# science highlights



**Science highlight July 2002**

## Fire-climate linkages in the Mid-latitude Americas

**Tucson, Arizona, 23-28 March 2002**

Climate, fire, and vegetation are interrelated elements of the earth system, and their variation and interaction through time have shaped the modern landscape. The strength of the linkages and feedbacks among these elements, however, is incompletely understood. At annual and decadal scales and at the level of watersheds, climate/weather, vegetation composition, fuel buildup, and ignition frequency all determine the fire regime (i.e., the occurrence of fire, as well as its size and severity). On these short time scales, the fire-vegetation linkages seem well developed, with vegetation determining the fuel availability, and fires in turn creating a landscape pattern that shapes vegetation recovery. On century and millennial temporal scales and landscape-to-regional spatial scales, however, large changes in climate determine both the fire regime and the potential vegetation composition, which are related to one another, as on the shorter time scales. Consequently, the linkages between fire and vegetation are less clear on these long time scales. The particular role of fire with respect to climate and vegetation change thus depends on the spatial and temporal scale of interest.

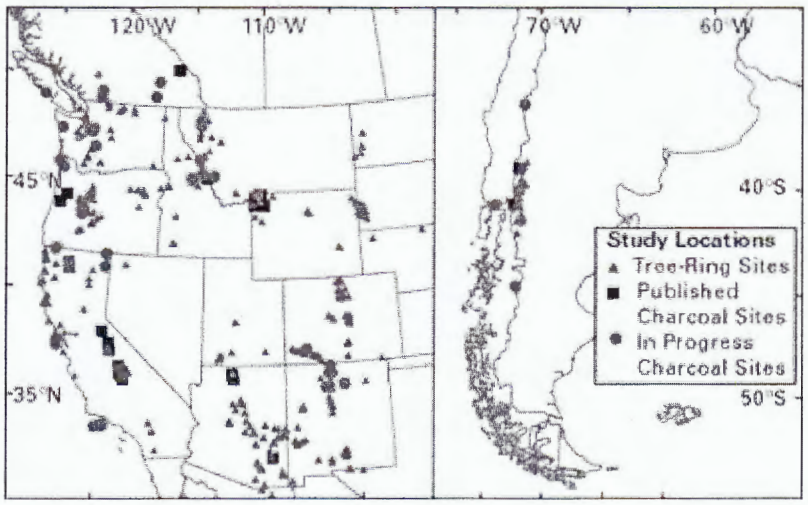


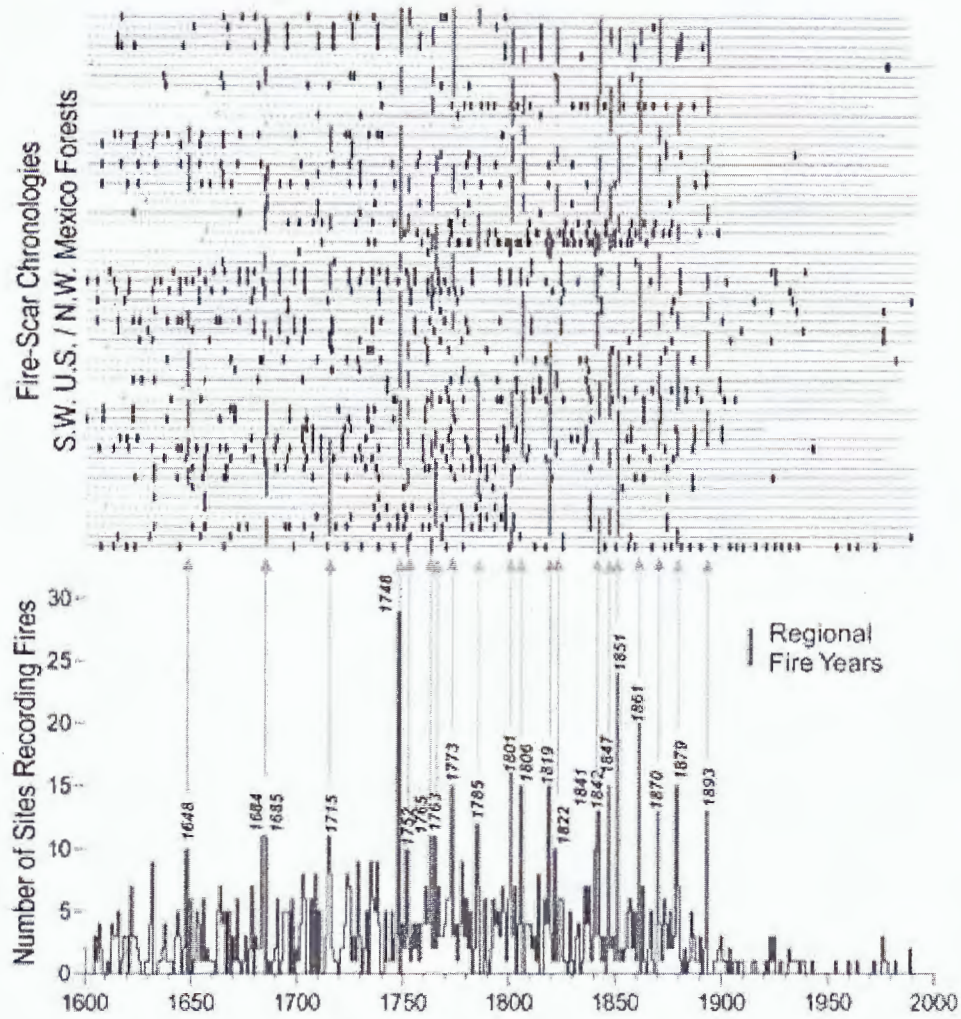

*Fig. 1*

The complexity of these linkages is especially evident in the forests of western North and South America, where fire regimes vary across a spectrum from low-severity nonlethal fires to high-severity stand-replacement events and also vary in their reccurrence from less than a decade to multiple centuries. Understanding the role of fire takes on heightened importance in light of the enormous crown fires that have recently occurred, even in areas that historically supported ground fires. Whether current fire regimes reflect a shift in climate or whether they are a product of Euro-American activity and 20th-century forest management practices is a topic of both scientific and public debate. To address this issue requires information on past fire regimes and a better understanding of the occurrence of fire in relation to climate and vegetation.

