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Publication trends in aeolian research: An analysis of the Bibliography of Aeolian Research

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ABSTRACT

An analysis of the Bibliography of Aeolian Research has provided information regarding publication trends in aeolian research. Results suggest that there has been a significant increase in the number of publications per year since the first aeolian-research publication appeared in 1646. Rates of publication have increased from only three publications in the 17th Century to nearly three publications per day in the 21st Century. The temporal distribution of publications follows a complex pattern that is influenced by many factors. In the 17th and 18th Centuries, publications appear as isolated clusters indicating limited interest in aeolian research and limited opportunities for individuals to contribute to scientific literature. With time, many new scientific societies are formed and many new scientific journals are established, opening new opportunities for scientists to contribute to scientific discourse. Landmark publications open up new research areas and define new directions for aeolian research. General advances in science and technology provide new techniques for sampling blowing sand and dust. In addition, clear signs exist that publication rates respond to major environmental and climatic events, especially large-scale disasters that focus attention on wind erosion and blowing dust. The Sirocco dust events of 1901–1903, the North American Dust Bowl of the1930s, and the recent sand and dust storm problems in China have all led to significant increases in the number of publications in aeolian research. Rates of publication are negatively influenced by major political and social upheavals, especially global conflicts such as World Wars I and II. Sudden shifts in government structure and support can also influence publication rates. A good example is the increased publication rates in China following the end of the Cultural Revolution, a trend that continues today.

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1. Introduction

Aeolian research is a sub-discipline of the physical sciences that focuses on the activity of the winds, with an emphasis on the winds' ability to interact with and shape the surface of the Earth and other planets. Aeolian research spans a broad array of disciplines and may include the study of aeolian processes and associated aeolian landforms, deposits, and sedimentary features; the study of wind erosion and its control by tillage, cover crops, shelterbelts, and other management practices; and the study of mineral dust, dust emissions and the effects of fine particulate matter on climate and air quality.

Over the past decade, an extensive Bibliography of Aeolian Research (BAR) has been constructed that contains references to every known scientific manuscript published in the field of aeolian research (http://www.lbk.ars.usda.gov/wewc/biblio/bar.htm). The BAR currently contains over 29,000 bibliographic citations and the number is steadily increasing as new publications are added each month.

As with most bibliographies, the Bibliography of Aeolian Research has benefited from past bibliographies. The BAR lists forty-six major bibliographies and many smaller ones that focus on at least one aspect of aeolian research and most of these have been incorporated into the BAR. The older bibliographies are especially important because they provide a record of early publications that otherwise may have been forgotten. The oldest bibliography that has been incorporated into the BAR is the *Bibliography of Meteorology* compiled by Oliver Lanard Fassig, a bibliographer and librarian working for the U.S. Signal Office of the United States War Department. Published in 1889, Dr. Fassig states that the *Bibliography of Meteorology* is "A classed catalogue of the printed literature of meteorology from the origin of printing to the close of 1881" (Fassig, 1889). Of special interest here is a section titled "Showers of Miscellaneous Matter", which includes a list of publications on dust storms, dust falls, and dust rains, topics of much interest in the early days of aeolian research.

Citations have also been extracted from the *Bibliography of Eolian Geology* prepared for the United States Department of Agriculture by

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Stuntz and Free (1911). Steven Conrad Stuntz was a bibliographer and librarian working at the National Agricultural Library and he collaborated with USDA soil scientist Edward Elway Free to construct a comprehensive bibliography of more than three thousand entries, all of which were published prior to 1911.

Other important bibliographies include two comprehensive bibliographies compiled by Andrew Warren of the University College London titled *A Bibliography of Wind Erosion and Related Phenomena* and *A Bibliography of Aeolian (Eolian) Sand Dunes and Related Phenomena*. The Bibliography of Aeolian Research contains more citations extracted from these two bibliographies than from any other source.

Within the last decade, additional bibliographic citations have been collected by searching databases and by perusing the "references" section of papers published in pertinent journals. In addition, members of the aeolian research community often send notification of recent publications or alert the editors to missing citations. New additions are uniformly formatted and merged into a central database maintained at the USDA-Agricultural Research Service in Lubbock, Texas.

Although the Bibliography of Aeolian Research is primarily a text-based data set, a proper analysis of the BAR can provide quantitative information regarding publication trends in aeolian research including information regarding historical changes in the number of publications per year, shifts in language, information regarding the nationality of authors responsible for aeolian research, and shifts in subject matter.

Here we begin our analysis by simply counting the number of publications in the Bibliography of Aeolian Research for each year. The results of this analysis are plotted for the period 1645 to 2005 in Fig. 1.

2. Aeolian research in the 17th Century

The oldest document listed in the Bibliography of Aeolian Research dates to 1646 when Godefroy Wendelin, a Flemish astronomer, published *Pluvia purpurea Bruxellensis*, which may be translated from the Latin as "The purple (or dark red) rain of Brussels" (Wendelin, 1646). This report was immediately followed by another edition with a different title: *De caussis naturalibus pluvia purpurea Bruxellensis*, or "The natural cause of the purple (or dark red) rain in Brussels" (Wendelin et al., 1647).

Historical accounts of what transpired suggest that a purple or dark-red rain fell on Brussels on 6 October 1646, and the shower elicited much interest and concern (State, 2004). Wendelin, who was visiting Brussels at the time, obtained a sample of the rainwater and began to examine it (Anonymous, 1901). Wendelin noted a yellowish color when a small quantity of the water was examined. Deposited on paper, it was also yellow, and this color persisted after desiccation. Wendelin also found that the rainwater had a tart taste, similar to the water of a mineral spa. Unfortunately, Wendelin's rudimentary experiments did not lead to a clear explanation as to the root cause of the dark-red rain. Today, we recognize that red rains typically result from the wet deposition of African dust that has blown across the European continent; however, at the time of Wendelin's investigation, red rains were still a great mystery.

The next publication listed in the Bibliography of Aeolian Research is a letter written in 1668 by an English gentleman, Thomas Wright, who describes a sand cloud that "overwhelmed a great tract of land in the County of Suffolk" and some measures taken to halt the encroachment of these sands, including the use of hedge-row wind-barriers (Wright, 1668). Wright's letter, published in the Philosophical Transactions of the Royal Society of London in 1668, is the earliest known publication that describes a sandstorm caused by improper land-use practices and it is the first to discuss control measures employed to stabilize drifting sands.

The two "red rain" reports by Wendelin and the "sand cloud" letter by Wright are the only known aeolian-research publications dating to the 17th Century. These early publications are important in that they mark the beginning of a long line of research that will follow in their path.

3. Aeolian research in the 18th Century

The Bibliography of Aeolian Research lists a total of forty-one 18th-Century publications with a varied mixture of languages including Dutch, English, French, German, Italian, Latin, Russian and Swedish. Of the forty-one publications, twenty-three (56%) focus on the wet deposition of dust, and thirteen publications (32%) report attempts to stabilize drifting sands. Two reports also describe sand storms, and three accounts address exploration and travel through lands with aeolian landforms.

