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Storm tracks activities over the Hudson Bay area and links with surface extremes: past and future changes

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Extremes Workshop, Winnipeg, 7-9 February, 2011

Content

- **Introduction** :
  - Main objectives of the study and outcomes
  - Main features of the Hudson Bay area (current & anticipated climate)
- **Methods**: data, storm track algorithm, diagnostic criteria
- **Results** :
  - Storm tracks characteristics (climato. 1979-2009 from NARR)
  - Storm track comparison between reanalysis and regional climate model (Canadian RCM, runs from Ouranos)
  - Under development : Buffer zone along the storms to analyze sensible areas affected by waves, winds, etc.
  - Links between temperature variables and NAO & BWA
- **Conclusion and next steps**

Main objectives of the project

MAIN OBJECTIVES

To support a vulnerability and adaptation study (coordinated by the Ministry of Transport of Québec) of the marine infrastructures in Nunavik (i.e. Hudson Bay area, Canada) to climate change:

✓ Improve the knowledge on water level variations, trajectories, the occurrence/recurrence and intensity of storms, as well as on the risk and scale of extreme events to come

✓ Provide necessary data and advice to help anticipate the impacts of climate change, i.e. maintenance program, define conservation and rehabilitation programs and users' safety along the Nunavik's coasts.

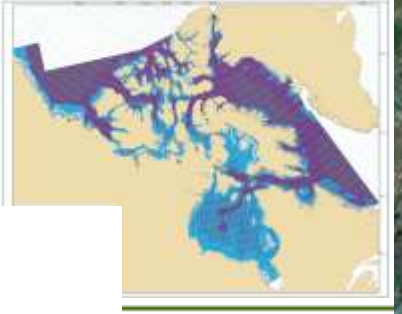
Main steps in analysing storms

- Analyze synoptic storm tracks and their main characteristics (intensity, duration/persistence & frequency) over the current period from:
  - ✓ Reanalysis products (regional, i.e. NARR, and global, i.e. NCEP and/or ERA40)
  - ✓ Various global and regional climate models (GCMs & RCMs), and forecast model (EC, GEM);

- Develop the links between storms and the associated variability and extremes in surface climate variables: final goal is to establish and evaluate the links between storms and oceanic waves and storm surge

- Analyze the potential changes in storm activities over the Hudson Bay area from available GCMs and RCMs simulations (i.e. future runs, on-going and future works) and their effects on changes in surface oceanic features.

INTRODUCTION



Relative sizes & features:

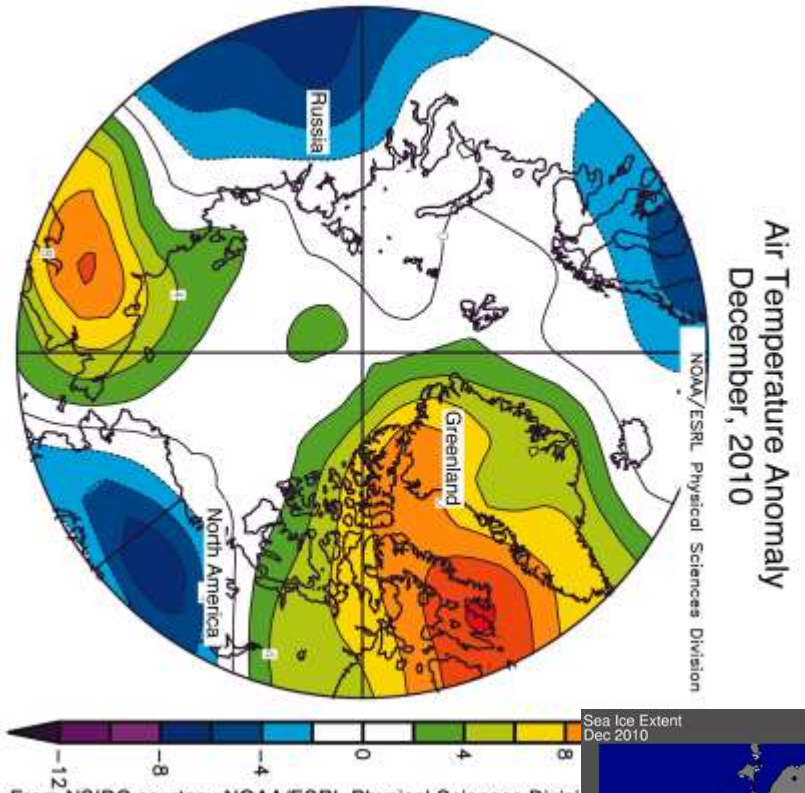
- Hudson Bay : 1.242 x 10^6 km^2 (Québec land area: 1.54 x 10^6 km^2)
- Relatively shallow feature, i.e. a mean depth of approximately 150 m

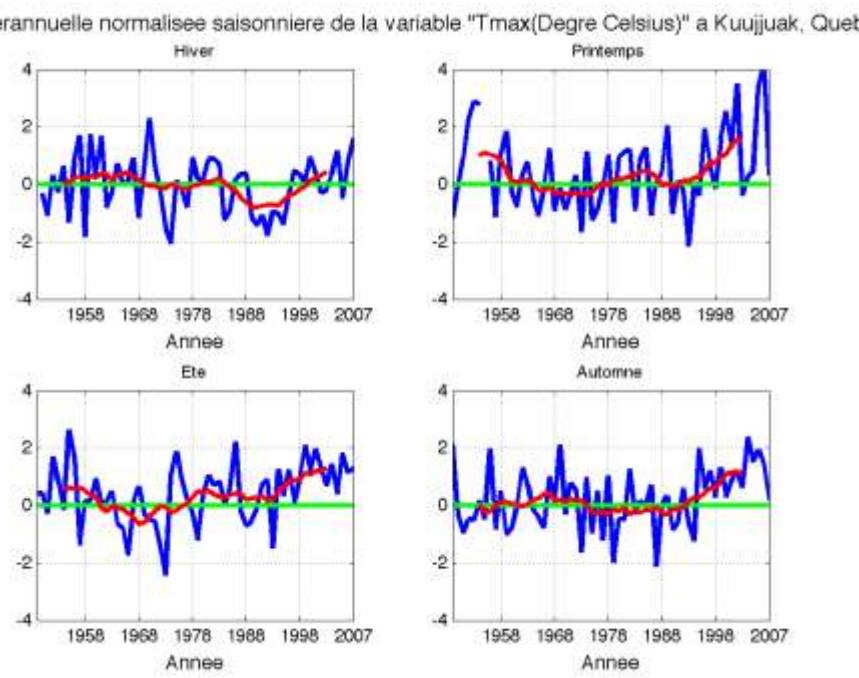
Characteristics (oceanic & atmospheric):

- Sea-Ice: Mid November to July (8-9 months)
- High tides (more than 10 m in Ungava Bay)
- Rapid answer of sea surface features (temp. & sea-ice) from atmospheric conditions & forcings (see Saucier et al., 2004)
- Attractive zone of synoptic & mesoscale cyclones (ex. polar lows, see Gachon et al., 2003) all over the year
- Cold atmospheric conditions (ex. median Temp. of -25/10°C in winter/summer) & windy area
- Located over one of the zone of the highest temperature gradients in Northern Hemisphere (polar vortex and coldest tropospheric area of the arctic basin; see Overland et al., 2004)

INTRODUCTION: Climate variability

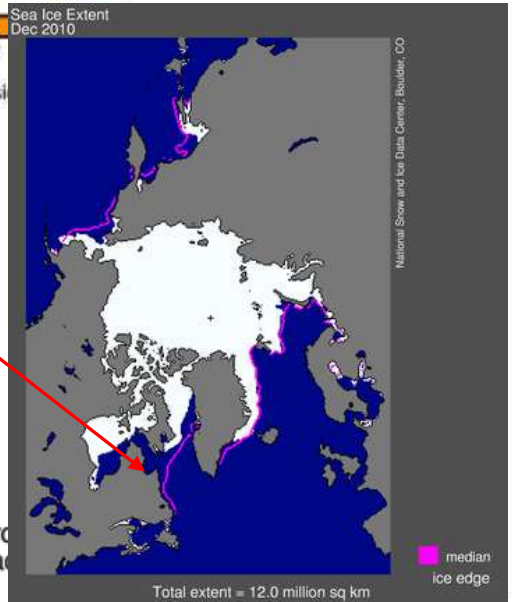
Ex. Temperature anomalies in Hudson Bay area

