A Study of Climate Monitoring Capabilities in Newfoundland and Labrador

Final Report

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	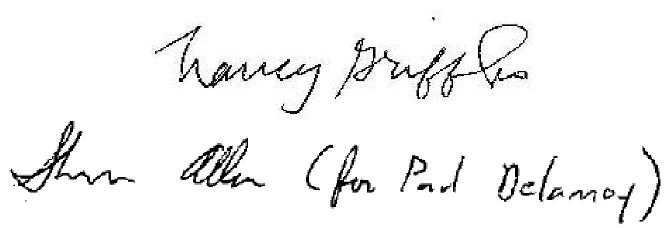
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EXECUTIVE SUMMARY

This report presents a three-part study of climate change monitoring capabilities in Newfoundland and Labrador prepared for the Government of Newfoundland and Labrador, Office of Climate Change, Energy Efficiency and Emissions Trading.

The study was conducted under the Provincial Government's 2011 Climate Change Action Plan – Charting Our Course. This Action Plan recognizes that climate change is one of the most important issues facing Newfoundland and Labrador. The province is exposed to a number of impacts of climate change including sea-level rise, coastal erosion, changes in seasonal weather patterns and more storm activity, and therefore the Provincial Government is committed to enhancing resilience in the province.

In order to understand, prepare for, and adapt to the impacts of climate change, it is essential that the province have access to timely, reliable and accurate data and information on the climate in the province. This is necessary to support immediate and short-term needs, such as storm preparation, as well as longer-term and more research-oriented needs that focus on, for example, changes in the climate over time.

Newfoundland and Labrador has a variety of climate monitoring stations and various information products, each of which may be owned and maintained by a variety of entities including government, academic institutions and the private sector. However, there has never been a study that looked at the state of monitoring in the province and the key needs of the user community. This study fills that gap.

There are three parts to the study:

Part I – Climate Station Inventory
The first part of the study consisted of preparing, for the first time, a detailed inventory of climate monitoring stations in Newfoundland and Labrador. This includes existing active, seasonal, regional, and discontinued stations (e.g., weather stations, water quality monitoring stations, and oceanographic buoys). The inventory lists the location and time period of record for each station, which atmospheric, freshwater, terrestrial, oceanographic, and ice climate or weather variables are physically measured, together with essential metadata on data access and quality, and additional supporting documentation. The inventory is comprehensive as all entities that own climate stations, including governments, industry and academia, are covered. The inventory is documented separately from this report as a standalone spreadsheet and companion documentation report.

Part II – User Needs Analysis
Climate monitoring data and climate information support various user needs and interests in Newfoundland and Labrador. These include study, understanding, and interpretation of the underlying atmospheric, oceanographic, freshwater and terrestrial sciences, and extend to assessing regional and large scale climate change. Climate affects a broad range of physical and ecological processes as well

as human social and economic activities and interests. At the extreme, climate impacts the welfare of the citizens of Newfoundland and Labrador and their property.

In the second part of this study, individuals from approximately 50 government, academia, private sector, and other groups were surveyed and/or interviewed to learn of their present and potential future needs for climate data and information in Newfoundland and Labrador. This engagement was based on a questionnaire that was completed in writing and via telephone and in face-to-face meetings. A synthesis of this information for a 'user needs profile' for the province was subsequently prepared and is presented in this report.

The user needs analysis focused on three key aspects. First, of fundamental importance for climate monitoring are the actual climate measurements. To this end, the needs, and present monitoring coverage in place for terrestrial, coastal, and marine climate variables were presented. The climate station inventory was used to visualize the monitoring coverage and record length of active and historical stations. For each variable (e.g., temperature, precipitation, and sea level, all three being main indicators of climate change) a conclusion is presented on the monitoring adequacy in the province.

One of the most significant impacts of climate change in Newfoundland and Labrador is expected to be higher levels of precipitation falling in short, intense rain events. In its current form, the province's monitoring network for precipitation intensity is sub-optimal and the coverage needs to expand to enable effective decision-making for planning and infrastructure development.

Another key area is monitoring in the offshore marine environment. The existing marine met-ocean buoy networks and oceanographic monitoring programs serve vital roles for many economic, public safety, and scientific needs for Newfoundland and Labrador, and for Atlantic Canada as a whole. Monitoring of coastal waters and the adjoining Northwest Atlantic Ocean upstream of the island and Labrador is a key for the well-being of the public; the measurements of air pressure, wind, and waves play critical roles in supporting weather forecasting and emergency preparedness and response – both at sea and on land for storms and flooding. Further, projects such as SmartBay demonstrate the ability to meet climate monitoring needs while also generating economic opportunities for technology development.

Second, in addition to the climate variables themselves, various climate information products are derived from the original measurements. These include simple statistics and normals, intensity-duration-frequency (IDF) curves, forecasts and seasonal outlooks, flood risk maps, indices used to characterize the status, timing, and evolution of various underlying climate mechanisms, and predictions used to simulate future climate scenarios. An investigation of these information products and how well the province's users are presently served by them comprised the second aspect to the user needs profile. For two key areas, IDF curves and flood risk maps, the province is currently underserved with either non-existent or out-dated documents for many locations.

Third, as a final aspect of the profile, data standards and quality issues, essential parts for users of the province's climate monitoring, were assessed. Monitoring equipment selection, siting, installation, maintenance, operation and data checks are all necessary considerations in ensuring data quality and maximum utility for short-term weather needs on the order of hours and days, weeks to months, and long-term climate time scales of several years to hundreds of years or more. Most climate data owners have infrastructure, processes, software and services to enable and support sharing, access, and visualization of data. Therefore, a common set of principles and standards for data collection, quality assurance, and publishing should be explicitly adopted and promoted to support effective climate monitoring and ensure the creation and longevity of quality climate data records for Newfoundland and Labrador.

Part III – Recommendations

The final part of the study consisted of a gap analysis of the user needs profile and preparation of 14 recommendations to improve the province's climate monitoring capabilities. These recommendations are intended to address three main areas: (1) address shortcomings of the coverage of present atmospheric and oceanographic monitoring stations; (2) expand the province's essential set of climate information products such as IDF curves, flood risk maps, and downscaled climate predictions; and, (3) strengthen the promotion of the province's climate monitoring networks, together with best practices for data quality, documentation, and access.

1.0 INTRODUCTION

AMEC Environment & Infrastructure, a Division of AMEC Americas Limited, (AMEC) has been retained by the Government of Newfoundland and Labrador, Office of Climate Change, Energy Efficiency and Emissions Trading (CCEEET) to complete a Study of Climate Change Monitoring Capabilities in Newfoundland and Labrador.

The study was developed by the province as part of its recognition of climate change as a long term challenge for planning and other aspects of the province's environment, economy, and social well-being. The work conducted through this study is anticipated to be of use to a variety of entities and end-users with an interest in climate change and others requiring access to timely, accurate, and reliable climate data and information.

While climate change adaptation, mitigation, and emissions reductions are key elements of the broader climate change challenge, the focus of this study is climate monitoring: this includes the collection, verification, publication, and distribution of climate data and information.

There are three primary objectives for the study.

- Part I: Conduct a detailed analysis of climate monitoring stations within Newfoundland and Labrador. This includes existing, discontinued, and any planned terrestrial, inland aquatic, and marine stations. The information to document includes station location, environmental parameters measured, history of record, Quality Assurance (QA) and Quality Control (QC) procedures in place, and data access. The results of this analysis have been documented in a Climate Station Inventory (AMEC, 2012).
- Part II: Through a canvassing, interview, and analysis process, assess and profile the climate monitoring data and information interests and needs of the province, including government (e.g., federal, provincial, municipal), industry, non-governmental organization (NGO), and educational institute users.
- Part III: Identify what gaps might exist between climate monitoring data availability and capabilities identified in Part I and the user needs from Part II. Prepare detailed recommendations on how to measurably address the resultant capabilities versus requirements gap to improve climate monitoring for Newfoundland and Labrador.

Section 2.0 provides a background of the key themes and discussion points used to facilitate the analysis and presentation of findings. Section 3.0 presents the study methodology. The Newfoundland and Labrador climate monitoring user profile is presented in Sections 4.0 to 9.0. This focuses on those environmental parameters which are of primary importance as climate change indicators and which support the majority of climate monitoring activities in the province. Section 4.0 provides a re-introduction of the environmental parameters captured in the earlier Part I inventory work. Section 5.0 discusses terrestrial climate variables and Section 6.0 discusses coastal and marine variables. Section 7.0 presents climate information products. The topics of data standards and quality, and data networks, are presented in Sections 8.0 and 9.0 respectively. Conclusions and Recommendations are presented in Sections 10.0 and 11.0. References are provided in Section 12.0.

2.0 BACKGROUND

Climate monitoring data and climate information support various user needs and interests in Newfoundland and Labrador. These needs and interests include study, understanding, and interpretation of the underlying atmospheric, oceanographic, freshwater and terrestrial sciences, and extend to assessing regional and large scale climate change. Climate affects a broad range of physical and ecological processes as well as human social and economic activities and interests. At the extreme, climate impacts the welfare of the citizens of Newfoundland and Labrador and their property.

Depending on the area of study or application, climate data time scales can be short-term weather on the order of hours and days, weeks to months, or long-term climate time scales of several years to hundreds of years or more. Weather deals with recent past records for specific locations and dates, to the here and now, and on to forecasts for perhaps several weeks into the future. It deals with the specific conditions at a precise time. Climate on the other hand, deals with average conditions and extremes over a time interval, usually starting at about one month, to seasonal, annual, and decadal and beyond. This is an inherent element of climate monitoring: attempting to serve both immediate requirements and the study of longer-term climates and associated impacts. Regardless of the end use, a fundamental requirement is to ensure that appropriate monitoring (data collection) programs are in place so that the essential climate variables are available now and in the future.

Of primary relevance for climate monitoring are the physical measurements themselves. These might focus on temperature, precipitation, and sea level, which are three main indicators of climate change, but also extend to other parameters. This study attempts to be inclusive of any climate and environmental variables of interest from the various stations across all monitoring geographic regions in Newfoundland and Labrador including the offshore environment. This includes the atmospheric, terrestrial, freshwater, oceanographic, and ice parameters identified in this study's Part I Climate Station Inventory (AMEC, 2012).

In addition to the climate variables themselves, various climate information products are derived from the original measurements. These include simple statistics and normals, intensity-duration-frequency (IDF) curves, forecasts and seasonal outlooks, flood risk maps, environmental design criteria for engineering construction or operation, and climate indices[1]. These support a spectrum of end users and a range of applications beyond climate study.

[1] oceanographic, freshwater, ice, atmospheric, and terrestrial climate indices are based on several measurements or patterns devised to characterize the status, timing, and evolution of various underlying climate mechanisms. Typically the indices are derived from (inter-annual) observations, monthly or seasonal "Normals" calculated from many years, e.g., 30 years 1971-2000, of observations, and anomalies (observations minus Normals). In the North Atlantic, examples of these include: Monthly-averaged sea level computed from selected tidal stations' records, e.g., for St. John's; St. Lawrence River freshwater runoff - Annual average discharge and seasonal cycle; Annual count of iceberg observations south of 48° Latitude; and North Atlantic Oscillation (NAO), the average annual difference in atmospheric pressure between the Iceland low and Azores high Winter severity and drought indices are terrestrial examples and there are many more.

Monitoring equipment, siting, installation, maintenance, and operation (QA) and data checks (QC) are also necessary considerations. This includes data quality control, data management, documentation, and maintenance of measurement equipment. At a detailed level, sampling frequency, data formats, and whether or not data are freely available in near real-time or historically are also relevant.

Data networks can be considered as a primary means of accessing and sharing monitoring data and associated documentation. A collection of some 35 networks were identified in the Climate Station Inventory, most of them with Internet data access.

These key themes then provide the focus and framework for the user needs analysis. From this, conclusions can be reached and recommendations can be formulated for improving the capabilities for climate monitoring in the province.

3.0 METHODOLOGY

The analysis of climate monitoring needs began by soliciting user input to enable a better understanding of particular interests, details of the climate data and networks in use, and the identification of gaps or possible future requirements. This was achieved through distribution of a survey questionnaire and through group meetings. This information was then analyzed and synthesized into a user profile.

The questionnaire was designed to solicit input from users and collect some foundational information on the following key elements of climate monitoring data and information needs:

- the specific goals and objectives targeted in using climate data and information in Newfoundland and Labrador
- physical measurements taken, including 'typical' climate elements of temperature, precipitation, and wind, but also inclusive of other atmospheric, freshwater, coastal, marine, and ice parameters
- data networks, considered as a primary means of organizing and accessing monitoring data and documentation
- the various information products derived from climate data analysis that are necessary or useful to support specific applications
- potential future requirements for monitoring data and capabilities, including understanding which of the data, networks, and requirements indentified in this study are critical to be maintained

A copy of the questionnaire, complete with introductory cover note, is provided in Appendix A. Thirty-five questionnaires were completed. Coincident with the questionnaires, 22 participants were consulted in meetings used to solicit input and discussion on the various aspects of climate monitoring and climate study.

AMEC and CCEEET prepared a list of government, industry, educational institute, and other potential users to contact. During the consultation process, several other potential interested users were identified by AMEC and study participants. As listed in Table 3.1, a broad range of users participated in this study, with representation from academia, the federal and provincial governments, Provincial Crown Corporations, municipalities, and the private sector.

Table 3.1 Study Participants

Academia
College of the North Atlantic, Adventure Tourism
Memorial University, Department of Geography
Memorial University, Department of Physics and Physical Oceanography
Memorial University, Faculty of Engineering and Applied Science
Memorial University, Fisheries and Marine Institute
Memorial University, Grenfell Campus - Environmental Science
Memorial University, Grenfell Campus - Social/Cultural Studies
Memorial University, Grenfell Campus - Sustainable Resource Management
Government of Canada
Environment Canada, Meteorological Service of Canada - Atlantic Operations
Environment Canada, Meteorological Service of Canada - Canadian Ice Service
Environment Canada, Meteorological Service of Canada - Monitoring
Environment Canada, Water Survey of Canada
Fisheries and Oceans Canada, Bedford Institute of Oceanography
Fisheries and Oceans Canada, Institut Maurice Lamontagne
Fisheries and Oceans Canada, Integrated Science Data Management
Fisheries and Oceans Canada, Science Branch - NL Region - Ecological Sciences
Fisheries and Oceans Canada, Science Branch - NL Region - Environmental Sciences
Fisheries and Oceans Canada, Small Craft Harbours
Government of Newfoundland and Labrador
Department of Environment and Conservation
Department of Fisheries and Aquaculture
Department of Innovation, Trade and Rural Development
Department of Municipal Affairs
Department of Natural Resources
Department of Transportation and Works
Fire and Emergency Services Newfoundland and Labrador
Forestry and Agrifoods Agency
Geological Survey of Newfoundland and Labrador
Office of Climate Change, Energy Efficiency and Emissions Trading
Office of the Chief Information Officer
Municipalities
City of Corner Brook
City of St. John's
Municipalities Newfoundland and Labrador
Private Sector, Crown Corporations, and Other
CBPP (Corner Brook Pulp and Paper Mill)
C-CORE, Earth Observation
Chevron, R&D
ExxonMobil Canada, Safety, Security, Health and Environment
FFAW (Fish, Food and Allied Workers)
Husky Energy, Logistics
Nalcor Energy, Newfoundland and Labrador Hydro
Newfoundland Power
PAL, Environmental Services
PRAC (Petroleum Research Atlantic Canada)
RDC (Research & Development Corporation)
Suncor
Vale NL, Voisey's Bay Mine Site Environmental Coordinator

4.0 ENVIRONMENTAL PARAMETERS AND INTERESTS

It became evident, from the user needs study, that virtually all of the over 60 parameters included in the Climate Station Inventory are of interest in the province though clearly some were of greater significance for climate monitoring than others. The complete set of parameters in the inventory is listed in Figure 4.1 together with a count of active, seasonal, regional, and inactive stations or sources which monitor each parameter. A station refers to a location where environmental parameters are measured, generally on a regular basis (e.g., hourly or daily). Examples of these include climate or weather stations, water quality monitoring stations, and oceanographic buoys.

Active stations are those presently providing year-round measurement of at least one, or as is usually the case, several environmental parameters.

Seasonal stations are active only during part of the year. There are primarily two seasonal station networks in the province. These include the Department of Transportation and Works, Road Weather Information Systems (RWIS) stations which operate only in the winter, and the Department of Natural Resources, Forestry Services Weather Observation program which operates only during the summer.

The regional sources, rather than being point-source station measurements, encompass measurements over a large geographic area, e.g., the North Atlantic, or a section east along latitude 47°N from the Avalon Peninsula to the Flemish Pass, and thus are defined by a range of latitude and longitude. These collections are all generally ‘active’ and include primarily the Fisheries and Oceans Canada (DFO) hydrographic and monitoring program databases. Measurement may be on a regular basis (e.g., hourly or daily) or may be less-frequent such as several times a year.

Inactive stations are those which were decommissioned and no longer measure any of the environmental variables which were once monitored. These include stations which may have been active for short or long periods of time, and those which may have been ‘discontinued’ recently (e.g., in the past five to ten years) or some time ago (e.g., in the 1960s or 1970s). A second key distinction is that although a measurement program (e.g., for precipitation intensity) may be ‘inactive’, the station itself may still be actively measuring other climate variables. In many such instances, the equipment for mounting of instrumentation, as well as power, and data logging or communications infrastructure may still be in place. As such, stations with reduced observing programs offer the benefit of a longer historical climate data record and the locations are potential candidates for cost-effective re-instatement of a fuller program, should such a need be identified.

The inventory provides summary of the spatial and temporal coverage of each environmental parameter. Study participants commented that there may be incomplete knowledge concerning active stations, data availability, and/or how to access it. The inventory provides valuable basic documentation to inform climate data users and should be kept current for this purpose. This requires access to up-to-date accurate metadata from station and network owners (e.g., Environment Canada, Fisheries and Oceans Canada, Department of Environment and Conservation, etc.).

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	Number of Stations or Sources			
Atmospheric	Active	Seasonal	Regional	Inactive
Air Temperature	109	48	2	248
Humidity (relative humidity, dew point, wet bulb)	75	48		28
Wind Direction	69	48	3	35
Wind Speed	72	48	3	34
Wind Gust	46	22		15
Pressure	67	22	2	22
Pressure Tendency	8			
Present Weather	15			5
Precipitation Amount	81	31		241
Precipitation Indicator	10	22		1
Visibility	48			19
Precipitation Intensity	26			21
Solar Radiation	4			2
Sunshine	9			10
Cloud Amount	37			14
Cloud Height	37			14
Freshwater				
Streamflow	111			74
Stage	93			
Water Quality			1	
Water Level	2			12
Water Temperature	77		1	1
pH Units	97			42
Specific Conductance	97			41
Dissolved Oxygen (Freshwater)	21			
% Saturation	21			
Turbidity	92			41
Total Dissolved Solids	22			1
Oxidation Reduction Potential	5			1
Salinity (Freshwater)	2			1
Water Elevation	7			
Colour	71			41

	Number of Stations or Sources			
Terrestrial	Active	Seasonal	Regional	Inactive
Depth of Snow on Ground	67			66
SWE	1			
Soil Temperature				3
Pavement Surface Temperature	4	22		
6 cm Sub-Surface Temperature	4	22		
Pavement Status	4	22		
Pavement Salinity	4	22		
Freezing Point Temperature	4	22		
40 cm Sub-Surface Temperature	4	22		
Soil Moisture	1			
Oceanographic				
Wave Height	11		3	
Wave Period	11		3	
Wave Direction	6		3	
Current Direction	6		4	1
Current Speed	6		5	1
Transport			1	
Tide	6		11	
Sea Level	8		1	
Sea Temperature	14		25	44
Salinity (Marine)	9		18	44
Density	5			1
Water Quality, Profiling			1	1
Cold Intermediate Layer Area			4	
Chlorophyll a			7	14
Dissolved Oxygen (Marine)			8	43
Phytoplankton				14
Ice				
Sea Ice Presence	3		3	
Sea Ice Thickness	3		2	
Iceberg Count	3		3	
Ice Coverage	3		2	

Figure 4.1 Climate Station Inventory, Environmental Parameters for Active, Seasonal, Regional, and Inactive Stations

4.1 Climate Regions of Newfoundland and Labrador

In assessing climate information user needs for the environmental parameters listed above, a key consideration is the spatial coverage provided by the monitoring stations in place. A logical question is what is an appropriate density of stations? Climate region boundaries in the province can be introduced with which to view the station coverage for different environmental parameters. This can serve as a basis to better assess monitoring adequacy and to support development of recommendations. This is the purpose of this short section, to introduce these boundaries.

Local weather and climate conditions are dependent on, and strongly influenced by, land surface characteristics, roughness, and changes from land to sea or lake. Figure 4.2 is a topographical relief map of Newfoundland and Labrador, showing the large range of elevations across the province and select spot elevations. Topography can funnel winds and cause local fog, cloud, precipitation, and temperature changes. Much of Newfoundland is rugged, but the terrain does not exceed 300 m, except in the Long Range Mountains on the West Coast where peaks reach 800 m, which in winter causes this region to receive the largest annual snowfall on the Island (500-600 cm).

All regions of Newfoundland and Labrador experience extreme weather, particularly in the winter. The two major contributing factors to these extreme conditions are the proximity of Newfoundland to several major storm tracks, and the proximity of any location on the Island, and Coastal Labrador to the ocean, where wind is relatively unimpeded by friction.

The Labrador Current and Gulf Stream are critical influences on the climate of Newfoundland. The Labrador Current flows from the Davis Strait off Western Greenland and the Labrador Sea, and keeps temperatures cool near the coast. The Labrador Current's proximity to the Gulf Stream to the south ensures abundance of fog offshore and for coastal areas, especially for the south coast, Burin, and Avalon peninsulas, as warm air flowing from the south moves across colder waters. The currents also provide a steering mechanism for developing oceanic storms, which feed off the "frontal zone" created by the contrast of water temperatures caused by the currents. The flow of cold Arctic air from the continent often enhances the frontal zone established by the ocean currents, leading to rapid development of storms in our region.

The climatology of Newfoundland and Labrador can naturally be divided into the following regions: Avalon and Bonavista Peninsulas, Central, West Coast, South Coast, Northern Peninsula, Coastal Labrador, and the Labrador Interior. A further breakdown is provided through the Environment Canada Public Weather Warning regions or zones for Newfoundland and Labrador shown in Figure 4.3 and Figure 4.4. There are 22 regions in Newfoundland and six in Labrador. The circles about Goose Bay, Churchill Falls, and Labrador City and Wabush are of radii about 80 km, 80 km, and 160 km.

On the marine front, Environment Canada similarly prepares forecasts for Maritime, Newfoundland, and Labrador regions as shown in Figure 4.5.

These climate region boundaries will be used in Sections 5.0 and 6.0 as a means of framing up the spatial coverage for each environment parameter discussed. The goal, for adequate monitoring of the province, then is to have at least one well-situated station with sufficient sampling frequency. Ideally, the site will have a long record for direct application in climate change study. The station(s) should be sited so as to represent the general conditions in that zone and be made as complete as possible. This then is the defined desired end state.

Additional orientation is provided in Figure 4.6 which presents a political map of the province showing boundaries, selected populated places, selected drainage, and selected roads.

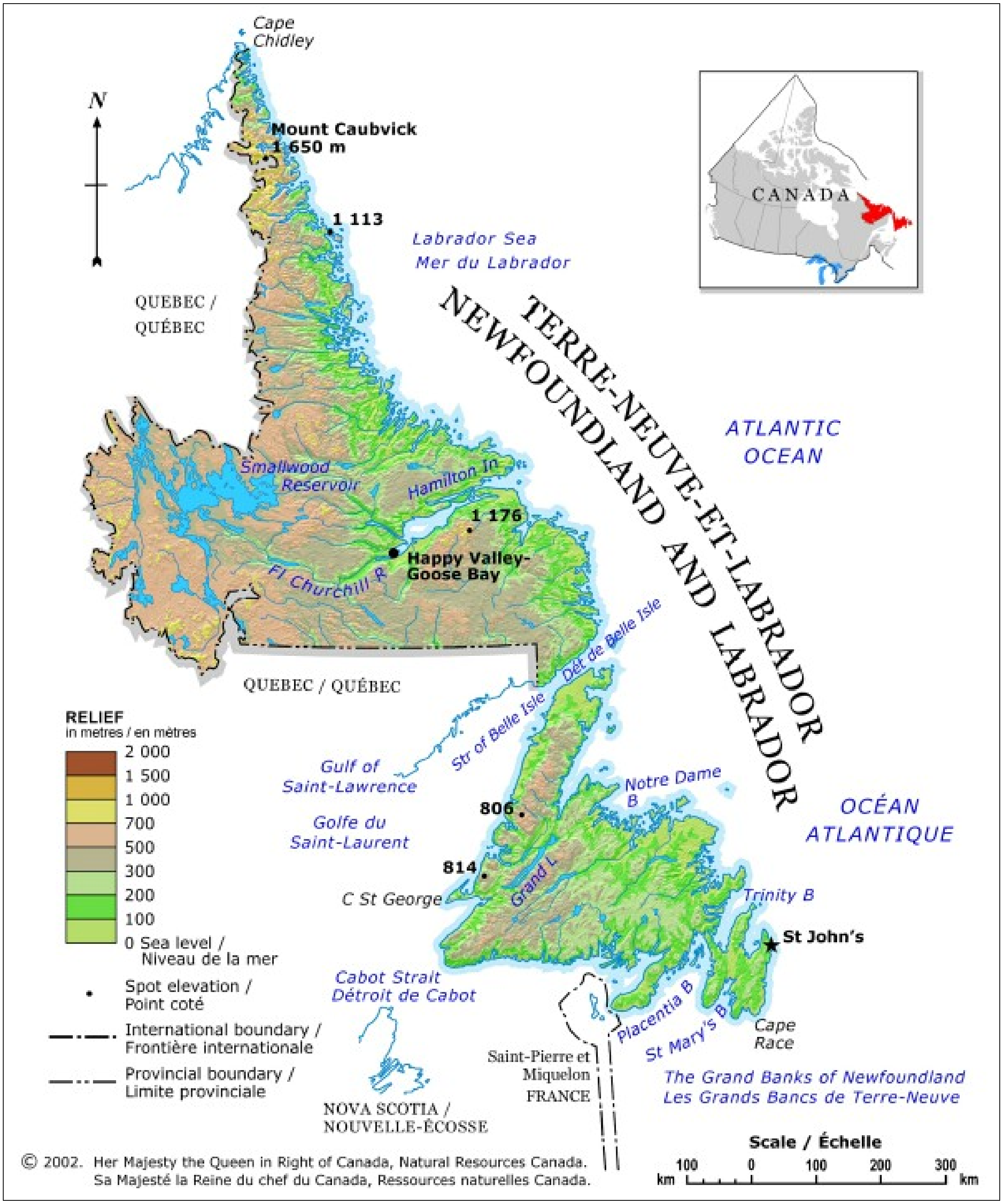

Figure 4.2 Relief Map of Newfoundland and Labrador (Source: http://atlas.nrcan.gc.ca/auth/english/maps/reference/provincesterritoriesrelief/nfld_relief)

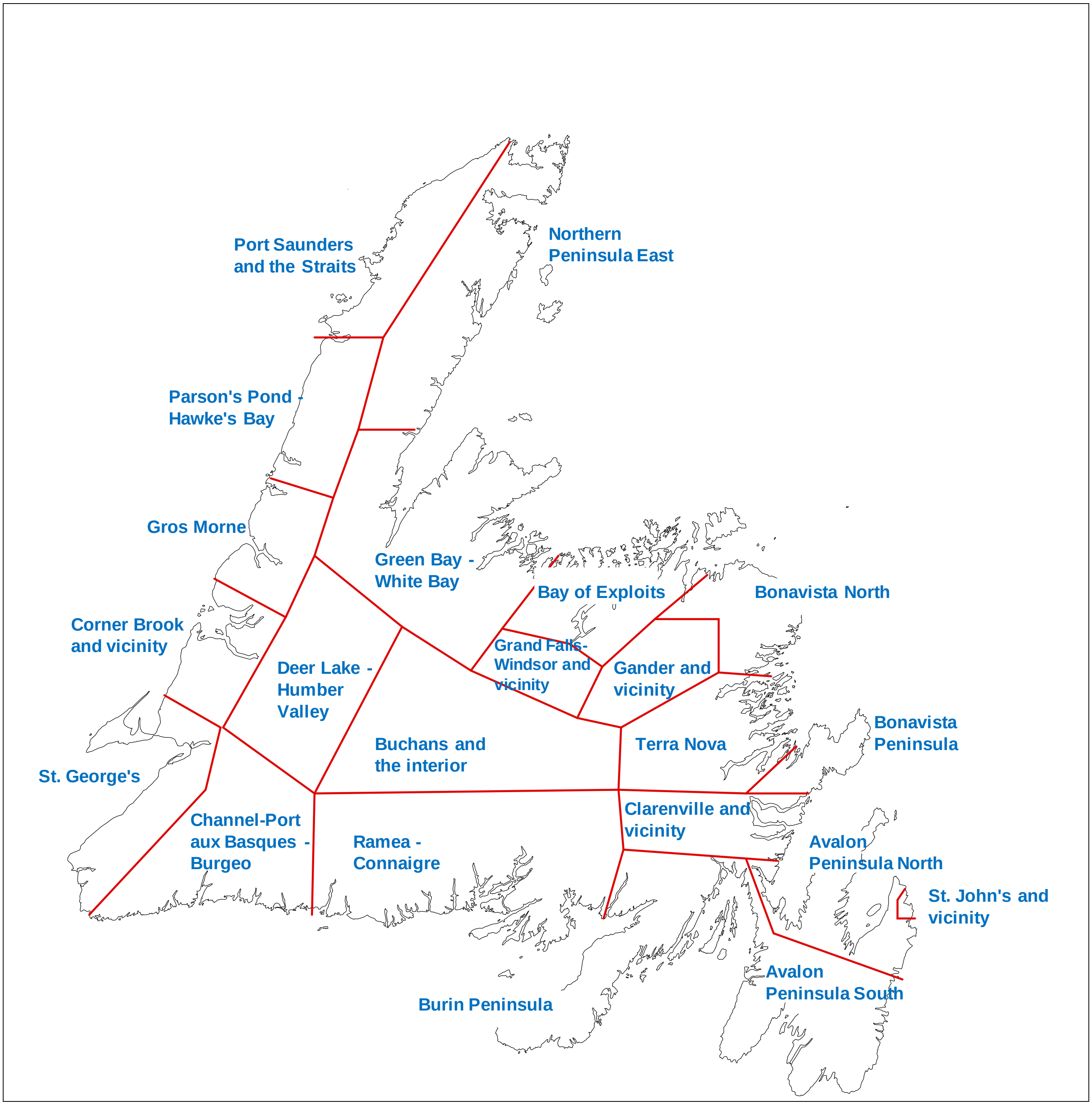

Figure 4.3 Public Weather Warning Regions for Newfoundland (Based on http://www.weatheroffice.gc.ca/warnings/nl_e.html)

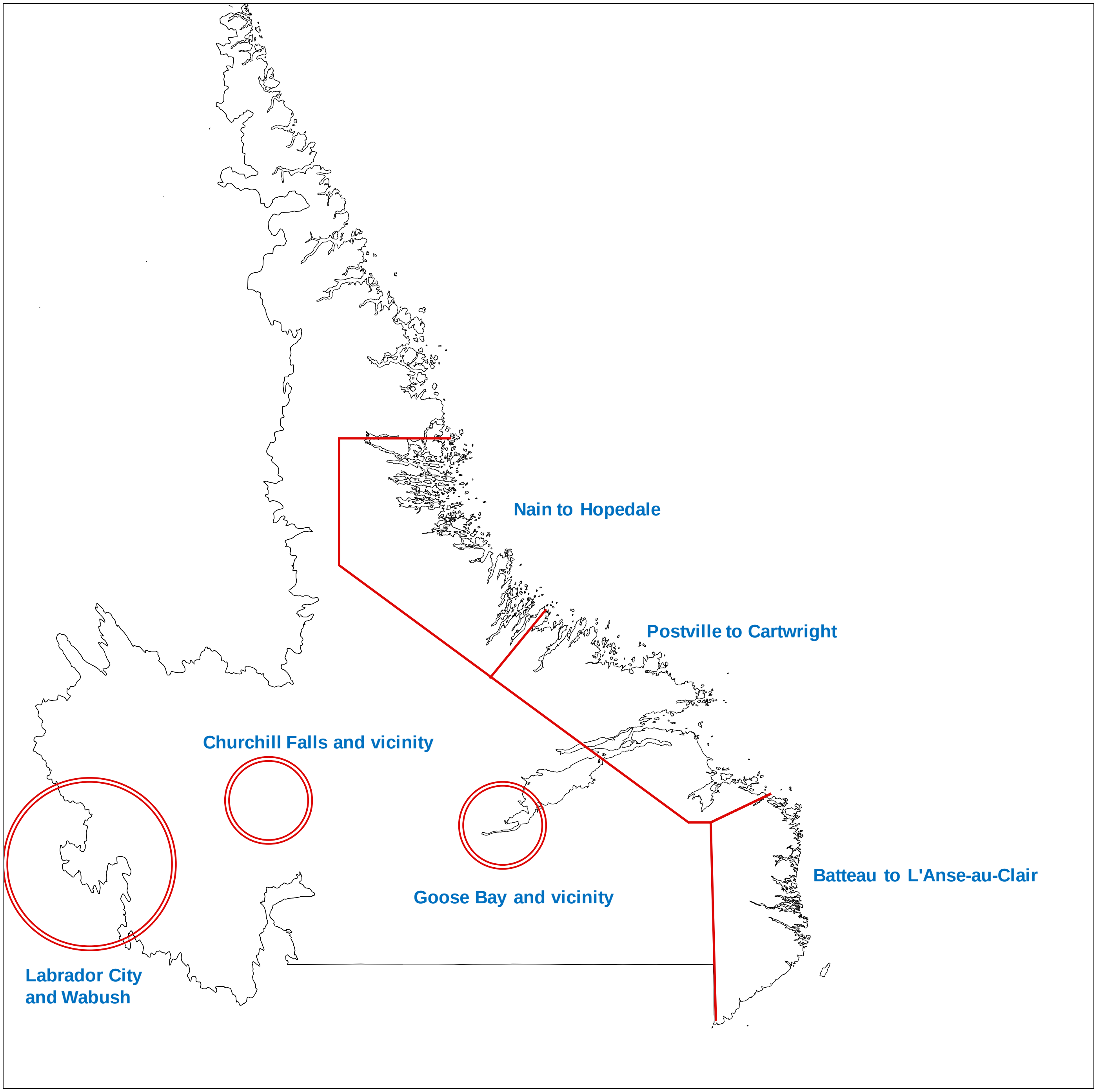

Figure 4.4 Public Weather Warning Regions for Labrador (Based on http://www.weatheroffice.gc.ca/warnings/nl_e.html)

