Environment Canada Environnement Canada

Canada

Climate variability and changes at the regional scale: what we can learn from various downscaling approaches

by

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GEC3EG Global Environmental and Climate Change Centre / Centre sur les changements climatiques et l'environnement global

Centre ESCER pour l'étude et la simulation du climat à l'échelle régionale

Content

- Introduction:
  - Main objectives of our on-going projects
  - Climate variability vs anticipated (Canada) from AOGCMs
- RCM evaluation over the current period (i.e. predictability):
  - Atmospheric variability: ex. simulated storms track (intensity, duration/persistence and frequency) vs reanalysis products
  - Extreme indices
  - Trends and interannual anomalies: ex. the use of weighting procedure
- Scenarios: spreading and consistency of results from ensemble runs
- Conclusion

NSERC-SRO & MDEIE projects (Canada): 2007-2010 & 2009-2012
"Probabilistic assessment of regional changes in climate variability and extremes"

Natural Sciences and Engineering Research Council of Canada
Conseil de recherches en sciences naturelles et en génie du Canada
Canada

Développement économique, Innovation et Exportation
Québec

Three main objectives:

- I) Development and application of statistical downscaling methods in order to generate (multi-site & multivariate) climate information
- II) Development and evaluation of current & future high-resolution RCMs. Applying statistical downscaling methods from GCM resolutions to future RCM resolutions
- III) Generate high resolution probabilistic climate change scenarios including extremes and variability with assessments of their associated uncertainties

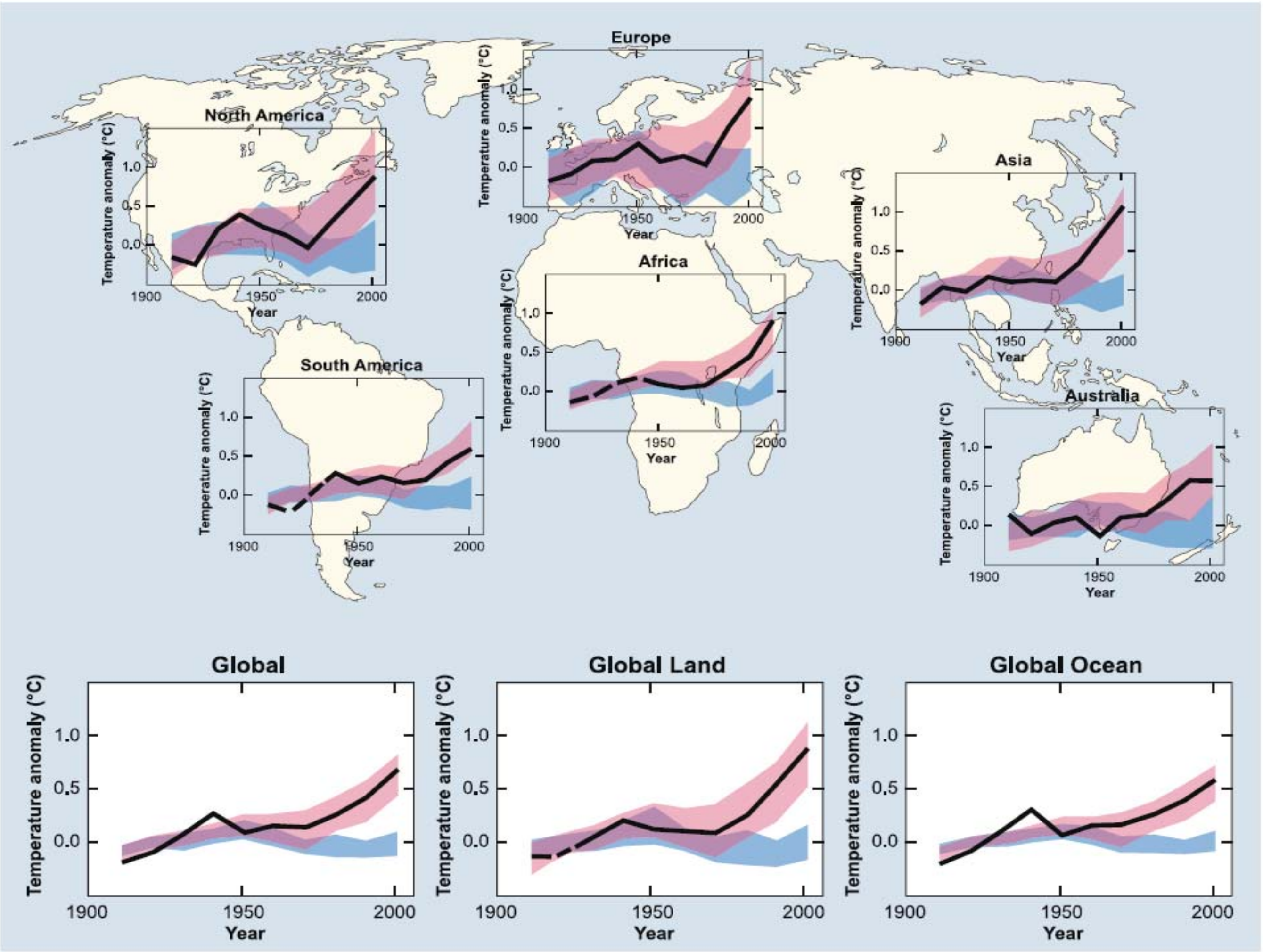
INTRODUCTION: Climate variability (observed vs simulated)

Global vs Continental scale:

Annual Mean 2-m air temperature Historical evolution (1900-2005)

Anomalies with respect to 1901-1950 mean values

GLOBAL AND CONTINENTAL TEMPERATURE CHANGE



models using only natural forcings

models using both natural and anthropogenic forcings

observations

[Source: IPCC (2007)]

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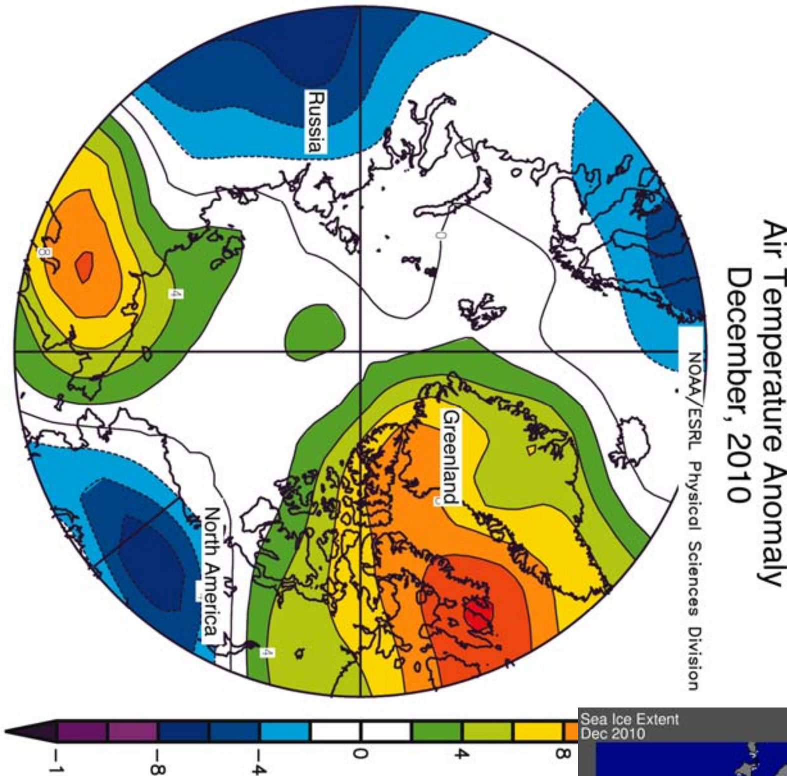
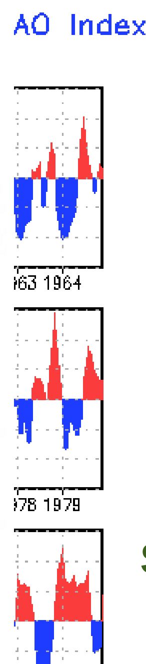
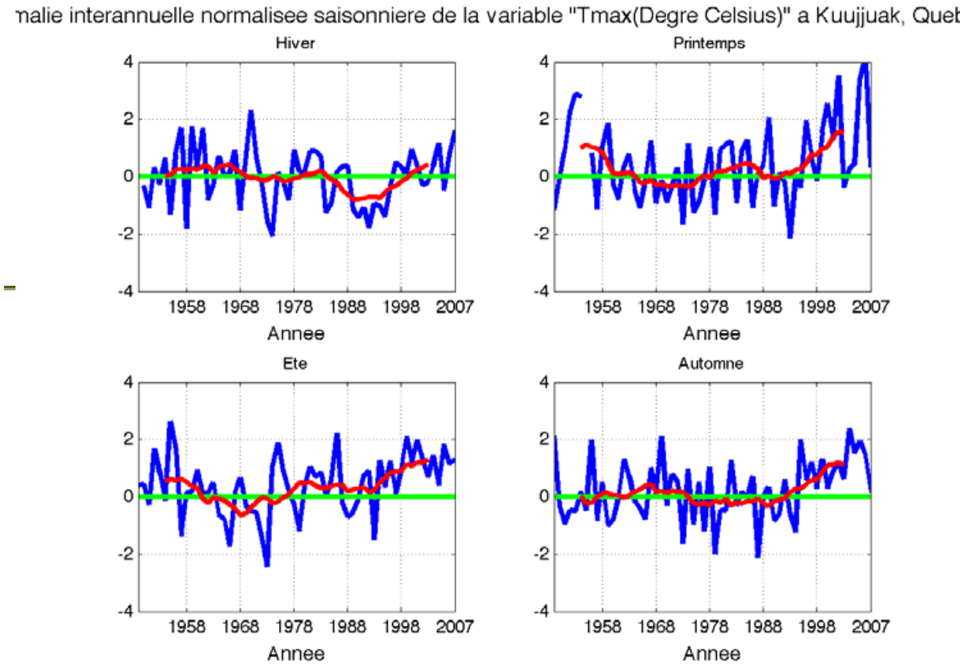
INTRODUCTION: Climate variability

Ex. NAO & Temperature anomalies in Canada



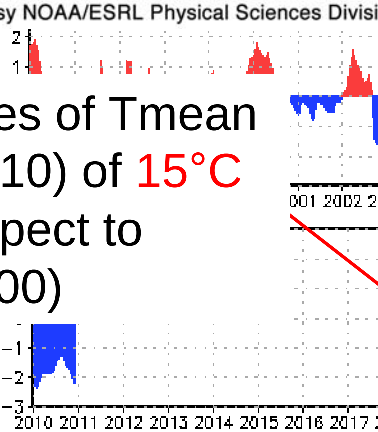
From NSIDC courtesy NOAA/ESRL Physical Sciences Divisi

