A unified Mw-based earthquake catalog for metropolitan France consistent with European catalogs

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INTRODUCTION

SI-Hex: the existing French catalog in Mw

The Si-Hex catalog (1962-2009) is the first catalog of instrumental seismicity in Mw published for metropolitan France (Cara et al., 2015, 2017). It represents a breakthrough in terms of merging all the data collected by the various French observation services. However, uncertainties remain especially concerning the coherence of Mw at the European level. The authors found that the Mw of Si-Hex are on average 0.3 units lower than the Mw of the European-Mediterranean earthquake catalog (EMEC, Grünthal and Wahlström, 2012).

The sources of uncertainties identified here are the followings:

- All Mw values are coming from a magnitude scale conversion: **no "direct" Mw** are included
- The **ordinary least square regression** is employed instead of an orthogonal regression which is more adapted to magnitude conversion issue
- Use of **several sources of Mw** to develop magnitude scale conversion without a verification of the coherency between them
- Use of **multiple strategies** to estimate Mw leading to unstable GR slopes depending on time, region and magnitude range

Goal: Build a new instrumental earthquake catalog for metropolitan France, as an alternative catalog to SI-Hex based on a **single** reference Mw

The challenge: Probabilistic seismic hazard assessment (PSHA) is based on probability distribution (Gutenberg-Richter law) of earthquakes. PSHA thus requires the establishment of earthquake catalogs with an homogeneously estimated magnitude scale compatible with the one used to establish Ground Motion Prediction Equations (GMPEs). This double requirement, often difficult to reach, led us to re-visit existing catalogs in metropolitan France and neighboring regions.

Does an alternative strategy improve the coherency of Mw estimates and the stability of the GR?

List of events from seismic bulletins published by the observatories (origin time, location and local magnitude)

e.g. the LDG bulletins

Step 1: Collection of all available « direct » Mw estimates and uniformization of them

e.g. Italian catalogCPTI15 (Gasperini et al., 2012) :

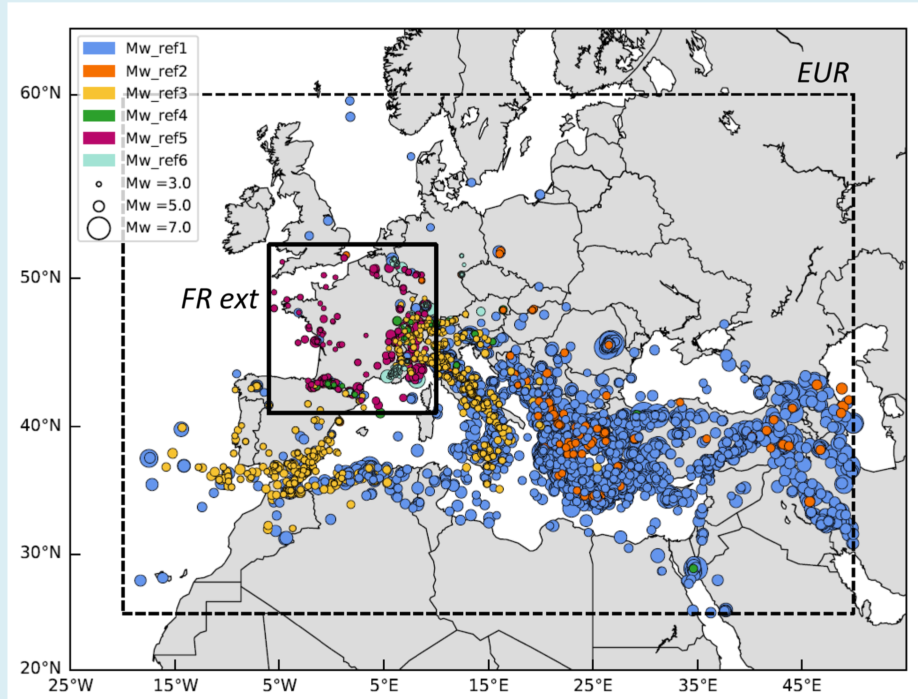
- *Mw of reference: GCMT and RCMT*
- *Correction of Mw: +0.05 à NEIC, -0.05 à ETHZ (SED specific studies), +0.2 à INGV-TDMT*