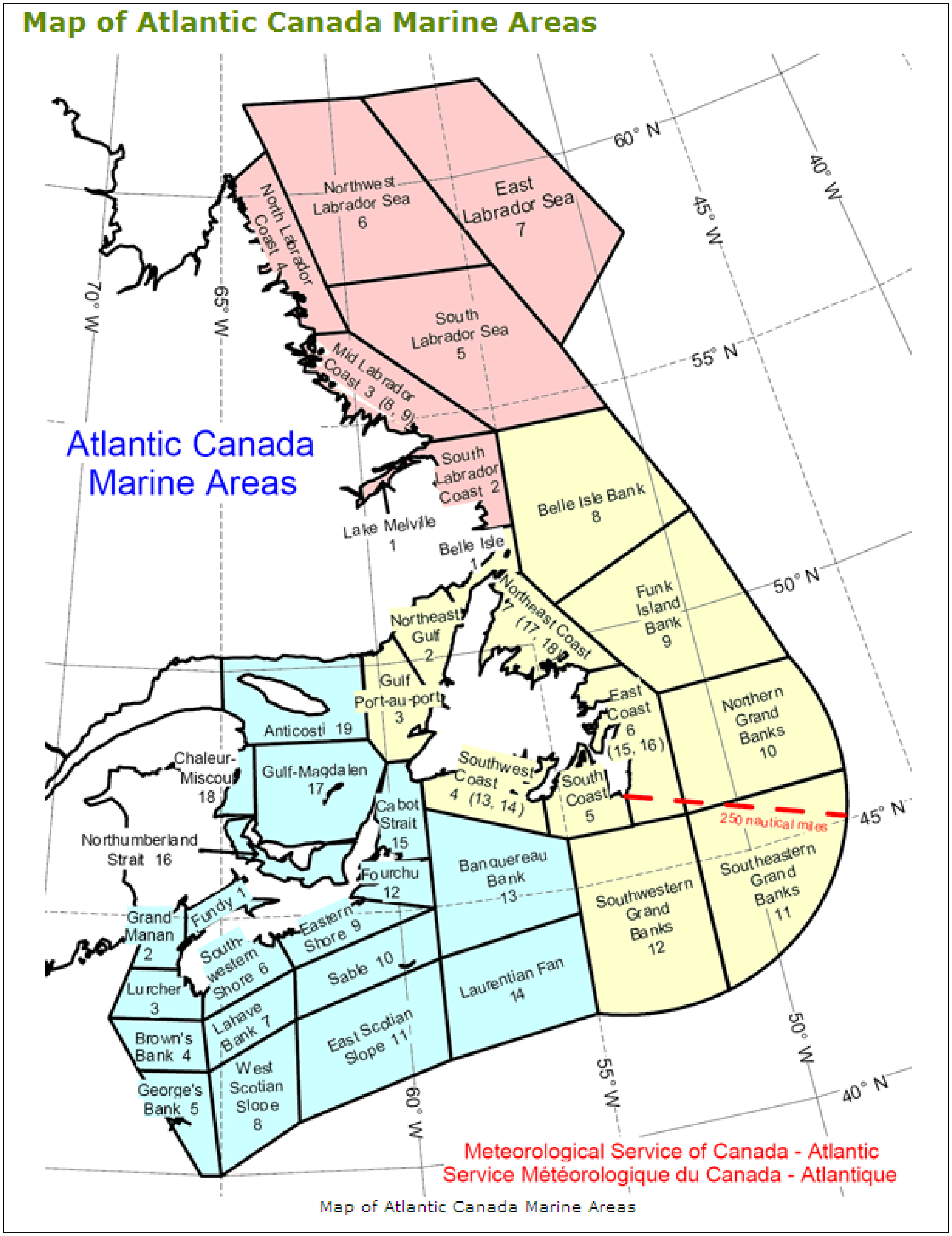

Figure 4.5 Map of Atlantic Canada Marine Forecast Areas (Source: http://www.ec.gc.ca/hurricane/default.asp?lang=En&n=CB66432B-1)

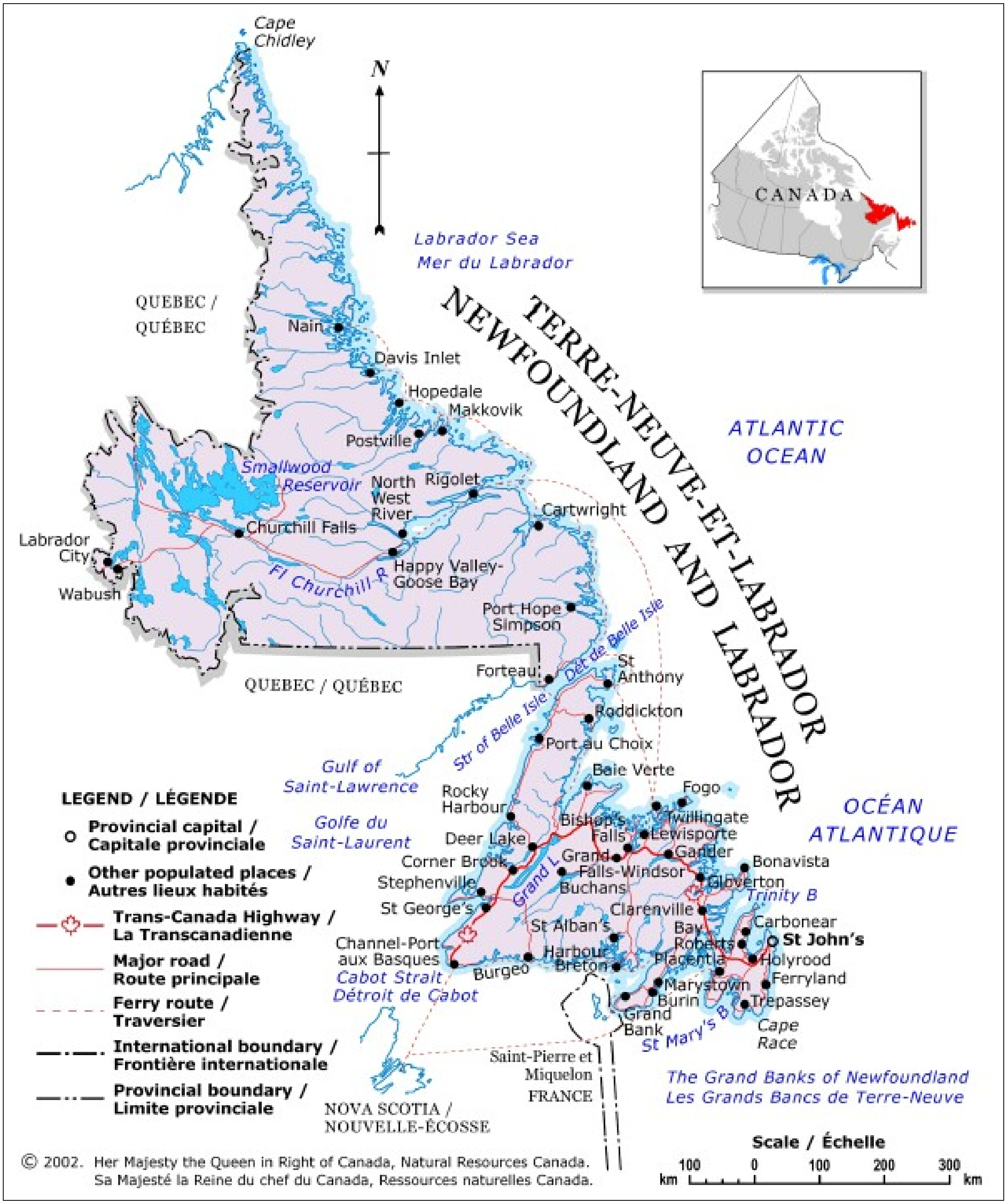

Figure 4.6 Political Map of Newfoundland and Labrador (Source: http://atlas.nrcan.gc.ca/site/english/maps/reference/provincesterritories/newfoundland)

5.0 TERRESTRIAL CLIMATE VARIABLES

5.1 Air Temperature

Air temperature measurement is of fundamental importance for climate monitoring and serves a wide range of social and economic user needs including the following:

- human health and safety (e.g., heat stress and frostbite), and also comfort indices (e.g., wind chill and humidex)
- agriculture
- effects on water quality, ecosystems, wildlife conservation
- demand and consumption of electricity for heating (and cooling) and home heating fuels (may also depend on wind and sunlight)
- heating and cooling degree days, building energy management
- drying days, for optimizing fibre quality for pulp and paper
- terrestrial and marine weather forecasting
- effects on forest fire risk (together with relative humidity, wind speed and precipitation)
- extreme weather: hot periods and droughts, cold spells
- icing potential: roads, transmission lines, marine vessels and structures
- effect on freeze-thaw cycles for snow, ice (river and sea), permafrost, and potential associated affects including flooding, slope stability
- validation and calibration of regional reanalysis and climate prediction models
- aviation: landing and take-off operations and helicopter air density estimations
- road, rail (Labrador), and marine transportation

Table 5.1 provides one brief illustration of the large range of air temperature conditions experienced in the province. In addition to seasonal and inter-annual temperature variations, air temperature monitoring on time scales of an hour is required for many of the needs noted above.

Table 5.1 St. John's, Nain Air Temperatures (Source: Environment Canada, Canadian Climate Normals 1971-2000)

	St. John's	Nain
Daily Mean (°C)	-5.4 (Feb) to 15.5 (Aug)	-18.5 (Jan) to 10.7 (Aug)
Extreme Minimum (°C)	-23.8 (Feb 1990)	-42.5 (Jan 1995)
Extreme Maximum (°C)	31.5 (Jul 1983)	33.3 (Jun 1999, Jul 2000)

Air temperature is a primary climate change indicator. Globally, 2010 was the 32nd consecutive year with above-normal temperatures and was also in the top three of the warmest years since observations began 160 years ago (Phillips, 2010). For St. John's, the mean annual air temperature was 6.45 °C in 2010, the second warmest year on record (6.6 °C degrees in 1999 was the warmest). The historical annual daily temperature is 4.7 °C. The mean daily air temperature for December 2010 was 3.4 °C; this was the warmest December mean on record. The mean overnight low (minimum temperature) in

December 2010 was 1.6 °C, the only December on record with a mean minimum temperature above 0 °C.

Figure 5.1 summarizes the number of active, seasonal fire weather and RWIS, and inactive terrestrial air temperature monitoring stations in the province, by length of measurement record.

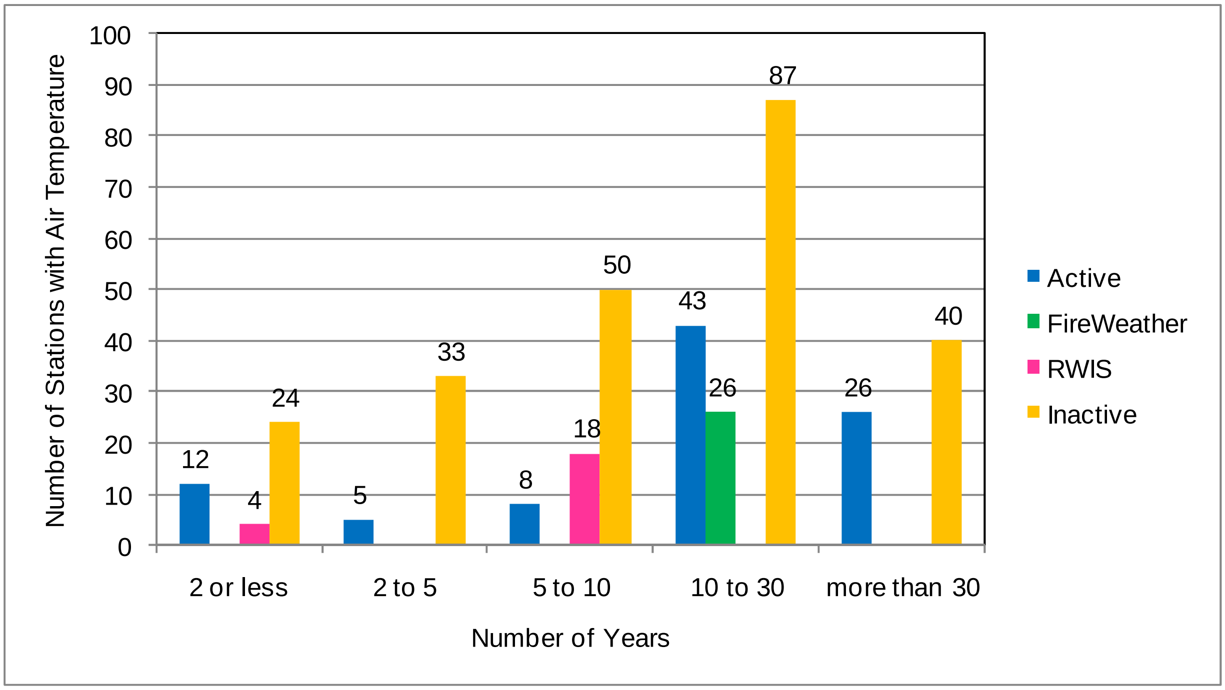

Figure 5.1 Newfoundland and Labrador Stations Monitoring Air Temperature: Number of Years

Of the 94 active stations, 69 have at least 10 years of record, and 26 with more than 30 years. Environment Canada, Provincial real time water resources data network, and Water Resources of Canada stations comprise the majority of these. There are 48 seasonal (RWIS and fire weather) stations active all with record lengths less than 30 years. Sites that have more than 30 years of record and are still active are particularly valuable from a climate change monitoring perspective since they have a long past record.

Figure 5.2 and Figure 5.3 illustrate the spatial coverage of active, inactive, and seasonal stations for the island of Newfoundland, and for Labrador. The size of each marker is proportional to the station record length for the particular climate variable shown, in this case air temperature[2]. A further aspect of these figures is they provide a visualization of the 'history' of stations for nearby locations (e.g., Gander and St. John's in particular) which is shown through the circle sizes, with smaller (shorter history) circles placed on top. As noted in Section 4.0, the (orange) inactive history may appear vast in some regions of the province in contrast to the blue active stations; however, it is important to realize the inactive

[2] i.e., some stations have much longer record length for one or several parameters, e.g., air temperature, than others, e.g., precipitation intensity

record spans many years and stations shown may not have been active at the same time. Therefore, while the past coverage is of general interest, a direct comparison of active-inactive stations is not possible with this visualization.

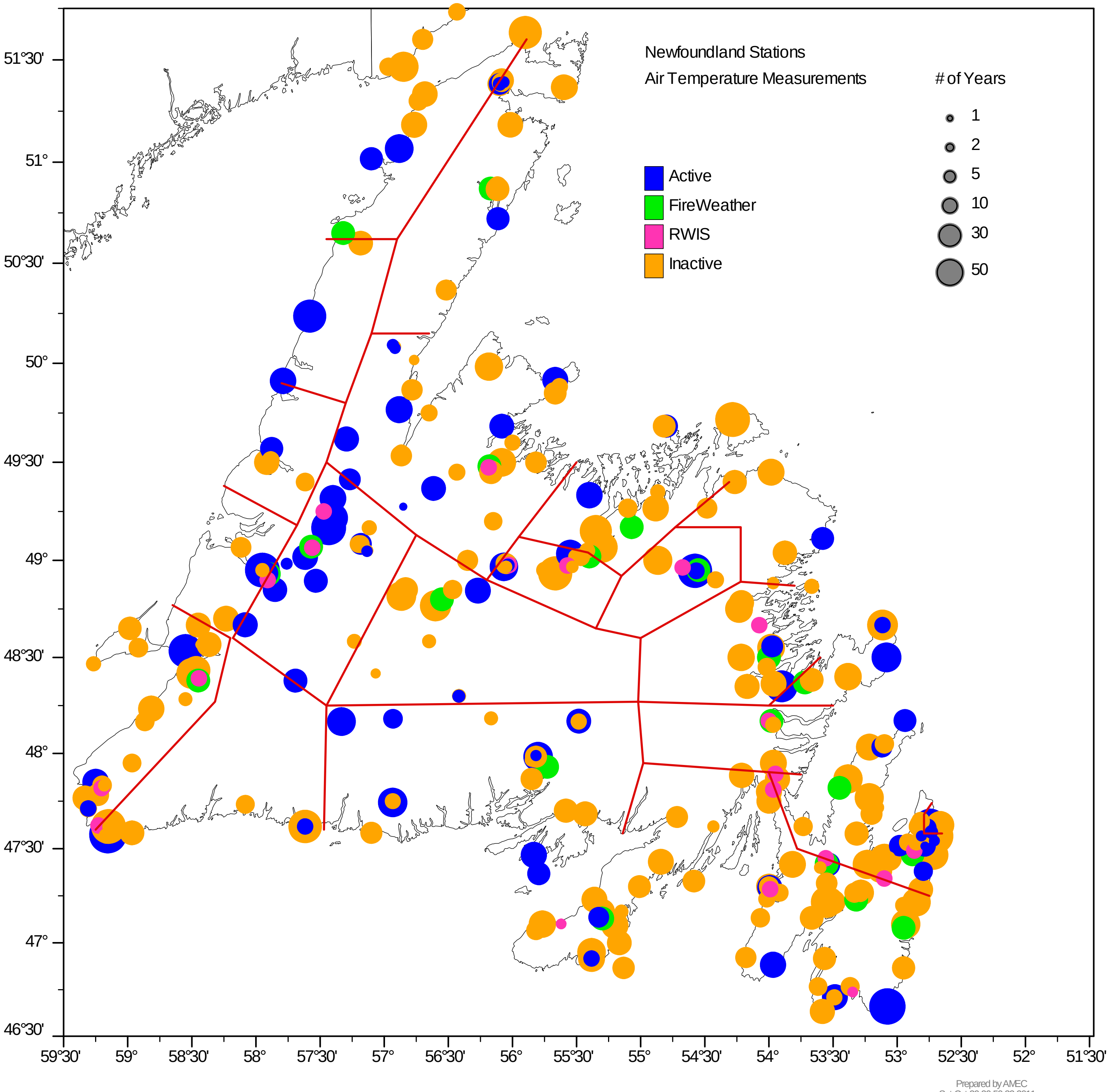

Figure 5.2 Climate Stations Monitoring Air Temperature, Newfoundland

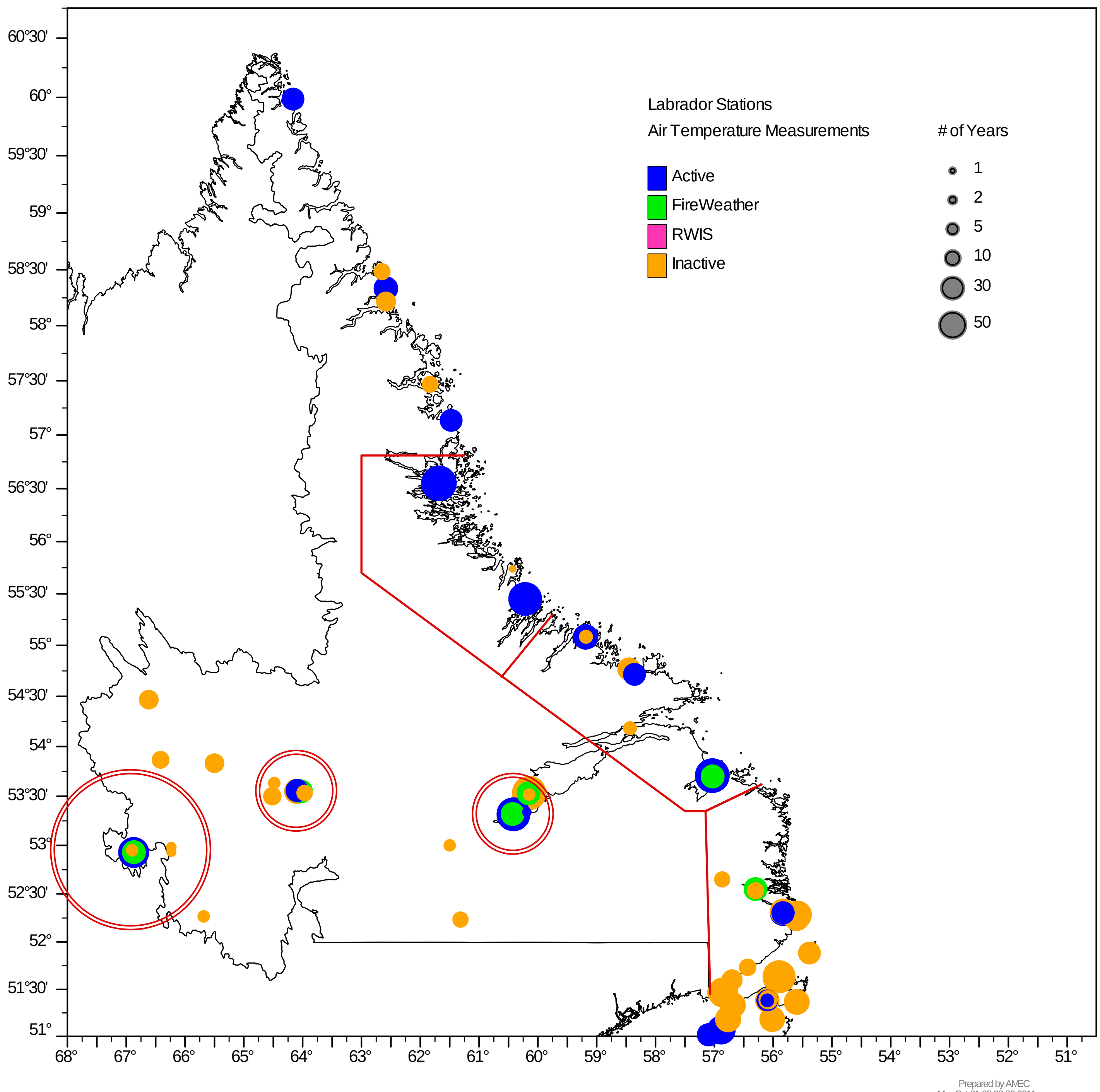

Figure 5.3 Climate Stations Monitoring Air Temperature, Labrador

Although inactive sites offer little utility going forward in examining climate change, the historical observations are still of inherent value and may be useful in filling data gaps that might exist in otherwise active station records. These comments apply for the other similar maps in this report.

As illustrated in Figure 5.2 and Figure 5.3, air temperature is well-monitored in the province, with at least one station (and generally several stations) active year-round in all but one of the forecast warning regions (shown in red on the maps). The sole exception is on the island for the region of *Clarenville and vicinity*. Though there is no year-round measurement here, there are seasonal fire weather and RWIS stations at Clarenville. Many active stations are located in *Deer Lake - Humber Valley*.

In Labrador, there is at least one station measuring air temperature in all six Environment Canada forecast regions. There are three additional stations located along the coast north of Nain. Potential monitoring gaps exist for higher elevation locations and inland monitoring outside of the communities of Goose Bay, Churchill Falls, Labrador City and Wabush. This lack of coverage would most likely be limited to larger scale user needs, such as ecological or wildlife studies.

<u>Conclusion – Air Temperature</u>

Due to the fundamental importance of air temperature measurement in climatology and meteorology, and the relative ease in measurement, most observation stations across the province record air temperature. Spatial coverage of observation locations, therefore, is generally evenly distributed across the province and is presently quite good; based on a comparison of coverage with the Environment Canada public weather forecast regions, 27 of 28 regions have active air temperature monitoring in place. The one region with a gap in year round observation points in the eastern half of central Newfoundland, near Clarenville, is partially compensated by seasonal station coverage.

5.2 Precipitation

Precipitation, both rain and snow, is essential for maintaining life on Earth. Excessive, as well as deficient, precipitation may cause loss of life, property damage (e.g., flooding, excessive snow on roofs) and crop damage, resulting in widespread socio-economic hardships. Precipitation monitoring serves a wide range of user needs for the province, including:

- agriculture
- effects on water quality, ecosystems, and wildlife conservation
- water reservoir levels and hydroelectric generation potential
- flooding and flood forecasting
- effects on forest fire risk (together with relative humidity, wind speed, and air temperature)
- extreme weather: droughts, storms
- effect on freeze-thaw cycles for snow, ice (river and sea), permafrost, and potential associated affects including flooding and slope stability
- development of Intensity-Duration-Frequency Curves, short duration rainfall intensity statistics, used for sizing and designing drainage systems, road culverts, and storm sewer systems to

structurally accommodate and safely carry water runoff (Section 7.1), and elsewhere in engineering buildings, etc.

- validation and calibration of regional reanalysis and climate prediction models
- road, rail (Labrador), and marine transportation

As part of the hydrologic cycle, water vapour evaporated over the Earth's oceans and lakes is partially recondensed and released locally in the form of precipitation and partially transported away from the place of origin. The continental land surface receives its moisture supply via surface precipitation, mainly from the import of moisture from adjacent oceans. Precipitation plays an important role in the Earth's climate control through its influence on ocean temperature and circulation. Input of fresh water from precipitation on the ocean surface may alter the salinity, resulting in alterations of ocean dynamics. Ocean circulation is extremely complex. The ocean temperature is the main factor in bringing about modified ocean currents, and hence impact on land climate regimes and species shifts. Solar heating is also a major influence. Persistent weather patterns in the Pacific lead to major temperature changes and then ocean circulation changes, such as those that occur quasi-periodically like El Niño and La Niña.

The 2007 Intergovernmental Panel on Climate Change (IPCC) report noted with a high confidence that the effects of climate change will produce more frequent heavier precipitation events leading to an increased risk of flooding. Long-term precipitation trends from 1900 to 2005 have been studied and a significant increase in precipitation was observed in eastern sections of North and South America. Based on long-term models, it has been determined that there is a strong likelihood that future tropical storms will become more intense with larger peak wind speeds and heavier precipitation associated with ongoing increases in tropical sea surface temperatures. According to the IPCC, an increase in the average global temperature is very likely to lead to changes in precipitation and atmospheric moisture because of changes in atmospheric circulation and increases in evaporation and water vapour.

Precipitation amounts and precipitation intensity, or rate can change quickly and vary significantly from one location to another within a region affected by a passing weather system. For example, thundershowers, which last on the order of several hours, can produce very heavy precipitation over a swath of less than a kilometre along their path, while major storm systems covering thousands of square kilometres may generate a lower rate of fall but last several days. Because of this wide variability, the long-term, accurate mapping of global precipitation is a difficult task. To obtain a global rainfall map, land-based rain gauge data, satellite-derived oceanic rainfall estimates, and model-generated hypothetical rainfalls are often blended in an optimal way to minimize biases. The results show there is strong year to year variability in the global precipitation pattern.

Two sections below present specific analysis and assessment of precipitation amount and precipitation intensity monitoring coverage in the province.

Surface observations of precipitation therefore also play a vital role in the validation and calibration of satellite remote sensing and model-based estimates of large-scale precipitation patterns. Rainfall measurements from rain gauge networks have been traditionally regarded as the "ground truth" for precipitation data. In recent decades, ground-based radar spatial estimates have also been used to fill in sparse rain gauge-derived precipitation data, though issues remain for this approach in Newfoundland and Labrador.

Environment Canada (EC) currently operates a network of 31 Doppler radar sites across Canada, including two in Newfoundland and Labrador installed at Marble Mountain and Holyrood (Figure 5.4). The network's primary purpose is the early detection of developing thunderstorms and high impact weather, as well the tracking of precipitation. Each radar has a radial range of 256 km from the radar site to detect reflectivity (i.e., precipitation), but radar reflectivity towards the edge of the radar beam is generally accepted to be considerably less accurate. Even though the Holyrood and Marble Mountain radar beams overlap over central regions of Newfoundland, they are often unable to properly detect precipitation in these areas. This is due to the larger distance from the radar beam origin, thus creating a void over central sections of the island where precipitation can go largely undetected. The area surrounding the Holyrood radar site presents challenging topography; precipitation is not accurately detected in the southeast quadrant due to the shadow of the surrounding hills. When powerful storms approach Newfoundland from the southeast, no precipitation is displayed while heavy precipitation is actually falling in the southeast quadrant of the radar area. No radar data are available for any part of Labrador.

Each of the Environment Canada radar sites is equipped with Doppler technology, which allows meteorologists to determine the motion of particles within precipitation systems. The maximum range for detecting these motion patterns within a storm is 128 km. These enhanced data are not made available outside of Environment Canada and are utilized primarily in the detection of tornadic motion within thunderstorm systems in the hopes of providing lead time in the prediction of tornadoes themselves. Tornadoes are a very rare occurrence in marine climates such as that of Newfoundland and Labrador where only one tornado was ever confirmed[3]. All of Canada's radars are currently single polarization, which has been almost completely abandonned in other areas of the world in favour of dual polarization radar[4]. Obviously, for most of Canada including Newfoundland and Labrador, the ability to distinguish between the different phases of precipitation, a multi-annual occurrence, would provide significantly greater returns. Environment Canada has plans to upgrade many of the radars at its sites to dual polarization. This would greatly improve the utility of radar data for precipitation detection and forecasting through most of the year.

Dual polarization radar are effectively utilized in parts of Europe and throughout the U.S. to estimate precipitation rates and predict flash flooding. The UK and Japan are particularly advanced in their use of precipitation estimation from radar data. Japan, for example, has more than 25 advanced radar stations spread over a relatively small area. With dense coverage, they are able to avoid the topography-related shadows and lack of coverage issues that are encountered in Newfoundland. More

[3] an F0 Tornado on 29 July 2007 at Wing's Point, Gander Bay

[4] single polarization radars measure the horizontal dimension only of cloud and precipitation particle motion; dual polarization radars measure both horizontal and vertical motion which, with appropriate radar data processors, yields assessments of precipitation type or phase (liquid, freezing, frozen) as well as rate of fall or intensity.

than half of Japan's stations utilize three-dimensional phased array radar with a search range of around 370 km and height-finding at 150 km. This is the level of technology and coverage that is needed to be able to use radar data quantitatively. Holyrood is being considered for upgrade to dual polarization within the next three to five years, which will improve its utility for forecasters and the public. However, there are no plans to upgrade Marble Mountain, and no plans to install any radar in Labrador.

For the world's oceans and over remote, sparsely populated, and poorer areas of the globe, precipitation is poorly observed with almost no ground data available. The database of the Global Historical Climatology Network (GHCN) contains monthly total precipitation from over 7500 stations throughout the world in order to serve the needs of the climate change community.

In Newfoundland and Labrador, there is particular interest in better understanding and future planning with the high frequency of recent extreme rain events. Extreme precipitation increases flood risk, a primary consideration for the province's roads, rail lines, drainage, and municipal infrastructures and can affect human and social well being and introduce added economic costs.

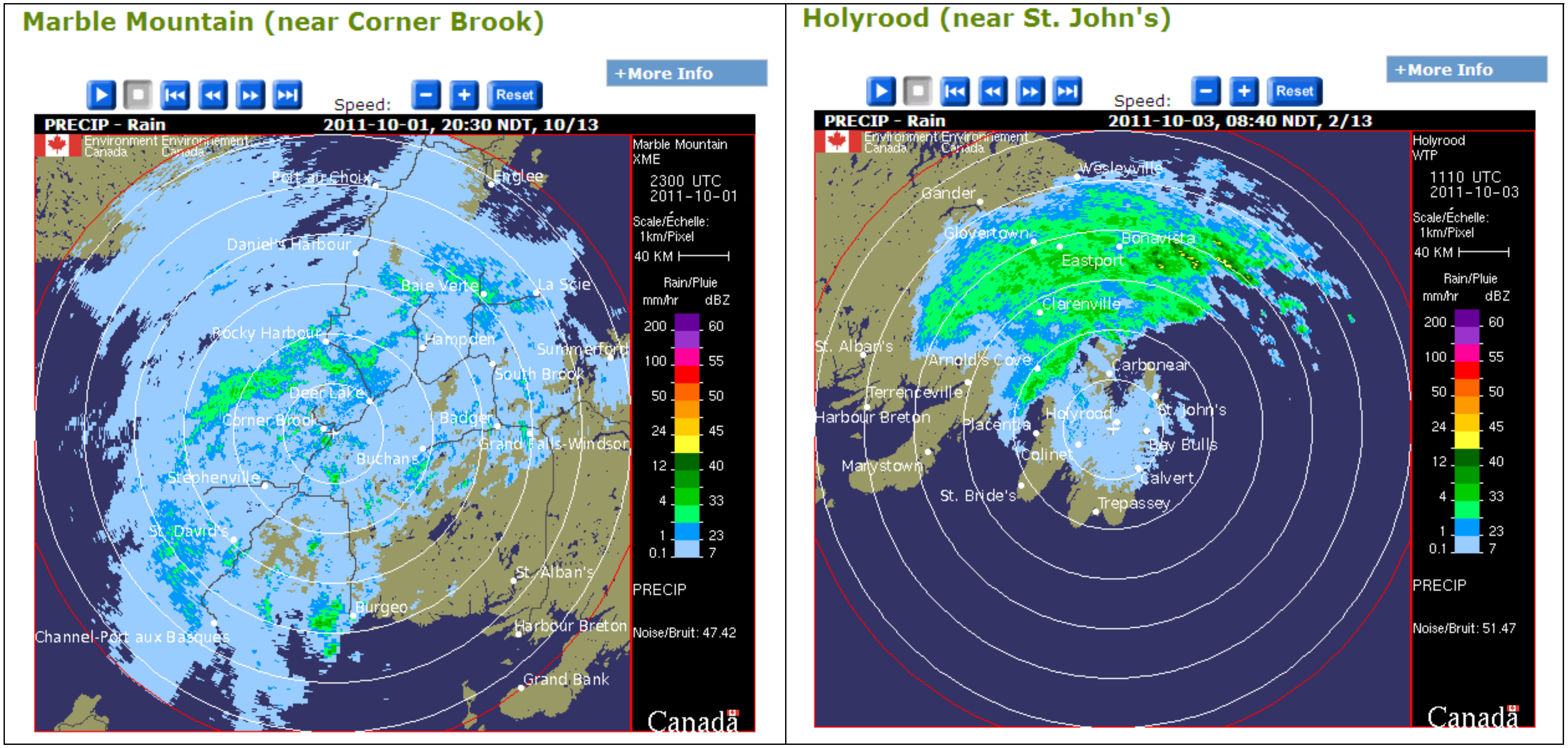

Figure 5.4 Canadian Weather Radar: Marble Mountain, Holyrood (Source: Canadian Historical Weather Radar, http://www.climate.weatheroffice.gc.ca/radar/index_e.html)

Precipitation Amount

Table 5.5 summarizes the number of active, seasonal fire weather and RWIS, and inactive terrestrial stations monitoring precipitation amount, by length of measurement record. Of the 81 active stations, there are 66 with more than 10 years of record, including 25 with more than 30 years. An additional 26 seasonal fire weather stations provide precipitation amounts over record lengths of 10 to 30 years. As noted for air temperature in Section 5.1, active sites with more than 30 years of record are particularly valuable from a climate change monitoring perspective since they have a long historical record.

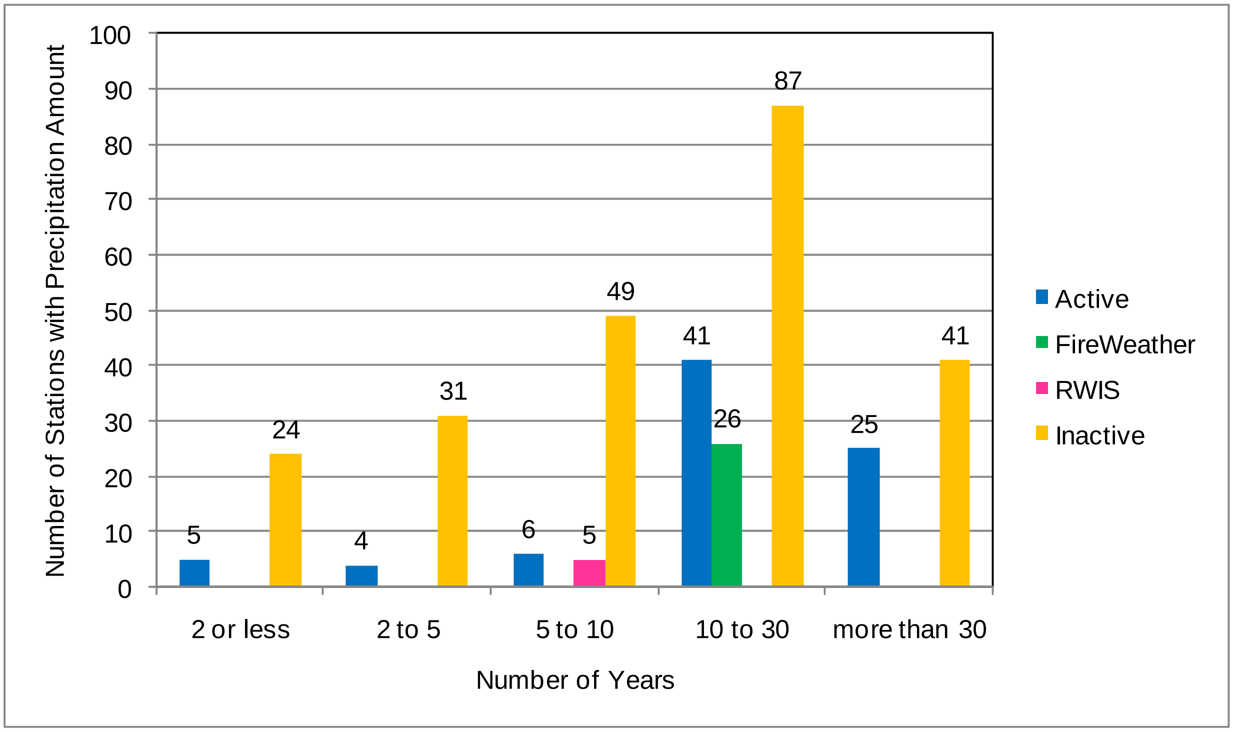

Figure 5.5 Newfoundland and Labrador Stations Monitoring Precipitation Amount: Number of Years

The spatial coverage of active precipitation stations are shown in Figure 5.6 and Figure 5.7 for the island of Newfoundland, and for Labrador. The size of each marker is proportional to the station record length for precipitation amount. As noted in Section 4.0, the (orange) inactive history appears vast in contrast to the blue active stations in some parts of the province. However, it is important to realize the inactive record spans many years and stations shown may not have been active at the same time.

