The Application and Utilization of Climate Information for Fire Management and Policy

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Abstract

Climate is recognized as a primary influence on ecosystems through feedback processes involving albedo, atmospheric moisture, atmospheric chemistry, evapotranspiration, solar radiation, temperature and wind. The major direct influences of climate on fire include drought, humidity, lightning and wind. Fire directly influences climate primarily by greenhouse gasses and aerosols, particulates, trace gasses and trace hydrocarbons. Despite these known (to varying extent) relationships, it is not uncommon for even the most basic climate information to be largely under-utilized in wildland fire decision-making and planning. In advanced wildfire management countries, where decision-support information includes a large number of components from both natural and human systems (e.g., vegetation, fuels, restoration, life, property and economics), climate information is often not directly incorporated into decision processes, although it may be implied in fire danger, fire behaviour or fire potential indices.

This paper will discuss the application and utilization of climate information for fire management and policy. The importance of understanding past, present and future climate in the context management and policy will be emphasized. Illustrations will include discussion on the application of climate for various aspects of management and policy such as the development of the wildland-urban interface, ecological change, agency policies versus fire management (e.g., air quality) and legacies (e.g., fire suppression policy). Some specific examples of the utilization of climate information include: 1) prescribed fire, fire use and other fuels treatments should be opportunistic in relation to seasonal climate; 2) monthly and seasonal climate forecasts, though currently considered low in predictive skill, can still have value in providing decision-makers with some quantitative information; 3) the potential impact of regional climate change should be incorporated into long-term planning, particularly in the context of rehabilitation and restoration efforts. For the fire community, education and an improved understanding of climate information are essential. This includes both processes and products (e.g., what, how good, interpretation, uses and misuses). Likewise, the climate community could benefit from an improved understanding of fire management processes to improve and develop climate information relevant for decision-making and planning. The global trend of climate information development and improved climate prediction should influence fire management in a positive manner. However, simply developing climate information and making it available will not be enough. Fire management and policy makers will have to incorporate this information directly into the decision and planning process to gain the desired benefits.

1. Introduction and history

Climate is the slowly varying aspects of the atmosphere-hydrosphere-land surface system (AMS 2000), typically characterized by averages over time (e.g., a month or longer), or averages over space (up to global in scale). The climate system (comprising the atmosphere, hydrosphere, lithosphere and biosphere) exhibits variability within both time and space; variability via feedback processes between these "spheres" due to complex natural processes, and to varying degrees of extent (and understanding) from anthropogenic influences.

The relationship between climate and fire has been understood in simple terms since hominids began utilizing fire (see Pyne 2001; fire colonizing by hominids). Burning was done in an organized manner and with intent, though likely at times the "management objective" failed because either the fire did not burn effectively or it got out of control and burned too much. But the fundamental knowledge was there – the fuels had to be dry enough to burn, and hence the first understanding of the link between climate and fire.

Science has elaborated on this rudimentary knowledge and elemental bond. Vegetation change mocks the timescales of climate, and for a good reason. Natural processes of ecosystem metabolism, succession and biogeography occur at timescales of seasonal-to-interannual, decadal-to-century and centuries-to-millennia, respectively. Human-mediated change through agroecosystems, farm abandonment and urbanization occur on roughly decadal timescales. The climate signal inherent in these processes varies with the type of change, but includes temperature, precipitation, latent heat, sensible heat, humidity, albedo, surface energy fluxes, carbon storage, CO_2 drawdown, and atmospheric pollution along with a host of other environmental signals (e.g., see Bonan 2002 for a detailed discussion on climate-ecosystem dynamics).

For many fire management agencies around the world, incorporating climate into the decision-making process may mean a paradigm shift. In United States (U.S.) fire management agencies, for example, weather (the day-to-day atmospheric conditions) is more frequently asked about than climate. It is one of the legs of the infamous fire behaviour triangle – fuels, topography and weather. There are historical reasons for this. The large fire seasons in the western U.S. during the 20th century that helped shape U.S. Forest Service fire suppression policy (Pyne 1997) occurred during drought years. But there was likely a perception that hot, dry winds were the "cause" of the large areas burned, and not necessarily dry fuels per se. Indeed wind would have been a critical factor in fire behaviour, and thus related to the fire spread and rates of spread that were hampering suppression efforts. Thus given the passionate Forest Service policies of suppression during the 1900s, it is easy to see how weather became the more prominent link to fire business.

