Effect of Combining Catalogs with Different Completeness

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Abstract

In most seismological studies, we prefer the earthquake catalog that covers a larger region and/or a longer period. We usually combine two or more catalogs to achieve this goal. When combining catalogs, however, care must be taken because their completeness is not identical so that unexpected flaws may be caused.

We tested the effect of combining inhomogeneous catalogs using the catalog of Korea Meteorological Administration (KMA). In fact, KMA provides a single catalog containing the earthquakes occurred in and around the whole Korean Peninsula. Like the other seismic networks, however, the configuration of the KMA seismic network is not uniform over its target monitoring region, neither is the earthquake detection capability. The network is denser in the land than in the offshore. Moreover, there are no seismic information available from North Korea. Based on these, we divided the KMA catalog into three sub-catalogs; SL, NL, and AO catalogs. The SL catalog contains the earthquakes occurred in the land of South Korea while the NL catalog contains those in the land of North Korea. The AO catalog contains all earthquakes occurred in the off-shore surrounding the peninsula.

In this study, the completeness of a catalog is expressed in terms of m_c, the minimum magnitude above which no earthquakes were missing; the larger m_c, the less complete is a catalog. We used the Chi-square algorithm by Noh (2017) to estimate the m_c. It turned out, as expected, that the m_c of the SL is the smallest among the three. Those of NL and AO are comparable. The m_c of the catalog combining the SL and AO is larger than those of individual catalogs before combining. The m_c is largest when combining all the three. Therefore, if one needs more complete catalogs, he or she had better divide the catalog into smaller ones based on the spatiotemporal detectability of the seismic network. Or, one may combine several catalogs to cover a larger region or a longer period at the expense of catalog completeness.

Chi-Square Test to Estimate m_c

Notations

- m_{max}: a maximum earthquake magnitude of a region or a seismic source
- m_{min}: a minimum earthquake magnitude to be included in the analysis
- Richter-b: a constant in Gutenberg & Richter relationship, $\log N = a - bM$
- m_c: minimum magnitude that preserves the information on seismicity parameters, i.e., m_{max} and Richter-b $\leftrightarrow$ all earthquakes above it were completely reported (Redelek & Sacks, 2000)

Probability Density Function (PDF) of Magnitude

- PDF for the continuous magnitude
  - $\log N = a - bM \;\rightarrow\; p_0(m) = k\beta e^{-\beta(m-m_{min})},\;\; m_{min} \le m \le m_{max}$

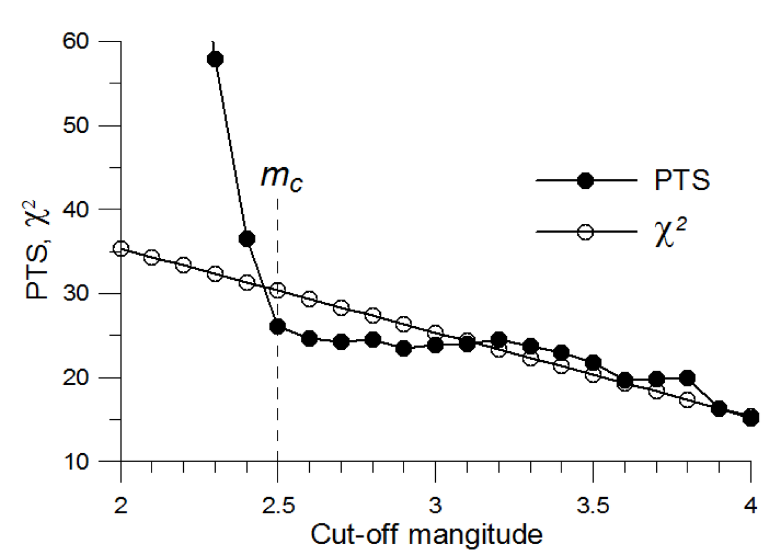
    where $\beta = b\ln 10$ and $k = \left[1 - e^{-\beta(m_{max}-m_{min})}\right]^{-1}$
- PDF for the discrete magnitude
  - $p_{0i} = \text{Probability}\left(m_i - \frac{\Delta m}{2} \le m < m_i + \frac{\Delta m}{2}\right) = \frac{e^{-\beta m_i}}{\sum_{k=1}^{M} e^{-\beta m_k}}$ (Weichert, 1980)

    where Δm is a width of magnitude intervals

Chi-Square Test (Noh, 2017)

