# Chapter 1

# History, Aim and Scope of the 1st and 2nd Edition of the IASPEI New Manual of Seismological Observatory Practice

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## 1.1 Introduction to the history of the manual editions

Most of what we know today about the internal structure and physical properties of the Earth, and thus about the internal forces which drive plate motions and produce major geological features, has been derived from seismological data. Seismology continues to be a fundamental tool for investigating the kinematics and dynamics of geological processes at all scales. With continued advances in seismological methods we hope to better understand and assess their current status as well as the diverse related potential benefits, hazards and risks for mankind.

Geological processes neither know nor care about human boundaries. Accordingly, both the resources and the hazards can be investigated and assessed effectively only when the causative phenomena are monitored not only on a local scale, but also on a regional and global scale. Moreover, geological phenomena typically must be recorded with great precision and reliability over long time-spans corresponding to geological time-scales. Such data, which are collected in different countries by different research groups, have to be compatible in subtle ways and need to be widely exchanged and jointly analyzed in order to have any global and lasting value. This necessitates global co-operation and agreement on standards for operational procedures and data formats. Therefore, it is not surprising that the international seismological community saw the need for developing a Manual of Seismological Observatory Practice (MSOP) already many decades ago.

This matter was taken up by the scientific establishments of many nations, finally resulting, in the early 1960s, in a resolution of the United Nations Economic and Social Council (ECOSOC). In response, the Committee for the Standardization of Seismographs and Seismograms of the International Association of Seismology and Physics of the Earth's Interior (IASPEI) specified in 1963 the general requirements of such a Manual as follows:

- act as a guide for governments in setting up or running seismological networks;
- contain all necessary information on instrumentation and procedure so as to enable stations to fulfil normal international and local functions; and
- not to contain any extensive account of the aims or methods of utilizing the seismic data, as these were in the province of existing textbooks.

The first edition of the Manual of Seismological Observatory Practice was published by the International Seismological Centre (ISC) in 1970 with the financial assistance of the United Nations Educational, Scientific and Cultural Organization (UNESCO). A sustained demand for copies and suggestions for new material prompted the Commission on Practice of IASPEI in 1975 to prepare a second edition. The authors worked to achieve balance between western and Soviet/Russian traditions of seismological practice. This resulted in the 1979 version of the Manual, edited by P. L. Willmore, in which the basic duties of seismological observatories were envisaged as follows:

- maintain equipment in continuous operation, with instruments calibrated and adjusted to conform with agreed-upon standards;

- produce records which conform with necessary standards for internal use and international exchange; and

- undertake preliminary readings needed to meet the immediate requirements of data reporting.

The "final" interpretation of seismic records was considered to be an optional activity for which the Manual should provide some background material only, with no attempt to fully cover it. On the other hand, the Manual did provide more detailed guidance for observatory personnel as required for the occasional, but at those times most important, collection and classification of macroseismic observations. In general, the international team of authors "...sought to extract the most general principles from a wide range of world practice, and to outline a course of action which will be consistent with those principles."

Even as the 1979 Edition of the Manual was published, it was obvious that there existed significant regional differences in practice and that the subject as a whole was rapidly advancing. Since this implied the need for continuous development, it was decided to produce the book in loose-leaf form and to identify chapters with descriptive code names so as to allow for easy reassembling, updating and insertion of new chapters. This useful concept was not achieved, however, and no updating or addition of new chapters happened after the 1979 edition. Yet, the general aims of the old MSOP are still quite valid, although the scope of modern practice has broadened significantly during the last few decades, and although old analog recording stations and data analysis procedures have meanwhile been replaced by the corresponding digital ones practically everywhere. But for a deeper understanding and full appreciation of these recent tremendous developments in seismological practice it has been important that, along with the IASPEI Centennial International Handbook on Earthquake and Engineering Seismology (2002), the 1979 edition of the MSOP has been made available on CD-ROM, and is now accessible, together with the electronic NMSOP editions, on the IASPEI home page (http://www.iaspei.org/projects/NMSOP.html) as well.

Since the last edition of the MSOP, seismology has in fact undergone a technological revolution. This is driven by cheap computer power, by the development of a new generation of seismometers and digital recording systems with very broad bandwidth and high dynamic range, by digital analysis tools that run on complex algorithms based on most recent theoretical concepts of seismic source processes, wave generation and propagation as well as signal processing and, finally, by the advent and breathtaking global progress of the Internet as an effective vehicle for rapid, large-scale data exchange and communication. This, however, made more and more sections of the 1979 Manual obsolete or irrelevant, providing no more guidance in many areas of critical importance for modern seismology.

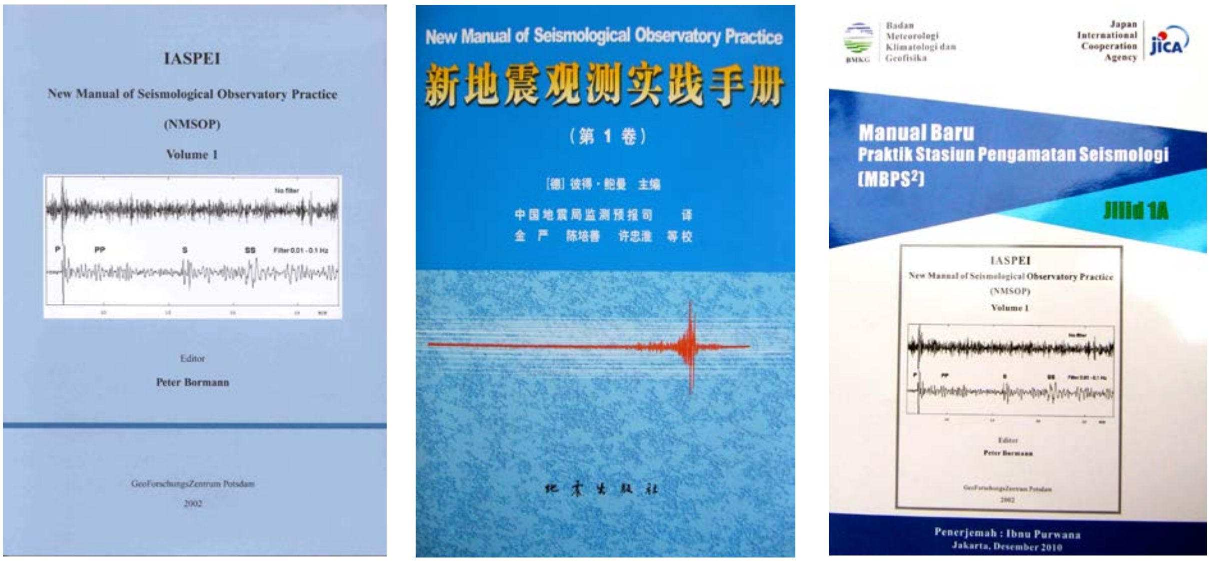
In a workshop meeting organized in late 1993 by the International Seismological Observing Period (ISOP) in Golden, Colorado, entitled "Measurement Protocols for Routine Analysis of Digital Data", it was acknowledged that existing documents and publications are clearly inadequate to guide routine practice in the 1990s at seismological observatories acquiring digital data. It was concluded that a new edition of MSOP is needed as well as tutorials showing examples of measuring important seismological parameters (Bergman and Sipkin, 1994). This recommendation prompted the IASPEI Commission on Practice (CoP) at its meeting in Wellington, New Zealand, 1994, to establish a MSOP Working Group (WG) entrusted with the elaboration of an IASPEI New Manual of Seismological Observatory Practice (NMSOP). Peter Bormann was asked to assemble and chair the working group and to elaborate a concept on the aims, scope and approach for a new Manual.

The first concept for the NMSOP was put forward at the XXIV General Assembly of the European Seismological Commission (ESC) in Athens, Greece, September 19-24, 1994 (Bormann, 1994) and in 1995 at the meeting of the IASPEI CoP on the occasion of the XXI General Assembly of the International Union of Geodesy and Geophysics (IUGG) in Boulder, Colorado. The concept was approved and both an IASPEI and an ESC Manual WG were formed. Most of the members met regularly at ESC and IASPEI Assemblies (ESC: 1996 in Reykjavík, 1998 in Tel Aviv and 2000 in Lisboa; IASPEI: 1997 in Thessaloniki, 1999 in Birmingham and 2001 in Hanoi) while others corresponded with the group and contributed to its work via ~~the~~ Internet. At these assemblies the Manual WG organized special workshop sessions, open to a broader public and well attended, with oral and poster presentations complemented by Internet demonstrations of the Manual web site under development. With a summary poster session at the IASPEI/IAGA meeting in Hanoi, 2001, the work of the IASPEI Manual WG was formally terminated and the WG chairman was entrusted with the final editorial work and the preparations for the publication of the Manual.

NMSOP was published in 2002 by the GeoForschungsZentrum (GFZ) Potsdam, Germany, with some financial support of IASPEI, as a hard cover loose-leaf collection of contributions in two volumes (Bormann, 2002; Fig. 1.1a). More than 2000 copies are meanwhile in use in more than 100 countries, several hundred copies alone bought and disseminated to seismological stations and member institutions by IASPEI, the Incorporated Research Institutions for Seismology (IRIS, USA) and the United Nations Comprehensive Test-Ban Treaty Organization (CTBTO). From feedback of users to the editor it is known that NMSOP has become not only a useful instruction material and guidance for the daily work of the personnel at seismological observatories and data analysis centers, but also for people working in field surveys taking along the NMSOP CD. Moreover, NMSOP Chapters and exercises are widely used by university lecturers as well as by trainers and participants in post-graduate international seismology courses.

In 2006 the Seismological Press Beijing published a Chinese translation of NMSOP as a two-volume book (Fig. 1.1b) and in 2010 the BMKG Indonesia, with support of the Japan International Co-operation Agency (JICA), issued a translation of the NMSOP Chapters 2-4 in Indonesian language (Fig. 1.1c), with more chapters still being in the process of translation.

Observatory practice relevant parts of NMSOP have been also translated into Russian by the Geophysical Survey of the Russian Academy of Sciences for use at its main seismological stations and networks and the first 4 Chapters have been translated also into Turkish by 2010.



a) b) c)

**Fig. 1.1** First NMSOP editions in a) English, b) Chinese and c) Indonesian language.

Despite the undoubted success in the wide distribution and use of NMSOP there have been annoying hindrances in making this instructional and educational material available to those that mostly needed it, especially observatories and institutions in earthquake-prone developing countries. NMSOP had deliberately not been submitted for publication by one of the prestigious commercial publishers. To buy its 1250 pages on the international book market might then have cost a few hundred dollars and thus become unaffordable for many institutions, observatories and individuals in these countries. Therefore, the GFZ Potsdam decided to pay in advance for the pure printing cost and to assure free storing and handling of the shipment to customers. However, it then turned out that the shipment cost to most countries for the two 5 kg volumes were twice as costly as their production, making NMSOP again not affordable for many.

