Chapter 1: Introduction

A century ago, in August 1910, fires burned more than 3 million acres in the northern Rocky Mountains of the United States and set the stage for fire management in the 20th Century (Egan 2009). Edward Beals (Beals 1914) reflecting on the August 1910 and other historic fires noted *"…Climate is defined as the sum of weather conditions affecting animal and plant life, and …climate in connection with forests may be considered…advance information about the weather [that] can be used to advantage in reducing fire losses in forested areas."* A few years before, in March 1908, the Swedish scientist Svante Arrhenius wrote: "*… any doubling of the percentage of carbon dioxide in the air would raise the temperature of the earth's surface by 4^o; and if the carbon dioxide were increased fourfold, the temperature would rise by 8^o… The question, however, is whether any such temperature fluctuations have really been observed on the surface of the earth. The geologists would answer: yes*." (Arrhenius 1908 page 53). Arrhenius explained the now well-documented (IPCC WG I 2007) correlation between the greenhouse gas (GHG) carbon dioxide (CO_2) and temperature at the Earth's surface. At the time of the August 1910 "Big Burn", the atmospheric concentration of CO_2 was ~300 parts per million volume (ppmv) and it is now[1] more than 390 ppmv. As emissions from fossil fuel consumption and land use change continue to increase, current projections are that atmospheric CO_2 will reach 600 ppmv, double pre-industrial levels, by mid-21st Century. Carbon dioxide concentrations of ~ 900 to 1100 ppmv, approaching a four-fold increase, are expected by the end of the Century (Kiehl 2011). Changing climate is now setting the stage for fire management in the 21st Century.

Climate is the description of the average weather and its variability over a given time period, commonly 30 years. Climate in the 21st Century will differ significantly from 19th and 20th Century climate (IPCC WG I 2007). Observed 20th Century warming is highly correlated with increases in human-induced emissions of heat trapping GHG (IPCC WG I 2007). The first decade of the 21st Century, 2001 – 2010, was the warmest decade in the 130-year period of recorded global temperature (NOAA NCDC 2011). Nine of the 10 warmest years on record occurred in the period 2001 to 2010 (1998 was the other), with 2010 tied with 2005 as the warmest on record, with a global mean annual surface temperature (MAT) 1.34^{o}F warmer than the 30-year average MAT from 1951 to 1980 (NASA 2011). During the past 30 years, global surface temperatures have increased approximately 0.16^{o}C (0.29^{o}F) per decade. Since 1895, when records began for the contiguous United States, temperature has increased at an average rate of 0.12^{o}F per decade and precipitation by 0.18 inches per decade. 2010 was the 14th consecutive year with MAT above the long-term average (NOAA 2011). The expected 2^{o}F to 10^{o}F warming in the 21st Century will be considerably greater than the 1.5^{o}F observed increase in the 20th Century (Karl, Melillo, and Peterson 2009). CO_2, the most important GHG (Hofmann, Butler, and Tans 2009), showed growth in 2010, reaching a concentration of 390 ppmv by years end (NOAA ESRL 2011). Even if anthropogenic GHG emissions had been reduced to zero by 2010, inertia in the Earth system would result in continued warming through the 21st Century and beyond (Gillett et al. 2011). In reality, increases in atmospheric CO_2 continued accelerating in 2010.

[1] Updated CO_2 information may be accessed at http://www.esrl.noaa.gov/gmd/ccgg/trends/

Continued business-as-usual energy consumption will result in an atmospheric CO_2 concentration of ~1000 ppmv by 2100 (IPCC WG I 2007). The Earth last experienced 1000 ppmv CO_2 concentration ~ 35 million years ago (Ma) when the tropics were 5 to 10°C warmer and the polar regions 15 to 20°C warmer than present (Kiehl 2011). In the past, biomes changed when Earth experienced warmer temperatures and higher CO_2 concentrations (Salzmann, Haywood, and Lunt 2009), and fire regimes changed as climate and vegetation changed (Bowman et al. 2009). 21st Century fire regimes will likewise change as ecosystems experience to changing 21st Century climate (Flannigan et al. 2009; Krawchuk et al. 2009; Pechony and Shindell 2010).

