

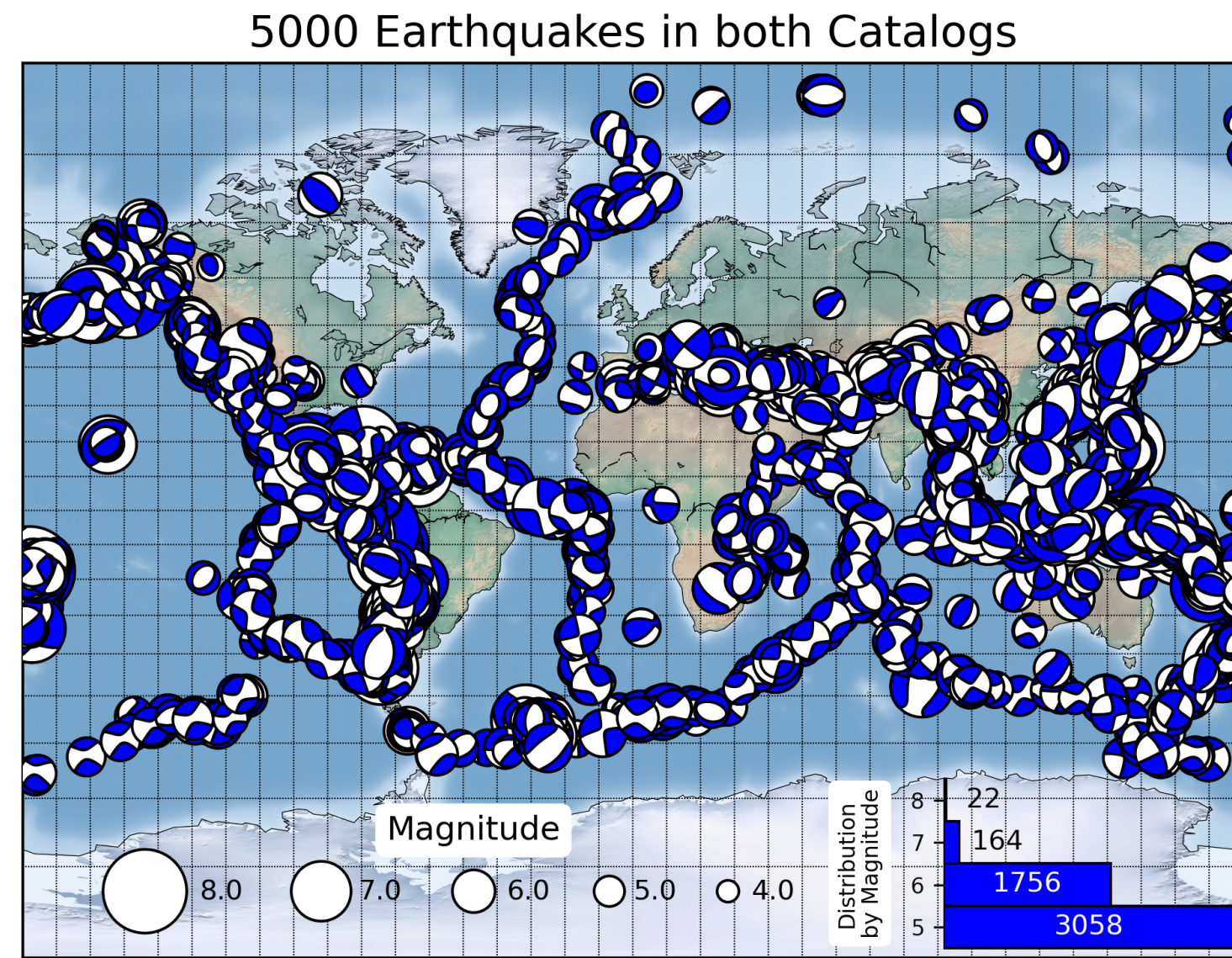
Uncertainties in Seismic Moment Tensors Inferred from Differences Between Global Catalogs

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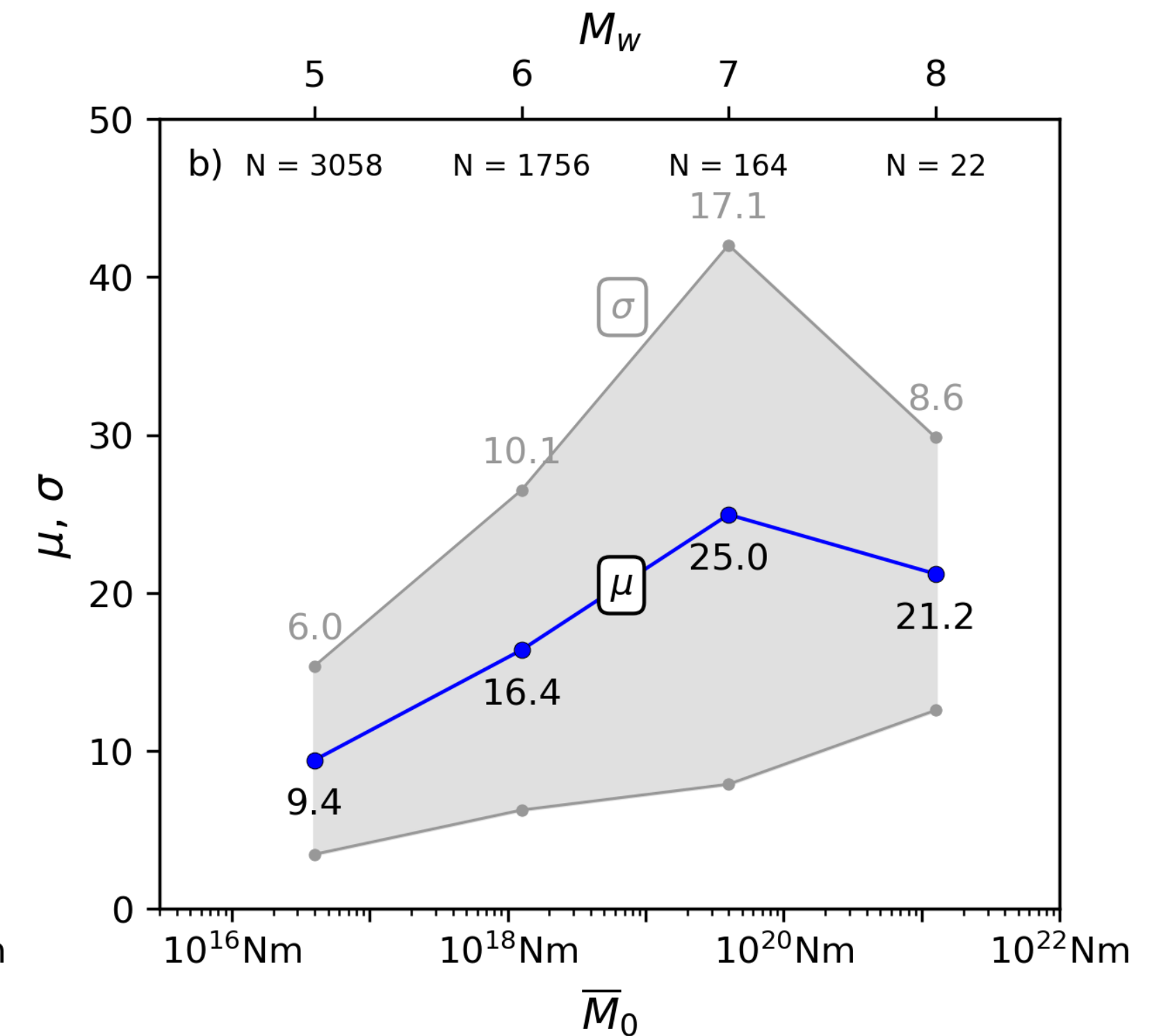
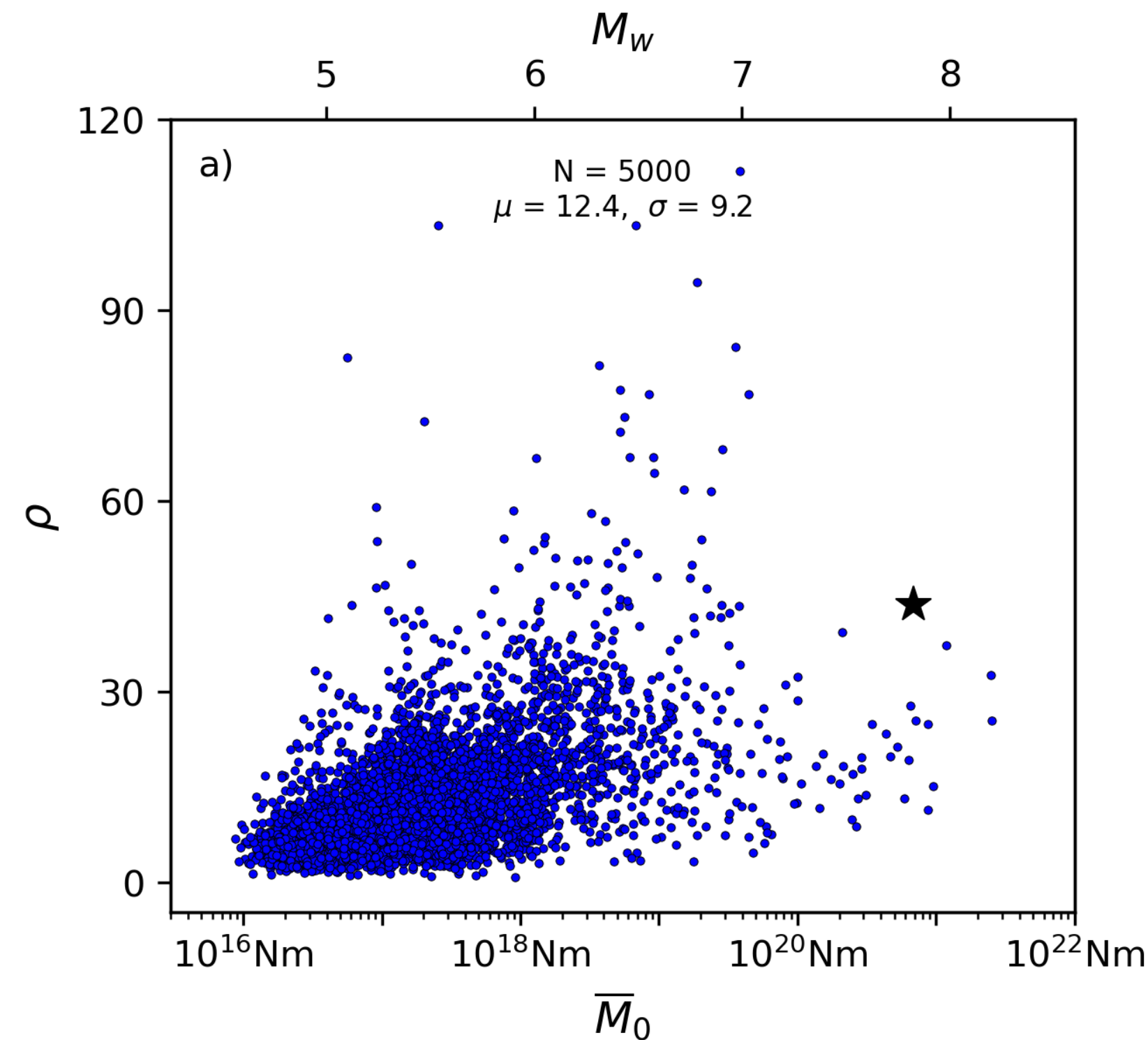
Northwestern
University

