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VI.2 P-wave Travel Time Studies using a Continental Array

Although the Jeffreys-Bullen (J-B) tables for travel times of seismic waves have been in existence for more than thirty years, they still form the most commonly used basis for global determination of earthquake locations. It is increasingly becoming clear that in order to obtain any significant improvement to these tables, region-dependent corrections are necessary, as the 'average' properties of the (J-B) tables seem to be close to optimal for world-wide applicability (possibly apart from a base-line correction). However, reliable region-dependent travel-time corrections are generally hard to come by, as the travel time residuals often exhibit strong and unpredictable variations even over small source and receiver regions. This has been manifested in recent years by the considerable time delay anomalies found across arrays such as LASA and NORSAR for given seismic signals. On the other hand, these observations have been the key to improving our understanding of the structure of the lithosphere and asthenosphere underneath these arrays, thereby providing important knowledge on the origin of travel time anomalies in general.

The present study is an attempt to extend the previously mentioned analysis techniques applied at NORSAR and LASA to continental 'arrays' consisting of a number of regionally deployed standard seismograph stations. The data base has been taken from the ISC bulletins and covers the years 1971-1975. We have used the following model to isolate the components of the observed travel-time residuals Y_{ijk} obtained from the ISC source parameters and using the J-B tables (for details, see Husebye and Ringdal, 1977):

$$Y_{ijk} = R_{ik} + S_k + \gamma_{jk} + \varepsilon_{ijk} \qquad (1)$$

i = i-th station
j = j-th event
k = k-th source region

where:

- R_{ik} denotes near-receiver effects and varies by station and region, but is assumed constant for events within a (small) source region

- S_k denotes source effects and is, for a given event and region, assumed constant for all stations within the network. The variations of source effects within a given source region are considered random and included in the term γ_{jk}, which is assumed to be normally distributed. Note that γ_{jk} will include apparent 'source effects' that are due to, e.g., possible mislocations of the events or erroneous origin time.

- ε_{ijk} is a normal random variate that incorporates effects not previously accounted for, such as inherent uncertainties in the travel time estimates caused by small-scale perturbations along the ray path. Possible minor errors in the reading of signal arrival times at different stations are also included in this term, while larger errors in these readings have been avoided by excluding all observed residuals of more than 5 seconds in absolute value.

We should like to comment on the physical realization of the R_{jk}-term which is tied to a 2-D modelling of structural heterogeneities in the lithosphere beneath the receiver. It is here assumed that these anomalies are restricted to a layer of thickness of the order of 30-50 km at the bottom of the lithosphere which thickness is typically 150-200 km within continental areas. The mentioned assumed heterogeneous layer is in turn subdivided into blocks, the areal extent of which is typically 15 x 15 km. The source regions are indirectly defined via this block pattern, in such a way that each source region comprises those events whose ray path to the center station of the network penetrates a given block. The above approach is a viable alternative approach to the more complicated 3-D modelling of Aki et al (1976, 1977), which in practice is restricted to the dense sampling of large aperture seismic arrays and similar networks as demonstrated by Haddon and Husebye (1977, see also section VI.3).

The model (1) is made complicated by the effect of missing observations, which in fact occur frequently when using ISC data. For example, when considering a network of 15-20 stations in Fennoscandia, the number of available observations for a given event would very seldom exceed 5-10. For this reason, the solution of (1) must take missing observations into account.

Referring to Husebye and Ringdal (1977) for details, Fig. VI.2.1 shows a 'Fennoscandian continental network' of 17 stations used in conjunction with the present model. Note that NORSAR is included in this network, but only as a single station, i.e., only the observed absolute arrival times at instrument 01A01 are used in the present context. Fig. VI.2.2 shows the pattern of residual terms R_{ik} obtained for NORSAR when applying the model (1) to the Fennoscandian network. For comparison, Fig. VI.3.2a shows a corresponding pattern of anomalies obtained by Haddon and Husebye (1977) using NORSAR data only, i.e., using NORSAR as an array station. The correspondence between the two figures is seen to be excellent. The apparent baseline shift between the two patterns is not important in the present context, as the baseline correction is arbitrarily defined as zero in Fig.VI.3.2a. Thus it has been demonstrated that the simple model (1) may indeed be used to extract information on the underlying structure of single seismograph stations. Moreover, our results suggest that the quality of this information, at least as concerns gross structures, will be comparable to that obtainable by analyzing time delay residuals from seismic arrays. Of course, it is necessary in this respect to have a suitable network nearby in order to apply (1) and eliminate 'average' source effects. We plan in the near future to conduct similar analyses for various subsets of the global network of stations reporting to the ISC, and also combine the resulting structures into more large-scale patterns wherever possible.

