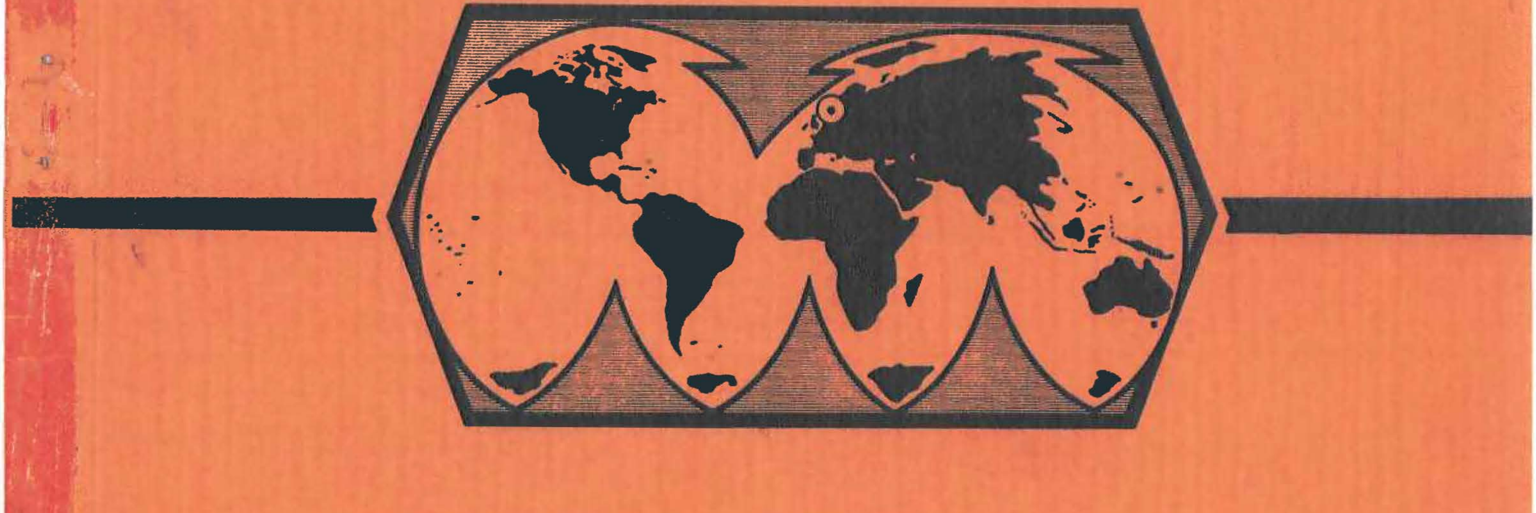
NORSAR ROYAL NORWEGIAN COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH

Scientific Report No. 2-80/81

SEMIANNUAL
TECHNICAL SUMMARY
1 October 1980—31 March 1981

By
Alf Kr. Nilsen (ed.)

Kjeller, June 1981



VI.5 Seismic Moment Tensors and Kinematic Source Parameters

Parameters pertaining to the kinematics of a finite source are usually estimated by fitting specific models to the data. On the other hand, these parameters, including source location, are also contained in the moment tensors of higher degree. The source can always be represented by a generalized function, the moment tensor density. In an explosion it represents an imposed stress pulse, but in an earthquake it is the difference between the true physical stress and the model stress which satisfies Hooke's law. If the source region is 'reasonably' small (compared to the wavelengths), it is possible to approximate the effect of a moment tensor density by a limited number of moment tensors of degree zero and higher. This representation was discussed by Backus (1977), but no attempts to do the inverse problem were reported, previous studies dealing almost exclusively with the moment tensor of degree zero (usually referred to as 'the moment tensor'). The zero degree tensor does not contain spatial information (including source location), and parameters like fault geometry and rupture velocity are still obtained by fitting observations to specific 'classical' models like those of Haskell and Savage. These source parameters represent averages over the fault, so it is the long-wavelength part of the seismograms (relative to source dimensions) that is used to estimate them. Clearly, these parameters must be related to the moment tensors of higher degree, and it thus appears worthwhile to explore the feasibility of estimating these moment tensors. In doing so it is important to keep the number of unknown parameters small, and this consideration suggests to approximate not only the spatial extent, but also the source time function, by a few parameters. Such a procedure is not only practical, but also meaningful in the sense that, ideally, spatial and temporal source functions should be approximated in the same way. The representation in terms of spatial and temporal moment tensors up to degree two involves 90 source parameters, together with spatial and temporal derivatives of Green's functions. Under fairly weak assumptions however (Doornbos, 1981), the number of source parameters may be reduced to 20, and spatial derivatives rewritten in terms of temporal derivatives of asymptotic wave functions which are easy to evaluate. The 20 source parameters are