Scientific research in the U.S. Forest Service has been an embedded component of the agency since its inception, and linked one way or another to fire protection policy (e.g., Pyne 1997). The evolution of research was first fire as forestry, then fire as physics, by the end of the 1980s fire effects, and perhaps most recently, global change. During the later years came the development of fire behaviour and fire danger models, both of which heavily emphasize weather conditions. In fact so much so, that the fire agencies began installing their own network of weather observation stations, first manual sites, then the implementation of the Remote Automatic Weather Station (RAWS) network. However, many of these stations have come and gone, been moved, or not well maintained, all of which do little justice for a climate record. Some sites now have a 15-20 year or longer record of observations, short by climatology standards, but enough to sense the value of having and utilizing historical weather records for fire management.

The absence of climatology thinking during these varied research eras was not necessarily a fault of the fire agencies. Characteristics of plant groups in relation to climate were first formalized in the late 1800s, but the field of meteorology (of which climatology is obviously closely related), did not start making significant advances until around World War II. The evolution of climatology lagged meteorology. Originally, climatology was simply summary statistics of weather. In the 1960s and 70s, climate dynamics (physics based concepts of the climate system) began to evolve, but the field of climatology did not become a highly popular scientific career until after the 1982-83 El Niño event. Media and public popularity of climate blossomed after the successful prediction and occurrence of the 1997-98 event, and in the politically charged atmosphere of global warming.

2. Climate information for fire management

In the context of fire management, climate provides the background of which weather will be compared. This comparison may be represented as departures from a long-term average, or as percentiles, where it is known what thresholds correspond to varying degrees of fire activity. The further away a weather element is from its central tendency (climate average), the more extreme the event. For example, this may mean unusually wet and cold, or unusually dry and hot. In either case, the extreme will likely attract the fire manager's attention, an otherwise unknown reaction to information without a comparative background. Thus, a useful starting point for climate information may simply be descriptive summaries of those weather factors that impact fire management decision-making. The obvious ones for fire are temperature, precipitation, humidity and wind, but other measures such as soil moisture, cloud cover, and lightning may be of operational interest as well. The U.S. is transitioning to solar radiation at RAWS locations as an automated estimator of "state of the weather" for the country's National Fire Danger Rating System (NFDRS). One facet of NFDRS is the fire danger rating area, which is usually tens of thousands of hectares in size, and is relatively homogeneous in climate, fuels and topography (NWCG 2002). Here, climate provides part of the background for which fire danger is calculated and assessed.

With meteorological instrumentation, one can collect the necessary data and develop a climatology. This is a relatively straightforward process, once the issues of instrument changes, observing practices, observation locations, sampling rates, site stability for observations, processing algorithms, record homogeneity, quality control requirements, network design, data management and data archive issues are all resolved (see Karl et al. 1996). Actually, there is a lot detail involved in the collection of climate data prior to any analysis. It is easy to assume that data are just there and ready to go. Fire agencies should consider that as long as the data are of value to them, then so are the "behind-the-scenes" to generate those data, and sufficient network resources should be provided. Hopefully, all fire agencies think data are of value to them.

An interesting challenge is finding climate data and interpreting the record, not from paper forms or computer files, but in the environment. This is the challenge that paleoclimatologists and dendrochronologists gladly accept. Climate reveals itself in tree rings, fire-scars, ice cores, pollen, glacial moraines, lake levels and ocean sediments. From these records hundreds to thousands of years of climate history can be ascertained. This type of climate information may at first seem of little relevance to the fire problem, until one begins to realize that these records show a history of regional and global fires, either directly from charcoal or atmospheric black carbon deposit or indirectly from drought.