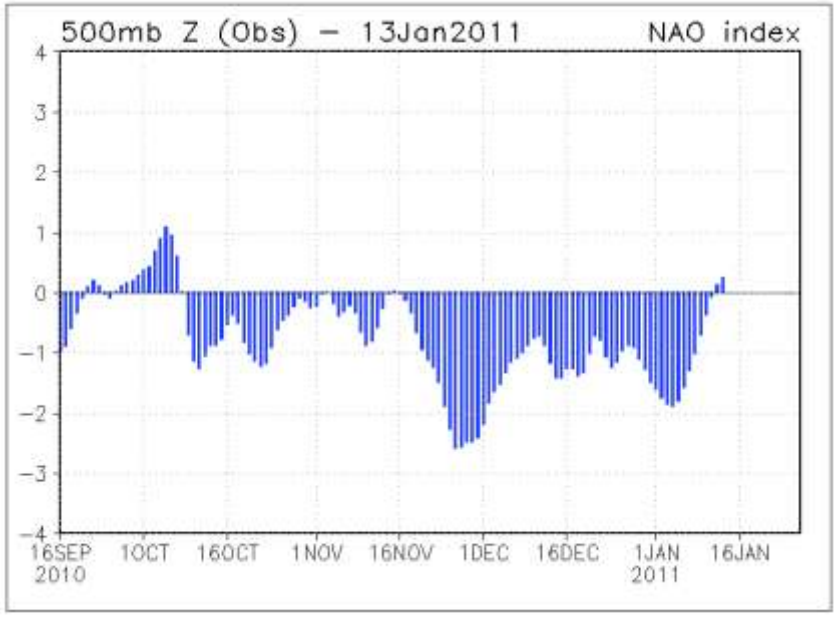




SD: 3 to 7°C from summer to winter at Kuujjuaq

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





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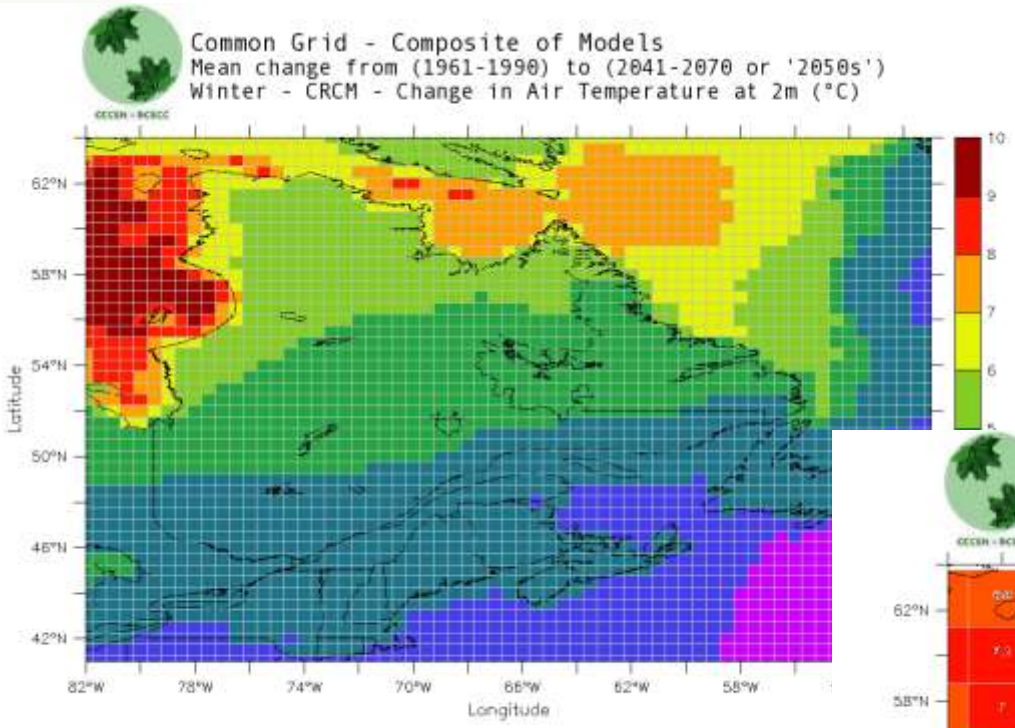
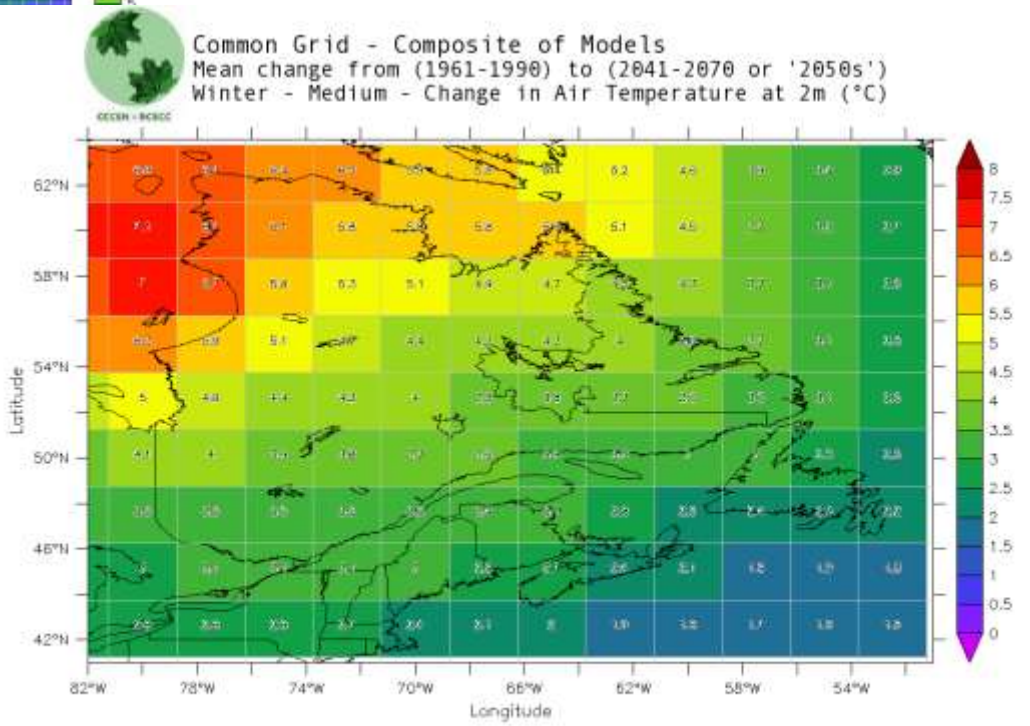
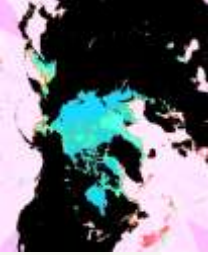
INTRODUCTION: Climate change (anticipated)

Ex. Temperature signals (winter) in Hudson Bay for 2050s (with respect to 1961-1990) from Canadian RCM and ensemble mean (GCMs)





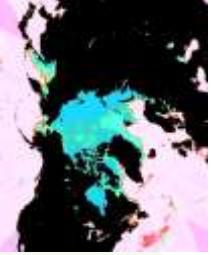
Source: CCCSN (2009). Ensemble Scenarios for Canada, 2009. Produced by the Canadian Climate Change Scenarios Network (CCCSN.CA). Editor: N. Comer. Adaptation and Impacts Research Section, Environment Canada..



Methods: data sources

List of data from various sources

Type of products	Description	Period	Original Resolution	Final or Used Resolution
NARR	North American Regional Reanalysis from NCEP	1979-2009	32 Km/3h	100 Km/3h
NCEP	Global Reanalysis from NCEP/NCAR	1979-2009	277Km/6h	100Km/3h
ERA40	Global Reanalysis from ECMWF	1979-2002	277Km/6h	100Km/3h
MRCC4.1.1	Canadian Regional Climate Model driven by NCEP (from Ouranos)	1979-2004	45 Km/6h	100Km/3h
MRCC4.2.3	Canadian Regional Climate Model driven by both NCEP & CGCM3 (from Ouranos)	1979-2100	45 Km/6h	100Km/3h
GEM regional	Canadian Forecast Model (high res. over Canada) from Environment Canada	1998-2009	24 Km/3h	100 Km/3h



Methods: storm track algorithm

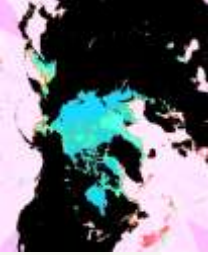
FROM the Algorithm developed by Sinclair (1997) & modified by Rosu (2005) & Radojevic (2006).

