Tornadoes in the US, 1955-2014

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1. Introduction

Over 1,200 tornadoes occur in the United States each year. Every state has experienced at least one tornado and tornadoes have happened at any time of year or day. The plains states, often referred to as "Tornado Alley", typically experience tornadoes in afternoons of the early summer months. The southeast also experiences a large number of tornadoes, and a perhaps lesser known fact is that the state of Florida experiences more tornadoes than almost every other state, though they are mostly of low severity and frequently related to tropical storms. NOAA's National Weather Service Storm Prediction Center assembles and provides a spatial dataset on tornadoes in the US since the 1950's. In this paper I will describe and demonstrate how I processed this dataset with ArcGIS, including using the components ArcPy and ArcObjects, to show where tornadoes have occurred across the continental US by features such as magnitude and date characteristics.

2. Objectives

My goals for this project were to spatially demonstrate tornado characteristics and trends over time using a combination of ArcMap, ModelBuilder, ArcPy and ArcObjects. I would create informative maps summarizing tornado activity in a variety of ways, and provide a mechanism by which users could select and display the type of map and/or particular characteristics they want to see, such as tornadoes by magnitude, time period or region.

Some questions my processing and analysis would be able to visually answer:

- Where have tornadoes occurred the most over the last 60 years?
- Where do the most severe tornadoes tend to occur?
- How have patterns of tornado activity across the country changed over the years?
- Tornadoes have been found to occur less frequently on Saturday than during mid-week. Do tornadoes have different patterns for the different days of the week?

3. Methodology

I approached processing the data for this project with 3 steps. I began by doing some exploratory analysis in order to understand and look for anomalies in the data as well as help me establish where I would focus my spatial analysis. Then in ArcGIS, after creating a file geodatabase to manage the data, I used a combination of ModelBuilder and ArcPy Python scripts to create a series of feature classes and surfaces that provide a variety of different ways of viewing tornadoes. Finally I used ArcObjects with Visual Studio and C# to create an interface that enabled me to quickly select and view the different layers I created.

3.A. Exploratory Data Analysis

The primary data source I used for this analysis was a shapefile of tornado data compiled by the National Weather Service's Storm Prediction Center (SPC)[i]. The shapefile's attribute table consisted of 58,959 rows representing tornadoes in the US from 1950 to 2014. An excerpt of the tornado shapefile's attribute table is shown below:

Table

Tornadoes 1950-2014

FID	Shape	om	yr	mo	dy	date	time	tz	st	stf	stn	mag	inj	fat	loss	closs	slat	slon	elat	elon	len	wid
0	Polyline	1	195	1	3	1950-01-03	11:00:00	3	MO	29	1	3	3	0	6	0	38.77	-90.22	38.83	-90.03	9.5	150
1	Polyline	2	195	1	3	1950-01-03	11:55:00	3	IL	17	2	3	3	0	5	0	39.1	-89.3	39.12	-89.23	3.6	130
2	Polyline	3	195	1	3	1950-01-03	16:00:00	3	OH	39	1	1	1	0	4	0	40.88	-84.58	0	0	0.1	10
3	Polyline	4	195	1	13	1950-01-13	05:25:00	3	AR	5	1	3	1	1	3	0	34.4	-94.37	0	0	0.6	17
4	Polyline	5	195	1	25	1950-01-25	19:30:00	3	MO	29	2	2	5	0	5	0	37.6	-90.68	37.63	-90.65	2.3	300
5	Polyline	6	195	1	25	1950-01-25	21:00:00	3	IL	17	3	2	0	0	5	0	41.17	-87.33	0	0	0.1	100
6	Polyline	7	195	1	26	1950-01-26	18:00:00	3	TX	48	1	2	2	0	0	0	26.88	-98.12	26.88	-98.05	4.7	133
7	Polyline	8	195	2	11	1950-02-11	13:10:00	3	TX	48	2	2	0	0	4	0	29.42	-95.25	29.52	-95.13	9.9	400
8	Polyline	9	195	2	11	1950-02-11	13:50:00	3	TX	48	3	3	12	1	4	0	29.67	-95.05	29.83	-95	12	1000
9	Polyline	10	195	2	11	1950-02-11	21:00:00	3	TX	48	4	2	5	0	5	0	32.35	-95.2	32.42	-95.2	4.6	100
10	Polyline	11	195	2	11	1950-02-11	23:55:00	3	TX	48	5	2	6	0	5	0	32.98	-94.63	33	-94.7	4.5	67

1 (0 out of 58959 Selected)

Tornadoes 1950-2014

3.A.1. Data Quality

I created summaries of the data using Microsoft Access and Excel to gain understanding and look for anomalies in the data. The quality of the data seemed fairly good. The "mag" field, for tornado magnitude, ranged from 0 to 5, with a few -9's (unknown) but only in 1950-1952. I consulted metadata which mentioned a change from Fujita to Enhanced Fujita scale in 2007; I also noticed some formatting differences in other fields (such as number of decimal places tracked) in 1996 and 2006. I suspected there could be methodology changes in how tornadoes were tracked at these times. There were fields for tornado length (in miles) and width (in yards), as well as fatalities, injuries and property loss figures, of which I did not notice any strange anomalies other than those already mentioned above.

Regarding the two Fujita scales: The Fujita scale has historically been used to impart magnitudes to tornadoes, and this measurement methodology went through some enhancements in 2007, resulting in subsequent measurements using a new Enhanced Fujita or EF scale. The 60 years of tornado data in the source dataset represent a mixture of Fujita and Enhanced Fujita scales; there are ways to translate between the two scales[ii], but it was not performed on this data and there isn't enough information within the data to allow one to attempt the transformation. This means we are not exactly comparing apples-to-apples in looking at, say, F1 tornadoes in 1990 versus F1 tornadoes in 2010. This point should be kept in mind in interpreting the results. In this paper, for simplicity I will preface magnitudes with "F", though it should be recognized that for tornadoes after 2006, it is really the "EF" scale that was used.

Another point of significance I noted at this time was that the number of tornadoes overall and for magnitude F0 in particular has increased considerably over the years. I suspected the increase could have multiple causes, including changes in reporting, classification, or true underlying increases in F0 tornadoes. In any event, this observation should also be kept in mind when interpreting results.

Tornado Counts by Decade

Decade	F0	F1	F2	F3	F4	F5	Total	F1-5	% F0
1955-1964	1,542	2,414	1,777	428	88	10	6,259	4,717	25%
1965-1974	2,051	3,194	2,059	552	130	18	8,004	5,953	26%
1975-1984	3,128	3,676	1,488	398	85	6	8,781	5,653	36%
1985-1994	5,004	3,132	988	279	70	6	9,479	4,475	53%
1995-2004	8,284	3,169	936	274	67	5	12,735	4,451	65%
2005-2014	6,992	3,593	1,066	302	67	9	12,029	5,037	58%

3.A.2. Project Focus

To take advantage of the lengthy period of years the data covered, I decided to confine my focus to different time period characteristics along with magnitude and geographic information. I wanted to show tornadoes by year, but realized 65 years would be hard to meaningfully display, so I decided on aggregating by decade. Since some of the earliest data had some tornadoes with unknown magnitude, and I wanted equally-sized decades, I chose to omit data before 1955 and have decades center on beginnings of the decennial years, for example, decade "1960" is 1/1/1955 to 12/31/1964.

