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Determination of Body-wave Magnitudes of the North Korean Underground Nuclear Tests

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Introduction

The explosive yields of underground nuclear explosions (UNE) are usually estimated by using the magnitudes determined from seismic waves recorded at distances greater than 2,000 km.

The magnitudes are converted to explosive yields using formulae based on some explosions with announced yields and their magnitude relations at the test sites in Nevada, USA, and east Kazakhstan in the former Soviet Union.

Motivation

North Korea carried out six underground nuclear explosions during 2006 – 2017, but their magnitude and yield estimates using the seismic observations are less certain, in particular for the latest and the largest test on 3 September 2017.
This is due to lack of good knowledge on the seismic wave propagation paths between the test site and seismic stations distributed world-wide, and on the station site corrections.

Method of Analysis

We model the station magnitude, m_{bij}, from i-th event at j-th station as the sum of E_i = the network-averaged event magnitude, S_j = the receiver effect term, and F_k = geophysically uniform regions for source-receiver path effect, and e_{ij} = the error term for censored data (e.g., missing stations for some events and high ambient noise level at stations) as:

$$m_{bij} = E_i + S_j + F_k + e_{ij}$$

We determine these parameters by least-squares fit using observed P-wave amplitudes.

Station magnitude of the North Korean UNE on 3 September 2017 are obtained by using waveform data from 390 stations and over 360 stations of IMS including 22 arrays. Station magnitude residuals [δm_b = station m_b – mean m_b] show a systematic distribution on a world-wide scale indicating that regional magnitude adjustments are necessary for unbiased magnitude estimates.

Observed Amplitude Data and Results

Station magnitude of the North Korean UNE on 3 September 2017 are obtained by using waveform data from 390 stations of global, national and regional seismic networks. Station magnitude residuals [δm_b = station m_b – mean m_b] show a systematic distribution on a world-wide scale indicating that regional magnitude adjustments are necessary for unbiased network magnitude estimates.

