Annual Letter Report for Year 4/1/87-3/31/88

(1) Title: Fundamentals of Middle-atmospheric dynamics.

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Principal Investigator: M.E. McIntyre
Department of Applied Mathematics
and Theoretical Physics,
Silver Street,
Cambridge, CB3 9EW.
Tel: (011-44-223) 337871

Program Manager: Dr P.F. Twitchell

(2) Technical Objectives: The long term aim over three years is to advance our fundamental understanding of middle atmospheric dynamics, particularly with regard to the vertical and horizontal dynamical coupling associated with planetary scale motions and their interactions with other scales. The immediate aims of the first year are to continue with high-resolution barotropic planetary wave-breaking simulations, to extend these to fully three-dimensional baroclinic simulations using the UK Research Councils' Cray X-MP/48, to continue to build new theoretical concepts using insights from abstract theories of Hamiltonian dynamical systems, and to carry out numerical experiments and diagnostic computations that test the limitations of the potential-vorticity invertibility principle. It is hoped that these activities will lead to a the development of a new and illuminating set of diagnostic methods for probing dynamical processes in high-resolution numerical models and, ultimately, in real observational data.

(3) Approach: The approach is three-pronged: first, to build and use a sophisticated numerical modelling capability, both locally and exploiting our involvement in the UK Universities' Global Atmospheric Modelling Project (UGAMP), second to develop abstract theoretical concepts that are likely to lead to dynamical insight and test them in numerical experiments, and third to develop new and efficient ways for scientists to interact with numerical models, exploiting modern workstation facilities.

(4) Accomplishments since April 1987: One milestone was the successful initiation of three-dimensional, high-resolution numerical simulations of breaking planetary waves, building upon the barotropic modelling work initiated earlier and still continuing. This has verified many of the features that we thought significant about the barotropic simulations, but has also taken a major step towards complete realism in representing the dynamics of the planetary "wave-turbulence jigsaw puzzle" (first results were presented at the March 1988 European Geophysical Soc. Symposium and are scheduled for the Snowmass Polar Ozone Workshop in May).

With the arrival of the new workstation system we are taking our first steps towards what we hope will be a new world of

man-machine interaction in numerical modelling. Grayscale graphics like the ones produced with so much labour for the Juckes and McIntyre Nature paper, using an oversubscribed central campus facility, are now being easily and routinely produced locally in the research group's working area. These give a far more powerful way of viewing dynamical phenomena in several kinds of numerical experiments now being done.

Progress has also been made on the conceptual frontier. Dr Haynes has succeeded in extending earlier work by McIntyre and Shepherd to take account of dissipative processes, (first Haynes reference in sec. 7a below), and McIntyre has discovered a new aspect of the mathematical structure of wave, mean-flow interaction theory (a Legendre transform relationship) that may prove fundamental.

Mr W.A. Norton has exercised great ingenuity in achieving high-order, nonlinear potential-vorticity inversions using several different algorithms. One surprise has been how difficult it is to obtain clear examples of the spontaneous breakdown of high-order balance in shallow-water systems on the hemisphere. Balance and invertibility are proving surprisingly robust. These together with some further barotropic modelling results are being written up for publication.

Dr Dritschel has been obtaining a flood of remarkable results on the fine-scale aspects of vorticity and potential vorticity evolution. This is building a bridge between the esoteric mathematical world of dynamical systems that forms the main thrust of Dr Dritschel's work (supported on UK funds) and the world of the real stratosphere and mesosphere that we are trying to understand.

Dr McIntyre has carried out a new analytical model calculation bearing on the so called "turbulent Prandtl number" question that is important in connection with breaking gravity waves in the mesosphere. Results were presented at Noctilucent Cloud (NLC) Workshop at Boulder in March.

Drs Haynes, McIntyre and Shepherd have begun new work to determine the robustness of the "downward control" principle for diabatic circulations and chemical transports. This is proving highly relevant to the mesospheric NLC environment as well as to understanding dynamical-chemical-radiative interactions in the stratosphere.

(5) Significance: The research described is giving us new insights into the subtle scale interactions that are central to the way in which the circulation of the middle atmosphere is controlled and shaped. With the progress of the numerical modelling and man-machine interaction facilities we are close to being able to use the models as a flexible testbench for hypothesis-testing and for the development of innovative diagnostics based on theoretical insights now emerging.

(6) Future efforts: The next step in three-dimensional modelling will be to incorporate a realistic radiation scheme. Hand calculations with simple radiation models are indicating that

the scale dependence of infrared radiative exchange in the 15 micron CO2 band may strongly affect small-scale potential vorticity features. We also hope to move to three-dimensional potential vorticity inversions and to further develop our work on the downward influence principle. Next year, should, in addition, see us able to pull together and crystallize the new theoretical concepts on wave, mean-flow interaction now under development. Also, we plan to continue active participation in UGAMP.

