

A GUIDEBOOK ON CLIMATE SCENARIOS

USING CLIMATE INFORMATION TO GUIDE ADAPTATION RESEARCH AND DECISIONS

2016 EDITION



Suggested citation: Charron, I. (2016). A Guidebook on Climate Scenarios: Using Climate Information to Guide Adaptation Research and Decisions, 2016 Edition. Ouranos, 94p.

ISBN (Impression): 978-2-923292-19-9

ISBN (PDF online): 978-2-923292-21-2

Copies of this guidebook can be downloaded from
www.ouranos.ca

May 2016

With support from Natural Resources Canada through the Adaptation Platform



Natural Resources
Canada

Ressources naturelles
Canada

Canada



.....
CONSORTIUM ON REGIONAL CLIMATOLOGY AND ADAPTATION TO CLIMATE CHANGE

550 Sherbrooke West,
19th floor Montreal, Quebec,
H3A1B9, Canada
Tel: 514-282-6464
Fax: 514-282-7131
www.ouranos.ca

ACKNOWLEDGEMENTS

A large number of contributors must be thanked for providing valuable feedback on the first and second versions of the guidebook:

- › *Valérie Bourduas Crouhen, Dominique Paquin, Travis Logan, Diane Chaumont, Caroline Larrivée, Hélène Côté, Marco Braun, David Huard, Patrick Grenier, and Ramón deElía (Ouranos)*
- › *René Pigeon, Don Lemmen, Mary-Ann Wilson, Pamela Kertland, John Sommerville, Liam Miller, and David Price (Natural Resources Canada)*
- › *Al Douglas (Ontario Centre for Climate Impacts and Adaptation Resources)*
- › *Trevor Murdock (Pacific Climate Impacts Consortium)*
- › *Linda Mortsch, Greg Flato, Jamie Smith, Grace Koshida, Marjorie Shepherd, Stewart Cohen, Xuebin Zhang, Kevin Anderson and Benita Tam (Environment Canada)*
- › *Dave Spittlehouse (BC Provincial Government)*
- › *Éric Larrivée (Ministère du Développement durable, Environnement, Faune et Parcs du Québec)*
- › *Nathalie Martel (Bureau des changements climatiques et de la santé, Québec)*
- › *Kate Germain (Chaire de tourisme Transat – Réseau de veille en tourisme)*

For this second version, a large number of organizations and individuals helped organize seminars and workshops that served to gather feedback and led to a revision of the information presented in this update:

- › *ICLEI*
- › *Ontario Climate Commissioner*
- › *Ontario Ministry of the Environment and Climate Change*
- › *Manitoba Hydro*
- › *Manitoba Government*
- › *Forestry Community of Practice*
- › *Forestry Adaptation working group (NRCan)*
- › *Association minière du Québec*

Special thanks are given to Travis Logan (Ouranos) for producing a large number of the maps and figures presented in the guidebook and to Valérie Bourduas Crouhen for designing and formatting the document and for her help with the organization of workshops.

FOREWORD

The “Guidebook on Climate Scenarios: Using Climate Information to Guide Adaptation Research and Decisions” was first published in the fall of 2014 and has since proven to be a useful tool of reference for both the climate change adaptation community and for those wanting to communicate climate information to decision-makers. Since its publication, the guidebook has been the subject of numerous presentations through different conferences, seminars, and webinars. It has also been tested through a series of workshops with users from different sectors of activity. Many of these presentations and workshops were designed to understand how the document was being used and to obtain specific feedback on the content presented in the guide. This updated version of the guidebook on climate scenarios was modified based on comments obtained by users throughout this process.

Both the original guidebook, the subsequent testing of the document, and this updated version were all funded by Natural Resources Canada under the [Adaptation Platform](#) Program. The Platform’s Regional Adaptation Collaborative (RAC) and Tools Working Group identified this as an important need for adaptation decision-making which would build on the results of the RAC and Tools Program (2009-2012). The RAC and Tools Program was a \$35 million, cost-shared initiative to support collaborative action towards the development of resources and tools to help local practitioners and decision-makers reduce the risks and maximize opportunities arising from a changing climate.

Users of the Guidebook are invited to send questions and comments to Isabelle Charron : charron.isabelle@ouranos.ca.

EXECUTIVE SUMMARY

Climate change is unequivocal. There is ample evidence from around the globe that changes have already occurred. This reality is forcing decision-makers to evaluate the potential impacts, risks, vulnerabilities and opportunities that climate change presents. The development of adaptation plans and actions to adjust to this new reality requires decision-makers to increase their understanding of climate information. However, given the complexity of climate science, climate change information often remains difficult to understand by many users.

There is clear need for providers of climate information to find different ways to present information in order to engage stakeholders from different sectors. This transfer of knowledge between climate scientists and users must not only include the climate information itself, but also a discussion about how climate information is produced and about the uncertainties that are associated with this information. These uncertainties are often viewed as barriers to climate change adaptation but a better understanding of them, and more importantly, a better comprehension of how they affect the interpretation of future impacts can alleviate some of the challenges associated with using climate information.

This guidebook is meant to address some of the main challenges practitioners of adaptation to climate change often face in using climate information. The main goals are to increase their capacity to better understand climate information, to better evaluate their own climate information needs, and to become more critical of the information that is provided to them.

This guide is arguably most useful to those with limited climate information experience as it provides a general introduction of many concepts related to climate science and climate scenarios production. Given the complexity of climate science, the document highlights the importance of working in collaboration with climate service providers and will help users engage more easily with them.

For users more familiar with climate information, or those who regularly use climate data, the document will help identify ways to best showcase their results for different target audiences. Indeed, it is not uncommon for users who are very familiar with climate information to have to translate that information for users or stakeholders who are themselves not as comfortable with such information.

The guide is divided into five chapters. **Chapter 1** provides fact sheets of key concepts in future climate modeling. This section helps users become more familiar with climate science jargon, which is often necessary to better understand climate information; **Chapter 2** outlines a framework to categorize climate information in terms of its purpose and complexity into three categories: basic, intermediate, and detailed. This section uses a decision-tree approach to help users better formulate their climate information needs; **Chapter 3** provides a catalogue of climate information formats that can be associated to one of the three categories identified in the previous chapter. This section describes different ways in which climate information may be provided to different users based on their level of expertise and preference; **Chapter 4** discusses best practices in using future climate information given its inherent uncertainty; **Chapter 5** highlights some case studies of how climate information can be used to guide decisions in climate change adaptation.

KEY MESSAGES

FOR THE INTERPRETATION AND USE OF CLIMATE INFORMATION

- › Take the time to properly evaluate your needs regarding climate information.
- › Interaction with climate service or information providers is of utmost importance throughout the planning or decision process- make sure that the provider understands your issues.
- › Seek advice and guidance from climate service providers and/or boundary organizations if the level of complexity of the information you seek is beyond the current capacity of your organization.
- › The same climate information can be presented or tailored using different formats – work in collaboration with climate service providers to find a format that works best for your specific needs.
- › Choosing the most adequate information product and format can ensure that the information is well understood and hence used most efficiently.
- › All types of climate information can be equally valuable – basic information can inform decisions just as well as detailed information.
- › Do not rely solely on the mean or median scenario – the range (i.e. the uncertainty) in model projections should always be considered.
- › There is no such thing as the best climate scenario – the use of an ensemble of simulations is crucial.
- › Understand the limitations of the climate information used and make sure the information is interpreted correctly.
- › The natural variability in the climate is valuable information – use it to put the projected changes into perspective.
- › Finer spatial resolution is not always needed and does not always yield better information.
- › The relative importance of sources of uncertainty varies over time and therefore impact the decision-making process differently.

LIST OF ACRONYMES

CMIP	.	.	.	.	Coupled Model Intercomparison Project
CRCM	.	.	.	.	Canadian Regional Climate Model
DJF	.	.	.	.	December, January, February (Winter)
EVT	.	.	.	.	Extreme Value Theory
GCM	.	.	.	.	Global Climate Model
GEV	.	.	.	.	Generalized Extreme Value
GHG	.	.	.	.	Greenhouse House Gazes
ICLEI	.	.	.	.	International Council for Local Environmental Initiatives
IPCC	.	.	.	.	Intergovernmental Panel on Climate Change
JJA	.	.	.	.	June, July, August (Summer)
MAM	.	.	.	.	March, April, May (Spring)
NRCan	.	.	.	.	Natural Resources Canada
OCCIAR	.	.	.	.	Ontario Centre for Climate Impacts and Adaptation Resources
PCIC	.	.	.	.	Pacific Climate Impacts Consortium
RCM	.	.	.	.	Regional Climate Model
RCP	.	.	.	.	Representative Concentration Pathway
SON	.	.	.	.	September, October, November (Fall)
SRES	.	.	.	.	Special Report on Emissions Scenarios
WMO	.	.	.	.	World Meteorological Organization



TABLE OF CONTENT

INTRODUCTION	1
THE NEED FOR THIS GUIDE	2
DEFINING ADAPTATION AND DECISION-MAKER	2
TARGET AUDIENCE	4
OBJECTIVES	4
HOW TO USE THIS GUIDE	4
CHAPTER ONE - CLIMATE MODEL CONCEPTS	6
1.1 NATURAL CLIMATE VARIABILITY	7
1.2 CLIMATE CHANGE	8
1.3 CLIMATE MODELS	9
1.4 EMISSIONS SCENARIOS	11
1.5 CLIMATE SIMULATIONS	14
1.6 CLIMATE PROJECTIONS	16
1.6.1 COUPLED MODEL INTERCOMPARAISON PROJECT (CMIP)	17
1.7 SOURCES OF UNCERTAINTY IN CLIMATE PROJECTIONS	18
1.8 SIMULATION ENSEMBLE	20
1.9 DOWNSCALING TECHNIQUES	22
1.9.1 WHEN IS DOWNSCALING NECESSARY	24
1.9.2 DYNAMICAL OR STATISTICAL DOWNSCALING	25
1.10 POST-PROCESSING TECHNIQUES	26
1.10.1 DELTA/SCALING METHOD (ALSO CALLED THE PERTURBATION METHOD)	27
1.10.2 BIAS CORRECTION	28
1.11 CLIMATE CHANGE SCENARIOS	29
1.11.1 REFERENCE PERIOD AND FUTURE HORIZONS	29
1.11.2 CONSTRUCTING CLIMATE SCENARIOS	30
CHAPTER TWO - CATEGORIZING CLIMATE INFORMATION	33
2.1 CLIMATE INFORMATION CATEGORIES	34
2.2 CLIMATE INFORMATION FORMATS	37

CHAPTER THREE - CATALOGUE OF CLIMATE INFORMATION FORMATS	39
BASIC CATEGORY	41
1. SYNTHESIS TABLE	43
2. CLIMATE NORMALS	45
3. HISTORICAL TRENDS	47
4. MAPS OF DELTA CHANGES	49
INTERMEDIATE CATEGORY	51
1. SPATIAL ANALOGUE	53
2. SCATTER PLOT	55
3. FUTURE VALUES	57
4. EVOLUTION OF FUTURE VALUES	59
5. CUMULATIVE DISTRIBUTION FUNCTION	61
DETAILED CATEGORY	63
1. TEMPORAL SERIES	65
2. INTENSITY-DURATION-FREQUENCY CURVES (ANALYSIS OF EXTREMES)	67
3. ANALYSIS OF LIMITED CONFIDENCE VARIABLES – THE CHOICE BETWEEN SYNTHETIC SCENARIOS OR CLIMATE MODEL SCENARIOS	69
CHAPTER FOUR - DECISION MAKING USING CLIMATE INFORMATION	74
CHAPTER FIVE - CASE STUDIES OF CLIMATE INFORMATION USE IN ADAPTATION	77
BASIC INFORMATION	78
INTERMEDIATE INFORMATION	79
DETAILED INFORMATION	81
GLOSSARY	83
EXAMPLES	89
REFERENCES	91

LIST OF FIGURES

Figure 1 |	Steps of a climate change adaptation framework.	3
Figure 2 |	Example of the natural variability in annual mean temperatures, as well as 10 and 30 year moving averages, without the effect of a long-term trend (such as would be produced under a climate signal with increases in GHG).	7
Figure 3 |	Time-series of annual temperature over Quebec, as simulated by the Canadian Regional Climate Model, along with trend lines for a relatively A. short period and B. longer period that highlight the fact that short-term trends may not reflect long-term climate change trends.	8
Figure 4 |	Interactions described by climate models (left panel) and an example of the discrete grids used to compartmentalize the climate system (right panel).	9
Figure 5 |	Global temperature change relative to 1986-2005 for the SRES scenarios run by CMIP3 and the RCP scenarios run by Coupled Model Intercomparison Project (CMIP5, see section 1.6.1). The number of models is given in brackets and the shading (coloured envelopes) represents all model results.	12
Figure 6 |	Timeline for the use of observed (pre-2005) and simulated CO ₂ (post 2005) concentrations in climate simulation production available in the CMIP5 ensemble.	13
Figure 7 |	Time series of global annual mean surface air temperature anomalies (relative to 1986-2005) from CMIP5 concentration-given experiments. Projections are shown for each RCP for the multi-model mean (solid lines) and the 5 to 95% range (± 1.64 standard deviation) across the distribution of individual models (shading). Discontinuities in 2100 are due to different numbers of models performing the extension runs beyond 21 st century and have no physical meaning. Only one ensemble member is used from each model and numbers in the figure indicate the number of different models contributing to the different time periods. No ranges are given for the RCP6.0 projections beyond 2100 as only two models are available.	15
Figure 8 |	Title as Figure 7. The red circle highlights the time period prior to 2050 where models run with all four RCPs project similar changes in global surface temperatures.	18
Figure 9 |	Maximizing the coverage of precipitation, temperature and snow distributions with the lowest number of simulations within a large ensemble.	20
Figure 10 |	Projected change in mean summer temperature (June, July and August) and mean winter temperature (December, January and February). The changes are shown for an ensemble of GCMs under three RCPs (2.6, 4.5 and 8.5). The elliptical lines indicate the 10 th , 50 th and 90 th percent confidence intervals. The scenarios close to the 10 th , 50 th and 90 th percentile changes are circled in blue and highlighted with blue arrows.	21
Figure 11 |	Example of the difference in grid cell size between a global climate models (left panel) with a resolution of approximately 200 km and information that has been downscaled to a 45 km grid cell (right panel).	22
Figure 12 |	Comparison between dynamical and statistical downscaling techniques.	23
Figure 13 |	Example of delta/scaling post-processing technique. The relative change between A. the reference and the future is first calculated and B. the change is then applied to the observed time-series.	27
Figure 14 |	Example of bias correction post-processing technique. The relative change between A. the reference and the future is first calculated and B. the change is then applied to the entire simulated time-series.	28
Figure 15 |	Climate scenario construction done improperly A. by comparing future simulation values with past observed values and done properly B. by comparing past and future simulated values.	31
Figure 16 |	Key criteria used to evaluate the climate information needs of decision-makers.	34
Figure 17 |	Decision tree to evaluate climate information needs	36
Figure 18 |	Climate normals of mean annual temperature (°C) for the reference period 1971-2000. The values are calculated using Environment Canada station data that has been interpolated on a 10 km by 10 km grid and made available through an NRCan database ⁴⁵⁻⁴⁶ (see text).	45
Figure 19 |	Historic annual total precipitation (mm) time series for the period 1901-2005 for an Environment Canada homogenized climatological station ⁴⁶ . Trends for 1901-2005 and 1971-2005 are shown in blue and red, respectively.	47
Figure 20 |	Maps of delta changes	49

- Figure 21** | Spatial analogue for the greater Toronto area for the 2080 horizon (2071-2100). A. The regions where the recent climate (1971-2000) is similar to the climate projected for the greater Toronto area in 2080 (2071-2100). B. The regions where the projected future climate (2071- 2100) is similar to that of the greater Toronto area for the recent past (1971-2000). The similitude categories indicate the level of similarity between the observed climate and the projected climate for the region of interest (using 136 global climate simulations). The analogues are based on a statistical comparison between the current and future distributions of mean annual temperature and total annual precipitation for the reference period 1971-2000 and the horizon 2080 (2071-2100). 53
- Figure 22** | Projected changes in mean temperature (°C) and total precipitation (%) for the provinces of New Brunswick and Nova Scotia for the winter months (DJF, December, January, and February) for the horizon 2080 (2071-2100) in comparison to a 1971-2000 reference period. The changes are shown for an ensemble of global climate simulations under RPC4.5 (n = 100, blue points) and RCP8.5 (n = 60, red points). The associated distributions of each set of simulations are shown on the left and bottom panels. 55
- Figure 23** | Climatic normals in the number of freezing-degree days for the period 1971-2000 along with projected future values for this index for the horizons 2050 (2046-2065) and 2090 (2081-2100), calculated using an ensemble of 79 simulations (75 from CMIP3 and 4 from CRCM4). The middle columns represent the median, while the left and right columns represent the 10th and 90th percentiles of the ensemble, respectively. 57
- Figure 24** | **Left:** Evolution of the mean annual number of growing degree-days for the years 1971-2100 for the Greater Slave Lake region. The values are calculated using an ensemble of 79 simulations (75 from CMIP3 and 4 from CRCM4), while the observations come from an NRCan dataset^{44,45}. **Right:** The distributions values of the regional mean for observed values (black curve) and projected values are shown as the 10th, 50th, and 90th percentiles of the ensemble of climate scenarios (green, blue, and red curves respectively). 59
- Figure 25** | Cumulative distribution function (CDF) of the regional mean annual number of growing degree-days for the reference period (1971-2000) and two future horizons (2050 and 2090) for the Greater Slave Lake region. The values are calculated using an ensemble of 79 simulations (75 from CMIP3 and 4 from CRCM4), while the observations come from an NRCan dataset^{44,45}. Shown are the observed values (black curve) and projected values for the 10th, 50th, and 90th percentiles of the ensemble of climate scenarios (green, blue and red curves). 61
- Figure 26** | A. Projected change in mean annual discharge (Q_{mean}) for the 2041-2070 period in comparison with the reference period 1971- 2000 using an ensemble of 89 CMIP3 simulations and B. mean annual hydrograph for the reference and future periods for one of the sub-watersheds. 65
- Figure 27** | Intensity-Duration-Frequency curves for the St-Lawrence valley simulated for the present (aet) and future (aeu) climate by the CRCM driven by a global climate model CGCM #4. The lines indicate the intensity for events with four different fixed frequency return intervals (2, 5, 10, and 25 years). 67
- Figure 28** | Extent of flood zone as simulated by synthetic scenario 9, presented in Table 8 (QT100 + 2000m³/s). 71

LIST OF TABLES

Table 1	| Key characteristics of RCPs and similarities with SRES scenarios.	12
Table 2	| The relative importance of the three sources of uncertainties in climate projections over time.	19
Table 3	| Comparison of the advantages and limitations of both dynamical and statistical downscaling.	25
Table 4	| Overview of three climate information categories, basic, intermediate, and detailed.	35
Table 5	| Climate information formats associated with each of the three climate information categories.	40
Table 6	| Summary of projected climate change for the province of British Columbia for the horizon 2050 (2041-2070) in comparison to the reference period 1961-1990. Values are calculated using an ensemble of 30 global climate model projections derived from 15 different GCMs each one using two SRES greenhouse gas emissions scenarios (A2 and B1).	43
Table 7	| Examples of climate indices or events with limited confidence	69
Table 8	| List of nine what-if (synthetic) scenarios constructed to simulate changes in discharge along the Rivières-des-Prairies, on the North shore of Montreal. Q2 and Q100 represent total annual discharges with a return period of 2 years and 100 years, respectively.	71





INTRODUCTION

THE NEED FOR THIS GUIDE

Climate change has become an important concern around the globe and in order to adapt to its impacts, the expected changes must first be understood. It can be argued that climate science has now reached a certain level of maturity that renders it more valuable and useful for decision-makers. At the same time, however, the potential impacts of climate change raise an increasing number of issues that decision-makers have to deal with. Consequently, making decisions based on climate information is far from straightforward. Identifying and obtaining the relevant information can be a challenge in and of itself but is one of many steps required to develop an adaptation framework (Figure 1). These steps largely stem from guidelines outlined by the Intergovernmental Panel on Climate Change (IPCC) in the early 1990s for impacts and adaptation studies¹⁻³. They have been described in a growing body of literature (e.g. ⁴⁻⁸), however, most guides focused on impacts and adaptation generally give very limited guidance regarding the various types of climate information available. In this context, this guide aims to provide a tool that will help decision-makers better understand different types of climate information and help them better identify how this information can be used at different stages of the adaptation process. Knowledge exchange between climate service providers and users is increasingly recognized as an important step in the decision making process⁹.

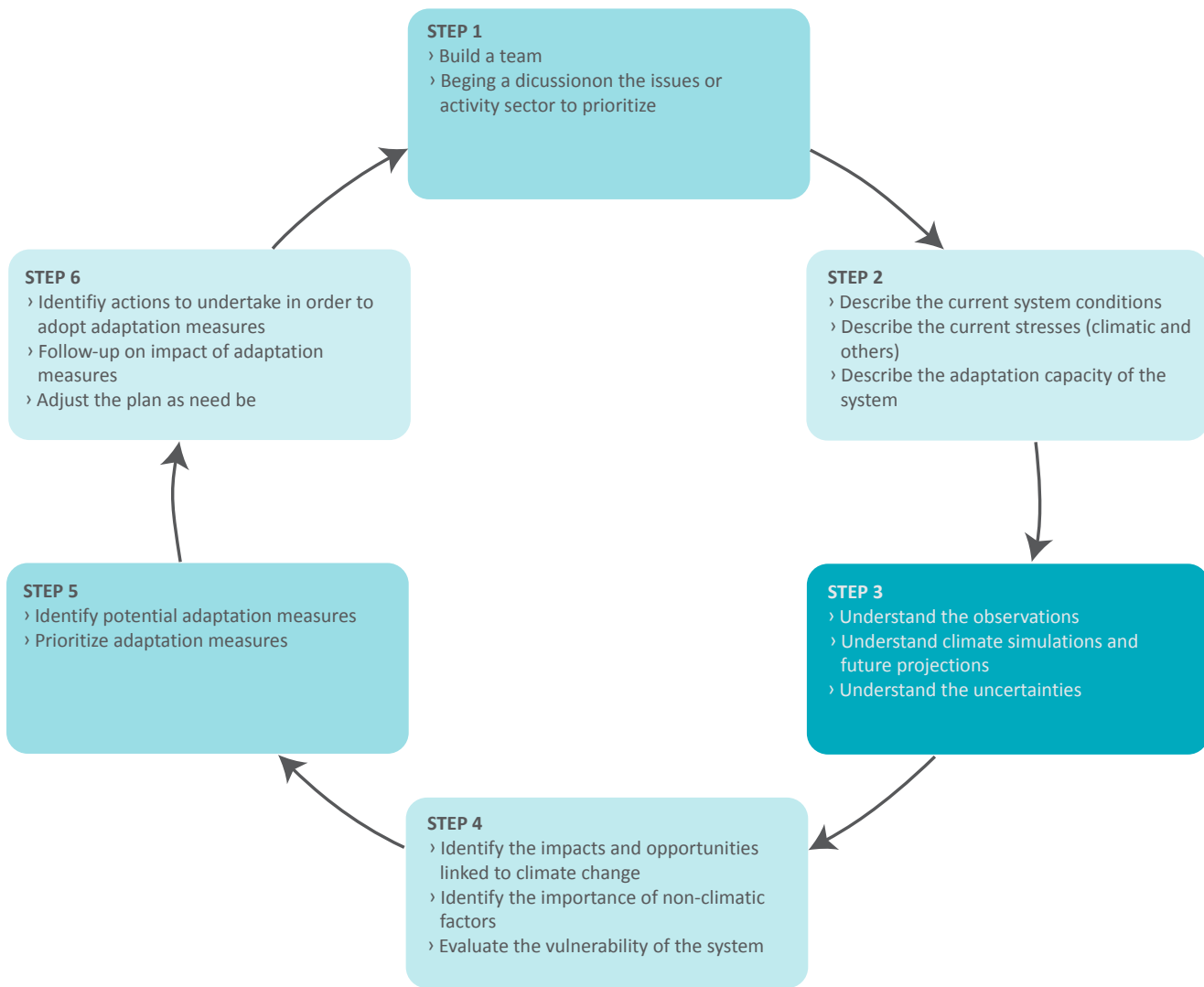
DEFINING ADAPTATION AND DECISION-MAKER

The term *adaptation* is used in this guide to refer to all processes, actions and strategies that allow individuals, communities, and organizations to cope with, manage, and adjust to changing climatic conditions such that risks are minimized and opportunities are seized¹⁰. Adaptation is therefore used in a broad sense and encompasses a number of actions that are often separated into two categories¹¹:

- › *In building adaptive capacity*, which includes establishing systems for data collection and research, increasing awareness, evaluating vulnerabilities and risks, supporting social structures as well as governance.
- › *In exploring adaptation outcomes*, which includes initiating activities that reduce vulnerabilities or exploit opportunities.

In concordance with the term adaptation, the term *decision-maker* is used in this guide to include all individuals that partake in any one of the activities listed above. It therefore includes a wide range of users from those starting a reflection on climate change to those ready to implement adaptation measures. It is important to recognize that a given decision-maker may, over time, find himself at different stages of the adaptation framework. For instance, decision-makers may consider or implement different decisions as their knowledge of climate information increases or as conditions change. For example, a policy maker may first want to evaluate the potential vulnerability of a city to climate change (Step 4 in Figure 1) and based on that first evaluation, he/she may ultimately want to revise norms and policies to include specific adaptation measures (Steps 5 and 6 in Figure 1).

The diversity and availability of climate information have evolved over the years. However, climate information is generally not exploited to its fullest potential. There are a few reasons for this. First, potential users of climate information are numerous and will vary in their knowledge, objectives, capacities, authority and responsibilities¹². Consequently, recognizing what and how to use climate information may not always be straightforward. In addition, their needs may require more specific information that must be customized to some degree to suit their expertise. Indeed, 'generic' decision support tools are not easily constructed given that climate related decisions are made at multiple levels and by a range of actors with varying capacities to handle the information^{13,14}. Finally, climate information must be communicated and transferred efficiently and the optimal format used to convey the information may differ among users.



Note that these steps are iterative. Users may find that they will need to go through some of the steps a number of times

Figure 1 | Steps of a climate change adaptation framework.

Source: I. Charron (Ouranos)

The information presented in the guidebook are particularly useful to the completion of the third step, an important stepping-stone to the identification of impacts and opportunities under a changing climate.

This guide will highlight the fact that climate information can be tailored to suit the needs of a variety of users. With increased interactions between scientists and decision-makers, the gap between these two groups is decreasing and ultimately, users should increase their understanding of the different types of climate information and their usefulness while climate service providers should increase their understanding of the diversity of climate information users. In other words, users must be aware that they may not always need specific ‘decision-driven’ information, while climate service providers must be willing to better format ‘science-driven’ information into something that the users can more readily incorporate into their studies. More specifically, the guide will help identify what are the right tools for the right job.

What is climate information?

The term climate information is used in this document to refer to climate data that are obtained from observations from meteorological stations or from climate models. The former provides information on historical events while the latter can simulate both past and future periods. The focus of the guide is largely on future climate information.

TARGET AUDIENCE

This guide is intended to be broad-reaching and written in a general fashion in order to help decision-makers from all sectors of activity faced with the task of evaluating the impacts of climate change and/or of implementing adaptation measures. In other words, the guide targets an audience already invested in climate change adaptation that is for example going through an adaptation process described in Figure 1. The information presented will be particularly useful for users who have limited experience with climate information and climate services. A better understanding of the available climate information will increase their ability to evaluate their particular needs and to either prepare the information themselves or to communicate their requirements to climate service providers.

Climate service providers will also benefit from the guide since it will help them better categorize demands in terms of the use or purpose of the climate information and acquire a better sense of the different types of climate formats that can be tailored according to user expertise. The latter is also true for those who regularly use climate data and therefore understand climate science concepts well but must often find a way to present their results to stakeholders who may not generally be as familiar with climate information.

OBJECTIVES

The overall objectives of this guidebook are to increase the capacity of decision-makers to understand climate information and to incorporate this information in a decision-making framework. The guide should, on one hand, serve as a reminder to users to become more critical of the information that is given to them, and on the other, it should also serve as a reminder to climate service providers to become more transparent about the way in which climate information is produced.

HOW TO USE THIS GUIDE

This guidebook is meant to appeal to a wide range of users and therefore contains information with varying levels of complexity. Consequently, many will not need to read the entire document. Rather, users may want to focus their efforts on sections that are most relevant to them.

