

The international seismological observing period in Africa

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ABSTRACT

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The International Seismological Observing Period (ISOP) is a specific time interval designated for enhanced international cooperation in the collection and dissemination of observatory measurements from the global seismographic network. The primary purpose of the ISOP is to strengthen the international infrastructure that supports current seismological practice and increase the cooperation among nations that operate seismological observatories. Measurements, reported by the existing global network and compiled by agencies such as the International Seismological Centre (ISC), are providing new information about earthquakes and the structure of the Earth of fundamental importance to the Earth sciences. However, these data represent but a small fraction of the information contained in the seismograms.

One of the goals of the ISOP is to collect improved sets of data. In particular, the measurement and reporting of later-arriving phases, during a fixed ISOP period, from earthquakes selected for detailed observation by the cooperating stations will be encouraged. The use of advanced, digital instrumentation provides an unprecedented opportunity for enhancing the methods of seismogram interpretation and seismic parameter extraction, by the implementation of digital processing methods at seismic observatories worldwide. It must be ensured that this new information will be available to the entire seismological community. It is believed that this purpose is best served with an ISOP that promotes increased on-site processing at digital stations in Africa and elsewhere.

Improvements in seismology require truly international cooperation and the educational aspects of seismological practice form one of the goals of the ISOP. Thus, workshops will be needed in Africa to train analysts in ISOP procedures and to introduce them to modern techniques and applications of the data. Participants will, thus, benefit from theoretical results and practical experience that are of direct relevance to their own work.

Introduction

The International Seismological Observing Period (ISOP) is a specific time interval designated for enhanced international cooperation in the collection and dissemination of observatory measurements from the global seismographic network. The ISOP project is sponsored jointly by the International Association of Seismology and Physics of the Earth's Interior (IASPEI), the IUGG Inter-Association Commission on the

Study of the Earth's Deep Interior (SEDI), and by the Inter-Union Commission on the Lithosphere (ICL). A brief history of and the initial planning activities for the ISOP are described in Engdahl (1989).

The benefits of the ISOP fall into two general categories:

- (1) significant improvements in the quality and quantity of data generated by the global network of seismic stations, especially the arrival times and amplitudes of seismic phases;

- (2) enhancement of the global infrastructure which supports observational seismology, including improvements in practice at seismological observatories, support for the trend towards station-based processing of digital data, increased opportunities for young scientists in developing

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countries to learn modern seismological methods, increased coordination among nations operating seismological networks, and improvements in practice at international data collection agencies.

A particular strength of the ISOP project is that it functions largely within the existing infrastructure of seismology, depending on a carefully managed program of extended communications, coordination, and cooperation, rather than major new capitalization. In this paper we describe some broad aspects of the ISOP project, with a focus on the African continent for examples.

Motivation and purpose of the ISOP

The concept of the ISOP project arose naturally from the recognition that seismology is a science which depends fundamentally on data gathered globally by an informal network of several thousand seismic stations. These stations voluntarily submit measurements from their records to agencies such as the National Earthquake Information Service (NEIS) and the International Seismological Centre (ISC). These data are processed for earthquake location and other source parameters and distributed to the seismological community in various forms. The consistent high quality of the data produced in this manner is a testament to the dedication of observatory personnel worldwide, and it has led to major scientific discoveries.

Nevertheless, significant improvements in the quantity and quality of the data produced by the global set of seismic stations could still be achieved by a carefully directed campaign to coordinate some of the observing activities of participating seismic observatories for a period of several years. In particular, the frequency of reporting of later-arriving seismic phases could be greatly increased. Such data would be of enormous benefit to studies of the deep structure of the Earth. The ISOP project is designed to produce a high-quality data set of arrival times and amplitudes of first- and later-arriving compressional and shear phases for a set of earthquakes selected to give optimal global coverage.

While this central observing activity has the clear scientific goal of providing improved resolu-

tion of the Earth's structure, numerous other benefits accrue from the activities needed to support this aspect of the ISOP project. Practices at participating observatories will be generally enhanced through the training activities envisaged under ISOP. For example, it is to be expected that the frequency and quality of reports of later-arriving phase data will, in many cases, remain at ISOP levels indefinitely. A general upgrading of procedures at the NEIS and ISC, for example, by installing new travel-time models, phase association algorithms, and telegraphic parsers to carry readings of later-arriving phases, is also planned under the ISOP, with the full participation of senior personnel from the appropriate agencies. The ISOP also offers a motivation for observatory operators to seek funding for equipment upgrades, including conversion to digital recording, which will permanently improve the capabilities of the global seismic network.

The ISOP includes activities which encourage the trend toward digital seismology, in particular, a much wider distribution of digital processing capabilities. At present, the raw digital data collected worldwide is processed at only a few major research centers, which, in most cases, have no mandate to process the data routinely and systematically for basic measurements such as arrival times and amplitudes. Those agencies which do conduct such processing are in danger of being overwhelmed by dramatic increases in data flow rates resulting from the widespread deployment of digitally recording seismic systems. Valuable data are effectively lost simply because resources are inadequate to perform even the most rudimentary processing and measurement protocols. Preprocessing of data at the observatory level is an important component of a strategy for alleviating this problem.

A less immediate problem arising from the trend toward digital recording of seismic data, but one with perhaps even more dire long-term results for the science, is the negative impact on observatory personnel when their role as seismic analysts is reduced or eliminated. Many promising young scientists can be expected to turn away from seismology if their major responsibilities are to maintain the equipment and mail tapes of raw

digital data to central processing agencies. This is especially important in developing countries, where qualified seismologists are desperately needed just to maintain current levels of operation at many observatories. Through workshops and by nurturing the capability for observatory-based processing of digital data, the ISOP provides opportunities for young scientists to learn modern seismological analysis techniques and gain a sense of involvement in an important international experiment.

Finally, the global infrastructure of seismology, so dependent on the cooperation between thousands of workers in over a hundred countries, can only benefit from the enhanced levels of communication and cooperation engendered during the ISOP. An important component of the project is to encourage individual and national observational initiatives which are consistent with the spirit of ISOP and to assist in the coordination and planning of such activities, especially where they require cooperation between seismological organizations which do not normally interact at this level.

Science goals of the ISOP

The purpose and structure of the ISOP project are distinctly different from other major initiatives in observational seismology, such as the development of a global digital seismograph network and the establishment of large portable seismic arrays, yet the scientific problems which are the basic motivation for all these activities to a large extent overlap. It is worthwhile emphasizing that, in addressing these problems, the role of the ISOP with relation to other organizations is, to a large extent, complementary. Below, we identify a set of important seismological problems whose solutions require improvements in operational practice in the spirit of the ISOP. (These issues are discussed at greater length in the ISOP Science Plan, available from the authors.) In doing so, we follow the common practice of distinguishing between problems involving the seismic source and those involving the structure of the Earth, although these problems are obviously strongly coupled.

