Strategic Project Grants Progress Report

Due Date: July 1, 2004 **Covers the Period: January 1, 2001 to June 30, 2004**

Please verify your personal information below and make the necessary corrections:

Dr. T.G. Shepherd
Department of Physics
McLennan Physical Laboratories
University of Toronto
60 ST GEORGE ST
Tel.: (416) 978-6824
E-mail Address: tgs@atmosp.physics.utoronto.ca

Please verify the project information below and make the necessary corrections:

Project title: Modelling of Global Chemistry for Climate

File No: STPGP 235109 - 00

Co-applicant(s):
J.C. McConnell, Earth and Atmospheric Science, York
N.A. McFarlane, Climate Modelling & Analysis (MSC), Environment Canada
I.A. Folkins, Physics and Atmospheric Science, Dalhousie
J.F. Scinocca, Climate Modelling & Analysis (MSC), Environment Canada
S.M. Polavarapu, Climate & Atmosph. Res. Dir. (MSC), Environment Canada
W.E. Ward, Physics, New Brunswick
P.A. Ariya, Chemistry, McGill
D.V. Michelangeli, Earth and Atmospheric Science, York
J. Li, Climate Modelling & Analysis (MSC), Environment Canada
U. Lohmann, Physics and Atmospheric Science, Dalhousie
J.P.D. Abbatt, Chemistry, Toronto

Supporting Organization(s):
D.M. Whelpdale, MSC, Environment Canada
D.J.W. Kendall, Canadian Space Agency

1. **1. Progress Towards Objectives/Milestones**

Using approximately 5 pages, please provide:
- a brief description of the overall objectives of the research project as awarded;
- a description of the progress made towards these objectives during the period covered by this report; and
- a description and justification for any deviations from the original objectives and a discussion of the path forward.

The broad objectives of the GCC project are the development and use of a capability for modelling the global chemical climate of the atmosphere, both for climate change studies and for the integration of models and measurements. The achievement of our objectives is discussed for each of these aspects in turn. With the exceptions noted below, all tasks are proceeding on schedule.

Climate model development and validation.

RA D. Plummer has coordinated the development of the tropospheric chemistry module in CMAM, including improved sources and sinks (Task I). More recently he has been investigating the use of a hybrid coordinate for the advection of chemical species. Basic research has been conducted on aerosol properties and formation processes by the Abbatt and Lohmann groups (Task II), and on organic and sulfate oxidation processes by the Ariya group (Tasks I, II). Basic research on dynamics and transport has been conducted by the Shepherd group (Task III). Implementation of the correlated-k radiation scheme in CMAM (Task IV) by Li and RA V.I. Fomichev has been delayed because of problems CCCma had with the scheme, but is proceeding; other aspects of Task IV have progressed in the meantime. Comparison of CMAM fields with a variety of in-situ and space-based measurements have been carried out by the Folkins, McConnell, Shepherd, and Ward groups (Task VI). We continued our participation in the SPARC GRIPS middle atmosphere GCM intercomparison activity, sending a delegation to the annual GRIPS workshops in Tskuba, Japan (2002), Washington D.C. (2003) and Bologna, Italy (2004).

Climate model applications.

Scinocca, RA C. McLandress, and post-doc L. Campbell, have investigated the driving of the QBO by parameterized gravity waves in the tropics (Task XII). The sensitivity of the resolved tropical waves to the parameterization of convection has been assessed (Task XIII) within the context of a SPARC GRIPS subproject, leading to an international collaborative paper submitted to *J. Atmos. Sci*. We participated (by invitation) in the inaugural SPARC/SCOSTEP workshop on temperature trends in the upper atmosphere (Kuhlungsborn, 2002). Resulting from this workshop, RA V.I. Fomichev was part of an international collaborative paper submitted to *Rev. Geophys*. that documented the temperature trends in the upper atmosphere and provided supporting model simulations including the results of CMAM. We were also asked to participate in an intercomparison of five fully interactive chemistry-climate models for the 2002 WMO/UNEP Ozone Assessment (falling within Task VII, although not specifically anticipated). (These Assessments, now conducted every four years, form the scientific basis for the Montréal Protocol and its amendments.) The latest generation of models - one from the UK, one from Japan, two from Germany, and CMAM - was used to provide the current best estimate of future ozone changes, focusing on the coupling between the ozone layer and climate change. This was a significant effort in terms of both human and computational resources (mainly by RA S.R. Beagley and Shepherd, though many others also contributed), but we felt it was important for Canada to contribute to this activity. The results are described in Austin *et al*. (2003), and had a major impact on the conclusions of the 2002 Assessment. Taken together, the new simulations predict that there will *not* be a severe Arctic ozone hole (resulting from climate change) rivalling that of the Antarctic in the coming decades; this is in contrast to simpler calculations considered in the 1998 Assessment. This underscores the importance of participating in international assessments, because the collective result was much stronger than an individual model result could ever be. We will publish more detailed analyses of our own simulations in due course.

Data assimilation development and validation

(Task V). After coupling CMAM to MSC's 3D variational (3DVAR) data assimilation scheme (referred to as CMAM-DA), statistics had to be defined that were appropriate for the model, and the 3DVAR scheme had to be adapted for a generalized vertical coordinate. Although originally an analysis of the early UARS period was planned, the lack of appropriate data precluded this. Instead, it was decided to analyse a more recent period, which would also have the added benefit of making the CMAM-DA product useful for current activities. It was specifically decided to produce analyses for January-March and August-October of 2002, in order to support the Canadian high Arctic (winter-spring) and MANTRA (late summer) measurement campaigns — as well as to assimilate the unprecedented Antarctic ozone hole of 2002. In early 2003 the CMAM-DA system was adapted to use the latest version of the CMAM with T47L65 resolution and interactive, heterogeneous chemistry. This updated system has been validated for one month (January 2002) and compared against the UKMO analysis. The results of this work have been submitted for publication. Polavarapu was invited to attend and speak at the SPARC data assimilation workshop held in Florence, Italy in early June 2003. As with all aspects of the project, the recent change of supercomputers at MSC Dorval has slowed development of the CMAM-DA model. The latest version of CMAM has now been modified to include the digital filter and will soon be run long-term as the basis of the CMAM-DA project.

The CSA has recently established a *Facility for Data Assimilation and Modelling* built around the CMAM, known as the *CMAM-FDAM*. The CMAM-FDAM will ensure that the capability developed by the GCC project will continue to be available for the benefit of the CSA Atmospheric Environment community. Initial funding has been provided for 3 years, which will support a core group of Research Associates. (Matching funding is currently provided through the GCC project.) A Steering Committee composed of MSC and university members will oversee the activity. We will have a initial event later this year, likely a workshop which could be part of the next CSA Atmospheric Environment workshop.

Interpretation and analysis of measurements (Task X).

RA C. McLandress has used CMAM data to construct synthetic measurements of stratospheric winds and ozone fluxes, in order to assess the measurement requirements (especially accuracy) needed to achieve the science goals of the Canadian SWIFT instrument. These calculations have formed the basis of the SWIFT "Mission Requirements Document" put together by the European Space Agency, which is managing the mission. RA K. Semeniuk has continued the work on developing a trajectory model to facilitate comparison between CMAM fields and retrievals from the Canadian OSIRIS, ACE and MAESTRO instruments. We have recently provided a comparison data set for ACE analyses, and are participating in the ACE validation effort. In related work, RA D. Sankey has assessed the validity of using chemical correlations to infer missing species. On the basis of this work, it can be argued that the limited latitudinal and temporal sampling from occultation instruments is mitigated, for long-lived species, by high-resolution vertical sampling. At the University of Toronto there is increasingly close collaboration between the CMAM activities and those of several Canadian measurement programs overseen by Prof. Kim Strong. In particular RAs C.