As I was reviewing the numbers, I casually wondered whether there are more or fewer tornadoes by day of the week, and discovered that Saturdays had significantly fewer tornadoes.

Tornado Counts by Decade and Weekday, % of Decade's Tornadoes

	1960	1970	1980	1990	2000	2010	Total
Sun	13.7%	14.9%	14.0%	13.9%	14.8%	13.2%	14.1%
Mon	15.1%	14.2%	13.6%	14.1%	13.6%	13.6%	13.9%
Tue	13.9%	14.6%	13.9%	15.7%	15.4%	13.4%	14.5%
Wed	13.7%	14.6%	15.4%	13.7%	14.2%	16.6%	14.8%
Thu	15.3%	15.2%	15.4%	13.1%	14.8%	15.9%	14.9%
Fri	15.5%	13.8%	15.1%	16.2%	13.9%	14.0%	14.6%
Sat	12.7%	12.7%	12.6%	13.4%	13.3%	13.4%	13.1%
Sum Days	100%	100%	100%	100%	100%	100%	100%

I found that some other researchers had also noticed this effect using data from 1995 to 2009[iii]. I was curious if there were different patterns in Saturday versus weekday tornadoes and decided to include weekday in my spatial analysis. I prepared a non-spatial table with decade and day of week by date that I would upload and join to the tornadoes so I could query on these cuts.

3.B. Using ArcMap ModelBuilder and ArcPy Scripts to Create Layers

Next, I moved to ArcMap, where I divided my processing into 3 steps:

1) establish a foundation of feature classes / layers for display or subsequent steps,
2) create density surfaces as an alternative way to display the data, and
3) create area-normalized state quantile/chloropleth maps.

3.B.1. Foundation Layers

For a simple yet effective background and orientation, I used a shapefile of states from the US census[iv]. For my coordinate system, the tornado data was in NAD83 geographic and Contiguous US Lambert Conformal Conic projected coordinate systems, which seemed reasonable to adopt in terms of appropriateness for a continental US focus. I used Select and Clip tools to limit my display to the 48 continental US states, joined to the weekday and decade translations from my non-spatial table, and performed some data management using an ArcPy script. My ArcPy script renames fields to add clarity, as well as adds and calculates fields capturing tornado counts by each of the 6 magnitudes, which would add flexibility to my subsequent displays. Appendix A shows my model and ArcPy script for this step.

3.B.2. Create Density Surfaces and Point Summaries

The tornado data was in a vector line data model. To better show areas of concentration of tornadoes across the US, I used the Line Density tool to transform the vector model to surface rasters, followed by the Extract by Mask tool which made the density look more continuous. In consideration that an F5 tornado is much more damaging than an F0 tornado, I created an alternate line density surface that applies weights, such that an F1 tornado has two times the impact of an F0 tornado, and similarly up to F5. This is consistent with findings mentioned by other researchers[v]. In addition, I considered that one might also be interested in counting tornadoes as points, without the length of the tornadoes making an impact, and created another alternative vector and raster pair where I converted each line using a Line to Point tool, followed by the Point Density tool to create a surface.

A note about performance: processing this data in ArcMap as-is was quite slow. I improved performance in two ways: one, I reduced the size of my attribute table by deleting columns I didn't plan to use (this was done in the "foundation" processing step). Two, I used the Dissolve tool, which had the effect of reducing attribute table rows without compromising the spatial qualities of the result. My dissolve fields were magnitude, decade, and day, allowing these characteristics to be queried before creating the surfaces. I used this functionality later in revisiting this step to create more layers as part of my user interface.

In this model I also created point features that summarize tornadoes over each decade to one point, by first dissolving on decade and then using the Feature to Point tool. Appendix B shows my model and ArcPy script for this step.

3.B.3. Creating State Quantile/Chloropleth Maps

In this step, I compiled tornado counts for each state and normalized them by area in order to produce maps fairly comparing tornado statistics by state. Texas leads in numbers with over 8,000 tornadoes, but it is also the largest state; it is not the state with the most tornadoes by area.

I first used the Intersect tool to divide tornadoes crossing state lines into separate segments for each state. It should be noted that this increases the overall number of tornadoes, in that a tornado crossing the state line between Mississippi and Alabama, for instance, would be counted as one tornado in each of those two states. I considered doing this differently, such as applying fractions to the counts by line lengths, but as I was not summing up tornadoes after this step I did not see a need to do so.

I employed two ArcPy scripts in this model to add fields for state area and for renaming and deleting fields as part of data cleanup. While I could have relied on symbolization to perform the by-area normalization, I wanted to also capture the calculated numbers in separate fields for availability and to better enable making comparisons among the states. For the tornado counts by area, I used 100 square miles as my area unit, which produced numbers that are easy on the eyes to make comparisons between states. Appendix C shows my model and ArcPy script for this step.

3.C. User Interface: ArcObjects, Visual Studio and C#

Finally, I considered what kind of interface would be most helpful for viewing the different vector and raster layers I had created in the previous step. I found myself wishing I could easily and quickly switch between different layers in my map document. I also wanted to look at a range of the surface rasters where criteria for certain combinations of magnitudes, decades or days had been applied. I decided to use a combo box to fulfill these needs, and also created a toolbar to contain it. I made the list of options in my combo box correspond to layers in my table of contents, and modified some C# code I found in a related snippet ("Toggle Visibility Of Composite Layer") so that selecting a layer from the combo box would turn on only that layer and the States layer only for orientation, with all other layers turned off.

My initial plan for a mechanism to select subsets of features was to make a second combo box that would list options that were in essence 'where' clauses for a query, such as 'day = Saturday'. A selection would trigger calculation and display of the layer selected in the first combo box. After some consideration, though, I realized that the processing triggered after selection would degrade performance substantially, so I instead decided to incorporate the selection capability into my first combo box. This meant I needed to create many more layers, each with different criteria applied. To accomplish this methodically, I created another ArcPy script with a function which applied the Select, Line Density and Extract by Mask tools, and called this function multiple times to create multiple additional layers. I applied my new script in the "surfaces" model, and manually added the resulting layers to my map document. In testing my final combo box functionality, I found it worked well for speed and flexibility, and was a great improvement over manually turning layers on/off in the table of contents and applying or changing selection criteria. My additional ArcPy script, C# code and a demonstration of the combo box in use are shown in Appendix D.

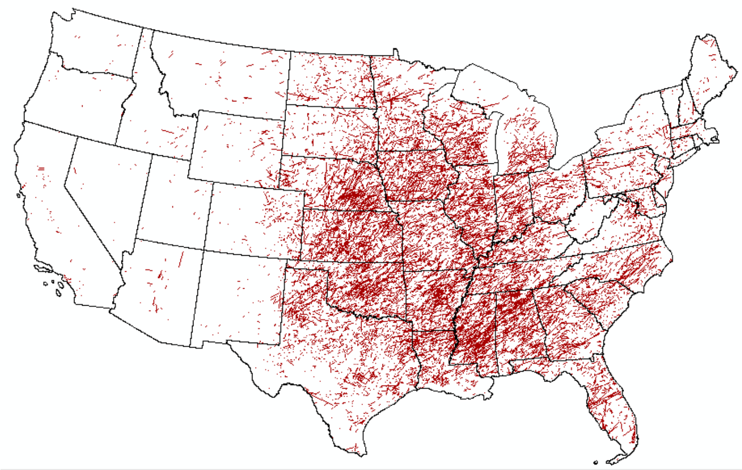
Another element in terms of user interface which I incorporated into my map documents was a set of bookmarks zooming in on different states or regions of the US. This simple solution achieved my objective of easily being able to change the map view to look at particular geographical regions.

