From Temporal GIS to Dynamics GIS

GIS day presentation at University of Kansas

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University of Oklahoma

Temporal RDBMS

Stock	Price	From	To
IBM	16	10-7-91 10:07am	10-15-91 4:35pm
IBM	19	10-15-91 4:35pm	10-30-91 4:57pm
IBM	16	10-30-91 4:57pm	11-2-91 12:53pm
IBM	25	11-2-91 12:53pm	11-5-91 2:02pm

Snodgrass and Ahn (1985):Time-stamped tuples (rows)

1993

County	Population	Avg. Income
Nixon	17,000	20,000

1994

County	Population	Avg. Income
Nixon	20,000	19,800
Cleveland	35,000	32,000

1995

County	Population	Avg. Income
Nixon	20,900	21,000
Cleveland	35,000	32,000
Oklahoma	86,000	28,000

Gadia and Vaishnav (1985): Time-stamped tables

Name	Salary	Department
[11,60] John	[11, 49] 15K [50, 54] 20K [55, 60] 25K	[11,44] Toys [45, 60] Shoes
[0,20] U [41,51] Tom	[0, 20] 20K [41, 51] 30K	[0, 20] Hardware [41, 51] Clothing
[0,44] U [50, Now] Mary	[0,44] U [50, Now] 25K	[0,44] U [50, Now] Credit

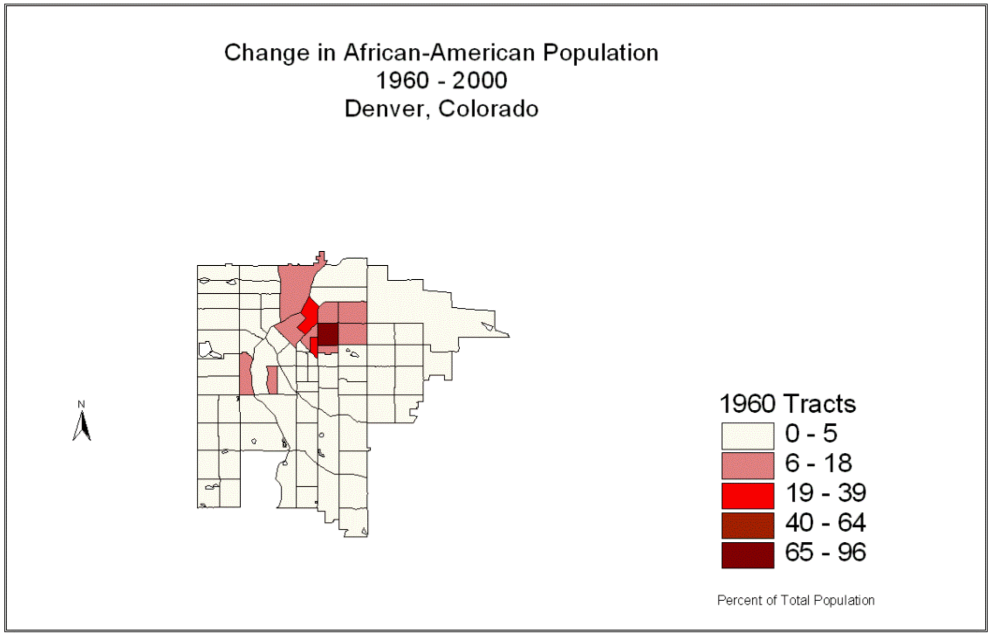
Gadia and Yeung (1988): Time-stamp values (cells).

Temporal GIS

- Snapshot: Time-stamping layers
- Space-time composite: Time-stamping spatial objects (rows)
- Spatiotemporal object: Time-stamping attributes

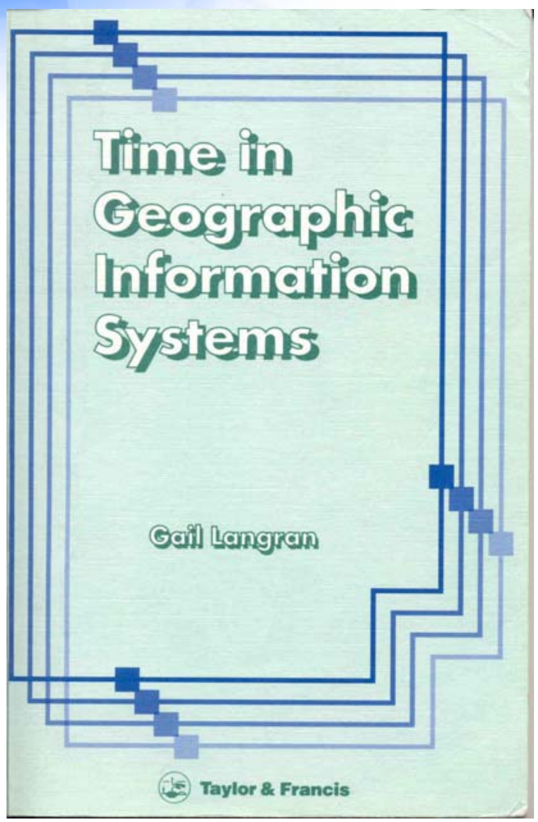
Snapshots

- Temporal time sets

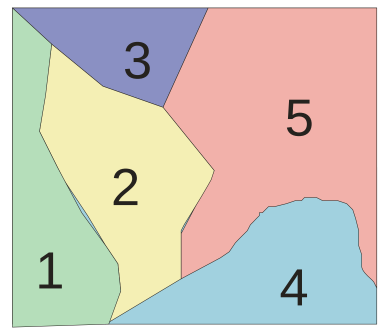


Metro Denver Temporal GIS Project by Temporal GIS, Inc.
http://www.rrcc-online.com/~gey235/bpop.html

Space-Time Composite



- Spatial change over time
  - History at location
  - Cadastral mapping

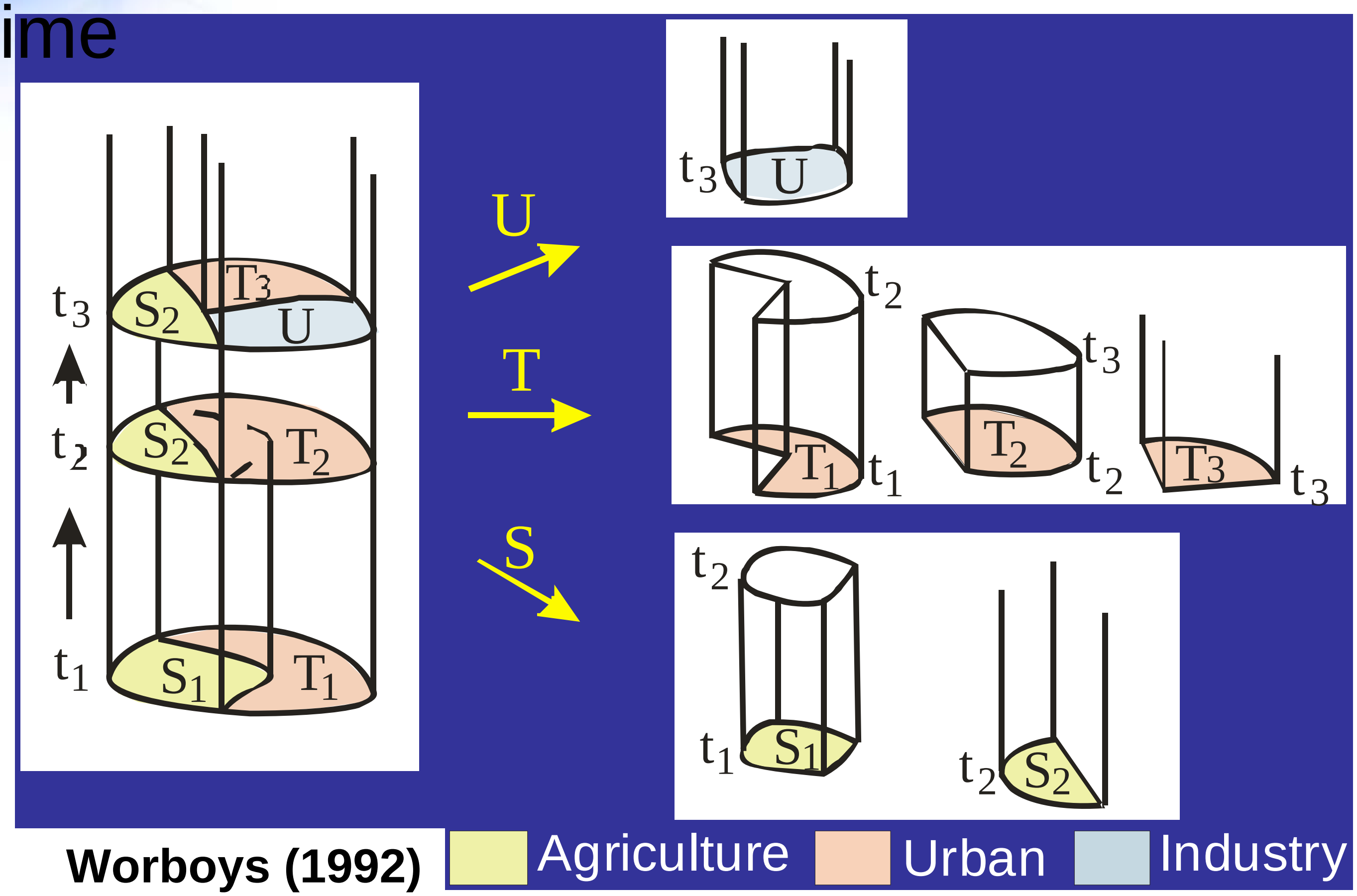


Poly id	T_1	T_2	T_3	T_4
1	Rural	Rural	Rural	Rural
2	Rural	Urban	Urban	Urban
3	Rural	Rural	Urban	Urban
4	Rural	Rural	Urban	Urban
5	Rural	Rural	Rural	Urban

Langran and Chrisman (1988)

Spatiotempoal Object Model

- Spatial objects with beginning time and ending time



Worboys (1992)

Change at Location

- History at a location
- Nothing moves

Space → **Time** → **Semantics**

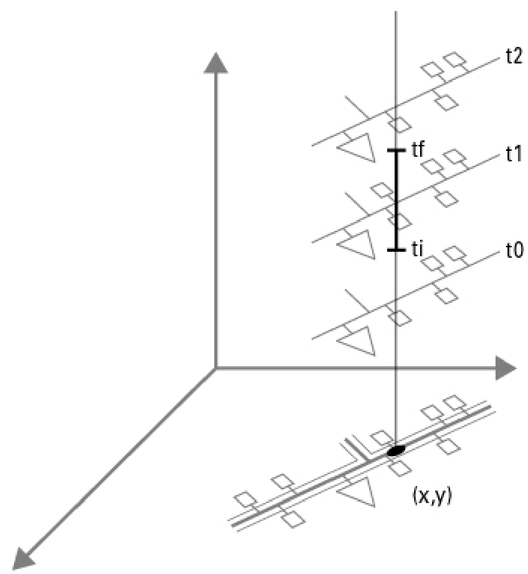
Geographic semantics = something (concrete or abstract) meaningful in geographic worlds, including objects, fields, ideas, authority, etc.

Commercial TGIS

- 4Datalink (2002)
- STEMgis (2003?)
- TerraSeer (2004)

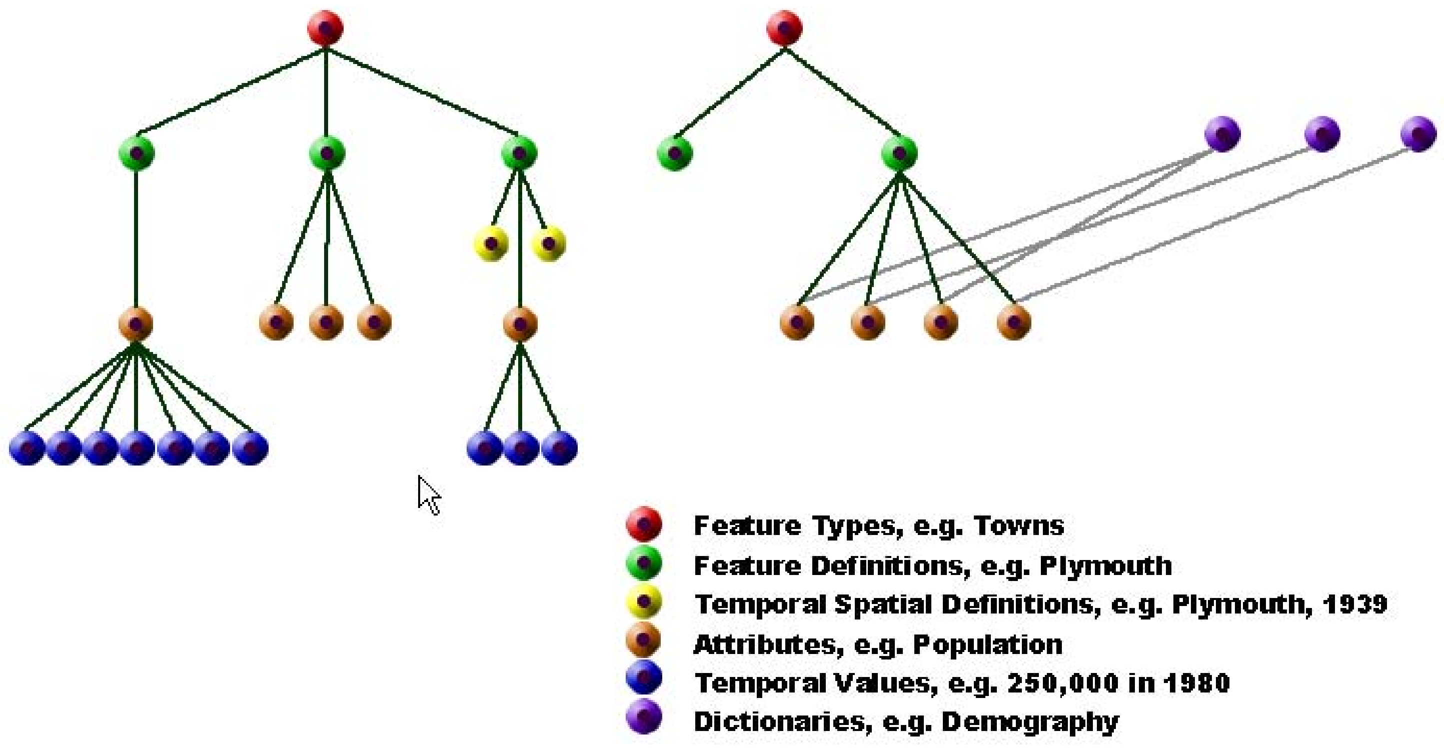
4Datalink (2002)

