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ECOSYSTEM OVERVIEW:

PACIFIC NORTH COAST INTEGRATED MANAGEMENT AREA (PNCIMA)

APPENDIX B: METEOROLOGY AND CLIMATE

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1.0 INTRODUCTION

British Colombia's coastal climate and weather conditions are a direct result of its position between the northeast Pacific Ocean and the Coast Mountains. Winds are dominated by the Aleutian Low in winter and the North Pacific high in summer. This means that winter storms absorb great amounts of moisture as they track eastward toward the British Columbia (BC) coast. Much of this moisture falls as precipitation when it hits the Coast Mountains, making BC's coast the wettest place in Canada. The positions of the air pressure systems often cause winter storms to hit the central and north coast of BC more frequently than the southern coast. This results in the highest rainfall totals occurring within the PNCIMA area.

The ocean also moderates temperatures, with the winter storm winds transporting heat across the central Pacific in winter and northwest summer winds bringing relatively cooler air masses onto the coast. These air pressure systems and their winds also drive ocean circulation, which controls the source, and thus temperature, of water off the BC coast.

Variations in climatic conditions strongly affect ecosystems. Most obvious is the seasonal variation that controls such things as the spring phytoplankton bloom, timing of peak stream flow, ocean wave intensity and ocean current strength. However, the variation between years and decades for a given season is of great significance as these conditions can strongly affect the timing of ecosystem functions, which can be critical to the success of various biota. El Niño events, for example, transport warm waters and their biological community northward to the BC coast, creating competition between indigenous and invasive organisms. There is an increasing focus in research on understanding how climate variability affects the ecosystem and whether that variability can be predicted.

1.1 Key Points

- The proximity of the Pacific Ocean moderates BC's coastal climate, producing relatively warm winters and cool summers compared to the interior of British Columbia. The position and strength of two large scale pressure systems over the northeast Pacific control much of the specific conditions of BC weather and climate. The Aleutian Low tends to dominate our winters. Storms track along its southern edge across the Pacific bringing warmth and abundant rain to the BC and Alaskan coasts. The North Pacific High dominates our summers and tends to deflect storms northward during this time. These pressure systems and their associated winds also drive the main ocean circulation patterns of the northeast Pacific (see Appendix C: Physical and Chemical Oceanography).
- The presence of the Coast Mountains produces very high rainfall on their coastal side (rainiest area in Canada), particularly along the north and central mainland

coast. Areas in the rain shadow of the coastal mountains receive significantly less rainfall.

- Climate variability is a critical factor in ecosystem function. It operates on a wide range of time scales, the most relevant of which are seasonal, interannual, interdecadal, and the climate change scale (10 to 100 yr).
- Warming of the earth's atmosphere and ocean (climate change) has been observed over the past century and is accelerating. This trend will have major effects on ecosystems.

1.2 Uncertainties, Limitations, and Variability

- Climate prediction on all time scales is difficult. Part of the problem is a lack of data gathered over and in the Pacific Ocean. The complexity of ocean-atmosphere systems and their interaction also prevents sufficient understanding for accurate predictions, although new observational programs are improving climate models through the collection of near real time oceanographic data. Thus, although it is known that climatic conditions are critical to ecosystem function, and that they vary significantly on various time scales, predictive capabilities need to be improved.
- Climate variability at various time scales is discussed in detail in section 4.0.

1.3 Major Sources of Information or Data

- The Meteorological Service of Canada (division of Environment Canada) collects and archives all meteorological information for Canada and provides weather forecasts and reports. They also conduct research on a variety of topics including climate, atmospheric science, and air quality. Victoria is the home of the Canadian Centre for Climate Modelling and Analysis (CCCma) of Environment Canada, which does significant work towards our understanding of climate variability and climate change.
- The Intergovernmental Panel on Climate Change (IPCC) has produced a number of reports relating to the evidence for, potential affects of, and possible reaction to climate change (http://www.ipcc.ch/). Reports on more local impacts and adaptations include work by the Canadian Climate Impacts and Adaptation Network (http://www.c-ciarn.ca/index_e.asp) as well as work by individual agencies (Fisheries and Oceans Canada *eds*. 2000; Bell *et al.* 2001; BC MWLAP 2002; Air & Waste Management Association 2003).
- An excellent summary of BC marine weather for the general reader is 'Living with the weather along the British Columbia coast: the veil of chaos' (Lange 2003).
- A detailed summary of BC climatology can be found in the World Survey of Climatology (Hare and Hay 1974). Brief summaries are found in a number of

broad topic reports (Scudder and Gessler *eds*. 1989; Ricker and McDonald 1992; Ricker and McDonald 1995; Hood and Zimmerman *eds*. 1986; Jacques Whitford Environment Limited 2001; Hall *et al.* 2004; Chevron Canada Resources Ltd. 1982; Petro-Canada 1983).

1.4 Identified Knowledge and Data Gaps

- Modelling of climate and coupled climate-ocean conditions is limited both by computing capacity (most of these efforts require supercomputers), and by a lack of monitoring data, especially over and within the Pacific Ocean. Advances in this area will improve climate prediction capabilities.
- A recent analysis was made of BC's climate observation capacity. The 'Review of the Adequacy of Climate Related Observation Networks' (M. Miles and Associates 2003), found that according to World Meteorological Organization standards, BC is severely lacking in climate and stream gauging, sediment discharge stations, and climate station density and is somewhat lacking in monitoring of evaporation, hydrometric networks and snow course density monitoring. Deficiencies are most common in areas that are remote, high elevation, or have small watersheds. This would describe most of the PNCIMA area. These deficiencies are specifically discussed in terms of the ability to verify and support climate modelling efforts.

2.0 WINDS AND PRESSURE SYSTEMS

The climate and weather conditions of the BC's coastal regions are largely governed by two Pacific Ocean air masses, as well as by the frequent west-to-east passage of cyclonic weather systems (most frequent from October through May), and the presence of large mountain belts parallel to the coast. It is one of the windiest areas of Canada: Cape St. James (at the southern end of the Queen Charlotte Islands, Figure B.0) holds the Canadian record for having the largest number of days each year (120 on average) with gale force winds. The strongest hourly winds measured in British Columbia (77 knots) were recorded at Bonilla Island on 20 February 1974 (Phillips 1990).

