P2.23 BUILDING CLIMATE CHANGE SCENARIOS OF TEMPERATURE AND PRECIPITATION IN ATLANTIC CANADA USING THE STATISTICAL DOWNSCALING MODEL (SDSM)

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1. INTRODUCTION

On a global scale, mean surface temperature has increased over the past century, by 0.6°C(IPCC,2001), with increases during the past 50 years due directly to Greenhouse Gas (GHG) emissions from human activity. Global Climate Models (GCMs), which are capable of providing credible projections of such climate changes into the next 100 years, do so on a course global grid scale (Ibid.). Temperature and precipitation trends however differ on a regional scale due to local climate forcing, resulting in differing impacts at regional scales. To date, impacts researchers have only had GCM scale output to help determine the impacts 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 (Ibid.).

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 on a Personal Computer (PC), with a moderate processor speed (400-600 MHz), in minutes, 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, which was downloaded from the SDSM UK website (http://www-staff.lboro.ac.uk/~cocwd/sdsm.html).

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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 forecast into the future by a GCM model.

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 Canadian Coupled General Circulation Model (CGCM1) running the Greenhouse Gas plus Aerosol (GHG+A1) simulation were obtained from the Canadian Climate Impacts Scenarios (CCIS) Project: web site (http://www.cics.uvic.ca/scenarios).

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.

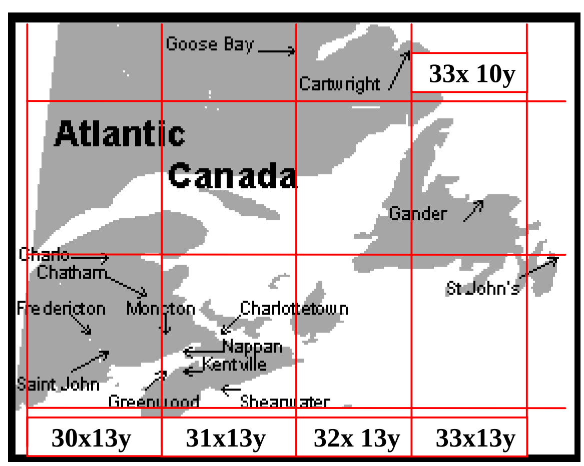


Fig 1 GCM Grid Boxes in Atlantic Canada.

Utilizing GCM output over this region limits the researcher to a small number of grid-boxes (six were used in this study) spanning 300 x 400km each, to cover all sites of interest. Some of these boxes are defined as ‘ocean’ boxes’ (e.g. 33x 10y), where the climate variables respond as if the surface boundary is North Atlantic ocean water.

Researchers require specific values for various climate variables 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.

3. DATA

Daily maximum temperature (Tmax), daily minimum temperature (Tmin), and total daily precipitation (Pcpn) for the 30 year period 1961-90 at 14 stations in Atlantic Canada were used in this study (Fig 1).

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.

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 was used.

3.3 Observed predictor sets

To provide gridded observational data sets, the National Centre for Environmental Prediction (NCEP) Re-analysis data sets 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 Figure 1by the CICS 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. The first version of the Coupled General Circulation Model (CGCM1) was used, and all predictor variables were prepared by the Canadian Climate Impacts Scenario (CCIS) project. Predictors ranged from basic variables such as mean temperature and mean sea level pressure, to calculated values such as specific humidity at 850Pa.

The predictor sets are available for three future tri-decadal periods; the 2020s (2011-2040); the 2050s (2041-2070); and the 2080s (2071-2100). 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 (Lines et al, 2002). The methodology is fully described in the SDSM ‘Users Manual’, by Wilby and Dawson, which can be downloaded from the SDSM web site.

What follows is an overview of the downscaling procedure.

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 are then run using known predictors. An internal random number weather generator within SDSM takes the calibrated output and stochastically synthesizes a 20 member ensemble of outputs that are statistically related to the original output. The means of this ensemble then becomes the synthesized downscaled values.

These synthesized values must be ‘tested’ 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 are inferred from the monthly, seasonal, and annual variation in explained variance (R^2), and standard error (SE). The fraction of the observed climate variability is accounted for by the explained variance (R^2), while downscaled values greater than the standard error are most likely due to local climate forcing.

4.2 Predictor selection

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

For this study the NCEP Re-analysis 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) are statistically compared. The user thus is required to select predictor variables that are physically related to the predictand, that produce the highest explained variance and the lowest standard error. In this study different sets of predictor variables were applied when either Tmax, Tmin, or Pcpn was downscaled. However, once selected, the same predictor sets were consistently applied at each site.

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 tested. Testing compares output from the calibrated model against known data from the normalized period 1961-1990. 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.

The validation procedure used in this study was to calibrate the model on the first half of the observational data set, and test the model on the second half.

4.4 Downscaled future scenarios

The final step in running SDSM is to use GCM projections to generate future scenarios 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 output. In addition, the monthly, seasonal, and annual value of explained variance and standard error were superimposed graphically on the results as a test of significance.

Although the above procedures sound fairly straight forward, different predictor or grid-box selections can produce different results. Furthermore, downscaling results are also known to vary with GCM model and model experiment. Fortunately, SDSM was designed to assist the user in making many of these choices and, due to its parsimonious nature, allows downscalers 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 in Figs 1-14 (Appendix). For each location Figs a, e, and i give the results of the test 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 predictors selected in this study are shown in Table 1 below.

Table 1

Selected 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 test 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 almost perfectly, suggesting that the calibrated models would be able to project future scenarios with reasonable accuracy.

In the case of Pcpn, the monthly fits were not exactly matched, suggesting a lower confidence in these results. The monthly and seasonal trends however were well replicated, as were the annual values.

5.3 Downscaled future scenarios

5.3.1 Monthly and seasonal

Monthly and seasonal projections for each climate variable, and for each tri-decadal period, as depicted in Figs 1-14, showed considerable variability, thus precluding any attempt at an overall summary. Although similarities may exist between adjacent sites, the monthly or seasonal results at each station are thought to be unique to that site. Users of this information are advised to analyze each site individually for any implied impacts.

5.3.2 Annual

Downscaled annual projections for each climate variable, and for each tri-decadal period, are also depicted in Figs 1-14. For convenience the mean values at those sites where projections were positive (all except Cartwright NF), are summarized in Table 2 below.

Table 2
SDSM vs.CGCM1 Mean Annual* Projections

Future	ΔTmax (°C)		
	SDSM	CGCM1	%Diff
2020's	1.7	1.2	42%
2050's	3.0	2.3	30
2080's	5.0	3.9	28
Mean			**34%**
	ΔTmin (°C)		
	SDSM	CGCM1	%Diff
2020's	1.3	1.5	-13%
2050's	2.4	2.5	-4
2080's	4.1	4.0	2.5
Mean			**-4.9%**
	ΔPcpn (%)		
	SDSM	CGCM1	%Diff
2020's	8	2	300%
2050's	8	2	300
2080's	8	5	60
Mean			**220%**

* Excludes Cartwright NF, where projections were mostly negative.

6. SUMMARY

This study examined SDSM downscaled values for daily maximum temperature (Tmax), daily minimum temperature (Tmin), and total daily precipitation (Pcpn), at 14 sites in Atlantic Canada. These values were compared, internally to synthesized data, as well as to non-downscaled values taken directly from the CGCM1 model output.

This study clearly demonstrated the ability of SDSM, to deliver reasonable downscaled climate projections, using economical computational methods, while simultaneously highlighting the role of regional climate forcing.

It must be remembered however, that downscaled scenarios in this study were generated using only one GCM model, running one experiment. Downscaled scenarios using other GCM models and experiments would likely produce slightly different, but equally plausible, results.

Impacts researchers would undoubtedly prefer to consider the implications of a range of climate scenarios, resulting from several different GCM models running different emission scenarios, however no other relevantly gridded GCM models are available at this time.

7. NEXT STEPS

1. Consider other GCM models and experiments, (e.g. the HADGCM1 GHG+A1).
2. Consider other climate, environmental, or hydrological variables (e.g. sunshine, air quality, or stream flow).
3. Determine projected changes in the monthly, seasonal, and annual frequency of occurrence values for; wet days; frost-free days; days with Tmax > 30°C; cooling degree days, heating degree days; and growing degree days.
4. Expand the work into other sites in Canada

8. ACKNOWLEDGEMENTS

The vital role played by Rob Wilby and C. Dawson, co-designers of the SDSM model, and by Elaine Barrow for her preparation of all NCEP and CGCM1 predictor data sets, is hereby gratefully acknowledged. Without their combined help this downscaling study would not have been possible.

9. REFERENCES

Canadian Climate Impacts Scenarios (CCIS) Project: http://www.cics.uvic.ca/scenarios

Intergovernmental Panel on Climate Change, 2001: Climate Change 2001; The Scientific Basis. *IPCC Third Assessment Report.* Cambridge University Press

Lines, G.S., Barrow, E.M., 2002. Regional Climate Change Scenarios in Atlantic Canada Utilizing Downscaling Techniques: Preliminary Results. *AMS Preprint*, 13-17 January 2002, Orlando FL,USA.

Statistical Downscaling Model download site: http://www-staff.lboro.ac.uk/~cocwd/sdsm.html

Vincent, L.A., 1998: A Technique for the Identification of Inhomogeneities in Canadian Temperature Series. *Journal of Climate*, **11**, 1094-1104.

Wilby, R.L., Dawson, C.W. and Barrow, E.M. 2001. SDSM User Manual- A Decision Support Tool for the Assessment of Regional Climate Change Impacts (http://www-staff.lboro.ac.uk/~cocwd/sdsm.html)

