P2.14 REGIONAL CLIMATE SCENARIOS SET DEVELOPMENT FOR HYDROLOGICAL IMPACT STUDIES

Jeanna Goldstein* and Jennifer Milton
Meteorological Service of Canada, Environment Canada, Quebec Region, Canada

1. INTRODUCTION

Natural events, such as floods and extreme temperatures, produce important impacts on societies. However, in the context of a changing climate, future impacts are yet to be determined. In order to supply stakeholders and policy makers with this information, weather events could be projected by the development of climate and hydrological scenarios sets, under different emission scenarios. Climate scenarios set data are the input data for the hydrological models which in their turn supply data for impact studies and risk assessments. Probability of a major climate change was considered minimal several decades ago. Later climate shifts were respected to be non-random and concepts of stationarity were proved to be false (Changnon, 1987). Voss et all (2002) studied changes in variability and extremes of the hydrological cycle for the thirty year Global Climate Models (GCMs) simulation slices and pointed out on the enhanced probability of heavy precipitation events almost all over the world in spite of a decrease in total precipitation for some parts of the globe. Large hydrological changes could be provoked by moderate trend in climate. Climate changes contribute to the enhanced storm, wave, surges activity, increase in the volume of runoff and sea level, changes of the river discharges trend, changes in the areal extent of the permafrost and sea-ice (Roy, 2001 ; Gagnon, 2002 ; Kaas and Andersen, 2000 ; Mirza, 2002). Climate scenarios set development plays an important role for estimation of the potential impacts on water resources. An approach to supply impact assessment and hydrological risk study researchers with Climate Scenarios Set is the following :

- Definition of the needed meteorological variables, time scale, localisation
- Evaluation of the existing methods to construct climate scenarios to simulate present climate
- Selection of the best techniques to develop climate scenario set
- Usage of the technique to treat uncertainty
- Creation of the meteorological future weather data sets ready to be applied for hydrological and impact models

This approach in constructing CSS handles the sources of uncertainty, applies products which are properly evaluated by scientific analysis and peer review directly into hydrological and impact models and includes study of statistical significance of the results, mastering of the new techniques, discussing uncertainties in the results attributed by emission and climate scenarios.

2. OBSERVED AND MODEL DATA

The IPCC Data Distribution Centre (DDC), the Canadian Centre for Climate Modelling and Analysis (CCCma) are the sources of the various monthly meteorological parameters. The Canadian Global Coupled Model (CGCM1) IS92a greenhouse gases plus sulphate aerosols (GHG+A1) experiment daily data are used to drive the Long Ashton Research Station Weather Generator (LARS-WG). Climate Impacts and Scenarios project (CCIS) supplies large-scale predictors information. This information is developed by CCIS using CGCM1 daily projected data and NCEP re-analysis data which are re-gridded to the CGCM1 grid. The CCIS set of predictors supports only Statistical DownScaling Model (SDSM) and can not be applied to drive any other statistical model. The source of the climate observations is from Regional Data Base operated by the division of the Atmospheric Sciences and Environmental Issues of Environment Canada / Quebec Region.

CSS construction is based on the data from 1961 till 2100. According to IPCC recommendations 1961-1990 is considered to be baseline (IPCC-TGCIA, 1999). Simulated climate models data for the simplicity of an interpolation are treated as grid-point quantities. This treatment of the GCMs data is justified by the point of view of Skelly and Henderson-Sellers (1996), however a modern tendency is to present GCMs data as grid-areal quantities (Osborn and Hulme, 1998 ; Booij, 2002). Point data of the temperature, precipitation, pressure are continuous and may be derived from grid-point simulated data. Cartesian geometry and geostatistics are the most popular interpolation methods. Inverse distance weighting (IDW) method which is based on the geometry of the data is used to interpolate the values of the closest GCMs grid points to the chosen place (Lam, 1983 ; Burrough, 1986).

