

WORKSHOP ON

IMPACT OF OBSERVING SYSTEMS AND PREDICTABILITY ON FORECASTING EXTREME WEATHER EVENTS IN THE SHORT, MEDIUM AND EXTENDED RANGE: A CANADIAN CONTRIBUTION TO THORPEX

AGENDA

16-17 October 2003

Burnside Hall Room BH-719

Department of Atmospheric and Oceanic Sciences

McGill University

Montréal, Québec

THURSDAY, 16 OCTOBER 2003

- 9:00 DAWN CONWAY, CFCAS
 Welcome remarks
- 9:15 PIERRE GAUTHIER
 Goals of the workshop
- 9:45 JOHN GYAKUM
 Weather Systems Research and its relationship to THORPEX
- 10:15 JIM ABRAHAM
 The Canadian contribution to the 2003 THORPEX Regional Campaign over the North Atlantic region
- 10:35 COFFEE BREAK**
- 11:05 DAVID PARSONS (INVITED SPEAKER)
 (to be announced)
- 11:35 STÉPHANE LAROCHE
 Use of adjoint sensitivity analysis to diagnose the CMC 3D-Var analysis performance
- 12:05 BRIAN MILLS
 High-impact weather and forecasting: a Canadian socio-economic perspective
- 12:35 LUNCH**
- 14:00 PETER BARTELLO
 Recent developments in rotating stratified turbulence and their implications for predictability

- 14:30 DAVID STRAUB
Breakdown of balance and its implications for predictability
- 14:50 MARK BUEHNER
Ensemble-derived background error covariances for variational assimilation
- 15:20 AYRTON ZADRA
Impact of the simplified physics on the calculation of singular vectors
- 15:50 COFFEE BREAK**
- 16:20 HAL RITCHIE AND STÉPHANE LAROCHE
Sensitivity of extratropical transition of hurricanes to initial conditions
- 16:50 JIM WHITEWAY
Airborne measurements of mixing in the tropopause region
- 17:20 PETER ZWACK
(to be announced)
- 17:50 ADJOURN

FRIDAY, 17 OCTOBER 2003

- 9:00 WILL PERRIE
The role of air-sea fluxes in midlatitude storm development
- 9:30 GILBERT BRUNET
Sensitivity studies for weather regimes with the use of a simplified general circulation system.
- 10:00 MARTIN CHARRON
Ensemble regional forecasting
- 10:30 COFFEE BREAK**
- 10:45 DISCUSSIONS
- 12:30 LUNCH

LIST OF ATTENDANTS TO THE WORKSHOP

PROFESSORS

Bartello, Peter	Professor, Department of Atmospheric and Oceanic Sciences and Department of Mathematics and Statistics McGill University, Montréal, Québec
Derome, Jacques*	Professor, Department of Atmospheric and Oceanic Sciences McGill University, Montréal, Québec
Gyakum, John	Professor, Department of Atmospheric and Oceanic Sciences McGill University, Montréal, Québec
Straub, David	Professor, Department of Atmospheric and Oceanic Sciences McGill University, Montréal, Québec
Whiteway, Jim	Professor York University, Toronto, Ontario
Yau, Peter*	Professor, Department of Atmospheric and Oceanic Sciences McGill University, Montréal, Québec
Zwack, Peter	Professor, Department of Earth and Atmospheric Sciences Université du Québec à Montréal, Montréal, Québec

ADJUNCT PROFESSORS

Brunet, Gilbert	Adjunct professor, Department of Atmospheric and Oceanic Sciences McGill University, Montréal, Québec and Adjunct professor, Department of Earth and Atmospheric Sciences Université du Québec à Montréal, Montréal, Québec and Division de Recherche en Prévision Numérique (RPN) Meteorological Service of Canada, Dorval, Québec
Gauthier, Pierre	Adjunct professor, Department of Earth and Atmospheric Sciences Université du Québec à Montréal, Montréal, Québec and Data Assimilation and Satellite Meteorology Division Meteorological Service of Canada, Dorval, Québec
Laroche, Stéphane	Adjunct professor, Department of Atmospheric and Oceanic Sciences McGill University, Montréal, Québec and Data Assimilation and Satellite Meteorology Division Meteorological Service of Canada, Dorval, Québec

