ABSTRACT

Was There a Northern Dust Bowl? Evidence for Heightened Wind Erosion and Dust Sources during the 1930s in the Northern Great Plains, USA.

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The 1930s Dust Bowl Drought was a catastrophic event that caused widespread soil erosion and dust storms in the United States Southern Great Plains (SGP). Despite evidence for similar drought conditions and enhanced erosion, the Northern Great Plains (NGP) has been largely overlooked as a region affected by the Dust Bowl. This study compiles climatic data, dust storm reports, and dust flux data in South Dakota during the 1930s to underscore the intensity of drought conditions in the NGP. A fundamental reorganization of North American climatology drove extreme drought conditions and dust storm occurrences in South Dakota. Heightened dust activity and erosion indicate Dust-Bowl-like conditions in the NGP, whereas PM_{10} flux data from analogous soils emphasize the susceptibility of NGP soils to erosion based on recorded windspeeds during dust storms. This evidence suggests a "Northern Dust Bowl" occurred as a separate landscape-scale response to that of the SGP Dust Bowl.

Was there a Northern Dust Bowl? Evidence for Heightened Wind Erosion and Dust Sources during the 1930s in the Northern Great Plains, USA.

by

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Thank you to the staff at the South Dakota State University Archives, who hauled countless boxes of archived climate data throughout the building so that I could view and compile these dust storm records.

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DEDICATION

To my parents, Carl and Michelle, who have always pushed me to be the best at what I do, and who this degree would not have been earned without

To my fiancé David, whose unwavering love and support helped me follow my dreams thousands of miles away

CHAPTER ONE

Introduction

Background

The Dust Bowl Drought of the 1930s was a widespread environmental catastrophe that resulted in the out-migration of over 350,000 people from the drought-stricken Great Plains, mostly to the west coast of the USA (Hurt, 1981; Gregory, 2004; Egan, 2006). Hundreds of widespread dust storms occurred during this time throughout the Great Plains, some depositing dust as far as Washington, DC (Hand, 1934), on ships in the North Atlantic Ocean, and on to the Greenland ice cap (Donarummo et al., 2003). The common occurrence of cyclonic activity intensified these storms and created 'black blizzards', which formed dust-laden clouds up to two km high that lasted for up to two days in the Dust Bowl area in the Southern Great Plains (Hand, 1934; Mattice, 1935; Martin, 1939). It is conventionally thought that these dust storms were a product of farm mismanagement and crop failure, where atmospheric dust originated from the eroded, overly-tilled soils (Bennett and Fowler, 1936; Johnson, 1947; Worster, 1979; Hansen and Libecap, 2004; Schubert et al., 2004; Peters et al., 2007; Cook et al., 2008, 2009, 2013; Lee and Gill, 2015). However, recent research in the panhandle region of the Great Plains indicates multiple sources for atmospheric dust loads originating from pre-existing, uncultivated eolian sources, rather than solely from eroded, cultivated land (Bolles et al., 2017; 2019). A Principal Components Analysis (PCA) found that surface to mid-tropospheric air temperatures and low-level relative humidity were the principal factors that controlled variance for dust storm generation (Bolles et al., 2019). The variance in dust events was preferentially associated with the presence of antecedent eolian deposits rather than prevalence of land under cultivation (Bolles et al., 2019). *In-situ* dust emissivity measurements using PI-SWERL technology (Etyemezian et al., 2007) revealed for former Dust Bowl surfaces in the panhandle areas of Texas and Oklahoma that the potential PM_{10} dust production from loose, uncultivated sandy soils was equivalent to the dust release from anthropogenically disturbed surface crusts. This previous study outlined the dominance of extreme climate variability during the Dust Bowl Drought, indicating widespread agricultural disturbance was not the sole causative factor in dust generation.

Recently, there has been renewed research on the land-atmosphere interactions for the Texas and Oklahoma panhandles in the 1930s to extreme drought conditions as bellwethers to future conditions with climate warming in the 21st century (e.g. Cook et al., 2014; Lee and Gill, 2015; Bolles et al., 2017, 2019; Bolles and Forman, 2018; Williams et al., 2020). This region, along with parts of New Mexico, Colorado, and Kansas, were recognized as areas with severe wind erosion and abundant dust storms in the 1930s, earning the region's name the "Dust Bowl" (Figure 1.1; Worster, 1979; Cunfer, 2005). An estimated ~4 million to ~5.5 million hectares of land in this region lost the upper 6 cm to ~12.5 cm of soil, amounting to 2.9×10^4 g m^{-2} yr^{-1} of soil loss between 1932 and 1939 (Hansen and Libecap, 2004; Bolles et al., 2017). These dust storms persisted over the Great Plains as unprecedented drought swept the region, drying out soils with up to a 50% reduction in precipitation. The average Palmer Drought Severity Index (PDSI) for the panhandle region dropped below -4, while daily temperatures > 41 °C exceeded temperature records across Kansas (Burnette et al., 2010; Burnette and Stahle, 2013; Cook et al., 2014).

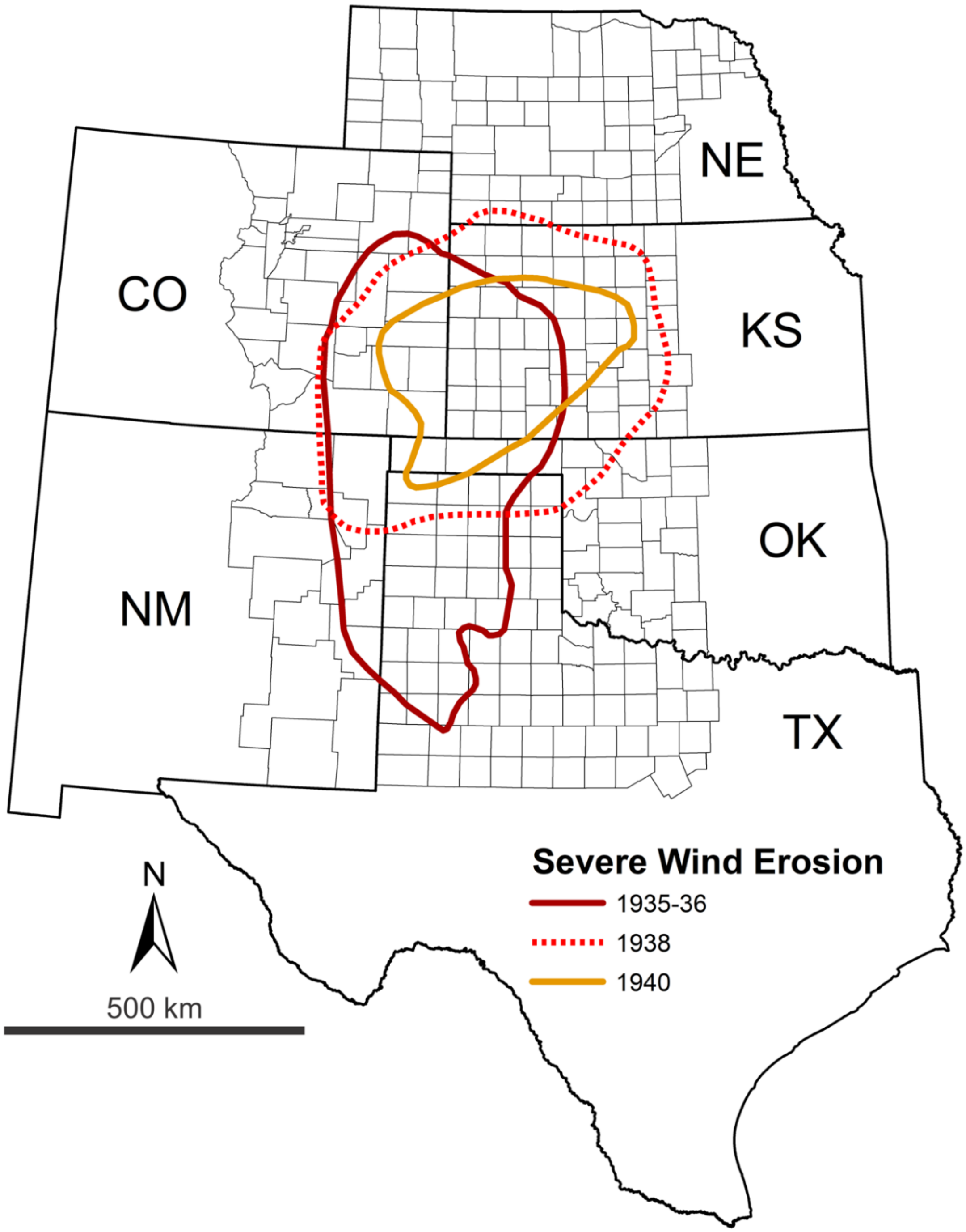

Figure 1.1. Counties in the Southern and Central Great Plains of the United States and locations of heightened wind erosion in the panhandle region during the 1930s (redrawn from Cunfer, 2005).

In contrast, there is a paucity of studies on land surface conditions and atmospheric dynamics for the Dust Bowl Drought in the U.S. Northern Great Plains. The Great Plains of southern Canada and the Dakotas contain an abundance of dune fields, many of which have been steadily recovering and stabilizing since the late 1700s (Figure 1.2; Hugenholtz and Wolfe, 2005b). Dune fields disturbed prior to ca. AD 1800 in the Canadian prairies show a multi-centuries lag in stabilization compared to eolian landforms on the Central and Southern Great Plains (Muhs et al. 1997; Hugenholtz and Wolfe, 2005b). This lag in landform stabilization has been related to a shorter growing season, leading to slower revegetation of dunes following major disturbances (Hugenholtz and Wolfe, 2005b). The rate of recovery of Canadian Prairie dune fields appears to have slowed during drought conditions in the 1930s, likely as a result of vegetation destabilization (Hugenholtz and Wolfe, 2005a). Research on the Minot dune field located in northern North Dakota reveals small-scale dune reactivation during the 1930s (Figure 1.2; Muhs et al., 1997). These dunes were found to be previously stabilized during the early 1900s and 1920s and re-stabilized during the wetter 1940s (Muhs et al., 1997). Studies like these provide evidence for heightened wind erosion in the Northern Great Plains and for the possible contribution of atmospheric dust from non-cultivated land during the Dust Bowl Drought.

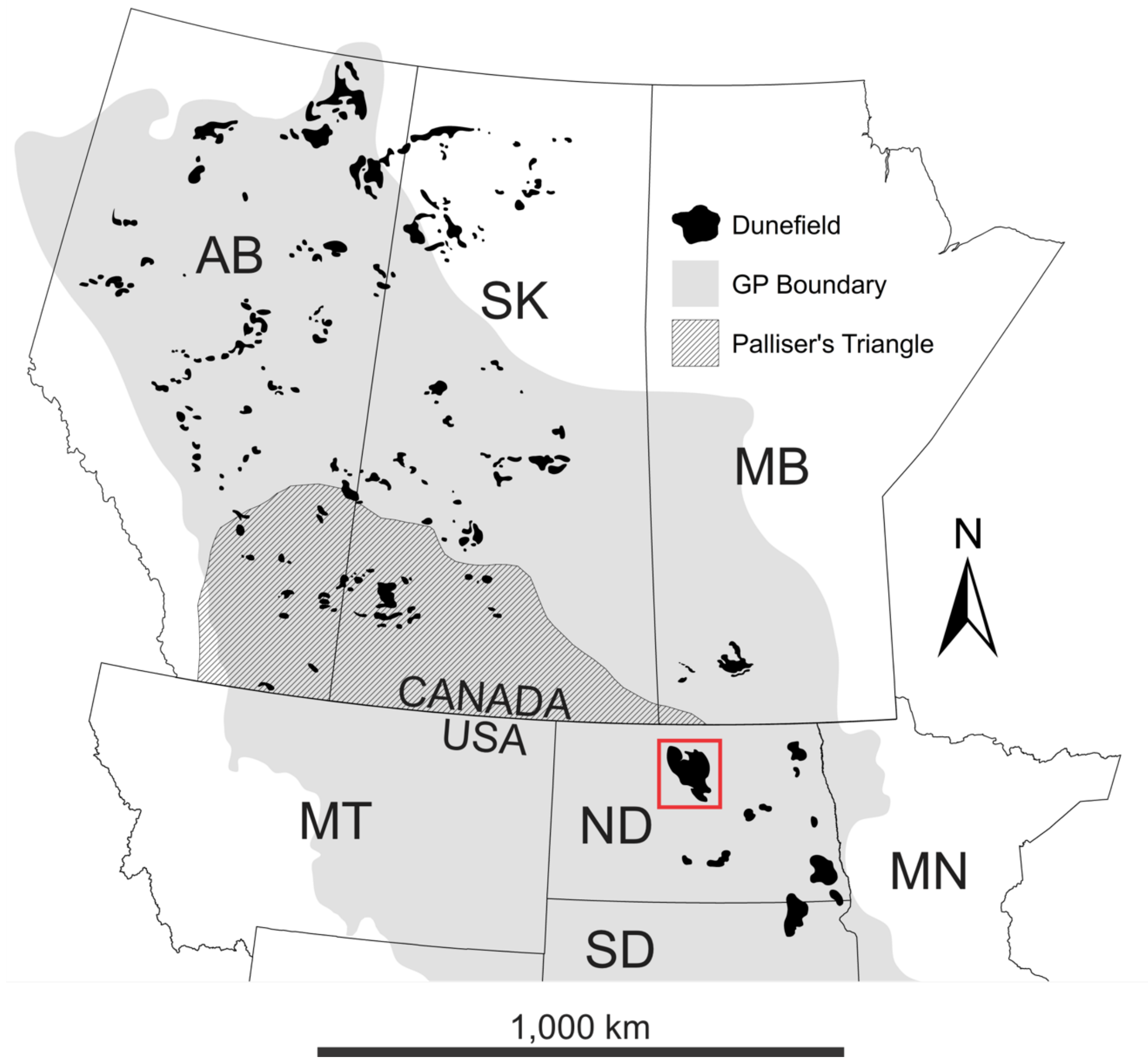

Figure 1.2. Locations of dune fields in the Northern Great Plains of the U.S. and Canada. Outlined in red is the Minot dune field (redrawn from Hugenholtz and Wolfe, 2005a).

Previous studies focusing on the Dust Bowl region of the Southern Great Plains have revealed loci of intense drought and dust storm activity in parts of the Northern Great Plains, specifically in parts of North and South Dakota (Bolles and Forman, 2018; Bolles et al., 2019). Research quantifying and ranking various drought conditions and surficial properties throughout the Great Plains during the Dust Bowl Drought reveals an area of intense susceptibility to drought in the Northern Great Plains (Figure 3; Bolles and Forman, 2018). Higher rankings indicate locations with the greatest increase in mean annual temperature (MAT) and decrease in mean annual precipitation (MAP) and in the Palmer Drought Severity Index (PDSI) (Bolles and Forman, 2018). These rankings also take into account surficial conditions, including the amount of sand in the upper 20 cm of soil, the average drainage density of the region, and the percent of land under cultivation in 1935 (Bolles and Forman, 2018). Many counties in the Dakotas rank highest for drought conditions and drought susceptibility, perhaps equal to or exceeding conditions observed in the severe erosion area of the southern Dust Bowl (Figure 1.3).

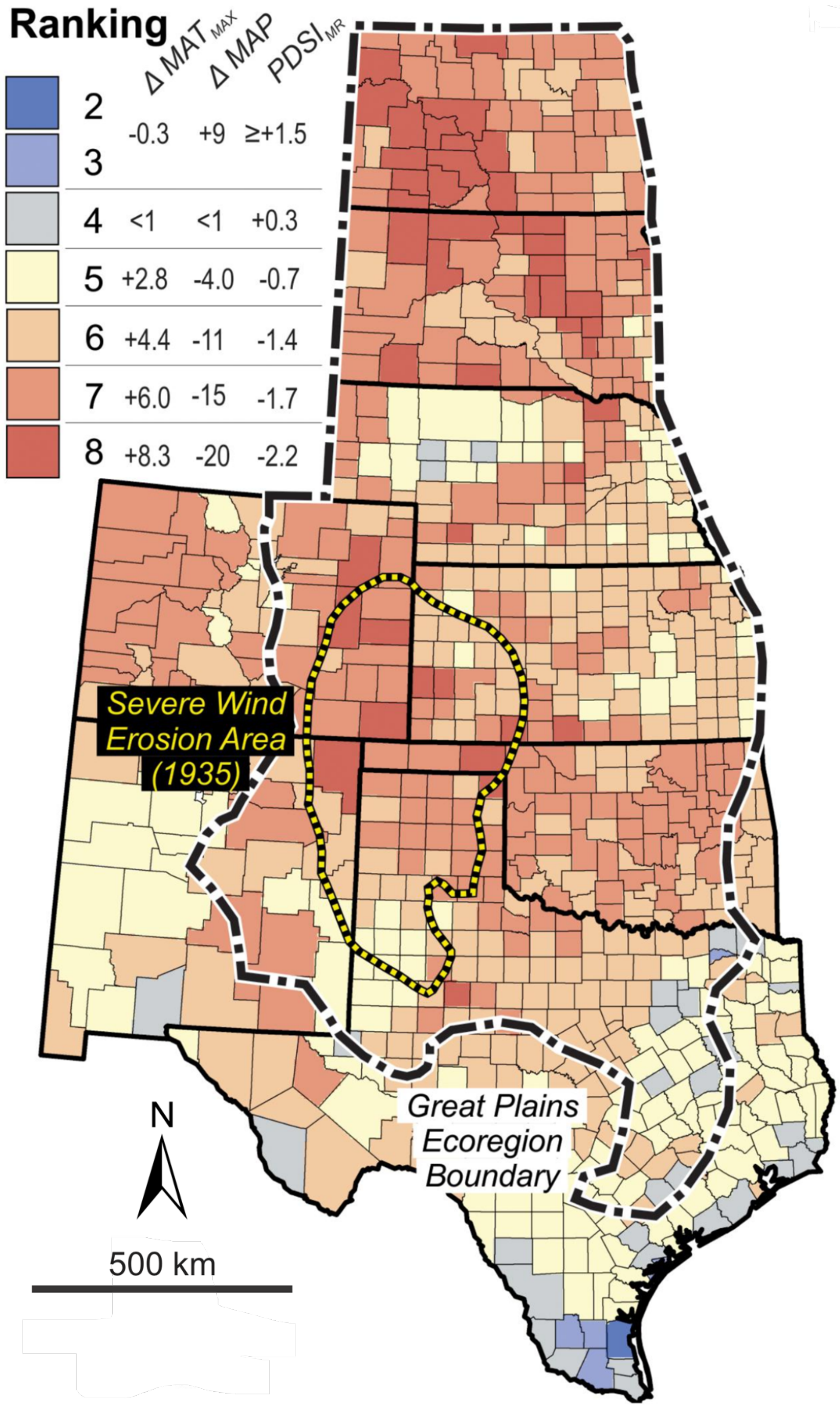

Figure 1.3. Ranking of the intensity of drought conditions (MAT, MAP, and PDSI) and drought susceptibility from surficial properties (% sand, drainage density, and % land cultivated) throughout the United States Great Plains (from Bolles and Forman, 2018).

The economic crisis that occurred in the United States during the Dust Bowl also sheds light on the severity in which the Northern Great Plains suffered during the drought. Whereas farmers' incomes were significantly reduced to lost across the Great Plains during the 1930s, state and federal relief through the Red Cross, state and emergency unemployment relief, pension plans, Works Progress Administration payments, and Civilian Conservation Corps payments were distributed to areas most affected by the drought (Stein 1973). The aid per capita throughout the Great Plains during the Dust Bowl from 1933 to 1936 reveals areas of high need for relief in the southern panhandle and large parts of the Northern Great Plains in the Dakotas (Figure 1.4). Nearly 40% of South Dakota's population in 1934 was utilizing federal relief, the highest in the country, followed by North Dakota (Kumlien 1937). A federal assessment underscored that no other contiguous states in the Great Plains were as thoroughly impacted by drought and dust as the Dakotas (Stock, 1992). The continued economic crisis that ensued as a result of the Dust Bowl provides further evidence for the intensity of the drought in the Northern Great Plains.

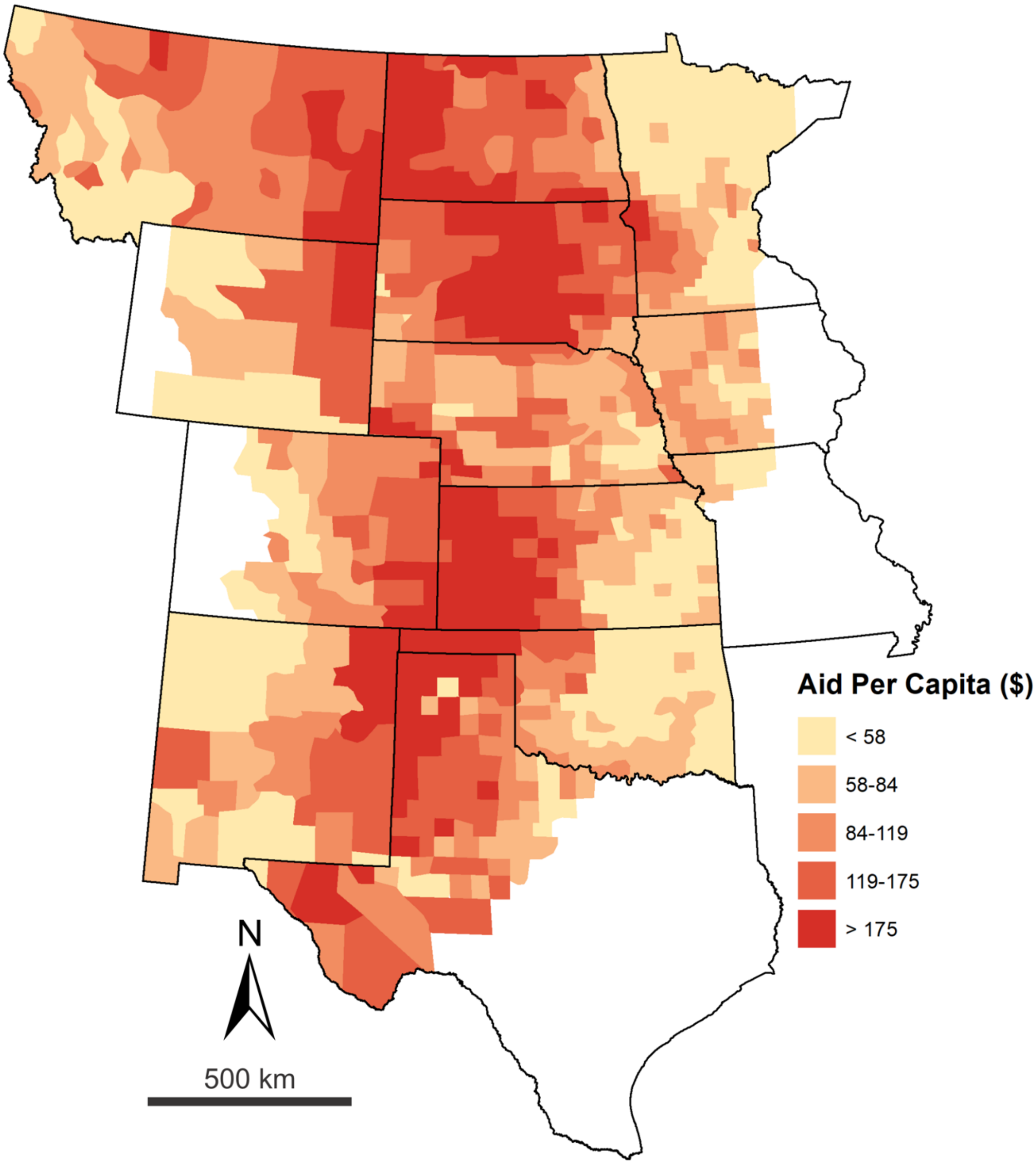

Figure 1.4. Intensity of federal aid per capita from 1933-1936 in the United States Great Plains region (redrawn from Works Progress Administration map, National Archives, Record Group 114, Entry 188).

An area of heightened dust events is revealed in the Dakotas region from observational accounts of dust storm activity in the U.S. Great Plains (Figure 1.5). These dust events were compiled from the *Monthly Weather Review* journal and indicate a dust source over North and South Dakota that is far removed from drought-affected areas in the Southern Great Plains (Bolles and Forman, 2018; Bolles et al., 2019). This evidence indicates heightened drought and dust storm events on average between 1934 and 1935 in the Northern Great Plains. Individual accounts confirm the passage of dust storms across the Dakotas with significantly reduced visibility and the occurrence of dust-associated electrical storms, some creating lightning, disabling automobile ignition systems, and electrifying barbed wire fences (Hovde, 1934). These intense storms had windspeeds up to ~30 m/s and much reduced visibility < 30 m (Hovde, 1934; Kohler, 1936).

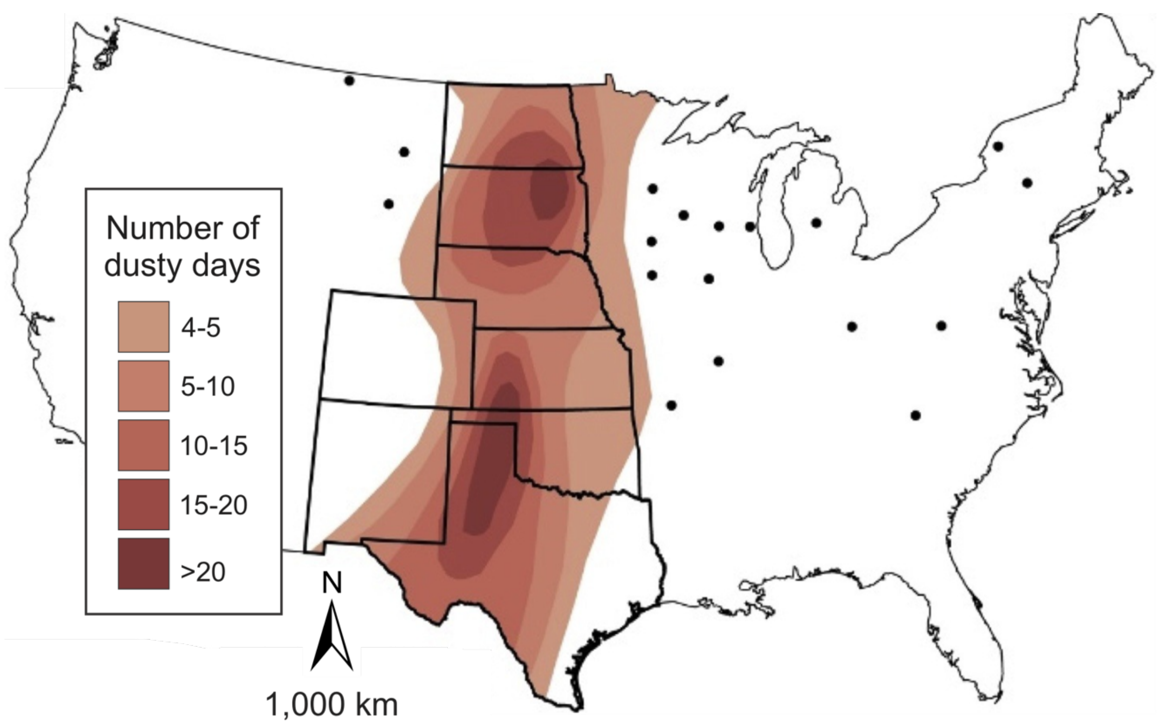

Figure 1.5. Distribution of recorded dust storms in the United States from May 1934 to February 1935 recorded in the *Monthly Weather Review* journal (modified from Bolles et al., 2019).

It has been reported that over ninety dust storms occurred in parts of South Dakota from November 1933 to 1934 (Griffith, 1965; Berg, 2015; Volk, 2020). These dust storms, and the drought conditions that caused them, were described as being centered in the Dakotas during 1934 (Griffith, 1965). The drought conditions in the Northern Great Plains States may have been equal to or more severe than the southern Dust Bowl states (Floyd 1950). Further, Rothman (2000) likened the aridity of the Dakotas during the 1930s to the Sonoran Desert of northern Mexico. Photographs taken in South Dakota during the 1930s underscore the significance of the Dust Bowl Drought in the Northern Great Plains (Figure 1.6). These images show drifts of sand accumulating along homes, fences, and vegetation both during and after dust storms. Heightened drought in the Northern Great Plains during the 1930s is further evidenced by extreme changes to the hydrology of the region. The Red River of the North, which divides North Dakota and Minnesota, was reported to have stopped flowing for a total of 823 days from July 1932 to October 1941, almost 25% of the time (United States Geological Survey [USGS], 2017). Devil’s Lake, the largest natural body of water in North Dakota, almost dried up completely during this timeframe (Wiche et al., 1997). There is clear evidence for the impact of the Dust Bowl Drought in the Northern Great Plains, though uncertainty remains of the footprint of 1930s drought, sources of dust, and recurrence of dust storms in the region.

Figure 1.6. (A) Farm buildings caved in from the piling of dust in Tripp County, SD – 9/10/1935. (B) Drifting dust piling around fence rows in Beadle County, SD – 1935. (C) 11.6 m s^{-1} winds creating a dust storm in Beadle County, SD – 10/19/1935. (D) Dust drifts accumulating on the protected side of Russian Thistle following the storm mentioned in (C) – 10/19/1935. All dust in (D) was reported to have accumulated from this single local storm (Joseph Hutton Collection, South Dakota Agricultural Heritage Museum Records).

