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Detection capability of the IMS seismic network in 2013

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Abstract

This study introduces a method of seismic threshold monitoring to assess an upper magnitude limit of a potential seismic event in a certain given geographical region. The method is based on ambient seismic background noise measurements at the individual IMS seismic stations in the year 2013 as well as on global distance correction terms for body wave magnitudes, which are calculated using the seismic reflectivity method. From our investigations we conclude that a global detection threshold of around mb 4.0 can be achieved using only stations from the primary seismic network, a clear latitudinal dependence for the detection threshold can be observed between northern and southern hemisphere. Including the seismic stations of the auxiliary seismic IMS network results in a slight improvement of global detection capability. However, including wave arrivals from distances greater than 120 degrees, mainly PKP-wave arrivals, leads to a significant improvement in average global detection capability. In special this leads to an improvement of the detection threshold on the southern hemisphere. We further investigate the dependence of the detection capability on spatial (latitude and longitude) and temporal parameters, as well as on parameters such as source type, noise level and percentage of operational IMS stations.

Seismic network of the IMS

The IMS seismic network can be considered as the backbone technology for the monitoring of nuclear explosion testing and in total consists out of 170 seismic stations. 50 of these stations are attributed to the primary seismic network (PS), 120 of these stations are part of the auxiliary seismic network (AS). Additionally five stations of the IMS hydroacoustic network are equipped with three component seismic instruments (T-phase stations, HA-3C) and, even not attributed to the seismic network, deliver seismic data that is routinely used in addition to the data from the seismic network. Figure 1 shows all PS-, AS and T-phase stations from the IMS network, independent of the current station status (certified, installed, planned or under construction).

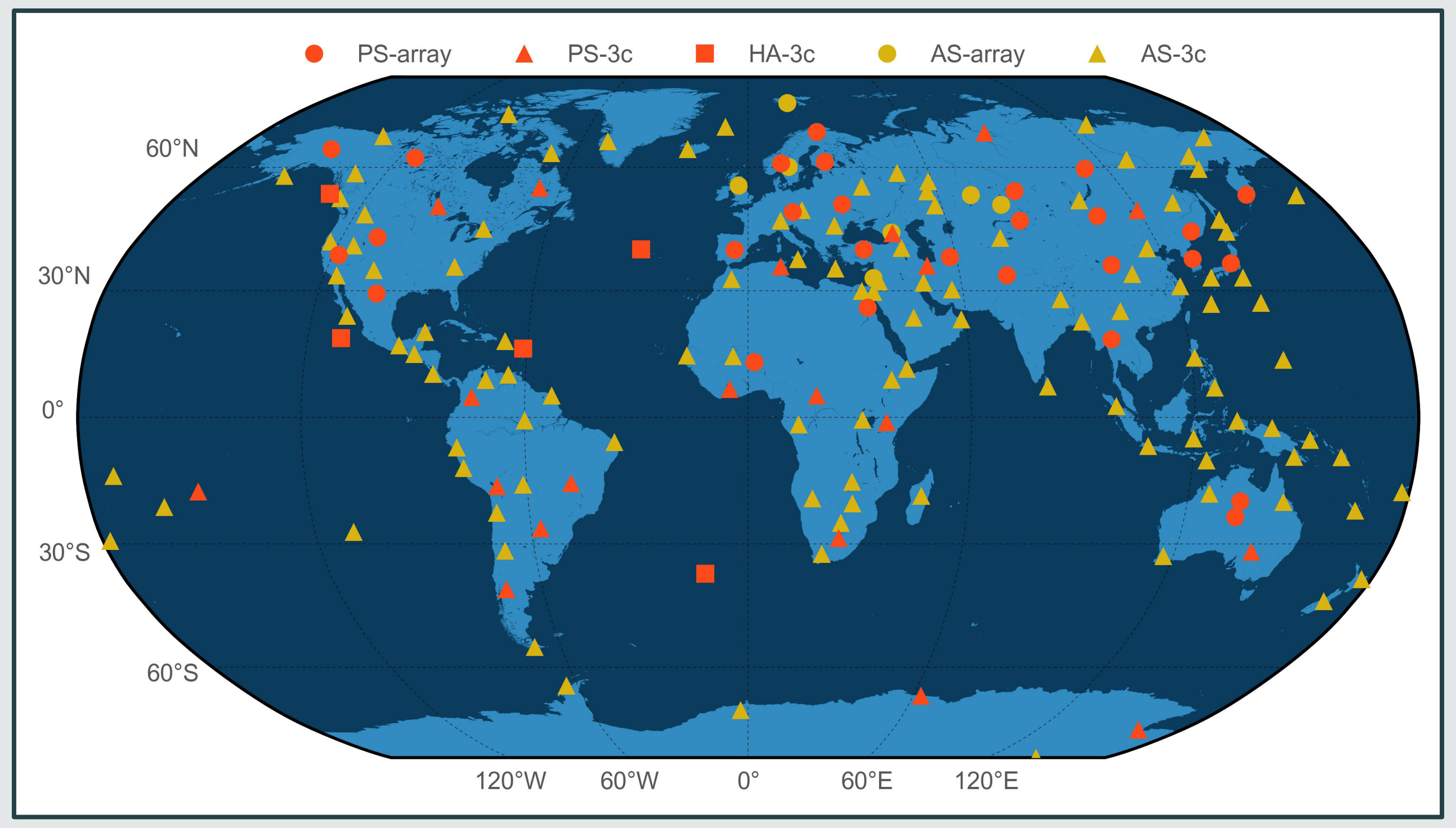

Figure 1: Seismic International Monitoring System.