submitted to SRL

Moment Tensor Differences & Reported Errors



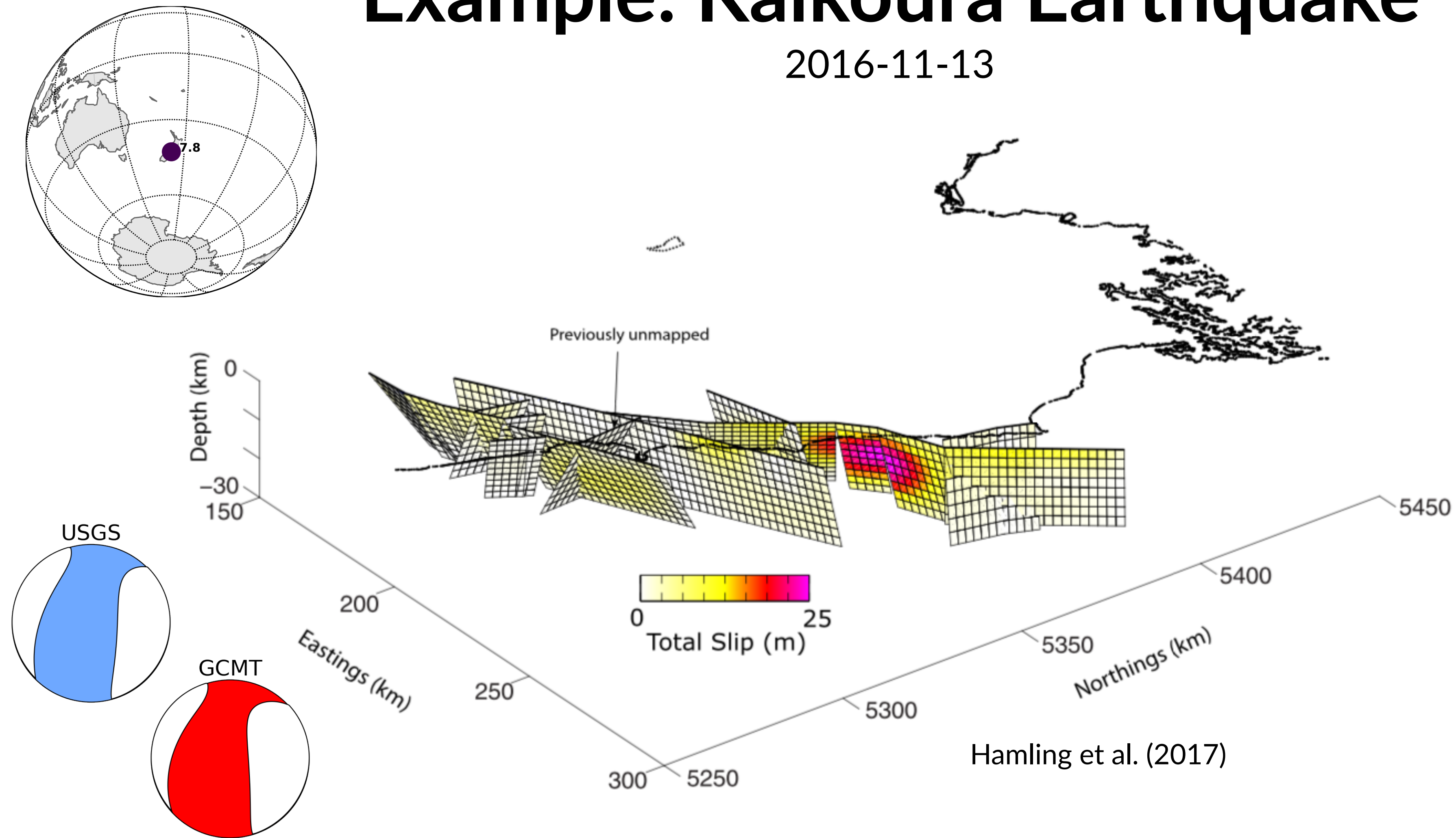
$$\rho \equiv \sqrt{\frac{1}{6} \sum_{i=1}^3 \sum_{j=1}^3 \left(\frac{M_{ij}^{\text{USGS}} - M_{ij}^{\text{GCMT}}}{\Delta M_{ij}^{\text{GCMT}}} \right)^2}$$



The differences between moment tensors are typically an order of magnitude larger than the reported errors, suggesting that the errors substantially underestimate the uncertainty.

Example: Kaikōura Earthquake

2016-11-13



The Kaikōura earthquake (marked in figures with ★) has a complicated rupture process and thus a large non-double-couple component.

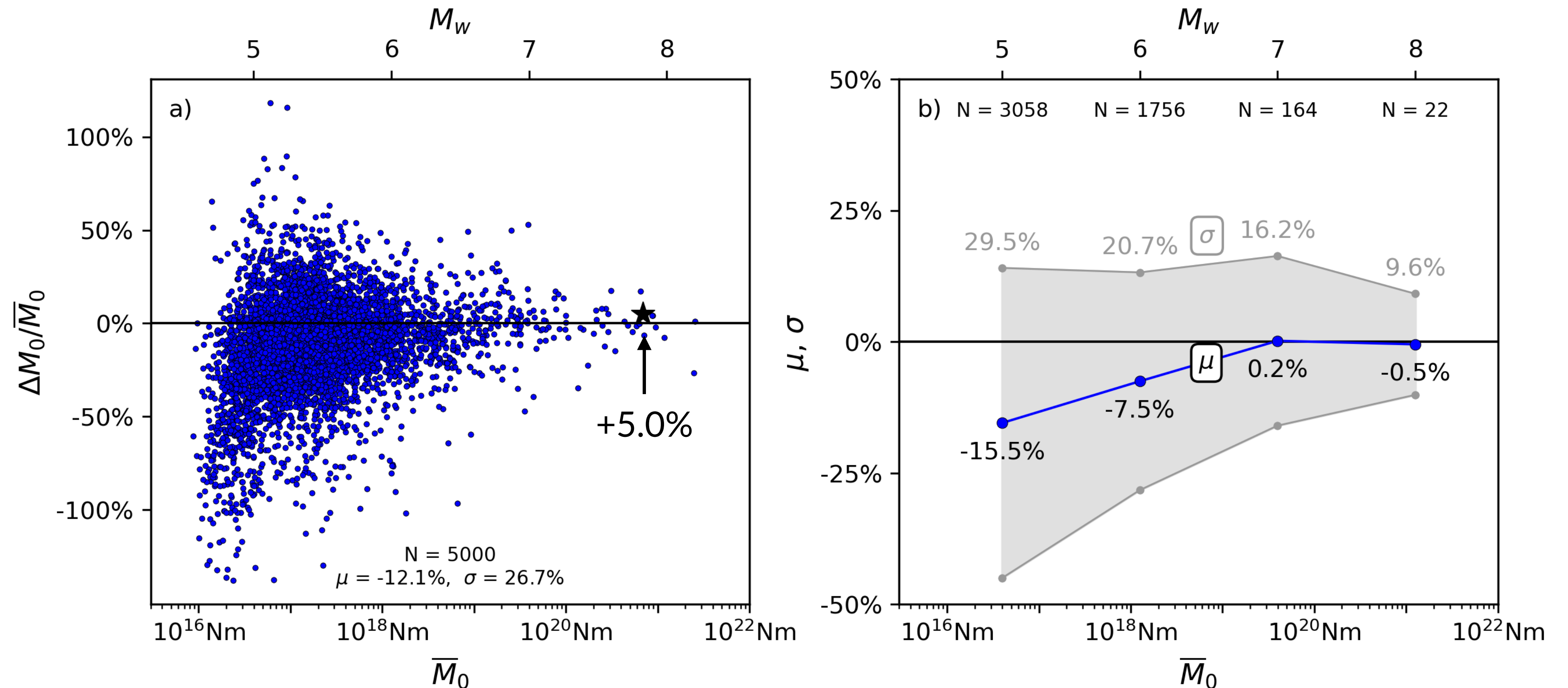
Differences in Scalar Moment

$$\Delta M_0 / \overline{M}_0 \equiv \frac{M_0^{\text{USGS}} - M_0^{\text{GCMT}}}{\frac{1}{2} (M_0^{\text{USGS}} + M_0^{\text{GCMT}})}$$

The scalar moment reported by GCMT is generally larger than that by the USGS.

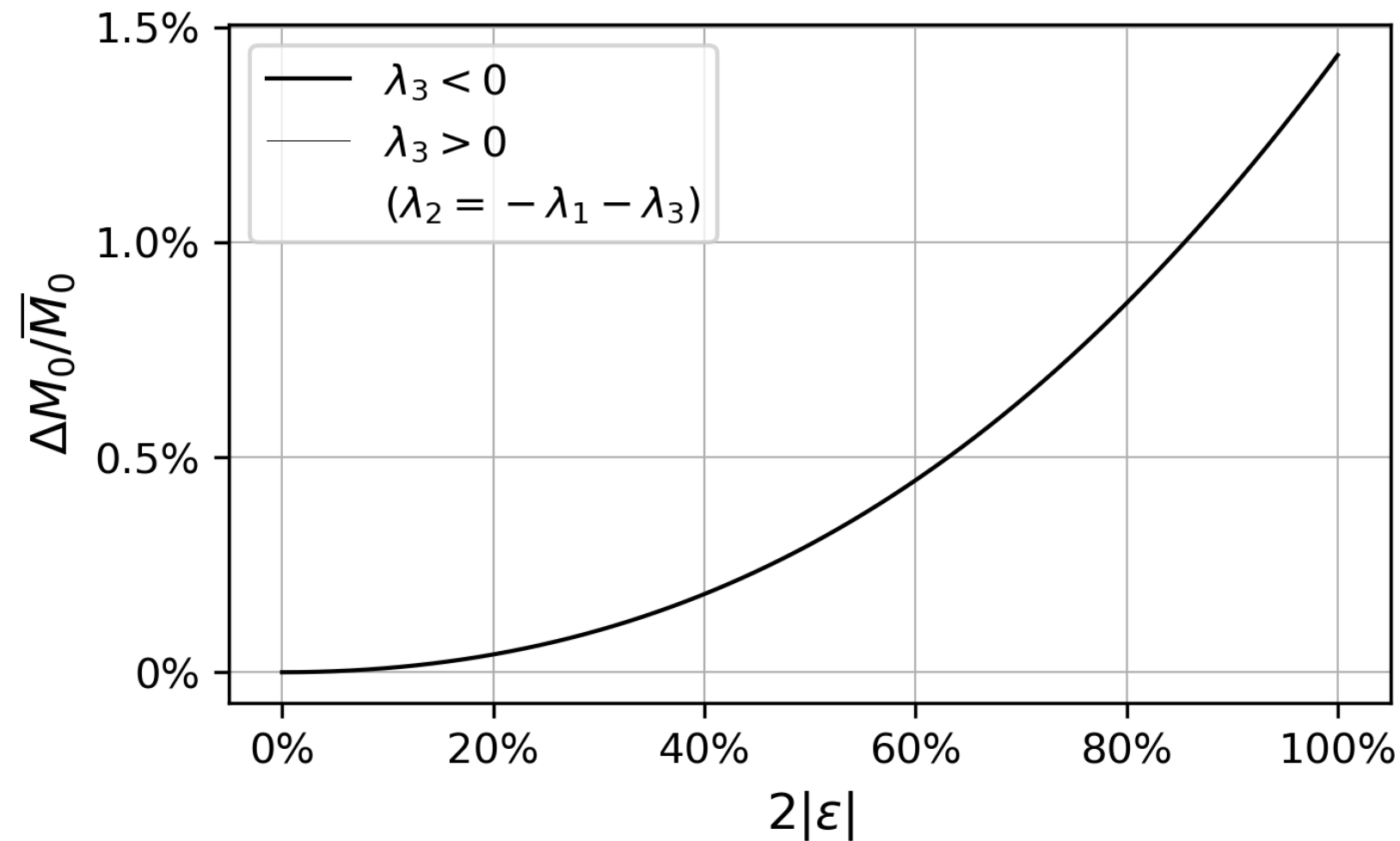
The difference in normalized scalar moment decreases with magnitude.