It has been this sobering experience that let the Editor propose already in 2007 at the IUGG/IASPEI General Assembly in Perugia the elaboration of an amended second electronic edition, NMSOP-2, that was to be made freely available to any interested user. A detailed NMSOP-2 project plan, agreed with about two dozen potential old and new authors, was posted and adopted at the IASPEI General Assembly early 2009 in Cape Town, South Africa, and a special IASPEI symposium on NMSOP-2 was planned to be held in conjunction with the IUGG General Assembly in Melbourne, 2011. As a first step into the direction of an electronic NMSOP the GFZ library put a slightly revised version of the first NMSOP edition, NMSOP-1 (Bormann, 2009), with doi-numbers for each reviewed contribution, on the Internet. It is accessible via http://www.iaspei.org/projects/NMSOP.html.

NMSOP-2 developed gradually. The first rigorously revised and largely amended Chapters, Information Sheets and Exercises of NMSOP-1 became available already in fall 2011, complemented by several new Chapters and rich auxiliary material by early 2012. On the other hand, quite a number of scheduled contributions could not be finalized in the planned time, due to both the serious chronic disease of the Editor and unforeseen priority obligations beyond the control of several committed authors. This led to the decision to open already in spring 2012 the NMSOP-2 website at http://nmsop.gfz-potsdam.de with the already available material. Even some contributions still under review, but earmarked differently, and amended by NMSOP-1 papers that remained either unchanged or were still under revision, were published. Thus, NMSOP-2 was “born” as – and will remain in future - a *dynamic publication*. It will develop and grow according to changing needs, new priorities, and available potentials in close collaboration between the IASPEI Commission on Seismic Observation and Interpretation (CoSOI) and the GFZ German Research Centre for Geosciences in Potsdam. The GFZ central library will assure the long-term competent maintenance of the NMSOP website. But at the same time the NMSOP is supposed to be also a mirror of the development of basic concepts, procedures and assumptions on which seismological observatory practice rests. Otherwise neither the reasons nor the appropriate ways for assuring long-term data continuity, stability and compatibility in Earth science will be understandable to the younger generation growing up in the computer age with its breathtakingly rapid changing possibilities and appealing new options.

By the end of 2013 more than 2000 Manual pages will be available for reading and downloading. They include, besides the 16 basic topical overview Chapters, plenty of complementary material such as specialized topical Information Sheets, Data Sheets, Tutorials, Exercises and Program Descriptions, Acronym explanations as well as the largest ever so far published Glossary of terms in seismology and related fields (see website cover page). Future NMSOP updates and complements will now be the main responsibility of the individual contributing authors and of IASPEI/CoSOI, in order to adapt to changing needs, newly developed procedures and gained insights. There is no more need to wait for an overall revision and new edition of the Manual before updates or complements can be made. This makes it easy to assure that with the Manual there will be in the field of seismological practice, which is usually not or only very marginally taught at universities, always a competent up-to-date educational and instructional material available. And many of its modules, animations and programs have proven to be even attractive at high-school level, suitable for promoting interdisciplinary problem understanding in general.

## 1.2 Scope of the NMSOP

### 1.2.1 Observatory seismology: Historically and regionally changing concepts, conditions and approaches

Emil Wiechert (1861-1928), professor of geophysics in Göttingen, Germany, and designer of the famous early mechanical seismographs named after him, had the following motto carved over the entrance to the seismometer house in Göttingen: “Ferne Kunde bringt Dir der schwankende Boden - deute die Zeichen.” (“The trembling rock bears tidings from afar – read the signs!”; see link to the dedication of this Manual to Emil Wiechert and Boris Galitzin). Wiechert also considered it as the supreme goal of seismology to "understand each wiggle" in a seismic record. Indeed, only then would we understand or at least have developed a reasonable model to explain the complicated system and “information chain” of seismology with its many interrelated sub-systems such as the seismic source, wave propagation through the Earth, the masking and distortion of "useful signals" by noise, as well as the influence of the seismic sensors, recorders and processing techniques on the seismogram (see Fig. 1.2).

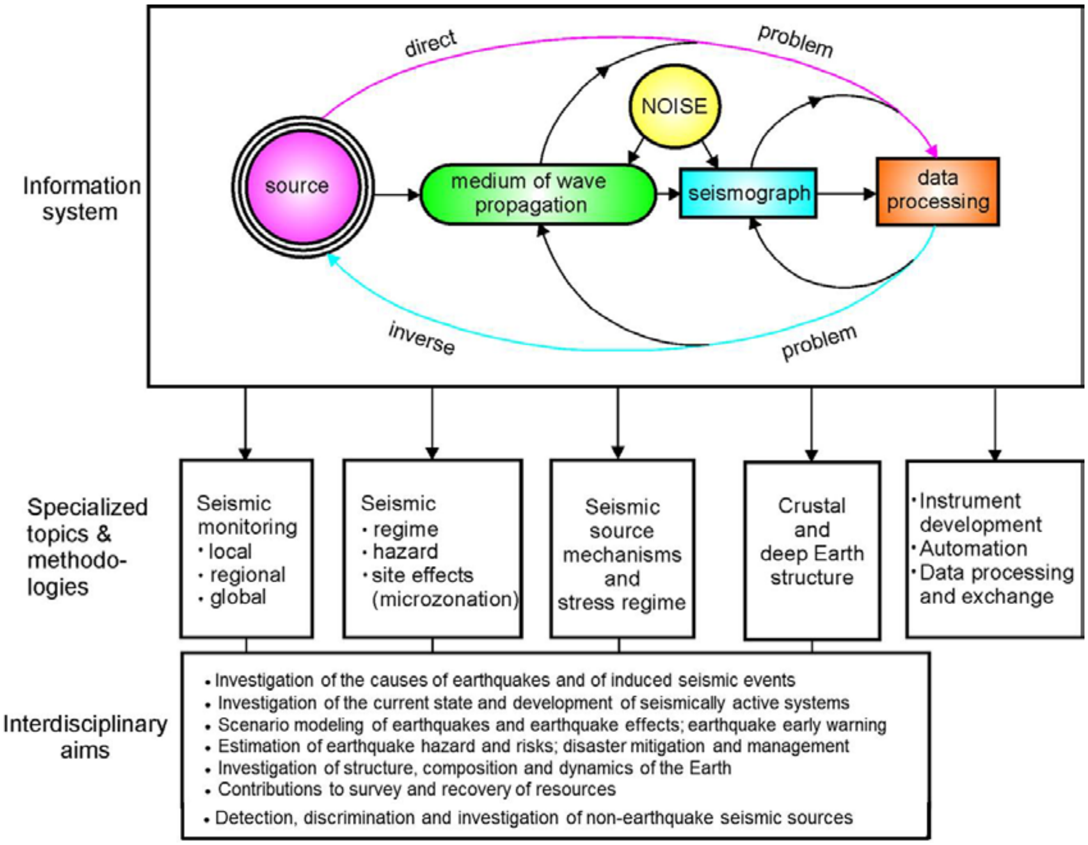


**Fig. 1.2** Scheme illustrating seismology as the analysis of a complex information system linked to a diversity of specialized and interdisciplinary tasks of research and applications.

During the early years of seismology analog seismic records have been precious unique documents for each station. Lending and shipping them to interested researches at other stations, even abroad, was a risky undertaking. Many valuable records got lost this way. Therefore, is has been a must to extract from each record as many as possible seismic phases and other parameter data and publish them in bulletins which could be printed and distributed instead of shipping original seismograms.

Yet, despite the tremendous progress made since Wiechert's time in understanding the most prominent features in seismic records, long-period ones in particular, we are still well short of reaching the goal he set. In fact, most operators and analysts at seismological observatories, even those who work with the most modern equipment, have not advanced much beyond the early 20th century with respect to their capability to understand and assign a proper "name" to each wiggle in a seismic record and to report their findings to international data centers. Even worse, some of the data centers are not even prepared to accept, publish and archive more detailed data reported to them if they consider them as not relevant for their duties. This has even discouraged many station and national data center operators to measure and/or report more phase data than those explicitly requested, e.g., by the NEIC of the USGS. Even pronounced seismic phases such as S shear-waves arrivals, which used to be almost as often measured and reported as P-wave arrivals before the 1960s, have often no longer been measured by many stations after the installation of the US World-Wide Standard Seismograph Network (WWSSN) in the 1960s and after the National Earthquake Information Center (NEIC) of the US Geological Survey and the International Seismological Center (ISC) in the United Kingdom (UK) resumed their operations (see Hwang and Clayton, 1991, and Figs. 1.3 -1.5). This happened irrespective of the unique importance of S-wave travel-time and amplitude readings for improving the shear-wave velocity and attenuation structure of the Earth and thus our understanding of the properties of the Earth matter.

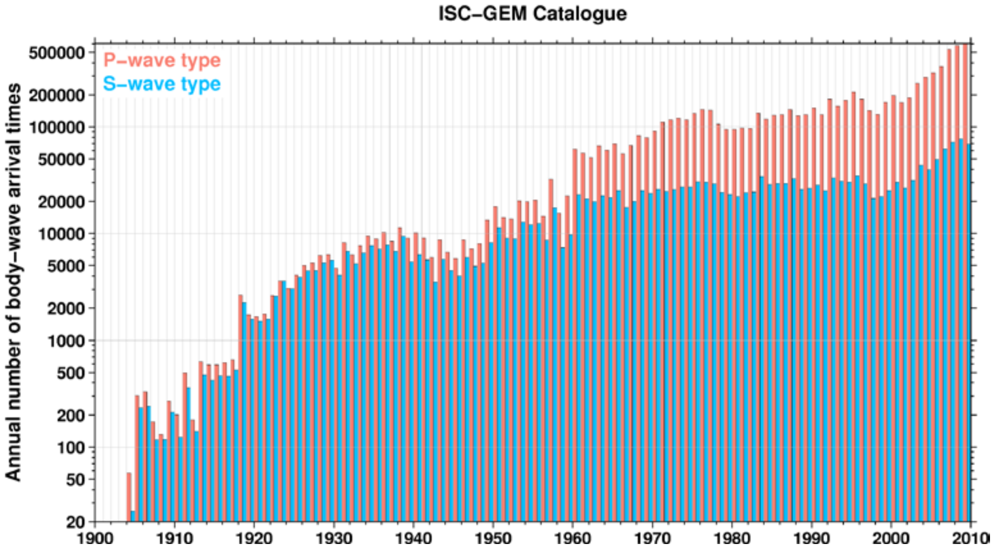


**Fig. 1.3** Annual number of arrival times of P-waves (red) and S-waves (blue) used to produce the ISC-GEM (Global Earthquake Model project) catalogue (see Storchak et al., 2013; Bondár et al., 2013; Di Giacomo et al., 2013a,b). Different data sources were used: Before 1918 the body-wave arrival data was collected from Gutenberg's notepads (1904-1912), the International Seismological Association (ISA; 1904-1907), the British Association of the Advancement of Science (BAAS; 1913-1918) and seismological station bulletins (since1904); between 1918 and 1963 from the International Seismological Summary (ISS) and seismological station bulletins; from 1964 until the end of 2009 from the ISC Bulletin. (Figure by courtesy of Domenico Di Giacomo, ISC, 2013).

