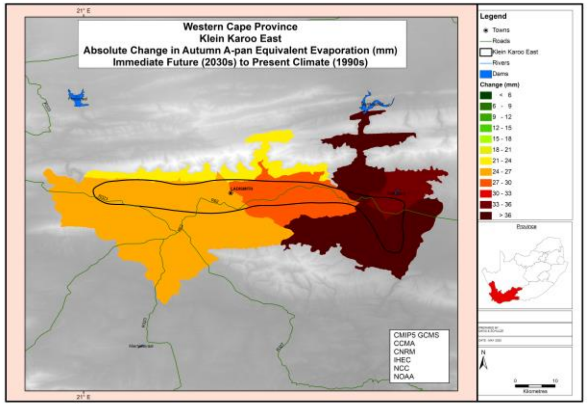




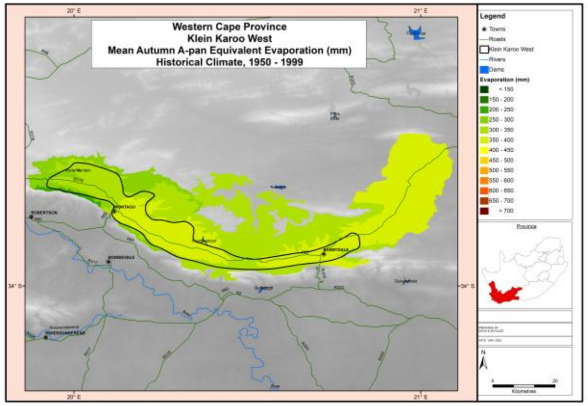
MEAN AUTUMN A-PAN EQUIVALENT EVAPORATION: KLEIN KAROO EAST

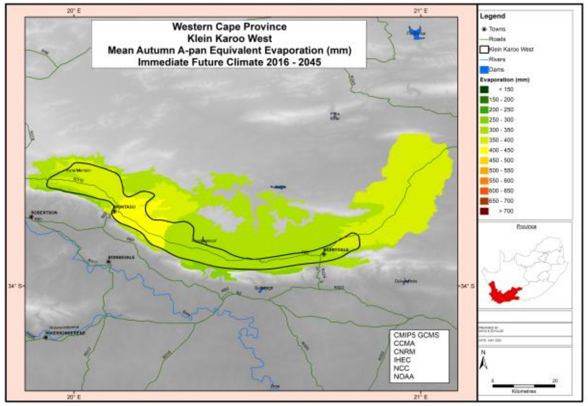


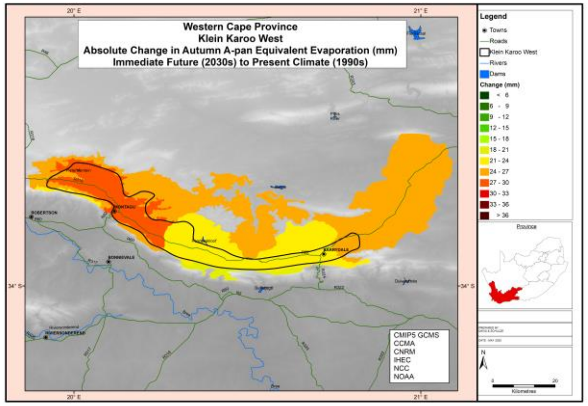




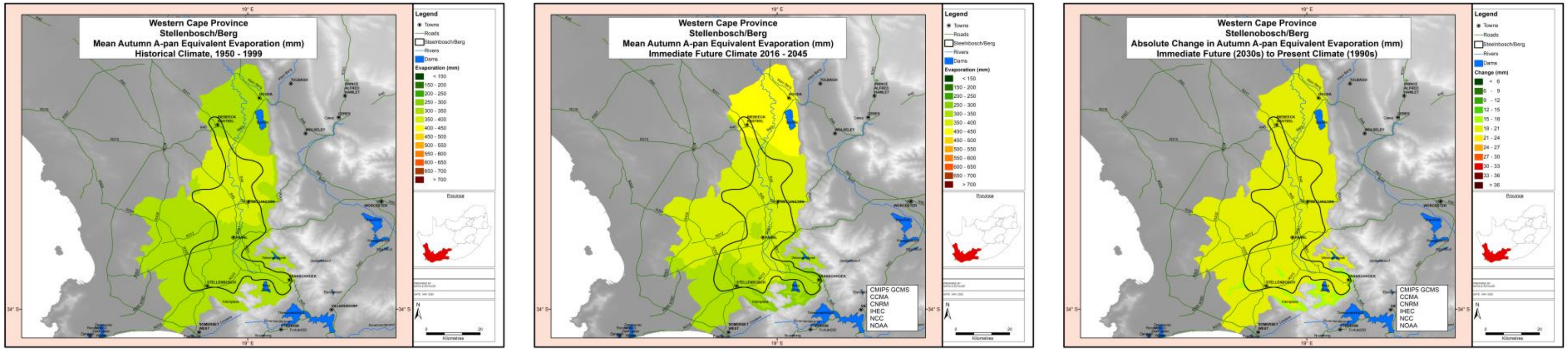
MEAN AUTUMN A-PAN EQUIVALENT EVAPORATION: KLEIN KAROO WEST







MEAN AUTUMN A-PAN EQUIVALENT EVAPORATION: STELLENBOSCH-BERG



MEAN AUTUMN A-PAN EQUIVALENT EVAPORATION: BREEDE

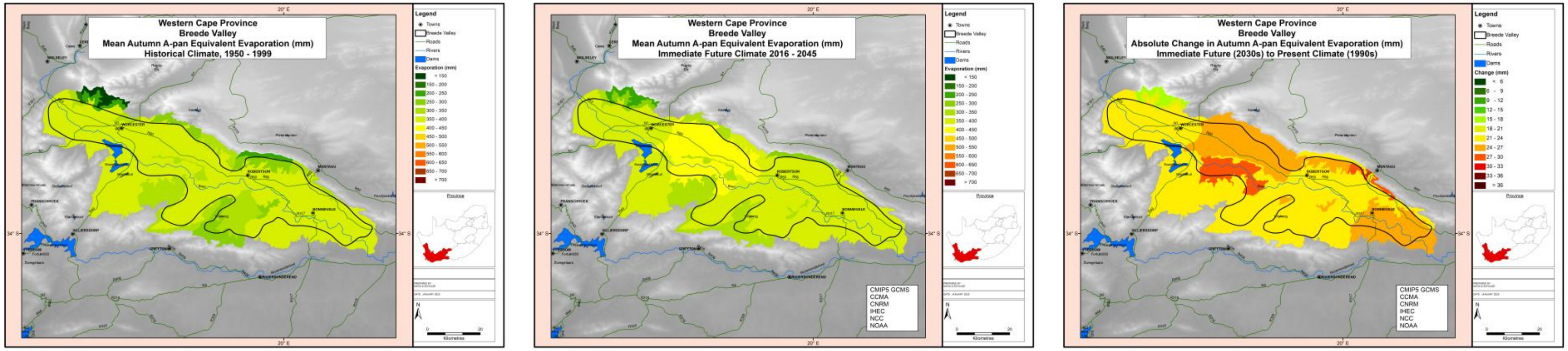
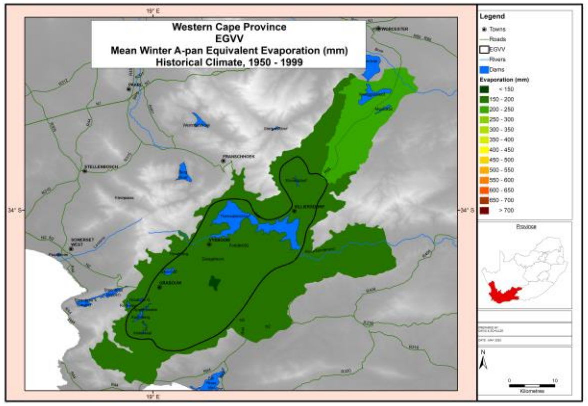
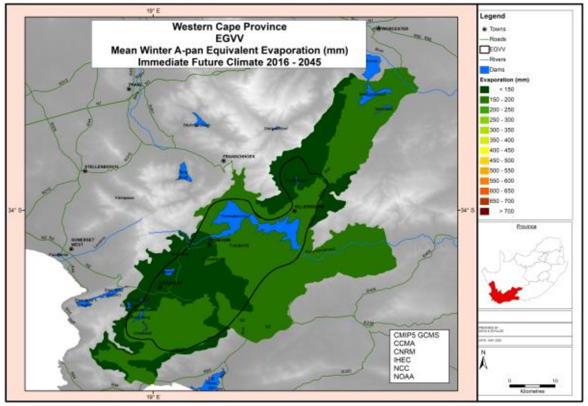
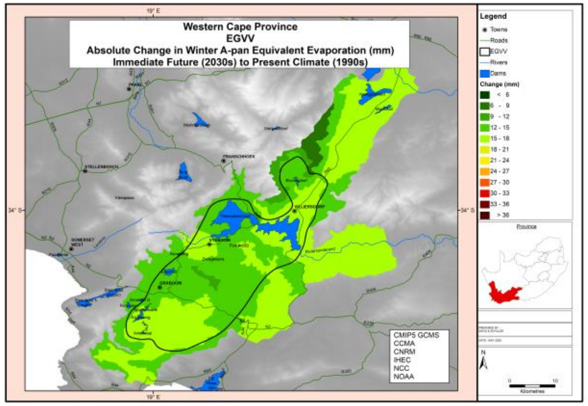


Figure 11. Mean A-pan equivalent reference potential evaporation (in mm) for AUTUMN under historical climatic conditions (left column), projected climatic conditions of the immediate future (middle column), and projected increases (in mm) from the present to immediate future climates (right column) for each of the eleven pome and stone fruit production regions. The immediate future maps are derived from multiple CMIP5 GCMs.