One of the more notable 18th-Century publications includes the first scientific description of European loess deposits by the Italian geographer and naturalist Luigi Ferdinando Marsigli (Marsigli, 1726). In his early career, Marsigli served the Habsburg rulers in the Hungarian wars against the Turks where he took part in military actions in the final decades of the 17th Century (Stoye, 1994). Marsigli spent a portion of his military service as a military engineer, where he was able to employ his excellent powers of observation and technical abilities. He also found time to devote to his favorite scientific pursuits. He made astronomical observations, measured the flow and size of

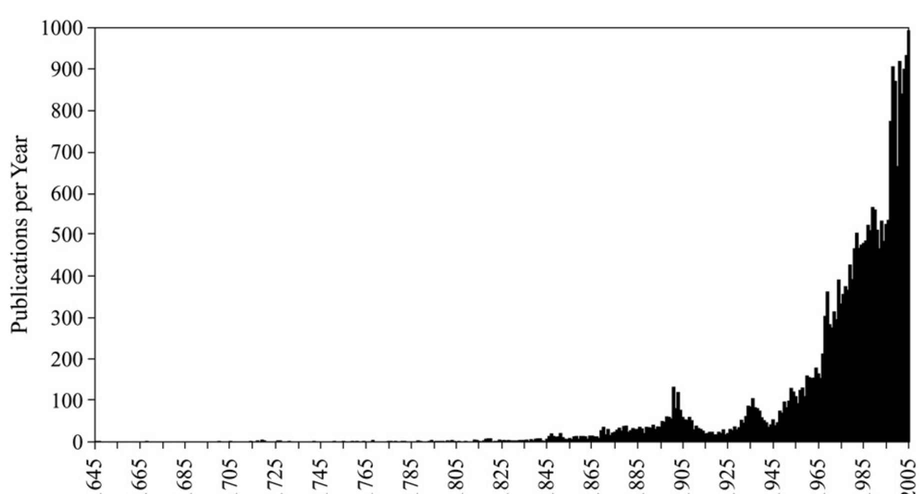

Fig. 1. Plot of the distribution of aeolian-research publications from 1645–2005.

rivers, studied sedimentary deposits, and sketched and recorded the birds, fish, and fossils of various places. In the course of his almost two decades in Hungary, Marsigli wrote a series of academic volumes including "Danubius Pannonico-Mysicus," published in The Hague in 1726. This six-volume work includes descriptions and sketches of loess exposures in the valley of the Danube River (Zöller and Semmel, 2001; Marković et al., 2004).

Another interesting 18th-Century publication includes early observations of the interaction between blowing sand and vegetation by the Swedish botanist and naturalist Carl Linnaeus. Linnaeus is well known as the "father of taxonomy" for laying the foundations of the modern scheme of nomenclature used in the classification of plants and animals. In 1749, Linnaeus journeyed to Skåne, the southernmost province of Sweden, to assess the natural resources in the region (Linnaeus, 1751). There he observed protective measures used to stabilize drifting sands and observed that sand accumulated in the wake of obstacles, forming dunes that were oriented in such a way as to indicate the prevailing direction of the erosive winds (Bärring et al., 2003).

Toward the end of the 18th Century, Nicolas-Théodore Brémontier began his work on "fixing" the drifting sands that were encroaching inland from the Bay of Biscay in Les Landes de Gascogne, France. Having learned from the failure of his predecessors, Brémontier conceived the idea of planting maritime pine to stabilize the sands and at the same time develop a viable forestry industry for the local economy (Faulkner, 1919). Brémontier summarized his work in a report titled "Mémoire sur les Dunes" published in 1796 (Brémontier, 1796). Techniques developed by Brémontier for the reclamation of "sand wastes" have proven to be highly influential in subsequent decades.

4. Aeolian research in the 19th Century

In the 19th Century, we begin to see the first signs of significant growth in publication rates. Compared to a total of three 17th-Century publications and forty-one 18th-Century publications, the Bibliography of Aeolian Research cites 1386 publications dating to the 19th Century. A plot of the temporal distribution of these 19th-Century publications is shown in Fig. 2.

Results suggest that throughout the early 1800s, intermittent packets or isolated clusters of aeolian-research publications occur. A small cluster of seven publications occur from 1801–1804, another cluster of eight publications appear from 1813–1815, and another cluster of thirty-five publications from 1818–1820. Most of the publications in these clusters, 71% to be exact, focus on wet deposition of dust ("red rains", "blood rains", "earth rains", etc.). Throughout the 19th Century, a report of dust deposition in one part of the world would often trigger numerous reports of dust deposition observed in other places and this may partly explain the clustering of these early 19th-Century publications.

Another more prominent cluster of 98 publications appears from 1846 to 1852 with peaks of 19 publications in 1847 and 20 publications in 1851. Within this seven-year cluster, 70% of the publications focus on the transport of dust from the African continent and the resulting dust rains and dust falls observed in Europe and off the Atlantic coast of Africa. One such paper was written by Charles Darwin, who was better known for his theory of evolution. Darwin summarized numerous reports of dust observed at sea and provided an account of African dust adhering to the rigging and accumulating in the windsock of the H.M.S. Beagle while sailing ten miles off the northwest coast of Africa (Darwin, 1846). During this same period, Christian Gottfried Ehrenberg, a German naturalist, published numerous papers on dust rains, blowing dust, and the study of the various microscopic organisms attached to airborne dust particles. As was common at this time, many of Ehrenberg's papers, which were written in German, were translated into French and English and republished in other journals so that a single paper often spawned numerous publications.

In 1853, Richard John Nelson, a British army officer assigned to the Royal Engineer Department, was the first to use the word "Æolian" to describe a geological process when he published a paper in the ninth volume of the Quarterly Journal of the Geological Society of London titled "On the geology of the Bahamas, and on coral formations generally" (Nelson, 1853). Nelson served in the British crown colony of the Bahamas from 1849 to 1851, where he was employed in the construction and maintenance of the various works of defense (Lee, 1894). Nelson noted that the Bahamas are mainly composed of calcareous sands formed from "comminuted" marine shell and coral fragments transported from the shore by strong winds. He also observed that, because of rain and the natural lime content of the calcareous grains, the sand deposits had in some locations consolidated into hard rock. Nelson named this calcareous sandstone "Æolian rock."

Among the more noteworthy mid-19th-Century publications involves the study of wind abrasion. In 1855, an English geologist visiting a beach near Land's End and an American geologist exploring a pass through the San Bernardino Mountains of California independently reached the same conclusion regarding the influence of drifting sand on the cutting and polishing of hard rocks and minerals.

Robert Were Fox of Cornwall, better known for his studies on terrestrial magnetism and subterranean temperatures, was visiting the shore of Whitsand Bay to the north of Land's End point in

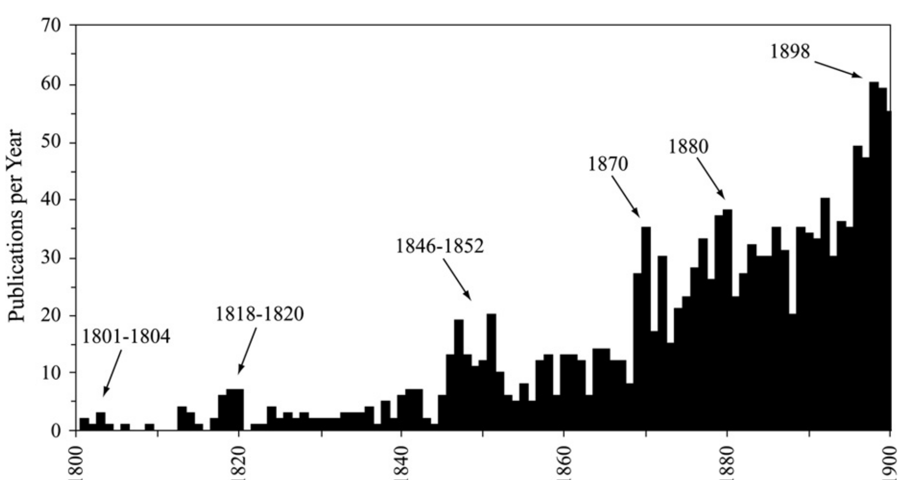

Fig. 2. Plot of the distribution of aeolian-research publications in the 19th Century.

southwest England when he noticed some striking evidence regarding the "influence of drifting sand in the wearing away the surfaces of hard granite rocks" (Fox, 1855). Fox recognized that dry sand, driven by strong onshore winds, had preferentially abraded and polished the faces of granite rocks inclined toward the beach. Fox summarized his observations in a short note which appeared in The Quarterly Journal of the Geological Society of London in 1855 (Fox, 1855).

