

# R. Jaffé, et al.: Closing a major gap in the global charcoal budget.

Mathematics of Climate Seminar  
11:15am Tuesday, May 7, 2013  
Lind Hall 305

Max Jodeit

# Global Charcoal Mobilization from Soils via Dissolution and Riverine Transport to the Oceans

Rudolf Jaffé,<sup>1\*</sup>† Yan Ding,<sup>1</sup> Jutta Niggemann,<sup>2</sup> Anssi V. Vähätalo,<sup>3,4</sup> Aron Stubbins,<sup>5</sup> Robert G. M. Spencer,<sup>6</sup> John Campbell,<sup>7</sup> Thorsten Dittmar<sup>2\*</sup>†

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Global biomass burning generates 40 million to 250 million tons of charcoal every year, part of which is preserved for millennia in soils and sediments. We have quantified dissolution products of charcoal in a wide range of rivers worldwide and show that globally, a major portion of the annual charcoal production is lost from soils via dissolution and subsequent transport to the ocean. The global flux of soluble charcoal accounts to  $26.5 \pm 1.8$  million tons per year, which is  $\sim 10\%$  of the global riverine flux of dissolved organic carbon (DOC). We suggest that the mobilization of charcoal and DOC out of soils is mechanistically coupled. This study closes a major gap in the global charcoal budget and provides critical information in the context of geoengineering.

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The first sentence is (probably) based on reference (6):

T. A. J. Kuhlbusch, P. J. Crutzen, in *Biomass Burning and Global Change*, J. S. Levine Ed., (MIT Press, Cambridge, MA 1996), chap. 16.

Instead, I looked at the authors' paper, "(6)," that I assume (6) was based on, and found very similar figures in its Abstract.

*Toward a global estimate of black carbon in residues of vegetation fires representing a sink of atmospheric CO<sub>2</sub> and a source of O<sub>2</sub>*, by

T. A. J. Kuhlbusch and P. J. Crutzen, in  
*Global Biogeochemical Cycles*, Vol. 9, No. 4, pp 491-501, December 1995.

Though I'm not certain, "(6)" might seem to say that a great deal of that charcoal, because it is not congenial to microbial activity, might sequester carbon – keeping it from putting more CO<sub>2</sub> into the atmosphere.

The second sentence seemed very startling, to me, in the context of "(6)," for it seems to say that a lot of that carbon is sent into rivers and, as dissolved black carbon (DBC), makes its way into the oceans.

The third sentence refers to the paper's details. The fourth, "We suggest that the mobilization of charcoal and dissolved organic carbon is mechanistically coupled," states a major contribution of the paper.



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Before going into details, let us ask what Black Carbon “is.” There is certainly no easy answer, and perhaps none at all (a man of 90 I recently met said he’d learned that “We don’t know *what* we don’t know!”)!

As an example of the difficulties, we look at the Abstract of (7) in Jaffé, *et al.*:

**Citation:** Hammes, K., et al. (2007), “Comparison of quantification methods to measure fire-derived (black/elemental) carbon in soils and sediments using reference materials from soil, water, sediment and the atmosphere,”

Global Biogeochem. Cycles, 21, GB3016, doi:10.1029/2006GB002914.