- Time Travel Through Data
- Spatiotemporal objects with initial time (t_i) and finishing time (t_f)
- AM/FM applications
- Allow no change in geometry or attribute



STEMgis (2003)

- Time-stamp spatial objects
- Hierarchical database



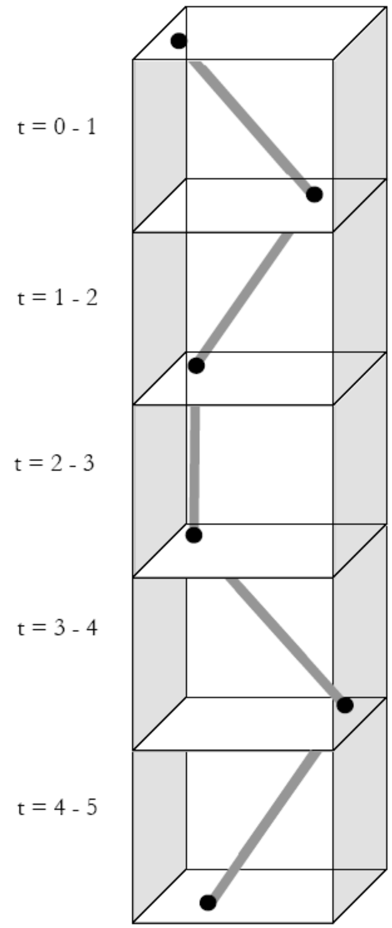
TerraSeer (2004)

- Object chains
- Public health and surveillance

Table of Object

Starting Locations

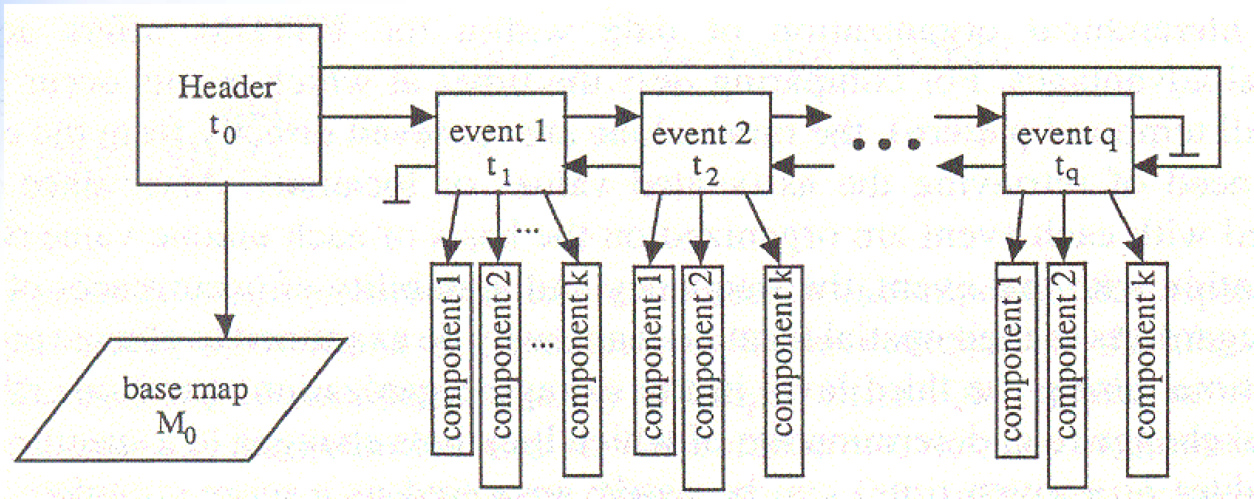
x	y	t
2	2	0
5	4	1
2	4	2
2	5	3
6	5	4
3	2	5



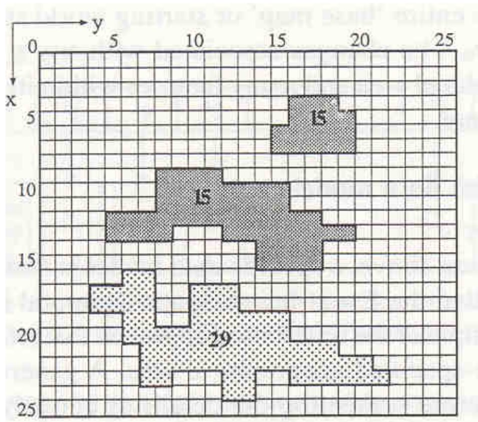
Drawbacks

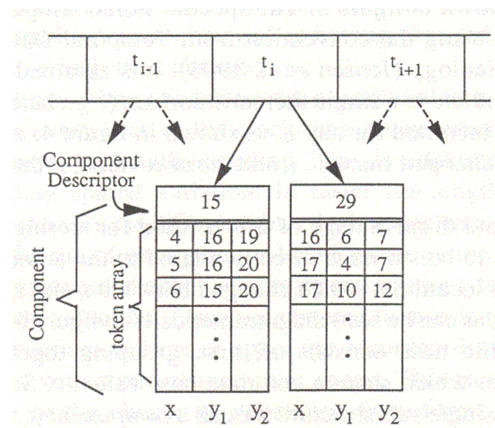
- Mostly point data
- Change-based information
- Uniform change
- Do not consider:
  - Change with spatial variation
  - Split
  - Merge
  - Development (temporal lineage)

TGIS based on "event" and "change"



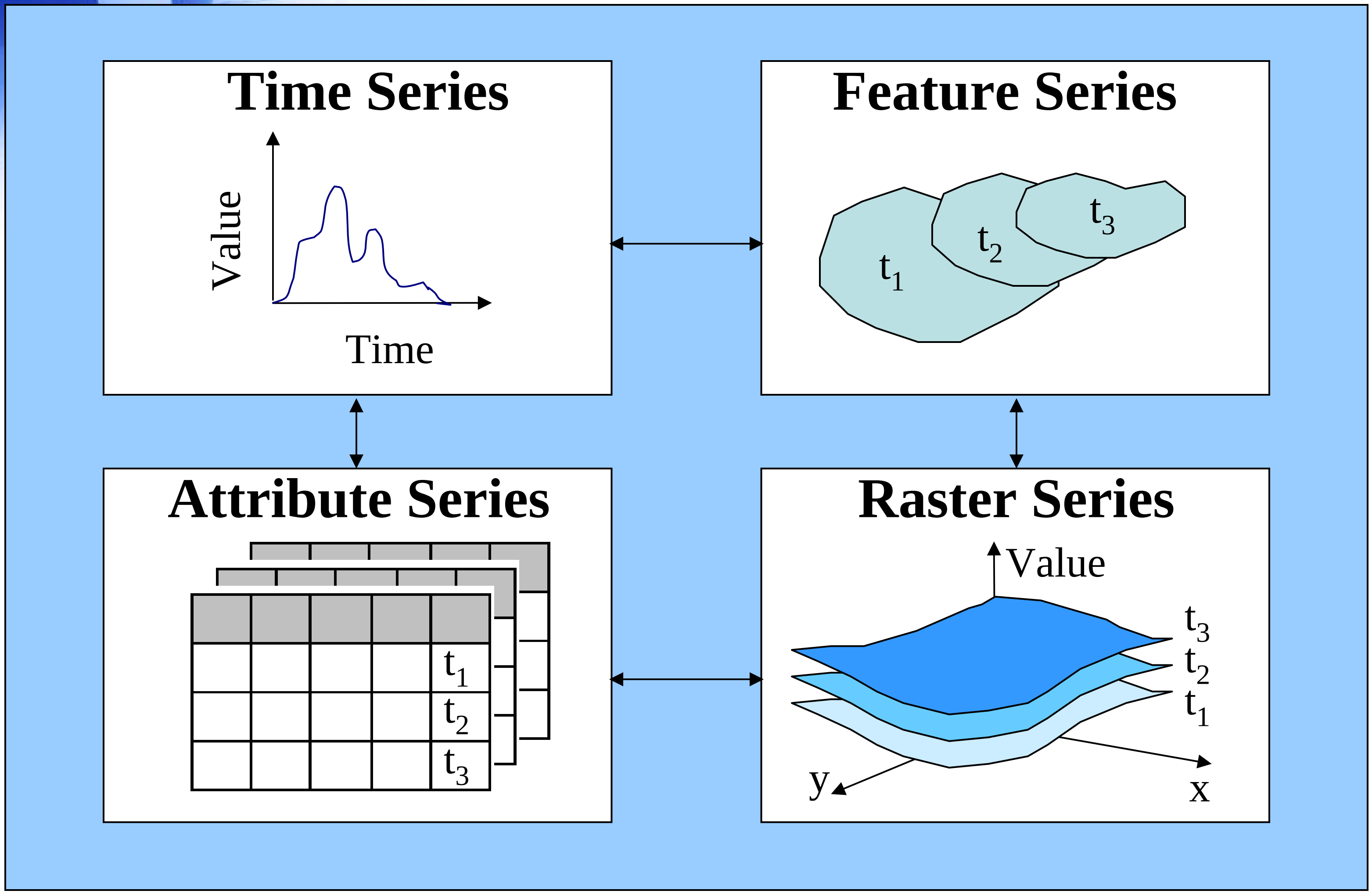
Changes from t_{i-1} to t_i





Peuquet and Duan (1995) Event-based SpatioTemporal Data Model (ESTDM)

ArcHydro (Maidment 2004)

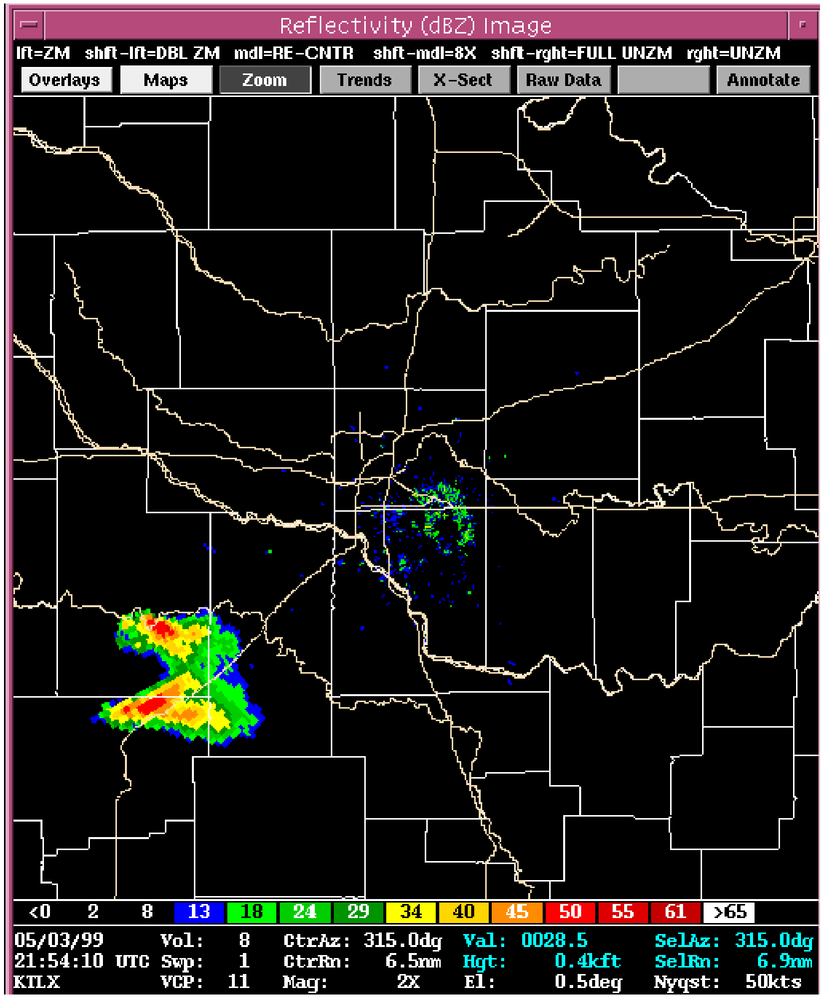


Geographic Dynamics

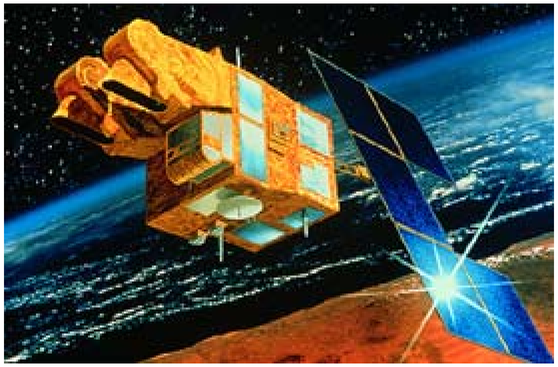
May 3 1999

Oklahoma City

Tornado outbreaks



From what we have …



- Observations: mostly captured by satellites, radars, or ground-based stations at discrete points in time.
- Raster or point-based data
- Point-based data: may be transformed to raster data through spatial interpolation.

