

**Geodesy and Geophysics in Canada
1991 — 1995**

**Quadrennial Report
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International Union of Geodesy and Geophysics**

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Introduction

This report summarises the research carried out in Canada in the fields of geodesy and geophysics during the quadrennium 1991 - 1995. It was prepared under the direction of the Canadian National Committee for the International Union of Geodesy and Geophysics (CNC/IUGG). The CNC/IUGG is administered by the Canadian Geophysical Union, in consultation with the Canadian Meteorological and Oceanographic Society and other Canadian scientific organisations including the Canadian Association of Physicists, the Geological Association of Canada, and the Canadian Institute of Geomatics. The IUGG adhering organisation for Canada is the National Research Council of Canada.

Among other duties, the CNC/IUGG is responsible for

- collecting and reconciling the many views of the constituent Canadian scientific community on relevant issues
- identifying, representing, and promoting the capabilities and distinctive competence of the community on the international stage
- enhancing the depth and breadth of the participation of the community in the activities and events of the IUGG and related organisations
- establishing the mechanisms for communicating to the community the views of the IUGG and information about the activities of the IUGG.

The aim of this report is to communicate to both the Canadian and international scientific communities the considerable progress that has been achieved in geodesy and geophysics research in Canada over the past four years.

The report is divided into seven sections — one for each of the seven major scientific disciplines as represented by the seven sister societies of the IUGG. Each section is titled with the name of the corresponding society and was compiled by, or under the direction of, a member of the CNC/IUGG affiliated with that society.

In the interest of compiling and disseminating this report in a timely fashion, no attempt has been made to harmonise the styles of the different sections.

The full text of this report, including the extensive lists of publications and presentations, is only available electronically. The full report may be obtained via the Internet in Unix-compressed, uuencoded, printer PostScript format by retrieving the file with the following universal resource locator (URL):

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<gopher://UNBMVS1.CSD.UNB.CA:1570/0EXEC%3aCANGET%20IUGG.CNC.REPORT.PS.Z.UUENC.TXT>.
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The report can be made available in other formats upon request to the chairman of the CNC/IUGG.

INTERNATIONAL ASSOCIATION OF GEODESY

Compiled by Richard B. Langley

Natural Resources Canada Pacific Geoscience Centre

Crustal Deformation Studies on Canada's West Coast

As part of its Earthquake Hazards Program, the Geological Survey of Canada (GSC) has utilized geodetic techniques to measure the effects of accumulating elastic strain within the northern Cascadia subduction zone. Through repeated precise levelling, gravity, and horizontal control surveys, relative crustal motions of the order of several millimetres per year have been resolved in this active seismic region. Recent observations have provided the most convincing evidence that the fault zone is locked, as well as the best constraints to date for the size and location of the seismogenic portion of the thrust zone capable of producing great ($M > 8$) earthquakes. A major research effort over the past four years has also gone into the establishment of the Western Canada Deformation Array (WCDA), a network of automated continuous GPS trackers intended to provide a precise, continuous fiducial reference frame for crustal motion studies in this region. The effectiveness of this network to provide day-to-day strain information at the sub-centimetre level over distances of hundreds of kilometres has already been demonstrated. Since 1991, the Pacific Geoscience Centre of the GSC has also been involved in a pioneering cooperative project to measure centimetre displacements of the ocean floor using a combination of acoustic and GPS techniques.

Relevant Publications:

Dragert, H., and R.D. Hyndman, Continuous GPS monitoring of elastic strain in the northern Cascadia subduction zone, *Geophys. Res. Let.*, Vol.22, 755-758, 1995.

Wang, K., H. Dragert, and H.J. Melosh, Finite element study of uplift and strain across Vancouver Island, *Can. J. Earth Sci.*, Vol. 31, 1510-1522, 1994.

Dragert, H., R.D. Hyndman, G.C. Rogers, K. Wang, Current deformation and the width of the seismogenic zone of the northern Cascadia subduction thrust, *J. Geophys. Res.*, Vol. 99, 653-668, 1994.

Dragert, H., M. Schmidt, and X. Chen, The use of continuous GPS tracking for deformation studies in southwestern British Columbia, *Proceedings of ION-GPS94*, Salt Lake City, Utah, Sept. 20-23, 97-103, 1994.

Chen, X., Analyses of continuous GPS data from the Western Canada Deformation Array, *Proceedings of ION-GPS94*, Salt Lake City, Utah, Sept. 20-23, 1339-1348, 1994.

Spiess, F.N., G. Purcell, L. Young, and H. Dragert, Determination of sea-floor displacements using precision transponders and GPS, *Proceedings of the International Symposium on Marine Positioning (INSMAP94)*, Hannover, Germany, Sept. 19-23, in press, 1994.

Delikaraoglou, D., H. Dragert, J. Kouba, K. Lochhead, and J. Popelar, The development of a Canadian GPS active control system: Status of the current array, *Proceedings of the Second International Symposium on Precise Positioning with GPS*, Ottawa, Canada, Sept. 3-7, 1990, 190-202, 1991.

The University of Calgary Department of Geomatics Engineering

Major research in the Department of Geomatics Engineering at The University of Calgary was done in four areas: Gravity and geoid, airborne gravimetry, positioning and navigation, and system integration and multi-sensor systems.

Gravity and geoid: A major emphasis in geoid-related research was the optimization of spectral geoid determination methods, Li (1993). It was shown that heterogeneous noisy data and error propagation can be handled by FFT methods (Sideris and Li, 1992; Li and Sideris, 1994) and that clever application of the DFT or the fast Hartley transform (FHT) can further improve the efficiency and the memory requirements of the spectral techniques (Sideris and Li, 1992; Li and Sideris, 1992 and 1995). It was also shown explicitly that FFT methods produce identical results to numerical integration when zero-padding is properly applied (Sideris and Li, 1993). Optimized algorithms for computing the effect of the topography were also developed (Li, 1993). Sideris (1994 and 1995) showed that irregular data and grids with incomplete data can be used with (hybrid) spectral methods. Direct and indirect effects of the topography on the geoid and on airborne gravity and gradiometry were computed by the 3D FFT method in order to avoid the approximations of the 2D techniques; very promising results have been reported in Peng (1994) and Peng et al. (1995). Improvements of the 2D FFT method on the sphere by using multiple bands of data were given in Forsberg and Sideris (1993). The rigorous 1D FFT method was used to produce a geoid for Canada and part of the US by She (1993). This geoid outperformed all existing geoids, giving absolute accuracy at the level of 5 cm and sub-ppm relative accuracies (Sideris, 1993; Sideris and She, 1995). Various tests of geoids on GPS benchmarks confirmed these accuracy levels (Tziavos et al., 1992; Mainville et al., 1992; Sideris and Teskey, 1993; Tsuei et al. 1994; Mainville et al., 1994; Li et al., 1995) and also showed that the geoid can also be used to check GPS for errors (Sideris et al., 1992a). Regional geoid determination methods are summarized in Sideris (1992 and 1994) and Schwarz and Sideris (1993). The construction of 3D gravity field models, together with the proper choice of upward and downward continuation methods, was studied by Argeseanu (1994) for the purpose of establishing a test field for checking the results of vector airborne gravimetry in rough topography (Sideris et al, 1992b). Applications of SEASAT and GEOSAT satellite altimetry have been investigated by Zhang and Blais (1993 and 1994). Zhang (1993) completed a Ph.D. thesis on the recovery of gravity information from satellite altimetry data and associated forward geopotential modeling. Satellite altimetry research using GEOSAT, ERS-1 and TOPEX data has commenced (Zhang and Sideris, 1994 and 1995) and is currently focusing on obtaining oceanic geoid and gravity by optimal combination of satellite altimetry and shipborne gravimetry data. Further research has also been done on inverse problems (Blais, 1994), multiresolution and wavelet transform applications Nie (1994); Blais et al. (1995), Li (1995).

Airborne gravimetry: A major emphasis during the reporting period was the development of airborne gravity systems for geodetic and geophysical tasks. Three projects are at different stages of completion. The first is the development of a GPS-aided stable platform for a scalar gravity system, done in cooperation with Sander Geophysics Ltd. Details are given in Wei et al (1991), Zhang (1993), Czompo (1993, 1994), Czompo and Ferguson (1995), and Zhang et al (1995). A thorough discussion of platform stabilization by GPS-velocity aiding is discussed in Zhang (1995). System testing is planned for the summer 1995. Second, the possibility of using an inertial strapdown system in conjunction with DGPS for vector gravimetry was explored together with Canagrav Research Ltd. The

principle of this approach is discussed in Schwarz et al (1991), a detailed error analysis is given in Wei and Schwarz (1994), and results of DGPS acceleration determination are presented in Van Dierendonck et al (1994) and Wei and Schwarz (1995). System tests are ongoing and the initial analysis will be completed in fall 1995. Third, the use of a high accuracy inertial stable platform system for both scalar and vector gravimetry was tested in cooperation with the Inertial Technology Scientific Center in Moscow, Russia and Canagrav Research Ltd. in Calgary. Results are reported in Salychev et al (1994), Salychev and Voronov (1995), Salychev and Schwarz (1995). They show that minimum wavelengths of about 3 km can be resolved with a standard deviation of about 1 mGal. The current state of airborne gravity research and some of the remaining problems are discussed in Schwarz and Wei (1994) and the contributions of this new measurement technique to geoid determination in Schwarz et al (1994) and Li and Schwarz (1995).

Positioning and navigation: A major part of departmental research activities was concentrated in this area.

Investigations into the performance of high performance Narrow Correlator*spacing C/A receivers for precise DGPS kinematic positioning were conducted [Cannon & Lachapelle 1992] and applications to various cases such as precision farming [Lachapelle et al 1994, Cannon et al 1994], hydrographic surveying [Lachapelle et al 1992, Lachapelle et al 1994a, Lachapelle et al 1993], and airborne positioning [Tiemeyer et al 1994], were demonstrated. Research into the problem of integer carrier phase ambiguity resolution on-the-fly was pursued [Lachapelle et al 1992a, Cannon et al 1993, Lachapelle et al 1993a]. The mathematical equivalence between the Ambiguity Function Method and the Least-Squares Search Method was established [Lachapelle et al 1992b]. A new OTF method, namely the Fast Ambiguity Search Filter, was developed [Chen 1993, Chen & Lachapelle 1994]. The use of a multi-receiver configuration to improve the effectiveness of ambiguity OTF was investigated with an application to aircraft-to-aircraft positioning [Lachapelle et al 1993b, 1994b]. The use of several non-dedicated receivers fixed to a mobile platform to determine the attitude parameters was analysed [Lu et al 1994, Lachapelle et al 1994c, McMillan et al 1994]. Research into the estimation of the ionospheric delay using single frequency measurements was conducted [Qiu et al 1994]. The use of GPS to calibrate Loran-C groundwave distortions [Lachapelle & Townsend 1991, Lachapelle et al 1992c, 1993d, 1994d] and as a complement to Loran-C [Lachapelle et al 1993c] was investigated. The use of post-mission orbits and satellite clock corrections to recover the effect of Selective Availability and obtain single point positions at the 1 m (rms) accuracy level in static and kinematic modes was investigated [Lachapelle et al 1994e, f].

Research into precise kinematic GPS algorithm development and subsequent testing in a variety of environments was conducted (Cannon et al., 1993a; Cannon and Lachapelle, 1992; Cannon et al., 1992a; Cannon et al., 1992d). Work into the use of narrow-correlator GPS technology for precise static positioning was carried out (Cannon et al., 1994c). The use of low-cost GPS receivers for cm-level positioning was investigated (Cannon et al., 1993b). Application of DGPS and kinematic methods to agriculture (Cannon et al., 1994a; Gehue et al.; 1994) as well as airborne gravimetry (Van Dierendonck et al., 1994). Investigations into the integration of GPS and INS for high accuracy positioning in land and airborne environments were conducted (Cannon, 1992; Sun et al., 1994). Research was conducted into the use of GPS for precise attitude determination in the marine environment (Lu and Cannon, 1994). Further research into aircraft attitude determination (Cannon and Haverland, 1993) including wing flexure estimation was also conducted (Cannon et al., 1994b). A land attitude determination system which integrated GPS with low-cost dead reckoning sensors was developed and tested (Cannon et al., 1992c).

Reliability in kinematic GPS positioning and navigation was another area of research. Standard covariance analysis using covariance matrices and DOPS (Dilution of Precision) have been extended to using reliability theory where the total error is computed. One part stems from the propagation of random errors, while the second is a measure of the effect that a potential bias would have on a solution. This procedure has been implemented for GPS and DGPS static and kinematic positioning. When both measurement covariance matrices for random errors and reliability measures for potential biases - fulfill the specifications, the solution is repeatable to that specification. It has been found, however, that even when the DOPS are satisfied, there are situations and configurations that cause the reliability measures not to be satisfied (i.e., outside of specs circle). In these cases the solution is not repeatable (i.e., the coordinates cannot be replicated by a separate and independent survey). Whereas, when both the covariance and reliability measures are within the specification, the coordinates are reproducible by the independent resurvey (see references for the documentation).

Three electronic books have been written over the past four years in which intelligent navigation systems being built worldwide have been documented as to the positioning technologies used, digital maps employed, and the communications technologies incorporated. As well, the specific types of systems for each sector is defined along with the intended application. A color schematic has been created for each system and the books can be read directly from a PC computer. The IVHS Navigation System Database consists of 230 systems; the Intelligent Ship Navigation Systems Database consists of 125 systems; while the Intelligent Air Navigation Systems consists of 50 systems. These books are available to interested persons, universities, agencies and companies.

Mathematical and practical investigations into the positional changes at various scales that resulted from the new North American Datum (NAD83) have confirmed the appropriateness of the National Transformation for revising geodetic positions at the federal, provincial and municipal levels [Blais, 1990; Abousalem et al., 1993].

INS/GPS integration and multi-sensor systems: This research area is closely related to the previous one because it deals mainly with the problem of georeferencing a primary sensor or an array of sensors (multi-spectral scanners, CCD cameras, scalar gravimeters, etc). Georeferencing requires continuous position and attitude determination of the primary sensors while in motion and usually uses the integration of INS and GPS for this purpose. The basic mathematics of the approach is discussed in Schwarz et al (1993) and the requirements for optimizing INS attitude accuracy are discussed in Liu (1992), Schwarz and Ming (1995), and Skaloud (1995). Some general implementation issues, such as ambiguity resolution on the fly and the treatment of fractal sensor noise, are discussed in Wei et al (1992), Schwarz et al (1994a), Li and Schwarz (1994), and Schwarz et al (1994b). Implementation options in airborne mode using current technology are analysed in Schwarz et al (1994) and test results for a high-accuracy system are presented in Skaloud et al (1994) and Skaloud (1995). Tests of a low-cost integrated INS/GPS are presented in Schwarz and Zhang (1994) and Zhang (1995). Tests of a helicopter system are discussed in Martell et al (1993). A major project in the area of multi-sensor system was the development of a mobile survey van which allows data acquisition within a radius of 50 m around the van, while driving with a speed of up to 60 km/h. This system was developed together with Geofit Inc., Laval, Quebec and combines an INS/GPS position and attitude system with an array of CCD cameras. The different stages of system development are described in Schwarz et al (1993), El-Sheimy and Schwarz (1993), and Schwarz et al (1994). Preliminary results are discussed in El-Sheimy and Schwarz (1994) and a more detailed analysis of a major pilot project is given in El-Sheimy and Schwarz (1995). These results show that an accuracy of about 0.25 m (RMS) in horizontal coordinates and 0.05 m (RMS) in height are achievable right now and that improvements are possible. The

possibility of replacing the INS by a GPS multi-antenna system for attitude determination has been explored in Schwarz et al (1992) and El-Mowafy and Schwarz (1994). Results are encouraging for low-accuracy applications. A comprehensive comparison of models and techniques for kinematic attitude determination from GPS is presented in El-Mowafy (1994). A review of inertial techniques in geodesy is given in Schwarz (1991) and their application to curvature detection problems is discussed in Martell (1991).

Others: Investigations related to the creosote environmental problem on the Bow River in Calgary have shown that evolutionary terrain modeling, rendering and visualization can greatly help the geoscientists in their studies [Blais et al., 1994]. Using aerial and other photographic coverage of the site over the past sixty years enables the reconstruction of the terrain and any spatial changes over the years and with modern computer technology, spatial visualization for engineering purposes can be realized.

Publications

Abousalem, M., D.J. Szabo, J.A.R. Blais, M.A. Chapman, E.J. Krakiwsky, Issues Related to the Implementation of an Alberta NAD27 to NAD83 Transformation Scheme, Final Report to Alberta Forestry Lands and Wildlife, December 1991, 16 pages.

Abousalem, M., J.A.R. Blais, M.A. Chapman and E.J. Krakiwsky (1992): Issues Related to the Implementation of an Alberta NAD27 to NAD 83 Transformation Scheme-2 Final Report submitted to Alberta Forestry, Lands and Wildlife, 23 pages.

Abousalem, M., J.F. McLellan and E.J. Krakiwsky (1994): A New Quality Control Technique for GPS Kinematic Positioning, IEEE Position, Location and Navigation Symposium, Las Vegas, PLANS'94, April 12 - 15, pp. 621 to 628.

Abousalem, M.A. and E.J. Krakiwsky (1993). A Quality Control Approach for GPS-Based Automatic Vehicle Location and Navigation Systems. IEEE Vehicle Navigation and Information Systems Conference (VNIS'93), Ottawa, pp. 466 to 470.

Abousalem, M.A., E.J. Krakiwsky, J.A.R. Blais and M.A. Chapman (1993), NAD27 to NAD83: The Alberta Experience. *Geomatica*, Vol. 47, No. 1, Spring, pp. 9-17.

Argeseanu, V. 1994. A three-dimensional gravity field model of the Kananaskis Area. UCSE Report No. 20070. Department of Geomatics Engineering, The University of Calgary, Calgary, Alberta.

Blais, J.A.R. [1990]: Optimal Modelling for the Revision of Positional Data in Spatial Information Systems. *CISM Journal ACSGC* (now *Geomatica*), vol. 44, no. 2, pp. 113-121.

Blais, J.A.R. [1994]: Generalized Inverse Problems and Information Theory. Presented at the IUGG 1993 General Meeting in Beijing and submitted for publication in *Manuscripta Geodaetica*, 15 pages.

Blais, J.A.R., K. He and C. Larouche [1994]: Spatial Rendering and Visualization in Geomatics for Environmental and Related Applications. *Geomatica*, vol. 48, no. 1, pp. 261-273.

Blais, J.A.R., K. He and C. Larouche [1995]: Multiresolution Analysis in Geomatics Applications. Proceedings of the Canadian 1995 GIS Conference in Ottawa, in press.

Bullock, J.B. and E.J. Krakiwsky (1994). Analysis of the Use of Digital Road Maps in Vehicle Navigation, Proceedings of the IEEE Position, Location and Navigation Symposium, Las Vegas, Nevada, April 12 - 15, pp. 494 to 501.

Bullock, J.B., E.J. Krakiwsky, M.J. Casey (1995). Marine Geomatics: An Overview of Intelligent Ship Navigation Systems. To be presented at GIS'95 June 11 - 15, Ottawa, Canada.

Bullock, J.B., E.J. Krakiwsky, N.G. Grant, K.L. Grandia (1995). Airborne Geomatics: An Overview of Intelligent Air Navigation Systems. To be presented at GIS'95 June 11 - 15, Ottawa, Canada.

Cannon, M.E. (1992), Integrated GPS-INS for High Accuracy Road Positioning, ASCE, Journal of Surveying Engineering, Vol. 118, No.4, pp.103-118.

Cannon, M.E. and M. Haverland (1993), Experiences of GPS Attitude Determination with a Helicopter Pod, Proceedings of the Sixth International Technical Meeting of the ION Satellite Division, GPS-93, Salt Lake City, September 22-24, pp. 633-641.

Cannon, M.E., and G. Lachapelle (1992) Analysis of a High Performance C/A Code GPS Receiver in Kinematic Mode. Navigation, Vol. 39, No. 3, The Institute of Navigation, Alexandria, VA, pp. 285-299.

Cannon, M.E., E. Berry and M. King (1993b), Testing a Lightweight GPS/GIS Terminal for Sub-Meter DGPS Positioning, Proceedings of the Sixth International Technical Meeting of the ION Satellite Division, GPS-93, Salt Lake City, September 22-24, pp. 1011-1020.

Cannon, M.E., G. Lachapelle and G. Lu (1992d), Ambiguity Resolution Without Static Initialization Using a High Performance C/A Code Receiver, Proceedings of the 48th Annual Meeting of The Institute of Navigation, Washington, D.C., June 29 - July 1, pp. 161-166.

Cannon, M.E., G. Lachapelle and G. Lu (1993a), Kinematic Ambiguity Resolution With a High Performance C/A Code Receiver, Journal of Surveying Engineering, American Society of Civil Engineering Vol. 119, No. 4, pp. 147-155.

Cannon, M.E., G. Lachapelle, W. Qiu, S.L. Frodge and B. Remondi (1994c), Performance Analysis of a Narrow Correlator Spacing Receiver for Precise Static GPS Positioning, Proceedings of the IEEE PLANS'94, Las Vegas, April 11-15, pp. 355-360.

Cannon, M.E., H. Sun, T.E. Owen and M.A. Meindl (1994b), Assessment of a Non-Dedicated GPS Receiver System for Precise Airborne Attitude Determination, Proceedings of the ION GPS-94, Salt Lake City, September 20-23, pp. 645-654.

Cannon, M.E., J.B. Schleppe, J.F. McLellan and T. Ollevier (1992c), Real-time Heading Determination Using an Integrated GPS-Dead Reckoning System, Proceedings of ION GPS-92, Institute of Navigation, Washington, D.C., pp. 767-773.

Cannon, M.E., J.F. McLellan and J.B. Schleppe (1992b), High Accuracy Static GPS Surveys with Low Cost Receivers, Canadian Institute of Surveying and Mapping Journal, Vol.46 , No. 2, pp. 497-504.

Cannon, M.E., K.P Schwarz, M. Wei and D. Delikaraoglou (1992a), A Consistency Test of Airborne GPS Using Multiple Monitor Stations, *Bulletin Geodetique*, Vol. 66, No. 1, pp. 2-11.

Cannon, M.E., R.C. McKenzie, and G. Lachapelle (1994a), Soil Salinity Mapping With Electromagnetic Induction and Satellite-Based Navigation Methods, *Canadian Journal of Soil Sciences*, Vol. 74, No. 3, pp. 335-343.

Chen, D. (1993) Fast Ambiguity Search Filter (FASF): A Novel Concept for GPS Ambiguity Resolution. Proceedings of GPS-93, The Institute of Navigation, Alexandria, VA, pp 781-787. {Best ION GPS-93 Student Paper Award}

Chen, D., and G. Lachapelle (1994) A Comparison of the FASF and Least-Squares Search Algorithms for Ambiguity Resolution On The Fly. Proceedings of International Symposium on Kinematic Systems in Geodesy, Geomatics and Navigation - KIS94, Dept of Geomatics Engineering, The University of Calgary, p. 241-253.

Czompo, J. (1993). GPS Accuracy Test for Airborne Gravimetry. Proceedings of the ION GPS-93 Sixth International Technical Meeting of the Satellite Division of the Institute of Navigation, Salt Lake City, Utah, USA.

Czompo, J. (1994). Airborne Scalar Gravimetry System Errors in the Spectral Domain. Ph.D. Thesis, UCGE Report No. 20067, Department of Geomatics Engineering, The University of Calgary, Calgary, Alberta.

Czompo, J. and S.T. Ferguson (1995). Design Considerations for a New Scalar Gravity Meter for Airborne Surveys. Accepted for Proceedings of IAG Symposium G4 on Airborne Gravity Field Determination, IUGG 21st General Assembly, Boulder, Colorado, July 2-14.

El-Mowafy, A. (1994). Kinematic Attitude Determination from GPS. UCGE Report No. 20074,

El-Mowafy, A. and K.P. Schwarz (1994). Epoch by Epoch Attitude Determination Using a GPS Multi-Antenna System in Kinematic Mode, Proc. International Symposium on Kinematic Systems in Geodesy, Geomatics and Navigation, KIS94, Banff, Canada, August 30 - September 2, 1994, 331-340.

El-Sheimy, N. and K.P. Schwarz (1993). Kinematic Positioning in Three Dimensions Using CCD Technology. Proc. IEEE - IEE Vehicle Navigation & Information System Conference (IVHS), October 12-15, 1993, 472-475.

El-Sheimy, N. and K.P. Schwarz (1994). Integrating Differential GPS with an Inertial Navigation System (INS) and CCD Cameras for a Mobile GIS Data Collection System. Proc. 'The Canadian Conference on GIS', Ottawa, Canada, June 6-10, 1994, 241-248.

El-Sheimy, N. and K.P. Schwarz (1995), Mobile 3-D Positioning using GPS/INS/Video Cameras. Proc. 1995 Mobile Mapping Symposium, Columbus, Ohio, May 24-26, 1995, 236-249.

Forsberg, R. and M.G. Sideris. 1993. Geoid computations by the multi-band spherical FFT approach. *Manuscripta Geodaetica* Vol. 18, No. 2.

Gao, Y., E.J. Krakiwsky and J. Czompo (1991), A Robust Testing Procedure for the Detection of Multiple Blunders. *Journal of Surveying Engineering*, Vol. 18, No. 1, pp. 11-23.

Gao, Y., E.J. Krakiwsky and J.F. McLellan (1992). Application of Federated Filter Design to Kinematic GPS Positioning. *Proceedings of the IEEE Position, Location and Navigation Symposium (PLANS 92)*, Monterey, March 25-27, pp. 314-320.

Gao, Y., E.J. Krakiwsky and Z.W. Liu (1991), A New Algorithm for Filtering a Colored Measurement Sequence. *Manuscripta Geodaetica*, Vol. 17, pp. 96-103.

Gao, Y., E.J. Krakiwsky, M.A. Abousalem and J.F. McLellan (1993). Comparison and Analysis of Centralized, decentralized and Federated filters. *NAVIGATION*, vol.40, no.1, Spring, pp.69 to 86.

Gehue, H., M. E. Cannon, G. Lachapelle, T.W. Goddard and D. Penney (1994), GPS System Integration and Field Approaches in Precision Farming, *Proceedings of the ION NTM*, San Diego, January 24-26, pp. 549-556.

Hashimi, S.R., E.J. Krakiwsky and Elizabeth Cannon (1993). Educating Surveying-Geomatics Engineers: United States and Canadian Perspectives. *Surveying and Land Information Systems, Journal of the American Congress on Surveying and Mapping*, Vol.53, no.4, pp 250 to 255.

Krakiwsky, E.J. (1993), The Diversity Among IVHS Navigation Systems Being Built Worldwide, *IEEE Vehicle Navigation and Information Systems Conference (VNIS'93)*, Ottawa, pp. 433-436.

Krakiwsky, E.J. (1993), Tracking the Worldwide Development of IVHS Navigation Systems, *GPS World*, Vol.4, No.10, October, pp.40-47.

Krakiwsky, E.J. (1994). Innovations in Vehicle Tracking and Navigation. *GPS World*, vol. 5, no. 2, February, pp. 42 to 46.

Krakiwsky, E.J. and Clyde Harris (1994). Communications for AVLN Systems. *GPS World*, vol. 5, no. 11, November, pp. 42 to 50.

Krakiwsky, E.J. and J. Blake Bullock (1994). Digital Road Data: Putting GPS on the Map. *GPS World*, vol. 5, no. 6, May, pp. 43 to 46.

Krakiwsky, E.J., and Ivan I. Mueller (1992), Towards World Surveying and Mapping Education. *Proceedings of the International Society for Photogrammetry and Remote Sensing (IUSM Session)*, Washington, D.C., August 2-14, pp 39-45.

Krakiwsky, E.J., M. Abousalem, J.A.R. Blais and M.A. Chapman (1992), NAD27 to NAD83: Good News. *Geodesy Column, CISM Journal ACSGC*, Vol. 46, No. 1, pp. 78-80.

Lachapelle, G., and B. Townsend (1991) En-Route Coverage Validation and Calibration of Loran-C with GPS. *GPS World*, Volume 2, No. 3, pp. 36-41.

Lachapelle, G., and B. Townsend (1993c) GPS/Loran-C: An Effective System Mix for Vehicular Navigation in Mountainous Areas. *Navigation*, Vol. 40, No. 1, The Institute of Navigation, Alexandria, VA, pp. 19-34.

- Lachapelle, G., B. Townsend, and D. Hains (1993d) Analysis and Calibration of Loran-C Signals in the Lower St. Lawrence Area Using GPS. *International Hydrographic Review*, Monaco, Vol. LXX, No. 2, pp. 7-27.
- Lachapelle, G., B. Townsend, and D.W. Halayko (1992c) Analysis of GPS and Loran-C Performance for Land Vehicle Navigation in the Canadian Rockies. *I.E.E.E. Aerospace and Electronic Systems Magazine*, Vol. 7, No. 5, pp. 24-28.
- Lachapelle, G., B. Townsend, D. Gray, R. Hare, and K. Lyngberg (1994d) GPS and Loran-C in Dixon Entrance: Availability, Reliability, Accuracy and Calibration. *Geomatica*, Canadian Institute of Geomatics, Ottawa, Vol 48, No. 2, pp. 111-130.
- Lachapelle, G., C. Liu, and G. Lu (1993b) Quadruple Single Frequency Receiver System for Ambiguity Resolution on the Fly. *Proceedings of ION GPS93*, The Institute of Navigation, Alexandria, VA, pp. 1167-72.
- Lachapelle, G., C. Liu, G. Lu, B. Townsend, M.E. Cannon, and R. Hare (1993) Precise Marine DGPS Positioning Using P Code and High Performance C/A Code Technologies. *Geomatica*, Canadian Institute of Geomatics, Ottawa, Vol 47, No. 2, pp. 117-128.
- Lachapelle, G., C. Liu, G. Lu, Q. Weigen, and R. Hare (1994a) Water-Borne Leveling with GPS. *Marine Geodesy*, Vol. 17, No. 4, pp. 271-278.
- Lachapelle, G., E.J. Krakiwsky, K.P. Schwarz and A. Chandan (1992). Navigation User Requirements and Emerging Navigation Technologies for the Canadian Transportation Sector. *Canadian Journal of Civil Engineering*, Vol. 19, pp. 1062-1080.
- Lachapelle, G., G. Lu, and B. Loncarevic (1994c) Precise Shipborne Attitude Determination Using Wide Antenna Spacing. *Proceedings of International Symposium on Kinematic Systems in Geodesy, Geomatics and Navigation - KIS94*, Dept of Geomatics Engineering, The University of Calgary, pp. 323-330.
- Lachapelle, G., H. Sun, M.E. Cannon, and G. Lu (1994b) Precise Aircraft-to-Aircraft Positioning Using a Multiple Receiver Configuration. *Canadian Aeronautics and Space Journal*, Can. Aeronautics and Space Institute, Vol. 40, No. 2, pp. 74-78.
- Lachapelle, G., M.E. Cannon, and G. Lu (1992a) High Precision GPS Navigation With Emphasis on Carrier Phase Ambiguity Resolution. *Marine Geodesy*, Vol 15, 4, pp. 253-269.
- Lachapelle, G., M.E. Cannon, and G. Lu (1993a) A comparison of P Code and High Performance C/A Code GPS Receivers for On The Fly Ambiguity Resolution. *Bulletin Géodésique*, Springer Verlag, New York, Vol. 67, No. 3, pp. 185-192.
- Lachapelle, G., M.E. Cannon, C. Erickson, and W. Falkenberg (1992b) High Precision C/A Code Technology for Rapid Static DGPS Surveys. *SPN - Journal for Satellite-Based Positioning, Navigation and Communication*, 1992, 3, Herbert Wichmann Verlag, Karlsruhe, pp. 84-88.
- Lachapelle, G., M.E. Cannon, H. Gehue, T. Goddard, and D. Penney (1994) GPS System Integration and Field Approaches In Precision Farming. *Navigation*, Vol. 41, No. 3, The Institute of Navigation, Alexandria, pp.323-335.

Lachapelle, G., P. Kielland, and M. Casey (1992) GPS for Marine Navigation and Hydrography. *International Hydrographic Review*, Monaco, Vol. LXIX, No. 1., pp. 43-69.

Lachapelle, G., R. Klukas, D. Roberts, W. Qiu, and C. Mcmillan (1994f) One-Meter Level Kinematic Point Positioning Using Precise Orbit and Timing Information. *Proceedings of GPS-94* (Salt Lake City, September 21-23), The Institute of Navigation, Alexandria, VA, pp. 1435-1443.

Lachapelle, G., R. Klukas, W. Qiu, and T. Melgard (1994e) Single Point Satellite Navigation Accuracy - What the Future May Bring. *Proceedings of PLANS'94*, IEEE, New York, pp. 16-22.

Langley, R.B. and Krakiwsky, E.J. (1992). The Role of Geodesy in Surveying and Mapping Education. *Proceedings of the International Society for Photogrammetry and Remote Sensing (IUSM Session)*, Washington, D.C., August 2-14, pp 60-62.

Li, R., M.A. Chapman, L. Qian, Y. Xiu, and K.P. Schwarz (1994). Rapid GIS Database Generation using GPS/INS Controlled CCD Images. *Proc. 'The Canadian Conference on GIS'*, Ottawa, Canada, June 6-10, 1994, 465-477.

Li, Y. and M.G. Sideris. (1992). The fast Hartley transform and its application in physical geodesy. *Manuscripta Geodaetica* Vol. 17, No. 6, pp. 381-387.

Li, Y. and M.G. Sideris. (1995). Evaluation of 2-D and 3-D geodetic convolutions by the Hartley transform. Paper submitted to *Australian Journal of Geodesy, Photogrammetry and Surveying*.

Li, Y.C. and K.P. Schwarz (1995). What Can Airborne Gravimetry Contribute to Geoid Determination. Accepted for *Proceedings of IAG Symposium G4 on Airborne Gravity Field Determination*, IUGG 2st General Assembly, Boulder, Colorado, July 2-14.

Li, Y.C. and M.G. Sideris. (1994). Improved gravimetric terrain corrections. *Geophysical Journal International* Vol. 119, No. 3, pp. 740-752.

Li, Y.C. and M.G. Sideris. (1994). Minimization and estimation of geoid undulation errors. *Bulletin Geodesique* Vol. 68, No. 4, pp. 201-219.

Li, Y.C., M.G. Sideris and K.P. Schwarz. (1995). A numerical investigation on height anomaly prediction in mountainous areas. Accepted for publication in *Bulletin Geodesique*.

Li, Z. and K.P. Schwarz.(1994) Chaotic Behaviour in Geodetic Sensors and Fractal Characteristics of Sensor Noise. *Proc. 3rd Hotine-Marussi Symposium on Mathematical Geodesy*, L'Aquila, Italy, May 29-June 3, 1994.

Li. Y. (1993). Optimized spectral geoid determination. UCSE Report No. 20050. Department of Geomatics Engineering, The University of Calgary, Calgary, Alberta.

Liu, Z.W., E.J. Krakiwsky and Y. Gao (1991), An Analysis of Three Methods for Filtering a Coloured Measurement Sequence. *Manuscripta Geodaetica*, Vol. 17, pp. 87-95.

Lu, G. and M. E. Cannon (1994), Attitude Determination Using A Multi-Antenna GPS System for Hydrographic Applications, *Marine Geodesy*, Volume 17, pp. 237-250.

- Lu, G., M.E. Cannon, G. Lachapelle, and P. Kielland (1994) Shipborne Attitude Determination Using Multi-Antenna GPS Technologies. *IEEE Transactions on Aerospace and Electronic Systems*, Correspondance, 30, 4, October 94, 1053-1058.
- Mainville, A., R. Forsberg and M.G. Sideris. (1992). Global Positioning System testing of geoids computed from geopotential models and local gravity data: A case study. *Journal of Geophysical Research* Vol. 97, No. B7, pp. 11,137-11,147.
- Mainville, A., Véronneau, M., Forsberg, R. and M.G. Sideris. (1994). A comparison geoid and quasigeoid modeling methods in rough topography. In *Proc. of the Joint Symposium of the IGC and the ICG: Gravity and Geoid*, Graz, Austria, Sept. 11-17.
- Martell, H., K.P. Schwarz, D. Cosandier, M. Wei (1993), *Boundary Surveys by Helicopter Using GPS/INS*. *Surveying and Land Information Systems*, 53, 2, pp 145-150.
- Martell, H.E. (1991) *Applications of Strapdown Inertial Systems in Curvature Detection Problems* UCSE Report No. 20043, M.Sc. thesis, Department of Geomatics Engineering, The University of Calgary, Calgary, Alberta.
- McLellan, J.F., E.J. Krakiwsky, J. Schleppe and P. Knapp (1992). *The NavTrax™ Fleet Management System*. *Proceedings of the IEEE Position, Location and Navigation Symposium (PLANS 92)*, Monterey, March 25-27, pp. 509-515.
- Mcmillan, J.C., D.A.G. Arden, G. Lachapelle, and G. Lu (1994) *Dynamic GPS Attitude Performance Using INS/GPS Reference*. *Proceedings of GPS-94 (Salt Lake City, September 21-23)*, The Institute of Navigation, Alexandria, VA, pp.675-682.
- Nie, J. (1994). *Investigations of Multiresolution Applications Through Wavelet Transforms*. M.Sc. Thesis, UCGE Report No. 20068, Department of Geomatics Engineering, The University of Calgary.
- Peng, M. (1994). *Topographic effects on gravity and gradiometry by the 3D FFT and FHT methods*. UCSE Report No. 20064. Department of Geomatics Engineering, The University of Calgary, Calgary, Alberta.
- Peng, M., Y.C. Li and M.G. Sideris. (1995). *First results on the computation of terrain corrections by the 3D-FFT method*. To appear in *Manuscripta Geodaetica* Vol. 20, No.6. Ph.D. thesis, Department of Geomatics Engineering, The University of Calgary, Calgary, Alberta.
- Qiu, W., G. Lachapelle, and M.E. Cannon (1994) *Recovery of the Absolute and Relative Ionospheric Effects Using the Single Frequency Code-Carrier Phase Divergence Technique*. *Proceedings of National Technical Meeting*, The Institute of Navigation, Alexandria, VA., pp. 911-919.
- Rauhut, A. C. (1993). *Regularization Methods for the Solution of the Inverse Stokes Problem*. UCGE Report 20045, Ph.D. thesis, Department of Geomatics Engineering, The University of Calgary, Calgary, Alberta.
- Salychev, O., A.V. Bykovsky, V.V. Voronov, K.P. Schwarz, Z. Liu, M. Wei and J. Panenka (1994). *Determination of Gravity and Deflections of the Vertical for Geophysical Applications Using the ITC-2 Platform*, *Proceedings of the International Symposium on*

Kinematic Systems in Geodesy, Geomatics and Navigation, KIS94, Banff, Canada, August 30 - September 2, pp. 521-529.

Salychev, O.S. and K.P. Schwarz (1995). Airborne Gravimetric Results Obtained with the ITC-2 Inertial Platform System. Accepted for Proceedings of IAG Symposium G4 on Airborne Gravity Field Determination, IUGG 21st General Assembly, Boulder, Colorado, July 2-14.

Salychev, O.S. and V.V. Voronov (1995). Airborne Gravimetry Application of the ITC-2 Inertial Survey System. UCGE Report 30012, Department of Geomatics Engineering, The University of Calgary, Calgary, Alberta.

Schwarz, K.P. (1991). Inertial Techniques in Geodesy - State of the Art and Trends. Proc. Second Int. Workshop on High Precision Navigation, Freudenstadt, Germany, Nov. 12-15, 1991. Dümmler Verlag, Bonn, pp. 423-440.

Schwarz, K.P. and G. Zhang (1994), Development and Testing of a Low Cost Integrated GPS/INS. Proc. ION GPS-94, Salt Lake City, Utah, Sept. 20-23, 1994. 1137-1144.

Schwarz, K.P. and M. Wei (1994). Some Unsolved Problems in Airborne Gravimetry. Accepted for Proceedings of the IAG Symposium, 'Gravity and Geoid', Graz, Austria, September 11-17.

Schwarz, K.P. and M. Wei (1995). Modelling INS/GPS for Attitude and Gravity Applications. Proc. of the Third Int. Workshop on High Precision Navigation, Stuttgart, Germany, April 3-6, 1995. Dümmler Verlag, Bonn, pp. 200-218.

Schwarz, K.P. and M.G. Sideris (1993). Heights and GPS. GPS World Vol. 4, No. 2, 50-56.

Schwarz, K.P., A. El-Mowafy, and M. Wei (1992). Testing a GPS Attitude System in Kinematic Mode. 5th Technical Meeting ION-GPS 92, Albuquerque, N.M., Sept. 16-18, 1992, pp. 801-809.

Schwarz, K.P., H.E. Martell, N. El-Shiemy, R. Li, M.A. Chapman, D. Cosandier (1993). VISAT - A Mobile Highway Survey System of High Accuracy. Proc. IEEE - IEE Vehicle Navigation & Information System Conference (IVHS), October 12-15, 1993, pp. 476-481.

Schwarz, K.P., M. Wei, M. van Gelderen (1994). Aided Versus Embedded - A Comparison of Two Approaches to GPS/INS Integration. IEEE PLANS 1994, Las Vegas, April 11-15, 1994, 314-322.

Schwarz, K.P., M.A. Chapman, M.E. Cannon, P. Gong (1993), An Integrated INS/GPS Approach to the Georeferencing of Remotely Sensed Data. Photogrammetric Engineering and Remote Sensing, 53, 2.

Schwarz, K.P., M.A. Chapman, M.E. Cannon, P. Gong, D. Cosandier (1994). A Precise Positioning/Attitude System in Support of Airborne Remote Sensing. Proc. ISPRS Commission II Symposium 'Systems for Data Processing, Analysis and Representation', Ottawa, Canada, June 6-10, 1994, 191-201.