Identification of cyclonic centres:

- From the wind of gradient (or geostrophic), the vorticity is computed
- Identify cyclonic centres near the surface (1000-hPa) using the maximum of vorticity
- Select synoptic systems : critical threshold for the vorticity (ex. 2.5 x 10^{-5} s^{-1}) according to the orographic features

Use the following variables:

- Topography (i.e. geopotential topography)
- Geopotential height at 1000-hPa (use to compute the wind & vorticity)
- Wind at 500-hPa (use to anticipate the future location/point of the track)



Methods: storm track analysis and diagnostic criteria

Main Features to take into account:

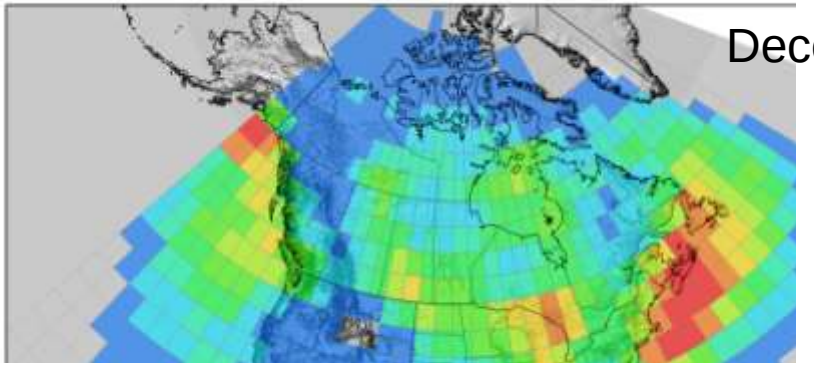
- Occurrence:
  - ✓ Density of storms
  - ✓ Cyclogenesis & cyclolysis
- Local re-development or stalled features:
  - ✓ Density of cyclonic centres (per track or along the track, i.e. stalled or re-development)
  - ✓ Maximum or minimum vorticity development (i.e. gradient) between 2 consecutive cyclonic centres
- Speed and Duration :
  - ✓ Speed of moving of storms
  - ✓ Mean duration per local area (i.e. persistence)
- Dimension (spatial):
  - ✓ Mean circulation or diameter of storms (i.e. affecting surface variables)
- Intensity & wind features:
  - ✓ Mean intensity per cyclone
  - ✓ Density of most intense storms (vorticity threshold)
  - ✓ Mean intensity of winds under various direction along the track
  - ✓ Maximum winds speed along the track (per direction)

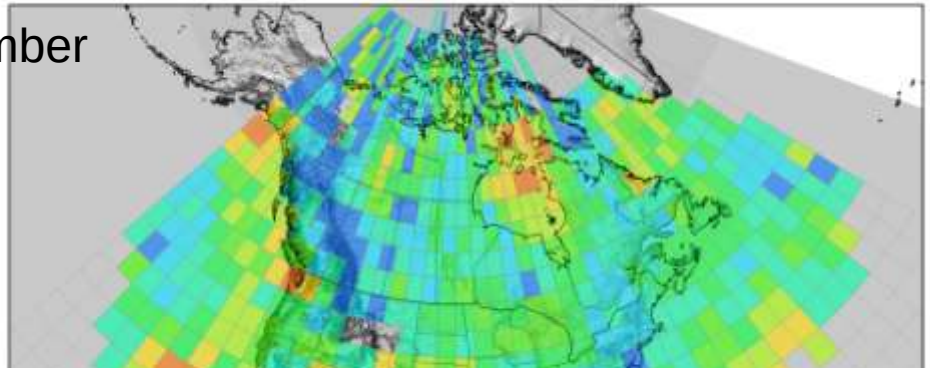
Strom track features over the current period (i.e. NARR): density of storms (i.e. occurrence) and persistence (stalled & re-development of cyclones, i.e. cyclonic centres per track) over winter and summer months

