

**2008 ESRI User Conference**  
**Technical Workshops**  
August 4–8, 2008

***Please!***  
*Turn OFF cell phones*  
*and paging devices*



# Working with Temporal Data in ArcGIS

*Steve Kopp*  
*Tom Brown*

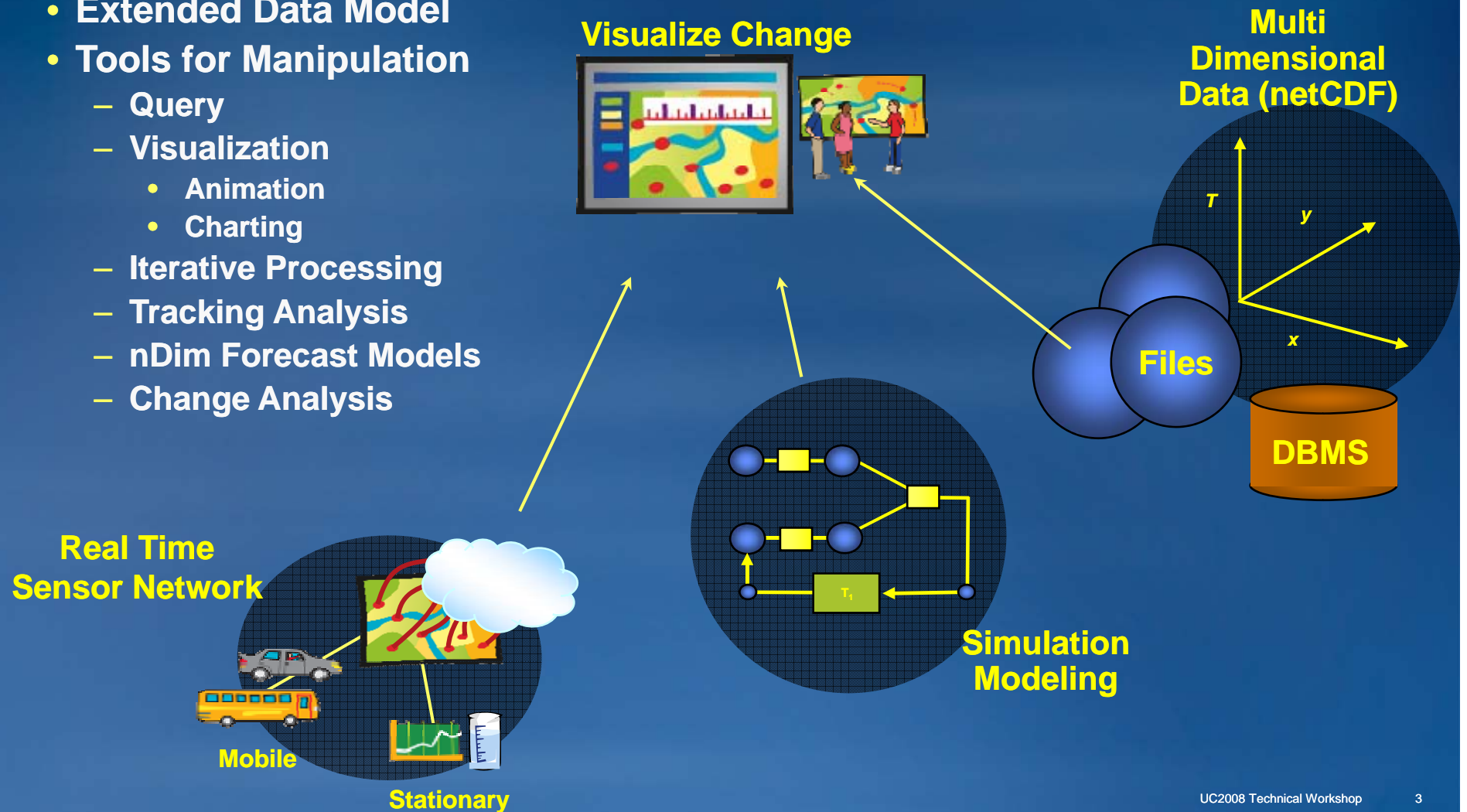
# Outline

- **Overview of Spatiotemporal data**
- **Storage and management of temporal data**
  - Feature
  - Raster
  - Array
- **Visualization of temporal data**
- **Analysis of temporal data**
- **Working with real-time data**

# GIS Integration of Time

*New Ways to Manage, Visualize & Analyze Geography*

- Extended Data Model
- Tools for Manipulation
  - Query
  - Visualization
    - Animation
    - Charting
  - Iterative Processing
  - Tracking Analysis
  - nDim Forecast Models
  - Change Analysis



# Time is Special

- **Linear**
  - Wednesday always follows Tuesday
- **Cyclical**
  - June 20<sup>th</sup> happens every year
- **Uni-directional**
  - Events which happen today don't affect yesterday

# Time can be difficult to work with

- **Its not metric or base 10 so its messy**
  - A Year is 365, or sometimes 364 days
  - A Month can be 28 days to 31 days
  - A Day is 24 hrs, but hours are 60 minutes, and minutes are 60 seconds
  - Don't forget time offsets from Greenwich
- **Can be stored as Integer, Double, String, or Date**
- **DATE is a special field type specific to time**
  - Specific code for that type make it easier to use and faster
  - Not all database support the same type and operators
  - ***Use DATE fields whenever possible for your temporal data***

# Storage and management of temporal data

- **What is temporal data**
- **How to represent temporal data in a relational system**
- **How to access temporal data**
  - What applications work with temporal data
  - Constructing queries
- **Indexing**
- **Performance**
  - Access paths
- **Storage**
  - Single table
  - Joins
  - DBMS partitioning

# Temporal

## *Time, Dates, Spatial-temporal, History*

- **First problem – the meaning is overloaded**
- **Each of us have our own definition and requirements**
- **Implementations may be unique, but all of them have many similarities...**
  - How to model
  - How to store
  - How to access
  - How to optimize

# What are “some” meanings of temporal

- **Point-in-time**
  - A specific moment
  - Event driven
- **Duration of time**
  - An interval
  - Describes characteristics over a period (start date – end date)
- **Transactional time**
  - System generated, auditing (in the database)
- **Valid time**
  - Legal representation

# Based on one's needs...

## *How to represent temporal data*

- Of course it all depends on the objective
- **Point-in-time**
  - Individual attribute
- **Duration**
  - Multiple attributes
  - Requires a start date and an ending date
- **Transactional**
  - Individual attribute
  - An audit
- **Valid**
  - Single or multiple attributes

# What does ArcGIS offer

- **Point-in-time**

- Simply a DATE attribute
- Metadata
- Can be leveraged by many geoprocessing tools

- **Transactional**

- Versioning
  - Multiple representations of the data for historical views or what-if-scenarios
- Archiving
  - System maintained for tracking individual objects changing through time

# Point-in-time

- **Simply a DATE attribute**
- **User maintained attribute**
  - Representing a moment event occurred
  - Domain specific
- **Likely indexed for quick data access**

# Transactional

- **Versioning**

- Provides the ability to create versions of your data representing specific “views” of the data for a given moment
- Benefits no data duplication
- Limitations are potentially the number of historical versions created

- **Archiving**

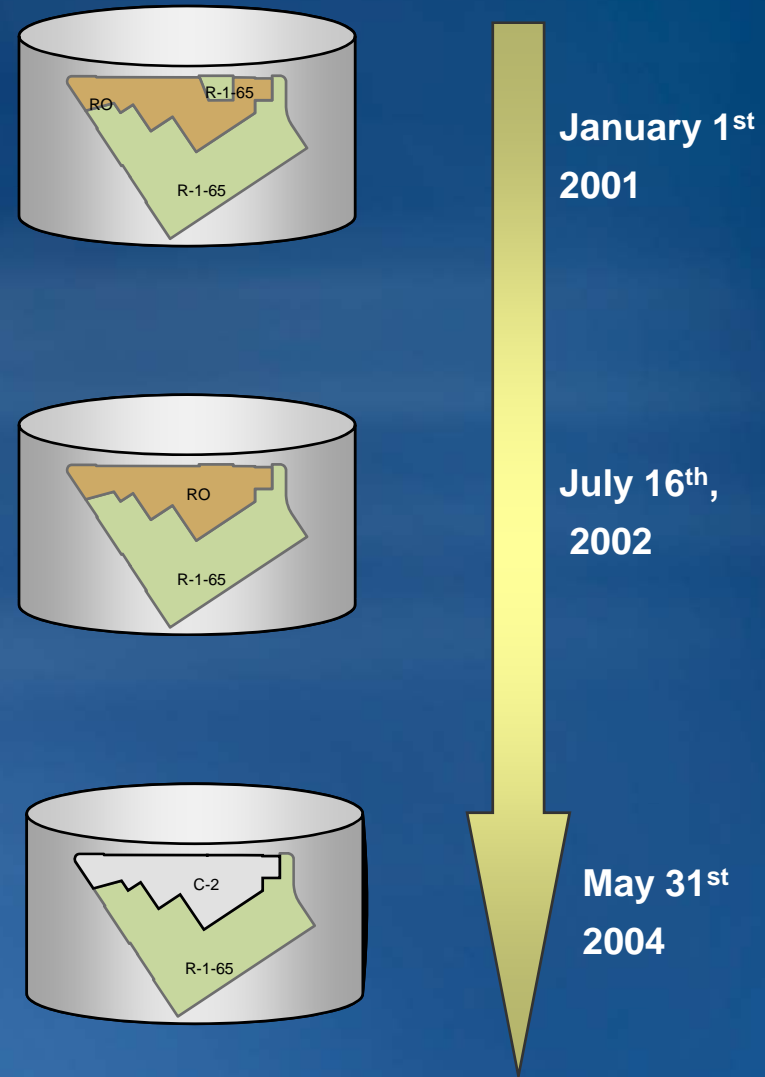
- Provides the capability to view an individual's object's changes through time
- System maintains the moment (timestamp) when the change occurred