The station coverage for precipitation amount is good in the province, with at least one station active year-round in all but two of the forecast warning regions (shown in red on the maps) in Newfoundland. The exceptions are for the regions of *Buchans and the interior*, and *Clarenville and vicinity* (see Figure 4.3 for region names and locations); however, there are seasonal fire weather stations at Millertown and Clarenville for which precipitation amounts are monitored. There are over half a dozen active stations in *Deer Lake - Humber Valley*.

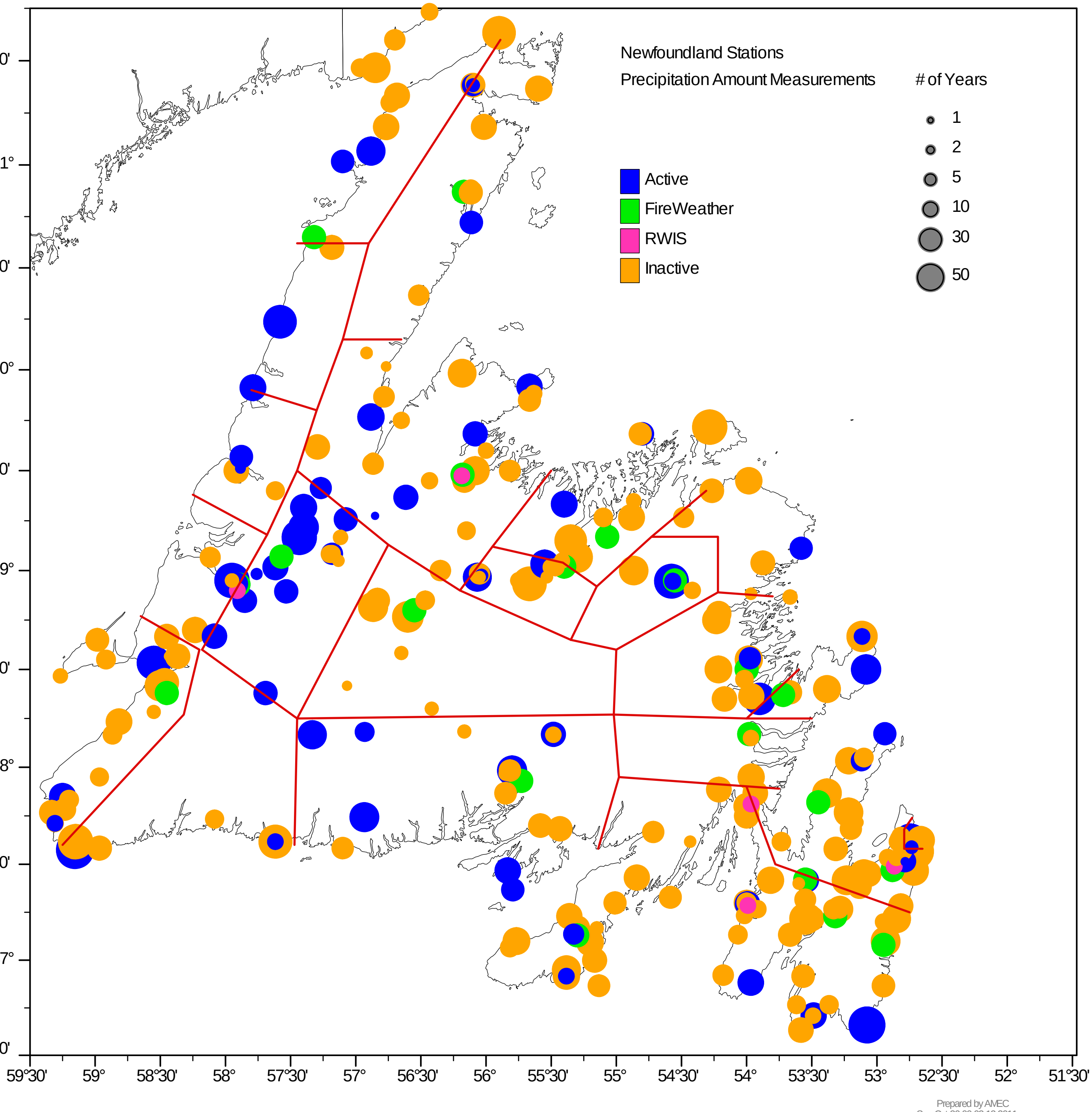

Figure 5.6 Climate Stations Monitoring Precipitation Amount, Newfoundland

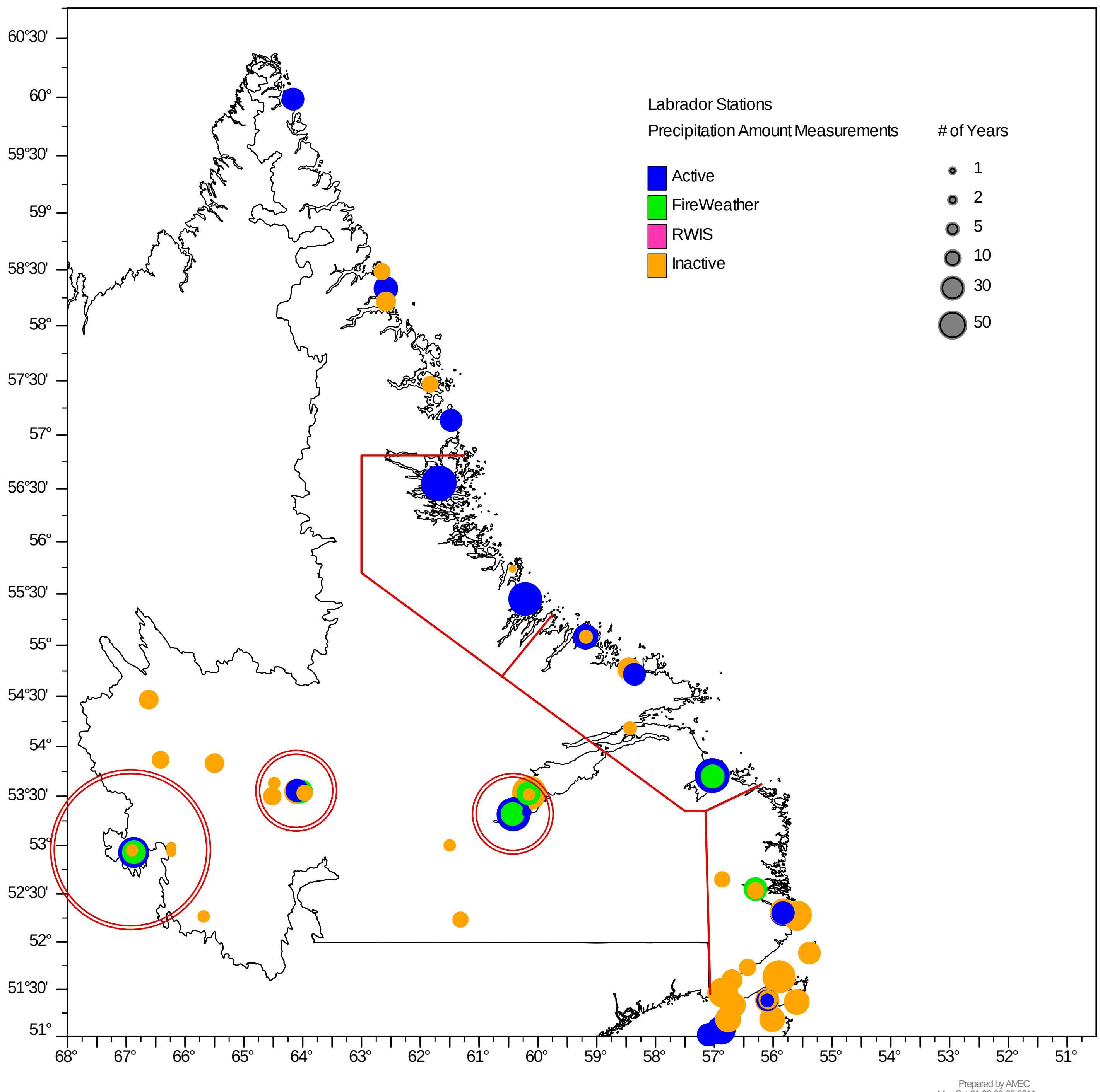

Figure 5.7 Climate Stations Monitoring Precipitation Amount, Labrador

In Labrador (Figure 5.7), there is at least one station measuring precipitation amount in all six Environment Canada forecast regions. There are three additional stations located along the coast north of Nain. Outside of the public forecast regions, precipitation measurements are absent for higher elevations inland from the coast, and also inland outside of Goose Bay, Churchill Falls, Labrador City and Wabush. This lack of coverage would most likely be limited to larger scale user needs, such as ecological or wildlife studies particularly over these larger areas of Labrador.

Conclusion – Precipitation Amount

Precipitation over the province is largely a result of large scale synoptic (on the order of 1000 sq km) weather systems given that precipitation from pure convective forces is much less common. However, there is considerable variation in exposure to such storms for different parts of the island; plus there are significant orographic upslope and coastal effects which can locally significantly enhance precipitation frequency and amount. Acknowledging these 'local effects', given that the vast majority of the Environment Canada public forecast regions in the province have stations actively measuring precipitation amount, it is concluded that the coverage for the province as a whole is generally adequate, with the exception being the interior portion of the island east to Clarenville and vicinity.

At the same time, there are localised interests for parts of the province which may not be adequately served. These interests include precipitation near a particular municipality, precipitation over a drainage basin or near a water reservoir. Analysis of precipitation monitoring for these particular geographical areas and user needs would either require data at that specific point or at several points representative of that location or larger scale area. Given there are potentially so many localised interests (e.g., municipalities) and some user needs involve a larger scale (e.g., effect on permafrost, verification of climate models) it is anticipated that some gaps in precipitation amount remain.

Precipitation Intensity

Precipitation *intensity* is a related, but critically different, measurement than precipitation amount. In brief, it refers to the amount of precipitation that is falling on a certain area within a certain time frame. This information is critical for decision makers in fields such as engineering, emergency response and water resource management. It is one of the most important variables for common Newfoundland and Labrador challenges such as flooding, both in the real time monitoring and response, and the long-term planning and mitigation of risks.

Precipitation intensity is measured differently than precipitation amount and it generally requires a specialized instrument. The preferred instrument, used by Environment Canada is the Tipping Bucket Rain Gauge (TBRG). The TBRG provides the best depiction of the amount of precipitation falling over a set duration. There are other techniques, such as measuring total accumulation and then comparing this against an elapsed time period, but it is less reliable and poorly suited to real time monitoring and decision making.

Newfoundland and Labrador has serious challenges with respect to measuring precipitation intensity as measurement is absent for much of the province.

Stations that are presently measuring precipitation intensity in the province are listed in Table 5.2[5]. Inactive stations are shown in Table 5.3. Stations are listed from north to south. In addition to station name, id, and location, the type of precipitation intensity measurement available and number of years of record are noted. For the inactive stations, the most recent year of record is also noted.

TBRG refers to tipping bucket rain gauge equipment which yield one 5 minute maximum precipitation rate each day. Precipitation Weighing Gauge equipment provide 15 minute[6] or 1 hourly precipitation rate values (i.e., 24 hourly values each day). While of limited interested due to the low frequency of measurement, for completeness, airport and volunteer monitoring programs, which employ plastic rain gauges, are also noted. These yield precipitation amounts either 6 hourly (airport) (from which a 6-hour intensity can be calculated) or once or twice a day (volunteer). The number of years refers to the instrument with greatest measurement resolution, so that additional years of data may also be available, though for a less optimal measurement type. For example, St. Lawrence has five years of TBRG data since 2007, and also precipitation weighing gauge data since 2006.

Of the 43 active sites (Table 5.2), 23 are equipped with TBRG: 18 of these are Environment Canada stations, five are stations which operate under the Provincial Real Time Water Resources Data network. Precipitation weighing gauges are the primary instrument type for 15 Environment Canada stations. Five stations listed are for airport or volunteer programs.

Of the 24 inactive precipitation intensity measurement sites, 22 stations previously operated TBRG equipment[7] and are no longer active, while six stations are still active but no longer with TBRG[8]. Fourteen of the 22 TBRG stations were discontinued between 1992 and 2007, nine of these with record lengths of over 20 years.

[5] Note that station names used in this report are the names given to the particular sites and include abbreviations such as A for airport, AUT for automatic station, NL for Newfoundland and Labrador, Int'l A for international airport, RCS for reference climate station, CS for climate station, CDA for Canadian Department of Agriculture, etc. In this way, they match the corresponding climate station inventory entries.

[6] Nine active stations reporting 15-minute precipitation rate include: Hopedale (AUT), Bonavista, Stephenville RCS, Terra Nova Nat Park CS, Wreckhouse, Burgeo NL, St Johns West Climate, Argentia (AUT), St Lawrence

[7] For Environment Canada stations, the operation of TBRG (or other instrument) is inferred by the presence of the associated data elements in the EC data archive (i.e., element 125 for 5-minute precipitation rate)

[8] Wabush Lake A, Daniels Harbour, Deer Lake A, St. John's A, Port Aux Basques, Cape Race (AUT)

Table 5.2 Stations Monitoring Precipitation Intensity

Status	Station Name	Station ID	Latitude (N)	Longitude (W)	TBRG	Precipitation Weighing Gauge	Airport and Volunteer	Number of Years
Active	Nain	8502799	56.55	61.68	x	x		8
Active	Nain A	8502800	56.55	61.68	x		x	17
Active	Hopedale (AUT)	8502400	55.45	60.22	x	x		6
Active	Makkovik A	8502NHR	55.08	59.19			x	25
Active	Cartwright	8501100	53.71	57.04			x	77
Active	Churchill Falls	8501130	53.56	64.09		x		18
Active	Churchill River at end of Mud Lake Road	NLENCL0004	53.34	60.19	x			1
Active	Goose A	8501900	53.32	60.42	x		x	51
Active	Wabush Lake A	8504175	52.93	66.87			x	51
Active	Mary's Harbour A	8502591	52.30	55.83	x	x	x	29
Active	St Anthony	8403399	51.38	56.10		x		8
Active	Plum Point	8402958	51.07	56.88			x	39
Active	Ferolle Point (AUT)	8401565	51.02	57.10		x		8
Active	Englee (AUT)	8401538	50.72	56.11		x		9
Active	Daniels Harbour	8401400	50.24	57.58		x		5
Active	Twillingate (AUT)	8404025	49.68	54.80	x	x		8
Active	Rocky Harbour CS	8403097	49.57	57.88		x		18
Active	Sandy Lake near Birchy Narrows (Camp 55)	NLENCL0005	49.27	56.85	x			0.4
Active	Deer Lake A	8401501	49.22	57.40		x	x	9
Active	Pools Island	840BR7C	49.11	53.58		x		2
Active	Humber River At Humber Village Bridge - Weather Station	NLENCL0003	48.98	57.76	x			2
Active	Exploits River at Badger East of Stadium - Weather Station	NLENCL0002	48.97	56.03	x			3
Active	Badger (AUT)	8400301	48.97	56.07	x	x		7
Active	Gander Int'l A	8401700	48.95	54.58	x		x	52
Active	Gander Airport CS	8401705	48.95	54.57	x	x		9
Active	Corner Brook	8401298	48.93	57.92		x		8
Active	Bonavista	8400601	48.67	53.11	x	x		6
Active	Stephenville RCS	8403820	48.56	58.57	x	x		3
Active	Terra Nova Nat Park CS	8403851	48.56	53.97	x	x		5
Active	Stephenville A	8403800	48.53	58.55	x		x	45
Active	Bay d'Espoir Gen Stn	8400413	47.98	55.80			x	43
Active	Wreckhouse	8404343	47.71	59.31	x	x		4
Active	St John's A	8403506	47.62	52.74		x	x	12
Active	Burgeo NL	8400801	47.62	57.62	x	x		6
Active	Pippy Park in St. Johns	NLENCL0001	47.59	52.73	x			2
Active	Port Aux Basques	8402975	47.57	59.15		x		14
Active	St John's West CDA CS	8403605	47.52	52.78		x		15
Active	St Johns West Climate	8403603	47.51	52.78	x	x		2
Active	Argentia (AUT)	8400104	47.29	53.99	x	x		9
Active	Salmonier Nature Park	8403622	47.26	53.29		x		6
Active	Winterland	8404241	47.14	55.33		x		12
Active	St Lawrence	8403619	46.92	55.38	x	x		5
Active	Cape Race (AUT)	8401000	46.66	53.08		x		8

Table 5.3 Stations Monitoring Precipitation Intensity: Inactive

Status	Station Name	Station ID	Latitude (N)	Longitude (W)	TBRG	Precipitation Weighing Gauge	Airport and Volunteer	Number of Years	Most Recent Year
Inactive	Twin Falls A	8504060	53.63	64.48	x		x	2	1968
Inactive	Churchill Falls A	8501132	53.55	64.10	x		x	24	1992
Inactive	Wabush Lake A	8504175	52.93	66.87	x			30	2003
Inactive	Battle Harbour Lor	8500398	52.25	55.60	x		x	13	1983
Inactive	St Anthony A	840C401	51.38	56.10	x		x	1	1994
Inactive	St Anthony	8403401	51.37	55.60	x			27	1996
Inactive	Daniels Harbour	8401400	50.24	57.58	x			28	1996
Inactive	La Scie	8402520	49.92	55.67	x	x	x	12	1995
Inactive	Comfort Cove	8401259	49.27	54.88	x		x	30	1996
Inactive	Deer Lake A	8401501	49.22	57.40	x			38	2002
Inactive	Buchans A	8400700	48.85	56.83	x		x	3	1965
Inactive	Terra Nova Nat Park Hq	8403852	48.55	53.98	x		x	7	1995
Inactive	St Albans	8403290	47.87	55.85	x		x	16	1983
Inactive	St Andrews	8403300	47.77	59.33	x		x	7	1966
Inactive	Wreckhouse	8404340	47.71	59.31	x			1	2007
Inactive	St John's A	8403506	47.62	52.74	x	x	x	51	1997
Inactive	Burgeo 2	8400800	47.62	57.62		x		29	1995
Inactive	Burgeo	8400798	47.62	57.62	x	x	x	29	1995
Inactive	St John's West CDA	8403600	47.52	52.78	x		x	5	1996
Inactive	Argentia A	8400102	47.30	54.00	x		x	11	1986
Inactive	Placentia	8402956	47.23	54.02	x		x	6	1976
Inactive	St Lawrence	8403616	46.92	55.38		x		3	2006
Inactive	St Lawrence	8403615	46.92	55.38	x		x	29	1996
Inactive	Cape Race (AUT)	8401000	46.66	53.08	x			2	1976

Figure 5.8 summarizes the number of active and inactive stations monitoring precipitation intensity for each of the three general measurement equipment modes, by length of measurement record. While the number of longer term (more than 30 years) active stations is limited to seven for the entire province, measurements from the 11 inactive-TBRG sites may still provide utility in ‘shoring up’ the record length of TBRG sites that are active. A specific illustration is as follows. Of the 22 stations listed as no longer active with TBRG (Table 5.3), for five of these geographical locations there are now active TBRG measurement though under a different station name and id.[9] These five locations are distinct from the six active stations no longer with TBRG noted above From the Environment Canada archives, some of these inactive-active station pairings appear to offer continuous coverage with some overlap, while gaps in coverage are clearly evident for others. For locations of the former ‘nature’ the potential therefore exists to extend the active record with historical measurements from a physically separate station that was active in the same general geographical location.

[9] Argentia (inactive: 1976-1986, active: 1987-2011), Burgeo (1966-1995, 2006-2011), St. Lawrence (1966-1997, 2006-2011), Terra Nova Nat’l Park (1962-1996, 1996-2011), Wreckhouse (2000-2006, 2006-2011)

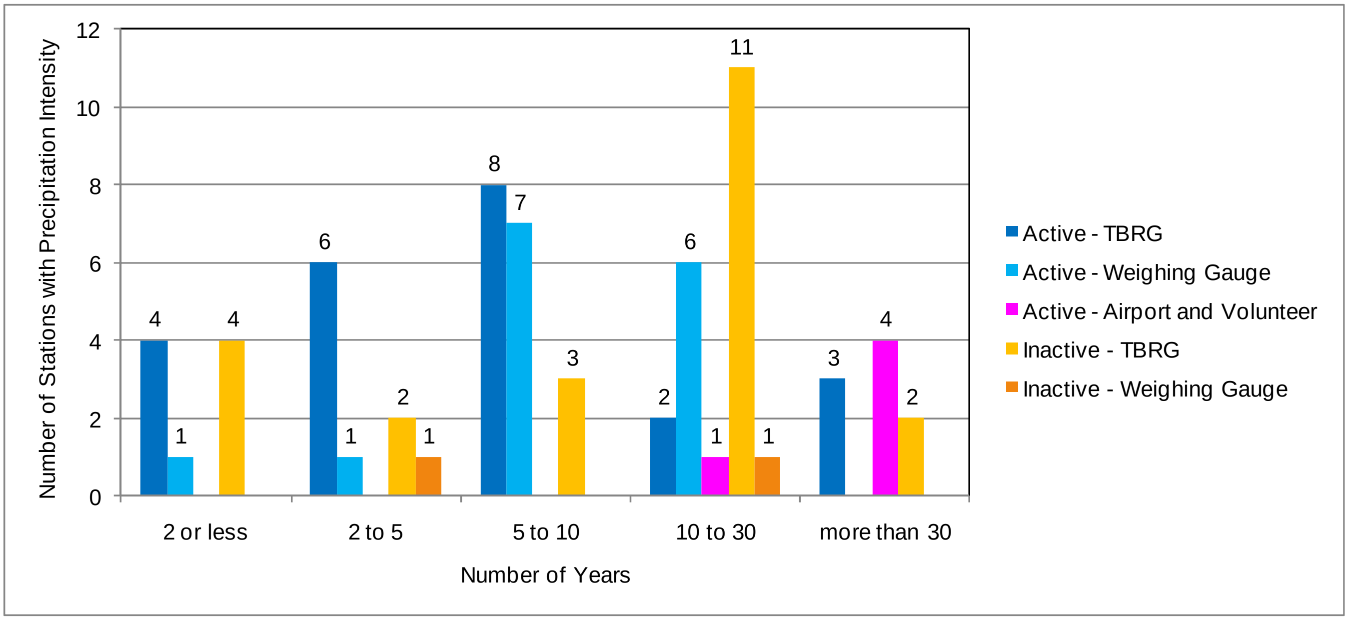

Figure 5.8 Newfoundland and Labrador Stations Monitoring Precipitation Intensity: Number of Years

Figure 5.9 and Figure 5.10 illustrate the spatial coverage of active and inactive precipitation rate stations for the island and for Labrador. The measurement type yielding the greatest resolution of data is shown. For example, the station at Nain is equipped with both TBRG and weighing gauge instruments[10]; however, one point to show TBRG at Nain is plotted.

The station coverage for precipitation intensity has significant gaps in the province. On the island, there is no active TBRG monitoring on the Northern Peninsula and the Avalon is poorly served, while in Labrador, there are no TBRG precipitation intensity measurements inland of Goose Bay. Active stations are, however, located at those regions where the greatest historical damage has occurred - Placentia, Badger (Exploits River), and Stephenville.

[10] Because the weighing gauge (sometimes referred to as an all-season gauge) is deployed throughout the year, it is particularly useful in assessing rainfall amounts when the TBRG is not available

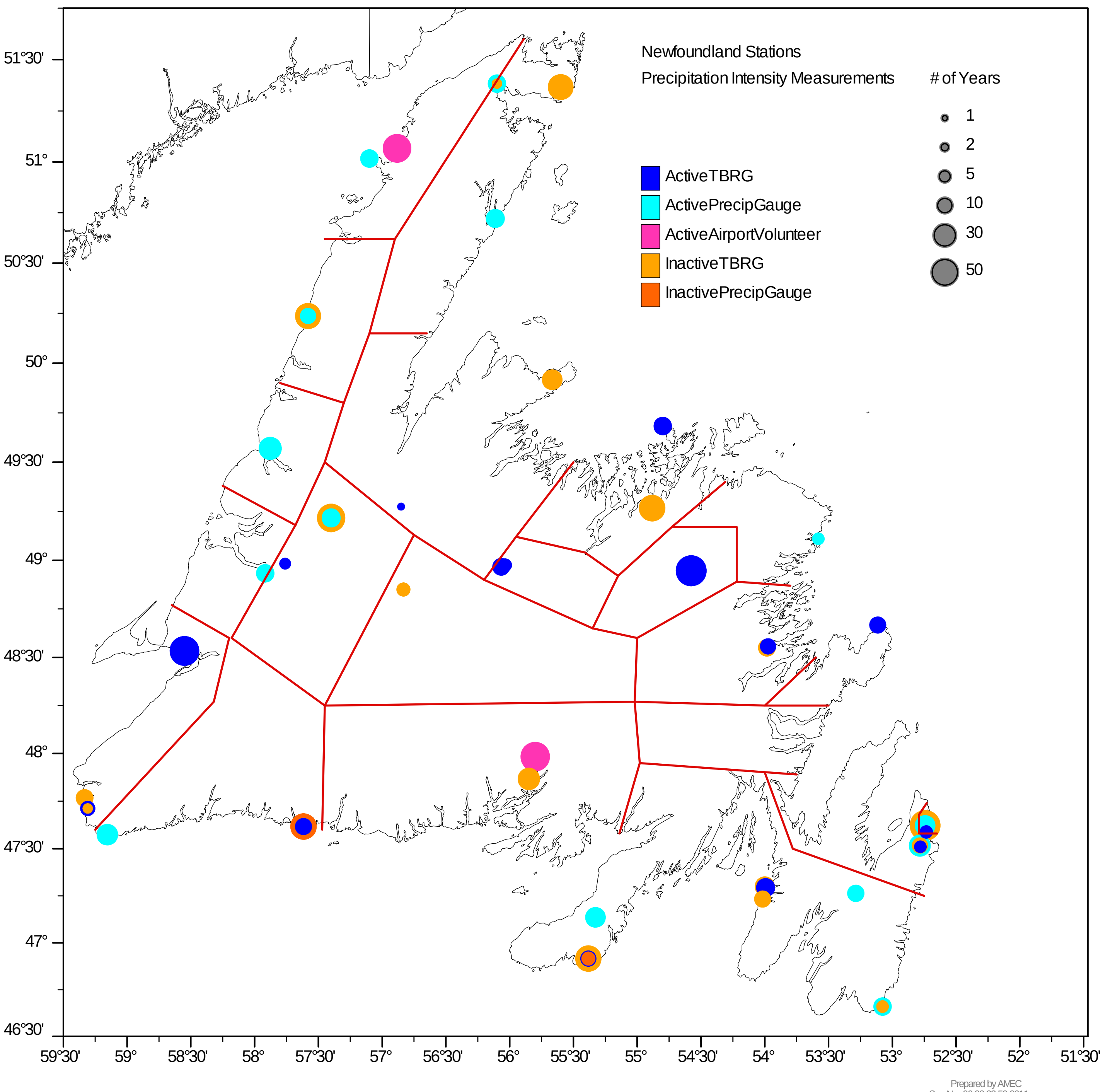

Figure 5.9 Climate Stations Monitoring Precipitation Intensity, Newfoundland

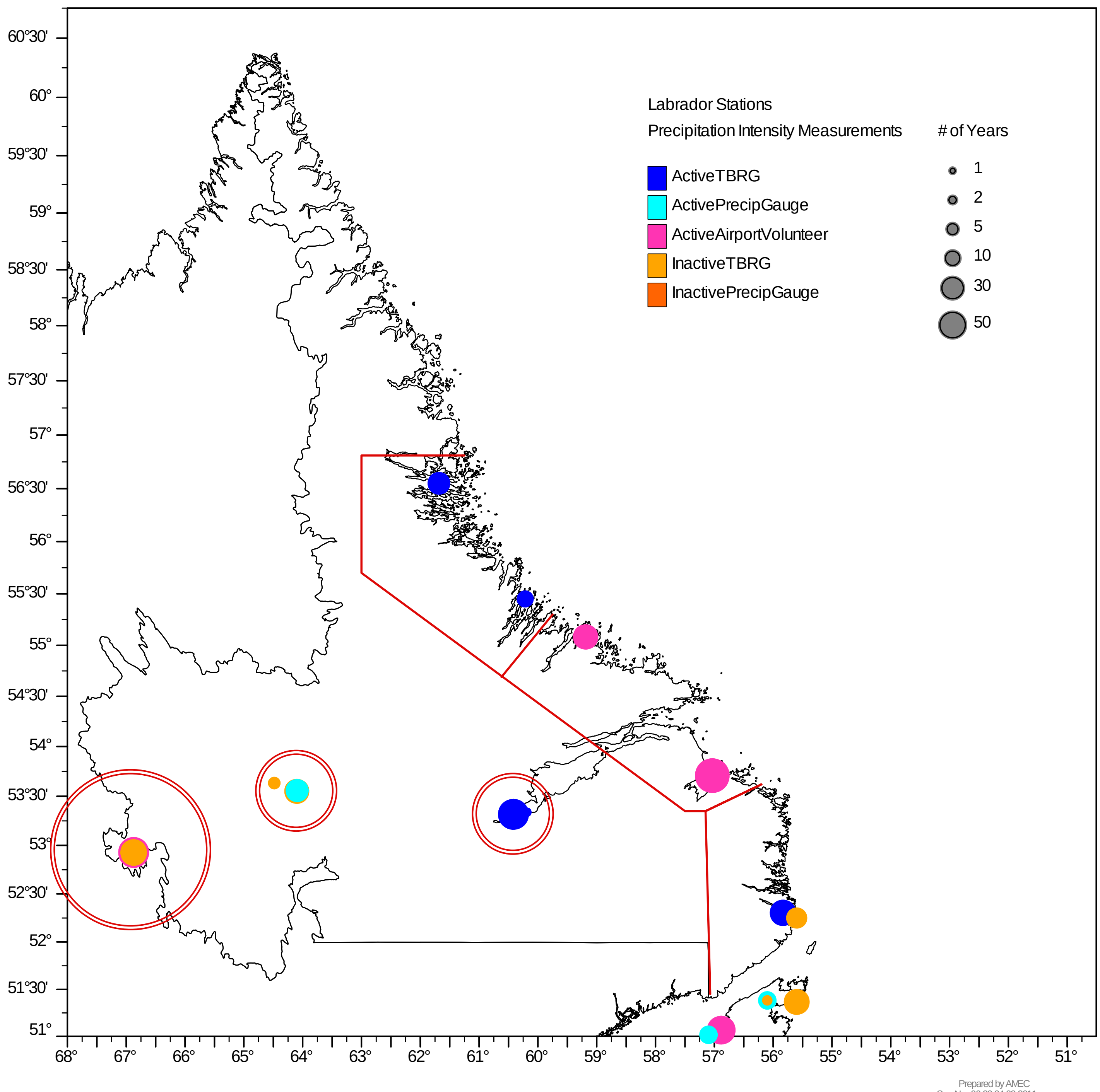

Figure 5.10 Climate Stations Monitoring Precipitation Intensity, Labrador

As summarized in Table 5.4, just 13 of the 22 forecast warning regions (or 60 %) on the island presently have stations which operate TBRG equipment. Further, if typically at least 10 years of data are required for IDF curve preparation (Section 7.1), this number of active TBRG sites is reduced to four: Nain A, Mary's Harbour A, Stephenville A, and Gander Int'l A. The continuation of the measurement records for these locations is therefore crucial. Six of the nine regions without TBRG are served by precipitation weighing gauge instrumentation, though these provide no greater resolution than 1 hourly. There is no precipitation intensity measurement for *Buchans and the interior* or *Clarenville and vicinity* while *Ramea – Connaigre* is served only with volunteer measurements once or twice a day from Bay d'Espoir Gen Stn.

In Labrador, just half of the six Environment Canada public forecast regions have stations with TBRG. *Postville to Cartwright* is only served by airport or volunteer sites and plastic rain gauge measurement. *Churchill Falls and vicinity* is served with weighing gauge measurement, while only observations six times a day at Wabush Lake A is the only active coverage afforded *Labrador City and Wabush*.

Conclusion – Precipitation Intensity

Newfoundland and Labrador has inadequate monitoring of precipitation intensity, particularly through the most accurate and preferred way to measure intensity – TBRG. The number of active TBRG station are too few and widespread, while monitoring in specific areas such as the Northern Peninsula and inland and northern Labrador is completely absent. This lack of measurement is affecting key user needs such as infrastructure design and construction, community planning and flood risk mapping.

Table 5.4 Monitoring Coverage for Precipitation Intensity with TBRG

	EC Warning Region (ref. Figure 4.3, 4.4)	Precipitation Intensity (TBRG)	Comments
1	*Port Saunders and the Straits*		weighing gauge
2	*Parson's Pond - Hawke's Bay*		weighing gauge
3	*Gros Morne*		weighing gauge
4	*Corner Brook and vicinity*		weighing gauge
5	*St. George's*	x	
6	*Channel-Port aux Basques - Burgeo*	x	
7	*Deer Lake - Humber Valley*	x	
8	*Green Bay - White Bay*	x	
9	*Northern Peninsula East*		weighing gauge
10	*Bay of Exploits*	x	
11	*Grand Falls-Windsor and vicinity*	x	
12	*Buchans and the interior*		no active measurements
13	*Ramea - Connaigre*		Bay d'Espoir Gen Stn (once or twice daily)
14	*Gander and vicinity*	x	
15	*Bonavista North*		weighing gauge
16	*Terra Nova*	x	
17	*Bonavista Peninsula*	x	
18	*Clarenville and vicinity*		no active measurements
19	*Burin Peninsula*	x	
20	*Avalon Peninsula South*	x	
21	*Avalon Peninsula North*	x	only near St. John's
22	*St. John's and vicinity*	x	
	total	13	
23	*Batteau to L'Anse-au-Clair*	x	
24	*Postville to Cartwright*		
25	*Nain to Hopedale*	x	nothing north of Nain
26	*Goose Bay and vicinity*	x	
27	*Churchill Falls and vicinity*		weighing gauge
28	*Labrador City and Wabush*		
	total	3	

5.3 Snow

The amount of snow on the ground, or snowpack, provides a number of challenges notably in road transportation and for building codes in so far as roof strength is concerned. Snow also serves as a form of natural water storage and is relevant for user needs in the province which include the following:

- drinking water supplies
- effects on water quality, ecosystems, and wildlife conservation
- agriculture
- water reservoir levels and hydroelectric generation, including interest in snow water equivalent (SWE) measurement
- groundwater resources
- flooding and flood forecasting
- terrestrial and marine weather forecasting
- extreme winter storms
- winter recreational activities, including skiing and snowmobiling
- effect on freeze-thaw cycles for snow, river ice, permafrost, and potential associated affects including flooding, and slope stability
- validation and calibration of regional reanalysis and climate prediction models
- to initialize forestry services fire weather models in spring based on abundance of ground moisture after melt
- road transportation: snow clearing and snow removal budgets are often based on expected snowfall and are adjusted based on actual amounts of snowfall

With climate change, predicted temperature increases are expected to result in more precipitation falling as rain rather than snow especially in the border seasons of fall and spring. Winter rain events can also occur in mid winter over frozen ground and so with normal run-off channels blocked thus leading to extensive flooding as has occurred in recent years. As part of these anticipated changes it is expected that snowpack will develop later, and will melt earlier than currently experienced. Changes to total seasonal snow pack or snow on ground are more difficult to pin down since the milder mid winter temperatures likely will lead to heavier snowfalls during the coldest parts of the winter. This is because milder air can hold more water vapour and produces greater amounts of snow than very cold dry air. Changes to the timing of snowmelt will impact seasonal flow patterns and may introduce increased river flooding risk for portions of the province. Therefore it is critical to accurately measure snowfall amounts and depth of snow on ground to monitor, predict, and respond where possible to changing conditions. Snow water equivalent (SWE) is a third important snow measurement: the amount of water contained within the snowpack.

<u>Snowfall</u>

Snowfall is the measured depth of newly fallen snow, usually measured using a snow ruler or snow gauge at manned climate stations. There are about 40 Environment Canada Surface Weather and

Reference Climate Station sites, usually those manned by an observer, as well as those at selected airports and through the COOLTAP[11] network of volunteers, for which daily total snowfall measurements are taken.

Depth of Snow on Ground

Figure 5.11 summarizes the number of active and inactive terrestrial stations monitoring depth of snow on ground, by length of measurement record. The figure serves to highlight the shorter record for this parameter and heightens the importance of the very meagre number of 10 active stations with a record length in the 10 to 30 years category.

