GeoTaos::Seismicity user guide

This user guide (GeoTaos_Seismicity_man.pdf) will be updated frequently for detailed guidance and changes in the program.

1. An introduction to GeoTaos::Seismicity

GeoTaos::Seismicity provides integrated utilities, which are embedded within GeoTaos_Map and GeoTaos, for seismic data process including statistical approaches of seismic activity, correlation between tidal force and seismicity and so on. GeoTaos_Map, GeoTaos, and GeoTaos_Seismicity are side productions of our ongoing researches and will be updated any time. However, there is no any time table for implementation.

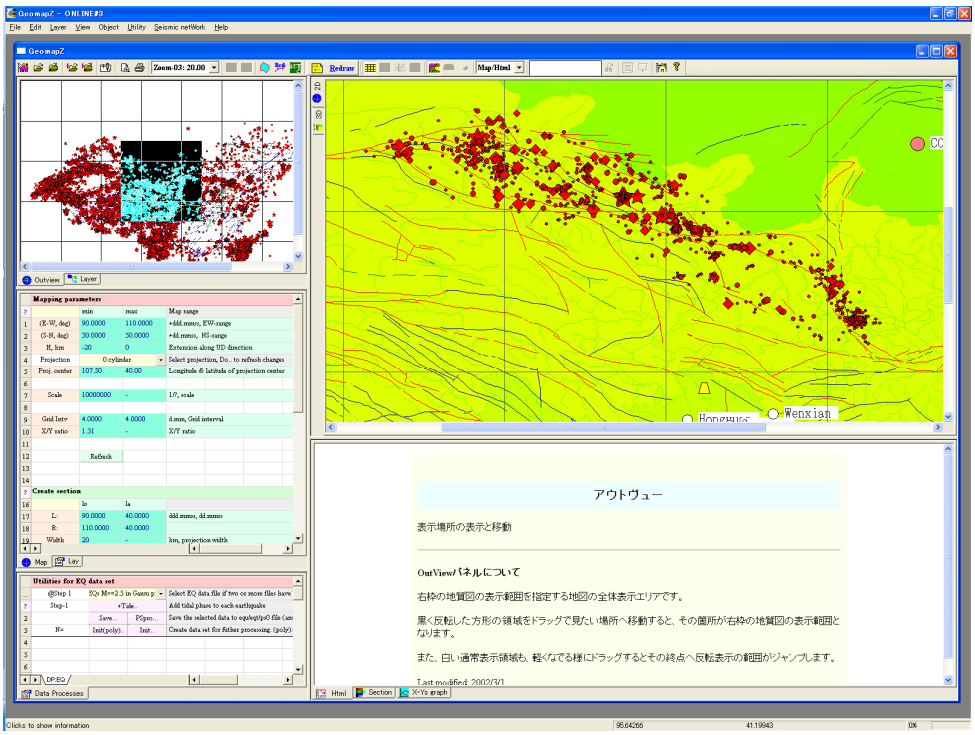
2. Some theoretic notes

[See GeoTaos_Seismicity.pdf]

3. A step-by-step tutorial to GeoTaos::Seismicity

3.1 Run GeoTaos_Map and load the online example of earthquake catalog

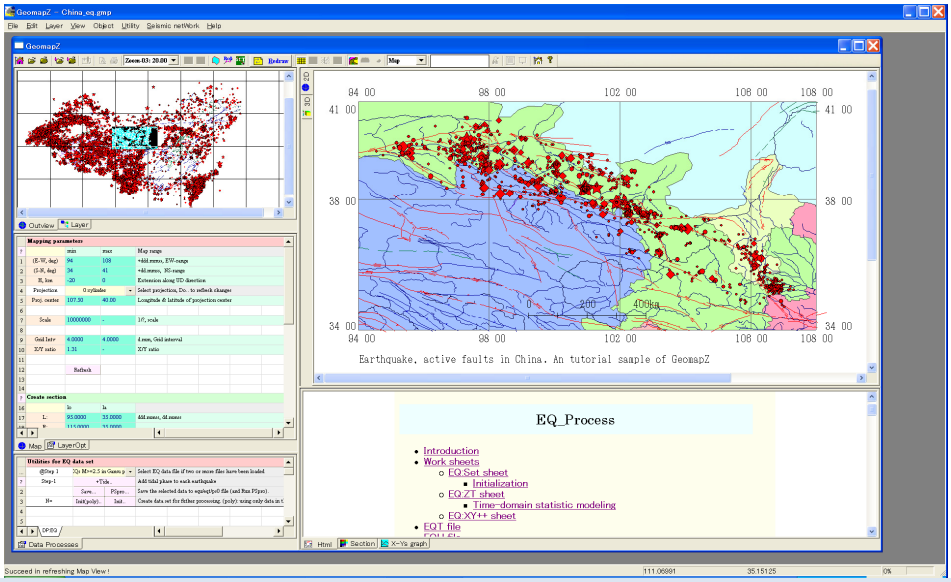
1) Run GeoTaos_Map.exe
2) Click [File][Online sample: M4+ in China] to load the pre-defined data set.
3) Use the Zoom drop-down list box to select a map size. Say 20.00 deg, which is large enough to cover Gansu province.
4) Click [Outview] tag to show the out view, drag the inverted rectangle to a position covering Gasu province.
5) Click [Map] tag to show the [Map] sheet for mapping options. Changes parameters or selections if necessary. For example one may select another projection method. Press <Refresh> to response any changes. You will see following window on your screen. For small screen you may say something different. You can move the splitters (boundaries between views and sheets) to adjustment the size of sheets and views. You may need to scroll a view to see a target portion. A screen of 1600x1200 is strongly recommended for smooth operation.



6) Edit parameters in Row:1-10, and then click <Refresh> in Row:12 to optimize the map.

Mapping parameters

?		min	max	Map range
1	(E-W, deg)	94	108	+ddd.mmss, EW-range
2	(S-N, deg)	34	41	+dd.mmss, NS-range
3	H, km	-20	0	Extension along UD direction
4	Projection	0:cylinder		Select projection, Do.. to refresh changes
5	Proj. center	107.50	40.00	Longitude & latitude of projection center
6				
7	Scale	10000000	-	1/?, scale
8				
9	Grid Intv	4.0000	4.0000	d.mm, Grid interval
10	X/Y ratio	1.31	-	X/Y ratio
11				
12		Refresh		

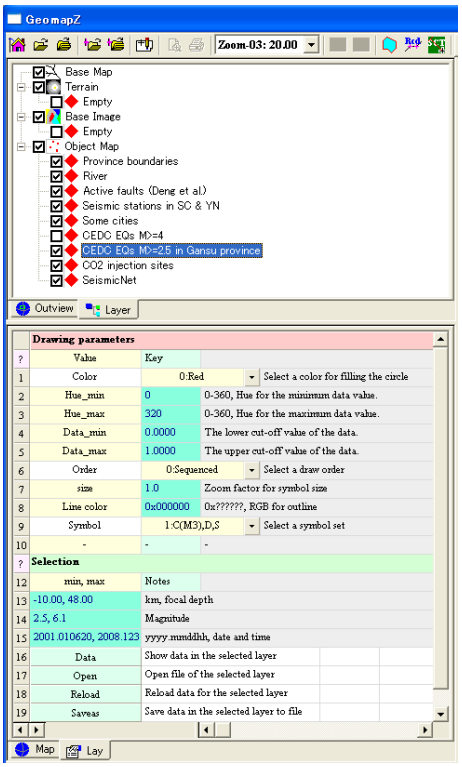


7) Click [Layer] tag to show layer list. Click “CEDC EQs M>=2.5 in Gasu province”, then the [LayerOpt] working sheet would be popped up automatically. One can change drawing options and selection parameters.