Also in 1855, William Phipps Blake published a paper in the American Journal of Science and Arts titled "On the grooving and polishing of hard rocks and minerals by dry sand" (Blake, 1855). Blake had been working as a geologist on a survey crew seeking the best route for a planned transcontinental railroad across the United States. While exploring a pass through the southern extension of the San Bernardino Mountains of California, Blake witnessed the process of wind abrasion first hand as he observed grains of sand "pouring over the rocks in countless myriads," driven by strong winds that sweep through the Pass of San Bernardino from the ocean to the interior (Blake, 1855). He writes, "Wherever I turned my eyes – on the horizontal tables of rock, or on the vertical faces turned to the wind – the effects of the sand were visible: there was not a point untouched, the grains had engraved their track on every stone." Blake's final report of his explorations titled "Report of a Geological Reconnaissance in California" contains a sketch labeled "Rock, cut by drifting sand" (Blake, 1858). This sketch is the earliest known graphical depiction of what would later be known as a "ventifact."

During the second half of the 19th Century, publication rates become less intermittent with the first signs of sustained growth. Annual publications jump from 8 publications in 1868 to 27 publications in 1869; peaking at 35 publications in 1870. Roughly 67% of the publications in 1869 and 71% of the publications in 1870 were focused on dust rains (wet deposition) or dust falls (dry deposition) observed primarily in Italy and Germany. This strongly suggests that occasional plumes of African dust were again blowing across the European continent and provoking widespread interest.

The second half of the 19th Century marks an important shift in our understanding of loess, especially with regard to its formation, for it was in 1870 that Ferdinand von Richthofen first proposed his "subaërial" hypothesis regarding the origin of loess (Richthofen, 1870). Richthofen, a German geologist, geographer, and explorer, traveled extensively throughout his life. He took part in a Prussian expedition in East Asia from 1860 to 1862, worked as a geologist in the western United States from 1862 to 1868, and then explored China and Japan from 1868 to 1872 (Larkin and Peters, 1993). While in China, Richthofen traveled across portions of the Taklimakan Desert, visited the salt incrusted dry lakebed of Lop Nor, and studied various mountain ranges, one of which was subsequently named the Richthofen Range (Richthofen, 1877–1912). Richthofen experienced numerous dust storms during his travels and observed how dust was transported over great distances from the arid regions of western China and deposited in the more humid and more vegetated regions of eastern China (Richthofen, 1882). He concluded that the extensive loess deposits of China were most likely constructed by this aeolian process (Richthofen, 1872).

Prior to the introduction of the "subaërial" hypothesis, loess deposits were believed to be of "subaqueous" origin, formed by the submergence of lands by great floods or by the settling of fine sediments in glacially dammed lakes (Belt, 1877; Howorth, 1882). Increasingly scientists began to recognize that the various subaqueous theories were not supported by the facts while other scientists tenaciously hung on to their discredited theories (Jentzsch, 1877; Whitney, 1877; Hilgard, 1879; Broadhead, 1879). As the debate over the aeolian versus aqueous origin of the loess raged on, numerous publications were generated. It mattered little whether a scientist was for or against the aeolian hypothesis; in either case, aeolian processes were discussed adding to the body of literature regarding aeolian research from 1870 to the end of the 19th Century.

Advances in science and technology in the 19th Century also led to new directions for aeolian research. One good example, of which there are many, involves advances in our understanding of electricity and the subsequent development in 1860 of a portable electrometer by William Thomson (Lord Kelvin) (Thomson, 1860). Charles Michie Smith, a professor of the Physical Sciences at Madras Christian College in India, used such a device to measure electrical potential gradients in the atmosphere above Madras (Smith, 1885). Smith noticed that negative readings were obtained with dry, dusty, westerly winds that blew across the arid lands of India before reaching Madras. If the winds veered around so as to blow from the sea, the electrical potential immediately reversed and became positive. He concluded that there was an "intimate connection between the presence of dust and the negative electrification of the air" (Smith, 1885).

The development of a "dust counter" by the Scottish physicist and meteorologist John Aitken allowed for the first truly quantitative measurements of the concentration of atmospheric dust (Aitken, 1889, 1891). In the past, reports of atmospheric dust were typically casual descriptions of dust storms or dust falls at various locations. Such reports were purely qualitative in nature. Aitken's dust counter allowed for precise measurements of dust concentration. Fridlander (1896) used a portable version of the Aitken dust counter to measure the number of dust particles per cubic centimeter of air at various locations during a voyage around the world. He was able to provide, for the first time, some information regarding the global distribution of dust over the open ocean. He also carried a "pocket dust counter" as he climbed various mountains in the Swiss Alps where he obtained measurements of dust concentration at altitudes from 2000 to over 4000 m. These early measurements of the vertical distribution of atmospheric dust by Fridlander (1896) and similar measurements by Aitken (1894) demonstrated that the quantity of dust diminishes rapidly as one ascends.

Toward the end of the 19th Century, annual publication numbers rise from 35 publications in 1895 to 49 publications in 1896, eventually reaching historical highpoints of 60 and 59 publications in 1898 and 1899, respectively. These late 1890s publications show a fairly diverse mix of subject matter with publications on dust storms, dust falls, dust devils, wind erosion, ventifacts, loess, sand dunes, and dry lakes. During the period 1898–1899, 25% of the publications were written by Russian authors whereas prior to this date, Russian publications rarely accounted for more than 10%. More than half of these Russian publications mention the word "mgla" which is the transliteration of "мгла", the Russian word for "dry haze" (United States Weather Bureau, 1943; Kotlyakov and Komarova, 2007). Here, мгла refers to a dust haze associated with dust storms that appear to have occurred in Russia's Voronezh, Saratov, and Astrakhan provinces, located in the East European Plain — an important agricultural region that is subject to frequent drought.

Important social and institutional factors also influenced rates of publication in the 19th Century. Throughout this century, especially during the latter half, substantial growth occurs in the number of scholarly societies devoted to various aspects of scientific research. One no longer had to travel to London, Paris, or Berlin to participate in meetings and contribute to the growing body of scientific literature. Scientists in far-flung places such as Australia could attend meetings at the Royal Society of New South Wales (founded 1821); or the Royal Society of Tasmania (founded 1843); or the Royal Society of South Australia (founded 1853). Researchers in South Africa could attend meetings at the Royal Society of South Africa (founded 1877) or the Geological Society of South Africa (founded 1895). Scientists in the United States could become members of the New York Academy of Sciences (founded 1817), the American Geological Society (founded 1819), or the American Geographical Society (founded 1851). Even those who lived far from the more populated regions of the United States had more opportunities with the establishment of science academies in the mid-west and western portions of the country. For example, the Kansas Academy of Science was founded in 1868, the Iowa Academy of Science in 1875, the Indiana Academy of Science in 1885, and the Texas Academy of Science was founded in 1892.