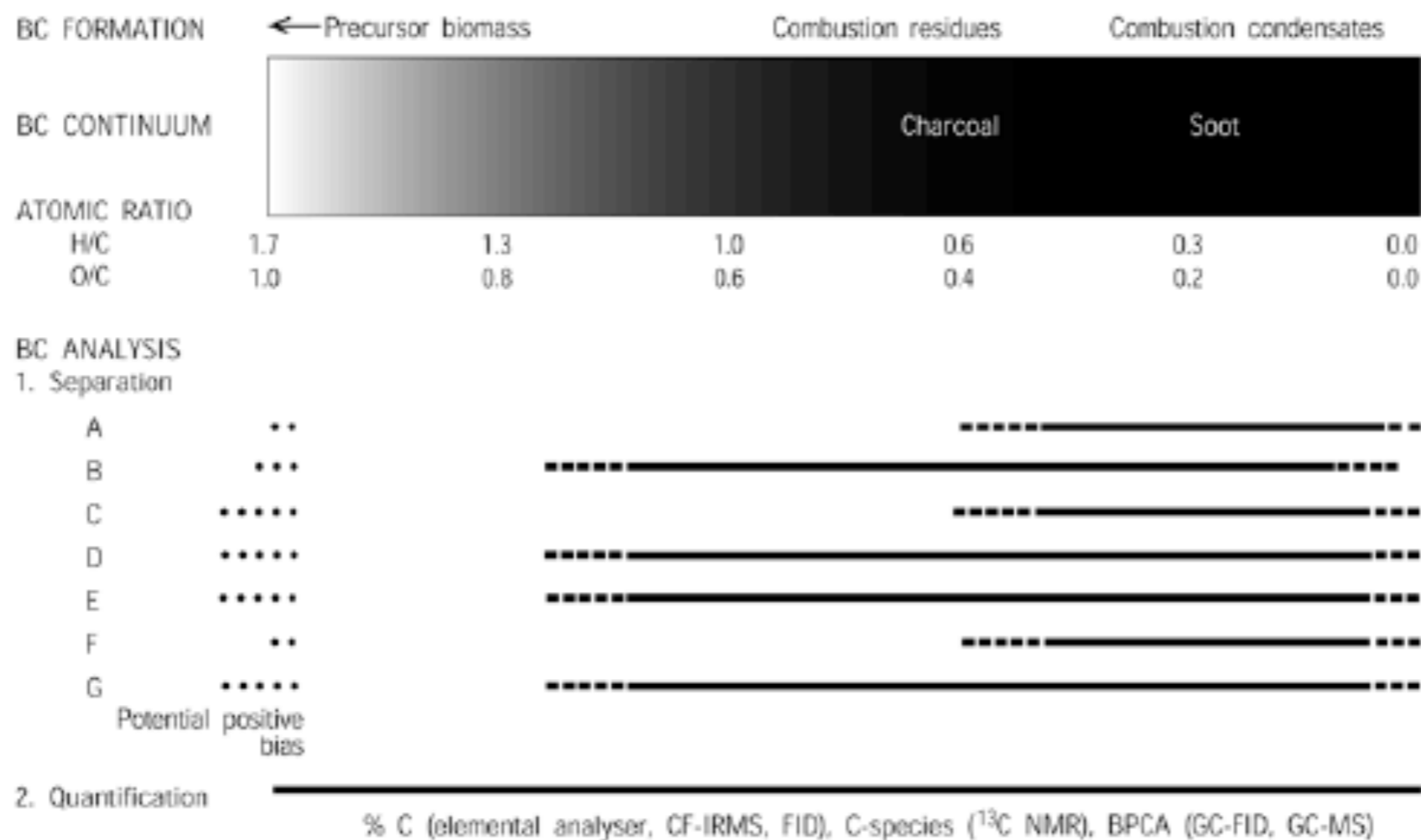
Karen Hammes, *et al.*, seem to have found we don’t seem to agree on what we *think* we know:

[1] Black carbon (BC), the product of incomplete combustion of fossil fuels and biomass (called elemental carbon (EC) in atmospheric sciences), was quantified in 12 different materials by 17 laboratories from different disciplines, using seven different methods. The materials were divided into three classes: (1) potentially interfering materials, (2) laboratory-produced BC-rich materials, and (3) BC-containing environmental matrices (from soil, water, sediment, and atmosphere). This is the first comprehensive intercomparison of this type (multimethod, multilab, and multisample), focusing mainly on methods used for soil and sediment BC studies. Results for the potentially interfering materials (which by definition contained no fire-derived organic carbon) highlighted situations where individual methods may overestimate BC concentrations. Results for the BC-rich materials (one soot and two chars) showed that some of the methods identified



most of the carbon in all three materials as BC, whereas other methods identified only soot carbon as BC. The different methods also gave widely different BC contents for the environmental matrices. However, these variations could be understood in the light of the findings for the other two groups of materials, i.e., that some methods incorrectly identify non-BC carbon as BC, and that the detection efficiency of each technique varies across the BC continuum. We found that atmospheric BC quantification methods are not ideal for soil and sediment studies as in their methodology these incorporate the definition of BC as light-absorbing material irrespective of its origin, leading to biases when applied to terrestrial and sedimentary materials. This study shows that any attempt to merge data generated via different methods must consider the different, operationally defined analytical windows of the BC continuum detected by each technique, as well as the limitations and potential biases of each technique. A major goal of this ring trial was to provide a basis on which to choose between the different BC quantification methods in soil and sediment studies. In this paper we summarize the advantages and disadvantages of each method. In future studies, we strongly recommend the evaluation of all methods analyzing for BC in soils and sediments against the set of BC reference materials analyzed here.

