TIME SERIES ANALYSIS:

THEORY AND PRACTICE 6

Edited by
O. D. ANDERSON
J. K. ORD, E. A. ROBINSON

TIME SERIES ANALYSIS:

Theory and Practice 6

Hydrological, Geophysical and Spatial Applications

Proceedings of the International Conference held at Toronto, Canada, 10-14 August 1983

Edited by

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and

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CONTENTS

TIME SERIES ANALYSIS: Theory and Practice 6
O.D. Anderson, J.K. Ord and E.A. Robinson (editors)

INTRODUCTION

About the Meeting

The 10th International Time Series Meeting (ITSM) took place in Toronto (Canada) 10-14 August, 1983, at the Sheraton Centre, immediately prior to the 1983 Joint Statistical Meetings (American Statistical Association, Biometric Society, Institute of Mathematical Statistics and the Statistical Society of Canada) which were held at the same location. The ITSM was a Special Topics Conference, with theme "Hydrological, Geophysical and Spatial Time Series".

This introduction lists the participants, provides the technical programme, and prints abstracts of those papers which were presented, but are not included in these Proceedings. It also acknowledges all individuals, who helped make the Meeting a success, and gives biographical sketches for those authors who filed appropriate details.

Conference Organisation

Oliver D. Anderson (UK), Convenor & General Chairman	TSA&F, Nottingham
Richard B. Anderson (Canada), Registration	York University, Downsview, Ontario
Leo A. Aroian (USA), Session Organiser, Spatial Stream	Union College, Schenectady, New York
J. Keith Ord (USA), Spatial Stream Leader	Pennsylvania State University
Enders A. Robinson (USA), Geophysical Stream Convenor	University of Tulsa, Oklahoma

Other Participants (making 58 people in all, from 11 countries)

Armine G. Aroian (USA)	Guest, Schenectady, New York
Piero Barone (Italy)	Institute Mauro Picone, Rome
Christine Baufays (Belgium)	Guest, Namur
Pierre Baufays (Belgium)	Namur University
Denis Bolduc (Canada)	University of Montreal, Quebec
Jean-Pierre Chanut (Canada)	University of Quebec, Rimouski
Keewhan Choi (USA)	Centers for Disease Control, Atlanta, Georgia
Daniel A. Cluis (Canada)	University of Quebec, Sante-Foy
Eivind Damsleth (Norway)	Norwegian Computing Center, Oslo
Peter R. Defize (Netherlands)	Institute TNO, The Hague
Janice A. Derr (USA)	Guest, Pennsylvania State University
Ferial El-Hawary (Canada)	Technical University of Nova Scotia, Halifax
Mo El-Hawary (Canada)	Guest, Technical University of Nova Scotia, Halifax
Ömer L. Gebizlioglu (Turkey)	Middle East Technical University, Ankara
Pierre Goupillaud (USA)	Systems, Science and Software, La Jolla, California
Daniel A. Griffith (USA)	State University of New York, Buffalo
Zhi-Gang Han (China)	Heilongjiang University, Harbin
Jon Helgeland (Norway)	Norwegian Computing Center, Oslo
Keith W. Hipel (Canada)	University of Waterloo, Ontario
Urban Hjorth (Sweden)	Linköping Institute of Technology
Shiv G. Kapoor (USA)	University of Illinois, Urbana-Champaign
Myron J. Katzoff (USA)	Bureau of Census, Washington DC