Discrimination and magnitude-yield relation

For compliance with the CTBT it is important to discriminate nuclear events from other natural and anthropogenic events. Discriminants are usually based on properties of the source in terms of source location and source dynamics. Location allows to discriminate between events on- and offshore, as well as allows to dismiss events as nuclear, that take place in depths that can only be associated to natural events. Further discriminants are source dynamic properties such as the content of short and long period seismic waves emitted by the source as well as the different patterns of energy release from the events. If identified as a potential nuclear event, the strength of the event in terms of yield estimation is of great interest. However, it is not possible to state a single relation between magnitude and yield, as this relation depends on many factors, such as geological settings, efficiency of wave propagation from source to receiver, depth of the explosion as well as coupling effects. An overview of the magnitude-yield relation for different geological settings is shown in figure 2.

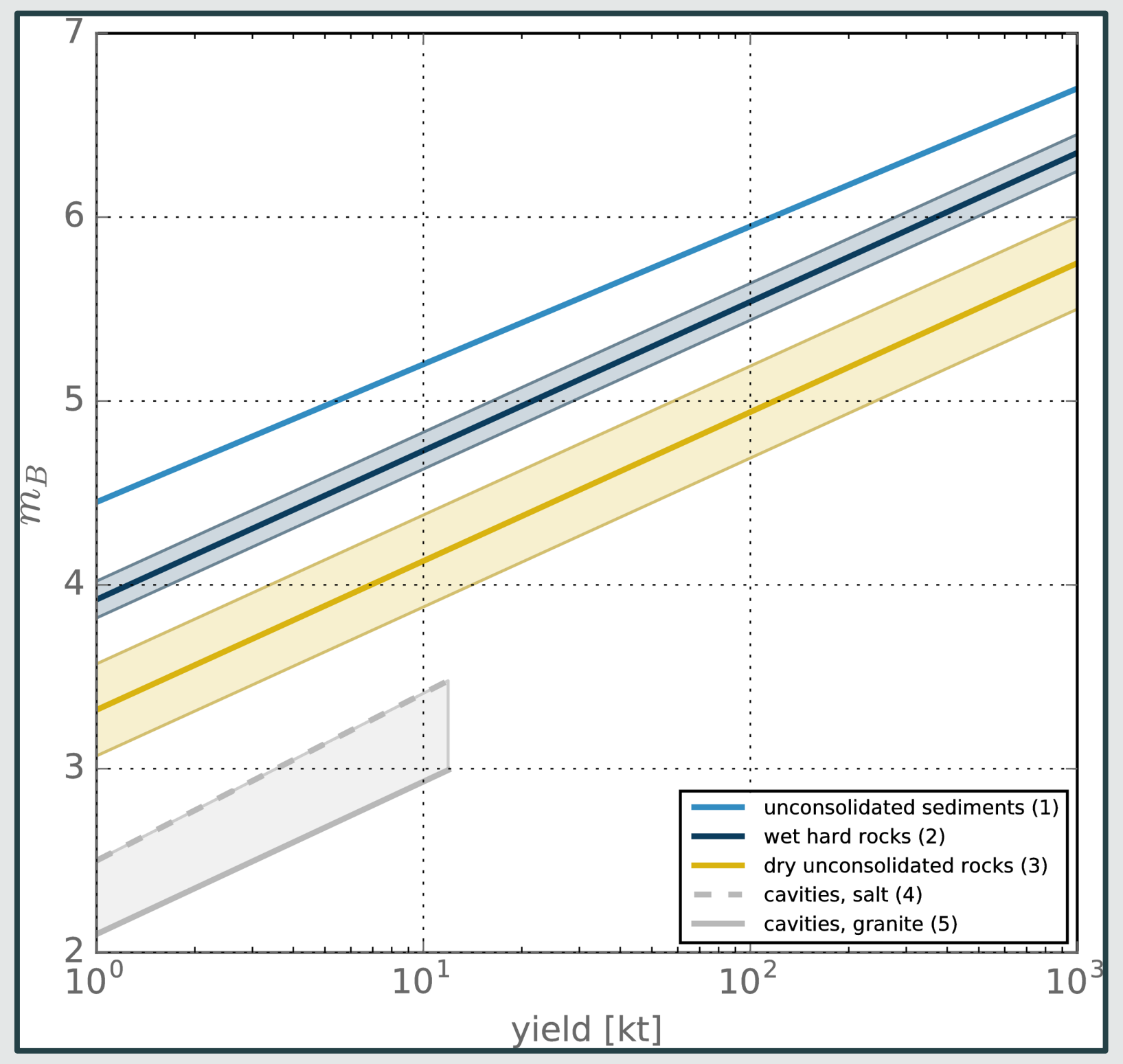

Figure 2: Magnitude yield-relations for different geological settings.