Scientific societies also became more specialized as the numbers expanded in the 19th Century. Thus, the Royal Society of London, a fairly broadly focused multidisciplinary organization, was joined by more narrowly-focused societies such as the Geological Society of London (founded 1807), the Meteorological Society of London (founded 1823), and the Royal Geographical Society of London (founded 1830). Other parts of the United Kingdom joined in with the formation of the Royal Geological Society of Cornwall (founded 1814), the Edinburgh Geological Society (founded 1834), the Yorkshire Geological Society (founded 1837), and the Liverpool Geological Society (founded 1859).

An attempt was made to quantify the growth of scientific societies in the 19th Century, especially those that pertain to aeolian research. Considering only those scientific societies whose publications appear in the Bibliography of Aeolian Research, one finds that the number of societies grew from around 28 at the beginning of the 19th Century to 168 societies at the close of the 19th Century. Similarly, one finds significant growth in the number of scientific journals available to aeolian researchers during the 19th Century. Considering only those journals that have more than one citation in the Bibliography of Aeolian Research, only 12 active scientific journals typically appear in the bibliography prior to 1800, whereas by 1850 this number had grown to 78, and by 1900 the number of active journals available to aeolian researchers had grown to 273. The growth in the number of scholarly societies and the associated growth in the number of scientific journals provided unprecedented opportunities for 19th-Century scientists to report interesting observations and discuss new theoretical ideas. This trend, which continues to the present day, has also led to a proliferation of publications in all aspects of scientific research.

5. Aeolian research in the 20th and 21st Centuries

Fig. 3 shows that publication rates reached historical high points at the dawn of the 20th Century with significant peaks of 132 publications in 1901, 80 publications in 1902, and 119 publications in 1903. Approximately half of the publications from 1901–1903 report blowing dust or dust deposition observed at various locations across Europe. This increased level of interest in aeolian dust appears to be in response to a climatic anomaly that produced a combination of dry conditions and strong winds in North Africa such that massive dust plumes were blowing from the African continent across Europe (Hellmann and Meinardus, 1901; White, 1901; Noble, 1903; Husar, 2000). These “Sirocco” dust events were primarily observed in March of 1901, January of 1902, and February of 1903 and were widely reported in various scientific journals, magazines, and newspapers (Barač, 1901; Hellmann, 1901; Mill, 1902; Hellmann, 1903; Mill and Lempfert, 1904; Husar, 2004). The 1901–1903 dust events provide clear examples of how singular environmental catastrophes can significantly influence publication rates in aeolian research.

In the early 20th Century, Europe remains the center of scientific research, thus, as Europe enters into the chaos of World War I (1914–1918), publication rates decline, reaching a minimum point of only 17 publications in 1919. Following WWI, rates of publication gradually increase as Europe gradually recovers and as the United States becomes a more significant factor in scientific research. The Dust Bowl on the Great Plains of North America contributes to the recovery of publication rates during the 1930s as this environmental disaster focuses attention on wind erosion and the consequences of improper agricultural practices. In 1936, for example, one third of the 104 publications listed in the Bibliography of Aeolian Research describe wind erosion, dust storms, or dust falls that can be attributed directly to the Dust Bowl.

Publication rates plunge downward again as the world is once again consumed by war. World War II (1939–1945) is clearly visible as a period with low publication rates with a minimum point of 35 publications in 1943. The War affected the number of publications and also affected the number of scientific journals available to researchers. Numerous journals either paused or permanently ceased publication during World War II; not surprisingly, the vast majority of these were German. Considering only those journals that appear in the Bibliography of Aeolian Research, we find that thirty German journals either paused or ceased publication because of the war. To a lesser extent other journals from other countries also paused or ceased publication during World War II, including two French, two Russian, two Hungarian, one British, one Polish, one Serbian and one Japanese journal. Across the Atlantic, three American journals also became casualties of the War. For example, the highly successful New York-based *Journal of Geomorphology* ceased publication in 1943 because the number of submitted manuscripts and the number of foreign subscribers had dropped to an unsustainable level (Johnson and Sharp, 1942).

Opinions varied regarding the importance of studying aeolian geomorphology during the War. The prominent geologist and geomorphologist, Eliot Blackwelder of Stanford University, wrote a letter to *Science* in which he argued that scientists should concentrate on work that contributes directly to the war effort (Blackwelder, 1942).

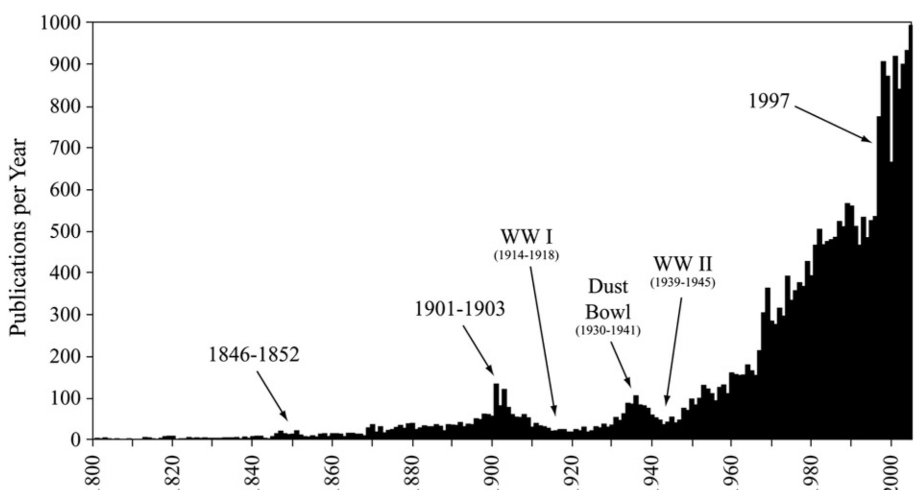

Fig. 3. Plot of the distribution of aeolian-research publications from 1800–2005.

He believed that, during this critical period in history, we could no longer afford to pursue esoteric research that had no immediate bearing on the war. Ralph Alger Bagnold, on the other hand, recognized that knowledge of the desert was critical to Allied war efforts in Africa. Even Bagnold was somewhat surprised, however, to find that the study of sand dunes, which he described as "our rather useless hobby," would play such a crucial role in the successful transport of military supplies and the successful execution of offensive actions as the war entered the "enormous empty solitudes of the inner desert" (Bagnold, 1945).

Bagnold had just finished his work on *The Physics of Blown Sand and Desert Dunes* (Bagnold, 1941) when he was recalled to the army in August 1939 (Bagnold, 1945). Bagnold's classic book, published in 1941, was one of only 358 aeolian-research publications to appear during the war years (1939–1945), yet it has proven to be one of the most influential publications in the history of aeolian research (Greeley and Iversen, 1985; Doyle and Julian, 2005).

Publication rates rapidly increased in the postwar period, partly because of the recovery of European science and partly because of the influence of the United States, which was left in a favorable position with regard to scientific research, being one of the few industrial countries not ravaged by war. Additionally, science and technology were recognized as critical factors leading to an Allied victory, and were seen as crucial in the Cold War era. As a result, the United States government became a significant supporter of basic and applied scientific research following World War II (Price, 1954).