Internal boundaries

Seismology's greatest contribution to the Earth sciences has been the characterization of the average radial velocity structure of a well differentiated Earth. Of particular importance are the discoveries of major internal boundaries revealed by rapid changes in velocity. It is perhaps surprising, therefore, that so little is known about the detailed structure of internal boundaries and about the possible existence of associated boundary layers. Notable examples include the 400 km and 650 km discontinuities and the core-mantle boundary region. A major barrier to progress in studies of these regions of the Earth is the lack of a well distributed and appropriate data set. The high quality ISOP data set of late-arriving phase arrival times and amplitudes for a well distributed set of earthquakes will stimulate significant progress in studies of these important boundary regions, as well as the three-dimensional structure of the entire Earth. The data set will be particularly appropriate for tomographic inversion studies of the Earth's interior.

Lateral heterogeneity

Inversions of global data sets of arrival time information for long-wavelength lateral variations are usually parameterized in terms of spherical harmonics up to some low degree and are thus insensitive to short-wavelength features in the Earth's structure. Parameterization schemes featuring block or cell structures alleviate this problem. However, such studies typically suffer from inadequate global coverage and relatively poor signal-to-noise ratio. It is known that small-scale structures are common even in the deep Earth, but not enough data are available to permit a systematic investigation of these features. Detailed studies of deep, short-wavelength heterogeneities will probably require the deployment of a dedicated observing system such as a (portable) array, but such investigations are both time-consuming and expensive. The ISOP would play a key role in the planning of intensive special-purpose studies by aiding in the identification of significant anomalies.

Earthquake location

It is the current practice of national and international agencies to use the arrival times of short-period P waves to estimate earthquake origin times and hypocenters. These are used, in turn, for such diverse purposes as analyzing seismic risk and studies of the Earth's structure. Accurate locations are vital for many of these applications, yet it is well known that current procedures often lead to inaccurate and biased hypocenters, especially in subduction zones. Additional problems may arise when inferences concerning source processes of larger earthquakes are made from the spatial and temporal offsets between the hypocentroid and the source centroid, which is estimated independently from long-period data. All of these problems suggest the use of phase information supplementary to the P waves. Supplementary information, involving shear waves from the source, is of interest not only because of the potential to improve resolution but also because it facilitates a comparison with the source centroid (which is constrained mainly by shear wave data). The use of shear waves requires an improved shear wave velocity model; the models currently in use lead to inconsistent locations from P and S phases. The construction and implementation of improved veloc-

ity models is one of the activities proceeding in conjunction with the ISOP (see, for example, Kennett and Engdahl, 1991).

Enhanced reporting of secondary phases during the ISOP

Traditionally, the basic measurements of global seismology are the arrival times and amplitudes of elastic waves recorded on seismographs. These readings are made by the operators of individual observatories (or local groups of observatories) and passed along, sometimes through national and regional agencies, to organizations such as the ISC in Reading, England, and the NEIS in Golden, Colorado, where they are used to produce estimates of earthquake locations and magnitudes. The earthquake source parameters, as well as the raw readings from individual seismograms, are distributed to the international seismological community in bulletins, on magnetic tape and, in some cases, on optical disc. Data have been systematically collected in this form for over half a century, and the maintenance of the continuity of this remarkable tradition of observation is an important concern of the ISOP project. Approximately 1500 observatories at present report arrival times and amplitudes to the ISC (Fig. 1) but, as the figure demonstrates, the distribu-

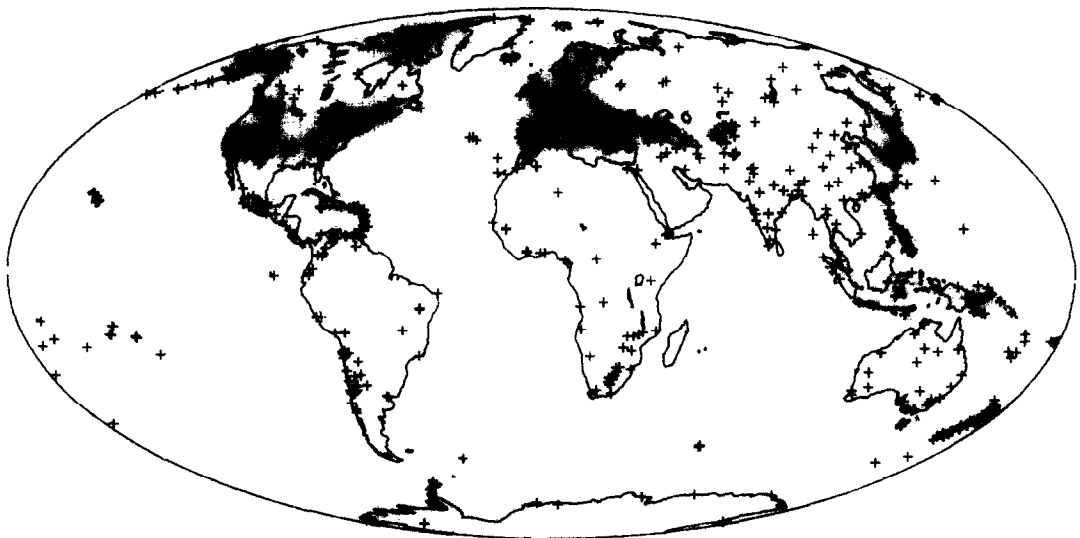


Fig. 1. Seismic stations reporting arrival times and amplitudes of teleseismic P phases to the ISC during the period 1964–1985. Mollweide projection.

tion of reporting stations is highly non-uniform. Africa and South America are very poorly monitored and coverage of oceanic areas is limited to island sites, which are normally quite noisy.

The enhanced reporting of the times of first- and later-arriving, high-frequency seismic phases will be an important ISOP activity. First, because such data have a clear role to play in resolving seismological issues of the first magnitude and, second, because the organizational structure planned for this purpose also supports a number of other ISOP activities which, in the long run, may have an even greater significance for the Earth sciences. To assist in planning the experiment, a series of investigations using the arrival time data base of the ISC were conducted to evaluate the past performance of the global network and to quantify the frequency with which primary and secondary phases are reported (Bergman and Jordan, 1987). A brief description of these experiments follows.

Performance of the global network

An overview of the performance of the network of seismic stations reporting to the ISC can be gained by plotting all reported arrival times

(relative to the origin time of the corresponding event) as a function of epicentral distance. Figure 2a shows these data for shallow earthquakes ($h < 50$ km) with body wave magnitude $m_b > 5$. A similar plot for earthquakes with focal depths between 550 and 600 km is shown in Figure 2b. In both cases, the data cover the years 1974–1984. The well-known one-minute-reading-error phase (preceding the first-arriving compressional phase) is clearly visible in both figures. The plot of arrivals from shallow-focus events contains 1,554,280 arrivals for 7,546 events; the plot for deep-focus events contains 80,632 arrivals for 337 events. Not surprisingly, P and PKP are reported most frequently. While some later arriving phases, such as PKKP and SKKS, are also observed, many important secondary phases are rarely reported, even though they are known to be clearly observable on many seismograms.