* Lead of other CFCAS network with interest in this project

Perrie, Will Adjunct Professor
 Department of Engineering Mathematics
 Dalhousie University
 Halifax, Nova Scotia
 and
 Bedford Institute of Oceanography
 Dartmouth, Nova Scotia

Zadra, Ayrton Adjunct professor, Department of Atmospheric and Oceanic Sciences
 McGill University, Montréal, Québec
 and
 Division de Recherche en Prévision Numérique (RPN)
 Meteorological Service of Canada, Dorval, Québec

RESEARCH AND DEVELOPMENT

Abraham, Jim Director, Meteorological Research Branch
 Dorval, Québec

Buehner, Mark Data Assimilation and Satellite Meteorology Division
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Charron, Martin Division de Recherche en Prévision Numérique (RPN)
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Conway, Dawn CFCAS
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Mills, Brian Adaptation and Impacts Research Group
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Tanguay, Monique Division de Recherche en Prévision Numérique (RPN)
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Verner, Gilles Canadian Meteorological Centre
 Meteorological Service of Canada, Dorval, Québec

GRADUATE AND POSTDOCTORAL STUDENTS

Jean-François Caron, Zhuo Liu, Cristina Lupu, Christian Pagé
 Department of Earth and Atmospheric Sciences
 Université du Québec à Montréal, Montréal, Québec

Ngan, Keith Department of Atmospheric and Oceanic Sciences
 McGill University, Montréal, Québec

ABSTRACTS

1. RECENT DEVELOPMENTS IN ROTATING STRATIFIED TURBULENCE AND THEIR IMPLICATIONS FOR PREDICTABILITY

Peter Bartello Department of Atmospheric and Oceanic Sciences
and Department of Mathematics and Statistics
McGill University, Montréal, Québec

According to the classical studies of predictability (especially Lorenz and Leith & Kraichnan), the time it takes for error initially confined to the smallest scales to contaminate the largest scales of a flow is a rather sensitive function of the wavenumber dependence of the energy spectrum. Specifically, predictability of the largest scales can be indefinitely maintained by confining the error to ever smaller scales only if the spectrum falls off more rapidly than k^{-3} . For a more shallow spectral decay, error propagates infinitely far upscale in finite time.

This result is, in itself, devastating for mesoscale predictability in that the atmospheric energy spectrum shows a transition from a large scale steep spectrum to the mesoscale $-5/3$ range (see e.g. Nastrom & Gage) at a few hundred kilometres. However, the dynamics over the mesoscale range are not completely clear. Early suggestions ranged from an inverse energy cascade in stratified turbulence to a downscale cascade of gravity wave energy. My own work seems to support the latter and points toward a decoupling of the wave and potential vorticity modes. While the former cascade downscale where they dominate the mix, the latter cascade upscale where they control the large-scale dynamics. In light of this decoupling, it seems reasonable to suspect that the predictability timescale in the mesoscale is not as short as the classical spectral arguments would suggest.

I would like to propose a more complete study of predictability in rotating stratified turbulence along the lines of the classical work, which was limited to isotropic two- and three-dimensional turbulence. Once a more thorough understanding of the real problem is obtained, it would be a good idea to investigate the linearisation error in such a setting, given the extensive use of linearisations in singular vectors, Kalman filtering and 4DVAR in the community. As pointed out previously by Tanguay, Bartello & Gauthier for barotropic QG flow, this error is a function of scale.

2. SENSITIVITIES STUDIES FOR WEATHER REGIMES WITH THE USE OF A SIMPLIFIED GENERAL CIRCULATION SYSTEM.

PI: Dr. G. Brunet
Collaborators: Dr. H. Lin and Prof. J. Derome

In Brunet et al. (1995) the possibility of studying diabatic forcing as a residual of the equation of potential vorticity conservation was examined. The average potential vorticity forcing found in this way was found consistent with knowledge of the mean diabatic heating and it was demonstrated that this dataset and methodology can be used for studies of transient-mean flow interactions. These diagnostics was also applied to a long ensemble of blocking events to study the anomaly of transient feedback during these weather regimes. This study was followed by studies to examine in more detailed how the diabatic forcing maintains flow regimes and the atmospheric general circulation, see Edouard et al. (1997) and Derome et al. (2001). A different line of inquiries was initiated also on seasonal forecasting using

empirical statistical models (Vautard et al., 1999) and state-of-the-art NWP and general circulation models (Derome et al., 2001).