Some of the references refer to a “black carbon continuum.” On the third page of Hemmes, *et al* [33 authors], Figure 1 presents such a continuum, devoted to their topic:



**Figure 1.** Conceptual summary of the comparative analyses of the seven methods to quantify black carbon (BC). The BC continuum ranges from biomass (not affected by fire) on the left-hand side to pyrogenic, highly condensed aromatic structures on the right-hand side, and is plotted along a scale of atomic H/C and O/C ratios, also used in van Krevelen plots. Note that the H/C scale is nonlinear. BC analysis has two steps: (1) Separation of BC was performed by seven methods: CTO-375, BPCA,  $\text{Cr}_2\text{O}_7$ , TOT/R, TG-DSC,  $\text{NaClO}$ , and UV. The analytical ranges of separation are conceptual only, visualized by the use of solid and dotted lines. The dashed lines at each end of the solid lines indicate the uncertainty in the range of the BC continuum that each method measures, for example, how much soot or partially charred biomass a certain method measures. The dots on the left of the figure indicate the potential for positive bias from the potential interfering materials for each method. (2) Quantification of BC in the operationally defined separates includes elemental analysis (to quantify carbon left after separation),  $^{13}\text{C}$  NMR spectroscopy (to identify condensed aromatic C), or the use of gas chromatography with different detectors (GC/FID, GC/MS) to quantify the molecular markers of black carbon (BPCA). The figure was inspired by *Hedges et al.* [2000] and *Masiello* [2004].



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Global Biogeochem. Cycles, 21, GB3016, doi:10.1029/2006GB002914.

We can look at one “soot” example, a 48-second video, within Wikipedia’s article “Black Carbon.”

First, two quotes associated with the video and some pictures:

“Date 16 December 2009

As interest in Earth’s changing climate heats up, a tiny dark particle is stepping into the limelight: black carbon. Commonly known as soot, black carbon enters the air when fossil fuels and biofuels, such as coal, wood, and diesel are burned. Black carbon is found worldwide, but its presence and impact are particularly strong in Asia. Black carbon, a short-lived particle, is in perpetual motion across the globe. The Tibetan Plateau’s high levels of black carbon likely impact the region’s temperature, clouds and monsoon season.”

The next paragraph introduces a 48-second video we’ll look at, then return to the slides.

“Date 14 December 2009

Tiny air pollution particles commonly called soot, but also known as black carbon, are in the air and on the move throughout our planet. The Indo-Gangetic plain, one of the most fertile and densely populated areas on Earth, has become a hotspot for emissions of black carbon (shown in purple and white). Winds push thick clouds of black carbon and dust, which absorb heat from sunlight, toward the base of the Himalayas where they accumulate, rise, and drive a “heat pump” that affects the region’s climate.”

**NOTE:** We’ll go to Wikipedia on the Web, then return to the slides...

[http://en.wikipedia.org/wiki/Black\\_carbon](http://en.wikipedia.org/wiki/Black_carbon)

Here is the URL for the Black Carbon article on Wikipedia:

[http://en.wikipedia.org/wiki/Black\\_carbon](http://en.wikipedia.org/wiki/Black_carbon)

The article has a wealth of references: 113 of them as of Saturday night.

We could see the “soot-laden” winds sweep across the Tibetan Plateau several times, though those winds seem somewhat constrained by the Himalayas. The Wikipedia article mentions effects on climate – especially monsoons – of the Black Carbon deposited there.

These soot deposits aren’t the carbon Jaffé, *et al.* worked on.

They use the term “polycyclic aromatic carbon” to refer to “the carbon that resides in a compound group called ‘polycyclic aromatic compounds.’ This compound group is defined by the same molecular structure as polycyclic aromatic hydrocarbons (PAHs), that contain only carbon and hydrogen, but can contain other elements aside from carbon and hydrogen, such as oxygen.”

The next slide shows a Google Earth view of that area, then back to Jaffé, *et al.*, with some help from a *ScienceDaily* news release and the paper “Fire in the Ocean,” in the same issue as Jaffé, *et al.* that adds explanations and a nice Figure, as well as its catchy title.