Frequency of Reporting

Over a dozen major seismic phases are reported to the ISC, but secondary phases are reported far less frequently than P and PKP (Fig. 3). The S phase is the most commonly reported secondary phase, but the number of reports is an

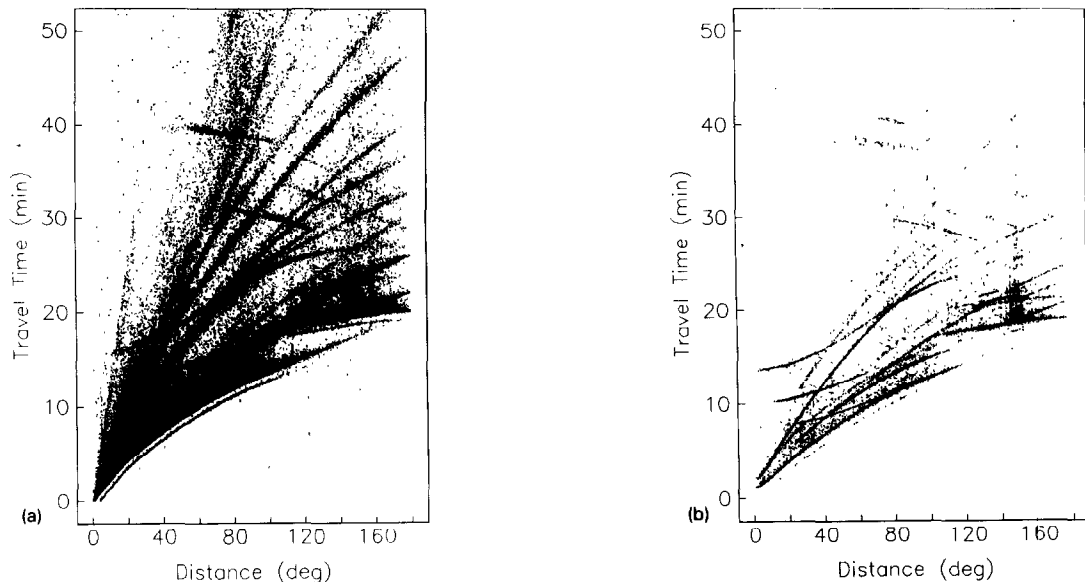


Fig. 2 (a) Scatter plot of travel time as a function of epicentral distance for 1.5×10^6 arrivals reported to the ISC for 7,546 shallow-focus ($h < 50$ km) earthquakes between 1974 and 1984. Only events with $m_b > 5$ are used. (b) Similar plot for 8×10^4 arrivals reported to the ISC for 337 deep-focus ($550 < h < 600$ km) earthquakes.

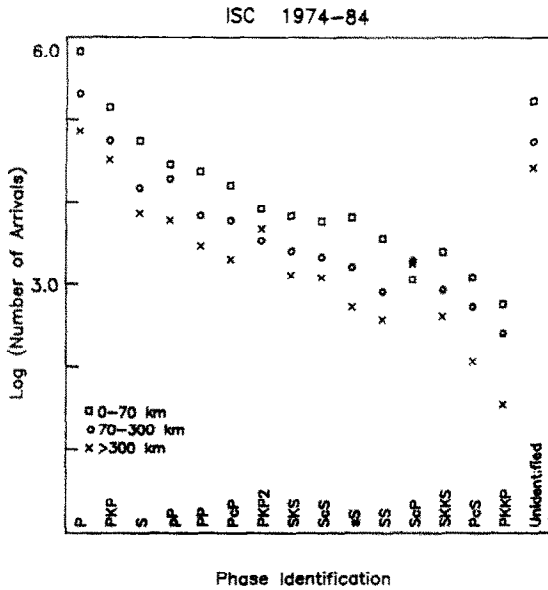


Fig. 3. Histogram of number of arrivals reported for different phases, divided into shallow (0-70 km), intermediate (70-300 km) and deep-focus (> 300 km) earthquakes.

order of magnitude less than for the first-arriving P or PKP. In Figure 3 "unidentified" phases are associated with a particular earthquake, but the ISC has been unable to assign a phase identifica-

tion. In general, the largest number of reports for any given phase occur for shallow-focus events, followed by intermediate-focus events; this is largely due to the more frequent occurrence of earthquakes at shallower depths. The difference in number of reported arrivals as a function of source depth is especially large for PcS and PKKP. There are several exceptions to this trend, however: the frequency of reports of PKP2 is higher for deep-focus than for intermediate-focus events, and ScP is reported more often for deep- and intermediate-focus events than for shallow events.

Station performance

For our purposes, station performance refers to the consistency and relative frequency with which a station reports the arrival times of major seismic phases. The station list contains 1379 stations, which approximates the number of stations that have reported to the ISC over the years 1964-1984. During the years 1974-1984, 582 stations reported fewer than 100 teleseismic ($\Delta > 30^\circ$) arrivals, 297 stations reported between 100