McLandress and D. Sankey have provided CMAM chemical data that is being used for comparison with ground-based measurements made in the Canadian high Arctic (Eureka, Resolute Bay) and at the Toronto Atmospheric Observatory, and also measurements obtained from the MANTRA balloon campaign at Vanscoy, Saskatchewan. Such collaborations help to validate or identify deficiencies in CMAM, while at the same time aiding the scientific interpretation and understanding of variability of the measurement studies. In the future, chemical analyses from CMAM-DA (which, unlike the case with the free-running CMAM, can be associated with the particular day of a given measurement) will be used, which will provide even more useful comparisons as well as possible a priori profiles for retrievals.

The technology transfer of the stratospheric chemistry module of CMAM to MSC (Task XIV), which is the responsibility of Scinocca and RA S.R. Beagley, is essentially complete ─ the code is now being run and further optimized within the CCCma environment. CCCma is now in a position to perform its own climate simulations addressing the interaction between ozone depletion and climate change. Later in the project, the tropospheric chemistry module being developed by GCC will also be transferred to MSC, and will be designed to extend its existing sulphate chemistry in a natural fashion. When coupled with other modules (land-surface, biogenic emission/uptake, ocean), CCCma will have the capability of simulating chemical climate in a fully interactive fashion, thereby helping it to stay at the leading edge of the IPCC assessment activity.

The development of a stratospheric data assimilation capability based on CMAM is now essentially complete, and CMAM will soon be running in a continuous data assimilation cycle using current data. This development has led to some spin-off benefits for the operational NWP assimilation activities at MSC. Because CMAM is being run with stratospheric chemistry, the stratospheric analyses will include chemical as well as dynamical fields. (Unlike with dynamical fields, it is not necessary to assimilate chemical fields in order to produce a useful chemical analysis; this fact underlies the use of Chemical Transport Models.) As a first application, it is anticipated that MSC may soon be able to use the CMAM ozone analyses. CMAM chemical analyses should also be useful for direct comparison with current Canadian stratospheric chemistry measurement programs such as MANTRA (balloon), OSIRIS, ACE and MAESTRO (satellite), and Eureka (ground-based). The CMAM middle atmosphere data assimilation capability (both dynamical and chemical) will be a unique tool within the international context, which will enable CSA to assess proposed new measurement strategies in a sophisticated fashion.

The highly collaborative nature of our project is reflected in various ways: in our active Scientific Steering Committee (which has met in person to coordinate the research for at least one full day ten times since 1 April 2001, with the next meeting scheduled for late July 2004); in the CMAM data assimilation subgroup (see further discussion in item 8); and in the many research collaborations between different members of the project.

As well as the paper and conference presentations in the table below, we have held our annual workshop in December of 2001, 2002 and 2003. Each year the workshop lasts for

2 days, and incorporates talks from the majority of the students, postdocs and research associates involved in the project. 3 internationally renowned speakers are invited from outside Canada to give talks, leading to an increased awareness of the project beyond the Canadian borders, as well as providing insight into topics with which we may not altogether be familiar.

During the past twelve months we have also sponsored two one-week summer schools. The first, held in Montréal during August 2003, was on the topic of Global Chemistry and Climate of the Troposphere and Lower Stratosphere. The lecturers were Jon Abbatt, Parisa Ariya, Ian Folkins, Glen Lesins, Ulrike Lohmann, Norm McFarlane, Diane Michelangeli, David Plummer, John Scinocca, Ted Shepherd, and Knut von Salzen. There were 50 attendees, the majority of which were from Canada, but there were several international applicants from both the USA and Eurpoe.

More recently we held a one-week summer school in Banff on Comparison of Models and Measurements during May 2004. The program was designed to bring together the modelling and measurement communities. For example, data assimilation and retrieval theory have a great deal in common but this is not always clear because of "language" differences. The lecturers were Jack McConnell, Ted Shepherd, Ian McDade, Dylan Jones, William Ward, Saroja Polavarapu, Michelle Santee, Tom McElroy, Charles McLandress, Stella Melo, and Richard Menard. There were 35 other participants. It was a tremendously successful event and we are considering the possibility of making it an annual event, with changing foci, perhaps within the auspices of the CMAM-FDAM.

The existence of the GCC network has permitted the use of CMAM to support other CFCAS-funded activities. Prof. K. Strong's project on Arctic measurements of stratospheric change (GR-029) involves comparison with CMAM chemical data: RA K. Semeniuk is now the designated GCC contact. Prof. G.G. Shepherd's project on analysis of long-term WINDII measurements in the mesopause region (GR-339) likewise involves comparison with CMAM climate simulations; RA C. McLandress is the primary GCC contact. Both activities will be represented in our GCC annual workshops.

Finally, it was noted at the MSC/CFCAS Climate Research Workshop in Ottawa on 5 March 2002 that Canadian scientists no longer played such prominent roles at the international level (e.g. WCRP, IPCC) as they had in the past. Certainly in the case of GCC, CFCAS is helping to rectify that situation. GCC actively promotes and facilitates the participation of its members in relevant international activities; many instances of this have been noted in this report.

We recently archived a special 20-year CMAM data set with high temporal resolution data at selected locations, output from the latest version of the model. (For chemistry: Toronto, Vanscoy, Eureka, Resolute Bay, OHP (France), Jungfraujoch, Kiruna, Lauder, and a Southern Hemisphere conjugate of Eureka. For dynamics: London (Ontario), Saskatoon, Platteville, Wakkanai, Yamagawa, Tromso, Hawaii and Christmas Island.) The data set is being used by Kim Strong's and Alan Manson's research groups, to compare with their measurements. Preliminary investigation has shown that these new data agree

much better with the results from MANTRA than those of the previous version of the model.

1. Research Team

Please provide an overview of the participation in, and scientific contributions to, the project of each member of the research team (principal investigator, co-investigators, senior research associates, company and government scientists, collaborators and students etc.).

- T.G. Shepherd, Principal Investigator, Toronto: Tasks III, V, VII
- J.C. McConnell, Co-investigator, York: Tasks I, VI, VII
- N.A. McFarlane, Co-investigator, Environment Canada: Tasks IV, VII
- I.A. Folkins, Co-investigator, Dalhousie: Task VI
- J.F. Scinocca, Co-investigator, Environment Canada: Tasks III, XIII, XIV
- S.M. Polavarapu, Co-investigator, Environment Canada: Tasks V, XI
- W.E. Ward, Co-investigator, New Brunswick: Tasks VI, X
- P.A. Ariya, Co-investigator, McGill: Tasks I, II
- D.V. Michelangeli, Co-investigator, York: Tasks I, II, IX
- J. Li, Co-investigator, Environment Canada: Task IV
- U. Lohmann, Co-investigator, Dalhousie: Task IX
- J.P.D. Abbatt, Co-investigator, Toronto: Task II

- R. Ménard, Collaborator, Environment Canada: Tasks V, XI
- Y. Rochon, Collaborator, Environment Canada: Tasks V, XI

- J. Anstey, Ph.D. student, Toronto: Task VII
- S.R. Beagley, Research Associate, York: Tasks VII, XIV
- F. Bender, undergrad summer student, Toronto: Task X
- C. Braban, Ph.D. student, Toronto: Task II
- C. Braun, Research Assistant, Dalhousie: Task VI
- L. Campbell, Post-doctoral fellow, Toronto: Task XII; now Assistant Professor at Carleton
- B. Carlin, Ph.D. student, Dalhousie: Task II
- D. Chartrand, Research Associate, York: Tasks IX, X; now with Jacques Whitford Environmental Consultants
- S. Codoban, Ph.D. student, Toronto: Task III
- J. de Grandpré, Research Assistant, McGill: Tasks III, XIII
- G. Folberth, Post-doctoral fellow, Victoria: Task I
- V.I. Fomichev, Research Associate, York: Tasks IV, VIII, X
- M. Fruman, Ph.D. student, Toronto: Task III
- C. Fu, Ph.D. student, York: Task VI
- R. Hallman, undergrad summer student, Toronto: Task VI
- A. Jonsson, Ph.D. student, Stockholm (long-term visitor at York): Task VI

