CHAPTER 1: INTRODUCTION

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PREFACE

Climate is changing—rising air and ocean temperatures, shifting precipitation patterns, shrinking glaciers, declining sea-ice extent, rising sea level and changes in extreme events have been observed globally (IPCC, 2013b) and in Canada (Bush et al., 2014). Climate models project that many of the observed trends will continue over the coming decades and beyond, even with aggressive global mitigation efforts (e.g., IPCC, 2013b). Reducing greenhouse gases is necessary to lessen the magnitude and rate of climate change, but it cannot prevent additional impacts from occurring due to the inertia in the climate system. Climate change impacts will continue to present risks and opportunities (Lemmen et al., 2008; Warren and Lemmen, 2014), and Canadians will need to adapt—make adjustments in their activities and decisions in order to reduce risks and moderate harm, or to take advantage of new opportunities.

Although all regions of the country will be affected by climate change, Canada's coastal regions face unique pressures. Changing sea levels, coastal and inland flooding, higher ocean temperatures and reduced sea ice cause a range of severe and often cumulative impacts. Furthermore, climate change stresses are superimposed upon the challenges already facing many coastal communities, including aging demographics, shifting economies and sometimes conflicting priorities regarding land use and development. Living near the coast also means recognizing its dynamic nature and adapting to an environment that is constantly in flux. It is important to understand the risks and opportunities that climate change presents for coastal regions within this context, in order to adapt effectively.

1 CANADA'S COASTS

Canada's coasts, the longest in the world, are a defining element of our national identity. (Mercer Clarke et al., Chapter 3, this volume)

The marine coastline of Canada fronts on three oceans (Atlantic, Arctic and Pacific) and includes major gulfs and bays (e.g., Hudson Bay and the Gulf of St. Lawrence). Canada's coastline, measuring more than 243 000 km, is the longest in world.[1] It extends from latitude 43°N to 83°N and includes landscapes as disparate as coastal rainforests and tundra barrens (Figure 1), as well as tidal ranges that range from negligible to the highest in the world. Canada's coasts are bordered by numerous straits, gulfs and bays, such as the Salish Sea on the southwest Pacific coast and the Bay of Fundy and Labrador Sea on the Atlantic margin. The large mass of northern islands, known collectively as the Canadian Arctic Archipelago, is divided from the mainland coast by a number of large water bodies and numerous interisland channels and straits, including the Northwest Passage.

FIGURE 1: Photos showing the diversity of Canada's marine coasts. East Coast region: **a)** and **b)**, North Coast region: **c)** and **d)**; and West Coast region: **e)** and **f)**. *Photos courtesy of a) J-P. Savard, b) D. van Proosdij, c) N. Couture, d) D. Evans, e) A. Blais Stevens and f) D. Lemmen.*

Coasts are important to all Canadians for their natural resources, beauty, biodiversity and other contributions to society and culture. Coasts have played, and will continue to play, a key role in supporting national, regional and local economies, and in facilitating the flow of imports and exports to meet the needs of people at home and around the globe. Marine ports in Canada annually ship merchandise worth more than $400 billion (Association of Canadian Port Authorities, 2013). Although Canada's coasts are increasingly urbanized, with the diverse economies associated with most modern cities, natural resources (including fisheries and forestry) continue to play an important role in many regions and are particularly sensitive to climate change. Tourism and transportation are other sectors of the coastal economy with high

1 Published values for the length of coastlines vary greatly, depending on the spatial scale at which measurements were taken. Coastal length is a classic fractal example (Mandelbrot, 1967) and, as such, all values are estimates. Values in this chapter are taken from Atlas of Canada (1972).

sensitivity to climate variability and change. Canada's coastal regions also provide ecosystem services that support the well-being of society and individuals (*see* Chapter 3), and that are especially important to many Indigenous peoples.

This report examines the implications of a changing climate in the three marine coastal regions of Canada: East Coast, North Coast and West Coast (Box 1; Figure 2). The boundaries were chosen to best facilitate discussion of the climate change issues facing each region, rather than being strictly based on geographic or political delineations. While the importance of inland freshwater coasts, such as the Great Lakes, is recognized, these are outside the scope of this assessment.