Color: color for filling the inner area of hypocenter symbols

Hue_min, Hue_max: hypocenter can be colored with some value such as occurrence time

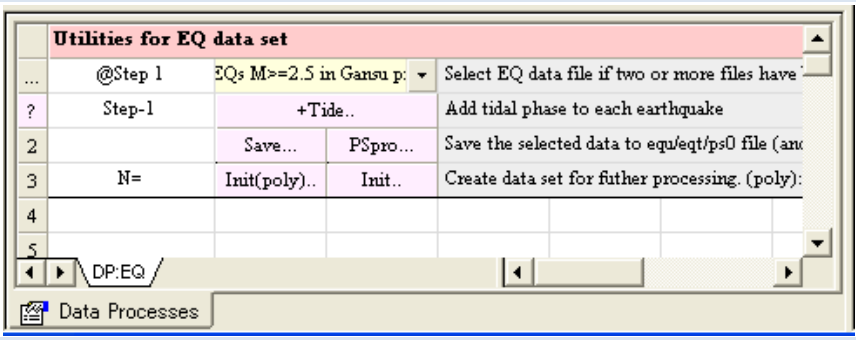
Symbol: select a symbol set



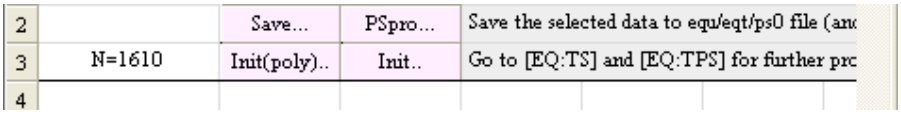
8) Changes parameters or selections if necessary. As an example, change magnitude range in row-15 to “3.0, 6.1”. Click the <Redraw> button on the tool bar to response any changes. As a 1st running do not

change anything. The data set contains only M2.5+ events and is considered to be complete. At this moment you are ready to test the statistical methods of Dao_Seismicity embedded in GeoTaos_Map now.

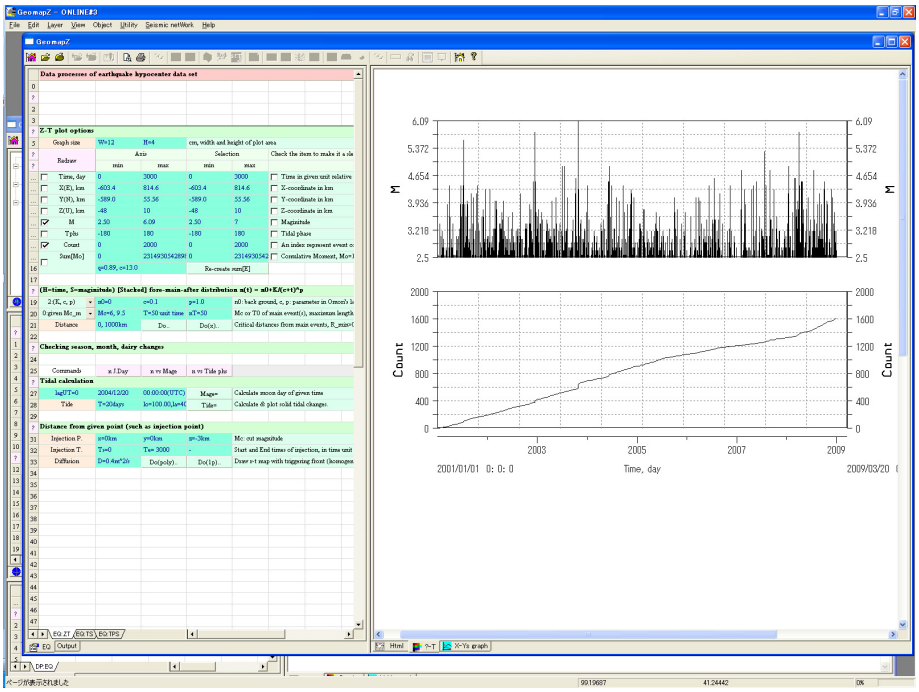
9) Go to the [DP:EQ] working sheet



10) Be sure “EQs M>=2.5 in Gansu province” is selected in the Combo list box in Row-0. Click <Init..> to prepare data for further data processing, statistic analysis of seismicity. All hypocenters shown in the 2D map of the specified data set are collected. Then Row-3 shows N=1610, means that there are 1610 hypocenters in total. When you clicked the <Init..> button a new frame would appear. All data processes are handled with in the EQ frame.



Following graph shows the frame in a screen of 1600x1200 pixels.



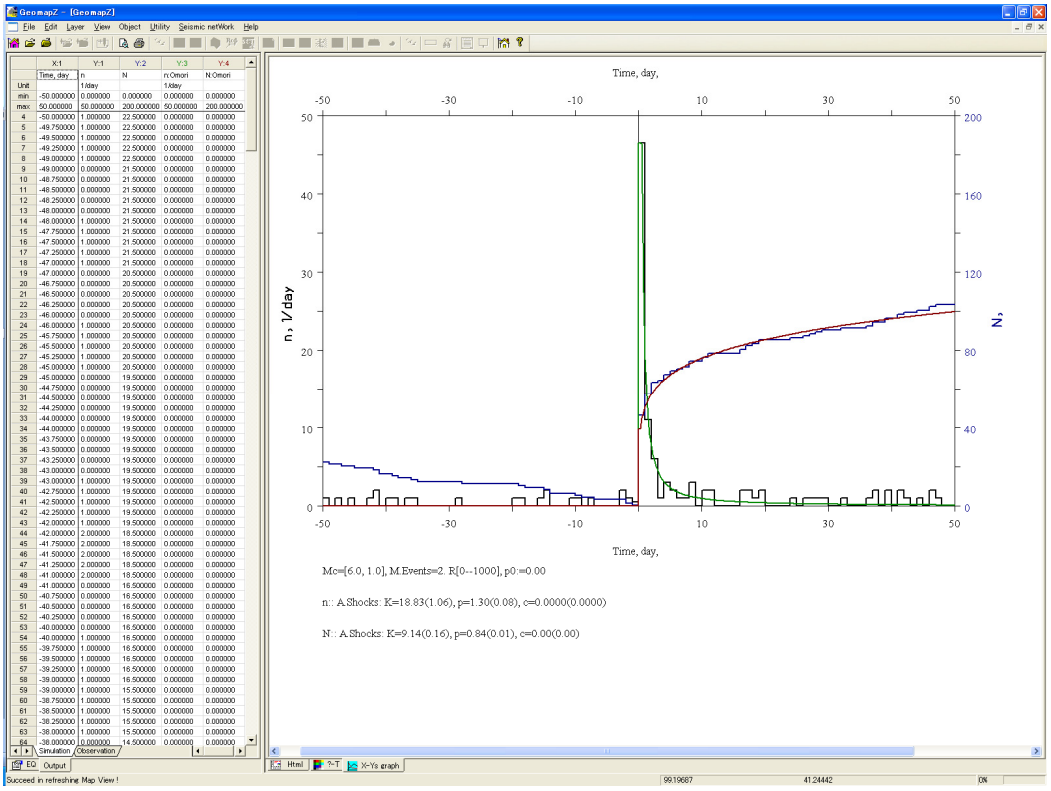
11) One can change parameters in rows 8-14 and check on/off any field to show different graph. Try to change min of time to 0.0, max of M to 6 click <Redraw> in row 6-7 to optimize the graph with better axis range and legends. It is better to change the min/max values of Axis for each field as follows for idealizing outputs.

?	Z-T plot options					
5	Graph size	W=16	H=4	cm, width and height of plot area		
?	Redraw	Axis		Selection		Check the item to make it a slection item for later processing
?		min	max	min	max	
...	☐ Time, day	0	3000	0	3000	☐ Time in given unit relative to a given date
...	☐ X(E), km	-1000	1000	-603.4	814.6	☐ X-coordinate in km
...	☐ Y(N), km	-100	700	-33.34	611.2	☐ Y-coordinate in km
...	☐ Z(U), km	-50	10	-48	10	☐ Z-coordinate in km
...	☑ M	2	7	2.50	7	☐ Maginitude
...	☐ Tphs	-180	180	-180	180	☐ Tidal phase
...	☑ Count	0	2000	0	2000	☐ An index represent event count
...	☐ Sum[Mo]	0	5e19	0	2314930542	☐ Comulative Moment, Mo=10^(q*M + c)
16		q=0.89, c=13.0		Re-create sum[E]		

3.2 Stacked foreshocks-main shock-aftershocks distribution

12) Specify a critical magnitude (row-20) for earthquakes being a main event, say 6.0. Click <Do..>. Then the [Output][Simulation] sheet and the [X-Ys graph] view would be activated simultaneously. The [Simulation] sheet contains obtained data which are showed in the [X-Ys graph] view.

