Decadal Changes in Growing Season Length within the Driftless Area, 1900-2010

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Abstract

Climate change is a topic of growing concern, and certain areas of high biodiversity and agricultural production, such as the Driftless Area, require special attention. This analysis serves two purposes: 1) it provides an initial database and processing framework for using Global Historical Climatology Network (GHCN) data with the Rclimdex toolset, and 2) it provides an example of data display and analysis for indices developed by the Rclimdex toolset through examination of the growing season length index. Overall, this analysis serves as a stepping stone to future climate-related analyses using GHCN data and statistical indexing tools.

Introduction

The Driftless Area of Wisconsin, Minnesota, Iowa, and Illinois is a unique geographical area within the Upper Mississippi River Basin (Figure 1). The Driftless Area Ecoregion is distinguished by hilly uplands dissected by streams. Glacial drift in this area was minimal in comparison to adjacent ecoregions (U.S. Environmental Protection Agency, 2013). This area is known for its biodiversity and agricultural production.

In recent years, farmland values within the four Driftless Area states have increased. From 2011 to 2012, state farmland and improvements values increased 20.7% in Minnesota, 7.4% in Wisconsin, 17.5% in Illinois, and 22.8% in Iowa (U.S. Department of Agriculture, 2013). Climate is a driver of agricultural practices and a key index for describing climate change is growing season length (GSL). The Expert Team on Climate Change Detection and Indices (ETCCDI) defines growing season length in the Northern Hemisphere as the count of days during a calendar year between the first six-day span with daily mean temperature above 5° C and the first six-day span after July 1st with daily mean temperature of less than 5° C (Expert Team on Climate Change Detection and Indices, 2013).

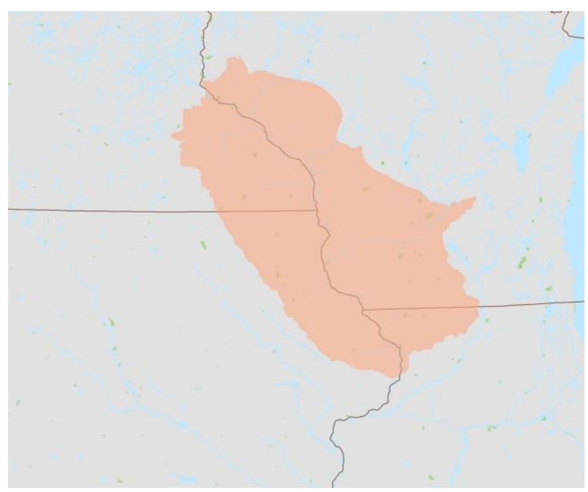

Figure 1. The Driftless Area, encompassing 16,203 mi^2 of area in Wisconsin, Minnesota, Iowa, and Illinois.

Purpose

The primary purpose of this analysis was to gain insight into a method for using the

Global Historical Climate Network data set to analyze practical problems within a landscape. Climate science is complex in nature, due to large data sets and contentious issues. Being able to develop simple-to-understand maps and results provides the public and land managers with vehicles for dialoguing about threats in an effective manner.

In the Driftless Area, climate change could have numerous implications. One of the most important is the change in GSL. As growing seasons change, the agriculture industry will need to adapt to ensure the most effective use of lands. Understanding areas that are more susceptible to decadal fluctuations GSL could provide valuable market insight to future agricultural investors.

Methods

This analysis utilized a suite of data processing and management tools: SQL Server 2008 R2, Microsoft Excel, ESRI Products, and R Statistical Program – rClimdex package. In conjunction with the development of the research in this paper, some of these methods were applied similarly to work at Saint Mary's University of Minnesota, GeoSpatial Services. Climate data records were downloaded from the Global Historical Climatology Network. Stations were selected using a spatial selection within the boundaries of the Driftless Area. Only stations with daily precipitation, maximum temperature, and minimum temperature were utilized in this analysis; the RClimdex statistical package needs those parameters to calculate the 27 different climate indices. Daily climate records from stations within the Driftless Area were selected and then imported into a SQL Server 2008 database for processing. Import processes consisted of merging 122 .dly files (daily climate flat-file) via command prompt and then importing via SQL Server 2008 tools.
Following data input to the SQL Server 2008 database, a dynamic T-SQL query was generated to decompose the data into separate tables with appropriate formatting for use in the R Statistical Program – Rclimdex Package. This query is shown in Figure 2. This query utilizes a cursor for station names, which allows the query to be reproduced for future applications, without having to manually adjust the query for unique station names. This significantly reduces the time necessary for initial data management.