Method

The detection capability of the IMS seismic network is estimated using a technique based on ambient seismic background noise measurements at the stations of the IMS network (figure 3) as well as on global distance correction curves for the body wave magnitude (figure 4). Correction curves are based on empirical global depth-distance correction terms based on seismic moments combined with wave propagation simulations using the reflectivity method for both a set of arbitrary double couple sources and an explosion source.

$$m_b(A,T,\Delta) = \log_{10}(A/T)+\delta m_b(\Delta)$$

- A = $SNR*A_{RMS}/\sqrt{N}$
- A_{RMS} = mean noise level
- Δ = distance from source
- N = number of sensors

- T = 0.67 s [0.8 Hz, 2.2 Hz]
- SNR = 3

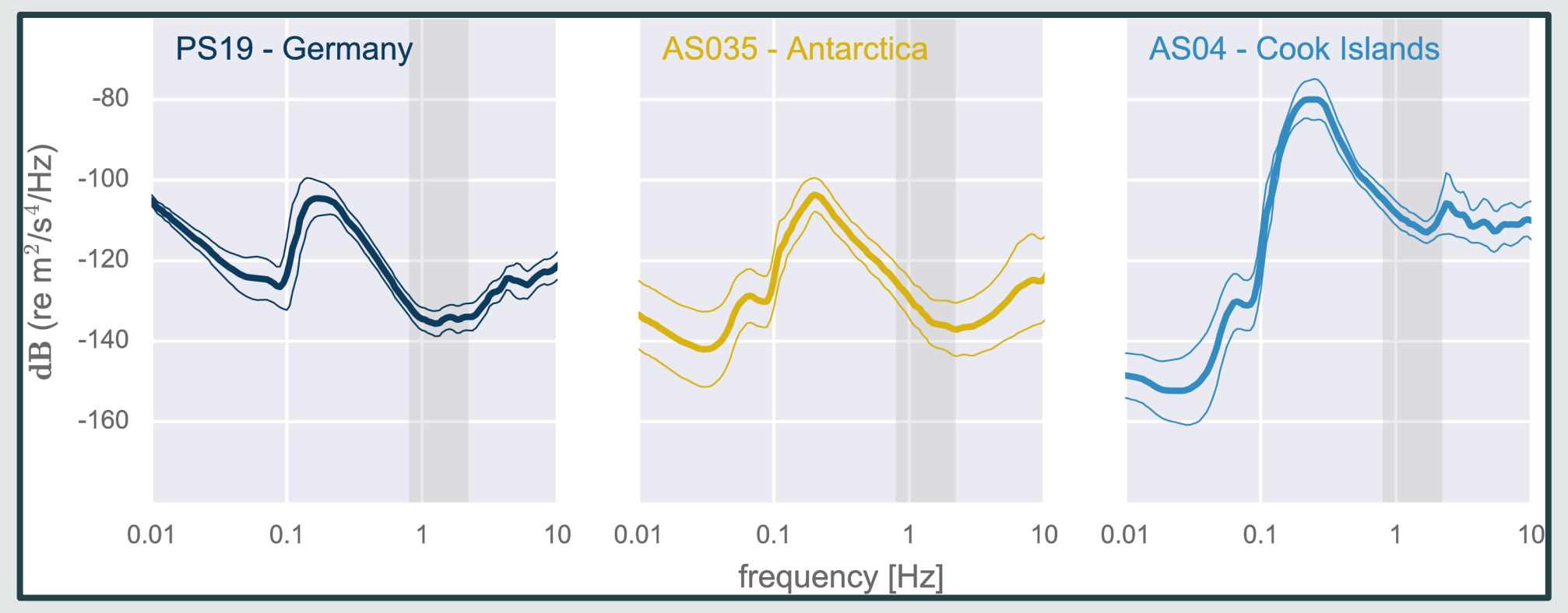

Figure 3: Ambient noise levels at three seismic IMS stations.