According to Fig. 1.3 the pre-1960 annual frequency of S-wave arrival times measured and documented in bulletins varied between about 55 to 100% of the P-wave readings. Since the 1960s this percentage has never been more than 40% in the ISC bulletins, dropped in recent years down to about 10%, and is even less in NEIC bulletins (PDE and EDR) (compare in Fig. 1.4 the CLL data in NEIC and ISC bulletins). There are two main reasons for this growing discrepancy. Firstly, for decades event location at both the NEIC and the ISC has been based solely on short-period P-wave first arrivals which also yielded the amplitude data for the short-period magnitude mb, the exclusive classical body-wave magnitude calculated at the NEIC. So there seemed to be no explicit need for reporting and using ~~of~~ any other later body-wave onsets. Secondly, high-gain short-period narrowband seismographs introduced with the WWSSN into global standard monitoring practice allowed to increase the number of detected events by one order and even more. But for weaker events only P-waves have still a sufficient signal-to-noise ratio (SNR) in short-period filtered high-gain records, not, however, S waves located in the much noisier broadband or long-period records.

Fig. 1.4a compares the relative frequency of secondary phase onset readings to respective P and PKP readings in bulletins of the seismic station MOX in Germany. It dropped strongly from the first bulletins between 1965-67 (published by the author) to the last decade of printed bulletins (1974-84). But even from the latter data not all S, SS and PKP2 readings were included in the ISC bulletin. Even more striking is the difference between the number of secondary phase data analysed between 1990 and 1995 at the seismological observatory CLL, Germany, and the number of phase data accepted by the ISC and (much less) by the NEIC in their bulletins (Fig. 1.4b).

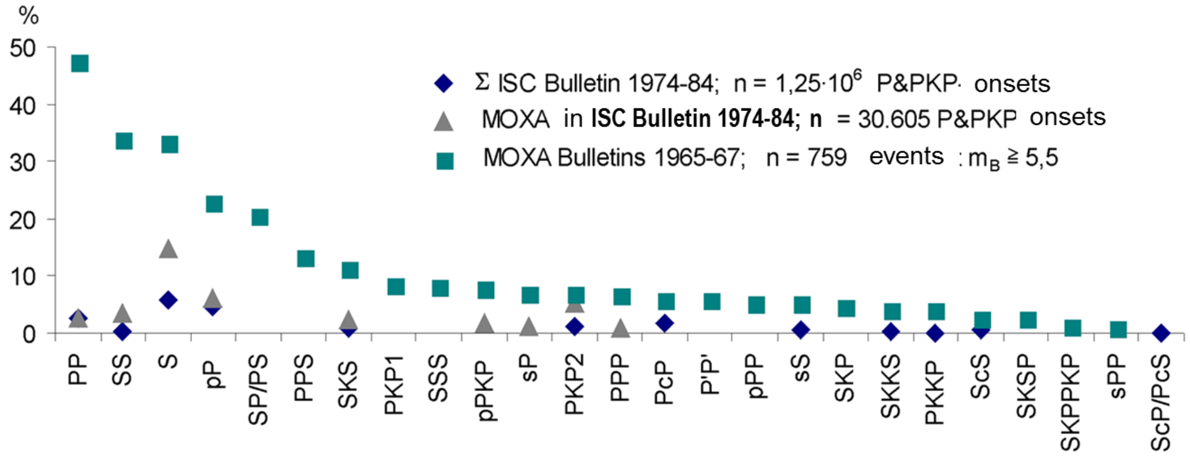


**Fig. 1.4a** Relative frequency of the measurement of identified secondary wave onsets as compared to P and PKP first arrivals by the author in early bulletins of station Moxa, Germany (squares), in later bulletins of station Moxa (triangles) and by the global network of seismic stations reporting to the ISC (diamonds).

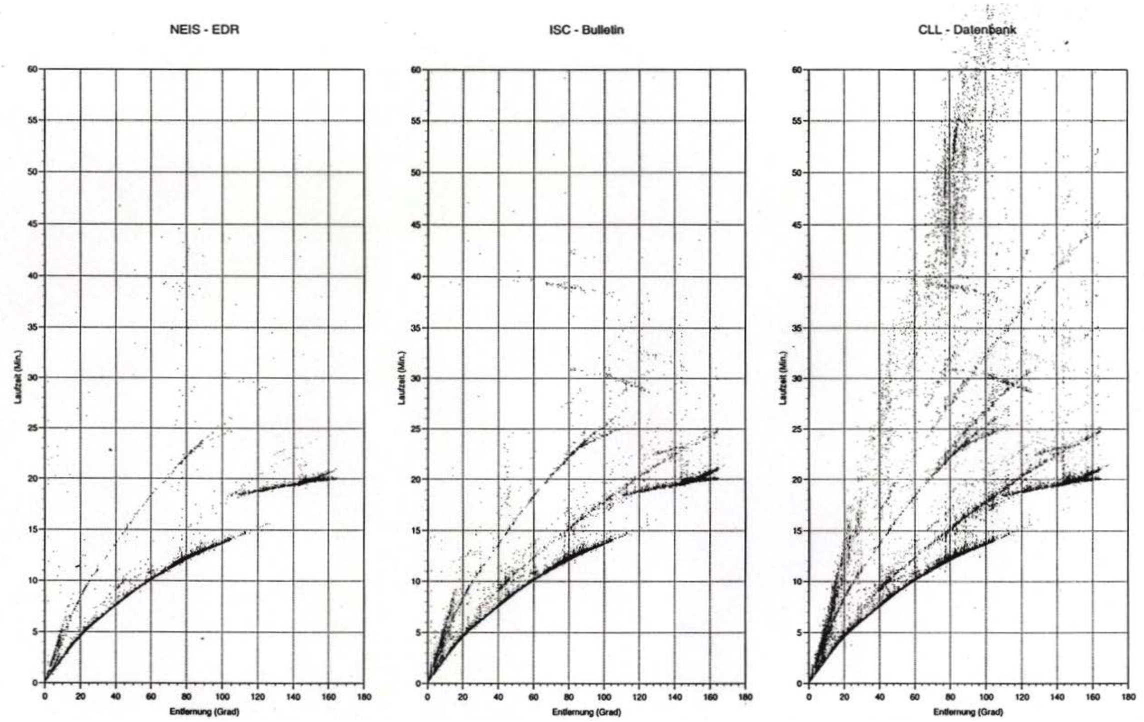


**Fig. 1.4b** Travel-time plots over epicentral distance of all seismic onsets analyzed at the observatory Collm (CLL), Germany, during the years 1990-95 (right-hand panel) and of the onsets reproduced for the same station during the same time span in the bulletins (EDR's) of the NEIC=NEIS (left-hand panel) and the ISC (central panel), respectively (Figure by courtesy of S. Wendt).

According to Bergman (1991), the first S-wave arrivals were reported on average to the ISC about twenty times less frequently than P, and other secondary phases were reported hundreds to thousands of times less often. These differences reflect operations practice at least as much as the usually reduced detectability of secondary phases. Because the NEIC did normally not use S phases in its routine processing, US station operators tended to interpret such readings as "wasted time". As a consequence, US stations reported between 1974 and 1984 also very seldom S-wave data to the ISC. Conversely, a heavy proportion of all S readings came from European and Asian stations, especially those in former Soviet Bloc countries, China and Japan, where standards of practice included an emphasis on complete reading of seismograms (Fig. 1.5).

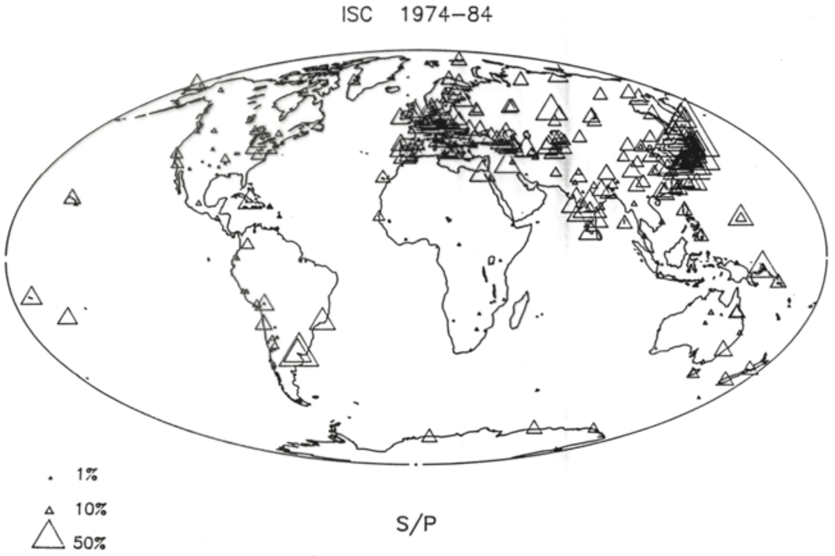


**Fig. 1.5** Relative frequency of reported S/P arrivals to the ISC by stations of the global seismic network during the decade 1974 to 1984. Note the embarrassing disregard of measuring S-wave arrivals, especially in the western Americas, Africa and Australia (Figure published by Doornbos et al., 1991).

Hwang and Clayton (1991) published a revealing analysis of the phase reports to the International Seismological Centre (ISC) by all the affiliated seismological stations of the global seismic network. Most of them, even those equipped with both short- and long-period or broadband seismographs, reported only the first P-wave onset even though later energy arrivals in teleseismic records of strong events are clearly discernible, even in fully automatic simple threshold detection procedures (see Chapter 2, Fig. 2.58), although much less frequently in short-period filtered records (Fig. 2.57). Even secondary phases with much larger amplitudes than P (e.g., Figs. 1.6 and 1.10, Fig. 2.25 in Chapter 2 and Figure 10c in DS 11.2) were usually not analyzed. And this situation has not generally changed to the better since then, rather often even worsened.

The scarcity of seismic body-wave phase readings, especially of depth phases, has strongly limited the accuracy of global seismic event locations (see Figure 7 in IS 11.1 and Engdahl et al., 1998). The same applies to the derived seismic velocity models, because the very limited number of frequently measured seismic body-wave phases is not able to sample the various lateral and depth ranges of the Earth homogeneously. This led IASPEI to launch the initiative for an International Seismological Observing Period (ISOP; see Doornbos et al., 1991). ISOP was scheduled to take place during the 1990s and aimed at training station operators in better recognizing, measuring (onset times, amplitudes and periods) and reporting relevant secondary seismic phase arrivals and providing suitable software tools for these tasks. The outcome of this initiative was supposed to assure a greatly improved and much more homogeneous future seismological database for the derivation of more detailed and better constrained structural, physical and compositional Earth models. Regrettably, after intensive preparations the project had to be cancelled even before proper take-off, because of drastic cuts in personnel at the planned ISOP co-ordination and analysis center at the NEIC. But this essential task still remains to be tackled in future. NMSOP offers a broad array of arguments, record data, seismological methods and suitable software tools to work in this direction.