The two Pacific Ocean air masses are the Aleutian Low and the North Pacific High (Figure B.1). They not only influence the winds, air temperature, air moisture, and storm tracks in the region, but they drive the main surface currents of the North Pacific, which strongly control the sea surface temperature and other oceanographic conditions (described in Appendix C: Physical and Chemical Oceanography). These pressure systems vary seasonally (as described below) and they vary in intensity from year to year (Hamilton 1984), often making them the root cause of inter-annual fluctuations in the wind, forcing corresponding variations in the North Pacific wind-driven surface currents and associated climatic and oceanographic parameters.

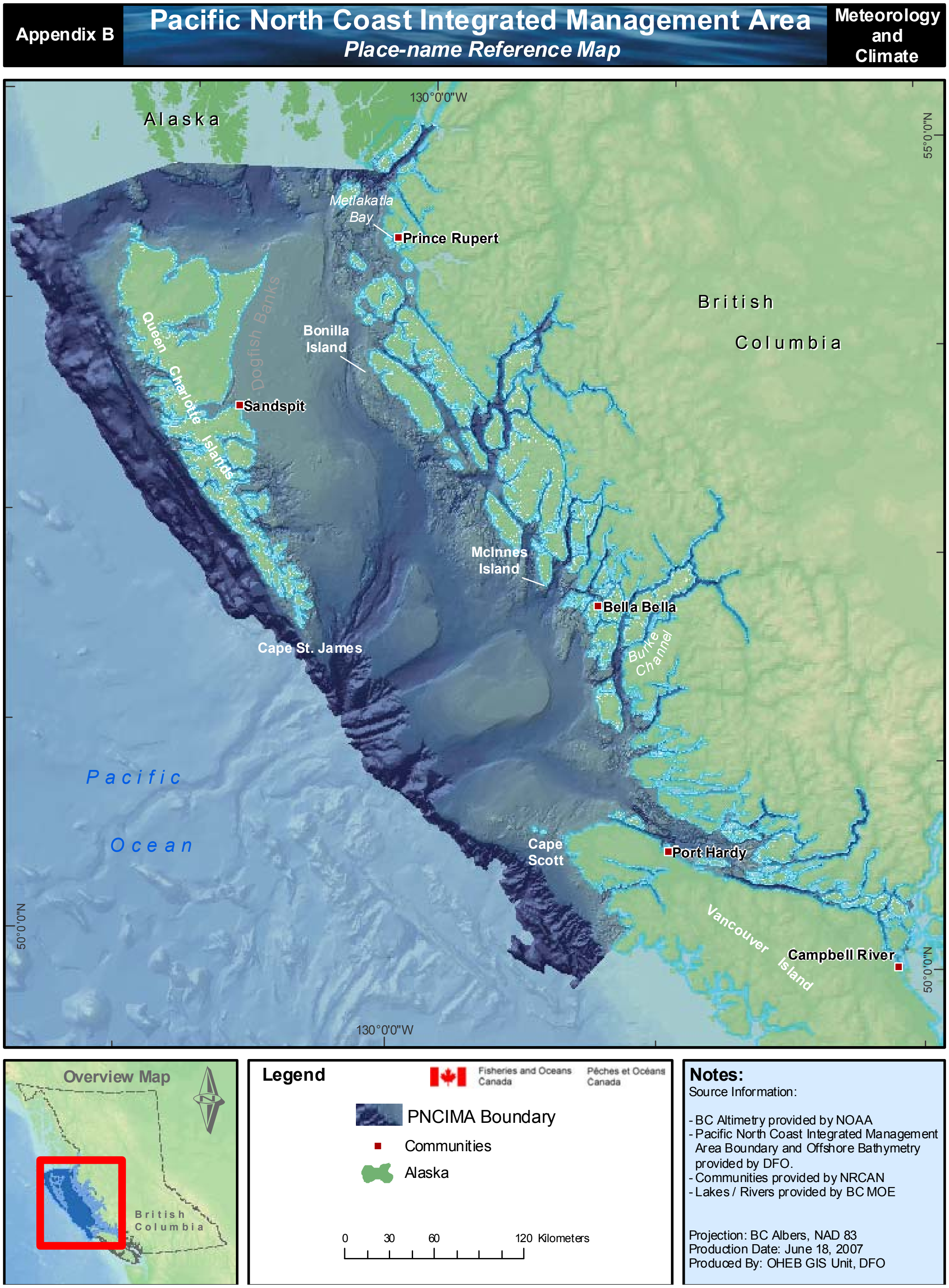

Figure B.0 PNCIMA region showing locations and features of BC waters.