Step 2: Defining one magnitude scale conversion law between the available magnitudes and the Mw of step 1 (majority of events) *e.g. ML_LDG -> Mw*

Step 1. Building a reference Mw dataset

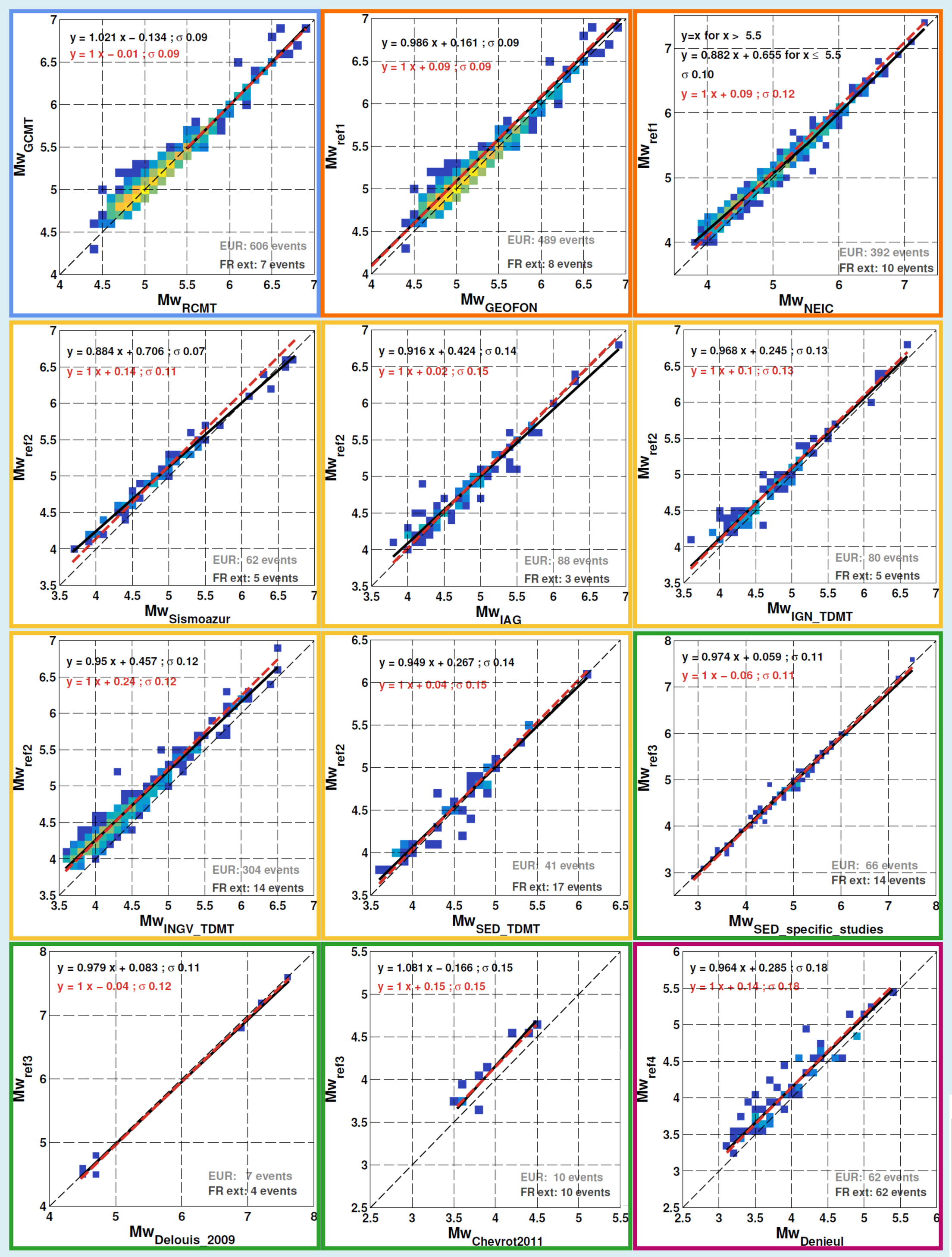
An extensive dataset of Mw is collected from several national and foreign agencies or specific studies. Heterogeneities exist between these Mw due to the use of different computation methods, input data and seismic networks. Firstly, the different sources of Mw are ranked from global to specific studies (see Table). Then, the Mw estimates are compared to the « Harvard » Mw (GCMT), and finally the Mw values are unified by correcting the systematic discrepancies.