?	(H=time, S=maginitude) [Stacked] fore-main-after distribution n(t) = n0+K/(c+t)^p				
19	2:(K, c, p)	n0=0	c=0.1	p=1.0	n0: back ground, c, p: parameter in Omori's law
20	0:given Mc_m	Mc=6, 9.5	T=50 unit time	nT=50	Mc or T0 of main event(s), maximum length of time and number of grids
21	Distance	0, 1000km	Do..	Do(x)..	Critical distances from main events, R_min>0 for remote triggering. Do(x):fore-



Very nice, there are two M6+ events in the data set and the stacked Main-shock-aftershcok sequency can be represented very well with the modified Omori-law with p=1.30. Try other Mc for fun!

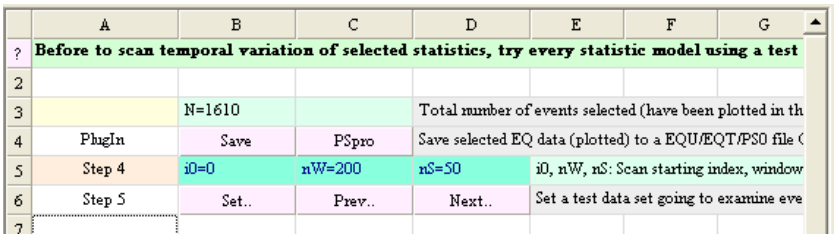
3.3 Seasonality and tidal response of seismic activity

The associated utilities have not been examined fully!! Wait for releasing.

3.4 [EQ:TS] working sheet

For examining the temporal evolution of seismicity in the specified area, major statistical parameters could be sequentially calculated for consecutive groups of given number (nW) of events with a given running step of nS events. This is handled within the [EQ:TS] working sheet. Default values of nW and nS are 200 and 50, respectively.

13) Click [EQ:TS], to show the [EQ:TS] working sheet. At the 1st time there are only 6 rows with buttons and texts.



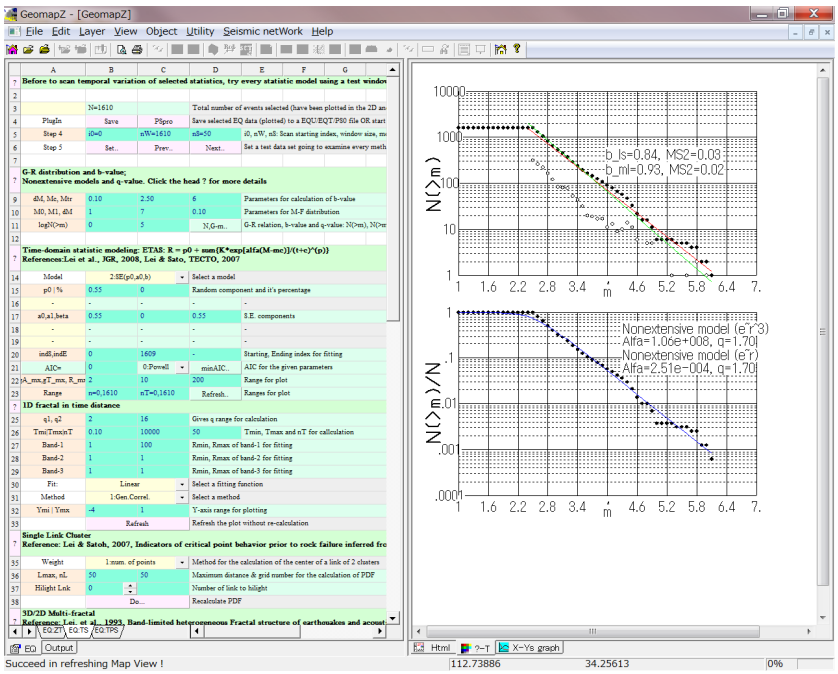
Before to scan parameters with a running time window, it is good way to examine all models been interested. One can test each model use any time window of nW events beginning at i0. For example, you can set i0=500, and nW=400, and click <Set..>. Then events from 500 to 900 are used for later examination. It is nice to examine every model using all hypocenters. For this purpose, type nW=1610 in (EQ:TS:5-C)(Row-5 and Column-C), let i0=0, and click <Set..>. The working sheet is thus extended.

3.5 Frequency-magnitude distribution and *b*-value

The frequency-magnitude distribution is automatically calculated every time when one of the buttons in Row:6 is clicked. The resulted distribution and Omori-law fittings in the [?-T] view are nice. The *b*-values estimated from all 1610 events using the least square method and the maximum likelihood method are 0.84 and 0.93, respectively. The lower plot in the [?-T] view shows results of Nonextensive Tsallis statistics and *q*-value (see A.2 for details).

?	**G-R distribution and b-value; Nonextensive models and q-value. Click the head ? for more details**				
9	dM, Mc, Mtr	0.10	2.50	6	Parameters for calculation of b-value
10	M0, M1, dM	1	7	0.10	Parameters for M-F distribution
11	logN(>m)	0	5	N,G-m..	G-R relation, b-value and q-value: N(>m), N(>m)/N vs. r

Mc in row-9, column-C is the lower cut-off magnitude and should be properly defined for estimating b-value. By default it would be the minimum magnitude in the selected data. The tutorial data set the lower cut-off Mc=2.5 is probably a reasonable value. Other parameters are used for plotting. Users are promoted to change numbers in Row 9-11 a little bit and click <N,G-m..> to see what will happen.



14) If necessary type new numbers for Mc and other parameters and then click N, <G-m..>.

3.6 ETAS modeling

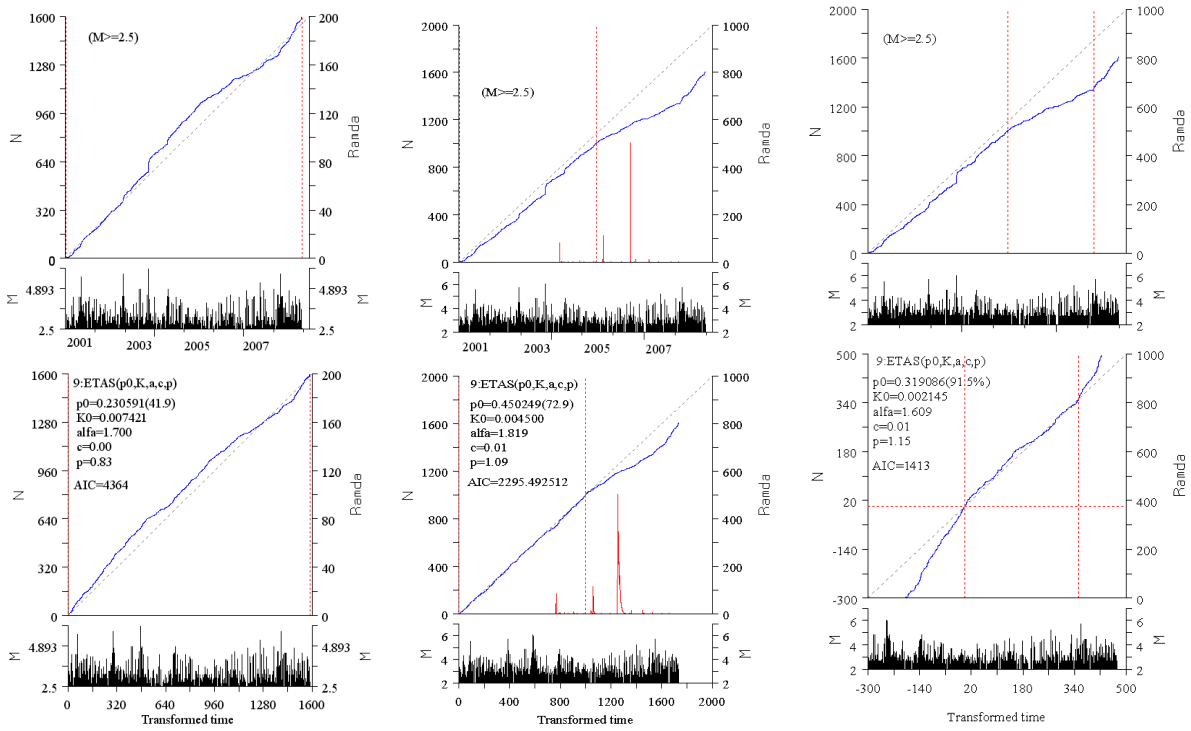
Before trying ETAS modeling please look over A.7 and cited references for basic knowledge on this issue. Completeness of the data set and thus the lower cut off magnitude are very important parameters controlling the precise of the estimated parameters. It has been found that ETAS is helpful for finding change points of seismic occurrence. For convenience, model parameters can be estimated for a sub event span specified by indS and indE in Row:20. At first let us try to fit the whole data set, say indS=0, indE=1609.

