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EARTHQUAKE PREFERRED DAYS IN THE LAKE BAIKAL AND YUNNAN-SICHUAN REGIONS

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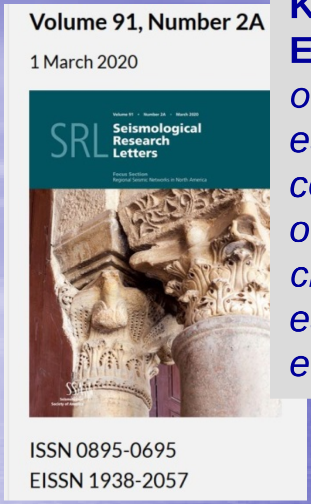


Kossobokov, V. G., and G. F. Panza (2020). A Myth of. Preferred Days of Strong Earthquakes? Seismol. Res. Lett. 91, 948–955 “*The existing evidence on the origin times of magnitude M ≥ 7.5 earthquakes worldwide, based on authoritative earthquake catalogs, does not permit to reject the null-hypotheses of random coincidental occurrence any time during the Earth or the Moon Cycles. ….On the other hand, the same Kuiper test permits to reject the null-hypotheses of the same chance of occurrence on any JD or MP for the strong magnitude M ≥ 6.0 earthquakes, …in particular, for earthquakes in Northern Hemisphere (with an evident seasonal pattern).”*

Understanding the cyclic and other forces governing geodynamics may provide fundamental clues for unravelling characteristics of earthquakes occurrence, which remains spectacular evidence induced by plate tectonics fuelled by tidal drag and associated global cooling of the Earth (Riguzzi et al., 2010; Doglioni and Panza, 2015). To check the hypotheses of earthquake-preferred days the nonparametric Kuiper test statistics for cyclic variations applied to the seismic evidence resulting from the empirical distributions of the earthquake origin time versus solar (Julian Day, JD) or lunar (Moon Phase, MP) cycles. We present the results of the Kuiper test application to seismicity of the Lake Baikal and Yúnnán-Sichuan Regions aimed at verification on a solid statistical base the hypotheses of uniform distribution of earthquake origin time JD’s and MP’s in respect to the earthquake magnitude cut-off.

Kuiper's Test (κ goodness-of-fit statistics)

To check the hypotheses of earthquake-preferred days we used nonparametric Kuiper's test. This goodness-of-fit test makes no assumptions about the distribution of data and, therefore, is commonly accepted as the most useful method for comparison of two samples. The invariance under cyclic transformations makes the Kuiper's test of particular value if the observations are points on a circle.

Kuiper, N.H. (1960). Tests concerning random points on a circle. Proceedings of the Koninklijke Nederlandse Akademie van Wetenschappen, Series A 63, 38–47.

Stephens, M.A. (1965). The goodness-of-fit statistic V_N: distribution and significance points. Biometrica 52(3-4), 309-321

Kuiper's test (κ goodness-of-fit statistics)

$F_n(x)$ - the empirical cumulative distribution function for n independent identically distributed observations X_i defined as

$$F_n(x) = \{\text{number of } X_i \le x\}/n.$$

The Kuiper's test considers the entire misfit of the two distributions accounting for the difference between both of the discrepancy statistics

$$V = D^+ - D^-$$

$D^+ = \max(F_{1,n}(x) - F_{2,m}(x))$ and $D^- = \min(F_{1,n}(x) - F_{2,m}(x))$

in the definition of

$$\kappa(D,n,m) = [nm/(n+m)]^{1/2} V.$$

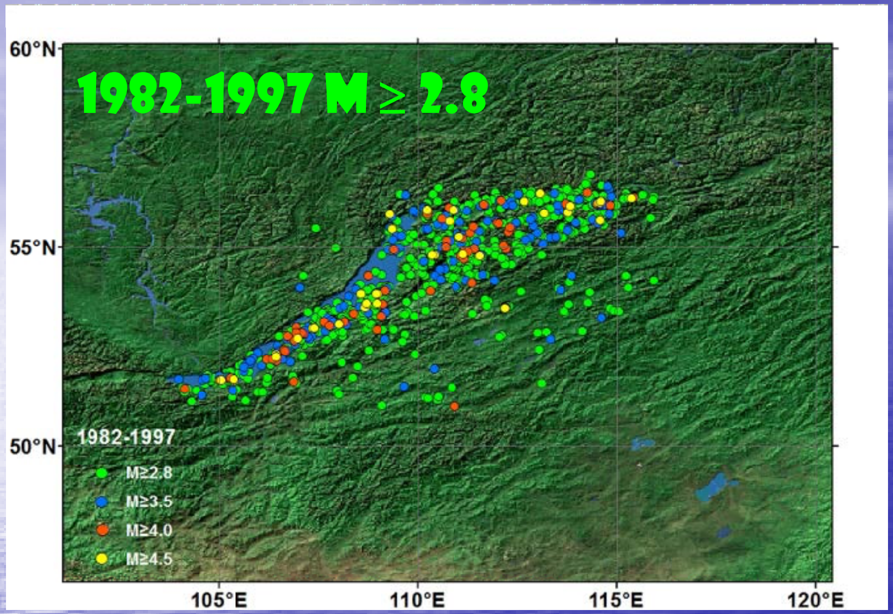
Asymptotically, when n and $m \to \infty$, the cumulative probability distribution of κ converge to