Fire history and fire-climate linkages were discussed by researchers from North and South America at a workshop held in Tucson Arizona in March. The purpose of the meeting was to bring together researchers who study past variations in fire activity as recorded by tree-ring and lake-sediment data and researchers who consider the climatic controls of fire on annual, decadal, and longer time scales. The similarities and differences between the western North America and southern South America present an opportunity to study the fire occurrence under an array of climate and vegetation conditions. The objective of the workshop was to describe recent advances in fire history and fire-climate research in these regions and to consider ways that different approaches might be integrated to develop a better understanding of the vegetation-fire-climate system. Discussions benefited from the concerted and collaborative effort among traditionally independent disciplines.

The workshop was attended by 70 scientists from Argentina, Australia, Canada, Chile, England, México, Russia, Switzerland, and the United States. Topics at the workshop included:

- specific mechanisms that link large-scale and secondary circulation features with the occurrence of fire in particular regions.
- analysis of past climatic variability and changing fire regimes on annual-to-millennial time scales;
- regional, inter-regional, and inter-hemispheric comparisons of the records of climate, fire, and vegetation on multiple time scales;
- integration of annual-to-centennial fire-climate information offered by dendrochronological records and decadal to millennial variations described by lake-sediment records;
- importance of fire and climate histories for improving our understanding of fire management strategies

