Geospatial Visual Analytics:
Visual analysis of spatio-temporal data
Part 2: spatially distributed events

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http://geoanalytics.net

Types of Temporal Variance

- Changes of thematic properties (values of attributes) associated with places
  - e.g. district population, data from stationary sensors
- Existential changes (appearance and disappearance)

  Events: objects with limited life time
  - e.g. earthquakes, traffic incidents, observations of rare plants or animals
- Changes of spatial properties: location, size, shape, orientation, altitude, etc.
  - e.g. movement of vehicles, growth of cities

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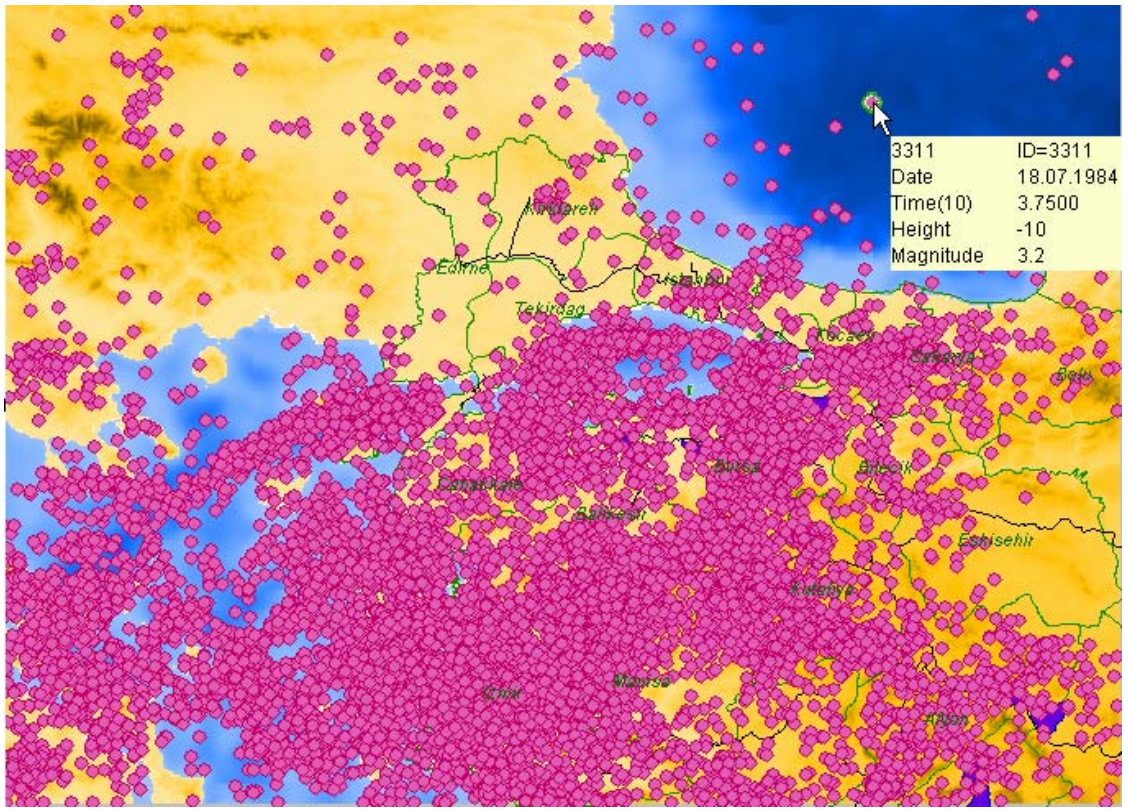
Example: earthquakes in Marmara region (western Turkey and around)

id	X	Y	Date	Time(10)	Height	Magnitude
1	23.88	38.27	01.01.1976	16.1667	0	2.9
2	23.26	39.21	07.01.1976	6.2333	0	3.2
3	29.8	38.8	07.01.1976	23.9667	0	3.3
4	30.82	38.71	09.01.1976	0.4833	0	3.6
5	30	38.83	12.01.1976	13.4667	0	3.5
6	27.8	38.9	16.01.1976	22.0333	0	3.3
7	23.92	38.86	17.01.1976	15	0	2.9
8	26.11	39.34	18.01.1976	19.6333	0	3.9
9	29.3	38.92	19.01.1976	7.1	0	3.5
10	26.3	38.4	19.01.1976	12.6333	0	3.3
11	27.429	40.565	20.01.1976	12.4167	-7	3.3
12	29.61	39.11	21.01.1976	18.25	-27	4
13	29.769	38.775	21.01.1976	21.6333	0	2.9
14	30.5	39.8	23.01.1976	2.2167	0	3
15	30.8	40.8	23.01.1976	9.2	0	3.2
16	26.89	38.97	23.01.1976	10.0667	0	2.9
17	30.1	40.38	23.01.1976	19.9333	0	3.2
18	26.05	38.77	24.01.1976	7.4667	0	3.2
…	…	…	…	…	…	…
10548	25.95	38.06	12.12.1999	14.6667	-10	3.4
10549	27.99	39.36	13.12.1999	11.75	-13	3.5
10550	27.989	39.326	18.12.1999	3.7667	-4	3.6
10551	28.28	39.48	18.12.1999	20.8167	-14	3
10552	30.88	39.3	24.12.1999	4.5333	-5	3.1
10553	27.98	38.71	24.12.1999	8.8167	-5	3.2
10554	27.92	38.63	24.12.1999	8.8667	-22	3.8
10555	28.01	38.52	24.12.1999	9.8167	-5	3.1
10556	28.64	40.78	25.12.1999	10.3167	-6	2.9
10557	28.58	40.83	29.12.1999	12.4333	-5	3.2
10558	29.369	40.465	29.12.1999	16.0833	-13	3.3
10559	28.15	40.87	29.12.1999	21.8833	-5	2.9
10560	25.99	38.91	30.12.1999	4.85	-5	4.7



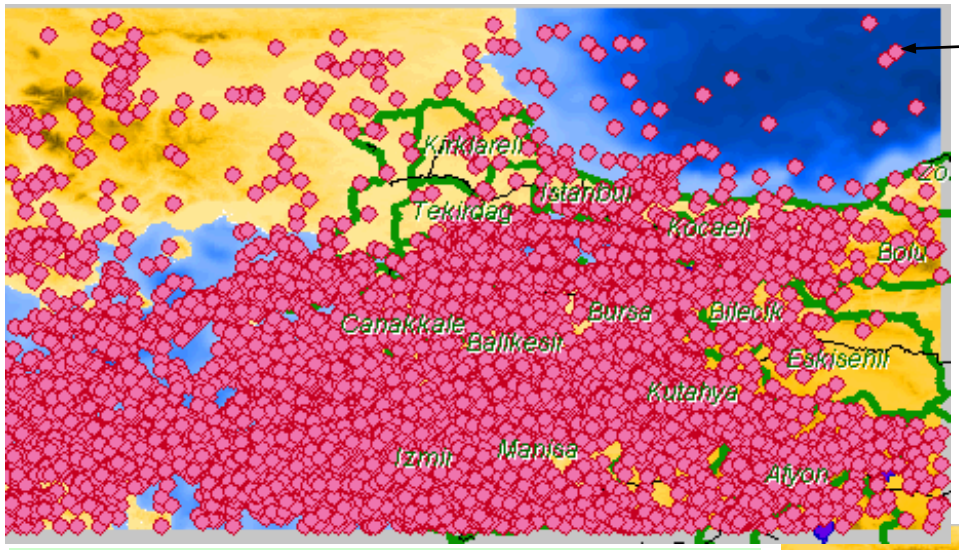
Data structure:

<event identifier, position, time, {other attributes}>

Analysis of Spatially Distributed Events: Major Questions

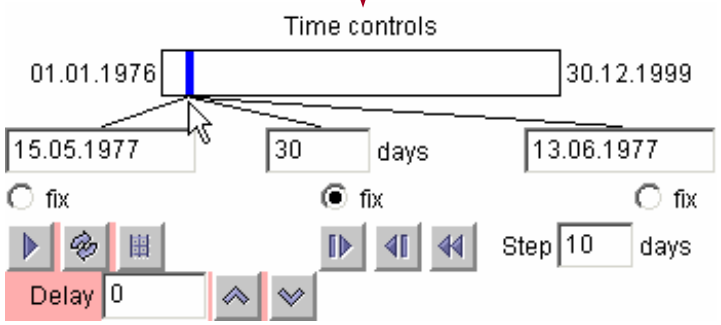
- How are the events distributed in space?
  - at a particular time moment or all events that occurred over a time period
- How are the event occurrences distributed over time?
  - E.g. how does the overall event frequency vary?
- How does the pattern of spatial distribution of the events change over time?
- How are the events distributed in space + time? Are there any spatio-temporal clusters?

Spatial Distribution of Events



The small circles represent the earthquakes that occurred in Western Turkey and the neighbourhood between 01.01.1976 and 30.12.1999

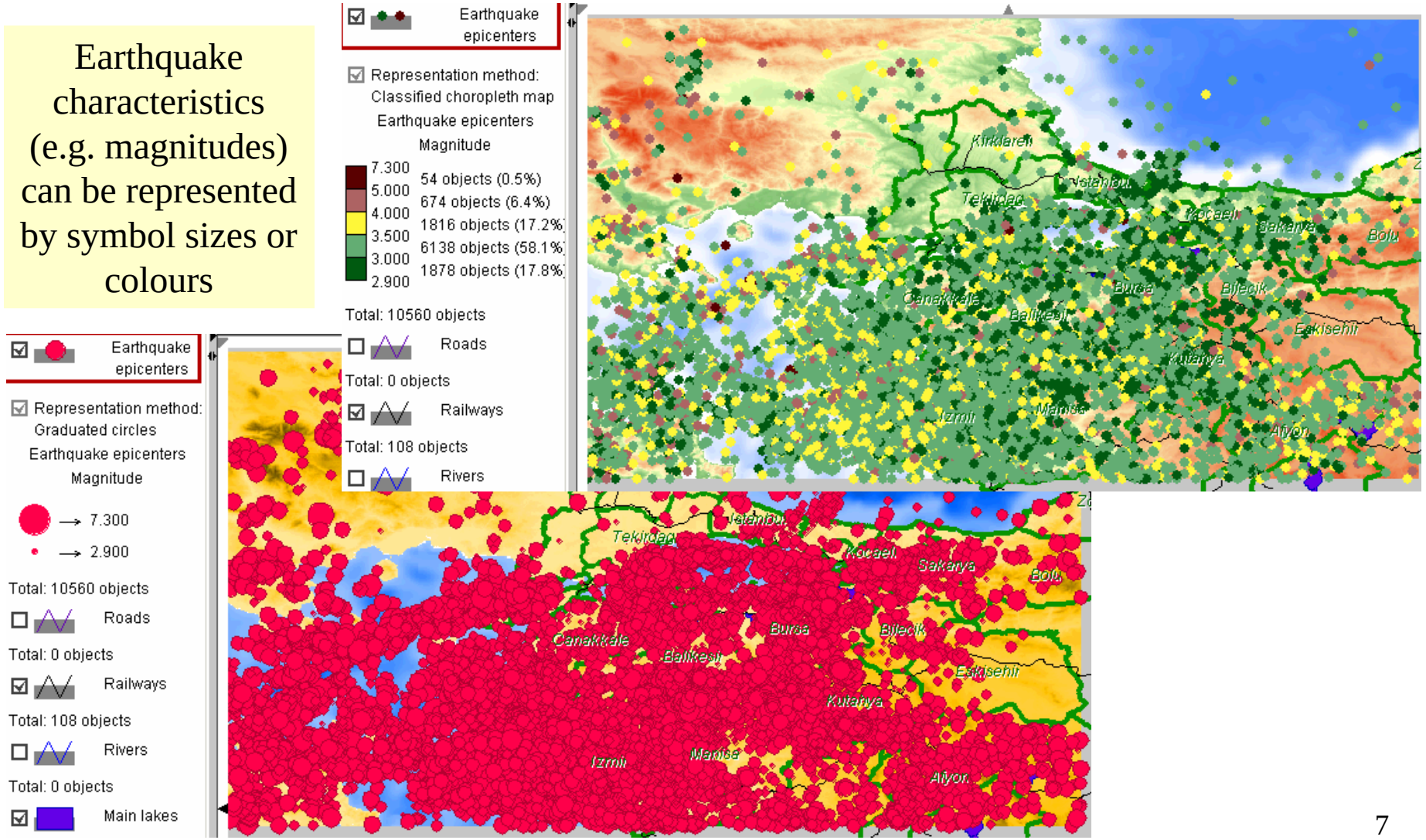
By applying the temporal filter, we can investigate the spatial distribution in any time interval



Here we see only the earthquakes that occurred during 30 days from 15.05.1977 till 13.06.1977

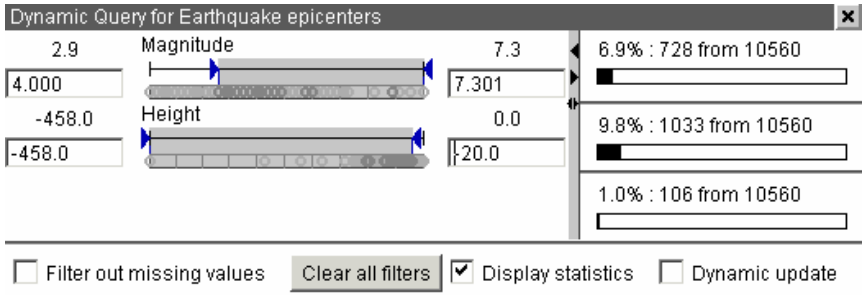
Spatial Distribution of Event Characteristics (1)

