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Fire in the Earth System – bridging data and modelling research

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General BAMS Information Box

Title bar: Paleofire: Data-Model Comparisons for the Past Millennium

What: Fire researchers from eleven countries, with expertise ranging from millennial-scale fire-proxy records to present-day biomass burning to multiple scales of fire modeling, examined how diverse fire datasets and fire modeling approaches could be used together to advance fire science. The workshop aimed to develop testable hypotheses about fire, climate, vegetation, and human interactions by leveraging the confluence of proxy, observational, and model data related to decadal to millennial scale fire activity on our planet. New research directions focused on broad interdisciplinary approaches to highlight how knowledge about past fire activity could provide a more complete understanding of the predictive capacity of fire models and inform fire policy in the face of our changing climate. The workshop was supported by the PAGES Global Paleofire Working Group (www.gpwg.paleofire.org) and the National Science Foundation Geography and Spatial Sciences program.

When: 27 September to 1 October 2015

Where: Harvard Forest, Massachusetts, USA

Introduction

Significant changes in wildfire occurrence, extent, and severity in areas such as western North America and Indonesia in 2015, have made the issue of fire increasingly salient in both the public and scientific spheres. Biomass combustion rapidly transforms land cover, smoke pours into the atmosphere, radiative heat from fires initiates dramatic pyrocumulus clouds, and the repeated ecological and atmospheric effects of fire can even impact regional and global climate. Furthermore, fires have a significant impact on human health, livelihoods, and social and economic systems.

Modeling and data based methods to understand fire have rapidly co-evolved over the past decade. Satellite and ground-based data about present-day fire are widely available for applications in research and fire management. Fire modeling has developed in part because of the evolution in vegetation and Earth system modeling efforts, but parameterizations and validation are largely focused on the present day due to the availability of satellite data. Charcoal deposits in sediment cores have emerged as a powerful method to evaluate trends in biomass burning extending back to the Last Glacial Maximum and beyond, and these records provide a context for present-day fire. The Global Charcoal Database version 3 compiled about 700 charcoal records and more than 1000 records are expected for the future version 4. Together, these advances offer a pathway to explore how the strengths of fire data and fire modeling could address the weaknesses in the overall understanding of human-climate-fire linkages.

A community of researchers studying fire in the Earth system with individual expertise that included paleoecology, paleoclimatology, modern ecology, archaeology, climate and Earth system modeling, statistics, geography, biogeochemistry, and atmospheric science, met at an intensive workshop in Massachusetts, USA, to explore new research directions and initiate new collaborations. Research themes, which emerged from the workshop participants via pre-workshop surveys, focused on addressing the following questions: What are the climatic, ecological, and human drivers of fire regimes, both past and future? What is the role of humans in shaping historical fire regimes? How does fire ecology affect land cover changes, biodiversity, carbon storage, and human land uses? What are the historical fire trends and their impacts across biomes? Are their impacts local and/or regional? Are the fire trends in the last two decades unprecedented from a historical perspective?

The participants discussed the current status of paleofire reconstructions focusing on charcoal records, present-day fire data, and the state of global fire modeling. This foundation helped focus the diverse expertise of workshop participants into working groups that independently developed ideas to address the research themes. The overarching objective that connected all working group discussions was to determine how fire data and fire models could be used together to promote advances in the understanding of fire in the Earth system. Research projects from working group discussions were related to paleofire proxy calibration, modeling human-fire-climate interactions, and understanding fire ecology. The workshop program and presentations are available online[1].

Methods to Calibrate Paleofire Proxies

Charcoal records collected from lacustrine, bog, peat and marine sites around the world and available in the Global Charcoal Database (GCD, www.paleofire.org) capture relative changes and trends in past fire occurrence and have advanced our understanding of the controls and impacts of fire in the Earth system on a wide range of spatial and temporal scales. However, due to the diversity of charcoal analysis procedures and the complexity of charcoal production, transportation, and deposition, current paleofire records in the GCD do not quantify biomass burning using physical units such as burned area or fuel consumed. A high priority research area identified by workshop participants is to calibrate the amount of charcoal found in sediments to a physical quantity of the fire regime.

One method focuses on transportation and deposition of charcoal. A statistical process model is being developed to connect charcoal accumulation rates to burned area, while separating process and

[1] http://www.gpwg.paleofire.org/paleofire-data-model-comparisons-for-the-past-millenium/

measurement errors. This approach requires abundant, high-resolution time series for the calibration and is therefore currently being developed for only a few locations.

Another approach will reconstruct biomass burning during the past few centuries where there is a high density of sediment samples in the GCD that capture the most recent 200 years. These trends will be iteratively evaluated against published historical records of fire activity that are tied to present-day burned area data sets (e.g. satellite-derived fire information). Each dataset has specific uncertainties that may limit the comparison in some regions, but studying how fire has or has not changed since the year 1750 is a critical component of nearly every climate modeling experiment that focuses on the evolution of the climate system since the pre-industrial era. These comparisons will require specific knowledge of the data sets in question to evaluate strengths and weaknesses in every attempt to merge metrics of fire activity from the recent past.