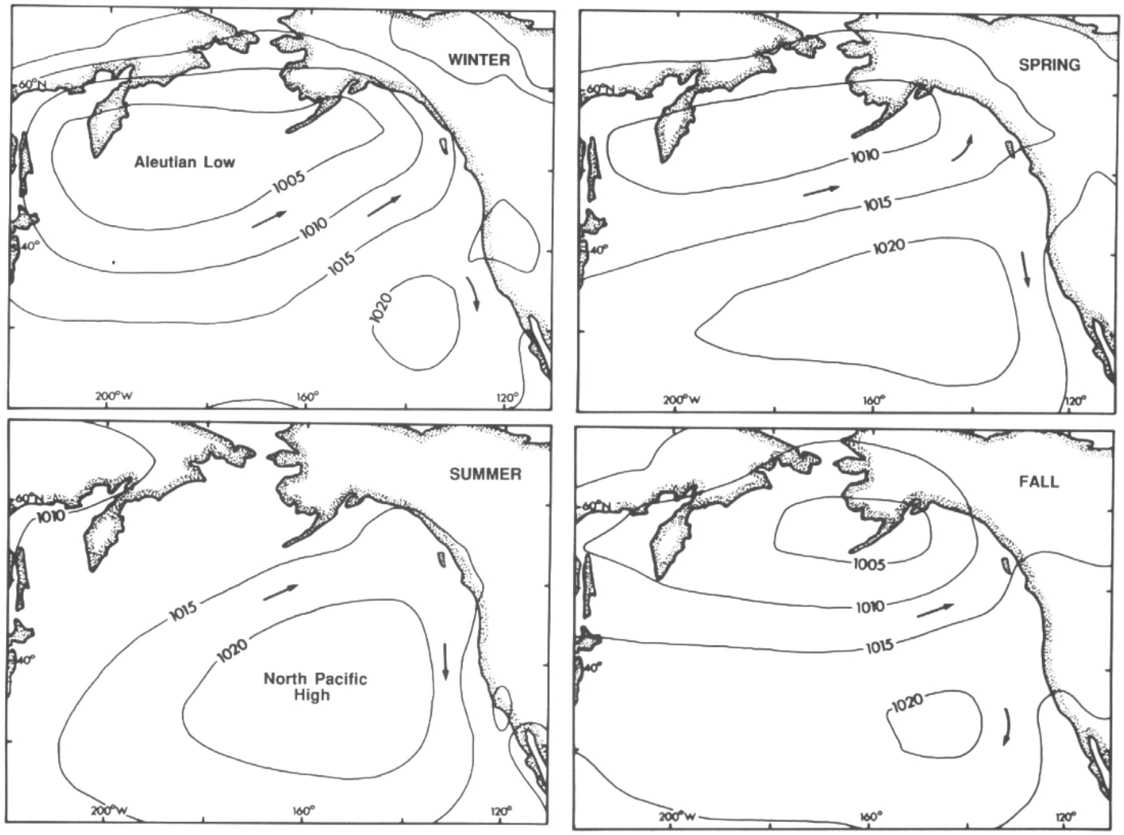

Figure B.1 Seasonal atmospheric pressure patterns (millibars), 1947-82 (from Thomson *et al.* 1989; Thomson 1989; Thomson and Tabata 1989, after Hamilton 1984).

During winter, a quasi-permanent low-pressure system, the Aleutian Low, dominates the North Pacific weather patterns (Figure B.1 top left). The average counter-clockwise flow around the Aleutian Low and the presence of the Coast Mountains results in mostly southeasterly winds along the BC coast. These extra-tropical cyclonic systems cross the North Pacific Ocean as two reasonably distinct storm tracks, one originating from the Kamchatka Peninsula of Russia and the other from southern Japan (Lambert 1988).

Raible *et al*. (2006) investigated the behaviour of the Aleutian Low in climate and proxy records as well as in global climate models. They found the intensification of this low from the year 1950 to 2000 was unlike its behaviour in the previous 500 years, and related this behaviour to climate warming.

Rapidly developing extra-tropical cyclones are more likely to impact the BC coast than other areas in Canada, with the exception of the Canadian Atlantic coast. These 'Coastal Low' weather systems are characterized by a rapid and sustained decrease in central air pressure and intensified wind speeds, and often by increased precipitation. These storms travel quickly and can be hazardous to marine operations. Winds up to 70 knots (gusts to 100 knots) are generated to the east and southeast of the Low. Over a typical winter, about 17 such storms develop and affect the British Columbia coastal area (Stewart *et al.* 1995). Gale force winds at Cape St. James are usually a precursor to the arrival of similar winds along the north and central mainland coast about 24 hours later. Figure B.2 shows a pressure pattern typical of a Coastal Low (Environment Canada 1992).

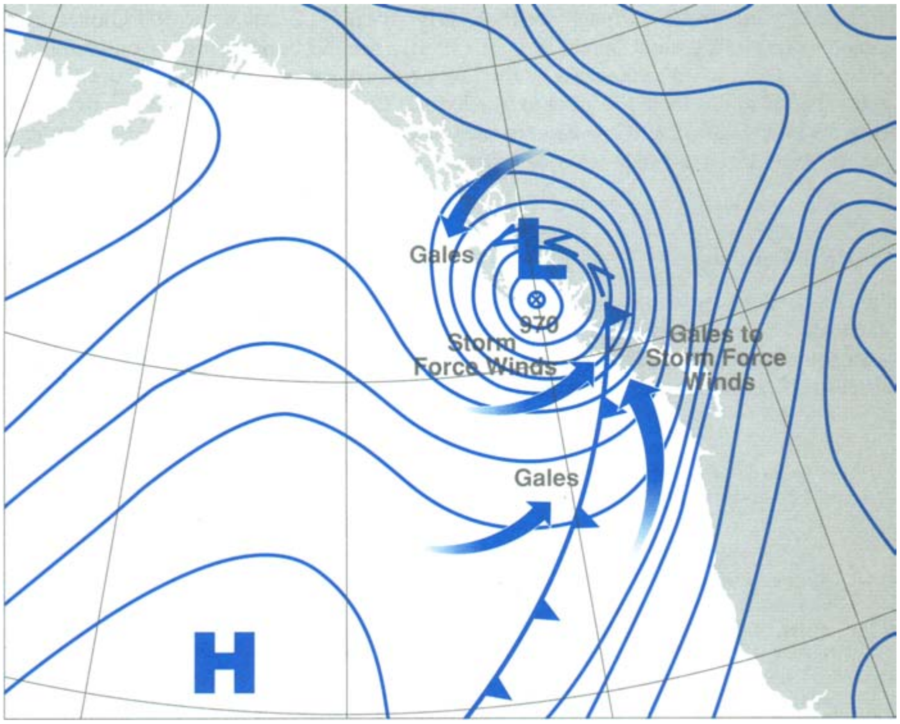

Figure B.2 Winter pressure pattern typical of a Coastal Low (millibars) (Environment Canada 1992).

