Robust Bearing Estimation for Three-component Stations

JOHN P. CLAASSEN

Abstract — A robust bearing estimation process for 3-component stations has been developed and explored. The method, called SEEC for Search, Estimate, Evaluate and Correct, intelligently exploits the inherent information in the arrival at every step of the process to achieve near-optimal results. In particular, the approach uses a consistent framework to define the optimal time-frequency windows on which to make estimates, to make the bearing estimates themselves, to construct metrics helpful in choosing the better estimates or admitting that the bearing is immeasurable, and finally to apply bias corrections when calibration information is available to yield a single final estimate. The algorithm was applied to a small but challenging set of events in a seismically active region. It demonstrated remarkable utility by providing better estimates and insights than previously available. Various monitoring implications are noted from these findings.

Key words: Bearings, estimation, polarization, corrections, location, association.

Introduction

As the monitoring thresholds of global and regional networks are lowered, bearing estimates become more important to the processes which associate sparse detections and which locate events. Current methods of estimating bearings from observations by three-component (3-c) stations lack both accuracy and precision (Alewine, 1992; Koch and Kradolfer, 1997). Methods are required which will develop all the precision inherently available in the arrival, determine the measurability of the arrival, provide better estimates of the bias induced by the medium, permit estimates at lower SNRs, provide an indication of the precision of the estimate, and develop insights into the effects of the medium on the estimates.

Various approaches have been advocated to estimate the polarization properties and bearings associated with seismic arrivals. The theoretical basis for defining the polarization properties of signals appears to have arisen from the seminal work of Born and Wolf (1975) where analytical (complex-valued) signals and notions of coherency were introduced for narrowband signals. It was perhaps this work that

---

1 Monitoring Technologies Department, Sandia National Laboratories, Albuquerque, NM 87185-0975, U.S.A., E-mail: jsclaass@swep.com
motivated SAMSON (1983) to define the degree to which signals are polarized in higher dimensional spaces. Later efforts by VIDALE (1986) reminded us how important it is to define polarization in terms of analytical signals and that the general vibrational modes associated with three-component observations are elliptically polarized. MAGOTRA et al. (1987) showed how the horizontal components of an entire wavetrain could be used to estimate backazimuths. Here the polarity of the \( z \) component relative to the horizontal signal components was used to remove the azimuthal ambiguity. JURKEVICS (1988), limiting the analysis of \( P \) arrivals to real-valued (as opposed to complex-valued) signals, demonstrated how to construct an observational covariance matrix by averaging the covariance matrix over 3-c elements of an array to realize bearing estimates having more precision. Although Jurkevics advocated the use of polarization properties to isolate intervals on which to make bearing estimates, no viable rationale to isolate the appropriate estimation interval was offered. Indeed, Jurkevics suggested using signal frequency bands having the best SNR relative to the background noise as a method for defining a measurement interval. However, this approach fails in practice because it does not account for signal-induced noise. In a more recent work WALCK and CHAEL (1991) evaluated various combinations of frequency bands and time-windows in the context of four bearing estimation techniques (MAGOTRA et al., 1987; FLINN, 1965; CHRISTOFFERSSON et al., 1988; ROBERTS et al., 1989) to demonstrate the bearing estimation capability of the three-component RSTN. They demonstrated that bearings for events in eastern North America could be estimated with an accuracy of 6 degrees rms if the estimates from station RSSD, residing on a “pathological” geology, are eliminated. In a notable work by LILLY and PARK (1995) complex-valued orthogonal Slepian wavelets were used to elegantly estimate the polarization properties of seismic signals.

The 3-c bearing estimation method disclosed in this work differs from prior efforts in that it makes the following assumptions: 1) not all frequencies or time intervals will be equally effective in producing measurable bearings, 2) only those time-frequency windows which have good polarization properties will result in precise estimates, 3) the estimates themselves may be frequency-dependent, 4) those estimates having the largest effective degrees of freedom (a confidence measure) will experience the greatest variance reduction and are the best candidates to combine into a refined estimate which may include bias corrections, and 5) the bearing estimates associated with an event from a given epicentral region will, in general, require correction for frequency-dependent lateral refraction or diffraction. A bearing estimation method, called SEEC for Search, Estimate, Evaluate, and Correct, was developed on these underlying assumptions. Earlier disclosures of this technique can be found in CLAASSEN (1998a, b).

In the following section the SEEC methodology is disclosed. To evaluate the bearing estimator the method was applied to a small but challenging set of regional events observed in an active tectonic region of the western United States by a station