Following export of the 122 station records, data were quality checked and then climate change indices were created. Fifty-nine stations included enough data to examine the decadal differences in growing season length. Following calculations of the indices, data from the 59 stations regarding growing season length were analyzed to determine decadal average growing season length. For each station, mean decadal growing season length was used for a given decade only when eight or greater yearly observations were available for that station. All of the decadal mean growing season length data were transferred into an Excel document and then spatially-enabled using ArcGIS 10.1.

Once data were spatially enabled, a variety of kriging methods were examined in order to create best fit surfaces to help describe the decadal changes in growing season length. Methods included linear regression kriging, and quadratic and linear drift kriging models. The final method used throughout for interpolating was a universal linear drift kriging model with unlimited search radii and points. Unlimited search radii was used because

```sql
Use DriftlessAnalysis

Declare @station varchar(20)
Declare @getstation CURSOR
SET @getstation = CURSOR FOR
Select Distinct Station
FROM Fullstations
OPEN @getstation
Fetch NEXT
FROM @getstation INTO @station
WHILE @@FETCH_STATUS = 0
BEGIN


DECLARE @stringcommand nvarchar(MAX)
set @stringcommand = 'Select YEAR, MONTH, daynumber, PRCP2= case when PRCP=-9999 then -99.9 else PRCP/10 end, TMAX2= case when TMAX_Temp=-9999 then -99.9 else TMAX_Temp/10 end,TMIN2= case when tmin_temp=-9999 then -99.9 else TMIN_Temp/10 end
Into ' + @station + ' from Tables_RClimdex
where Tables_RClimdex.station=''' + @station + '''
    order by Year asc, Month asc

delete from ' + @station + '
     where Month=9 and daynumber=31
delete from  ' + @station + '
    where MONTH = 11 and daynumber=31
delete from  ' + @station + '
    where MONTH = 4 and daynumber = 31
delete from  ' + @station + '
    where MONTH = 6 and daynumber = 31
delete from  ' + @station + '
    where MONTH =2 and daynumber>28'
Print @stringcommand
Exec(@stringcommand)
Set @stringcommand = ''



Fetch NEXT
FROM @getstation INTO @station
End
Close @getstation
DEALLOCATE @getstation
```

Figure 2. A dynamic SQL query used to extract data from .dly flat files imported into a SQL Server 2008 DB into a format useable by RClimdex Statistical software.

of the assumption that climate, and GSL, are continuous parameters (i.e., all station locations have some effect on each other). Universal linear was chosen because of the overarching trend for GSL to increase from North-to-South.

Following interpolation of decadal, mean growing season length surfaces, raster math was used to display a variety of quantitative aspects regarding change. Mean absolute change was determined by summing the absolute differences between each raster cell and then dividing by the total; this provides an indication of areas with highest volatility to change in growing season length. Visual interpretations of growing season length were created using 3d Analyst Extension in ESRI ArcGIS along directional polylines; this provides information regarding trend in growing season length. Summary statistics based on decade and station provided general statistical insight. Zonal statistics were also incorporated to analyze directional changes in volatility.