A few important points should guide the reader through this document:

- › Part of the challenge for decision-makers in using climate information is often to understand the terminology used by climate scientists. Many such concepts are addressed in [Chapter 1](#) and are highlighted using bold coloured font throughout the guide.
- › The level of complexity of the climate information increases fairly rapidly with the progression through the different figures and graphics presented in Chapter 3. It may therefore be helpful to evaluate one's needs in [Chapter 2](#) and then use that information to focus on the associated climate information category in [Chapter 3](#).





CHAPTER ONE

CLIMATE MODEL CONCEPTS

1.1 NATURAL CLIMATE VARIABILITY

The climate is not constant. While the weather varies on a daily basis, climate captures variations on all time scales, from one decade or century to the next, and even on a seasonal and yearly basis (Figure 2). For example some winters are warmer than others and annual precipitation is greater in some years than others. These differences are referred to as the *natural variability* in the climate, or *climate variability*. Some of these natural fluctuations in the climate are chaotic and unpredictable, while

others are caused by phenomena that are more or less cyclic, and may occur at different time-scales. Examples of factors that impact the response of the climate include the solar cycle¹⁵, the role of the stratosphere¹⁶, and the role of oceanic circulation patterns¹⁷. Many such climatic phenomena that are part of real world natural variability emerge from climate model simulations but they often exhibit different statistical properties.

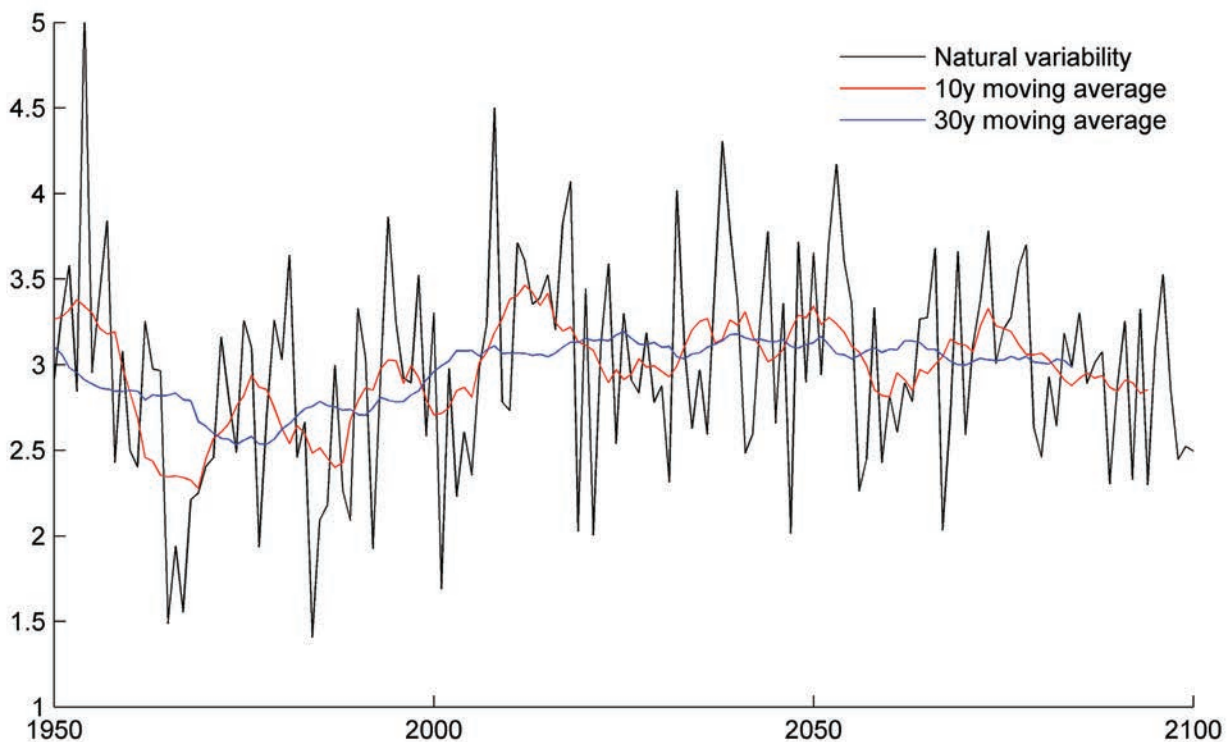


Figure 2 | Example of the natural variability in annual mean temperatures, as well as 10 and 30 year moving averages, without the effect of a long-term trend (such as would be produced under a climate signal with increases in GHG).

Source: T. Logan (Ouranos)

1.2 CLIMATE CHANGE

Climate change is a long-term continuous change, an increasing or decreasing trend, in relation to average baseline conditions. This change is strongly modulated by the natural variability in the climate. Figure 2 shows annual mean temperature data plotted over time. Clearly, the annual temperature is not constant but varies from year-to-year. This natural variability will persist, even if the long-term trend is for annual mean temperature to increase, as shown in Figure 3.

This implies that, in order to pick up a clear climate change signal (Figure 3), climate data must be averaged over relatively long periods of time (see Box on Climate normals). Given the natural variability in the climate, it will still be possible with climate change, to experience short terms trends that are opposite to the overall projected trend due to climate change. It is therefore important to beware of trends that are calculated over a relatively small number of years (Figure 3a).

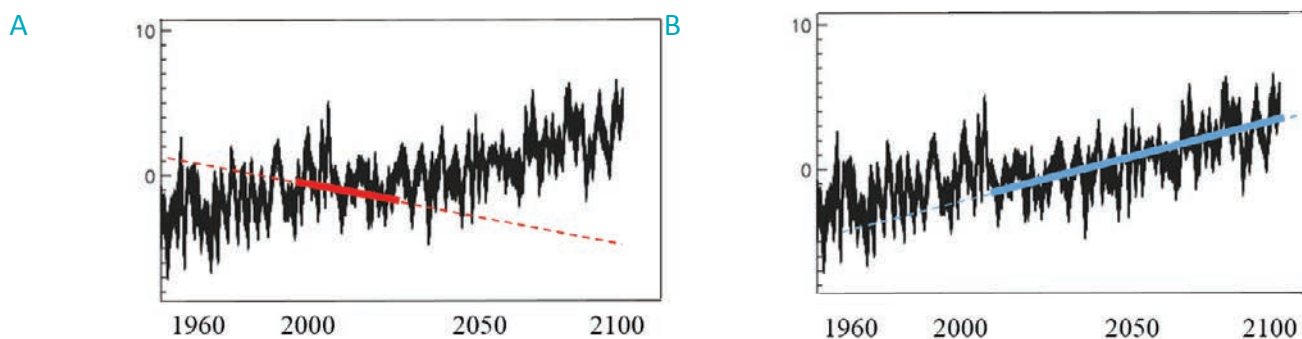


Figure 3 | Time-series of annual temperature over Quebec, as simulated by the Canadian Regional Climate Model, along with trend lines for a relatively A. short period and B. longer period that highlight the fact that short-term trends may not reflect long-term climate change trends.

Source: R. deElia (Ouranos)

Climate normals

Climate normals are averages of climate indices used to represent the recent past climate for a given area. The time period used for climate normals often corresponds to the time period used as a baseline or reference period in climate change calculations. **Note that climate normals should not be confused with reference period. Climate normals are calculated using observed station data while reference period values are calculated using outputs from simulations.** Climate normals are calculated using observations of temperature and precipitation that have been collected globally since the mid-19th century (some stations have longer time series), along with other climate variables on a more selective basis. To facilitate comparisons among studies, climate centers around the world tend to converge on a similar 30-year timeframe to represent climate normals, which are endorsed by the WMO. However, it is important to note that other sources of observations such as satellite data are available for much shorter and more recent time periods. The particularities of the study undertaken by the decision-maker can influence the baseline period chosen. **What is important is that the reference or baseline period be long enough to adequately characterize the long-term climatic conditions and not be overly influenced by short-term variability.** For example, a 10 year average could easily be influenced by a short-term warming or cooling trend, whereas a 30 year average would likely smooth out much of this effect (as seen in Figure 2).

1.3 CLIMATE MODELS

Climate models are numerical tools based on mathematical equations that aim to represent processes of the climate system. These equations are based on physical laws which govern fluid mechanics, such as the laws of conservation of mass, energy, and momentum. They describe

the behaviour and interactions between the atmosphere, lithosphere, hydrosphere, cryosphere and biosphere, under external forcings such as solar radiation, aerosols, as well as natural and anthropogenic greenhouse gas (GHG) emissions (Figure 4).

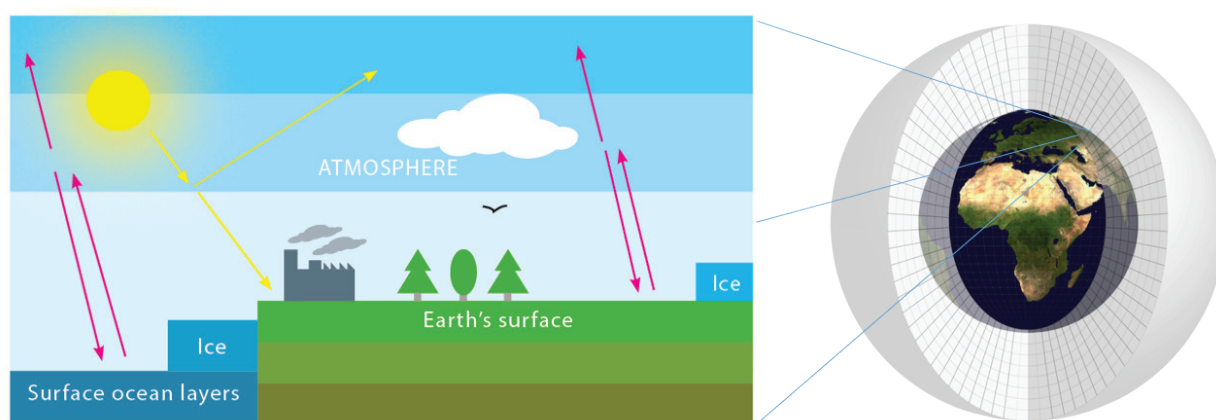


Figure 4 | Interactions described by climate models (left panel) and an example of the discrete grids used to compartmentalize the climate system (right panel).

Source: Ouranos

As the nature of the climatic system is non-linear (chaotic), obtaining an exact analytical solution of the mathematical equations over the entire globe would require so many simplifications that the solution would be too different from the real system to be very useful. The way to minimize these simplifications is to solve the system of equations numerically with a supercomputer and sophisticated numerical methods. In order to obtain the most accurate representation of the climate, these equations would ideally be solved for every point of the atmosphere, oceans and of the upper layer of the soil, but in practice this is impossible. Instead, these components of the climate system are divided into discrete boxes or grid cells covering the planet (Figure 4, right panel). The size of the grid cells, both horizontally and vertically, determines the resolution of the climate model. Thus, a climate model is a simulator consisting of computer code that provides a discrete representation (i.e. on a grid) in space and time of the basic equations of fluid mechanics solved using a numerical scheme.

Numerous climate models have been developed by different climate science centers around the world. The models differ in a number of factors, such as the choice of the numerical scheme, the degree of simplification, the resolution of their grid and the way in which they represent physical phenomena that occur at scales finer than the one resolved directly by the basic equations (known as parameterization). Also, an important difference among models comes from the geophysical fields used to represent the soil textures and the vegetation types and cover. These fields along with the topography and the GHG concentration / emission are needed as inputs in climate models. Such differences imply that each model is unique and will generate a slightly different outcome with the same forcing data.

Climate models are divided into two main groups based on the size of their calculation grid, an area referred to as the model domain:

Global Climate Models (GCMs): as the name suggests, GCM calculation grids (domains) cover the entire planet. Current GCMs typically have a horizontal resolution around 200 km. GCMs are divided into three main categories. The very first GCM generation of models to be developed were referred to as atmospheric general circulation models (AGCM), and only included the atmosphere portion of the climate system and its interaction with the continental land surface. The second generation of models, termed atmosphere-ocean general circulation models (AOGCM), coupled the atmosphere and land with physical ocean models. The latest generation of models, known as Earth system models (ESM), now include the addition of biogeochemical interactions and cycles, as well as changes in land cover (such as vegetation types). Thus far, the carbon cycle has been implemented in most ESMs and research is ongoing to include other cycles.

Regional Climate Models (RCMs): RCMs have smaller domains that cover only a portion of the planet. By focusing on a limited area of the globe, it is possible to solve the climate model equations over a finer horizontal resolution (45 km or less) within a reasonable amount of time. In order to run regional climate models, data from global climate models must be integrated at their boundaries (this can also be done using reanalyses; essentially a technique that uses computer models to combine historical data from various sources to recreate the past climate). This procedure is called driving a regional climate model.

Model Resolution

There is a tendency to believe that the finer the resolution over which the information is given, the more adequate, usable or richer it is. As a result, there may be a desire to use regional climate models or statistically downscaled data instead of the outputs from global climate models directly. Ultimately, the choice of one type of data versus another resides in the evaluation of numerous factors, but it is important to understand that increased model resolution does not guarantee a superior model performance for all variables. Moreover, increased resolution (through the use of downscaling techniques for example) will not necessarily yield more useful information to the decision-maker. However, higher resolution allows for a finer representation of topographic features, which may be very important for some variables, particularly those representing extreme events.

1.4 EMISSIONS SCENARIOS

As discussed above, an important component (forcing) of the climate is the emission of greenhouse gases (GHG), and consequently GHG forcing is also an important component of the numerical simulation of the climate. There are two sources of data for these emissions. First, for the past, emissions inputs come from observations made at different stations around the globe. Second, for the future, the evolution of greenhouse gases is obtained from what are called *emissions scenarios*.

Emissions scenarios describe plausible future releases of greenhouse gases, aerosols and other anthropogenic gases into the atmosphere. They are based on a coherent and internally consistent set of assumptions about driving forces, such as technological change, demographic and socioeconomic development, and their key interactions (IPCC 2007¹⁸). Many factors influence future global emissions, the most important are mitigation policies that can play an important role in regulating anthropogenic emissions. Consequently, levels of future emissions are uncertain and thus these scenarios provide alternative visions of how the future may unfold. The choice of the emission scenario is responsible for a large proportion of the uncertainty in climate projections, particularly in the latter part of the 21st century (see *uncertainties*). The range in the different emissions scenarios reflects our current understanding and knowledge about future socioeconomic and technological developments that may or may not be realized. As new knowledge becomes available about these underlying assumptions, emissions scenarios are revised and made available to the scientific community.

Emission scenario development is a process that occurs in parallel with the development of climate models. Teams of researchers are dedicated to evaluating how emissions will evolve in the future and these scenarios are then used to run climate models in order to produce simulations of future climate, each dependent upon a given emissions scenario.

Concentrations of greenhouse gases are currently being described using Representative Concentration Pathways (RCPs). These emission scenarios were the basis of the latest, Fifth Assessment Report (AR5) published in 2013 by the IPCC¹⁹. RCPs contain emission, concentration and land-use trajectories and are meant to be representative of the current literature on emissions and concentration of greenhouse gases. The premise is that any single RCP trajectory can result from a diverse range of socioeconomic and technological development scenarios. Future climate projections presented in the third and fourth IPCC Assessment reports were based on SRES scenarios (Table 1, Figure 5).

Four RCP families were developed and named according to their total radiative forcing (in W/m²) around 2100 (Table 1, Figure 5). They range from RCP2.6, which assumes an eventual decline in CO₂ concentrations in the atmosphere during the 21st century and projects the smallest changes in global surface temperatures, to RCP8.5, which is based on steadily increasing CO₂ concentrations, leading to the highest projected changes in surface temperatures by 2100 and beyond (Table 1, Figure 5).

Emissions scenarios over time

Emissions scenarios over time: RCPs replaced an earlier set of emission scenarios, published in a Special Report on Emissions Scenarios (IPCC 2000²⁰), hence known as the SRES scenarios. The SRES scenarios were used as inputs to climate models for the IPCC Third and Fourth Assessment reports, published in 2001 and 2007 respectively^{18,21}. Table 1 and Figure 5 can be used to compare both sets of emissions scenarios.

Table 1 | Key characteristics of RCPs and similarities with SRES scenarios.

Name	Radiative forcing	CO ₂ equivalent (ppm)	Temp anomaly (°C)	Pathway	SRES temp anomaly equivalent
RCP8.5	8.5 W/m ² in 2100	>1370	4.9	Rising	SRES A1FI*
RCP6.0	6 W/m ² post 2100	~850	3.0	Stabilizing without overshoot	SRES B2
RCP4.5	4.5 W/m ² post 2100	~650	2.4	Stabilizing without overshoot	SRES B1
RCP2.6 (RCP3PD)	3W/m ² mid-century, decline to 2.6Wm ² by 2100	~490	1.5	Peak and decline	None

Adapted from Rogelj et al. 2012²²

*Note that SRES A1F1 was not used in the CMIP3 experiment and therefore does not appear on Figure 5 below. However, if it was shown, it would appear above SRES A2.

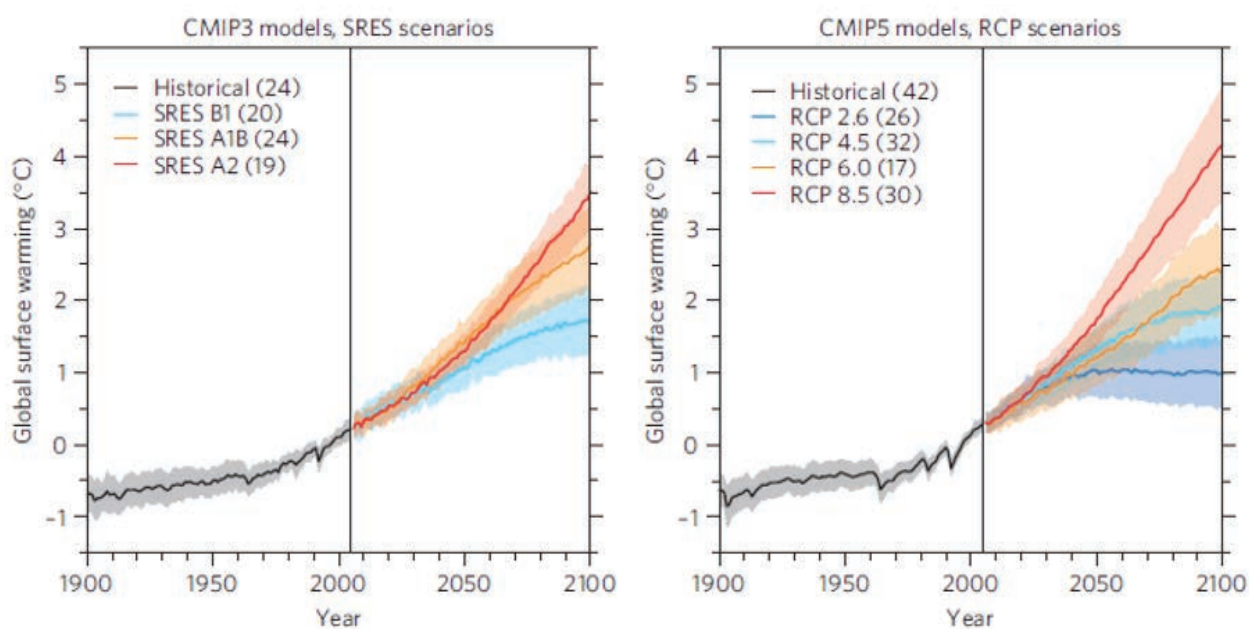


Figure 5 | Global temperature change relative to 1986-2005 for the SRES scenarios run by CMIP3 and the RCP scenarios run by Coupled Model Intercomparison Project (CMIP5, see section 1.6.1). The number of models is given in brackets and the shading (coloured envelopes) represents all model results.

Adapted from Knutti and Sedláček (2012)²³.

The definition of the ‘past period’ for which observed GHG emissions are available and used to drive climate models is updated with each new IPCC assessment. For the most recent, Fifth Assessment Report, observations of GHG were used until 2005, after which *emissions scenarios* were used as inputs (see black vertical lines on Figure 5, Figure 6). Given that the IPCC report was published in 2013, one could question why the observations, which are

available until the present day, stop being used in 2005? The decision on the last ‘past’ year is made by the climate community and reflects the time needed for climate scientists to produce climate simulations, publish their results in peer-reviewed scientific literature, and to write the chapters of the IPCC report. These processes are all time consuming endeavors and simply cannot be accomplished in one year.

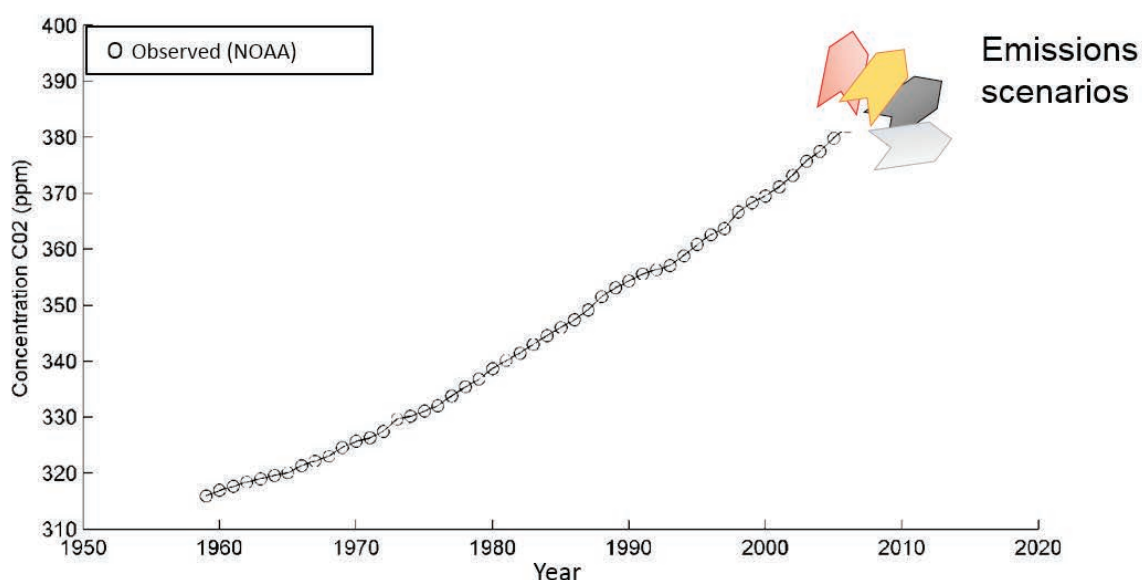


Figure 6 | Timeline for the use of observed (pre-2005) and simulated CO₂ (post 2005) concentrations in climate simulation production available in the CMIP5 ensemble.
Source: T. Logan (Ouranos)

1.5 CLIMATE SIMULATIONS

Climate simulations are the end product of climate models. They represent the result of running a climate model and thus solving the equations that are represented in a model, for a certain period of time. As discussed earlier, each climate model has its own set of equations to represent the climate system. To obtain a climate simulation, many different inputs are required in a climate model, such as a detailed portrait of the Earth's surface including geophysical data (soil types, types of vegetation, continental contours, location and bathymetry of large bodies of water, description of the topography, etc.). In addition, as addressed previously, *emission scenarios* are a main driver to climate models in climate change studies. Different climate simulations are obtained as each climate model responds differently to greenhouse gas emissions scenarios, and hence will produce a different future climate (also see Box on Members). It is important to understand that none of these future climates should be considered a prediction: all the future climates projected by different climate models with different GHG forcing scenarios should be considered equally plausible.

The time span of a simulation can range from a few years to thousands of years, both for the past and future periods (Figure 7). The length of time over which climate models are run to produce simulations differs from one climate center to another but can range for example from 1850 or 1900 to 2100 or even 2300 (see example of Figure 7). Each simulation is computed iteratively at different time intervals. These intervals, also called time steps, indicate the time period within the model between two states of the climate system as simulated by solving the equations. The length of the time step defines the temporal resolution, which is typically 5 to 20 minutes. At each time step and at each point on the calculation grid (horizontal and vertical level), the numerical solution of the equations gives the values of the variables included in the basic equations, along with several others derived from physical parameterizations. Thus, a climate simulation contains more than one hundred descriptive climate variables (temperature, winds, barometric pressure, rainfall, snow, etc.), which should all be physically consistent with one another from one point on the grid to another and also in time.

Model Bias

Climate models are a representation of the real climate system and the mathematical equations that are solved to represent this system are a simplification of the real world. A climate simulation is therefore an imperfect numerical representation of the meteorology that could have occurred over the globe, based on the assumption that the simulation of the natural variability is close to the real one. This means that even if we have observations of greenhouse gases emissions for the past and we run a climate model using those observations as input, the resulting simulation will give a response that is different from what is recorded at meteorological stations.

Furthermore, due to the chaotic nature of the climate system and climate model sensitivity to things such as initial conditions at the start of a simulation, even a “perfect” climate model would not reproduce the succession or timing of observed historical meteorological events, and the best we can expect is that the model reproduces the statistical properties (mean, variance, inter-annual variability, etc.) of the observed records. Given that each model represents the climate system differently and imperfectly, they each have their own particular bias. This will mean for example, that some models may always yield temperatures that are slightly colder on average than the other models, while some may always project more precipitation than others. . Furthermore, a model's bias is not necessarily equal for all parts of the globe, and can vary for different regions. It is important to consider this bias when calculating *climate change scenarios*. Biases are present in both GCMs and RCMs, and in gridded observations.

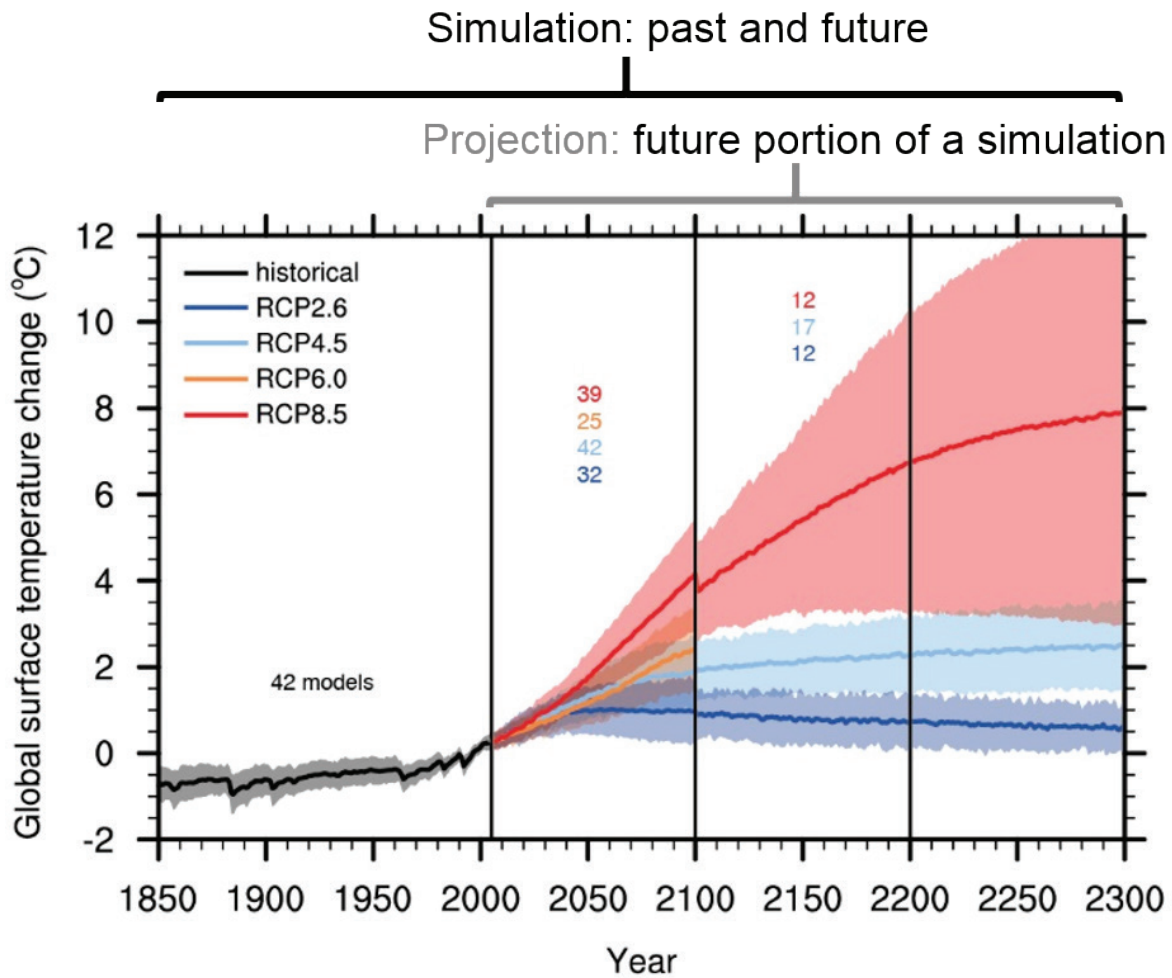


Figure 7 | Time series of global annual mean surface air temperature anomalies (relative to 1986-2005) from CMIP5 concentration-given experiments. Projections are shown for each RCP for the multi-model mean (solid lines) and the 5 to 95% rang (± 1.64 standard deviation) across the distribution of individual models (shading). Discontinuities in 2100 are due to different numbers of models performing the extension runs beyond 21st century and have no physical meaning. Only one ensemble member is used from each model and numbers in the figure indicate the number of different models contributing to the different time periods. No ranges are given for the RCP6.0 projections beyond 2100 as only two models are available.