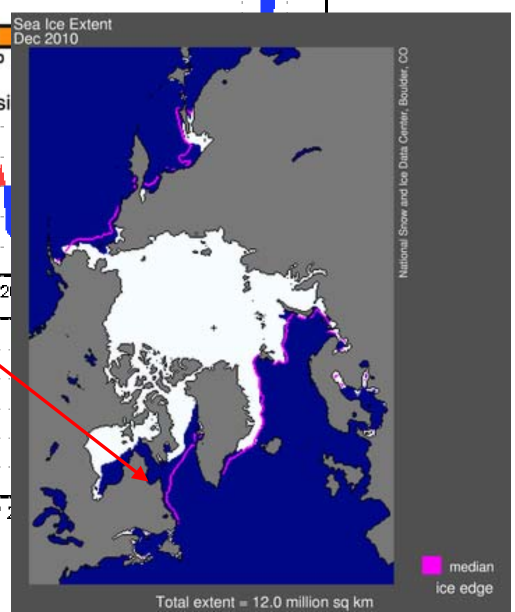


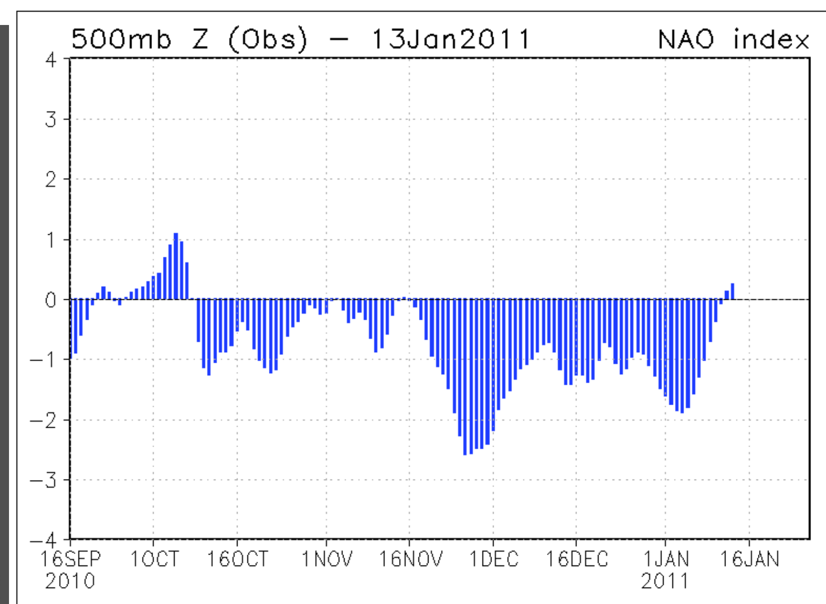


SD: 3 to 7°C from summer to winter at Kuujjuaq)

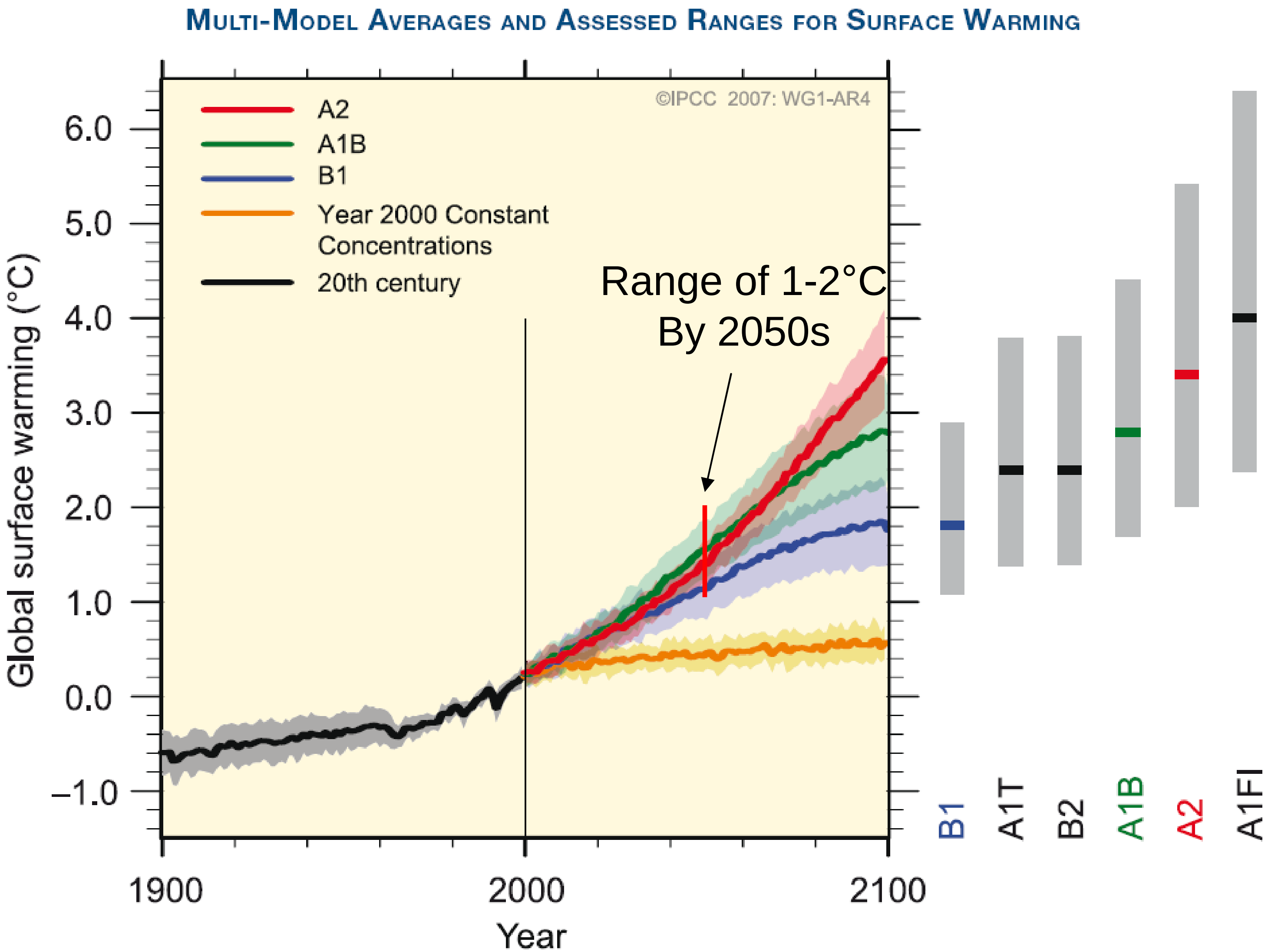
Anomalies of Tmean (Dec. 2010) of 15°C (with respect to 1971-2000)







INTRODUCTION: Climate change (anticipated 21st century) Global Annual Mean near-surface temperature changes (°C) From various AOGCMs and emission scenarios (2000-2100)



[Source: IPCC (2007)]

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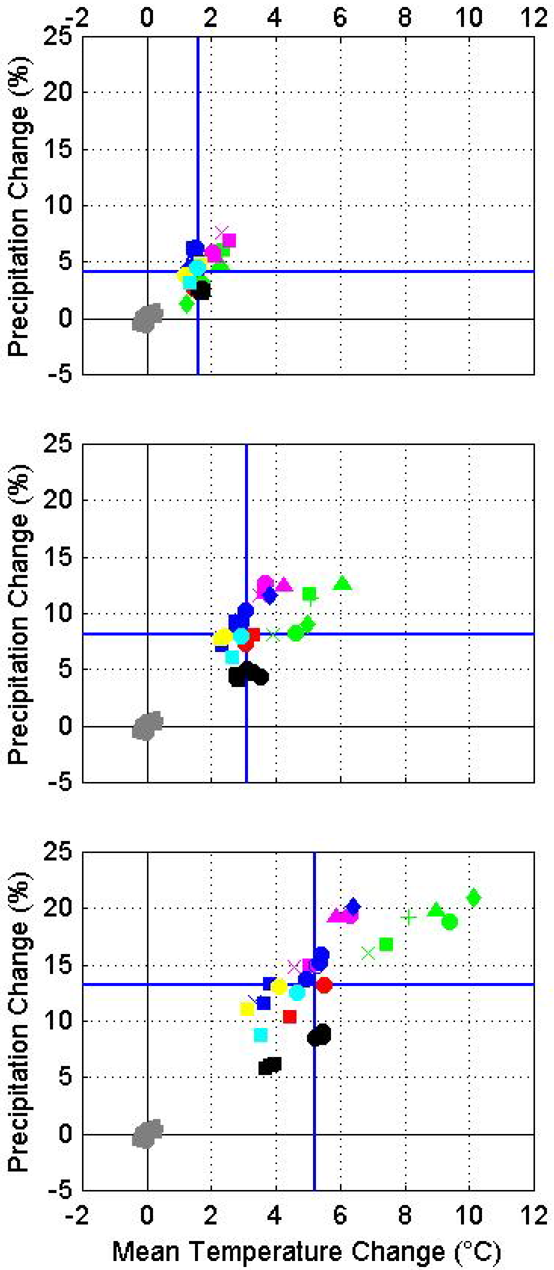
INTRODUCTION: Climate change (anticipated 21st century)

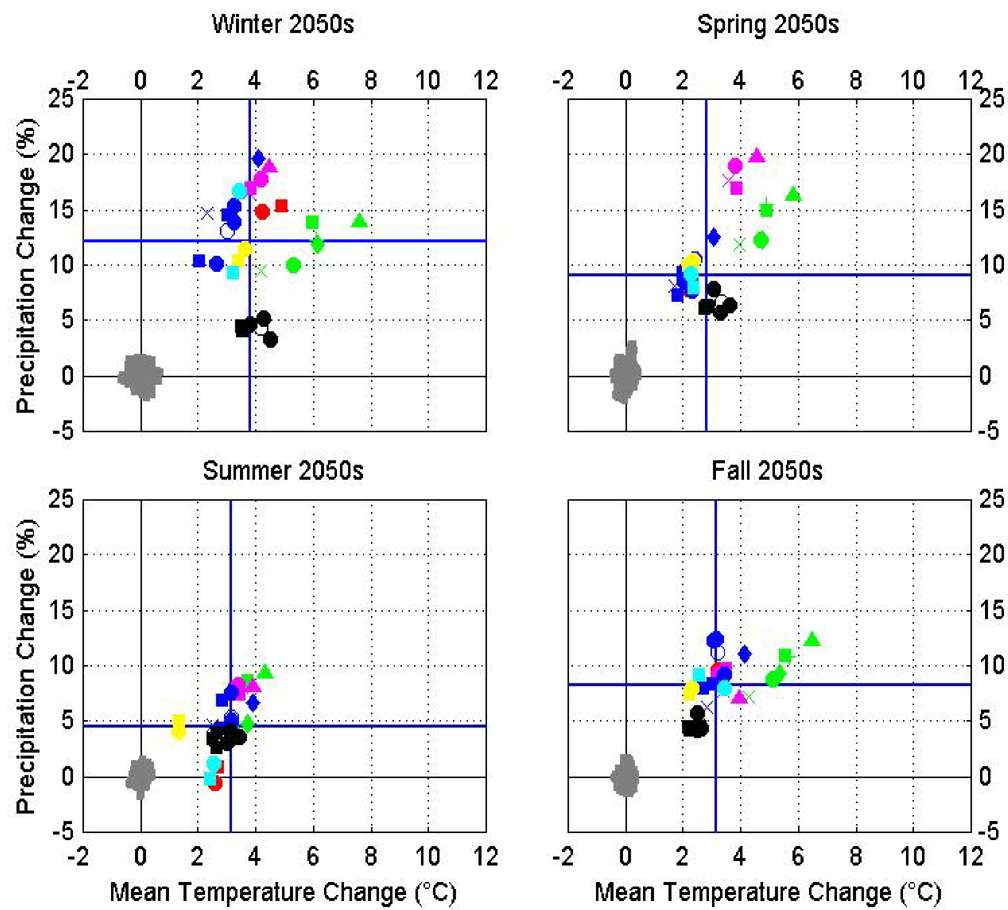
AOGCMs information: increase of uncertainties over time & through seasons



2020s

2050s

2080s



[Source: Barrow et al. (2004)]

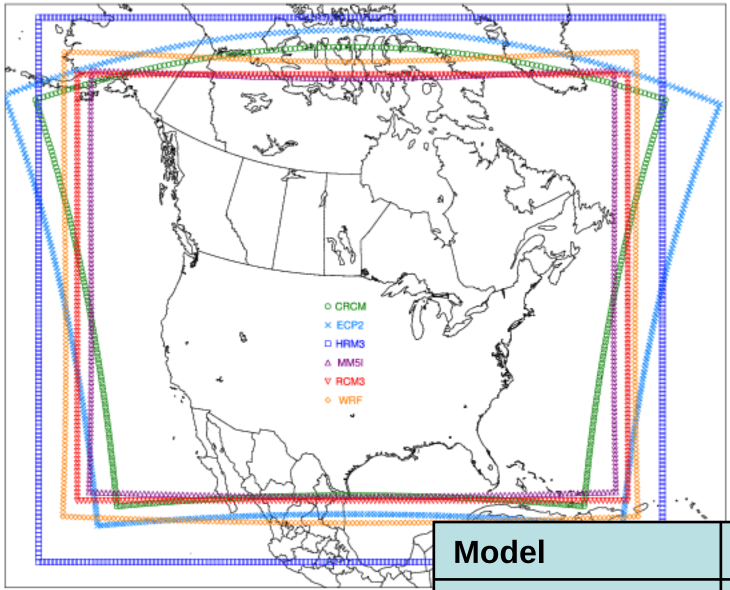
RCM EVALUATION: need to incorporate major sources of uncertainties or to capture the main source of predictability