Zones (Figure 3) were defined by East/West of the Mississippi River and

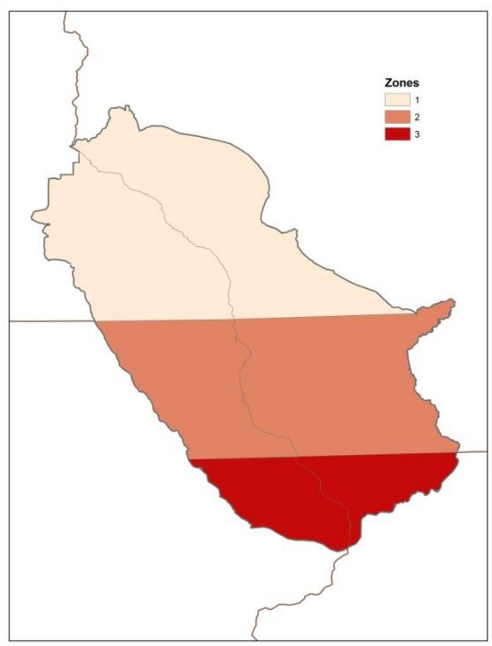

Figure 3. North-south zones (1-3) and east-west zones (according to location relative to Mississippi River).

north of the Minnesota-Iowa border, between the Minnesota-Iowa and Illinois-

Wisconsin border, and south of the Illinois Wisconsin border.

Results

Decadal Averages and Variance

Fifty-nine stations included enough data to determine a decadal average for at least one decade. Table 1 provides a summary of decadal means for stations and the number of decadal averages (samples) obtained where n>7 for a valid decadal average. Stations in closer proximity (<10 miles) to the Mississippi River had greater decadal variance (st. dev.=5.59) than stations farther from the river (st. dev.=4.58).

Table 1. Summary statistics of decadal growing season length samples. Samples refers to the number of stations with 8 or more yearly growing season length calculations.

Decade	Mean	Variance	Samples
1900	213.4217	18.54196	10
1910	213.7064	31.80842	13
1920	215.5908	76.02551	10
1930	216.9075	80.42304	17
1940	219.3275	59.88864	28
1950	210.0319	35.92589	34
1960	214.5592	32.73709	40
1970	215.7395	48.89857	36
1980	220.2136	59.67755	33
1990	216.5172	44.77082	38
2000	218.7805	54.48657	42

Directional and Spatial Trends in Growing Season Length

Figure 4 displays an interpolated mean growing season length surface for the Driftless Area for 2000-2009. Directional change is most pronounced from southwest to northeast; in this general direction, it appears that growing season length decreases the farther a point is from the Mississippi River Valley. The four profile graphs provide numerical context for this change. From northwest to southeast, change in growing season length gradually increased for the decade of 2000-2009. These patterns of change were similar for other decades as well. Figure 5 displays an interpolated mean growing season length surface for the Driftless Area for 1990-1999. Spatial trends in growing season length were similar to 2000-2009 during this decade. For other decades, similar trends were observed.

Growing Season Length Volatility Trends

The variance in mean decadal growing season length for each station ranged from 0.91 to 75.8. Variance tended to be higher for stations located closer to the Mississippi River Valley (Figure 6).

Decade over decade from the 1950s through the 2000s, mean change in mean growing season length varied from 1.79 to 13.5. This measure of volatility tended to increase as distance to the Mississippi River decreased (Figure 7). No apparent directional trends exist regarding this measure of volatility.

Linear regression analysis yields a significant downward trend for elevation versus mean absolute decadal GSL change ($p<0.001$). While the overall volatility of mean decadal change when spanning 177-466m of elevation within the Driftless Area is significant, the linear regression indicates a decrease of less than 1/20 day change in volatility per foot of elevation. However, because this analysis focuses solely on decadal trends, yearly volatility is likely to be higher.