Schwarz, K.P., N. El-Sheimy and Z. Liu (1994). Fixing GPS Cycle Slips by INS/GPS - Methods and Experiences, Proc. International Symposium on Kinematic Systems in Geodesy, Geomatics and Navigation, KIS94, Banff, Canada, August 30 - September 2, 1994, 265-275.

Schwarz, K.P., N. El-Sheimy, R. Li, M.A. Chapman (1994). VISAT - A Mobile System for Precise GIS Highway Inventory Applications, Proc. 3rd Int. Conf. on Land Vehicle Navigation, EURONAV 94, Dresden, Germany, June 14-16, 1994, 283-297.

Schwarz, K.P., O. Colombo, G. Hein, E.T. Knickmeyer (1992). Requirements for Airborne Vector Gravimetry. Proceedings of the IAG Symposium From Mars to Greenland: Charting Gravity with Space and Airborne Instruments, Springer Verlag, New York, pp. 273-283.

Schwarz, K.P., Y. Li, and M. Wei (1994). The Spectral Window for Airborne Gravity and Geoid Determination, Proceedings of the International Symposium on Kinematic Systems in Geodesy, Geomatics and Navigation, KIS94, Banff, Canada, August 30 - September 2, pp. 445-456.

Schwarz, K.P., Z. Li and Z. Liu (1994). Kalman Filtering with Fractal Noise, Proc. International Symposium on Kinematic Systems in Geodesy, Geomatics and Navigation, KIS94, Banff, Canada, August 30 - September 2, 1994, 155-161.

She, B.B. (1993). A PC-based unified geoid for Canada. UCSE Report No. 20051. Department of Geomatics Engineering, The University of Calgary, Calgary, Alberta.

Sideris M.G. (1995). "Chapter 4: Regional Geoid Determination" of the book Geophysical Interpretation of the Geoid edited by P. Vanicek and N. Christou. CRC Press Inc.

Sideris, M.G. (1992). Fast vertical positioning for exploration projects. In Proc. of the Sixty-Second Annual International Meeting of the Society of Exploration Geophysics, pp. 577-580. New Orleans, Louisiana, October 25-29.

Sideris, M.G. (1993). Tests of a gravimetric geoid in GPS networks. Surveying and Land Information Systems, Vol. 53, No. 2, pp. 94-102.

Sideris, M.G. (1994). Geoid determination by FFT techniques. Lecture notes for the International School for the Determination and Use of the Geoid. Milan, Italy, Oct. 10-15.

Sideris, M.G. (1994). On the reconstruction of regular grids from incomplete, filtered or unevenly sampled band-limited data. In Proc. of the III Hotine-Marussi Symposium on Mathematical Geodesy, L'Aquila, Italy, May 29 - June 3.

Sideris, M.G. (1995). Fourier geoid determination with irregular data. To appear in Manuscripta Geodaetica Vol. 20, No.6.

Sideris, M.G. and B.B. She. (1995). A new, high-resolution geoid for Canada and part of the U.S. by the 1D FFT method. Bulletin Geodesique Vol. 69, No. 2, pp. 92-108.

Sideris, M.G. and Y. Li. (1992). Improved geoid determination for leveling by GPS. In Proc. of the Sixth International Geodetic Symposium on Satellite Positioning, pp. 873-882. Columbus, Ohio, March 17-20.

Sideris, M.G. and Y. Li. (1993). Gravity field convolutions without windowing and edge effects. *Bulletin Geodesique* Vol. 67, No. 2.

Sideris, M.G., A. Mainville and R. Forsberg. (1992a). Geoid testing using GPS and leveling (or GPS testing using leveling and the geoid?). *Australian Journal of Geodesy, Photogrammetry and Surveying* No. 57, pp. 62-67.

Sideris, M.G., Wei, M., Cannon, M.E. and K.P. Schwarz. (1992b). Airborne gravimetry and gradiometry for geophysical prospecting. In *Proc. of the International Workshop on Global Positioning Systems in Geosciences*, pp. 327-346. Chania, Greece, June 8-10.

Sideris, M.G. and W.F. Teskey. (1993). Local gravity field effects on precise trigonometric leveling. In *Proc. of the Seventh International FIG Symposium on deformation measurements*, pp. 131-140. Banff, Alberta, May 3-5.

Skaloud, J. (1995). Strapdown INS Orientation Accuracy with GPS Aiding. UCGE Report 20079, M.Sc. thesis, Department of Geomatics Engineering, The University of Calgary, Calgary, Alberta.

Skaloud, J., D. Cosandier, K.P. Schwarz, and M.A. Chapman. (1994). GPS/INS Orientation Accuracy Derived From a Medium Scale Photogrammetry Test, *Proc. International Symposium on Kinematic Systems in Geodesy, Geomatics and Navigation, KIS94, Banff, Canada, August 30 - September 2, 1994*, 341-348.

Sun, H., M.E. Cannon, T. Owen and M. Meindl (1994). An Investigation of Airborne GPS/INS for High Accuracy Position and Velocity Determination, *Proceedings of the ION NTM, San Diego, January 24-26*, pp. 801-809.

Tiemeyer, B., M.E. Cannon, G. Lachapelle, and G. Schuster (1994). Satellite Navigation for High Precision Aircraft Navigation with Emphasis on Atmospheric Effects. *Proceedings of IEEE PLANS'94, IEEE, New York*, pp. 394-401.

Tsuei, G.-C., Arabelos, D., Forsberg, R., Sideris, M.G. and I.N. Tziavos. (1994). Geoid computations in Taiwan. In *Proc. of the Joint Symposium of the IGC and the ICG: Gravity and Geoid, Graz, Austria, Sept. 11-17*.

Tziavos, I.N., M.G. Sideris and K.P. Schwarz. (1992). A study of the contributions of various gravimetric data types on the estimation of gravity field parameters in the mountains. *Journal of Geophysical Research* Vol. 97, No B6, pp. 8,843-8,852.

Van Dierendonck, K., M.E. Cannon, M. Wei, K.P. Schwarz (1994). Error Sources in GPS-Determined Acceleration for Airborne Gravimetry. *ION National Technical Conference, San Diego, January 24-26*.

Van Dierendonck, K.J., M.E. Cannon, M. Wei and K.P. Schwarz (1994), Error Sources in GPS-Determined Acceleration for Airborne Gravimetry, *Proceedings of the ION NTM, San Diego, January 24-26*, pp. 811-820.

Wei, M. and K.P. Schwarz (1994). An Error Analysis of Airborne Vector Gravimetry. *Proceedings of the International Symposium on Kinematic Systems in Geodesy, Geomatics and Navigation, KIS94, Banff, Canada, August 30 - September 2*, pp. 509-520.

Wei, M. and K.P. Schwarz (1995). Analysis of GPS-derived Acceleration from Airborne Tests. Accepted for Proceedings of IAG Symposium G4 on Airborne Gravity Field Determination, IUGG 21st General Assembly, Boulder, Colorado, July 2-14.

Wei, M., M.E. Cannon, K.P. Schwarz, D. Delikaraoglu. (1992). Maintaining High Accuracy GPS Positioning 'On the Fly'. Proc. IEEE Plans '92 Symposium, Monterey, Cal., March 23-27, 1992, pp. 403-411.

Wei, M., S. Ferguson, K.P. Schwarz (1991). Accuracy of GPS-Derived Acceleration from Moving Platforms. Proceedings IAG Symposium 100, From Mars to Greenland: Charting Gravity with Space and Airborne Instruments, Springer Verlag, New York., pp. 235-249.

Zhang, C. and J.A.R. Blais (1993). Recovery of Gravity Disturbances from Satellite Altimetry by FFT Techniques: A Synthetic Study. Manuscripta Geodaetica, vol. 18, no. 3, pp. 158-170.

Zhang, C. and J.A.R. Blais (1994). The Determination of Marine Gravity Using Satellite Altimetry Data. Submitted for publication in Manuscripta Geodaetica, 14 pages.

Zhang, C. and M.G. Sideris. (1994). Gravity disturbances from GEOSAT data and forward geopotential models in the Labrador Sea. In Proc. of the Joint Symposium of the IGC and the ICG: Gravity and Geoid, Graz, Austria, Sept. 11-17.

Zhang, C. and M.G. Sideris. (1995). On the analytical inversion of the Hotine formula for estimating gravity disturbances in the oceans. Paper submitted to Marine Geodesy.

Zhang, C. (1993). Recovery of Gravity Information and Associated Forward Geopotential Models. Ph.D. Thesis, UCGE Report No. 20058, Department of Geomatics Engineering, The University of Calgary.

Zhang, G. (1995). A Low-Cost Integrated INS/GPS. UCGE Report 20078, M.Sc. thesis, Department of Geomatics Engineering, The University of Calgary, Calgary, Alberta.

Zhang, J.Q. (1993). Inertial Platform Stabilization Using GPS Velocity Feedback. Proceedings ION GPS 93 Technical Meeting, Salt Lake City, September 22-24, pp. 757-764.

Zhang, J.Q., K.P. Schwarz and O.S. Salychev (1995). Accuracy of Inertial Platform Stabilization by GPS Velocity. Accepted for Proceedings of IAG Symposium G4 on Airborne Gravity Field Determination, IUGG 21st General Assembly, Boulder, Colorado, July 2-14.

Université Laval
Département des Sciences Géomatiques and Centre de Recherche en
Géomatique

The geodesy activities carried out at the Département des sciences géomatiques and at the Centre de Recherche en Géomatique of Université Laval mainly dealt with the following topics:

The potential of GPS for dam deformation monitoring has been studied by Bélanger et al. [1991]. Important errors encountered in precise GPS positioning, needed for dam deformation, are the multipath and phase center variations. The impact of those errors in GPS positioning results has been studied by Arbour [1994] and Bourassa [1994], respectively. A method has been proposed by Santerre and Beutler [1993a, 1993b] to improve GPS height determination for small GPS networks.

GPS orbit improvement process has been addressed by Huot [1993] and Salamanca-Chaves [1993]. Alaoui [1992] and Leclerc and Alaoui [1992] made studies on tropospheric delay modelling for GPS applications.

Papers have been published on the efficiency of using a telescopic mast to improve GPS positioning in wooded and urban areas where satellites are obstructed by trees and buildings [Santerre et Roy, 1993; Santerre and Boulianne, 1995].

Kinematic positioning software has been developed at the Centre de Recherche en Géomatique [Santerre, Parrot et Roy, 1994]. The software called POSICIEL (logiCIEL de POSItionnement CInématique) allows positioning with smoothed code measurements as well as with fixed ambiguity phase measurements (with OTF capability).

Publications and Presentations

Alaoui, A. El (1992). "Modilisation atmosphérique en trois dimensions pour le calcul du délai de propagation troposphérique: Application au système de positionnement global GPS." Mémoire de maîtrise (M.Sc.), Département des sciences géodésiques et de Télédétection, Université Laval.

Arbour, B. (1994). "Etude des effets des multitrajets sur le positionnement GPS avec les mesures de phase des ondes porteuses." Mémoire de maîtrise (M.Sc.), Département des sciences géodésiques et de Télédétection, Université Laval, 108 p.

Bélanger, P., R. Santerre et D. Parrot (1991). "Etude de faisabilité sur l'utilisation du système de positionnement GPS pour les travaux d'auscultation topographique des ouvrages hydro-électriques." Rapport de recherche pour Hydro-Québec, Division Ouvrages de Génie Civil, Service Appareillage, Région La Grande Rivière, décembre, 84 p.

Bourassa, M. (1994). "Etude des effets de la variation des centres de phase des antennes GPS." Mémoire de maîtrise (M.Sc.), Département des sciences géodésiques et de Télédétection, Université Laval, 109 p.

Huot, C. (1993). "Application des séries de Lagrange étendues à la détermination précise des orbites des satellites GPS." Mémoire de maîtrise (M.Sc.), Département des sciences géodésiques et de Télédétection, Université Laval.

Leclerc, J.-G. and A. El Alaoui (1992). "A three dimensional representation of tropospheric refractivity with application to GPS." Proceedings of the Symposium Refraction to Transatmospheric Signals in Geodesy, The Hague, The Netherlands, 19-22 May, pp. 105-108.

Salamanca-Chaves, F. (1993). "Solution de l'équation variationnelle avec les séries de Lagrange étendues." Mémoire de maîtrise (M.Sc.), Département des sciences géodésiques et de Télédétection, Université Laval.

Santerre, R. and M. Boulianne (1995). "New Tools for Urban GPS Surveyors." *GPS World*, 6(2), pp. 49-54.

Santerre, R., D. Parrot et E. Roy (1994). "Positionnement cinématique GPS à l'aide des mesures de pseudodistance lissées." Rapport scientifique du Module Télédétection-GPS, Projet PREDIR, mars, 109 p.

Santerre, R. and G. Beutler (1993a). "A proposed GPS method with multi-antennae and single receiver for the improvement of baseline height component." Presented at the International Association of Geodesy General Meeting, Beijing, China, 6-13 August.

Santerre, R. and G. Beutler (1993b). "A proposed GPS method with multi-antennae and single receiver." *Bulletin Géodésique*, 67(4), pp. 210-223.

Santerre, R. et Y. Roy (1993). "Optimisation de l'utilisation du système GPS en milieu boisé." *Geomatica*, 47(1), pp. 39-46.

University of New Brunswick Department of Geodesy and Geomatics Engineering

Researchers in the Department of Geodesy and Geomatics Engineering (formerly the Department of Surveying Engineering) of the University of New Brunswick were involved in the following projects over the past four years:

Transfer of Positioning Technology to Chilean Geomatics Agencies • Y. Georgiadou.

The objective was to examine the requirements for using the Global Positioning System (GPS) for densification of existing control networks related to a regionally defined geodetic datum, such as the Provisional South American Datum 1956 in Chile. Various steps involving the differential GPS data reduction were examined, and the required subsequent coordinate difference transformation was investigated. A pilot GPS project was designed and carried out in Chile. Cooperation with this project was received from the National Service for Geology and Mining, the National Geographic Institute, the Department of National Assets, universities, and leading private companies. This pilot project was designed to determine the relation between the World Geodetic System 1984 and the local datum. During the pilot campaign, the participants were introduced to rigorous procedures of GPS data collection and analysis, and several professionals were trained to conduct future projects.

GPS Technology Activities Relevant to Developing Countries • Y. Georgiadou.

A summary analysis was undertaken on the nature of Global Positioning System (GPS) technology and its usefulness in addressing development issues in developing countries. The project involved the identification of the needs of developing country users in research applications and activities with GPS technology, and sectoral potential uses of this

technology of interest to international development. Interviews of some key Canadian researchers working with government, industry, and academia were conducted to identify, analyse, and evaluate their views on GPS research activities that should be supported by the International Development Research Centre (IDRC) in developing countries. Recommendations were made to the geomatics program of the IDRC on research activities relevant to developing countries that should be considered for support, and on the appropriate ways to deliver this support.

GPS for Airborne Gravimetry • A. Kleusberg.

In airborne gravimetry, GPS can be utilized to provide position, velocity, and acceleration of the measurement unit with respect to an earth-fixed coordinate system. This project investigates the capabilities and limitations of the Global Positioning System for the separation of inertial and gravitational accelerations

Network Differential GPS • A. Kleusberg.

This project is concerned with the development of algorithms and software for the spatial interpolation of differential GPS correction messages. This interpolation will reduce the accuracy deterioration of DGPS over larger distances.

Accuracy Assessment in GPS Positioning • A. Kleusberg.

This project is concerned with the estimation of proper covariance information for GPS differential positioning results, primarily coordinates and carrier phase ambiguities. Models for spatial and temporal correlations between GPS measurements are developed to account for unmodelled error terms.

Precise Solution of the Geodetic Boundary Value Problem • A. Kleusberg, P. Vaníček, P. Ong, M. Najafi, P. Vajda, Z. Martinec, E.W. Grafarend, L.E. Sjöberg, B. Heck, and Sun Wenke.

Existing theories for solving the scalar boundary value problem (BVP) of geodesy, which are used in computing the geoid from observed gravity data, were formulated in an era when the accuracy of the solution was not the most pressing consideration. Thus the existing theories are inadequate for today's needs, when the users are calling for a geoid accurate to 1 cm. To re-formulate the pertinent equations to a sufficient accuracy requires adequate modelling of the effect of topographical masses, and topographical and atmospheric density. It has turned out that our limited knowledge of topographical density can be overcome if the Stokes-Helmert approach is used. The re-formulation has called for a very different and more sophisticated treatment of the geodetic BVP.

Evaluation of Estimation Techniques for Neutral Atmosphere Propagation Delays in GPS Measurements • R.B. Langley, A.D. van der Wal, and J. P. Collins.

The aim of the research is to determine, by analysis of actual data, the 'best' estimation techniques for the removal of neutral-atmosphere-induced errors on geodetic baselines determined using GPS. To accomplish this task, neutral atmosphere delay estimators are being included as unknown parameters in UNB's Differential POSitioning Program (DIPOP) package. The evaluation will be an empirical one requiring the selection of suitable data sets for testing. The analysis of these data will provide statistical evidence as to which estimation options are the most likely to give optimal results under given conditions.

DIPOP currently uses models for the neutral atmosphere delays which are driven by measurements of surface meteorological parameters or default values for these parameters. Estimating delays or corrections to modelled delays directly from GPS data, however, has shown to be a very effective tool in improving the reliability of estimates of geodetic parameters. The current version of DIPOP uses a sequential least-squares algorithm for

parameter estimation. Part of this research will involve implementing Kalman filter and square root information filter algorithms in DIPOP so that the time varying nature of the neutral atmosphere can be adequately accommodated. Statistical comparisons of each estimation technique will be performed to determine the 'best' option. Repeatability of geodetic parameters will be used as the main criterion for comparison — particularly the repeatability of height and length baseline components.

Robust Analysis and Automatic Processing of GPS Data from the Western Canada Deformation Array • R.B. Langley, and X. Chen.

Vancouver Island, off the coast of British Columbia, is a tectonically and seismically active region. The Juan de Fuca, Explorer, and North America Plates converge beneath the region. To assess the earthquake hazard and study tectonic movement, the Western Canada Deformation Array (WCDA) has been established by the Pacific Geoscience Centre (PGC) and has been operating continuously since July 1992. So far, data spanning 1.5 years have been processed on a daily basis. Repeatabilities of a few parts per billion have been routinely achieved for both horizontal and vertical components on baselines spanning 301 km to 630 km. The process of data reduction has been streamlined and automated using CGPS22 software on a Unix-based Sun workstation at PGC. Further developments are being undertaken to fully automate the process of daily data reductions and to facilitate analyses for deformation study. They include: (1) enhancing the software's capability in handling remaining cycle slips after automatic processing;(2) making the user interface more friendly; (3) developing additional analysis tools such as a spectral analysis facility; (4) thoroughly testing and improving the models in CGPS22. In addition, strain analysis with all available geodetic information, will be carried out in this project.

Estimation of Earth Rotation Parameters, Site Coordinates, and Satellite Orbits Using the IGS Epoch'92 GPS Data Sets • R.B. Langley, and P. Li.

Global GPS data sets collected during GPS weeks 654 and 655 of the Epoch '92 campaign organized by the International GPS Service for Geodynamics (IGS) were successfully processed using an advanced version of UNB's DIPOP software dubbed DIPOP.ERP. This version runs on an IBM 9121, model 320, mainframe computer. Daily values of earth rotation parameters were determined with an accuracy of about a few tenths of a milli-arcsecond. The daily repeatabilities of baseline lengths from a few parts to ten parts in 10^9 for most continental baselines over eight thousand kilometres in length were achieved. The daily repeatabilities for the coordinates of most of the stations ranged from a few centimetres to about ten centimetres. Comparisons with the results from other processing centres show that precise GPS satellite orbits with a mean precision of less than one metre were provided and that the mean differences between the precise and broadcast orbits, during the weeks of Epoch '92 for which data was processed, appear to be less than five metres.

Application of the Global Positioning System to the Monitoring of Crustal Deformation in the Charlevoix Seismic Zone • R.B. Langley, and V. de Brito Mendes.

One high-precision application of the Global Positioning System (GPS) with significant impact on the scientific community is the monitoring of crustal deformation. In addition to its high accuracy capability, the reduced costs and ease of operation make GPS more attractive than conventional terrestrial geodetic techniques or other extraterrestrial techniques, such as satellite laser ranging and very long baseline interferometry, for such monitoring.

Since 1987, GPS has been one of the techniques used to detect strain accumulation in the Charlevoix Seismic Zone (CSZ). The CSZ is defined by an area of approximately 35 km x 80 km, developing parallel to the St. Lawrence River, about 100 km northeast of

Québec City. It is historically the most seismically active zone in eastern Canada, with records of six earthquakes with magnitude 6 or greater in 1638, 1663, 1791, 1860, 1870, and 1925. The repetitive nature of large earthquakes in this zone, which may presage the occurrence of a future major earthquake, has prompted the development of a program of extensive geodetic and geophysical monitoring, which began in 1974. Precise gravity, levelling, and horizontal control surveys have been carried out to detect long-term deformation and strain accumulation. The estimate of the maximum long-term horizontal shear-strain across the CSZ based on the analysis of conventional terrestrial techniques is $0.16 \mu\text{strain/yr}$.

Two GPS campaigns were carried out in the CSZ, in 1987 and 1991. In 1987, four Texas Instruments TI 4100 receivers were used in a seven-day campaign. In 1991, five Ashtech XII P-code receivers were used in a five-day campaign.

A preliminary analysis of the data using a modified version of UNB's program package DIPOP 2.1 to check for data quality has been performed. The first results indicate baseline agreement of typically a few parts in 10^7 , for the 1987 campaign, and few parts in 10^8 , for the 1991 campaign. Following this preliminary analysis, efforts have been directed to the improvement of tropospheric modelling and carrier phase integer ambiguity resolution in DIPOP.

Seventeen different tropospheric mapping functions developed in the last few decades for use in the analysis of space geodetic data have been tested against raytracing through the U.S. Standard Atmosphere Supplements, 1966, and radiosonde data. In addition, repeated baselines were used to evaluate the performance of these mapping functions in the processing of GPS data. From this study, a set of new mapping functions was recommended for incorporation into DIPOP. The ambiguity resolution has been improved in DIPOP. In addition to the ionosphere-free linear combination, the narrow-lane and wide-lane combinations have been implemented. These combinations, along with a new algorithm which allows an iterative fixing of ambiguities in the L1 and L2 data, look to be very promising tools for the bias fixing. The success of this algorithm seems to be limited only by the influence of the ionosphere. This problem is currently under investigation.

The Effect of the Ionosphere on the Global Positioning System • R.B. Langley, and A. Komjathy.

One of the major error sources in GPS positioning is that due to ionospheric refraction which causes signal propagation delays. The disturbing influences of the temporally- and spatially-varying ionisation of the ionosphere have great impact on satellite geodesy, especially on GPS. For a better understanding of the ionospheric effect on observed pseudorange and carrier phase signals, more knowledge about the actual state of the ionosphere is needed — this is especially true when precise positions are required in low and high latitude regions of the earth. It is possible to use partially-empirical models to make predictions of transionospheric propagation delays. We are investigating the accuracy and practicability of ionospheric models for single frequency users and are comparing their use with modelling ionospheric effects using dual frequency data processing. The new IRI90 reference ionosphere model is included in the comparisons. Previous research on several ionospheric models at the Geodetic Research Laboratory was carried out solely in terms of the effect on the satellite-receiver vector. The current research investigates the behaviour of ionospheric models with respect to their effect on position solutions.

Precise GPS Positioning for Aircraft Navigation • R.B. Langley, A. Komjathy, and J. Cesium.

We are currently involved in two projects applying GPS to aircraft navigation. Transport Canada Aviation, in conjunction with Cougar Helicopters Inc., has initiated an in-service trial of helicopter precision approaches using local differential GPS (LDGPS). Cougar

Helicopters, a Halifax-based commercial helicopter operator (specialising in oil rig supply, search and rescue, and medevac operations), has equipped a Sikorsky S-76A helicopter with a Trimble TNL 3100 DZUS-mounted GPS/Loran-C avionics receiver. A high power TNL-2800G landing system base station at Halifax International Airport provides DGPS signals. Simultaneously, both at the base station and the remote station, Ashtech LM-XII single frequency geodetic receivers collect data using the same antennas supplying the Trimble equipment. At UNB, we are investigating the validity of using the position solutions from the post-processed Ashtech carrier phase data as “truth.” Once we have assessed the accuracy of the Ashtech results, we will use them as a benchmark against which we can assess the accuracy of the Trimble DGPS results. This trial of LDGPS is co-sponsored by the National Energy Board and the U.S. Federal Aviation Administration.

The other project with which we are involved — also with Transport Canada Aviation — is the accurate positioning of airport runway thresholds using a combination of conventional static and stop-and-go surveying. Procedures have been developed for efficiently carrying out the surveys, and Transport Canada personnel have been trained in the operation of GPS equipment, in the processing of the collected data, and in the assessment of results.

Real-Time GPS Orbit Improvement • P. Vaníček, R.B. Langley, and M. Santos.

The aim of this research has been to investigate the possibility of real-time, high-accuracy GPS orbit improvement; i.e., the possibility of obtaining at any time the best possible estimate of an orbit based on all observations collected up to that time. The algorithm formulated could be used by a regional/continental tracking network. The best regional orbits for all GPS satellites will be available to the subscribers of the network without having to wait days or even weeks. The availability of improved orbits with as small a delay as possible would find manifold applications in geodesy and surveying. The approach is based on a sequential updating algorithm. Tests with the orbital integrator have been carried out. The algorithm for the real time orbit improvement has been implemented. The software implementation is based upon UNB’s DIPOP software package.

Sequential Tidal Analysis • P. Vaníček, and T. Hou.

Research has continued into the performance of the sequential tidal analysis algorithm developed at UNB. The program has been transferred into the private domain for commercialization.

Determination of Residual Scale Error in Levelling Rods • P. Vaníček, M. Craymer (EMR), and R.O. Castle (U.S. Geodetic Survey).

The idea behind this project is to use repeated levellings with different pairs of rods and determine residual scale errors in these rods by a series of regression analyses, local and global. The main problem is that collected levelling data are contaminated crustal motions and bench mark disturbances.

Navigation Algorithm Using Probability Space and Non-Newtonian Dynamics • P. Vaníček, and B. Xu.

The study has been concerned with the particular problem of determining the two-dimensional position and velocity of a vehicle, say a ship at sea. Modelling the movement of a vehicle requires either the knowledge of the forces causing the motion or the measurement of the vehicle motion in a given coordinate system. We have concentrated on kinematic modelling.

Differential Use of Tide-Gauge Data for Vertical Crustal Movements Determination • P. Vaníček, and G. Carrera.

For modelling linear vertical crustal movements over Canadian territory, we use the vertical velocity surface in the form of a two-dimensional algebraic polynomial. This is a known technique that allows us to combine point velocities, computed from tide gauge records, with scattered segments of relevellings and water transfers supplying the information on velocity differences. Here we concentrate on the question of how best to incorporate the point velocity values into the mathematical model. It has been repeatedly pointed out that the standard deviations of individual linear trends (point velocities) of tide-gauge records are significantly larger than the corresponding standard deviations of trend differences (velocity differences) between close-by tide gauges. This is due to a high degree of coherence between sea level variations at close-by sites; a large portion of these variations disappear when the records are differenced. This behaviour offers an alternative, and better, way of treating sea level trends: Use only one trend value as a point velocity input and difference the rest to obtain velocity differences. We show the use of regional correlation matrices and correlation coefficient confidence intervals for selecting the optimal pairing of sites, i.e., a tree diagram for optimal differencing, that gives the most precise and accurate velocity differences to be used in the modelling.

Global Vertical Datum Establishment • P. Vaníček.

Offshore boundary demarcation, following the United Nations Convention on the Law of the Sea, is invariably based on the behaviour of local sea level, having thus nothing to do with the vertical datum as understood in geodesy. So why do we need a global vertical datum in boundary demarcation? The only reason is to put the maritime boundaries on a sound geometrical foundation as is done elsewhere in geodesy. In this contribution, we discuss the definition of a global vertical datum, its relation to local sea level behaviour, sea surface topography, and other geodetic aspects encountered in the UNCLOS applications.

Determination of Continental Slope Foot-Line • P. Vaníček, D. E. Wells, Z. Ou, and T. Hou.

The goal of this project is to find a practical and automated implementation for Article 76.4(b) of the UN Convention on the Law of the Sea, which states that, *the foot of the continental slope shall be determined as the point of maximum change in the gradient at its base*. Significant progress has been made on the project during the last year. We have selected the most flexible from three equivalent techniques — a local fitting of a second-order surface — which works with regular as well as irregular data sets, to become the basis of the package we are developing. The package has been tested on real data for three different locations off Canada's east coast, and on simulated data.

Robustness Analysis for Horizontal Geodetic Networks • P. Vaníček, and P. Ong, in cooperation with E.J. Krakiwsky (The University of Calgary), and M. Craymer (Geodetic Survey).

This investigation addressed the problem of geodetic network analysis techniques and proposed alternatives to the standard statistical analysis techniques designed to analyse network sensitivity to gross errors and blunders. The reliability technique, introduced by Baarda and implemented by The University of Calgary, and the geometrical strength analysis, formulated by UNB, were combined into what we call robustness analysis. It was concluded that robustness analysis should be carried out side-by-side with the standard statistical analysis from which it differs fundamentally. The developed software has been tested and streamlined on simulated and real networks.

Truncated Geoid • P. Vaníček, and P. Vajda.

Research has been carried on into the performance of truncated geoids and their use in solving the inverse problem of gravimetry.

Accurate Geoid for Canada • P. Vaníček, A. Kleusberg, M. Najafi, P. Ong, P. Vajda, and Z. Martinec.

Work has continued on the completion of an accurate geoid for Canada. The completed first step consists of the revision of all the theoretical aspects of geodetic BVB. The second step consisted of the revision of numerical procedures involved in the computations. The next step will concentrate on the formulation of appropriate data averaging procedures and solution accuracy estimation.

Horizontal Datum Transformations • P. Vaníček, R.R. Steeves, and Y. Okia.

The aim of this project has been to formulate the theoretically most appropriate way of distinguishing between datum transformation parameters and the parameters designed to describe the existing distortions in coordinates. Development of an algorithm for estimating both kinds of parameters and their errors is being investigated.

GPS Tides • D. Wells, and S. DeLoach.

This project will precisely measure, in real time, a time series of heights of a floating buoy, using on-the-fly differential GPS. This time series will be evaluated to assess the ability of GPS to serve as a tide gauge.

Integration of Hydrographic Systems • D.E. Wells, A. Kleusberg, D. Dodd, R. Phelan, Z. Du, and H. Nanton.

Integration of high performance position, depth, and tidal data acquisition systems, with powerful real-time data processing, management, and visualization systems is feasible. Such integrated systems have many potential new applications. Several aspects of such integration are being studied in this project. A high density bathymetric data cleaning and management system was developed. Methods for assessing high density swath mapping system data quality are being investigated. The reliability of practical real-time DGPS data links has been investigated. Innovative methods for GPS carrier-phase “on the fly” ambiguity resolution were elaborated. Using these methods, real-time three-dimensional differential GPS (DGPS) positioning with an internal consistency of a few centimetres was demonstrated.

During one trial in 1993 in Kennebecasis Bay, differential GPS data was analysed in detail using on-the-fly ambiguity resolutions techniques. This provided three-dimensional antenna positions accurate to a few centimetres. The results indicate that the GPS data were mapping water level slopes at the 1 ppm level, and appears even to detect water level hydraulic effects of a few centimetres, arising from current flow over bathymetric ridges.

Hydrographic Ground Truthing • D.E. Wells, Y.C. Lee, L. Mayer, E. Derenyi, P. Vaníček, and J. Hughes Clarke, with C. Ware, B.G. Nickerson (Computer Science), J. Tranquilla (Electrical Engineering), and A. Hay (Memorial University of Newfoundland).

The Hydrographic Ground Truthing project (HYGRO) is aimed at studying the relationship between actual seabed characteristics (topography, texture, and composition) and acoustic measurements of these same characteristics. Careful attention has been paid to precise positioning, critical to co-registration of our data sets, and thus our ability to compare acoustic and ground truth measurements. Differential GPS and OTF DGPS are used for vessel positioning. Precise total station and digital levelling instruments are used for detailed topographic surveys for photo control, to map exposed boundaries of various sediment types, and to position representative seabed samples.

In order to handle our massive raster and vector datasets, we have taken advantage of the capabilities of the CARIS Geographic Information System (GIS) that assigns a “layer” to each dataset, allowing co-registration and quantitative comparison of similarities and differences between layers. The new CARIS tools based on our work have attracted private and public sector users, and we have been asked to process sample data sets for

both manufacturers of swath-map systems (Simrad, Krupp Atlas, Reson, Honeywell Elac, Meridata, and Navitronics) and their users (Canadian Hydrographic Service, Public Works Canada, Canadian Coast Guard, Teleglobe Canada, Atlantic Geoscience Centre, National Defence Canada, U.S. Navy, U.S. Army Corps of Engineers, and U.S. National Oceanic and Atmospheric Administration).

A second field program was begun the summer of 1993 in the Bay of Fundy. The simplicity and practicality of using Bay of Fundy tides to reveal (at low tide) what we mapped remotely (at high tide) has captured the imagination of the international ocean mapping community. Collaborators from Dartmouth, N.S.; Rimouski, Québec; Ottawa, Ontario; Washington, D.C.; Florida, Louisiana, Helsinki, Massachusetts, and Hamburg travelled to Saint John, New Brunswick, to conduct trials of acoustic mapping systems well into the new year.

The results obtained from demonstrate both the potential and the limitations of ocean mapping systems. Careful analysis of return signal waveforms from multi-transducer vertical-incidence acoustic mapping systems can distinguish seabed material types. Quester Tangent Corp., one of our industrial collaborators, has produced a commercial product, ISAH-S, which was used in 1993 to collect six channels of digital waveform data in the Bay. Several performance enhancements required of multibeam systems for hydrographic-quality surveys have been identified, e.g., improved shallow-water performance, reduced influence of measurement errors in ship's roll, and water column acoustic velocity profile.

The development of vertical-incidence seabed classification tools benefited from a second trial in August of the ISAH-S system developed by Quester Tangent Ltd. These data collected at high tide in Saint John Harbour have been compared to our low tide ground truth measurements and aided in the refinement of our classification algorithms.

Publications and Presentations

Abidin, H.Z. (1991). "New strategy for 'on the fly' ambiguity resolution." In: *ION GPS-91*, Proceedings of the Fourth International Technical Meeting of the Satellite Division of The Institute of Navigation, Albuquerque, N. Mex., 11-13 September, pp. 875-886.

Abidin, H.Z. (1992). "Computational and geometrical aspects of on-the-fly ambiguity resolution." Ph.D. dissertation, Department of Surveying Engineering Technical Report No. 164, University of New Brunswick, Fredericton, N.B., December.

Abidin, H.Z. (1993). Computational and geometrical aspects of on-the-fly ambiguity resolution. Ph.D. dissertation, Department of Surveying Engineering Technical Report No. 164, University of New Brunswick, Fredericton.

Abidin, H.Z., D.E. Wells, and A. Kleusberg (1991). "Multi-monitor station 'on the fly' ambiguity resolution: Theory and preliminary results." *Proceedings of DGPS '91, First International Symposium on Real Time Differential Applications of the Global Positioning System*, Braunschweig, Germany, 16-20 September, Verlag Tiev Rheinland, Vol. I, pp. 44-56.

Abidin, H.Z., D.E. Wells, and A. Kleusberg (1992). "Some aspects of 'on the fly' ambiguity resolution." *Proceedings of the Sixth International Geodetic Symposium on Satellite Positioning*, Columbus, Ohio, 17-20 March, The Ohio State University, Columbus, Ohio, Vol. II, pp. 660-669.

Adamos, C. (1992). "Automated target detection in digital imagery using Hough transform." Presented at the 4th Atlantic Institute Seminar, University of Maine, Orono, 2-3 October.

Carrera, G., P. Vaníček, and M.R. Craymer (1991). "Recompilation of a map of recent vertical crustal movements in Canada." Department of Surveying Engineering Technical Report No. 153, University of New Brunswick, Fredericton, N.B., May. Also Energy, Mines and Resources Canada Contract Report 91-001, 107 pp.

Chen Ding-Sheng (1991). "A long arc approach to GPS satellite orbit improvement." M.Sc.E. thesis, Department of Surveying Engineering Technical Report No. 154, University of New Brunswick, Fredericton, N.B., May.

Chen, Y.Q., A. Chrzanowski, J. Secord, and J. Grodecki (1992). "Manual for the reduction of geodetic observations to a conformal mapping plane." Report by the PB/MK Team for the Superconducting Super Collider Laboratory, Dallas, Texas, August, 24 pp.

Chrzanowski, A., and J.M. Secord (1992). "The 1991 analysis of deformation measurements at the Mactaquac Generating Station." Final contract report for the N.B. Electric Power Commission, Fredericton, February.

Chrzanowski, A., and Y.Q. Chen (1992). "Evaluation and modelling of GPS errors in integrated deformation surveys: Case studies." Presented at the International Workshop on Global Positioning Systems in Geosciences, Chania, Greece, 8-10 June.

Chrzanowski, A., Chen Yong-qi, J. Leal, and T. Poplawski (1991). "Use of the Global Positioning System in ground subsidence studies." *Proceedings of the VIII International Congress of the International Society for Mine Surveying*, Lexington, Ky., 22-27 September, pp. 203-209.

Chrzanowski, A., Chen Yong-qi, J. Leal, J. Murria, and T. Poplawski (1991). "Use of the Global Positioning System (GPS) for ground subsidence measurements in western Venezuela oil fields." In: *Land Subsidence*, Proceedings of the 4th International Symposium on Land Subsidence, Ed. A.I. Johnson, Houston, Tex., 12-17 May, International Association of Hydrological Sciences, Publication No. 200, pp. 419-432.

Chrzanowski, A., Chen Yong-qi, J.M. Secord, and A. Szostak-Chrzanowski (1991). "Problems and solutions in the integrated monitoring and analysis of dam deformations." *CISM Journal ACSGC*, Vol. 45, No. 4, Winter.

Craymer, M.R., P. Vaníček, E.J. Krakiwsky, and D. Szabo (1993). Robustness analysis. Presented at the First International Symposium on Mathematical and Physical Foundations of Geodesy, Stuttgart, Germany, 7-9 September.

Craymer, M.R., P. Vaníček, E.J. Krakiwsky, and D. Szabo (1993). Robustness analysis: A new method of assessing the strength of geodetic networks. Presented at the Annual Meeting of the Canadian Institute of Geomatics, Toronto.

Craymer, M.R., S. Blackie, P. Vaníček, E.J. Krakiwsky, and D. Szabo (1992). "Robustness analysis of geodetic networks." Presented at the AGU/CGU/MSA Joint Spring Meeting, Montreal, Quebec, 12-14 May.

DeLoach, S., D. E. Wells, and D. Dodd (1994). The role of on-the-fly DGPS in 3D ECDIS. *Proceedings of Hydro '94, 9th Biennial International Symposium of the Hydrographic Society*, Aberdeen, Scotland, 13-15 September, pp. 15/1 to 15/14, Hydrographic Society, Aberdeen, Scotland.

DeLoach, S., D. E. Wells, D. Dodd, R. Phelan, A. Morley, and B. Shannon (1994). Delineation of tidal datums and water surface slopes with the GPS. *Proceedings of the U.S. Hydrographic Conference '94*, Norfolk, Virginia, 18-23 April, Special Publication No. 32, U.S. Hydrographic Society, Norfolk, Virginia, pp. 214-221.

Dijkstra, S., D.E. Wells, L. Mayer, J. Hughes Clarke (1992). "Integrating high volume bathymetric data." *Proceedings of HYDRO '92*, International Hydrographic Conference, Copenhagen, Denmark, December, 13 pp.

Doucet, K., Y. Georgiadou, A. Kleusberg, and R.B. Langley (1991). "A real-time GPS-based differential positioning system." In: *Kinematic Systems in Geodesy, Surveying, and Remote Sensing*, Proceedings of International Association of Geodesy Symposium No. 107, Banff, Alberta, 10-13 September 1990, Springer-Verlag, N.Y., pp. 178-187.

El-Rabbany, A., and A. Kleusberg (1992). "Physical correlations in GPS differential positioning." *Proceedings of the Sixth International Geodetic Symposium on Satellite Positioning*, Columbus, Ohio, 17-20 March, The Ohio State University, Columbus Ohio, Vol. I, pp. 281-290.

El-Rabbany, A., and A. Kleusberg (1993). Efficient algorithm for the inverse of the fully populated covariance matrix in GPS differential positioning. Presented at the European Geophysical Society XVIII General Assembly, Wiesbaden, Germany, 3-7 May.

El-Rabbany, A., and A. Kleusberg (1993). Improved accuracy estimation of differential GPS: Theory and results. *ION GPS-93*, Sixth International Technical Meeting of the Satellite Division of The Institute of Navigation, Salt Lake City, Utah, 22-24 September, The Institute of Navigation, Alexandria, Va., pp. 1303-1311.

El-Rabbany, A., and A. Kleusberg (1993). Modelling temporal correlations in GPS differential positioning. Presented at the European Geophysical Society XVIII General Assembly, Wiesbaden, Germany, 3-7 May.

El-Rabbany, A., and A. Kleusberg (1994). On the stochastic modelling of GPS measurement errors. In: *Istanbul 94 – Abstracts*, First International Symposium on Deformations in Turkey, Istanbul, Turkey, 5-9 September, abstract only.

