EXTENSION OF M_S(VMAX) TO GLOBAL PATHS

Jill M. Franks[1], Brian M. Pope[2], Richard A. Reed[2], Michael F. Jezard[1], Gordon D. Kraft[1], Siroos Motlagh[1], Steven J. LeClaire[2], Michael S. Antolik[1], Anne S. Henson[2], and Kevin D. Hutchenson[1]

Quantum Technology Sciences, Inc.[1] and Science Applications International, Corp.[2]

Sponsored by Air Force Technical Applications Center

Contract No. FA8620-05-C-4301

ABSTRACT

Recent work with a prototype application for variable-period Rayleigh-wave magnitudes (Russell, 2006) has reported use of the M_s(VMAX) technique for periods between 8 and 25 seconds (Bonner et al., 2006a, 2006b, 2007). More recently, the technique has been extended to 40 seconds (Bonner, 2007). In all previous studies, the data were limited to continental paths and thoroughly reviewed.

This study has attempted to evaluate an operational scenario whereby all surface-wave paths are considered. Two groups of data have been utilized, twenty-seven (27) shallow events from the Asian continent and a larger (143 events) global event group with a broader depth range. All events have been reviewed by an analyst for validity. To obtain a better understanding of period and path effects, the data have been subdivided into three period ranges (8–17 seconds, 17–25 seconds, and 25–40 seconds) and separated by predicted group slowness into oceanic paths (*slow* < 32.25 sec/deg), continental paths (*slow* > 38.0 sec/deg), and mixed oceanic-continental paths (32.25 sec/deg ≤ *slow* ≤ 38.0 sec/deg).

Past studies have demonstrated the M_S(VMAX) technique works well for continental paths between 8 and 25 seconds (Bonner et al., 2006b, 2007). This study shows stable results for all paths (oceanic, mixed, and continental) between 8 and 25 seconds. Since the data have been shown to be path independent, the M_S(VMAX) technique may provide an automated replacement for M_S, allowing the inclusion of regional stations with Airy phases and reducing the analyst burden.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **SEP 2008**	2. REPORT TYPE	3. DATES COVERED **00-00-2008 to 00-00-2008**

4. TITLE AND SUBTITLE
Extension of Ms(VMAX) to Global Paths

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Quantum Technology Sciences Inc,1980 North Atlantic Avenue, Suite 930 ,Cocoa Beach,FL,32931

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
Proceedings of the 30th Monitoring Research Review: Ground-Based Nuclear Explosion Monitoring Technologies, 23-25 Sep 2008, Portsmouth, VA sponsored by the National Nuclear Security Administration (NNSA) and the Air Force Research Laboratory (AFRL)

14. ABSTRACT
see report

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

OBJECTIVES

Our objective is to extend and evaluate the M_s(VMAX) magnitude calculation on a global scale, utilizing all available station paths, rather than being limited to continental paths. Extending the technique to all surface-wave paths is an important step towards automating the process in an operational monitoring environment, where manual analysis and calculation are not feasible for all events.

RESEARCH ACCOMPLISHED

Background. Russell (2006) developed a magnitude equation, called M_s(VMAX), which was originally intended for surface wave paths through typical continental crust, however, it was unclear how well the original equation would extend beyond continental paths to other paths (oceanic or mixed continental-oceanic). The equation is

$$M_{s(b)} = \log(a_b) + \frac{1}{2}\log(\sin(\Delta)) + 0.0031\left(\frac{20}{T}\right)^{1.8}\Delta - 0.66\log(f_c) - 0.43$$

where T is the period, a_b is the amplitude of the Butterworth-filtered surface waves, Δ is the distance in degrees, and $f_c \le \frac{0.6}{T\sqrt{\Delta}}$ is the corner filter frequency of a third-order Butterworth band-pass filter with center period T and bandwidth $2f_c$. The M_s(VMAX) method allows measurement of surface-wave magnitudes at both regional and teleseismic distances, while conventional M_s measures magnitudes at teleseismic distances with periods between 17–23 seconds.

Methodologies using this approach have been presented by Bonner et al. (2006b, 2007). Differences between this and prior studies are the incorporation of all paths from an event and the use of an automated code to routinely process data. The automated results were subsequently reviewed; however, only automated measurements are presented. The interactive review of the measurements was used to evaluate outliers.