To what we want

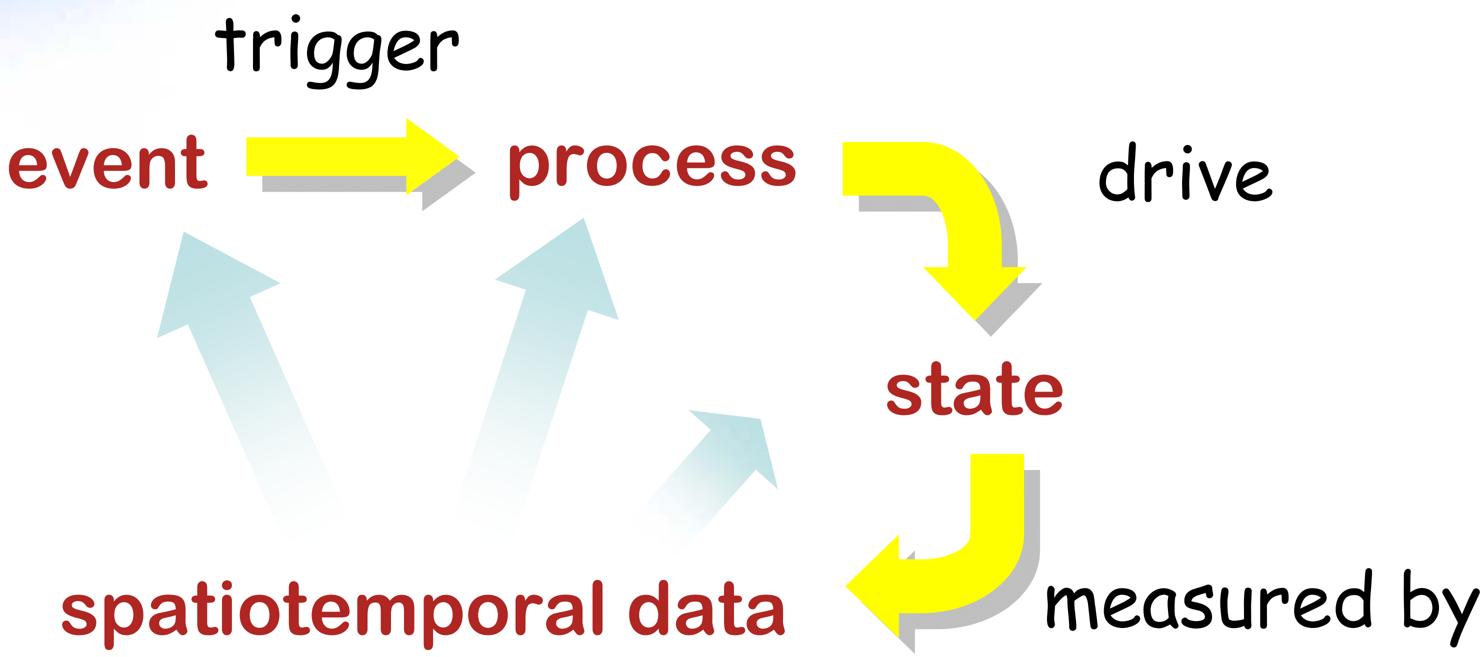
Information beyond pixels and points:

- How does “something” vary in space?
- How does “something” change over time?
- How does “something” progress in space?
- How does “something” develop over time?
- How often do similar “things” occur in space and time?

Want to know about “something”

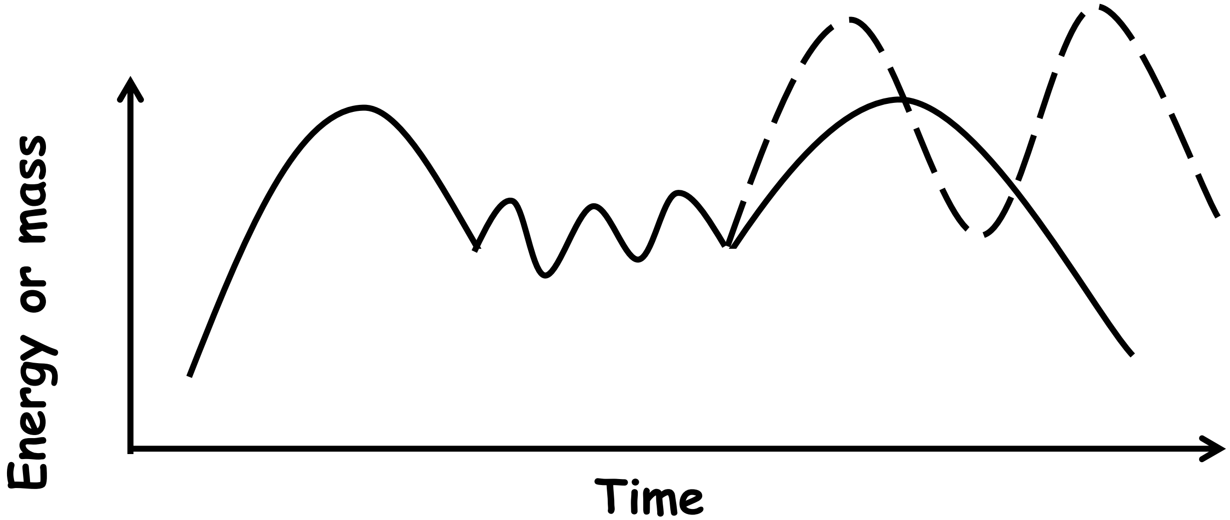
What is “something”?

Event, Process and State



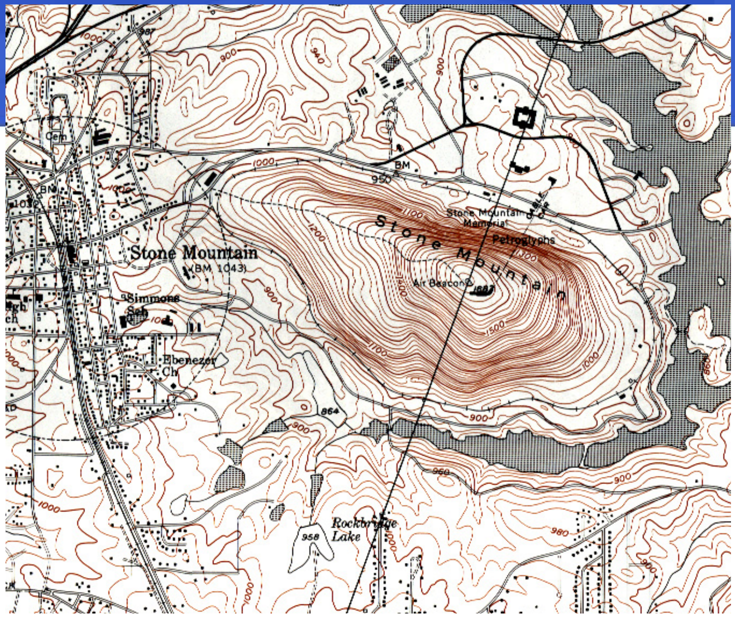
A system's perspective

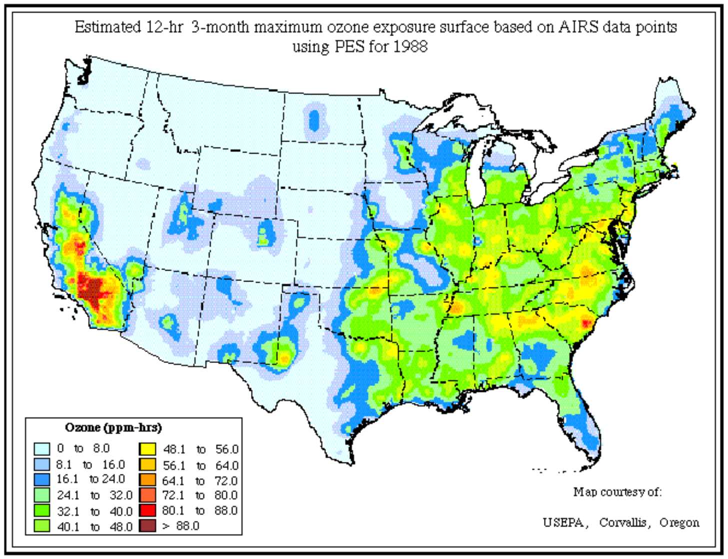
- An event introduces additional energy or mass into a system
- Triggers processes to adjust the system

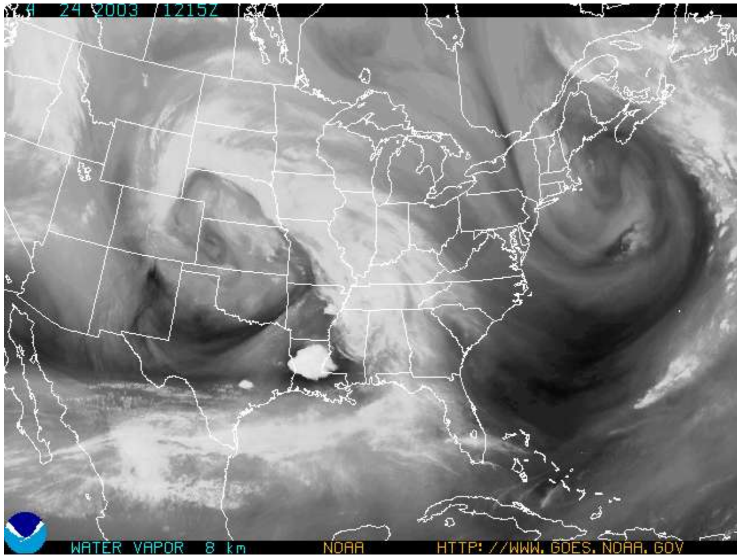


State

- Fields
- Objects
- Fields of objects
- Objects of fields







Beyond states in geography

- Event: an incidence of rain
- Process: the development of a weather system (e.g. convective storms or frontal passage)
- State: the distribution of rain at a given time
- Data: images or observations from in-situ sensors taken at a give time across space)

An event indicates the start or end of processes.
A process drives transitions of states.
A state is sampled by data.

Issues

- Scale
- Granularity
- uncertainty

Represent geographic dynamics

Shift our emphasis

- From “storage”
  - Observation based
  - Organize data accordingly how data were collected by sensors or observers
- To “analysis”
  - Process based
  - Data are results of processes and should be organized accordingly

Now our problem is…

How to represent geographic processes in GIS databases?

So that …

we can develop GIS query and analytical functions to characterize behaviors of processes in space and time.

i.e. to enable information support for geographic dynamics

Considerations

- Integration of fields and objects;
- Hierarchy of events, processes, and states

Koestler (1967): holons

- Duality of a holon:
  - <u>Self-assertive tendency</u>: preserve and assert its individuality as a quasi autonomous whole;
  - <u>Integrative tendency</u>: function as an integrated part of an existing or evolving larger whole.

objects

fields

- Field of objects: rainfield of storms
- Object of fields: storm of rainfields

Weinberg (1975)
General Systems Theory

- Small-number simple systems
  - Individuals' behaviors
  - Mathematical
- Large-number simple systems
  - Collective behaviors
  - Statistics
- Middle-number complex systems
  - Too large for math
  - Too small for stats
  - Both individually and collectively

Hierarchy Theory Is For …

Middle-number complex systems in which elements are…

- Few enough to be self-assertive and noticeably unique in their behavior.
- Too numerous to be modeled one at a time with any economy and understanding.

A hierarchy is necessary to understand middle-number complex systems (Simon 1962).

Hierarchy Theory (HT)

- Reality may or may not be hierarchical.
- Hierarchy structures facilitate observations and understanding.
- Processes at higher levels constrain processes at lower levels.
- Fine details are related to large outcomes across levels.
- Scale is the function that relates holons and behavior interconnections across levels.

Key HT Elements

- Grain (resolution)
- Scale (extent)
- Identification of entities
- Hierarchy of levels
- Dynamics across levels
- Incorporation of disturbances

Grain and Scale

- Related to observations and measurements.
- The observed remains the same.
- Grain and scale determine what and how much of the observed that the observer is able to obtain for examination.

Identification of Entities

- Definitional entities:
  - Observer- generated to outline what is expected to examine.
  - Fixed the level of observation at the outset.
- Empirical entities:
  - Observed and measured in the field.

Hierarchy of Levels

- Levels of organization.
  - For definitional entities.
  - Theoretical structures how things are organized.
  - Predictive models.
- Levels of observations.
  - For empirical entities.
  - Derived from empirical studies.
  - Provide suggestions to fine tune the levels of organization.