# Archiving

- Archiving represents time as the transaction time
  - **Transaction time**: DBMS time the change was saved (DEFAULT version)
  - **Valid time**: Real-world time that the event occurred
    - Example: A parcel was sold on April 6, 2006; due to backlog, the new owner was not entered until April 30, 2006
- **Valid time** and **transaction time** are rarely the same
  - Option: Add user maintained column to enabled class to maintain valid time
- Objects archived in the order they are modified (posted to DEFAULT)
  - Transaction time may be out of order from real world event
  - Example: Work orders saved out of sequence are archived out of sequence

# Archiving

- Preserves change to data
- Persistent history
  - Change maintained separately in archive class
- Archive class can persist if object unregistered as versioned
- Requirements vary
  - Which object needs archiving?
  - What granularity of change is needed?



# Archive class

- **New feature class created**
  - Built when archiving enabled
  - Not visible in ArcCatalog
- **Same schema as enabled class**
  - Plus attributes for timestamp
  - Any schema changes on enabled class will affect archive class
- **Archive class is **not** registered as versioned**
- **During registration, all rows part of DEFAULT lineage copied to archive class**
  - All archived with same timestamp

## PARCELS

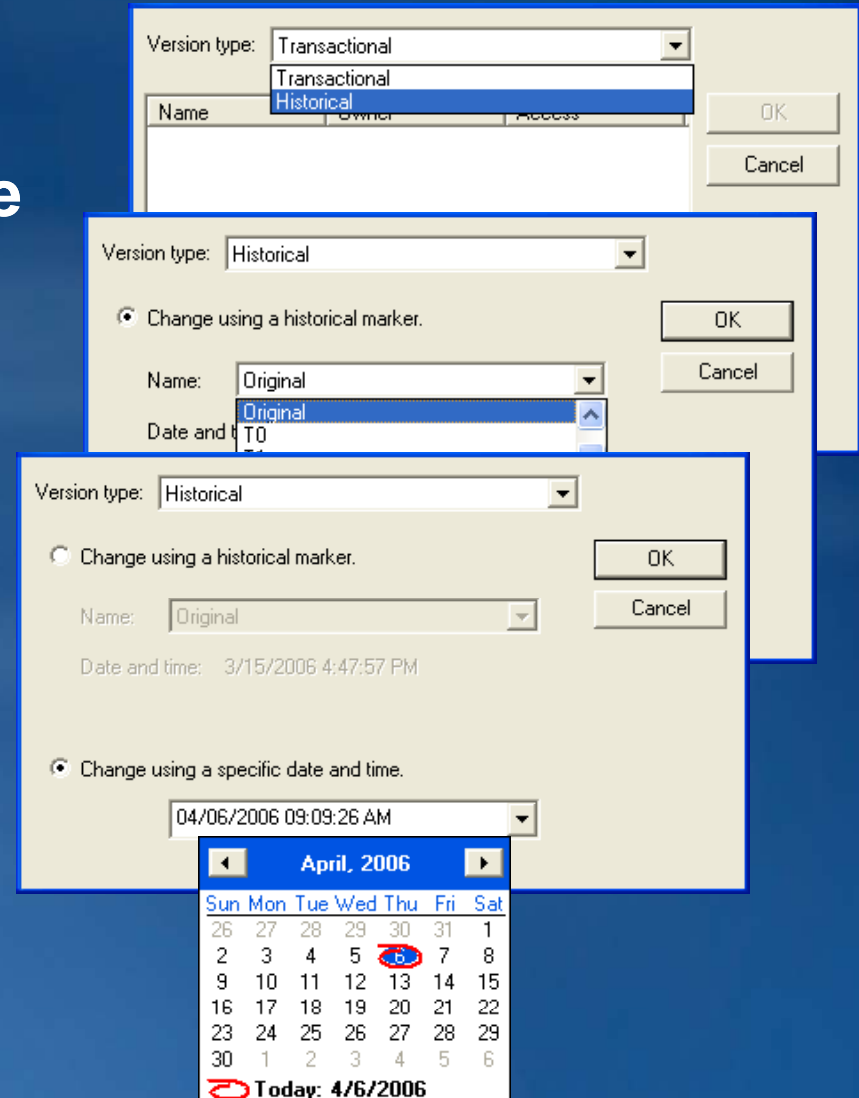
Name
OBJECTID (int, not null)
APN (nvarchar(9), null)
CITY_OWNED (nvarchar(3), null)
METROSCAN (nvarchar(26), null)
SHAPE (int, null)

## PARCELS\_H

Name
OBJECTID (int, not null)
APN (nvarchar(9), null)
CITY_OWNED (nvarchar(3), null)
METROSCAN (nvarchar(26), null)
SHAPE (int, null)
GDB_FROM_DATE (datetime, not null)
GDB_TO_DATE (datetime, not null)
GDB_ARCHIVE_OID (int, not null)

# Historical versions

- Read only view of geodatabase
  - Transactional versions are used for editing
- References particular moment
  - Created by user
  - References specific time
  - Like a *bookmark*
- Specific date and time
  - Pick date and time from calendar



# Accessing temporal data

- **How to construct the correct query...**
- **Point-in-time**
  - WHERE event = '12-4-2006'
- **Duration**
  - WHERE start\_time >= 'JAN-1-2005  
AND end\_time <= 'DEC-31-2005'
- **Transactional**
  - WHERE audit\_date BETWEEN ('11:15:00' and '11:45')
- **Valid**
  - WHERE since\_date = 'MAY 12, 2007'

# Importance of indexing

- **Required for efficient/fast data retrieval**
  - Index search verses full table scans
- **When to create depends on the lifecycle**
  - Wait till the data is loaded
  - Drop indexes during large data appends
- **Cost of maintaining the index**
  - On each insert, update and delete

# Why isn't the index being used

## *Selectivity*

- How would the DBMS *optimizer* determine the best access path for the following statement
  - (recording\_date has a non-unique index)

```
SELECT * FROM river_flow WHERE recording_date = '6-15-07'
```

*Index scan?*

*Full table scan?*

# Answer: It depends!

- How many rows are in the table
  - 1 – *Full table scan* (less *i/o*)
  - 1,000,000 – might still read the entire table
- How many rows in the table where **recording\_date = '6-15-07'**
  - 1 of 1,000,000 – *Index scan*
  - 900,000 of 1,000,000 – *Full table scan*
  - 50% of the table – *Index scan* or *Full table scan*
  - 25% of the table – *Index scan* or *Full table scan*

# Importance of database statistics

- **Optimizer leverages table and index statistics to determine the optimal access path**
  - **Statistics inform the optimizer about...**
    - **Counts**
    - **Occurrences/frequency**
    - **Distribution**

# Temporal storage models

- **When to use just one table**
  - Data access typically to one table is highly efficient
  - Consequences of storing redundant attributes
    - Same location, but different values for the moment being recorded
    - Can generate millions of entries
- **When to use a layer and a second attribute table for joining**
  - Data access might be impacted by the join operation
  - Provides better data access for the feature class, no redundant storage of geometries

# Leveraging DBMS storage options

- **Optimize data access**
- **Table partitioning**
  - DATE attributes are perfect attributes for partitioning tables
  - Partition by range
    - All JAN recordings in partition 1
    - All FEB recordings in partition 2
    - All MAR recordings in partition 3...

**Based on predicate value optimizer knows exactly which partition to access**

# Temporal Raster Data Storage

*Raster catalogs:*

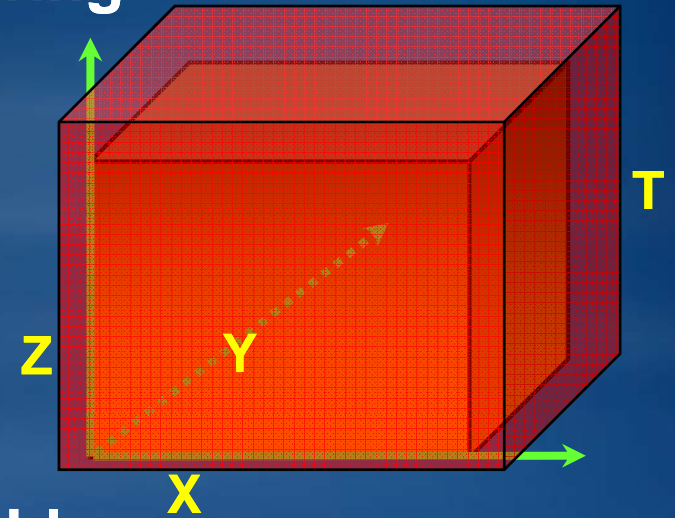
- Use a date/time field
- Use an index field (i.e. ObjectID)