Normalized Scalar Moment Differences Between Catalogs



Reasons for Differences in Scalar Moment

Scalar Moment Differences Due to Deviation from a Double-Couple Source

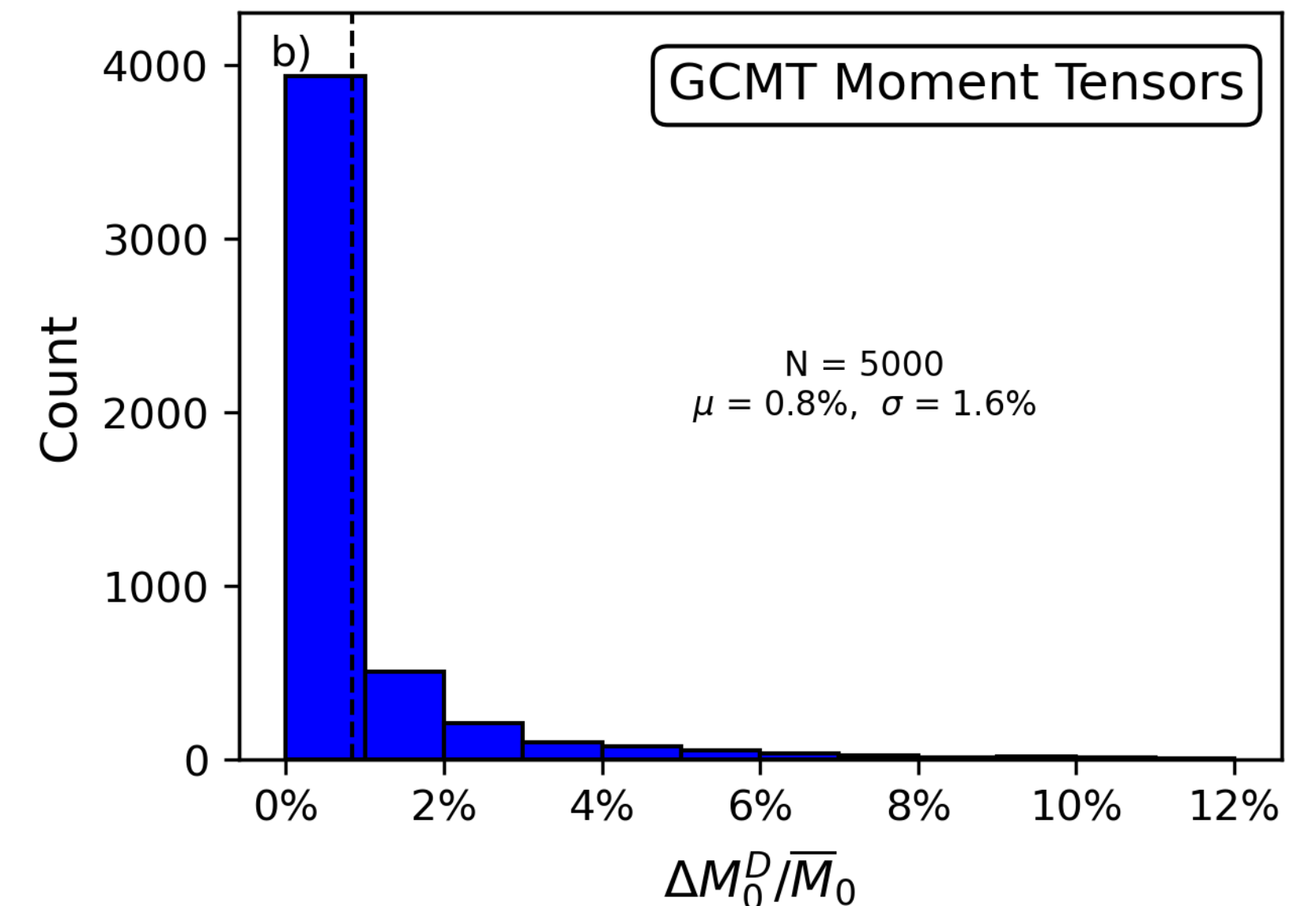
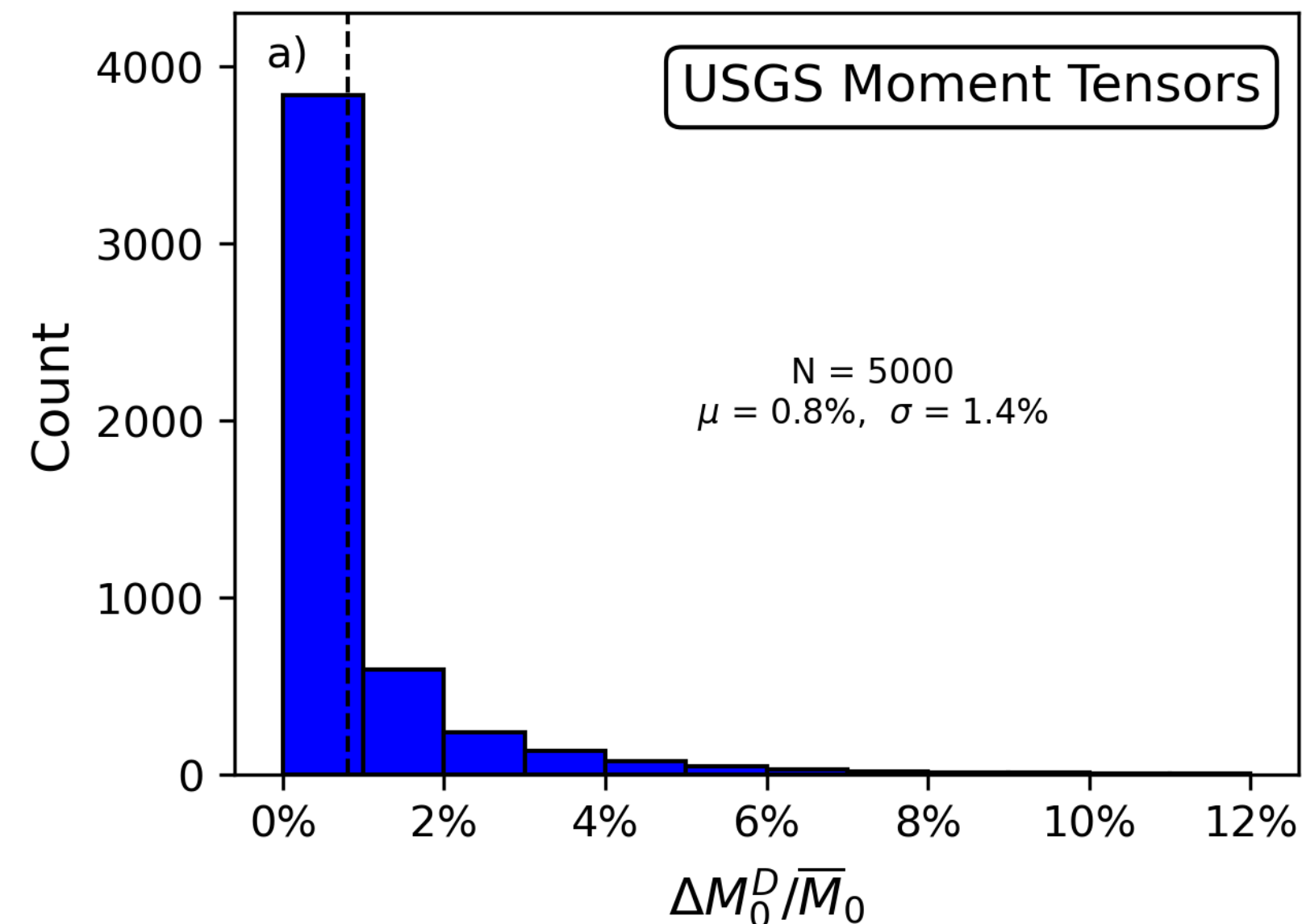


$$M_0^{\text{USGS}} = \sqrt{\frac{1}{2} \sum_{i=1}^3 \sum_{j=i}^3 M_{ij}^2} = \sqrt{\lambda_1'^2 + \lambda_2'^2 + \lambda_3'^2}$$

