Observations and Projections:

Extreme Weather

5. Observations and Projections: Extreme Weather

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Introduction

According to the Intergovernmental Panel on Climate change (IPCC), "based on a range of models, it is *likely* that future tropical cyclones (typhoons and hurricanes) will become more intense, with larger peak wind speeds and more heavy precipitation associated with ongoing increases of tropical sea surface temperature" (IPCC 2007, p. 15). Since the IPCC contends the Earth already has experienced a warming unprecedented over the past millennium or more, the validity of these claims can be assessed by examining the extent to which the planet's emergence from the global chill of the Little Ice Age affected the frequency and magnitude of these extreme and often-deadly forces of nature.

When the historical record is reviewed, the data reveal there have not been any significant warminginduced increases in extreme weather events. This was the conclusion of the 2009 Nongovernmental International Panel on Climate Change (NIPCC) report (Idso and Singer 2009), and it is supported by the new scientific papers presented in this chapter.

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5.1 Precipitation

As noted in the previous chapter (see Section 4.3.1), Chu et al. (2010) found the precipitation predictions of the IPCC had not been realized throughout the part of the Pacific that is home to the Hawaiian Islands, and in fact just the opposite had occurred there: The three scientists determined, "since the 1980s, there has been a change in the types of precipitation intensity, resulting in more frequent light precipitation and less frequent moderate and heavy precipitation intensity," as well as a "shorter annual number of days with intense precipitation and smaller consecutive 5-day precipitation amounts and smaller fraction of annual precipitation due to events exceeding the 1961–1990 95th percentile in the recent epoch [1980–2007] relative to the first epoch [1950–1979]."

Similarly, in that chapter we noted Stankoviansky (2003) found extreme and destructive rainfall events were much more common throughout the Myjava Hill Land of Slovakia during the Little Ice Age than they have been subsequently, and this, in his words (and in harmony with the many references he cites), "is often regarded as generally valid for Central Europe." This conclusion runs counter to that of the IPCC, which equates destructive precipitation events and the flooding they cause with global warming.

In a model-based study of precipitation, Schliep et al. (2010) compared estimates of local extreme precipitation events using six regional climate models (RCMs), which run at a higher spatial resolution than global climate models (GCMs). The six RCMs were forced with a common set of reanalysis data, created by running a climate model that was fed real-world data for a 20-year simulation period. The area analyzed was North America, where winter precipitation was the response variable and the onehundred-year extremum of daily winter precipitation was the test statistic, extreme values of which were estimated by fitting a tailed distribution to the data, taking into account their spatial aspects.

The six RCMs showed similar general spatial patterns of extremes across North America, with the highest extremes in the Southeast and along the West Coast. However, when comparing absolute levels, which are most relevant to risk forecasts, the models exhibited strong disagreement. The lowest-predicting model was low almost everywhere in North America compared to the mean of the six models and, similarly, the highest-predicting model was above the mean almost everywhere. The difference between the two models was almost 60mm of daily precipitation (for the one-hundred-year extreme event) over much of the United States.

The other four models showed greatly differing spatial patterns of extremes from each other, and those differences were found to be statistically significant by F test. The researchers speculate that when driven by multiple GCMs rather than reanalysis data, the range of extreme outcomes would only increase. As a result, extreme rainfall event predictions may vary considerably among models and extend well beyond the realm of reality. The lesson we take from Schliep et al. is that model-based claims of a CO₂-induced increase in extreme precipitation events should be treated with considerable skepticism.

Another way to approach the question is to consider research on other possible causes of extreme participation events. The larger the effect of other causes, the less likely it is that CO_2 or warmer temperatures are responsible for observed trends. Along these lines, Hossain et al. (2009) review and discuss meteorological effects observed to occur in response to the impounding of water behind large dams.

Hossain et al. begin by noting, "in the United States alone, about 75,000 dams are capable of storing a volume of water equaling almost 1 year's mean runoff of the nation (Graf, 1999)," and "at least 45,000 large dams have been built worldwide since the 1930s." They also report "dam-driven land cover change can trigger changes in extreme precipitation patterns," citing the finding of Avissar and Liu (1996) that land use and land cover [LULC] patchiness "can enhance heavy rainfall." Likewise, they report "through LULC sensitivity studies (Pielke et al., 1997; Pielke and Zeng, 1989; Pielke et al., 2007), irrigated land near multipurpose reservoirs is seen to enhance thunderstorm development more than natural land cover conditions do (meaning before the dam was built)." They add, "Kishtawal et al. (2009) showed recently that increased urbanization downstream of large flood control dams can also trigger heavy rainfall patterns."

With respect to additional findings suggestive of the phenomenon they describe, Hossain et al. (2010) report Hossain et al. (2009) and Hossain (2010) have shown "extreme precipitation (99th percentile) has increased considerably more than increases seen in median precipitation (50th percentile) during the past century" and "this alteration may be more pronounced in arid and semiarid regions after the dam is built." Regarding the latter, they note "large dams in the regions of southern Africa, India, western United States, and Central Asia appeared to induce a greater increase in extreme precipitation than in other regions." Although there is a clear correlation between the building of large dams throughout the world and subsequent increases in extreme precipitation, the three scientists state in a cautionary note, "other factors may be involved, such as global climate change."

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5.2. Floods

The IPCC claims flooding has become more frequent and severe in response to twentieth century global warming. But it is important to establish whether floods are truly becoming more frequent or severe, and whether other factors might be behind such trends if they in fact exist. In this section we highlight studies addressing both questions.

To test for long-term changes in flood magnitudes and frequencies in the Mississippi River system of the United States, Pinter et al. (2008) "constructed a hydrologic database consisting of data from 26 rated both stations (with stage and discharge measurements) and 40 stage-only stations." Then, to help "quantify changes in flood levels at each station in response to construction of wing dikes, bendway weirs, meander cutoffs, navigational dams, bridges, and other modifications," they put together a geospatial database consisting of "the locations, emplacement dates, and physical characteristics of over 15,000 structural features constructed along the study rivers over the past 100-150 years." As a result of these operations. Pinter et al. write, "significant climate- and/or land use-driven increases in flow were detected," but they indicate "the largest and most pervasive contributors to increased flooding on the Mississippi River system were wing dikes and related navigational structures, followed by progressive levee construction."

In discussing the implications of their findings, Pinter et al. write, "the navigable rivers of the Mississippi system have been intensively engineered, and some of these modifications are associated with large decreases in the rivers' capacity to convey flood flows." Hence, it would appear man has indeed been responsible for the majority of the increased flooding of the rivers of the Mississippi system over the past century or so, but not in the way suggested by the IPCC. The question that needs addressing by the region's inhabitants has nothing to do with CO_2 and everything to do with how to "balance the local benefits of river engineering against the potential for large-scale flood magnification."

In a study designed to determine the environmental origins of extreme flooding events throughout the southwestern United States, Ely (1997) wrote, "paleoflood records from nineteen rivers in Arizona and southern Utah, including over 150 radiocarbon dates and evidence of over 250 flood deposits, were combined to identify regional variations in the frequency of extreme floods," and that information "was then compared with paleoclimatic data to determine how the temporal and spatial patterns in the occurrence of floods reflect the prevailing climate." The results of this comparison indicated "long-term variations in the frequency of extreme floods over the Holocene are related to changes in the climate and prevailing large-scale atmospheric circulation patterns that affect the conditions conducive to extreme flood-generating storms in each region." These changes, in Ely's view, "are very plausibly related to global-scale changes in the climate system."

With respect to the Colorado River watershed, which integrates a large portion of the interior western United States, she writes, "the largest floods tend to be from spring snowmelt after winters of heavy snow accumulation in the mountains of Utah, western Colorado, and northern New Mexico," such as occurred with the "cluster of floods from 5 to 3.6 ka," which occurred in conjunction with "glacial advances in mountain ranges throughout the western United States" during the "cool, wet period immediately following the warm mid-Holocene."

The frequency of extreme floods also increased during the early and middle portions of the first millennium AD, many of which coincided "with glacial advances and cool, moist conditions both in the western U.S. and globally." Then came a "sharp drop in the frequency of large floods in the southwest from AD 1100-1300," which corresponded, in her words, "to the widespread Medieval Warm Period, which was first noted in European historical records." With the advent of the Little Ice Age, however, there was another "substantial jump in the number of floods in the southwestern U.S.," which was "associated with a switch to glacial advances, high lake levels, and cooler, wetter conditions." Distilling her findings down to a single succinct statement and speaking specifically of the southwestern United States. Elv writes, "global warm periods, such as the Medieval Warm Period, are times of dramatic decreases in the number of high-magnitude floods in this region" [emphasis added].

Looking at the other side of the continent, Villarini and Smith (2010) "examined the distribution of flood peaks for the eastern United States using annual maximum flood peak records from 572 U.S. Geological Survey stream gaging stations with at least 75 years of observations." This work revealed, "in general, the largest flood magnitudes are concentrated in the mountainous central Appalachians and the smallest flood peaks are concentrated along the lowgradient Coastal Plain and in the northeastern United States." They also found "landfalling tropical cyclones play an important role in the mixture of flood generating mechanisms, with the frequency of tropical cyclone floods exhibiting large spatial heterogeneity over the region." They additionally write, "warm season thunderstorm systems during the peak of the warm season and winter-spring extratropical systems contribute in complex fashion to the spatial mixture of flood frequency over the eastern United States."

Of greater interest to the climate change debate, however, were their more basic findings: (1) "only a small fraction of stations exhibited significant linear trends," (2) "for those stations with trends, there was a split between increasing and decreasing trends," and (3) "no spatial structure was found for stations exhibiting trends." Thus they concluded, (4) "there is little indication that human-induced climate change has resulted in increasing flood magnitudes for the eastern United States."

Much the same was reported for Canada by Cunderlik and Ouarda (2009). They evaluated trends in the timing and magnitude of seasonal maximum flood events across that country, based on pertinent data obtained from 162 stations of the Reference Hydrometric Basin Network established by Environment Canada over the 30-year period 1974 to 2003. In spite of the supposedly unprecedented warming over the period of time they studied, the Canadian researchers report finding "only 10% of the analyzed stations show significant trends in the timing of snowmelt floods during the last three decades (1974–2003)," and they say these results imply "the occurrence of snowmelt floods is shifting towards the earlier times of the year," as would be expected in a warming world. However, they note most of the identified trends "are only weakly or medium significant results," and they add "no significant trends were found in the timing of rainfall-dominated flood events."

With respect to flood magnitudes, the two scientists state the trends they observed "are much more pronounced than the trends in the timing of the floods," but they note most of these trends "had negative signs, suggesting that the magnitude of the annual maximum floods has been decreasing over the last three decades." In addition, they found "the level of significance was also higher in these trends compared to the level of significance of the trends in the timing of annual maximum floods."