4. Results

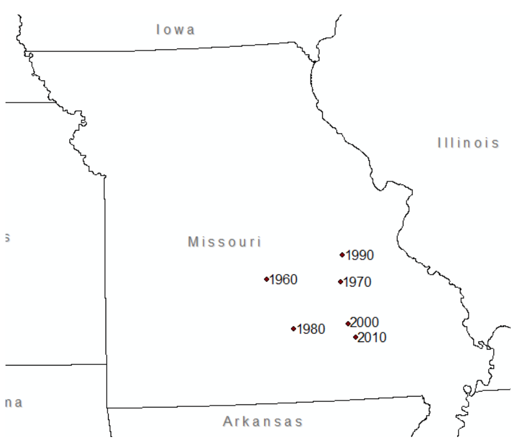
What follows are some screenshots of my ArcMap window and a map layout illustrating the different types of layers I created as described in the Methodology section, along with some observations about the data. Unless otherwise mentioned, the maps represent all tornadoes from 1955 to 2014.

4.A. Tornado Line Vector Map; Decades Summarized as Points

Below shows all tornadoes as equally weighted lines representing their paths from the dataset. It seems like there are higher concentrations of tornadoes in certain parts of the country, but it is hard to gauge this; thus the need for additional processing and displays.



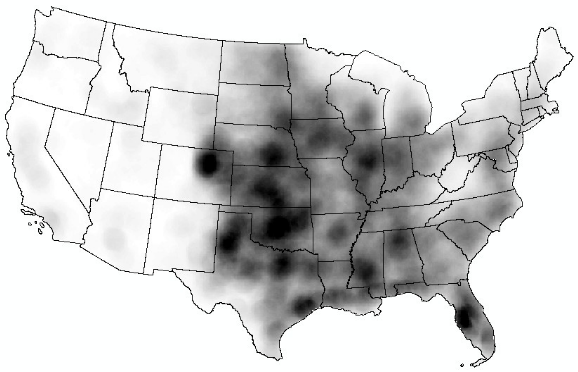
I wondered if the "center of mass" of tornadoes has moved over the years. The following shows the centroids for each decade; there hasn't been much overall movement and there is no consistent trend in any direction. I applied the same methodology for day of week and results were very similar (not shown).



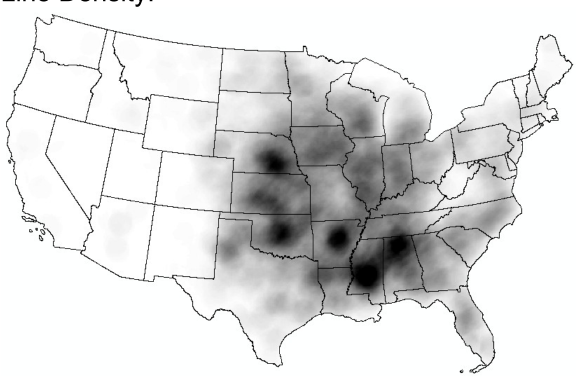
4.B. Density Surfaces

The following maps resulted from transforming the vector data to density surface rasters:

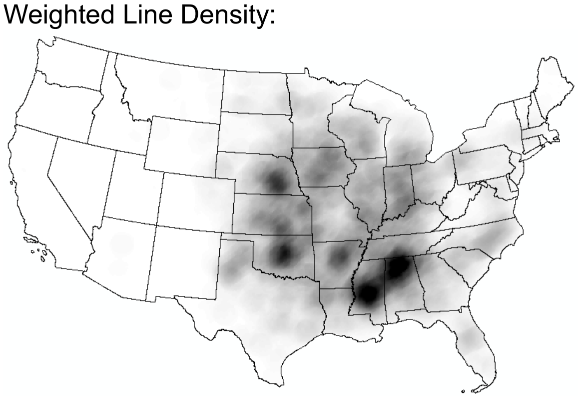
Point Density: (converts lines to points first, then performs density)



Line Density:



Weighted Line Density:

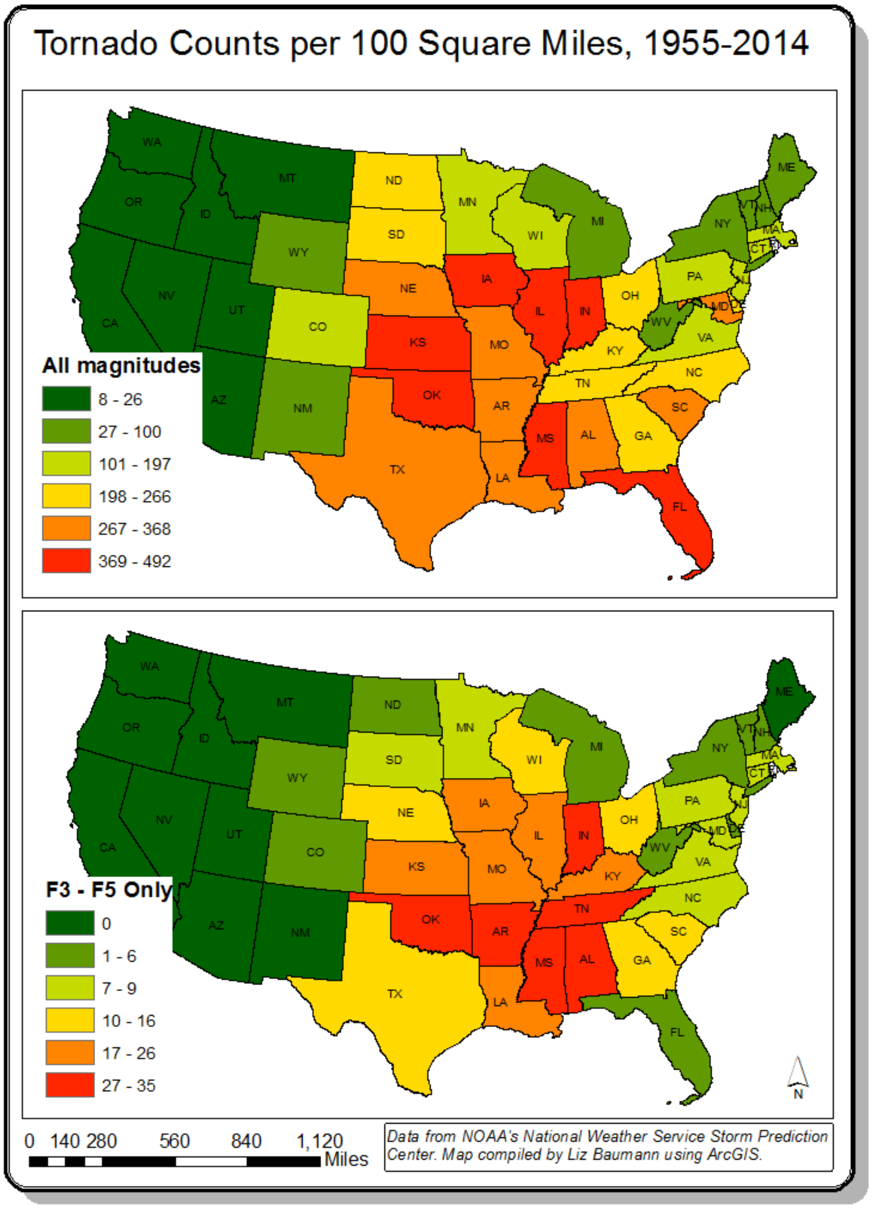


Observations:

- Note the areas with strong concentrations in the Point Density map but weak concentrations in Line Density, such as the Tampa area of Florida, parts of Texas, and Northeastern Colorado. These regions tend to have more frequent but shorter or less long-lived tornadoes than other areas.
- By contrast, the high Line Density concentrations in Mississippi and Alabama and the plains states are indicative of tornadoes with longer paths.
- Weighted Line Density gives higher weight to stronger tornadoes, with the map suggesting that not only are Mississippi and Alabama tornadoes longer, they are of stronger intensity as well compared with other states. A correlation between tornado length and strength seems logical.

4.C. By-State Quantile Maps

The following map layout contrasts the states most frequently experiencing tornadoes of all magnitudes versus only the more severe tornado magnitudes F3, F4 and F5. I applied 6-class quantile symbolization to both maps, on the variable for tornado counts divided by 100 square mile area (to normalize the data for varying state sizes). As pointed out earlier, Florida experiences more tornadoes than other states overall, but very few of the more severe magnitudes; this can be seen here as well by comparing the two maps.

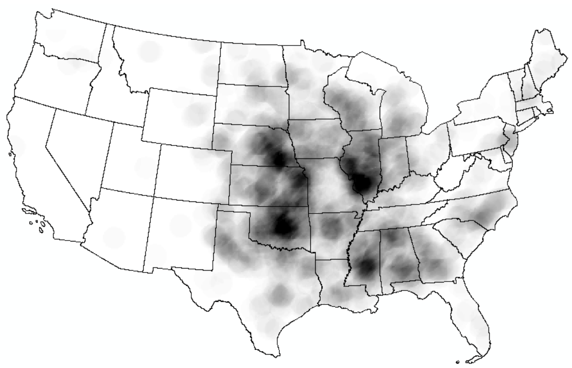


Which state has most tornadoes per area? The top 5 in order are: OK, FL, KS, IA, MS.
Which state has most major tornadoes (F3 or higher) per area? Top 5: OK, MS, IN, AL, AR.

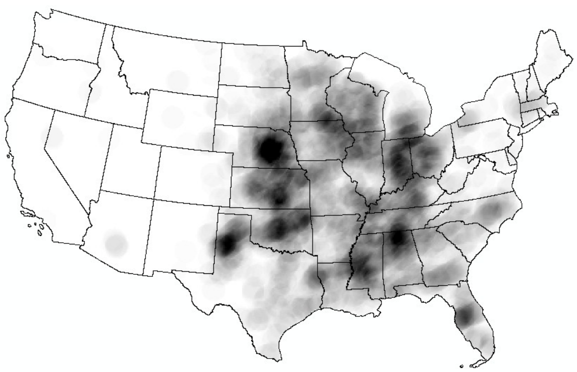
4.C. Line Densities For Each Decade

The 2010 decade seems a bit more concentrated to the southern states, but overall, the results here do not seem very suggestive of a particular changing pattern or trend. Keep in mind that fewer tornadoes were reported in general in the earlier years.

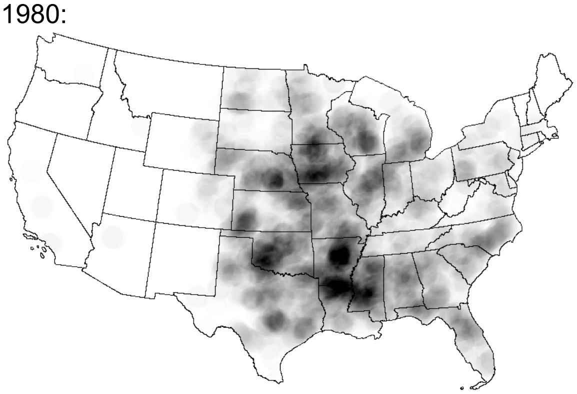
1960:



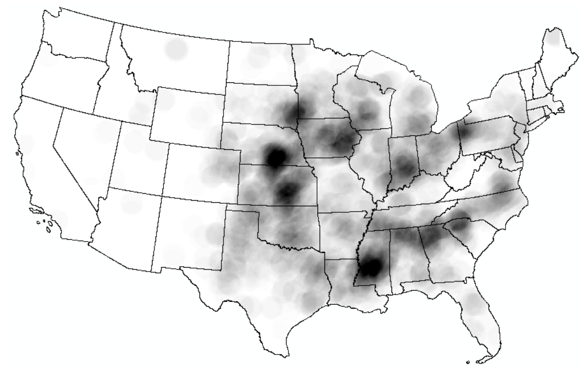
1970:



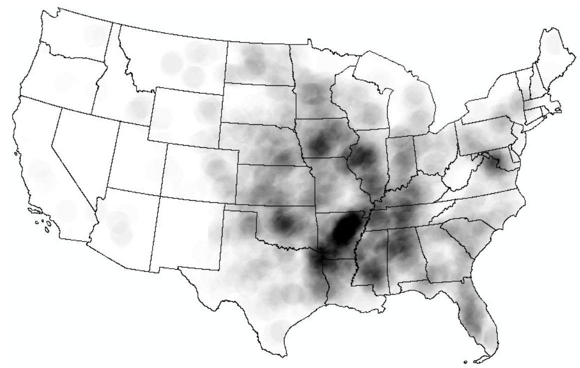
1980:



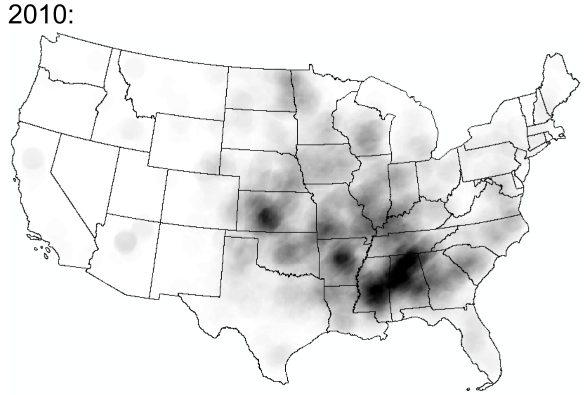
1990:



2000:



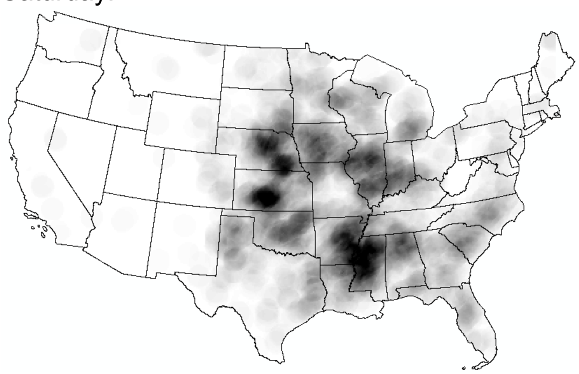
2010:



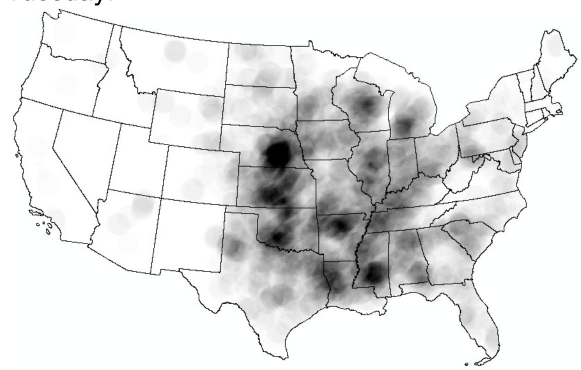
4.D. Line Densities For Each Day of the Week

As previously noted, I discovered during exploring the data that there are statistically fewer tornadoes on Saturday than other days of the week. I wondered if there might be a different pattern by weekday. While Wednesdays did show a different pattern, there doesn't seem to be much consistency within the 5 weekdays, nor do Saturday and Sunday look especially alike and/or especially different from weekdays.

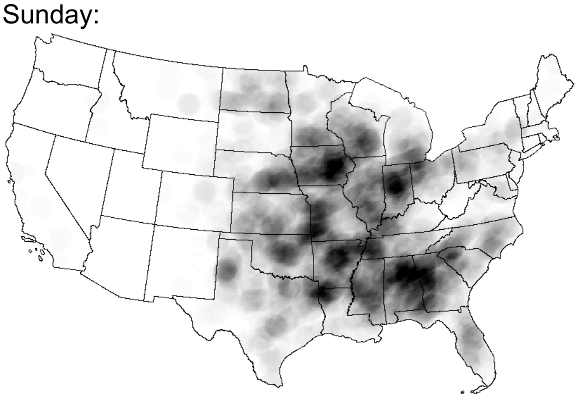
Saturday:



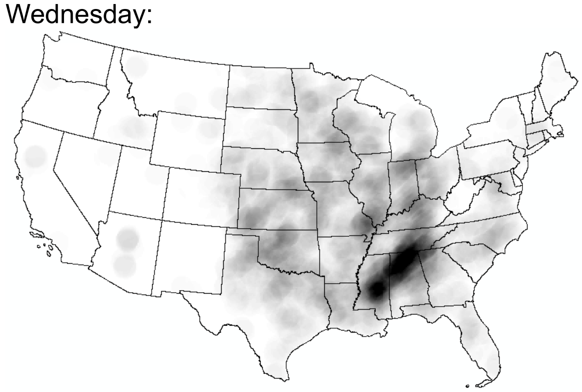
Tuesday:



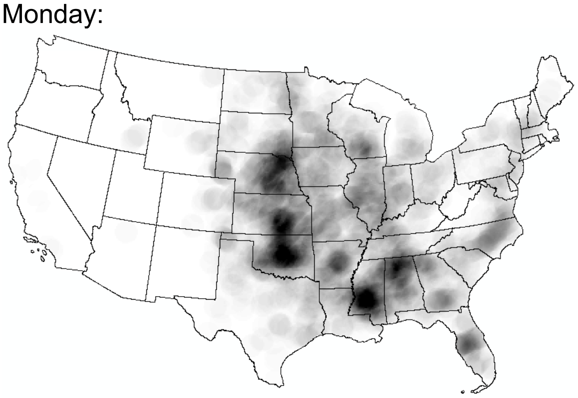
Sunday:



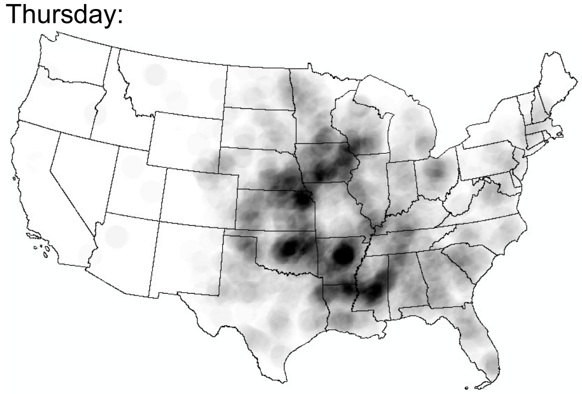
Wednesday:



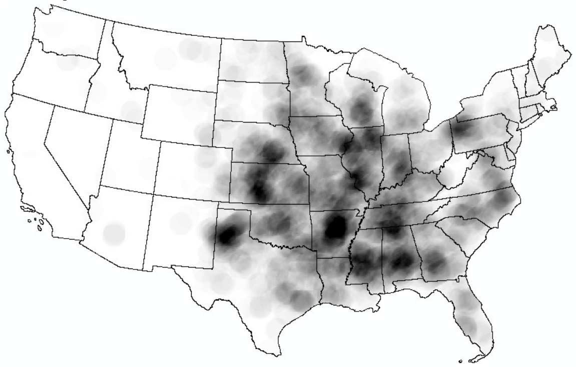
Monday:



Thursday:



Friday:



Noting some similarities between the Wednesday density and the 2010 decade density, I investigated the attributes and found that the most tornadoes on a single day occurred on Wednesday, April 27, 2011. There were 207 tornadoes that day in the tornado dataset, and the event is known as the 2011 Super Outbreak[vi]. The Line Densities and other demonstrations are undoubtedly influenced by this outbreak.