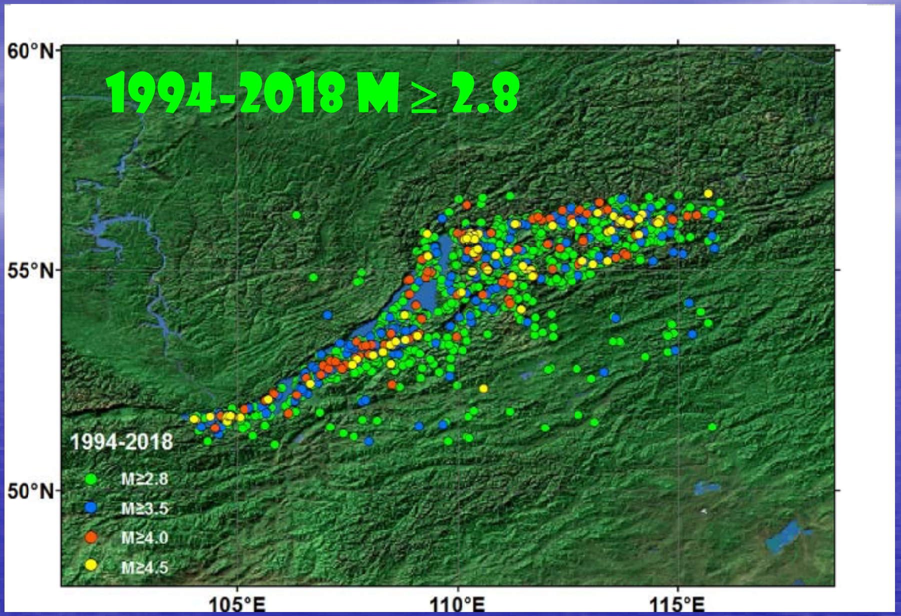
$$\text{Prob}(\kappa \le x) = 1 - 2\sum_{k=1}^{\infty}(4k^2x^2 - 1)\exp(-2k^2x^2).$$

Kuiper's test (κ goodness-of-fit statistics)

When the probability of exceeding the achieved value of statistic is less than α, the null hypothesis is rejected at the significance level α,
In terms of confidence level 1–α, the null hypothesis is rejected, if
Prob(κ ≤ *x*) > 1–α.

DATA : LAKE BAIKAL REGION

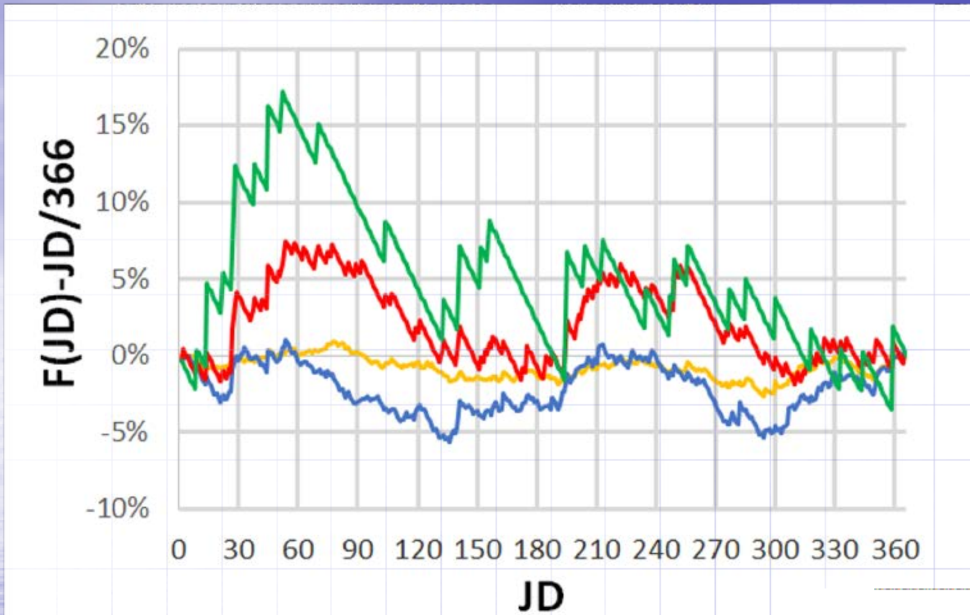




Seismicity of Lake Baikal region is considered within 48◦–58◦N and 96◦–126◦E.
1982-1997 : The regional catalog is compiled using the annual periodical “Earthquakes in USSR” and its continuation “ “Earthquakes in Russia”.
1982-1997 : open data, http://seis-bykl.ru, Baikal Division of Geophysic Survey of the Siberian Branch of the RAS

The regional catalog is sufficiently complete in reporting earthquakes of energy class K=9 or above, which range corresponds to magnitude M = 2.78 or larger. (The energy class determinations were officially adopted and widely used in the Soviet Union.)