Data. The data used in this study consist of earthquakes obtained from the U.S. National Data Center (USNDC). The data were divided into two sets: 27 shallow events from the Asian continent and 143 globally-distributed events that contain a broader depth range and more path diversity (Figure 1). All events were reviewed by an analyst for validity prior to inclusion in this study.

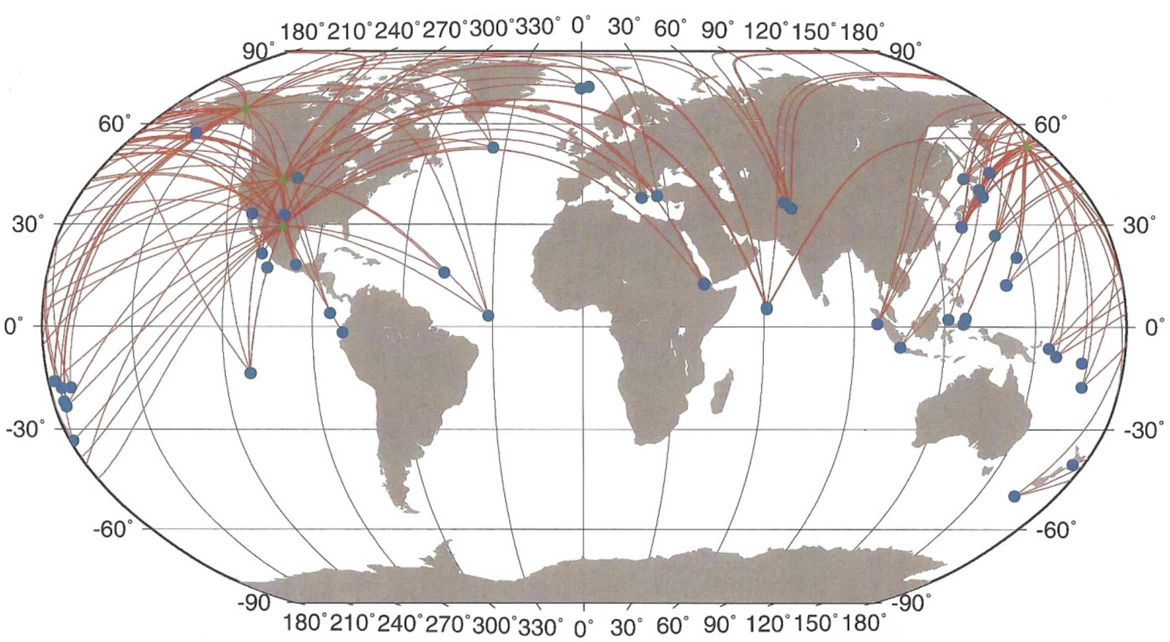

Figure 1. Representative paths showing the inclusion of oceanic, mixed, and continental components.

In order to better understand path and period-dependent effects, the data were partitioned into three period ranges: – 8–17 seconds, 17–25 seconds, and 25-40 seconds. These partitions were chosen based on the applicable period ranges of conventional M_s (17–23 seconds) and to investigate the application of M_s(VMAX) to shorter (8–17 seconds) and longer periods (25-40 seconds). The 25–40-second period results are not presented in this study.

In addition, the data were also partitioned by predicted group slowness into three paths: oceanic paths (*slow* < 32.25 sec/deg), continental paths (*slow* > 38.0 sec/deg), and mixed oceanic-continental paths (32.25 sec/deg < *slow* < 38.0 sec/deg). This partitioning enabled determination of bias for the M_s(VMAX) calculations for each path and period range. The final slowness values used in the study were empirically determined using the data and paths.

All amplitudes were corrected to displacement using frequency/amplitude/response files. Contrary to conventional M_s amplitudes measured on a long-period channel, the M_s(VMAX) amplitudes were measured on a decimated broad-band channel to provide a larger period range.

Results. Processing of the data used an automated code to perform all calculations following the methodology outlined by Bonner (2006a, b; 2007). The waveform data were windowed using the predicted Rayleigh arrival and representative noise using predetermined parameters. The predicted group-velocity limits used a recent surface-wave group velocity model (Pasyanos, 2005).