BOX 1
CANADA'S COASTAL REGIONS

The **East Coast region** includes the entire coasts of New Brunswick, Nova Scotia, Prince Edward Island and the island of Newfoundland; the southern coast of Labrador as far north as Hamilton Inlet; and the coast of Quebec that extends along the estuary and Gulf of St. Lawrence, reaching upriver to Québec. The total length of this coastline is approximately 42 000 km, with a coastal population of about 3 million. Important economic sectors include fisheries, aquaculture, transportation, tourism and manufacturing.

The **North Coast region** encompasses the coasts of the three northern territories, as well as Labrador (north of Hamilton Inlet), Manitoba, Ontario and Quebec along Hudson Bay and Hudson Strait. The region includes 176 000 km of coastline, representing more than 70% of Canada's marine coasts, but is sparsely populated by about 70 000 people. All but one of the 25 communities in Nunavut are located on the coast, and centres such as Inuvik, NT, Iqaluit, NU and Kuujjuaq, QC provide important regional services, including the import and export of goods. Sea ice and permafrost have a strong influence on northern coasts and livelihoods.

The **West Coast region** includes 26 000 km of coastline, all within the Province of British Columbia. The population of coastal British Columbia is approximately 3.5 million, concentrated largely in the lower mainland (Greater Vancouver) and southwestern Vancouver Island. In an analysis of current (2005) assets exposed to climate extremes, Vancouver was ranked 15th most vulnerable among all global port cities, with exposed assets of more than $55 billion (Nicholls et al., 2008), by far the greatest in Canada. Although the provincial economy is diverse, the economies of many small coastal communities remain strongly tied to fishery, forestry and tourism activities.

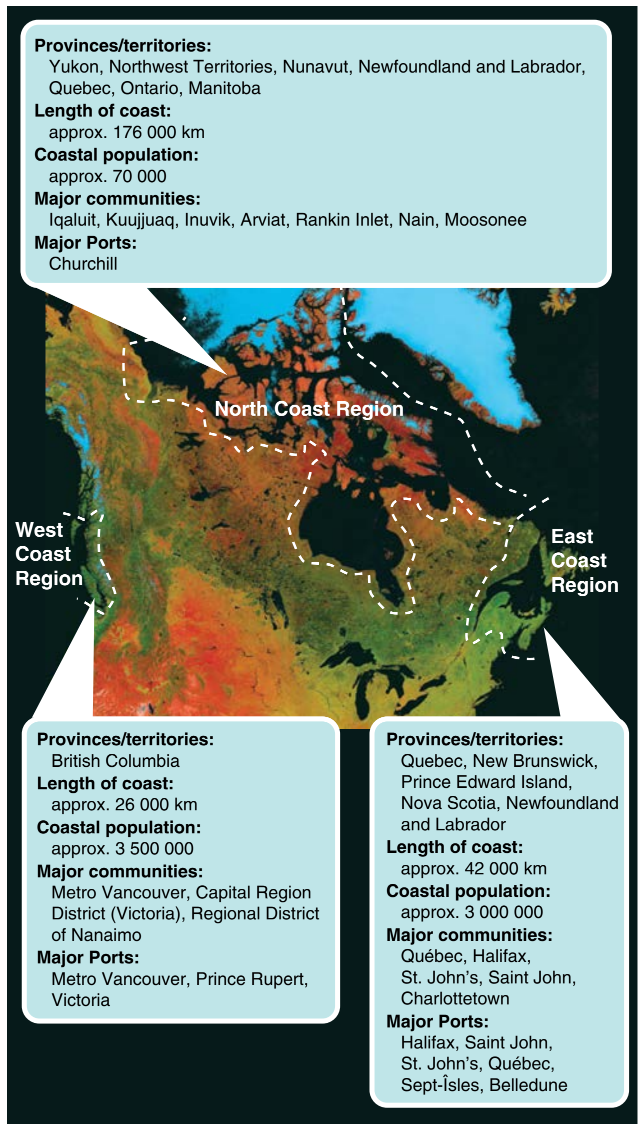

FIGURE 2: Canada's marine coasts, broadly delineating the three regions discussed in this report.