Zonal Trends in Volatility

Zonal statistics yielded trends in volatility

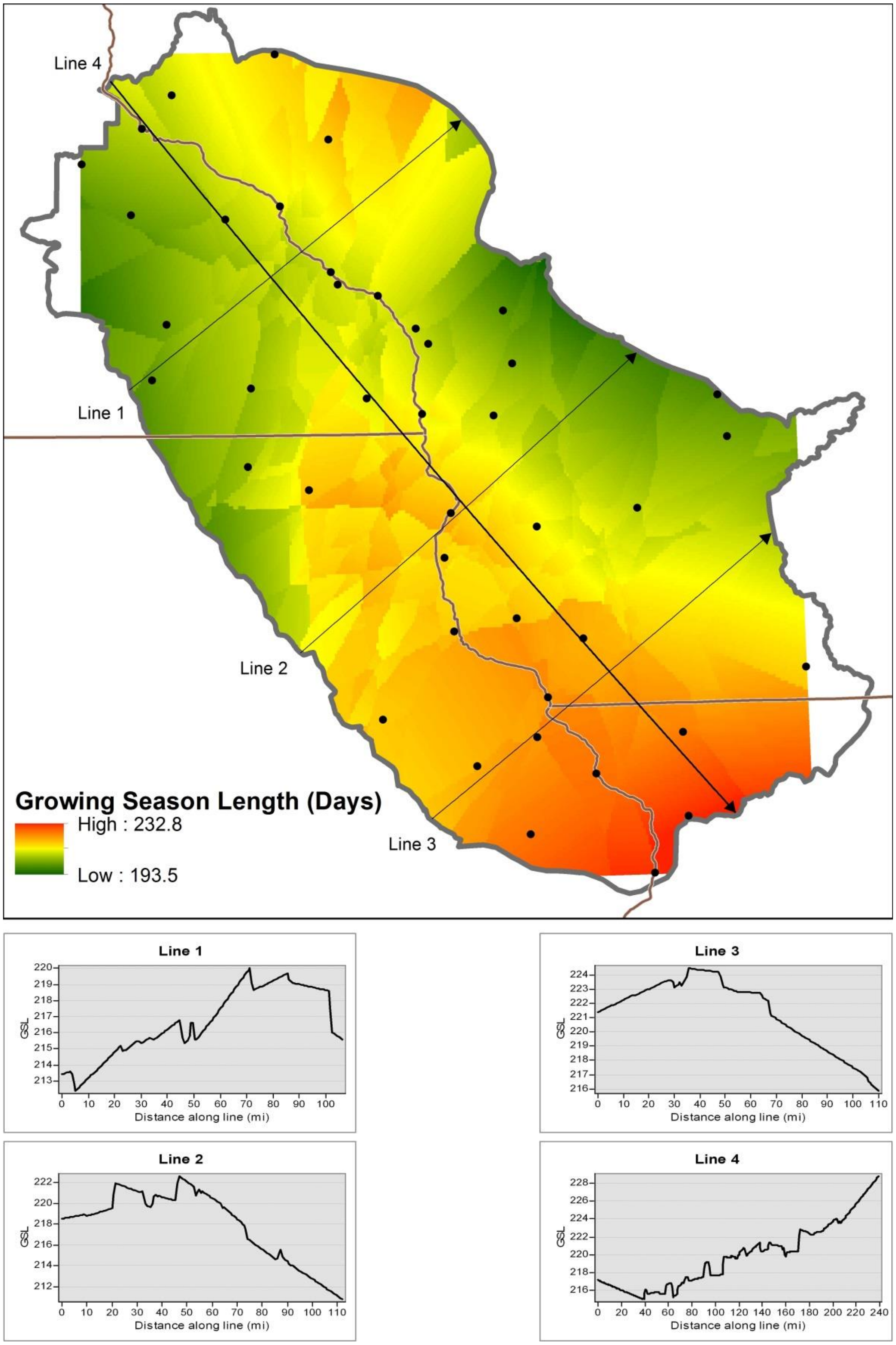

Figure 4. 2000-2009 interpolated mean growing season length for the Driftless area. Cross-sectional lines provide context for directional change. Interpolated using linear drift kriging with unlimited search radius and points.