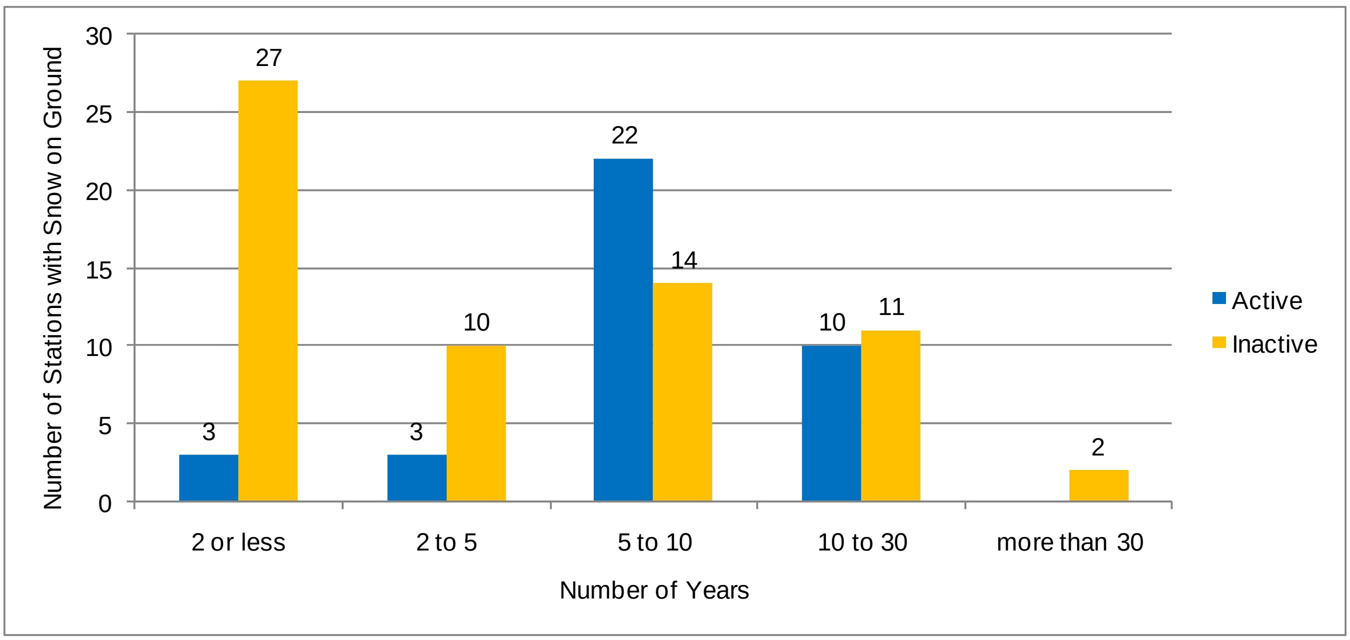

Figure 5.11 Newfoundland and Labrador Stations Monitoring Snow on Ground: Number of Years

Figure 5.12 and Figure 5.13 illustrate the spatial coverage of depth of snow on ground measurements for Newfoundland, and for Labrador. The size of each marker is proportional to the station record length[12]. A total of 38 active and 64 inactive snow on ground measurement programs are shown. The

[11] In 2004, the Meteorological Service of Canada developed a web-based application called COOLTAP (Cooperative Online Temperature and Precipitation Entry System) to collect climate information from volunteer and cooperative observers (originally part of the Temperature and Precipitation Climate Observer Network) with access to internet-enabled computers. Observers that do not have access to the internet enter their observations via a touch-tone (dial-up phone) reporting system called ONTAP-IVR. COOLTAP observations include maximum and minimum temperatures, total rainfall, snowfall, and snow depth (snow on ground) data. Observations are taken once or twice (7am and 4pm) a day.
http://climate.weatheroffice.gc.ca/prods_servs/documentation_index_e.html#note31

[12] estimated from Environment Canada historical climate data queries: actual record length, including gaps, and data quality would need to be analyzed and accurately determined

‘primary’ stations are those of Environment Canada’s Surface Weather and Reference Climate Station (RCS) networks together with four Provincial Real Time Water Resources Data network stations.

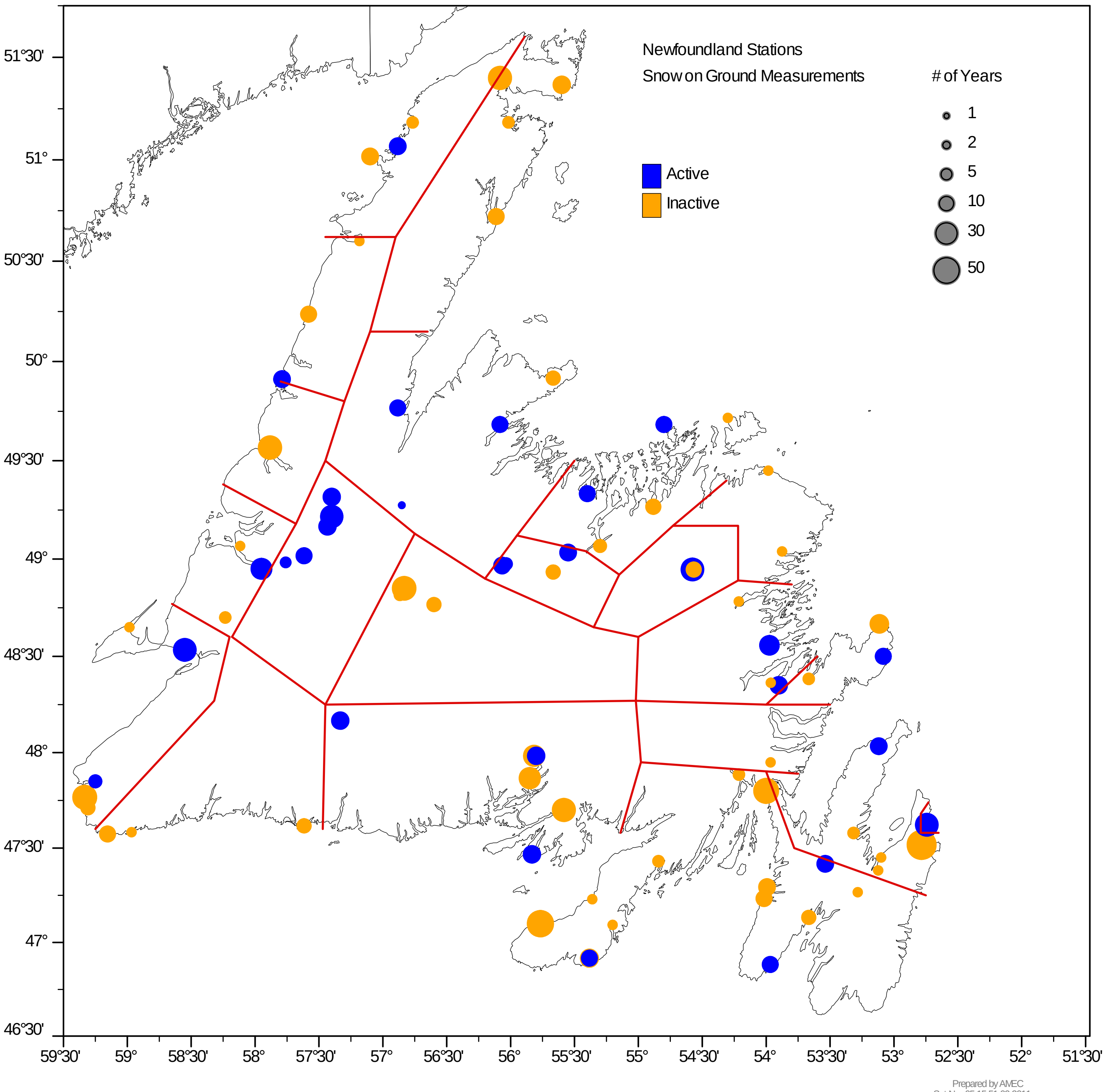

Figure 5.12 Climate Stations Monitoring Snow on Ground, Newfoundland

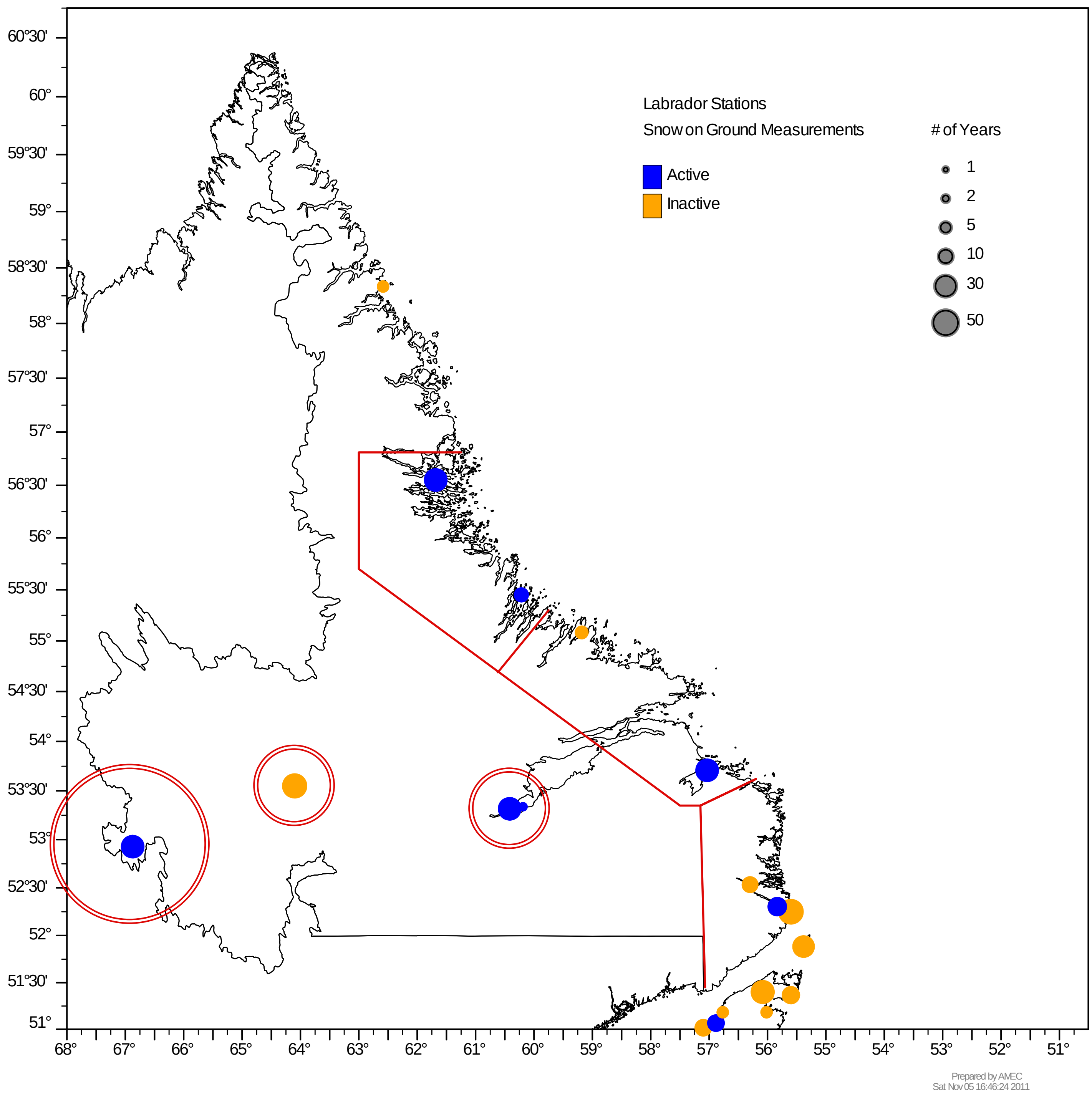

Figure 5.13 Climate Stations Monitoring Snow on Ground, Labrador

The figures show active and inactive stations independent of measurement network. A station summary is provided in Table 5.5. For a number of locations including Bonavista, St. Anthony, and St. Lawrence, data from multiple historical stations exist. For this presentation a single point and record length are indicated for each.

Table 5.5 Stations Monitoring Snow on Ground

	Active	Inactive	Active (Volunteer)	Inactive (Volunteer)
# stations on the island	11	28	19	27
# stations in Labrador	8	8	0	1
total	19	36	19	28

Snow depth is measured by meteorological technicians at four stations across the island and three in Labrador. In addition, the Environment Canada Atlantic COOLTAP volunteer program, mostly active on the island, inputs snow on ground data as well as measurements from several automatic stations around the province. A short discussion on automatic versus staffed climate stations is given in Section 8.0.

On the island, monitoring of depth of snow on ground is incomplete, being limited to less than three quarters of the Environment Canada public forecast regions (16/22 regions; see Figure 5.12 and Figure 4.3). While there are measurement locations in the northern half of the central portion of the island and along the southern portion of the west coast, there are also gaps in adjoining regions: *Gros Morne*, *Channel-Port aux Basques – Burgeo*, and *Northern Peninsula East* with no monitoring over the Long Range Mountains along the Northern Peninsula. Farther east, as with precipitation measurement , there is no monitoring for *Buchans and the interior* or *Clarenville and vicinity*, or on the northeast coast, *Bonavista North*.

In Labrador, consistent data measurements are limited to population centres, with four locations along the coast from Mary's Harbour to Nain, and two inland locations at Labrador City-Wabush and Goose Bay. Of the six Environment Canada public forecast regions for Labrador (Figure 4.4), *Churchill Falls and vicinity* is the sole region lacking depth of snow on ground. There is no depth of snow measurement north of Nain. A further observation is that higher elevations of Labrador where snowfall is generally higher are not monitored.

In addition to snow on ground monitoring station coverage, the Meteorological Service of Canada (MSC)'s Canadian Meteorological Centre (CMC) produces a daily global snow depth surface analysis chart (Figure 5.14). This type of product provides an indication of snow extent and a coarse spatial estimate of snow depth. Details of how the model considers topography the spatial resolution of the model would be useful to ascertain to confirm its utility for the province.

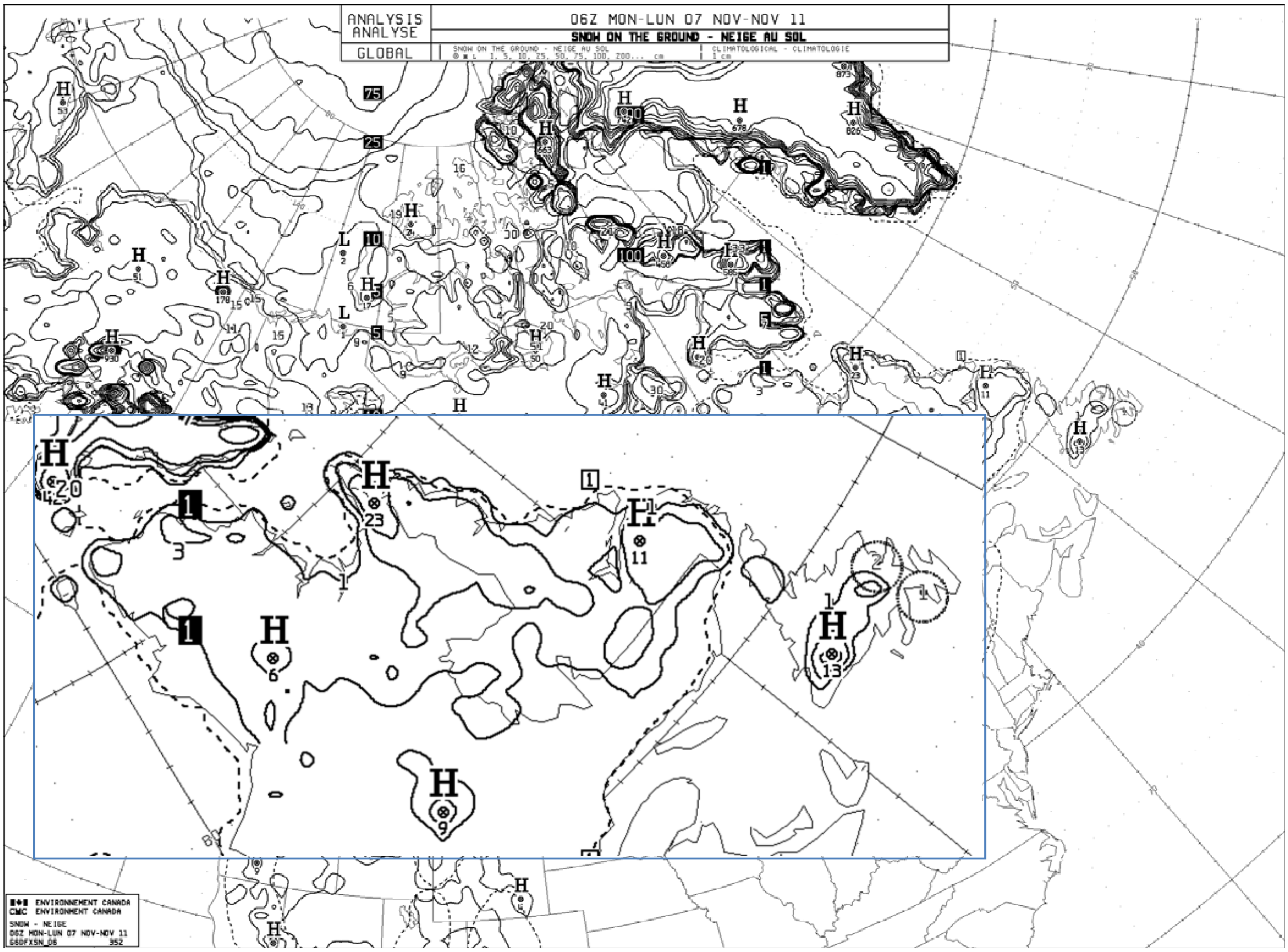

Figure 5.14 Environment Canada Snow Depth Surface Analysis Chart, 7 Nov 2011, with inset view of Newfoundland and Labrador, depth contours are in cm (Source: http://www.weatheroffice.gc.ca/analysis/index_e.html)

Snow Water Equivalent

Snow water equivalent (SWE) is an important element determined in measuring snowpack. As a rule of thumb, the water equivalent of solid precipitation can be estimated from the snow depth or snowfall amount using a 10:1 ratio (e.g., 1 cm of snow is approximately equivalent to 1 mm of water) This method can be quite inaccurate where processes in the atmosphere and on the ground can significantly alter the density of falling snow and snow already on the ground (e.g., SWE for heavy wet snow can be as high as 5:1 and range down to less than 20:1 for dry snow with very cold temperatures). Manual measurement of snow on the ground, automated instruments, or remote sensing can be used to measure SWE (e.g., the manual method typically involves melting and weighing a given sample volume of snow).

Currently snow monitoring is undertaken by various agencies on a largely user project-specific basis. There is a lack of program coordination and a need to reaffirm standards for snow water equivalent measurement across the province.

Conclusion – Snow

A comprehensive observation network for snowfall amount, depth of snow on ground, and snow water equivalent is critical for a broad range of user needs, from business development to transportation safety to resourcing. Snowfall and snow on ground measurement coverage is adequate for about three quarters of the island; however, parts of the Northern Peninsula, south coast near Port aux Basques, and portions of the interior and northeast coast are without monitoring. For Labrador, the coast south of Nain, and inland, except for Churchill Falls and vicinity where there is no monitoring, is adequately covered. Gaps remain for the unpopulated higher elevation and northern coast regions of Labrador. At the same time, measurement of snow water equivalent in the province is totally inadequate. This is due to a lack of measurement programs for this parameter and limitations from inherently inaccurate estimation methods which must be presently used. Overall, there is a lack of snow measurement program coordination with the resultant need to engage operators and reaffirm standards for snow water equivalent measurement across the province.

5.4 Wind

Wind measurement is of key importance for climate monitoring and serves a wide range of social and economic user needs including the following:

- terrestrial and marine weather forecasting
- marine navigation and fishing
- travel advisories
- design and construction of structures (e.g., roofs, bridges, towers, etc.)
- effects on forest fire risk (together with relative humidity, air temperature and precipitation)
- extreme weather: storms
- icing potential: transmission lines, marine vessels and structures
- wind modelling (e.g., wind energy, air quality monitoring, air emissions and dispersion)
- wave and storm surge modelling
- coastal developments and activities, including aquaculture farm siting, and management and oil exploration and platform operations
- validation and calibration of regional reanalysis and climate prediction models

With global warming, oceans are expected to warm with this factor being a major contributor to sea level rise. Sea surface temperatures correlate directly with hurricane frequency and intensity. Increases in sea surface temperatures at higher latitudes (e.g., near Newfoundland and Labrador) may increase hurricane risk in a number of ways. Hurricanes may survive longer as they travel northwards due to the warmer water, they may form farther north, or they may be more intense to begin with. These factors would all result in hurricanes posing a greater threat to the province. This is particularly noteworthy given such recent outbreaks as the 2010 Hurricane Igor and its impacts. The effect of climate change on tropical and extra-tropical storm tracks is unknown, but barring any significant alterations in mean storm tracks, more frequent and intense hurricane remnants would continue to brush the island in the coming decades, leading to greater risks of wind damage and increased flooding due to precipitation and storm surges.

Coastal and offshore wind monitoring is treated separately in Section 6.3.

A tally of the number of years recorded for active, seasonal fire weather and RWIS, and inactive terrestrial stations monitoring wind is given in Figure 5.15. A total of 38 active stations have historical records of 10 years or more, with 13 stations having a record length longer than 30 years: 10 of these are for longer than 65 years. The 10 'new' stations showing record length less than two years comprise a range of sources including Environment Canada, Provincial Real Time Water Resources Data network, City of St. John's (year-round RWIS operation), and Newfoundland Hydro near their Cat Arm and Hinds Lake Reservoirs.

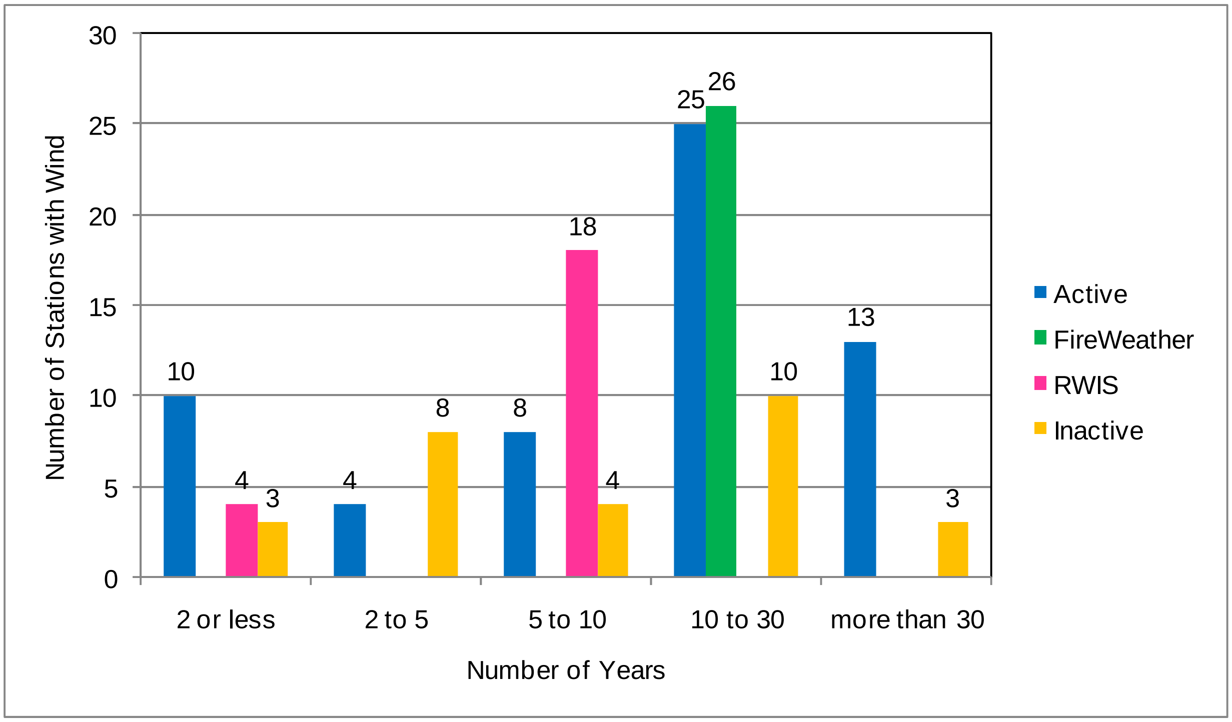

Figure 5.15 Newfoundland and Labrador Stations Monitoring Wind: Number of Years

Figure 5.16 and Figure 5.17 show wind monitoring stations in Newfoundland and in Labrador. The majority of the 68 active stations are part of the Environment Canada Surface Weather and RCS network (46 stations) originally established for monitoring synoptic, or large scale weather systems (approximately 1000 sq km in size), and the Province's seasonal fire weather (26) and RWIS (22) networks sited to meet local condition monitoring and forecasting for specific requirements (i.e., forest fire risk, and road conditions, respectively). Similarly, other local siting strategies are driven by specific user needs (e.g., for Newfoundland Hydro reservoir locations).

Wind monitoring coverage in the province is quite good, with at least one station (and generally more than one) active year-round in all but one of the forecast warning regions (shown in red on the maps). The sole exception is on the island for the region of *Clarenville and vicinity*. Though there is no year-round measurement, there are seasonal fire weather and RWIS stations at Clarenville.

Labrador is likewise, well-covered in terms of active stations. All six Environment Canada forecast regions have wind measurement stations. There are three additional stations located along the coast north of Nain, plus seasonal stations in all regions save *Nain to Hopedale.*

For wind research study in particular, but also for other climate variables, the general approach makes use of measurements, reanalysis (see Section 0), and wind prediction models, together with topography and land use, where the desired spatial coverage may ultimately determine the adequacy of wind measurements. For some of the user needs identified above, this approach would be necessary, and for others, project specific observation points would need to be determined.

Conclusion - Wind

Across the province, wind monitoring is concentrated along the coastlines and inland along the Trans-Canada highway. As such, virtually all regions are covered and in general the wind monitoring coverage in Newfoundland and Labrador is quite good. In addition, there are numerous seasonal climate stations which monitor wind: this information enhances the existing year-round wind network. Wind is also a climate variable that can be greatly influenced by very localised effects, so that depending on the user need application, station measurements may not necessarily be representative of the larger surrounding regions.

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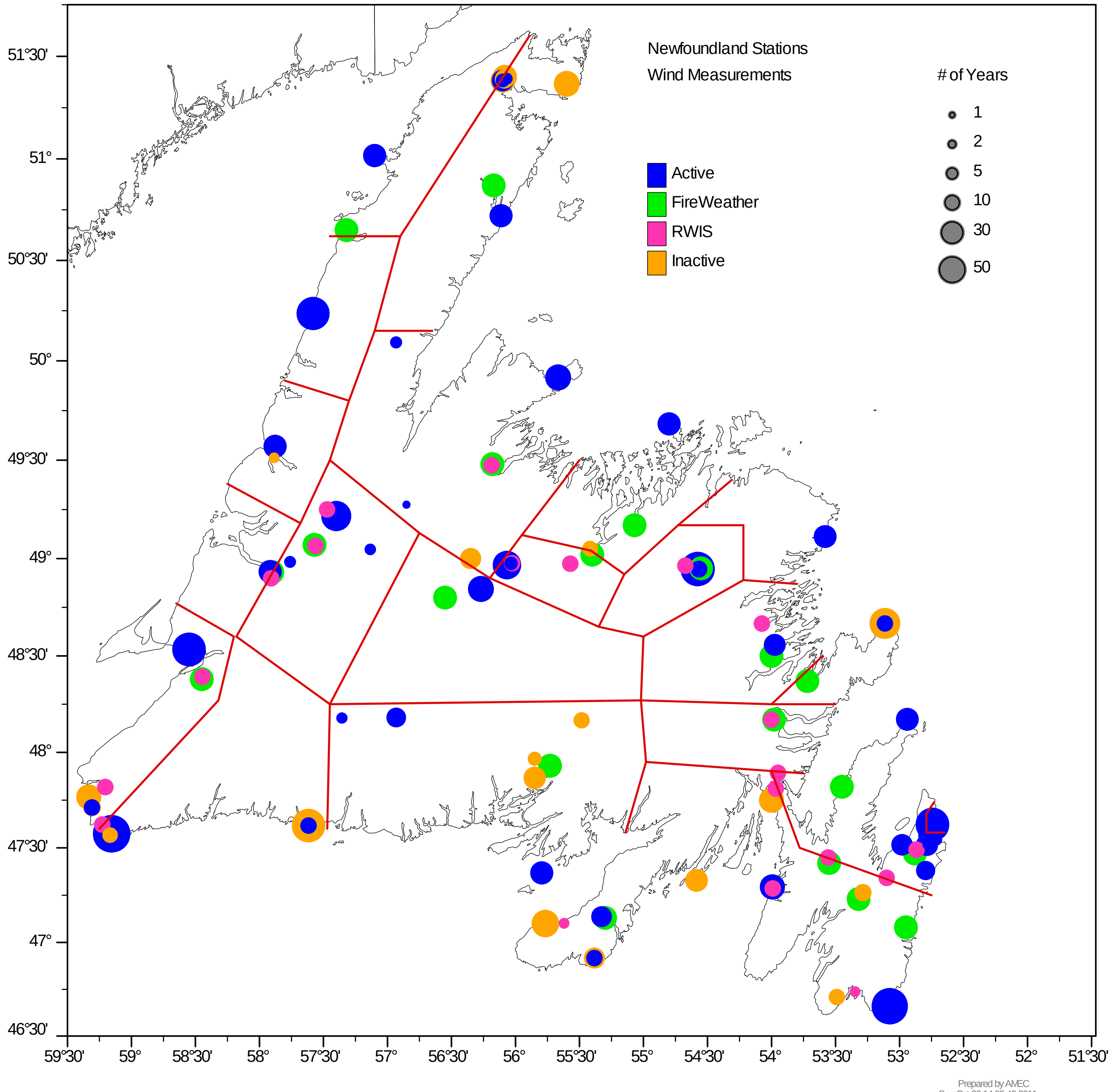
Newfoundland Stations
Wind Measurements
# of Years
1
2
5
10
30
50
Active
FireWeather
RWIS
Inactive
51°30'
51°
50°30'
50°
49°30'
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48°30'
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Figure 5.16 Climate Stations Monitoring Wind, Newfoundland

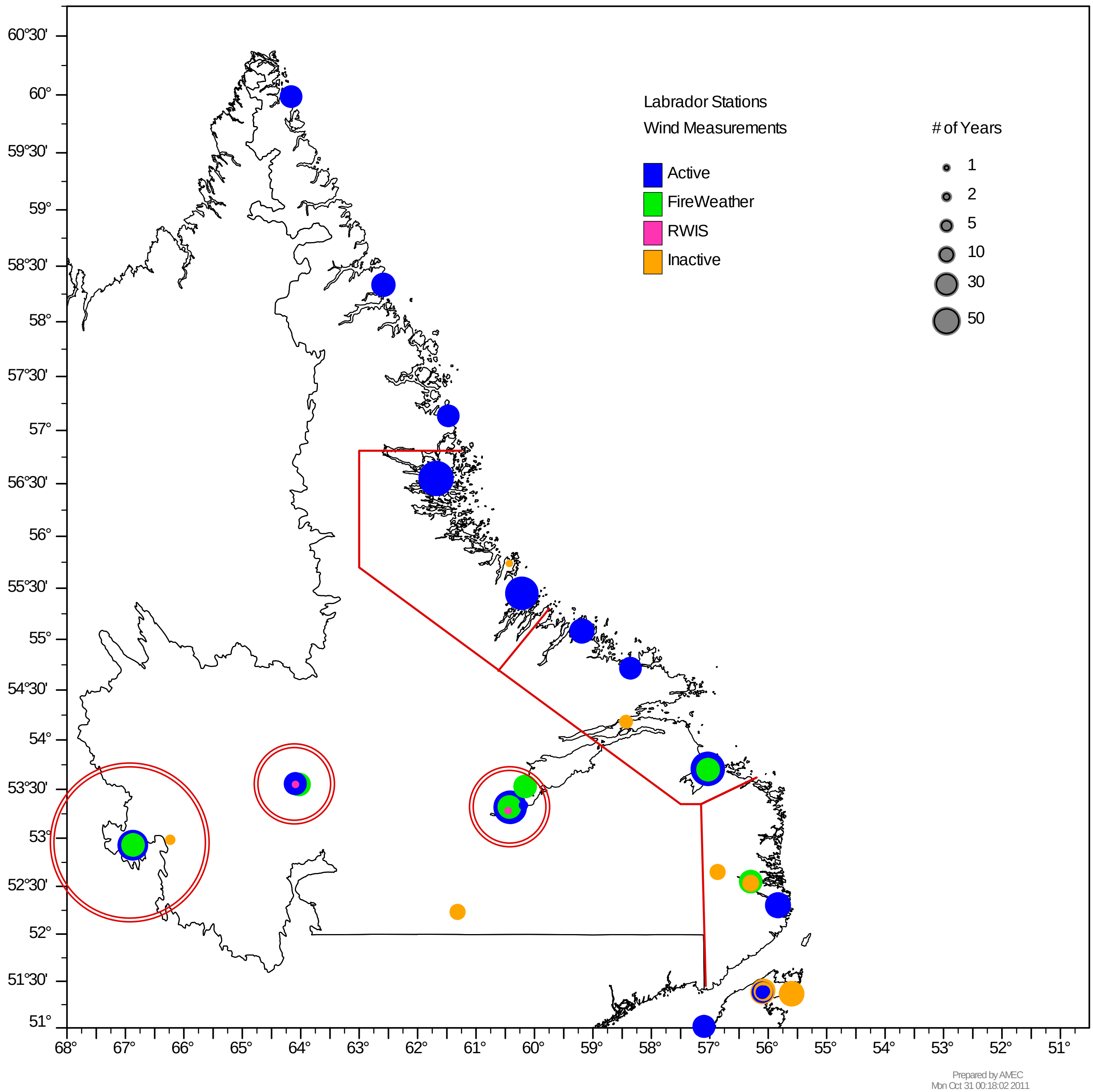

Figure 5.17 Climate Stations Monitoring Wind, Labrador

6.0 COASTAL AND MARINE CLIMATE VARIABLES

6.1 Sea Level

Sea level is affected by short-term and longer-term causes. Short-term changes may include tides, seasonal fluctuations due to precipitation and evaporation, and temporary sea level changes due to storms which result in reduced atmospheric pressure and storm surge or wind setup; both conditions that can effectively raise the sea level at the shoreline.

Sea level monitoring is required for a number of user needs, including:

- increased sea level combined with large storm waves can result in flooding, coastal erosion, and landslides
- salt water intrusion into freshwater habitats and groundwater systems can be worsened under increased sea level conditions
- sea level is of primary importance for understanding and assessing the risk of coastal flooding, particularly to low lying areas
- relevance for coastal zone land use planning and policy development and mitigation
- validation of climate change models; input to flood risk mapping
- a range of activities including aquaculture, shipping, offshore oil and gas exploration and production, harbour infrastructure and operations

This information can be used directly as part of flood forecasting and emergency measures response activities, and as input to the development of flood risk maps (Section 7.2) including sea level rises under climate change scenarios and guidelines for infrastructure planning and development. This is particularly relevant for a province with many coastal municipalities.

For the longer term, sea level is an ocean indicator for climate change. Sea level in the province has been observed to be rising relative to benchmarks and wharf deck elevations. The mean sea level rise is presently estimated at about 3 mm/year globally, with regional differences. For the North Atlantic, a comparable value of about 2.5 mm/year can be predicted. This is illustrated in Figure 6.1 which is based on satellite altimetry data[13]. These rates may increase with continued melting of the polar ice caps and warming of the oceans.