RCM Reliability & uncertainties mainly related to:

- **Boundary conditions (GCMs or/vs reanalysis driven)**
- **Physical parameterizations**
- **Complexity of the physiographic conditions to simulate (ex. northern Canada)**
- **Downscaling approaches (ex. one or two-way nesting approach, spectral nudging, domain size, resolution, numerical scheme, etc.)**

RCM evaluation: Matrix of runs

NARCCAP RCM Domains



Canadian Regional Climate Model

[available runs from Ouranos & CRCMD]

Model	Full name	Modeling group
CRCM	Canadian Regional Climate Model	UQÀM, Ouranos and CCCma (EC)
HRM3	Hadley Regional Model version 3	Hadley Center
WRFG/WRFP	Weather Research & Forecasting model	Pacific Northwest National Lab
MM5I	MM5-PSU/NCAR mesoscale model	IOWA State University
ECPC2/ECPC1	Experimental Climate Prediction Center	UC San Diego / Scripps
RCM3	Regional Climate Model version 3	UC Santa Cruz
ARPEGE	Action Recherche Petite Echelle et Grande Echelle	Météo France (runs available at Ouranos)
GEMCLIM	Climate version of Environment Canada's Global Environmental Multiscale (GEM) model	Environment Canada available runs from the CRCMD network (UQÀM)

***Source: http://www.narccap.ucar.edu/data/model-info.html**

23 runs over the current period driven by reanalysis & AOGCMs

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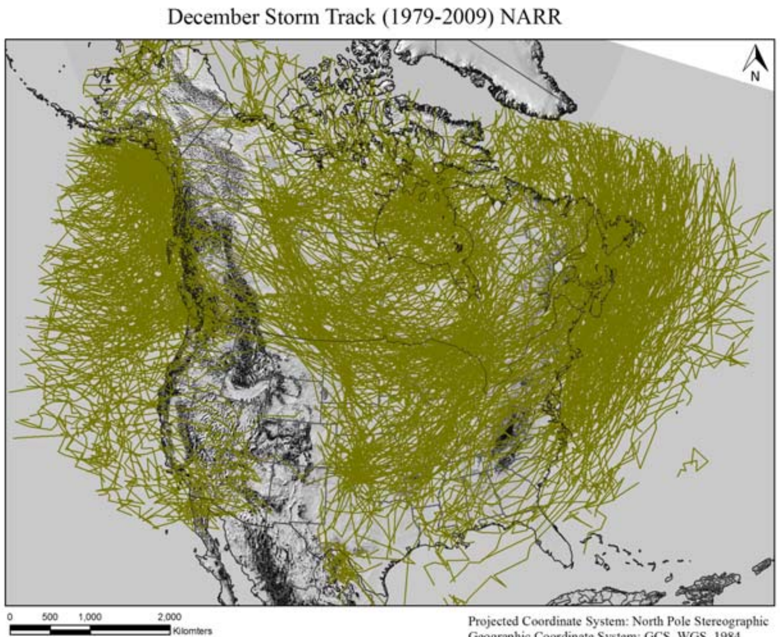
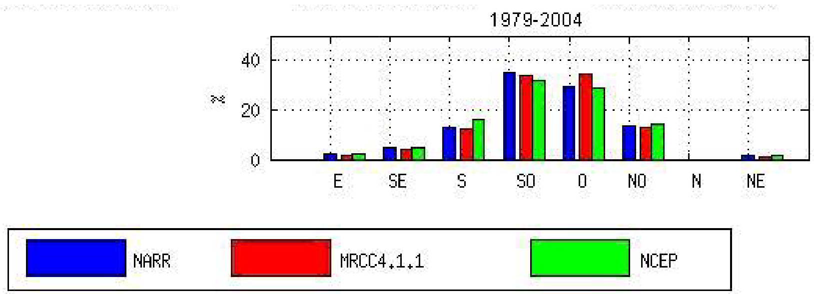
RCM evaluation over the current period (i.e. predictability): Atmospheric variability: ex. storms track (intensity, duration/persistence and frequency) with comparison with reanalysis products

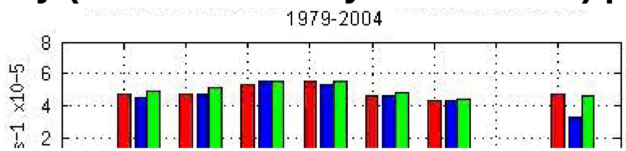
ANALYSIS OVER THE HUDSON BAY AREA (ex. December month) under a maritime infrastructure project (vulnerability study)

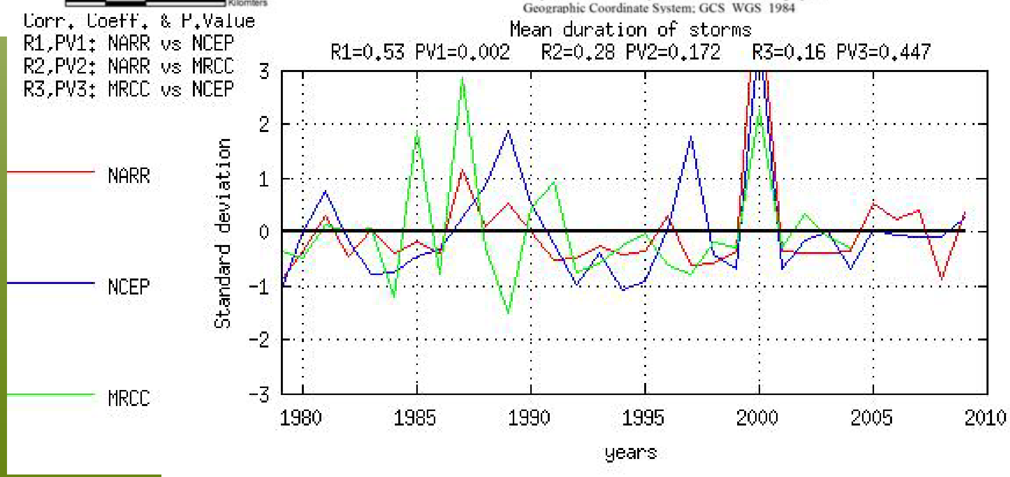


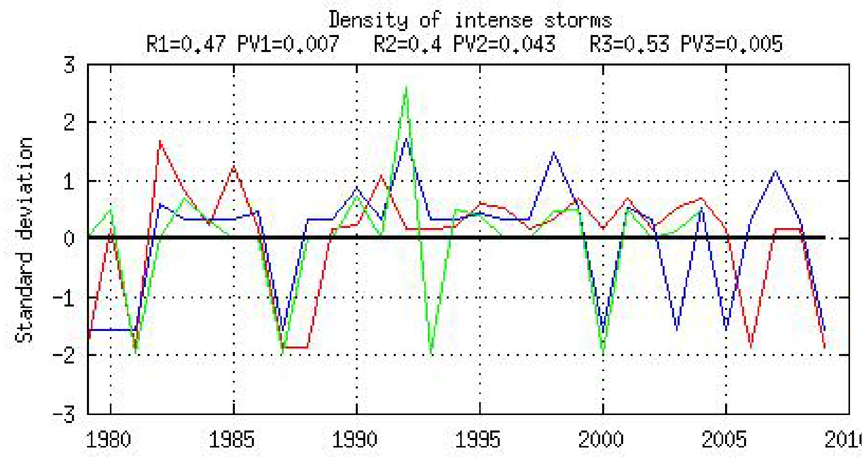
Origin of cyclone per direction



Mean Intensity (absolute vorticy at 1000-hPa) per direction

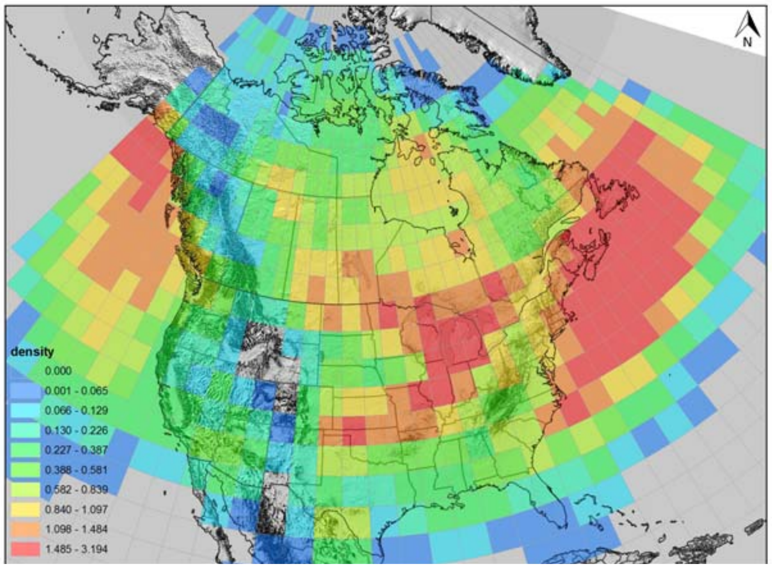






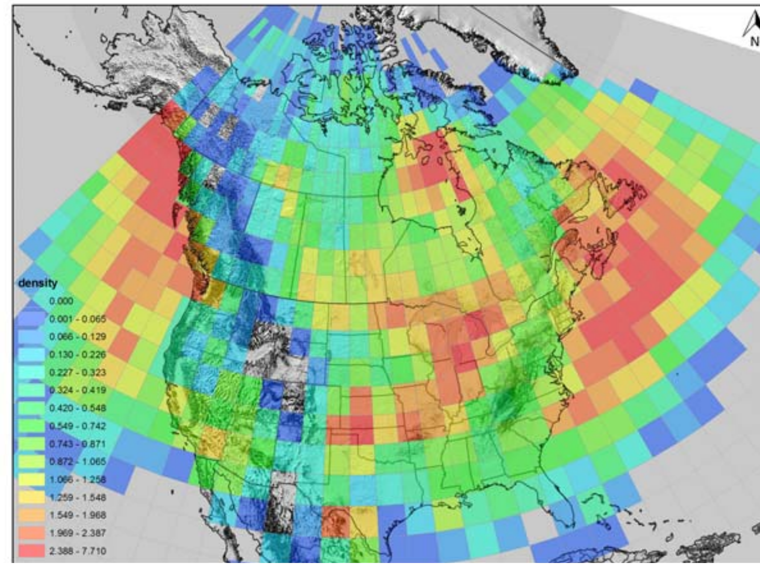
RCM evaluation over the current period (i.e. predictability): main issues is not only related to the density of storms (i.e. occurrence) BUT also to their persistence (stalled & new development of cyclones, i.e. centres, speed of moving, explosive develop. along the track)