In Europe, Schmocker-Fackel and Naef (2010a) explored the relationship between climate and flooding from a paleo-perspective. Specifically, they collected and analyzed historical flood time-series of

14 catchments located in northern Switzerland, datasets for which stretched back a full five centuries. From these data the two Swiss scientists were able to identify four periods of frequent flooding in northern Switzerland, lasting between 30 and 100 years each (1560-1590, 1740-1790, 1820-1940, and since 1970). They report the first three periods of intervening low flood frequency (1500-1560, 1590-1740, and 1790-1810) were found to correspond to periods of low solar activity. However, they report, "after 1810 no relationship between solar activity and flood frequency was found, nor could a relationship be established between reconstructed North Atlantic indices Oscillation or reconstructed Swiss temperatures." In addition, they determined "the current period of increased flood frequencies has not vet exceeded those observed in the past." They also write, "a comparison with the flood patterns of other European rivers suggests that flood frequencies are not in phase over Europe." In light of their several diverse findings, Schmocker-Fackel and Naef (2010a) thus concluded "the current period with more floods in northern Switzerland, which started in the mid 1970s, might continue for some decades," even under conditions of "natural climatic variation."

In a contemporaneous paper on Switzerland floods, also authored by Schmocker-Fackel and Naef (2010b), the two researchers further explored this subject by analyzing "streamflow data from 83 stations with a record length of up to 105 years, complemented with data from historical floods dating back to 1850," in an effort to place the extreme flooding that occurred in their country in 1999, 2005, and 2007 in an historical construct. This expanded analysis indicated "in Switzerland, periods with frequent floods have alternated with quieter periods during the last 150 years" and "since 1900, flood-rich periods in northern Switzerland corresponded to quiet periods in southern Switzerland and vice versa." As for the fact that over the same period of time "three of the four largest large-scale flood events in northern Switzerland have all occurred within the last ten years," they report "a similar accumulation of large floods has already been observed in the second half of the 19th century." In addition, they state, "studies about changes in precipitation frequencies in Switzerland come to similar conclusions," citing the work of Bader and Bantle (2004).

In another paper from Europe, Diodato et al. (2008) conducted a detailed study of erosive rainfall in the Calore River Basin (southern Italy) "using data from 425-year-long series of both observations (1922–2004) and proxy-based reconstructions (1580–1921)." Their results showed pronounced interdecadal variations, "with multi-decadal erosivity reflecting the mixed population of thermo-convective and cyclonic rainstorms with large anomalies," while noting "the so-called Little Ice Age (16th to mid-19th centuries) was identified as the stormiest period, with mixed rainstorm types and high frequency of floods and erosive rainfall."

In the concluding section of their paper, the three researchers write, "in recent years, climate change (generally assumed as synonymous with global warming) has become a global concern and is widely reported in the media." In regard to concern over floods becoming more frequent and more severe as the planet warms, however, Diodato et al. say their study shows "climate in the Calore River Basin has been largely characterized by naturally occurring weather anomalies in past centuries (long before industrial CO_2 emissions), not only in recent years," and there has been a "relevant smoothing" of such events during the modern era.

Working in southeast Spain, Benito et al. (2010) reconstructed flood frequencies of the Upper Guadalentin River using "geomorphological evidence, combined with one-dimensional hydraulic supported by modeling and records from documentary sources at Lorca in the lower catchment." Guadalentin According to these scientists, the combined palaeoflood and documentary records indicated past floods were clustered during particular time periods: AD 950-1200 (10), AD 1648-1672 (10), AD 1769-1802 (9), AD 1830-1840 (6), and AD 1877-1900 (10). The first time interval coincides with the Medieval Warm Period, and the latter four fall within the confines of the Little Ice Age. By calculating mean rates of flood occurrence over each of the five intervals, one obtains a value of 0.40 floods per decade during the Medieval Warm Period and an average value of 4.31 floods per decade over the four parts of the Little Ice Age.

Czymzik et al. (2010) explored the relationship between level of warmth and degree of flooding as it may have been manifested in southern Germany over the past 450 years. In the opening paragraph of their paper, they observe "assumptions about an increase in extreme flood events due to an intensified hydrological cycle caused by global warming are still under discussion and must be better verified," while noting some historical flood records indicate "flood frequencies were higher during colder periods (Knox, 1993; Glaser and Stangl, 2004), challenging the hypothesis of a correlation between the frequency of extreme floods and a warmer climate."

Against this backdrop, Czymzik et al. retrieved two sediment cores from the deepest part of Lake Ammersee in southern Germany (48°00'N, 11°07'E), which they then analyzed via what they describe as "a novel methodological approach that combines microfacies analyses, high-resolution element scanning (μ -XRF), stable isotope data from bulk carbonate samples ($\delta^{13}C_{carb}$, $\delta^{18}O_{carb}$), and X-ray diffraction (XRD) analyses (Brauer et al., 2009)."

The six scientists determined the flood frequency distribution over the entire 450-year time series "is not stationary but reveals maxima for colder periods of the Little Ice Age when solar activity was reduced," while reporting "similar observations have been made in historical flood time series of the River Main, located approximately 200 km north of Ammersee (Glaser and Stangl, 2004), pointing to a wider regional significance of this finding."

Working in the United Kingdom a couple years earlier, Hannaford and Marsh (2008) noted "recent flood events have led to speculation that climate change is influencing the high-flow regimes of UK catchments" and "projections suggest that flooding may increase in [the] future as a result of humaninduced warming." Utilizing the U.K. "benchmark network" of 87 "near-natural catchments" identified by Bradford and Marsh (2003), Hannaford and Marsh conducted "a UK-wide appraisal of trends in highflow regimes unaffected by human disturbances" to test such speculation. They found "significant positive trends were observed in all high-flow indicators ... over the 30-40 years prior to 2003, primarily in the maritime-influenced, upland catchments in the north and west of the UK." However, they state, "there is little compelling evidence for high-flow trends in lowland areas in the south and east." They also note, "in western areas, high-flow indicators are correlated with the North Atlantic Oscillation Index (NAOI)," so "recent trends may therefore reflect an influence of multi-decadal variability related to the NAOI." In addition, they state, longer river flow records from five additional catchments they studied "provide little compelling evidence for long-term (>50 year) trends but show evidence of pronounced multi-decadal fluctuations." Finally, they note, "in comparison with other indicators, there were fewer trends in flood magnitude" and "trends in peaks-over-threshold frequency and extended-duration maxima at a gauging station were not necessarily associated with increasing annual maximum instantaneous flow." In light of their several observations, Hannaford and Marsh conclude, "considerable caution should be exercised in extrapolating from any future increases in runoff or high-flow frequency to an increasing vulnerability to extreme flood events."

In another paper from Europe, Matthews et al. (2009) conducted detailed investigations at three alpine slope-foot mires located in the valley of Leirdalen in an area known as Sletthamn, above the treeline among some of the highest mountains in southern Norway, where they say "exceptionally detailed radiocarbon-dating controlled chronologies of Holocene debris-flow events have been reconstructed." This allowed them to analyze "the frequency and timing of debris flows since c. 8500 cal. BP which, in turn, are related to climatic variability, extreme climatic events and site conditions."

The results of this exercise revealed "no obvious correlation between debris-flow frequency and a relative warm climate." In fact, they write, "debrisflow frequency was lowest post-8000 cal. BP during the Holocene Thermal Maximum" and most of the "century- to millennial-scale phases of enhanced debris-flow activity appear to correlate with Neoglacial events," one of which was the Little Ice Age. In addition, they write, "the Sletthamn record agrees quite closely with a compilation of other debris-flow records from widely distributed sites in east and west Norway." What is more-citing the work of Berrisford and Matthews (1997). Stoffel and Beniston (2006), Pelfini and Santilli (2008), and Stoffel et al. (2008)-they report "there appears to be no consistent upward trend in debris-flow frequencies over recent decades," when one might have expected them to be growing in both number and magnitude if the model-based claims were correct. Given these findings, the Norwegian and U.K. researchers conclude there is little real-world evidence "for the association of higher debris-flow frequencies with an increasingly warm climate." In fact, they state, "the evidence suggests the opposite."

Panin and Nefedov (2010) identified "a series of alternating low-water (low levels of seasonal peaks, many-year periods without inundation of flood plains) and high-water (high spring floods, regular inundation of floodplains) intervals of various hierarchal rank" for the Upper Volga and Zapadnaya Dvina Rivers of

Russia. The two Russian researchers report "lowwater epochs coincide with epochs of relative warming, while high-water epochs [coincide] with cooling epochs," because "during the climate warming epochs, a decrease in duration and severity of winters should have resulted in a drop in snow cover water equivalent by the snowmelt period, a decrease in water discharge and flood stage, and a decrease in seasonal peaks in lake levels," noting "a model of past warming epochs can be the warming in the late 20th century, still continuing now." They also report finding, "in the Middle Ages (1.8–0.3 Ky ago), the conditions were favorable for long-time inhabiting [of] river and lake floodplains, which are subject to inundation nowadays." In addition, their results indicate that of this time interval, the period AD 1000-1300 hosted the greatest number of floodplain occupations.

Interestingly, Panin and Nefedov state this last period and other "epochs of floodplain occupation by humans in the past can be regarded as hydrological analogues of the situation of the late 20th-early current century," which they say "is forming under the effect of directed climate change." This relationship clearly implies the current level of warmth in the portion of Russia that hosts the Upper Volga and Zapadnaya Dvina Rivers is not yet as great as it was during the AD 1000–1300 portion of the Medieval Warm Period.

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5.3. Drought

As in the case of floods, the IPCC foresees drought as one of the many dangers of CO_2 -induced global warming. An examination of the pertinent scientific literature, however, demonstrates droughts are not becoming more frequent, more severe, or longerlasting.

Springer et al. (2008) constructed a multidecadalscale history of east-central North America's hydroclimate over the past 7,000 years, based on Sr/Ca ratios and δ^{13} C data obtained from a stalagmite in West Virginia, USA. Their results indicated the presence of seven significant mid- to late-Holocene droughts that "correlate with cooling of the Atlantic and Pacific Oceans as part of the North Atlantic Ocean ice-rafted debris [IRD] cycle, which has been linked to the solar irradiance cycle," as demonstrated by Bond et al. (1997, 2001). In addition, they found "the Sr/Ca and δ^{13} C time series display periodicities of ~200 and ~500 years," and "the ~200-year periodicity is consistent with the de Vries (Suess) solar irradiance cycle," and that the ~500-year periodicity is likely "a harmonic of the IRD oscillations." They also reported "cross-spectral analysis of the Sr/Ca and IRD time series yields statistically significant coherencies at periodicities of 455 and 715 years," noting the latter values "are very similar to the second (725-years) and third (480years) harmonics of the 1450 ± 500 -years IRD periodicity."

The five researchers concluded these findings "corroborate works indicating that millennial-scale solar-forcing is responsible for droughts and ecosystem changes in central and eastern North America (Viau et al., 2002; Willard et al., 2005; Denniston et al., 2007)" and that their high-resolution time series "provide much stronger evidence in favor of solar-forcing of North American drought by yielding unambiguous spectral analysis results."