Publication rates reach a historical highpoint of 129 aeolian-research publications in 1953. This peak falls toward the center of an extreme drought period, often referred to as the "1950s drought", that primarily affected the Great Plains and the American Southwest from 1942 through 1956 (Thomas, 1962; Swetnam and Betancourt, 1998). Within this drought period, William S. Chepil, a soil scientist and pioneer of wind erosion research in Canada, moved to Manhattan, Kansas to work for the Agricultural Research Service (ARS), a branch of the United States Department of Agriculture. Chepil along with other ARS scientists, such as Austin W. Zingg and Neil P. Woodruff, begin to conduct numerous studies of wind erosion and publish numerous reports and papers. Throughout the 1940s and 1950s, these three individuals would be responsible for over eighty research publications focused on wind erosion.

Rates of publication increase from 153 to 362 publications per year between the years 1966 and 1969 partly because of an increase in the number of publications focused on atmospheric dust. Interest in atmospheric dust and dust storms received a significant boost in the 1960s and 1970s from the passage of the Clean Air Act in the United States. The Clean Air Act of 1963 and its subsequent amendment in 1970 set National Ambient Air Quality Standards for Total Suspended Particulates (TSP), which provided an incentive for sampling airborne particulate matter.

Variability in the number of publications from year to year is considerable throughout the nineteen-seventies and eighties but the overall trend is clearly upward. By 1989, publication rates rise to an unprecedented level of 565 publications per year. Following this high point, publication rates appear to stabilize at values hovering around 510 publications per year for a six-year period from 1991 to 1996. Then in 1997, publication rates suddenly increase, achieving a new high of 905 publications per year in 1998. Such high publication rates continue to the present day. The highest rate of publication was recently recorded in 2005 with a value of 992 publications per year, which is equivalent to 2.7 publications per day.

China has had a major influence on recent rates of publication. One way to assess the influence of Chinese scientists is to count the number of publications each year that have Chinese first authors. Here we are not limiting our count to publications written in Chinese nor are we limiting consideration to scientists working in China; rather we are counting all publications with first authors that have Chinese names regardless of the language of publication or the affiliation of the scientist.

Chinese-authored publications first appear in the BAR starting with a paper on loess deposits by Lee (1928) and a small number of publications appear throughout the 1930s (Fig. 4). Large fractions of these early Chinese papers were published in the Bulletin of the Geological Society of China, a journal that was published in English. Chinese publication rates drop to zero during World War II and remain low immediately after the war. Following the formation of the People's Republic of China in 1949, Chinese publication rates do not immediately improve. A small number of Chinese publications begin to appear in the early 1960s but then Mao Zedong launched the Cultural Revolution in 1966. In the chaos and violence that ensued, many Chinese scientists were persecuted, imprisoned or killed, and as a consequence, the rate of Chinese publication declined. The few publications that appeared during the Cultural Revolution were most likely written by Chinese scientists working abroad. Following the death of Chairman Mao in 1976 and the subsequent end of the Cultural Revolution, Deng Xiaoping emerges as a pro-science leader and the number of Chinese publications begins to rise. Interest in wind erosion and sand and dust storms is fueled by the worsening environmental conditions in the marginal lands of Inner Mongolia and Western China. Chinese publication rates rise slowly but steadily from 1977 to 1996, and then publication rates shoot upward in 1997 and again in 2001, eventually reaching a peak of 449 Chinese-authored publications in 2005. This dramatic rise in Chinese-authored publications from 1996 to the present has contributed to the observed step-change

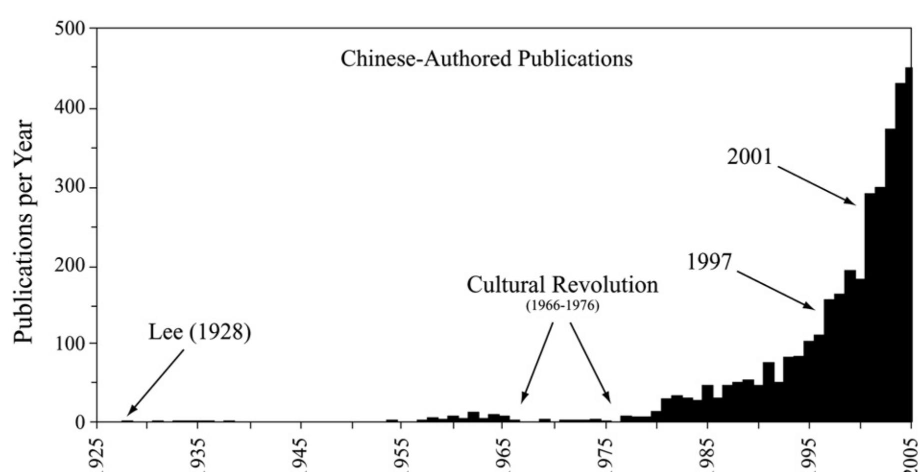

Fig. 4. Plot of the distribution of Chinese-authored aeolian-research publications from 1925 to 2005.

that is visible in the plot of all aeolian-research publications (Fig. 3), where annual publication numbers increase from 534 publications in 1996 to 992 publications in 2005.

6. Language trends

Publications cited in the Bibliography of Aeolian Research have been written in 38 different languages. These include Afrikaans, Arabic, Bulgarian, Catalan, Chinese, Croatian, Czech, Danish, Dutch, English, Estonian, Farsi, Finnish, Flemish, French, German, Hebrew, Hungarian, Icelandic, Indonesian, Italian, Japanese, Korean, Latin, Lithuanian, Norwegian, Polish, Portuguese, Romanian, Russian, Serbian, Slovakian, Slovenian, Somali, Spanish, Swedish, Turkish, and Ukrainian. Of course, not all languages are equally represented. Overall we find that 67.9% were written in English, followed by Chinese (9.5%), German (5.9%), French (5.5%), Russian (5.0%) and Polish (1.8%). All other languages account for less than 1%.

Further analysis of the Bibliography of Aeolian Research suggests that the relative proportions of the various languages have shifted through time (see Table 1). In the early years of aeolian research, Latin was the *lingua franca* for scientific communication. Of the three 17th-Century publications listed in the BAR, two were written in Latin and the remaining publication was written in English. As shown in Table 1, Latin remains a dominant language in the first half of the 18th Century, accounting for 53% of all publications. As we move into the second half of the 18th Century, the proportion of Latin publications drops to 4%, and thereafter Latin essentially ceases to be used for scientific communication. German, on the other hand, remains an important publication language throughout the 18th and 19th centuries, consistently accounting for over 40% of the publications listed in the Bibliography of Aeolian Research from 1700 to 1850 and 29% from 1850 to 1900. During the 20th Century, however, the fraction of German-language publications declines reaching a low point of 1% as we enter the 21st Century.

Other languages have brief periods with moderately high fractional values. Publications in Italian and Swedish reach high points of 21% and 13%, respectively, in the second half of the 18th Century. French reaches a peak value of 28% in the first half of the 19th Century and Russian peaks at 7% in the second half of the 20th Century. Other languages such as Polish, Dutch and Spanish remain at fairly low fractional values throughout history. English, in contrast, steadily increases with time and becomes the most common language for scientific communication. At its highest point in 1992, English accounted for 83% of all publications. Although English remains the dominant language for scientific communication, the proportion of publications written in English has recently declined from 83% in 1992 to 66% in 2005, whereas the fraction written in Chinese has risen from 5% in 1992 to 32% in 2005.