[13] satellites, such as Jason-1 (and previously TOPEX/Poseidon), use radar altimetry to measure ocean surface topography: radio waves are sent to the ocean surface and timing their return gives very accurate (within a few centimeters) measurement of sea level

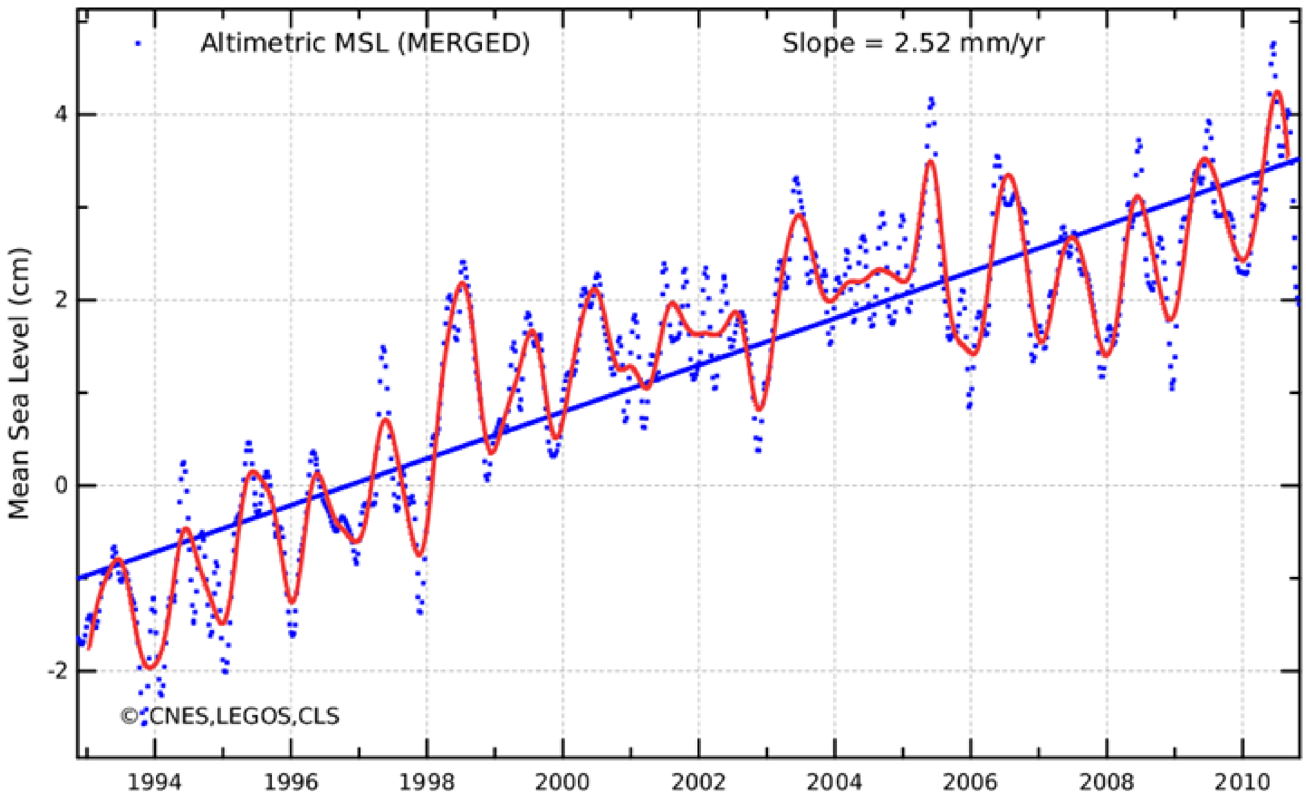

Figure 6.1 Change in Mean Sea Level, North Atlantic (Source: Aviso, 2011; Reference Satellite and Seasonal Signal removed settings)

Sea level also changes locally in relation to the geological uplift or subsidence of the earth which is in response to the retreat of the ice sheets that covered and depressed the land during the last glaciation, some 10,000 to 20,000 years ago. Though uplift has slowed since the glacial sheet melted, it is still occurring at different rates over the province. Geophysical modelling indicates uplift rates of 0 to 4 mm/year for Labrador and the Northern Peninsula, and subsidence rates of 0 to 2 mm/year for Newfoundland (Batterson and Liverman, 2010).

The net sea level effect is the sum of global and local sea level change predictions. Batterson and Liverman (2010) have prepared projections of sea level rise by 2049 and 2099 relative to 1990 levels for four zones in Newfoundland and Labrador. The 2099 projections are shown in Figure 6.2. The projections are based on the Intergovernmental Panel on Climate Change (IPCC) predicted global sea level rises (~30 mm by 2049; ~59 mm by 2099), potential accelerated ice melt (~20 mm by 2099), and regional trends of crustal rebound (uplift or subsidence) ranging from -1 to 2 mm/year. Sea level increases of 70 cm to over 100 cm are projected across the province. Clearly the potential of a full one metre net higher water level in the next 100 years is hugely significant. These longer term changes are cumulative to the short-term changes. When compounded with the increased frequency and intensity of storms, ocean defences or flood plains may no longer be sufficient in some locations.

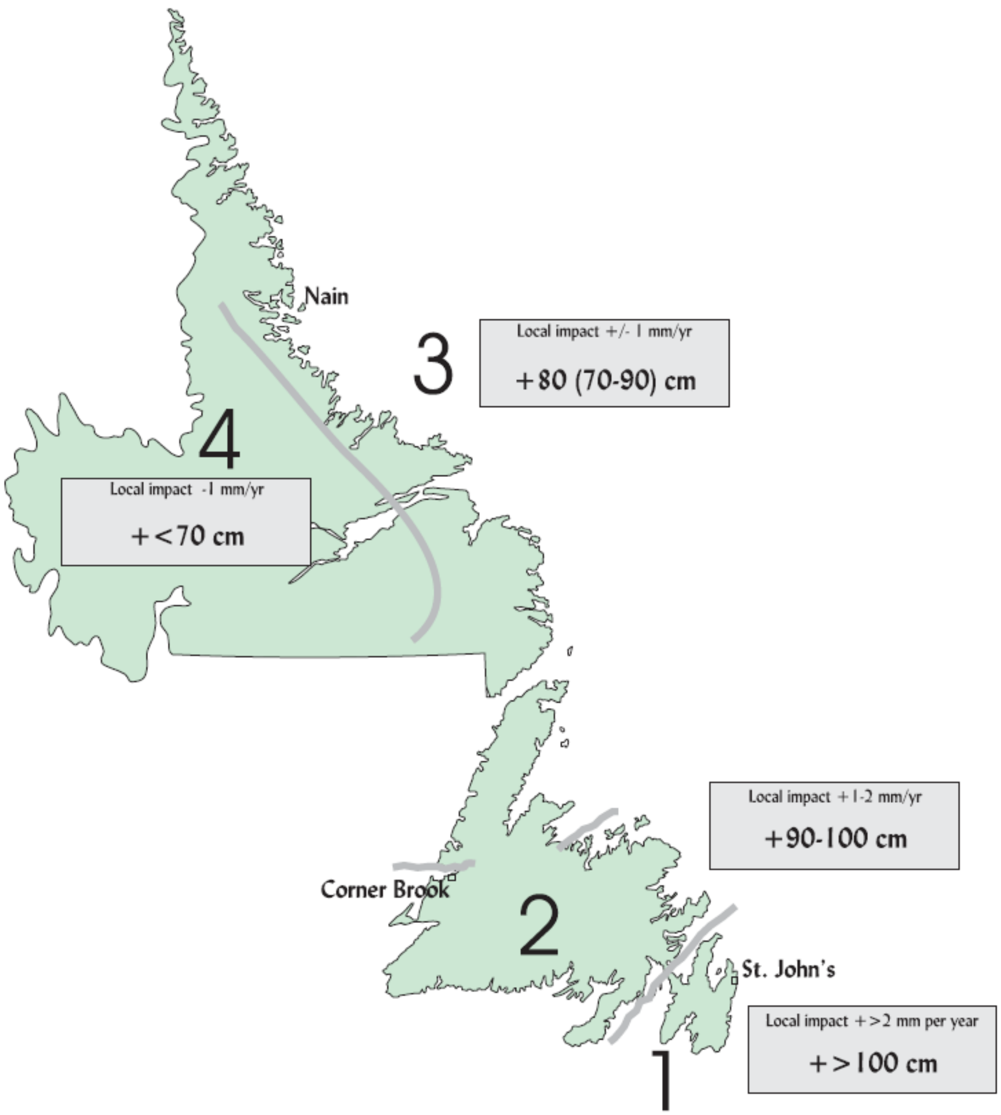

Figure 6.2 Projections of Potential Sea Level Rise in Newfoundland and Labrador by 2099, relative to 1990 Mean Sea Levels (Source: Batterson and Liverman, 2010)

In additional to sea level monitoring efforts to validate climate change sea level predictions, adequate tide and water level measurements are needed to improve the monitoring base for research and study into coastal flooding and related processes. The study of coastal erosion is further supported through monitoring of beach profiles and conditions at a number of shoreline stations being re-established around the island.

Six active tide and water level gauge stations are currently operating in the province (Figure 6.3). Stations at St. John's and Port aux Basques were installed in 1935, though the continuous record dates back to the mid-1950s. Stations were installed at Nain in 1963 and Argentia in 1971. Stations were re-established at Bonavista and St. Lawrence in 2005 and 2006.

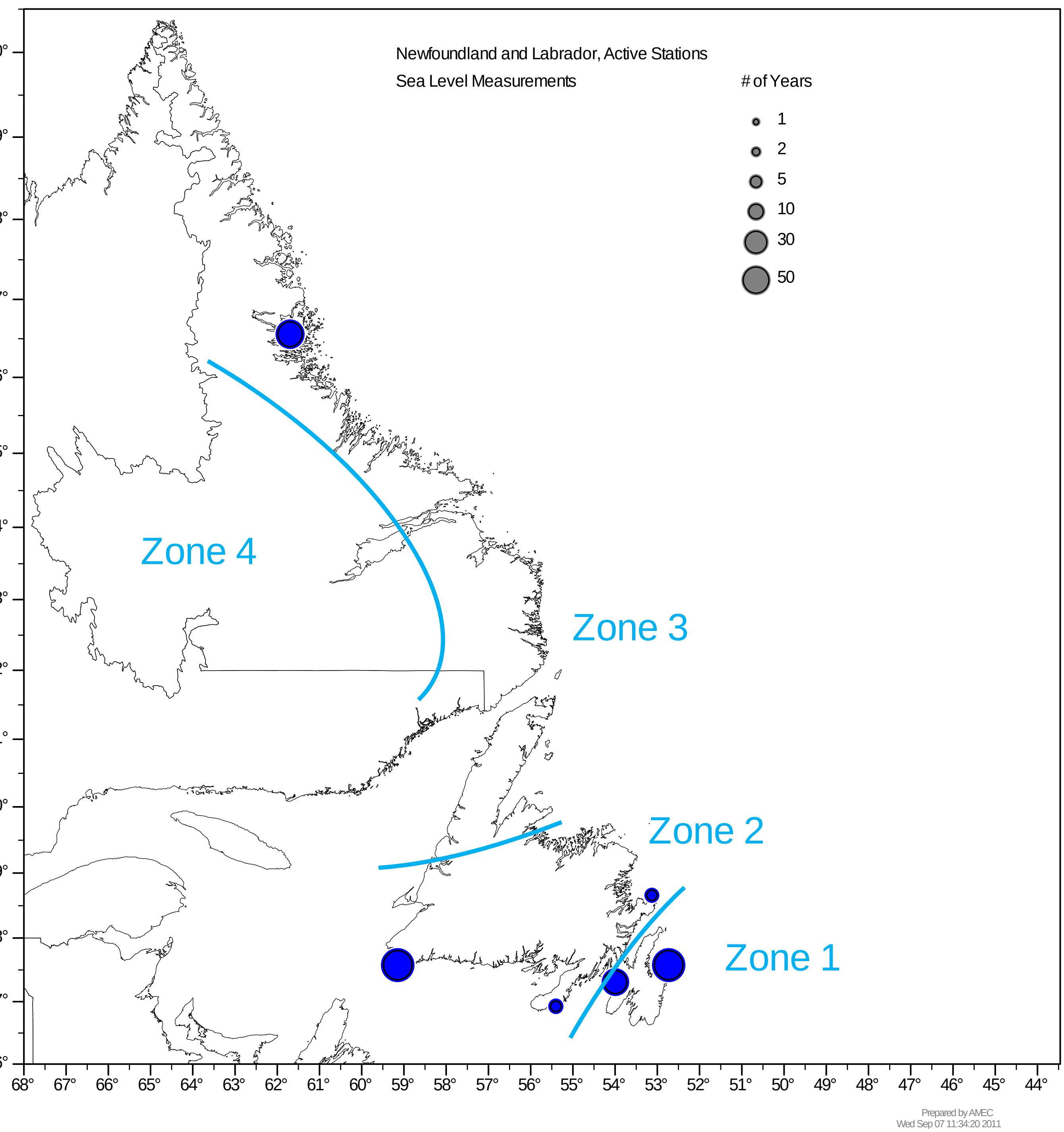

Figure 6.3 Climate Stations Monitoring Sea Level, Newfoundland and Labrador (shown with sea level change prediction zones; based on Batterson and Liverman, 2010)

Predicted times and heights of high and low water level, and hourly water levels for numerous stations in Atlantic Canada are available from the Canadian Hydrographic Service (CHS). These predictions are generally each based on nearby (to the location of the prediction stations) tide measurements over several weeks, but frequently for not much longer than that. Additional historical measurements are available for locations around the island, but these are generally of short duration and the monitoring is no longer active at those locations. Recent research (e.g., G. Han and Y. Shi (2008)) has been directed at modelling of coastal water levels in Atlantic Canada. Such information may be directly relevant in assessing needs for the number and location of any additional tide gauge stations.

Conclusion – Sea Level

Sea level monitoring plays a crucial role for supporting many user needs including study of coastal ecosystems, aquaculture and other coastal developments, and, particularly, coastal flooding and coastal erosion. These coastal hazards in particular have the potential to result in significant infrastructure planning, development, and maintenance costs, and risks to public safety.

While the southeast half of the island of Newfoundland is well-monitored, there are no sea level measuring sites anywhere in the northern half of the island or the southern half of Labrador – a huge contiguous area with a very long and complex coastline.

Some specific observations can be made with reference to four potential sea level rise zones, presented in Figure 6.2, which span the province. These zones are the main areas with differential sea level rises expected and they serve as the basis for sea level monitoring needs. It is presently assessed that only one of the four zones has good sea level monitoring coverage. One zone has marginally adequate coverage, while two zones are not sufficiently monitored. These gaps in coverage are heightened due to the predicted large increases in sea level for the province over the next century. In addition, there is still a high level of uncertainty with these predictions.

Zone 1 (see Figure 6.3): the Avalon Peninsula is well-monitored with two stations, including a station at Argentia, near to Placentia which is particularly susceptible to coastal flooding. For the broad, central portion of the island, Zone 2, stations are located on the Bonavista and Burin Peninsulas, as well as at Port aux Basques. These portions are adequately monitored; however, there is no coverage along the south or northeast coasts (north of Bonavista) or in St. George's Bay or Bay of Islands on the west coast. These parts of the province are not directly served by a monitoring station. Zone 3, encompassing well over 1000 km of the Northern Peninsula and Coastal Labrador, has only one monitoring station at Nain. Knowledge of sea level conditions at more than one point over this large expanse of coastline is required to monitor sea level changes under climate change as well as support the study of coastal processes. Zone 4, which encompasses Goose Bay and Lake Melville, is not presently served by any sea level monitoring: any consideration of sea level would need to be inferred from numerical modelling or approximation efforts, which are limited, stop-gap measures.

6.2 Sea Ice and Icebergs

Knowledge and monitoring of landfast and sea (or pack) ice and iceberg conditions is required for a number of user needs, including:

- marine vessel navigation
- safe winter navigation over-ice, (e.g., on snowmobile) particularly in parts of Labrador, through the communities and coastal inlets is dependent on knowledge of local sea ice conditions.
- study of the timing and distribution of sea ice growth, maximum extent, and break-up
- study of heat exchange between the ocean and atmosphere during ice formation and melt
- forecasting of ice conditions and ice drift motion (e.g., due to winds, currents, air and sea temperature)
- ice-structure interaction research
- ice management as part of offshore oil and gas exploration and development
- tourism

For coastal locations, the design and operation of harbour infrastructure and activities is affected by sea ice presence. Sea ice conditions can have additional, sometimes beneficial, effects, including changes to shoreline erosion, and reducing potential sea water intrusion of freshwater habitats during storm surge or other flooding events.

Increased storm occurrence, duration, and intensity have been experienced in the province in recent years, together with evidence of increased damage occurring in winter storms due to less presence of landfast or sea ice which mitigates the effects of waves. Table 6.1 summarizes general sea ice freeze-up and break-up mean dates for the province based on the Canadian Ice Service (CIS) 1981-2010 Sea Ice Climatic Atlases (Environment Canada, 2011a, 2011b).

Table 6.1 Times of Ice Freeze-Up and Break-Up (Source: Environment Canada, 2011a, 2011b)

	Freeze-up	**Break-up**
Northern Labrador	mid-late November to early December	early June to mid-July
Southern Labrador	early to mid December	late April
Northern Newfoundland	early-mid January to early-mid February	early April to early May
Southern Newfoundland	mid to late February	mid-March

While the magnitude and extent of changes is unclear, with global warming, some changes to sea ice and iceberg conditions should be expected. This may include reduced sea ice extent and ice thicknesses. Iceberg occurrence in the North Atlantic and Offshore Labrador may also retreat to the north leaving fewer icebergs at the southern latitudes they historically have been encountered.

The iceberg climate consists of the rate at which icebergs calve from glacial regions to the north (i.e., Greenland, and to lesser extent ice caps on Ellesmere, Devon and Baffin Islands), and size distribution, (e.g., mass and draft, geographic distribution and circulation). This is affected by a number of factors, including: local oceanic and atmospheric circulation patterns, water temperature, the frequency of occurrence and duration of open water conditions (influenced by sea ice extent - iceberg drift is impeded through regions of sea ice) and by a variety of factors affecting the principal iceberg source regions.

While each year is different, icebergs can typically appear off the coast and northern bays of Newfoundland by February or March. The presence of easterly and northeasterly winds can strongly influence the numbers of icebergs that make their way into the coast. Once there, icebergs may become grounded or become trapped in sea ice. These factors combined with the prevailing wind directions and sea and air temperatures will determine whether and for how long icebergs stay along the coast. The majority of icebergs are present from April to June or July. By July or August in most years, icebergs along the coast of Newfoundland have drifted south of the Grand Banks or melted. Off Labrador, the iceberg season can be year-round.

Forecasting of sea ice and icebergs is provided by the Canadian Ice Service (CIS) of Environment Canada. Operational daily and weekly ice chart products and the satellite imagery used to generate them are routinely archived. However, there has been no dedicated in-situ observation of sea ice thickness in the province since the mid-1990s (Table 6.2; the nearest active station is located in Iqaluit, Nunavut.)

Table 6.2 CIS Original Ice Thickness Program (1947-2002) Newfoundland and Labrador Stations

StationID	Station Name	Start Date	End Date	Latitude (°N)	Longitude (°W)	Number of Years
YYR	GOOSE BAY	2/27/1959	5/5/1995	53.32	-60.42	36
YHO	HOPEDALE	12/13/1960	6/8/1984	55.45	-60.23	24
YJT	CORNER BROOK	2/8/1974	3/22/1996	48.95	-57.94	22
WCA	CARTWRIGHT	12/18/1959	4/28/1995	53.71	-57.01	36
YQX	BOTWOOD	2/8/1974	4/22/1995	48.95	-54.57	21

Ice product validation is provided opportunistically by ice observers on Canadian Coast Guard vessels in the field. Some in-situ monitoring and dedicated campaigns to calibrate and validate information extracted from satellite imagery also occur on a project basis.

Additional ice observations and measurements have been compiled by C-CORE, a St. John's-based engineering and applied R&D corporation active since 1975. The majority of ice-related information collected by C-CORE's ice engineering group constitute in-situ measurements and reanalysis of existing ice charts, complemented by satellite-based ice observations. However, since 2003, C-CORE has been generating systematic satellite-based observations for some areas, particularly for river ice and icebergs, as part of its Northern View and Polar View[14] programs. A specific example is provided

[14] Polar View (and its predecessor, Northern View) is an international consortium, led by C CORE, to deliver operational satellite-based monitoring of sea ice, river and lake ice and glaciers and snow covers. Initially funded under the European Space Agency's GMES program, Polar View represents an international network of more than 90 participants from 17 countries, including the Newfoundland and Labrador Department of Environment and Conservation.

by the Badger river ice monitoring service described in Section 7.3. Polar View constitutes a significant resource for datasets, observations and knowledge relevant to climate change and adaptation in Newfoundland and Labrador.

Icebergs are monitored by CIS, the U.S. Coast Guard International Ice Patrol (IIP), and oil and gas environmental service providers. This includes primarily visual and radar sightings from ships and fixed-wing aircraft, and remote sensing satellite radar (e.g., RADARSAT-1 and -2, and ENVISAT). Good archives of iceberg conditions exist. These include the PERD[15] Iceberg Sighting and Comprehensive Iceberg Management Databases, both most recently updated in March 2010.

<u>Conclusion – Sea Ice and Icebergs</u>
Primary needs for sea ice information relate to basic ice-atmosphere-ocean research, aboriginal communities which rely on sea ice for their livelihood, and ice management and engineering for marine transportation, and offshore oil and gas industries. As there presently are no dedicated sea ice monitoring programs in the province, re-instatement of ice thickness monitoring at one or several locations is needed. This would provide time-series measurements that could be used to calibrate and validate remote sensing measurement and climate model predictions of sea ice conditions, essential technologies for monitoring remote northern regions of the province. Without this there is no continuous measurement of sea ice conditions which also serve as a measure of climate change. Iceberg monitoring needs are generally well-met presently. This is due to the existence of the PERD Iceberg Sighting and Comprehensive Iceberg Management Databases, which should be maintained and updated on a regular, annual, basis, following each ice season.

[15] PERD, The Program of Energy Research and Development, is a federal, interdepartmental program operated by Natural Resources Canada (NRCan)

6.3 Oceanography

Monitoring of oceanographic conditions serves to support a wide range of needs in the province and is of great importance for basic scientific and climate change research. As evidenced in the list of topics below, the domains of activity and interest include the coastal environment and bays of Newfoundland and Labrador, together with the vast surrounding marine waters of the Northwest Atlantic Ocean. Key user needs include:

coastal processes, economic development, public safety, weather forecasting

- coastal process study requiring wind and wave measurements to better understand, predict, and respond to flooding, erosion, slope failure, and landslides. These hazards can be made worse with large storm waves which can contribute to shoreline erosion and sediment transport fishing activity, including sustainable coastal development and management of the marine aquaculture industry
- sustainable development of coastal and ocean areas and the safety and security of life at sea
- support of the province's offshore oil and gas exploration and production
- shipping and marine navigation
- renewable energy development
- national defence (e.g., temperature profile critical in tracking submarines)
- marine emergency response including search and research, and oil spill
- marine and terrestrial weather forecasting

physical and chemical oceanographic processes, ecosystems

- sea surface temperature (SST)
- sub-surface sea temperature, mixed layer depths, salinity
- estimation of the variability of surface and deep currents in the Labrador Sea, Laurentian Channel, Grand Banks, Flemish Cap, and Scotian Shelf
- studies of the temporal and spatial hydrographical properties in these areas and compilation of the corresponding charts
- deep ocean monitoring data for inter-annual variability in water masses
- waves and currents, including modelling[16]
- seasonal and annual variability of marine biological data, including indices of biological processes (e.g., reproduction and recruitment)
- nutrients

[16] there is academic research interest in studying offshore waves and how they might be changing with time, and how this might affect oil and gas planning and operations. Currents are of particular relevance for search and rescue and oil spill response

- ecological analyses on marine ecosystems in support of development and implementation of ecosystem approaches to fisheries management; includes time-series analyses of fish stocks, including environmental covariates, as well as multispecies modelling
- long term changes in biological activities
- quantity and quality of phytoplankton
- strategic environmental assessments, project-specific environmental assessments and related study to "protect our fragile environment while building a strong economy"[17]

The ocean plays a major role in the Earth's climate. The huge volume, heat capacity, and inertia of the oceans are factors driving long-term climate change. Ocean circulation is thus a major climate control factor. Ocean circulation is the result of the combined effects of thermohaline (temperature and salinity and therefore water density properties) motions and the wind-driven motions. Thermohaline motions prevail in the deep water while the latter prevail in the upper waters. In both cases the motions continue far beyond the places where they are initiated, so that Global and North Atlantic domains of study are necessary for Newfoundland and Labrador. The Gulf of St. Lawrence and Scotian Shelf which border Newfoundland and Labrador, as well as areas farther away including the Gulf of Maine, and the Arctic together with the Labrador Current are of interest for those studying the North Atlantic as it affects the climate of Newfoundland and Labrador marine offshore.

Ocean ecosystems are strongly affected by climate change. Further study of the heat exchange between the ocean and atmosphere and of physical and chemical processes involved are required to better understand the complex interrelationships of pollutants, overfishing, and ocean acidification and warming. Ocean warming is also relevant for retreat of sea ice and sea level rise.

Two main areas of oceanographic monitoring are presented in this section. The first focuses largely on the first group of user needs noted above, those that relate to coastal processes, economic development, public safety, and weather forecasting. The second focuses more on oceanographic sciences, largely the domain and discipline of Fisheries and Oceans Canada (DFO). There are clearly overlaps in presenting these two overviews, both geographically and in which environmental parameters are measured; however, it is intended that the key monitoring activities and interests are described.

Coastal Processes, Economic Development, Public Safety, Weather Forecasting

The need for environmental monitoring to better mitigate and adapt to the effects of coastal flooding and erosion was introduced in Sections 6.1 and 6.2 with description of sea level and sea ice monitoring. Wind and wave conditions are also instrumental for this type of study. Wind measurements for example are required to support wave modelling and the study of coastal processes which may contribute to shoreline erosion and sediment transport. While there is a reasonable network of wind stations around the coast of Newfoundland and Labrador (see Section 5.4), and excellent wind and wave hindcast resources available (see Section 7.5), as discussed below, there is also an absence of

[17] "Environmental assessment responds to this challenge by helping to eliminate or reduce a project's potential impact on the environment before a project begins" Canadian Environmental Assessment Agency
http://www.ceaa.gc.ca/default.asp?lang=En&n=4F451DCA-1

direct wave measurement for much of the island. The transition from coastal monitoring to the offshore is perhaps best conducted through Placentia Bay located on the island's south coast.

Placentia Bay supports a broad range of activities including fishing, shipping and an interprovincial ferry service, mining (hydromet processing facilities at Long Harbour), oil refining (at Come By Chance), and recreational use. The SmartBay demonstration project supports improved safety and wellbeing for the many users of Placentia Bay together with more efficient marine transport operations.

<u>SmartBay – Placentia Bay</u>

SmartBay Placentia Bay[18] is an initiative of the Centre for Applied Ocean Technology, the applied research arm of Memorial University's Marine Institute's School of Ocean Technology, developed and operated with industry team partners. Initially funded in 2006 under the federal government's Ocean Action Plan, SmartBay has also received critical ongoing financial and in-kind support from the Government of Newfoundland and Labrador Department of Innovation Trade and Rural Development (INTRD), ACOA, the Marine Institute of Memorial University and the Canadian Coast Guard, and significant in-kind support from its industry partners. SmartBay infrastructure includes four met-ocean buoys strategically situated throughout in Placentia Bay and at the head of Conception Bay.[19].

Key benefits of SmartBay include improvement in the following areas[20]:

- operational efficiency: a real-time feed of met/ocean conditions to the web and custom forecasting allows for better planning of vessel movements, pilot scheduling and maintenance. An independent assessment of SmartBay estimated that in the first year of operation SmartBay directly resulted in approx. $1 million in fuel savings.
- met-ocean information: resulting in better operational decisions minimizing the potential of an incident, and improved emergency response time for real or simulated events.
- heightened situational awareness for all operating in and around Placentia Bay: improved awareness reduces the potential of user conflict or incident such as between a tanker and a fishing vessel.

Figure 6.4 shows the four SmartBay buoys together with other active Atlantic Canada marine monitoring locations. The physical parameters measured and record length are noted for each location. There are two MSC buoys nearshore on Burgeo Bank and off Trepassey Bay[21], additional

[18] http://www.smartbay.ca/ SmartBay is owned and operated by the Fisheries and Marine Institute of Memorial University of Newfoundland. The vision of SmartBay is *"to provide simple access by all stakeholders to data and information in support of effective management and sustainable development of coastal ocean areas and the safety and security of life at sea".*

[19] Mouth of Placentia Bay, Pilot Boarding Station / Red Island Shoal, Come By Chance Point, Holyrood SmartBuoy

[20] The SmartBay infrastructure also represents a cost-effective alternative for product developers, e.g., for marine monitoring. Rather than having to ramp up and deploy infrastructure to carry out testing, the developer is able to work in a turnkey testing environment. The SmartBay buoys and support infrastructure have been engineered with the size, power and data capacity to carry and support 'project tenants'. New products can be tested in the actual harsh marine environment and test data can be collected and delivered to the developer

[21] NE Burgeo Bank, Nickerson Bank

MSC buoys off Nova Scotia, and the oil-producing Hibernia platform, and Terra Nova and White Rose FPSO (floating production storage and offloading systems) vessels on the Grand Banks.

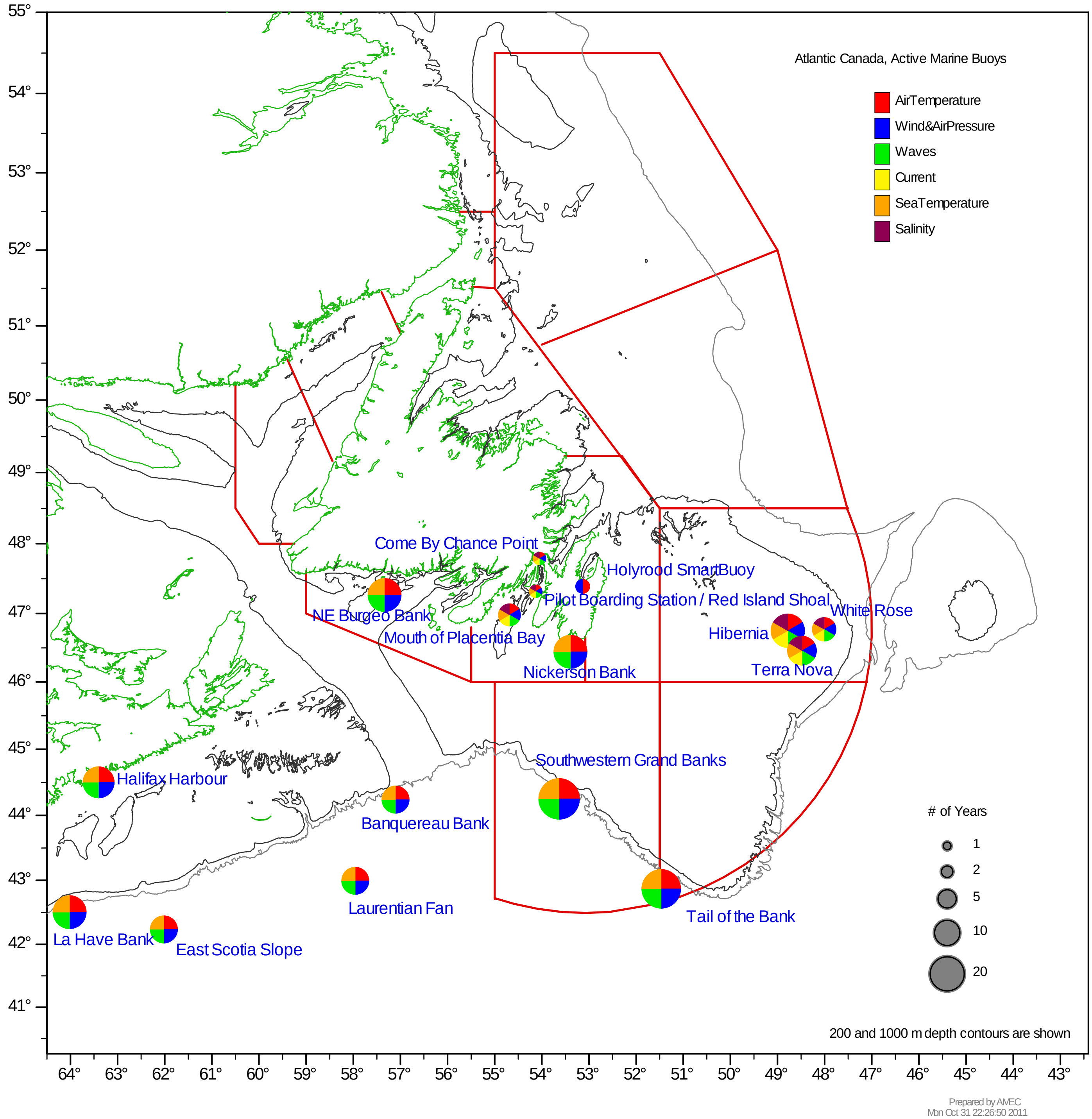

Figure 6.4 Marine Buoys for Newfoundland and Labrador: Parameters Sensed and Record Length (Environment Canada Marine Forecast Areas for Newfoundland shown in red)

In addition to wind and waves, most of these buoys/platform/vessels measure some or all of air temperature, air pressure, currents, sea temperature, and salinity. The MSC buoys, and closer to shore, the SmartBay buoys, provide essential monitoring of conditions upstream (i.e., to the south) of the island and play a vital role for weather forecasting and emergency preparedness measures for the province. Marine forecasts are also of primary interest to the province's fishers. This is true for all tropical storms and hurricanes, and the importance may be heightened with increased storm severity under climate change.

The area south of the Grand Banks (i.e., southeast of the Laurentian Fan and Tail of the Bank buoys) is presently not well-monitored for wind, air pressure, and wave conditions. The province is susceptible to storms approaching through this region. A similar gap exists for the *East Coast*, and *Northeast Coast* marine areas (see Figure 4.5 for marine forecast area names). The area east of the Avalon Peninsula in particular sees considerable vessel traffic. These areas can also be susceptible to large swells from the northeast, where presently there are no active marine buoys.

Less than half of the 11 marine forecast regions surrounding Newfoundland have marine buoys. There is no monitoring coverage near Port Aux Basques and the *Cabot Strait* area, or on the west coast for the *Gulf Port-au-Port, Northeast Gulf,* and *Belle Isle* regions (see Figure 4.5). While no active marine buoys exist on the west coast there is the prospect of further collaboration and information sharing for a Smart Basin type project[22] to monitor weather and water conditions (perhaps waves) for the Humber Valley Basin and the Bay of Islands. This is in response to a need to support decisions for, and use of, the area's water and land resources.

There are no met-ocean buoys monitoring off Labrador which are upstream areas for major storms affecting Newfoundland and Labrador. When a large low pressure system moves off the continent or up along the Gulf Stream it often re-intensifies off of Greenland/Iceland. There are often persistent strong Lows there. The Icelandic Low, is a semi-permanent and dominant feature of the North Atlantic, and can persist for weeks at a time and recurs multiple times each winter season[23]. In the counter-clockwise circulation around those systems, the winds and waves can build and persist for days and cause major havoc all along the east coasts of the island and Labrador. Having buoys well off those coasts would be extremely useful in dealing with these frequent occurrences.

The availability of marine buoy measurements upstream would result in two direct benefits to forecasting for the province and the surrounding marine areas. Firstly, the observations would be valuable additional inputs to forecast models. Wind and wave measurements can be compared with predictions from the different forecast models; greater weight can be then given to those models which better match the observations. Secondly, the observations would also facilitate forecast model validation. Improved forecasting in turn enables early warning and more effective preparedness by government emergency response personnel and the public. This contributes to the timely issuance of advisories and warnings for the public and the early launch of any necessary response measures.

[22] e.g., Pamela Gill, "An Informed Basin for Decisions", in Luminus, Spring 2011, 35, No. 1

[23] The Icelandic Low, is usually located between Iceland and southern Greenland. It is most intense during winter when the ocean is considerably warmer than the continents, causing strong winter winds over the North Atlantic Ocean. In summer, it weakens and splits into two centers, one near Davis Strait and the other west of Iceland.

Weather forecasts must also be produced in a timely fashion and have the necessary content and format to be readily ingested into flood forecasting and other extreme weather prediction tools by federal or provincial emergency response agencies. There is also a need to consider how weather scenarios under climate change might play out for the province's emergency preparedness as well.

Oil and Gas Exploration and Production

Met-ocean monitoring is an essential support for the province's oil and gas exploration and production activities offshore presently on the Grand Banks,. These presently include Hibernia (315 km east of St. John's), Terra Nova (39 km farther to the southeast), and White Rose (56 km northeast of Hibernia and Terra Nova) (Figure 6.4). Physical environmental monitoring, including air temperature, wind, pressure, waves, currents, sea temperature and salinity, is established at these locations as per the Offshore Physical Environment Guidelines (PEG) (NEB et al., 2008).