$$M_{jk},\quad \Delta\tau,\quad \Delta\xi_{\ell},\quad \Delta(\tau^2),\quad \Delta(\tau\xi_{\ell}),\quad \Delta(\xi_{\ell}\xi_m)\ ;\ j,k,\ell,m = 1,2,3$$

and the tensors M_{jk}, $\Delta(\xi_{\ell}\xi_m)$ are symmetric. Here M_{jk} determines the final static moment, $\Delta\tau$, $\Delta\xi_{\ell}$ determine the source 'center' in time and space, $\Delta(\tau^2)$ represents source 'rise time', $\Delta(\tau\xi_{\ell})$ involves average rupture velocity, and $\Delta(\xi_{\ell}\xi_m)$ represents the spatial geometry. The equation relating these source parameters to the seismic response is nonlinear (unlike the moment tensor representation of degree zero), but for inversion purposes it can be efficiently linearized. Fig. VI.5.1 shows long-period SRO and ASRO records of a deep event in the Bali Sea, with P, SH and SV phases. Of these, SV was not used because of suspected interference with SP. With two components of P, one of SH, and record lengths 40 seconds, we have in the time domain, after resampling to a 4 sec interval, 240 equations for the 20 unknowns. Although these equations will not all be independent, there is reason to expect that the problem is sufficiently overdetermined for the source inversion to be feasible. This is one of the principle advantages of inversion in the time domain.

In Figs. VI.5.2-4, results are shown from experiments involving different options and conditions (denoted by case numbers in the figures). Some features of the source relocation (Fig. VI.5.2) deserve further investigation. In particular, the relocations in time and space seem to be too large to be explained by finite source effects alone; these results were essentially unchanged after including depth phases (case number 7,8). The use of an earth model different from that used in PDE determinations might be a factor. In some cases we allowed an isotropic component to develop. The moment of this component is illustrated in Fig. VI.5.3 for two cases. The event location was fixed in case 2; in case 5 the event was relocated, and it appears that the inferred isotropic component can be made to essentially disappear by relocating the source.
In Fig. VI.5.3, the deviatoric part of the moment tensor was decomposed into a major and minor double couple; this decomposition, though non-unique, serves to illustrate the deviation from a representation by one double couple only, and the major double couple can be used to construct conventional fault plane solutions (Fig. VI.5.4). It appears that differences among the various solutions are small, and the solutions are consistent with observed polarities and amplitudes (corrected for path effects). In one of these cases, moments of degree

two have been estimated. The RMS error of fit (not shown) is smaller than in all other cases, as expected with the larger number of degrees of freedom. However, the solution does not satisfy some of the physical criteria (including positivity of some of the parameters), and it appears necessary to incorporate these criteria as constraints in the inversion. The reasons for this are now being explored, and methods for constrained inversion are evaluated. The constraints are precisely those appearing as a priori assumptions in the conventional methods of source anlaysis; thus it will also be possible to investigate the impact of these assumptions.

D.J. Doornbos

References

Backus, G.E., 1977. Interpreting the seismic glut moments of total degree two or less, Geophys. J.R. astr. Soc., 51, 1-25.