7. Subject trends

As bibliographic citations are entered into the master file of the Bibliography of Aeolian Research they are assigned a subject category that describes the primary focus of the paper. Admittedly, subject classification is somewhat subjective: the subject of a paper may overlap between categories and it is sometimes difficult to assign a single category. In such cases, additional research was necessary to ascertain the primary focus of a paper. Fortunately, the number of questionable publications was a small fraction of the total.

In this analysis, subject categories chosen for comparison include wind erosion, aeolian dust, and aeolian geomorphology. These categories are fairly broad so that each category contains many thousands of publications. In addition, these categories have a sufficient amount of separation from one another such that the instances in which publications overlap between categories are minimized.

By counting the number of publications in a given subject category for each year, one can establish subject-specific publication trends in aeolian research (Fig. 5). In addition to plotting the annual number of publications in each subject category, one can also plot the annual fraction of publications in each subject category (Fig. 6). Here we count the number of publications in a given subject category for each year and then divide by the total number of aeolian-research publications for the same year. The temporal distributions of these subject-specific fractions provide information regarding shifting levels of interest in various subjects over time.

7.1. Wind erosion

There are a total of 4938 publications in the wind erosion category, which accounts for 18% of all the publications in the Bibliography of Aeolian Research. Wind-erosion publications primarily focus on the loss of topsoil due to wind and the various control practices used to protect the soil, including the use of tillage, the planting of cover crops, and the use of shelterbelts or wind barriers.

The temporal distribution of the annual number and the annual fraction of publications on wind erosion are plotted as a function of time for the period 1850 to 2005 in the upper plots of Figs. 5 and 6. A careful examination of these plots reveals a number of interesting features. First, a conspicuous cluster of wind-erosion publications occurs in the 1890s to the early 1900s, with a peak occurring in 1899. This period of heightened interest in wind erosion appears to be associated with a far-reaching drought that, according to Eliot (1904), affected large portions of the British Empire from 1892–1902. This is the same drought period that culminated in the 1901–1903 Sirocco dust events, as discussed earlier. This dry period was also sensed in Australia where it was given the name “Federation Drought” (1895–1903) in honor of the formation of the Commonwealth of Australia in 1901 (Foley, 1957). According to Australian publications cited in the BAR for this period, problems with wind erosion were primarily concentrated in New South Wales (Maiden, 1903; McMaster, 1903). This same climatic anomaly also appears to have seriously affected portions of Russia. As mentioned previously, 25% of aeolian-research publications from 1898–1899 were written by Russian scientists. Here we can further refine this statement. An analysis of the BAR reveals that 41% of all the wind-erosion publications from 1891 to 1904 were written by Russian scientists. At the highpoint in 1899, twelve of fourteen papers classified as wind-erosion publications were written by Russian authors.

Table 1
The fraction of aeolian research papers written in various languages

Period	Number of Publications	Latin (%)	English (%)	Chinese (%)	German (%)	French (%)	Russian (%)	Polish (%)	Dutch (%)	Spanish (%)	Italian (%)	Swedish (%)
1645–1700	3	67	33	0	0	0	0	0	0	0	0	0
1700–1750	17	53	0	0	41	6	0	0	0	0	0	0
1750–1800	23	4	4	0	43	9	4	0	0	0	22	13
1800–1850	157	0	22	0	40	29	0	0	1	0	6	0
1850–1900	1157	0	40	0	29	18	4	0	1	0	6	1
1900–1950	2386	0	52	0	20	13	5	2	3	1	1	0
1950–2000	16640	0	72	5	4	5	7	2	1	1	0	0
2000–2005	4252	0	70	25	1	1	1	1	0	0	0	0

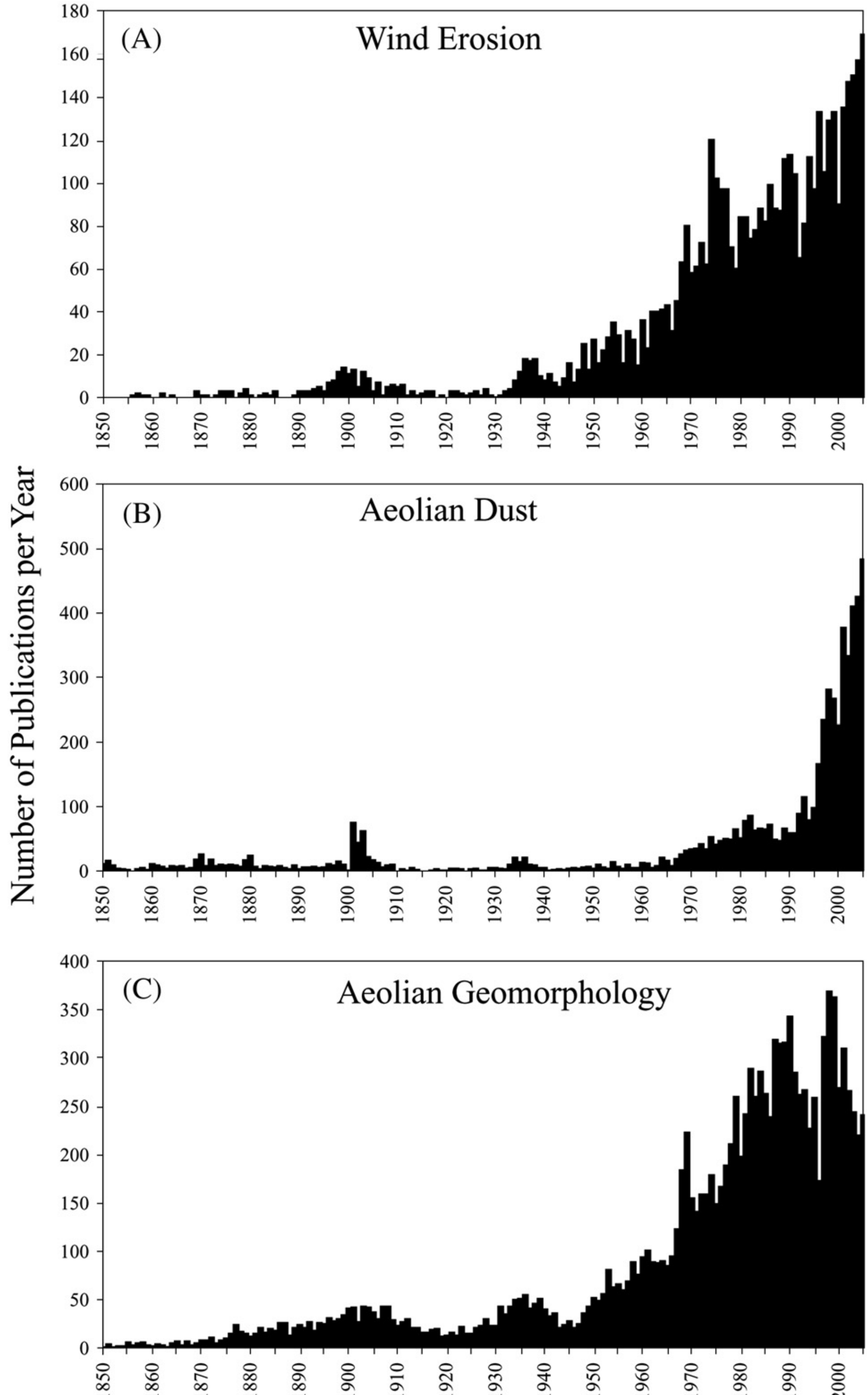

Fig. 5. The annual number of publications in the subject categories of (A) wind erosion, (B) aeolian dust, and (C) aeolian geomorphology from 1850 to 2005.