Figure 1 shows the annual number of sites recording fire in Arizona and New Mexico, USA, for the period 1700-1980 based on fire-scars (Swetnam 2002). There are at least three key features seen in the chronology series. First, prior to around 1900, when fire suppression and other land use practices took hold, there was substantial interannual variability in regional fire occurrence. Second, for the same reasons, there tended to be more regional fires prior to the 1900s. Third, there are a number of years (indicated in yellow) with extensive regional fire occurrence. In other words, large areas burned were not unusual in the first two centuries of this record. Most large fires today pale in size comparison, but there are real and perceived differences between then and now in terms of fire severity, life, property and resource values. It turns out that further analysis showed the high fire occurrence years were correlated with drought years preceded by two or three wet years, and the low occurrence years (labelled in blue), were a wet year preceded by a dry year. So climate and environmental records provide at least two important pieces of information – natural or pre-industrial human fire occurrence for comparison with today's fire activity (an aid in establishing policy and assessing its implications), and a physical connection between fire and drought. But the latter goes further than just a local or regional connection, because there appears to be inter-hemispheric synchrony in fire occurrence. The same pattern of fire occurrence in the South-Western U.S. was happening in Patagonia Argentina, likely a result of ENSO (Kitzberger et al. 2001).

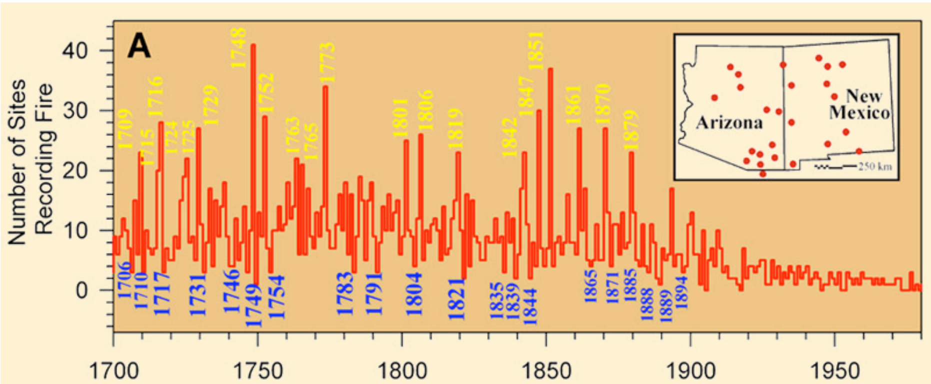

Figure 1. Annual number of sites recording fire in Arizona and New Mexico, USA, for the period 1700-1980 based on fire-scars. Yellow dates indicate years with a large number of regional fires, and blue dates indicate years of low fire occurrence prior to 1900. (Graphic source: Swetnam 2002).

ENSO

ENSO (El Niño-Southern Oscillation) refers to the coherent physical linkages between sea surface temperatures, convection, rainfall, surface air pressure and atmospheric circulation across the equatorial Pacific Ocean. The term is sometimes generically used in place of El Niño (the equatorial Pacific warm water phase), or La Niña (the equatorial Pacific cool water phase), but these two episodes represent the opposite extremes of the ENSO cycle. There are well-established statistical and physical based links between these events and global weather circulation patterns. The upper left map in Figure 2 shows the generic global response in temperature and precipitation anomalies to a December-January-February season warm episode. Large portions of southern Asia, Indonesia, Australia and South America fall under a response of dry. June-July-August warm episodes (lower left map) relate to dry Indonesia and eastern Australia. Note for the cool seasonal episodes (right maps) a generally opposite pattern.