Writing in the Journal of Quaternary Science, Cook et al. (2009) note "IPCC Assessment Report 4 model projections suggest that the subtropical dry zones of the world will both dry and expand poleward in the future due to greenhouse warming" and "the US southwest is particularly vulnerable in this regard and model projections indicate a progressive drying there out to the end of the 21st century." They then note "the USA has been in a state of drought over much of the West for about 10 years now," but "while severe, this turn of the century drought has not yet clearly exceeded the severity of two exceptional droughts in the 20th century." Therefore, they conclude, "while the coincidence between the turn of the century drought and projected drying in the Southwest is cause for concern, it is premature to claim that the model projections are correct."

We begin to understand this fact when we compare the turn-of-the-century-drought with the two "exceptional droughts" that preceded it by a few decades. Based on gridded instrumental Palmer Drought Severity indices for tree-ring reconstruction that extend back to 1900, Cook et al. calculated the turn-of-the-century drought had its greatest Drought Area Index value of 59 percent in the year 2002, whereas the Great Plains/Southwest drought covered 62 percent of the United States in its peak year of 1954 and the Dust Bowl drought covered 77 percent of the United States in 1934.

In terms of drought duration, things are not quite as clear. Stahle et al. (2007) estimated the first two droughts lasted for 12 and 14 years, respectively; Seager et al. (2005) estimated them to have lasted for eight and ten years; and Andreadis et al. (2005) estimated periods of seven and eight years. That yields means of nine and 11 years for the two exceptional droughts, compared to ten or so years for the turn-of-the-century drought. This, too, makes the latter drought not unprecedented compared with those that occurred in the twentieth century.

Real clarity, however, comes when the turn-ofthe-century drought is compared to droughts of the prior millennium. Cook et al. write, "perhaps the most famous example is the 'Great Drouth' [sic] of AD 1276–1299 described by A.E. Douglass (1929, 1935)." This 24-year drought was eclipsed by the 38year drought found by Weakley (1965) to have occurred in Nebraska from AD 1276 to 1313, which Cook et al. say "may have been a more prolonged northerly extension of the 'Great Drouth'." But even these multi-decade droughts pale in comparison with the "two extraordinary droughts discovered by Stine (1994) in California that lasted more than two centuries before AD 1112 and more than 140 years before AD 1350." Each of these megadroughts, as Cook et al. describe them, occurred, in their words, "in the so-called Medieval Warm Period." They add, "all of this happened prior to the strong greenhouse gas warming that began with the Industrial Revolution."

In further ruminating about these facts in the "Conclusions and Recommendations" section of their paper, Cook et al. again state the medieval megadroughts "occurred without any need for enhanced radiative forcing due to anthropogenic greenhouse gas forcing"—because, of course, there was none at that time—and therefore, they say, "there is no guarantee that the response of the climate system to greenhouse gas forcing will result in megadroughts of the kind experienced by North America in the past."

Reinforcing the findings of Cook et al. two years later, Stambaugh et al. (2011) "used a new long treering chronology developed from the central U.S. to reconstruct annual drought and characterize past drought duration, frequency, and cycles in the U.S. Corn Belt during the last millennium." This new record, in their words, "is the first paleoclimate reconstruction achieved with subfossil oak wood in the U.S.," and they indicate it "increases the current dendroclimatic record in the central U.S. agricultural region by over 500 years."

Of great significance among their findings is the fact that the new drought reconstruction indicates "drought conditions over the period of instrumental records (since 1895) do not exhibit the full range of variability, severity, or duration of droughts during the last millennium." As an example, the six scientists compared the 1930s-era Dust Bowl drought with other prior severe events, finding "three years in the last millennium were drier than 1934, a classic Dust-Bowl year and the driest year of the instrumental period," and "three of the top ten most severe droughts occurred within a 25-year period corresponding to the late 16th century." Likewise, they state "the four longest droughts occurred prior to Euro-American settlement of the region (ca. AD 1850)," the longest of which occurred in the middle of the Medieval Warm Period and, as the authors describe it, "lasted approximately 61 years (AD 1148–1208)."

Other studies in North America also point to a large and persistent Medieval drought unequaled in modern times. Working in the Sierra de Manantlan Biosphere Reserve (SMBR) in west-central Mexico, Figueroa-Rangel et al. (2010) constructed a 1,300-year history of cloud forest vegetation dynamics via analyses of fossil pollen, microfossil charcoal, and organic and inorganic sediment data obtained from a 96-cm core of black organic material retrieved from a small forest hollow (19°35'32"N, 104°16'56"W). Their results showed oscillating intervals of humidity, including a major dry period that lasted from approximately AD 800 to 1200 in the SMBR, a dry period that corresponds with those of other locations in the region.

Quoting the four researchers, "results from this study corroborate the existence of a dry period from 1200 to 800 cal years BP in mountain forests of the region (B.L. Figueroa-Rangel, unpublished data); in central Mexico (Metcalfe and Hales, 1994; Metcalfe, 1995; Arnauld et al., 1997; O'Hara and Metcalfe, 1997; Almeida-Lenero et al., 2005; Ludlow-Wiechers et al., 2005; Metcalfe et al., 2007); lowlands of the Yucatan Peninsula (Hodell et al., 1995, 2001, 2005a,b) and the Cariaco Basin in Venezuela (Haug et al., 2003)." In addition, they write, "the causes associated to this phase of climate change have been attributed to solar activity (Hodell et al., 2001; Haug et al., 2003), changes in the latitudinal migration of the Intertropical Convergence Zone (ITCZ, Metcalfe et al., 2000; Hodell et al., 2005a,b; Berrio et al., 2006) and to ENSO variability (Metcalfe, 2006)."

In one final study from Mexico, Escobar et al. (2010) analyzed sediment cores from Lakes Punta Laguna, Chichancanab, and Peten Itza on the Yucatan Peninsula. With respect to drought, they report "relatively dry periods were persistently dry, whereas relatively wet periods were composed of wet and dry times." Their findings also "confirm the interpretations of Hodell et al. (1995, 2007) and Curtis et al. (1996) that there were persistent dry climate episodes associated with the Terminal Classic Maya Period." In fact, they find "the Terminal Classic Period from ca. AD 910 to 990 was not only the driest period in the last 3,000 years, but also a persistently dry period." In further support of this interpretation, they note "the core section encompassing the Classic Maya collapse has the lowest sedimentation rate

among all layers and the lowest oxygen isotope variability."

Moving to South America, Marengo (2009) examined the hydrological history of the Amazon Basin in an effort "to explore long-term variability of climate since the late 1920s and the presence of trends and/or cycles in rainfall and river indices in the basin." These analyses were based on northern and southern Amazonian rainfall data originally developed by Marengo (1992) and Marengo and Hastenrath (1993) and subsequently updated by Marengo (2004).

In describing the results of the analysis, the Brazilian researcher reports, "no systematic unidirectional long-term trends towards drier or wetter conditions have been identified since the 1920s." Instead, he found "the rainfall and river series show variability at inter-annual scales." Marengo states the patterns he uncovered are "characteristic of decadal and multi-decadal modes," which he describes as "indicators of natural climate variability" that are linked to the El Niño Southern Oscillation, "rather than any unidirectional trend towards drier conditions (as one would expect, due to increased deforestation or to global warming)."

In Europe, based on data obtained from hundreds of moisture-sensitive Scots pine tree-ring records originating in Finland, and using regional curve standardization (RCS) procedures, Helama et al. (2009) developed what they describe as "the first European dendroclimatic precipitation reconstruction," which "covers the classical climatic periods of the Little Ice Age (LIA), the Medieval Climate Anomaly (MCA), and the Dark Ages Cold Period (DACP)," running from AD 670 to AD 1993.

The authors state their data indicate "the special feature of this period in climate history is the distinct and persistent drought, from the early ninth century AD to the early thirteenth century AD," which "precisely overlaps the period commonly referred to as the MCA, due to its geographically widespread climatic anomalies both in temperature and moisture." In addition, they report, "the reconstruction also agrees well with the general picture of wetter conditions prevailing during the cool periods of the LIA (here, AD 1220–1650) and the DACP (here, AD 720–930)."

The three Finnish scientists note "the global medieval drought that we found occurred in striking temporal synchrony with the multicentennial droughts previously described for North America (Stine, 1994;

Cook et al., 2004, 2007), eastern South America (Stine, 1994; Rein et al., 2004), and equatorial East Africa (Verschuren et al., 2000; Russell and Johnson, 2005, 2007: Stager et al., 2005) between AD 900 and 1300." Noting further "the global evidence argues for a common force behind the hydrological component of the MCA," they report "previous studies have associated coeval megadroughts during the MCA in various parts of the globe with either solar forcing (Verschuren et al., 2000; Stager et al., 2005) or the ENSO (Cook et al., 2004, 2007; Rein et al., 2004; Herweijer et al., 2006, 2007; Graham et al., 2007, Seager et al., 2007)." They state, "the evidence so far points to the medieval solar activity maximum (AD 1100–1250), because it is observed in the Δ^{14} C and ¹⁰Be series recovered from the chemistry of tree rings and ice cores, respectively (Solanki et al., 2004)."

Moving next to Asia, Sinha et al. (2011) write of "the potential consequences that would be associated with a drought lasting years to decades, or even a century (*megadrought*)."They state such a phenomenon "constitutes one of the greatest threats to human welfare," noting it would be "a particular serious threat for the predominantly agrarian-based societies of monsoon Asia, where the lives of billions of people are tightly intertwined with the annual monsoon cycle."

In exploring this ominous subject in great detail, Sinha et al. review what is known about it as a result of numerous pertinent studies, relying heavily on the work of Sinha et al. (2007) and Berkelhammer et al. (2010), based on the δ^{18} O record of a speleothem from Dandak Cave in central-eastern India, which documents Indian monsoon rainfall variations between AD 600 and 1500.

The eight researchers, from China, Germany, and the United States, report "proxy reconstructions of precipitation from central India, north-central China [Zhang et al., 2008], and southern Vietnam [Buckley et al., 2010] reveal a series of monsoon droughts during the mid 14th-15th centuries that each lasted for several years to decades," and they say "these monsoon megadroughts have no analog during the instrumental period." They also note "emerging tree ring-based reconstructions of monsoon variability from SE Asia (Buckley et al., 2007; Sano et al., 2009) and India (Borgaonkar et al., 2010) suggest that the mid 14th-15th century megadroughts were the first in a series of spatially widespread megadroughts that occurred during the Little Ice Age" and that they "appear to have played a major role in shaping significant regional societal changes at that time." Among these upheavals, they make special mention of "famines and significant political reorganization within India (Dando, 1980; Pant et al., 1993; Maharatna, 1996), the collapse of the Yuan dynasty in China (Zhang et al., 2008), Rajarata civilization in Sri Lanka (Indrapala, 1971), and the Khmer civilization of Angkor Wat fame in Cambodia (Buckley et al., 2010)," noting the evidence suggests "monsoon megadroughts may have played a major contributing role in shaping these societal changes."

In light of the fact that there were, in the words of Sinha et al., "at least five episodes of monsoon megadroughts during the Little Ice Age (nominally, AD 1350–1850)," we should be extremely thankful the Earth has emerged from this unique period of global coolness—which is universally recognized as having been the coldest interval of the current interglacial—especially because "the present-day water-resource infrastructure and planning are barely sufficient to meet the welfare of billions of people during a single season of anomalous weak monsoon, let alone a protracted failure," such as what occurred repeatedly during the global chill of the Little Ice Age.