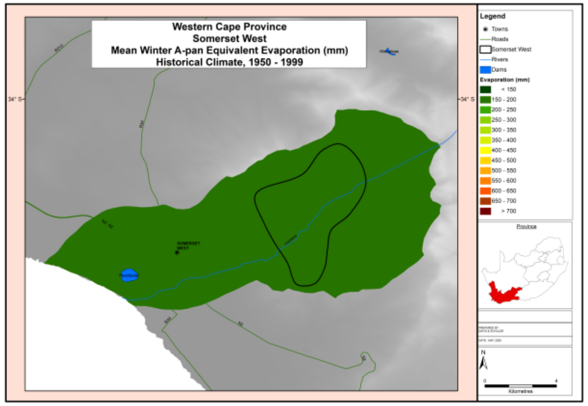
MEAN WINTER A-PAN EQUIVALENT EVAPORATION: EGVV

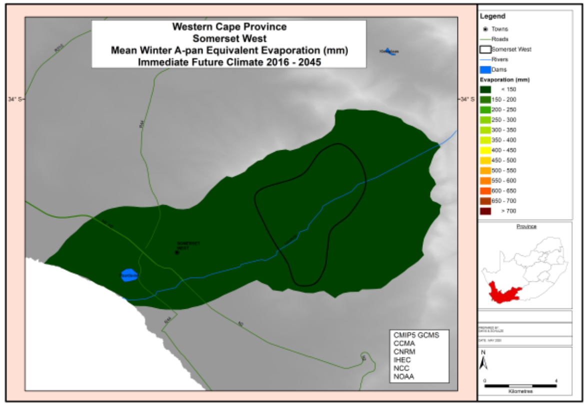


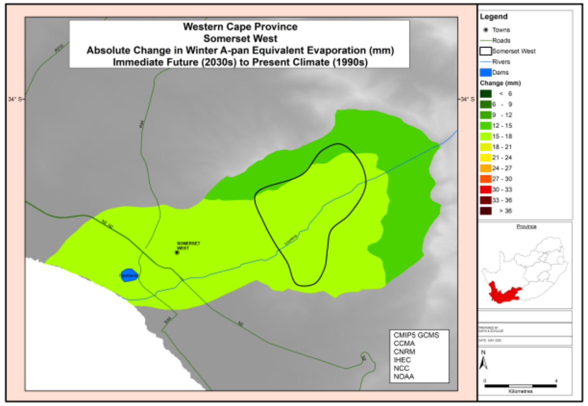




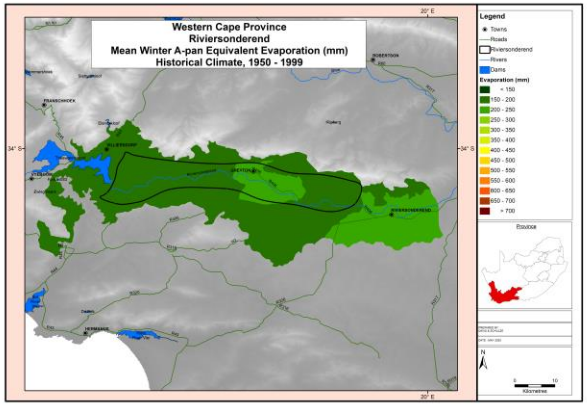
MEAN WINTER A-PAN EQUIVALENT EVAPORATION: SOMERSET WEST

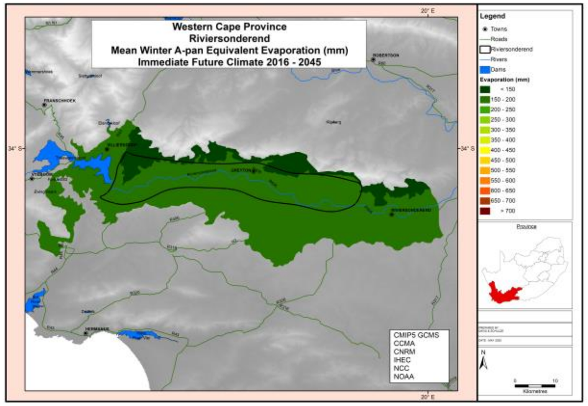


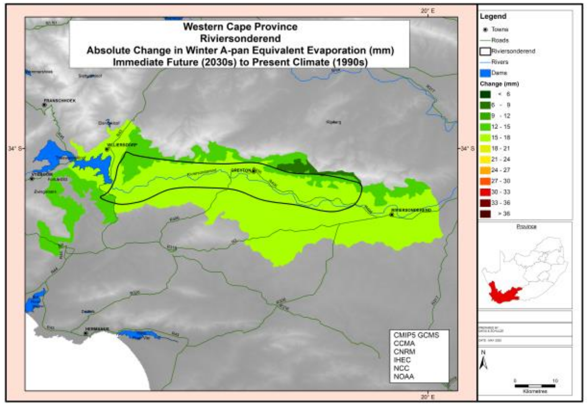




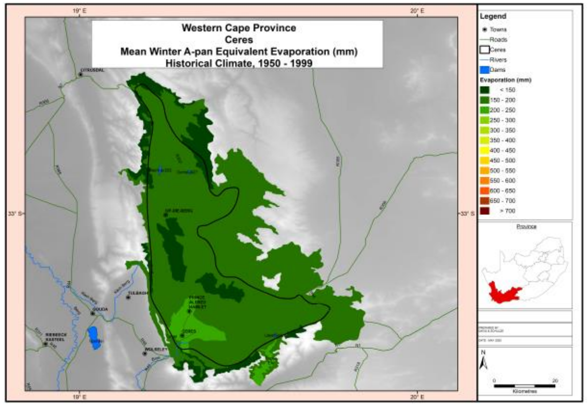
MEAN WINTER A-PAN EQUIVALENT EVAPORATION: RIVIERSONDEREND

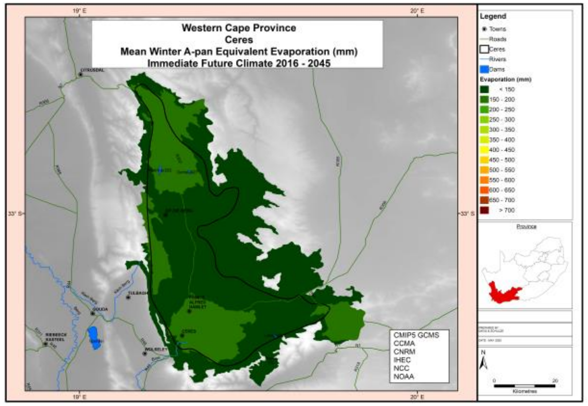


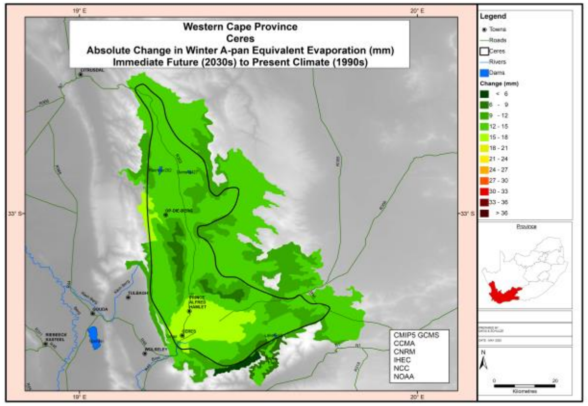




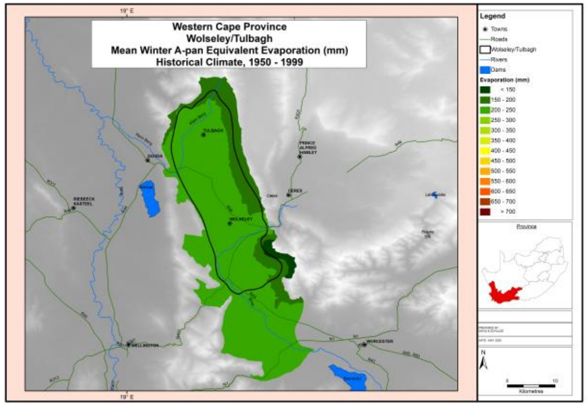
MEAN WINTER A-PAN EQUIVALENT EVAPORATION: CERES

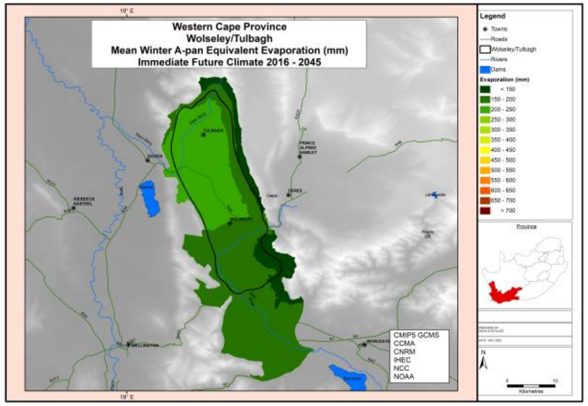


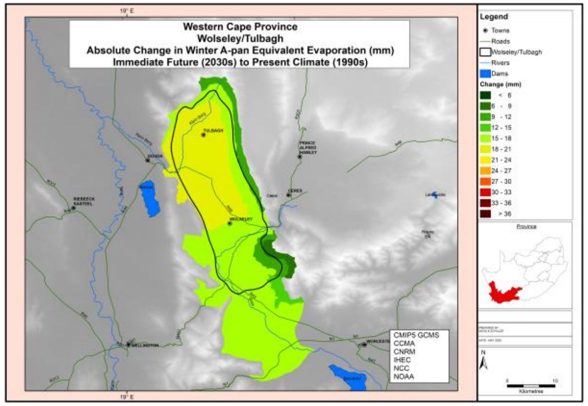




MEAN WINTER A-PAN EQUIVALENT EVAPORATION: WOLSELEY-TULBAGH







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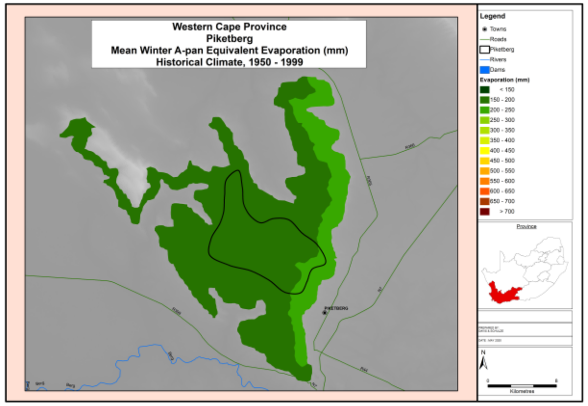
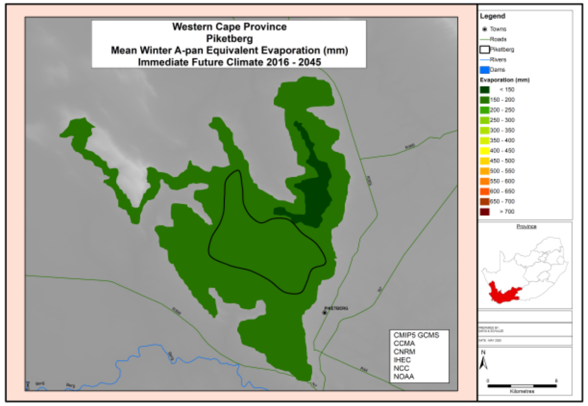
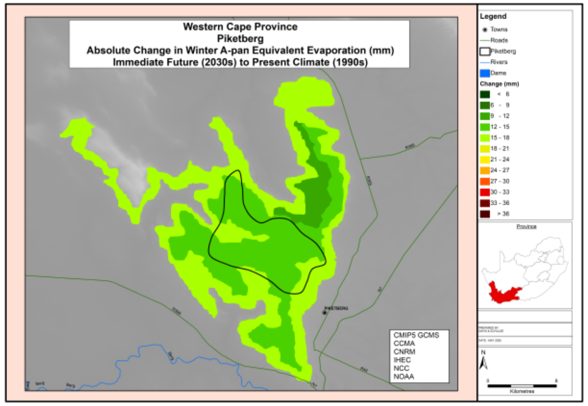
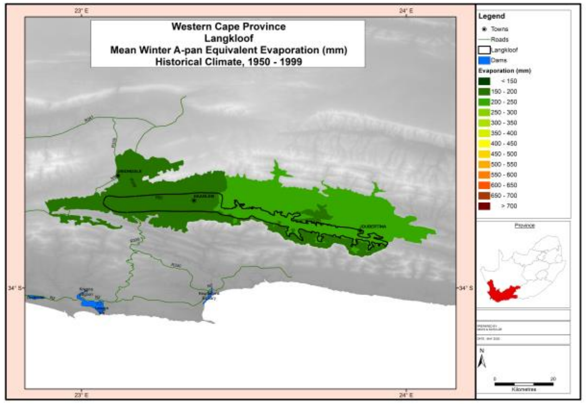
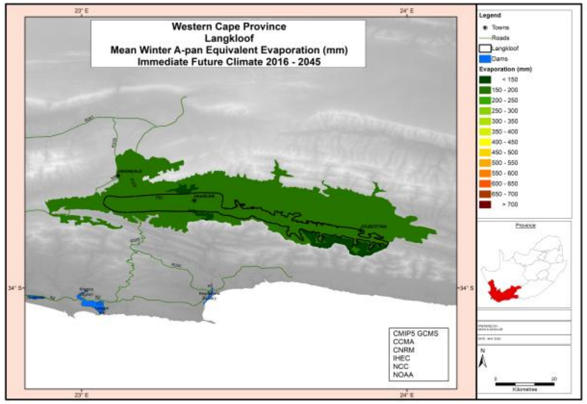


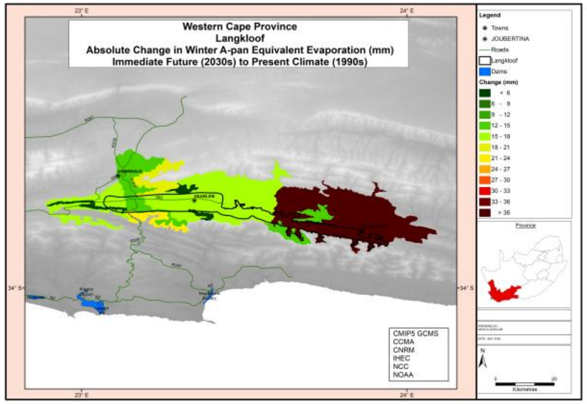




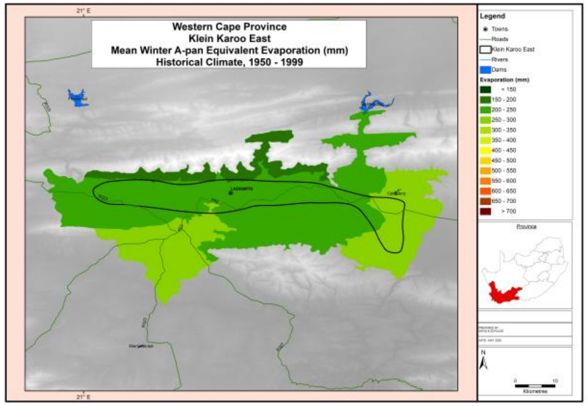
MEAN WINTER A-PAN EQUIVALENT EVAPORATION: LANGKLOOF

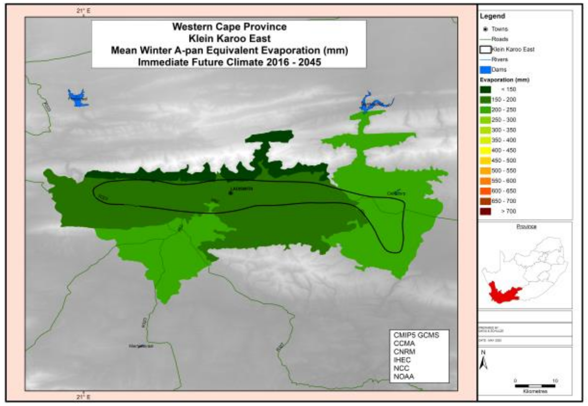


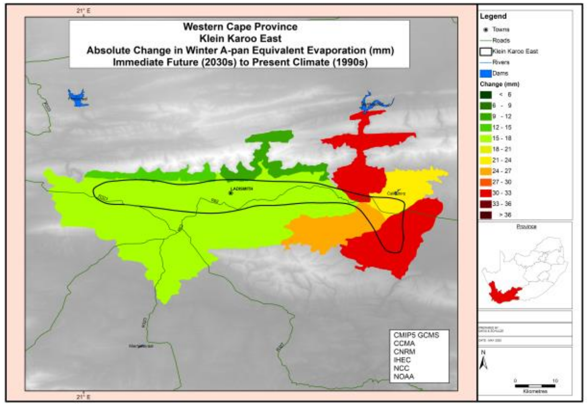




MEAN WINTER A-PAN EQUIVALENT EVAPORATION: KLEIN KAROO EAST







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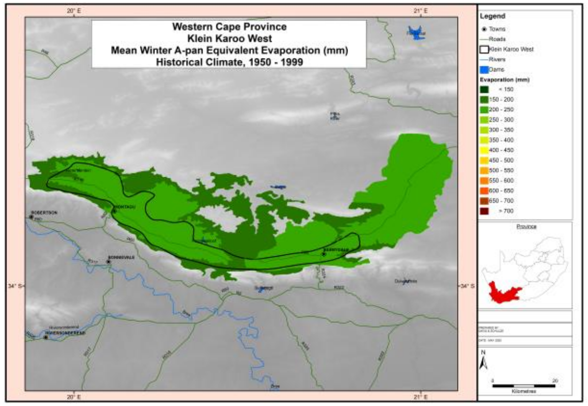
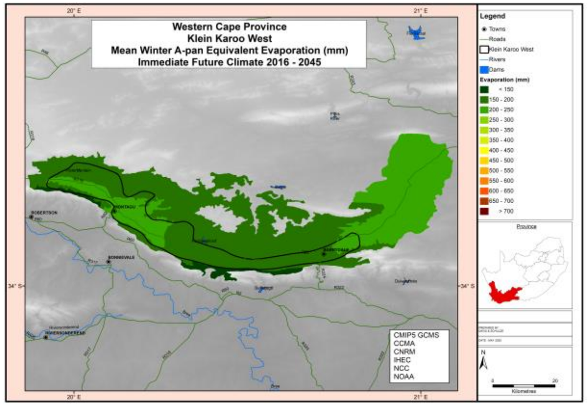
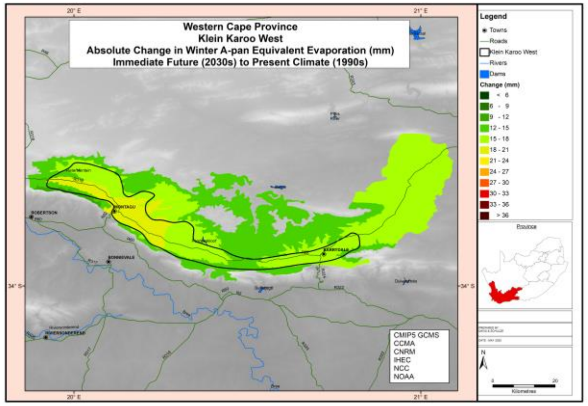
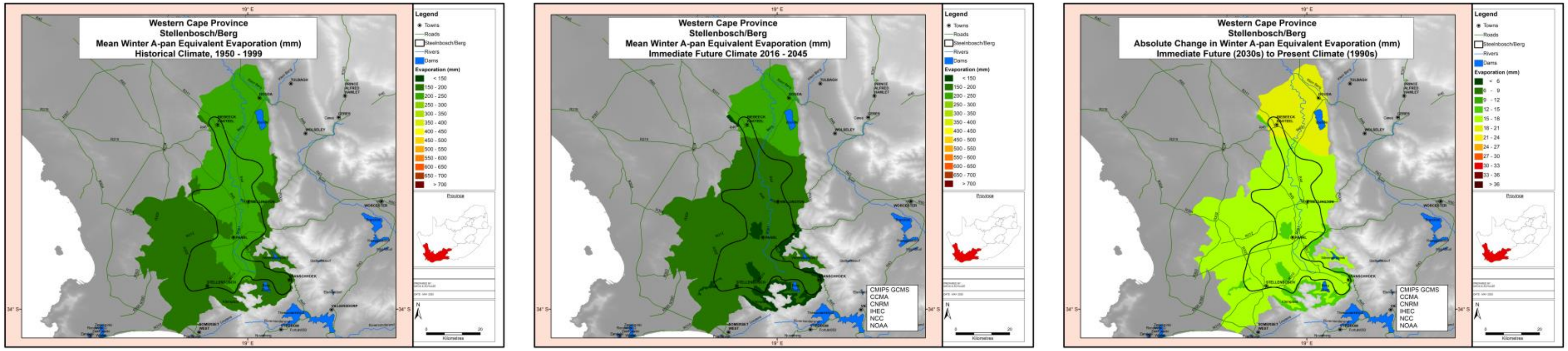






MEAN WINTER A-PAN EQUIVALENT EVAPORATION: STELLENBOSCH-BERG



MEAN WINTER A-PAN EQUIVALENT EVAPORATION: BREEDE

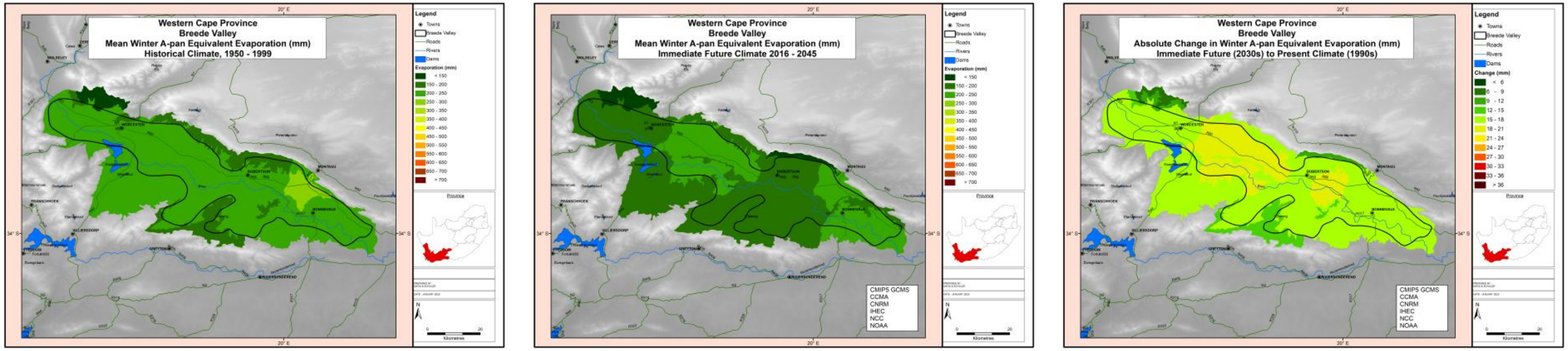


Figure 12. Mean A-pan equivalent reference potential evaporation (in mm) for WINTER under historical climatic conditions (left column), under projected climatic conditions for the immediate future (middle column), and projected increases (in mm) from the present to immediate future climates (right column) for each of the eleven pome and stone fruit production regions. The immediate future maps are derived from multiple CMIP5 GCMs.

11. Chill units: months to reach 250/500/700

In autumn, deciduous fruit trees lose their leaves and enter a dormant phase (i.e. rest) to survive the winter. To end this dormancy, they require a certain amount of winter cold below a certain threshold (their 'chilling requirement') followed by a certain amount of heat. Insufficient winter chilling may result in delayed foliation, reduced fruit set, and reduced fruit quality. The required amount of chilling for completion of the rest period varies between species and cultivars. Many chill accumulation models have been formulated, most of them requiring observed or estimated hourly temperatures. For this study, the Utah Chill Unit model, with its South African based modification to the Daily Positive Chill Unit (or *PCU*) model was used. From the hourly *PCU* calculations, daily *PCU*s were accumulated, from which time taken (months) to reach three levels of chilling were computed, starting on 1 April: 250 *PCU*s (low chill requirement), 500 *PCU*s, (medium chill requirement), and 700 *PCU*s (high chill requirement).

Figure 13 (250 *PCU*s), Figure 14 (500 *PCU*s) and Figure 15 (700 *PCU*s) present the results for month by which PCUs are reached for the eleven pome and stone fruit regions. In each case, the results for the historical climate are shown in the left column, and those for the intermediate future (mid-century) are shown in the right column.

Historically, low *PCU*s (250) are reached by May in the cooler parts of the region, and by June in the remainder of the areas where deciduous fruit can be grown. By the intermediate future, 250 *PCU*s are generally reached one month later, but in some areas up to two months later. On the other hand, 500 *PCU*s are achieved historically largely by May-June (cooler areas) or July (warmer areas) in the fruit growing areas. By the intermediate future, the southern parts of the fruit growing areas only achieve 500 *PCU*s by August or September or even later (too late!), whereas the cooler northern regions (with the exception of Wolseley-Tulbagh) and Langkloof mostly still achieve 500 *PCU*s by June or July. Under historical climatic conditions, high *PCU*s (700) are reached by June-July (cooler northern fruit areas and western Langkloof) or July-August (warmer southern areas, Klein Karoo and eastern Langkloof). Into the intermediate future, this shifts to mostly July in the north, August in the western Langkloof, and to September to October (cooler south, eastern Langkloof) or never (warmer south e.g. Berg and Breede River Valleys).

If climate change continues as projected under the emissions scenario used in the modelling (RCP8.5), this will present severe challenges regarding the loss of chill accumulation. The regions at most risk regarding production of high chill requiring pome fruit cultivars (even considering the use of rest-breaking agents) include the whole south-western coastal region, and Wolseley. For medium chill requiring cultivars, Elgin, Riviersonderend and Somerset West could become unsuited. There is a wide range of stone fruit cultivars available with differing chill requirements, so the situation for this industry will depend on whether new climates can be matched with suitable cultivars. Challenges could arise around Tulbagh and in large parts of the Klein Karoo, Berg and Breede River valleys.

SOUTH-WESTERN COASTAL REGION (POME):

- **Historical Month to 250 PCU:**
  May: Grabouw, Vyeboom
  June: Elgin, Villiersdorp, Elandskloof, Somerset West, Riviersonderend

- **Change in Month to 250 PCU:**
  June: Grabouw, Vyeboom, Villiersdorp, Elandskloof, Riviersonderend-west
  July-August: Elgin, Somerset West, Riviersonderend-east

NORTH-WESTERN HIGH-LYING REGION (POME AND STONE):

- **Historical Month to 250 PCU:**
  May: Klondyke, Koue Bokkeveld, Witzenberg, Ceres, Prince Alfred Hamlet, Wolseley
  June: Tulbagh, Piketberg

- **Change in Month to 250 PCU:**
  May: Klondyke, Lower Koue Bokkeveld, Witzenberg
  June: Upper Koue Bokkeveld, Ceres, Prince Alfred Hamlet, Wolseley, Piketberg
  July: Tulbagh

EASTERN INTERIOR REGION (POME AND STONE):

- **Historical Month to 250 PCU:**
  May: Langkloof (west), Koo, Akkerboom (between Montagu and Barrydale)
  June: Langkloof (east), Klein Karoo East, Montagu, Poortjieskloof, Barrydale

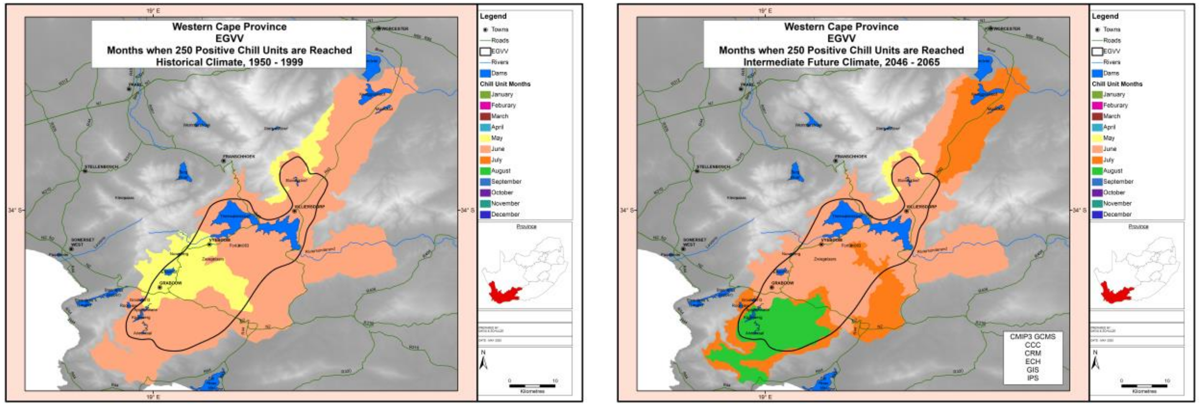
- **Change in Month to 250 PCU:**
  June: Langkloof, Ladismith, Klein Karoo West
  July: Klein Karoo East (west), Calitzdorp

SOUTH-WESTERN RIVER VALLEYS REGION (STONE):