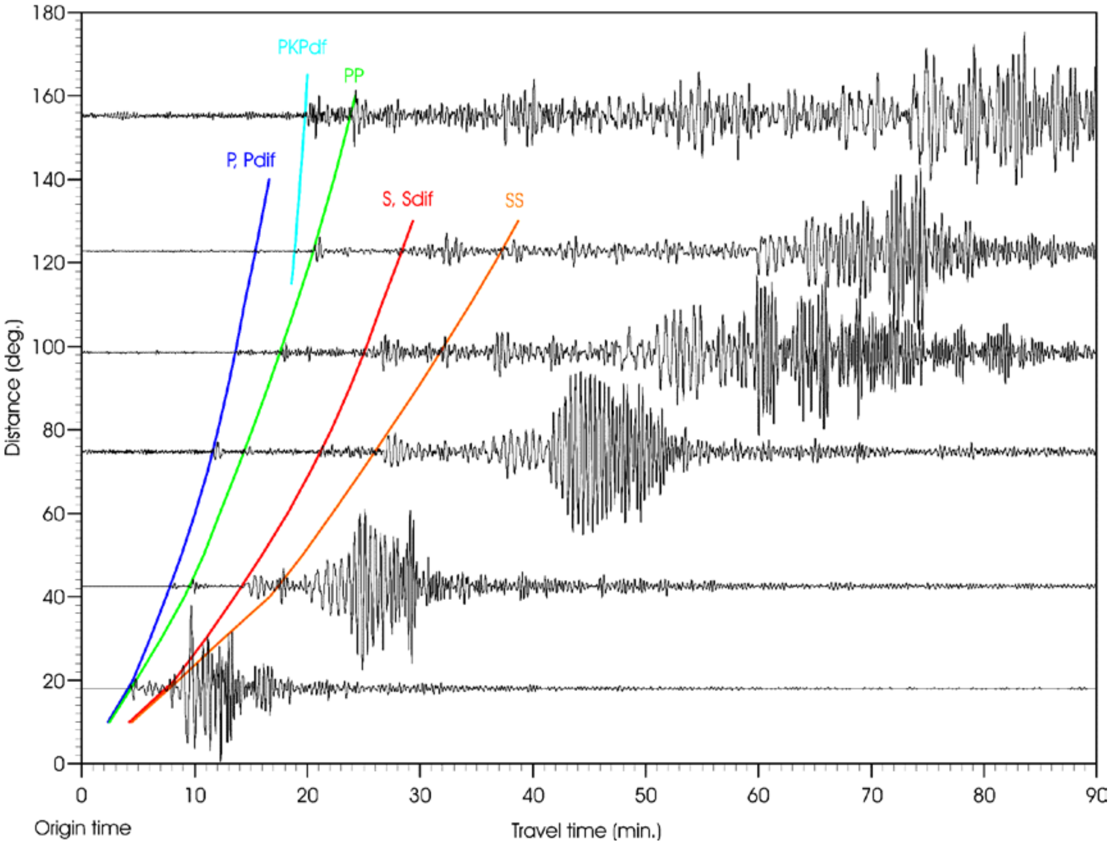


**Fig. 1.6** Long-period filtered vertical-component broadband records of station CLL, Germany, of shallow earthquakes in the distance range 18° to 157°. Note the strong later longitudinal (PP) and transverse energy arrivals (S, SS) that are recognizable in the whole distance range, and the dispersed surface wave trains with large amplitudes. The record duration increases with distance (courtesy of S. Wendt, 2002).

There are several reasons for the lack of progress in the deeper understanding of seismogram analysis by station operators. Early seismic stations were mostly run or supervised by broadly educated scientists who pioneered both the technical and scientific development of these observatories. They took an immediate interest in the analysis of the data themselves and had the necessary background knowledge to do it. After World War II the installation of new seismic stations boomed and rapid technological advance required an increasing specialization. Station operators became more and more technically oriented, focusing on equipment maintenance and raw data production with a minimum of effort and interest in routine data analysis. Thus, they have tended to become separated from the more comprehensive scientific and application-oriented use of their data products in society. Also the seismological research community itself has become increasingly specialized, e.g., in conjunction with the monitoring and identification of underground nuclear tests. This trend has often caused changes in priorities and narrowed the view with respect to the kind of data and routine analysis required to better serve current scientific as well as public interest in earthquake seismology, improved hazard assessment and risk mitigation.

As a consequence, "classical" seismological observatories, as, e.g., Moxa (MOX) and Collm (CLL) in former East Germany (see Figs. 1.4a and b), belong now to an “endangered species”. They depended on a social and political system that was prepared to devote relatively large numbers of personnel and other resources to station operation and analysis, with the goal of extracting the maximum amount of information out of a limited number of recordings. One can think of this as the "observatory-centered" model for observational seismology. Beginning in the 1960s, seismology in the West favored deployment of global networks (e.g., the WWSSN - World-wide Standard Seismograph Network) with relatively less attention given to individual stations or records, making up in quantity what they gave away in quality. This "network model" of observational seismology now dominates global seismology. But a reasonable balance between quantity and quality has to be preserved. This Manual is explicitly intended to support the side of quality and completeness in the acquisition, processing, and analysis of seismic data. Currently some excesses in a pure network-centered model of observatory seismology are already questioned. In its report 2013 to CoSOI the IASPEI Working Group on Magnitude Measurements states:

> *” The number of digital stations world-wide has increased dramatically, so that it is not unusual for the NEIC to have several thousand amplitude/period observations for a single, moderately strong, earthquake, …. At the NEIC, this situation has led to consideration of computing magnitudes only for a preferred subset of the overall station set, with preferred stations being selected on the basis of such criteria as geographic location, station sensitivity and reliability, or extent to which current observations would continue a long-running data set.”*

Interestingly, this concept had already been proposed some 30 years ago at the time of analog seismology. It aimed at the creation of a homogeneous magnitude system (HMS) for Eurasia, based on a sub-set of first-rate stations, improved calibration functions, taking into account carefully determined station residuals for reducing drastically the data scatter in estimating event magnitudes, etc. But the proposal, although widely published (Christoskov et al, 1978; 1983; 1985; 1991), was not followed up further by the IASPEI magnitude WG and even discredited by the believers in the global network mass-data approach. Similarly, many other procedures discussed, examples presented and recommendations given in the NMSOP may appear for today’s reader to be old-fashioned and off the current mainstream. This, however, should not prevent realizing their rationale and considering seriously how they might be taken into account in the modification/amendment of current procedures.

The accelerating advancement of computer capabilities during the last few decades is a strong incentive to automate more and more of the traditional tasks that need to be performed at seismological observatories. Most decision makers in seismology consider nowadays detailed seismogram parameter readings and event location nothing but time consuming and boring routine tasks, not worth paying qualified manpower for it with the exception of a clever programmer to automate these tasks. Such an assessment is apparently supported also by the facts that we can nowadays

- exchange world-wide full seismic waveform data/seismograms electronically, so that high-quality data for parameter extraction or specific research are now available (almost) everywhere (see IS 8.3);
- make use of algorithms and software for reliable and robust phase picking;
- synthesize the most important basic features in medium- to long-period seismic records;

- derive information on the source process, structure and properties of the medium from fitting synthetic waveforms to measured ones.

However, despite significant progress made in this direction, automated phase identification and parameter determination is still inferior to the results achievable by a well-trained analyst (see Chapter 3, section 3.2.3.2; Chapters 11 and 16). And for short-period records synthetics of both travel-times and waveforms look still rather different from records in real 3D media (see, e.g., Chapter 2, Fig. 2.85 and Figures 3 und 4 in IS 11.4.). Although it is likely that in future good documentations of progress made in detailed automatic seismogram interpretation can be added to the NMSOP, this second edition still heavily focuses on providing guidance, based on rich empirical experience, to: (i) the developers of software for interactive and automatic routines, (ii) to station operators and seismologists with less experience and (iii) to countries which lack specialists in the fields that should be covered by well-educated observatory personnel and application-oriented seismologists. But good knowledge of the complexity and diversity of actual body-wave waveforms is not only important for manual seismogram interpretation, but also for basic research and the development of appropriate methodologies and algorithms in general.

In any case, even in developing nations, observatory personnel has nowadays computers and software for seismogram analysis together with Internet connection for downloading the NMSOP and free shareware. During the classical analog days station analysts reading parametric data on records with fixed and limited time resolution and dynamic range, and performing their calculations with the aid of map projections, nomograms, travel-time curves, tables and logarithmic rulers, could not even dream of such comfortable tools.

Digital data, using such interactive analysis and processing tools in connection with real-time data links (see IS 8.3) and (virtual) network/array data processing (Chapters 8 and 9), now open the door for:

- Filtering standard and non-standard instrument responses;
- Phase identification using theoretical travel-times;
- Three-component processing and thus phase identification and event location based on polarization criteria;
- Hilbert transform to correct for phase distortions at caustics;
- Routine determination of spectral source parameters;
- Source parameter determination and phase identification by fitting synthetic seismograms to real seismic records;
- Frequency-wavenumber filtering and thus the application of array-processing for improved event detection, event location and phase identification;
- Automatic report generation.

Despite all these potential benefits, it is a fact that digital stations are increasingly less frequently read manually in a comprehensive way; if they are, then it happens usually only for strong events at first-order main analysis centers or at lucky stations that still have one or more well-trained analysts. Therefore, in the context of planning for ISOP, E.R. Engdahl and E. Bergmann asked already in a 1994 IASPEI talk the following question:

> *“Why does detailed routine seismogram analysis discontinue when modern digital data acquisition, processing and analysis tools become available although they significantly ease and improve to achieve ISOP goals?”*

For an ISOP Pilot experiment between September 1993 and April 1994, 33 stations had been selected worldwide. The task was to identify and report secondary phase arrivals after P or PKP from records of some strong earthquakes with clear records of such secondary phases. 30% of the participating stations reported in the average less than one later onset. Only five stations, all from Eastern Europe, reported on the average four or more later onsets!

What are the reasons for such a disturbing development?

- Narrow-band high-frequency data, also from seismic arrays, lowered the detection threshold by at least 1 magnitude unit, i.e., the amount of data to be analyzed at WDCs increased by more than a factor of about 10.
- The tremendous increase of the number of stations in many seismically active countries decreased detection thresholds and increased the number of records even further.
- Nobody wants (or gets the money) to pay for more qualified manpower needed to carry out high-level routine analysis of these much improved modern data for general use. To the contrary, funds for so-called “routine tasks” are decreasing everywhere.
- Such a budget policy and lacking commitment of governments to assure sustained funding for high-quality long-term monitoring programs kill scientifically meaningful and necessary tasks.