Another interesting pattern that is evident is the effect of the North American Dust Bowl on wind-erosion publication rates. Prior to the start of the Dust Bowl of the 1930s; numerous short periods occur without a single publication on wind erosion whereas after the Dust Bowl, not a single year occurs with less than a 14% wind erosion fraction. Similarly, a noticeable increase occurs in the number and fraction of publications on wind erosion from 1931 to 1938, which suggests that during the Dust Bowl years, interest in wind erosion grew significantly. Whereas the actual number of aeolian-research publications declined during World War II, the fraction of publications focused on wind erosion continued to rise during the war years and into the post-war period, reaching a highpoint of 34% in 1948. Other peaks of wind-erosion publication occur in 1954 and 1974–1975. Over the last quarter century, the fraction of publications focused on wind erosion has remained fairly stable, maintaining an average value of around 17%.

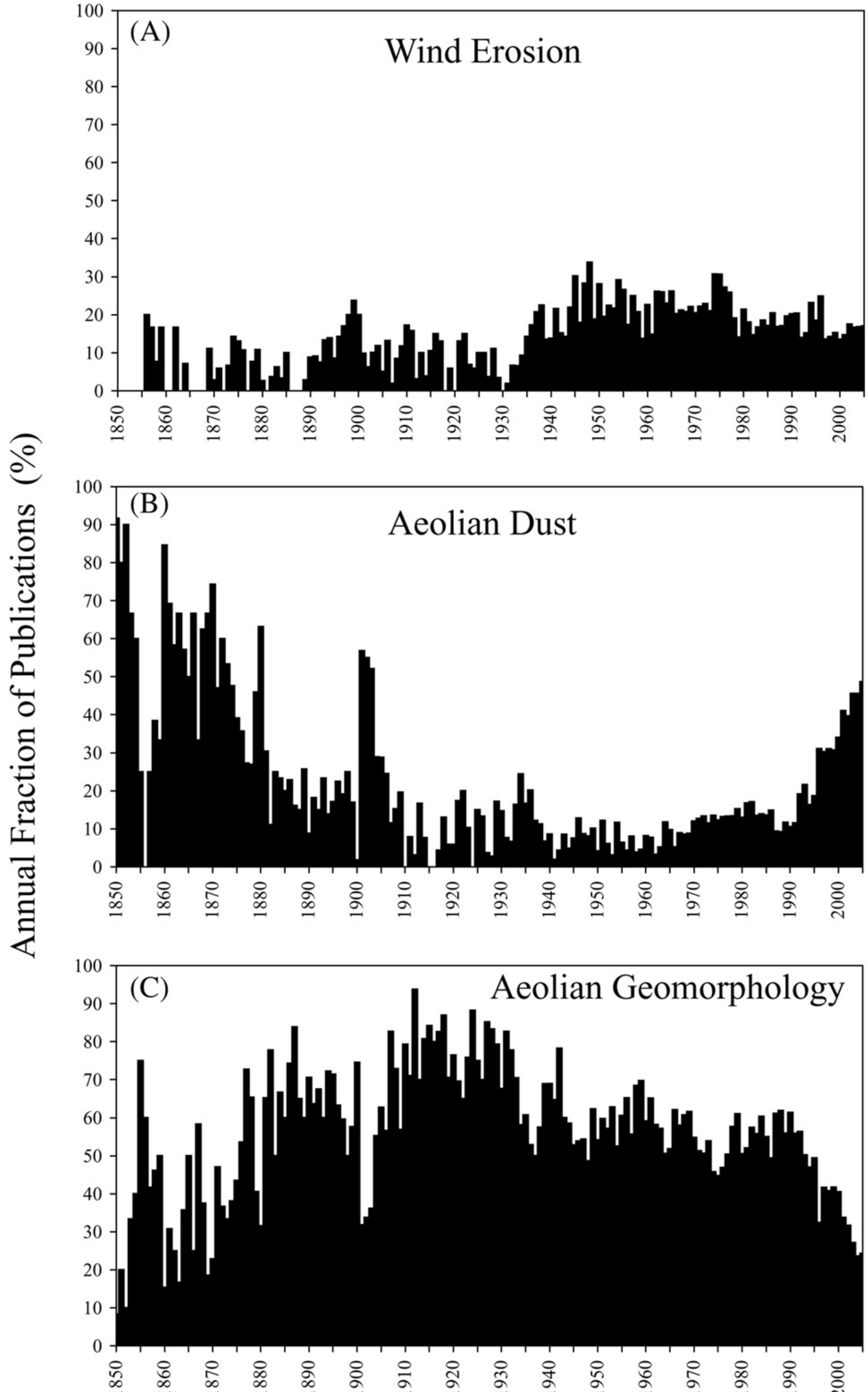

Fig. 6. The annual fraction of publications in the subject categories of (A) wind erosion, (B) aeolian dust, and (C) aeolian geomorphology from 1850 to 2005.

7.2. Aeolian dust

A total of 6627 publications address aeolian dust, which accounts for 24% of all the publications in the Bibliography of Aeolian Research. Publications on dust typically focus on the emission, transport, and deposition of dust or they describe the physical and chemical properties of atmospheric dust. A significant number of publications on dust also provide accounts of individual dust storms that may have occurred at various places or discuss the changing frequency and intensity of regional dust storms. This category also includes 93 publications that focus on the electrical effects of dust storms, 154 publications on dust devils, and 515 publications that focus on dust rains (wet deposition of dust).

The annual number and the annual fraction of papers on aeolian dust published from 1850 to 2005 are shown in the center plots of Figs. 5 and 6. An examination of the temporal pattern of publications on aeolian dust reveals a pattern that differs appreciably from that of the wind erosion category. Whereas sustained growth of publications on wind erosion began in the 1930s, sustained growth of publications on aeolian dust does not occur until the late 1960s, with more significant growth starting in 1996 and continuing to the present. This relatively recent surge in publications on dust has been driven partly by strong interest in recent Chinese sand and dust storms.

With regard to the annual fraction of publications on aeolian dust (Fig. 6), the overall distribution forms a U-shaped pattern with relatively large dust fractions occurring in the early 1850s followed by a decline, reaching a minimum in the mid-20th Century, and then increasing in the late 20th and early 21st Century. A number of prominent peaks stand out from the basic "U" pattern; these peaks correspond to major historical dust events, such as the 1901–1903 Sirocco dust events and, to a lesser extent, the 1930s Dust Bowl. With regard to publications on dust, the Dust Bowl does not stand out as prominently as one might expect. Considerably more dust publications were written from 1901 to 1903 than there were during the entire 1930s Dust Bowl. This suggests that despite the word "Dust" in "Dust Bowl," papers published during this period tended to focus more on wind erosion and practices to control wind erosion rather than blowing dust.

7.3. Aeolian geomorphology

Of the three subject categories, the aeolian geomorphology category contains the largest number of publications — a total of 13,300 publications. This number accounts for 48% of all the publications in the Bibliography of Aeolian Research. Publications in this category primarily focus on the description of aeolian landforms and deposits or the study of the various aeolian processes involved in the formation of aeolian landforms and deposits. The vast majority of the publications in the geomorphology category discuss sand dunes; however, it is difficult to provide a precise estimate of the fraction that focus exclusively on sand dunes because geomorphology publications often describe a mixture of landforms. This is especially true in the early days when explorers would venture to distant lands and then write large volumes that contained descriptions of all the various landforms they encountered during their travels. Thus, in this analysis, any publication that focuses on a single aeolian landform or a mixture of aeolian landforms was designated as an aeolian geomorphology publication and no attempt was made to separate them further.