*Note: The layer will initially draw as a wire frame if more than 9 rasters.*

OBJECTID <sup>^</sup>	NAME	Shape <sup>^</sup>	Raster	Date_Time	SHAPE_Length	SHAPE_Area
1	Image1.gif	Polygon	Raster	1998-10-14 12:00:00	3068	522753
2	Image2.gif	Polygon	Raster	1998-10-15	3068	522753
3	Image3.gif	Polygon	Raster	1998-10-15 12:00:00	3068	522753
4	Image4.gif	Polygon	Raster	1998-10-16	3068	522753
5	Image5.gif	Polygon	Raster	1998-10-16 12:00:00	3068	522753
6	Image6.gif	Polygon	Raster	1998-10-17	3068	522753
7	Image7.gif	Polygon	Raster	1998-10-17 12:00:00	3068	522753

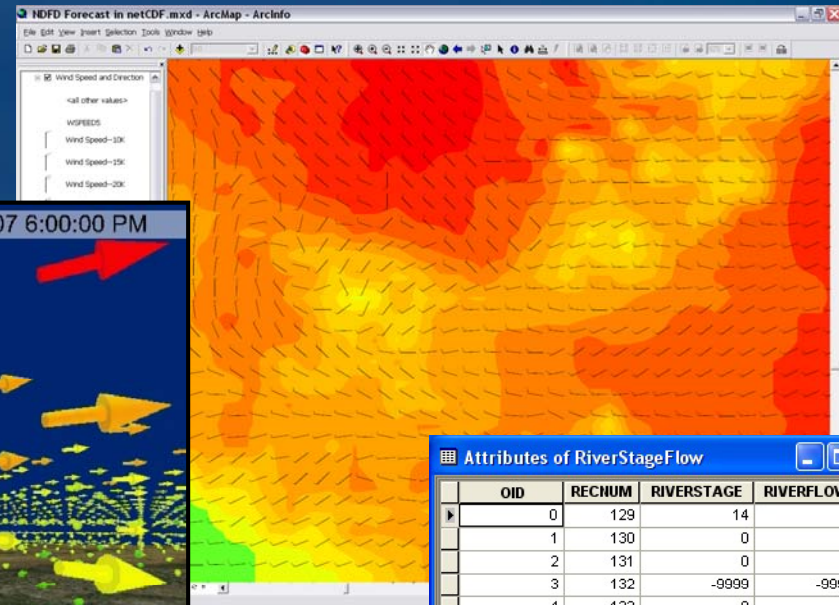
# Temporal Array Data in ArcGIS

- ArcGIS 9.2 reads/writes netCDF
- An array based data structure for storing multidimensional data.
- N-dimensional coordinates systems
  - X coordinate (e.g. longitude)
  - Y coordinate (e.g. latitude)
  - Z coordinate (e.g. altitude)
  - Time dimension
  - ... other dimensions
- Variables – support for multiple variables
  - Temperature, humidity, pressure, salinity, etc
- Geometry – implicit or explicit
  - Regular grid (implicit)
  - Irregular grid
  - Points



# NetCDF in ArcGIS

- NetCDF data is accessed as
  - Raster
  - Feature
  - Table



Attributes of RiverStageFlow

OID	RECNUM	RIVERSTAGE	RIVERFLOW
0	129	14	0
1	130	0	0
2	131	0	0
3	132	-9999	-9999
4	133	0	0
5	134	0	0
6	135	-9999	-9999
7	136	0	1
8	137	-9999	-9999
9	138	15	0
10	139	-9999	-9999
11	140	-9999	-9999
12	141	7	2
13	142	3	0
14	143	16	1
15	144	-9999	-9999
16	145	-9999	-9999
17	146	-9999	-9999

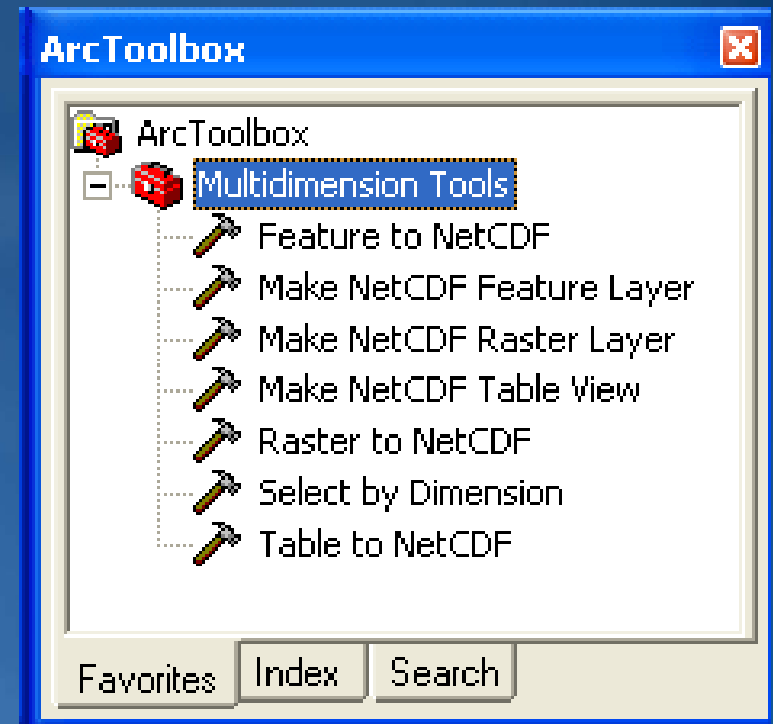
Record: 1 Show: All Selected Re

- Direct read
- Exports GIS data to netCDF

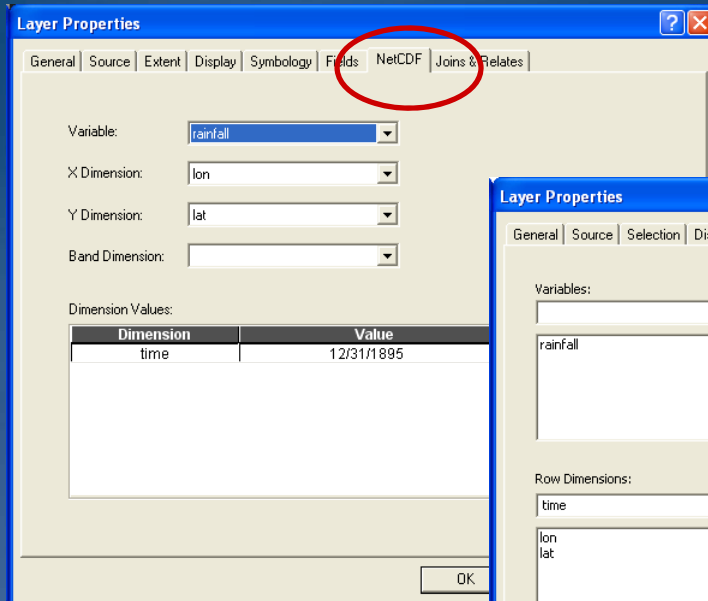
# NetCDF Tools

## Toolbox: Multidimension Tools

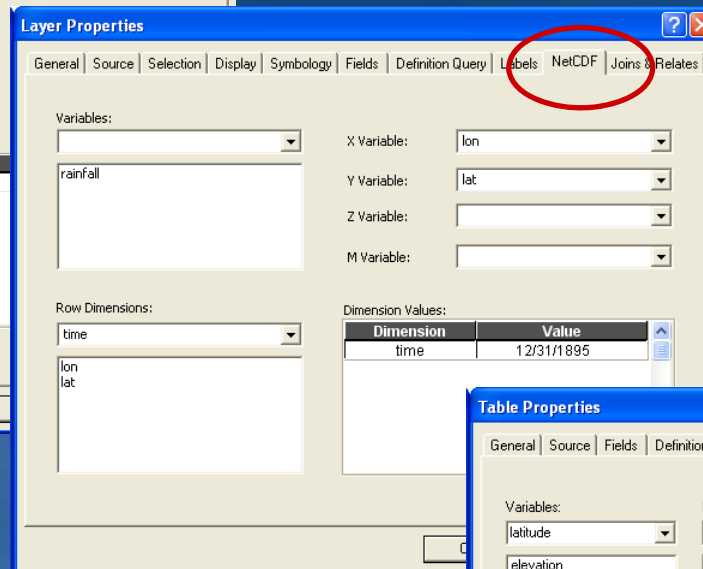
- Make NetCDF Raster Layer
- Make NetCDF Feature Layer
- Make NetCDF Table View
- Raster to NetCDF
- Feature to NetCDF
- Table to NetCDF
- Select by Dimension



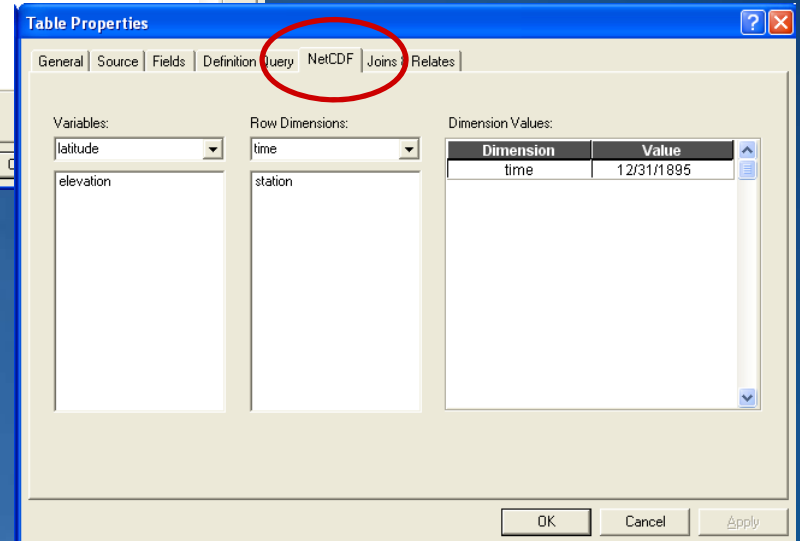
# NetCDF Layer/Table Properties



Raster



Feature



Table

# Using NetCDF Data

## Behaves the same as any layer or table

- **Display**

- Same display tools for raster and feature layers will work on netCDF raster and netCDF feature layers.