Larry R. Lines (USA)	Amoco Production Co, Tulsa
Donald J. Malec (USA)	Bureau of Census, Washington DC
A. Ian McLeod (Canada)	University of Western Ontario, London
Priya Ranjan Mohanty (Canada)	University of Manitoba, Winnipeg
Marc Moore (Canada)	Ecole Polytechnique, Montreal, Quebec
Pedro A. Morettin (Brazil)	University of São Paulo
Ishard Mufti (USA)	Superior Oil, Houston
Trygve S. Nilsen (Norway)	University of Bergen
France Paradis (Canada)	Guest, Montreal, Quebec
Anne M. Perry (USA)	Guest, Schenectady, New York
Robert J. Perry (USA)	Schenectady, New York
Charles H. Proctor (USA)	North Carolina State University, Raleigh
David L. Quigg (USA)	Bradley University, Peoria, Illinois
Tom Schilperoort (Netherlands)	Delft Hydraulics Laboratory
Charles Schmid (USA)	Honeywell, Seattle
Laurel Sharp (USA)	Guest, Columbia, South Carolina
Will Sharp (USA)	Guest, Columbia, South Carolina
W. Ed Sharp (USA)	University of South Carolina, Columbia
Janice Singh-Stoffer (USA)	Guest, Pittsburgh, Pennsylvania
Lena Smolon (USA)	Guest, Schenectady, New York
William J Smolon (USA)	Union College, Schenectady, New York
David S. Stoffer (USA)	University of Pittsburgh, Pennsylvania
Mathew Stoffer (USA)	Guest, Pittsburgh, Pennsylvania
Marcia Synnott (USA)	Guest, Columbia, South Carolina
Lucille Terry (USA)	Guest, Bowling Green State University, Ohio
W. Robert Terry (USA)	University of Toledo, Ohio
Robert M. Thompstone (Canada)	Alcan Smelters and Chemicals Ltd, Jonquière, Quebec
George Treviño (USA)	CHIRES Associates, Las Cruces, New Mexico
Dan Wartenburg (USA)	State University of New York, Stoney Brook
Terry L. Watt (USA)	University of Tulsa, Oklahoma
Zhi-Ming Wu (China)	Shanghai Jiao Tong University.

Technical Programme (30 contributions in a single stream)

Thursday, 11 August

Session 1 Plenary 1 08.30-10.15

O.D. Anderson (UK) Welcome to 10th International Time Series Meeting (ITSM) and 4th American Conference
J.K. Ord (USA) Forecasting the Spread of an Epidemic (with *A.D. Cliff*, UK)
L.A. Aroian (USA) Time Series in M-Dimensions: Past, Present and Future

Session 2 Hydrological 1 10.45-12.30

D. Cluis (Canada) Information Content of the Mean and Rescaled Range of Short Samples derived from AR(2) Processes
W.R. Terry (USA) A Markovian State Vector Representation for the Influence of Wind Speed and Atmospheric Stability on Sulfur Dioxide Concentration (with *A. Kumar*)
R.M. Thompstone (Canada) Grouping of Periodic Autoregressive Models (with *K.W. Hipel & A.I. McLeod*)

Session 3 Geophysical 1 14.30-16.15 *Organised by Professor E.A. Robinson*

E.A. Robinson (USA) A Bridge between Geophysical and Other Time Series Analysts
T.L. Watt (USA) Robust Homomorphic Filtering (with *J.B. Bednar*)
L.R. Lines (USA) A Review of Nonlinear Regression and its Applications to Problems in Geophysical Inverse Theory (with *S. Treitel*)

Session 4 Spatial 1 16.45-18.30 *Organised by Professors J.K. Ord & L.A. Aroian*

D.A. Griffith (USA) Estimating Missing Values in Space-Time Data Series (with *R.P. Haining & R.J. Bennett*, UK)
D. Wartenburg (USA) Blocked Quadratic Variance or Spectral Density: Speed versus Power in Transect Analysis
W.E. Sharp (USA) Statistical Space Series on a Square Net (with *L.A. Aroian*)

Friday, 12 August

Session 5 Hydrological 2 08.30-10.15

P.A. Morettin (Brazil) Rainfall at Fortaleza in Brazil Revisited (with *A.R. de Mesquita*)
T. Schilperoort (Netherlands) Identification and Parameter Estimation of Models for the Phosphate Balance in Drinking Water Reservoirs (with *H. Koppelman*)
S. Kapoor (USA) A Vector Time Series Analysis of the Primary Pollutants which Cause Acid Rain (with *W.R. Terry*)

Session 6 Geophysical 2 10.45-12.30 *Organised by Professor E.A. Robinson*

F. El-Hawary (Canada) An Approach to Seismic Information Extraction
I.R. Mufti (USA) Recent Developments in Seismic Migration
P. Goupillaud (USA) The Layer-Cake Model Revisited

Session 7 Spatial 2 16.45-18.30 *Organised by Professors J.K. Ord & L.A. Aroian*

R.J. Perry (USA) An Investigation into the Suitability of a Space-Time Autoregressive Model for Forecasting Highway Condition Data
Ö.L. Gebizlioglu (Turkey) On the Modelling, Estimation and Hypothesis Testing for Spatial ARMA Processes
D.L. Quigg (USA) ARMA Model Identification: Time Series in M-Dimensions