- J.N. Koshyk, Research Associate, Toronto: Tasks V, VI; now with TD Bank
- E. Leon, Research Assistant, Toronto: Task VI
- J. Liang, undergrad summer student, Toronto: Task V; now a grad student at York
- J.V. Lukovich, Ph.D. student, Toronto: Task III; now an RA at Manitoba
- D. Matthews, M.Sc. student, McGill: Task II
- C. McLandress, Research Associate, Toronto: Tasks X, XII
- L. Neef, M.Sc. and Ph.D. student, Toronto: Task V
- D. Pendlebury, Ph.D. student, Toronto: Task III; now Project Scientist with the SPARC International Project Office, Toronto
- D. Plummer, Research Associate, York: Task I; now Research Scientist with Environment Canada
- M. Pritchard, undergrad summer student, Toronto: Task VI; now a grad student at Alberta
- G. Probst, M.Sc. student, McGill: Task I
- C. Reader, Research Associate, Victoria: Task II
- S. Ren, Research Associate, Toronto: Task V
- M. Reszka, Post-doctoral fellow, Toronto: Task V
- B. Revenaz, M.Sc. student, McGill: Task I; now with an environmental consulting company in the US
- J. Russell, Post-doctoral fellow, UNB: Task VI
- A. Ryzhkov, Post-doctoral fellow, McGill: Task I
- D. Sankey, Research Associate, Toronto: Tasks III, V, X, XI
- K. Semeniuk, Research Associate, York: Task IX, X
- T. Shaw, undergrad summer student and then grad student, Toronto: Task XIII
- A. Tang, Ph.D. student, York: Task X
- J. Taylor, undergrad summer student, UNB: Task X; now a grad student at Toronto
- Y. Tomikawa, Post-doctoral fellow, Toronto: Task VI
- D. Vyushin, Research Assistant, Toronto: Task III; now a grad student at Toronto
- X. Wang, Post-doctoral fellow, York: Task IX
- Y. Yang, Research Associate, Toronto: Task V
- X. Zhang, M.Sc. student, York: Task VI; now an RA at York

3. Training

Please provide the number of each type of trainee involved in the strategic project to date and the percentage (%) of time each type of trainee spent on this project.

	Number	% time spent on project
Undergraduate Students	6	100 (summer only)
Master's Students	5	35
Doctoral Students	11	80
Postdoctoral Fellows	7	90
Research Associates	11	100
Technicians		
Other (research assistants)	4	100
total	44	

4. Dissemination of Research Results and Knowledge or Technology Transfer

Please list all publications (specify if submitted, accepted or published), conference presentations, workshops, patents (applied for and granted), and licenses to date arising from the research project supported by the grant.

Publications, Conference Presentations, etc.

☐ None to date

-or-

FULL CITATION (TITLE/REFERENCE)	REFEREED JOURNAL ARTICLES	CONFERENCE PRESENTATION/POSTER	OTHER (INCLUDING TECHNICAL REPORTS, NON-REFEREED ARTICLES, ETC.)
ACCEPTED/PUBLISHED:			
Austin, J., Shindell, D., Beagley, S.R., Brühl, C., Dameris, M., Manzini, E., Nagashima, T., Newman, P., Pawson, S., Pitari, G., Rozanov, E., Schnadt, C. and T.G. Shepherd, 2003: Uncertainties and assessments of chemistry-climate models of the stratosphere**.** *Atmos. Chem. Phys***.**, **3**, 1-27.	YES		
Avzyanova, E. and P.A. Ariya, 2002: Kinetic studies of ozonolysis of selected terminal and internal alkenes: evaluation of HO yield. *Int. J. Chem. Kinet***., 34,** 678-684.	YES		
Beig, G., Keckhut, P., Lowe, R.P., Roble, R.G., Mlynczak, M.G., Scheer, J., Fomichev, V.I., Offermann, D., French, W.J.R., Shepherd, M.G., Semenov, A.I., Remsberg, E.E., She, C.Y., Lubken, F.J., Bremer, J., Clemesha, B.R., Stegman, J., Sigernes, F. and S. Fadnavis, 2003: Review of mesospheric temperature trends. *Rev.Geophys*., **41**, 10.1029/2002RG000121.	YES		
Codoban, S. and T.G. Shepherd, 2003: Energetics of a symmetric circulation including momentum constraints. *J. Atmos. Sci.*, **60**, 2019-2028.	YES		
Eyring, V., Harris, N.R.P., Rex, M., Shepherd, T.G. *et al*., 2004: Comprehensive summary of the workshop on "Process-oriented validation of coupled chemistry-climate models". *SPARC Newsletter*, **No.23,** 5-11.			YES
Fioletov, V.E. and T.G. Shepherd, 2003: Seasonal persistence of midlatitude total ozone anomalies. *Geophys. Res. Lett.*, **30**, 10.1029/2002GL016739.	YES		
Folkins, I., 2002: Origin of lapse rate changes in the upper tropical troposphere. *J. Atmos. Sci.*, **59**, 992-1005.	YES		
Folkins, I. and C. Braun, 2003: Tropical rainfall and boundary layer moist entropy. *J.Clim*., **16**, 1807-1820.	YES		
Folkins, I., Braun, C., Thompson, A.M. and J.C. Witte, 2002: Tropical ozone as an indicator of deep convection. *J.Geophys.Res*., **107**, 10.1029/2001JD001178.	YES		
Folkins, I., Kelly, K.K. and E.M. Weinstock, 2002: A simple explanation for the increase in tropical relative humidity between 11 and 14 km. J. *Geophys. Res.*, **107**, 10.1029/2002JD002185.	YES		
Fomichev, V.I., Ward, W.E., Beagley, S.R., McLandress, C., McConnell, J.C., McFarlane, N.A. and T.G. Shepherd, 2002: The extended Canadian Middle Atmosphere Model: zonal--mean climatology and physical parameterizations. *J. Geophys. Res*., **107**, 10.1029/2001JD000479.	YES		

Forbes, J.M., Zhang, X., Ward, W.E., and E. Talaat, 2002: Climatological features of stationary planetary waves in the stratosphere, mesosphere and lower thermosphere between 40° latitude. *J. Geophys. Res*., **107**, 10.1029/2001JD001232.	YES		
Forbes, J.M., Zhang, X., Talaat, E. and W.E. Ward, 2002: Nonmigrating diurnal tides in the thermosphere. *J. Geophys. Res*., **108**, 10.1029/2002JA009262.	YES		
Haynes, P.H. and T.G. Shepherd, 2001: Report on the SPARC Tropopause Workshop. *SPARC Newsletter*, **No. 17**, 3-10.			YES
Horinouchi, T., Pawson, S., Shibata, K., Langematz, U., Manzini, E., Sassi, F., Wilson, R.J., Hamilton, K.P., de Grandpré, J. and A.A. Scaife, 2003: Tropical cumulus convection and upward propagating waves in middle atmospheric GCMs. *J.Atmos.Sci*., **60**, 2765-2782.	YES		
Jonsson, A., de Grandpré, J. and J. C. McConnell, 2002: A comparison of mesospheric temperatures from the Canadian Middle Atmosphere Model and HALOE observations: zonal mean and signature of the solar diurnal tide. *Geophys.Res.Lett*., **29**, 10.1029/2001GL014476.	YES		
Kärcher, B. and U. Lohmann, 2002: A parameterization of cirrus cloud formation: homogeneous freezing of supercooled aerosols. *J. Geophys. Res*., **107**, 10.1029/2001JD000470.	YES		
Kärcher, B. and U. Lohmann, 2002: A parameterization of cirrus cloud formation: homogeneous freezing including effects of aerosol size. *J. Geophys. Res*., **107**, 10.1029/2001JD001429.	YES		
Kärcher, B. and U. Lohmann, 2003: A parameterization of cirrus cloudformation: heterogeneous freezing. *J. Geophys. Res*., **108**, 10.1029/2002JD003220.	YES		
Koshyk, J.N. and K. Hamilton, 2001: The horizontal kinetic energy spectrum and spectral budget simulated by a high—resolution troposphere--stratosphere--mesosphere GCM. *J. Atmos. Sci*., **58**, 329-348.	YES		
Lesins, G. and U. Lohmann, 2003: GCM aerosol forcing estimates using geographically varying aerosol sizes deduced from AERONET measurements. *J. Atmos. Sci*., **60**, 2747-2764.	YES		
Lohmann, U., 2002: Possible aerosol effects on ice clouds via contact nucleation. *J. Atmos. Sci*., **59**, 647--656.	YES		
Lohmann, U., 2002: A glaciation indirect aerosol effect caused by soot aerosols. *Geophys. Res. Lett*., **29**, 10.1029/2001GL014357.	YES		
Lohmann, U. and B. Kaercher, 2002: First interactive simulations of cirrus clouds formed by homogeneous freezing in the ECHAM GCM. *J. Geophys. Res*., **107**, 10.1029/2001JD000767.	YES		
Lohmann, U., Kaercher. B. and C. Timmreck, 2003: Impact of the Mt. Pinatubo eruption on cirrus clouds formed by homogeneous freezing in the ECHAM GCM. *J. Geophys. Res*., **108**, 10.1029/2002JD003185.	YES		
Lukovich, J.V, 2001: Large-scale mixing in the middle atmosphere. PhD Thesis, Department of Physics, University of Toronto.			THESIS
Manson, A.H., Meek, C.E., Hagan, M., Koshyk, J.N. *et al*., 2002: Seasonal variations of the semi-diurnal and diurnal tides in the MLT: multi-year MF radar observations from 2-70°N, modelled tides (GSWM, CMAM). *Ann. Geophys.*, **20**, 661-677.	YES		
Manson, A.H., Meek, C.E., Koshyk, J.N. *et al*., 2002: Gravity-wave activity and dynamical effects in the middle atmosphere (60-90 km): observations from an MF/MLT radar network and results from the Canadian Middle Atmosphere Model (CMAM). *J. Atmos. Sol.-Terr. Phys*., **64**, 65-90.	YES		