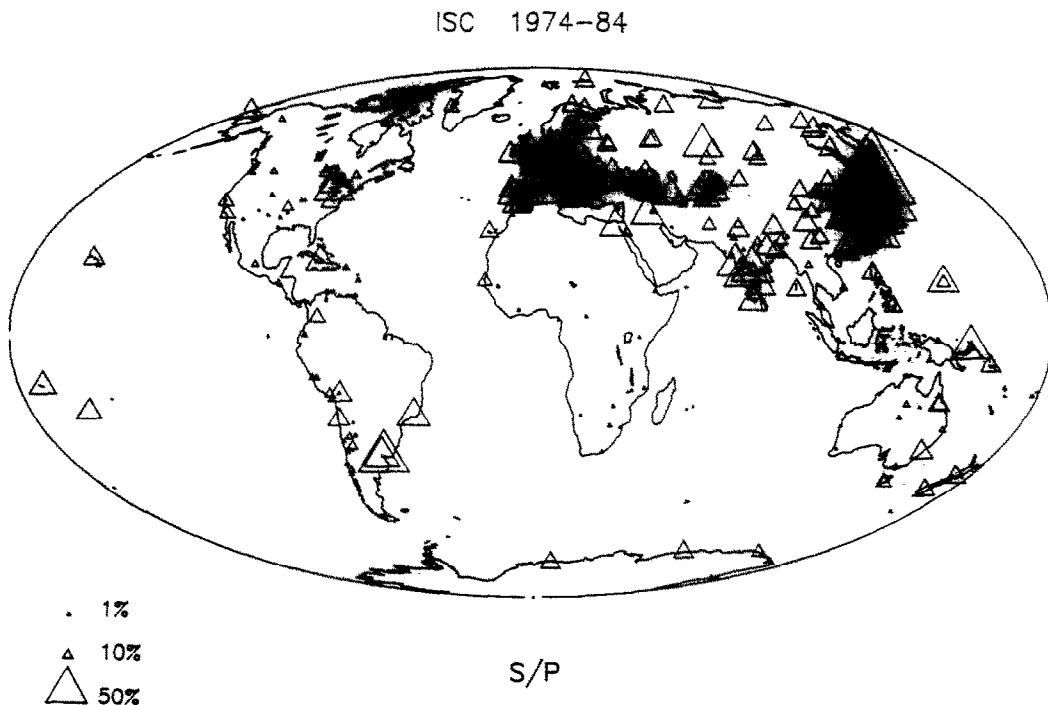


Fig. 4. Map showing the distribution of seismic stations reporting S waves at least 1% as often as they report P waves during the period 1974-84. Symbol size is proportional to the ratio S/P.

and 1000 arrivals, and 500 stations reported over 1000 arrivals. Many of the stations reporting few teleseismic arrivals are members of local networks whose primary responsibility it is to monitor local earthquakes. This is particularly true in Middle America and Japan.

Considering source–receiver pairs in the epicentral distance range $30^\circ < D < 80^\circ$, Bergman and Jordan (1987) investigated the frequency of reporting for several important secondary phases (PcP, ScS, and S), relative to the reports of P for shallow focus ($h < 50$ km) events for the years 1974–1984. Only 305 stations have a ratio of PcP/P greater than 0.01. Similarly, only 297 stations have a ratio of ScS/P greater than 0.01, and the geographic distribution of these stations is even poorer than for PcP. Very few stations have ratios of PcP/P or ScS/P exceeding a few percent. The situation is better for reports of S (Fig. 4): 386 stations have a ratio greater than 0.01 for S/P and for many the ratio exceeds 0.1. However, the reporting of S phases is dominated by

stations in Europe and Asia. The poor distribution of reported secondary phases is clearly a serious problem for global seismology.

Unassociated phases

The ISC graciously made available to us a data set containing the times of unassociated phases for the years 1981–1985, that is, arrivals which could not be identified as any standard phase for any earthquake processed by the ISC. While many unassociated phases are undoubtedly related to local seismicity or noise, some of these arrivals may correspond to important teleseismic phases which are not included in the ISC's association algorithm. Bergman and Jordan (1987) analyzed these data to search for evidence of such phases, particularly the PnKP phases. For each arrival time, they computed a travel time corresponding to each earthquake ($h < 70$ km, $m_b > 5.0$) during the previous 50 min. This procedure results in 55,677 travel times for 5,427 events, which are

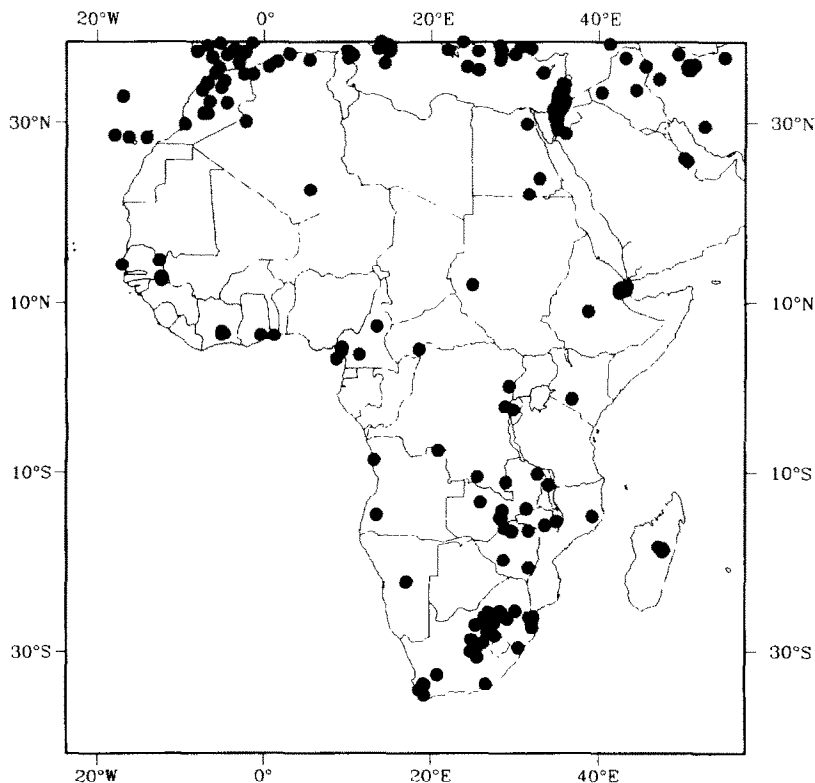


Fig. 5. Map showing the distribution of seismic stations in Africa reporting more than 10 phases to the ISC during the period 1964–1986.

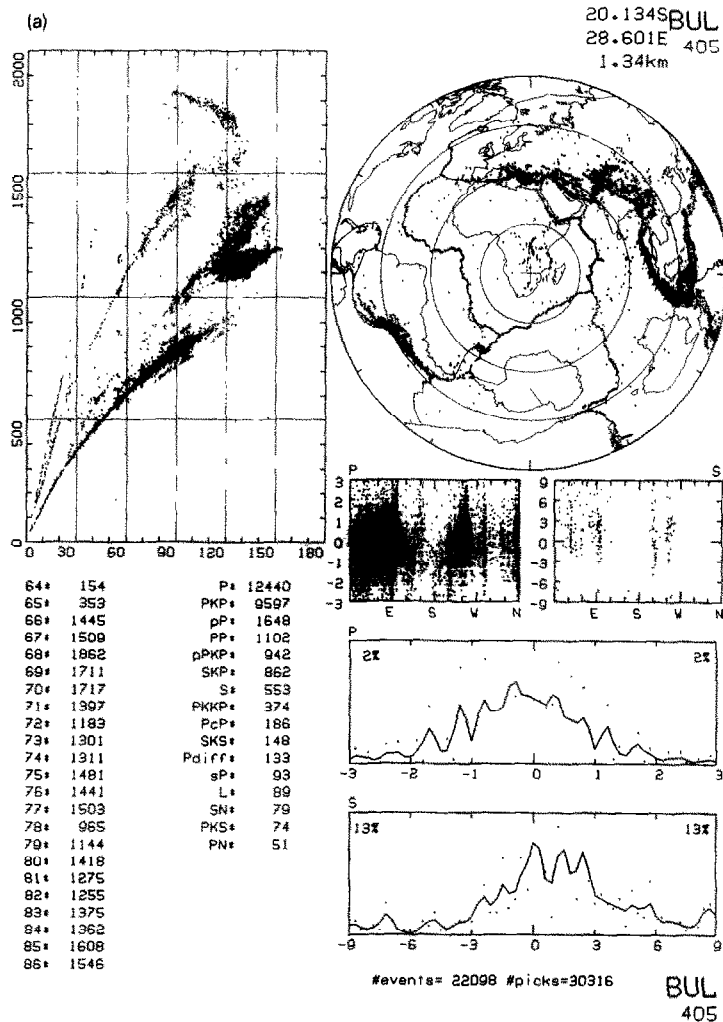


Fig. 6 (a).