Location

This study focuses on the Northern Great Plains during the 1930s Dust Bowl Drought, specifically in South Dakota (Figure 1.7). These rangelands are a part of the Northern Great Plains Steppe ecoregion that extends northward into the Canadian Prairies. Palliser's Triangle, a region that experienced a drought of similar capacity to the Dust Bowl in the late 1920s and into the 1930s, is located in this part of the Canadian Prairies and extends down to the northern border of the U.S. (See Figure 1.2; Gray, 1967).

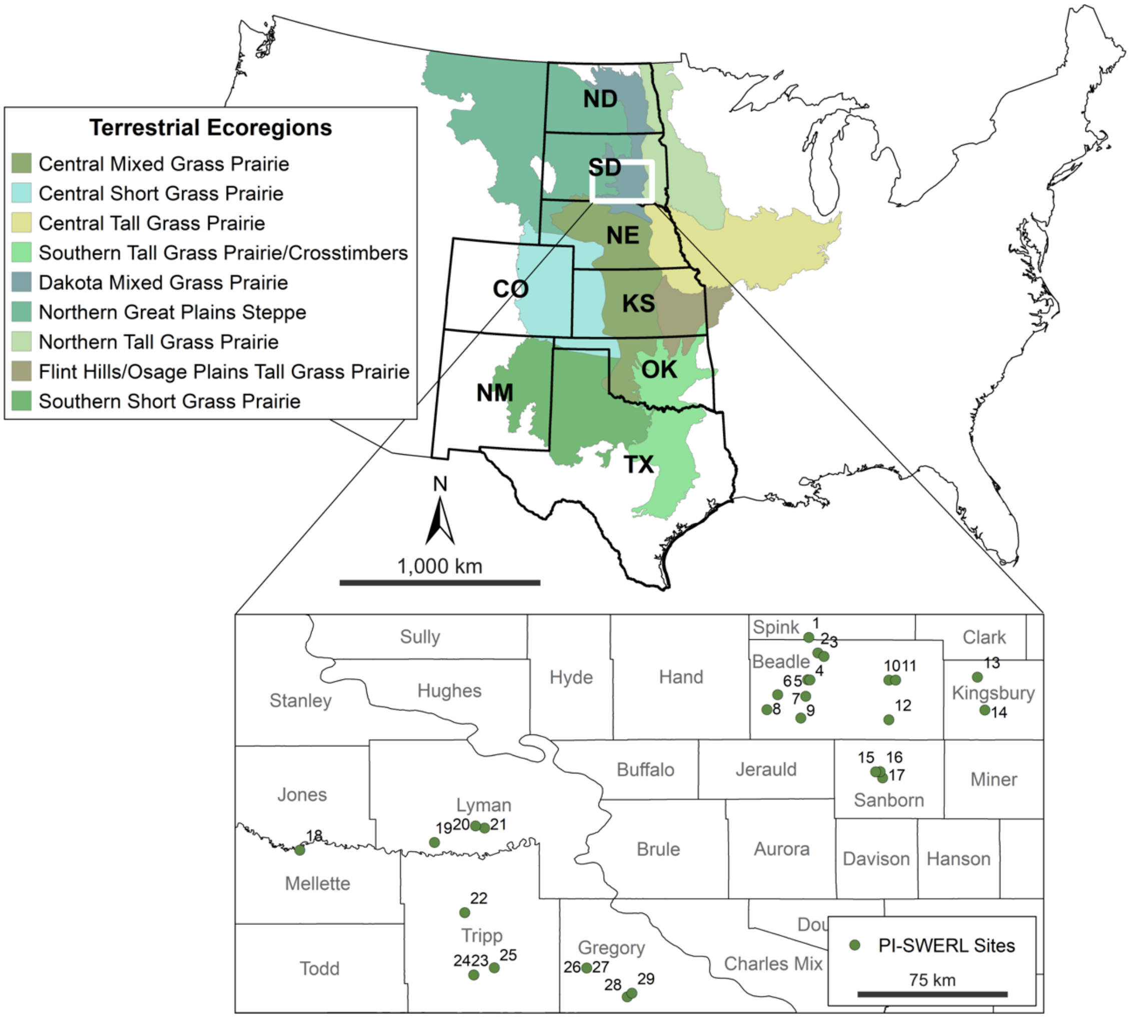

Figure 1.7. The United States Great Plains divided by terrestrial ecoregion (The Nature Conservancy [TNC] et al., 1995) with PI-SWERL sites located in South Dakota. See Appendix A for PI-SWERL location data.

The United States Great Plains is delineated by specific ecoregions composed of short, mixed, and tall grasses (Figure 1.7; The Nature Conservancy [TNC] et al., 1995). These grasslands are highly productive and have the ability to sequester carbon through both above- and below-ground net primary productivity (Sims and Bradford, 2001; Petrie et al., 2016). The precipitation gradient across the Great Plains (see Figure 3.6A) produces a wide range of grassland ecosystems, where greater precipitation to the east creates more productive C_3-dominated grasslands compared to the C_4-grasslands in the west (Sala et al., 1988; Derner et al., 2006). The response of these grasslands to drought can be highly variable, while carbon flux is sensitive to water availability on both short (daily) and long (decadal) timescales (Sims and Bradford, 2001; Petrie et al., 2016).

South Dakota is dominated by mixed grass prairies in the eastern portion of the state, while the western portion of the state is primarily dominated by short grassland (Figure 1.7; The Nature Conservancy [TNC] et al., 1995). Agriculture tends to dominate in the eastern portion of the state, where many counties east of the Missouri River are > 70% cultivated and counties west of the river are generally < 20% cultivated (see Figure 3.1B; Gutmann, 2005). Extensive eolian deposits exist in the southcentral portion of the state as a northward continuation of the Nebraska Sand hills (Wieczorek, 2014; Soil Survey Staff [SSS] et al., 2017) in addition to eolian deposits in the northeast derived from glacial outwash (Flint, 1955; see Figures 1.2, 3.1A).

Scientific Objectives and Hypotheses

The purpose of this study is to determine the existence of, and if identified, the spatial and temporal context for eolian activity and dust storm generation for a "Northern Dust Bowl" located in the Northern Great Plains region, USA. This study will compile climatic data, dust storm accounts, and agricultural census data in South Dakota to assess the severity of the Dust Bowl Drought in the Northern Great Plains. These data will be compared to findings in similar studies in the panhandle region of Texas to evaluate the overall effects of the drought in the Northern Great Plains compared to the Southern Great Plains, where it is traditionally viewed as the area most affected by the 1930s drought (Worster, 1979; Cunfer, 2005). This portion of this study aims to re-evaluate the severity of the 1930s drought in localities that are not considered part of the "Dust Bowl" region. Finally, this research will evaluate the potential dust emissivity of both cultivated, crusted surfaces and undisturbed eolian deposits in parts of South Dakota with recorded heightened dust activity during the 1930s. This was accomplished by using PI-SWERL technology used in conjunction with Prof. Mark Sweeney of the University of South Dakota, the Co-PI on this NSF-funded project. This will test previous scientific research that documents pre-existing uncultivated land contributed to dust generation during the drought, rather than from cultivated land alone (Bolles et al., 2017; 2019).

The specific questions this study aims to address are:

1. Was there a Northern Great Plains "Dust Bowl" of comparative activity and intensity to the dust generating areas of the Southern Great Plains?
2. What is the potential dust flux for soil surfaces in areas with high dust storm activity in the Northern Great Plains?

These findings contribute to the growing database of knowledge on the persistent widespread drought during the 1930s as a result of land-atmosphere interactions. Understanding the ways in which climate systems aid in the formation of these largescale droughts has become increasingly important as 21st-century dynamic climate conditions increase the susceptibility for megadrought-like conditions in the Great Plains region (Dai, 2013; Cook et al., 2015; Bolles et al., 2017).

CHAPTER TWO

Methodology

Surficial and Climatological Data

A time-series of land surface and climatic data for the Great Plains are used in this study. The percent sand, silt, and clay in the upper 20 cm of soil in South Dakota was calculated from the National Resources Conservation Service (NRCS) soil survey (Wieczorek, 2014; Soil Survey Staff [SSS] et al., 2017). The percentage of South Dakota counties under cultivation and percentage of crop failure was calculated from the United States Department of Agriculture (USDA) Agricultural Census (Gutmann, 2005). Mean annual precipitation (MAP) and mean annual temperature (MAT) from 1930 to 1940 in the United States were compiled from the PRISM Climate Group Historical Past dataset (PRISM Climate Group, 2020). Average annual precipitation for South Dakota was processed from the NOAA Statewide Time Series (National Oceanic and Atmospheric Administration [NOAA], 2020). Mean sea-level pressure (MSLP) and winds at 850 hPa in the United States were calculated from the NOAA 20th Century Reanalysis Project, V2c (Compo et al., 2011). Finally, instrumental PDSI values for the United States were compiled for the 1930s using the North American Drought Atlas (Cook et al., 2010).

Dust storm activity in the Northern Great Plains was initially compiled through journal accounts in the *Monthly Weather Review* (see Figure 1.5; Mattice, 1935a, 1935b; Choun, 1936; Martin, 1936a, 1936b, 1936c). However, these journal articles are limited to only the most severe weather phenomena reported throughout the United States. A daily record of dust events from January 1930 to December 1940 was compiled from the South Dakota State Climate Records (South Dakota State Climate Records, 2018). This is a spatially extensive and previously unused database for dust storm activity within the region. Daily weather events and conditions were recorded by hand at seventy-nine different weather stations across South Dakota, including both local and large-scale dust storms (Figure 2.1). The data include the date of dust storm activity, wind direction, and occasionally windspeeds recorded during dust storms. Dust storms reported in these records include the storms mentioned in the *Monthly Weather Review* during the 1930s, and hundreds of other dust storms not reported in these journal articles. Contour maps were created in ArcMap 10.6 using the Topo to Raster tool to determine the spatial and temporal extent of dust storms throughout the 1930s in South Dakota. Each weather station was set as a "point elevation" based on the number of dust storms it reported each year. These points were interpolated as singular data rather than elevation data, thus negative values were excluded, and zeroes were retained reflecting no reported dust storms. Wind rose diagrams were created from reported wind directions during dust storms using Stereonet 11 (Allmendinger et al., 2012; Cardozo and Allmendinger, 2013).

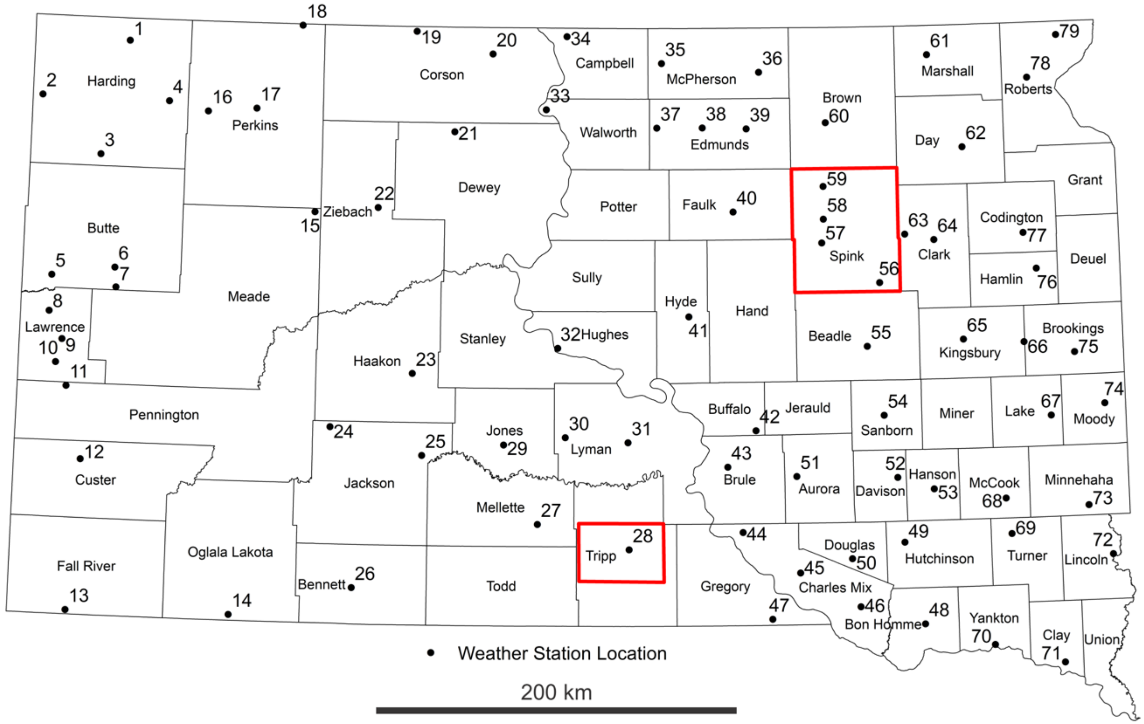

Figure 2.1. Locations of weather stations reporting dust storms from 1930 to 1940. Red boxes indicate areas of interest mentioned throughout the text. Compiled from the South Dakota State Climate Records (South Dakota State Climate Records, 2018). See Appendix B for tabulated location data.

Grain Size

Soil samples were collected from twenty-nine sites in South Dakota for grain-size and aggregate analysis (see Figure 1.7). Locations were determined based on areas with increased reports of dust storm activity during the 1930s and a variety of soil types were tested. Particle aggregation was assessed for selected samples following similar procedures outlined in Mason et al. (2003). Granulometry was determined with a high-resolution Malvern Mastersizer 3000 instrument based on laser diffraction measurements. The granulometry of each sediment sample was averaged over five measurements with a 10 second background of the Mastersizer. Samples were passed through a 2 mm sieve for optimal measurement conditions in the Mastersizer and were prepared by three procedures to evaluate aggregate versus particle size, critical parameters for dust generation:

1. *No disaggregation*. Samples were not pre-treated and were analyzed immediately after adding dry sample into the circulating deionized (DI) water suspension of the Mastersizer, similar to Mason et al. (2003). Samples were not sonicated before measurement. This allowed for the grain size measurement of aggregates present in the sample.
2. *Mechanical disaggregation.* Samples were pretreated by submerging the sample in 10% sodium hexametaphosphate (NaHMP) and sonicating for 30 minutes. Subsequently, samples were spun in a centrifuge for 5 minutes at 3000 RPM, decanted, rinsed with DI water, and dried overnight. Once dry, samples were further disaggregated by gentle action in a mortar and pestle and turned into paste by adding 10% NaHMP. This paste was then added into the circulating DI water suspension of the Mastersizer. Prior to initializing measurement, the sample was sonicated by the Mastersizer for 300 s.
3. *Chemical disaggregation*. Samples were pretreated by soaking in 11% HCl to dissolve all carbonates, similar to Mason et al. (2013). Sediments were then centrifuged, decanted, and rinsed with DI water. Next, 35% hydrogen peroxide was added to the sample, followed by centrifugation, decanting, and rinsing in DI water to dry overnight. Once dry, samples were further disaggregated by gentle motion with a mortar and pestle, turned into a paste by adding 10% NaHMP, and added into the circulating DI water suspension of the Mastersizer. Prior to measurement, the sample was sonicated for 300 s by the Mastersizer.

Dust Flux

The Portable *In-Situ* Wind Erosion Lab (PI-SWERL; Etyemezian et al., 2007) was used to measure the potential dust emissivity of surfaces in South Dakota. PI-SWERL has been applied to a multitude of surfaces in arid and semiarid areas (i.e. Goossens and Buck, 2009; Bacon et al., 2011; King et al., 2011; Sweeney et al., 2011, 2016a, 2016b; Sweeney and Mason, 2013; Bolles et al., 2018) and has been tested against larger-scale wind tunnels with concordant results (Sweeney et al., 2008). In this study, dust flux was calculated directly on surfaces in the field for ten sites and in the laboratory from samples collected in nineteen additional sites (see Appendix A). Field sites include both disturbed cultivated land and undisturbed eolian deposits. Lab samples were collected in the field and passed through a 2 mm sieve and placed in a round pan for PI-SWERL measurement. To estimate 10-m windspeeds from PI-SWERL friction velocities, a surface roughness coefficient of 0.0006 m was applied, a value similar to that of bare to sparsely vegetated agricultural field soils (Gillette, 1988).

The PI-SWERL is a circular field instrument about 45 cm in diameter that simulates the wind fields that release dust emissions from a variety of surfaces through a rotating vaned annular ring (Desert Research Institute, 2020). This ring spins at increasing predetermined speeds which yield well-defined friction velocities (u^*, m s^{-1}) for particle entrainment. Tests are completed with a stepwise increase in speed by 1000 RPM for 60 seconds. The emissions of PM_{10} dust (particles $\leq$ 10 μm) and total suspended particles (TSP; particles $\leq$ 20 μm) from the surface are measured using a DustTrak II aerosol monitor. These dust concentrations are measured in mg m^{-3} and converted into the rate of dust emission in mg m^{-2} s^{-1} (Sweeney et al., 2008).

CHAPTER THREE

Results

Surface Conditions and Climate

Agriculture in South Dakota during the 1930s was prominent, more so east than west of the Missouri River (Figure 3.1B). The percentage of land under cultivation exceeded 70% in some areas east of the Missouri River, whereas cultivation west of the river was mostly below 20%. The soils with the sandiest parent material in the state occur in south-central counties, where the Nebraska Sand Hills extend into South Dakota (Figure 3.1A). There are additional eolian deposits in the northeastern part of the state, between Brown and Marshall counties, which exist as glacial lake sediments composed chiefly of sand and till (see Figure 1.2; Flint, 1955). Crop failure was extensive throughout South Dakota in 1934 (Figure 3.1C). Agricultural census data indicates most counties in the state experienced > 30% crop failure in 1934, with extreme crop failure > 70% for many counties adjacent to the Missouri River. In contrast, crop failure, five years prior in 1929, rarely exceeded 10% in these counties. Crop conditions showed improvement by 1939 but was highly variable with crop failure between 10 and 50% (Figure 3.2).

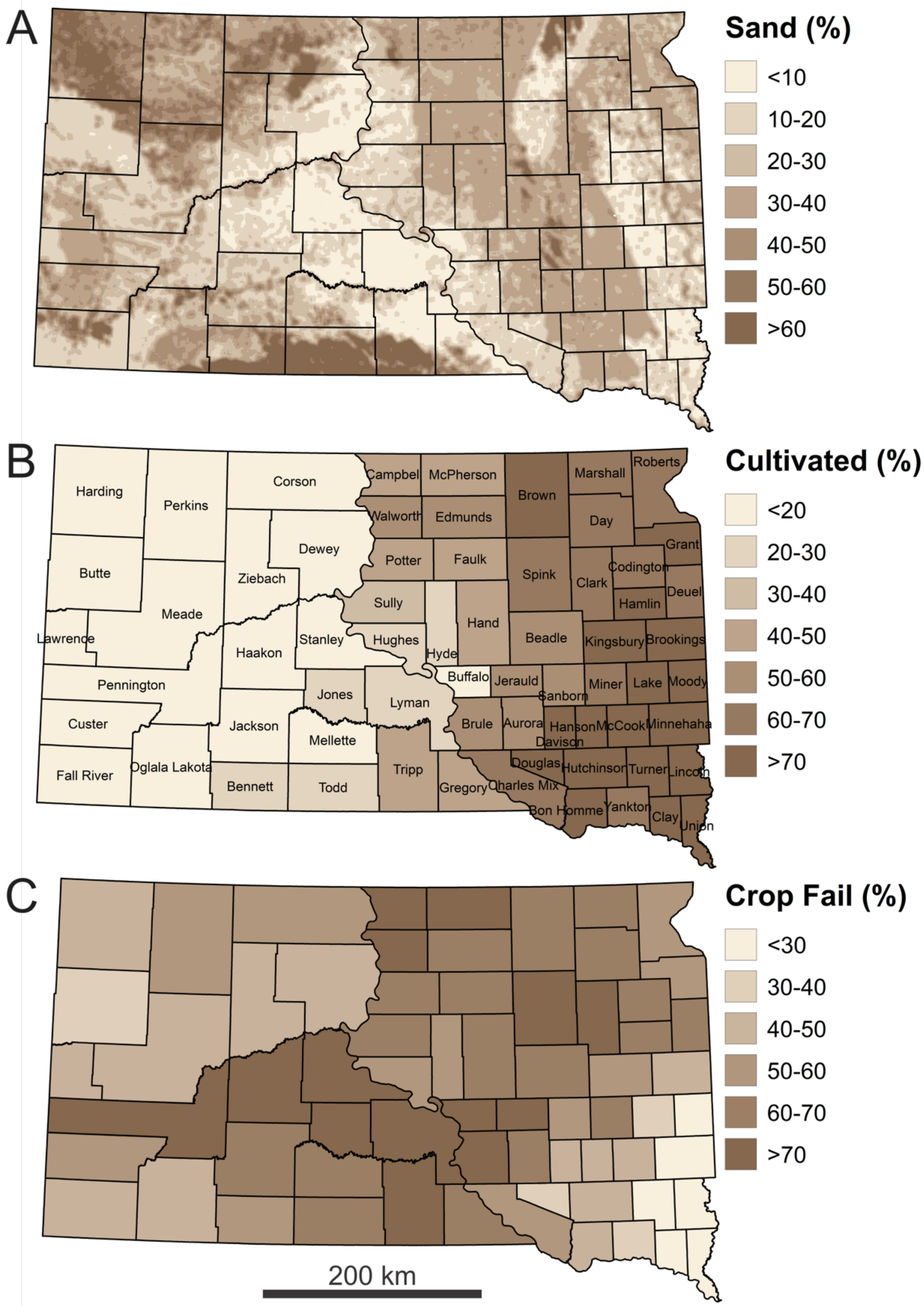

Figure 3.1. Surficial conditions in South Dakota, including (A) percent sand in the upper 20 cm of soil (Wieczorek, 2014; Soil Survey Staff [SSS] et al., 2017), (B) percentage of county land cultivated in 1934, and (C) percentage of crop failure per county in 1934 (Gutmann, 2005).

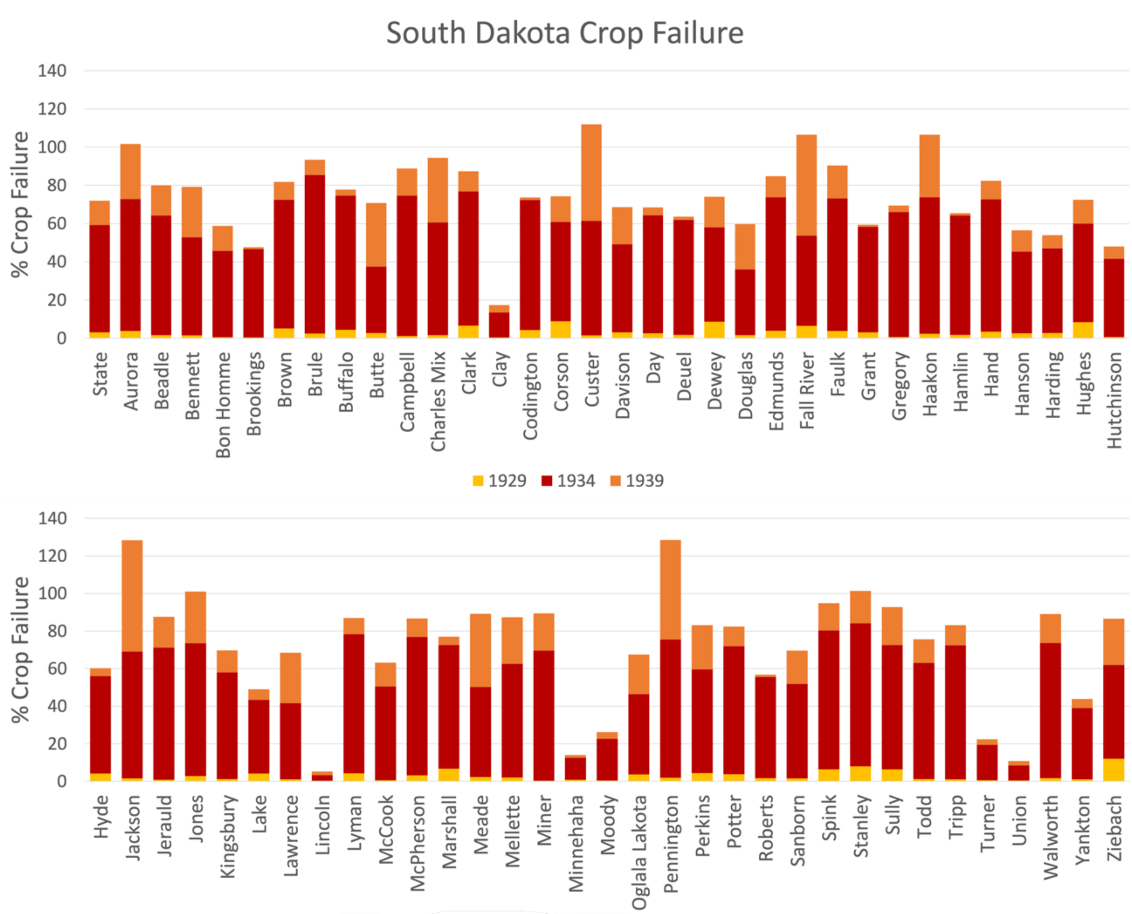

Figure 3.2. Crop failure percentages per county in 1929, 1934, and 1939 compiled from the South Dakota USDA Agricultural Census (Gutmann, 2005). See Figure 3.1B for locations of counties.

Reports from the Soil Conservation Service reveal areas of intense wind and soil erosion during the 1930s in the Great Plains (Figure 3.3). There are two primary regions in the Great Plains that exhibit severe wind erosion in 1934: the panhandle region of the Southern Great Plains, and parts of the Northern Great Plains in the Dakotas (Figure 3.3A). Much of the Northern Great Plains and parts of the Central and Southern Great Plains are also delineated by regions of moderate wind erosion. In 1935, the Soil Conservation Service outlined principal wind erosion areas in South Dakota during the Dust Bowl Drought (Figure 3.3B). These regions of severe wind erosion are centered in south central

South Dakota around Tripp, Lyman, and Jones counties and extend north through the eastern part of the state into Spink and Marshall counties.

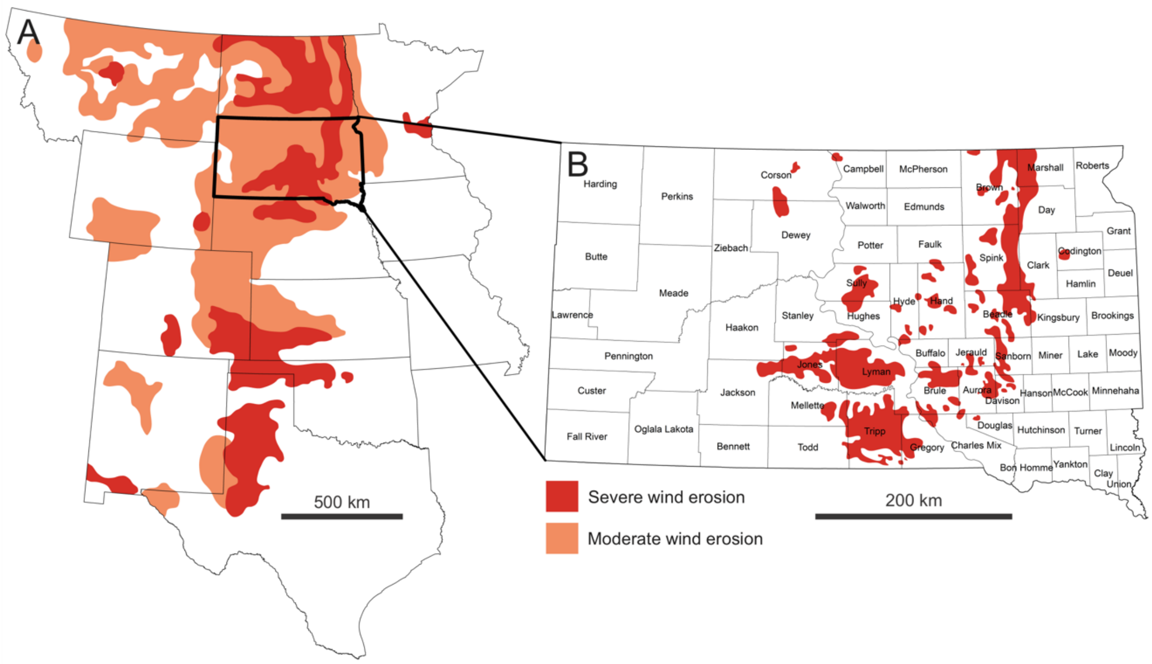

Figure 3.3. (A) Extent of wind erosion in the Great Plains, 1934 and (B) principal wind erosion areas in South Dakota, 1935 (redrawn from Soil Conservation Service maps, National Archives, Record Group 114, Entry 88).

Mean annual temperature (MAT) in the Great Plains prior to the 1930s typically ranged between 25 °C in the south and 2 °C in the north whereas the average temperature in South Dakota was ~7 °C (Figure 3.4A). MAT increased significantly in the Northern Great Plains during the 1930s as evidenced by the position change in the 9°C isotherm, which shifted northward by > 200 km (Figure 3.4A-B). MAT throughout most of the Great Plains increased by at least 1 °C during the 1930s (Figure 3.4C). The greatest increase in MAT in the Great Plains occurred in central South Dakota with an increase > 1.25 °C.