Engels, J., E. Grafarend, W. Keller, Z. Martinec, F. Sanso, and P. Vaníček, (1993). The geoid as an inverse problem to be regularized. *Proceedings of the International Conference on Inverse Problems: Principles and Applications in Geophysics, Technology and Medicine*, Potsdam, Germany, 30 August-3 September, Akademie Verlag GmbH, Berlin, pp. 122-166.

Georgiadou, Y. (1992). "El Sistema de Posicionamiento Global: Principios y Aplicaciones" Keynote address presented at the 17th Meeting of the Argentine Association of Geodesy and Geophysics, Buenos Aires, Argentina, 26-30 October.

Georgiadou, Y. (1992). "Evaluación de la Exactitud en la Determinación de las Trayectorias de Aviones utilizando Posicionamiento Diferencial GPS." Presented at the 17th Meeting of the Argentine Association of Geodesy and Geophysics, Buenos Aires, Argentina, 26-30 October.

Georgiadou, Y. (1992). "GPS technology activities relevant to developing countries." Contract report to the International Development Research Centre, Ottawa, Ontario, March.

Georgiadou, Y. (1992). "Precise positioning using the Global Positioning System." Invited seminar at the School of Civil Engineering, Purdue University, West Lafayette, Indiana, April.

Georgiadou, Y. (1992). "Transfer of positioning technology." Final report to the Canadian International Development Agency, Professional Award Program, September.

Georgiadou, Y. I. Webster, and D. Delikaraoglou (1993). GPS ionospheric modelling for moving platforms. *Proceedings of the International Workshop on Global Positioning System in Geosciences*, Ed. S.P. Mertikas, Chania, Greece, 8-10 June 1992, Technical University of Crete, Chania, Greece, pp. 392-399.

Georgiadou, Y., A. Kleusberg, C. Escudero (1993). Datum transformations for GPS applications. In: *Recent Geodetic and Gravimetric Research in Latin America*, Eds. W. Torge, G. Fletcher, and J. Tanner, Springer, Berlin.

Georgiadou, Y., and A. Kleusberg (1991). "Algorithms and results of kinematic GPS positioning." *CISM Journal ACSGC*, Vol. 45, No. 4, Winter.

Georgiadou, Y., C. Escudero, and A. Kleusberg (1991). "Datum transformation in South America: A case study." Presented at the XX General Assembly of the International Union of Geodesy and Geophysics, Second Joint Symposium of the IAG and the Pan-American Institution of Geography and History, Vienna, Austria, August.

Georgiadou, Y., D. Delikaraoglou, and A. Kleusberg (1991). "Accuracy assessment of aircraft trajectories using differential GPS." Presented at the XX General Assembly of the IUGG, Section 1, Vienna, Austria, August.

Georgiadou, Y., D. Delikaraoglou, and A. Kleusberg (1991). "Evaluation of the accuracy of GPS-derived aircraft trajectories." Presented at the American Geophysical Union meeting, Baltimore, Md., May (abstract: *EOS*, Vol. 72, No. 17, p. 91).

Georgiadou, Y., H. Contreras, C. Escudero, and A. Polanco (1992). "Campaña GPS Chileno-Canadiense: Metodología y Resultados." Presented at the Second Congress for Earth Sciences, Santiago, Chile, 17-21 August.

Georgiadou, Y., I. Webster, and D. Delikaraoglou (1992). "GPS ionospheric modelling for moving platforms." Presented at the International Workshop on Global Positioning Systems in Geosciences, Chania, Greece, 8-10 June.

Hottendorff, T., and M.V. Hullmeine (1992). "U.S. Coast Guard marine accident database." Department of Surveying Engineering Technical Report No. 159, University of New Brunswick, Fredericton, N.B., August.

Hou Tianhang, and P. Vaníček (1994). Towards a real-time analysis of tides. *International Hydrographic Review*, Vol. LXXI, No. 1, pp.29-52.

Hughes Clarke, J.E., G. Costello, L.A. Mayer, and D.E. Wells (1991). "Ocean mapping: A Canadian perspective." *Proceedings of the Pacific Exclusive Economic Zone Symposium*, Ed. M. Lockwood, Portland, Oregon, November.

Hughes Clarke, J.E., G. Costello, L.A. Mayer, D.E. Wells (1992). "Ocean mapping: A Canadian perspective." In: *1991 Exclusive Economic Zone Symposium*, ed. M. Lockwood, U.S. Geological Circular 1092, pp. 20-28.

- Janes, H.W., R.B. Langley, and S.P. Newby (1991). "Analysis of tropospheric delay prediction models: Comparisons with ray-tracing and implications for GPS relative positioning." *Bulletin Géodésique*, Vol. 65, pp. 151-161.
- Kleusberg, A. (1992). "Precise differential positioning and surveying." *GPS World*, July, Vol. 3, No. 7, pp. 50-52. Also in *Civil Engineering Surveyor*, October, pp. 23-24.
- Kleusberg, A. (1993). GPS and the measurement of gravity. *GPS World*, Vol. 4, No. 10, pp. 54-56.
- Kleusberg, A. (1993). Integer identification in the context of least-squares estimation. Presented at the Second International Symposium on Differential Satellite Navigation Systems, Amsterdam, The Netherlands, 29 March-2 April.
- Kleusberg, A. (1994). Die Direkte Lösung des Räumlichen Hyperbelschnitts. *Zeitschrift für Vermessungswesen*, Vol. 117, pp. 188-192.
- Kleusberg, A., (1993). The Global Positioning System and ionospheric conditions. *Proceedings of the 4th Solar-Terrestrial Predictions Workshop*, Hanscom AFB, Mass.
- Kleusberg, A., and Y. Georgiadou (1991). "Analysis of airborne and ground GPS data." Final contract report for Canada Centre for Surveying, Surveys, Mapping and Remote Sensing Branch, 28 March.
- Kleusberg, A., J. McLaughlin, and W. Faig (1991). "Surveying education at the University of New Brunswick: A perspective." Invited paper, presented at the joint European/North American Surveying Education Board meeting, Berlin, Germany, May.
- Klobuchar, J.A., H.W. Kuenzler, W.A. Pakula, P.F. Fougere, R.E. Sheehan, P.H. Doherty, M.J. Buonsanto, J.C. Foster, and R.B. Langley (1992). "The first North American ionospheric tomography campaign." *EOS, Transactions of the American Geophysical Union*, Vol. 73, No. 43, Fall Meeting Supplement, p. 410.
- Krakiwsky, E. J., P. Vaníček, D. Szabo, and M. R. Craymer (1994). Development and testing of in-context confidence regions for geodetic survey networks. Report for the Geodetic Survey Division, Ottawa, Ontario.
- Krakiwsky, E.J., P. Vaníček, and D. Szabo (1993). Further development and testing of robustness analysis. Final Contract Report to Geodetic Survey of Canada, Ottawa, Ontario, by Department of Surveying Engineering, Fredericton, N.B., March, 77 pp.
- Kuang Shan-long (1991). "Optimization and design of deformation monitoring schemes." Ph.D. dissertation, Department of Surveying Engineering Technical Report No. 157, University of New Brunswick, Fredericton, N.B., September.
- Kuang Shan-long, A. Chrzanowski, and Chen Yong-qi (1991). "A unified mathematical modelling for the optimal design of monitoring networks." *Manuscripta Geodaetica*, Vol. 16, No. 6, pp. 376-383.
- Kuang, S.L., and A. Chrzanowski (1992). "Multi-objective optimization design of geodetic networks." *Manuscripta Geodaetica*, Vol. 17, No. 4, pp. 233-244.

- Kuang, S.L., and A. Chrzanowski (1992). "Rigorous combined first order and second order optimal design of geodetic networks." *Bolletino di Geodesia e Science Affini*, No. 2, pp. 141-156.
- Langley, R. B. (1994). RTCM SC-104 DGPS standards. *GPS World*, Vol. 5, No. 5, pp. 48-53.
- Langley, R.B. (1991). "Future trends and expected changes in the GPS environment." Presented at Trends in GPS Development — Towards a G/LIS Based on Hard Data, Hartford, Conn., 26-27 April.
- Langley, R.B. (1991). "The GPS receiver — An introduction." *GPS World*, Vol. 2, No. 1, pp. 50-53.
- Langley, R.B. (1991). "The mathematics of GPS." *GPS World*, Vol. 2, No. 7, pp. 45-50.
- Langley, R.B. (1991). "The orbits of GPS satellites." *GPS World*, Vol. 2, No. 3, pp. 50-53.
- Langley, R.B. (1991). "Time, clocks, and GPS." *GPS World*, Vol. 2, No. 10, pp. 38-42.
- Langley, R.B. (1992). "An introduction to the Navstar Global Positioning System." Presented at the Twenty-Fourth Annual Precise Time and Time Interval (PTTI) Applications and Planning Meeting, McLean, Virginia, 1-3 December.
- Langley, R.B. (1992). "Basic geodesy for GPS." *GPS World*, Vol. 3, No. 2, pp. 44-49.
- Langley, R.B. (1992). "Letter to the Editor." *GPS World*, Vol. 3, No. 4, p. 12.
- Langley, R.B. (1992). "The basics: GPS satellite and receiver technology." In: *On Common Ground*, collected papers of the GPS/GIS conference, Denver, Colo., 13-14 April, 59 pp.
- Langley, R.B. (1992). "The effect of the ionosphere and troposphere on satellite positioning systems." *Proceedings of the Refraction of Transatmospheric Signals in Geodesy Symposium*, Ed. J.C. de Munck, T.A.Th. Spoelstra, The Hague, The Netherlands, 19-22 May, Netherlands Geodetic Commission Publications on Geodesy, Delft, New Series, Number 36, p. 97 (abstract only).
- Langley, R.B. (1992). "The Federal Radionavigation Plan." *GPS World*, Vol. 3, No. 3, pp. 50-53.
- Langley, R.B. (1993). Canadian Space Geodesy Forum. *EOS, Transactions, American Geophysical Union*, Vol. 74, No. 6, p. 68.
- Langley, R.B. (1993). Communication links for DGPS. *GPS World*, Vol. 4, No. 5, pp. 47-51.
- Langley, R.B. (1993). GPS for the GIS & CAD users. *Proceedings of On Common Ground Conference 93*, Denver, Colo., 19-20 April, Advanstar Communications, Eugene, Oreg., pp. 59-150.

- Langley, R.B. (1993). The GPS observables. *GPS World*, Vol. 4, No. 4, pp. 52-59.
- Langley, R.B., and E.J. Krakiwsky (1992). "The role of geodesy in surveying and mapping education." *Presented papers of the International Union for Surveys and Mapping Working Group Sessions of the XVII Congress of the International Society of Photogrammetry and Remote Sensing*, Washington, D.C., 8-12 August, pp. 60-62.
- Langley, R.B., K. Doucet, A. Kleusberg, and D. Scott (1991). "An investigation of the impact of the auroral ionosphere on the performance of Global Positioning System receivers." Presented at the 1991 North American Radio Science Meeting and the International IEEE/AP-S Symposium, London, Ontario, 24-28 June.
- Langley, R.B., K. Doucet, and A. Kleusberg (1991). "The testing of Global Positioning System receivers under ionospheric influences." Final contract report for the Geodetic Survey Division of the Canada Centre for Surveying, Ottawa, Ontario, April.
- Light, E. (1992). "Boundary delineation of wilderness and ecological reserves in Newfoundland." M.Eng. thesis, Department of Surveying Engineering Technical Report No. 163, University of New Brunswick, Fredericton, N.B., December.
- Martinec, Z. and P. Vaníček (1994). Direct topographical effect of Helmert's condensation for a spherical geoid. *Manuscripta Geodaetica*, Vol. 19, pp. 257-268.
- Martinec, Z. and P. Vaníček (1994). The indirect effect of Stokes-Helmert's technique for the spherical approximation of the geoid. *Manuscripta Geodaetica*, Vol. 19, pp. 213-219
- Martinec, Z., C. Matyska, E. Grafarend, and P. Vaníček (1993). On Helmert's 2nd condensation method. *Manuscripta Geodaetica*, Vol. 18, No. 6, pp. 417-421.
- McLean, A.Y., Y. Georgiadou, and G. Post (1992). "The geomatics industry in Atlantic Canada: A network of technological entrepreneurs." *Proceedings of 22nd European Small Business Seminar*, Amsterdam, The Netherlands, 23-25 September, pp. 435-354.
- Mendes, V. B., and R. B. Langley (1994). Modelling the tropospheric delay from meteorological surface measurements: Comparison of models. American Geophysical Union Spring Meeting, Baltimore, Md., 23-27 May, *EOS, Spring Meeting Supplement*, Vol. 75, No. 16, p. 105 abstract only.
- Mendes, V. de B. (1992). "Posicionamento relativo de alta precisão com o Sistema de Posicionamento Global." *Revista do Instituto Geografico e Cadastral*, No. 11, pp. 57-61.
- Mendes, V.B., and R. B. Langley (1994). A comprehensive analysis of mapping functions used in modelling tropospheric propagation delay in space geodetic data. *Proceedings of KIS94*, International Symposium on Kinematic Systems in Geodesy, Geomatics and Navigation, Banff, Alberta, 30 August-2 September, The University of Calgary, Calgary, Alberta, pp. 87-98.
- Mendes, V.B., and R.B. Langley (1993). Application of the Global Positioning System to the assessment of crustal deformation in the Charlevoix Seismic Zone. *ION GPS-93*, Sixth International Technical Meeting of the Satellite Division of The Institute of Navigation, Salt Lake City, Utah, 22-24 September, The Institute of Navigation, Alexandria, Va., pp. 1205-1219.

Mendes, V.B., and R.B. Langley (1993). Assessment of crustal deformation in the Charlevoix Seismic Zone using the Global Positioning System. *Abstracts of International Association of Geodesy General Meeting*, Beijing, China, 8-13 August, IAG, p. 377.

Mills, G., and D. E. Wells (1994). International standards of competence for hydrographic surveyors. *Proceedings of the XX Congress of the International Federation of Surveyors (FIG)*, Melbourne, Australia, 5-12 March, FIG, Melbourne, Australia, pp. 408.4/1 to 408.4/8

Newby, S., and R.B. Langley (1991). "Ionospheric models and the Global Positioning System." Presented at the International Union of Geodesy and Geophysics XX General Assembly, Vienna, Austria, 11-24 August.

Newby, S.P. (1992). "An assessment of empirical models for the prediction of the transionospheric propagation delay of radio signals." M.Sc.E. thesis, Department of Surveying Engineering Technical Report No. 160, University of New Brunswick, Fredericton, N.B., August.

Newby, S.P., and R.B. Langley (1992). "Three alternative empirical ionospheric models — Are they better than the GPS broadcast model?" *Proceedings of the Sixth International Geodetic Symposium on Satellite Positioning*, Columbus, Ohio, 17-20 March, The Ohio State University, Columbus Ohio, Vol. I, pp. 240-244.

Rapatz, P.J.V. (1991). "Vessel heave determination using the Global Positioning System." M.Sc.E. thesis, Department of Surveying Engineering Technical Report No. 155, University of New Brunswick, Fredericton, N.B., September.

Robinson, G.L. (1991). "Verification of gravimetric geoidal models by a combination of GPS and orthometric heights." M.Sc.E. thesis, Department of Surveying Engineering Technical Report No. 152, University of New Brunswick, Fredericton, N.B., May.

Santos, M.C. (1991). "Análise espectral da duração do dia, através de 3 anos de dados diários do iers." *Proceedings of the XV Congresso Brasileiro de Cartografia*, Sao Paulo, Brazil, Vol. I, pp. 53-60.

Schneider, D., and P. Vaníček (1991). "A new look at the U.S. Geological Survey 1970-1980 horizontal crustal deformation data around Hollister, California." *Journal of Geophysical Research*, Vol. 96, No. B13, pp. 21,641-21,657.

Sideris, M.G., P. Vaníček, and A. Mainville (1992). "The Canadian Geoid Committee and the geoid in Canada." Presented at the AGU/CGU/MSA Joint Spring Meeting, Montreal, Quebec, 12-14 May.

Szabo, D.J., M.R. Craymer, E.J. Krakiwsky, and P. Vaníček (1993). Robustness measures for geodetic networks. *Proceedings of the 7th International FIG Symposium on Deformation Measurements*, Banff, Alberta, 3-7 May, pp. 151-160.

Tsen A. (1992). "Determination of geoidal height difference using ring integration method." M.Sc.E. thesis, Department of Surveying Engineering Technical Report No. 158, University of New Brunswick, Fredericton, N.B., August.

Vajda, P. P. Ong, M.C. Santos, P. Vaníček, and M.R. Craymer (1992). "Comparison of geoidal deflections computed from UNB'91 geoid with observed astrodeflections." Presented at the AGU/CGU/MSA Joint Spring Meeting, Montreal, Quebec, 12-14 May.

- Vajda, P., and P. Vaníček (1993). Truncated geoid and its geophysical interpretation. Presented at the Canadian Geophysical Union Annual Meeting, Banff, Alberta, 9-12 May.
- Vaníček, P., Zhang Changyou, and L.E. Sjöberg (1992). "A comparison of Stokes's and Hotine's approaches to geoid computation." *Manuscripta Geodaetica*, Vol. 17, No. 1, pp. 29-35.
- Vaníček, P. (1991). "Chairman's report on GALOS Special Study Group." Presented at the IUGG General Assembly, Vienna, Austria, 20 August.
- Vaníček, P. (1991). "Geodetic modelling of superficial earth deformations." Presented at the AGU Chapman Conference on Crustal Motions, Annapolis, Md., 22-25 September.
- Vaníček, P. (1991). "Robustness of geodetic networks." *Journal of the Association of Czechoslovakian Surveyors* (in Czech), Vol. 79, No. 6, pp. 111-113.
- Vaníček, P. (1991). Book review of "R. Teisseyre's *Gravity and Low-Frequency Geodynamics*." *PAGEOPH*, Vol. 135, No. 3, pp. 498-499.
- Vaníček, P. (1992). "The problem of a maritime boundary involving two horizontal geodetic datums." Presented at the First International Conference on Geodetic Aspects of the Law of the Sea, Bali, Indonesia, 8-13 June.
- Vaníček, P. (1994). New home for the Finnish Geodetic Institute. *Geomatica*, Vol. 48, No. 3, p. 243.
- Vaníček, P. and Z. Martinec (1994). Stokes-Helmert scheme for the evaluation of a precise geoid. *Manuscripta Geodaetica*, Vol. 19, pp. 119-128.
- Vaníček, P., and G. Carrera (1993). Treatment of sea level records in linear vertical crustal motion modelling. Presented at the Eighth International Symposium on Recent Crustal Movements, Kobe, Japan, 6-11 December.
- Vaníček, P., and M. Kwimbere (1991). "Towards the determination of continental slope footline." Presented at the GALOS Technical Meeting at the IUGG General Assembly, Vienna, Austria, 22 August.
- Vaníček, P., and N. Christou (Eds.) (1993). *Geoid and its Geophysical Interpretations*. CRC Press, Boca Raton, Florida, 343 pp.
- Vaníček, P., and Z. Martinec (1993). Can the geoid be evaluated to a one-centimetre accuracy? A look at the theory. Presented at the Canadian Geophysical Union Annual Meeting, Banff, Alberta, 9-12 May.
- Vaníček, P., D.E. Wells, and Hou Tianhang (1994). Determination of the foot of the continental slope. Report for Geological Survey of Canada, Atlantic Geoscience Centre, Geological Survey of Canada, Dartmouth, N.S., 49 pp.
- Vaníček, P., D.E. Wells, and Tianhang Hou (1994). Continental slope foot-line determination: Geometrical aspects. *Proceedings of LOS Article 76 Workshop*, Eds. S. Nichols, W. Wells, Fredericton, N.B., 14-15 April, Geodesy and Geomatics Engineering, Fredericton, N.B., pp. 57-67.

Vaniček, P., E.J. Krakiwsky, M.R. Craymer, Yang Gao, and P.S. Ong (1991). "Robustness analysis." Department of Surveying Engineering Technical Report No. 156, University of New Brunswick, Fredericton, N.B., September.

Vaniček, P., P. Ong, and Zhang Changyou (1991). "New gravimetric geoid for Canada: The 'UNB'90' solution." In: *Determination of the Geoid, Present and Future*, Springer-Verlag, N.Y., pp. 214-219.

Vaniček, P., R.B. Langley, and A. Kleusberg (1991). "Geodesy: Still the scientific backbone of surveying and mapping." *CISM Journal ACSGC*, Vol. 45, No. 4, Winter.

Ware, C., L. Slipp, K.W. Wong, B. Nickerson, D. Wells, Y.C. Lee, D. Dodd, and G. Costello (1992). "A system for cleaning high volume bathymetry." *International Hydrographic Review*, Vol. LXIX, No. 2, pp. 77-94.

Ware, C., W. Knight, and D. Wells (1991). "Memory intensive statistical algorithms for multibeam bathymetric data." *Computers & Geosciences*, Vol. 17, No. 7, pp. 985-993.

Webster, I. (1993). A regional model for the prediction of ionospheric delay for single frequency users of the Global Positioning system. Department of Surveying Engineering Technical Report No. 166, University of New Brunswick, Fredericton, N.B.

Webster, I., and A. Kleusberg (1992). "Regional modelling of the ionosphere for single frequency users of the Global Positioning System." *Proceedings of the Sixth International Geodetic Symposium on Satellite Positioning*, Columbus, Ohio, 17-20 March, The Ohio State University, Columbus Ohio, Vol. I, pp. 230-239.

Wells, D. (1991). "Canada's marine GIS industry expands." *GIS World*, September, pp. 29-31.

Wells, D., and C. Ware (1991). "Ocean mapping initiatives in Canada." *Proceedings of the 1991 Canadian Hydrographic Conference*, Rimouski, Québec, April, pp. 32-1 to 32-7.

Wells, D., and S. Nichols (1991). "Curriculum content for proposed short course on offshore boundary delimitation." In: *Étude de faisabilité pour la mise en place du cours Délimitation des frontières maritimes pour les pays francophones coopérante avec le Centre International D'exploitation des Océans*, contract report for the International Centre for Ocean Development, February, pp. 12-18.

Wells, D., C. Ware, B. Nickerson, and Y.C. Lee (1991). "Mapping the oceans." Presented at the Joint Annual Meeting of the Canadian Cartographic Association and the Ontario Institute of Chartered Cartographers, St. Catherines, Ont., 31 May-3 June.

Wells, D., L. Mayer, and J.E. Hughes Clarke (1991). "Ocean mapping: From where? to what?" *CISM Journal ACSGC*, Vol. 45, No. 4, Winter.

Wells, D.E. (1993). GIS applications in ocean mapping. Presented at the Department of National Defence workshop on Applications of GIS to Canadian Forces mission planning and decision support, Ottawa, June.

Wells, D.E. (1993). New techniques, new tools, new demands for storing and processing hydrographic data. Department of Fisheries and Oceans industry development workshop on New Dimensions for Spatial Data Management and Utilization, Ottawa, April.

Wells, D.E. (1993). Ocean mapping activities at the University of New Brunswick. *Proceedings of Land Information Forum 193*, Fredericton, N.B., 6-7 April, pp. 58-59.

Wells, D.E. (1993). Technology trends influencing marine geomatics applications. Presented at the Geomatics in the Marine Environment, Geomatics Industry Association of Canada and CHA, Toronto, June.

Wells, D.E. (1994). GPS advanced applications and impact on hydrography. Collected papers of Ad Hoc Expert Group Meeting on Maritime Hydrographic Surveying and Nautical Charting, Aqaba, Jordan, United Nations Economic and Social Commission for Western Asia, Amman, Jordan, 8-12 May, 25 pp.

Wells, D.E. (1994). GPS introduction and standard applications. Collected papers of Ad Hoc Expert Group Meeting on Maritime Hydrographic Surveying and Nautical Charting, Amman, Jordan, United Nations Economic and Social Commission for Western Asia, Amman, Jordan, 8-12 May, 25 pp.

Wells, D.E. (1994). Working Group 419a Report: Processing of high density data sets. *Proceedings of the XX Congress of the International Federation of Surveyors (FIG)*, Melbourne, Australia, 5-12 March, FIG, Melbourne, Australia, pp. 408.1/1 to 408.1/10

Wells, D.E., and A. Kleusberg (1992). "Feasibility of a kinematic differential Global Positioning System." Final report to Department of the Army, U.S. Army Corps of Engineers, Dredging Research Program Technical Report DRP-92-1, Washington, D.C., March, 34 pp.

Wells, D.E., and Y.C. Lee (1992). "The use of GPS for GIS." Presented at the 4th International Conference on Geographical Information Systems, Ottawa, Ontario, March.

Wells, D.E., J. Eichholz, M. Eaton, and S. Makinen (1992). "What would make small boat electronic charts safe for navigation?" *Proceedings of the Fifth Biennial National Ocean Service International Hydrographic Conference*, Baltimore, Maryland, 25-28 February, pp. 186 (abstract only).

Wells, W., and S. Nichols (Eds.) (1994). *Proceedings of the Law of the Sea Article 76 Workshop*. Department of Geodesy and Geomatics Engineering, Fredericton, N.B., 218 pp.

Wells, W., D.E. Wells, and A. Kleusberg (1992). "Global Positioning System bibliography." Final report to Department of the Army, U.S. Army Corps of Engineers, Dredging Research Program Technical Report DRP-92-2, Washington, D.C., March, 64 pp.

University of Toronto Program in Geomatics — Department of Geography

Geodesy research at University of Toronto in the quadrennium 1991-1995 focussed on enhancing the usefulness of geodetic measurements for the monitoring of crustal movements and structural deformation.

A comprehensive review of the approaches to weight estimation in geodetic levelling (Kelly, 1991) confirms that combining the random and non-random components of variance determined by analyzing the discrepancies between the direct and the reverse measurements remains the best way of estimating the weights of the height differences over levelling lines.

An experimental study of the performance of electronic theodolites (Kingston, 1991; Wassef, 1991) shows that the tests in use overrate the accuracy, and develop alternative field tests and improved analytical procedures.

Studies into the use of GPS (El-Maghraby, 1991; Wassef and El-Maghraby, 1991; Wassef, 1992) show that the individual quality parameters are not reliable identifiers of the accuracy of GPS results but they provide powerful means of classifying individual estimates when combined in linear discriminant functions.

Discussions of the concept of hypothesis testing in the context of the monitoring of the deformation of engineering structures (Aseno, 1992; Wassef and Aseno, 1992) bring out the importance of randomizing the observations to ensure inferential validity, and question the suitability of the network-least squares approach.

An examination of the characteristic features of geodynamic networks (Wassef, 1993) brings out the inappropriateness of the tests of significance that are based on random sampling, substantiates the intuitive concern that a geodynamic network may be of little value for crustal deformation studies simply because the network is small in the number of stations, and establishes norms for the size and the testing procedure. More recent work (Wassef, 1995) addresses the implications of parameterization of undeterminable and poorly determined factors affecting GPS observations.

Continuing work includes studies in the modelling of the gravity potential and the bearing of GPS on GIS.

Publications

Al-Sayel, Mohammed Y. 1995. Quality control for surveying projects. M.Eng. thesis, University of Toronto.

Aseno, Joseph O. 1992. The design of observations for monitoring horizontal deformations of engineering structures and the analysis of subsequent data. Ph.D. thesis, University of Toronto.

El-Maghraby, Mohamed F.H. 1991. Use of geodetic methods in detecting terrain movements, with special reference to the Global Positioning System. Ph.D. thesis, University of Toronto.

Kelly, Kevin M. 1991. Weight estimation in geodetic levelling using variance components derived from analysis of variance. M.A.Sc. thesis, University of Toronto.

Kingston, Laura A. 1991. Electronic theodolites: Distinguishing features and sources of error, and their impact on field performance and observational procedures. M.A.Sc. thesis, University of Toronto.

Vyskocil, P.A., A. Tealeb and A. Wassef (eds.) 1991. Proceedings of the third International Symposium on Recent Crustal Movement in Africa, *Journal of Geodynamics*, Vol. 14, nos. 1-4.

Wassef, A.M. 1991. Performance of electronic theodolites. Final report on research carried out for the Ontario Ministry of Transportation, Toronto, Canada.

Wassef, A.M. 1991. On GPS and NAD 83. NAD 83 Implementation Seminar. The Canadian Institute of Surveying and Mapping, Ottawa.

Wassef, A.M. 1992. Measuring the integrity of GPS for crustal movement monitoring. Proceedings of the Cartography-Geodesy International Conference, pp. 86-95. Instituto de Astronomia y Geodesia, Madrid.

Wassef, A.M. 1993. Relative impact on human life of various types of natural disasters: An interpretation of data for the period 1947-1991. In Merriman and Browitt (eds.) *Natural Disasters: Protecting Vulnerable Communities*, pp. 15-24. Thomas Telford, London.

Wassef, A.M. 1993. Significance of crustal movements deduced from repeated measurements on geodynamic networks. *Journal of Geodynamics*, Vol. 17, No. 4, pp. 213-223.

Wassef, A.M. 1994. Progress of work on recent crustal movements involving measurements at stations in Africa. Proceedings of the Eighth International Symposium on Recent Crustal Movements (CRCM 93). *Journal of the Geodetic Society of Japan*, Special Issue, pp. 47-56.

Wassef, A.M. 1994. The goals and mechanics of participation in the regional and the global programmes of crustal movement studies. Keynote address delivered at the Fourth International Symposium on Recent Crustal Movements in Africa (RCMA 94), Nairobi, Kenya, November 28 - December 2, 1994.

Wassef, A.M. 1995. GPS for monitoring geodynamic networks The parameterization issue (Abstract) *Annales Geophysicae*, Volume 13, Supplement 1, p. C161.

Wassef, A.M. and J.O. Aseu. 1992. Networks, least-squares, and the quest for meaningful deformation data. Sixth International FIG Symposium on Deformation Measurements, Hannover, Germany.

Wassef, A.M. and M. El-Maghraby. 1991. An investigation into the integrity of surveying with the Global Positioning System. Proceedings of the Third International Symposium on Recent Crustal Movements in Africa. *Journal of Geodynamics*, Vol. 14, No. 1-4, pp. 51-58.

Wassef, A.M. and M. El-Maghraby. 1992. GPS: An experimental investigation of the feasibility of inferring the amount of inaccuracy in each vector determined from carrier phase measurements. Proceedings of the Sixth International Geodetic Symposium on Satellite Positioning, pp. 583-589. Defense Mapping Agency, Washington.

Wassef, A.M. and G. Gracie. 1995. The maintenance of the horizontal and vertical control networks of Metropolitan Toronto viewed in the context of the continuing need for a consistent reference system for development projects and the services. Prepared for Corporate Services Department, The Municipality of Metropolitan Toronto, Toronto, Canada.

International Association of Geomagnetism and Aeronomy

Compiled by Alan G. Jones

1. Aeromagnetism
2. Geomagnetism, including geomagnetic observatories
3. Electromagnetism
4. Paleomagnetism and Rock Magnetism
5. Space Physics

1. Aeromagnetism

Compiled by Walter Roest, Geological Survey of Canada

Aeromagnetic data processing and interpretation.

A simple user-friendly method to computationally "drape" constant elevation aeromagnetic surveys onto any specified surface has been developed using a Taylor series approach (Pilkington and Roest, 1992). This results in a significant improvement in the resolving power of such surveys and allows adjacent areas flown at different elevations to be merged in a straightforward manner. Comparison between this approach and truly drape-flown surveys shows computational draping is a viable method (Pilkington et al., 1995).

W. Roest and co-workers have devised a technique for estimating the depth and position of magnetic sources without any a priori knowledge concerning their geometry (Roest et al., 1992). Their approach, using the 3-D analytic signal, is computationally cheap (only requiring derivatives of the observed magnetic field) and delineates the edges of magnetic sources irrespective of the direction in which the body is magnetized. The analytic signal has also been used to derive an observational method to evaluate the level of remanent magnetization present in a particular source body (Roest and Pilkington, 1993).

Using aeromagnetic data, susceptibility measurements and well-logs M. Pilkington and co-workers have demonstrated that continental crustal magnetization can be well-described as fractal - having the same behaviour over a range of length scales (Pilkington and Todoeschuck, 1993; 1995). Furthermore, they have shown how to incorporate this information into existing interpretation methods and have demonstrated that more accurate interpretations are obtained (Pilkington et al., 1994).

J. Ostrowski (Horler Information) under contract and in cooperation with the GSC has developed a versatile form of Werner deconvolution which can be used on aeromagnetic data collected at varying altitudes (Ostrowski et al., 1993). This allows "draped" surveys to be processed directly with this approach, thus exploiting the high resolving power of such data. Effectively, all aeromagnetic surveys can now be interpreted with this method, irrespective of how the survey was flown.

A method originally developed for removing distortions in potential field maps has been applied (along with a simple strain analysis) to reconstruct the original shape of the Sudbury Basin, demonstrating, through the presentation of

potential field data, that it could have been circular and supporting a probable origin by impact (Roest and Pilkington, 1994). Work is now under way on applying this approach to the Kapuskasing Zone in Ontario and other areas with distributed deformation in the Canadian Shield.

Keating (1995) has successfully used pattern recognition techniques to identify circular magnetic anomalies caused by kimberlite pipes in the Kirkland Lake region of north-eastern Ontario, Canada. Using high resolution magnetic, electromagnetic and gravity data, an integrated geophysical interpretation of the Chibougamau mining camp, northwest Quebec, Canada, was completed (Dion et al., 1992).

In conjunction with gravity data, aeromagnetic survey data over the 65 Myr-old Chicxulub impact crater in Mexico has been processed and interpreted to provide important constraints on the size and morphology of this structure (Pilkington et al., 1994). Magnetic data suggest the presence of reversely magnetized bodies within the melt rocks and a central uplift offset from the geometric centre of the crater.

Aeromagnetic Surveys

Approximately 300,000 sq km have been added to the regional aeromagnetic coverage of Canada available for the Geophysical Data Centre of the GSC. Surveying has taken place in three principal areas: 1) Southern Saskatchewan and Manitoba, stimulated by interest in diamond exploration; 2) Southwest Alberta/Southeast British Columbia stimulated by oil and gas exploration and 3) in the Interior Plateau of British Columbia as part of a multi-disciplinary program to stimulate mineral exploration in an area with extensive glacial and miocene and younger volcanic cover. The Manitoba, Saskatchewan and British Columbia Interior Plateau portions were flown on an 800 m by 4 km grid at 400 m mean terrain clearance, whereas the Alberta/SE BC portion was flown on a 1600 m by 5 km grid in constant elevation blocks. The surveys in Manitoba, Saskatchewan, Alberta and Southeastern BC have also provided information on the structure and divisions of the precambrian basement beneath sedimentary cover and the eastern Cordillera as a complement to the Lithoprobe Deep Seismic Reflection Program.

Magnetic Compilation Project

In 1990, the Atlantic Geoscience Centre of the Geological Survey of Canada initiated a project to create a research-grade data base for use in investigating large-scale, regional tectonic problems of the Arctic and North Atlantic and surrounding land areas. As we near the end of this project, we estimate that we have assembled and processed about forty million magnetic data points, contributed by thirty-five organizations in fifteen countries, to develop a coherent 5-km grid throughout the study area (Verhoef et al., 1994). Contributors delivered data in a variety of forms: digital marine magnetic and aeromagnetic profiles, digital grids from previous compilations, and paper maps portraying contours or profiles along track. During the life of the project, numerous innovative computer techniques to cope with this major influx of data were designed and developed: semi-automatic error detection and correction, modelling of different classes of time-dependent magnetic field variations,

statistical cross-over analyses, interactive visualization, and grid manipulation (including levelling and adjustment). As a resource for regional studies, the new data base has already demonstrated its value by providing a departure point for a wide range of investigations performed jointly with personnel from data-contributing organizations. One of the most interesting results of the data base has been the new perspective it offers on the tectonic framework and early history of the Arctic Ocean - one of the world's most poorly known: marked disparities in the Amerasian and Eurasian Basis suggest significantly different modes of formation for these two segments of the seafloor. In the North Atlantic, the data base provides an enhanced definition of seafloor spreading anomalies, and contains interesting new evidence for ridge axis propagation and oceanic fracture zone displacements.

Bibliography

Dion, D.J., Morin R., and Keating, P., Synthèse Géologique de la région de Chapais: portion orientale de la ceinture de l'Abiti quibicoise, CJES, 29, 2, 314-327.

Roest, W.R., Verhoef, J. and Pilkington, M., 1992, Magnetic interpretation using the 3-D analytic signal: *Geophysics*, v.57, 16-125.

Pilkington, M. and Roest, W.R., 1992, Draping aeromagnetic data in areas of rugged topography: *J. Appl. Geophys.*, v.29, 135-142.

Pilkington, M. and Todoeschuck, J.P., 1993, Fractal magnetization of continental crust: *Geophys. Res. Lett.*, v.20, 627-630.

Roest, W.R. and Pilkington, M., 1993, Identifying remanent magnetization effects in magnetic data: *Geophysics*, v.58, 653-659.

Ostrowski, J.A., Pilkington, M. and Teskey, D.J., 1993, Werner deconvolution for variable elevation aeromagnetic data: *Geophysics*, v.58, 1481-1490.

Roest, W.R. and Pilkington, M., 1994, Restoring post-impact deformation at Sudbury: a circular argument: *Geophys. Res. Lett.*, v.21, 959-962.

Pilkington, M., Hildebrand, A.R. and Ortiz A., C. 1994, Gravity and magnetic modelling and structure of the Chicxulub crater, Mexico: *J. Geophys. Res.*, v.99, 13147-13162.

Pilkington, M., Gregotski, M.E. and Todoeschuck, J.P. 1994, Using fractal crustal magnetization models in magnetic interpretation: *Geophys. Prosp.*, v.42, 677-692.

Pilkington, M., Roest, W.R., Kwan, K.C.H. and Dumont, R., 1995, Comparison of drape-flown and computationally draped aeromagnetic data in British Columbia: in *Current Research, Part A, Geol. Surv. Canada Paper 95-1*, 61-65.

Pilkington, M. and Todoeschuck, J.P., 1995, Scaling nature of crustal susceptibilities: *Geophys. Res. Lett.*, v.22, in press.

Keating, P. 1995, A simple technique to identify magnetic anomalies due to

kimberlite pipes, *Mining and Exploration Geology*, 4, no.2.

Catalogue of Products and Services, Geophysical Data Centre, Geological Survey of Canada, 1995.

Verhoef J, Roest WR, Macnab, R and Project team, 1994. A compilation of magnetic observations from the Arctic and North Atlantic Oceans and adjacent land areas, Society of Exploration Geophysicists, International exposition and 64th Annual Meeting, Expanded Abstracts 853-855

2. Geomagnetic Surveys, Magnetic Observatories and Instrumentation (Geological Survey of Canada, Ottawa - prepared by L.R. Newitt, D.H. Boteler, and R.L. Coles)

i. Magnetic Observatories and Repeat Station Surveys

Instrumentation at Canadian magnetic observatories has been upgraded with the installation of the CANMOS magnetometer and data collection system. CANMOS provides faster sampling rates, increased resolution, and greater stability than was possible with the previous AMOS system. CANMOS also enables near-real-time data transmission via satellite, permitting Canada to become a major participant in INTERMAGNET, a global near-real-time observatory network. A new magnetic observatory has been established at Iqaluit, NWT, in support of the Orsted mission.

The Canadian repeat station network consists of approximately 40 sites at which magnetic observations are made about every four years to determine the secular variation of the magnetic field. In 1994, in addition to the normal repeat observations, a special survey was carried out to redetermine the position of the North Magnetic Pole. Its 1994 location was 78.3 degrees N, 104.0 degrees W.

ii. Regional Modelling of the Magnetic Field

The development of a new method for modelling secular variation, by main field differences, eliminates many of the problems inherent in the previous techniques. The technique has also been extended to modelling the main field by incorporating spatial magnetic field data, including scalar data. A spherical cap harmonic analysis was performed using the new method to produce the Canadian Geomagnetic Reference Field for 1995.

A method has been developed for calculating equivalent ionospheric and induced currents over a portion of the globe using the intrinsic ability of spherical cap harmonic analysis to separate internal and external sources. A near-real-time magnetic activity modelling routine has been developed. This routine uses data obtained via INTERMAGNET and other sources, to produce hourly models of magnetic activity and ionospheric currents over Canada, and to output them graphically for remote access.

iii. Forecasting Magnetic Activity

Magnetic activity forecasts continue to be used by a broad spectrum of users. Forecasts are available in a variety of forms. These include 27-day forecasts, 4-day computer bulletin-board forecasts, and magnetic alerts. Recently, a new method of superposed epoch analysis was developed to investigate the time delay between solar events and geomagnetic disturbances.

iv. Effects of geomagnetic activity on electric power transmission

Several joint ventures are underway with Canadian electric power utilities to investigate the effects of geomagnetic disturbances on power systems. A study for the Canadian Electrical Association investigated the occurrence of dB/dt levels likely to be a problem to power systems, and a follow-on study is now examining the whole question of geomagnetic hazard to power systems. This includes an analysis of the characteristics of magnetic variations and the earth conductivity structure in order to calculate the electric fields expected during disturbances. This is then being fed into power system models to determine the expected flow of geomagnetically induced currents (GIC) throughout a number of power systems. Growth of GIC in a power system can be affected by the inductance of the power transformers but this has been hard to calculate because the inductance changes for part of each AC cycle when the GIC causes transformer saturation. However, recent work by Boteler has shown how to calculate the effective value of an inductance that is changing with time.

Bibliography

Basham, P.W. and Newitt, L.R. 1993. An historical summary of earthquake seismology and geomagnetism in the Geological Survey of Canada, Canadian Journal of Earth Sciences, 30, p.372-390.

Boteler, D.H. 1992. Telluric current effects on pipelines, Proceedings of International Conference on Pipeline Reliability, June 2-5, 1992, Calgary, vol II, p.VII-13-1 - VII-13-12.