15) Select "9:ETAS(p0,K,a,c,p)" from the drop-down list box in ROW:14. All the 5 parameters, (p0,K,a,c,p), are to be estimated using a optimization method, which can be selected from the drop-down list at (21-C). By default the Powell method is selected. It works well for most cases.

16) Let all other parameters being default and Click the <minAIC> button in ROW:21

?	**Time-domain statistic modeling: ETAS: R = p0 + sum{K*exp[alfa(M-mc)]/(t+c)^(p)}** **References:Lei et al., JGR, 2008, Lei & Sato, TECTO, 2007**				
14	Model	9:ETAS(p0,K,a,c,p)		Select a model	
15	p0 | %	0.55	0	Random component and it's percentage	
16	-	-	-	-	-
17	-	-	-	-	-
18	Mc, Alfa	2.50	1	Reset	ETAS components
19	K, c, p	0.0055	0.10	1	ETAS components
20	indS,indE	0	1609	-	Starting, Ending index for fitting
21	AIC=	0	0:Powell	minAIC..	<AIC> calcualte AIC for the given model and parameters, <minAIC>: searching p
22	:A_mx,gT_mx, R_mx	2	10	200	Range for plot
23	Range	n=0,1610	nT=0,1610	Refresh..	Ranges for plot

Then the program begins to search ETAS parameter set (p0,K,a,c,p) which minimize the Akaike information criterion (AIC) of the model. It may take a few minutes to tens of minutes depending on the performance of your PC. In the test PC with a Intel Xeron CPU of 3.00GHz and Window XP, it take about 2 minutes. The estimated parameters are p0=0.230591(41.9%), K0=0.007421, α=1.700, c=0.00, p=0.83. However, the fitting is not good, indicating there are some changes on seismic activity and it cannot be represented by a single model. It is clear there is decreasing tendency from 2005 with event number ~1000. Let us try to analyze the 1st 1000 events.



ETAS modeling indicates two major change points of activity, one is in the middle of 2005 and another in early 2008

17) Change "indE" in Row:20 Col:C from 1610 to 1000. At the same time change number in Row:22-23 as that shown in following figure for better output.

14	Model	9:ETAS(p0,K,a,c,p)		Select a model	
15	p0|%	0.4502	72.9	Random component and it's percentage	
16	-	-	-	-	-
17	-	-	-	-	-
18	Mc, Alfa	2.5000	1.8188	Reset	ETAS components
19	K, c, p	0.0045	0.0106	1.0850	ETAS components
20	indS,indE	0	1000	-	Starting, Ending index for fitting
21	AIC=	2295.49	0:Powell	minAIC..	AIC for the given parameters
22	gA_mx,gT_mx, R_mx	2	10	1000	Range for plot
23	Range	n=0,2000	nT=0,2000	Refresh..	Ranges for plot

18) Click <minAIC> to start the optimization. The program has done very good works. The estimated parameters are p0=0.450249(72.9%), K0=0.004500, α=1.819, c=0.01, p=1.09 and the resulted fitting is very nice. Values of α=1.819, c=0.01, p=1.09 are typical values for non-swarm earthquakes. The change point in 2005 has been clearly indicated.

19) Next, let us model earthquakes of event number from 1000 to 1350. Change Row-20 as follows.

18	Mc, Alfa	2.5000	1.6086	Reset	ETAS components
19	K, c, p	0.0021	0.0059	1.1453	ETAS components
20	indS,indE	1000	1350	-	Starting, Ending index for fitting
21	AIC=	1413.34	0:Powell	minAIC..	AIC for the given parameters
22	gA_mx,gT_mx, R_mx	2	10	1000	Range for plot
23	Range	n=0,2000	nT=-300,500	Refresh..	Ranges for plot

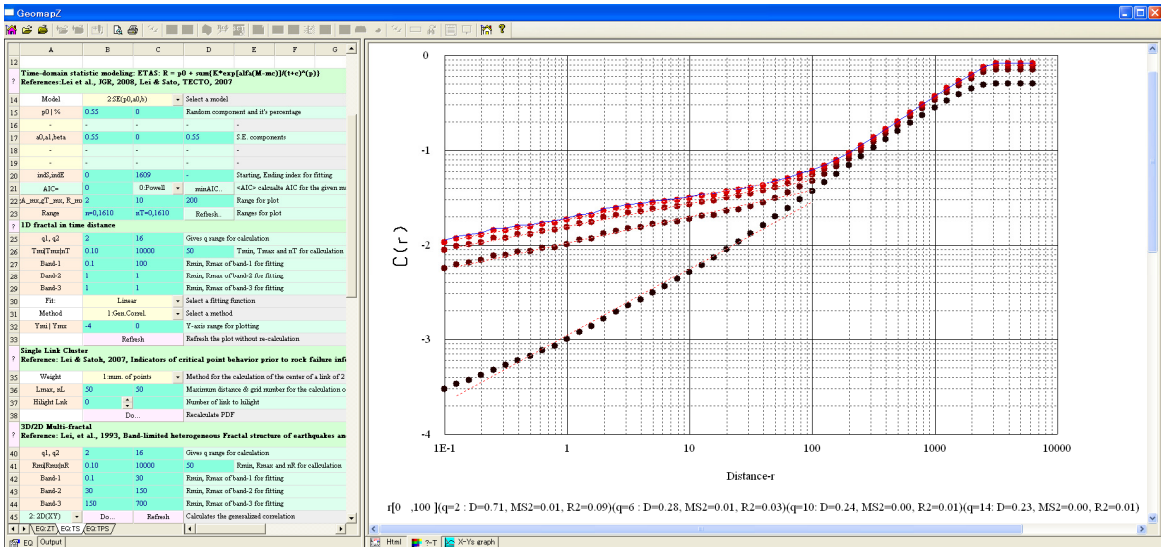
20) Numbers in Row:22-23 are used to idealize output. Click <Refresh> in Row:23 to redraw the graph. Button <AIC=> in Row:21 is used for calculation of AIC (not minimum AIC!!) of the selected model and parameters specified in Row18-20. Every time when <minAIC..> clicked, model parameters would be renewed with the newly estimated parameters. You can change some parameters a LITTL BIT and click <AIC=> to check whether the estimated parameters really result in minimum AIC or not. When click <minAIC..>, parameters on the grids would be used as initial guess of searching. If you disbelieve the estimated parameters, type some numbers you like and try <minAIC..> again. Do not forgot to compare the resulted AIC values and keep in mind that the AIC of ETAS model depends on the number of events and hence of different number of events are not compatible.