McLandress, C., 2002: The seasonal variation of the propagating diurnal tide. Part I: The role of gravity waves and planetary waves. *J.Atmos.Sci*., **59**, 893-906.	YES		
McLandress, C., 2002: The seasonal variation of the propagating diurnal tide. Part II: The role of tidal heating and zonal-mean winds. *J.Atmos.Sci*., **59**, 907-922.	YES		
McLandress, C., 2002: Interannual variations of the diurnal tide in the mesosphere induced by zonal-mean wind oscillations in the tropics. *Geophys. Res. Lett*., **29**, 10.1029/2001GL014551.	YES		
Ménard R., Edouard, S., Clerbaux, C., Granier, C., Pétron, G. and C. Reeves, 2004: Data assimilation and inverse modelling. In "Emissions of Atmospheric Trace Compounds", eds. C. Granier, P. Artaxo and C. Reeves, Kluwer Academic Publishers, Dordrecht, The Netherlands, 544 pp.	YES		
Ménard, R., Yang, Y. and S. Polavarapu, 2004, Model error estimation: Its application to chemical data assimilation. Proceedings of the ECMWF/SPARC Workshop on Modelling and Assimilation for the Stratosphere and Tropopause, June 23-26, 2003, 137-145.			YES
Ogibalov, V.P. and V.I. Fomichev, 2003: Parameterization of solar heating by near IR CO2 bands in the mesosphere. *Adv. Space Res*., **32**, 759-764.	YES		
Pendlebury, D., 2001: Planetary-wave-induced transport in the stratosphere, PhD Thesis, Department of Physics, University of Toronto.			THESIS
Pendlebury, D. and T.G. Shepherd, 2003: Planetary-wave-induced transport in the stratosphere. *J. Atmos. Sci*., **60**, 1456-1470.	YES		
Polavarapu, S., Ren, S., Clayton, A., Sankey, D. and Y. Rochon, 2004: On the relationship between incremental analysis updating and incremental digital filtering, *Mon.Wea.Rev*., accepted.	YES		
Reeves, C.E., Cunnold, D.M., Derwent, R.G., Dlugokencky, E., Edouard, S., Granier, C., Ménard, R., Novelli, P. and D. Parrish, 2004: Determination of emissions from observations of atmospheric compounds. In "Emissions of Atmospheric Trace Compounds", eds C. Granier, P. Artaxo and C. Reeves, Kluwer Academic Publishers, Dordrecht, The Netherlands, 544 pp.	YES		
Revenaz, B., 2001: Box modelling of HOx formation upon ozonolysis of alkenes, MSc Thesis, Department of Chemistry, McGill University.			THESIS
Russell, J.P. and R.P. Lowe, 2003: Atomic oxygen profiles (80-94 km) derived from Wind Imaging Interferometer/Upper Atmospheric Reseatch Satellite measurements of the hydroxyl airglow: 1 Validation of technique, *J.Geophys.Res*., **108**, 10.1029/2003JD003454.	YES		
Russell, J.P., Lowe, R.P. and W.E. Ward: Atomic oxygen annual and semi-annual oscillations in the mesopause region for mid and equatorial latitudes, *J.Atmos.Sol.-Terr.Phys*., in press.	YES		
Ryzhkov, A.B. and P.A. Ariya, 2003: A theoretical study of the reactions of carbonyl oxide with water in atmosphere: the role of water dimer. *Chem. Phys. Lett*., **367**, 423-429.	YES		
Sankey, D. and T.G. Shepherd, 2003: Correlations of long-lived chemical species in a middle atmosphere general circulation model. *J. Geophys. Res*., **108**, 10.1029/2002JD002799.	YES		
Scinocca, J.F., 2002: The effect of back-reflection in the parametrization of non-orographic gravity-wave drag. *J. Meteor. Soc. Japan*, **80**, 939-962.	YES		

Scinocca, J.F., 2003: An accurate spectral non-orographic gravity wave parameterization for general circulation models. *J. Atmos. Sci*., **60**, 667-682.	YES		
Scinocca, J.F. and N.A. McFarlane, 2004: The variability of modelled tropical precipitation. *J.Atmos.Sci.,***61**, 1993-2015.	YES		
Semeniuk, K. and T.G. Shepherd, 2001: The middle atmosphere Hadley circulation and equatorial inertial adjustment. *J. Atmos. Sci*., **58**, 3077-3096.	YES		
Semeniuk, K. and T.G. Shepherd, 2001: Mechanisms for tropical upwelling in the stratosphere. *J.Atmos.Sci*., **58**, 3097-3115.	YES		
Semeniuk, K. and T.G. Shepherd, 2002: The effect of non-uniform radiative damping on the zonal-mean dynamics of the extratropical middle atmosphere. *Quart. J. Roy. Meteor. Soc*., **128**, 259-284.	YES		
Shepherd, T.G., 2002: Issues in stratosphere-troposphere coupling. *J. Meteor. Soc. Japan*, **80**, 769-792.	YES		
Shepherd, T.G., 2003: Large-scale atmospheric dynamics for atmospheric chemists. *Chem. Reviews*, **103**, 4509-4531.	YES		
Shepherd, T.G., 2004: Issues for stratospheric modelling and assimilation. Proceedings of the ECMWF/SPARC Workshop on Modelling and Assimilation for the Stratosphere and Tropopause, June 23-26, 2003, 29-36.			YES
Shepherd, T.G. and T.A. Shaw, 2004: The angular momentum constraint on climate sensitivity and downward influence in the middle atmosphere. *J.Atmos.Sci.*, in press.	YES		
Wang, D.Y., Ward, W.E., Rochon, Y.J. and G.G. Shepherd, 2001: Airglow intensity variations induced by gravity waves. Part I: Generalization of the Hines-Tarasick theory. *J. Atmos. Sol.-Terr. Phys*., **63**, 35-46.	YES		
Wang, D.Y., Rochon, Y.J., Zhang, S.P., Ward, W.E., Wiens, R.H., Liang, D.Y., Gault, W.A., Solheim, B.H. and G.G. Shepherd, 2001: Airglow intensity variations induced by gravity waves. Part II: Comparisons with observations. *J. Atmos. Sol.-Terr. Phys*., **63**, 47-60.	YES		
Wang, D.Y., Ward, W.E., Solheim, B.H. and G.G. Shepherd, 2002: Longitudinal variations of green line emission rates observed by WINDII at altitudes 90-120 km during 1991-1996. *J. Atmos. Sol.-Terr. Phys*., **64**, 1273-1286.	YES		
Wunch, D., Tingley, M.P., Shepherd, T.G., Drummond, J.R., Moore, G.W.K. and K. Strong, 2004: Climatology and predictability of the late summer stratospheric zonal wind turnaround over Vanscoy, Saskatchewan. *Atmos.-Ocean*, in press.	YES		
Zhang, X., 2002: A comparison of CMAM and HALOE mesospheric data, MSc Thesis, Department of Earth and Atmospheric Science, York University			THESIS
GRIPS WORKSHOP (HAMBURG, GERMANY, 26 FEBRUARY-1 MARCH, 2001)			
de Grandpré, J.: Transport of constituents in the lower stratosphere.		ORAL	
McFarlane, N.A.: Update on the CMAM.		ORAL	
McFarlane, N.A.: Resolved wave driving of tropical oscillations.		ORAL	
JAPAN-U.S. SEMINAR ON COUPLING OF THE TROPOSPHERE AND STRATOSPHERE BY DYNAMICAL, RADIATIVE AND CHEMICAL PROCESSES (KYOTO, JAPAN, 13-17 MARCH, 2001)			
Scinocca, J.F.: Nonhydrostatic effects in the parameterization of non-orographic gravity-wave drag (INVITED).		ORAL	
Shepherd, T.G.: Issues in stratospheric-tropospheric coupling (INVITED).		ORAL	