Another paper from Asia, Kim et al. (2009), was previously summarized in Chapter 4. The only major multiyear deviation from long-term normalcy they found were a decadal-scale decrease in precipitation and ensuing drought, both of which achieved their most extreme values (low in the case of precipitation, high in the case of drought) around AD 1900. The warming of the twentieth century had essentially no effect on the long-term histories of either precipitation or drought at Seoul, Korea.

Closing out this section on drought, we highlight a study published in *Science* by Zhao and Running (2010), who raised some concerns that global warming was affecting global net primary production of biomass due to the increased frequency of drought. In introducing their work, the two authors note "previous studies have shown that climate constraints [on global production of biomass] were relaxing with increasing temperature and solar radiation, allowing an upward trend in NPP [net primary production] from 1982–1999," but over the past decade (2000– 2009), satellite data "suggest a reduction in the global NPP." Closer examination of this study, however, shows little reason for concern.

Zhao and Running state their work shows "a reduction in the global NPP of 0.55 petagrams of carbon" over the period 2000–2009. But in viewing a graphical representation of their results (see Figure 5.3.1 below), it can be seen that apart from the starting point of the initial year (2000) of their study, there is only one other year (2004) in which the global NPP was greater than what it was at the end of the study (2009). And since global NPP was on the rise from 1982 to 1999, what the more recent data show would more accurately be described as a leveling off from that prior upward trend.

Zhao and Running say the leveling off of global NPP over the past decade was induced by drought, and that "NPP in the tropics explains 93% of variations in the global NPP" and "tropical rainforests explain 61% of global NPP variations." These findings also serve to undermine whatever concerns that selective reporting of their study's results might have raised, since the recent work of Coelho and Goddard (2009) shows climate models forecast fewer tropical droughts in a warming world.

Coelho and Goddard write, "the majority of drought-related hazards and the attendant economic losses and mortality risks reside in the tropics," citing Dilley et al. (2005). They write, "El Niño brings widespread drought (i.e., precipitation deficit) to the tropics," and "stronger or more frequent El Niño events in the future" would "exacerbate drought risk in highly vulnerable tropical areas."

The two researchers evaluated "the patterns, magnitude, and spatial extent of El Niño-induced tropical droughts during a control period in the twentieth century in climate simulations, which have realistic evolution of greenhouse gases," after which they examined "the projected changes in the characteristics of El Niño and in the strength of the identified patterns of El Niño-induced tropical drought in the twenty-first century." That allowed them to examine patterns of mean precipitation changes in order to "assess whether those changes exacerbate or ameliorate the risk of El Niño-induced drought conditions in the twenty-first century."



Figure 5.3.1. Interannual variations from the mean of global Net Primary Production (NPP) over the past ten years. Adapted from Zhao and Running (2010).

Coelho and Goddard report "a possible slight reduction in the spatial extent of droughts is indicated over the tropics as a whole," and they report "all model groups investigated show similar changes in mean precipitation for the end of the twenty-first century, with increased precipitation projected between 10°S and 10°N." So it would appear—at least from a climate modeling perspective—that we can probably expect tropical drought to *decrease* throughout the remainder of the twenty-first century, which should enable the historical "greening of the Earth" to continue.

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5.4. Storms

Among the highly publicized changes in weather phenomena predicted to accompany the ongoing rise in the air's CO_2 content are increases in the frequency and severity of storms. Many researchers have examined historical and proxy records in an attempt to determine how temperature changes over the recent or more distant past have affected this aspect of Earth's climate. This section reviews the latest findings from this research.

Based on surface pressure data for January 1874 through January 2008, obtained from 11 sites

scattered throughout the northeast Atlantic region, Wang et al. (2009) computed, and analyzed trends in, the seasonality and regional differences of storm conditions characterized by the 95th and 99th percentiles of geostrophic wind speeds, which they calculated from sea level pressure data over the period of time when the Earth recovered from the global chill of the Little Ice Age and transited into the Current Warm Period.

Wang et al. determined that storminess conditions in their study region "have undergone substantial decadal or longer time scale fluctuations, with considerable seasonal and regional differences." With respect to annual percentiles of geostrophic wind speeds for the entire study region, however, they state "the Kendall test identifies a downward trend of at least 5% significance in both the 99th and 95th percentile series." The four Canadian researchers state the question of whether there is an anthropogenic contribution to the changes they observed "remains open."

In another paper from the same vicinity, Gascon et al. (2010) write, "autumn and winter storms in the eastern Canadian Arctic are typically characterized by heavy precipitation and strong winds [that] can have major effects on the human population and infrastructures, as well as paralyzing transport," and they state local Inuit "have reported higher occurrences of hazardous weather and unanticipated changes, which increase northern communities' vulnerability and limit their capacity to adapt to environmental change." In a study they describe as "the first to document the climatology of major coldseason precipitation events that affect southern Baffin Island," Gascon et al. examined the characteristics and climatology of the 1955-2006 major cold-season precipitation events that occurred at Iqaluit-the capital of Nunavut, located on the southeastern part of Baffin Island in the northwestern end of Frobisher Bay-based on analyses of hourly surface meteorological data obtained from the public archives of Environment Canada. They corrected the data to account for gauge catchment errors due to wind effects, snow-water equivalence variations, and human error in the manually retrieved precipitation data for the period 1955–1996, while the remainder of the data were used in their uncorrected state.

The three researchers report they detected a nonsignificant decrease in autumn and winter storm activity over the period of their study, which they say is in line with the results of Curtis et al. (1998), who observed a concomitant decrease in annual precipitation in the western Arctic. And this was the case in spite of the findings of Zhang et al. (2004), who the Canadian scientists say "reported an increase in cyclonic activity over the past fifty years, as well as McCabe et al. (2001), Wang et al. (2004) and Yin (2005)," who reported a northward shift in such activity, but which was apparently not great enough to "translate into major precipitation events, or at least not in Iqaluit," as revealed by the authors' results depicted in Figure 5.4.1.

The results of this data-based analysis would appear to raise questions about the validity of the collective memory of the local Inuit or, perhaps more fairly, of the usefulness of anecdotes about the weather.

Moving on to Europe, "based on an approach combining AMS ¹⁴C [radiocarbon] dating, sedimentological and rock magnetic analyses on sediment cores complemented with seismic data collected in the macrotidal Bay of Vilaine [47°20'-47°35'N, 2°50'-2°30'W]," Sorrel et al. (2010) documented "the depositional history of the inner bay coeval to the mid- to late-Holocene transgression in south Brittany."

The results of this study indicated an increase in

the contribution of riverine inputs during the Medieval Warm Period at "times of strong fluvial influences in the estuary during ca. 880-1050 AD" and "preservation of medieval estuarine flood deposits implies that sediment remobilization by swells considerably waned at that time, and thus that the influence of winter storminess was minimal," in accordance with the findings of Proctor et al. (2000) and Meeker and Mayewski (2002). They also state the preservation of fine-grained sediments during the Middle Ages has been reported in other coastal settings, citing the studies of Chaumillon et al. (2004) and Billeaud et al. (2005). In fact, the researchers state "all sedimentary records from the French and Spanish Atlantic coasts" suggest "the MWP appears to correspond to a period of marked and recurrent increases in soil erosion with enhanced transport of suspended matter to the shelf as a result of a likely accelerated human land-use development." In addition, they write, "milder climatic conditions during ca. 880-1050 AD may have favored the preservation of estuarine flood deposits in estuarine sediments through a waning of winter storminess, and, thus, reduced coastal hydrodynamics at subtidal depths."

The eight researchers also note the upper



Figure 5.4.1. Cold-season occurrences of major precipitation events at Iqaluit, Nunavut, Canada. Adapted from Gascon et al. (2010).

successions of the sediment cores "mark the return to more energetic conditions in the Bay of Vilaine, with coarse sands and shelly sediments sealing the medieval clay intervals," adding "this shift most probably documents the transition from the MWP to the Little Ice Age," which led to the "increased storminess both in the marine and continental ecosystems (Lamb, 1979; Clarke and Rendell, 2009)" that was associated with "the formation of dune systems over a great variety of coastal environments in northern Europe: Denmark (Aagaard et al., 2007; Clemmensen et al., 2007, 2009; Matthews and Briffa, 2005), France (Meurisse et al., 2005), Netherlands (Jelgersma et al., 1995) and Scotland (Dawson et al., 2004)." And in what they call an even "wider perspective," they note the Medieval Warm Period "is recognized as the warmest period of the last two millennia (Mavewski et al., 2004; Moberg et al., 2005)."

Also in Europe, but three years earlier, Ogrin (2007) presented "an overview of severe storms and a reconstruction of periods with their reiterative occurrence in sub-Mediterranean Slovenia in the warm half of the year during the so-called pre-instrumental period," based on "data gathered in secondary and tertiary historical sources."

Speaking of "violent storms" and "the periods in which these phenomena were more frequent and reached, as to the costs of damage caused, the level of natural disasters or even catastrophes," Ogrin reports "the 17th and 18th centuries were undoubtedly such periods, particularly their first halves, when besides storms also some other weather-caused natural disasters occurred quite often, so that the inhabitants, who mainly depended on the self-subsistent agriculture, could not recover for several years after some consecutive severe rigors of the weather." In addition, he notes, "the frequency of violent storms in that time was comparable to the incidence towards the end of the 20th century."

In commenting on these findings, Ogrin, who is in the Department of Geography of the University of Ljubljana, writes that the late twentieth-century increase in violent storms "is supposed to be a human-generated consequence of emitting greenhouse gasses and of the resulting global warming of the atmosphere." However, he reports "the damage done by severe storms in the past does not differ significantly from the damage in the present." And this suggests the weather extremes of today may well be caused by something else, for if they have occurred in the past for a different reason (and they have), they can be occurring today for a different reason as well.

Moving to the Southern Hemisphere, Page et al. (2010) extracted sediment cores from Lake Tutira on the eastern North Island of New Zealand in an effort to develop a 7,200-year history of the frequency and magnitude of storm activity, based on analyses of (1) sediment grain size; (2) diatom, pollen, and spore types and concentrations; plus (3) carbon and nitrogen concentrations; together with (4) tephra and radiocarbon dating. Results indicated "the average frequency of all storm layers is one in five years," but that "for storm layers ≥ 1.0 cm thick, the average frequency is every 53 years." And in this regard, they state that over the course of their record, "there are 25 periods with an increased frequency of large storms" and the onset and cessation of these stormy periods "was usually abrupt, occurring on an inter-annual to decadal scale." They also note the duration of these stormy periods "ranged mainly from several decades to a century," but "a few were up to several centuries long" and "intervals between stormy periods range from about thirty years to a century." In addition, they find millennial-scale cooling periods tend to "coincide with periods of increased storminess in the Tutira record, while warmer events match less stormy periods."