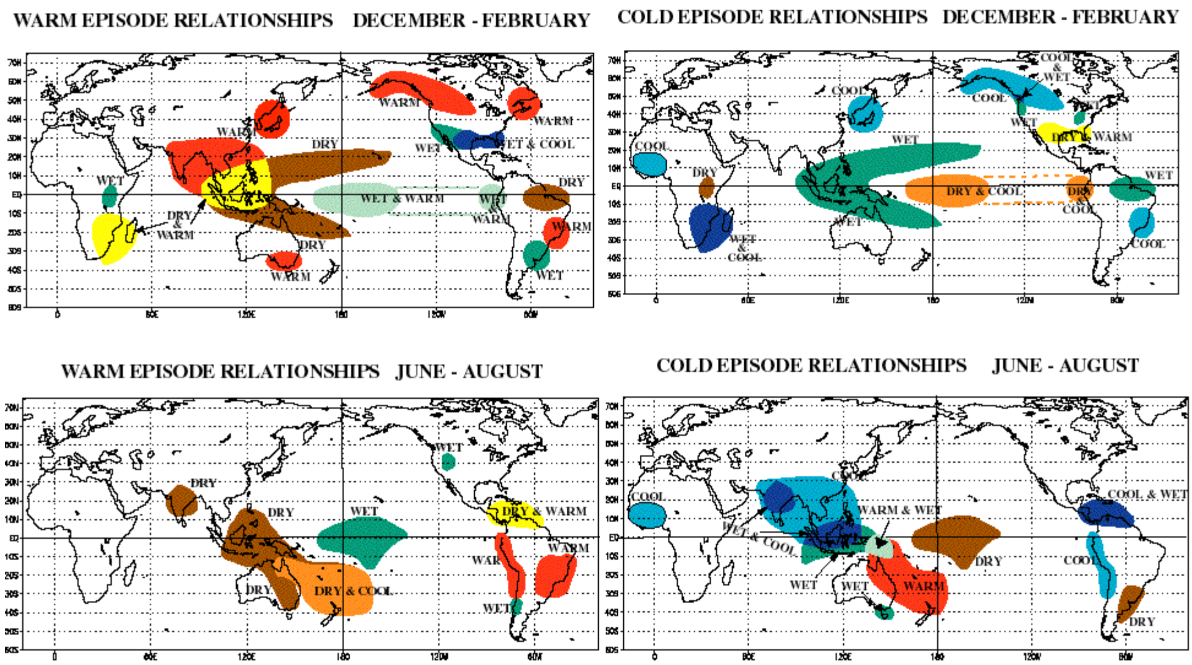

Figure 2. Generic global response to the warm and cool episodes of ENSO for the two seasons December-February and June-August. Colour areas represent regions of anomalous warm, cool, wet, dry or a combination of temperature and precipitation in response to the ongoing episode. (Graphic source: National Centers for Environmental Prediction, Climate Prediction Center, http://www.cpc.noaa.gov/products/analysis_monitoring/ensostuff/)

It is easy to have some climate anomaly with a concurrent ENSO event, and subsequently give the event credit for the anomaly. However, some regions respond more faithfully to ENSO, and ENSO comes in a variety of "flavours". Not all anomalies are a direct response, and even those that are do not always respond in the same way (Hoerling and Kumar 1997). So do not blame everything on ENSO. But for those regions where the ENSO signal is strongest, there seems to be a fairly consistent response, and even for those regions with less obvious impacts, there is still value in ENSO awareness. ENSO is probably the best-known global climate signal we have, and it exhibits some predictability. This should give encouragement to fire agencies to utilize the ENSO information available to them, and if need be, better determine if and how their management regions are impacted.

Drought

If ENSO is not now the best-known climate signal, then drought is. It has certainly been around longer in the sense of awareness and directly recorded human impacts. Redmond (2002) suggests that the preferred definition of drought is one that has "the most universal range of application, the one that works in the largest number of circumstances". Though most physical concepts of drought involve a water balance, to the stakeholder it is often the impact of drought that matters. This is clearly the case for fire management. Drought means dry fuels. To depict drought, various indices have been formulated. For example, in the U.S. there have been no less than 13 drought indices developed since the early 1900s (see Heim 2002 for descriptions and comparisons of these indices and those discussed here). In fact one particular index, the Keetch-Byram Drought Index, was developed specifically for fire control managers. Though each index was developed for a specific purpose, several of them have been adopted over the years by fire management. This may or may not be problematic, but caution should be used when a tool developed for one application is then used for another.

An index such as Palmer's Index correlates generally well with fire in a regional sense (e.g., Westerling et al. 2002), but actual detailed quantitative relationships between drought indices and fire are generally not available. Few fire experts could say with certainty how the impact on fire activity changes with a Palmer Drought Severity Index of say 0, -1, -2 or -3, if there is indeed a clear distinction. But the physical evidence of the link between drought, vegetation and fire is usually obvious, and drought indices at least provide a coarse indication of the current state and a suggestion of fire potential. Perhaps future research will achieve better connections.