Workshop on nitrogen oxides in the lower stratosphere and upper troposphere (University of Heidelberg, Heidelberg, Germany, 19-22 March, 2001)			
Plummer, D.A., McConnell, J.C., Beagley, S.R., and J. de Grandpré: Simulation of tropospheric chemistry in the Canadian Middle Atmosphere Model.		ORAL	
26th General Assembly of the European Geophysical Society (Nice, France, 25-30 March, 2001)			
Plummer, D.A., McConnell, J.C., Beagley, S.R. and J. de Grandpré: Simulation of tropospheric chemistry in the Canadian Middle Atmosphere Model.		ORAL	
SPARC Tropopause Workshop (Bad Tölz, Germany, 17-21 April, 2001)			
Folkins, I.: Upper tropospheric chemical budgets (INVITED).		ORAL	
Canadian Chemical Society (Montréal, Québec, Canada, 26-30 May, 2001)			
Avzianova E.V. and P.A. Ariya: Temperature dependence kinetics and product studies of selected tropospheric ozonolysis reactions of alkenes.		ORAL	
Conference on Atmospheric and Oceanic Fluid Dynamics (Breckenridge, Colorado, 4-8 June, 2001)			
Campbell, L.: Wave-mean-flow interactions in a gravity wave packet critical layer.		ORAL	
Fruman, M. and T.G. Shepherd: The traditional approximation and equatorial inertial instability.		ORAL	
Pendlebury, D.: A comparison of wave-induced residual and Lagrangian transport in the stratosphere.		ORAL	
Scinocca, J.: Nonhydrostatic effects in the parameterization of non-orographic gravity-wave drag.		ORAL	
Wave Phenomena III (University of Alberta, 11-15 June, 2001)			
Campbell, L.: Wave-mean-flow interactions in a Rossby wave packet critical layer.		ORAL	
Scinocca, J.: Nonhydrostatic effects in the parameterization of non-orographic gravity-wave drag.		ORAL	
Shepherd, T.G.: Wave-vortex interactions and implications for mixing in the middle atmosphere (INVITED PLENARY TALK).		ORAL	
8th Scientific Assembly of IAMAS (Innsbruck, Austria, 10-18 July, 2001)			
Beagley, S.R.: Chemical-dynamical and transport impacts in the middle atmosphere of green-house-gas forcing.		ORAL	
Fomichev V.I., Ward, W.E., Beagley, S.R., and C. McLandress: Energy budget of the middle atmosphere produced by the Extended Canadian Middle Atmosphere Model.		ORAL	
Lohmann, U.: Possible effects on clouds by aerosol-induced changes in heterogeneous and homogeneous ice nucleation.		ORAL	
McLandress, C.: The seasonal variation of the diurnal tide: results from a middle atmosphere GCM and a linear mechanistic model (INVITED).		ORAL	
First international conference on global warming and the next ice age (Halifax, 19-24 August, 2001)			
Lohmann, U.: The magnitude of different aerosol-cloud effects between pre-industrial times and present day.		ORAL	
AGU Fall Meeting, San Francisco (California, 10-14 December, 2001)			
Rochon, Y., Polavarapu, S., Ren, S., Sankey, D. and D. Tarasick: Data Assimilation with the Canadian Middle Atmosphere Model.		ORAL	

UK NERC UTLS Ozone Workshop (Cambridge, UK, 17-19 December, 2001)			
Shepherd, T.G.: Transport processes in the UTLS (INVITED).		ORAL	
Molecular Modelling Symposium (Montréal, Québec, 17-19 January 2002)			
Ryzhkov, A. and P.A. Ariya: Reaction of CH2OO radicals with atmospheric water vapour.		ORAL	
AMS Observations, Data Assimilation and Probabilistic Prediction meeting (Orlando, Florida, 14-17 January 2002)			
Polavarapu, S., Ren, S., Rochon, Y. and D. Sankey: Middle atmosphere data assimilation with a climate model.		ORAL	
IGAC workshop (Stockholm, Sweden, 27-30 January, 2002)			
Lohmann, U.: Interactions between atmospheric chemistry and the hydrological cycle (INVITED).		ORAL	
DASP Winter Workshop (Fredericton, NB, 21-23 February, 2002)			
Fomichev, V.I., Ward, W.E., Beagley, S.R. and C. McLandress: Energy processes in the Extended Canadian Middle Atmosphere Model.		ORAL	
GRIPS Workshop (Tsukuba, Japan, 12-15 March, 2002)			
de Grandpré, J., Beagley, S.R. and J. C. McConnell: Transport and chemistry processes in the Canadian Middle Atmosphere Model.		ORAL	
McLandress, C.: Report on the gravity wave parameterization assessment (task 2D).		ORAL	
International Symposium on Equatorial Processes Involving Coupling (EPIC) (Uji, Kyoto, Japan, 18-22 March, 2002)			
McLandress, C.: Mechanisms responsible for the seasonal variation of the diurnal tide in the mesosphere and lower thermosphere (INVITED).		ORAL	
XVII EGS General Assembly (Nice, France, 21-26 April, 2002)			
Braban, C.F. and J.P.D. Abbatt: Studies of deliquescence and efflorescence phase transitions of dicarboxylic acid particles.		ORAL	
Fomichev V.I., Beagley, S.R. and J. de Grandpré: Temperature changes in the upper stratosphere and mesosphere due to doubling of CO2 as simulated by the CMAM.		ORAL	
Scinocca, J.F.: The nonlinear forcing of large-scale internal gravity waves by stratified shear instability (INVITED).		ORAL	
5th Workshop on Adjoint Applications in Dynamic Meteorology (Mount Bethel, Pennsylvania, 21-26 April 2002)			
Polavarapu, S.: Balance issues in data assimilation (INVITED).		ORAL	
SPARC Data Assimilation workshop (Baltimore, Maryland, 10-12 June 2002)			
Polavarapu, S., Ren, S., Rochon, Y. and D. Sankey: Recent developments in the data assimilation system for the Canadian Middle Atmosphere Model (CMAM).		ORAL	
WE-Heraeus-Seminar on Trends in the Upper Atmosphere (Kuehlungsborn, Germany, May 13-16, 2002)			
Fomichev, V.I., de Grandpré, J. and S.R. Beagley: Cooling of the middle atmosphere and ozone radiative feedback induced by doubling of CO2 in the CMAM (INVITED).		ORAL	
4th Canadian Space Agency Atmospheric Environment Workshop (University of Western Ontario, 15-17 May, 2002)			
Polavarapu, S.: Data assimilation with the Canadian Middle Atmosphere Model (INVITED).		ORAL	
Shepherd, T.G.: Earth System science (INVITED).		ORAL	
36th CMOS Congress (Rimouski, Quebec, Canada, 22-25 May, 2002)			