Good monitoring of weather conditions throughout the year helps to ensure safety in the harsh North Atlantic environment, plan work scopes in appropriate weather windows, conduct safe supply and crew change helicopter flight operations, and establish a sound and reliable environmental database. This in turn assists operators in the implementation of environmental effects monitoring programs and assessing future operational needs in the area. It also enables regulators to perform their duties relating to environmental assessment, to the review of design and operating criteria, and to the review and approval of applications and contingency plans. In addition to the Grand Banks, new areas that are expected to become of increasing interest include the Orphan Basin, Flemish Pass, and Offshore Labrador.

To augment the available, but inherently very limited, physical measurements, numerous models are employed. For some domains of activity or interest (e.g., Grand Banks oil and gas exploration and development) marine (and weather) forecast models are the only other source of information used on a regular basis.

An essential requirement for all marine buoys serving Atlantic Canada is sufficient resources be allocated to ensure all buoys are properly maintained and that any operational downtime is minimized. This is true whether the buoy is funded by the federal government (e.g., MSC buoys), an academic initiative (e.g., SmartBay), or industry-driven (e.g., ExxonMobil, Suncor, and Husky Energy as operators of Hibernia, Terra Nova, and White Rose, respectively).

Aquaculture

The province's marine aquaculture industry, at present situated primarily along the northeast coast, Notre Dame Bay, and Coast of Bays,[24] consists of mussel and salmonid aquaculture development. These projects require monitoring of wind and wave and other atmospheric and oceanographic physical parameters, together with freshwater and marine biological contaminants and nutrient parameters. Monitoring programs and locations are generally specific to active aquaculture sites or those sites being

[24] located on the south coast of Newfoundland, and includes the Fortune Bay north shore, Bay d'Espoir, and the Connaigre Peninsula

considered for development, and generally last for only one or several years rather than being of any ongoing or long term nature. Over the past eight years, specific aquaculture site monitoring has included sea temperature, salinity, dissolved oxygen, chlorophyll a, and phytoplankton. The locations of these measurement sites are shown in Figure 6.5 together with indication of some of the broader DFO temperature and salinity monitoring programs discussed below.

Physical and Chemical Oceanographic Processes, Ecosystems

The DFO Atlantic Zone Monitoring Program (AZMP)[25,] involving Québec, the Maritimes, and Newfoundland and Labrador is a significant and successful example or oceanographic monitoring. Further to the list of user needs presented above, AZMP is cited to summarize objectives for collecting and analyzing the physical, chemical, and biological field data necessary to:

- characterize and understand the causes of oceanic variability at the seasonal, inter-annual, and decadal scales
- provide multidisciplinary data sets that can be used to establish relationships among the physical, chemical, and biological variables
- provide adequate data to support the sound development of ocean activities

The AZMP Newfoundland and Labrador Transects and Station 27, located immediately east of St. John's, are shown in Figure 6.5. The six hydrographic sections that run offshore from the province collect water profile measurements of sea temperature, salinity, fluorescence, and oxygen, chlorophyll a, and nutrients

AZMP includes an annual ecosystem trawl survey to observe numbers and distributions of various fish species in relation to bathymetry, temperature, salinity and lower trophic levels; and an annual fall survey of temperature, salinity, nutrients and plankton across the entire Atlantic zone.[26] Measurements from fixed Station 27, occupied on a regular basis since 1946, include sea temperature, salinity, dissolved oxygen, fluorescence, and chlorophyll a, nitrate, and phosphate content. Derived data products include climate indices of annual average temperatures and seasonal cycles at surface and bottom depths.

[25] http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/azmp-pmza/index-eng.html (see also Climate Station Inventory, Source ID GC-DFO-6)

[26] The AZMP sampling strategy is based on: seasonal and opportunistic sampling along "sections" to quantify the oceanographic variability in the Canadian Northwest Atlantic shelf region; higher-frequency temporal sampling at more accessible "fixed sites" to monitor the shorter time scale dynamics in representative areas; fish survey and remote sensing data to provide broader spatial coverage and a context to interpret other data; and complementary data from other existing monitoring programs such as CPR (Continuous Plankton Recorder) lines, sea level network, nearshore long-term temperature monitoring, toxic algae monitoring, etc., or from other external organizations (e.g., winds and air temperatures from Environment Canada)

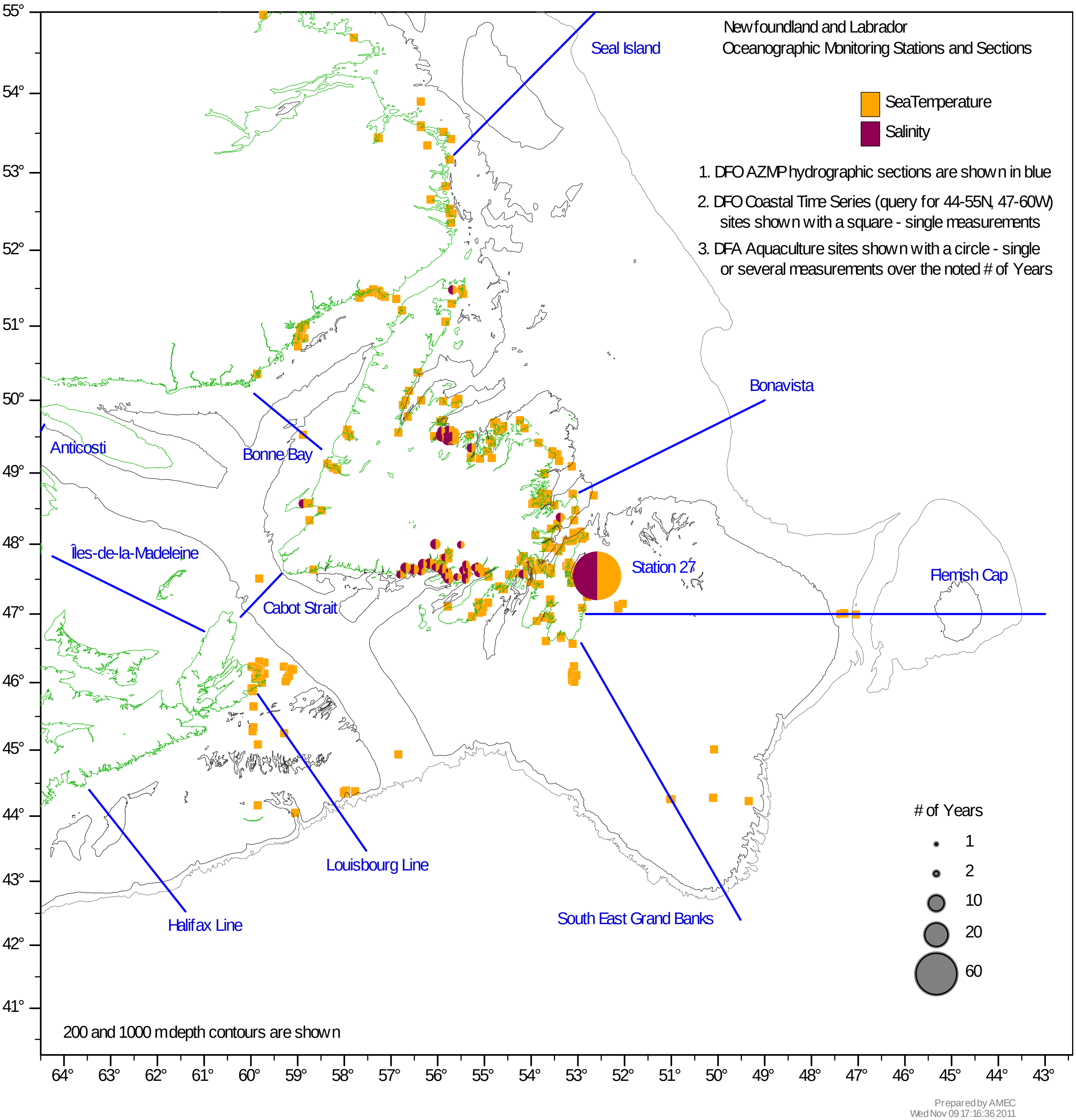

Figure 6.5 Coastal Temperature and Salinity Monitoring

An additional oceanographic section, for the Labrador Sea Monitoring Program of the Atlantic Zone Off-Shelf Monitoring Program (AZOMP[27]), runs from Labrador, near the Seal Island section, northeast to southern Greenland.

There are additional significant monitoring sources. They include the following where, for reference in Climate Station Inventory, their "Source ID" is noted in the footnotes:

- DFO archive databases for current, tide, temperature and salinity, sea surface temperature (satellite-derived)[28]
- the DFO ocean monitoring workstation (OMW) for identification of ocean features (vessel location, speed, and heading), ocean current boundaries, ocean wavelength, height, and direction, slicks (e.g., biological films or oil spills), and winds[29]
- long-term (coastal) temperature monitoring program (LTTM, mainly in support of fisheries and study of long term changes of temperature), and ocean colour (e.g., chlorophyll, sediments, dissolved organic material) (temperature measurements from a Coastal Time Series database query is shown in Figure 6.5)[30]
- drifting buoys, largely archives of currents (inferred from position of the buoy), air temperature, wind [31]
- thermosalinographs from ships for surface sea temperature and salinity[32]
- near-bottom current moorings[33]
- wave buoys, including those from oil and gas operators, and coastal SmartBay and MSC marine buoys noted above[34]

The key need is to maintain those programs already developed and operational. Data provided by these programs is a basic requirement for all researchers.

[27] AZOMP – "The DFO Atlantic Zone Off-Shelf Monitoring Program (AZOMP) collects and analyzes physical, chemical and biological oceanographic observations from the continental slope and deeper waters of the NW Atlantic. Its objective is to monitor variability in the ocean climate and plankton affecting regional climate and ecosystems off Atlantic Canada and the global climate system" http://www.bio.gc.ca/monitoring-monitorage/azomp-pmzao/index-eng.htm

[28] GC-DFO-1 ODI Ocean Data Inventory, -2 Hydrographic Climate database, -3 SST satellite-derived)

[29] GC-DFO-12 OWM Ocean Monitoring Workstation

[30] GC-DFO-4 LTTM,-5 OCDC Ocean Colour

[31] GC-DFO-13 Drifting Buoys

[32] GC-DFO-16 Thermosalinographs

[33] GC-DFO-17 Near-Bottom Currents

[34] GC-DFO-14,-15, PS-OIL-1, AC-MUN_MI-1, GC-EC-3 Wave Buoys

Oceanography – Conclusion

The existing marine met-ocean buoy networks and oceanographic monitoring programs serve vital roles for many economic, public safety, and scientific needs for Newfoundland and Labrador, and for Atlantic Canada as a whole. Monitoring of coastal waters and the adjoining Northwest Atlantic Ocean upstream of the island and Labrador is a key for the well-being of the public; the measurements of air pressure, wind, and waves play critical roles in supporting weather forecasting and emergency preparedness and response – both at sea and on land for storms and flooding. Acknowledging the seasonal presence of sea ice can limit the deployment of marine buoys for parts of the province, it remains that less than half of the marine forecast regions surrounding Newfoundland, and none of those off Labrador, are adequately monitored.

Due to its integral and significant role in the climate and weather, not only of Atlantic Canada but of the earth as a whole, study of the ocean and its ecosystems, particularly under climate change, is of paramount importance. Essential oceanographic science research, led by DFO, is only made possible by the various programs that have been carefully designed, refined, and implemented for decades and they must be preserved. The key need is for maintenance and continuation of these programs, expansion where possible to include additional regions of the North Atlantic, additional physical, chemical, and biological parameters, and additional times of the year. Equally important is that adequate equipment and research vessel resources (particularly those of lead agency DFO) are available to safely and successfully conduct these activities. Failure to do so will compromise the significant historical record achieved and hamper future efforts directed towards climate monitoring, climate mitigation and climate adaption.

7.0 CLIMATE INFORMATION PRODUCTS

This section highlights key climate information products and particular climate monitoring topics and activities of interest identified during the study.

7.1 IDF Curves

With concern over more frequent and intense extreme rainfall events, a generally anticipated outcome of global warming, there is increased interest and need for estimates of precipitation rate or intensity to support design of bridges, culverts, dams, spillways, storm stewage systems, and other hydraulic structures or infrastructure. Extreme rainfall events also affect storm surges and coastal flooding and so are critical in city planning and land allocation. Intensity-Duration-Frequency (IDF) curves, which characterize the relationship between the intensity (e.g., in mm/hr) of precipitation, over a specified duration of time (e.g., 5 minutes, 1, 6, or 24 hours), and the frequency of occurrence or return period, are one design criteria. A sample IDF curve is shown in Figure 7.1. For this study IDF curves are identified as a climate information product of particular importance for a range of users including engineers, municipalities, industry, and academia in addition to climate change scientists.

Precipitation intensity is the essential measurement parameter required to derive IDF curves. This need has been detailed in Section 5.2. The last publication of IDF curves by Environment Canada was in 2010 for 18 locations in the province. The most recent of these include three stations with data up to 2007 (Stephenville A, Goose A, Nain A), three from 2002 to 2005, and 11 from the early to mid-1990s. Since some of these locations have not availed of more recent data, there is a requirement to apply any existing measurements not yet incorporated to update existing IDF curves in the province. While one should not attempt to update IDF curves to add just a few more years of data, those IDFs (11 of them) that include data only to the early or mid 1990s should be updated. The updating of IDF curves should be undertaken, and as a minimum, every ten years to be consistent with World Meteorological Organization (WMO) recommendations to update Normals every decade (Section 7.4). IDFs should be based, ideally, on at least 50 or 60 years of data. In an era of more rapid climate change, it would be prudent to adhere to these minimum guidelines.

A larger general need is to reinstate the real-time precipitation intensity or rate monitoring for those stations which had measured this parameter in the past and give consideration to additional stations. The eastern portion of the province is an area in particular need with IDF curves existing presently just for St. John's and Gander[35]. More than half of the province's population resides on the Avalon Peninsula so that support of infrastructure development through IDF curves is a clear requirement. The need for additional precipitation intensity monitoring in the province, including the Avalon Peninsula, is further illustrated in Section 7.2 where communities at risk from flooding are discussed.

The reinstatement of sufficient monitoring stations and proper updating of IDF curves would have the significant, beneficial effect of assisting in the assessment of infrastructure design for buildings, roads, bridges, storm sewers, and other hydraulic structures and their capabilities to deal with intense and excessive rainfall and coastal flooding that are predicted with climate change.

[35] IDF curves were prepared for Placentia as part of a 2008 vulnerability assessment of public infrastructure to predicted impacts of climate change: these are not part of the current EC collection (Cameron Consulting, 2008)

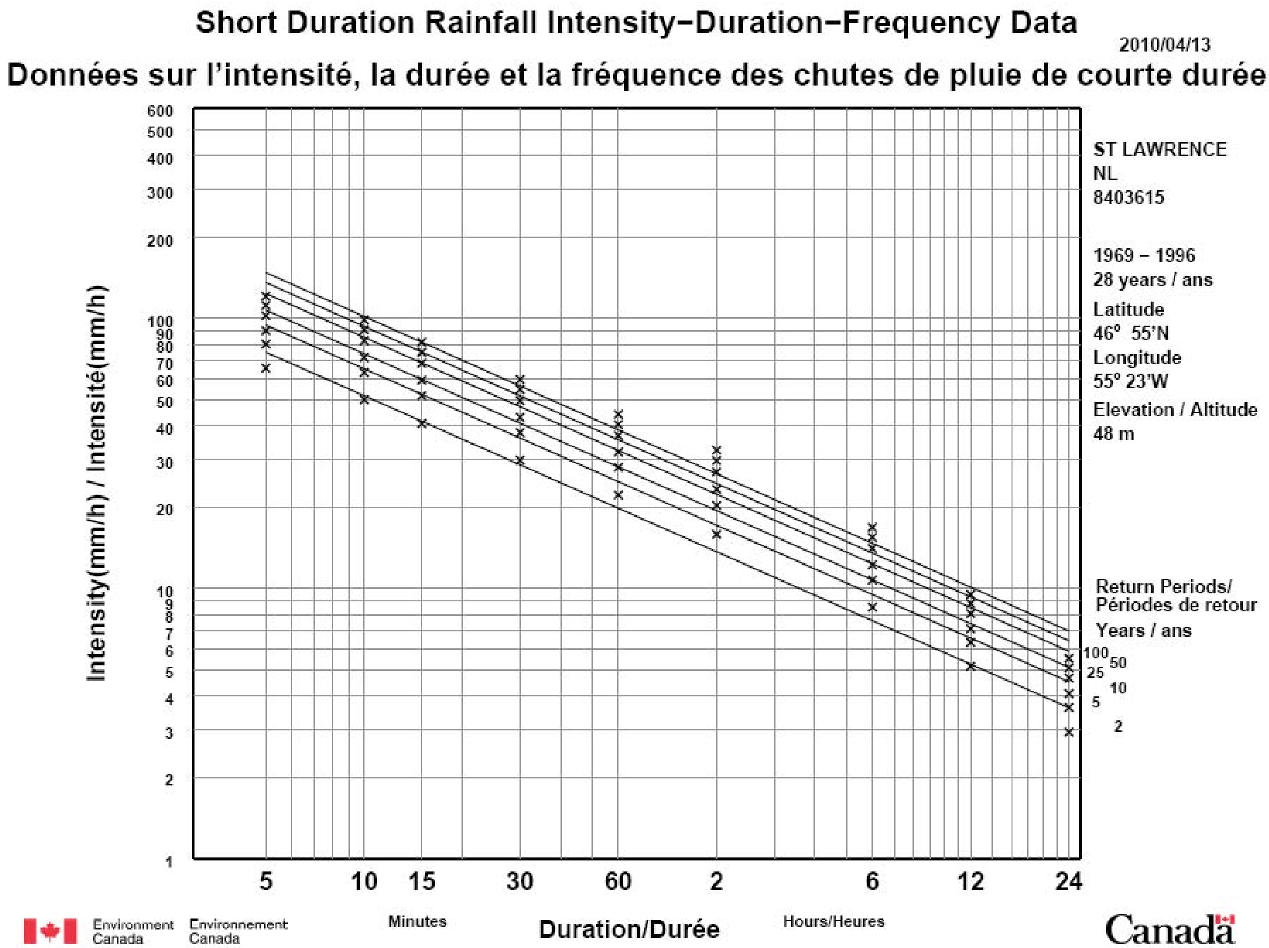

Figure 7.1 IDF Curve Example, St. Lawrence (Source: Environment Canada)

7.2 Flood Risk Mapping and Forecasting

Floods are a hazard in Newfoundland and Labrador, particularly for the many communities and towns located on the coast or in river flood plains. The province has a history of regular flooding, with some communities more prone to flood risk than others. Near the sea, high sea levels, frequently raised due to storm surge conditions, result in wave uprush and overtopping of shorelines with subsequent flooding inland. Rivers can overflow their banks due to heavy or intense precipitation events resulting from hurricane/tropical storm or atmospheric depression, large runoffs in spring, or during periods of increased snowmelt. In winter, ice jams can further worsen river flooding conditions. In recent years, occurrences of heavy rains in mid-winter when the ground surface and sub-surface were still frozen has caused significant flooding which inconvenienced many people for a lengthy period of time. Such occurrences could become more common in a warming climate.

Newfoundland and Labrador experiences about six floods per year with an average annual cost greater than $3.2 million. The areas that are particularly flood prone and have resulted in greatest damage costs include Placentia, Badger (Exploits River), and Stephenville. Additional measures such as new infrastructure design and construction, and relocation introduce additional adaptation and mitigation costs.

An anticipated effect of climate change is changes in precipitation patterns with a likely shift towards perhaps shorter but more intense rainfall events, and seasonal shifts in winter snowpack melt and runoff resulting in changed river flow regimes. For coastal communities, there is increased risk from rising sea levels. Under these changing conditions and predictions, there is a need to both update existing flood risk maps and a potential need for new mapping for communities or areas which may be subject to increased flood risk. In order to meet this need and the requirements of future flood risk study, adequate climate data and climate predictions will be required. This information is also critical in the near term to support flood forecasting annually, particularly in winter and spring, and during storms.

Flooding can pose risks to the welfare and safety of human life and property. Together with land use policy for flood prone areas, preparedness and mitigation measures include flood risk mapping which defines the 1:20 year and 1:100 year flood zones.

In cooperation with the federal government, the province has completed flood information maps for some 37 communities to date (e.g., Figure 7.2; normal water surface is shown in blue, 1:20 year flood zone or "designated floodway" in orange, 1:100 year flood zone or "designated floodway fringe" in yellow). However, most of these were completed in the 1980s and 1990s. These are now outdated and need to be updated, particularly with increased flood risk with climate change. Essential updates that need to be incorporated in the flood maps are inclusion of a 1:100 year flood zone under climate change. This approach has already been pioneered for Stephenville and quantitative results from this type of study improve the ability to assess flood risk and directly benefit climate change mitigation and adaptation measures.

In designing infrastructure or considering flood plains under a rapidly warming climate, one needs to consider, as part of the solution along with sea level rise, geological rebound/subsidence etc., the changed precipitation intensity-frequency-duration in the future, i.e., the concept of a 'forecast' IDF curve. IDF curves need to be updated with all the most recent data, but then they have to be further tuned to be representative of the character of precipitation at those locations in a further 50 or 100 years – in fact for the life expectancy of the infrastructure whose design will be based on the IDFs. Modeling, statistical, and downscaling techniques are used to come up with these.

<u>IDF Curves and Flood Information Maps - Assessment of Precipitation Intensity Measurement</u>

Following the importance noted above for IDF curves and flood information maps, an initial assessment is presented of how well these are served in their locations by the essential precipitation intensity measurements. These locations are illustrated in Figure 7.3 and Figure 7.5 for Newfoundland and

Labrador respectively, with Figure 7.4 devoted to the eastern portion of the island. The Environment Canada forecast regions for Newfoundland and Labrador (Figure 4.3, Figure 4.4) are shown in red. On the island, only five of the 12 IDF curve locations have active precipitation intensity measurement, and less than one third of the flood information map communities have active precipitation rate measurement stations directly nearby. The paucity of coverage for much of the Avalon and Bonavista Peninsulas and northern portion of the Burin Peninsula is well evident in Figure 7.4. In Labrador, while there are no current flood information map locations, there are six locations for IDF curves for which half are directly served by active precipitation rate measurement.

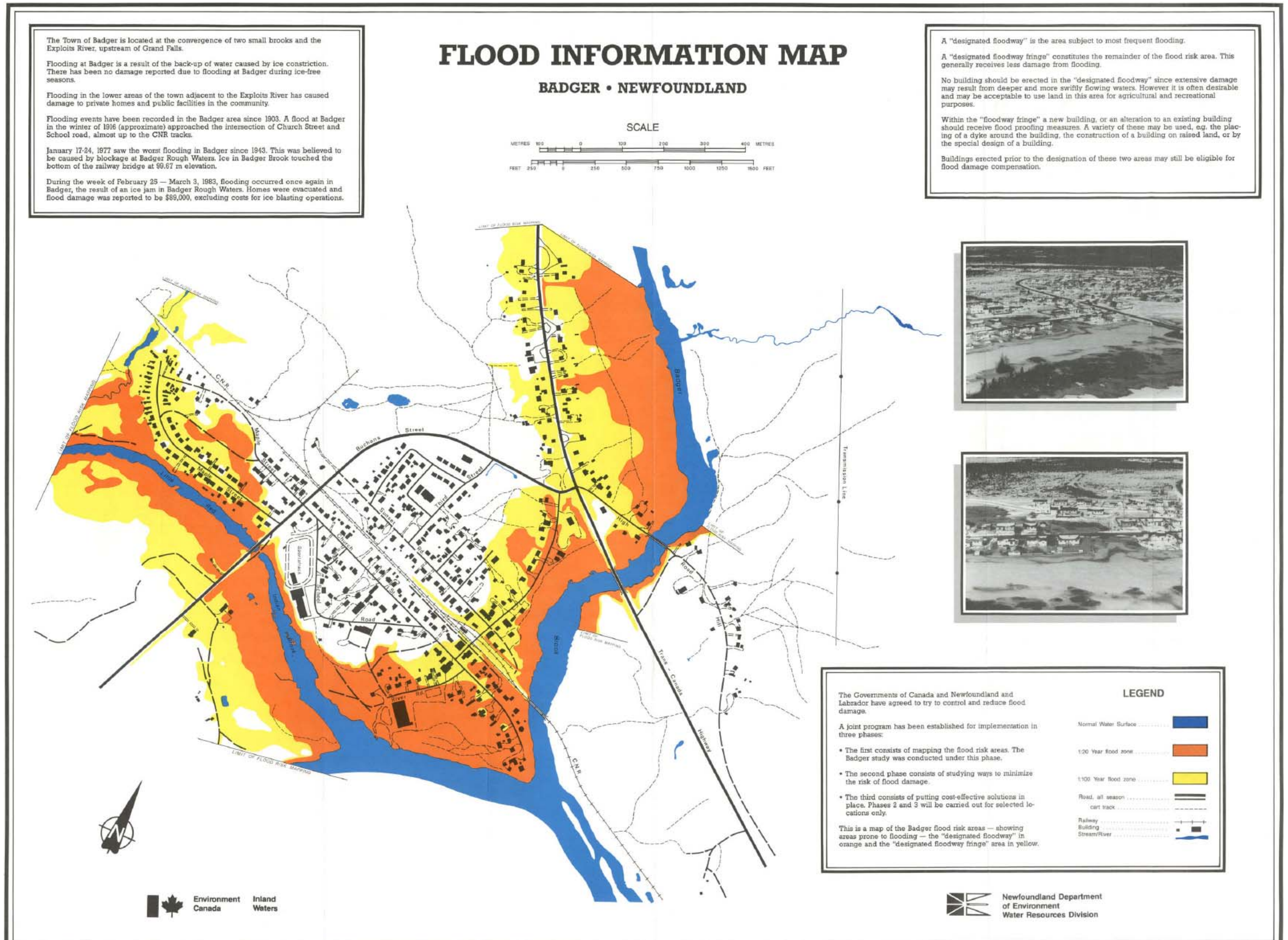

Figure 7.2 Flood Information Map, Badger (Source: Government of Newfoundland and Labrador, Department of Environment and Conservation, 2011)

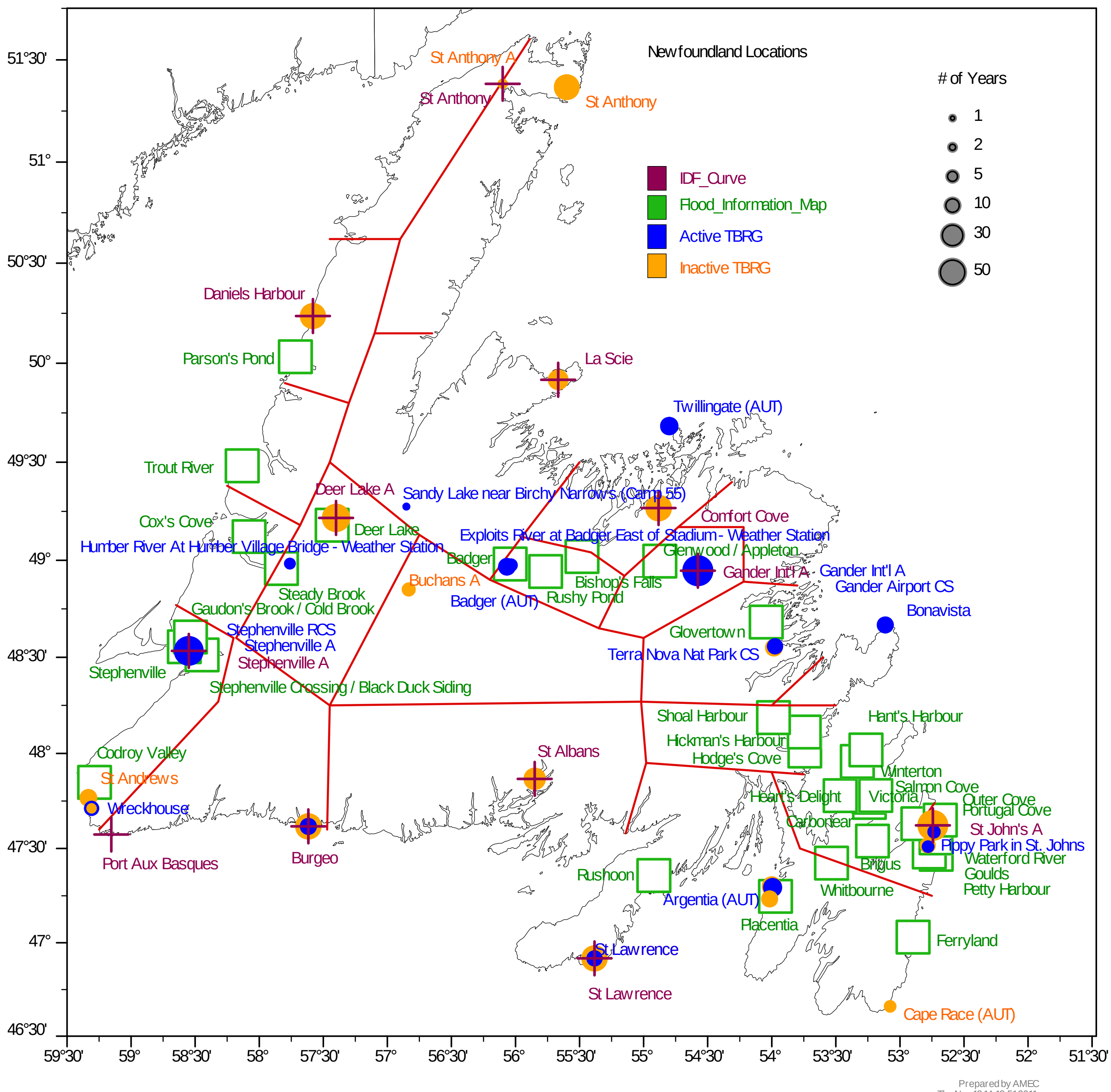

Figure 7.3 IDF Curve and Flood Information Map Locations in Newfoundland

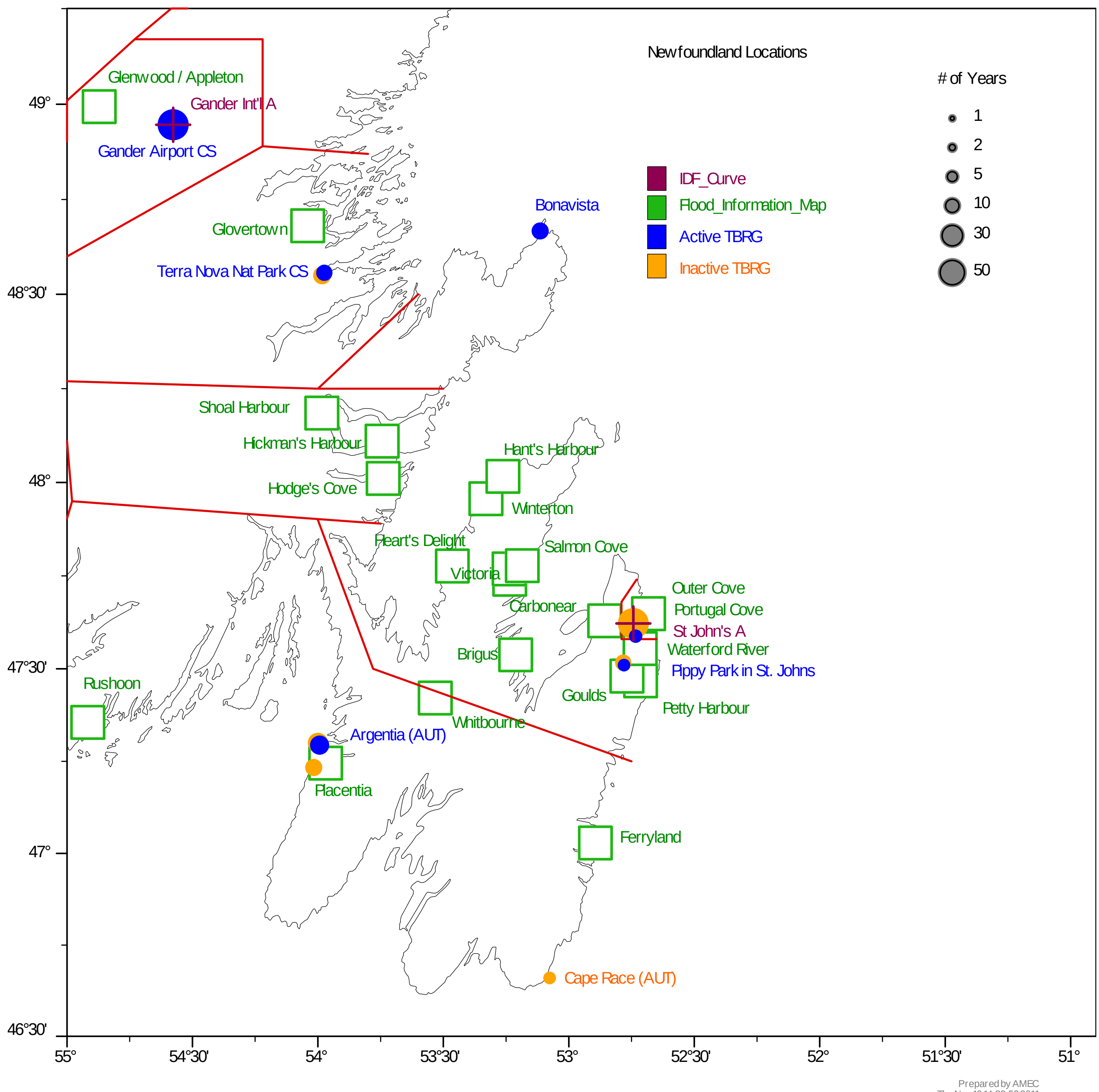

Figure 7.4 IDF Curve and Flood Information Map Locations in Eastern Newfoundland

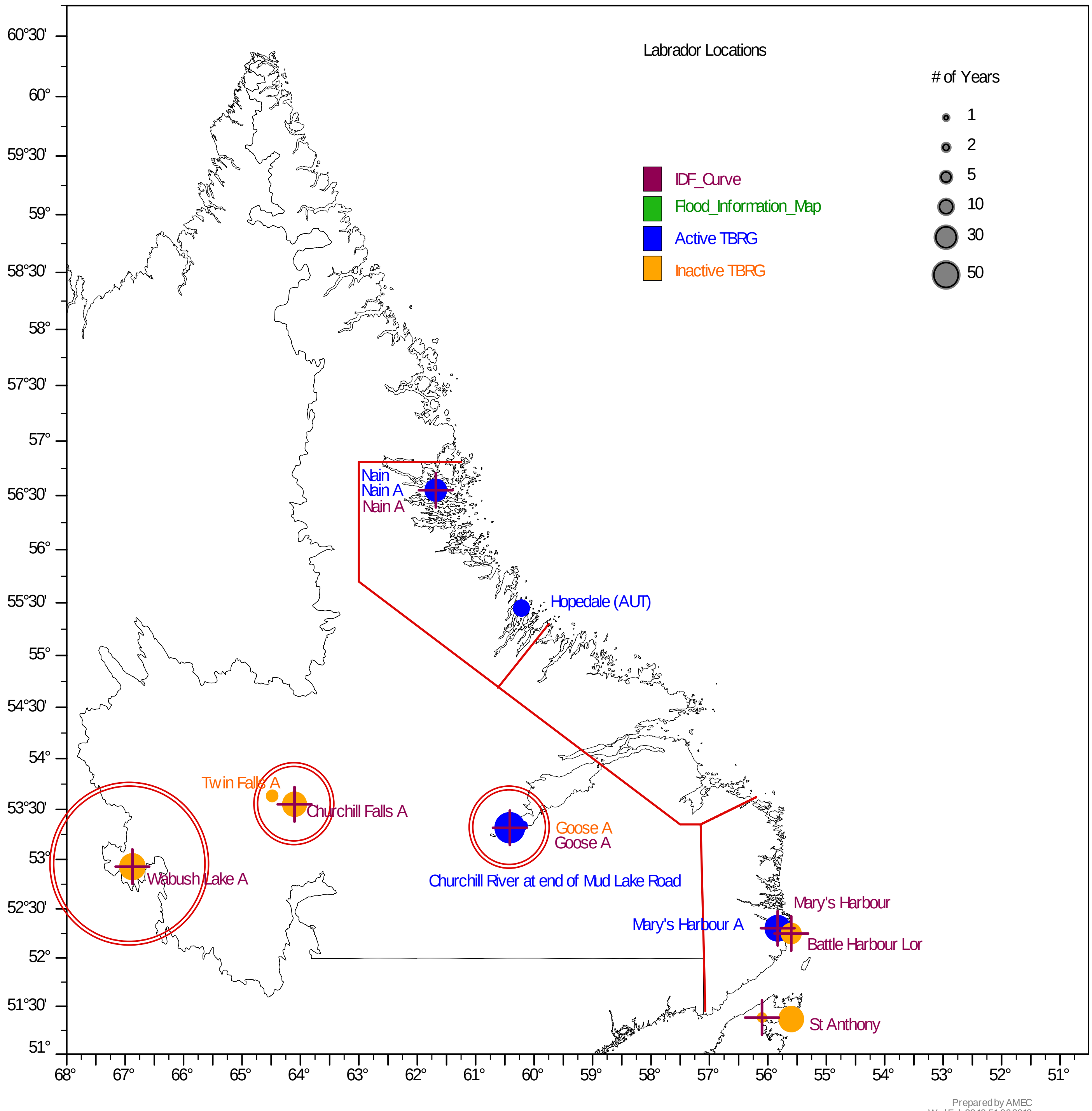

Figure 7.5 IDF Curve and Flood Information Map Locations in Labrador

7.3 Remote Sensing Technologies

Remote sensing technologies such as satellite imagery can be used to fill in and expand the conventional in-situ land and sea based climate monitoring means of land or sea based measurements. Imaging satellites are relevant for monitoring key environmental parameters (e.g., ice, land cover, water quality). These satellites include RADARSAT-1, RADARSAT-2, ENVISAT, TERRASAR-X, LANDSAT, MODIS, AVHRR. RADARSAT-2 for example is capable of covering areas or swath widths of up to 500 km x 500 km at a resolution of 100 m (ScanSAR Wide mode) down to fine resolutions of 10 m over a 50 km swath width (Fine mode) and can 'see' through clouds. Image acquisitions can be effectively planned well in advance, though shorter ordering and data delivery times generally introduce additional costs. Coverage for the province and the North Atlantic is good, with repeat orbits generally every one to two days, with more frequent coverage to the north.

