BUILDING CLIMATE CHANGE SCENARIOS OF TEMPERATURE AND PRECIPITATION IN ATLANTIC CANADA USING THE STATISTICAL DOWNSCALING MODEL (SDSM)

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ABSTRACT
Atlantic Canada is situated in a very diverse environmental area along the east coast of Canada, spanning almost 20 degrees of latitude and 20 degrees of longitude. The climate of the region is varied, encompassing both marine and continental regimes and influenced by several major ocean currents and mountain ranges. In order to best describe the expected climate change impacts for the region, climate change scenarios and climate variables must be developed on a regional, or even site-specific, scale.

Two methods exist that could potentially provide this information, output from a Regional Climate Model (RCM) and statistical techniques to "downscale" climate variables from global climate models. Since the RCM capability for Canadian territory is presently being developed and output for Atlantic Canada is not readily available, the statistical techniques were explored to generate the downscaled climate variables in that region.

Homogenized daily mean, maximum and minimum temperature, and quality controlled precipitation data for 14 sites across Atlantic Canada over the last 30 years was taken from the Historical Canadian Climate Database and used as the basis for developing the initial statistical relationships. Essentially, a predictor-predictand relationship is defined between global climate model values and the observed values at specific sites. Future climate variables (predictors) are then extracted from various model experiments. Those predictors are used to provide downscaled climate variables (predictand) that are applicable to those specific observed data sites. The resulting values are intended for use by climate change impacts researchers who want to apply climate variables on a regional scale in future climate impact studies. These researchers' interests span many sectors including agriculture, forestry, biodiversity and natural resources.

The statistical techniques are embodied in the Statistical Downscaling Model (SDSM) developed by Rob Wilby et al., King's College, London. The model results are primarily from the Canadian coupled global climate model version 1 (CGCM1) from the University of Victoria, in British Columbia.

The monthly, seasonal and annual results show that in general downscaled SDSM values differed from, and in most cases were greater than, the raw CGCM1 global grid box projections, due presumably to local climatic forcing, and that the SDSM downscaling skill (as represented by explained variance) was highest for temperature (69-79%), lowest for precipitation (7-18%) and in both cases showed only slight spatial variability.

Users of these projections should be aware of the limitations of the methods used, and that downscaling using other GCM models running the same emission scenarios may produce slightly different but equally plausible results.

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1. INTRODUCTION

On a global scale, mean annual surface temperature has increased over the past century by 0.6°C (IPCC, 2001). In the scientific community, there is a general consensus that this increase during the past 50 years can be attributed partly to Greenhouse Gas (GHG) emissions from human activity. Global Climate Models (GCMs), which are capable of providing credible projections of climate changes into the next 100 years, use a coarse global grid scale (IPCC, 2001). Temperature and precipitation trends, however, differ on a regional scale due to different feedbacks appearing from synoptic to local scales. This results in differing impacts at different regional scales. To date, impacts researchers have only had GCM scale output to help determine the impacts of climate change to species and ecosystems on a 50-100 year time scale.

In order to best assess the expected climate change impacts on a species, ecosystem or natural resource in a region, climate variables and climate change scenarios must be developed on a regional or even site-specific scale (Wilby et al, 2001). To provide these values, projections of climate variables must be 'downscaled' from the GCM results, utilizing either dynamical or statistical methods (IPCC, 2001)

Downscaling can be accomplished by using either a Regional Climate Model (RCM), or a statistical technique. Since RCM model output is not readily available for Atlantic Canada, a statistical technique was chosen for this study. Statistical models are not only readily available, but have the added advantage of being extremely parsimonious. Thus most downscaling experiments can be run in minutes on a Personal Computer (PC) with a moderate processor speed (400-600 MHz), allowing for multiple computations to be run in real time, if required.

This study utilized the Statistical Downscaling Model (SDSM), developed by Wilby, Dawson and Barrow (2001), which was downloaded from the SDSM UK website (http://www-staff.lboro.ac.uk/~cocwd/sdsm.html).

Observed data sets of daily maximum temperature (Tmax), daily minimum temperature (Tmin), and total daily precipitation (Pcpn) were used as predictands. SDSM was calibrated using physically related 'predictor' variables, i.e. meteorological variables capable of being accurately simulated into the future by a GCM, fully realizing that some variables (temperature or atmospheric circulation) are more confidently projected than humidity (Gachon,2005).

Calibrated models were tested and fine tuned against known data. These validated models were then used to construct suites of downscaled climate variable projections at selected sites in Atlantic Canada. Predictor values from the first generation of the Canadian Coupled General Circulation Model (CGCM1) (Boer et al., 2000; Flato et al., 2000) running the Greenhouse Gas plus Aerosol simulation (GHG+A1) were obtained from the Canadian Climate Impacts Scenarios

(CCIS) Project web site (http://www.cics.uvic.ca/scenarios).

The major impetus for this study came from the desire of the modelling community to see downscaled results, the availability of both the SDSM and CGCM1 in the proper input formats, and the willingness of Environment Canada, Climate Change Division (Atlantic Region) to provide the resources to carry out this task. Determination of the efficacy of using either the SDSM, or SDSM and the CGCM1 in conjunction, for downscaling purposes was beyond the scope of this paper. Subsequent work was done to address these issues; first by Goldstein et al (2004), showing that of several statistical downscaling models, SDSM produced optimal results; and secondly by Barrow et al (2004), and Gachon (2005), who investigated bias within GCM models, and particularly within the CGCM1.

2. BACKGROUND

Atlantic Canada includes the provinces of Nova Scotia, New Brunswick, Prince Edward Island, and Newfoundland and Labrador. It is situated along the east coast of Canada covering nearly 20 degrees of latitude and 20 degrees of longitude. The climate of the region is varied, including Atlantic, Boreal, and Sub-Arctic climates and is strongly influenced by both the warm Gulf Stream and the cold Labrador Current.

Utilizing GCM output over this region limits the researcher to a small number of grid-boxes to cover all sites of interest. Six were used in this study, spanning 300 x 400km each according to the horizontal resolution of the CGCM1. Some of these boxes are defined as 'ocean' boxes' (e.g. box 33x10y, which is closest to Cartwright), and where the climate variables respond as if the surface boundary is North Atlantic Ocean water.

Researchers often require site specific values for various climate variables accurately reproduced at sites of interest within the region, based on the sensitivities of the species or ecosystem that they happen to be studying. If the species lives on the boundary of a grid box, or two species with different sensitivities live in the same grid box, no substantive conclusions can be made about the impact of climate change by simply using GCM global grid-box output, due to the coarse resolution of these models which cannot simulate some highly sensitive fine-scale feedbacks.

3. DATA

Daily maximum temperature (Tmax), daily minimum temperature (Tmin), and total daily wet day precipitation >0.25mm/day (Pcpn) for the 30 year period 1961-90 at 14 stations in Atlantic Canada were used in this study, as shown in Fig 1 below.

3.1 Observed temperature data sets

The observed temperature data sets were extracted from the Historical Canadian Climate Database (HCCD). The HCCD consists of daily minimum, maximum, and mean temperatures for 210 stations across Canada (Vincent, 1998). The data have been adjusted for inhomogeneities caused by non-climatic factors, such as station relocation and changes in observing practices, using a regression model technique. Monthly adjustment factors from previous work were interpolated to generate daily factors. These factors were used to obtain the adjusted daily temperatures resulting in the reliable long-term daily temperature data set used in this analysis.

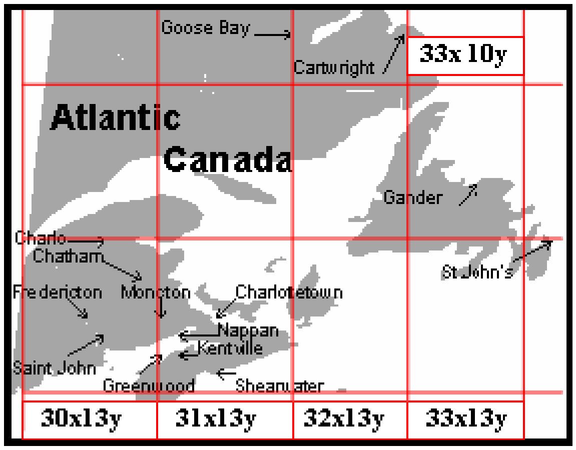

Fig 1 CGCM1 Grid Boxes in Atlantic Canada.

3.2 Observed precipitation data sets

Adjustments for inhomogeneities in Canadian precipitation data is a work in progress. For this study, quality controlled archived data were used.

3.3 Reanalysis predictor sets used for the calibration process

To provide gridded reanalysis data sets used in the calibration process of SDSM, the National Centre for Environmental Prediction (NCEP) products were interpolated to the CGCM1 grid over the Atlantic Region. Both the GCM variables and the NCEP data sets were made available for the grid-boxes illustrated in Fig 1 by the CCIS project.

3.4 Forecast predictor sets

The projected GCM output over Atlantic Canada was taken from the Canadian Climate Centre for Modeling and Analysis (CCCma) web site. Predictors ranged from basic variables such as mean surface temperature, mean sea level pressure, and specific humidity, to geopotential heights and geostrophic winds reconstructed from pressure gradients, all at three different levels in the troposphere (i.e. at 1000, 850 and 500 hPa).

The predictor sets are available for three future tri-decadal periods; the 2020s (2010-2039), the 2050s (2040-2069), and the 2080s (2070-2099). They are in the form of daily data from the CGCM1 GHG+A1 experiment normalized with respect to 1961-1990.

4. METHODOLOGY

The methodology used in this study followed the procedure previously outlined by Lines and Barrow (2002). The methodology is fully described in the SDSM 'Users Manual', by Wilby Dawson and Barrow (2001), which can be downloaded from the SDSM web site.

What follows is an overview of the downscaling process.

4.1 Model overview

SDSM is a hybrid of multiple regression and stochastic downscaling methods. Observed data sets (predictands) are first regressed against a 'selection' of climate predictor(s) to develop regression equations. SDSM is said to be calibrated when the regression coefficients, explained variance, and standard error are within acceptable limits for each regression model. The calibrated models using NCEP series are then run using relevant predictors. The number and choice of predictors will normally vary from one site to another depending on the predictand and the local climatic forcing factors. An internal random number weather generator takes the calibrated output and stochastically synthesizes a number of ensembles that are statistically related to the original output. (SDSM can synthesize up to 100 ensembles, 20 being the default number). The means of these ensemble simulations can then be used as the synthesized downscaled values.

These synthesized values must be 'validated' to see how closely they replicate the actual data. Best fit is obtained by making adjustments to the two stochastic parameters (variance inflation and bias correction). The regression equations, once validated, can now be used to 'generate' future downscaled sets of these climate variables, using output from different GCM models and experiments.

The significance of the downscaled variables is inferred from the monthly, seasonal, and annual variation in explained variance (R^2), and standard error (SE).

4.2 Predictor selection

To calibrate the model and determine the regression coefficients, a specific climate variable is chosen as the predictand. For predictor(s), a set of variables are constructed, recalculated to the same grid as the CGCM1, and based on the reanalysis data set.

For this study the NCEP reanalysis over Atlantic Canada was used as the comparative observational data set. Only variables from within the same grid box as the site were selected. These variables were then screened by SDSM to determine what amount of explained variance exists when the predictand and predictor(s) were statistically compared**.** The user is required to select predictor variables that produce the highest explained variance and the lowest standard error. In this study, sets of predictor variables were initially selected that were physically related to the predictand. It was found that over large regions of the study area for any given predictand, the same set of predictor gave consistently high explained variance (R^2). It was therefore decided that these 'generic' predictor sets, once selected, would consistently be applied at all sites.

SDSM is said to be calibrated when the predictor-predictand relationships are finalized, and a parameter file is created.

4.3 Calibration tests

Once the parameter file is created, and before entire sets of synthesized data are generated for any future time and site of interest, the calibrated model must be validated. The validation procedure used in this study was to calibrate the model on the first half of the observational data set, and validate the model on the second half. The closeness of fit between these two data sets is a measure of how accurately the calibrated model is likely to downscale any future climate variable.

An additional and perhaps more important validation of the downscaled results would have been to compare downscaled projections using CGCM1 predictors from the current climate period (1961-90) against actual values from 1961-90. This aspect was not performed in this study.

4.4 Downscaled future scenarios

The final step in running SDSM is to use GCM predictors issued from future simulations for the three tri-decadal periods centred on the 2020's, 2050's, and 2080's. For each tri-decade the results were compared to the global CGCM1 raw output. In addition, the monthly, seasonal, and annual value of explained variance and standard error were superimposed on each graphic as an aide in evaluating and interpreting the results.

Although the above procedures sound fairly straight forward, the designers of SDSM have pointed out that different predictor or grid-box selections can produce different results. Fortunately, SDSM was designed to assist the user in making many of these choices and, due to its parsimonious nature, allows the downscaler to experiment with various combinations of predictor/GCM grid-box selections in real time.

5. RESULTS

Downscaled SDSM results for Tmax, Tmin, and Pcpn, at 14 locations in Atlantic Canada, for the three tri-decadal periods centred on the 2020's, 2050's, and the 2080's, are shown as Figs 1-14 in the Appendix. For each location, Figs a, e, and i give the results of the validation procedure; Figs a-d show the downscaled results for Tmax; Figs e-h show the downscaled results for Tmin; and Figs i-l show the downscaled results for Pcpn.

This format resulted in 12 graphics per station, with downscaled SDSM results compared to CGCM1 global output at each projected time period. The standard error (SE) and explained variance (R^2), as calculated by SDSM, were superimposed in each appropriate figure.

5.1 Predictor selection

The generic predictor sets selected in this study are summarized in Table 1 below.

Table 1 Selected Generic Predictor Variables For Atlantic Canada Downscaling			
Predictor	***Predictand***		
	Tmax	***Tmin***	***Pcpn***
p__u	✓	✓	✓
p__v	✓	✓	✓
p__z	✓	✓	
p_zh			✓
p5_z			✓
p500	✓	✓	
p5zh			✓
s850	✓	✓	✓
sphu	✓	✓	✓
temp	✓	✓	

where
p__u = zonal velocity component @ surface
p__v = meridional velocity component @ surface
p__z = vorticity @ surface
p_zh = divergence @ surface
p5_z = vorticity @ 500hPa
p500 = 500hPa geopotential height
p5zh = divergence @ 500hPa
s850 = specific humidity @ 850hPa
sphu = specific humidity @ surface
temp = mean surface temperature

5.2 Calibration tests

The monthly seasonal and annual comparisons between observed and synthesized data during the validation period (1976-90) are illustrated in Figs a, e, and i for each site. For Tmax and Tmin, the synthesized curves replicated the actual data using NCEP predictors rather well, inferring that future projections would also be well replicated. In the case of Pcpn the seasonal and annual values were well replicated, however the monthly fits were less well matched. Impacts researchers are urged to use caution when using downscaled monthly precipitation values from this or other regression based downscaling studies (Wilby,2003).

Using SDSM to downscale the current climate (1961-90) using CGCM1 driven predictors, and then comparing these outputs to actual values, might have further demonstrated the ability of SDSM to produce accurate projections. The current climate however was not downscaled in this study.

5.3 Downscaled future scenarios

5.3.1 Monthly

Monthly projections for each climate variable, as well as each tri-decadal period, as depicted in the Appendix (Figs 1-14), showed considerable variability, thus precluding any attempt at an overall summary. Although similarities may exist between adjacent sites, the monthly results at each station are thought to be unique to that site. Furthermore, users of this information are advised to analyze each site individually for any implied impacts, and particularly to allow for the less than perfect fit between synthesized and observed monthly Pcpn data.

5.3.2 Seasonal

Seasonal projections for each climate variable, as well as for each tri-decadal period, as depicted in the Appendix (Figs 1-14), also showed considerable variability. Table 2 below shows a summary of the projected variability in winter/summer seasonal precipitation.

TABLE 2 SEASONAL PRECIPITATION PROJECTIONS						
	2020'S		2050'S		2080'S	
	WINTER	SUMMER	WINTER	SUMMER	WINTER	SUMMER
NS	%	%	%	%	%	%
Greenwood	8	14	11	18	15	11
Kentville	11	19	12	19	18	30
Shearwater	-9	4	0	2	-1	-6
Nappan	-7	0	-6	-2	-6	-5
NS MEAN	**1**	**9**	**4**	**9**	**6**	**8**
PEI						
Charlottetown	4	12	4	13	5	10
PEI MEAN	**4**	**12**	**4**	**13**	**5**	**10**
NB						
Moncton	-12	7	-8	8	-5	9
Chatham	12	18	20	9	7	1
Charlo	-4	2	-5	-5	-3	-4
Fredericton	4	20	6	25	7	30
Saint John	8	21	10	22	12	35
NB MEAN	**2**	**17**	**6**	**15**	**4**	**18**
NL						
Gander	-3	19	-2	20	-1	27
St. Johns	11	26	17	24	25	21
Cartwright	-9	6	-7	7	-4	13
Goose Bay	-6	6	-6	7	-2	13
NL MEAN	**-2**	**14**	**1**	**14**	**5**	**18**
OVERALL	**1**	**13**	**4**	**13**	**5**	**14**

Table 2 above suggests that, on average across the district, both winters and summers will become wetter, and by the 2080's projections are for winters to become 4-6% wetter, and summers to become 8-18% wetter than the base climate period.

5.3.3 Annual

Downscaled projections for each climate variable, and for each tri-decadal period, are depicted in the Appendix (Figs 1-14). For convenience the mean annual values are summarized in Table 3 below.

Table 3 Annual Projected Change in Downscaled Variables																		
	Tmax						Tmin						Pcpn*					
	SDSM			CGCM1			SDSM			CGCM1			SDSM			CGCM1		
Tri-decade	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80
	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	%	%	%	%	%	%
NS																		

Greenwood	1.8	3.2	5.3	1.3	2.5	4.1	1.1	2.7	4.0	1.5	2.5	4.0	12	12	10	2	2	5
Kentville	1.8	3.2	5.3	1.3	2.6	4.1	1.0	2.1	3.8	1.5	2.6	4.0	15	11	15	2	2	5
Shearwater	1.7	2.8	4.7	1.4	2.5	4.2	1.2	2.2	3.9	1.3	2.3	4.0	7	7	2	2	2	5
Nappan	1.8	3.1	5.1	1.3	2.5	4.1	1.1	2.1	3.9	1.5	2.5	4.0	-6	-7	-9	2	2	5
NS MEAN	**1.9**	**3.1**	**5.1**	**1.3**	**2.5**	**4.1**	**1.1**	**2.3**	**3.9**	**1.4**	**2.5**	**4.0**	**7**	**6**	**4**	**2**	**2**	**5**
PEI																		
Charlottetown	1.7	3.0	5.0	1.3	2.5	4.1	1.2	2.2	4.1	1.5	2.5	4.0	10	9	8	2	2	5
PEI MEAN	**1.7**	**3.0**	**5.0**	**1.3**	**2.5**	**4.1**	**1.2**	**2.2**	**4.1**	**1.5**	**2.5**	**4.0**	**10**	**9**	**8**	**2**	**2**	**5**
NB																		
Moncton	1.8	3.2	5.6	1.3	2.5	4.1	1.3	2.6	4.3	1.5	2.6	4.0	-1	0	1	2	2	5
Chatham	1.8	3.3	5.6	1.3	2.5	4.1	1.5	2.9	4.8	1.6	2.6	4.0	14	12	0	2	2	5
Charlo	1.5	2.9	4.8	1.1	2.1	3.9	1.2	2.1	4.0	1.6	2.3	4.2	-4	-7	-6	2	-2	3
Fredericton	1.8	3.1	5.0	1.1	2.1	3.9	1.8	2.8	4.2	1.8	2.9	4.2	20	21	21	2	-2	3
Saint John	1.8	2.9	4.2	1.1	2.1	3.9	1.5	2.2	3.8	1.6	2.9	4.2	18	20	21	2	-2	2
NB MEAN	**1.7**	**3.1**	**5.0**	**1.2**	**2.2**	**4.0**	**1.5**	**2.5**	**4.2**	**1.6**	**2.7**	**4.1**	**10**	**10**	**7**	**2**	**0**	**4**
NL																		
Gander	1.2	2.3	4.1	0.9	1.7	3.2	0.7	1.7	3.2	1.3	2.3	4.0	8	8	10	3	4	7
St Johns	2.0	3.2	5.1	1.0	1.9	2.7	2.0	3.2	5.0	1.0	1.8	2.7	13	15	19	3	8	6
Cartwright	-0.2	-1.0	1.0	-1.2	-2.1	-1.8	-1.0	-2.2	-1.8	-1.0	-2.0	-1.8	-5	1	4	-3	4	8
Goose Bay	1.8	2.3	4.7	1.6	2.1	3.8	1.3	2.2	4.1	1.7	2.9	5.0	2	3	5	-3	3	9
NL MEAN	**1.2**	**1.7**	**3.7**	**0.6**	**0.9**	**2.0**	**0.8**	**1.2**	**2.6**	**0.8**	**1.2**	**2.4**	**6**	**5**	**7**	**0**	**5**	**8**
OVERALL	**1.6**	**2.7**	**4.7**	**1.1**	**2.0**	**3.6**	**1.2**	**2.1**	**3.7**	**1.3**	**2.2**	**3.6**	**8**	**8**	**7**	**2**	**2**	**6**

* Precipitation percentages can be converted to actual mm values by applying the % to the mean annual precipitation values for each site as shown in Table 4 below.