Density of Storms

Density of Cyclonic Centres per storms

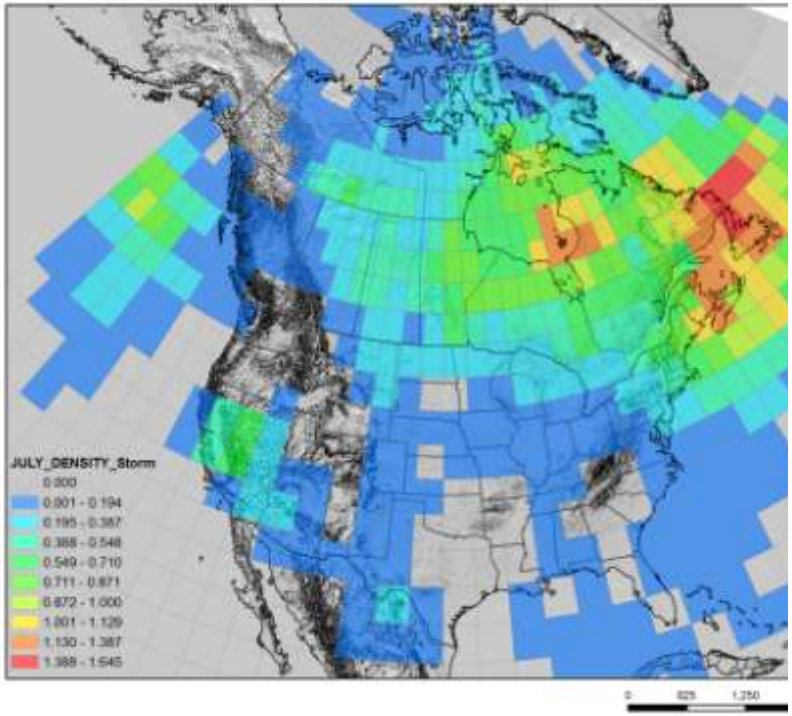
December

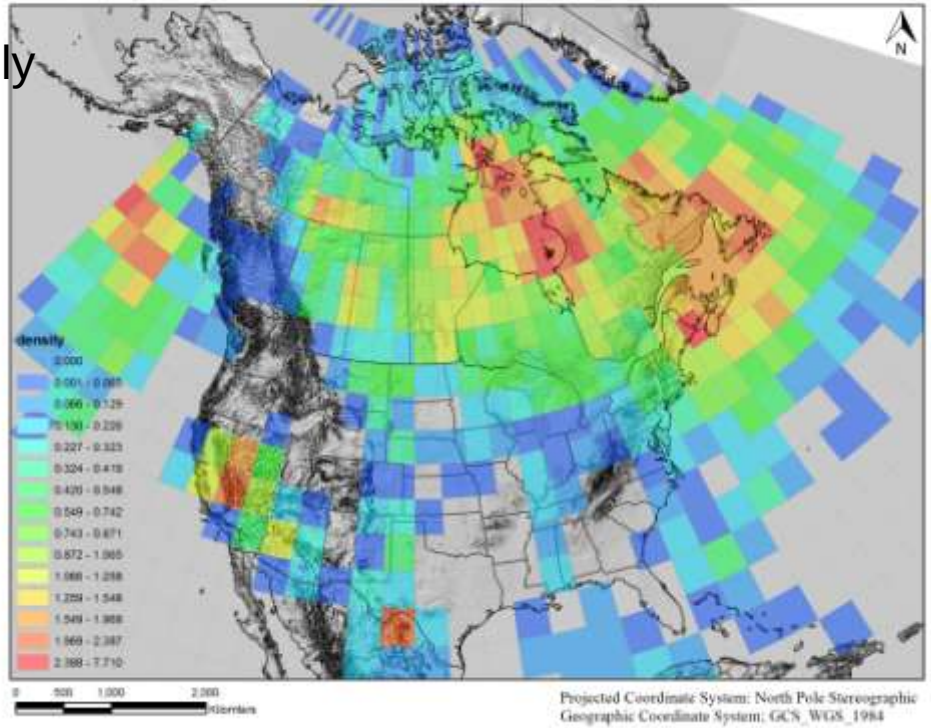




July Density of Cyclone Centers (1979-2009) NARR / grid 300 KM

July



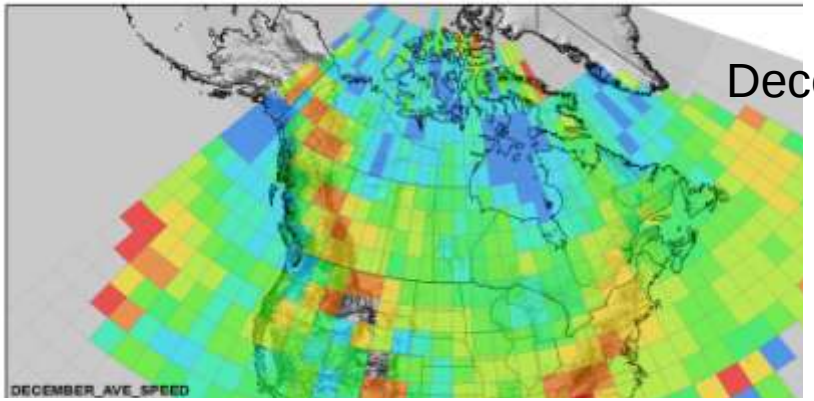


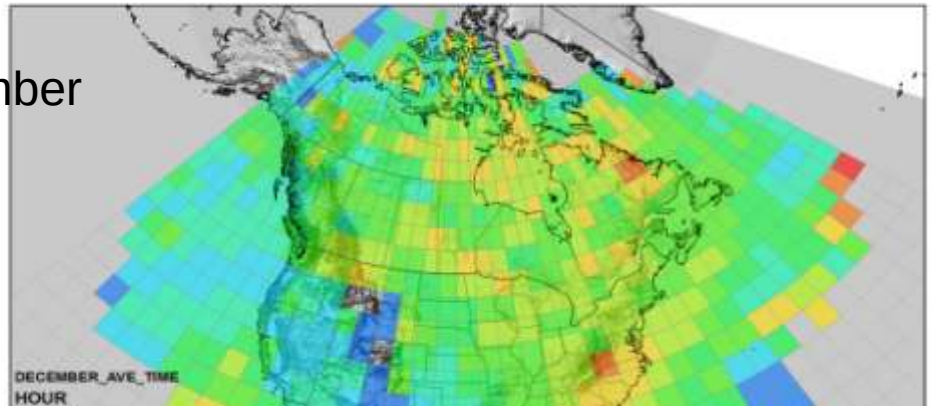
Strom track features over the current period (i.e. NARR): speed of moving (km/h) or mean duration (hour) over winter month (ex.December)

Speed of moving

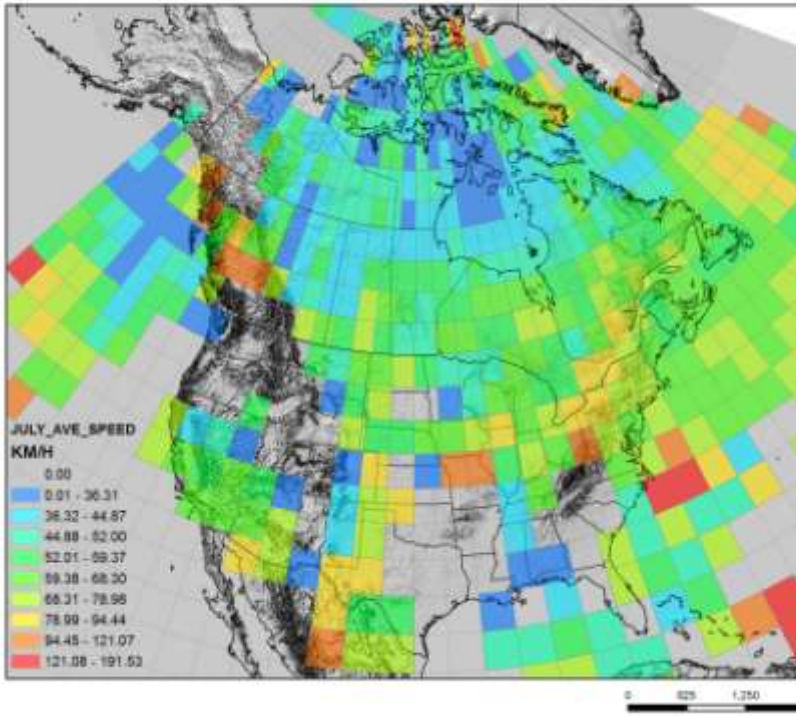
Mean duration

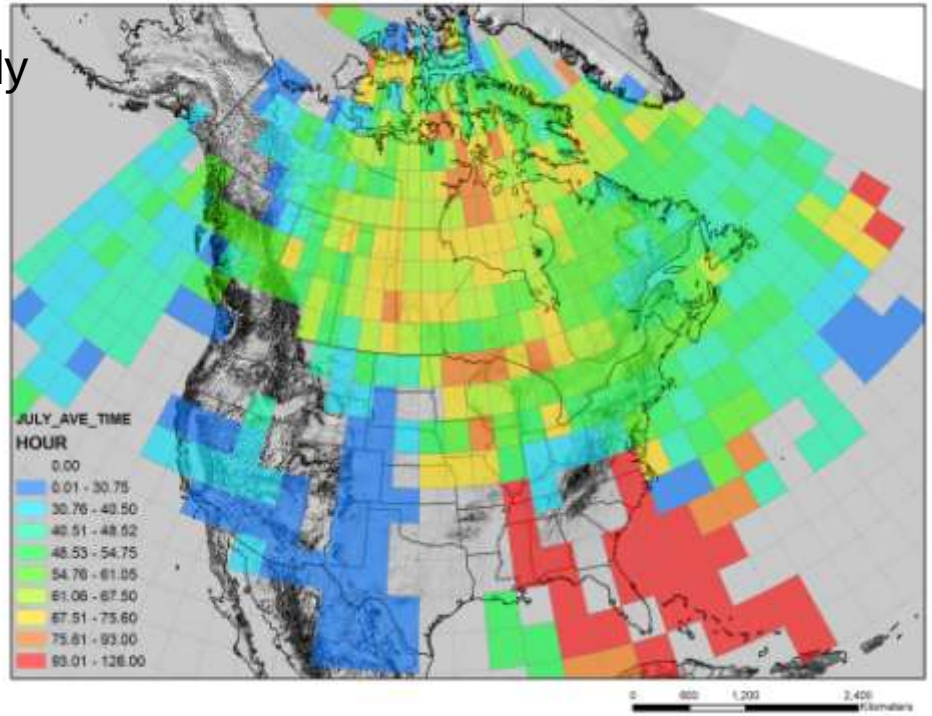
December





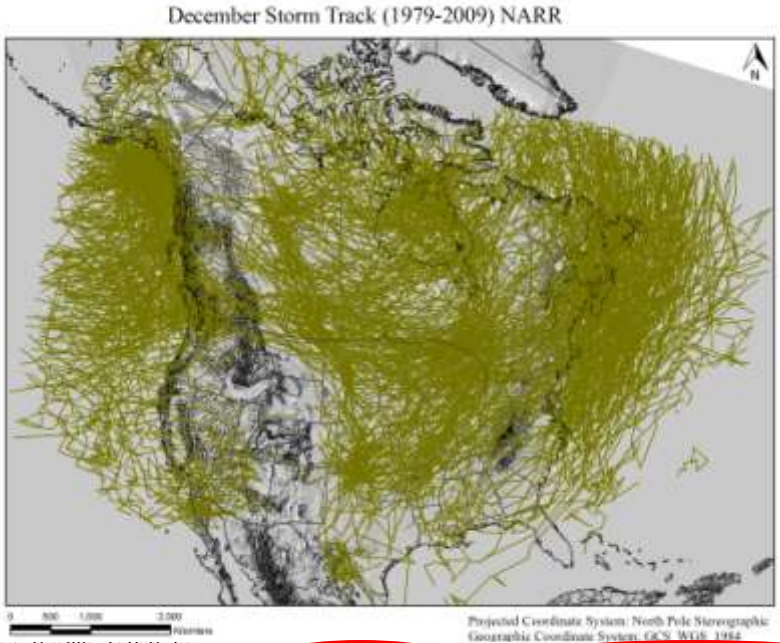
July



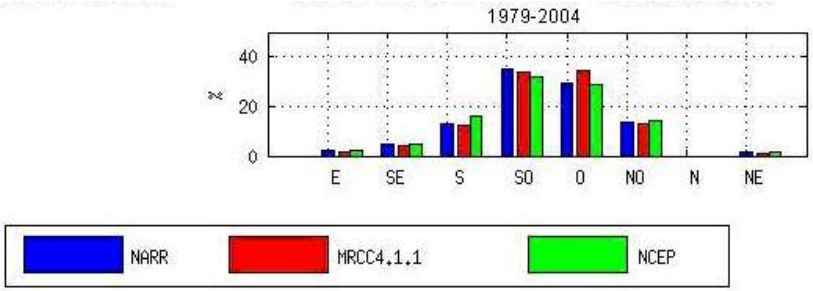


RCM evaluation over the current period (i.e. vs NARR and NCEP):
origin of storms track (per direction), mean intensity, mean duration and density of intense storms (6 x 10^{-5} s^{-1})