Climate change is a statistically significant variation in the mean state of the climate or in its variability that persists for an extended period (typically decades or longer) (IPCC WG I 2007). Climate has changed over time scales of decades to millions of years during the Earth's history (Cronin 2009). Predictions of 21st Century Climate Change are based on projected GHG concentrations in the atmosphere that will result from past, present and future GHG emissions. Recorded atmospheric concentration of CO_2, the principal GHG, has increased by over 24% during the 50 years of active measurement (US Department of Commerce 2010) and an estimated 40% since 1750 (IPCC 2007). Global GHG emissions (CO_2 plus other GHG) due to human activities increased 70% between 1970 and 2004 (IPCC 2007). GHG emissions in the first decade of the 21st Century are tracking at the high end (most carbon intensive) of the range of emissions scenarios (Le Quéré et al. 2009), used by the Intergovernmental Panel on Climate Change (IPCC) in its Fourth Assessment Report (AR4) issued in 2007 (IPCC WG I 2007). The various scenarios are based on different socioeconomic conditions and patterns of energy use (Nakicenovic and Swart 2000). Managers and planners need to be aware that current global GHG emissions and emissions trends will result in 21st Century warming that exceeds the temperature increases currently being considered by policy makers (Rogelj et al. 2010). As models have improved over time, the remaining uncertainty about the precise magnitude and timing of 21st Century climate change is largely due to uncertainty about future global GHG emissions (Anderson and Bows 2008).

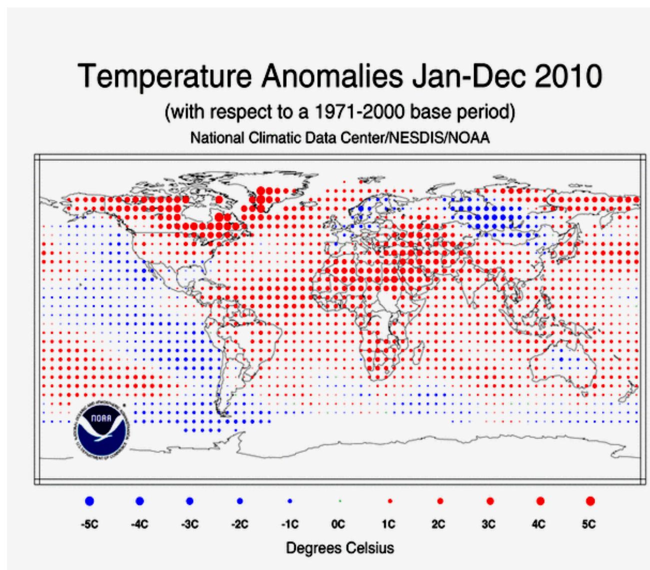

Figure 1.1: Source: NOAA
http://www.noaanews.noaa.gov/stories2011/20110112_globalstats.html Last accessed July 12, 2011

Climate largely determines ecosystem differences, and ecosystems of different climates differ significantly (Bailey 2010). Projected climate change will strongly influence ecosystem characteristics and fire regimes (Flannigan et al. 2009). Land managers will need to plan and manage for these changing conditions (Joyce et al. 2009; West et al. 2009; US Government Accountability Office 2007). Mitigation and adaptation are the common categories for planning and managing climate change responses (IPCC 2007). Mitigation involves actions to reduce the concentration of GHG in the atmosphere and adaptation involves actions that address minimizing the negative effects of climate change on ecosystems and societies. Changing fire regimes will affect both mitigation and adaptation, meaning land managers will be involved in both aspects of climate change response. For example, management that enhances the long-term retention of carbon in ecosystems and reduces fire emissions to the atmosphere will benefit mitigation (Hurteau, Koch, and Hungate 2008). Management that contributes to increased ecosystem resilience will benefit adaptation (National Academy of Science 2010).

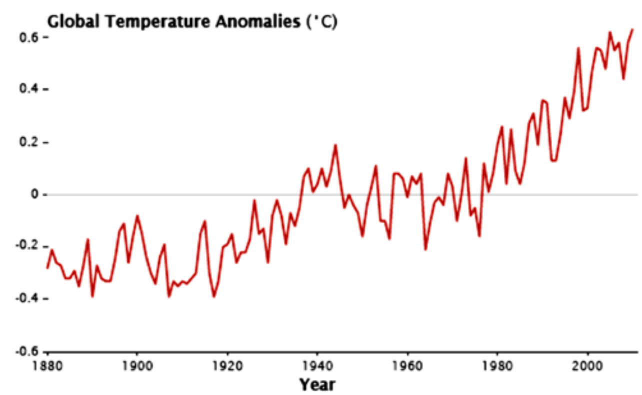

Figure 1.2: Global Temperature Anomalies 1880-2010. Source: NASA http://www.giss.nasa.gov/research/news/20110112/ Last accessed July 12, 2011