The combination of these studies in seasonal forecasting and diabatic heating diagnostics has culminated in using a simplified general circulation model (SGCM) with parameterized diabatic forcing to do seasonal prediction, see Derome et al. (2003). The strength of the SGCM approach for seasonal forecasting lies in the correction of the model diabatic forcing error. The estimate of the diabatic forcing correction comes from comparison to the NCEP reanalyses. The skill of the SGCM in predicting the amplitude of the main patterns of Northern Hemisphere mean-seasonal variability, the Arctic Oscillation (AO) and the Pacific North American (PNA) pattern was demonstrated. The simple GCM has skill not only in predicting the PNA pattern during winters with strong ENSO forcing, but it also has skill in predicting the AO in winters without appreciable ENSO forcing. It is shown that a diabatic forcing dipole in the Indonesian region that is strongly link to the winter East Asian monsoon (and probably also link to the Indian Ocean SST dipole) is responsible for the SGCM skill in the AO. We propose to extend this work to a more detailed analysis of the source of skill in seasonal forecasting and its relationship to the diabatic forcing of a SGCM model based on GEM. The probabilistic interpretation of the ensemble generated by the SGCM system will be also explored with a focus on weather regimes.

3. ENSEMBLE-DERIVED BACKGROUND ERROR COVARIANCES FOR VARIATIONAL ASSIMILATION

Mark Buehner Data Assimilation and Satellite Meteorology Division
 Meteorological Service of Canada, Dorval, Québec

The background error covariances represent our knowledge of the 6 hour forecast uncertainty and play an important role in operational data assimilation systems. They govern the amount of influence the observations have on the analysis and how this influence is distributed both spatially and among all variable types. Unfortunately, obtaining estimates of these covariances is difficult and current approaches have many known short-comings.

Recently, several approaches to improve the background error covariances in the operational 3d-var and the developmental version of 4D-var have been evaluated. These include the use of flow-dependent covariances estimated from an ensemble Kalman filter and the relaxation of the assumptions that the correlations are homogeneous and isotropic. Diagnostic tests that demonstrate the impact of flow-dependence in the 3D-var and 4D-var will be presented in addition to results from several 2 week assimilation experiments. Preliminary results show a small positive impact on the 5 day forecasts from these improvements.

4. HIGH-IMPACT WEATHER AND FORECASTING: A CANADIAN SOCIO-ECONOMIC PERSPECTIVE

Brian Mills Adaptation and Impacts Research Group
 Atmospheric and Climate Science Directorate
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The value of weather forecasts is ultimately measured in terms of changes in impacts or risks both to the general public and to specific interests in energy, transportation, agriculture, healthcare, forestry, construction, emergency management, insurance and other sectors. Understanding the weather-

sensitivities in these sectors and the needs of the users of weather information is therefore critical to reducing vulnerability to meteorological hazards. This brief presentation will illustrate the extent and variability of high-impact weather, using examples from the transportation sector, and will review the current list of socio-economic research themes within the THORPEX International Science Plan (August 2003) from a Canadian perspective.

5. THE ROLE OF AIR-SEA FLUXES IN MIDLATITUDE STORM DEVELOPMENT

William Perrie¹, Xuejuan Ren^{1,2}, Weiqing Zhang^{1,3}, Zhenxia Long^{1,3}, Edgar L Andreas⁴, John Gyakum⁵, and Ron Mc-Taggart-Cowan⁵

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- (2) Department of Atmospheric Sciences, Nanjing University, Nanjing, PR China
- (3) Department of Engineering Mathematics, Dalhousie University, Halifax, Canada
- (4) U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, NH
- (5) McGill University, Montréal, Québec, Canada

A coupled atmosphere-wave-sea spray-ocean model system is used to study North Atlantic midlatitude storms to evaluate the combined impacts of wave drag, sea spray, and upper ocean sea surface temperature (SST) on storm development. Our focus is on storm intensity and development. We consider the role of air-sea fluxes and boundary layer/atmosphere implications. The composite model consists of MC2 atmospheric model, the NCEP operational wave model WaveWatch3, preliminary parameterization for heat and momentum fluxes due to sea spray, and POM (Princeton Ocean Model).