When reading through the Manual, especially through Chapter 3 on seismic source parameters and through Chapter 11 on seismogram interpretation with their associated Data Sheets and Exercises, it becomes soon very clear that there is no simple stupid routine in measuring the relevant parameters. Even worse, the deviations from some simplified general rules are the most important ones to identify, measure and document. Rapid automatic default analysis programs can only work efficient on the basis of simplified general rules. Their development requires software specialists who usually possess, however, only a very basic understanding of the measurement parameters. On the other hand, the analysts trained over many years of analyzing tens of thousands of such parameters in all their diversity for earthquakes in very different distance, depth and magnitude ranges, do not usually have the top programming expertise needed for the development of highly efficient complex automatic data processing and analysis systems. Finally, an efficient communication and co-operation between these two types of experts as well as a comprehensive systematization and codification of complex empirical expertise, is also not a trivial task. Therefore, preserving and promoting rich empirical expertise, gained by daily tedious work with real data, preferably associated with a broad-enough seismological problem and with a good theoretical background understanding, is the indispensable precondition for any real progress in valuable automation efforts. In any event, the latter should be restricted to simplified rapid mass data handling and processing jobs and to those where rapidity counts most, and not to achieve data completeness, accuracy and novelty/peculiarity of the extracted information. The programmer and the empirically working seismologist have to be equally valued partners and the latter should not be discredited by considering him to be occupied with futile and boring routine work. NMSOP therefore focuses on the diversity and breathtaking complexity of the work with real seismological waveform data, which is usually only a minor part in most seismology text books.

In designing the Manual for a global audience, we have tried to take into account the widely varying circumstances of observatory operators worldwide. Whereas in developing countries proper education and full use of trained manpower for self-reliant development has (or should have) priority, highly advanced countries often push for the opposite, namely the advancement of automatic data acquisition and analysis. The main reasons for the latter tendency, besides the desire to limit personnel costs in high-wage countries, are:

- special requirements to assure a most rapid and objective data processing and reporting by the primary (mostly array) stations of the International Monitoring System (IMS) in the framework of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) (see Chapter 15);
- coping with the huge data rates at dense digital seismic networks and arrays in areas of high seismicity;
- extracting within seconds or minutes only the most important first information from local, regional and/or global virtual network data on strong earthquakes with great risk potential (tsunami and earthquake early warning systems), which is required to assist risk mitigation, disaster management and relief operations.

Seismologists in highly industrialized countries can usually address their special concerns and requirements to national forums. Specialists in program development and automation algorithms in these countries, however, often lack the required background knowledge in seismology and/or the practical experience of operational applications in routine practice. A similar argument applies to young scientists, beginning their careers in seismological research, who often remain ignorant of the long history of operational seismology that produced the data now available for their research. A typical graduate program in seismology gives scant attention to the historical development of methods and measurement standards. This may lead either to neglect valuable older data and results, or to their incorrect interpretation and usage. In this sense, the NMSOP also aims at passing on the knowledge, experience and skills of previous generations of seismologists by addressing the educational needs of current highly specialized advanced user communities with a view to broaden both their historical and topical perspective, as well as their ability to contribute more efficiently to interdisciplinary basic research and methodological development.

## 1.2.2 Creation of awareness

The subject of standards of practice at seismological observatories normally stays well below the active consciousness of most seismologists, yet it sometimes plays a central role in important research and policy debates. Also the awareness of the tremendous impact of recent technological advances, in both sensor developments and data communication, on the observatory and monitoring practice is not yet generally well developed. Even less developed is the understanding of the need for a much more detailed reading and reporting of secondary phases, not only of their onset times for improved event location but also of their amplitudes and periods for the determination of magnitudes and the derivation of improved attenuation models. However, both development and proper use of appropriate modern analysis tools require a profound understanding of seismic waveform data, their properties and variability. Moreover, accurate amplitude readings and reliable waveform-fitting inversion procedures require careful instrument calibration, i.e., knowledge of the transfer function and gain of the seismographs. However, there is no common standard practice yet of instrument calibration and control. And finally, both the earthquake rupture process and the wave propagation are highly kinematic-dynamic phenomena, which are too often only explained with simplified static images and the 3D event patterns by their 2D projections. We believe that for their illustration animations are often much more suitable to create awareness of the complexity of these phenomena, easier to comprehend and much more appealing. Therefore, animations are a very valuable complementary educational tool to formal lectures, tutorials and exercises, suitable not only for academic and professional audience but also for public lectures and demonstrations at high schools. Therefore, the number and topics of animations has been significantly increased in NMSOP-2 (see IS 1.1 and IS 11.3). Yet, this is just a beginning. More such examples from other authors and on other subjects related to seismology and seismic effects are very much welcome. Authors are kindly invited to link their contributions to NMSOP-2. We will come back on some of these issues in the sections below.

#### 1.2.2.1 The magnitude issue

Earthquake magnitude is one of the most widely used parameters in seismological practice, and one that is particularly subject to misunderstanding, even among seismologists. A striking example on how changing operational procedures have contaminated a valuable data set has been published by Hutton and Jones (1993). After re-examining the earthquake catalogue for southern California between 1932 and 1990 they concluded:

- ML magnitudes (in the following termed Ml with l for “local”) had not been consistently determined over that period;
- amplitudes of ground velocities recorded on Wood-Anderson instruments and thus Ml were systematically overestimated prior to 1944 compared to present reading procedures;
- in addition, changes from human to computerized estimation of Ml led to slightly lower magnitude estimates after 1975;
- these changes contributed to an *apparently higher rate of seismicity* in the 1930’s and 1940’s and a later decrease in seismicity rate which has been interpreted as being related to the subsequent 1952 Kern County (Mw = 7.5) earthquake;
- variations in the rate of seismic activity have often been related to precursory activity prior to major earthquakes and therefore been considered suitable for earthquake prediction;
- the re-determination of ML in the catalogue for southern California, however, *does not confirm any changes in seismicity* rate above the level of 90% significance for the time interval considered.

Similar experiences with other local and global catalogues led Habermann (1995) to state:

> *"... the heterogeneity of these catalogues makes characterizing the long-term behavior of seismic regions extremely difficult and interpreting time-dependent changes in those regions hazardous at best. ... Several proposed precursory seismicity behaviors (activation and quiescence) can be caused by simple errors in the catalogues used to identify them. ... Such mistakes have the potential to undermine the relationship between the seismological community and the public we serve. They are, therefore, a serious threat to the well-being of our community."*

Two striking examples of the consequences of disregarding procedural and nomenclature differences of teleseismic magnitude data, or even deliberately misusing them in the interest of political priorities, are given below:

Classical seismology was based on the recordings of medium-period instruments of relatively wide bandwidth such as Wiechert, Galitzin, Mainka, and Press-Ewing seismographs. Gutenberg's (1945 b and c; 1956) and Gutenberg and Richter's (1956 a and b) work on earthquake body-wave magnitude scales for teleseismic event scaling and energy determination was mainly based on records of such seismographs. Then, with the introduction of the WWSSN short-period instruments, body-wave magnitudes were determined routinely in the United States only from amplitude-measurements of these short-period narrowband records, which have better detection performance for weaker events than medium- and long-period seismographs and yield a better discrimination between earthquakes and underground nuclear explosions on the basis of the mb-Ms criterion (see 11.2.5.2 and Chapter 15). However, American seismologists calibrated their amplitude measurements with the Gutenberg-Richter Q-functions for medium-period body waves. This resulted in a systematic underestimation of the P-wave magnitudes (termed mb). In contrast, at Soviet "basic" stations, the standard instrument was the medium-period broadband Kirnos seismometer (displacement proportional between about 0.1 s to 10 s, later even 20 s. Accordingly, Russian medium-period body-wave magnitudes mB are more properly scaled to Gutenberg-Richters mB-Ms and logEs-Ms relations. Thus it happened that the corresponding global magnitude-frequency relationship logN-mB yielded a smaller number of annual m = 4 events than the U.S. short-period mb data (Riznichenko, 1960). Accordingly, in the late 1950s at the Geneva talks to negotiate a nuclear test ban treaty, the US delegation assumed a much larger number of not reliably discriminated seismic events per year, since only teleseismic records were available to them. This prompted them to demand some 200 to 600 unmanned stations on Soviet territory at local and regional distances as well as on-site inspections in case of uncertain events (Gilpin, 1962). Thus, a biased magnitude-frequency assessment based on equalizing mb and mB played a significant role in the failure of these early negotiations aimed at achieving a Comprehensive Nuclear-Test-Ban Treaty (CTBT). The underground testing continued for several more decades.

In 1996 the CTBT was finally agreed upon, and signed by 71 States as of 2002. The United Nations CTBT Organization in Vienna runs an International Data Centre (IDC) that also determines body-wave magnitudes from records of the International Monitoring System (IMS). However, in the interest of the best possible discrimination between natural earthquakes and underground explosions by means of the body-wave/surface-wave magnitude ratio mb/Ms, they measure P-wave amplitudes after filtering the broadband records with a displacement frequency-response peaked around 4.5 Hz instead of around 1 Hz or 0.1 Hz. However, they calibrate their amplitude readings with a calibration function developed for 1 Hz data. Finally, they measure the maximum amplitudes for mb determination not, as recommended by IASPEI in 1977, within the whole P-wave train, up to 60 s after the first onset, but within the first 5.5 seconds after the P-wave onset. These differences in practice result in systematically smaller mb(IDC) values as compared to mb(NEIC). Although this difference is negligible for explosions, it is significant for earthquakes. The discrepancy grows with magnitude and may reach 0.5 to 1.5 magnitude units. Nonetheless, the IDC magnitudes are given the same name mb, although they sample different properties of the P-wave signal. Users who are not aware of the underlying causes and tricky procedural problems behind magnitude determination, may not realize this incompatibility of data and come to completely different conclusions when using, e.g., the mb data of different data centers for seismic hazard assessment.

Such inconsistencies in the procedures to determine and name magnitude prompted IASPEI to set up again in 2002 a Working Group on magnitude measurements. It aimed at elaborating measurement standards for widely used magnitudes. The results are summarized in the Working Group recommendation (IASPEI, 2005 and 2013) and discussed in great detail in NMSOP-2, also with respect to the relationship between classical magnitudes and the newly proposed standards (see Chapter 3, sections 3.2.4, 3.2.5; IS 3.3 and 3.4).

But there are other important magnitudes, such as the moment magnitude Mw which is even considered to be an exclusively recommended *de facto* standard, that are determined with not yet standardized procedures using different wave types and period ranges. Accordingly, their magnitude values for identical events may differ by several tenths of magnitude units, such as for different versions of USGS moment magnitudes (see, e.g., Chapter 10, Tab. 10.5), or between authoritative Global Centroid Moment Tensor (GCMT) solutions and various rapid Mw proxy estimates that are available already within the first few minutes after origin times. Even magnitude estimates from the very first few seconds of a seismic record in earthquake early warning (EEW) schemes may underestimate the magnitude of strong to great (M > 8) earthquakes by more than one magnitude unit. All these different types and procedures of magnitude estimation, the reasons for discrepancies and magnitude saturation, as well as the development of non-saturating near real-time magnitude procedures in the earthquake and tsunami early warning context, are discussed in detail in Chapter 3 and on specific issues also in IS 3.3 and IS 3.9 of this Manual.