Doornbos, D.J., 1981. Seismic moment tensors, in 'Identification of Seismic Sources', eds. E.S. Husebye and S. Mykkeltveit, D. Reidel Publ. Co., in press.

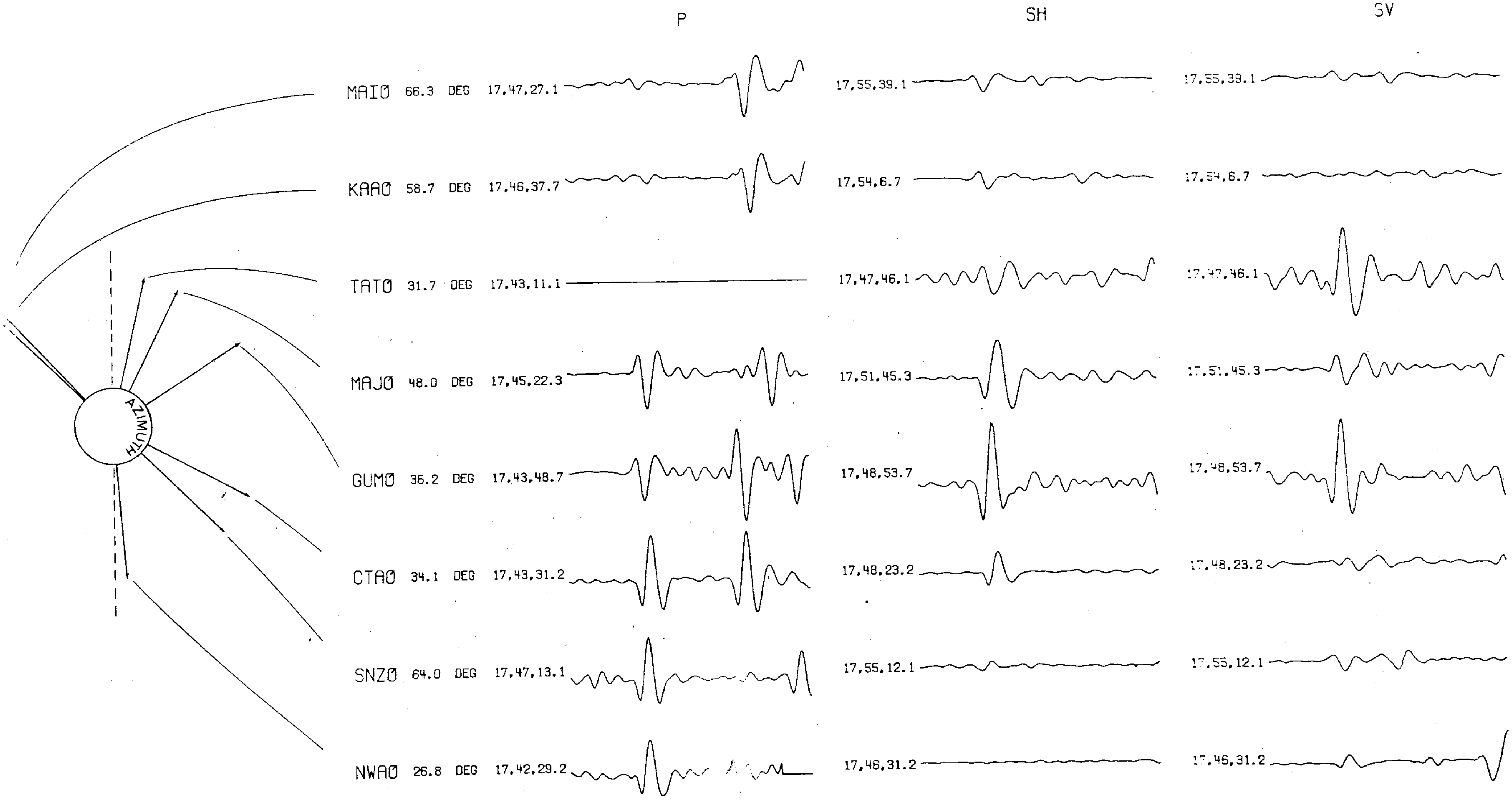


Fig. VI.5.1 SRO and ASRO records from Bali Sea event of 1978, June 10. Vertical component with P, horizontal components rotated into transverse and radial, with SH and SV. Record length is 4 minutes. Different amplitude scale for different components. The P vertical component of TATO was not used because of presumed nonlinearity effects.