APPENDIX

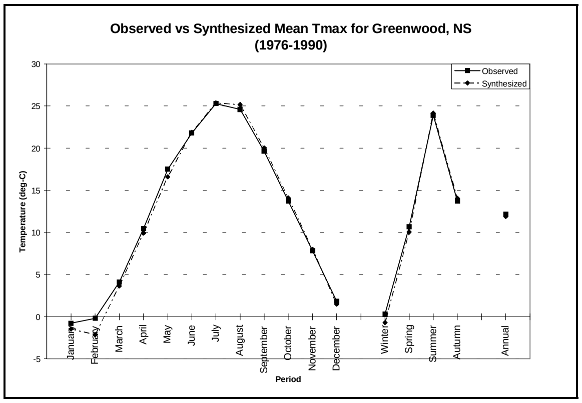


Figure 1a: Observed vs Synthesized Tmax at Greenwood, NS

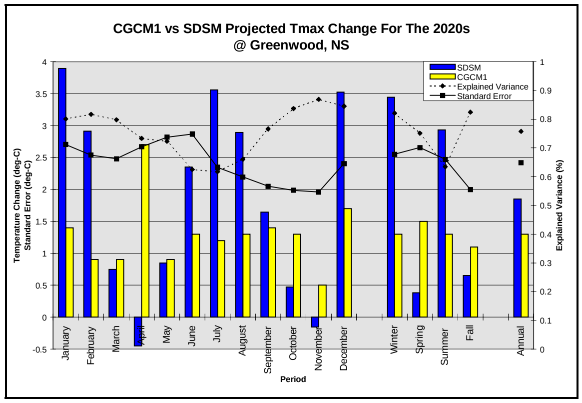


Figure 1b: Projected 2020s Tmax Change at Greenwood, NS

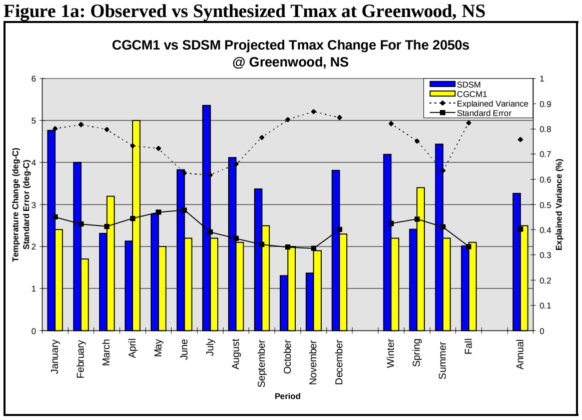


Figure 1c: Projected 2050s Tmax Change at Greenwood, NS

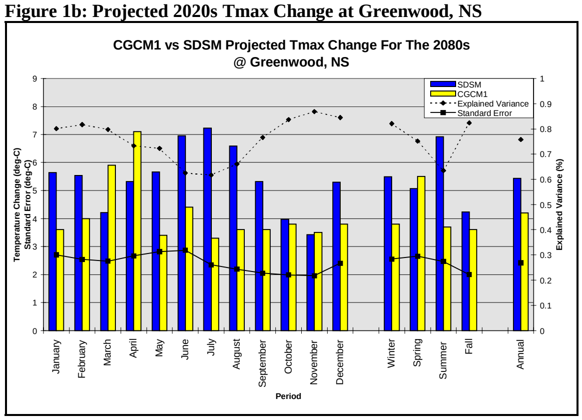


Figure 1d: Projected 2080s Tmax Change at Greenwood, NS

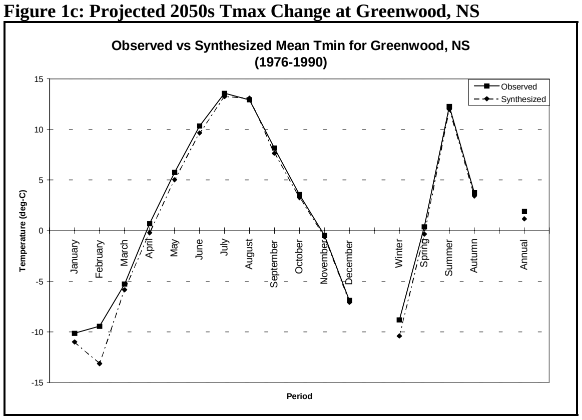


Figure 1e: Observed vs Synthesized Tmin at Greenwood, NS

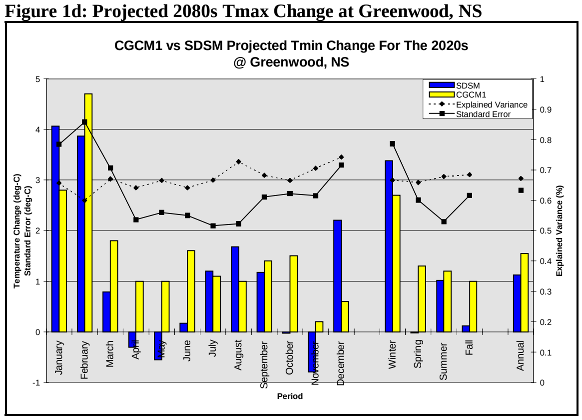


Figure 1f: Projected 2020s Tmin Change at Greenwood, NS

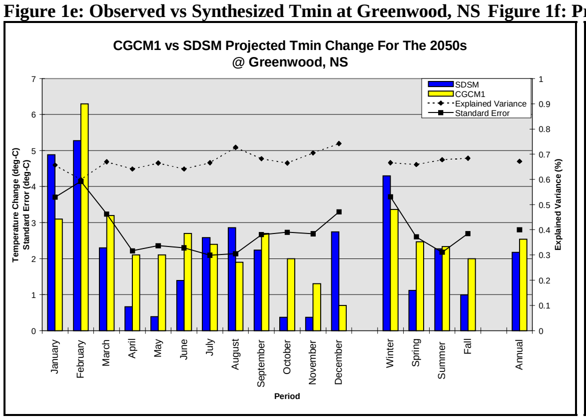


Figure 1g: Projected 2050s Tmin Change at Greenwood, NS

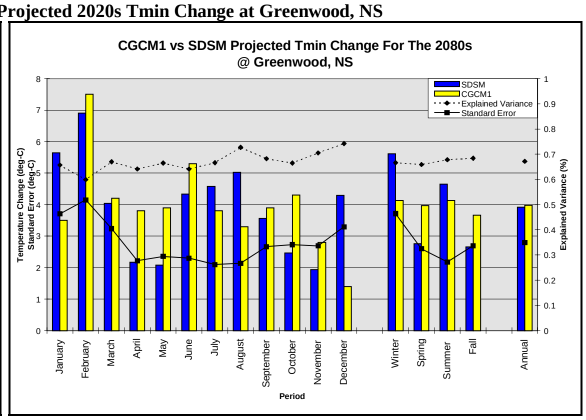


Figure 1h: Projected 2080s Tmin Change at Greenwood, NS

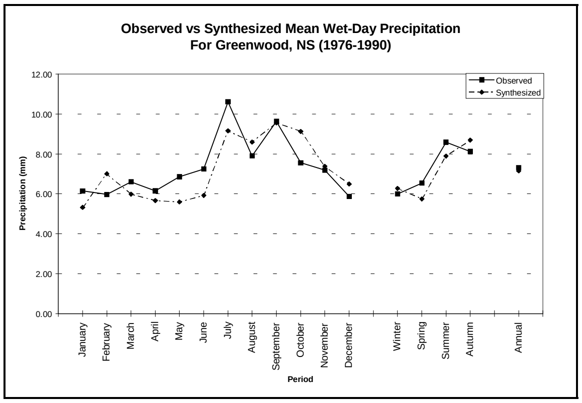


Figure 1i: Observed vs Synthesized Pcpn at Greenwood, NS

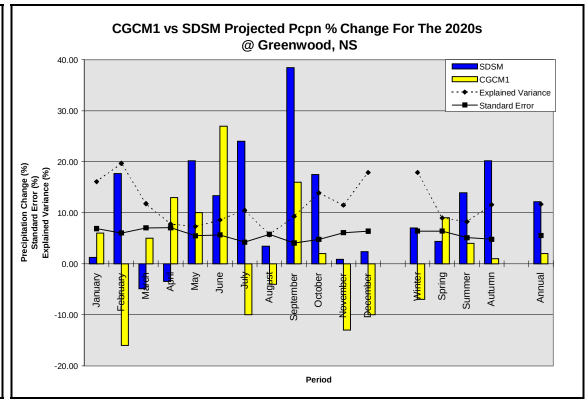


Figure 1j: Projected 2020s Pcpn Change at Greenwood, NS

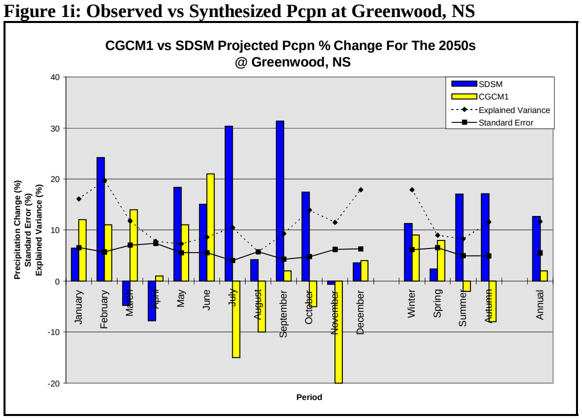


Figure 1k: Projected 2050s Pcpn Change at Greenwood, NS

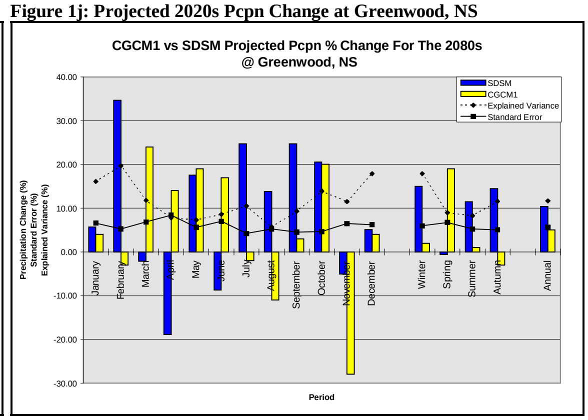


Figure 1l: Projected 2080s Pcpn Change at Greenwood, NS

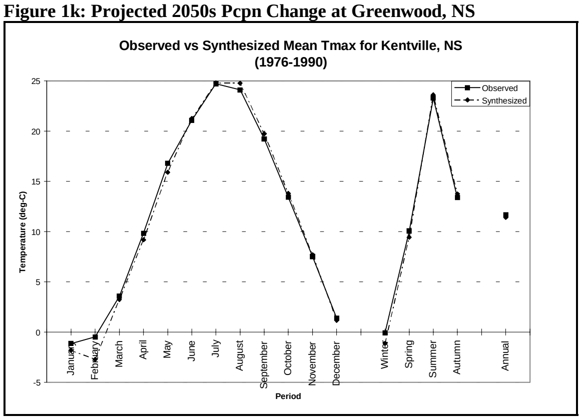


Figure 2a: Observed vs Synthesized Tmax at Kentville, NS

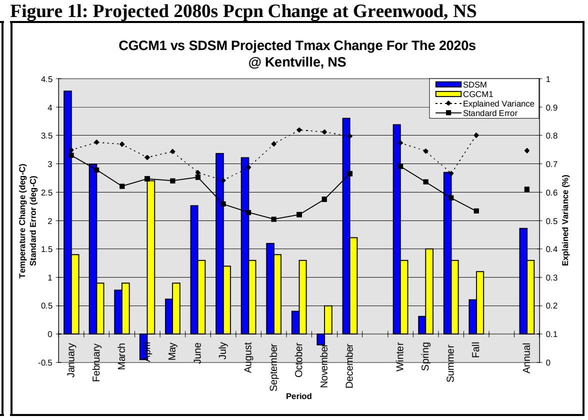


Figure 2b: Projected 2020s Tmax Change at Kentville, NS

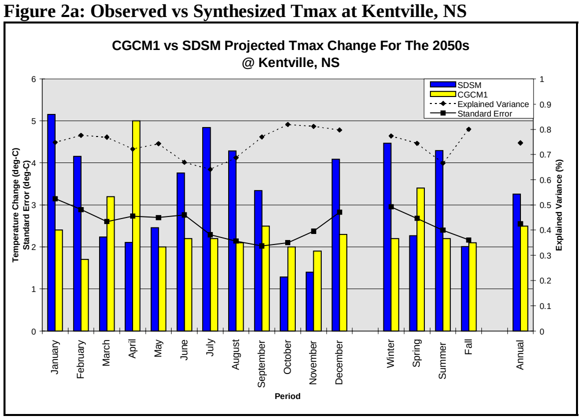


Figure 2c: Projected 2050s Tmax Change at Kentville, NS

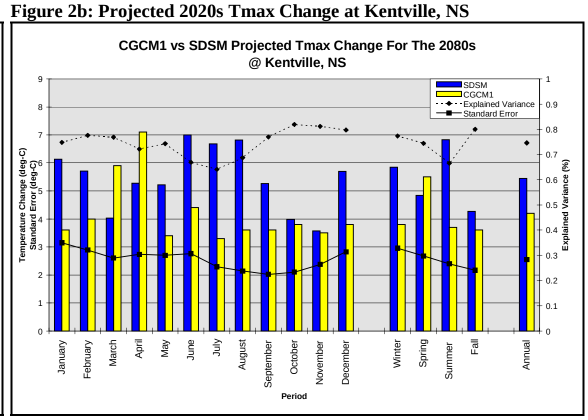


Figure 2d: Projected 2080s Tmax Change at Kentville, NS

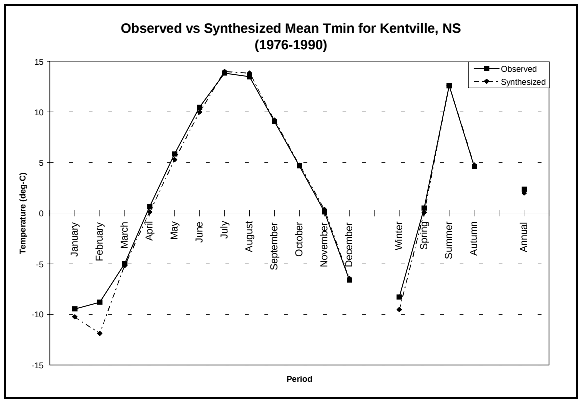


Figure 2e: Observed vs Synthesized Tmin at Kentville, NS

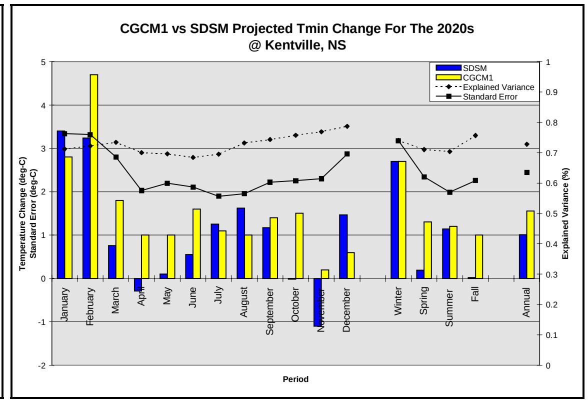


Figure 2f: Projected 2020s Tmin Change at Kentville, NS

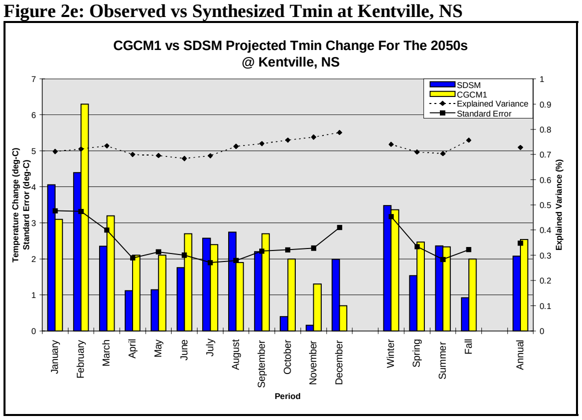


Figure 2g: Projected 2050s Tmin Change at Kentville, NS

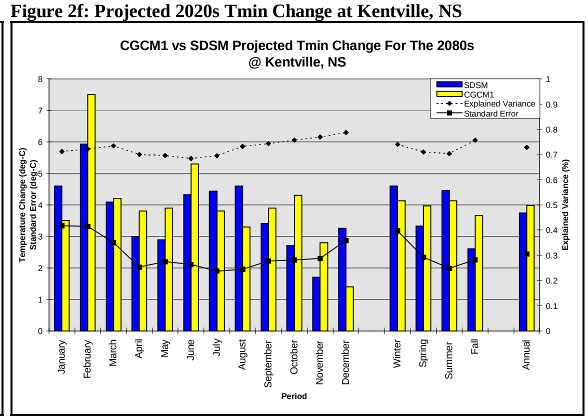


Figure 2h: Projected 2080s Tmin Change at Kentville, NS

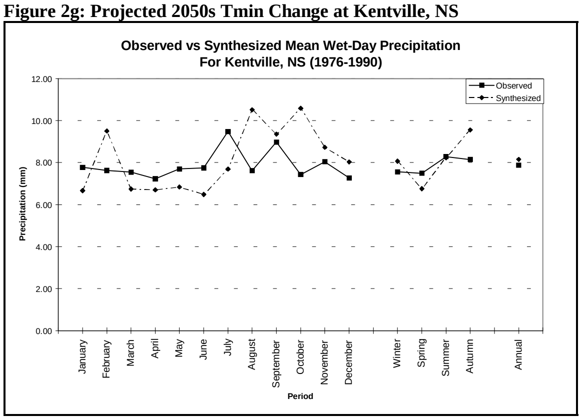


Figure 2i: Observed vs Synthesized Pcpn at Kentville, NS

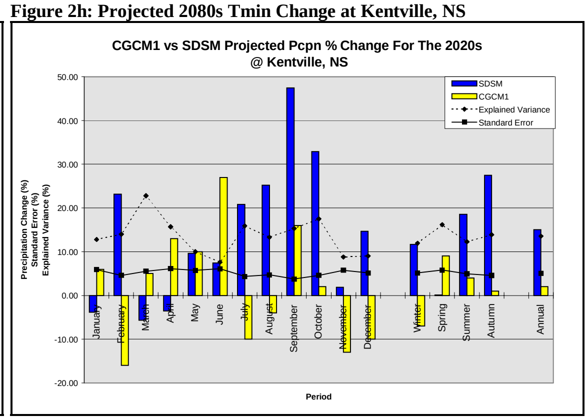


Figure 2j: Projected 2020s Pcpn Change at Kentville, NS

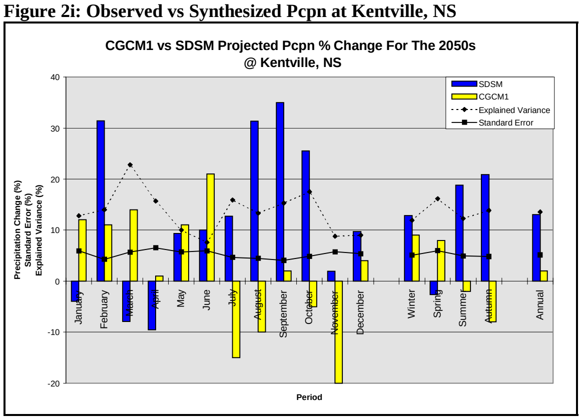


Figure 2k: Projected 2050s Pcpn Change at Kentville, NS