- Pearson's Test Statics
  - $PTS = \sum_{i=1}^{M} \frac{\left(n_i^{obs} - n_i^{pre}\right)^2}{n_i^{pre}} \sim \chi^2$, provided $n_i^{pre} \ge 5$

    where n_i^{obs} and n_i^{pre} are frequencies of the observed and predicted earthquakes in the i-th magnitude interval, respectively.
- Null Hypothesis, H_0
  - Observed magnitude follows the distribution $p_{0i} = \frac{e^{-\beta m_i}}{\sum_{k=1}^{M} e^{-\beta m_k}}$
  - H_0 cannot be rejected if $PTS \le \chi^2_{1-\alpha}(M-3)$
  - H_0 is rejected if $PTS > \chi^2_{1-\alpha}(M-3)$
    - α: significance level
    - $\chi^2_{1-\alpha}(M-3)$: Chi-square variable at the $(1-\alpha)$ percentile
- Estimation Procedure
  - Events smaller than the cut-off magnitude m_{cut} are excluded from the analysis
    - Initial value: $m_{cut} = m_{min}$
  - m_{cut} successively increases by Δm until the PTS goes below the χ^2
  - The first cross-over m_{cut} is designated as the m_c

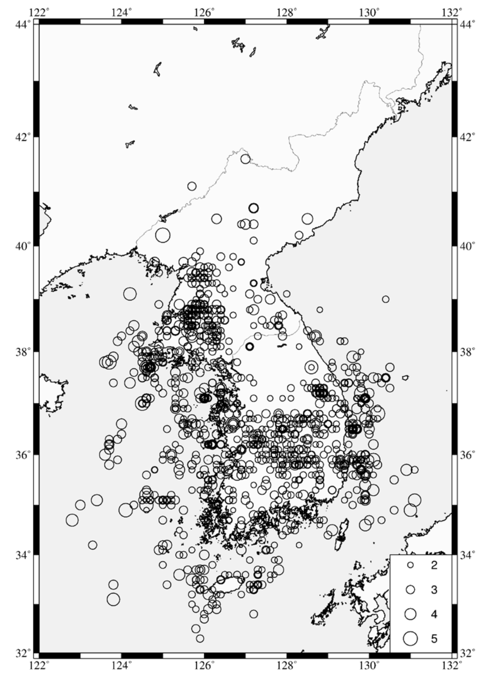


Earthquake Data and Catalogs

Earthquakes

- From Korea Meteorological Administration (KMA) for
  - Period: 1981~2015
  - Events designated as 'domestic' by KMA