Mw dataset



Inter-comparison of Mw values

Figure: Inter-comparison of the Mw values from different observatories or specific studies according to an upgradeable Mw_{ref} for common events occurring in Europe. A general orthogonal regression (GOR) assuming equal variances (η=1) between the two Mw datasets is computed for two linear models: i. a classical model (Y=aX+b) and ii. a model with the slope forced to be equal to one (a=1; Y=X+b). The second model is preferred, except when the first one explains significantly better the data (lower σ)



Inventory and ranking of Mw sources

	Observatory / Study	Period	Range of magnitude	Region	Applied correction	σ inter-méthodes	Merging of sources	Number of data added (EUR/ FR ext)
$Mw_{ref}1$	**1. GCMT**	1976-	5.5≤Mw	Global	-	0.09	Selection according to the order of preference if available	2843/ 51
	2. RCMT	1997-	4.5≤Mw≤5.5	Europe				
	3. Italian CMT	1976-2015	4.0≤Mw	Italy				
$Mw_{ref}2$	**NEIC**	1990-	2.2≤Mw	Global	For Mw<=5.5, **Mw_{ref}=0.882.Mw +0.655**	0.10	Mean	143/5
	GEOFON	2008-	4.0≤Mw	Global	Mw_{ref}=Mw+0.09	0.09		
$Mw_{ref}3$	**Sismoazur - FMNEAR**	2014-	2.8≤Mw	South of Europe - Mediterranean	**Mw_{ref}=0.884.Mw +0.706**	0.07	Mean	710/115
	IAG	1984-2013	3.2≤Mw	Ibero – Maghreb	Mw_{ref}=Mw+0.02	0.15		
	IGN-TDMT	2002-	3.1≤Mw	Spain	Mw_{ref}=Mw+0.1	0.13		
	INGV-TDMT	2004-	2.8≤Mw	Italy	**Mw_{ref}=Mw+0.24**	0.12		
	SED-TDMT	1999-2015	2.8≤Mw	Switzerland	Mw_{ref}=Mw+0.04	0.15		
$Mw_{ref}4$	**Specific studies on large dataset**	SED specific studies selected in this order of preference (similar to ECOS): 1.Bernardi et al. (2005); 2. Baer et al. (2007); 3. Braunmiller et al. (2005); 4. Braunmiller et al. (2002);			Mw_{ref}=Mw-0.06	0.11	Mean	42/29
		Delouis et al. (2009)			Mw_{ref}=Mw-0.04	0.12		
		Chevrot et al. (2011)			**Mw_{ref}=Mw+0.15**	0.15		
$Mw_{ref}5$	**Denieul et al. (2014, 2015) Mw_{coda}**	1963-2013	2.65≤Mw	France	**Mw_{ref}=Mw+0.14**	**0.18**	-	195/195
$Mw_{ref}6$	**Studies for which no comparison is done**				-	-	Direct (no event provided in at least 2 different sources)	528/498
	IRSN-Durance	1998-2007	0.6≤Mw≤3.5	Durance region (France)				
	Godano et al. (2013)	2010-10-13 2010-11-12	1.1≤Mw≤3.15	Sempeyre				
	Specific studies	Grunthal and Wahlström (2003); Larroque et al. (2009); Nechtschein and Lesueur (2011); Diehl et al. (2018); ISC GEM bibliog;						

Step 2. Magnitude scale conversion law

ML_{LDG} data: The seismic events are provided by the Laboratory for Detection and Geophysics (LDG) Bulletins. We have selected events that occurred between 1976 and 2017 in the FR extended zone and associated with a « good » estimate of ML_{LDG} (at least 5 stations and ellipse area ≤ 100 km²) to develop a national magnitude scale conversion law.