Concluding their analysis, Page et al. note there is growing concern today, driven by climate models, that global warming may cause abrupt changes in various short-term meteorological phenomena, "when either rapid or gradual forces on components of the earth system exceed a threshold or tipping point." However, as is demonstrated by the results of their work in the real world, the sudden occurrence of a string of years—or even decades—of unusually large storms can happen at almost any time on its own, without being driven by human activities such as the burning of fossil fuels.

Noting "hail is one of the most extreme weather phenomena, causing great loss to agriculture every year in China (Han, 1999)," Xie and Zhang (2010) decided to see whether this particular storm phenomenon had gotten any worse throughout China in recent years.

Xie et al. (2008) had previously found a "significant decreasing trend of hail frequency in most of China from the early 1980s based on 46 years of data during 1960–2005." Thus Xie and Zhang began with the knowledge that for this vast country

one of two types of potential hail extremes (hailstorm frequency) had not complied with the IPCC's predictions. Therefore, the two researchers focused on the other type of extreme (hailstone size), noting "changes in hail size are also an important aspect of hail climatology." They went on to study the longterm trend of hail size in four regions of China over the period 1980–2005, using maximum hail diameter data obtained from the Meteorological Administrations of Xinjiang Uygur Autonomous Region (XUAR), Inner Mongolia Autonomous Region (IMAR), Guizhou Province, and Hebei Province.

The two authors report their work revealed an uptrend in maximum hail diameter in Hebei, a flat trend in XUAR, and a slight downtrend in Guizhou and IMAR, but they add "none of the trends is statistically significant." In light of these findings, it seems clear the global warming of the past few decades has led to no increase in the extremeness of Chinese hail storms.

Examining dust storms in China, Zhu et al. (2008) write, "changes in occurrences of natural disasters, which are possibly associated with global warming, have been receiving ever-increasing attention worldwide" and the "dust storm is one of the severe disastrous weather [phenomena] in China." In this regard, however, and in contrast to the general tenor of most discussions of the issue, they say "a number of studies have shown that the spring dust storm frequency (DSF) bears a negative correlation with the local surface air temperature, and exhibits a downward trend over the past 50 years," citing the studies of Oian et al. (2002a). Zhou and Zhang (2003), Zhai and Li (2003), Zhao et al. (2004), Fan et al. (2006), and Gong et al. (2006, 2007) in support of this statement.

Zhu et al. explored "the long-term variation of Chinese DSF in spring (March to May), and its possible linkage with the global warming and its related circulation changes in the Northern Hemisphere," using data from 258 stations within the region surrounding Lake Baikal (70–130°E, 45– 65°N) over the period 1954 to 2007. The results of this effort indicated a "prominent warming" in recent decades, as well as "an anomalous dipole circulation pattern" in the troposphere that "consists of a warm anti-cyclone centered at 55°N and a cold cyclone centered around 30°N," leading to "a weakening of the westerly jet stream and the atmospheric baroclinicity in northern China and Mongolian regions, which suppress the frequency of occurrence and the intensity of the Mongolian cyclones and result in the decreasing DSF in North China."

Peng et al. (2010) used snow-depth measurements collected at 279 meteorological stations scattered across the country, plus collocated satellite-derived Normalized Difference Vegetation Index (NDVI) data, to investigate spatio-temporal changes in snow depth over the period 1980-2006 and the effects of those changes on vegetative growth the following spring and summer. The five researchers report, "over the past three decades, winter snow depth overall increased in northern China, particularly in the most arid and semiarid regions of western China where desert and grassland are mainly distributed," and they state that in those specific areas there were positive correlations between mean winter snow depth and spring NDVI data. In addition, they note Piao et al. (2005) determined the net primary productivity of the same desert and grasslands during 1982-1999 "increased by 1.6% per year and 1.1% per year, respectively," and "desertification has been reversed in some areas of western China since the 1980s," citing the work of Runnstrom (2000), Wu (2001), Zhang et al. (2003), and Piao et al. (2005).

In discussing the implications of their findings, Peng et al. write the "increase in vegetation coverage in arid and semiarid regions of China, possibly driven by winter snow, will likely restore soil and enhance its antiwind-erosion ability, reducing the possibility of released dust and mitigating sand-dust storms," while noting the frequency of sand-dust storms has indeed "declined in China since the early 1980s (Qian et al., 2002b; Zhao et al., 2004)." Thus, as the world has warmed over the past three decades, there has been another concomitant climatic change across China above 40°N latitude (an increase in winter snow depth) that has prompted a biological change (increased vegetative growth in desert areas and grasslands) that has prompted yet another climatic change (a reduction in sand-dust storms), all of which could be considered positive developments.

In examining another storm-related extreme weather event, Diffenbaugh et al. (2008) briefly reviewed what is known about responses of U.S. tornadoes to rising temperatures. On the theoretical side of the issue, Diffenbaugh et al. indicate there are competing ideas about whether tornadoes might become more or less frequent and/or severe as the planet warms. On the observational side, there is also much uncertainty about the matter. They write, for example, "the number of tornadoes reported in the United States per year has been increasing steadily (~14 per year) over the past half century." However, they state, "determining whether this is a robust trend in tornado occurrence is difficult" because "the historical record is both relatively short and non-uniform in space and time." In addition, the increase in yearly tornado numbers runs parallel with the concurrent increase in the country's population, which makes for that much better geographical coverage and more complete (i.e., numerous) observations.

On the other hand, the three researchers report the number of tornadoes classified as the most damaging (F2-F5 on the Fujita scale) may have decreased over the past five decades (1954-2003), as their reported frequency of occurrence runs counter to the trend of the country's population. The graphs they present show yearly F2-F5 tornado numbers in the latter half of the record period dropping to only about half of what they were during its first half, while corresponding data from the U.S. Southern Great Plains show damaging tornado numbers dropping to only about a third of what they were initially. Nevertheless, Diffenbaugh et al. consider the question posed in the title of their paper-"Does global influence tornado activity?"-to warming be unresolved, "determining the stating, actual background occurrence and trend in tornado activity over recent decades will certainly require further development of other analysis approaches."

In another study of the subject published two years later, Timbal et al. (2010) explored the presumed effect of global warming on cool-season tornadoes in southern Australia, where four climate models were employed in their analysis, with the IPCC's highest greenhouse gas emissions scenario (A2) being used for projections. Previously, it had been shown two climate variables were strongly predictive of tornado frequency in this region: (1) an atmospheric instability threshold, and (2) the strength of vertical wind shear. These two variables were tuned to each climate model employed so the predicted tornado frequency for the base-case model run matched actual data in order to accommodate different spatial resolution and bias in the models.

The exercise revealed the future climates projected by the four models over the next 100 years all yielded *lower* probabilities of cool-season tornado occurrence. The authors attributed this decline to increases in the Southern Annular Mode index, which causes increased atmospheric stability in the lower troposphere. This study demonstrates that even climate models, in which we admittedly do not have much confidence, do not always forecast worse weather in a warmer world.

Barredo (2010) writes, "on 18 January 2007, windstorm Kyrill battered Europe with hurricaneforce winds killing 47 people and causing 10 billion US\$ in damage." In light of model-based predictions that such storms will increase in the future, the author "put Kyrill into an historical context by examining large historical windstorm event losses in Europe for the period 1970–2008 across 29 European countries," asking the question "what economic losses would these historical events cause if they were to recur under 2008 societal conditions?"

According to the researcher-who is employed by the Institute for Environment and Sustainability, European Commission-Joint Research Centre in Ispra, Italy—loss data resulting from numerous prior storms "were sourced from reinsurance firms and augmented with historical reports, peer-reviewed articles and other ancillary sources," and the extracted data were "adjusted for changes in population, wealth, and inflation at the country level and for inter-country price differences using purchasing power parity." The results obtained indicate "no trend in the normalized windstorm losses and confirm increasing disaster losses are driven by society factors and increasing exposure." Barredo thus concludes, "increasing disaster losses are overwhelmingly a consequence of changing societal factors."

Although it is frequently claimed that recent destructive storms of all types are the result of the historical warming of the world over the past several decades, it is incorrect to do so, for Barredo states that what is true of windstorms in Europe also has "been shown to be the case for flood and hurricane losses in the US (Pielke Jr. and Landsea, 1998; Pielke Jr. and Downton, 2000; Pielke Jr. et al., 2008), tornadoes in the U.S. (Brooks and Doswell, 2001), hurricane losses in the Caribbean region (Pielke Jr. et al., 2003), weather extremes in the U.S. (Changnon et al., 2000; Changnon, 2003), flood losses in Europe (Barredo, 2009), tropical cyclones in India (Raghavan and Rajesh, 2003), and weather-driven disasters in Australia (Crompton and McAneney, 2008)." He notes "all of these studies found no significant trends of losses after historical events were normalized to current conditions in order to account for

demonstrably changing societal/demographic factors."

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5.5. Hurricanes

In its Fourth Assessment Report, the IPCC states "it is *likely* that future tropical cyclones (typhoons and hurricanes) will become more intense, with larger peak wind speeds and more heavy precipitation associated with ongoing increases of tropical sea surface temperatures" (IPCC, 2007). However, as was shown in the 2009 NIPCC report (Idso and Singer, 2009), numerous peer-reviewed studies reveal that will not be the case. In this section we present the results of more recent studies not reviewed in the 2009 NIPCC report.

Fan and Liu (2008) note "the recent increase in typhoon (tropical cyclone) activity has attracted great interest and induced heated debates over whether it is linked to global warming" and "skeptics of the global warming connection think that we are just at an active phase of multi-decadal variations in typhoons." They present "a brief review and synthesis on the major research advances and findings ofpaleotempestology," which they describe as "a young science" that "studies past typhoon activity spanning several centuries to millennia before the instrumental era through the use of geological proxies and historical documentary records."

The two researchers report "typhoon-proxy data show that there does not exist a simple linear relationship between typhoon frequency and Holocene climate (temperature) change," noting "case studies based on geological proxy records show that a warmer climate alone during the Holocene Optimum may not have increased the frequency of intense typhoons" and "in the last millennium, the frequency of typhoon activity was not found to fluctuate linearly with climatic change over the centennial timescale." In fact, and "on the contrary," as they continue, "typhoon frequency seemed to have increased at least regionally during the coldest phases of the Little Ice Age." In addition, they report "more typhoons and hurricanes make landfalls in China, Central and North America during La Niña years than El Niño years," which finding, if anything, is the opposite of what the IPCC contends.

Swinging the pendulum slightly in the opposite direction one year later were Mann et al. (2009), who developed two 1,500-year histories of North Atlantic tropical cyclone (TC) activity. The first of these proxy records, as they describe it, was derived from "a composite of regional sedimentary evidence of landfalling hurricanes," which included "a site from the Caribbean (Vieques, Puerto Rico), one from the US Gulf Coast, one from the southeastern US coast, three from the mid-Atlantic coast (one from New York and two from New Jersey) and two from southeastern New England (one from Rhode Island and another from Massachusetts)."