Boteler, D.H. and Jansen van Beek, G. 1993. Mapping the March 13, 1989, magnetic disturbance and its consequences across North America, Proceedings of Solar-Terrestrial Predictions Workshop, May 18-22, 1993, Ottawa, vol. 3, p.57-70.

Boteler, D.H. 1993. Real-time simulation of geomagnetically induced currents, Proceedings of International Workshop on Artificial Intelligence Applications in Solar-Terrestrial Physics, Sept 22-24, 1993, Lund, Sweden, p.183-191.

Boteler, D.H., Bui-Van, Q., and Lemay, J. 1994. Directional sensitivity to geomagnetically induced currents of the Hydro-Quebec 735 kV power system, IEEE Transactions on Power Delivery, 9, p.1963-1971.

Boteler, D.H. 1994. Characteristics of time-varying inductance, IEEE Transactions on Magnetics, 30, p.172-176.

- Boteler, D.H. 1994. Geomagnetically induced currents: present knowledge and future knowledge, *IEEE Transactions on Power Delivery*, 9, p.50-58.
- Coles, R.L. and Boteler, D.H. 1992. Geomagnetic Induced Currents: Assessment of Geomagnetic Hazard, Geological Survey of Canada, Open File No. 2635.
- Haines, G.V. 1991. Power of sub-periodic functions. *Physics of the Earth and Planetary Interiors*, 65, p.231-247.
- Haines, G.V. 1993. Modelling geomagnetic secular variation by main-field differences. *Geophysical Journal International*, 114, p.490-500.
- Haines, G.V. and Torta, J.M. 1994. Determination of equivalent current sources from spherical cap harmonic models of geomagnetic field variations. *Geophysical Journal International*, 118, p.499-514.
- Lam, H.-L. 1993. A superposed epoch analysis of magnetic data keyed to solar events. *Proceedings of Solar-Terrestrial Predictions Workshop*, May 18-22, 1992, Ottawa, vol. 3, p.171-176.
- Lam, H.-L. and Samson, J.C. 1994. An investigation of the time-delay between solar events and geomagnetic disturbances using a new method of superposed epoch analysis. *Journal of Geomagnetism and Geoelectricity*, 46, p.107-113.
- Newitt, L.R. 1991. The effects of changing magnetic declination on the compass. Geological Survey of Canada Miscellaneous Report 52.
- Newitt, L.R. and Haines, G.V. 1991. The Canadian Geomagnetic Reference Field 1990. *Current Research, Part E*, Geological Survey of Canada, Paper 91-1E, p.275-281.
- Newitt, L.R. and Haines, G.V. 1992. Comparison of IGRF candidate models with the Canadian geomagnetic reference field for 1985-1995. *Journal of Geomagnetism and Geoelectricity*, 44, p.871-880.

3. Electromagnetism

Compiled by Alan G. Jones

University of Victoria, Victoria, British Columbia
(J.T. Weaver, A.K. Agarwal)

At the University of Victoria theoretical work in geo-electromagnetic induction has centred on three-dimensional numerical modelling by finite differences and two-dimensional inversion using a modelling method. Recent progress has involved the development of automatic grid generators in two and three dimensions, the use of parallel computing for both forward modelling and inversion, and an investigation of conjugate gradient techniques for solving the large system of equations generated in three-dimensional modelling.

University of Victoria, Victoria, British Columbia
(H.W. Dosso and J. Chen)

Our research has been concentrated on studying coast effect EM induction and removing this component from geomagnetic measurements in coastal sites. The resulting difference induction arrows can then be interpreted as responses of any anomalous conductors in the field site region.

University of Manitoba
(Ian Ferguson, Trevor Boyce, Yu Sheng)

The University of Manitoba participated in the 138-site magnetotelluric investigation of crustal and mantle lithosphere structure in the LITHOPROBE Trans Hudson Orogen Transect and collected an additional 15 long-period MT recordings on the transect. Modelling of the theoretical seafloor magnetotelluric response, and vertical gradient sounding analysis of magnetic field recordings from the Juan de Fuca Ridge, have been completed. In controlled-source studies, we have performed finite element modelling of the response of seafloor EM surveys for a range of hydrocarbon targets and in addition completed a number of field surveys, employing both frequency and time-domain methods, for shallow environmental targets.

Geological Survey of Canada
(A.G. Jones, D.E. Boerner, R.D. Kurtz, W. Qian)

Under Lithoprobe auspices, magnetotelluric surveys have been undertaken in Newfoundland (Lithoprobe East transect, 1991; 67 sites), Quebec (Abitibi-Grenville transect, 1992; 80 sites), Saskatchewan and Manitoba (Trans-Hudson Orogen transect, 1992 and 1994; 138 sites), and Alberta (Alberta Basement transect, 1993 and 1994; 110 sites). The analyses of these data are at varying stages of maturity, and a number of papers have already been published.

The Long period Intelligent Magnetotelluric System (LIMS) was finally completed and undertook the first successful field trials in 1992. A total of sixteen LIMS have been built, and they have already been used on a number of surveys both in Canada and the U.S. The technology was transferred to Phoenix Geophysics Ltd., who now manufactured clones for commercial sale.

Collaborative projects with the University of Washington (J. Booker) have taken place in North Dakota and the southern Appalachians. Long period measurements were made on both surveys using the LIMS systems. The North Dakota survey mapped the fine structure of the North American Central Plains (NACP) anomaly.

Modeling of passive electromagnetic responses of powerlines and pipelines has been attempted by using integral equation method. The derived solution can account for the current channelling and induction in this kinds of cultural conductors.

Ecole Polytechnique
(M.Mareschal, M.Chouteau, P. Zhang, D. Livelybrooks)

Together with colleagues at the GSC and at Univ. of Toronto, we have observed upper mantle electrical anisotropy. The direction of enhanced conductivity has recently been shown to correspond to the fast axis of seismic anisotropy. we have also developed new techniques for analysing the vertical component of the magnetic field; finally several MT surveys have been completed over mining camps.

University of New Brunswick
(R. Kellett)

1991-1993 Investigating electrical anisotropy in the lower crust and upper mantle beneath the Archean Superior Province. Using geophysical methods including AMT and airborne magnetics to determine the geometry of Proterozoic Gabbro-anorthosite intrusions.

1993-1995 Processing C-band Synthetic Aperture Radar and airborne EM data over the Sudbury Structure. Developing a methodology for the integration of airborne and ground based EM data into a GIS.

University of British Columbia
(D.W. Oldenburg, R.G. Ellis)

Geophysical inversion studies, especially, EM tomography.

Bibliography

Arzate, J., Urrutia, J. and Mareschal, M (1993)

A preliminary crustal model of the Oaxaca continental margin and subduction zone from magnetotelluric and gravity measurements
Geofisica Intern., 32, 441-452

Arzate, J. and Mareschal, M. (1995)

An electrical image of the subducting Cocos plate from magnetotelluric observations
Geology, Submitted Nov. 1994

Agarwal, A.K. and Dosso, W.H., 1993. The characteristic periods of the induction arrows for a conductive-resistive interface-- a numerical model study. *Phys. Earth Planet. Inter.*, 76, 67-74.

Agarwal, A.K. and Weaver, J.T. 1993. Inversion of the COPROD2 data by a method of modelling. *J. Geomag. Geoelec.*, 45, 969-983.

Agarwal, A.K., Poll, H.E. and Weaver, J.T. 1993. One and two dimensional inversions of MT data in continental regions. *Phys. Earth Planet. Inter.*, 81, 155-176.

Boerner, D, Kellett, R. and Mareschal, M (1994)

Inductive source EM sounding of the Sudbury structure
G. Res. Let., 21, 943-946

Boerner, D.E., Kurtz, R.D. and Jones, A.G., 1993.

Orthogonality in CSAMT and MT measurements.
Geophysics, v. 58, 924-934.

Boyce, T.T., Finite element modelling for marine electromagnetic petroleum exploration. M.Sc. Thesis, University of Manitoba, Winnipeg (submitted May 1995).

Chakridi, R., Chouteau, M. and Mareschal, M. (1992)

A simple technique for analysing and partly removing galvanic distortion from the magnetotelluric impedance tensor: application to Abitibi and Kapuskasing data

Geophys. J. Intern., 108, 917-929

Chen, J., Dosso, H.W. and Ingham, M.R., 1993.
Electromagnetic induction in the New Zealand South Island.
Phys. Earth Planet. Inter., 81, 253-260.

Cook, F.A. and Jones, A.G., 1995.
Seismic reflections and electrical conductivity: A case of Holmes' curious dog?
Geology, v. 23, 141-144.

Dosso, H.W. and Meng, M., 1992.
The coast effect response in geomagnetic field measurements.
Phys. Earth Planet. Inter., 70, 39-56.

Dosso, H.W., Agarwal, A.K. and Chen, J., 1992. EM induction in the Vancouver Island region: 3D numerical, analogue model, and field site results. PAGEOPH, 138, No.2, 193-206.

Ellis, R.G., Farquharson, C.G. and Oldenburg, D.W., 1993.
Approximate Inverse Mapping inversion of the COPROD2 data.
J. Geomag. Geoelectr., 45, 1001-1012.

Ellis, Rob G. and Douglas W. Oldenburg
The pole pole 3d DC Resistivity inverse problem: a conjugate gradient approach
Geophysical Journal International, Vol. 119, 187-194, 1994

Ellis, Rob G. and Douglas W. Oldenburg
Applied Geophysical Inversion
Geophysical Journal International, Vol. 116, 5-11, 1994

Ellis, Robert G., Colin G. Farquharson and Douglas W. Oldenburg
Approximate Inverse Mapping Inversion of the COPROD2 Data
Journal of Geomagnetism and Geoelectricity, Vol. 45, 1001-1012, 1993

Farquharson, C.G. & Oldenburg, D.W., 1993.
Inversion of time-domain electromagnetic data for a horizontally layered Earth.
Geophys. J. Int., 114, 433-442.

Ferguson, I.J. and Edwards, R.N. 1994. Electromagnetic mode-conversion by surface conductivity anomalies: applications for conductivity soundings, Geophysical Journal International, 117, 48-68.

Ferguson, I.J. and Edwards, R.N., Vertical gradient sounding analysis of a magnetic storm recording from the Juan de Fuca Ridge, Geophys. J. Int., (in revision, accepted March 1994).

Ferguson, I.J., Taylor, W.J. & Schmigel, K., Electromagnetic mapping of saline

contamination at an active brine-pit. Canadian Geotechnical Journal, (Submitted January 1995).

Fischer, G., Szarka, L., Adam, A. and Weaver, J.T. 1992. The magnetotelluric phase over 2-D structures, Geophys. J. Int., v. 108, 778-786.

Gough, D.I. and Majorowicz, J.A., 1992.
Magnetotelluric soundings, structure and fluids in the southern Canadian Cordillera.
Canadian Journal of Earth Sciences, v. 29, 609-620

Groom, R.W. and Bahr, K., 1992.
Corrections for near surface effects: decomposition of the magnetotelluric impedance tensor and scaling corrections for regional resistivities: a tutorial.
Surveys Geophys., v. 13, 341-380.

Groom, R.W. and Bailey, R.C., 1991.
Analytical investigations of the effects of near-surface three-dimensional galvanic scatterers on MT tensor decomposition.
Geophysics, v. 56, 496-518.

Groom, R.W., Kurtz, R.D., Jones, A.G. and Boerner, D.E., 1993.
A quantitative methodology for determining the dimensionality of conductive structure from magnetotelluric data
Geophys. J. Inter., v. 115, 1095-1118.

Gupta, J.C. and Jones, A.G., 1995.
Electrical conductivity structure of the Purcell Anticlinorium in southeast British Columbia and northwest Montana
Can. J. Earth Sci., accepted.

Jones, A.G., 1992.
Electrical conductivity of the continental lower crust.
In "Continental Lower Crust", edited by D.M. Fountain, R.J. Arculus and R.W. Kay, published by Elsevier, Amsterdam,
Chapter 3, pp. 81-143

Jones, A.G., 1993.
Electromagnetic images of modern and ancient subduction zones.
In: A.G. Green, A. Kroner, H.-J. Gotze and N. Pavlenkova (Editors),
Plate Tectonic Signatures in the Continental Lithosphere.
Tectonophys., v. 219, 29-45.

Jones, A.G., 1993.
Introduction to MT-DIW1 special section
J. Geomagn. Geoelectr., v. 45, 931-932.

Jones, A.G., 1993.
The COPROD2 dataset: Tectonic setting, recorded MT data and comparison of models
J. Geomagn. Geoelectr., v. 45, 933-955.

Jones, A.G., 1993.

The BC87 dataset: tectonic setting, previous EM results, and recorded MT data
J. Geomagn. Geoelectr., v. 45, 1089-1105.

Jones, A., Bailey, R. and Mareschal, M. (1994)
High resolution electromagnetic images of conducting zones in an upthrust crustal block
G. Res. Lett., 21, 1807-1810

Jones, A.G., Craven, J.A., McNeice, G.A., Ferguson, I.J., Boyce, T., Farquarson, C. and Ellis, R.G., 1993.
The North American Central Plains conductivity anomaly within the Trans-Hudson orogen in northern Saskatchewan.
Geology, v. 21, 1027-1030.

Jones, A.G. and Dumas, I., 1993.
Electromagnetic images of a volcanic zone.
Phys. Earth Planet. Inter., v. 81, 289-314.

Jones, A.G., Gough, D.I., Kurtz, R.D., DeLaurier, J.M., Boerner, D.E., Craven, J.A., Ellis, R.G. and McNeice, G.W., 1992.
Electromagnetic images of regional structure in the southern Canadian cordillera
Geophys. Res. Lett., v. 12, 2373-2376.

Jones, A.G. and Groom, R.W., 1993.
Strike angle determination from the magnetotelluric tensor in the presence of noise and local distortion: rotate at your peril!
Geophys. J. Inter., v. 113, 524-534.

Jones, A.G., Groom, R.W. and Kurtz, R.D., 1993.
Decomposition and modelling of the BC87 dataset
J. Geomagn., Geoelectr., v. 45, 1127-1150.

Jones, A.G., Kurtz, R.D., Boerner, D.E., Craven, J.A., McNeice, G., Gough, D.I., DeLaurier, J.M. and Ellis, R.G., 1992.
Electromagnetic constraints on strike-slip fault geometry -- the Fraser River fault system
Geology, v. 20, 561-564.

Kang, S, Dosso, H.W. and Ogunade, S.O., 1993. Electromagnetic induction in South-west Nigeria: analogue model and field results.
J. Geomag. Geoelectr., 45, 805-816.

Kastube, J., Mareschal, M. and Aucoin, F. (1991)
Electrical characteristics of a graphitic rock from the Kapuskasing structural zone
Current Research, GSC, part E, 257-263

Katsube, J., Scromeda, N, Mareschal, M. and Bailey, R. (1992)
Electrical resistivity and porosity of crystalline rock samples from the Kapuskasing structural zone, Ontario
Current Research, GSC, part E, 225-236

- Katsube, J. and Mareschal, M., (1993)
 Petrophysical model of deep electrical conductors: graphite lining as a source
 and its disconnection due to uplift
JGR, 98, 8019-8030
- Kellett, R. L., Barnes, A. E., and Rive, M., 1994
 The deep structure of the Grenville Front: a new
 perspective from western Quebec.
CJES, 31, 282-292.
- Kellett, R. L., Bishop, J., and Reed, E. V., 1993
 The effects of source polarisation in CSAMT data over
 two massive sulfide deposits in Australia.
Geophysics, 59, 1764-1772.
- Kellett, R., Mareschal, M., and Kurtz, R. (1992)
 A model of lower crustal anisotropy for the Pontiac subprovince of the
 Canadian shield
Geophys. J. Intern., 111, 141-150
- Livelybrooks, D., Mareschal, M., Blais, E. and Smith, T. (1995)
 A magnetotelluric survey to delineate the Trillabelle massive sulphide
 body in Sudbury, Ontario
Geophysics, submitted march 1995
- Majorowicz, J.A. and Gough, D.I., 1991.
 Crustal structures from MT soundings in the Canadian Cordillera.
Earth and Planetary Science Letters, 102: 444-454.
- Majorowicz, J.A. and Gough, D.I., 1994.
 A model of conductive structure in the Canadian Cordillera.
Geophysical Journal International, in press.
- Majorowicz, J.A., Gough, D.I. and Lewis, T.J., 1993.
 Electrical conductivity and temperature in the Canadian Cordilleran crust.
Earth and Planetary Science Letters, 115: 57-64.
- Majorowicz, J.A., Gough, D.I. and Lewis, T.J., 1993.
 Correlation between the depth to the lower crustal high conductive layer
 and heat flow in the Canadian Cordillera.
Tectonophysics, 225: 49-56.
- Mareschal, M., Fyfe, W., Percival, J. and Chang, T. (1992)
 Grain-boundary graphite in Kapuskasing gneisses and implications for
 lower-crustal conductivity
Nature, 357, 674-676
- Mareschal, M., Jouanne, V., Menvielle, M., Chouteau, M., Grandis, H., and
 Tarits, P. (1992)
 Magnetotelluric observations over the Rhine Graben, France: a simple impedance
 tensor analysis helps constrain the dominant electrical features.
Phys. Earth Planet. Int., 74, 191-197

Mareschal, M., Kellett, R., Kurtz, R., Ludden, J. Ji, S. and Bailey, R (1995)
Archean cratonic roots, mantle shear zones and deep electrical anisotropy.
Nature, accepted march 1995

Mareschal, M., Kurtz, R., Chouteau, M. and Chakridi, R. (1991)
A magnetotelluric survey in manitoulin Island and Bruce Peninsula along
GLIMPCE seismic line J: black shales mask the Grenville Front.
Geophys. J. Intern., 105, 173-183

Mareschal, M., Kurtz, R. and Bailey, R. (1994)
Electromagnetic investigations in the Kapuskasing Uplift and surrounding
terraces: electrical properties of key rocks: a summary.
Can. J. Earth Sc., 31, 1042-1051

Marquis, G., Jones, A.G. and Hyndman, R.D., 1995.
Coincident conductive and reflective lower crust across a thermal boundary
in southern British Columbia, Canada
Geophys. J. Inter., v. 120, 111-131.

McGillivray, Peter R., Douglas W. Oldenburg, Rob G. Ellis and Tarek M.
Habashy
Calculation of sensitivities for the frequency domain
electromagnetic problem
Geophysical Journal International, Vol. 116, 1-4, 1994

Nelson, K.D., Baird, D.J., Walters, J.J., Hauck, M., Brown, L.D.,
Oliver, J.E., Ahern, J.L., Hajnal, Z., Jones, A.G. and Sloss, L.L., 1993.
Trans-Hudson orogen and Williston basin in Montana and North Dakota: New
COCORP deep profiling results
Geology, v. 21, 447-450.

Oldenburg, Douglas W. and Rob G. Ellis
Inversion of Geophysical Data using an approximate inverse mapping
Geophysical Journal International, Vol. 105, 325-353, 1991

Oldenburg, Douglas W. and Robert G. Ellis
Efficient Inversion of magnetotelluric data in two
dimensions
Physics of the Earth and Planetary Interiors, Vol. 81,
177-200, 1993

Percival, J. Shaw, D., Milkereit, B., White, D., Jones, A., Salisbury, M.,
Bursnall, J., Moser, D., Green, A., Thurston, P., Bailey, R. and Mareschal, M.
(1991)
A closer look at deep crustal reflections
EOS, 72, 337-341

Pu, X.H., Agarwal, A.K. and Weaver, J.T. 1993. Magnetic field
solutions of E-polarization induction problems. J. Geomag. Geoelec., 45,
859-872.

Qian W. and D.E. Boerner, 1994, Electromagnetic response of a
discretely grounded circuit- An integral equation solution, Geophysics,
59, 1680-1694.

- Qian W. and D.E. Boerner, 1995, Electromagnetic modelling of buried line conductors using an integral equation, *Geophys. J. Int.*, In press.
- Schultz, A., Kurtz, R.D., Chave, A.D. and Jones, A.G., 1993. Conductivity discontinuities in the upper mantle beneath a stable craton. *Geophys. Res. Lett.*, v. 20, 2941-2944.
- Senechal, G., Mareschal, M., Hubert, C., Calvert, A. and Grandjean, J (1995) A novel approach to processing seismic reflection data: a combination of deep geophysical investigations enlighten the significance of Casa Berardi Tectonic Zone
Can. J. earth Sc., submitted march 1995
- Spies, Brian R. and Rob G. Ellis
 Bore Hole Resistivity Tomography of a Pilot-Scale In Situ Vitrification Test
Geophysics, June, 1995
- Stettler, E., de Beer, J., Eberle, D., Ludden, J. and Mareschal, M. (1995) Greenstone belts: their boundaries, surrounding rock terranes and their interrelationships, in "Tectonic Evolution of Greenstone Belts", M. deWit and L. Aswal eds
 Oxford Univ. Press, in press
- Weaver, J.T. and Agarwal, A.K. 1991.
 Is addition of induction vectors meaningful?
Phys. Earth Planet. Inter., 65, 267-275.
- Weaver, J.T. and Dawson, T.W. 1992.
 Adjustment distance in TM mode electromagnetic induction,
Geophys. J. Int., 108, 293-300.
- Weaver, J.T. 1992.
 Thin sheet modelling and its application to geo-electromagnetic induction in the Indian Peninsula by electrojet and uniform sources, in *Geomagnetic Studies at Low Latitudes* (G.K. Rangarajan & B.R. Arora, editors), Geological Society of India Memoir No. 24, 39-62.
- Weaver, J.T. and Agarwal, A.K. 1993.
 Automatic 1-D inversion of magnetotelluric data by the method of modelling,
Geophys. J. Int., 112, 115-123.
- Weaver, J.T. 1994.
Mathematical Methods for Geo-electromagnetic Induction, 316pp, Research Studies Press (John Wiley & Sons), Taunton, U.K. (Monograph).
- Zhang, P., Pedersen, L., Mareschal, M. and Chouteau, M. (1993) Channeling contribution to tipper vectors: a magnetic equivalent to electrical distortion
Geophys. J. Intern., 113 693-700
- Zhang, P., Chouteau, M., Mareschal, M. and Kurtz, R. (1995)

High frequency magnetotelluric investigations of crustal structure in northern Abitib, Canada.
Geophys. J. Intern., in press (Feb 95)

4. Paleomagnetism and Rock Magnetism

Compiled by Randy Enkin, Geological Survey of Canada

Department of Earth Science, Memorial University, St. John's, Newfoundland
(J.P.Hodych, G.S.Murthy)

Hodych and Bijaksana (1993) showed that remanence anisotropy can be useful in detecting and correcting paleomagnetic inclination shallowing induced by compaction in deep-sea sediments. Low temperature demagnetization experiments were used to identify internal stresses as important in remanence retention in mafic igneous rocks (Hodych 1991). Paleomagnetic studies in central Newfoundland with K.L. Buchan of the Geological Survey of Canada have shown that the Iapetus Ocean was likely closed (or nearly so) by the Silurian in Newfoundland (Hodych and Buchan 1994). Gummuluru Murthy is continuing his studies of the diabase dyke swarms from coastal Labrador. Suites of dykes exposed along the coast from Port Hope Simpson south all the way south to Belle Isle were sampled along with Charlie Gower of the Newfoundland Department of Natural Resources. Both the Lighthousecove and the Bradore magnetizations are likely remagnetizations and it seems the southeastern region of Labrador was exposed to some regional metamorphism. Ernest Deutsch and Gummuluru Murthy are collaborating with Karsten Storetvedt of the University of Bergen on the study of the Lower Paleozoic of Ireland.

Department of Geology, University of Ottawa (K.Benn)

Research over the last four years has concentrated on the use of the anisotropy of (low-field) magnetic susceptibility (AMS) as a tool to measure petrofabrics in granites and gneisses. In the Archean Opatika Gneiss Belt (Southeastern Superior Province, Canada), AMS was used to confirm orientations of regionally consistent lineations which give partial kinematics of ductile thrusting of the Opatika Belt and the Abitibi Greenstone Belt, ca. 2.7 Ga. Detailed susceptibility and magnetic mineralogy data was also presented for the mid-crustal gneisses and granites. AMS is currently being used to measure petrofabrics in Appalachian syntectonic granite plutons. In the Rose Blanche granites (Central Mobile Belt, Newfoundland), the AMS measures orogen-parallel biotite fabrics which are related to late-orogenic regional transpression. In the Canso area (Meguma Terrane, Nova Scotia), the AMS fabric pattern in granites provides an excellent criteria for syntectonic pluton emplacement during regional dextral transpression along the Meguma-Avalon terrane boundary. Applications of AMS to the study of fabric overprinting relationships, finite strains, and strain histories in granites are also being investigated.

Continental Geoscience Division, Geological Survey of Canada, Ottawa
(K.L.Buchan, J.K.Park, with R.E.Ernst)

Until recently, large uncertainties in the ages that are assigned to Precambrian paleopoles have limited their use in the construction of apparent polar wander paths and the investigation of relative movement of the Precambrian terranes. However, during the past four years a new

collaborative approach to paleomagnetic and U-Pb geochronologic studies has reduced uncertainties in the dating of many paleopoles from >100my to <50my (e.g. Buchan et al. 1993). These studies have been concentrated on mafic dykes and sills, and require that (a) samples be collected for both paleomagnetism and U-Pb baddeleyite (or zircon) dating at the same locality, (b) a U-Pb age and well-defined paleopoles be obtained, and (c) a rigorous field test be carried out to ensure that the remanence is primary and therefore dated by the U-Pb age. Studies have been reported on several Early Proterozoic units in the Canadian Shield (Buchan et al. 1994) and demonstrate that there are serious problems with segments of widely-used apparent polar wander paths.

Department of Physics, University of Toronto (D.J. Dunlop, O.Ozdemir, S.Xu)

The rock magnetism group has been investigating experimental and theoretical magnetic domain structures, new theories of thermoremanent magnetization (TRM), and paleomagnetic studies of post-metamorphic uplift and cooling in the Grenville Province in Ontario. For the first time, clear closure domains have been photographed on carefully oriented magnetite crystals. Two- and three-dimensional calculations of micromagnetic structures in magnetite have traced the evolution of complex domains from simple ones as crystals grow, but have also demonstrated that simple structures do also exist in crystals as large as 1 μm in size. Transitions between metastable equilibrium structures at high temperature ("transdomain TRM") have been computed with a one-dimensional model, while the thermal demagnetization and partial TRM processes have been solved analytically for domain wall motions in larger crystals. Lithotectonic domains in the Central Gneiss Belt of the Grenville Province have broadly similar uplift signatures, but uplift occurred at times differing by 50-100 Ma in the more southerly and more northerly domains. The Grenville Front Tectonic Zone has a distinct history, with widespread hydrothermal alteration and remagnetization.

Department of Geology, University of Toronto (H.C. Halls)

Paleomagnetic studies of the 2.45 Ga Matachewan dyke swarm of northern Ontario show that Proterozoic deformation of the Superior Province is more widespread than previously thought. Regional changes in paleomagnetic declination and dyke strike are positively correlated and reveal that the swarm has been distorted both within and NW of the Kapuskasing Zone (KZ) from an originally linear, radiating pattern. The new results show that the KZ is sinistrally offset and depressed progressively towards the SW. A paleomagnetic investigation of the 1883 Ma Molson dykes of Manitoba shows that older dykes are present which are estimated from APW curves to be about 2.1 Ga old. This discovery is significant because the older dykes document for the first time the opening stages of the Manikewan Ocean, the closure of which led to the Trans-Hudson Orogen at 1.8 Ga. Ferrofluid has been used to impregnate porous rocks and to render the pore volumes magnetic. AMS measurements then provide a measure of the pore shape anisotropy. The method, called Magnetic Pore Fabric Analysis, provides a new and rapid way for estimating permeability anisotropy, an important parameter in the petroleum and hydrological industries.

Department of Geology, McMaster University, Hamilton, Ontario (W.A.Morris)

Topics of research include joint paleomagnetic / aeromagnetic / seismic interpretation of the Sudbury Igneous Complex and the Grenville Front, Holocene magnetostratigraphy in the Great Lakes, and using susceptibility to

trace pollutants in Hamilton Harbour.

Department of Earth Sciences, University of Western Ontario, London, Ontario
(H.C.Palmer)

The personal research of H. Currie Palmer concerns a study of the structure, paleomagnetism and anisotropy of magnetic susceptibility of early and mid-Tertiary ashflow tuffs of the Basin and Range Province exposed in southern Idaho and east central Nevada. This work is done jointly with W.D. MacDonald (SUNY, Binghamton). The object of the research is to decipher the style of deformation associated with the north Nevada Rift and with B&R extensional faulting in general. The AMS data is used to infer flow patterns and hence source vent locations. Paleomagnetic research of graduate student M.G. Gala involves Late Paleozoic and Early Mesozoic rocks from the Stikine Terrane, Iskut River area, B.C., and of Precambrian rocks in the Hanson Lake block of the Trans-Hudson orogen. This research is directed towards the understanding of the tectonic history of these regions.

Department of Geology, University of Windsor (D.T.A.Symons)

Paleomagnetic methods have been used to date the genesis of epithermal Mississippi Valley-type Pb-Zn-Ba ore deposits (Gays River, Newfoundland Zinc, Pine Point and Polaris in Canada; Central Missouri and Central Tennessee in U.S.A.; Silesia in Poland) H. Pan and M.T. Lewchuk (PhD students, Univ. of Western Ontario), D.F. Sangster (Geol. Surv. Canada) and D.L. Leach (U.S. Geol. Surv.) were each involved in several of these studies. M. MacDonald (M.Sc. student, Univ. of Windsor) continues work on other deposits. Most other studies examined Cambrian or Precambrian geotectonic problems under the auspices of LITHOPROBE in the Kapuskasing Structural Zone (e.g. Callendar, Chipman Lake and Seabrook carbonanites), in the Trans-Hudson Orogen (THO) (Wathaman Batholith, Peter Lake Domain, Macoun pluton, Hanson Lake pluton, Missi conglomerate), and in the Cordillera (Aldridge Fm.). A.D. Chiasson, C.A. Lohnes, and E.A. Timmins did B.Sc. theses (Univ. of Windsor) on these rocks. M. Gala and M. Harris (Ph.D. students, Univ. of Western Ontario) continue to work on studies in the THO and Cordillera, respectively. Improvements to the data acquisition system for the automated CTF DRM420 cryogenic magnetometer give it now a sensitivity of 2×10^{-6} A/m.

Department of Geology, Lakehead University, Thunder Bay, Ontario
(G.J.Borradaile)

The research program involves studies of strain in rocks as revealed by magnetic anisotropy, with application to tectonics in the Precambrian shield.

Institute of Earth and Planetary Physics, University of Alberta (M.E.Evans)

One primary focus has been the magnetostratigraphic investigation of the thick loess/paleosol sequence at Baoji, China. A concurrent study of the paleoclimatic information encoded in the corresponding magnetic susceptibility has also been carried out, including scrutiny of the mineral-magnetic basis for susceptibility as a climate proxy. This project involves a doctoral thesis (Y.Wang, 1991), and the active collaboration of N.W.Rutter (Department of Geology, University of Alberta), Z.L. Ding and T.S. Liu (Academia Sinica, Beijing), and F. Heller (ETH, Zurich). Work on the Permo- Carboniferous Reversed Superchron has been completed (doctoral thesis, J.-M. Maillol, 1992). Magnetostratigraphic work has also been

carried out on the last interglacial in the Yukon Territory (with J.V. Mathews, Geological Survey of Canada, Ottawa), on permafrost cores in the MacKenzie Delta (with S. Dallimore, Geological Survey of Canada, Ottawa), and on the Cretaceous/Tertiary boundary (with J.F. Lerbekmo, Department of Geology, University of Alberta / Canadian Continental Drilling Program). Archeomagnetic studies in the Mediterranean area are continuing; the work to date was summarized in an invited review to appear shortly in a special publication of the Geological Society of London.

Department of Geology, University of Lethbridge (R.W. Barendregt)

The recent flourishing of research in the areas of paleoenvironmental reconstruction and global change has underscored the need for reliable geochronological data. Our research has focussed on paleomagnetic properties as a correlation and dating tool for sediments and rocks of the Quaternary and Neogene. Remanence measurements of deposits containing proxy records of paleoclimates have been carried out in the Canadian Arctic (Barendregt et al., 1990), Canadian prairies (Barendregt et al., 1991), Canadian Cordillera (Barendregt et al., 1991), east Africa (Mahaney et al., 1989), Colombia (Helmens et al., 1995) and elsewhere. In addition to providing age constraints, the work has proven valuable as a measure of relative weathering histories, soil formation, and extent of Cordilleran and Laurentide ice in North America.

Geological Survey of Canada - Victoria (R.J. Enkin, P.J. Wynne, E. Irving)

A) Cordilleran Studies: With the recognition that plutons may have systematic tilts, study of Cretaceous displacements in the Cordilleran belts has been focussed on plutons with bathozonal tilt corrections or well-bedded rocks. Recent data confirms the large scale northward motion from the mid-Cretaceous to the Eocene, and in particular has discriminated between 3000 km displacement in the coastal belt versus 1500 km displacement in the intermontane. B) Quaternary Magnetostratigraphy (with R. Barendregt, U. Lethbridge): We have applied magnetostratigraphic study of periglacial deposits to a variety of settings (Arctic Islands, the Northern Cordillera, the Prairies) to correlate and date glacial events. The distribution of pre-Wisconsin glaciation in Canada is being built up and is used towards constructing better surficial maps. C) Diagenesis and Mineralization Studies: Iron oxides are easily transformed by hydrothermal events, thus providing the opportunity for paleomagnetic dating. We have studies concerning Uranium mineralization in the Athabaska basin, alteration of the Saskatchewan potash, the maturation and migration of hydrocarbons in the Canadian Rockies and Foothills, and on kimberlite properties.

Royal Roads Military College, Victoria, B.C. (J.S. Mothersill)

During the 1993 and 1994 field seasons, 16 cores were obtained from Lakes Victoria, Albert and Edward in Uganda, East Africa. Paleomagnetic measurements have been carried out on aligned samples from these cores using a Schonstadt spinner magnetometer at RRMC and on a C.T.F. System cryogenic magnetometer for those cores with low intensity of magnetization values. Palynologic analyses of the cores are being carried out at Makerere University, Uganda.

Bibliography

- Barendregt, R.W., Thomas, F.F., Irving, E., Baker, J. Stalker A.M. and C.S. Churcher 1991 "Stratigraphy and paleomagnetism of the Jaw Face section, Wellsch Valley site, Saskatchewan, Canadian Journal of Earth Sciences, v 28, pp. 1840-1850.
- Bates, M.P. and Halls, H.C. 1991. Broad-scale deformation of the central Superior Province revealed by paleomagnetism of the 2.45 Ga Matachewan dyke swarm. *Can. J. Earth Sci.*, 28: 1780-1796.
- Benn, K., 1994. Overprinting of magnetic fabrics in granites by small strains: numerical modelling. *Tectonophysics*, 233: 153-162.
- Benn, K., Sawyer, E.W. and Bouchez, J.-L., 1992. Orogen Parallel and transverse shearing in the Opatica Belt, Quebec: implications for the structure of the Abitibi Subprovince. *Canadian Journal of Earth Sciences*, 29: 2429-2444.
- Benn, K., Rochette, P., Bouchez, J.-L. and Hattori, K., 1993. Magnetic susceptibility, magnetic mineralogy and magnetic fabrics in a late Archean granitoid-gneiss belt. *Precambrian Research*, 63: 59-81.
- Buchan, K.L., Mortensen, J.K., and Card, K.D., 1994. Integrated paleomagnetic and Upb geochronologic studies of mafic intrusions in the southern Canadian Shield: implication for the Early Proterozoic polar wander path. *Precambrian Research* 69, 1-10.
- Costanzo-Alvarez, V., and D. J. Dunlop, 1993. Paleomagnetism of the Red Lake greenstone belt, northwestern Ontario: Possible evidence for the timing of gold mineralization. *Earth Planet. Sci. Lett.* 119, 599-615.
- Evans, M.E. and Heller, F., magnetic enhancement and paleoclimate: study of loess/paleosol couplet across the Loess Plateau of China, *Geophysical journal International*, 117, 257-264, 1994.
- Halls, H.C. and Palmer, H.C. The tectonic relationship of two early Proterozoic dyke swarms to the Kapuskasing Structural Zone: a paleomagnetic and petrographic study. *Can. J. Earth Sci.*, 27: 87-103.
- Hearst, R.B., Morris, W.A., and Thomas, M.D., 1994. Magnetic Interpretation along the Sudbury Structure Lithoprobe Transect. *Geophysical Research Letters*, v.21 (10), p.951-954.
- Hodych, J.P. and Bijaksana, S. 1993. Can remanence anisotropy be used to detect paleomagnetic inclination shallowing due to compaction? A case study using Cretaceous deep-sea limestones. *Journal of Geophysical Research*, 98B, pp. 22,429-22,441.
- Hodych, J.P. 1991. Low temperature demagnetization of saturation remanence in rocks bearing multidomain magnetite. *Physics of the Earth and Planetary Interiors*, 66, pp. 144-152.
- Irving, E., and Wynne, P.J., 1991, Paleomagnetic evidence bearing on the

evolution of the Canadian Cordillera. *Phil. Trans. Roy. Soc. Lond. A*, 331, 487-509

Lerbeckmo, J.F., Demchuk, T.D., Evans, M.E., and Hoye, G.S.,
Magnetostratigraphy and biostratigraphy of the continental Paleocene of the
Red Deer valley, Alberta, Canada, *Bull. Can. Pet. Geol.*, 40, 24-35, 1992.

Maillol, J.M. and Evans, M.E., Magnetic intensity variations in Red Beds of
the Lodeve Basin (southern France) and their bearing on the magnetization
acquisition process, *Geophys. J. Int.*, 111, 281-290, 1992.

Morris, W.A., Versteeg, J.K., McCarry, B., Marvin, C., and Rukavina, N.,
1994. Preliminary comparison of magnetic property and polycyclic aromatic
hydrocarbon (PAH) profiles in Hamilton Harbour sediments. *Science of the
Total Environment*, v.152, p.153 - 160.

Murthy, G.S., C.F. Gower, M. Tubrett and R. Patzold 1992. Paleomagnetism of
the Eocambrian Long Range dykes and Double Mer Formation from Labrador,
Canada. *Canadian Journal of Earth Sciences*, 29, p1224-1234.

Ozdemir, O., and D. J. Dunlop, 1993. Magnetic domain structures on a
natural single crystal of magnetite. *Geophys. Res. Lett.* 20, 1835-1838.

Palmer, H.C., MacDonald, W.D. and Hayatsu, A., 1991. Magnetic, structural
and geochronological evidence bearing on volcanic sources and Oligocene
deformation of ash-flow tuffs, northeast Nevada, *J. Geophys. Res.*, 96, 2185-2202

Pfleiderer, S. and Halls, H.C. 1994. Magnetic pore fabric analysis: a rapid
way to estimate permeability anisotropy. *Geophys. J. Internat.*, 116: 39-45.

Symons, D.T.A., Lewchuk, M.T., Dunlop, D.J., Costanzo-Alvarez, V., Halls,
H.C., Bates, M.P., Palmer, H.C., and Vandall, T.A., 1994. Synopsis of
paleomagnetic studies in the Kapuskasing structural zone. *Can. J. Earth
Sc.*, 31: 1206-1217.

Symons, D.T.A., 1994. Geotectonics of the Peter lake Domain in the
Proterozoic Trans-Hudson orogenic belt of Saskatchewan, Canada, from
paleomagnetism. *Precamb. Res.* 69: 11-24.

Symons, D.T.A., 1994. Paleomagnetism and the Late Jurassic genesis of the
Illinois-Kentucky fluorspar deposits. *Econ. Geol.*, 89: 438-449.

Xu, S., D. J. Dunlop, and A. J. Newell, 1993. Micromagnetic modeling of
two-dimensional domain structures in magnetite. *J. Geophys. Res.* 99, 9035-9044.

5. Aeronomy and Space Physics

Compiled by D. McDiarmid

Publications

Abe, T., B. A. Whalen, A. W. Yau, R. E. Horita, S. Watanabe, and E.

- Sagawa, EXOS-D (Akebono) suprathermal mass spectrometer observations of the polar wind. *J. Geophys. Res.* 98, 11191-11203, 1993.
- Abe, T., B. A. Whalen, A. W. Yau, S. Watanabe, E. Sagawa, and K. I. Oyama, Altitude profile of the polar wind velocity and its relationships to ionospheric conditions. *Geophys. Res. Lett.* 20, 2825-2828, 1993.
- Akasofu, S.-I., H.C. Stenbaek-Neilsen, T.J. Hallinen, G. Rostoker and D.N. Baker, A new era in magnetospheric research, *Eos*, 73, 305, 1992.
- Atkinson, G., Magnetospheric Convection, *J. Geomag, Geoelectr.*, 43, 183-192, 1991.
- Atkinson, G., A magnetosphere wags the tail model of substorms, In *Magnetospheric Substorms*, ed. J.R. Kan, T.A. Potemra, S. Kokabur, T. Iigima, Geophysical Monograph G4, AGU, Washington, 1991.
- Atkinson, G., Mechanism by which merging at X lines causes discrete auroral arcs, *J. Geophys. Res.*, 97, 1337-1344, 1992.
- Atkinson, G., Auroral Arcs - A Conceptual Overview In *Physics of Space Plasmas (1992) SPI Conference Proceedings and Reprint Series*, Number 12, Ed. T. Chang, Scientific Publishers Inc., Cambridge, Mass., 1992.
- Atkinson, G., How does magnetospheric convection relate to the expansion onset of substorms?, *J. Atmospheric and Terrestrial Physics*, 55, 1151-1157, 1993.
- Atkinson, G., *Collisionless Plasmas: Fluid Behaviour and the Breakdown Thereof, Rarefied Gas Dynamics: Space Science and Engineering*, Vol. 160, *Progress in Astronautics and Aeronautics*, Ed. A.R. Seebass, Published by AIAA, Washington, 1994.
- Atkinson, G., Convection as a Free-Boundary Problem: The Substorm Cycle, *J. Geophys. Res.* 99, 2447-2459, 1994.
- Atkinson, G., Substorms and Nightside Convection, *Proceedings of International Conference on Substorms, II*, In press, 1994.
- Atkinson, G., Nightside Magnetospheric Convection, *Proceedings of 1995 MIT Symposium: Multiscale Phenomena in Space Plasmas*, Ed. T. Chang - In press, 1995.
- Allan, W, J.R. Manuel and E.M. Poulter, Magnetospheric cavity modes: some nonlinear effects, *J. Geophys. Res.*, 96, 11461, 1991.
- Allan, W., E.M. Poulter and J.R. Manuel, Mass transport in the magnetosphere by ponderomotive forces, in *South Pacific STEP Workshop Proceedings*, edited by E.A. Essex and J.D. Whitehead, pp. 35-38, La Trobe University, Bundoora (Australia), 1992.