Mw_{ref} - ML_{LDG} scaling laws:

- We notice a large dispersion of the observations
- For the extreme ML_{LDG} values, the different magnitude conversion laws predict a large range of Mw values
- For the median ML_{LDG} values, our law leads to larger Mw values than the published laws
- For all ML_{LDG} values, our law predicts larger Mw than the SI-Hex law

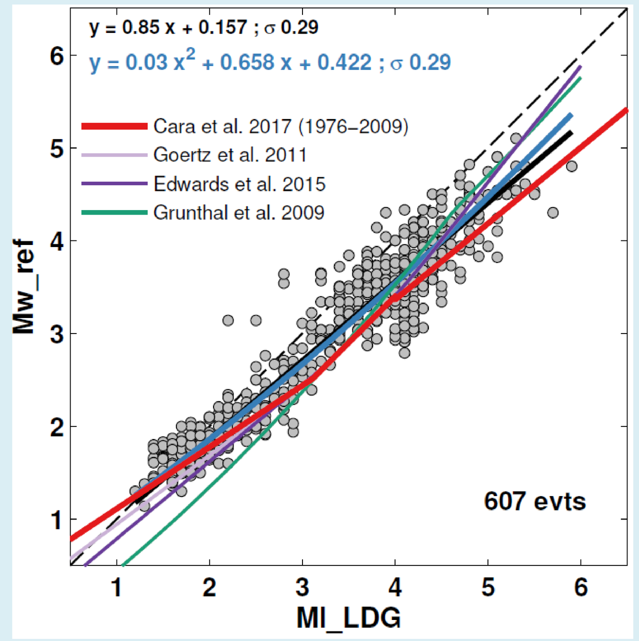
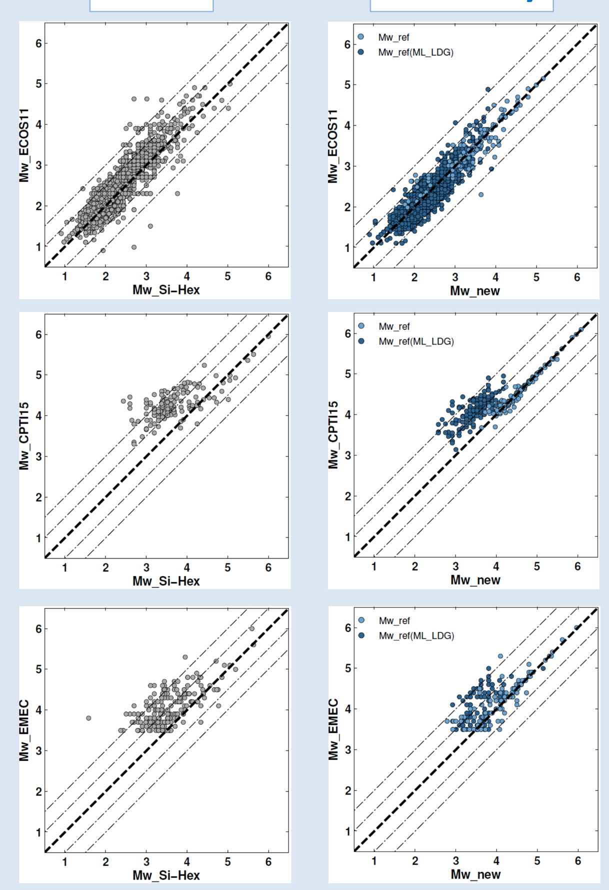
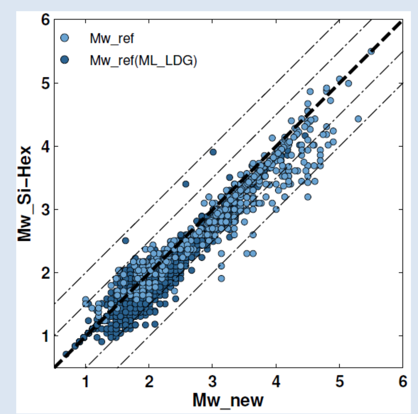


Figure: Magnitude scale national conversion laws for Mw_{ref} versus ML_{LDG}. The events included in the LDG bulletins are associated to the Mw catalog events using criteria on the delay between two origin times (Δt±15 s) and the differences between epicentral locations (Δd < 100 km). We used a general orthogonal regression assuming equal variances (η=1) to develop linear (black) and polynomial (blue) models. The conversion laws already published and involving the ML_{LDG} are displayed: SI-Hex (red), ECOS11 -Swiss laws (purple) and EMEC (green).