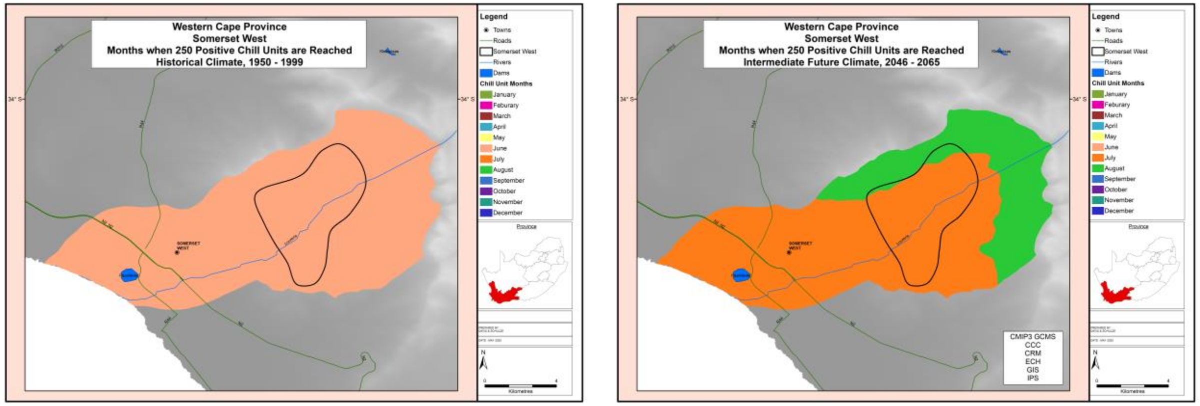
- **Historical Month to 250 PCU:**
  June: All areas

- **Change in Month to 250 PCU:**
  July: Franschhoek, Paarl, all Breede areas
  August: Stellenbosch, Wellington, Riebeeck Kasteel

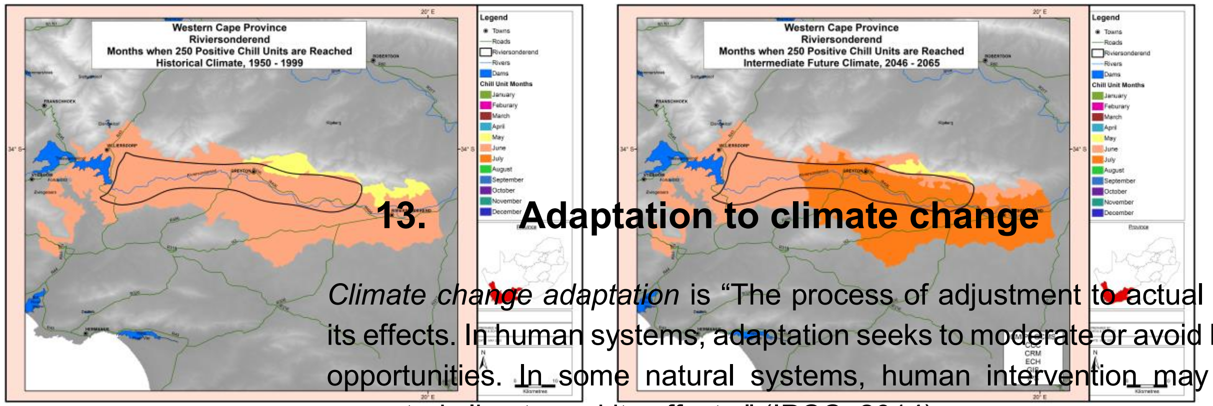
MONTH WHEN 250 PCU REACHED: EGVV



MONTH WHEN 250 PCU REACHED: SOMERSET WEST



MONTH WHEN 250 PCU REACHED: RIVIERSONDEREND

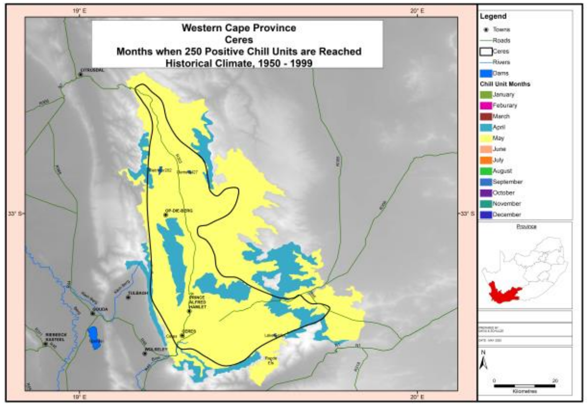


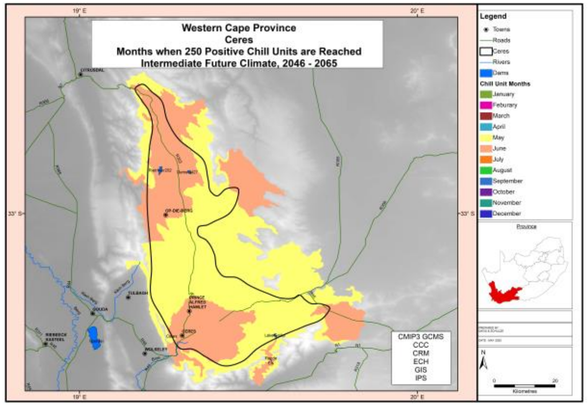
13. Adaptation to climate change

Climate change adaptation is "The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects." (IPCC, 2014)

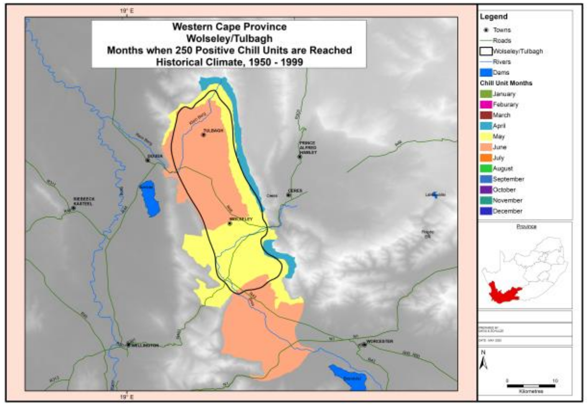
Furthermore, climate change scientists generally agree that *adaptive capacity* refers to "the ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences." Adaptive capacity varies

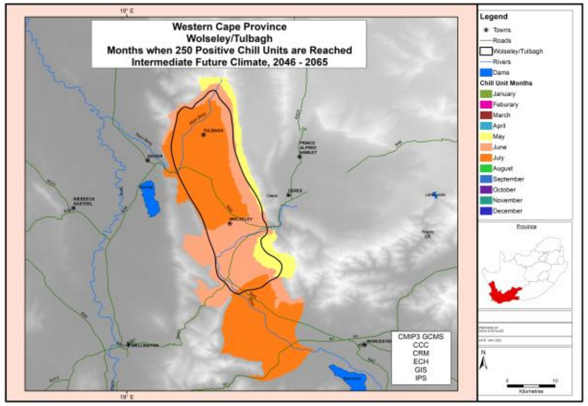
MONTH WHEN 250 PCU REACHED: CERES



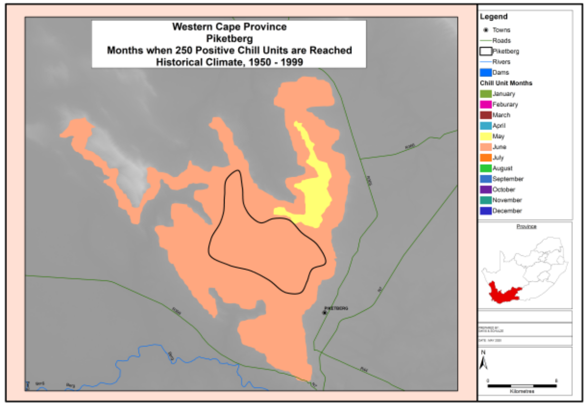


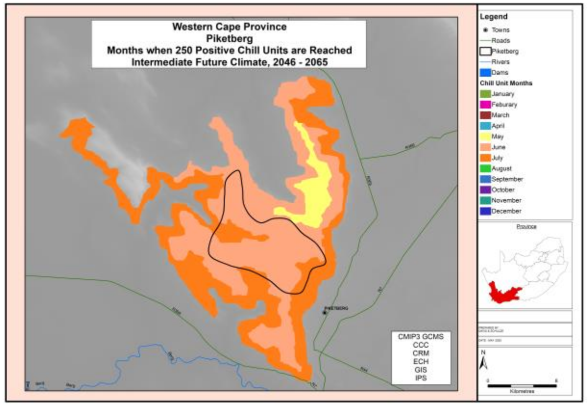
MONTH WHEN 250 PCU REACHED: WOLSELEY-TULBAGH



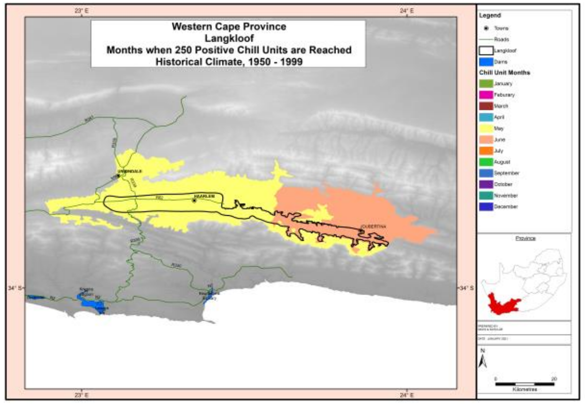


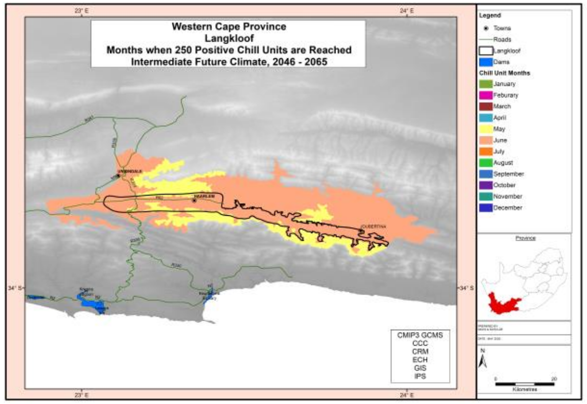
MONTH WHEN 250 PCU REACHED: PIKETBERG



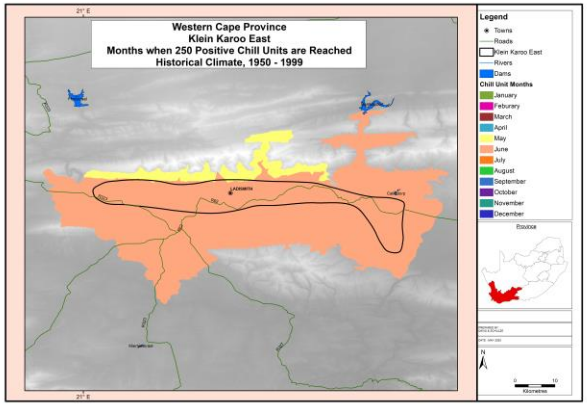


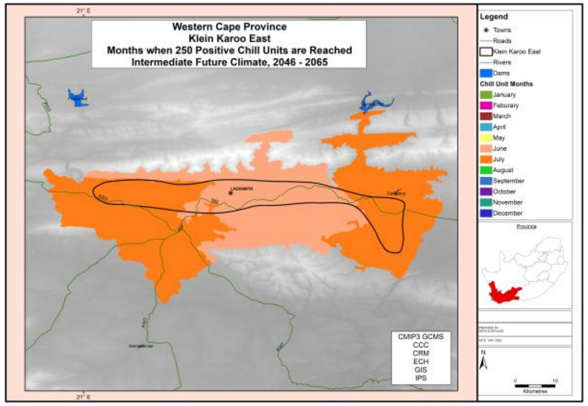
MONTH WHEN 250 PCU REACHED: LANGKLOOF



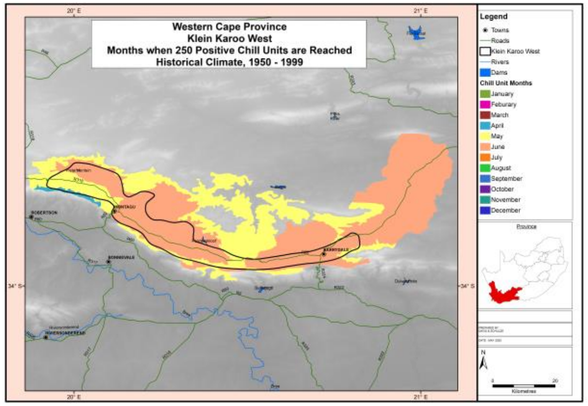


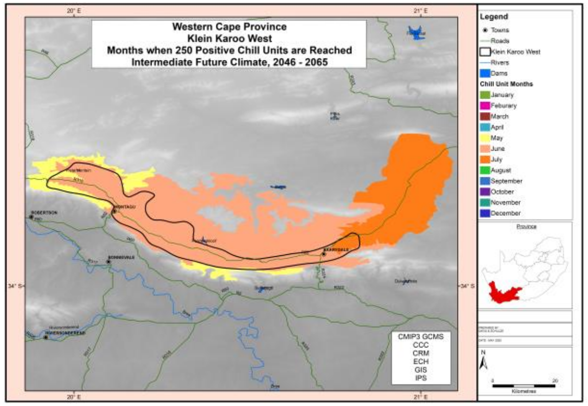
MONTH WHEN 250 PCU REACHED: KLEIN KAROO EAST



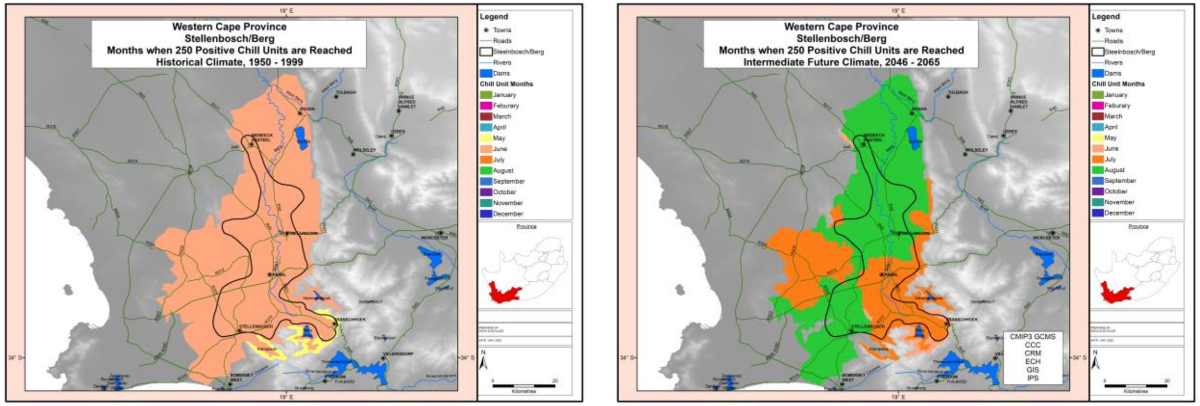


MONTH WHEN 250 PCU REACHED: KLEIN KAROO WEST





MONTH WHEN 250 PCU REACHED: STELLENBOSCH-BERG



MONTH WHEN 250 PCU REACHED: BREEDE

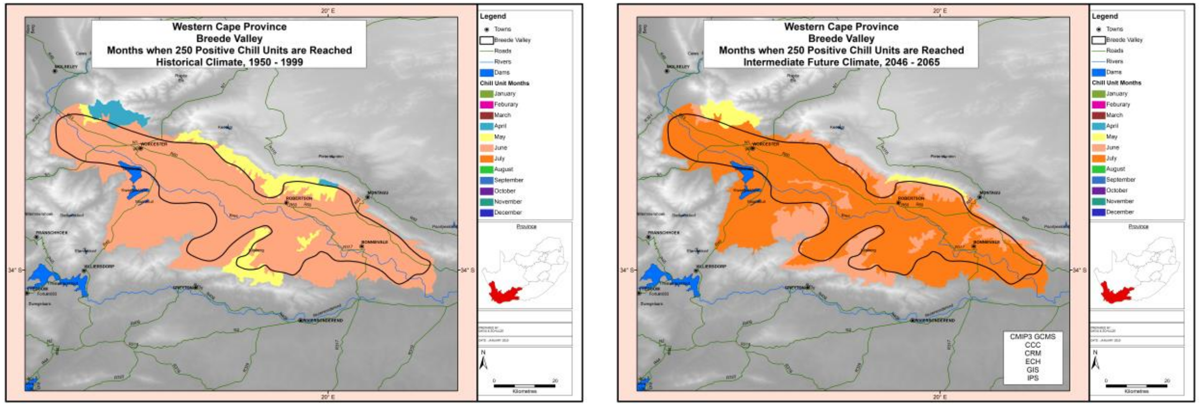


Figure 13. Month by which 250 PCUs are reached under historical climatic conditions (left column), as well as under intermediate future climatic conditions (right column), for each of the eleven pome and stone fruit production regions. The intermediate future maps are derived from multiple CMIP3 GCMs.

SOUTH-WESTERN COASTAL REGION (POME):

- **Historical Month to 500 PCU:**
  June: Elgin, Grabouw, Vyeboom
  July: Villiersdorp, Elandskloof, Somerset West, Riviersonderend

- **Change in Month to 500 PCU:**
  August: Grabouw, Vyeboom, Villiersdorp, Elandskloof, Riviersonderend (Helderstroom)
  September-October: Riviersonderend-east
  Not reached: Elgin, Somerset West

NORTH-WESTERN HIGH-LYING REGION (POME AND STONE):

- **Historical Month to 500 PCU:**
  May: Klondyke, Lower Koue Bokkeveld
  June: Upper Koue Bokkeveld, Witzenberg, Ceres, Prince Alfred Hamlet, Wolseley, Piketberg
  July: Tulbagh

- **Change in Month to 500 PCU:**
  June: Klondyke, Lower Koue Bokkeveld, Witzenberg, Op-die-Berg
  July: Upper Koue Bokkeveld, Ceres, Prince Alfred Hamlet, Piketberg
  August: Wolseley
  Not reached: Tulbagh

EASTERN INTERIOR REGION (POME AND STONE):

- **Historical Month to 500 PCU:**
  June: Langkloof (west), Koo, Akkerboom (between Montagu and Barrydale)
  July: Langkloof (east), Klein Karoo East, Montagu, Poortjieskloof, Barrydale

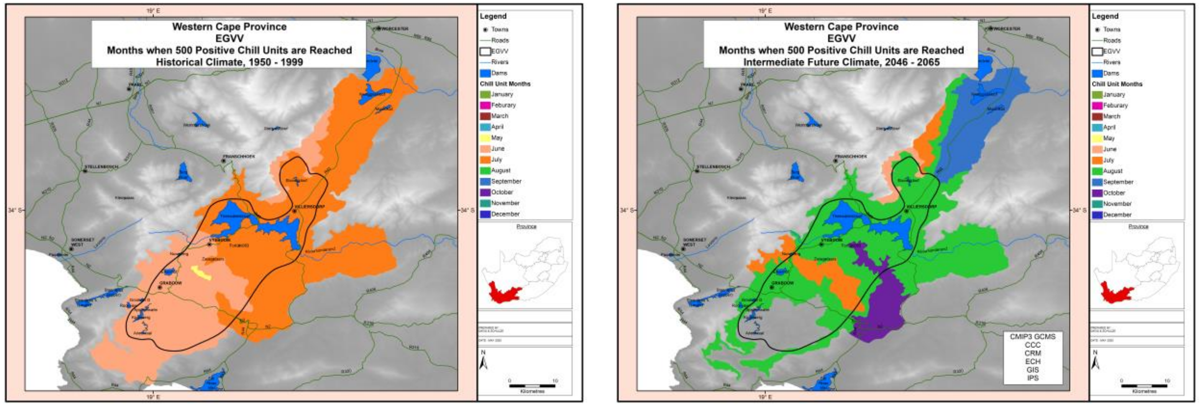
- **Change in Month to 500 PCU:**
  July: Langkloof (west), Akkerboom
  August: Langkloof (east), Klein Karoo East, Klein Karoo West (except Akkerboom)
  October: Calitzdorp

SOUTH-WESTERN RIVER VALLEYS REGION (STONE):