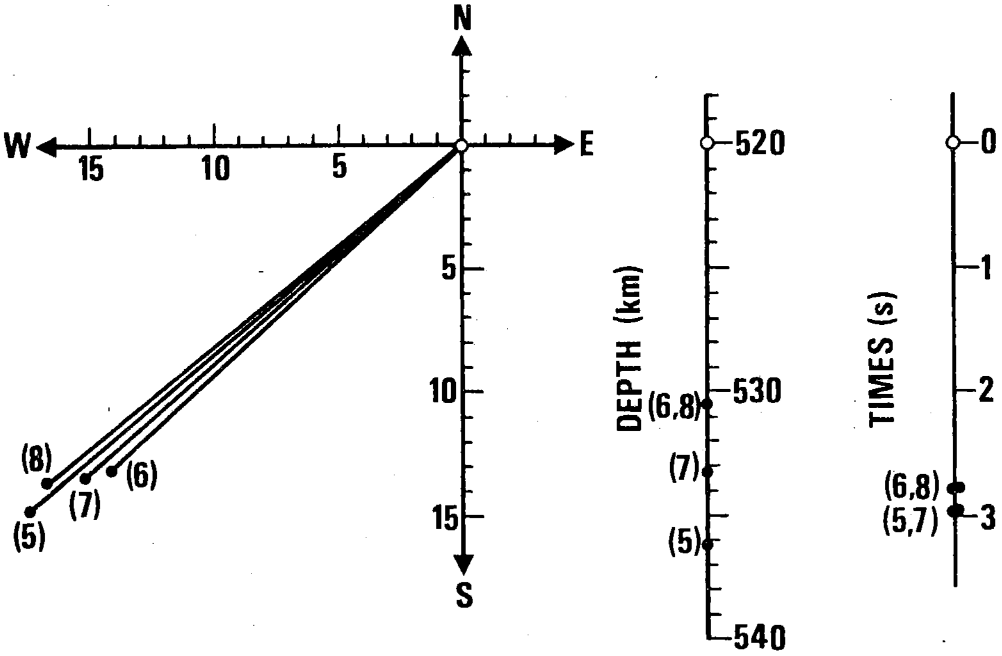


Fig. VI.5.2 Results of source relocation in space and time. Case numbers refer to different conditions and options in the inversion.

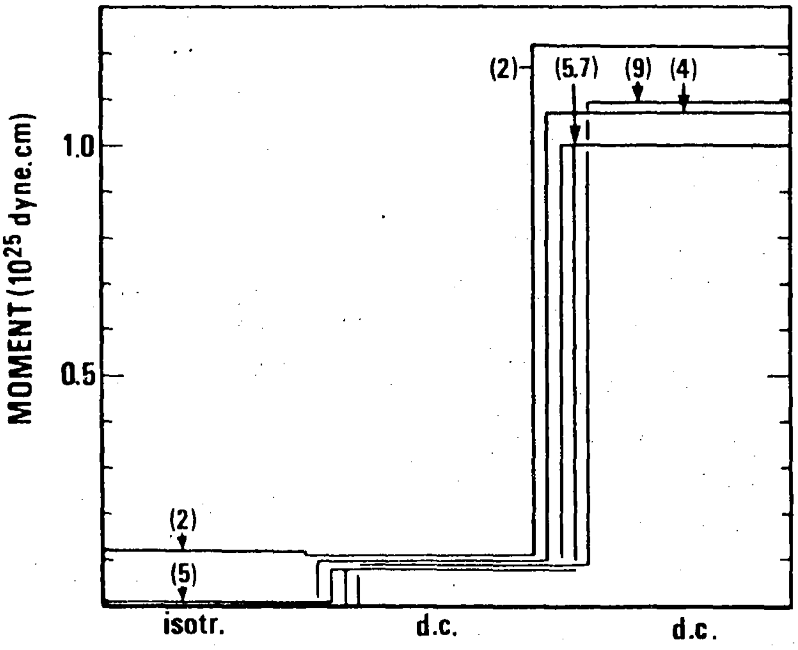


Fig. VI.5.3 Scalar moments of decomposed source, for different inversions. Decomposition in isotropic part and major and minor double couple.

