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GEOPHYSICAL INVERSE PROBLEMS

Elizabeth and Frederick White Research Conference, Canberra, July 1987

The first of the Elizabeth and Frederick White Research Conferences sponsored by the Academy of Science was held on the 2nd and 3rd July 1987 at Ellerton Becker House in Canberra. The research conference on 'Geophysical Inverse Problems' was organised by Dr Brian Kennett, Professorial Fellow in Seismology, Research School of Earth Sciences, Australian National University and Professor Keeva Vozoff, Professor of Geophysics at Macquarie University. The meeting attracted 70 participants, from universities, mining companies, CSIRO and the Bureau of Mineral Resources with a good student representation. Three distinguished speakers came from overseas to give invited lectures.

Sir Frederick White attended the first morning's sessions of the meeting and a formal opening of the conference series was made by the President of the Academy of Science, Professor D. R. Curtis, FAA, FRS just before lunch on the first day.

The aim of this research conference was to encourage work in Australia on the development of techniques for the construction of geophysical models from observed data. Such methods have applications to a wide range of situations in exploration and larger scales especially for seismic and electromagnetic problems. Inverse problems of this type are particularly important in geophysics because the places where observations can be made are limited to close to the earth's surface, so that often only rather restricted types of data are available. This creates problems which do not arise in other disciplines, e.g. medical tomography, where a full coverage of source and receiver positions can be achieved.

In most cases the dependence of the observable geophysical quantities on model parameters is nonlinear and this poses considerable mathematical and computational difficulties. In the last few years considerable progress has been made on the problem of nonlinearity, with some significant work in Australia, and the papers in the conference focussed particularly on the newer nonlinear inversion schemes.

The sessions began with an invited paper by Professor G. Nolet of the University of Utrecht, the Netherlands, who gave a general introduction to the problems encountered in the inversion of large data sets in seismology. His talk was illustrated by numerous examples drawn from the work of his group on the construction of three-dimensional models of the structure of the Earth beneath Europe from earthquake travel times and on the use of the waveforms of seismic surface waves. His practically oriented approach was complemented by the viewpoint expressed by the second invited speaker, Professor A. Tarantola from the Institut de Physique du Globe in Paris, who showed how probabilistic arguments could be used to establish a formal framework for studying inverse problems. The common assumption that the errors of physical processes have a Gaussian probability density leads to familiar methods of the least-square type. However, when the statistics of error processes are studied in detail, e.g. for seismic travel times, the Gaussian assumption is rarely justified and it may be necessary to make allowance for errors in the physical modelling leading to estimated data values.

Dr R. S. Anderssen (CSIRO, Mathematics & Statistics) pointed out that in many problems a full construction of a geophysical model may be neither necessary nor desirable, because what was really sought was a specific linear functional of the model parameters. For many problems such a quantity can be estimated quite well from the available data values.

Dr B. L. N. Kennett (R.S.E.S., A.N.U.) gave an account of some of the recent methods which have been developed to deal with large scale inverse problems, especially those where the geophysical model contains parameters of a number of different dimensions. Such 'subspace' methods have been successfully applied in a number of problems involving the estimation of seismic structure from travel times. Examples of the method and its extensions were given by Dr. P. R. Williamson (C.G.E.R., Macquarie University) who discussed the construction of the seismic velocity field above a reflector and its shape from observations of the times of reflected seismic waves, and Mr M. S. Sambridge (R.S.E.S., A.N.U.) who was trying to extract the three-dimensional seismic structure of southeastern Australia using data from both earthquakes and explosions.

A number of other talks at the meeting were directed at the 'Seismic Tomography' problem of estimating seismic velocities, using a variety of different methods. Dr S. Edwards (Monash University) summarised the approach taken by the groups at Monash and Macquarie Universities in association with CSIRO Radiophysics, in determining structure between boreholes. In this treatment extensive efforts are made to incorporate geological information about the structure, to guide the subsequent inversion. Such information might come, for example, from the downhole seismic reflection experiments described by Dr H. Holmes (University of New South Wales). The use of tomographic methods in association with seismic reflection and refraction experiments in joint work between Flinders University and the Bureau of Mineral Resources was described by S. Sugiharto (Flinders University) with application to velocity structures in Central Australia. Dr G. Bock (University of New England) showed how observations of travel times to seismic stations in the Tonga Islands from different groups of deep earthquakes in the Tonga-Fiji seismic zone could be used to constrain the shape of the subducting plate.

A second contribution by Professor A. Tarantola showed that it is now possible to attempt to invert entire waveforms in seismic reflection experiments, to try to recover velocity and density information. The numbers of parameters and data values are both very large indeed and require the resources of supercomputers to attempt the inversion. Considerable success has been achieved with synthetic data and progress is now being made with real data as well.

Inverse problems have application in a wide range of geophysical situations, and papers were delivered on electromagnetic and signal processing problems as well as seismology. The third invited speaker, Professor R. L. Parker from the University of California, San Diego, discussed a class of nonlinear inversion procedures in the determination of electrical conductivity structures. He showed that the best possible fit between observed and calculated data would be achieved by a model consisting of a limited number of conducting sheets, but that this model would be of very little geophysical relevance. In addition to fit to data, it was very important to place constraints on the class of model parameters which were to be determined in order to prevent extreme behaviour. One could, for example, look for models which possessed least structure in some sense (e.g. smallest gradient in conductivity) at the expense of only slightly worse fit to the data. A practical example of such an approach was provided by Mr I. Ferguson (RSES, ANU) using electromagnetic induction (MT) data collected from the bed of the Tasman Sea.

The question of the relative requirements on data fit, model constraints and the complexity of the resulting models was addressed by Dr D. Jupp (CSIRO Water Resources Research). He pointed out that inversion designed to produce the models with minimum structure, whilst useful in indicating what features could definitely be determined, suffered the disadvantage of suppressing marginal features which might be of potential commercial interest. An inversion had therefore to be tailored to suit the needs of the problem in hand. It could often be useful to vary the relative importance of data fit and model constraints to get the maximum information on the range of possible models which might give an acceptable fit between calculated and observed data values.

Dr P. Fullagar (Western Mining Corporation) discussed the problem of the deconvolution of seismic reflection traces when accurate knowledge of the seismic source wavelet was not available. By casting the problem of the recovery of the reflectivity of the earth in depth as an inverse problem he showed how ignorance of the seismic wavelet introduces nonlinear behaviour, whose influence can be assessed by looking at the way in which features in the earth model can be resolved.

The conference stimulated vigorous discussion which overran the allotted periods and extended well into the night, and served as a very useful forum for bringing together nearly all those actively working on geophysical inverse problems in Australia.