  → 3,255 events, M0.1~M5.2



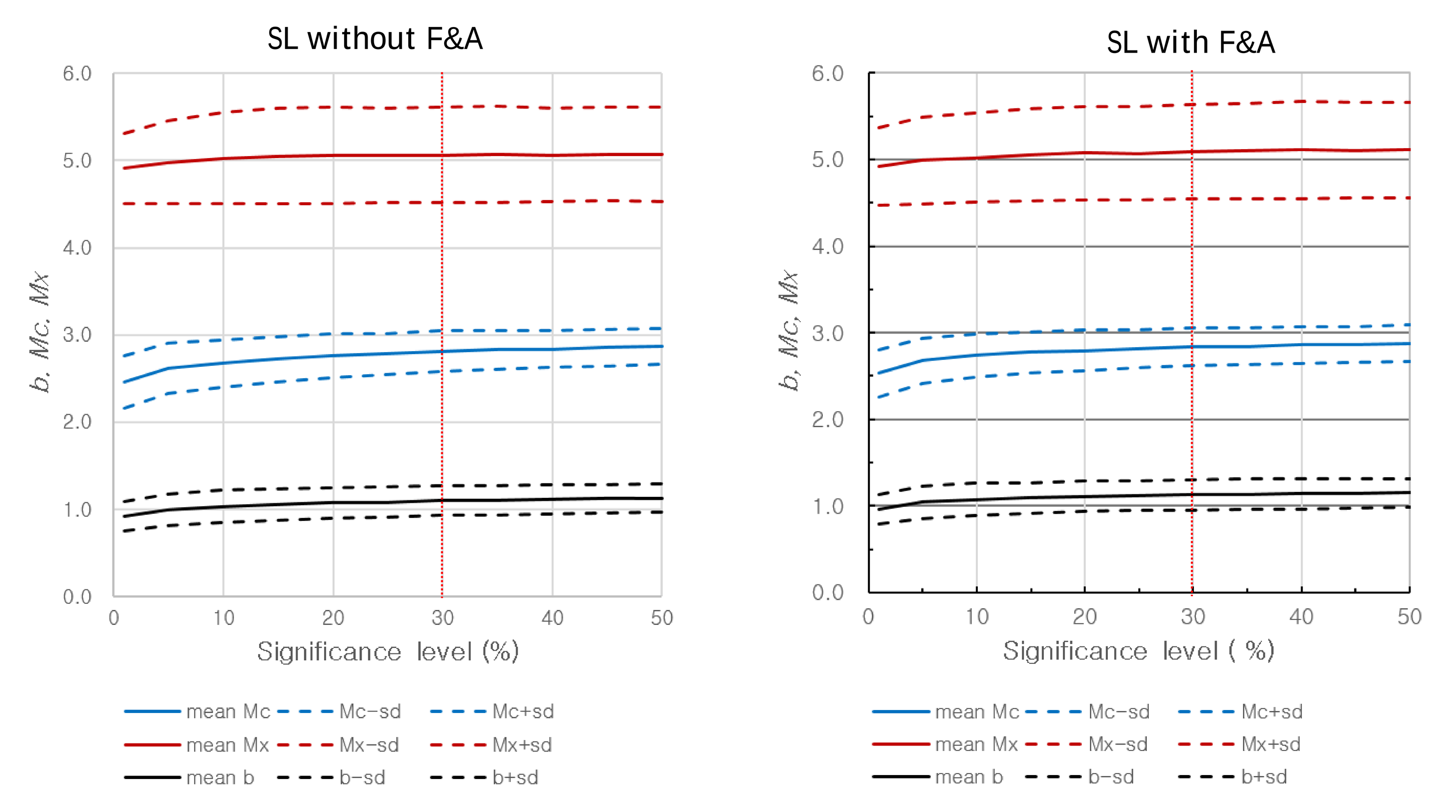
Sub-catalogs

- Sub-catalog **SL**
  - Composed of only those earthquakes occurred in the land of South Korea (Republic of)
- Sub-catalog **AO**
  - Composed of the off-shore earthquakes only
- Sub-catalog **NL**
  - Composed of only those earthquakes occurred in the land of north Korea
- Combined sub-catalog **SL+AO**
  - Sum of sub-catalogs SL and AO
- Combined sub-catalog **SL+AO+NL**
  - Sum of sub-catalogs SL, AO, and NL