Dynamics Across Levels

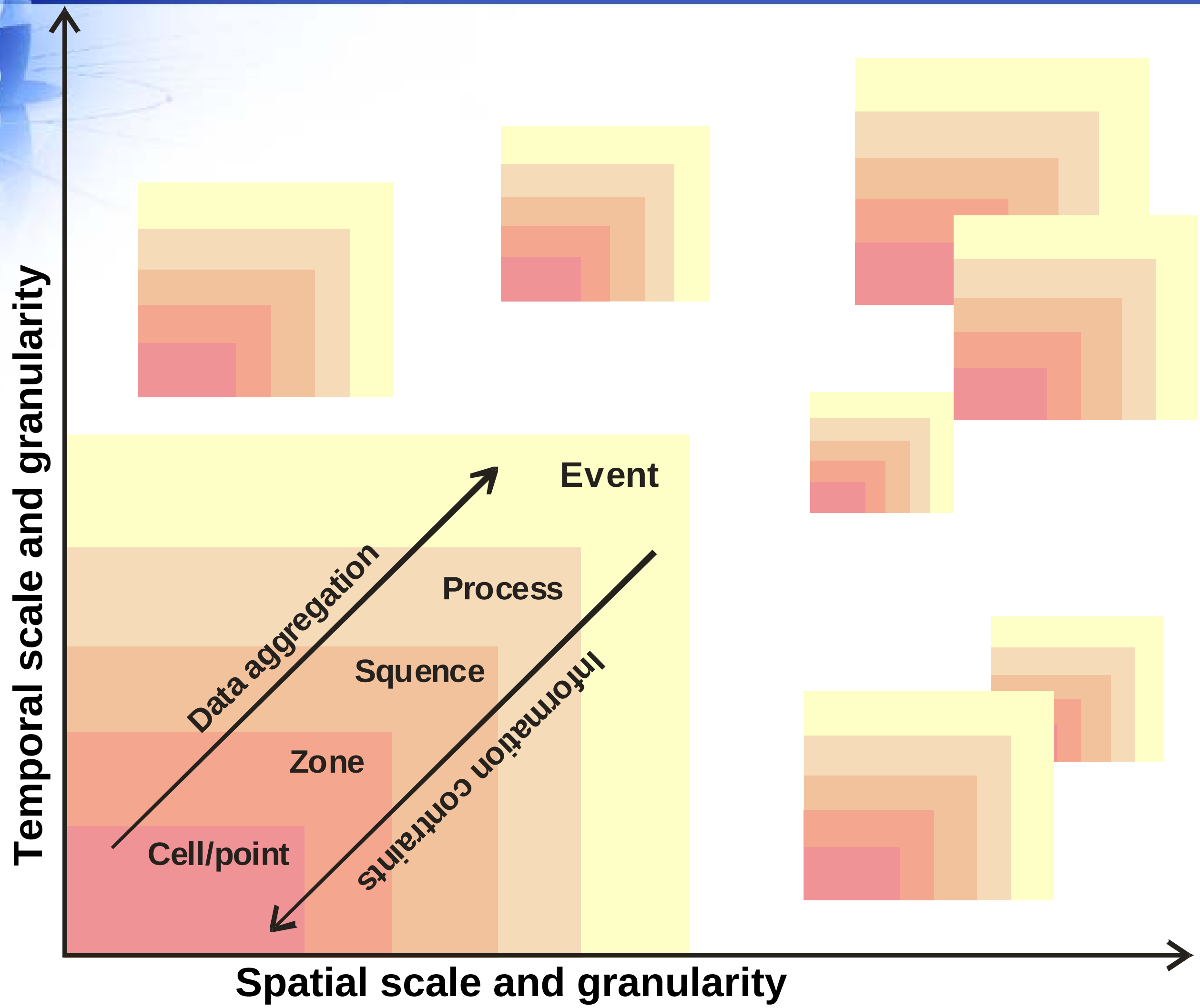
- Hierarchical levels are dynamically and functionally related.
- Higher-level entities in a non-nested hierarchy:
  - Behave at a lower frequency.
  - Provide a context and set environmental constraints to the lower-level entities.
- In a nested hierarchy:
  - The behavior of higher-level entities is determinable from knowledge of its component levels.

Incorporation of Disturbances

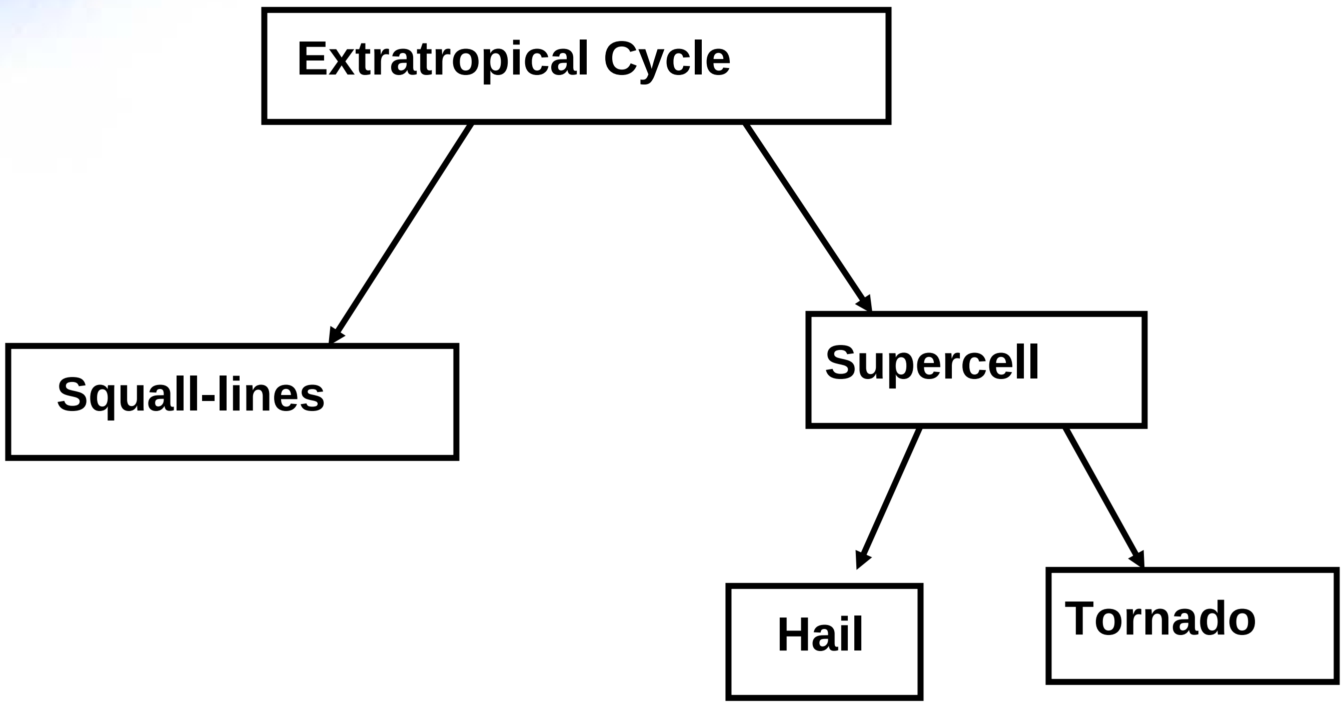
The evolvement of a hierarchy system to handle disturbances:

- Collapse to a diffuse, low level of organization; Or
- Move to a higher level of organization via a new set of upper-level constraints.