Source: IPCC 2013¹⁹

1.6 CLIMATE PROJECTIONS

Climate projections are the portions of a simulation that represent the future (Figure 7). They therefore represent the plausible evolution of different climate variables that describe the climate system over several decades to centuries under different

emissions scenarios. The first year of this future period is the year that corresponds to the first year when emissions scenarios are used to run climate models changes, as opposed to observed GHG emissions.

Ensemble members

It is possible to produce a large ensemble of simulations, or of plausible climate outcomes by running numerous models with different emissions scenarios. A model can also be run multiple times with the same RCP with slight perturbations in the initial conditions, for example by changing the start date of the simulation to obtain what are called ensemble **members**. Because of the chaotic nature of the climate system, these small changes will yield different responses (succession of meteorological events) and thus slightly different climate projection values.

1.6.1 COUPLED MODEL INTERCOMPARISON PROJECT (CMIP)

As discussed above, there are numerous climate modeling centers around the world, each developing their own climate model and there are currently four plausible emissions scenarios to consider when producing climate simulations. Obtaining such a simulation, i.e. running one model with one RCP for example, is computationally intensive and even with today's high performance super computers, it can take up to several months to run a global model over the entire globe for a meaningful simulation period, say 1850 to 2100. Consequently, it would be impractical, if not impossible, for each climate modeling center to run all available models with all available RCPs. Therefore, to obtain a common frame of simulations and the largest possible ensemble, the modeling centers have agreed to run their own models with the different RCPs and to make the resulting simulations available to the rest of the climate community. This collaboration is done through an initiative called the Coupled Model Intercomparison Project (CMIP). Through a web interface, it is possible to download different simulations from different modeling centers that are part of this project in order to obtain a large ensemble of simulations. The CMIP ensemble forms the backbone of the results presented in the IPCC reports.

As models and emissions scenarios are updated, so is the collection of simulations, also known as the ensemble, made available through CMIP. Currently, the scientific community is using the fifth ensemble, called CMIP5. This newest generation of participating models are run using the RCPs whereas simulations made available from the previous CMIP3 used the SRES scenarios. CMIP5 simulations

are generally executed at a higher spatial resolution and the models typically have a more complete representation of physical parameterizations (particularly of biophysical processes such as the carbon-cycle) than their predecessors. It is generally expected that the new generation of models will provide a better representation of the climate; however, not all models have evolved equally²⁴. It is worth mentioning that this development process is always on-going. Climate centers are currently developing a CMIP6 ensemble, which will be the basis of the next IPCC report.

Comparisons of projected future outputs between the two generations of simulations are not straightforward because the two ensembles used two different sets of GHG scenarios. Nonetheless, recent studies have shown that comparisons of model means of temperature and precipitation change are similar in CMIP3 and CMIP5 for climate projections with similar forcing²⁵. Yet, the CMIP5 ensemble compares more favourably with observations for past climate simulations (^{23,26-28}). These conclusions should reassure users that climate information provided using CMIP3 models remains valid and robust even if there is now a gradual shift towards use of CMIP5 model results. The conclusions also support the argument that an ensemble of models should be used when making decisions, as it has been shown that any single model chosen from the ensemble scores lower than the entire ensemble when multiple variables are validated against observations²⁹. In other words, the mean of the simulation ensemble for the past climate is generally closer to the observed values than any given individual simulation.

CMIP5 vs CMIP3

It is generally believed that recent climate model simulations are likely to be more reliable than those of an earlier generation of models (vintage). They are, after all, based on more recent knowledge and incorporate more processes and feedbacks. However, the differences between the two vintages are not always very distinct. Consequently, information provided with an older vintage remains valid when a new vintage is produced. Indeed, impacts studies conducted with an older ensemble should not be automatically disregarded when new simulations are made available. As such, the information in this guide is often based on the newest generation of models (from the CMIP5 ensemble), but older simulations (from the CMIP3 ensemble) are also presented in some cases. The focus of the guide is on the interpretation of the climate information, and hence depends very little on the particular generation of models or scenarios that were used.

1.7 SOURCES OF UNCERTAINTY IN CLIMATE PROJECTIONS

Climate projection uncertainties stem from three main sources: natural variability in the climate, climate model structural inaccuracies, and the future trajectories of greenhouse gas emissions^{30–32}. As seen previously, the evolution of the climate is influenced by important unpredictable natural fluctuations that occur even without any change in greenhouse gases concentration. In addition, the models are simulating their own climate, which differs from reality (more or less, depending on the model, see Box on Model Bias) and each models can differ to a certain degree in its response to greenhouse gas emissions. Finally, the evolution of greenhouse gas emissions is also uncertain and it is not possible at this time, to determine which, if any, of the four RCP trajectories will be realized.

The relative importance of each source of uncertainty depends on the timescale considered. Over a timescale of a few decades, the natural variability in the climate is the most important source of uncertainty and can even hide the climate change signal over the short term. This is extremely

important since this variability can be in opposition, at least for a few decades, to the longer-term trends that are associated with anthropogenic climate change (Figure 3). It may take several decades before the climate ‘signal’ emerges from the ‘noise’ of year-to-year variability. Consequently, over short time scales, the choice of the emissions scenarios is relatively unimportant (red circle, Figure 8). This is perhaps surprising but it takes approximately 30 years for any difference between current emissions scenarios to have an appreciable impact on the climate^{3,31}. For example, on Figure 8, one can notice that the coloured line start to diverge around 2030 and that a clearer distinction can be made among the different scenarios by 2050.

However, over longer time horizons, the choice of the emission scenario becomes very important (coloured envelopes on Figure 8), while the model uncertainty remains fairly large irrespective of the timescale over which decisions are made. These patterns have been shown to be consistent for both global and regional analysis of the uncertainties^{30,32–35}.

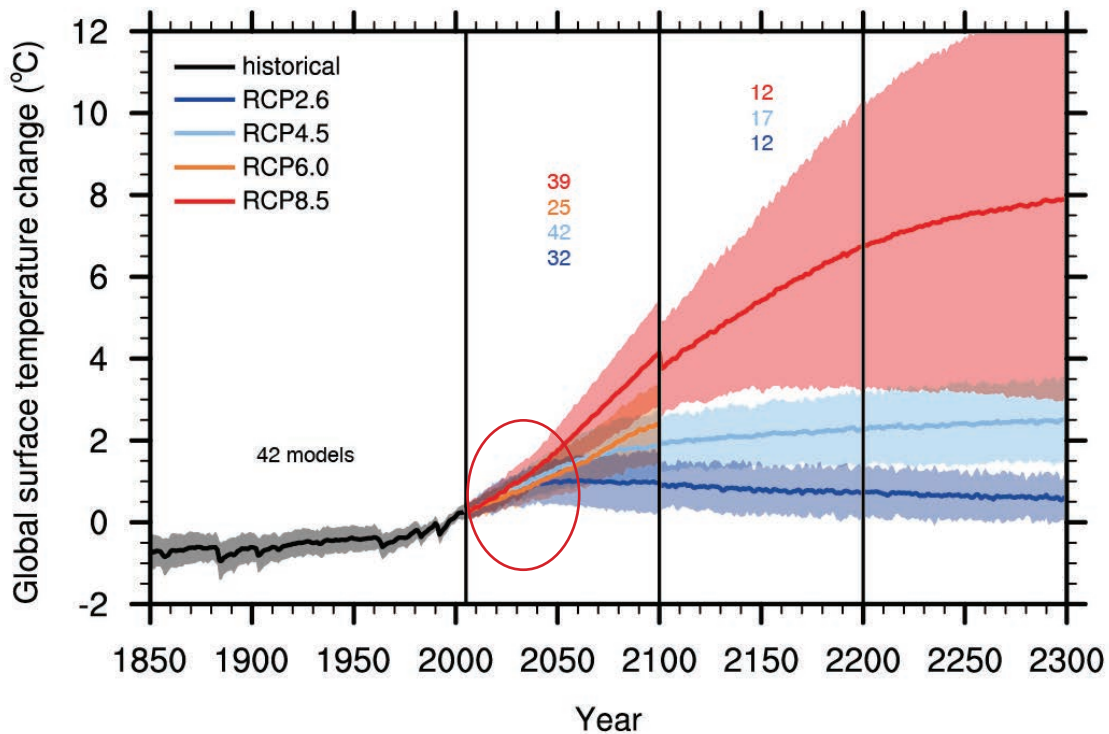


Figure 8 | Title as Figure 7. The red circle highlights the time period prior to 2050 where models run with all four RCPs project similar changes in global surface temperatures.

Source: IPCC 2013¹⁹

In many cases, stakeholders already make decisions in the face of some uncertainty since they have to manage variability in local weather and climate over the short-term, as well as uncertainties in many other areas of their workflows and decision-making. Consequently, the uncertainty in climate projections need not be a deterrent from making decisions over a longer time scale.

What is important is to understand what the main sources of uncertainty are and how their relative importance changes over time. Within a decision-making framework, the timescale of the planning horizon must be considered in order to weigh the importance of the different sources of uncertainty (Table 2). The planning horizon will also greatly impact the type of climate information that would be most appropriate.

Table 2 | The relative importance of the three sources of uncertainties in climate projections over time.

Planning horizon	Relative importance of sources of uncertainties			Key source to consider for decision-making
	Natural variability	Emissions scenario	Climate model	
Short term (<30 years)	***	*	**	Natural variability
Medium term (30-50 years)	*	**	**	Emissions scenario and climate model
Long term (>50 years)	*	***	**	Emissions scenario

Over a near-term planning horizon, decision-makers may want to give greater importance to the natural variability in the observations over the region of interest, while keeping in mind that the underlying climate change signal is still relevant because it will have impact over the long term. In other words, even for short-term objectives, a long-term vision is necessary. The importance of relying on an iterative process of revisiting climate projections and re-evaluating adaptation measures put into place, as recommended by an adaptation framework, may be particularly beneficial here (Figure 1).

On the other hand, for longer planning horizons, the uncertainties related to the emissions scenario should be given particular consideration. Over these horizons, the climate change signal is stronger than the variability in the climate but it is heavily influenced by which emission scenario is chosen. Given the high level of uncertainty associated with the evolution of anthropogenic greenhouse gas emissions, decisions should consider all plausible futures.

1.8 SIMULATION ENSEMBLE

Users of climate information often express the desire to be provided with the «best» future scenario or the one that is most likely to be the «true» scenario. However, it is not possible for climate service providers to pick such a climate change scenario. The reasons why this cannot be done reside in the intrinsic properties of climate models, climate simulation, and the emissions scenarios outlined above. All together, they provide a plausible representation of what the real world is and of what the climate may become given the current state of knowledge. State-of-the-art climate models provide a sophisticated but imperfect representation of the real world climatic system. It is very difficult to test which model is the best as they all possess different strengths and weaknesses. As stated previously, models have biases and therefore produce slightly different results. There is no climate model that is always able to give the best results for all variables for all seasons over all regions. Furthermore, it is not possible to determine at this time which scenario of future greenhouse gas emissions will be closest to reality.

Therefore, when providing climate information, the most prudent advice is to consider a *simulation ensemble*, or a large number of simulations in the decision-making process. In other words, it is best to take into account an ensemble that includes both the best and worst case scenarios.

However, deciding on the exact number of simulations that should be used is not straightforward. Indeed, general guidelines suggest that users should obtain climate projections based

on as many simulations that represent as many models and emission scenarios as possible³⁶ but the term «large ensemble» remains vague. Ultimately, the choice of the number of simulations to be considered for a given project will be influenced by the time and resources available. The expertise of a climate service provider may prove valuable in helping the decision-maker choose an appropriate number.

Different statistical techniques can serve to select a limited number of simulations that best represent the properties of the entire available simulation ensemble. The goal is to ensure that the chosen simulations adequately represent the full range of possible future conditions of the indices of interest³⁷.

One such technique is a cluster analysis³⁸. Briefly, this method consists of first selecting the climate variables that are of interest for a particular project. Next, for each simulation, the variables are computed for the reference period and for the future horizon and the difference between the two values is calculated (i.e. the climatic change). The differences are then standardized and an algorithm can be used to calculate the distances between all the simulations in a multi-dimensional space (the dimensions correspond to the climate variables chosen). Figure 9 illustrates an example, and highlights the outcome of maximizing the range in the response (i.e. the uncertainty) while minimizing the number of simulations chosen. The figure shows the number of simulations needed to adequately cover the range of the simulation ensemble for three climatic variables, namely

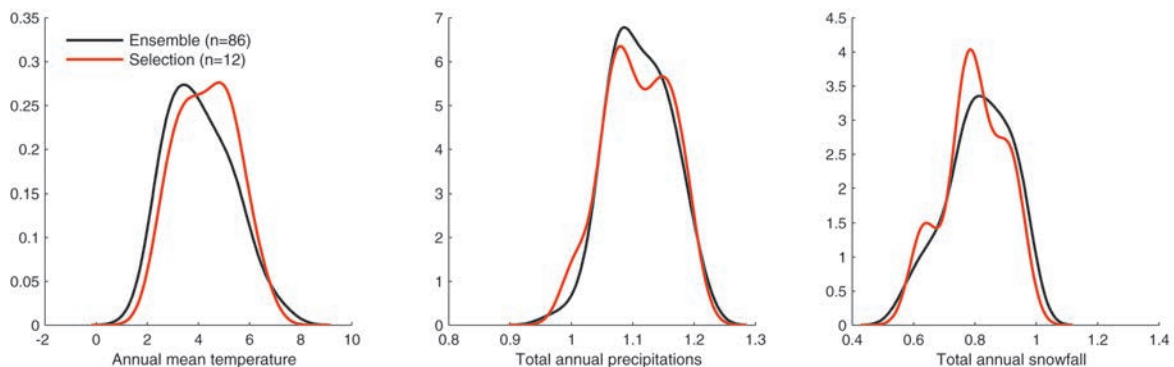


Figure 9 | Maximizing the coverage of precipitation, temperature and snow distributions with the lowest number of simulations within a large ensemble.

Source: T. Logan (Ouranos)

winter temperature, precipitation and snow cover. The analysis reveals that selecting 12 simulations out of a possible 86 allows a good representation of the range.

Moreover, some input from users and climate service providers can help the selection process in some cases³⁷. For example, some planning exercises may warrant the need to focus on evaluating worst case scenarios (which could imply only considering

models run with RCP 8.5). A method that is often adopted by users is to select a «low», «median» and «high» climate change scenario that will adequately cover the range of all the simulations that are available. Figure 10 highlights an example of this technique, where the temperature and precipitation outputs are used to select the scenarios that are closest to the 10th, 50th and 90th percentile changes out of the available simulations.

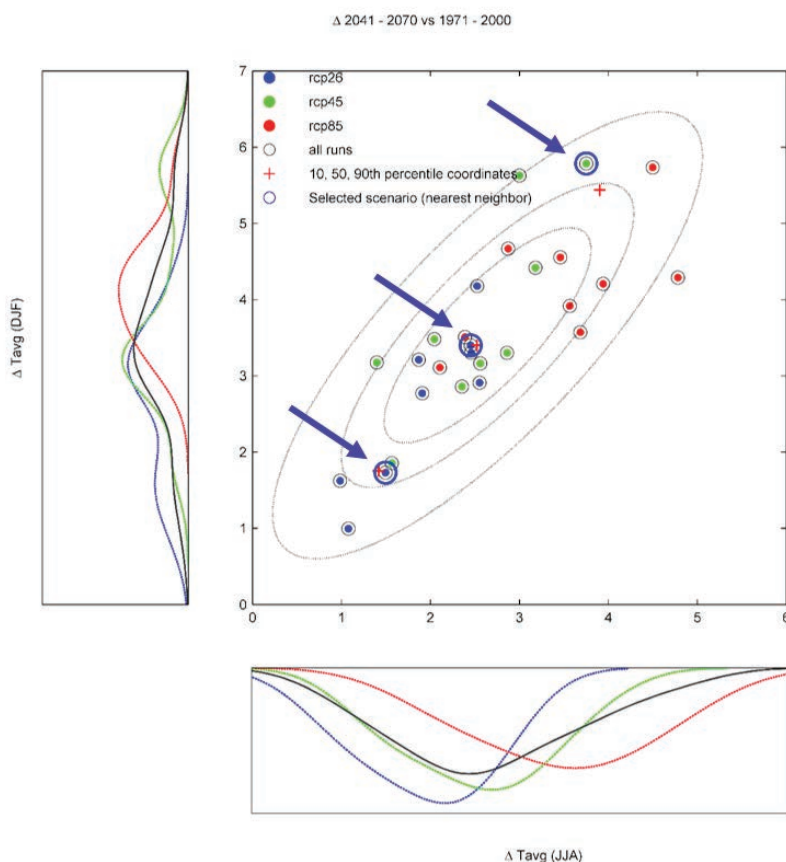


Figure 10 | Projected change in mean summer temperature (June, July and August) and mean winter temperature (December, January and February). The changes are shown for an ensemble of GCMs under three RCPs (2.6, 4.5 and 8.5). The elliptical lines indicate the 10th, 50th and 90th percent confidence intervals. The scenarios close to the 10th, 50th and 90th percentile changes are circled in blue and highlighted with blue arrows.

Source: T. Logan (Ouranos)

Limitations of selection

An important point to remember is that selections of a few representative simulations out of a range of available outputs are invariably based on a limited number of climate indices over a given temporal window (annual temperature and precipitation for example). They may therefore not be representative of other indices over different temporal timescales (monthly snow cover for example). In other words, the selection is only valid for the indices and timescales that were used to choose the scenarios in the first place.

1.9 DOWNSCALING TECHNIQUES

GCMs simulate the evolution of the climate system over the entire planet, with a horizontal resolution of around one hundred to three hundred kilometres (left panel on Figure 11), for periods that can reach thousands of years. The calculation time required to simulate the global climate of required length at

a finer resolution of a few kilometres, or even finer, is generally not within the reach of even today's fastest computers. However, there is an increasing demand by the user community to obtain climate projections at a finer scale (right panel on Figure 11).

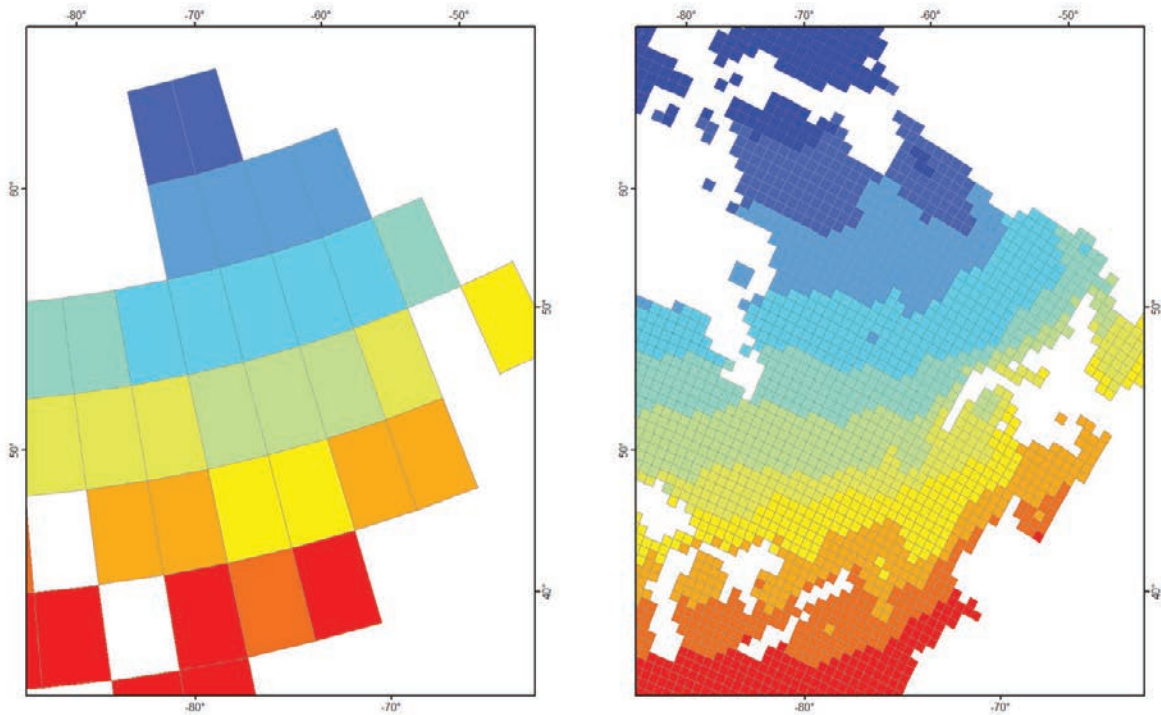


Figure 11 | Example of the difference in grid cell size between a global climate models (left panel) with a resolution of approximately 200 km and information that has been downscaled to a 45 km grid cell (right panel).
Source: T. Logan (Ouranos)

Techniques to produce climate information at a finer resolution, referred to as *downscaling techniques* (Figure 12) fall into two categories, namely dynamical and statistical downscaling (see³⁹).

Dynamical downscaling: This approach relies on the use of regional climate models (RCMs) which, like the GCMs, are based on a realistic representation of the physical laws that affect the climate system. Such models are used to refine the horizontal resolution of the climate in a selected region of the globe. Their finer spatial resolution (typically 10 to 50 km) means they can develop more detailed characteristics of climate because they benefit from a much more precise representation of land surface features (such as mountains, coastal contours, or the presence of lakes and rivers). To stay linked with the global climate, an RCM has to be supplied at its periphery with large-scale variables from a driving model, which is generally a GCM. Although costly in terms of computing time, this downscaling technique ensures consistency in time and space of climate variables. In addition, climate models like RCMs and GCMs have the capacity to simulate the interactions among greenhouse gases and aerosols with other components of the climate system, which will improve their capacity to reproduce the climate system.

Statistical downscaling: This approach is based on the premise that the characteristics of local observed climate can be derived from a series of large-scale global climate variables (predictors). It can involve various techniques (multiple regressions, stochastic generators, neural networks), which are used to establish statistical relationships between observed local conditions and predictors obtained using data from the recent climate (e.g. 1971-2000). The statistical downscaling of a GCM simulation relies on the hypothesis that the statistical relationships established for the recent past will remain the same for the future. In the context of climate change, this hypothesis is problematic because climate is not stationary and the validity of the assumption is difficult to test. Moreover, downscaling several climate variables simultaneously still presents a challenge. Consequently, climate variables are often processed separately, resulting in a possible decline of spatiotemporal consistency. Nonetheless, statistical downscaling is a relatively inexpensive and quick approach compared to dynamical downscaling. It is important to mention that statistical downscaling may also be applied to already higher resolution RCM data.

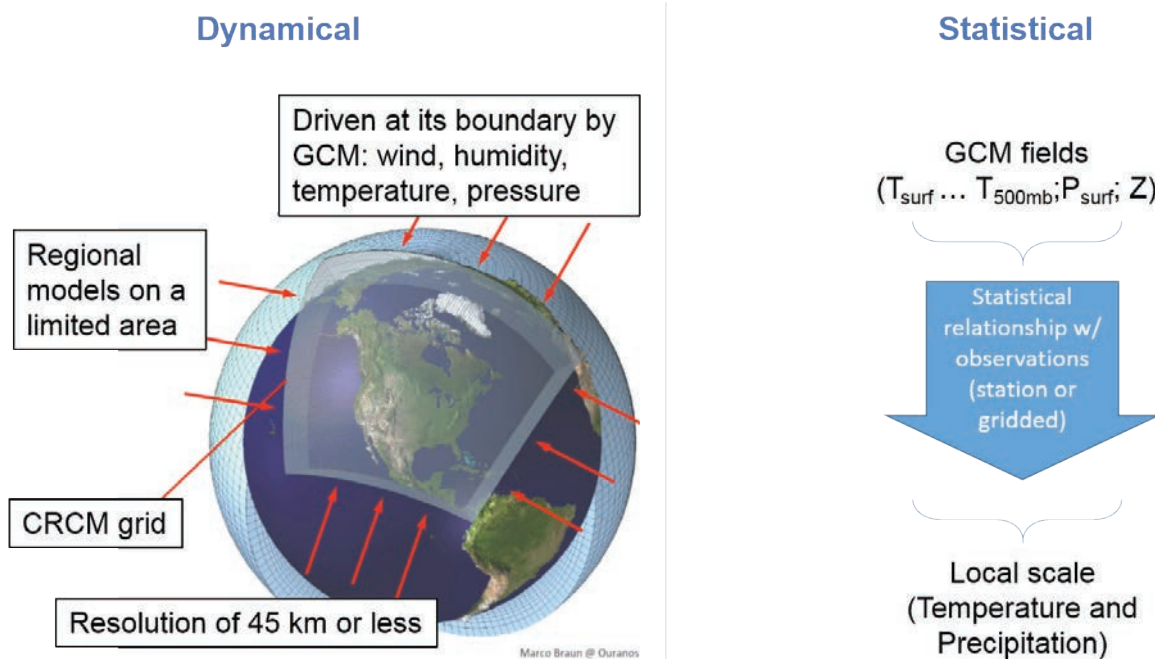


Figure 12 | Comparison between dynamical and statistical downscaling techniques.
Source: Ouranos

1.9.1 WHEN IS DOWNSCALING NECESSARY

The idea that finer resolution climate data is better can be attractive; however, **downscaling will not necessarily yield more useful information to the decision-maker. Moreover, increased model resolution does not guarantee superior model performance for all variables and all time-scales.** Arguably, many adaptation strategies will be developed for a relatively small area (local scale), which may therefore require finer resolution climate information. However, the mean change projected from a GCM over a 200 km grid cell may not be very different from what is projected once the data are downscaled to a smaller grid cell (from either dynamical or statistical downscaling), particularly given the uncertainties around the model ensemble projections. **In other words, downscaling may improve the accuracy of some of the information given, but not for all variables over all time periods.**

Before deciding on the necessity and added-value of downscaled information, the climate variable of interest and the landscape features of the region of interest must be analyzed. Surface characteristics like topography, coastlines or the vicinity of a body of water do not have the same effect on the various climate variables and this influence could also vary from one season to another. For instance, air surface temperature is generally uniform over larger regions of flat terrain, but changes abruptly by the seashore. On the other hand, precipitation generally tends to be more variable in space. Thus, in the latter case, the choice of reverting to a dynamical downscaling technique may be preferable but it might not be necessary for someone interested in the temperature over a large region. In addition, the added time needed to resolve the information at a finer scale is non-negligible and should be accounted for (in deciding if downscaling is necessary).

Downscaling and bias correction (post-processing)

There is often some confusion in separating downscaling and bias correction concepts. Bias correction techniques are part of what are often referred to as post-processing techniques (see next section) and are not, strictly speaking, related to downscaling techniques. However, many statistical downscaling methods often involve a bias-correction step. In addition, while dynamical downscaling in and of itself does not involve any form of bias correction, the outputs from regional climate models are at times bias corrected. Hence, users often wrongly assume that bias correction and downscaling are one and the same.

1.9.2 DYNAMICAL OR STATISTICAL DOWNSCALING

The choice of downscaling method to use is not a simple one. There are a number of factors (listed in Table 3) that must be considered by climate service providers in deciding which method to use. First, with statistical downscaling techniques, each climate variable is generally treated individually, which may result in the physical coherence between the variables being broken. In other words, the mathematical representation of the physics behind the climate that are present in a global climate model may no longer hold true. Some climate variables may be more sensitive than others to this issue.

