# Wildfires and Global Climate Change Along a Transect Through the Americas

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## Abstract

A line drawn from the tundra of Alaska to the Atlantic forest of Brazil transects virtually all of the Earth's biomes. This "*Transect of the Americas*" provides a compact global ecological laboratory for comparative ecosystem studies; and for testing the rigor of theories across multiple ecosystems. Nearly all of the major ecosystems and fire environments in the world, with some in Australia being notable exceptions, can be studied somewhere in the Americas. Replicated experiments and assessment methodologies along the transect can provide a consistent means of predicting fire danger, fire effects, and the impact of fire management on carbon sequestration.

This paper presents over 25 years of research experience that the Fire and Environmental Research Applications (FERA) team of the USDA Forest Service, Pacific Northwest Research Station has been conducting in the boreal, temperate forests, and rangelands of the United States and Mexico, and tropical ecosystems in Florida, Hawaii, and Brazil. FERA's research underlies decision support systems for fire management, air quality management, and global change response. The applied and theoretical research conducted by FERA addresses issues that concern to those management and scientific communities in the United States and elsewhere. Some of FERA products include: tools for biomass loading and flammability assessment, predicting biomass consumption across major ecosystems, thermodynamic modeling of smoldering consumption, smoke management and health assessment tools, and biomass emissions assessing greenhouse gas emissions from wildland fires.

Since the 70's, the group has conducted extensive research on combustion and carbon emissions through North America, Mexico and Brazil that has lead to the development of combustion algorithms used by fire managers and scientists. Research in tropical savannas and temperate rangelands is conducive to the development of equations and methods to evaluate fuelbed characteristics, biomass consumption, air pollution, and greenhouse gas emissions from fires across environmental gradients. Flammability and fire severity thresholds are being investigated in the boreal, temperate forests, and rangelands in the United States, as well as logged and primary Amazon forest. FERA scientists are responsible for assessing the risk of smoke exposure to the health of firefighters and rural communities in the United States.

## Wildfires as a Global Environmental Issue

Environmental policy and management issues are becoming increasingly global. Relative to fires in the wildlands, these issues include global climate change, carbon sequestration, internationally-transported air pollution, and international cooperation in responding to catastrophic wildfire. Climate change feedbacks involving changes in the rate of liberation or sequestration of carbon stored in the biosphere are perhaps the greatest environmental policy issues of all time, and require by definition analysis tools and accounting mechanisms that are globally consistent. There is no current agreement how fires, management of fires, or the use of fire will be counted in relation to carbon balance or international carbon trading, but it is apparent that internationally-accepted accounting methods will be needed. The question is not just how much carbon is released into the atmosphere by fires, but how fires will affect decomposition rates and the biological composition and productivity of ecosystems.

A globally consistent decision support should be able to monitor, model, and predict fire occurrence and severity in all of the world's ecosystems based on characteristics of the fire environments such as fuels, weather, topography, ignition, and human influence. Fundamental components of such a system include the ability to monitor fire occurrence and activity, plus:

1. Inventory of biomass in all of the major ecosystems of the world, especially of biomass susceptible to consumption by fire.
2. Methods to infer total and consumable biomass based on knowledge of vegetation cover, structure, and condition obtained from inventory or remote sensing.
3. Knowledge of the thresholds of flammability (in the flaming and smoldering stages), of spread, and of vegetation mortality for fuelbed components.
4. Predictability of the mass of biomass consumed in each combustion stage for all types of fire in all ecosystems under all fuel conditions.
5. Duration and strength (i.e. rates of heat release rates and combustion products' release) for all types of fires in all types of fuelbeds under all environmental conditions.