- **Graphing**

- Driven by the table just like any other chart.

- **Animation**

- Multidimensional data can be animated through a dimension (e.g. time, pressure, elevation)

- **Analysis Tools**

- A netCDF layer or table will work just like any other raster layer, feature layer, or table. (e.g. create buffers around netCDF points, reproject rasters, query tables, etc.)

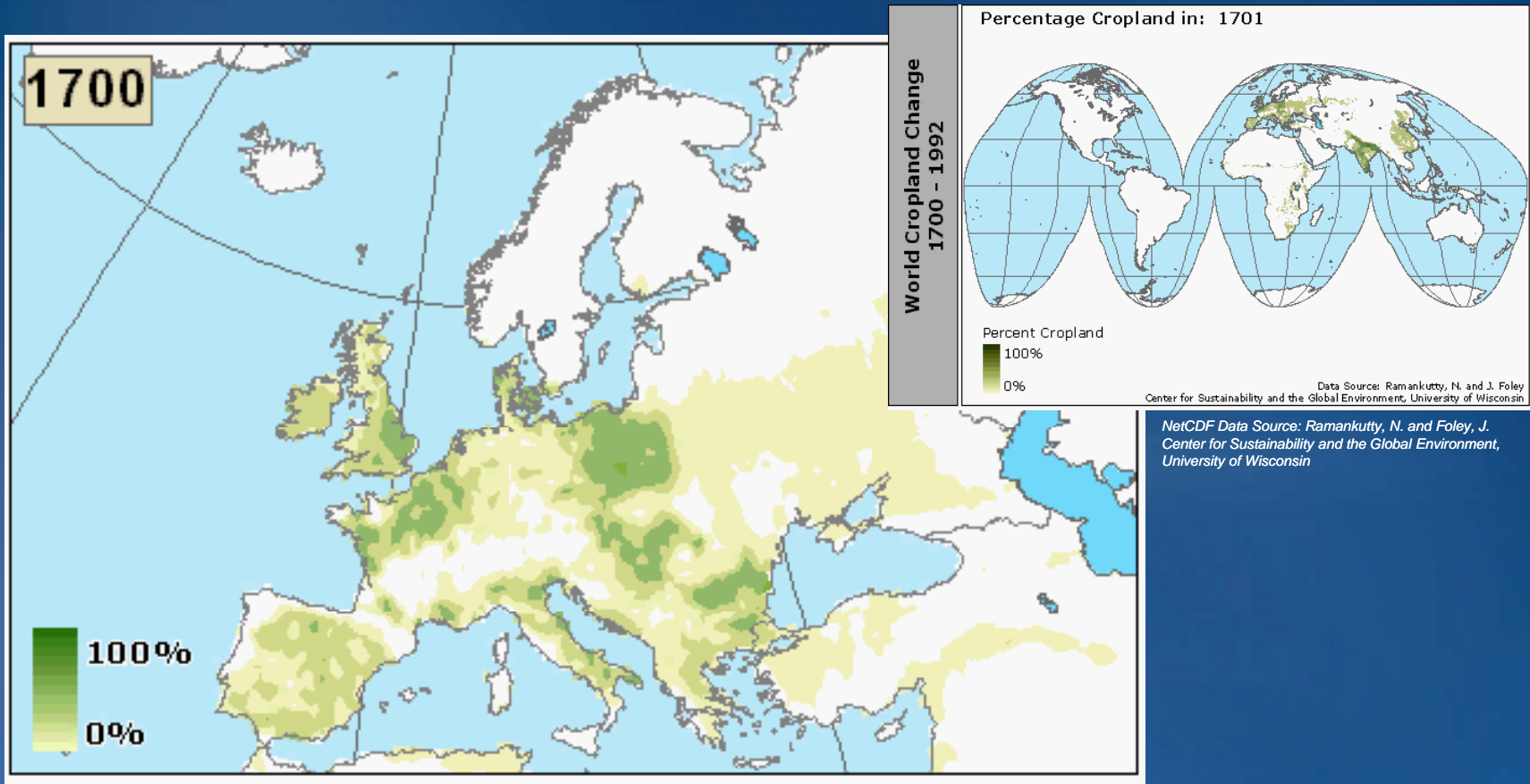
# Temporal Visualization

- **The most effective way to convey changes over time and space is through temporal animation.**
  - **Temporal Animation in ArcGIS core**
  - **Temporal Animation with the Tracking Analyst extension**



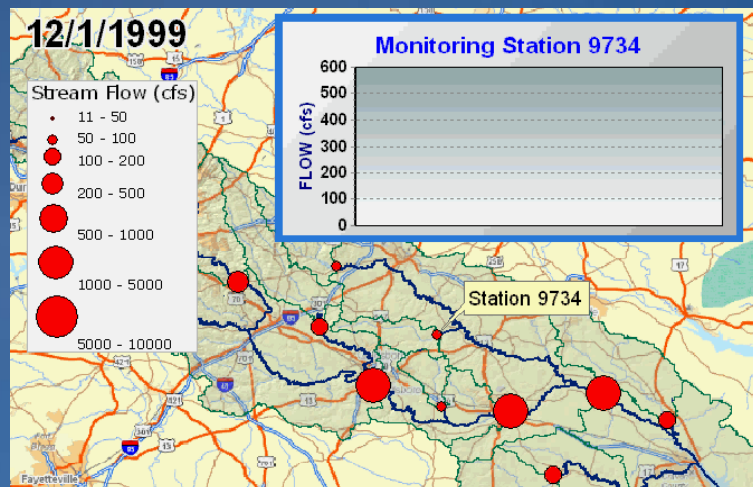
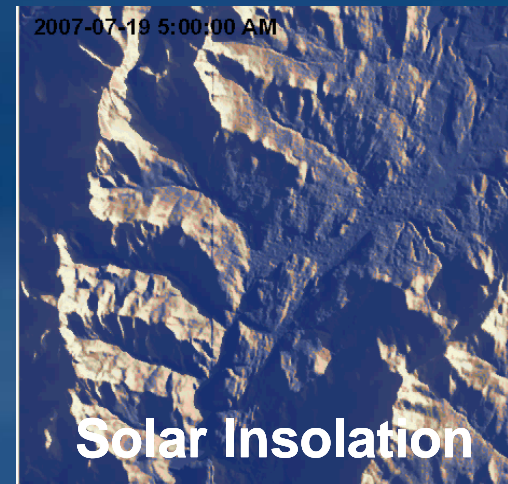
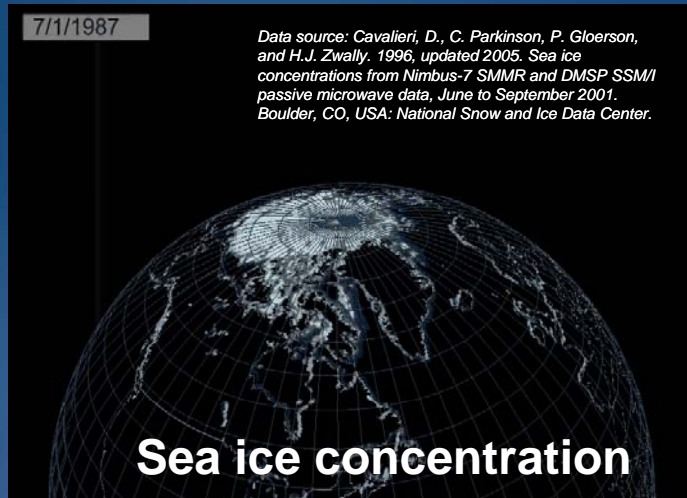
# Animation example

- The sequential display of data with time stamps



Cropland intensity over time

# Animation examples



Stream flow analysis

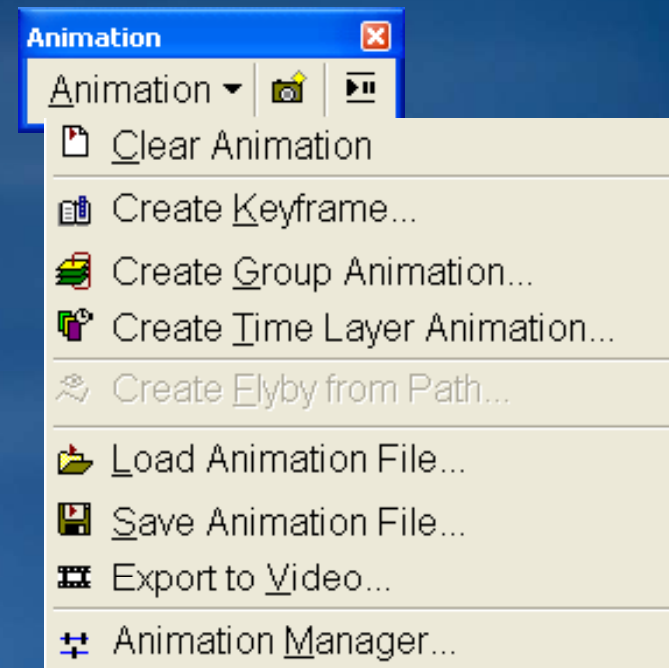
Data provided courtesy of Declan Butler - <http://declanbutler.info/blog/>