Saturday, 13 August

Session 8 Mixed Session 08.30-10.15

G. Treviño (USA) A Method for Approximating the Mean-Value of Nonstationary Random Data
C.E. Schmid (USA) ARMA Maximum Entropy Spectral Analysis Using Iterative Prewhitening
D.J. Malec (USA) Spatial Analysis of Census Data (with *M.J. Katzoff*)

Session 9 Spatial 3 10.45-12.30

U. Hjorth (Sweden) Space-Time Modeling of a Moving Field
P. Barone (Italy) A Class of STAR Models for Stationary Processes Smoothly Varying in Space
D.S. Stoffer (USA) Maximum Likelihood Fitting of STARMAX Models to Incomplete Space-Time Series Data

Session 10 Plenary 2 16.45-18.30

K.W. Hipel (Canada) Causal and Dynamic Relationships between Natural Phenomena (with *W.-K. Li*, Hong Kong, & *A.I. McLeod*)
E.A. Robinson (USA) The Right-Half Autocorrelation Theorem (with *S. Treitel*)
O.D. Anderson (UK) Closing Remarks.

Edited Abstracts (for presented papers not included in these Proceedings)

1. P. BARONE (Italy)
A Class of STAR models for Stationary Processes Smoothly Varying in Space

In biological environments, one often measures the same phenomenon from different spatial locations and within a given time interval. The detrended series, corresponding to each site, is generally correlated with those at all other sites, and may exhibit a time dependent correlation structure which varies smoothly over space. To model such series, a general multivariate AR model was simplified by partitioning the parameter matrix, for each lag, into subsets and then imposing deterministic constraints on each subset. This gives rise to a STAR model with specific weighting matrices.

2. Ö.L. GEBIZLIOGLU (Turkey)
On the Modelling, Estimation and Hyopthesis Testing for Spatial ARMA Processes

This paper attempts to provide a theoretical development for the representation of purely spatial series by ARMA family models. With an appropriate sampling scheme it is shown that, using the correlation structure of an observed spatial process, a suitable model can be fit with parameters estimated by minimum variance prediction error, least squares, or maximum likelihood methods. A means of hypothesis testing the representation is presented.

3. P.L. GOUPILLAUD (USA)
The Layer-Cake Model Revisited

After 25 years, the layer-cake (1-D) model of the stratified earth is today one of the major tools for seismic exploration. Being a lattice model, it can be viewed as a Markov chain or an ARMA system; therefore standard spectral estimation methods can be applied to both the forward and inverse problems. The application of statistical concepts to seismic exploration, introduced by E.A. Robinson 30 years ago, has not yet produced its full potential return. An attempt is made to explain why, and suggestions are offered to show where, in the author's opinion, research efforts should be focused.

4. U. HJORTH (Sweden)
Space-Time Modeling of a Moving Field

A stationary or periodically stationary field is moving relatively to a reference coordinate system. A covariance model is derived for the multivariate time series observed at a given set of points in the reference system. Applications to weather observations are indicated.

5. S.G. KAPOOR & W.R. TERRY (USA)
*A Vector Time Series Analysis of the Primary Pollutants which Cause Acid Rain**

This paper evaluates two automatic methods for modeling time series: (1) the Data Dependent Systems approach of Pandit and Wu, and (2) Akaike's Markovian State Vector representation. These are compared with respect to the form of the family of models each uses, and the means by which they select an appropriate model. Results obtained from modeling atmospheric concentrations of nitrogen and sulfur dioxides are discussed.

6. D.K. QUIGG (USA)
ARMA Model Identification: Time Series in M-Dimensions

Time series in M-dimensions form a class of models developed to study data

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* Paper to appear in Time Series Analysis: Theory and Practice 7.

dependent upon both time and space via an extension of Box-Jenkins analysis. The identification and subsequent analysis of ARMA models is crucial. In this paper we extend to time series in M-dimensions the generalized partial autocorrelation array, the GPAC. We study the theoretical and sample properties of the GPAC, the autocorrelation function, and the partial autocorrelation function, for such series with M = 1; and comment upon correct model order identification using these means.

