LETTER OF INTENT

Request for three years funding in support of the project

Impact of observing systems and predictability on forecasting extreme weather events in the short, medium and extended range: a Canadian contribution to THORPEX

Prepared by Pierre Gauthier, PI for this project

Principal investigator: Pierre Gauthier

Adjunct Professor
Department of Earth and Atmospheric Sciences
Université du Québec à Montréal
C.P. 8888 Succ. Centre-ville
Montréal, Québec H3C 3P8

Research Scientist
Data Assimilation and Satellite Meteorology Division
Meteorological Service of Canada
2121, Trans-Canada
Dorval, Québec H9P 1J3

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1. Introduction

THe Observing-system Research and Predictability EXperiment (THORPEX) is a ten-year international research program, proposed under the auspices of the World Meteorological Organisation/World Weather Research Program (WMO/WWRP). Its *International Science Steering Committee* (ISSC) is co-chaired by Dr. Mel Shapiro (NOAA/IPO) and Prof. Alan J. Thorpe (University of Reading) who are the instigators of this project. Dr. Michel Béland of the Meteorological Service of Canada currently chairs the International Core Steering Committee. Information on THORPEX can be found on the following Web site:

http://www.mmm.ucar.edu/uswrp/programs/thorpex.html

As stated in the THORPEX program overview, this program

> "(...) will examine predictability and observing system issues, and establish the potential to produce significant statistically-verifiable improvements in forecasts of high-impact weather. The program builds upon and coordinates advances being made in the operational forecasting and basic-research communities. The weather events to be considered include systems of mid-latitude, arctic, or tropical origin, are primarily synoptic scale, and often contain significant embedded mesoscale features. THORPEX is fully global in scope (...)" (Shapiro and Thorpe, *THORPEX Program Overview 2002*).

In recent years, targeting of observations has been used in measurement campaigns like the Fronts and Atlantic Storm-track EXperiment (FASTEX), the NORth Pacific EXperiment (NORPEX) and the Winter Storm Reconnaissance program (WSR). Targeting makes it possible to establish where new observations could lead to the most significant improvement to forecasts of developing meteorological systems. The

targeting methods are based on sensitivity functions, which identify those regions where small changes to the initial conditions could translate into significantly different forecasts. Different approaches are used based on either adjoint modelling or the ensemble transform technique.

The impact of the collected data has been shown to depend on the way the assimilation is performed and this can lead to significantly different conclusions. One of the key motives for THORPEX is to experiment with different targeting methods and assess the impact of the collected data within different assimilation/forecasting systems. Its long-range goal is to evaluate how to optimally use observations with a particular emphasis on satellite data from existing or upcoming instruments (AIRS, IASI, GIFTS). The impact of data collected from measurement campaigns need to be evaluated not in isolation but when added to existing observations used in operational assimilation systems. A number of THORPEX Observing Systems Tests (TOSTs) are planned each being a full-fledged measurement campaign guided with state-of-the-art targeting methods. These TOSTs will be managed through regional committees in Europe, North America, Asia and the Tropics. The first Atlantic TOST will take place from October to December 2003 to test the impact of targeted observations within "sensitive" regions over the Atlantic and the east coast of North America identified 24-48 hours in advance by ECMWF and Météo-France. In North American TOST experiments, targeted observations would be over the Pacific storm-track and North America. This could take into account the sensitivity of north-American high-impact weather to the phase of the El Niño-Southern Oscillation (ENSO) and its intra-seasonal variability.

2. A Canadian contribution to THORPEX

Within its Meteorological Research Branch (MRB), the Meteorological Service of Canada (MSC) has developed a variational data assimilation system, the 3D-Var (Gauthier *et al,* 1999), to improve the operational analyses of the Canadian Meteorological Centre (CMC). This has made it possible to assimilate a broad range of new types of observations that were previously difficult to assimilate. In particular, the operational 3D-Var is now able to assimilate directly ATOVS (AMSU-A and AMSU-B) radiances. The work at MRB is currently focused on extending the 3D-Var to make it a full-fledged quadri-dimensional variational assimilation system, the 4D-Var, considered to be the state-of-the-art data assimilation method.