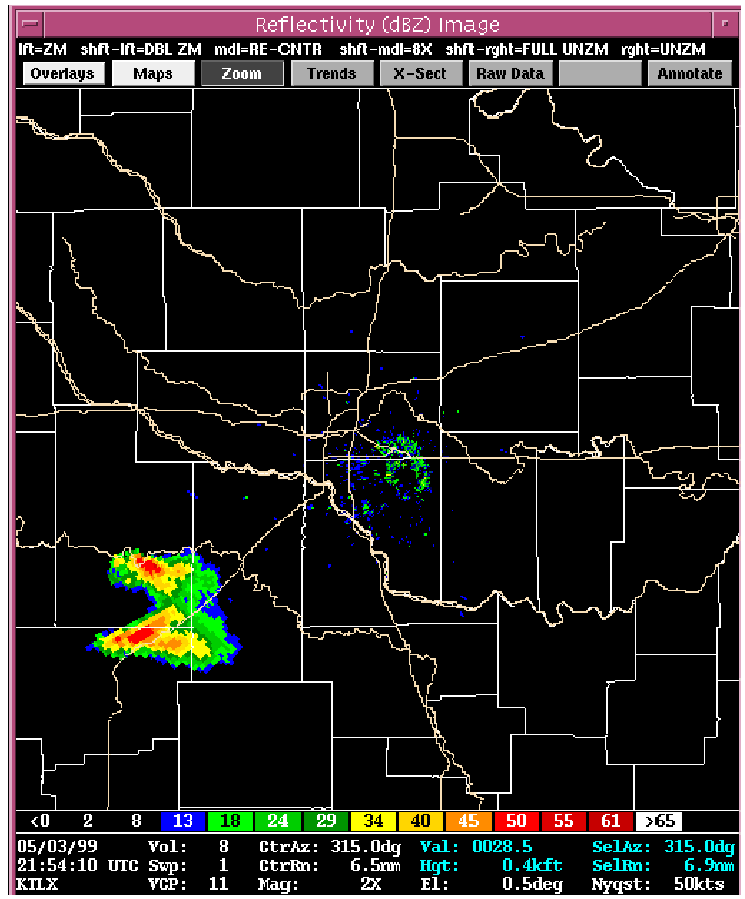
Levels of fields and objects



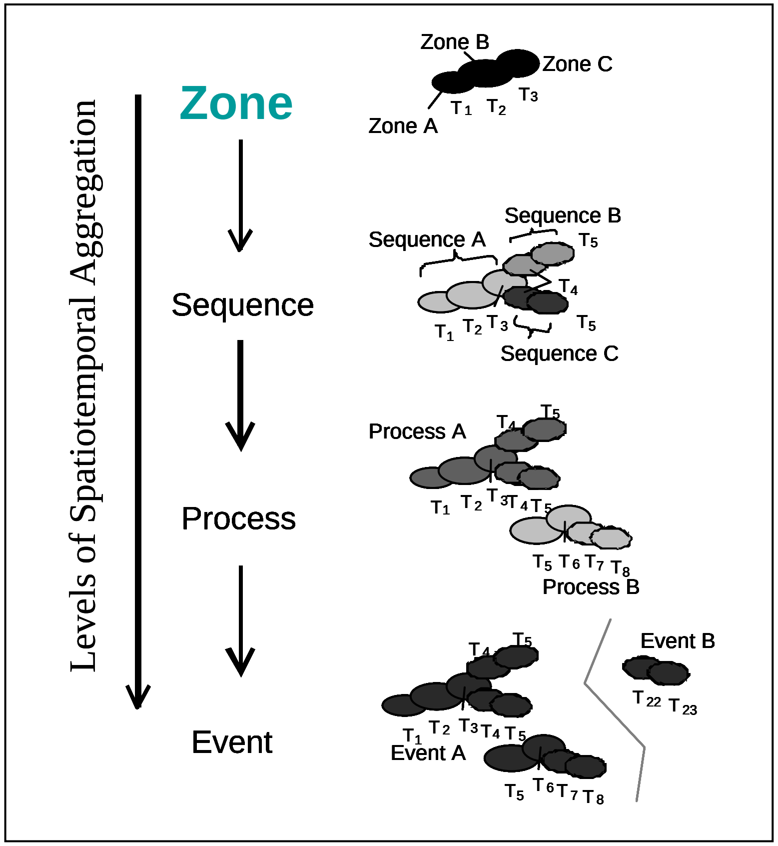
Levels of Organization

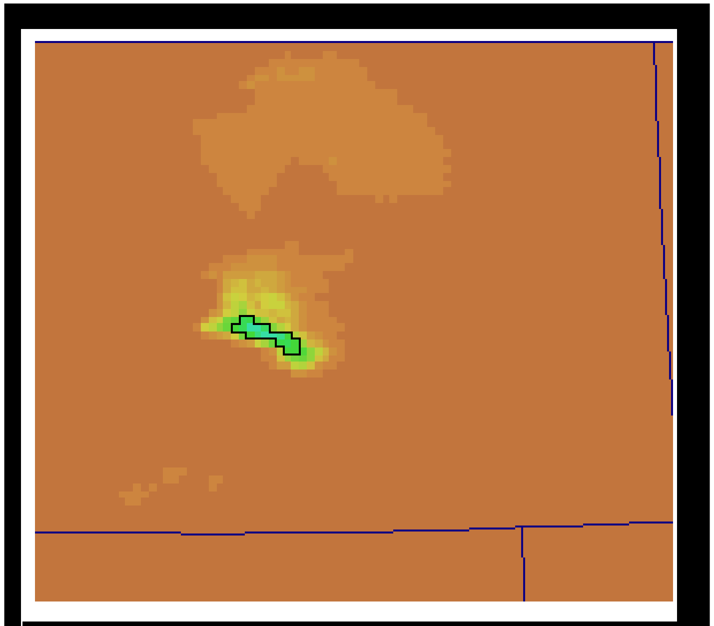


Data, States, Processes, and Events



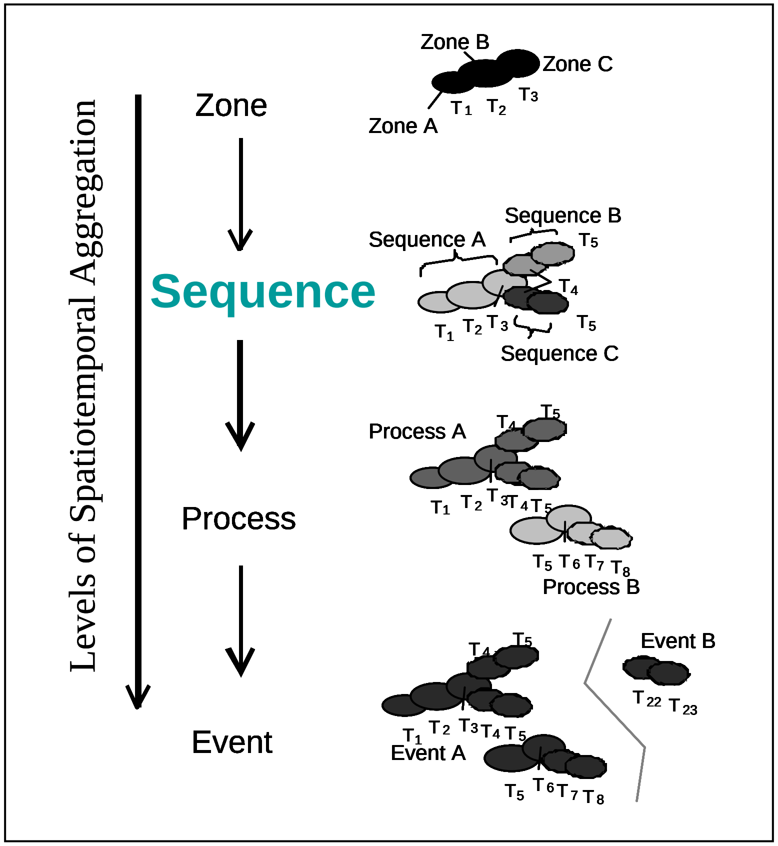
Zones

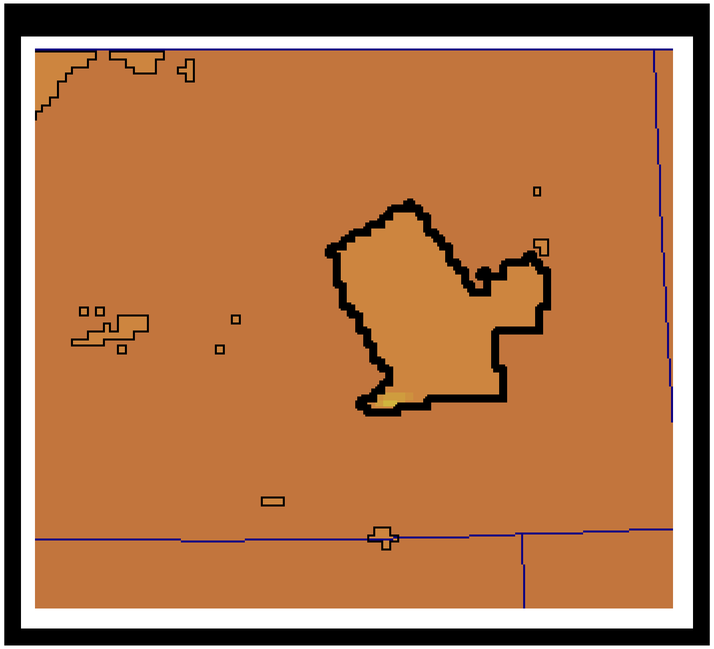




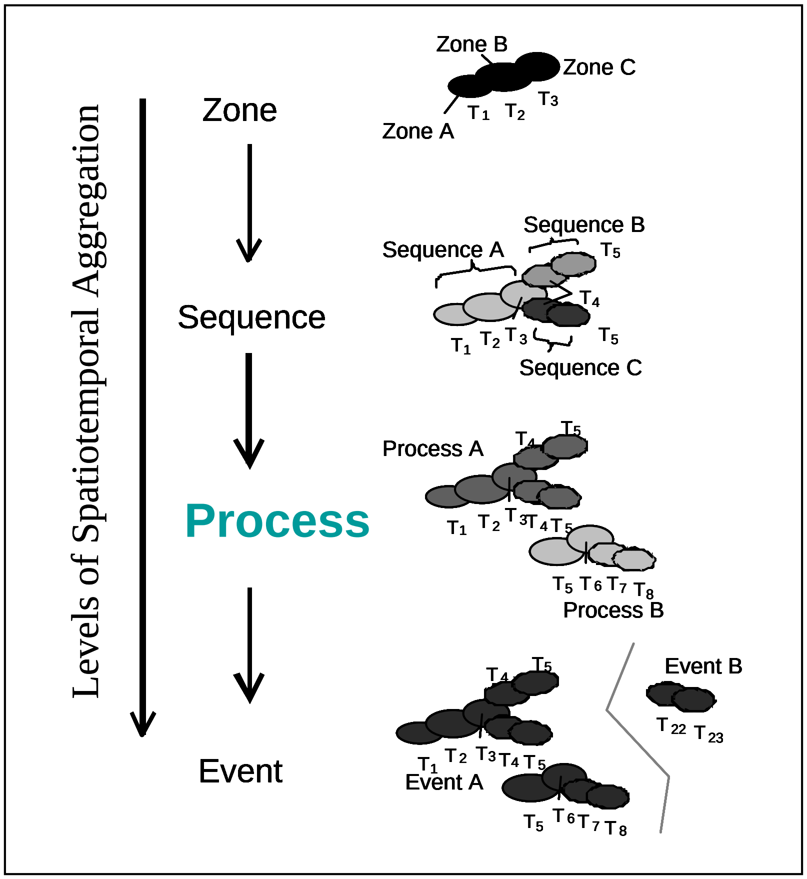
4 mm/hr threshold

Sequences

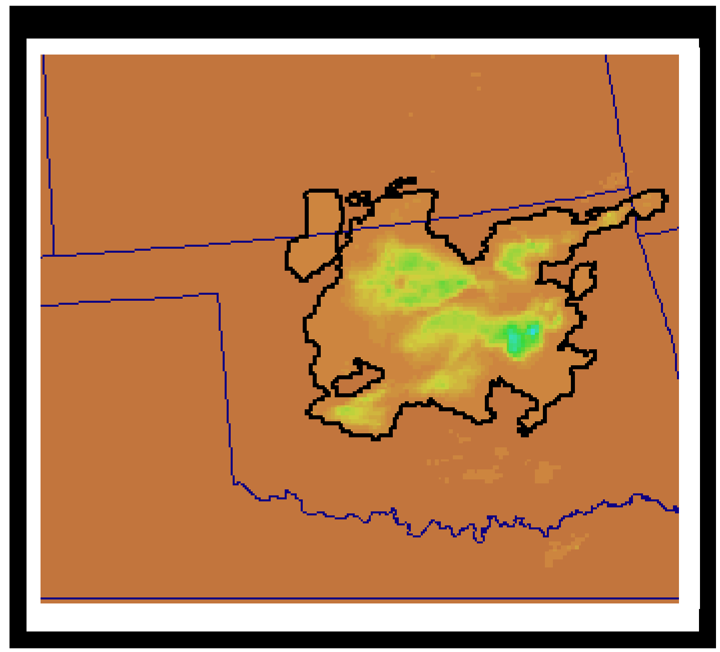

Levels of Spatiotemporal Aggregation
Zone
Sequence
Process
Event
Zone B
Zone C
Zone A
Sequence A
Sequence B
Sequence C
Process A
Process B
Event A
Event B



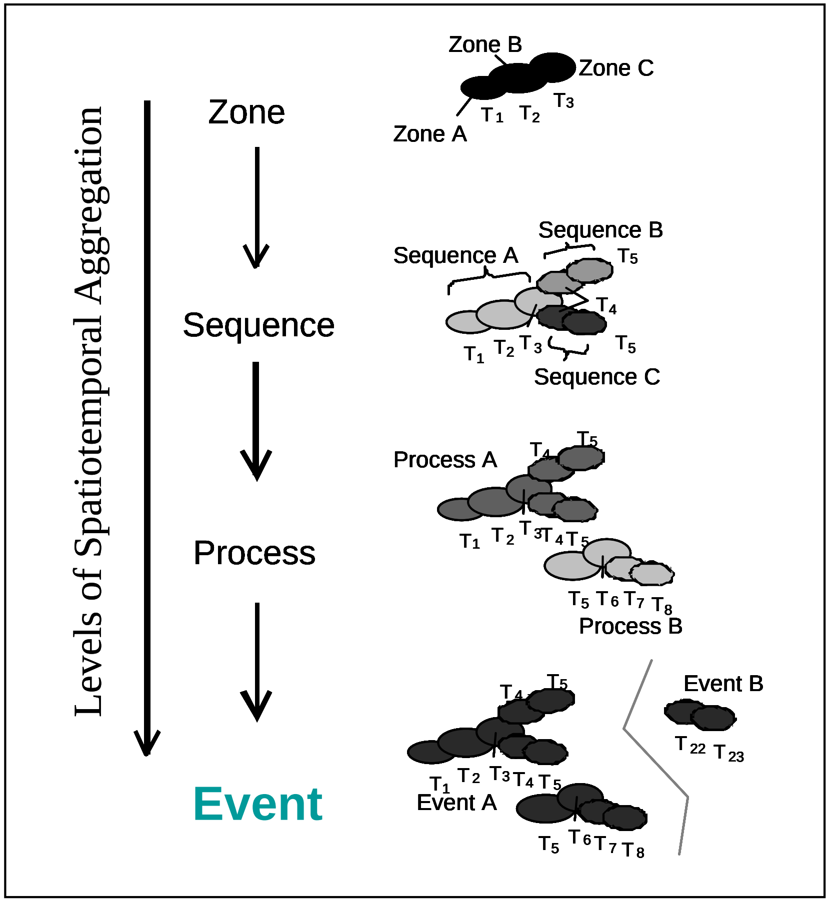
Process

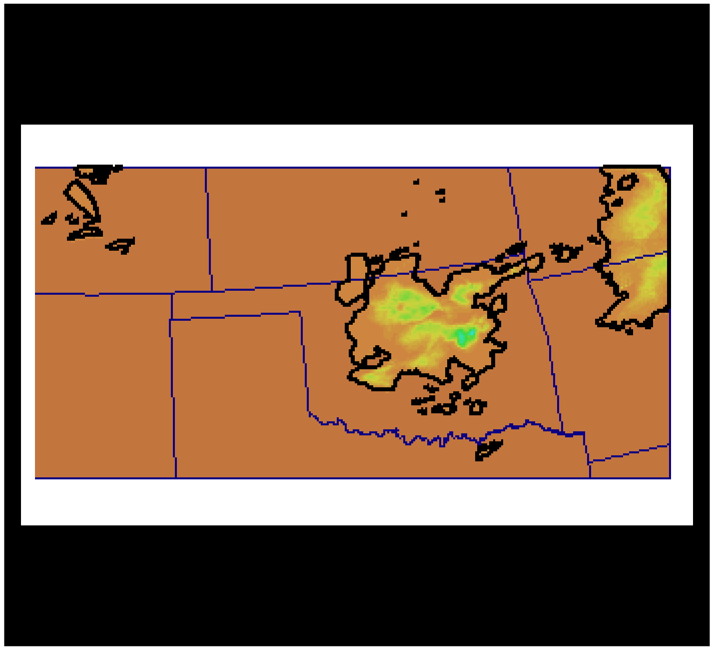


Levels of Spatiotemporal Aggregation
Zone
Sequence
Process
Event
Zone B
Zone C
Zone A
T_1 T_2 T_3
Sequence B
Sequence A
T_5
T_4
T_1 T_2 T_3
T_5
Sequence C
Process A
T_4 T_5
T_1 T_2 $T_3 T_4 T_5$
T_5 T_6 T_7 T_8
Process B
Event B
T_4 T_5
T_{22} T_{23}
T_1 T_2 $T_3 T_4 T_5$
Event A
T_5 $T_6 T_7 T_8$

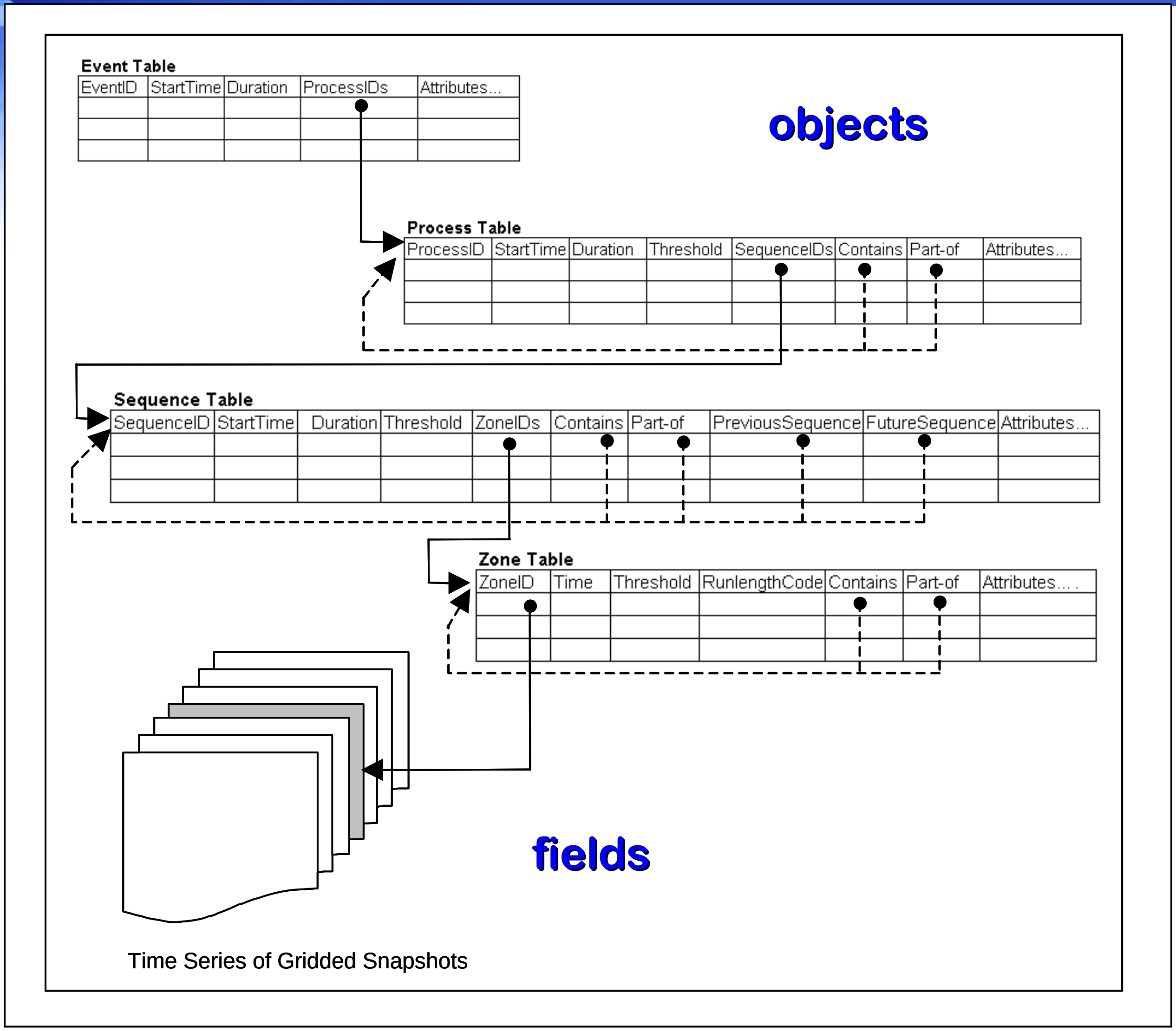


Event


Levels of Spatiotemporal Aggregation
Zone
Sequence
Process
Event
Zone B
Zone C
Zone A
T1 T2 T3
Sequence A
Sequence B
Sequence C
T1 T2 T3 T4 T5
Process A
Process B
T1 T2 T3 T4 T5
T5 T6 T7 T8
Event A
Event B
T22 T23