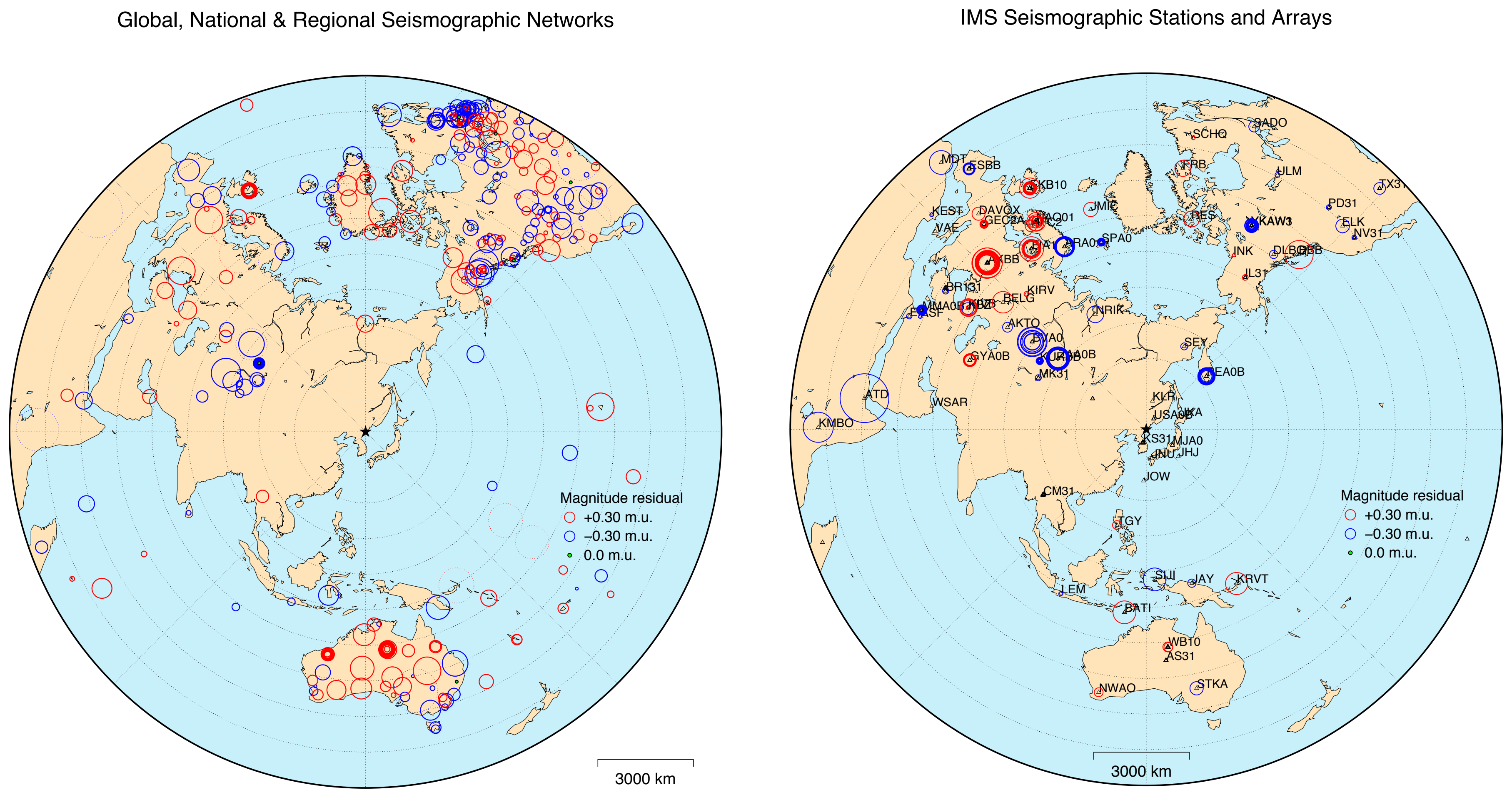
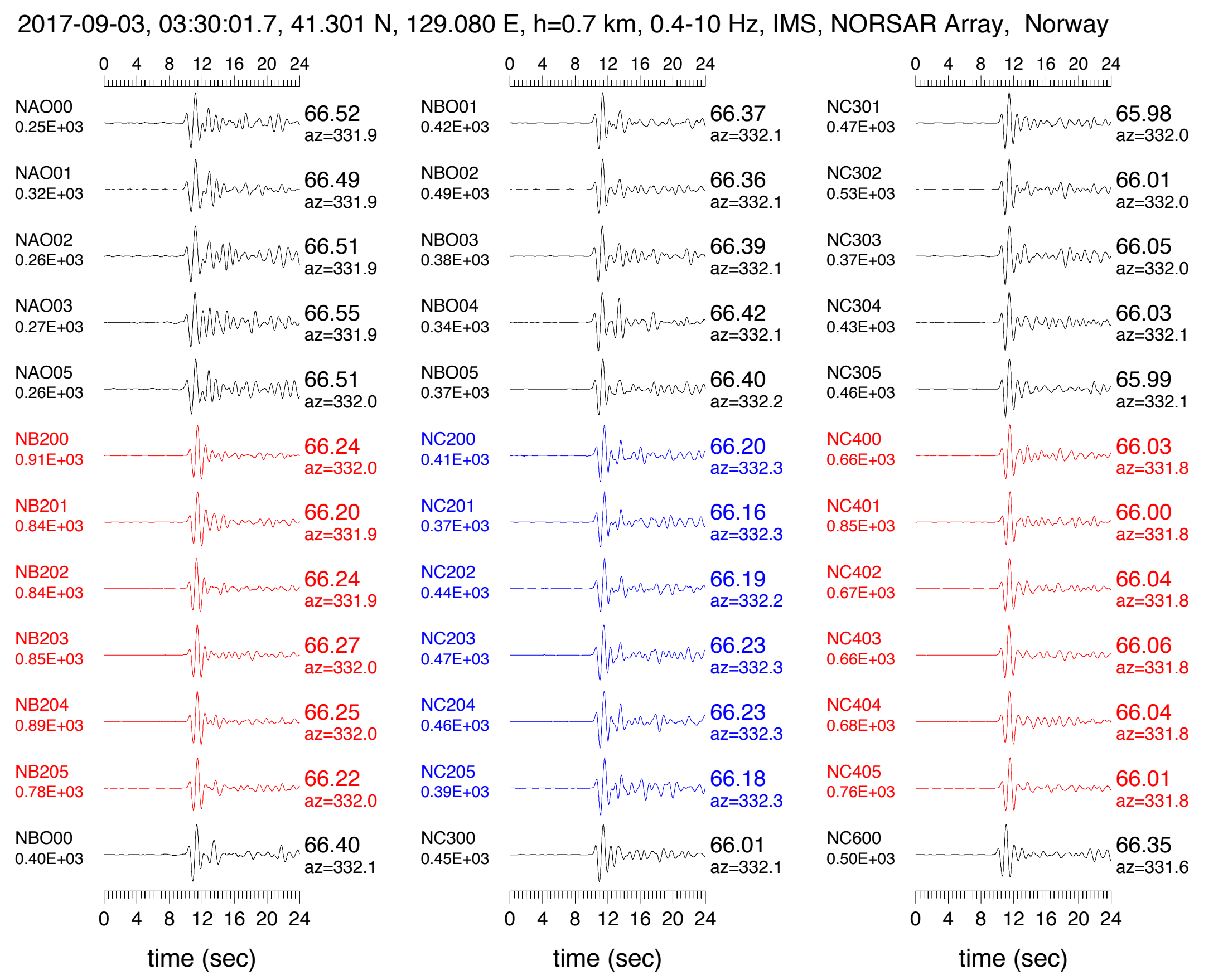