3.7 Fractal analysis in time domain

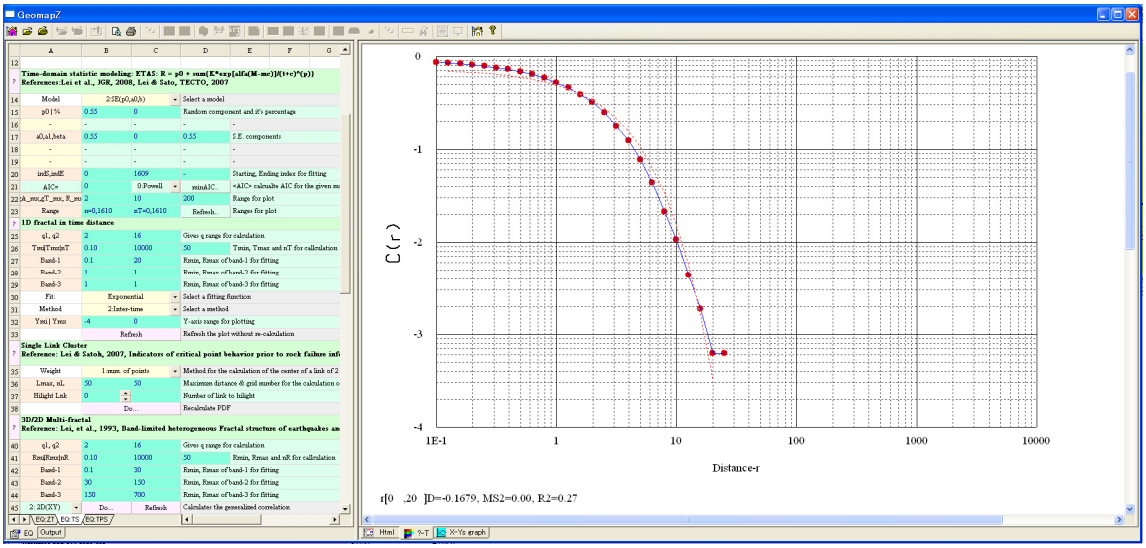
Waits for detailed description in later version.

21) Row:25-26 are parameter controlling calculation. Row:27-31 host parameters for fitting. Row:32 are minimum and maximum values of vertical axis. Click the <refresh> button in Row:33, Numbers in Row:22-23 are used to idealize output. Click <Refresh> in Row:23 to redraw the graph. Try different methods from the drop-down list box in Row:31

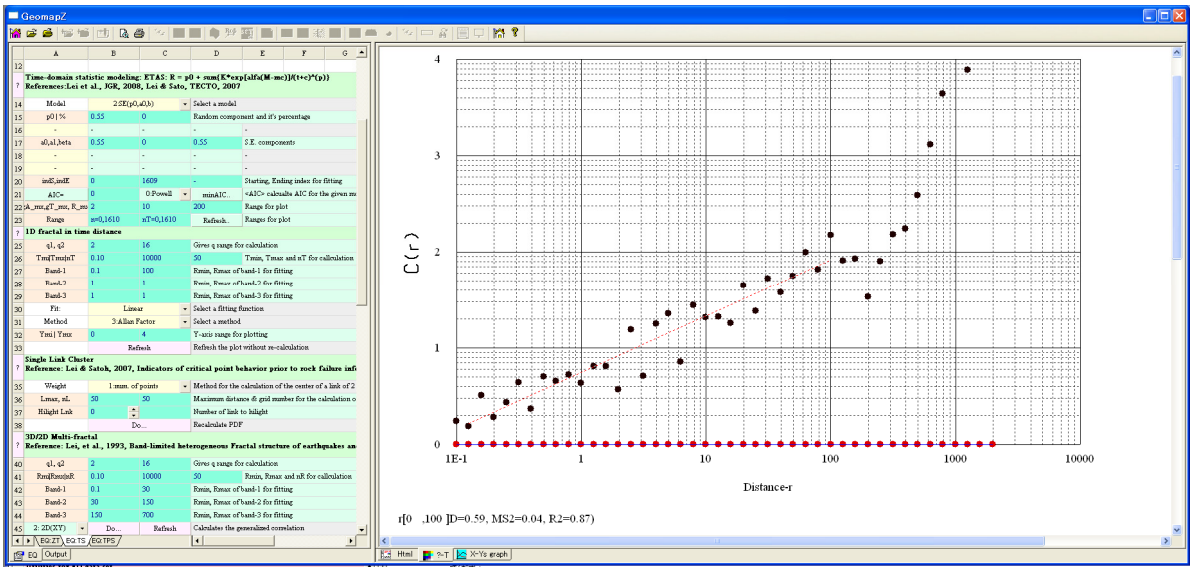
?	1D fractal in time distance			
25	q1, q2	2	16	Gives q range for calculation
26	Tmi|Tmx|nT	0.10	10000	50 Tmin, Tmax and nT for callculation
27	Band-1	0.1	100	Rmin, Rmax of band-1 for fitting
28	Band-2	1	1	Rmin, Rmax of band-2 for fitting
29	Band-3	1	1	Rmin, Rmax of band-3 for fitting
30	Fit:	Linear		Select a fitting function
31	Method	1:Gen.Correl.		Select a method
32	Ymi | Ymx	-4	0	Y-axis range for plotting
33		Refresh		Refresh the plot without re-calculation



	1D fractal in time distance			
25	q1, q2	2	16	Gives q range for calculation
26	Tmi|Tmx|nT	0.10	10000	50 Tmin, Tmax and nT for callculation
27	Band-1	0.1	20	Rmin, Rmax of band-1 for fitting
28	Band-2	1	1	Rmin, Rmax of band-2 for fitting
29	Band-3	1	1	Rmin, Rmax of band-3 for fitting
30	Fit:	Exponential		Select a fitting function
31	Method	2:Inter-time		Select a method
32	Ymi | Ymx	-4	0	Y-axis range for plotting
33		Refresh		Refresh the plot without re-calculation



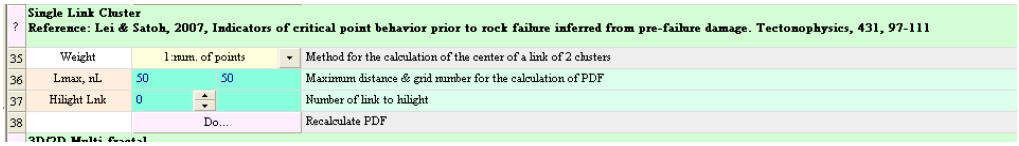
	1D fractal in time distance			
25	q1, q2	2	16	Gives q range for calculation
26	Tmi|Tmx|nT	0.10	10000	50 Tmin, Tmax and nT for callculation
27	Band-1	0.1	100	Rmin, Rmax of band-1 for fitting
28	Band-2	1	1	Rmin, Rmax of band-2 for fitting
29	Band-3	1	1	Rmin, Rmax of band-3 for fitting
30	Fit:	Linear		Select a fitting function
31	Method	3:Allan Factor		Select a method
32	Ymi | Ymx	0	4	Y-axis range for plotting
33		Refresh		Refresh the plot without re-calculation



3.8 Single link cluster and spatial correlation length (SCL)

Some basic concepts can be found in A.6. Beginners should look it over.

22) Row:34-38 host parameter and command button for Single-Link Cluster analysis and estimation of Spatial Correlation Length. The only parameter need caution should be the “Lmax”. It should be properly defined to obtain a nice PDF curve, showing full transient from rapid increasing to **almost** flat.



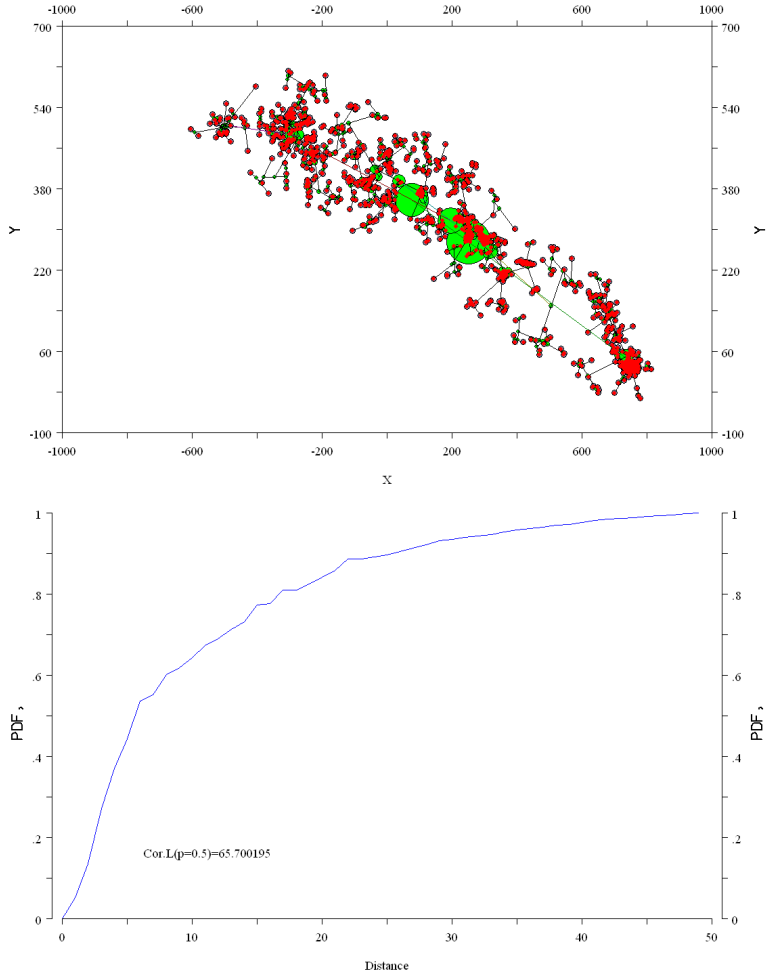
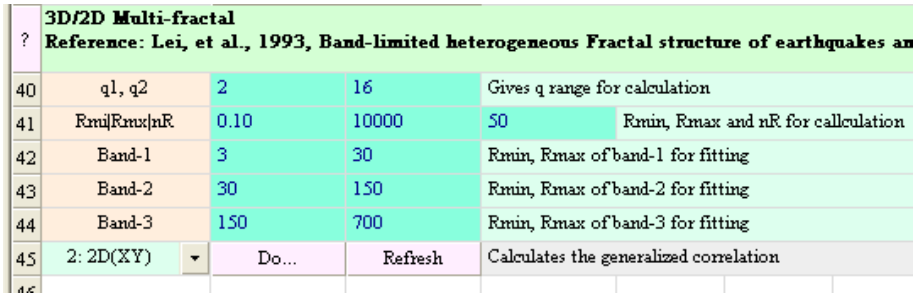