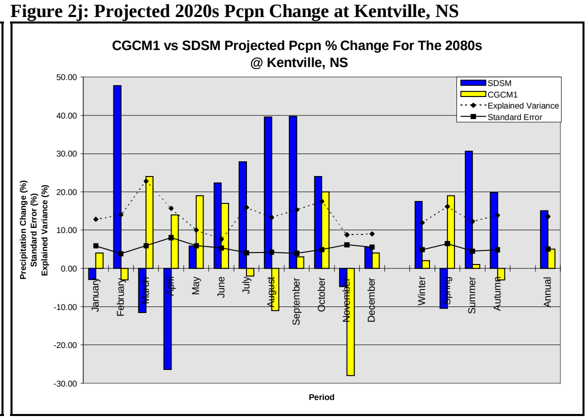


Figure 2l: Projected 2080s Pcpn Change at Kentville, NS

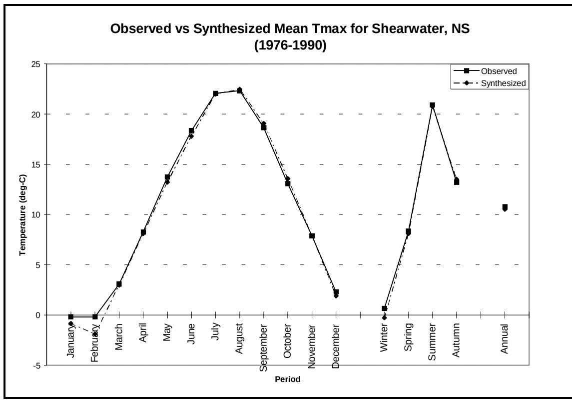


Figure 3a: Observed vs Synthesized Tmax at Shearwater, NS

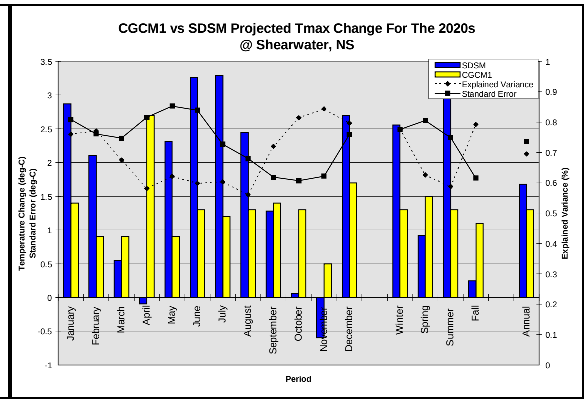


Figure 3b: Projected 2020s Tmax Change at Shearwater, NS

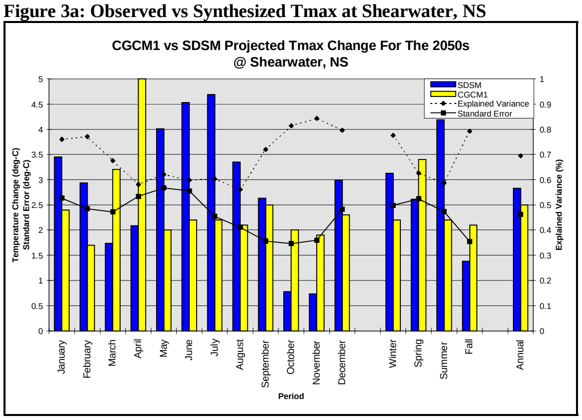


Figure 3c: Projected 2050s Tmax Change at Shearwater, NS

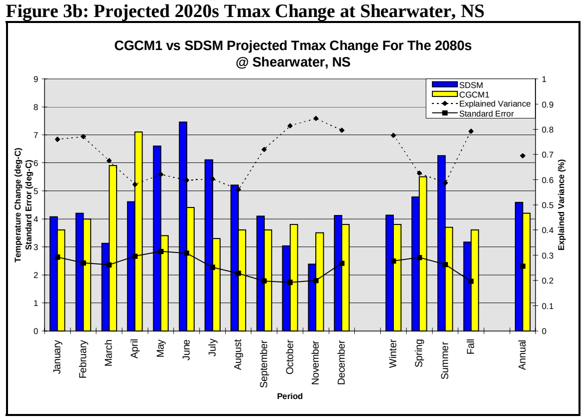


Figure 3d: Projected 2080s Tmax Change at Shearwater, NS

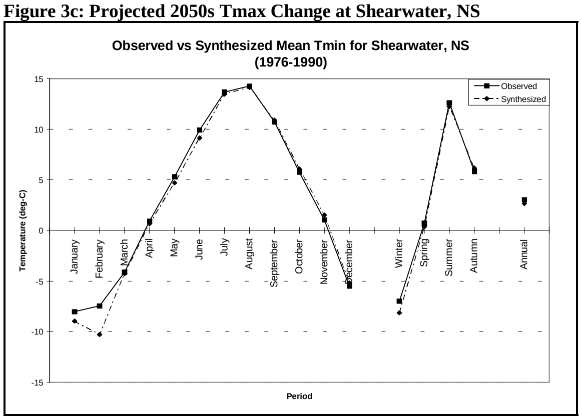


Figure 3e: Observed vs Synthesized Tmin at Shearwater, NS

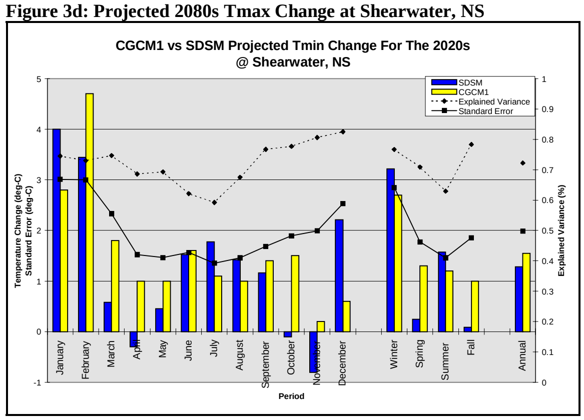


Figure 3f: Projected 2020s Tmin Change at Shearwater, NS

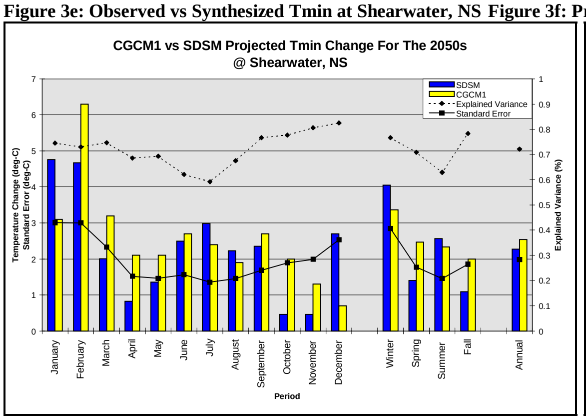


Figure 3g: Projected 2050s Tmin Change at Shearwater, NS

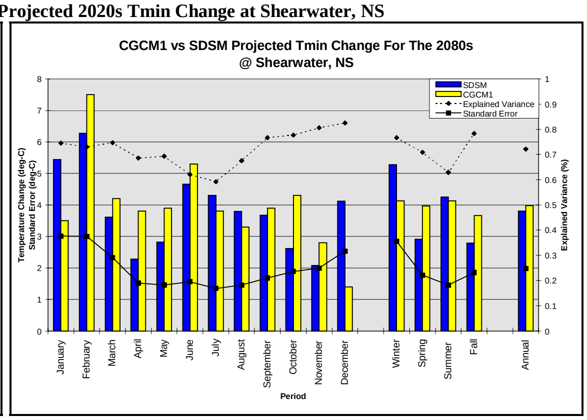


Figure 3h: Projected 2080s Tmin Change at Shearwater, NS

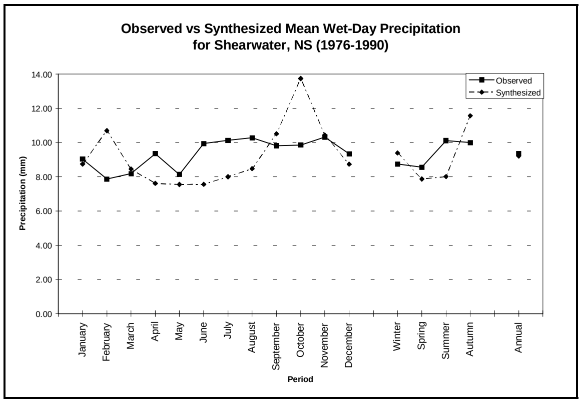


Figure 3i: Observed vs Synthesized Pcpn at Shearwater, NS

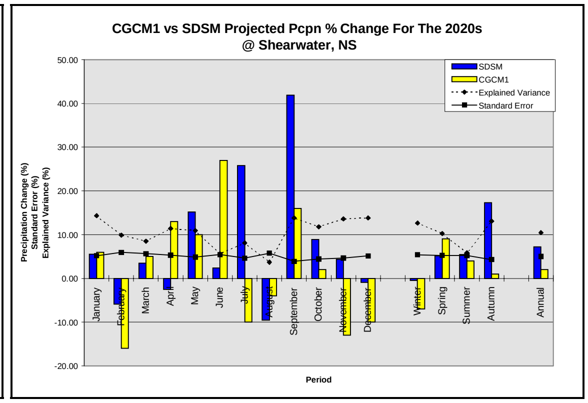


Figure 3j: Projected 2020s Pcpn Change at Shearwater, NS

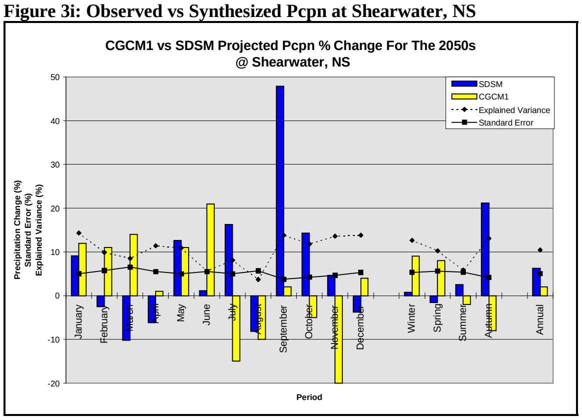


Figure 3k: Projected 2050s Pcpn Change at Shearwater, NS

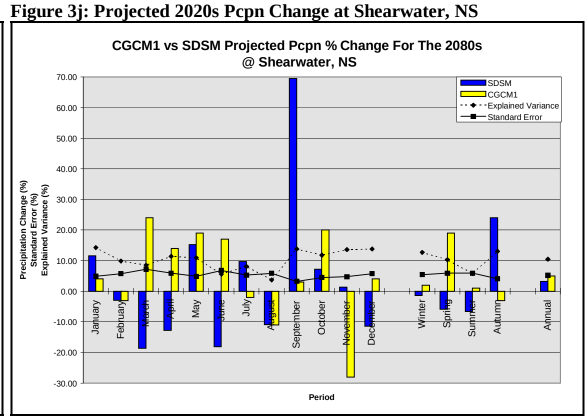


Figure 3l: Projected 2080s Pcpn Change at Shearwater, NS

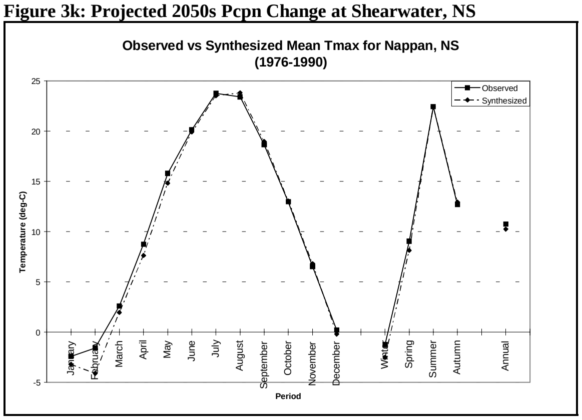


Figure 4a: Observed vs Synthesized Tmax at Nappan, NS

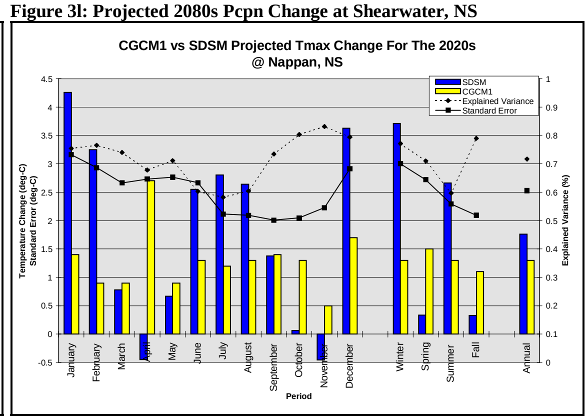


Figure 4b: Projected 2020s Tmax Change at Nappan, NS

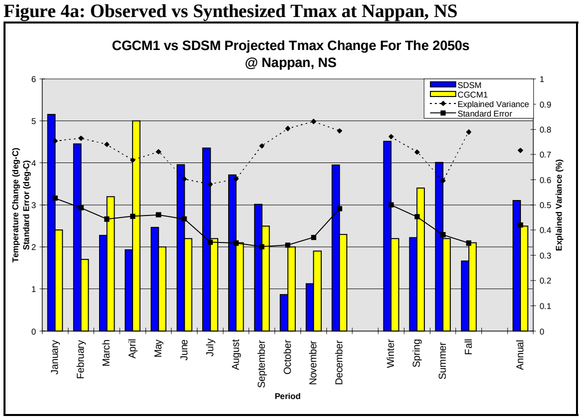


Figure 4c: Projected 2050s Tmax Change at Nappan, NS

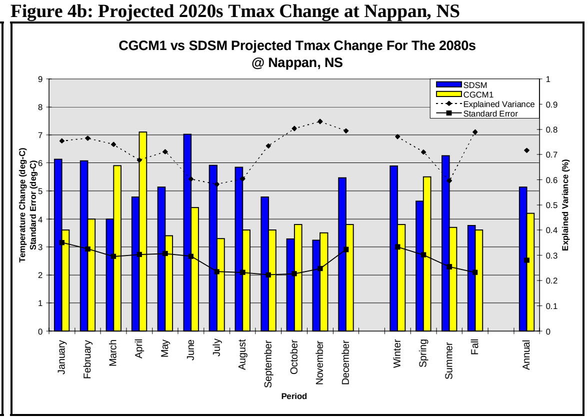


Figure 4d: Projected 2080s Tmax Change at Nappan, NS

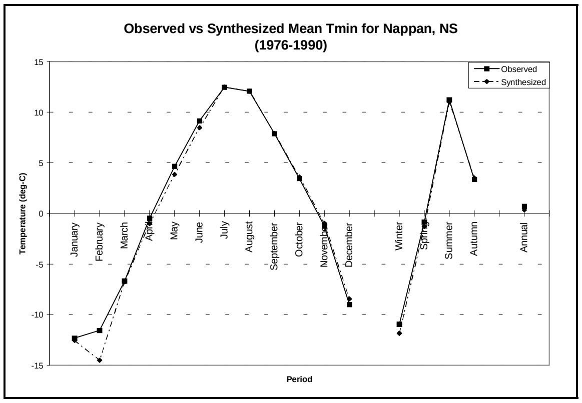


Figure 4e: Observed vs Synthesized Tmin at Nappan, NS

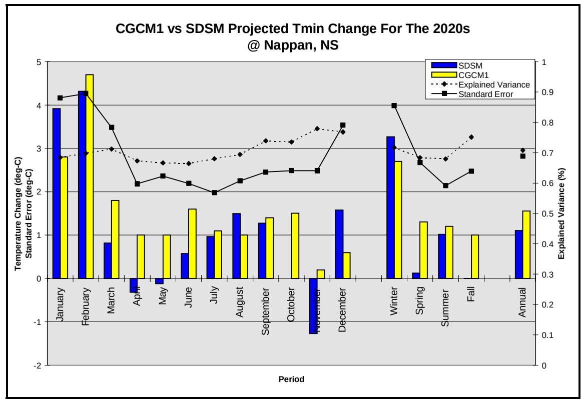


Figure 4f: Projected 2020s Tmin Change at Nappan, NS

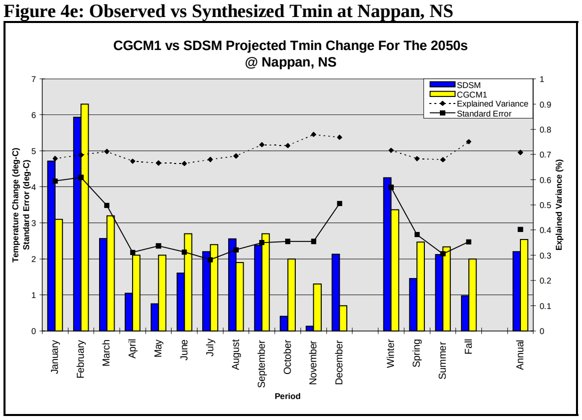


Figure 4g: Projected 2050s Tmin Change at Nappan, NS

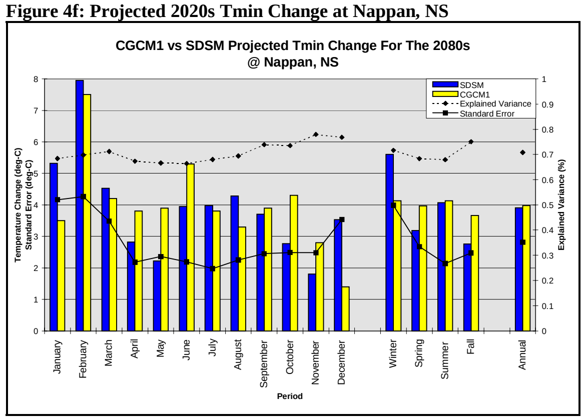


Figure 4h: Projected 2080s Tmin Change at Nappan, NS

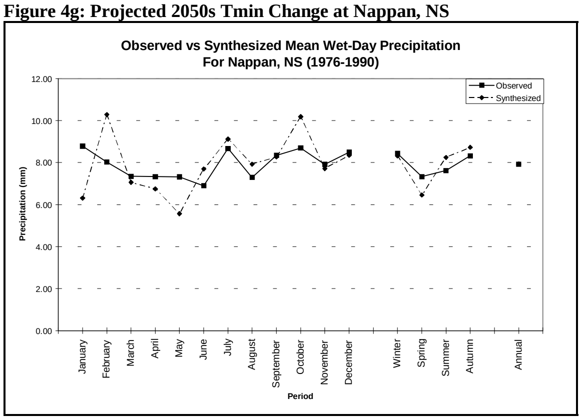


Figure 4i: Observed vs Synthesized Pcpn at Nappan, NS

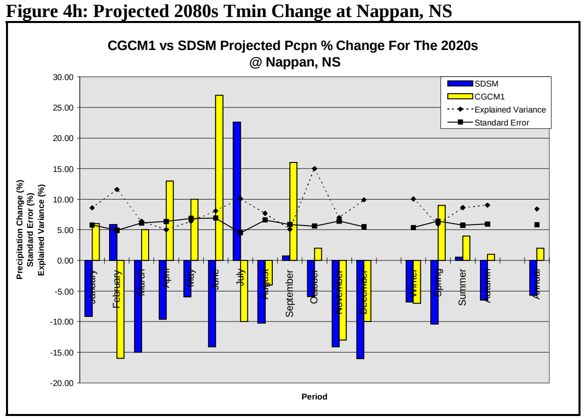


Figure 4j: Projected 2020s Pcpn Change at Nappan, NS

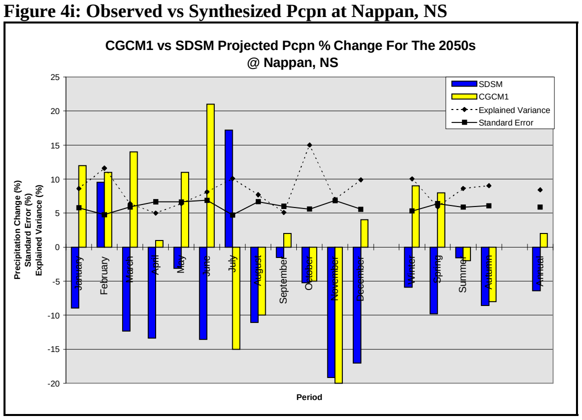