Spread of Human Avian Flu

# Where is temporal animation in ArcGIS?

- Animation toolbar
  - ArcMap
  - ArcScene
  - ArcGlobe
- No 3D Analyst license is required to animate in ArcMap



# New Create Time Layer Animation

## 9.2 sample and in 9.3

- Very simple single panel interface to create a temporal animation
- Only 2 required inputs
  - Layer you want to animate
  - The field containing the time

The screenshot shows the 'Create Time Layer Animation' dialog box. It features a blue title bar with a help icon and a close button. The main area is divided into several sections:

- Source Object:** A dropdown menu.
- Start Time:** A section containing a 'Field:' dropdown and a 'Format:' dropdown.
- End Time (Optional):** A section containing a 'Field:' dropdown and a 'Format:' dropdown.
- Time Interval:** A text input field containing the number '1'.
- Time Units:** A dropdown menu currently set to 'Unknown'.
- Animate fields cumulatively:** An unchecked checkbox.
- Display Properties:** A section containing a checked checkbox for 'Show time in the display' and a 'Time label:' text input field.
- Buttons:** 'Create' and 'Cancel' buttons at the bottom right.

<http://arcscripts.esri.com/details.asp?dbid=15052>

# Animation is based upon *records* in a Table

- With one table, features repeat for each time stamp
- Each time stamp has an attribute value

	FID	Shape *	FeatureID	TSValue	TSDateTime
▶	0	Point	9679	33	12/1/1999
	1	Point	9679	29	12/2/1999
	2	Point	9679	26	12/3/1999
	3	Point	9680	66	12/1/1999
	4	Point	9680	58	12/2/1999
	5	Point	9680	54	12/3/1999
	6	Point	9685	71	12/1/1999
	7	Point	9685	63	12/2/1999
	8	Point	9685	58	12/3/1999
	9	Point	9694	184	12/1/1999
	10	Point	9694	183	12/2/1999
	11	Point	9694	183	12/3/1999
	12	Point	9705	56	12/1/1999
	13	Point	9705	51	12/2/1999
	14	Point	9705	47	12/3/1999

E.g. 5 features, 3 time steps



# Animating with Joined Tables

- With two tables, if your table relationship is:
  - One-to-many
  - One-to-one
  - Many-to-one

## One-to-many

Stations feature class		
OBJECTID*	SHAPE*	StationID
1	Point	43
2	Point	55
3	Point	21
4	Point	15
5	Point	30

Temperature table				
OBJECTID*	StationID	Date_1	Temp	
1	43	1/1/2000	50	
2	43	1/1/2001	53	
3	43	1/1/2002	49	
4	43	1/1/2003	58	
5	43	1/1/2004	55	
6	55	1/1/2000	65	
7	55	1/1/2001	70	
8	55	1/1/2002	72	
9	55	1/1/2003	69	
10	55	1/1/2004	75	
11	21	1/1/2000	40	
12	21	1/1/2001	45	

## Many-to-one

FID	Shape *	AREA	PERIMETER	Date_*	ID_*
1585	Polygon	2954870	11945.6	8/6/1988	1
1673	Polygon	926243	4991.03	0/6/1900	1
1696	Polygon	123337	2570.8	8/6/1988	1
1716	Polygon	420788	3659.89	8/6/1988	1
1720	Polygon	1716590	7127.38	8/6/1988	1
1758	Polygon	850621	4802.35	8/6/1988	1
1817	Polygon	303861	2535.12	8/6/1988	1
1590	Polygon	573254	6817.78	8/8/1988	1
1667	Polygon	202705	2201.92	8/8/1988	1
1676	Polygon	491833	5369.46	8/8/1988	1
1727	Polygon	12049700	31541.1	8/8/1988	1
1757	Polygon	311894	2899.82	8/8/1988	1
1951	Polygon	234916	2174.22	8/16/1988	2
3	Polygon	17246200	33480	8/19/1988	3
7	Polygon	227399	1972.64	8/19/1988	3

OID	ID_*	FIRE
0	1	Shoshone
1	2	Snake
2	3	Storm Creek

**Run the Make Query Table tool to perform an in-memory join**

# Supported time field formats for Animation

- Any DATE field
- String fields of these formats:
  - YYYYMMDD
  - YYYY/MM/DD
  - YYYY-MM-DD
  - YYYYMMDDhhmmss
  - YYYY/MM/DD hh:mm:ss
  - YYYY-MM-DD hh:mm:ss
- Numeric fields of these formats:
  - YYYYMMDD
  - YYYYMMDDhhmmss
- **9.3 adds YYYY and YYYYMM**

# What if your time is not one of those formats?

- Use the Add Field and Calculate Field tools

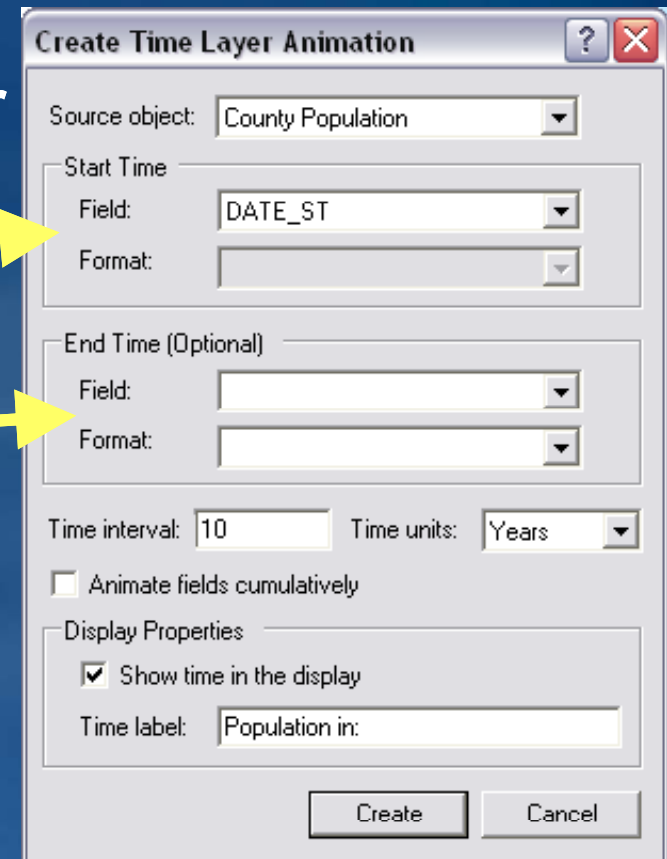
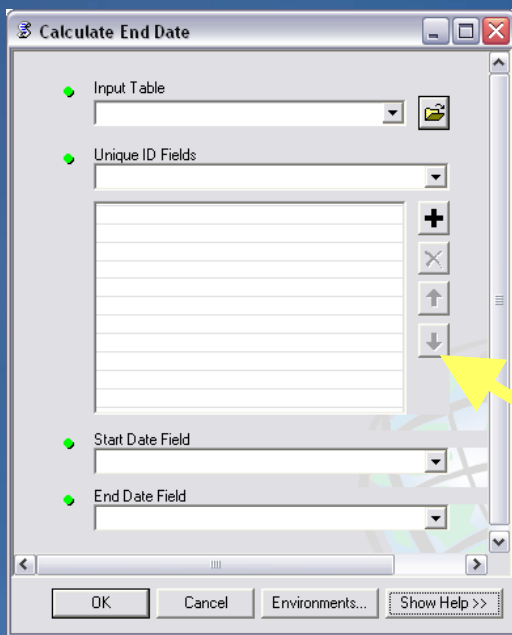
**EXAMPLE:** For a string field [StrDate] formatted as **DD/MM/YYYY hh:mm:ss**, add a new string field (StrDateNew), then using the field calculator, populate its values as **YYYY/MM/DD hh:mm:ss** using:

**StrDateNew =**

***Mid( [StrDate], 7, 4) & "/" & Mid( [StrDate], 4, 2) & "/" & Left( [StrDate], 2) & " " & Right( [StrDate], 8)***

# Do you need an End Date?

- If your Start Time is not regularly spaced, use an End Time for better animation appearance
- Start time Field is required
- Optionally, set an end time field when irregular time stamps are present



The Calculate End Date tool creates this field for you.