On broad scales, the ecological response to decadal climate variability, a time scale not uncommon for drought, has been observed (e.g., Swetnam and Betancourt 1998). Drought perhaps even exhibits a bit of predictability (e.g., Gray et al. 2003). But, it is not obvious that drought's impact is always fully appreciated. The best example of this is a multi-year drought, followed by an average precipitation year. The recent average year can give a false sense of recovery, but in reality, the multi-years of dry are still felt in the vegetation. Though perhaps the fine fuels are moisture laden, the heavier ones still thirst, and there is persistent underlying fire danger. An index such as the Standardized Precipitation Index (SPI) may help improve the understanding of the background climate in these circumstances, because at virtually any time scale, integrated precipitation can be examined given a sufficient historical record. Figure 3 provides an example of the SPI for U.S. climate divisions. The left map is the SPI for the 6-month integrated period ending in June 2003 (February-June 2003), and the right map for the 60-month (5-year) integrated period also ending June 2003 (July 1999-June 2003). Red and brown colours indicate substantially dry areas, and green colours wet areas. On the short time scale (6 months), the western U.S. pattern is generally average precipitation, but over the longer period (5 years), the West has been quite dry. Nearly opposite patterns are seen in portions of the Southeast.

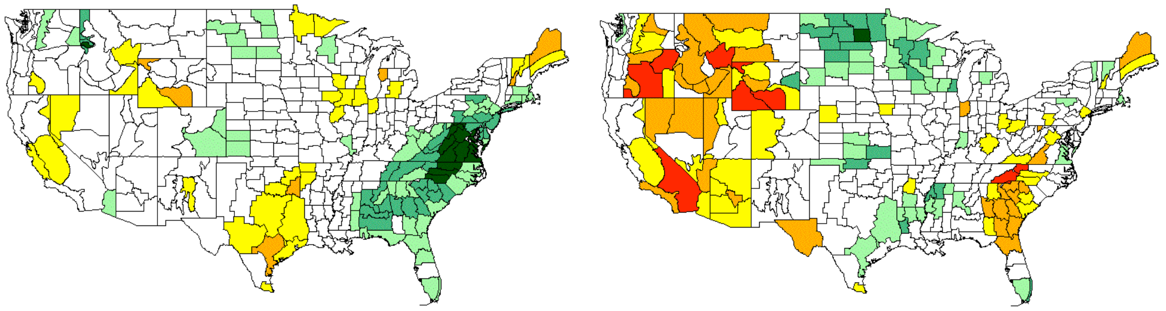

Figure 3. Example maps of the Standardized Precipitation Index for U.S. climate divisions. Left map is for the 6-month integrated period ending in June 2003, and the right map is for the 60-month integrated period ending in June 2003. Red and brown colours indicate substantially dry, and green colours wet. [Source: Western Regional Climate Center; http://www.wrcc.dri.edu]

Prediction

Climate prediction is evolving, and there is forecast skill, albeit small for many regions, at monthly and especially seasonal time scales. The International Research Institute for Climate

Prediction, for example, is one of a few organizations that produce global seasonal climate forecasts of precipitation and temperature (among other climate elements). They utilize a number of global numerical climate models and statistical forecasts in their production of seasonal global forecasts. Figure 4 shows the seasonal skill of one particular model used as example here, the European Community - HAMburg (ECHAM4.5) model that was developed at the Max Plank Institut fur Meteorolgie in Germany. The left map is for the December-February season, and the right map June-August. The darker red colours indicate areas of highest seasonal forecast skill. Regions within the tropics typically exhibit the highest values.