- Allan, W. and D.R. McDiarmid, Frequency ratios and resonance positions for magnetospheric cavity/waveguide modes, *Ann. Geophysicae*, 11, 916-924, 1993.
- Arnoldy, R. L., G. P. Garbe and P. M. Kintner, Transverse ion acceleration measured at rocket altitudes, in *Physics of Space Plasmas*, SPI Conference Proceedings and Reprint Series, 11, Tom Chang, editor, 1990.
- Austin, J. B., J. S. Murphree and J. Woch, Polar Arcs : New Results from Viking UV Images, *J. Geophys. Res.*, 98, 13,545-13,555, 1993.
- Bahsoun-Hamade, F., R. H. Wiens, and G.G. Shepherd, Thermospheric O I 844.6-nm emission in twilight, *J. Geophys. Res.* 99, 6289-6295, 1994.
- Bahsoun-Hamade, F., R.H. Wiens, A. Moise, and G.G. Shepherd, Imaging Fabry-Perot Spectrometer for Twilight Observations, *Applied Optics*, 33, 1100-1107, 1994.
- Baker, D. N., T. I. Pulkkinen, R. L. McPherron, J. D. Craven, L. A. Frank, R. D. Elphinstone, J. S. Murphree, J. F. Fennell, R. E. Lopez and T. Nagai, CDAW 9 Analysis of Magnetospheric Events on May 3, 1986: Event C, *J. Geophys. Res.*, 98, 3815-3834, 1993.
- Baker, D.N. Baker, S. Kanekal, J.B. Blake, B. Klecker and G. Rostoker, Satellite anomalies linked to electron increase in the magnetosphere, *Eos*, 75, 401, 1994.
- Barker, H.W., S.R. Pal and A.I. Carswell, Infrared Flux Transmittances of Inhomogeneous Cirrus Clouds, In *Current Problems in Atmospheric Radiation*, Deepak Pub. pp.145-148, 1993.
- Ben-Jaffel, L., R. Prange, C. Emerich, A. Vidal-Madjar and J.C. McConnell, A Model for the Disc Lyman Alpha Emission of Uranus, *J. Geophys. Res., Lett.*, 96, 9781-9791, 1991.
- Bird, J.C., G.G. Shepherd and C.A. Tepley, Comparison of lower thermospheric winds measured by a Polarizing Michelson Interferometer and a Fabry-Perot spectrometer during the AIDA campaign, *J. Atmos. Terr. Phys.* 55, 313-324 1993.
- Blanchard, G.T., L.R. Lyons, J.C. Samson and F.J. Rich, Locating the polar cap boundary from observations of 6300 Å auroral emission, *J. Geophys. Res.*, in press, 1995.
- Boreiko R.T., T.A. Clark, D.A. Naylor and J.R. Busler, High-n Hydrogen Lines in Solar IR Spectra from Balloon-borne, Mauna Kea and ATMOS Observations, in *IAU Symposium 154 Proceedings, (Infrared Solar Physics*, 367, 1993.
- Bristow, W.A., R.A. Greenwald and J.C. Samson, Identification of high latitude acoustic gravity wave sources using the Goose Bay HF Radar, *J. Geophys. Res.*, 99, 319-331, 1994.

- Bruning, K., L. P. Block, G. T. Marklund, L. Eliasson, R. Pottelette, J. S. Murphree, T. A. Potemra and S. Perraut, Viking Observations Above a Post Noon Aurora, *J. Geophys. Res.*, 95, 6039-6050, 1990.
- Burns, G. B., D. J. McEwen, R. A. Eather, F. T. Berkey and J. S. Murphree, Optical Auroral Conjugacy : Viking UV Imager - South Pole Station Ground Data, *J. Geophys. Res.*, 95, 5781-5790, 1990.
- Burns, G. B., D. J. McEwen, F. T. Berkey, J. S. Murphree, D. Hearn and R. A. Eather, Dynamics of the Conjugate Post-Noon Regions During an Auroral Enhancement, *J. Geomag. Geoelectr.*, 44, 65-90, 1992.
- Calder, A.C., G.W. Hulbert, J.G. Laframboise, Sheath dynamics of electrodes stepped to large negative potentials, *Physics of Fluids B5*, No. 3, 674-690, 1993.
- Cann, M.W.P. and R.W. Nicholls, Spectrum Line Parameters for the O₂ Herzberg I Band system, *Can. J. Phys.* 69 1163-1165, 1991.
- Carswell, A.I., S.R. Pal, W. Steinbrecht, J.A. Whiteway, A. Ulitsky and T.Y. Yang, Lidar Measurements of the Middle Atmospheric, *Can. J. Phys.* 69, 1076-1086, 1991.
- Carswell, A.I., A. Ulitsky and D.I. Wardle, Lidar Measurements of the Arctic Stratosphere, In *Atmospheric Radiation*, SPIE Vol. 2049, 9-23, 1993.
- Carswell, A.I., A. Fong, S.R. Pal and I. Gordon, Lidar-Derived Distribution of Cloud Vertical Location and Extent *J. Appl. Meteorol.* 34, 107-120, 1995.
- Carswell, A.I., A. Fong, S.R. Pal and I. Gordon, Lidar-Derived Distribution of Cloud Vertical Location and Extent, *J. Appl. Meteorol.* 34, 107-120, 1995.
- Chang, C.A. and J.-P. St.-Maurice, Two-dimensional high latitude thermospheric modeling; a comparison between moderate and extremely disturbed conditions, *Can. J. Phys.*, 69, 1007-1031, 1991.
- Chang, Jen-Shih and J.G. Laframboise, Theory of electrostatic probes in a flowing continuum plasma: numerical solutions for cylindrical probes in cross flow, *J. Phys.* 26, 42-48, 1993.
- Chen, G.M. and R.E. Horita, Proton cyclotron echoes at 3f_H and 4f_H resonances, *Radio Sci.*, 26, 23-29, 1991.
- Clark, T.A., D.A. Naylor, G.J. Tompkins and W.D. Duncan, Extension of the Solar Limb at Sub-millimeter and Millimeter Wavelengths, *Solar Physics*, 140, 393, 1992.
- Clark, T.A., D.A. Naylor, G.J. Tompkins, C.A. Lindsey, D.C. Braun, R.A. Harrison, M.K. Carter, T.L. Roellig, J.T. Jefferies, E.E. Becklin and G. Watt, ncd Near Infrared Observations of the 11 July

- 1991 Total Solar Eclipse from Mauna Kea, Hawaii, in IAU Symposium 154 Proceedings, (Infrared Solar Physics}, 173, 1993.
- Clark, T. A., Naylor, D. A. & Tompkins, G. J., Observation of the N=8--7 Rydberg transition of Hydrogen in emission in the solar infrared spectrum and the search for equivalent magnesium lines, ASP Conference Series, 64, 608, 1994.
- Clark, H.R., A.C. Current, A.H. Manson, C.E. Meek, S.K. Avery, S.E. Palo and T. Aso., Hemispheric properties of the 2-d wave from mesosphere-lower thermosphere radar observations, J. Atmos. Terr. Phys., 56, 1279-1288, 1994.
- Collis, P.N., M.T. Rietveld, J. Roettger, and W.K. Hocking, Turbulence scattering layers in the middle-mesosphere observed by the Eiscat 224 MHz radar, Radio Sci., 27, 97- 107, 1992.
- Connors, M. and G. Rostoker, Source mechanisms for morning auroral features, Geophys. Res. Lett., 20, 1535-1538, 1993.
- Cogger, L. L., J. S. Murphree, R. D. Elphinstone, D. J. Hearn and R. A. King, The UV Imager Experiment on the Swedish Viking Satellite : Contributions to Auroral Physics, Can. J. Physics, 69,1032-1039, 1991.
- Cogger, L., R. Gattinger, K. Smith, and R. Buckingham, The AURIO Instrument Ensemble Conceptual Design, Can. Aeronautics and Space J., 39, 3, 135-141, 1993.
- Craven, J. D., J. S. Murphree, L. A. Frank and L. L. Cogger, Simultaneous Optical Observations of Transpolar Arcs in the Two Polar Caps with DE 1 and Viking, Geophys. Res. Lett., 18, 2297-2300, 1991.
- Danilin, M. Yu., and J. C. McConnell, Heterogeneous reactions in a stratospheric box-model: A sensitivity study, J. Geophys. Res., 99, 25681-25696, 1994.
- Danilin, M. Yu., and J. C. McConnell, Stratospheric effects of bromine activation on/in sulfate aerosol, J. Geophys. Res., in press, 1995
- Davis, G.R., I. Furniss, W.A. Towlson, P.A.R. Ade, R.J. Emery, W.M. Glencross, D.A. Naylor, T.J. Patrick, R.C. Sidey and B.M. Swinyard. Design and performance of cryogenic, scanning Fabry-Perot interferometers for the Long Wavelength Spectrometer on the Infrared Space Observatory, Applied Optics, in press, 1995.
- DelPozo, C.F., J.C. Foster and J-P. St.-Maurice, Dual-mode E region plasma wave observations from Millstone Hill. J. Geophys. Res., 98, 6013-6032, 1993.
- Donovan, E. F., and D. R. Moorcroft, The effect of multiple scattering on the aspect sensitivity and polarization of radio auroral echoes, Radio Sci., 27, 169-188, 1992.

- Donovan, E.F., Modelling the magnetic effects of field-aligned currents, *J. Geophys. Res.*, 98, 13529-13543, 1993.
- Donovan, E.F. and G. Rostoker, Internal consistency of the Tsyganenko magnetic field model and the Heppner-Maynard empirical model of the ionospheric electric field distribution, *Geophys. Res. Lett.*, 18, 1043-1046, 1991.
- Donovan, E.F., G. Rostoker and C.Y. Huang, Regions of negative Bz in the Tsyganenko 1989 model neutral sheet, *J. Geophys. Res.*, 97, 8697-8700, 1992.
- Donovan, E.F., G. Rostoker and B. Jackel, The effects of field-aligned currents on mapping from the ionosphere to the magnetotail, in *Proceedings of the International Conference on Substorms (ICS-1)*, ESA Publ. SP-335, 19-23, Paris, France, 1992.
- Donovan, D.P., J.A. Whiteway and A.I. Carswell, Correlation of Nonlinear Photon Counting Effects in Lidar Systems, *Appl. Opt.*, 32, 6742-6753, 1993.
- Eckermann, S.D., Hirota, I. and Hocking, W.K., Gravity wave and equatorial wave morphology of the stratosphere derived from long-term rocket soundings, *Q.J.R. Meteorol. Soc.*, 121, 149-186, 1994.
- Elphinstone, R., K. Jankowska, J. S. Murphree and L. L. Cogger, The Configuration of the Auroral Distribution for IMF \$B_z\$ Northward 1 : IMF \$B_x\$, \$B_y\$ Dependencies as Observed by the Viking Satellite, *J. Geophys. Res.*, 95, 5791-5804, 1990.
- Elphinstone, R. D., D. Hearn, J. S. Murphree and L. L. Cogger, Mapping Using the Tsyganenko Long Magnetospheric Model and its Relationship to Viking Auroral Images, *J. Geophys. Res.*, 96, 1467-1480, 1991.
- Elphinstone, R. D. J. S. Murphree, D. J. Hearn, L. L. Cogger, P. T. Newell and H. Vo, Viking Observations of the UV Dayside Aurora and Their Relationship to DMSP Particle Boundary Definitions, *Ann. Geophys.*, 10, 815-826, 1992.
- Elphinstone, R. D., and D. J. Hearn, The Auroral Distribution and its Relation to Magnetospheric Processes, *Adv. Space Res.*, 13, No. 4, pp. (4)17 - (4)27, 1993.
- Elphinstone, R. D., J. S. Murphree, D. J. Hearn, W. Heikkila, M. G. Henderson, L. L. Cogger and I. Sandahl, The Auroral Distribution and its Mapping According to Substorm Phase, *J. Atmos. Terr. Phys.*, 55, 1741-1762, 1993.
- Elphinstone, R. D., D. J. Hearn, L. L. Cogger, J. S. Murphree, H. Singer, V. Sergeev, K. Mursula, D. Klumpar, G. D. Reeves, M. Johnson, S. Ohtani, I. Sandahl, E. Nielsen, M. Persson, H. Opgenoorth, P. T. Newell and Y. I. Feldstein, Observations in the Vicinity of Substorm Onset : Implications for the Substorm Process,

- J. Geophys. Res., in press, Nov. 1994.
- Elphinstone, R. D., J. S. Murphree, D. J. Hearn, L. L. Cogger, I. Sandahl, P. T. Newell, D. M. Klumpar, S. Ohtani, J. A. Sauvaud, T. A. Potemra, K. Mursula, A. Wright, and M. Shapshak, The Double Oval UV Auroral Distribution: 1. Implications for the Mapping of Auroral Arcs, J. Geophys. Res., in press, 1995.
- Elphinstone, R. D., D. J. Hearn, L. L. Cogger, J. S. Murphree, A. Wright, I. Sandahl, S. Ohtani, P. T. Newell, D. M. Klumpar, M. Shapshak, T. A. Potemra, K. Mursula, and J. A. Sauvaud, The Double Oval UV Auroral Distribution: 2. The Most Poleward Arc System and the Dynamics of the Magnetotail, J. Geophys. Res., in press, 1995.
- Eliasson, L., O. Norberg, R. Lundin, K. Lundin, S. Olsen, H. Borg, M. Andre, H. Koshinen, P. Riihela, M. Boehm, and B. Whalen, The Freja Hot Plasma Experiment-Instrument and first results. Space Science Reviews, 70, 525-540, 1994.
- Feldstein, Y. I., D. J. Hearn, R. D. Elphinstone, J. S. Murphree and L. L. Cogger, The Auroral Oval and the Geomagnetic Field, Geomag. and Aeron. (Russian), 32, N6, p. 162-166, 1992.
- Feldstein, Y. I., R. D. Elphinstone, D. J. Hearn, J. S. Murphree, and L. L. Cogger, Mapping of the Statistical Auroral Distribution into The Magnetosphere, Can. J. Phys., 72, 266-269, 1994.
- Feng, Q., B.J. Fraser, F.W. Menk, C.W.S. Ziesolleck, O. Saka, T. Kitamura, Pc 3-4 geomagnetic pulsations observed at very low latitude conjugate stations, J. Geophys. Res., in press, 1995.
- Forbes, J.M., M.E. Hagan, S. Miyahara, F. Vial, A. Manson, Yu. I. Portnyagin, Quasi 16-d oscillation in the mesosphere and lower thermosphere, J. Geophys. Res., in press, 1995.
- Forbes, J.M., A.H. Manson, R.A. Vincent, G.J. Fraser, F. Vial, R. Wand, S.K. Avery, R.R. Clark, R. Johnson, R. Roper, R. Schmitter, T. Tsuda and E. S. Kazimirovsky, Semidiurnal tide in the 80-150 km region: an assimilative data analysis, J. Atmos. Terr. Phys., 10, 1237-1250, 1994.
- Foster, J. C., D. Tetenbaum, C. F. del Pozo, J.-P. St.-Maurice, and D. R. Moorcroft, Aspect angle variations in intensity, phase velocity and altitude for high-latitude 34 cm E region irregularities, J. Geophys. Res., 97, 8601-8617, 1992.
- Fraser, B.J., J.C. Samson, Y. Hu, R.L. McPherron and C.T. Russell, Electromagnetic ion cyclotron waves observed near the oxygen cyclotron frequency by ISEE -1 and -2, J. Geophys. Res., 97, 3063-3074, 1992.
- Frycz, P., E. Infeld and J.C. Samson, 1992, Spontaneous transition from flat to spherical solitons, Phys. Rev. Lett., 69, 1057-1060, 1992.

- Frycz, P., R. Rankin and J.C. Samson, Stability of electron inertia Alfvén solitons, *J. Plasma Physics*, 48, 335-343, 1992.
- Fukao, S., Yamanaka, M.D., Ao, N., Hocking, W.K., Sato, T., Yamamoto, M., Nakamura, T., Tsuda, T. and Kato, S. (1994) Seasonal variability of vertical eddy diffusivity in the middle atmosphere 1. Three-year observations by the middle and upper atmosphere radar, *J. Geophys. Res.*, 99, 18973-18987, 1994.
- Gao, S. and MacDougall, J. W., A dynamic ionosonde design using pulse coding, *Can. J. Phys.*, 69, pp. 1184-1189, 1991.
- Garbe, G. P., R. L. Arnoldy, T. E. Moore, P. M. Kintner and J. Vago, Observations of ion heating in the topside auroral ionosphere, *J. Geophys. Res.*, 97, 1257, 1992.
- Garbe, G. P., J. S. Murphree, L. L. Cogger and J. Woch, The Cusp/Cleft Region as Observed by the Viking UV Imager, *J. Geophys. Res.*, 98, 6059-6068, 1993.
- Gardner, C.S., T.J. Kane, J.H. Yee, R.J. Niciejewski, J.H. Hecht, R.L. Walterscheid, R.P. Lowe, and D.N. Turnbull, Formation characteristics of sporadic Na layers observed simultaneously by LIDAR and airglow instruments during ALOHA-90, *Geophys. Res. Lett.*, 18, 1369-1372, 1991.
- Gattinger, R.L., A. Vallance Jones, J.H. Hecht, D.J. Strickland, J. Kelly, Comparison of Ground Based Optical Observations of N₂ Second Positive to N₂⁺ First Negative Emission Ratios with Electron Precipitation Energies Inferred from the Sondre Stromfjord Radar, *J. Geophys. Res.* 96, 11341-11351, 1991.
- Gattinger, R.L., R.W. Little, F. Meo, J. Nicholson, Calibration of the VIKING Auroral Imager Using Ultraviolet Stars. *S.P.I.E.* 2050, 132-139, 1993.
- Gattinger, R.L., A. Vallance Jones, K.D. Tyler, Observations of H beta 4861 A Proton Auroral Emissions at Mid-Latitude. *S.P.I.E.* 2050, 140-147, 1993.
- Gault, W.A., D.-L. Desaulniers, R.H. Hum, D.W. Miller, G.G. Shepherd, W. Ward and J. Wimperis, Design and On-Orbit Performance of the WINDII Instrument's Michelson Interferometer on UARS, *Proceedings of the Eighteenth Intern. Sym. on Space Tech. Sci.*, 1889-1894, 1993.
- Gault, W., G. Thuillier, G.G. Shepherd, S.P. Zhang, R.H. Weins, W.E. Ward, C. Tai, B.H. Solheim, Y.J. Rochon, C. McLandress, C. Lathuillere, V. Fauliot, M. Herse, C. Hersom, R. Gattinger, L. Bourg, M.D. Burrage, S.J. Franke, G. Hernandez, A. Manson, R. Niciejewski, R.A. Vincent, Validation of O(1S) Wind Measurements by WINDII: the WIND Imaging Interferometer on UARS. *J. Geophys. Res.* Submitted 1994.

- Gertner, Bluma S. and Gordon G. Shepherd, Ten years of calibration for the ISIS-II Red Line Photometer, *Can. J. Phys.* 69, 938-940, 1991.
- Gioulgkidis, K. and R.P. Lowe, Inclusion of the second Umkehr in the conventional Umkehr retrieval analysis as a means of improving ozone retrievals in the upper stratosphere, *Proceedings of the Quadrennial Ozone Symposium, Williamsburg, Virginia, June 1992.*
- Gioulgkidis, K., R.P. Lowe, and C.T. McElroy, Improved ozone retrievals in the upper stratosphere due to the inclusion of the second Umkehr in the conventional Umkehr retrieval analysis, *Proceedings of the 19th Annual Meeting on Atmospheric Studies by Optical Methods, Kiruna, Sweden, November 1992, p. 391-396, ISSN 0284-1703, 1992.*
- Godard, R., H.G. James, J.G. Laframboise, B. Macintosh, A.G. McNamara, S. Watanabe and B.A. Whalen, OEDIPUS experiment: analysis of the current/voltage data, *J. Geophys. Res.* 96, 17,879 - 17890, 1991.
- Gonzalez, N., A. Hauchecorne, S. Kirkwood, F.-J. Lubken, A.H. Manson, A. Mourier, F.J. Schmidlin, R. Schminder, D. Kurschner, W. Singer and H.-U. Widdel., Intercomparisons of simultaneous remote and in situ wind measurements, *J. Atmos. Terr. Phys.*, 56, 1985-2001, 1994.
- Gonzalez, W.D., J.A. Joselyn, Y. Kamide, H.W. Kroehl, G. Rostoker, B.T. Tsurutani and V.M. Vasyliunas, What is a geomagnetic substorm? *J. Geophys. Res.*, 99, 5771-5792, 1994.
- Grant, I.F., D.R. McDiarmid and A.G. McNamara, A class of high-m pulsations and its auroral radar signature, *J. Geophys. Res.*, 97, 8439-8451, 1992.
- Grant, I. F., J. W. MacDougall, J. M. Ruohoniemi, W. A. Bristow, G. J. Sofko, J. A. Koehler, D. Danskin, D. Andre, Ionosonde drift measurements in the polar cap verified by the SuperDARN radars and patch motion, *Radio Sci.*, in press 1995.
- Griffioen, E., J. C. McConnell, J. S. Murphree, G. G. Shepherd, L. L. Cogger and A. Vallance Jones, Viking UV Cameras : Calibration Using Model Calculations and Long Wavelength Light Leakage, *Can. J. Physics*, 69, 1154-1162, 1991.
- Griffioen, E., J.C. McConnell, and G.G. Shepherd, Rapidly Convergent Lambda Operator Method for Solving Resonance Line scattering in planetary atmospheres, *J. Geophys. Res.* 99 21,383-21,396, 1994.
- Haerendel, G., H.U. Frey, O.H. Bauer, E. Rieger, J. Clemmons, M.H. Boehm, D.D. Wallis, H. Luhr, Inverted-V Events simultaneously observed with the FREJA Satellite and from the Ground, *Geophys. Res. Letters*, 21, 1891-1894, 1994.
- Haldoupis, C., J.A. Koehler, G.J. Sofko, J. Mu, D. Andre, A.V. Kustov, and D.W. Danskin., Auroral radar frequency broadening measurements at large aspect angles and comparison with theory, *J. Geophys. Res.*, 99, 8925-8935, 1994.

- Haldoupis, C., G.J. Sofko, G.C. Hussey, and Jun Mu., An overview of type-3 radar auroral research: basic observational properties and new interpretation propositions, *Ann. Geophysicae.*, in press, 1995.
- Hall, G., D. R. Moorcroft, L. L. Cogger and D. Andre, Spatial Relationship Between Large Aspect Angle VHF Radio Aurora and 557.7 nm Emissions: Evidence for Refraction, *J. Geophys. Res.*, 95, 15,281, 1990.
- Hall, G. E., and D. R. Moorcroft, Magnetic aspect angle effects in radar aurora at 48.5 MHz, corrected for refraction, *J. Geophys. Res.*, 97, 19471-19488, 1992.
- Hall, T.M., J.Y.N. Cho, M.C. Kelley, and W.K. Hocking, A re-evaluation of the Stokes drift in the polar summer mesosphere, *J. Geophys. Res.*, 97:887-897, 1992.
- Hall, G.E., C.E. Meek, and A.H. Manson., Hodograph analysis of mesopause region winds observed by three MF radars in the Canadian Prairies, *J. Geophys. Res.*, in press, 1995.
- Hall, G.E., S.P. Namboothiri, A.H. Manson, and C.E. Meek., Daily tidal, planetary waves, and gravity wave amplitudes over the Canadian Prairies, *J. Atmos. Terr. Phys.*, in press, 1995.
- Hall, G.E., G.J. Sofko, and J.A. Koehler, Variations of spectral width with aspect angle for Type II VHF echoes from the eastward electrojet, *J. Geophys. Res.*, 99, 6345-6350, 1994.
- Hamza, A.M., A nonlinear theory for large aspect angle echoes in the auroral E-region, *J. Geophys. Res.*, 97, 16981-16993, 1992.
- Hamza, A.M., Nonlinear-electron-response impact on the evolution of ion-acoustic wave packets in a magnetized plasma, *Phys. Rev. E*, 48, 2055-2066, 1993.
- Hamza, A.M., A kinetic derivation of a generalized Zakharov-Kuznetsov equation for ion acoustic turbulence in a magnetized plasma, *Phys. Letts. A*, 190, 309-316, 1994.
- Hamza, A.M. and St.-Maurice, J.-P., Large aspect angles in auroral E region echoes: A self-consistent turbulent fluid theory, *J. Geophys. Res.*, 100, 5723-5732, 1995.
- Hamza, A.M. and R. N. Sudan, Subgrid modeling of convective turbulence in weakly ionized collisional plasma by renormalization group analysis, *J. Geophys. Res.*, 100, 3669-3680, 1995.
- Hamza, A.M. and J-P. St-Maurice, A turbulent theoretical framework for the study of current-driven E region irregularities at high latitudes: Basic derivation and application to gradient-free situations, *J. Geophys. Res.*, 98, 11587-11599, 1993.

- Hamza, A.M. and J-P. St-Maurice, A self-consistent fully turbulent theory of auroral E region irregularities, *J. Geophys. Res.*, 98, 11601-11613, 1993.
- Harris, F.R., R.L.Gattinger, I.P.Powell, F.Creutzberg, D.T.Bradley, F.Gauthier, J.W.Pygas, J.G.Rumbold, 'LISA' - A Limb Imaging Spectrograph for Airglow. *Can. Aero. Space J.* 37, 72-77, 1991.
- Harris, F.R., R.L.Gattinger, I.C.McDade, I.P.Powell, E.J.Llewellyn, J.Yuen, P.Moorhouse, S.Chakrabarti, Visible Airglow Limb Imaging Spectrograph for Sounding Rockets. *S.P.I.E.* 1745, 242-250, 1992.
- Harris, F.R., R.L.Gattinger, I.P.Powell, I.C.McDade, E.J. Llewellyn, J.Yuen, P.Moorhouse, S.Chakrabarti, W.E.Sharp, Near-Ultraviolet Limb Imaging Spectrograph for Sounding Rockets. *Optical Engineering* 32, 3075-3082, 1993.
- Harrison, R.A., M.K. Carter, T.A. Clark, C.A. Lindsey, J.T. Jefferies, D.G. Sime, G. Watt, T.L. Roellig, E.E. Becklin, D.A. Naylor, G.J. Tompkins and D.C. Braun, First Millimeter Wavelength Observations of an Active Solar Prominence Observed during the July 11, 1991 Total Solar Eclipse, *Astron. Ap.*, 274, L9, 1993.
- Harrold, B.G. and J.C. Samson, Standing ULF modes in the magnetosphere: A theory, *Geophys. Res. Lett.*, 19, 1811-1814, 1992.
- Hauchecorne, A., N. Gonzalez, C. Souprayen, A.H. Manson, C.E. Meek, W. Singer, A.N. Fakhruddinova, U.-P. Hoppe, J. Boska, J. Lastovicka, J. Scheer, E.R. Reisin, and H. Graef, Gravity wave activity and interaction with the general circulation during DYANA, *J. Atmos. Terr. Phys.*, 56, 1765-1778, 1994.
- Hearn, D. J. and E. S. Krebs, On Computing Ray-Synthetic Seismograms for Anelastic Media Using Complex Rays, *Geophysics*, 55, 422-432, 1990.
- Hearn, D. J., R. D. Elphinstone, J. S. Murphree and L. L. Cogger, Geographic Asymmetries of the Viking Auroral Distribution: Implications for Ionospheric Coordinate Systems, *J. Geophys. Res.*, 98, 1653-1668, 1993.
- Hedin, A.E., M.A. Biondi, R.G. Burnside, G. Hernandez, R.M. Johnson, T.L. Killeen, C. Mazaudier, J.W. Meriwether, J.E. Salah, R.J. Sica, R.W. Smith, N.W. Spencer, V.B. Wickwar, and T.S. Viridi, Revised global model of thermosphere winds using satellite and ground based observations, *J. Geophys. Res.*, 96, 7657-7688, 1991.
- Henderson, G.S., J.C. McConnell, S.R. Beagley, and W.F.J. Evans, Polar Ozone Depletion: an update, *Can. J. Phys.*, 69, 1110-1122, 1991.
- Henderson, M. G. and J. S. Murphree, A Comparison of Viking Onset Locations with the Predictions of the Thermal Catastrophe Model, *J. Geophys. Res.*, in press, Dec. 1994.

- Hocking, W.K., The effects of middle atmosphere turbulence on coupling between atmospheric regions, *J. Geomag. and Geoelect.*, 43, 621-636, 1991.
- Hocking, W.K., On the relationship between the strength of atmospheric radar backscatter and the intensity of atmospheric turbulence , *Adv. Space Res.*, 12, 207-213, 1992.
- Hocking, W.K., S. Fukao, M. Yamamoto, T. Tsuda, and S. Kato, Viscosity waves and thermal-conduction waves as a cause of "specular" reflectors in radar studies of the atmosphere, *Radio Sci.*, 26, 1281-1303, 1991.
- Horita, R.E. and G.M. Chen, Proton cyclotron echoes at the fQ3 resonance, *Radio Science*, in press, 1995.
- Horita, R.E., A. W. Yau, B. A. Whalen, T. Abe, and S. Watanabe, Ion depletion zones in the polar wind: EXOS-D suprathermal mass spectrometer observations in the polar cap. *J. Geophys. Res.* 98, 11439-11448, 1993.
- Huang, C.Y., L.A. Frank, G. Rostoker, J. Fennell and D.G. Mitchell, Nonadiabatic heating of the central plasma sheet at substorm onset, *J. Geophys. Res.*, 97, 1481-1496, 1992.
- Huang, K., D.J. McEwen, and I. Oznovich, Analysis of a polar auroral arc observed from Eureka (89=F8N) and by DMSP satellites on December 4, 1990, *J. Geophys. Res.*, 99, 21,353-21,360, 1994.
- Ierkic, H.M., C. Haldoupis, D. R. Moorcroft, and E. Nielsen , Coherent radar interferometry of vertical irregularity structures in the auroral E region, *Radio Sci.*, 27, 743-758, 1992.
- James, H.G., Guided Z mode propagation observed in the OEDIPUS-A tethered rocket experiment, *J. Geophys. Res.* 96 (A10), 17,865 - 17,878, 1991.
- James, H.G., Tether phenomena observed in the OEDIPUS-A experiment, in *The Behavior of Systems in the Space Environment*, ed. R.N. DeWitt et al., NATO ASI Series E, Vol. 245, Kluwer Academic, Dordrecht, Netherlands, 581 - 603, 1993.
- James, H.G., Ionospheric wave emissions passively detected by the OEDIPUS A tether, *J. Geophys. Res.* 98 (A11), 19,099 - 19,110, 1993.
- James, H.G., Wave results from OEDIPUS A, *Adv. Space Res.* 13, 10(5)-10(13), 1993.
- James, H.G., Three-dimensional ray paths in cylindrical ducts: upper branch O and X modes, *Radio Science* 29, 1201-1214, 1994.
- James, H.G., High-frequency ducting in the high-latitude bottomside F region, *Radio Science* 30, 445-461, 1995.

- James, H.G. and B.A. Whalen, OEDIPUS-A: space research with a new tether, *Eos, Trans. Am. Geophys. Union* 72, 137-144, 1991.
- James, H.G., K.G. Balmain, C.C. Bantin and G.W. Hulbert, Sheath waves observed on OEDIPUS A, *Radio Science* 30, 57 - 73, 1995.
- Jankowska, K., R. D. Elphinstone, J. S. Murphree, L. L. Cogger, D. Hearn and G. Marklund, The Configuration of the Auroral Distribution for Interplanetary Magnetic Field B_z Northward 2 : Ionospheric Convection Consistent with Viking Observations, *J. Geophys. Res.*, 95, 5805-5816, 1990.
- Jones, J. and Brown, P. (1994) The radiant distribution of sporadic meteors, *Planet. Space Sci.*, 42, 123-126, 1994.
- Jones, J., Brown, P., Webster, A.R. and Ellis, K., A forward-scatter determination of the radiant distribution of sporadic meteors. *Planet. Space Sci.*, 42, 127-134, 1994
- Jones, J. and A.R. Webster, Visual and radar studies of meteor head echoes, *Planet. Space Sci.*, 39, 873, 1991.
- Jones, J. and W. Jones, Oblique-scatter of radio waves from meteor trains: full-wave calculations, *Planet. Space. Sci.*, 39, 1289-1296, 1991.
- Kaminski, J.W. and J.C. McConnell, A note on the enhancement of J values in optically thick scattering atmospheres, *Can. J. Phys.*, 69, 1166-1174, 1991.
- Kendall, D.J.W., E.J.Llewellyn, M.R.Gale, S.B.Mende, G.R.Swenso, R.L.Gattinger, High Resolution Spectroscopic Measurements from the Space Shuttle: Orbiter Glow and Atmospheric Emissions, *Can. J. Phys.* 69, 1209-1215, 1991.
- Kidd, S.R. and G. Rostoker, Distribution of auroral surges in the evening sector, *J. Geophys. Res.*, 96, 5697-5706, 1991.
- Kintner, P.M., W. Scales, J. Vago, A. W. Yau, B. A. Whalen, R. Arnoldy, and T. Moore, Harmonic H^+ gyrofrequency structures in auroral hiss observed by high-altitude auroral sounding rockets. *J. Geophys. Res.* 96, 9627-9638, 1991.
- Kissack, R.S., St.-Maurice, J.-P. and Moorcroft, D.R., Electron thermal effects on the Farley-Buneman fluid dispersion relation, *Phys. Plasmas*, 2, 1032-1055, 1995.
- Kivelson, M.G., C.F. Kennel, R.L. McPherron, C.T. Russell, D.J. Southwood, R.J. Walker, K.K. Khurana, P.J. Coleman, C.M. Hammond, V. Angelopoulos, A.J. Lazarus, R.P. Lepping, and T.J. Hughes, The Galileo Earth Encounter: Magnetometer and Allied Measurements, *J. Geophys. Res.*, 98, 11299-11318, 1993.

- Knudsen, D.J., B. A. Whalen, T. Abe, and A. W. Yau, Temporal evolution and spatial dispersion of ion conics: evidence for a polar cusp heating wall. *Resolution of Processes in Space and Time, Geophys. Monog. Ser. 84*, 163-169, 1994.
- Knudsen, D.J., B. A. Whalen, A. W. Yau, M. J. Greffen, A. I. Eriksson, N. Lloyd, M. Boehm, J. Clemmons, and L. G. Blomberg, Sub-kilometer thermal plasma structure near 1750 km altitude in the polar cusp/cleft. *Geophys. Res. Lett.* 21, 1907-1910, 1994.
- Koehler, J.A., G.J. Sofko, and J. Mu, Type-III echoes of radar aurora: observational aspects, *Ann. Geophysicae*, in press, 1995.
- Koehler, J.A., G.J. Sofko, D. Andre, M. Maguire, R. Osterried, M. McKibben, J. Mu, D. Danskin, and A. Ortlepp, The SAPHIRE auroral radar system, *Can. J. Phys.*, in press, 1995.
- Kofman, W., J-P. St-Maurice, and A.P. van Eyken, Heat flow effect on the plasma line frequency, *J. Geophys. Res.*, 98(A4):6079-6085, 1993.
- Kotikov, A. L., A. V. Frank-Kamenetsky, Yu. O. Latov, O. A. Troshichev, E. M. Shishkina, J. S. Murphree and R. D. Elphinstone, Filamentary Structure of the Westward Electrojet in the Midnight Sector Auroral Distribution During Substorms: Comparison with Viking Auroral Observations, *J. Atmos. Terr. Phys.*, 55, 1763-1774, 1993.
- Kustov, A.V., J.A. Koehler, G.J. Sofko, D.W. Danskin, and M.J. McKibben, Observations of 50-MHz type II coherent echoes from within the polar cap, *Ann. Geophysicae*, 12, 765-774, 1994.
- Kustov, A.V., J.A. Koehler, G.J. Sofko, D.W. Danskin, M.J. McKibben, Ya. I. Feldstein, L.I. Gromova, and A.E. Levitin, Electrodynamics of the upper atmosphere and the radar aurora in the northern polar cap, *Geomagnetism and Aeronomy (in Russian)*, 34, 38-48, 1994.
- Kustov A.V. and M.V. Uspensky., Altitude integration effects in the skewness of type 2 coherent echoes, *Ann. Geophysicae*, in press, 1995.
- Kustov, A.V., M.V. Uspensky, G.J. Sofko, J.A. Koehler, and J. Mu, Aspect angle dependence of the radar aurora Doppler velocity, *J. Geophys. Res.*, 99, 2131-2144, 1994.
- Laframboise, J.G. and L.J. Sonmor, Physics of current collection by electrodes in space magnetoplasmas: A review, In: *Physics of Charged Bodies in Space Plasmas*, edited by M. Dobrowolny and E. Sindoni, *Societa Italiana di Fisica, Bologna, Italy*, 77-92, 1992.
- Laframboise, J.G., Planetary Citizen, A reminiscence of the Space Age, *Journal of the Royal Astronomical Society of Canada*, 87, 389-391, 1993.
- Lamframboise, J.G., L.J. Sonmor, Current Collection by Probes and

- Electrodes in Space Magnetoplasmas: A Review, *J. Geophys. Res.* 98 No. A1, 337-357, 1993.
- Lam, H.-L. and J.C. Samson, An investigation of the time delay between solar events and geomagnetic disturbances using a new method of superposed epoch analysis, *J. Geomag. Geoelect.*, 46, 107-113, 1994.
- Lesicar D. and W.K. Hocking, Studies of seasonal behaviour of the shape of mesospheric scatterers using a 1.98 MHz radar, *J. Atmos. Terr. Phys.*, 54, 295-309, 1992.
- Lindsey, C.A., J.T. Jefferies, T.A. Clark, R.A. Harrison, M.K. Carter, G. Watt, E.E. Becklin, T.L. Roellig, D.C. Braun, D.A. Naylor and G.J. Tompkins, Extreme-infrared Brightness Profile of the Solar Chromosphere obtained during the Total Eclipse of 1991, *Nature*, 358, 308, 1992.
- Liu, W.W., Chaos driven by kinetic Alfvén waves, *Geophys. Res. Lett.*, 18, 1611-1614, 1991.
- Liu, W.W., Rotating magnetic anomalies as a possible accelerator of charged particles, *J. Geophys. Res.*, 97, 8145-8155, 1992.
- Liu, W.W., Ambipolar limit of electron precipitation, *Geophys. Res. Lett.*, 20, 343-346, 1993.
- Liu, W.W., Field-aligned flow in a centrifugally confined magnetodisc, *J. Geophys. Res.*, 98, 15365-15371, 1993.
- Liu, W.W., An explicit bounce average calculation of adiabatic particle drifts, *J. Geophys. Res.*, 99, 2383-2386, 1994.
- Liu, W.W. and G. Rostoker, Effects of dawn-dusk pressure asymmetry on convection in the central plasma sheet, *J. Geophys. Res.*, 96, 11501-11512, 1991.
- Liu, W.W. and G. Rostoker, Origin of auroral fingers, *J. Geophys. Res.*, 98, 17401-17407, 1993.
- Liu, W.W., B.-L. Xu, J.C. Samson and G. Rostoker, Theory and observation of auroral substorms: A magnetohydrodynamic mode, *J. Geophys. Res.*, 100, 79-95, 1994.
- Llewellyn, E.J., McDade, I.C., Moorhouse, P. and Lockerbie, M.D., Possible Reference Models for Atomic Oxygen in the Terrestrial Atmosphere, *Adv. Space Res.*, 13, 135-144, 1993.
- Llewellyn, E.J., Brooks, W.S.C., McDade, I.C. and Johnson, D.W., Tomography from a Canadian Small Satellite in Low Earth Orbit, *Aeronaut. Space J.*, in press, 1995
- Llewellyn, E.J., I.C. McDade, P. Moorhouse, and M.D. Lockerbie, Possible reference models for atomic oxygen in the terrestrial atmosphere., *Adv. Space Res.*, in press, 1995.