February Density of Storm Tracks (1979-2009) NARR / grid 300 KM

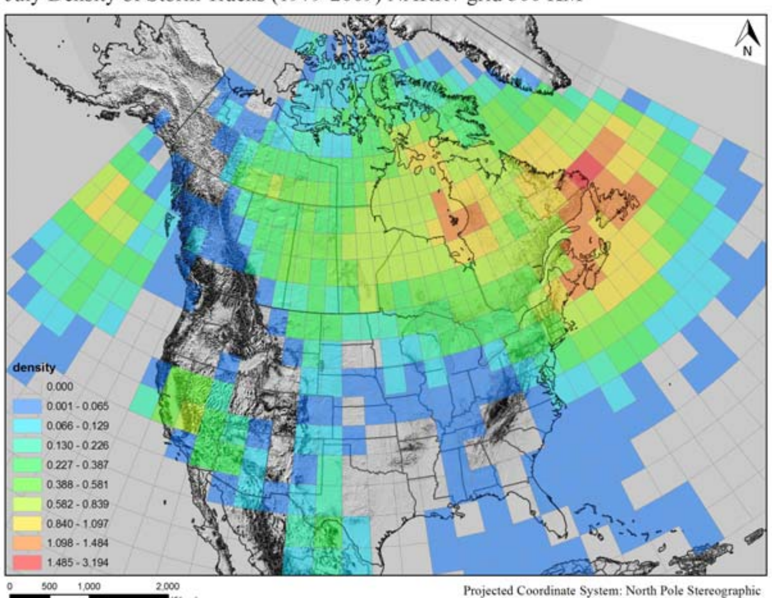


February
(NARR only)

February Density of Cyclone Centers (1979-2009) NARR / grid 300 KM

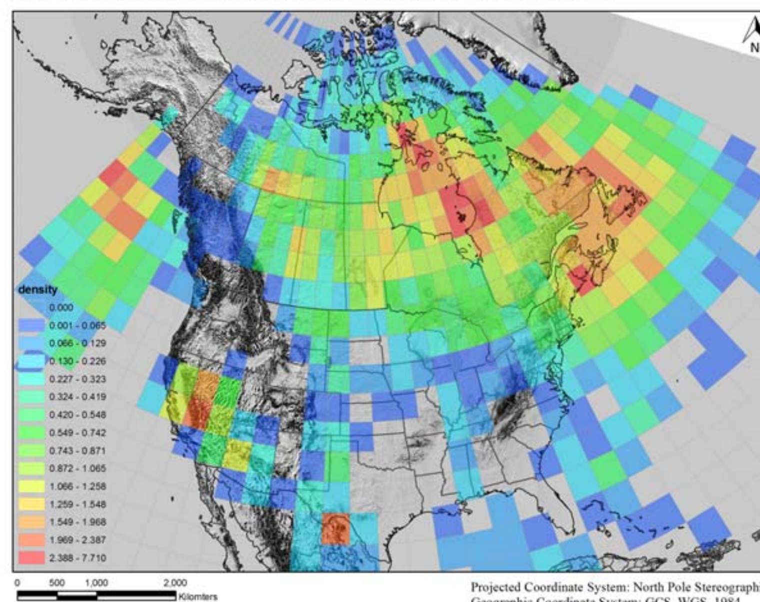


July Density of Storm Tracks (1979-2009) NARR / grid 300 KM

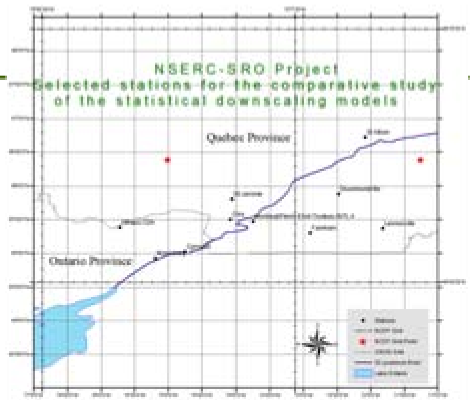


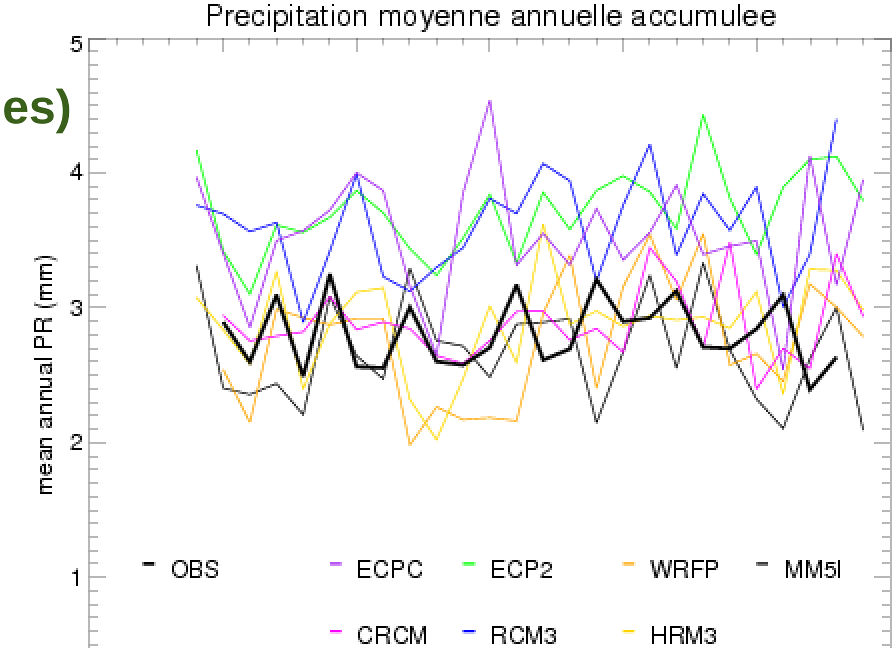
July
(NARR only)

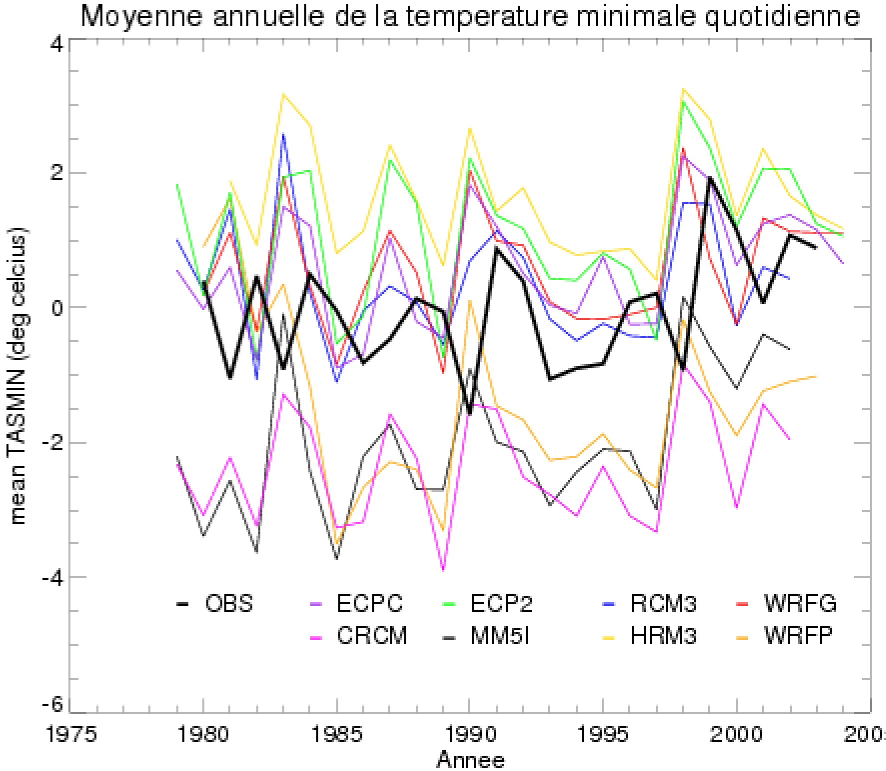
July Density of Cyclone Centers (1979-2009) NARR / grid 300 KM

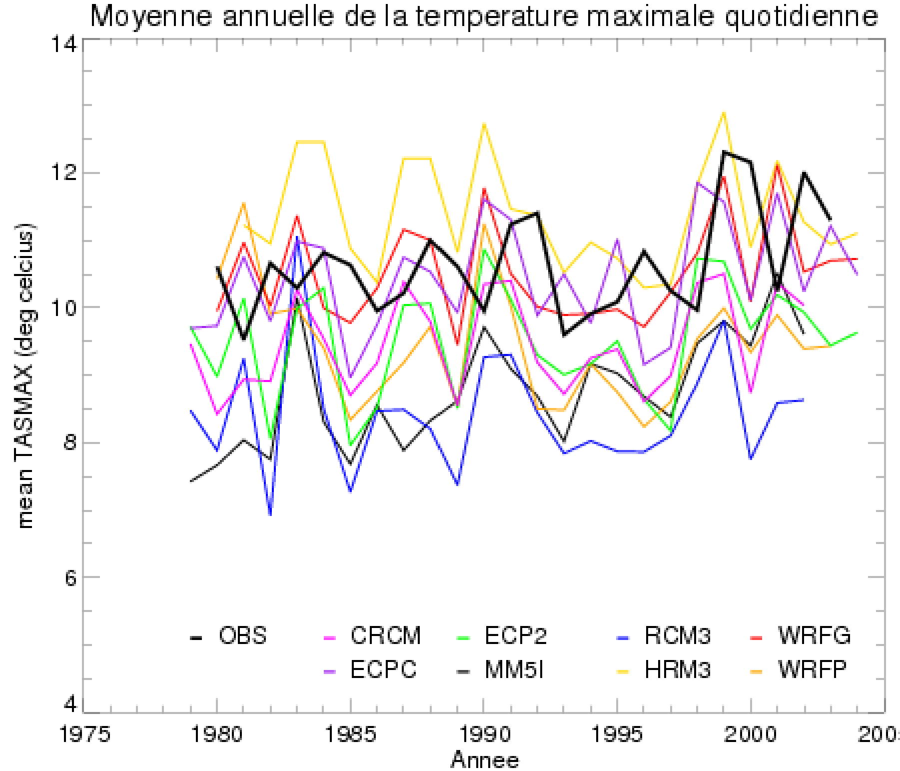


RCM evaluation: southern Québec – INTERANNUAL VARIABILITY (annual values) Reanalysis driven (NARCCAP runs)