Case studies are extratropical hurricanes Earl (1998), Danielle (1998), Gustav (2002), and two intense winter bombs from January 2000 and 2002. Results show that, when wind speeds exceed 25 ms^{-1} , sea spray can significantly increase the sea surface fluxes, especially the latent heat flux over the high-wind core of the hurricane region. Wave-induced drag is important during the rapid-development phase of the storm and decreases as the storm waves reach maturity. Thus, sea spray tends to intensify storms particularly during the storm peak when winds are maximal, whereas wave-related momentum drag takes energy from the storm, primarily during the rapid development phase of the storm. The impact of coupling to POM is the generation of sea surface temperature (SST) cooling through entrainment mixing at the bottom of the mixed layer with the passage of the storm. SST cooling reduces the sea surface heat fluxes compared to uncoupled simulations, which use a time-invariant SST. Reduced heat fluxes lead to reduced storm intensity. These also tend to become notable during the storm peak, when winds are maximal. The overall impact of air-sea fluxes depends on the balance of competing processes and in the manner in which storm development occurs.

6. USE OF ADJOINT SENSITIVITY ANALYSIS TO DIAGNOSE THE CMC 3D-VAR ANALYSIS PERFORMANCE

Stéphane Laroche, Monique Tanguay, Ayrton Zadra and Josée Morneau
 Meteorological Service of Canada, Dorval, Québec

The sensitivity of forecast errors to initial conditions obtained from the adjoint of a numerical weather prediction model provides new insights to the analysis errors that largely explain poor short to medium-range forecasts. In recent years, we have developed a sensitivity analysis system based on the algorithm proposed by the European Center for Medium-range Weather Forecasts, in which key analysis errors that

partly explained short-range forecast errors are calculated. The algorithm has proven useful to understand improvements in the new 3D-Var implemented in the Canadian Meteorological Centre operational suite in December 2001. In particular, we will examine the key analysis errors of the former 3D-Var analysis (before December 2001), which lead to a poor 3-day forecast over Eastern Canada on 7 February 2000. It turns out that the 3-day forecast from the new 3D-Var analysis was much better. The difference between the two 3D-Var analyses will be compared to the key analysis errors in this case.

7. SENSITIVITY OF EXTRATROPICAL TRANSITION OF HURRICANES TO INITIAL CONDITIONS

Project proposed by
Hal Ritchie and Stéphane Laroche
Meteorological Research Branch

Collaborators: (MWC/AEPRI) Steve Miller, Chris Fogarty, Serge Desjardins
(MRB) Monique Tanguay, Ayrton Zadra

The purpose of this project will be to capture and study atmospheric structures that are important for numerical weather prediction of extratropical transition (ET) of hurricanes by using the adjoint sensitivity analysis system that has been developed by Meteorological Research Branch (MRB) and is used routinely by the Canadian Meteorological Centre (CMC). It will also relate these structures to vortex initialization techniques (some of which are already in use operationally in other forecasting centres).

This research will be particularly relevant for two graduate studies on ET that are in progress at Dalhousie University. For his M.Sc. in the Department of Physics and Atmospheric Science, Steve Miller is studying the structure and forecast accuracy for the Karen case in October 2001. Chris Fogarty's Ph.D. thesis is on atmosphere-ocean coupling for ET and explosively deepening storms, and will examine several ET cases, including Karen, Michael (2000), Juan (2003) and others anticipated in 2003 and 2004. For these cases there are or will be additional special observations available (e.g., dropsonde winds and temperatures, ocean temperature and salinity profiles). In support of these studies, it will be important to have the most accurate atmospheric analyses possible, produced taking advantage of the special observations. Recent improvements to the data assimilation system at CMC make it possible to now assimilate dropsonde data, and to perform adjoint sensitivity tests to identify the "key analysis errors" that would produce the most accurate possible hindcasts using certain configurations of the operational GEM forecast model.