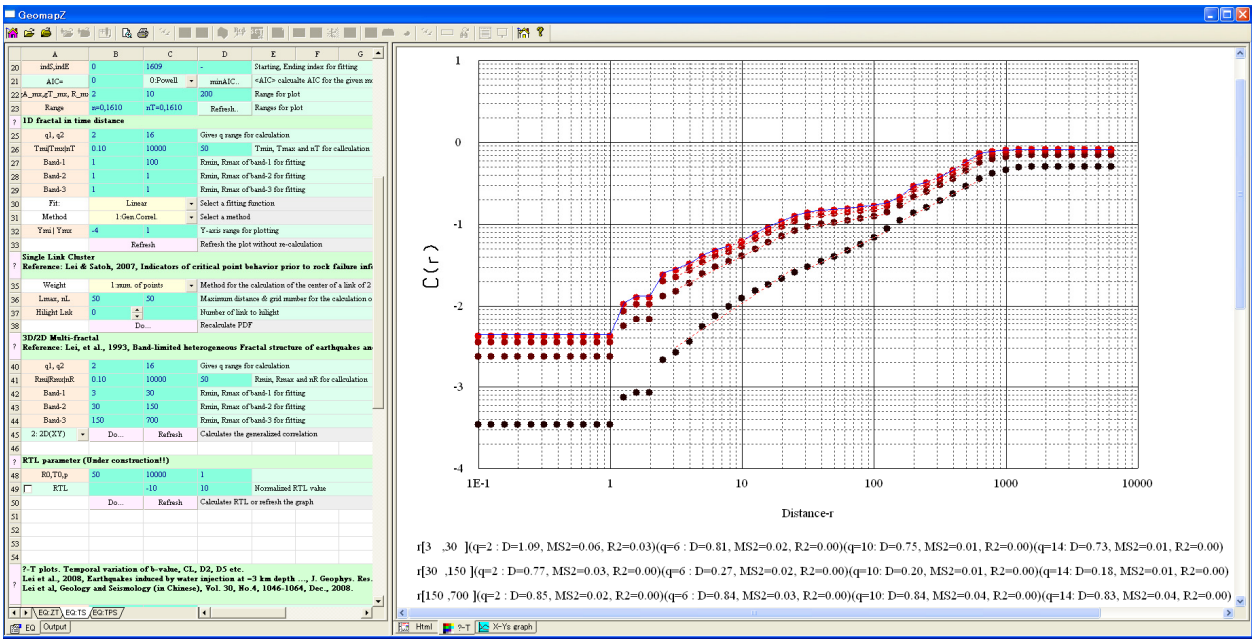
Figure 4-8-1 Single links of earthquake hypocenters and distribution of link distance (PDF) for the calculation of the spatial correlation length (SCL).

3.9 Fractal analysis in space domain

Band-limited and multiple fractal analysis.

23) Row:40-45 host parameter and command buttons for visualization of 3D hypocenter or 2D epicenter distribution. The general correlation integers are plotted in a double logarithm coordinate system. One can specified at most three bands for linear fitting to get fractal dimensions. The lower and upper cutoff distances correspond to the location error and dimension of the data set, respectively. Click the <Do..> button at first and every time parameters in Row:40-41 have been changed. Click <Refresh> to reflect changes of fitting parameters in Row:42-44.

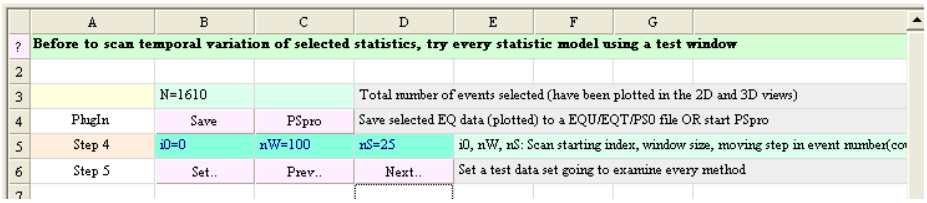




3.10 Temporal scanning of statistic parameters

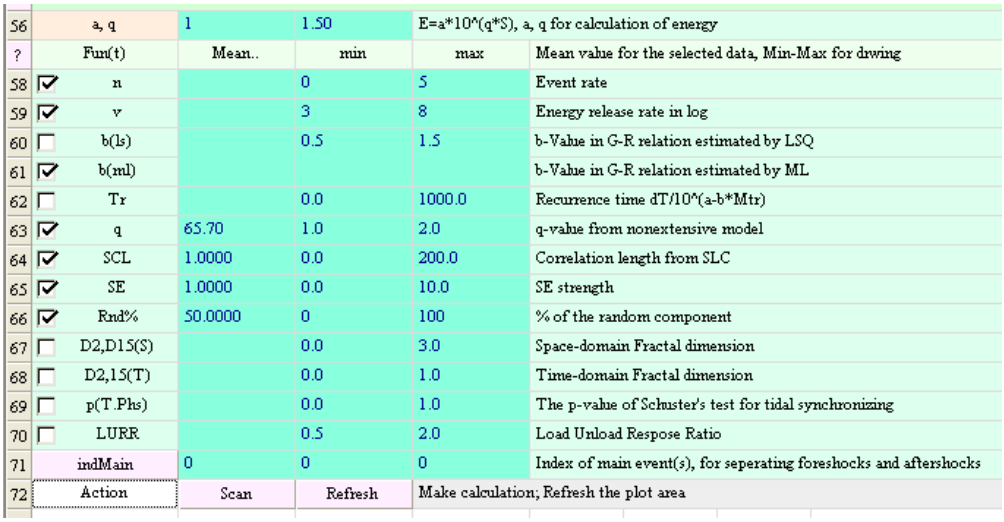
For examining the temporal evolution of seismicity in the specified area, major statistical parameters were sequentially calculated for consecutive groups of given number (nW) of events with a given running step (nS). This is handled within the [EQ:TS] working sheet. Default vale of nW and nS are 200 and 50, respectively. It has been found for statistical significance, nW >= 50 is required. Larger nW results in stable estimations, while smaller nW explores details. Let try nW=100 and nS=25.

24) Type i0=0, nW=100, nS=25 in Row-5. Then click the <Set..> button in row 6.



25) Scroll the [EQ:TS] working sheet so Row:55-72 are visible. Check on parameters to be estimated from row:58-69 and the click the <Scan> button in Row:72. The temporal variations of selected

parameters would be drawn in the [?-T] view. Note some models such as ETAS require large number of events for statistical significance.