grouped in quarter-degree by 3 s bins. A bin is considered occupied if it contains two or more travel times. Some of the patterns observed are caused by problems with the association algorithm for P at epicentral distances near 100° and the crossovers for PP and PcP, PP and PKP, and SP and PKKP. On the basis of this analysis it appears that a relatively small fraction of the unassociated phase data correspond to unidentified teleseismic phases.

African stations

To assess the performance of African stations, we show in Figure 5 seismic stations in Africa and surrounding regions that have contributed more

than 10 phase reports to the ISC during the period 1964–1986. Many of these reports are for regional earthquakes (R.D. Adams, pers. commun., 1991). While the distribution is not ideal, it does indicate the potential for more complete reporting in Africa. The performance of all African stations has been more fully investigated using an approach developed by Hwang and Clayton (1991). The ISC catalog from 1964 to 1986 was reformatted in order to create station history plots that display all travel time picks, event locations, and P and S wave residuals for each station. Figure 6a shows plots of the raw travel time data for the station at Bulawayo (BUL, see figure caption for details). Also shown is a summary of activity on a yearly basis and a list of

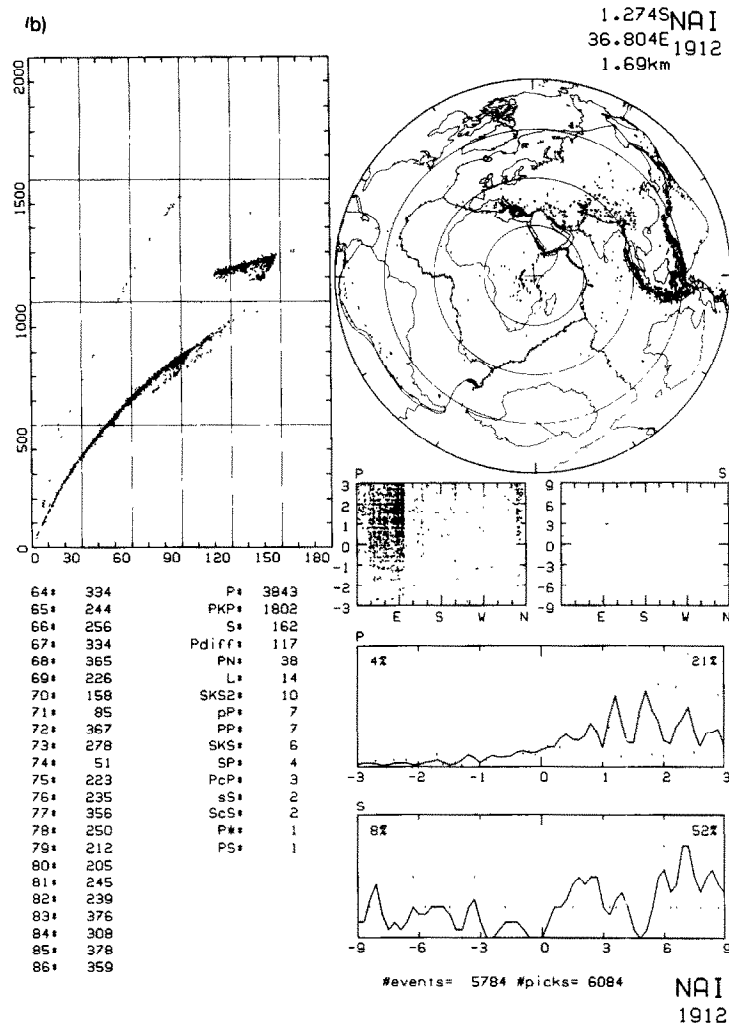


Fig. 6. (continued). (a) Station history plot for station BUL. The station name is shown in the upper right hand corner. Underneath the name is a station identification number. To the left is the station latitude, longitude, and elevation. Part of this information is repeated in the lower right hand corner. Plotted in the upper left hand corner are all the arrival times reported for that station at epicentral distances from 0–180° and times from 0–2000 s. Each event reporting a phase is plotted on the world map to the right. The map is centered on the station and each concentric ring represents a 30° increment in epicentral distance. The bottom line in the figure displays the total number of events and the total number of picks plotted. On the lower left-hand side, the first column displays how many phases were reported in that year. The second column shows the sixteen most frequently picked phases in descending order. The lower right-hand side of the figure displays the travel time residuals. The top set of figures displays the residuals of P (left) and S (right) phases with respect to azimuth. The bottom set of figures displays a histogram of the residuals sorted into 0.1 s bins. The plot of P wave residuals is clipped at ± 3 s and the S waves at ± 9 s. The height of each histogram is normalized to the height of the bin with the largest number of picks. The dots represent the actual data. The line is a smoothed version of the histogram through these data points. The numbers to the right and left of the histogram give the percentage of positive and negative residuals, respectively, not shown in the figure. (b) Station history plot for station NAI.

the most frequently reported phases. BUL is one of the best stations in Africa, in terms of the number of phases picked and the reporting consistency through the years, but even in this case the reporting of phases other than P and PKP

drops off sharply. The station at Nairobi (NAI), where reporting is largely limited to the direct-arriving P or PKP phase (Fig. 6b), is more typical of African stations, indeed, of most stations worldwide.

Observable phases

It is natural to wonder what teleseismic phases are clearly enough recorded to be widely reported, even when an effort to read them is made. A partial answer to this question has been obtained by applying a simple stacking procedure to GDSN long-period waveform data (Shearer, 1991; see Fig. 7 caption for details). Figure 7 demonstrates the clear presence of many secondary phases on most seismograms from moderate size events, although the pattern would be different at the 1 Hz frequency typically used for picking arrival times.

In conclusion, seismic station operators in Africa (and worldwide) are capable of picking numerous secondary phases but, for various reasons, the effort is not being made. It seems likely that legible secondary phases are not being picked at all at some stations, while they are picked but not reported systematically from others. Stations reporting secondary phases regularly are concentrated in a few geographic regions. Under the

ISOP project there would be a concerted effort to improve the general distribution and reporting level of stations worldwide. To some extent, this may be achievable simply by emphasizing to station operators the scientific importance of later-arriving phases and encouraging them to report all the phases they read. With perhaps only small increases in the level of effort of station operators and the ISC, the quantity and quality of data suitable for studies of the deep interior of the Earth could be greatly enhanced.