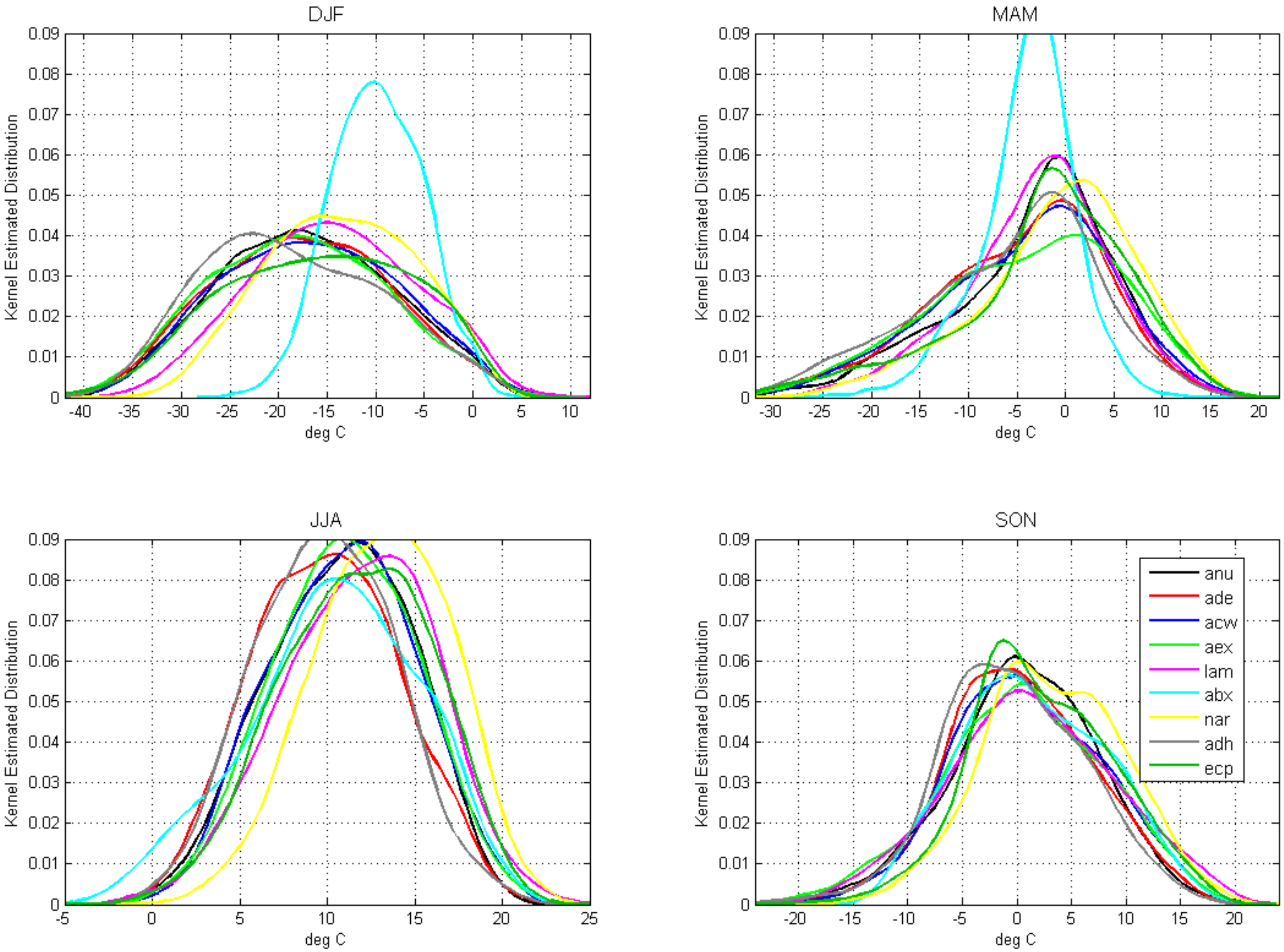
RCM evaluation: southern Québec

Spearman correlation between RCM vs OBS
(annual standardized values over 1979-2001)
NARCCAP runs (driven by NCEP/DOE)

Variable	Indice	CRCM	ECP2	ECPC	HRM3	MM5I	RCM3	WRFP	WRFG
tmin	rho	**0.7831**	**0.8554**	**0.7846**	**0.7253**	**0.7885**	**0.69**	**0.4296**	**0.6826**
	p	0.7 10-6	2.1783 10-6	6.286 10-6	1.3735 10-4	5.3863 10-6	1.9867 10-4	0.0373	3.392 10-4
tmax	rho	**0.8485**	**0.8162**	**0.78**	**0.6502**	**0.5531**	**074**	**0.5435**	**0.7443**
	p	2.135 10-6	2.3766 10-6	7.6 10-6	0.001	0.0047	3.8039 10-5	0.0068	4.8124 10-5
pr	rho	0.3377	0.0615	0.0677	0.1885	0.0038	0.3069	0.2261	
	p	0.0992	0.7698	0.7473	0.3653	0.9868	0.1356	0.2867	

Reliability & uncertainties depend on: Downscaling approaches and mean versus extremes (seasonally dependent)

… no single model is best for all climate variables and statistics. Thus, multimodel information has value, which can be enhanced with a performance-based weighting of the contributing models.



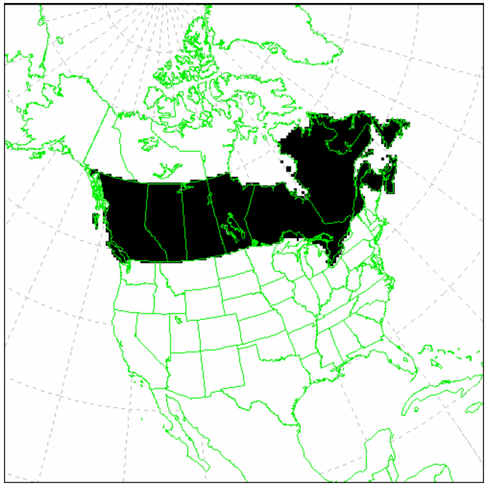
Ex. for Tmin at seasonal scale over southern Québec (**1980-2001**)

RCM Evaluation using ANUSPLIN (gridded observed data) over various regions of Canada (south of 60°N)

- National Daily 10km Gridded Dataset over Canada's continental area (south of 60°N) represents Environment Canada's climate station observations interpolated (using ANUSPLIN) on 10km horizontal resolution grid (Hutchinson et al., 2009; www.agr.gc.ca/nwlis-snite)

- This dataset used as reference in this study

  has been previously interpolated on CRCM grid (resolution of 45km @ 60°N) Black grid points



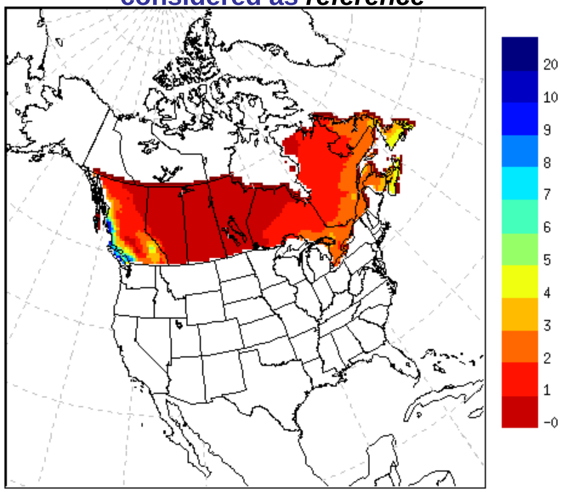
Region covered by ANUSPLIN data interpolated on Polar Stereographic grid of CRCM (AMNO: 182x174)

RCM Evaluation : Seasonal biases across Canada (runs from NARCCAP & CRCMD)

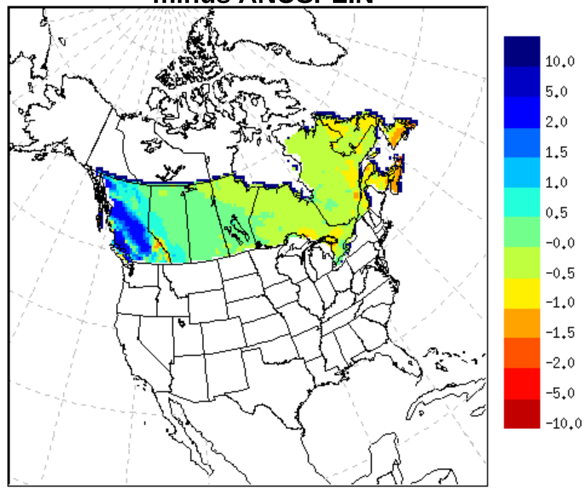
Precipitation amount (mm/day)

21-yr Winter (Dec-Jan-Feb) Climatology (1980-2001)

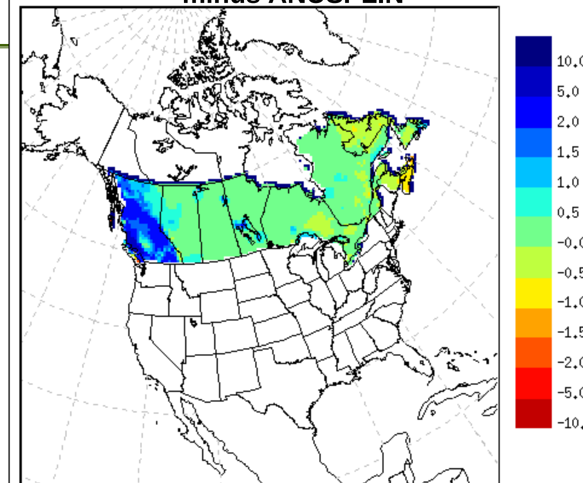
ANUSPLIN interpolated on CRCM grid considered as *reference*



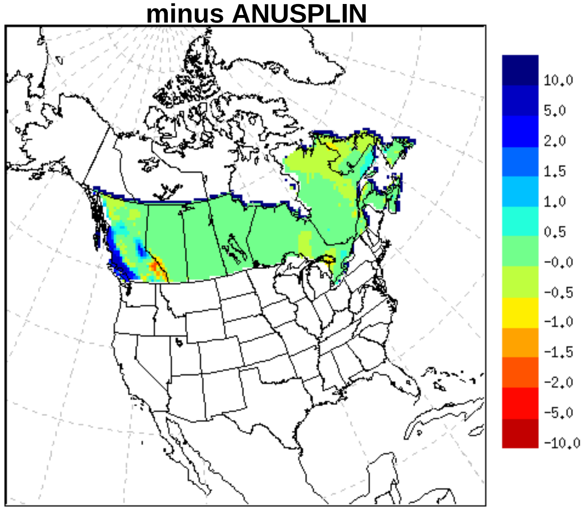
CRCM-NCEP-NARCCAP minus ANUSPLIN



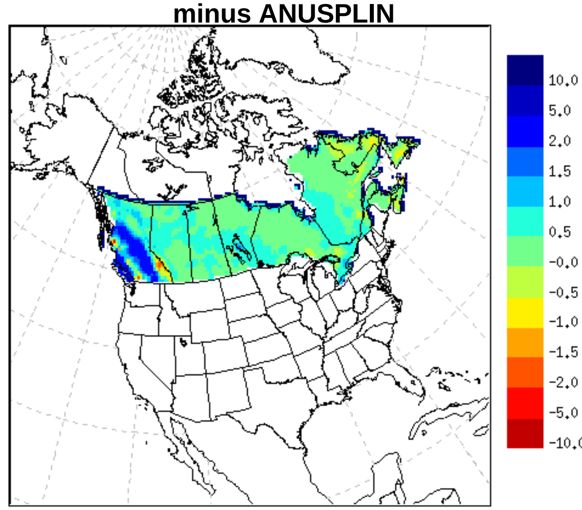
MM5I-NCEP-NARCCAP minus ANUSPLIN



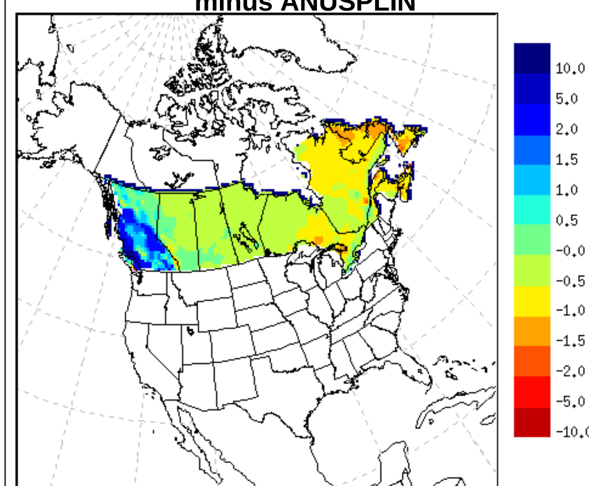
GEMCLIM-ERA40-CRCMD minus ANUSPLIN



ECPC2-NCEP-NARCCAP minus ANUSPLIN



WRFG-NCEP-NARCCAP minus ANUSPLIN

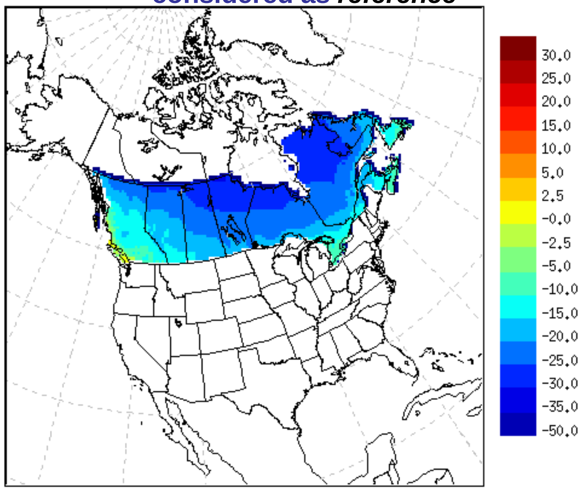


RCM Evaluation : Seasonal biases across Canada (runs from NARCCAP & CRCMD)

