Development of a Wildland Fire Smoke Marker Emissions Map for the Contiguous United States

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Overview

Motivation

- Smoke from biomass burning impairs visibility in National Parks and other scenic areas and contributes to elevated fine particle concentrations and associated adverse health effects in populated areas. Receptor models are often used to estimate the the contributions of smoke to sensitive receptor areas.
- Application of receptor models requires appropriate smoke source profiles to accurately quantify contributions of biomass burning to regional air pollution. Few source profiles are currently available to represent the wide range of fuel types combusted in wild and prescribed fires.

Objective

- Combine recent smoke marker measurements and spatial vegetation information to construct maps of wildland fire smoke source profiles for the contiguous United States.

Smoke Markers

- During the Fire Lab at Missoula Experiment (FLAME), 31 fuels were burned in over 100 burns in a combustion chamber at the USDA Forest Service Fire Science lab in Missoula, Montana.
- Anhydrosugars including levoglucosan, mannosan and galactosan are formed during the burning of cellulose and hemicellulose, important components of biomass. They have been commonly used as smoke markers. K^+ is sometimes also used as a marker.

FLAME Sample Analysis

- $PM_{2.5}$ filter samples were collected from diluted biomass combustion smoke during FLAME.
- Ion concentrations were measured by ion chromatography. Anhydrosugars were quantified using Ion Exchange Chromatography with Pulsed Amperometric Detection.
- Organic (OC) and elemental carbon (EC) concentrations were measured using a Sunset OC/EC analyzer.
- For detailed information on the analysis methods, see Sullivan et. al. 2008.

Vegetation Differences

Because the amount of hemicellulose and cellulose varies between different vegetation types, it is likely that the levoglucosan (from cellulose combustion) and mannosan (from hemicellulose combustion) concentrations in smoke from different vegetation types would vary as well. Using a t-test, differences in wood smoke marker to $PM_{2.5}$ total carbon (TC) ratios have been identified at the 0.05 significance level. The mannosan/TC ratio shows the most promise to statistically distinguish between combustion of different vegetation types.

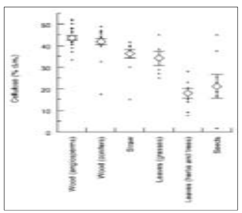
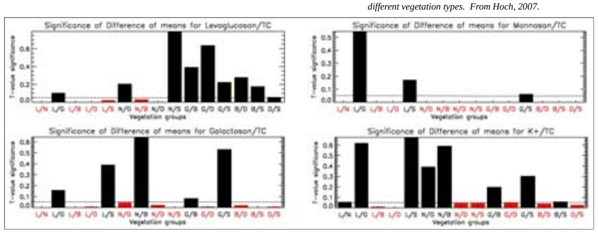


Figure 1: Cellulose percentages of dry mass found in different vegetation types. From Hoch, 2007.



Figures 2-5: Significance of difference of means for four smoke marker/TC ratios for five different vegetation groups. L = leaves, N = needles, G= grasses, B = branches, D = duffs and S = straws. The red columns are significant t-values, the black columns are insignificant t-values.

Mapping Algorithm

Step 1: Vegetation Map

A 1 by 1 km gridded map of wildland fuels throughout the contiguous United States produced by the U.S. Forest Service was used to obtain fuel spatial distributions.

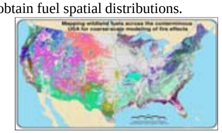


Figure 6: Wildland fuel map for the contiguous United States

Step 2: Biome Classification

Based upon measured differences in smoke marker chemical concentrations from different vegetation types, it is expected that combustion in different biomes would emit different smoke marker/TC ratios. Softwood forests, which primarily burn needles and branches, for example, would differ from grasslands. Accordingly, each fuel is assigned to a biome classification. Six classifications are identified:

- Softwood Forests (e.g. pine-fir forests)
- Hardwood Forests (e.g. oak forests)
- Scrub shrublands (e.g. chapparal shrublands)
- Floral shrublands (e.g. rhododendron shrublands)
- Southern mixed forest (e.g. sabal palm forests)
- Grasslands (e.g. bluestem – Indian grass grasslands)