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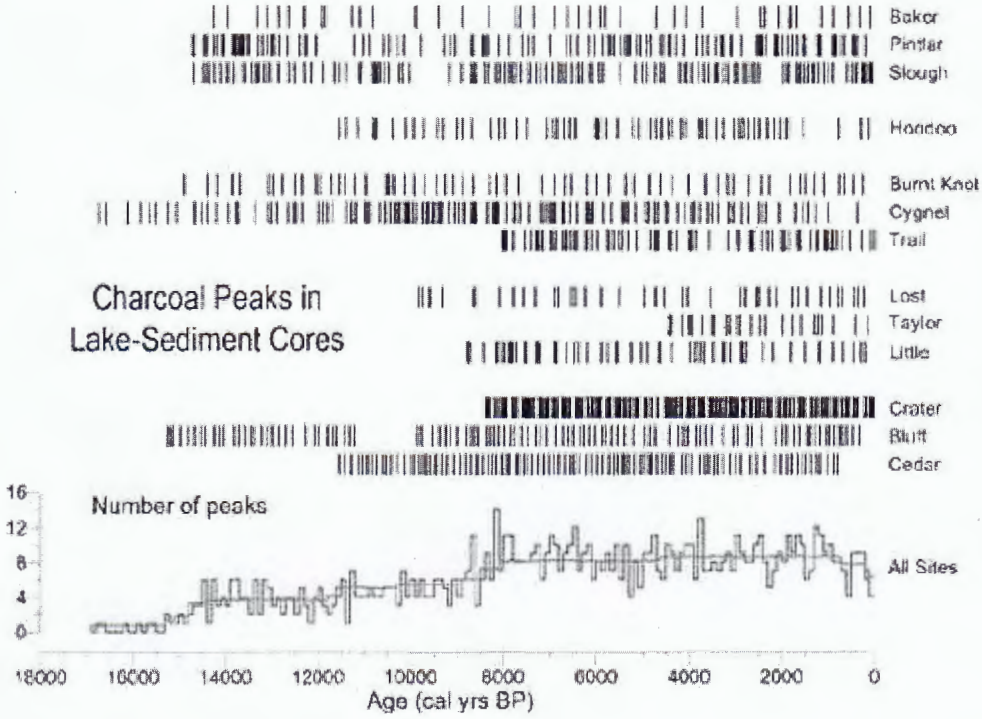
Reconstructions of past fire occurrence during the last few centuries are based on tree-ring records and tree stand-age analysis, both of which offer high spatial and temporal resolution. Networks of dendrochronological sites are now available from the western U.S. and southern South America that reveal spatially coherent patterns in fire occurrence (Fig. 1 and 2). In general, drought conditions promote fire, but there is considerable regional variability in the antecedent conditions that lead to years with frequent large fires. For example, Emily Heyerdahl presented data from eastern Oregon that showed how fire years correlate with summer drought and below-average winter snowpack, but in the Southwest research by Henri Grissino-Mayer (United States) and Tom Swetnam (United States) indicated that large fire years are preceded by above-average precipitation in winter or the previous year. Similar wet antecedent conditions characterize fire years in the dry forests in northern Patagonia, based on studies presented by Thomas Kitzberger (Argentina), Thomas Veblen (United States), and Joseph Donnegan (United States).

A second fire proxy, stratigraphic records of charred particulate matter (charcoal), represents an old discipline that has undergone a revitalization with new high-resolution approaches and careful calibration. Stratigraphic charcoal records from varved and non-varved lake and marine sediments, ice cores, peatlands, and soils have been used to reconstruct fire history across a range of latitudes. Because

these records of fire activity span thousands of years, they provide information on the role of fire during periods of climate and vegetation change. Networks of charcoal records are now available to describe fire history on centennial and millennial time scales (Fig. 1). These data also provide information on fire activity through time that, like the dendrochronological records, shows both spatial and temporal coherency (Fig. 3). For example, Cathy Whitlock (United States) noted that highest fire activity in the Holocene was associated with centennial-to-millennial periods of drought, but the controls of fire on this time scale were sometimes overridden by shorter term variations. In the northwestern North America, high fire frequency was associated with the intensification of the subtropical high-pressure system, which occurred as a result of higher-than-present summer insolation in the early Holocene. In contrast, Scott Anderson (United States) presented data to suggest that an increase in fire frequency in the American Southwest occurred in the late Holocene, when relatively dry conditions were established there. In Patagonia, Maria Marta Bianchi (Argentina) and Patricio Moreno (Chile) showed highest fire activity (both frequency and magnitude) in the early Holocene, perhaps as a result of high interdecadal climate variability at that time, and during the last few centuries. Extremely wet Patagonian sites had little evidence of fires in the Holocene (Simon Haberle, Australia), and infrequent fires in the tree-ring record (Antonia Lara, Chile).