Table 3 above shows a consistent rise in projected Tmax and Tmin temperatures across the district except over coastal Labrador where temperatures are expected to decrease. Precipitation is also expected to rise by 8-20%, except over northern Nova Scotia and eastern New Brunswick, where decreases of about 5% are projected.

However, in most cases SDSM projections differ from, and are greater than CGCM1 projections, due predominately to local climatic forcing.

5.3.4 SDSM Explained Variance (Skill)

The amount of explained variance (or downscaling skill), is shown in Table 4 below for the 2080's (1970-1999).

TABLE 4											
SDSM SKILL IN ANNUAL PROJECTED DOWNSCALED VARIABLES 2080'S											
Tmax				**Tmin**			**Pcpn**				
REGION	**SDSM**			**SDSM**			**SDSM**				
	R^2	**SE**	**2080'S**	**R^2**	**SE**	**2080'S**	**R^2**	**SE**	**2080'S**		**Mean**
	%	**° C**	**° C**	**%**	**° C**	**° C**	**%**	**mm**	**%**	**mm**	**Annual**
NS											61-90
Greenwood	70	2.5	5.3	69	2.9	4.0	11	5	10	110	1100
Kentville	78	2.7	5.3	73	2.4	3.8	15	5	15	181	1206
Shearwater	70	2.2	4.7	73	2.0	3.9	10	5	2	28	1371
Nappan	71	2.6	5.1	70	2.9	3.9	9	7	-9	-104	1158
NS MEAN	**74**	**2.5**	**5.1**	**71**	**2.6**	**3.9**	**11**	**6**	**4.5**	**54**	**1209**
PEI											
Charlottetown	78	2.3	5.0	75	2.2	4.1	10	6	8	96	1201
PEI MEAN	**78**	**2.3**	**5.0**	**75**	**2.2**	**4.1**	**10**	**6**	**8**	**96**	**1201**
NB											
Moncton	78	2.7	5.6	75	2.4	4.3	14	7	1	13	1228

Chatham	70	3.0	5.6	70	2.9	4.8	15	7	0	0	1087
Charlo	69	2.9	4.8	69	2.9	4.0	7	4	-6	-63	1052
Fredericton	79	2.6	5.0	73	2.8	4.3	12	5	21	238	1131
Saint John	69	2.3	4.2	69	2.5	3.8	11	4	21	301	1433
NB MEAN	**73**	**2.7**	**5.0**	**71**	**2.7**	**4.2**	**12**	**5**	**7.4**	**117**	**1186**
NL											
Gander	79	2.3	4.1	75	2.1	3.2	12	8	10	118	1182
St. Johns	72	2.5	5.1	69	2.2	5.0	18	5	19	282	1482
Cartwright	75	3.0	1.0	77	1.8	-1.8	15	7	4	40	996
Goose Bay	79	2.3	4.7	71	2.9	4.1	15	7	5	48	960
NL MEAN	**76**	**2.5**	**3.7**	**73**	**2.2**	**2.6**	**15**	**7**	**9.5**	**122**	**1155**
OVERALL	**75**	**2.5**	**4.7**	**72**	**2.4**	**3.7**	**12**	**6**	**7.4**	**97**	**1188**

In this study, overall, downscaling skill (R^2) was highest for Tmax (73-78%) and Tmin (71-75%) and lowest for Pcpn (10-15%). In addition temperature downscaling skill showed only a slight spatial variability while Pcpn skill was highest (18%) at St Johns (coastal) and lowest (10-12%) farther west (inland). These findings compared favourably to SDSM downscaled results reported earlier from central Canada (Toronto) by Wilby (2001, p18).

6. SUMMARY

The purpose of this paper was to statistically downscale climate change scenarios at 14 sites in Atlantic Canada to highlight the role played by local climate forcing. Projected GCM raw output was thus compared to downscaled scenarios driven by the CGCM1 (GHG+A1) using the Statistical Downscaling Model (SDSM). Parameters downscaled were daily maximum temperature (Tmax), daily minimum temperature (Tmin), and total daily precipitation per wet day (Pcpn).

In general SDSM downscaled values differed from, and in most cases were greater than the raw CGCM1 projections, due predominately to the effects of local climatic forcing. Across the district downscaling skill (as represented by explained variance) was highest for temperature (69-79%), and lowest for precipitation (7-18%) and in both cases showed only slight spatial variability.

Downscaling accuracy, using multiple linear regression techniques as in SDSM, is based largely on the assumption that the predictor-predictand relationships developed for the historical period are time-invariant. It should be noted that the latest research results indicate that this assumption (of time invariance) has already been violated in the observational data (Wilby, 1997).

Furthermore, downscaled scenarios in this study were generated using only one GCM model, running one experiment. Downscaled scenarios using other GCM models running the same experiment may likely produce slightly different, but equally plausible results. This is especially important in this case since the CGCM1 has been reported to be strongly biased in certain predictor sets, namely temperature and specific humidity (Gachon, 2005). Impacts researchers working at site specific scales would ultimately benefit by comparing downscaled projections from two or more GCM models running the same emission scenarios.

7. NEXT STEPS

1. Downscale two additional GCM models (HADCM3 and CGCM2), running identical emission experiments, and compare projections.
2. Select predictor sets using the 'cross correlation matrix' contained within subsequent SDSM versions.
3. Downscale the current climate and compare the results to actual values as a further gauge of the accuracy of the regression technique.
4. Analyze all downscaled values for variability and extremes using Stardex (2002) software.
5. Consider other climate, environmental, or hydrological variables (e.g. sunshine, air quality, or stream flow) as candidates for downscaling.
6. Downscale other sites in Canada.
7. Develop a GIS system to display all data.

8. REFERENCES

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APPENDIX

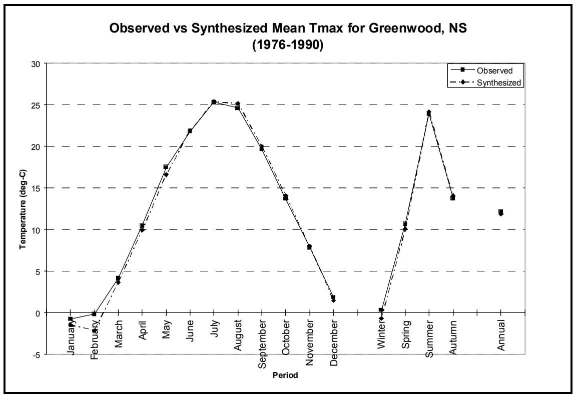


Figure 1a: Observed vs Synthesized Tmax at Greenwood, NS

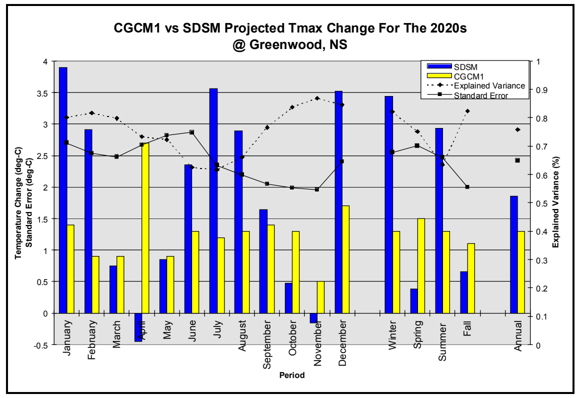


Figure 1b: Projected 2020s Tmax Change at Greenwood, NS

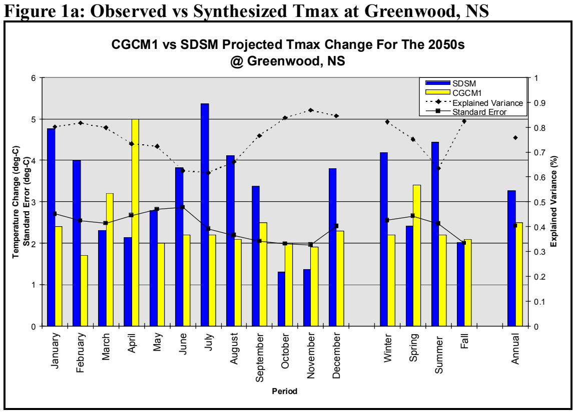


Figure 1c: Projected 2050s Tmax Change at Greenwood, NS

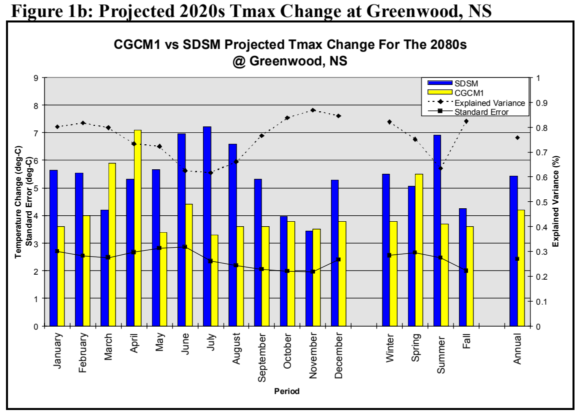


Figure 1d: Projected 2080s Tmax Change at Greenwood, NS

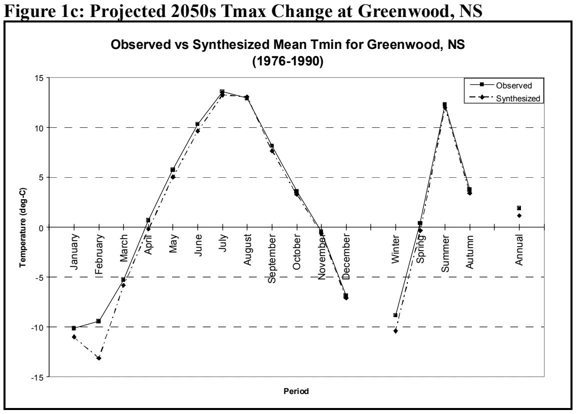
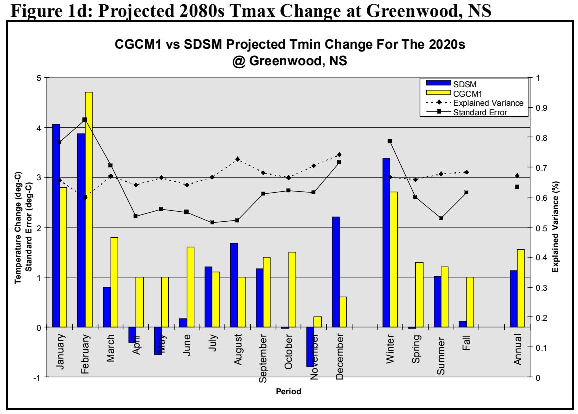


Figure 1e: Observed vs Synthesized Tmin at Greenwood, NS



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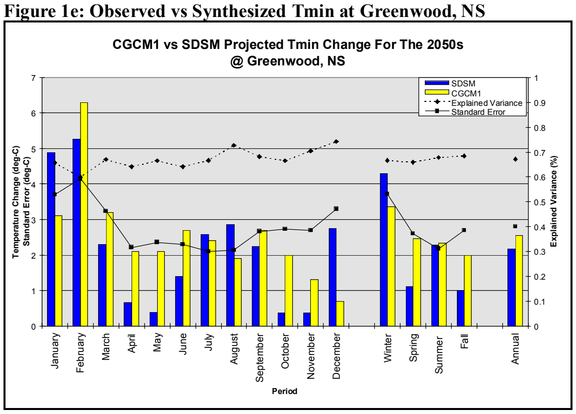

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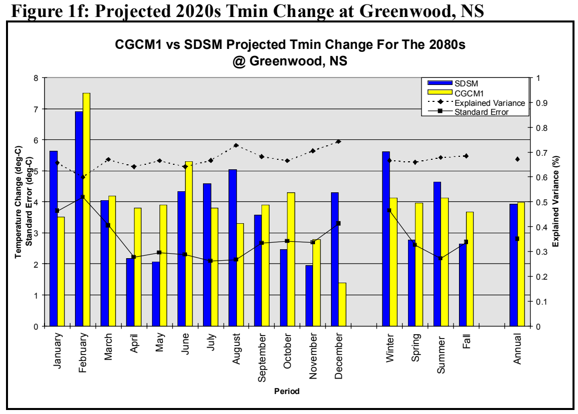


Figure 1h: Projected 2080s Tmin Change at Greenwood, NS

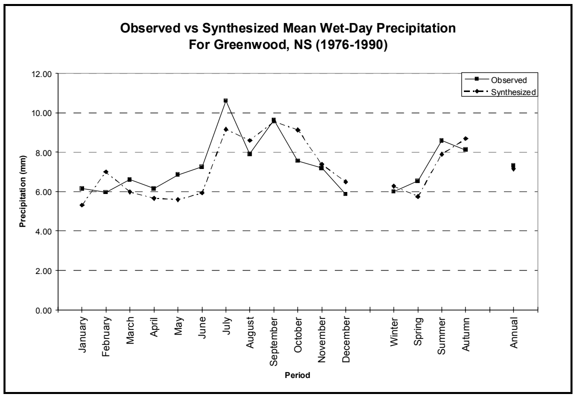


Figure 1i: Observed vs Synthesized Pcpn at Greenwood, NS

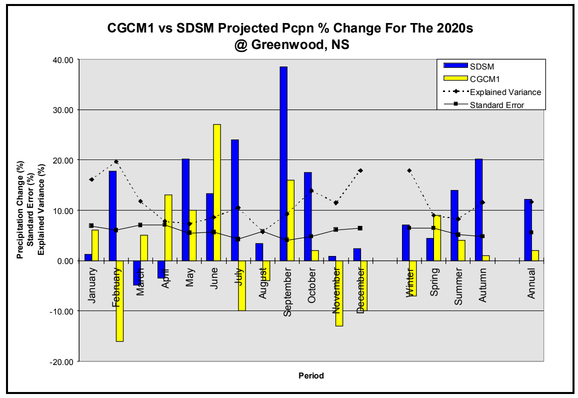


Figure 1j: Projected 2020s Pcpn Change at Greenwood, NS

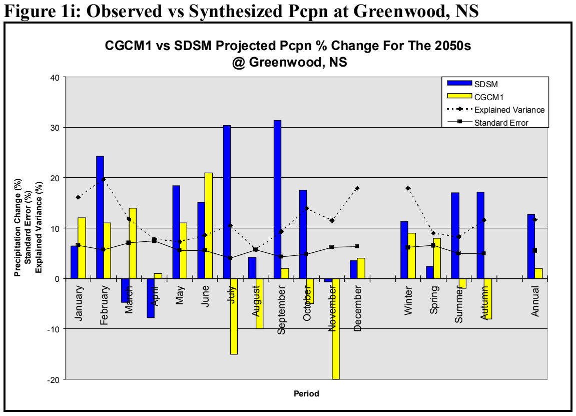


Figure 1k: Projected 2050s Pcpn Change at Greenwood, NS

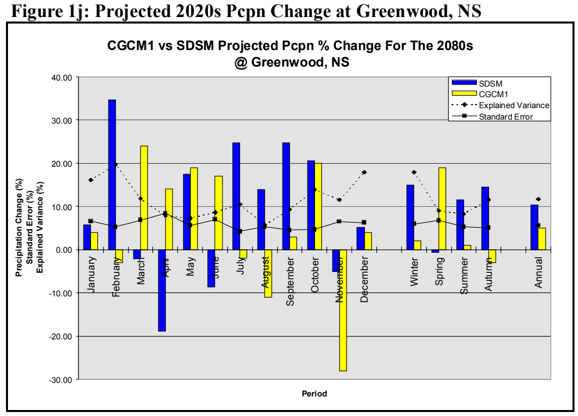


Figure 1l: Projected 2080s Pcpn Change at Greenwood, NS

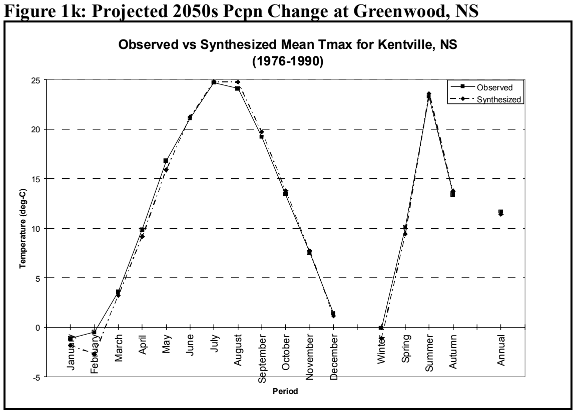


Figure 2a: Observed vs Synthesized Tmax at Kentville, NS

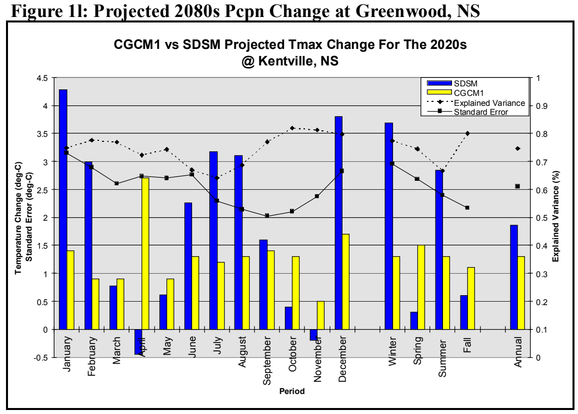
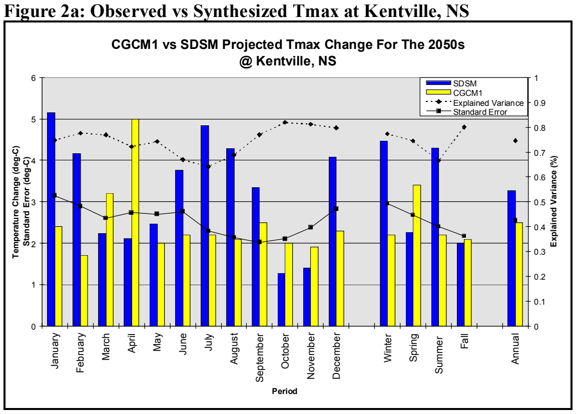


Figure 2b: Projected 2020s Tmax Change at Kentville, NS



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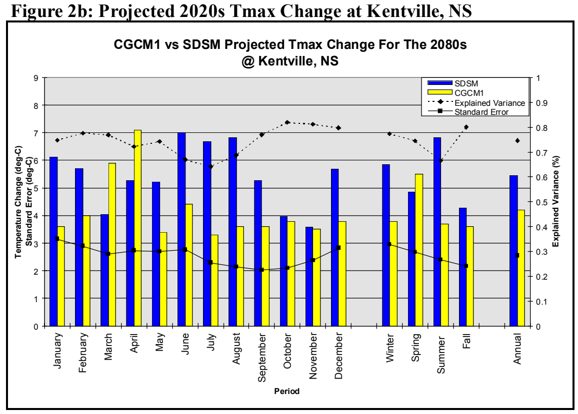

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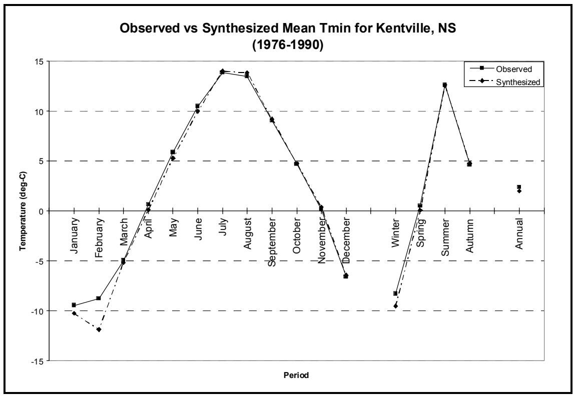

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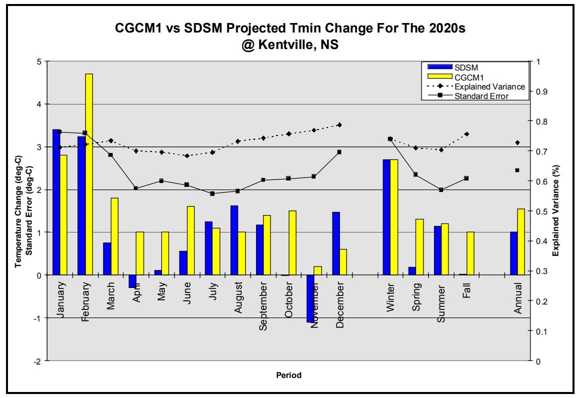