The Great Fire of 1910 burned 3 million acres of the recently created Bitterroot, Cabinet, Clearwater, Coeur d'Alene, Flathead, Kaniksu, Kootenai, Lewis and Clark, Lolo, and St. Joe national forests (Egan 2009). A two-day wind driven blow-up (August 20–21, 1910) killed 87 people, including 78 firefighters (Beals 1914). The three million acres burned rank the Great Fire of 1910 with previous large fires in 1825 in Maine and New Brunswick, 1871 in Wisconsin and Michigan and 1898 in South Carolina (National Interagency Fire Center). The importance of the 1910 Idaho and Montana burn on fire policy has been noted by several authors (Pyne 1982; Pyne 2001; Busenberg 2004; Stephens and Ruth 2005; Stephens and Sugihara 2006). The year 1910 is also a useful reference for discussing the converging paths of fire history and climate science. At that time, much of the wildland acreage of the United States had recently come under modern jurisdictions, with the establishment of the Forest Reserves (later National Forests) under the 1891 Forest Reserve Act, the 1897 Organic Act, and the 1911 Weeks Act. The role that atmospheric GHG concentrations played in warming our planet had been identified (Arrhenius 1908). By 1910, we had begun to practice both modern forest management with Pinchot and others in the United States and modern meteorology, including weekly forecasts issued by the U.S. Weather Bureau (Huffman 1977; Lorenz 2006; Pietruska 2011). Looking forward a century from 1910 we can see the impacts of demographic change and begin to witness the impacts of climate change on wildland fire management. Looking backward a century from 1910 we can see growing changes between the landscape traversed by the Lewis and Clark Voyage of Discovery and that burned in 1910 (Ambrose 1996). Looking forward two Centuries, climate will be significantly different from that experienced in the two Centuries since Lewis and Clark traversed the area of the Great Fire of 1910 (National Research Council 2010). Looking back two Centuries, and more, from 1910 we see the changes associated with European settlement of the United States, view fire in a pre-European dominated landscape and gain a sense of how our current landscape evolved under climate and demographic change over the past ~12,000 years of the Holocene epoch (Delcourt and Delcourt 1997; Delcourt and Delcourt 1988).

The Great Fire of 1910, and the Palouser[2] wind that drove it, also produced scientific studies and human narratives on the mixture of climate, fuels, weather and fire that define Earth as a fire planet. *"It is the plan of this work to investigate ... climatic causes for forest fires ... in order to discover whether or not the last three years are usual or unusual..."* (Lennon 2000; Beals 1916; Koch 1978; Pyne 1990; Larsen and Delavan 1922). Those post-1910 studies were steps in the development of modern fire weather forecasting, fire behavior, fire effects, fire danger and many other technologies that form the basis of our understanding of fire in relation to weather. Science is now extending our 20th century understanding of the relationship of fire and weather into the realm of relationships between fire and climate variability, as exemplified by ENSO (El Nino-Southern Oscillation), and climate change (Crimmins 2006; Trouet et al. 2009; Thuiller 2007). Developing widely applicable ecosystem classification systems and relating them to fire regimes has greatly enhanced our ability to understand the interrelationships between climate, ecosystems and fire that are necessary for our ability to plan and manage for fire during 21st Century climate change (Holdridge 1947; Bailey 1985; Grossman et al. 1998; Lugo et al. 1999; Host et al. 1996; Brown and Smith 2000; Bailey 2006; Hostetler, Bartlein, and Holman 2006; US Government Accountability Office 2007).