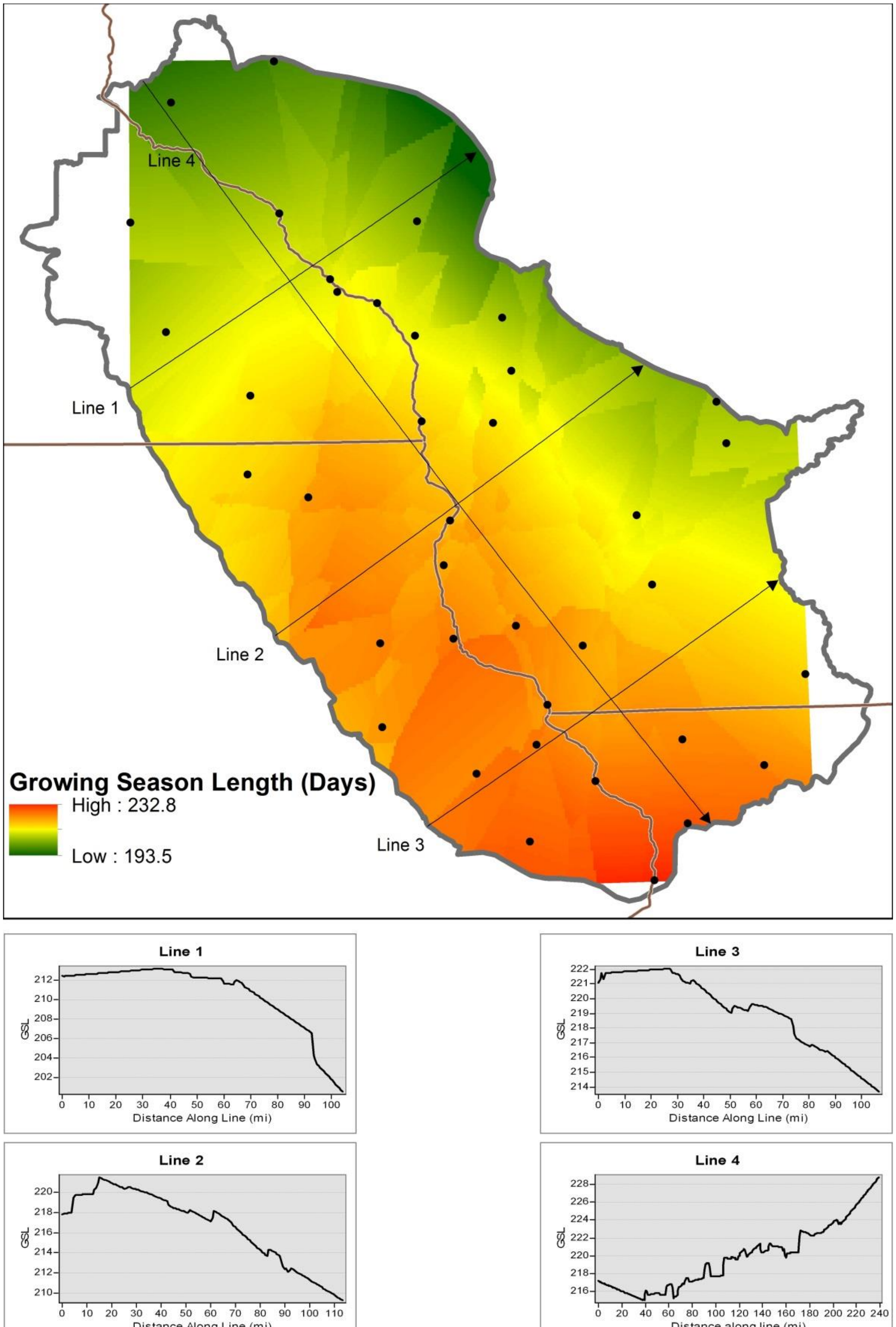

Figure 5. 1990-1999 interpolated mean growing season length for the Driftless area. Cross-sectional lines provide context for change from southwest to northeast. Interpolated using linear drift kriging with unlimited search radius and points.