In addition, statistical downscaling is based on statistical relationships between the local observations of a variable of interest and other coarser resolution climate variables used as predictors. Adequate local observations from meteorological stations are therefore necessary. In addition, these statistical relationships are assumed to be constant (or stationary) over time which may not be true in a changing climate. This assumption may not be too problematic for some

variables for shorter term projections but the uncertainty is greater for projections for the end of the century.

Finally, the number of global climate model simulations far outweighs the number of regional climate model simulations that have currently been produced over North America. Consequently, a much larger number of projections can be provided by statistically downscaling GCM simulation results. If a large ensemble of projections is important to the study at hand, then statistical downscaling could be the preferred choice. If, on the other hand, a smaller – but carefully chosen – simulation sample suffices, then dynamical downscaling could be used.

The factors listed above highlight the complexity in choosing, first whether to downscale at all, and second, which method to use. There is not a sole correct answer here and ultimately the selection will depend on the objectives and resources of the project.

Table 3 | Comparison of the advantages and limitations of both dynamical and statistical downscaling.

Dynamical	Statistical
<ul style="list-style-type: none">› Reproduces more detailed characteristics of the climate› Consistency in time and space among variables› More costly and longer to produce› Small number of regional climate simulations available› More variables (wind, soil moisture, etc.)	<ul style="list-style-type: none">› Assumes that past relationships hold true in the future› Decline in spatiotemporal consistency (one variable at a time)› Quicker and less expensive to produce› Large number of global simulations available› Dependent on observations (more difficult for certain variables)

1.10 POST-PROCESSING TECHNIQUES

As discussed previously, climate models (both GCMs and RCMs) are mathematical representations of the real world and often present a bias in their estimate of climate variables. This is one of the main reasons why climate simulations should never be compared directly with observations.

These differences with real-world values often mean that model outputs are rarely used «as-is» without some sort of *post-processing*. This post-processing step is often required in order to transform raw, or even downscaled, climate model outputs into climate information that is better suited for users.

Model bias is not an issue (and therefore does not need to be corrected) when simply calculating the relative changes between a future horizon and the reference horizon from the same simulation (i.e. coming from the same model with the same emissions scenario). Indeed, the bias in the models is generally assumed to be the same in the reference and future simulated data and it therefore cancelled out when calculating the relative change, or the delta, between the two periods.

However, post-processing becomes necessary when calculating future simulated values, in other words when applying the change projected by the model to the observations, the biases become relevant and must be corrected. This is particularly important for threshold values, which are highly susceptible to small changes. For example, if a model has a warm bias compared to the observations, the likelihood of reaching a warm temperature threshold (for example days with an average temperature above 30°C) will be amplified in the simulated data compared to the real world. Consequently, if the bias is not removed, a decision-maker might conclude that, in the future, there will be more days with an average temperature above 30°C, when this is in fact simply an artifact of the model bias.

There is a large number of post-processing techniques available and it is far beyond the scope of this guidebook to review them in detail^{40,41}. However, two simple methods are presented as examples to highlight the main objectives and general methodologies of post-processing methods.

Note that the main assumption made with post-processing is that biases are (almost) identical for the reference period and the future period, which may not be the case. In addition, as mentioned previously post-processing can be used independently from, or in combination with downscaling techniques, which often results in some confusion between the two concepts.

An important warning regarding post-processing technique must be raised. These techniques strongly rely on the observation network, and thus the only variables that can be post-processed are those for which observations are available. In places such as the USA, or much of Europe, the high-density network generally provides a sufficiently high number of climate stations in different types of location, with the possible exclusion of high mountains, to build an adequate observational dataset for some variables, namely temperature and / or precipitation. In Canada, particularly in the north, the station density is very low and strongly biased as most of the stations are located along the coastline and in valleys. Meteorological stations are also very far from one another. Such a coarse representation of reality is also present in gridded observational datasets, which are created from the interpolation of station data to fill regions where there are none. The bottom line is that post-processing is only as good as the observations that are used to conduct it, and given the limitations just outlined here, caution is often advised.

1.10.1 DELTA/SCALING METHOD (ALSO CALLED THE PERTURBATION METHOD)

This method involves a perturbation of the observed climate data based on the relative change between the simulated reference and simulated future periods within a given simulation. The relative change between the reference and the future is first calculated (Figure 13a) and the change (or delta) is then applied to the observed time-series (Figure 13b).

This method can be done using two approaches, namely by calculating a mean change over the entire distribution

of observations or by using the corresponding quantiles of the distribution (e.g.⁴² for an example of quantile mapping technique). The latter allows for a different correction factor to be applied to the distribution tails, so that it is possible to change the extremes of the distribution differently than the rest of the distribution. An important point here is that this technique is applied to specific time horizons (such as 30-year periods), not to the entire time-series.

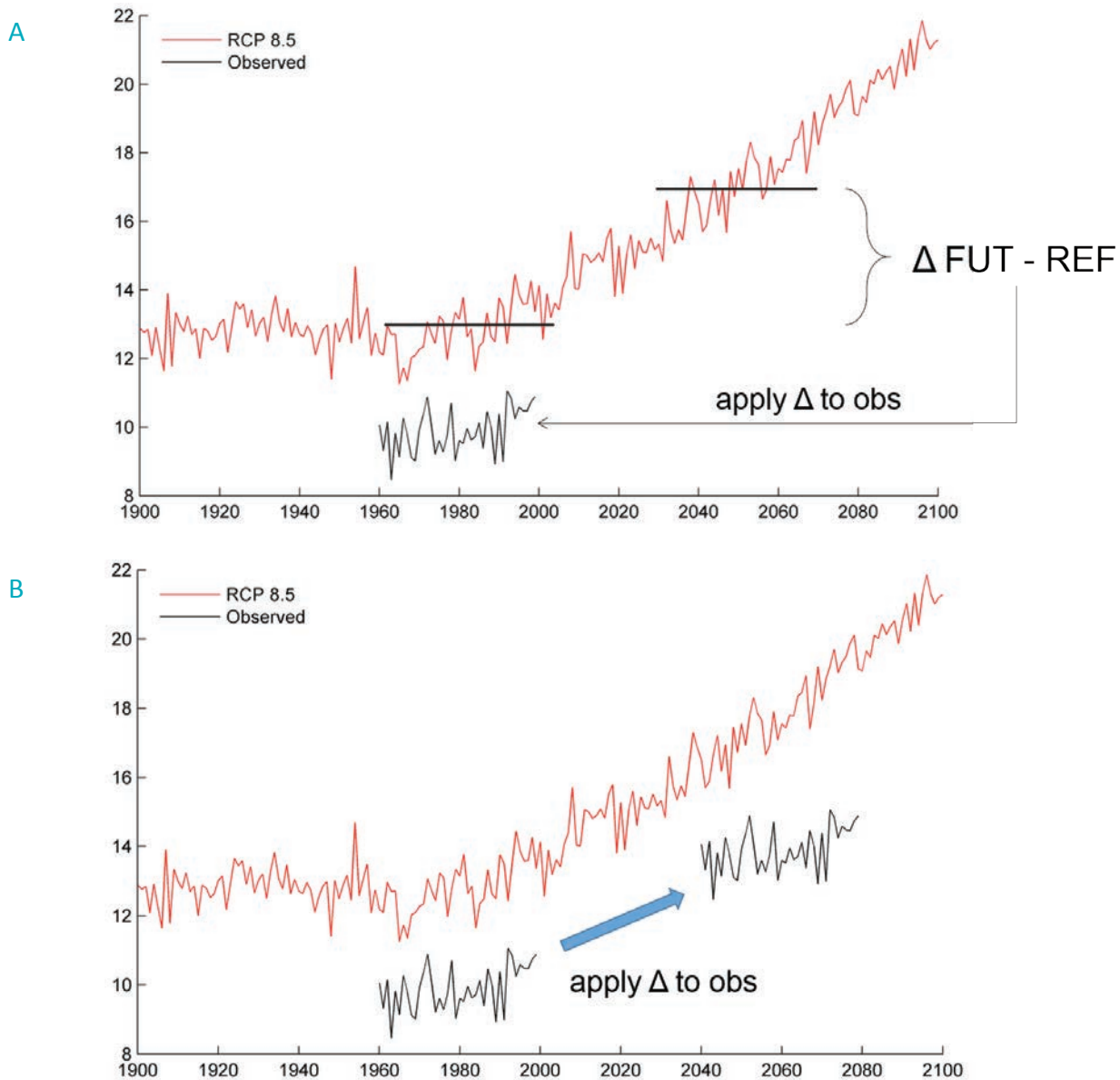


Figure 13 | Example of delta/scaling post-processing technique. The relative change between A. the reference and the future is first calculated and B. the change is then applied to the observed time-series.

Source: T. Logan (Ouranos)

1.10.2 BIAS CORRECTION

This method involves an adjustment or correction of the entire simulated time-series (reference and future periods) using a bias or correction factor such that differences between the simulated reference period data and the observations are reduced. The correction factor is first calculated by comparing the simulated reference period and the observed data over the same time period, such as 1961-1990 (Figure 14a). The correction is then

applied to the entire simulated series (Figure 14b). As for the perturbation method, a bias correction can be based on a mean correction or on quantiles. However, unlike the perturbation method where the correction is done for a given time horizon, this method allows for the bias to be removed from the entire simulated time-series.

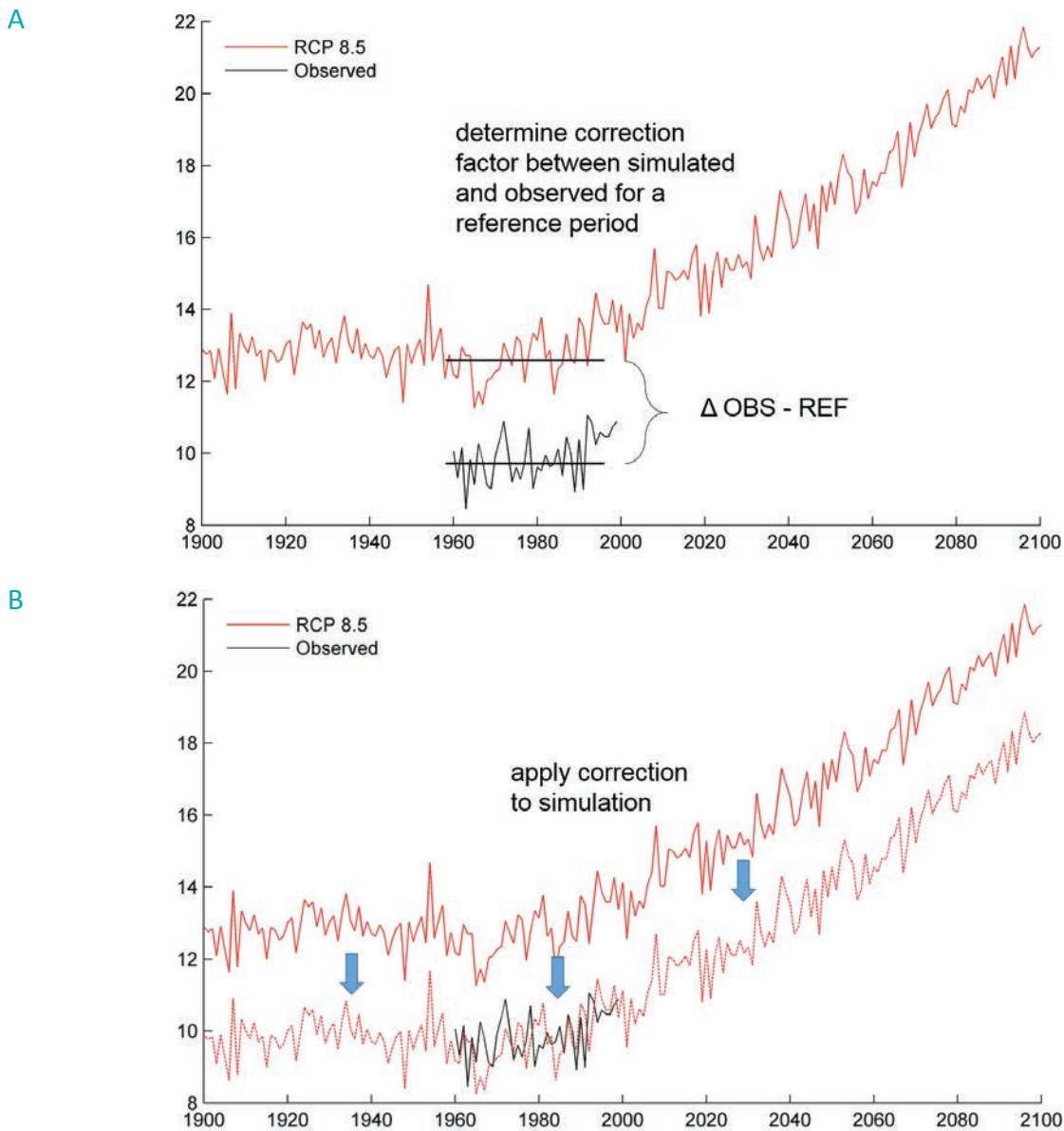


Figure 14 | Example of bias correction post-processing technique. The relative change between A. the reference and the future is first calculated and B. the change is then applied to the entire simulated time-series.

Source: T. Logan (Ouranos)

1.11 CLIMATE CHANGE SCENARIOS

Climate scenarios are plausible and simplified representations of the future climate, constructed from climate simulations. They represent the difference between the current climate and a future climate. In essence, they represent a more tailored product than climate model outputs (where the time steps are minutes long). Climate scenarios give the portrait of the future by averaging the outputs of the simulations into a temporal resolution that is better suited for impact studies (over years or seasons for example). They are arguably the climate information product most often used to evaluate the potential impacts and consequences of our changing climate.

Climate scenarios are generally grouped into the following classes³:

- › *Climate model scenarios* are constructed using climate data output from climate models that simulate the future response of the climate to increasing greenhouse gas concentrations;
- › *Analogue scenarios* are constructed by identifying recorded climate regimes that resemble the future climate of a given region;
- › *Synthetic scenarios* are produced by varying a particular climate variable by a realistic but arbitrary amount to obtain probable futures.

1.11.1 REFERENCE PERIOD AND FUTURE HORIZONS

Climate change scenarios compare the average climate between a past period, referred to as the reference period or horizon, and a future horizon. Given that inter-annual variability can remain important in the future, the length of the reference and future periods must be relatively long to detect clear projected climate change trends. Two main periods are used, one is a 30-year average, for which the reference horizon corresponds to the same timescale as the one used to calculate climate normals (WMO standards). **Note however that an important distinction must be made here with climate normals, which are calculated from observations and the data over the reference period, which comes from climate simulations.**

Averages may also be calculated over 20-year time periods, as is the case in most IPCC reports.

The future horizons will follow the time period for the reference period, meaning that if the reference period used is 30-years then the future horizons will also be 30-years.

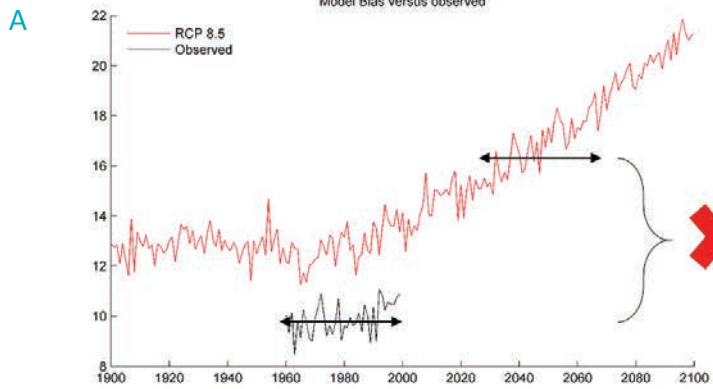
The time periods used as reference and future horizons are used by climate research organisations and are revised every decade. For example, a few years ago, the reference period used by the WMO was 1971 to 2000, while it is now 1981-2010 (the AR5 from the IPCC uses 1986 to 2005).

1.11.2 CONSTRUCTING CLIMATE SCENARIOS

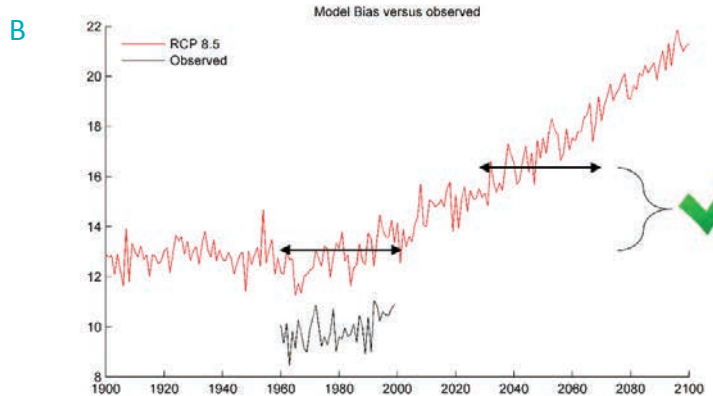
One of the most important ‘best-practice’ messages to remember when producing or using climate scenarios is that they are constructed from climate simulations only and consequently, they compare values simulated for the past (reference period) with values simulated for the future (future horizon). These comparisons are made within each individual simulation.

Climate projections should NEVER be compared directly with observations. The reason climate model outputs or simulations cannot be compared directly with observations is that climate model results (i.e. simulations) are always slightly different (as seen in section 1.10), or biased compared to true observations (see Figure 15) and never reproduce the observations perfectly. In addition, for precipitation, model projections are simulating the total amount of precipitation that would be moved around the atmosphere and fall over the entire grid cell while the observation is only measuring the finite amount that fall on the sensor at a particular station location.

As an example, Figure 15 presents an example of a climate simulation (red line) that produces values that are higher than the true observations (black line) over the 1961-1990. In other words, this simulation is warm-biased. Consequently, if a comparison is made between the simulated future values and the observations (top panel), the projected change is inflated (6°C in this case). On the other hand, if the projected change is calculated using simulated future and simulated past values (bottom panel), the resulting change is smaller (3°C) as the warm bias in the simulation is removed. Given that each simulation yields slight different results, the only way to insure that the projected changes are not artifacts of biases, is to calculate deltas within each simulation and not with the observations (and not among simulations).



	1971-2000	2041-2070	Delta (change)
Observations	10°C	na	na
Simulation		16°C	6°C X



	1971-2000	2041-2070	Delta (change)
Observations	10°C	na	na
Simulation	13°C	16°C	3°C ✓

Figure 15 | Climate scenario construction done improperly A. by comparing future simulation values with past observed values and done properly B. by comparing past and future simulated values.

Source: T. Logan (Ouranos)

It is important to remember that post-processing techniques (see section 1.10) are often used to remove some of the bias in climate simulations in order to better match simulation values to true

observed values. However, the match is never perfect and so climate scenarios should still be calculated using simulated past and future values, even if simulations have been bias corrected.





CHAPTER TWO

CATEGORIZING CLIMATE INFORMATION

Part of the challenge in incorporating climate information into an adaptation framework or into a decision-making process is deciding what type of climate information is needed. Indeed, while the previous chapter explained many of the underlying climate science concepts, it is just as important for a decision-maker to understand the various climate information products that can be used to deliver that information.

In order to familiarize decision-makers with climate information and its different uses, this chapter presents a simple categorization framework that divides climate information into three levels: **basic**, **intermediate**, and **detailed** information. The choice of the most appropriate climate information is often made in collaboration with climate service providers. The goal here is to help decision-makers better evaluate their climate information needs.

Two main concepts are addressed here: **climate information categories**, which reflect the climate data needed and **climate information formats**, which reflect the way the data is presented.

2.1 CLIMATE INFORMATION CATEGORIES

Climate information categories represent the climate data or climate information; namely the climate variable, the horizon, and the resolution of the model, which is provided to the user. The categories are based on a few key criteria that are specifically related to the type of climate information that is required. These criteria are shown in Figure 16. The categories are meant to separate climate information into three very broad complexity levels, from information that is fairly simple to prepare and understand to information that is more complex to produce and often more difficult to understand and where the uncertainties are more important.

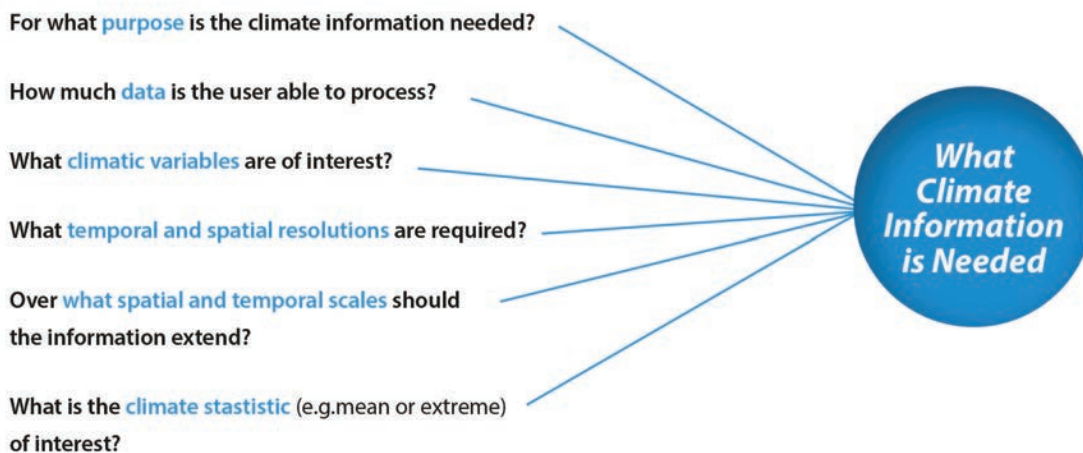


Figure 16 | Key criteria used to evaluate the climate information needs of decision-makers (*adapted from Lu 2006⁴³*).

Categories and user type

Climate information categories **do not reflect** a type of decision-maker but rather reflect the reason why the information is required, and the specifics of the climate data itself. This implies that users that may be very familiar with climate information may, at times, only require basic information, while users unfamiliar with climate information may require detailed information.

It is important to note that all criteria presented in Figure 16 can be equally important in influencing the classification outcome. Thus, it is possible that evaluating the impacts of climate change (which is an example of evaluating the purpose of the information) on a given species is not automatically part of the intermediate needs category, as it will also depend, for example, on the climate variables needed. By the same token, evaluating adaptation options is not, de facto, part of the detailed category.

In addition, the categories are presented here as well-defined entities but in fact they represent a gradient of increasing complexity in the climate data requested and/or produced. Examples of answers to each of the questions and how they can be associated with one category are presented in Table 4.

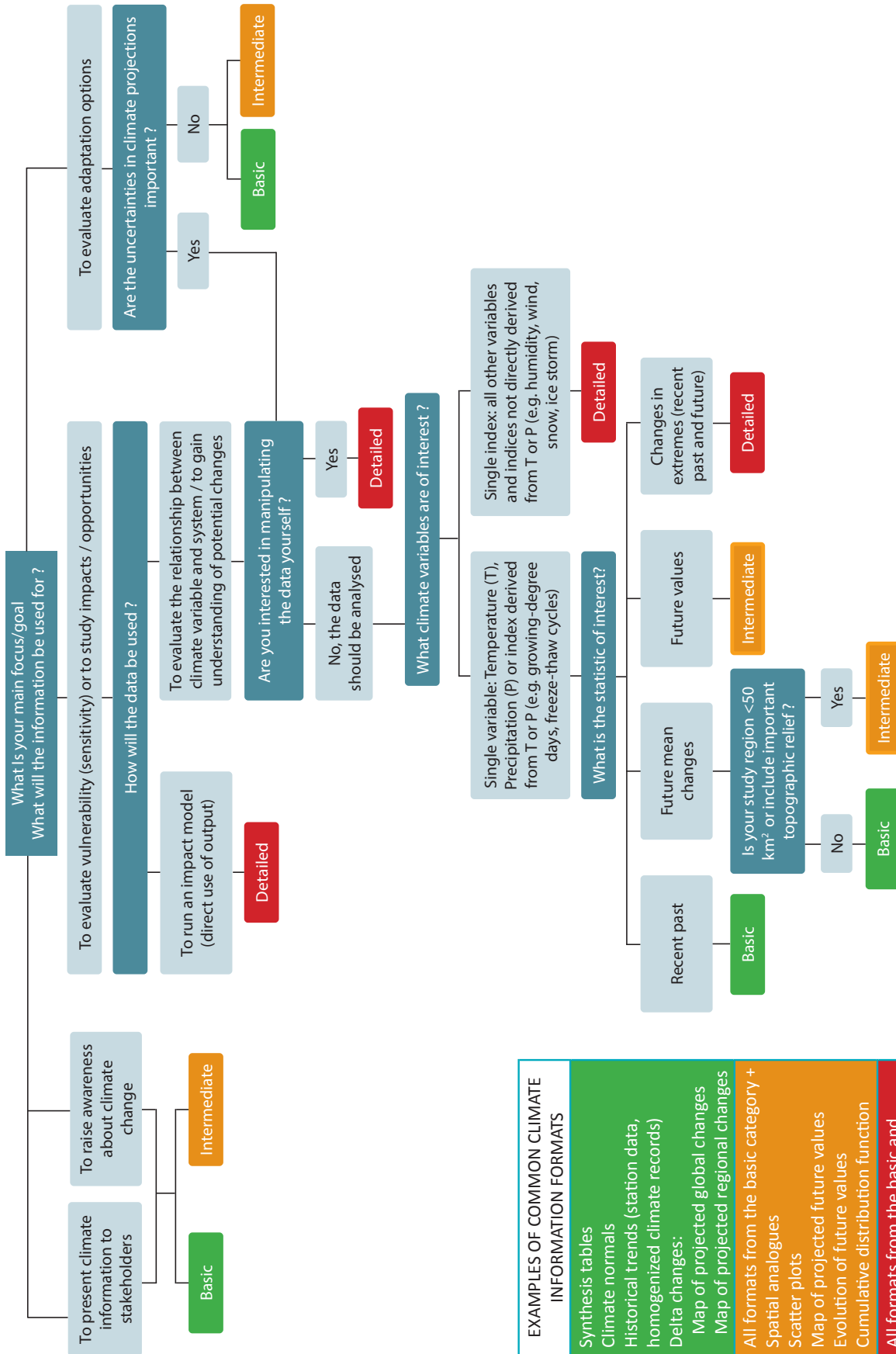
Table 4 | Overview of three climate information categories, **basic**, **intermediate**, and **detailed**.

CATEGORY	EXAMPLE OF PURPOSE	EXAMPLE OF CLIMATE INDEX	EXAMPLE OF SPATIAL RESOLUTION	EXAMPLE OF CLIMATE STATISTIC	
BASIC	To raise awareness: -initial awareness -risk scanning -high level governance	Annual temperature Annual precipitation	Coarse scale (e.g. the globe)	Mean (delta) change	<p>Increasing complexity in the type of climate variable, increase in the spatial and temporal resolution, increase in the uncertainties associated with information, increase in amount of data</p>
INTERMEDIATE	To evaluate vulnerability/ impact study: -vulnerability assessment -impact study -increase resilience -early development of adaptation plan	Growing degree-days Heating degree-days Freeze-thaw cycles	Variable (e.g. a country, province, watershed)	Future values	
DETAILED	To evaluate adaptation options: -evaluate adaptation measures -research and development -local governance	Wind	Typically finer scale (e.g. a municipality)	Extremes	

Note that the goal is not necessarily to ‘advance’ from one category to the next but simply to choose the most appropriate category for a given purpose. For some users, there will be a progression in the type of information they require based on their current knowledge and on the types of decisions they have to make over time. However, for others, basic climate information will suffice to inform fairly complex decisions.

To further help users visualize and evaluate their own climate information needs, the criteria described above have been used to develop a decision-tree (Figure 17) that is in essence a roadmap to producing climate information. By answering the roadmap questions, users are guided to one of three broad categories of climate information: **basic**, **intermediate**, and **detailed**.

Figure 17 | Decision tree to evaluate climate information needs



2.2 CLIMATE INFORMATION FORMATS

As stated above, climate information categories evaluate the general level of information complexity required by users. However, the way in which the information is presented may be equally as important. Proper formatting of the information may ensure the data is not only useful but becomes more usable. User backgrounds and areas of expertise will play a large role in determining the optimal format. In other words, the same climate information can be presented differently depending on expertise or preference.

The term format is used to refer to the way in which the information is presented, or the layout of the information. For example, the projected changes in annual temperature over Canada for the horizon 2050 (the climate information) can be communicated using a table, or a map, or a regression line (the format).