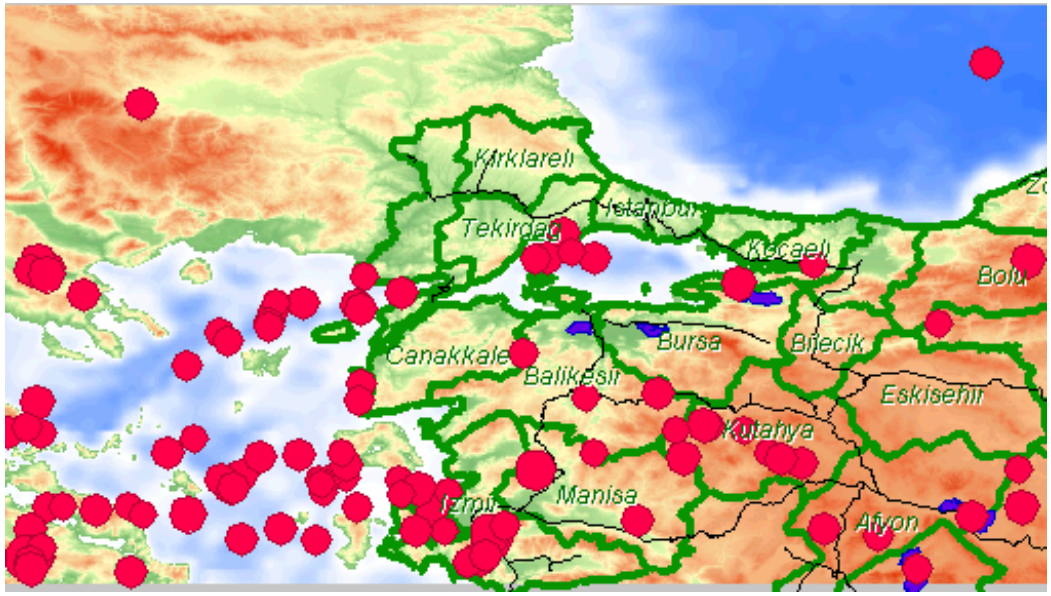
Earthquake characteristics (e.g. magnitudes) can be represented by symbol sizes or colours



Spatial Distribution of Event Characteristics (2)

To explore the spatial distribution of earthquake characteristics, we can also apply the thematic filter (dynamic query)

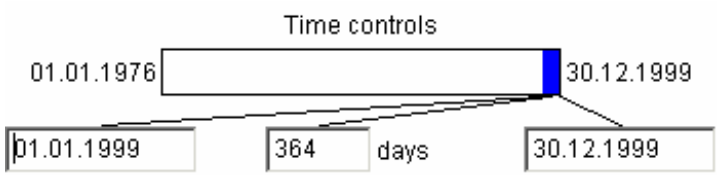


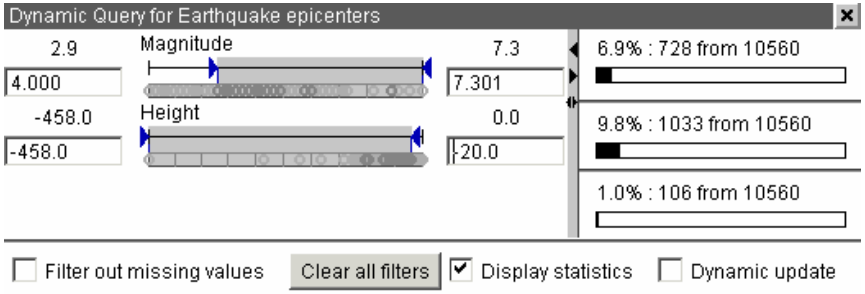


Now we see only the earthquakes with magnitudes 4 and more that occurred at depths not less than 20 meters

Spatial Distribution of Event Characteristics (3)

The temporal and thematic filters may be combined



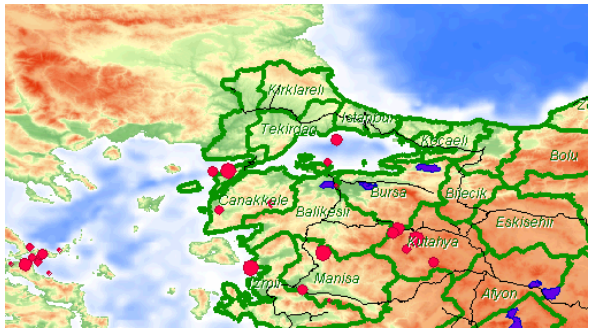


Now we see only the earthquakes with magnitudes 4 and more that occurred at depths not less than 20 meters during the year 1999

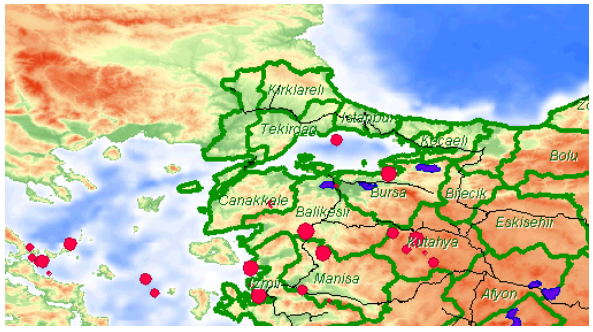
Progress of Spatial Patterns over Time

Map animation allows us to see how the spatial distribution of events and their characteristics evolve over time

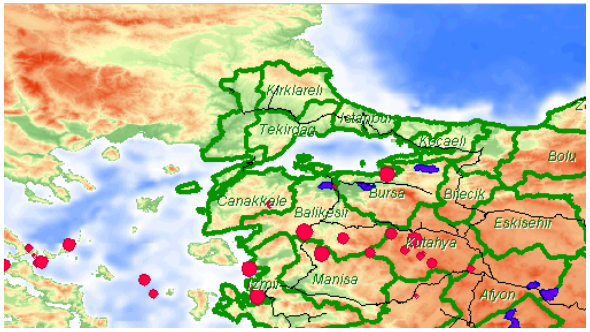
15.05.1977 - 13.06.1977



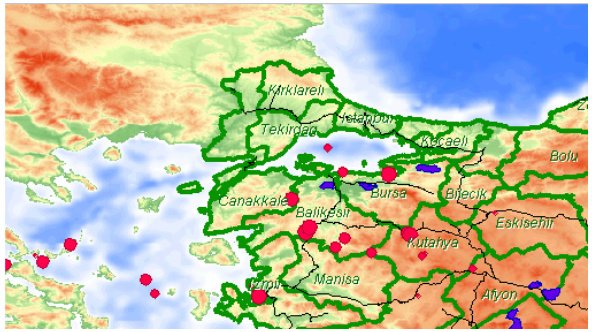
25.05.1977 - 23.06.1977



04.06.1977 - 03.07.1977

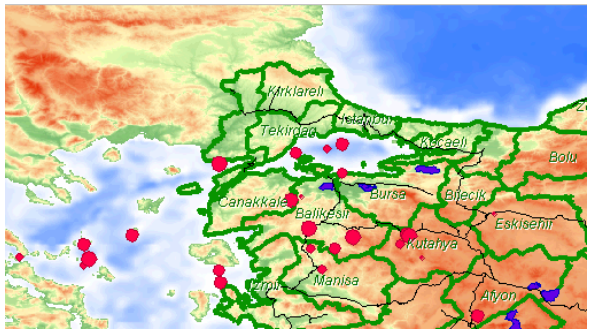


14.06.1977 - 13.07.1977



24.06.1977 - 23.07.1977

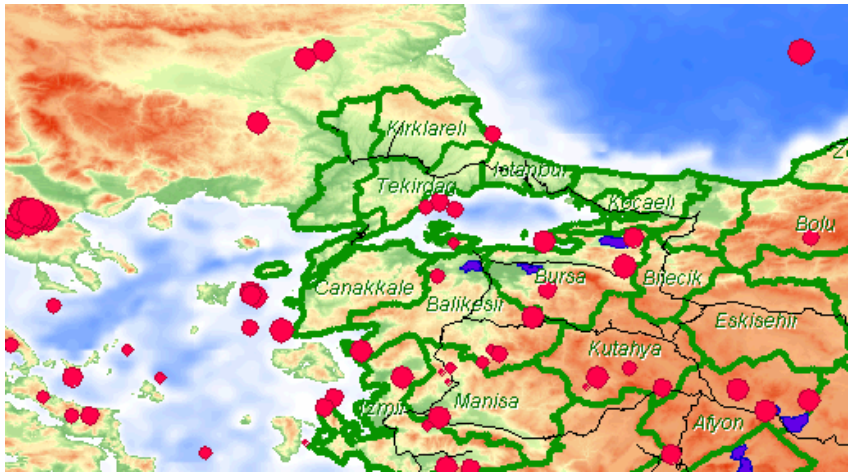
04.07.1977 - 02.08.1977

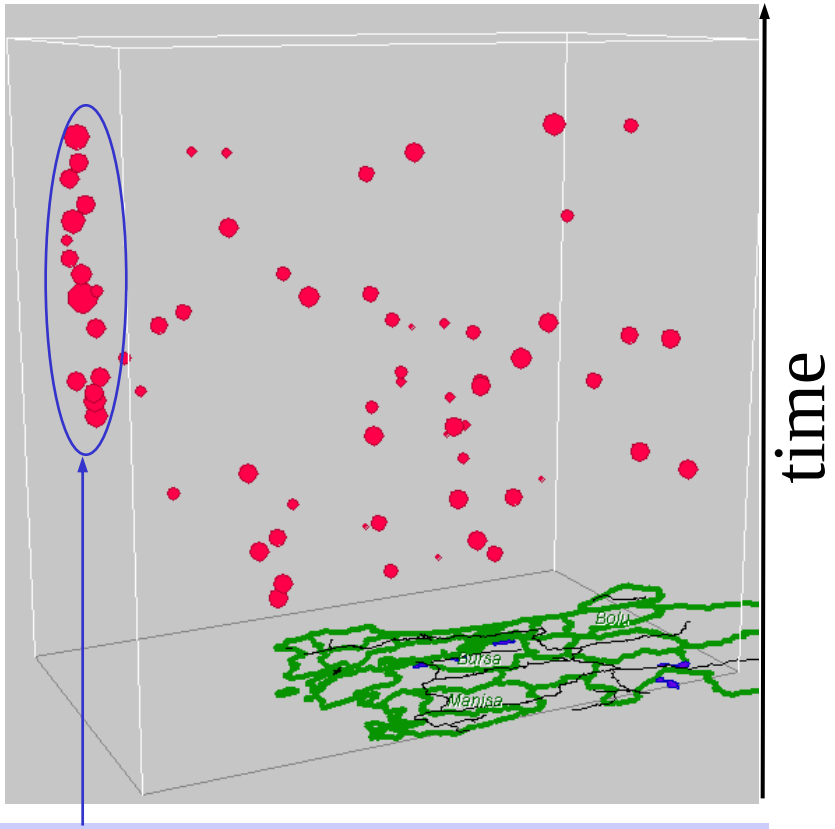


Each animation frame in this example covers 30-days time interval. The step between the frames is 10 days. Hence, there is 20 days overlap between the adjacent frames.

Event Distribution in Space-Time

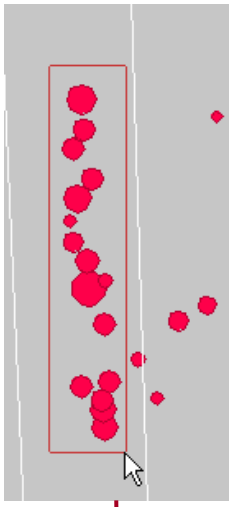
The perspective view (space-time cube) uses the vertical dimension to represent time while two other dimensions represent geographical coordinates. Events are placed in the cube according to their spatial locations and time of occurrence.



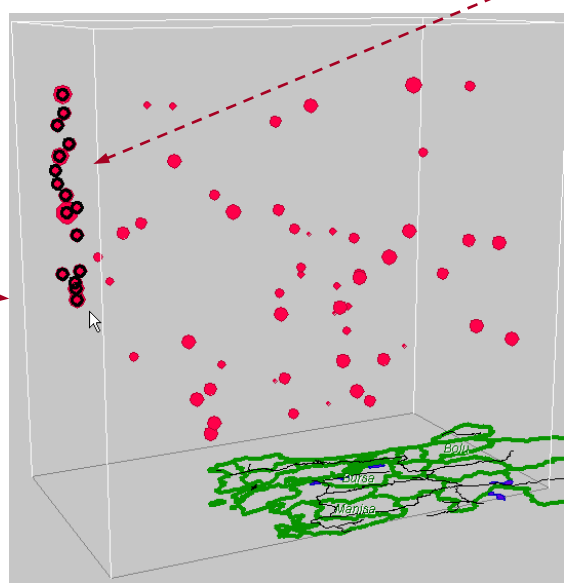


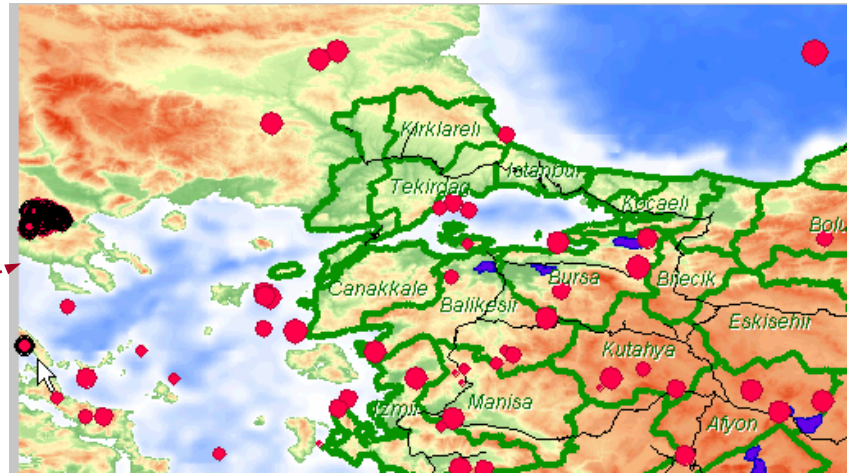
This is how a spatio-temporal cluster looks like, i.e. sequence of events close in space and time

Using Display Links for Exploring Spatio-Temporal Distribution (1)



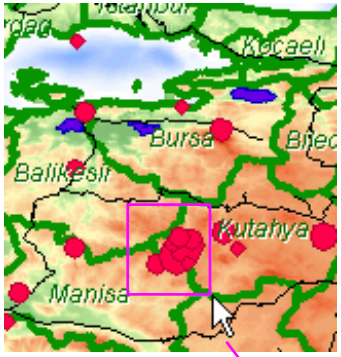
Let us select this "snake" in the cube and look where these events are on the map