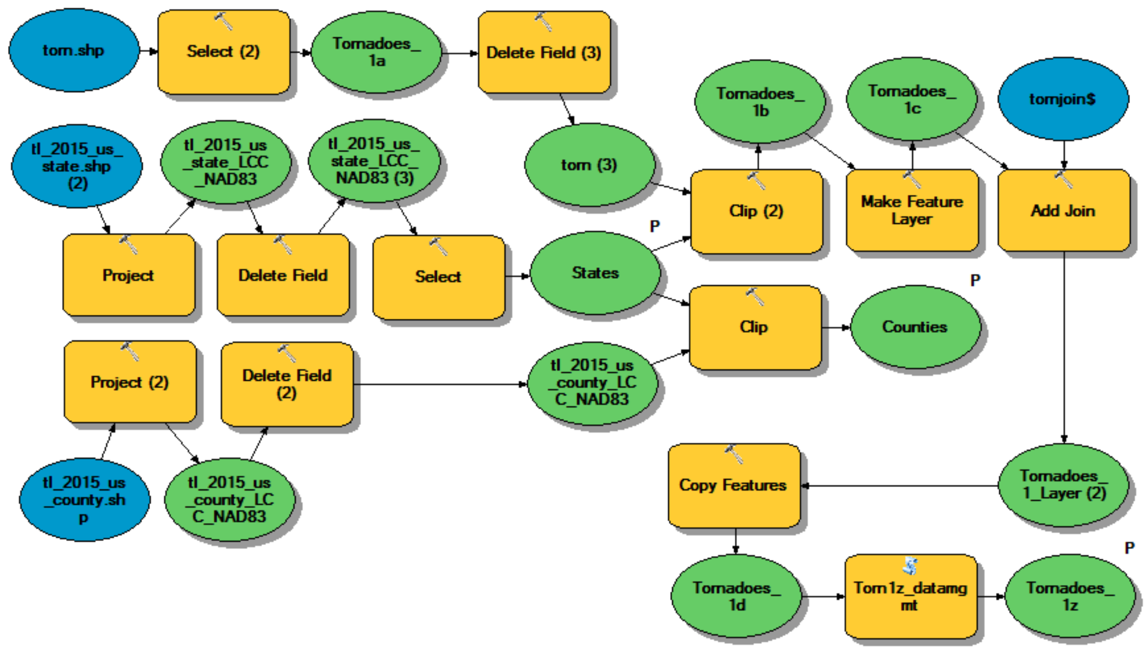
5. Summary

There are many ways one could explore weather data with ArcMap. In this project I focused on showing different time periods and magnitude combinations, and was able to spatially demonstrate answers to questions such as where tornadoes occur the most and how the patterns of tornadoes differ for various date characteristics. Using ArcPy and ArcObjects allowed me to automate repetitive tasks and provide a richer user interface, which helped me with analysis and quickly displaying different results.

Appendix A: Methodology for Foundation Layers

A.1. Model

Note, the output layer "Tornadoes_1z" is used in both subsequent processing steps.



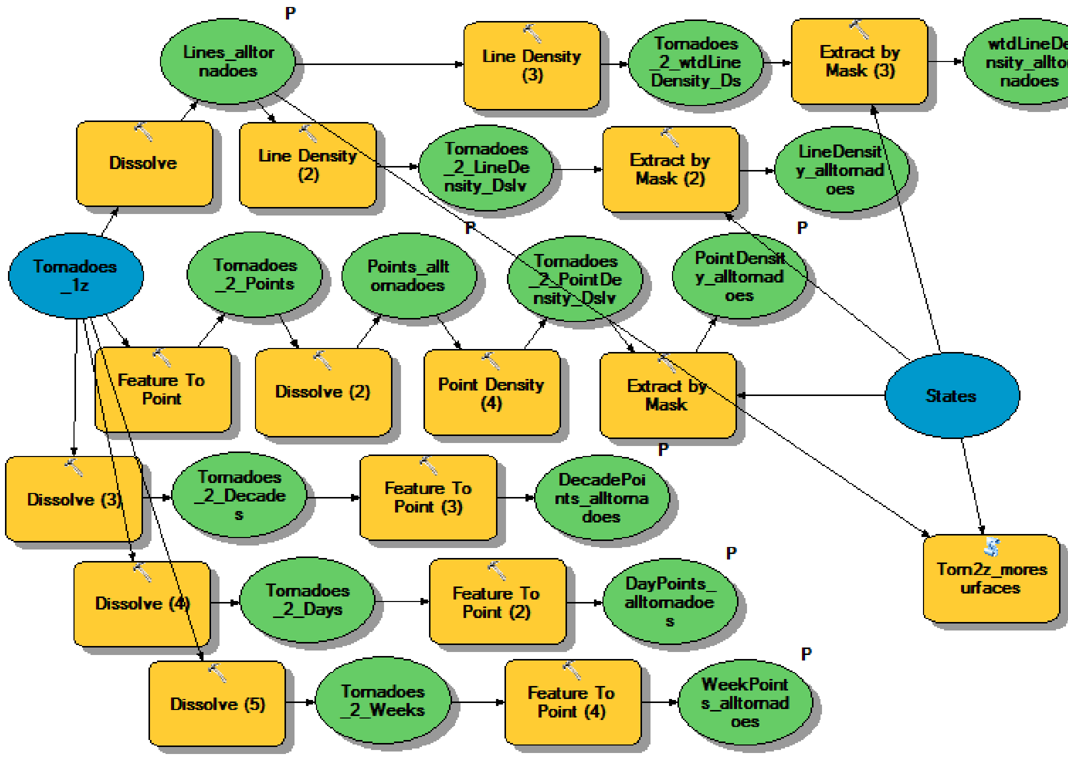
A.2. ArcPy Script for Data Management

```
# Torn1z_datamgmt.py
#  rename fields after join; delete, add new fields

import arcpy

# Local variables:
inputfc = arcpy.GetParameterAsText(0)
outputfc = arcpy.GetParameterAsText(1)

# 1. Alter Fields (renaming)

# below adapted from: http://joshwerts.com/blog/2014/04/01/arcpy-rename-fields/
def rename_fields(table, out_table, new_name_by_old_name):
    """ Renames specified fields in input feature class/table
    :table:                 input table (fc, table, layer, etc)
    :out_table:             output table (fc, table, layer, etc)
    :new_name_by_old_name:  {'old_field_name':'new_field_name',...}
    ->  out_table
    """
    existing_field_names = [field.name for field in arcpy.ListFields(table)]

    field_mappings = arcpy.FieldMappings()
    field_mappings.addTable(table)

    for old_field_name, new_field_name in new_name_by_old_name.iteritems():
```

```
        if old_field_name not in existing_field_names:
            message = "Field: {0} not in {1}".format(old_field_name, table)
            raise Exception(message)

        mapping_index = field_mappings.findFieldMapIndex(old_field_name)
        field_map = field_mappings.fieldMappings[mapping_index]
        output_field = field_map.outputField
        output_field.name = new_field_name
        output_field.aliasName = new_field_name
        field_map.outputField = output_field
        field_mappings.replaceFieldMap(mapping_index, field_map)

    # use merge with single input just to use new field_mappings
    arcpy.Merge_management(table, out_table, field_mappings)

    return out_table


new_name_by_old_name = {
    'Tornadoes_1b_om'   : 'torn_id',
    'Tornadoes_1b_yr'   : 'year',
    'Tornadoes_1b_mo'   : 'month',
    'Tornadoes_1b_date' : 'date',
    'Tornadoes_1b_st'   : 'state_start',
    'Tornadoes_1b_mag'  : 'magnitude',
    'Tornadoes_1b_len'  : 'length_torndata',
    'Tornadoes_1b_wid'  : 'width',
    'tornjoin__dayname' : 'day',
    'tornjoin__decade'  : 'decade',
    'tornjoin__week'    : 'week',
}
rename_fields(inputfc, outputfc, new_name_by_old_name)

# 2. Delete the join field
arcpy.DeleteField_management(outputfc, "tornjoin__date")

# 3. Add/Calculate Fields
arcpy.AddField_management(outputfc, "torn_count", "LONG", \
    "", "", "", "", "NULLABLE", "NON_REQUIRED", "")
arcpy.AddField_management(outputfc, "magweight", "LONG", \
    "", "", "", "", "NULLABLE", "NON_REQUIRED", "")

arcpy.CalculateField_management(outputfc, "torn_count", "1", "PYTHON_9.3")
arcpy.CalculateField_management(outputfc, "magweight", \
    "CalcMagWt(!magnitude!)", "PYTHON_9.3", \
    "def CalcMagWt(mag):\\n  if mag == 0:\\n    magwt = 1" \
    + "\\n  elif mag == 1:\\n    magwt = 2" \
    + "\\n  elif mag == 2:\\n    magwt = 4" \
    + "\\n  elif mag == 3:\\n    magwt = 8" \
    + "\\n  elif mag == 4:\\n    magwt = 16" \
    + "\\n  else:\\n    magwt = 32\\n  return magwt")
```