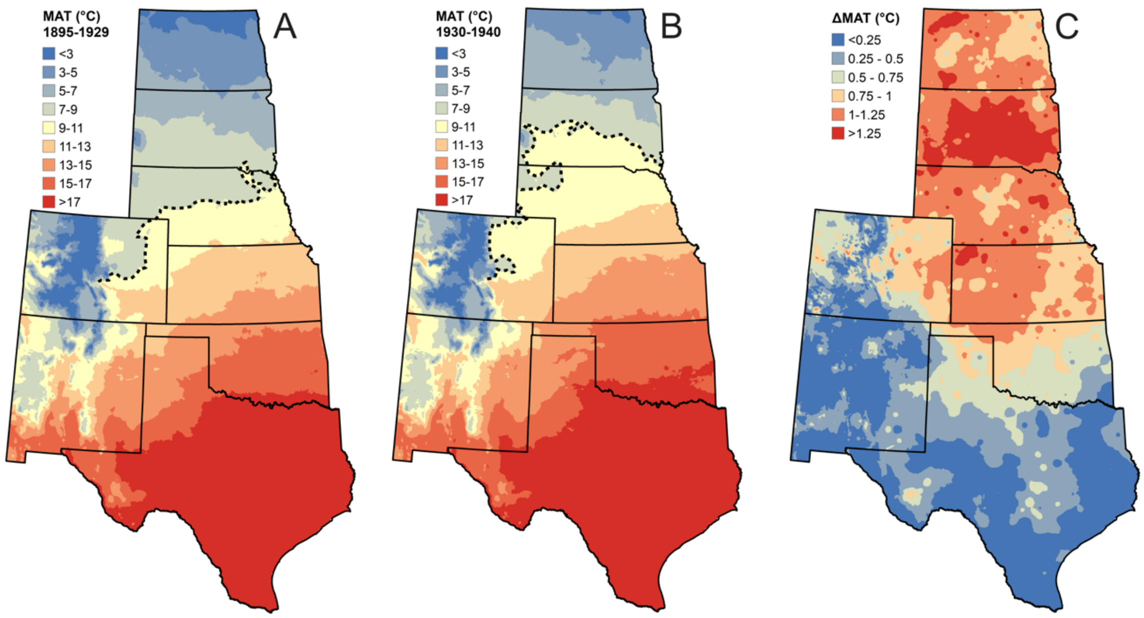

Figure 3.4. Mean annual temperature in the U.S. Great Plains from (A) 1895-1929 and (B) 1930-1940, and (C) the change in temperature between the two time periods. Dashed line represents the 9 °C isotherm. Calculated from the PRISM Climate Group Historical Past dataset (PRISM Climate Group, 2020).

Precipitation decreased markedly in South Dakota during the 1930s (Figure 3.5). Average annual precipitation fell below the AD 1900-2020 mean for ten years straight during the Dust Bowl Drought, whereas the average precipitation level in 1936 is the lowest recorded in the state at only 10.9 mm for the entire year (National Oceanic and Atmospheric Administration [NOAA], 2020). Mean annual precipitation (MAP) in the Great Plains prior to the 1930s ranged from 185 to 1,900 mm, with precipitation generally increasing eastward (Figure 3.6A). Most of the Great Plains experienced a decrease in precipitation of at least 40 mm during the 1930s, with parts of South Dakota experiencing an average loss > 160 mm through the decade (Figure 3.6B). Precipitation declined throughout the Dakotas by at least 11%, with parts of central and eastern South Dakota declining by as much as 40% (Figure 3.6C).

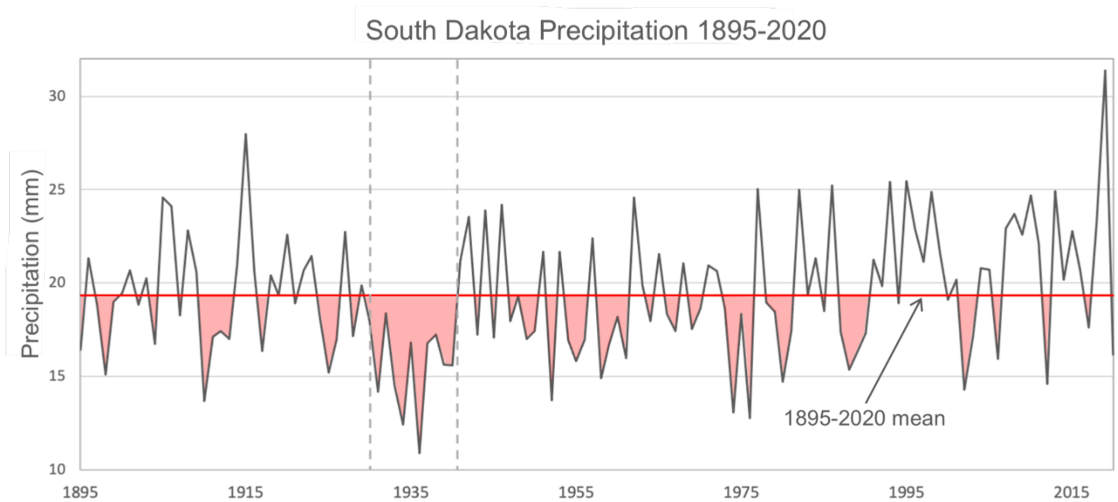

Figure 3.5. Average annual precipitation in South Dakota from 1895-2020. Red line demarcates the 1895-2020 mean, while dashed lines encompass the 1930s. Compiled from NOAA Statewide Timeseries (National Oceanic and Atmospheric Administration [NOAA], 2020).

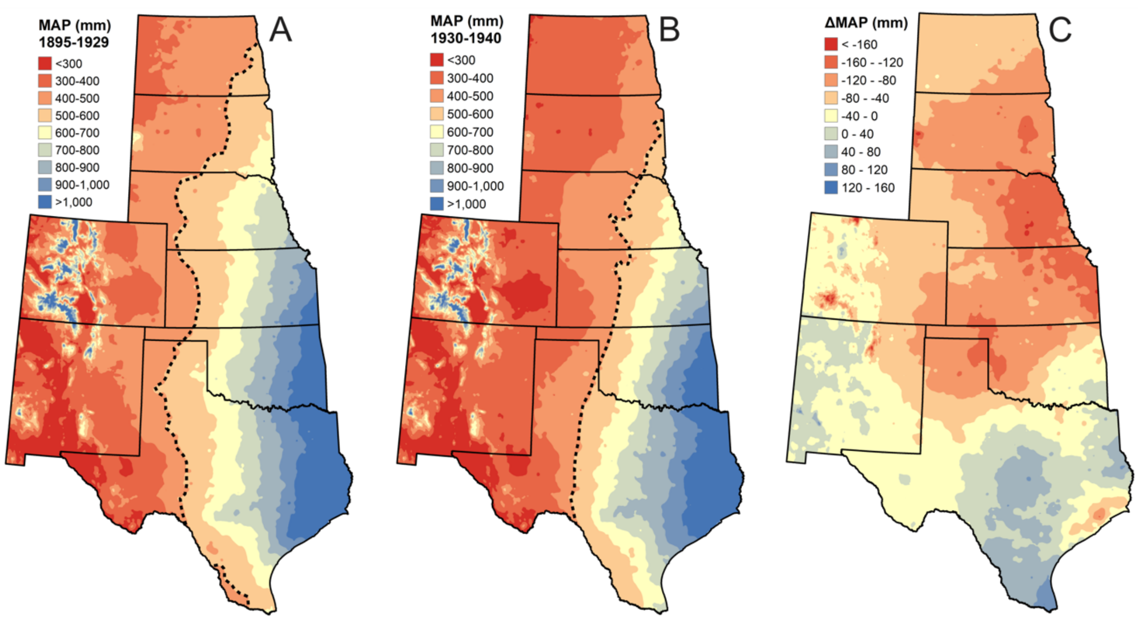

Figure 3.6. Mean annual precipitation in the United States Great Plains from (A) 1895-1929 and (B) 1930-1940, and (C) the change in precipitation between the two time periods. Dashed line represents the 500 mm isohyet. Calculated from the PRISM Climate Group Historical Past dataset (PRISM Climate Group, 2020).

The Palmer Drought Severity Index (PDSI) values during the 1930s provide spatial and temporal context to the Dust Bowl Drought in the United States Great Plains (Figure 3.7). Summer PDSI values during the worst years of the drought (1934, 1936-1937) were well below -4 in many parts of the Great Plains (Figure 3.7E, G-H). Mean PDSI values encompassing the 1930s indicate much of the Great Plains experienced extreme drought conditions throughout parts of the decade (Figure 3.7L).

The temporal scale of summer PDSI values in South Dakota during the 1930s reveals the parts of the state most impacted by drought (Figure 3.8). The mean PDSI from 1930 to 1940 in South Dakota reveals that much of the eastern and central and up into the northwestern part of the state experienced extreme drought conditions during at least part of the decade (Figure 3.8A). 1930 was the wettest year of the decade, with southwestern counties experiencing overall positive PDSI values up to 5 (Figure 3.8B). In 1931, most of the state was below -1 on the PDSI scale, whereas many counties in eastern South Dakota were below -5 (Figure 3.8C). During the following year in 1932, the eastern part of the state continued to experience negative PDSI values down to -5, but the western part of the state experienced wetter conditions with positive PDSI values up to 4. In 1933 the severity of the drought expanded in the eastern part of the state, and by 1934 the drought reached its peak, where the entire state registered PDSI levels below -4 with the eastern part of the state below -7 (Figure 3.8E-F). The severity of the drought subsided in 1935 with four southwestern counties experiencing positive PDSI values and parts of eastern and northwestern South Dakota under moderate drought (Figure 3.8G). During the following year in 1936 a secondary peak in drought occurred, with PDSI values below -1 for the entirety of South Dakota and below -7 in the northwestern part of the state (Figure 3.8H).

In the following years from 1937 to 1940, the drought appears to have affected the western part of the state more so than the east, with PDSI levels generally between -1 and -4 (Figure 3.8I-L).

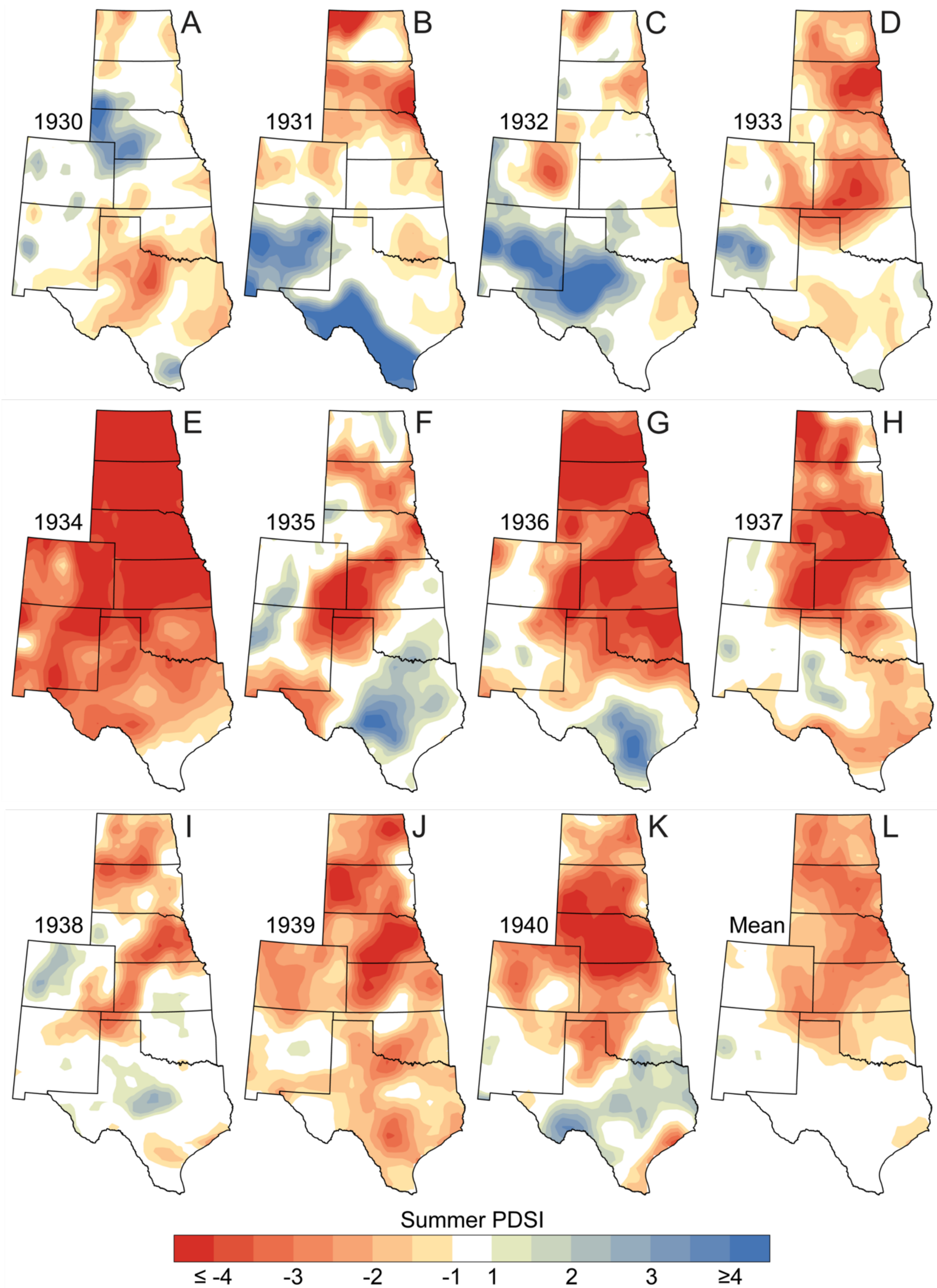

Figure 3.7. Summer (June-August) PDSI values in the U.S. Great Plains from (A-K) 1930-1940 and (L) the mean for the decade. Calculated from the North American Drought Atlas (Cook et al., 2010).

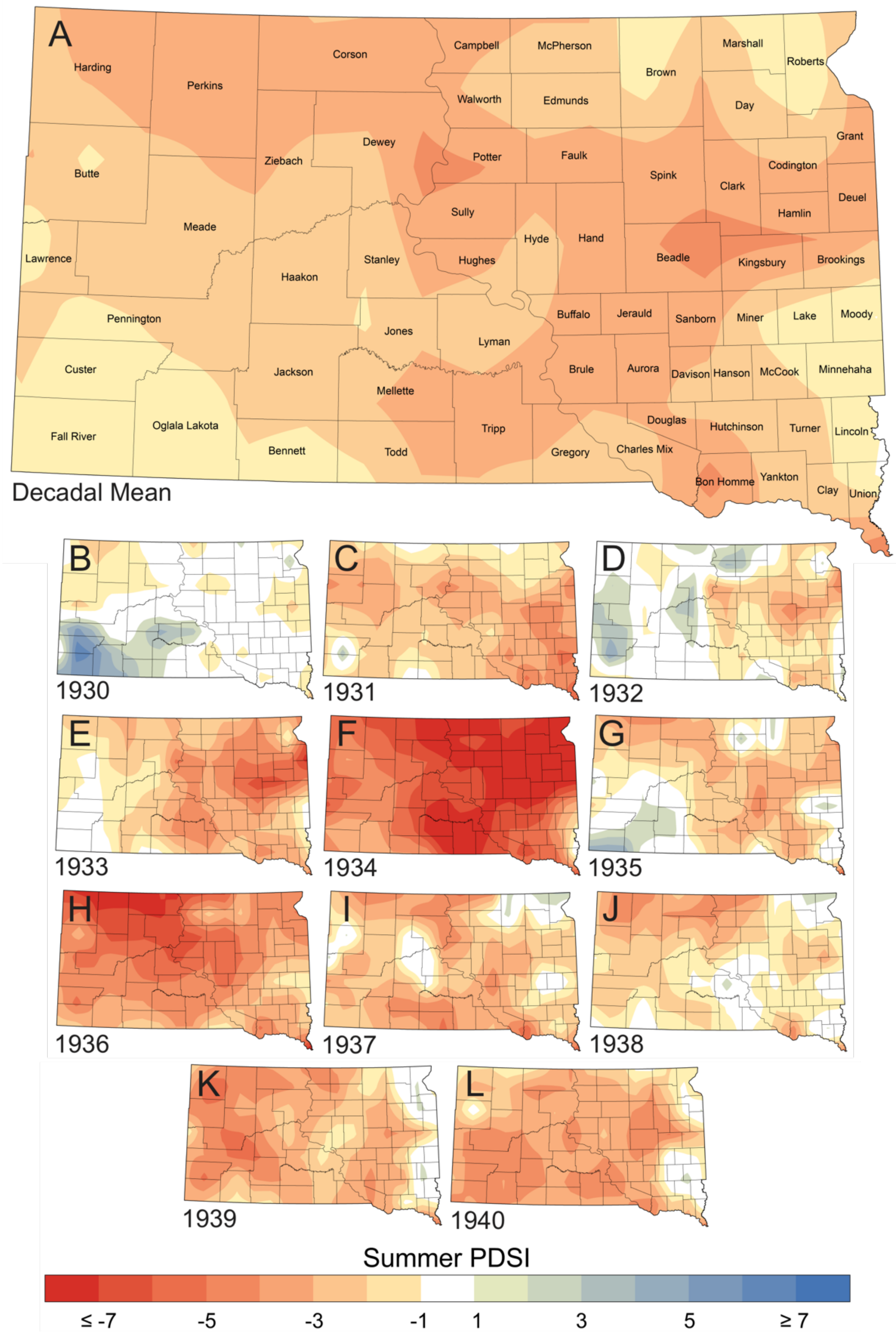

Figure 3.8. Summer (June-August) PDSI values in South Dakota for (A) the 1930-1940 decadal mean and (B-L) individual years from 1930-1940. Calculated from the North American Drought Atlas (Cook et al., 2010).

Drought conditions in South Dakota were heightened in 1934 during all seasons (Figure 3.9). PDSI values indicate drought conditions were worst during summer months (June-August; Figure 3.9C), followed by fall (September-November; Figure 3.9D) and spring (March-May; Figure 3.9B) with PDSI values below -8. During the winter (December-February; Figure 3.9E) PDSI values increased throughout much of the state, but with values down to -6 the eastern part of the state was still under severe drought. Regardless of season, 1934 was an intense drought year for South Dakota, with average PDSI values near -7 in the eastern portion of the state (Figure 3.9A).

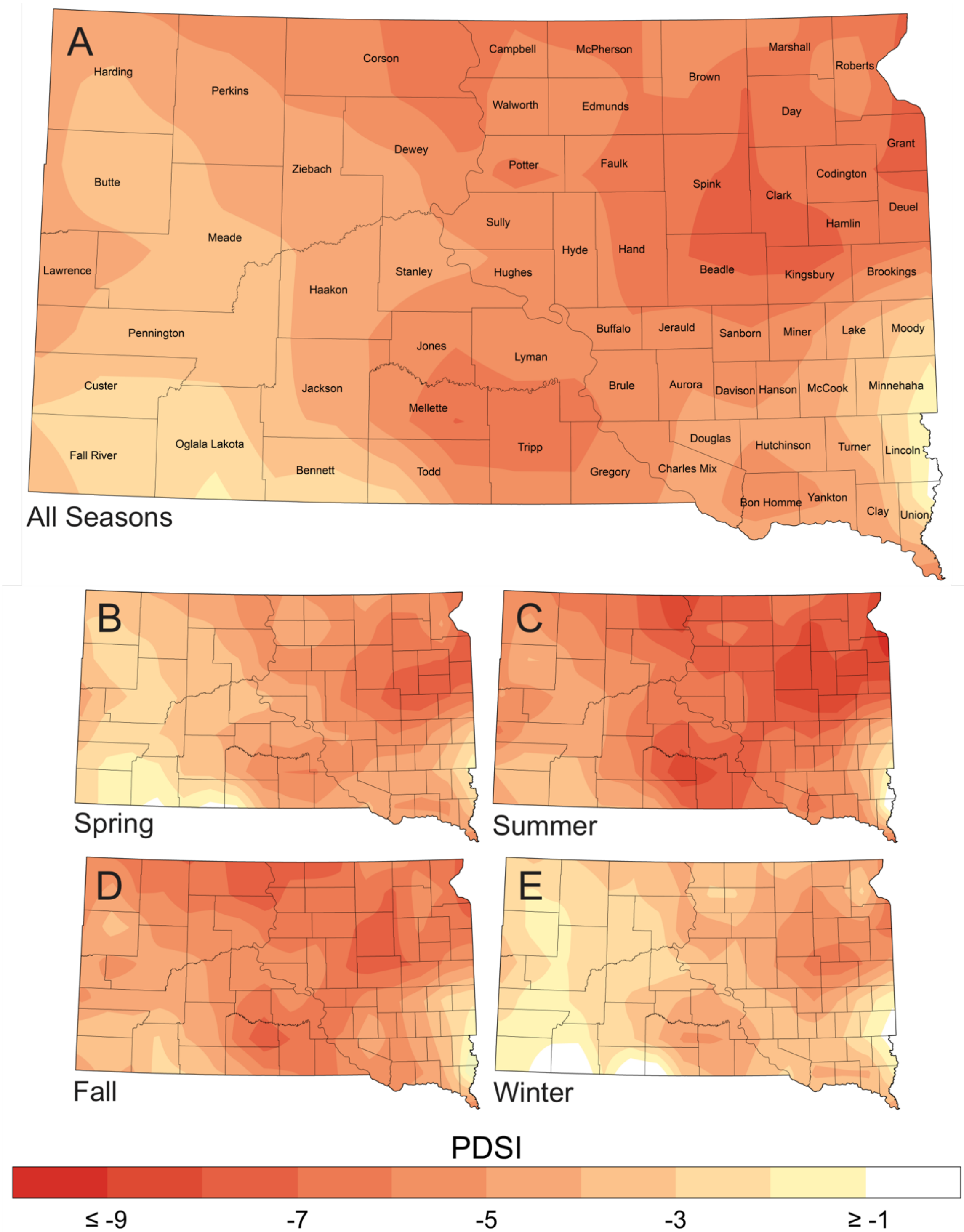

Figure 3.9. 1934 PDSI values in South Dakota for the (A) entire year, (B) spring (March-May), (C) summer (June-August), (D) fall (September-November), and (E) winter (December-February). Calculated from the North American Drought Atlas (Cook et al., (2010).

There is a fundamental reorganization of the synoptic climatology of North America during drought conditions in the conterminous USA (Donat et al., 2016). During the 1930s, the development of a dynamic high-pressure ridge over the western United States led to a reversal in mean airflow over the Great Plains (Donat et al., 2016). This reversal weakened the Great Plains Low Level Jet (GPLLJ), which typically provides the Great Plains with moisture-laden air from the Gulf of Mexico, leading to a severe reduction in precipitation and fueling the Dust Bowl Drought (Donat et al., 2016).

Anomalies in MSLP and winds at 850 hPa in North America were calculated during widespread dust events in South Dakota to better understand climatic conditions associated with dust storms (Figures 3.10-3.14 G-H; see Appendix C). These anomalies were then compared to MSLP and wind anomalies during extreme precipitation events (Figures 3.10-3.14 I-J; see Appendix D). MSLP and wind anomalies were calculated by season: spring (Figure 3.10), summer (Figure 3.11), fall (Figure 3.12), and winter (Figure 3.13), and throughout all seasons (Figure 3.14). Further, synoptic MSLP and winds were calculated for dust storm days (Figure 3.15) and extreme precipitation days (Figure 3.16).

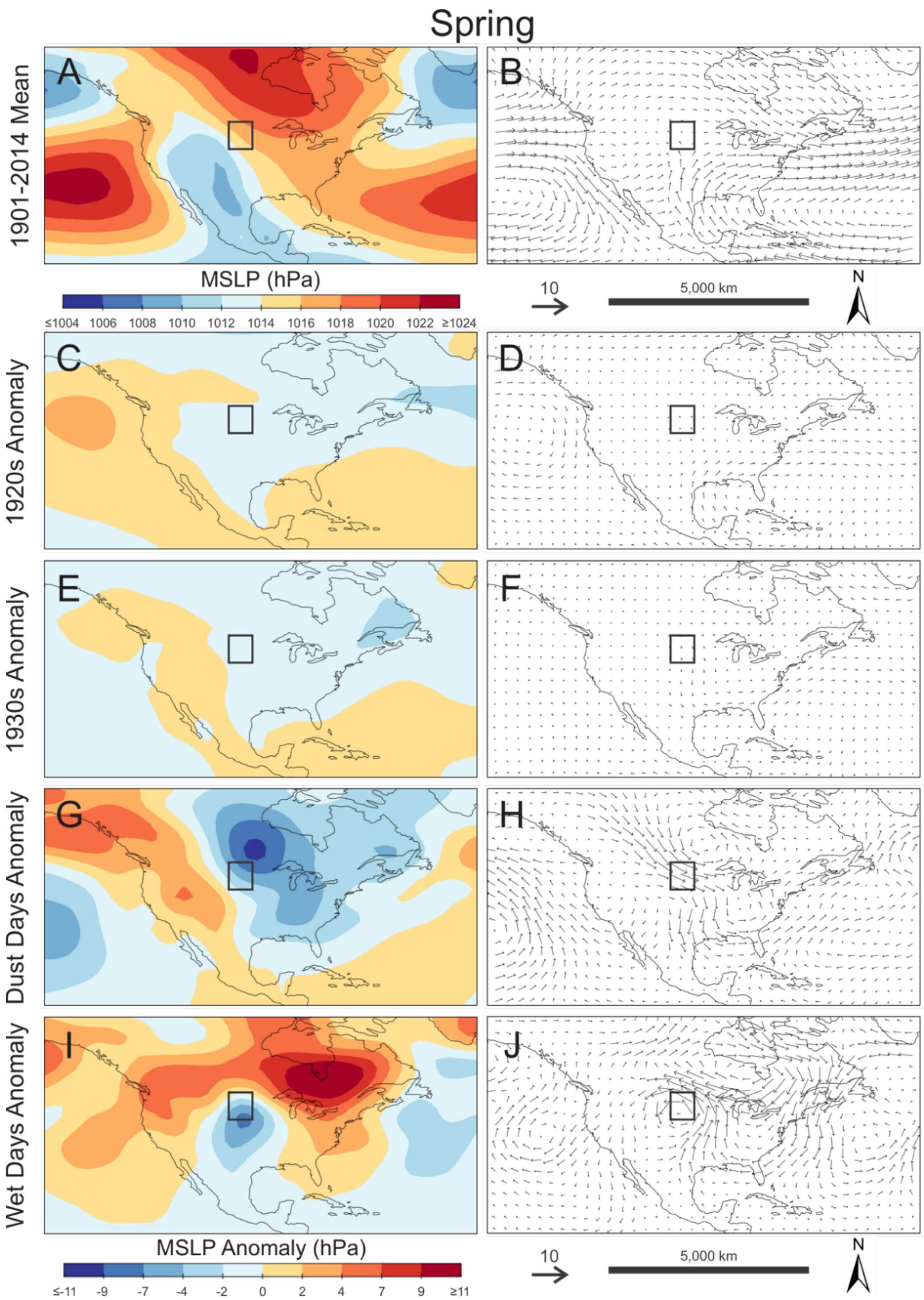

Figure 3.10. Long-term mean of spring (A) MSLP and (B) winds (m s^{-1}) at 850 hPa. Followed are anomalies in spring MSLP and winds during the 1920s (C-D) and 1930s (E-F). MSLP and wind anomalies during widespread spring dust storms in the 1930s (G-H) and during dates of heightened precipitation (I-J) shown last. Box demarcates the Dakotas. Calculated from 20th Century Reanalysis Project, V2c (Compo et al., 2011). See Appendix C for tabulated dust storm data and Appendix D for extreme precipitation dates used here.