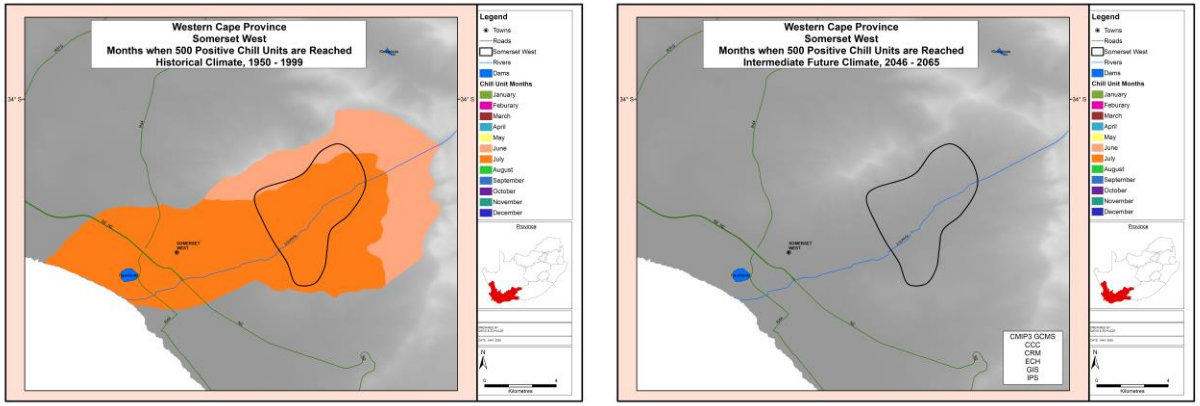
- **Historical Month to 500 PCU:**
  July: All areas

- **Change in Month to 500 PCU:**
  August: Nuy
  September: Franschhoek, Windmeul, Slanghoek, Ashton, McGregor
  October: Worcester, Robertson, Bonnievale
  Not reached: rest of Stellenbosch-Berg region

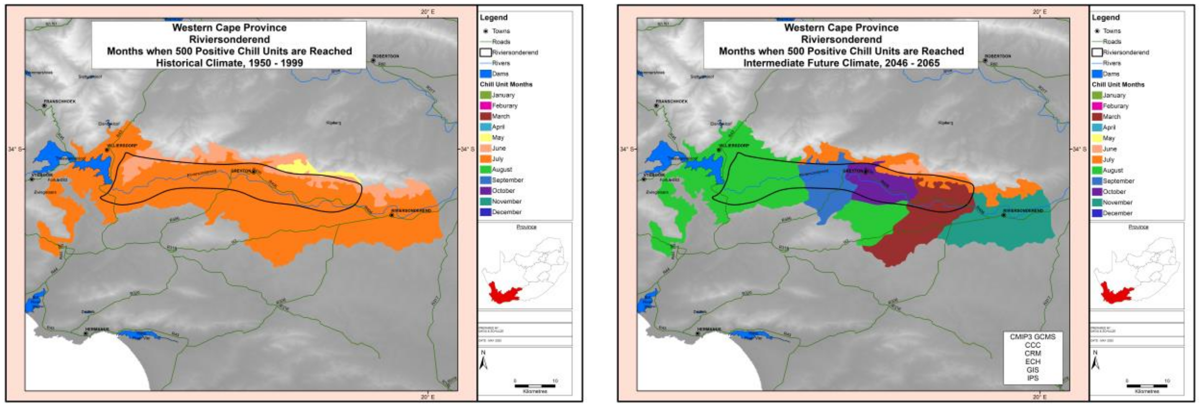
MONTH WHEN 500 PCU REACHED: EGVV



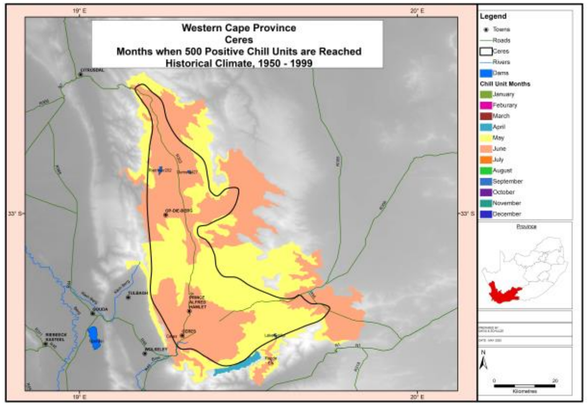
MONTH WHEN 500 PCU REACHED: SOMERSET WEST

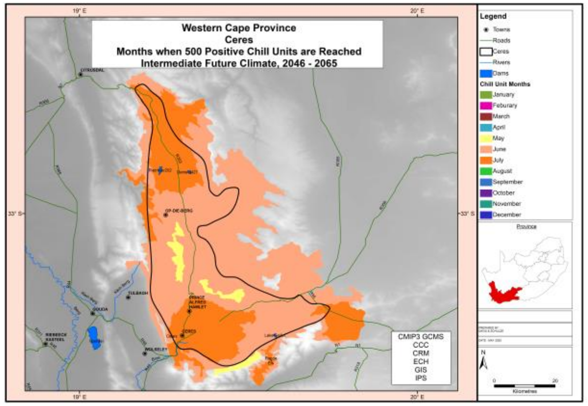


MONTH WHEN 500 PCU REACHED: RIVIERSONDEREND

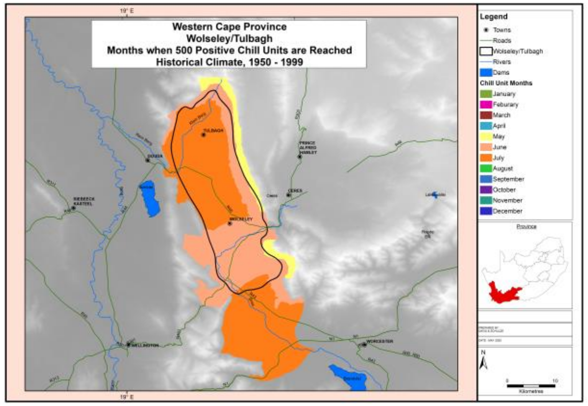


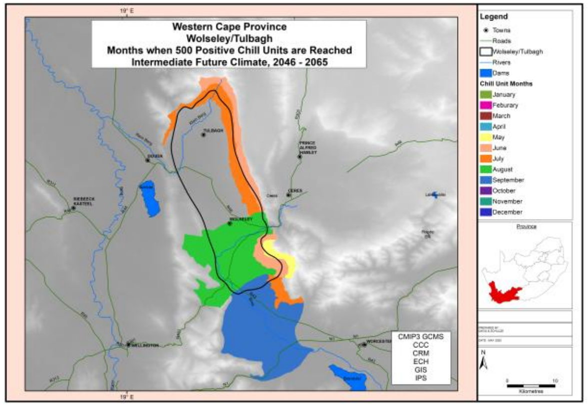
MONTH WHEN 500 PCU REACHED: CERES



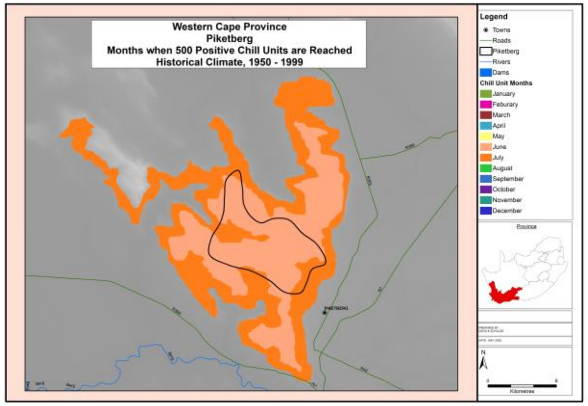


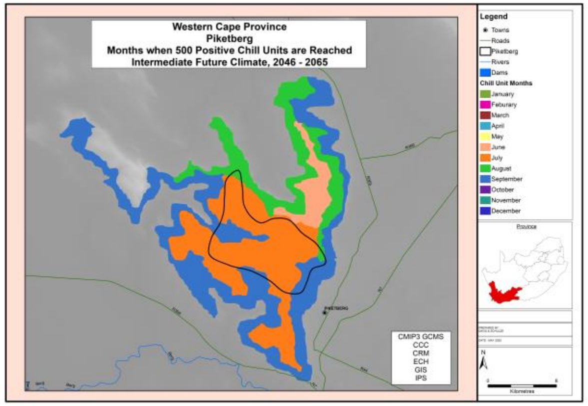
MONTH WHEN 500 PCU REACHED: WOLSELEY-TULBAGH



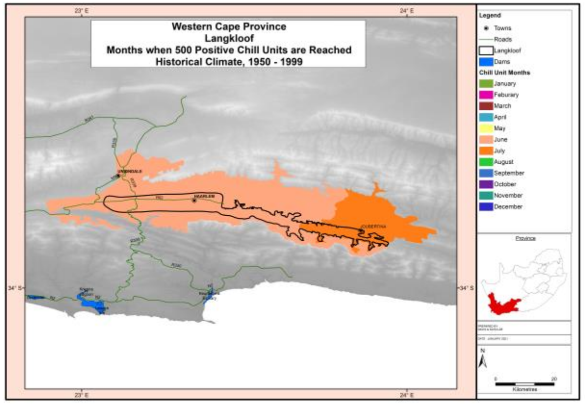


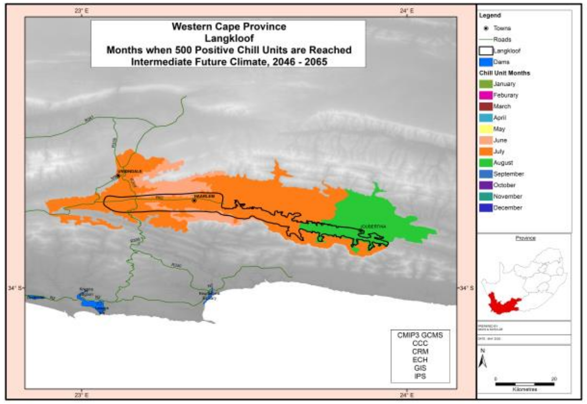
MONTH WHEN 500 PCU REACHED: PIKETBERG



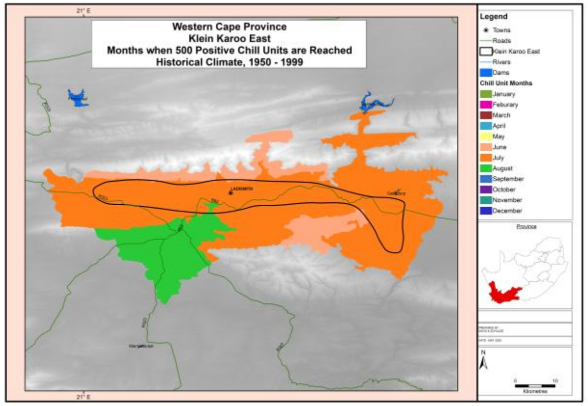


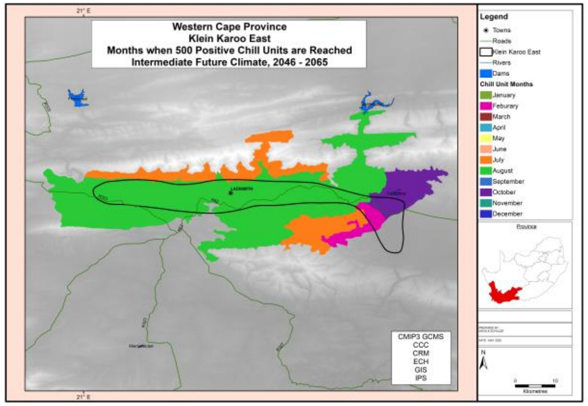
MONTH WHEN 500 PCU REACHED: LANGKLOOF



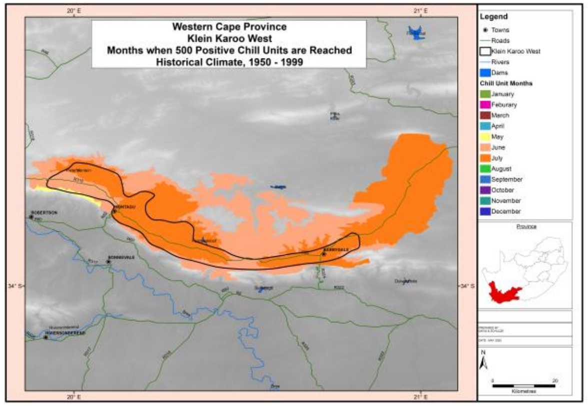


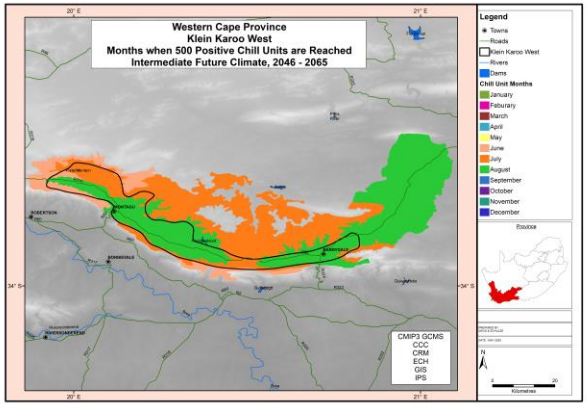
MONTH WHEN 500 PCU REACHED: KLEIN KAROO EAST



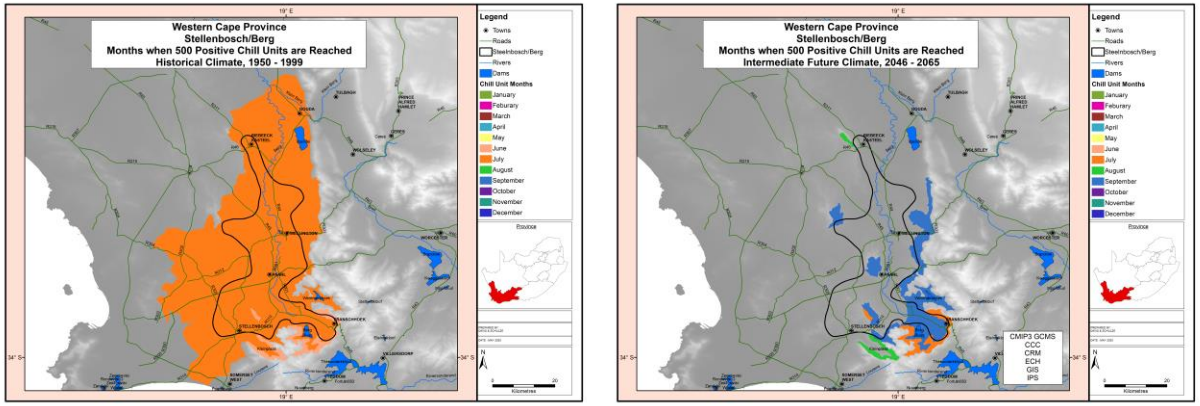


MONTH WHEN 500PCU REACHED: KLEIN KAROO WEST





MONTH WHEN 500 PCU REACHED: STELLENBOSCH-BERG



MONTH WHEN 500 PCU REACHED: BREEDE

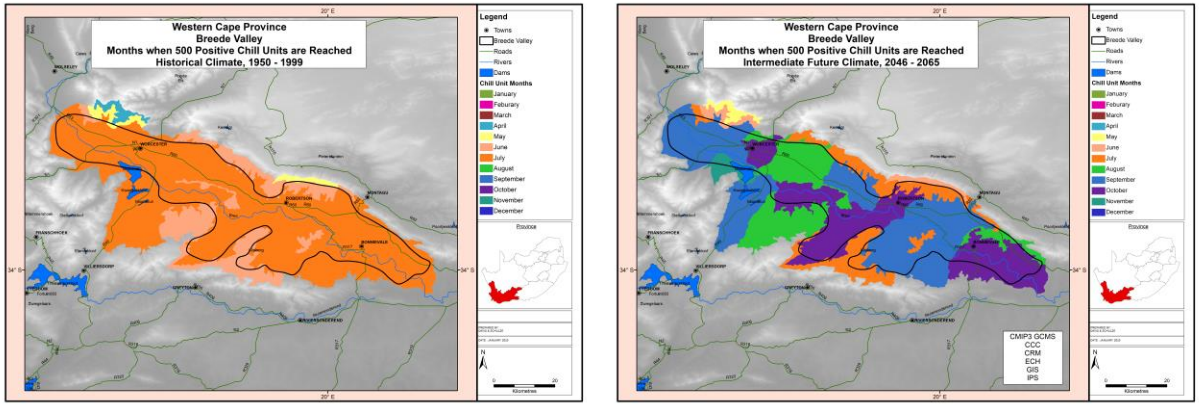


Figure 14. Month by which 500 PCUs are reached under historical climatic conditions (left column), as well as under intermediate future climatic conditions (right column), for each of the eleven pome and stone fruit production regions. The intermediate future maps are derived from multiple CMIP3 GCMs.

SOUTH-WESTERN COASTAL REGION (POME):

- **Historical Month to 700 PCU:**
  July: Elgin, Grabouw, Vyeboom, Elandskloof, Somerset West
  August: Villiersdorp, Riviersonderend

- **Change in Month to 700 PCU:**
  September: Vyeboom, Elandskloof
  October: Grabouw, Villiersdorp, Riviersonderend-west
  Not reached: Elgin, Somerset West, Riviersonderend-east

NORTH-WESTERN HIGH-LYING REGION (POME AND STONE):

- **Historical Month to 700 PCU:**
  June: Klondyke, Koue Bokkeveld, Witzenberg
  July: Ceres, Prince Alfred Hamlet, Wolseley, Piketberg
  August: Tulbagh

- **Change in Month to 700 PCU:**
  June: Lower Koue Bokkeveld
  July: Klondyke, Upper Koue Bokkeveld, Witzenberg
  August: Ceres, Prince Alfred Hamlet, Piketberg
  October: Wolseley
  Not reached: Tulbagh

EASTERN INTERIOR REGION (POME AND STONE):

- **Historical Month to 700 PCU:**
  June: Langkloof (west)
  July: Langkloof (central), Klein Karoo East (parts), Koo, Barrydale
  August: Langkloof (east), Ladismith, Calitzdorp, Montagu

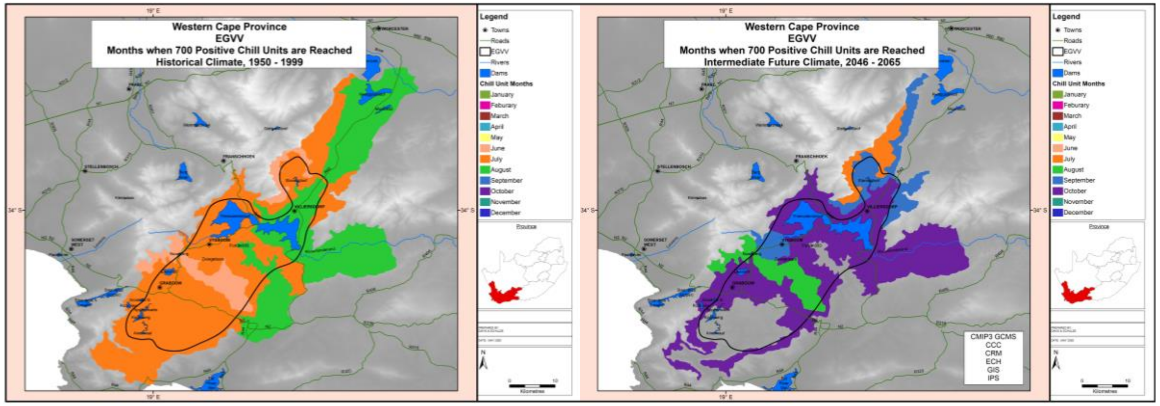
- **Change in Month to 700 PCU:**
  August: Langkloof (west)
  September: Langkloof (central), Klein Karoo East (Zoar), Koo, Poortjieskloof, Barrydale
  October: Langkloof (east), Ladismith, Montagu
  Not reached: Klein Karoo East (west of Ladismith)