56		a, q	1	1.50	E=a*10^(q*S), a, q for calculation of energy
?		Fun(t)	Mean..	min	max	Mean value for the selected data, Min-Max for drwing
58	☑	n		0	5	Event rate
59	☑	v		3	8	Energy release rate in log
60	☐	b(ls)		0.5	1.5	b-Value in G-R relation estimated by LSQ
61	☑	b(ml)				b-Value in G-R relation estimated by ML
62	☐	Tr		0.0	1000.0	Recurrence time dT/10^(a-b*Mtr)
63	☑	q	65.70	1.0	2.0	q-value from nonextensive model
64	☑	SCL	1.0000	0.0	200.0	Correlation length from SLC
65	☑	SE	1.0000	0.0	10.0	SE strength
66	☑	Rnd%	50.0000	0	100	% of the random component
67	☐	D2,D15(S)		0.0	3.0	Space-domain Fractal dimension
68	☐	D2,15(T)		0.0	1.0	Time-domain Fractal dimension
69	☐	p(T.Phs)		0.0	1.0	The p-value of Schuster's test for tidal synchronizing
70	☐	LURR		0.5	2.0	Load Unload Respose Ratio
71		indMain	0	0	0	Index of main event(s), for seperating foreshocks and aftershocks
72		Action	Scan	Refresh	Make calculation; Refresh the plot area	

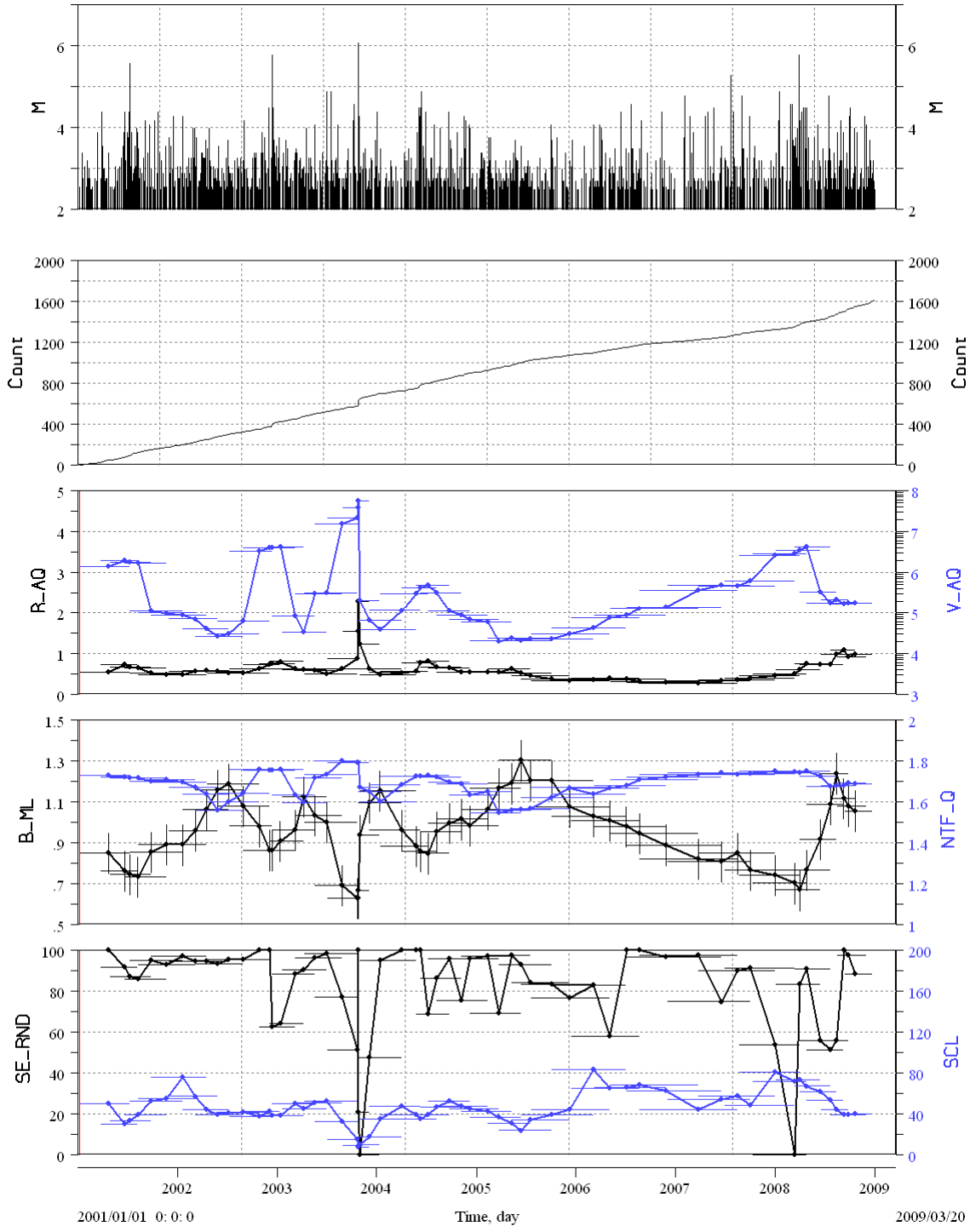


Figure 4-10-1 Temporal evolution of Magnitude, acumulated event number, event rate, energy release rate, b-value , q-value, and spatial correlation length. Statistical parameters were sequentially calculated for consecutive groups of 100 events with a running step of 25 events..

Results are also send to [Simulation] data sheet and [X-Y graph] view. It is possible to make both “Xs-Y” plot (one Y variable and multi X variables) and “X-Ys” plot by alter X- and Y-axis from the popup menu when

R-Click the column head of the [Simulation] sheet. Change “min”, “max” to optimized the graph. It is continence to examine possible cross correlation between the estimated parameters. Data in the [Simulation] sheet can copied and pasted to Excel sheet.

3.11 Temporal evolution of foreshocks or/and aftershocks

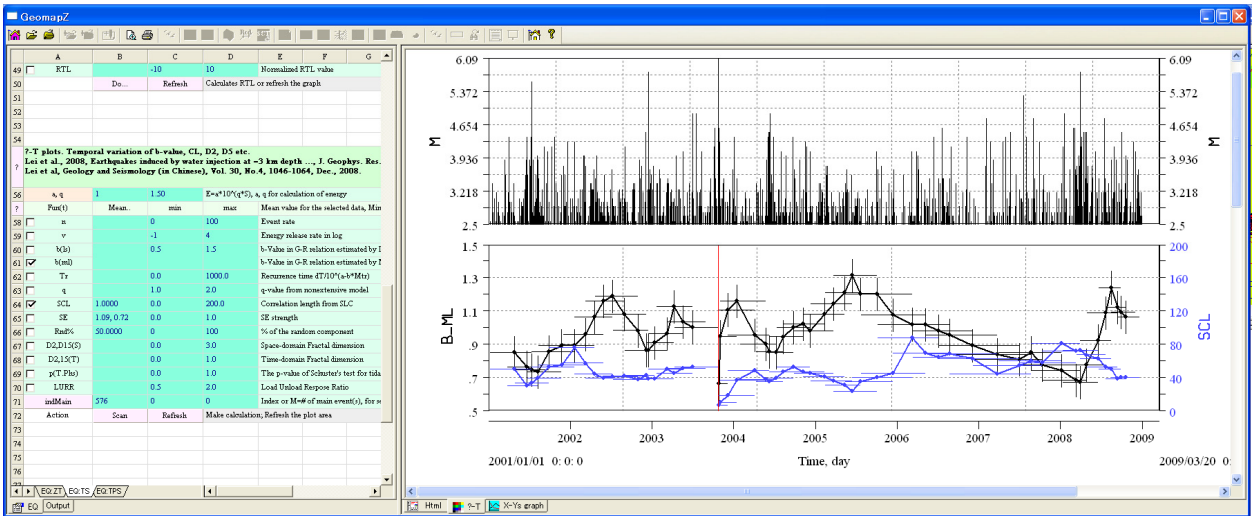
Sometimes it is helpful to be able to scan the temporal evolutions for foreshocks and aftershock so that results of foreshocks do not include any aftershocks and vice versa. It can be done by specify the index number of the main event in the data set. For example, if the data set contains a main events which is numbered as the 1500th event, then one should type 1500 in the B-column of Row 71 and remain C, D-Columns as 0. The resulted curves break at the main event. This is helpful for examining whether there are some precursory changes or not. One can input as many as 3 number of index if there are 3 main events in the data set. If the index of the mainshock is unknown, one can type critical magnitudes as, for example, “M=6.0” in associated cells and click <indMain> to pick up their indexes. This set the first event with a magnitude equal to or larger than the critical magnitude as the first mainshock, and so on for later mainshock.