Following the processing methodologies of Bonner et al. (2006b, 2007), once the data were windowed, the largest signal amplitude at each center frequency was selected to calculate the magnitude. Results were automatically stored using a data model within a relational database.

The results were compared against the standard M_s value. The Rayleigh phase amplitude for each waveform was determined by an analyst, selecting a peak-to-peak amplitude with a period in the 17 to 25 second range. An M_s formula similar to the Prague formula (Vaněk et al., 1962) was used as the comparison.

Results from the globally distributed data showing the scatter and bias at the station level are shown for the three path types, oceanic, mixed oceanic-continental, and continental, and a combination of all three types in Figure 2. Development (Russell, 2006) and early work by Bonner (2006a, b; 2007) concentrated only on continental paths. Note the nearly constant 0.1 M_s unit bias. Scatter may be acceptable for an operational mode.

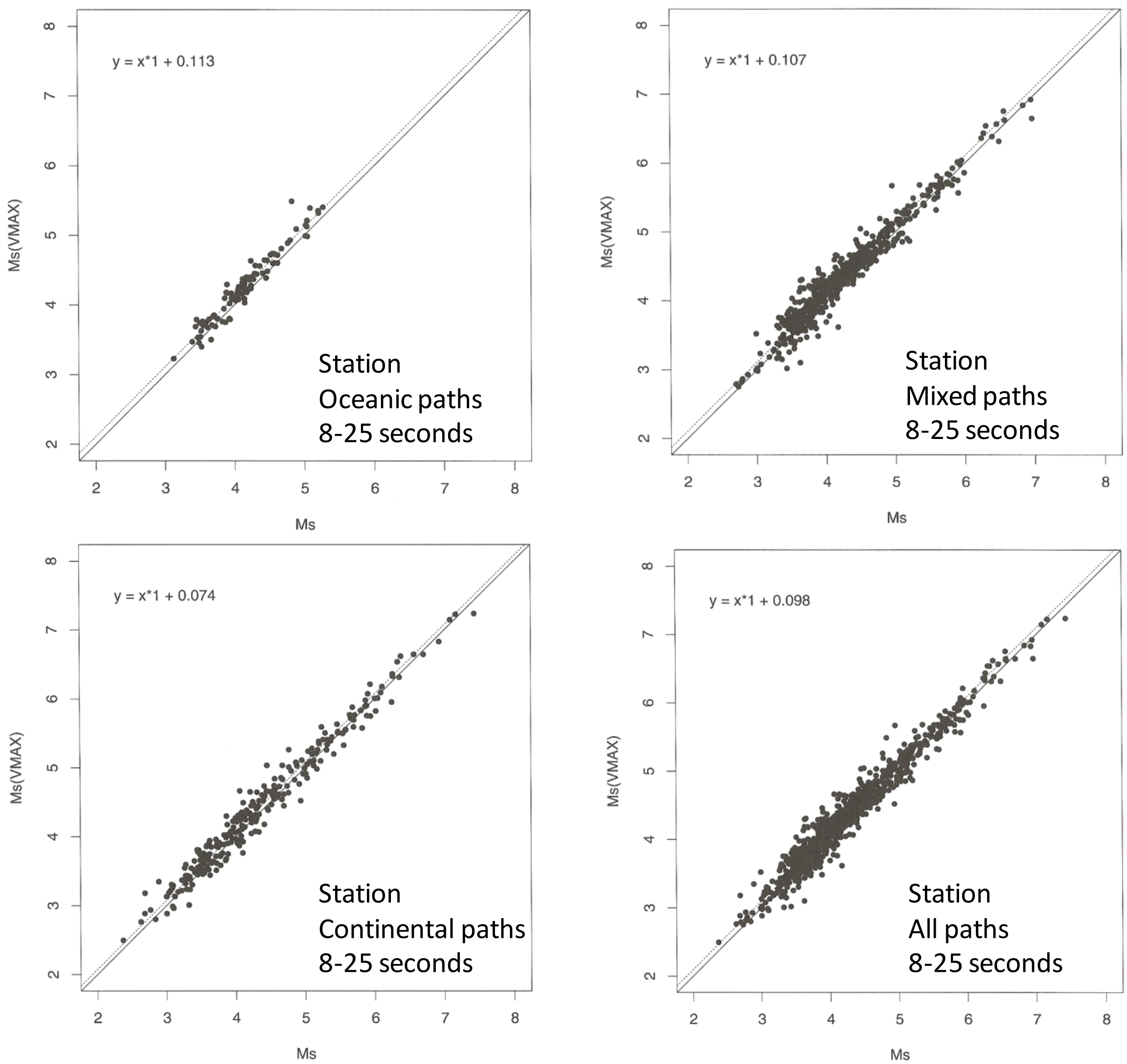

Figure 2. Results showing the station-magnitude scatter and bias for each type of path and combined path for the investigated period range (8–25 seconds).

We also investigated whether the bias contribution resulted from the shorter periods (8–17 seconds). To investigate this possibility, the paths were separated by period and path (Figure 3). No discernable bias is detectable. The results are consistent regardless of path and period.