In summer, the mean monthly weather patterns change with the North Pacific High moving northward and displacing the Aleutian Low (Figure B.1 bottom left). This pressure pattern tends to deflect most storms to the north as indicated by Figure B.3 (Environment Canada 1992). The clockwise airflow around this High results in weaker, mostly northwesterly winds along the central coast.

Summer wind speeds are much reduced from those of winter (Figures B.4 and B.5). However, strong marine winds can occur during late spring and summer, associated with the passage of frontal systems through the BC central and north coast. Even diurnal sea-breezes, caused by heating/cooling of the land, can be strong enough to disrupt vessel traffic during late afternoons.

In all seasons, wind intensity decreases towards the mainland coast.

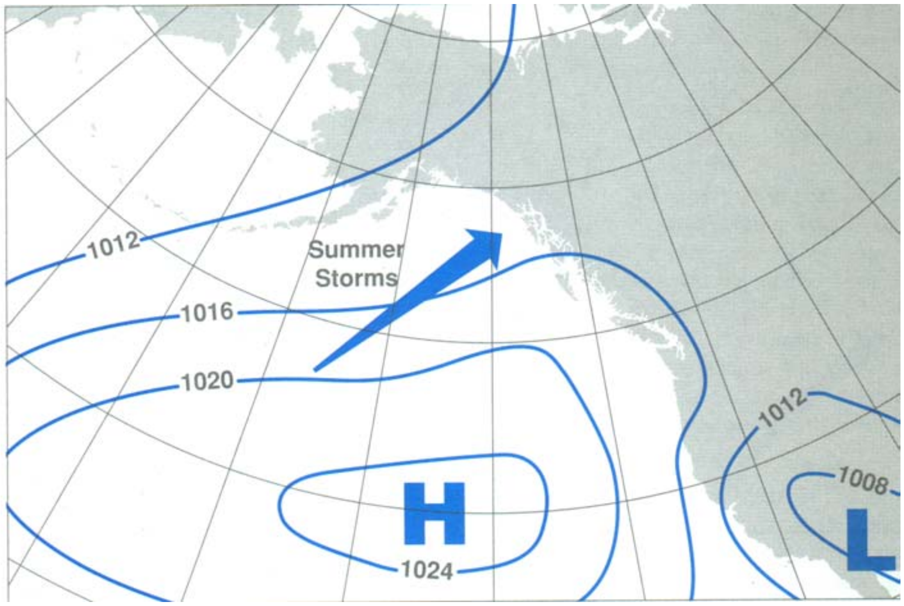

Figure B.3 Summer pressure pattern (millibars) (Environment Canada 1992).

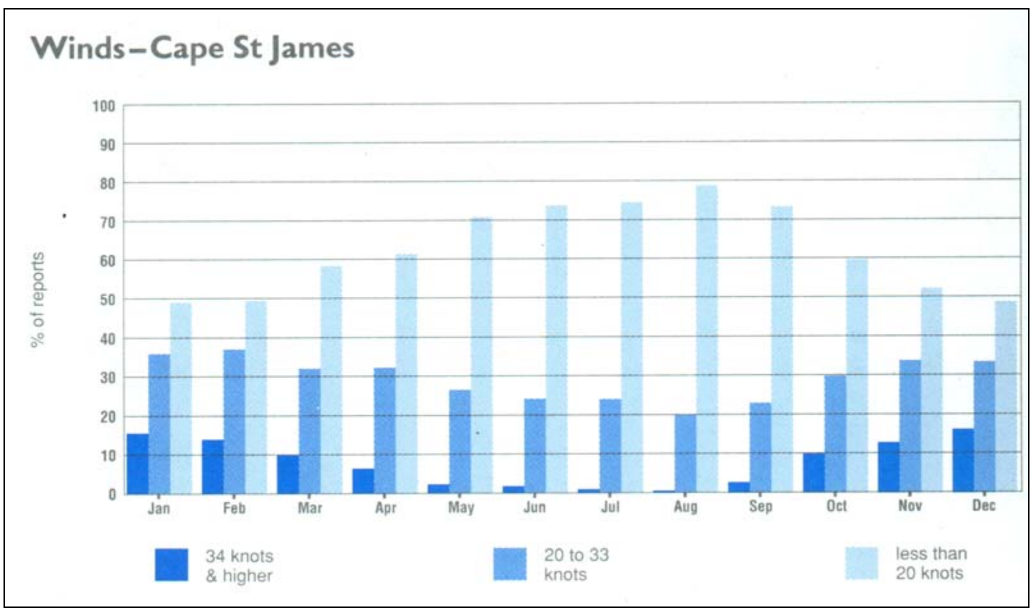

Figure B.4 The seasonal distribution of wind speeds for Cape St. James in the <20, 20-33, and >34 knot range (Environment Canada 1992).