Figure 7: scrub shrubland

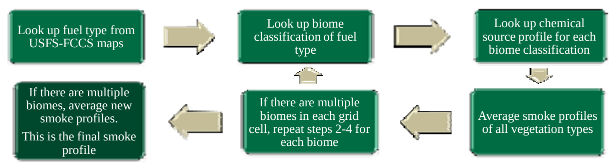
Figure 8: Softwood forest

Steps 3 & 4: Biome Source Profile

Some biomes are comprised of a single vegetation type, like grasslands. In this case, the biome smoke profile for grasslands is taken as the smoke profile for the grass vegetation type. However, some biomes are comprised of multiple vegetation types and a fire burns different fuel components, such as branches and leaves. Here we average source profiles for relevant vegetation types to determine a biome profile.

Steps 5 & 6: Create final source profile

Many grid cells are comprised of mixtures of biomes, for example, a mixed forest of trembling aspen and ponderosa pine, one of which is a softwood and one of which is a hardwood. The USFS-FCCS map does not give percentages of how much of each fuel type is present in a grid cell, so percentages are assumed to be equal. Therefore, the individual biome smoke profiles are simply averaged to determine a final source profile for the grid.



Sensitivity Study

In our base mapping algorithm, all vegetation types contribute equally to smoke emissions. However, some vegetation types are more easily burned than others; for example, during a fire in a pine forest, needles burn more easily than branches. To assess this error, two sets of maps are created: one using equal vegetation weighting, and another that weights herbaceous materials by 80%, and woody materials by 20%. Only the scrub brush and softwood biome profiles are affected, because the other biomes only had one vegetation type included due to lack of measurements. In the scrub brush biome, levoglucosan/TC ratios are reduced by 0.2 in the 80%/20% experiment, and for softwood forests, the levoglucosan/TC ratio does not change significantly.

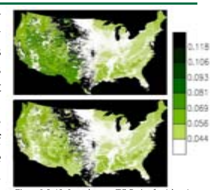
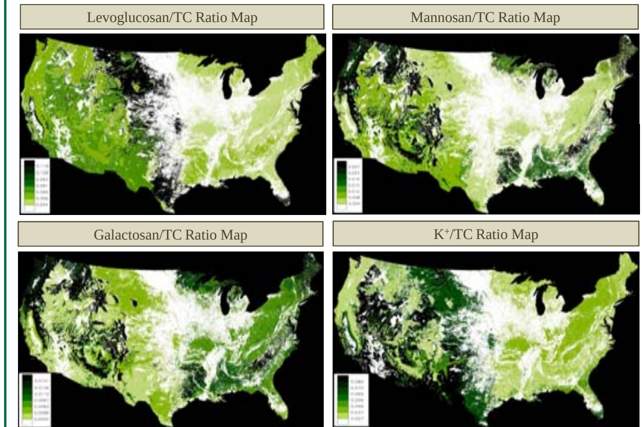


Figure 9 & 10: Levoglucosan/TC Ratios for (above) equal weighting and (below) 80%/20% weighting

Smoke Marker Emissions Maps



Figures 11-14: Emission maps of smoke marker/TC ratios throughout the contiguous United States.

Conclusions

Emissions maps have been created for the contiguous United States for four smoke marker species. Throughout the country, smoke marker to total particulate carbon ratios vary by different factors.

- Levoglucosan/TC ratios vary by a factor of 3
- Mannosan/TC ratios vary by a factor of 7
- Galactosan/TC ratios vary by a factor of 3
- K^+/TC ratios vary by a factor of 4

The maps provide estimates of the source profiles for different wildland fuels as distributed throughout the United States, that can be used in receptor models. When the smoke source region is known, e.g., from back-trajectories and satellite fire detects, the maps can be used to refine the choice of source profile beyond standard values calculated for national or regional application.

A sensitivity study revealed that differing consumption of herbaceous and woody materials in a fire may impact emission marker/TC ratios. More work is needed to determine the best method of assigning consumption percentages for each vegetation type.

References

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