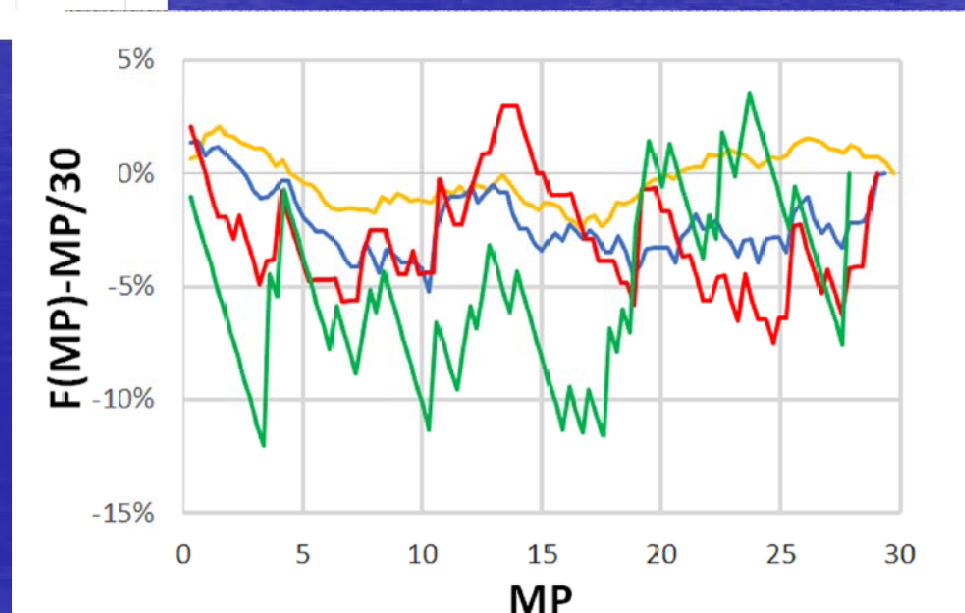
Lake Baikal Region: 1982-1997



M ≥ 2.8　M ≥ 4.0

M ≥ 3.5　M ≥ 4.5

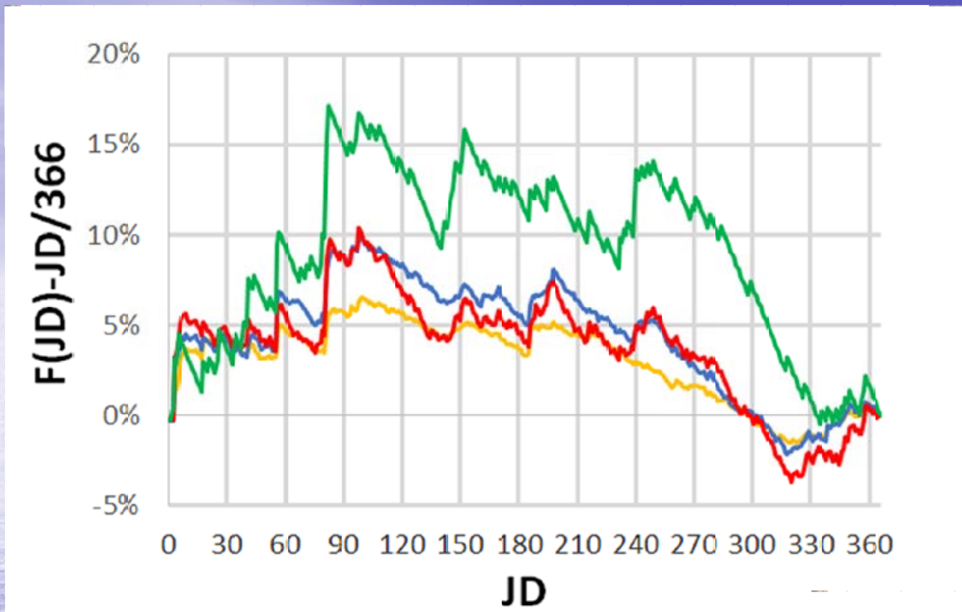
Earthquake origin time
versus
Julian Day, JD



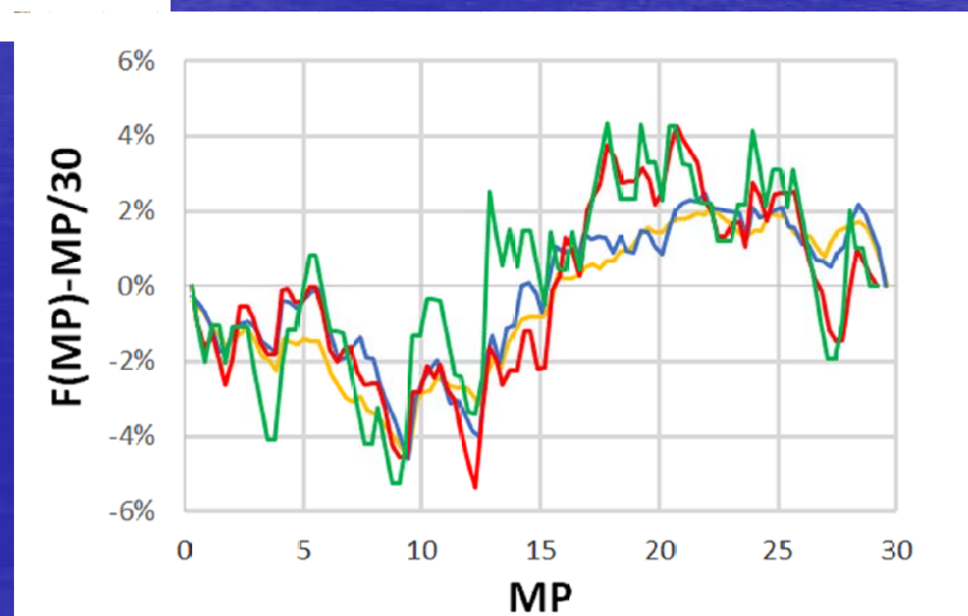
Earthquake origin time
versus
Moon Phase, MP