#### 1.2.2.2 Consequences of recent technical developments

When assembling the NMSOP we took into account that:

- modern seismic sensors (Chapter 5 and DS 5.1), in conjunction with advanced digital data acquisition (Chapter 6), transmission (Fig. 1.7, IS 8.2 and 8.6) and processing, allow event and magnitude determination (Fig. 1.8), as well as the analysis of seismic waves (Chapters 9 and 11), in a very broad frequency band with extremely high resolution within a much larger dynamic range (Fig. 1.9 and Fig. 4.7 in Chapter 4) and within a much shorter time than it was possible in the days of analog seismology;
- modern computer hardware and versatile interactive analysis software tremendously ease the task of comprehensive and accurate seismogram analysis (e.g., IS 11.6). This allows one to routinely determine also parameters which were far beyond the scope of seismogram analysis a few decades ago;
- precise time-keeping and reading is nowadays much less of a problem than it was in the pre-GPS (Global Positioning System) and pre-computer era;
- the rapid global spread of high-speed communication links largely eliminates any technical barrier to widespread data exchange of full waveform data in near-real time.

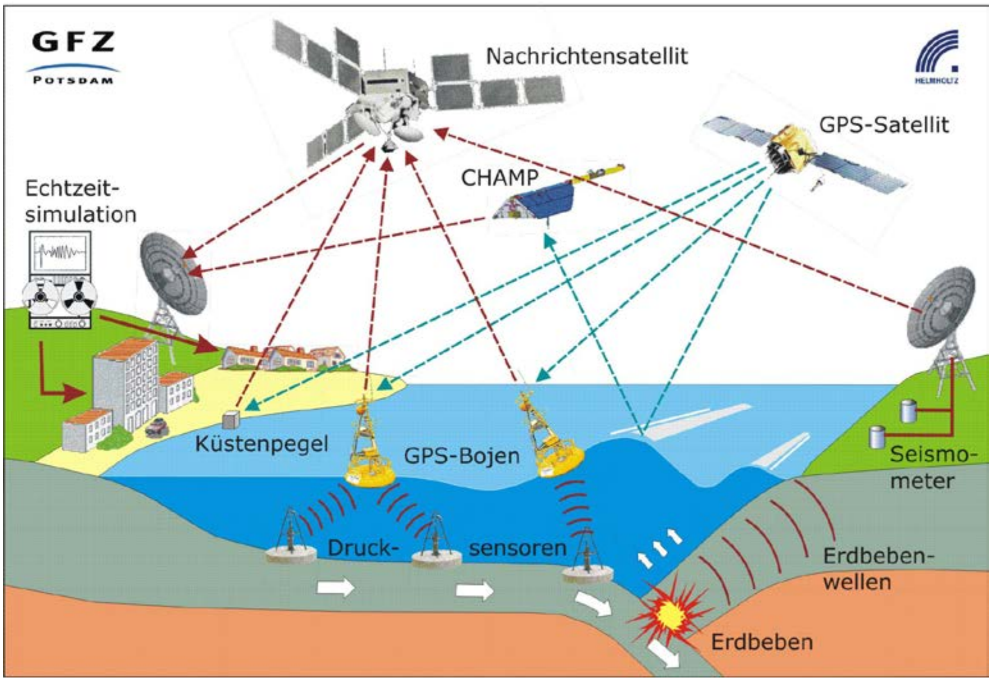
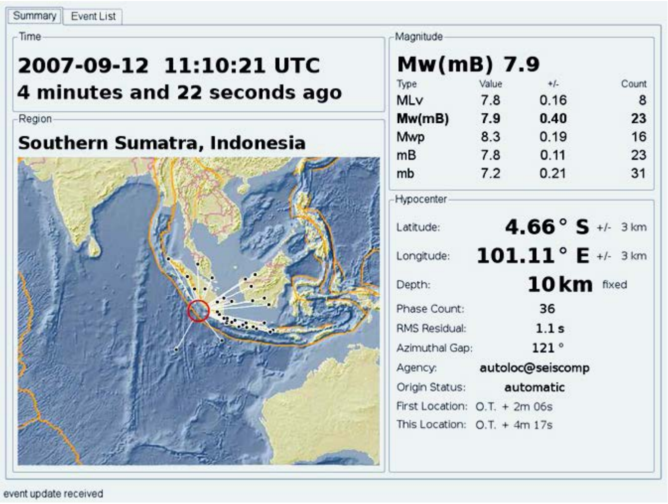


Fig. 1.7 Principal scheme of a modern ocean-spanning data acquisition and transmission system for seismological and complementary geodetic and oceanographic data as required for a tsunami early warning system (item names in German, courtesy of GFZ, Potsdam).



Time
**2007-09-12 11:10:21 UTC**
**4 minutes and 22 seconds ago**

Region
**Southern Sumatra, Indonesia**

Magnitude
**Mw(mB) 7.9**

| Type | Value | +/- | Count |
|---|---|---|---|
| MLv | 7.8 | 0.16 | 8 |
| **Mw(mB)** | **7.9** | **0.40** | **23** |
| Mwp | 8.3 | 0.19 | 16 |
| mB | 7.8 | 0.11 | 23 |
| mb | 7.2 | 0.21 | 31 |

Hypocenter
Latitude: **4.66 ° S** +/- 3 km
Longitude: **101.11 ° E** +/- 3 km
Depth: **10 km** fixed
Phase Count: 36
RMS Residual: 1.1 s
Azimuthal Gap: 121 °
Agency: autoloc@seiscomp
Origin Status: automatic
First Location: O.T. + 2m 06s
This Location: O.T. + 4m 17s

event update received

**Fig. 1.8** Screen plot of the results of earthquake location and magnitude determination within the first few minutes after origin time using stations of the German-Indonesian Tsunami Early Warning System (GITEWS; http: www.gitews.org) and the GFZ developed SeisComp3 Software (http://www.seiscomp3.org/).

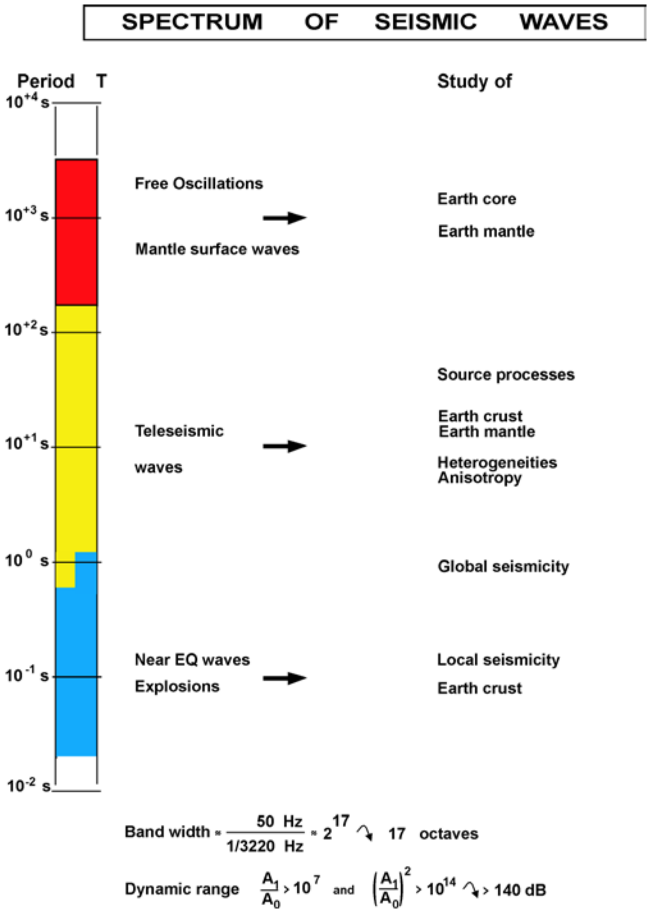


**Fig. 1.9** Frequency range, bandwidth and dynamic range covered by modern seismological records and related objects of research. The wavelengths of seismic waves vary, depending on their period and propagation velocity, between several meters (m) and more than 10,000 kilometers (km) and the spatial resolution of the investigated objects accordingly. The ground motion displacement amplitudes considered here range from nanometer (nm) to decimeter (dm). Continuous GPS may even measure displacements between cm and several m. Respective velocity amplitudes range between about 1 nm/s to several dm/s, however, strong-motion seismometers may even record accelerations up to about 20 $m/s^2$ (≈ 2 g). When investigating with seismic methods even small-scale upper-crustal and near-surface structures or when recording induced seismic events in industrial seismology applications in conjunction with mining activities, liquid waste disposal, hydro-carbon extraction, tunnel drilling, or non-destructive material testing, even much higher frequencies than 50 Hz, up to MHz (ultra-sound), may need to be recorded. This is, however, beyond the scope of the NMSOP.

At the same time, these new possibilities carry new risks:

- analysts who only use ready-made computer programs for solving a diversity of tasks, by feeding in the data and pressing the button, tend to lose a deeper understanding of the underlying model assumptions, inherent limitations and possible sources of error, and the quality of the results is sometimes judged by the attractiveness of the graphic user interface;
- Easily calculated and displayed standard deviations for all conceivable solutions often seem to indicate a reliability of the results, which is far from the truth. Therefore, an understanding of the difference between internal, computational and also model-dependent *precision* on the one hand, and *accuracy* of the solutions with

reference to reality on the other hand, has to be encouraged (see Glossary for the definition of terms);

- specialists are increasingly required to operate and properly maintain modern seismic equipment and software. They usually lack a broader geo-scientific background and thus an active interest in the use of the data themselves. This may result in a declining concern for long-term data continuity and reliability, which is the backbone for any geo-scientific observatory practice.

In consideration of these factors, the authors took as prime aims of the new Manual:

- to create an interdisciplinary problem understanding;
- to present a multitude of seismic waveforms depending on source type and size, epicentral distance, hypocentral depth, seismic component decomposition and axis rotation, transfer function of the seismic recordings, and with respect to the applied filters;
- to provide guidance for the selection of the most suitable station sites and the installation and shielding of modern seismic stations, vaults and sensors;
- to provide guidance for using modern tools and procedures for seismological data acquisition, processing and analysis;
- to motivate observatory personnel to overcome boring routines by developing curiosity and an active interest in the use of the data they produce both in science and society;
- to provide material for teaching, from high school to Bachelor and Master levels.

#### 1.2.2.3 The need for secondary phase readings

The currently still dominant practice of analyzing and reporting mainly first-arriving seismic phases results in conjunction with the inhomogeneous distribution of seismic sources and receivers over the globe results in a very incomplete and inhomogeneous sampling of the structural features and properties of the Earth's interior. The consequences are not only ill-constrained Earth models of low resolution, but also earthquake locations of insufficient accuracy (with mislocations up to several tens of km). This is reflected in the difficulty in understanding the seismotectonic origin of earthquakes and in the identification of the most likely places of their future occurrence. This prompted seismologists in the late 1980s (e.g., Doornbos et al., 1991) to conceive an International Seismological Observing Period (ISOP) aimed at:

- maximizing the reports of secondary phases from routine record readings aimed at improving source locations and sampling of the Earth (e.g., Fig. 1.10);
- taking best advantage, in the routine analysis, of the increasing availability of digital broadband records and easy-to-use data preprocessing and analysis software;
- improving the training of station operators and analysts;
- improving the communication, co-ordination and co-operation between the stations of the global and regional seismic networks.