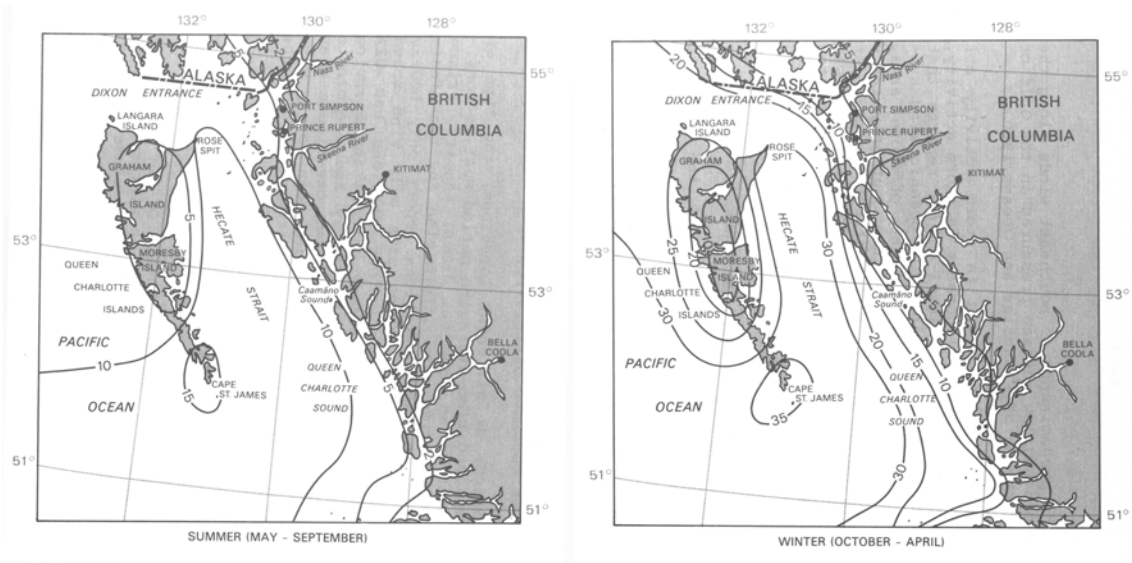

Figure B.5 Percent frequency of winds ≥40 km hr^{-1} (22 knots), during summer (left) & winter (right) (from (Petro-Canada 1983), based on (Faulkner and Schaefer 1978).

During winter, when cold arctic air collects over northern BC, arctic outbreaks can occur with cold dense air funnelling down the coastal inlets (Kendrew and Kerr 1955). The winds can be very strong, often up to 60 knots, and occasionally to 100 knots. Sustained northeasterly outflow winds have been observed to remain above 60 knots for over 24 hours. The combination of strong winds and frigid temperatures can result in heavy freezing spray within and at the entrances to mainland inlets (Stewart *et al.* 1995). Some inlets, such as Burke Channel, are aligned with the outflows and can have particularly severe cold outflow conditions.

Environment Canada and Fisheries & Oceans Canada maintain an array of weather buoys (Figure B.6). Wind, wave and sea-surface temperature, air temperature and a variety of other data are available real-time via satellite at http://weatheroffice.ec.gc.ca/natmarine/bc/north_coast_e.html and at http://www.ndbc.noaa.gov/station_page.php?station=46204. Lighthouse locations are from the BC Lighthouse website http://fogwhistle.ca/bclights/gps.php.

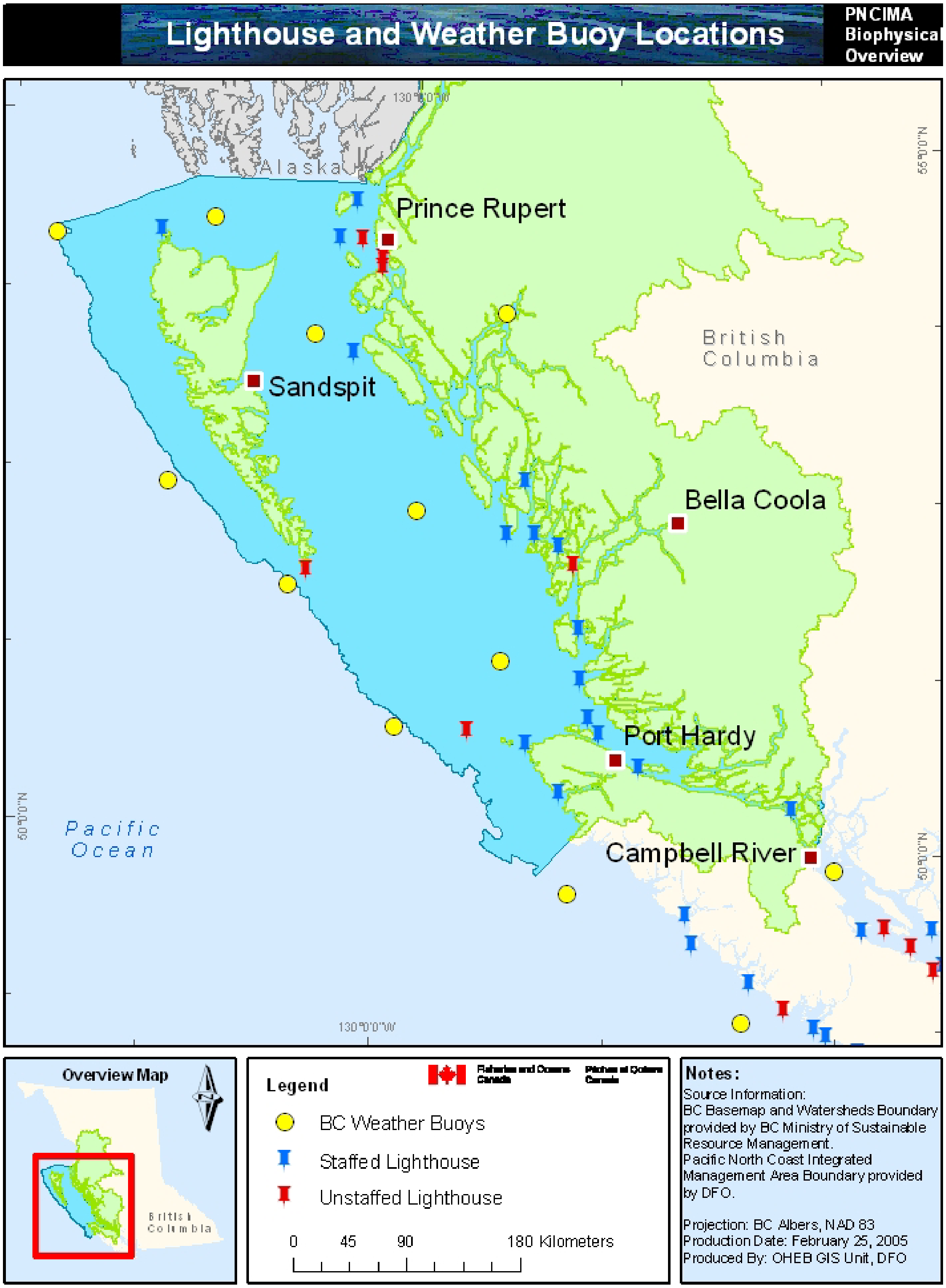

Figure B.6 The location of BC weather buoys and lighthouses.