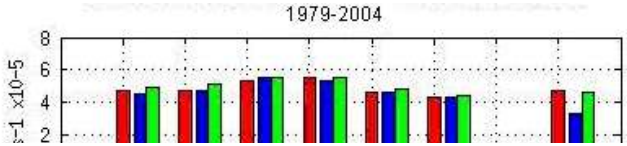
ANALYSIS OVER THE HUDSON BAY AREA (ex. December month)

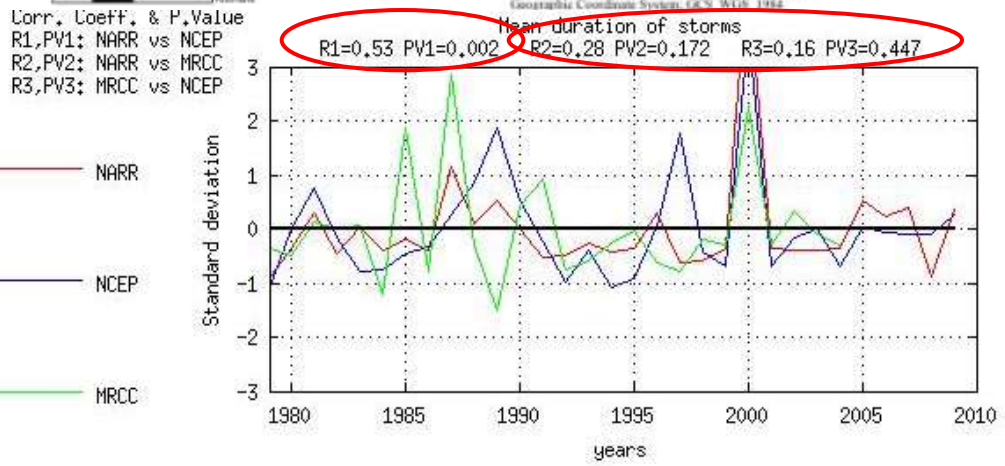


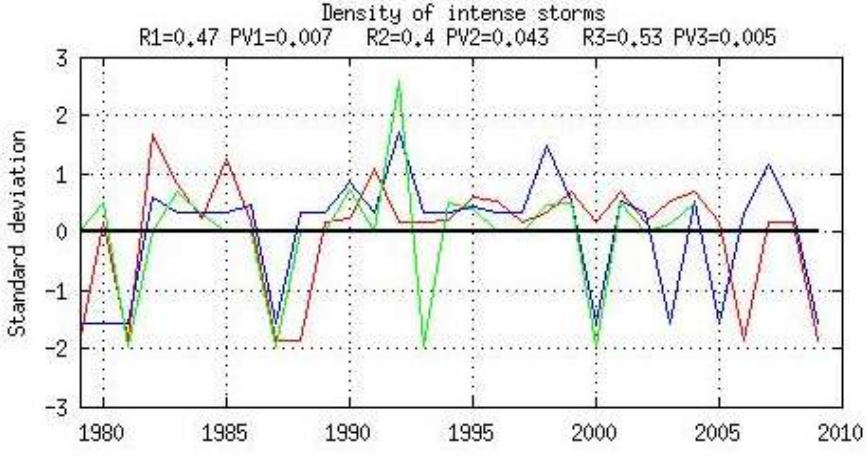
Origin of cyclone per direction



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



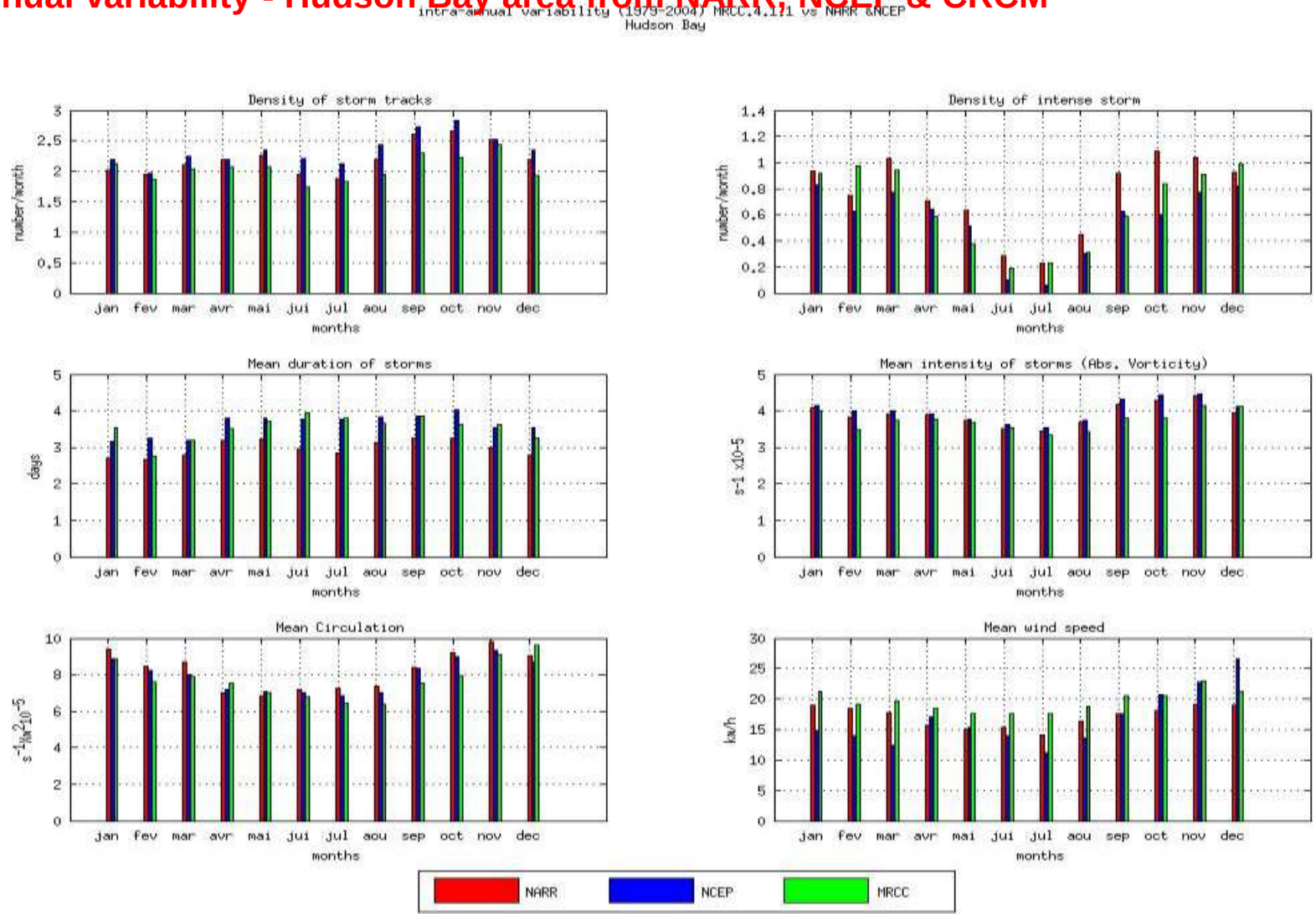


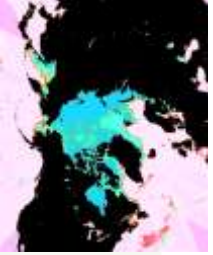


Results : storm track analysis - Hudson Bay

(comparison between different data sources)