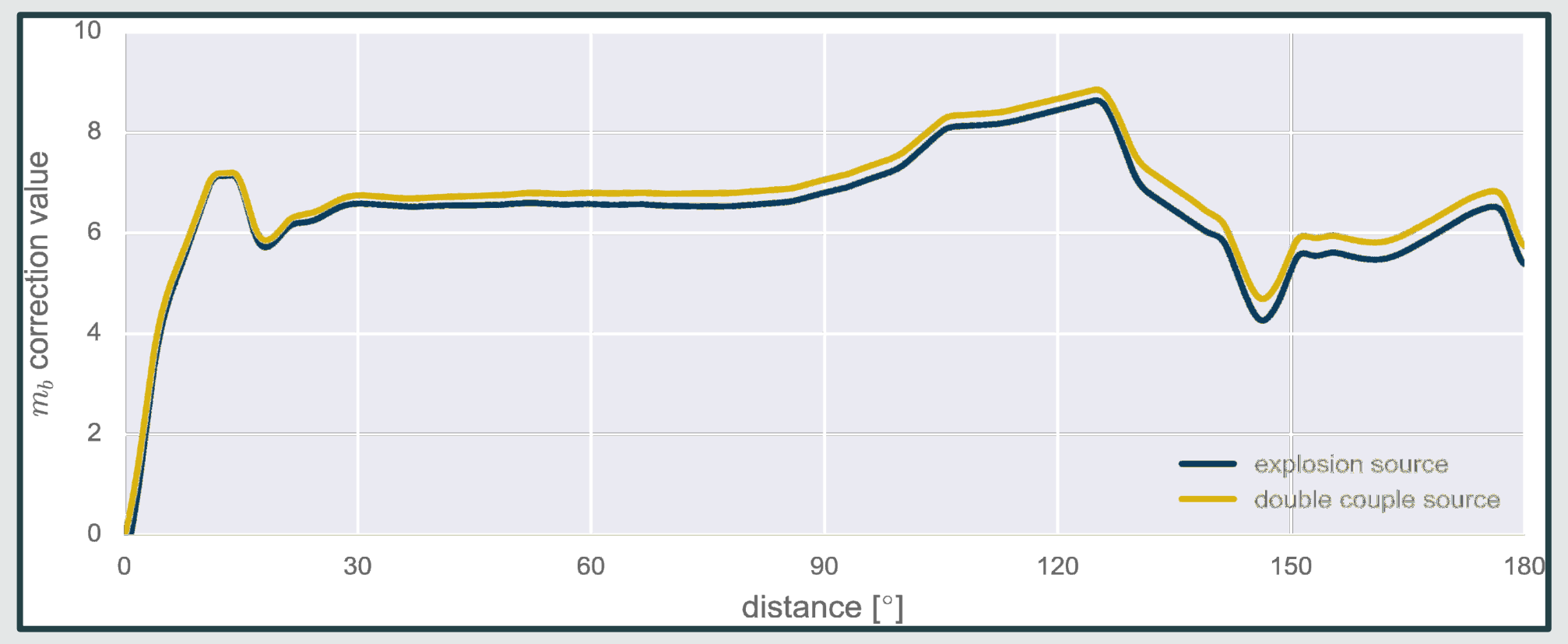

Figure 4: Body wave magnitude correction curves.

Detection capability using P-wave arrivals

Figure 5 illustrates the detection capability of the IMS-seismic network for the months January and June 2013. A SNR of three is required for the detection of a signal, the minimum number of detections necessary for the identification of an event is three. Due to the heterogeneous station distribution a clear difference in detection capability between northern and southern hemisphere can be observed.

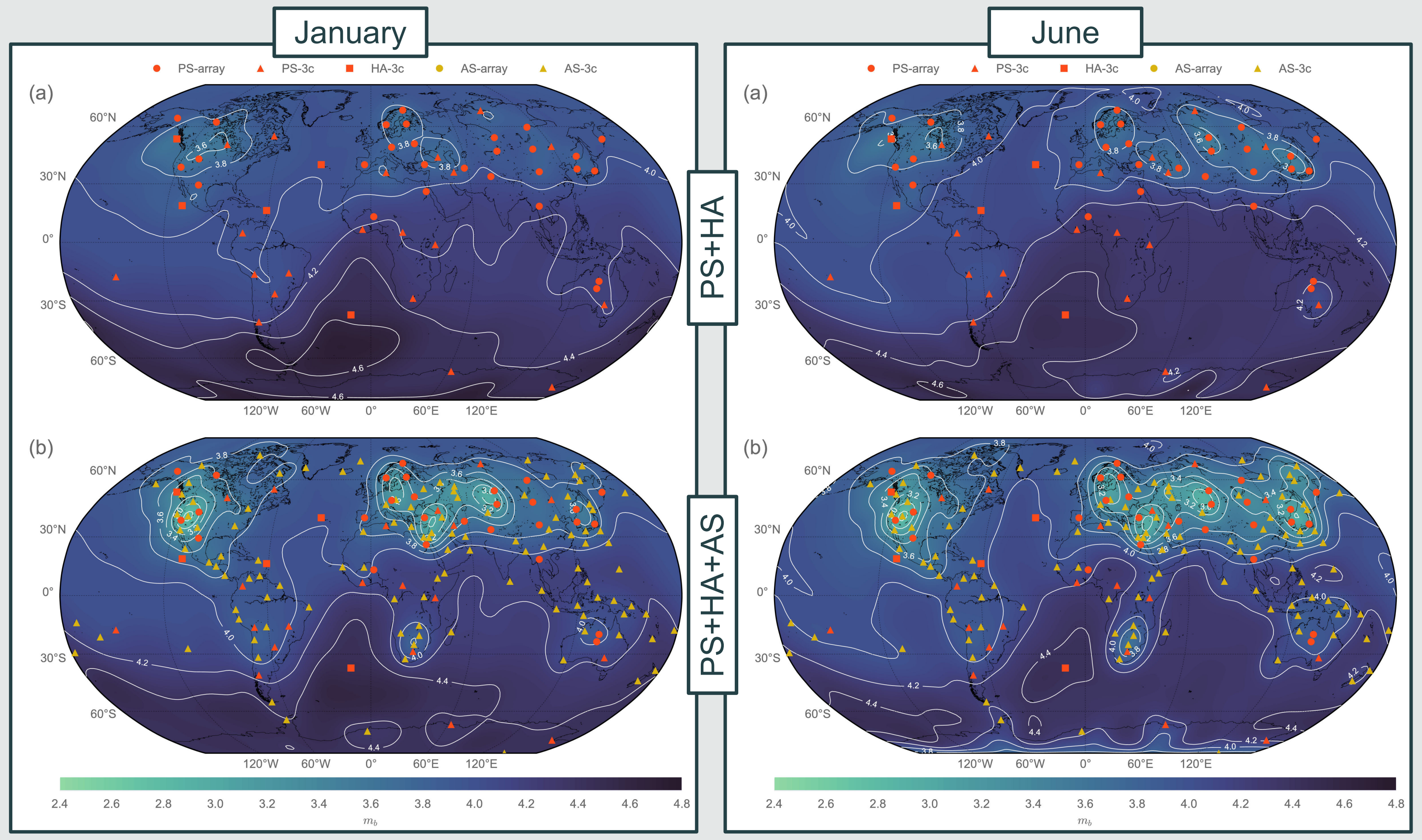

Figure 5: Detection capability of the IMS seismic network in January (left) and June (right) 2013 using seismic phase arrivals in the distance range from 0 to 120 degrees. (top) Only stations from the PS- and HA-network are used. (bottom) Additional usage of stations from the AS-network.