# What if your time is stored in columns?

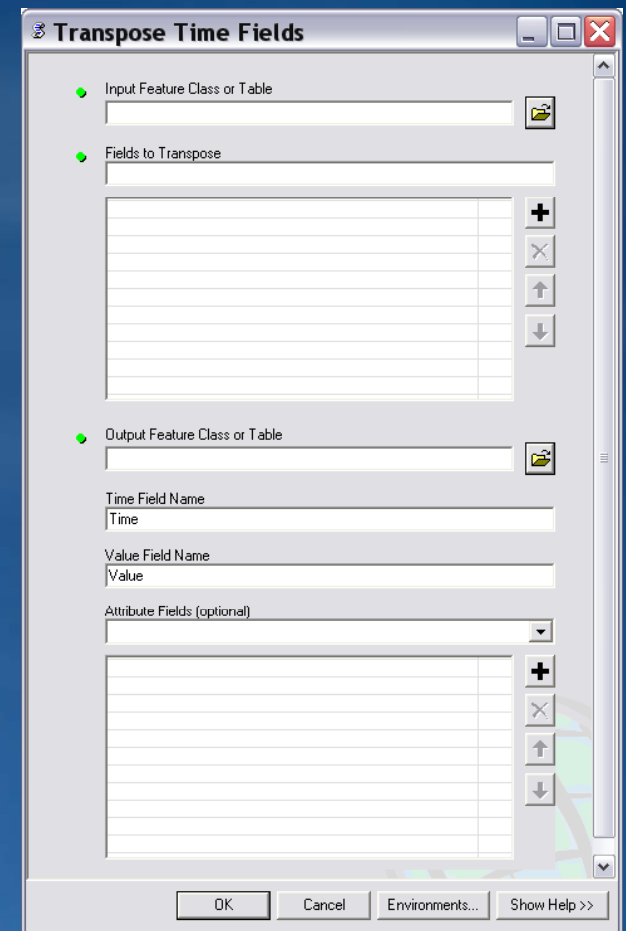
- ArcGIS animates across records, not columns
- Use the Transpose Time Fields tool to reformat the table

Input table:

OBJECTID*	Shape*	Shape_Length	Shape_Area	STATE_NAME	Y1980	Y1981	Y1982	Y1983
1	Polygon	17.237647	12.897167	Alabama	106	105	115	129
2	Polygon	407.571028	277.524118	Alaska	20	22	22	25
3	Polygon	23.257265	28.859093	Arizona	0	0	0	0
4	Polygon	20.877157	13.517466	Arkansas	109	115	111	117
5	Polygon	42.260167	41.533613	California	539	706	697	707
6	Polygon	22.025629	28.0416	Colorado	101	113	122	136
7	Polygon	5.722455	1.392525	Connecticut	180	215	245	274

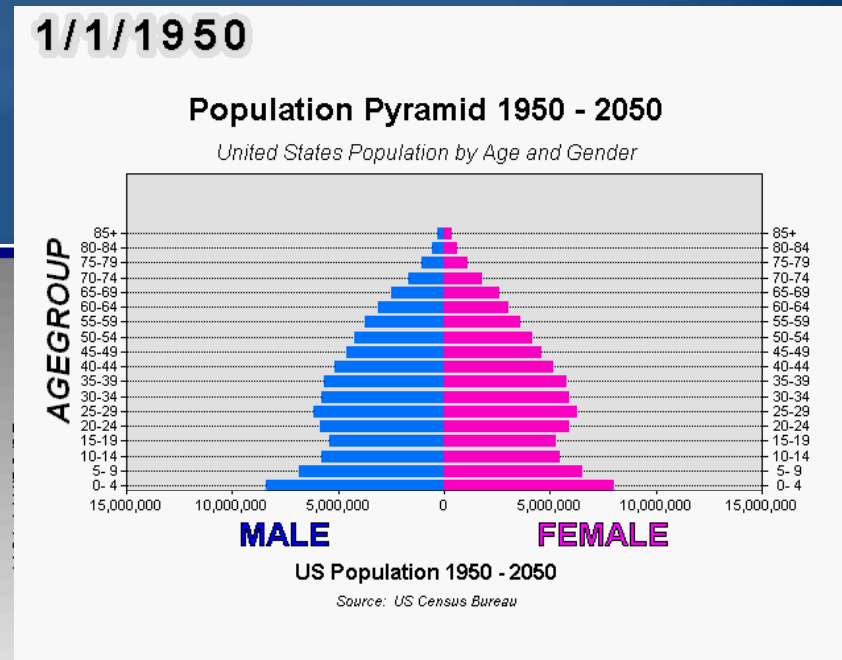
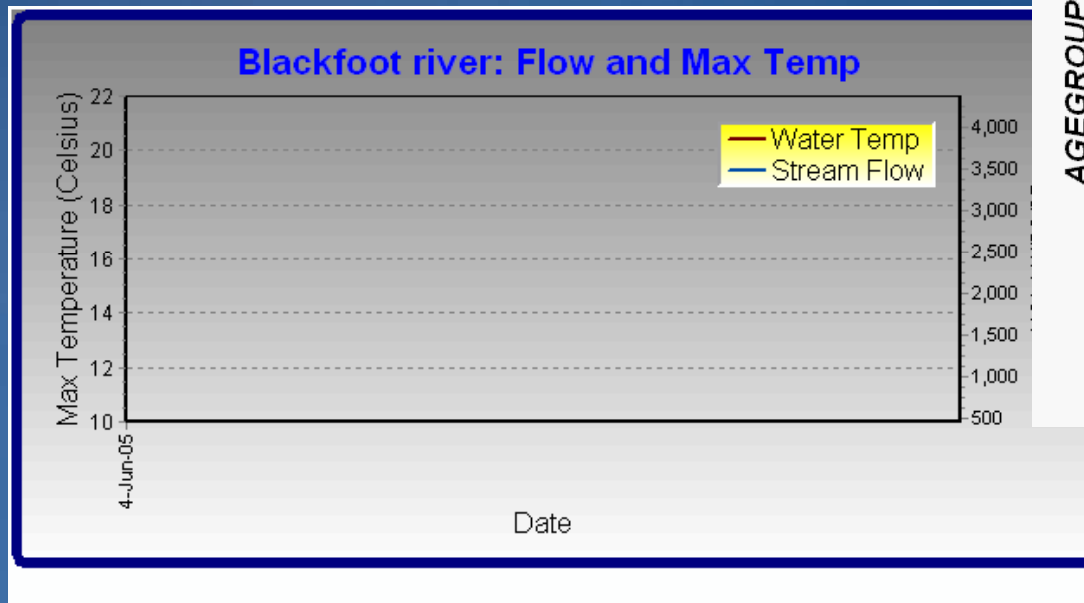
Output reformatted for time animation:

OBJECTID*	SHAPE*	SHAPE_Length	SHAPE_Area	Name	Time_	Expense
1	Polygon	17.237645	12.897165	Alabama	1980	106
2	Polygon	407.57095	277.52409	Alaska	1980	20
3	Polygon	23.257266	28.859101	Arizona	1980	0
4	Polygon	20.877127	13.517461	Arkansas	1980	109
5	Polygon	42.260156	41.533616	California	1980	539
6	Polvaon	22.025622	28.041602	Colorado	1980	101



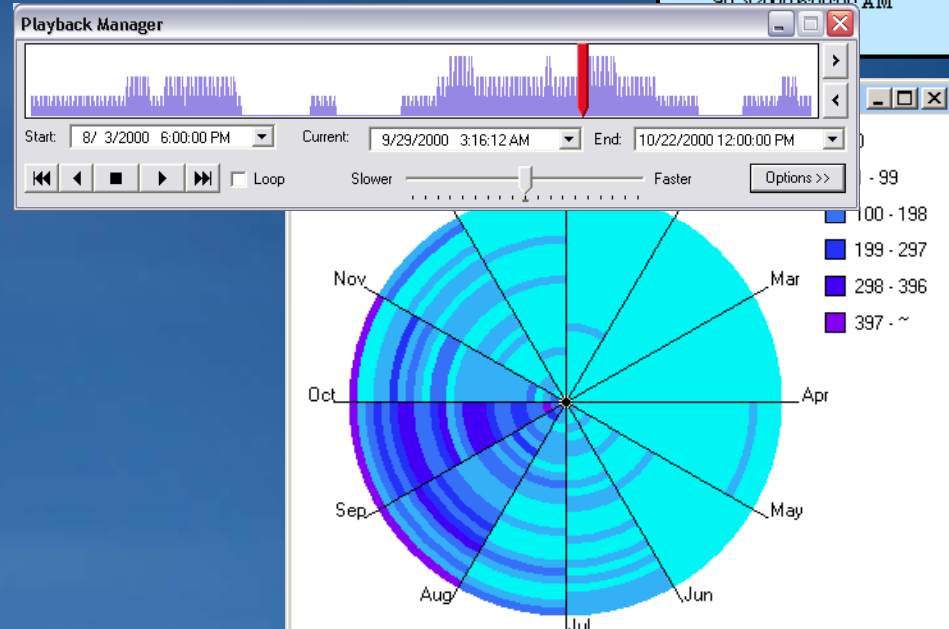
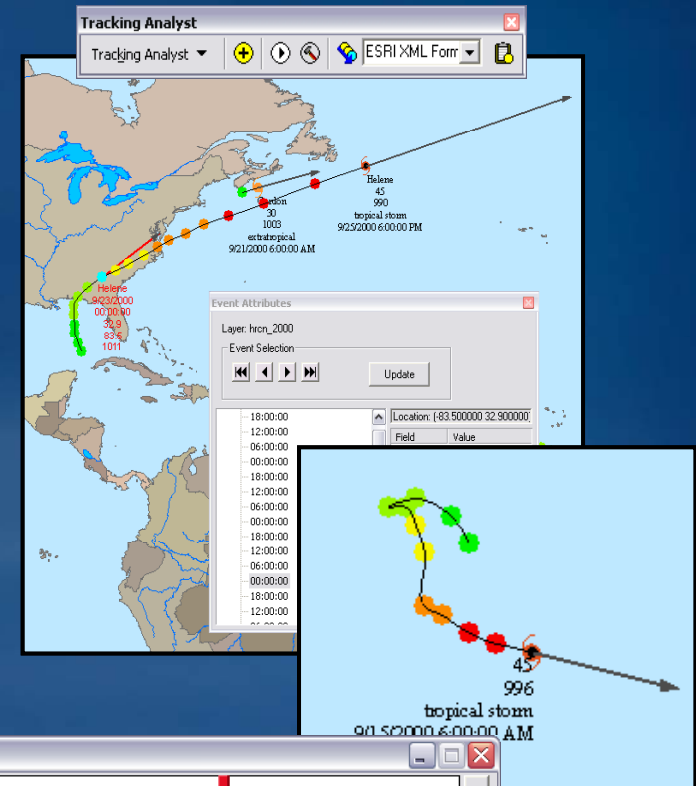
# Animating data in graphs