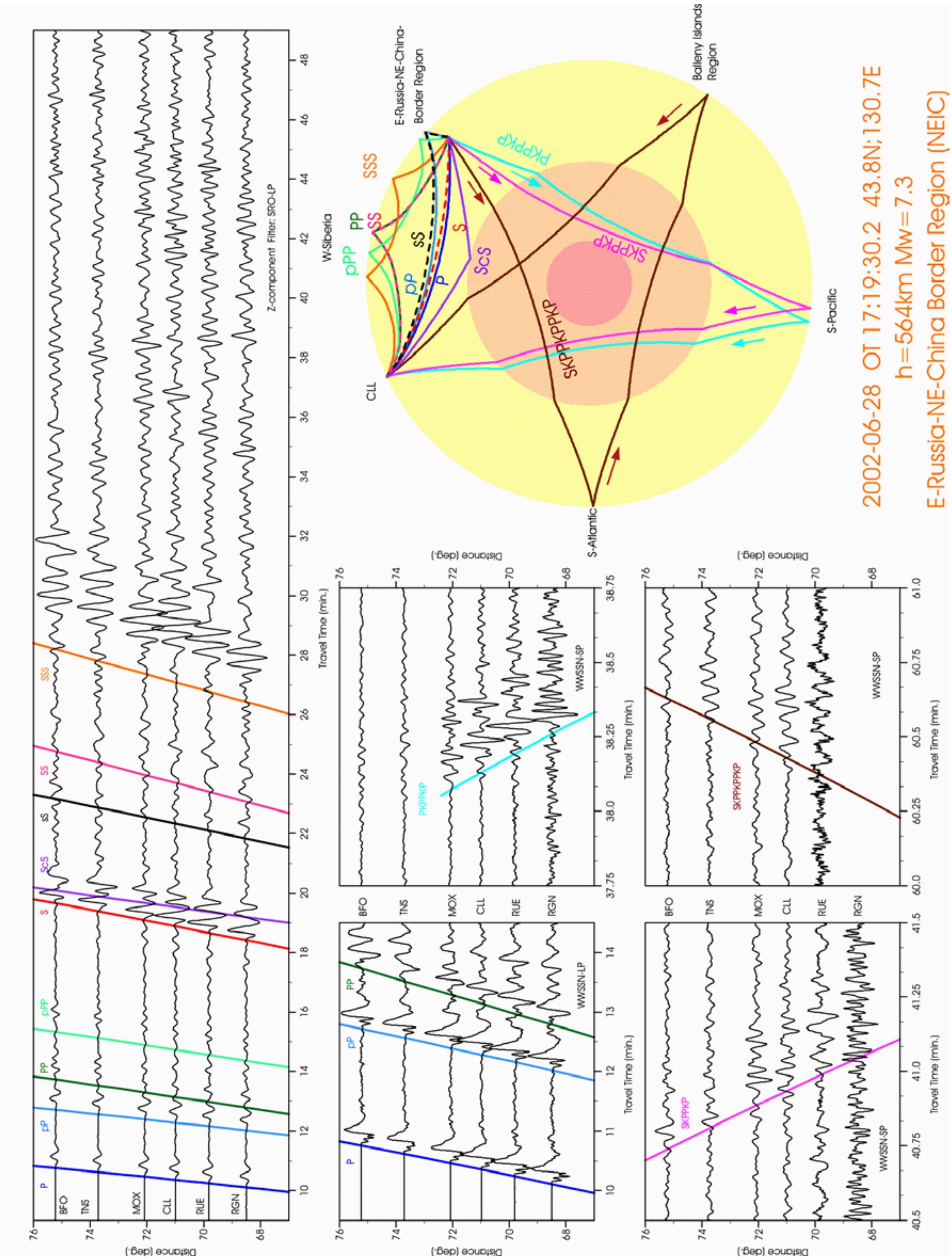


**Fig. 1.10** Detailed interpretation of long-period (LP) and short-period (SP) filtered broadband records of the stations of the German Regional Seismic Network (GRSN). Note the clearly recognizable depth phases pP, pPP and sS, which are extremely important for a more accurate depth determination of the event (see Figure 11 in IS 11.1), as well as the rare but well developed multiple core phases PKPPKP, SKPPKP and SKPPKPPKP which sample very different parts of the deep Earth's interior than the direct mantle phases (courtesy of S. Wendt, 2002).

Ultimately, the ISOP plan for an international observational experiment focused on expanded reporting of secondary body wave phases collapsed in the face of entropy and inertia, but the issues raised in the ISOP project have remained important to many seismologists. The need for the NMSOP grew out of discussions within the ISOP project and has been developed in the spirit of ISOP. It is largely based on training material and practical exercises used in international training courses for station operators and analysts (see Bormann, 2000). Accordingly, Chapter 11 on Data Analysis and Seismogram Interpretation is, together with its extended annexes of seismogram examples (DS 11.1-11.4), information sheets and exercises on event location and phase identification together with related software the most extensive part of the NMSOP.

#### 1.2.2.4 New seismic sensors, data acquisition systems and sensor calibration

NMSOP-2 presents an even more elaborated Chapter 5 on the basic theory of seismometry and the practice of instrument calibration and parameter determination. The theory is complemented by an extended Data Sheet 5.1 giving the essential parameters of two dozens of modern seismometer types, as well as by different exercises and links to freely available software for parameter determination and response calculations. NMSOP-2 introduces not only traditional inertial seismometers and strainmeters (IS 5.1), but for the first time also rotational sensors and rotation measurements (IS 5.3). In other chapters, the effects of different seismograph responses, post-record filtering or computational signal restitution on the appearance of seismograms and the reliability and reproducibility of parameter readings is demonstrated with many examples. Complementary to it, the updated Chapter 6 introduces the most recent developments and concepts of modern data acquisition systems.

Modern broadband seismographs record ground motions with a minimum of distortion and it is possible to restore true ground motion computationally with high accuracy. Seismic waveforms carry much more information about the seismic source and wave-propagation process than simple parameter readings of onset times, amplitudes and prevailing periods of seismic phases. Therefore, waveform modeling and fitting has now become a major tool both of advanced seismic research and increasingly also of routine processing and analysis. Seismic waveforms and amplitudes, however, strongly depend on the transfer function and gain of the seismograph, which must be known with high accuracy if the full potential of waveform analysis is to be exploited. Also reliable amplitude-based magnitude estimates, most of them still being determined from band-limited recordings, require accurate knowledge of the recording system's frequency-dependent magnification. Consequently, instrument parameters that control the instrument response must be known and kept stable with an accuracy of better than a few percent.

Unfortunately, at many seismic stations the seismographs have never been carefully calibrated, the actual gain and response shape is not precisely known and their stability with time is not regularly controlled. Some station operators rely on the parameters given in the data sheets of the manufacturers or those determined (possibly) by the primary installer of the stations. However, these parameters, instrumental gain in particular, are often not accurate enough. Therefore, station operators themselves should be able to carry out an independent, complete calibration of their instruments. For modern feedback-controlled broadband seismographs the basic parameters, eigenperiod and gain, are rather stable, provided that the seismometer mass is kept in the zero position. This, however, should be regularly controlled, more frequently (e.g., every few weeks) in temporary installations and every few months in more stable permanent installations. Chapter 5 deals extensively with this issue and provides links to calibration software. Moreover, long-period seismographs are strongly influenced by the stability of the underground and installation platform. Variations in ambient temperature, air pressure fluctuations and other environmental disturbances may result in unwanted drifts and noise. Therefore, a new IS 5.4 deals specifically with the shielding and installation of broadband seismometers.

Although short-period instruments are generally considered to be much more robust and stable in their parameters, experience has shown that their eigenperiod and attenuation may change with time up to several tens percent, especially when these instruments are repeatedly deployed in temporary installations. Parameter changes of this order are not tolerable for quantitative analysis of waveform parameters. Therefore, more frequent control and absolute determination of these critical sensor parameters are strongly recommended after each re-installation.

### 1.2.2.5 What has to be considered when installing new seismic networks?

More and more countries now realize the importance of seismic monitoring of their territories for improved seismic hazard assessment and the development of appropriate risk-mitigation strategies. The installation and long-term operation of a self-reliant modern seismic network is quite a demanding and costly undertaking. Cost-efficiency largely depends on proper project definition, instrument and site selection based on a good knowledge of the actual seismotectonic and geographic-climatic situation, the availability of trained manpower and required infrastructure, and many other factors. Project-related funds are often available only within a limited time-window. Therefore, they are often spent quickly on high-tech hardware and *keys-in-hands* installations by foreign manufacturers without a careful site selection and proper allocation of funds for training and follow-up operation. If local people are not involved in these initial efforts and capable of using and maintaining these new facilities and data according to their potential, then the whole project might turn out to be a major investment with little or no meaningful return. These crucial practical and financial aspects are usually not discussed in any of the textbooks in seismology that mostly serve general academic education or research. Chapter 7, covering site selection, preparation and installation of seismic stations has therefore become, after adding 31 pages alone on seismic installations and observations in the marine environment, the second largest NMSOP-2 topic. Possible achievements using modern seismological networks, both physical and virtual ones, at local, regional and global scales, and their relation with respect to aperture, data processing and results to specialized seismic arrays, is extensively dealt with in Chapters 8, 9 and 14 of NMSOP-2.

## 1.3 Philosophy of the NMSOP

The concept for the NMSOP was developed with consideration of the benefits and drawbacks of the old Willmore (1979) Manual, taking into account the technological developments and opportunities which have appeared during the last few decades, as well as the existing in-equalities in scientific-technical conditions and availability of trained manpower world-wide (Bormann, 1994).

Seismological stations and observatories are currently operated by a great variety of agencies, whose staff consists of seismologists and technicians with widely varying training and interests, or with no staff at all and operated remotely from a seismological data or analysis center. They are equipped with hardware and software ranging from very traditional analog technology to highly versatile and sophisticated digital technology. While in industrialized countries the observatory personnel normally have easy access to up-to-date technologies, spare parts, infrastructure, know-how, consultancy and maintenance services, those working in developing counties are often required to do a reliable job with very modest means, without much outside assistance and usually lacking textbooks on the fundamentals of seismology or information about standard observatory procedures.

To ensure that data from observatories can be properly processed and interpreted under these diverse conditions, it is necessary to establish protocols for all aspects of observatory operation that may affect the seismological data itself. In addition, competent guidance is often required in the stages of planning, bidding, procurement, site-selection, installation of new seismic observatories and networks and the calibration of equipment so that they will later meet basic international standards for data exchange and processing in a cost-effective and efficient manner.

One drawback of the old Manual was that its chapters were organized purely according to components or tasks of observatory practice, namely:

- Organization of station networks;
- Instruments;
- Station operation;
- Record content;
- The determination of earthquake parameters;
- Reporting output;
- Macroseismic observations;
- International services.

A consequence of this structuring was that the seismological fundamentals required to understand the relevance and particulars of the various observatory tasks were sometimes referred to in various chapters and dealt with in a fragmented manner. This approach makes it difficult for observatory personnel to comprehend the interdisciplinary problems and aims behind observatory practice and to appreciate the related, often stringent requirements with respect to data quality, completeness, consistency of procedures etc. Further, this approach puts together in the same chapters basic scientific information, which is rather static, with technical aspects, which may change rapidly. This makes it difficult to keep the Manual up-to-date without frequent rewritings of entire chapters.