3.0 CLIMATE

The coast of BC falls within the Pacific Maritime ecozone (Ecological Stratification Working Group 1996). The climate is moderated by the influence of the Pacific Ocean and affected by the presence of high-elevation mountains along the mainland coast (Meidinger and Pojar *eds*. 1991; Hare and Hay 1974). Mean daily coastal air temperatures range from about 4-5°C in winter to about 13-15°C in summer (Table B.1), the lowest summer temperatures in Canada (Ryder 1989)(Figure B.7). Recorded extremes range from lows of -11 to -17°C during winter to +27 to +32°C in summer. This moderating effect of the ocean causes fairly uniform mild temperatures along the coast, with Vancouver summer temperatures slightly warmer than those of both exposed and protected areas of the central and north coast (Figure B.7). However, higher elevation locations in the PNCIMA watersheds show less moderating influence from the ocean and temperatures are much cooler in winter, though not hotter in summer.

Table B.0 Climatology of the QC Sound region, based on climate normals (1971-2000) for Cape St. James (southern Queen Charlotte Islands), Cape Scott (northern Vancouver Island), & McInnes Island (along central coast) (Environment Canada 2003).

	Cape St James	**Cape Scott**	**McInnes Island**
Air temperatures			
Mean daily	~13°C in July; ~5°C in Jan	~14°C in Aug; ~5°C in Dec-Jan	14-15°C in Jul-Aug; ~4°C in Jan
Extremes	28°C in summer; -14°C in winter	27°C summer; -11°C in winter	32°C in summer; -17°C in winter
Precipitation			
Annual rainfall	1560 mm	2600 mm	2522 mm
Wet months	Oct-Jan (avg. 188 mm)	Oct-Jan (avg. 327 mm)	Oct-Jan (avg. 302 mm)
Dry months	Jun-Aug (avg. 74 mm)	Jun-Aug (avg. 103 mm)	Jun-Aug (avg. 121 mm)
Extreme daily rainfall	Up to 63 mm	Up to 145 mm	Up to 319 mm
Snowfall	~50 cm yearly, mostly Nov-Apr	~50 cm yearly, mostly Nov-Apr	~70 cm yearly, mostly Nov-Apr
Visibility			
Fog days during summer (June-Oct)	10-13	7-13	2-8
Fog days during winter (Nov-May)	5-8	3-5	1-3

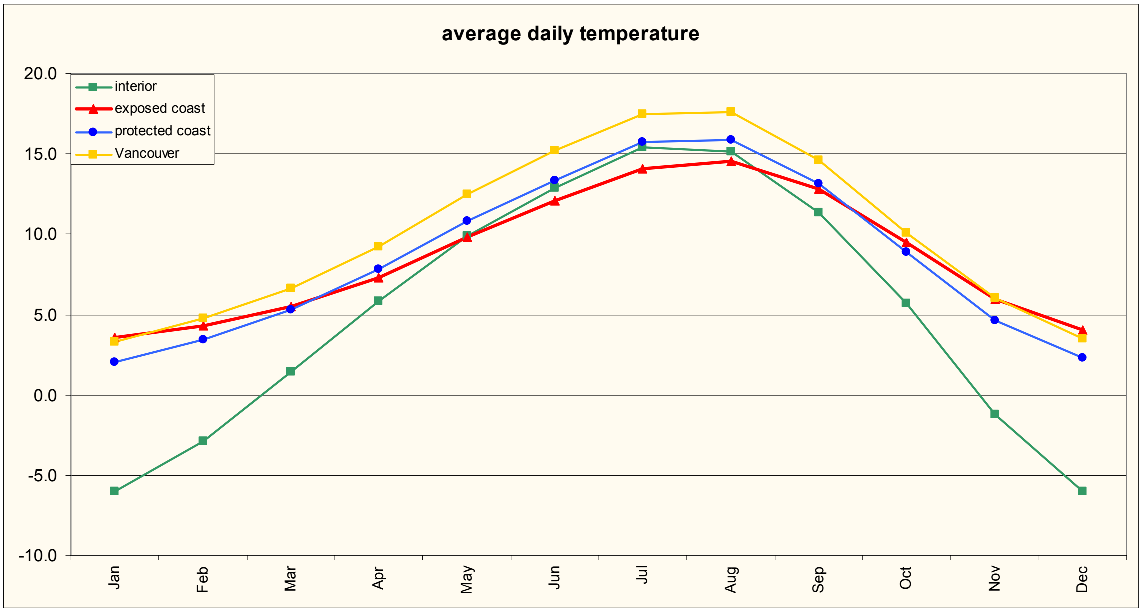

Figure B.7 Average monthly temperatures for climate stations on the protected coast, exposed coast, in elevated interior locations (coastal mountains) and in Vancouver (data from Environment Canada climate normals).

This area receives relatively high amounts of rainfall: 1560 mm annually at Cape St. James, increasing to 2600 mm at Cape Scott. The wettest months are October through January, with monthly average precipitation of 188 mm at Cape St. James, increasing to 327 mm along the mainland coast (~10 mm per day). Extreme daily rainfall can reach 63 mm offshore (Cape St. James), and 319 mm along the coast (McInnes Island). Summers are much drier (74 mm per month at Cape Scott; 121 mm per month along the mainland coast). There is little snowfall at sea level, only 50-70 cm/year, most of which occurs during November-April. The rainfall pattern shows strong orographic effects. Figure B.8 shows that the highest rainfall occurs along the mainland coast at the base of the Coast Mountains. Locations farther from the mountains (mainland islands), or near the lower elevation Queen Charlotte and Vancouver islands mountains, show more moderate to low rainfall levels. Locations in rain shadows show the least rainfall, especially those in the shadow of the coast range (east of Prince Rupert and Bella Coola, Figure B.8).

Visibility can be greatly reduced by fog, particularly during summer and fall. Fog is more common offshore, with 10-13 fog days at Cape St. James during June-October, and decreases towards the mainland coast where McInnes Island has 2-8 fog days.