- *Create a graph using a layer or table*
- Create an animation in the usual way, attaching the layer or table to a time layer track
- When the animation is played, the graph will animate



# Tracking Analyst Extension

- ArcGIS Desktop Extension
- Historical and Real-Time Display
- Track Symbology
- Animation Tool
- Playback Manager with temporal event histogram
- Actions
- Temporal Offset
- Data Clock

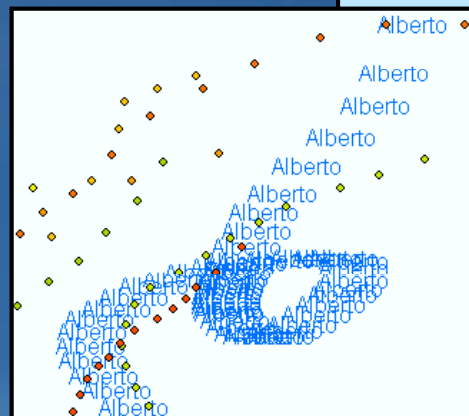
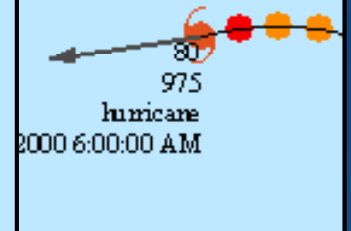
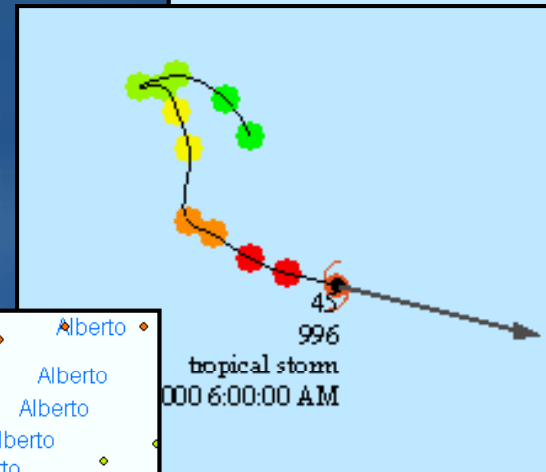
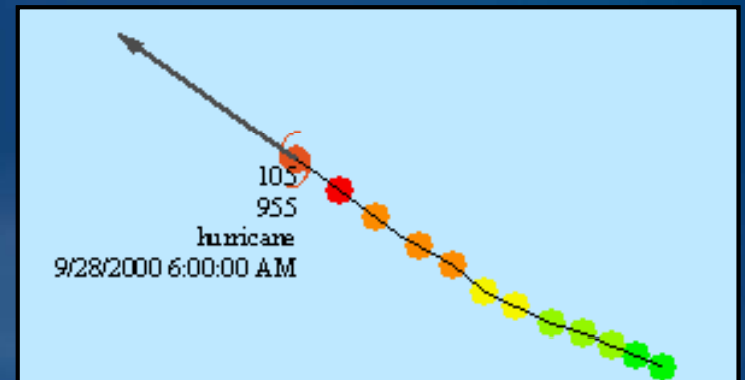


# Tracking Layer

- **Unique to Tracking Analyst**
- **Data Sources**
  - Shapefile
  - Personal GeoDatabase
  - File GeoDatabase (9.2)
  - ArcSDE
  - Real-Time Feeds
- **Required Field**
  - Date/Time Field (Windows format)
  - EventID (if you want to organize into tracks)

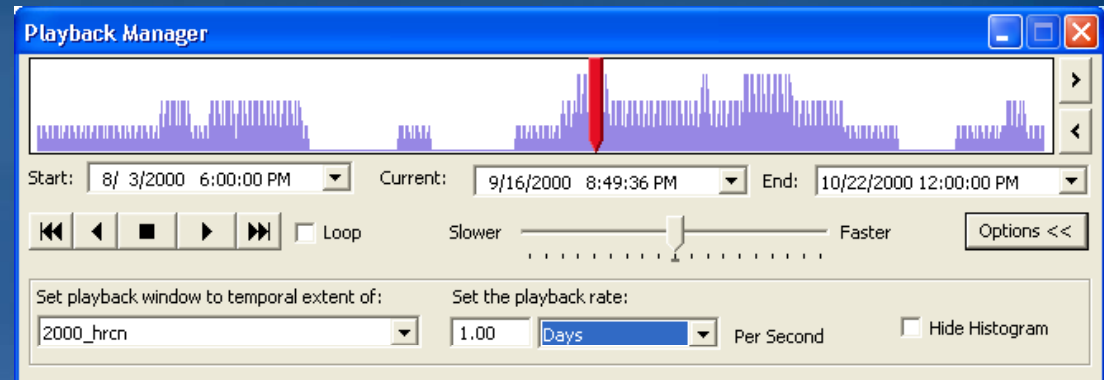
# Advanced Symbology Options

- Smooth tracks
- Text symbol
- Multiple attribute display
- Directional Vector
- Most Current



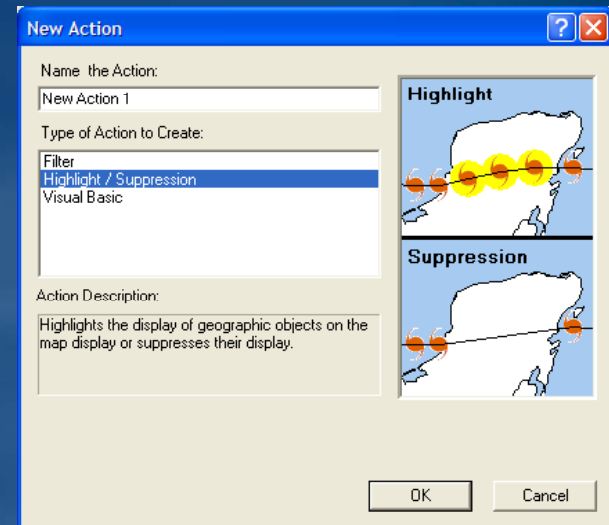
# Tracking Analyst Playback Manager

- Temporal Histogram
- Slidebar
- Playback Rate
- Playback Multiple Layers at Once
  - Concurrently Using Temporal Offset