- Loranc, M., R.A. Heelis, W.B. Hanson and J.-P. St.-Maurice, A morphological study of vertical ionospheric flows in the high-latitude F region, *J. Geophys. Res.* 93, 3627-3646, 1991.
- Loranc, M. and St.-Maurice, J.-P., A time-dependent gyro-kinetic model of thermal ion upflows in the high-latitude F region, *J. Geophys. Res.*, 99, 17429-17451, 1994.
- Lowe, R.P., K.L. Gilbert, and D.N. Turnbull (1991) High latitude summer observations of the hydroxyl airglow, *Planet. Space Sci.*, 39, 1263-1270, 1991.
- Lowe, R.P., D.N. Turnbull, K.L. Gilbert, and L. LeBlanc, Validation of WINDII hydroxyl rotational temperature measurements. Proceedings of the 19th Annual European Meeting on Atmospheric Studies by Optical Methods, Kiruna, Sweden, November 1992, p. 94-98, ISSN 0284-1703.
- Lu, G., A.D. Richmond, B.A. Emory, P.H. Reiff, O. de la Beaujardiere, F.J. Rich, W.F. Denig, H.W. Kroehl, L.R. Lyons, J.M. Ruohoniemi, E. Friis-Christensen, H. Opgenoorth, M.A.L. Persson, R.P. Lepping, A.S. Rodger, T. Hughes, A. McEwin, S. Dennis, R. Morris, G. Burns, and L. Tomlinson, Interhemispheric asymmetry of the high-latitude ionospheric convection pattern, *J. Geophys. Res.*, 99, 6491-6510, 1994.
- Luhr, H., J. Warnecke, L.J. Zanetti, P.A. Lindqvist, T.J. Hughes, Fine structure of field-aligned current sheets deduced from spacecraft and ground-based observations: initial FREJA results, *Geophys. Res. Letters*, 21, 1883-1886, 1994.
- Lundin, R., L. Eliasson, O. Norberg, G. Marklund, L. R. Zanetti, B. A. Whalen, B. Holback, J. S. Murphree, G. Haerendel, M. Boehm, and G. Paschmann, First High-Resolution Measurements by the Freja Satellite. *Solar System Plasmas in Space and Time*, *Geophys. Monog. Ser.* 84, 247- 274, 1994.
- Lui, A. T. Y., R. D. Elphinstone, J. S. Murphree, M. G. Henderson, H. B. Vo, L. L. Cogger, S. Ohtani, P. T. Newell and G. D. Reeves, An Auroral Substorm on July 24, 1986, *J. Geophys. Res.*, in press, 1995.
- Lui, C.W., M.W.P. Cann and R.W. Nicholls, Inclusion of clouds and rain in atmospheric slant path calculations, *Journal of Quantitative Spectroscopy and Radiative Transfer*, 46, 99-107, 1991.
- Lyons, L. R., O. de la Beaujardiere, G. Rostoker, J. S. Murphree, and E. Friis-Christensen, Analysis of Substorm Expansion and Surge Development, *J. Geophys. Res.*, 95, 10575-10589, 1990.
- Lyons, L.R. and J.C. Samson, Formation of the stable auroral arc that breaks-up at substorm onset, *Geophys. Res. Lett.*, 19, 2171-2174, 1992.
- Lysenko, I.A., Yu. I. Portnyagin, A.N. Fakhruddinova, R.A. Ishmuratov, A.H. Manson, and C.E. Meek., Wind regime at 80-110 km at

- midlatitudes of the northern hemisphere, *J. Atmos. Terr. Phys.*, 56, 31-42, 1994.
- MacDougall, J. W., I. F. Grant, and X. Shen, The Canadian Advanced Digital Ionosonde: Design and Results, UAG, 104, 1995.
- MacDougall, J.W., Length measurements of mid-latitude scintillation irregularities, *Radio Sci.*, 27, pp. 275-281, 1992.
- McConnell, J.C., W.F.J. Evans, and E.M.J. Templeton, Model Simulation of Chemical Depletion of Arctic Ozone during the Winter of 1989, *J. Geophys. Res.*, 96,10930-10933, 1991.
- McCrea, I.W., M. Lester, T.R. Robinson, J-P. St.-Maurice, N.M. Wade and T.B. Jones, Derivation of the ion temperature partition coefficients from the study of ion frictional heating events, *J. Geophys. Res.*, 98, 15701-15715, 1993.
- McDade, I.C. , Sharp, W.E., Richards, P.G. and Torr, D.G., On the Inversion of O+(2D-2P)Twilight Airglow Observations: A Method for Recovering Both the Ionization Frequency and the Thermospheric Oxygen Atom Densities, *J. Geophys. Res.*, 96, 259, 1991.
- McDade, I.C., Lloyd, N.D. and Llewellyn, E.J., A Rocket Tomography Measurement of the N₂⁺ 3914Å Emission in an Auroral Arc, *Planet. Space Sci.*, 39, 895, 1991.
- McDade, I.C., The Altitude Dependence of the OH(X²P) Vibrational Distribution in the Nightglow: Some Model Expectations, *Planet. Space Sci.*, 39, 1049, 1991.
- McDade, I.C. and Llewellyn, E.J., Comment on Middle Atmosphere Heating by Exothermic Chemical Reactions Involving Odd-Hydrogen Species, *Geophys. Res. Lett.*, 18, 1791, 1991.
- McDade, I.C. and Llewellyn, E.J., Inversion Techniques for Recovering Two-Dimensional Distributions of Auroral Emission Rates from Tomographic Rocket Photometer Measurements, *Can. J. Phys.*, 69, 1059, 1991.
- McDade, I.C. and Llewellyn, E.J., Satellite Airglow Limb Tomography: Methods for Recovering Structured Emission Rates in the Mesospheric Airglow Layer, *Can. J. Phys.*, 71, 552, 1993.
- McDade, I.C. and Llewellyn, E.J., An Assessment of the H+O₃ Heating Efficiencies in the Nighttime Mesopause Region, *Ann. Geophysicae.*, 11, 47, 1993.
- McDiarmid, D.R., T.K. Yeoman, I.F. Grant and W.Allan, Simultaneous observation of a traveling vortex structure in the morning sector and a field line resonance in postnoon sector, *J. Geophys. Res.*, 99, 8891-8904, 1994.
- McPherron, R.L. and G. Rostoker, Comment on "Prediction of Geomagnetic

- Activity," by C.K. Goertz, L.-H. Shan and R.A. Smith, *J. Geophys. Res.*, 98, 7685-7686, 1993.
- McLandress, C., Y. Rochon, G.G. Shepherd, B.H. Solheim, G. Thuillier, and F. Vial, The Meridional Wind Component of the Thermospheric Tide Observed by WINDII on UARS, *J. Geophys. Res.*, 21 2417-2420, 1994.
- McElroy, C.T., J.B. Kerr, D.I. Wardle, G.M. Shah, M. Garneau, S. G. Maclean R. Thirsk, J. A. Davis, W.F. Evans, R.W. Nicholls, J.C. McConnell and M.W.P. Cann, SPEAM 1: (Sunphotometer Earth Atmospheric Measurement) Observation of High Altitude Ozone from STS 41G, *Can. J. Phys* 69, 1123-1127, 1991.
- Majeed, T., and J.C. McConnell, The upper ionospheres of Jupiter and Saturn, *Planet Space Sci.*, 39, 1715-1732, 1991.
- Majeed, T., J.C. McConnell, and R.V. Yelle, Vibrationally excited H in the Outer Planets: Role of the Fluorescence Source, *Planet. Space Sci.*, 39, 1591-1606, 1991.
- Manuel, J. and J.C. Samson, The spatial development of the low latitude boundary layer, *J. Geophys. Res.*, 98, 17367-17385, 1993.
- Manson, A.H., R.R. Clark, C.G. Fesen, J.M. Forbes, R.M. Johnson, S. Miyahara, J.E. Salah, and W. Singer, The mesosphere lower thermosphere coupling study: campaigns and study groups, *COSPAR Colloquia Series*, 5, Solar-Terrestrial Energy Program, pp. 339-348, 1994.
- Marklund, G. T., L. G. Blomberg, J. S. Murphree, R. D. Elphinstone, L. J. Zanetti, R. E. Erlandson, I. Sandahl, O. de la Beaujardiere, H. Opgenoorth and F. J. Rich, On the Electrodynamical State of the Auroral Ionosphere During Northward IMF : A Transpolar Arc Case Study, *J. Geophys. Res.*, 96, 9567-9578, 1991.
- Miyake, W., B. A. Whalen, A. W. Yau, A. Matsuoka, H. Hayakawa, T. Mukai, Soft ion precipitation at very high latitudes during northward interplanetary magnetic field. *J. Geophys. Res.* 99, 15025-15033, 1994.
- Miyake, W., B. A. Whalen, A. W. Yau, A. Matsuoka, H. Hayakawa, T. Mukai, EXOS-D observation of soft ion precipitation events at very high latitudes. *Adv. in Space Res.* 15, 305- 308, 1994.
- Mounaix, Ph., D. Pesme, W. Rozmus and M. Casanova, Space and time behavior of parametric instabilities for a finite pump wave duration in a bounded plasma, *Phys. Fluids B*, 5, 3304-3318, 1993.
- Murphy, D., W.K. Hocking, and D.C. Fritts, An assessment of the effect of gravity waves on the width of radar Doppler spectra, *J. Atmos. Terr. Phys.*, 56, 17-29, 1994.
- Murphree, J. S., R. D. Elphinstone, D. Hearn and L. L. Cogger, Large

- Scale High Latitude Dayside Auroral Emissions, *J. Geophys. Res.*, 95, 2345-2354, 1990.
- Murphree, J. S., L. L. Cogger, R. D. Elphinstone and D. Hearn, The Response of the Quiet Time Auroral Configuration to Short and Long Term IMF Variations, *Can. J. Phys.*, 69, 1040-1046, 1991.
- Murphree, J. S., R. D. Elphinstone, M. G. Henderson, L. L. Cogger and D. J. Hearn, Interpretation of Optical Substorm Onset Observations, *J. Atmos. Terr. Phys.*, 55, 1159-1170, 1993.
- Murphree, J. S., R. A. King, T. Payne, K. Smith, D. Reid, J. Adema, B. Gordon, and R. Wlochowicz, The Freja Ultraviolet Imager, *Space Science Reviews*, 70, 421-446, 1994.
- Murphree, J. S., M. L. Johnson, L. L. Cogger and D. J. Hearn, Freja UV Imager Observations of Spatially Periodic Auroral Distortions, *Geophys. Res. Lett.*, 21, 1887-1890, 1994.
- Murphree, J. S., J. B. Austin, D. J. Hearn, L. L. Cogger, R. D. Elphinstone and J. Woch, Satellite Observations of Polar Arcs, *J. Atmos. Terr. Phys.*, 56, 265-284, 1994.
- Namboothiri, S.P., C.E. Meek, and A.H. Manson, Variations of mean winds and solar tides in the mesosphere and lower thermosphere over time scales ranging from 6 months to 11 years: Saskatoon, 52N, 107W, *J. Atmos. Terr. Phys.*, 56, 1313-1325, 1994.
- Namboothiri, S.P., A.H. Manson, and C.E. Meek, Extension of MF radar tidal measurements to E-region heights (95-125 km): Saskatoon (52N, 107W), Canada, *Ann. Geophysicae*, 12, 333-341, 1994.
- Naylor, D.A., G.R. Davis, M.J. Griffin, T.A. Clark, D. Gautier, and A. Marten, Broadband spectroscopic detection of the CO J=3D3-2 tropospheric absorption in the atmosphere of Neptune, *Astron. Astrophys.*, 291, L51-L53, 1994.
- Manson, A.H., R.R. Clark, C.G. Fesen, J.M. Forbes, R.M. Johnson, S. Miyahara, J.E. Salah, and W. Singer, The mesosphere lower thermosphere coupling study: campaigns and study groups, *COSPAR Colloquia Series*, 5, Solar-Terrestrial Energy Program, pp. 339-348, 1994.
- Namboothiri, S.P., C.E. Meek, and A.H. Manson, Variations of mean winds and solar tides in the mesosphere and lower thermosphere over time scales ranging from 6 months to 11 years: Saskatoon, 52N, 107W, *J. Atmos. Terr. Phys.*, 56, 1313-1325, 1994.
- Namboothiri, S.P., A.H. Manson, and C.E. Meek, Extension of MF radar tidal measurements to E-region heights (95-125 km): Saskatoon (52N, 107W), Canada, *Ann. Geophysicae*, 12, 333-341, 1994.
- Naylor, D.A., A Versatile Optical Alignment Tool, OSA Engineering and Laboratory Notes S11, May 1994.

- Naylor, D.A., T.A. Clark & G.R. Davis, Polarizing Fourier Transform Spectroscopy: A Forgotten Frontier?, 9th International Conference on FTS, (Eds Bertie, J. E. & Wieser, H.), S.P.I.E., Proc., 2089, 288, 1993.
- Naylor, D.A., T.A. Clark, G.R. Davis, W.D. Duncan and G.J. Tompkins, Broad-band Spectroscopy on the JCMT using a Polarizing Fourier Transform Spectrometer, Monthly Notices of the Royal Astronomical Society, 260, 875, 1993.
- Naylor, D.A., G.J. Tompkins, T.A. Clark and G.R. Davis, A Polarizing Fourier Transform Spectrometer for Astronomical Spectroscopy}, ASP Conference Series (Astronomical Infrared Spectroscopy}, 41, 405, 1993.
- Naylor, D.A., G.J. Tompkins, T.A. Clark and G.R. Davis, Solar Sub-millimeter and Millimeter Spectroscopy between 7 and 30 cm⁻¹ from the JCMT, in IAU Symposium 154 Proceedings, (Infrared Solar Physics), 371, 1993.
- Naylor, D.A., G.R. Davis, M.J. Griffin, T.A. Clark, D. Gautier, and A. Marten, Broadband spectroscopic detection of the CO J=3D3-2 tropospheric absorption in the atmosphere of Neptune, Astron. Astrophys., 291, L51-L53, 1994.
- Naylor, D.A., Tompkins, G. J., Clark, T. A. & Davis, G. R., A Polarizing Fourier Transform Spectrometer at Sub-mm and Mid IR Wavelengths, SPIE Symposium Proceedings "Astronomical Telescopes and Instrumentation for the 21st Century", S.P.I.E., Proc., 2198, 703, 1994.
- Nicholls, R.W., Space Research, Can J. Phys. 69, 921-1215, 1991.
- Nielsen, E., R. Elphinstone, D. Hearn, J. S. Murphree and T. Potemra, Oval Intensification Event Observed by Stare and Viking, J. Geophys. Res., 98, 6163-6171, 1993.
- Ohtani, S., T. A. Potemra, P. T. Newell, L. J. Zanetti, T. Iijima, M. Watanabe, L. G. Blomberg, R. D. Elphinstone, J. S. Murphree, M. Yamauchi and J. G. Woch, Four Large-Scale Field-Aligned Current Systems in the Dayside High-Latitude Region, J. Geophys. Res., 100, 137-153, 1995.
- Osterried, R., A.V. Kustov, G.J. Sofko, J.A. Koehler, and D. Andre, The spectral asymmetry of Type II coherent echoes at large aspect angles, J. Geophys. Res., in press, 1995.
- Oznovich, I. and D.J. McEwen, Auroral emissions at the North Magnetic Pole - a February 17, 1993 case study, J. Geomagnetism and Geoelectricity, 46, 861-871, 1994.
- Oznovich, I., R. Yee, A. Schiffler, D.J. McEwen, and G.J. Sofko, The all-sky camera revitalized, Applied Optics, 33, 7141-7150, 1994.

- Pal, S.R., W. Steinbrecht and A.I. Carswell, Automated Method for Lidar Determination of Cloud Base Height and Vertical Extent, *Applied Optics*, 31, 1488-1494, 1992.
- Pao, Q., L.L. Cogger, D.D. Wallis, A.G. McNamara, Spatial relationship of visual arcs to auroral electrojets, *Can. J. Phys.*, 69, 1047-1954, 1991.
- Pao, Q., L. L. Cogger, D. D. Wallis and A. G. McNamara, Spatial Relationship of Visual Arcs to Auroral Electrojets, *Can. J. Phys.*, 69, 1047, 1991.
- Parks, G., T. Freeman, M. McCarthy, S. Werden, J. Ducareron, J. Treilhou, R. D. Elphinstone, and J. Murphree, X-ray imaging of Electron Precipitation Sources during the Various Phases of a Substorm, submitted to *J. Geophys. Res.*, June 1994.
- Pedersen, B. M., R. Pottelette, L. Eliasson, J. S. Murphree, R. D. Elphinstone, A. Bahnsen and M. Jespersen, Auroral Kilometric Radiation From Transpolar Arcs, *J. Geophys. Res.*, 97, 10,567-10,573, 1992.
- Pellinen, R., H. E. J. Koskinen, T. Pulkkinen, J. S. Murphree, G. Rostoker H. J. Opgenoorth, Satellite and Ground-Based Observations of a Fading Transpolar Arc, *J. Geophys. Res.*, 95, 5817-5824, 1990.
- Pellinen-Wannberg, A., I. Sandahl, G. Wannberg, H. Opgenoorth, F. Soraas and J. S. Murphree, EISCAT Observations on Plasma Drifts Connected with the Aureld-VIP Rocket and the Viking Satellite, *J. Geophys. Res.*, 95, 6073-6080, 1990.
- Peterson, W.K., A. W. Yau, and B. A. Whalen, Simultaneous observations of H⁺ and O⁺ ions at two altitudes by the Akebono and Dynamics Explorer-1 satellites. *J. Geophys. Res.* 98, 11177- 11190, 1993.
- Peterson, W.K., T. Abe, M. Andre, M. J. Engebretson, H. Fukunishi, H. Hayakawa, A. Matsuoka, T. Mukai, A. M. Persoon, J. M. Retterer, R. M. Robinson, M. Sugiura, K. Tsuruda, D. D. Wallis, and A. W. Yau, Observations of a transverse magnetic field perturbation at two altitudes on the equatorward edge of the magnetospheric cusp. *J. Geophys. Res.* 98, 21463-21470, 1993.
- Peterson, W.K., T. Abe, H. Fukunishi, M. J. Greffen, H. Hayakawa, Y. Kasahara, I. Kimura, A. Matsuoka, T. Mukai, T. Nagatsuma, K. Tsuruda, B. A. Whalen, and A. W. Yau, On the sources of energization of molecular ions at ionospheric altitudes. *J. Geophys. Res.* 99, 23257-23274, 1994.
- Pfaff, R.F. J. Sahr, J. F. Providakes, W. E. Swartz, D. T. Farley, P. M. Kintner, I. Hegström, A. Hedberg, H. Opgenoorth, G. Holmgren, A. G. McNamara, D. D. Wallis, B. A. Whalen, A. W. Yau, S. Watanabe, F. Creutzberg, P. Williams, E. Nielsen, K. Schlegel, and T.R. Robinson, The E-Region Rocket/Radar Instability Study

- (ERRRIS): Scientific Objectives and Campaign Overview. *J. Atmospheric Terr. Phys.* 54, 779-808, 1992.
- Phillips, A., A.H. Manson, C.E. Meek, and E.J. Llewellyn, A long-term comparison of middle atmosphere winds measured at Saskatoon (52N, 107 W) by a medium-frequency radar and a Fabry-Perot interferometer, *J. Geophys. Res.*, 99, 12,923-12,935, 1994.
- Platt, C.M., S.A. Young, A.I. Carswell, S.R. Pal et al., The Experimental Cloud Lidar Pilot Study (ECLIPS) for Cloud-Radiation Research, *Bull. Amer. Meteor. Soc.* 75, 1635-1654, 1994.
- Portnyagin, Yu. I., N.A. Makarov, R.P. Chebotarev, A.M. Nikonov, E.S. Kazimirovsky, V.D. Kokourov, V.V. Sidorov, A.N. Fakhruddinova, G. Cevolani, R.R. Clark, D. Kurschner, R. Schminder, A.H. Manson, C.E. Meek, H.G. Muller, J.C. Stoddart, W. Singer, and P. Hoffman, The wind regime of the meso sphere and lower thermosphere during the DYANA campaign - II. Semi-diurnal tide, *J. Atmos. Terr. Phys.*, 56, 1731-1752, 1994.
- Potemra, T. A., H. Vo, D. Venkatesan, L. L. Cogger, R. E. Erlandson, L. J. Zanetti, P. F. Bythrow and B. J. Anderson, Periodic Auroral Forms and Geomagnetic Field Oscillations in the 1400 MLT Region, *J. Geophys. Res.*, 95, 5835, 1990.
- Potemra, T. A., L. J. Zanetti, R. Elphinstone, J. S. Murphree and D. M. Klumpar, The Pulsating Magnetosphere and Flux Transfer Events, *Geophys. Res. Lett.*, 19, 1615-1618, 1992.
- Prikryl, P. and L. L. Cogger, Statistical analysis of the spatial relationship between the radio and optical aurora: Further evidence for refraction, *Radio Sci.*, 27, 469, 1992.
- Prikryl, P., D. Andre, G.J. Sofko, J.A. Koehler, M.J. McKibben, D.D. Wallis, T.J. Hughes, A. McNamara, D.R. McDiarmid, B.A. McIntosh and J. Watermann, Observations of type 4 radar Doppler spectra during a Ps6 event, *Planet. Space Sci.*, 39, 785-799, 1991.
- Prikryl, P., D. Andre', J. A. Koehler, G. J. Sofko, J.-P. St.-Maurice, D. D. Wallis and F. Creutzberg, Type 4 VHF radio aurora observations during low to moderate geomagnetic activity, *Planet. Space. Sci.*, 40, 1371-1389, 1992.
- Prikryl, P., G. J. Sofko, J. A. Koehler, J. Mu, D. Andre', Steep electron density gradients associated with discrete aurorae explaining the diversity of auroral VHF Doppler spectra, *Ann. Geophysicae*, 13, 25, 1995.
- Pulkkinen, T. I., D. N. Baker, R. J. Pellinen, J. S. Murphree, and L. A. Frank, Mapping of the Auroral Oval and Individual Arcs During Substorms, *J. Geophys. Res.*, in press, 1995.
- Pulkkinen, T. I., D. N. Baker, D. H. Fairfield, R. J. Pellinen, J. S. Murphree, R. D. Elphinstone, R. L. McPherron, J. F. Fennell, R. E.

- Lopez and T. Nagai, Modeling the Growth Phase of a Substorm Using the Tsyganenko Model and Multi-Spacecraft Observations : CDAW-9, *Geophys. Res. Lett.*, 18, 1963-1966, 1991.
- Rankin, R., B.G. Harrold, J.C. Samson and P. Frycz, The nonlinear evolution of field line resonances in the Earth's magnetosphere, *J. Geophys. Res.*, 98, 5839-5844, 1993.
- Rankin, R., J.C. Samson and P. Frycz, Simulations of driven field line resonances in the Earth's magnetosphere, *J. Geophys. Res.*, 98, 21341-21352, 1993.
- Rankin, R., J.P. DeVilliers and J.C. Samson, Parallel magnetohydrodynamics on Myrias MIMD computers, in *Parallel Computational Fluid Dynamics: New Trends and Advances*, edited by A. Ecer et al., pp. 117-124, Elsevier Science B.V., 1995.
- Rankin, R., P. Frycz, V. Tikhonchuk and J.C. Samson, Nonlinear standing shear Alfvén waves in the Earth's magnetosphere, *J. Geophys. Res.*, in press, 1995.
- Rietveld, M.T., P.N. Collis, and J.-P. St.-Maurice, Naturally enhanced ion-acoustic waves in the auroral ionosphere observed with the EISCAT (933 MHz) radar, *J. Geophys. Res.*, 96, 19291-19305, 1991.
- Rostoker, G., Overview of observations and models of auroral substorms, in *Auroral Physics*, ed. by C.-I. Meng, M.J. Rycroft and L.A. Frank, 257-271, Cambridge Univ. Press, 1991.
- Rostoker, G., A quantitative relationship between AE and Kp, *J. Geophys. Res.*, 96, 5853-5857, 1991.
- Rostoker, G., Auroral signatures of magnetospheric substorms and constraints which they provide for substorm theories, *J. Geomag. and Geoelectr.*, 43, 233-243, 1991.
- Rostoker, G., Some observational constraints for substorm models, in *Magnetospheric Substorms*, edited by J.R. Kan, T.A. Potemra, S. Kokobun and T. Iijima, *Geophysical Monograph* 64, pp. 61-72, American Geophysical Union, Washington, D.C., 1991.
- Rostoker, G., Mapping of regions of auroral activation in the ionosphere to the magnetotail, in *Proceedings of the International Conference on Substorms (ICS-1)*, ESA Publ. SP-335, 71-74, Paris, France, 1992.
- Rostoker, G., Low latitude signatures of substorm activity, *J. Atmos. Terr. Phys.*, 55, 985-994, 1993.
- Rostoker, G., Magnetospheric substorms-their phenomenology and predictability, in *Solar-Terrestrial predictions-IV*, ed. by J. Hruska, M.A. Shea, D.F. Smart and G. Heckman, pp. 21-35, NOAA/ERL, Boulder, CO, 1993.
- Rostoker, G., A question of substorm size - how large must a magnetic

- disturbance be before it can be called a substorm?, *J. Geomag. Geoelectr.*, 45, 439-442, 1993.
- Rostoker, G., STEP: past, present and future, in *Proceedings of the STEP Symposium*, edited by M. Teague, pp. 5-14, Pergammon Press, NY, 1993.
- Rostoker, G., A renovated boundary layer dynamics model for magnetospheric substorms, in *Proceedings of the Second International Conference on Substorms*, edited by J.R. Kan, J.D. Craven and S.-I. Akasofu, pp. 189-194, University of Alaska, Fairbanks, 1994.
- Rostoker, G., The role of substorms in the development of the storm time ring current, in *Proceedings of the International Conference on Magnetic Storms*, edited by Y. Kamide, STEL, Japan, pp. 109-114, 1994.
- Rostoker, G., The role of substorms in the formation of the ring current, in *Proceedings of the Workshop on the Earth's Trapped Particle Environment*, edited by G.D. Reeves, in press, 1994.
- Rostoker, G. and S. Skone, Magnetic flux considerations in the auroral oval and the Earth's magnetotail, *J. Geophys. Res.*, 98, 1377-1384, 1993.
- Rostoker, G., B. Jackel and R.L. Arnoldy, The relationship of periodic structures in auroral luminosity in the afternoon sector to ULF pulsations, *Geophys. Res. Lett.*, 19, 613-616, 1992.
- Rostoker, G., T.D. Phan and F. Pascal, Inference of magnetospheric and ionospheric electrical properties from the decay of geomagnetic activity, *Can. J. Phys.*, 69, 921-928, 1991.
- Rostoker, G., J.C. Samson, F. Creutzberg, T.J. Hughes, D.R. McDiarmid, A.G. McNamara, A. Vallance Jones, D.D. Wallis and L.L. Cogger, CANOPUS-A ground based instrument array for remote sensing the high latitude ionosphere during the ISTEP/GGS program, *Space Sci. Rev.*, in press, 1995.
- Ruohoniemi, J.M., R.A. Greenwald, K.B. Baker and J.C. Samson, HF radar observations of Pc5 field line resonance pulsations observed in the midnight/early morning MLT sector, *J. Geophys. Res.*, 96, 15697-15710, 1991.
- Sagawa, E., I. Iwamoto, S. Watanabe, B. A. Whalen, A. W. Yau, and H. Fukunishi, Low energy upflowing ion events observed by EXOS-D: Initial results. *Geophys. Res. Lett.* 18, 337-340, 1991.
- Salah, J.E., R.R. Clark, J.M. Forbes, A.H. Manson, S.K. Avery, and R. Schminder, Radar observations of the semi-diurnal tide in the mesosphere and lower thermosphere at midlatitudes *J. Atmos. Terr. Phys.*, 56, 1251-1262, 1994.
- Samson, J.C., Geomagnetic pulsations and plasma waves in the Earth's magnetosphere, in *Geomagnetism*, Volume 4, edited by J.A. Jacobs,

- Academic Press, pp. 481-592, 1991.
- Samson, J.C., Mapping substorm intensifications from the ionosphere to the magnetosphere, in Proceedings of the Second International Conference on Substorms, edited by J.R. Kan, J.D. Craven and S.-I. Akasofu, University of Alaska, Fairbanks, pp. 237-243, 1994.
- Samson, J.C., Pure states in multichannel data, European Space Agency Publication, in press, 1994.
- Samson, J.C., R.A. Greenwald, J.M. Ruohoniemi, T.J. Hughes and D.D. Wallis, Magnetometer and radar observations of MHD cavity modes in the Earth's magnetosphere, *Can. J. Phys.*, 69, 929-937, 1991.
- Samson, J.C., T.J. Hughes, D.D. Wallis, F. Creutzberg, R.A. Greenwald and J.M. Ruohoniemi, Observations of a discrete detached arc in association with field line resonances, *J. Geophys. Res.*, 96, 15683-15695, 1991.
- Samson, J.C., B.G. Harrold, J.M. Ruohoniemi, R.A. Greenwald, K.B. Baker and A.D.M. Walker, Field line resonances associated with MHD waveguides in the magnetosphere, *Geophys. Res. Lett.*, 19, 441-444, 1992.
- Samson, J.C., L.R. Lyons, P.T. Newell, F. Creutzberg and B. Xu, Proton aurora and substorm intensifications, *Geophys. Res. Lett.*, 19, 2167-2170, 1992.
- Samson, J.C., R. Rankin and B.G. Harrold. The coupling of solar wind energy to MHD cavity modes, waveguide modes, and field line resonances in the Earth's magnetosphere, in *Solar Wind Sources of Magnetospheric ULF Pulsations*, Proceedings of the Chapman Conference, Williamsburg, VA, September, 1992.
- Samson, J.C., R. Rankin and B.G. Harrold, Substorm intensifications and the nonlinear evolution of field line resonances in the Earth's magnetosphere, Proceedings of the International Conference on Substorms (ICS-1), ESA Publ. SP-335, Paris, France, 1992.
- Samson, J.C., D.D. Wallis, T.J. Hughes, F. Creutzberg, J.M. Ruohoniemi and R.A. Greenwald, Substorm intensifications and field line resonances in the nightside magnetosphere, *J. Geophys. Res.*, 97, 8495-8518, 1992.
- Samson, J.C. and R. Rankin, The coupling of solar wind energy to MHD cavity modes, waveguide modes, and field line resonances in the Earth's magnetosphere, in *Solar Wind Sources of Magnetospheric ULF Pulsations*, American Geophysical Union monograph, 81, 253-264, 1994.
- Sandahl, I., L. Eliasson, A. Pellinen-Wannberg, G. Rostoker, L. P. Block, R. E. Erlandson, E. Friis-Christensen, B. Jacobsen, H. Luhr and J. S. Murphree, Distribution of Auroral Precipitation at Midnight During a Magnetic Storm, *J. Geophys. Res.*, 95, 6051-6072, 1990.

- Saunders, M.A., M.P. Freeman, D.J. Southwood, S.W.H. Cowley, M. Lockwood, J.C. Samson, C.J. Farrugia and T.J. Hughes, Dayside ionospheric convection changes in response to long period IMF oscillations: Determination of the ionospheric phase velocity, *J. Geophys. Res.*, 97, 19373-19380, 1992.
- Sergeev, V. A., L. L. Vagina, R. D. Elphinstone, J. S. Murphree, D. J. Hearn, L. L. Cogger and M. L. Johnson, Comparison of UV Optical Signatures with the Substorm Current Wedge as Predicted by an Inversion Algorithm, *J. Geophys. Res.*, in press, 1995.
- Shelley, E.G., A. G. Ghielmetti, H. Balsiger, R. K. Black, J. A. Bowles, R. P. Bowman, O. Bratschi, J. L. Burch, C. W. Carlson, A. J. Coker, J. F. Drake, J. Fischer, J. Geiss, A. Johnstone, D. L. Kloza, O. W. Lennartsson, A. L. Magoncelli, G. Paschmann, H. Rosenbaure, T. C. Sanders, M. Steinacher, D. M. Walton, B. A. Whalen, and D. T. Young, The Toroidal Imaging Mass- Angle Spectrograph (TIMAS) for the POLAR Mission. *Space Science Reviews*, 71, 497-530, 1995.
- Shepherd, G.G. and J.S. Murphree, Diagnosis of Auroral Dynamics using Global Auroral Imaging with Emphasis on Localized and Transient Features, *Auroral Physics*, 1991.
- Shepherd, G.G., K.V. Paulson, S. Brown, W.A. Gault, A. Moise, and B.H. Solheim, Identification of the Auroral O(1S) Precursor in Photometric Time Sequences of Pulsating Aurora, *Geophys. Res. Lett.*, 18, 1939-1942, 1991.
- Shepherd, G.G., W.A. Gault, and R.A. Koehler, The Development of Wide-Angle Michelson Interferometers in Canada, *Can. J. Phys.* 69, 1175 - 1183, 1991.
- Shepherd, G. G., A. Steen, and J. S. Murphree, Auroral Boundary Dynamics Observed Simultaneously from the Viking Spacecraft and from the Ground, *J. Geophys. Res.*, 95, 5845-5866, 1990.
- Shepherd, G. G., G. Thuillier, B. H. Solheim, S. Chandra, L. L. Cogger, M. L. Duboin, W. F. J. Evans, R. L. Gattinger, W. A. Gault, M. Herse, A. Hauchecorne, C. Lathuilliere, E. J. Llewellyn, R. P. Lowe, H. Teitelbaum, and F. Vial, Longitudinal Structure in Atomic Oxygen Concentrations Observed with WINDII on UARS, *Geophys. Res. Lett.*, 20, 1303, 1993.
- Shepherd, G.G., G.Thuillier, W.A.Gault, B.H.Solheim, C.Hersom, J.M.Alunni, J.-F.Brun, S.Brune, P.Charlot, L.L.Cogger, D.-L.Desaulniers, W.F.J.Evans, R.L.Gattinger, F.Girod, D.Harvie, R.H.Hum, D.J.W.Kendall, E.J.Llewellyn, R.P.Lowe, J.Ohrt, F.Pasternak, O.Peillet, I.Powell, Y.Rochon, W.E.Ward, R.H.Weins, J.Wimperis, WINDII - The WIND Imaging Interferometer on the Upper Atmosphere Research Satellite. *J. Geophys. Res.* 98, 10725-10750, 1993.
- Shepherd, G.G., G.Thuillier, B.H.Solheim, S.Chandra, L.L.Cogger,

- M.L.Duboin, W.F.J.Evans, R.L.Gattinger, W.A.Gault, M.Herse, A.Hauchecorne, C.Lathuilliere, E.J.Llewellyn, R.P.Lowe, H.Teitelbaum, F.Vial, Longitudinal Structure in Atomic Oxygen Concentrations Observed with WINDII on UARS. *Geophys. Res. Letters* 20, 1303-1306, 1993.
- Shepherd, G.G., C. McLandress, and B.H. Solheim, Tidal Influence on O(1S) Airglow Emission Rate Distributions at the Geographic Equator as Observed by WINDII, *J. Geophys. Res.*, in press, 1995
- Shepherd, M.G., J.C. McConnell, W.K. Tobiska, G.R. Gladstone, S. Chakrabarti, G. Schmidtke, Inference of atomic oxygen concentration from remote sensing of optical aurora, *J. Geophys. Res.*, in press, 1995.
- Shepherd, M.G., R.L.Gattinger, Y.Rochon, G.G.Shepherd, B.H.Solheim, D.J.W.Kendall, Auroral Observations with the WIND Imaging Interferometer (WINDII) on UARS. *Advances in Space Research*, In Press, 1995.
- Shepherd, M.G., R.L.Gattinger, A.Vallance Jones, Observation and Analysis of NI 520.0 nm Auroral Emissions. *J. Atmos. Terr. Phys.* In Press, 1995.
- Sica, R.J., Inferring middle-atmospheric ozone height profiles from ground-based measurements of molecular oxygen emission rates, I. Model description and sensitivity to inputs, *Can. J. Phys.*, 69, 1069-1075, 1991.
- Sica, R.J., Multi-instrument measurements of ionosphere-thermosphere coupling involving optical interferometry, *J. Geomagn. Geoelectr.*, 43, 467-478, 1991.
- Sica, R.J., Inferring middle atmosphere ozone height profiles from ground-based measurements of molecular oxygen emission rates, III. Can twilight measurements of the atmospheric band be used to retrieve an ozone density profile?, *J. Geophys. Res.*, 98, 1057-1067, 1993.
- Sica, R.J. and R.P. Lowe, Inferring middle atmospheric ozone height profiles from ground-based measurements of molecular oxygen emission rates, II. Comparison with O₂(\sim g)(0,1) band measurements at sunset, *J. Geophys. Res.*, 98, 1051-1055, 1993.
- Sica, R.J., R.W. Schunk, and P.J. Wilkinson, A study of the undisturbed mid-latitude ionosphere using simultaneous, multiple site ionosonde measurements during the Sundial-86 campaign, *J. Geophys. Res.*, 95, 8271-8279, 1991.
- Sica, R.J., J-P. St-Maurice, G. Hernandez, G.J. Romick, and R. Tsunoda, Computations of local ion energy balance in the auroral zone, *J. Geophys. Res.*, 98, 15667-15676, 1993.
- Sica, R. J., S. Sargoytchev, P. S. Argall, E. F. Borra, L. Girard, C. T.

- Sparrow, and S. Flatt, Lidar Measurements Using a Large Aperture Liquid Mirror: 1. The Rayleigh-Scatter System, *Appl. Opt.*, in press, 1995.
- Singer, W., J. Bremer, P. Hoffmann, A.H. Manson, C.E. Meek, R. Schminder, D. Kurschner, Yu. I. Portnyagin, N.A. Makarov, H.G. Muller, E.S. Kazimirovsky, and R.R. Clark, Geomagnetic influences upon tides - winds from MLT radars, *J. Atmos. Terr. Phys.*, 56, 1301-1312, 1994.
- Singer, W., P. Hoffmann, A.H. Manson, C.E. Meek, R. Schminder, D. Kurschner, G.A. Kokin, A.K. Knyazen, Yu. I. Portnyagin, N.A. Makarov, A.N. Fakhrutdinova, V.V. Sidorov, G. Cevolani, H.G. Muller, E.S. Kazimirovsky, V.A. Gaidukov, R.R. Clark, R.P. Chebotarev, and Y. Karadjaev, The wind regime of the mesosphere and lower thermosphere during the DYANA campaign - I. Prevailing winds, *J. Atmos. Terr. Phys.*, 56, 1717-1729, 1994.
- Singh, V., I.C. McDade, G.G. Shepherd, B.H. Solheim, W.E. Ward, The O(1D) Dayglow Emission as observed by the WIND Imaging Interferometer on UARS, *Adv. Space Res.*, in press, 1995.
- Sonmor, L.J. and J.G. Laframboise, Exact current to be spherical electrode in a collisionless, large-Debye-length Magnetoplasma, *Physics of Fluids B3*, 9 2472-2490, 1991.
- Sonmor, L.J., J.G. Laframboise, Chaotic particle motion in Coulomb electric and uniform magnetic fields, *Geo. Res. Let.*, 18 1619-1622, 1994.
- St. Maurice, J.-P., P. Prikryl, D. Danskin, A. Hamza, G.J. Sofko, J.A. Koehler, A. Kustov, and J. Chen, On the origin of narrow non-ion-acoustic coherent radar spectra in the high latitude E-region, *J. Geophys. Res.*, 99, 6447-6474, 1994.
- St.-Maurice, J.-P., Winkler, E., and Hamza, A.M., Ionospheric ion velocity distributions and associated transport properties in the presence of auroral electric field gradients, *J. Geophys. Res.*, 99, 19527-19548, 1994.
- Steele, D. P., and D. J. McEwen, Auroral Excitation Efficiencies and Intensity Ratios, *J. Geophys. Res.*, 95, 10321-10336, 1990.
- Steele, D. P., D. J. McEwen and J. S. Murphree, On Auroral Remote Sensing with the Viking Ultraviolet Imager, *J. Geophys. Res.*, 97, 2845-2862, 1992.
- Steele, D. P., D. J. McEwen and J. S. Murphree, A Comparison of Viking UVI Auroral Observations and Model Calculations of Camera Responses, *J. Geophys. Res.*, in press, 1994.
- Stening, R.J., A.H. Manson, C.E. Meek, and R.A. Vincent, Lunar tidal winds at Adelaide and Saskatoon at 80 to 100 km heights: 1985-1990, *J. Geophys. Res.*, 99, 13,273-13,280, 1994.