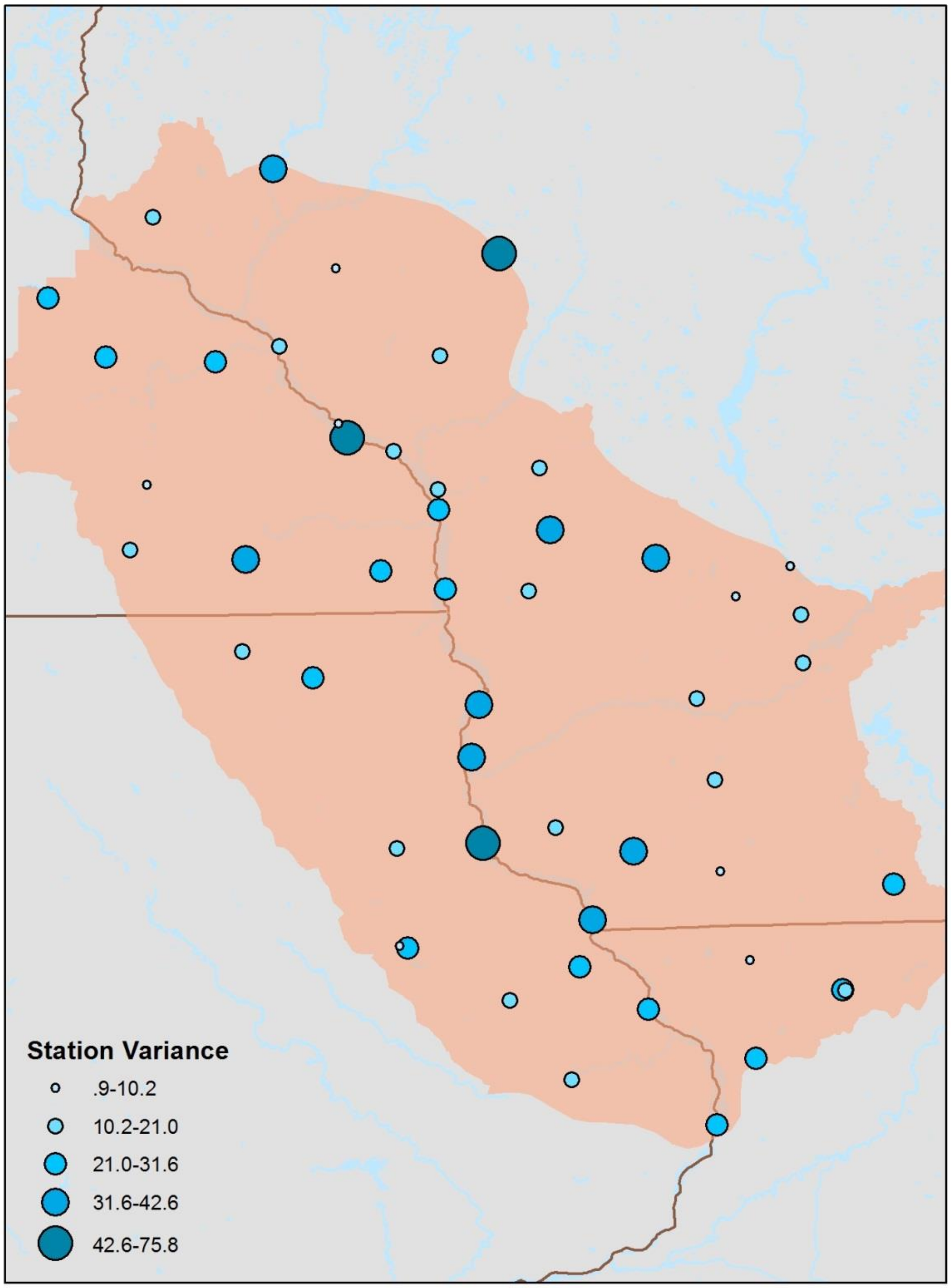

Figure 6. Station variance in mean decadal growing season length, 1900-2009.