Fire occurs in the vegetation that grows in the thin boundary layer where the Earth interacts with its atmosphere. Fire has been occurring and influencing Earth's ecosystems since at least 420 million years ago (Mya), when terrestrial vegetation arose and the Earth's atmosphere became sufficiently oxygenated for combustion to take place with the presence of lightning and other ignition sources (Bowman et al. 2009; Scott and Glasspool 2006). Fire has been a presence on Earth while climate varied and changed and humans rose to dominance to use and change the way fire influenced ecosystems. Fire has been a feature of the long interaction of atmosphere and vegetation that has modified atmospheric chemistry and produced a richly diverse mosaic of terrestrial vegetation (Marlon et al. 2009). Atmospheric oxygen concentrations of 15% or higher demarcate the times in geologic history when fire was present in the Earth's landscapes (Marynowski and Simoneit 2009). Fire played a critical role in human ascendancy and enabled humans to join climate as important ecosystem drivers (Pausas and Keeley 2009; Bowman et al. 2011). Human activities are also causing climate change, which will result in different climate in the 21st Century than experienced in the 19th and 20th Centuries (National Research Council 2010). Climate change will alter the geographic distribution of wildfire and lead to increased fire activity in many parts of the world (Krawchuk et al. 2009; Flannigan et al. 2009).

We follow this Introduction with eight chapters covering: the current status of climate change science; the importance of fire regimes for understanding climate change impacts; the interrelationships among ecosystems, climate and fuels; the importance of understanding variability, change, scale and pattern for interpreting climate-fire interaction; fire history and climate change from an ecosystem perspective; scientific progress we can expect in the upcoming decade; some recommendations for managers for using fire history to inform their decision making under 21st Century climate change, and concluding thoughts.

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[2] A strong, dangerous, katabatic wind that descends from the mountains into the Palouse River valley in northern Idaho and eastern Washington. http://www.superglossary.com/Definition/Weather/Palouser.html

Our approach to *Chapter 2: Climate Change – State of the Science* recognizes that an unprecedented volume of already synthesized information on climate change is readily available. After briefly relating the history of climate change science and available syntheses products, we discuss currently available synthesis documents, and provide information on how they can be accessed. As wildland ecosystems evolved under the influence of demographic and climate change during the Holocene, the frequency, intensity, seasonality, extent, and other characteristics of fire that define fire regimes (Agee 1996) have also changed. Fire regimes constitute a means for understanding and summarizing the many components of fire as they vary through time. The fire regime concept closely parallels how climatology constitutes a means for understanding and summarizing how the many components of weather vary though time. As such, understanding fire regimes becomes a critical link for understanding the relationship between fire history and climate. As climate changes during the 21st Century and beyond, fire regimes serve as a critical bridge for interpreting the impacts of climate change on ecosystems through the empirical extension of fire history information. For these reasons, we provide an overview of fire regime theory and literature in *Chapter 3: Fire Regimes*. We build on this foundation in *Chapter 4: Ecosystems, Climate and Fuels* to consider how climate has historically affected ecosystems and fuels in relation to climate to aid our understanding of the potential impacts of future climate change. We find that Bailey ecoregions are a particularly useful basis for understanding current ecosystem, climate and fuels and their historic development, as well as for linking fire history/climate change information to a large array of existing and expanding fire information sources such as, for example, LANDFIRE. Fire history is greatly enriched by an expanding array of paleoecological studies and information bases that portray the evolution of ecosystems and fire over time, and particularly during the past 12,000 years since North America emerged from the last glacial period of Earth history. Fire is a disturbance process that is integral to most ecosystems at various time and space scales (Levin 1992). In *Chapter 5: Variability, Change, Scale and Pattern*, we examine the importance of scale for understanding variability and change in both ecosystems and the atmosphere, and in their interaction. We specifically address *Fire-Atmosphere Interaction* in order to provide information at three specific "scales": Short (synoptic to seasonal), Intermediate (annual to interannual), and Long (decadal to centennial). In *Chapter 6: Fire History and Climate Change - The View from Ecosystems (East and West)* we provide a historical perspective of fire in the United States. That history derives from a variety of sources ranging from historical and anecdotal accounts through tree ring data and sediment cores. Fire history sources are not evenly distributed around the United States. Some areas have multiple sources of measurement data while others must rely more on written history. We expect that fire history will be most useful for contemplating climate change impacts when organized on an ecosystem basis. *Chapter 7: Scientific Progress Expected in the Next Decade* looks out to the science horizon, and a bit over, to point out areas of expected progress and emphasize areas of continuing uncertainty. In *Chapter 8: Recommendations for Managers* we provide some specific suggestions so managers can use both available and expected information about fire history and climate change to better understand potential fire regimes in the face of climate change, and use this information to help shape fire and fuel management decisions in the 21st Century. Chapter references for literature cited and five Appendices (A through E) follow the main body of the report. Appendix D provides additional links to expanded bibliographic information associated with this effort, including an online bibliographic database.