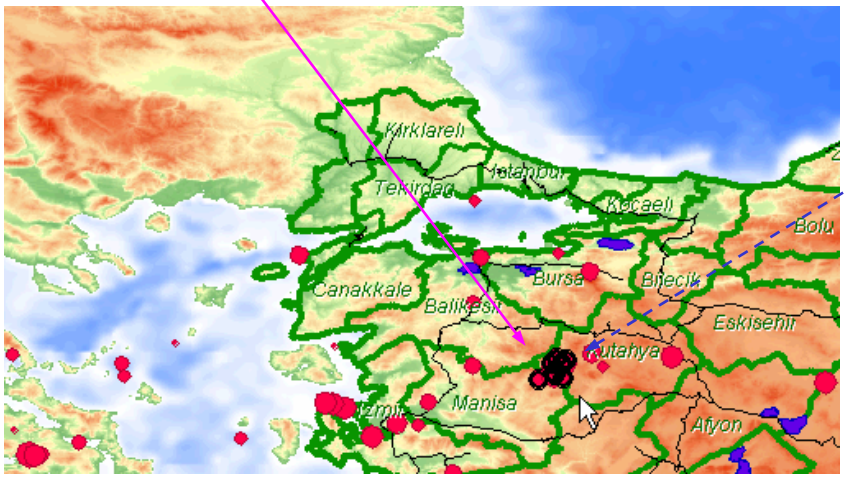


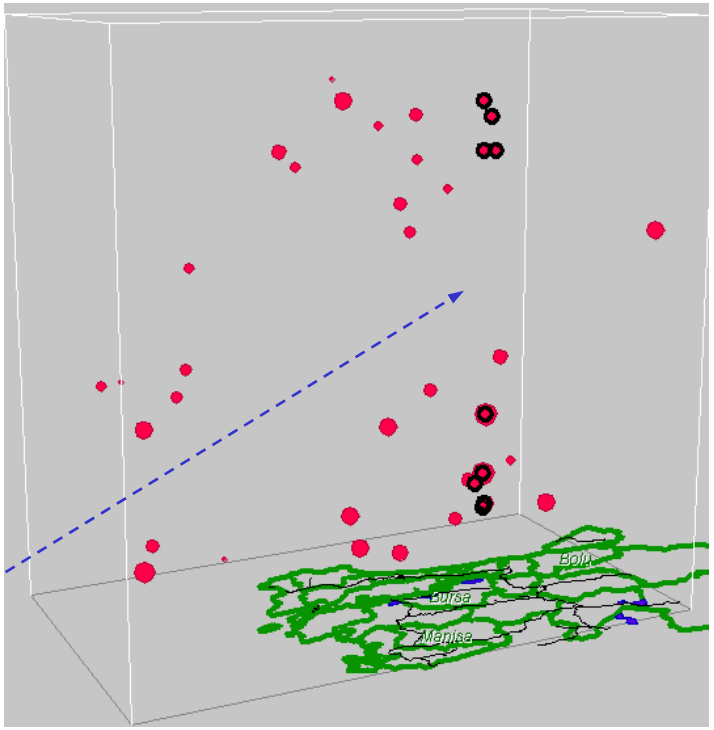
We see that all but one events really occurred very close to each other. We can conclude that this is indeed a spatio-temporal cluster and, hence, there may be a relationship between these events

Using Display Links for Exploring Spatio-Temporal Distribution (2)



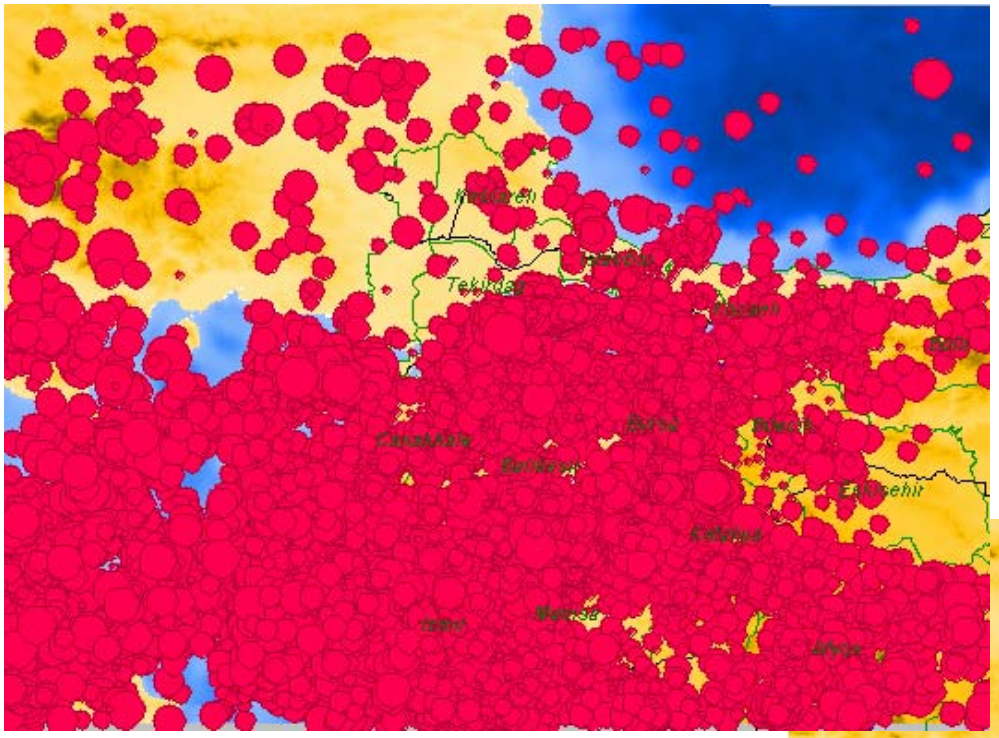
This is a spatial cluster of events. Let us see whether they are close in time





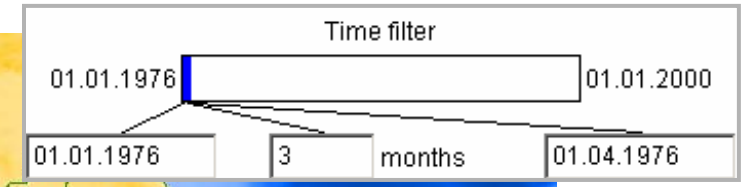
We see that the events seem to split into two sequences with a certain time lapse between them

A problem: too many events



The large number of events results in extremely overlapping symbols on a map and in the space-time cube

The problem exists even when quite short time intervals are selected



This greatly complicates the analysis of the spatial distribution of the events and its variation over time.

Spatio-temporal aggregation

Spatial aggregation:
by units of any territory division
- e.g. cells of a regular grid

Temporal aggregation:
by time intervals

For each spatial unit and time interval:

• number of events

• statistics of the attribute values: minimum, maximum, mean, median, mode, …

The structure of so aggregated data:

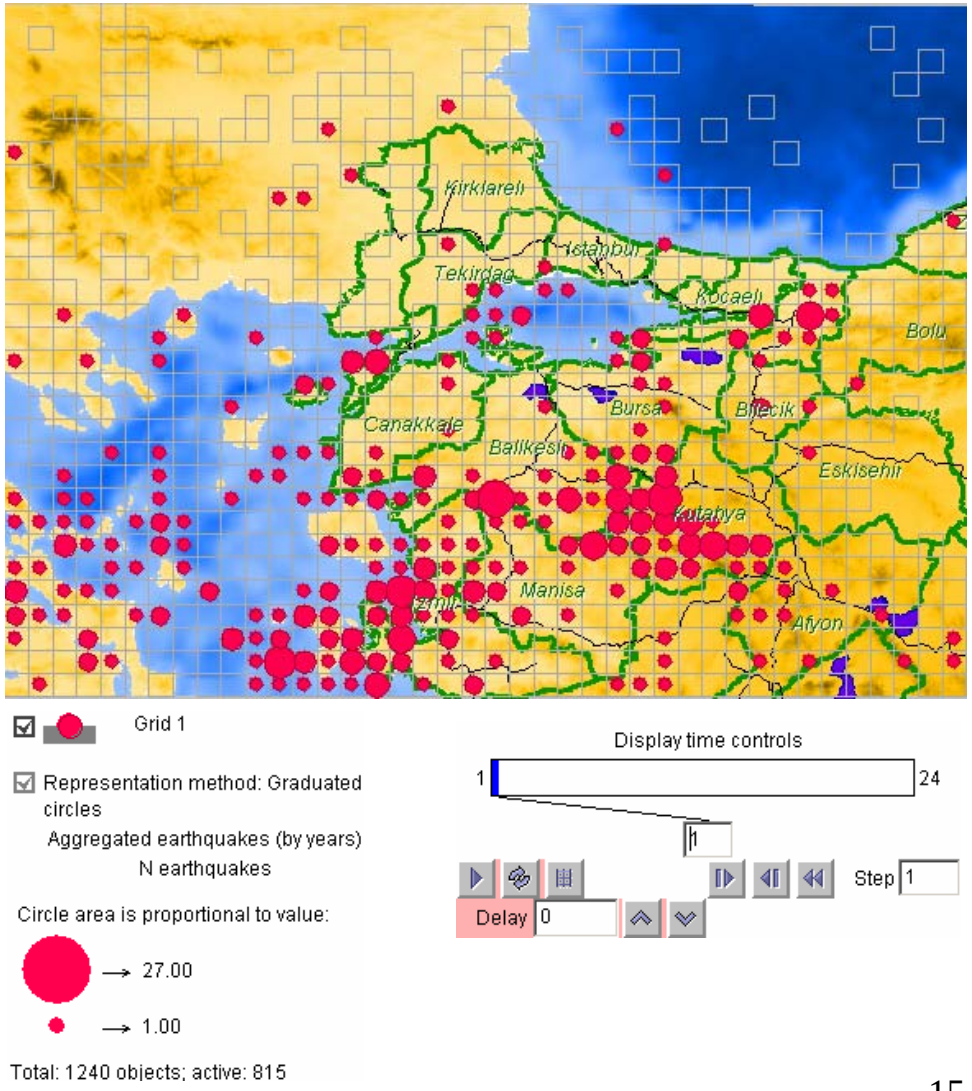
• spatial reference (spatial unit)

• temporal reference (time interval)

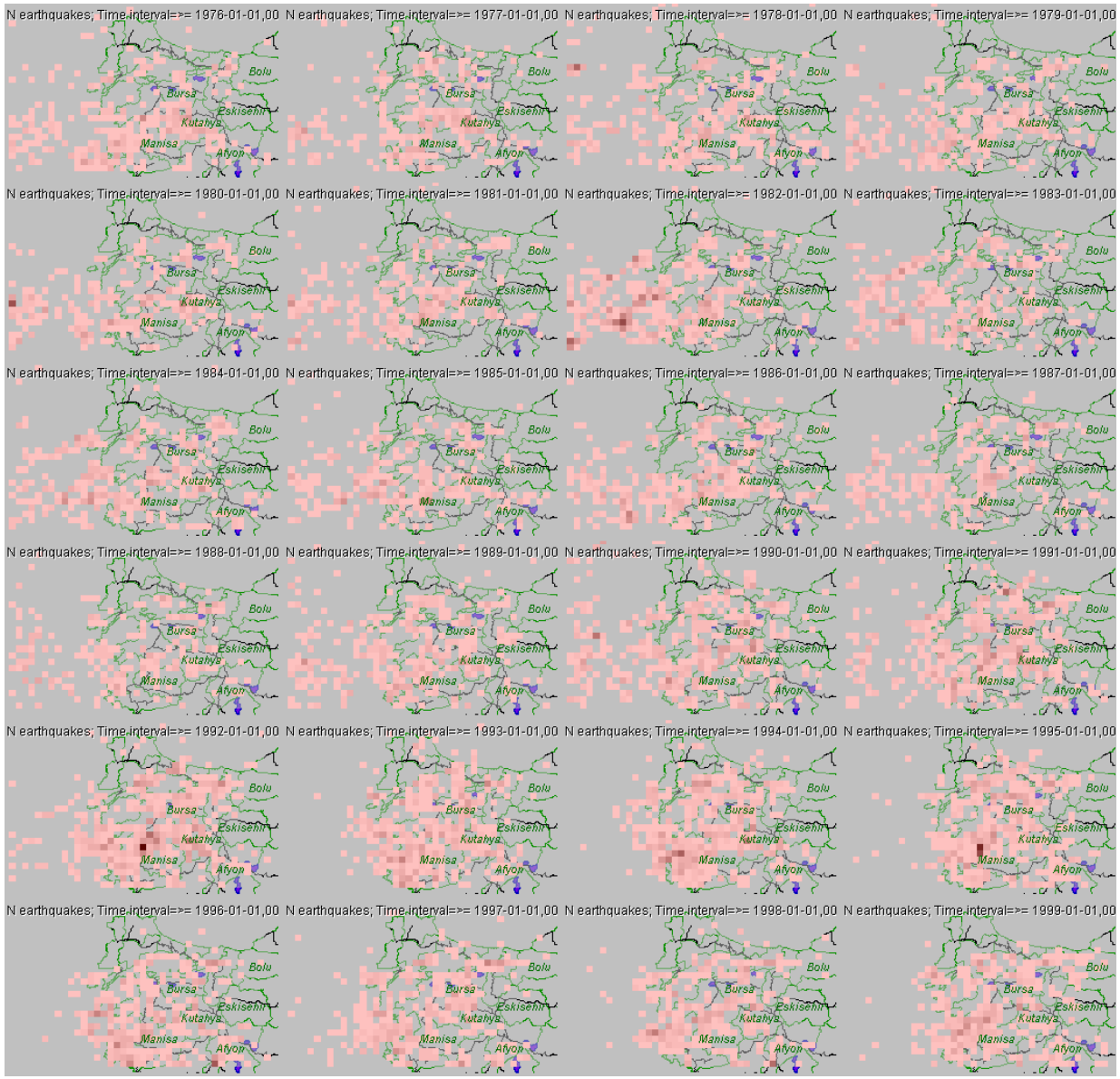
• attributes: number of events, other computed aggregate characteristics