## Fire and Environmental Research Applications

This paper presents over 25 years of research experience that the Fire and Environmental Research Applications (FERA) team of the USDA Forest Service, Pacific Northwest Research Station has been conducting in boreal and temperate forests, rangelands of the United States and Mexico, and tropical ecosystems in Florida, Hawaii, and Brazil. FERA's research underlies decision support systems for fire management, air quality management, and global change response. The applied and theoretical research conducted by FERA addresses issues that concern to those management and scientific communities in the United States and elsewhere. Some of FERA products include tools for biomass loading and flammability assessment, predicting biomass consumption across major ecosystems, thermodynamic modelling of smoldering consumption, smoke management and health assessment tools, and biomass emissions assessing greenhouse gas emissions from wildland fires. With respect to the 5 fundamental components listed above, FERA is replicating studies under a variety of conditions to accomplish:

1. <u>Photo Series:</u> Inventory methods based on a series of photographs taken in conjunction with biomass inventories over the typical range of fuel characteristics within fuelbeds or vegetation types of interest to fire managers (fig. 1). To date, FERA has published

fourteen volumes of "Photo Series" ranging from the boreal forests of Alaska (Ottmar and Vihnanek 1998, 1999) to the savannas of Brazil (Ottmar et al. 2001). The series' provides managers with a way to inventory fuels about fifty times more efficiently than using transect methods.

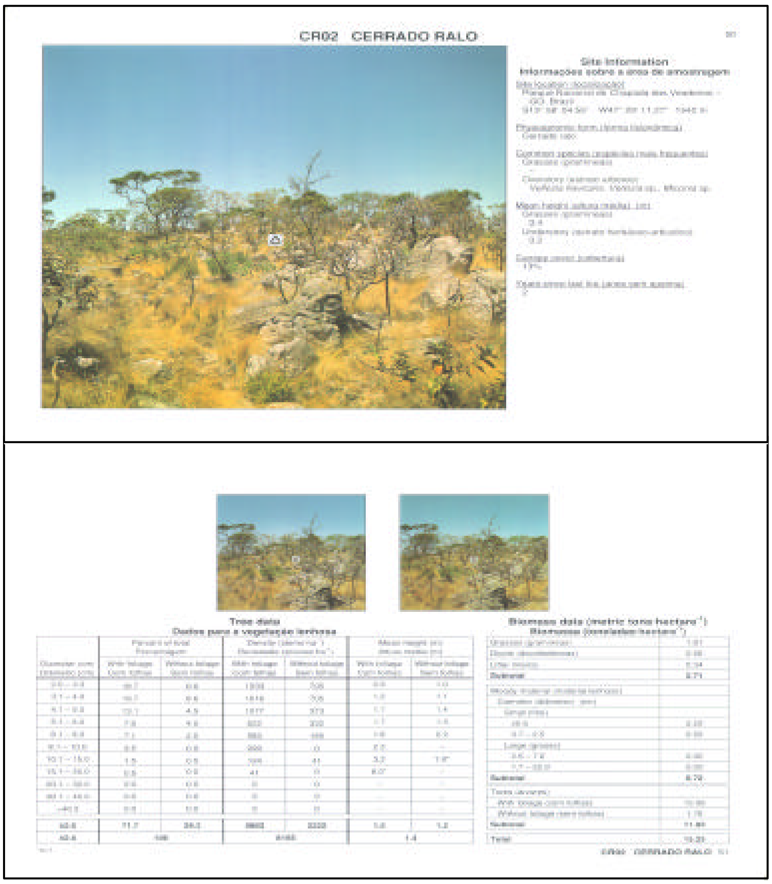



Figure 1. Example of a photo and data page from the Brazilian savanna series (Ottmar and others 2001)

2. FCCS: A Fuelbed Characteristic Classification System, or FCCS, (Sandberg et al. 2001) is a systematic catalogue of inherent physical properties of any wildland fuelbed. FCCS is designed to provide the best possible fuel estimates and potential fire parameters based on as much or as little site-specific information as is available. Detailed fuel estimates are needed to support fire hazard assessments and fuel treatment decisions, as well as other research initiatives. FCCS will provide these detailed estimates based on either *specific fuel data* (types of fuel and their relative abundance) or *general site data* that are available for broader areas (such as ecosystem division, vegetation form, cover type, or other data obtained from remote sensing, forest inventories, or models). The system will also accept a mixture of both types of data. FCCS is comprised of:

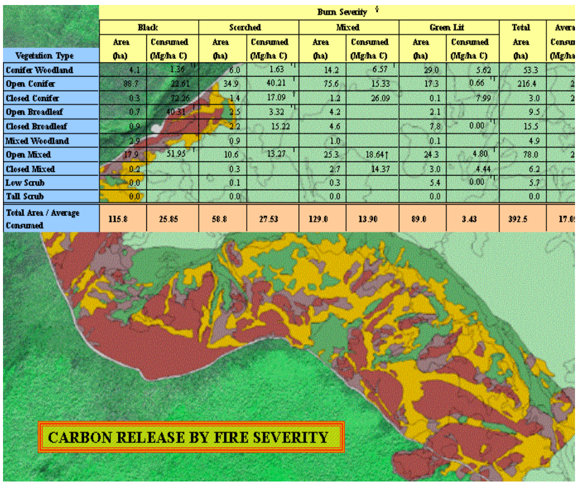
   a. A large database of physical parameters that describe the size, abundance, physical character, and arrangement of the several dozen components that comprise a wildland fuelbed; compartmentalized by vertical position from forest canopy, shrub vegetation, low vegetation, woody fuels, litter, and moss/duff strata. The prototype FCCS database includes 200+ fuelbeds common to North America, and a process has been established to add several tens of thousands more fuelbeds in the next several years.

b. An expert system to interactively select fuelbed from general site data and to adjust fuelbeds in the database based on specific site data or other information available to the user. This component of the system also calculates and summarizes fuelbed properties by vertical strata, and used a set of look-up tables to assign properties based on vegetation species or physiognomic character.
c. Calculation of relative (normalized to a scale of 0-10) fuelbed fire potentials, i.e. the intrinsic capacity of a fuelbed for surface fire behaviour, crowning potential, and fuel consumption. These potentials are calculated from the loading, heat content, bulk density, and characteristic thickness of fuel elements without consideration of moisture content or environmental conditions. Essentially, they represent the potential fire behaviour and effects of an oven-dry fuelbed with no wind or slope influence.

3. Combustion Limits: FERA, along with many research partners, has initiated a study to establish the thresholds of combustion in boreal forest crowns and deep moss/duff layers (Hinzman et al. 2002), in tropical forest clearings and understory leaf litter (Carvalho et al. 2001), in shrublands in the Western United States, and in temperate forests of the United States and Mexico. Our design is to establish a fire danger rating system that is more robust and interchangeable across climate zones.

4. CONSUME: The CONSUME model (Ottmar et al. 1993) was developed in the Pacific Northwest United States in order to predict fire severity and inventory air pollutant emissions from fires. CONSUME is a theoretically based model of biomass consumption that has been calibrated with over 300 field experiments in prescribed and wildland fires. The model may be used in a homogenous fire environment or to map the distribution of fire severity over a landscape (fig. 2). FERA is currently evaluating and adapting the predictive model for use in a wide variety of ecosystems in all climate zones and ecosystem structures (e.g. Gielow et al. *in press*).

Figure 2. Example of an application of CONSUME to map the distribution of fire severity over a boreal landscape in the *FrostFire* experiment.



| | Burn Severity | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Black | | Scorched | | Mixed | | Green Lit | | Total | Avera |
| Vegetation Type | Area (ha) | Consumed (Mg/ha C) | Area (ha) | Consumed (Mg/ha C) | Area (ha) | Consumed (Mg/ha C) | Area (ha) | Consumed (Mg/ha C) | Area (ha) | Consu (Mg/ha |
| Conifer Woodland | 4.1 | 1.36 | 6.0 | 1.63 | 14.2 | 6.57 | 29.0 | 5.62 | 53.3 | |
| Open Conifer | 88.7 | 22.61 | 34.9 | 40.21 | 75.6 | 15.33 | 17.3 | 0.66 | 216.4 | 2 |
| Closed Conifer | 0.3 | 72.26 | 1.4 | 17.09 | 1.2 | 26.09 | 0.1 | 7.99 | 3.0 | 2 |
| Open Broadleaf | 0.7 | 40.31 | 2.5 | 3.32 | 4.2 | | 2.1 | | 9.5 | |
| Closed Broadleaf | 0.9 | | 2.2 | 15.22 | 4.6 | | 7.8 | 0.00 | 15.5 | |
| Mixed Woodland | 2.9 | | 0.9 | | 1.0 | | 0.1 | | 4.9 | |
| Open Mixed | 17.9 | 51.95 | 10.6 | 13.27 | 25.3 | 18.64 | 24.3 | 4.80 | 78.0 | 2 |
| Closed Mixed | 0.2 | | 0.3 | | 2.7 | 14.37 | 3.0 | 4.44 | 6.2 | |
| Low Scrub | 0.0 | | 0.1 | | 0.3 | | 5.4 | 0.00 | 5.7 | |
| Tall Scrub | 0.0 | | 0.0 | | 0.0 | | 0.0 | | 0.0 | |
| Total Area / Average Consumed | 115.8 | 25.85 | 58.8 | 27.53 | 129.0 | 13.90 | 89.0 | 3.43 | 392.5 | 17.0 |