Climate change is more readily and strikingly evident in many of the applications related to ice and snow cover (especially the timing of freeze-up and melting and the variability and severity of ice seasons), environmental parameters which are well-suited to remote sensing satellites. Satellite observations are critical for ongoing monitoring of large, inaccessible, data-sparse areas, where conventional monitoring approaches are often prohibitively expensive, unsafe and/or impractical. Conversely, in-situ monitoring networks and dedicated short-term intensive campaigns are used to calibrate and validate information extracted from satellite imagery. It will also be necessary to increase the coherence of remote and in-situ measurement efforts to ensure the consistent extraction of relevant readily applicable information from satellite data.

Specific and beneficial applications of this technology have already been pioneered in the province, including the Badger River Ice Service. This is an innovative project (in the Town of Badger) comprised of real-time cameras on the Exploits River and flood forecast models, satellite imagery and risk alert systems for provincial, community and emergency response personnel. The project was developed in partnership with the European Space Agency and has been presented internationally as a model for other jurisdictions to learn from, including at the 2008 United Nations Climate Change Conference in Poland. The Badger River Ice Service is currently supported in part by the Canadian Space Agency and Public Safety Canada. Primary information products include ice classification maps of the Exploits River showing areas of water, or possibly water on ice, non-consolidated or intact ice, and consolidated ice. This information directly assists decision makers in assessing where ice is building up and becoming consolidated which increases the potential for an ice jam and flooding in Badger.

The archives of satellite imagery service providers are generally searchable which can facilitate study of monitoring data already acquired.

7.4 Climate Normals and Atlases

Climate Normals, long-term averages and extremes of climate data, including temperature, precipitation, wind, degree days, and humidity, are used to summarize or describe the average climatic conditions for a particular location. Consistent with WMO recommendations, Environment Canada publishes 30-year Canadian Climate Normals and extremes on a decadal basis. The latest normals are for 1971-2000[36], with an update to follow soon for 1981-2010. Normals are used as a measure or to classify a region's climate and support decisions for a variety of purposes including basic habitability, energy use, transportation, agriculture, tourism, and research in many environmental fields. Normals are a key information product for basic climate study in the province. Normals also provide a reference value for the calculation of climate anomalies, and in the field of climate change, they provide stakeholders, planners, and decision makers with a detailed quantitative assessment of a location's latest or, more correctly, recent past climate conditions (e.g., Arguez and Vose, 2011). In a changing climate scenario, the base climate from the last 30 years may not be indicative of the conditions for the next 50 or 100 years into the future – in fact almost assuredly not.

The definition of climate Normals have several key attributes including: they are temporal averages (typically 30 years), averages are unweighted (one could give the observations of more recent years a greater weight as being more indicative of current and likely future conditions), and they are updated once every 10 years. In addition to adjusting time periods and weighting factors, there are viable alternatives to the average or mean as the statistic to characterize the 'normal'. For instance, the median still provides a measure of the central tendency of the climate variable of interest. Further, for climate series for which trends are observed, a temporal average (a constant value) is an unsuitable measure of background climate conditions. Alternatively, combinations of constant values and a linear fit (e.g., constant over the first 15 years and a trend over the most recent 15 years) may be useful for defining "normal" conditions for climate time-series with observed large positive or negative trends (Arguez and Vose, 2011).

If one accepts that climate conditions are changing, then to provide a more accurate measure of current and future climate conditions, climate normals should be both updated as frequently as possible (i.e., annually[37]) and/or computed in alternative manners such as noted above. The best alternatives may not be the same for each physical parameter; for example, a 30-year average may be most useful for temperature, whereas a 10-year median may be most useful for ice conditions. If it is determined to alter the base averaging periods (e.g., from 30 years), this should be done with caution since, for example, computation of anomalies from the base condition will be directly affected (Arguez and Vose, 2011).

The CIS sea ice atlases are similar Normals products requiring updating as frequently as possible (e.g., at least every decade, ideally every five years). This is especially true given the notable melting of polar ice regions and northern retreats of the ice extents in the North Atlantic, and the requirement for researchers, stakeholders, and decision makers to be made keenly aware of changes resulting from climate change.

[36] http://climate.weatheroffice.gc.ca/climate_normals/index_e.html? ; 1961-1990 normals are still available online

[37] it is acknowledged that while the computation of Normals may be simple in concept (e.g., calculate average values), there is considerable effort required to address missing values and data quality issues, and typically several environmental parameters and derived values are computed, so that resources must be allocated in a timely manner to analyze and publish the various Normals collections

Users in the province should ensure they are aware of the latest WMO standards and recommendations for the publication of Normals as well as any developments of alternative Normal products.

7.5 Climate Reanalysis Products

Climate measurements are frequently unavailable for remote regions or are of insufficient record length to have a good long term history of normal and extreme weather events which may be encountered. This is particularly true for Newfoundland and Labrador with its many bays, isolated shorelines, and vast marine expanses, where monitoring data can be limited. In order to support a range of atmospheric and marine modelling study efforts, alternative sources of data are frequently required both to provide a longer, continuous record of conditions, and a fine enough spatial resolution to resolve topographic or other local effects which may exist. Increasingly, hindcasts and reanalysis products are used in many fields of study that require an observational record of the state of the atmosphere and/or its underlying land and ocean surface conditions.

"Reanalysis is a scientific method for developing a comprehensive record of how weather and climate are changing over time. In it, observations and a numerical model that simulates one or more aspects of the Earth system are combined objectively to generate a synthesized estimate of the state of the system. A reanalysis typically extends over several decades or longer, and covers the entire globe from the Earth's surface to well above the stratosphere. Reanalysis products are used extensively in climate research and services, including for monitoring and comparing current climate conditions with those of the past, identifying the causes of climate variations and change, and preparing climate predictions. Information derived from reanalyses is also being used increasingly in commercial and business applications in sectors such as energy, agriculture, water resources, and insurance"[38]

In addition to any particular monitoring need being identified, climate reanalysis products are a significant resource for climate study wherever data is unavailable. As examples, several key products with coverage for the province are noted below.

- the Meteorological Service of Canada 50-year (MSC50) marine wind and wave climatology hindcast covers the North Atlantic for the period 1954-2008 (Swail et al., 2006). The hindcast consists of gridpoints of data at a resolution of 0.5° (about 38 km at the latitude of St. John's) over the open ocean and 0.1° over shallower coastal regions. Each gridpoint consists of hourly time-series of wind speed and direction, significant wave height and peak wave period, wave direction, and associated parameters
- the National Centers for Environmental Prediction/ National Center for Atmospheric Research or, NCEP/NCAR, Global Reanalysis Project (at the National Oceanic and Atmospheric Administration (NOAA)/ Earth System Research Laboratory (ESRL) Physical Sciences Division) (Kalnay et al., 1996). This is a data set whose primary use is to spatially fill in gaps in the historical record where measurement data may be missing. Spatial fields of air temperature,

[38] http://reanalyses.org/

pressure, relative humidity, precipitation, etc. are created over the entire globe both in space and in time from 1948 to the present. The derived fields are created by blending actual measurements from instruments with high resolution weather models that re-create the atmosphere over this time, based on what was actually observed. While the variables in this dataset are approximations, in general the fields are well calibrated and fairly accurate

- the North American Regional Reanalysis (NARR)[39] is an extension of the NCEP performed over the North American Region, and includes high resolution topography and additional sources of information that allow the spatial fields to show extra detail that is physically plausible. The dataset includes temperatures, winds, moisture, pressure, and snow depth from a range of observing platforms. In addition, a major component of the NARR is the assimilation of precipitation. The precipitation dataset comes from a variety of sources. Over Canada, the precipitation comes from 1° (rain) gauge datasets

7.6 Climate Predictions

The historical record, while illustrating a range of conditions encountered, does not readily provide an indication of future climate conditions. This is especially true in an era of more rapid climate change. As one example, climate change and global warming are anticipated to affect the province's water budget through changes to runoff of the drainage basins, direct precipitation, and evaporation. Warming will lead to increased evaporation both from land and water bodies. Whether a possible increase in precipitation or increased evaporation dominates will determine the net effect on water supplies and lake and river levels.

In an attempt to determine the effects of projected future minimum and maximum temperatures and high and low precipitation amounts for hydrological analysis, a number of different general circulation models can be used to simulate future climate scenarios (e.g., combinations of warmer or cooler, and wetter or drier conditions)[40]. There has been a buildup of carbon in the atmosphere and significant warming already over the last decade. Even if emissions were capped now, warming would continue for likely a century. Temperature increases do need to be minimized for beyond that through carbon emissions reductions (cimate change mitigation); however, there will still be warming and climate change adaptation will be required for the coming decades. It is clear Newfoundland will warm but at a lower rate than most of the rest of the continent in the coming decades. Most models do agree quite well on temperature; however, they do not agree well for precipitation.

[39] http://nomads.ncdc.noaa.gov/data.php#narr_datasets

[40] The IPCC is the lead group globally in this regard with the recently published 7th Assessment Report. In a nutshell, the approach is as follows. Start with some specific scenarios for carbon, three main categories with each containing sub-scenarios: business as usual, some reductions in GHG, and significant reductions in GHG together with major technological breakthroughs in extracting carbon from the atmosphere (e.g., carbon sequestration). Atmospheric modelling groups and research institutes around the world (e.g., US, EU, Japan, Canada, and research institutes) then apply these scenarios for the amounts of gases in the atmosphere to their own General Circulation Models (GCMs – all models have some parameterization of the earth's surface and atmosphere and some different simplifying assumptions in atmospheric dynamics and thermodynamics). Each comes up with their own solutions for what the world's future climate will look like. This is the basis for consistency in temperature change predictions five or more decades out and the uncertainly in precipitation changes five or more decades out.

There is a need for users in the province to be aware of and efficiently avail of global and regional climate change model predictions. This requires liaison with those (lead) scientists (e.g., with Environment Canada and in leading universities (Victoria, Toronto, McGill and UQAM) presently applying these models to North American and Arctic domains which will be relevant for Newfoundland and Labrador. Current global climate models provide predictions for air temperature, precipitation, and other parameters including sea ice, under different scenarios. Separate general circulation models typically yield (at least somewhat) different predictions. Also required are statistical downscaling, or use of different regional dynamical models, to extract and assimilate information for the Newfoundland and Labrador geographic region. These are essential for input to longer term forecasts out to 20, 50, 100 years or other future timelines.

Future climate conditions inherently have some uncertainty, but, establishing a range of possible outcomes for selected scenarios offers the best chance of successful planning and preparation in order to adapt to the changes. The need exists to identify a ‘basis set’ of climate models to consider for decision making. The model strengths and weaknesses, specifically for the Newfoundland and Labrador atmospheric, oceanic, and terrestrial domains, must be established. Suitable measurements at the boundaries of these domains and with some adequate spatial resolution throughout will also be required in order to validate and calibrate each model.

8.0 DATA STANDARDS AND QUALITY

From the range of shorter operational and longer planning and research study interests pursued by users in the province, there is a wide range of sampling frequency requirements. Users focus both on time scales of minutes to hours, or daily, consistent with 'weather' outlooks and activities, and on interannual to multi-decade 'climate' study. For climate study, a lengthy past record for a site, 50 years or more, is required in addition to measures to ensure the longevity of data acquisition activities at or very near that location going forward.

The selection of measurement sampling frequencies is usually based on the time scales over which the physical phenomenon might typically vary significantly and sufficiently to cause impacts of concern (e.g., precipitation Intensity) and any analysis requirements (e.g., as a minimum, measurements of daily minimum and daily maximum air temperatures also enable calculation of a daily mean and hourly measurements provide greater resolution from which these statistics can also be readily calculated). These are sometimes further dictated by any operational requirements and applicable guidelines. As an example, for oil and gas exploration and production on the Grand Banks, operators follow the minimum met-ocean-ice measurement recording intervals set out in the Offshore Physical Environment Guidelines (PEG) (NEB et al., 2008) as noted in Table 8.1.

Table 8.1 Met-Oean-Ice Measurement Recording Intervals (Source: NEB et al., 2008)

Parameter	Frequency
air temperature	1 minute average (if using electronic sensor), hourly
wind	gust: 2 minute averaged wind speed and direction, hourly average: 10 minute averaged wind speed and direction, every 10 minutes
waves	20 minutes
ocean currents	Ocean currents should be measured at least once every 30 minutes with a view to resolving the vertical structure and temporal variability during the program period (NEB et al., 2008)
ocean temperature and salinity	Regular measurements that resolve vertical and seasonal variability should be made, until sufficiency of data has been clearly established. This could be accomplished by moored sensors at representative depths (such as the current measurement depths), or by regular monthly (preferably) or seasonal CTD profiles (NEB et al., 2008)
marine synoptic ship reports	every 3 hours

The UN-chartered World Meteorological Organization (WMO) is the source of the standards for the atmospheric elements (air temperature and wind) cited in Table 8.1. Similarly, the WMO provides guidelines for other atmospheric parameters to ensure common exposure across the nations of the world and so common interpretation and use of data in support of activities such as international aviation.

Most users require both real-time and historical data. Historical data (e.g., following verification or quality control of original measurements) are a necessary companion to any access to information in near real-time (i.e., within an hour or less[41]). In general, the availability of near real-time data is beneficial, though in general some caveats must be provided in the event that quality control is not yet completed. For some monitoring stations near real-time access is not supported or is costly to provide. This can be due to a number of factors: large data volumes, long durations between data polling or downloading, and error-correcting quality control and processing efforts which may need to be applied first. While these may be operational considerations, such a delay should not limit the utility of data for study of weather and climate change on time scales of months to years to decades. In practice, users should be able to access the Climate Station Inventory to determine the most appropriate methods of data access, including limitations, and then pursue any subsequent customized data reports needed.

Manned and Automatic Climate Stations

Climate monitoring stations are a mix of staffed (or manned) and automatic stations as shown for the province in Figure 8.1. During the survey of user needs, some expressed concerns as to whether automated stations provided the same level of accuracy and continuity of record, particularly with an Environment Canada trend over the past number of years towards ever increased use of automatic stations.

At staffed stations, a trained observer takes measurements using the instrumentation installed. Meteorological observers are required for a number of reasons, the essential ones including (see also WMO, 2008):

- to make synoptic and/or climatological observations to the required uncertainty and representativeness with the aid of appropriate instruments
- to maintain instruments, metadata documentation and observing sites in good order
- to code and dispatch observations (in the absence of automatic coding and communication systems)
- to maintain in situ recording devices, including the changing of charts when provided
- to make or collate weekly and/or monthly records of climatological data where automatic systems are unavailable or inadequate
- to provide supplementary or backup observations when automatic equipment does not make observations of all required elements, or when it is out of service

The level of service and support provided by an observer is dependent on the training they have received and the role at the station (e.g., meteorological observer at an airport vs. a volunteer at a climate station).

[41] Normally, real-time in a telecommunications and sensing context is taken to mean within a few minutes but not more than about 5 minutes.

In comparison, automatic weather stations can adequately provide most required parameters except for observed weather (e.g., precipitation type identification, sky cover, obstructions to visibility, where any instrument systems available today would provide much less complete and useful information). They are particularly well-suited for remote coastal locations (as evidenced in Figure 8.1) and have lower labour costs than manned stations. There are a number of potential downsides with automatic stations, particularly those in remote locations. Firstly, such stations may have to be installed based on what land is accessible or where power is available, which can result in sheltering or other exposure issues. With an unmanned station, there is added potential that instrument readings may drift or equipment may not be operating properly. This is in contrast to manned stations where observers should confirm proper operation first hand and can refer to data from nearby stations to ensure that equipment are operating properly. If equipment malfunctions are identified, or data reporting fails, for automatic stations there can be added delays, sometimes on the order of months, before someone can be sent to the site and problems are identified and resolved.

The overlying need is that station siting and exposure, changes to instrumentation, and inspection and timely maintenance are of paramount importance and apply equally to automatic and staffed stations.

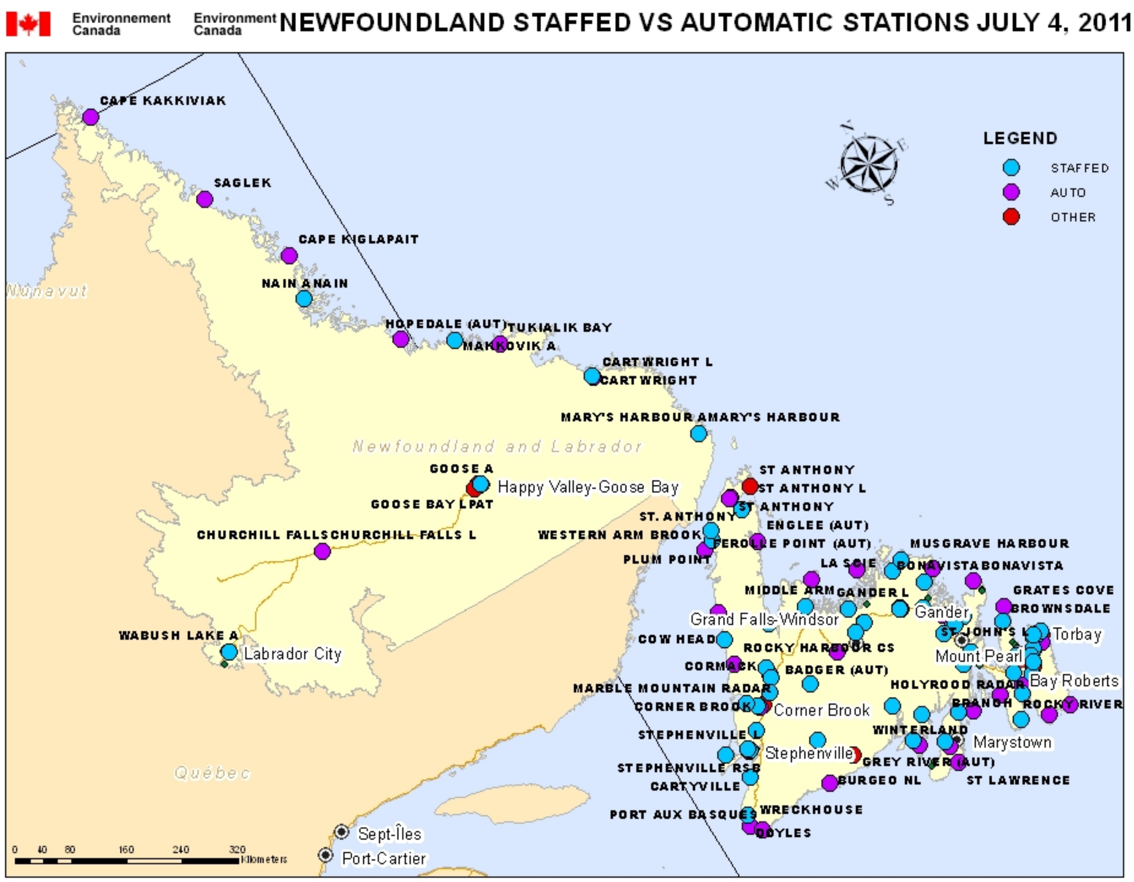

Figure 8.1 Newfoundland Staffed vs. Automatic Stations (Source: Environment Canada)

A significant strength for climate monitoring study is the personnel with experience and expertise to interpret and use these data. There is a need to recognize, and find ways to address, the loss of corporate knowledge that exists when experienced workers and scientists retire or are lost due to staffing and resource cuts. Special attention is warranted to ensure that key knowledge is documented and transferred to others. This knowledge pertains to the operation and maintenance of key equipment and technologies employed as well as the chronology of events and methods employed to collect and analyse the particular data as part of one-time studies and recurrent, multi-year, monitoring programs.

A basic, essential need, that should not be overlooked and applies to all climate stations, is proper equipment and system maintenance. This is particularly key for stations located in data sparse regions (e.g., marine buoys to monitor conditions upstream of the island), and those that directly support severe weather prediction, flood monitoring, or other emergency response activities. Sufficient resources must be made available to ensure that any operational downtime is minimized. Further, the metadata history of all stations needs to be available and kept current so that those who need to avail of the data for study have up-to-date and accurate records of the station history.

9.0 DATA NETWORKS, ACCESS, AND SHARING

A desire for more frequent updating of the various hourly, daily and monthly data published was expressed by some users. This would support more regular access to climate data. Data that are publicly available, which covers most of the networks, are generally available within a day or so, if perhaps sometimes in provisional form. Increased lead times are introduced when a rigorous quality control process remains to be completed. Automated QC that seeks to only identify 'missing, doubtful, and erroneous' data can be done automatically and does not create delays in availability; however, 'error-correcting' QC, typically requires human intervention and does add delays. Depending on the data or derived data products, sometimes these additional times are significant, and may be from months to years due to frequent personnel resource limitations. From a technology and procedures point of view, Environment Canada is actively addressing the requirement to shorten the time required for QC processing of data through system upgrades for their National Climate Data and Information Archive, and the Water Survey of Canada hydrometric data archive.

Station downtime, particularly during storms, and at strategic locations where there is limited weather monitoring coverage is a concern. This may indicate a need for station and network managers to have additional resources available to respond as soon as possible to any downtime. Even in non-storm periods, a measurement gap is undesirable due to the potential to comprise the long term record.

As already noted in Sections 5 and 6, there is a need for increased measurement of some environmental parameters. For land-based monitoring, some of these additions might require siting, design, and construction of new or enhanced stations. In other instances, it may be sufficient to add new measurement equipment to existing station infrastructure. From the point of view of data communications, processing, and publishing, for the most part, no additional infrastructure or significant network modifications would likely be required. For marine-based monitoring, infrastructure relates more to research vessel capabilities and time allocated for oceanographic cruises rather than the networks used to publish collected data. Concerns were expressed through the user survey by the oceanographic research user community about both federal cuts to the workforce and whether present research vessel resources are adequate.

In the presence of climate change, ongoing measurements are required to ensure that any shifts in climate and environmental parameters are adequately captured. This requires station and network maintenance to ensure all equipment are monitoring as intended.

A commitment is needed to maintain existing networks with appropriate expansion as necessary to enable climate change to be quantified and its impacts assessed.

A broad range of climate data are acquired in the province for various uses. To ensure optimal use of this information, promote collaboration, and reduce cost and duplication of efforts, it is essential to ensure that all potential users are aware that the data are being collected and are available. The information must be in accessible and well-documented formats. For users of climate information products, such as flood risk maps, weather and marine forecasts, or climate change adaptation materials, there may also be a need, particularly for members of the public or workers not well-versed in weather or the physical environment, to have practical guidance and contact information readily available.

Climate data must be made as accessible as possible to as wide a range of users as possible. Means to achieve this include online data servers with strong pre-processing and computing power, adequate support for a range of data formats, and data visualization options. While some users prefer simpler spreadsheet formats, there is a predominant interest for database and GIS formats.

Overall it is indicated that data should ideally be provided in suitably documented electronic formats which can be imported into the many mapping, analysis, or other visualization software packages in use. The most important aspect is that the structure of the data, as well as its associated metadata, are properly documented. There is a need to apply the best technologies to facilitate the effective sharing of climate data and metadata. Any measures to harmonize access to climate data and metadata in the province would be beneficial.

Sharing enables users to avail themselves of the latest and most accurate services, whether these are maps, reports, data, or computational processing. This is especially important for work within departments or working groups. Aside from any legal or confidentiality constraints, and sometimes human resource limitations in making data available, it was evident from the user survey that all individuals support data sharing.

Most government departments have infrastructure, processes, software and services to enable and support sharing, access, and visualization of data. These need to be promoted and implemented for the broader user good.

10.0 CONCLUSIONS

Individuals from approximately 50 government, academia, private sector, and other groups were surveyed to learn of their potential present needs for climate data and information in Newfoundland and Labrador. The survey was based on a questionnaire that was completed in writing and via telephone and in face-to-face meetings. A synthesis of this information for a 'user needs profile' for the province was subsequently prepared.

The majority of climate measurements being collected, and the networks in place to distribute this information, are all in use and of critical importance for these individuals and departments or agencies in providing their mandated services to the public and to their clients. There is a continuing basic need to maintain and expand the climate data networks in place and to fill gaps identified in the monitoring of various environmental parameters and geographical regions of the province. Several additional climate monitoring stations were identified in the process of completing the questionnaire and user consultation process and they have been documented in the Climate Station Inventory (AMEC, 2012).

Through the survey, a number of specific needs were identified and an attempt has been made to further articulate them in this report. This includes an assessment of selected climate variables that are instrumental to weather-related activities in the province and fundamental indicators of climate change. These include air temperature, precipitation, snow, wind, sea level, ice, waves and additional oceanographic parameters. Particular needs have been detailed and summarized for each to provide a base from which recommendations for improving climate monitoring can be made.

There is a continuing basic need for all network or data owners to validate, document, and publish data and metadata on a regular basis for timely access by all stakeholders. Increased awareness and sharing of these data sets and expertise is needed.

Practical requirements also include ensuring weather stations are operational and reporting, and that stakeholder applications (e.g., GIS tools, flood risk maps) are sharing and using the most up-to-date information. Following extreme events, such as a hurricane or a large storm surge, there is a greater need for measurements to quantify conditions experienced and support post-storm analyses and responses. This is relevant particularly for coastal wave and sea level, and inland wind and precipitation conditions.

Recognizing the spectrum of interests for users around the province, there is a need for continued coordination and collaboration of coastal and offshore climate monitoring resources. This includes government, industry, academia, and local interest groups. Specifically, as new monitoring regions are identified, appropriate technologies, synergies and roles must be established and communicated amongst stakeholders.

All needs should be viewed by the various responsible and interested parties to establish priorities for action. This includes determining what efforts are required to lead and champion the preservation and expansion of climate networks moving forwards. These items have been framed with this in mind in anticipation of the recommendations part of this broader climate change monitoring study which is presented in Section 11.0.

11.0 RECOMMENDATIONS

Based on a gap analysis of the user needs profile presented in this report, a set of recommendations to improve the province's climate monitoring capabilities has been prepared. These are in addition to the basic assumption, and essential requirement, not explicitly detailed as a recommendation, to maintain, and where possible expand, the climate monitoring stations and networks presently in place.

The gap analysis focused on the following key aspects as ways to measurably address data gaps and user needs and subsequently identify steps for effectively moving forwards:

- improvements to address shortcomings of the spatial coverage of present atmospheric and oceanographic monitoring stations, and, for direct application in climate change study, station operation and maintenance to ensure long temporal records
- updates and broader coverage to expand the province's essential set of climate information products. This includes those products which directly support immediate and longer term planning and engineering (e.g., IDF curves and flood information maps) as well as a province-wide set of downscaled global climate model predictions
- ongoing support and promotion of the province's climate monitoring networks, and best practices for data quality, documentation, and access

A set of 14 recommendations were developed as listed in Table 11.1.

Table 11.1 List of Recommendations

#	Recommendation
1	Publish and Maintain the Climate Station Inventory
2	Champion the Climate Data Community in Newfoundland and Labrador
3	Establish Common Data Standards and Reporting Guidelines
4	Pilot a Combination of Seasonal Monitoring Programs in the Province
5	Establish a Formalized Snow Monitoring Program
6	Promote Greater Awareness and Utilization of Remote Sensing Technologies
7	Enhance the Coverage and Operation of the Coastal Marine Buoy Network
8	Enhance Sea Level Monitoring in the Province
9	Enhance Sea Ice Monitoring Programs in Labrador
10	Strengthen Coverage of Precipitation Intensity Measurement
11	Enhance IDF Curve Inventory for Newfoundland and Labrador
12	Enhance Coverage of Climate Change Predictions for Newfoundland and Labrador
13	Continue Updating Flood Risk Maps for Newfoundland and Labrador
14	Continue Coastal Erosion Monitoring and Mapping

Each recommendation is presented in a separate table below (Recommendation 1 to 14) with the following elements:

- Rationale – a brief review or restatement of the issue or gap to be addressed and basis for the recommendation
- Proposed Solution – an outline of the technical steps required to meet the recommendation
- Strengths and Benefits – some key technical and practical benefits which should be realized from meeting the recommendation
- Weaknesses or Challenges – potential technical, commercial or perceived challenges

Recommendation 1: Publish and Maintain the Climate Station Inventory

Rationale	For the first time, Newfoundland and Labrador has a comprehensive inventory of climate stations throughout the province and in the offshore – including existing, discontinued and planned. The inventory listing which environmental parameters, locations, and time periods are available, is comprehensive as all entities that own climate stations, including governments, industry and academia, are covered. Maintaining this inventory over time will promote up-to-date information sharing and help identify synergies, and avoid redundancies, in the provincial monitoring network.
Proposed Solution	Publish the inventory in a single repository where users can easily access the information. Provide appropriate contact information so that individuals can correct any inaccuracies and contribute new information, if and when it becomes available. In time, evolve the inventory (currently in Excel spreadsheet form, with additional metadata in Word document form) into a searchable database with more sophisticated reporting options. Ideally, this would also be incorporated with geographic information system (GIS) capabilities such as the Provincial Government's online Water Resources Portal which "displays a wide variety of water resources data to assist in decision making"[42],or Google Earth. Establish a variety of data integrity parameters to ensure that future editors maintain the information to a high quality. This should include establishing public updates on the site which periodically notify users what information has changed.
Strengths and Benefits	This will serve as a fundamental tool to access daily information relating to weather and climate monitoring as well as long-term climate change study and forecasting. Maintaining the inventory will enable the province's user community access to, for the first time, a full and complete picture of all data sources in the province: this should increase the likelihood that the most recent and relevant data are used for climate monitoring and climate change action efforts. It will provide users and climate stations owners with a tool to identify synergies and avoid any duplication. In doing so, it can serve as a key enabling tool for greater collaboration amongst owners which is needed in the province. The inventory will serve as a key tool in responding to climate change. It will provide users with access to climate data and, if maintained, when data have changed and what stations were removed or added, and where.
Weaknesses or	While the most significant expenditure of effort has already occurred in establishing

[42] http://maps.gov.nl.ca/water/mapbrowser/Default.aspx

Challenges	the inventory, keeping it accurate and up to date will require dedicated human resources on an ongoing basis. Should the inventory be enhanced to also include a searchable database and the integration into GIS platforms, these expenditures will increase. For that reason, these enhancements are not recommended for the first publication. While the Provincial Government invested in the creation of the inventory, it is not considered beyond the scope of possibility that some other entity – such as the federal government or Memorial University – could propose to own and maintain the inventory. That issue is beyond the scope of this study; however, the core consideration is that, in any scenario, there will have to be strong communication channels among climate station owners and the user community to maintain the inventory, address weaknesses and exploit opportunities. The ability to maintain the inventory will be challenging, regardless of the investment in human or other technical resources. It requires that all climate station owners maintain accurate and up-to-date records of their own networks and stations and communicate them to the inventory owner. History has shown that information sharing is not always optimal and greater efforts are needed on this overall area. The present structure of the inventory, with key spreadsheet parameters and accompanying metadata structure, should facilitate that information gathering and sharing.

Recommendation 2: Champion the Climate Data Community in Newfoundland and Labrador

Rationale	There is no single champion for climate data in Newfoundland and Labrador that promotes awareness, facilitates the sharing of interests, expertise and data, and serves as a key hub to promote the development of collaborative networks. This applies to both climate data owners as well as key users of the data.
Proposed Solution	That the Provincial Government serve as champion for the climate data community in Newfoundland and Labrador, covering both the owners of climate data as well as the broader user community. This could be a logical role as part of the Province's Climate Change Action Plan to provide high-level leadership and direct and coordinate those aspects of climate monitoring data and climate change study affecting Newfoundland and Labrador and its people, economy, environment. Those individuals and groups that participated in this study would be invited to join the community. Creating such a community could be a key, high-profile and centralizing effort in the province. However, this should also be extended into broader network building efforts to promote better awareness of ongoing activities as well as foster collaboration on known challenges and opportunities. This recommendation is not intended to extend; however, to the Provincial Government inheriting all responsibilities for climate monitoring which would still be undertaken by those entities currently involved in this space at this time. Further, this recommendation does not extend to the Provincial Government acting as a quasi-industry association that would speak on behalf of other entities to, for example, the federal government.
Strengths and Benefits	By establishing a champion for the climate data community in Newfoundland and Labrador, the Provincial Government could advance much needed collaboration and information sharing among the climate data owner and user communities, including Provincial Government departments and agencies. The champion could be the coordinating body acting as part of the Province's Climate Change Action Plan for planning and implementing recommendations of this study and other related topics moving forwards. This could enable the identification of synergies across the provincial network and connect cross-sectoral experts within the user community, and opportunities for the private sector in the areas of terrestrial and ocean technologies, and climate change mitigation and adaptation study and services. The establishment of this collaborative community would act as a key support in ongoing efforts to maintain the provincial network to a high standard and, over time, improve it to ensure it is continuing to meet the needs of the province.

Weaknesses or Challenges	Clear communications is critical to taking this recommendation forward as the challenge of ‘managing expectation’ will likely come into play. For example, some entities may come to see the Provincial Government as the place to take all issues or criticisms. Others may perceive the Provincial Government not as a champion of collaboration and data sharing, but rather as an actor that is seeking to takeover or unduly influence their own work. In addition, there are potentially many stakeholders and activities to ‘coordinate’as part of championing the climate monitoring cause. These concerns could be alleviated by determining early on which roles and responsibilities the Provincial Government is comfortable assuming. In the same manner that federal-provincial network sharing has been successful, similar dialogue with Environment Canada, Fisheries and Oceans Canada would be in order to seek clarity on roles. Nevertheless, for this reason, this recommendation is likely best taken forward informally at the officials level rather than as a major government announcement which would affect perceptions.