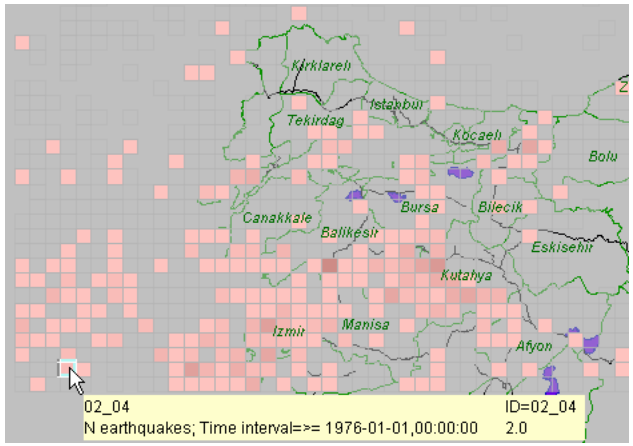
➢ This is the typical structure of spatial time series

⇒ We can apply all analytical methods and tools suitable for spatial time series



Earthquakes aggregated by years





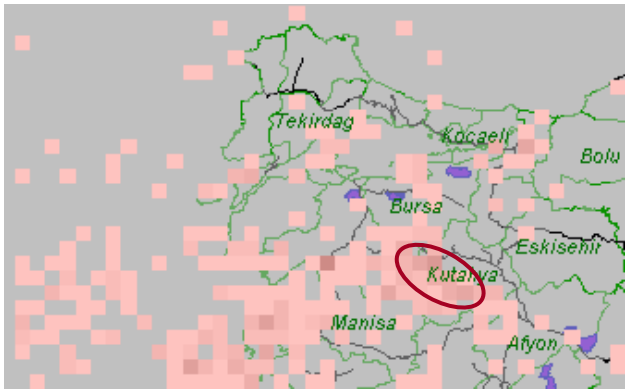
Spatial aggregation:
by cells of a regular grid

Temporal aggregation:
by yearly time intervals

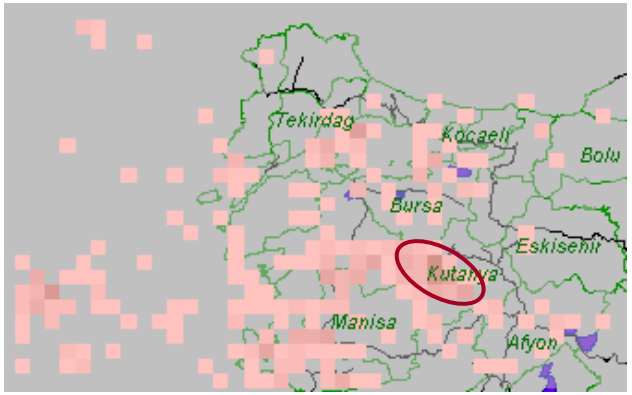
Here we can see the spatial distribution of earthquake frequencies in each year and explore how the patterns changed over time

Areas of high event frequency

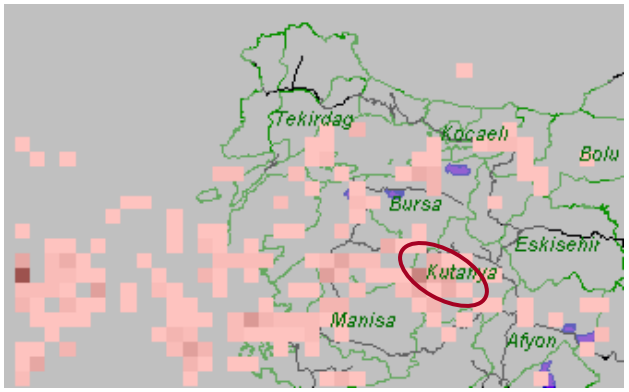
1976



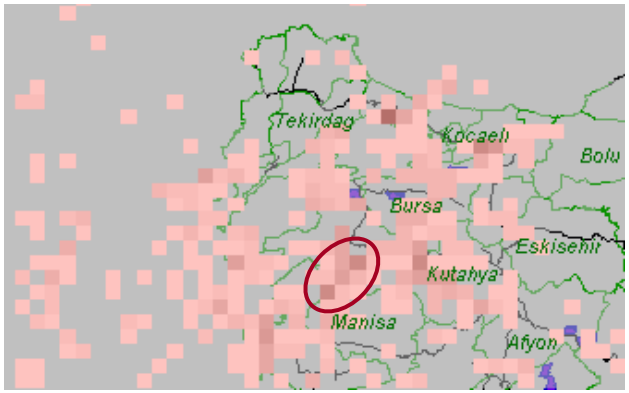
1977



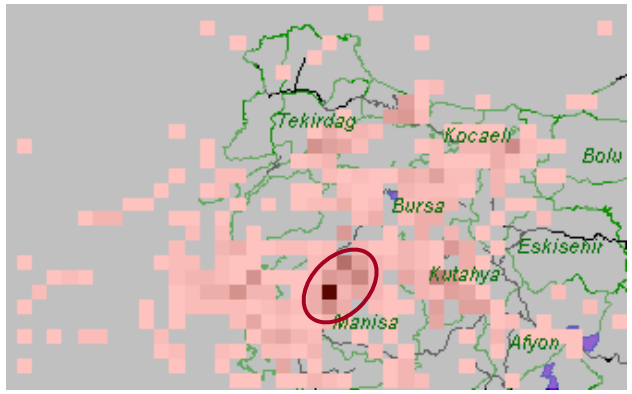
... 1980



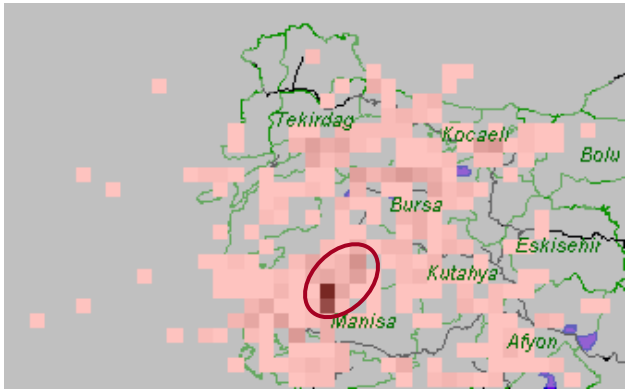
1991



1992

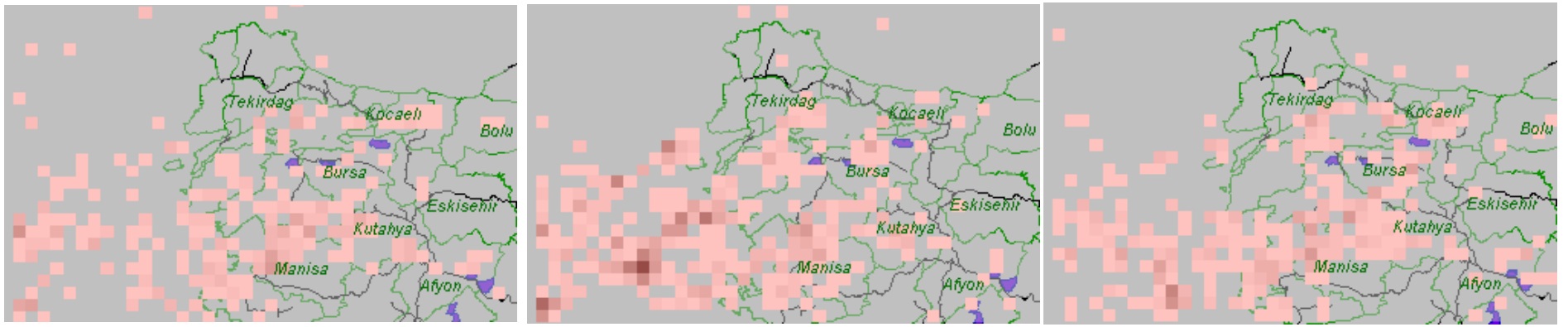


... 1995 ...

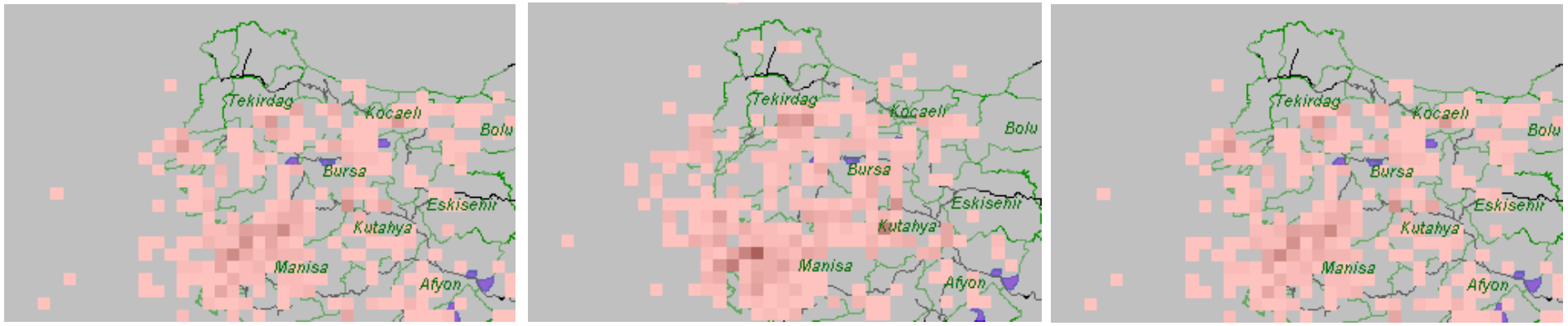


Changes of spatial patterns

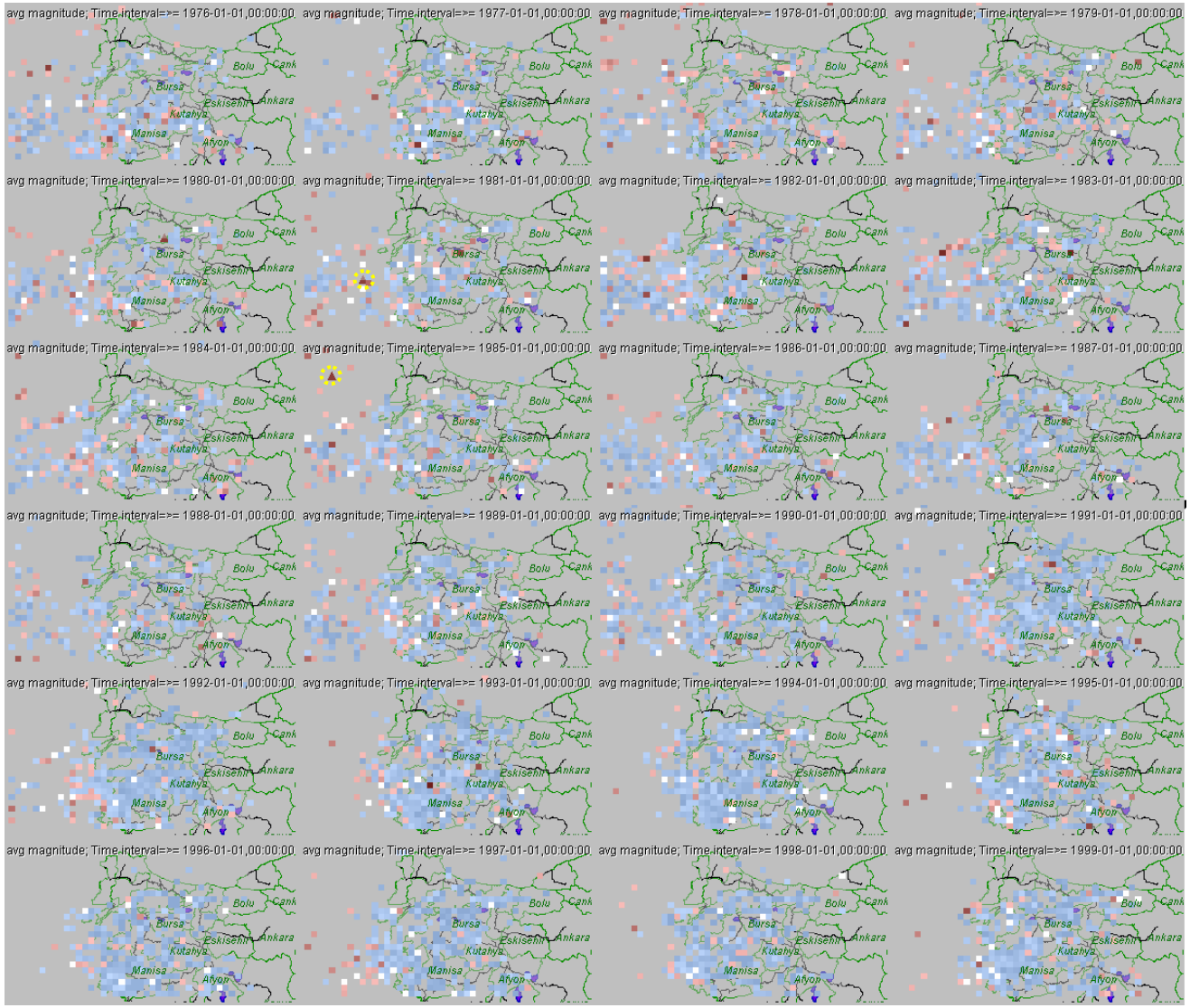
We can observe high frequency of the earthquake events on the west in 1976-1991, especially in 1982 (centre)



Since 1992, this pattern does not appear any more.