SOUTH-WESTERN RIVER VALLEYS REGION (STONE):

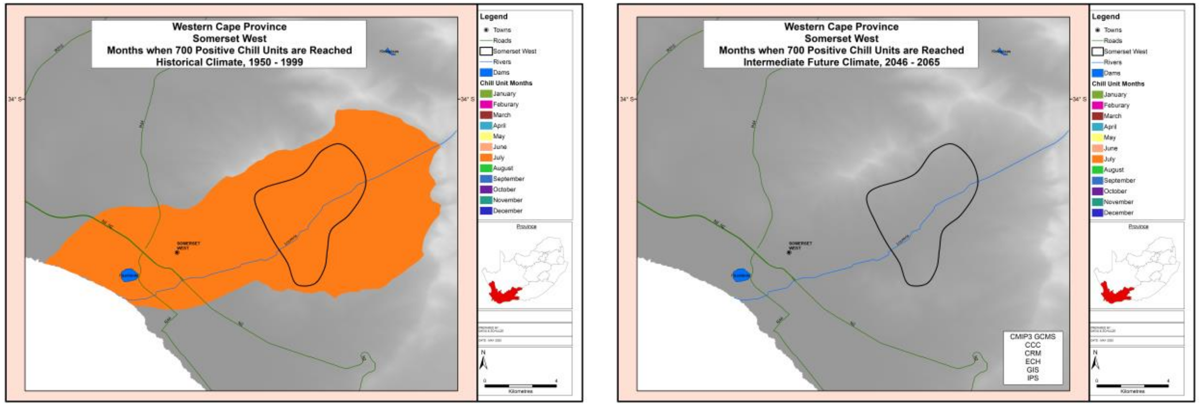
- **Historical Month to 700 PCU:**
  July: Worcester, Nuy
  August: All other areas

- **Change in Month to 700 PCU:**
  September and October: isolated patches in the Breede River valley
  Not reached: All other areas

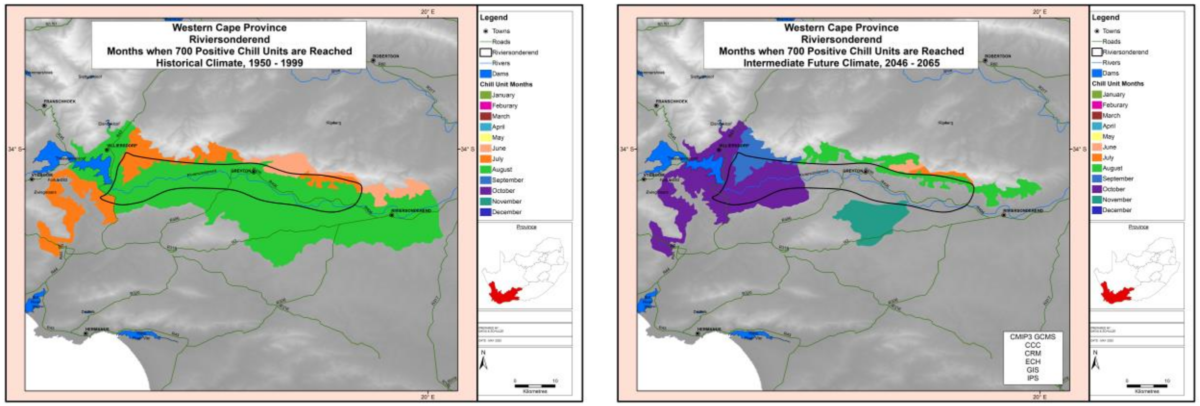
MONTH WHEN 700 PCU REACHED: EGVV



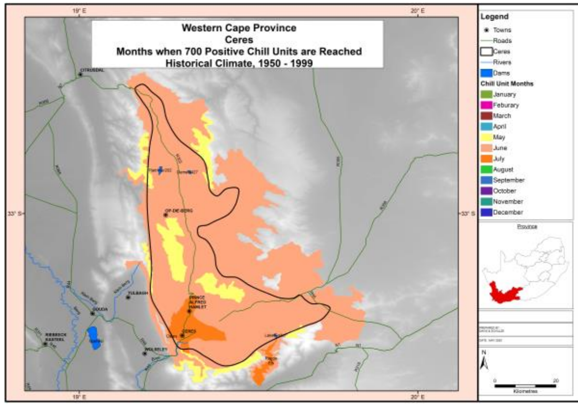
MONTH WHEN 700 PCU REACHED: SOMERSET WEST

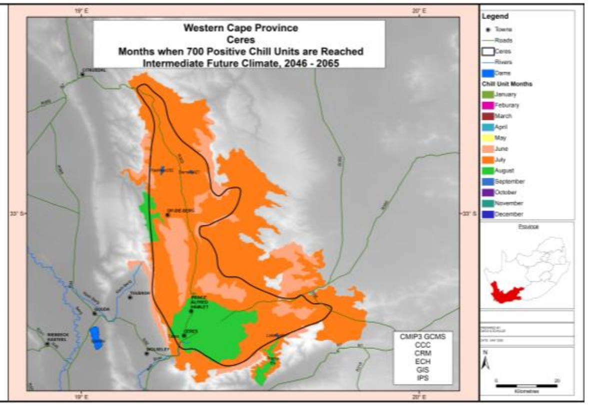


MONTH WHEN 700 PCU REACHED: RIVIERSONDEREND

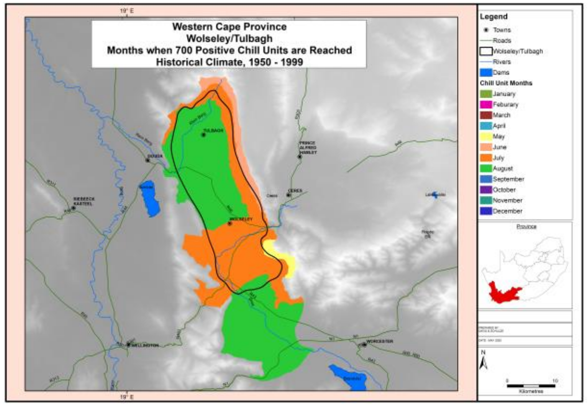


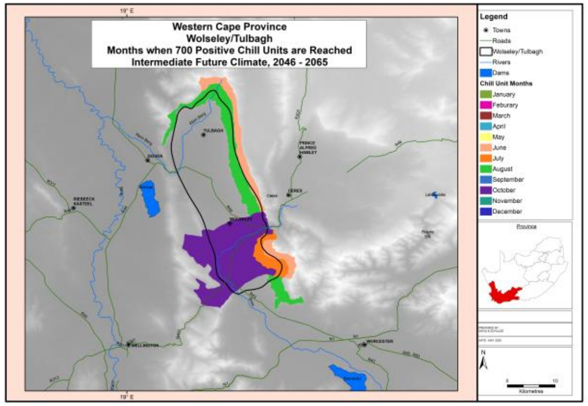
MONTH WHEN 700 PCU REACHED: CERES



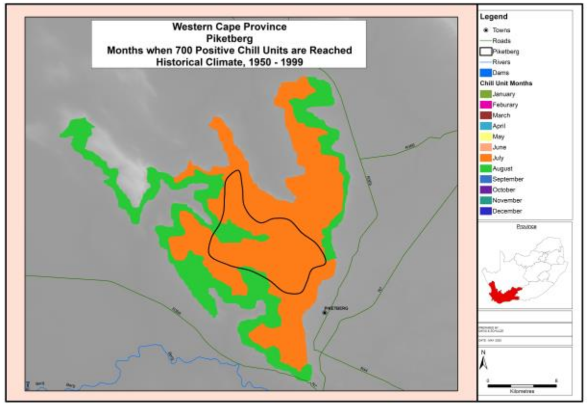


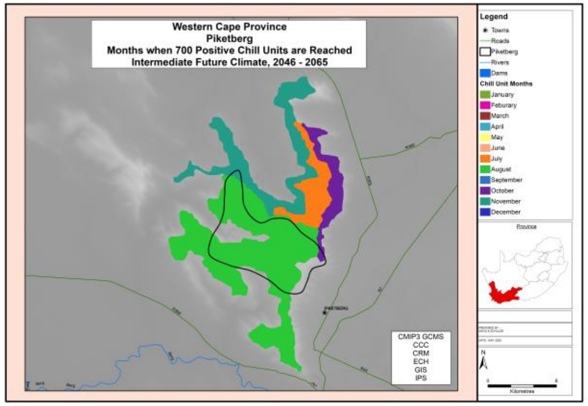
MONTH WHEN 700 PCU REACHED: WOLSELEY-TULBAGH



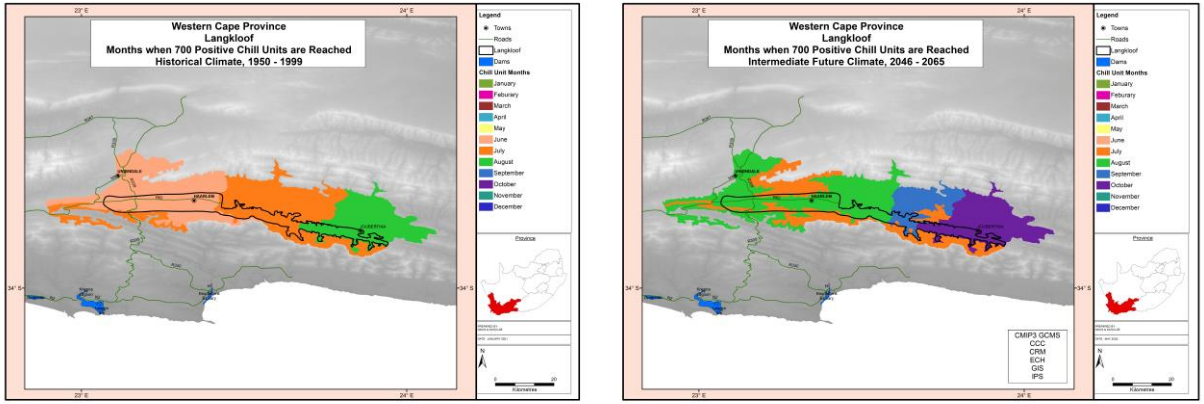


MONTH WHEN 700 PCU REACHED: PIKETBERG

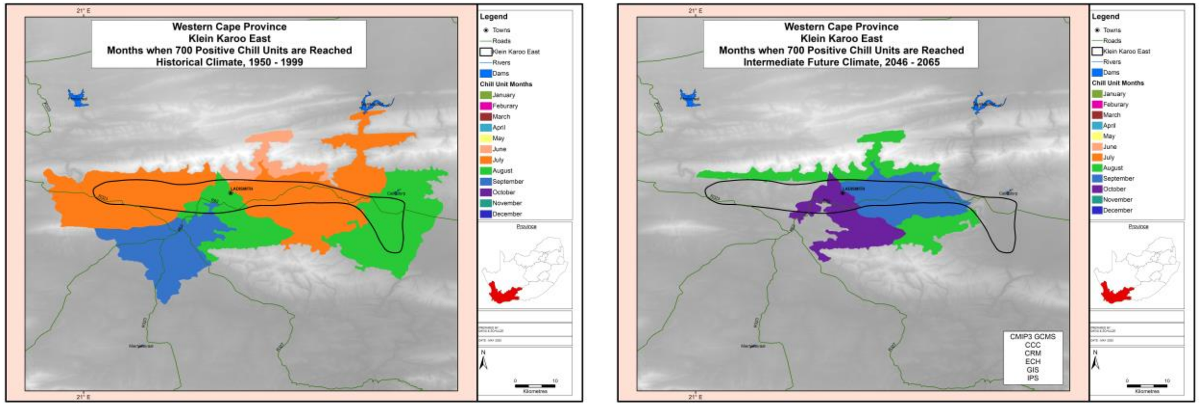




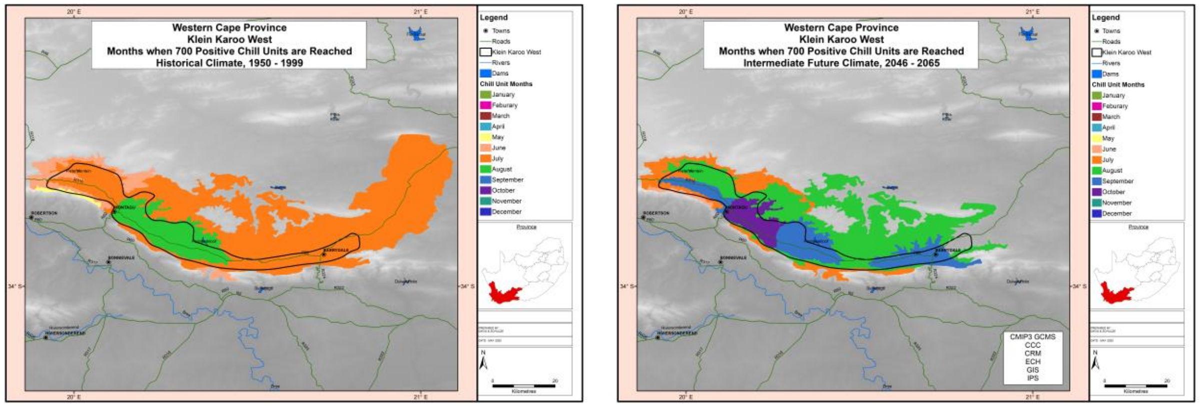
MONTH WHEN 700 PCU REACHED: LANGKLOOF



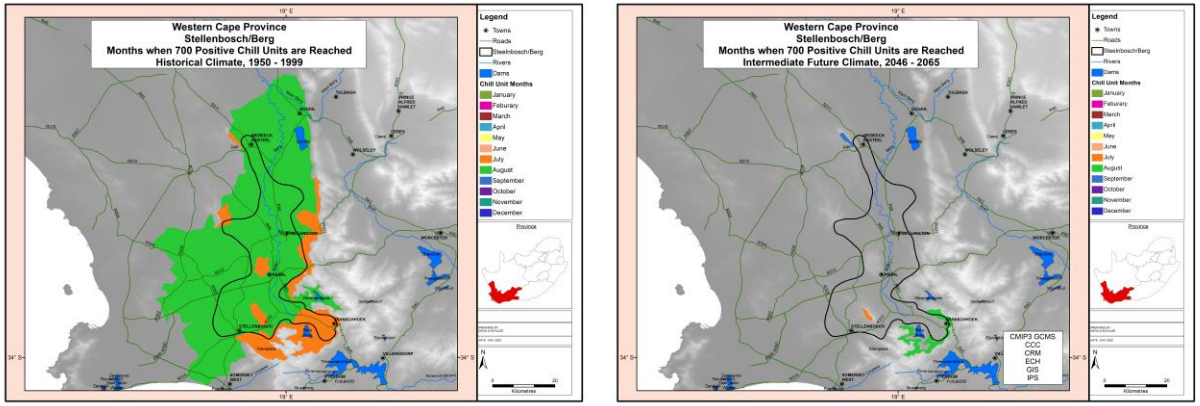
MONTH WHEN 700 PCU REACHED: KLEIN KAROO EAST



MONTH WHEN 700 PCU REACHED: KLEIN KAROO WEST



MONTH WHEN 700 PCU REACHED: STELLENBOSCH-BERG



MONTH WHEN 700 PCU REACHED: BREEDE

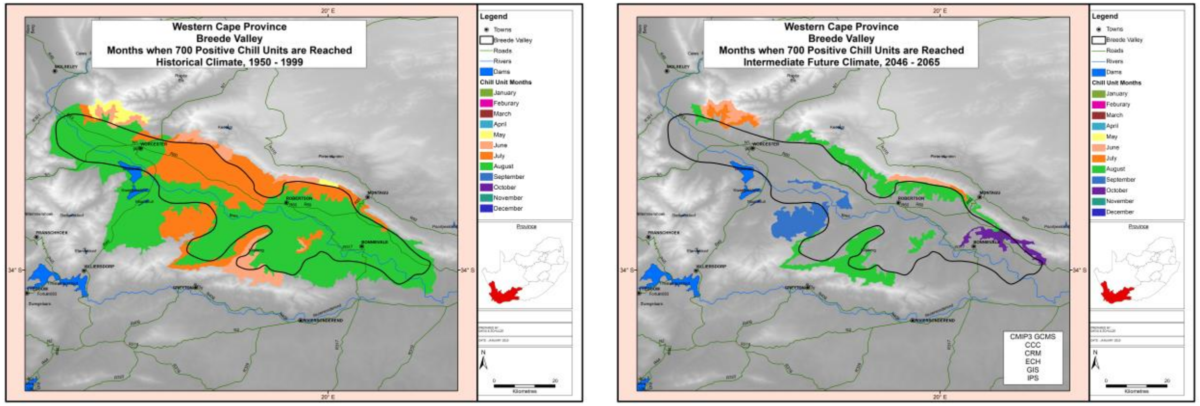


Figure 15. Month by which 700 PCUs are reached under historical climatic conditions (left column), as well as under intermediate future climatic conditions (right column), for each of the eleven pome and stone fruit production regions. The intermediate future maps are derived from multiple CMIP3 GCMs.

12. Red colour development in apples

Apple fruit skin colour is an important factor determining market acceptance and price. There is a strong genetic component to red colouring potential, and different cultivars can have either full red colour, blushed/striped red colour, or a bi-colour appearance. Although early season red-streaked cultivars are widely grown in South Africa (e.g. 'Royal Gala' and its mutants), the later season (March-April harvest) blushed and bi-colour apple cultivars (e.g. 'Fuji' and 'Cripps Pink'/Pink Lady®, 'Cripps Red'/Sundowner®/Joya® and 'Rosy Glow') are potentially highly profitable and increasingly popular. Growers are preferring to plant cultivars with a high red colouring potential that are less temperature sensitive.

The development of red colour, owing to the synthesis of anthocyanins in the peel, is primarily driven by a combination of temperature and solar radiation, although other factors such as water stress and nitrogen status can play a role. As apple fruits develop, anthocyanin synthesis first peaks towards the end of fruit cell division, and peaks again as the fruits mature. Anthocyanin synthesis is induced by cool night-time temperatures in the pre-harvest period, generally below 15°C, with optimum synthesis occurring thereafter under warm (20-25°C) and sunny days (with slight variation between cultivars). Little synthesis occurs below 15°C or above 35°C. Temperatures exceeding 35°C inhibit anthocyanin can cause pigment degradation.

For this study, climatic conditions conducive to peel red colour development were modelled for mid- to late-season blushed/bi-colour cultivars for the months March and April. The criteria included one day of minimum temperature below 12°C followed by daytime maximum temperatures in the range 20-28°C for three consecutive days, conditional upon solar radiation on the qualifying days being at least 60% of those days' maximum solar radiation potential.

Figure 16 presents the results for number of days meeting red colouring criteria for the three main apple production regions in March (top row), April (middle row) and combined March-April (bottom row). Results for historical climatic conditions are shown in left column for each region, results into the intermediate future are shown in the middle column, and those for the change between the periods are shown in the right column. In March, the criteria are met on 8-14 and sometimes more days (except for Villiersdorp: 2-4 days) in all regions. In the intermediate future, projections show that the region could warm to the extent that climatic criteria for red colouring are met on 0-9 days fewer in the warmer EGVV and 0-15 days fewer in the Ceres and Langkloof regions. In April, under the historical climatic regime, the red colouring criteria are met on 6 or more days, and in several areas more than 14 days. However, the April of the intermediate future sees projected reductions in qualifying days by 3-15 days in EGVV, 0-15 days in Ceres, and 6-12 days in the Langkloof.