The formats presented in the guidebook have been separated into the three climate information categories. However, just as it was the case for the categories, the formats also represent a gradient from very simple representations of climate data to more complex visuals. It can be difficult at times to clearly associate them with one specific category. More importantly, the climate data requested may be complex and hence fall into the detailed category, but the way the information must be presented may need to be simplified.

Formats and user type

Climate information formats are about how to present the climate data and as such **reflect** a *type of decision-maker or end-user*, their expertise and preferences.





CHAPTER THREE

CATALOGUE OF CLIMATE INFORMATION FORMATS

The goal of this section is to present how climate information can be tailored to the audience. **In other words, the same climate information** (e.g. past trends or projected future changes) **can be presented using different formats**. For example, projected changes in temperatures can be presented using a synthesis table (e.g. p.43), a map (e.g. p.48), or using a graph that plots the evolution of the change over time (e.g. p.59).

The objective of this chapter is to present as many of the most commonly used formats as possible (Table 5). However, new formats are continually being developed by climate service providers and particular formats can always be created to meet the preferences of decision-makers or the particularities of a project.

In order to increase the capacity of decision-makers to critically evaluate the information that is provided to them, all figures, graphs and maps presented in this section are accompanied by explanations that describe: 1) what climate information is presented and how should it be interpreted, 2) how the figure is constructed and 3) what are the limitations/caveats/possible ways to misinterpret the information. In addition, the use of *coloured font* will remind the reader that additional information on key climate science concepts can be found in Chapter 1.

Table 5 | Climate information formats associated with each of the three climate information categories.

CATEGORY	TYPE OF CLIMATE INFORMATION COMMONLY PROVIDED	EXAMPLES OF COMMON CLIMATE INFORMATION FORMATS
BASIC	Historical trends and future mean changes over large spatial and temporal scales and for simple climate variables	Synthesis tables Climate normals Historical trends (station data, homogenized climate records) Delta changes: Map of projected global changes Map of projected regional changes
INTERMEDIATE	Future changes or future absolute values of more complex climate variables over finer spatial scales	All formats from the basic category + Spatial analogues Scatter plots Map of projected future values Evolution of future values Cumulative distribution function
DETAILED	Future changes in means, absolute values and extremes over finer spatial scales	All formats from the basic and intermediate categories + Temporal series Analysis of extremes –IDF curves Analysis of low-confidence climate indices and events



BASIC CATEGORY

This category includes historical climate information that comes from observed climate data along with projected mean future changes that are simulated from climate models.

The climate information included in this category is generally produced for large areas and long time periods. Coarse spatial and temporal scales and resolutions make this type of information relevant to a large number of users. It represents the type of information more readily available in summary reports and on websites.

Five examples are presented to highlight how past and future climate information can be tailored using varying formats. From the simplest format to the slightly more complex, they are:

- › **Synthesis table** – used to present both past and future changes
- › **Climate normals** – used to present climatic averages (e.g. 30-year)
- › **Historical trends** – used to present long-term evolution of the past climate
- › **Delta changes**
 - **Global maps** – used to present projected changes on a global scale
 - **Regional maps** – used to present projected changes on a smaller spatial scale

1. SYNTHESIS TABLE

Table 6 | Summary of projected climate change for the province of British Columbia for the horizon 2050 (2041-2070) in comparison to the reference period 1961-1990. Values are calculated using an ensemble of 30 global climate model projections derived from 15 different GCMs each one using two SRES greenhouse gas emissions scenarios (A2 and B1).

Source: Information was taken from PCIC website (<http://www.pacifi climate.org/analysis-tools/plan2adapt>)

Climate Variable	Season	Projected changes for horizon 2050 (2041-2070)	
		Ensemble Median	Range (10 th to 90 th percentile)
Mean temperature (°C)	Annual	+1.8 °C	+1.3 °C to 2.7 °C
Precipitation	Annual	+6%	+2% to +12%
	Summer	-1%	-8% to +6%
	Winter	+8%	-2% to +15%
Growing degree days (degree days)	Annual	+283 degree days	+179 to +429 degree days
Frost-free days (days)	Annual	+20 days	+12 to +29 days

 **What climate information is presented and how should it be interpreted?**

Table 6 shows projected changes (deltas) in mean temperature, precipitation, growing degree-days and frost-free days for the horizon 2050 (2041-2070) compared to the **reference period** 1961-1990 for the province of British Columbia.

The projected changes presented in the table are straightforward increases for annual temperature, annual growing degree-days, annual frost-free days, as well as for annual and winter precipitation over the province of British Columbia. On the other hand, the median projection for summer precipitation shows a slight decrease. The range in the values highlights that there can be large differences among all the **simulations** used. For example, one simulation projects increases as low as +179 degree-days per year while another projects values of +429 degree-days per year.

 **How is the table constructed?**

Synthesis tables can summarize historical trends or projected changes (such as the example given here) for a given **future time horizon** and region of interest, and can be expressed for different time periods (monthly, seasonal, or annual). The summary can be done for any area of interest, such as global, provincial, or regional scales.

Projected changes are calculated as the change between the 2050 horizon (2041-2070) and the 1961-1990 reference period using 15 **global climate models** with two **SRES** emission scenarios. An important point here is that, as shown in section 1.11.2, the changes represent the difference between simulated future values and simulated reference values. In other words, the changes do not represent the difference between a model simulation and observed **climate normals** (or reference) values but rather the difference within a simulation.

In the table presented here, the changes in the four climatic variables are expressed as the median change and the spread in the **simulation ensemble**. The ensemble median is a mid-point value of all simulations used to calculate the changes (30 in this case), while the range represents the 10th and 90th percentiles of all values. The range in values from the different models is generally referred to as the **uncertainty** in the models, although it is made up of more than just differences between models.

 **What are the limitations/caveats/possible ways to misinterpret the information?**

The main limitation of this information resides in the fact that the changes are often estimated over large areas, and may therefore not represent potentially important local differences. For example, in this particular case, the values are given for all of British Columbia, a province with large topographic relief in some regions. Given the importance of topographic features of this province, it is easy to imagine that the 'average' changes given in the table may not adequately represent all environments found in British Columbia.

In addition, it is important to remember that while the changes are projected over the 2050 horizon, the actual change may be gradual and therefore not felt exactly during the year 2050. In addition, the absence of changes at the annual scale could mean that there are no changes at all, or that changes during one season offset changes in another. More importantly, because of the natural variability in the climate, there may be individual years (or a series of consecutive years) where the annual change is in opposition to the average change calculated over the 30-year period (2041-2070). In other words, while the table presents an increase in average annual temperatures compared to the reference period, it is quite likely that some years will show annual temperatures that are lower than what has been experienced on average over the reference period.

2. CLIMATE NORMALS

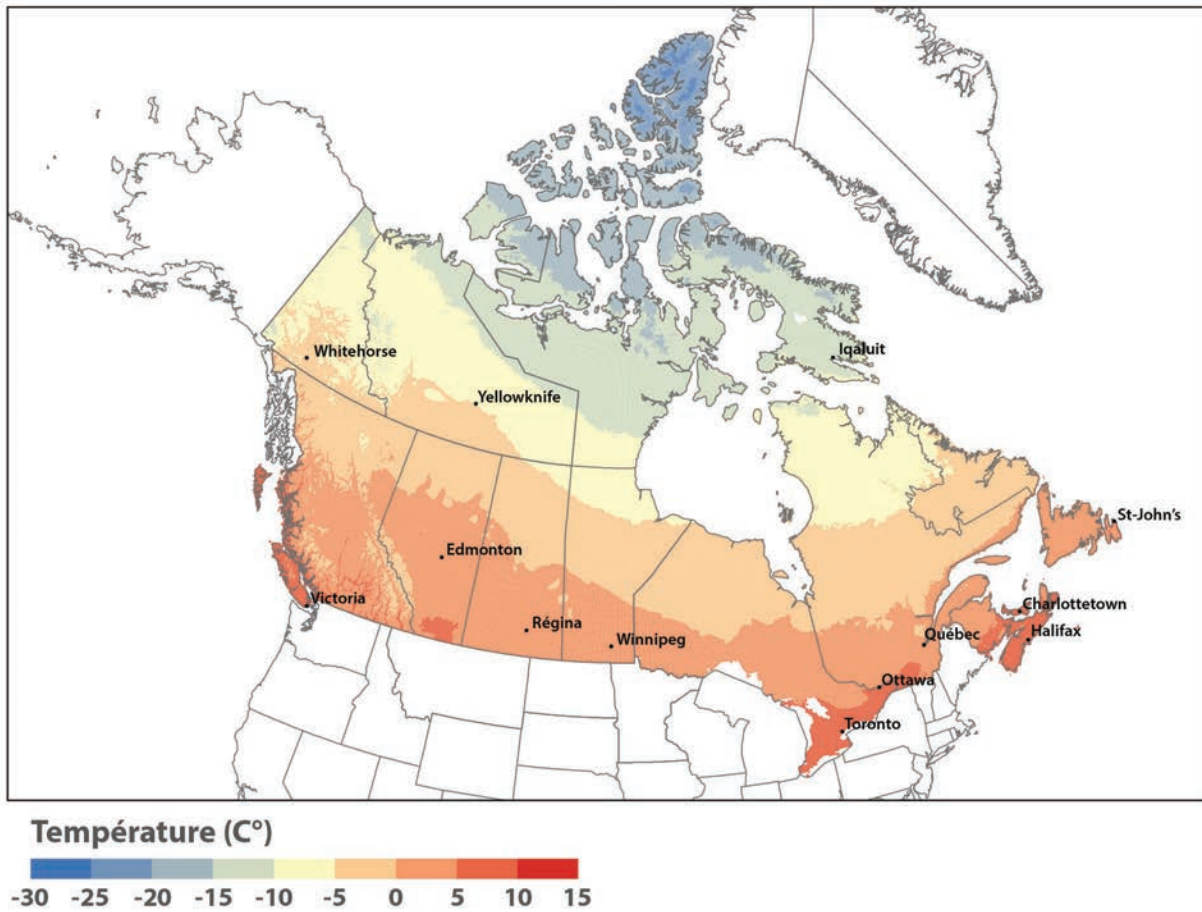


Figure 18 | Climate normals of mean annual temperature (°C) for the reference period 1971-2000. The values are calculated using Environment Canada station data that has been interpolated on a 10 km by 10 km grid and made available through an NRCan database⁴⁵⁻⁴⁶ (see text).
Source: T. Logan, Ouranos

? **What climate information is presented and how should it be interpreted?**

The figure presents a map of observed average annual temperatures across Canada for the period 1971-2000 on a 10 km by 10 km grid.

This figure shows that average or normal annual temperatures vary greatly across Canada. For example, while average temperatures in Toronto are around 5°C, average annual temperatures in Whitehorse and Yellowknife are closer to -5 to -10°C. This implies that populations, infrastructures and ecosystems are already adapted to different climatic conditions.

🔗 **How is the figure constructed?**

Climate normals are observed climate variable averages calculated using time-series of climatic data obtained from meteorological stations across Canada*. Such maps can represent simple climatic variables such as mean temperature and precipitation but the same format can be used to showcase any other climatic indices, such as growing degree-days or number of freeze-thaw cycles. Meteorological station data can be averaged over any given region of interest (a single province for example) and for any given time step, depending on data availability (such as annual or monthly for example).

In this case, the figure shows 30-year temperature normals on a regular grid (where each polygon or grid point is 10 km by 10 km), and where each polygon value corresponds to the average temperature for the 1971-2000 period. The daily temperature values are averaged for each year from 1971 and 2000 and the average of those 30 values is plotted on the figure. Note that climate normals are generally given for the same timeframe that is used as a **reference** in the construction of climate scenarios, but that it is not necessarily always the case.

⚠️ **What are the limitations/caveats/possible ways to misinterpret the information?**

Figures of this type give decision-makers an estimate of past general conditions for their area of interest. However, the values are averaged for a relatively long period of time that masks the season-to-season or year-to-year **variability in the climate**. This information is more adequate for 'big picture' decisions. For example, it is clear from such information that while you may be able to grow grain species in southern Canada, it is not possible to do so in Northern Canada. However, the information may not provide enough detail for more local decisions; for example, such as deciding what specific crop species to plant. This decision would require additional information, such as the range in climate conditions that will be experienced by the crop species. In addition, the map shows average recent past conditions but gives no indication about how those conditions may change in the future. Consequently, using historical information alone could lead to maladaptation.

* This data comes from a Natural Resources Canada database⁴⁴ in the form of a gridded data set that covers all of Canada with a grid size of 10 km by 10 km with a daily time step (Environment Canada meteorological station data is interpolated on this grid). The data covers the period 1950-2010. The same analysis could be done using station data itself or using other similar datasets with different grid sizes (e.g. CANGRID).

3. HISTORICAL TRENDS

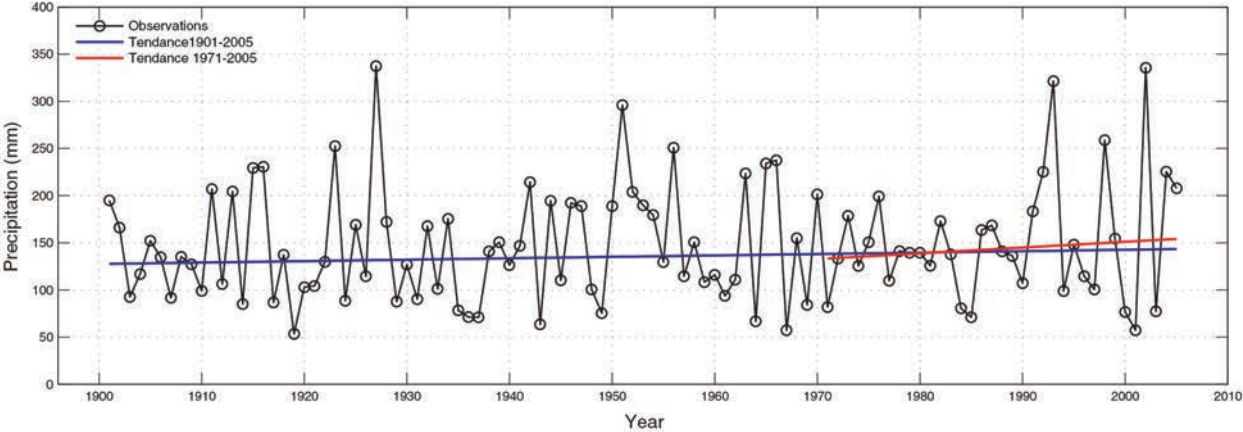
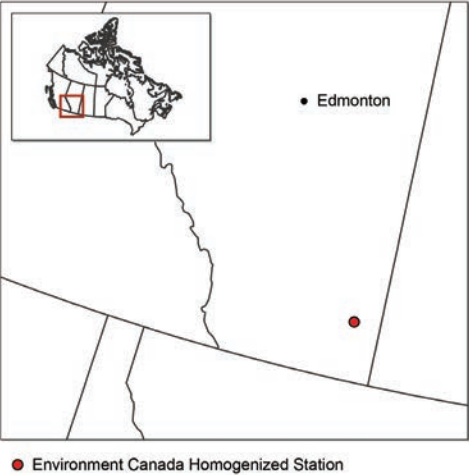



Figure 19 | Historic annual total precipitation (mm) time series for the period 1901-2005 for an Environment Canada homogenized climatological station⁴⁶. Trends for 1901-2005 and 1971-2005 are shown in blue and red, respectively.
Source: T. Logan, Ouranos

 **What climate information is presented and how should it be interpreted?**

The figure shows observed total annual precipitation values (mm) over the years 1901-2005 at a southern Alberta station along with linear trends for two periods, namely 1901-2005 and 1971-2005.

The figure demonstrates the extent of the **natural variability** (black line) in total annual precipitation for the period 1901-2005. This natural range shows years with as little as 50mm of total precipitation and years with close to 350 mm of precipitation. The figure also illustrates that while the 1901-2005 trend is insignificant, total precipitation amounts start to increase slightly in the seventies.

 **How is the figure constructed?**

Trends over the historical period are calculated using climatic time-series obtained from an Environment Canada database for the location indicated on the map (Adjusted and Homogenized Canadian Climate Data, AHCCD⁴⁶). This dataset provides adjusted and homogenized climate data for many meteorological stations across Canada. Homogenized means that the data at those stations has been corrected for changes in instrumentation, measurement technique, or changes in the location of the stations, which may have occurred over time. This type of data is better suited for evaluating climate trends, compared to non-homogenized data.

The figure can represent simple climatic variables such as mean temperature and precipitation or other climatic variables or indices. The data from meteorological stations can be averaged over different regions of interest and for different time steps such as 'seasonal', 'monthly' or 'annual', depending on the availability of the data.

The black line and dots represent the yearly observed values for the chosen location, while the blue and red lines represent the trends for the periods 1901-2005 and 1971-2005, respectively. The trends are calculated using a linear non-parametric regression technique (Sen slope).

 **What are the limitations/caveats/possible ways to misinterpret the information?**

It is very important to remember that, in this type of analysis, the chosen period over which the trends are calculated will greatly influence whether a trend is found or not. In other words, different trends can be observed depending on the start and end dates chosen, which can lead to a misinterpretation of the overall long-term trends. For example, a closer examination of the figure can quickly reveal certain periods over which decreasing trends are observed (from 1951-1961 for example) or where an increasing trend prevails (e.g. from 1919-1928).

Consequently, it cannot be assumed that the past trend will be an indication of the future and therefore informing decisions based on a given past trend should be done with extreme caution. Rather, the most appropriate use of historical trends is to give context to the magnitude of future projections. This is the reason why climate models play such a central role in our understanding of the climate to come.

4. MAPS OF DELTA CHANGES

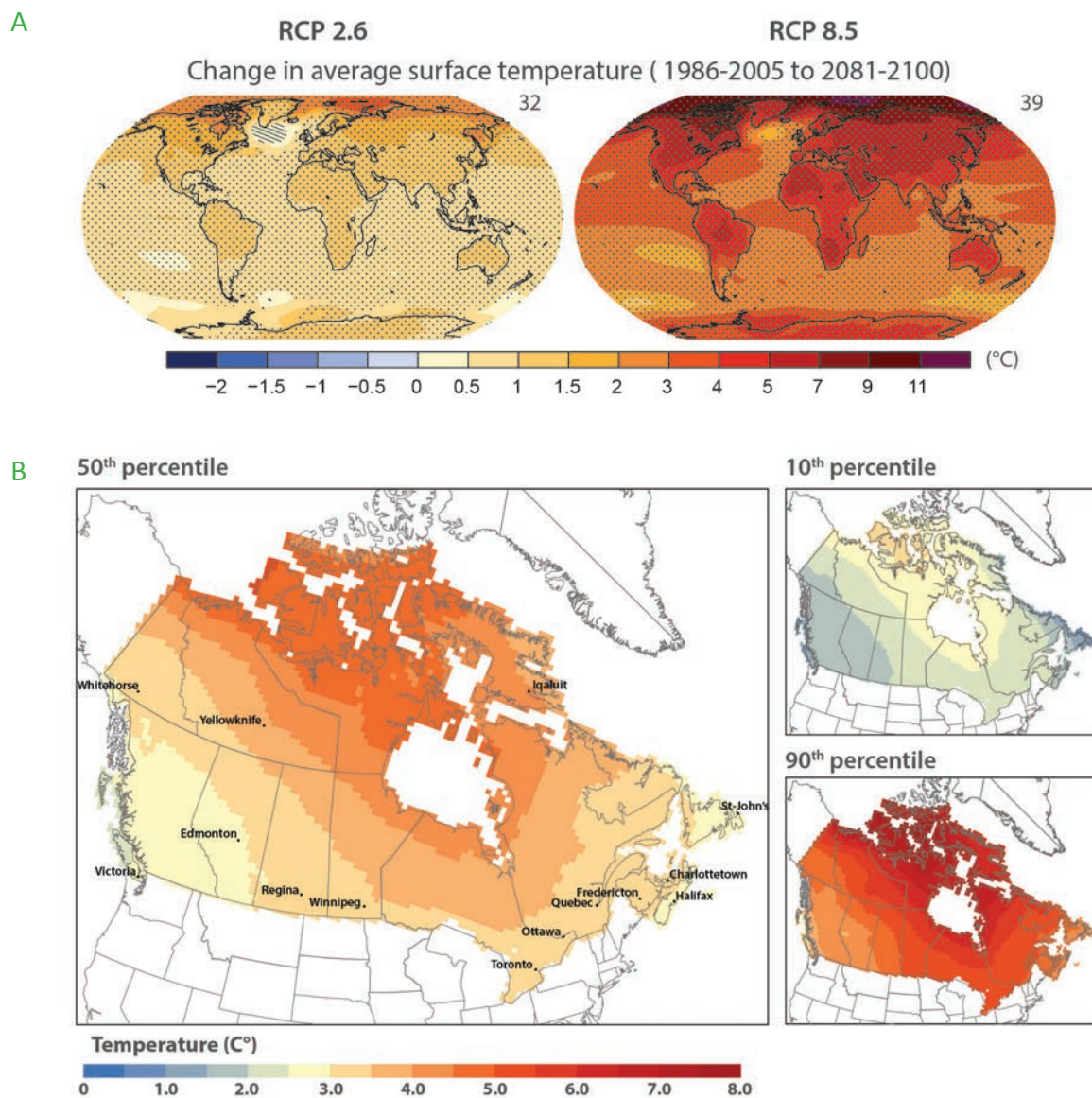


Figure 20| A. Maps of CMIP5 multi-model mean results for the scenarios RCP2.6 and RCP8.5 in 2081-2100 of annual mean surface temperature change. The number of CMIP5 models used to calculate multi-model mean is indicated in the upper right corner of each panel. Hatching indicates regions where the multi-model mean is small compared to natural variability (i.e. less than one standard deviation of natural internal variability in 20-year means) and the stippling indicate regions where the multi-model mean is large relative to the natural variability (greater than two standard deviations of the internal variability in 20-year means) and where at least 90% of models agree on the sign of change.
Source: IPCC 2013¹⁹

B. Map of projected changes in temperature (°C) between the reference period 1971-2000 and the 2080 horizon (2071-2100). The values are calculated from an ensemble of 137 global climate simulations from the CMIP3 ensemble. The large panel on the left shows the median values from the ensemble, while the smaller panels on the right show the 10th and 90th percentile values at each grid cell from the ensemble.
Source: T. Logan, Ouranos

? **What climate information is presented and how should it be interpreted?**

The top figure shows projected changes in annual mean temperature across the globe for the **horizon** 2081-2100 in comparison to the **reference period** 1986-2005, for **RCPs** 2.6 and 8.5, as published by the Intergovernmental Panel on Climate Change (IPCC) in their latest assessment report, published in 2013¹⁹. The figure suggests that the Arctic region will warm more rapidly than the global mean, and that mean warming over land will be larger than over the ocean.

The bottom figure also presents projected changes in mean annual temperature but for a smaller domain, namely across Canada, for the horizon 2080 (2071-2100) in comparison with the reference period 1971-2000. Median changes in annual temperature for the 2080 horizon range from 2.5°C to 5°C, while the 10th and 90th percentiles suggest changes as low as 1°C and as high as 8°C (not in the same locations however). The greatest changes are expected to occur in Northern regions.

🔧 **How is the figure constructed?**

The information presented in these figures is essentially the same as the information given in synthesis tables except that the expected changes are presented as maps, usually based on gridded data. The changes are calculated for a specific future horizon by comparing it to the reference period (this is often referred to as the change-field method). The difference is calculated for each polygon (or model grid cell) and for all **climate simulations** that have been chosen. The changes can be calculated for any given time frame, such as monthly, seasonal or annual changes (as is the case here).

In both figures, a large number of **models** were used to compute the changes. In Figure A, 32 models from the **CMIP5 ensemble** were used with RCP2.6 and 39 CMIP5 models with RCP8.5. For Figure B, the changes or deltas were obtained using 137 global model **simulations from the CMIP3** using 3 **SRES emissions scenarios** (A2, A1b, B1). The changes are subsequently plotted over a common grid. Note that the size of the polygons is generally driven by the resolution of the climate models used. For example, global climate models typically have a resolution of approximately 200-300 km whereas regional climate models have a resolution of approximately 45 km and less.

To synthesize the outputs from all the simulations used, a mean (as in the top Figure) or a median (as in the bottom Figure) of the ensemble is often shown. As with the synthesis table, the range in the simulations, which gives an estimate of the **uncertainty** in the **projections**, should also be represented. In Figure A (globe), this is done by the use of hatching and stippling that indicate whether the multi-model mean presented on the figure is small or large in comparison with the **natural variability**. In Figure B (Canada), this is done by giving not only the median value of the **simulation ensemble** (left panel) but also giving complementary maps that show the range in the simulations, expressed by the 10th and 90th percentiles. The choice of the percentiles is arbitrary, and could potentially take on any value of choice, such as 25th and 75th percentiles for example.

⚠️ **What are the limitations/caveats/possible ways to misinterpret the information?**

While such figures point to the fact that temperatures are increasing across large scales, they also highlight the fact that not all regions will experience the same increase. Consequently, this type of climate information may be useful to raise the awareness of stakeholders to climate change. However, it does not detail how local changes may differ significantly from this global or national picture. Consequently, using such coarse projections implies that the local relevance of adaptation decisions is less certain.

In addition, the values shown on such figures give the amount of change that is estimated by the models. However, in order to appreciate how important that change may be, it is often necessary to combine this information with climate normals, which give users a baseline value upon which to evaluate the projected changes. Similarly, climate trends can provide additional context to aid with the interpretation of the magnitude of future changes.



INTERMEDIATE CATEGORY

This category only includes information about projected future climate changes. The climate information produced for this category often tends to be for a more specific spatial scale than the information produced in the basic category. Consequently, the climate information is increasingly tailored to suit the specific needs of users. The examples shown here will help users familiarize themselves with the interpretation of the different formats.

Five examples are presented to highlight how climate information can be tailored using varying levels of complexity. From the simplest format to the most complex, they are:

- › **Spatial analogues** – used to present where the historical climate will be in the future
- › **Scatter plots** – used to show changes in climate variables for different climate simulations
- › **Map of projected future values** – used to present projected future values of a climate variable
- › **Evolution of future values** – used to present projected evolution of future values
- › **Cumulative distribution function** – used to present the distribution of the projected future values

Note that the last three formats show the same climate information for the exact same location – they are therefore a good example of what is meant by «presenting the same climate information using different formats».