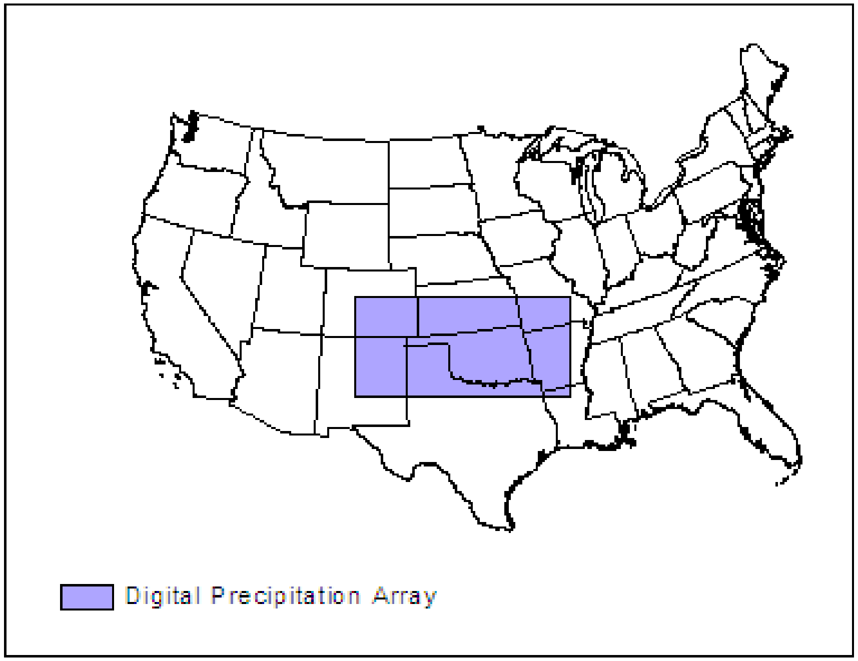
Data Structures



Disco

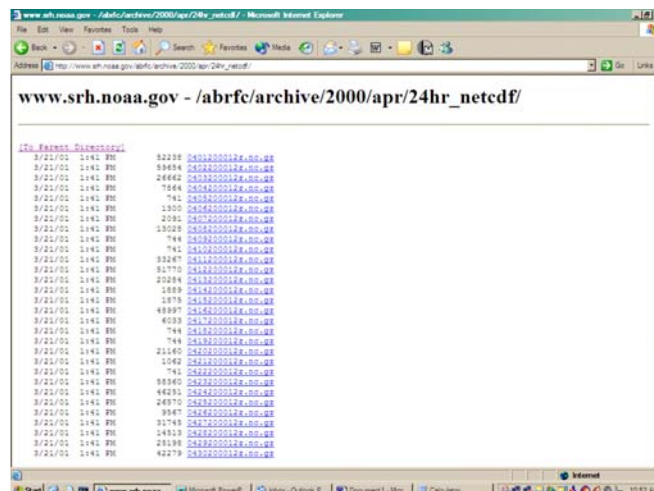
Collaborator: John McIntosh

Data for Our Case Study



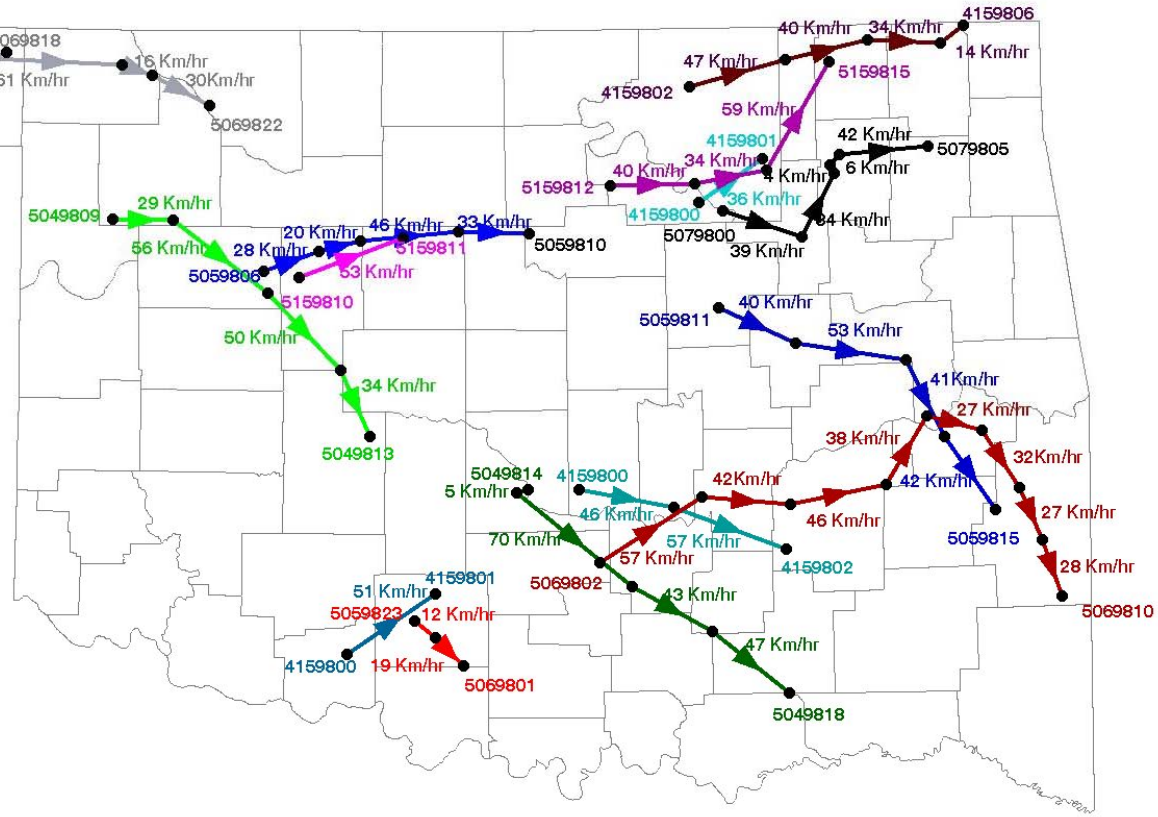
Arkansas-Red Basin River Forecast Center Digital Precipitation Array (DPA).

- The Arkansas Red River Basin Forecast Center generates hourly radar derived digital precipitation arrays
  - 8760 raster layers per year



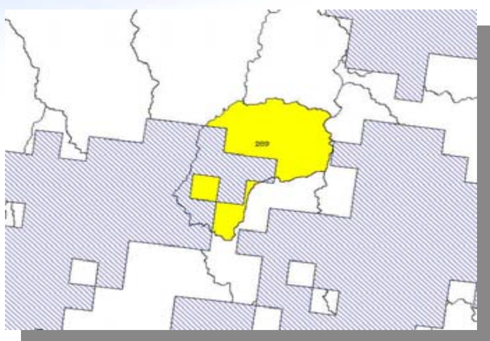
Organized as temporal snapshots and available online

Storm paths and velocity

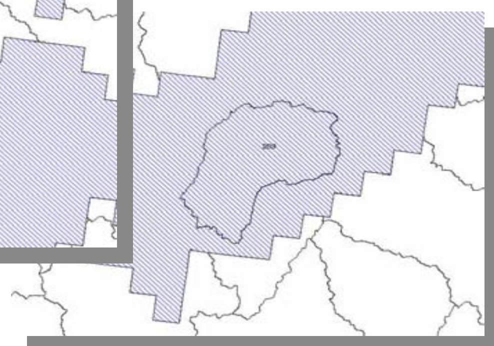


Interactions with a geographic feature

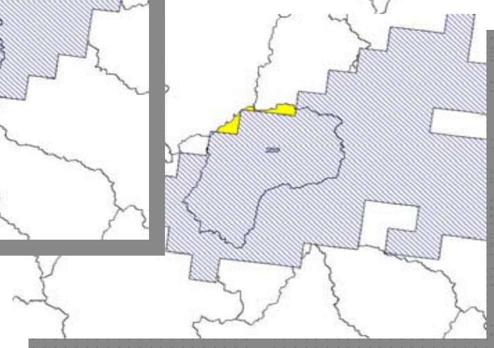
How long did a storm last and how much rainfall was received in this watershed?



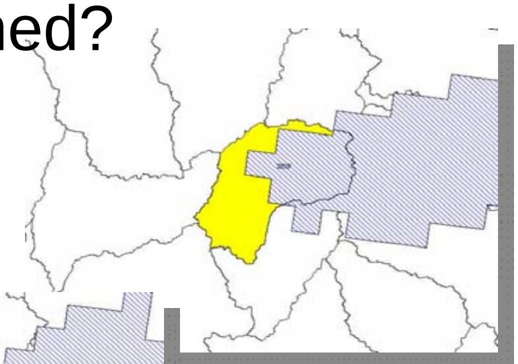
4/15/98/00
116,670 m^3



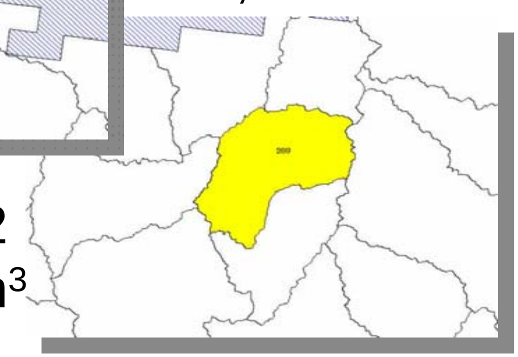
4/15/98/01
2,193,379 m^3



4/15/98/02
697,902 m^3



4/15/98/03
491,908 m^3

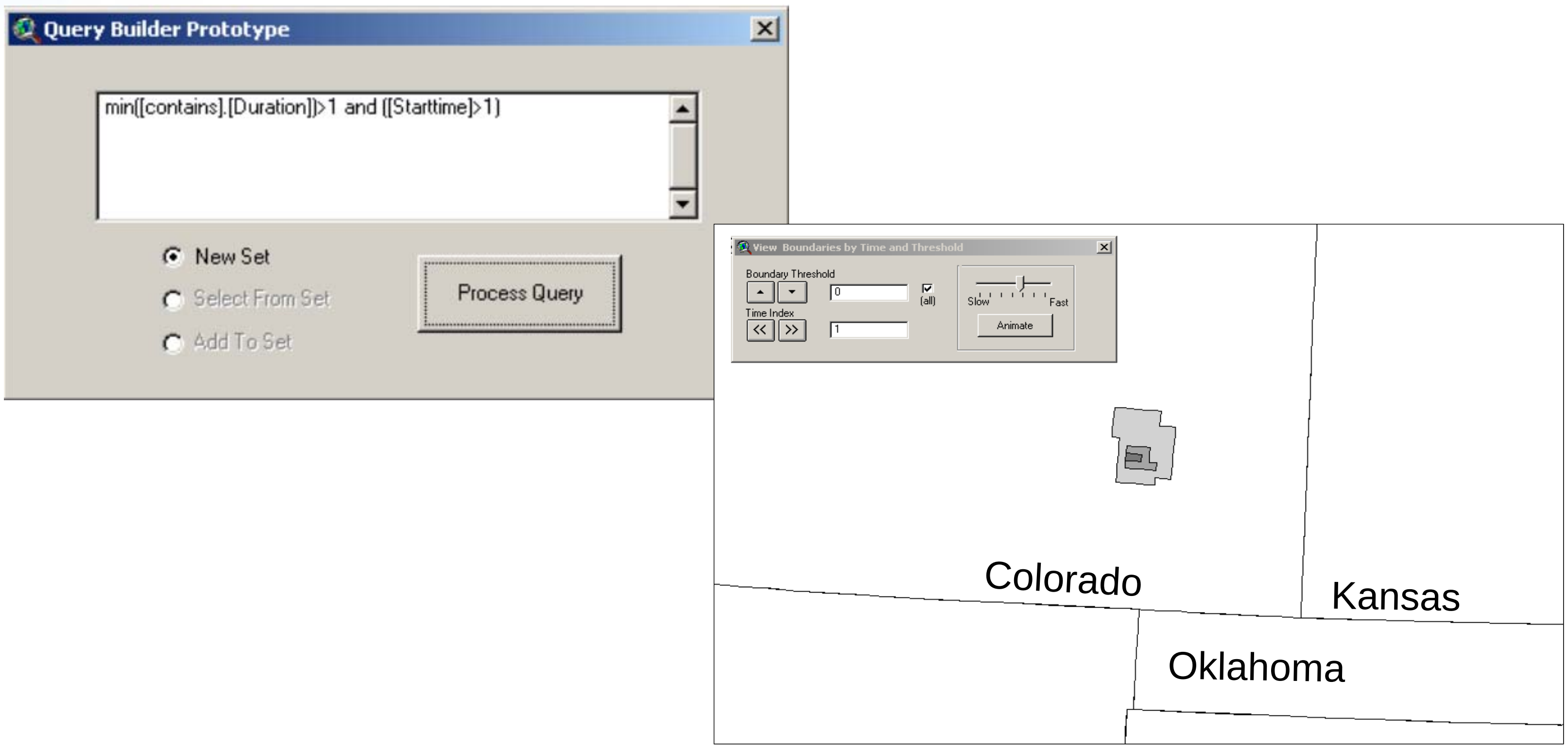


4/15/98/04
0 m^3

Duration: 4 hours
Cumulative volume: 3,499,857 m^3

Find storms occurring at certain time and duration

A query builder dialog to support queries based on the modeled relationships and object attribute values