Figure 4k: Projected 2050s Pcpn Change at Nappan, NS

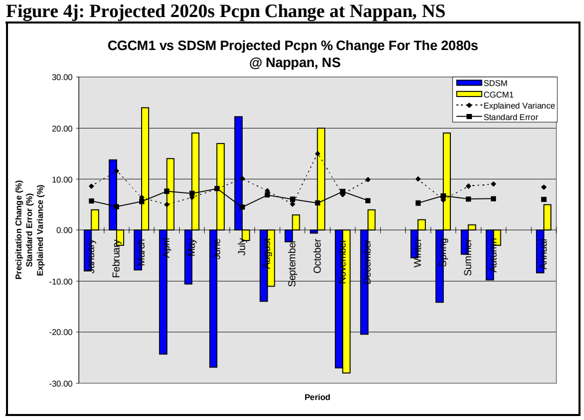


Figure 4l: Projected 2080s Pcpn Change at Nappan, NS

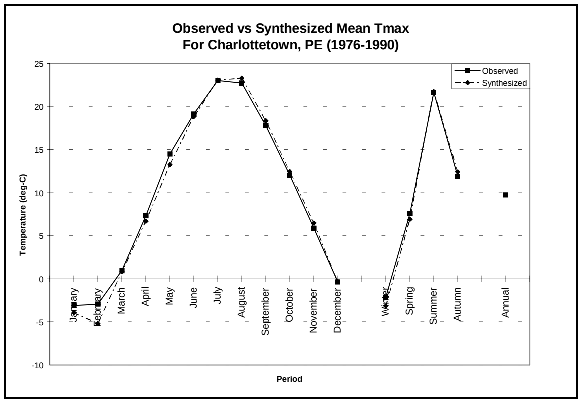


Figure 5a: Observed vs Synthesized Tmax at Charlottetown, PE

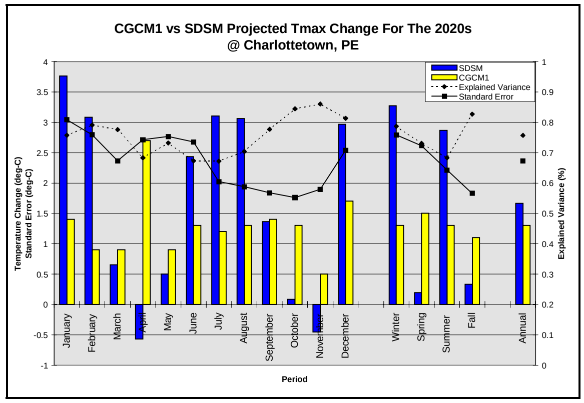


Figure 5b: Projected 2020s Tmax Change at Charlottetown, PE

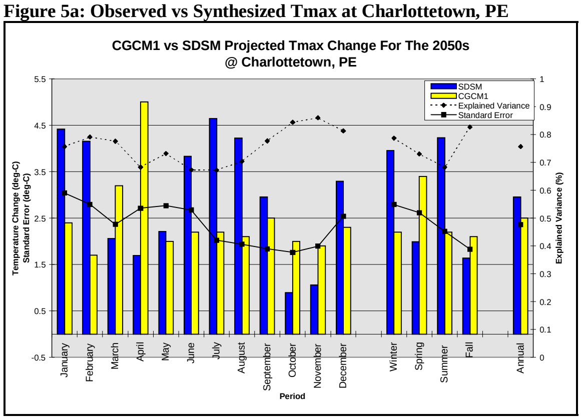


Figure 5c: Projected 2050s Tmax Change at Charlottetown, PE

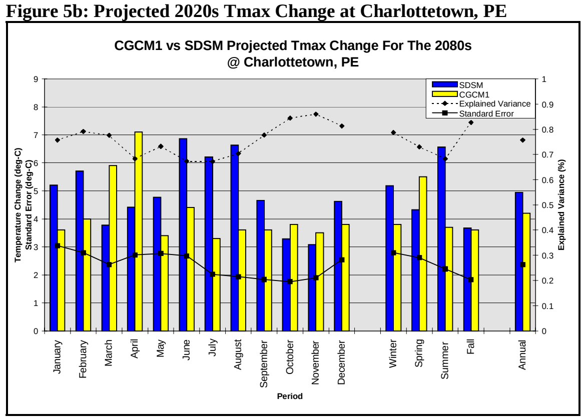


Figure 5d: Projected 2080s Tmax Change at Charlottetown, PE

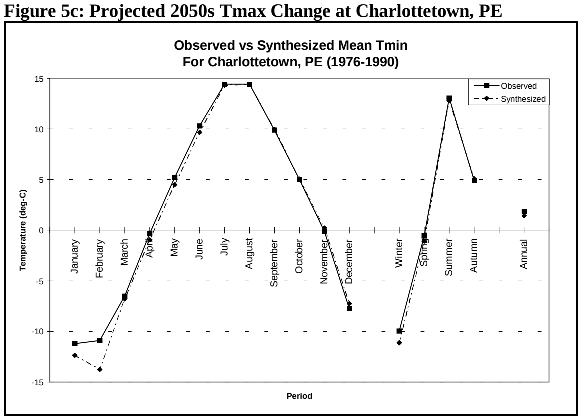


Figure 5e: Observed vs Synthesized Tmin at Charlottetown, PE

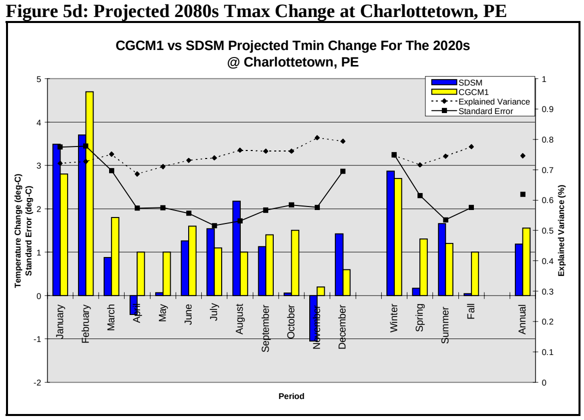


Figure 5f: Projected 2020s Tmin Change at Charlottetown, PE

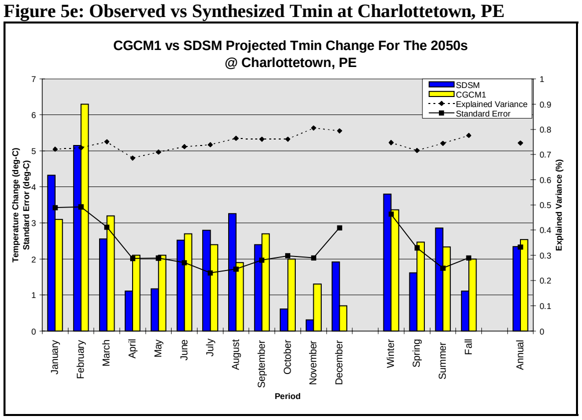


Figure 5g: Projected 2050s Tmin Change at Charlottetown, PE

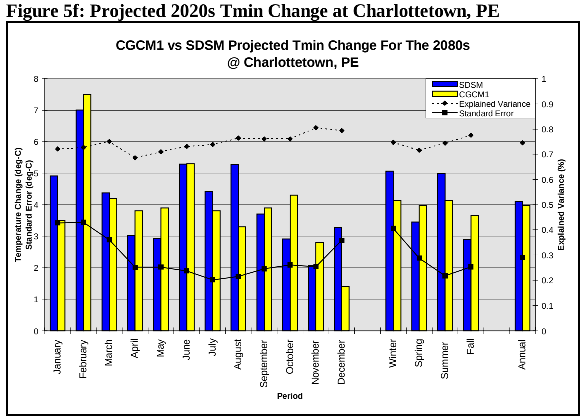


Figure 5h: Projected 2080s Tmin Change at Charlottetown, PE

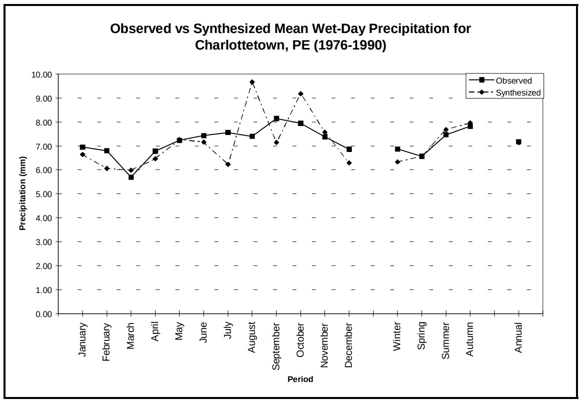


Figure 5i: Observed vs Synthesized Pcpn at Charlottetown, PE

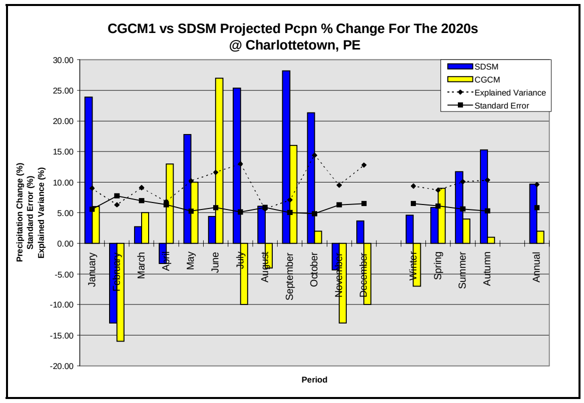


Figure 5j: Projected 2020s Pcpn Change at Charlottetown, PE

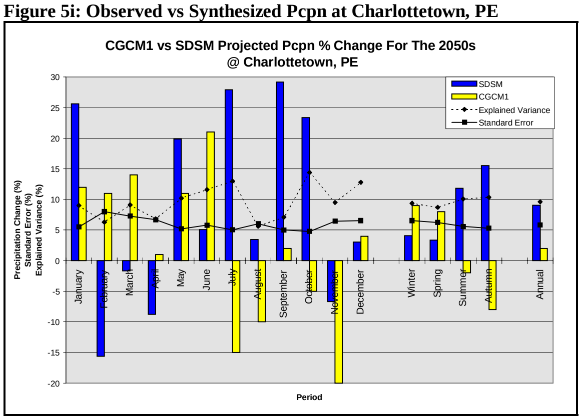


Figure 5k: Projected 2050s Pcpn Change at Charlottetown, PE

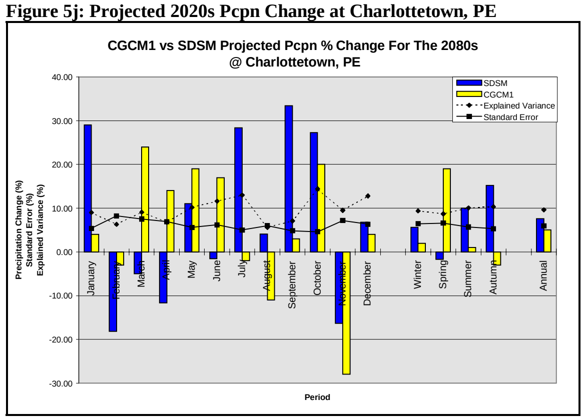


Figure 5l: Projected 2080s Pcpn Change at Charlottetown, PE

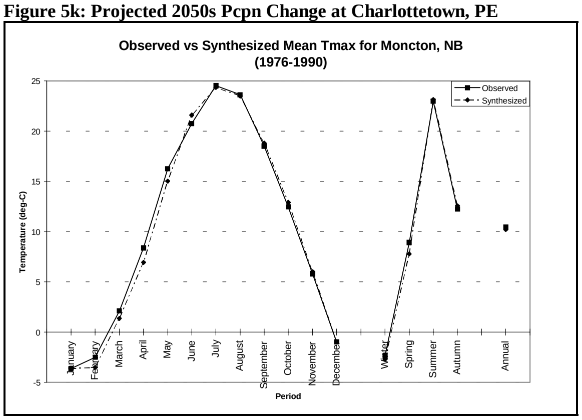


Figure 6a: Observed vs Synthesized Tmax at Moncton, NB

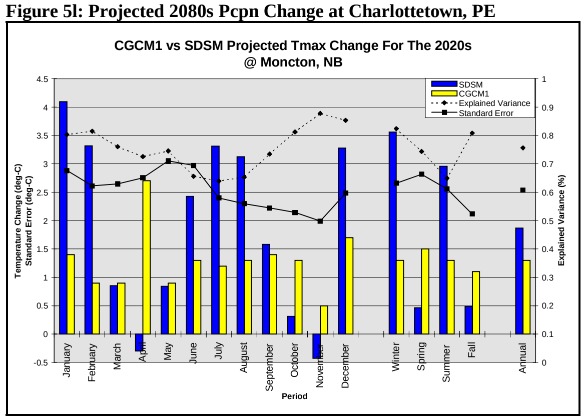


Figure 6b: Projected 2020s Tmax Change at Moncton, NB

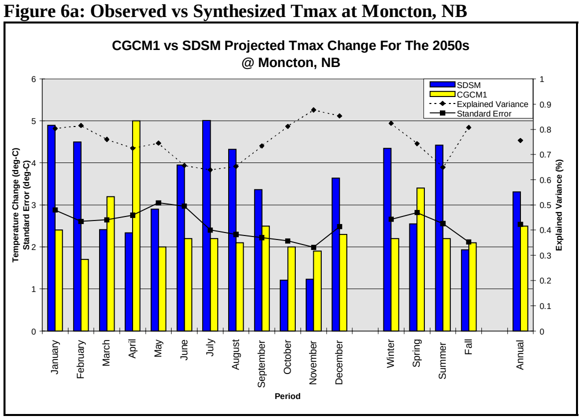


Figure 6c: Projected 2050s Tmax Change at Moncton, NB

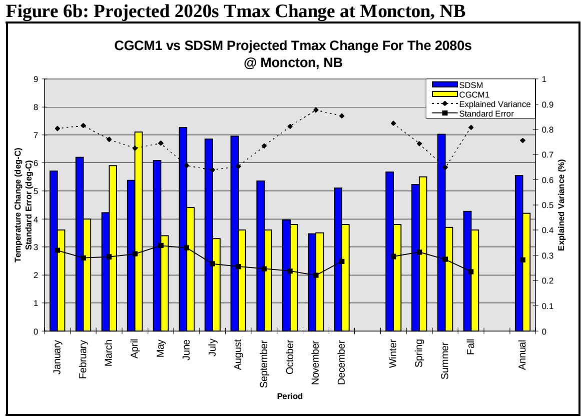


Figure 6d: Projected 2080s Tmax Change at Moncton, NB

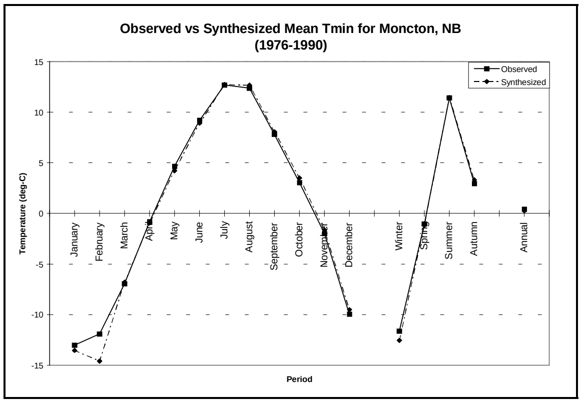


Figure 6e: Observed vs Synthesized Tmin at Moncton, NB

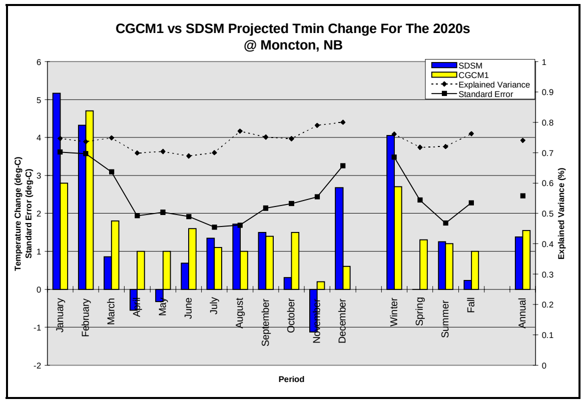


Figure 6f: Projected 2020s Tmin Change at Moncton, NB

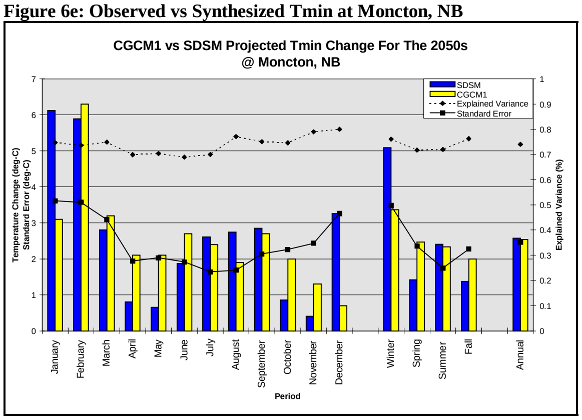


Figure 6g: Projected 2050s Tmin Change at Moncton, NB

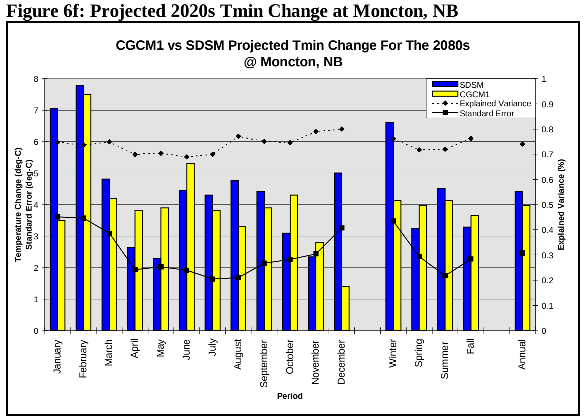


Figure 6h: Projected 2080s Tmin Change at Moncton, NB

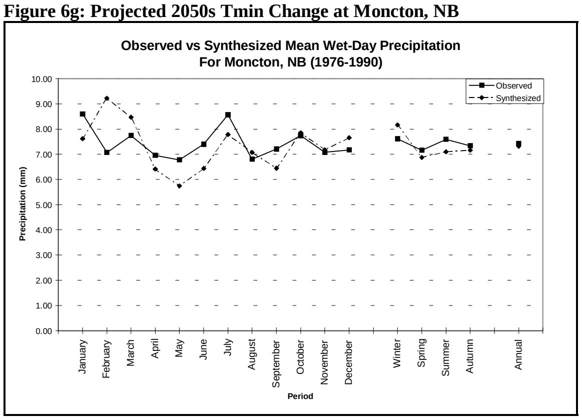


Figure 6i: Observed vs Synthesized Pcpn at Moncton, NB

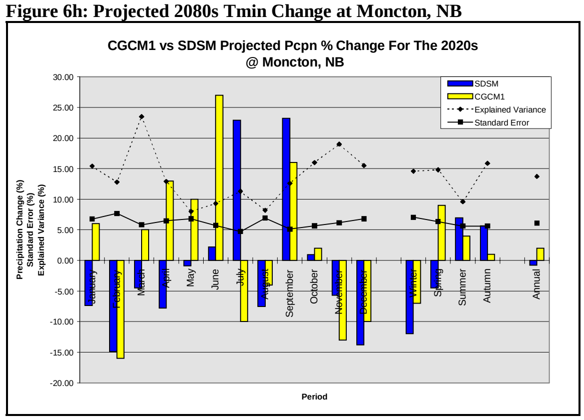