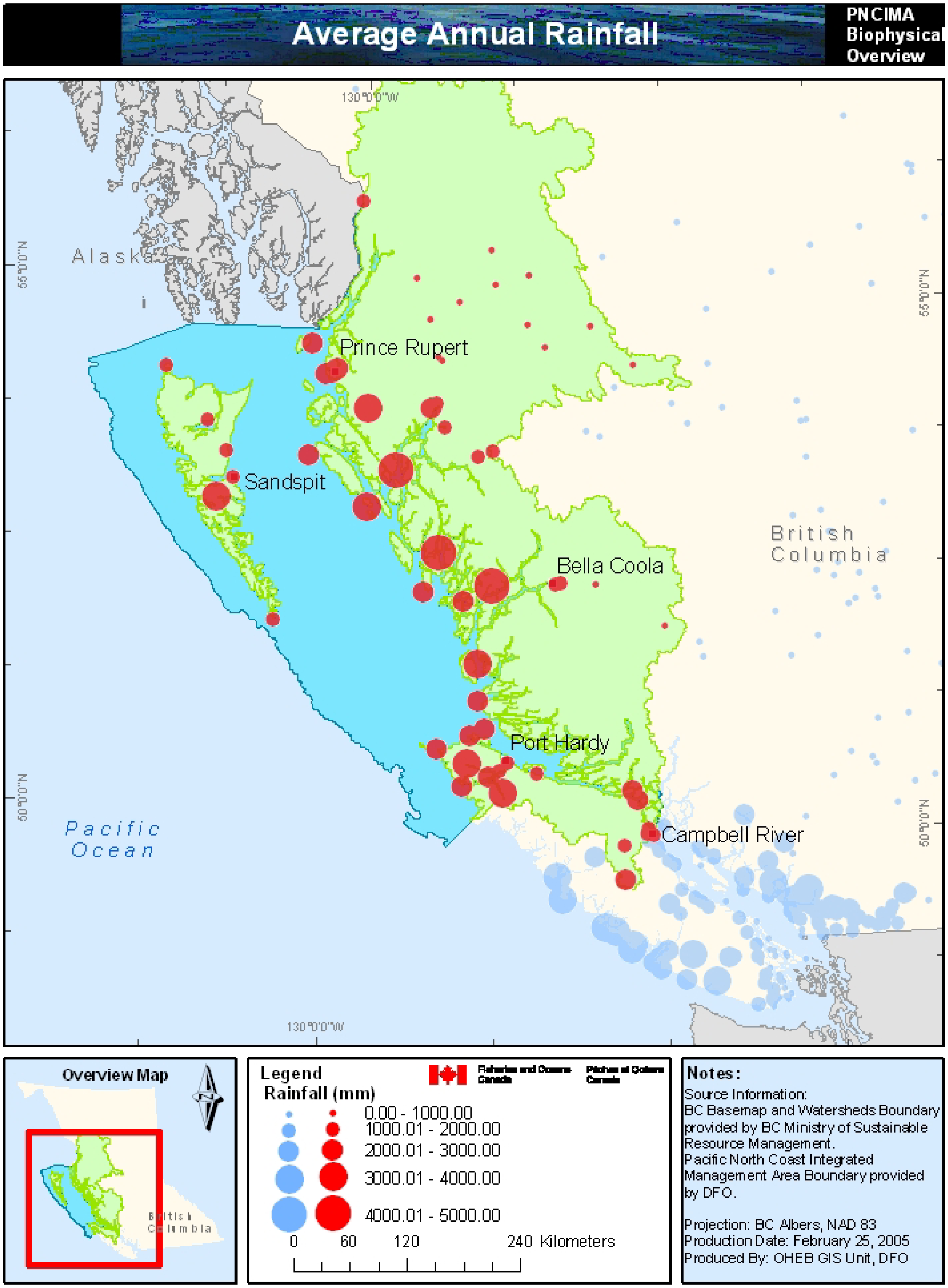

Figure B.8 Average annual rainfall for climate stations in the PNCIMA and adjacent BC (data from Environment Canada's climate normals).

4.0 CLIMATE VARIABILITY AND CLIMATE CHANGE

4.1 Scales and Measures of Climate Variability

The climate of BC as described above is based on averages of data over long time periods (generally over 30 years of data). However, significant variability exists within that data on a number of time scales. The shortest scale generally discussed is seasonal variability. This refers to changes in the climate from season to season and is captured in the discussion in section 3.0. This seasonal variability is the highest in magnitude because the seasons differ from one another so greatly (winter weather vs. summer weather). Longer scales of variability compare the same months or seasons between different years, decades, etc. or compare annual averages over decades, centuries etc.

Annual variability refers to the differences in monthly or seasonal data between different years. These differences are largely a result of variation in the position and strength of the Aleutian Low and North Pacific High pressure systems. These variations can have a significant effect on oceanographic conditions and on biological functions in the coastal ecosystem.

In addition to this 'normal' or local annual variability, climatic changes in other parts of the world can disrupt local weather patterns on scales of a few months to a few years and are often termed interannual variability. El Niño is the most well known of these effects and its pattern of change is called the El Niño Southern Oscillation (ENSO). A change in trade winds causes a reduction in upwelling of cold waters off the coasts of Ecuador and Peru with resulting added heat and moisture brought into these normally arid countries from the central Pacific. The western equatorial Pacific experiences drier weather and these tropical conditions alter the weather in extra-tropical regions. For PNCIMA, this generally results in a milder and wetter winter except for portions of the Central Coast. The Environment Canada Web page below lists impacts of El Niño in Canada: http://www.msc-smc.ec.gc.ca/education/elnino/canadian/index_e.cfm. The ENSO index is used by oceanographers to monitor and predict changes in ocean conditions in the North Pacific (further detail in Appendix C: Physical and Chemical Oceanography).