5. EPM: An emission production model. EPM (Ferguson et al. 1998, Sandberg and Peterson 1984) has been widely used for twenty years to calculate the rate of biomass combustion, heat release, and smoke production from prescribed fires. Fire effects cannot be estimated from fire intensity or total fuel consumed; it is also essential to predict and monitor durations and rates. EPM predicts fire duration and source strength (i.e. rates of heat release rates and combustion products' release) for all stages of combustion for types of fires in all types of fuelbeds under all environmental conditions. The second generation of EPM underwent testing in 2003 and should be available for download before this

publication. Unfortunately, the fundamental combustion science for all post-flaming combustion is poorly understood, so the accuracy of prediction is limited.

## Global Ecosystem Distribution

A globally consistent system should be useful in at least all of the climatic zones and major ecosystems of the world, although even a system this robust will fail in some social systems or where unusual fire-adaptive ecosystems exist. FERA initiated a field research program in 1991, as part of the Forest Service Global Change Research Program, to characterize fuels and immediate fire effects in an example of every major ecosystem in the world. In order to reduce that daunting task to a possible endeavour, we looked at many ecosystem classifications in order to design the most compact and efficient global laboratory.

Ecologists and geographers have proposed numerous systems for classifying the world's ecosystems since early in the last century (e.g. Herbertson 1905). The USDA Forest Service adopted a hierarchical classification system (ECOMAP 1993), following the classification system developed by Bailey (1983, 1996, 1998) after a system developed by Koppen (1931). The system identifies 28 ecosystem divisions that contain vegetation (fig. 3) within four climatically-defined domains (Polar, Humid Temperate, Dry, and Humid Tropical).