Figure 6j: Projected 2020s Pcpn Change at Moncton, NB

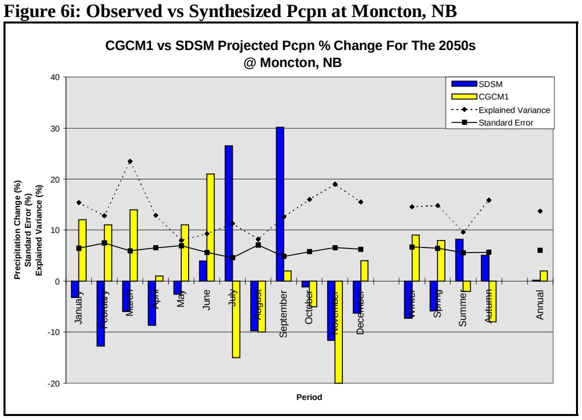


Figure 6k: Projected 2050s Pcpn Change at Moncton, NB

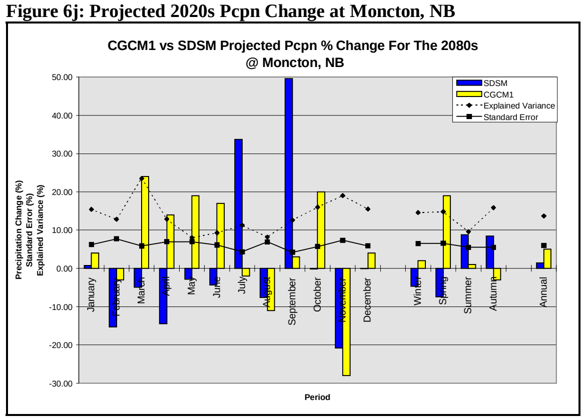


Figure 6l: Projected 2080s Pcpn Change at Moncton, NB

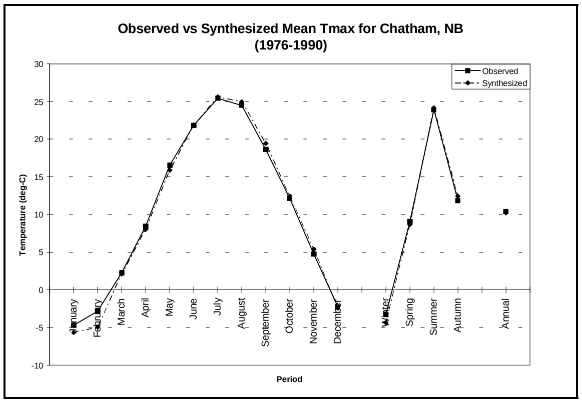


Figure 7a: Observed vs Synthesized Tmax for Chatham, NB

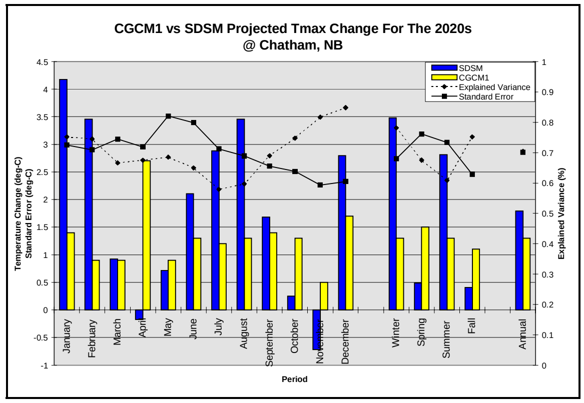


Figure 7b: Projected 2020s Tmax Change at Chatham, NB

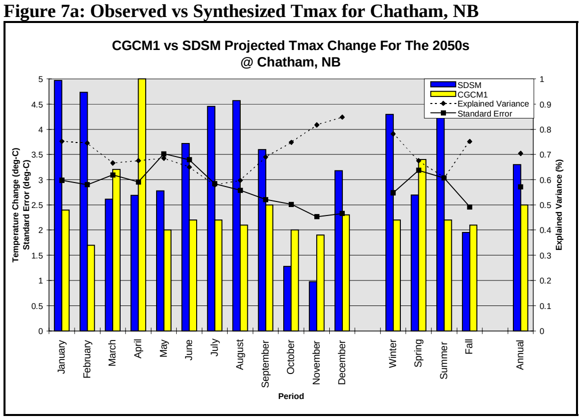


Figure 7c: Projected 2050s Tmax Change at Chatham, NB

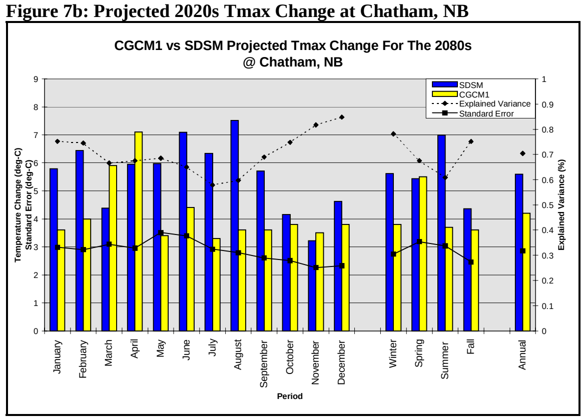


Figure 7d: Projected 2080s Tmax Change at Chatham, NB

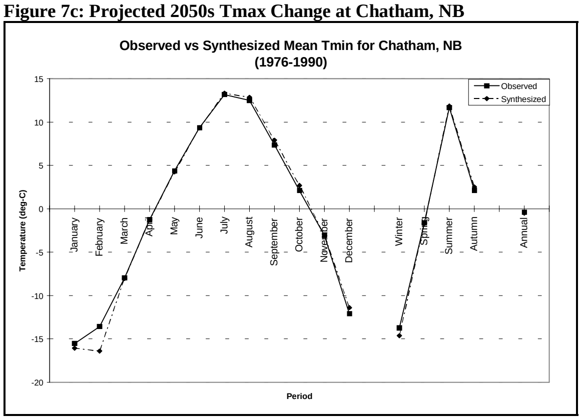


Figure 7e: Observed vs Synthesized Tmin for Chatham, NB

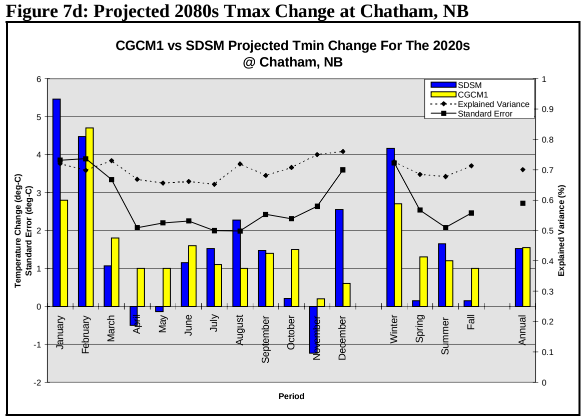


Figure 7f: Projected 2020s Tmin Change at Chatham, NB

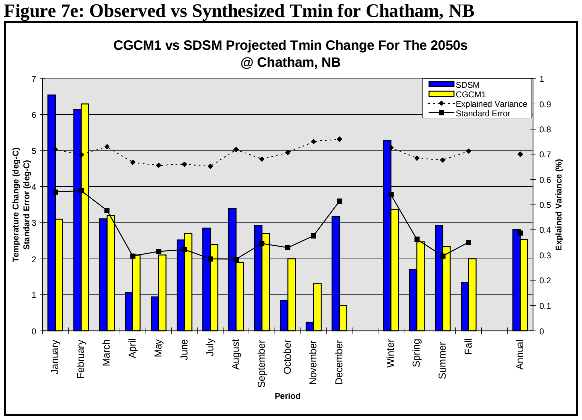


Figure 7g: Projected 2050s Tmin Change at Chatham, NB

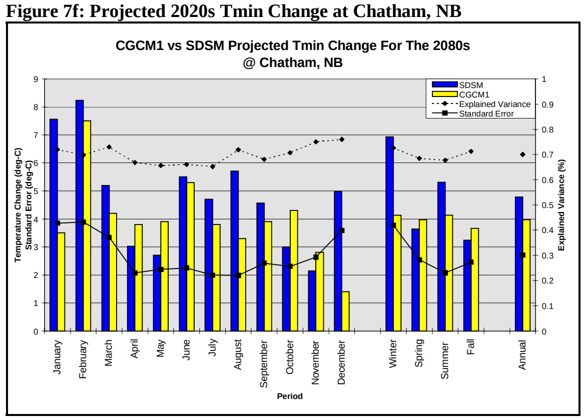


Figure 7h: Projected 2080s Tmin Change at Chatham, NB

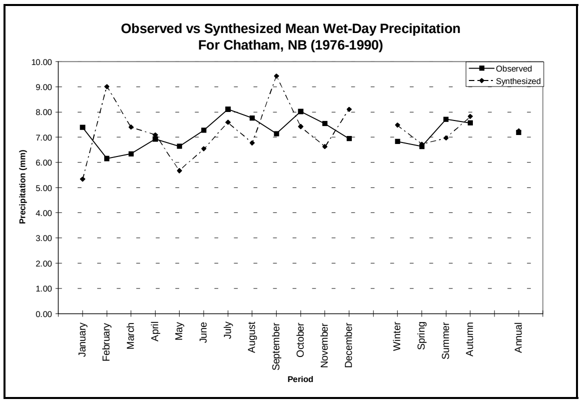


Figure 7i: Observed vs Synthesized Pcpn for Chatham, NB

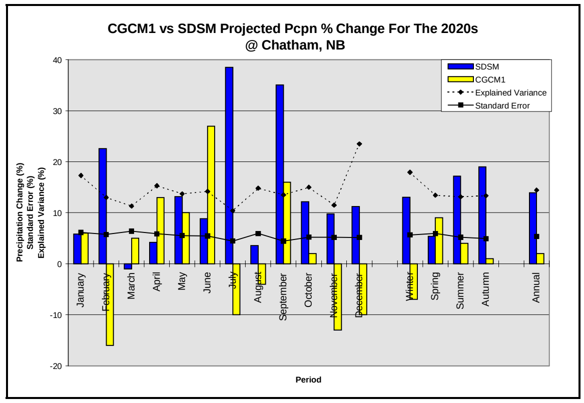


Figure 7j: Projected 2020s Pcpn Change at Chatham, NB

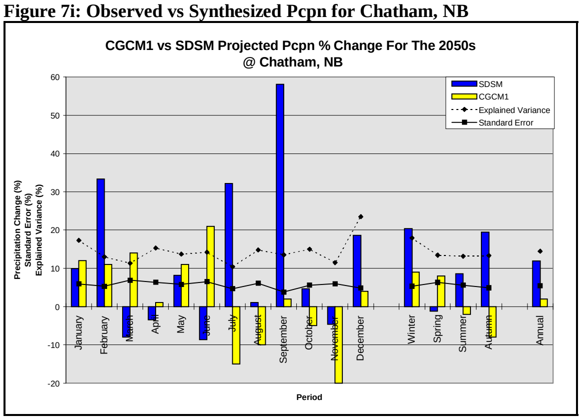


Figure 7k: Projected 2050s Pcpn Change at Chatham, NB

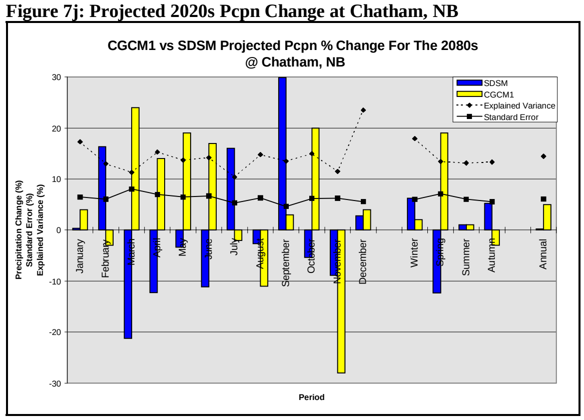


Figure 7l: Projected 2080s Pcpn Change at Chatham, NB

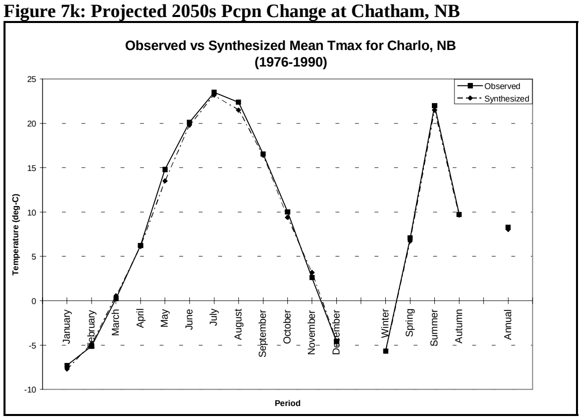


Figure 8a: Observed vs Synthesized Tmax for Charlo, NB

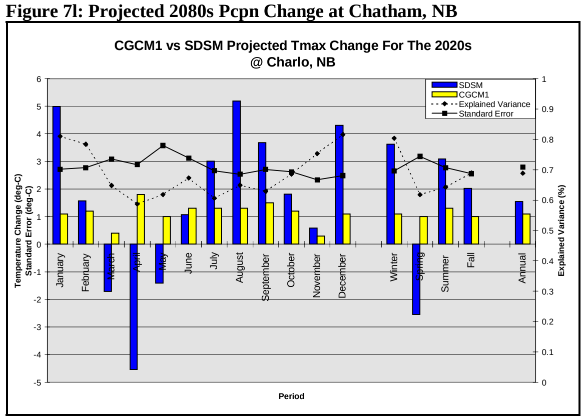


Figure 8b: Projected 2020s Tmax Change at Charlo, NB

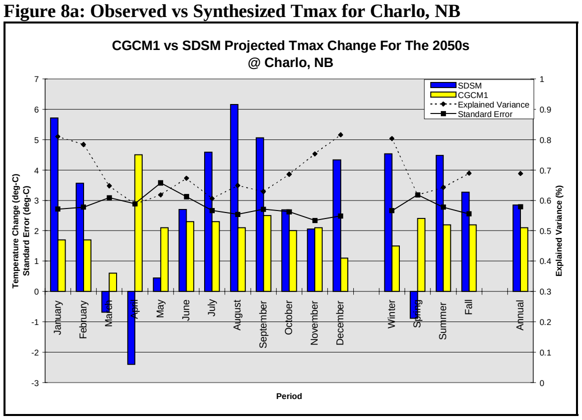


Figure 8c: Projected 2050s Tmax Change at Charlo, NB

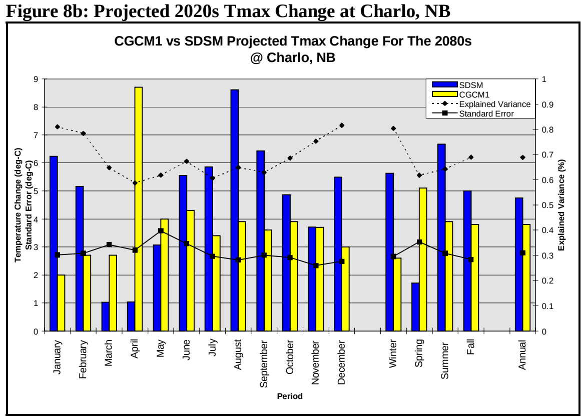


Figure 8d: Projected 2080s Tmax Change at Charlo, NB

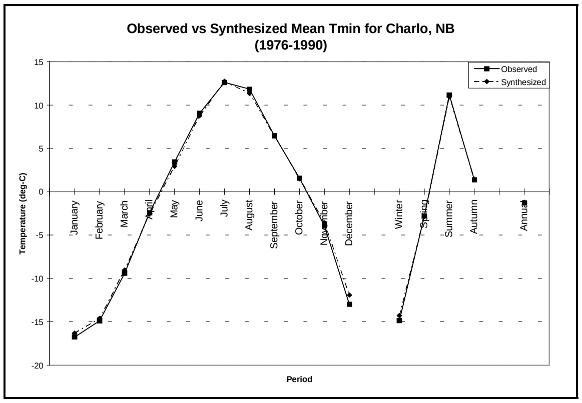


Figure 8e: Observed vs Synthesized Tmin for Charlo, NB

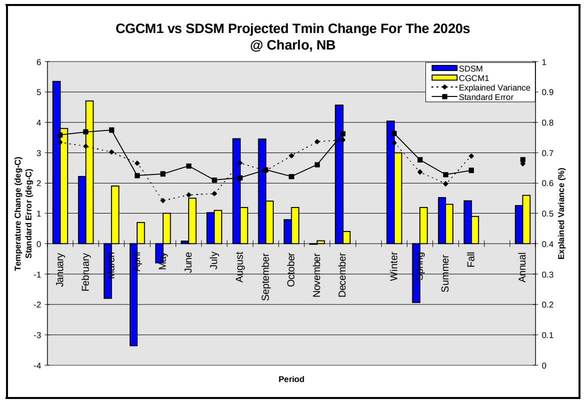


Figure 8f: Projected 2020s Tmin Change at Charlo, NB

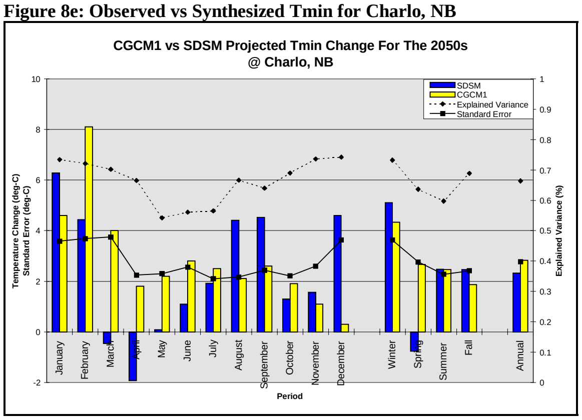


Figure 8g: Projected 2050s Tmin Change at Charlo, NB

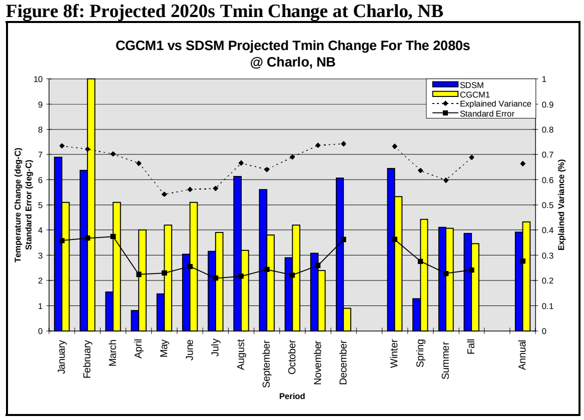


Figure 8h: Projected 2080s Tmin Change at Charlo, NB

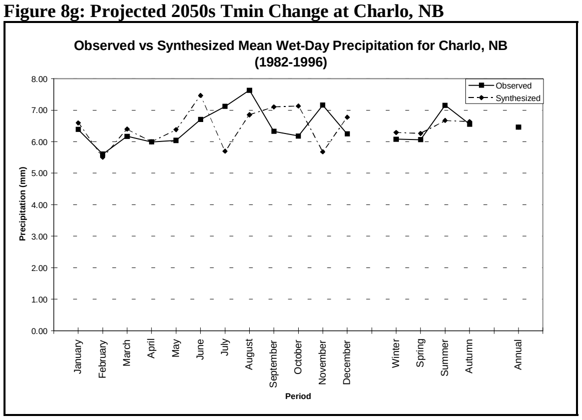


Figure 8i: Observed vs Synthesized Pcpn for Charlo, NB