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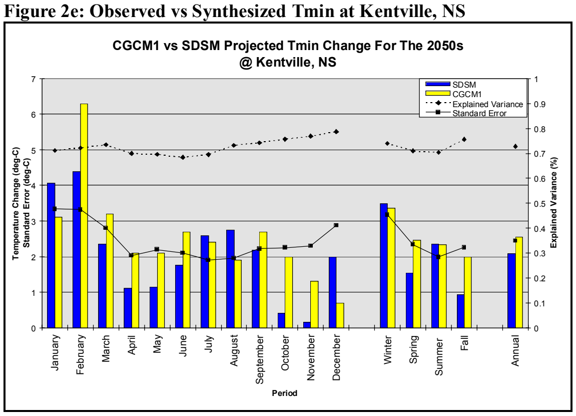

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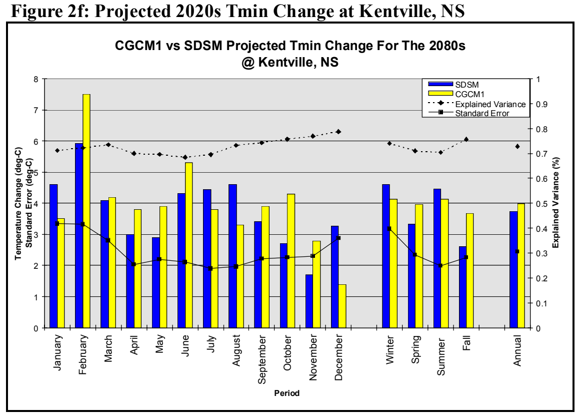


Figure 2h: Projected 2080s Tmin Change at Kentville, NS

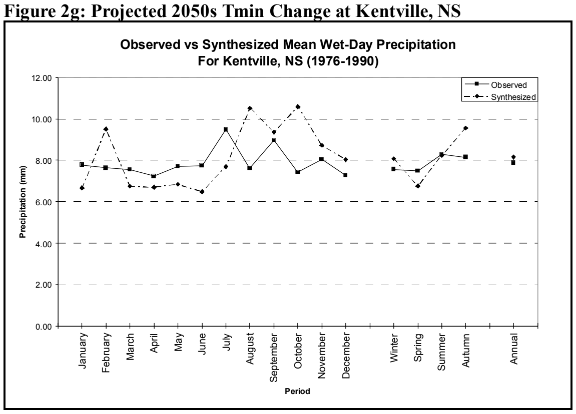


Figure 2i: Observed vs Synthesized Pcpn at Kentville, NS

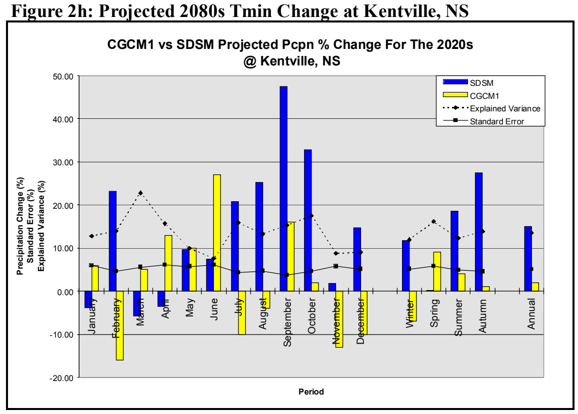


Figure 2j: Projected 2020s Pcpn Change at Kentville, NS

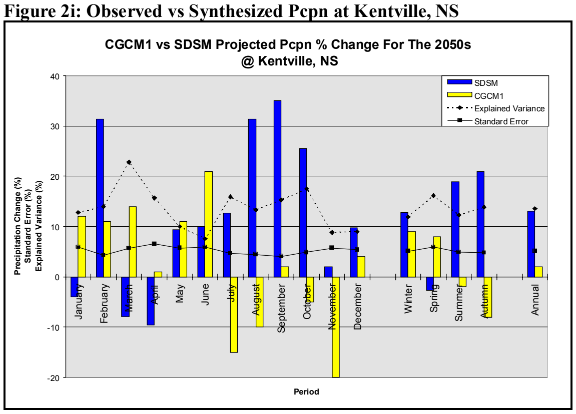


Figure 2k: Projected 2050s Pcpn Change at Kentville, NS

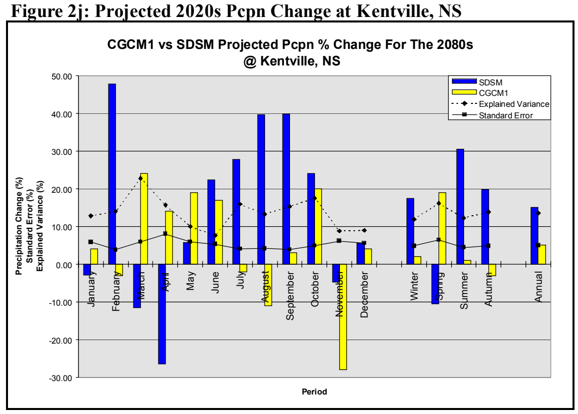


Figure 2l: Projected 2080s Pcpn Change at Kentville, NS

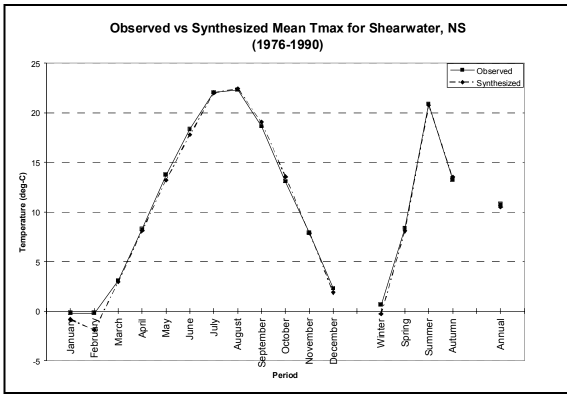


Figure 3a: Observed vs Synthesized Tmax at Shearwater, NS

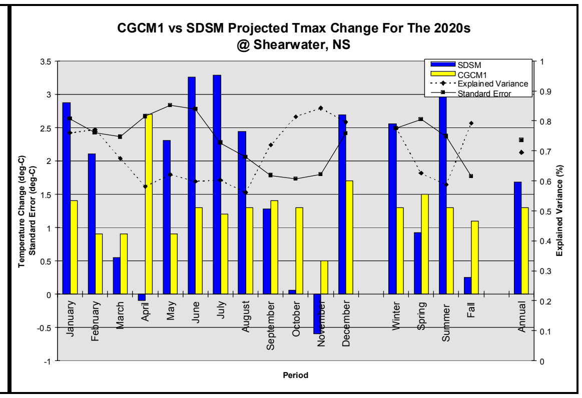


Figure 3b: Projected 2020s Tmax Change at Shearwater, NS

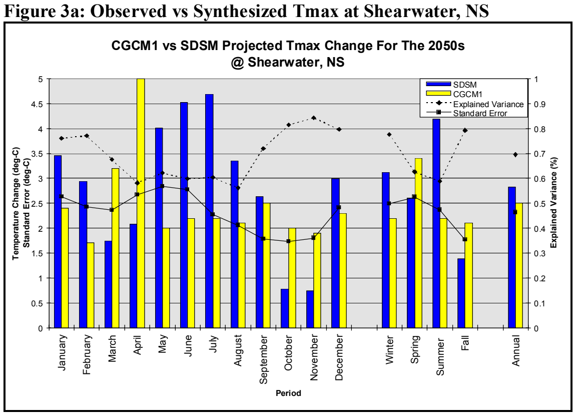


Figure 3c: Projected 2050s Tmax Change at Shearwater, NS

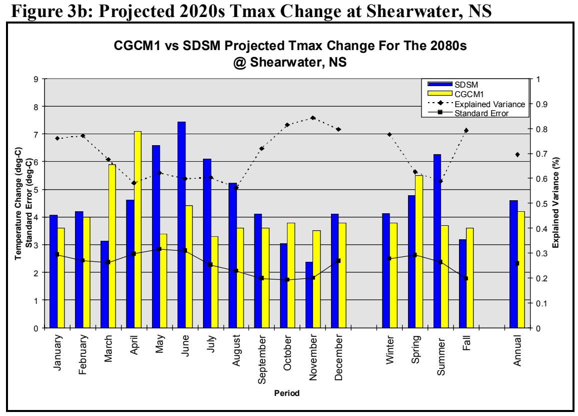


Figure 3d: Projected 2080s Tmax Change at Shearwater, NS

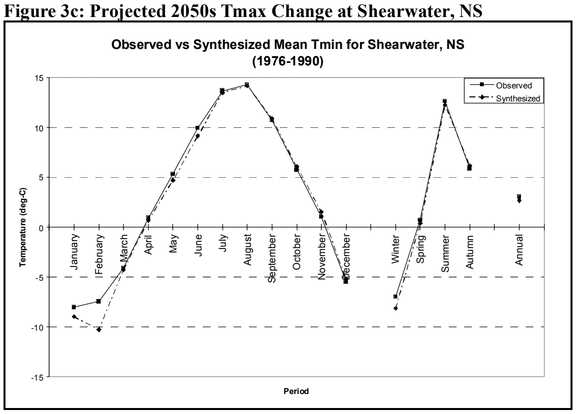


Figure 3e: Observed vs Synthesized Tmin at Shearwater, NS

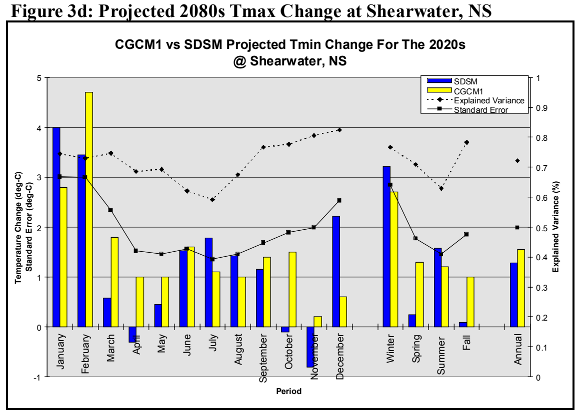


Figure 3f: Projected 2020s Tmin Change at Shearwater, NS

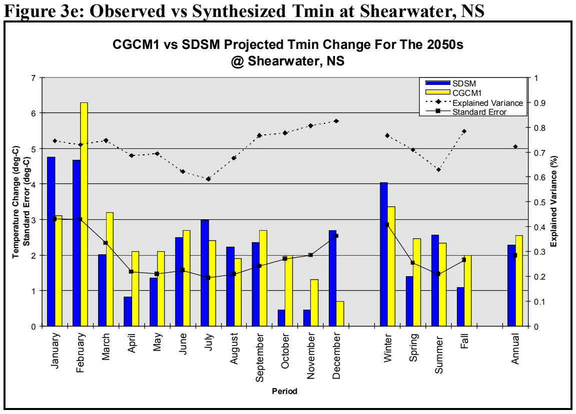


Figure 3g: Projected 2050s Tmin Change at Shearwater, NS

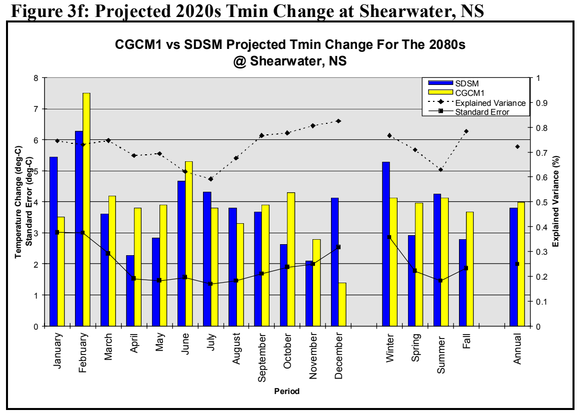


Figure 3h: Projected 2080s Tmin Change at Shearwater, NS

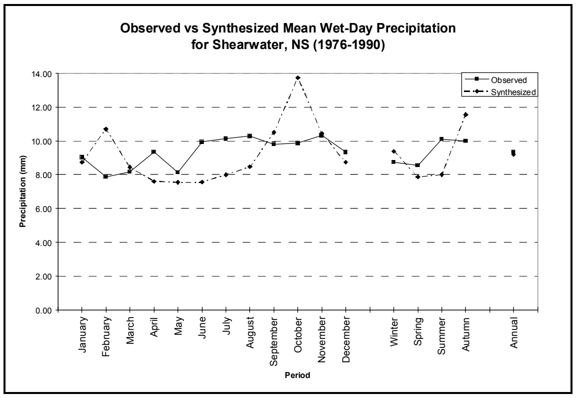
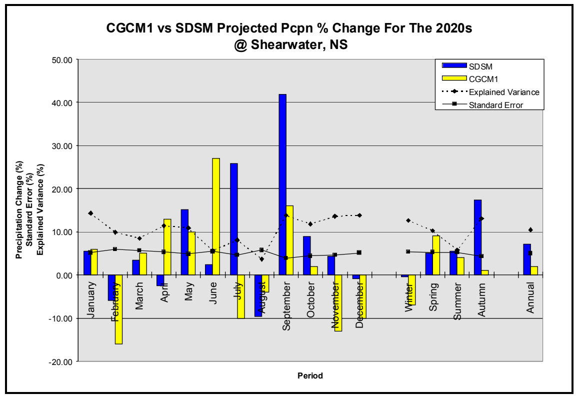


Figure 3i: Observed vs Synthesized Pcpn at Shearwater, NS



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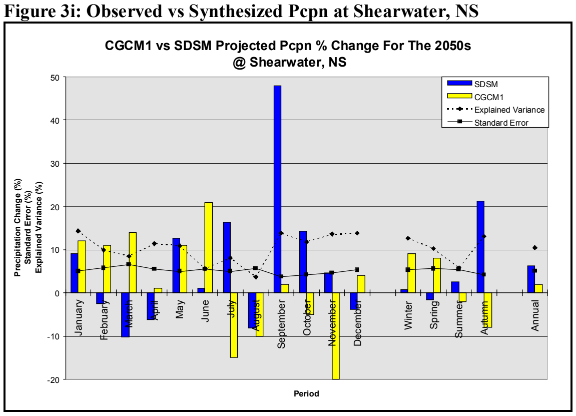