Beagley, S.R., de Grandpré, J., Fomichev, V.I. and J.C. McConnell: Simulating lower stratospheric ozone loss in a GCM: dynamical issues.		ORAL	
de Grandpré, J.: Ozone change in the middle atmosphere.		ORAL	
Chemical Society of Canada (Vancouver, 1-5 June, 2002)			
Kwemena, N., Meritis, D. and P.A. Ariya: Product studies of peroxide formation upon ozonolysis of alkenes.		ORAL	
Ryzhkov, A., Leighton, H. and P.A. Ariya: Theoretical studies of criegee radical with water.		ORAL	
SPARC Data Assimilation Workshop (Washington D.C., 10-12 June, 2002)			
Polavarapu, S., S. Ren, Y. Rochon and D. Sankey: Recent developments in the data assimilation system for the Canadian Middle Atmosphere Model (CMAM).		ORAL	
Summer School of the Advanced Study Program of the National Center for Atmospheric Research (Boulder, CO, 8-19 July, 2002)			
Lohmann, U.: Influence of aerosols on ice clouds (INVITED).		ORAL	
IGAC Conference (Crete, 18-25 September, 2002)			
Lohmann, U.: Sensitivity of cloud droplet nucleation to kinetic effects and varying updraft velocity.		ORAL	
American Meteorological Society 12th Conference on the Middle Atmosphere (San Antonio, Texas, 4-7 November, 2002.)			
Campbell, L. and T.G. Shepherd: Wave drag parameterization in simple models of the quasi-biennial oscillation.		ORAL	
Lukovich, J.V. and T.G. Shepherd: Large-scale mixing in the middle atmosphere.		ORAL	
Sankey, D. and T.G. Shepherd: Quantifying the tropopause mixing barrier in the Canadian Middle Atmosphere Model.		ORAL	
Semeniuk, K. and R.A. Plumb: Isolation from planetary wave breaking of the lower tropical stratosphere.		ORAL	
Shepherd, T.G.: Understanding past and future northern hemisphere ozone.		ORAL	
ACE Science Team Meeting (University of Waterloo, Ontario, Canada, 2-5 December, 2002)			
Semeniuk, K.: ACE validation by trajectory and photochemical box modelling.		ORAL	
Wang, X. and D.V. Michelangeli: Model development of polar stratospheric clouds and their effect on stratospheric chemistry.		ORAL	
American Geophysical Union (San Francisco, 6-10 December, 2002)			
Abbatt, J.P.D.: Are Organic Aerosols Good Cloud Condensation Nuclei? (INVITED)		ORAL	
3rd CERMM Computational Modeling Symposium (Concordia University, Montreal, Canada, 11-12 January, 2003)			
Ryzhkov, A. and P.A. Ariya: Theoretical studies of carbonyl oxide intermediates.		ORAL	
GOA-MAPSCORE-ASSET workshop on Chemical Data Assimilation (KNMI, Utrecht, The Netherlands, 15-17 January 2003)			
Polavarapu, S., Ren, S., Rochon, Y., Sankey, D. and Y. Yang: The impact of dynamic variable assimilation on ozone fields.		ORAL	
Aha Hulikoa Hawaiian Winter Workshop (Honolulu, Hawaii, 21-24 January, 2003)			
Scinocca, J.: Low-level topographic drag in atmospheric flows.		ORAL	
Atmospheric Tides Workshop (Honolulu, Hawaii, 4-7 March, 2003)			

McLandress, C.: Simulations of the migrating diurnal tide in the Canadian Middle Atmosphere Model (CMAM).		ORAL	
GRIPS Workshop (Washington D.C., 4-7 March, 2003)			
de Grandpré: Perturbation scenarios and ozone response in the CMAM.		ORAL	
Fomichev V. I.: Radiation code intercomparison: recap of results.		ORAL	
Sankey D. and T.G. Shepherd: Correlations of long-lived chemical species in a middle atmosphere general circulation model.		ORAL	
American Chemical Society (New Orleans, 23-28 March, 2003)			
Ryzhkov, A. and P.A. Ariya: Reactions of substituted criegee biradical with water and water dimer.		ORAL	
Joint SPARC-IGAC workshop on climate-chemistry interactions (Giens, France, 3-5 April, 2003)			
Lohmann, U.: Water vapour and clouds (INVITED).		ORAL	
EGS-AGU-EUG Joint Assembly (Nice, France, 6-11 April, 2003)			
Abbatt, J.P.D. and K. Broekhuizen: Organic Aerosols as Cloud Condensation Nuclei.		ORAL	
Lohmann, U.: Impact of Mt. Pinatubo eruption on cirrus clouds formed by homogeneous freezing in the ECHAM GCM.		ORAL	
Plummer, D.A., J.C. McConnell, S.R. Beagley and J. de Grandpré: Development of tropospheric chemistry in the Canadian Middle Atmosphere Model.		ORAL	
Shepherd, T.G. and V.E. Fioletov: Seasonal persistence of midlatitude total ozone anomalies.		ORAL	
Wang, X., D.V. Michelangeli and I. Kletskin: Status of detailed numerical modelling of polar stratospheric clouds and their effect on stratospheric chemistry.		ORAL	
SPARC Workshop on the Role of the Stratosphere in Tropospheric Climate (Whistler, B.C., 29 April-2 May, 2003)			
Shepherd, T.G.: Mechanisms for stratospheric influences on tropospheric climate (INVITED).		ORAL	
37th Congress of the Canadian Meteorological and Oceanographic Society (Ottawa, Canada, 2-6 June, 2003)			
Abbatt, J.P.D.: Interactions of atmospheric trace gases with ice: heterogeneous reactions and scavenging (INVITED).		ORAL	
Beagley,. S.R. *et al*.: Development of a Mars spectral general circulation model with chemistry and aerosols in support of future Mars missions.		ORAL	
Codoban, S. and T.G. Shepherd: Energetics of a symmetric circulation with momentum constraints.		ORAL	
de Grandpré, J., A. Jonsson and J.C. McConnell: The Canadian Middle Atmosphere Model: model vs. observation.		ORAL	
Lukovich, J., I. McDade, T.G. Shepherd and C.S. Haley: Observational analysis of the containment of Antarctic vortex air following the split ozone hole of 2002.		ORAL	
McLandress, C., R. Hallman and T.G. Shepherd: Mesospheric temperature inversions: the role of stationary planetary waves.		ORAL	
Neef, L.J., T.G. Shepherd and S.M. Polavarapu: Kalman filter data assimilation and balanced dynamics.		ORAL	
Plummer, D.A., J.C. McConnell, S.R. Beagley and J. de Grandpré: Modelling of tropospheric chemistry in the Canadian Middle Atmosphere Model.		ORAL	
Polavarapu, S., R. Shuzhan, Y. Rochon and D. Sankey: The Canadian Middle Atmosphere Model (CMAM) Data Assimilation Scheme (INVITED).		ORAL	