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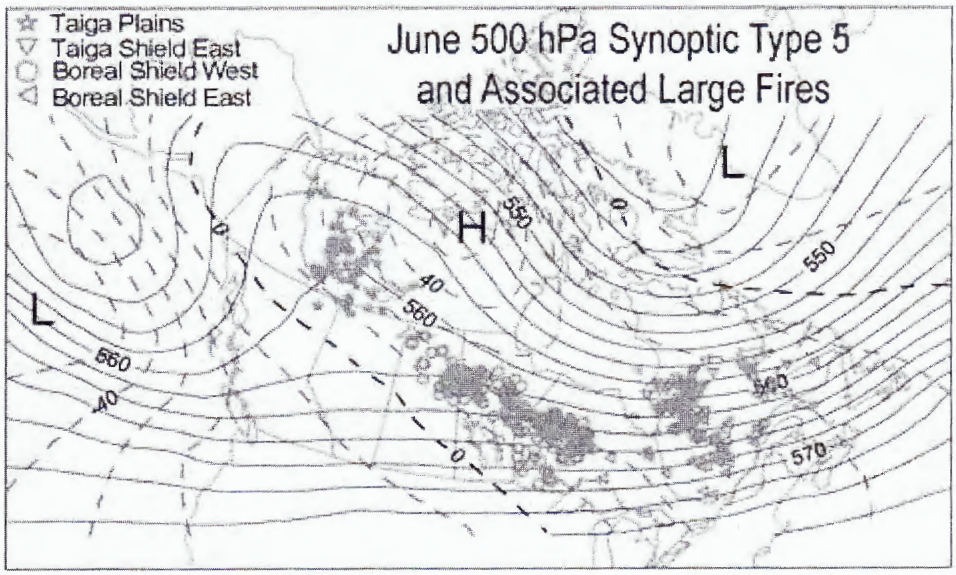
In several studies, charcoal and tree-ring records were used together to reconstruct the fire histories of particular watersheds. For example, integrated studies in the northern Rockies and Pacific Northwest by Andrea Brunelle, Kurt Kipfmuller, Colin Long, and Linda Brubaker (United States) revealed the generally close match between the age of charcoal peaks in lake cores and reconstructed fire events observed in the dendrochronological record. The tree-ring record thus provided an important tool for calibrating the charcoal record. Research in British Columbia underway by Daniel Gavin (United States) and Douglas Hallett (Canada) also compared particulate charcoal in soil profiles with charcoal records from lakes Fire events inferred from the age of soil charcoal provided a spatial context for the fire reconstruction based on the lake time-series. Further collaboration between tree-ring and lake-sediment researchers is now underway in Canada, the United States, Argentina, and Chile as a result of discussions at the workshop.

The use of multiple lines of proxy evidence to reconstruct past fires was also encouraged by participants at the workshop. Ulrike Huber (Switzerland) examined both plant macrofossils and charcoal in a wetland in southern Chile and found that periods of drought, inferred from the plant remains, were also associated with periods of increased burning. In this way, the paleobotanical record provided a climate signal that could be used to help interpret the fire record. Another study from Yellowstone National Park by Grant Meyer (United States) showed that periods with frequent fire-related debris flows were also times when fires occurred in a wide range of environmental conditions, as in 1988 and during the Medieval Warm Period. Close-interval pollen sampling was proposed as another approach that might shed light on long-term ecological response to changes in disturbance regime. Comparison of pollen and charcoal data at the same time resolution has documented forest recovery following ancient fires in Europe and eastern North America, and this high-resolution examination will be an important area of study in the western Americas as well.

The broad-scale climatic controls that give rise to conditions conducive to fires at the local scale were also described for North America and Patagonia by Patrick Bartlein (United States), Michael Flannigan (Canada), Tony Westerling (United States), Cary Mock (United States), Tim Brown (United States), and Henry Diaz (United States). The location of upper-level ridges, area of rising vertical motions, and the seasonal variations in lightning occurrence are significant elements of western and northern North American fire climatology. However, synoptic-scale circulation configurations that favor fire and are evident on monthly composite-anomaly maps often differ substantially from the specific daily circulation patterns that prevail during the initiation of fires. For example, Flannigan illustrated the specific conditions that attend the outbreak of large fires in Canada (the "breakdown" of upper-level ridges). Similarly during the summer of 1988, Bartlein described an upper-level ridge and associated secondary circulation features that combined to suppress precipitation in the Northern Rocky Mountains through the generation of large-scale subsidence and reduction of moist-air flow into the region. In contrast, specific days when large fires were initiated in the region were associated with upper-level circulation features that encouraged convection and the consequent outbreak of lightning-started fires (Fig. 4). The climatology of lightning in the western United States was illustrated by Brown, while Westerling discussed the temporal and spatial patterns of fire in the western United States, and their link to teleconnection indices that can be exploited for fire-season prediction.