7. W.R. TERRY & A. KUMAR (USA)
A Markovian State Vector Representation for the Influence of Wind Speed and Atmospheric Stability on Sulfur Dioxide Concentration

Considering the physical phenomena suggested that wind speed and atmospheric stability are important determinants for the maximum sulfur dioxide (SO_2) concentration in the immediate vicinity of a major pollutant source. Since all these variables vary continuously and randomly in time, their dynamic behavior was conceptually represented by a stochastic differential equation in which maximum SO_2 concentration is the dependent variable and wind speed and atmospheric stability are independent variables. Since such a stochastic differential equation has an equivalent state vector representation, the work of Akaike was used to determine the most appropriate Markovian state vector representation for the system. Implications of the resulting model are discussed.

8. G. TREVIÑO (USA)
A Method for Approximating the Mean-Value of Nonstationary Random Data[*]

By "nonstationary" is meant data whose mean-value, $\mu(t)$, is a definite function of time, in contrast to "stationary" data where $\mu(t)$ is constant. The method is formulated by first assuming that while the functional form of $\mu(t)$, $0 \leq t \leq T$, is some polynomial in t, $\mu(t) = \sum_{n=0}^{\infty} a_n t^n$, this can be approximated linearly in a "small enough" time interval. The defining slope and intercept are then determined from the available data. The slope is computed following Treviño (1982), while the intercept is computed using a "shifted-average" scheme, the application of which is new.

9. D. WARTENBURG (USA)
Blocked Quadrat Variance or Spectral Density: Speed versus Power in Transect Analysis

Field ecologists collecting survey data are often confronted with a dilemma in data analysis: should one analyze transect data by quick, easy to compute, blocksize ANOVA techniques or should one use spectral techniques which require computer processing? It has been shown elsewhere that blocksize approaches are equivalent to considering spectra of filtered series, and thus only use a portion of the information available through spectral techniques. Blocksize techniques are recommended for quick field analysis, and to focus attention on features of interest, but rigorous spectral approaches are valuable in providing a more complete picture of the variation. Examples using actual data are given.

These Proceedings

Regrettably, only about half of the papers offered for this Conference have eventually made the present book. Some were not accepted for final presentation, others could not be presented; and the remainder failed to be

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* Paper to appear in Time Series Analysis: Theory and Practice 7.

completed, or were not revised satisfactorily. We share the disappointment of the unpublished authors, but our aim to hold standards high must be maintained.

Although some contributions span more than one of the Special Topic areas of Time Series Analysis, which were considered at the Conference, the published papers are ordered within the three (interconnected) streams: Hydrological, Geophysical, and Spatial.

The Referees

We are most grateful to the following 52 specialists (from 9 countries) who helped with the refereeing, and in the reviewing process, for this volume:

A. Abakuks (UK)
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S. Zachary (UK).

The Authors

OLIVER D. ANDERSON is a graduate of the UK Universities of Cambridge, London, Birmingham and Nottingham; with first class honours degrees in Mathematics and Economics, and master's degrees in Mathematics and Statistics.

He has worked in Industry, for Government, and as a Consultant Statistician; and taught in Schools, Colleges and Universities. He has lectured in over 20 countries and published some 200 items. He is an active member of a dozen professional societies (in England and abroad) concerned with Education, Mathematics, Statistics, Operations Research, Management Science, Economics and Ēconometrics; and, in 1979, was honoured by election to the International Statistical Institute. More recently he has become involved with Management, Marketing and Information Science.

Dr LEO A. AROIAN has been Research Professor of Management and Administration at Union College, Schenectady, New York, USA, since 1974; and, before that, Professor from 1968, after considerable previous experience in both industry and academia. He has received much recognition during his outstanding career and many honours, including election to Fellowship of the American Statistical Association.

ANDREW D. CLIFF is University Lecturer in Geography, and a Fellow of Christ's College, at Cambridge University, England. His research interests include spatial diffusion processes and related areas of quantitative geography. His publications include Spatial Processes: Models and Applications with Keith Ord, and Locational Analysis with Peter Haggett and Alan Frey.