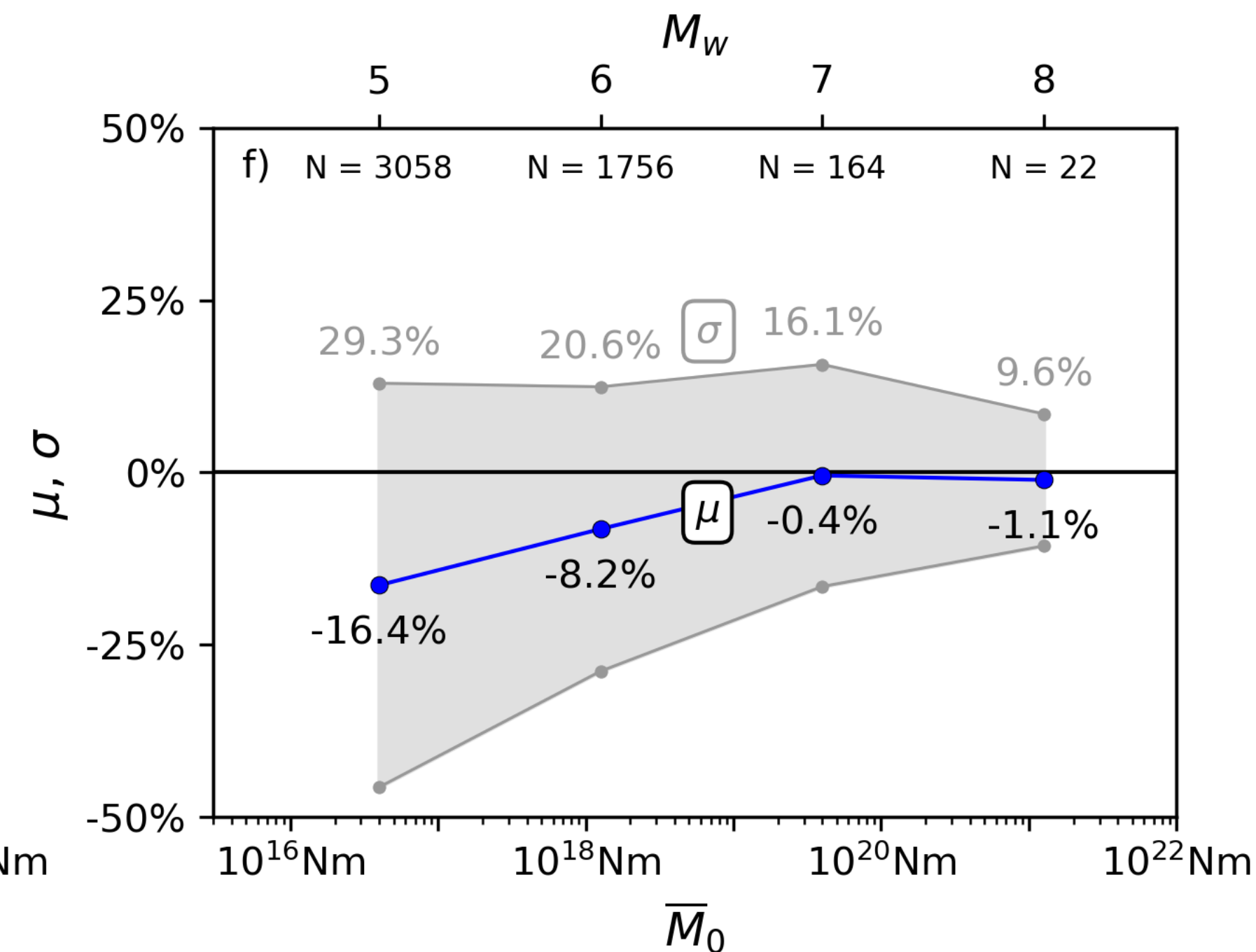
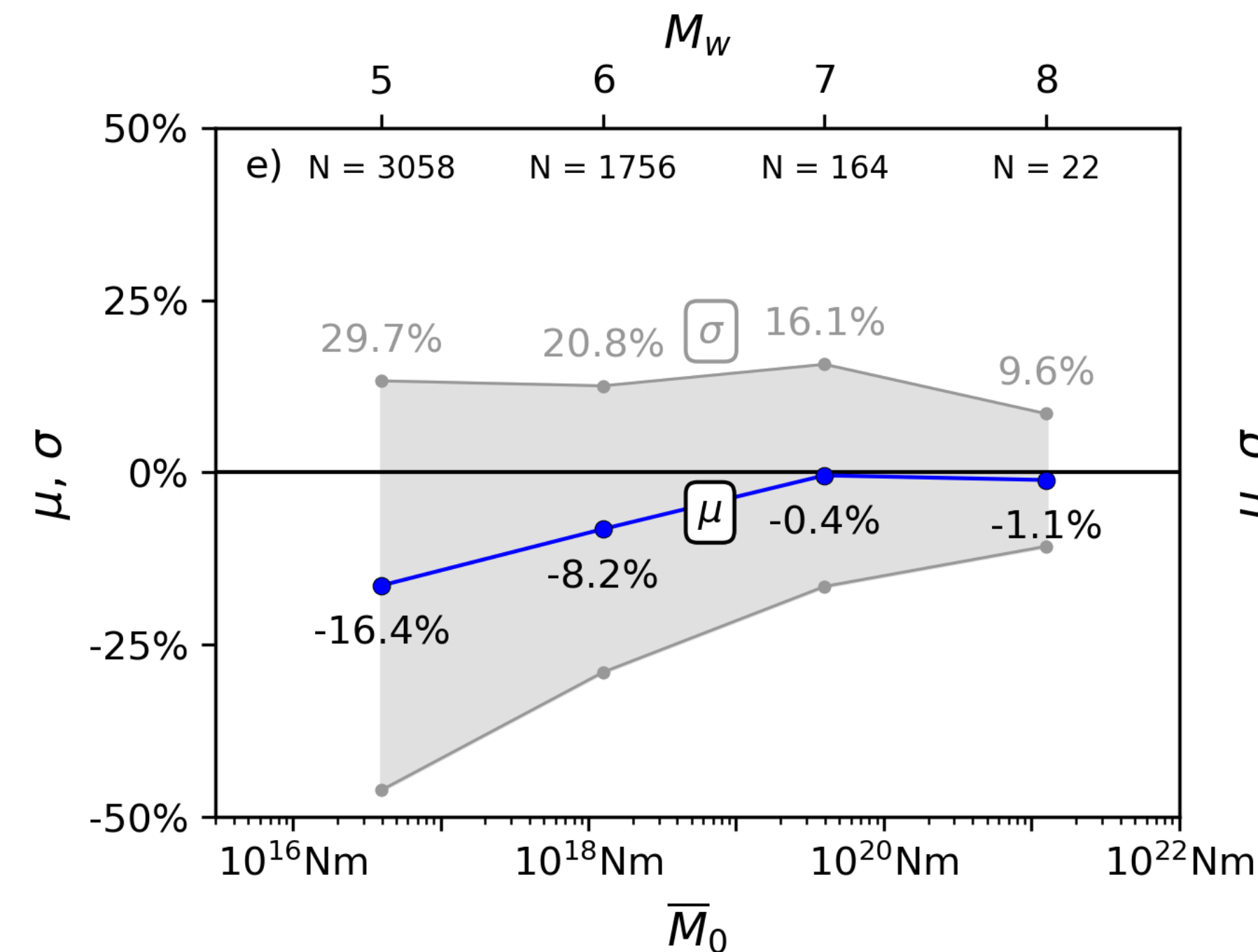
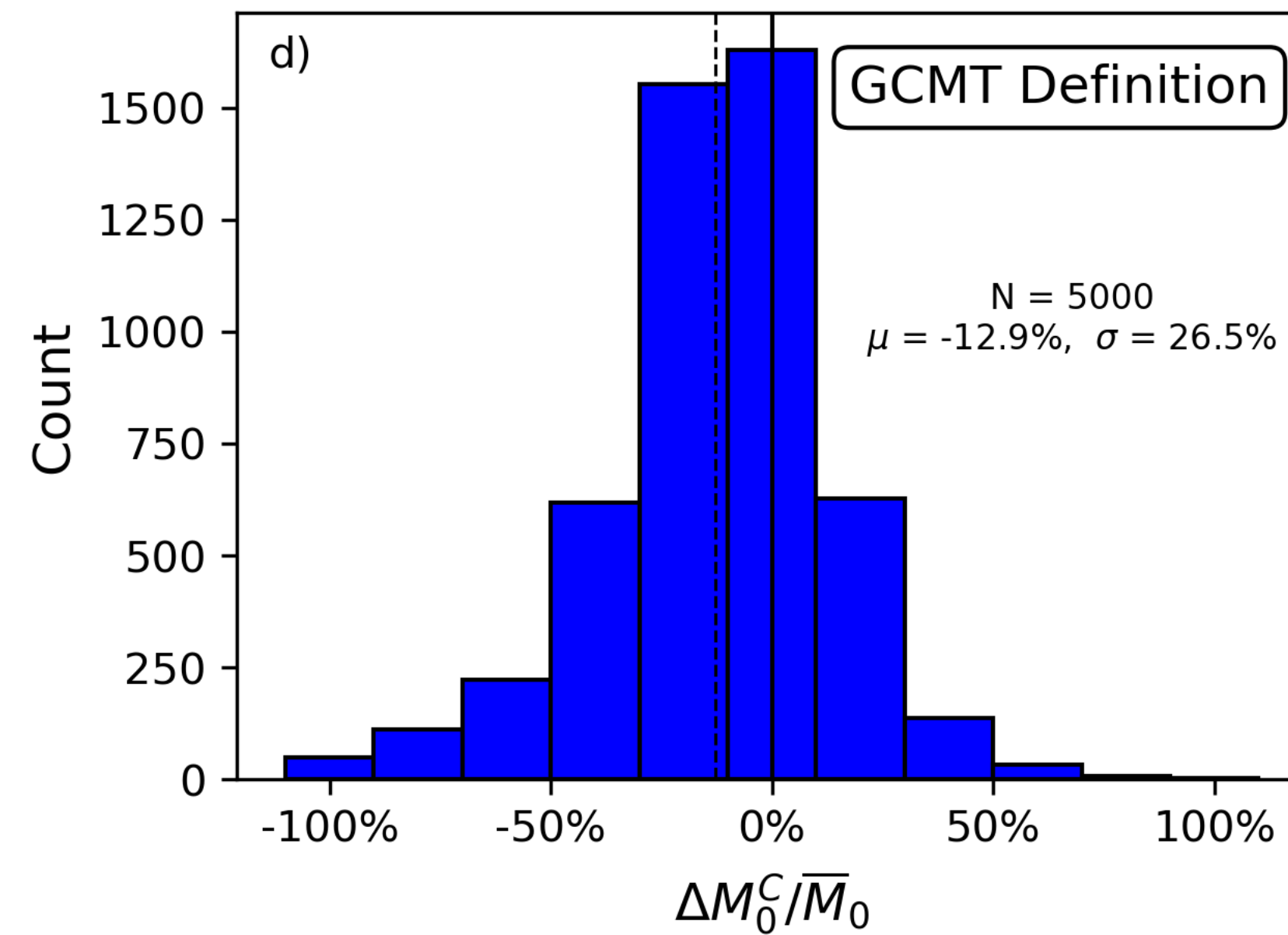
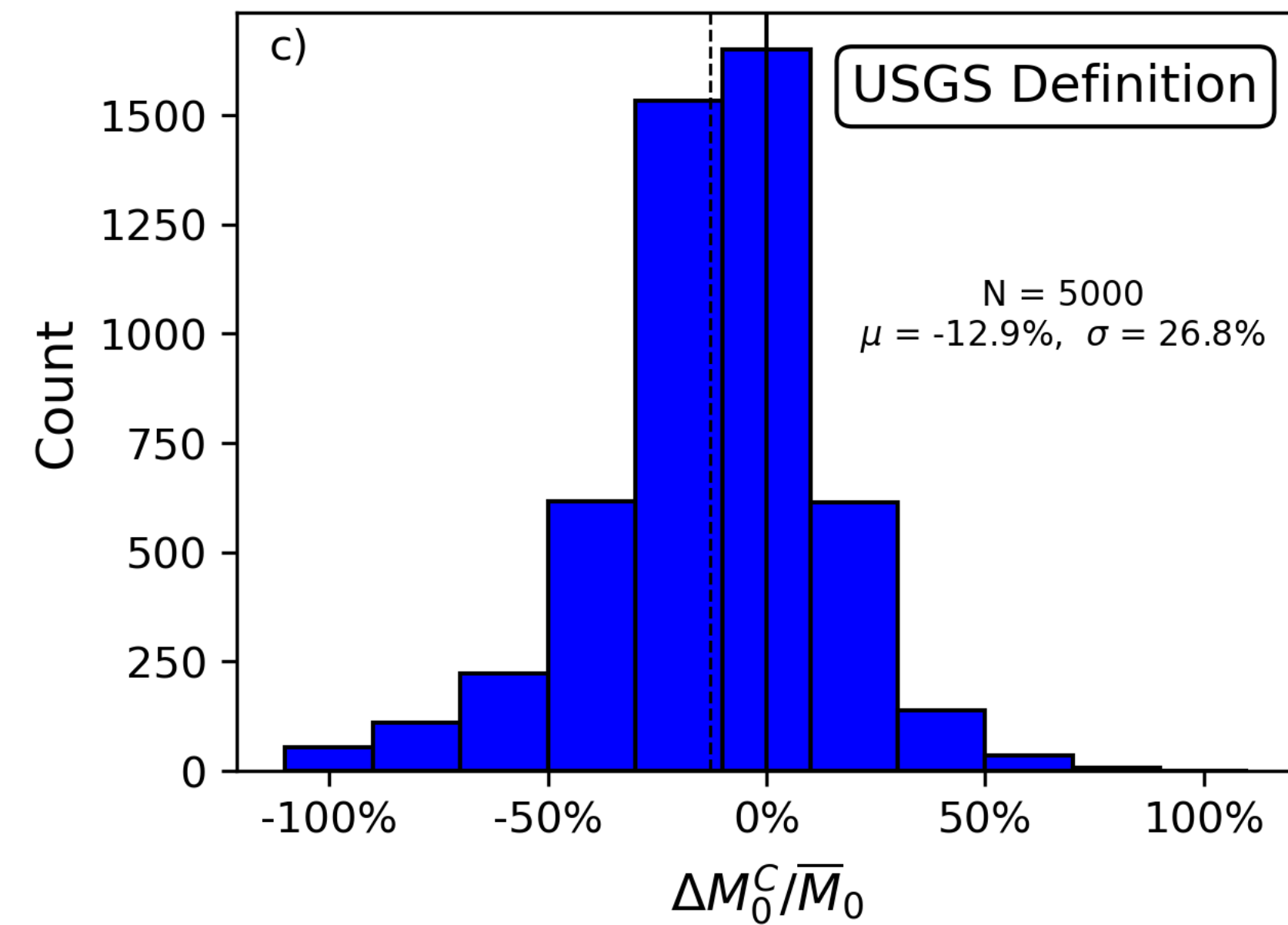
$$M_0^{\text{GCMT}} = \frac{1}{2} (|\lambda_1'| + |\lambda_2'|) \quad \epsilon = \frac{\lambda_3'}{\max(|\lambda_1'|, |\lambda_2'|)}$$

Differences Due to the Definition

The USGS definition of the moment yields larger values, opposite to what is observed in the catalogs. Moreover, the effect is smaller than observed.