Intra-annual variability - Hudson Bay area from NARR, NCEP & CRCM

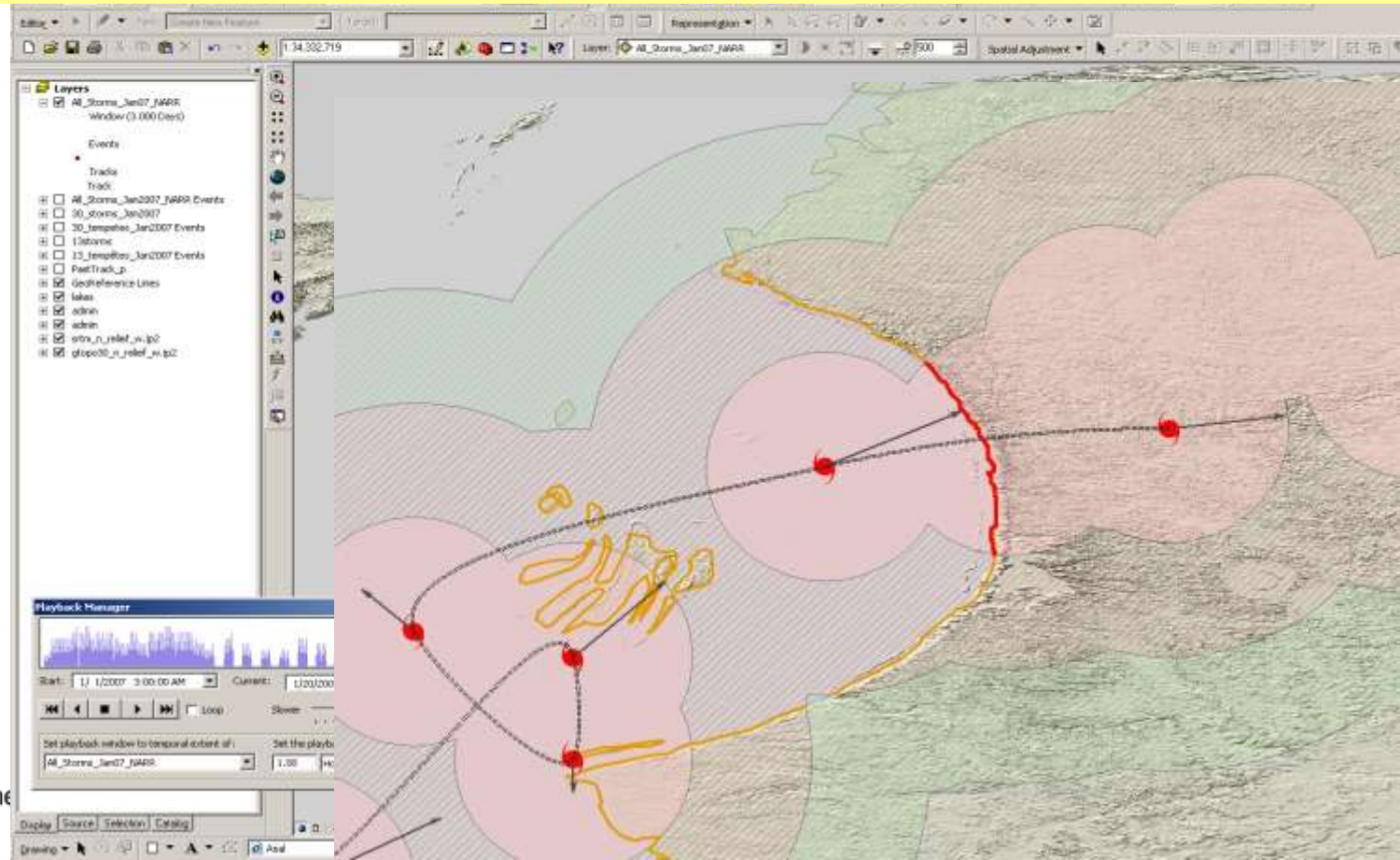




Under development: Links with surface extremes & Maritime infrastructures

Inputs from Ethan Gibney (NOAA) who has developed the code using ArcGIS which allows to follow storm tracks (use in Atlantic storm track activities, ex. Hurricane)

Ex. using **ArcGIS to define buffer zone along each storm with strong winds, significant waves, etc.**



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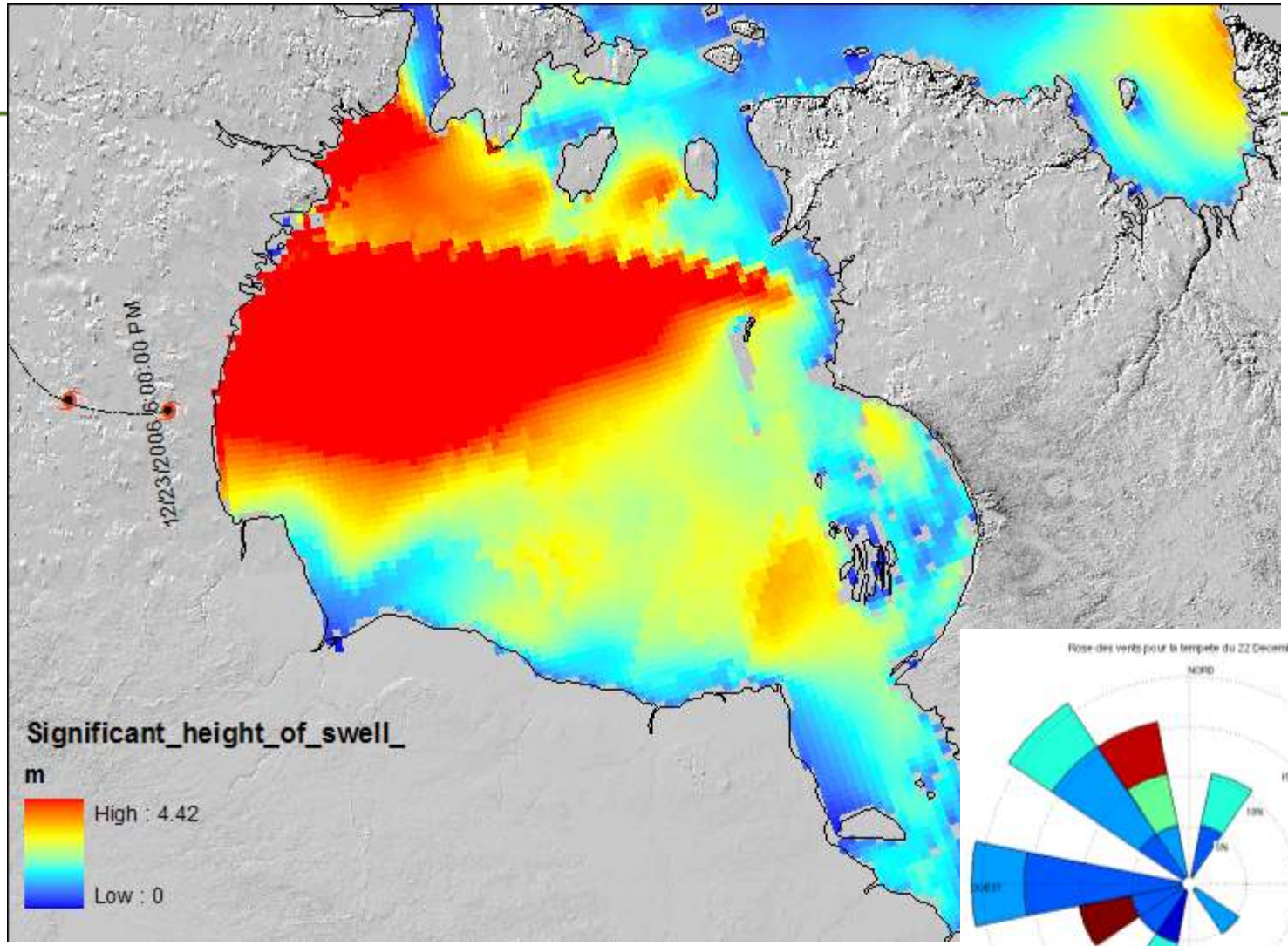
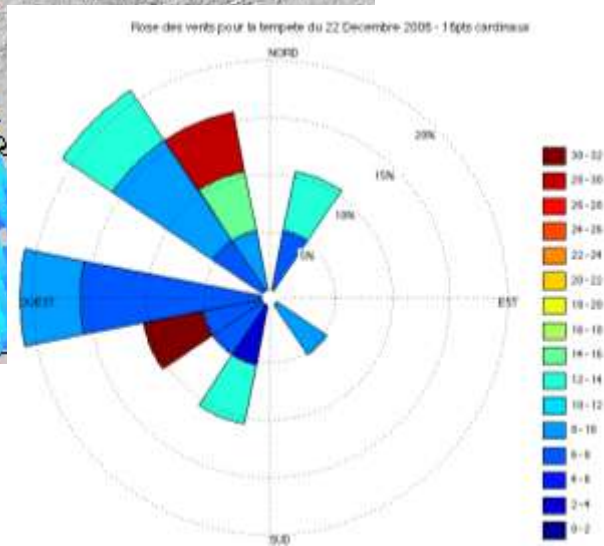
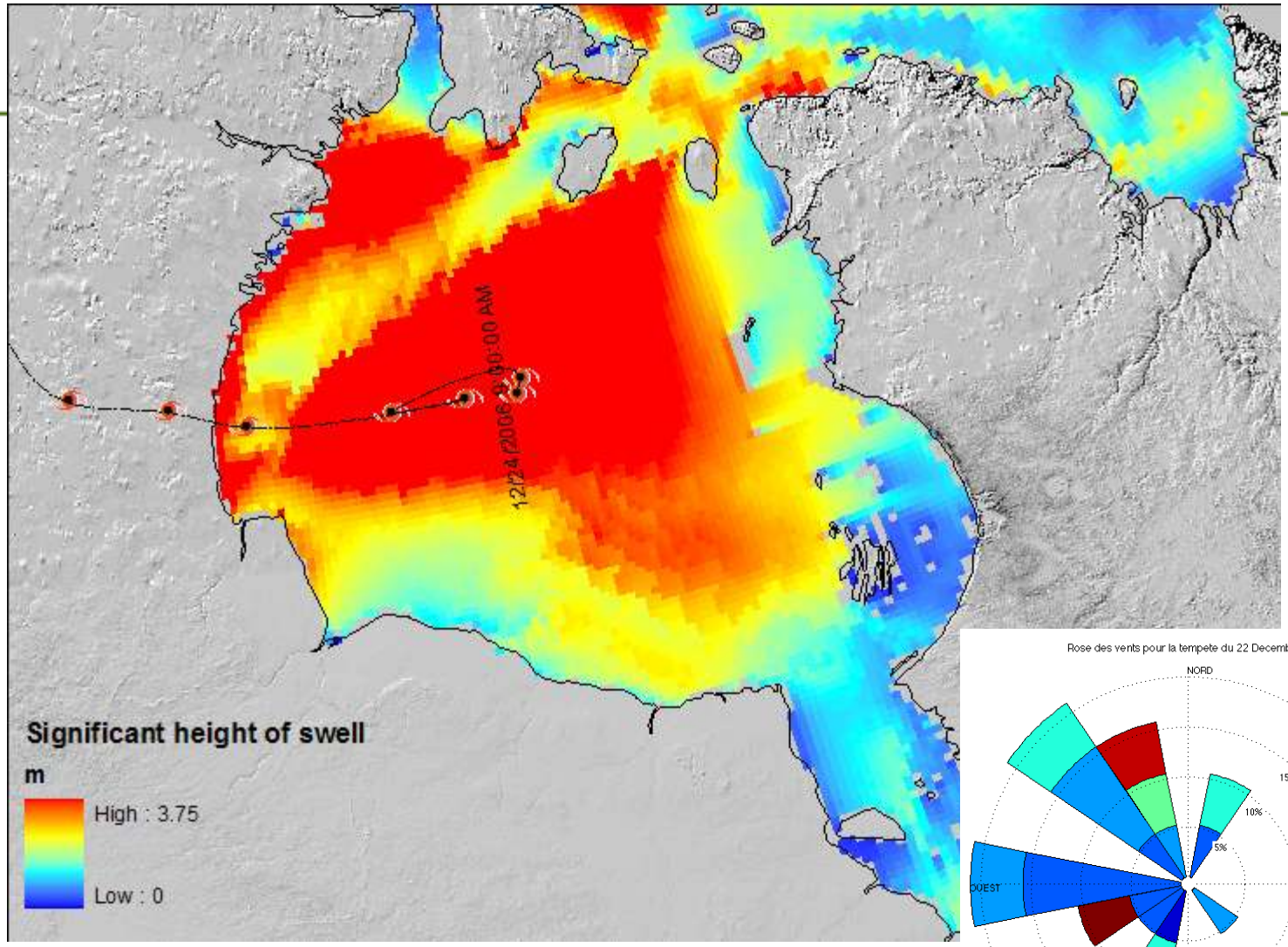
Next step: Integrate oceanic waves in the buffer zone