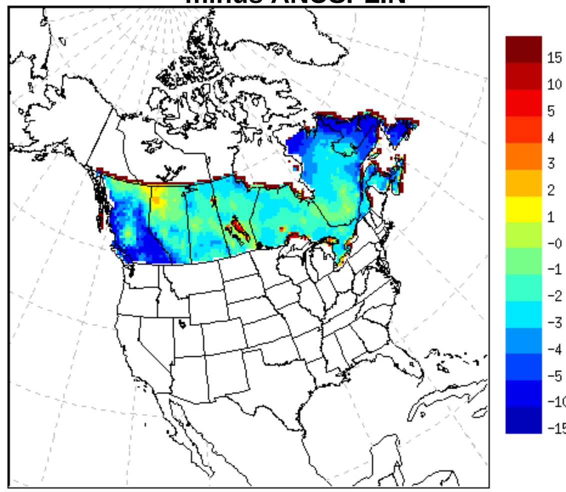
Daily Minimum 2m Temperature (°C)

21-yr Winter (Dec-Jan-Feb) Climatology (1980-2001)

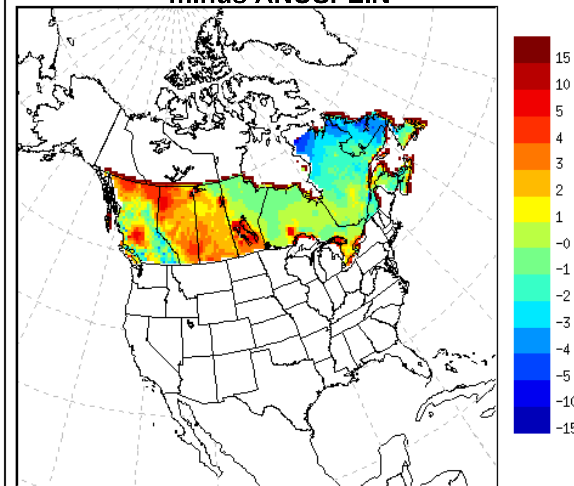
ANUSPLIN interpolated on CRCM grid considered as *reference*



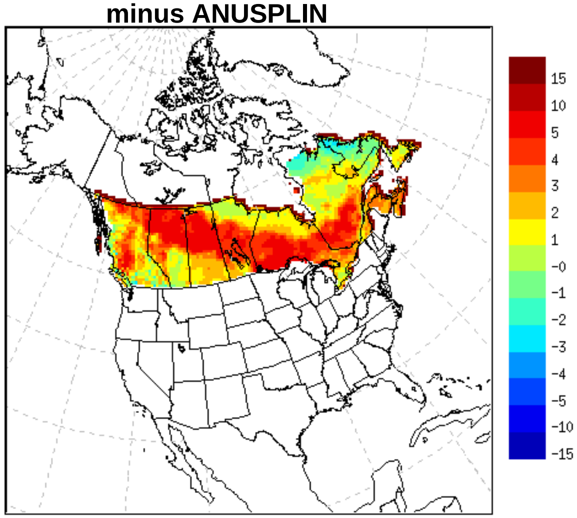
CRCM-NCEP-NARCCAP minus ANUSPLIN



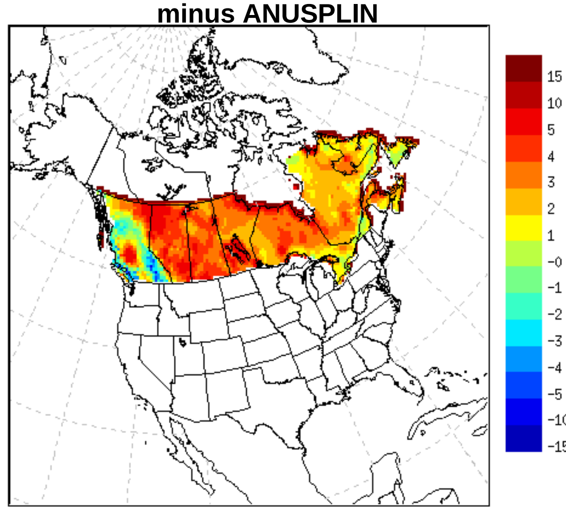
MM5I-NCEP-NARCCAP minus ANUSPLIN



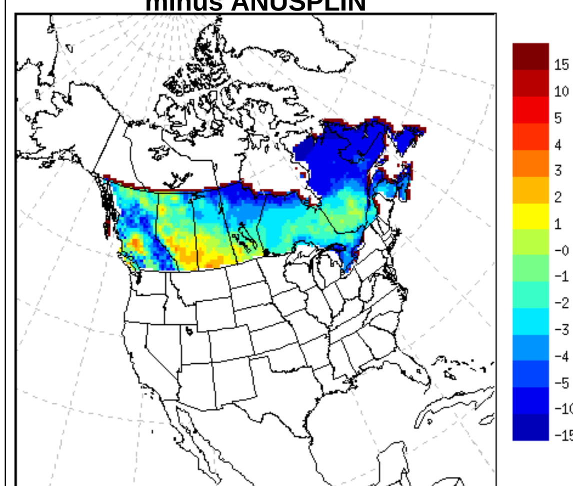
GEMCLIM-ERA40-CRCMD minus ANUSPLIN



ECPC2-NCEP-NARCCAP minus ANUSPLIN



WRFG-NCEP-NARCCAP minus ANUSPLIN



RCM Evaluation : Seasonal biases across Canada (different versions of the Canadian RCM, & ARPEGE, all runs from Ouranos)

1971-2000

Daily Minimum (2m) Temperature (STMN) in °C

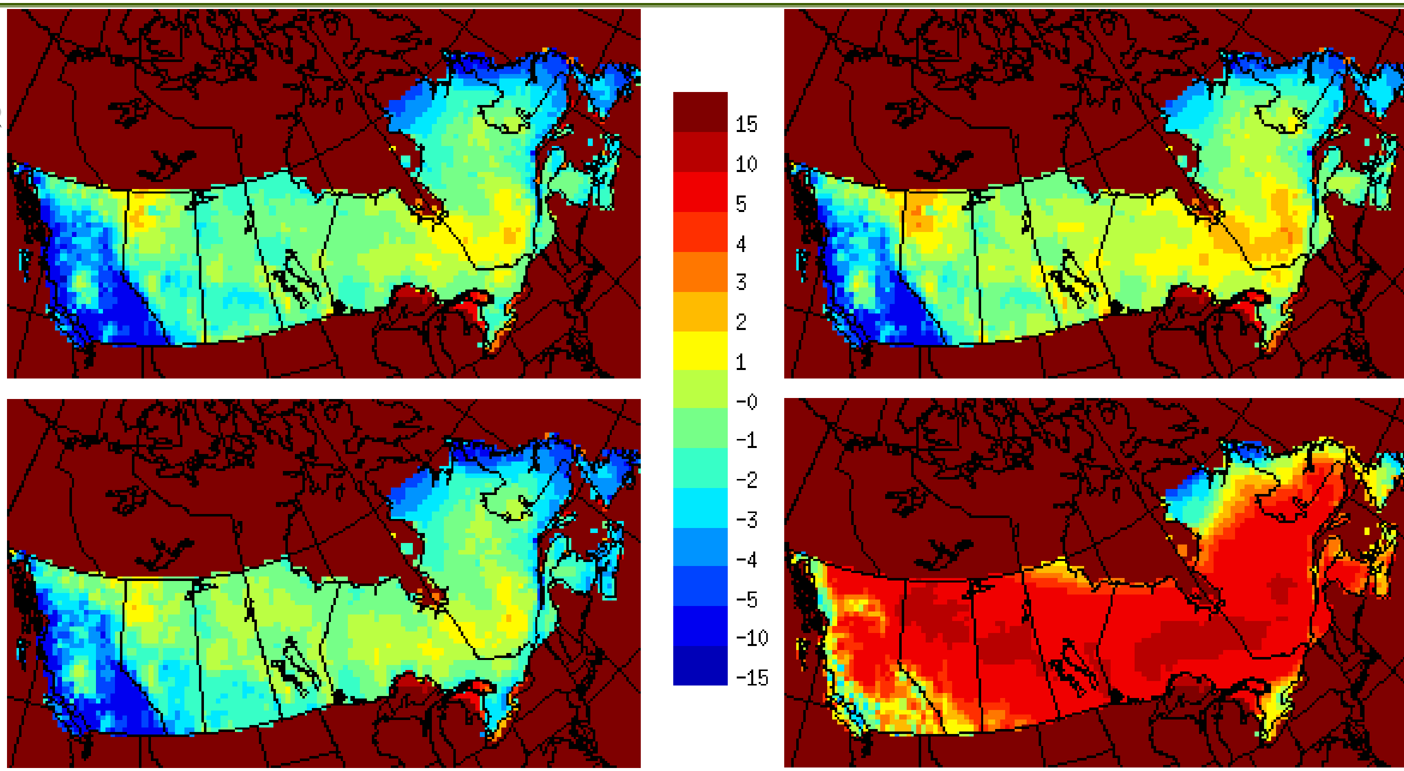
Difference between RCMs & observed gridded values (ANUSPLIN)

CRCM4.1.1 driven by NCEP/NCAR

CRCM4.1.1 driven by ERA-40

CRCM4.2.3 driven by ERA-40

ARPEGE4.4 driven by ERA-40



#1 Strong cold biases (> 3°C for CRCMs) in British Columbia and north-eastern area of Labrador, except in southern Quebec

#2 Strong warm biases across Canada in ARPEGE (> 4 °C)

Some RCMs have systematic biases, and also a clear tendency to enhance these in more extremely cold or warm conditions

1971-2000 Extreme *Cold* Winter Temperature 10th percentile of STMN, (°C)

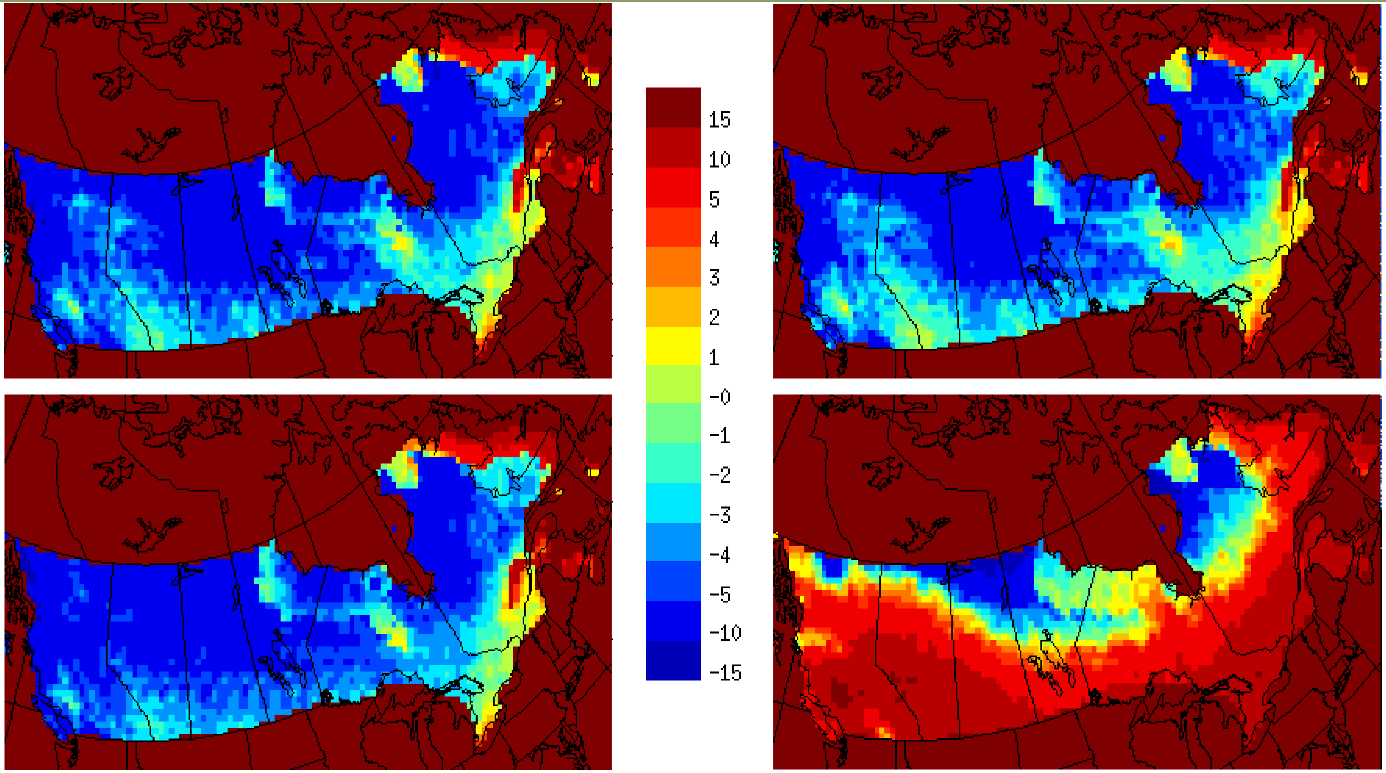
Difference between RCMs output & observed gridded values (ANUSPLIN)