Characterization indices

Index Type		Index Name
Static	Object	Elongation
		Orientation
	Object Relationship	Distribution
Dynamic	Object	Growth
		Granularity of Change
	Object Relationship	Relative Movement

Elongation

- Elongation and absolute orientation are calculated using the Moments of Inertia method (Gardoll et al 2000)

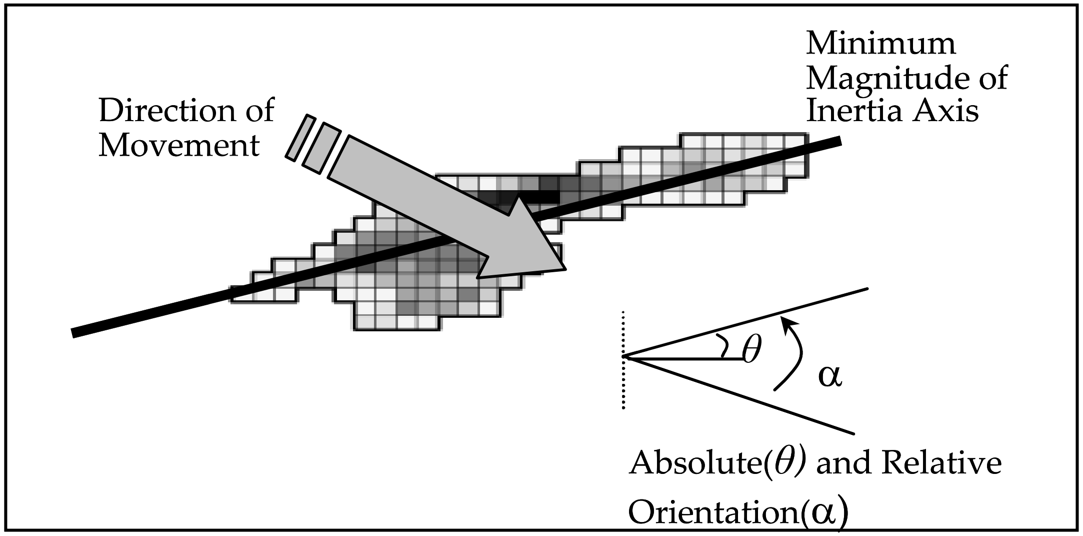
$$I_\theta = \sum_{i=1}^{n} r_i^2 z_i$$

- Elongation is determined using the maximum and minimum inertia

$$E = \frac{(I_{Max} - I_{Min})}{(I_{Max} + I_{Min})}$$

Relative Orientation

- The absolute orientation of the major axis is the angle with the minimum inertia. Relative orientation is that angle relative to the movement direction



Distribution

- Compare the observed average nearest neighbor distance to the calculated random nearest neighbor distance. Index values>1 more dispersed value = 1 random, value<1 clustered

$$D = \frac{\overline{NND}}{\overline{NND_R}}$$

- The average nearest neighbor distance for a random distribution is calculated according like (McGrew and Monroe, 2000)

$$\overline{NND}_R = \frac{1}{2\sqrt{d}}$$

Percent Growth

- Percent growth Index

$$G = \frac{Area_{t2} - Area_{t1}}{Area_{t1}}$$

Granularity of Change

- Determine the granularity at which the most significant change occurred from T_1 to T_2
- Measured by averaged spatial variance of difference fields within objects
- E.g. precipitation resulted from a frontal passage vs. a convective storm
- Based on the local variance method (Woodcock and Strahler, 1987)

Determine Granularity of Change

- Start with the observed resolution (R)
- Calculate the difference grid of two snapshots
- Apply a 3x3 roving window to calculate averaged local spatial variance at R
- Increase R to 2*R and calculate the averaged local spatial variance at 2*R
- Continue until the calculated averaged local spatial variance is smaller than the previous
- The resolution at the previous is the granularity of change

Movement Variation

- Characterize the variation in movement among objects of fields
- Based on the average maximum shear of each object to other objects in the domain.

$$S = \frac{\left|\vec{V}_{diff}\right|}{d} \qquad MV = \frac{\sum_{i=1}^{n} S\max_i}{n}$$

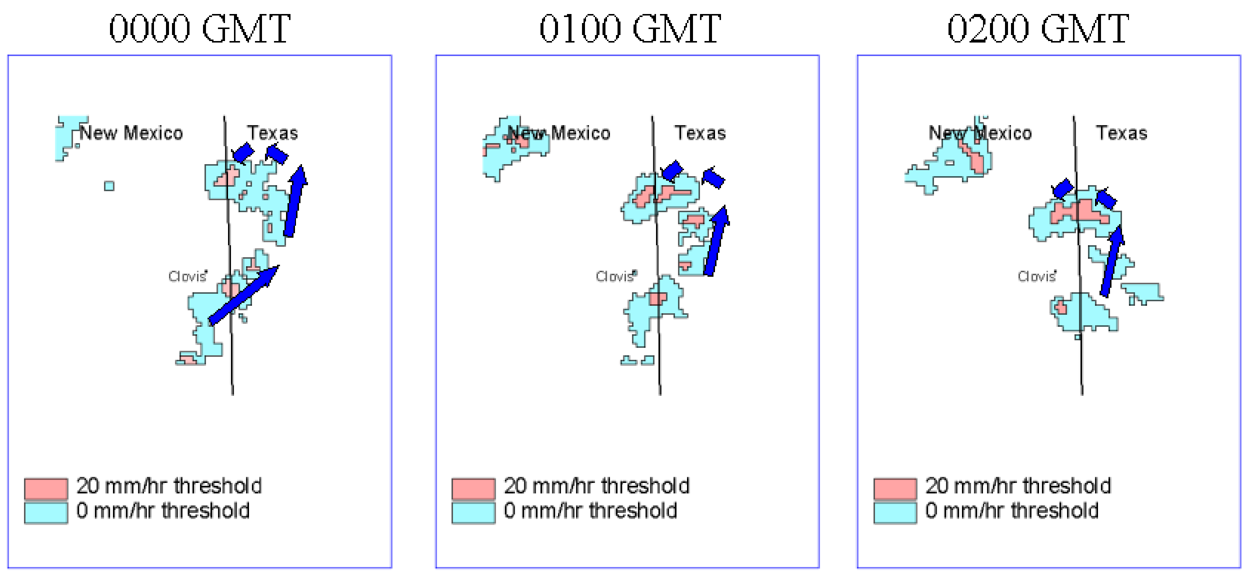
Cross Correlation Matrices

process	*Elongation*	*Orientation*	*Growth*	*Granularity of Change*	*Distribution*	*Relative Movement*
Elongation	1.000					
Orientation	-0.096	1.000				
Growth	-0.088	0.001	1.000			
Granularity of Change	-0.158	-0.023	0.241	1.000		
Distribution	0.003	0.014	-0.106	-0.001	1.000	
Relative Movement	0.167	-0.033	-0.022	-0.251	-0.009	1.000

event	*Elongation*	*Orientation*	*Growth*	*Granularity of Change*	*Distribution*	*Relative Movement*
Elongation	1.000					
Orientation	-0.184	1.000				
Growth	-0.085	0.031	1.000			
Granularity of Change	-0.123	0.033	0.009	1.000		
Distribution	0.217	-0.156	0.151	-0.321	1.000	
Relative Movement	-0.126	0.052	0.103	-0.128	0.233	1.000

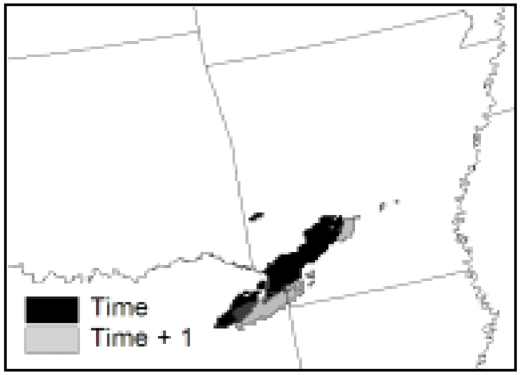
Little shared information among the indices for both process and event objects.