Russell, J.M., W.E. Ward, R.P. Lowe and R.G. Roble: Multi-year tidal trends in mesospheric atomic oxygen profiles derived from remote sensing of the nightglow.		ORAL	
Reszka, M. and T.G. Shepherd: Dynamical balances in the tropical middle atmosphere.		POSTER	
Sankey, D. and T.G. Shepherd: Correlations of long-lived chemical species in a middle atmosphere general circulation model.		ORAL	
Sankey, D. and T.G. Shepherd: Quantifying the tropopause mixing barrier in the Canadian Middle Atmosphere Model.		POSTER	
Sankey, D., Y. Rochon, S. Polavarapu, S. Ren and Y. Yang: The influence of assimilating dynamical variables on ozone in the Canadian Middle Atmosphere Model.		POSTER	
Shepherd, T.G.: Modelling of chemical-climate coupling in the middle atmosphere (INVITED).		ORAL	
Semeniuk, K.: On the limitations of trajectory-following photochemical box modelling.		ORAL	
Wang, X., D.V. Michelangeli and I. Kletskin: A numerical model for polar stratospheric clouds and stratospheric chemistry.		ORAL	
Ward, W.E., V.I. Fomichev, S.R. Beagley, and C. McLandress: Non-migrating tides in the extended Canadian Middle Atmosphere Model.		ORAL	
SPARC-DA workshop (Florence, Italy, 4-6 June 2003)			
Polavarapu, S., D. Sankey, Y. Rochon, S. Ren and Y. Yang: The impact of dynamic variable assimilation on ozone fields.		ORAL	
14th Conference on Atmospheric and Oceanic Fluid Dynamics (San Antonio, Texas, 9-13 June 2003)			
Campbell, L. and T.G. Shepherd: Constraints on gravity-wave-drag parameterization schemes for simulating the quasi-biennial oscillation.		ORAL	
Codoban, S. and T.G. Shepherd: Energetics of a symmetric circulation with momentum constraints.		ORAL	
Neef, L.J., T.G. Shepherd and S.M. Polavarapu: Balance dynamics and four-dimensional data assimilation.		ORAL	
Scinocca, J.F.: The variability of modelled tropical precipitation.		ORAL	
Workshop on Chemistry-Dynamics Coupling near the Mesopause (Hamburg, Germany, 10-13 June, 2003)			
Fomichev V.I.: Impact of the CMAM radiative scheme updates on the thermal budget (INVITED).		ORAL	
ECMWF Workshop on the Stratosphere (Reading, U.K., 23-26 June, 2003)			
Ménard, R.: Model error estimation: its application to chemical data assimilation (INVITED).		ORAL	
Shepherd, T.G.: Issues for stratospheric modelling and assimilation (INVITED).		ORAL	
XXIII IUGG General Assembly (Sapporo, Japan, 30 June-11 July, 2003)			
Beagley, S.R., J. de Grandpré, V.I. Fomichev, J.C. McConnell and T.G. Shepherd: Simulating Antarctic stratospheric ozone loss in a GCM: variability.		ORAL	
Fioletov, V. and T.G. Shepherd: Seasonal persistence of midlatitude total ozone anomalies.		ORAL	
Folkins, I: The interface between the tropical troposphere and stratosphere (INVITED).		ORAL	
Fomichev V.I.: Model thermal response to minor energy sources and sinks (INVITED).		ORAL	
Lohmann, U.: Different aspects of aerosol effects on clouds, climate and the hydrological cycle (INVITED).		ORAL	

McLandress, C.: What damps the vertically propagating diurnal tide in the mesosphere and lower thermosphere? (INVITED).		ORAL	
McLandress, C., R. Hallmann, and T. G. Shepherd: Mesospheric temperature inversions in middle atmosphere general circulation models: the role of quasi-stationary planetary waves.		ORAL	
Neef, L.J., T.G. Shepherd and S.M. Polavarapu: Kalman filter data assimilation and balanced dynamics.		ORAL	
Plummer, D.A., J.C. McConnell, S.R. Beagley and J. deGrandpré: Simulation of Rn-222 and Pb-210 in the Canadian Middle Atmosphere Model.		ORAL	
Ren, S., S. Polavarapu, Y. Rochon and D. Sankey: Middle atmosphere data assimilation in Canada.		ORAL	
Sankey, D. and T.G. Shepherd: Quantifying the tropopause mixing barrier in the Canadian Middle Atmosphere Model.		ORAL	
Sankey, D., Y. Rochon, S. Polavarapu, S. Ren and Y. Yang: The influence of assimilating dynamical variables on ozone in the Canadian Middle Atmosphere Model.		ORAL	
Shepherd, T.G.: Large-scale transport and mixing in the middle atmosphere (INVITED).		ORAL	
Shepherd, T.G.: Dynamical influences on ozone changes (INVITED).		ORAL	
Shepherd, T.G.: Some issues in stratosphere-troposphere coupling (INVITED).		ORAL	
Ward, W.E.: Dynamical fields in the mesopause region: insights from the extended CMAM (INVITED)		ORAL	
Ward, W.E. and J.P. Russell: The effect of dynamical processes on nightglow profiles (INVITED)		ORAL	
European aerosol conference (Madrid, Spain, 4 Sept, 2003)			
Lohmann, U.: Global simulations of upper tropospheric aerosols and their effects on clouds and climate (INVITED).		ORAL	
UTLS Workshop (Boulder, Colorado, 27-28 October, 2003)			
Folkins, I.: Structure and issues in the UT/LS.		ORAL	
SPARC Workshop on Understanding Seasonal Temperature Trends in the Atmosphere (Silver Springs, Maryland, 5 November, 2003)			
Shepherd, T.G.: Variability and changes in stratospheric circulation (INVITED).		ORAL	
SPARC Workshop on Process-oriented Validation of Coupled Chemistry-Climate Models (Garmisch-Partenkirchen, Germany, 17-19 November, 2003)			
Shepherd, T.G.: Stratospheric dynamics (INVITED).		ORAL	
AGU Chapman Conference on Gravity Wave Processes and Parameterization (Kohala Coast, Hawaii, 10-14 January, 2004)			
McLandress, C. and J. Scinocca: A self-consistent intercomparison of gravity wave drag parameterizations.		ORAL	
Shaw, T.A. and T.G. Shepherd: Assessing the importance of momentum conservation in the parameterization of gravity wave drag in atmospheric models.		ORAL	
DASP Workshop (London, Ontario, Canada, 19-20 February, 2004)			
McLandress, C. and J. Scinocca: A self-consistent intercomparison of gravity wave drag parameterizations.		ORAL	
Sankey, D. and T.G. Shepherd: Correlations of long-lived chemical species in a middle atmosphere general circulation model.		ORAL	
Semeniuk, K.: Testing trajectory-based satellite validation methods in a GCM.		ORAL	
GRIPS Workshop (Bologna, Italy, 24-26 March, 2004)			

Fomichev, V. I.: Solar heating by the near-IR CO_2 bands in thermosphere.		ORAL	
SUBMITTED:			
Braban, C.F., Carroll, M.F., Styler, S.A. and J.P.D. Abbatt: Phase transitions of malonic and oxalic acid aerosols, *J.Phys.Chem*., submitted.	YES		
Campbell, L.J. and T.G. Shepherd, 2004: Constraints on wave-drag parameterization schemes for simulating the quasi-biennial oscillation. Part 1: Gravity wave forcing. *J. Atmos. Sci*., submitted.	YES		
Campbell, L.J. and T.G. Shepherd, 2004: Constraints on wave-drag parameterization schemes for simulating the quasi-biennial oscillation. Part 2: Combined effects of gravity waves and equatorial planetary waves. *J. Atmos. Sci*., submitted.	YES		
Folkins, I. and R. Martin, The vertical structure of the tropical troposphere. *J.Atmos.Sci*., submitted.	YES		
Fomichev, V.I., Fu, C., de Grandpré, J., Beagley, S.R., Ogibalov, V.P. and J.C. McConnell, Model thermal response to minor radiative energy sources and sinks in the middle atmosphere. *J.Geophys.Res*., submitted.	YES		
Lohmann, U., Kärcher, B. and J. Hendricks, Sensitivity studies of cirrus clouds formed by heterogeneous freezing in the ECHAM GCM. *J.Geophys.Res*., submitted.	YES		
Lukovich, J.V. and T.G. Shepherd: Stirring and mixing in two-dimensional divergent flow. Part I: Zonal dispersion. *J.Atmos.Sci*., submitted.	YES		
Lukovich, J.V. and T.G. Shepherd: Stirring and mixing in two-dimensional divergent flow. Part II: Meridional dispersion. *J.Atmos.Sci*., submitted.	YES		
McLandress, C. and J. Scinocca: A self-consistent intercomparison of gravity wave drag parameterizations. *J.Atmos.Sci*., submitted.	YES		
Polavarapu, S., Ren, S., Rochon, Y., Sankey, D., Ek, N., Koshyk, J. and D. Tarasick: Data assimilation with the Canadian Middle Atmosphere Model, *Atmos-Ocean*, submitted.	YES		
Tomikawa, Y., Sato, K. and T.G. Shepherd, 2004: Relationship between medium-scale stratospheric vortex-edge waves and medium-scale tropopausal waves. *J. Atmos. Sci*., submitted.	YES		
TOTALS:	**61**	**121**	**8**