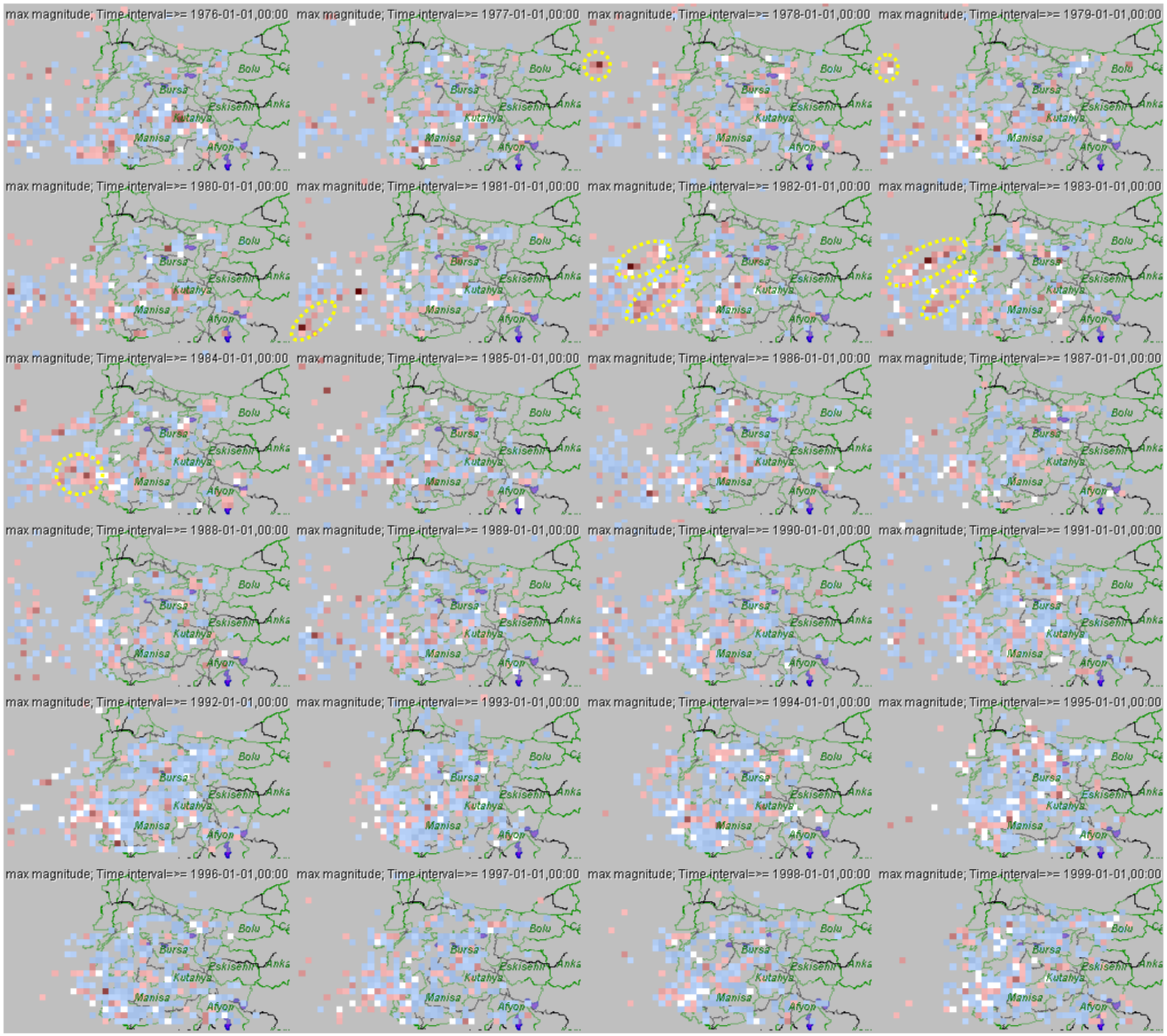


Average magnitude



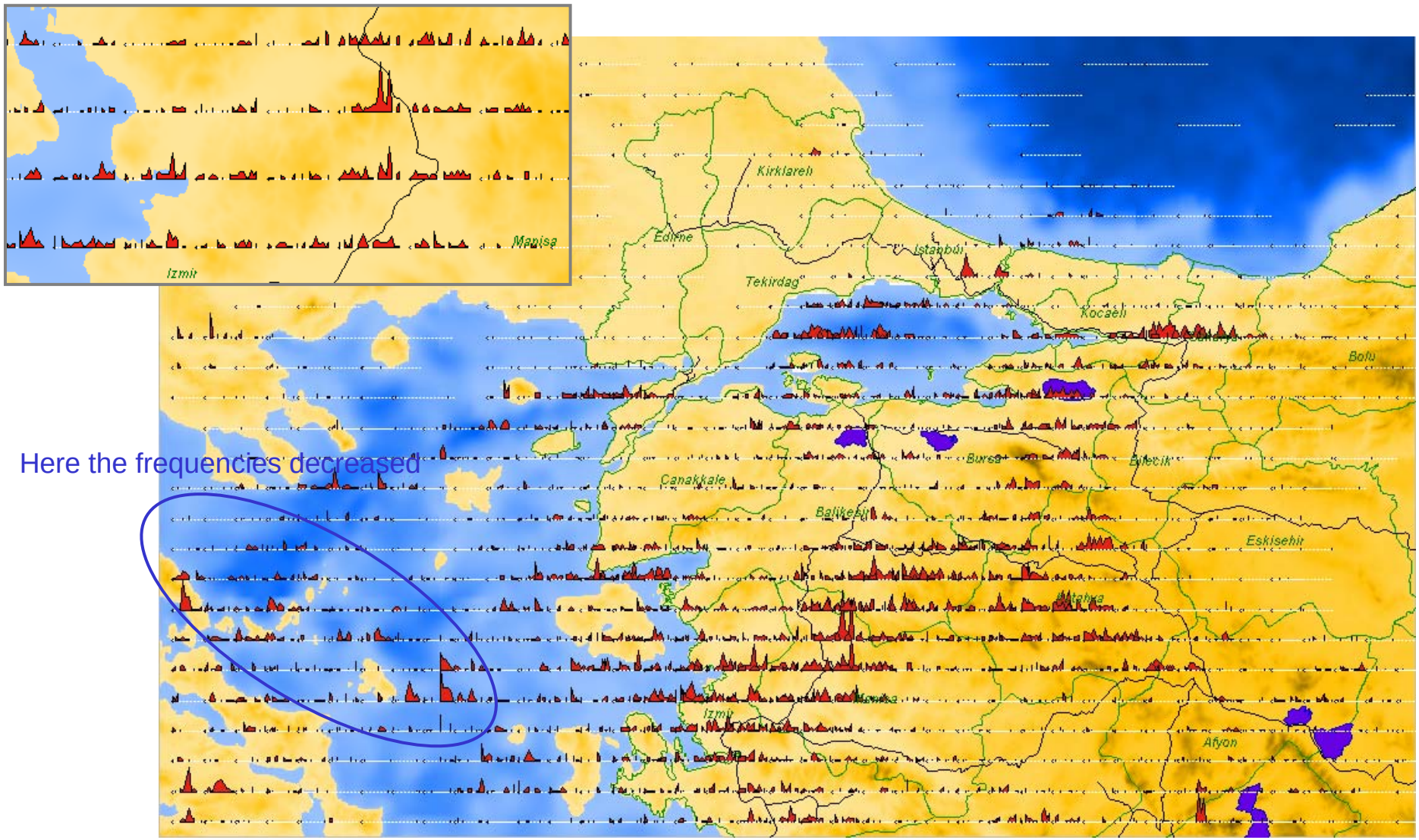
Values over 5.8 (outliers)

Maximal magnitude



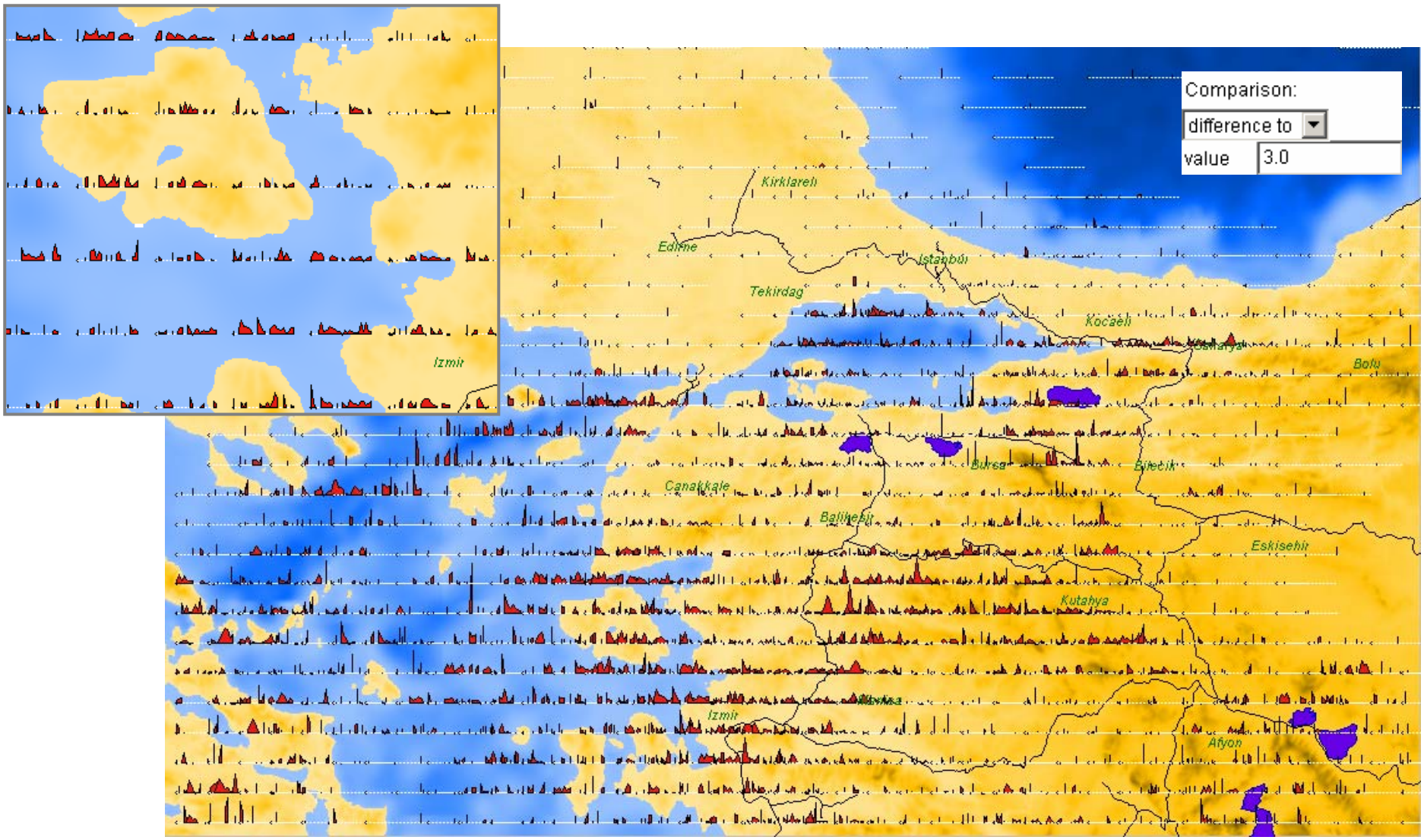
The areas of higher magnitudes are often elongated and oriented SW - NE

Distribution of local temporal behaviours: earthquake frequencies

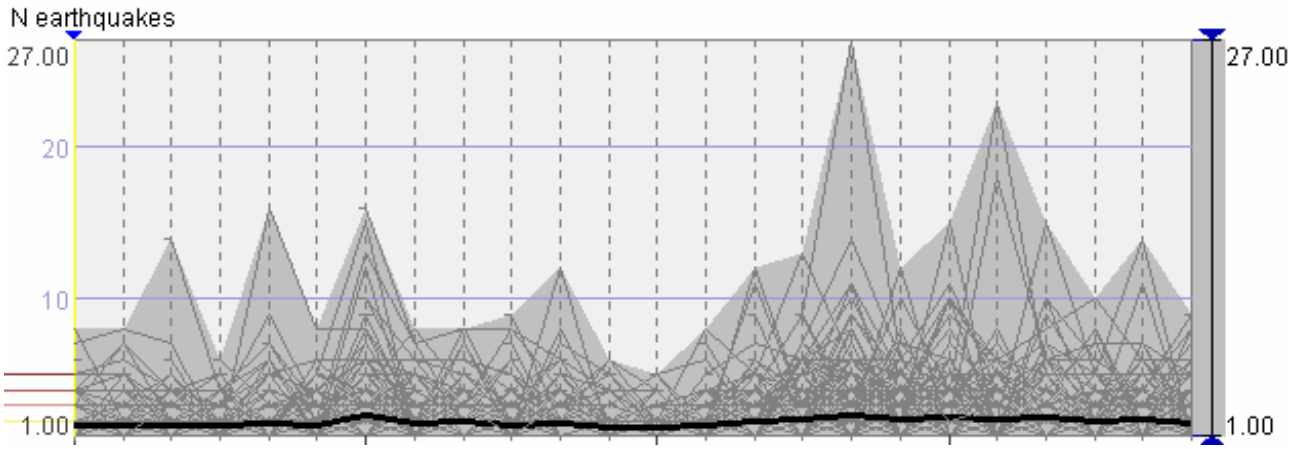


Here the frequencies decreased

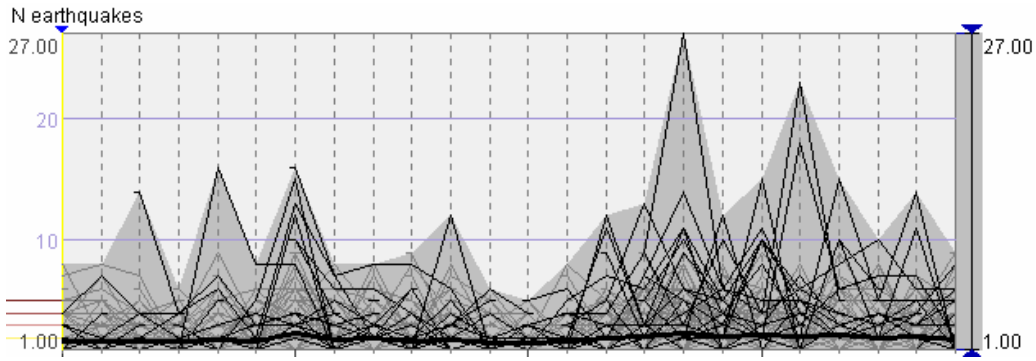
Distribution of local temporal behaviours: average magnitudes