DANIEL A. CLUIS is a graduate of the French universities of Paris and Grenoble, with a doctorate in Statistical Fluid Mechanics. In 1970, he joined the Institut National de la Recherche Scientifique (INRS-Eau), a research center of the University of Quebec devoted to multidisciplinary water research and graduate studies. His research concerns water quality modelling, network rationalization and the application of statistical techniques to the hydrosciences.

AFRANIO R. DE MESQUITA has an MPhil (1972) in Statistics from the University of Southampton, UK; and an MS (1969) and PhD (1978), in Oceanography, from the University of São Paulo, Brazil, where he is currently an Associate Professor in the Department of Physical Oceanography.

FERIAL EL-HAWARY received her BSc (1967) and MSc (1971) in Electrical Engineering from the Universities of, respectively, Alexandria (Egypt) and Alberta (Canada); and, in 1981, was awarded a PhD in Ocean Engineering by the Memorial University of Newfoundland. Currently, she is a Research Assistant Professor at the Technical University of Nova Scotia, and has published several papers in "modeling and seismic signal processing for identificatfon of ocean subsurface features". Dr El-Hawary is a member of Sigma Xi, IEEE, and the Marine Technology Society.

DANIEL A. GRIFFITH graduated from Indiana University, Pennsylvania, and the University of Toronto; his degrees include a BS in mathematics, and an MA and PhD in Geography. He has taught in Schools, Polytechnical Institutes, and Universities, and has had a dozen research projects funded. He has directed two NATO Advanced Studies Institutes, has lectured in 7 countries, and has published some 32 items, including two edited books. He is an active member of the Association of American Geographers and the Regional Science Association, and serves on the editorial board of Geographical Analysis. In 1980 he was selected a Nystrom Competition finalist for his doctoral dissertation work.

KEITH W. HIPEL is an Associate Professor, and Associate Chairman for Undergraduate Studies, within the Department of Systems Design Engineering at the University of Waterloo. He obtained his Bachelors and PhD degrees in Civil Engineering, and his Master's degree in Systems Design Engineering, from the University of Waterloo.

As well as being a member of the American Water Resources Association, the American Geophysical Union and the Association of Professional Engineers of Ontario, Dr Hipel is an Associate Editor of Water Resources Bulletin and Chairman of the Surface Runoff Committee of the Hydrology Section in the American Geophysical Union. Besides doing engineering consulting in operational research, Dr Hipel has taught special courses and seminars in foreign countries such as Brazil, China, Japan, Singapore and the United States. His present research interests include the use and development of stochastic modelling techniques in the geophysical sciences and the incorporation of political and non-quantitative considerations into the systems design of large scale engineering projects.

Dr Hipel has co-authored two textbooks and co-edited two volumes on stochastic modelling, and has published his research in various international journals of engineering and operational research.

A. IAN McLEOD is an Assistant Professor in the Department of Statistical and Actuarial Sciences at the University of Western Ontario. He holds a PhD in Statistics from the University of Waterloo, for which he won the doctoral gold medal prize in 1978. His main research interests are in the theory and application of time series models, stochastic hydrology and statistical algorithms.

PEDRO A. MORETTIN, MA (1971) and PhD (1972) in Statistics, from the University of California at Berkeley, is Chairman of the Statistics Department, University of São Paulo, Brazil. He is also Editor (Theory and Methods) for Estadistica, journal of the Inter-American Statistical Institute.

IRSHAD R. MUFTI received his PhD in geophysics in 1966 from Clausthal Technische Universitaet, West Germany. He has served as senior research scientist, Amoco Production Co (1971-1980); research physicist, Geological Survey of West Germany (1963-1967); and geophysicist, Geological Survey of Pakistan (1958-1962). He has been actively engaged in various research and exploration projects dealing with seismics, geoelectrics, gravity and aeromagnetics. He holds two patents dealing with geoelectric and thermal remote-sensing along boreholes.

Dr Mufti joined Superior Oil in 1980 as research consultant. His current interests include the application of numerical and iterative techniques to the processing and interpretation of seismic data. He is a member of SEG, EAEG and the Geophysical Society of Houston.

J. KEITH ORD is Professor of Management Science and Statistics at the Pennsylvania State University, USA. Previously he was Reader in Statistics at Warwick University, England. His main research interests lie in forecasting and in spatial processes. His publications include Spatial Processes: Models and Applications with Andrew Cliff, and The Advanced Theory of Statistics, Volume 3, with the late Sir Maurice Kendall and Alan Stuart.