When March and April are combined (note the change in the legend), the EGVV region has 18-30 days that meet the colouring criteria under historical climate conditions, the Ceres region has more than 21 days (>30 in the Koue Bokkeveld), and the Langkloof has 24-30 days. This decreases significantly into the intermediate future, with reductions of more than 15 days in the Koue Bokkeveld, Langkloof and parts of EGVV. By mid-century, the EGVV region will possibly be left with 6-9 days conducive to red colouring in March-April (but Elgin 3-6 days), the Ceres region is left with 9-15 days, and Langkloof is left with 6-12 days.

ELGIN-GRABOUW-VYEBOOM-VILLIERSDORP (EGVV) - APPLES:

- **Historical Days for Colour:**
  March: 8-10 days mostly, but 2-4 days around Villiersdorp
  April: 12-14 days, but >14 days around Villiersdorp and Elandskloof
  March & April: 18-24 days mostly, but 27-30 days in Elandskloof

- **Change in Days for Colour:**
  March: 3-9 days fewer, but 0-3 days fewer around Villiersdorp
  April: 3-12 days fewer mostly, but up to 15 days fewer in Elandskloof
  March & April: 9-18 days fewer, but more than 18 days fewer in Elandskloof
  2050s: Most apple areas have 6-9 days conducive to red colouring in March-April by mid-century, but Elgin has 3-6 days.

CERES - APPLES:

- **Historical Days for Colour:**
  March: 12 and more days in the apple areas
  April: 6-12 days in the colder areas, 12 days and more in the main apple areas
  March & April: 21-30 days in the Warm Bokkeveld/Witzenberg; >30 days in the Koue Bokkeveld

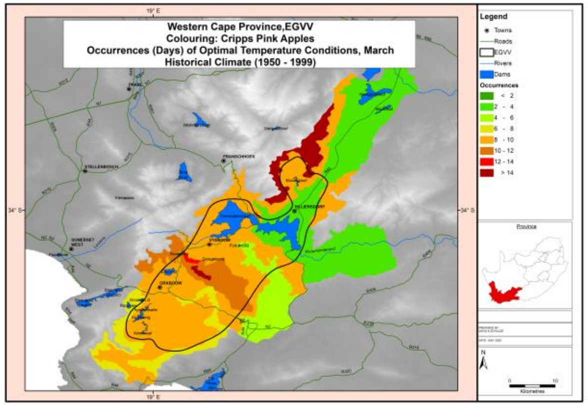
- **Change in Days for Colour:**
  March: 3-9 days fewer in the Warm Bokkeveld/Witzenberg; but 9-15 days fewer in the Koue Bokkeveld
  April: 0-9 days fewer in the Warm Bokkeveld/Witzenberg; but 9-15 days fewer in the Koue Bokkeveld
  March & April: 0-12 days fewer in the coldest areas, 12-18 days fewer in Ceres/ Prince Alfred Hamlet/ Witzenberg, and >18 days fewer in the Koue Bokkeveld
  2050s: Apple areas have 9-15 days conducive to red colouring in March-April by mid-century.

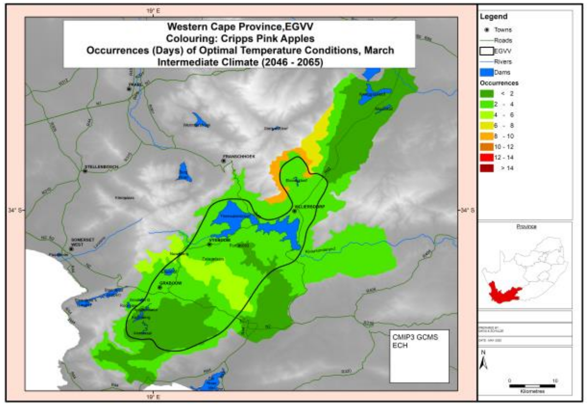
LANGKLOOF - APPLES:

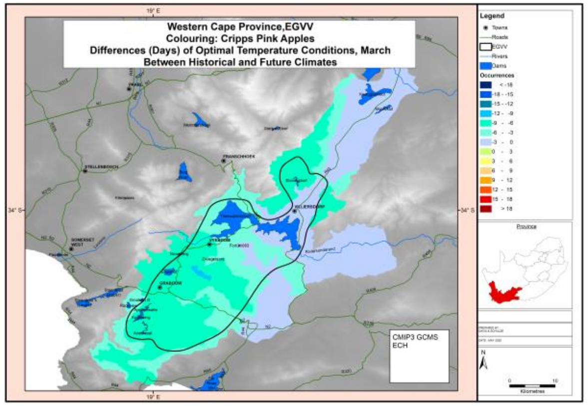
- **Historical Days for Colour:**
  March: 10-14 days (west) and 2-8 (east)
  April: >14 days (west) and 12-14 (east)
  March & April: 21-30 days (west and central) and 15-18 (east)

- **Change in Days for Colour:**
  March: 0-3 days fewer (east) and 3-12 days fewer (west)
  April: 6-9 days fewer (west and east) and 9-12 days fewer (central)
  March & April: 6-9 days fewer (east) and 12 to >18 days fewer (west)
  2050s: Apple areas have 6-9 days (east) or 9-12 days (west) conducive to red colouring in March-April by mid-century.

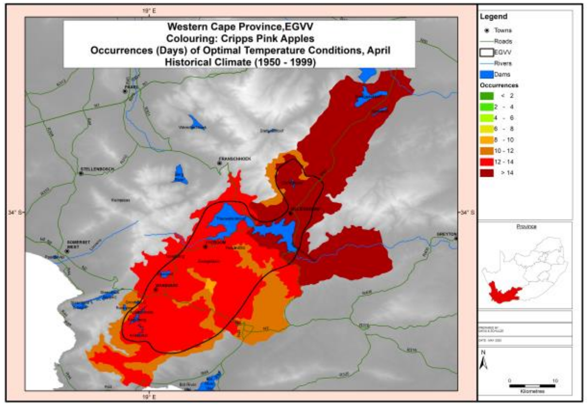
APPLE RED COLOUR CONDITIONS MARCH: EGVV

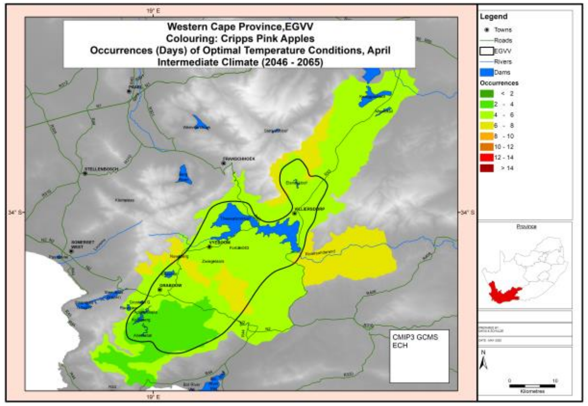


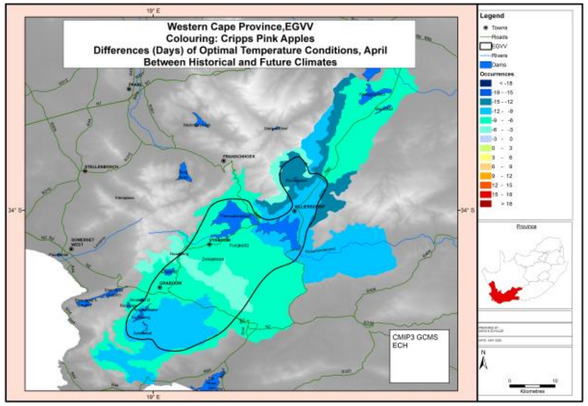




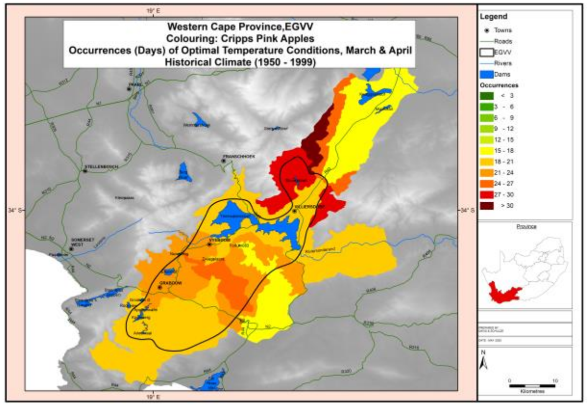
APPLE RED COLOUR CONDITIONS APRIL: EGVV

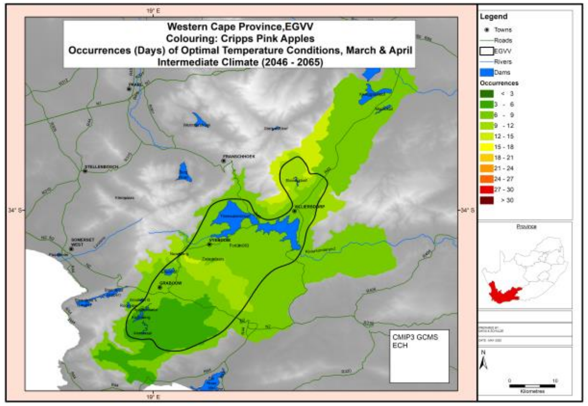


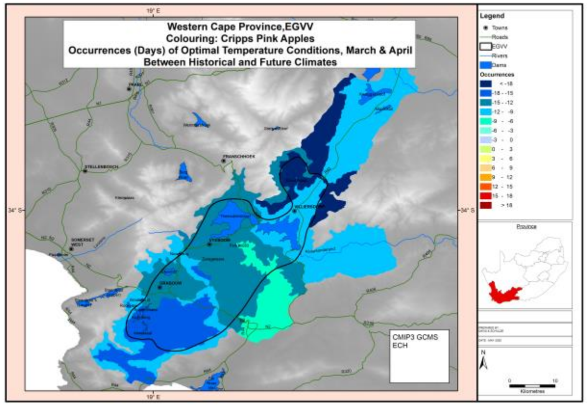




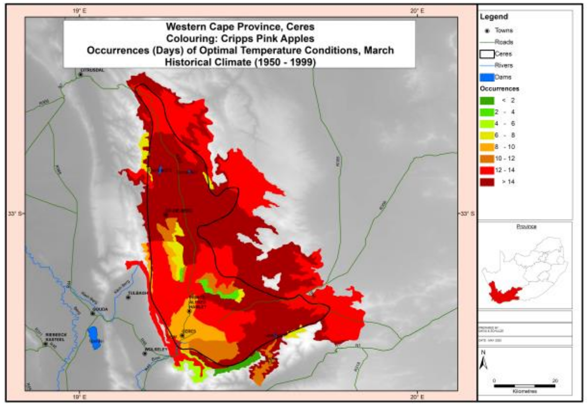
APPLE RED COLOUR CONDITIONS MARCH + APRIL: EGVV

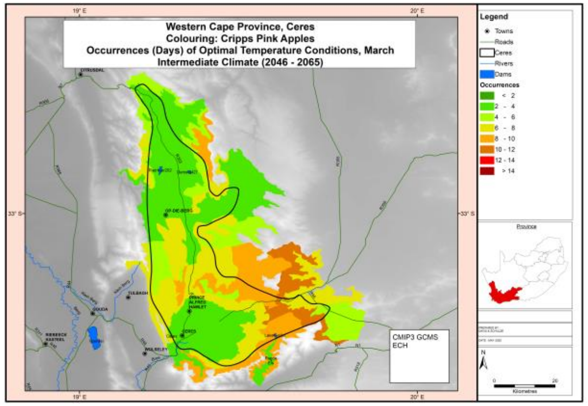


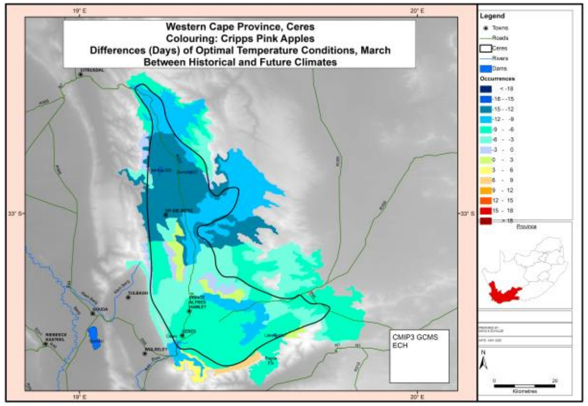




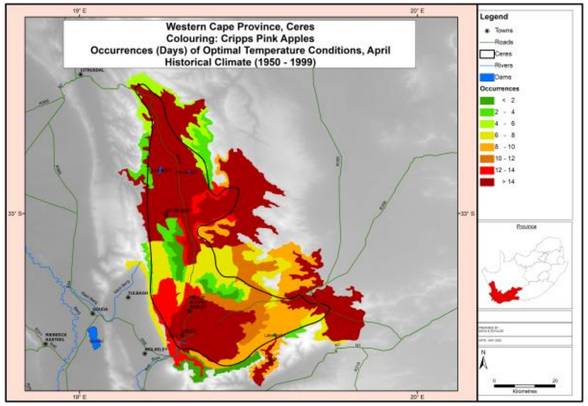
APPLE RED COLOUR CONDITIONS MARCH: CERES