CRCM4.1.1 driven by NCEP/NCAR

CRCM4.1.1 driven by ERA-40

CRCM4.2.3 driven by ERA-40

ARPEGE4.4 driven by ERA-40



#1 CRCMs: Strong cold biases (> 4°C) across most of Canada and south-eastern border

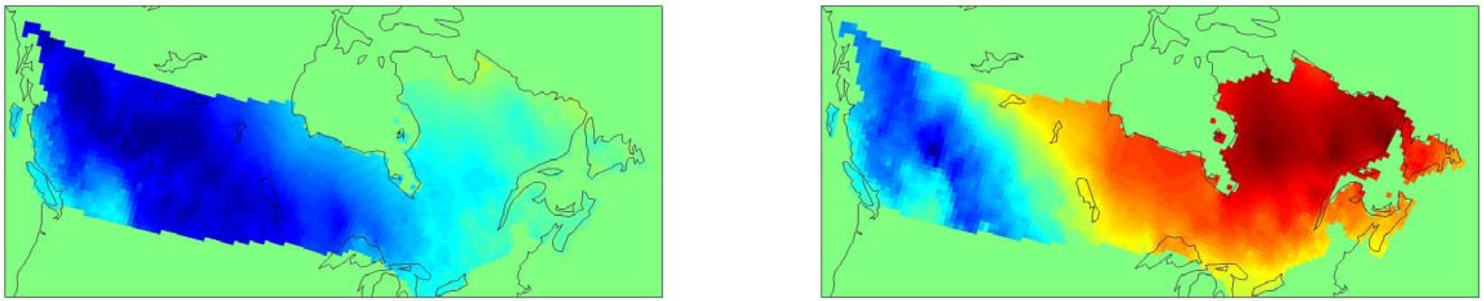
#2 ARPEGE: Strong warm biases across Canada, except in northern part of the region

Different versions of the Canadian RCM, & ARPEGE, all from Ouranos

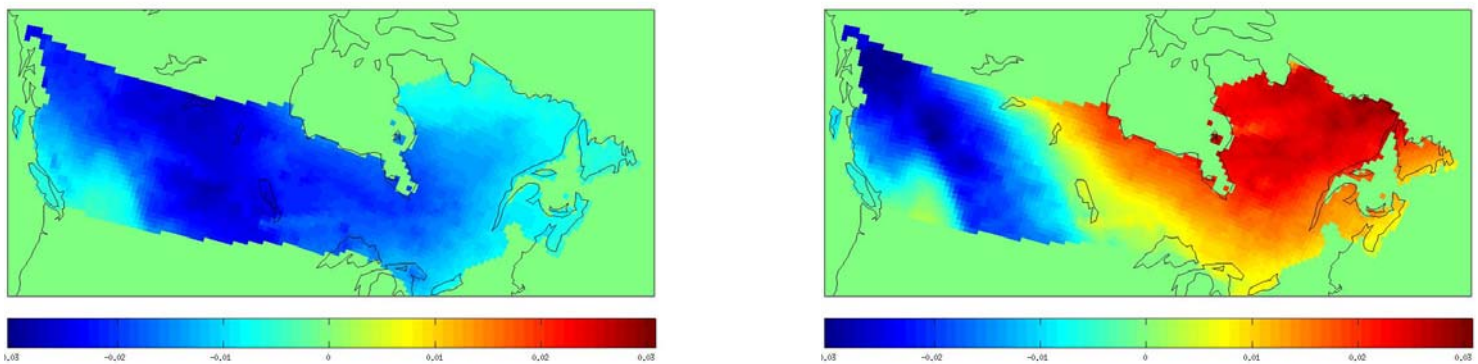
RCM evaluation: variability of fields and their links with atmospheric circulation

Spatial distribution the first two PC coefficients for ***winter minimum temperature***

Spatial pattern from observed gridded values and GEMCLIM (50-km)



a) first PC from ANUSPLIN **b)** second PC from ANUSPLIN



c) first PC from GEMCLIM **d)** second PC from GEMCLIM

ANUSPLIN (Tmin)					GEMCLIM (Tmin)				
%	winter	spring	summer	autumn	%	winter	spring	summer	autumn
PC1	55.1	61.2	52.9	51.9	PC1	57.9	67.5	56.9	61.1
PC2	24.5	17.8	13.3	26.0	PC2	20.9	11.3	15.7	18.8
PC3	7.5	5.7	7.3	6.6	PC3	8.0	7.3	9.5	6.6

How to address these uncertainties ?
Ex. Weighting procedure
Rationale behind its use

- Construct a system for probabilistic regional climate change Projections;

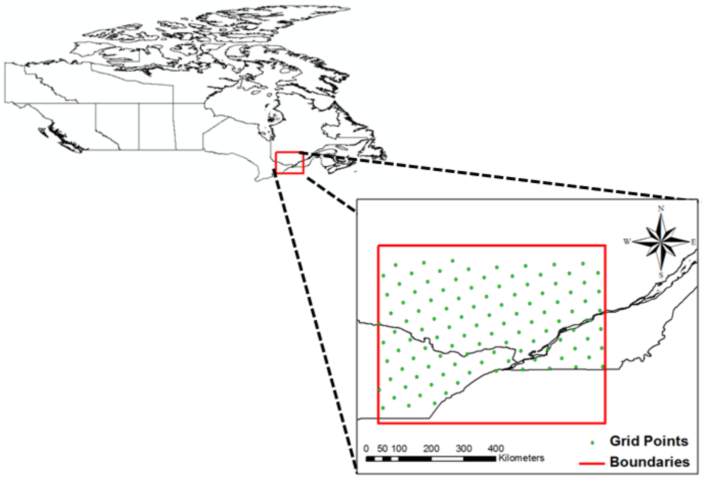
- Concerning RCMs, this included exploration of performance-based model weights;

- Allow the combination of individual model simulations in a more skilled sense than just taking each model as being equally good and providing arithmetic model averages and simple model spreads

Hence

Weighting scheme can be potentially useful to have comprehensive & independent evaluation against reanalyses/observations & to construct probabilistic scenarios

Application of the weighting scheme



Southern Quebec and Ontario regions

- 43.93 to 48.08 °N
- 71.97 to 78.13 °W
- 113 grid points

Climate Data (daily simulated and observed)

- 1) NARR, 2) CRCM4.1.1 driven by NCEP, 3) CRCM4.1.1 driven by ERA40, and 4) CRCM4.2.3 driven by ERA40
- ANUSPLIN (10-km gridded observations*) downgraded data on the CRCM grid (1961-2003)

*Hutchinson et al. (2009) : Canada-wide daily interpolated observations (10 km gridded climate dataset)

Common time window

- 1979-2001

Monthly weighting factors for the considered variables (aggregated per season)

- Daily precipitation, minimum, and maximum temperature

Methodology

➢5 Attributes (RCM or reanalysis against observations)

$$W_i = \prod_j f_j^{n_j}$$

- Relative Absolute Mean Error (from daily values): **ATT1**
- Annual variability (mid-term): **ATT2**
  - Difference in annual anomalies between observation and RCMs/reanalysis
- Spatial Pattern: **ATT3**
  - Spatial similarity of mean value between observation and RCMs/reanalysis at a grid point
- Extreme & median values: **ATT4**
  - 0.1, 0.5 and 0.9 percentile values
- Multi-decadal trend (long-term): **ATT5**

  Temporal trends in climate variables

Seasonal weighting factors averaged over the study area from NARR, CRCM4.1.1_NCEP, CRCM4.1.1_ERA40, and CRCM4.2.3ERA40 runs, computed with respect to ANUSPLIN downgraded values (Eum et al., 2010)

Variables	RCMs	Spring (MAM)	Summer (JJA)	Autumn (SON)	Winter (DJF)
Precipitation	CRCM4.1.1_NCEP	0.287	0.276	0.219	0.446
	CRCM4.1.1_ERA40	0.143	0.019	0.141	0.171
	CRCM4.2.3_ERA40	0.184	0.225	0.170	0.263
	NARR	0.386	0.481	0.470	0.120
Minimum Temperature	CRCM4.1.1_NCEP	0.254	0.243	0.315	0.207
	CRCM4.1.1_ERA40	0.247	0.238	0.171	0.289
	CRCM4.2.3_ERA40	0.132	0.299	0.223	0.279
	NARR	0.368	0.220	0.292	0.225
Maximum Temperature	CRCM4.1.1_NCEP	0.084	0.138	0.131	0.173
	CRCM4.1.1_ERA40	0.132	0.079	0.086	0.106
	CRCM4.2.3_ERA40	0.141	0.123	0.071	0.201
	NARR	0.643	0.660	0.711	0.520

The higher weighting factor represents the higher accuracy.

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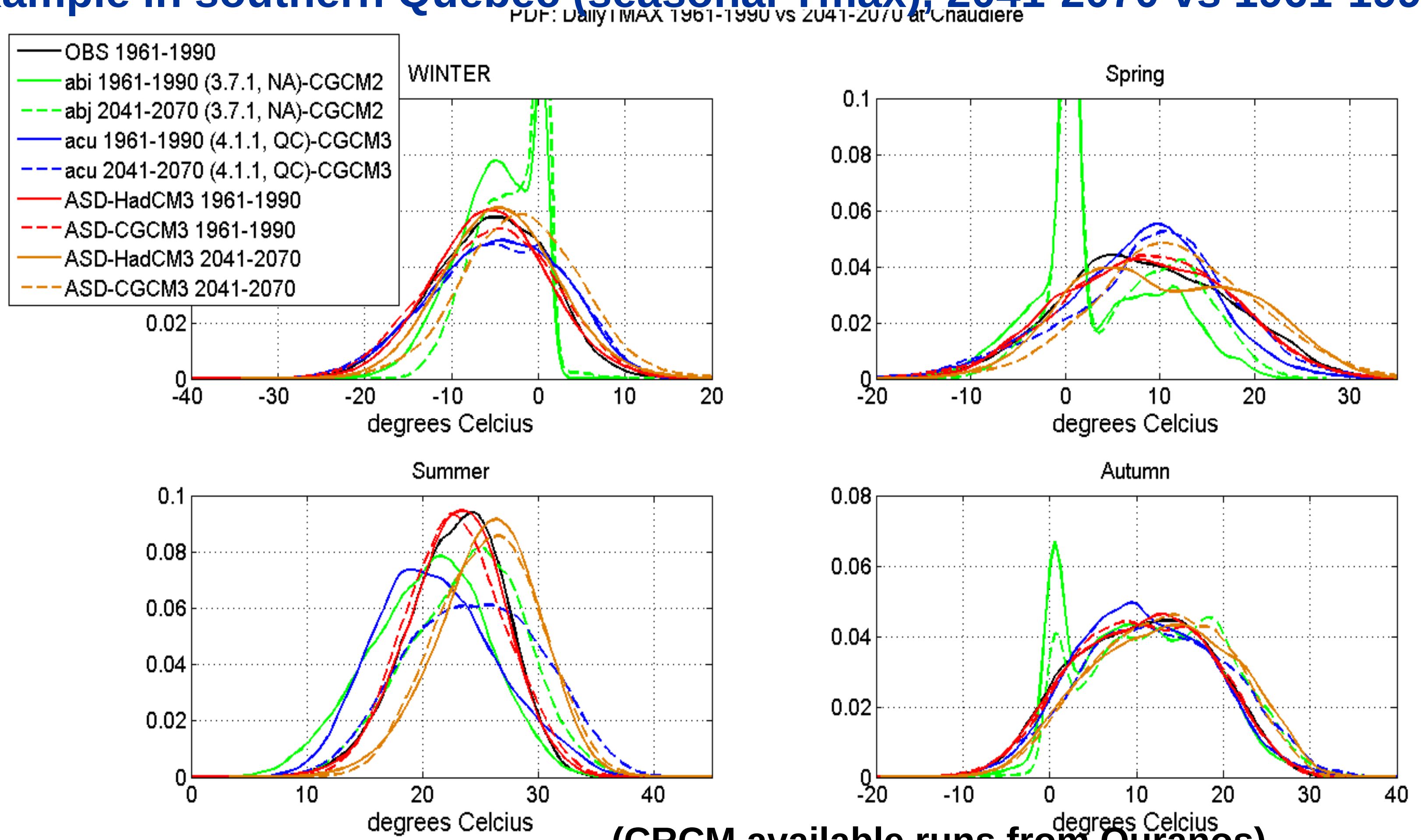
How to address these uncertainties ?