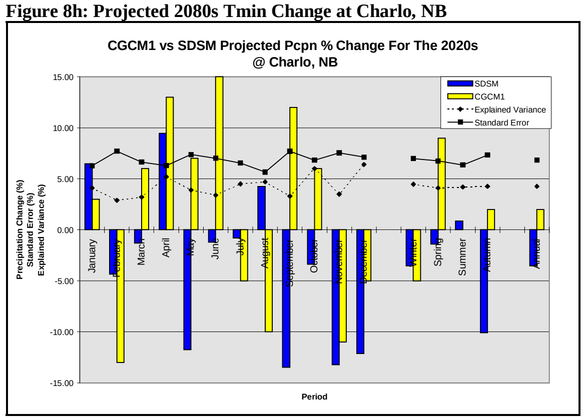


Figure 8j: Projected 2020s Pcpn Change at Charlo, NB

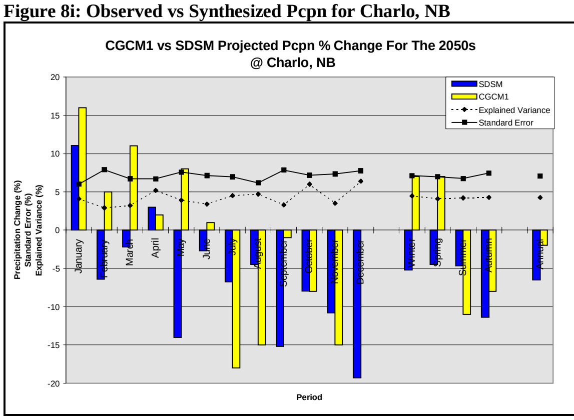


Figure 8k: Projected 2050s Pcpn Change at Charlo, NB

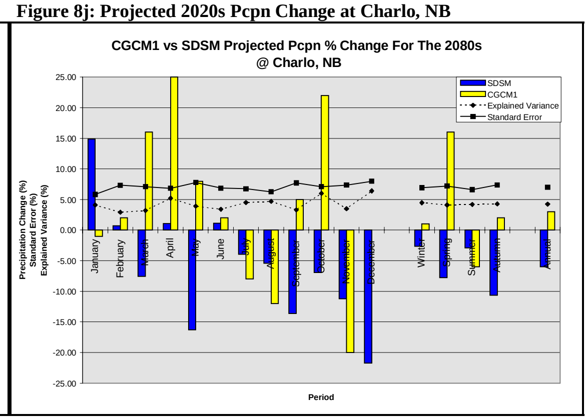


Figure 8l: Projected 2080s Pcpn Change at Charlo, NB

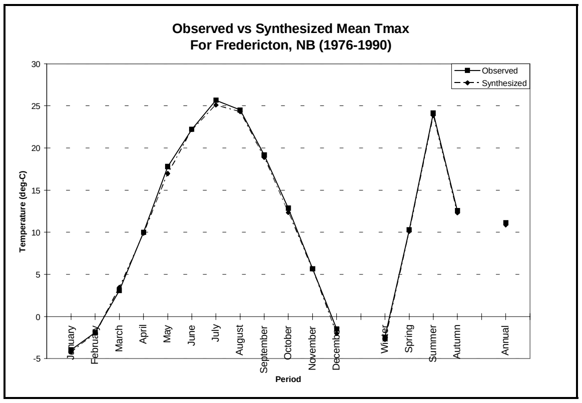


Figure 9a: Observed vs Synthesized Tmax for Fredericton, NB

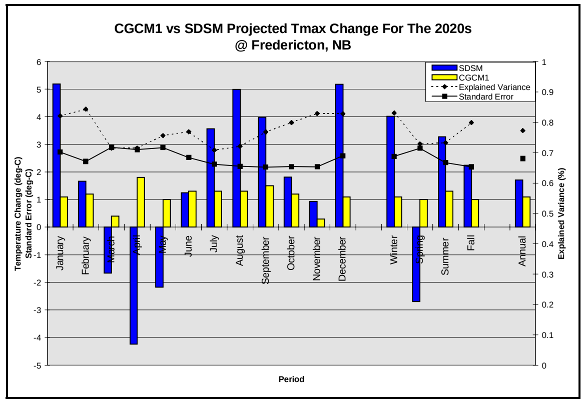


Figure 9b: Projected 2020s Tmax Change at Fredericton, NB

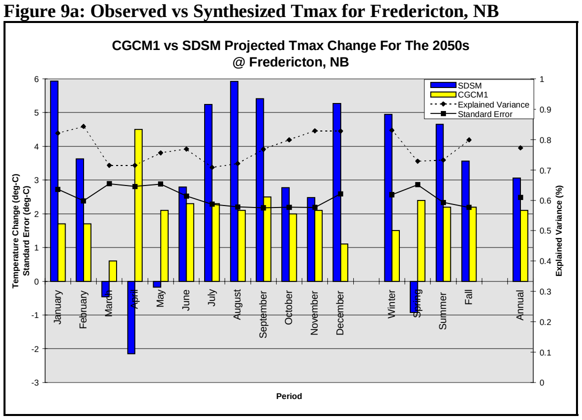


Figure 9c: Projected 2050s Tmax Change at Fredericton, NB

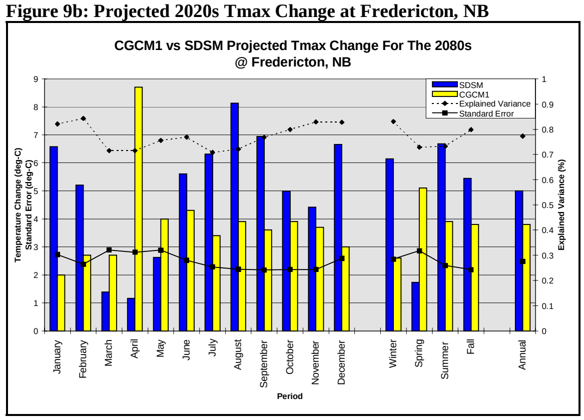


Figure 9d: Projected 2080s Tmax Change at Fredericton, NB

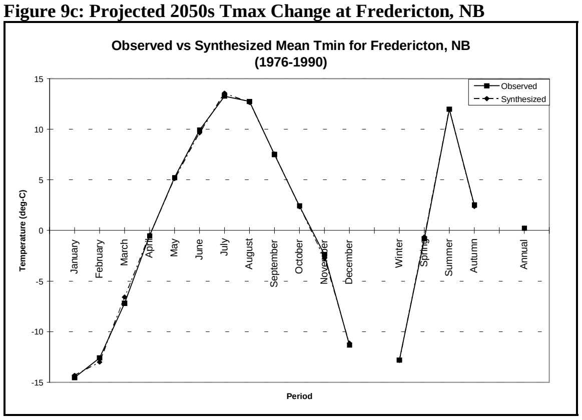


Figure 9e: Observed vs Synthesized Tmin for Fredericton, NB

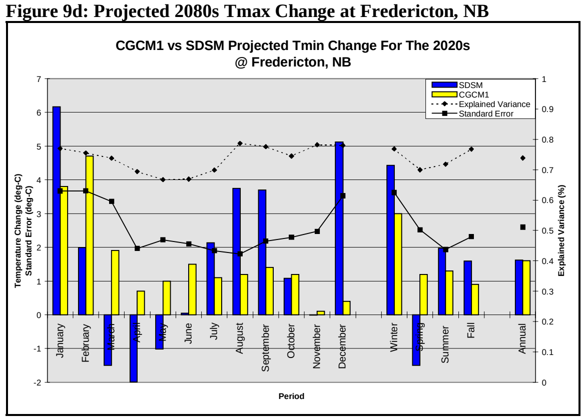


Figure 9f: Projected 2020s Tmin Change at Fredericton, NB

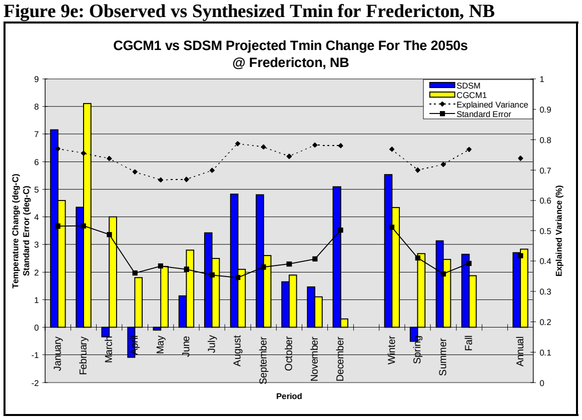


Figure 9g: Projected 2050s Tmin Change at Fredericton, NB

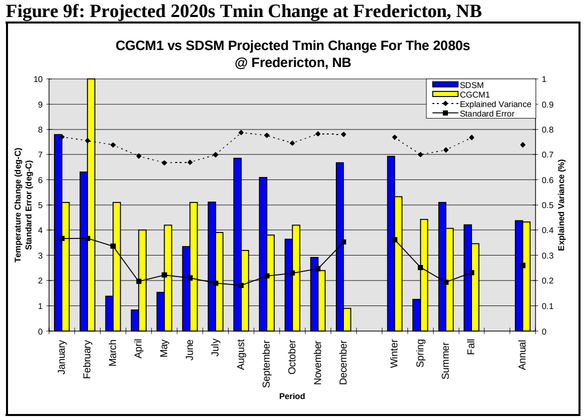


Figure 9h: Projected 2080s Tmin Change at Fredericton, NB

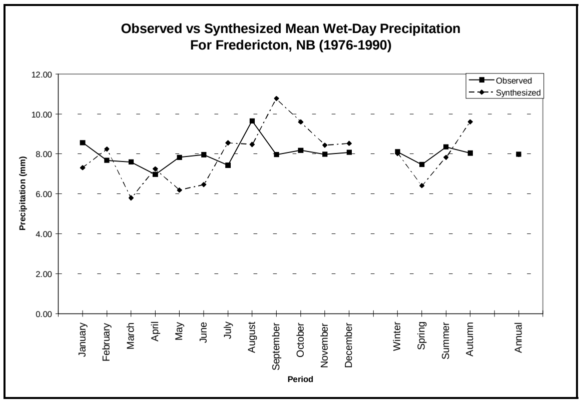


Figure 9i: Observed vs Synthesized Pcpn for Fredericton, NB

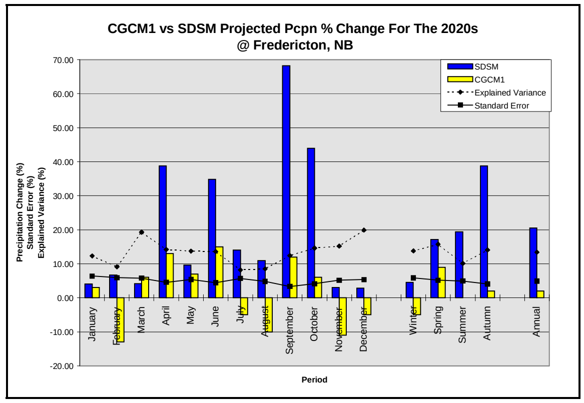


Figure 9j: Projected 2020s Pcpn Change at Fredericton, NB

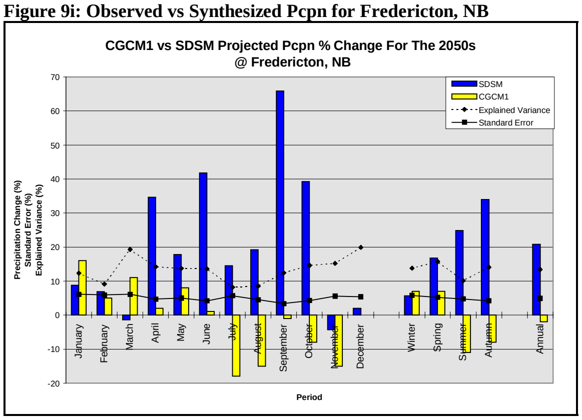


Figure 9k: Projected 2050s Pcpn Change at Fredericton, NB

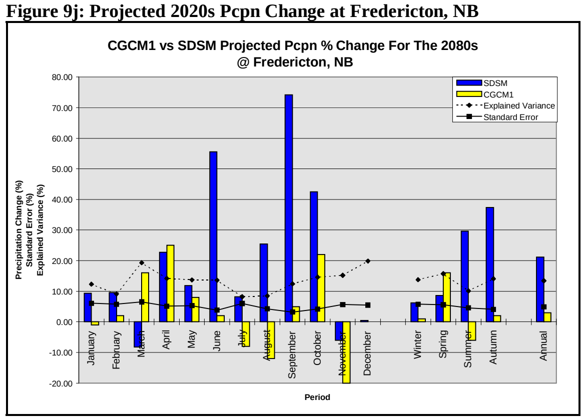


Figure 9l: Projected 2080s Pcpn Change at Fredericton, NB

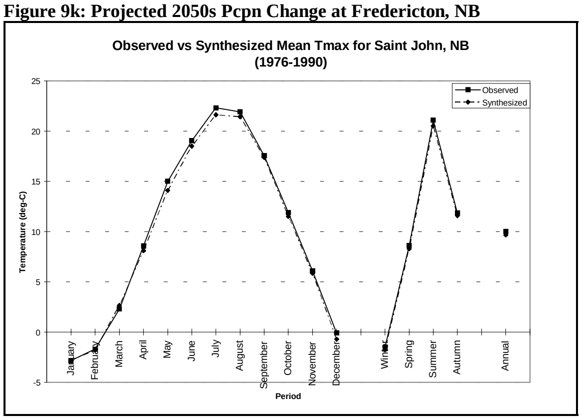


Figure 10a: Observed vs Synthesized Tmax for Saint John, NB

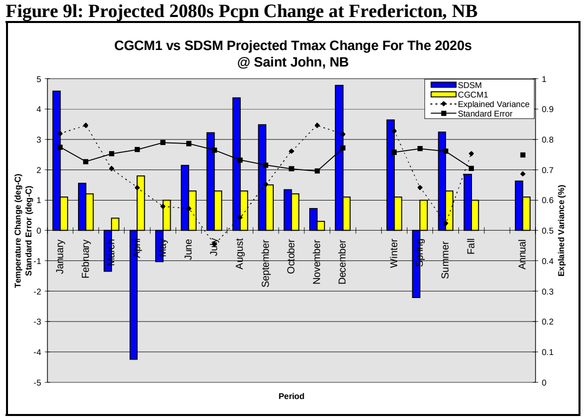


Figure 10b: Projected 2020s Tmax Change at Saint John, NB

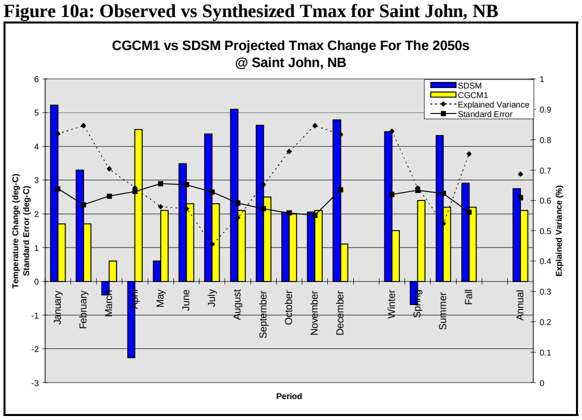


Figure 10c: Projected 2050s Tmax Change at Saint John, NB

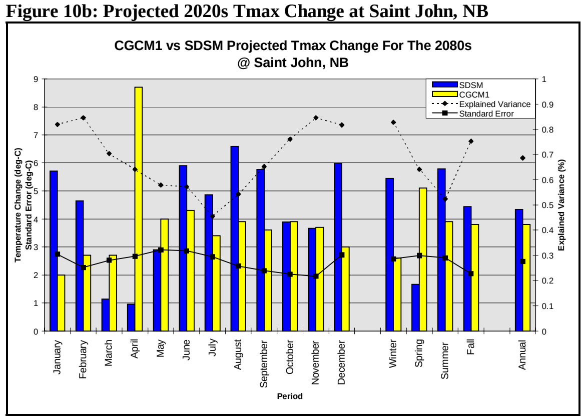


Figure 10d: Projected 2080s Tmax Change at Saint John, NB

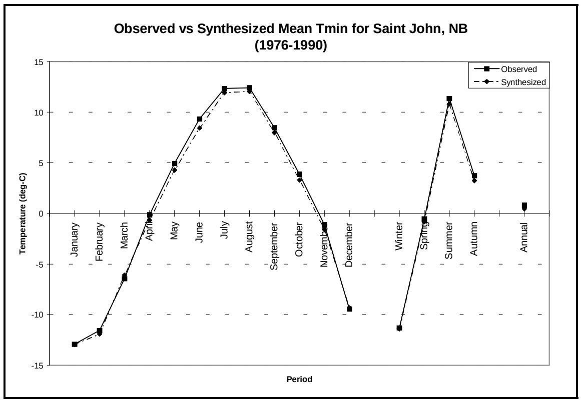


Figure 10e: Observed vs Synthesized Tmin for Saint John, NB

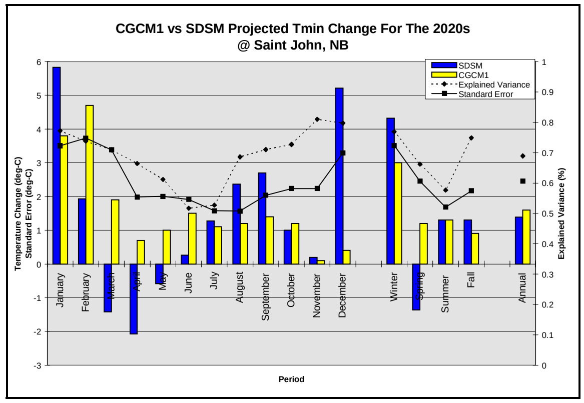
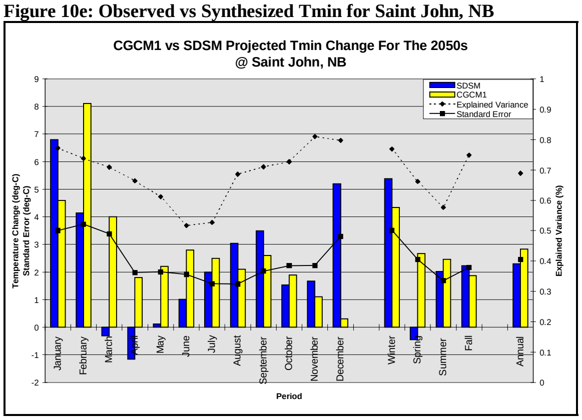


Figure 10f: Projected 2020s Tmin Change at Saint John, NB



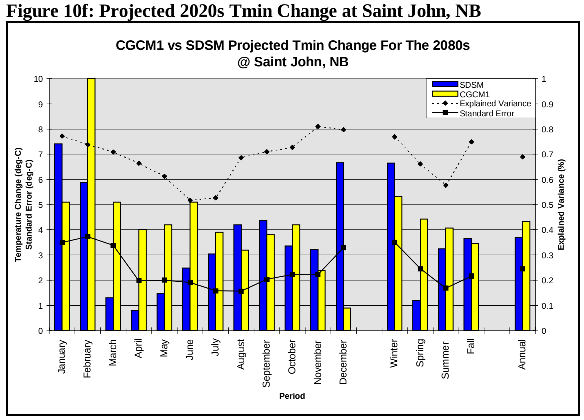


Figure 10g: Projected 2050s Tmin Change at Saint John, NB Figure 10h: Projected 2080s Tmin Change at Saint John, NB