Predictability issues need also to be addressed within the context of an ensemble prediction system (EPS). At MSC, an EPS has been developed and there is a significant effort to improve it by having its analysis performed with an Ensemble Kalman filter, or EnKF (Houtekamer and Mitchell, 2001). The goal of ensemble prediction is to provide some estimates of the variability of forecasts associated with errors in the initial conditions and the forecast model.

The optimality of a data assimilation system requires monitoring of the observations to identify potential biases in either the model or the observations. Estimates of the error statistics, a key element of any assimilation system, are obtained by comparing the observations against a short-term forecast, the

background-state, which implicitly contains information extracted from the observations assimilated in the past. These observations minus forecast statistics contain useful information to diagnose both the model itself and the assimilation procedure.

This being said, there are some areas in which Canada could contribute to THORPEX.

i. Assessing the impact of newly gathered data from measurement campaigns on the forecast quality of extreme events. (PI: Pierre Gauthier)

In North America, MSC offers the unique possibility to use 3D-Var, 4D-Var and an EnKF to examine if and how the assimilation method influences our conclusions on the impact of new data gathered from measurements campaigns. There are a number of outstanding issues associated with the assimilation methodology that could be addressed within this context. A visiting scientist program would be a good way to provide the means to scientists to put their theories to the test in a quasi-operational setting. At a THORPEX workshop in Monterey in December 2002, the discussions indicated clearly that if such a program existed, there would be many American and European scientists willing to take advantage of it. Interaction with universities could be an asset to better understand the results obtained from very complex experiments. There is a clear potential here for improvements to our assimilation/forecasting capability of extreme weather in the short to medium range.

Ensemble prediction would be used to obtain estimates of the forecast uncertainty due not only to analysis error but to external forcing as well. For instance, Barsugli *et al.* (1999) used ensemble forecasting to assess the sensitivity to sea surface temperature anomalies of forecasts of up to 2 weeks. Ensemble prediction is also appropriate to diagnose changes to the deterministic model which could lead to improvements to its physical parameterization.

RESOURCES NEEDED: 2 postdoctoral positions (2 × $45K), 2 visiting scientists (2 × $60K),
1 computer assistant ($45K), 2 Ph.D. students ($40K): Total $315/year

These objectives could be achieved by instating a visiting scientists program for 2 visiting scientists (for visits of 1 to 2 years) and 2 postdoctoral positions. This work would be essentially to design and conduct assimilation experiments based on the existing systems mentioned above. This activity could be based at the OURANOS facilities. Workstations for our people would need to be covered with our own funds. Given the complexity of using the assimilation/prediction system, a computer assistant would be needed to help maintain consistency between the MSC system and the local facility to be used for development. Finally, expertise in the theory and practice of advanced data assimilation and ensemble prediction offer a unique training opportunity for Ph.D. students in an area of expertise for which there is an increasing need.

ii. Organise the Canadian contribution to THORPEX during measurement campaigns over the Atlantic or the North Pacific. (PI: John Gyakum)

Each TOST involves significant resources to produce analyses, forecasts, ensemble and targeting products in real time to optimize the deployment of observations. Afterwards, a mobile observation network has to be deployed on the ground (e.g., launch of more frequent radiosondes), in the air with flights to launch dropsondes and even in space with additional satellite data (by increasing the scan frequency of spaceborne instruments). This can only be done in collaboration with either Europe or the United States. Recently, there was a request regarding the possibility for Canada conducting flights during the European campaign next fall. There will be many more such campaigns and it would certainly be important to have a point of contact to which these requests could be addressed.

These campaigns sometimes overlap existing experiments. In the Atlantic, there is a program to study the extratropical transition of tropical cyclones, which involves the launch of dropsondes over tropical cyclones that reached the East Coast of Canada. Collaboration with this project clearly falls within the objectives of THORPEX. Relying on the experience gained during FASTEX, the Atlantic TOSTs will likely be dealing with sensitive regions located on the East Coast of Canada. The United States have participated by sending some flights to launch dropsondes while Canada has provided more frequent radiosondes at 4 stations. With some supplementary funding, it would be possible to make a noteworthy contribution to the Atlantic TOSTs.