- Tarasick, David and Gordon G. Shepherd, Effects of Gravity Waves on Complex Airglow Chemistries I O₂(b¹Sg⁺) Emission, *J. Geophys. Res.* 97 3195-3208, 1992.
- Tarasick, David and Gordon G. Shepherd, Effects of Gravity Waves on Complex Airglow Chemistries II OH Emission, *J. Geophys. Res.* 97, 3195-3208, 1992.
- Taylor, M.J., P.J. Espy, D.J. Baker, R.J. Sica, P.C. Neal, and W.R. Pendleton, Jr., Simultaneous intensity temperature and imaging measurements of short period wave structure in the OH nightglow emission, *Planet. Space Sci.*, 39, 1171-1188, 1991.
- Taylor, M.J., D.N. Turnbull, and R.P. Lowe, Coincident imaging and spectrometric observations of zenith OH nightglow structure, *Geophys. Res. Lett.*, 18, 1349-1352, 1991.
- Thayaparan, T., Hocking, W.K. and MacDougall, J. (1995) Observational evidence of tidal/ gravity wave interactions using the UWO 2 MHz radar. *Geophys. Res. Lett.*, 22, 373-376, 1995.
- Thayaparan, T., W. Hocking and J. MacDougall, Middle atmospheric tides over London, Canada (43N, 81W) during 1992-93, *Radio Sci.*, in press 1995.
- Tobiska, W.K., G.R. Gladstone, S. Chakrabarti, M.G. Shepherd, J.C. McConnell, R. Link, G. Schmidtke, and G. Stasek, FUV- Visible Photometric Imaging of Aurorae, *J. Geophys. Res.*, 17525-17535, 1993.
- Tsuda, T., Y. Murayama, T. Nakamura, R.A. Vincent, A.H. Manson, C.E. Meek, and R.L. Wilson, Variations of the gravity wave characteristics with height, season and latitude revealed by comparative observations, *J. Atmos. Terr. Phys.*, 56, 555-568, 1994.
- Turnbull, D.N. and R.P. Lowe, Temporal variations in the hydroxyl nightglow observed during ALOHA-90, *Geophys. Res. Lett.*, 18, 1345-1348, 1991.
- Uspensky, M.V., A.V. Kustov, G. Sofko, J. Koehler, J.P. Villain, C. Hanuise, J.M. Ruohoniemi, and P.J.S. Williams, Ionospheric refraction effects in slant range profiles of auroral HF coherent echoes, *Radio Sci.*, 29, 503-517, 1994.
- Uspensky, M.V., P.J.S. Williams, V.I. Romanov, V.G. Pivovarov, G.J. Sofko, and J.A. Koehler, Auroral radar backscatter at off-perpendicular aspect angles due to enhanced ionospheric refraction, *J. Geophys. Res.*, 99, 17,503-17,509, 1994.
- Vallance Jones, A., R.L.Gattinger, F.R.Harris, A.G.McNamara, A.W.Yau, E.J.Llewellyn, D.Lummerzheim, M.H.Rees, I.C.McDade, J.Margot, The ARIES Auroral Modelling Campaign: Characterization and Modelling of an Evening Auroral Arc Observed from a Rocket and a Ground-Based

- Line of Meridian Scanners. *Planet. Space Sci.* 39, 1677-1705, 1991.
- Vandepier, B.G.W. and W.K. Hocking, A comparison of Doppler and spaced antenna radar techniques for the measurement of turbulent energy dissipation rates, *Geophys. Res. Lett.*, 20, 17-20, 1993.
- Vervack, J., B. R. Sandel, G. R. Gladstone, J. C. McConnell, and C. D. Parkinson, A re-evaluation of the Jovian He 584 A emissions, *Icarus*, in press, 1995.
- Vo, H. B., J. S. Murphree, R. D. Elphinstone, R. C. Elphic, E. Friis-Christensen, H. Luhr and D. G. Sibeck, Multipoint Observations of A Dayside Transient Event, *J. Geophys. Res.*, 99, 13,409-13,423, 1994.
- Vo, H. B. and J. S. Murphree, A Survey Study of Dayside Aurora as Seen by the Viking Auroral Imager, *J. Geophys. Res.*, 100, 3649-3655, 1995.
- Walker, A.D.M., J.M. Ruohoniemi, K.B. Baker, R.A. Greenwald and J.C. Samson, Spatial and temporal behavior of ULF pulsations observed by the Goose Bay HF radar, *J. Geophys. Res.*, 97, 12187-12202, 1992.
- Walker, A.D.M., J.M. Ruohoniemi, K.B. Baker, R.A. Greenwald and J.C. Samson, Spectral properties of magnetotail oscillations as a source of Pc5 pulsations, *Adv. Space Res.*, 13, (4)59-(4)65, 1993.
- Walterscheid, R.L. and W.K. Hocking, Stokes diffusion by atmospheric internal gravity waves, *J. Atmos. Sci.*, 48, 2213-2230, 1991.
- Wang, D.Y., S.P. Zhang, R. H. Wiens and G.G. Shepherd, Gravity waves from O nightglow during the AIDA '89 campaign III: effects of gravity wave saturation, *J. Atmos. Terr. Phys.* 55, 325-3340, 1993.
- Ward, W.E., Y.J. Rochon, C. McLandress, D.Y. Wang, J.R. Criswick, B.H. Solheim, G.G. Shepherd, Correlations between the Mesospheric O(1S) Emission Peak Intensity and Height and Temperature at 98 km using WINDII Data, *Adv. Space Res.*, 14, 57-60, 1994.
- Ward, W.E., E.J. Llewellyn, Y. Rochon, C.C. Tai, W.S.C. Brooks, B.H. Solheim Spatial Variability in O(1S) and O2(b1Sg) Emissions as Observed with the Wind Imaging Interferometer (WINDII) on UARS In Upper Mesosphere and Lower Thermosphere, *AGU Monograph*, 323-328, 1995.
- Ward, W.E., E.J. Llewellyn, Y. Rochon, C.C. Tai, W.S.C. Brooks, B.H. Solheim, and G.G. Shepherd, Spatial variability in O and O2 emissions as observed with the Wind Imaging Interferometer (WINDII) on UARS, *Proc. of the Asilomar Chapman Conference*, in press, 1995.
- Watanabe, S., B.A. Whalen, D.D. Wallis, R.F. Pfaff, Observations of ion-neutral collisional effects in the auroral E region. *J. Geophys. Res.* 96, 9761-9771, 1991.

- Watanabe, S., B. A. Whalen, and A. W. Yau, Thermal ion observations during plasmasphere depletion and refilling. *J. Geophys. Res.* 97, 1081-1096, 1992.
- Watanabe, S., T. Abe, E. Sagawa, B. A. Whalen, and A. W. Yau, EXOS-D observations of thermal ion energy distributions in transverse ion energization regions. *J. Geomag. Geoelect.* 47, in press, 1995.
- Waters, C.L., J.C. Samson and E.F. Donovan, The temporal variation of the frequency of high latitude field line resonances, *J. Geophys. Res.*, in press, 1995.
- Webster, A.R. and J. Jones, Rough elevated layers and tropospheric microwave propagation, *IEEE APS Symp.*, June 1991, UWO, Digest 3, 1552, 1991.
- Wei, C.Q., J.C. Samson, R. Rankin, and P. Frycz, Electron inertia effects on geomagnetic field line resonances, *J. Geophys. Res.*, 99, 11265-11276, 1994.
- Whalen, B.A., S. Watanabe, and A. W. Yau, Observations in the transverse ion energization region. *Geophys. Res. Lett.* 18, 725-728, 1991.
- Whalen, B.A., D. J. Knudsen, A. W. Yau, A. M. Pilon, T. A. Cameron, J. F. Sebesta, D. J. McEwen, J. A. Koehler, N. D. Lloyd, G. Pocobelli, J. G. Laframboise, W. Li, R. Lundin, L. Eliasson, S. Watanabe, and G. S. Campbell, The Freja F3C Cold Plasma Analyzer. *Space Sci. Rev.* 70, 541-561, 1994.
- Whiteway, J.A. and A.I. Carswell, Rayleigh Lidar Observations of Thermal Structure and Gravity Wave Activity in the High Arctic during a Stratospheric Warming, *J. Atmos. Sci.* 51, 3122-3136, 1994.
- Whiteway, J.A., A.I. Carswell and W.E. Ward, Mesospheric Temperature Inversions with Overlying Nearly Adiabatic Lapse Rate: An Indication of a Well-Mixed Turbulent Layer, *Geophys. Res. Lett.*, in press, 1995.
- Whiteway, J.A., and A.I. Carswell, Lidar Observations of Gravity Wave Activity in the Upper Stratosphere Over Toronto, *J. Geophys. Res.*, in press, 1995.
- Wiens, R.H., S.-P. Zhang, R.N. Peterson and G. G. Shepherd, MORTI: A Mesopause Oxygen Rotational Temperature Imager, *Planet. Space Sci.*, 39, 1363-1375, 1991.
- Wiens, R.H., S.-P. Zhang, R.N. Peterson and G.G. Shepherd C.A. Tepley, L. Kieffaber, R. Niciejewski and J.H. Hecht, Simultaneous Optical Observations of Long-Period Gravity during AIDA '89, *J. Atmos. Terr. Phys.*, 55 325-3340, 1993.
- Winkler, E., J.-P. St.-Maurice and A.R. Barakat, Results from improved Monte Carlo calculations of auroral ion velocity distributions, *J. Geophys. Res.*, 97, 8399-8423, 1992.

- Xu, B., J.C. Samson, W. Liu, F. Creutzberg and T. J. Hughes,
Observations of optical aurora modulated by resonant Alfvén waves,
J. Geophys. Res., 98, 11531-11541, 1993.
- Yanhua Ma, R.N. Peterson, S.P. Zhang, I.C. McDade, R.H. Wiens, and G.G.
Shepherd, Interference Filter Spectral Imaging of Twilight
O⁺(2P-2D) emission, Ann Geophys 13, 189-195, 1995.
- Yau, A.W., B. A. Whalen, and E. Sagawa, Minor ion composition in the
polar ionosphere. Geophys. Res. Lett. 18, 345-348, 1991.
- Yau, A.W., and B. A. Whalen, Auroral ion composition during large
magnetic storms. Can. J. Physics 70, 500-509, 1992.
- Yau, A.W., B. A. Whalen, C. Goodenough, E. Sagawa, and T. Mukai, EXOS-D
(Akebono) observations of molecular NO⁺ and N₂⁺ upflowing ions in
the high-altitude auroral ionosphere. J. Geophys. Res. 98,
11205-11224, 1993.
- Yau, A.W., and B.A. Whalen, Ion acceleration in the low- and mid-altitude
auroral ionosphere. Auroral Plasma Dynamics, Geophys. Monog. Ser.
80, 183-193, 1993.
- Yau, A.W., T. Abe, M. J. Greffen, R. E. Horita, D. J. Knudsen, T. Mukai,
K. I. Oyama, W. K. Peterson, E. Sagawa, S. Watanabe, and B. A.
Whalen, Akebono observations of the polar wind and suprathermal
auroral ions: an overview. J. Geomag. Geoelect., in press, 1995.
- Yau, A.W., B. A. Whalen, T. Abe, T. Mukai, K. I. Oyama, and T. Chang,
Akebono observations of electron temperature anisotropy in the
polar wind. J. Geophys. Res. 100, in press, 1995.
- Zanetti, L. J., T. A. Potemra, R. E. Erlandson, P. F. Bythrow, B. J.
Anderson, J. S. Murphree and G. T. Marklund, Polar Region Birkeland
Current, Convection and Aurora for Northward Interplanetary
Magnetic Field, J. Geophys. Res., 95, 5825-5834, 1990.
- Zhang, S.P., R.W. Wiens and G.G. Shepherd, Gravity Waves from Nightglow
During the AIDA '89 Campaign II: Numerical Modelling of the Emission
Rate/Temperature Ratio, J. Atmos. Terr. Phys. 55, 377-396, 1993.
- Zhong, L., L.J. Sonmor, A.H. Manson, and C.E. Meek, The influence of
time-dependent wind on gravity-wave propagation in the middle
atmosphere, Ann. Geophysicae, in press, 1995.
- Ziesolleck, C.W.S. and D.R. McDiarmid, Auroral latitude Pc5 field line
resonances: Quantized frequencies, spatial characteristics, and
diurnal variations, J. Geophys. Res., 99, 5817-5830, 1994.
- Ziesolleck, C.W.S. and D.R. McDiarmid, Statistical survey of auroral
latitude Pc5 spectral and polarization characteristics, J. Geophys.
Res, in press 1995.

Zverev V. L., G. V. Starkov, V. G. Vorobjev, S. V. Leontyev, Y. I. Feldstein, R. D. Elphinstone, J. S. Murphree and L. L. Cogger, Simultaneous Observations of Aurorae in Northern and Southern Polar Caps, *Geomag. and Aeron. (Russian)*, 32, N5, p. 62-70, 1992.

International Association of Meteorology and Atmospheric Science

Report not yet available.

International Association of Physical Sciences of the Oceans

Compiled by Yves Gratton

In Canada, the focus of the physical sciences of the ocean has changed during the past four years. In government laboratories, the emphasis was placed on fisheries related environmental problems: salmon on the West Coast and cod on the East Coast, and on the path of contaminants in the environment. In academic institutes, the shift was towards national and international multidisciplinary programs: global changes, large-scale ocean circulation, carbon budget, sea-ice biological production, etc. There also has been a "bloom" in numerical circulation models, climate models, ice models and remote sensing studies, with the emphasis on nutrients, eggs, larvae and contaminant distribution and transport. In general, the tendency has been towards large, fully integrated, multidisciplinary teams and studies. Since it is impossible to cover all the research activities in Canada in such a short report, the Canadian contribution to the large national and international multidisciplinary programs will be presented.

Canadian scientists are participating in many national and international multidisciplinary programs, including the World Ocean Circulation Experiment (WOCE), the Joint Global Ocean Flux Study (JGOFS), the Northeast Water Polynya (NEW), the Saroma-Resolute Project (SARES), the Canada - US 1994 Arctic Ocean Section, the Ocean Production Enhancement Network (OPEN), the Global Ocean Ecosystems Dynamics Experiment (GLOBEC) and the Land-Ocean Interaction Zone Experiment (LOICZ). Although the Canadian contributions to the last two are still in the planning stage. A few Canadian scientists are already participating in the US -GLOBEC program.

WOCE (World Ocean Circulation Experiment).

The objective of WOCE is to develop ocean circulation models for the purpose of climate prediction and to make the observations necessary to test them. The Canadian WOCE field oriented projects comprises sections in the Pacific and Atlantic Oceans, a surface velocity measurement program from drifters released in the North Pacific, and a full depth section across the Labrador Sea. They also occupied one of the important WOCE hydrographic sections in the Sea of Okhotsk, area of possible intermediate water formation, in 1993. Preliminary studies from this data will be presented at the Canadian Meteorological and Oceanographic (CMOS) meeting in May 1995. Some of the ocean circulation models developed in Canada include numerical models of coupled atmosphere-ocean interactions (e.g. Weaver and Hughes, 1994), models of the North Atlantic thermohaline circulation (Weaver et al. 1993), models of the North Atlantic interdecadal variability (Greatbatch et al. 1995), and models the North Pacific Gyre (Lee et al. 1992). Climate studies of century-scale variability (e.g. Mysak et al., 1993) were also carried out.

JGOFS (Joint Global Ocean Flux Study).

Canadian JGOFS addresses the challenging "global warming» problem". The program attempts to determine the ocean CO₂ budget through three main themes: (1) gas exchange at the sea surface, (2) transformation and transport of carbon in the ocean, and (3) the burial of carbon in the sediments. Field programs are being conducted in the Northern and Equatorial Pacific Ocean, Lake Ontario, the Gulf of St. Lawrence, Nova Scotia South Shore, Labrador Sea, Northwest Atlantic, and the Arctic. Physical sciences studies are being conducted in the three themes. The physical sciences contribution to the first theme is in the area of physical transfer of N₂ and O₂ between the atmosphere and the ocean (e.g. Farmer et al., 1993; McNeil et al. 1995), while the contribution to the last theme pertains to the processes of diffusion, mixing and irrigation of the sediments (e.g. Boudreau 1994). The second theme has the largest physical sciences contribution. This

theme addresses the horizontal and vertical transport of carbon in the oceans (e.g. Anderson and Jones, 1992; Jones et al. 1994). The physical processes under study include the measurement and the modelling of turbulence, mixing, deep water formation, upwelling and coastal jets (e.g. Denman, 1993). Studies exploring the fate of light in ocean (e.g. Hoepffner and Sathyendranath, 1992; Sathyendranath et al., 1994), with a view to understanding the implications for primary production at sea, and for interpretation of remotely-sensed data have also been carried out. Most of the JGOFS work is at the analysis stage. A Canadian-JGOFS session will be held at the Ocean Sciences Meeting in San Diego, in February 1996.

NEW (Northeast Water).

The general objective of the NEW project is to study the physical, geophysical and biological processes taking place in the Northeast Water Polynya. The field work was conducted under the leadership of the Alfred-Wegener-Institut für Meeresforschung on the F.S. Polarstern, in the summer of 1993. The research objective of the physical sciences was to identify the hydrodynamic mechanisms that govern nutrient and light availability in the surface waters of the polynya, at its edge and in the surrounding ice-covered waters. The preliminary results will be presented at the NEW symposium in Helsingor (Dannemark) in May 1995. A steady state nonlinear simulation of the polynya may be found in Darby et al. (1994).

SARES (Saroma-Resolute Project).

A Japan-Canada project was conducted on the first-year ice in Saroma-ko lagoon (Northern Hokkaido, Japan) and Resolute Passage (Northwest Territories, Canada), during the winter of 1992. The objectives of the the SARES Project were to measure the activity of the biological CO₂ pump under the first-year sea-ice and to characterize its main physical controls. The main difference between the two sites is that the Saroma-ko site is the southernmost area in the Northern Hemisphere with seasonal sea-ice while the Resolute Passage is one of the northernmost area with recurrent first-year sea-ice. A special issue of the Journal of Marine Systems will be devoted to the principal findings. Some preliminary results may be found in Marsden et al. (1994a, b), and Shirasawa et al. (1994). The most interesting physical observations (Marsden et al. 1994a) are the two basic high frequency structures of the flow: tidally driven pulses of finite amplitude internal waves and linear internal waves. Most of the pulses are generated by the interaction of the tidal flow with a compression ridge.

Canada - US Arctic Ocean Section.

There is a growing international concern that the Arctic has been polluted by a variety of contaminants. We know neither the regional nor the global consequences of a changing or a polluted Arctic, the major reason being the lack of measurements upon which analyses and models can be based. The objective of the Canada - US 1994 Arctic Ocean Section was to increase the observational base necessary for understanding the role of the Arctic in global change. From July 17 to September 9, 1994, measurements were gathered along a section from the Norwegian Sea to the Bering Strait, on the USCGC Polar Sea and the CCGS Louis L. St-Laurent. The measurements included (1) physical properties of the ocean and of the ice cover, (2) biological parameters, (3) geological observations, (4) contaminant distribution, and (5) atmospheric and upper ocean chemistry and physics relevant to climate studies.

OPEN (Ocean Production Enhancement Network).

OPEN is a Canadian action plan designed to promote the collaboration between Canadian marine scientists. OPEN's objective is to study the processes that control the survival, growth, reproduction and distribution of fish and shellfish in general and of Atlantic cod and scallops, in particular. The importance of currents on the sockeye salmon

migration patterns was also studied by the West Coast team (Thomson et al. 1994). The physical module, "Coastal Ocean Dynamics" was mostly involved with field work and numerical modelling of Eastern Canada coastal regions. The study regions include the Newfoundland coast (de Young and Sanderson, 1994; de Young et al., 1995), Baie des Chaleurs (Bonardelli et al., 1993; Gan et al., 1995; Le Quéré 1992) and the Scotian Shelf. The first successful, real-time larvae-tracking numerical model-data assimilation experiment was performed in Emerald basin (Scotian Shelf) and is discussed in Bowen et al. (1993).

Other regional models

The Canadian contributions to the physical sciences of the ocean over the period 1991-1994 were not restricted to the international programs. Since a large number of numerical circulation models appeared over the past four years, a few regional models are considered in order to complete the coverage of Canadian waters.

Numerical models, including data assimilation, account for a large part of recent research projects. The availability of cheap, powerful computers, the need to look at more realistic coastlines and bathymetry, and the urge to solve «the nonlinear problem», especially for the long-term atmosphere-ocean climate interactions, water quality evaluation and emergency response purposes, are responsible for this bloom. On the West Coast, the modelling effort covered individual inlets (e.g. Stacey and Pond, 1992; Stronach et al., 1993), as well as the Vancouver Island Shelf (Walters and Foreman, 1992) and the North Coast of British Columbia (Foreman et al., 1993). One of the promising future applications is the removal of tidal currents from ship-mounted acoustic Doppler measurements (Foreman and Freeland, 1991). Wang et al. (1994a, b) and more recently Saucier and Dionne (1995) studied the circulation and the interannual variability of the sea-ice response to atmospheric climate forcing and runoff in Hudson Bay. These studies were motivated by the question of cumulative impacts of the Hudson and James Bays hydro-electric projects. On the East Coast, a 3-D circulation model for the Gulf of Maine Region is being developed at the Bedford Institute of Oceanography (BIO) by J. Loder and D.A. Greenberg. The objective is to study the fate of pollutants and the distribution of fish eggs and larvae. A set of circulation and ice models (and studies) for the Labrador Sea and Coast, as well as the Baffin Island Coast, are also being developed at the Bedford Institute, the Northwest Atlantic Fisheries Centre and Memorial University. Finally, the modelling wave reached the St. Lawrence system where Chassé et al. (1993) modelled the barotropic tides in the estuary while Chassé (1994) developed a full 3-D baroclinic model. Toro (1992) developed a 3-D diagnostic model for the buoyancy driven seasonal circulation in the Gulf of St. Lawrence.

Canadian scientists have been active in many other branches of the physical sciences of the ocean: remote sensing, turbulence, double diffusion, waves, fronts, other climatic studies, air-sea interactions, physical-biological interactions, sediment transport. They also have contributed to the study of many bodies of water, in addition to Canadian waters. It is simply just not possible to present every study in a five page report. Therefore, this report was restricted to the large national and international programs because that is where most of the Canadian research funds were allocated.

References

Boudreau, B.P. 1994. Is burial velocity a master parameter for bioturbation? *Geochimica et Cosmochimica Acta* 58: 1243-1249.

- Bowen, A., D. Griffin, D. Hazen, S. Lochmann, T. Miller, B. Sanderson, C. Taggart, and K.R. Thompson. 1993. Tracking cod larvae in the open ocean. *Channels* 3 (1): 3-7.
- Chassé, J. 1994. Modélisation numérique tridimensionnelle de la circulation dans l'estuaire du St-Laurent, Ph. D. Thesis, Univ. du Québec à Rimouski., Rimouski, Québec, Canada.
- Chassé, J., M.I. El-Sabh, and T.S. Murty. 1993. A numerical model for Water Level Oscillations in the St. Lawrence Estuary, Canada Part I: Tides. *Marine Geodesy* 16: 109-124.
- Darby, M.S., A.J. Willmott, and L.A. Mysak. 1994. A nonlinear steady state model of North Water Polynya, Baffin bay. *Journal of Physical Oceanography* 24 (5): 1011-1020.
- de Young, B., T. Otterson, and R.J. Greatbatch. 1995. The local and non-local response of Conception Bay to wind forcing. *Journal of Physical Oceanography* 23: 2636-2649.
- de Young, B., and B. Sanderson. 1994. The circulation and hydrography of Conception Bay, Newfoundland. *Atmosphere-Ocean* 33 (1): 135-162.
- Fang, W. and W.W. Hsieh 1993. Summer sea surface temperature variability off Vancouver Island from satellite data.. *Journal of Geophysical Research*, 98 [C8] , 14391-14400.
- Farmer, D.M., C. McNeil, and B.D. Johnson. 1993. Evidence for the importance of bubbles in increasing air-sea gas flux. *Nature* 361: 620-623.
- Foreman, M.G.G., and H.J. Freeland. 1991. Comparison of techniques for tidal removal from ship-mounted acoustic Doppler measurements along the Southwest Coast of Vancouver island. *Journal of Geophysical Research* 96 (C9): 17007-17021.
- Foreman, M.G.G.; Henry, R.F.; Walters, R.A.; Ballantyne, V.A. A finite element model for tides and resonance along the north coast of British Columbia. *Journal of Geophysical Research*, 98 [C2] , 2509-2531.; 1993
- Gan, J., R.G. Ingram, and R.J. Greatbatch. 1995. Sensivity Study of an Upper Ocean Model in Coastal Bay. *Journal of Marine Systems*.
- Gan, J., R.G. Ingram, R.J. Greatbatch, and P. Chen. 1995. Upper Ocean Modelling in a Coastal Bay. *Journal of Geophysical Research* In press.
- Greatbatch, R.J., and S. Zhang. 1995. An interdecadal oscillation in an idealized ocean basin forced by constant heat flux. *Journal of Climate* 8 (1): 81-91.
- Hoepffner, N., et al. 1992. Bio-optical characteristics of coastal waters: absorption spectra and pigmemnt distribution in the western North Atlantic. *Limnology and Oceanography* 37: 1660-1679.
- Le Quéré, C. 1992. Physical Oceanography of the Baie des Chaleurs, Gulf of St. Lawrence, M.Sc. Thesis, McGill University, Montreal, Canada.
- Lee, W.R., G. Holloway, and W.W. Hsieh. 1992. Importance of bottom topography in the seasonal cycle of the North Pacific subarctic gyre. *Atmosphere-Ocean* 30 (1): 140-145.

Marsden, R.F., R.G. Ingram, and L. Legendre. 1994a. Currents under land-fast ice in the Canadian Arctic Archipelago Part 2: Vertical mixing. *Journal of Marine Research* 52.

Marsden, R.F., R. Paquet, and R.G. Ingram. 1994b. Currents under land-fast ice in the Canadian Arctic Archipelago Part I: Vertical velocities. *Journal of Marine Research* 52: 1017-1036.

McNeil, C., B.D. Johnson, and D.M. Farmer. 1995. In situ measurement of dissolved nitrogen and oxygen in the ocean. *Deep Sea Research* In press.

Mysak, L.A.T.F. Stocker and F. Huang. 1993. Century-scale variability in a randomly forced, two-dimensional thermohaline ocean circulation model. *Climate Dynamics* 8: 103-116.

Sathyendranath, S., F.E. Hoge, T. Platt, and R.N. Swift. 1994. Detection of phytoplankton pigments from ocean colour: Improved algorithms. *Applied Optics* 36 (6): 1081-1089.

Saucier, F.J., and J. Dionne. 1995. 3-D coupled ice-ocean model applied to Hudson Bay, Canada: the seasonal cycle and time dependent climate response to atmospheric forcing and runoff. *Journal of Geophysical Research* In press.

Shirasawa, K., and R.G. Ingram. 1994. Comparative study of atmospheric and oceanic characteristics above/under first-year ice at low and high latitudes in the Arctic. *Proc. NIPR Symp. Polar Biol.* 8: In press.

Stacey, M. and S. Pond. 1992. A numerical model of the internal tide in Knight Inlet, British Columbia. *Atmosphere-Ocean*, 30 [3], 383-418

Stronach, J.A., M.K. Ng, M.G.G. Goreman, and T.S. Murty. 1993. Tides and currents in Barkley Sound and Alberni Inlet. *Marine Geodesy* 16 (1): 1-41.

Toro, C. 1992. Modelisation diagnostique de la circulation tri-dimensionnelle induite par la densite dans le golfe du St-Laurent, Univ. du Quebec a Rimouski.

Walters, R.A.; Foreman, M.G.G. 1992. A 3D, finite element model for baroclinic circulation on the Vancouver Island continental shelf. *Journal of Marine Systems*, 3 [6], 507-518.

Wang, J., L.A. Mysak, and R.G. Ingram. 1994a. A numerical simulation of sea-ice cover in Hudson Bay. *Journal of Physical Oceanography* 24 (12): 2515-2533.

Wang, J., L.A. Mysak, and R.G. Ingram. 1994b. A three-dimensional numerical simulation of Hudson Bay summer ocean circulation: topographic gyres, separation and coastal jets. *Journal of Physical Oceanography* 24 (12): 2496-2514.

Weaver, A.J., and T.M.C. Hughes. 1995. Rapid interglacial climate fluctuations driven by North Atlantic ocean circulation. *Nature* 367: 447-450.

Weaver, A.J., J. Marotzke, P.F. Cummings, and E.S. Sarachik. 1993. Stability and variability of the thermohaline circulation. *Journal of Physical Oceanography* 23: 39-60.

International Association of Hydrological Sciences

Compiled by H. Gerry Jones

1) Directions in Canadian Hydrology 1990-1994: An overview

In the period covered by the present quadrennial report (1990-94) Canadian Hydrologists have faced many challenges. At the beginning of the decade a synopsis on the state of Canadian Hydrological Science (NRC/ACH 1991) defined the effects of a changing World on Canadian Water resources and the difficulties in adapting hydrological research to rapid social and environmental change. The report recognised that a major challenge concerns the necessity to produce "*the kind of information needed for making and defending intelligent decisions, and then making it available*" i.e. in a form that can be used by the public, policy makers and political leaders to promote and legislate the conservation and protection of both the resource and the Canadian environment.

To this end, Canadian Hydrologists addressed themselves to major environmental issues concerning Canada such as Global warming and climate change, surface-atmosphere exchange and the redistribution of airborne toxic compounds in terrestrial and aquatic ecosystems, land-use changes, and habitat destruction. Workers in both fundamental and applied hydrological research responded to the problems posed by these changes by the study of small and large-scale hydrological processes often within the framework of more wide-ranging interdisciplinary programs. The latter search for the relationships between hydrological pathways and biogeochemical cycling that permit the development of distributed models for ecosystem dynamics and change.

Participation of Canadian hydrologists in four working groups of the International Hydrological Programme (IHP-IV; 1990-1995; Projects H-3-2, H-5-3, M-4-3 and E-1-1) and major international programs such as the Global Energy and Water Cycle Experiment (GEWEX; McBean, 1992) and Boreal Ecosystem-Atmosphere Study (BOREAS; Hall et al, 1993) reflect the direction taken in recent years. Much of the research is focused on studies in the North (e.g GEWEX, the Mackenzie Basin; BOREAS, northern Saskatchewan and northern Manitoba). Research into the role of snow and ice in Arctic and subarctic hydrology is thus become one of the major concerns of Canadian workers (Prowse and Ommanney, 1990; Gray and Prowse, 1993). In the case of GEWEX, for example, a particular effort to model the water and energy balances of the Canadian Arctic basin at spatial scales of 100 km² and temporal scales of one month is being made.

The necessity of linking hydrological processes and northern ecosystem dynamics has resulted in innovated approaches to the study of northern hydrology. Much of this work is reported on an ongoing basis in the Northern Research Basin (NRB) workshops and symposia where Canadians have shown leadership and strong participation. The NRB, formed in 1975 by the IHP national committees of Canada, Denmark, Finland, Norway, Sweden, U.S.A., and the former Soviet Union, held a very successful meeting in the Yukon and the Northwest Territories in 1992 (NRB, 1992) and another at Svalbard in 1994 (in press). Examples of new directions in Canadian hydrology from the 1992 NRB meeting are the application of fractal geometry to snowmelt, the role of wind-blown snow in the nutrient cycling of cold ecosystems, and the ecological repercussions of river ice (NRB, 1992).

In spite of the increasing emphasis on the Canadian North, a significant part of hydrological research is still to be found in the southern half of the country. Much of the work concerns the impact of high levels of pollution on biological productivity and species

diversity. Studies are interdisciplinary and consist of integrated projects on hydrological pathways, geochemical mechanisms and population dynamics of well-defined catchment areas (e.g. acid deposition and aquatic ecology; FPCCRM, 1990).

These research efforts have not, however, been without difficulty as the organization of scientific hydrology in Canada went through important changes during the 1990-94 period. The demise of the Associated Committee for Hydrology (ACH), which handled the international obligations of the Canadian scientific community towards IAHS, occurred in 1991. This led to a regroupment of hydrologists which became the basis of the Hydrology Section of the Canadian Geophysical Union (CGU-HS), formed at the CGU General Meeting at Banff, Alberta, in 1993, and the Canadian Society of Hydrological Sciences (CSHS) of the Canadian Water Resources Association (CWRA) formed in 1992.

In addition to the CGU-HS annual meetings, CSHS and NRB symposia, other conferences and workshops held by CWRA, the Hydrological Special Interest Group of the Canadian Meteorological and Oceanographic Society (CMOS), the Canadian Global Change Program (CGCP), the Canadian Chapter of the International Association of Hydrogeologists (IAH) and the Government of Canada (e.g. Environment Canada) all provide a forum for the dissemination of information of knowledge in many fields of hydrological research and water management.

New directions in hydrological research in 1990-1994 include hydrological models of the Mackenzie River, streamflow measurements in ice-covered rivers, the estimation of evapotranspiration using surface temperature data from NOAA AVHRR observations, the presence of complex subglacial drainage containing high and low-pressure systems not previously described, and new knowledge on the role of active layer depth, water table elevation, and soil moisture on the routing of runoff in tundra soils (CGU, 1993; CGU, 1994).

Finally, in 1994, the CGU-HS Bureau formed the interim Canadian National Committee for IAHS (CNC/IAHS) made up of members from CGU-HS, CSHS (CWRA), IAH, and CMOS. The secretariat is located at the National Hydrology Research Institute (NHRI) in Saskatoon. The interim committee is in the process of defining the terms of reference, regulations and procedures for the future CNC/IAHS so that it may better represent all of Canadian scientific hydrology particularly at the international level.

2) Reports of the Canadian representatives for IAHS commissions and committees

The International Commission on Continental Erosion

Work on terrestrial erosion and sedimentation may be classified into four major themes. Traditional preoccupations with natural surface erosion, and with erosion induced by forestry and agricultural activities, are being extended to provide a distributed view of the drainage basin by linking functional models of erosion to GIS-based models of land surface attributes (e.g., Martz and deJong, 1991). At the same time, it is now firmly recognised that in most of the relatively undisturbed Canadian landscape, the bulk of fluvially mobilised sediment derives, not from the land surface, but from the streambanks of the rivers themselves (see review by Ashmore, 1993). Accordingly, the sediment balance of river reaches is receiving major attention (Goff and Ashmore, 1994; Martin and Church, 1995). The approach, based on surveys and sediment continuity, promises results for the bed sediments of rivers that are far more economical to obtain than traditional hydraulic measurements. The extension of this technique to study major alluvial deposits (and thereby to connect sediment transfers firmly with geomorphology) has received a

major technical acceleration from the deployment of ground penetrating radar to view the three-dimensional structure of surficial materials (e.g., Moorman et al., 1991). Hickin (1993) has contributed a recent critical review of sedimentary studies. Studies of fluvial sediment transport mechanics have focused upon turbulent sediment entrainment and movement, and upon the statistics of sediment grain displacements (see review in Robert, 1993). At the same time, there has been a significant increase in interest in aeolian sediment movement in the northern, continental environment (McKenna Neuman, 1993).

For about two decades, the Water Survey of Canada maintained a program of routine measurements of suspended sediment transport in a number of Canadian rivers. Fiscal constraint has forced a major reduction in this program, but a series of useful station summaries is being published which define magnitude and frequency of sediment transport. The initiative for routine measurements of sediment transfer appears now to be passing to land use agencies - primarily provincial - interested in forestry and agricultural effects.

The International Commission on Snow and Ice

The past four years has seen the production of comprehensive state-of-the-science reviews and future-research needs in the fields of floating ice, snow, ground waters, permafrost, and glacier hydrology in Canada (Gerard, Marsh, van Everdingen, Woo, and Young; respective contributions in Prowse and Ommanney, 1990). Most of the new advances in snow hydrology have been in the study of melt processes. Marsh (1991) summarized the physics and thermodynamics of water flux within melting snow covers. On a larger scale, Shook et al (1993) studied the melting of snow covers through the use of fractal geometry, while fractal analysis was also applied by Pomeroy and Schmidt (1993) to the evolution of intercepted snow. In the field of hydrogeochemistry, new relationships between the nutrient content of snow meltwaters and the microbiological productivity of snow algae were examined by Jones (1991). Pomeroy et al (1991) also studied the redistribution of nutrients by landscape form and the effects of wind on the chemical composition of snow crystals. New formulations for the subsequent flux of meltwater into the permafrost active layer were also developed using simplified thermal and hydrological parameters (Xia and Woo, 1993).

Significant new steps in glacier hydrology were made during 1990-1994. Gratton et al. (1994) modelled the energy terms controlling surface melt by devising methods to map terrain irradiance in glacier basins from satellites. Other studies included the calculation of hydraulic properties of the internal flow system from measurements of basal water pressure (e.g., Stone and Clarke, 1993), and methods to obtain reliable time-series measurements of glacial runoff (Kite, 1994).

In the field of floating ice, further refinements have been made in numerical modelling of river ice jams (e.g., Beltaos, 1993) but this field has also broadened into river ecology through such review papers as Scrimgeour et al. (1994) and by the publication of a state of the science review on environmental aspects (biology, hydrology, chemistry, etc.) of river ice (Prowse and Gridley, 1994).

The International Commission on Water Quality

During the last four years, major water quality research and monitoring programs have taken place throughout Canada. The largest of these all involve an ecosystem approach to water quality issues. The most complex has been in the Great Lakes where the programme has dealt with remedial action plans for the most polluted nearshore sites, with plans for management of the open lakes, with the problem of contaminated sediments, and with the role of the atmosphere and groundwater on water quality (Government of Canada, 1991).

The main issues have been related to toxic chemicals but most recently with the impact on water quality of exotic species such as the zebra mussel. Similar programmes have taken place in the St. Lawrence River and in western Canada in the Athabasca and Fraser River basins. In the case of the last two, the focus has been on the impact of pulp and paper mills (Carey and Hall, 1992). In Eastern Canada, similar approaches have been taken to the most polluted coastal harbours and bays. In the Arctic and sub-Arctic, the last four years have seen extensive research and monitoring on the fate of atmospherical deposited toxic chemicals in freshwater ecosystems (Government of Canada, 1992). It has been shown that flocculation is an important factor in sediment and contaminant transport (Droppo and Ongley, 1994). Research on numerous rivers in Ontario as well as the St. Lawrence, Fraser and Mackenzie Rivers has demonstrated that, irrespective of river size and location, fine-grained suspended sediment moves preferentially as flocculated particles.

These programs involved government and university scientists as well as contractors and consultants. Canada continues to conduct major water quality groundwater program from federal institutes and universities but emphasis has shifted to the development of in situ remedial techniques for polluted groundwater. In terms of acid rain, there is a renewed interest in the role of nitrogen. Other stressors on water quality and aquatic ecosystem health that are seeing a new and renewed interest include the impacts of ultraviolet light, climate change and long-range atmospheric transport and deposition of metals, particularly mercury.

The International Committee on Remote Sensing and Data Transmission

Remote sensing projects in Canada relevant to hydrology primarily involve passive and active microwave sensors. The Climate Research Branch of AES has developed, and now uses operationally, SSM/I based algorithms to map snowcover state over the open prairie of western Canada (Goodison, 1989). Work is in progress to adapt the procedure for boreal forest and tundra environments. Active sensor research has been strongly influenced by the impending launch of RADARSAT, scheduled for late summer 1995. The Canada Centre for Remote Sensing along with investigators at NHRI and the Universities of Waterloo, Sherbrooke and Quebec have explored the mapping of snow properties and soil moisture using airborne and ERS-1 radar images. Mapping of snowcovered area during melt appears practical (Donald et al. 1993). Also glacier extent and snow-line mapping using a multi-sensor approach. Soil moisture mapping appears to be feasible to some extent using C-band for bare ground and possibly for pasture fields (Pietroniro et al. 1993; Brown et al, 1993). Models under development to use the new data sets include CANTEL, HYDROTEL, SLURP and WATFLOOD (Kouwen et al. 1993). All are distributed or semi-distributed and use landcover data derived from LANDSAT-TM or SPOT imagery to address within-basin heterogeneity.

The International Committee on Tracers

The International Committee on Tracers (ITC) has compiled a data base of tracer scientists and the use of tracers in hydrology, which was distributed and analyzed at NHRI, Saskatoon. The data base includes approximately 300 scientists world-wide and is being used by the President of ICT to disseminate information on tracer methods and to plan for future needs of the tracer community.

Tracers are widely used in hydrological investigations in Canada, ranging from the use of naturally occurring isotopes in precipitation, surface and ground waters, and ice cores to the use of artificial dye and salt tracers. Recent examples of studies include: the dating of ground water using $^3\text{H}/^3\text{He}$ (Solomon et al. 1991), runoff generation and water balance

using ^{18}O and ^2H (Gibson et al. 1993 a,b) paleohydrology of ground waters using ^{18}O (Remenda et al. 1994), and stream discharge measurements by automatic conductivity analyses (Kite, 1994).

3) References

Ashmore, P.E. (1993). Contemporary erosion of the Canadian landscape. *Progress in Physical Geography*, 17: 190-204.

Beltaos, S. (1993). Numerical computation of river ice jams. *Canadian Journal of Civil Engineering*, 20(1): 88-99.

Brown, R.J., R. Leconte, B.G. Brisco, C.A. Hutton, D. Mullins J.G. Gairns, Q.H.J. Gwyn, R. Protz, J. Fischer, P.J. Howarth, P.M. Treitz, J. Boisvert, and K.B.P. Thompson. (1993). Oxford Soil Moisture Experiment (OX SOME) Overview, Proceedings of the Fourteenth Canadian Symposium on Remote Sensing, Calgary, Alberta, May, pp. 512-518.

CGU (1993) Scientific meeting of the Canadian Geophysical Union Banff, Alberta, Canada May 10-14, 1993. Program and Abstracts only

CGU (1994) Scientific meeting of the Canadian Geophysical Union Banff, Alberta, Canada May 14-May 18, 1994. Program and Abstracts only

Carey, J.H. and Hall, E.R. (1992). Pulp and paper Effluent Impacts: Assessment and Remediation. *Water Pollution Research Journal of Canada*. Special Issue, Eds. Carey, J.H. and Hall, E.R. Volume 27(3) 638 pp.

Donald, J.R., Seglenieks, F.R., Soulis, E.D., Kouwen, N. and Mullins, D.W. (1993). Mapping Partial Snowcover During the Melt Season Using C-Band SAR Imagery. *Canadian Journal of Remote Sensing*, Special Issue - 15th Canadian Symposium on Remote Sensing. Vol. 19, No. 1, pp. 68-76.

Droppo, I.G. and Ongley, E.D. (1994) Flocculation of suspended sediment in rivers of southeastern Canada *Water Research* 28: 1799-1805.

FPCCRM (1990) Report on the long-range transport of atmospheric pollutants and acid deposition. Federal-Provincial Coordination Committee, Canada, Parts 1-8.

Gibson, J.J, Edwards T.W.D., Burse, G.G. and Prowse, T.D. (1993a) Estimation of evaporation from stable isotopes: quantitative results and sensitivity analysis from two catchments in northern Canada. *Nordic Hydrology* 24: 79-94.

Gibson, J.J, Edwards T.W.D., and Prowse, T.D. (1993b) Runoff generation in a high boreal wetland in northern Canada. *Nordic Hydrology* 24: 213-224.

Goff, J.R. and Ashmore, P.E. (1994). Gravel transport and morphological change in braided Sunwapta River: Alberta, Canada. *Earth Surface Processes and Landforms*, 19: 205-212.

Goodison, B.E. (1989). Determination of Areal Snow Water Equivalent on the Canadian Prairies Using Passive Microwave Satellite Data. *Proceeding of the IGARSS*, 1989, 3, pp. 1243-1246.