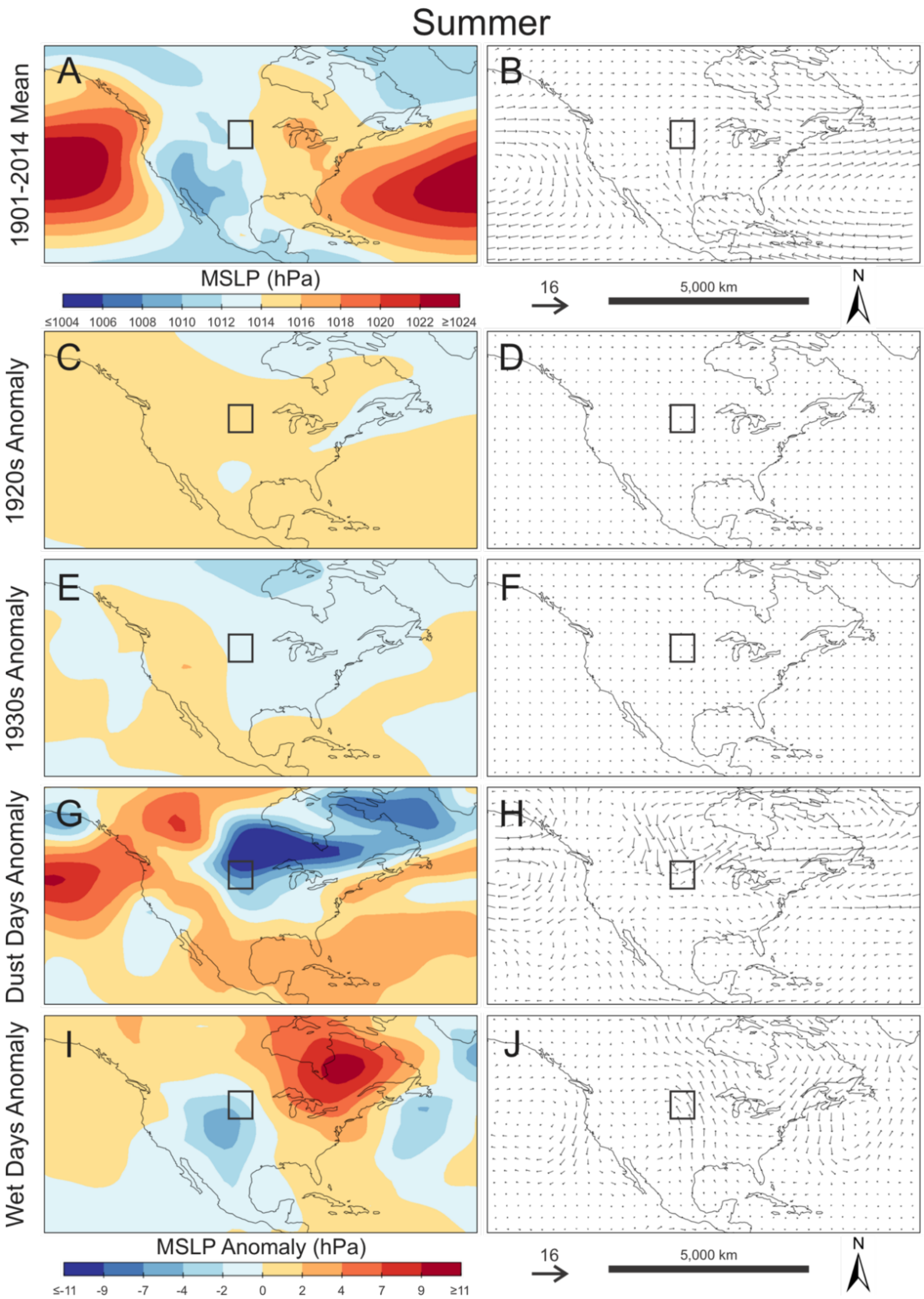

Figure 3.11. Same as Figure 3.10, but for summer months.

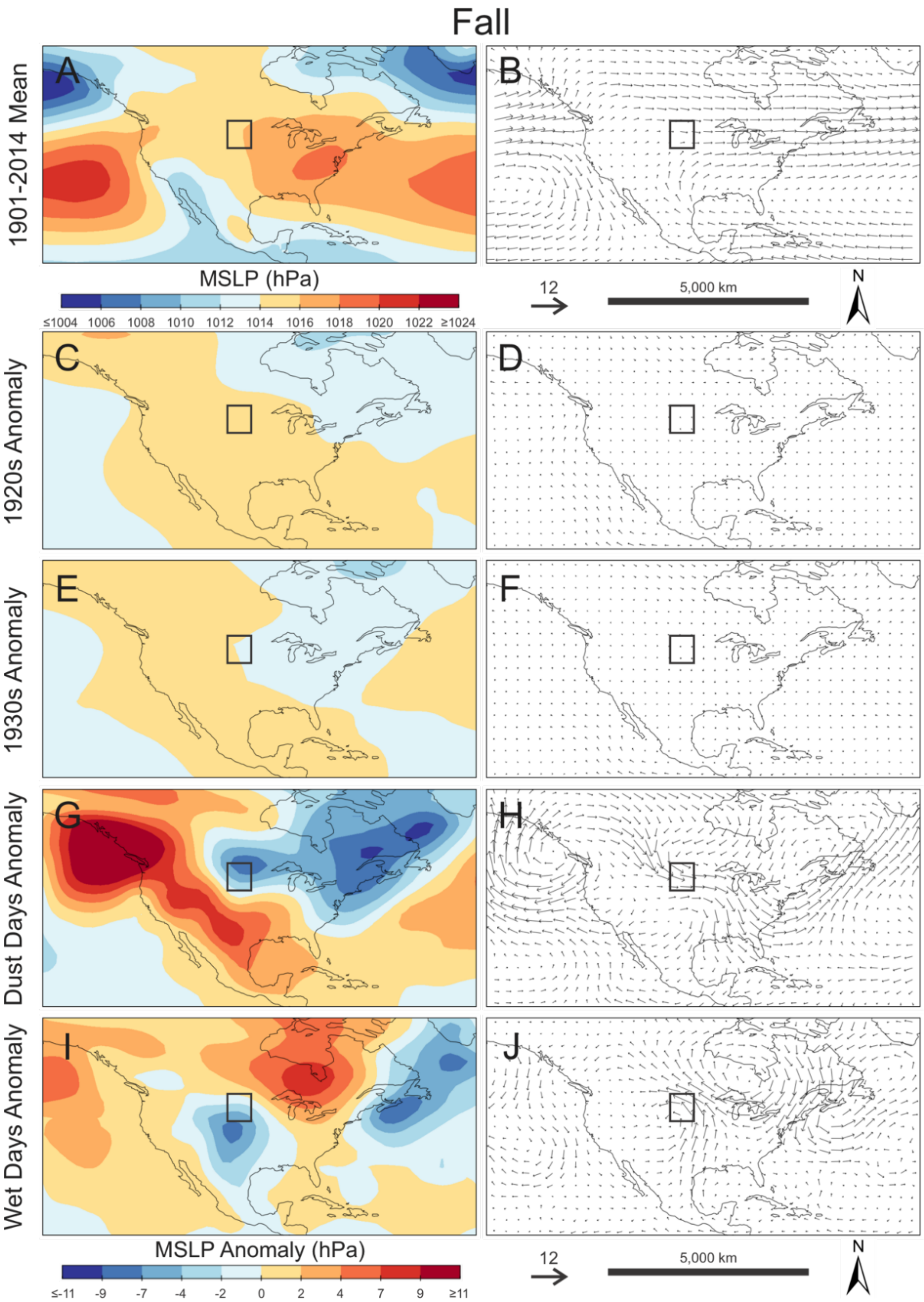

Figure 3.12. Same as Figure 3.10, but for fall months.

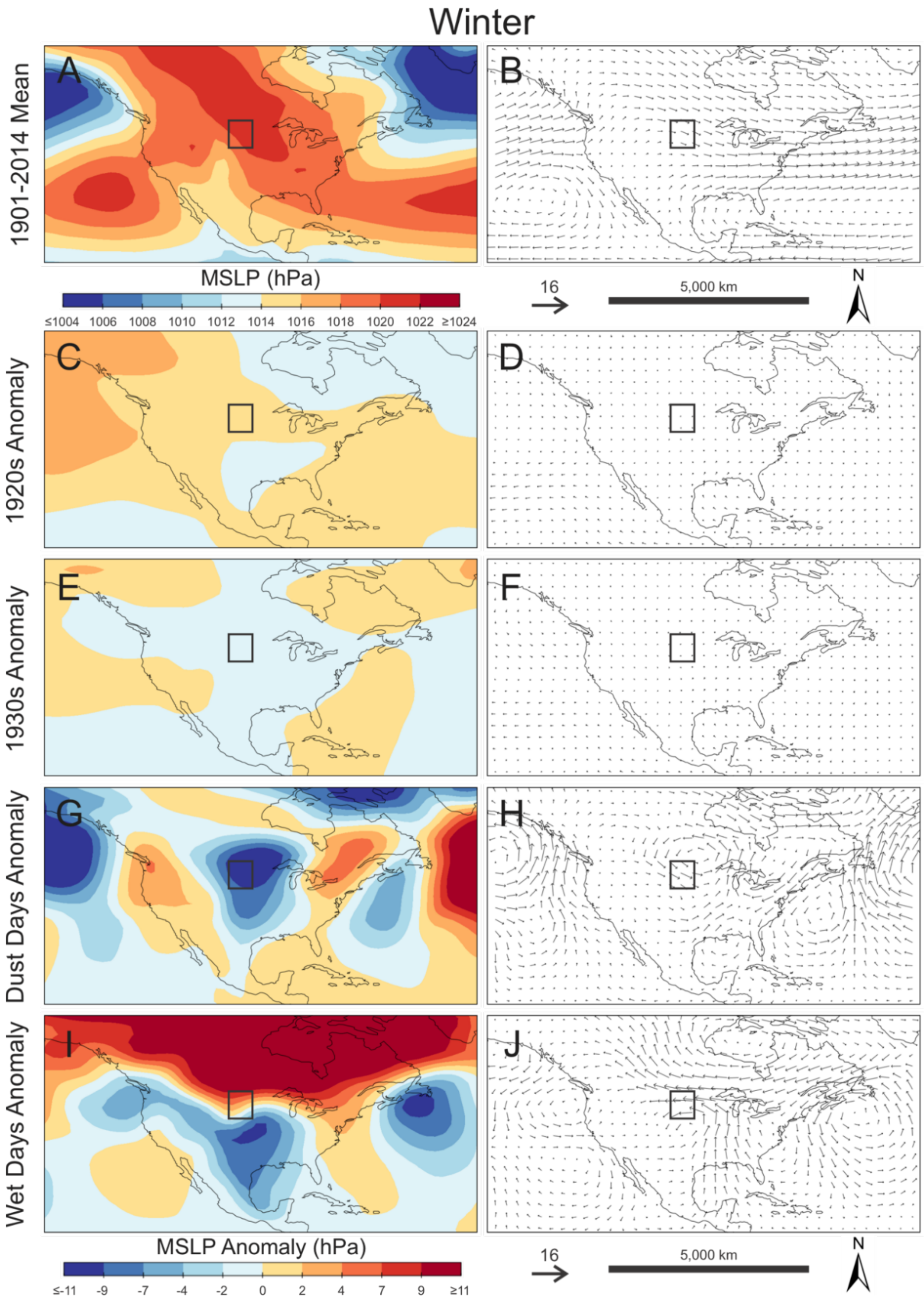

Figure 3.13. Same as Figure 3.10, but for winter months.

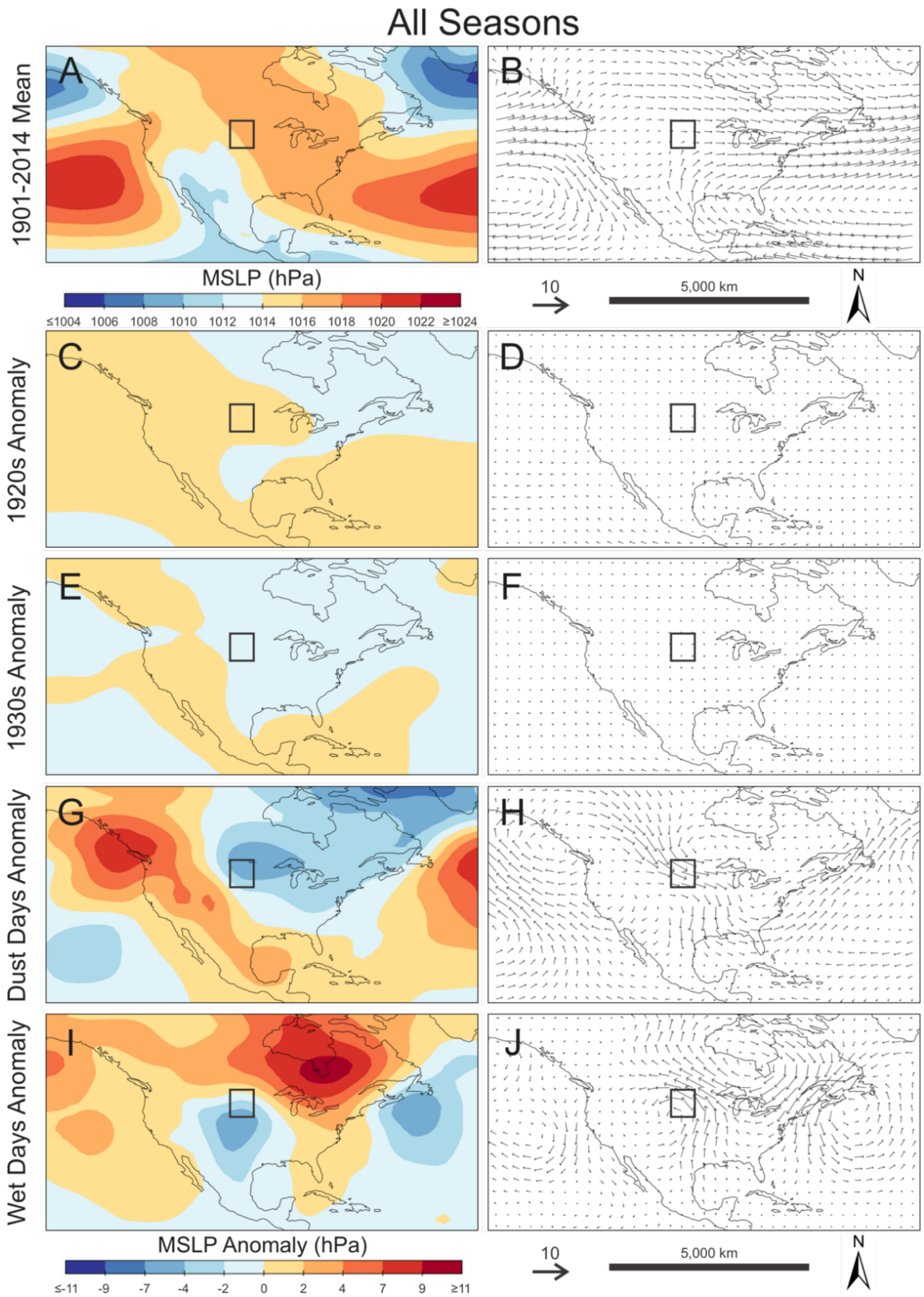

Figure 3.14. Same as Figure 3.10, but for all seasons.

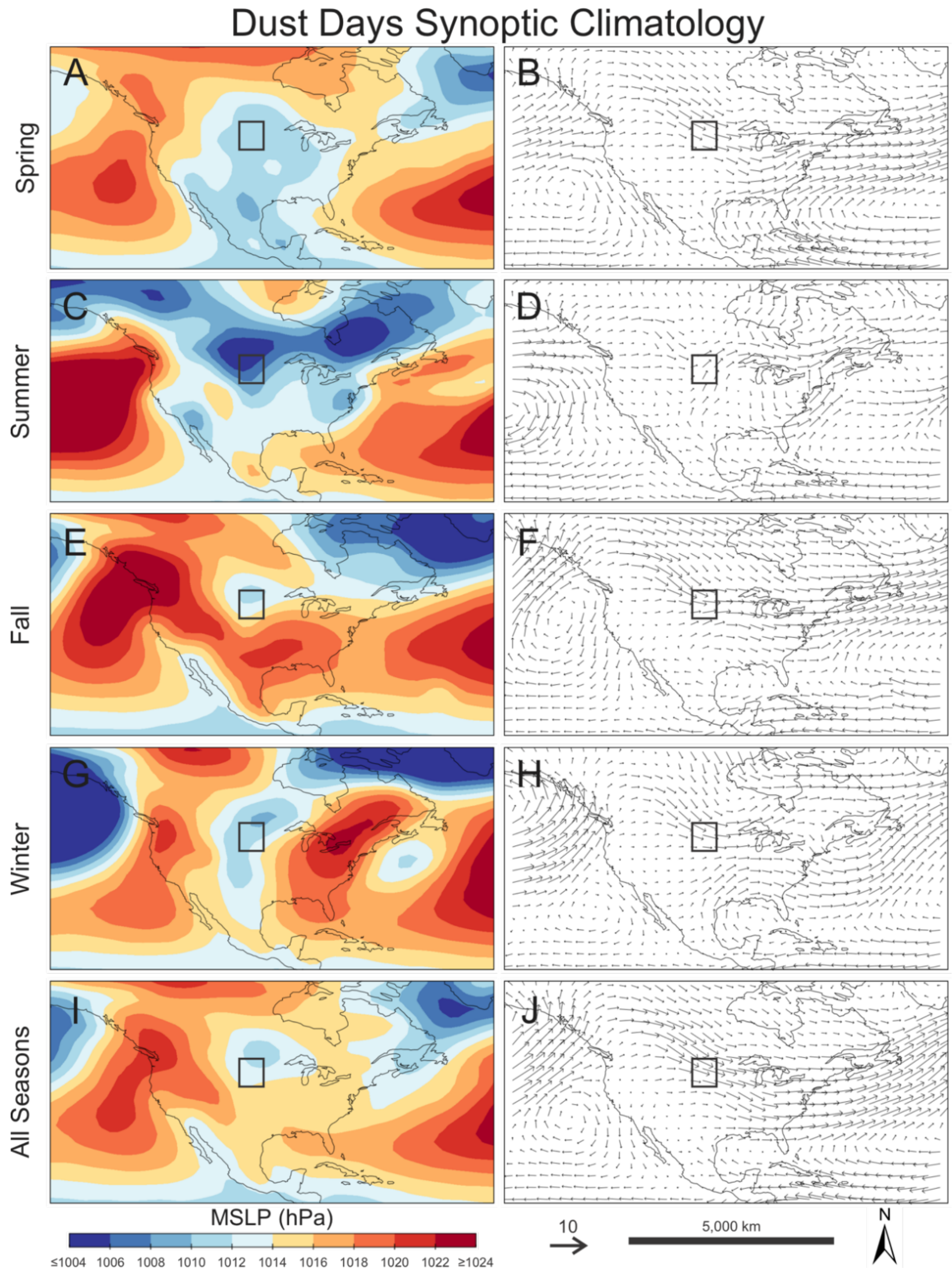

Figure 3.15. Synoptic MSLP and winds (m s^{-1}) during widespread dust storms in the 1930s during the spring (A-B), summer (C-D), fall (E-F) and winter (G-H), and during all months (I-J). See Appendix C for tabulated dust storm data used here.

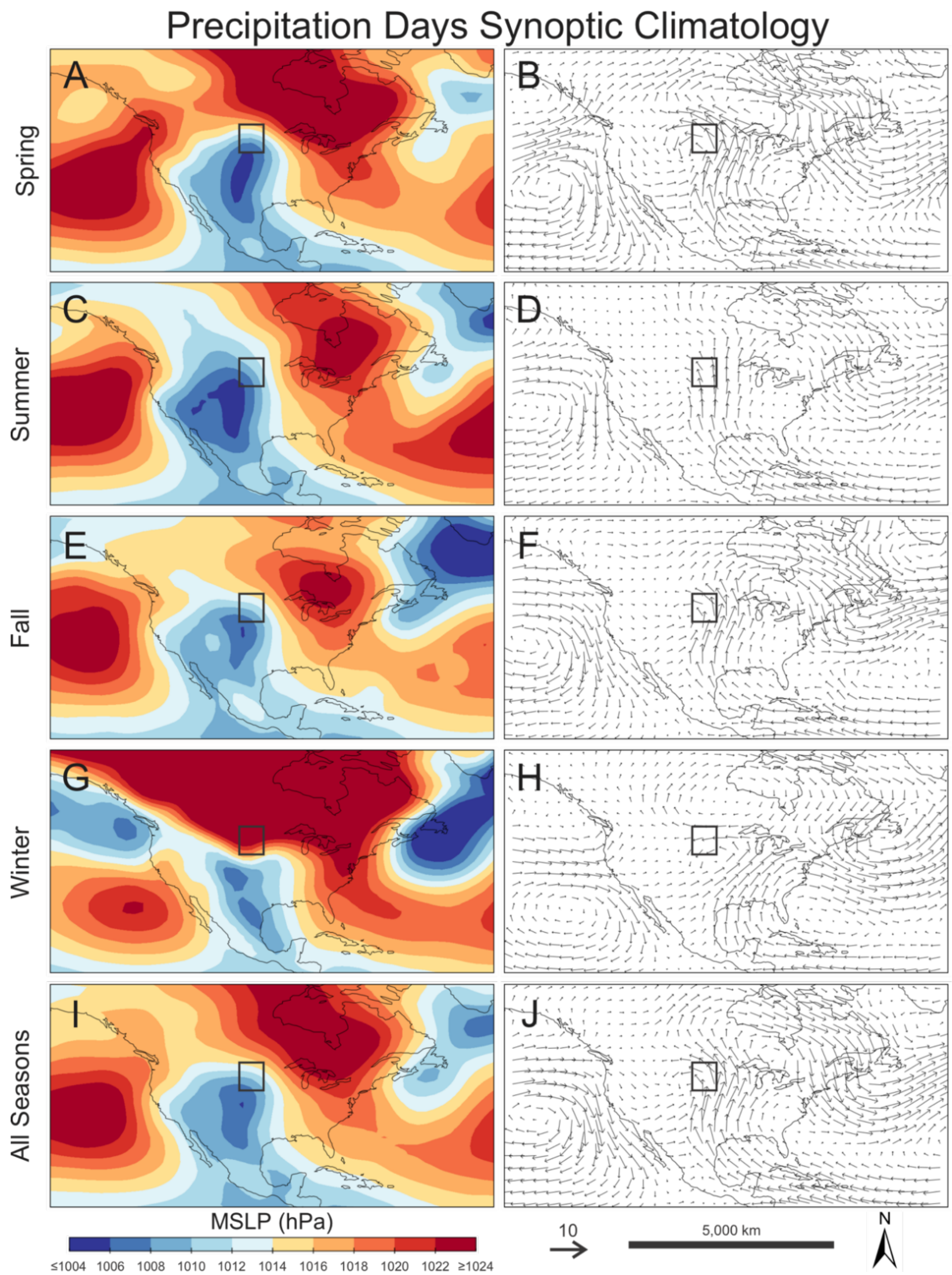

Figure 3.16. Synoptic MSLP and winds (m s^{-1}) during extreme precipitation events in the spring (A-B), summer (C-D), fall (E-F) and winter (G-H), and during all months (I-J). See Appendix D for tabulated precipitation data used here.

Decadal average anomalies in MSLP and winds appear to be relatively small during the 1920s (Figures 3.10-3.14 C-D) and the 1930s (Figures 3.10-3.14 E-F) irrespective of season. However, during widespread dust storms in South Dakota during the 1930s, anomalies in MSLP increase substantially during all seasons (Figures 3.10-3.14G). A commonality between all seasons is a strengthened high-pressure ridge aloft over the western United States and southwestern Canada (Figures 3.10-3.14G). This increase in pressure coupled with a decrease in pressure over southcentral Canada appears to enhance northwesterly winds through the Northern Great Plains and weaken the GPLLJ over the Gulf of Mexico (Figures 3.10-3.14H). The effects of these anomalies are observed in synoptic MSLP and winds during dust storm events, where the high-pressure system over the Pacific Ocean moves into the western United States, driving increased winds out of the northwest in the Northern Great Plains and deflecting airflow out of the Gulf of Mexico to the east (Figure 3.15). This is most pronounced in the spring, fall, and winter months, while summer months do not appear to reflect this high-pressure encroachment into the western United States as much, leading to a decrease in northwesterly winds in the Northern Great Plains (Figure 3.15C-D).

During extreme precipitation events, anomalies in MSLP and winds juxtapose those during dust storm events (Figures 3.10-3.14 I-J). An increase in pressure occurs over the northeastern United States and a decrease in pressure occurs over the central United States, which drives an increase in windspeeds out of the Gulf of Mexico into the northwest United States. This occurs irrespective of season and leads to an overall high-pressure system over the northeastern United States and low-pressure system over the central United States, driving southeasterly flow in the Great Plains (Figure 3.16).

Dust Storms

A total of 732 individual dust storms were reported in South Dakota from 1930 to 1940 (Figure 3.17; see Appendix E for tabulated data). Early in the decade ~20 dust storms/year occurred from 1930 to 1932. This number increased rapidly into 1934 to 120 dust storms. Secondary peaks in dust storm events occurred in 1937 and 1939, and by 1940 dust events had subsided to ~40/year. Most dust storms occurred in the spring, with April a peak month for dust storm events (Figure 3.17). There is also a smaller, secondary peak of dust storm occurrence in the fall months.

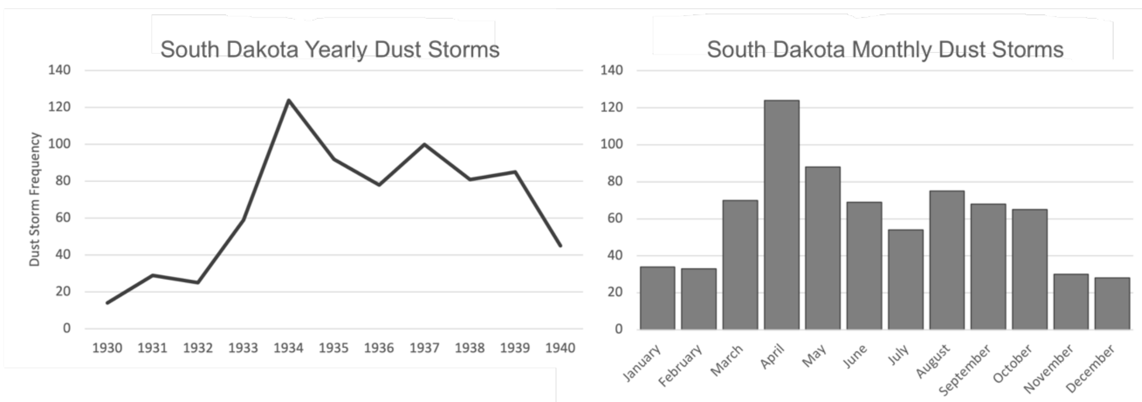

Figure 3.17. (left) Number of dust events reported in South Dakota by year and (right) by month from 1930-1940. Compiled from the South Dakota State Climate Records (South Dakota State Climate Records, 2018).

These dust storms were widespread throughout South Dakota during the 1930s with a preferential occurrence in the central and eastern half of the state (Figure 3.18A). There is surprising spatial and temporal variability in registered dust storms in South Dakota during the 1930s (Figure 3.18B-L). One location in Hamlin County, located in far eastern South Dakota, reported over five dust storms in 1930 (Figure 3.18B). There are similar results in 1931 and 1932 with no reports greater than ten dust storms/year (Figure 3.18C-

D). Storm occurrence then appears to increase in 1933 in eastern and southern areas of South Dakota, particularly in Tripp and Spink counties with reports of over ten dust storms/year (Figure 3.18E). The worst year for dust storms in South Dakota was in 1934 with an apparent 124 individual dust storms throughout the state (Figures 3.17, 3.18F). A large portion of eastern South Dakota reported over 25 dust storms in 1934 with centers around Tripp and Spink counties. South Dakota post-1934 continued to experience heightened dust storms in multiple locations, but with an apparent westward shift in storm locality. Parts of Tripp and Ziebach counties during 1935 and 1936 reported > 25 dust storms/year (Figure 3.18G-H). Dust storms continued to persist from 1937 to 1939, but only with few instances of > 20 dust storms/year (Figure 3.18I-K). The number of dust storms by 1940 in the state decreased to a distribution similar to 1930 with the majority of the state only reporting between 0 and 5 dust storms/year (Figure 3.18L).

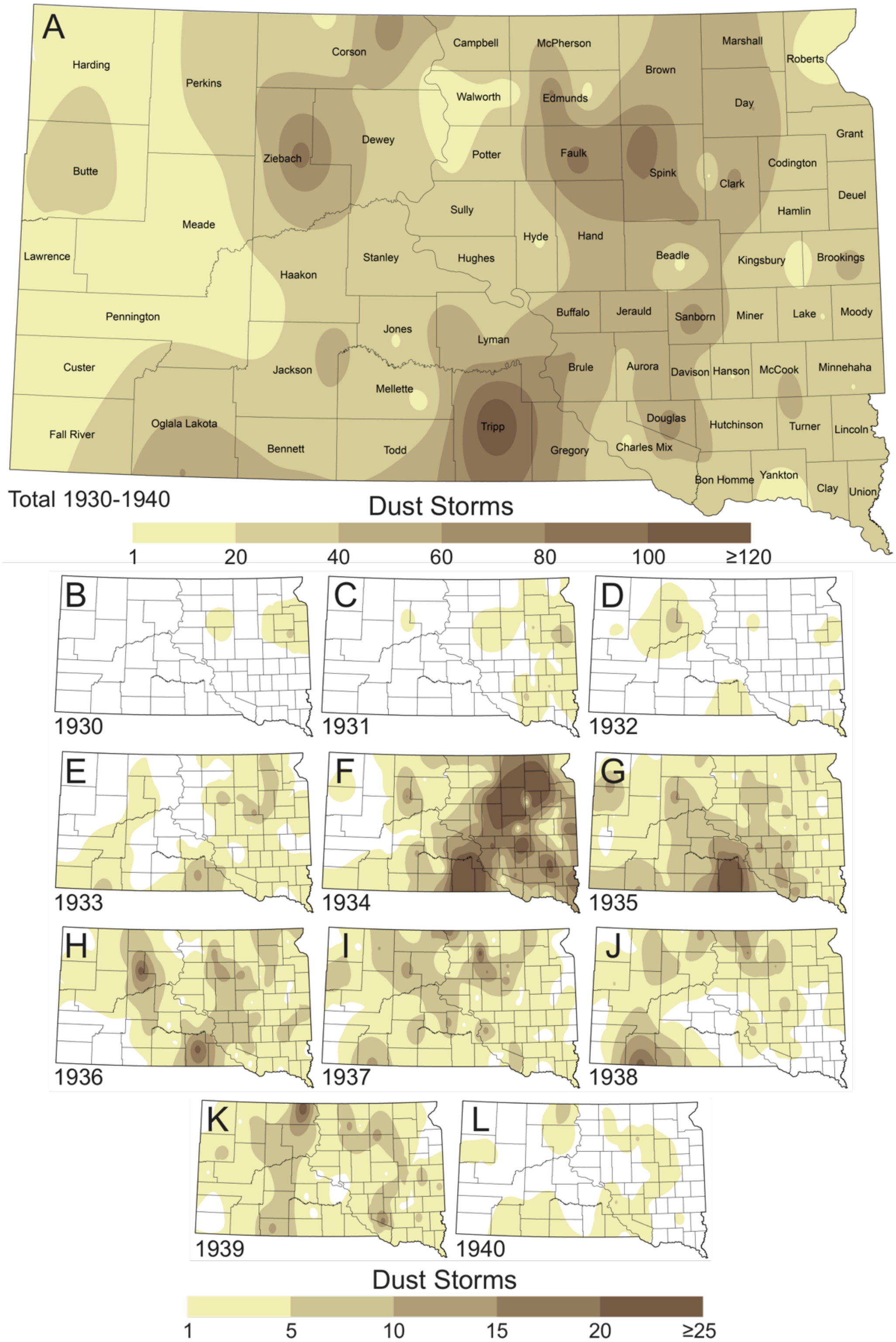

Figure 3.18. Spatial scale of dust events reported in South Dakota from (A) the 1930s decadal mean and (B-L) individual years throughout the decade. Compiled from the South Dakota State Climate Records (South Dakota State Climate Records, 2018). See Figure 2.1 for data points used to construct contours.