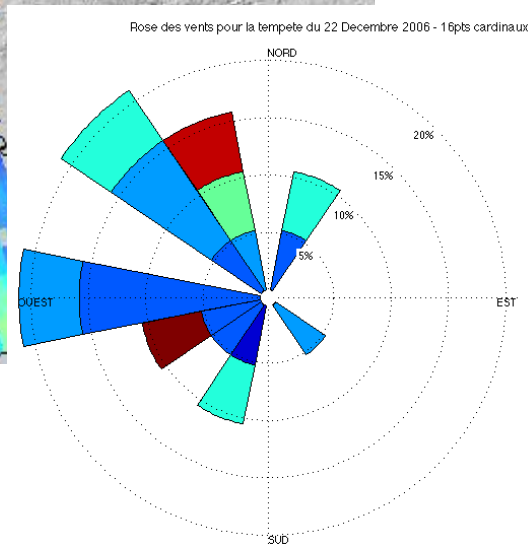
Storm33 December 22..26-2006 (NARR) / Wave Model (EC) Hudson Bay





Storm33 December 22..26-2006 (NARR) / Wave Model Hudson Bay





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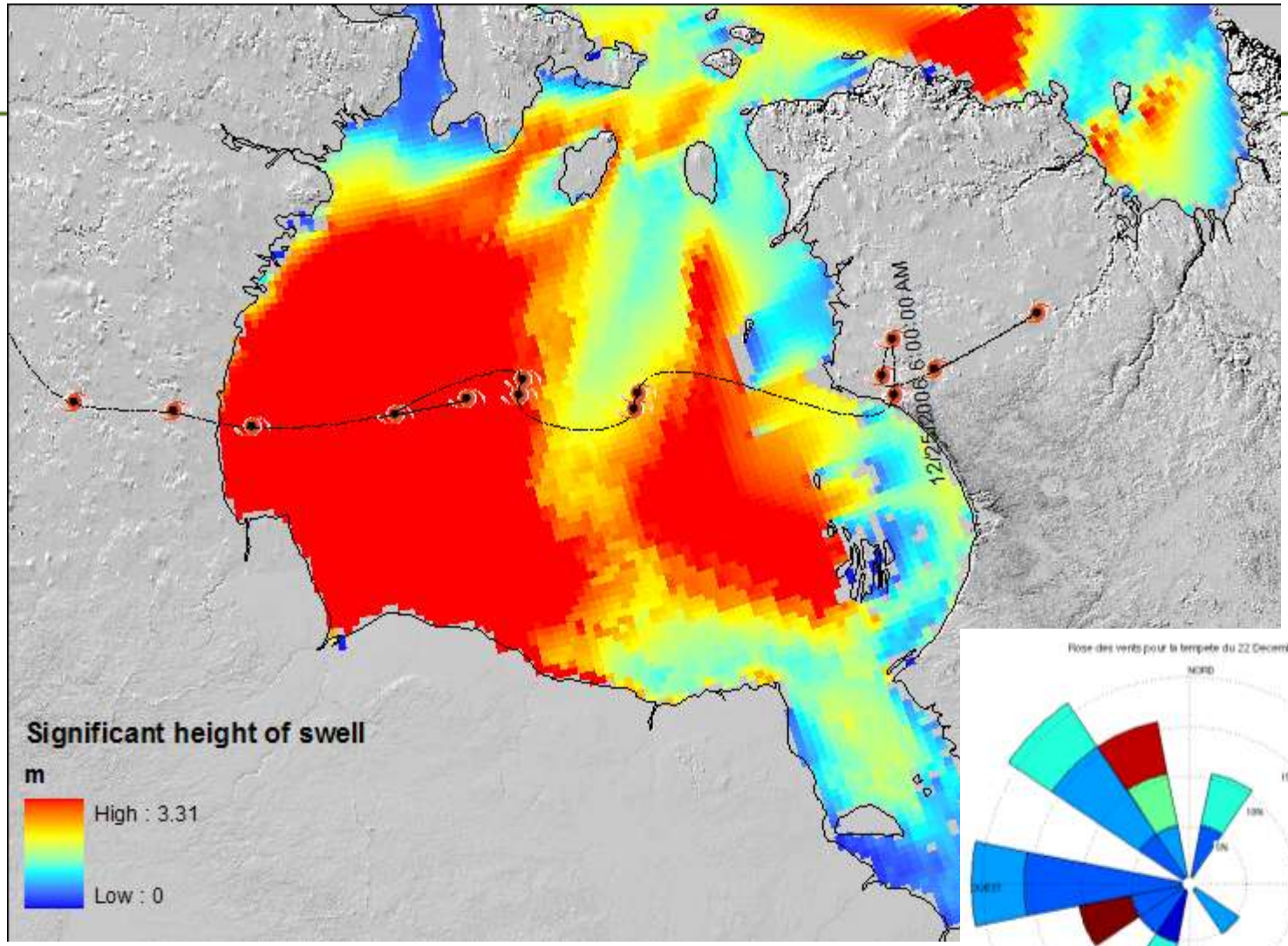
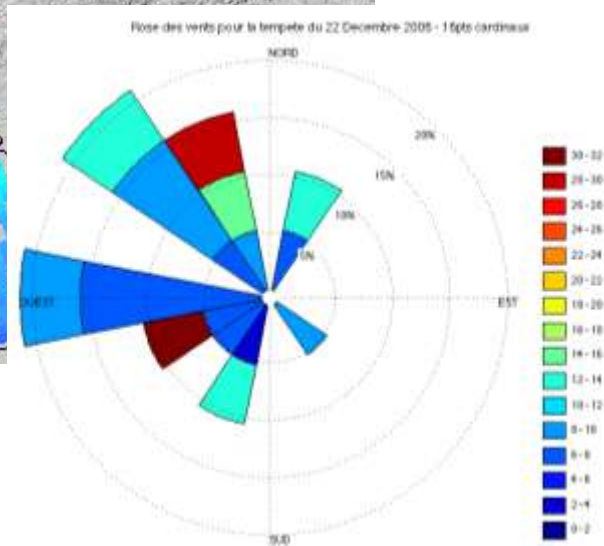
Storm33 December 22..26-2006 (NARR) / Wave Model Hudson Bay