Assessment of Catalogs

Effects of Foreshocks and Aftershocks

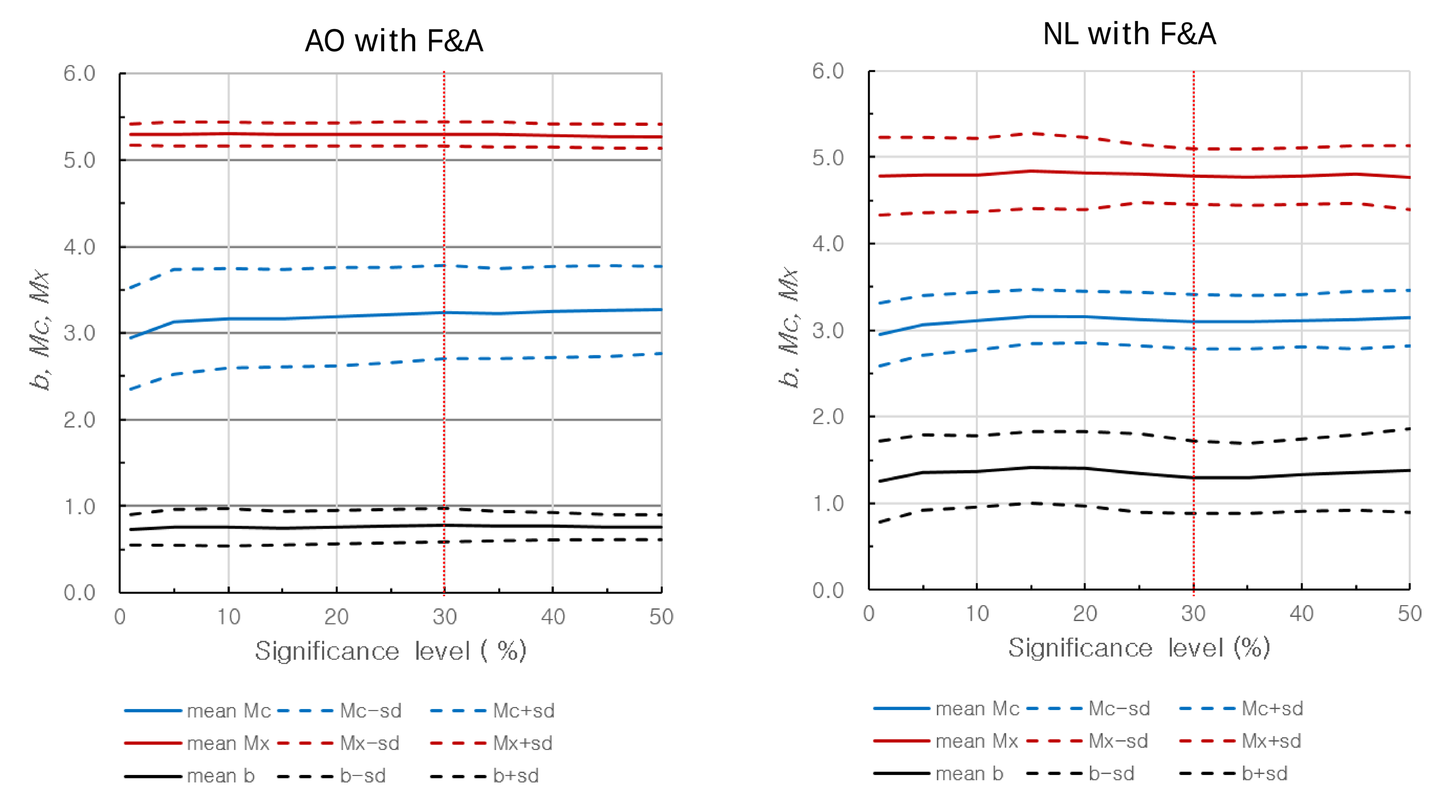
- Sub-catalog SL without and with foreshocks and aftershocks (F&A)