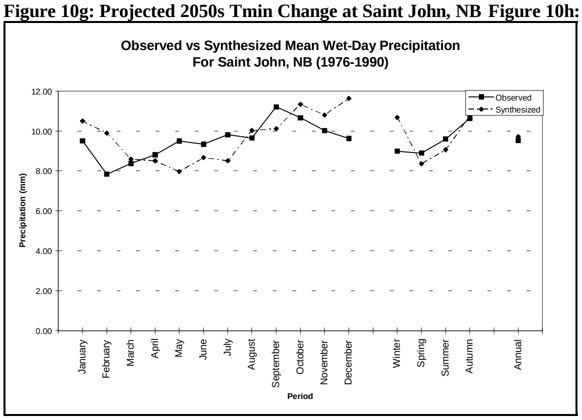


Figure 10i: Observed vs Synthesized Pcpn for Saint John, NB

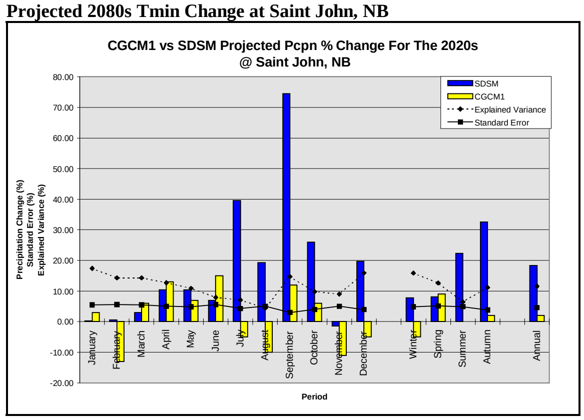


Figure 10j: Projected 2020s Pcpn Change at Saint John, NB

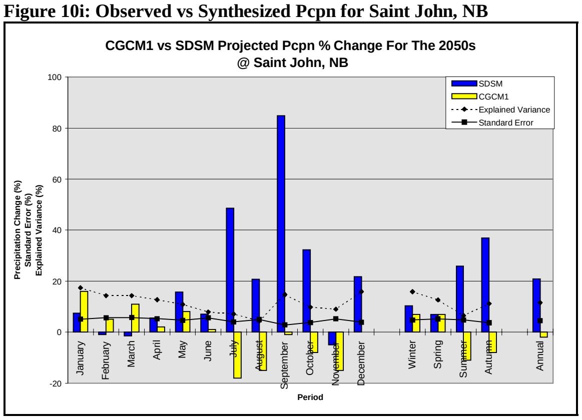


Figure 10k: Projected 2050s Pcpn Change at Saint John, NB

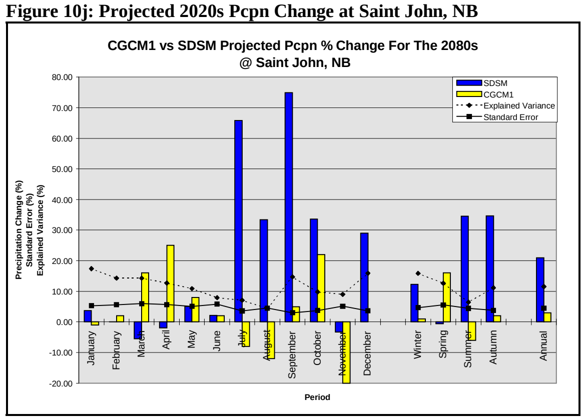


Figure 10l: Projected 2080s Pcpn Change at Saint John, NB

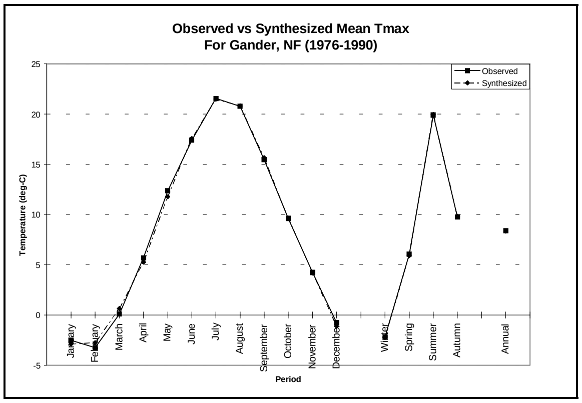


Figure 11a: Observed vs Synthesized Tmax for Gander, NF

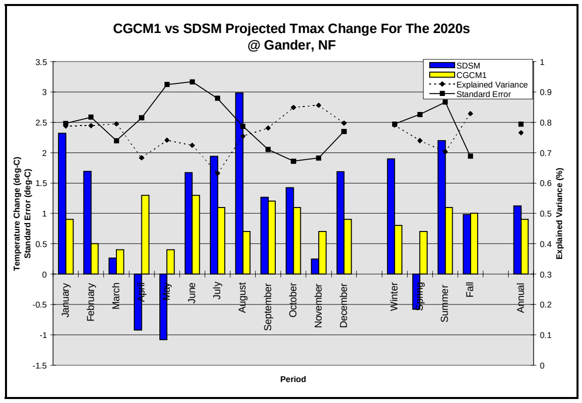


Figure 11b: Projected 2020s Tmax Change at Gander, NF

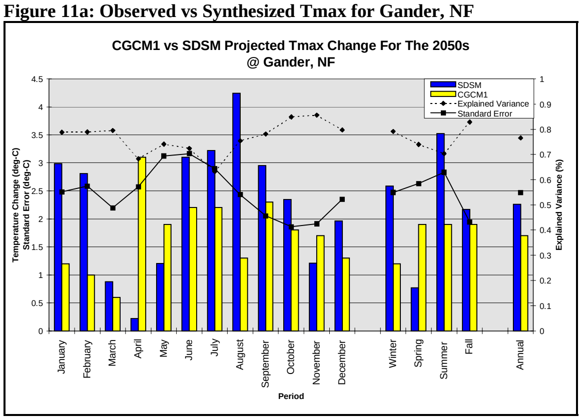


Figure 11c: Projected 2050s Tmax Change at Gander, NF

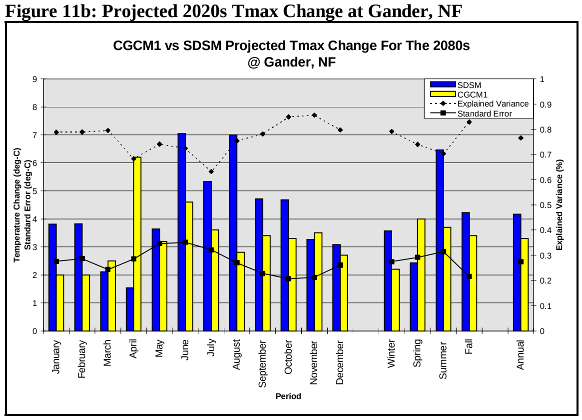


Figure 11d: Projected 2080s Tmax Change at Gander, NF

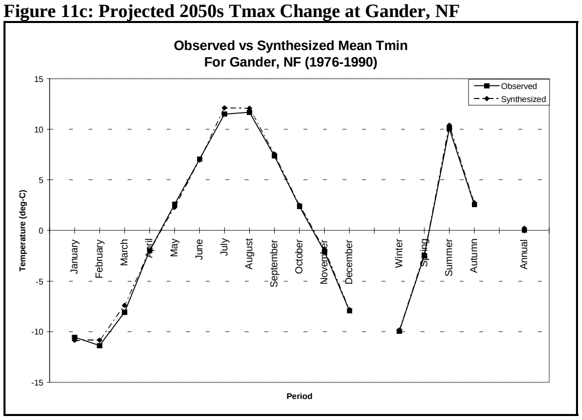


Figure 11e: Observed vs Synthesized Tmin for Gander, NF

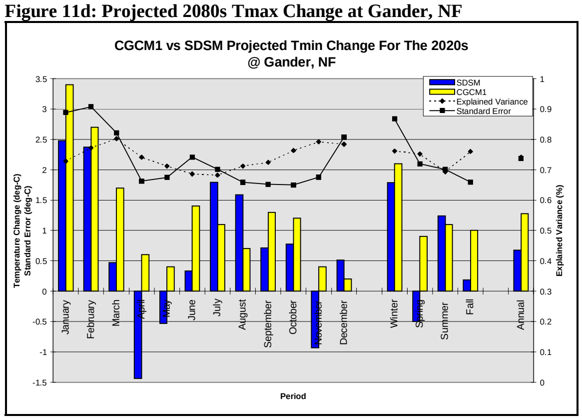


Figure 11f: Projected 2020s Tmin Change at Gander, NF

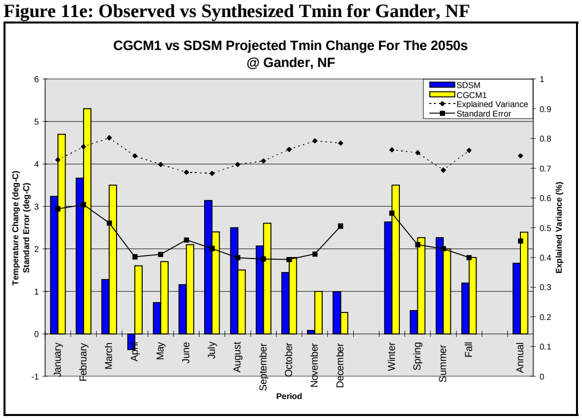


Figure 11g: Projected 2050s Tmin Change at Gander, NF

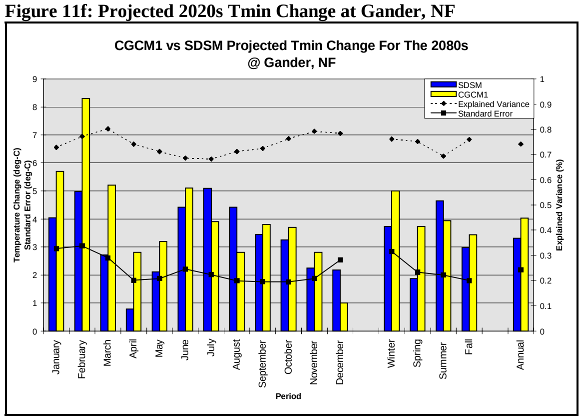


Figure 11h: Projected 2080s Tmin Change at Gander, NF

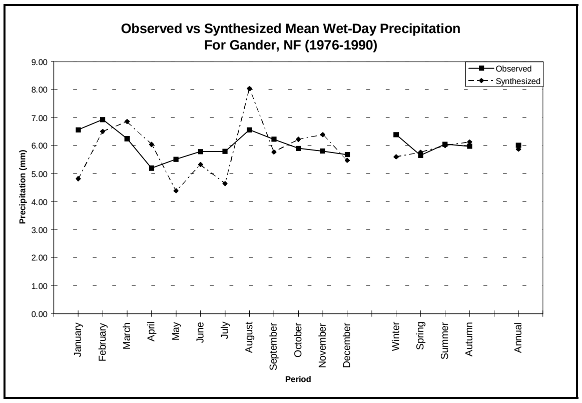


Figure 11i: Observed vs Synthesized Pcpn for Gander, NF

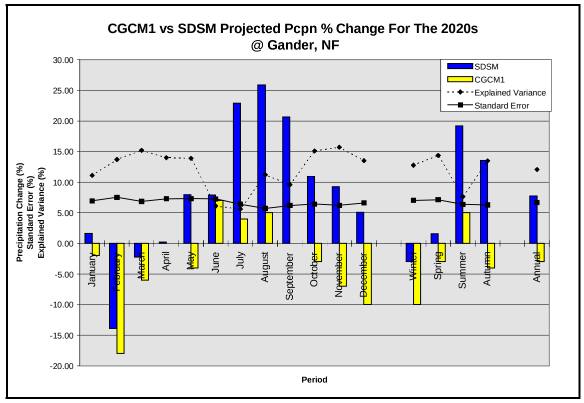


Figure 11j: Projected 2020s Pcpn Change at Gander, NF

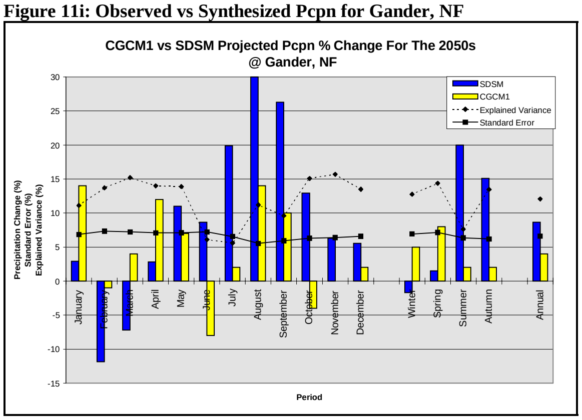


Figure 11k: Projected 2050s Pcpn Change at Gander, NF

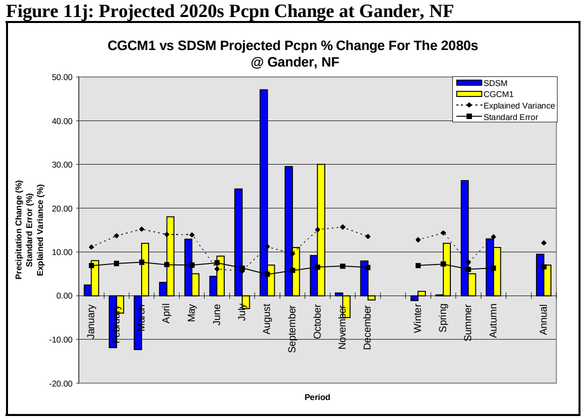


Figure 11l: Projected 2080s Pcpn Change at Gander, NF

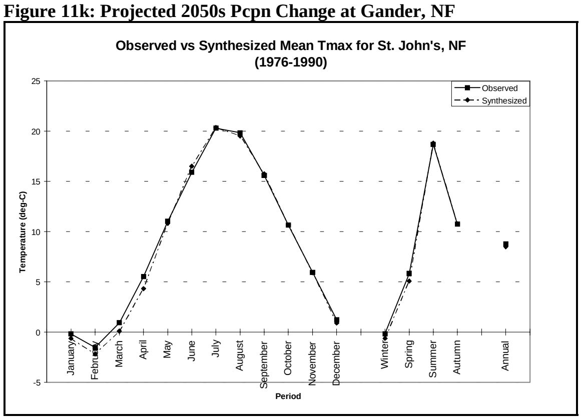


Figure 12a: Observed vs Synthesized Tmax for St. John's, NF

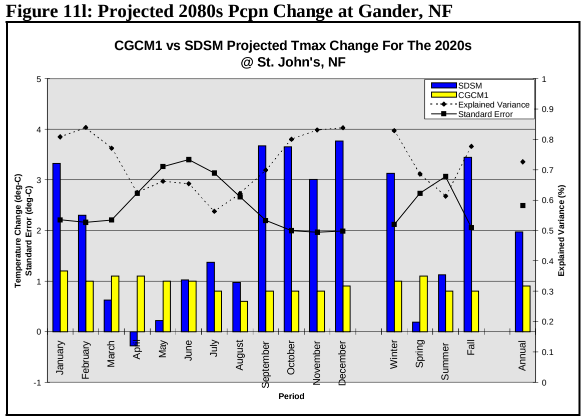


Figure 12b: Projected 2020s Tmax Change at St. John's, NF

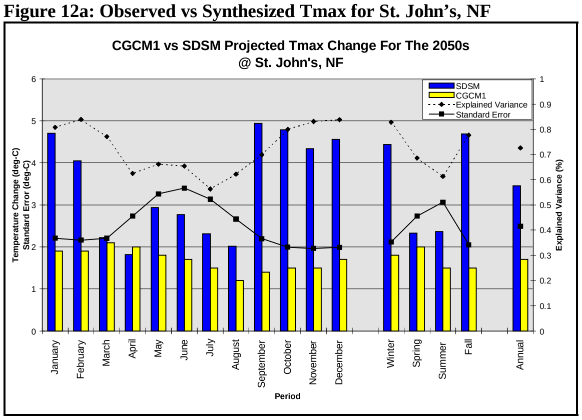


Figure 12c: Projected 2050s Tmax Change at St. John's, NF

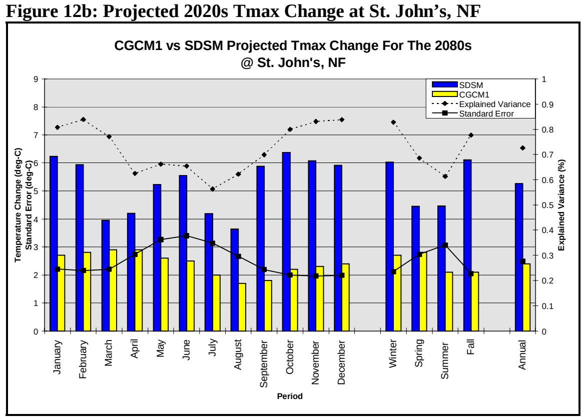


Figure 12d: Projected 2080s Tmax Change at St. John's, NF

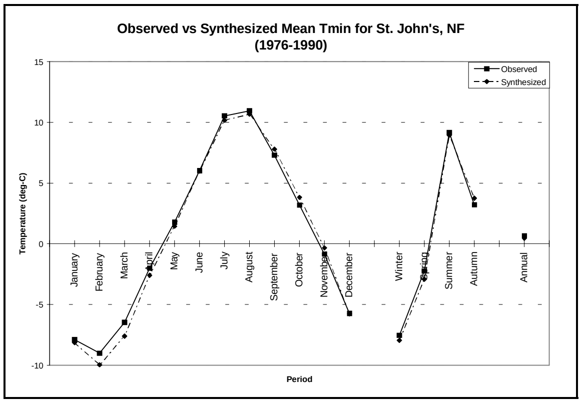


Figure 12e: Observed vs Synthesized Tmin for St. John's, NF

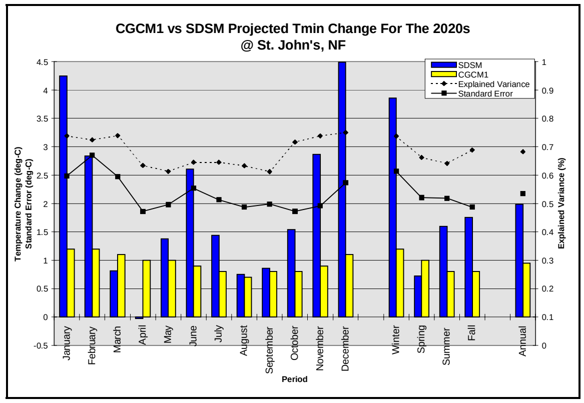


Figure 12f: Projected 2020s Tmin Change at St. John's, NF

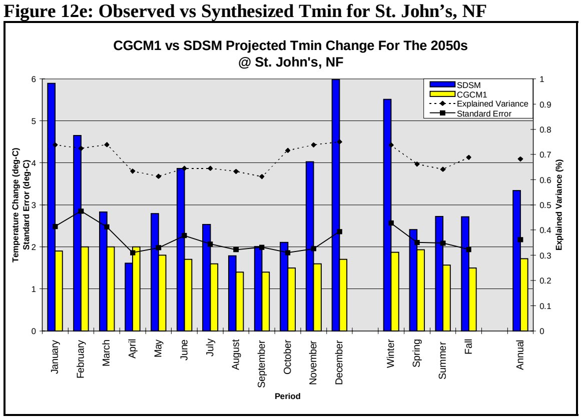


Figure 12g: Projected 2050s Tmin Change at St. John's, NF

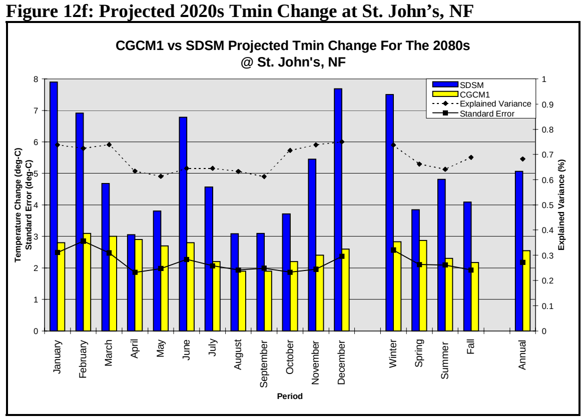


Figure 12h: Projected 2080s Tmin Change at St. John's, NF

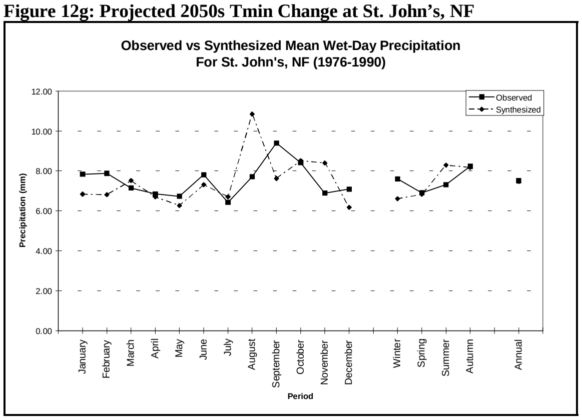


Figure 12i: Observed vs Synthesized Pcpn for St. John's, NF

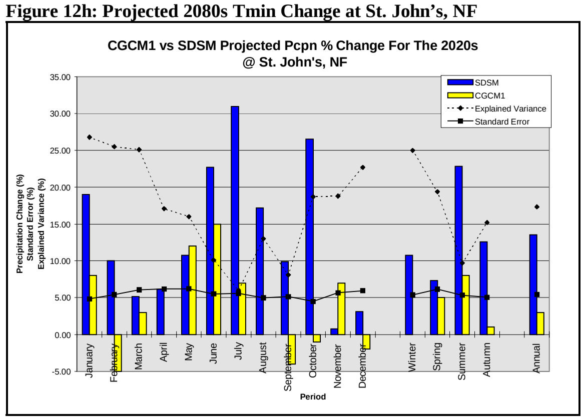


Figure 12j: Projected 2020s Pcpn Change at St. John's, NF