Government of Canada (1991). Toxic Chemicals in the Great Lakes and Associated Effects. Volume I. Contaminant levels and trends , 448 pp; Volume II, Effects, 260 pp. Ministry of Supply and Services, Cat No. EN-37-95/1990-1E, ISBN 0-662-18317-7.

Government of Canada (1992). Synopsis of Research Conducted under the 1991/1992 Northern Contaminants Program. Environmental Studies No. 68. Ministry of Supply and Services, Cat No. R71-19/68-1992E, ISBN 0-662-19979-0.

Gratton, D.J., Howarth, P.J., and Marceau, D.J. (1994). An investigation of terrain irradiance in a mountain-glacier basin. *Journal of Glaciology*, 40(136):519-526.

Gray, D.M. and Prowse, T.D. (1993). Snow and Floating Ice. In: *Handbook of Hydrology* (D. Maidment, Editor), McGraw-Hill, New York, pp. 7.1-7.58

Hall, F.G., Sellers, P.J., Apps, M., Baldocchi, D., Cihlar, J., Goodison, B., Margolis, H.A., and Nelson, A. (1993) BOREAS: Boreal Ecosystem-Atmosphere Study. *IEEE Geoscience and Remote Sensing Society Newsletter*. March 1993, pp. 9-17.

Hickin, E.G. (1993). Fluvial facies models: a review of Canadian research. *Progress in Physical Geography*, 17: 205-222.

Jones H.G. (1991). Snow chemistry and biological activity: a particular perspective on nutrient cycling. In: *Seasonal Snowpacks: Processes for compositional change* Eds. T.D. Davies, M. Tranter and H.G. Jones NATO Advanced Study Institute Publication Series G 28: 173-228

Kite, G. (1994). Measuring glacier outflows using a computerized conductivity system. *Journal of Glaciology*, 40(134): 93-96.

Kouwen, N., Soulis, E.D. Pietroniro, A., Donald, J.R. and Harrington, R.A. (1993) Grouped response units for distributed hydrologic modelling *J. Water Res. Management and Planning* 119: 289-305)

Marin, Y. and Church, M. (1995). Bed material transport estimated from channel surveys: Vedder River, British Columbia. *Earth Surface Processes and Landforms*, 20: in press.

Marsh, P. (1991). Water flux in melting snow covers. In *Advances in Porous Media*, Vol. 1. M. Yavuz Corapcioglu (editor), 61-124.

Martz, L.W. and DeJong, E. (1991). Using Caesium-137 and landform classification to develop a net soil erosion budget for small Canadian prairie watershed. *Catena*, 18: 289-308.

McBean, G. (1992) Canadian GEWEX Programme: a conceptual overview. Canadian GEWEX Science Committee. Ed. McBean, G. 25 pages.

McKenna Neuman, C. (1993). A review of aeolian transport processes in cold environments. *Progress in Physical Geography*, 17: 137-155.

Moorman, B.J., Judge, A.S. and Smith, D.G. (1991). Examining fluvial sediments using ground penetrating radar in British Columbia. In: *Current Research Part A. Geological Survey of Canada Paper*, 91-1A: 31-36.

Pomeroy, J.W., Davies, T.D., and Tranter, M. (1991). The impact of blowing snow on snow chemistry. In: Seasonal Snowpacks: Processes for compositional change" Eds. T.D. Davies, M. Tranter and H.G. Jones NATO Advanced Study Institute Publication Series G 28: 71-114

Pomeroy, J.W. and Schmidt, R.A.. (1993). The use of fractal geometry in modelling intercepted snow accumulation and sublimation. Proceedings of the Eastern Snow Conference, 50th Annual meeting, June 1993, Quebec City, 1-10.

Prowse, T.D. and Ommanney, C.S.L. (Editors) 1990. Northern hydrology: Canadian Perspectives. NHRI Science Report No. 1, National Hydrology Research Institute, Environment Canada, Saskatoon, Saskatchewan, 324 pp.

Prowse, T.D. and Gridley, N.C. (Editors) 1993. Environmental Aspects of River Ice. NHRI Science Report No. 5, National Hydrology Research Institute, Environment Canada, Saskatoon, Saskatchewan, 155 pp.

NRB (1992) Proceedings of the 9th International Northern research basins Symposium/workshop August 1992, Whitehorse, Dawson City, Eagle Plains, Yukon, Inuvik, Northwest Territories, Canada. in two volumes Eds. Prowse, T.D., Ommanney, C.S.L., and Ulmer, K. ISBN 0660-14765-3 918 pages, including appendices.

NRC/ACH (1991) Canadian Hydrological Science: Facing the challenges of a changing World" National Research Council of Canada, Associate Committee on Hydrology in cooperation with Inland Waters Directorate Environment Canada (1991) 17 pages

Pietroniro, A., Soulis, E.D., Kouwen, N., Rotunno, O. and Mullins, D.W. (1993). Extracting Distributed Soil Moisture Information From C-Band Wide Swath SAR Imagery. Canadian Journal of Remote Sensing, Special Issue - 15th Canadian Symposium on Remote Sensing. Vol. 19, No. 1, pp. 77-82.

Remenda, V.H., Edwards, T.W.D. and Cherry, J.A. (1994) Isotopic composition of old groundwaters from Lake Agassiz: implications for late Pliocene Climate. Science 266: 1975-1978

Robert, A. (1993). Bed configuration and microscale processes in alluvial channels. Progress in Physical Geography, 17: 123-136.

Scrimgeour, G.A., Prowse, T.D., Culp, J.M. and Chambers, P.A. (1994). Ecological effects of river ice break-up: a review and perspective. Freshwater Biology, 32(2): 261-276.

Shook, K., D.M. Gray, and Pomeroy, J.W. (1993). Temporal variations in snowcover area during melt in prairie and alpine environments. Nordic Hydrology, 24(2/3): 183-198.

Solomon, D.K. and Sudicky, E.A. (1991). Tritium and helium-3 isotopes ratios for direct estimation of spatial variations in groundwater recharge. Water Resour. Res. 27: 2309-2319.

Stone, D.B. and Clarke, G.K.C. (1993). Estimation of hydraulic properties from induced changes in basal water pressure: a theoretical framework for borehole response tests. Journal of Glaciology 39(132): 327-340.

Xia, Zhao-jun and Woo, M.-K. (1993). Active layer thaw calculations using simplified thermal and hydrological parameters. Proceedings, Permafrost Sixth International Conference, Beijing, China, 725-729.

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The quadrennial reports of The International Committee on Atmosphere-Soil-Vegetation Relations (ICASVR), The International Commission on Water Resource Systems (ICWRS), The International Commission on Surface Water (ICSW), and The International Commission on Groundwater (ICGW) were not available at the time of publication.

International Association of Volcanology and Chemistry of the Earth's Interior

Compiled by P. Metcalfe

Summary

Volcanological research in Canada has continued in its popularity over the course of the last year. The report presents an overview of current activities in Canada.

Introduction

Volcanology in Canada has undergone a rapid increase over the course of the last twenty years, to the extent that nearly every large earth science department includes volcanology, in some form, in its curriculum. The discovery, in the Canadian Cordillera, of volcanoes active during the Holocene closed the circum-Pacific "Ring of Fire" and opened up a new field of research in an area where much work remains to be done. During the past two years, the interest in all aspects of igneous processes has acquired new momentum as a result of the presence of diamond-bearing pipes in the Canadian Shield, an occurrence long suspected, but which has only recently been widely publicized.

On May 22nd, 1974, the Volcanology Subcommittee of the Associate Committee on Geodesy and Geophysics (Canada's liaison with the International Union of Geodesy and Geophysics or IUGG) was replaced by the newly formed Volcanology Division of the Geological Association of Canada. This division was renamed the Volcanology and Igneous Petrology Division in 1993, to reflect its broad disciplinary base. The division publishes a newsletter thrice annually and sponsors field trips short courses, symposia and workshops, both independently and under the auspices of its parent body. Membership in the division is presently greater than 100.

The executive of the Volcanology and Igneous Petrology Division is as follows:

Chairman: Catherine J. Hickson
Geological Survey of Canada, Vancouver, British Columbia

Vice-Chairman: Tom Pearce
Queen's University, Kingston, Ontario

Secretary-Treasurer: Paul Metcalfe
Geological Survey of Canada, Vancouver, British Columbia

Councillor on Research: Kelly Russell
University of British Columbia, Vancouver, British Columbia

Past Chairman: Les Coleman
University of Saskatchewan, Saskatoon

Councillor, East: John Stix
Universite de Montreal, Montreal, Quebec

Councillor, Central: Tony Fowler
University of Ottawa, Ottawa, Ontario

Councillor, West: Stephen Juras
Westmin, Campbell River, British Columbia

Councillor, Student: Shirley Peloquin
Universite de Montreal, Montreal, Quebec

Current Activities

Activities in Canada of a volcanological nature are numerous and diverse. No report of this nature can do justice to them all. Accordingly they have been grouped on a somewhat arbitrary basis partly by geological age and province and partly by specialty.

The Modern Regime

Under this heading are included activities that can be related directly to the present era of plate tectonic movements. Not surprisingly, these studies in Canada are centred on the east and west coasts. On the west coast, the presence of volcanoes which have been active during the Holocene has focused studies, carried out by the Geological Survey of Canada, on volcanic hazards. In addition, petrological studies have been carried out on basaltic subaerial and ice-contact volcanic rocks in northern, northwestern and east central British Columbia and in the Yukon Territory, by the Geological Survey of Canada, McGill University, Carleton University and the University of British Columbia. Studies are being carried out at the Universite de Montreal on the seismic properties of mantle xenoliths. Mapping and petrological of Eocene volcanic rocks in the Intermontane Belt is being carried out by the Geological Survey of Canada and by the Geological Survey Branch of British Columbia. These rocks host epithermal gold-bearing mineralization. In northwestern B.C., the Mineral Deposit Research Unit at the University of British Columbia is concluding a study of the Hazelton Group volcanic rocks which are related to much of the gold-bearing mineralization in the "Golden Triangle".

On the east coast, studies are focused on older volcanic products. The Atlantic Geoscience Centre (Geological Survey of Canada) is conducting studies modelling the processes of rifting and comparing these with the distribution of Cretaceous volcanic rocks. Complementary studies are taking place on occurrences of Cretaceous volcanic products in the Arctic Islands (Geological Survey of Canada, St. Mary's University and the Universities of Dalhousie and Calgary).

The Early Geosynclines

Volcanic rocks of Palaeozoic and Proterozoic geosynclines which have many of the attributes of plate-generated volcanism of more recent times are more difficult to interpret in terms of the modern concepts because of their remoteness from known plate movements. The Appalachian Geosyncline has been attributed to a former opening and closing of the Atlantic Ocean. Research is continuing on boninite and peridotite magmatism in the Bay of Islands ophiolite complex (Geological Survey of Canada, Laval and Memorial

Universities). Several studies of the Palaeozoic magmatism in Appalachia are proceeding at Memorial University of Newfoundland, University of Western Ontario, Université de Québec à Montréal, University of Ottawa, Geological Survey of Canada and the Nova Scotia Department of Mines and Energy. The Avalon Zone is a subject of research at Acadia University and the University of Dalhousie. The Proterozoic magmatism of the Nain Complex has produced publications from the Newfoundland Department of Mines and Energy, the Geological Survey of Canada, Windsor University and the Geological Survey of Newfoundland and Labrador.

Volcanism in some of the major Proterozoic geosynclines; Circum-Ungava, Coronation and Grenville has been and continues to be of prime interest. Former work by the Geological Survey of Canada and the Quebec Department of Natural Resources in the Circum-Ungava Geosyncline indicated that the volcanic rocks were mainly oceanic in character and that calc-alkaline rocks, the hallmark of subduction zones, were essentially lacking. The Geological Survey of Canada and McGill University are presently active in this research field. The Grenville Province is under study by researchers from the Ontario Geological Survey, University of Dalhousie, University of Toronto and Université de Montréal.

Archean Greenstone Belts

Archean greenstone belts are characteristically composed of thick sequences of predominantly subaqueous mafic to felsic volcanic cycles, with variable thicknesses of interbedded and overlying clastic sedimentary rocks. They are chemically analogous to modern island arcs but their tectonic setting and structural style are unique. Fragmentary evidence suggests that they may have been deposited in part on a continental crust. Some workers believe that they were formed by a primitive type of plate tectonics.

Geochemical and stratigraphic studies have been carried out on many of these belts and are ongoing at the University of Manitoba, the University of Toronto, the Ontario Geological Survey and the Quebec Department of Natural Resources. The Abitibi Greenstone Belt has received the most attention in the past year, producing publications from the Université de Québec à Montréal, Université de Québec à Chicoutimi, University of Toronto, University of Western Ontario, McMaster University and Queen's University. The University of Saskatchewan, Saskatchewan Geological Survey, Royal Ontario Museum and St. Mary's University have all been active in such studies.

Volcanism of the Stable Crustal Platforms

Plateau basalts are the principal representatives of this type of volcanism. In Canada, the major provinces are the Coppermine River, the Keweenaw, the Seal Lake and the Natkusiak, all of Proterozoic age and basalts of Miocene age in central British Columbia. Although known to be related to tensional faults, the place of these basalts in the global tectonic system is still obscure. All have received past study and the Miocene lavas of British Columbia are currently under study by the Geological Survey of Canada.

Coordinated Studies of the Continental Lithosphere; the Lithoprobe SNORCLE Transects

A group of Canadian petrologists has initiated a number of individual projects under the Lithoprobe Supporting Geosciences Program to provide petrological constraints for the SNORCLE geophysical transects. The 3 proposed SNORCLE Transects will provide new insight to the structure of both ancient and modern orogenic belts. The detailed petrological studies focus on xenoliths brought to the earth's surface in Tertiary and Quaternary volcanoes (B.C., Yukon) and Cretaceous kimberlites (N.W.T.) for "petrological imaging" of the composition and structure of the subcontinental lithosphere along the transects. In the Northern Cordillera, the volcanic rocks both parallel and cross-cut the proposed transects and also cross-cut several terrane and major structural boundaries.

The group has met twice in the past 14 months (1994 Spring Lithoprobe Transect workshop in Edmonton; 1995 Annual GAC-MAC meeting in Victoria) to discuss specific research interests and coordinate the sharing of existing and future xenolith collections. Organizations involved in this research are the University of Victoria (Crustal and mantle xenoliths brought up in kimberlites within the Slave Province), Université de Québec à Montréal (Geochemistry and radiogenic isotopes of xenoliths), Carleton University (U-Pb dating of crustal xenoliths from the Slave Province and the Cordillera); St. Mary's University (Geochemistry of lower crustal and mantle xenoliths); University of British Columbia (Reactions between crustal xenoliths and lavas in the Cordillera); McGill University (Geochemistry of mantle xenoliths and lavas in the Cordillera); Pacific Geoscience Centre (Physical properties of crustal and mantle xenoliths in the Cordillera); University of Calgary (Thermobarometry of mantle xenoliths and lithospheric magma storage in the Cordillera); Université de Montréal (Physical properties of mantle xenoliths from Cordillera and Slave Province).

Economic Geology

Concepts relating ore deposits and volcanism have developed rapidly in recent years and have expanded to include a great diversity of ore deposits. The study of volcanic stratigraphy has become a vital adjunct at all levels of mineral exploration. The volcanic belts of principal current interest in Canada are the Mesozoic volcanic and subvolcanic assemblages of the Cordillera, the Palaeozoic volcanic rocks of the Appalachians and the Archaean greenstone belts. In the Cordillera, much of the work is related to subvolcanic phases, such as porphyry copper and epithermal deposits, but massive sulphide deposits are also a focus of study at the University of British Columbia. In the Appalachians and the Archaean studies are primarily directed at stratigraphic ores, and interest is also focused on the Sudbury ore-forming environment (Geological Survey of Canada and Ontario Geological Survey). Ongoing palaeomagnetic and geochronology studies at a number of laboratories in Canada are contributing indirectly to volcanology by helping to formulate a tectonic framework for past volcanic events. Experimental petrology studies are being conducted at the Universities of New Brunswick and Alberta. Most importantly, new methods of manipulation of igneous geochemical data have been modified to allow for alteration processes; studies in this field are ongoing at several institutes, including the Mineral Deposit Research Unit at the University of British Columbia.

International Association of Seismology and Physics of the Earth's Interior

Compiled by Peter W. Basham

LITHOPROBE

LITHOPROBE is Canada's national, collaborative earth science research project, established to develop a comprehensive understanding of how the North American continent has evolved. Ten transects, or study areas, have been chosen to investigate pivotal geological features to their deep lithospheric roots. They span the country from the Pacific to the Atlantic Oceans and from the U.S. border to the Yukon and Northwest Territories, and geological time from four billion years ago to the present. A multidisciplinary geoscientific approach has been found to be essential in developing complete interpretations and outstanding scientific results. From the geophysical perspective, the project is spearheaded by seismic reflection experiments and includes complementary seismic refraction/wide-angle reflection, magnetotelluric (and some other electromagnetic procedures), gravity, magnetic, heat flow, paleomagnetic, physical property and geodynamical modeling studies.

For LITHOPROBE in the last quadrennium, the most important development was the response of our principal funding agency, the Natural Sciences and Engineering Research Council of Canada (NSERC), to the submission and evaluation in 1993 of LITHOPROBE Phase IV Proposal -- Studies of the Evolution of a Continent, our proposal for the continuation of the project. The LITHOPROBE community of scientists was very gratified with the acceptance of both the 5-year program and the proposal for a further 5 years of support during which the project would be brought to its planned conclusion. This acceptance was strongly supported by the second primary funding agency for the project, the Geological Survey of Canada.

During the period 1991-94, a number of seismic reflection surveys were carried out across the continent. Studies in the Trans-Hudson Orogen and Alberta Basement transects are examining the history and processes of Precambrian continental assembly of western North America. In the Trans-Hudson Orogen transect, about 2000 km of high quality data have been obtained across and along the orogen in Manitoba and Saskatchewan. With the participation of many oil and gas companies, about 1140 km of new reflection data were acquired on the western Canada sedimentary basin of Alberta, producing excellent images of both the sediments and underlying Precambrian crust. As part of our Eastern Canadian Shield Onshore-Offshore Transect in Labrador and Quebec where a series of Proterozoic orogenic belts stitch together three Archean cratons, 1250 km of marine seismic reflection data were recorded across Ungava Bay, around northern Labrador and off the southeast coast of Labrador. To augment data acquired in an earlier stage of studies in the Abitibi-Grenville transect, investigating the Archean Abitibi greenstone belt and Mesoproterozoic Grenville orogen, 900 km of reflection profiles were acquired across the northern Abitibi and Opatoca belts and along two crossings of the Grenville. A significant LITHOPROBE contribution has been the demonstration of the applicability of the seismic reflection technique to exploration problems in the mining industry.

A combined onshore-offshore seismic refraction/wide-angle reflection (R/WAR) survey was carried out in our Lithoprobe East transect, examining the Paleozoic orogenic belt of the Appalachians on and around Newfoundland. Other extensive R/WAR surveys were carried out in the region of the Abitibi-Grenville transect in Ontario and Quebec, and the Trans-Hudson Orogen transect in Saskatchewan and Manitoba where we recorded strong first arrivals to 730 km offset. Our unique +Deep Probe+ experiment, an expanding R/WAR survey with north-south offset distances to greater than 2000 km to enable arrivals from as deep as the 410 km discontinuity and centred below the Archean Hearne craton of southeastern Alberta, is planned for 1995. During the quadrennium, large magnetotelluric surveys, to determine the conductivity structure of the crust and upper mantle and its relation to physical properties determined by other studies, have been carried out in the following transects: Lithoprobe East, Abitibi-Grenville, Trans-Hudson Orogen and Alberta Basement. In regions of exposed crystalline rock near mining interests, higher frequency controlled source electromagnetic experiments also were carried out. Use of gravity and aeromagnetic maps, paleomagnetic studies, heat flow studies, physical properties measurements and geodynamic have all been active during the last four years.

During the past four years, more than 400 contributions from all disciplines have been added to the LITHOPROBE Publication List, which is available from the LITHOPROBE Secretariat (Geological Sciences Centre, 6339 Stores Road, University of British Columbia, Vancouver, B.C. V6T 1Z4; clowes@lithoprobe.ubc.ca) and on the World Wide Web network (<http://www.geop.ubc.ca/.Lithoprobe/lithopb.html>). These have been separated into contributions relating to individual transects, geophysical data processing and general crustal studies, but not according to discipline. A few general articles relating to the project and a special seismological publication for which LITHOPROBE was a principal sponsor are in the bibliography below.

UNIVERSITY OF BRITISH COLUMBIA

R.M. Clowes and R.M. Ellis with their crustal studies research group have continued the analysis of several seismic R/WAR data sets: the crustal structure and its tectonic implications of the Hecate sub-basin of the Queen Charlotte sedimentary basin; structure within a triangular array within the southern Canadian Cordillera; a profile within the Coast Belt of southern British Columbia and two crossing profiles from the northern Yukon-Mackenzie Delta region of northwestern Canada; the west coast of Vancouver Island to determine velocity structure below the continental shelf; a profile in the Trans-Hudson Orogen of western Canada; data recorded in northwestern British Columbia from the airgun source; and a reflection survey in southeastern Alaska as part of the U.S.-funded ACCRETE project.

R.M. Ellis and his students have continued their studies of the lithosphere using teleseismic sources: a receiver function study across the Juan de Fuca-North America plate margin with a primary result being the imaging of the dipping subducting plate to near 65 km as well as shallower structures; a similar data set across the Explorer-North America plate for a comparative analysis of the two interaction zones; the combined use of

receiver function and tomographic techniques to image the lithosphere in the Trans-Hudson Orogen, a region of very complex structure.

R.M. Clowes with his students and postdoctoral fellows have continued a number of research projects using multichannel seismic reflection and other data: the northern Cascadia subduction zone through an integrated geophysical modeling study involving gravity and magnetic data constrained by geology, seismic refraction and reflection interpretations and physical properties data; analysis and interpretation of 230 km of marine reflection data recorded across the northern Juan de Fuca plate; reprocessing and reinterpretation of LITHOPROBE reflection data from the southern Canadian Cordillera in British Columbia and the Trans-Hudson Orogen in Saskatchewan; reprocessing and interpretation of a reflection profile across the Fraser fault, a crustal-scale strike-slip fault system; analysis of data recorded near the Mt. Cayley volcanic centre, part of the Garibaldi-Cascades volcanic belt, and reanalysis of crustal and upper mantle reflections from below the southwestern Coast belt northwest of Vancouver; the central and eastern Coast belt north of Vancouver in a region of mining interest; and reflection data along a line crossing the Paleoproterozoic western Trans-Hudson Orogen and extending into the Archean Hearne craton.

M.G. Bostock has commenced a series of projects with the aim of acquiring a better understanding of the upper mantle beneath Canada at a range of scales. With J.C. VanDecar (Carnegie Institute of Washington) he has inverted P-wave teleseismic traveltimes residuals to delineate mantle structure of the Cascadia subduction zone. With J.F. Cassidy (Geological Survey of Canada) he has investigated upper mantle anisotropy using the broadband stations of the Canadian National Seismic Network, and variations in depth to the upper mantle discontinuities and overlying velocity structure over Canada.

A study to monitor detailed variations in mantle structure across the northern Cordillera through to the Slave province as part of the Lithoprobe SNORCLE transect is currently underway.

B. A. Buffett continues to work on a number of problems related to the structure and dynamics of Earth's interior. With J.R. Lister (University of Cambridge), he has investigated the relative importance of thermal and compositional convection in the dynamo problem. Studies with P.M. Mathews (Harvard-Smithsonian Center for Astrophysics) continue on the tidal deformation of a rotating, spheroidal Earth. A new investigation with J. Douglass addresses the interseismic deformation above a subduction zone. Other studies currently in progress include the magnetic damping of inner-core oscillations, the effects of a heterogeneous lower mantle on the flow and magnetic field at the top of the core, and the formation of gas hydrates in porous media.

R.D. Russell, K.E. Butler and A.W. Keping have been continuing their research on methods of seismoelectric exploration. There are at least four phenomena of interest: modulation by seismic stress of the resistivity of a volume of earth through which telluric currents flow, seismically induced electrokinetic effects, piezoelectric effect of quartz veins, and generation of radio-frequency impulsive responses in sulphide-rich rocks. Regardless of the conversion mechanism, the methods use a seismic source, and electric or magnetic receivers. Data from different shotpoints can be used to locate or

delineate the target. They have made detailed studies of the electrokinetic effect on an unimproved dirt road within the Malcolm Knapp Reserach Forest at Haney, near Vancouver, Canada. The road fill consists of a permeable, organic-rich soil which overlies a highly impermeable, silty glacial till. Using a sledgehammer source and grounded dipole receivers, they have observed that electric currents are generated when the seismic wave impinges upon the boundary at the base of the till. Four boreholes confirmed the interpretation. Among several studies of sulphides in underground mines, the most productive have been those at the Lynx Mine on Vancouver Island. By placing shotpoints around a target, it has been shown that a credible psuedo-tomographic representation of the orebody can be constructed. The latest experiment, made with a data acquisition capable of observing electromagnetic signal components to approximately 5 MHz, showed that the arrivals are rich in frequencies up to 2.5 MHz, and contain a characteristic band centered around 1.3 MHz.

QUEEN'S UNIVERSITY

C.J. Thomson and students have focussed their current activities in three areas: (i) surface waves in anisotropic media using a new anisotropic reflection-matrix program to investigate the excitation and propagation of surface waves in laterally-homogeneous and slowly laterally-varying media. As with body waves, new effects such as phasefront folding and mode coupling arise from the anisotropy. (ii) The same reflection-matrix technique is being adapted for the modelling and interpretation of broadband teleseismic body waves. The aim is to understand what constraints can be placed on a multilayered anisotropic near-receiver structure by teleseismic data. (iii) Studies on the folding and coupling of quasi-shear body waves are being extended to 3D anisotropic structure, with emphasis on subduction-zone applications. A 3D anisotropic one-way wave-equation (finite difference) technique is being developed.

GEOLOGICAL SURVEY OF CANADA

(a) Crustal Seismology

In the Continental Geoscience Division, I. Asudeh has been involved in design, acquisition and interpretation of crustal refraction profiles from Trans Hudson orogen (northern Saskatchewan and Manitoba) and New Brunswick Appalachians. D. Eaton has been Involved in acquisition, processing and interpretation of deep seismic reflection data from central Alberta, the Grenville province in eastern Quebec and the Peace River Arch region of northern Alberta. He is also developing new techniques for true-amplitude processing and new algorithms to model seismic scattering in 3-D heterogeneous media using the Born approximation and finite-difference techniques. These methods are being applied to model the scattering response of ore bodies in structurally complex settings. New techniques are being developed for borehole seismic imaging of near vertical structures, in collaboration with industry.

D.A.Forsyth and colleagues, including COCORP, are working with Ontario Hydro who have supported work to license, acquire, process and interpret

reflection seismic data from Lake Huron. They are continuing interpretation of deep reflection data from lakes Ontario, Erie and Lithoprobe data from the northern Central Metasedimentary Belt; and interpretation of wide-angle crustal data from the northeastern Sverdrup Basin and continental margin. Forsyth is also involved in the acquisition, processing and interpretation of new, higher resolution aeromagnetic data from the Canadian polar margin; and in the acquisition of long range wide-angle seismic data across the Appalachian Orogen of Nova Scotia, New Brunswick and the Quebec Gaspé from a source provided by a shock test in the navy's new Canadian Frigate program.

B. Milkereit and colleagues are involved in acquisition, processing and interpretation of high resolution 2-D seismic data, borehole geophysical surveys and physical property studies at base metal mining camps in northern Ontario and Quebec. He is designing the first-ever 3-D seismic surveys for mineral exploration in Canada, in close cooperation with industry.

B. Roberts is reprocessing seismic reflection data from the Huronian segment of the Southern Province, and continuing to process and interpret data from Newfoundland (Lithoprobe East). D. White is involved in acquisition, processing and interpretation of deep seismic reflection data and crustal refraction profiles from the Paleoproterozoic Trans Hudson orogen of northern Saskatchewan and Manitoba, including high resolution profiling in the Thompson nickel belt. He is developing new algorithms to position dipping reflectors correctly in three dimensions for crooked-line 2-D profiles. J. Wu is involved in processing and interpretation of 2-D high-resolution seismic reflection profiles and borehole geophysical measurements from the Sudbury Impact Structure and the Thompson nickel belt; and developing new techniques for processing seismic reflection data acquired in a hard rock environment.

At the Atlantic Geoscience Centre, C.E. Keen, H.R. Jackson, I.D. Reid, S.P. Srivastava, F. Marillier and colleagues has been active in geodynamic studies of rifted continental margin and rift basin formation and evolution. These studies encompass the following: (i) finite element-based dynamical models of extension of the lithosphere; (ii) studies, based on observations of crustal thinning and subsidence, of the kinematics of continental margin extension off eastern Canada and the conjugate European margins; and (iii) predictions of the volume and composition of magmas generated through decompression melting; and (iv) numerical modelling of the rift-generated small scale convection in the asthenosphere below rifts.

Extensive wide-angle seismic studies were carried out around Newfoundland (Part of LITHOPROBE EAST), in northern Baffin Bay, and in the Canada Basin, Arctic Ocean. A deep seismic reflection survey was undertaken (in collaboration with IFREMER, France) in the Flemish Cap region. Analysis and interpretation (with Dalhousie University) of the combined reflection/refraction transect of the Labrador Sea and its conjugate margins was completed; as was interpretation of continental margin structures across the Grand Banks from wide angle seismic data and across the Nova Scotian margin from vertical incidence data. These margin studies have allowed delineation of the structure of non volcanic margins, including the presence of very thin crust against the margin and the probable presence of serpentinised mantle. Off Nova Scotia the transition from volcanic to non-volcanic margin has illuminated the role of volcanism. The Baffin Bay work supports the conclusion that significant motion has taken place between Greenland and North America.

The crust under the central Newfoundland Appalachians is substantially thinner than under its margins, and it is underlain by a layered upper mantle.

(b) Earthquake Seismology

The upgrade of the Canadian National Seismograph Network (CNSN) is well underway. As of 1 May 1995 the CNSN consisted of 22 broadband or very broadband and 16 short-period stations. During the next year, 3 additional broadband stations will be added and the remaining short-period stations comprising the dense networks in eastern and western Canada will be converted to CNSN format. Network data can be easily accessed by the external seismological community through an internet-email based retrieval system.

A.L. Bent has been systematically re-examining and applying modern waveform analysis techniques to early instrumental (pre-WWSSN) earthquakes in eastern Canada in an effort to better understand their source characteristics.

In a recent study of the 1929 Grand Banks earthquake (M_s 7.2), she showed that the source mechanism was not a single force (landslide) as had been suggested, but a double couple (earthquake) consisting of several strike-slip subevents.

R.A.W. Haddon has focused his attention on modeling strong motion records and the use of empirical Green's functions as tools for gaining insight into the details of the earthquake rupture process. He found that the unusually high levels of high-frequency ground motion for the 25 November 1988 Saguenay earthquake (m_b 6.0) were a result of source directivity rather than high stress drop.

The M_s 6.3 earthquake that occurred in the Ungava Peninsula on 25 December 1989 was unique in that it produced the first known surface rupture from an eastern North American earthquake. Field observations under the direction of J. Adams and a waveform analysis study by Bent both found evidence for a complex rupture consisting of both thrust and strike-slip faulting.

In western Canada, the Cascadia subduction zone has been of particular interest because of its potential for a catastrophic earthquake. J.F. Cassidy and R.M. Ellis (UBC) have employed receiver function analysis to determine the shear wave velocity structure of various segments of the zone. H. Dragert, R.D. Hyndman, K. Wang and colleagues have synthesized heat flow and geodetic data to map the location of the locked portion of the subduction zone. J.J. Clague and colleagues have found evidence from buried marsh surfaces and sand layers for previous Cascadia subduction earthquakes on the west coast of Vancouver Island.

Cassidy has also been studying the source characteristics of large west coast earthquakes, of which the 6 April 1992 (M_s 6.8) offshore earthquake is an example. Employing a variety of modeling techniques he has been able to work out a detailed picture of the slip distribution of this earthquake.

J. Adams, D.H. Weichert and colleagues have produced the fourth generation of seismic hazard maps of Canada. New techniques have been

employed to develop ground motion estimates that can be used to produce uniform hazard spectra. These hazard maps and associated changes to the seismic provisions of the National Building Code will be issued for trial use by the engineering community in 1995. Revisions as necessary will be carried out in about 1997 to produce new seismic zoning maps for the year 2000 building code.

R.G. North, P.W. Basham and colleagues have continued to make the Canadian seismological contributions to the Comprehensive Test Ban monitoring system. Basham and North represent Canada in the Geneva discussions; North and colleagues have developed a substantial Canadian contribution to the experimental international seismic monitoring system, GSETT-3.

BIBLIOGRAPHY

Adams, J., Wetmiller, R. J., Hasegawa, H.S., and Drysdale, J. 1991. The first surface faulting from a historical intraplate earthquake in eastern North America, *Nature*, 352, 617-618.

Bassi, G., Keen, C.E., and Potter, D.P. 1993. Contrasting styles of rifting: models and examples from the eastern Canadian margin. *Tectonics*, 12, 639-655.

Bent, A. L. 1994. The 1989 (Ms 6.3) Ungava, Quebec earthquake: A complex intraplate event, *Bull. Seism. Soc. Am.*, 84, 1075-1088.

Bostock, M.G. and Cassidy, J.F. 1995. Variations in SKS splitting across western Canada, *Geophys. Res. Lett.*, 22, 5-8.

Bostock, M.G. and VanDecar, J.C. 1995. Upper mantle structure of the northern Cascadia subduction zone, *Can. J. Earth. Sci.*, 32, 1-12.

Boutilier, R.R., and Keen, C.E. 1994. Geodynamic models of fault-controlled extension. *Tectonics*, 13, 439-454.

Buffett, B.A. and Goertz, D.E. 1995. Magnetic damping of the translational oscillations of the inner core, *Geophys. J. Int.*, 120, 103-110.

Butler, K.E., Russell, R.D., Kopic, A.W., and Maxwell, M. 1994. Mapping of a stratigraphic boundary by its seismoelectric response. *SAGEEP '94 Conference Proceedings*, 689-699.

Cassidy, J. and Ellis, R.M. 1991. Shear wave constraints on a deep crustal reflective zone beneath Vancouver Island, *J. Geophys. Res.*, 96, 19843-19851.

Cassidy, J.F. and Ellis, R.M. 1993. S-wave velocity structure of the northern Cascadia subduction zone, *J. Geophys. Res.*, 98, 4407-4421.

Clowes, R.M., Cook, F.A., Green, A.G., Keen, C.E., Ludden, J.N., Percival, J.A., Quinlan, G.M. and West, G.F. 1992. LITHOPROBE -- New perspectives on crustal evolution. *Can. J. Earth Sci.*, 29, 1813-1864.

Clowes, R.M. 1992. LITHOPROBE - An integrated approach to studies of crustal evolution. *Geotimes*, 12-14, August.

- Clowes, R.M. 1993. Variations in continental crustal structure in Canada from LITHOPROBE seismic reflection and other data. *Tectonophysics*, 219, 1-27.
- Clowes, R.M. 1994. LITHOPROBE - geoscience probing of inner space leads to new developments for mining exploration. *CIM Bulletin*, 87, 36-48.
- Clowes, R.M. and Green, A.G., (Editors). 1994. Special Issue on "Seismic Reflection Probing of the Continents and Their Margins." *Tectonophysics*, 232, 1-450.
- Dehler, S.A. and Clowes, R.M. 1992. Integrated geophysical modelling of terranes and other structural features along the western Canadian margin. *Can. J. Earth Sci.*, 29, 1492-1508.
- Dehler, S.A. and Keen, C.E. 1993. Effects of rifting and subsidence on thermal evolution of sediments in Canada's east coast basins. *Can. J. Earth Sci.*, 30, 1782-1798.
- Dragert, H., Hyndman, R.D., Rogers, G.C., and Wang, K. 1994. Current deformation and the width of the seismogenic zone of the northern Cascadia subduction thrust, *J. Geophys. Res.*, 99, 653-668.
- Eaton, D.W.S. and Stewart, R.R. 1994. Migration/inversion for transversely isotropic elastic media. *Geophys. J. Int.*, 119, 667-683.
- Forsyth, D.A., Milkereit, B., Zelt, C.A. and White, D.J. 1994. Deep crustal structure beneath Lake Ontario: crustal-scale Grenville subdivisions. *Canadian Journal of Earth Sciences*, 31, 255-270.
- Fuis, G.S. and Clowes, R.M. 1993. Comparison of deep structure along three transects of the western North American continental margin. *Tectonics*, 12, 1420-1435.
- Haddon, R. A. W. 1995. Modeling of source rupture characteristics for the Saguenay earthquake of November 1988, *Bull. Seism. Soc. Am.*, 85, 525-551.
- Hole, J.A., Clowes, R.M. and Ellis, R.M. 1993. Interpretation of three-dimensional seismic refraction data from western Hecate Strait, British Columbia: structure of the Queen Charlotte Basin, *Can. J. Earth Sci.*, 30, 1427-1439.
- Hole, J.A., Clowes, R.M. and Ellis, R.M. 1992. Interface inversion using broadside seismic refraction data and three-dimensional travel time calculations, *J. Geophys. Res.*, 97, 3417-3429.
- Jackson, H.R., and Reid, I. 1994. Seismic refraction results from Greenland/Ellesmere Island margins: contrasts and comparisons. *Can. J. Earth Sci.*, 31, 1407-1418.
- Keen, C.E. and Dehler, S.A. 1993. Stretching and Subsidence: Rifting of Conjugate Margins in the North Atlantic Region, *Tectonics*, 12, 1209-1229.
- Keen, C.E., Courtney, R.C., Dehler, S.A., and Williamson, M.-C. 1994.

Decompression melting at rifted margins: comparison of model predictions with the distribution of igneous rocks on the eastern Canadian margin. *Earth and Planet. Sci. Letters*, 121, 403-416.

Kepic, A.W., Maxwell, M., and Russell, R.D. 1995. Field trials of a seismoelectric method for detecting massive sulfides. *Geophysics*, 60, 363-373.

Lucas, S.B., Green, A., Hajnal, Z., White, D., Lewry, J., Ashton, K. Weber, W. and Clowes, R. 1993. Deep seismic profile across a Proterozoic collision zone: Surprises at depth: *Nature*, 363, 339-342.

Marillier, F., and 14 others. 1994. Lithoprobe East onshore-offshore seismic refraction survey-constraints on interpretation of reflection data in the Newfoundland Appalachians. *Tectonophysics*, 232, 43-58.

Mathews, P.M, Buffett, B.A., and Shapiro, I.I. 1995. Love numbers for a rotating spheroidal Earth: New definitions and numerical values, *Geophys. Res. Lett.*, 22, 579-582.

Maxwell, M., Russell, R.D., Kepic, A.W., and Butler, K.E. 1992. Electromagnetic responses from seismically excited targets, B: Non-piezoelectric phenomena. *Exploration Geophysics*, 23, 201-208.

North, R. and Beverley, K. 1994. The Canadian National Seismograph Network, *Iris Newsletter*, 13, 20-22.

O'Leary, D.M., Clowes, R.M., and Ellis, R.M. 1993. Crustal velocity structure in the southern Coast Belt, British Columbia, *Can. J. Earth Sci.* 30, 2389-2403.

Reid, I.D. 1993. Velocity structure of reflective lower crust beneath the Grand Banks of Newfoundland. *J. Geophys. Res.*, 98, 9845-9859.

Reid, I.D. 1994. Crustal Structure of a nonvolcanic rifted margin east of Newfoundland. *Journal of Geophysical Research*, 99, 15161-15180.

Ross, G.M., Milkereit, B., Eaton, D., White, D., Kanasewich, E. and Burianyck, M. 1995. Paleoproterozoic collisional orogen beneath the western Canada sedimentary basin imaged by Lithoprobe crustal seismic-reflection data. *Geology*, 23, 195-199.

Russell, R.D., and Barker, Jr., A.S. 1991. Seismoelectric exploration: expected signal amplitudes. *Geophysical Prospecting*, 39, 105-118.

Russell, R.D., Maxwell, M., Butler, K.E., and Kepic, A.W. 1992. Electromagnetic responses from seismically excited targets, A: Piezoelectric phenomena at Humbolt, Australia. *Exploration Geophysics*, 23, 281-286.

Varsek, J.L., Cook, F.A., Clowes, R.M., and 5 others. 1993. LITHOPROBE crustal reflection structure of the southern Canadian Cordillera II: Coast Mountains transect. *Tectonics*, 12, 334-360.

Wang, K., and Rogers, G.C. 1994. An explanation for the double seismic layers north of the Mendicino triple junction, *Geophys. Res. Lett.*, 21, 121-124.

Weichert, D.H. 1994. Omar rock and the 1872 Pacific Northwest earthquake, *Bull. Seis. Soc. Am.*, 84, 444-450.

Whalstrom, R., and Rogers, G.C. 1992. Relocation of earthquakes west of Vancouver Island, British Columbia, 1965-1983. *Can. J. Earth Sci.*, 29, 953-961.

White, D.J. and Clowes, R.M. 1994. Seismic attenuation structure beneath the Juan de Fuca Ridge from tomographic inversion of amplitudes. *J. Geophys. Res.*, 99, 3043-3056.

Wu, J., Milkereit, B. and Boerner, D. 1995. Seismic imaging of the enigmatic Sudbury Structure, *J. Geophys. Res.*, 100, 4117-4130.

Zelt, B.C., Ellis R.M., and Clowes, R.M. 1993. Crustal velocity structure in the eastern Insular and southernmost Coast belts, Canadian Cordillera, *Can. J. Earth Sci.*, 30, 1014-1027.