1. SPATIAL ANALOGUE

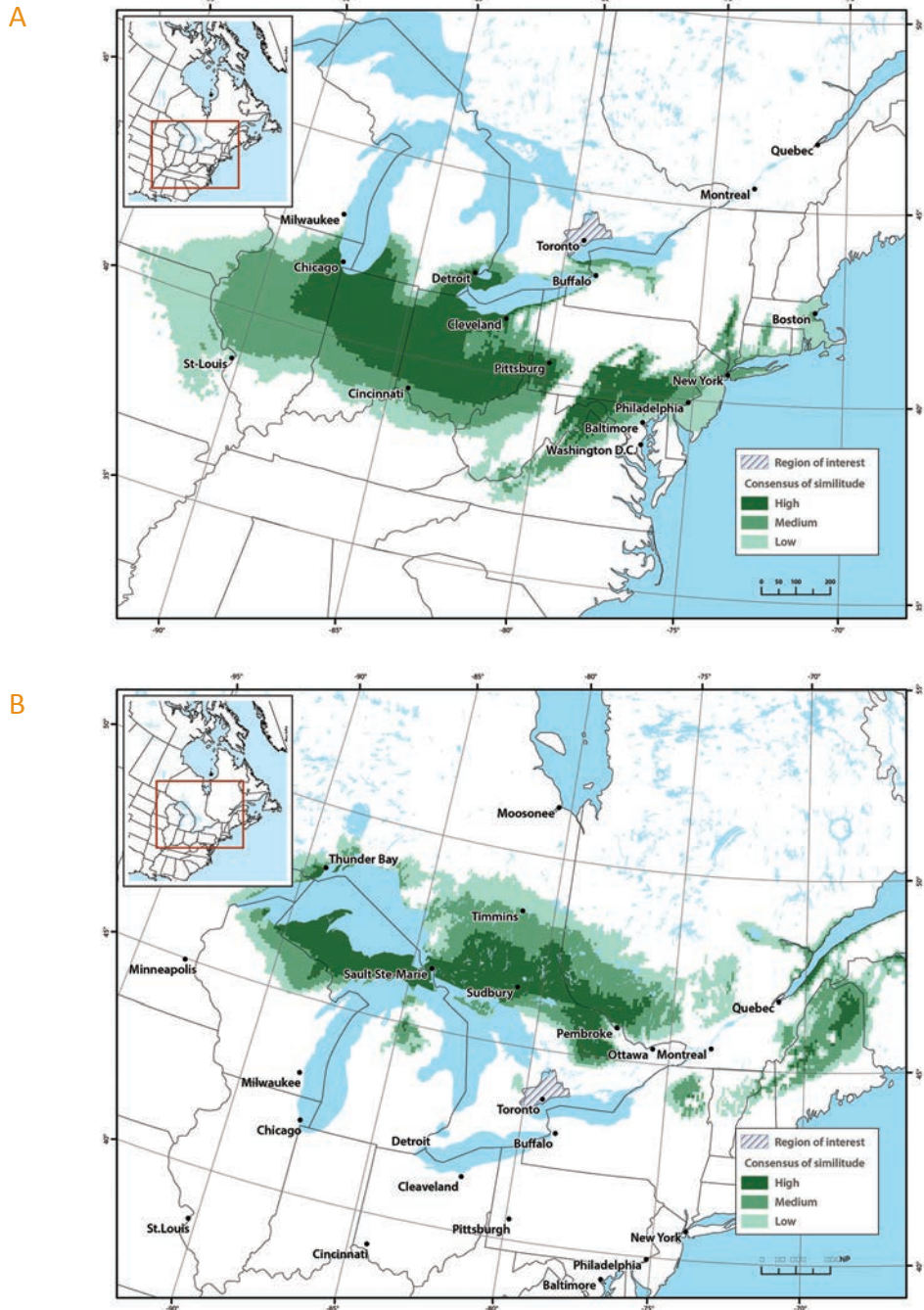


Figure 21 | Spatial analogue for the greater Toronto area for the 2080 horizon (2071-2100). **A.** The regions where the recent climate (1971-2000) is similar to the climate projected for the greater Toronto area in 2080 (2071-2100). **B.** The regions where the projected future climate (2071- 2100) is similar to that of the greater Toronto area for the recent past (1971-2000). The similitude categories indicate the level of similarity between the observed climate and the projected climate for the region of interest (using 136 global climate simulations). The analogues are based on a statistical comparison between the current and future distributions of mean annual temperature and total annual precipitation for the reference period 1971-2000 and the horizon 2080 (2071-2100).

Source: T. Logan, Ouranos

 **What climate information is presented and how should it be interpreted?**

The figure presents spatial analogues for the greater Toronto area (GTA) for the 2080 **time horizon** (2071-2100). On the top panel, the green areas illustrate regions where the **reference climate** (1971-2000) resembles what the climate of the GTA is projected to be in 2080. On the bottom panel, the green areas represent areas where the reference climate of Toronto may be found in 2080.

The top panel indicates that the area where recent past (1971-2000) temperatures and precipitation resemble the most what the greater Toronto area may look like in 2080 is fairly large and includes cities like Detroit, Cleveland, Chicago, and Pittsburgh. New York and Philadelphia also exhibit a high level of similarity in the simulations.

As for the 2080 location of Toronto's current temperature and precipitation distributions (bottom panel), the highest similarities are obtained along a transect that cuts through an area south of Lake Superior and North of Lake Huron, encompassing the cities of Sault Ste-Marie and Sudbury. The analogue region extends past Timmins in the North.

One of the interesting uses of this information is to identify analogue regions in terms of their current ability to adapt to the climate. This allows an evaluation of whether the region of interest can take advantage of some of the practices developed in the analogue region to adapt to climate change.

 **How is the figure constructed?**

Analogue techniques involve a comparison between the anticipated future climate of a region of interest with historical climate of other regions⁴⁷. The comparison is based on the similarity between the distributions of climate variables between the reference and future horizons (1971-2000 and 2071-2100 in this case). The similarity indices can be calculated using various metrics (e.g.⁴⁸⁻⁵¹).

In theory, this method of climate data communication allows for any number of variables to be considered in the comparison. For example, one could simply want to find a temperature analogue for a given city, while another user may

instead be interested in finding an analogue for the same region that takes into account temperature, precipitation, and growing degree-days.

In this particular case, the analogues for the future climate around Toronto in 2071-2100 are based on two climate indices, namely total annual precipitation and annual temperature. To simplify the interpretation, the median distance values for 136 **CMIP3 simulations** were divided into three levels of similarity, plotted using a colour gradient. The «high» level of similarity represents the first 10% of the median distance values, the «medium» level represents the 10 to 20%, and the «low» level represents the next 20 to 30% of values. Values with a smaller similarity index (greater than 30%) were not considered as analogues and are therefore not shown on the map.

 **What are the limitations/caveats/possible ways to misinterpret the information?**

A noteworthy drawback of this technique is that it can be difficult to find analogues that share the same characteristics for a large number of climate variables. In fact, analogues often capture only a few key aspects of the climate because they are based on a few climate indices, not the whole thing. For example, in this case, New York shows a high level of similitude with Toronto. However, New York, being a much more coastal city compared to Toronto, will experience climate events that are vastly different from what Toronto will ever experience. Consequently, the choice of the climate variables of interest will influence the results. In addition, analyses that includes analogues often rely on the hypothesis that regions with similarities in certain aspects could also share similarities in other aspects (such as soil type, topography, vegetation)⁵², which may not always be the case. Caution must therefore be exercised when comparing a given region with its analogues.

2. SCATTER PLOT

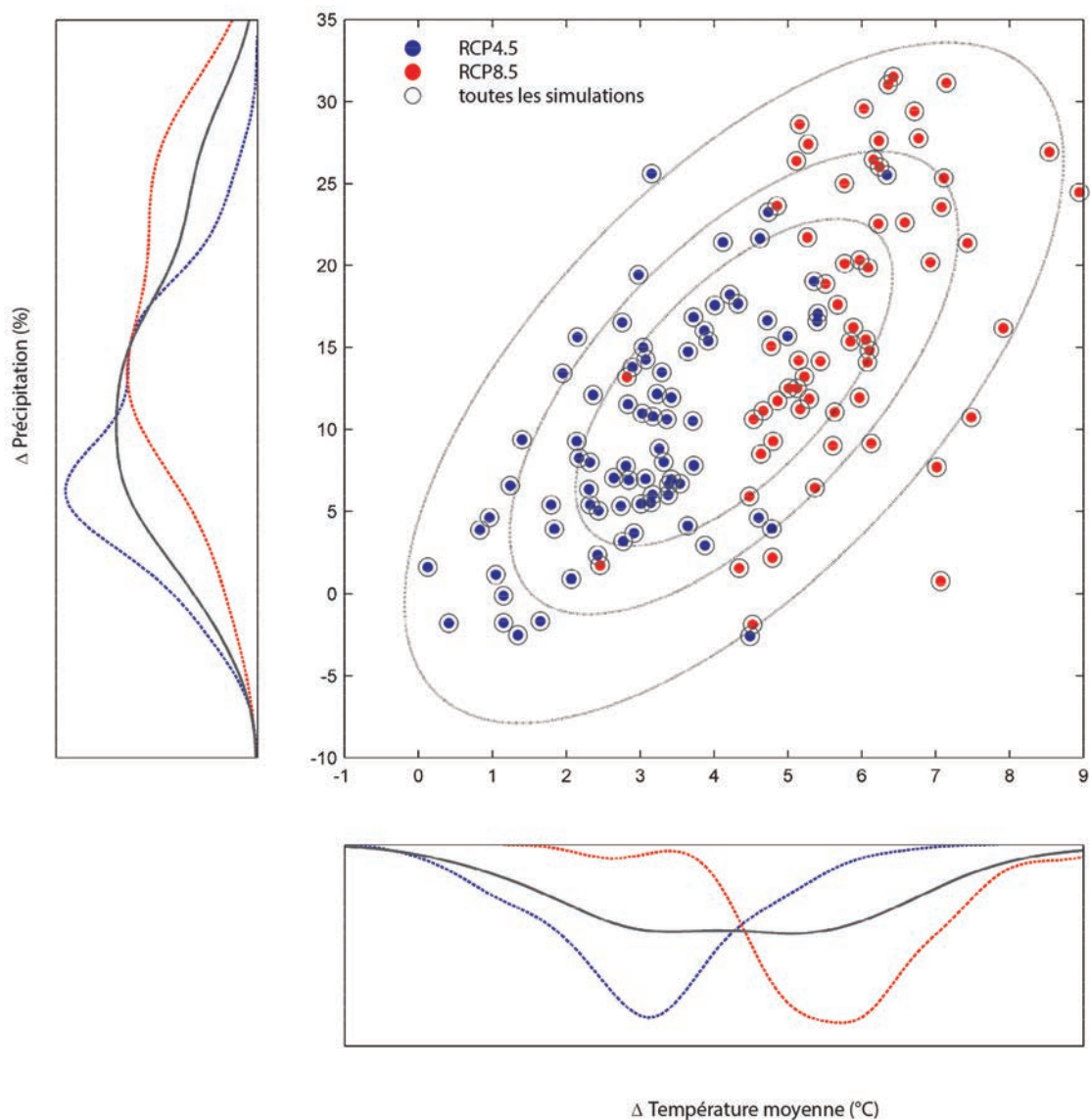



Figure 22 | Projected changes in mean temperature (°C) and total precipitation (%) for the provinces of New Brunswick and Nova Scotia for the winter months (DJF, December, January, and February) for the horizon 2080 (2071-2100) in comparison to a 1971-2000 reference period. The changes are shown for an ensemble of global climate simulations under RCP4.5 (n = 100, blue points) and RCP8.5 (n = 60, red points). The associated distributions of each set of simulations are shown on the left and bottom panels.
Source: T. Logan, Ouranos

 **What climate information is presented and how should it be interpreted?**

The figure presents projected changes in winter (DJF) precipitation and winter (DJF) temperature for the 2080 horizon (2071-2100) by different **global simulations** with **RCPs** 4.5 and 8.5 for the provinces of New Brunswick and Nova Scotia, in comparison with the 1971-2000 **reference period**.

The main panel shows a clear separation in the projected changes between the two RCP emission scenarios. Climate models that were run with RCP8.5 show greater precipitation and temperature changes. When all simulations are considered, the range in temperatures deltas for 2080 varies from 0°C to 9°C, while changes in precipitation range from -3% to 30%.

The density functions, on the left and bottom of the figure, highlight a peak in the number of simulations that show increases in temperatures around 3°C for RCP4.5 and of 6°C for RCP8.5. In term of changes in precipitation, the density functions peak around 5% for RCP4.5 and around 15% for RCP8.5. The curves show a good degree of separation, with two distinct peaks, between the two RCP families for temperature. In contrast, the precipitation curves overlap a great deal.

 **How is the figure constructed?**

Scatter plots typically illustrate projected changes (deltas) in precipitation and temperature, although any two climate variables of interest could be used, simulated by different climate models under different emissions scenarios for a region and future horizon of interest. They allow a general view of the expected changes and more importantly, of the range projected by an ensemble of simulations. A rapid comparison between what is expected under different emissions scenarios is also possible.

This particular case presents the changes in winter temperatures and precipitation for the 2080 (2071-2100) horizon with respect to the 1971-2000 reference period as projected by an ensemble of **CMIP5 simulations** (100 simulations with RCP4.5 and 60 simulations with RCP8.5). The elliptical lines indicate the 50th, 75th, and 95th percent confidence intervals.

The figure presented here also shows density functions on the left and on the bottom of the figure for all scenarios (black curve) and each RCP family (coloured curves) for both climatic variable. Note that these curves are not always presented with scatter plots.

 **What are the limitations/caveats/possible ways to misinterpret the information?**

While this figure clearly highlights that there can be a large spread in the projected changes under different simulations, the causes (or sources) of the spread in the simulations are not explained in the graphic. However, understanding that different sources of **uncertainties** (stemming from **natural variability**, **emissions scenarios** or **model differences**) have a different relative importance over different timescales can be valuable complementary information to decision-makers.

The fact that the changes in precipitation are expressed as percentages should also be viewed cautiously as some simulations can exhibit very large changes in comparison to very low absolute reference values.

Scatter plots are sometimes used to manually select a sub-set of future scenarios; for example scenarios showing the largest changes in annual temperature and precipitation. However, the position of individual scenarios in a scatter plot can be highly variable from season to season and from region to region. Consequently, selecting scenarios using a two-dimensional scatter plot based on annual changes may not be appropriate if the seasonal impacts are of interest.

3. FUTURE VALUES

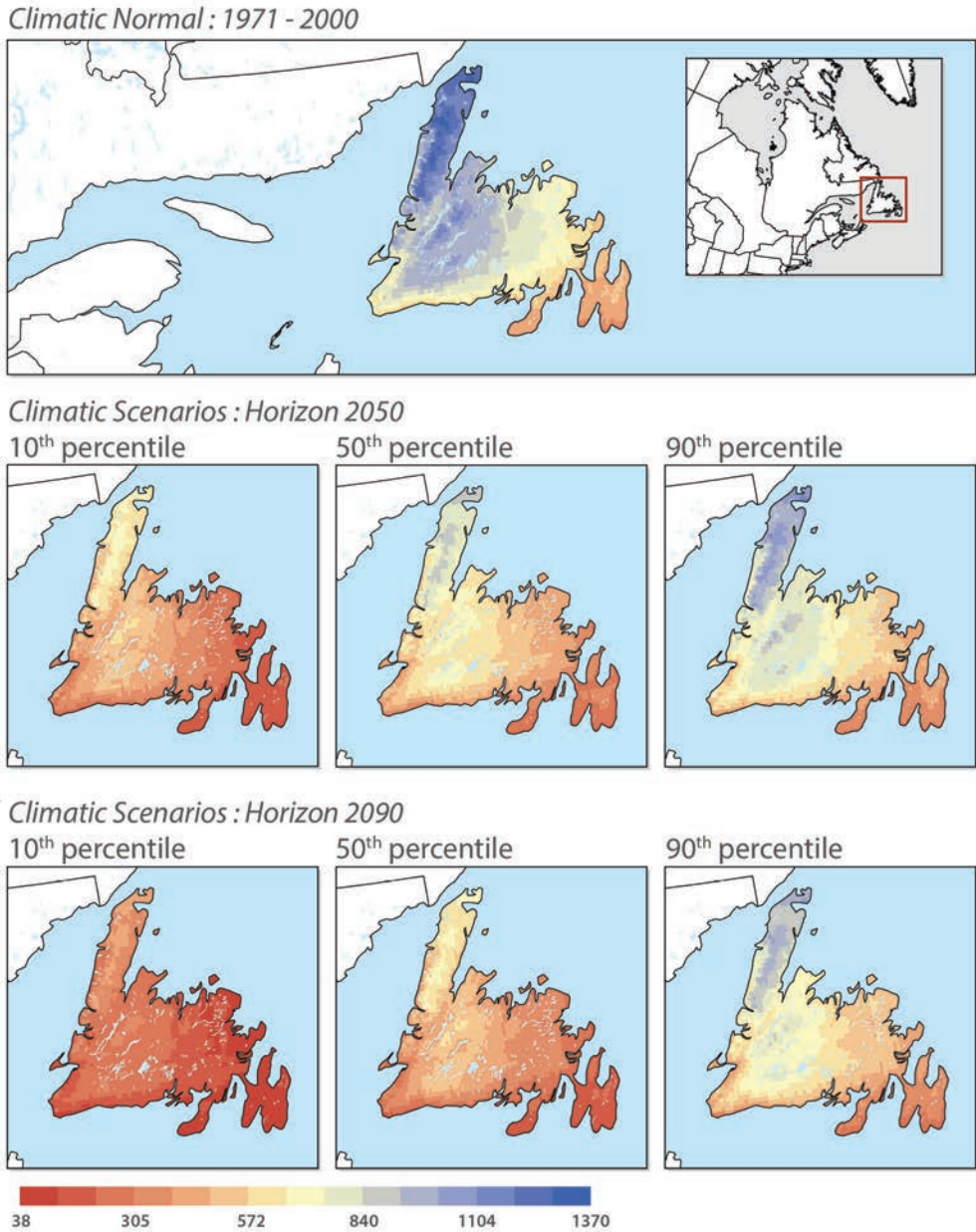


Figure 23 | Climatic normals in the number of freezing-degree days for the period 1971-2000 along with projected future values for this index for the horizons 2050 (2046-2065) and 2090 (2081-2100), calculated using an ensemble of 79 simulations (75 from CMIP3 and 4 from CRCM4). The middle columns represent the median, while the left and right columns represent the 10th and 90th percentiles of the ensemble, respectively.
 Source: T. Logan, Ouranos

 **What climate information is presented and how should it be interpreted?**

The figure shows the **climatic normals** and the **projections** of absolute future values in annual freezing degree-days for the province of Newfoundland for the horizon 2050 (2046-2065) and 2090 (2081-2100) on a 10 km by 10 km grid. Freezing degree-days correspond to the absolute difference between the mean daily temperature and a threshold of 0°C. For example, if the daily mean temperature is equal to -5°C, the number of freezing degree-days for that day is equal to 5. If the temperature is above 0°C, the freezing degree-days are equal to zero. Annual values are obtained by adding up the freezing degree-day values of all days of the year.

The top panel first highlights the fact that climate normals in annual number of freezing degree-days are spatially variable over the province of Newfoundland, with values ranging from approximately 300 to 1300 for the period 1971-2000. Note that these normals come from station data; they are not simulated by climate models. These values are used in the bias-correction process to obtain future values presented in the bottom panels.

The future maps point to a decrease in the number of freezing degree-days, due to warming temperatures. The median values (50th percentile maps) show that there are fewer freezing degree-days in 2090 than in 2050. Notice that the biggest differences in values are shown in the 10th percentile maps.

 **How is the figure constructed?**

The top panel presents climatic normals for the period 1971- 2000, which are derived as shown in section 1.2.

Just as with the maps presented in the basic category, the future values are calculated over a specific future horizon. Values are calculated for each of the **climate simulations** over every polygon over a time frame of interest. In this case, projected values in the annual number of freezing degree-days are given for two **future horizons**, namely 2050 and 2090. The 10th, 50th and 90th percentile values represent the range in the simulations used, namely 79 simulations (75 from the **CMIP3 global ensemble** and 4 from the regional CRCM 4.2.3 model).

The largest difference between this data and that presented in the previous category is that these results do not present deltas or mean changes between two time periods but rather present future projected absolute values of freezing degree-days for the two time horizons. This information is often considered as an added value to the more basic delta maps shown in the previous sections and one that requires additional **post-processing** of the data. The **climate scenarios** obtained using a total of 79 simulations underwent a **bias-correction method** to obtain absolute values over a 10 km grid.

 **What are the limitations/caveats/possible ways to misinterpret the information?**

The fact that the 10th percentile maps show the biggest changes as opposed to the 90th percentile maps is important and may be somewhat confusing. Indeed, the largest change is typically represented by the 90th percentile simulations. Imagine comparing future temperature values with average annual temperatures for example. One intuitively knows that if temperatures are increasing, there will be a gradient in the projected temperatures, such that 10th percentile temperature < 50th percentile temperature < 90th percentile temperature. However, for the case of freezing degree-days, there is an overall decreasing trend and as a result, the lowest percentile map of future values shows the largest decrease.

4. EVOLUTION OF FUTURE VALUES

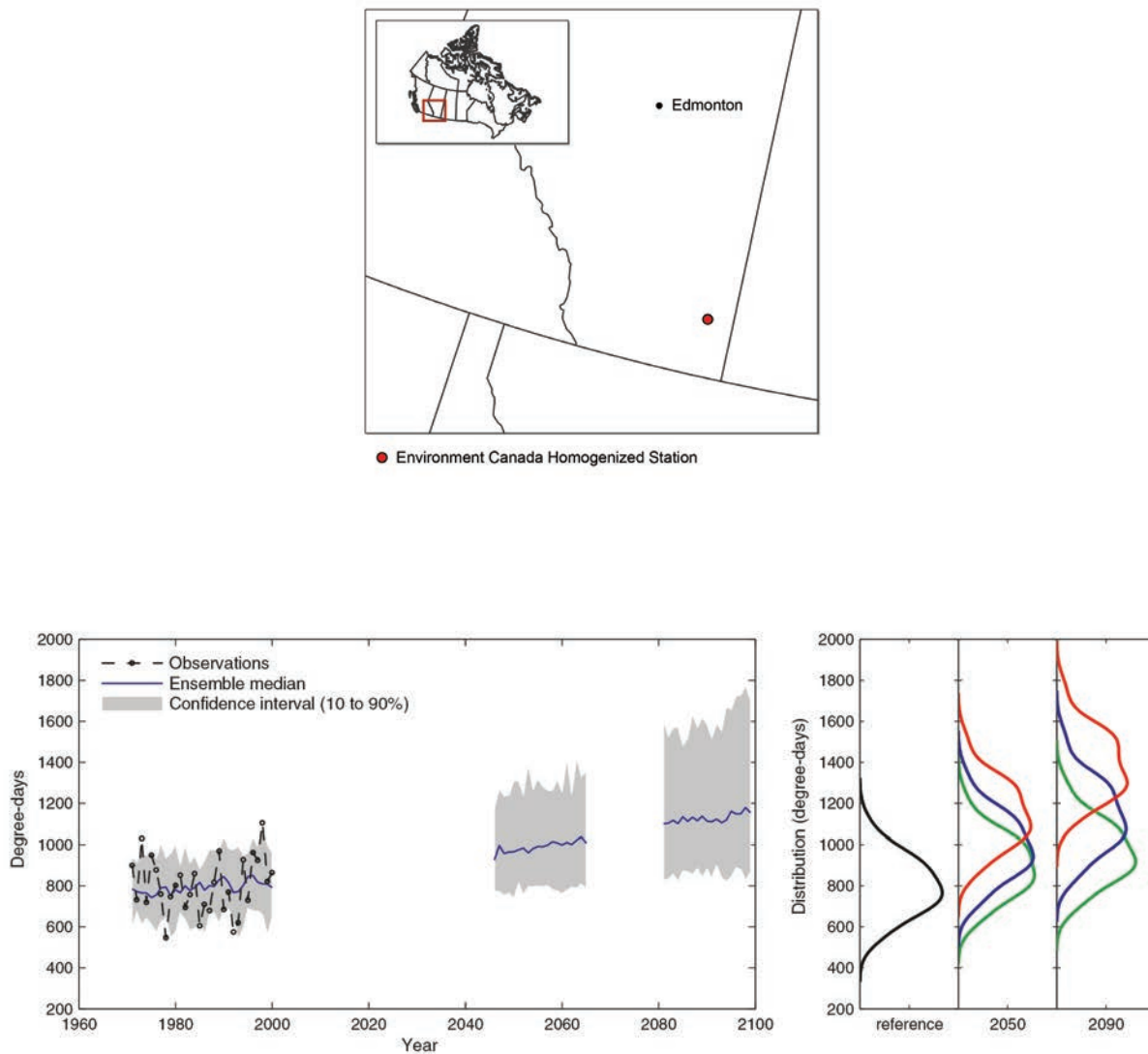


Figure 24 | Left: Evolution of the mean annual number of growing degree-days for the years 1971-2100 for the Greater Slave Lake region. The values are calculated using an ensemble of 79 simulations (75 from CMIP3 and 4 from CRCM4), while the observations come from an NRCan dataset^{44,45}. **Right:** The distributions values of the regional mean for observed values (black curve) and projected values are shown as the 10th, 50th, and 90th percentiles of the ensemble of climate scenarios (green, blue, and red curves respectively).

Source: T. Logan, Ouranos

? **What climate information is presented and how should it be interpreted?**

The figure presents the evolution of the number of annual growing degree-days from 1971 to 2100 for a region surrounding Yellowknife in the North West Territories. Growing-degree days correspond to the absolute difference in mean daily temperature above a threshold of 5°C. For example, if the daily mean temperature is equal to 10°C, the number of growing degree-days for that day is equal to 5. If the temperature is below 5°C, the growing degree-days are equal to zero.

The left panel shows a projected increase in the number of growing degree-days from 1971 to 2100. The **simulation ensemble** (grey envelope) covers approximately the same range as the **natural variability** (black dots). The right panel shows an upward shift in the distributions of the simulations for 2050 and 2090, particularly for the median and 90th percentile distributions indicating a change in mean climate conditions. The shapes of the coloured future distributions do not change drastically (compared to the black observed distribution) indicating that the inter-annual variability is relatively similar between the observed and future horizons.

🔑 **How is the figure constructed?**

This type of figure presents the evolution of projected values of a specific climatic variable for a particular region of interest. Hence, it shows how the values evolve over time. Here, three horizons are represented, a 1971-2000 reference period, a 2050 horizon (2045-2065) and a 2090 horizon (2081-2100) with a total of 79 simulations (75 from the **CMIP3 global ensemble** and 4 from the regional CRCM 4.2.3 model).

The left panel is constructed by averaging the growing degree-days for all grid points for the region of interest shown in the hatched area. The black line shows observed values (notice the observed natural variability of the climate over that time period), the blue line represents the median of the CMIP3 ensemble simulations and the grey envelope represents the confidence interval around the median. A **bias correction post-processing** method is used to obtain future values.

The right panel shows the distribution of the 30 observed annual growing degree-day values for the reference period (black line), as well as the distributions of the 30 projected years for three individual climate scenarios for both the 2050 (2046-2065) and 2090 (2081-2100) horizons. The three plotted scenarios are selected from the 79 available simulations by first calculating the average delta values for all scenarios for the two time horizons. The

three individual scenarios for each horizon are then chosen as those having (1) the median (blue curve), (2) the 10th (green curve) and (3) the 90th (red curve) percentile values of the average projected change out of the 79 simulations for the horizon in question. Note that the three scenarios are not necessarily the same for each horizon of interest (i.e. the scenario showing the median change in 2050 is probably not the median scenario in 2090). This panel uses a scaling post-processing method which allows a direct comparison of future scenarios with the observed distribution.

⚠️ **What are the limitations/caveats/possible ways to misinterpret the information?**

The left panel reveals that while there is definitely a projected increase in growing degree-days, there is also a widening of the grey envelope (**uncertainty**) into the future. An important point is that the grey envelope contains all sources of uncertainty, not just the inter-annual variability. For example, the widening of the envelope could lead a user to mistakenly conclude that in the future, the simulations project both warmer average conditions (centered approximately in the middle of the envelope) and an increased variability between individual years (inter-annual variability). However, this is not how the figure should be interpreted. The width of the grey envelope for the future horizons is in fact the result of multiple sources of uncertainty, not only inter-annual natural variability, but also uncertainty between the different **SRES families** (i.e. more or less GHGs in the atmosphere), as well as uncertainties in **climate model** sensitivity (i.e. how sensitive different climate models are to a given increase in GHG concentrations). It is therefore false to assume that the wider grey envelope for future horizons solely represents greater inter-annual variability, as represented by the grey envelope for the reference period.

In order to better understand whether there is indeed an increase in the inter-annual variability (increased fluctuations between years) we need to investigate the panel on the right. Comparing the coloured future distributions with the observed distribution highlights the fact that the distribution shape does not change much in the future (similar widths, tails, etc.). What is projected is a simple upward shift of the distribution in the future, with an increased separation between the green, blue and red curves between 2050 to 2090. Going back to the left panel we can now much more easily conclude that, in this case, the change in the grey envelope width is due to this increasing separation between the individual climate scenarios (due to differences in emissions and climate model sensitivity) and not because of an increase in inter-annual variability.