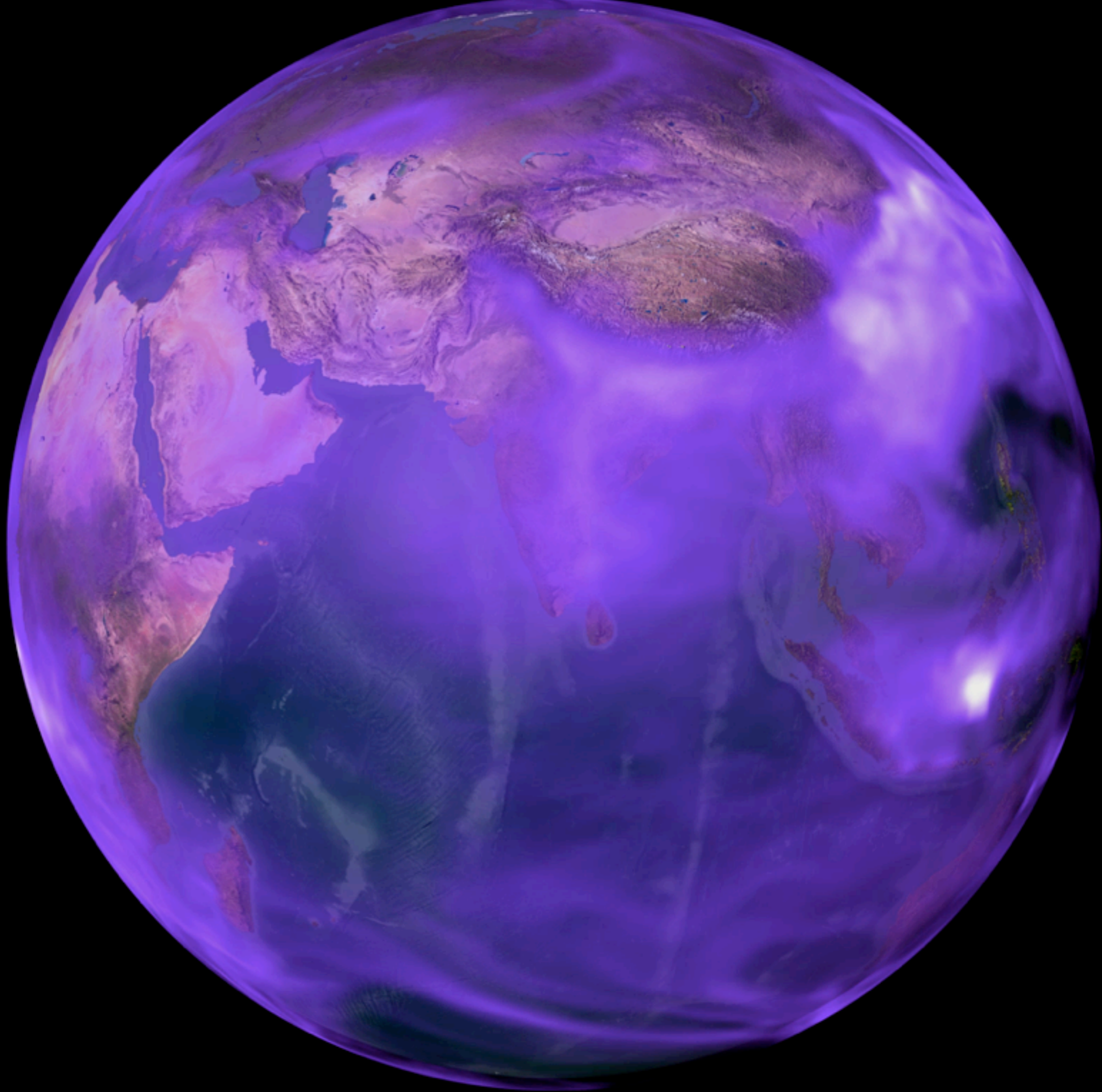
This is a Google Earth view of, roughly, where that 48-second movie of Black Carbon aerosol winds in Wikipedia's article on BC, from August 1 to November 19, 2009, was located. The Tibetan Plateau looks like a "stage," and the plain, "flat" spot at "stage right" is the Taklimakan Desert, in the Xinjiang Uyghur Autonomous Region in Northwest China. {Also see: Characteristics and source of black carbon aerosol over Taklimakan Desert, LI Juan et al, Science China - Chemistry, 53 (2010) 1202-1209}