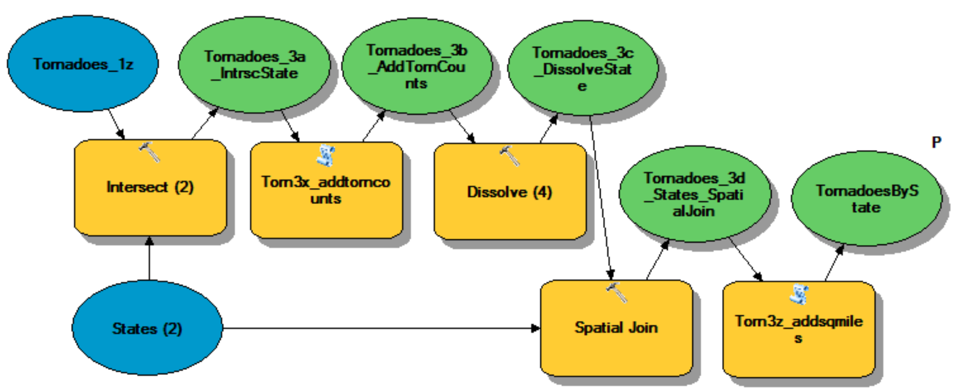
Appendix B: Methodology for Creating Density Surfaces (Model)

Note, "Torn2z_moresurfaces" is an ArcPy script that repeats the processing of Line Density on a subset of the data, using the Select tool to get the subset - refer to the user interface step for more information.



Appendix C: Methodology for Creating State Quantiles

C.1. Model



C.2. ArcPy Script for Adding Tornado Counts

```
# Torn3x_addtorncounts.py: add new fields: counts for each magnitude of tornado

import arcpy
```

```
inputfc = arcpy.GetParameterAsText(0)
outputfc = arcpy.GetParameterAsText(1)

# 1. Copy to new feature class
arcpy.CopyFeatures_management(inputfc, outputfc, "", "0", "0", "0")

# 2. Add/Calculate Fields
mags = [0,1,2,3,4,5]
for magnum in mags:
    nm = "torn_count_F" + str(magnum)
    func = "def tct(mag):\\n  if mag == " + str(magnum) + \
          ":\\n    tct = 1\\n  else:\\n    tct = 0\\n  return tct"
    arcpy.AddField_management(outputfc, nm, "LONG", \
        "", "", "", "", "NULLABLE", "NON_REQUIRED", "")
    arcpy.CalculateField_management(outputfc, nm, \
        "tct(!magnitude!)", "PYTHON_9.3", func)

arcpy.AddField_management(outputfc, "torn_count_F345", "LONG", \
    "", "", "", "", "NULLABLE", "NON_REQUIRED", "")
arcpy.CalculateField_management(outputfc, "torn_count_F345", \
    "tct(!magnitude!)", "PYTHON_9.3", \
    "def tct(mag):\\n  if mag >= 3:\\n    tct = 1" \
    + "\\n  else:\\n    tct = 0\\n  return tct")
```

C.3. ArcPy Script for Adding Square Miles Calculations

```
# Torn3z_addsqmiles.py: rename fields after join; delete, add new fields

import arcpy

inputfc = arcpy.GetParameterAsText(0)
outputfc = arcpy.GetParameterAsText(1)

# 1. Alter Fields (renaming)
## note the "rename_fields" function defined same as above, omitted here to save space

new_name_by_old_name = {
    'STUSPS' : 'state',
    'NAME' : 'statename',
    'SUM_torn_count' : 'torn_count_allmags',
    'SUM_torn_count_F0' : 'torn_count_F0',
    'SUM_torn_count_F1' : 'torn_count_F1',
    'SUM_torn_count_F2' : 'torn_count_F2',
    'SUM_torn_count_F3' : 'torn_count_F3',
    'SUM_torn_count_F4' : 'torn_count_F4',
    'SUM_torn_count_F5' : 'torn_count_F5',
    'SUM_torn_count_F345' : 'torn_count_F345',
    'SUM_torn_count_F45' : 'torn_count_F45',
    'SUM_length_torndata' : 'length_torndata',
    'SUM_Shape_Length' : 'tornado_length_meters',
}
rename_fields(inputfc, outputfc, new_name_by_old_name)

# 2. Delete the join field
deletefields = [
    'Join_Count',
    'TARGET_FID',
    'STUSPS_1',
    'NAME_1',
]
for delfield in deletefields:
```

```
    arcpy.DeleteField_management(outputfc, delfield)

# 3. Add/Calculate Fields
arcpy.AddField_management(outputfc, "state_area_sqmi", \
    "FLOAT", "", "", "", "", "NULLABLE", "NON_REQUIRED", "")
arcpy.AddField_management(outputfc, "state_area_100sqmi", \
    "FLOAT", "", "", "", "", "NULLABLE", "NON_REQUIRED", "")
arcpy.AddField_management(outputfc, "torn_count_allmags_per_area", \
    "LONG", "", "", "", "", "NULLABLE", "NON_REQUIRED", "")
arcpy.AddField_management(outputfc, "torn_count_F345_per_area", \
    "LONG", "", "", "", "", "NULLABLE", "NON_REQUIRED", "")
arcpy.AddField_management(outputfc, "torn_count_F45_per_area", \
    "LONG", "", "", "", "", "NULLABLE", "NON_REQUIRED", "")
arcpy.CalculateField_management(outputfc, "state_area_sqmi", \
    "!Shape_Area!/1609.344/1609.344", "PYTHON_9.3")
arcpy.CalculateField_management(outputfc, "state_area_100sqmi", \
    "!Shape_Area!/1609.344/1609.344/100/100", "PYTHON_9.3")
arcpy.CalculateField_management(outputfc, "torn_count_allmags_per_area", \
    "!torn_count_allmags!/!state_area_100sqmi!", "PYTHON_9.3")
arcpy.CalculateField_management(outputfc, "torn_count_F345_per_area", \
    "!torn_count_F345!/!state_area_100sqmi!", "PYTHON_9.3")
arcpy.CalculateField_management(outputfc, "torn_count_F45_per_area", \
    "!torn_count_F45!/!state_area_100sqmi!", "PYTHON_9.3")

mags = [0,1,2,3,4,5]
for magnum in mags:
    count_nm = "torn_count_F" + str(magnum)
    norm_nm = "torn_count_F" + str(magnum) + "_per_area"
    formula = "!" + count_nm + "!/!state_area_100sqmi!"
    arcpy.AddField_management(outputfc, norm_nm, "LONG", \
        "", "", "", "", "NULLABLE", "NON_REQUIRED", "")
    arcpy.CalculateField_management(outputfc, norm_nm, formula, "PYTHON_9.3")
```