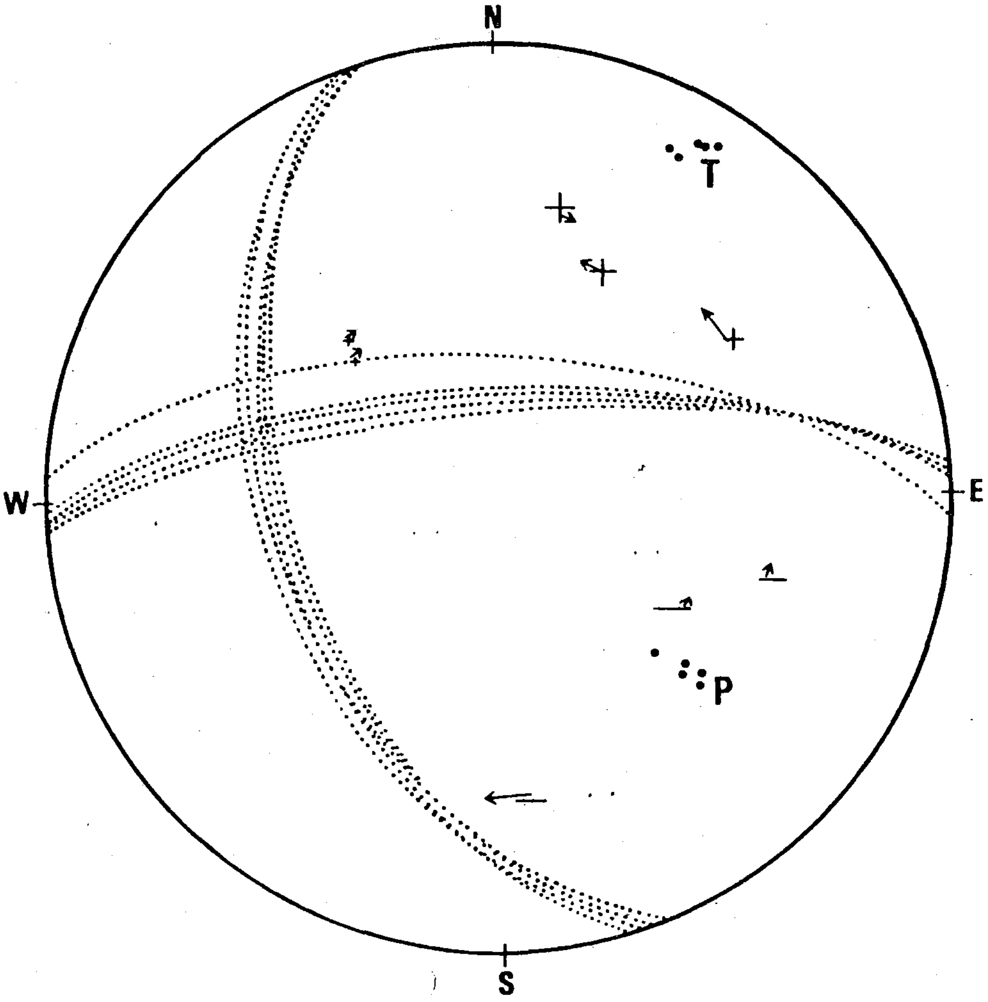


Fig. VI.5.4 Fault plane solutions in equal area projections, for different inversions. Also shown are observed polarities and amplitudes of P(±) and SH(→).