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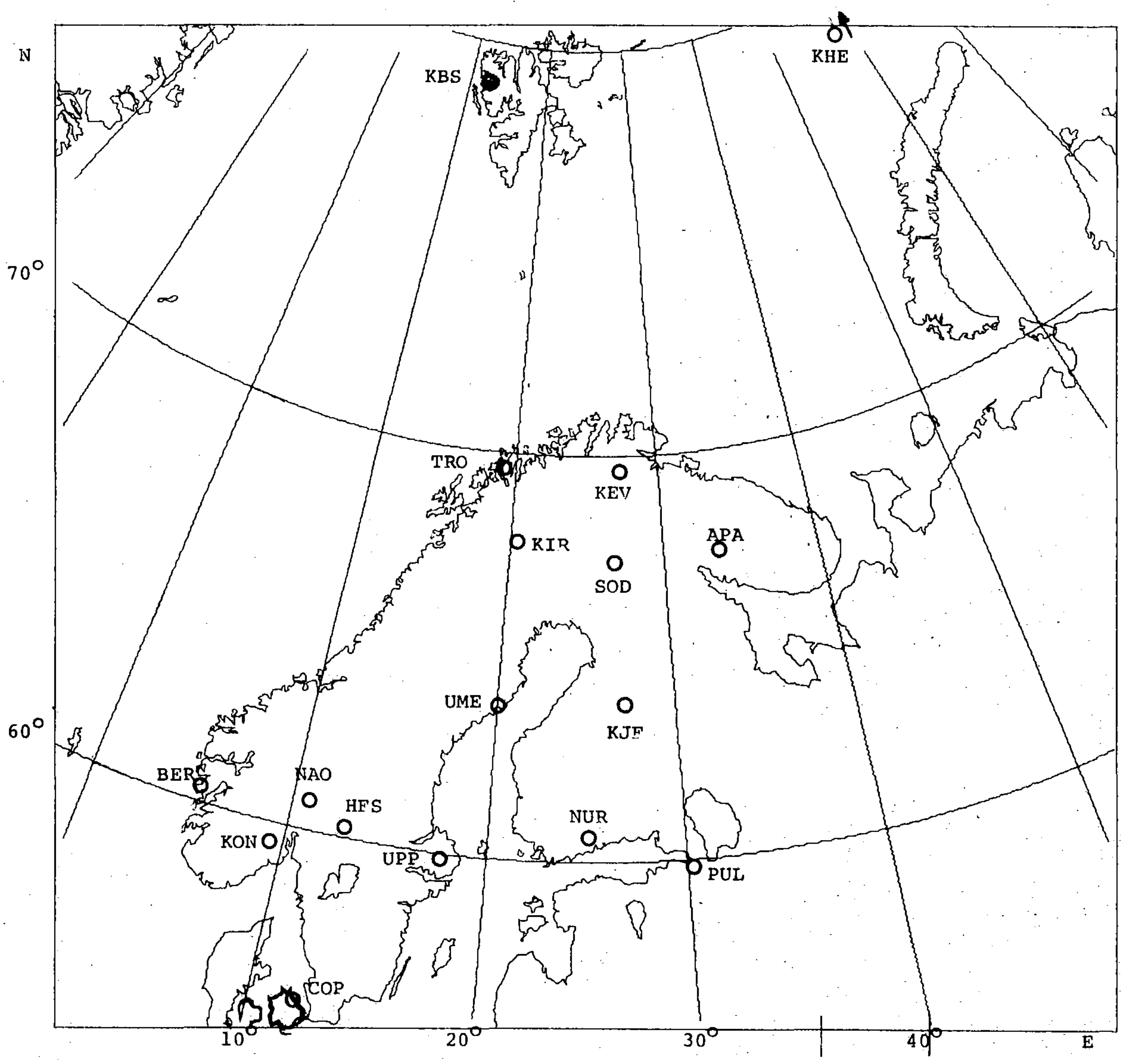

Fig. VI.2.1 Location of stations within the extended Fennoscandian continental array used in this study.