No siginificant differences in detection capability can be observed for the month January and June in figure 5. Additionally to the seasonal variations, the data set allows to investigate the hourly variations of the detection capability. This variations are shown in figure 6 for the months January and June 2013, typical months for northern hemispheric early winter and early summer. In summary, we do not find any dependencies of the detection capability on daily or seasonal variations.

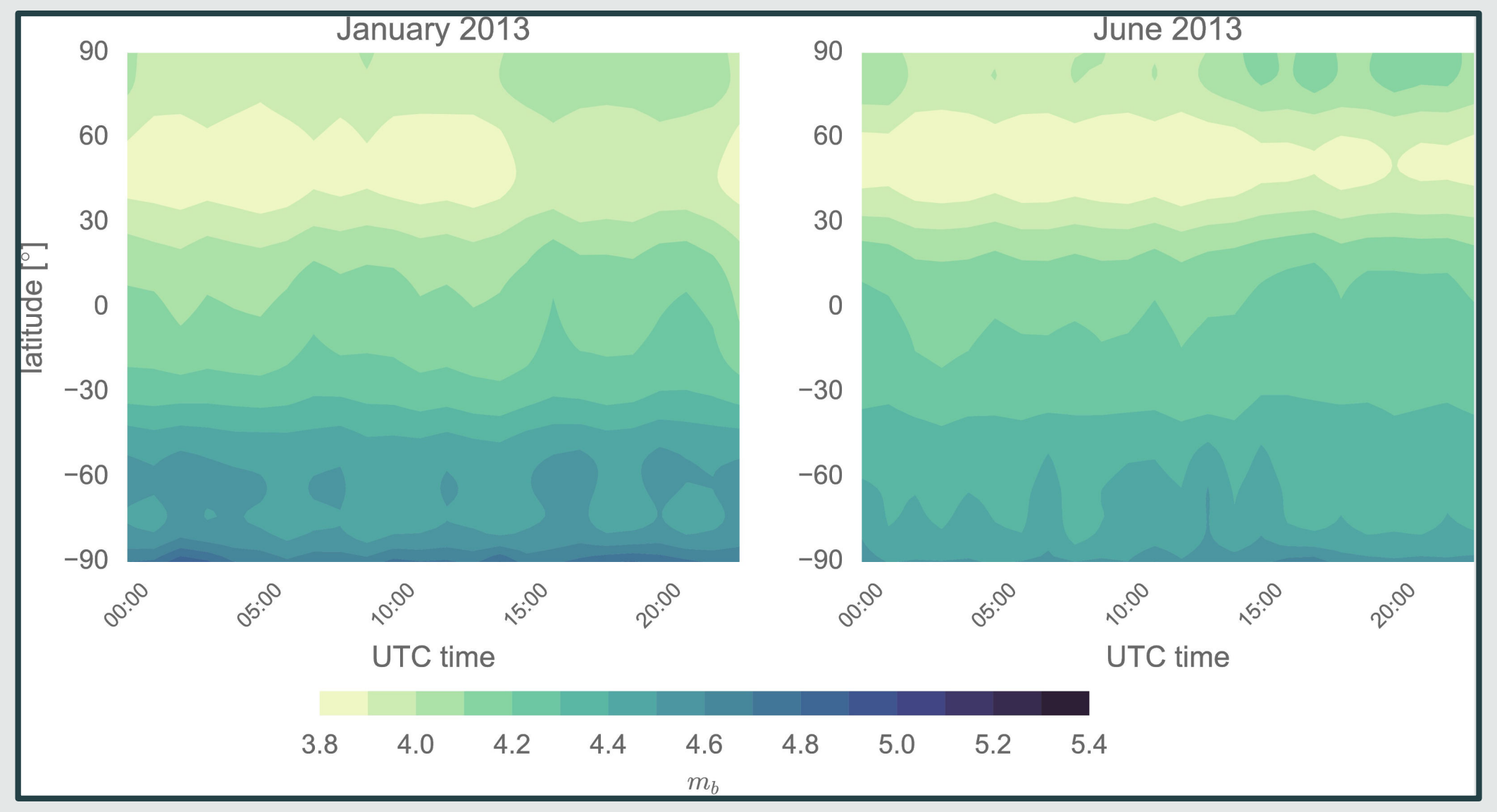

Figure 6: Temporal dependency of the detection capability.

Inclusion of PKP-wave arrivals

In figure 5 only wave arrivals in the distance range from 0 to 120 degrees are utilized. The inclusion of phases from distances greater than 120 degrees leads to a significant improvement of the detection capability, especially on the southern hemisphere (see figures 7 and 8). This is attributed to the fact, that in the distance window of around 145 degrees, refracted core phases are able to provide very good detection possibilities.