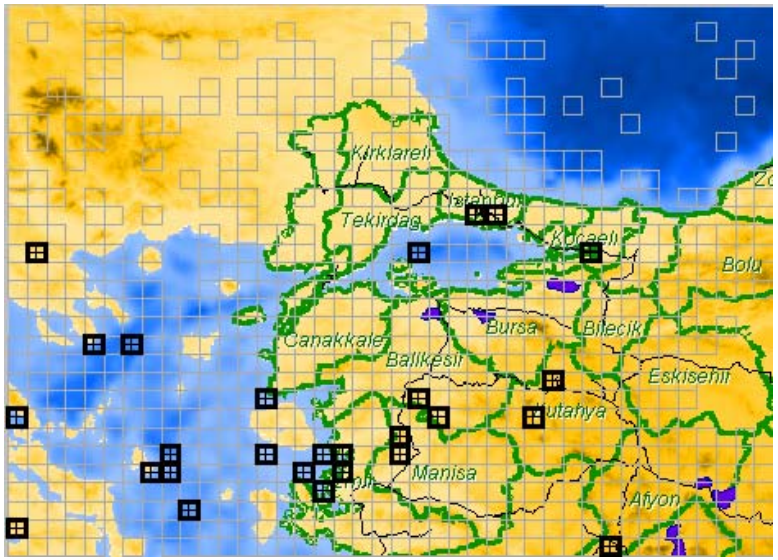


Time graph: number of earthquakes in cells

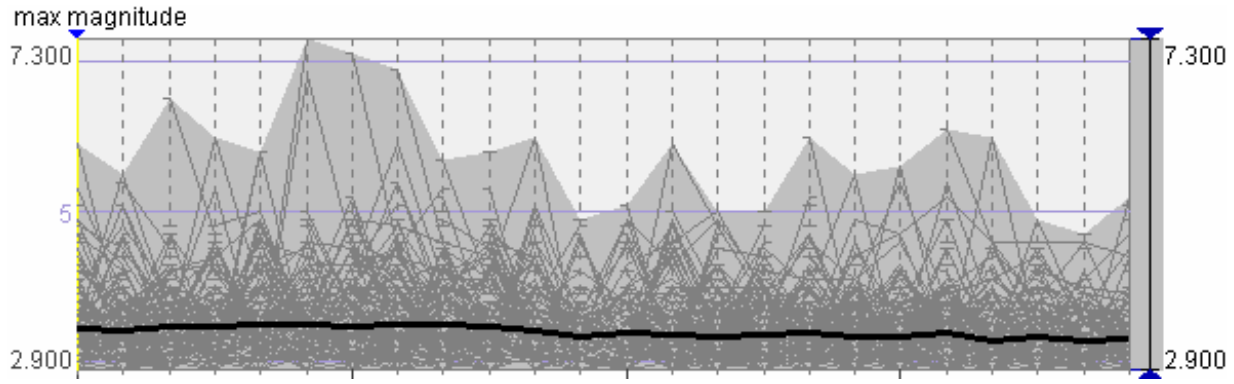


The cells where 10 or more earthquakes ever occurred in the same year:

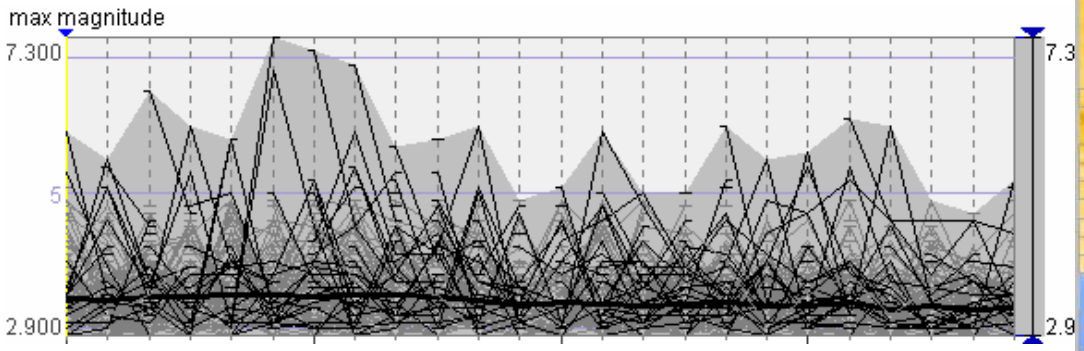


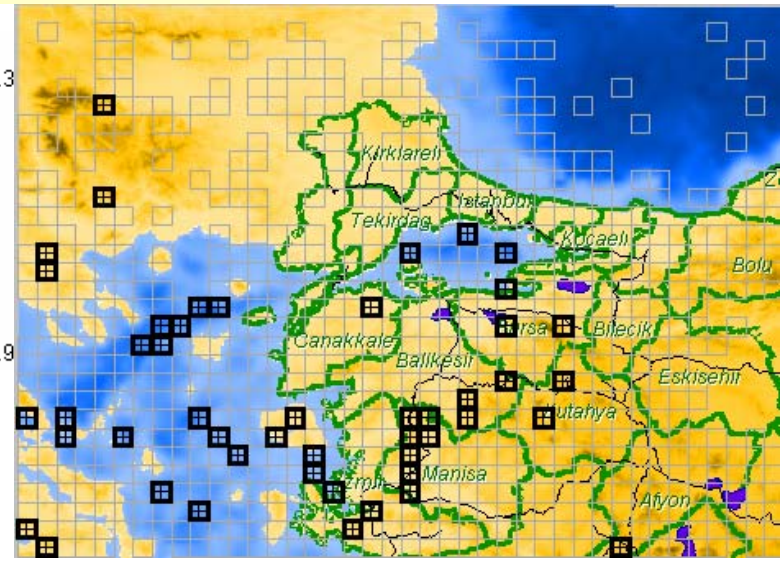


Time graph: maximal magnitudes in cells

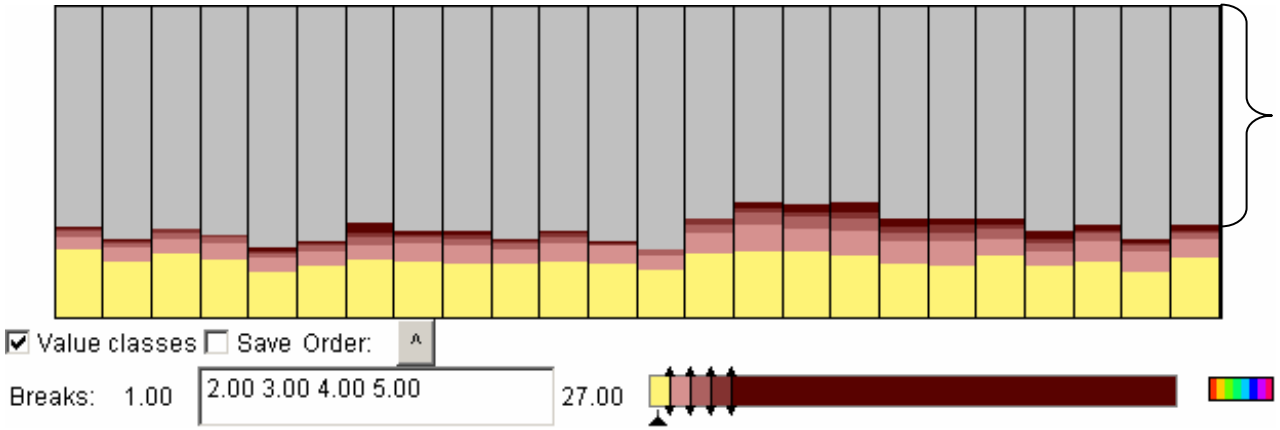


The cells where earthquakes with magnitudes 5 or more ever occurred:





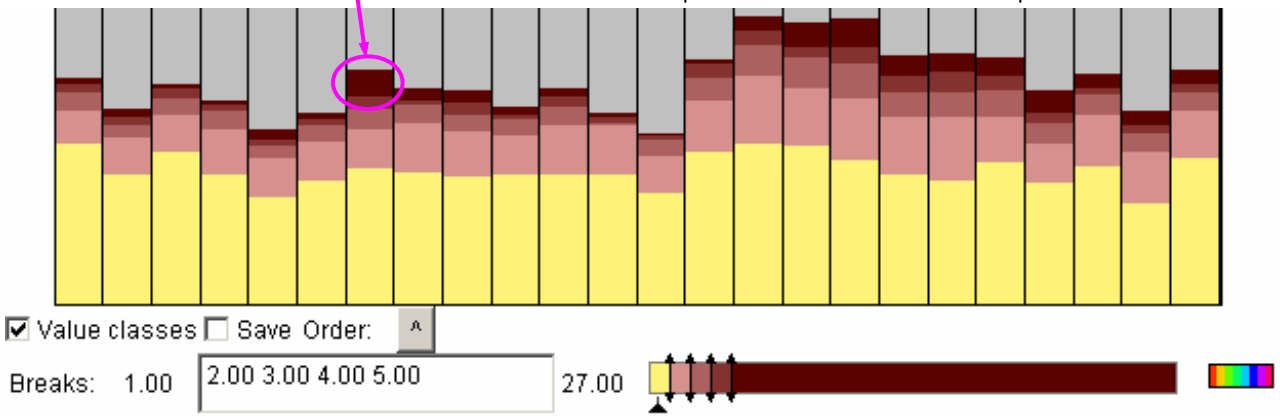
Time histogram: number of earthquakes in cells



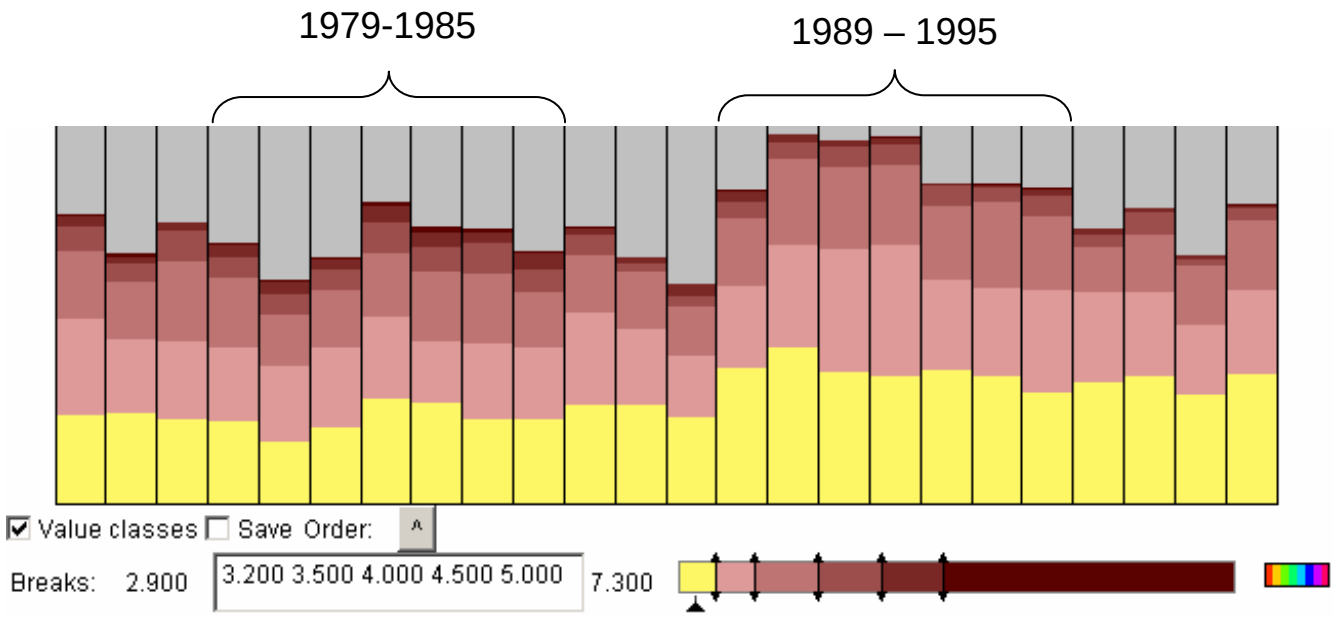
Grey represents the cells where no earthquakes occurred in the respective years

Extremely high number of cells with more than 5 earthquakes per year (1982)

In 1989 – 1995 both the number of cells with earthquake occurrences and the number of cells with more than 5 earthquakes increased as compared to the previous period

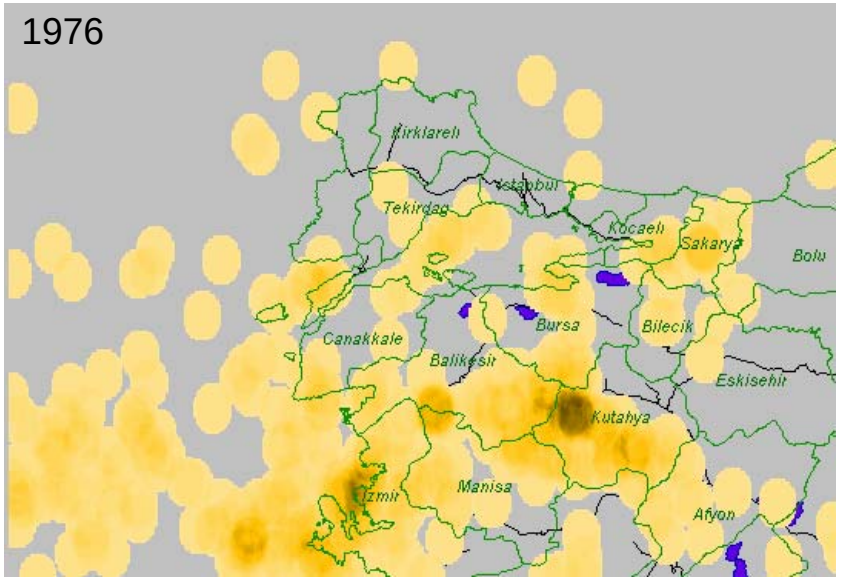


Time histogram: maximal magnitudes of earthquakes in cells



Although earthquakes occurred more frequently in 1989-1995 than before, stronger earthquakes were more frequent in 1979-1985