3. SOURCE AND TREATMENT OF UNCERTAINTIES

GCMs misrepresentations and systematic errors are the sources of uncertainties that are inherent in climate scenarios. Treatment of uncertainties for CCS development takes into consideration inter-emission-

* *Corresponding author address :* Dr. Jeanna Goldstein, Environment Canada Quebec Region, 100 Alexis-Nihon Blvd, 3rd Floor, Saint-Laurent, Quebec, Canada, H4M 2N8 ;
e-mail : Jeanna.Goldstein@ec.gc.ca
http://www.criacc.qc.ca/scenario/cs/climate_scenario.html

scenarios, inter-model variability and scaling sources. Various emission IS92a and SRES (A1, A2, B1, B2) forcing scenarios are applied to deal with inter-scenarios variability source. Different GCMs approved by IPCC (CGCM1, CGCM2, ECHAM4/OPYC3, HadCM2, HadCM3, CSIRO-Mk2b, CCSR/NIES) and several realizations of a given forcing scenario with a given climate model are used to handle inter-model variability source. The source of scaling uncertainties is treated by downscaling GCMs output with the SDSM and LARS-WG models. Both models are ruled using conditional means involving stochastic weather generators. Such approach provides necessary uncertainty analysis and should be implied even in the case that its application does not improve GCMs output (Katz, 2002). The sources of the uncertainties associated with downscaled results could be (Benestad, 2001): weak, non-linear relationship between large scale anomalies and local variability; quality of the observations; design of the SDS model. These uncertainties might be overcome by the calibration of the SDS model for a small region characterized by large-scale features; by the use interval of time for the calibration more than 50 years.

4. ADOPTED METHODS

GCMs output based method and empirical statistical downscaling are methods that are adopted for CCS development. GCMs approved by IPCC were used to construct climate scenarios (CGCM1, CGCM2, ECHAM4/OPYC3, HadCM2, HadCM3, CSIRO-Mk2b, CCSR/NIES).

GCMs output based method consists of the following steps (IPCC-TGCIA, 1999) :

- Use recent model simulations (SRES) along with the results from IS92a which are widely adopted in impact studies
- Use GCMs with increased resolution
- Choose GCMs that simulate the present-day climate most faithfully
- Select experiments which more reflect average change and show a contradictory extreme range of the meteorological variable changes (Fig.1)
- Calculate climate change fields: mean differences (or ratio) between the simulated baseline period (1961-1990) and future climate for chosen GCMs experiments for the three 30 year periods (2010 - 2039, 2040 - 2069 and 2070 -2099)
- Adjust baseline observations by the differences (or ratio) between 30 year period-averaged results for the GCM experiment

The step of the GCMs validation against the present climate likely will be omitted in the nearest future in the climate scenarios construction procedure. The process of model validation is mainly defined by the methods which are applied for the model results interpretation. Technique of interpretation depends on the GCM structure (de Boer, 2001) thus involving expertise that climate scenarios researchers do not necessary possess.

Statistical DownScaling models (SDS) are proved to model hydrology with more reliable results than methods that produce coarse resolution data which are used to drive them. (Wilby and al., 2000).

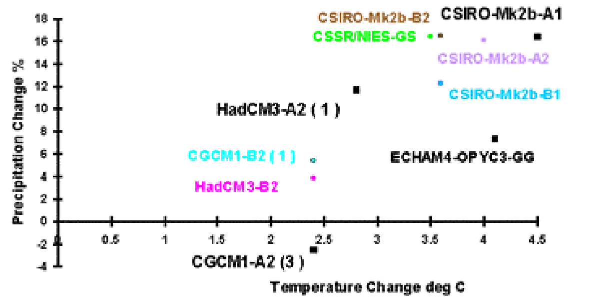

Fig.1 Changes in average temperature and precipitation for 2040s relative to 1961 - 1990 for Montreal region using different emission scenarios. Four experiments in black are chosen for CSS construction.