Targeting over the North Atlantic aims at improving forecasts over Europe while the North Pacific is where the initial conditions need to be improved to obtain better forecasts in the short to medium-range over North America. Sensitivity studies based on the Canadian global model have been able to track down the source of the 3-day forecast of the February 10, 2003 storm that caused important damages and loss of lives (Laroche *et al.,* 2002) over central Canada. The North American regional committee will organize TOSTs over the North Pacific to which Canada should contribute to help optimize the observation network for improving short to medium-range forecasts.

RESOURCES NEEDED: 1 research assistant ($55K), 1 Ph.D. student ($20K). Total: $75K

During TOSTs, a detailed synoptic analysis has to be made and combined with targeting information provided by the international desk. The deployment of the observations is then decided based on all this information. Scientists need to be involved to make sure that the targeting information is correctly interpreted and used.

RESOURCES NEEDED FOR AN ACTIVE CANADIAN INVOLVMENT IN THE MEASUREMENT CAMPAIGNS: three 6-h flights (3×$40K) and 5 days of rawinsondes launches every 3-h (5×$20K). **TOTAL: $220K** per campaign. During the three-year period of this grant, we would probably take part to ONE such campaign.

Funds would be needed to cover *partly* the technical support during a measurement campaign. The operation of the MSC research plane including the launch of dropsondes over targeted areas costs around $40K for one 6-h flight. On top of this, surface stations would launch sondes at a 3-h interval over

specific intensive observation period (IOP). If the Canadian participation to TOSTS could include three flights (3×$40K) over the whole period and 5 days of radiosondes launches at 5 stations (5× $20K), one comes up with an estimate of $220K for an active participation to a THORPEX experiment. One should realize that the overall quantity of measurements made by all participating organizations would more than justify such an investment. This is a unique opportunity to produce a high-resolution dataset required to understand the physics and dynamics of THORPEX weather systems.

This would be associated with our participation to TOSTs either over the Atlantic or North Pacific. The work involved has to start at the planning stage and, during the campaign itself, operational support will have to be provided.

iii. Studies on subseasonal variability (PI: to be determined)

Improvements to forecasts in the longer range (~ 2 weeks) require a better understanding of the subseasonal variability which is largely governed by the ENSO mechanism. Experiments have shown indications that in some cases, improvements to the 5-day forecast could possibly be related to the SST anomalies present during the El Niño winters. There is much still to be understood to enable us to improve our ability to forecast weekly means of the weather.

RESOURCES NEEDED: 1 postdoctoral position ($45K), 1Ph.D. student ($20K). Total: $65K

It would be natural that this work be done in collaboration with the group of Prof. René Laprise of UQAM/OURANOS. Collaboration is expected with he CLIVAR group that includes Prof. Jacques Derome (McGill) and Dr. Gilbert Brunet (MSC/McGill).

3. Link with existing research activities

At this stage, it is only possible to offer a list of collaborations that would need to be explicitly developed in the proposal. The purpose here is only to indicate the complementary aspects between the proposed research activities and currently ongoing projects.

i. Quantitative precipitation forecasting: a CFCAS network (PI: Prof. M.K. Yau, McGill University)

Collaboration already exists with the extreme weather networks funded by CFCAS in particular with the Quantitative Precipitation Forecast project which focuses on the mesoscale dynamics associated with heavy precipitation. Data assimilation is being used to focus on the key synoptic scale features that would trigger mesoscale processes associated with extreme weather.

ii. Assessing the economic impact of severe weather

Improving the accuracy of weather forecasts could result in significant economic impacts. This has been acknowledged within the THORPEX science plan that pays special attention to the question of translating a probability of occurrence of a case of severe weather into societal and economic impact. The

OURANOS project based in Montréal focuses on climate change and its implications. This THORPEX proposal fits very well with the objectives of OURANOS and would complement the current work already done. Regular contacts with scientists in the modeling group of OURANOS, lead by Prof. René Laprise, would result in a synergy beneficial to the research in both areas.