Appendix D: User Interface: ArcPy and C# Code

D.1. ArcPy Script to Create Additional Surfaces

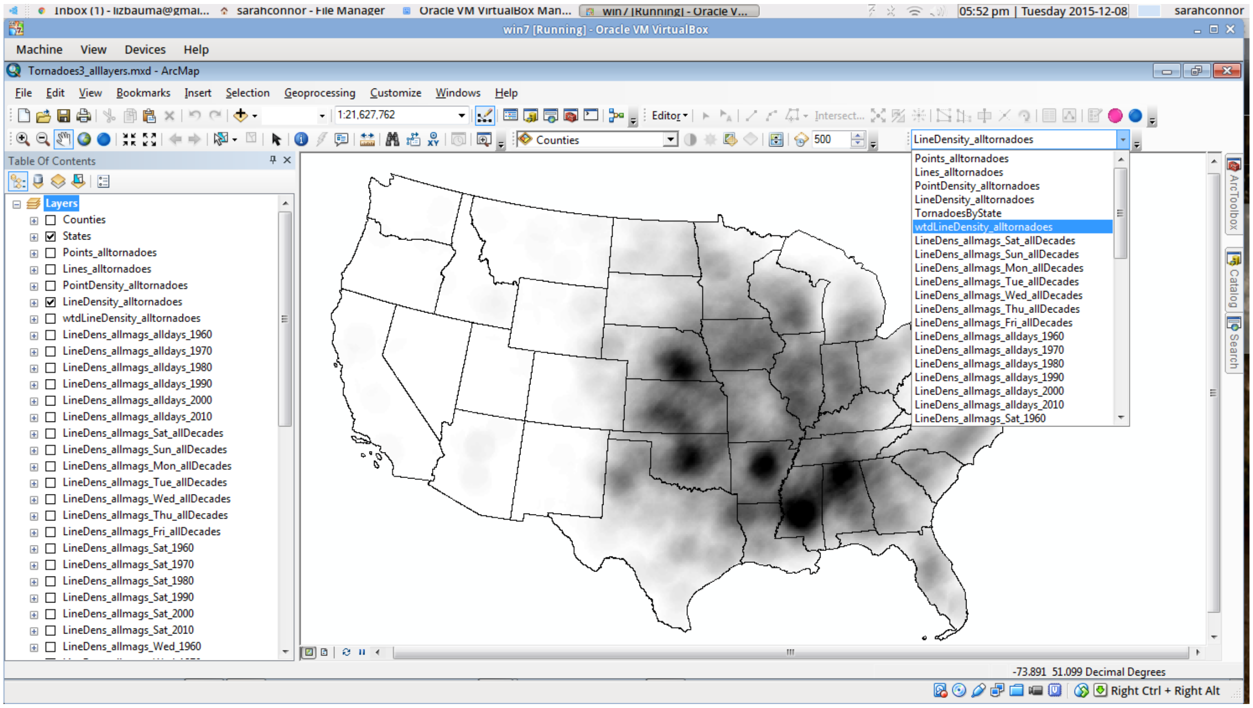
```
# Torn2z_moresurfaces.py: create multiple additional surfaces for day/decade/magnitude combos

import arcpy

inputLines = arcpy.GetParameterAsText(0)
inputStates = arcpy.GetParameterAsText(1)
Lines_Dslv_Select = "E:/GISdata/Tornadoes/Tornadoes.gdb/temp1"
LineDens = "E:/GISdata/Tornadoes/Tornadoes.gdb/temp2"

def createSurface(selectQuery, outputName):
    global inputLines, inputStates, Lines_Dslv_Select, LineDens
    arcpy.Select_analysis(inputLines, Lines_Dslv_Select, selectQuery)
    arcpy.gp.LineDensity_sa(Lines_Dslv_Select, "NONE", LineDens, \
        "11161.272812", "93010.6067666667", "SQUARE_KILOMETERS")
    outputRaster = "E:/GISdata/Tornadoes/Tornadoes.gdb/" + outputName
    arcpy.gp.ExtractByMask_sa(LineDens, inputStates, outputRaster)

createSurface("day = 'Sat'", 'LineDens_allmags_Sat_allDecades')
createSurface("day = 'Sun'", 'LineDens_allmags_Sun_allDecades')
###  ... +many more lines of these similar function calls ###
```

D.2. C# Code for "Select Visible Layer" Combo Box + Implementation

```
using System;
using System.Collections.Generic;
using System.Text;
using System.IO;

namespace TornadoTools
{
   public class SelectVisibleLayer : ESRI.ArcGIS.Desktop.AddIns.ComboBox
   {
      public SelectVisibleLayer()
      {
         string[] choices =
         {
            "Points_alltornadoes",
            "Lines_alltornadoes",
            "PointDensity_alltornadoes",
            "LineDensity_alltornadoes",
            "TornadoesByState",
            "wtdLineDensity_alltornadoes",

            "LineDens_allmags_Sat_allDecades",
      . . .
    ### many more like these, removed to save space ###
      . . .
            "LineDens_mag12345_alldays_2010",
         };
         foreach (string currChoice in choices)
         {
            Add(currChoice);
         }
      }

      protected override void OnSelChange(int cookie)
      {
         /// Expected layer order: Counties, States (always on), the rest...

         ESRI.ArcGIS.Carto.IActiveView activeView = ArcMap.Document.ActiveView;
         ESRI.ArcGIS.Carto.IMap map = activeView.FocusMap;
         int numberOfLayers = map.LayerCount;

         /// Layers: turn 1=states on, turn selected layer on and the rest off
         map.get_Layer(1).Visible = true;
         if (Value != "")
         {
            for (int i = 2; i < numberOfLayers; i++)
            {
               ESRI.ArcGIS.Carto.ILayer layer = map.get_Layer(i);
               if (layer.Name == Value)
               {
                  map.get_Layer(i).Visible = true;
               }
               else
               {
                  map.get_Layer(i).Visible = false;
               }
            }
         }

         //Refresh map
         activeView.ContentsChanged();
```

```
            activeView.Refresh();

            base.OnSelChange(cookie);
        }
    }
}
```

D.3. Combo Box Implementation



Appendix E: Acknowledgements

[i] Data Source: Shapefiles on tornadoes in the US from 1950 to 2014 from NOAA's National Weather Service Storm Prediction Center: http://www.spc.noaa.gov/gis/svrgis/

[ii] *Enhanced F Scale for Tornado Damage* (comparison of Fujita with Enhanced Fujita scales), NOAA's National Weather Service Storm Prediction Center, 2007

[iii] *Why Tornadoes Take the Weekends Off in Summer*, Charles Q. Choi for National Geographic News, 2011

[iv] Data Source: State and County boundary shapefiles from the US Census Bureau, 2015

[v] *Daily tornado frequency distributions in the United States*, Elsner, Jagger, et.al., 2014

[vi] *2011 Tornado Super Outbreak* (Wikipedia reference)