(7) (a) Publications:

Haynes, P.H., 1988: Forced, dissipative generalizations of finite-amplitude wave-activity conservation relations for zonal and non-zonal basic flows. J. Atmos. Sci., in press.

Haynes, P.H., 1988: The role of barotropic instability in the nonlinear evolution of a Rossby-wave critical layer. J. Fluid Mech., in press.

Juckes, M.N. and McIntyre, M.E., 1987: A high resolution, one-layer model of breaking planetary waves in the stratosphere. Nature, 328, 590-596.

McIntyre, M.E., 1988: The dynamical significance of isentropic distributions of potential vorticity and low-level distributions of potential temperature. Invited paper for ECMWF Seminar "The Nature and Prediction of Extratropical Weather Systems", 7-11 September 1987, pp. 237-259. Obtainable from Librarian, European Centre for Medium-Range Weather Forecasts, Shinfield Park, Reading RG2 9AX, U.K.

McIntyre, M.E., 1988: The use of PV and low-level temperature/moisture to understand extratropical cyclogenesis". Ibid., pp. 261-280.

(b) Presentations:

D.G. Dritschel (1 September 1987): "Repeated filamentation of two-dimensional vorticity interfaces". IUTAM Symposium on Vortex Dynamics, Tokyo.

P.H. Haynes (23 March 1988): "High resolution dynamical modelling of the Antarctic stratospheric vortex. Symposium on the Ozone Problem at General Assembly XIII of the European Geophysical Society, Bologna, Italy, invited paper.

M.E. McIntyre (11 April 1987): "On the effective vertical diffusivity due to breaking internal gravity waves". European Geophysical Society 12th General Assembly, Strasbourg, France, invited paper to Symposium on Modelling of Internal Gravity Waves and their Influence in the Lower Atmosphere.

M.E. McIntyre (14 April 1987): "What do theoreticians and modellers need to know about gravity waves and turbulence?" European Geophysical Society 12th General Assembly, Strasbourg, France, invited paper to Workshop on Atmospheric Gravity Waves and Tides.

M.E. McIntyre (19 August 1987): "On the Antarctic Ozone Hole". IUGG 19 General Assembly, Vancouver, invited paper.

M.E. McIntyre (27 August 1987): "On the Atmospheric General Circulation". AMS meeting on Waves and Stability, Seattle, WA, invited paper.

M.E. McIntyre (7 September 1987): "The dynamical significance of isentropic distributions of potential vorticity and low-level distributions of potential temperature." ECMWF Seminar, The Nature and Prediction of Extratropical Weather Systems, Reading, invited paper.

M.E. McIntyre (8 September 1987): "The use of PV and low-level temperature/moisture to understand extratropical cyclogenesis". ECMWF Seminar, The Nature and Prediction of Extratropical Weather Systems, Reading, invited paper.

M.E. McIntyre (15 December 1987): "On the atmospheric general circulation". Edward Lorenz Symposium, invited paper.

M.E. McIntyre (17 March 1988): "On dynamics and transport near the polar mesopause in summer". International Workshop on Noctalucent Clouds, Boulder, CO, invited paper.

T.G. Shepherd (12 August 1987): "Nonlinear stability and some of its implications," Woods Hole Oceanographic Institution Summer Study Program in Geophysical Fluid Dynamics, Woods Hole, Massachusetts.

T.G. Shepherd (28 August 1987): "Nonlinear stability of two-dimensional steady flows," American Meteorological Society 6th Conference on Atmospheric and Oceanic Waves and Stability, Seattle, Washington.

T.G. Shepherd (1 March 1988): "Theory of two-dimensional turbulence," Institute for Meteorology, University of Stockholm.

T.G. Shepherd (22 March 1988): "Non-ergodicity and other implications of finite-amplitude stability theorems," Symposium on Chaos and Turbulence, European Geophysical Society 13th General Assembly, Bologna, Italy.

(8) Scientific personnel involved in the project:

Dr M.E. McIntyre (PI, Reader in Atmospheric Dynamics)
Dr P.H. Haynes (Royal Society Research Fellow)
Dr D.G. Dritschel (Sci. Engg. Res. Council)
Dr T.G. Shepherd (Nat. Environm. Res. Council)

Ms. L.I. Kurtul (programmer)
Ms. J.M. Wilkins (programmer)

Mr W.A. Norton (graduate student)
Mr M.N. Juckes (graduate student)