The director of OURANOS, Mr. Réal Decoste, has offered to provide an in-kind support in the form of office space and computer support for a group of 4 to 6 people.

iii. MSC and CMC

The most important contribution from MSC would be to provide the assimilation/forecasting system and its ensemble prediction system. It can also provide partial technical support required to run assimilation and forecasting experiments on its super-computers. Moreover, research scientists of MSC within the data assimilation division will be natural collaborators in the project. They are identified below.

As mentioned above, MSC has the resources to actively participate in measurement campaigns by manning an operational desk during TOSTs. A research plane is also available provided funds are available to cover whole or part of the operation costs during the TOSTs. The project would only need to cover part of the overhead associated with the participation of MSC in these international experiments.

iv. Canadian Space Agency

One of the goals of THORPEX is to provide measurements that would improve the usage of satellite data. Currently, the *Meteorological Service of Canada* funds research in teledetection and the *Canadian Space Agency* has recently implemented a program to fund research aiming at a better usage of satellite data. Assimilation of satellite data in cloudy areas is one of the difficulties. Targeting has identified that sensitive regions are often located in cloudy regions and this justifies the deployment of new observations during the field experiments. Research on the assimilation of radiances in cloudy areas would benefit from the data collected during TOSTs. It would also be interesting to assess the impact of satellite data in episodes of cyclogenesis.

4. Collaborators

The table below lists people who have expressed interest in this project and would commit themselves to be actively participating to it.

NAME	AFFILIATION	RESEARCH INTEREST
Pierre Gauthier	MSC/UQAM	Variational data assimilation and predictability
Stéphane Laroche	MSC/McGill	Sensitivity studies based on adjoint modelling
John Gyakum	McGill University	Extratropical-tropical transitions

William Perrie	DFO/Dalhousie	Ocean-atmosphere interactions
Mark Buehner	MSC	Adjoint modeling, Kalman filtering, ensemble prediction
Peter Zwack	UQAM	Synoptic meteorology

The following persons have expressed their interest in the project which could lead to collaboration with their own research activities.

NAME	AFFILIATION	RESEARCH INTEREST
René Laprise	UQAM/OURANOS	Regional Climate Modelling
Jacques Derome	McGill University	Dynamics of mean-seasonal conditions
Gilbert Brunet	MSC/McGill	Low-Frequency Variability Diagnostic and Prediction
Louis Garand	MSC	Radiative transfer and assimilation of satellite radiances

5. Budget summary

The following table summarizes our preliminary estimate of the budget needed for this project over a period of three-years

	Personnel	Equipment	Travel	Total
YEAR 1	$455K	$55K	$20K	$530K
YEAR 2	$455K	———	$20K	$475K
YEAR 3	$455K	———	$20K	$475K

For each year, a total of 3 Post-doctoral fellows, 4 Ph.D. students, 1 research assistant, 2 visiting scientists, and 1 computer assistant would be needed. The total budget for three years is then $1,480,000.

As discussed above, an active participation to the THORPEX observing system tests would bring an additional cost of $220K to the project.

6. References

Barsugli, J.J., J.S. Whitaker, A.F. Loughe, P.D. Sardeshmukh and Z. Toth, 1999: The effects of the 1997/98 El Niño on individual large-scale weather events. *Bull. Amer.Meteor. Soc.,* **80**, 1399-1411.

Gauthier, P., C. Charette, L. Fillion, P. Koclas and S. Laroche, 1999: Implementation of a 3D variational data assimilation system at the Canadian Meteorological Centre. Part I: The global analysis. *Atmosphere-Ocean*, **37**, 103-156.

Houtekamer, P. and H.L. Mitchell, 2001: A sequential ensemble Kalman filter for atmospheric data assimilation. *Mon. Wea. Rev.,***129**, 123-137.

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