Future weather is simulated by SDS models with the assumption that the empirical relationships between large-scale and regional climate which are estimated for present time will also be valid in future. This assumption is a main weakness of the SDS models. SDS results are also very sensitive to the choice of transfer functions; to the value of the conditional model parameters; to the chosen period of time and its length, to the local knowledge to define combination of predictors (Wilby and al., 2001). Statistical DownScaling Model (SDSM) (Wilby et al, 2001) and LARS-WG (Semenov and Barrow, 2000) are included into the climate scenarios construction in order to represent regional climate. These models take into consideration local climate variability. SDSM is based on regression-based downscaing methods and includes stochastic weather generator. LARS-WG is a stochastic weather generator. The latest version of LARS-WG simulates length of the dry and wet spells as the first step in the weather generation process in order to overcome limitations of the Markov chain model of the precipitation occurrence (Semenov and Barrow, 2002). LARS-WG smoothes observations and demands long series of observations. It is not recommended to use LARS-WG for the places with climate anomalies (Semenov and Barrow, 2000). SDS models could demonstrate high or low skill in simulating climate variables for some particular region or season.

5. STATISTICAL DOWNSCALING MODELS PERFORMANCE

SDS models should be validated to simulate present day climate for a chosen region and thereafter be included in CSS construction. The skill of the SDS performance depends on available observations and could differ for different geographical regions.

The 1961-1975 time period is chosen to calibrate SDSM and LARS-WG statistical downscaling models. The

1976-1990 time period is chosen for validation. Hanssen-Bauer and Forland (2000) underline the importance in using more than the last 5 decades for calibration of the empirical downscaling models. Fifteen year periods could be considered insufficient to test a statistical downscaling model but justified by the fact that National Centre for Environmental Prediction (NCEP) re-analysis data and GCM data used by SDSM are available only from 1961-1990. The SDSM data are the mean results from an ensemble of the twenty members. LARS-WG data are the mean results from an ensemble of five simulations with different random seeds. Daily precipitation and mean surface temperature series were simulated for the Montreal region. The ability of the statistical downscaling models to simulate these variables was evaluated using time series plots, model bias and explained variance statistic. The bias indicates a presence of systematic errors and was calculated as:

$$\text{bias} = \frac{1}{n}\sum_{i=1}^{n}\left(v_{m_i} - v_{o_i}\right) \qquad (1)$$

where v_{mi} and v_{oi} respectively simulated and observed daily values; n is a total number of days. The explained variance statistic β is a measure of the similarity between two variables and was evaluated as (Schmidli et al.):

$$\beta = 1 - \frac{\sum_{i}^{n}\left(v_{m\,i} - v_{o_i}\right)^2}{\sum_{i}^{n}\left(\bar{v}_o - v_{o_i}\right)^2}, \qquad (2)$$

where $\bar{v}_o$ is the mean of the observations.

SDS models simulate well monthly mean daily temperature (fig. 2). SDSM has bias of 0.5° C and high value of the explained variance statistic (Table 1). LARS-WG shows cold bias in JFM, high correlation for November and December, warm bias the rest of the year. Furthermore LARS-WG overestimates temperature in total by 1.8° C (Table 1). LARS-WG Spearmen's rank coefficient is high and β statistic shows skilful simulation. SDSM and LARS-WG demonstrated statistically significant results generating mean daily temperature and are recommended for CSS temperature construction for a chosen region. Fig. 3 depicts monthly mean daily precipitation and statistical characteristics for this parameter are reported in Table 1. SDSM weather generator overestimates daily precipitation by 10%. SDSM has Spearman's rank coefficient value of 0.57 which demonstrates relatively high skill for the simulation of precipitation. Explained variance statistic β equals 0.22 which is consistent with results reported by SDS investigations (Wilby, 2000). LARS-WG has bias of 60%. LARS-WG explained variance statistic of -0.26 characterises low generation skill of precipitation (Table 1). A possible explanation of this result might be requirement of longer calibration period.