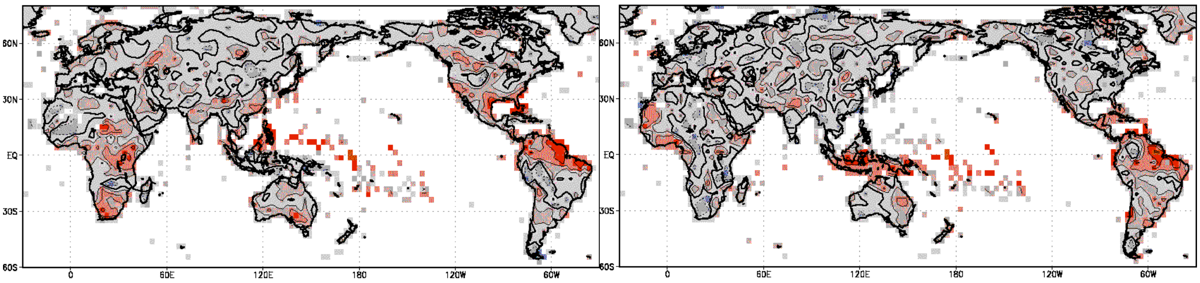

Figure 4. Seasonal precipitation forecast skill for the European Community HAMburg (ECHAM4.5) global numerical climate model for December-February (left map) and June-August (right map). The darkest red colours indicate areas of highest forecast skill. [Source: IRI; http://iri.columbia.edu/]

Unfortunately, many fire prone areas are also in areas of low forecast skill, and fire management who are aware of this are understandably reluctant to use these forecasts for strategic planning. But a fire manager should consider the value of scientific quantitative information, even if it is fraught with uncertainty, to improve decision-making accountability. Still within the infant stages of climate prediction, U.S. fire agencies have recently begun to take a proactive role, and are generating monthly and seasonal forecasts of fire potential (see [http://www.nifc.gov/news/nicc.html] for recent forecasts). The new concept of seasonal forecasts is discussed in Garfin et al. (2003), but the essence of the output stems from a remarkable synergy of fire weather meteorologists, fuels and fire specialists, fire management and climatologists exchanging information and general knowledge to produce regional and national fire potential outlooks. Past, present and future climate is part of the discussion process.

Fire data

It should not be discounted that the record of fire occurrence, and its equally important components of area burned, costs, cause, etc., are as important in understanding fire-climate relationships, as are the climate data. The data collection issues are similar to climate regarding the information quality and homogeneity of records. The problem is further compounded by resources and desires to coordinate multiple fire agencies in organizing collection procedures and data archive management. Some attempts to describe issues and make recommendations have been outlined such as Brown et al. (2002).

3. Fire climate information and policy

Atmospheric scientists have been largely responsible for bringing public awareness of the bond between climate and fire. Nuclear winter, greenhouse summer, ENSO, carbon dioxide and satellite detection of smoke and fire have all increased public and agency consciousness

(Pyne 1997; 2001). Science can lead to policy, and policy to science. Whether or not science and policy are misguided is another question. As Pyne (1997) thoroughly describes, the U.S. Forest Service has always embraced scientific research. During the 1900s as U.S. fire policy formally came into existence and evolved, climate drove large fires, and the large fires drove policy deeper and deeper into suppression as the most important strategy. There is little question that climate helped formulate this national policy, but it is unlikely that few, if any, were consciously aware of it. Climate has shaped fire policy in every country whether knowingly or not.

With recent growing interest in global and regional change though, there have been corresponding changes in thinking about how climate information can and should influence policy. The Kyoto Protocol to the United Nations Framework Convention on Climate Change is a prime example of using climate information to reshape policy. There is no reason to think that global fire would not change if climate did. The scientific papers are relatively recent, but since the early 1990s several have described the impacts of a changing climate on boreal and tropical forests, ecosystems, and on fire activity itself (e.g., Brown et al. 2003). A changing climate will constitute change in suppression, fuels treatments, and managed ecosystem strategies. It seems more prudent to plan for such change, rather than react to it. What if climate did not cooperate with a 30-50 year restoration project, or next year's suppression budget and resource allocations, or fuel treatment target goals?