LAKE BAIKAL REGION : 1994-2018

M ≥ 2.8 M ≥ 4.0
M ≥ 3.5 M ≥ 4.5



Earthquake origin time
versus
Julian Day, JD



Earthquake origin time
versus
Moon Phase, MP

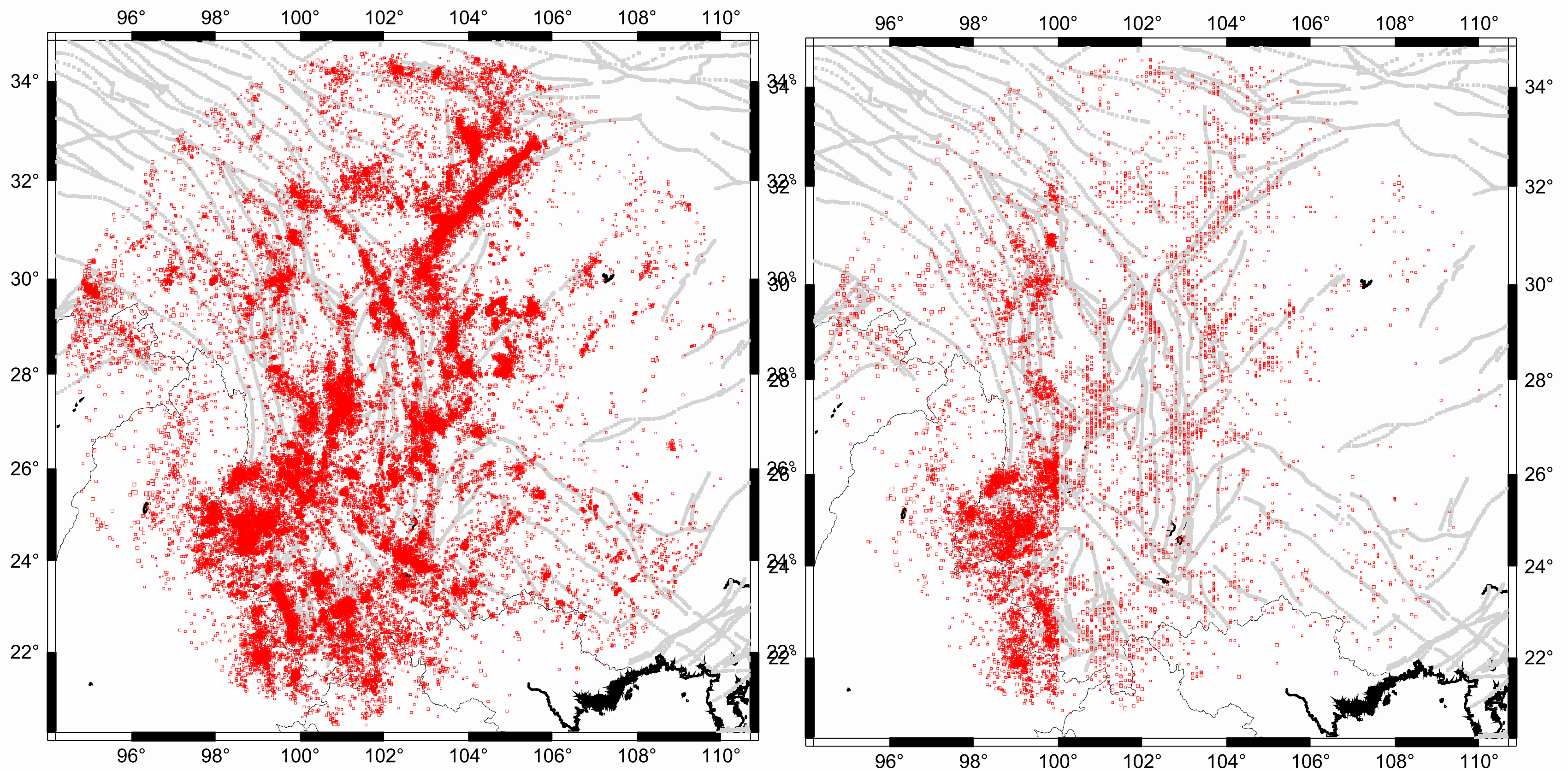
Lake Baikal Region:

Kuiper's Test Results

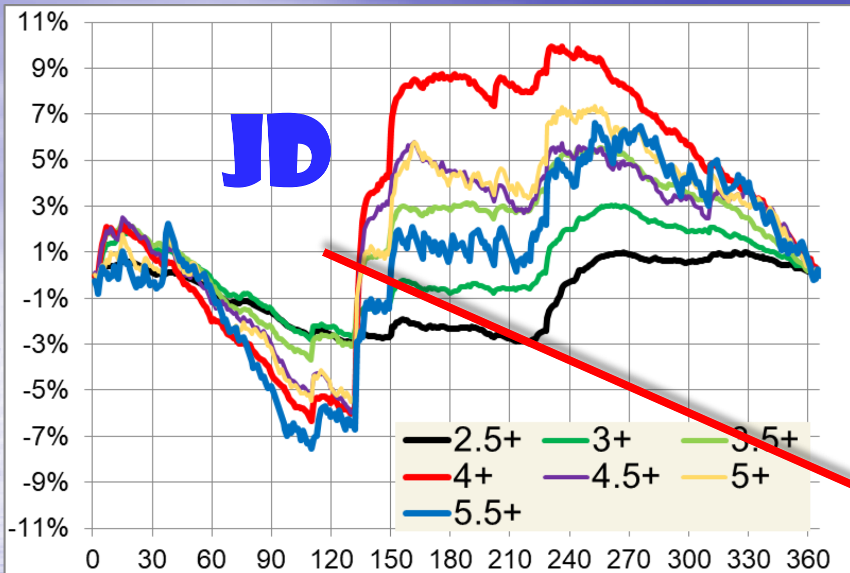
Data			MP			JD		
Time interval	M	N	V_n	$\kappa(\alpha) = N^{1/2}´ V$	α	V_n	$\kappa(\alpha) = N^{1/2}´ V$	α
1987-1998	**>2.8**	**1394**	**0.05**	**1.69**	**0.07**	**0.04**	**1.32**	**0.35**
	>3.5	**292**	**0.07**	**1.12**	**0.64**	**0.07**	**1.13**	**0.63**
	>4.0	**99**	**0.11**	**1.11**	**0.78**	**0.09**	**0.93**	**0.90**
	>4.5	**35**	**0.16**	**0.92**	**0.91**	**0.22**	**1.27**	**0.49**
1994-2018	**>2.8**	**3634**	**0.07**	**3.03**	**< 0.01**	**0.08**	**4.90**	**< 0.01**
	>3.5	**830**	**0.07**	**2.04**	**0.01**	**0.12**	**3.49**	**< 0.01**
	>4.0	**296**	**0.10**	**1.64**	**0.08**	**0.14**	**2.47**	**< 0.01**
	>4.5	**101**	**0.10**	**1.04**	**0.86**	**0.19**	**1.85**	**0.04**

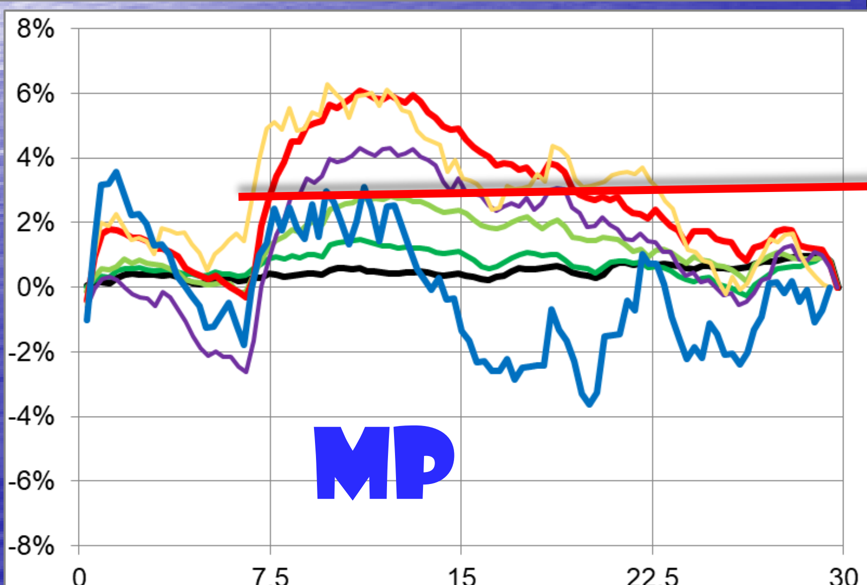
Data : Yunnan-Sichuan Region

1970-2020 M ≥ 2.5 1970-2008 M ≥ 2.5



Yunnan-Sichuan Region: 1970 - 2020





α << 0.01 ….