Computation of density surfaces*

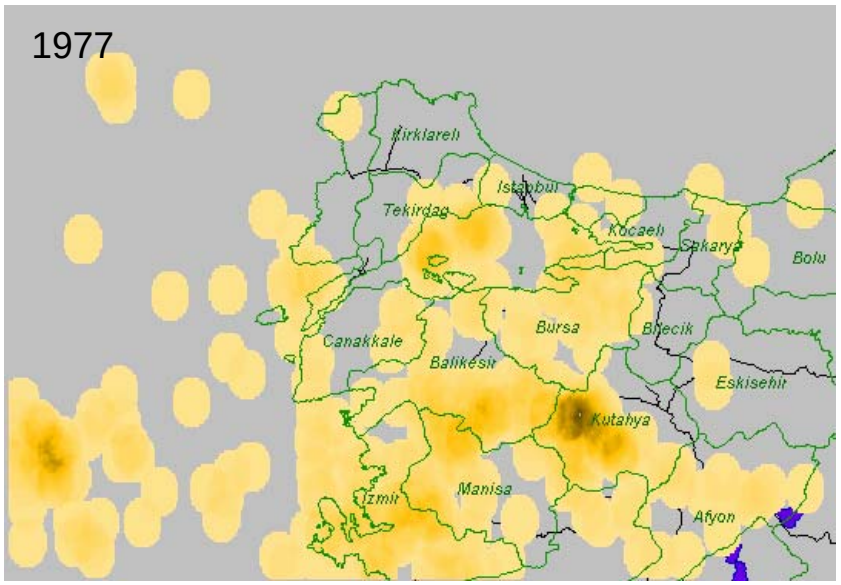


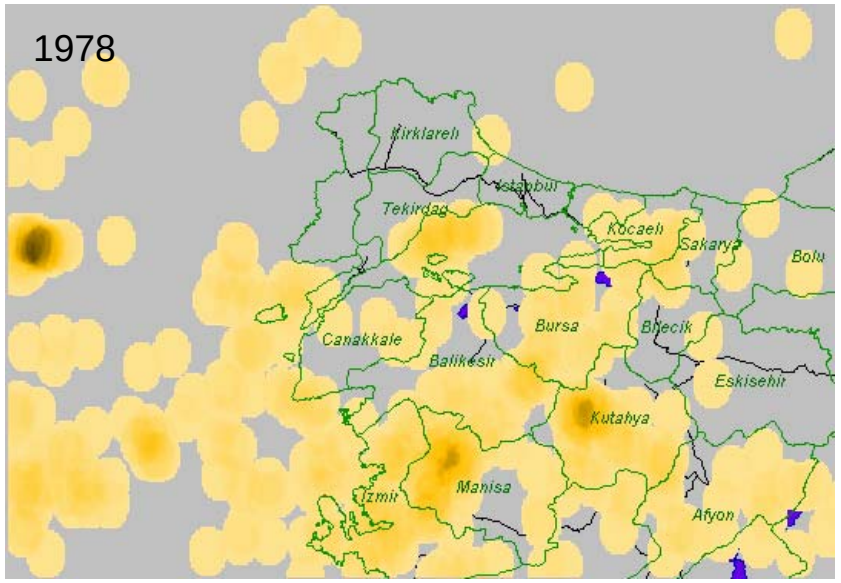
** There are better methods than the one we used for making these illustrations*

\+ Smoother image → spatial patterns better perceivable

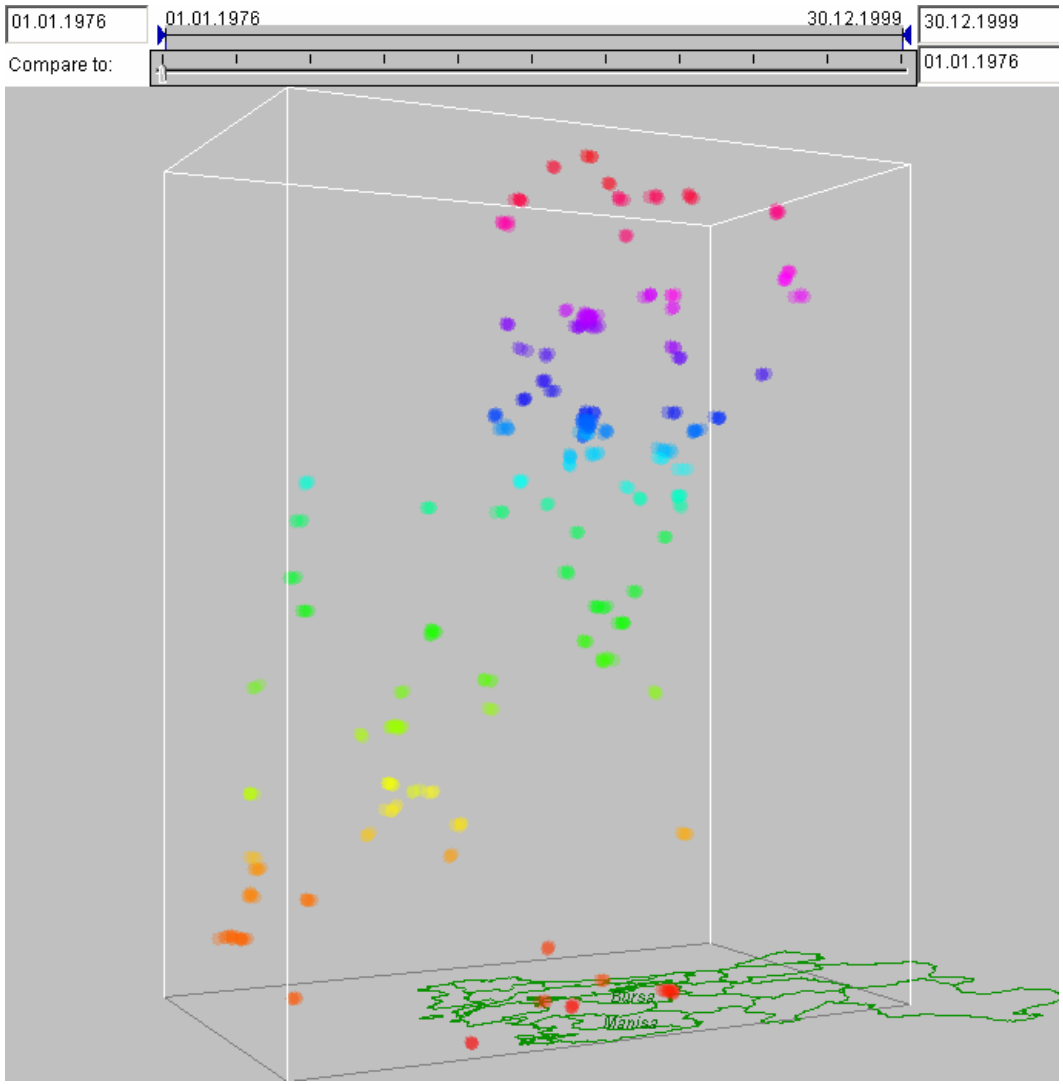
– No statistics of attribute values

– Limited visualisation and interaction possibilities





Automated detection of spatio-temporal clusters of events

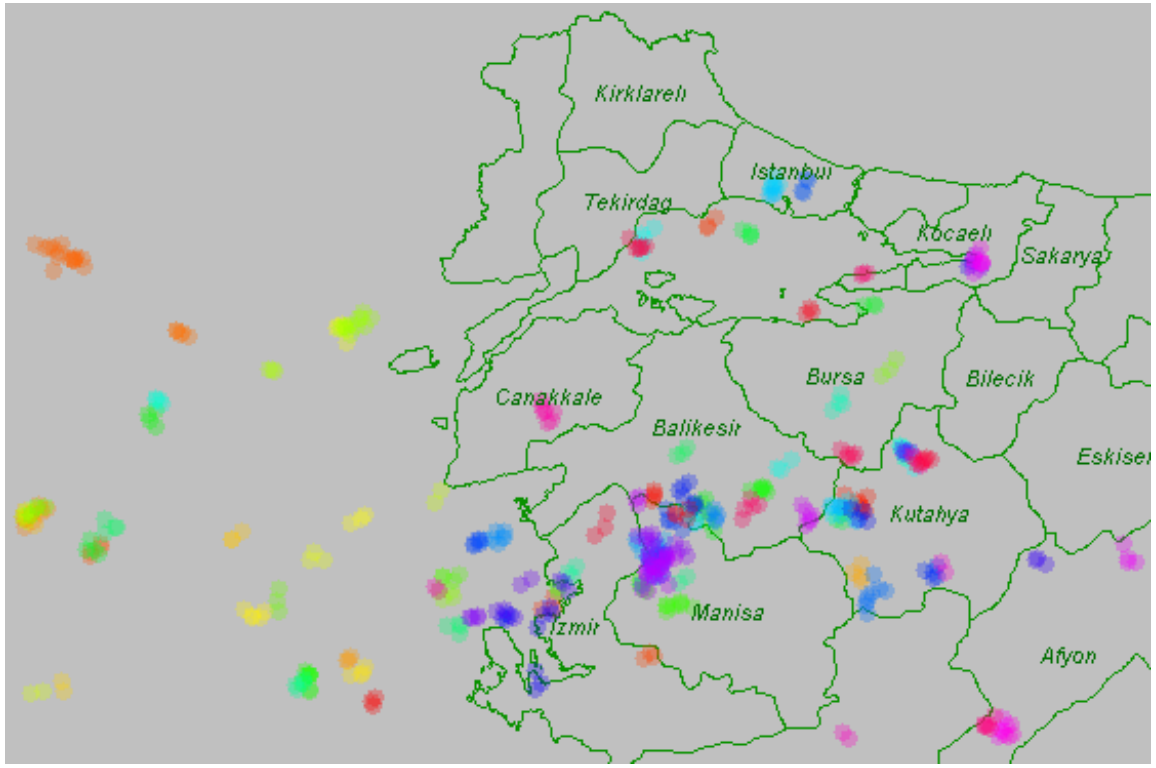


These clusters have been detected using a computational clustering method.
Parameters:
- spatial distance threshold = 10 km
- temporal distance threshold = 30 days

The number of detected clusters (108) exceeds the number of discernible colours, therefore different clusters are often coloured very similarly

The space-time cube demonstrates an interesting pattern: a west-east shift of the locations of the clusters during the studied time period

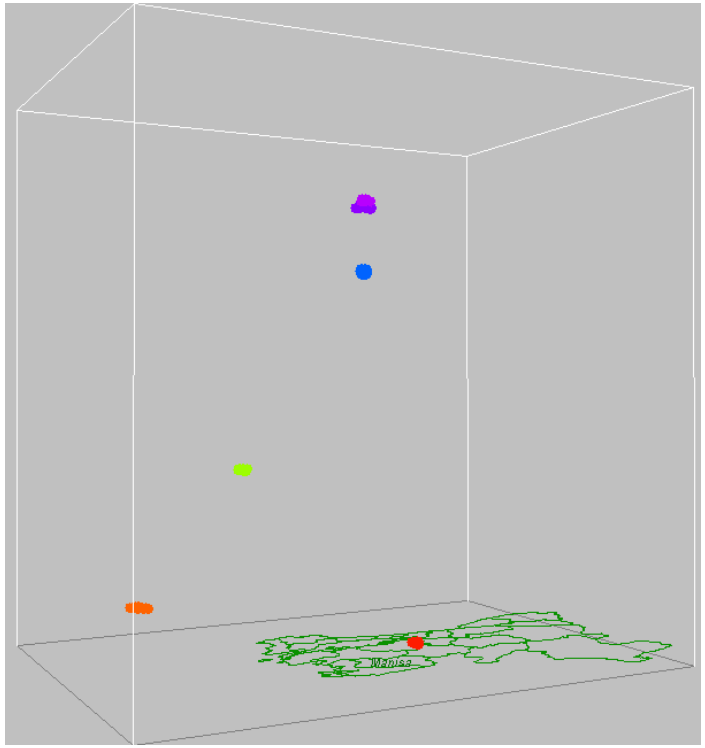
The clusters on the map



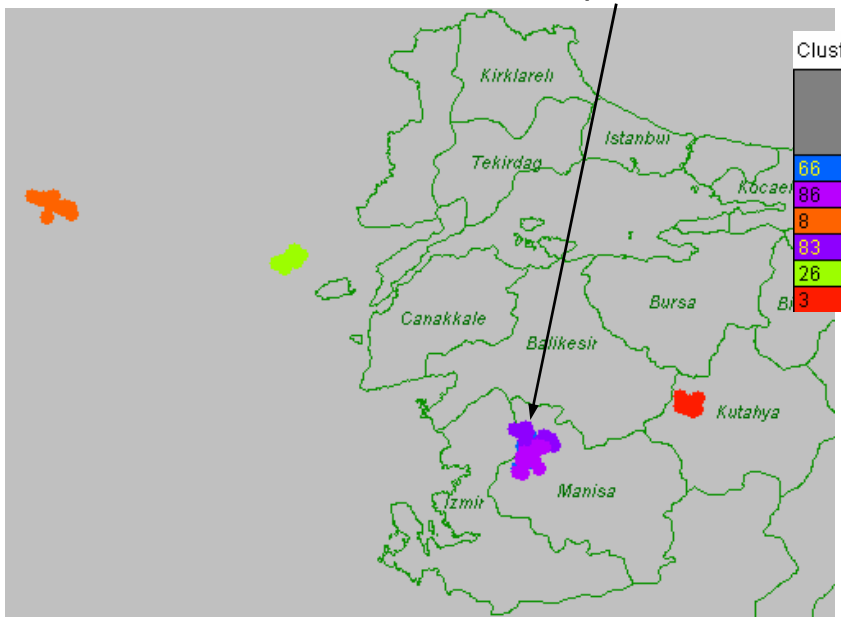
The transparent drawing of the symbols allows us to see the places of re-occurring clusters of earthquakes

The biggest clusters (10 or more events)

6 different clusters



3 of the 6 clusters are in the same place



Clusters (10km, 30 days)

	Overall frequency	Frequency after filtering
66	20	20
86	16	16
8	15	15
83	14	14
26	11	11
3	10	10

	Clusters (10km, 30 days)	Date	Magnitude
99	3	14.04.1976	3.2
107	3	21.04.1976	3.3
118	3	04.05.1976	3.2
120	3	05.05.1976	4.1
133	3	10.05.1976	4
134	3	12.05.1976	5.9
143	3	18.05.1976	3.6
144	3	19.05.1976	3.6
146	3	21.05.1976	3.6
147	3	24.05.1976	3.5

844	8	08.05.1978	4.4
845	8	08.05.1978	4.1
849	8	10.05.1978	4.6
854	8	11.05.1978	3.7
855	8	13.05.1978	4.1
865	8	19.05.1978	3.9
869	8	23.05.1978	5.9
872	8	26.05.1978	4.2
877	8	30.05.1978	3.1
879	8	02.06.1978	4.7
880	8	04.06.1978	3.7
881	8	07.06.1978	3.9
883	8	09.06.1978	3.7
889	8	12.06.1978	5
900	8	20.06.1978	6.5