Patents and Licences

☒ Not Applicable

-or-

☐ None Yet Filed/Granted

DESCRIPTION	CANADA	US	OTHER (SPECIFY)
Patent Applications Filed:			

Patents Issued:			
Licences or Options:			
TOTALS:			

Prospects for the Transfer of the Results to the User Sector
Describe how the results achieved to date are being transferred to the user sector and the prospects for their commercial/industrial exploitation or their use by other sectors (e.g., revising or formulating policy or regulations).

As mentioned above, the technology transfer of the stratospheric chemistry module of CMAM to MSC is essentially complete, and the code is now being run and further optimized within the CCCma environment. CCCma is now in a position to perform its own climate simulations addressing the interaction between ozone depletion and climate change. Later in the project, the tropospheric chemistry module curently being developed by GCC will also be transferred to MSC, and will be designed to extend its existing sulfate chemistry in a natural fashion.

5. Problems Encountered

Identify the main problems encountered during this instalment of the grant from the list below (select all that apply):

☐ Technical or scientific problems
☐ Problems with direction of research or findings
☒ Equipment and facilities
☐ Staffing issues (including students)
☐ Funding problems
☐ Partner(s) abandoned project
☐ Other (specify): _____

-or-

☐ No problems occurred during this instalment of the grant.

Briefly describe the main problems identified above and the steps taken to resolve each one:

The main problem encountered during this phase of the grant has been the several transitions to new supercomputers at MSC, each of which has caused significant delays in turnaround. This has slowed progress in both climate model applications and data assimilation. However, both the global climate model and the CMAM-DA version of the model are now working well on the new supercomputers.

6. Collaboration with Partners

Who initiated this strategic project?
☒ the university researcher;
☐ the industry partner (if applicable);
☐ the government partner (if applicable); and/or
☐ other (specify):_____.

In what way were the partners directly involved in the project (select any that apply)?
☐ Partners were not involved in the project apart from their financial and/or in-kind contribution.
☒ Partners were available for consultation.
☒ Partners provided facilities.
☒ Partners participated in the training.
☒ Partners discussed the project regularly with the university team. (List the number of meetings during the period covered by this report.)
☒ Partners were involved in the research.

Describe their involvement and comment on the collaboration:

Our non-academic partners are the Meteorological Service of Canada (MSC) and the Canadian Space Agency (CSA). From the MSC, Drs. Li, McFarlane, Polavarapu and Scinocca are involved as co-Investigators, and Drs. R. Ménard (ARQI), Y. Rochon (ARQX) and K. von Salzen (CCCma) are involved as Collaborators; together they represent four different MSC divisions across all three research branches. MSC provides considerable in-kind support of the GCC project, consisting of the time of its scientists as well as supercomputing time on the MSC computing system. MSC also provided cash support through its Climate Research Network during the first two years of the project. Since the phase-out of the CRN and its replacement by CFCAS funding, NSERC has regarded the CFCAS funding as part of our partner funding.

To supplement the interactions at our thrice-yearly Scientific Steering Committee meetings and annual workshops, the university-based RAs in our project have had the opportunity to spend extended periods of time at the MSC (CCCma) lab in Victoria. RAs C. McLandress, D. Plummer, S.R. Beagley, and V.I. Fomichev have all visited Victoria. Toronto-based S. Ren, Y. Yang and D. Sankey spend significant amounts of their time each week at the MSC (ARMA) lab in Toronto, including a biweekly meeting of the CMAM data assimilation subgroup (Task V) attended by Ren, Yang, Sankey from the university side, and by Rochon and Polavarapu from the MSC side. This CMAM data assimilation subgroup receives guidance from an Advisory Committee consisting of Shepherd and McConnell from the university side, and McFarlane, Ménard, and ARMA Chief D. Steenbergen from the MSC side, which meets three times per year.

CSA provides cash support for GCC. It has neither the capacity nor the mandate to conduct its own scientific research. However, CSA represents the key interface between GCGCC and the Canadian space-based atmospheric measurement community, and supports the Canadian space industry through the development of satellite instruments. Interaction wiwith the CSA occurs on an ongoing basis through the specification of our

workplan each year, by which we focus our efforts to most effectively meet the needs of CSA's space science program. We also participate in CSA workshops.

Value of the cash received from the partners during the period covered by this report (if any):

$1,987,130

Value of the in-kind contributions received during the period covered by this report:

$2,812,250

Describe the in-kind received:

Principally time on the MSC supercomputing system; also the time of MSC scientists involved in the project

7. Financial Information

Please provide the following financial information:

Amount remaining in grant account as of June 30th: $124,401.85

Budget Item	Budget for Year 1 (or Year 3 of five-year grant)	Actual Expenditures	Budget for Year 2 (or Year 4 of five-year grant)	Actual Expenditures to date	Projections to September 30 (current year)	Planned Expenditures for the Next Term of Support
Salaries and Benefits						
a) Students	120,000.00	83,285.76	120,000.00	25,974.45+?	30,503.95+?	120,000.00
b) Postdoctoral fellows	80,000.00	164,035.28	120,000.00	2,390.00+?	2,390.00+?	80,000.00
c) Technical/professional assistants						
d) Other (specify)	72,000.00	41,501.01	75,000.00	48,820.90+?	54,820.90+?	78,000.00
Equipment or Facility						
a) Purchase or rental	40,000.00	50,659.61	0.00	0.00	0.00	0.00
b) Operation and maintenance costs	20,000.00	32,352.16	20,000.00	525.44+?	825.00+?	20,000.00
c) User fees						
Materials and Supplies						
a) Materials and supplies	1,000.00	2,246.78	1,000.00	771.23	900.00	1,000.00
Travel						
a) Conferences	10,375.00	44,141.02	10,375.00	16,920.51+?	19,920.51+?	10,375.00
b) Field work						
c) Collaboration/consultation	10,375.00	7,564.80	10,375.00	8,902.99	11,902.99	10,375.00
Dissemination Costs						
a) Publication costs	7,500.00	6,738.16	7,500.00	0.00	0.00	7,500.00
b) Summer school	0.00	13,532.24	0.00	1,815.38	1,815.38	0.00
Other (specify)						
a) Annual Workshop	5,000.00	4,824.45	5,000.00	8,141.35	8,141.35	5,000.00
b)						

Please provide detailed explanations for any deviation in the current period and in the budget for the coming year. (Note that deviations from the budget of greater than 20 per cent require pre-approval from NSERC):

The salaries to others represent salaries paid to the research associates and assistants at the University of Toronto, York University, McGill University, Dalhousie University and the University of Victoria.

In several cases, investigators were either not able to find suitable graduate students, or those students were supported from scholarships, so the funds were used to hire postdocs. The overall salary costs are close to budget.

The annual costs don't necessarily balance the budget in any given year, because of carry-over between years. For example, the summer school was budgeted at $15,000 in year 2.

The total conference travel budget for the project, including CFCAS support, is $39,000 per year. However, to avoid the proliferation of numerous CFCAS sub-grants for travel alone, the travel is mainly charged to the NSERC account.

Actual expenditures for the current year are not available from the other universities, so columns 4 and 5 are quite incomplete.