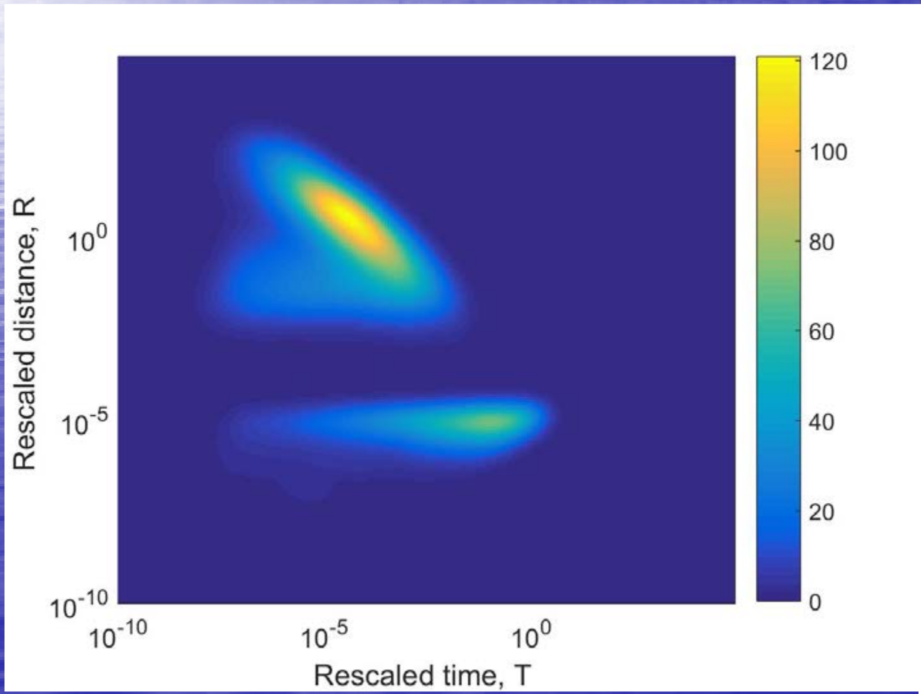
The one Special Day

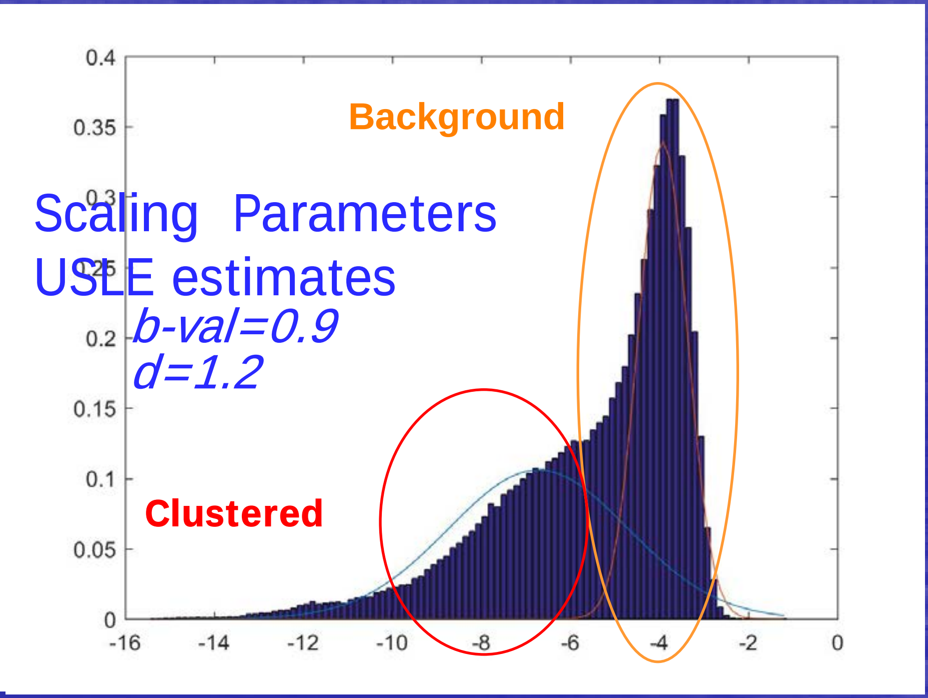
Great **Sichuan Earthquake**

Yunnan-Sichuan Region: Clusters identification

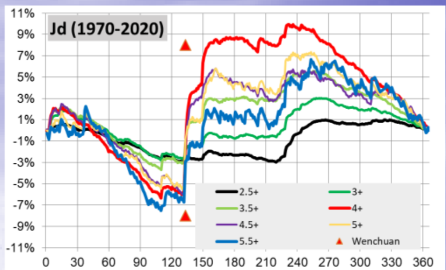
The method is based on the nearest-neighbor distance in the 2D decomposition of the USLE control parameter $\eta = R \times T$ (Baiesi and Paczuski, 2004).