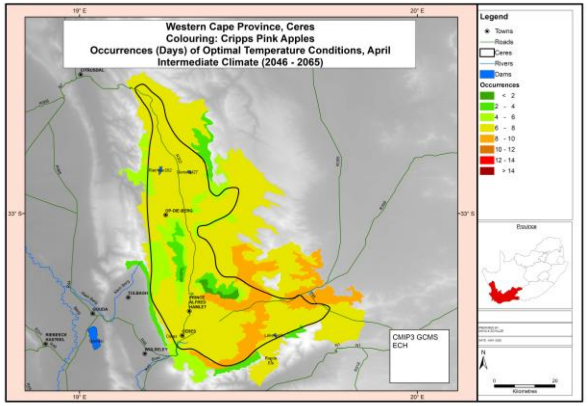


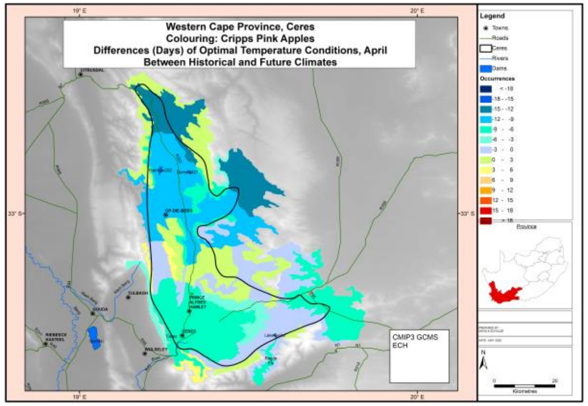




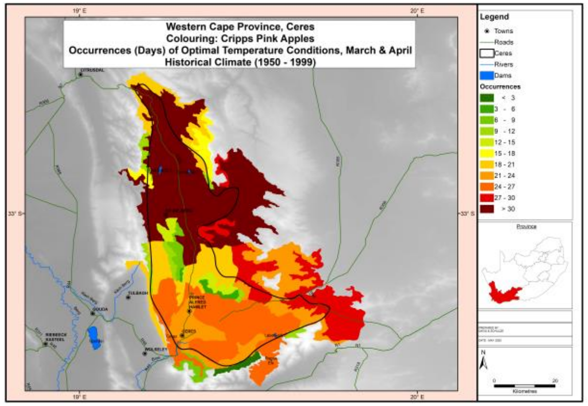
APPLE RED COLOUR CONDITIONS APRIL: CERES

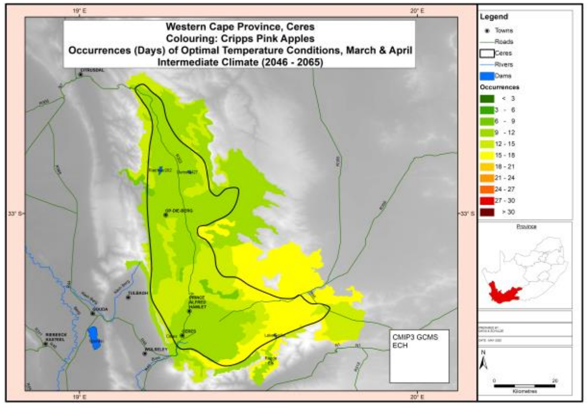


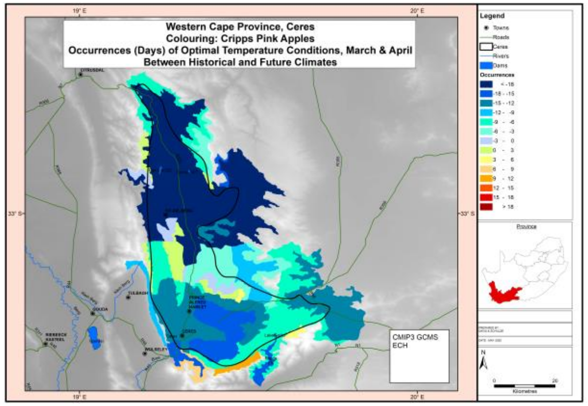




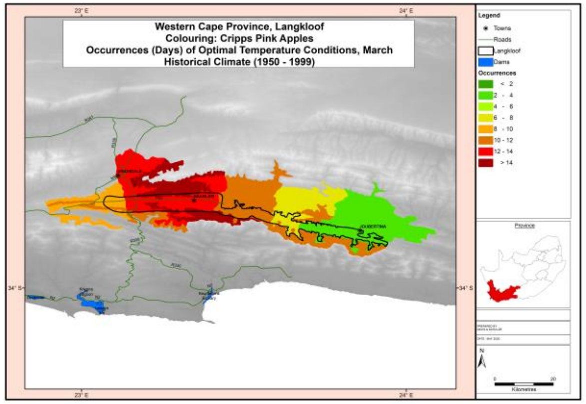
APPLE RED COLOUR CONDITIONS MARCH + APRIL: CERES

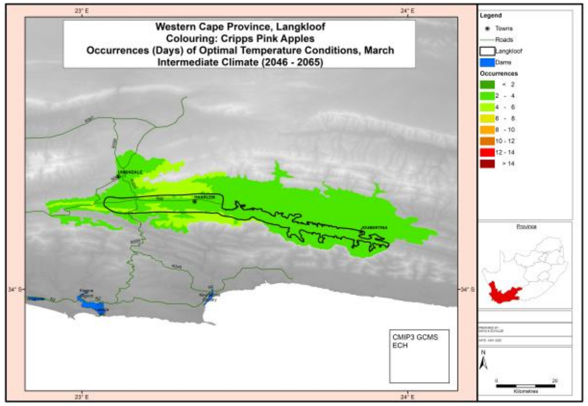


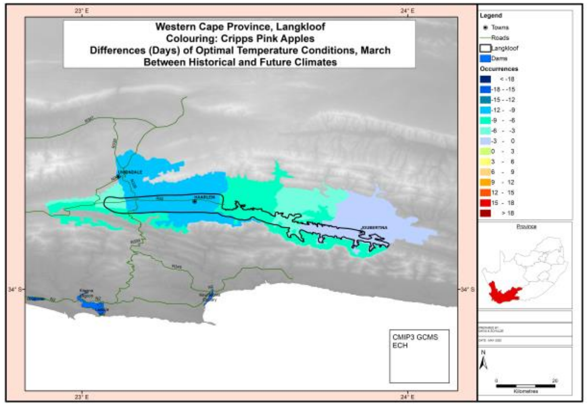




APPLE RED COLOUR CONDITIONS MARCH: LANGKLOOF







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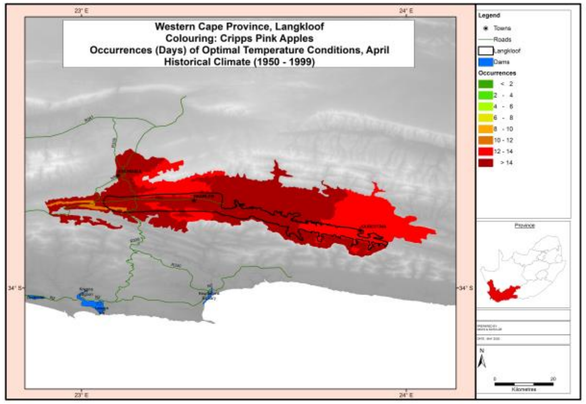
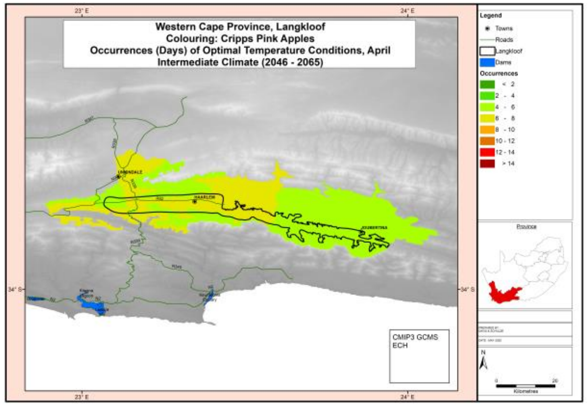
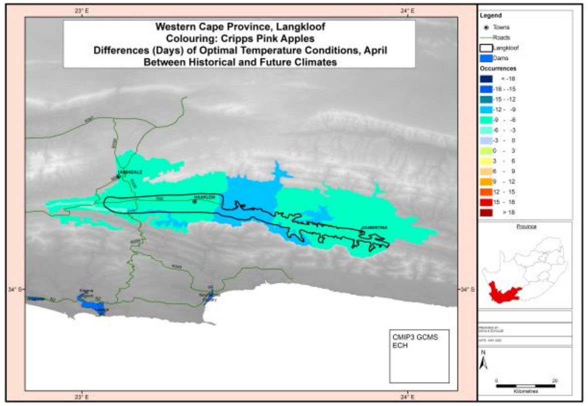
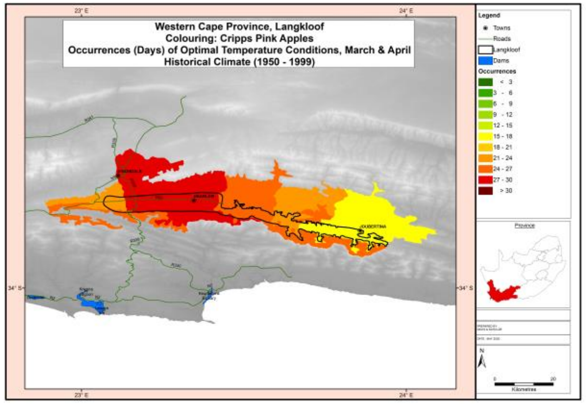
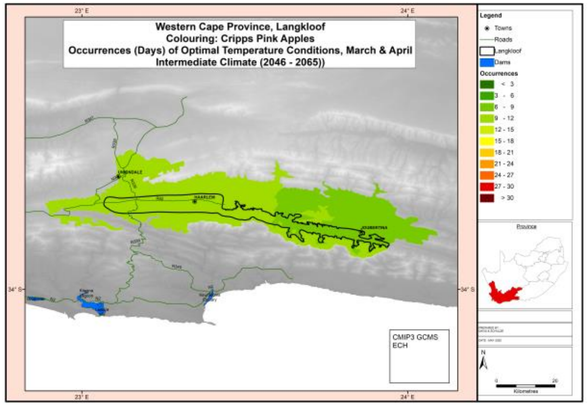






APPLE RED COLOUR CONDITIONS MARCH + APRIL: LANGKLOOF





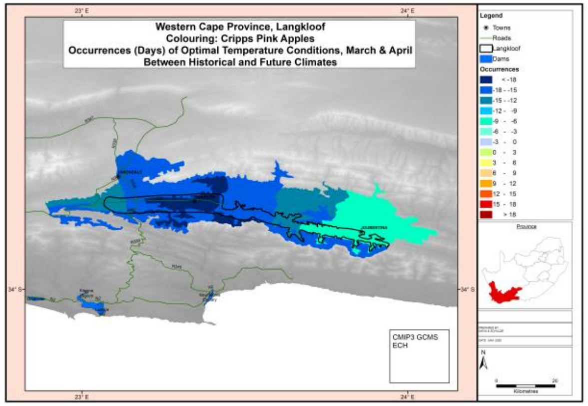


Figure 16. Number of days in March (top row), April (middle row) and March + April (bottom row) that climatic temperature criteria are met for red colouring of apples under historical climatic conditions (left column), under projected climatic conditions of the intermediate future (middle column), and the difference between historical and intermediate future climatic conditions (right column), for each of the three main apple production regions. The intermediate future maps are derived from one CMIP3 GCM.

13. Adaptation to climate change

Climate change adaptation is "The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects." (IPCC, 2014)

Furthermore, climate change scientists generally agree that *adaptive capacity* refers to "the ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences." Adaptive capacity varies widely within and between sectors, geographically, and between social/ecological/economic systems. Adaptive capacity within an industry such as the fruit industry is the sum of all the capacities and efforts of every chain in the link, namely, growers, farm workers, input suppliers, packers, processors, marketers, insurers, financial institutions, industry bodies, government institutions (e.g. for water governance, disaster planning and response), and researchers.

It is important to be clear on what risks the actors within this system need to be adapting *to*. For this reason, a grower or other actor must first identify the specific risks and impacts arising from the climate at a given location with a specific context, for the present climate and future time periods. A first step towards adaptation to future climate change can be to reduce vulnerability and exposure to present climate variability and risk. This then leads to planning for the short- to longer-term future, considering changes in average climate (e.g. gradual warming), changes in variability from year to year, and changing risks of weather extremes. Poor planning, overemphasizing short-term outcomes, or failing to sufficiently anticipate the varied consequences of actions taken can result in *maladaptation*. Some responses that may seem desirable in the short term can turn out to be maladaptive over longer time periods because they either increase vulnerability (e.g. building of below-specification agricultural infrastructure in disaster-prone areas), or they run the risk of becoming white elephants (e.g. capital-intensive projects such as dams or cold storage facilities which become under-utilised as the climate and associated production regions shift geographically).

Another concept that must be considered is the *adaptation limit*, defined as "the point at which an actor's objectives (or system needs) cannot be secured from intolerable risks through adaptive actions" (IPCC, 2014). We can distinguish between a 'hard adaptation limit' (i.e. no adaptive actions are possible to avoid intolerable risks) and 'soft adaptation limit' (i.e. options are currently not available to avoid intolerable risks through adaptive action). The latter situation can be overcome through innovation and technology development, and transformations in farming practices.

The SmartAgri Plan[2] (Midgley et al., 2016a) states: "Responding to climate-related risks involves decision-making in a changing world, with continuing uncertainty about the severity and timing of climate change impacts and with limits to the effectiveness of adaptation. Iterative risk management with multiple feedbacks [see Figure 17] is a useful approach for adaptation in agriculture. Assessment of the widest possible range of potential impacts, including low-probability outcomes with large consequences, is central to understanding the

[2] Western Cape Climate Change Response Framework and Implementation Plan for the Agricultural Sector (2016). Available at: https://www.greenagri.org.za/smartagri-2/smartagri-plan/

benefits and trade-offs of alternative risk management actions. The complexity of adaptation actions across scales and contexts means that monitoring and learning are important components of effective adaptation."

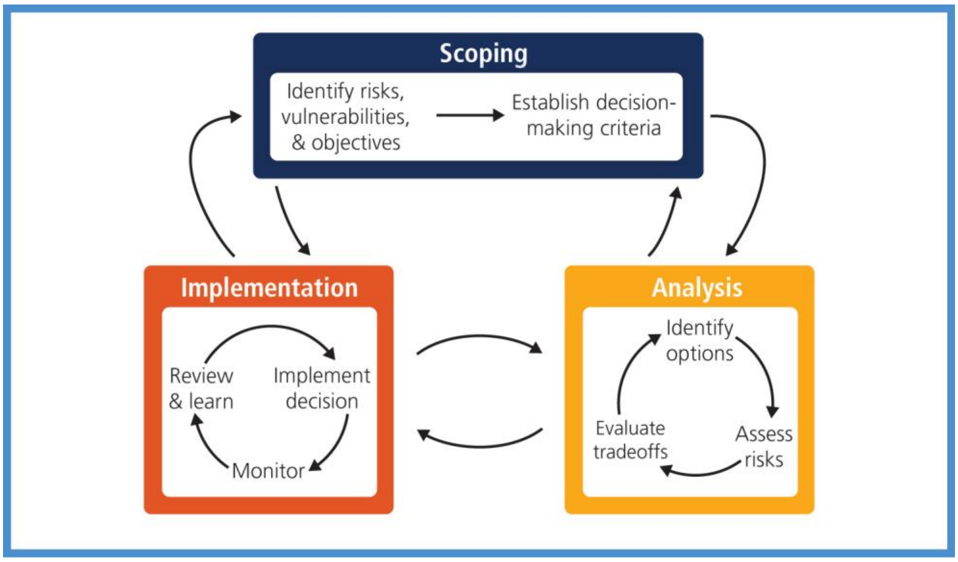


Figure 17 Climate-change adaptation as an iterative risk management process with multiple feedbacks. People and knowledge shape the process and its outcomes. Jones et al. (2014).

Growers need a wide range of hard and soft technologies and approaches from which to make appropriate choices tailored to their own situation and needs. The inherent uncertainty in weather and climate projections means that sometimes very specific measures can be taken (e.g. flood defenses), whereas at other times so-called 'no-regret' measures, which are robust to a wide range of possibilities (e.g. good land management), are more appropriate. These prevent 'lock-in' and allow for flexibility in future choices.

In the agricultural sector, technology clearly plays a very important part in productive potential and adaptive capacity. Improvements of technologies support greater and more efficient production, lower costs, help farmers to reach new markets, and can also be employed to reduce risks. Technology includes physical infrastructure, machinery and equipment (e.g. irrigation systems), knowledge and skills (e.g. farmer training and awareness raising) and the capacity to organize and use all of these (e.g. water user associations); but also the biological technology (e.g. genetic choices) with which farmers produce. Biological technology complemented with advances in crop nutrition and crop protection, equipment and knowledge have been the primary drivers of increased productivity in agriculture. These should be reevaluated and improved in the light of evolving situations and needs. Appropriate technologies are those which can be managed and maintained by farmers over the long term, and which integrate environmental, economic, and social sustainability principles.

In the past, agricultural capital investments were planned for an economic lifetime of decades. However, the accelerating pace of changing consumer preferences and market price fluctuations has changed this situation significantly over the last 20 years or so. Perennial orchards are now replaced over shorter cycles as new cultivars become more popular, fetching a premium which justifies the investment. In this context, the notion that growers are always planning for the next 30-40 years has become outdated. However, built infrastructure, such as packhouses and cold storage facilities, has a long economic lifetime to achieve a return on investment.

Strategic choices can be made for the shorter term, e.g. planting lucrative current crops or cultivars even though risks of climate related crop losses are understood and factored into the farm's strategy. For less adapted crops and cultivars, climate ameliorating technologies such as protective netting can reduce the risks. At the same time, growers can begin to test the viability of more adapted crops or cultivars for the future and prepare for more transformational changes. Such a phased approach can be very effective by ensuring continued profitability while lessons are learned, and affordable and sustainable technologies are developed and tested. Eventually, decisions must be made regarding the infrastructure that supports the whole value chain, such as placement of pack houses and processing facilities.

In summary, the following types of adaptation options can be considered. Further details are provided in Part 1 of this Guide.

- Adapting to higher winter temperatures and reduced chilling
- Adapting to higher growing season temperatures
- Adapting soil and water management practices
- Adapting to changing pest and disease pressures
- Adopting agro-ecological / regenerative farming systems
- Using weather and climate data smartly

14. Summary of regional climate changes

This section provides an overall summary of current (historical) and projected future climate, and the key risks that must be considered, for each production region.

14.1 EGVV

Current: Of the three core pome fruit regions (together with Ceres and Langkloof), EGVV is the warmest, with the Grabouw area of EGVV providing the coolest microclimate. The Villiersdorp area is warmer annually, in summer and in winter, with more hot days. Nevertheless, EGVV experiences relatively cool summers and hot days are comparatively rare, owing to cooling coastal winds arising in the afternoons. Moderately cold winters mean that there is insufficient chill accumulation for pome fruit, necessitating the use of rest-breaking agents. Historically, low (250) to medium (500) chill units are achieved in May to July, and high chill units (700) in July or August. Conditions conducive to red colouring are achieved on a moderate number of days in March and a high number of days in April, with a high total for both months (18-30). Annual reference potential evaporation (1300-1500 mm) is comparable with the western Langkloof (but lower in summer than this region) and the Koue Bokkeveld.

Future (2050s): A warming of around 2°C is projected, which could mean that most of this region becomes marginal for pome fruit production unless effective adaptation measures are taken. Mean annual temperature, mid-summer maximum temperature and number of hot days annually now resemble those of current stone fruit and wine regions. There are significantly fewer days in autumn conducive to red colour development in apples, with a projected maximum of 9 such days. Winter warming means a significant loss of chill units: low chill units (250) are generally still achieved in June-July but possibly only in August in some areas, while medium chill units (500) are only achieved in August or later (with challenges in Elgin), and high chill units (700) are out of reach for the start of the pome season. A higher probability of 2-month dry spells and a lower probability of 2-month wet spells are projected. The models project moderate annual increases (by ca. 100 mm) in reference potential evaporation, particularly in spring (ca. 30-36 mm).

Adaptations:

- Low chill fruit types
- Low chill pome fruit cultivars
- High red colouring potential pome fruit cultivars
- Protective netting
- Rest-breaking technologies
- Optimal irrigation, starting earlier
- Practices to increase water use efficiency.

14.2 Somerset West

Current: Somerset West is a small pome fruit region (with some plum orchards) that is better known for wine production since it is warmer than EGVV. It can experience a similar coastal cooling influence in summer as EGVV and hot days are also relatively rare. Moderately cold winters lead to insufficient chill accumulation for pome fruit, necessitating the use of rest-breaking agents. Historically, low (250) to medium (500) chill units are achieved in June to July, and high chill units (700) in July. Annual reference potential evaporation (1300-1400 mm) is comparable with the western Langkloof (but lower in summer than this region) and the Koue Bokkeveld.

Future (2050s): With a projected warming of around 2°C this region will struggle to remain suited to pome fruit production without significant adaptation. Annual temperature regimes become like those currently experienced in the warmest parts of the Berg River region. Mid-summer daily maximum temperatures become like those of Wolseley, the Breede River valley and the Klein Karoo currently. The accumulation of chill units is severely affected: low chill units (250) are now achieved in July, while medium (500) and high (700) chill units are not reached. A higher probability of 2-month dry spells and a lower probability of 2-month wet spells are projected. The models project moderate annual increases (by ca. 100 mm) in reference potential evaporation, particularly in spring (ca. 33-36 mm).

Adaptations:

- Low chill fruit types
- Low chill pome fruit cultivars
- High red colouring potential pome fruit cultivars
- Protective netting
- Rest-breaking technologies
- Optimal irrigation, starting earlier
- Practices to increase water use efficiency.

14.3 Riviersonderend

Current: This is not a core pome fruit region owing to its warmer climate but has recently seen significant plantings. The region is bounded to the north by the Riviersonderend Mountains and the south-facing aspects provide for some cooling. The western part, from the Theewaterskloof Dam wall to around Genadendal, is cooler than the eastern part of the region. A smaller coastal influence means that mid-summer days can get quite warm, but most of the region does not experience many hot days annually, although more than EGVV. The winters are moderately cold and there is insufficient chill accumulation for pome fruit, necessitating the use of rest-breaking agents. Historically, low (250) to medium (500) chill units are achieved in June to July, and high chill units (700) in August. Annual reference potential evaporation is higher than in other southern coastal pome regions at 1500-1700 mm but is comparable with the Warm Bokkeveld and Stellenbosch.

Future (2050s): This region is projected to warm by around 2°C. Already marginal for pome fruit production, significant adaptation will be required. Annual temperature regimes become like those currently experienced in the warmest parts of the Berg River region. Mid-summer daily maximum temperatures become like those of Tulbagh and Montagu currently. The accumulation of chill units is severely affected: low chill units (250) are now achieved in June to July, medium chill units (500) are achieved between August and October, and high (700) chill units are not reached in time for the start of the season. A slightly higher probability of 2-month dry spells and a slightly lower probability of 2-month wet spells are projected. The models project moderate annual increases (by ca. 100 mm) in reference potential evaporation, particularly in spring (ca. 30-33 mm).

Adaptations:

- Low chill fruit types
- Low chill pome fruit cultivars
- High red colouring potential pome fruit cultivars
- Protective netting
- Rest-breaking technologies
- Optimal irrigation, starting earlier
- Practices to increase water use efficiency.

14.4 Ceres

Current: This is a core pome fruit region (together with EGVV and Langkloof) characterised by cold winters and warm summers. The Koue Bokkeveld (including the Witzenberg Valley), at around 500 m higher altitude, is colder than the Warm Bokkeveld (around Ceres and Prince Alfred's Hamlet). This makes it ideal for apple production. The latter can get hot in summer and has a higher probability of hot days per annum compared to the Koue Bokkeveld, making it suited to pear and stone fruit production. High chill accumulation occurs across the region and rest-breaking agents are only partially used. Historically, low (250) to medium (500) chill units are achieved in May to June, and high chill units (700) mainly in June (July around Ceres). Since temperatures towards the end of the season decline earlier than in the south-western production regions, a high number of days conducive to red colouring is achieved in March and April, with a high total in both months (21-30 and higher), especially in the Koue Bokkeveld (>30 days). Annual reference potential evaporation varies between 1200-1400 mm in the coldest microclimates (comparable with large parts of EGVV and the western Langkloof), and 1500-1700 mm around Ceres and Prince Alfred's Hamlet (comparable with Riviersonderend).

Future (2050s): A warming of more than 2°C is projected in this region, especially in the Koue Bokkeveld. Mid-summer temperatures could increase significantly in many parts, but the largest increases in the number of hot days annually are confined to the area around Ceres. Annual and summer temperature regimes become more like those currently experienced in Piketberg, Wolseley-Tulbagh, the Klein Karoo and the Berg and Breede River regions. However, winters remain relatively cold. There are significantly fewer days in autumn conducive to red colour development in apples (with greater reductions in the Koue Bokkeveld), with a projected range of 9-15 such days. Chill unit accumulation is reduced but remains viable for pome fruit production: low chill units (250) are achieved in May-June, medium chill units (500) are achieved in June-July, and high chill units (700) are reached in July (except around Ceres and Prince Alfred's Hamlet where they are reached in August). A higher probability of 2-month dry spells and a lower probability of 2-month wet spells are projected. The models project moderate annual increases (just above 100 mm) in reference potential evaporation, but possibly higher around Ceres and Prince Alfred's Hamlet. The increases are seen in spring, summer and autumn.

Adaptations:

- Rest-breaking technologies
- Low and medium chill pome fruit cultivars in the Warm Bokkeveld
- High red colouring potential pome fruit cultivars
- More stone fruit in the Warm Bokkeveld
- Protective netting
- Optimal irrigation, starting earlier and ending later
- Practices to increase water use efficiency
- Diversified water supply sources.

14.5 Wolseley-Tulbagh

Current: Wolseley and Tulbagh are in proximity but have contrasting climates. Wolseley is climatologically more like Ceres on the other side of the Michell's Pass, having relatively cold winters, but Tulbagh is substantially warmer throughout the year. This makes Wolseley ideal for pear production, whereas Tulbagh is more suited to stone fruit. In Wolseley, low (250) to medium (500) chill units are historically achieved in May to June, and high chill units (700) are achieved in July. In Tulbagh, 250 and 500 chill units are reached in June and July, respectively, while 700 units are reached in August. Annual reference potential evaporation is 1500-1700 mm in Wolseley (like Ceres), and 1700-1800 mm in Tulbagh (comparable with Calitzdorp, Wellington and Robertson).