Differences Due to the Moment Tensors

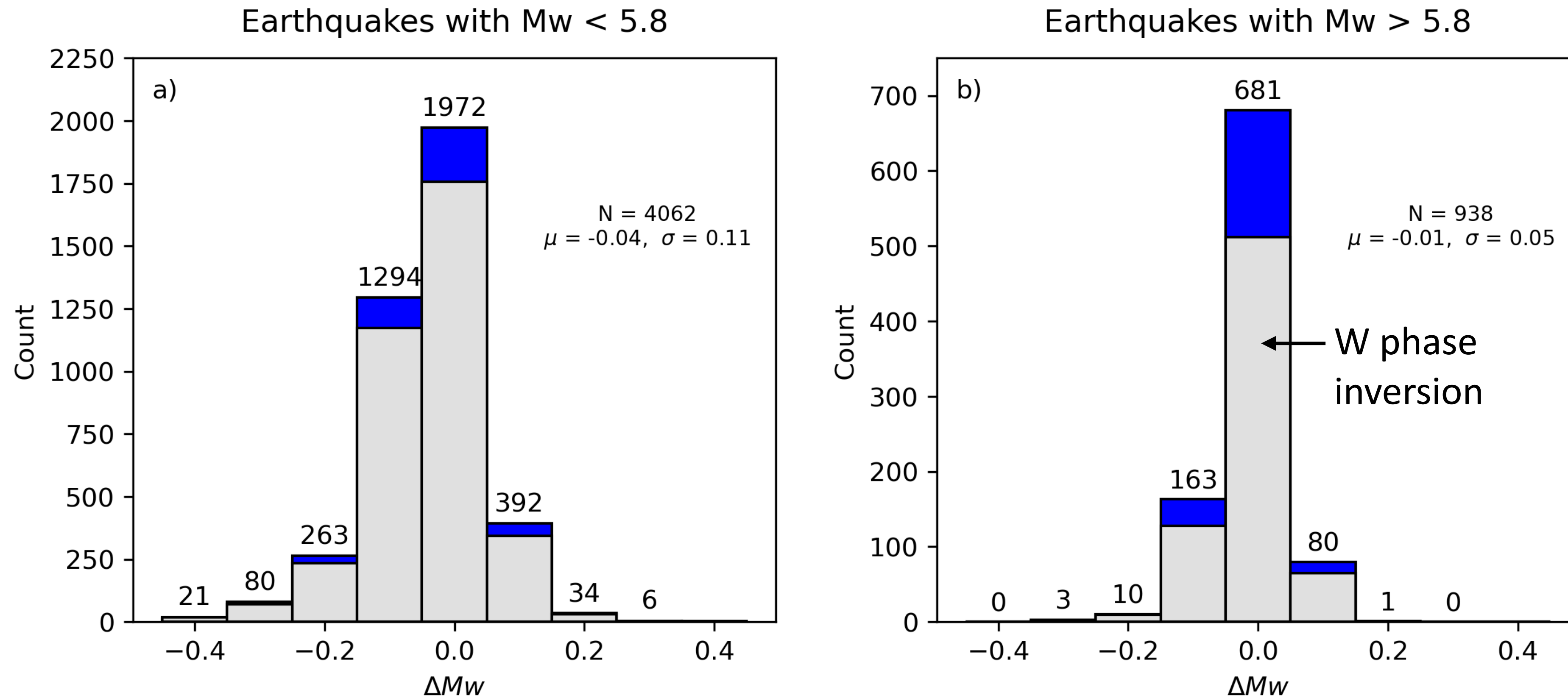


Reasons for Differences in Scalar Moment

The scalar moment differences are intrinsic to the moment tensors, with the GCMT catalog yielding larger values using either definition of the scalar moment.

Corresponding Magnitude Differences

(USGS-GCMT)



USGS inversions based on W phase are consistent with the GCMT magnitudes to ± 0.2 units as noted in earlier data (Hayes, 2009; Duputel 2012), or a factor of 2 in moment.

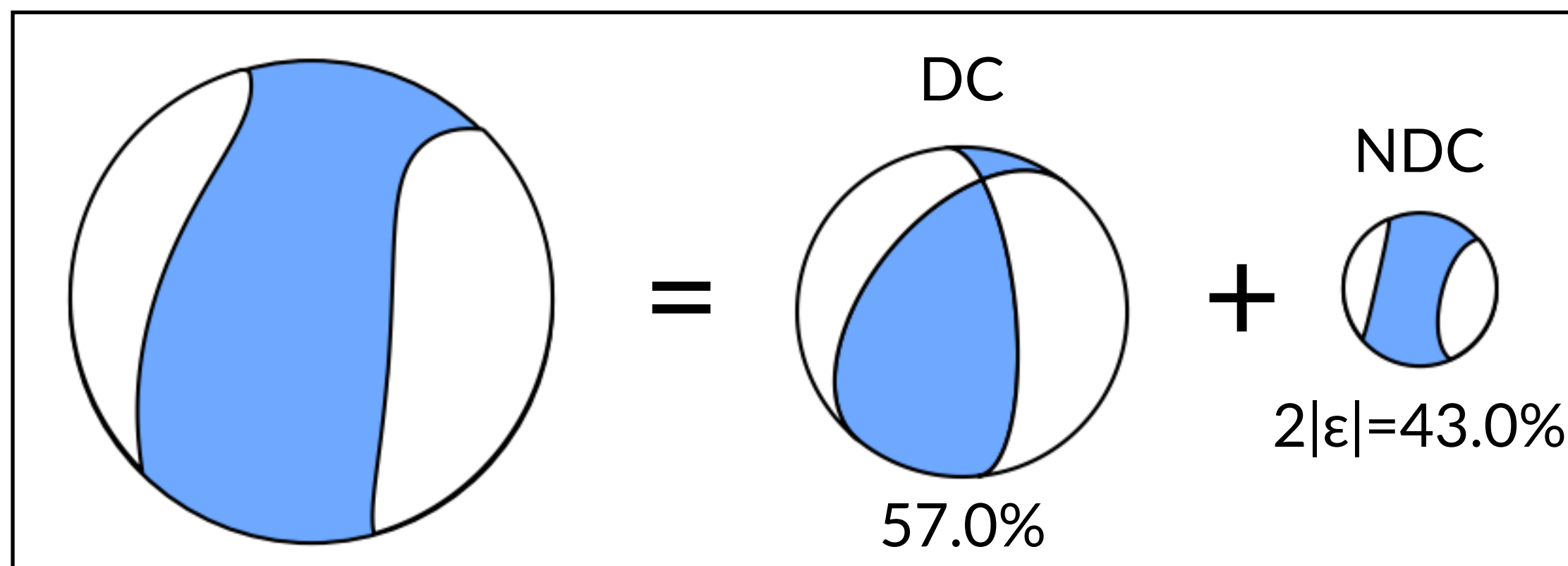
Moment Tensor Components

The deviatoric moment tensor can be decomposed in double-couple (DC) and non-double-couple (NDC) components.

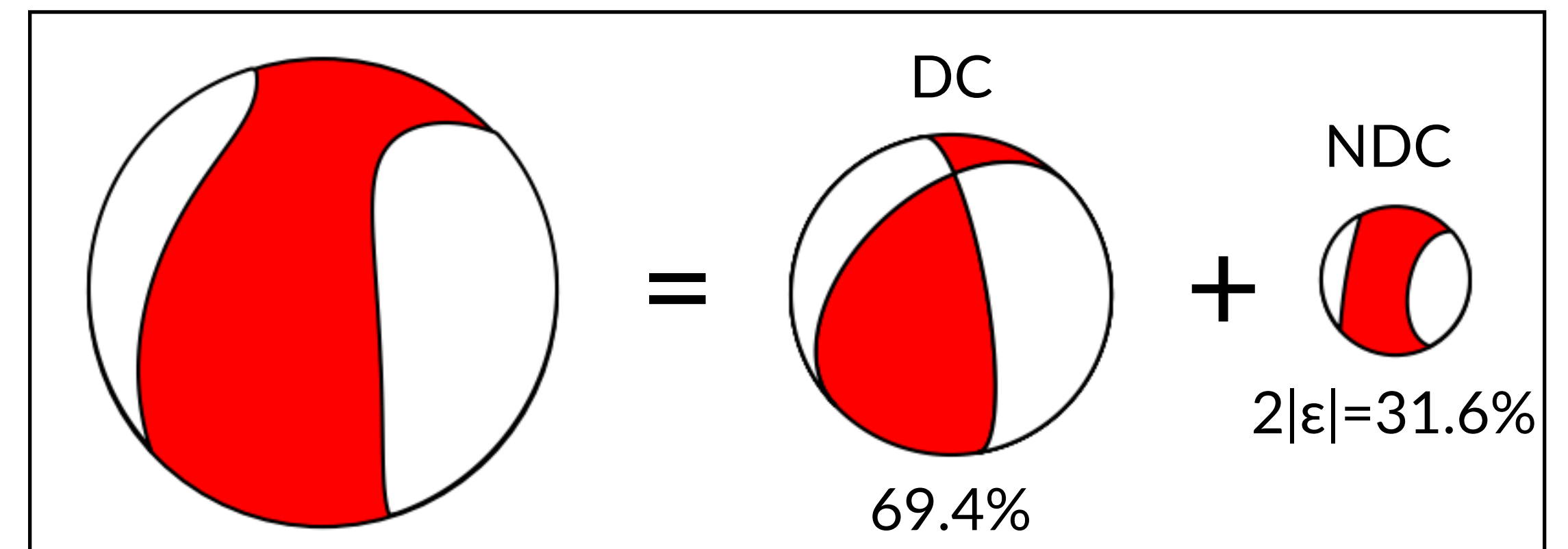
$$\underline{\underline{M}}^{\text{dev}} = \begin{pmatrix} \lambda'_1 & 0 & 0 \\ 0 & \lambda'_2 & 0 \\ 0 & 0 & \lambda'_3 \end{pmatrix} = \underbrace{\lambda'_1 (1 + 2\epsilon)}_{M_0^{\text{DC}}} \begin{pmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 0 \end{pmatrix} + \underbrace{\lambda'_3}_{M_0^{\text{NDC}}} \begin{pmatrix} -2 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

Kaikōura Earthquake

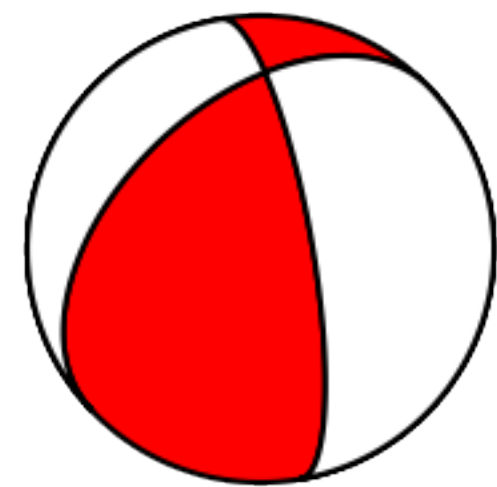
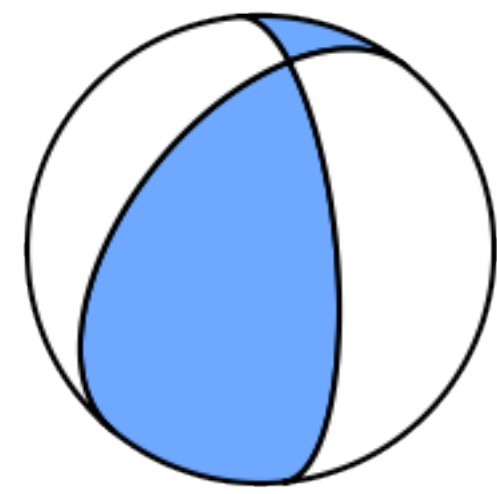
USGS