The second of the two estimates employed "a previously published statistical model of Atlantic cyclone activity driven by tropical proxy reconstructions of past climate changes," the three climate factors being "(1) the sea surface temperature over the main development region for tropical Atlantic tropical cyclones, which reflects the favorability of the local thermodynamic environment, (2) the El Niño/Southern Oscillation, which influences the amount of (unfavorable) vertical wind shear, and (3) the North Atlantic Oscillation, which affects the tracking of storms, determining how favorable an environment they encounter."

The results of this enterprise revealed, in their words, "periods of high [TC] activity (that is, comparable to current levels) during a medieval era of roughly AD 900–1100." And because they found the level of medieval activity "matches or even exceeds current levels of activity within uncertainties for the statistical model," it is highly likely the temperatures of the North Atlantic's main TC development region, as well as the Niño3 region, were equivalent to, or even greater than, those of the recent past.

Even more support for this conclusion is provided by the study of Landsea et al. (2009), who explored the influence of TC duration on observed changes in TC frequency, using the HURDAT Atlantic TC database. Their work revealed "the occurrence of short-lived storms (duration two days or less) in the database has increased dramatically, from less than one per year in the late-19th/early-20th Century to about five per year since about 2000, while moderate to long-lived storms have increased little, if at all." They conclude, "the previously documented increase in total TC frequency since the late 19th Century in the database is primarily due to an increase in very short-lived TCs," which they attribute to "improvements in the quantity and quality of observations, along with enhanced interpretation techniques."

Interestingly, just as in the case of the discredited "hockey stick" temperature history of Mann et al. (1998, 1999) and Mann and Jones (2003), the Atlantic TC history of Mann et al. (2009) consists of reconstructed results ("apples") up until the midnineteenth century, after which observational results ("oranges") are employed. And those oranges pile up ever faster over the most recent 150 years of observational data, leaving the prior apples in their dust, just as the results of Landsea et al.'s analysis suggest they should. But when the latter researchers adjust for this artifactual phenomenon, they find "no significant [TC] trend remains using either an 1878 or a 1900 starting point." This development suggests the Medieval Warm Period may have been much warmer than what the Current Warm Period has been to date.

Further tilting the scales in favor of the skeptics, Wallace and Anderson (2010) collected 37 sediment cores along eight transects within Laguna Madre, an elongate water body located behind the narrow lowelevation barrier that is Texas, USA's South Padre Island. Based on the vertical distribution and grain size of storm over-wash sediments contained within four of those cores from two transects that were most ideally positioned, they were able to construct a detailed history of intense hurricane strikes from 5,300 to 900 years before present (BP).

Based on their analyses, Wallace and Anderson report "there has been no notable variation in intense storm impacts across the northwestern Gulf of Mexico coast during this time interval," i.e., 5,300– 900 yr BP, "implying no direct link between changing climate conditions and annual hurricane impact probability." In addition, they state, "there have been no significant differences in the landfall probabilities of storms between the eastern and western Gulf of Mexico during the late Holocene, suggesting that storm steering mechanisms have not varied during this time."

In discussing their findings—as well as the similar results obtained by others for Western Lake,

Florida, and Lake Shelby, Alabama—the two Rice University (Houston, Texas) researchers say current rates of intense hurricane impacts "do not seem unprecedented when compared to intense strikes over the past 5000 years" and "similar probabilities in high-intensity hurricane strikes for the eastern and western Gulf of Mexico do not show any clear-cut out-of-phase relationship that would enlighten us as to climate controls on storm pathways."

In a study of tropical cyclone trends in the more recent past, Vecchi et al. (2008) write "a key question in the study of near-term climate change is whether there is a causal connection between warming tropical sea surface temperatures (SSTs) and Atlantic hurricane activity." As they explain in more detail, there are two schools of thought on this topic. One posits that the intensity of Atlantic Basin hurricanes is directly related to the absolute SST of the basin's main development region, which would be expected to rise in response to global warming. The other posits that Atlantic hurricane intensity is directly related to the SST of the Atlantic basin's main development region relative to the SSTs of the other tropical ocean basins, a factor that could rise or fall to a modest degree in response to global warming.

In conducting their analysis of the subject, based on pertinent data obtained between 1946 and 2007, Vecchi et al. plotted Atlantic hurricane power dissipation index (PDI) anomalies calculated from both the absolute SST values of the Atlantic Basin and the relative SST values derived from all tropical ocean basins as a function of time, extending them throughout most of the current century based on projections of the two parameters obtained from 24 different climate models. They then compared the results they obtained between1946 and 2007 with the measured PDI anomalies. "Between 1946 and 2007," the researchers found, the relative SST "is as well correlated with Atlantic hurricane activity as the absolute SST." However, they report the "relative SST does not experience a substantial trend in 21stcentury projections" and, therefore, they conclude, "a future where relative SST controls Atlantic hurricane activity is a future similar to the recent past, with periods of higher and lower hurricane activity relative to present-day conditions due to natural climate variability, but with little long-term trend."

This result, as Vecchi et al. describe it, "suggests that we are presently at an impasse" and that "many years of data will be required to reject one hypothesis in favor of the other," as the projections derived from the absolute and relative SST parameters "do not diverge completely until the mid-2020s." Consequently, if the absolute SST ultimately proves to be the proper forcing factor, concerns based on this thesis would have some validity. But if the relative SST proves to be the controlling factor, the researchers state, "an attribution of the recent increase in hurricane activity to human activities is not appropriate, because the recent changes in relative SST in the Atlantic are not yet distinct from natural climate variability."

In a contemporaneous study also focused on the Atlantic basin, Chylek and Lesins (2008) write, "on the basis of hurricane thermodynamics it is plausible to expect hurricane strength to increase with increasing sea surface temperature," and they say some recent papers have "claimed detection of such an increase (Emanuel, 2005; Webster et al., 2005; Holland and Webster, 2007) while others reported little or no trend (Solow and Moore, 2002; Landsea, 2005; Pielke, 2005; Klotzbach, 2006; Landsea et al., 2006; Nyberg et al., 2007; Kossin et al., 2007)."

To explore this issue, Chylek and Lesins "apply simple statistical methods to the NOAA HURDAT record of storm activity in the North Atlantic basin between 1851 and 2007 to investigate a possible linear trend, periodicity and other features of interest." Using "a hurricane activity index that integrates over hurricane numbers, durations, and strengths," the two researchers report discovering "a quasi-periodic behavior with a period around 60 years superimposed upon a linearly increasing background." However, they note "the linearly increasing background is significantly reduced or removed when various corrections were applied for hurricane undercounting in the early portion of the record."

Further noting "the last minimum in hurricane activity occurred around 1980," Chylek and Lesins compare the two 28-year periods on either side of this date and find "a modest increase of minor hurricanes, no change in the number of major hurricanes, and a decrease in cases of rapid hurricane intensification." They conclude, "if there is an increase in hurricane activity connected to a greenhouse gas induced global warming, it is currently obscured by the 60-year quasi-periodic cycle." In another study published the same year, Klotzbach and Gray (2008) employed sea surface temperature (SST) data for the far North Atlantic (50– 60°N, 50–10°W) and sea-level pressure (SLP) data for the North Atlantic (0–50°N, 70–10°W) to construct an index of the Atlantic Multidecadal Oscillation (AMO), which they defined as the difference between the standardized SST and SLP anomalies (SST-SLP) for the hurricane season of June–November, and which they evaluated for the period 1878–2006. They then compared their results (to which they applied a 1-2-3-2-1 filter) with several hurricane properties.

Klotzbach and Gray's analysis revealed the existence of three positive and two negative AMO phases over the period of their study, as can be seen in Figure 5.5.1.

In comparing annually averaged results for tropical cyclone (TC) characteristics between the positive and negative AMO phases indicated in the above graph, it can be calculated from the TC data of the authors that the positive AMO phase-to-negative AMO phase ratios of hurricane numbers, hurricane days, major hurricane numbers, and major hurricane days were 1.53, 1.89, 2.00, and 2.46, respectively, over the period studied, while for the 20 most positive and 20 most negative AMO years the same ratios, in the same order, were 1.73, 2.41, 2.80, and 4.94.

Given such findings, it is clear the state of the North Atlantic AMO is tremendously important to hurricane genesis and development, and this striking natural variability makes it impossible to determine whether there is any long-term trend in the TC data that might be due to twentieth-century global warming.

In one final study of the Atlantic basin, Bender et al. (2010) "explored the influence of future global warming on Atlantic hurricanes with a downscaling strategy by using an operational hurricane-prediction model that produces a realistic distribution of intense hurricane activity for present-day conditions." The researchers worked with 18 models from the World Climate Research Program's Coupled Model Intercomparison Project 3 and employed the Intergovernmental Panel on Climate Change's A1B emissions scenario.



Figure 5.5.1. North Atlantic Multidecadal Oscillation (AMO) Index. Adapted from Klotzbach and Gray (2008).

The result of this exercise was, in their words, "an increase in the number of the most intense storms for the warmer climate compared with the control climate." Bender et al.'s modeling work predicted that for "category 4 and 5 hurricanes with maximum winds greater than 60 m/s, the total number increased sharply from 24 to 46," and "hurricanes with winds greater than 65 m/s increased from 6 to 21." However, they report there were reductions in the total number of hurricanes of all categories, which seems to contradict that finding.

In further discussing their findings, the researchers comment on the wide range of variability in what the various models predicted. They note, for example, that an increase in hurricane-caused "damage potential" of +30% was projected for the 18-model ensemble, while a range of -50% to +70% was found for four models for which they did more detailed work. This extreme range of variability reduces confidence in their mean result.

On another point, Bender et al.'s findings contradict the popular claim of a link between the occurrence of strong hurricanes of the recent past and supposedly unnatural and unprecedented CO_2 -induced global warming. Although the new model results suggest "a significant anthropogenic increase in the frequency of very intense Atlantic hurricanes may emerge from the background climate variability," the researchers find this development would likely not occur until "the latter half of the 21st century."

Kerr (2010) reports, in a commentary on Bender et al.'s study, that the researchers "are looking for yet more computer power and higher resolution to boost the realism of simulations." Kerr further writes, "if the models continue to converge as realism increases, the monster storms that seemed to be already upon us would be removed to decades hence."

But who really knows, when one is working with much-less-than-perfect models of a complex planetary climate/weather system? As Kerr reports, even the researchers themselves "caution" that their findings are still "far from the last word" on the subject.

Moving next to the Pacific Ocean, Harper et al. (2008) begin their analysis by noting there is "increasing concern that anthropogenic climate change may be increasing TC [tropical cyclone] intensity." In their contribution to the debate, they analyze several "potential influences on the accuracy of estimating TC intensity over time due to increasing technology, methodology, knowledge and skill" for TCs that occurred off the coast of northwestern Australia, primarily in a band between 5 and 25°S, over the period 1968/69 to 2000/01.

The results of this research show, in the words of the four Australian researchers, that "a bias towards lower intensities likely exists in earlier (mainly pre-1980) TC central pressure deficit estimates of the order of at least 20 per cent in 1970, reducing to around ten per cent by 1980 and to five per cent in 1985," indicating "inferred temporal trends in the estimated intensity from the original data-sets are therefore significantly reduced in the objectively reviewed data-set." They conclude, "there is no prima facie evidence of a potential climate-change induced trend in TC intensity in northwestern Australia over the past 30 years."