71	indMain	M=6.0	0	0	Index or M=# of main event(s), for s
72	Action	Scan	Refresh	Make calculation; Refresh the plot area	

Then click <indMain>

71	indMain	576	0	0	Index or M=# of main event(s), for s
72	Action	Scan	Refresh	Make calculation; Refresh the plot area	

26) Now click <Scan> to scan selected parameters over the total time span. The results curves break at the main shock(s).



3.12 Spatial variation of statistics of earthquake hypocenters

Scanning of some statistics (*b*-value and *q*-value in the current version) are valid through [EQ:TPS] working sheet. For horizontal distribution area mapped in the 2D view is divided to a set of nX (EQ:TPS::12-C) x nY

(EQ:TPS::12-C) grids. For each grid, the *b*-value and other parameters are estimated for the nearest N (EQ:TPS::3-B) events with a distance less than the maximum searching radius is Rmax given by (EQ:TPS::4-B). If there is no enough number of hypocenter with a distance less than the maximum searching distance, no estimation is given for the point.

27) Click [EQ:TPS] tag to show [EQ:TPS] working sheet. Type 50 in (3-B) and 100 in (4-B). Thus the number of events used for statistics is 50, and the maximum searching distance is 100 km.

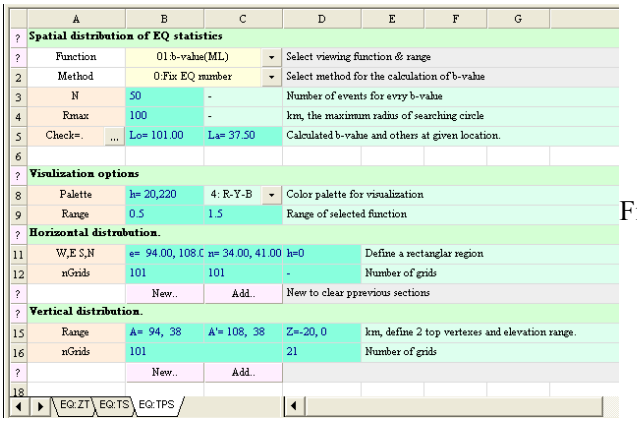


Figure 3-12-1

28) The default number grids for horizontal distribution is 101 x 101. Any reasonable number, say >10 and <1000, is acceptable. Thus the number of events used for statistics is 50, and the maximum searching distance is 100 km.

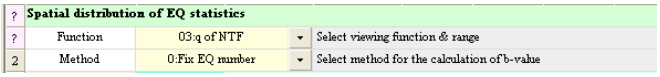


Figure 3-12-2

29) The spatial distribution of b-value and other parameters are determined simultaneously. However, only one function can be overlapped on the 2D map. One can alter functions for overlapping from the drop-down list in Row:1. It is probably to uncheck some layers to get clear image. In following figures, color mosaic of *b*-value overlaps the color code of Province while in the lower plot for color mosaic of q-value the Province layer is invisible.

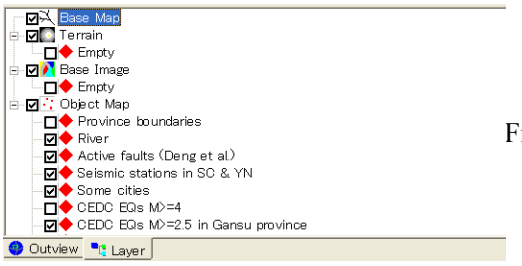


Figure 3-12-3

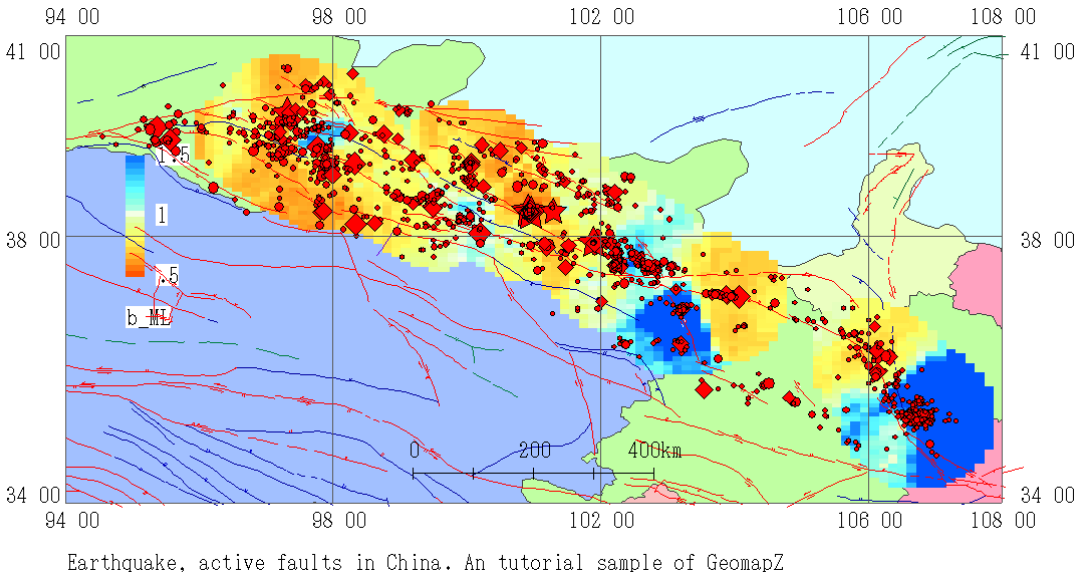


Figure 3-12-4 X-Y distribution of *b*-value in gansu province. The *b*-value at a given grid is estimated for the nearest 50 events. The maximum searching radius is 100km. If there is no enough number of hypocenter with a distance less than the maximum searching distance, no estimation is given for the point.

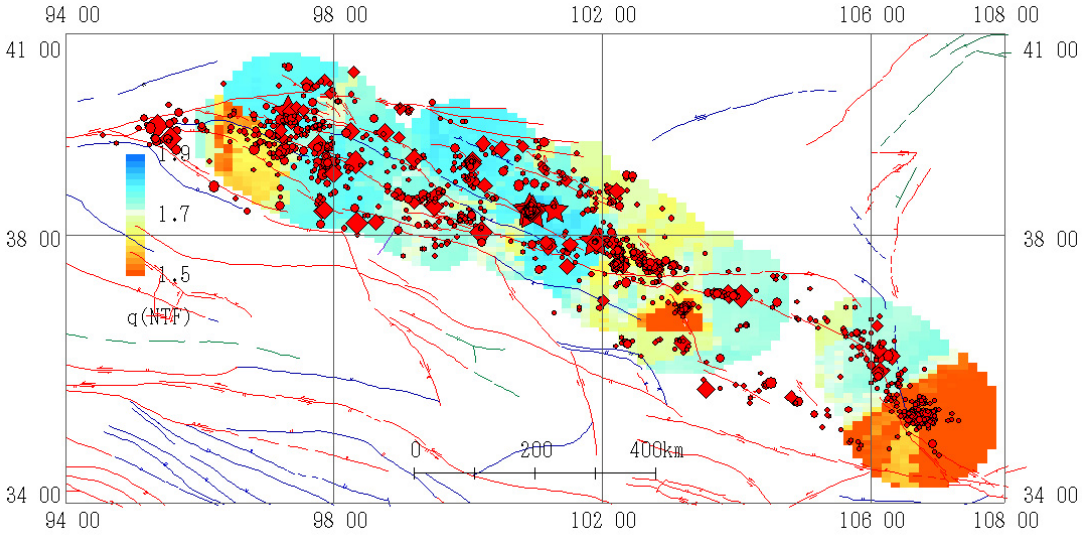


Figure 3-12-5 X-Y distribution of *q*-value in gansu province.

4. Relocation of earthquake hypocenters using hypoDD

See GeoTaos_Seis_Reloc.pdf