5. CUMULATIVE DISTRIBUTION FUNCTION

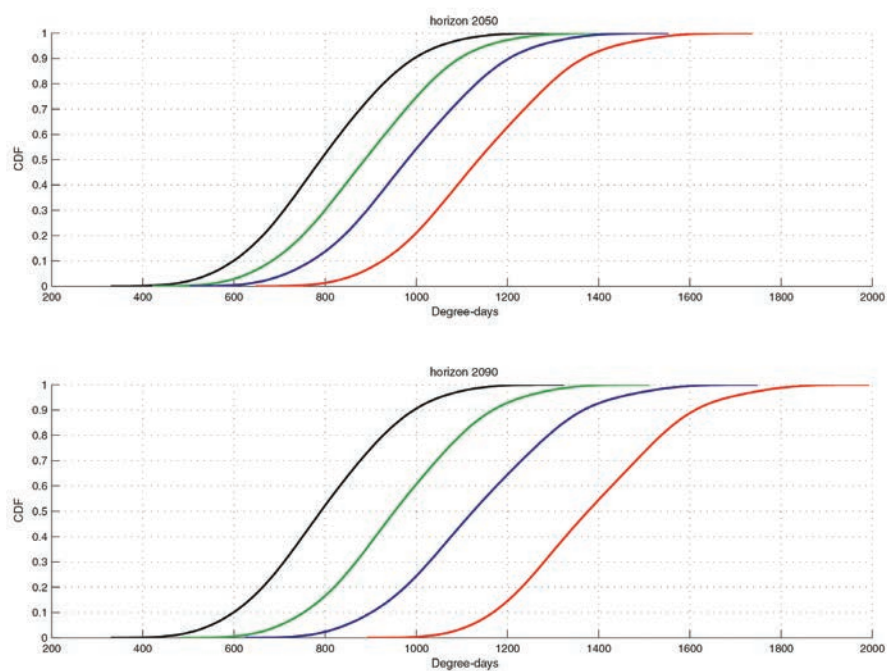



Figure 25 | Cumulative distribution function (CDF) of the regional mean annual number of growing degree-days for the reference period (1971-2000) and two future horizons (2050 and 2090) for the Greater Slave Lake region. The values are calculated using an ensemble of 79 simulations (75 from CMIP3 and 4 from CRCM4), while the observations come from an NRCan dataset^{44,45}. Shown are the observed values (black curve) and projected values for the 10th, 50th, and 90th percentiles of the ensemble of climate scenarios (green, blue and red curves).
Source: T. Logan, Ouranos

 **What climate information is presented and how should it be interpreted?**

The figure presents cumulative distribution functions (CDF) of the projected number of growing degree-days for the **reference period** and the 2050 (top) and 2090 (bottom) **future horizons** for the Yellowknife region.

This format of presentation allows for an easy comparison between the different percentile distribution of observed and projected changes, as well as an evaluation of exceeding given thresholds. For example, a year with a growing degree-day mean of around 800, which is a fairly common occurrence in the observations (black line), is projected to occur less than 5% of the time by the median scenario over the 2050 horizon. Over the 2090 horizon, the proportion of projected values that will be inferior or equal to 800 is only about 0.18 for the 10th percentile scenario (green line). On the other hand, the 90th percentile scenario (red line) points to an increasing proportion of years with higher numbers of growing degree-days.

 **How is the figure constructed?**

The figure presents the same information shown on the distribution curves of the previous evolution figure (right panel) but displayed in a different manner. The cumulative curves show the proportion of years (vertical axis) that have values inferior or equal to a given value of growing degree-days (horizontal axis).

 **What are the limitations/caveats/possible ways to misinterpret the information?**

Users have to keep in mind that the proportion values presented in this figure do not represent a probability of occurrence. The **uncertainty** in the **simulations**, represented here by the coloured lines, remains important. More weight or importance cannot be assigned to one curve over another. In other words, one scenario (line) is not more likely than another.

In addition, it may be fairly difficult to visualize what the information presented in this type of figure actually represents for a given area. This type of graphic is in fact rarely given on its own but tends to be complementary to a map (where differences over the study area are better represented) or to an evolution figure (where average changes over the study area more easily discerned).



DETAILED CATEGORY

Similarly to the intermediate category, the climate information in this last category is focused on projected future climate changes. However, the analysis targets not only average or mean changes in a climate variable over time but also estimates changes in extreme events and for climate indices for which there is less confidence in model projections at this time.

The information given to users in this category is often tailored specifically to their needs and will often not be relevant or usable by others.

The examples used to highlight the type of information available in this category have been grouped into four examples. From the simplest to the most complex, they are:

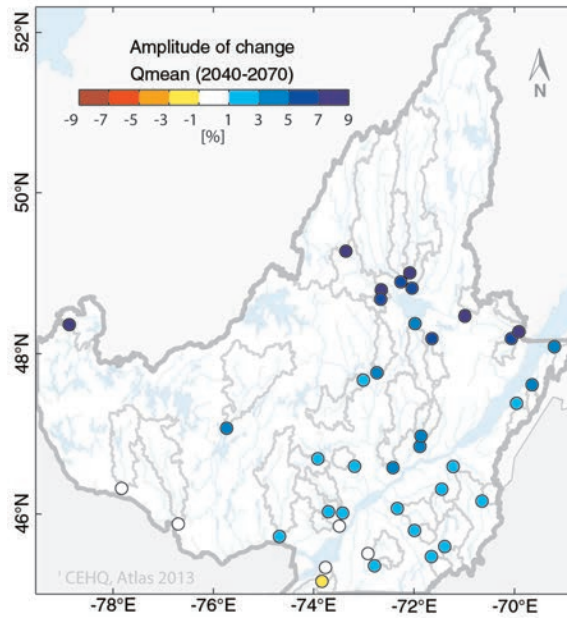
- › **Temporal series** – used to provide outputs from climate models for impacts models
 - Hydrology

- › **Intensity-Duration-Frequency curves** – used to analyze extreme precipitation events

- › **Analysis of low-confidence climate indices and events**
 - Climate model scenarios
 - Synthetic scenarios

1. TEMPORAL SERIES

A



B

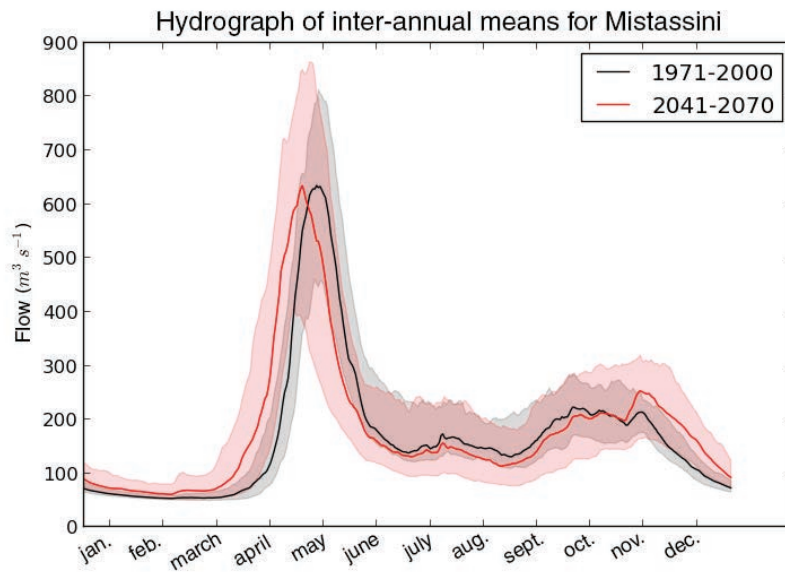


Figure 26 | A. Projected change in mean annual discharge (Q_{mean}) for the 2041-2070 period in comparison with the reference period 1971- 2000 using an ensemble of 89 CMIP3 simulations and B. mean annual hydrograph for the reference and future periods for one of the sub-watersheds.

Source: A. Centre d'expertise hydrique du Québec (2013)⁵³ and B. Gauvin- St-Denis, Ouranos

? **What climate information is presented and how should it be interpreted?**

Figure 26 shows projected changes in mean annual discharge values for the 2050 **time horizon** for a small watershed in Quebec (left panel) along with a mean annual hydrograph for one sub-basin (right panel). The left panel shows a south-north gradient in annual discharge changes with little change in the south and increases on the order of 7-9% in the northern portion of the region of interest. On the right, the corresponding mean annual hydrograph for one of the sub-basins shows changes in the periodicity of the flow for that location. The figure shows a projected shift in the peak discharge in the spring, with an earlier peak for the future 2041-2070 horizon compared to the 1971-2000 **reference period**. In addition, discharge values are lower in the summer and fall months in 2041-2070 while they are higher for the winter months.

🔧 **How is the figure constructed?**

In this example, outputs from **global climate model simulations** were imported into an impacts model, namely a hydrological model to evaluate how future discharges would be change.

The climate model output data provided was relatively simple and consisted of total annual precipitation values, maximum and minimum daily temperatures for both the reference period (1971-2000) and for the 2050 future time horizon. These three climate variables were subsequently imported into one hydrological model that calculated daily discharge values for both periods and the change between the two periods. This analysis used a total number of 89 **CMIP3 simulations** and five different **bias-correction-post processing techniques** along with the hydrological model to generate 445 **climate change scenarios**. These scenario results are then used to calculate the amplitude of the mean change in discharge which is shown on the left panel. The 445 climate scenarios are also used to produce the mean annual hydrograph on the right panel. The solid lines represent a daily 30-year mean (either for the reference period in black or the future in red), while the envelopes represent the 10th and 90th percentiles for each time period.

⚠️ **What are the limitations/caveats/possible ways to misinterpret the information?**

One of the biggest difficulties with using temporal series is that it demands a capacity to handle very large datasets. In addition, it is important to remember that the information provided is often very case specific and it may be difficult to extrapolate the results to other regions. This is true for the example shown here, where both the climate data used as inputs and/or the parametrization of the impacts model is done for certain conditions only. Given the specificity of the information used for one region, one must be careful when extrapolating the projected changes to other regions.

More specific caveats for this example include that fact that the information given by the percent change in discharge may not be complete or detailed enough to make decisions. Indeed, the analysis involved in producing this type of figure is complex and results in a very large number of scenarios. The mean change shown from all scenarios can be considered as an advantage in having a single scenario, and therefore a simple to understand value. However, the **uncertainty** associated with the **ensemble** is also very large, with scenarios often exhibiting opposite trends that are not shown in the figure. Given that our current knowledge does not allow us to reject any of the scenarios, this uncertainty should not be ignored. The fact that the changes are expressed as percentages should also be viewed cautiously as some scenarios can exhibit very large changes in comparison to a very low reference discharge value (large relative change but small absolute change).

2. INTENSITY-DURATION-FREQUENCY CURVES (ANALYSIS OF EXTREMES)

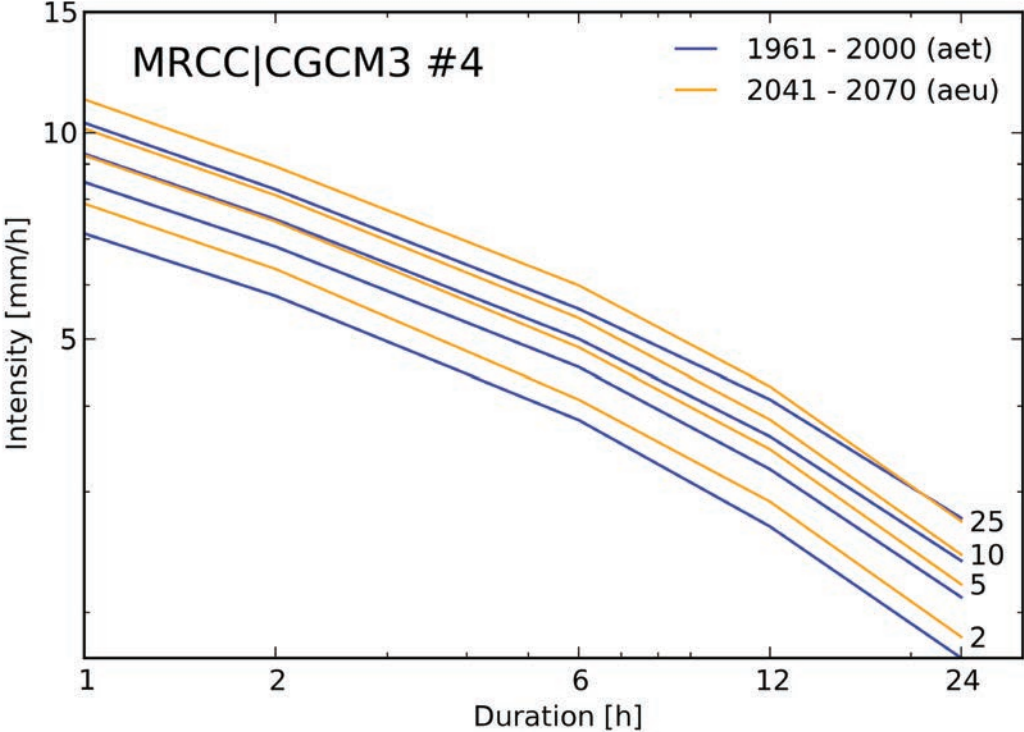



Figure 27 | Intensity-Duration-Frequency curves for the St-Lawrence valley simulated for the present (aet) and future (aeu) climate by the CRCM driven by a global climate model CGCM #4. The lines indicate the intensity for events with four different fixed frequency return intervals (2, 5, 10, and 25 years).
Source: David Huard (Ouranos)

 **What climate information is presented and how should it be interpreted?**

This figure presents the Intensity-Duration-Frequency (IDF) curves for the **reference period** (1961-2000, yellow lines) and the 2050 time **horizon** (2041-2070, blue lines) for the St-Lawrence valley for return periods of 2, 5, 10, and 25 years using a single **simulation** from the Canadian Regional Climate Model (CRCM 4.2.3 driven by the global model CGCM3#4).

The figure shows rainfall intensity (mm/hr) on the y-axis, rainfall duration (hr) on the x-axis, and rainfall frequency (how often rainfall occurs), as the coloured lines. In this case, rainfall durations (accumulation period on the x-axis) are calculated for five durations: 1, 2, 6, 12, and 24 hours. The simulation projects increases in the amount of rainfall accumulated for all four return intensities, particularly for the 6 and 12 hour rainfall events. For the 10 and 25 year return intensities, the accumulation over 24 hours is very similar between the 1961-2000 and 2041-2070 horizons.

 **How is the figure constructed?**

An Intensity-Duration-Frequency curve is a graphical representation of the probability that a given average rainfall intensity will occur. The simulated precipitation for both the reference and future periods are in this case calculated using one CRCM simulation. Such curves are of considerable importance to engineers and others that must design municipal infrastructure to deal with precipitation events.

 **What are the limitations/caveats/possible ways to misinterpret the information?**

It is important to remember that this particular case represents the values for the region of interest (meaning the average of many grid points is shown), which may not adequately represent specific locations. In addition, a single simulation is used and therefore the figure does not showcase the range (**uncertainty**) of a **simulation ensemble**. This is an important limitation for decision-makers as there is no way of evaluating how this simulation compares with others. Thus, relying solely on this single simulation would not be advised.

3. ANALYSIS OF LIMITED CONFIDENCE VARIABLES – THE CHOICE BETWEEN SYNTHETIC SCENARIOS OR CLIMATE MODEL SCENARIOS

There are numerous climatic indices and climate events requested by decision-makers (Table 7) for which the confidence in the climate information that can be provided is limited. Different causes are responsible for this lower confidence. First, the resolution of models may not allow the model to ‘see’ the phenomena (e.g. convective storms); second, the physics behind the phenomena may not be fully understood (e.g. sea ice); third, the inclusion of the equations that represent the phenomena into a climate model may increase the cost of running the simulation by a factor that renders this inclusion prohibitive (e.g. ice storms); fourth, for some indices and events, there is very little available observed data, which prevents an adequate evaluation of the performance of models (e.g. soil moisture); and finally, the information for some indices and events may be available but not at a resolution that suits the needs of users (e.g. atmospheric pressure).

Table 7 | Examples of climate indices or events with limited confidence

INDEX
<i>Wind speed</i>
<i>Ice storm</i>
<i>Humidity</i>
<i>Tropical cyclones (or other storms)</i>
<i>Soil moisture</i>
<i>Atmospheric pressure</i>
<i>Sea ice</i>
<i>Convective storms</i>
<i>Snow on the ground</i>
<i>Droughts</i>
<i>Wave height</i>

Collaboration between the user and climate service provider will be of utmost importance for these variables and caution must be exercised. Indeed, the limitations in either the observations (which would influence the understanding of historical trends) or in the skill of the models (which would influence the reliability of future projections) have to be carefully examined and understood before the data is used by a decision-maker. The confidence will vary greatly depending on the variable of interest and on the study region.

Two methods can be used to evaluate the impacts of future changes in these variables:

- › The first is to rely on climate model simulations, such as what is presented by the formats given in the guidebook, but with a clear understanding that the uncertainties for these variables are important. Nonetheless, the availability of observations for the climate variables identified in Table 7 is increasing along with the understanding of the processes generating them. Consequently, it is expected that our confidence in climate model projections for these lesser known variables will likely increase in the near future.
- › The second is to rely on synthetic scenarios (also often called ‘what-if’ scenarios), where hypothetical futures are derived based on the best available information. Very simply, synthetic scenarios are created by adjusting climate elements incrementally by arbitrary amounts into the future, based on expert judgment. The way in which they are adjusted should be consistent with either GCM outputs or historical climate data³. They can be constructed for climate variables for which we have a high degree of confidence (such as temperature for example) but where resources to run climate models are limited. In such cases, the scenarios will allow a rapid first evaluation of the potential sensitivity of a system. They are particularly useful, however, for cases where the climate index of interest is not well understood at this time or is not well represented by climate models. In such cases, climate scientists develop hypothetical futures based on the best available information.

SYNTHETIC SCENARIO

Table 8 | List of nine what-if (synthetic) scenarios constructed to simulate changes in discharge along the Rivières-des-Prairies, on the North shore of Montreal. Q2 and Q100 represent total annual discharges with a return period of 2 years and 100 years, respectively.

Source: Adapted from Thomas et al. 2012⁵⁴

SCENARIO	PROJECTED CHANGE IN DISCHARGE
1	Q2 years
2	Q2 years +234 m3/s
3	Q2 years +468 m3/s
4	Q2 years +702 m3/s
5	Q100 years + 468 m3/s
6	Q100 years
7	Q100 years + 1000 m3/s
8	Q100 years + 1500 m3/s
9	Q100 years + 2000 m3/s

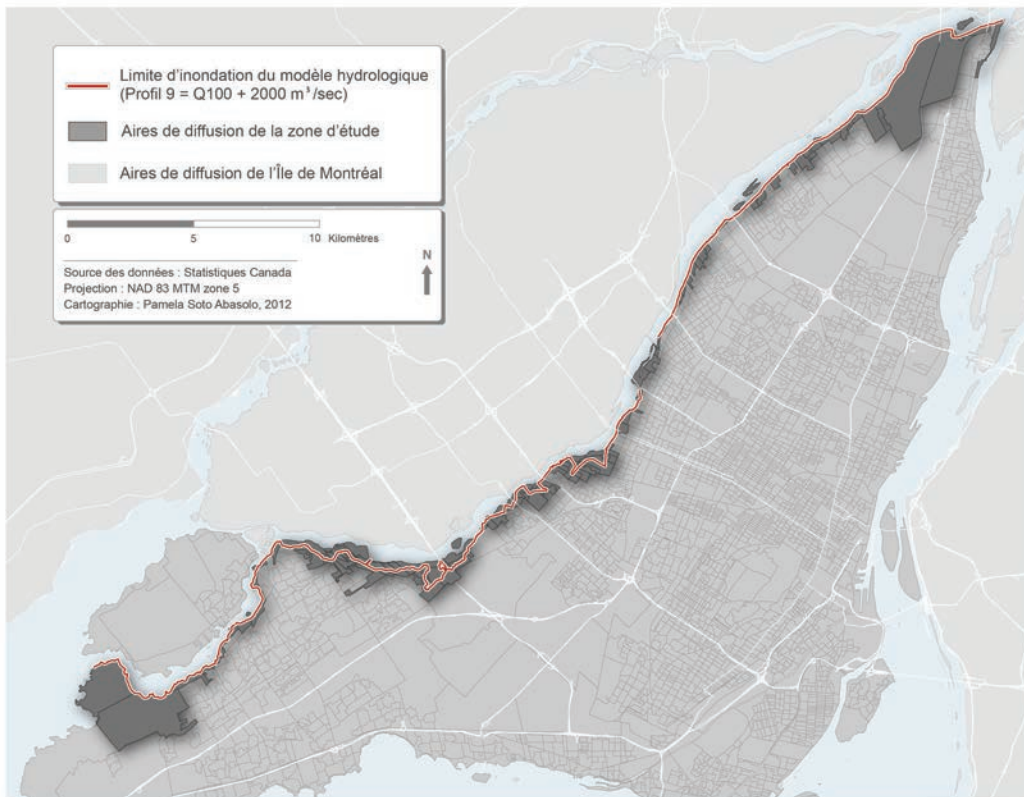


Figure 28 | Extent of flood zone as simulated by synthetic scenario 9, presented in Table 8 (QT100 + 2000m3/s).

Source: Thomas et al. 2012⁵⁴

 **What climate information is presented and how should it be interpreted?**

Table 8 presents nine synthetic scenarios that were derived to simulate increases in river discharge along the North Shore of Montreal Island. Figure 28 presents a map of the maximum area (in pink) that would be affected by a flood of the magnitude simulated by one of the scenarios presented in Table 8, namely a discharge equivalent to Q100 + 2000m³/s.

 **How is the table/figure constructed?**

Nine synthetic **scenarios** of future discharge values were used to simulate a range of flooding events (Table 8). The discharges used were based on hydrological modelling of measured discharge values for the river. Plausible scenarios of increases in discharge were based on both historical discharge values and expert opinions by hydrologists working on the project. Examples of simulated values were: Q2 (maximum discharge with a 2 year return period), Q100 (discharge with a 100 year return), and Q100 + 2000m³/s. Once the scenarios were developed, they were used to project water levels on a digital elevation map of the area of interest. The goal was to model different discharge overflow scenarios in order to identify areas most likely to be submerged (potential flood zones). These scenarios allowed the development of a map of the potential flood zones (e.g. Figure 28) and ultimately permitted a first evaluation of the sensitivity of the populations to increases in future discharge.

 **What are the limitations/caveats/possible ways to misinterpret the information?**

Synthetic scenarios can be a useful approach in evaluating different possible futures in impacts and adaptation studies. Some of the main advantages of this type of scenarios are that they can help identify sensitivities in the system, they are quickly and easily constructed (i.e. do not require major computational resources), and they are typically easy to use and understand. In this case, mapping flood zones needed to be modeled into the future and while the extent of flooding is obviously highly dependent on the discharge of the river, this river is regulated and so water discharge is a complex variable to simulate. This complexity is heightened by climate change. Indeed, while precipitation will explain a large portion of the variability in the discharge, other factors which are more difficult to model may also play a role, such as water uptake from the river upstream of the region of interest and other management decisions regarding flow regulations for example. The decision to use what-if scenarios therefore allowed a first evaluation of potential vulnerabilities of populations along this river.

However, an important disadvantage is that synthetic scenarios may not be physically plausible and may not represent the physical properties of the climate system. For example, some of the future discharge values used may be very large compared to what can actually occur. Synthetic scenarios must therefore be constructed with care with the help of experts and their underlying assumptions must clearly be outlined.





CHAPTER FOUR

DECISION MAKING USING CLIMATE INFORMATION

Understanding climate information is a foundation step in making well-informed decisions in the face of climate change. However, climate information is only one of many aspects that must be considered in a decision-making process. Numerous other factors, such as demographic changes, technological advances and tolerance to risk, to name a few, also play critical roles⁹. While it is beyond the scope of this guide to detail the adaptation decision-making process, key messages relevant to the information presented in this guidebook include:

1. Decision-makers routinely deal with many different sources of uncertainty concerning the future, aside from the fact that the climate or the weather is also changing. Variables such as demographic changes, economic growth and many others, impact the way decisions are made, but do not prevent long-term decisions such as investing in major infrastructure or protecting areas from development. Lessons learned from decision-making in the face of these other uncertainties can help inform the decision-making process under a changing climate.

2. Climate information should never be the sole basis upon which decisions are made but instead must be used in combination with other decision-support tools such as cost-benefit, multi-criteria analyses or hazard mapping tools. Including a range of factors will help ensure that decisions are robust and more readily implemented. Such analysis will help recognize adaptation measures that may be theoretically attractive but that could generate undesired impacts, may not be economically viable or do not have enough public support to be put in place.

3. There is no such thing as the best climate scenario. The range of results obtained from a large number of climate simulations must be used to guide decisions. This spread in climate model results informs the decision-maker on the probable outcomes from worse to best given the current state of knowledge.

One way that the range in climate model results feeds into an effective decision-making framework is through the use of a sensitivity analysis that allows decision-makers to assess the consequences of each alternative future. The goal is to evaluate the impacts associated with the range of different climate scenarios and assess how adaptation measures perform in the face of this range of plausible futures. Different approaches can be used to conduct a sensitivity analysis, such as:

- › estimating the consequences of each alternative future;
- › identifying climate scenarios under which a given policy or adaptation measure would fail and what the consequences might be;
- › using the full range of available scenarios to determine which adaptation measures will perform well regardless of the magnitude or intensity of the expected climate change – these are often referred to as no-regret measures.

Scenario planning represents another way to consider the uncertainties. In this approach, initial common steps are identified for a number of different possible solutions that do not confine the results to only one end point, but rather leave many options open. Critical milestones can be used to reassess the adaptation measures in light of the best available science, and adjustments to plans made as required.

4. Decision-making in a changing world implies that an iterative risk management approach should be prioritized. Decisions must be re-evaluated and adjusted as new knowledge about both climatic and non-climatic variables becomes available. Monitoring and learning should be an important part of the process.





CHAPTER FIVE

CASE STUDIES OF CLIMATE INFORMATION USE IN ADAPTATION

BASIC INFORMATION

Project Title: Regional Climate Summaries Series produced by the Pacific Climate Impacts Consortium (PCIC)

Region: Eight resource regions of British Columbia, namely the Cariboo, Kootenay-Boundary, Northeast, Omineca, Skeena, South Coast, Thompson-Okanagan, and West Coast.

Summary and Application: The summaries were produced with the support of the [BC Ministry of Forestry, Lands and Natural Resource Operations](#), as part of PCIC's ongoing mission to help regional stakeholders in British Columbia plan for projected changes to climate.

The summaries describe climate change projections for each region in the context of historical observations and province-wide climate change. Each summary begins with a brief, general overview of climate change in BC and a short discussion of the topography, climate influences, ecosystems and economies of the region.

The summaries present the historical temperature and precipitation trends of the regions using both summary tables and evolution figures. Projected changes of a number of climatic variables, such as temperature, precipitation, snowfall, growing degree-days, heating

degree-days, and frost-free days, are also given for the 2050 horizon in a table format. These projections are reproduced from Plan2Adapt.ca, PCIC's web platform for basic climate projections.

In addition to highlighting historical trends and the future projections, the summaries also outline key impacts that may be felt by various sectors, infrastructure and ecosystems.

The information presented in the summaries has been used by the Government of British Columbia to present a portrait of the climate to decision-makers and planners of the province. By giving a general overview of the evolution of the climate over the past 100 years and of the projected changes over the next 50 years, the information can be used to start a dialogue about the impacts that have already been felt by different actors of the sector and to begin a reflection on possible future impacts.

Website: <http://www.pacificclimate.org/resources/publications>

Project Title: Rosemont – La Petite-Patrie's zoning bylaw to reduce the urban heat island effect.

Region: Montreal's borough of Rosemont – La Petite-Patrie

Summary and Application: This borough is densely built and subject to significant heat island effects. This phenomenon occurs in cities where ambient air temperatures tend to be hotter than in surrounding areas due to the high percentage of dark surfaces (such as tar roofs and asphalt roads), the amount of heat-retaining (namely concrete) buildings that cool more slowly than the surrounding air, and limited vegetated areas.

In order to combat this problem, the borough council revised its zoning bylaw in April 2011 to include the following four regulatory measures: (1) when replacing an existing roof or constructing a new building, the owner must install either a green roof or a highly reflective roof; (2) for all new parking lots of 10 or more spaces, at least 15 percent of the area must be open

ground landscaped with plants, bushes and trees; (3) all new paving materials must meet a minimum specified surface reflectivity rating; and (4) when constructing a new building, at least 20 percent of the building site must remain open ground and be landscaped with plants, bushes and trees.

This example highlights the fact that complex climate information is not always required in order to implement adaptation measures. Indeed, basic climate information, such as recent past trends and projected changes in temperatures are sufficient in this case to appreciate that the issue of urban heat islands is most likely going to become increasingly important in the future.

Website: http://ville.montreal.qc.ca/portal/page?_pageid=7357,82287591&_dad=portal&_schema=PORTAL See also : Richardson and Otero (2012)⁵⁵

INTERMEDIATE INFORMATION

Project Title: The impacts of climate change on the synchronicity between pests and their natural enemies: implications for the biological fight of the agriculture sector in Quebec.

Region: Southern Quebec

Summary and Application: Researchers involved in this project sought to explore the potential risks of certain crop pests through an evaluation of analogue regions⁵⁶. More specifically, the aim was to identify spatial analogues further south in the United States that corresponded to different administrative regions in Quebec in order to examine which pests were already present in the analogue regions and what adaptation measures had been taken to combat associated problems. The analogues were based on growing season length, growing degree-days, and precipitation during the growing season.