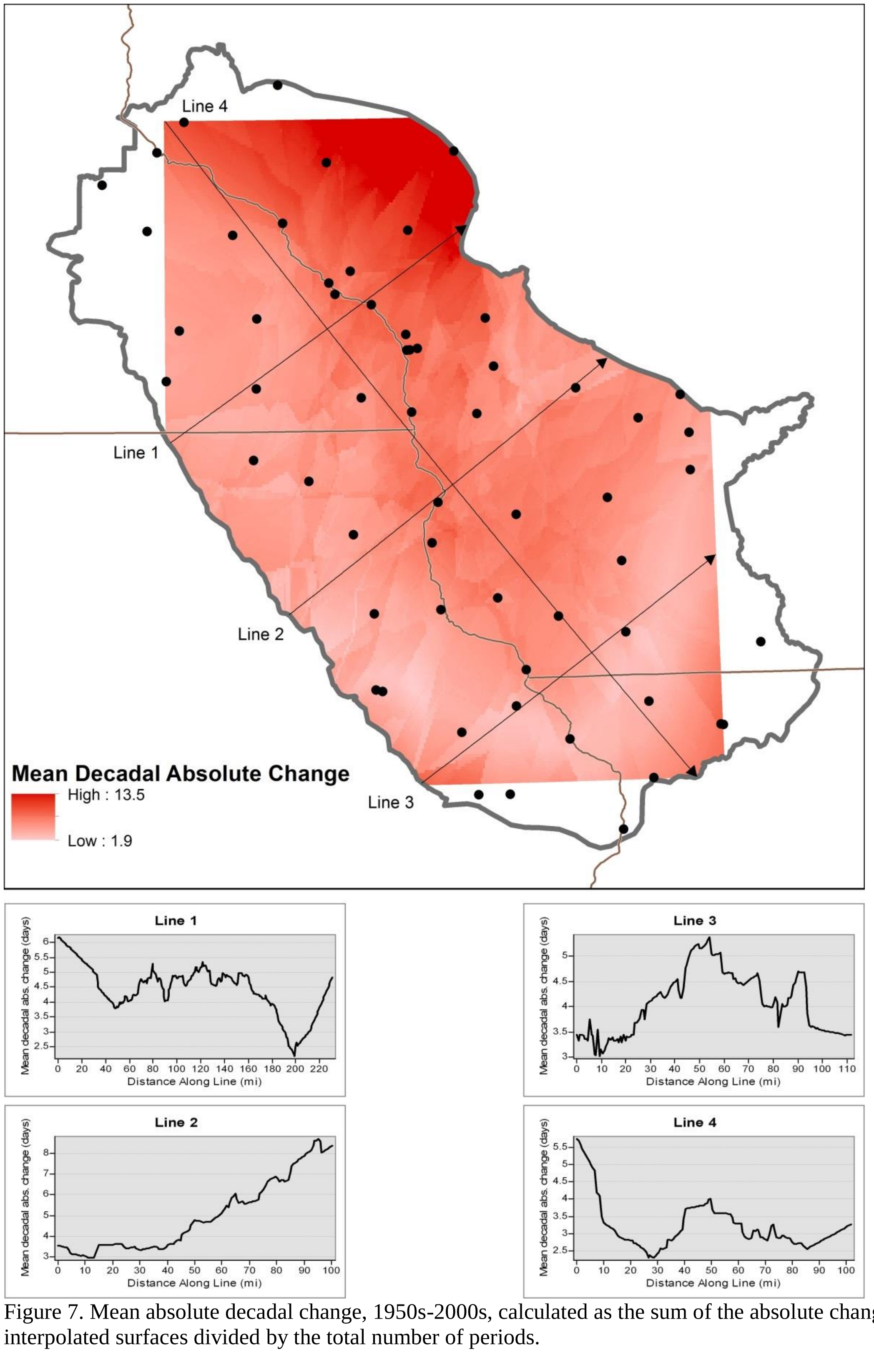

Figure 7. Mean absolute decadal change, 1950s-2000s, calculated as the sum of the absolute change of interpolated surfaces divided by the total number of periods.

from North to South. Mean, range, and standard deviation decreased for each step south from the Zone 1 (northernmost zone delineated as all are north of the Minnesota-Iowa border). The difference in mean decadal volatility between Zones 1 and 3 was 2.04 GSL days.

Standard deviation for Zone 1 (1.92) was 1.2 GSL days higher than Zone 3 (Table 2). East to West of the Mississippi River comparison showed that the eastern area was less volatile (Table 3).