Weighing in on the subject two years later were Song et al. (2010), who write, "in recent years, there has been increasing interest in whether global warming is enhancing tropical cyclone (TC) activity," as has been claimed by Emanuel (2005) and Webster et al. (2005). One of the main sources of contention over this matter has been the work of Wu et al. (2006) and Yeung (2006), who examined the best track data from the Regional Specialized Meteorological Center (RSMC), Tokyo, Japan, and of the Hong Kong Observatory of China (HKO). "In contrast to Webster et al. (2005)," as Song et al. describe it, these authors (Wu et al. and Yeung) found "there was no increase in category 4-5 typhoon activity in the western North Pacific [WNP] basin," and that "neither RSMC nor HKO best track data suggest an increase in TC destructiveness." They further state, "other studies also examined the differences in TC data sets from the Joint Typhoon Warning Center (JTWC) of the U.S. Naval Pacific Meteorology Oceanography Center in Hawaii, the RSMC, and the Shanghai Typhoon Institute (STI) of [the] China Meteorological Administration in Shanghai (Lei, 2001; Kamahori et al., 2006; Ott, 2006; Yu et al., 2007)," and they indicate, "so far, the reported trends in TC activity in the WNP basin have been detected mainly in the JTWC best track data set." This anomalous dataset was employed by Emanuel (2005) and Webster et al. (2005) in drawing their anomalous conclusions.

To help resolve the discrepancies exhibited by the JTWC typhoon database, Song et al. analyzed differences of track, intensity, frequency, and the associated long-term trends of those TCs that were simultaneously recorded and included within the best track data sets of the JTWC, the RSMC, and the STI from 1945 to 2007. In the words of the Chinese researchers, "though the differences in TC tracks among these data sets are negligibly small, the JTWC data set tends to classify TCs of category 2–3 as

category 4–5, leading to an upward trend in the annual frequency of category 4–5 TCs and the annual accumulated power dissipation index, as reported by Webster et al. (2005) and Emanuel (2005)." They add "this trend and potential destructiveness over the period 1977–2007 are found only with the JTWC data set," and that actual downward trends "are apparent in the RSMC and STI data sets."

In light of the findings of Song et al., plus those of the other scientists they cite, there would appear to be little doubt that the studies of Emanuel (2005) and Webster et al. (2005), which the IPCC has hailed as proof of their claim that global warming leads to more intense tropical cyclones/hurricanes, actually provide no such evidence at all.

Concerns over the possibility of more frequent and more intense tropical cyclones for China were discussed in a contemporaneous study by Fengjin and Ziniu (2010). They note, "in 2006, meteorological disasters in China caused 3485 casualties and 25.2 billion yuan RMB in direct economic losses, of which TCs accounted for 30% of the total economic losses and 43% of the casualties." In an attempt to establish whether the past few decades give any indication of the alarmist expectations occurring any time soon, Fengjin and Ziniu used "data on the time and site of TC generation and landfall, TC tracks, and the intensity and duration of TCs in the Western North Pacific [WNP] and China during 1951-2008," which they obtained from the China Meteorological Administration, to analyze the characteristics of TCs that made landfall in China over that period.

According to the two researchers, the data indicate "a decreasing trend in the generation of TCs in the WNP since the 1980s" and "the number of TCs making landfall has remained constant or shown only a slight decreasing trend." They report "the number of casualties caused by TCs in China appears to show a slight decreasing trend," as would be expected under these less-dangerous circumstances. On the other hand, they find "the value of economic loss is increasing significantly," which they attribute to "the rapid economic development in China, particularly in TC-prone areas."

Working in the northwest Australian (NWAUS) sub-basin of the southeastern Indian Ocean (0–35°S, 105°–135°E), Goebbert and Leslie (2010) examined interannual TC variability over the 39-year time period 1970–2008, using the Woodside Petroleum Ltd. reanalysis TC dataset described by Harper et al. (2008), in order to focus on these two important TC

characteristics (frequency and intensity), as well as 11 other TC metrics.

The two researchers found "no significant linear trends in either mean annual TC frequencies or TC days," and there was also "no trend in the number of intense TCs for the NWAUS sub-basin." In fact, they state, "none of the 13 NWAUS TC metrics exhibited statistically significant linear trends." In addition, they note, "known climate indices—such as Niño-3.4, Niño-4, SOI, NOI, PDO, NAO, and others—generally were found not to be significantly correlated to the variability of TC frequency or TC days in the NWAUS region." Once again, theoretical concerns are not supported by real-world data.

Examining hurricane trends in two ocean basins, Wang and Lee (2009) write that in the Western Hemisphere, tropical cyclones (TCs) "can form and develop in both the tropical North Atlantic (NA) and eastern North Pacific (ENP) Oceans, which are separated by the narrow landmass of Central America," and "in comparison with TCs in the NA, TCs in the ENP have received less attention although TC activity is generally greater in the ENP than in the NA (e.g., Maloney and Hartmann, 2000; Romero-Vadillo et al., 2007)." In exploring how the TC activities of the NA and ENP ocean basins might be related to each other over the period 1949-2007, as well as over the shorter period of 1979–2007, Wang and Lee employed several different datasets to calculate the index of accumulated cyclone energy (ACE), which accounts for the number, strength, and duration of all TCs in a given season.

The two U.S. scientists discovered "TC activity in the NA varies out-of-phase with that in the ENP on both interannual and multidecadal timescales," meaning "when TC activity in the NA increases (decreases), TC activity in the ENP decreases (increases)." They found "the out-of-phase relationship seems to [have] become stronger in the recent decades," as evidenced by interannual and multidecadal correlations between the NA and ENP ACE indices of -0.70 and -0.43, respectively, for the period 1949-2007, but -0.79 and -0.59, respectively, for the period 1979–2007.

Thus, in terms of the combined TC activity over the NA and ENP ocean basins as a whole, there is little variability on either interannual or multidecadal timescales, and real-world empirical data suggest the variability that does exist over the two basins has grown slightly weaker as the Earth has warmed over the past six decades. This, too, contradicts claims that hurricanes or tropical cyclones become more numerous, stronger, and longer-lasting as temperatures rise.

In another multiple-ocean-basin study focusing on five ocean basins—the Atlantic (1960–2007), the Western North Pacific (1960–2007), the Eastern North Pacific (1960–2007), the South Indian Ocean (1981–2007), and the South Pacific (1981–2007)— Chan (2009) examined the relationship between the seasonally averaged maximum potential intensity (MPI, an index of thermodynamic forcing) over each basin where TCs typically form and the seasonal frequency of occurrence of intense TCs.

The results of this work indicated "only in the Atlantic does the MPI have a statistically significant relationship with the number of intense TCs, explaining about 40% of the [observed] variance," whereas "in other ocean basins, there is either no correlation or the correlation is not significant." Moreover, "even in the Atlantic, where a significant correlation between the thermodynamic [temperaturerelated] factors and the frequency of intense TCs exists," the Chinese researcher states, "it is not clear whether global warming will produce a net increase in such a frequency, because model projections suggest an increase in vertical wind shear associated with an increase in sea surface temperature," and this phenomenon tends to inhibit intense TC development. He concludes, "it remains uncertain whether the frequency of occurrence of intense TCs will increase under a global warming scenario."

Finally, Wang et al. (2010) examined the impact of the rising sea surface temperature (SST) on tropical cyclone activity, noting, "with the observed warming of the tropics of around 0.5°C over the past four to five decades, detecting the observed change in the TC activity may shed light on the impact of the global warming on TC activity."

Wang et al. examined cross-basin spatialtemporal variations of TC storm days for the Western North Pacific (WNP), the Eastern North Pacific (ENP), the North Atlantic (NAT), the North Indian Ocean (NIO), and the Southern Hemisphere Ocean (SHO) over the period 1965–2008, for which time interval pertinent satellite data were obtained from the U.S. Navy's Joint Typhoon Warning Center for the WNP, NIO and SHO, and from the U.S. NASA's National Hurricane Center for the NAT and ENP.

The five researchers report, "over the period of 1965–2008, the global TC activity, as measured by storm days, shows a large amplitude fluctuation

regulated by the El Niño-Southern Oscillation and the Pacific Decadal Oscillation, but has no trend, suggesting that the rising temperature so far has not yet [had] an impact on the global total number of storm days." This implies "the spatial variation of SST, rather than the global mean temperature, may be more relevant to understanding the change of the global storm days."

In conclusion, four decades of data and the many studies discussed here conclusively disprove the claim that global warming increases tropical storm activity on a global basis.

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5.6. Fire

According to model-based predictions, CO₂-induced global warming will cause larger and more intense wildfires. Girardin et al. (2009), for example, write, "in boreal forests, climate change may act upon fuels evapotranspiration through increased not compensated for by increasing precipitation, or increased frequency of extreme drought years due to more persistent and frequent blocking high-pressure systems," both of which phenomena are typically predicted to lead to more and larger wildfires. In addition, they state, "earlier snowmelt and longer summer droughts with climate change [i.e., warming] could also expose forests to higher wildfire risk."

To explore this possibility, Girardin et al. investigated "changes in wildfire risk over the 1901-2002 period with an analysis of broad-scale patterns of drought variability on forested eco-regions of the North American and Eurasian continents." The seven scientists report their analyses "did not reveal widespread patterns of linear increases in dryness through time as a response to rising Northern Hemisphere temperatures." Instead, they "found heterogeneous patterns of drought severity changes that were inherent to the non-uniformly distributed impacts of climate change on dryness." In addition, they note, "despite warming since about 1850 and increased incidence of large forest fires in the 1980s, a number of studies indicated a decrease in boreal fire activity in the last 150 years or so (e.g. Masters, 1990; Johnson and Larsen, 1991; Larsen, 1997; Lehtonen and Kolstrom, 2000; Bergeron et al., 2001, 2004a,b; Mouillot and Field, 2005)." And they state "this holds true for boreal southeastern Canada, British Columbia, northwestern Canada and Russia."

With respect to this long-term "diminishing fire activity," as they describe it, Girardin et al. state, "the spatial extent for these long-term changes is large enough to suggest that climate is likely to have played a key role in their induction." Interestingly, that role would appear to be one of *reducing* fire activity, just the opposite of what the IPCC contends should occur. To emphasize that point and provide still more evidence for it, they state, "the fact that diminishing fire activity has also been detected on lake islands on which fire suppression has never been conducted provides another argument in support of climate control" over the incidence of fires.

Working on a much smaller geographical scale, Turner et al. (2008) analyzed micro-charcoal, pollen, and stable oxygen isotope (δ^{18} O) data from sediment cores extracted from two crater lake basins in central Turkey, from which they reconstructed synchronized fire, vegetation, and climate histories extending back more than 15,000 years. Based on this analysis, the authors determined "climatically-induced variation in biomass availability was the main factor controlling the timing of regional fire activity during the Last Glacial-Interglacial climatic transition, and again during Mid-Holocene times, with fire frequency and magnitude increasing during wetter climatic phases." In addition, spectral analysis of the Holocene part of the record "indicates significant cyclicity with a periodicity of ~1500 years that may be linked with large-scale climate forcing."