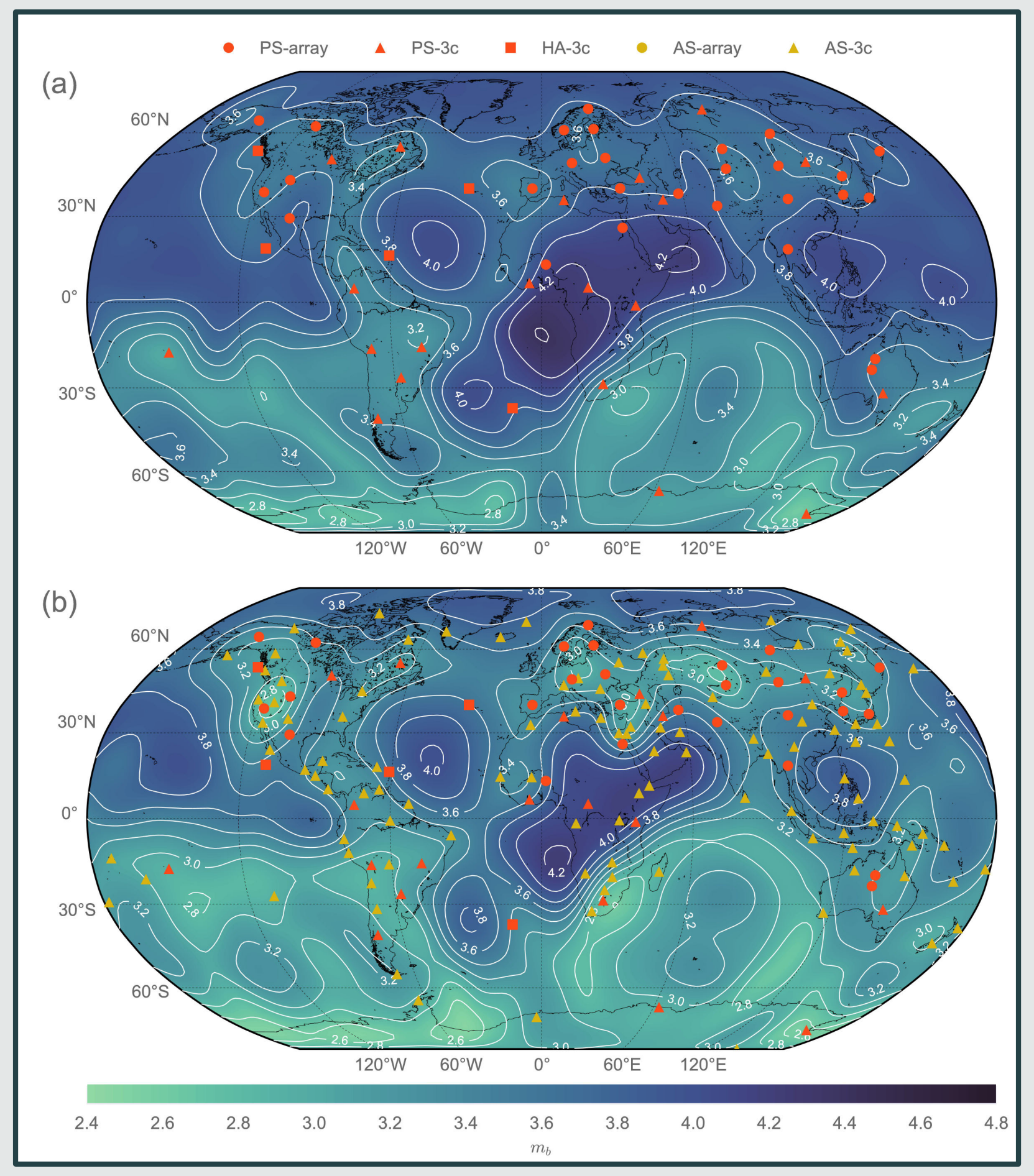

Figure 7: Same as left part of figure 5, but using wave arrivals from distances between 0 -180 degrees, therefore including arrivals of PKP-phase.