Recommendation 3: Establish Common Data Standards and Reporting Guidelines

Rationale	In order for climate data to have maximum impact and value, it needs to be measured and reported in a consistent manner and made available to all users. This is not occurring at this time, as data standards vary or are non-existent, and getting access to some information can be challenging. This study has identified the standards and practices in place for the provincial monitoring networks. The remaining tasks relate largely to a gap analysis and developing recommendations and an implementation plan.
Proposed Solution	To support effective climate monitoring and ensure the creation and longevity of quality climate data records for Newfoundland and Labrador, a common set of principles and standards for data collection, quality assurance, and publishing should be explicitly adopted and promoted. For consistency and completeness, and as a part to ensuring the data are available for reuse many times over in the future, the following essential elements, at a minimum, should be provided in one place: • climate station quality assurance guidelines including proper equipment siting and installation, sensor selection, data processing algorithms and data formats, communications, scheduled and unscheduled maintenance, documentation • metadata standards to be adopted and maintained • documentation of quality control applied • Adherence to World Meteorological Organization climate monitoring principles (e.g., Global Climate Observing System (GCOS) http://www.wmo.int/pages/prog/gcos/documents/GCOS_Climate_Monitoring_Principles.pdf) Climate data owners should also provide for a regular and timely submission/publishing/sharing of data for stakeholders and the public, in an easy to understand and access format. This should be made available online, at a minimum, but preferably as a web service that would be publicly available for geographic information systems. This study has identified the standards and practices in place for the provincial monitoring networks. The remaining tasks relate largely to a gap analysis and developing recommendations and an implementation plan.
Strengths and Benefits	By adopting common data standards and reporting guidelines in Newfoundland and Labrador, individuals and businesses will be able to extract the maximum value from the monitoring network. They will know where to find data, understand what is and what is not available, and be aware of any particular details on the climate station which may affect how the data is used, such as quality assurance practices. There would be no need to design and develop a new standard. Many of the appropriate standards and principles already exists; therefore, the key remaining tasks relate to comparing standards against existing practices and making any necessary adjustments to current practices.

	It would support improved data quality and help harmonize access to climate data and metadata in the province. Would also be beneficial for submission and acceptance of data for users outside of the Newfoundland and Labrador or Canada, such as International Data Centres. It would support enhanced study of climate change as more commonality would be brought to how data is captured and maintained. Further, broader reporting and promotion would ensure maximum exposure for climatologists and other individuals interested in this data.
Weaknesses or Challenges	There are numerous standards to adopt and each has strengths and weaknesses. It could be a long-term exercise to re-orient some existing monitoring networks to adopt new or modified standards. Further, the scope of this challenge could lead to some resistance to change. However, while in practice there may always some disparity in which standards are employed to measure, quality control, and document data, there is still value to be gained if, at a minimum, data owners subscribe to a set of guiding principle to govern their operations. This could include commitments to maintain metadata, record any changes to station technology which could affect data measurement, assurances of quality control and publish on a regular basis so users could rely on its availability.

Recommendation 4: Pilot a Combination of Seasonal Monitoring Programs in the Province

Rationale	Some of the Environment Canada Forecast Regions have gaps in the year-round measurement of some climate parameters. However, there are two key seasonal monitoring programs – the Province's RWIS (Road Weather Information System) (in winter) and Fire Weather Network (in summer) – that could be utilized and combined to fill these data gaps.
Proposed Solution	Pilot three trial projects within those Environment Canada Forecast Regions where there are recognized gaps in the year-round measurement of some climate parameters, but data from seasonal programs is available. This is known to exist for parameters such as precipitation for the region *Buchans and the interior* and for air temperature, precipitation, and wind for *Clarenville and vicinity*. The plan would be to combine, where stations are nearby, the monitoring from the two networks, i.e., have one station operating year-round compared with two stations operating for part of the year. This is essentially a data management exercise and therefore would likely require some modifications to the data collection standards within one, or possibly two, of the seasonal programs. This is to ensure they could essentially be perceived as a single climate station that is operating year round.
Strengths and Benefits	This would expand the province's monitoring network and provide year-round information on some climate parameters that are currently only available for a limited amount of time during the year. Many of the stations are in close proximity to one another and therefore the ability to trail the notion is possible. By combining data from seasonal programs, which are already in place and operational, there would be cost savings on network operation relative to the establishment of a new climate station or enhanced instrumentation to existing platforms.
Weaknesses or Challenges	In an ideal scenario, climate parameters should be monitored from a single location that is maintained long-term according to accepted World Meteorological Organization standards. Leveraging data from two separate sites as an alternative to an optimized single site may not be initially perceived as optimal, but the proximity of some of these sites to one another could mitigate any concerns about data integrity. It is possible that the operational season for one or both of these networks may need to be extended to ensure that, together, they are measuring the required parameters for 365 days a year. This may come with some additional costs.
Technical Considerations	As part of the solution approach: • confirm monitoring requirements for both networks are met under this plan, (e.g., station siting, instrumentation, data polling/communications, network operation and data QA/QC)

	• consider the potential to upgrade one or more stations with TBRG (e.g. *Clarenville and vicinity* is a region with three flood risk map communities, no calculated IDF curve, and no precipitation intensity measurement)

Recommendation 5: Establish a Formalized Snow Monitoring Program

Rationale	Newfoundland and Labrador does not currently have a formalized snow monitoring program. There are a number of entities undertaking some, albeit limited, snow monitoring work but there are no common standards and no broader collaborative framework for data and information sharing. Greater efficiencies and synergies are possible and all current efforts would be enhanced by adherence to common measurement standards. Providing province wide mapping during the winter months of monthly snow cover extent (SE) - the area covered by snow, and snow water equivalent (SWE) – the amount of water that would be released by the melting snow, would be fundamental to supporting a broad range of user needs, from business development to transportation safety to resourcing. The mapping would require remote sensing and in-situ monitoring observations.
Proposed Solution	Implement a state of the art provincial snow monitoring and mapping program that will utilize a combination of ground sensors with space satellite based sensors to provide province wide information on: • Snow cover extent per month, meaning the total area covered by snow; and • Snow water equivalent, meaning the total amount of water that is held by the amount of snow on the ground. This program should be developed in consultation among all key stakeholders including various levels of government and other key users, particularly Nalcor Energy given interests in water sheds and hydroelectric reservoirs. A key part of this exercise is leveraging existing monitoring platforms and developing common data standards to better facilitate information sharing.
Strengths and Benefits	The monitoring program and corresponding snow maps would provide, for the first time, an ongoing, systematic and reliable record of the spatial and temporal distribution of snow cover in the province. The information would have broad appeal and have applications for near-term applications and long-term climate study. It would provide province wide information needed for flood forecasting and alerts, flood risk mapping, wildlife studies, hydropower operation and recreational users. The information and maps could easily be shared through existing public GIS platforms such as the Water Resources Portal.
Weaknesses or Challenges	The program should rely on remote sensing technologies which can be costly to obtain and, in some environmental conditions, can be challenging (e.g., period of cloud cover). It is in place for some limited locations but a province-wide application may present cost challenges.

	Extraction of snow water equivalent information from remote sites is not yet known to be operational anywhere in the province, so there may be technical challenges to incorporating this feature in the early stages; however, this does introduce an opportunity for developing and applying new and emerging sensing and processing technologies into the process, perhaps with economic benefits. To achieve its goals, it is preferable that all stakeholders subscribe to a common data standard for measuring snow. There could be some resistance to change among the user community that may take time to rectify.

Recommendation 6: Promote Greater Awareness and Utilization of Remote Sensing Technologies

Rationale	Globally, there are increasing capabilities by remote sensing technologies such as radar and satellites that are not being exploited in Newfoundland and Labrador to the extent they could be. Newfoundland and Labrador is an ideal location to focus on these capabilities due to its large geography, sparse population and remote areas, and given some of the existing private sector technologies are already in place.
Proposed Solution	Develop a public information service that includes information on available remote sensing technologies, capabilities, terms of use and contact information. This should include an orientation, with focus on Newfoundland and Labrador, for users on the scope and benefits of remote sensing and a searchable archive of available data and information products covering, for example: • the environmental parameters they have been designed to monitor • the typical geographical areas covered, operation modes, image sizes and resolutions available • how to plan, order, acquire, and analyze the imagery • describe applications which presently use remotely sensed data for terrestrial and marine monitoring and detection, such as the Badger River Ice Service and Grand Banks Iceberg Detection Program. This is intended to provide users with better awareness of the local capabilities.
Strengths and Benefits	Remote sensing is the only measurement means available for monitoring remote locations, which comprise a large portion of the province and offshore marine areas. It can also provide a key complement to ground stations where information on large geographical areas can be further analyzed with very local conditions. The information service could help promote and facilitate greater utilization of a powerful tool that is currently only being used at a minimal level in the province. In doing so, it could serve to broaden, complement, and strengthen the current coverage provided by ground or sea-based climate monitoring capabilities, and as such would be a logical addition to the climate station inventory. By promoting greater awareness and, ideally, utilization of remote sensing capabilities, there may be cost-saving or cost-sharing opportunities identified among the user community to acquire imagery which is generally the largest expense (e.g., imagery costs can be eliminated for some work with the Federal Government). Increasing the awareness and utilization of remote sensing capabilities can also generate new opportunities for the private sector, as this work is not typically within the capabilities of most governments.
Weaknesses or Challenges	There are numerous remote sensing technologies available, each of which can provide a variety of services, so there needs to be a focused selection on which are appropriate to include, exclude, or highlight for the province. The provision of information is a useful first step but there may still be obstacles to greater

	utilization of remote sensing due to a lack of familiarity and experience and, most likely, the costs of acquiring imagery. However, if done effectively and with accurate research, the information service will likely identify opportunities where some imagery may be provided free of charge for a period of time. The Provincial Government has some experience in this area, such as the imagery it secured for the Badger River Ice Service.

Recommendation 7: Enhance the Coverage and Operation of the Coastal Marine Buoy Network

Rationale	The existing marine buoy network provides vital support for economic, public safety, and scientific needs for the province and for Atlantic Canada as a whole. Knowledge of coastal water conditions and the adjoining Northwest Atlantic Ocean is key for the well-being of the public; the measurements of air pressure, wind, and waves play critical roles in supporting weather forecasting and emergency preparedness and response – both at sea and on land for storms and flooding. In Placentia Bay, marine buoy monitoring through the SmartBay project has also provided the backbone for technology development and demonstration for the provincial ocean technology sector. However, there are two key challenges in the current network: (1) much of the province's marine offshore is not well-monitored, including the west and north coasts of the island and all of Labrador; and (2) there could be enhancements to current operating procedures to ensure proper alerts are provided automatically to users where buoys are out of service.
Proposed Solution	Part A – Expand the current monitoring coverage to ideally include at least one marine buoy in each of the Environment Canada marine forecast areas for Newfoundland. This work could also explore alternatives to conventional marine buoy technologies as a means to expand coverage, e.g. by using gliders or remote sensing. Part B – For existing and future stations, buoy owners should collaborate to enhance operating and maintenance procedures that should include, at a minimum, This could include alerts to the owner and user community when a buoy is not operating.
Strengths and Benefits	Improved decision-making capabilities for all activities relating to the marine environment through weather forecasts and forecast model validation. Enables early warning and more effective preparedness by government emergency response personnel and the public. Could underpin economic development activities relating to offshore oil and gas exploration off Newfoundland or Labrador, as well as in the ocean technology industry from marine buoy development, deployment and operation. By enhancing operation procedures relating to outages and downtime, users of these data would be made immediately aware that some information is out; which could in turn affect key products that rely on the information such as weather forecasts.
Weaknesses or Challenges	Climate monitoring through marine buoy networks is difficult given the harsh conditions and time and expense involved with launching a buoy and reaching it for service or maintenance. As a result, expanding the current network could be challenging. Expanded buoy coverage and improved maintenance is more difficult in those locations with deeper waters or seasonal sea ice occurrence; therefore, feasibility studies may be required in those locations deemed to be most challenging.

	There are also risks to utilizing more “non-conventional” approaches such as gliders, autonomous vehicles or remote sensing, which may be best advanced through limited pilot approaches with a research and demonstration focus.

Recommendation 8: Enhance Sea Level Monitoring in the Province

Rationale	One of the most significant coastal impacts of climate change in Newfoundland and Labrador is sea level rise. The Geological Survey has estimated that, by 2100, all areas of the province will experience sea level rise. Province-wide monitoring is necessary because sea level rise is not consistent in all locations. Sea level rise at any location is a combination of global sea level rise, as a result of warming oceans and ice sheet melting, and regional effects of crustal adjustment following the last glacial period to have affected the province. These combined effects mean that some areas of the province are experiencing different rates of sea level change than others. The Geological Survey has divided the Province into four zones, which will experience different rates of sea level rise, with eastern Newfoundland experiencing the highest rates of sea level rise and Labrador the lowest. Two zones are adequately monitored, by tide gauge stations at St. John's and Port aux Basques, whereas the other two zones that comprise the Northern Peninsula and Coastal Labrador, and Goose Bay and Lake Melville, are not. These two gaps should be filled with additional tide gauge stations.
Proposed Solution	Four zones indicating different rates of sea level rise were delineated in a 2010 study by the Geological Survey of Newfoundland and Labrador (see Section 6.1, and Batterson and Liverman (2010)). Two of these zones are currently being monitored. It is recommended that enhancements be made to the additional two zones with new installations on the tip of the Northern Peninsula (Zone 3) and one at Goose Bay / Lake Melville (Zone 4).
Strengths and Benefits	This will start to fill the sea level monitoring gaps in the province and provide key baseline information needed for climate change monitoring. It will have broad appeal to a variety of stakeholders including communities, engineers, and those responsible for harbour infrastructure (e.g., DFO Small Craft Harbours). For technology service providers, there is the opportunity with this recommendation to bring together in-situ measurements, remote sensing, and modelling technologies, for one of the environmental parameters of greatest practical interest for the province. The data can also be utilized to enhance other efforts on climate change adaptation; the data would be of particular use for long-term climate predictions, the development of flood risk maps, coastal erosion monitoring, local planning efforts, the study of coastal ecosystems and aquaculture development.
Weaknesses or Challenges	The installation of the two sites could be costly and, given the harsh environment, would require ongoing allocations to ensure proper operation, calibration, and maintenance.

Recommendation 9: Enhance Sea Ice Monitoring Programs in Labrador

Rationale	Ice conditions off the coast of Labrador have shown some vulnerability in recent years as a result of warmer, milder weather. This is expected to become more of an issue over time as a result of climate change and given the potential for more shipping traffic due to mineral shipping or oil and gas exploration. However, there is limited monitoring of ice conditions and no dedicated ground-level monitoring stations to provide data on key parameters such as ice thickness or velocity.
Proposed Solution	Re-instate a network of ice thickness monitoring stations from the Lake Melville area north, up the coast of Labrador along major transportation routes. These sites should include weather stations as part of the monitoring configuration to monitor atmospheric conditions, as well as time lapse photography and real-time cameras for visuals of ice conditions. This information should be made available in an accessible and easy-to-understand format to promote community usage. Consideration may have to be given to translating the material into local languages.
Strengths and Benefits	The information that could be provided by this suite of monitoring sites would be of significant interest to individuals that rely on winter sea ice for transportation. Currently, the scope of the daily and weekly ice chart products from the Canadian Ice Service includes ice thickness and concentration derived from satellite rather than in-situ ice measurements. Thus, there is limited information on ice thickness or ice velocity which are critical parameters relating to stability and safety. While it would be of paramount interest to public safety and transportation, the data would also be of use for the development of ice charts and forecasts, ice management and engineering for marine transportation, and is needed for basic ice-atmospheric-ocean research, and long-term climate modelling. The information could also support study of trends over time, particularly the timing of freezing and breakup and any events that occurred throughout the typical ice season that may have placed public safety at risk, such as a variety of freeze/thaw events. Finally, it would also serve as a valuable complement to the current suite of remote sensing technologies that monitor these regions.
Weaknesses or Challenges	Ice monitoring occurs in a very harsh environment and there is a regular risk of losing equipment. As a result, costs to establish monitoring sites in this environment would likely be higher, over time, than a similar site in a terrestrial environment. The value of these sites would only be realized to the extent that the data are used. Therefore, should it be taken forward, consultations should be undertaken with Aboriginal groups in northern Labrador and researchers in the area for the optimal configuration and the development of useful information products for the community. The incorporation of land based stations with remote sensing technologies would be

	possible, but costly. Remote sensing imagery could run in the range of $100,000 annually, but there may be existing programs such as Polar View where some imagery may be available.

Recommendation 10: Strengthen Coverage of Precipitation Intensity Measurement

Rationale	One of the most significant impacts of climate change in Newfoundland and Labrador is expected to be higher levels of precipitation falling in short, intense rain events. In its current form, the province's monitoring network for precipitation intensity is sub-optimal; coverage to effectively measure precipitation intensity is limited to only 16 of the 28 Environment Canada forecast regions in the province. This coverage needs to expand to enable effective decision-making for planning and infrastructure development.
Proposed Solution	Maintain the province's existing precipitation intensity stations and expand the network to have, at a minimum, one active, year-round climate station with a tipping bucket rain gauge (TBRG) in the remaining 12 Environment Canada forecast regions in the province. As this recommendation would likely be a multi-year project to advance, consideration should be given to identifying priority areas for immediate installation. It is recommended that prioritization be guided by those regions with the highest ongoing or planned infrastructure investment, compared against known or potential flood risk. Further, a focus on reinstating discontinued stations at previous sites, and capitalizing on existing climate station platforms for new sites, is likely the most efficient use of scarce resources.
Strengths and Benefits	Precipitation intensity measurement is critical for key decision making tools relating to planning and infrastructure maintenance and development including emergency response planning, flood risk maps and Intensity-Duration-Frequency (IDF) curves. These data, even in raw form, could be made available through existing platforms such as the Water Resources Portal. By increased coverage, engineers and decision-makers will have enhanced localized data on which to base decisions. Currently, much of the available information covers large regions, at best. With an enhanced monitoring network, the province would also be better positioned to measure and respond to changes over time. Reinstatement of discontinued precipitation intensity monitoring may re-establish the utility of existing historical data from those stations: sites with long records, e.g., 30 years or more, are particularly valuable from a climate change monitoring perspective since they have a long past record.
Weaknesses or Challenges	In order to maximize the potential from an enhanced measurement network, some level of government would have to commit to performing the quality assurance testing on the data to ensure it is valid. Tipping bucket rain gauges are sensitive

	instruments that can be affected by a variety of conditions. Quality assurance is critical. There may be limitations to how many sites can be upgraded each year as they require financial and human resource investment. An implementation plan would have to be developed to advance this recommendation.
Technical Considerations	As part of the solution approach: • select the TBRG technology (e.g., Hydrological Services, rate of rainfall gauge, TB3, or MSC, TBRG, type B2) best-suited for operations in the Newfoundland and Labrador climate (e.g., challenge of accurate measurement during windy conditions). This should ensure provision of the essential data sampling, processing, and data logging or communication capabilities to support development of IDF curves and flood information maps, and flood alert services • explore potential synergies with existing Environment Canada stations • considering seasonal sites may help identify locations with telemetry capabilities of opportunity that could mitigate costs

Recommendation 11: Enhance IDF Curve Inventory for Newfoundland and Labrador

Rationale	Intensity-Duration-Frequency (IDF) curves provide planners and engineers with design criteria statistics of how intense precipitation may be for a given location over a set period of time, from minutes to hours, and how frequently such events may occur in a given year. Given that the most recent update of 18 IDF curves for the province was completed in 2009, and that data for 13 locations were earlier than 2000, it is necessary to perform a full update of IDF curves for all locations. 11 of the 28 Environment Canada forecast regions have never had IDF curves prepared.
Proposed Solution	Develop new IDF curves and post them publicly for decision-makers. This would include updating previous IDF curves and developing new IDF curves for those locations that are currently underserved. This work should also pilot the incorporation of climate change predictions into a select set of new IDF curves to ascertain the merits of this tool for climate change adaptation in the province. It is a new technique that has been utilized in other locations (e.g., Moncton), but has not yet been explored in the province. This approach would be a reasonable complement to the work being done for flood risk maps where climate change predictions have been incorporated to expand the perspective of the decision-makers. This work would require the acquisition of the most recent precipitation intensity data for each location in the province which previously had, or should now have, an IDF curve. It will also require confirmation of the most appropriate IDF curve development standards. This has been a topic of interest lately and the Canadian Standards Association, for example, recently published a standard for IDF curves.
Strengths and Benefits	As a result of climate change which is predicted to increase the intense precipitation events in the province, this will ensure up-to-date knowledge for adaptation of infrastructure, more effective implementation of government policies, increased public safety, improved flood alerts to communities, and minimized flooding damages due to under design of essential drainage and related hydraulic structures. This can be a win-win-win investment; the public, private and academic sectors would have a keen interest in acquiring new or updated IDF curves. This includes multiple provincial and federal departments as well as communities, municipal engineers, industry and engineering consultants for the design and permitting of key hydraulic structures like bridges, culverts, dams. IDF curves are a key tool used to prepare flood risk maps. With new or updated curves, the province would be in a better position to continue to enhance its flood risk map inventory.
Weaknesses or Challenges	The preparation of IDF curves relies on an accurate and long data record from tipping bucket rain gauges, which should ideally range into the decades. This may not be in place for all locations and could limit IDF curve development; at least until enhancements are made to the precipitation intensity monitoring, should that recommendation outlined above

	be acted upon. While this may be a challenge, there are precedents for developing new IDF curves without ideal data records using other statistical techniques. The City of Moncton, for example, faced such a challenge but filled in data gaps with 'hindcasting', which looks backward to predict what the data may have been. This is less than optimal, but is provided to show that new curves are still possible even where data gaps may exists.

Recommendation 12: Enhance Coverage of Climate Change Predictions for Newfoundland and Labrador

Rationale	There are sophisticated and proven global climate models that have been downscaled to a greater extent in Newfoundland and Labrador. Currently, the scope of climate prediction work is largely on a province-wide scale with very little application at the local level. The amount of downscaled climate modelling work specific to the province is limited, with the exception of a few localized municipalities where work was done on a sample basis by the federal government or funded by the province to prepare flood risk maps, and a general overview of regional climate model (RCM) projections of change across Newfoundland out to 2050. Additional downscaling work is recommended for the province, to provide greater detail on magnitude and distribution of climate change impact. This is a powerful tool to prepare for climate change on provincial, regional and community geographic scales. Climate change has rendered the past observed historical climate record inappropriate for setting design criteria (e.g., for drainage networks and hazard planning).
Proposed Solution	Develop a province-wide set of downscaled global climate model predictions to 2050 and 2100 to provide estimates of air temperature, precipitation, sea ice, and other environmental parameters. These should utilize a common methodology and global climate model(s) for the entire province. The annual climate patterns should be tracked against these predictions and they should be updated, as a full package, regularly (e.g., once every 10 years) to assess their accuracy and utility of the predictions. Updating also provides the opportunity to avail of the latest climate change scenarios expected to come from the IPCC (e.g., tracking how governments and industry around the world are faring in reducing GHG emissions, technology developments, changes to world population, etc.) and new global climate model science. This work should be promoted heavily and made publicly available. The awareness, and utilization of climate predictions is still at a low level in the province and any new model outputs should be complemented by an aggressive promotional exercise so the public, private and academic sectors could utilize the findings.
Strengths and Benefits	Climate predictions are no longer a “nice to have” tool for climate change adaptation. On the contrary, climate predictions are now becoming a key decision-making tools and the information is increasingly incorporated into other tools such as flood risk maps, IDF curves and the long-term study of watersheds. These planning tools have traditionally been developed using the observational record; however, in the face of climate change, past observations become increasingly less relevant for future predictions and additional guidance from regional-scale projections becomes necessary. Developing a single set of climate predictions, using the same methodology and climate model(s), would be a significant improvement over the current situation where climate predictions are difficult to resolve on a provincial geographic scale, and hence sometimes spotty at best and, quite often, different methodologies and

	climate models have been used.
Weaknesses or Challenges	Newfoundland and Labrador has been recognized as a particularly difficult location for climate model given the interplay of the Gulf Stream and Labrador Current. As a result, evidence has shown that different climate models can show very different conclusions for the province. However, there has been work under the Atlantic Climate Adaptation Solutions initiative to look at the best models for the province. These results could provide the basis for this project. Particular scrutiny should be given to how different models predict different climate parameters. Further, climate modelling is an expensive undertaking. The most useful results would be obtained if there was adequate and stable funding to ensure the models could be updated periodically.

Recommendation 13: Continue Updating Flood Risk Maps for Newfoundland and Labrador

Rationale	Flood information maps have been prepared for over 30 communities in the province with a history of flooding. However, most of these maps were originally completed in the 1980s and 1990s and the inventory is out-of-date. Efforts have been initiated to update this inventory, through the Atlantic Climate Adaptation Solutions initiative and targeted funding from the provincial Budget 2011, but more work remains.
Proposed Solution	Continue updating the province's flood risk mapping inventory. This should follow Government's prescribed standard for the analyses, which includes the following essential steps: o Conduct updated hydrological and hydraulic analyses for each flood watershed o Undertaken new mapping of the flood plain and flood watershed to delineate flood levels in the flood plains. o Include determination of the various climate change scenarios to be added to the standard 1:20 and 1:100 year flood zones. Climate change scenarios for coastal flood plains will also need to include factors such as potential sea level rise. o Develop climate change inundation maps. This is an evolving technique which provides decision-makers with the depths of flooding in certain areas under the 1:20 and 1:100 year flood zones. These maps should be kept up to date over time, preferably at a 10 year time frame. When developed, the flood risk maps should be made available publicly and through geographic information systems.
Strengths and Benefits	The use of the latest historical precipitation (and topography and land use) data and climate change scenarios will ensure up-to-date knowledge for adaptation of infrastructure, more effective implementation of government policies, increased public safety, and minimized flooding damages due to under design of essential drainage and related hydraulic structures. Directly benefits communities, many provincial government as well as municipal engineers, industry and engineering consultants. Would support the Provincial Government implement its land use policy for flood risk areas, which provides guidance and planning restrictions on those areas at risk of flooding, for which a flood risk map has been development.
Weaknesses or Challenges	The development of flood risk maps are expensive and take time to develop. Further, they rely on having adequate input data to develop an accurate map. In some cases this data is not available and has to be developed, which can increase the costs. Given the cost and time involved in developing flood risk maps, there will likely be limitations on how many can be done each year. It will be necessary to prioritize which communities

	are to be updated first, and in what order. This will also rely on having updated IDF curves in place and, preferably, climate change predictions for the province. Currently, flood risk maps have been developed through funding from either the provincial and/or federal government. As such, there would be expectations for these levels of governments to continue to provide funding for flood risk maps. However, there is no requirement that only these governments can develop flood risk maps. Any municipality, or in some cases a group of adjacent communities, could develop a flood risk map given their own interests.

Recommendation 14: Continue Coastal Erosion Monitoring and Mapping

Rationale	Newfoundland and Labrador has over 17,000 km of coastline. Coastal erosion is a threat in many areas where coastal cliffs are composed of sand and gravel, or other sediment, and in low-lying areas adjacent to the coast.. These threats are expected to intensify with climate change as a result of rising sea-levels, stronger and more frequent storm surges, and less winter sea-ice to protect coastal areas in the winter months. Given the high percentage of the population that lives on the coast, approximately 90%, towns need to have good data on coastal conditions to make the right planning and development decisions.
Proposed Solution	The Provincial Government is already advancing a coastal erosion monitoring and mapping program. This work is led by the Geological Survey of Newfoundland and Labrador. This information, while not traditional climate data compared to what is collected at a climate station, provides a much needed picture of the impacts of climate change on the province's coast. The program involves the establishment of monitoring sites around the province in areas that are considered to be particularly sensitive to coastal erosion. 45 sites were established in the first year of the program, with more to be established in the remaining two years of allotted funding. These sites will be monitored on an annual basis to assess erosion rates, if any.
Strengths and Benefits	The continuation of this program would provide valuable long-term data to governments and communities about the impacts of climate change. In the past, efforts to assess coastal erosion risk were ad-hoc and undertaken on a limited basis by government or university scientists. By establishing a systematic approach to measure coastal erosion around the province, communities will have access to data that will help them make informed community planning decisions. As communities have limited capacity to undertake this work themselves, but yet are impacted by change in the coastline, it fills an important gap. It would also provide a key complement to other recommendations in this report, particularly those relating to measuring sea-level rise and coastal ice conditions, and future climate change predictions. The establishment of this program will be particularly valuable to communities, but the results will also be important to understand risks to archaeological sites. There is increasing attention on the impacts of climate change, e.g. sea level rise, on coastal archaeological sites, but often the potential threat, or rate of change in a location, is not well known. By establishing monitoring locations, the province would be better equipped to assess and monitor the threats to archaeological sites.

Weaknesses or Challenges	Coastal erosion is a very local issue. While one location may be at high risk due to a sandy coastline, a location only a short time away may have a rocky shore that can readily withstand storms or sea-level rise. As a result, there will likely be high demand for the establishment of monitoring sites in most communities. This may challenge the existing resources. Further, many areas at risk of climate change are in remote areas, i.e., not directly within a community and accessible by road. If the province wanted to expand its monitoring network to also include heritage areas, such as archaeological sites, additional resources and selection of priority sites would be required.

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Appendix A

Study of Climate Change Monitoring in Newfoundland and Labrador: Introduction and Questionnaire

Introduction

Dear N

AMEC has been contracted by the Government of Newfoundland and Labrador, Office of Climate Change, Energy Efficiency and Emissions Trading (CCEEET), to complete a study of climate change monitoring capabilities and needs in Newfoundland and Labrador.

The study has been conceived by the Provincial Government as part of its recognition of climate change as a long term challenge for the province, and the need for all sectors of the economy to have access to the right information to support decision-making. The work conducted through this study is anticipated to be of use to a variety of agencies and end-users with an interest in climate change and in having access to timely, accurate and reliable climate data and information.

The objectives of this comprehensive study are three-fold:

1. To prepare a full inventory of existing, discontinued and planned climate monitoring stations in the province. This includes those owned by all levels of government, the private sector and academia. This inventory has been compiled, and a draft is attached with this memo.

2. To understand the needs of the user community on specific elements of climate data and information. This will provide the study with the right information on what is working well, where gaps might exist, and what steps should be taken in the future. We are currently working on this part, and are engaging a cross-section of representatives from government, the private sector, the research and academic communities, and any other interested parties.

3. To develop recommendations to improve the current state of climate monitoring in the province, building on the analysis of the current inventory and the input from the broader user community.

To support this work, a short questionnaire is provided below (a copy is also attached with word check boxes to simplify edits) to gather some foundational information. We kindly request that if possible you complete and return this questionnaire to me by early next week. Alternatively, or in addition, I'd be happy to go over the questionnaire together on the phone or meet in person and to further discuss the study and your perspective. Please let me know.

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You may also direct questions or comments about this study to CCEEET:

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[43] AMEC contacts also included meteorologists Carolyn Evans, Brian Walsh, and oceanographer Maud Guarracino

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Thank you for your time and assistance in contributing to this study!

Instructions: please click on the grey fields to enter your text comments; please click on any check boxes as appropriate

1. What is the nature of your work or interest as it relates to accessing and using reliable climate data and information?

2. Do you currently use any climate monitoring data for the Newfoundland and Labrador region, and, if so, which data networks or sources do you access, and how? To assist in this question, please review the draft inventory list of data networks given at the end, noting any you use.

3. Do you own or operate any climate monitoring sites, and if so, would you be willing to share this information within the broader NL climate monitoring network?

4. Do you currently make use of climate 'capabilities' or information products derived from climate data analysis, e.g., intensity-duration-frequency curves, forecasts or seasonal outlooks, or environmental design criteria for engineering construction or operation?

5. Which environmental parameters are you typically interested in? Please check all that apply:

Atmospheric and Terrestrial:
☐ air temperature ☐ dew point temperature ☐ humidity ☐ station pressure

☐ precipitation amount ☐ precipitation rate or intensity ☐ precipitation indicator (yes/no)

☐ solar radiation ☐ degree days ☐ moisture

☐ wind ☐ cloud cover ☐ ground temperature ☐ pavement temperature

Freshwater:
☐ stream or river flow ☐ stage ☐ water level
☐ water quality (pH, DO, turbidity, TDS, conductivity) ☐ water temperature ☐ salinity

Marine:
☐ currents ☐ tides ☐ wave height ☐ sea temperature ☐ salinity

☐ sea ice ☐ icebergs ☐ sea level ☐ air temperature ☐ wind speed ☐ mean sea level pressure

Other: Any other specific environmental parameters:

6. What are your geographical areas of interest?

7. Is there a minimum measurement sampling frequency you require?

8. Do you require real-time access to data and/or access to historical data?

9. Do you desire data in any particular format, e.g., document, database, GIS, or other file formats?

10. Do you require data which have undergone a Quality Assessment / Quality Control process?

11. Please indicate any existing monitoring networks, or other sources of data and information products (e.g., forecasts, IDF curves) you feel are critical to be maintained?

12. Can you identify any future requirements for data or information products that you or your group would anticipate to be particularly useful for studying climate change allow you to carry out your mandate?

13. Are there limitations in existing monitoring technologies that you are aware of? e.g., are there data you would wish to have, but the current suite of technologies cannot capture?

14. Do you have any suggestions for Government regarding climate monitoring, related capabilities, data access, or other climate change monitoring items?

15. Have you any additional thoughts, comments, or recommendations for this study?

16. Would you be interested in receiving a final copy of the report associated with this study?

Thank you for your time and assistance in contributing to this study!

For question 2. Do you currently use any climate monitoring data for Newfoundland and Labrador and the adjoining marine areas, and, if so, which data networks or sources do you access, and how? To assist in this question, please review the draft inventory list of data networks, noting any you use.

Used?	Data Network Source ID	Network	Comments?
☐	AC-MUN_MI-1	SmartBay Ocean Observatory	
☐	AC-MUN_Physics-1-1	Bonne Bay Observatory	
☐	GC-DFO-1	Ocean Data Inventory (ODI)	
☐	GC-DFO-2	Hydrographic (Climate)	
☐	GC-DFO-3	Sea-surface Temperature (SST) Database	
☐	GC-DFO-4	Coastal Time-Series Database (CTS)	
☐	GC-DFO-5	Ocean Colour Database (OCDB)	
☐	GC-DFO-6	Atlantic Zone monitoring Program (AZMP), Hydrographic stations, sections, Climate Indices	
☐	GC-DFO-7	Atlantic Zone Monitoring Program (AZMP), Sea Level	
☐	GC-DFO-8	Atlantic Zone Monitoring Program (AZMP), Meteorological Data	
☐	GC-DFO-9	Canadian Hydrographic Services (CHS), Tides, Currents, Water Levels Archive	
☐	GC-DFO-10	Canadian Hydrographic Services (CHS), Tides, Currents, Water Levels Real-time	
☐	GC-DFO-11	Canadian Hydrographic Services (CHS), Tides, Currents, Water Levels Prediction	
☐	GC-DFO-12	Ocean Monitoring Workstation (OWS)	
☐	GC-DFO-13	Drifting Buoys	
☐	GC-DFO-14	Offshore Oil and Gas	
☐	GC-DFO-15	Waves	
☐	GC-DFO-16	Thermosalinographs	
☐	GC-DFO-17	Near-Bottom Currents	
☐	GC-DFO-18	Temperature-Salinities Climatologies	
☐	GC-DFO-19	Sea Ice Studies	
☐	GC-DFO-20	WebTide Prediction Model	
☐	GC-DFO-21	Biological and Chemical (BioChem)	
☐	GC-EC-1	National Climate Data and Information Archive	
☐	GC-EC-2	Canadian Ice Service	
☐	GC-EC-3	Marine Buoy Observations	
☐	MU-CSJ-1	City of St. John's RWIS	
☐	NL-DEC-1	Water Quality, Water Quantity, and Climate	
☐	NL-DFA-1	Shellfish Environmental Biological Monitoring Program (EBMP)	
☐	NL-DFA-2	Finfish Environmental Biological Monitoring Program (EBMP)	
☐	NL-DFA-3	Green Bay Carrying Capacity Study	
☐	NL-TW-1	Newfoundland and Labrador RWIS	
☐	PS-NLH-1	Newfoundland Hydro System Monitoring	
☐	OT-GLOSS-1	Global Sea-Level Observing System (GLOSS)	
☐	others?		

Data Source Abbreviations

Abbreviation	**Definition**
AC	Academia
AZMP	Atlantic Zone Monitoring Program

CHS	Canadian Hydrographic Service
CIS	Canadian Ice Service
CSJ	City of St. John's
DEC	Department of Environment and Conservation (Gov NL)
DFA	Department of Fisheries and Aquaculture (Gov NL)
DFO	Department of Fisheries and Oceans Canada
EC	Environment Canada
GC	Government of Canada
GLOSS	Global Sea Level Observing System
MI	Marine Institute
MU	Municipalities of NL
MUN	Memorial University of Newfoundland
MUN_MI	Marine Institute, Memorial University of Newfoundland
MUN_Physics	Department of Physics and Physical Oceanography, Memorial University of Newfoundland
NL	Newfoundland and Labrador, Government of Newfoundland and Labrador
NLH	Newfoundland and Labrador Hydro (a Nalcor company)
ODI	Ocean Data Inventory
OT	Other, including Not for Profit
PS	Private Sector
RWIS	Road Weather Information System
SST	Sea Surface Temperature
TW	Department of Transportation and Works (Gov NL)
WSC	Water Survey of Canada