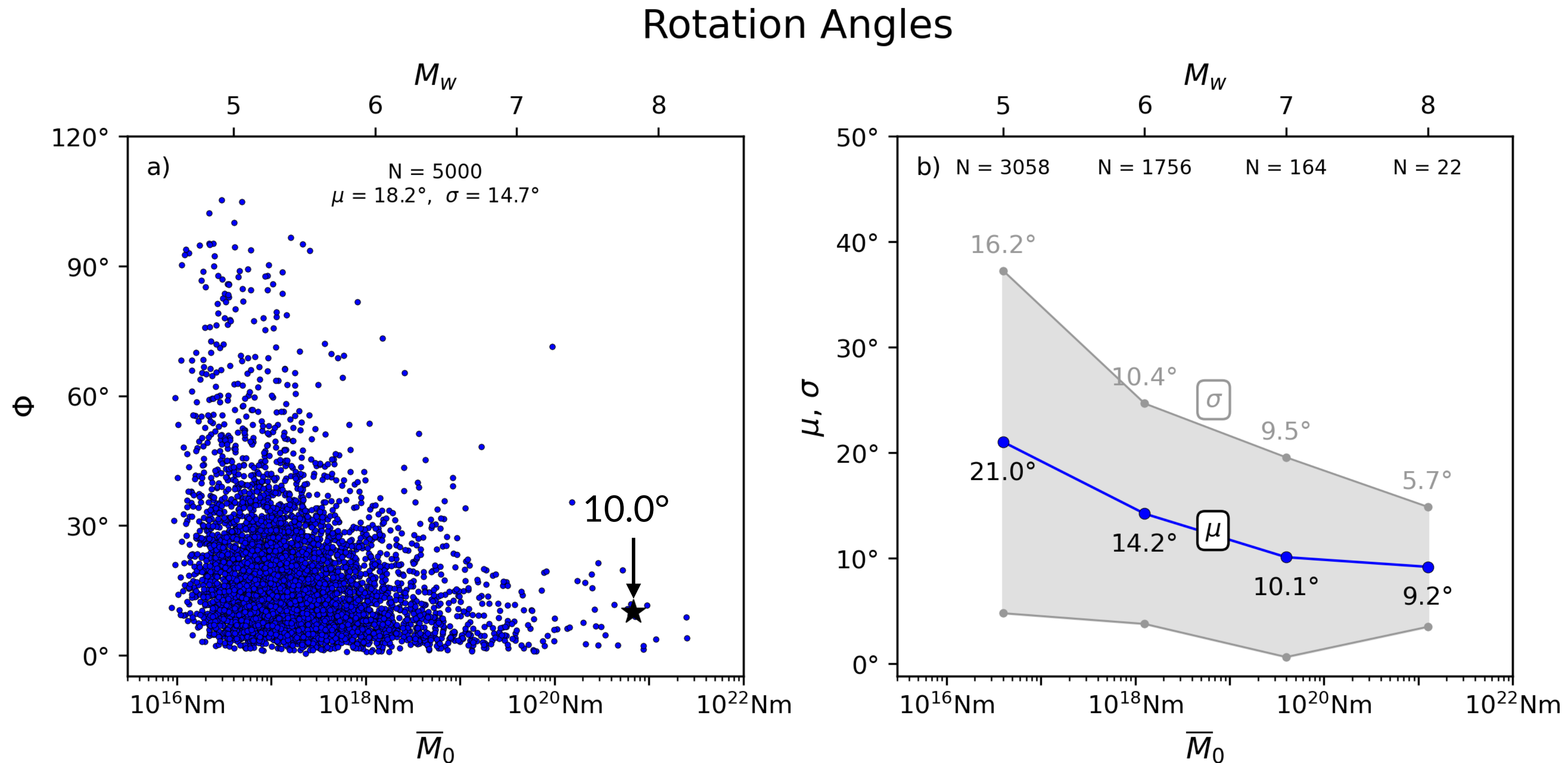
GCMT



Differences in Double-Couple Component



$$\begin{aligned}\Delta\Phi_f &= 7.3^\circ \\ \Delta\delta &= 5.1^\circ \\ \Delta\lambda &= 4.2^\circ\end{aligned}$$



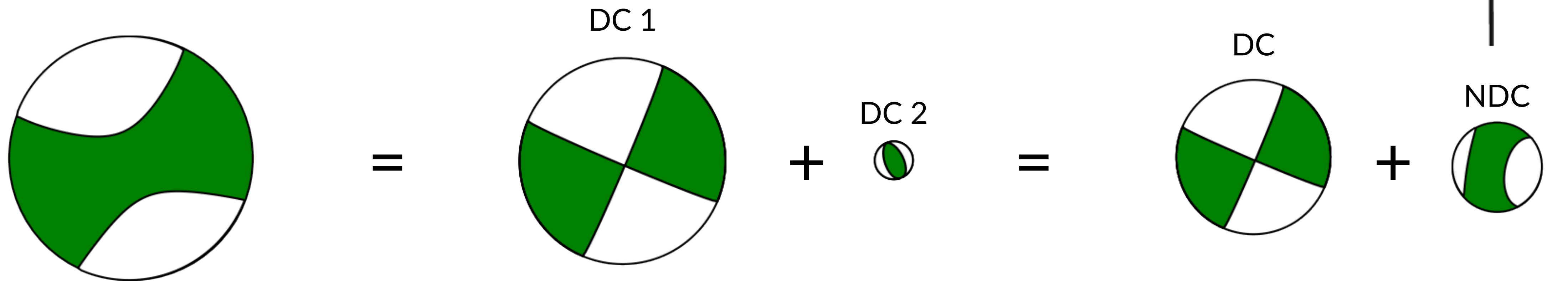
The differences in source geometry decrease with magnitude, showing that the inversions are more consistent for larger earthquakes. Rotation angles (Kagan, 1991) of 10° are common for earthquakes of all magnitudes.

Non-Double-Couple Components

represent deformation without volume change at the source in addition to the major double-couple component.

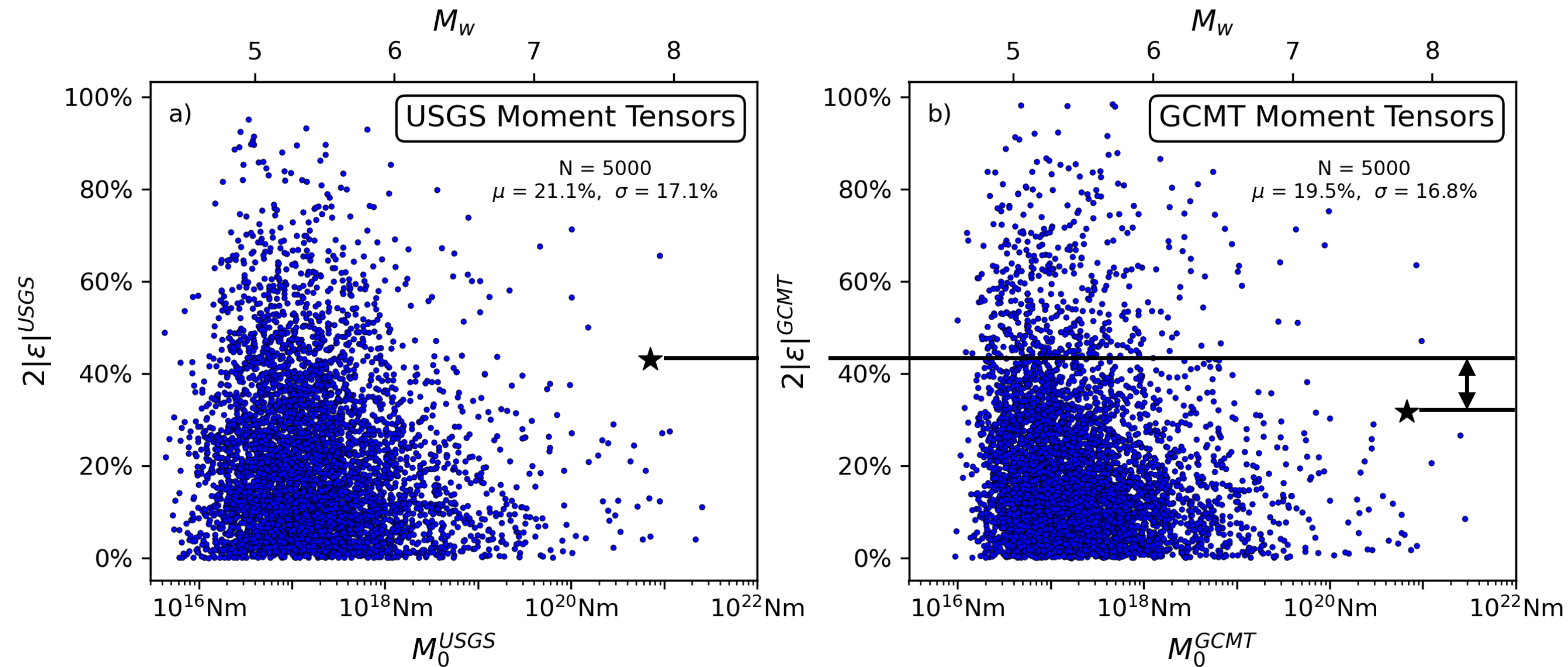
They appear in the moment tensor inversion for

- complex source processes (rupture on multiple faults, spatially varying source processes)



- in specific geologic environments (volcanic earthquakes, magmatic intrusions, geysers)
- artifacts in the inversion (noisy data, insufficient station coverage, uncertainties in Earth model, uncertainties in earthquake location)