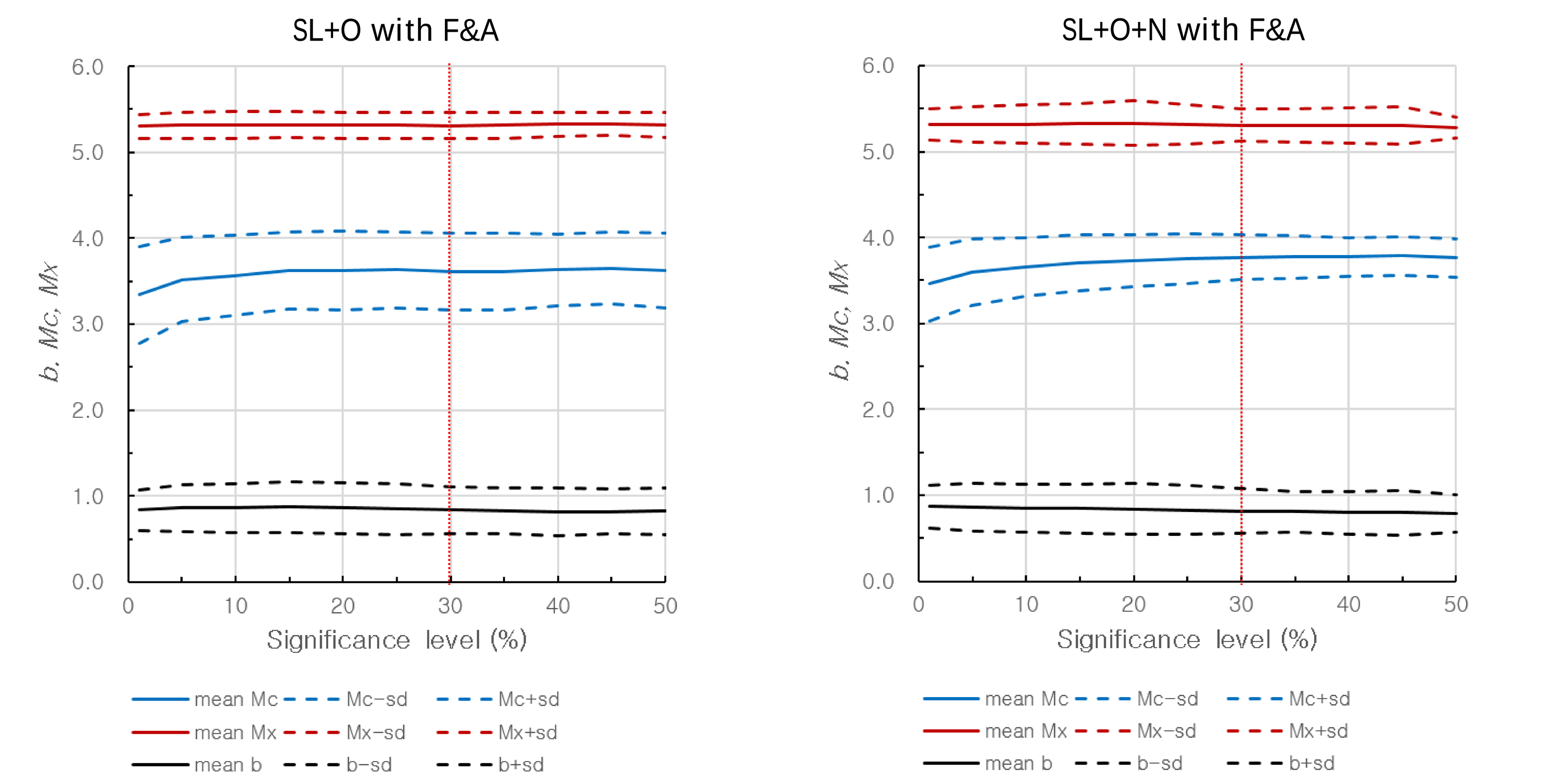
- Effects of foreshocks and aftershocks are insignificant

Assessment Results

- Sub-catalog AO and sub-catalog NL



- Sub-catalog SL+O and sub-catalog SL+O+N



Discussion and Conclusion

Determination of significance level

- Estimates for all sub-catalogs become stable at or above the significance level of 30%
- Estimation at the significance level of 30%

Catalog	m_c		m_{max}		b	
	mean	s.d.	mean	s.d.	mean	s.d.
SL	2.8	0.22	5.1	0.55	1.13	0.173
AO	3.2	0.54	5.3	0.14	0.778	0.194
NL	3.1	0.31	4.8	0.32	1.298	0.415
SL+AO	3.6	0.45	5.3	0.15	0.838	0.274
SL+AO+NL	3.8	0.26	5.3	0.19	0.818	0.256

Estimates of m_c

- Estimates of m_c are high even for the SL, considering the Korean seismic network density

  ← Mainly due to inconsistent magnitude scales over the observation period
- m_c for the AO and the NL are lager than that for the inland events SL

  ← The off-shore seismic network is much poorer than the inland seismic network

  ← No information from the North Korea
- m_c for the sub-catalogs (SL+AO) or (SL+AO+NL) is much higher than those for the sub-catalog SL as well as the sub-catalog AO or the sub-catalog NL

Conclusions

- There exits a trade-off between the completeness and the spatiotemporal coverage of an earthquake catalog
- To enhance the completeness of an earthquake catalog, divide the catalog into sub-catalogs considering the spatiotemporal detectability of the seismic network

References

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