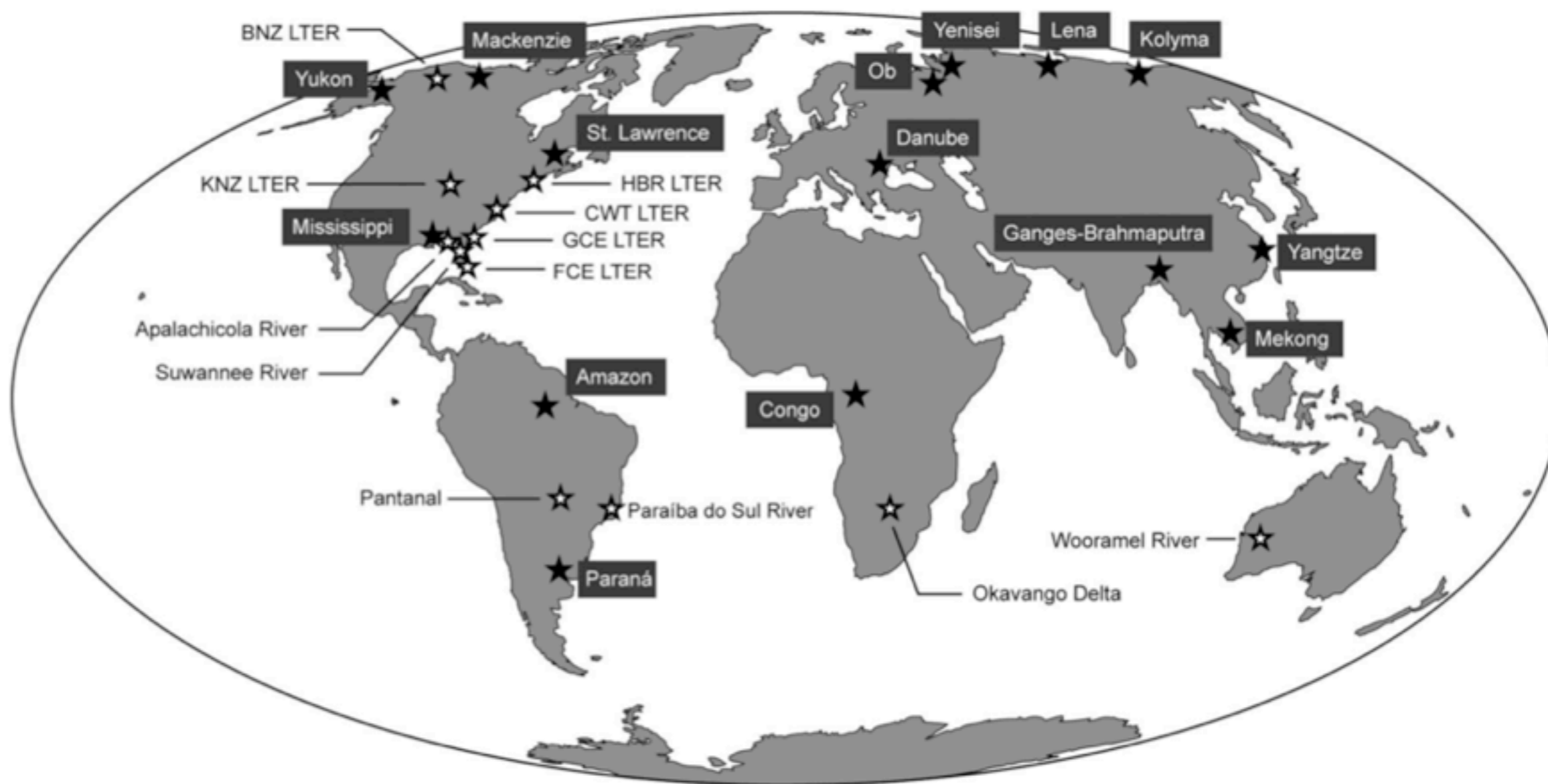
The next slide is from Wikipedia - Black Carbon:

## **The Dark Side of Carbon.jpg**

Then comes Figure 1 from Jaffé, *et al*,  
showing their sampling locations,  
followed by slides sketching details.