ISOP events

As discussed above, secondary phases are not consistently reported by the global observational network. One approach to the problem of infrequent reporting of later phases is to select specific earthquakes for detailed observation by cooperating observatories during a fixed ISOP period. Earthquakes would be chosen for this purpose on the basis of their location and depth, so as to obtain the broadest possible distribution of

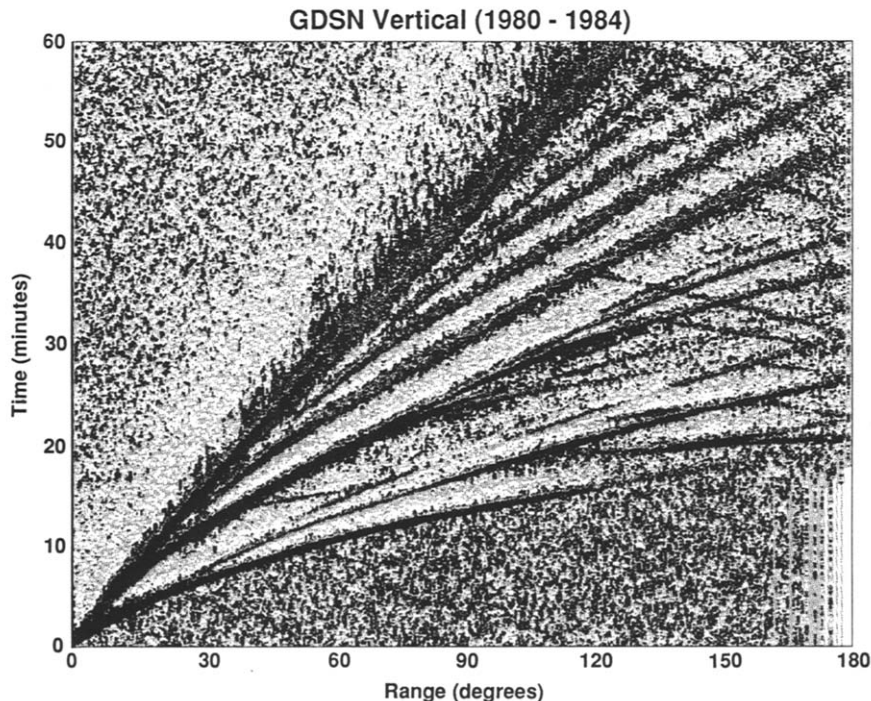


Fig. 7. Travel-time versus epicentral distance plot produced by stacking long period, vertical component GDSN data. All available data are normalized and binned at a spacing of 0.5° in range and 5 s in time. The amplitudes in the image are a measure of the average signal-to-noise ratio for the entire data set.

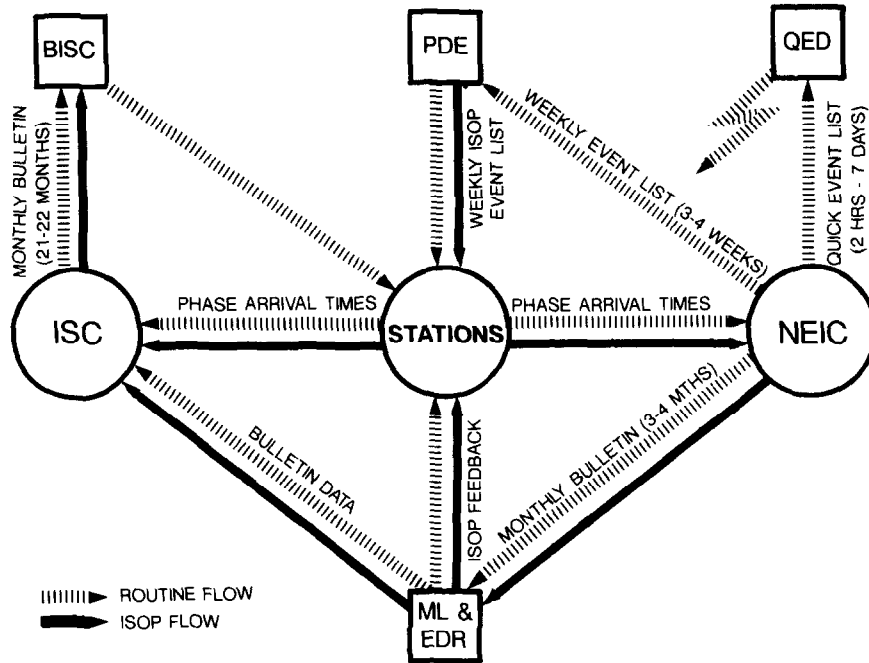


Fig. 8. Proposed data flow for the ISOP project. The routine flow of seismological data between contributing observatories and the NEIS and ISC is shown by the hachured lines. The special data flow for the ISOP project is shown by the solid lines; it remains almost completely within the normal channels.

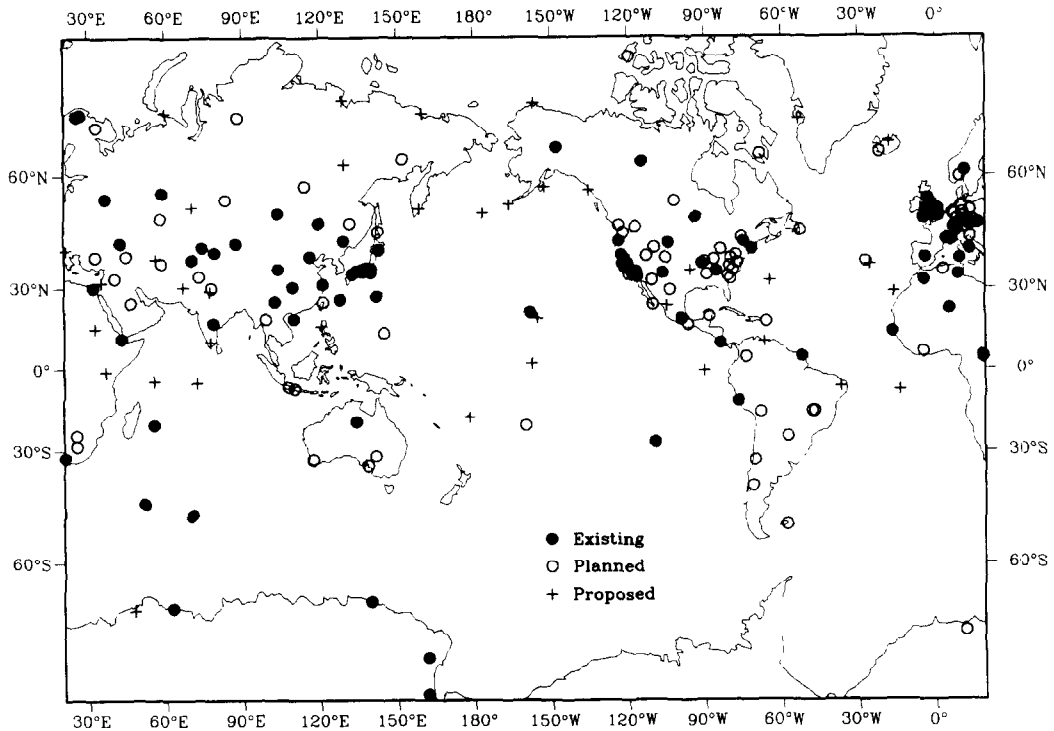


Fig. 9. Global deployment (as of August 1991) of new high dynamic range, broadband, digitally recording, three-component seismic systems.