The footprint of dust storm activity from 1934 to 1936 reveals areas of intense susceptibility in South Dakota (Figure 3.19). There is an apparent region centered over Tripp County that experienced heightened dust storm activity throughout each of these years (Figure 3.19). In total, the weather station in Winner, SD located in Tripp County reported 133 dust storms during the 1930s and 49 dust storms in 1934 alone (Figure 3.20). Similarly, four weather stations located in Spink County experienced heightened dust storm events, with an apparent 214 individual dust storms reported for the county throughout the 1930s and 69 storms in 1934 (Figure 3.20). The dust storms that occurred in Winner, SD, located in Tripp County, reflected a similar seasonality to that of the rest of the state, with peaks occurring in both the spring and fall.

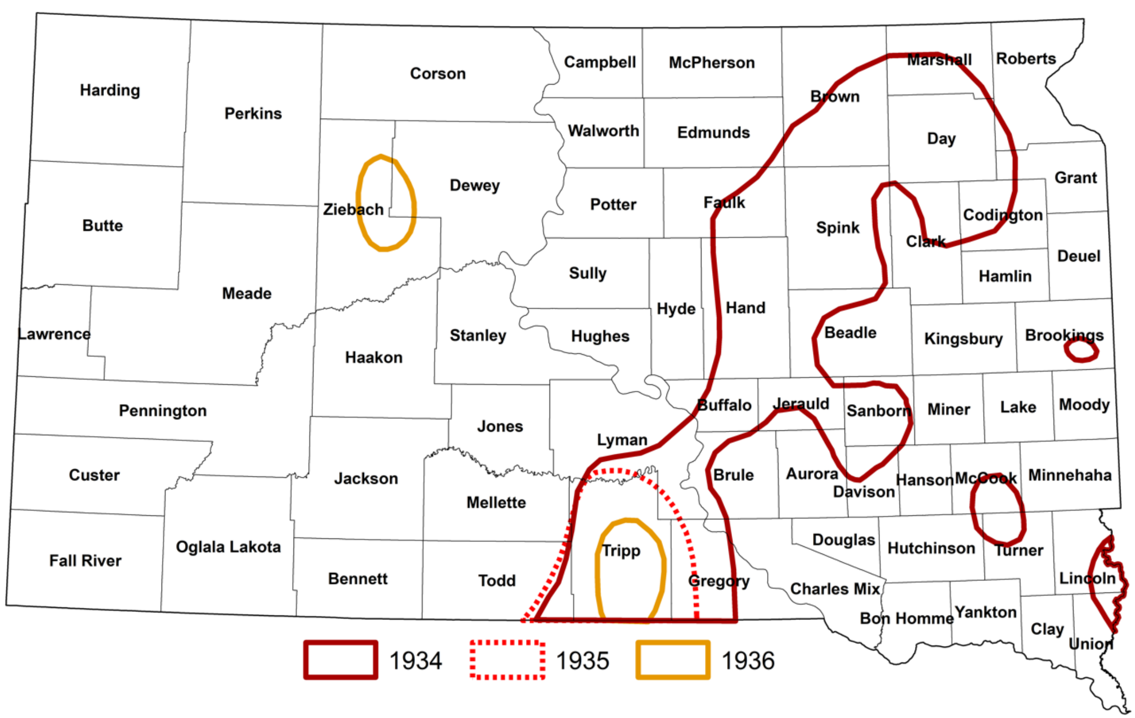

Figure 3.19. Heightened dust activity in South Dakota from 1934-1936. Colored lines delineate regions that experienced greater than 20 dust storms per indicated year. Compiled from the South Dakota State Climate Records (South Dakota State Climate Records, 2018).

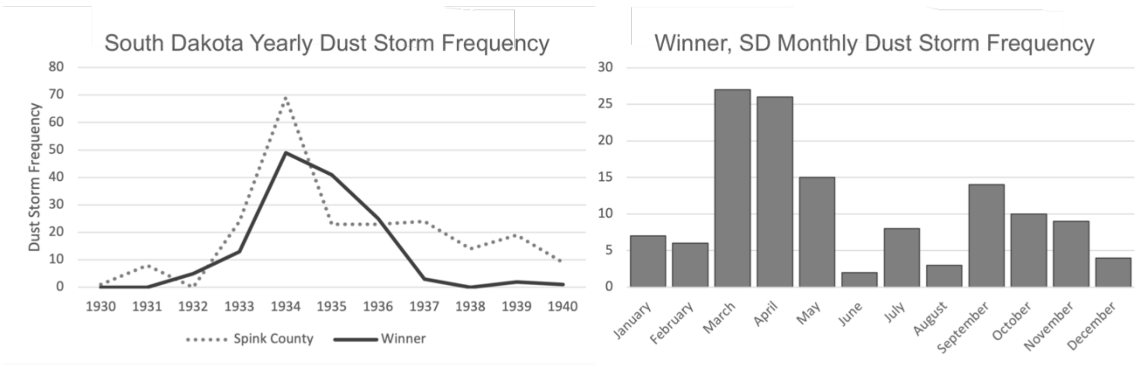

Figure 3.20. (left) Number of dust events reported in Spink County and Winner, SD (Tripp County) by year and (right) number of dust events reported in Winner, SD by month from 1930-1940. Compiled from the South Dakota State Climate Records (South Dakota State Climate Records, 2018).

Winds were mostly out of the northwest during dust events in the spring (Figure 3.21B) and fall (Figure 3.21D). Summer dust storm trajectories during the summer are variable with the majority coming from the northwest, but also with winds from the southeast, southwest, and northeast (Figure 3.21C). Winds during dust events in the winter appear to be bimodal, with near equal occurrences from the northwest and southeast (Figure 3.21E). Thirty individual dust storm records had windspeeds recorded during these events (Table 3.1). These storms range in velocity from 3.4 to 28.2 m s^{-1}.

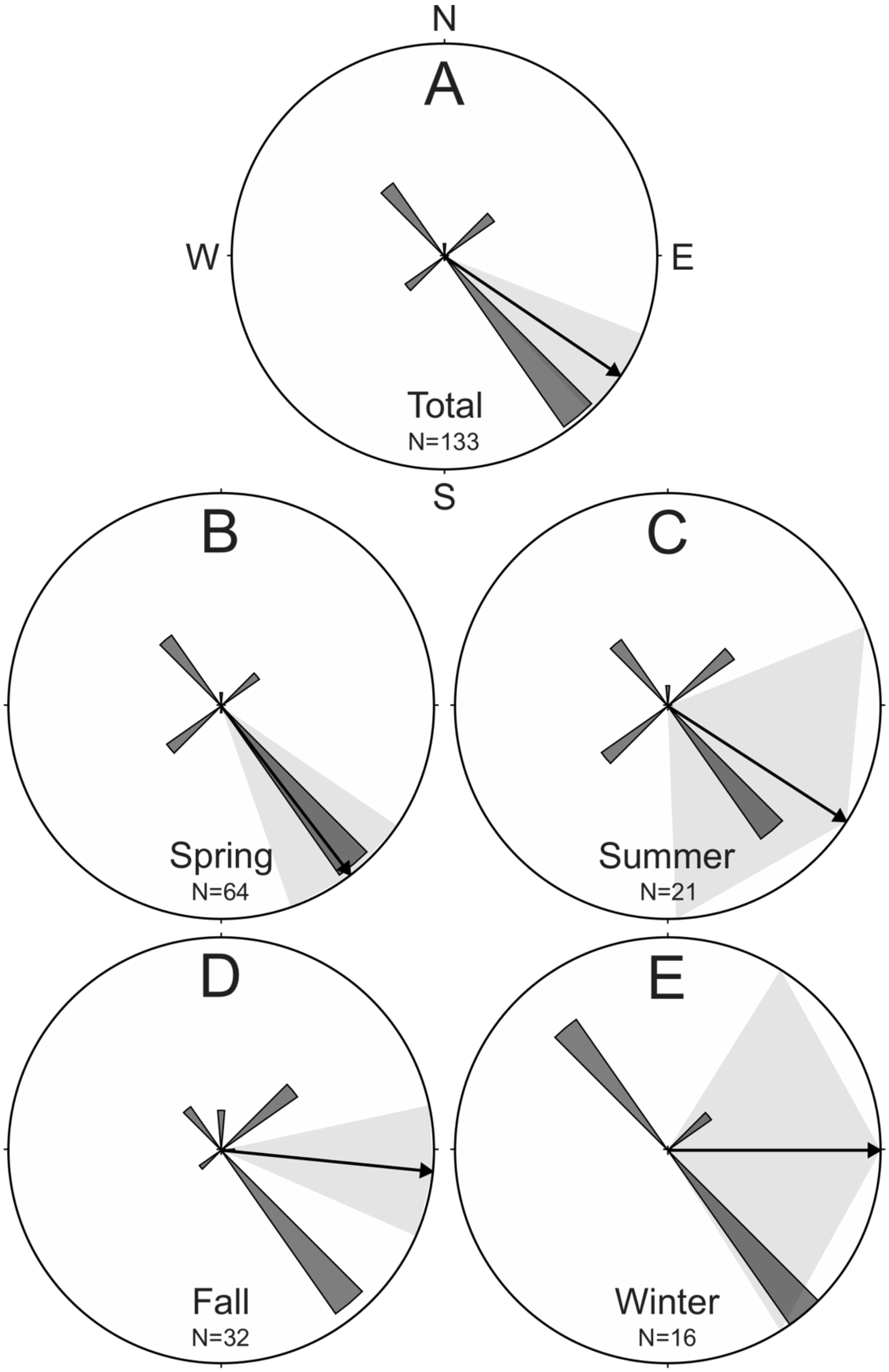

Figure 3.21. (A) Wind rose diagrams for dust events reported in Winner, SD from 1930-1940 and wind roses for (B) spring, (C) summer, (D) fall, and (E) winter dust events. Light gray region indicates 95% confidence. Compiled from the South Dakota State Climate Records (South Dakota State Climate Records, 2018) in Stereonet 11 (Allmendinger et al., 2012; Cardozo and Allmendinger, 2013). See Appendix C for tabulated data used here.

Table 3.1. Reported wind speeds during dust events in South Dakota. Compiled from the South Dakota State Climate Archives (SDSU) and *Monthly Weather Review* journal (MWR).

Date	Location	Windspeed ($m\ s^{-1}$)	Source
11/12/1933	Tyndall	17.9-20.1	SDSU
11/12/1933	Rapid City	19.7	MWR
11/12/1933	Huron	22.8	MWR
11/12/1933	Watertown	21.5-25.9	SDSU
11/12/1933	Badlands	20.1-28.2	MWR
11/25/1933	Watertown	21.5	SDSU
02/03/1934	Watertown	23.3	SDSU
05/31/1934	Kennebec	21.5	SDSU
02/19/1935	Armour	11.2	SDSU
03/08/1935	Armour	13.4	SDSU
04/24/1937	Pierre	21.5	SDSU
05/13/1938	Faith	8-10.7	SDSU
06/14/1938	Faith	8-10.7	SDSU
07/13/1938	Faith	10.8-13.8	SDSU
08/18/1938	Faith	10.8-13.8	SDSU
09/19/1938	Faith	8-10.7	SDSU
10/21/1938	Faith	17.2-20.7	SDSU
10/29/1938	Faith	3.4-5.5	SDSU
11/25/1938	Faith	10.8-13.8	SDSU
12/25/1938	Faith	22.4	SDSU
01/21/1939	Faith	17	SDSU
02/25/1939	Faith	17.9	SDSU
04/04/1939	Faith	5.5-7.9	SDSU
05/06/1939	Faith	17.2-20.7	SDSU
05/19/1939	McLaughlin	>22.4	SDSU
12/01/1939	Highmore	17.9	SDSU
12/11/1939	Faith	13.9-17.1	SDSU
12/12/1939	Vermillion	20.1	SDSU
05/05/1940	Lemmon	17.9	SDSU
05/05/1940	Faith	13.9-17.1	SDSU

Climatic and surficial variables were plotted against dust storm occurrence to determine which variables explained the most variance in dust storm events (Table 3.2). The R^2 values indicate that there is no single variable that alone can explain the variance in dust events in South Dakota, but climatic variables including windspeed, PDSI, temperature, and precipitation tend to correlate with dust storm occurrence more so than surficial variables, such as soil texture, crop failure, and cultivation (see Figure 3.22). The failure of this bivariate analysis to produce any strong correlations between climatic and/or surficial variables and dust storm occurrence indicates a multivariate analysis is needed in the future.

Table 3.2. Top fifteen climatic and surficial variables and their correlation to dust storm occurrence in South Dakota.

Variable	R^2
Windspeed	0.3215
Spring 1934 PDSI	0.1494
April 1934 precipitation anomaly	0.1402
Summer 1934 PDSI	0.1366
Percent clay in soil	0.1216
Spring 1934 precipitation anomaly	0.111
April 1934 maximum temperature anomaly	0.1082
April 1934 MAT anomaly	0.0901
April 1934 PDSI	0.0891
Percent crop failure in county	0.0655
Spring 1934 MAT anomaly	0.0637
Percent of county cultivated	0.0553
1934 precipitation anomaly	0.0483
Spring 1934 maximum temperature anomaly	0.0099
Percent silt in soil	0.0079

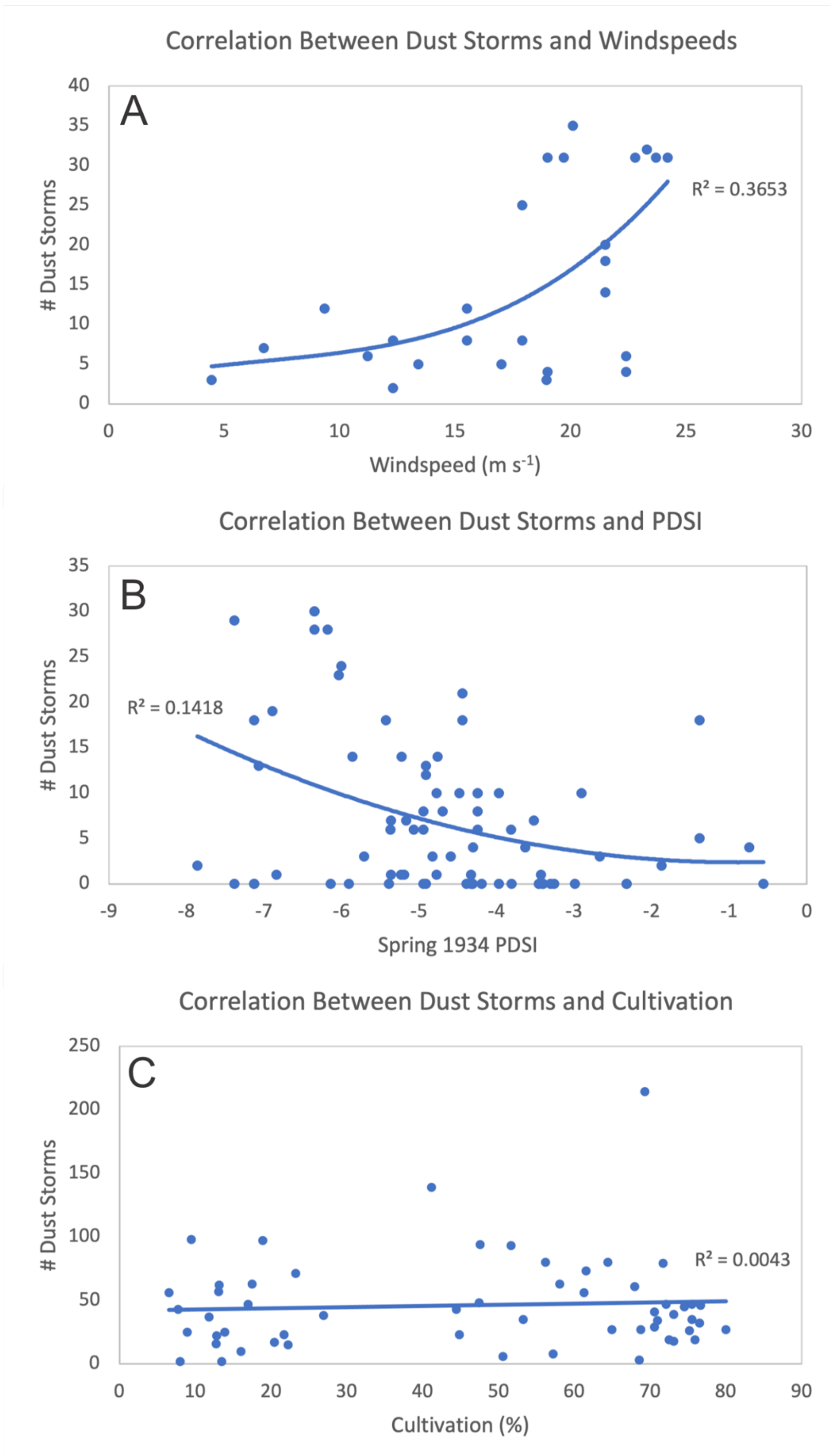

Figure 3.22. Bivariate analysis of the correlation between dust storm occurrence and (A) windspeed, (B) PDSI in the spring of 1934, and (C) the cultivation percentage per county.

Soil Texture and Emissivity

Granulometry was determined for twenty-nine soil samples to better understand the sources of eolian material with dust storms during the 1930s in South Dakota. Many samples included hardened aggregates, in which grain size was measured both with and without disaggregation methods. Larger aggregates generated by tilling processes were abundant in the field, and evidence for similar soil conditions exist during the Dust Bowl Drought of the 1930s (Figure 3.23). The abrasive force of windblown sand and soil particles during heightened windspeeds tend to loosen the bonds holding aggregates together, which increases their erodibility by wind and leads to dust generation (Chepil, 1958; Chepil and Woodruff, 1963).

Soil aggregate and particle textures were initially determined by three separate procedures: chemical disaggregation, mechanical disaggregation, and no disaggregation (meaning aggregates were still present in the sample; Figure 3.24). The granulometry of soils range from sandy silt to silt loam with variance in sand content. When applied to the same sample, both chemical and mechanical disaggregation treatments produced similar grain sizes (Figure 3.24A). However, a significant shift in sand content occurred between chemically disaggregated samples and samples with aggregates (Figure 3.24B). Sand content increased by as much as 88% in samples with aggregates when compared to chemically disaggregated samples, with one sample decreasing in sand content (Table 3.3). This indicates that aggregates make up a large portion of soil samples and in turn are likely susceptible to wind entrainment and dust generation through saltation processes (Chepil and Woodruff, 1963). For this reason, PI-SWERL dust flux data are grouped based on soil textures determined by the granulometry of samples that contain aggregates, rather than chemically disaggregated samples.

Figure 3.23. (A-B) Unspecified areas of South Dakota in 1935 exhibiting the appearance of aggregates, similar to what was observed in the field (C) in Kingsbury County, SD. A-B from the Joseph Hutton Collection, South Dakota Agricultural Heritage Museum Records.

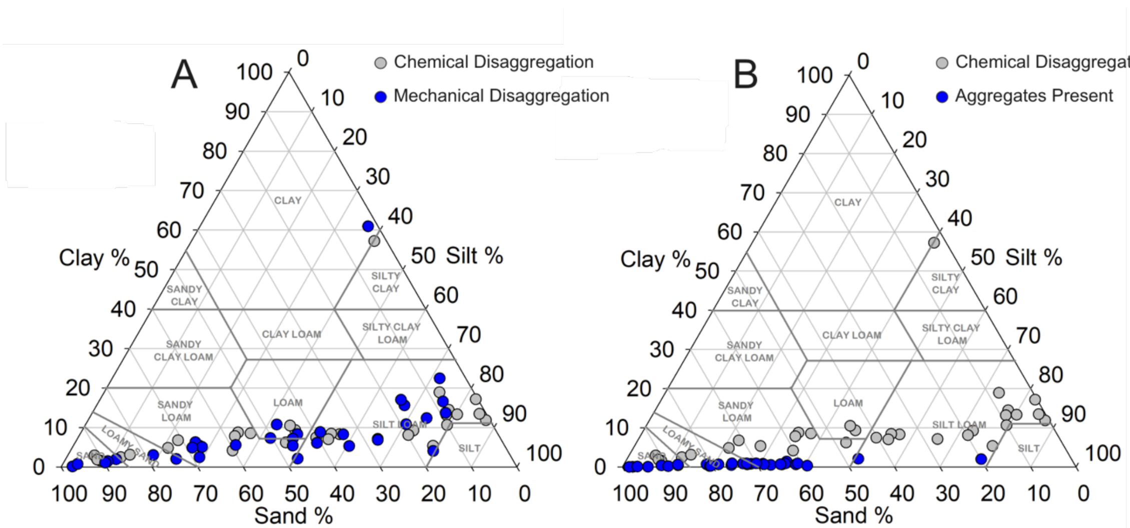

Figure 3.24. Soil textures determined by particle size analysis from (A) chemical and mechanical disaggregation procedures and (B) chemical disaggregation and no disaggregation procedures (aggregates present).

Table 3.3. Particle size, soil texture, and change in percent sand between chemically disaggregated samples and samples with aggregates.

	Disaggregated Samples				Samples with Aggregates				
Sample #	Clay (%)	Silt (%)	Sand (%)	Texture	Clay (%)	Silt (%)	Sand (%)	Texture	Δ % Sand
BH1	8.74	34.46	56.80	sandy loam	0.77	27.96	71.27	loamy sand	14.47
BH2A	7.81	34.23	57.97	sandy loam	0.63	27.18	72.18	loamy sand	14.22
BH2B	8.53	37.30	54.15	sandy loam	1.03	35.67	63.31	sandy loam	9.16
BP1	8.28	56.97	34.74	silt loam	0.62	34.83	64.54	sandy loam	29.80
BS1	9.25	72.67	18.08	silt loam	1.38	35.52	63.10	sandy loam	45.02
BS2	8.42	55.06	36.53	silt loam	0.49	32.49	67.02	sandy loam	30.49
BV1	7.44	52.26	40.29	silt loam	0.79	30.57	68.62	sandy loam	28.33
BV2	8.10	72.13	19.76	silt loam	2.06	50.30	42.94	silt loam	23.18
BW1	7.11	65.92	26.95	silt loam	0.63	37.94	61.42	sandy loam	34.47
BW2	7.01	55.14	37.85	silt loam	0.86	38.21	60.95	sandy loam	23.10
BW3	2.89	5.91	91.21	sand	0.38	8.42	91.18	sand	-0.03
BW4	4.18	35.55	60.27	sandy loam	0.86	35.45	63.69	sandy loam	3.42
GG1	14.45	77.81	7.74	silt loam	0.66	30.87	68.47	sandy loam	60.73
GG2	13.18	77.95	8.84	silt loam	0.69	34.50	64.80	sandy loam	55.95
GH1	9.32	46.71	43.97	loam	0.87	26.15	72.98	loamy sand	29.02
GH2	5.31	27.80	66.88	sandy loam	0.46	23.80	75.75	loamy sand	8.87
KM1	13.31	80.25	6.46	silt loam	0.88	26.97	72.13	loamy sand	65.68
KM2	10.63	79.35	10.02	silt loam	0.88	29.05	70.09	sandy loam	60.07
LK1	11.83	87.28	0.89	silt loam	0.17	10.03	89.80	sand	88.91
LK2	17.14	82.41	0.44	silt loam	0.65	20.90	78.46	loamy sand	78.02
LK3	13.45	85.05	1.50	silt loam	0.67	18.24	81.09	loamy sand	79.59
Pierre2	57.20	40.11	2.71	silty clay	0.40	12.09	87.51	sand	84.80
SF1	2.46	11.88	85.66	loamy sand	0.01	2.28	97.70	sand	12.04
SF2	10.47	44.99	44.52	loam	0.20	19.17	80.62	loamy sand	36.10
SF3	1.61	7.75	90.63	sand	0.00	1.53	98.46	sand	7.84
SPH1	6.75	22.29	70.96	sandy loam	0.27	19.36	80.37	loamy sand	9.40
TC1	3.10	13.59	83.30	loamy sand	0.03	5.64	94.33	sand	11.03
TC2	1.87	7.03	91.09	sand	0.09	3.27	96.63	sand	5.55
TC3	4.81	21.07	74.12	sandy loam	0.60	11.93	87.46	sand	13.34
TW1	18.89	73.56	7.56	silt loam	0.89	23.72	75.38	loamy sand	67.82
WR1	5.34	78.92	15.74	silt loam	1.98	78.10	19.93	silt loam	4.19
WR2	6.19	46.21	47.60	sandy loam	0.30	40.60	59.90	sandy loam	11.49

The PM_{10} and total suspended particle (TSP) flux quantified by field and lab experiments with PI-SWERL was assessed by soil texture to determine changes in dust emissivity between soil types. PI-SWERL was used on samples in the field in which many contained hardened aggregates. Resulting dust flux data were in turn sorted into soil textures determined by the presence of aggregates to accurately reflect field conditions (Table 3.4). These data reflect the apparent dust flux from a shear velocity of 0.56 m s^{-1}, which equates to a 10-m wind velocity of ~13.6 m s^{-1}.

Table 3.4. PM_{10} and TSP fluxes for soil textures determined with aggregates present. Fluxes are at u* = 0.56 m s^{-1} (~13.6 m s^{-1} in 10-m wind velocity).

	PM_{10} Flux (mg m^{-2} s^{-1})					TSP Flux (mg m^{-2} s^{-1})				
Soil Texture	N	Mean	Min	Max	STD	N	Mean	Min	Max	STD
silt loam	5	0.369	0.038	3.729	1.547	5	0.679	0.062	9.825	4.178
sandy loam	23	0.679	0.249	4.262	0.829	23	1.106	0.458	5.009	1.029
loamy sand	28	0.186	0.003	5.892	1.206	20	0.210	0.005	4.035	1.342
sand	18	0.120	0.002	1.875	0.539	7	0.799	0.086	3.324	1.283

The PM_{10} emissivity varies among soil types and as shear velocity increases, PM_{10} flux increases among each soil type (Figure 3.25). The maximum PM_{10} flux range at a shear velocity of 0.56 m s^{-1} (~13.4 m s^{-1} in 10-m wind velocity) is 3.3 – 9.8 mg m^{-2} s^{-1} (Figure 3.25A). The flux range then increases to 14.9 – 17.4 mg m^{-2} s^{-1} at a shear velocity of 0.8 m s^{-1} (~43 m s^{-1} in 10-m wind velocity; Figure 3.25B). This increase in PM_{10} flux with increasing shear velocity is apparent as wind speed increases (Figure 3.26). Each soil texture experienced an increase in PM_{10} flux as windspeed increased, however there were no significant differences in PM_{10} flux between each soil type.

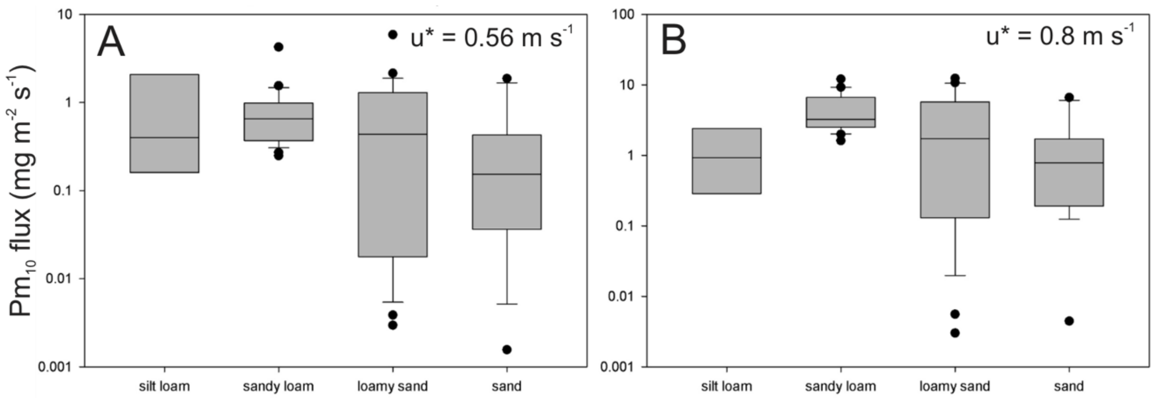

Figure 3.25. PM_{10} fluxes for various soil textures containing aggregates at (A) u* = 0.56 m s^{-1} (~13.4 m s^{-1} in 10-m wind velocity) and (B) 0.8 m s^{-1} (~43 m s^{-1} in 10-m wind velocity).