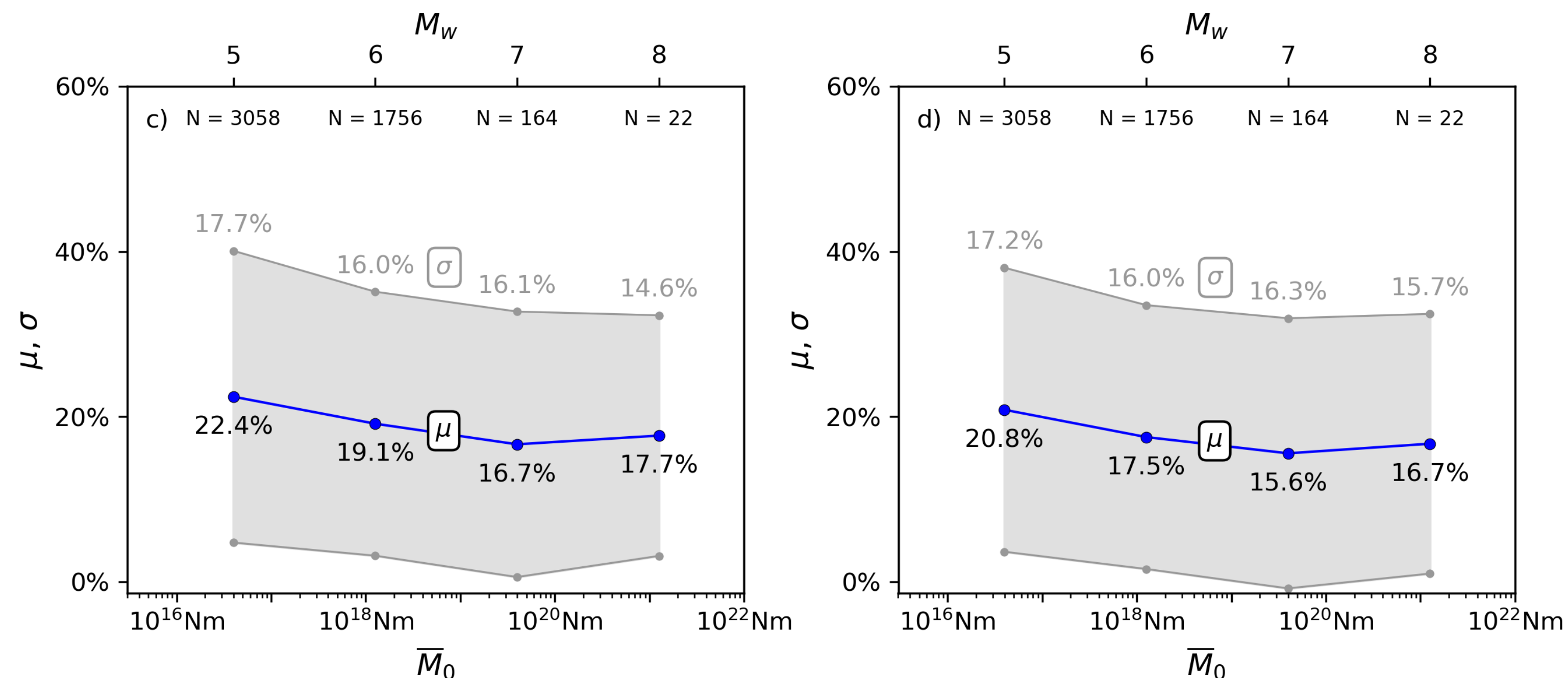
Deviations From a Double-Couple Source



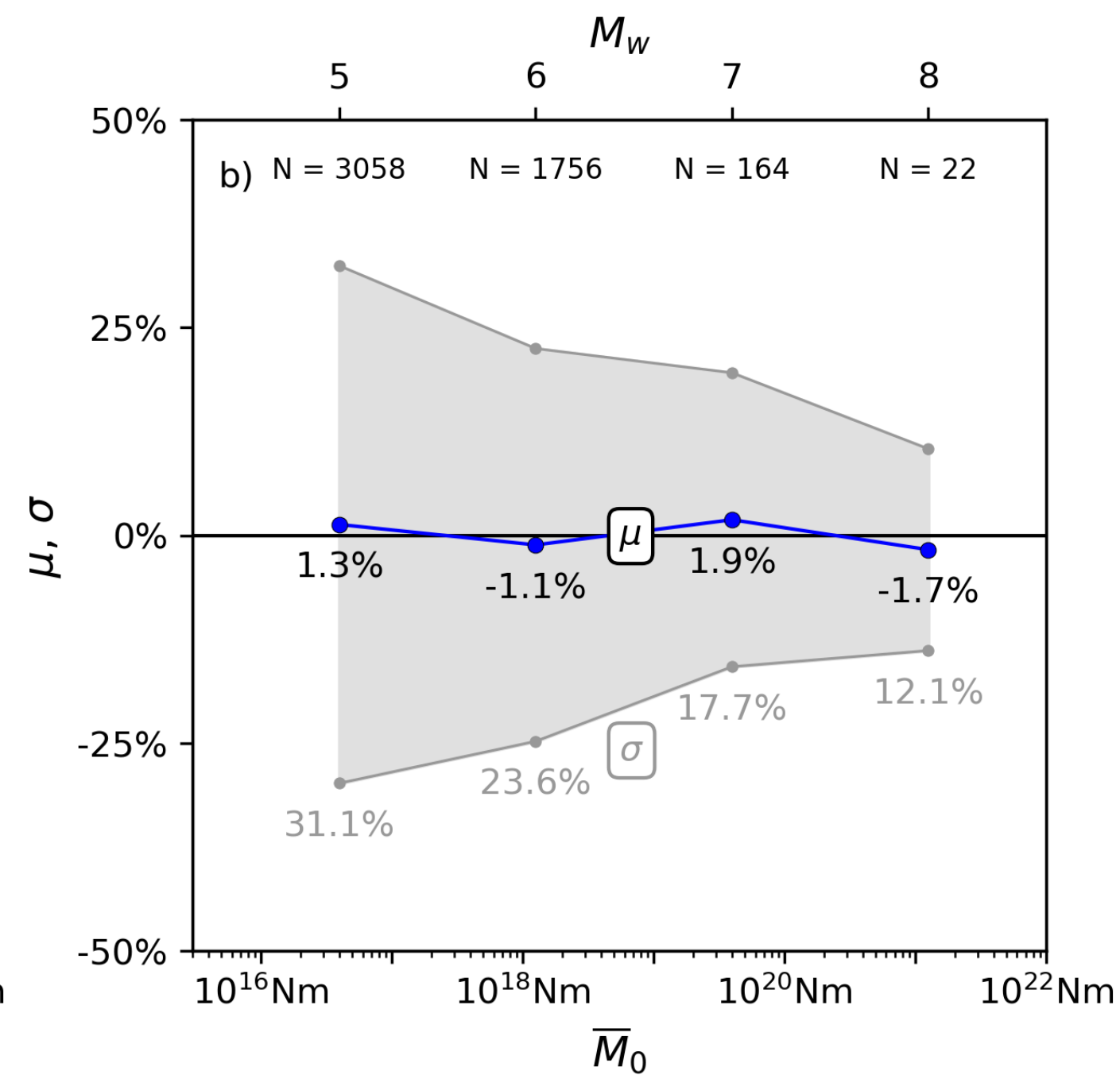
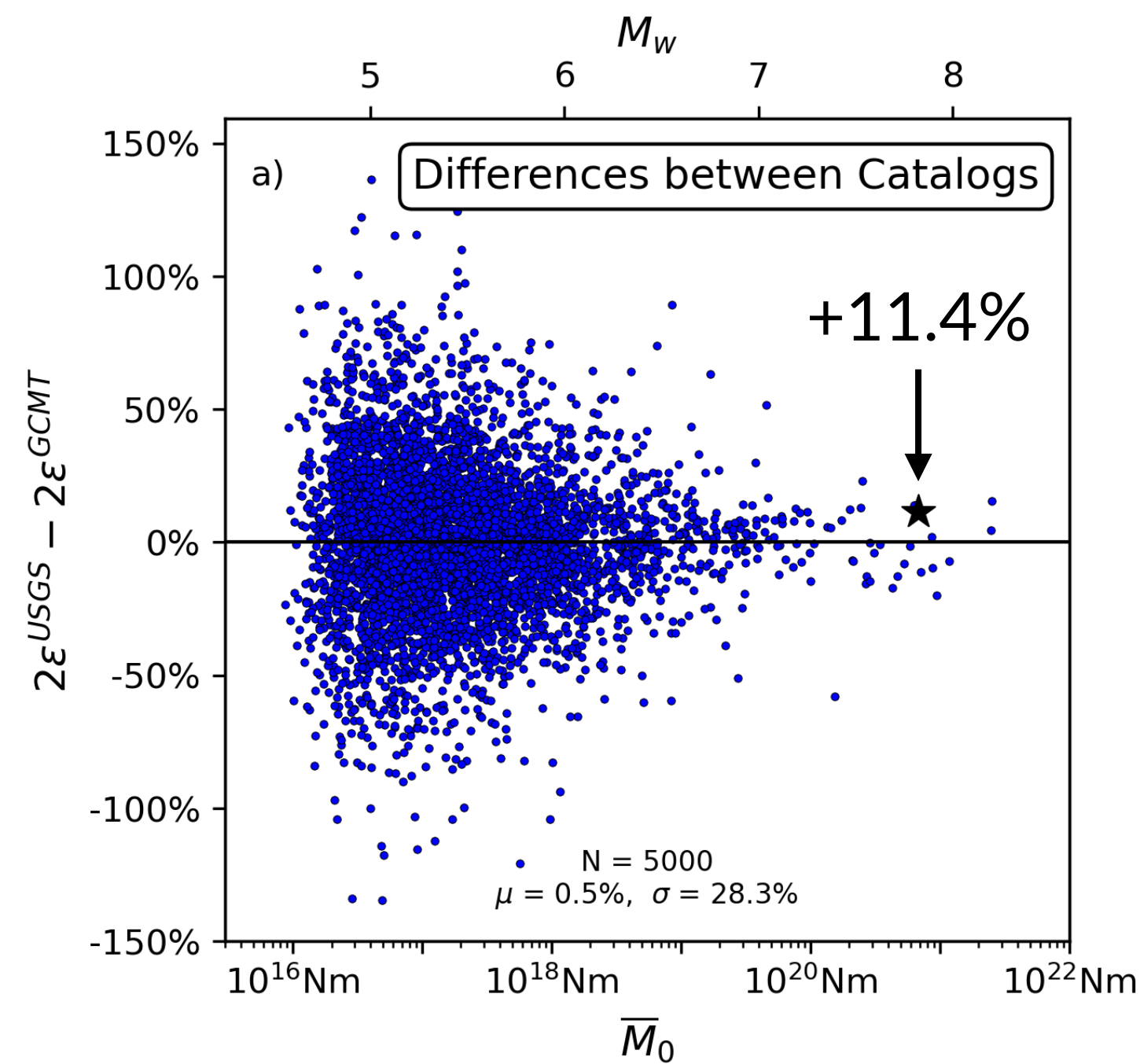
Non-Double-Couple Components

Both catalogs show more earthquakes with small non-double-couple components than large ones.

Large earthquakes tend to have somewhat smaller non-double-couple components.