As with all subject categories, it is necessary to establish boundaries that provide criteria for the inclusion or exclusion of publications from the category of interest. The geomorphology category primarily includes those publications that focus on natural aeolian landforms that result from natural aeolian processes. Publications that focus on the anthropogenic modification of landforms, especially those publications that report attempts at sand fixation or dune stabilization by the installation of sand fences or the application of soil binding agents, are considered to be more appropriately classified as publications on control of wind erosion and, therefore, are not included in the aeolian geomorphology category. A similar distinction can be made with regard to vegetation. If the focus of a publication is on the fixation of dunes by the planting of vegetation or the planting of shelterbelts, then such publications are considered to be wind erosion control publications. On the other hand, those publications that discuss natural dune forms that result from the natural interaction between plants and winds are included in the aeolian geomorphology category.

A plot of the temporal distribution of the number and fraction of geomorphology publications from 1850 to 2005 are summarized in the lower plots of Figs. 5 and 6. With regard to annual publication numbers, the distribution of aeolian geomorphology papers (Fig. 5) is quite similar to the plot of all aeolian research publications, shown in Fig. 1. With regard to the annual geomorphology fraction (Fig. 6), however, considerable variation occurs from year to year such that the temporal distribution of publications forms a somewhat complex pattern. The overall trend, however, appears to be one of gradual growth from 1850 to a peak value of 94% in 1912, followed by a downward trend.

One naturally wonders what drives publication trends in the subject category of aeolian geomorphology. Unlike the subject categories of wind erosion or aeolian dust, one would not expect the fraction of aeolian geomorphology publications to be influenced by major droughts, such as the Dust Bowl of the 1930s. Such environmental catastrophes tend to focus attention on wind erosion and associated dust storms but they do not necessarily focus attention on aeolian landforms. Certainly, basic human curiosity is a major motivating factor that drives individuals to study aeolian landforms. Human curiosity is not unique to this subject category, however, and it is not sufficient to explain publication trends in aeolian geomorphology.

Perhaps one possible reason for the increased interest in aeolian geomorphology from 1850 to the early 1900s may be related to the influence of European colonial expansion (Goudie, 1999). By the dawn of the 20th Century, the colonial powers of Europe had spread their empires to the ends of the Earth. As the colonial empires grew, a need arose to explore, survey, and catalog the natural resources of the growing dominion. As European geologists, geographers, and naturalists explored these territories, they encountered new and fascinating landscapes and they reported their findings in scientific journals and published various books and reports. In addition, non-scientists such as administrators, missionaries, farmers, businessmen, and military personnel were moving into the colonies and writing about their experiences. Because many of the new colonies were located in arid environments, these individuals would occasionally write about the various aeolian landforms that they observed.

Also during this period in history, the United States government was funding a series of geological surveys of the Western Territories. These investigations began in the 1830s, paused during the Civil War (1861–1865), and then continued after the war (Brookings Institution, 1919). In 1867, Ferdinand Vandeveer Hayden was appointed head geologist of the United States Geological and Geographical Survey of the Territories, and under his direction numerous geological expeditions and surveys were conducted and numerous reports were generated. In 1879, the United States Geological Survey (USGS) was established and under the direction of such legendary figures as Clarence King and John Wesley Powell, scientific investigations of the Great Plains and western United States grew at a more rapid pace. This increased interest in the geology and geography of the arid and semiarid regions of the United States helped to increase the overall number of publications that discuss various aspects of aeolian geomorphology in the second half of the 19th Century.

In addition to the formation of the United States Geological Survey, geological surveys were also established at the state level, starting with the North Carolina Geological Survey, founded in 1823. By the start of the 20th Century, most states had established some form of a geological survey that issued reports on a regular basis. Although these reports focused on a variety of topics, they occasionally included discussions of aeolian landforms and deposits. Annual reports from state geological surveys from states, such as Illinois, Iowa, Kansas, Missouri, Minnesota, North Carolina, and Texas, begin to appear in the Bibliography of Aeolian Research starting in the 1850s and help to increase the number of publications that discuss aeolian geomorphology from 1850 to the early 1900s.

Eventually, World War I and II impact publication rates, the colonial empires unravel, and increasing environmental concerns shift interest toward wind erosion and blowing dust. The result is a general downward trend in the fraction of papers focused on aeolian geomorphology from a high of 94% in 1912 to a low of 24% in 2005.

8. Summary

An analysis of the Bibliography of Aeolian Research has provided quantitative information regarding publication trends in aeolian research. Overall, results suggest that a tremendous growth occurred in the number of papers published each year since the initiation of aeolian research in the mid-17th Century. In the early years one would be lucky to find a single publication every few decades; today publication rates are approaching an unprecedented level of three publications per day. Depending on your point of view, such high rates of publication may be viewed either as a tremendous achievement or as an overwhelming flood of mostly unread papers. Certainly, it has become increasingly difficult to stay abreast of such a rapidly expanding body of scientific literature.

The temporal distribution of publications over the years has been shown to form a complex pattern with many peaks and troughs. In the 18th and early 19th Century, occasional clusters appear in the bibliographic record indicating isolated pockets of interest in aeolian research. Many new scientific societies are formed and many new scientific journals are established, opening new opportunities for scientists and setting the stage for future growth. In addition, general advances in science and technology provide new techniques for sampling dust and blowing sand. Throughout the 19th Century, many landmark papers were published that open up new research areas and define new directions for aeolian research. Thus, as we enter the 20th Century conditions are favorable for major advances in aeolian research.

Throughout the 20th Century clear signs indicate that publication rates respond to major environmental disasters, especially those disasters that focus attention on wind erosion and blowing dust. The African dust plumes that blew across Europe from 1901–1903, the North American Dust Bowl of the1930s, and the recent wind erosion problems in China have all spurred increases in the number of publications focused on aeolian research. On the other hand, global conflicts, such as World War I and II, disrupt the pursuit of knowledge in all scientific disciplines and aeolian research is no exception. In the aftermath of World War II, the United States emerges as an important contributor to global science, and publication rates increase rapidly as the scientific world, previously dominated by European institutions, is impacted by scholars from the United States. As more North American publications appear in the literature along with papers from other English-speaking nations, the English language gradually becomes the *de facto* language for scientific communication. At its highest point in 1992, English publications account for 83% of all publications in aeolian research.

Following the end of the Cultural Revolution in 1976, science in China begins to play a more important role as Chinese government support for science increases. Desertification of the semi-arid and arid regions of Inner Mongolia and Western China produces massive sand and dust storms that blow across China and well beyond its borders. The environmental problems in China focus attention on aeolian research and Chinese-authored publications begin to grow from 7 publications in 1977 to 449 publications in 2005. Similarly, the fraction of papers written in Chinese rise from 5% in 1992 to 32% in 2005 while the fraction of papers written in English drops from a high of 83% in 1992 to 66% in 2005.

One wonders what the future holds for aeolian research. Only time will tell because it is next to impossible to predict with any certainty the future based upon an analysis of the past. It is safe to say, however, that future publication trends will continue to be influenced by many of the same factors that influenced past publication trends. These include global conflicts, environmental disasters, technological innovations, political changes in government, and perhaps the most important factor, and the most difficult to predict, is the affect of the creative individual who single-handedly changes the course of aeolian research.

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