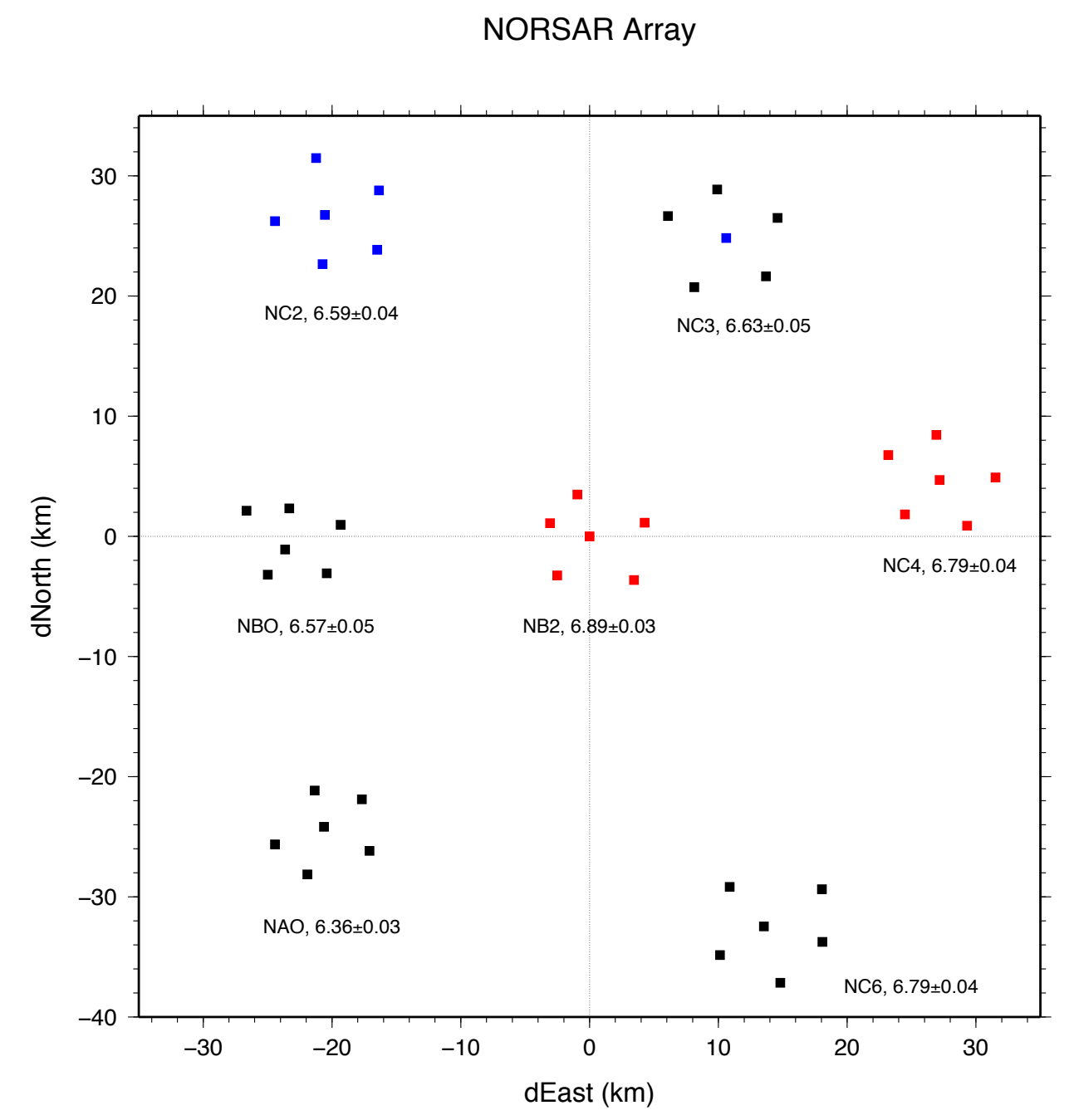