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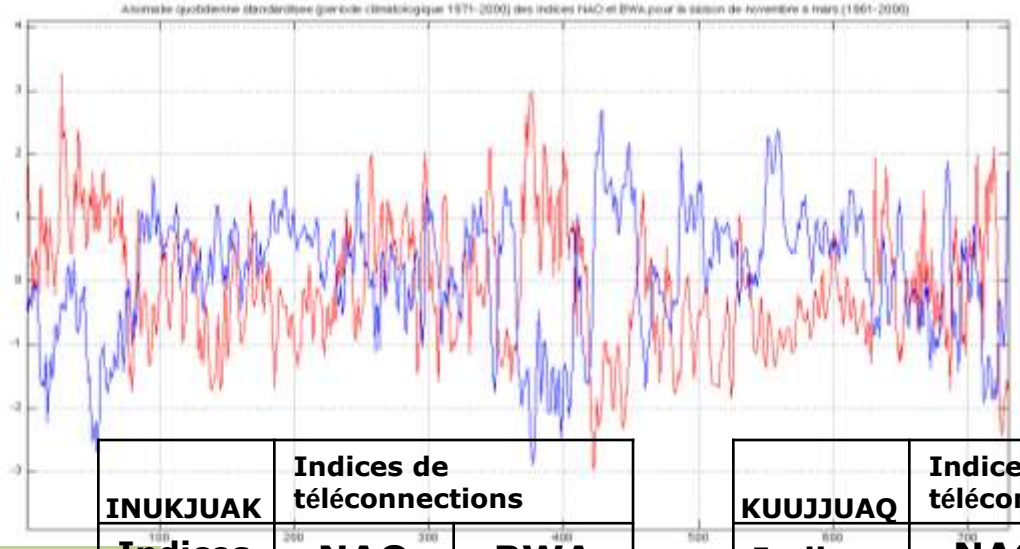
Links between temperature indices and NAO & BWA (Nov-March seasonal standardized variables)



Daiy basis
CC = -0.43

Seasonal
CC = -0.80
(NAO vs BWA)

Statistically significant at 95-99% level

INUKJUAK	Indices de téléconnections	
Indices	**NAO**	**BWA**
Tmin01p	**0,01**	**0,16**
Tmin05p	**-0,01**	**0,24**
Tmin10p	**-0,17**	**0,40**
Tmin90p	**-0,21**	**0,35**
Tmin95p	**-0,23**	**0,32**
Tmin99p	**-0,15**	**0,23**
Tmax10p	**-0,32**	**0,58**
Tmax90p	**-0,19**	**0,36**
Tmax95p	**-0,31**	**0,48**
Tmax99p	**-0,21**	**0,37**

KUUJJUAQ	Indices de téléconnections	
Indices	**NAO**	**BWA**
Tmin01p	**0,022**	**0,31**
Tmin05p	**-0,11**	**0,48**
Tmin10p	**-0,15**	**0,50**
Tmin90p	**-0,27**	**0,55**
Tmin95p	**-0,22**	**0,41**
Tmin99p	**-0,19**	**0,41**
Tmax10p	**-0,38**	**0,67**
Tmax90p	**-0,35**	**0,51**
Tmax95p	**-0,28**	**0,49**
Tmax99p	**-0,22**	**0,38**

IQALUIT	Indices de téléconnections	
Indices	**NAO**	**BWA**
Tmin01p	**-0,34**	**0,50**
Tmin05p	**-0,47**	**0,65**
Tmin10p	**-0,45**	**0,61**
Tmin90p	**-0,41**	**0,58**
Tmin95p	**-0,36**	**0,48**
Tmin99p	**-0,45**	**0,51**
Tmax10p	**-0,51**	**0,65**
Tmax90p	**-0,53**	**0,63**
Tmax95p	**-0,48**	**0,55**
Tmax99p	**-0,40**	**0,54**

BWA (Baffin/ West Atlantic): Calculated as half the difference of the 500-hPa Geopotential heights between Baffin Island (65°N, 60°W) and West Atlantic (30°N,60°W). See Shabbar *et al*. (1997)

Links between temperature (daily min. and max.) and NAO & BWA:

EOF from 9 observed stations (Hudson Bay) and Spearman correlation between PCs and NAO or BWA (Nov. – March, daily variables)

Correlation with daily normalized values

PCs on Tmin (daily) from HB stations	NAO	BWA
PC 1 (52.02%)	0.19	-0.36
PC 2 (15.27%)	-0.12	0.12

PCs on Tmax (daily) from HB stations	NAO	BWA
PC 1 (50.86%)	0.19	-0.35
PC 2 (17.37%)	-0.13	0.15

Correlation with seasonal normalized values

PCs on Tmin from HB stations	NAO	BWA
PC 1 (70.45%)	0.45	-0.74
PC 2 (19.08%)	-0.51	0.45

PCs on Tmax from HB stations	NAO	BWA
PC 1 (73.08%)	0.54	-0.78
PC 2 (17.30%)	-0.41	0.38

Conclusion & further steps

Storm track characteristics and comparison (Hudson Bay area)
High density of cyclonic centres

- High density of cyclonic centres, re-development, weak speed and high duration over HB
- Quite compatible storms are produced during the years (intra- & interannual scales) by both the reanalysis products and regional climate model (mean density, circulation, intensity, and duration of storms);
- More differences between models (RCM) vs. reanalysis for the most intense events and winds.

In progress: Links with surface extremes & Maritime infrastructures

- Strong large-scale and regional scale influences (ex. NAO & BWA with more effects on the eastern area, and stronger links with BWA) on mean and extremes of Temp.
- Fluctuations of storms (density, circulation, intensity, duration, origin, and persistence vs. occurrence) and links with blocking events or other relevant indices (ex. NAO, BWA and other indices) are underway
- The analysis of RCM driven by GCMs are underway (1st results suggest that the intra-annual variability of storms is less accurate than with reanalysis driven conditions) using CRCM and runs from NARCCAP;
- The changes in storms will be soon analyzed using future simulations (ex. CRCM driven by CGCM3; RegCM3 driven by GFDL, etc.).

References

Gachon, P. 1999. Effets de la distribution de la glace marine sur le d´eveloppement des d´epressions `a m´eso-´echelle et sur le climat régional (Effects of the sea-ice distribution on mesoscale low pressure development and on regional climate). Ph.D. Thesis, Université du Québec à Montréal, Montréal, Canada. 352 pp.

Gachon, P., R. Laprise, P. Zwack and F.J. Saucier, 2003: The effects of interactions between surface forcings in the development of a model-simulated polar low in Hudson Bay, *Tellus*, **55A**, 61-87.

Radojevic, M, 2006: Activité des cyclones Extra-tropicaux simulés par le modèle canadien de circulation general. Mémoire de maîtrise en Sciences de l'Atmosphère, Université du Québec à Montréal, Montréal, Québec, Canada, 119p.

Rosu, C., 2005 : Les caractéristiques des cyclones et l'apport d'eau dans les bassins versants du Québec Mémoire de maîtrise en Sciences de l'Atmosphère, Université du Québec à Montréal, Montréal, Québec, Canada, 118p.

Saucier, F.J., S. Senneville, S. Prinsenberg, F. Roy, P. Gachon, D. Caya, and R. Laprise, 2004: Modeling the ice-ocean seasonal cycle in Hudson Bay, Foxe Basin and Hudson Strait, Canada. *Climate Dynamics*, **23**, 303-326.

Sinclair, R.M., 1997: Objective Identification of Cyclones and Their Circulation Intensity, and Climatology, *Weather and Forecasting*, **12**, 595–612.

Acknowledgements

- Environment Canada (Adaptation and Impacts Research Section and Meteorological Service of Canada-Québec region) for financial and in-kind support;
- The National Sciences and Enginering Research Council of Canada for its financial support
- My colleagues at the University of Québec at Montréal (R. Laprise)