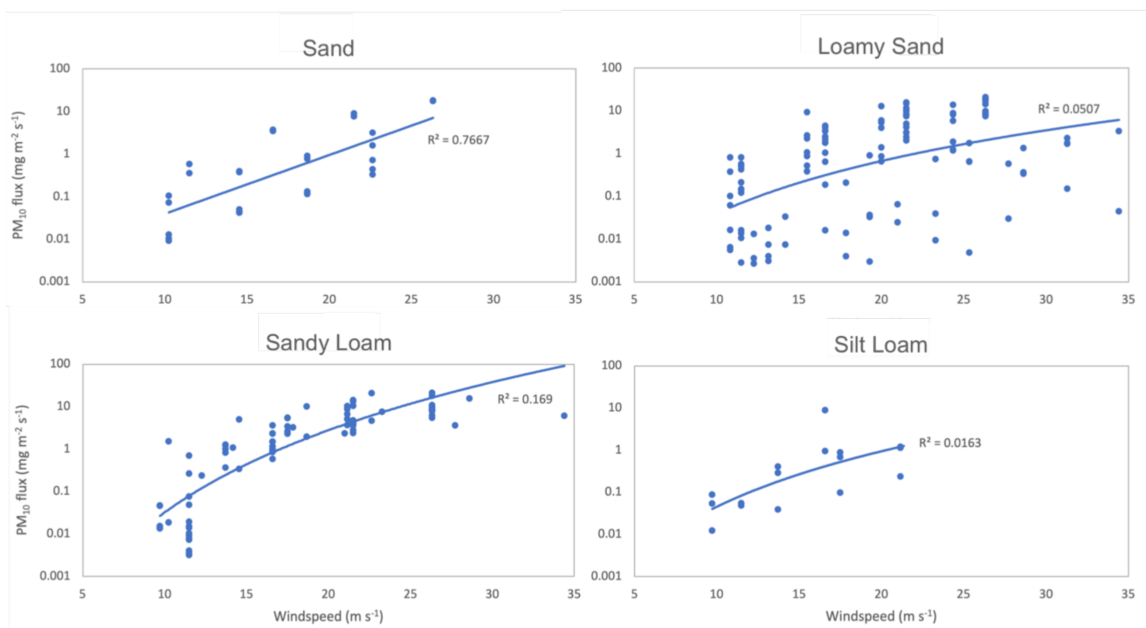

Figure 3.26. PM_{10} flux as a function of windspeed between various soil textures determined by the presence of aggregates.

CHAPTER FOUR

Discussion

1930s Drought Conditions in the Northern Great Plains

Throughout the 1930s the United States Northern Great Plains underwent extreme drought. South Dakota experienced the longest recorded drop in precipitation below the long-term mean in its recorded history from 1930 to 1940, whereas an average precipitation of only 10.9 mm in 1936 remains the lowest recorded in the state (Figure 3.5). In 1934 South Dakota experienced the worst of the drought, with average PDSI levels for the year < -5 throughout most of the state (Figure 3.9A), which led to extreme crop losses > 70% in many counties (Figures 3.1C, 3.2). Summer PDSI levels were the lowest this year, with parts of eastern South Dakota reaching levels below -8 (Figure 3.9C). The summer PDSI timeseries throughout the Great Plains highlights the earlier onset of drought conditions in South Dakota than in the Southern Great Plains prior to 1934. Much of eastern South Dakota was under extreme drought starting in 1931 with summer PDSI levels < -4, whereas the Southern Great Plains did not experience these levels of summer PDSI until 1933.

A reorganization of the synoptic climatology of North America appears to have occurred during the presence of dust storms in South Dakota. On these days, a dynamic high-pressure ridge developed over the western United States and a low-pressure system formed over the central United States (Figure 3.15). This created high northwesterly winds out of the Canadian Rockies into the Northern Great Plains and weakened the GPLLJ, which blocked the penetration of moisture into the Great Plains from the Gulf of Mexico.

This occurred most prominently during the spring and fall months, which could have led to peaks in reported dust storm activity during these months (Figure 3.17). The high northwesterly winds observed over the Dakotas region during dust events is further corroborated by reported wind directions during dust storms in spring and fall months (Figure 3.21) and reports of winds shifting to the northwest during these events (South Dakota State Climate Records, 2018). The anomalistic increase in MSLP over the western United States and northwesterly winds over the Northern Great Plains were not as pronounced during dust storms in summer and winter months (Figures 3.11, 3.13G-H) likely leading to decreased reports of dust events (Figure 3.17) and the wide range in wind directions reported during these months (Figure 3.21C, E).

The synoptic MSLP and wind patterns present during dust storm events were in stark contrast to those present during extreme precipitation events (Figure 3.16). The high-pressure ridge over the western United States present during dust storms was replaced by an enhanced low-pressure system during extreme precipitation. This, coupled with an enhanced high-pressure system over the northeastern United States, led to strong, moisture-rich winds out of the Gulf of Mexico throughout the Great Plains, especially in the Dakotas. The opposite occurred during dust storm events, where cold, dry winds from the Canadian Rockies flowed out of the northwest in the Dakotas.

The extreme climatic variability observed in the Northern Great Plains likely led to an increased susceptibility of erosion among soils. The principal wind erosion areas in South Dakota delineated by the Soil Conservation Service in 1935 (Figure 3.3B) experienced heightened dust storm activity during the 1930s (Figure 3.19). The weather station located in Tripp County, on the border with Nebraska, recorded the greatest number of dust storms in the state during the 1930s, while Spink County also reported multiple locations of intense dust storm activity. These locations, along with other locations reporting heightened dust events (see Figure 3.18A), occur in areas that were marked for severe wind erosion across the state (Figure 3.3B).

Northern Dust Storms & Dust Generation

The number and severity of dust storms in South Dakota peaked in 1934, with secondary peak occurrences in 1937 and 1939 (Figure 3.17). This peak in dust storms in the Northern Great Plains did not co-occur in the Southern Great Plains, which had a peak of dust storm occurrence in 1937 (Bolles et al., 2019). Dust storms in South Dakota were most frequent in spring months, especially April (Figure 3.17), similar to the Southern Great Plains. However, a secondary well-defined peak in dust storms occurred in the fall in the Northern Great Plains that was less pronounced in the Southern Great Plains (Bolles et al., 2019). The spatial and temporal extent of drought conditions in South Dakota evidenced by PDSI values (Figure 3.8) tend to reflect heightened dust storm occurrences in the state (Figure 3.18). Years with highly negative PDSI values tend to correspond to years with heightened dust activity. PDSI values from 1930-1935 were generally lowest in the eastern portion of the state (Figure 3.8B-G), and heightened dust events mostly occurred in the eastern part of the state during these years (Figure 3.18B-G). The location of lowest PDSI levels after 1936 shifted to the western part of the state (Figure 3.8I-L), and heightened dust activity generally occurred more so in the west as well after 1936 (Figure 3.18I-L).

There appears to be evidence for the existence of soil aggregates during the 1930s, based on concurrent images and observations, similar to what is seen today (see Figure

3.23). Soil samples that were disaggregated showed an abundance of clay-sized particles that were not observed in samples with aggregates, which indicates that these aggregates are rich in clay-sized particles (Figure 3.24B). During dust storms, these aggregates have the potential to be a sustained source of dust through saltation processes (Chepil and Woodruff, 1963). Individual soil textures exhibit a wide range of PM_{10} and TSP fluxes (Table 3.4), indicating that soil texture is a non-significant predictor of dust flux. Among each soil type, however, there is a clear increase in PM_{10} flux as windspeeds increase (Figure 3.26). Windspeeds of up to 28.2 m s^{-1} were reported during dust storm events in South Dakota (Table 3.1), which correspond to exceptionally high PM_{10} emissions of South Dakota soils (Figure 3.26). This indicates that soil surfaces in South Dakota were capable of producing heightened levels of PM_{10} dust during dust storms.

Was there a "Northern Dust Bowl"?

The 1930s Dust Bowl Drought has historically been viewed as a catastrophe limited to the Southern Great Plains. However, evidence suggests that drought conditions in the Northern Great Plains during the 1930s were equal to or exceeded those of the Southern Great Plains. Further, heightened wind erosion and dust events in South Dakota reveal Dust-Bowl-like conditions in the Northern Plains preceding those in the Southern Plains (Bolles et al., 2019). The most intense drought and dust storm occurrences between the Northern and Southern Great Plains appear to be out of phase with one another. 1934 was a peak year for dust activity in South Dakota, whereas the Southern Great Plains panhandle region had peak dust events in 1937 (Bolles et al., 2019). However, it is important to note that the number of dust storms reported here in South Dakota appears at a smaller scale than that of the Southern Great Plains (Bolles et al., 2019). Although it is clear that the

Northern Great Plains underwent a separate landscape response to that of the Southern Great Plains, the evidence for extreme drought and dust storms in the Northern Great Plains suggests there was a "Northern Dust Bowl" separate from that of the traditional Dust Bowl in the Southern Great Plains.

The Northern Dust Bowl region encompasses an area of intense dust storm activity and soil erosion from 1934-1936 (Figure 3.19). This region is demarcated by locations with heightened dust storm occurrence and accounts of intense wind erosion (see Figure 3.3A), mostly in the eastern half of South Dakota. Drought indices and accounts of wind erosion likely extend the Northern Dust Bowl Region into parts of Nebraska, North Dakota, Montana, and Colorado, but additional investigations on 1930s dust storm generation and activity in these regions are needed to better constrain the extent of the Northern Dust Bowl outside of South Dakota.

CHAPTER FIVE

Conclusions

The Dust Bowl Drought of the 1930s was a catastrophic climatic event in the United States Southern Great Plains that resulted in widespread wind erosion and dust storms. Recent work has demonstrated the need to reevaluate the extent of the 1930s drought into the Northern Great Plains, where heightened drought conditions and dust storm activity persisted in the region (Figures 1.3, 1.5; Bolles and Forman, 2018; Bolles et al., 2019). This study provides evidence for a Northern Dust Bowl that occurred separately from the traditional Dust Bowl in the Southern Great Plains as a result of two separate landscape-scale responses:

(1) South Dakota experienced record-breaking drought during the Dust Bowl, with the entire decade of the 1930s reporting precipitation levels below the long-term mean and an all-time low recording of 10.9 mm in 1936 (Figure 3.5). Summer PDSI levels indicate that extreme drought occurred earlier in the decade in the Northern Great Plains compared to the Southern Great Plains (Figure 3.7).

(2) Extensive dust storm activity was reported throughout South Dakota, with 732 individual dust storms occurring from 1930 to 1940 (Figure 3.17). These dust storms peaked in 1934, prior to the 1937 peak in the Southern Great Plains (Bolles et al., 2019), and had increased events in both the spring and fall.

(3) A fundamental reorganization of the synoptic climatology in North America, including the presence of a high-pressure ridge over the western United States,

enhanced northwesterly winds in the Dakotas and weakened the GPLLJ, fueling the Northern Dust Bowl Drought and contributing to the occurrence of dust storms.

(4) Soil samples taken from regions with increased accounts of dust storm activity and soil erosion indicate increased PM_{10} flux with high windspeeds recorded during dust events (Figure 3.26, Table 3.1). It is hypothesized that aggregates in South Dakota soils during the 1930s (see Figure 3.23) had the capability of releasing increased PM_{10} dust during dust storms.

APPENDICES

APPENDIX A

PI-SWERL location data

Table A.1. Location data for PI-SWERL measurements. Measurement locations listed as "lab" were collected in the field and measured by the PI-SWERL in a lab setting. See Figure 1.7 for map of locations.

Location #	Site Name	Lat.	Lon.	Measurement Location
1	SPH1	44.642767	-98.443037	lab
2	BH1	44.575147	-98.40316	lab
3	BH2	44.560169	-98.37651	lab
4	BW4	44.457132	-98.438876	lab
5	BW3	44.457875	-98.448453	lab
6	BW2	44.392368	-98.579489	lab
7	BW1	44.3853	-98.4566	lab
8	BV2	44.326874	-98.626444	lab
9	BV1	44.290394	-98.477963	lab
10	BS1	44.456723	-98.093126	lab
11	BS2	44.456444	-98.063322	lab
12	BP1	44.282742	-98.092981	lab
13	KM1	44.4698	-97.7049	lab
14	KM2	44.325165	-97.672874	lab
15	SF3	44.054906	-98.15048	lab
16	SF2	44.056311	-98.130952	lab
17	SF1	44.02833	-98.1205	lab
18	WR1	43.712454	-100.670834	field
19	WR2	43.746042	-100.082047	lab
20	LK3	43.818245	-99.90172	lab
21	LK2	43.808921	-99.862206	field
22	TW1	43.439233	-99.94919	field
23	TC2	43.166727	-99.909649	field
24	TC1	43.166621	-99.909573	field
25	TC3	43.197955	-99.820113	field
26	GG1	43.197216	-99.415651	field
27	GG2	43.197117	-99.415252	field
28	GH1	43.070335	-99.237871	field
29	GH2	43.086423	-99.217397	field

APPENDIX B

Weather station location data

Table B.1. Location data for weather stations reporting dust storms in South Dakota from 1930-1940. Compiled from the South Dakota State Climate Records (South Dakota State Climate Records, 2018). See Figure 2.1 for map of locations.

Station #	City	County	Lat.	Lon.
1	Ludlow	Harding	45.83510	-103.37700
2	Camp Crook	Harding	45.55130	-103.97400
3	Redig	Harding	45.27110	-103.54800
4	Reva	Harding	45.54520	-103.08300
5	Belle Fourche	Butte	44.66710	-103.85200
6	Newell	Butte	44.71620	-103.41800
7	Vale	Butte	44.61920	-103.40500
8	Spearfish	Lawrence	44.48930	-103.85900
9	Lead	Lawrence	44.35340	-103.76200
10	Dumont	Lawrence	44.23860	-103.79800
11	Rochford	Pennington	44.12430	-103.71900
12	Custer	Custer	43.76640	-103.60000
13	Ardmore	Fall River	43.02170	-103.65800
14	Pine Ridge	Oglala Lakota	43.02780	-102.55800
15	Faith	Meade	45.02170	-102.04000
16	Strool	Perkins	45.50200	-102.80700
17	Bison	Perkins	45.52350	-102.46700
18	Lemmon	Perkins	45.93810	-102.15800
19	McIntosh	Corson	45.92030	-101.35000
20	McLaughlin	Corson	45.81340	-100.81100
21	Timber Lake	Dewey	45.42830	-101.07400
22	Dupree	Ziebach	45.04940	-101.60100
23	Ottumwa	Haakon	44.23570	-101.34500
24	Cottonwood	Jackson	43.96570	-101.90200
25	Belvidere	Jackson	43.83270	-101.27100
26	Martin	Bennett	43.17580	-101.73300
27	Wood	Mellette	43.49900	-100.47900
28	Winner	Tripp	43.37460	-99.85650

Table B.1. Location data for weather stations reporting dust storms in South Dakota from 1930-1940. Compiled from the South Dakota State Climate Records (South Dakota State Climate Records, 2018). See Figure 2.1 for map of locations (continued).

Station #	City	County	Lat.	Lon.
29	Murdo	Jones	43.88890	-100.71300
30	Vivian	Lyman	43.92690	-100.29200
31	Kennebec	Lyman	43.90180	-99.86310
32	Pierre	Hughes	44.36650	-100.34600
33	Mobridge	Walworth	45.54090	-100.43300
34	Pollock	Campbell	45.90140	-100.28900
35	Eureka	McPherson	45.76870	-99.62200
36	Leola	McPherson	45.72140	-98.93790
37	Bowdle	Edmunds	45.45070	-99.65730
38	Roscoe	Edmunds	45.45040	-99.33830
39	Ipswich	Edmunds	45.44350	-99.03030
40	Faulkton	Faulk	45.03490	-99.12880
41	Highmore	Hyde	44.52040	-99.44100
42	Gann Valley	Buffalo	43.95680	-98.98740
43	Pukwana	Brule	43.77910	-99.18270
44	Academy	Charles Mix	43.45650	-99.08310
45	Geddes	Charles Mix	43.25330	-98.69760
46	Wagner	Charles Mix	43.08160	-98.29350
47	Fairfax	Gregory	43.02770	-98.88950
48	Tyndall	Bon Homme	42.99010	-97.86220
49	Parkston	Hutchinson	43.39470	-97.98740
50	Armour	Douglas	43.31910	-98.34450
51	White Lake	Aurora	43.72870	-98.71310
52	Mitchell	Davison	43.71440	-98.02560
53	Alexandria	Hanson	43.65350	-97.77920
54	Forestburg	Sanborn	44.02200	-98.10830
55	Huron	Beadle	44.36330	-98.21410
56	LaDelle	Spink	44.67530	-98.11860
57	Redfield	Spink	44.87660	-98.51440
58	Ashton	Spink	44.99320	-98.50030
59	Mellette	Spink	45.15460	-98.49810
60	Aberdeen	Brown	45.46800	-98.47420
61	Britton	Marshall	45.79120	-97.75050
62	Webster	Day	45.33310	-97.52010
63	Raymond	Clark	44.91080	-97.93700

Table B.1. Location data for weather stations reporting dust storms in South Dakota from 1930-1940. Compiled from the South Dakota State Climate Records (South Dakota State Climate Records, 2018). See Figure 2.1 for map of locations (continued).

Station #	City	County	Lat.	Lon.
64	Clark	Clark	44.88060	-97.73510
65	De Smet	Kingsbury	44.38630	-97.55080
66	Arlington	Kingsbury	44.36410	-97.13390
67	Wentworth	Lake	43.99840	-96.96470
68	Canistota	McCook	43.59780	-97.29230
69	Marion	Turner	43.42220	-97.26030
70	Yankton	Yankton	42.87870	-97.39680
71	Vermillion	Clay	42.78090	-96.93030
72	Canton	Lincoln	43.30420	-96.57880
73	Sioux Falls	Minnehaha	43.55010	-96.73090
74	Flandreau	Moody	44.04840	-96.59540
75	Brookings	Brookings	44.30640	-96.78850
76	Castlewood	Hamlin	44.72360	-97.03120
77	Watertown	Codington	44.90180	-97.11410
78	Sisseton	Roberts	45.66460	-97.04970
79	Victor	Roberts	45.86950	-96.83430

APPENDIX C

Selected South Dakota dust storms for individual studies

Table C.1. Dust storms from 1930-1940 in South Dakota used in MSLP and wind direction calculations. Data below depict days in which 10 or more individual weather stations reported dust storms. Compiled from the South Dakota State Climate records (South Dakota State Climate Records, 2018).

Year	Month	Day	# Stations Reporting
1934	May	9	41
1934	April	21	40
1936	November	20	39
1936	November	24	37
1934	April	11	35
1939	December	12	35
1934	February	3	32
1933	November	12	31
1934	April	10	31
1934	April	18	28
1934	March	16	26
1934	May	12	25
1934	August	18	25
1935	March	26	25
1936	October	30	25
1939	December	1	25
1935	March	27	24
1934	March	27	23
1934	March	14	21
1936	November	22	21
1938	May	14	21
1934	May	31	20
1936	September	25	20
1937	May	12	20
1934	May	1	19
1939	May	9	19
1934	February	17	18
1934	March	13	18
1937	April	24	18

Table C.1. Dust storms from 1930-1940 in South Dakota used in MSLP and wind direction calculations. Data below depict days in which 10 or more individual weather stations reported dust storms. Compiled from the South Dakota State Climate records (South Dakota State Climate Records, 2018; continued).

Year	Month	Day	# Stations Reporting
1934	March	5	16
1935	April	22	16
1934	May	10	15
1935	March	28	15
1936	October	9	15
1937	February	23	15
1933	November	25	14
1934	April	19	14
1937	April	14	14
1938	April	19	14
1934	January	31	13
1934	March	28	13
1934	April	23	13
1934	April	15	13
1934	April	14	13
1937	April	25	13
1937	September	23	13
1939	April	24	13
1939	April	10	13
1931	April	18	12
1938	May	13	12
1939	December	11	12
1931	April	8	11
1934	February	9	11
1934	March	15	11
1934	May	11	11
1934	June	19	11
1937	May	20	11
1939	May	5	11
1931	April	11	10
1933	October	20	10
1934	April	12	10
1934	July	7	10
1936	September	17	10
1936	November	25	10
1937	March	16	10

Table C.1. Dust storms from 1930-1940 in South Dakota used in MSLP and wind direction calculations. Data below depict days in which 10 or more individual weather stations reported dust storms. Compiled from the South Dakota State Climate records (South Dakota State Climate Records, 2018; continued).

Year	Month	Day	# Stations Reporting
1937	May	29	10
1939	March	30	10
1939	April	25	10

Table C.2. Dust storms reported in Winner, SD (Tripp County) from 1930-1940 with reported windspeeds used in wind rose diagrams. Compiled from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above.

Year	Month	Date	Wind Direction
1932	April	3	NW
-	-	4	NW
-	-	5	SW
-	-	6	NW
-	-	21	SE
1933	January	6	NW
-	-	10	NW
-	-	18	SW
-	-	28	SE
-	July	1	NW
-	-	30	SW
-	August	15	NW
-	September	5	SW
-	October	15	NW
-	November	3	NW
-	-	12	NW
-	-	16	SW
-	-	25	NW
1934	February	3	NW
-	-	8	SE
-	-	17	NW
-	March	4	NW
-	-	13	NW

Table C.2. Dust storms reported in Winner, SD (Tripp County) from 1930-1940 with reported windspeeds used in wind rose diagrams. Compiled from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above (continued).

Year	Month	Date	Wind Direction
-	-	14	SW
-	-	16	NE
-	-	27	S
-	-	28	NW
-	April	10	NW
-	-	11	NW
-	-	14	NW
-	-	18	NW
-	-	19	NE
-	-	20	NW
-	-	21	NW
-	-	23	NE
-	May	1	SE
-	-	6	NW
-	-	7	SE
-	-	9	NW
-	-	11	SE
-	-	12	NW
-	-	27	SW
-	-	30	SW
-	-	31	NW
-	June	6	SE
-	-	19	NW
-	July	4	NE
-	-	13	SE
-	-	15	SE
-	-	16	NE
-	-	17	NE
-	-	20	SW
-	August	8	NW
-	-	18	NW
-	September	5	NE
-	-	7	SE
-	-	8	SW

Table C.2. Dust storms reported in Winner, SD (Tripp County) from 1930-1940 with reported windspeeds used in wind rose diagrams. Compiled from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above (continued).

Year	Month	Date	Wind Direction
-	-	13	NW
-	-	14	NE
-	-	18	SE
-	-	19	NW
-	-	22	SE
-	October	8	W
-	-	15	SE
-	-	23	NW
-	-	24	NW
-	December	15	SE
1935	January	3	NW
-	-	15	SE
-	-	27	SE
-	February	12	SE
-	-	24	NW
-	-	27	SW
-	March	3	SE
-	-	7	SE
-	-	8	SE
-	-	9	SW
-	-	10	NW
-	-	12	NW
-	-	15	NW
-	-	17	SW
-	-	18	NW
-	-	20	NW
-	-	21	NW
-	-	22	NW
-	-	26	NW
-	-	27	NW
-	-	28	NW
-	-	29	NE
-	April	14	NW
-	-	16	SE

Table C.2. Dust storms reported in Winner, SD (Tripp County) from 1930-1940 with reported windspeeds used in wind rose diagrams. Compiled from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above (continued).

Year	Month	Date	Wind Direction
-	-	17	NW
-	-	21	SE
-	-	22	NW
-	-	27	NW
-	-	31	NW
-	May	10	SE
-	June	1	NW
-	-	3	NW
-	-	4	NW
-	-	5	NE
-	-	23	SW
-	July	1	SE
-	September	15	S
-	October	15	SW
-	-	20	NW
-	November	1	NW
-	-	16	S
1936	March	9	NW
-	-	19	NE
-	-	20	NE
-	-	21	SE
-	-	22	N
-	April	4	NE
-	-	20	NE
-	-	21	NE
-	-	23	NE
-	May	14	S
-	-	17	SW
-	-	20	SE
-	-	21	SE
-	July	7	SW
-	-	31	S
-	September	17	SE
-	-	24	SW

Table C.2. Dust storms reported in Winner, SD (Tripp County) from 1930-1940 with reported windspeeds used in wind rose diagrams. Compiled from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above (continued).

Year	Month	Date	Wind Direction
-	-	25	NW
-	October	9	NW
-	-	11	SW
-	-	14	SW
-	November	20	NW
-	-	22	NW
-	-	24	NW
-	December	19	NW
1937	April	23	NW
-	-	24	NW
-	May	12	NW
1939	December	1	NW
-	-	12	NW
1940	September	18	S

APPENDIX D

Extreme precipitation event data

Table D.1. Dates of extreme precipitation events in South Dakota used in MSLP and wind calculations.

Date	Location	Type	Precipitation (cm)
05/06/2007	Groton	rain	22.1996
06/16/2014	Canton	rain	21.4122
06/18/1967	Huron	rain	13.4874
10/03/1998	Gregory	rain	13.208
09/03/1996	Vermillion	rain	12.2428
05/09/1995	Deadwood	rain	12.192
06/21/1984	Highmore	rain	12.065
09/19/1996	Platte	rain	11.684
05/15/1982	Deadwood	rain	11.4808
06/07/1925	Oelrichs	rain	11.43
05/01/1972	Wentworth	rain	11.2268
09/17/1986	Arlington	rain	10.7188
06/21/1947	Hermosa	rain	10.4648
06/24/1993	Raymond	rain	9.7536
10/11/2013	Lead	rain	9.0932
05/30/1942	Eureka	rain	8.9916
05/21/1962	Faith	rain	8.509
10/04/2013	Lead	rain	7.2644
02/16/1962	Sioux Falls	snow	81.788
02/08/1909	Sioux Falls	snow	53.34
02/19/1952	Sioux Falls	snow	44.958
12/21/2020	Sioux Falls	snow	40.64

APPENDIX E

Total dust storm data in South Dakota

Table E.1. Dust storm data acquired from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above. See Appendix B for weather station location data and Figure 2.1 for weather station map.

Station #	County	City	Year	Month	# Dust Storms
1	Harding	Ludlow	1936	November	1
-	-	-	1937	February	1
-	-	-	-	March	1
-	-	-	-	May	1
-	-	-	-	June	1
-	-	-	1939	May	2
2	-	Camp Crook	1938	August	1
3	-	Redig	1934	April	1
-	-	-	-	May	2
-	-	-	-	June	1
-	-	-	1935	February	3
-	-	-	-	March	3
-	-	-	-	April	7
-	-	-	-	May	2
-	-	-	1936	May	1
-	-	-	-	November	3
-	-	-	1937	April	3
-	-	-	-	May	2
-	-	-	-	June	2
-	-	-	1938	May	2
-	-	-	-	August	1
-	-	-	1939	May	1
4	-	Reva	1939	May	2
-	-	-	-	August	1
-	-	-	-	October	1
5	Butte	Belle Fourche	1935	January	1
-	-	-	-	February	1

Table E.1. Dust storm data acquired from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above. See Appendix B for weather station location data and Figure 2.1 for weather station map (continued).

Station #	County	City	Year	Month	# Dust Storms
-	-	-	-	March	2
-	-	-	-	April	1
-	-	-	1936	May	1
-	-	-	1937	February	1
-	-	-	-	March	1
-	-	-	-	April	2
-	-	-	-	May	2
-	-	-	-	June	1
-	-	-	-	July	1
-	-	-	-	October	1
-	-	-	1938	February	1
-	-	-	-	April	1
-	-	-	1939	September	1
-	-	-	-	December	1
-	-	-	1940	June	1
-	-	-	-	August	1
6	-	Newell	1932	March	2
-	-	-	1935	April	7
-	-	-	1936	November	4
-	-	-	1937	January	3
-	-	-	-	April	3
-	-	-	1938	February	2
-	-	-	-	March	3
-	-	-	-	December	1
-	-	-	1939	January	2
-	-	-	-	March	3
-	-	-	-	April	1
-	-	-	-	May	2
-	-	-	-	December	2
-	-	-	1940	February	1
-	-	-	-	May	1
-	-	-	-	June	2
7	-	Vale	1936	November	2
-	-	-	1937	April	1

Table E.1. Dust storm data acquired from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above. See Appendix B for weather station location data and Figure 2.1 for weather station map (continued).

Station #	County	City	Year	Month	# Dust Storms
-	-	-	-	March	1
-	-	-	1938	December	1
-	-	-	1939	March	1
-	-	-	-	May	2
8	Lawrence	Spearfish	1935	January	1
-	-	-	-	March	2
-	-	-	-	April	1
-	-	-	1936	May	1
-	-	-	-	November	2
-	-	-	1937	January	1
-	-	-	-	February	1
-	-	-	-	June	1
-	-	-	1938	January	1
-	-	-	-	March	1
-	-	-	-	August	1
-	-	-	1939	March	1
-	-	-	-	May	3
9	-	Lead	1935	March	1
-	-	-	1936	December	1
-	-	-	1937	May	1
-	-	-	-	June	1
10	-	Dumont	1935	October	1
-	-	-	1939	April	1
-	-	-	-	May	1
-	-	-	-	December	1
-	-	-	1940	August	1
11	Pennington	Rochford	1939	December	2
12	Custer	Custer	1936	November	1
-	-	-	1938	August	1
13	Fall River	Ardmore	1932	March	1
-	-	-	1933	January	2
-	-	-	-	February	1
-	-	-	1934	April	2
-	-	-	1935	March	7

Table E.1. Dust storm data acquired from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above. See Appendix B for weather station location data and Figure 2.1 for weather station map (continued).