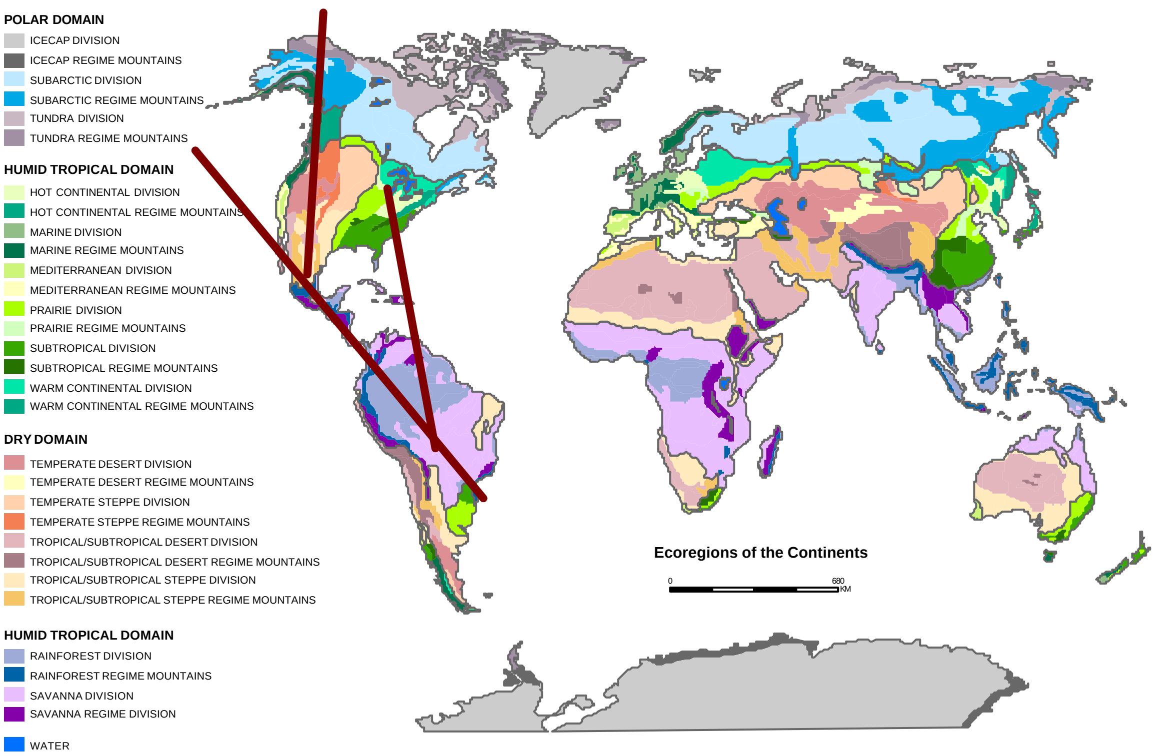



Figure 3. Bailey's (1996) classification of the world's ecosystems delineates 28 vegetated Ecosystem Divisions within four climatic Domains. A "Transect of the Americas" encounters an example of every Division except one, providing a compact global field laboratory.

The *“Transect of the Americas”*

A line drawn from the tundra of Alaska to the Atlantic forest of Brazil transects virtually the Earth’s entire ecosystem divisions. The one exception is the Prairie Regime Mountain Division comprising approximately 0.9% of the world’s terrestrial surface (Bailey 1996) and occurs in Central Asia and Eastern Europe. This "*Transect of the Americas*" provides a compact global ecological laboratory for comparative ecosystem studies, and for testing the rigor of theories across multiple ecosystems. Nearly all of the major ecosystems and fire environments in the world, with some in Australia being notable exceptions, can be studied somewhere in the Americas. Replicated experiments and assessment methodologies along the transect can provide a consistent means of predicting fire danger, fire effects, and the impact of fire management on carbon sequestration.

The United States is very diverse ecologically, owing to the longitudinal extent from the polar in Alaska to the tropical systems of Florida and Hawaii, the influence of two oceans, and north-south mountain ranges. The U.S. alone has 25 ecosystem divisions (table 1), although it would be a stretch to claim that the few small tropical systems are representative of the Humid Tropical Domain, or that the boreal forests of Alaska represent the variety of boreal systems in Russia and Canada. Nonetheless, it is reasonable to assert that a series of experiments replicated in across the United States and one other country diversely represented in tropical ecosystems can represent a global experiment.

FERA, representing the USDA Forest Service International Programs and USAID, has established research collaboration with several Brazilian institutions since 1992. Among them are the National Space Research Institute, the University of Sao Paulo, and the University of Brasilia. Brazil is rich in tropical ecosystem diversity and

Table 1. The United States, together with any one of several countries that have tropical ecosystems, could form a compact global laboratory containing ane example of all but one of Bailey’s (1996) divisions.