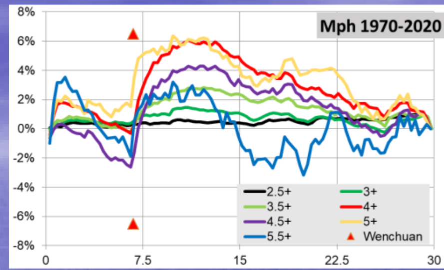
The Nearest-Neighbor analysis

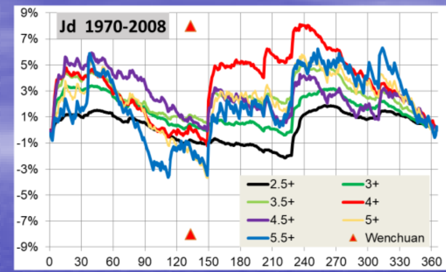


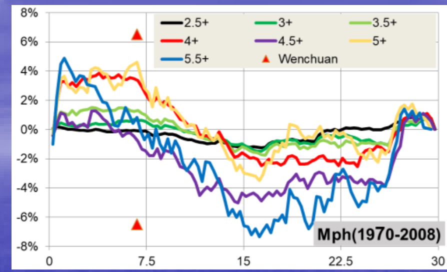


Yunnan-Sichuan Region: Main Shocks, Foreshocks and Aftershocks





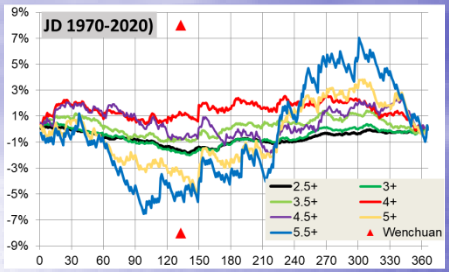


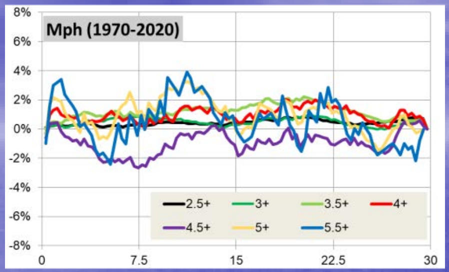


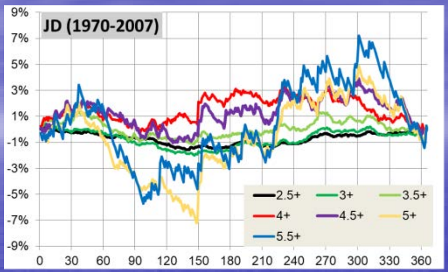
Kuiper's test results

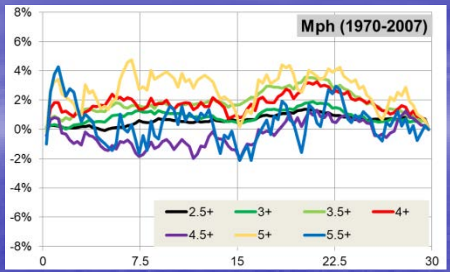
M	1970-2020							1970-2008						
	N	JD			Mph			N	JD			Mph		
		V_N	$\kappa(\alpha) = V_N \times N^{½}$	α	V_N	$\kappa(\alpha) = V_N \times N^{½}$	α		V_N	$\kappa(\alpha) = V_N \times N^{½}$	α	V_N	$\kappa(\alpha) = V_N \times N^{½}$	α
5.5+	293	0.142	2.426	*< 0.001*	0.072	1.227	0.495	215	0.099	1.455	0.216	0.122	1.787	0.040
5+	663	0.129	3.333	*< 0.001*	0.068	1.755	0.048	432	0.095	1.970	0.012	0.081	1.682	0.072
4.5+	1574	0.118	4.688	*< 0.001*	0.069	2.746	*< 0.001*	896	0.063	1.885	0.022	0.063	1.888	0.021
4+	3678	0.163	9.878	*< 0.001*	0.065	3.940	*< 0.001*	2130	0.093	4.305	*< 0.001*	0.064	2.949	*< 0.001*
3.5+	9052	0.092	8.796	*< 0.001*	0.030	2.846	*< 0.001*	5544	0.050	3.736	*< 0.001*	0.033	2.428	*< 0.001*
3+	24315	0.058	9.122	*< 0.001*	0.017	2.688	*< 0.001*	15283	0.038	4.690	*< 0.001*	0.022	2.738	*< 0.001*
2.5+	65910	0.040	10.202	*< 0.001*	0.010	2.513	*< 0.001*	41896	0.040	8.187	*< 0.001*	0.022	4.532	*< 0.001*

YUNNAN-SICHUAN REGION: FORESHOCKS AND MAIN SHOCKS





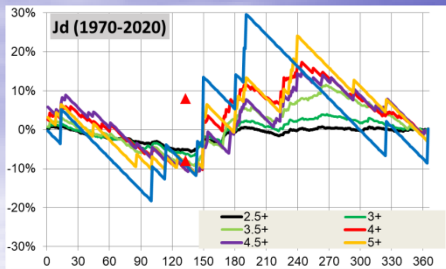


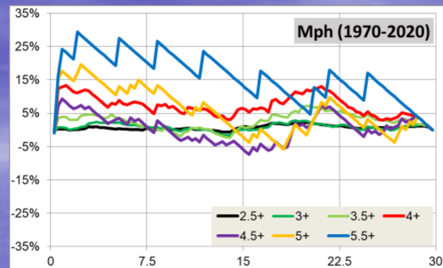


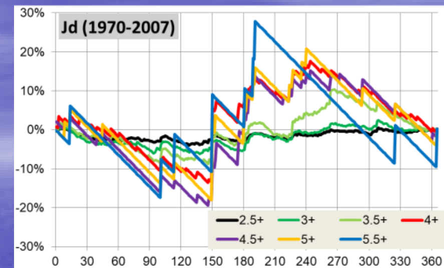
KUIPER'S TEST RESULTS

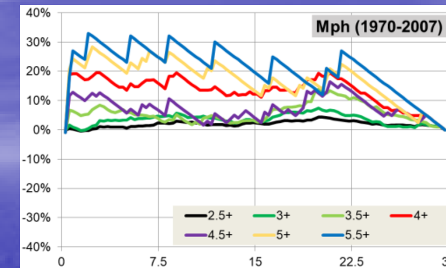
M	1970-2020							1970-2008						
	N	JD			Mph			N	JD			Mph		
		V_N	κ (α) = $V_N \times N^{½}$	α	V_N	κ (α) = $V_N \times N^{½}$	α		V_N	κ (α) = $V_N \times N^{½}$	α	V_N	κ (α) = $V_N \times N^{½}$	α
5.5+	168	0.136	1.761	0.046	0.063	0.820	0.971	133	0.130	1.494	0.182	0.064	0.738	0.993
5+	350	0.088	1.652	0.084	0.047	0.883	0.936	256	0.121	1.936	0.015	0.050	0.792	0.981
4.5+	765	0.043	1.200	0.535	0.032	0.888	0.933	527	0.049	1.133	0.635	0.033	0.767	0.988
4+	1608	0.027	1.064	0.738	0.024	0.949	0.880	1118	0.036	1.190	0.550	0.034	1.148	0.613
3.5+	4425	0.024	1.595	0.113	0.022	1.473	0.200	3074	0.025	1.372	0.302	0.036	1.978	0.012
3+	12008	0.025	2.729	*< 0.001*	0.010	1.044	0.766	8402	0.024	2.224	0.002	0.019	1.719	0.059
2.5+	31900	0.020	3.639	*< 0.001*	0.009	1.612	0.104	22043	0.017	2.540	*< 0.001*	0.014	2.143	*0.004*