Figure 1. (left) Station magnitude residuals at 390 stations are plotted by circles. Stations in western Europe and central North America and Australia show larger magnitude than the mean (*red circles*), stations in central Asia (notably Kazakhstan) and eastern North America show smaller magnitudes than the mean (*blue circles*). (right) Magnitude residuals at IMS stations and arrays show a consistent pattern with global and national networks.





Seven sub-arrays used for simulated WWSSN-SP data.

Figure 2. Waveform data at 7 sub-arrays of NORSAR Array. P waves are coherent in each sub-array of radius ~5 km, but differ by up to 0.5 m.u. among the sub-arrays.

RMS Lg Amplitude Measurements

We determined root mean square (RMS) amplitudes of *Lg* waves from the six known North Korean UNEs at seismic stations situated on continental crustal paths from the UNEs. The RMS *Lg* amplitude measurements show consistency between the stations with comparable propagation paths.

The RMS *Lg* amplitudes correlate well with m_b and suggest that the RMS *Lg* amplitudes can be useful to estimate the yield of the six North Koran nuclear tests.

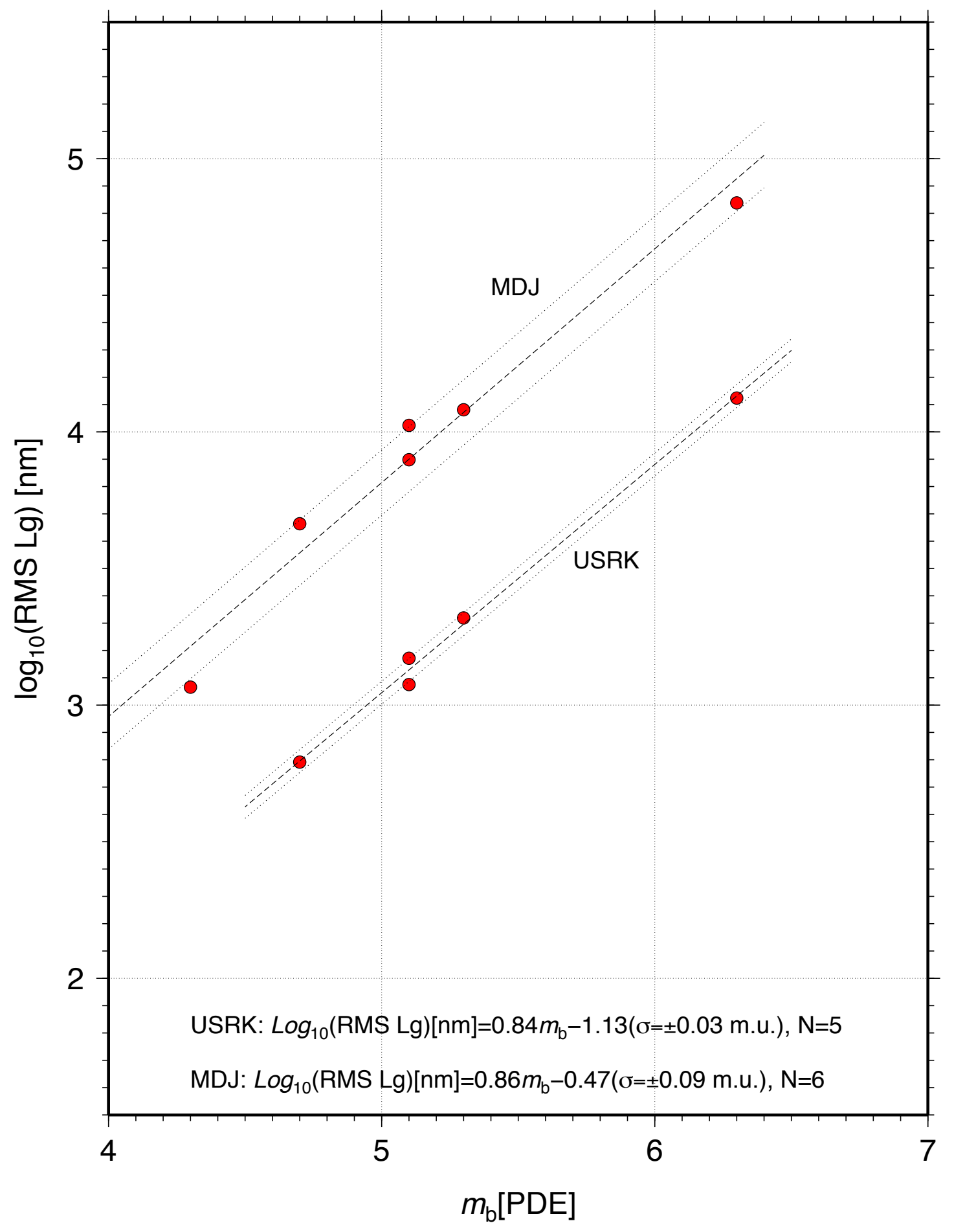


Figure 3. RMS *Lg* amplitude measurements at MDJ (371 km) and USRK (401 km) for six UNEs are compared with m_b (PDE). RMS *Lg* have small scatter of 0.03 to 0.09 magnitude units.

Concluding Remarks

- We evaluated station site effects for globally distributed seismic stations of IMS, global, national and regional networks for North Korean test site.
- Geophysically uniform regions with positive and negative magnitude residuals suggest regional scale path effects on teleseismic P wave magnitude.
- We propose to use region specific magnitude adjustments for estimating unbiased magnitude for the underground nuclear explosions in North Korea.