DEFINING COASTS – A LANDSCAPE APPROACH

Derived predominantly from fisheries management and international marine law, the coast is often described as a zone or area along a shoreline, largely marine in focus, whose landward boundary is either determined by the highest anticipated inland intrusion of seawater or designated as a specified distance from the shore, and whose marine boundary extends to the limits of national territorial seas (i.e., 12 nautical miles [nm] seaward from the shore). More integrated (landscape-scale) approaches to coastal management take a broader view of coasts that acknowledges the linkages among terrestrial, aquatic and marine ecosystems, transcends jurisdictional and disciplinary boundaries, and improves understanding (and management) of human-environment interactions and of long-term coastal change (Figure 3; UNEP-GPA, 1995; Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection and Advisory Committee on Protection of the Sea, 2001; Mercer Clarke, 2010).

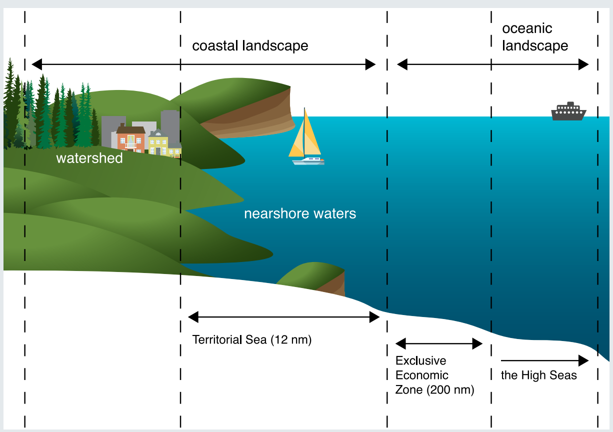

FIGURE 3: The coastal landscape (*modified from* Mercer Clarke, 2010). Abbreviation: nm, nautical mile (22.2 km).

Working at a landscape scale provides opportunities for the collaborative development of new insights and for the effective planning and management of coastal environments (Bekkby et al., 2002; Stewart and Neily, 2008). It also eliminates the need for defined coastal boundaries. This assessment recognizes the importance of this broader perspective in the development of strategies and measures to address climate change. Although the primary focus of the report remains the shoreline, as the interface between land and water, the scope of the report extends landward and oceanward to the extent that such territory affects the sustainability and well-being of coastal communities and ecosystems.

2 CHANGING CLIMATE

> *Warming in the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia.* (IPCC, 2013b)

International and national science assessments have concluded unequivocally that the climate is changing (e.g., IPCC, 2013b; Melillo et al., 2014; Warren and Lemmen, 2014; *see* Chapter 2). Coasts in Canada are already experiencing escalating changes related, in part, to shifting climate and/or changes in severe weather events (Lane et al., 2013). Rising sea level, warming air and water temperatures, storms of greater intensity and reduced sea ice are some examples of the environmental shifts that coastal regions are facing (*see* Chapter 2). These changes will affect regions and communities in different ways, depending on the physiography of the coastline, exposure to wind and waves, presence of natural and built protection (e.g., beaches, dunes, marshes, seawalls, dikes and breakwaters), proximity of the built environment to hazardous conditions, and local preparedness (e.g., Boateng, 2008; Simpson et al., 2012).

While the rate, scope and nature of impacts will vary with location, there are some commonly identified issues, including effects on coastal ecosystems (e.g., wetlands and aquatic ecosystems), infrastructure (e.g., transportation, water supply and discharge, and buildings) and economic sectors (e.g., fisheries, natural resources and tourism). Although emphasis is commonly placed on the risks associated with climate change, there will also be opportunities. Table 1 provides examples of climate-related risks and opportunities for sectors of importance to Canada's coasts, as identified in previous national-scale assessments in Canada.

Comparatively little is known about the economic costs associated with a changing climate along Canada's marine coasts. A national-scale analysis estimated that the cost of flooding of coastal dwellings (only one of many climate change impacts of concern) could be $4–17 billion per year by the middle of this century (National Round Table on the Environment and the Economy, 2011). The significance of economic impacts varies regionally. For example, the *National Round Table on the Environment and the Economy* study noted that, in terms of percentage of total land area, Prince Edward Island's coastal areas are at the most risk, whereas the number of dwellings impacted will be greatest in British Columbia and the per capita costs of dwellings damaged will be greatest in Nunavut.

TABLE 1: Examples of climate change impacts (by sector) in Canada's coastal regions (*from* relevant regional chapters of Lemmen et al. [2008] and sectoral chapters of Warren and Lemmen [2014]).