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Fire and climate proxy records show the strong influence of annual-to-decadal scale climate variability in fire occurrence. While the importance of El Nino-Southern Oscillation in the American Southwest and northern Patagonia was acknowledged, Ricardo Villalba (Argentina) emphasized that ENSO did not explain all the fire variability on annual and decadal time scales. For example, decadal timescale climate modes such as the Pacific Decadal Oscillation or Trans Polar Index which themselves may mediate the local expression of ENSO-related climate variations can also be tied to the occurrence of fire on interannual-to-centennial timescales. Research documenting, comparing, and assessing such patterns in additional regions of the western U.S. and South America will advance the predictive capability of climate-ecosystem response models.

The examination of fire occurrence on different time scales provided an opportunity to reevaluate some of the basic concepts and terms used to describe fire regimes. The term "mean fire interval" (the inverse of fire frequency) was critiqued by both communities as a commonly misunderstood or misused fire regime variable. Both data sets show quite clearly that fire frequency is nonstationary through time and is dependent upon the size of the area represented, requiring that both the areas and time periods sampled must be specified when reporting fire interval statistics.

The comparison between charcoal and tree-ring records was also discussed. The uncertain source area of charcoal data could be better identified with additional studies of charcoal deposition after modern fires. Likewise, the impact of different sampling strategies in tree-ring studies needs to be examined more closely to evaluate the spatial coherency of fire area. Application of the various approaches to describe variations in fire activity over time was discussed by both disciplines. Intervals with high levels of charcoal accumulation—so-called charcoal peaks—are inferred to represent a period of time in which one or more fires took place. It was agreed that these peaks should be referred to as fire episodes to convey the imprecision of dating and source area. The tree-ring community agreed that this longer time series provided a context for understanding the fire activity in the last few centuries.

The importance of retrospective fire-climate studies as a tool for fire management was also addressed at the workshop. Long-term perspective suggests the variability of fire regimes and the role of climate variability in shaping fire regimes. The legacy of past fires and periods of no fire also needs to be considered in strategies that attempt to restore forests to a prehistoric condition. While the effects of fire suppression policies are evident in low-elevation dry forests, fire history data suggests that fire suppression may have only limited impact in wet forests at higher elevation and along the coast, according to presentations by Carl Skinner (United States), Alan Taylor (United States), Peter Brown (United States), and Fred Swanson (United States). Moreover, projections of future climate changes indicate that fire activity in most regions will increase, suggesting the need for adaptive management in many regions.

Research that considers both tree-ring and charcoal records contributes to other themes in global-change research noted by the workshop participants. Fire is only beginning to be explicitly considered in, for example, dynamic global vegetation models and other terrestrial ecosystem models. In addition to providing a long-term perspective on the incidence of fire and its covariation with climate and vegetation, the kinds of records discussed at the workshop can also be applied in testing or validating the fire modules included in such dynamic ecosystem models.

Products of the workshop include the development of a fire-history database that includes both tree-ring and high-resolution lake-sediment records; a web page for further exchange of research ideas and public information; and a series of synthesis papers that describe fire-climate-vegetation linkages both within and between continents.

Sponsors of the workshop included the USDA Forest Service PNW Research Station (Forest and Inventory Analysis Program), the IGBP Past Global Changes Program, the U.S. Interagency Joint Fire Sciences Program, the NSF Earth Systems History Program (PEP-1 activity), the Inter-American Institute, and the University of Arizona.

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- Figure 3. Charcoal peaks in lake-sediment records from sites in the northwestern United States. The tick marks indicate the occurrence of charcoal influx values greater than background values, and are interpreted as "fire episodes" within the watersheds of the lakes. The total number of peaks each century is plotted at the bottom in black, while the red curve indicates the number of peaks expectable by chance (as determined by a Monte-Carlo experiment). Comparison of the curves suggests that the frequency of fire episodes across the region was generally high during the early Holocene (9000 to 6000 cal yr BP).
- Figure 4. A typical atmospheric circulation pattern that favors the occurrence of large fires in Canada. The solid contour lines show 500 hPa height patterns that describe one of several synoptic circulation types defined for June over the interval 1959-1996, while the dashed lines show the associated height anomalies. Large fires that occurred when this circulation pattern prevailed are plotted as orange symbols. The circulation anomalies suggest that a deeper-than-normal trough over the northeastern Pacific suppresses large fires in western Canada (through greater-than-normal on-shore flow and precipitation), while a stronger-than-normal ridge and associated subsidence and absence of precipitation encourages fires over the eastern two-thirds of the country. [After Skinner et al. (2002), and courtesy of Mike Flannigan]

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