DISCUSSION

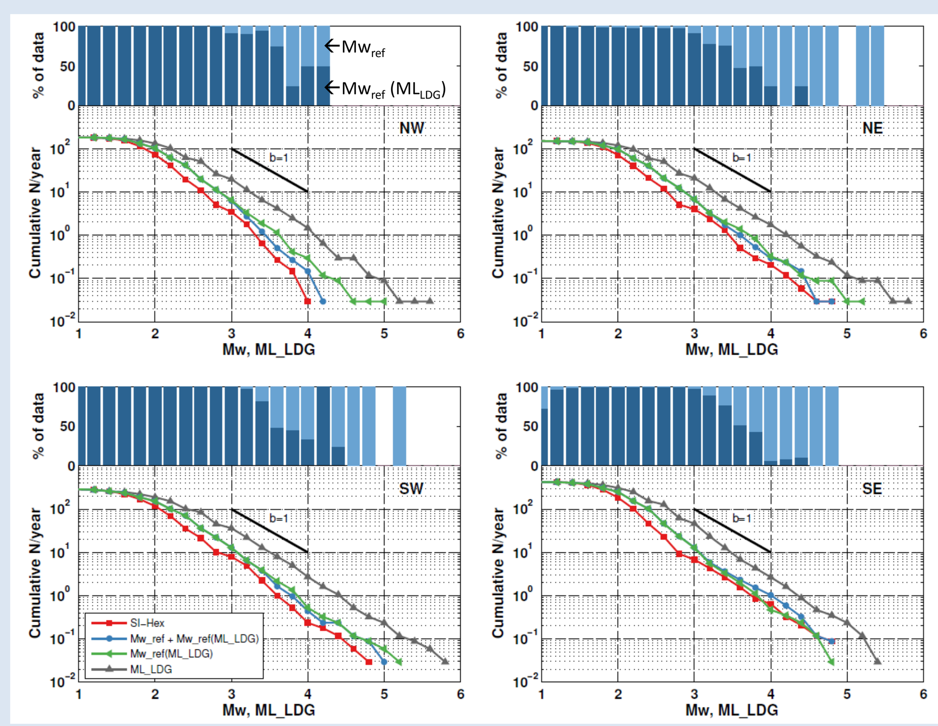
Improved coherency of the Mw values w.r.t. neighboring catalogs





- The Mw values of this study are larger than SI-Hex for the larger Mw values and are thus more consistent with the ones from neighboring catalogs (especially CPTI15)
- However, for the smallest Mw values a systematic bias exists with CPTI15 and EMEC when the national conversion is used

Improved GR statistics



- We predict for a same Mw value a larger rate of earthquake than SI-Hex for all Mw and zones (cf. SI-Hex zonation)
- Difference in regional GR slopes of Mw catalogs are strongest for the NW region whereas GR slope is stable and closer to 1 for the ML_{LDG}
- Merging 2 types of Mw is certainly one source of "heterogeneity" that affects the GR behavior; a second source is probably the use of a nonlinear law

Figure: Cumulative number of events per year for the four SI-Hex regions computed for four catalogs: SI-Hex (red), our catalogs based on LDG bulletins with 1. Mw from both Mw_{ref} and the conversion Mw_{ref} –ML_{LDG} (blue), 2. Mw only from the conversion (green) and 3. directly ML_{LDG} (grey). Each curve is computed for the same common events. For each point of the blue curve, the histograms gives the percent of data coming from Mw_{ref} (light blue) and $Mw_{ref}(ML_{LDG})$ (dark blue).

Regionalization: the unsolved issues

- Previous studies already tried to estimate Mw from local intensity/magnitude measures by correcting regional attenuation characteristics (e.g., Bakun & Scotti, 2006; Denieul et al., 2015) but application remains limited due to the lack of observations.