| | Division Name | USA | Mexico | Brasil | Bolivia |
|---|---|---|---|---|---|
| **100 Polar Domain** | | | | | |
| 120 | Tundra Div. | X | | | |
| M120 | Tundra Regime Mts. | X | | | |
| 130 | Subarctic Div. | X | | | |
| M130 | Subarctic Regime Mts. | X | | | |
| **200 Humid Temperate Domain** | | | | | |
| 210 | Warm Continental Div. | X | | | |
| M210 | Warm Continental Regime Mts. | X | | | |
| 220 | Hot Continental Div. | X | | | |
| M220 | Hot Continental Regime Mts. | X | | | |
| 230 | Subtropical Div. | X | | X | |
| M230 | Subtropical Regime Mts. | X | | | |
| 240 | Marine Div. | X | | | |
| M240 | Marine Regime Mts. | X | | | |
| 250 | Prairie Div. | X | | X | |
| M250 | Prairie Regime Mts. | | | | |
| 260 | Mediterranean Div. | X | X | | |
| M260 | Mediterranean Regime Mts. | X | X | | |
| **300 Dry Domain** | | | | | |
| 310 | Tropical/Subtropical Steppe Div. | X | X | X | X |
| M310 | Tropical/Subtropical Regime Mts. | X | X | | X |
| 320 | Desert Div. | X | X | | X |
| M320 | Desert Regime Mts. | X | X | | |
| 330 | Temperate Steppe Div. | X | | | |
| M330 | Temperate Steppe Regime Mts. | X | | | |
| 340 | Temperate Desert Div. | X | | | |
| M340 | Temperate Desert Regime Mts. | X | | | |
| **400 Humid Tropical Domain** | | | | | |
| 410 | Savanna Div. | X | X | X | X |
| M410 | Savanna Regime Mts. | | X | X | X |
| 420 | Rainforest Div. | | X | X | X |
| M420 | Rainforest Regime Mts. | X | X | X | X |

research infrastructure in the physical and ecological sciences. Each of the tropical systems in Brazil span a wide range of precipitation and fire regimes resulting in gradients of species composition and adaptations to fire. The collaboration includes extensive laboratory and field combustion experiments, theoretical development, and technology transfer efforts.

More recently, FERA has established collaboration in Mexico and Bolivia, in order to enrich representation in drier and more mountainous ecosystems not replicated in the United States or Brazil.

## What's Left to be Done?

Some progress has been made to underpin a globally consistent decision support system for fire management in wildlands in the past decade or two. (1) We are approaching an inventory and access to inventory methods in most common ecosystems in the Americas. However, there is still no easy-to-use biomass inventory system for tropical forests, and the Photo Series developed in the Americas does not represent the characteristics of fuelbeds in several environments of Australia, Africa, and Asia. (2) A robust system of inferring and summarizing the physical characteristics of fuelbeds is nearing availability, but has only been adopted for use in the United States. (3) Fundamental understanding of thresholds of flammability; especially with regards to the transition to no-wind spread in hardwood litter, transition to crown and canopy involvement in a spreading fire, and the transition to independent smoldering in deep duff and moss layers is still far from adequate. (4) Consumption of biomass is widely predictable in all fuelbed components other than the forest floor, but there is still a lot of development needed to produce spatially explicit maps where fire severity varies over the landscape. (5) Prediction of smoke production and fire effects that depend of heat release rates is steadily improving, but still inadequate.

At a higher level, we are a long way from adopting consistent methodologies to support management and policy decisions required for international cooperation in fire, ecosystem, and climate change management. Reliable fire danger rating systems exist for some temperate regions and for the boreal forests of Canada, but there is still no reliable system for the tropics and only a limited ability to compare fire danger in one climate domain with that in another. Although biomass consumption is predictable in most places; nowhere in the world do managers systematically assess biomass consumption, carbon release, or air pollutant emissions using the best methods available.

## Conclusion

Since the 1970s, the Fire and Environmental Applications Research team of the USDA Forest Service, and its many partners, has conducted extensive research on combustion and carbon emissions through North America, Mexico and Brazil that has led to the development of combustion algorithms used by fire managers and scientists. Research in tropical savannas and temperate rangelands is conducive to the development of equations and methods to evaluate fuelbed characteristics, biomass consumption, air pollution, and greenhouse gas emissions from fires across environmental gradients. Flammability and fire severity thresholds are being investigated in the boreal, temperate forests, and rangelands in the United States, as well as logged and primary Amazon forest. FERA scientists are responsible for assessing the risk of smoke exposure to the health of firefighters and rural communities in the United States.

There is more to be done. We are not satisfied with our ability to predict combustion limits and transitions. We have yet to simplify biomass inventory in tropical forests. And we have not made the leap from developing predictive methodologies to developing information systems that promote widespread international collaboration on environmental policy issues that involve wildfires and the use of fire in wildlands.

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