Finally, the past few decades are perhaps the least studied period of the paleofire proxy data in the GCD, but a new initiative from this workshop called the "modern Global Charcoal Database" (mGCD)[2], will address this gap. The mGCD will begin by developing a global fire proxy surface sample dataset that can be used to analyze the relationships between burned area estimates from satellite and historical data and charcoal in many different environments. A core component of the mGCD will be a standardized sampling protocol to collect surface sediment samples from terrestrial and marine sites around the world. The protocol will allow researchers with and without direct expertise in sediment collection to participate in the mGCD development via a "citizen science" or "crowd-sourcing" approach. The protocol also establishes a common physical unit to quantify charcoal in sediment. Results from this initiative could transform fire research by linking charcoal accumulated in sediments to prolific present-day data on fire activity, which in turn is the connection that is needed to link present-day fire data to paleofire data.

Interactions among Climate, Ecology, Humans, and Fire

[2] http://www.gpwg.paleofire.org/crosscutting-initiatives1/

Understanding the interactions between all drivers of global fire occurrence is required to project fire occurrence under future conditions. Vegetation variability, land use, and fire management are important determinants of fire dynamics and future-risk estimate, but some studies limit fire projections to changes in climate only. A firm understanding of the baseline relationships between fire ecology and vegetation, fire risk and fire management, as well as fire and biodiversity conservation is necessary for making accurate projections about changing regional fire regimes.

While fire activity over millennial timescales is mainly driven by climate, archaeological, historical, and contemporary evidence suggest that human societies have likely modified fire regimes during the Holocene and certainly during the last millennium. Human behaviors that alter ignition frequency and seasonal timing or change landscape flammability can modulate the strength and amplitude of the relationship between a fire regime and weather conditions. To date, efforts to quantify the human contribution to historical fire regimes at global to regional levels have used limited proxies for human behaviors. Active debate surrounds efforts to parameterize the human influence on fire activity within fire models, specifically with regards to simulating human ignition patterns.

Fire management by different societies has varied in time following socioeconomic and technological change, and in space due to differences in climate and the structure of fuels. In a changing world, where increasing fire activity constitutes a pending unknown in the global carbon cycle and a potential threat to ecosystem services, fire management based on interdisciplinary knowledge represents a challenge. Fire is an important determinant of forest structure and species composition, but its role in long-term biodiversity changes is largely unknown. Baseline information from paleofire data is particularly needed for restoration programs in many biodiversity hotspots, including for instance alpine meadows, Mediterranean maquis shrubland, and tropical ecosystems.

Another priority identified by workshop participants is to account changes in land use/land management over time when developing empirical human-fire relationships. Key research identified by workshop participants included how to scale human-related parameterizations in fire models, analysis of the charcoal records for signals indicative of human influence on fire regimes, and combining fire models with the charcoal database to design and test hypotheses about the spatial and temporal magnitude of the climate and human influences on fire regimes. One outcome of the workshop discussions concerned the need to move beyond univariate representations of humans in fire models (i.e. population density), and to embrace complexity in the human relationship with fire. For example, spatially explicit models of land use or resource procurement strategies may provide more accurate estimations of human effects on fire frequency and spread through changes in ignition timing and through the alteration of fuel type and structure.

Finally, while much research focuses on overall burned area, extreme fire events or megafires – severe fire episodes that cause catastrophic damage in terms of ecological or economic losses, or both – are driven by critical weather conditions, which induce a concentration of numerous large fires in time and space. Climate change might impact the frequency of such extreme fire events, hence present-day records might already be biased to this increased frequency. The group discussed about how to identify and characterize extreme fire events both in fire models and in charcoal observations for the last millennium. The combination of charcoal observations and fire models can help identify mechanisms that lead to changes in the frequency of extreme events related to climate or ecological thresholds. Furthermore, fire models that capture extreme fire events could inform the spatial gaps in the GCD where data has not been collected to better capture the interconnections among climate, ecology, humans, and fire.

Summary

Modeling and data based methods to study fire have rapidly co-evolved over the past decade. Currently, however, very few initiatives link these important data types. The goal during the recent paleofire-themed workshop was to outline methods to link paleofire datasets with fire modeling to increase our understanding of variability in the global fire regime. The workshop facilitated advances in efforts to calibrate relative trends of biomass burning determined from charcoal accumulated in sediments to physical fire metrics, such as burned area or fuel consumption. Our discussions advanced linking data and modeling to study interactions between climate, ecology, humans, and fire, with a focus on the effect of humans on biomass burning at regional to global scales. This workshop highlighted how interdisciplinary discussions among scientists can initiate advances that disciplinary research in fire science cannot accomplish.

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