Two main enemies of crops were investigated. The first was the Fusarium head blight (*F. graminearum*), a disease of wheat, which renders the grain unsuitable for human and animal consumption. This disease has been on the rise in southern Canada and has caused important economic losses in many regions⁵⁷. For this disease, it was found that Pennsylvania was a good climate analogue for the Bas-Saint-Laurent region in 2050. Based on this information, researchers have

begun to explore adaptation measures adopted by the state of Pennsylvania, such as relying on different strains that mature at different times throughout the summer, to combat this potential problem in the Bas-Saint-Laurent. The second problem was the corn borer (*O. nubilalis*), an insect that causes important damage to crops of sweet corn, which is destined for human consumption. Regarding this insect, it was found that the climate in the Montérégie may become more similar to the recent climate of Illinois. In this state, the insect has a more rapid growth rate than in Quebec and represents one of the most important sweet corn diseases⁵⁶.

The results of this project initiated a revision of the surveillance strategies and norms in Quebec. The project was the subject of an article in a local Montreal newspaper (La Presse, Allard, June 10, 2013), which serves to illustrate how attractive this analogue format is for communicating the challenges of climate change.

Website: A French copy of the report can be found at: <http://www.ouranos.ca/fr/publications>

Project Title: Planning for climate change adaptation: lessons learned from a community-based workshop.

Region: City of Prince George, British Columbia

Climate information used: Climate normals, climate evolution and trends, graphs and maps of projected future changes.

Summary and Application: The overall goal of this project was to provide an analysis of historical and projected changes in the hydro-climatology for the Prince George region. This information produced by the Pacific Climate Impacts Consortium (PCIC) was meant as a tool to inform the public, municipal officers, planners, and researchers of the potential risks, vulnerabilities and opportunities of climate change in this region⁵⁸.

The city was given information on both historical normals and trends along with future projections for temperature and precipitation. This allowed an analysis of the strong natural climate variability observed in that region, due in part to the effects of El Niño, the Southern Oscillation, and the Pacific Decadal Oscillation. The magnitude of projected changes could then be compared with this variability. The results informed the City of Prince George that important changes in temperature and precipitation were projected, which were likely to have important impacts on many factors, such as flood risks, forest fires, water supply, and transportation infrastructure, to name a few.

This climate information was presented at two workshops in Prince George, which allowed the city officials a valuable opportunity to visualize the information, to digest it and importantly, to address questions directly to the climate scientist who had produced the information⁵⁹. Based on this information, they could then discuss specific impacts and explore adaptation options for the city.

The outcome of these exercises was the development of an adaptation strategy for the City of Prince George, where top adaptation priorities were identified along with potential actions to address them. Workshops and discussions between city officials and climate scientists also helped identify additional climate information and analysis needed to improve city planning, notably in terms of infrastructure and emergency planning.

Website: A copy of the report can be found at: <http://www.pacificclimate.org/sites/default/files/publications/Werner.ClimateChangePrinceGeorge.Aug2009.pdf>

For a copy of a journal article on the project: DOI: 10.1016/j.envsci.2011.12.011

DETAILED INFORMATION

Project Title: Study of storm patterns in Nunavik

Region: Nunavik

Summary and Application: The objective of this study was to evaluate the impacts of climate change on coastal maritime infrastructures for seven villages in the Nunavik region⁶⁰. More specifically, the goal was to study the impacts of storms and oceanic processes on premiums (water levels higher than the predicted tide) and on strong wave development. Both regional and global climate models were used to simulate storm characteristics, such as the number of events, their speed, and their trajectories. Projected changes in these large systems, namely in the periodicity of storm events, are predicted to have important impacts on coastal environments.

Generally, the study results lead to a better understanding of the processes responsible for the creation and maintenance of large systems over Hudson Bay. This includes the links between their occurrences and their impact on the development of waves and premiums, which are responsible for damage to coastal infrastructures.

This study also serves as an example of how results may be valuable to decision-makers despite some obvious limitations, such as the restricted number of climate simulations and associated increased uncertainty. The overall patterns in the changes for example are consistent for all simulations. This in itself is information that decision-makers can retrieve from the study. As for the uncertainties in the projections given, this information can be combined with other information, such as the vulnerability assessments of populations or infrastructures (where for example resilience thresholds can be identified) in order to better evaluate the urgency of putting adaptation measures in place.

Website: A French copy of this report can be obtained by contacting Ouranos.

Project Title: Development of a warning system prototype for low flows and excessive water withdrawals on the Yamaska River watershed

Region: Southern Quebec

Summary and Application: The global objective of the project was to raise awareness of both the public and decision-makers to current low flow vulnerabilities and the misuse of water during summer periods. A second goal was to assess the impacts of climate change on low flows in order to start developing adaptation strategies. The project involved the construction of a website where real-time river discharges and 7-day forecasts can be consulted and compared to low flow indices during the summer period. The project proposed to link each low flow index to a set of water use restriction measures. Selected cities along the Yamaska watershed remain free to implement the restrictions when the flow falls below these indices.

Real-time river flow data are measured by the Centre d'Expertise Hydrique du Québec while the forecast and the low flows indices are based on observed discharge data. The impacts of climate change on future discharges were assessed by importing the outputs of

regional climate models into the hydrological model Hydrotel, an impact model. The results show that longer and more severe low flows are expected for this watershed in the future (over the 2050 horizon, 2041-2070).

This project is a good example of how to introduce climate model data in projects at the municipal government level. While the issue of water management has been an important one for the watershed-based organization of this river, this project is bringing the issue to a larger audience. More specifically, the warning system prototype is used to raise awareness and to make a better use of the resource. The climate change assessment results will be helpful in speeding up the adaptation process on the watershed.

Website: A French copy of this report can be obtained by contacting Ouranos.





GLOSSARY

Adaptation: Initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change impacts.

Adaptive capacity: A system's ability to implement adaptation measures to climate change (including climate variability and extremes).

Aerosols: A collection of airborne solid and liquid particles that reside in the atmosphere for at least several hours. They can be either natural or anthropogenic in origin and may influence the climate in several ways: directly through scattering and absorbing radiation, and indirectly through acting as cloud and ice condensation nuclei which impact the optical properties and lifetime of clouds.

Analogues: Climate analogues are a type of climate scenario constructed by identifying a recorded climate regime that resembles the future climate of a region of interest. The climate regimes can be obtained from the past (temporal analogues) or from another region in the present (spatial analogues).

Anomalies: Anomalies represent the difference between the value of a climate variable for a given year or season and the average value of the reference period.

Baseline: See reference period. A measurable quantity from which alternative outcomes can be estimated.

Boundary organization: Organizations that facilitate the exchange of knowledge between science and policy.

Change fields: See Deltas

Climate adaptation: The process that leads to a reduction in harm or risk of harm, or the realization of benefits, associated with climate variability and climate change.

Climate change: Long-term continuous increase or decrease to climatic variables (such as 30 year averages of temperature and precipitation).

Climate information: This term is used in the guidebook to refer to climatic data that describe either past conditions, obtained from meteorological stations, or the future, obtained from the outputs of climate models.

Climate model: A numerical representation of the climate system based on the physical, chemical, and biological properties of its components, their interactions and feedback processes, and accounting for all or some of its known properties.

Climate normals: The average of weather conditions as obtained from observations for a historical 30-year time interval defines «typical» conditions for a given area. Note that climate normals are typically given for the time span that corresponds to the reference period.

Climate projection: Projections represent the future portion of climate model simulations. They are based on assumptions such as those concerning future socioeconomic and technological developments that may or may not be realized and thus are subject to uncertainty.

Climate scenario: A coherent and internally-consistent description of the evolution in the climate for a given time period in the future, using a specific modelling technique and under specific assumptions about the evolution of greenhouse gas emissions and other factors that may influence the climate in the future. Climate projections serve as the raw material for constructing climate scenarios, but climate scenarios usually require additional information such as observed current climate.

Climate service providers: An organization that supplies climate information to users. The roles of these organizations may include providing historical climate data, running climate simulations, and tailoring their outputs to suit the needs of individual users.

Climate simulation: Climate simulations represent the outcome of running a climate model for a certain period of time. The time span of a simulation can range from a few years to thousands of years and will iteratively be computed at intervals of a few minutes. They are run for both the past and the future.

Climate statistic: Any statistics used to describe the state of the climate system or of one of its components. Examples include mean values, the occurrence or frequency of extremes and standard deviations.

Climate variability: The variations above or below a long-term mean state of the climate. This variability can be due to natural internal processes within the climate system (internal variability) or to variations in anthropogenic external forcing (external variability).

Consensus: The term is used to refer to agreement between models. It represents the proportion of members of a simulation ensemble that 'agree' with the sign (whether positive or negative) of the projected change.

Delta: The relative change for a climate variable between the future and baseline or reference period, as simulated by a climate model.

Downscaling: A method that allows climate model output to be delivered over a finer resolution than the one generally obtained from global climate models. Two different approaches are prioritized: statistical downscaling and dynamical downscaling (see Section 4 for more detail on each method).

Emission scenario: A plausible representation of the future development of emission of substances that are potentially radiatively active in the atmosphere, such as greenhouse gases and aerosols). They are based on assumptions regarding driving forces like demographic and socioeconomic development, or technological change.

Ensemble: The term ensemble is used in this guidebook to refer to the complete set of climate simulations or scenarios that is used for a particular study. It is used synonymously with the term multimodel ensemble. Note, however, that other, more restrictive, definitions exist (for example, an ensemble could represent a set of simulations made with the same climate model, using the same emissions scenario, but initialized using different starting conditions).

Global Climate Model (GCM): Computer model that is a mathematical representation of the climate system, based on equations that drive the physical processes governing the climate, including the role of the atmosphere, hydrosphere, biosphere, etc. It represents a unique tool that helps reproduce a complex ensemble of processes relevant for climate evolution. Note the term Global Circulation Model is often used as a synonym.

Greenhouse gases (GHG): Gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths and that cause the greenhouse effect. Primary greenhouse gases include water vapour (H₂O), carbon dioxide (CO₂), nitrous oxide (N₂O), methane (CH₄) and ozone (O₃).

Grid (grid points): Discrete model «cells» which represent computational units of a climate model. The simplest model grids typically divide the globe (or model domain) into constant angular grid spacing (i.e. a latitude / longitude grid). A climate model's horizontal resolution is often expressed as the size of a single grid cell (e.g. 1° x 1° grid or 10 km by 10 km grid).

Horizon: A future time period of interest over which the outputs of climate simulations are examined or for which future scenarios are produced. The climate science community tends to converge on common time horizons that are recommended by the World Meteorological Organization (WMO). The horizons typically encompass a 30- or 20- year period. For example, horizon 2050 often corresponds to the years 2041-2070.

Index: The term (climate) index is used to refer to properties of the climate that are not measured in the field or calculated by climate models but rather that are calculated or derived from more basic climate variables such as temperature and precipitation. Examples include the number of growing degree-days, freeze-thaw cycles, and the drought code index. (see Variable).

Mitigation: Technological change or substitution that reduces greenhouse gas sources and emissions and that enhance sinks of GHG.

Natural variability: Component of the overall uncertainty that stems from the inherent unpredictability and apparent randomness of the climate. It is characterized by monitoring observations and can be studied by the initial conditions of an ensemble.

No regret (adaptation) option: Adaptation measure that would be the most justified under all plausible future scenarios.

Normals: See Climate normals

Polygon: See Grid

Radiative forcing: The change in the net, downward minus upward, irradiance (expressed in Watts per square metre) at the tropopause due to a change in an external driver of climate change; for example, a change in the concentration of carbon dioxide or the output from the Sun.

Range: The term range is used to represent the spectrum of output data from an ensemble of simulations or scenarios.

Representative Concentration Pathway (RCP): Scenarios that include time series of emissions and concentrations of the full suite of greenhouse gases and aerosols as well as chemically active gases, and land use. The word representative signifies that each RCP provides only one of many possible scenarios that would lead to the specific radiative forcing characteristics. Four RCPs were selected as the basis for the climate projections used in the Fifth Assessment Report published by the IPCC.

Reanalysis: Reanalyses are estimates of historical atmospheric and oceanic temperatures, wind, current, and other meteorological and oceanographic quantities, created by processing past meteorological and oceanographic data using fixed state-of-the-art weather forecasting models and data assimilation techniques. They allow the analysis of numerous climatic variables and are also used to validate RCMs and GCMs in the current climate and to drive RCM simulations.

Reference period: In practice, it often refers to a period of time from the recent past used in the production of climate scenarios. Future period values produced by climate models are compared with those from this period to evaluate changes. The WMO recommends 30-year intervals as reference periods, such as 1971-2000; however there are exceptions. For example, the current reference period used by the IPCC is 1985-2005. A synonymous term is baseline period. Accordingly, the terms 'reference scenario' or 'baseline scenario' are used to refer to climate scenarios for a reference period.

Regional Climate Model (RCM): Just like a GCM, the regional climate model is a mathematical representation of the climate system, based on equations describing the physical processes governing the climate. This includes processes and characteristics of the atmosphere, lithosphere, hydrosphere, cryosphere, and biosphere. RCMs have a finer resolution than (GCMs). RCMs are typically 'limited domain' models meaning that they cover only a portion of the globe.

Resilience: The ability of a social or ecological system to absorb disturbances while retaining the same basic structure and functions, and the capacity to recover from an impact that may have caused harm.

Resolution: In climate models, this term refers to the physical distance (metres or degrees) between each point on the grid used to compute the equations. Temporal resolution refers to the time step or time elapsed between each model computation of the equations. See Grid

Return period: The expected mean time between occurrences that equal or exceed a particular threshold. It is often used to express the frequency of occurrence of an event (freq = 1/return period).

Risk: The likelihood (probability of occurrence) of an event occurring and its impact or consequence where the outcome is uncertain.

Risk assessment: The process by which hazards and consequences are identified, characterized either qualitatively or quantitatively.

Scenario: See Climate scenario

Sensitivity: The change that results (in a variable or a system) from a specific perturbation in a parameter, input or assumption. Climate sensitivity is the degree by which a system would be affected, either beneficially or adversely, by climate-related stimuli (e.g. radiative forcing). For example, the sensitivity of a climate model could be estimated by calculating its projected increases in temperature for a given increase in CO₂ concentration

Scale -Spatial and temporal: Climate may vary on a range of spatial and temporal scales. Spatial scale may range from local (such as a city), through regional (such as a province) to continental or global. Temporal scales may range from monthly, to seasonal to geological for example.

SRES scenarios: The term stands for Special Report on Emissions Scenarios. They are emission scenarios developed by Nakićenovič and Swart (2000) and used, among others, as the basis for some of the climate projections used in the Fourth Assessment Report published by the IPCC.

Synthetic scenario: A way of constructing future climates without relying on climate models. The scenarios are built by adjusting meteorological parameters in a time series by incremental amounts, which are loosely based on either GCM outputs, past climate reconstructions, or expert opinion.

Uncertainty: An expression of the degree to which a value (e.g. the future state of the climate system) is unknown. Uncertainty can result from lack of information or from disagreement about what is known or even knowable. It can have many types of sources, from quantifiable errors in data to ambiguously defined concepts or terminology, or uncertain projections of human behaviour.

Variable: The term climate variable is used to refer to a variable that can be measured directly in the field (at meteorological stations for example) or that is calculated by climate models. (See Index)

Variability: See Climate variability

Vintage: The term vintage is used in the guide to refer to global climate model ensembles that are issued from one particular Coupled Model Intercomparison Project, such as CMIP3 and CMIP5.

Vulnerability: The degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change. It is a function of the character, magnitude and rate of change to which a system is exposed and the sensitivity and adaptive capacity of that system.

References for this glossary:

IPCC, 2013: Annex III: Glossary [Planton, S. (ed.)]. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC, 2014: Annex XX: Glossary [Agard, J., E.L.F. Schipper, J. Birkmann, M. Campos, C. Dubeux, Y. Nojiri, L. Olson, B. Osman-Elasha, M. Pelling, M.J. Prather, M.G. Rivera-Ferre, O.C. Ruppel, A. Sallenger, K.R. Smith, A.L. St. Clair, K.J. Mach, M.D. Mastrandrea, and T.E. Bilir (eds.)]. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Nakićenovič, N., and R. Swart (eds.), 2000: *Special Report on Emissions Scenarios. A Special Report of Working Group III of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 599 pp.



EXAMPLES

OF WHERE TO FIND CLIMATE
INFORMATION

Note that this list is not meant as an exhaustive enumeration of Canadian climate service providers but rather to provide different examples of what can be found on the web. In addition, while the list only includes public providers, we recognize that private organizations can also provide valuable support to users.

Environment Canada

National Climate Data and Information Archive

http://climate.weather.gc.ca/index_e.html

Homogenized climate dataset

This site provides homogenized climate data for many climatological stations in Canada for temperature, precipitation, surface pressure, and wind.

<http://www.ec.gc.ca/dccha-ahccd/Default.asp?lang=En&n=B1F8423A-1>

Canadian Centre for Climate Modelling and Analysis

This site provides information on Canadian global and regional models along with plots of future projections.
www.cccma.ec.gc.ca

Canadian Climate Change Scenarios Network (CCCSN)

This site provides various formats for visualizing future climate scenarios for Canada.
www.cccsn.ec.gc.ca

Recent climate trends

This site summarizes recent climate data and presents it in a historical context.

<http://www.ec.gc.ca/adsc-cmda/>

The Canadian Regional Climate Model (MRCC)

<http://www.ec.gc.ca/ccmac-cccma/default.asp?lang=En&n=82DD0FCC-1>

Pacific Climate Impacts Consortium

Plan2Adapt

This Web site generates maps, plots and data describing projected future climate conditions for British Columbia.

<http://www.plan2adapt.ca/>

Government of Québec – Développement durable, Environnement et Lutte contre les changements climatiques

Climate surveillance

This site provides data on climatic normals (1981-2010), temperature trends (1961-2010) as well as daily climate data for the province of Quebec.

<http://www.mddelcc.gouv.qc.ca/climat/surveillance/index.asp>

North American Regional Climate Change Assessment Program (NARCCAP)

This program is dedicated to the production of high resolution climate simulations over North America.

<http://www.narccap.ucar.edu/about/index.html>



REFERENCES

1. Feenstra, J., Burton, I., Smith, J. B. & Tol, R. S. J. Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies. (1998).
2. Burton, I., Huq, S., Lim, B., Pilifosova, O. & Schipper, E. L. From impacts assessment to adaptation priorities: the shaping of adaptation policy. *Clim. Policy* 2, 145–159 (2002).
3. Carter, T. . General guidelines on the use of scenario data for climate impact and adaptation assessment- Version 2. (2007).
4. Bizikova, L., Neale, T. & Burton, I. Canadian communities' guidebook for adaptation to climate change. Including an approach to generate mitigation co-benefits in the context of sustainable development. (Environment Canada and University of British Columbia, 2008).
5. Pearce, C. Pathways to climate resilience : A guidebook for forest-based communities. (2008).
6. OCCIAR. A Practitioner ' s Guide to Climate Change Adaptation in Ontario ' s Ecosystems. (2011). at <www.climateontario.ca>
7. OCCIAR. Adaptation Planning in Eastern Ontario. (2012). at <www.climateontario.ca>
8. ICLEI. Changing Climate , Changing Communities : Guide and Workbook for Municipal Climate Adaptation. (2010).
9. IPCC. FINAL DRAFT IPCC WGII AR5 Chapter 2. (2014).
10. Smit, B. & Wandel, J. Adaptation, adaptive capacity and vulnerability. *Glob. Environ. Chang.* 16, 282–292 (2006).
11. Willows, R. I. & Connel, R. K. (Eds. . Climate adaptation : Risk , uncertainty and decision-making. (2003).
12. Parson, E. A. Useful global-change scenarios: current issues and challenges. *Environ. Res. Lett.* 3, 5pp (2008).
13. Lemos, M. C. & Rood, R. B. Climate projections and their impact on policy and practice. *Wiley Interdiscip. Rev. Clim. Chang.* 1, 670–682 (2010).
14. Lemos, M. C. & Morehouse, B. J. The co-production of science and policy in integrated climate assessments. *Glob. Environ. Chang.* 15, 57–68 (2005).
15. Lockwood, M., Harrison, R. G., Woollings, T. & Solanki, S. K. Are cold winters in Europe associated with low solar activity? *Environ. Res. Lett.* 5, 024001 (2010).
16. Scaife, A. A., Knight, J. R., Vallis, G. K. & Folland, C. K. A stratospheric influence on the winter NAO and North Atlantic surface climate. *Geophys. Res. Lett.* 32, L18715 (2005).
17. Sutton, R. T. & Hodson, D. L. R. Atlantic Ocean forcing of North American and European summer climate. *Science* (80-.). 309, 115–8 (2005).
18. Intergovernmental Panel on Climate Change (IPCC). Climate Change 2007 : Synthesis Report. Change 446, (Cambridge University Press, 2007).
19. IPCC. CLIMATE CHANGE 2013 The Physical Science Basis. (2013).
20. Intergovernmental Panel on Climate Change (IPCC). Special Report on Emissions Scenarios. (Cambridge University Press, 2000).
21. Intergovernmental Panel on Climate Change (IPCC). Climate Change 2001: Synthesis Report. Summary for Policymakers. Assessment (2001). at <http://www.grida.no/publications/other/ipcc_tar/?src=/CLIMATE/IPCC_TAR/vol4/english/index.htm>
22. Rogelj, J., Meinshausen, M. & Knutti, R. Global warming under old and new scenarios using IPCC climate sensitivity range estimates. *Nat. Clim. Chang.* 2, 248–253 (2012).
23. Knutti, R. & Sedláček, J. Robustness and uncertainties in the new CMIP5 climate model projections. *Nat. Clim. Chang.* 3, 369–373 (2012).
24. Knutti, R., Masson, D. & Gettelman, A. Climate model genealogy: Generation CMIP5 and how we got there. *Geophys. Res. Lett.* 40, 1194–1199 (2013).

- 25.** Markovic, M., Elía, R., Frigon, A. & Matthews, H. D. A transition from CMIP3 to CMIP5 for climate information providers: the case of surface temperature over eastern North America. *Clim. Change* 120, 197–210 (2013).
- 26.** McSweeney, C. F. & Jones, R. G. No consensus on consensus: the challenge of finding a universal approach to measuring and mapping ensemble consistency in GCM projections. *Clim. Change* 119, 617–629 (2013).
- 27.** Sheffield, J. et al. North American Climate in CMIP5 Experiments. Part I: Evaluation of Historical Simulations of Continental and Regional Climatology*. *J. Clim.* 26, 9209–9245 (2013).
- 28.** Sheffield, J. et al. North American Climate in CMIP5 Experiments. Part II: Evaluation of Historical Simulations of Intraseasonal to Decadal Variability. *J. Clim.* 26, 9247–9290 (2013).
- 29.** Gleckler, P. J., Taylor, K. E. & Doutriaux, C. Performance metrics for climate models. *J. Geophys. Res.* 113, D06104 (2008).
- 30.** Hawkins, E. & Sutton, R. The Potential to Narrow Uncertainty in Regional Climate Predictions. *Bull. Am. Meteorol. Soc.* 90, 1095–1107 (2009).
- 31.** Hawkins, E. Our evolving climate : communicating the effects of climate variability. *Weather* 66, 175–179 (2011).
- 32.** Hawkins, E. & Sutton, R. The potential to narrow uncertainty in projections of regional precipitation change. *Clim. Dyn.* 37, 407–418 (2011).
- 33.** Smith, D. M. et al. Improved surface temperature prediction for the coming decade from a global climate model. *Science* (80-.). 317, 796–9 (2007).
- 34.** Cox, P. & Stephenson, D. Climate change. A changing climate for prediction. *Science* 317, 207–8 (2007).
- 35.** Knutti, R. et al. A Review of Uncertainties in Global Temperature Projections over the Twenty-First Century. *J. Clim.* 21, 2651–2663 (2008).
- 36.** Mote, P., Brekke, L. & Duffy, P. Guidelines for Constructing Climate Scenarios. (2007). doi:10.1007/s00703
- 37.** Murdock, T. Q. & Spittlehouse, D. L. Selecting and Using Climate Change Scenarios for British Columbia. *Environment* (2011).
- 38.** Casajus, N. et al. An Objective Approach to Select Climate Scenarios when Projecting Species Distribution under Climate Change. *PLoS One* 1–17 (2016). doi:10.5061/dryad.1sf74
- 39.** Mearns, L. O. et al. Guidelines for Use of Climate Scenarios Developed from Regional Climate Model Experiments. (2003).
- 40.** Themeßl, M. J., Gobiet, A. & Heinrich, G. Empirical-statistical downscaling and error correction of regional climate models and its impact on the climate change signal. *Clim. Change* 112, 449–468 (2011).
- 41.** Mpelasoka, F. S. & Chiew, F. H. S. Influence of Rainfall Scenario Construction Methods on Runoff Projections. *J. Hydrometeorol.* 10, 1168–1183 (2009).
- 42.** Gennaretti, F., Sangelantoni, L. & Grenier, P. Toward daily climate scenarios for Canadian Arctic coastal zones with more realistic temperature-precipitation interdependence. *J. Geophys. Res. Atmos.* 11862–11877 (2015). doi:10.1002/2015JD023890. Received
- 43.** Lu, X. Guidance on the Development of Regional Climate scenarios for Vulnerability and Adaptation Assessments. (2006).
- 44.** Hutchinson, M. F. et al. Development and Testing of Canada-Wide Interpolated Spatial Models of Daily Minimum–Maximum Temperature and Precipitation for 1961–2003. *J. Appl. Meteorol. Climatol.* 48, 725–741 (2009).
- 45.** McKenney, D. W. et al. Customized Spatial Climate Models for North America. *Bull. Am. Meteorol. Soc.* 92, 1611–1622 (2011).
- 46.** Mekis, É. & Vincent, L. a. An Overview of the Second Generation Adjusted Daily Precipitation Dataset for Trend Analysis in Canada. *Atmosphere-Ocean* 49, 163–177 (2011).

47. Ramirez-Villegas, J. et al. Climate Analogues : Finding tomorrow's agriculture today. (2011).
48. Grenier, P., Parent, A.-C., Huard, D., Anctil, F. & Chaumont, D. An Assessment of Six Dissimilarity Metrics for Climate Analogs. *J. Appl. Meteorol. Climatol.* 52, 733–752 (2013).
49. Veloz, S. et al. Identifying climatic analogs for Wisconsin under 21st-century climate-change scenarios. *Clim. Change* 112, 1037–1058 (2011).
50. Williams, J. W., Jackson, S. T. & Kutzbach, J. E. Projected distributions of novel and disappearing climates by 2100 AD. *Proc. Natl. Acad. Sci. U. S. A.* 104, 5738–42 (2007).
51. Kopf, S., Ha-Duong, M. & Hallegatte, S. Using maps of city analogues to display and interpret climate change scenarios and their uncertainty. *Nat. Hazards Earth Syst. Sci.* 8, 905–918 (2008).
52. Ford, J. D. et al. Case study and analogue methodologies in climate change vulnerability research. *Wiley Interdiscip. Rev. Clim. Chang.* 1, 374–392 (2010).
53. Centre d'expertise hydrique du Québec (CEHQ). Atlas hydroclimatique du Québec méridional. 51 (2013).
54. Thomas, I. et al. Analyser la vulnérabilité sociétale et territoriale aux inondations en milieu urbain dans le contexte des changements climatiques, en prenant comme cas d'étude la Ville de Montréal. (2012).
55. Richardson, G. R. A. & Otero, J. Land use planning tools for local adaptation to climate change. (2012).
56. Gagnon, A.-E. et al. Études de cas pour faciliter une gestion efficace des ennemis des cultures dans le contexte de l'augmentation des risques phytosanitaires liés aux changements climatiques. (2013).
57. Chakraborty, S. & Newton, A. C. Climate change, plant diseases and food security: an overview. *Plant Pathol.* 60, 2–14 (2011).
58. Picketts, I. M., Werner, A. T. & Murdock, T. Q. Climate Change in Prince George - Summary of past trends and future projections. (2009).
59. Picketts, I. M. et al. Planning for climate change adaptation: lessons learned from a community-based workshop. *Environ. Sci. Policy* 17, 82–93 (2012).
60. Savard, J. et al. Étude du régime des tempêtes dans le Nunavik. (2013).



.....
CONSORTIUM ON REGIONAL CLIMATOLOGY AND ADAPTATION TO CLIMATE CHANGE