Station #	County	City	Year	Month	# Dust Storms
-	-	-	-	April	2
-	-	-	1939	April	1
14	Oglala Lakota	Pine Ridge	1933	January	1
-	-	-	-	March	1
-	-	-	-	April	3
-	-	-	-	May	1
-	-	-	-	December	1
-	-	-	1934	April	4
-	-	-	1935	January	8
-	-	-	-	April	3
-	-	-	1937	February	1
-	-	-	-	March	2
-	-	-	-	April	4
-	-	-	-	May	2
-	-	-	-	August	2
-	-	-	-	September	2
-	-	-	1938	April	1
-	-	-	-	May	1
-	-	-	-	June	5
-	-	-	-	July	2
-	-	-	-	August	5
-	-	-	-	September	4
-	-	-	-	October	6
-	-	-	1939	May	1
-	-	-	1940	August	2
15	Mead	Faith	1932	April	1
-	-	-	-	June	1
-	-	-	1934	May	1
-	-	-	1936	December	1
-	-	-	1937	April	4
-	-	-	-	May	1
-	-	-	-	July	1
-	-	-	1938	May	2

Table E.1. Dust storm data acquired from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above. See Appendix B for weather station location data and Figure 2.1 for weather station map (continued).

Station #	County	City	Year	Month	# Dust Storms
-	-	-	-	July	1
-	-	-	-	August	1
-	-	-	-	October	2
-	-	-	-	December	1
-	-	-	1939	January	2
-	-	-	-	March	1
-	-	-	-	April	1
-	-	-	-	May	2
-	-	-	-	December	1
-	-	-	1940	May	1
16	Perkins	Strool	1935	March	2
-	-	-	1936	November	4
-	-	-	-	December	1
-	-	-	1937	February	1
-	-	-	-	June	1
17	-	Bison	1935	March	2
-	-	-	-	April	2
-	-	-	1936	May	4
-	-	-	-	September	1
-	-	-	-	November	4
-	-	-	1937	February	1
-	-	-	-	April	2
-	-	-	-	May	2
-	-	-	-	June	1
-	-	-	-	August	1
-	-	-	-	September	2
-	-	-	-	October	1
-	-	-	1938	March	3
-	-	-	-	August	3
-	-	-	-	October	1
-	-	-	-	December	2
-	-	-	1939	January	2
-	-	-	-	March	1
-	-	-	-	April	1

Table E.1. Dust storm data acquired from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above. See Appendix B for weather station location data and Figure 2.1 for weather station map (continued).

Station #	County	City	Year	Month	# Dust Storms
-	-	-	-	May	2
18	-	Lemmon	1930	April	1
-	-	-	1934	April	3
-	-	-	-	August	1
-	-	-	1935	March	3
-	-	-	-	April	2
-	-	-	-	May	1
-	-	-	1936	April	1
-	-	-	-	November	4
-	-	-	1937	March	1
-	-	-	-	May	3
-	-	-	-	June	2
-	-	-	1938	April	1
-	-	-	-	August	2
-	-	-	-	October	1
-	-	-	-	December	1
-	-	-	1939	April	1
-	-	-	-	May	3
-	-	-	1940	May	1
19	Corson	McIntosh	1933	November	1
-	-	-	1934	May	4
-	-	-	1935	August	1
-	-	-	1936	June	1
-	-	-	-	November	3
-	-	-	1937	February	1
20	-	McLaughlin	1934	May	1
-	-	-	-	July	1
-	-	-	-	August	4
-	-	-	-	September	1
-	-	-	-	October	2
-	-	-	1935	January	1
-	-	-	-	March	4
-	-	-	-	April	1
-	-	-	-	July	1

Table E.1. Dust storm data acquired from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above. See Appendix B for weather station location data and Figure 2.1 for weather station map (continued).

Station #	County	City	Year	Month	# Dust Storms
-	-	-	1937	May	3
-	-	-	-	August	2
-	-	-	-	September	4
-	-	-	-	November	2
-	-	-	1938	April	6
-	-	-	-	May	1
-	-	-	-	June	2
-	-	-	-	August	2
-	-	-	-	October	1
-	-	-	-	December	1
-	-	-	1939	January	3
-	-	-	-	April	13
-	-	-	-	May	8
-	-	-	-	November	1
-	-	-	-	December	3
-	-	-	1940	May	2
-	-	-	-	June	3
-	-	-	-	August	4
-	-	-	-	September	1
21	Dewey	Timber Lake	1935	March	3
-	-	-	-	April	1
-	-	-	1936	November	2
-	-	-	1937	April	6
-	-	-	1938	April	2
-	-	-	-	May	1
-	-	-	-	June	2
-	-	-	-	August	1
-	-	-	1939	January	3
-	-	-	-	March	1
-	-	-	-	April	3
-	-	-	-	May	4
-	-	-	-	November	1
-	-	-	-	December	2
-	-	-	1940	June	2

Table E.1. Dust storm data acquired from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above. See Appendix B for weather station location data and Figure 2.1 for weather station map (continued).

Station #	County	City	Year	Month	# Dust Storms
-	-	-	-	July	1
-	-	-	-	August	1
-	-	-	-	September	1
22	Ziebach	Dupree	1931	November	2
-	-	-	1932	April	6
-	-	-	-	November	1
-	-	-	-	December	1
-	-	-	1933	January	2
-	-	-	-	October	1
-	-	-	-	November	2
-	-	-	1934	January	1
-	-	-	-	February	1
-	-	-	-	April	7
-	-	-	-	June	1
-	-	-	-	July	3
-	-	-	-	August	2
-	-	-	-	September	1
-	-	-	1935	January	1
-	-	-	-	March	4
-	-	-	-	April	5
-	-	-	-	May	3
-	-	-	-	October	1
-	-	-	1936	March	1
-	-	-	-	May	3
-	-	-	-	September	9
-	-	-	-	October	7
-	-	-	-	November	5
-	-	-	-	December	1
-	-	-	1937	February	2
-	-	-	-	March	4
-	-	-	-	April	1
-	-	-	-	May	4
-	-	-	-	June	1
-	-	-	-	September	1

Table E.1. Dust storm data acquired from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above. See Appendix B for weather station location data and Figure 2.1 for weather station map (continued).

Station #	County	City	Year	Month	# Dust Storms
-	-	-	-	October	1
-	-	-	1938	May	2
-	-	-	-	July	1
-	-	-	-	August	1
-	-	-	-	December	2
-	-	-	1939	January	2
-	-	-	-	April	1
-	-	-	-	December	1
23	Haakon	Ottumwa	1935	March	3
-	-	-	-	April	2
-	-	-	-	May	1
-	-	-	1936	July	2
-	-	-	-	November	4
-	-	-	1937	April	2
-	-	-	1939	March	2
-	-	-	-	April	1
-	-	-	-	May	2
-	-	-	-	December	2
-	-	-	1940	April	1
24	Jackson	Cottonwood	1930	April	1
-	-	-	1933	November	1
-	-	-	1935	March	2
-	-	-	1937	November	1
-	-	-	1939	July	1
-	-	-	-	December	1
25	-	Belvidere	1933	November	1
-	-	-	1934	March	2
-	-	-	-	April	5
-	-	-	-	May	3
-	-	-	-	June	1
-	-	-	-	September	1
-	-	-	1935	March	10
-	-	-	1936	March	1
-	-	-	-	April	1

Table E.1. Dust storm data acquired from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above. See Appendix B for weather station location data and Figure 2.1 for weather station map (continued).

Station #	County	City	Year	Month	# Dust Storms
-	-	-	-	July	1
-	-	-	-	September	1
-	-	-	-	October	1
-	-	-	-	November	4
-	-	-	1937	March	1
-	-	-	-	April	4
-	-	-	-	May	2
-	-	-	-	June	1
-	-	-	-	July	2
-	-	-	1938	August	1
-	-	-	1939	March	1
-	-	-	-	April	1
-	-	-	-	May	3
-	-	-	-	June	1
-	-	-	-	July	1
-	-	-	-	September	1
-	-	-	1940	June	1
-	-	-	-	December	1
26	Bennett	Martin	1934	July	1
-	-	-	-	August	1
-	-	-	-	October	1
-	-	-	1935	January	2
-	-	-	-	April	2
-	-	-	1937	February	1
-	-	-	-	May	1
-	-	-	1938	March	2
-	-	-	-	April	1
-	-	-	-	June	2
-	-	-	-	July	3
-	-	-	-	October	3
-	-	-	1939	May	4
-	-	-	-	June	1
-	-	-	-	July	2
-	-	-	-	September	2

Table E.1. Dust storm data acquired from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above. See Appendix B for weather station location data and Figure 2.1 for weather station map (continued).

Station #	County	City	Year	Month	# Dust Storms
-	-	-	-	December	3
-	-	-	1940	August	3
-	-	-	-	September	2
27	Mellette	Wood	1930	April	1
-	-	-	1935	March	6
-	-	-	1937	April	2
-	-	-	-	May	1
28	Tripp	Winner	1932	April	5
-	-	-	1933	January	4
-	-	-	-	July	2
-	-	-	-	August	1
-	-	-	-	September	1
-	-	-	-	October	1
-	-	-	-	November	4
-	-	-	1934	February	3
-	-	-	-	March	6
-	-	-	-	April	8
-	-	-	-	May	9
-	-	-	-	June	2
-	-	-	-	July	6
-	-	-	-	August	2
-	-	-	-	September	8
-	-	-	-	October	4
-	-	-	-	December	1
-	-	-	1935	January	3
-	-	-	-	February	3
-	-	-	-	March	16
-	-	-	-	April	7
-	-	-	-	May	1
-	-	-	-	June	5
-	-	-	-	July	1
-	-	-	-	September	1
-	-	-	-	October	2
-	-	-	-	November	2

Table E.1. Dust storm data acquired from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above. See Appendix B for weather station location data and Figure 2.1 for weather station map (continued).

Station #	County	City	Year	Month	# Dust Storms
-	-	-	1936	March	5
-	-	-	-	April	4
-	-	-	-	May	4
-	-	-	-	July	2
-	-	-	-	September	3
-	-	-	-	October	3
-	-	-	-	November	3
-	-	-	-	December	1
-	-	-	1937	April	2
-	-	-	-	May	1
-	-	-	1939	December	2
-	-	-	1940	September	1
29	Jones	Murdo	1934	February	1
-	-	-	-	March	1
-	-	-	-	June	2
-	-	-	-	July	4
-	-	-	-	September	1
-	-	-	1935	March	6
-	-	-	-	April	1
-	-	-	1937	September	1
30	Lyman	Vivian	1930	June	1
-	-	-	1931	April	1
-	-	-	1933	October	1
-	-	-	-	November	2
-	-	-	1934	February	2
-	-	-	-	March	3
-	-	-	-	April	4
-	-	-	-	May	3
-	-	-	-	July	1
-	-	-	-	August	1
-	-	-	1935	January	1
-	-	-	-	March	10
-	-	-	-	April	4
-	-	-	1936	September	1

Table E.1. Dust storm data acquired from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above. See Appendix B for weather station location data and Figure 2.1 for weather station map (continued).

Station #	County	City	Year	Month	# Dust Storms
-	-	-	-	October	2
-	-	-	-	November	4
-	-	-	1937	March	1
-	-	-	-	April	6
-	-	-	-	May	3
-	-	-	-	June	1
-	-	-	-	September	1
-	-	-	-	November	1
-	-	-	1938	December	1
-	-	-	1939	April	1
-	-	-	-	May	1
-	-	-	-	July	1
-	-	-	-	November	1
31	-	Kennebec	1933	November	1
-	-	-	1934	February	2
-	-	-	-	March	4
-	-	-	-	April	4
-	-	-	-	May	2
-	-	-	-	July	1
-	-	-	-	August	1
-	-	-	-	September	1
-	-	-	-	December	1
-	-	-	1935	March	9
-	-	-	-	April	3
-	-	-	1936	November	2
32	Hughes	Pierre	1934	April	4
-	-	-	-	August	2
-	-	-	1935	March	3
-	-	-	-	April	3
-	-	-	-	May	1
-	-	-	1937	April	5
-	-	-	-	May	4
-	-	-	-	September	1
33	Walworth	Mobridge	1938	May	2

Table E.1. Dust storm data acquired from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above. See Appendix B for weather station location data and Figure 2.1 for weather station map (continued).

Station #	County	City	Year	Month	# Dust Storms
-	-	-	1939	April	1
-	-	-	-	December	3
34	Campbell	Pollock	1934	April	1
-	-	-	-	May	2
-	-	-	-	July	1
-	-	-	-	August	1
-	-	-	-	September	1
-	-	-	-	October	2
-	-	-	1935	January	1
-	-	-	-	March	3
-	-	-	-	April	1
-	-	-	1936	November	2
-	-	-	1937	February	1
-	-	-	-	March	1
-	-	-	-	April	8
-	-	-	-	May	4
-	-	-	-	August	5
-	-	-	1938	April	3
-	-	-	-	May	3
-	-	-	1939	April	2
35	McPherson	Eureka	1931	April	1
-	-	-	1933	June	1
-	-	-	-	November	1
-	-	-	1934	April	5
-	-	-	-	May	1
-	-	-	1935	April	1
-	-	-	1936	November	1
-	-	-	1937	April	3
-	-	-	1938	April	5
-	-	-	-	May	3
-	-	-	-	June	3
-	-	-	-	August	1
-	-	-	-	October	1
-	-	-	1939	March	2

Table E.1. Dust storm data acquired from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above. See Appendix B for weather station location data and Figure 2.1 for weather station map (continued).

Station #	County	City	Year	Month	# Dust Storms
-	-	-	-	April	2
-	-	-	-	December	2
-	-	-	1940	October	1
36	-	Leola	1933	June	1
-	-	-	1934	February	2
-	-	-	-	March	1
-	-	-	-	April	3
-	-	-	-	May	3
-	-	-	-	October	1
-	-	-	1935	February	1
-	-	-	-	April	1
-	-	-	1936	November	2
-	-	-	1938	April	1
-	-	-	-	August	2
-	-	-	-	October	1
-	-	-	1939	January	2
37	Edmunds	Bowdle	1934	March	1
-	-	-	1938	August	2
-	-	-	-	October	1
-	-	-	1939	April	1
-	-	-	-	May	1
-	-	-	-	December	2
38	-	Roscoe	1934	December	2
-	-	-	1935	January	1
-	-	-	-	February	1
-	-	-	-	March	6
-	-	-	-	April	1
-	-	-	-	June	1
-	-	-	1936	April	1
-	-	-	-	May	1
-	-	-	-	June	1
-	-	-	-	July	3
-	-	-	-	September	2
-	-	-	-	October	5

Table E.1. Dust storm data acquired from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above. See Appendix B for weather station location data and Figure 2.1 for weather station map (continued).

Station #	County	City	Year	Month	# Dust Storms
-	-	-	-	November	1
-	-	-	-	December	1
-	-	-	1937	February	1
-	-	-	-	March	1
-	-	-	-	April	4
-	-	-	-	May	4
-	-	-	-	June	2
-	-	-	-	July	3
-	-	-	-	August	3
-	-	-	-	September	3
-	-	-	-	October	4
-	-	-	-	November	1
-	-	-	1938	March	2
-	-	-	-	April	6
-	-	-	-	May	3
-	-	-	-	June	1
-	-	-	-	July	1
-	-	-	-	August	2
-	-	-	-	October	2
-	-	-	1939	March	2
-	-	-	-	April	6
-	-	-	-	May	3
-	-	-	-	December	3
-	-	-	1940	May	1
-	-	-	-	October	1
-	-	-	-	December	1
39	-	Ipswich	1934	May	1
-	-	-	1935	March	3
-	-	-	-	October	1
-	-	-	1936	November	1
40	Faulk	Faulkton	1930	April	2
-	-	-	-	May	2
-	-	-	1931	April	1
-	-	-	-	May	2

Table E.1. Dust storm data acquired from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above. See Appendix B for weather station location data and Figure 2.1 for weather station map (continued).

Station #	County	City	Year	Month	# Dust Storms
-	-	-	1932	June	1
-	-	-	-	July	1
-	-	-	1933	August	1
-	-	-	-	September	2
-	-	-	-	October	3
-	-	-	-	November	2
-	-	-	1934	January	1
-	-	-	-	February	3
-	-	-	-	March	5
-	-	-	-	April	6
-	-	-	-	May	3
-	-	-	-	June	1
-	-	-	-	July	2
-	-	-	-	October	1
-	-	-	1935	January	1
-	-	-	-	March	3
-	-	-	-	April	2
-	-	-	-	May	1
-	-	-	-	August	1
-	-	-	-	October	2
-	-	-	1936	April	1
-	-	-	-	May	1
-	-	-	-	July	3
-	-	-	-	August	2
-	-	-	-	September	2
-	-	-	-	October	3
-	-	-	-	November	1
-	-	-	-	December	1
-	-	-	1937	February	1
-	-	-	-	March	1
-	-	-	-	April	4
-	-	-	-	May	3
-	-	-	-	June	1
-	-	-	-	July	3

Table E.1. Dust storm data acquired from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above. See Appendix B for weather station location data and Figure 2.1 for weather station map (continued).

Station #	County	City	Year	Month	# Dust Storms
-	-	-	-	August	2
-	-	-	-	October	1
-	-	-	1938	April	2
-	-	-	-	May	2
-	-	-	-	August	1
-	-	-	-	October	1
-	-	-	1939	March	1
-	-	-	-	April	3
-	-	-	-	May	1
-	-	-	-	September	2
-	-	-	-	December	1
-	-	-	1940	October	1
41	Hyde	Highmore	1931	September	1
-	-	-	1934	April	5
-	-	-	-	May	3
-	-	-	-	June	1
-	-	-	1935	March	2
-	-	-	1936	September	1
-	-	-	-	October	1
-	-	-	1939	December	1
42	Buffalo	Gann Valley	1933	January	1
-	-	-	1934	January	1
-	-	-	-	February	3
-	-	-	-	March	6
-	-	-	-	April	3
-	-	-	-	May	3
-	-	-	-	July	1
-	-	-	-	August	1
-	-	-	-	September	2
-	-	-	-	October	2
-	-	-	1935	February	1
-	-	-	-	March	5
-	-	-	-	April	3
-	-	-	-	May	2

Table E.1. Dust storm data acquired from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above. See Appendix B for weather station location data and Figure 2.1 for weather station map (continued).

Station #	County	City	Year	Month	# Dust Storms
-	-	-	-	August	1
-	-	-	-	September	1
-	-	-	1936	April	2
-	-	-	-	July	1
-	-	-	-	October	2
-	-	-	-	November	3
-	-	-	1937	March	1
-	-	-	-	April	2
-	-	-	1939	April	1
43	Brule	Pukwana	1933	November	1
-	-	-	1934	March	6
-	-	-	-	April	3
-	-	-	-	May	4
-	-	-	-	August	2
-	-	-	1935	March	8
-	-	-	1936	August	1
-	-	-	-	September	3
-	-	-	-	October	2
-	-	-	-	November	3
-	-	-	1937	March	2
-	-	-	-	April	4
-	-	-	-	May	2
-	-	-	-	July	1
-	-	-	-	August	1
-	-	-	-	September	1
-	-	-	-	October	1
-	-	-	-	November	2
-	-	-	1938	March	2
-	-	-	-	May	2
-	-	-	-	August	2
-	-	-	-	October	2
-	-	-	1939	July	2
-	-	-	-	December	1
-	-	-	1940	September	4

Table E.1. Dust storm data acquired from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above. See Appendix B for weather station location data and Figure 2.1 for weather station map (continued).

Station #	County	City	Year	Month	# Dust Storms
-	-	-	-	October	2
44	Charles Mix	Academy	1933	July	2
-	-	-	-	September	2
-	-	-	-	October	1
-	-	-	-	November	2
-	-	-	1934	January	1
-	-	-	-	February	2
-	-	-	-	March	4
-	-	-	-	April	6
-	-	-	-	May	4
-	-	-	-	July	1
-	-	-	1935	March	6
-	-	-	1936	April	1
-	-	-	-	May	1
-	-	-	-	October	2
-	-	-	-	November	2
-	-	-	1937	February	15
-	-	-	1938	May	2
-	-	-	1939	April	1
-	-	-	-	December	2
-	-	-	1940	September	1
-	-	-	-	December	2
45	-	Geddes	1933	June	1
-	-	-	1935	March	6
-	-	-	1939	August	1
-	-	-	-	September	1
-	-	-	-	November	1
-	-	-	-	December	1
-	-	-	1940	July	2
-	-	-	-	October	1
46	-	Wagner	1933	October	1
-	-	-	-	November	1
-	-	-	1934	February	1
-	-	-	-	March	2

Table E.1. Dust storm data acquired from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above. See Appendix B for weather station location data and Figure 2.1 for weather station map (continued).

Station #	County	City	Year	Month	# Dust Storms
-	-	-	-	April	3
-	-	-	-	May	1
-	-	-	1935	March	7
-	-	-	-	April	1
-	-	-	-	August	1
-	-	-	-	September	1
-	-	-	1937	March	1
-	-	-	-	April	1
-	-	-	-	May	3
-	-	-	-	June	1
-	-	-	-	November	3
-	-	-	-	December	1
-	-	-	1939	December	1
-	-	-	1940	October	1
47	Gregory	Fairfax	1933	June	1
-	-	-	-	July	1
-	-	-	-	November	1
-	-	-	1934	February	1
-	-	-	-	March	2
-	-	-	-	April	4
-	-	-	-	May	2
-	-	-	-	June	2
-	-	-	1935	March	6
-	-	-	1937	September	2
-	-	-	1939	April	1
48	Bon Homme	Tyndall	1930	April	1
-	-	-	1931	April	3
-	-	-	1932	March	3
-	-	-	1933	November	2
-	-	-	1934	February	2
-	-	-	-	March	1
-	-	-	-	April	3
-	-	-	-	May	2
-	-	-	-	August	1

Table E.1. Dust storm data acquired from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above. See Appendix B for weather station location data and Figure 2.1 for weather station map (continued).

Station #	County	City	Year	Month	# Dust Storms
-	-	-	-	December	1
-	-	-	1935	January	1
-	-	-	-	March	8
-	-	-	-	April	2
-	-	-	-	October	1
-	-	-	1936	September	1
-	-	-	-	October	1
-	-	-	-	November	2
-	-	-	1937	April	1
-	-	-	1939	August	1
-	-	-	-	September	1
-	-	-	-	October	1
-	-	-	-	November	1
-	-	-	-	December	1
49	Hutchinson	Parkston	1931	April	3
-	-	-	-	September	3
-	-	-	-	October	1
-	-	-	1933	January	2
-	-	-	-	November	2
-	-	-	1934	January	1
-	-	-	-	February	2
-	-	-	-	March	5
-	-	-	-	May	1
-	-	-	-	June	1
-	-	-	-	August	1
-	-	-	1935	February	1
-	-	-	-	March	4
-	-	-	1936	October	1
-	-	-	-	November	3
-	-	-	1937	August	1
-	-	-	-	November	1
-	-	-	1938	May	3
-	-	-	1939	May	1
-	-	-	-	June	1

Table E.1. Dust storm data acquired from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above. See Appendix B for weather station location data and Figure 2.1 for weather station map (continued).

Station #	County	City	Year	Month	# Dust Storms
-	-	-	-	December	1
50	Douglas	Armour	1933	June	1
-	-	-	-	November	1
-	-	-	1934	February	2
-	-	-	-	March	2
-	-	-	-	April	4
-	-	-	-	May	2
-	-	-	-	June	2
-	-	-	-	July	1
-	-	-	-	August	1
-	-	-	-	December	3
-	-	-	1935	January	2
-	-	-	-	February	1
-	-	-	-	March	9
-	-	-	-	April	3
-	-	-	1936	July	1
-	-	-	-	September	3
-	-	-	-	October	2
-	-	-	-	November	3
-	-	-	1937	March	1
-	-	-	-	April	3
-	-	-	-	May	4
-	-	-	-	November	1
-	-	-	1938	May	1
-	-	-	-	August	2
-	-	-	1939	April	3
-	-	-	-	July	3
-	-	-	-	August	2
-	-	-	-	September	8
-	-	-	-	October	1
-	-	-	-	November	1
-	-	-	-	December	3
-	-	-	1940	July	1
-	-	-	-	September	1

Table E.1. Dust storm data acquired from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above. See Appendix B for weather station location data and Figure 2.1 for weather station map (continued).

Station #	County	City	Year	Month	# Dust Storms
-	-	-	-	October	1
51	Aurora	White Lake	1934	March	1
-	-	-	-	April	4
-	-	-	-	May	1
-	-	-	-	June	1
-	-	-	1935	January	1
-	-	-	-	March	5
-	-	-	-	April	1
-	-	-	-	October	2
-	-	-	1936	March	1
-	-	-	-	July	2
-	-	-	-	September	1
-	-	-	-	November	3
-	-	-	1937	February	1
-	-	-	-	May	3
-	-	-	-	September	1
-	-	-	1938	May	1
-	-	-	1939	June	2
-	-	-	-	July	1
-	-	-	-	December	2
-	-	-	1940	October	1
52	Davison	Mitchell	1931	April	2
-	-	-	-	September	1
-	-	-	1933	November	1
-	-	-	1934	January	2
-	-	-	-	March	3
-	-	-	-	April	4
-	-	-	-	May	3
-	-	-	-	June	1
-	-	-	1935	February	1
-	-	-	-	March	2
-	-	-	-	April	1
-	-	-	1936	October	1
-	-	-	-	November	1

Table E.1. Dust storm data acquired from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above. See Appendix B for weather station location data and Figure 2.1 for weather station map (continued).

Station #	County	City	Year	Month	# Dust Storms
-	-	-	1937	September	1
-	-	-	1939	April	1
-	-	-	-	December	1
53	Hanson	Alexandria	1933	November	2
-	-	-	1934	February	1
-	-	-	-	March	3
-	-	-	-	April	4
-	-	-	-	May	3
-	-	-	-	August	1
-	-	-	1935	April	1
-	-	-	1936	November	2
-	-	-	1937	February	1
54	Sanborn	Forestburg	1933	November	2
-	-	-	1934	January	1
-	-	-	-	February	2
-	-	-	-	March	6
-	-	-	-	April	12
-	-	-	-	May	6
-	-	-	-	June	3
-	-	-	-	July	1
-	-	-	-	October	2
-	-	-	-	December	1
-	-	-	1935	January	2
-	-	-	-	February	1
-	-	-	-	March	7
-	-	-	-	April	1
-	-	-	-	May	1
-	-	-	-	August	1
-	-	-	-	October	1
-	-	-	1936	April	1
-	-	-	-	July	1
-	-	-	-	September	2
-	-	-	-	October	2
-	-	-	-	November	2

Table E.1. Dust storm data acquired from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above. See Appendix B for weather station location data and Figure 2.1 for weather station map (continued).

Station #	County	City	Year	Month	# Dust Storms
-	-	-	1937	February	1
-	-	-	-	April	2
-	-	-	-	May	1
-	-	-	-	June	1
-	-	-	1938	April	1
-	-	-	-	May	3
-	-	-	1939	April	2
-	-	-	-	May	1
-	-	-	-	June	3
-	-	-	-	July	1
-	-	-	-	December	3
-	-	-	1940	August	1
-	-	-	-	September	1
-	-	-	-	October	1
55	Beadle	Huron	1938	May	3
-	-	-	-	August	2
-	-	-	-	October	1
-	-	-	-	November	1
-	-	-	-	December	1
56	Spink	LaDelle	1933	April	14
-	-	-	1934	February	5
-	-	-	-	March	11
-	-	-	-	April	11
-	-	-	-	May	7
-	-	-	-	August	2
-	-	-	-	October	1
-	-	-	1935	January	2
-	-	-	-	February	1
-	-	-	-	March	5
-	-	-	-	April	1
-	-	-	1936	April	3
-	-	-	-	September	2
-	-	-	-	October	2
-	-	-	1938	April	1

Table E.1. Dust storm data acquired from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above. See Appendix B for weather station location data and Figure 2.1 for weather station map (continued).

Station #	County	City	Year	Month	# Dust Storms
-	-	-	-	May	1
-	-	-	1939	March	1
-	-	-	-	April	1
-	-	-	-	May	1
-	-	-	-	December	1
-	-	-	1940	August	1
-	-	-	-	December	2
57	-	Redfield	1931	April	3
-	-	-	1933	October	2
-	-	-	-	November	1
-	-	-	1934	January	1
-	-	-	-	February	4
-	-	-	-	March	9
-	-	-	-	April	5
-	-	-	-	May	16
-	-	-	-	June	4
-	-	-	-	Ju	1
-	-	-	-	October	2
-	-	-	1936	September	1
-	-	-	-	October	7
-	-	-	-	November	2
-	-	-	1937	February	3
-	-	-	-	March	2
-	-	-	-	April	3
-	-	-	-	May	2
-	-	-	-	June	1
-	-	-	-	August	3
-	-	-	-	October	2
-	-	-	1938	April	2
-	-	-	-	May	1
-	-	-	1939	March	1
-	-	-	-	May	1
58	-	Ashton	1931	March	1
-	-	-	-	April	2

Table E.1. Dust storm data acquired from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above. See Appendix B for weather station location data and Figure 2.1 for weather station map (continued).