Likewise working on a small geographical scale in a drainage basin located in southeastern Arizona (USA) and northeastern Sonora (Mexico), Brunelle et al. (2010) collected sediments during the summers of 2004 and 2005 from the incised channel wall of the Rio de San Bernardino arroyo and the *cienega* (a wet, marshy area where groundwater bubbles to the surface) surface of the San Bernardino National Wildlife Refuge, from which samples were taken, as they describe it, "for charcoal analysis to reconstruct fire history," as well as pollen data to infer something about climate.

The U.S. and Mexican researchers say "preliminary pollen data show taxa that reflect winterdominated precipitation [which implies summer drought] correspond to times of greater fire activity." The results from the fire reconstruction "show an increase in fire activity coincident with the onset of ENSO, and an increase in fire frequency during the Medieval Climate Anomaly." During this latter period, from approximately AD 900 to 1260, "background charcoal reaches the highest level of the entire record and fire peaks are frequent," after which they state, "the end of the MCA shows a decline in both background charcoal and fire frequency, likely associated with the end of the MCA-related drought in western North America (Cook et al., 2004)."

With respect to the future, Brunelle et al. forecast that if the region of their study warms, "the role of fire in the desert grasslands is likely to change," such that "warming and the continuation of ENSO variability will likely increase fire frequency (similar to the MCA) while extreme warming and the shift to a persistent El Niño climate would likely lead to the absence of fires, similar to >5000 cal yr BP." Consequently, it would appear that the region of their study is not yet as warm as it was during the MCA, and if the region's temperature ever were to significantly eclipse that of the MCA, the frequency of wildfires there could drop to a barely noticeable level.

Moving further west and north, Beaty and Taylor (2009) developed a 14,000-year record of fire frequency based on high-resolution charcoal analysis of a 5.5-m-long sediment core extracted from Lily Pond (39°3'26"N, 120°7'21"W) in the General Creek Watershed on the west shore of Lake Tahoe in the northern Sierra Nevada in California (USA), as well as a 20-cm-long surface core that "preserved the sediment-water interface."

The results of this effort indicated "fire episode frequency was low during the Lateglacial period but increased through the middle Holocene to a maximum frequency around 6500 cal. yr BP," which "corresponded with the Holocene temperature maximum (7000-4000 cal. yr BP)." Thereafter, as the temperature gradually declined, so too did fire frequency decline, except for a multi-century aberration they describe as "a similar peak in fire episode frequency [that] occurred between c. 1000 and 600 cal. yr BP during the 'Medieval Warm Period'." This, they write, was followed by an interval "between c. 500 and 200 cal. yr BP with few charcoal peaks [that] corresponded with the so-called 'Little Ice Age'." Regarding the present, they found the "current fire episode frequency on the west shore of Lake Tahoe is at one of its lowest points in at least the last 14,000 years."

As for the future, the two researchers state, "given the strong relationship between climate and fire episode frequency, warming due to increased levels of greenhouse gases in the atmosphere may increase fire episode frequency to levels experienced during the 'Medieval Warm Period'," which is saying a lot since the part of the planet they studied is currently experiencing one of the lowest levels of fire frequency of the last 14,000 years.

Approaching the subject from a different angle were McAneney et al. (2009), who assembled a much different database for evaluating the global warming/fire relationship in Australia. Their primary source of information for their study was "Risk Frontiers' disaster database of historic building losses—PerilAUS—which provides a reasonably faithful testimony of national building losses from 1900," with additional information being provided by the Insurance Council of Australia's database of significant insured losses. The three researchers noted "the annual aggregate numbers of buildings destroyed by bushfire since 1926 ... is 84," but "most historical losses have taken place in a few extreme fires." They state "the most salient result is that the annual probability of building destruction has remained almost constant over the last century," even in the face of "large demographic and social changes as well as improvements in fire fighting technique and resources."

They find: (1) "the historical evidence shows no obvious trend," (2) "the likelihood of losing homes to bushfire has remained remarkably stable over the last century with some building destruction expected in around 55% of years," (3) "this same stability is also exhibited for the bigger events with an annual probability of losing more than 25 or 100 homes in a single week remaining around 40% and 20% respectively," and (4) "the statistics on home destruction have remained obstinately invariant over time." What is more, McAneney et al. note "Australia's population has increased from around 4 to 20 million over the last century," and therefore we might logically have expected "the likelihood of bushfire losses to have increased with population or at least with the population living immediately adjacent to bushlands." However, their data clearly reveal it "is not so."

Given these findings, McAneney et al. conclude in the final sentence of their paper's abstract, "despite predictions of an increasing likelihood of conditions favoring bushfires under global climate change, we suspect that building losses due to bushfires are unlikely to alter materially in the near future."

Finally, Marlon et al. (2008) examined the subject on a global scale and report, "large, well-documented wildfires have recently generated worldwide attention, and raised concerns about the impacts of humans and climate change on wildfire regimes," noting "climate-change projections indicate that we will be moving quickly out of the range of the natural variability of the past few centuries."

To see what the global wildfire "range of natural variability" actually has been, Marlon et al. used "sedimentary charcoal records spanning six continents to document trends in both natural and anthropogenic biomass burning [over] the past two millennia." The international team of researchers reports "global biomass burning declined from AD 1 to ~1750, before rising sharply between 1750 and 1870," after which it "declined abruptly." In

attributing the cause of these variations, the researchers state the initial long-term decline in global biomass burning was due to "a long-term global cooling trend," and they suggest the rise in fires that followed was "linked to increasing human influences." With respect to the final decline in fires after 1870, however, they note it occurred "despite increasing air temperatures and population." As for what may have overpowered the tendency for increased global wildfires that "normally" would have been expected to result from the global warming of the transition from the Little Ice Age to the Current Warm Period, the nine scientists attribute the "reduction in the amount of biomass burned over the past 150 years to the global expansion of intensive grazing, agriculture and fire management."

In conclusion, in spite of evidence from prior centuries that global warming may have had a tendency to promote wildfires on a global basis (since global cooling had a tendency to reduce them), technological developments during the industrial age appear to have overpowered this natural tendency, leading to a decrease in global wildfires over the past century and a half.

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5.7. Other Weather-Related Events

In this section we discuss other weather-related events not addressed in earlier sections of this chapter.

5.7.1. Debris Flows

Authors Bollschweiler and Stoffel (2010) note it has been suggested global warming may increase the frequency of extreme precipitation events and, therefore, may increase the occurrence of natural mass-movement processes such as debris flows in mountainous regions. In fact, they state in regard to this particular phenomenon that there is a "widely accepted assumption that climatic changes will univocally lead to an increase in event frequency."

In a study designed to explore this question, Bollschweiler and Stoffel developed a history of debris-flow frequencies for eight different areas in the Zermatt Valley-a dry inner-alpine valley of the Valais Alps (Switzerland, with central coordinates of 46°10'N, 47°7'E)-based on data obtained from "tree-ring series of affected conifers and complemented, where available, with data from local archives," which entailed the sampling of 2,467 individual trees that had been affected by debris-flow activity in order to obtain 4,491 pertinent increment cores.

The two Swiss scientists found there were peaks in debris-flow activity "toward the end of the Little Ice Age and in the early twentieth century when warm-wet conditions prevailed during summers in the Swiss Alps," but they also observed "a considerable decrease in frequency over the past decades which results from a decrease in the frequency of triggering precipitation events." Most importantly, they report that when longer-term changes were sought, they could not identify "any significant trends in the debris-flow series between 1850 and 2009."

In discussing their real-world debris-flow results, Bollschweiler and Stoffel say they "contradict the widely accepted assumption that climatic changes will univocally lead to an increase in event frequency." They then note their findings "are in concert with data from Jomelli et al. (2007), indicating that the most recent past (2000–2009) represents the period with the lowest frequency of debris-flow events since AD 1900," even though the intervening century presumably experienced what the IPCC calls global warming unprecedented in the past millennium or more.

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5.7.2. Financial Losses Due to Extreme Weather Events

If global warming causes more frequent and more extreme bad weather, it also could increase the loss of human life and hardship due to hurricanes, floods, landslides, etc. Monetary losses due to extreme weather events have been trending upwards over the past several decades, a fact that mistakenly has been taken to be proof that global warming has been causing real harms to human well-being. However, several factors make these trends misleading and the conclusion wrong.

As the population and the economy grow, loss of life and property increase even if storm intensity and frequency remain the same. It also has been shown that increased wealth in a country like the United States has led to disproportionately increased development in places most likely to be hit by tropical storms: e.g., the U.S. Southeast coastal zone. Inflation also must be taken into account. The standard approach for dealing with these factors is to correct (normalize) for them by adjusting for inflation and by accounting for increases in population and wealth.

Bouwer (2010) conducted a meta-analysis based on 22 studies from around the world that had previously analyzed losses due to storms, tornados, floods, landslides, and other weather, seeking to determine if (1) proper normalization had been done, (2) how much of the effect was removed by normalization, and (3) whether extraneous factorssuch as deforestation causing increased flood riskcould explain any remaining trends. The metaanalysis concluded the following: "All 22 studies show that increases in exposure and wealth are the most important drivers for growing disaster losses. Most studies show that disaster losses have remained constant after normalization, including losses from earthquakes (see Vranes and Pielke 2009). Studies that did find increases after normalization did not fully correct for wealth or population increases, or identified other sources of exposure increases or vulnerability changes, or changing environmental conditions. No study identified changes in extreme weather due to anthropogenic climate change as the main driver for any remaining trend" [emphasis added].

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5.7.3. Heat Waves

Jeong et al. (2010) note modeling studies in the IPCC AR4 suggest future heat waves over Europe will be more severe, longer-lasting, and more frequent than those of the recent past, due largely to an intensification of quasi-stationary anticyclone anomalies accompanying future warming. They cite in support of this statement the publications of Meehl and Tebaldi (2004) and Della-Marta et al. (2007).

In conducting their own analysis of the subject, Jeong et al. investigated "the impact of vegetationclimate feedback on the changes in temperature and the frequency and duration of heat waves in Europe under the condition of doubled atmospheric CO_2 concentration in a series of global climate model experiments." Land surface processes were calculated by the Community Land Model (version 3) described by Oleson et al. (2004), which includes a modified version of the Lund-Potsdam-Jena scheme for computing vegetation establishment and phenology for specified climate variables.

The calculations performed by the six scientists indicated "the projected warming of 4°C over most of Europe with static vegetation has been reduced by 1°C as the dynamic vegetation feedback effects are included" and "examination of the simulated surface energy fluxes suggests that additional greening in the presence of vegetation feedback effects enhances evapotranspiration and precipitation, thereby limiting the warming, particularly in the daily maximum temperature." In addition, they state, "the greening also tends to reduce the frequency and duration of heat waves."

Although Jeong et al.'s findings by no means constitute the final word on the climatic consequences of a doubling of the air's CO_2 content, they indicate just how easily the incorporation of a new suite of knowledge, in even the best climate models of the day, can dramatically alter what the IPCC and some individual scientists purport to be reality.

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