Mean Decadal Change in GSL Versus Elevation

Figure 8 displays cell values for decadal volatility versus elevation. As elevation increased in the Driftless Area, mean absolute decadal change decreased on a cell-by-cell basis. Linear regression proved significant, suggesting a slope other than zero ($p<0.001$).

Table 2. North-South zonal trends in decade over decade volatility.

Zone Number (N-S)	Min	Max	Range	Mean	St. Dev.
1	2.73	13.48	10.7	5.3	1.92
2	1.97	6.14	4.17	3.81	.74
3	1.95	5.77	3.82	3.26	.72

Table 3. East-West of the Mississippi River zonal trends in decade over decade volatility.

Zone	Min	Max	Range	Mean	St. Dev.
East	1.95	6.07	4.11	3.66	0.71
West	2.09	13.48	11.39	4.94	1.86

Discussion

A Framework for Index Analysis

Concern regarding climate change continues to increase. As citizens become more concerned about climate, it is important that data, tools, and graphics are developed to depict change. To achieve this, a method for converting data into a format digestible by climate analysis tools is essential. For the Driftless Area, this project provided this first, crucial step.

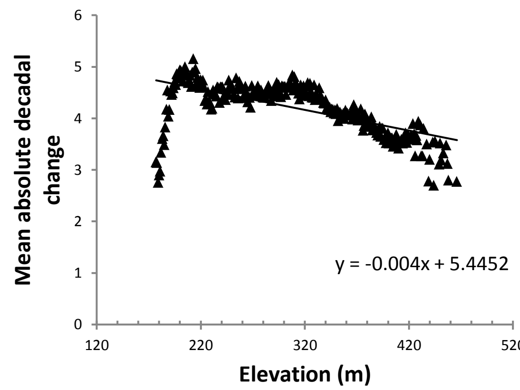

Figure 8. Mean absolute decadal change in growing season length (days) versus elevation (m) within the Driftless Area. Linear regression proved significant ($p<0.001$).

Getting past the initial barrier of data organization and manipulation can often be difficult. With this project, complex data manipulations were required to simply get the data in a format useable by the Rclimdex toolset.

Once data are in a format that a tool can utilize, the next step is developing a framework for analysis. The analysis of the growing season length index can provide a framework for analyzing other climate change indices available through the Rclimdex toolset. While growing season length is directly applicable to the agricultural industry, other indices may provide value to other stakeholder groups.

Growing Season Length Observations

Overall, some aspect of the Mississippi River Valley appears to have a broad influence on decadal mean growing season length and volatility. Directionally, from north to south, growing season length tends to decrease as expected. However, southwest to northeast cross sections of interpolated growing season length show that proximity to the Mississippi River may have an amplifying effect on growing season length.

Proximity to the Mississippi River also appears to influence the volatility of growing season length within the Driftless Area. Stations with higher variance and interpolated mean decade-over-decade change in growing season length both tend to occur closer to the Mississippi River. Elevation also seems to play a factor in volatility from decade to decade, with higher elevation interpolated points being more stable than lower elevation interpolated points.

Further Analysis

As with most analyses focused on process development, a number of further questions exist: 1) what appropriate normalcy and power tests could be applied to make GHCN data incorporation more robust; 2) are there adjustments necessary for kriging parameters that could explain small-scale topography changes (e.g., slope, aspect); 3) could increasing directional bands and incorporating regression analysis allow for inference to fit latitude correlation models; 4) could regression analysis be applied at cell-based levels to understand variance in GSL slope from decade to decade or year to year; 5) what is the best buffer strategy when defining a station point cloud to eliminate surface fall off. Answering these questions will only lead to more robust and credible results for future similar analyses.

Another focal point for further analysis is the incorporation of streamlined processes in data development. Manual intervention to identify and correct GHCN data errors was necessary for all station inputs. Using a database program to address these errors prior to running analyses with Rclimdex would significantly reduce data preprocessing time in the future.

Acknowledgements

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