Yunnan-Sichuan Region: Foreshocks





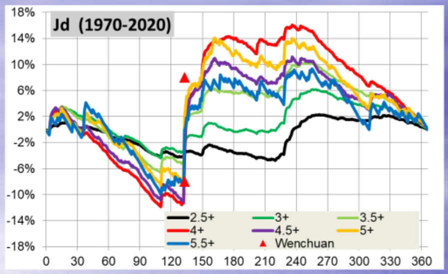


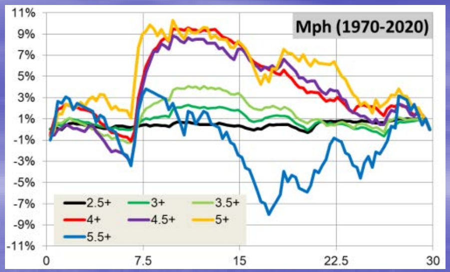


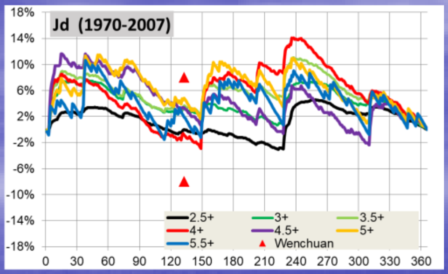
Kuiper's Test Results

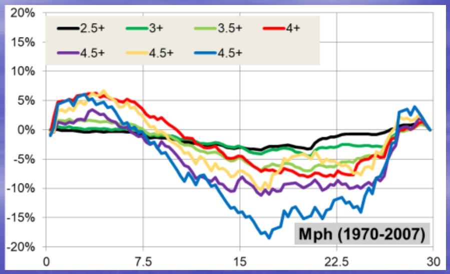
M	1970-2020							1970-2008						
	N	JD			Mph			N	JD			Mph		
		V_N	$\kappa(\alpha) = V_N \times N^{½}$	α	V_N	$\kappa(\alpha) = V_N \times N^{½}$	α		V_N	$\kappa(\alpha) = V_N \times N^{½}$	α	V_N	$\kappa(\alpha) = V_N \times N^{½}$	α
5.5+	11	0.479	1.587	0.118	0.304	1.007	0.813	10	0.451	1.427	0.243	0.340	1.075	0.721
5+	29	0.356	1.915	0.018	0.254	1.369	0.307	22	0.388	1.819	0.033	0.294	1.377	0.297
4.5+	65	0.263	2.116	*0.004*	0.167	1.346	0.334	44	0.346	2.294	*< 0.001*	0.174	1.152	0.608
4+	138	0.289	3.398	*< 0.001*	0.144	1.691	0.069	95	0.311	3.033	*< 0.001*	0.205	1.996	0.010
3.5+	452	0.209	4.440	*< 0.001*	0.095	2.026	0.008	276	0.191	3.175	*< 0.001*	0.144	2.398	*< 0.001*
3+	1486	0.108	4.181	*< 0.001*	0.045	1.729	0.055	921	0.087	2.626	*< 0.001*	0.077	2.344	*< 0.001*
2.5+	4941	0.065	4.574	*< 0.001*	0.029	2.063	0.006	3044	0.044	2.422	*< 0.001*	0.048	2.623	*< 0.001*

YUNNAN-SICHUAN REGION: AFTERSHOCKS









KUIPER'S TEST RESULTS

M	1970-2020							1970-2008						
	N	JD			Mph			N	JD			Mph		
		V_N	$\kappa(\alpha) = V_N \times N^{1/2}$	α	V_N	$\kappa(\alpha) = V_N \times N^{1/2}$	α		V_N	$\kappa(\alpha) = V_N \times N^{1/2}$	α	V_N	$\kappa(\alpha) = V_N \times N^{1/2}$	α
5.5+	124	0.193	2.144	*0.004*	0.118	1.318	0.368	81	0.121	1.091	0.698	0.245	2.209	*0.002*
5+	312	0.227	4.001	*< 0.001*	0.109	1.934	0.016	175	0.118	1.558	0.136	0.170	2.249	*0.002*
4.5+	806	0.223	6.339	*< 0.001*	0.120	3.393	< 0.001	368	0.140	2.690	*< 0.001*	0.147	2.811	*< 0.001*
4+	2066	0.280	12.733	*< 0.001*	0.106	4.820	< 0.001	1011	0.170	5.414	*< 0.001*	0.143	4.562	*< 0.001*
3.5+	4620	0.170	11.542	*< 0.001*	0.053	3.622	< 0.001	2466	0.113	5.631	*< 0.001*	0.089	4.408	*< 0.001*
3+	12290	0.105	11.694	*< 0.001*	0.030	3.305	< 0.001	6872	0.079	6.569	*< 0.001*	0.054	4.465	*< 0.001*
2.5+	33990	0.070	12.879	*< 0.001*	0.013	2.435	< 0.001	19843	0.076	10.749	*< 0.001*	0.046	6.477	*< 0.001*

Conclusions

Our study permits emphasizing the importance of regional seismic and tectonic environment in hypothesis testing:

In Lake Baikal region earthquake seasonality pattern is evident for all magnitude ranges from M>4.5 and below in the recent decades of presumably better earthquake determination than before 1990s, while earthquake preferable Moon phases are suggestive when numerous smaller magnitude events (M<4.0) are brought into the Kuiper’s test analysis.

Conclusions

Our study permits emphasizing the importance of regional seismic and tectonic environment in hypothesis testing:

In Yunnan-Sichuan region earthquake seasonality and Moon phase patterns are evident for all magnitude ranges from M>5.5 and below but disappear for M down to M3.5+ when aftershocks are excluded. This observation calls for a special attention to the main shock impact on the state of stability of the regional blocks-and-faults system.

The 2008 Great Wenchuan earthquake to be mentioned.