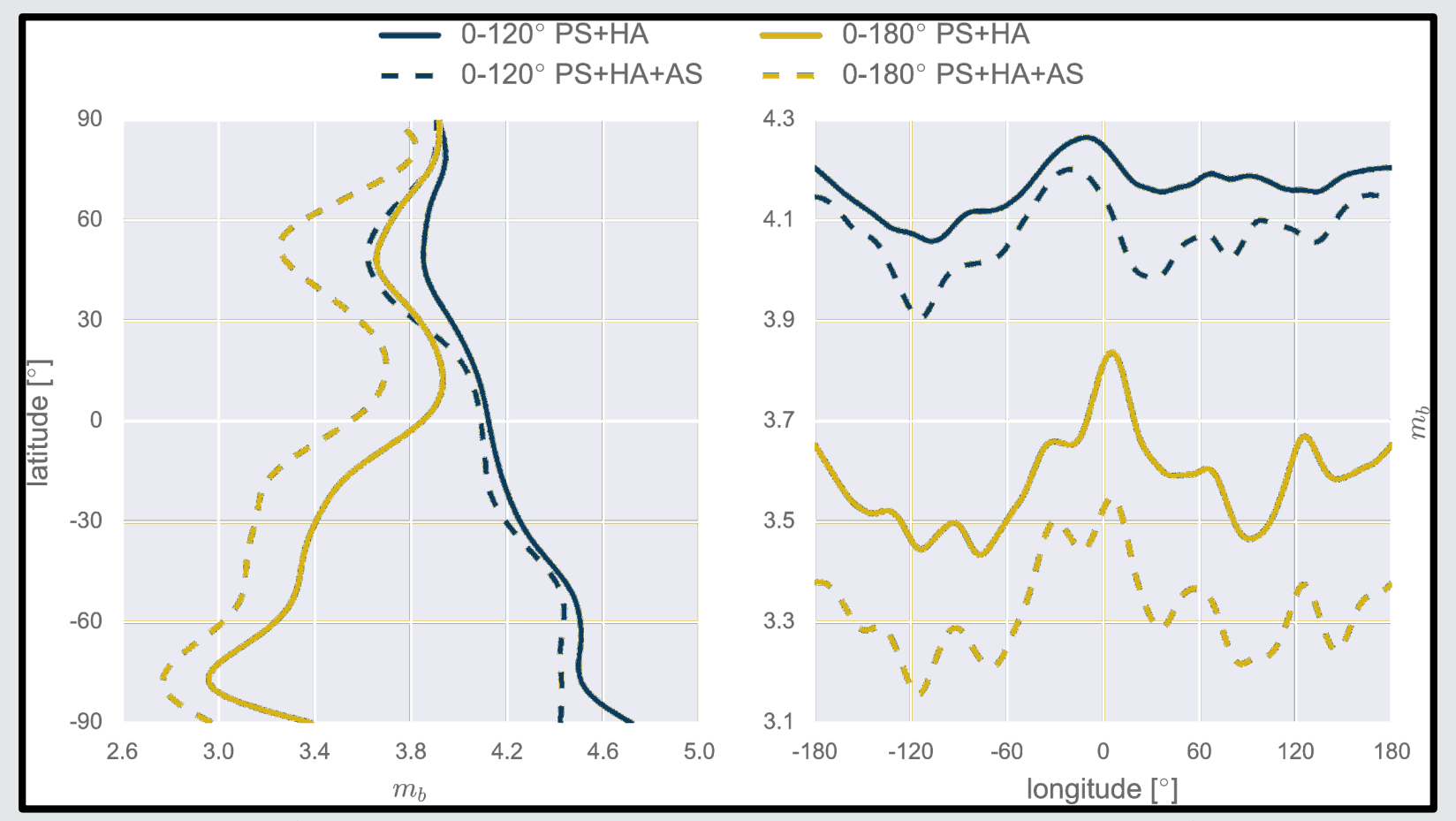

Figure 8: Spatial latitudinal and longitudinal dependency of the detection capability from the scenarios presented in figure 5 and 7.

Source type, noise level and number of operational stations

As a final aspect the influence of source type, noise level and number of operational stations on the detection capability of the IMS network are investigated. These three dependencies are jointly illustrated in figure 9. The figure shows the average global detection threshold for a double couple soure (left) and a explosion source (right) for a different number of operational PS-stations. Furthermore global detections capabilities are shown for different assumptions of noise levels at the stations: average, low and high (compare figure 3).

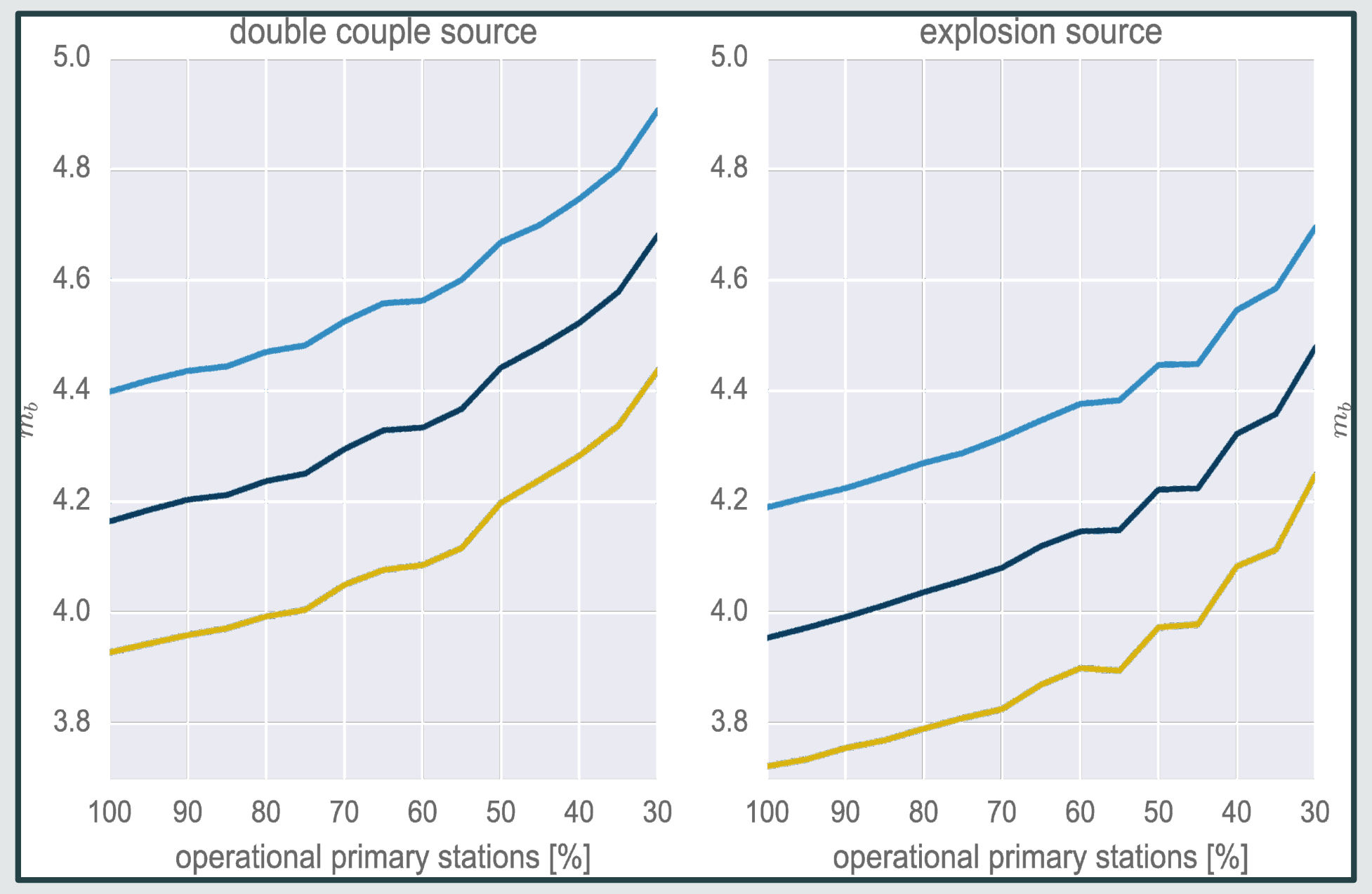

Figure 9: Influence of station outage, source type and noise level.