Figure 3k: Projected 2050s Pcpn Change at Shearwater, NS

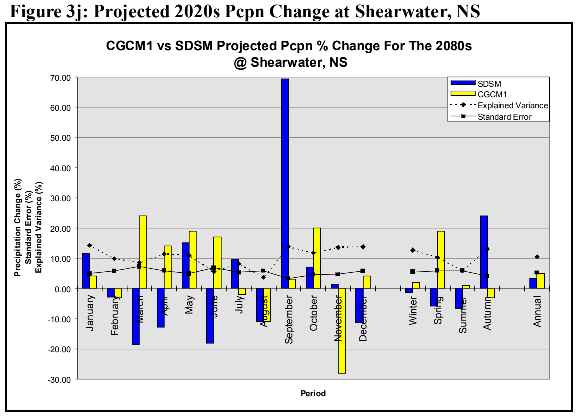

Figure 3l: Projected 2080s Pcpn Change at Shearwater, NS

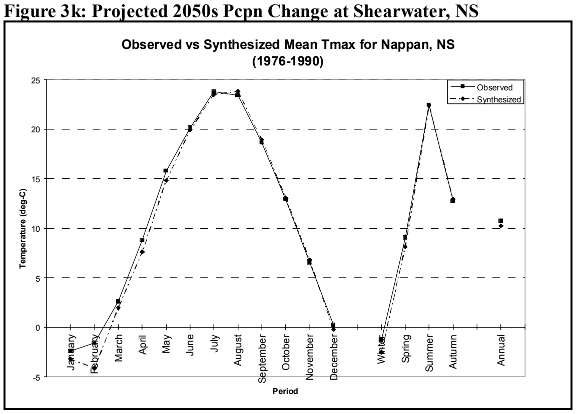

Figure 4a: Observed vs Synthesized Tmax at Nappan, NS

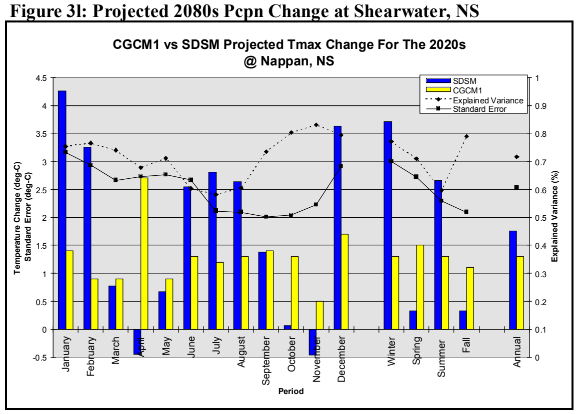

Figure 4b: Projected 2020s Tmax Change at Nappan, NS

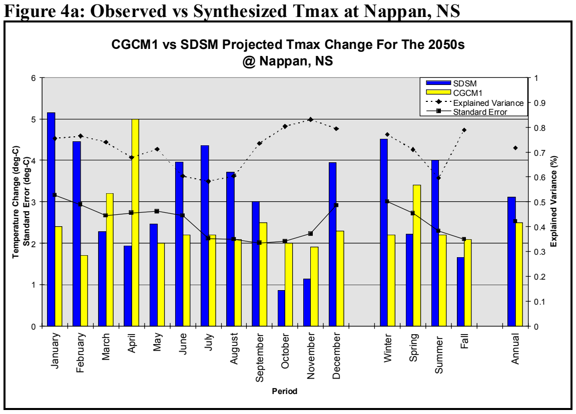

Figure 4c: Projected 2050s Tmax Change at Nappan, NS

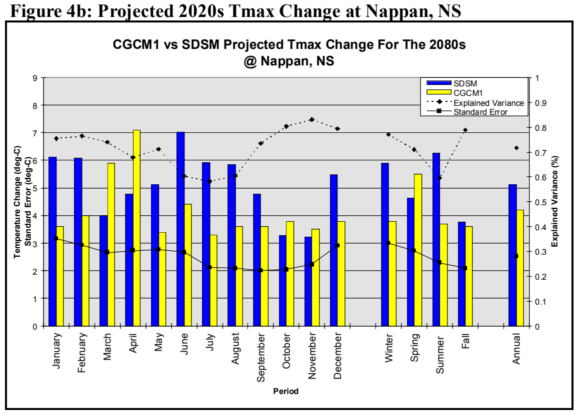

Figure 4d: Projected 2080s Tmax Change at Nappan, NS

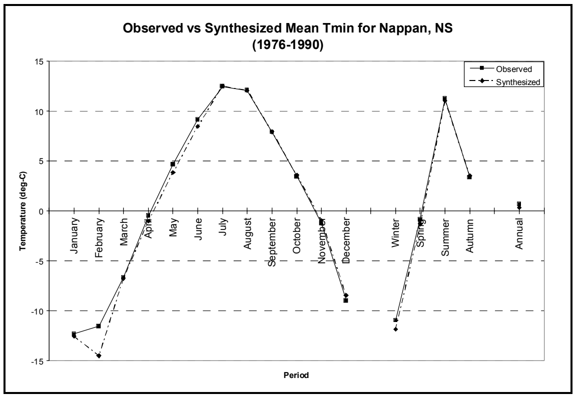

Figure 4e: Observed vs Synthesized Tmin at Nappan, NS

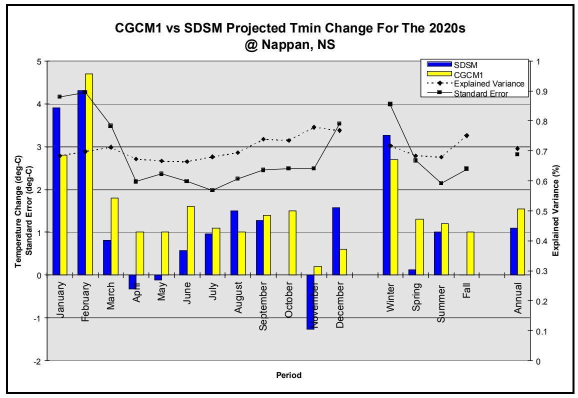

Figure 4f: Projected 2020s Tmin Change at Nappan, NS

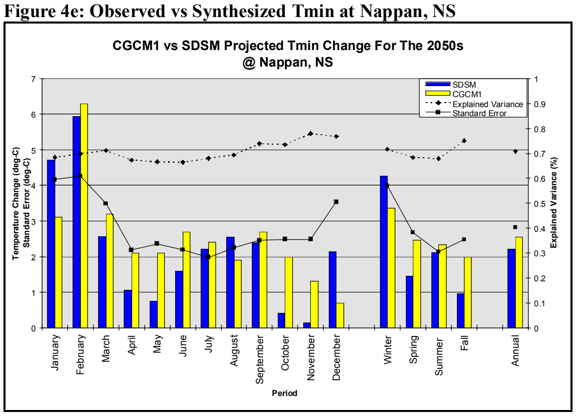

Figure 4g: Projected 2050s Tmin Change at Nappan, NS

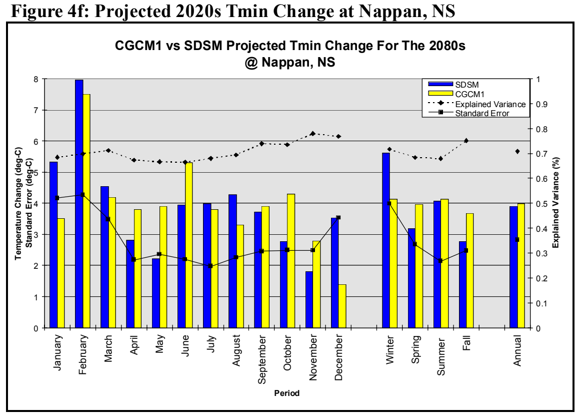

Figure 4h: Projected 2080s Tmin Change at Nappan, NS

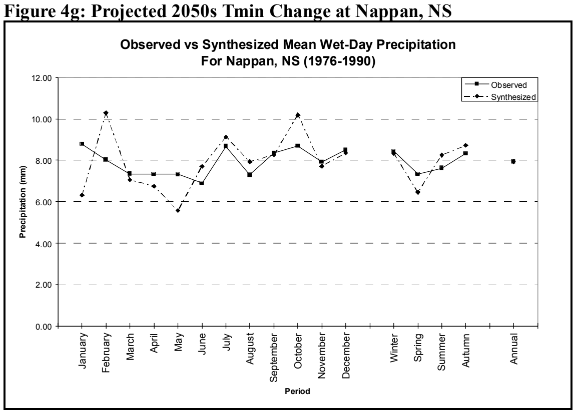

Figure 4i: Observed vs Synthesized Pcpn at Nappan, NS

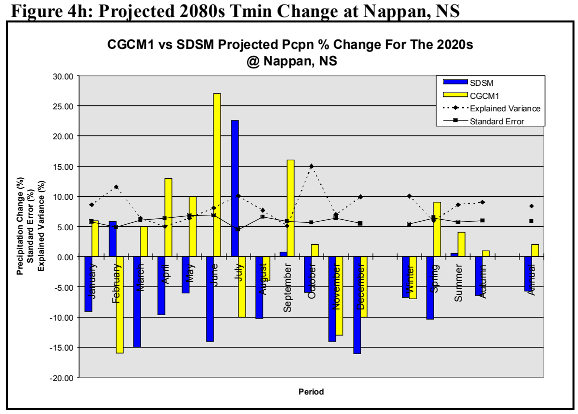

Figure 4j: Projected 2020s Pcpn Change at Nappan, NS

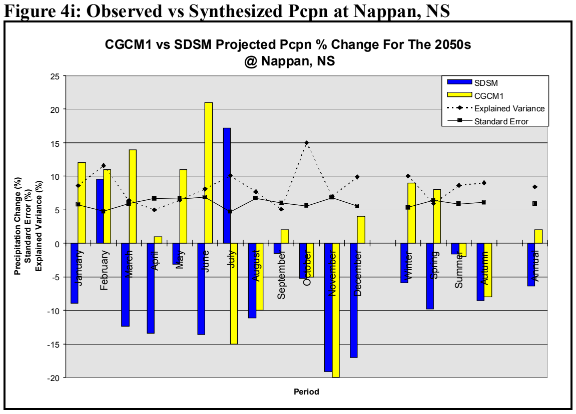

Figure 4k: Projected 2050s Pcpn Change at Nappan, NS

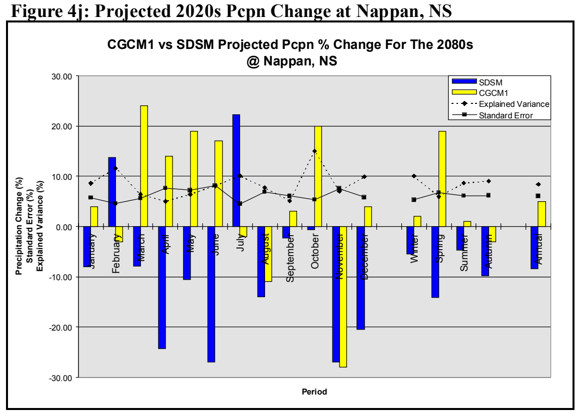

Figure 4l: Projected 2080s Pcpn Change at Nappan, NS

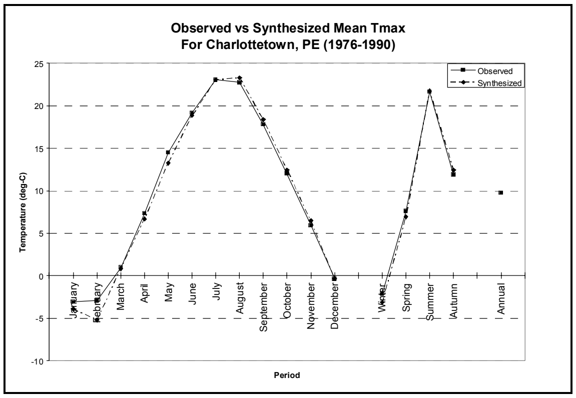

Figure 5a: Observed vs Synthesized Tmax at Charlottetown, PE

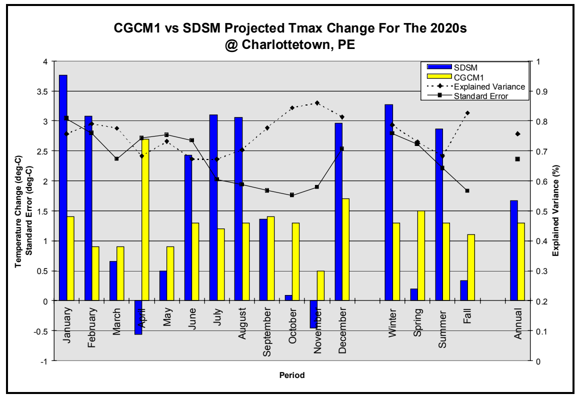

Figure 5b: Projected 2020s Tmax Change at Charlottetown, PE

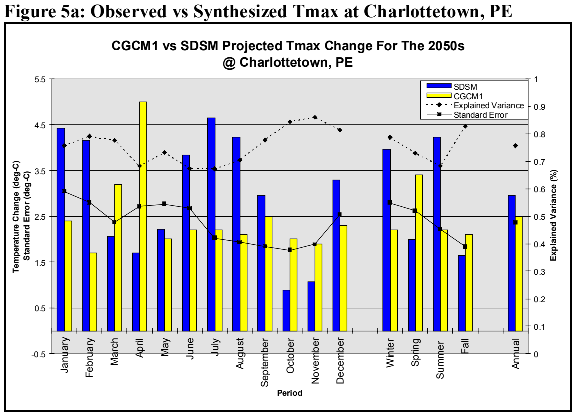

Figure 5c: Projected 2050s Tmax Change at Charlottetown, PE

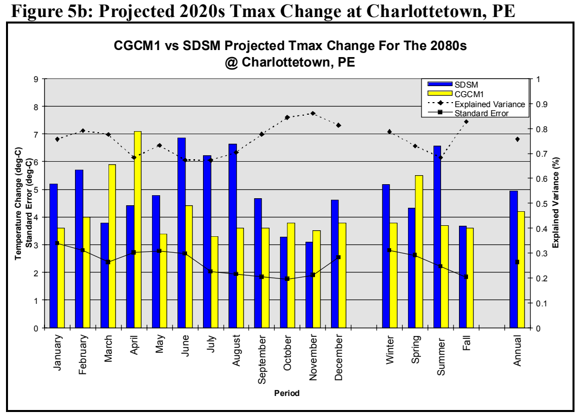

Figure 5d: Projected 2080s Tmax Change at Charlottetown, PE

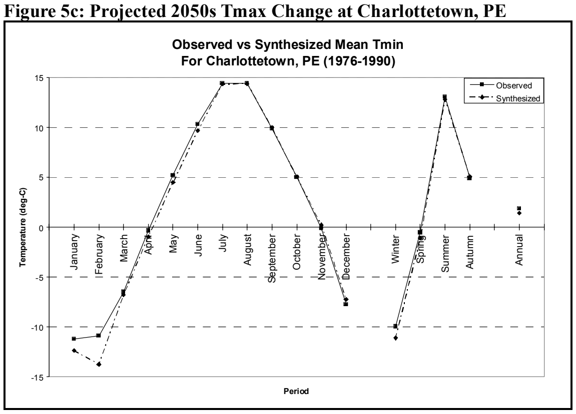

Figure 5e: Observed vs Synthesized Tmin at Charlottetown, PE

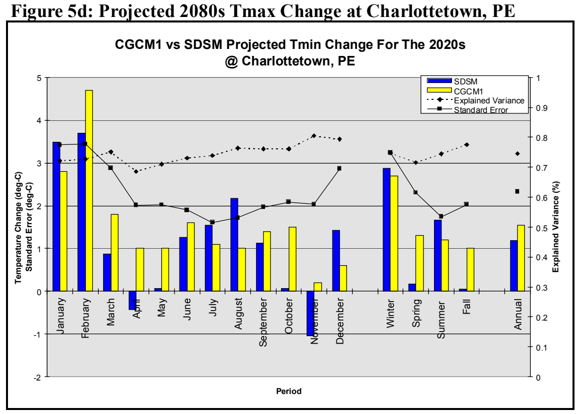

Figure 5f: Projected 2020s Tmin Change at Charlottetown, PE

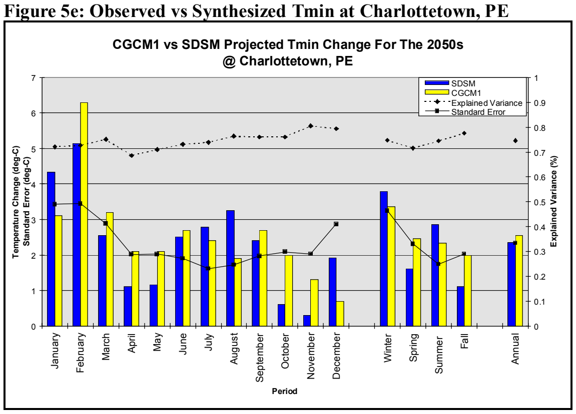

Figure 5g: Projected 2050s Tmin Change at Charlottetown, PE

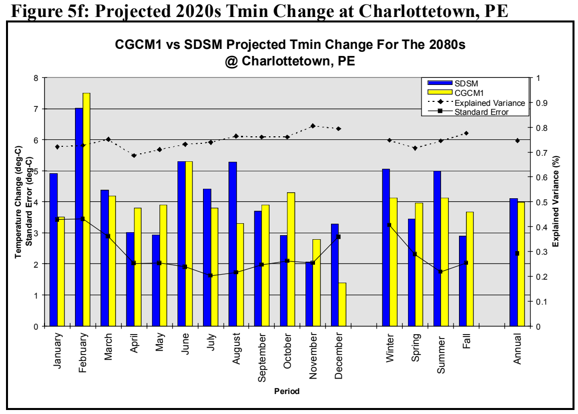

Figure 5h: Projected 2080s Tmin Change at Charlottetown, PE

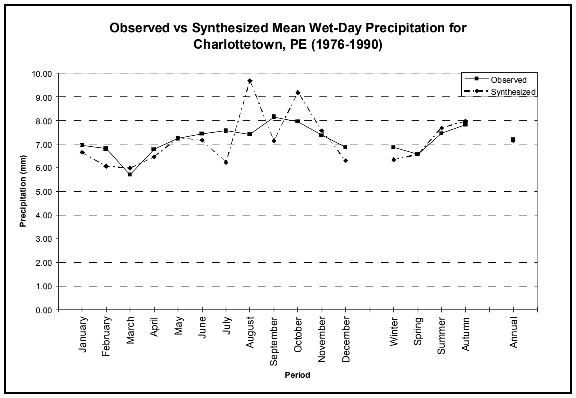

Figure 5i: Observed vs Synthesized Pcpn at Charlottetown, PE

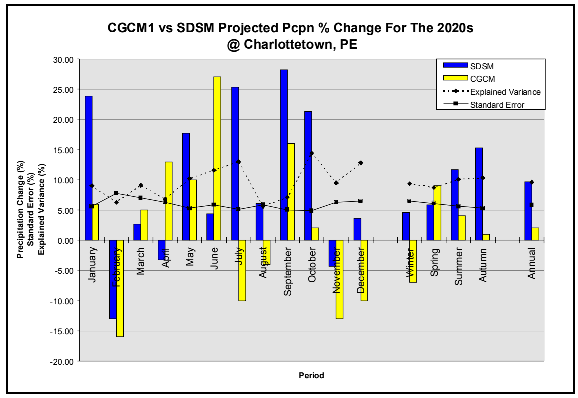

Figure 5j: Projected 2020s Pcpn Change at Charlottetown, PE

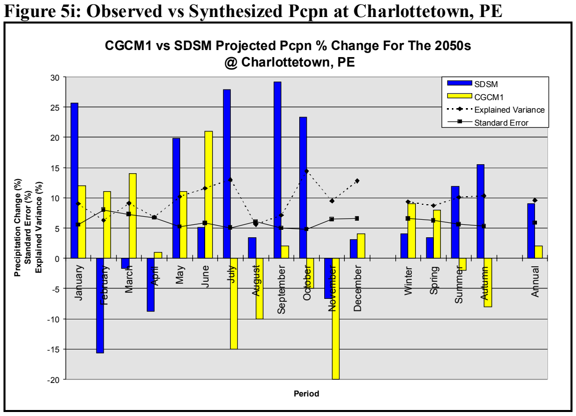

Figure 5k: Projected 2050s Pcpn Change at Charlottetown, PE

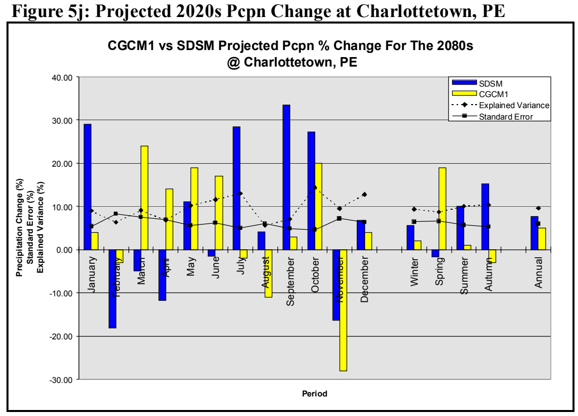

Figure 5l: Projected 2080s Pcpn Change at Charlottetown, PE

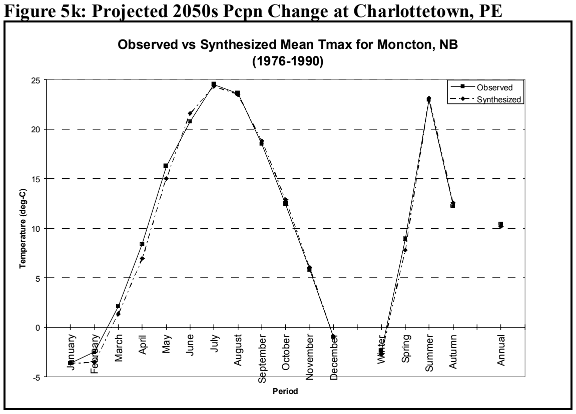

Figure 6a: Observed vs Synthesized Tmax at Moncton, NB