Sector	Climate-related risks and opportunities
Infrastructure	▪ Risks associated with coastal erosion, storm-surge flooding and sea-level rise, and wind ▪ Failure of dikes and other protection structures, increased construction and maintenance costs
Transportation	▪ Increased maintenance costs of ports, coastal roads and railroads, traffic disruption and delays ▪ Increased marine traffic in the North due to decreased sea-ice
Fisheries	▪ Higher water temperatures and increased acidity that will affect species distribution and ecosystem health, including fish reproduction and distribution ▪ Increasing impacts from invasive species ▪ Potential increase in total biomass of production from wild-capture fisheries
Tourism	▪ Increased duration of warm-weather recreation season ▪ Decreased duration of cold-weather recreation season ▪ Risks to infrastructure and safety associated with extreme weather events
Energy	▪ Seasonal shifts in energy demand: increased summer cooling, decreased winter heating ▪ Risks to energy transmission infrastructure from extreme weather events ▪ Risks to offshore production facilities due to increased storminess and changes in ice risk
Forestry	▪ Increased forest disturbance related to pests, disease and fire ▪ Changes in forest composition and potential for increases in productivity
Mining	▪ Increased risks to transportation infrastructure ▪ Changes in sea-ice conditions that could improve marine access to northern mine sites
Agriculture	▪ Increased duration of growing season ▪ Groundwater salinization as a result of sea-level rise and pumping ▪ Changes in agricultural pests

3 ADAPTATION – PREPARING FOR CHANGE

> *Planning by coastal communities that considers the impacts of climate change reduces the risk of harm from those impacts. In particular, proactive planning reduces the need for reactive response to the damage caused by extreme events. Handling things after the fact can be more expensive and less effective.* (Wong et al., 2014)

Adaptation to climate change is defined as "the process of adjustment to actual or expected climate and its effects" (IPCC, 2014b). Adaptation is needed both to reduce the risks and to benefit from potential opportunities associated with changing climate. There are many different approaches to adaptation, including behavioural changes, operational modifications, technological interventions, planning changes and revised investment practices, regulations and legislation (Warren and Lemmen, 2014). While adaptation in the natural environment occurs spontaneously, adaptation in human systems often requires careful planning and collaboration that are guided by both scientific research and detailed understanding of the systems involved. This guidance is especially important in coastal regions, where there are many actors involved, and the potential for maladaptation (actions that inadvertently increase vulnerability to climate change) is high.

Because adaptation involves changes in both thinking and process, it is by necessity an iterative process that is continually evolving, informed by new understanding, changing socio-economic conditions and practical experience. For example, adaptation choices and effectiveness will be influenced in many cases by the success of mitigation efforts (Box 2).

Specific objectives of adaptation processes can include building awareness and capacity, mobilizing resources, and assessing and implementing options (Figure 4; Eyzaguirre and Warren, 2014). Effective adaptation measures will not only enhance climate resilience, but can contribute to other policy priorities, such as emergency preparedness and economic diversification (Box 3). Indeed, the concept of mainstreaming, advocated by Canada's Federal Adaptation Policy Framework, involves consideration of climate change as one of many factors in all relevant processes, such as policy development, planning exercises and decision-making.

BOX 2
ADAPTATION AND MITIGATION

Although adaptation and mitigation (the reduction of greenhouse gas emissions and enhancement of greenhouse gas sinks) are sometimes portrayed as distinct responses to climate change, they are inextricably linked. The success of mitigation directly affects the need for adaptation, as well as the viability of different adaptation options. Mitigation reduces both the magnitude and the rate of climate change. The greater the reductions in greenhouse gas emissions, the greater the potential for successful adaptation.

For example, scenarios presented in the most recent report of the Intergovernmental Panel on Climate Change (IPCC, 2013b) include a range of plausible futures where mean global surface temperature is likely to increase by 0.3–4.8°C for the period 2081–2100 (relative to the 1985–2005 mean), with associated rises in global sea level of 0.26–0.82 m. Lower increases in temperature are associated with very ambitious greenhouse gas mitigation and would lead to reduced amounts of sea-level rise that would require less investment in adaptation. This relationship becomes even more important when one considers that sea level will continue to change beyond the current century. Although ambitious greenhouse gas mitigation in the coming decades can limit global sea-level rise to about 1 m during the next 500 years, scenarios with only limited mitigation efforts could result in global sea level rising by 1 m to more than 3 m by the year 2300 (Church et al., 2013).