Comparison to the Revised Event Bulletin

In general a reasonable agreement, especially in the distance range 0 to 120 degrees can be observed between magnitudes obtained from the REB and magnitudes calculated using our theoretical, noise based model. However some issues and discrepancies between the magnitudes in certain distance ranges, especially from 0 to 20 degrees, 100 to 130 degrees and 140 to 155 degrees, have to be addressed and discussed.

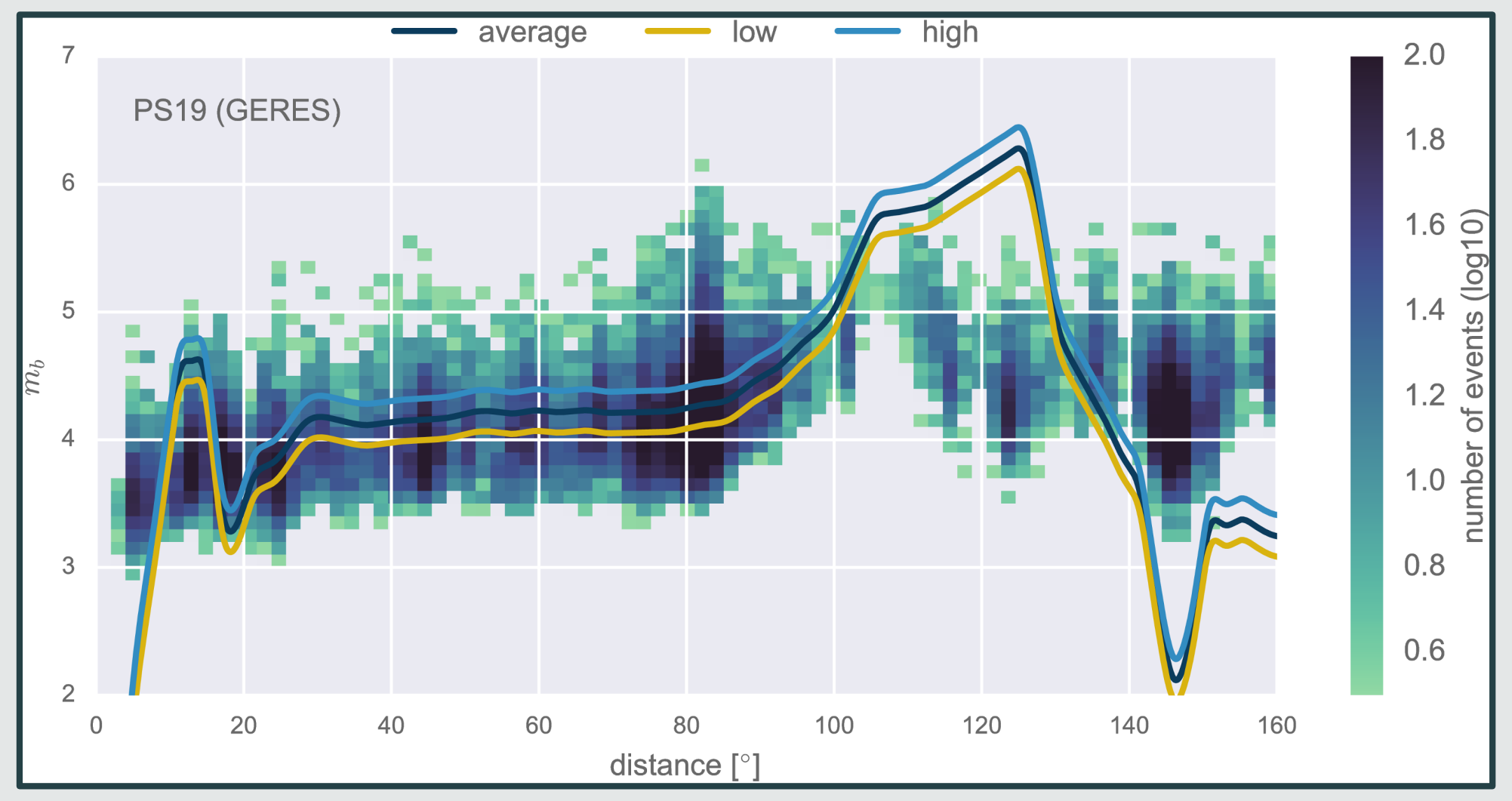

Figure 10: Comparison of theoretical and observed event magnitudes.

Conclusions

Our simulations suggest a strong latitudinal dependency of the IMS network detection capability. Furthermore no significant longitudinal and temporal dependencies can be observed. The inclusion of AS-stations in the estimation process leads to a slight improvement of the global detection capability. A strong improvement of the detection capability, especially on the southern hemisphere, can be achieved by using PKP-wave arrivals. Our method yields a conservative estimation of the detection capability of the IMS network. This conclusion is drawn from an example comparison between our approach for estimating the detection capability and manually retrieved events from the REB provided by the CTBT.

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