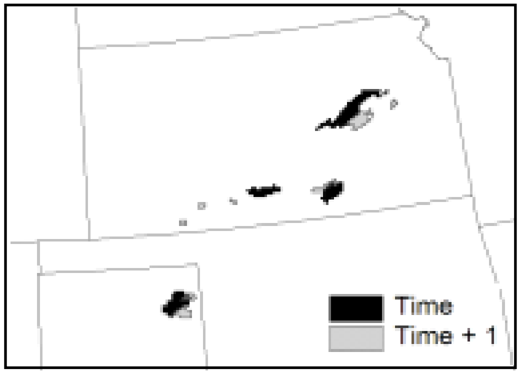
Find storms with rotations

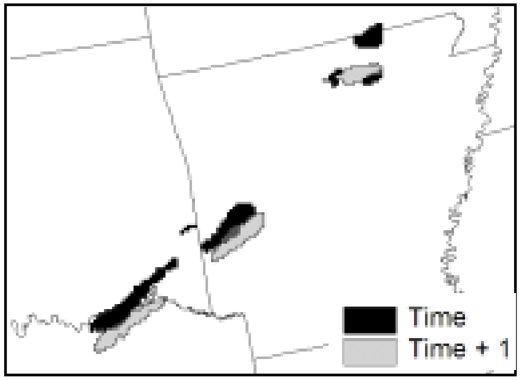


Similar change from T1 to T2

Cases from a cluster determined by the six indices

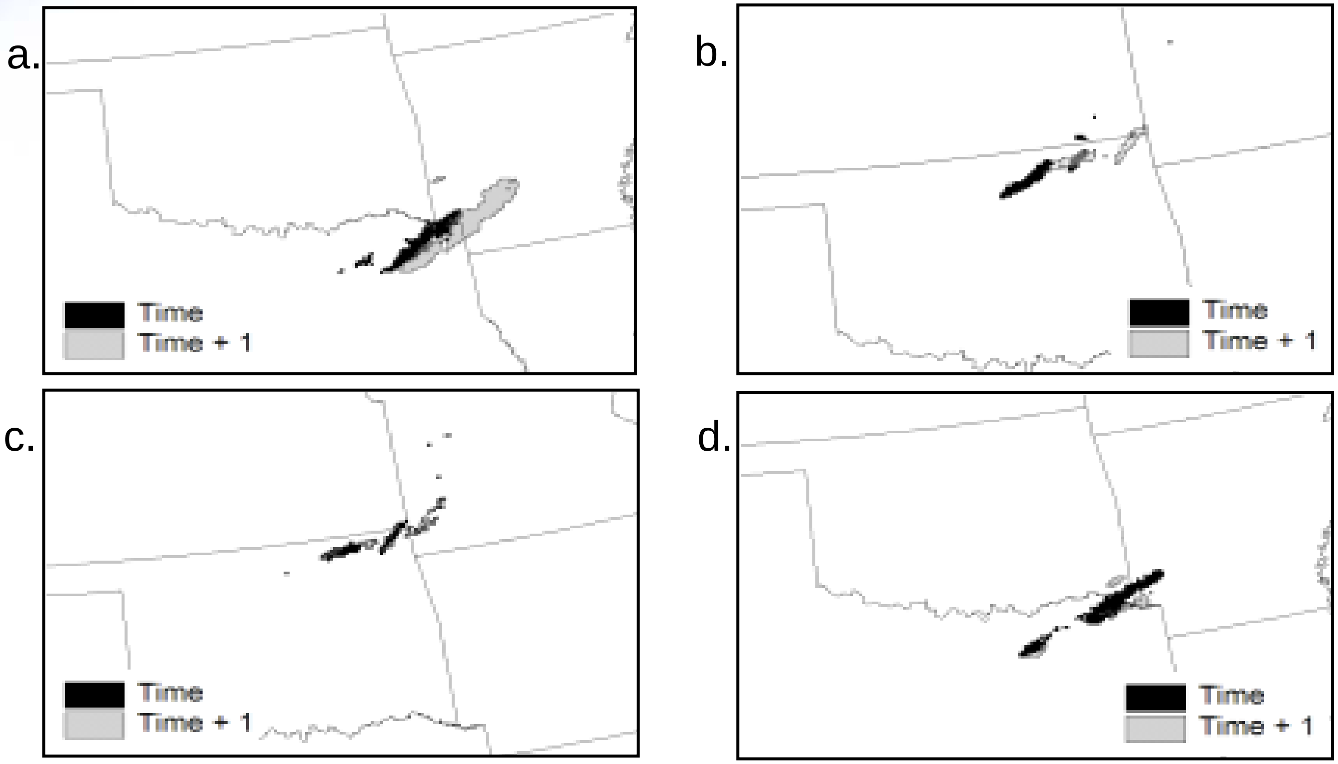






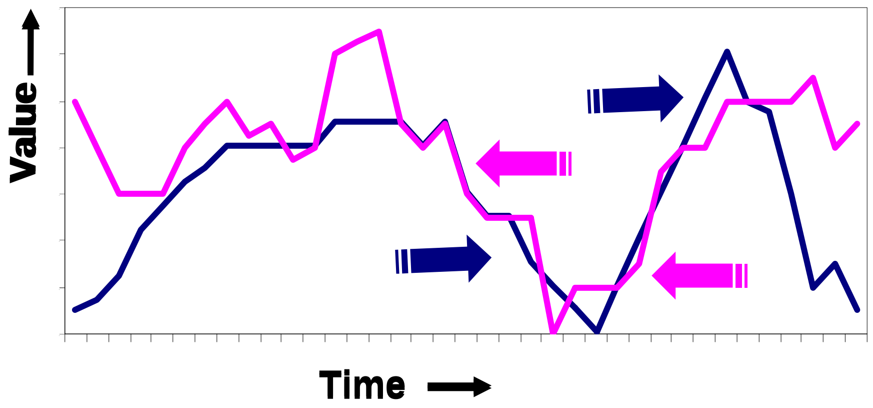
Similar change from T1 to T2

Cases from a cluster determined by the six indices



Compare two processes

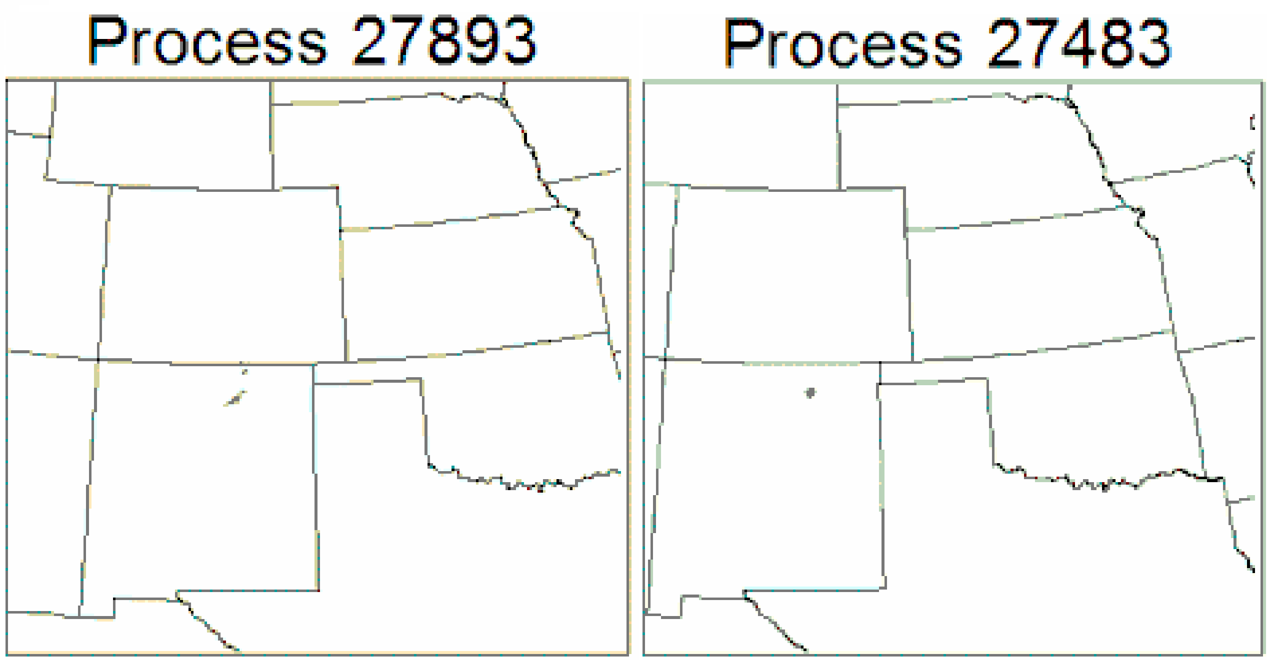
- Dynamic time warping: the sequences are stretched so that Imperfectly aligned common features align



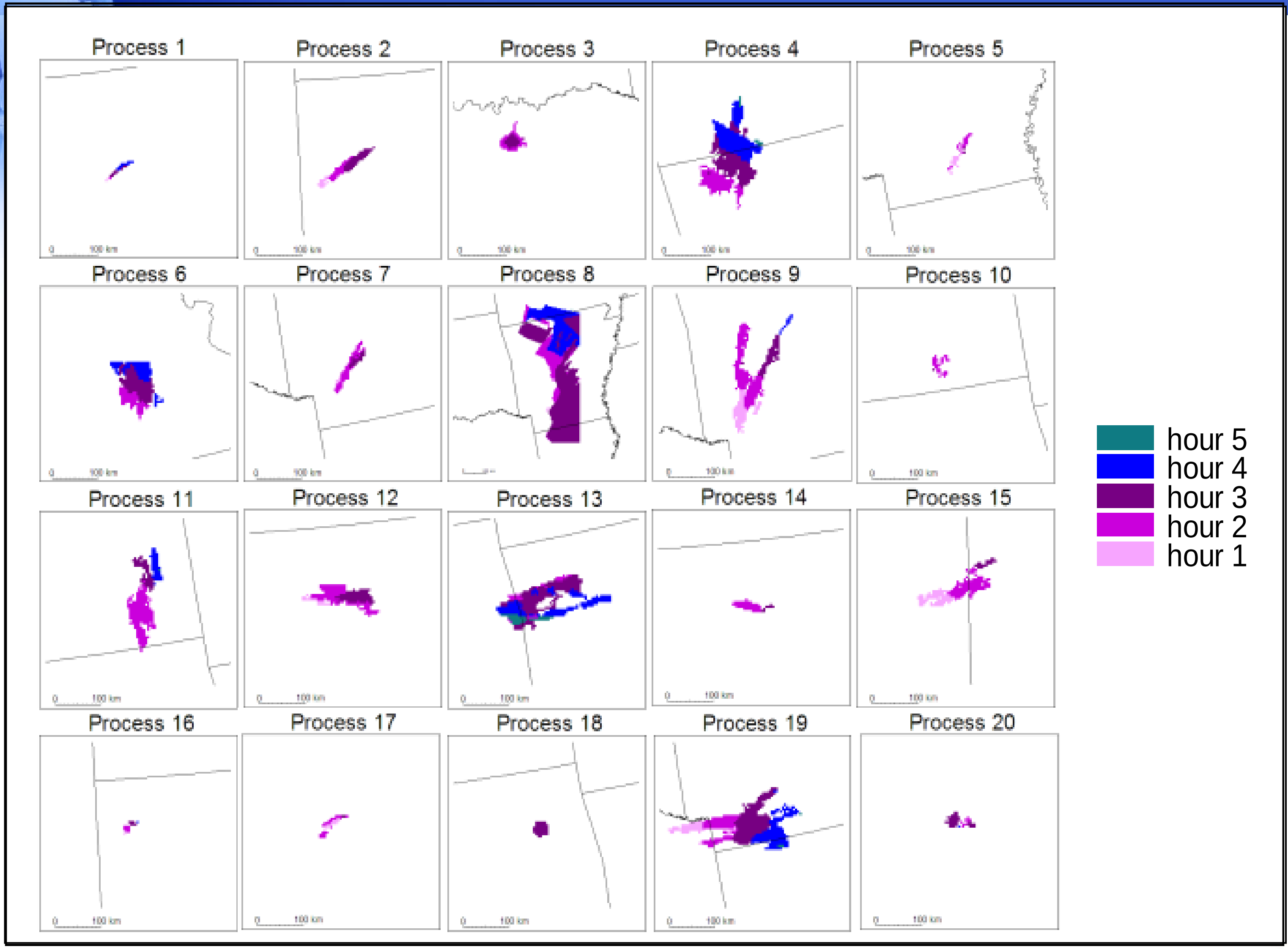
Find matching storms …

Query

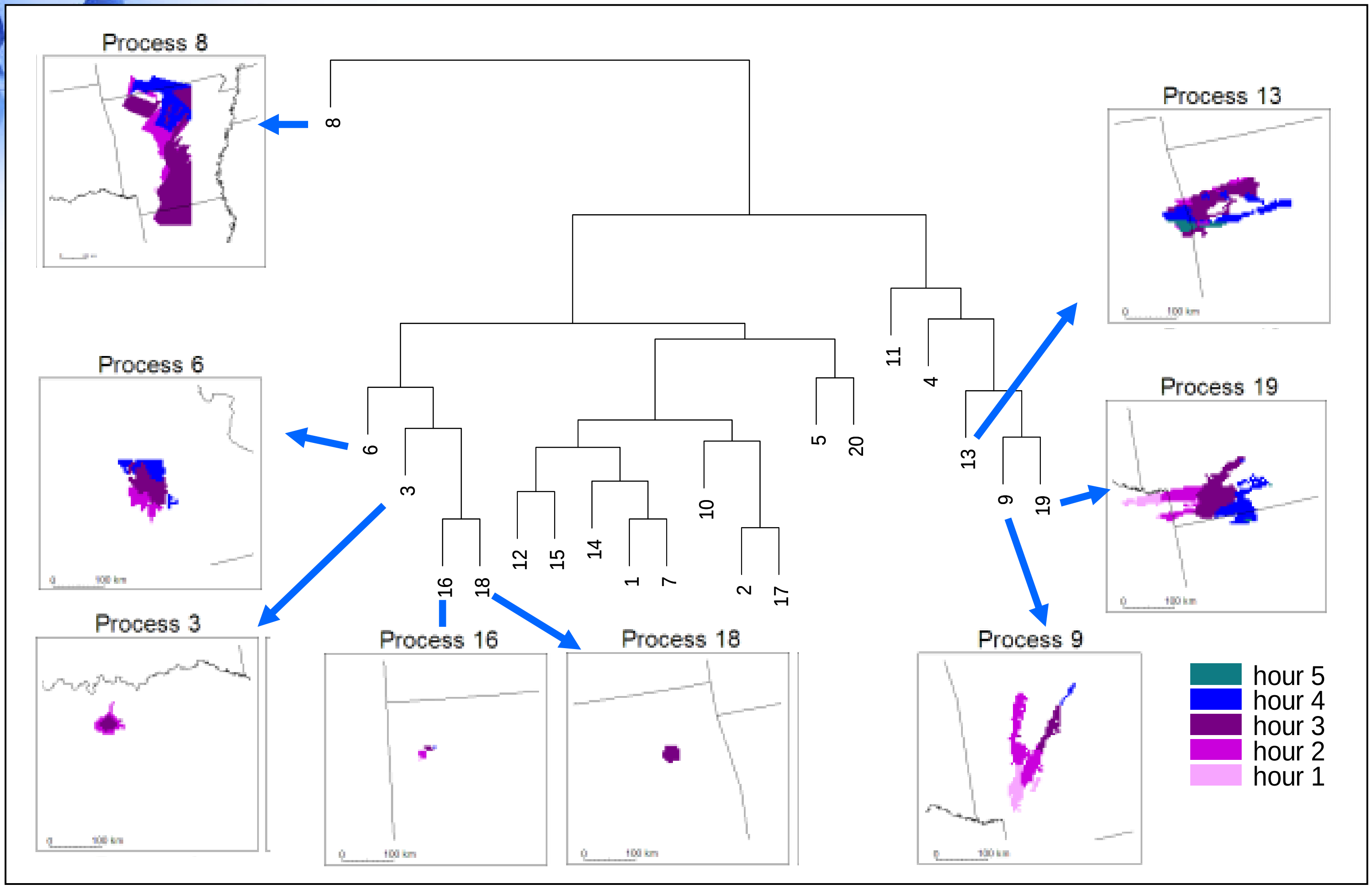
Return: storm systems with similar behaviors



Categorize processes

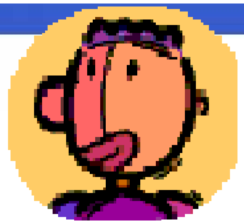


Hierarchical Clustering



From Temporal GIS to Dynamics GIS

	Temporal GIS	Dynamics GIS
Emphasis	Integrate spatial and temporal data	Represent geographic dynamics
Data objects	Tables or geometric objects over space and time	Geographic objects, states, processes, and events
Relationships	Spatial and temporal	Spatial, temporal, hierarchical, mechanistic, causal
Query, analysis and modeling	What, when, and where Similarity of space, time, and change	What, when, where, and how Similarity of drivers, evolution, and consequences



THANK YOU