**Fig. 1 Map of global freshwater DBC sampling sites. Black stars indicate major world rivers, and white stars indicate all other sites, including minor to intermediate rivers and wetland-associated streams, including Long-Term Ecological Research (LTER) sites.**



R Jaffé et al. *Science* 2013;340:345-347





The authors assert that good estimates of the amount of dissolved organic carbon (DOC) are known and that the percent of *that* making its way from land by way of rivers is also “known.” They seek to quantify the amount of incompletely burned, dissolved, biomass as a percent of all dissolved *organic* carbon that makes its way from land to the oceans’ carbon pool by way of rivers. They assert that it’s about 10%.

The paper reports on carefully analyzed water samples from rivers around the world. About ten percent of each sample consisted of “polycyclic aromatic carbon,” that *forms at the highest temperatures and is among the most stable components of charred biomass* [italics mine].

*From the Supplementary Materials:* Samples: Surface water, 174 from 27 different river systems and wetlands. The samples were filtered first, acidified, stored at 4° and taken to the home labs for analysis. **First, Ten major rivers:**

Congo River

Mekong River

Mississippi River

Parana River

St Lawrence River

Amazon River

Danube River

Ganges-Brahmaputra River

Yangtze River

Lena River

Collected during peak flow; transported in the dark to two labs:

Florida International University (FIU), Miami

University of Oldenburg, Germany

“**Other**” Paraba do Sul River: 20 samples,

Suwannee River: 9 samples,

Shark River Slough: 20 samples,

Taylor Slough, Florida Coastal Everglades (FCE LTER): 20 samples.

These latter samples were averaged; reduction to 109 data points. . .

The objective of this study was to introduce a routine analytical technique for the reliable determination of black carbon in marine DOM. A molecular tracer technique, first employed on soils by Glaser et al. (1998) and later improved by Brodowski et al. (2005), seemed most promising for the routine analysis of black carbon in marine DOM. Black carbon is here structurally defined as condensed polyaromatic moieties. Polyaromatic hydrocarbons (PAHs) which are not substituted by oxygen can be oxidized with nitric acid into benzenepolycarboxylic acids (BPCAs, Fig. 1). BPCAs can then be analyzed via gas chromatography (GC) as specific markers for black carbon. A major advantage of this method is the clear molecular definition of black carbon. Furthermore, production of BPCAs from black carbon free sample material during the analytical procedure does not occur if pretreatment with HCl is avoided (Brodowski et al., 2005). GC

This material is taken from pages 397-398 of:

*The molecular level determination of black carbon in marine dissolved organic matter,*

Thorsten Dittmar,  
Organic Geochemistry 39 (2008) 396–407

Dittmar outlines his method, *used in the paper we're studying*, to measure amounts of what they call “polycyclic aromatic carbon.”

requires derivatization and relative extensive sample cleanup after the nitric acid oxidation. Less sample processing would facilitate routine analysis and reduce the potential risk of considerable methodological artifacts (Brodowski et al., 2005). An alternative analytical technique for the separation of BPCAs via high-performance liquid chromatography (HPLC) was introduced by Kawamura et al. (2006a). A reversed phase HPLC column is modified with quaternary ammonium salts on which the BPCAs are separated via ion exchange. This method was originally developed for BPCA analysis in alkaline coal oxidation products (Kawamura et al., 2006b). The aim of this study was to combine the advantages of the nitric acid oxidation method with HPLC detection for the molecular level determination of black carbon in marine DOM. Both, the oxidation and HPLC techniques were originally developed for large sample amounts and relative high concentrations, an adoption of these methods for the analysis of marine DOM required therefore considerable reduction of sample amount and increase in sensitivity. The new combined approach includes the isolation of dissolved black carbon from the saline seawater matrix, microwave-assisted nitric acid oxidation and semi-micro HPLC determination of BPCAs.



Here, we see examples of what they call the “molecular signature” of (DBC), that their samples are analyzed to find.

These are included, then in their samples and in deep ocean carbon pools...

*The truly astonishing thing they found is that each of their samples usually contained about the same 10% of “their” DBC as the DOC in the same samples!*

Next, Figure 2:

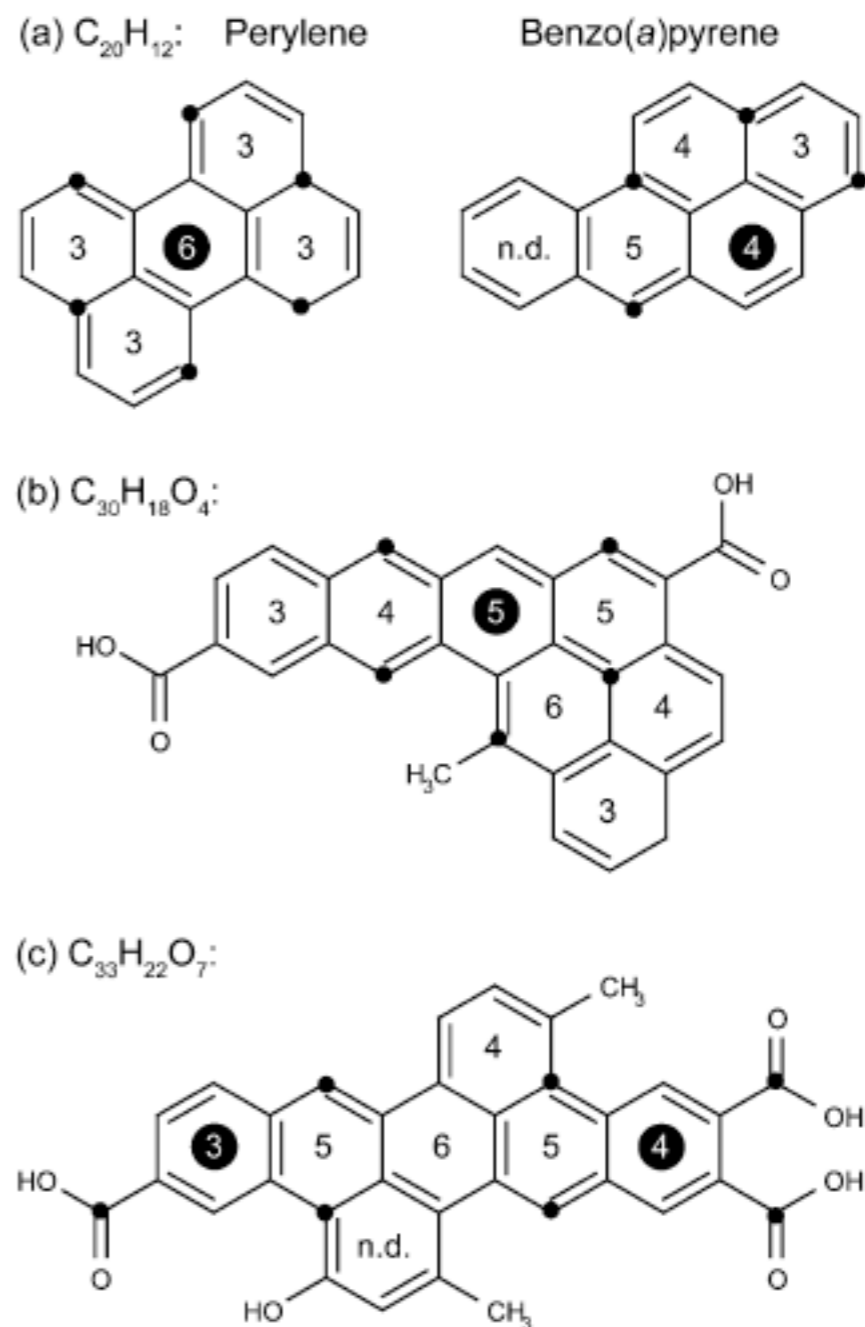
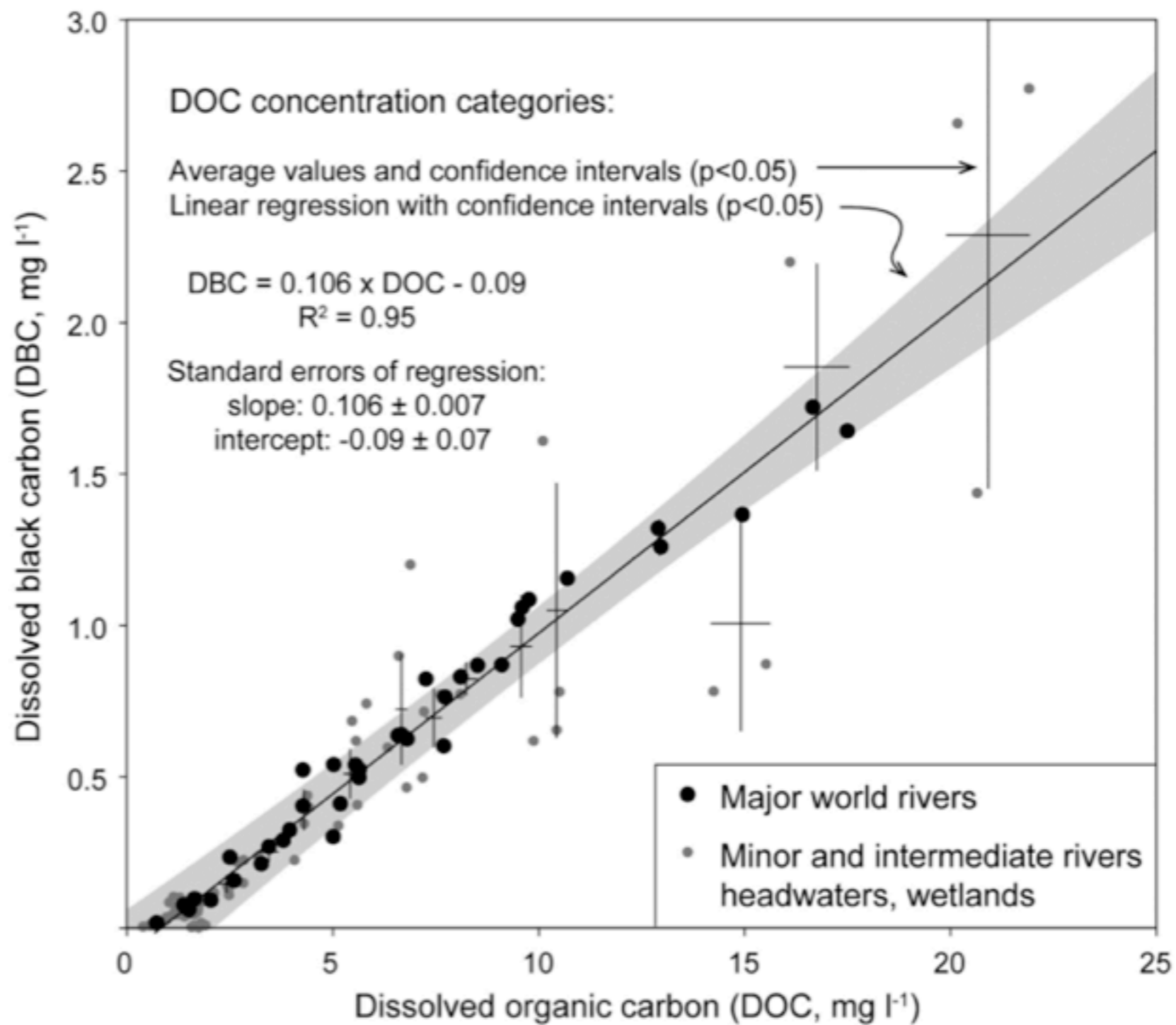