Future (2050s): A warming of around 2°C is projected in this region, bringing the mean annual temperature to over 18°C. The projected number of hot days annually increases strongly, especially in Tulbagh. Chill unit accumulation is reduced as follows in Wolseley: low chill units (250) are achieved in June, medium chill units (500) are achieved in August, and high chill units (700) are achieved in October (too late for the start of the season). In Tulbagh, low chill units are achieved in July, and medium and high chill units are not achieved. A slightly higher probability of 2-month dry spells and a slightly lower probability of 2-month wet spells are projected. The models project moderate annual increases (just above 100 mm) in reference potential evaporation in Wolseley but possibly higher in Tulbagh. The increases are strong in spring, summer and autumn, and even in winter in Tulbagh.

Adaptations:

- Rest-breaking technologies for pome fruit in Wolseley
- Low and medium chill pome fruit cultivars in Wolseley
- More stone fruit in Wolseley
- Other low chill fruit types, especially in Tulbagh
- Protective netting
- Optimal irrigation, starting earlier and ending later
- Practices to increase water use efficiency
- Diversified water supply sources.

14.6 Piketberg

Current: Through its situation on top of the Piketberg Mountain, this region enjoys a microclimate suited to a wide range of fruit production (like Elgin and Riviersonderend). Mid-summer days are on average quite warm, but hot days are relatively rare owing to cooling mists frequently rolling over the mountain. The winters are moderately cold (again, like Elgin) and there is insufficient chill accumulation for pome fruit, necessitating the use of rest-breaking agents. Historically, low (250) to medium (500) chill units are achieved in June, and high chill units (700) in July. Annual reference potential evaporation is 1400-1500 mm, comparable with Villiersdorp and Witzenberg.

Future (2050s): Climate models project a warming of around 2°C which could mean that Piketberg becomes marginal for pome fruit production unless effective adaptation measures are taken. Annual temperature regimes become more like those currently experienced in the warmest parts of the Berg River region. Mid-summer daily maximum temperatures become more like those of Tulbagh and Montagu currently. Winter warming means a more moderate loss of chill units compared to some other regions: low chill units (250) are still achieved in June, medium chill units (500) are achieved in July, and high chill units (700) are achieved in August. However, the probability of 2-month dry spells and of 2-month wet spells increases according to the projections. Reference potential evaporation is projected to increase by ca. 100 mm, particularly in spring (30-33 mm) and summer (>36 mm).

Adaptations:

- Low and medium chill fruit cultivars
- Heat resilient fruit cultivars
- Protective netting
- Rest-breaking technologies
- Optimal irrigation, starting earlier
- Practices to increase water use efficiency.

14.7 Langkloof

Current: This is a core pome fruit region (together with EGVV and Ceres), characterised by cold winters and cool to warm summers. Coastal afternoon winds move into the valley and provide cooling on summer days. Mid-summer maximum temperatures are moderate (like Grabouw and Witzenberg) and the occurrence of hot days is rare. However, there is a climatic gradient from the western to the eastern parts of the valley. The eastern parts, around Joubertina, are generally warmer in all seasons with a higher potential evapotranspiration and lower winter chill accumulation. The region is ideal for apple production (apart from the risks of frost and hail). Winters in the western parts of the valley are as cold as in the Koue Bokkeveld and chill unit accumulation is relatively rapid. Historically, low (250) and medium (500) chill units are achieved in May and June, respectively, and high chill units (700) are achieved in June-July in the west, but only in August in the east. Since temperatures decline earlier than in the south-western production regions, a high number of days conducive to red colouring is achieved in March and April, with a high total in both months (21-30 days in the west, but 15-21 days in the east). Annual reference potential evaporation in the west is 1300-1400 mm (comparable with large parts of EGVV and the colder parts of the Koue Bokkeveld), but 1400-1500 mm in the east.

Future (2050s): A warming of more than 2°C is projected, relatively more strongly in the western valley. Mid-summer temperatures could increase significantly across the valley, with corresponding increases in the number of hot days. Summer temperature regimes become more like those currently experienced in the warmer parts of EGVV and the Koue Bokkeveld, but with more hot days as in Ceres and Wolseley currently. The models project significant winter warming in the west, so that winter temperature regimes resemble those of EGVV currently. There are significantly fewer days in autumn conducive to red colour development in apples, with a projected range of 6-12 such days. Chill unit accumulation is reduced but remains viable for pome fruit production in the western valley: low chill units (250) are achieved in June-July, medium chill units (500) are achieved in July, but high chill units (700) are only reached in August. In the eastern valley, the future climate could become less favourable in terms of winter chilling. A higher probability of 2-month dry spells and a lower probability of 2-month wet spells are projected (possibly significantly more so in the east). The models project moderate annual increases (just under 100 mm) in reference potential evaporation in the western valley, particularly in autumn (24-33 mm). The increase for the eastern valley is projected to be up to 120 mm, with high increases in all seasons.

Adaptations:

- Low and medium chill pome fruit cultivars
- High red colouring potential pome fruit cultivars
- Heat resilient cultivars
- In the east: low chill fruit types including more stone fruit
- Protective netting
- Rest-breaking technologies
- Increased water storage
- Optimal irrigation, ending later
- Practices to increase water use efficiency.

14.8 Klein Karoo East

Current: This region, characterised by hot summers and moderately cold winters, is suited to pear and stone fruit production, as well as grapes. The areas around Ladismith and Calitzdorp are particularly hot. Fruit is grown along the rivers and close to other sources of irrigation water, and close to the cooler south-facing slopes of the Swartberg Mountains. The probability of hot days in these areas is moderate. Winter temperatures and chill accumulation are like that of EGVV. Historically, low (250) and medium (500) chill units are achieved in June and July, respectively, and high chill units (700) in July (warmest areas in August). Annual reference potential evaporation is 1500-1600 mm in the vicinity of Zoar, and 1700-1800 mm in most of the remainder of the region. Irrigation is critical. Historical annual streamflow (see Appendix A) is very low in the central and western parts of the region, and only somewhat higher in the eastern part.

Future (2050s): A warming of around 2°C is projected, with greater warming in the Calitzdorp area. Given the already hot climate, this area could become very hot in future. The mean annual number of hot days also increases substantially, although the Zoar area may be less seriously affected. Mid-winter warming could be high, but future mid-winter temperatures would still be relatively cool. However, the accumulation of chill units is projected to be severely affected: low chill units (250) are generally achieved in June or July, while medium chill units (500) are only achieved in August, and high chill units (700) are achieved in September or October, with the western parts not reaching this level. A higher probability of 2-month dry spells and a lower probability of 2-month wet spells are projected. The models project moderate annual increases in reference potential evaporation (by ca. 100 mm, but more in the Calitzdorp area), in spring, summer and autumn, and in winter in the Calitzdorp area. However, annual streamflow could decrease (Appendix A), leaving the whole region with very low flows. However, these results are close to zero and should not be over-interpreted.

Adaptations:

- Low chill fruit types
- Heat resilient fruit cultivars
- Protective netting
- Increased water storage and other sources of water
- Optimal irrigation, starting earlier and ending later
- Practices to increase water use efficiency.

14.9 Klein Karoo West

Current: The western-most part of this region, the Koo Valley, lies at higher altitude and has a very different climate to Montagu. It is much cooler year-round, with warm summer days but a very low probability of hot days, and a relatively cold winter, much like the Warm Bokkeveld. In the Koo, low (250) and medium (500) chill units are achieved in May and June, respectively, and high chill units (700) in June or July. Annual reference potential evaporation is 1400-1500 mm. Annual streamflows are low in the Koo Valley.

The Montagu to Barrydale area is much warmer, resembling other parts of the Klein Karoo climatically. Montagu and the area south of the Poortjieskloof Dam can get very hot in summer. The eastern parts around Barrydale, on the northern slopes of the Swellendam Mountains, are somewhat cooler in summer, and experience colder winters. Low (250) and medium (500) chill units are achieved in June and July, respectively, and high chill units (700) in July (Barrydale area) or August (Montagu-Poortjieskloof). Annual reference potential evaporation is 1500-1700 mm (Barrydale area) and 1700-1900 mm (Montagu-Poortjieskloof). Irrigation is critical. Historical annual streamflows are low in the western parts of the region, and slightly higher in the eastern part (Appendix A).

Future (2050s): In the Koo Valley, annual and mid-summer warming of around 2°C is projected, with only a small increase in the probability of hot days. Moderate winter warming is projected, but there are significant effects on chill accumulation. Low (250) chill units are achieved in May or June, medium (500) chill units are achieved in June (mountain slopes) or August, and high chill units (700) are achieved in July (slopes) or September. A slightly higher probability of 2-month dry spells and a lower probability of 2-month wet spells are projected. Annual increases in reference potential evaporation of around 100 mm are seen, with increases in spring, summer and autumn, but also in winter. Annual streamflows are projected to decrease somewhat (Appendix A). However, these results are close to zero and should not be over-interpreted.

Across the Montagu-Barrydale area, annual and summer warming is projected of around 2°C, with possibly greater summer warming and a greater increase in hot days in the eastern parts. Similar levels of winter warming lead to significant changes in chill accumulation: Low (250) chill units are still achieved in June, medium (500) chill units are achieved in August, and high chill units (700) are achieved in September or October. The probability of 2-month dry spells and of 2-month wet spells increases, particularly in the Poortjieskloof area. This is a concern given the location of the dam in this area. Reference potential evaporation is projected to increase by around 100mm, in spring, summer and autumn, but also in winter. Annual streamflows are projected to decrease in the western parts, with an indication of slight increases in the eastern parts. As noted above, these results are close to zero and should not be over-interpreted.

Adaptations:

Koo Valley:

- Low and medium chill pome fruit cultivars
- High red colouring potential pome fruit cultivars
- Low chill fruit types including more stone fruit
- Protective netting
- Optimal irrigation, starting earlier and ending later
- Practices to increase water use efficiency.

Montagu to Barrydale:

- Low chill fruit types
- Heat resilient fruit cultivars
- Protective netting
- Increased water storage and other sources of water
- Optimal irrigation, starting earlier and ending later
- Practices to increase water use efficiency.

14.10 Stellenbosch-Berg

Current: This region is better known as a wine producing region, but it is also well suited to plums, other stone fruit and citrus. The southern areas (Stellenbosch, Franschhoek) are moderately warm, and the northern areas can get hot in summer, especially around Wellington. Moderately cold winters lead to generally low chill accumulation. Historically, low (250) to medium (500) chill units are achieved in June and July, respectively, and high chill units (700) in August. Annual reference potential evaporation varies widely from 1400-1500 mm in Franschhoek to 1700-1800 mm in Wellington.

Future (2050s): Warming of more than 2°C is projected, with greater warming possible in the northern areas in summer, and a greater increase in hot days around Paarl-Wellington. Wellington could become very hot. Winter warming across the region will reduce the accumulation of chill units: low chill units (250) are now achieved in July (Franschhoek, Paarl) or August (other areas), medium (500) chill units are achieved too late for the season's start, or not at all; and high (700) chill units are not reached anywhere. A strongly increased probability of 2-month dry spells, especially in parts of the Berg River valley, and a lower probability of 2-month wet spells are projected. The models project annual increases (by ca. 100 mm or more) in reference potential evaporation, particularly in spring (ca. 33 mm to >36 mm) and in summer (30 mm to >36 mm).

Adaptations:

- Low chill fruit types
- Heat resilient fruit cultivars
- Protective netting
- Increased water storage and other sources of water
- Optimal irrigation, starting earlier
- Practices to increase water use efficiency.

14.11 Breede Valley

Current: This is primarily a wine producing region, but some parts are ideally suited to stone fruit production (Robertson/Ashton/Bonnievale). Annual temperatures vary from moderately warm (Nuy, McGregor) to hot (Worcester, Bonnievale), and summers are hot across the region. A moderately high to high (Robertson-Ashton) number of hot days are experienced annually. Winters are slightly colder around Robertson-McGregor-Ashton. Chill unit accumulation is as follows: low (250) to medium (500) chill units are achieved in June and July, respectively, and high chill units (700) are achieved in July (Nuy) or August (elsewhere). Annual reference potential evaporation is high at 1600-1800 mm, and slightly higher (1800-1900 mm) in the Ashton area.

Future (2050s): Warming of more than 2°C is projected, annually and in summer and winter. The models project a reduction in chill unit accumulation: low chill units (250) are now achieved in July, medium (500) chill units are achieved in August (Nuy), or too late for the season's start; and high (700) chill units are not reached anywhere. The probability of 2-month dry spells is increased, and the probability of 2-month wet spells is decreased. Annual increases (by ca. 100 mm) in reference potential evaporation are projected, particularly in spring (27-36 mm) and in summer (24-33 mm), extending in some areas into autumn and winter.

Adaptations:

- Low chill fruit types
- Heat resilient fruit cultivars
- Protective netting
- Optimal irrigation, starting earlier and ending later
- Practices to increase water use efficiency.

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APPENDIX A: Annual streamflow

'Accumulated streamflow' is here defined as the runoff (i.e. stormflow plus baseflow) from a specific catchment *plus* the runoff from all catchment areas upstream of the specific catchment in question. Across the Western Cape, a very wide range of mean annual streamflows is encountered. These range from < 10 mm equivalent to ~ 400 mm under historical climatic conditions, with highest streamflows in the high-altitude mountains and in the major river systems such as the Olifants in the north-west and the Breede in the south. Equally striking is the wide range in the inter-annual variability of streamflows, with coefficients of variation (CV, %) ranging from < 40% to > 200%. In general, an inverse relationship exists between the magnitude of streamflows and the magnitude of CVs, with low CVs in the high streamflow mountains and the major river systems and highest variability of flows in the north-west and in the Karoo, where annual streamflows are low. An interesting exception is the southern Cape, where annual streamflows are relatively high but a higher CV is experienced compared to the river systems in the west.

In this section, we focus on the two pome and stone fruit regions of the Klein Karoo, where historically streamflows are low and erratic, and any possibly decreases in the future would have severe impacts on the sector. Figure 18 presents the results for median annual streamflow in mm equivalents for the historical period (left column), for the immediate future (middle column) and the change from the present to the immediate future of the 2030s (right column). Present day streamflows are generally lower in Klein Karoo East (especially around Zoar) compared to Klein Karoo West. Projected changes into the future are highly variable, with increases up to 10 mm indicated for the Barrydale area and parts of the Klein Karoo East, and decreases up to 10 mm indicated over all other areas.

These changes are relatively small in absolute (volumetric) terms, but when considered as percentage changes relative to present streamflows, relatively high reductions of 10-30%, and up to 50% in the Zoar area, are seen in the two regions (with the exception of the Barrydale area).

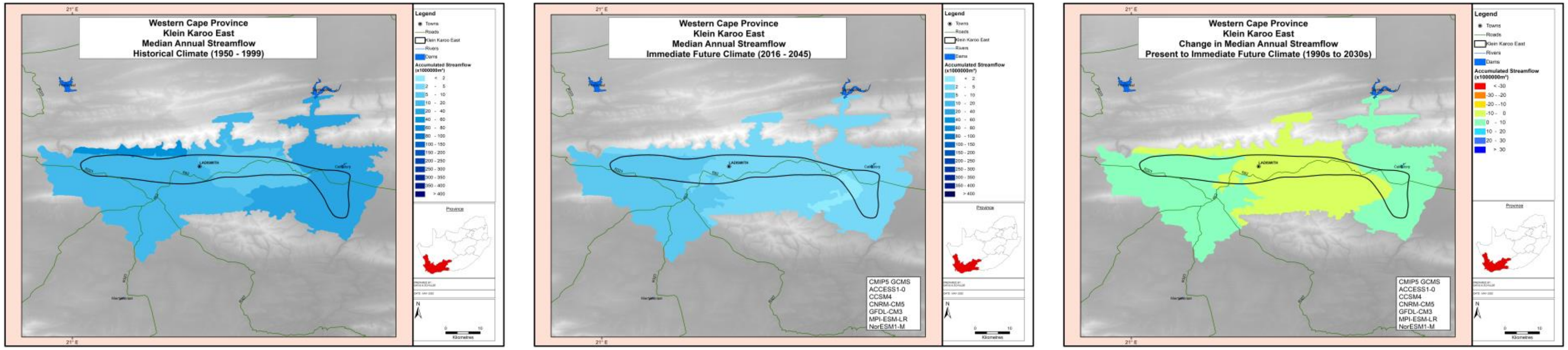
In an already water stressed region, any projected reductions in streamflows do not auger well for the pome and stone fruit sectors which are heavily irrigation dependent. In addition to these regions potentially experiencing lower streamflows in future, the higher temperatures and enhanced evaporation rates will imply higher irrigation demands. However, in some catchments, projected increases in streamflows could alleviate future conditions to some extent. Given the relatively small volumetric changes one should, however, be cautious in over-interpreting the significance and impact on agriculture.

EASTERN INTERIOR REGION (POME AND STONE):

- **Historical Annual Streamflow:**
  <10 mm: Zoar
  10-20 mm: west of Ladismith
  20-40 mm: Calitzdorp, Koo, Montagu, Poortjieskloof
  40-60 mm: Barrydale

- **Change in Annual Streamflow:**
  0 to +10 mm: west of Ladismith, Calitzdorp, Barrydale
  0 to -10 mm: Ladismith, Zoar, Koo, Montagu, Poortjieskloof

ANNUAL MEDIAN STREAMFLOW: KLEIN KAROO EAST



ANNUAL MEDIAN STREAMFLOW: KLEIN KAROO WEST

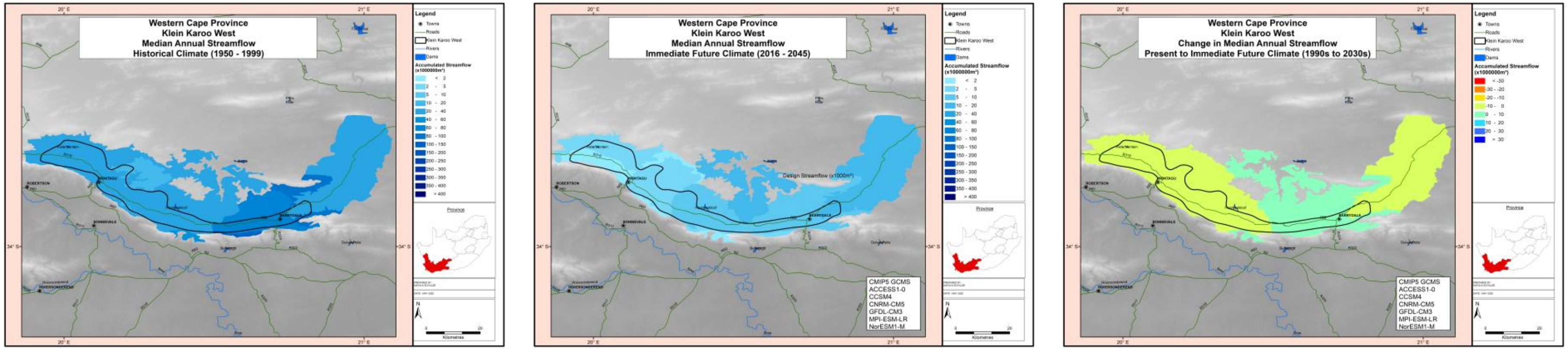


Figure 18. ACRU model derived median annual streamflow (in mm) under historical climatic conditions (left column), under projected climatic conditions for the immediate future (middle column), and projected changes (in mm) from the present to immediate future climates (right column) for two pome and stone fruit production regions in the Klein Karoo (those of greatest concern). The immediate future maps are derived from multiple CMIP5 GCMs.