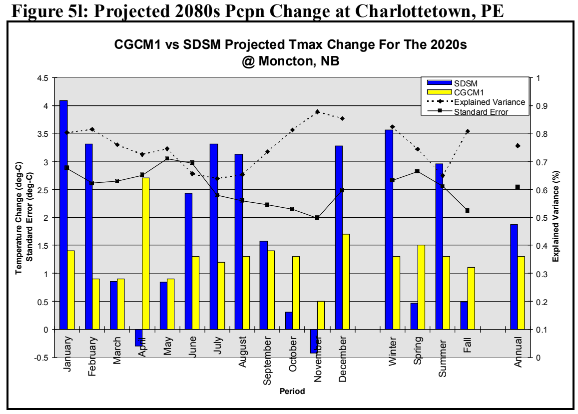

Figure 6b: Projected 2020s Tmax Change at Moncton, NB

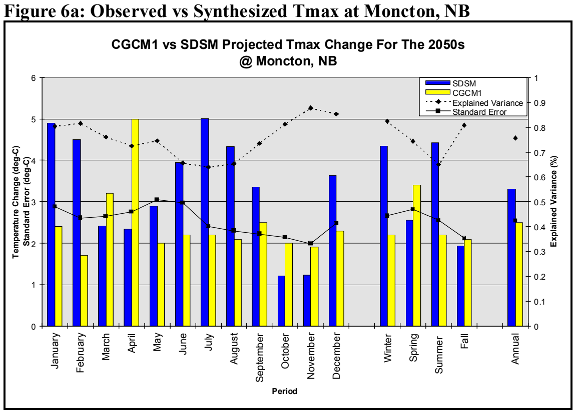

Figure 6c: Projected 2050s Tmax Change at Moncton, NB

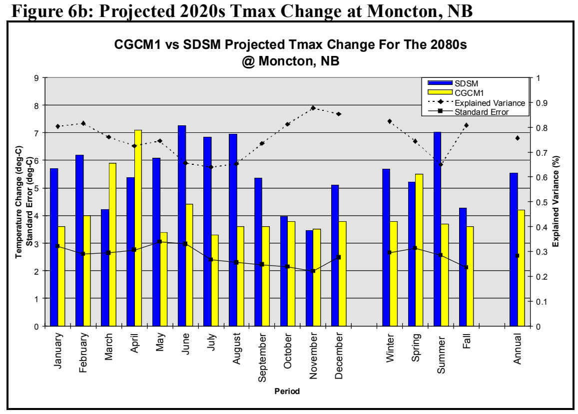

Figure 6d: Projected 2080s Tmax Change at Moncton, NB

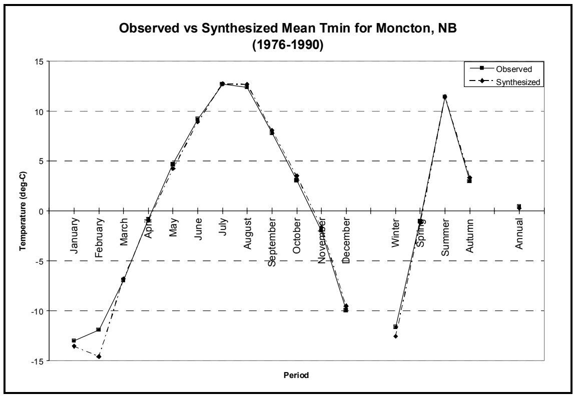

Figure 6e: Observed vs Synthesized Tmin at Moncton, NB

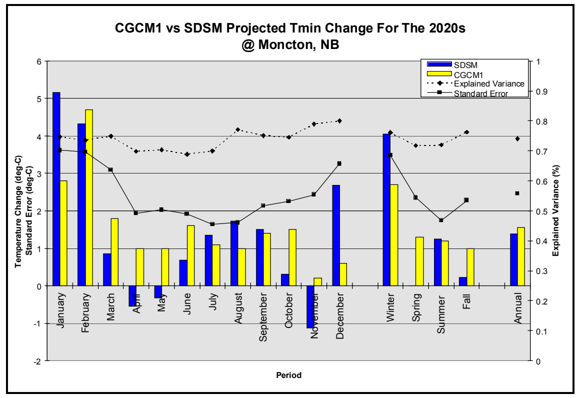

Figure 6f: Projected 2020s Tmin Change at Moncton, NB

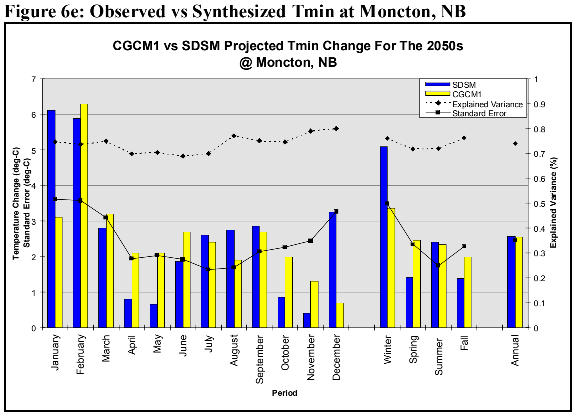

Figure 6g: Projected 2050s Tmin Change at Moncton, NB

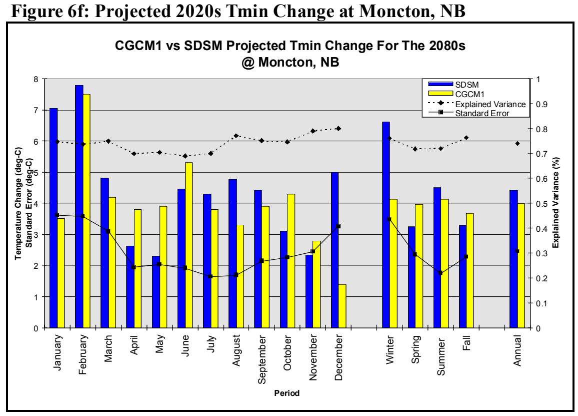

Figure 6h: Projected 2080s Tmin Change at Moncton, NB

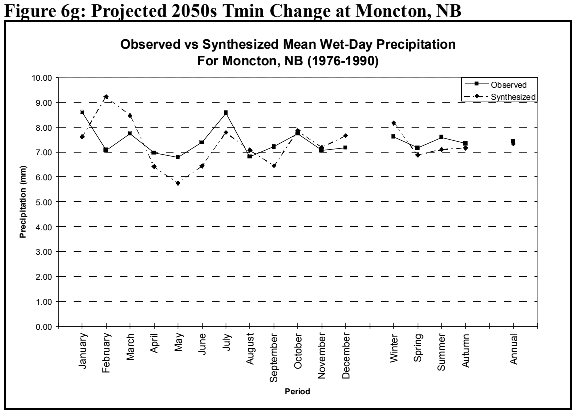

Figure 6i: Observed vs Synthesized Pcpn at Moncton, NB

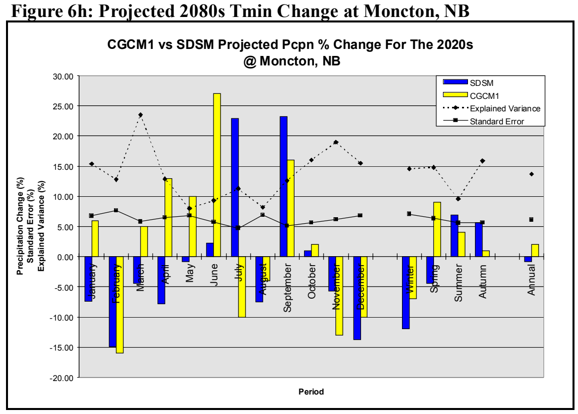

Figure 6j: Projected 2020s Pcpn Change at Moncton, NB

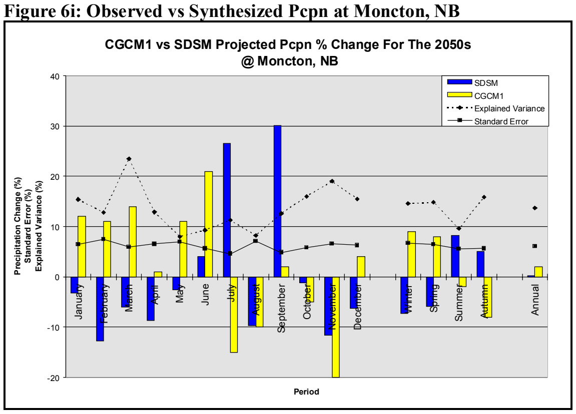

Figure 6k: Projected 2050s Pcpn Change at Moncton, NB

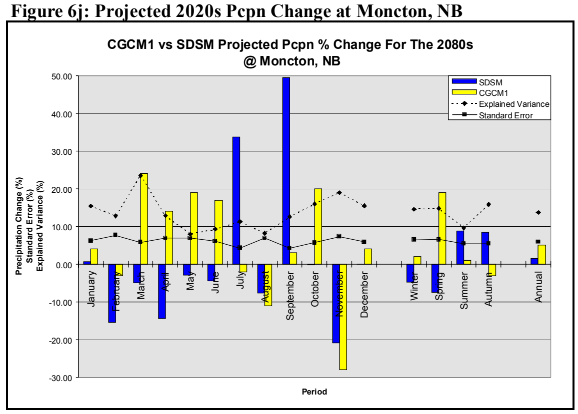

Figure 6l: Projected 2080s Pcpn Change at Moncton, NB

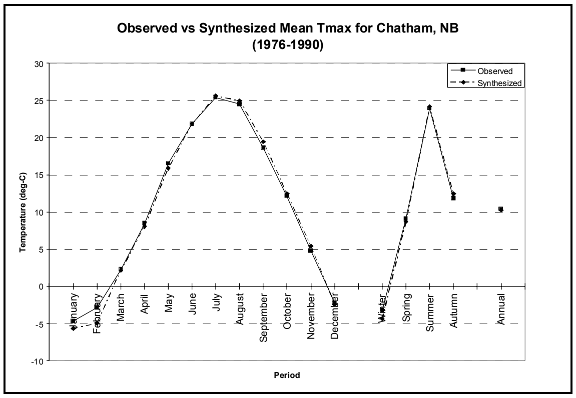

Figure 7a: Observed vs Synthesized Tmax for Chatham, NB

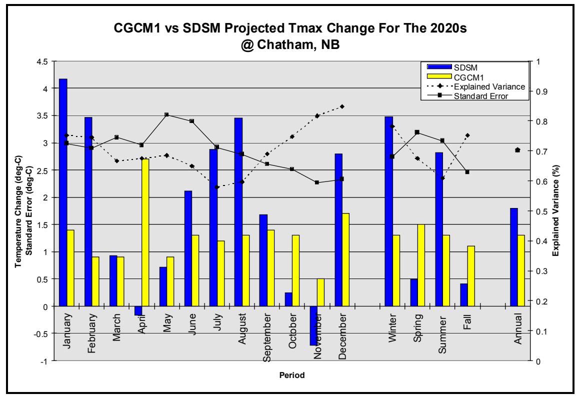

Figure 7b: Projected 2020s Tmax Change at Chatham, NB

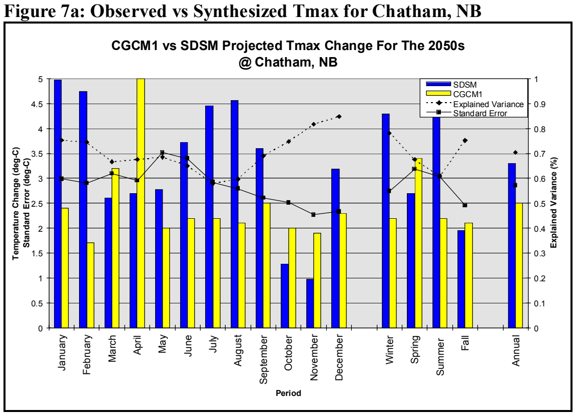

Figure 7c: Projected 2050s Tmax Change at Chatham, NB

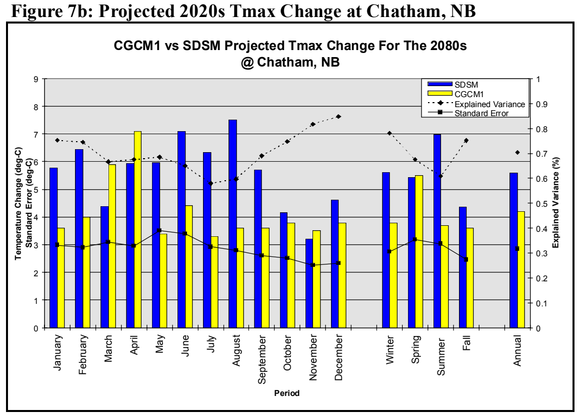

Figure 7d: Projected 2080s Tmax Change at Chatham, NB

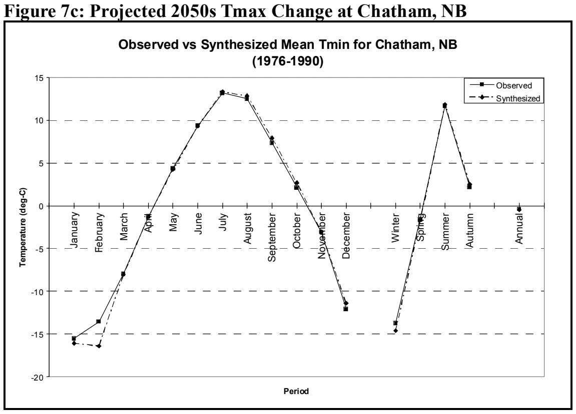

Figure 7e: Observed vs Synthesized Tmin for Chatham, NB

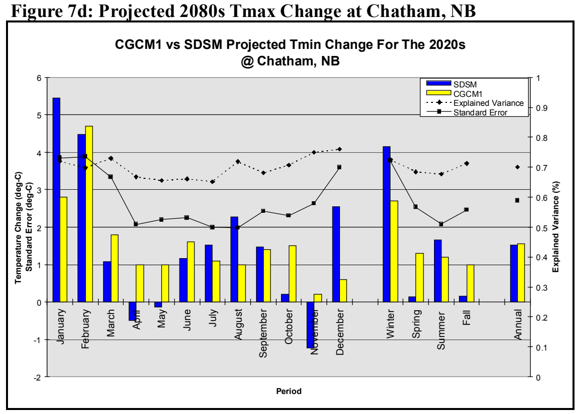

Figure 7f: Projected 2020s Tmin Change at Chatham, NB

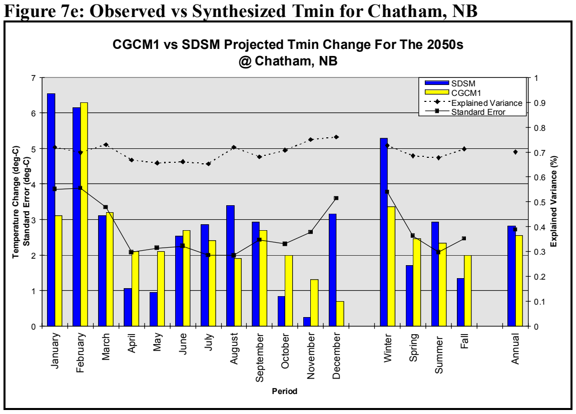

Figure 7g: Projected 2050s Tmin Change at Chatham, NB

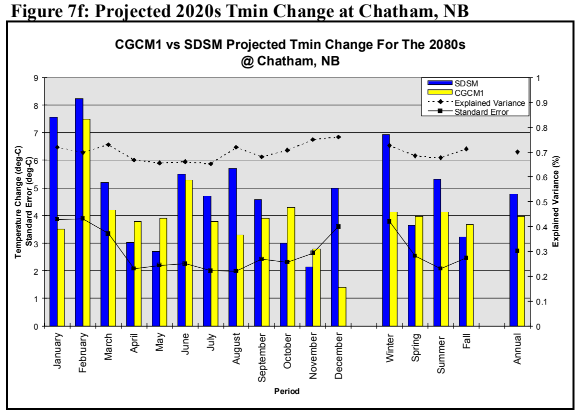

Figure 7h: Projected 2080s Tmin Change at Chatham, NB

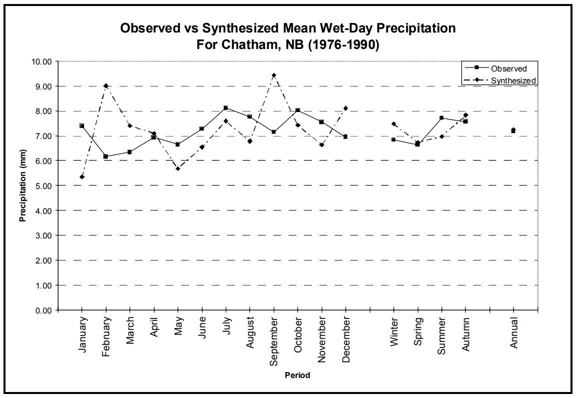

Figure 7i: Observed vs Synthesized Pcpn for Chatham, NB

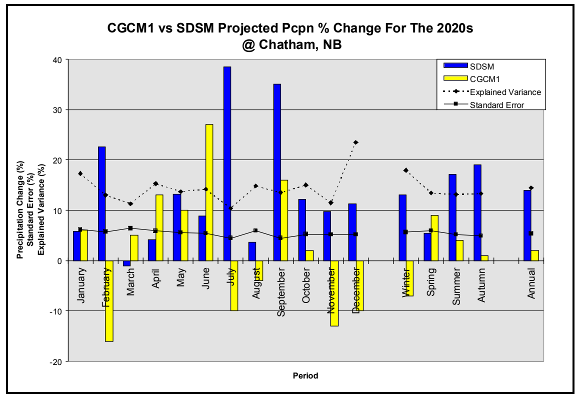

Figure 7j: Projected 2020s Pcpn Change at Chatham, NB

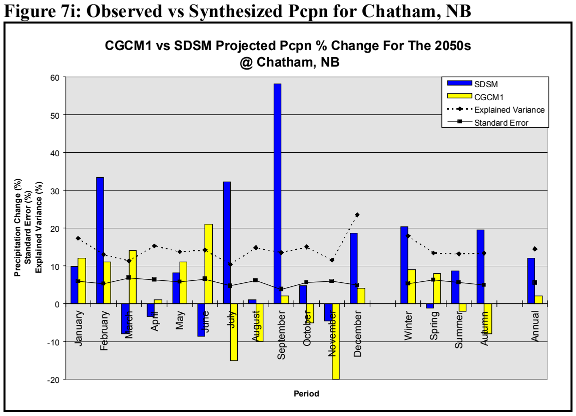

Figure 7k: Projected 2050s Pcpn Change at Chatham, NB

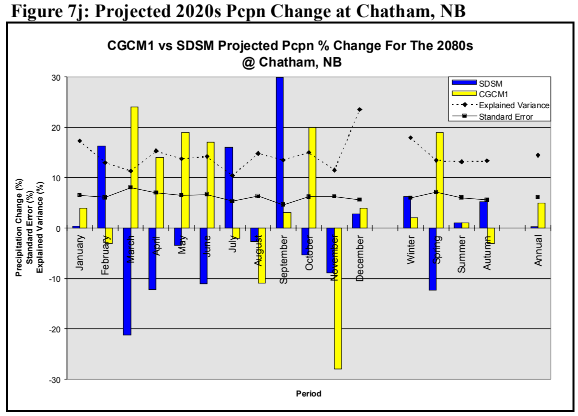

Figure 7l: Projected 2080s Pcpn Change at Chatham, NB

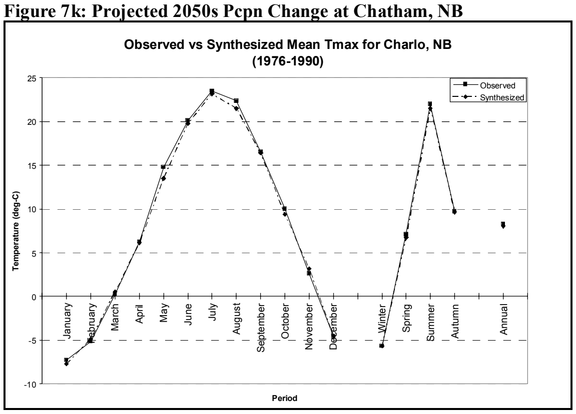

Figure 8a: Observed vs Synthesized Tmax for Charlo, NB

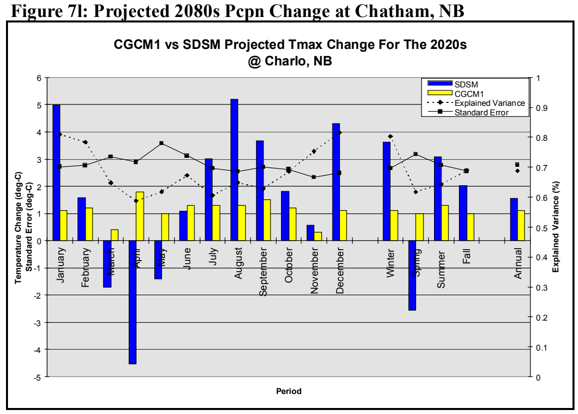

Figure 8b: Projected 2020s Tmax Change at Charlo, NB

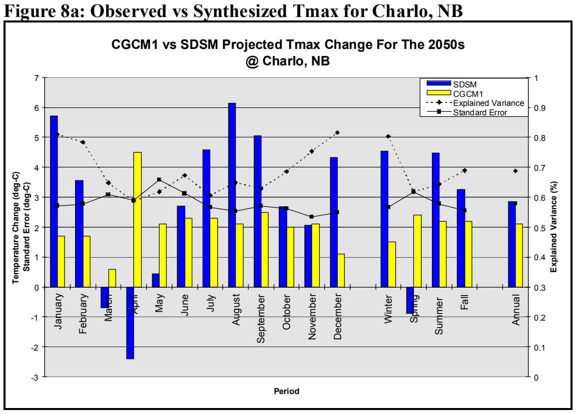

Figure 8c: Projected 2050s Tmax Change at Charlo, NB

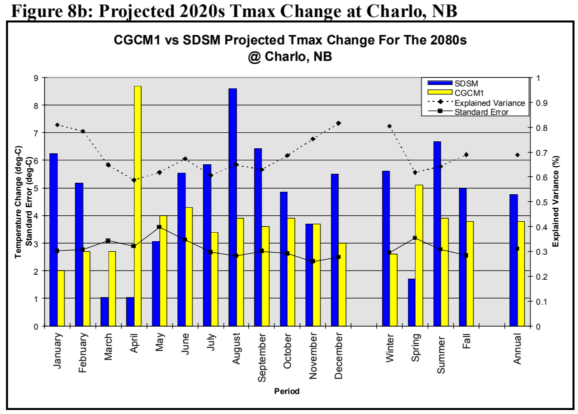

Figure 8d: Projected 2080s Tmax Change at Charlo, NB

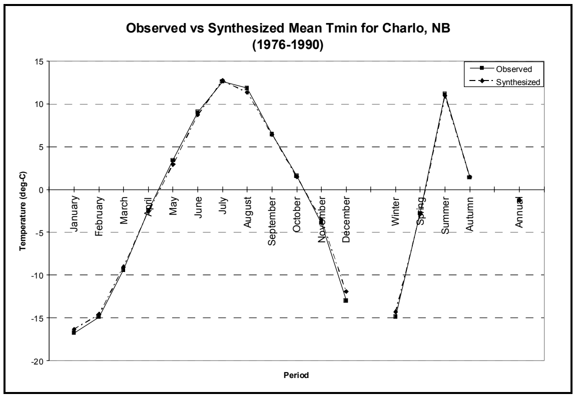