Decadal variability refers to changes that take place in tens of years. The Pacific Decadal Oscillation (PDO) is an example of this kind of climate variability that affects Canada's Pacific coast. The PDO is developed from analysis of sea surface temperature anomalies in the Pacific Ocean north of 20˚N. Changes associated with this index have recently been linked to the concept of 'Regime Change', which refers to large scale changes seen in many parts of the ecosystem that may reflect a change from one relatively stable ecosystem state to another. The Aleutian Low Pressure Index (ALPI) is related to the PDO but is a more direct measure of winter-time sea surface air pressure in the northeast Pacific, and thus a measure of the intensity of the Aleutian Low in winter (Beamish *et al.* 1997).

Variability on longer time scales approaches the geological time scale. The entire Quaternary Period (~ last 2 million years) is defined as a time of climate variability on the scale of tens to hundreds of thousands of years cycling between glacial advances and retreats during cold and warm periods (see Appendix A: Geology 1.0). This scale of variability is too long to be of use in management or planning processes.

4.2 Climate Change

Climate Change is a term often used to refer to alterations in the climate that are understood to be anthropogenic in nature. In particular, it is clear from recent studies that we are in a time of global warming. Warming of the globe is not in itself unusual in the geologic record, however, the current rate of warming is believed to be completely unprecedented in human experience (Figure B.9). Warming results from the steady increase in atmospheric greenhouse gases such as CO_2, methane, ozone and others. A greenhouse gas lets in solar energy to the surface of the earth, but absorbs radiation at wavelengths that are emitted from the earth. When concentrations of these gases are increasing, the earth gains more heat energy than it releases. Much greater detail on this topic can be found in the publications of the Intergovernmental Panel on Climate Change (IPCC) at http://www.ipcc.ch/ particularly in its report on the scientific basis of climate change (Intergovernmental Panel for Climate Change 2001). Increases of greenhouse gases will clearly have significant and increasing effects on the structure and function of ecosystems all over the globe.

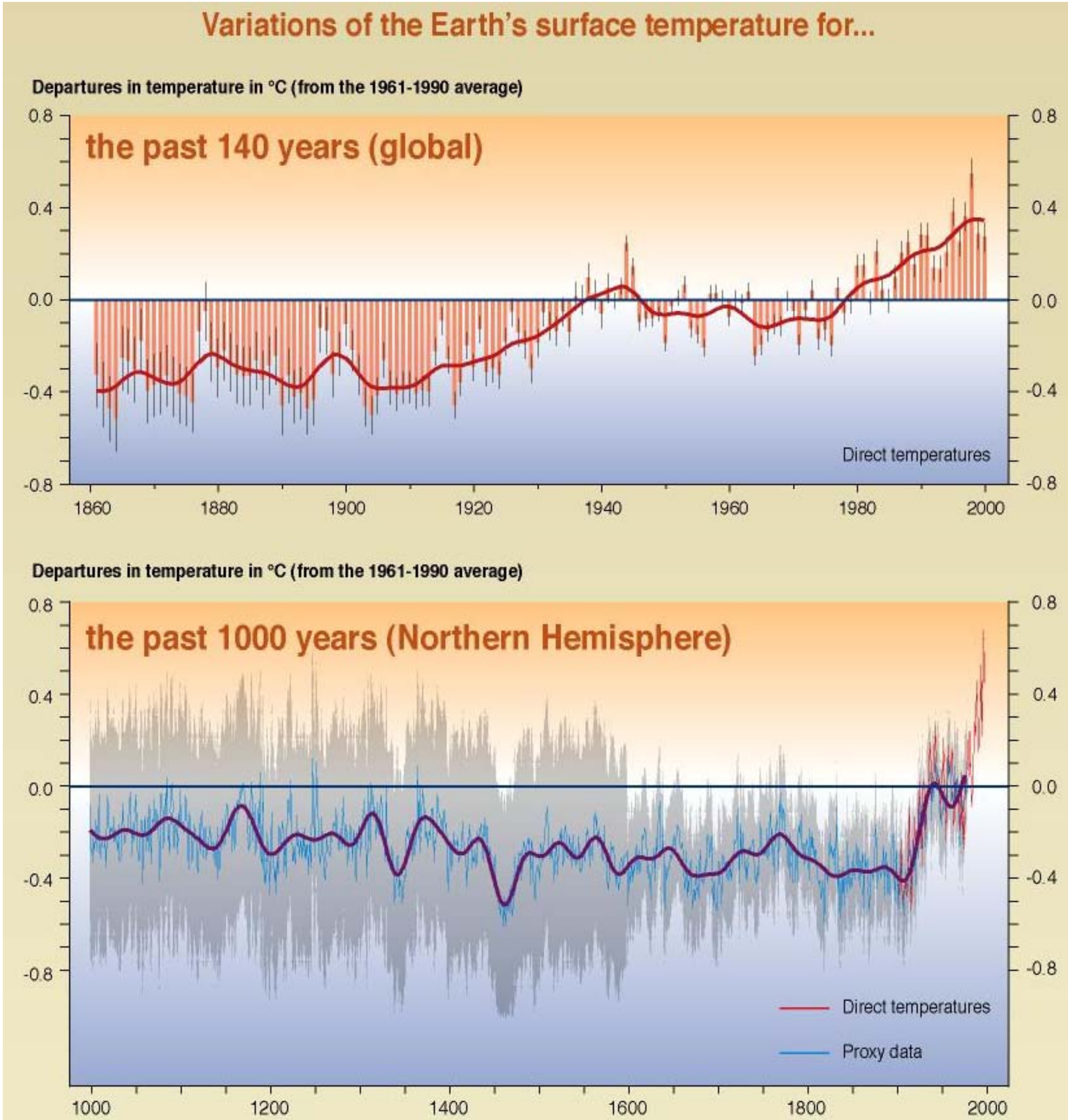

Figure B.9 Global air temperature change from 1861 to 2000 and northern hemisphere temperature change from 1000 to 2000 AD (figure from IPCC synthesis report acquired from the website http://www.ipcc.ch/present/graphics.htm).

5.0 GLOSSARY

Orographic effect - Rainfall that results from or is enhanced by mechanical lifting of an air mass over mountains.

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