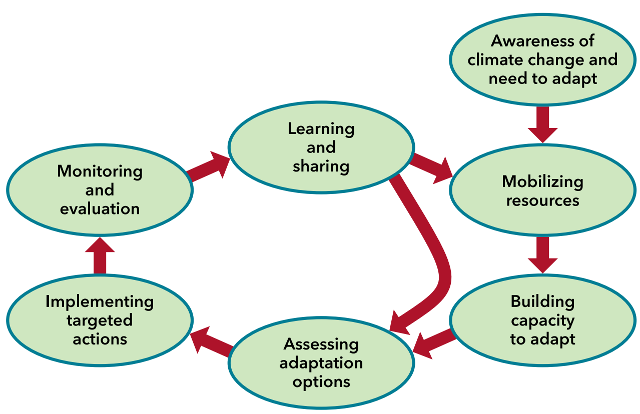

FIGURE 4: The iterative process of adaptation (*modified from* Eyzaguirre and Warren, 2014).

CONFIDENCE AND UNCERTAINTY

Planning for any future activity inevitably involves some degree of uncertainty. The global scientific assessments of the IPCC use predefined terminology to express uncertainty in terms of likelihood, based upon either statistical analysis or expert opinion (IPCC, 2014b, p. 6). In this assessment, we use common-sense language to convey likelihood, rather than using statistically defined terms. This approach is used because it is rare to have quantitative data on the probability of impacts at the national scale, so there is a strong reliance on the expert opinion of the author teams.

Similarly, while other assessments adopt predefined terminology for depicting scientific confidence in findings, this report uses common-sense language. Confidence is greatest where projected impacts are consistent with impacts observed in historical trends and/or where a number of studies have independently arrived at similar conclusions.

Recent years have seen a rapid expansion in literature on the topic of adaptation (Burkett et al., 2014). A number of specific approaches have proven useful in coastal settings globally, including community-based adaptation and ecosystem-based adaptation (Shaw et al., 2014; Wong et al., 2014), with a common goal of enhancing resilience. The most appropriate approaches to adaptation will be location and context specific. In Canada, including along the coasts, there has been a strong focus on adaptation at the community scale (Eyzaguirre and Warren, 2014). The value of ecosystem-based approaches, which involve the use of biodiversity and ecosystem services as part of an overall adaptation strategy, is increasingly recognized in Canada as a means to address some coastal issues (*see* Chapters 3, 4 and 6).

There are also many ways of classifying adaptation actions to address climate change impacts along coasts. In scientific and technical literature, it is common to group coastal adaptation, particularly with respect to addressing sea-level rise and coastal flooding, into four categories (*see* Chapter 3): no active intervention; accommodation; protection (hard and soft measures); and avoidance or retreat. In reality, most coastal adaptation strategies are likely to involve several, and perhaps all, of these groups of actions.

BOX 3

PRINCIPLES FOR EFFECTIVE ADAPTATION

(IPCC, 2014b, p. 25–28)

The *Summary for Policymakers* of the Working Group II (Impacts, Adaptation and Vulnerability) contribution to the IPCC Fifth Assessment Report highlights a number of broad principles that underlie successful adaptation. Those of direct relevance to the issues discussed in this report include the following:

- Adaptation is place and context specific, with no single approach for reducing risks appropriate across all settings.
- Adaptation planning and implementation can be enhanced through complementary actions across levels, from individuals to governments.
- A first step toward adaptation to future climate change is reducing vulnerability and exposure to present climate variability.
- Effective adaptation strategies include actions with co-benefits for other objectives.
- Adaptation planning and implementation are contingent on societal values, objectives and risk perceptions.
- Existing and emerging economic instruments can foster adaptation by providing incentives for anticipating and reducing impacts.
- Poor planning, overemphasizing short-term outcomes or failing to sufficiently anticipate consequences can result in maladaptation.

4 SCOPE AND FORMAT OF THE REPORT

This assessment, *Canada's Marine Coasts in a Changing Climate*, discusses current and future risks and opportunities that climate change presents to coastal regions of Canada. It highlights what we know regarding vulnerability and the key issues facing each coastal region, with the goal of being a policy-relevant resource to inform regional and national decision-making on coastal management and the development of climate change adaptation strategies. The assessment is based on a critical analysis of existing knowledge, drawing from the published scientific and technical literature (peer-reviewed and 'grey' literature), and from expert (including traditional) knowledge. Although emphasis is on studies conducted within Canada, international sources are incorporated as appropriate. Ecosystem impacts and adaptation, noted in all chapters, are discussed primarily in the context of ecosystem services and the fisheries sector. Key concepts mirror those of past Canadian (Lemmen et al., 2008; Warren and Lemmen, 2014) and international (IPCC, 2014b) assessments of climate change impacts and adaptation. Key terminology is presented in Box 4.