sources; and on the basis of magnitude, to ensure that clear arrivals are recorded at larger epicentral distances. Ideally, an algorithm could be designed which makes the selection process semi-automated and which produces a reasonably stable workload for participating seismic observatories. A selection algorithm which appears to meet these goals has been described by Bergman (1989). From simulations of observing periods of varying durations using epicentral data from the ISC catalog, it appears that a 3 year ISOP, later-arriving phase experiment would provide a reasonably complete sample of seismicity from the major seismic zones of the Earth. In addition, a simply parameterized selection algorithm based on seismological priorities would lead to a stable, manageable workload of about one event per day, on average, during the life of such an experiment.

Data flow

To be successful, the program to enhance the reporting of secondary phases must be implemented in a way which produces the maximum scientific benefit with the minimum impact on observatory operators and on the flow of seismological data between those operators and international data centers, such as the ISC and the PDE program of the NEIS. Figure 8 shows one means of achieving this goal. The routine flow of seismological data between contributing observatories and the NEIS and ISC is shown by hachured lines and the special data flow for the ISOP is shown by solid lines. The ISOP data will remain almost entirely part of the current routine data flow. An important aspect of this flow diagram is the provision for rapid feedback to participating observatories, which will aid them in evaluating and improving their operational practices.

Digital seismology in the ISOP project

Recent technological advances in the digital recording of seismic data have precipitated a virtual revolution in digital seismology. Under programs sponsored by a number of countries, high dynamic range, broadband, digitally recording, three-component stations are being installed

at observatories worldwide (Fig. 9). Many of these efforts are being coordinated by the international Federation of Digital Broadband Seismograph Networks (FDSN). Data from these new stations have already revolutionized the study of earthquake processes and Earth structure. The ISOP project seeks to accelerate this trend, which will open up new opportunities for global studies, local and regional hazard reduction programs, and for observatory-based research. Some of the benefits of digital processing are summarized below.

Routine processing of digital data

An important aspect of the ISOP project is the goal of encouraging and assisting in the transition from analog to digital instrumentation at seismic observatories, particularly in developing countries which have minimal resources and minimal experience in this technology. A common impediment to this transition is the difficulty in processing digitally recorded data for the routine measurement of seismological parameters such as phase arrival times and amplitudes. This is the traditional task of the seismic observatory, one which is vital both to the progress of the science and to the long-term health of the global seismological infrastructure, but one which is often neglected as analog instruments are replaced by digital seismograph systems.

To address this issue, an international ISOP workshop sponsored by the FDSN and the US Geological Survey was held in Denver, Colorado, in March, 1991. The workshop brought together experts in the fields of digital seismometry and seismic analysis software. They explored the options currently available for performing routine seismological processing of digital data at seismic observatories, using inexpensive personal computers or more powerful workstations, and established guidelines for the measurement of the standard seismological parameters from digital data. The proceedings of this workshop have been compiled in a report which can be used as a guide for routine practice by observatory personnel making the transition to digital operations. By developing and distributing resources of this type,

the ISOP project can play an important role in helping to establish a global seismological network which is fully capable of carrying out the traditional observational programs of global seismology, as well as initiating new programs based on the expanded capabilities of digital instrumentation.

High frequency information, in the form of arrival times of seismic phases, is essential for many seismological applications, especially when high resolution is desired. Digital stations whose operation includes the high frequency range can provide this information in a relatively fast and objective way, and it is recommended that these stations supply such data, particularly where analog instruments have been replaced by digital ones, so that a uniform data base is maintained. Basic digital processing methods applied at broadband digital stations can significantly improve the measurement of travel-times of certain phases. Such methods have been applied successfully in the analysis of long-period data: Hilbert

transforming phases, such as PP, which are distorted during propagation constitute but one example of what is possible.

An important ongoing task of national seismic networks is to locate and analyze regional earthquakes. These events clearly form an important subset of data for studies involving global seismicity and the ISOP represents an excellent opportunity for standardizing the parameterization of such information and promoting greater regional cooperation among seismic networks to better meet these needs.

Parameterization

Parametric representations are common in many branches of science and technology. Fairly general, parsimonious parametric models have been developed, especially in the field of time series analysis. Parameterization is also a common procedure in seismology: examples are the times and amplitudes of seismic phases, and the

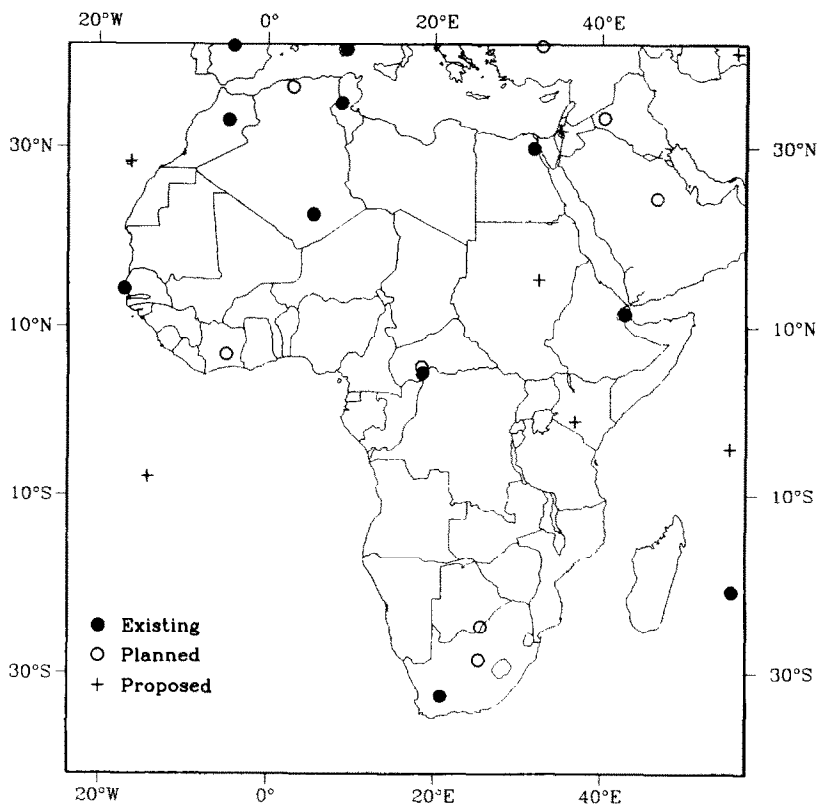


Fig. 10. Deployment (as of August 1991) of digital broadband seismograph stations in Africa.