3031	26	09.12.1983	4.3
3051	26	20.12.1983	4.2
3061	26	25.12.1983	4
3069	26	29.12.1983	3
3077	26	07.01.1984	3.7
3081	26	12.01.1984	3.1
3082	26	13.01.1984	3.2
3085	26	15.01.1984	2.9
3095	26	19.01.1984	3.3
3105	26	23.01.1984	3.1
3108	26	27.01.1984	3

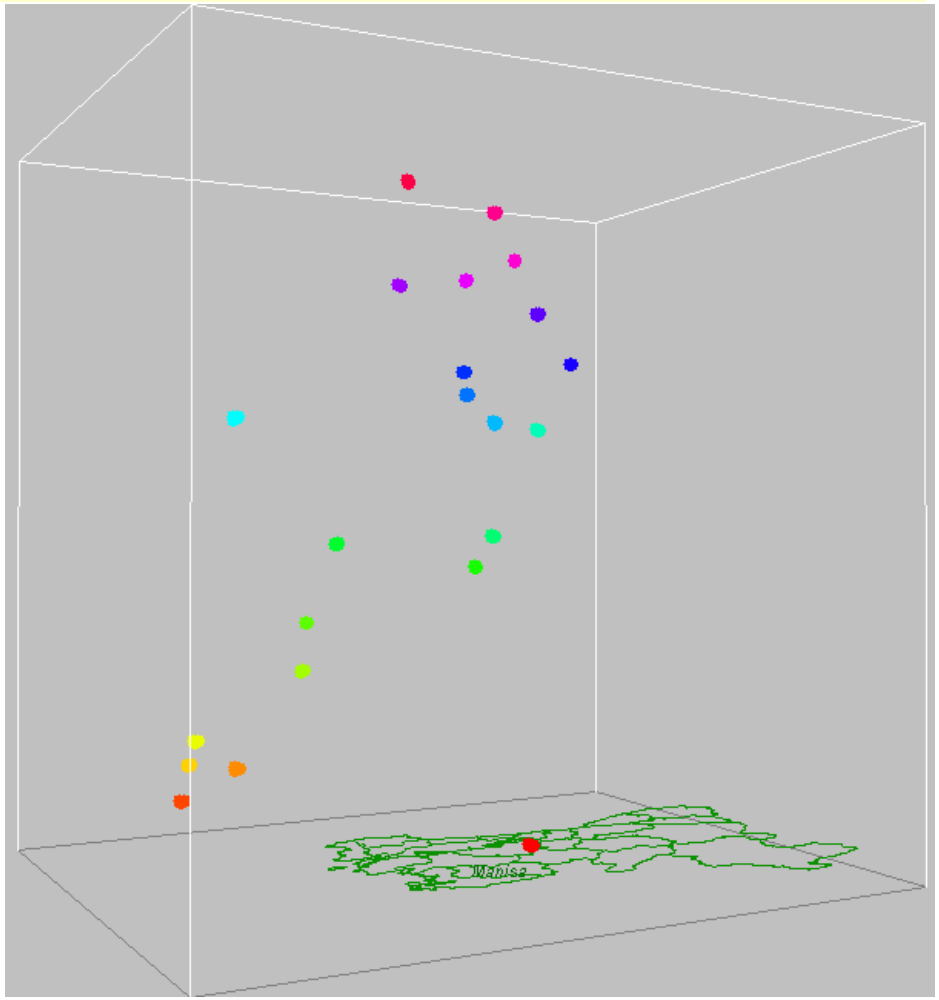
6604	66	06.04.1992	3
6613	66	09.04.1992	3
6615	66	09.04.1992	2.9
6617	66	10.04.1992	2.9
6619	66	11.04.1992	2.9
6629	66	16.04.1992	3
6634	66	18.04.1992	2.9
6639	66	20.04.1992	3.1
6643	66	22.04.1992	3
6682	66	09.05.1992	3.1
6688	66	11.05.1992	3.1
6740	66	27.05.1992	2.9
6744	66	28.05.1992	2.9
6749	66	29.05.1992	3.1
6753	66	30.05.1992	3.1
6801	66	20.06.1992	3
6802	66	20.06.1992	3.1
6821	66	28.06.1992	3.1
6833	66	05.07.1992	3
6836	66	06.07.1992	2.9

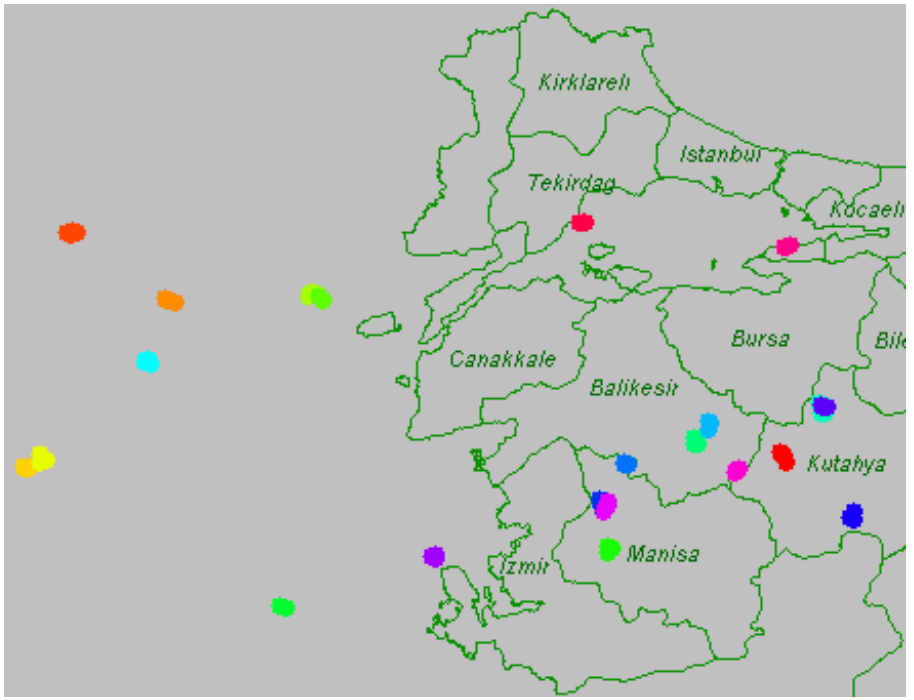
8283	83	22.01.1995	3
8286	83	23.01.1995	3.5
8291	83	26.01.1995	3.3
8301	83	29.01.1995	3.2
8305	83	30.01.1995	3.2
8306	83	31.01.1995	3.3
8308	83	01.02.1995	3.3
8323	83	05.02.1995	3.1
8324	83	05.02.1995	2.9
8328	83	06.02.1995	3
8332	83	07.02.1995	3
8339	83	11.02.1995	3.1
8357	83	22.02.1995	3.9
8377	83	07.03.1995	2.9

8422	86	08.04.1995	3.9
8427	86	11.04.1995	2.9
8436	86	19.04.1995	2.9
8438	86	20.04.1995	3
8444	86	25.04.1995	3.2
8445	86	25.04.1995	3.6
8448	86	27.04.1995	3
8451	86	28.04.1995	3.1
8453	86	29.04.1995	3.4
8454	86	01.05.1995	3.1
8459	86	07.05.1995	3
8461	86	07.05.1995	3.1
8473	86	16.05.1995	3.2
8474	86	17.05.1995	3
8495	86	30.05.1995	2.9
8501	86	02.06.1995	3.9

Sensitivity to parameters

Spatial threshold = 5km; temporal threshold = 30 days
Result: 22 clusters with sizes from 3 to 6



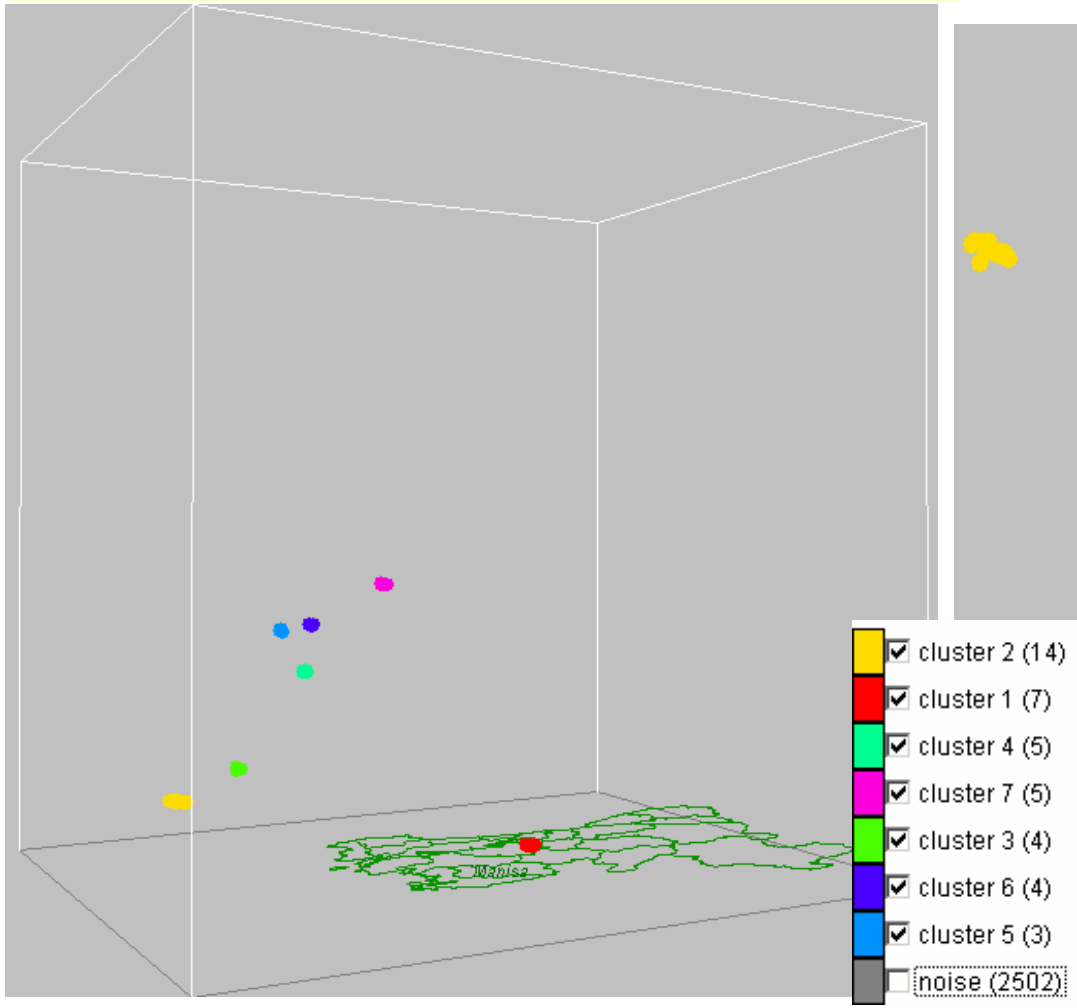


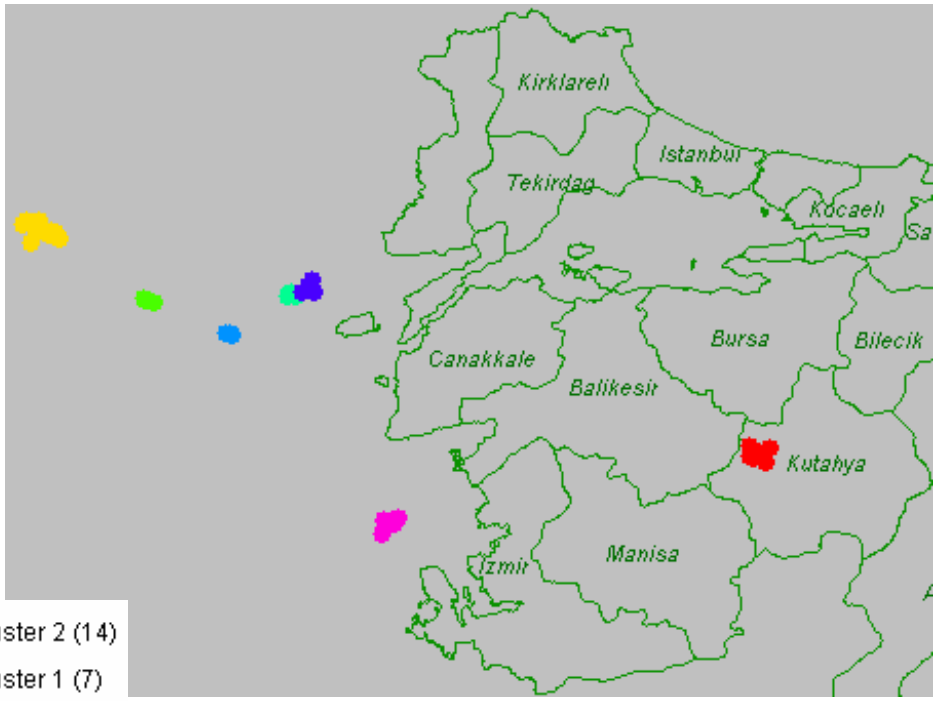
Note that the shift of the locations of the clusters from the west to the east is also visible here

Clusters of earthquakes with magnitudes at least 3.5*

Spatial threshold = 10km; temporal threshold = 30 days
Result: 7 clusters with sizes from 3 to 14

** The clustering tool can be applied to results of any filtering (e.g. according to magnitudes)*





Summary

- Spatial events: spatial objects with limited life time
- Analysis task: study the variation of spatial distribution of events and their characteristics over time
  - Detailed data (not aggregated): time maps, map series, filtering
  - Spatio-temporal aggregation (produces spatial time series)
    + techniques suitable for spatial time series
- Analysis task: detect spatio-temporal clusters
  - Visual detection using space-time cube (vertically aligned groups of symbols)
  - Automated detection using computational clustering tools

See also

- Natalia and Gennady Andrienko
  Exploratory Analysis of Spatial and Temporal Data
  A Systematic Approach
  Springer-Verlag, December 2005

  section 5.6, pp.613-630