SIMPLE COMPARISON between different downscaling methods i.e. To construct PDF of future climate change from an ensemble of statistical & dynamical downscaling models

RCMs and Statistical Downscaling

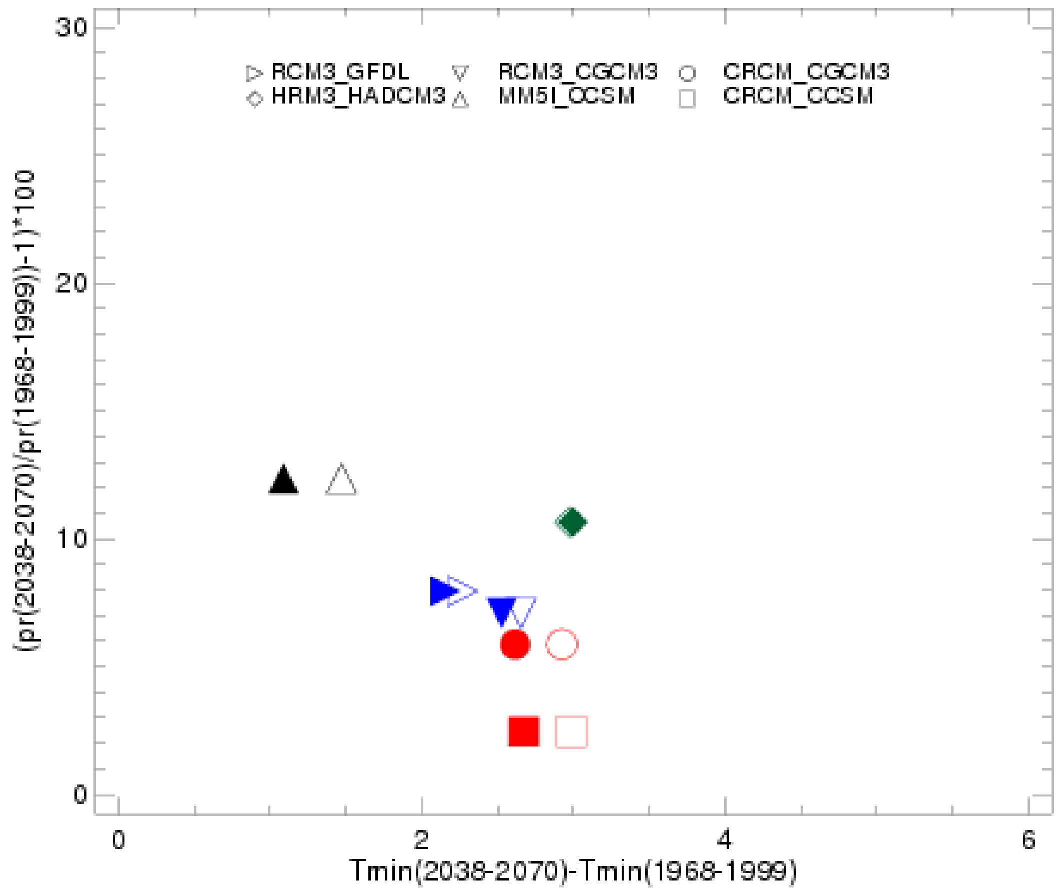
Example in southern Québec (seasonal Tmax), 2041-2070 vs 1961-1990



(CRCM available runs from Ouranos)

RCMs Scenarios (comparison of signals over southern Québec)

Annual Precipitation vs Temperatures (min. empty symbol; max. plain symbol) changes for 2050s (vs 1970-1999)



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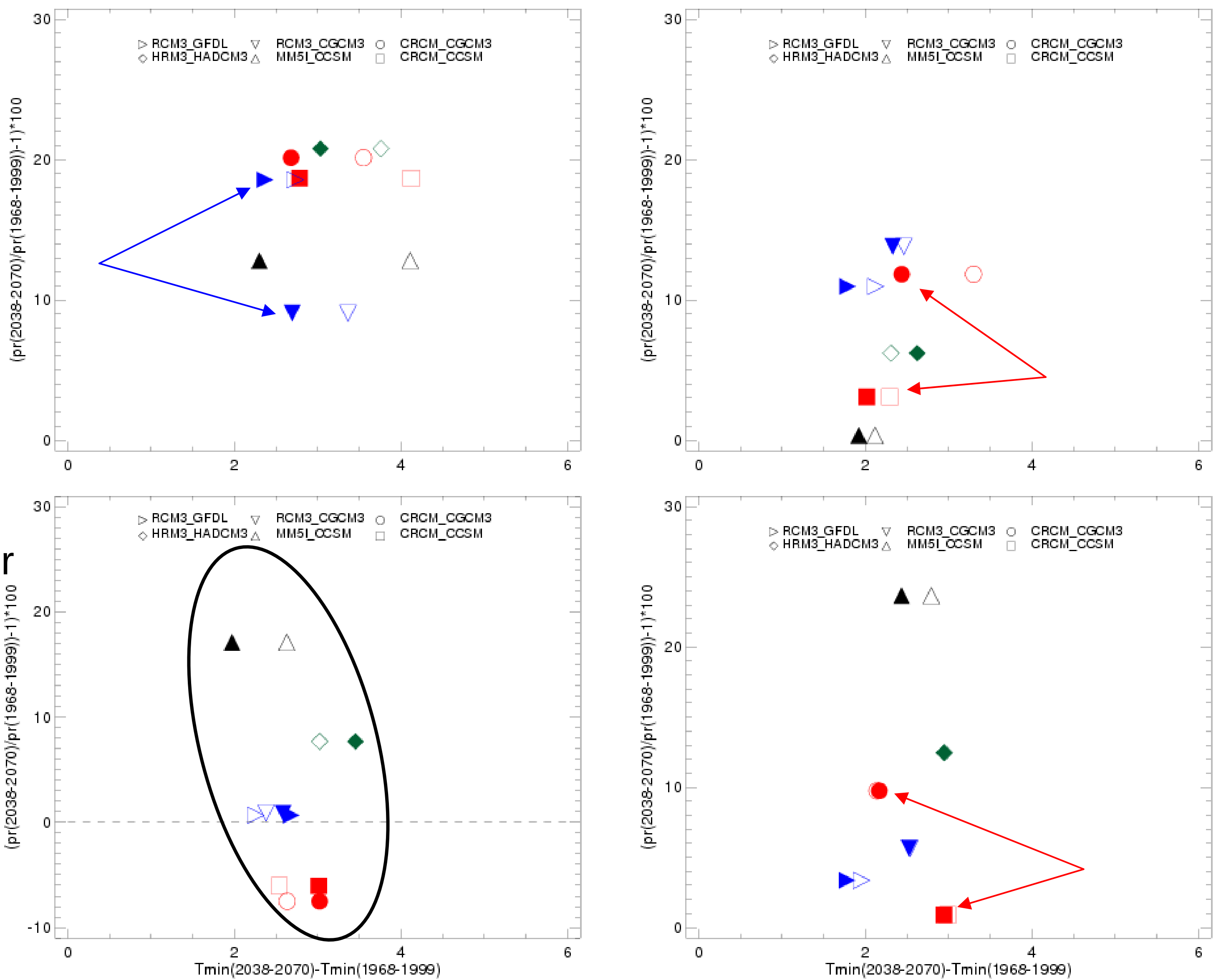
RCMs Scenarios (comparison of signals over southern Québec)

Seasonal Precipitation vs Temperatures (min. empty symbol; max. plain symbol) changes for 2050s (vs 1970-1999)



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Conclusion (RCMs evaluation and inter-comparison)

The results suggest that:

- As noted in previous studies (ex. over Europe), certain RCMs have systematic biases, and also a clear tendency to enhance these in more extremely cold or warm conditions;
- RCMs with different classes of model error, and biases are strongly seasonally based (ex. Large spread of accuracy for Temp. in winter)
- Quite good simulated values of temperatures across southern Québec from the Canadian RCM (not as much for precipitation)

Regional and seasonal variation or accuracy over whether the GCMs or the RCMs had the dominant influence.

Hence, the need for a comprehensive sampling of both (GCMs and GCMs/RCMs cascade or extensive matrix of simulations) is requisite in order to provide a set of projections suitable to inform risk assessments for adaptation

Conclusion on Climate variability and changes at the regional scale: what we can learn from various downscaling approaches

The results suggest that:

- Predictability of climate variability from RCMs:
  - ✓ Teleconnections indices (GCM driven; see CMIP conclusion and Harding et al. 2010) not explicitly yet analyzed within the RCM domains and their effects on surface variables
  - ✓ Storm track (synoptic scale): quite compatible with observed-reanalysis when driven by reanalysis (except strongest storms and associated winds; i.e. problematic for extremes ?)
  - ✓ Hazard problems (impact issues): under evaluation for combination of key variables (ex. storms with storm surge and oceanic waves; heat waves with various duration and threshold levels for both Tmin and Tmax joint occurrence)

Many Thanks for your attention !

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Eum, H.-I., P. Gachon, R. Laprise, T. Ouarda, and A. St-Hilaire (2010). Evaluation of regional climate model simulations versus gridded observed and regional reanalysis products using a combined weighting scheme. Climate Dynamics (Submitted, Nov. 2, 2010).

Hutchinson, M. F., et al., 2009: Development and Testing of Canada Winde-Interpolated Spatial Models of Daily Minimum-Maximum Temperature and Precipitation for 1961-2003. Journal of Applied Meteorologyand Climatology, 48, 725-741.

WEB SITE & LINKS (information):

- Climate Analysis Group: http://loki.qc.ec.gc.ca/GAC/ (further details about projects, and publications)

Works on downscaling intercomparison organized through a project entitled: « PROBABILISTIC ASSESSMENT OF REGIONAL CHANGE IN CLIMATE VARIABILITY & EXTREMES », NSERC Canadian project

- CANADIAN CLIMATE CHANGE SCENARIOS NETWORK (CCCSN): http://www.cccsn.ca

- DATA ACCESS & INTEGRATION (global predictors and RCM/GCM daily and sub-daily outputs for North America): http://loki.qc.ec.gc.ca/DAI/login-e.php