Station #	County	City	Year	Month	# Dust Storms
-	-	-	-	May	1
-	-	-	1933	January	1
-	-	-	-	August	1
-	-	-	-	October	4
-	-	-	-	November	2
-	-	-	1934	January	1
-	-	-	-	February	1
-	-	-	-	March	3
-	-	-	-	April	13
-	-	-	-	May	12
-	-	-	-	June	4
-	-	-	-	July	2
-	-	-	-	August	2
-	-	-	-	September	2
-	-	-	-	October	2
-	-	-	1935	January	3
-	-	-	-	February	1
-	-	-	-	March	1
-	-	-	-	April	1
-	-	-	-	May	1
-	-	-	-	June	2
-	-	-	-	October	1
-	-	-	1936	April	1
-	-	-	-	May	1
-	-	-	-	June	3
-	-	-	-	July	3
-	-	-	-	September	1
-	-	-	-	October	4
-	-	-	-	November	2
-	-	-	1937	September	1
-	-	-	-	October	1
-	-	-	1938	January	1
-	-	-	-	April	1
-	-	-	-	May	3

Table E.1. Dust storm data acquired from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above. See Appendix B for weather station location data and Figure 2.1 for weather station map (continued).

Station #	County	City	Year	Month	# Dust Storms
-	-	-	1939	December	1
59	-	Mellette	1930	April	1
-	-	-	1931	April	1
-	-	-	-	September	1
-	-	-	1933	March	1
-	-	-	-	October	1
-	-	-	-	November	1
-	-	-	1934	February	4
-	-	-	-	March	6
-	-	-	-	April	12
-	-	-	-	May	12
-	-	-	-	July	1
-	-	-	1935	January	1
-	-	-	-	March	3
-	-	-	-	May	2
-	-	-	-	October	3
-	-	-	1936	July	1
-	-	-	-	November	1
-	-	-	1937	May	1
-	-	-	-	July	1
-	-	-	-	August	3
-	-	-	-	September	2
-	-	-	-	October	3
-	-	-	-	November	1
-	-	-	-	December	1
-	-	-	1938	April	3
-	-	-	-	May	1
-	-	-	-	June	1
-	-	-	-	August	3
-	-	-	-	October	3
-	-	-	1939	April	3
-	-	-	-	May	2
-	-	-	-	August	5
-	-	-	-	September	2

Table E.1. Dust storm data acquired from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above. See Appendix B for weather station location data and Figure 2.1 for weather station map (continued).

Station #	County	City	Year	Month	# Dust Storms
-	-	-	-	October	1
-	-	-	-	December	3
-	-	-	1940	May	1
-	-	-	-	June	2
-	-	-	-	August	1
-	-	-	-	September	1
-	-	-	-	October	1
-	-	-	-	November	1
60	Brown	Aberdeen	1933	November	3
-	-	-	1934	February	4
-	-	-	-	March	7
-	-	-	-	April	6
-	-	-	-	May	5
-	-	-	1936	July	1
-	-	-	-	November	1
-	-	-	1937	April	2
-	-	-	-	May	2
-	-	-	1938	March	2
-	-	-	-	April	5
-	-	-	1939	March	1
-	-	-	-	April	3
-	-	-	-	May	1
-	-	-	-	December	4
61	Marshall	Britton	1930	June	1
-	-	-	1931	May	2
-	-	-	1932	January	1
-	-	-	1933	April	2
-	-	-	-	October	3
-	-	-	-	November	1
-	-	-	1934	February	3
-	-	-	-	March	5
-	-	-	-	April	5
-	-	-	-	May	4
-	-	-	-	June	1

Table E.1. Dust storm data acquired from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above. See Appendix B for weather station location data and Figure 2.1 for weather station map (continued).

Station #	County	City	Year	Month	# Dust Storms
-	-	-	-	August	2
-	-	-	1935	January	1
-	-	-	-	March	2
-	-	-	-	August	3
-	-	-	1936	April	1
-	-	-	-	July	2
-	-	-	-	September	1
-	-	-	-	October	2
-	-	-	-	November	2
-	-	-	-	December	1
-	-	-	1937	March	2
-	-	-	-	May	1
-	-	-	-	August	2
-	-	-	-	September	2
-	-	-	1938	June	1
-	-	-	-	August	1
-	-	-	1939	October	1
-	-	-	-	November	1
62	Day	Webster	1930	June	1
-	-	-	1931	May	2
-	-	-	1933	April	3
-	-	-	-	August	1
-	-	-	-	October	2
-	-	-	-	November	1
-	-	-	1934	February	1
-	-	-	-	March	7
-	-	-	-	April	12
-	-	-	-	May	9
-	-	-	-	August	1
-	-	-	1935	March	4
-	-	-	-	April	1
-	-	-	-	July	1
-	-	-	1936	September	2
-	-	-	-	October	1

Table E.1. Dust storm data acquired from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above. See Appendix B for weather station location data and Figure 2.1 for weather station map (continued).

Station #	County	City	Year	Month	# Dust Storms
-	-	-	-	November	2
-	-	-	1937	May	1
-	-	-	-	September	2
-	-	-	-	October	1
-	-	-	1938	April	3
-	-	-	1939	April	1
-	-	-	-	May	1
63	Clark	Raymond	1934	April	1
-	-	-	1935	November	1
-	-	-	1937	August	1
-	-	-	-	October	3
-	-	-	1938	April	1
-	-	-	1939	September	2
-	-	-	-	November	1
-	-	-	-	December	4
-	-	-	1940	August	1
-	-	-	-	October	1
64	-	Clark	1930	February	1
-	-	-	-	September	1
-	-	-	-	December	1
-	-	-	1931	April	3
-	-	-	-	May	1
-	-	-	-	July	1
-	-	-	-	September	1
-	-	-	1932	March	1
-	-	-	1933	January	1
-	-	-	-	July	1
-	-	-	-	September	1
-	-	-	-	October	5
-	-	-	-	November	2
-	-	-	1934	February	3
-	-	-	-	March	7
-	-	-	-	April	6
-	-	-	-	May	6

Table E.1. Dust storm data acquired from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above. See Appendix B for weather station location data and Figure 2.1 for weather station map (continued).

Station #	County	City	Year	Month	# Dust Storms
-	-	-	-	June	2
-	-	-	-	August	1
-	-	-	1935	January	1
-	-	-	-	February	1
-	-	-	1936	April	2
-	-	-	-	July	1
-	-	-	-	September	1
-	-	-	-	October	3
-	-	-	-	November	1
-	-	-	1937	September	1
-	-	-	-	October	2
-	-	-	1938	April	2
-	-	-	-	September	2
-	-	-	-	October	2
-	-	-	-	December	2
-	-	-	1940	May	2
-	-	-	-	August	1
-	-	-	-	October	1
-	-	-	-	December	1
65	Kingsbury	De Smet	1931	April	1
-	-	-	1933	November	1
-	-	-	1934	April	1
-	-	-	-	May	1
-	-	-	1935	January	1
-	-	-	-	March	5
-	-	-	-	April	1
-	-	-	1936	November	2
-	-	-	1937	April	2
-	-	-	-	November	1
-	-	-	1938	April	1
-	-	-	1939	March	1
-	-	-	-	April	1
-	-	-	-	May	1
-	-	-	-	September	1

Table E.1. Dust storm data acquired from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above. See Appendix B for weather station location data and Figure 2.1 for weather station map (continued).

Station #	County	City	Year	Month	# Dust Storms
-	-	-	-	October	1
-	-	-	-	December	2
-	-	-	1940	August	1
-	-	-	-	September	1
66	-	Arlington	1935	September	1
-	-	-	1939	April	1
-	-	-	-	May	2
-	-	-	-	June	2
-	-	-	-	September	1
-	-	-	-	October	1
-	-	-	-	December	2
-	-	-	1940	May	1
67	Lake	Wentworth	1936	August	1
-	-	-	-	September	1
-	-	-	-	October	2
-	-	-	-	November	2
-	-	-	1937	February	1
-	-	-	-	May	2
-	-	-	-	July	1
-	-	-	1938	April	1
-	-	-	-	May	1
-	-	-	1939	June	2
-	-	-	-	December	2
68	McCook	Canistota	1931	February	1
-	-	-	-	April	5
-	-	-	1933	November	2
-	-	-	1934	February	2
-	-	-	-	March	6
-	-	-	-	April	9
-	-	-	-	May	6
-	-	-	-	August	1
-	-	-	1935	March	3
-	-	-	1936	August	2
-	-	-	-	September	2

Table E.1. Dust storm data acquired from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above. See Appendix B for weather station location data and Figure 2.1 for weather station map (continued).

Station #	County	City	Year	Month	# Dust Storms
-	-	-	-	October	2
-	-	-	-	November	2
-	-	-	1939	December	2
69	Turner	Marion	1933	November	2
-	-	-	1934	February	2
-	-	-	-	March	5
-	-	-	-	April	8
-	-	-	-	May	5
-	-	-	-	June	2
-	-	-	-	August	1
-	-	-	1935	January	1
-	-	-	-	March	5
-	-	-	1936	September	1
-	-	-	-	October	1
-	-	-	-	November	2
-	-	-	1937	February	1
-	-	-	-	April	1
-	-	-	-	May	1
-	-	-	1939	April	2
-	-	-	-	June	1
-	-	-	-	October	1
-	-	-	-	December	3
-	-	-	1940	October	2
70	Yankton	Yankton	1934	May	1
-	-	-	1939	May	1
-	-	-	-	December	1
71	Clay	Vermillion	1932	March	2
-	-	-	1933	January	1
-	-	-	1934	February	1
-	-	-	-	April	6
-	-	-	-	May	1
-	-	-	-	August	1
-	-	-	1935	March	6
-	-	-	1936	April	1

Table E.1. Dust storm data acquired from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above. See Appendix B for weather station location data and Figure 2.1 for weather station map (continued).

Station #	County	City	Year	Month	# Dust Storms
-	-	-	-	September	1
-	-	-	-	October	1
-	-	-	-	November	1
-	-	-	1937	February	2
-	-	-	1939	April	2
-	-	-	-	December	1
72	Lincoln	Canton	1930	April	-
-	-	-	1931	April	3
-	-	-	1933	November	2
-	-	-	1934	January	2
-	-	-	-	February	2
-	-	-	-	March	3
-	-	-	-	April	9
-	-	-	-	May	6
-	-	-	1937	February	1
-	-	-	-	May	1
-	-	-	1938	January	1
-	-	-	1939	April	1
-	-	-	-	December	1
73	Minnehaha	Sioux Falls	1930	April	1
-	-	-	1931	April	2
-	-	-	1932	March	2
-	-	-	1933	November	2
-	-	-	1934	January	1
-	-	-	-	February	1
-	-	-	-	April	3
-	-	-	-	May	2
-	-	-	1935	March	2
-	-	-	1936	November	2
-	-	-	1939	December	1
74	Moody	Flandreau	1931	April	3
-	-	-	1934	February	2
-	-	-	-	March	4
-	-	-	-	April	3

Table E.1. Dust storm data acquired from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above. See Appendix B for weather station location data and Figure 2.1 for weather station map (continued).

Station #	County	City	Year	Month	# Dust Storms
-	-	-	-	May	3
-	-	-	-	August	2
-	-	-	1935	January	2
-	-	-	-	June	1
-	-	-	1936	May	2
-	-	-	-	June	2
-	-	-	-	August	1
-	-	-	-	October	1
-	-	-	1938	May	2
-	-	-	1939	April	2
-	-	-	-	October	2
-	-	-	-	December	2
-	-	-	1940	May	1
75	Brookings	Brookings	1930	April	1
-	-	-	1931	April	3
-	-	-	-	May	1
-	-	-	-	September	1
-	-	-	1933	May	1
-	-	-	-	June	1
-	-	-	-	September	1
-	-	-	1934	January	1
-	-	-	-	February	1
-	-	-	-	March	6
-	-	-	-	April	8
-	-	-	-	May	4
-	-	-	1935	March	2
-	-	-	-	April	1
-	-	-	-	June	1
-	-	-	1936	April	1
-	-	-	-	September	1
-	-	-	-	October	1
-	-	-	-	November	2
-	-	-	1937	February	1
-	-	-	-	October	1

Table E.1. Dust storm data acquired from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above. See Appendix B for weather station location data and Figure 2.1 for weather station map (continued).

Station #	County	City	Year	Month	# Dust Storms
-	-	-	-	November	1
-	-	-	1938	April	1
-	-	-	-	May	1
-	-	-	-	November	1
-	-	-	1939	April	2
-	-	-	-	September	1
76	Hamlin	Castlewood	1930	February	1
-	-	-	-	April	3
-	-	-	-	May	1
-	-	-	-	June	1
-	-	-	-	August	2
-	-	-	1931	April	2
-	-	-	-	July	2
-	-	-	-	August	3
-	-	-	-	September	2
-	-	-	1932	May	1
-	-	-	-	July	2
-	-	-	-	August	1
-	-	-	1933	June	1
-	-	-	-	September	1
-	-	-	-	October	2
-	-	-	1934	January	1
77	Codington	Watertown	1930	February	1
-	-	-	1931	April	3
-	-	-	1933	November	1
-	-	-	1934	February	1
-	-	-	-	March	6
-	-	-	-	April	3
-	-	-	-	May	4
-	-	-	-	August	1
-	-	-	1936	September	1
-	-	-	-	October	1
-	-	-	1937	September	1
-	-	-	-	November	1

Table E.1. Dust storm data acquired from the South Dakota State Climate records (South Dakota State Climate Records, 2018). Dash indicates continuation of data entry above. See Appendix B for weather station location data and Figure 2.1 for weather station map (continued).

Station #	County	City	Year	Month	# Dust Storms
-	-	-	1938	May	3
78	Roberts	Sisseton	1933	October	1
-	-	-	1934	April	2
-	-	-	-	May	1
-	-	-	1935	March	1
-	-	-	-	August	1
-	-	-	1938	April	1
-	-	-	1939	December	2
79	-	Victor	1931	May	1
-	-	-	1934	June	1
-	-	-	1935	March	1
-	-	-	-	June	2
-	-	-	1936	April	1
-	-	-	-	May	1
-	-	-	-	July	1
-	-	-	-	October	2
-	-	-	-	November	2
-	-	-	-	December	1
-	-	-	1937	November	1
-	-	-	1938	June	3
-	-	-	1940	May	1

REFERENCES CITED

Allmendinger, R. W., Cardozo, N. C., and Fisher, D., 2012, Structural Geology Algorithms: Vector and Tensors: Cambridge, England, Cambridge University Press, 289 p.

Bacon, S.N., McDonald, E.V., Amit, R., Enzel, Y., and Crouvi, O., 2011, Total suspended particulate matter emissions at high friction velocities from desert landforms. Journal of Geophysical Research, v. 116, no. F03019.

Bennett, H. H., and Fowler, F. H., 1936, Report of the Great Plains Drought Area Committee: Washington, DC, Government Printing Office.

Berg, D. J., 2015, Dusting off the Dust Bowl: The Historical Geography of the Northern Plains during the 1930s, West River Conference, Rapid City, SD, p. 1-31.

Bolles, K., and Forman, S. L., 2018, Evaluating landscape degradation along climatic gradients during the 1930s Dust Bowl Drought from panchromatic historical aerial photographs, United States Great Plains: Frontiers in Earth Science, v. 6, no. 153.

Bolles, K., Forman, S. L., and Sweeney, M., 2017, Eolian processes and heterogeneous dust emissivity during the 1930s Dust Bowl Drought and implications for projected 21st-century megadroughts, The Holocene, v. 27, p. 1578-1588.

Bolles, K., Sweeney, M., and Forman, S. L., 2019, Meteorological catalysts of dust events and particle source dynamics of affected soils during the 1930s Dust Bowl drought, Southern High Plains, USA, Anthropocene, v. 27, no. 100216.

Burnette, D. J., and Stahle, D. W., 2013, Historical perspective on the dust bowl drought in the central United States, Climatic Change, v. 116, p. 479–494.

Burnette, D. J., Stahle, D. W., and Mock, C. J., 2010, Daily mean temperature reconstructed for Kansas from early instrumental and modern observations, Journal of Climate, v. 23, p. 1308–1333.

Cardozo, N., and Allmendinger, R. W., 2013, Spherical projections with OSXStereonet, Computers and Geosciences, v. 51, no. 0, p. 193-205.

Chepil, W. S., 1958, Soil conditions that influence wind erosion, U.S. Department of Agriculture Technical Bulletin, v. 1185.

Chepil, W. S., and Woodruff, N. P., 1963, The physics of wind erosion and its control, Advances in Agronomy, v. 15, p. 211-302.

Choun, H. F., 1936, Dust storms in the southwestern plains area, Monthly Weather Review, v. 64, p. 195-199.

Compo, G.P., Whitaker, J.S., Sardeshmukh, P.D., Matsui, N., Allan, R.J., Yin, X., Gleason, B.E., Vose, R.S., Rutledge, G., Bessemoulin, P., Brönnimann, S., Brunet, M., Crouthamel, R.I., Grant, A.N., Groisman, P.Y., Jones, P.D., Kruk, M., Kruger, A.C., Marshall, G.J., Maugeri, M., Mok, H.Y., Nordli, Ø., Ross, T.F., Trigo, R.M., Wang, X.L., Woodruff, S.D., and Worley, S.J., 2011, The twentieth century reanalysis project, Quarterly Journal of the Royal Meteorological Society, v. 137, p. 1–28.

Cook, B., Ault, T. R., and Smerdon, J. E., 2015, Unprecedented 21st century drought risk in the american southwest and central plains, Science Advances, 1:e1400082.

Cook, B. I., Miller, R. L., and Seager, R., 2008, Dust and sea surface temperature forcing of the 1930s "Dust Bowl" drought, Geophysical Research Letters, v. 35, no. 8.

Cook, B. I., Miller, R. L., and Seager, R., 2009, Amplification of the North American 'Dust Bowl' drought through human-induced land degradation, Proceedings of the National Academy of Sciences, v. 106 p. 4997–5001.

Cook, B. I., Seager, R., Miller, R.L., and Mason, J. A., 2013, Intensification of North American megadroughts through surface and dust aerosol forcing, Journal of Climate, v. 26, p. 4414–4430.

Cook, B. I., Seager, R., and Smerdon, J. E., 2014, The worst North American drought year of the last millennium: 1934, Geophysical Research Letters, v. 41, p. 7298 7305.

Cook, E. R., Seager, R., Heim, R. R., Vose, R. S., Herweijer, C., and Woodhouse, C., 2010, Megadroughts in North America: placing IPCC projections of hydroclimatic change in a long–term palaeoclimate context, Journal of Quaternary Science, v. 25, p. 48–61.

Cunfer, G., 2005, On the Great Plains: Agriculture and Environment: College Station, TX, Texas A&M University Press, 292 p.

Dai, A., 2013, Increasing drought under global warming in observations and models, Nature Climate Change, v. 3, p. 52–58.

Derner, J. D., Boutton, T. W., and Briske, D. D., 2006, Grazing and ecosystem carbon storage in the North American great plains, Plant Soil, v. 280, p. 77–90.

Desert Research Institute, 2020, Portable In-Situ Wind ERosion Lab: PI-SWERL: https://www.dri.edu/project/pi-swerl/ (accessed August 2020).

Donarummo, J., 2003, Possible deposit of soil dust from the 1930s U.S. dust bowl identified in Greenland ice, Geophysical Research Letters, v. 30, no. 6.

Donat, M. G., King, A. D., Overpeck, J. T., Alexander, L. V., Duure, I., and Karoly, D. J., 2016, Extraordinary heat during the 1930s US Dust Bowl and associated large scale conditions, Climate Dynamics, v. 46, p. 413–426.

Egan, T., 2006, The Worst Hard Time: The Untold Story of Those Who Survived the Great American Dust Bowl: New York, Houghton Mifflin Harcourt, 340 p.

Etyemezian, V. Nikolich, G., Ahonen, S., Pitchford, M., Sweeney, M., Gillies, J., and Kuhns, H., 2007, The Portable In-Situ Wind Erosion Laboratory (PI-SWERL): a new method to measure PM10 windblown dust properties and potential for emissions. Atmospheric Environment, v. 41, p. 3789-3796.

Flint, R. F., 1955, Pleistocene Geology of Eastern South Dakota, Professional Paper 262, United States Geological Survey, 173 p.

Floyd, F., 1950, History of the Dust Bowl [Ph.D. dissertation]: Norman, University of Oklahoma, 311 p.

Gillette, D. A., 1988, Threshold friction velocities for dust production for agricultural soils, Journal of Geophysical Research, v. 93, p. 12645–12662.

Goossens, D., and Buck, B., 2009, Dust emission by off-road driving: experiments on 17 arid soil types, Nevada, USA, Geomorphology, v. 107, p. 118–138.

Gray, J. H., 1967, Men Against the Desert: Calgary, AB, Canada, Western Producer Prairie Books, 263 p.

Gregory, J. N., 2004, The Dust Bowl migration, *in* Mink, G., and O'Connor, A. M., eds., Poverty in the United States: An Encyclopedia of History, Politics and Policy: Santa Barbara, CA, ABC-Clio, p. 242-248.

Griffith, W., 1965, Humphrey, a Candid Biography: New York, NY, William Morrow and Co., 337 p.

Gutmann, M. P., 2005, Great Plains Population and Environment Data: Agricultural Data, 1870-1997 [United States]: Ann Arbor, MI, Interuniversity Consortium for Political and Social Research (accessed August 2020).

Hand, I. F., 1934, The character and magnitude of the dense dust cloud which passed over Washington, DC, May 11, 1934, Monthly Weather Review, v. 62, p. 156.

Hansen, Z. K., and Libecap, G. D., 2004, Small farms, externalities, and the Dust Bowl of the 1930s, Journal of Political Economy, v. 112, p. 665–694.

Hovde, M. R., 1934, The great dust storm of November 12, 1933, Monthly Weather Review, v. 62, p. 12–13.

Hugenholtz, C. H., and Wolfe, S. A., 2005a, Biogeomorphic model of dunefield activation and stabilization on the northern Great Plains, Geomorphology, v. 70, p. 53-70.

Hugenholtz, C. H., and Wolfe, S. A., 2005b, Recent stabilization of active sand dunes on the Canadian prairies and relation to recent climate variations, Geomorphology, v. 68, p. 131-147.

Hurt, R. D., 1981, The Dust Bowl: An Agricultural and Social History: Chicago, IL, Taylor Trade Publications, 214 p.

Johnson, V., 1947, Heaven's Tableland: The Dust Bowl Story: New York, NY, Da Capo Press, 288 p.

Joseph Hutton Collection, South Dakota Agricultural Heritage Museum Records, UA 39, South Dakota State University Archives and Special Collections, Hilton M. Briggs Library, Brookings, South Dakota.

King, J., Etyemezian, V., Sweeney, M., Buck, B.J., and Nikolich, G., 2011, Dust emission variability at the Salton Sea, California, USA, Aeolian Research, v. 3, p. 67–79.

Kohler, J. P., 1936, Dust storms in the United States, June 1936, Monthly Weather Review, v. 64, p. 206.

Kumlien, W. F., 1937, A Graphic Summary of the Relief Situation in South Dakota (1930-1935), Bulletin 310 South Dakota Experiment Station, Brookings, SD, p. 5-63.

Lee, J. A., and Gill, T. E., 2015, Multiple causes of wind erosion in the Dust Bowl, Aeolian Research, v. 19, p. 15–36.

Martin, R. J., 1936a, Dust storms in the United States, April 1936, Monthly Weather Review, v. 64, p. 137.

Martin, R. J., 1936b, Dust storms of May 1936 in the United States, Monthly Weather Review, v. 64, p. 176.

Martin, R. J., 1936c, Dust storms of July 1936 in the United States, Monthly Weather Review, v. 64, p. 239.

Martin, R. J., 1939, Dust storms of 1938 in the United States, Monthly Weather Review, v. 67, p. 12–15.

Mason, J. A., Jacobs, P. M., Greene, R. S., and Nettleton, W. D., 2003, Sedimentary aggregates in the Peoria Loess of Nebraska, USA, Catena, v. 53, p. 377-397.

Mattice, W. A., 1935, Dust storms, May 1935, Monthly Weather Review, v. 63, p. 175.

Muhs, D. R., Stafford, T. W., Been, J., Mahan, S. A., Burdett, J., Skipp, G., and Rowland, Z. M., 1997, Holocene eolian activity in the Minot dune field, North Dakota. Canadian Journal of Earth Sciences, v. 34, p. 1442-1459.

National Oceanic and Atmospheric Administration [NOAA], 2020, Climate at a Glance: Statewide Time Series: https://www.ncdc.noaa.gov/cag/statewide/timeseries/ (accessed August 2020).

Peters, D. P., Sala, O. E., Allen, C. D., Covich, A., and Brunson, M., 2007, Cascading events in linked ecological and socioeconomic systems, Frontiers in Ecology and the Environment, v. 5, p. 221–224.

Petrie, M. D., Brunsell, N. A., Vargas, R., Collins, S. L., Glanagan, L. B., Hanan, N. P., Litvak, M. E., and Suyker, A. E, 2016, The sensitivity of carbon exchanges in Great Plains grasslands to precipitation variability, Journal of Geophysical Research and Biogeosciences, v. 121, p. 280–294.

PRISM Climate Group, 2020, Historical Past Time Series Datasets, Oregon State University, Corvallis, OR. Available at: http://prism.oregonstate.edu (accessed August 2020).

Records of the Natural Resources Conservation Service, 1875-2002, Record Group 114, National Archives at College Park, College Park, MD.

Rothman, H. K., 2000, Saving the Planet: The American Response to the Environment in the Twentieth Century: Chicago, IL, Ivan R. Dee, 224 p.

Sala, O. E., Parton, W. J., Joyce, L. A., and Lauenroth, W. K., 1988, Primary production of the central grassland region of the United States, Ecology, v. 69, p. 40–45.

Schubert, S., Suarez, M., Pegion, P., Koster, R. D., and Bacmeister, J. T., 2004, On the cause of the 1930s Dust Bowl, Science, v. 303, p. 1855–1859.

Sims, P. L., and Bradford, J. A., 2001, Carbon dioxide fluxes in a southern plains prairie, Agriculture and Forest Meteorology, v. 109, p. 117–134.

Soil Survey Staff [SSS], Natural Resources Conservation Service, and United States Department of Agriculture (2017) Web Soil Survey. Available at: https://websoilsurvey.sc.egov.usda.gov/ (accessed August 2020).

South Dakota State Climate Office Records, 2018, South Dakota State University Archives and Special Collections, Hilton M. Briggs Library, Brookings, South Dakota, MA 37.

Stein, W. J., 1973, California and the Dust Bowl: Westport, CT, Greenwood Press, Inc.

Stock, C. M., 1992, Main Street in Crisis: The Great Depression and the Old Middle Class on the Northern Plains: Chapel Hill, NC, University of North Carolina Press, 305 p.

Sweeney, M. R., and Mason, J. A., 2013, Mechanisms of dust emission from Pleistocene loess deposits, Nebraska, USA, Journal of Geophysical Research: Earth Surface, v. 118 p. 1460–1471.

Sweeney, M. R., Etyemezian, V., Macpherson, T., Nickling, W., Gillies, J., Nikolich, G., and McDonald, E., 2008, Comparison of PI-SWERL with dust emission measurements from a straight-line field wind tunnel, Journal of Geophysical Research: Earth Surface, v. 113, no. F01012.

Sweeney, M. R., Lu, H., Cui, M., Mason, J. A., Feng, H., and Xu, Z., 2016a, Sand dunes as potential sources of dust in northern China, Science China Earth Sciences, v. 59, p. 760–769.

Sweeney, M. R., Zlotnik, V.A., Joeckel, R. M., and Stout, J. E., 2016b. Geomorphic and hydrologic controls of dust emissions during drought from Yellow Lake playa, West Texas, USA, Journal of Arid Environments, v. 133, p. 37–46.

The Nature Conservancy [TNC], USDA Forest Service and U.S. Geological Survey, based on Bailey, and Robert, G., 1995, Description of the Ecoregions of the United States (2nd ed.). Misc. Pub. No. 1391, Map scale 1:7,500,000. Washington, DC: USDA Forest Service, 108.

United States Geological Survey [USGS], 2017, Red River of the North at Fargo, North Dakota – 110 years: https://www.usgs.gov/centers/dakota-water/science/red-river north-fargo-north-dakota-110-years?qt-science_center_objects=0#qt science_center_objects (accessed March 2021).

Wiche, G., Lent, R. M, Rannie, W. F., and Vecchia, A. V., 1997, A History of Lake Level Fluctuations for Devils Lake, North Dakota, since the early 1800s, Proceedings of the 89th Annual Meeting, North Dakota Academy of Science: Grand Forks, ND, p. 34-39.

Wieczorek, M. E., 2014, Area- and Depth-Weighted Averages of Selected SSURGO Variables for the Conterminous United States and District of Columbia: U.S. Geological Survey Data Series 866.

Williams, P.A., Cook, E. R., Smerdon, J.E., Cook, B. I., Abatzoglou, J. T., Bolles, K., Baek, S. H., Badger, A. M., and Livneh, A. M., 2020, Large contribution from anthropogenic warming to an emerging North American megadrought, Science, v. 368, p. 314-318.

Worster, D., 1979, Dust Bowl: The Southern Plains in the 1930s: New York, NY, Oxford University Press, 322 p.