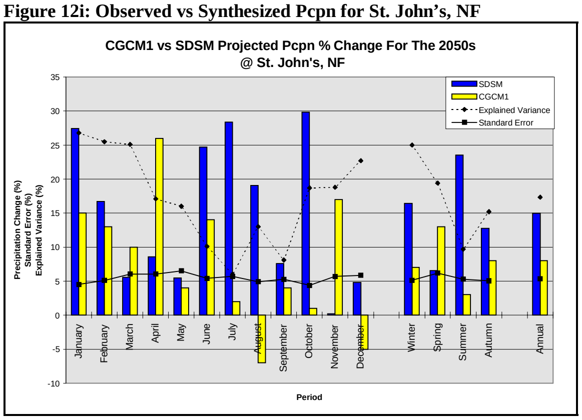


Figure 12k: Projected 2050s Pcpn Change at St. John's, NF

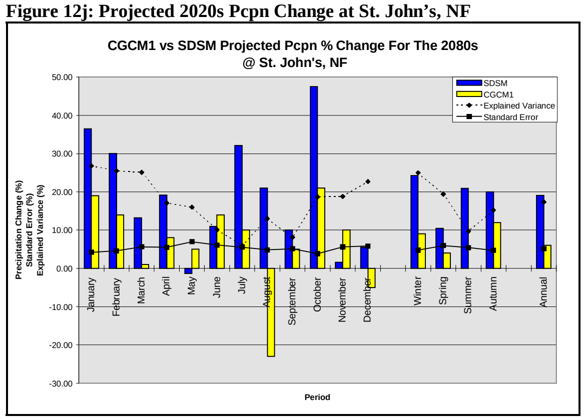


Figure 12l: Projected 2080s Pcpn Change at St. John's, NF

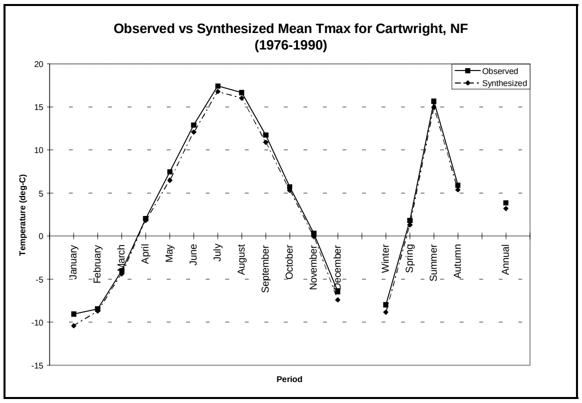


Figure 13a: Observed vs Synthesized Tmax for Cartwright, NF

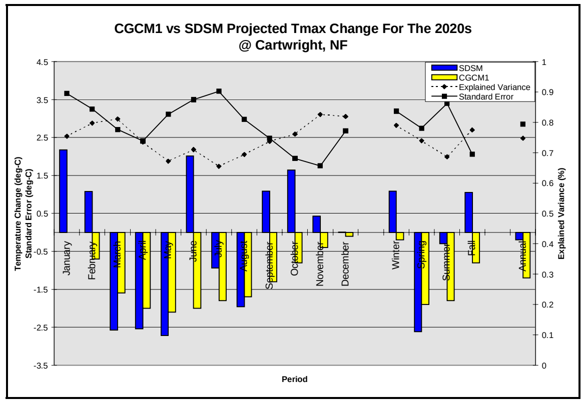


Figure 13b: Projected 2020s Tmax Change at Cartwright, NF

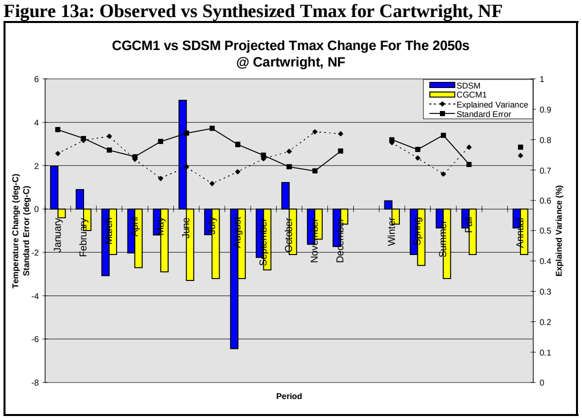


Figure 13c: Projected 2050s Tmax Change at Cartwright, NF

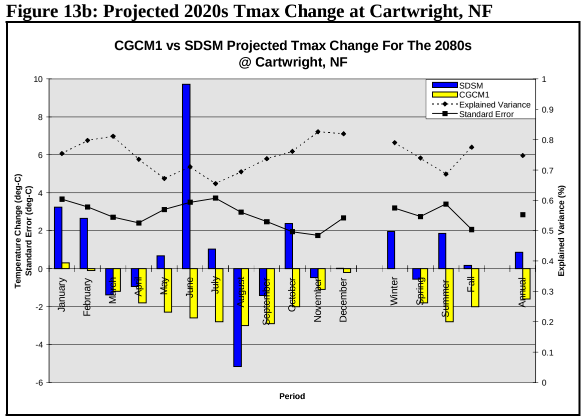


Figure 13d: Projected 2080s Tmax Change at Cartwright, NF

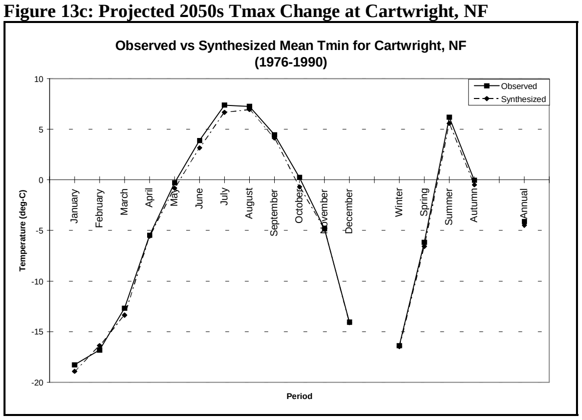


Figure 13e: Observed vs Synthesized Tmin for Cartwright, NF

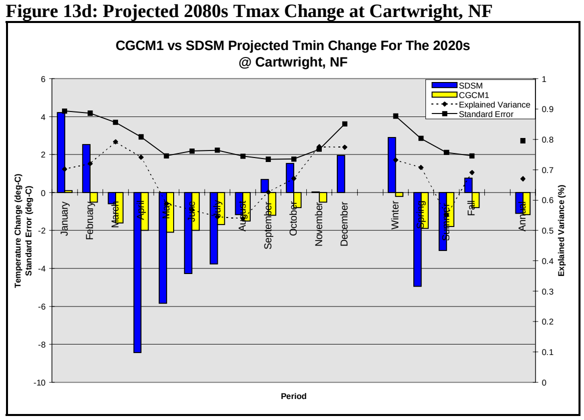


Figure 13f: Projected 2020s Tmin Change at Cartwright, NF

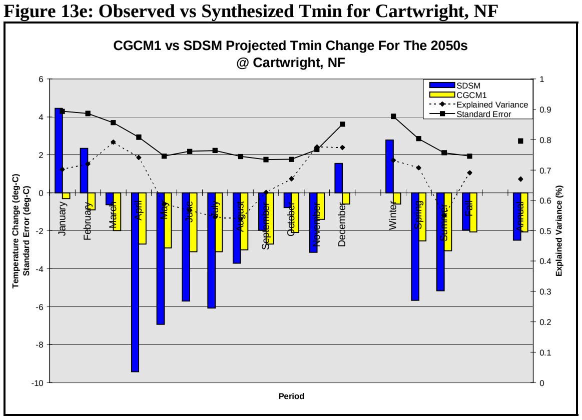


Figure 13g: Projected 2050s Tmin Change at Cartwright, NF

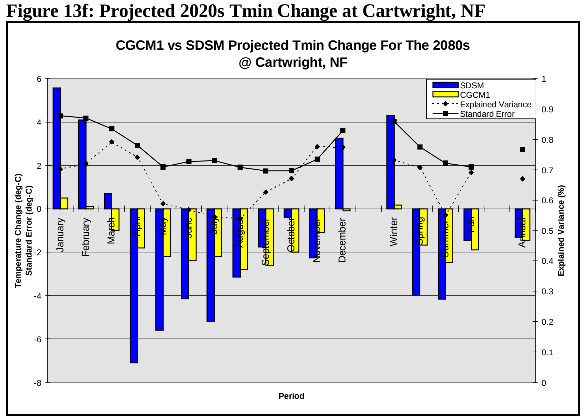


Figure 13h: Projected 2080s Tmin Change at Cartwright, NF

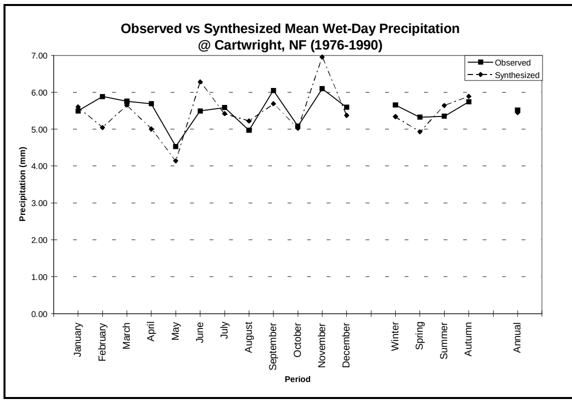


Figure 13i: Observed vs Synthesized Pcpn for Cartwright, NF

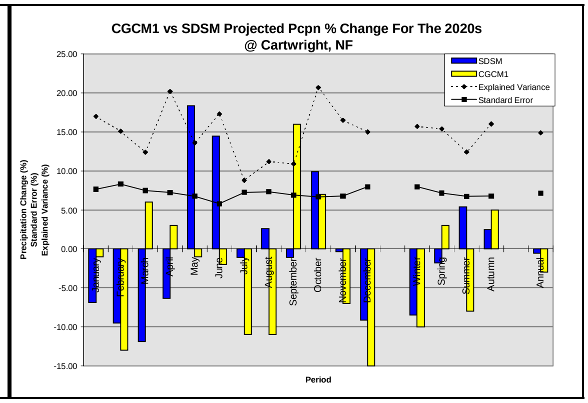


Figure 13j: Projected 2020s Pcpn Change at Cartwright, NF

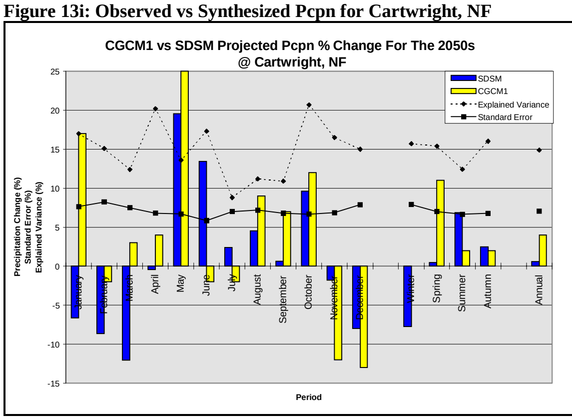


Figure 13k: Projected 2050s Pcpn Change at Cartwright, NF

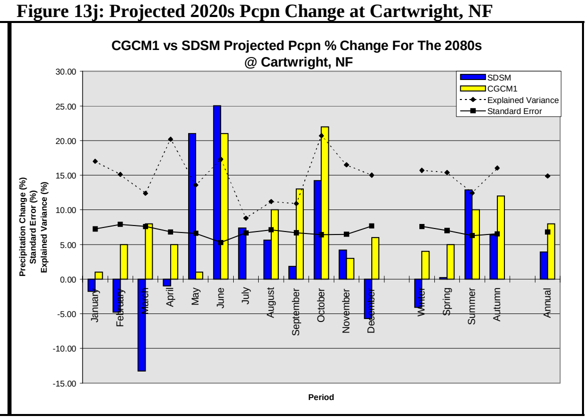


Figure 13l: Projected 2080s Pcpn Change at Cartwright, NF

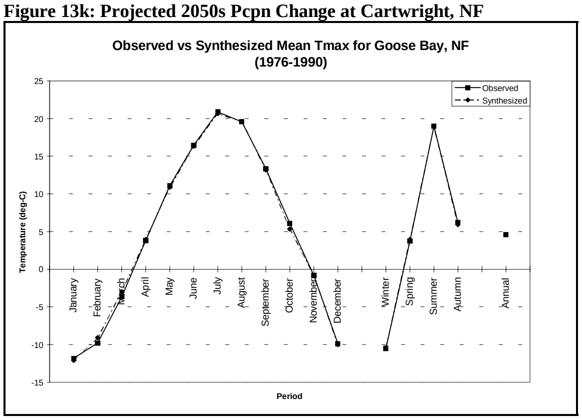


Figure 14a: Observed vs Synthesized Tmax for Goose Bay, NF

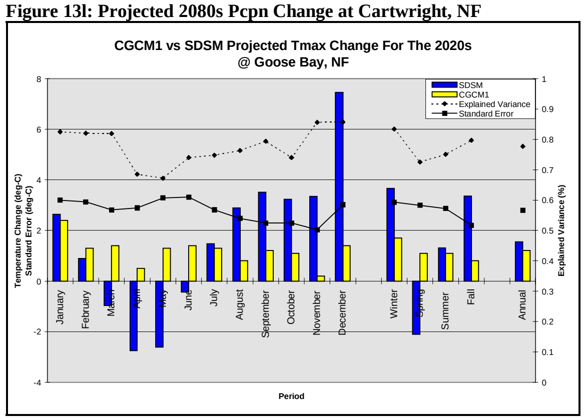


Figure 14b: Projected 2020s Tmax Change at Goose Bay, NF

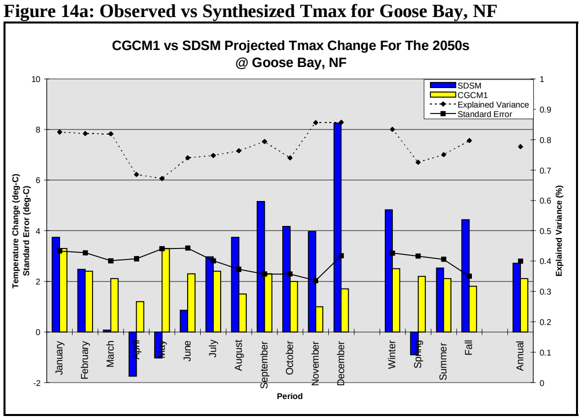


Figure 14c: Projected 2050s Tmax Change at Goose Bay, NF

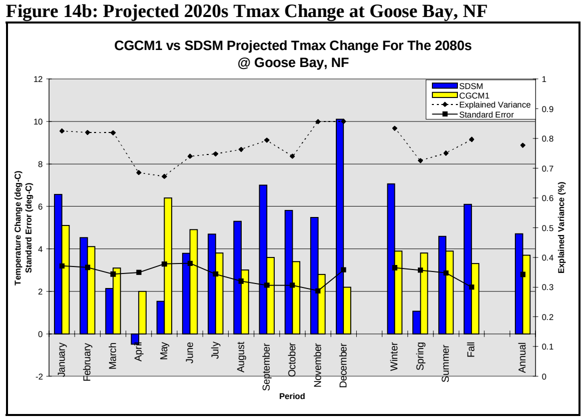


Figure 14d: Projected 2080s Tmax Change at Goose Bay, NF

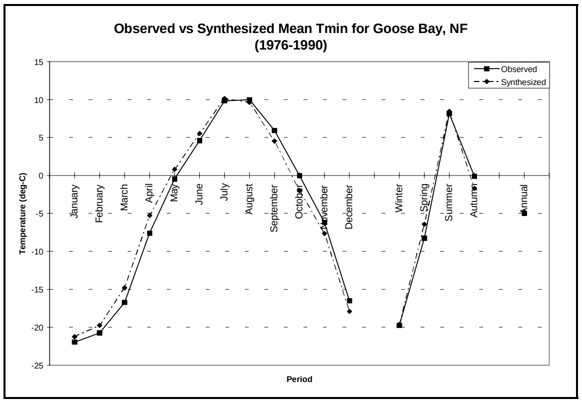


Figure 14e: Observed vs Synthesized Tmin for Goose Bay, NF

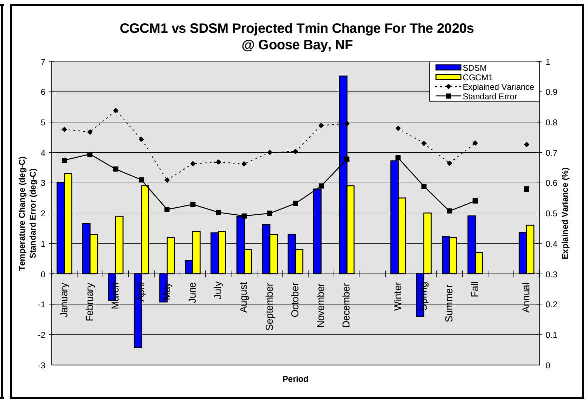


Figure 14f: Projected 2020s Tmin Change at Goose Bay, NF

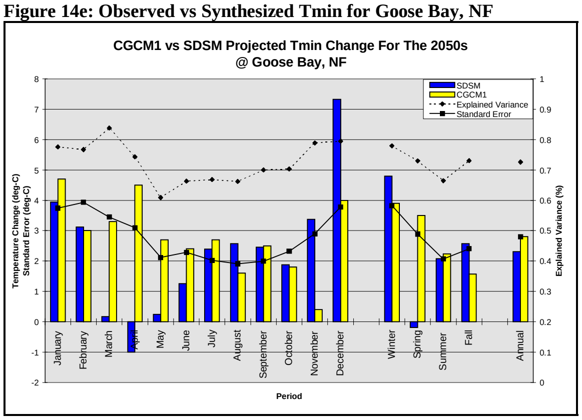


Figure 14g: Projected 2050s Tmin Change at Goose Bay, NF

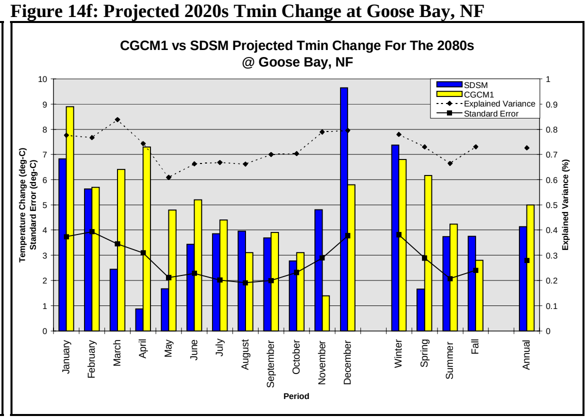


Figure 14h: Projected 2080s Tmin Change at Goose Bay, NF

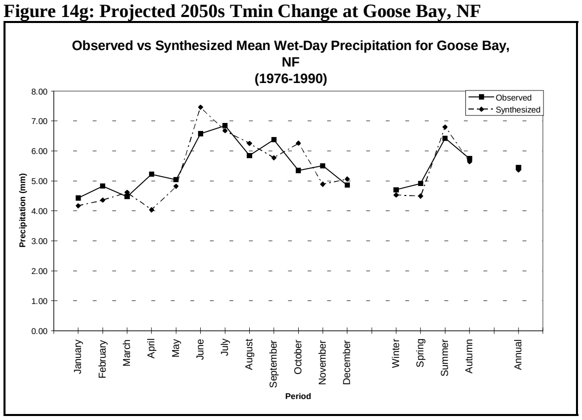


Figure 14i: Observed vs Synthesized Pcpn for Goose Bay, NF

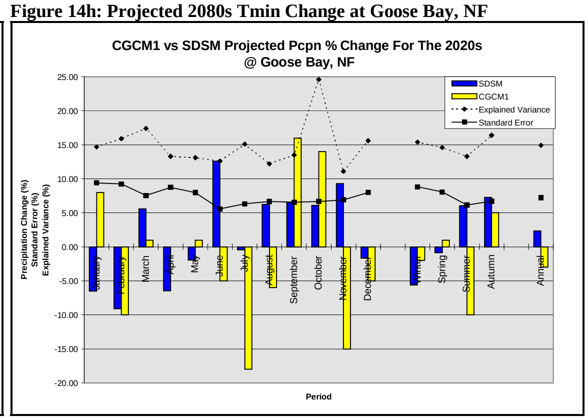


Figure 14j: Projected 2020s Pcpn Change at Goose Bay, NF

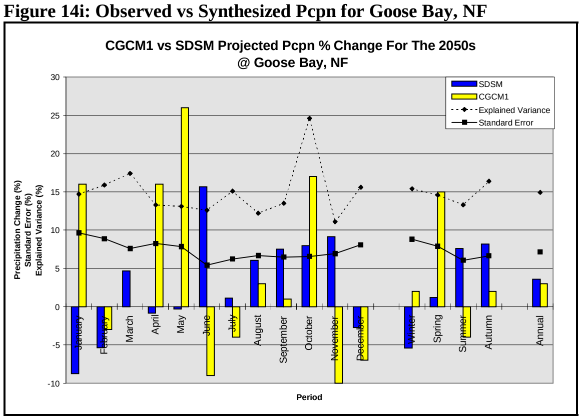


Figure 14k: Projected 2050s Pcpn Change at Goose Bay, NF

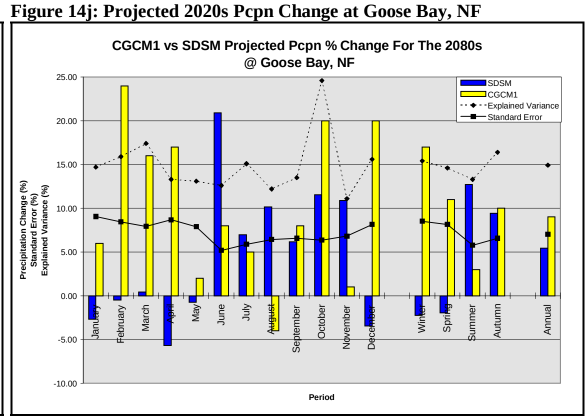


Figure 14l: Projected 2080s Pcpn Change at Goose Bay, NF