ROBERT J. PERRY is a graduate of Rensselaer Polytechnic Institute, the Graduate School of Public Affairs at the State University of New York, and Union College, Schenectady; with a bachelor's degree in Chemical Engineering, masters degrees in Public Administration and Applied Statistics, and a doctorate in Administrative and Engineering Systems. He has been employed by the New York State Department of Transportation since 1962; and, at present, is a Principal Civil Engineer in the Construction Division. He is a licensed Professional Engineer and a member of Sigma Xi, the American Statistical Association, and the American Society of Public Administration. Prior to 1977, Dr Perry was a member of the American Society for Testing and Materials' Committee D4, "Road and Paving Materials", and the Transportation Research Board Committee A2G04, "Adhesives".

ENDERS A. ROBINSON has made enormous contributions to signal processing, in geophysics; and to time series analysis, in general. He has published numerous research papers and books on these subjects, which combine outstanding scholarship with exceptional readability. A giant in both theory and practice, Dr Robinson is rightly regarded as the Father of Deconvolution, which he has nurtured and developed for over 30 years. Enders is currently a Distinguished Professor at the University of Tulsa, Oklahoma.

TOM SCHILPEROORT received an MSc (1977) in electrical engineering and mathematical engineering from the Twente University of Technology, Netherlands; and is currently project engineer at the Delft Hydraulics Laboratory. His main research interests are in time series analysis, system identification and parameter estimation, and adaptive filtering and control. Within the framework of consulting activities he has carried out applied work on many different hydrological and hydraulic problems; including optimization of monitoring networks, spectral analysis of waves and turbulence, optimization of depth of channels, identification of water quality models, and prediction of water levels and wave energy in estuaries.

CHARLES E. SCHMID received a BSEE (1963) from Cornell University, an MSEE (1968) from the University of Connecticut, and a PhD (1977) in electrical engineering from the University of Washington. He has been with Honeywell since 1966, where he works on various aspects of underwater acoustics and digital signal processing. In 1980 he spent 3 months with Honeywell ELAC in Keil, West Germany. Most

recently, he has been working on sonar trainers in conjunction with Honeywell's training organization in West Covina, California. Dr Schmid is a member of Tau Beta Pi and belongs to the Acoustical Society of America (presently serving as chairman of its N.W. Chapter).

W. EDWIN SHARP, BA (1958), MA (1960) and PhD (1964), from the University of California at Los Angeles, is currently Associate Professor, Department of Geology, University of South Carolina, Columbia, USA. He has also worked as a Research Scientist (1964-66) in Johannesburg, South Africa, and held a post-doctoral Fellowship from the Royal Norwegian Council for Scientific and Industrial Research (1976-77). Dr Sharp has published 35 papers and a number of maps, monographs and reports.

ROBERT M. THOMPSTONE is Senior Coordinator of the Hydraulic Resources Group Power Operations in Quebec for Alcan Smelters and Chemicals Ltd, where he has been employed for the last nine years. Prior to that, he spent two years with a private consulting firm specializing in water resources management. Mr Thompstone holds a BASc in civil engineering and an MASc in management sciences from the University of Waterloo, and a BSpAdm in business administration from the University of Quebec at Chicoutimi. He is also currently a part-time PhD candidate in the Department of Systems Design Engineering, University of Waterloo.

Acknowledgements

I would like to thank all participants for coming, speakers for presenting their work, referees for assessing it, and authors for preparing final copy for publication; and, especially, the Organising Committee and the other Editors, for all their extensive and extended efforts. As usual, I think everyone will agree that Inez van der Heide, at North-Holland, has done an excellent job in preparing this volume for print.

Looking Forward

The Proceedings for the final 1983 ITSM are also in press:

Time Series Analysis: Theory and Practice 7
General Interest ITSM, Toronto (Canada) 18-21 August, 1983.

Although there will be no ITSMs held in 1984, we have begun to plan for 1985. Prospective authors should write to the first Editor, at the address below, for details on submitting abstracts and papers.

OLIVER D. ANDERSON
TSA&F, 9 Ingham Grove, Lenton Gardens, Nottingham NG7 2LQ, England
July 1984

Part 1
Hydrological Time Series