Mw_{ref} – Mw_{pred}

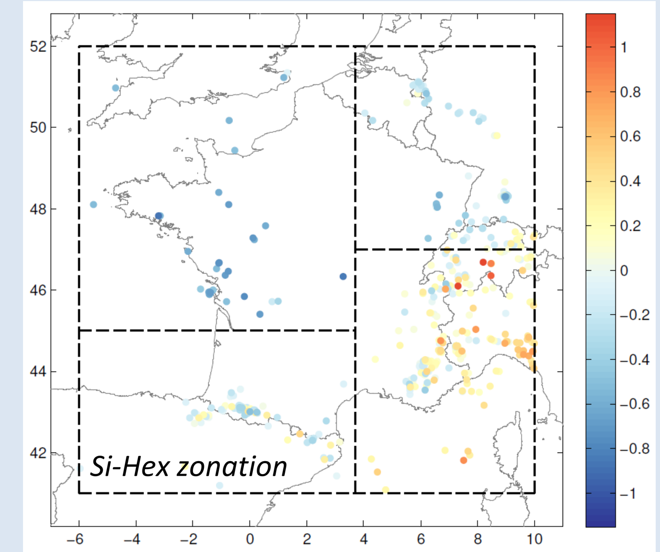
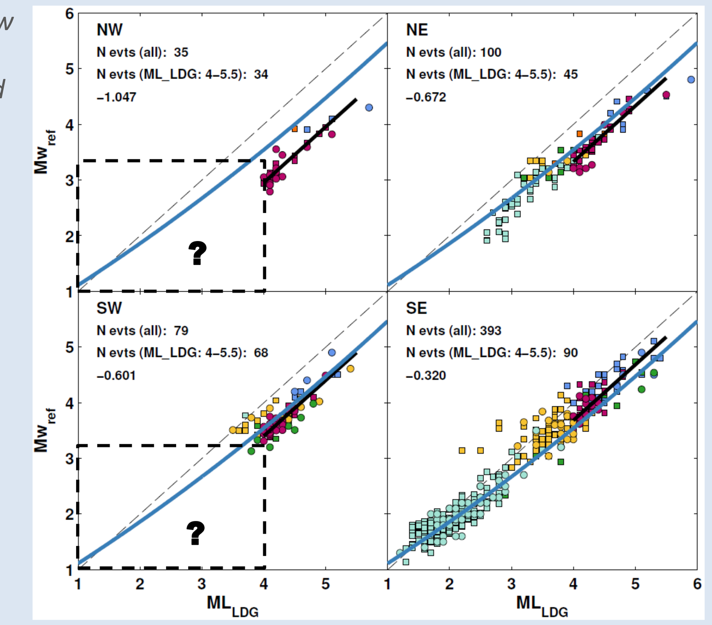


Figure: Differences between observations (Mw_{ref}) and the predicted Mw from the polynomial national conversion magnitude law. The zonation shown here is the one used by Denieul et al. (2015) to estimate Mw_{coda} from 4 attenuation models. Mw_{coda} are included in Si-Hex.

- As expected, a regionalization of the residuals appears when a national conversion law is used.

Figure: Mw_{ref} versus ML_{LDG} for the 4 zones. Comparison of the national conversion law (blue line) and the regional systematic tendencies (black) obtained with GOR and a slope of 1 for 4≤ML_{LDG}≤5.5 (range of ML_{LDG} with data available for each zone).



- **For 4<ML_{LDG}:**
  - Similar tendencies in SW & NE close to the national law
  - On the contrary, the tendencies deviate from the national law for NW & SE: smaller Mw in NW and larger in SE
- **For ML_{LDG}<4**, the national law is only constrained by data from SE. Lack of data does not allow calibrating regional Mw_{ref} - ML_{LDG} laws.

- **No regionalization:** leads to spatially distributed discrepancies with under/over -estimates of Mw values in the SE/NW respectively.
- **Regionalization:** requires defining boundaries and strong hypothesis in regions where there is a lack of Mw

- **Perspectives:** In the future, the French RESIF network will provide more systematic evaluation of Mw over the territory. However, the challenge of how to best convert the past ML_{LDG} earthquakes into unified Mw accounting for regional effects remains a challenge.

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