Figure 8e: Observed vs Synthesized Tmin for Charlo, NB

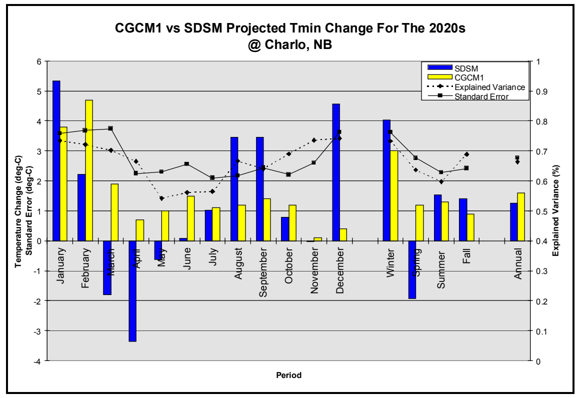

Figure 8f: Projected 2020s Tmin Change at Charlo, NB

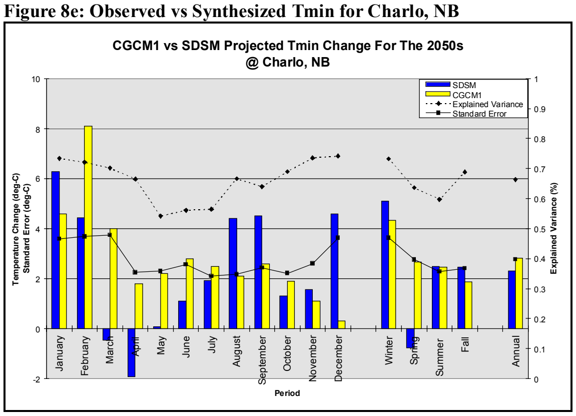

Figure 8g: Projected 2050s Tmin Change at Charlo, NB

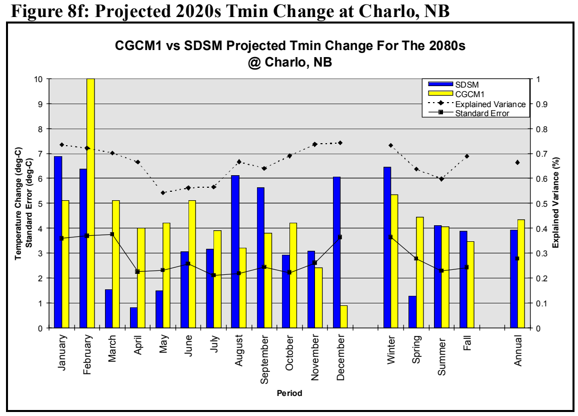

Figure 8h: Projected 2080s Tmin Change at Charlo, NB

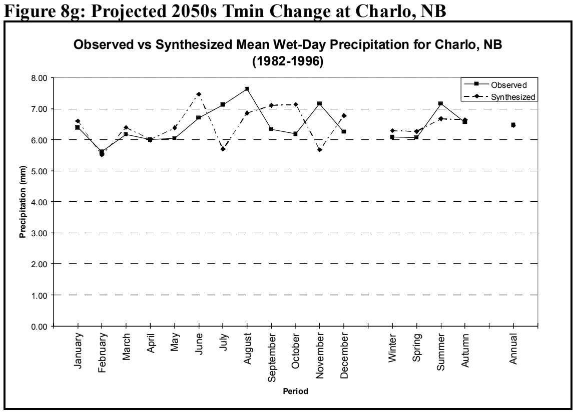

Figure 8i: Observed vs Synthesized Pcpn for Charlo, NB

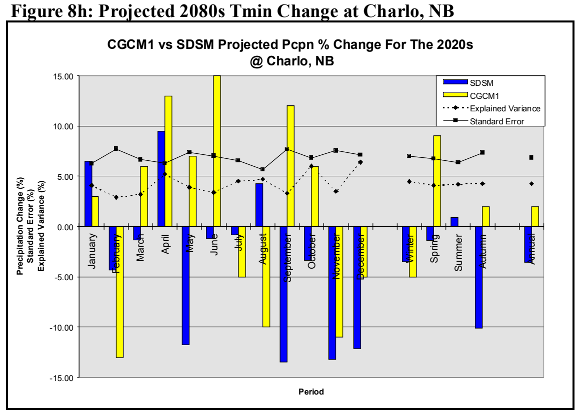

Figure 8j: Projected 2020s Pcpn Change at Charlo, NB

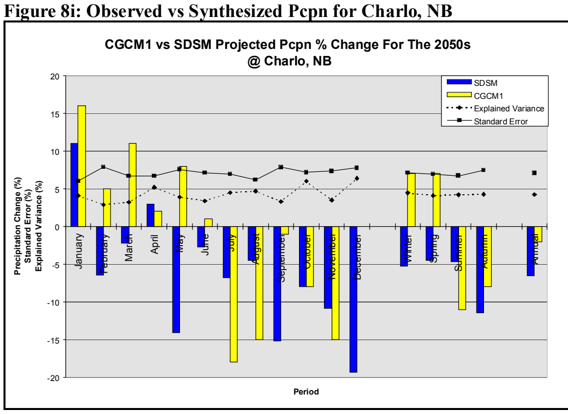

Figure 8k: Projected 2050s Pcpn Change at Charlo, NB

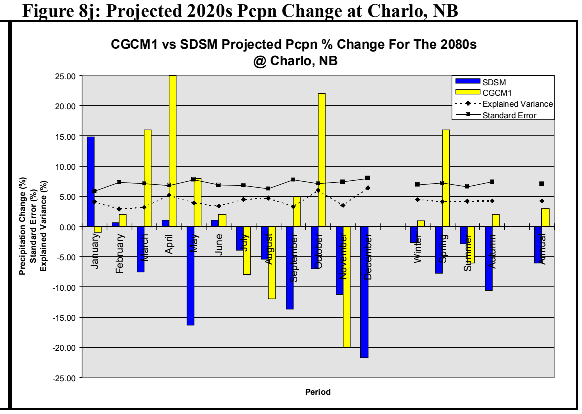

Figure 8l: Projected 2080s Pcpn Change at Charlo, NB

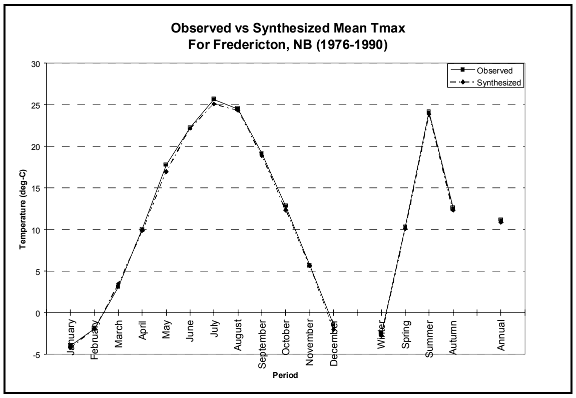

Figure 9a: Observed vs Synthesized Tmax for Fredericton, NB

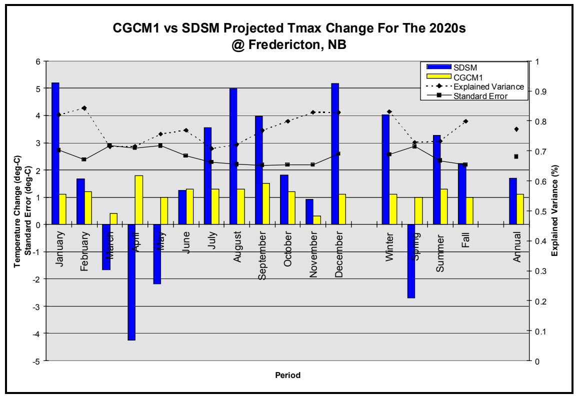

Figure 9b: Projected 2020s Tmax Change at Fredericton, NB

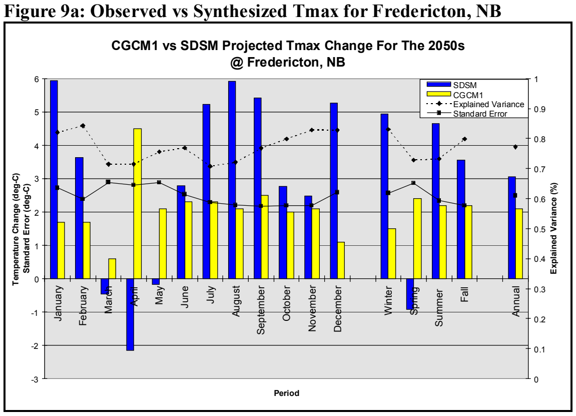

Figure 9c: Projected 2050s Tmax Change at Fredericton, NB

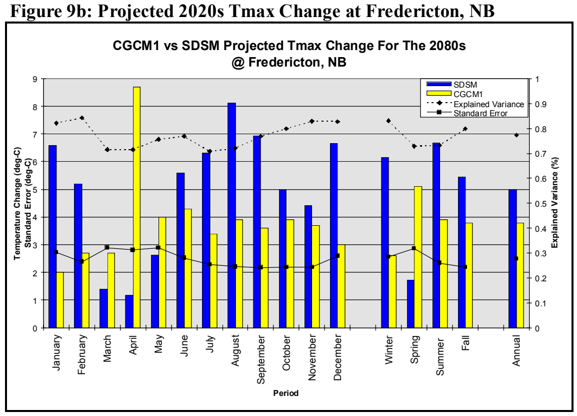

Figure 9d: Projected 2080s Tmax Change at Fredericton, NB

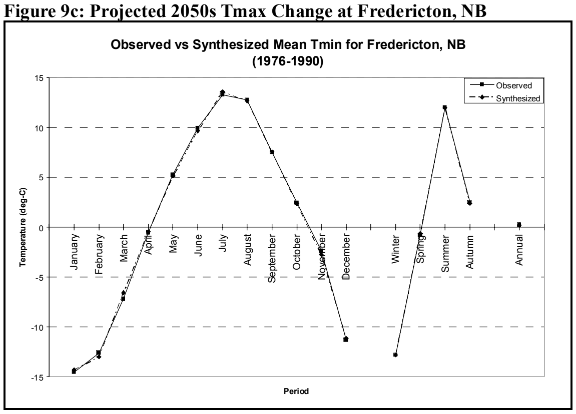

Figure 9e: Observed vs Synthesized Tmin for Fredericton, NB

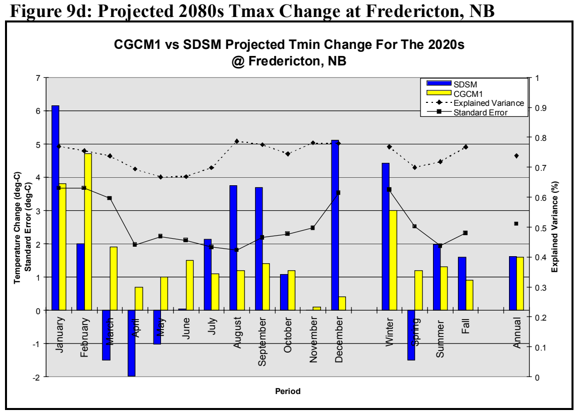

Figure 9f: Projected 2020s Tmin Change at Fredericton, NB

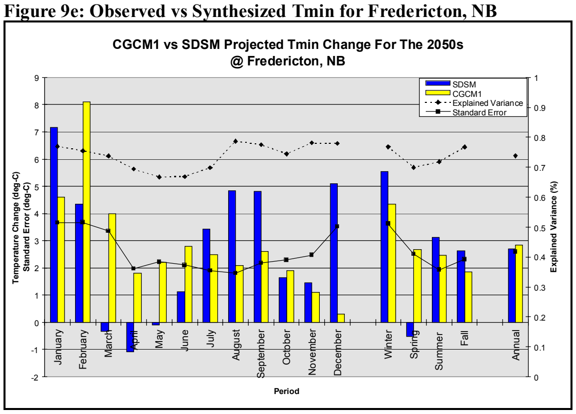

Figure 9g: Projected 2050s Tmin Change at Fredericton, NB

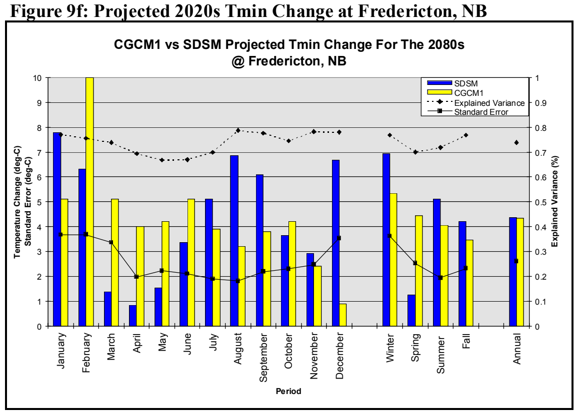

Figure 9h: Projected 2080s Tmin Change at Fredericton, NB

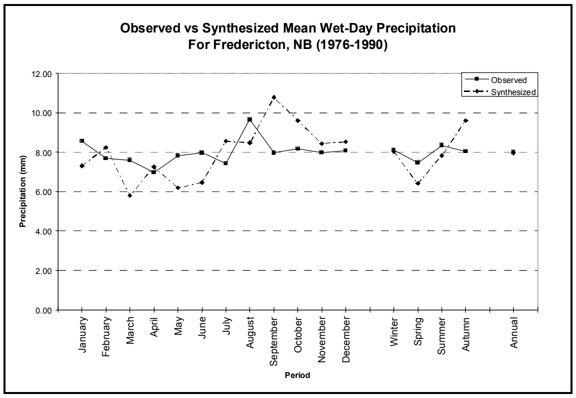

Figure 9i: Observed vs Synthesized Pcpn for Fredericton, NB

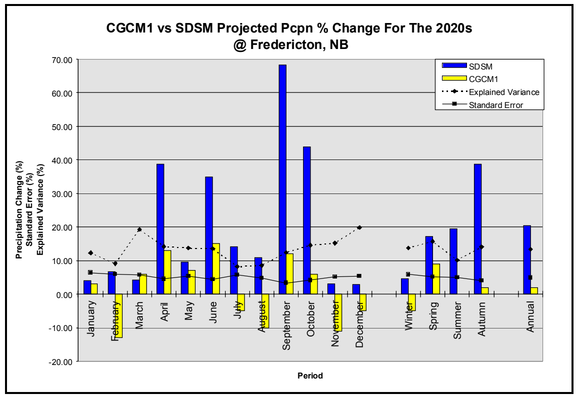

Figure 9j: Projected 2020s Pcpn Change at Fredericton, NB

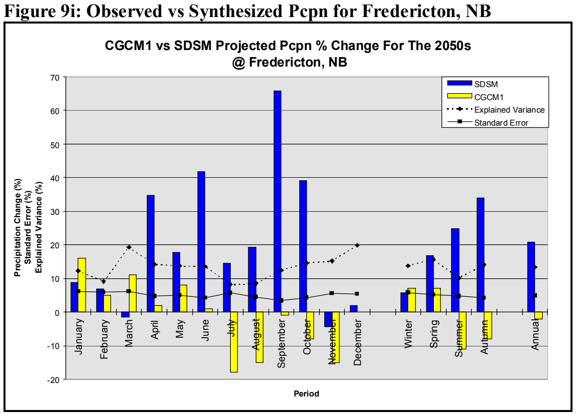

Figure 9k: Projected 2050s Pcpn Change at Fredericton, NB

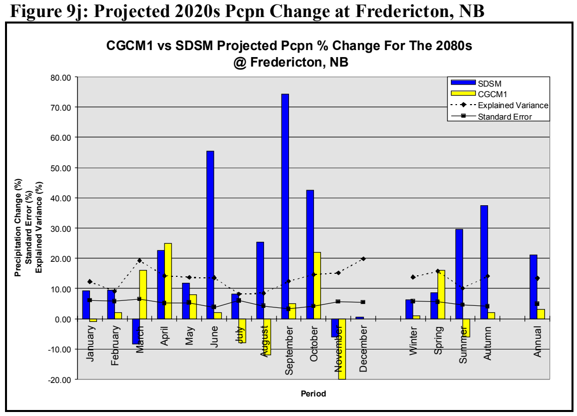

Figure 9l: Projected 2080s Pcpn Change at Fredericton, NB

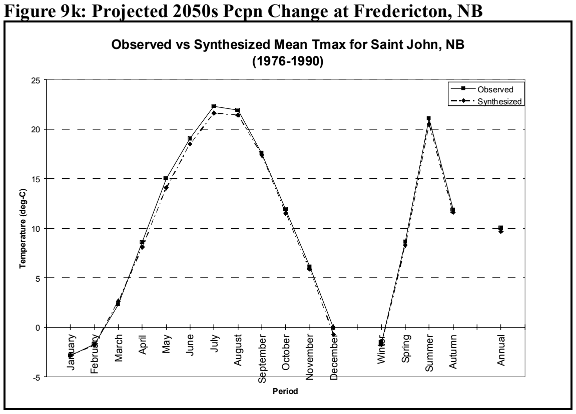

Figure 10a: Observed vs Synthesized Tmax for Saint John, NB

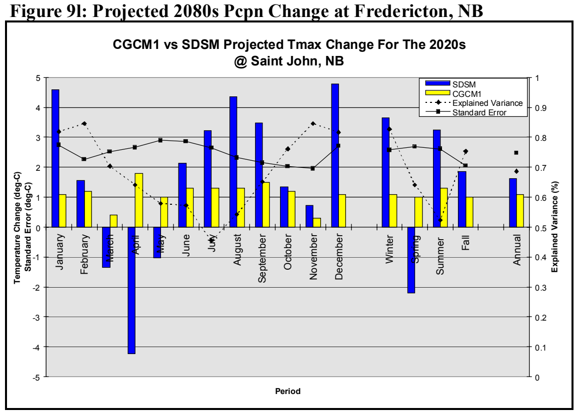

Figure 10b: Projected 2020s Tmax Change at Saint John, NB

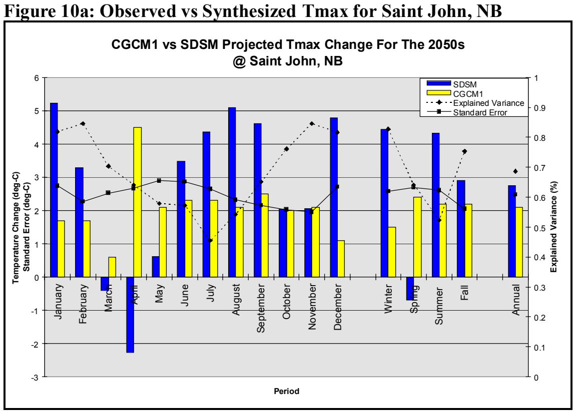

Figure 10c: Projected 2050s Tmax Change at Saint John, NB

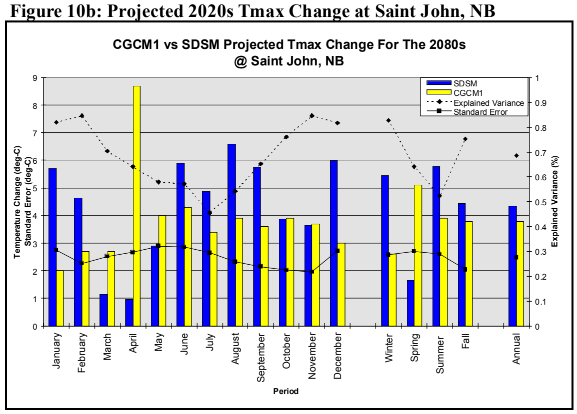

Figure 10d: Projected 2080s Tmax Change at Saint John, NB

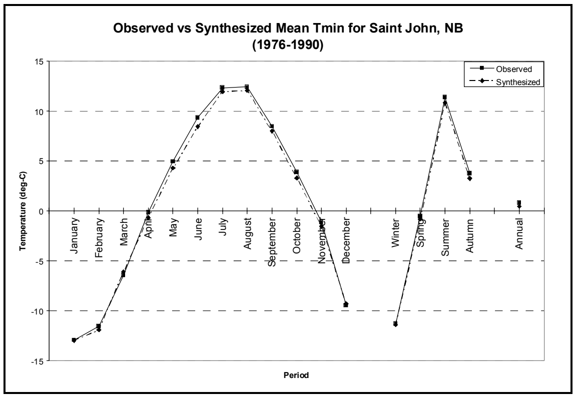

Figure 10e: Observed vs Synthesized Tmin for Saint John, NB

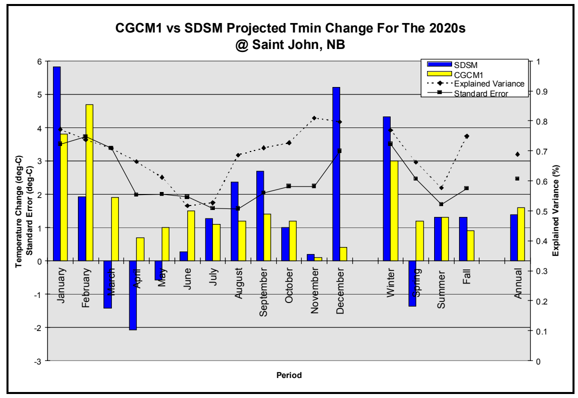

Figure 10f: Projected 2020s Tmin Change at Saint John, NB

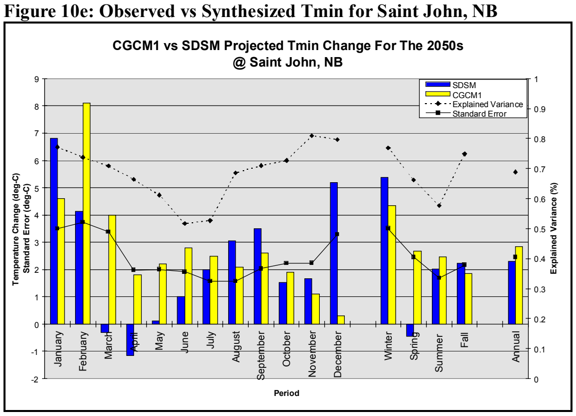

Figure 10g: Projected 2050s Tmin Change at Saint John, NB