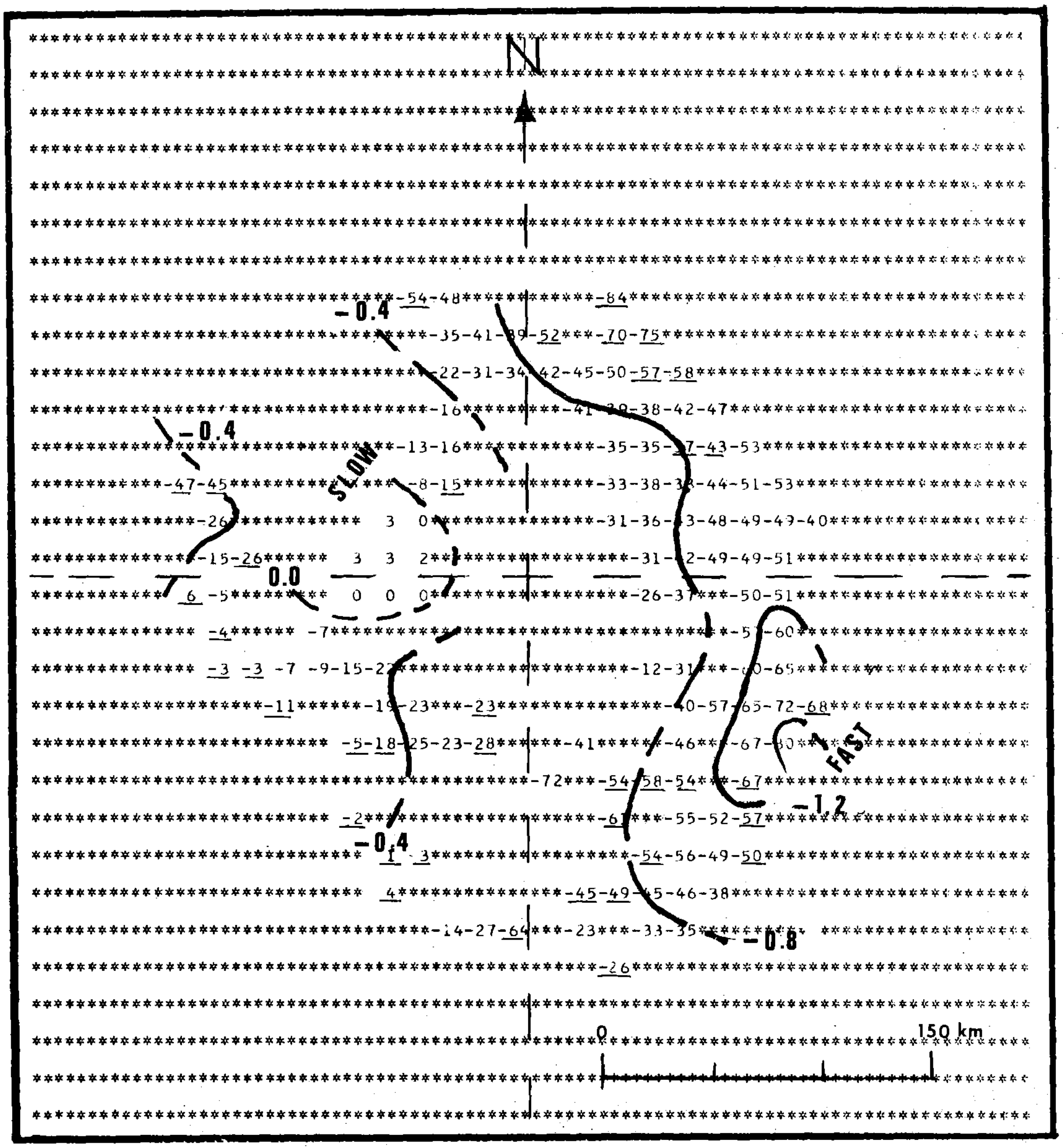

Fig. VI.2.2 NORSAR travel time residuals derived from ISC-data files using the continental array shown in Fig. VI.2.1. The given numbers are in units of 1/50 sec, except for the time residuals associated to the contours which are specified in seconds. The time anomaly pattern presented here (and derived from absolute time observations) is in good agreement with similar results presented in Fig. VI.3.2a (and derived from relative time observations). Although areas of slow and fast structures are almost coincident, a flat baseline shift of approx. 0.5 sec is apparent. The non-uniqueness in estimating this parameter is discussed in detail in Husebye and Ringdal (1977).