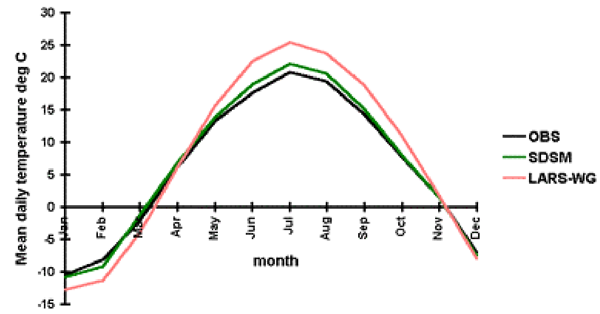

Fig. 2 Mean daily temperature for 1976-1990 vs observations for Montreal region

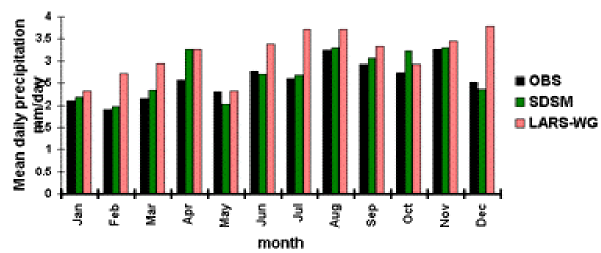

Fig. 3 Mean daily precipitation for 1976-1990 vs observations for Montreal region

Table 1. Statistical characteristics for simulated mean temperature and daily precipitation vs observations for Montreal region for 1976-1990. Mean daily observed temperature mean = 6.1 deg. C and mean daily observed precipitation mean = 2.6 mm/day (5479 degrees of freedom)

	Mean	bias	Rs	P	β
SDSM					
mean temperature	6.6	0.5	0.98	0.000	0.95
daily precipitation	2.7	0.1	0.57	0.000	0.22
LARS-WG					
mean temperature	7.5	1.8	0.91	0.000	0.69
daily precipitation	3.2	0.6	0.003	0.81	-0.26

Rs – non-parametric Spearman's correlation coefficient ; P - P-value (P-value > 0.05 notes that results are not statistically significant); β - explained variance.

SDSM is recommended to be included to CSS for simulation of precipitation for a chosen region. Table 2 shows results of statistical characteristics of the SDSM downscaled CGCM1 (IS92a, GHG+A1) precipitation and series without downscaling for baseline climate (1961-1990). SDSM reduces value of the bias from 1.1 mm/day to -0,2 mm/day. Explained variance statistic was increased from - 0.86 to - 0.27 demonstrating the fact that SDSM generates precipitation more similar to observation than CGCM1 for Montreal region (Table 2) .

6. FUTURE SCENARIOS

The Climate Scenarios Set (CSS) provides daily values of meteorological parameters for the three thirty years slices: 2010-2039, 2040-2069, 2070-2099. CSS has been developed for Montreal region.

Table 2. Statistical characteristics for simulated daily precipitation vs observations for Montreal region for 1961-1990. Obs. mean = 2.6 mm/day (10957 degrees of freedom)

	Mean mm/day	Bias mm/day	β
SDSM (current CGCM1)	2.4	-0.2	-0.27
CGCM1 (IS92, GHG+A1)	3.7	1.1	-0.86

β - explained variance

Table 3. Daily mean projected temperature (°C) and absolute temperature change (°C) vs 6.1°C (1961-1990 normal) for Montreal region

	2020s deg C	2050s deg C	2080s deg C
SDSM	7.9 (1.8)	8.5 (2.4)	8.1 (2.0)
LARS-WG	9.6 (3.5)	11.1 (5.0)	13.4 (7.4)
CGCM1-A2 (3)	7.3 (1.2)	8.5 (2.4)	10.4 (4.3)
HadCM3-A2 (1)	7.4 (1.3)	8.8 (2.7)	11.1 (5.0)
ECHAM4/OPYC3-GG	8.5 (2.4)	10.2 (4.1)	11.9 (5.8)
CSIRO-Mk2b-A1	8.1 (2.0)	10.5 (4.4)	12.4 (6.3)