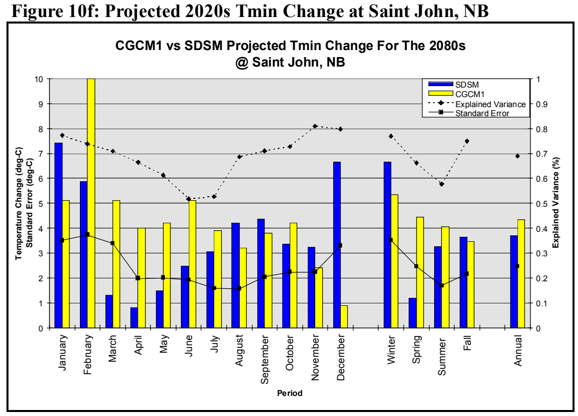

Figure 10h: Projected 2080s Tmin Change at Saint John, NB

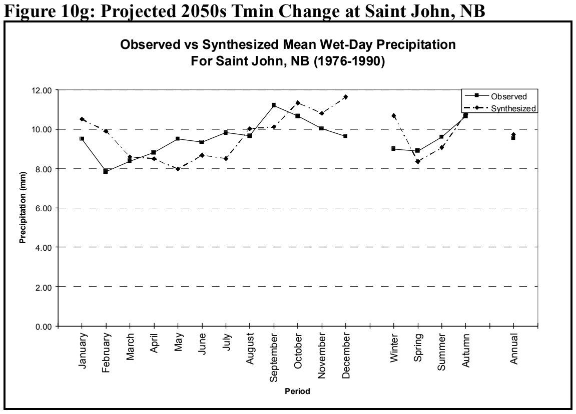

Figure 10i: Observed vs Synthesized Pcpn for Saint John, NB

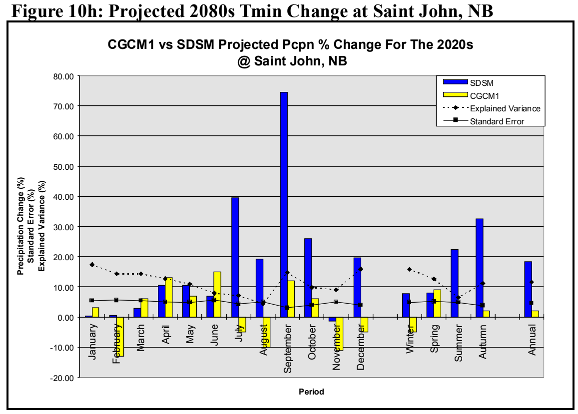

Figure 10j: Projected 2020s Pcpn Change at Saint John, NB

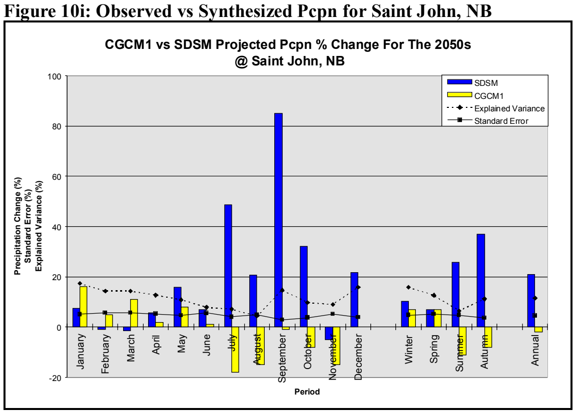

Figure 10k: Projected 2050s Pcpn Change at Saint John, NB

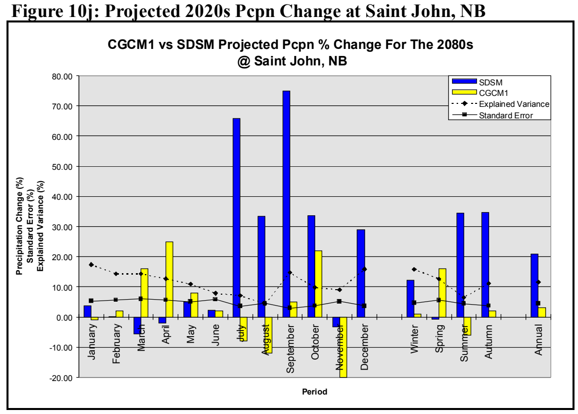

Figure 10l: Projected 2080s Pcpn Change at Saint John, NB

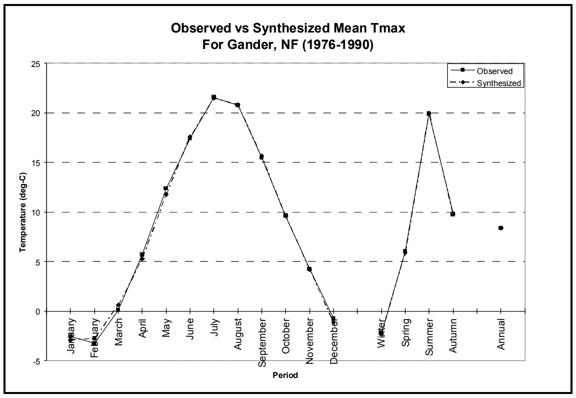

Figure 11a: Observed vs Synthesized Tmax for Gander, NF

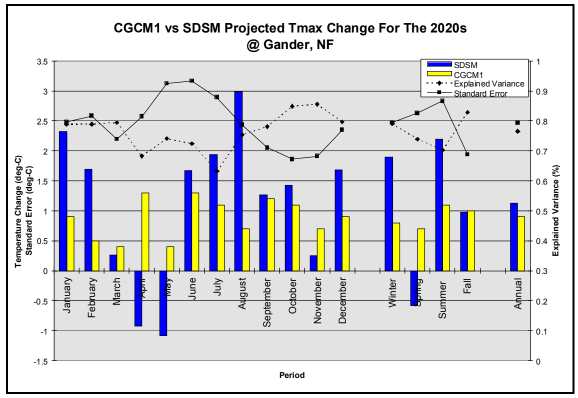

Figure 11b: Projected 2020s Tmax Change at Gander, NF

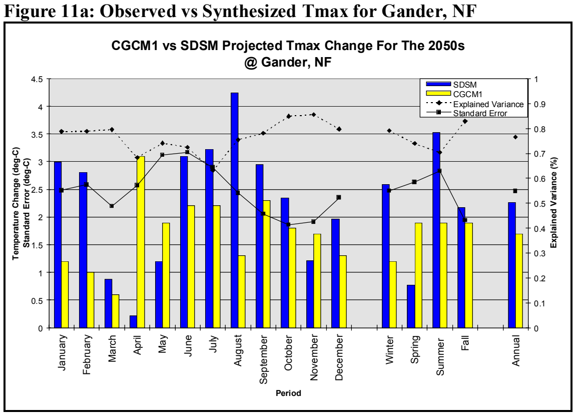

Figure 11c: Projected 2050s Tmax Change at Gander, NF

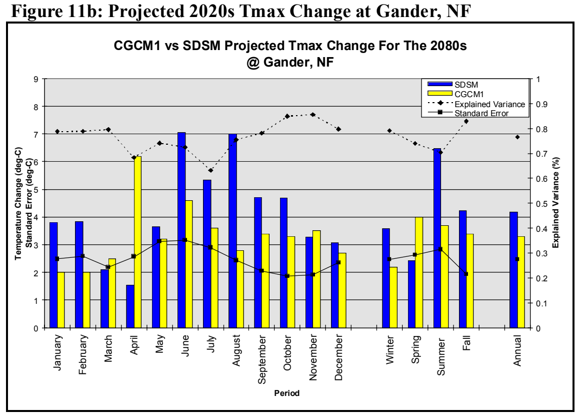

Figure 11d: Projected 2080s Tmax Change at Gander, NF

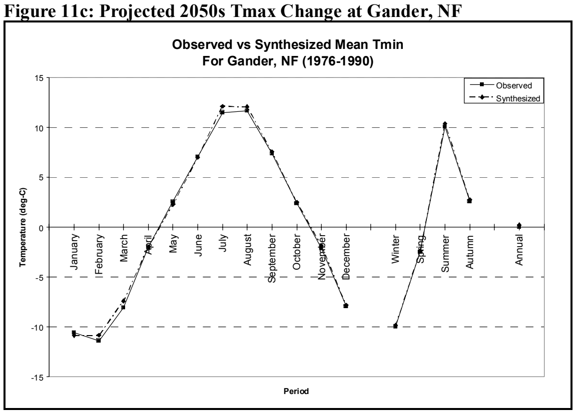

Figure 11e: Observed vs Synthesized Tmin for Gander, NF

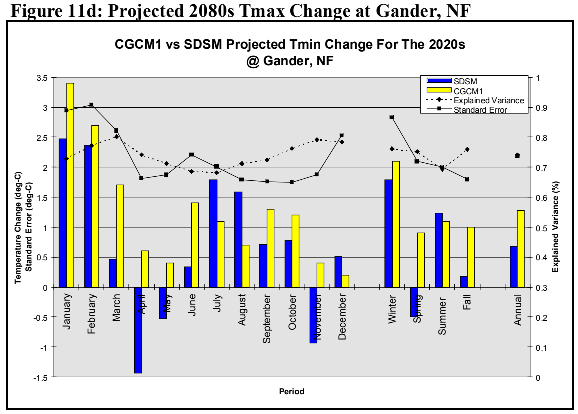

Figure 11f: Projected 2020s Tmin Change at Gander, NF

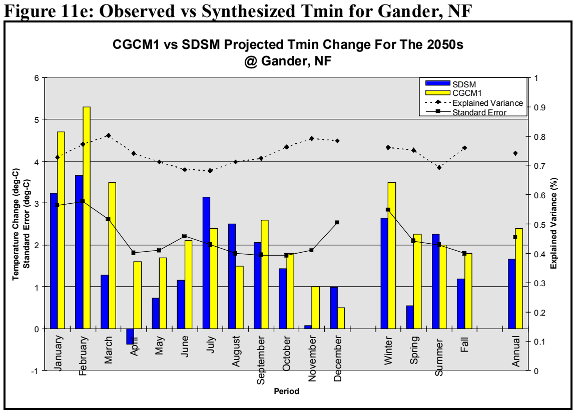

Figure 11g: Projected 2050s Tmin Change at Gander, NF

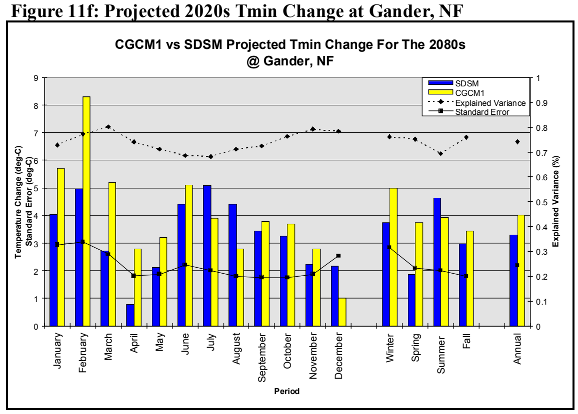

Figure 11h: Projected 2080s Tmin Change at Gander, NF

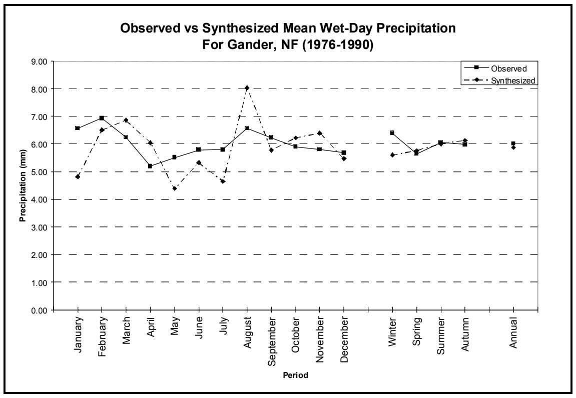

Figure 11i: Observed vs Synthesized Pcpn for Gander, NF

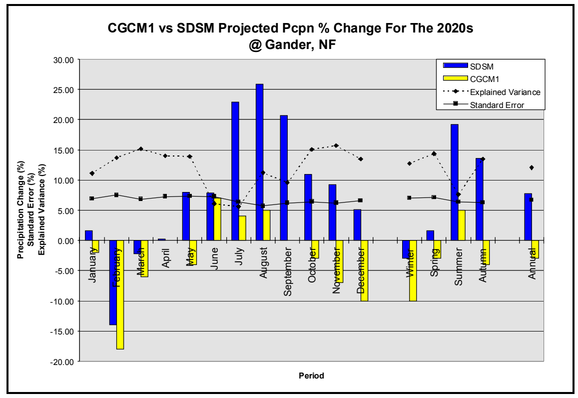

Figure 11j: Projected 2020s Pcpn Change at Gander, NF

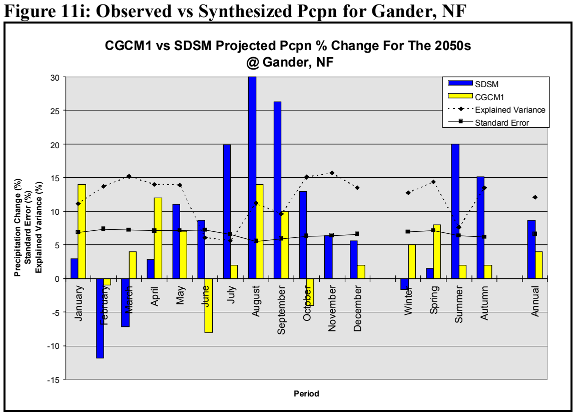

Figure 11k: Projected 2050s Pcpn Change at Gander, NF

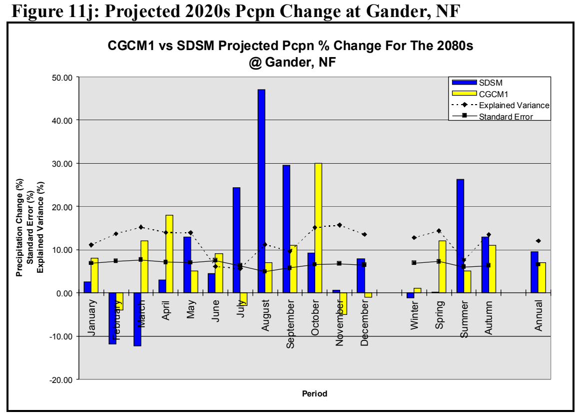

Figure 11l: Projected 2080s Pcpn Change at Gander, NF

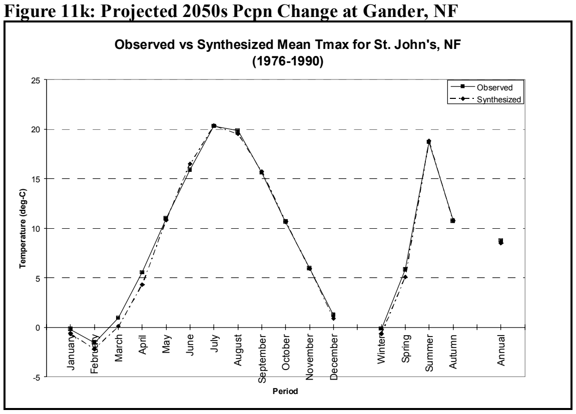

Figure 12a: Observed vs Synthesized Tmax for St. John's, NF

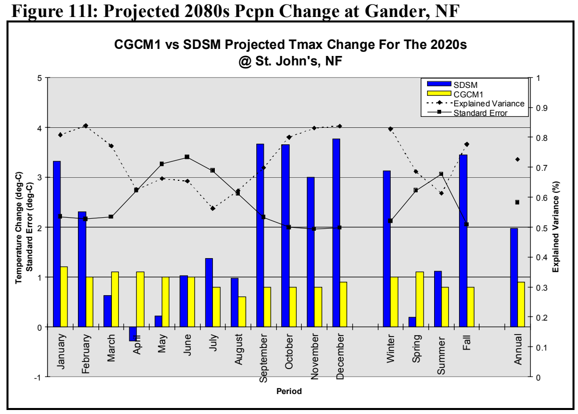

Figure 12b: Projected 2020s Tmax Change at St. John's, NF

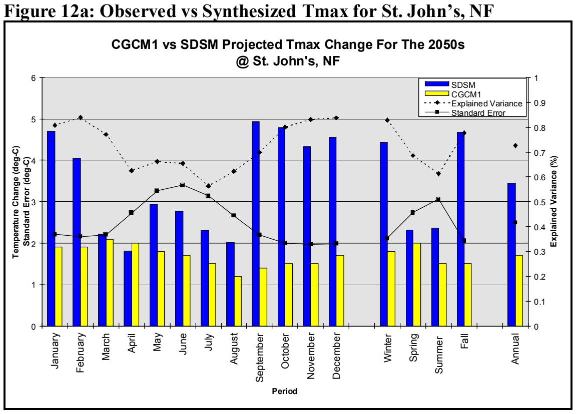

Figure 12c: Projected 2050s Tmax Change at St. John's, NF

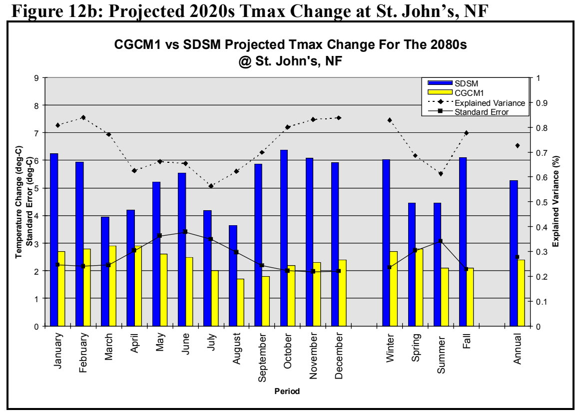

Figure 12d: Projected 2080s Tmax Change at St. John's, NF

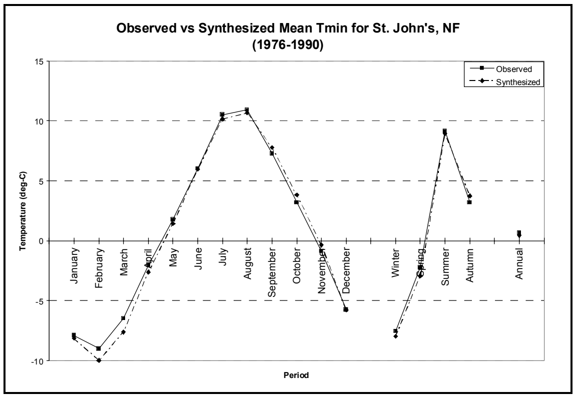

Figure 12e: Observed vs Synthesized Tmin for St. John's, NF

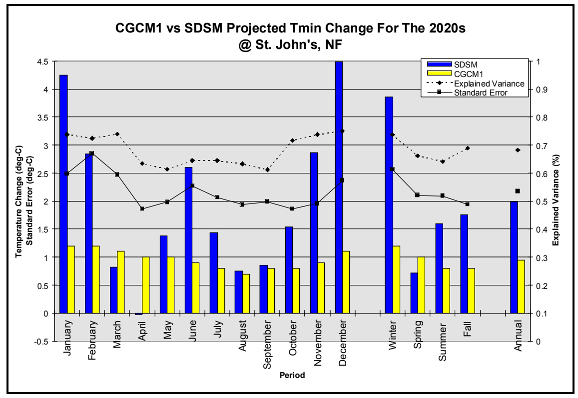

Figure 12f: Projected 2020s Tmin Change at St. John's, NF

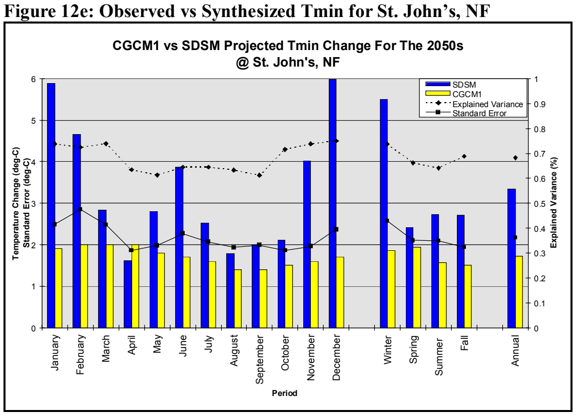

Figure 12g: Projected 2050s Tmin Change at St. John's, NF

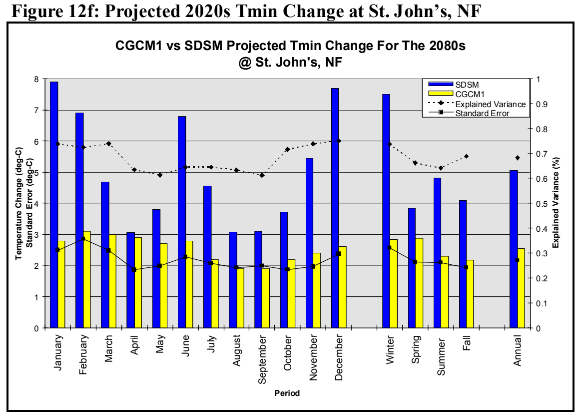

Figure 12h: Projected 2080s Tmin Change at St. John's, NF

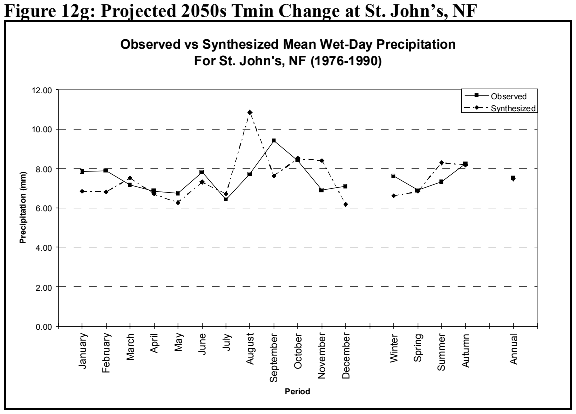

Figure 12i: Observed vs Synthesized Pcpn for St. John's, NF

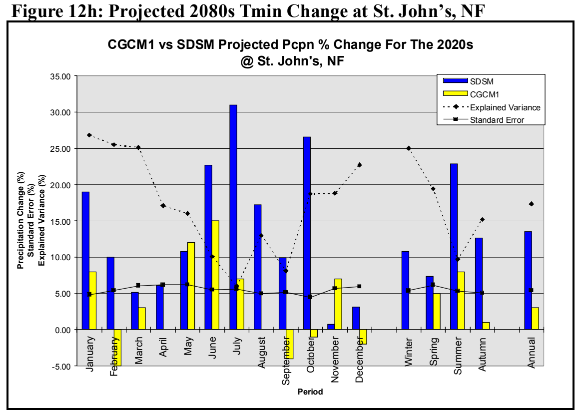