The IASPEI WG on the NMSOP agreed, therefore, to structure the new Manual differently:

- The body of the Manual should have a long-term character, outlining the scope, terms of reference, philosophy, basic procedures as well as the scientific-technical and social background of observatory practice. It should aim at creating the necessary awareness and sense of responsibility to meet the required standards in observatory work in the best interests of scientific progress and social service.
- The main body or backbone of the NMSOP should be structured in a didactically systematic way, introducing first the scientific-technical fundamentals underlying

each of the main components in the "information chain" (see Fig 1.2) before going on to major tasks of observatory work.

- This Manual core composed of thematic Chapters should be complemented by annexed material of complementary information, which can stand for itself. Some of these topics are too bulky or specific to be included in the body of the Manual, while others may require more frequent updating than the thematic Manual Chapters. Therefore, they should be kept separate and individualized. Some annexes give more detailed descriptions of special problems (e.g., event location or theory of source representation; seismic moment tensor and energy release calculations) others provide data about commonly-used Earth models, shareware for problem solving, seismic record examples, calibration functions for magnitude determination, widely-used sensors and their key parameters, or job-related exercises with solutions for specific observatory tasks such as phase identification, event location, magnitude estimation, fault-plane determination, complemented by a list of acronyms and a very detailed glossary of terms.
- While the printed first edition tried - for the sake of paper saving and cost reduction - to avoid any duplication throughout the Manual and therefore had an overall reference list und index, the electronic NMSOP-2 is more a compilation of stand-alone contributions. All are peer reviewed and have their own doi-number, overview listing of contents at the outset and a complete reference list at the end. They contain all essential information and illustrations required for understanding the problem or carrying out a specified task without the need to download or printout additional NMSOP material. Links and cross references to other NMSOP items or external sources of information mainly aim at stimulating further readings for the sake of justifying the statements made and/or deepening the understanding of the subject, as is the case of references in journal publications. This structuring also eases future independent upgrading of the MSOP contributions by the individual authors.

Thus, we hope to provide a new Manual which is a sufficiently complete, self-explanatory reference source ("cook and recipe book") aimed at providing awareness of the complexity of problems, basic background information, and specific instructions for the self-reliant execution of common "routine" or "pre-research" jobs by the technical and scientific staff at seismological stations, observatories, and network centers. This includes system planning, site investigation and preparation, instrument calibration, installation, shielding, data acquisition, processing and analysis, documentation and reporting to relevant national and international agencies, data centers or the public, and occasionally, also assessing and classifying earthquake damage.

The NMSOP will not cover the often highly automated procedures now in use at many international seismological data centers. These centers normally neither record nor analyze seismic records themselves, but rather use the parameters or waveforms reported to them by stations, networks or arrays. They usually have the expertise and the scientific-technical environment and international connections needed to carry out their duties effectively. Rather, the NMSOP mainly serves the needs of the majority of less experienced or too narrowly specialized operators and analysts in both developing and industrialized countries, so as to assure that all the necessary tasks within the scope and required standards for national and international data acquisition and exchange can be properly performed.

Worldwide there is no formal university education or professional training available for seismic station operators and data analysts. Observatory personnel usually acquire their training through "learning by doing". The formal educational background of observatory personnel may be very different: Physicists, geologists, electronic or computer engineers, rarely geophysicists. Accordingly, the NMSOP tries to be comprehensible for people with different backgrounds, to stimulate their interest in interdisciplinary problems and to guide the development of their required practical skills. The method of instruction is mainly descriptive. Higher mathematics is only used where it is indispensable, e.g., in the seismometry chapter or in the information sheets about theoretical source representation (IS 3.1) and seismic moment tensor determination and decomposition (IS 3.9).

The NMSOP should, however, also be a contribution, at least in part, to public, high school and university education in the field of geosciences. Therefore, NMSOP-2 has been enriched by several new tutorials and quite many appealing animations on seismic rupture and ray propagation, event location, source radiation patterns, 3-D event-cluster presentation and its development in space and time. We hope that some of these components and practicals will be useful also for students of geophysics.

## 1.4 Contents of the NMSOP

The NMSOP has been made available in different forms:

- the first edition in 2002 as a loose-leaf collection of printed material in two volumes, complemented by a CD-ROM;
- the 1st slightly revised edition in 2009 (NMSOP-1) in electronic form as pdf-files on the Internet, accessible via http://www.iaspei.org/projects/NMSOP.html and http//nmsop.gfz-potsdam.de.
- the 2nd edition in electronic form only, accessible via the same websites and downloadable in all its components, as NMSOP-1 too. However, users with still insufficient or too slow internet connections my also request a NMSOP-2 DVD from the GFZ library (bib@gfz-potsdam.de).

### 1.4.1 The printed Manual (2002) and its electronic edition (NMSOP-1; 2009)

The IASPEI and ESC Working Groups for the NMSOP agreed on the following topical Manual chapters for the first edition (for details see List of Contents accessible via the websites http://nmsop.gfz-potsdam.de and http://www.iaspei.org/projects/NMSOP.html):

Chapter 1: Aim and scope of the IASPEI New Manual of Seismological Observatory Practice (NMSOP)
Chapter 2: Seismic Wave Propagation and Earth Models
Chapter 3: Seismic Sources and Source Parameters
Chapter 4: Seismic Signals and Noise
Chapter 5: Seismic Sensors and their Calibration
Chapter 6: Seismic Recording Systems
Chapter 7: Site Selection, Preparation and Installation of Seismic Stations
Chapter 8: Seismic Networks
Chapter 9: Seismic Arrays

Chapter 10: Data Formats, Storage, and Exchange
Chapter 11: Data Analysis and Seismogram Interpretation
Chapter 12: Intensity and Intensity Scales
Chapter 13: Volcano Seismology

These chapters form Volume 1 of the printed NMSOP and cover either the fundamental aspects of the main sub-systems of the "Information Chain of Seismology" as presented schematically in Fig. 1.2, or related specific tasks, technologies or methodologies of data acquisition, formatting, processing and application.

Volume 1 is complemented by Volume 2. The latter contains annexes in the following categories:

- **7 Datasheets (DS):** Lists of sensor parameters; record examples, travel-time curves, Earth models, calibration functions, etc.;
- **18 Information Sheets (IS):** They contain more detailed treatments of special topics or condensed summaries of special instructions/recommendations for quick orientation, present the standard nomenclature of seismic phase and magnitude names, give examples for parameter reports and bulletins, etc.;
- **14 Exercises (EX):** Practical exercises with solutions on basic observatory tasks such as event location, magnitude estimation, determination of fault-plane solutions and other source parameters, instrument calibration and response construction. For educational purposes, most of these exercises are carried out manually with very modest technical and computational means, however links are given to related software tools;
- **12 Program Descriptions (PD):** Short descriptions of essential features of freely available software for observatory practice and how to access it;
- **Miscellaneous:** A list of acronyms, an extensive index, the list of authors with complete addresses, an overall list of references for Volume 1 and a 28 page glossary of terms.

In total, NMSOP-1 comprises some 1250 pages.

### 1.4.2 The 2nd electronic edition (NMSOP-2; 2012-13)

All NMSOP-1 Chapters have been preserved in NMSOP-2, but significantly revised and/or amended. Four three Chapters have been added:

Chapter 14: Investigation of Site Response in Urban Areas by using Earthquake Data and Seismic Noise
Chapter 15: CTBTO: Goal, Networks, Data Analysis and Data Availability
Chapter 16: Automated Event and Phase Identification

The 16 Chapters comprise already as many pages as the two volumes of NMSOP-1. An originally planned major new Chapter on "Seismological Contributions to Seismic Risk Mitigation", meant to become the crucial missing link to the engineering seismology, earthquake engineering, strong-motion recording, hazard and risk assessing and mitigating communities, could regrettably not be realized. It is hoped that this gap can at least partially be closed by related topical information sheets in future amendments to NMSOP-2 under a new editorship.

The number of information sheets (now 36), tutorials (5), exercises (16), and movie demonstrations (16 animations) has been greatly expanded in NMSOP-2, making for approximately another 850 pages, to which 200 pages of the currently most elaborate Glossary of terms in seismology, global and seismotectonics, engineering seismology and other related disciplines have been added. Thus, in total, NMSOP-2 will comprise about 2400 pages of material, complemented by many links to external sources.

## 1.5 Outreach of the NMSOP

The printed English version of the first edition of the NMSOP is meanwhile in use with some 2000 copies in more than 100 countries, complemented by another 2000 copies of a 2 volume book edition in Chinese and several 100 copies of partial translations into Russian, Indonesian and Turkish language, respectively. Accessibility and usage as well as the diversity of the user community will grow significantly with the two Internet editions now being available free of charge.

It is expected, therefore, that the user community of the NMSOP will not be limited to observatory personnel. Many chapters, sections, auxiliary materials and educational animations (for the latter see IS 1.1) will be of general interest to lecturers and students in seismology, geophysics or geosciences in general but also for increasingly popular courses of "seismology at schools" in many countries. Training institutions in the field of applied seismology may use any NMSOP-2 material, compiling training modules from it that are tailored to their specific requirements, provided that the data source and the individual authors of the related Manual contribution are properly cited (click on cover page: Rights, Permissions, Acknowledgments and References to NMSOP-2, respectively NMSOP-1). Also, technical people from other disciplines might find (at least partially) useful pieces of information in the Manuals for their work and cooperation with seismologists such as disaster managers and risk mitigation planners. Thus NMSOP is hoped to be of long-term benefit to a rather diverse user community, including also those interested in historical approaches and results of observatory seismology.

Permanent maintenance and regular updating of NMSOP-2 will assure its wide and long-term outreach, in keeping with continuing developments and changing requirements. This will be a permanent duty of the IASPEI Commission on Seismological Observation and Interpretation (CoSOI) and its relevant Working Groups. The library of the GFZ German Research Centre of Geosciences will serve as the long-term host of the NMSOP website, assuring its presentation and maintenance according to international bibliographic and publishing standards, including the handling of all rights and permission affairs on behalf of IASPEI. Accordingly, the acting CoSOI chairman (see http://www.iaspei.org/) and the GFZ chief librarian, presently Mr. R. Bertelmann (rab@gfz-potsdam.de), are the two main focal points of contact in this grand international cooperative project. Related general questions and proposals should be addressed to them, in contrast to specific topical NMSOP-item inquiries and suggestions which should be addressed to the respective lead author.

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# Recommended overview readings on seismology

Aki and Richards (1980, 2002)
Båth (1979)
Bolt (1982, 1993, 1999)
Havskov and Alguacil (2006)
Havskov and Ottemöller (2010)
Kennett (2001 and 2002)
Kulhánek (1990, 2002)
Lay and Wallace (1995)
Lilie (1998)
Scherbaum (2007)
Shearer (1999)
Stein and Wysession (2003)
Udias (1999, 2002)
Willmore (1979)

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