The report is structured by region, with the main chapters of the assessment providing regional perspectives on Canada's East Coast, North Coast and West Coast regions (Chapters 4–6). Each of these chapters provides regional context, then discusses observed and projected climate changes in the region, and climate change risks, opportunities and adaptation approaches. Case studies are used to provide more detail on selected issues, to highlight examples of effective adaptation initiatives and to identify transferable lessons learned. In recognition of the significant differences between the regions, the regional chapters do not follow a common template.

In addition to this 'Introduction', there are two supporting chapters. 'Chapter 2: Dynamic Coasts in a Changing Climate' provides an overview of the diversity and dynamic nature of Canada's marine coasts, discussing past and projected climate change, sea-level change and the impacts and implications of changing mean and extreme water levels. 'Chapter 3: The Coastal Challenge' discusses how ongoing and projected changes may affect coastal environments and coastal societies, and provides an overview of approaches to adaptation, outlining how they are being used along Canada's coastlines. The report concludes with 'Chapter 7: Frequently Asked Questions', which builds on the content of the other chapters, to provide an easily accessible resource that explains, in plain language, the main climate change issues facing Canada's coastal regions.

BOX 4

KEY TERMINOLOGY IN THIS REPORT

(*modified from* IPCC, 2013a, 2014a, p. 5)

Adaptation is the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm, or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects.

Adaptive capacity is the ability of systems, institutions, humans and other organisms to adjust to potential damages, to take advantage of opportunities, or to respond to consequences.

Climate change refers to a change in the state of the climate that can be identified (e.g., using statistical tests) by changes in the mean and/or variability of its properties, and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or human activity.

Climate variability refers to variations in the mean state and other statistics (such as standard deviations and the occurrence of extremes) of the climate on all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system or to variations in natural or anthropogenic external forcing.

Ecosystem services are ecological processes or functions having monetary or nonmonetary value to individuals or society at large. These are frequently classified as 1) supporting services, such as productivity or biodiversity maintenance; 2) provisioning services, such as food, fibre or fish; 3) regulating services, such as climate regulation or carbon sequestration; and 4) cultural services, such as tourism or spiritual and aesthetic appreciation.

Exposure refers to the presence of people, livelihoods species or ecosystems; environmental functions, services and resources; infrastructure; or economic, social or cultural assets in places and settings that could be adversely affected.

Hazard is the potential occurrence of a natural or human-induced physical event or trend, or physical impact that may cause loss of life, injury or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources.

Impacts are effects on natural and human systems. The term 'impacts' is used primarily to refer to the effects on natural and human systems of extreme weather and climate events, and of climate change. Impacts generally refer to effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period, and the vulnerability of an exposed society or system. Impacts are also referred to as 'consequences' and 'outcomes'. The impacts of climate change on natural physical systems, including precipitation regimes (e.g., floods, droughts) and the global hydrological cycle (e.g., sea-level rise), are a subset of impacts called physical impacts.

Maladaptation are actions that may lead to increased risk of adverse climate-related outcomes, increased vulnerability to climate change or diminished welfare, now or in the future.

Resilience is the capacity of social, economic and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure, while also maintaining the capacity for adaptation, learning and transformation.

Risk is the potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. Risk results from the interaction of vulnerability, exposure and hazard.

Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate variability or climate change. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range or variability of temperature) or indirect (e.g., damage caused by an increase in the frequency of coastal flooding due to sea-level rise).

Storm surge is the temporary difference between the expected water level and that experienced at a particular location due to meteorological conditions, especially atmospheric pressure. Strong onshore winds and low atmospheric pressure can cause a positive storm surge that brings water levels higher than expected. Strong offshore winds and high atmospheric pressure can cause a negative surge that brings water levels lower than expected.

Uncertainty is a state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from imprecision in the data to ambiguously defined concepts or terminology, or uncertain projections of human behaviour.

Vulnerability is the propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

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