The reintroduction of fire to ecosystems and landscapes encompasses a variety of management objectives – hazardous fuels reduction, exotic species removal and overall ecosystem health. Early human fires were less complex than today because they did not have thousands of pages of regulations and likely not persistent complaints to their societal representatives. Every burn boss knows the check list to perform a prescribed fire is long, there is a certain risk in implementing the fire, and only certain times of the year to perform the task. Risk is partially a function of climate. Escaped burns from an area that is moderately moist into one stricken by drought can lead to catastrophic results in both human and environmental terms. From a climate perspective, windows of opportunity to burn are flexible, but the policy and guidelines regulating the burns are not. Many opportunities to meet management objectives are missed because of seasonal climate anomalies (Brown and Betancourt 1999). But none of the U.S. checklists explicitly includes climate as a burn factor (it may be implied in fire danger), and fiscal year boundaries, bookkeeping, and paperwork place limitations on target goals. A missed goal one year means more to deal with the following year. It is very rare that more can be burned in a year than originally planned, at least in a controlled manner.

The global intermix, wildland/urban interface to some, exurban population in other contexts, creates even more demand for policy. Here, people want a "natural" environment to live, probably no fire, and certainly no smoke. There are not many places where these three desires occur simultaneously. Even in very moist tropical and coastal climates, or arid desert regions, where there is no nearby fire, biomass smoke migrates and disperses, driven by weather patterns. Normally wet regions may dry out, allowing for unusual fire occurrence. Other populated regions may experience annual drying and fire occurrence, some seasons more or less. The intermix is not immune to the impulse of climate.

The universally heard phrase "where there is smoke, there is fire", clearly implies "where there is fire, there is smoke". Climatology of the atmosphere's chemistry and pollutants is just as important as temperature and moisture (in fact, they are related). Smoke climatology provides climate information for assessment and policy-making (e.g., Ferguson et al. 2003). Residents loathe smoke despite its natural occurrence in many places, just as tornadoes, floods, earthquakes and hurricanes are natural disasters in many places. Of course, most residents likely loathe these other natural societal impacts too, and technically they all can be bad for one's health. But, education is essential, and thus to inform residents that they are moving into or indeed live in a non-smoke free area heightens the public awareness of the issues and the need for proactive rather than reactive policy.

4. Utilization of climate information

Despite all of the climate information made available in the world, its utilization is another manner. Producing a scientific result does not mean it has to get used, but it does not necessarily mean it gets used either. Risk-taking from and accountability of decisions often generates a real or perceived need for more, better and new information. Scientists are generally happy to produce it, but its accessibility and applicability may be far reaching for the manager. Some fire agencies employ by title "technology transfer" specialists, but knowledge must also be transferred – in both directions. Knowledge about where the information comes from, what it is meant to represent, how it might be used, etc. In this manner, the specialist is indeed a specialist, for the person would know something about both the science and decision aspects of the information.

In the U.S., a regional integrated sciences and assessments (RISA) program is underway to address the environment-society interface (see http://www.ogp.noaa.gov/mpe/csi/risa/). Adapted slightly from the program description: "The RISA program supports integrated research and assessments at the 'regional scale' that account for the institutional and social management objectives, processes and constraints set on decision-makers. Critical climate-sensitive issues in this context are assessed iteratively in a manner that integrates interdisciplinary knowledge and experience about risks and vulnerabilities in a region commensurate with the design and support of effective responses. The Integrated Sciences component informs the assessment function by focusing ongoing research on (1) linkages between critical components of physical systems (e.g. climate-fire interactions), (2) linkages between social and economic activities (e.g. climate and the intermix) and relevant variations and changes in these systems, and (3) linkages between this integrated knowledge, and decision processes." This is the integration of science and society. This is a very valid framework for the fire research and management communities, for it integrates science and society in ways not unlike the undeniable integration of humans and fire.

5. Conclusion

It is not feasible for space sake here to be all inclusive of climate and fire. But the topics raised allow for a fundamental question. Is there value in climate information for fire management decision-making and policy setting? Intuitively the answer seems yes because of the broadly known climate-vegetation relationships and many of the scientifically discovered detailed linkages and feedbacks. But this physical component of the fire-climate system does not tell all. Information by itself has no intrinsic value. The value comes from use of the information. Thus, the answer will be in how the management and scientific communities identify their respective problems, and then integrate and assess the newfound information in the context of both science and society paradigms. The ultimate outcome is the environmental and societal impacts of the decisions and policies anchored in two of Earth's natural powers that have ever been and ever will be – climate and fire.

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