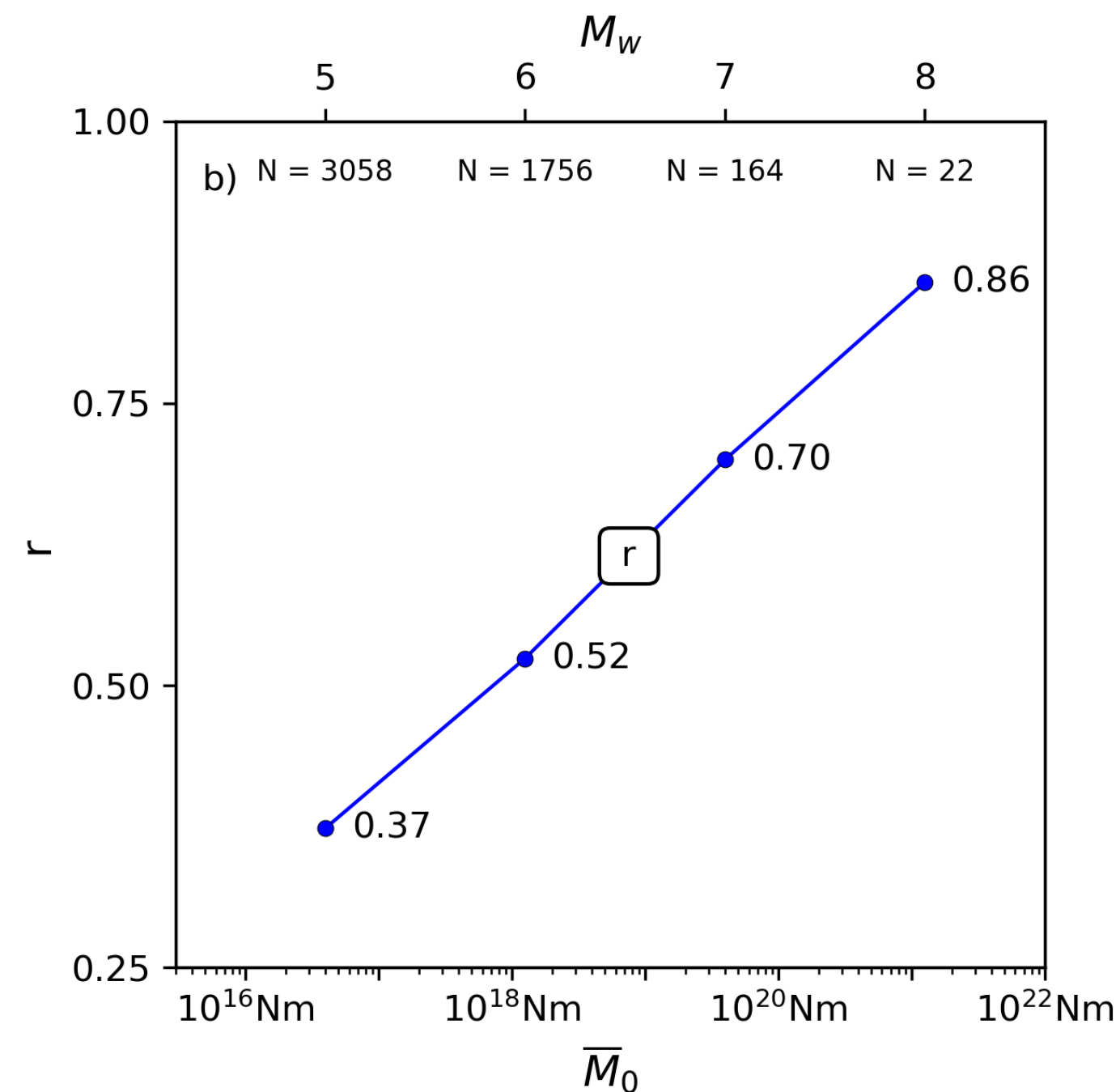
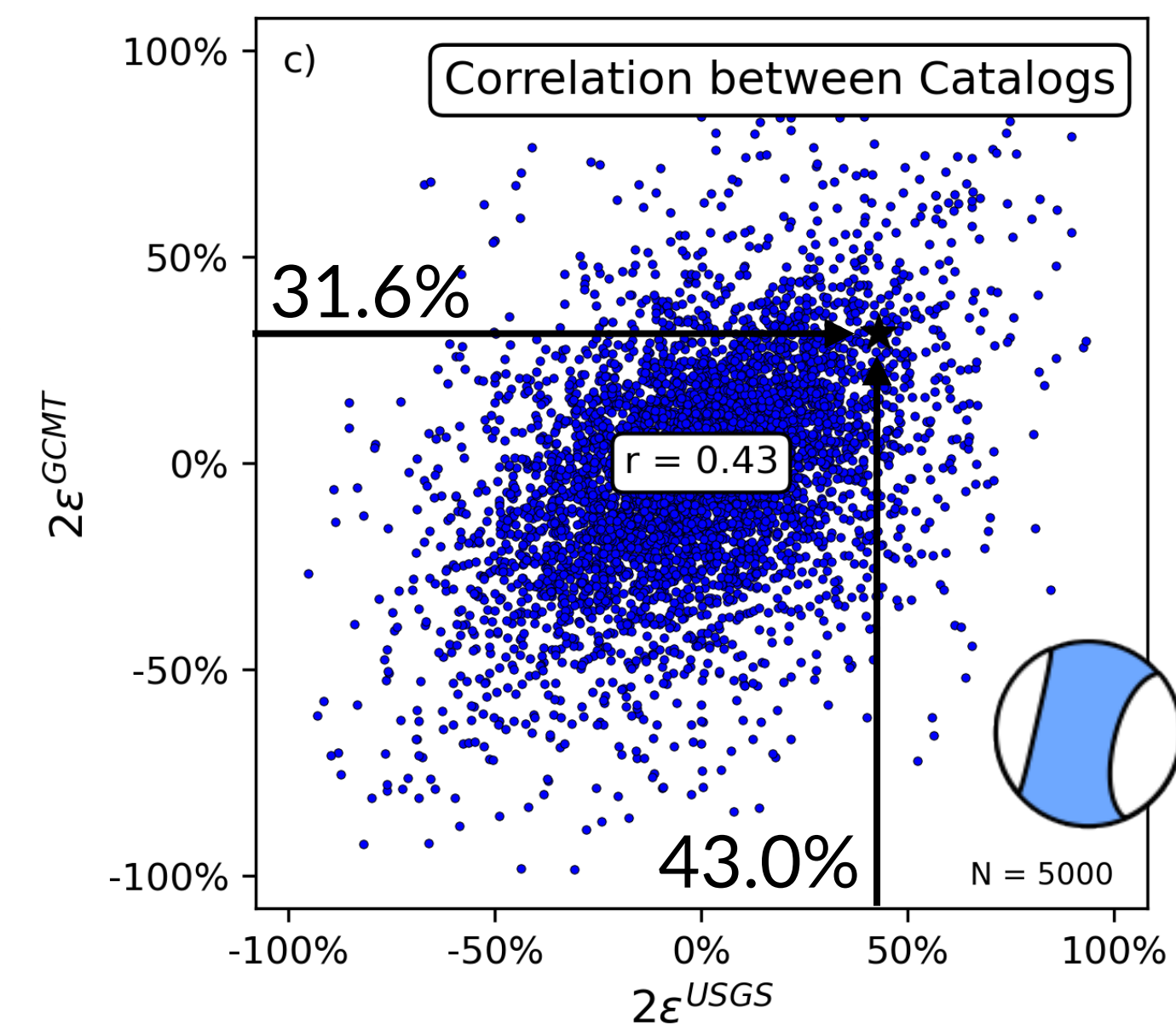


Reliability of Non-Double-Couple Components

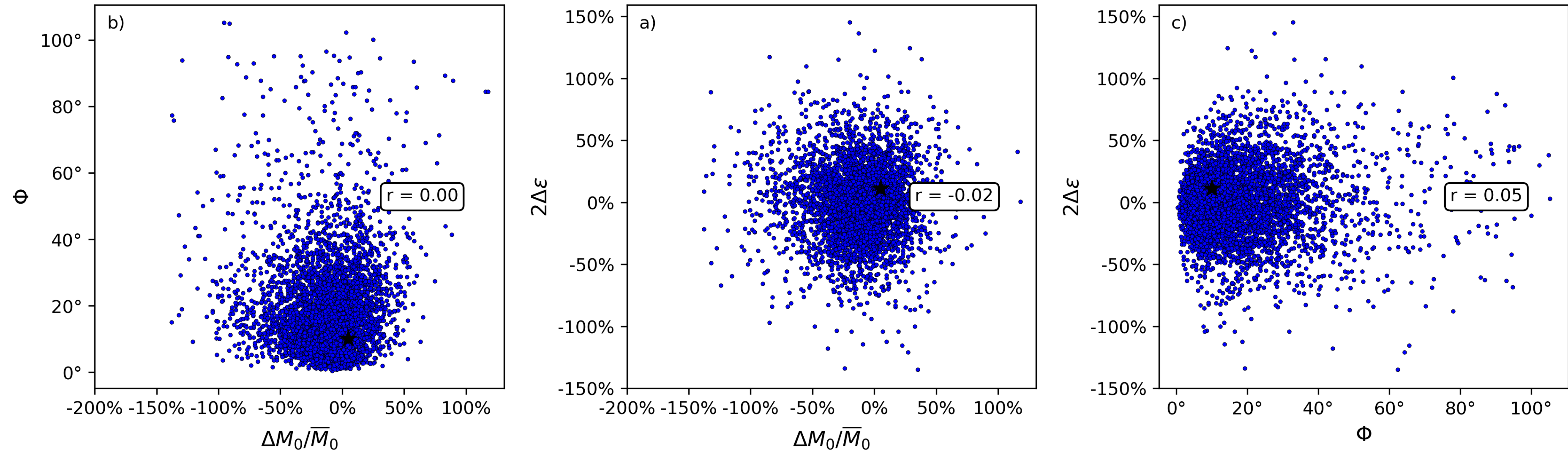


Differences of Deviations from Double-Couple Sources

The deviations from a double-couple source decrease, and the correlation between non-double-couple components increases with magnitude, hinting at a better determination of source mechanisms for large earthquakes.

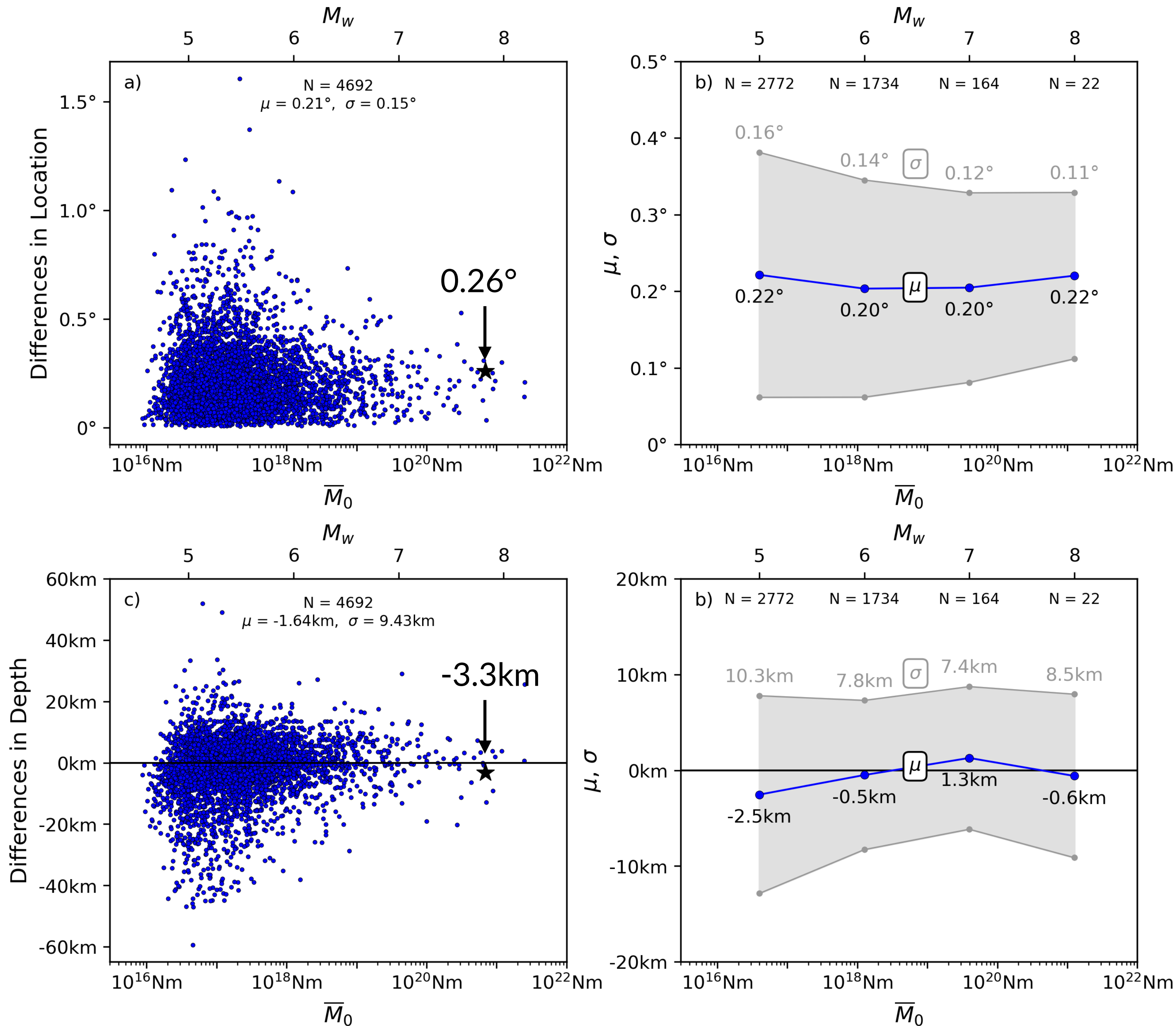


Correlation between Differences in Source Parameters



The differences between catalogs all decrease with magnitude and are uncorrelated, implying that they are generally artifacts of the inversion rather than real source effects.

Differences in Location and Depth Between Catalogs



Location and Depth

Location and depth are consistent between catalogs and only the differences in depth vary with magnitude.

Summary

Reported errors underestimate differences between catalogs substantially,
implying larger uncertainties.

Systematic scalar moment differences between the catalogs
likely reflect differences in inversion methodology.

Non-double-couple components of small earthquakes
likely do not represent real source processes.

Uncorrelated differences between moment tensors in different catalogs
are likely artifacts of the inversion.