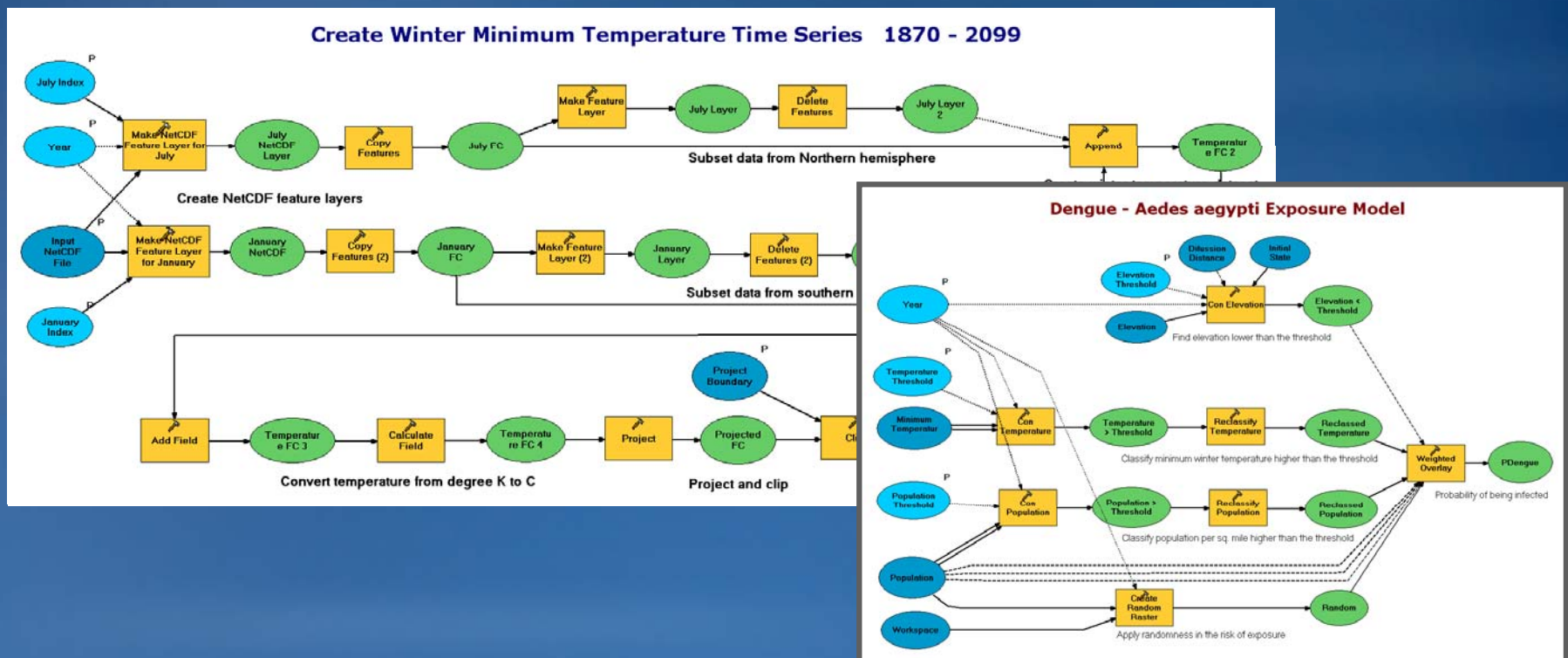
# Using Actions with Tracking Analyst

- **Layer Actions**
  - Highlight
  - Suppress
  - Run a VB script (real-time only)
- **Service Actions (ArcCatalog)**
  - Filter the event from further action processing (ArcMap)
  - Filter events you receive from Tracking Server
  - Run a VB script (real-time only)
- **Rules check for**
  - Some attribute in the data tables
  - Location of the event in relationship to polygon
  - Both



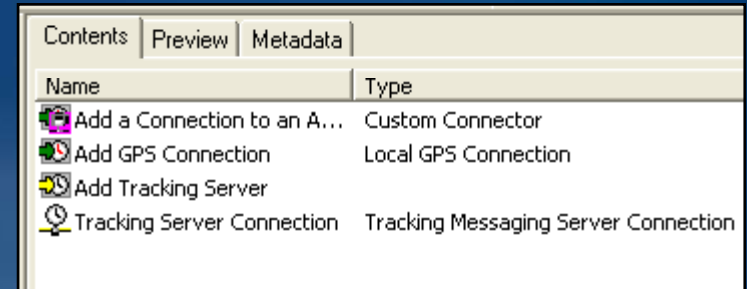
# Temporal Analysis

- Conflict detection in Tracking Analyst
- Custom processing tasks in Tracking Server
- Temporal Modeling
  - Looping and iteration in ModelBuilder and Python







# Working with Real-Time Data

- **GPS Unit**
  - Integration with GPS Toolbar
- **Tracking Server**
  - Can receive multiple feeds from multiple servers
- **SDK: Connection Wizard (9.2)**
  - Applications that don't require Tracking Server
  - Existing servers sending temporal data

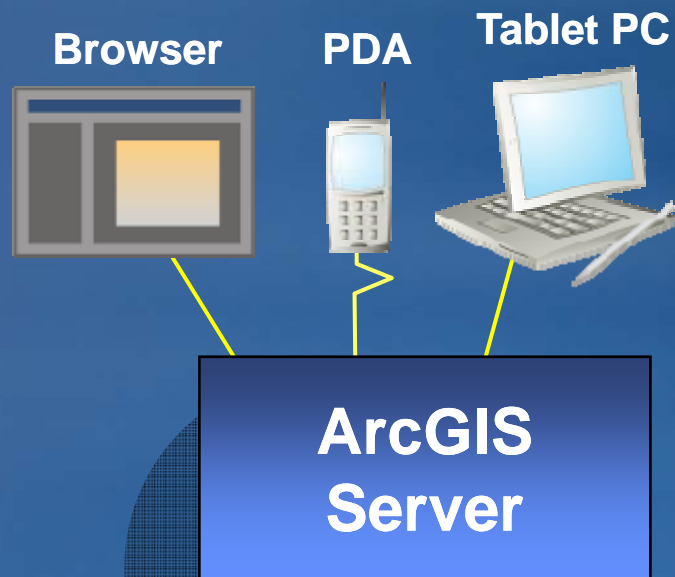


The screenshot shows a window with three tabs: 'Contents', 'Preview', and 'Metadata'. Below the tabs is a table with two columns: 'Name' and 'Type'. The table contains four rows of data, each with a small icon to the left of the name.

Name	Type
 Add a Connection to an A...	Custom Connector
 Add GPS Connection	Local GPS Connection
 Add Tracking Server	
 Tracking Server Connection	Tracking Messaging Server Connection

# Developer framework supports real time data

- ArcGIS Server Extension
  - Optimized for wireless data transfer
  - Connects to Geodatabase
  - .Net framework



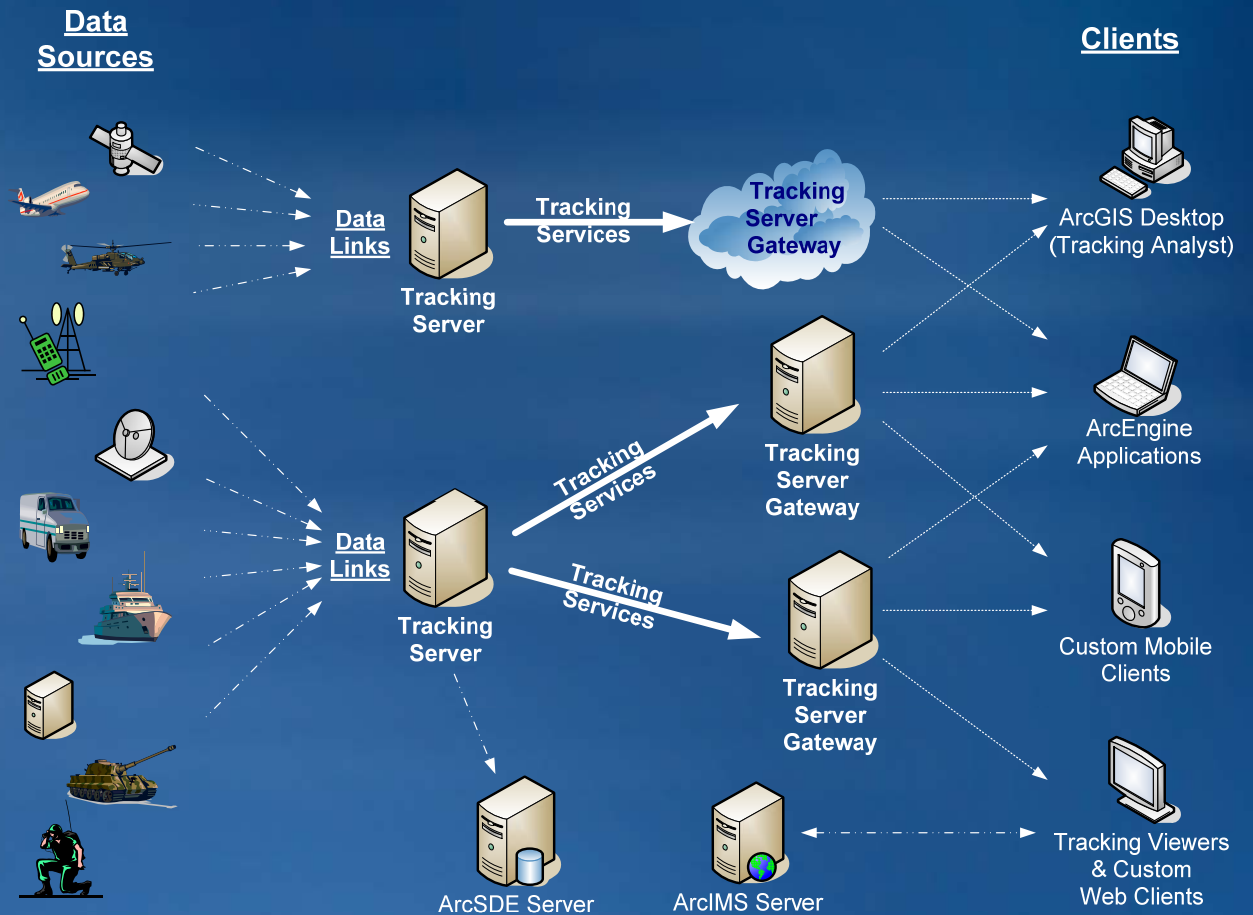
# Tracking Server

- **Acts as Real-time message hub**
- **Performs server-side processing**
- **Publishes data to GIS clients**
  - Tracking Analyst
  - Tracking Viewer
  - Custom Clients
- **Built with an open architecture for customization**
- **Sold as a Services product**

# Tracking Server

- **Manages**

- Data Links
- Actions
- Tracking Services
- Gateway Settings



# Future directions

- **Temporal reference framework**
- **Temporal metadata**
- **Temporal data management**
  - Gap filling, time synch, etc.
- **Temporal analysis tools**
  
- *What do you need?*



## ***The most important points to leave with today...***

- **Basic guidelines for working with temporal data in ArcGIS**
  - Use DATE fields whenever possible
  - Don't store time steps as separate fields
- **The DBMS can affect performance, its not a black box**
- **Temporal visualization and animation is easy**

# Questions & Answers

Please fill out the session evaluation forms

*Thank you*

Wind Speed and Direction: 5/17/2007