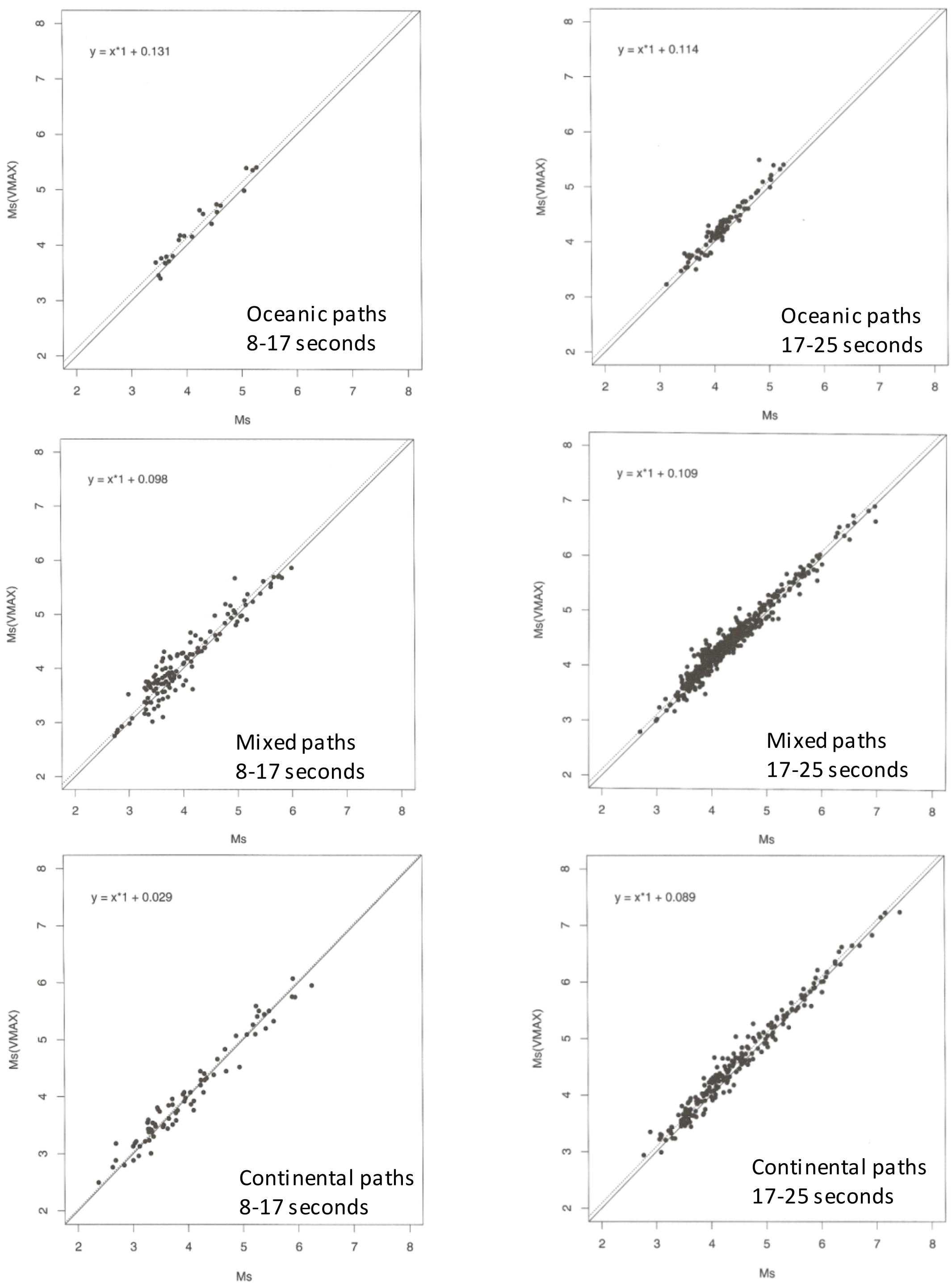

Figure 3. Results showing the station magnitude scatter and bias for each type of path and separated by period ranges to include 8–17 seconds and 17–25 seconds.

When the station magnitudes are combined into a network magnitude for each event, similar results are observed (Figure 4). The data show good agreement with a small bias of less than 0.1 M_s units. Since the Russell (2006) magnitude equation was empirically determined, any real bias terms can be incorporated into the formula.