location and magnitude of earthquakes. These parameters will continue to form an important data base for future seismological work and digital recordings can result in more accurate measurements. Nevertheless, the potential of broadband three-component registrations is not fully exploited with the parameterization in current use and, for certain research problems, standard data bases are not adequate in their present form. On the other hand, large data sets are needed for a satisfactory solution of some of these problems, and this again invokes the need to compress information in parametric form. Hence, the problem of earthquake signal parameterization is of great practical interest, with an immediate impact on the development of

station-based analysis. Appropriate experiments within the ISOP will be encouraged.

Regional studies

Research based on regional seismic data has seen a resurgence due to the increased deployment of three-component broadband stations and arrays. Array studies have revealed that local site effects severely distort the propagation of regional waves, such as P_n and S_n ; teleseismic phases are also affected. Three-component recordings are used in studies of anisotropy beneath the station by analyzing shear-wave splitting. An important product of such studies might be a formulation for generalized corrections for site re-

TABLE 1

Digital broadband seismograph stations in Africa

Station	Location	Code	Latitude (°N)	Longitude (°E)	Program	Status	Characteristics
Medea	Algeria		36.00	3.00	MEDNET	Planned	VBB, 140dB
Tamanrasset	Algeria	TAM	22.79	5.53	GEOSCOPE	Existing	VBB, 140dB (dual-gain)
Lobatse	Botswana	LBTB	-25.01	25.60	GTSN	Planned	VBB, 140dB
Bogoin	Central African Republic	BGCA	5.17	18.40	GTSN	Planned	VBB, 140dB
Bangui	Central African Republic	BNG	4.44	18.55	GEOSCOPE	Existing	BB, VLP, 140dB
					GEOSCOPE	Planned	VBB, 140dB (dual-gain)
Arta Cave	Djibouti	ACD	11	42	GEOSCOPE	Planned	VBB, 140dB (dual-gain)
Arta Grotte	Djibouti	AGD	11.53	42.82	GEOSCOPE	Existing	BB, VLP, 140dB
Kottamya	Egypt	KEG	29.93	31.83	MEDNET	Existing	VBB, 140dB
Dimbokro	Ivory Coast	DBIC	6.67	-4.86	GTSN	Planned	VBB, 140dB
Nairobi	Kenya	NAI	-1.27	36.80	IRIS (GSN)	Proposed	VBB, 140dB
Midelt	Morocco	MDT	32.74	-4.58	MEDNET	Existing	VBB, 140dB
Riyadh	Saudi Arabia		24.60	46.70	MEDNET	Planned	VBB, 140dB
M'Bour	Senegal	MBO	14.39	-16.96	GEOSCOPE	Existing	BB, VLP, 140dB
					GEOSCOPE	Planned	VBB, 140dB (dual-gain)
Silverton	South Africa	SLR	-25.74	28.28	GDSN (DWWSSN)	Existing	IP, LP, SP, 90dB
Sutherland	South Africa	SUR	-32.38	20.81	IRIS (GSN)	Existing	VBB, 140dB (dual-gain)
Boshof	South Africa	BOSA	-28.61	25.42	GTSN	Planned	VBB, 140dB
Khartoum	Sudan		15.50	32.50	IRIS (GSN)	Proposed	VBB, 140dB
Gafsa	Tunisia	GFA	31.34	9.73	MEDNET	Existing	VBB, 140dB

Programs: DWWSSN = Digital World-Wide Standardized Seismograph Network; GDSN = Global Digital Seismograph Network; GEOSCOPE = Project GEOSCOPE; GSN = Global Seismographic Network; GTSN = Global Telemetered Seismograph Network; IRIS = Incorporated Research Institutions for Seismology; MEDNET = Mediterranean Network.

Characteristics: bb = broadband; db = decibels; IP = intermediate period; LP = long period; SP = short period; VBB = very broadband; VLP = very long period.

sponse. The ISOP provides an opportunity to encourage and expedite such site characterization programs at participating observatories.

Digital instrumentation in Africa

The developments in digital seismology summarized above have important consequences for seismology in Africa. Figure 10 and Table 1 summarize current plans for the deployment of digital broadband seismograph stations in Africa. This deployment is sponsored by a number of programs with a variety of instrumentation meeting FDSN standards. Such programs provide an unprecedented opportunity to enhance the methods of seismogram interpretation and seismic parameter extraction through implementation of digital processing methods at seismic observatories in Africa and elsewhere. This opportunity will not easily be realized, however, until effective ways are found of transferring to them the appropriate aspects of the technological and seismological expertise which already exist in those countries which have heavily invested in digital seismology. The ISOP project is designed to facilitate this transfer.

Conclusions

The program of observation planned during the International Seismological Observing Period (ISOP) to gather an improved set of arrival times for secondary phases will significantly advance our knowledge of the Earth's deep interior. This experiment will be realized largely within the existing infrastructure of global observational seismology, which has evolved through years of international cooperation under the guidance of advisory bodies such as the IASPEI. For the ISOP to be successful it must take full advantage of existing capabilities and facilities. Most of the improvements to practice envisioned for the ISOP can be accomplished at very little cost and with only minor modifications to existing procedures. This will be of special relevance to seismic stations in Africa.

The ISOP project is not limited to this single observing program, however. Virtually any exper-

iment in observational seismology can be enhanced by seeking opportunities for expanded participation and cooperation. All participants also benefit in proportion to the number and variety of observing programs, which are united in nothing more than their acknowledgement of a "specific time interval designated for enhanced international cooperation in the collection and dissemination of observatory measurements from the global seismographic network", that is, an ISOP.

As great as the scientific rewards of a fully realized ISOP (that is, one based on a full utilization of the existing infrastructure for international seismology) could be, the role it could play in developing a new infrastructure; one that complements conventional analog technology, yet takes full advantage of the digital revolution, is of even greater importance. Due to the emphasis on improved practice at the observatory, ISOP is a natural vehicle for providing information and instruction to young scientists in Africa. This education will help them to qualify for and participate in advanced educational and research opportunities at major seismological centers. This can be one of the most effective ways of distributing the results of research in these centers to the many parts of the world where it may have the most fruitful application; for example, programs for earthquake hazards mitigation in Africa and other developing regions.

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