SDSM projected temperature changes for 2020s and 2080s (Table 3) are less than 2.3°C (standard error of the SDSM that was estimated during the SDSM calibration). It is an indication that the model sensitivity to future climate forcing is less than the model accuracy (Wilby et al., 2001). Among SDSM temperature simulations only 2050s temperature change (Table 3) is statistically significant. SDSM generated mean daily temperature data for 2050s will be included in Climate Scenarios Set for Montreal region. All developed scenarios report increasing of the daily mean temperature in the interval from 1.2 to 7.4°C over the period 2010 to 2099 (Table 3). Averaged annual precipitation has a tendency to increase during 21st century from 1% to 19.7%. On the contrary CGCM1-SRES-A1(3) experiment reports decreases in precipitation of about 2.4% (Table 4). CSS presents a range of monthly mean daily projected precipitation for 2070-2099 (Table 5). Observed precipitations for 1961-1990 baseline values are also included in Table 5 for comparison. For example, according to SDSM, daily precipitations in April are projected to increase by 84%. CSIRO-Mk2b also reports a 55% increase in precipitation for April. Daily precipitation are simulated by SDSM to increase by 51% in August and September and to decrease by 31% in July. CSS values (Tables 3-5) reflect climate change that is induced by the different emission scenarios and also by the uncertainties connected with the reliability of the GCMs, SDS models and observations.

Table 4. Averaged annual projected precipitation (mm) and relative precipitation change (%) vs 939.7 mm (1961-1990 normal) for Montreal region

	2020s mm (%)	2050s mm (%)	2080s mm (%)
SDSM	971.1 (3.3)	964.3 (2.6)	1071.6 (13.9)
CGCM2-A2 (3)	926.6 (-1.1)	916.8 (-2.4)	923.2 (-1.8)
HadCM3-A2 (1)	949.5 (1.0)	1052.8 (12.0)	1017.1 (8.2)
ECHAM4/OPYC3-GG	956.3 (1.8)	997.2 (6.1)	994.9 (5.9)
CSIRO-Mk2b-A1	974.0 (3.7)	1093.3 (16.3)	1124.8 (19.7)

Table 5. Monthly mean daily observed (1961-1990) and projected precipitation (mm) for 2080s for Montreal region

	obs	SDSM	CGCM1 A2 (3)	CSIRO -Mk2b A2	ECHAM4 -OPYC3 GG	HadCM3 A2 (1)
Jan	2.0	2.1	1.8	2.8	2.5	2.4
Feb	2.0	2.5	1.9	3.0	2.3	2.5
Mar	2.1	2.3	2.1	3.0	2.8	2.7
Apr	2.5	4.6	2.9	3.9	2.5	2.5
May	2.2	1.5	2.4	2.4	1.9	3.0
Jun	2.8	2.6	2.7	3.2	2.5	2.8
Jul	2.8	1.7	3.0	3.3	3.0	2.3
Aug	3.2	4.9	2.9	3.4	3.2	3.3
Sep	2.9	4.4	2.7	2.7	2.7	2.3
Oct	2.5	2.7	2.6	2.4	2.3	2.8
Nov	3.1	3.3	2.6	3.6	3.7	3.9
Dec	2.8	2.7	2.6	3.4	3.3	3.0

7. CONCLUSIONS

A method to construct Climate Scenarios Set (CCS) for hydrological impact studies with treatment and discussion of uncertainties has been described. Future climate change for Montreal region (Canada) has been estimated. Statistical analysis to justify application of the Statistical DownScaling models (SDS) has been presented. SDS application proved to be an instrument to estimate uncertainties presented by GCMs. The use of SDSM gives the possibility to estimate statistical significance of the downscaled projected climate. SDSM and LARS-WG are recommended to be used for CCS development. Validation of the SDS models shows that SDS models represent adequately mean surface temperature; simulation of the precipitation is less accurate. Discrepancies between observed and SDSM simulated precipitation could be attributed by the choice of the transfer function and predictor variables. LARS-

WG requires fitting series of precipitation's more than fifteen years.

Future efforts will be directed to (1) the development of the extreme climate scenarios using Extreme Value Theory (EVT) and to the verification of the ability of the SDS models to catch extremes events, to (2) the estimation of the effect of errors introduced by different methods of CSS construction as a technique of uncertainty analysis.

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