Figure 12j: Projected 2020s Pcpn Change at St. John's, NF

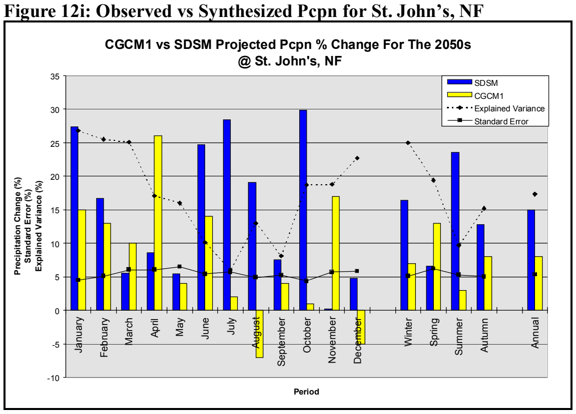

Figure 12k: Projected 2050s Pcpn Change at St. John's, NF

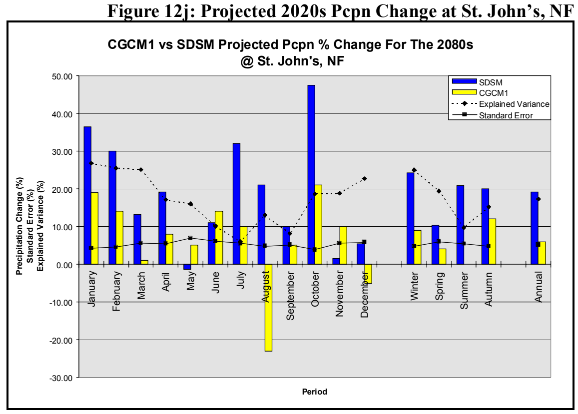

Figure 12l: Projected 2080s Pcpn Change at St. John's, NF

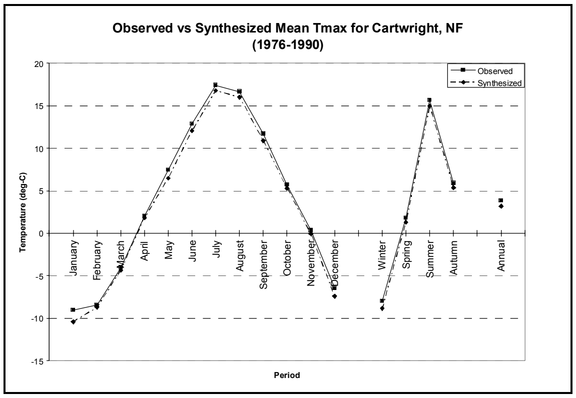

Figure 13a: Observed vs Synthesized Tmax for Cartwright, NF

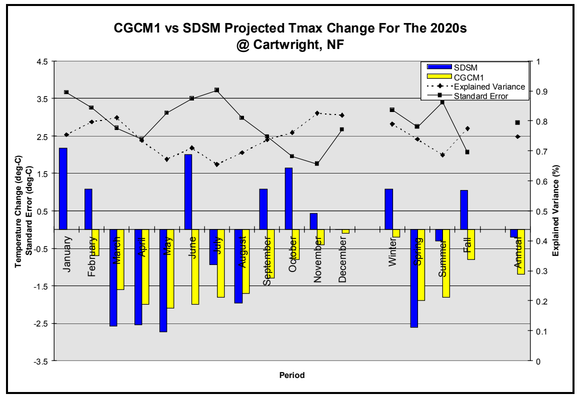

Figure 13b: Projected 2020s Tmax Change at Cartwright, NF

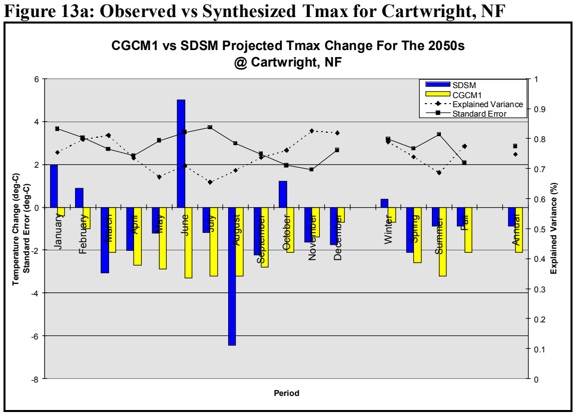

Figure 13c: Projected 2050s Tmax Change at Cartwright, NF

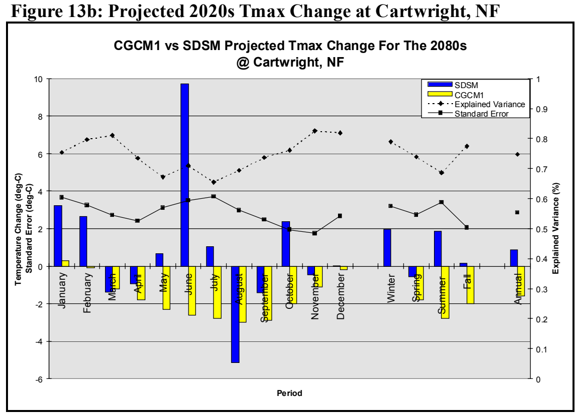

Figure 13d: Projected 2080s Tmax Change at Cartwright, NF

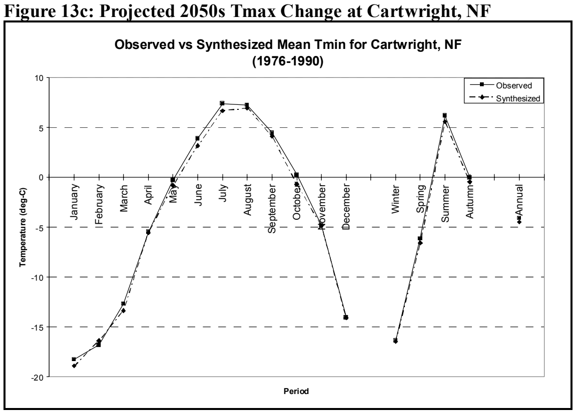

Figure 13e: Observed vs Synthesized Tmin for Cartwright, NF

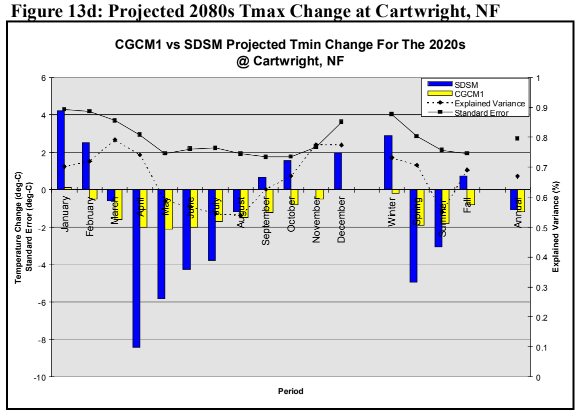

Figure 13f: Projected 2020s Tmin Change at Cartwright, NF

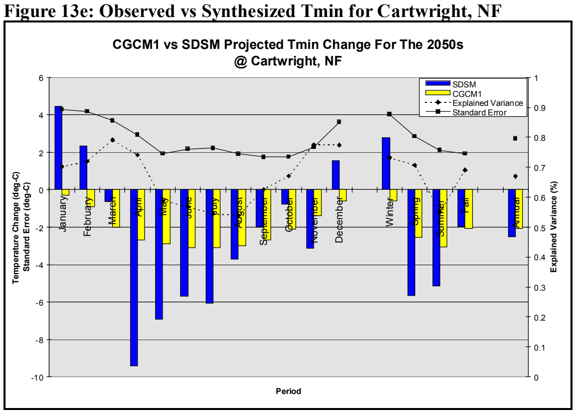

Figure 13g: Projected 2050s Tmin Change at Cartwright, NF

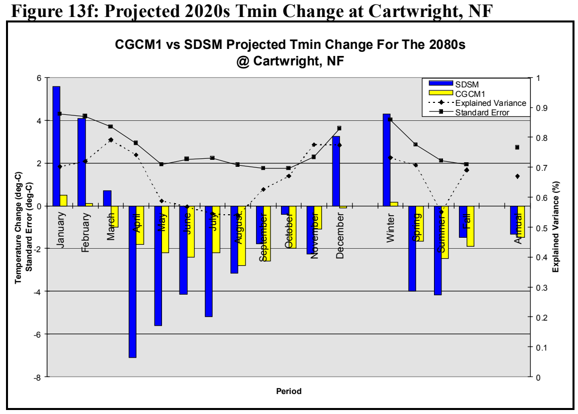

Figure 13h: Projected 2080s Tmin Change at Cartwright, NF

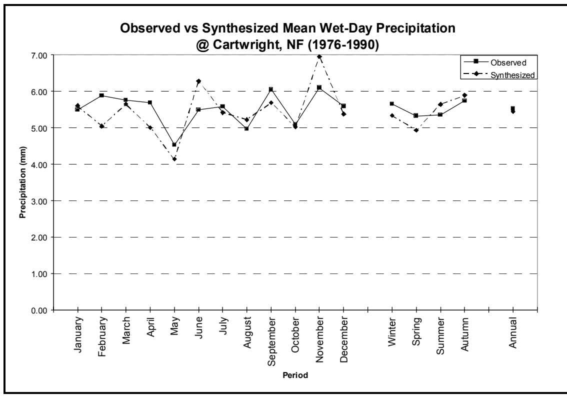

Figure 13i: Observed vs Synthesized Pcpn for Cartwright, NF

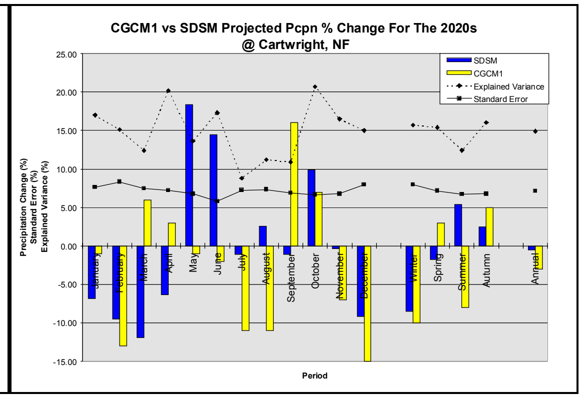

Figure 13j: Projected 2020s Pcpn Change at Cartwright, NF

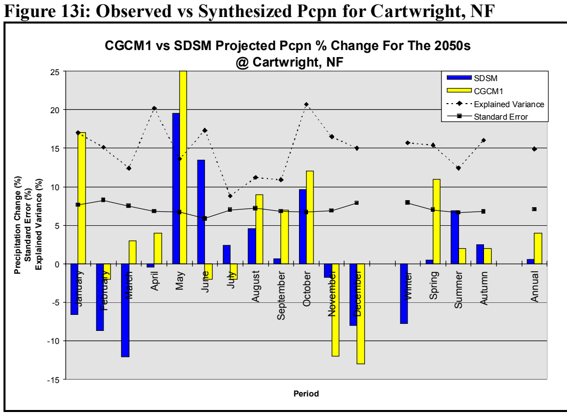

Figure 13k: Projected 2050s Pcpn Change at Cartwright, NF

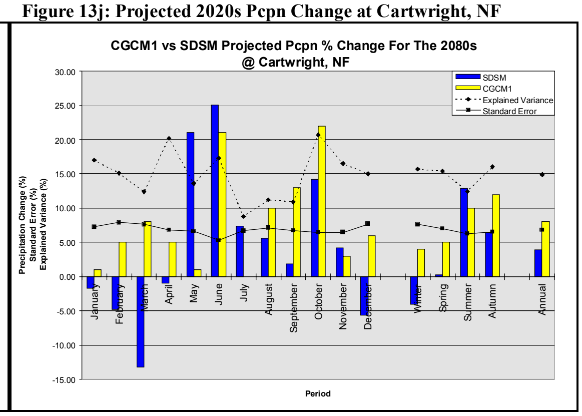

Figure 13l: Projected 2080s Pcpn Change at Cartwright, NF

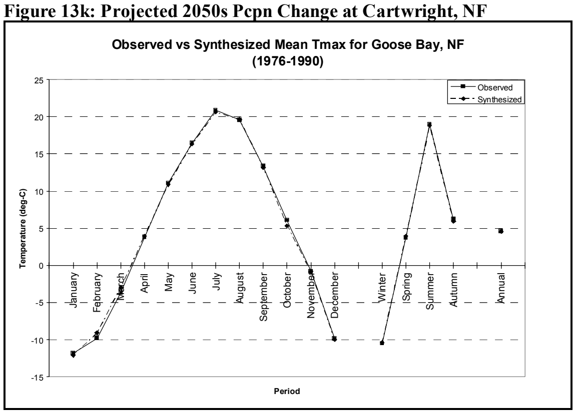

Figure 14a: Observed vs Synthesized Tmax for Goose Bay, NF

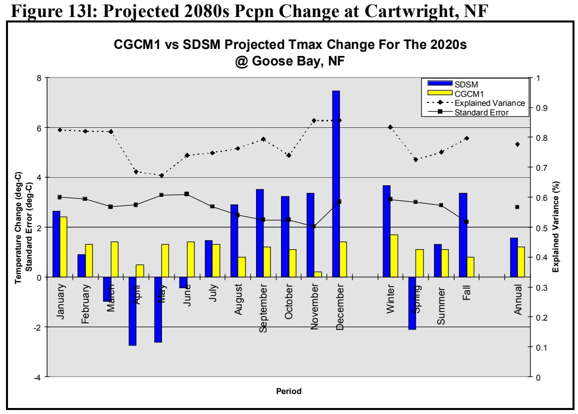

Figure 14b: Projected 2020s Tmax Change at Goose Bay, NF

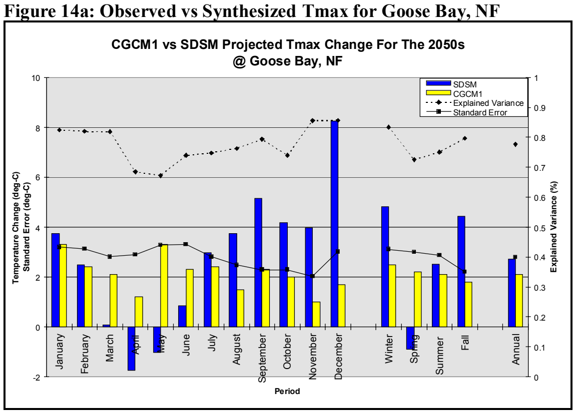

Figure 14c: Projected 2050s Tmax Change at Goose Bay, NF

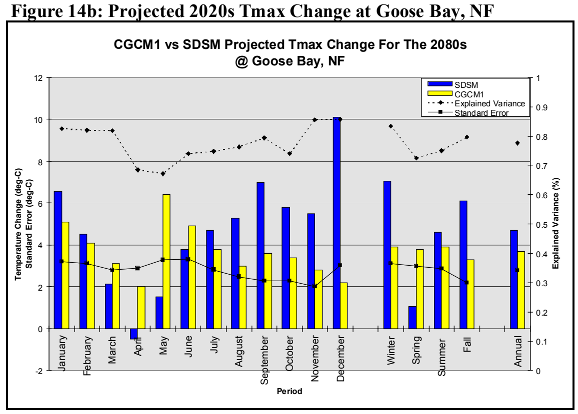

Figure 14d: Projected 2080s Tmax Change at Goose Bay, NF

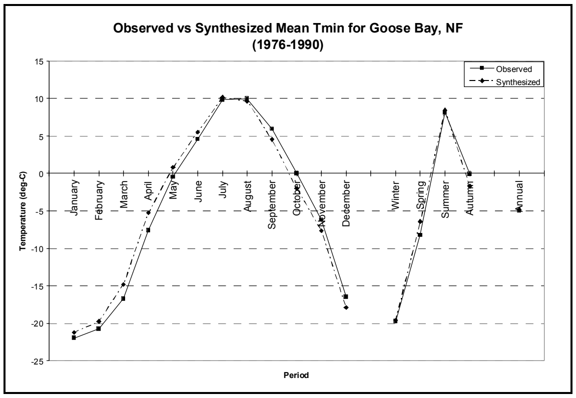

Figure 14e: Observed vs Synthesized Tmin for Goose Bay, NF

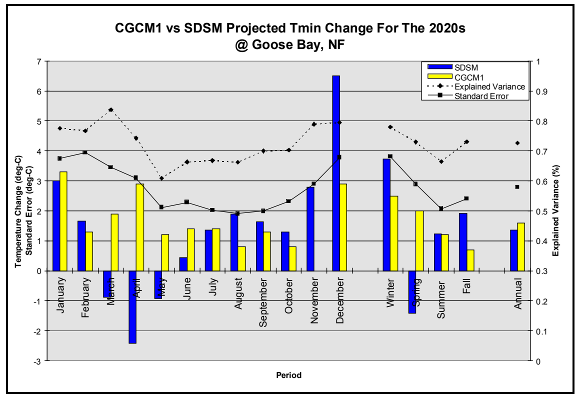

Figure 14f: Projected 2020s Tmin Change at Goose Bay, NF

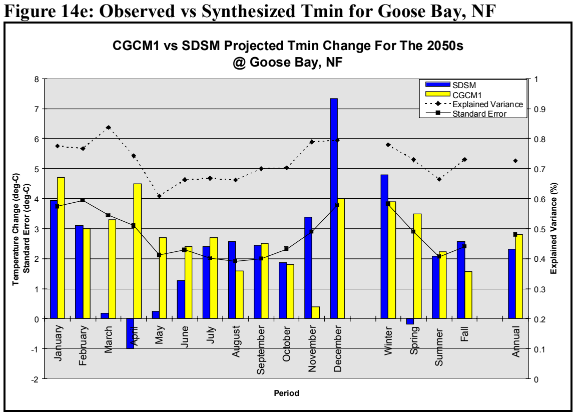

Figure 14g: Projected 2050s Tmin Change at Goose Bay, NF

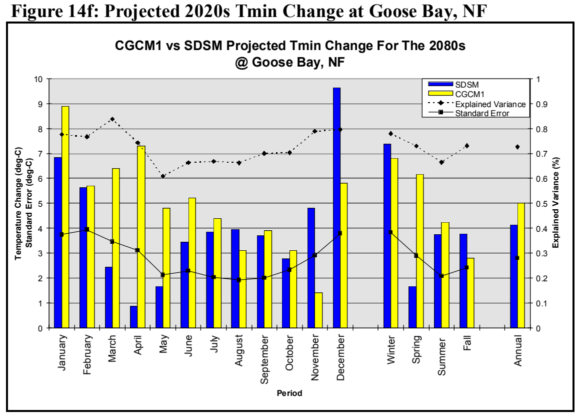

Figure 14h: Projected 2080s Tmin Change at Goose Bay, NF

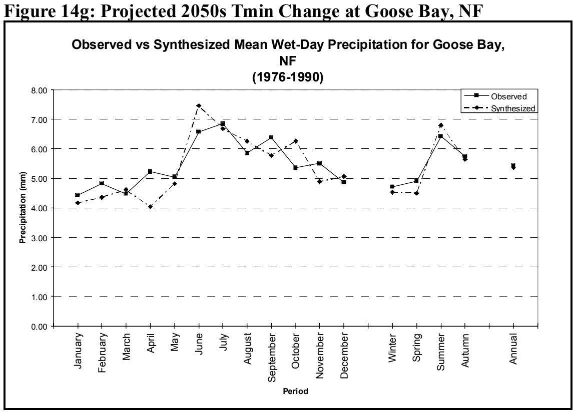

Figure 14i: Observed vs Synthesized Pcpn for Goose Bay, NF

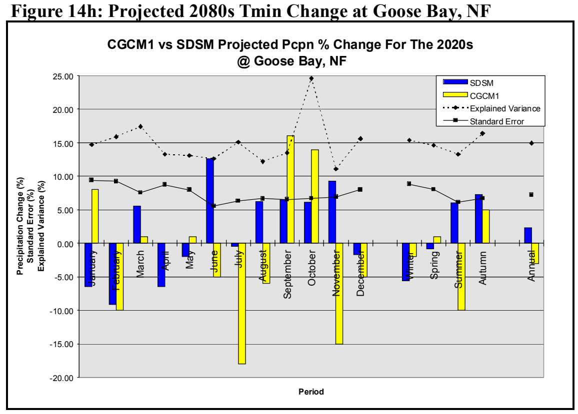

Figure 14j: Projected 2020s Pcpn Change at Goose Bay, NF

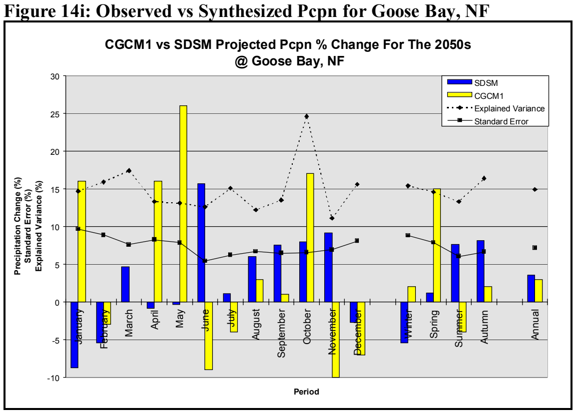

Figure 14k: Projected 2050s Pcpn Change at Goose Bay, NF

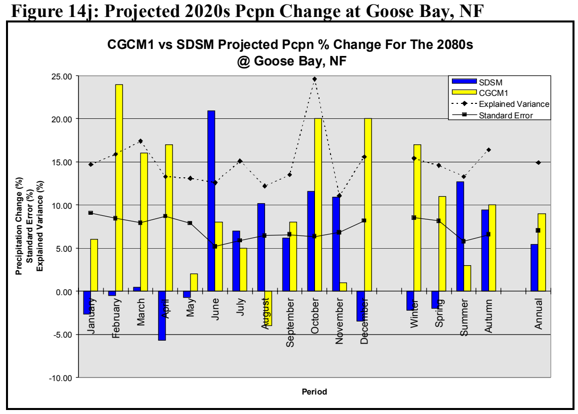

Figure 14l: Projected 2080s Pcpn Change at Goose Bay, NF