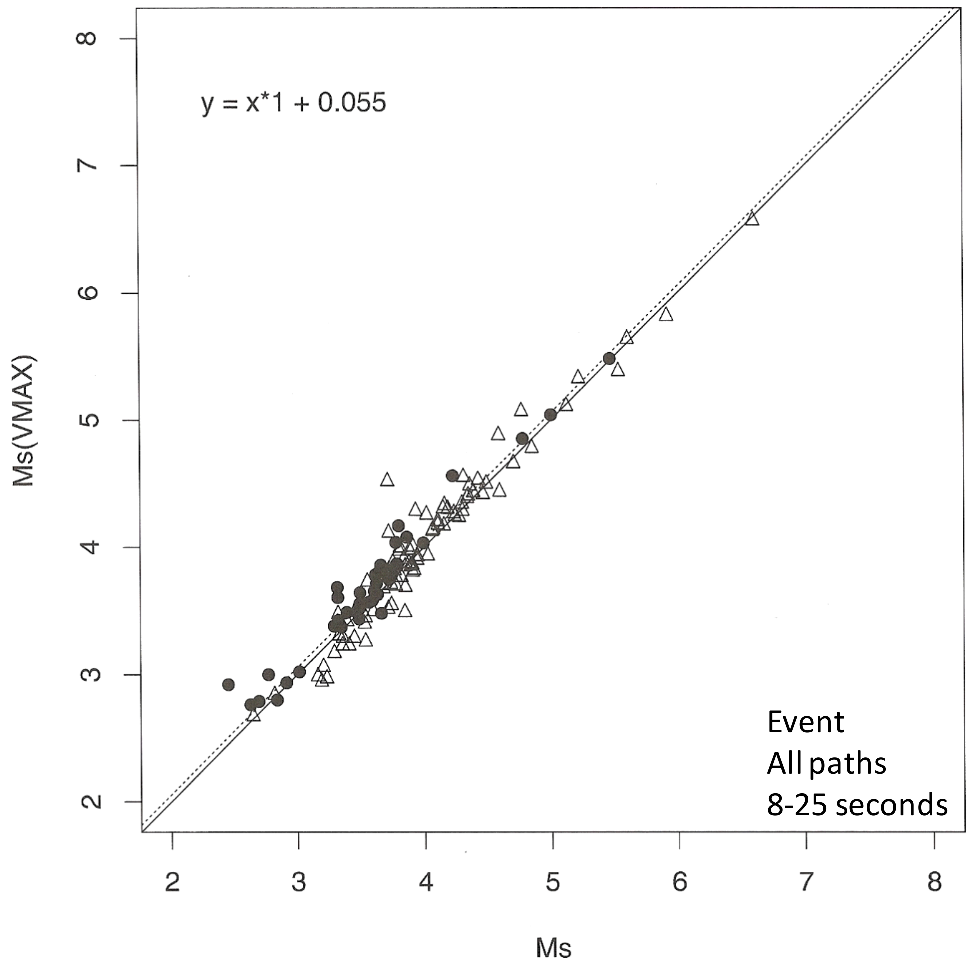

Figure 4. Network magnitude results with all paths for the investigated period range (8–25 seconds). The solid circles (●) represent those event magnitudes where the number of M_s(VMAX) station contributions are equal to those for M_s. The triangles (Δ) represent the event magnitudes where additional station M_s(VMAX) measurements contribute to the event average.