A very powerful methodology was recently published in an article entitled "Use of adjoint sensitivity analysis to diagnose the CMC 3D-var analysis performance" (Laroche et. al., 2002, Atmosphere-Ocean, 40, pp. 423-443). This case study showed that the sensitivity analysis approach could identify the analysis errors responsible for a poorly forecast case of explosive deepening over eastern Canada in February 2001. This was a case where the large scale atmospheric circulation patterns were responsible for the deepening, and the medium range forecast (MRF) global GEM configuration was able to resolve the important features. Stéphane Laroche recently visited Halifax and presented very preliminary results of a sensitivity study using this configuration and the archived operational analysis and forecast for ET Karen. The key analysis errors were able to correct a phasing error in the analysis and forecast for Karen, but much of the error remains unexplained. Karen was a dissipating rather than deepening case, and it is thought that physical parameterizations may have also played an important role.

In the proposed project this promising approach will be pursued with the following steps:

- Repeat the Karen re-analysis and diagnosis using the experimental 35-km resolution version of the MRF GEM that includes updated physical parameterizations.
- Perform an adjoint sensitivity analysis using the updated adjoint code including more physical parameterizations when it becomes available. This should permit an assessment of the importance of physical parameterizations for correcting the initial conditions for ET Karen. The key analysis errors should also provide the best possible “bogus” for ET Karen in this hindcast mode. This could be compared with idealized vortices that might be usable to improve the handling of ET cases in forecast mode.
- Repeat the re-analyses and sensitivity tests using a high resolution configuration of the nested GEM code that is expected to become available during the coming year.
- Repeat the re-analyses and sensitivity tests for ET Michael, Juan and other anticipated cases in 2003 and 2004 for use in Chris Fogarty’s coupled modeling studies.

Further developments on the methodology would be included to achieve the project’s objectives, for example:

- Replace the energy norm by an estimate of analysis error variances;
- Include an initial reference analysis as additional constraint;
- Increase the number of iterations in the inner loops to achieve convergence;
- Perform outer loops to refresh the trajectory;
- Add the other components of the simplified physics;
- Increase the horizontal resolution by using the LAM configuration of GEM.

This research is expected to lead to worthwhile improvements in the sensitivity analysis system and ultimately in the CMC operational assimilation and forecast system’s ability to capture and predict hurricanes and ET.

8. BREAKDOWN OF BALANCE AND ITS AFFECT ON PREDICTABILITY

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At low Rossby number, balanced dynamics evolves essentially independently from the unbalanced flow that appears to dominate the atmospheric mesoscale. This fact has long been exploited in weather prediction, with early prediction based on quasigeostrophic dynamics. Locally, however, the Rossby number can easily obtain $O(1)$ values and in these regions, it seems likely that balanced motion can shunt energy into unbalanced modes. In some of my recent work, I have argued that this occurs when an appropriately defined Rossby number approaches 1. Two questions then arise. How strong is the leakage of energy into unbalanced motion and to what extent does this leakage influence the predictability. For example, one might ask whether ensemble members diverge more rapidly in situations where these exchanges occur. Or, it seems plausible that the situations may be worse in specific locations, such as over rough topography where there would typically be “external” sources of unbalanced motion.

9. IMPACT OF THE SIMPLIFIED PHYSICS ON THE CALCULATION OF SINGULAR VECTORS

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A set of simplified parametrizations accompanied by the respective tangent-linear and adjoint versions were built for the 4DVAR assimilation system that is being developed for the GEM model. This set of parametrizations currently contains four elements, a simplified vertical diffusion, subgrid-scale orographic drag, large-scale condensation and moist convection. In this presentation, the influence of this physics package in the properties of total-energy singular vectors is discussed.

[Total-energy singular vectors, or TESVs, are defined as the orthogonal set of perturbations that provide maximum energy growth in a chosen time interval, for a given initial state of the atmosphere.]