In Figures 2 and 3, the scatter plots show station-magnitude data, only a direct comparison between M_s (VMAX) and M_s is possible. However, the M_s(VMAX) technique is able to determine additional station contributions not obtainable using traditional M_s techniques. Figure 4 separates those network averages to illustrate the additional M_s (VMAX) station contributions. Stated differently, those network averages marked as solid circles (●) contain equal M_s and M_s (VMAX) stations in the network magnitude. The remaining network magnitudes (Δ) have additional station contributions in the averages, all from M_s (VMAX). The additional contributions cover the entire magnitude range. This was an unanticipated result.

Obvious outliers were examined and removed from the data. Outliers were strictly a result of processing, not methodology. For example, when two events were closely spaced, the automated group-velocity windowing may have included both events. The methodology would pick the largest amplitude, whether it corresponded to the event of interest or not. Also, automated quality-control methodologies were not implemented on the selected data. A data spike, glitch, or flat spot creates ripples in the time domain from edge effects associated with the filtering process.

Any remaining outliers could not be removed. A likely scenario is a case of two overlapping signals, two simultaneously arriving signals from different events.

CONCLUSIONS AND RECOMMENDATIONS

The M_s(VMAX) technique has been known to work well for continental paths between 8–25 seconds (Bonner et. al., 2006b, 2007). However this study shows stable results for oceanic and mixed oceanic-continental paths as well. Since the data were partitioned to ensure path independence, we have demonstrated the M_s(VMAX) technique is capable of functioning as an automated replacement for M_s. This allows the inclusion of regional stations with Airy phases, and stations for which a traditional M_s may not be easily determined. Overall, the use of automated results should reduce the analyst burden of picking individual phases, only requiring checks when anomalies may be present.

ACKOWLEDGEMENTS

The authors wish to thank the Air Force Technical Applications Center (AFTAC) for allowing the data to be used. Valid discussions were held between Team NDC, composed of QTSI and SAIC members, and AFTAC technical staff. In addition, Mr. Fredrick Ward (QTSI) assisted in investigating outliers and their cause.

REFERENCES

Bonner, J. L., D. Russell, D. Harkrider, D. Reiter, and R. Herrmann (2006a). Development of a time-domain, variable-period surface wave magnitude measurement procedure for application at regional and teleseismic distances, Part II: Application and Ms-mb Performance, *Bull. Seism. Soc. Am.* 96: 678–696.

Bonner, J. L., M. Pasyanos, M. Leidig, H. Hooper, and D. Harkrider, (2006b). A comparison of different surface wave magnitude measurement procedures on a Eurasian dataset, in *Proceedings of the 28th Seismic Research Review: Ground-Based Nuclear Explosion Monitoring Technologies*, LA-UR-06-5471, Vol. 1, pp. 560–569.

Bonner, J.L., M. Pasyanos, M. Johnson, and D. Harkrider. (2007). Calibration of the M_s(VMAX) technique in Eurasia, in *Proceedings of the 29th Monitoring Research Review: Ground-Based Nuclear Explosion Monitoring Technologies*, LA-UR-07-5613,Vol. 1, pp. 541-550.

Pasyanos, M.E. (2005). A variable-resolution surface wave dispersion study of Eurasia, North Africa, and surrounding regions, *J. Geophys. Res.* 110: B12301.

Russell, D.R. (2006). Development of a time-domain, variable-period surface wave magnitude measurement procedure for application at regional and teleseismic distances, Part I: Theory, *Bull. Seism. Soc. Am.* 96: 665–677.

Vaněk, J., A. Zatopek, V. Karnik, N.V. Kondorskaya, Y.V. Riznichenko, E.F. Savarensky, S.L. Solov'ev, and N.V. Shebalin (1962). Standardization of magnitude scales, *Bull. Acad. Sci. USSR, Geophys. Ser*., no. 2, 108–111 (English Translation).