Fig. 1. (a) Molecular structures of reference compounds used for method validation (perylene and benzo(a)pyrene). (b), (c) Two possible structures of black carbon derived molecules dissolved in seawater (based on Dittmar and Koch, 2006). The numbers in the rings denote the number of carboxylic substitutions if the respective ring is oxidized to BPCA. The black numbers are examples for rings that can be oxidized to BPCA, with the black dots marking the positions which are oxidized to carboxylic acid. The oxidation of rings marked with “n.d.” results in products outside the analytical window of the presented method.



**Fig. 2 DBC versus DOC concentrations of global rivers. The regression parameters are for the average values of 15 DOC concentration groups (crosses).**



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Here is the paper's description of its statistical conclusions:

“The DBC concentrations varied strongly among the freshwater systems, ranging from  $1.94 \times 10^{-3}$  to 2.77 mg carbon/liter (average  $\pm$  SD of  $0.48 \pm 0.55$ ) mg carbon/ liter. DBC comprised from 0.1 to 17.5% of DOC (average  $\pm$  SD of  $7.1 \pm 3.6\%$ ). Despite this apparent variability, DBC and DOC concentrations were highly correlated [correlation coefficient ( $r^2$ ) = 0.88,  $n$  = 109 data points,  $P < 0.0001$ ]. Recent case studies that examined the relationship between DOC and DBC (20–22), as well as soil BC and soil organic matter (10, 26), are consistent with our observation. Because our DOC and DBC concentrations were not normally distributed, we grouped the samples according to their DOC concentrations into 15 groups for further statistical analysis (Fig. 2). The slope of the resulting regression indicates that the global DOC pool contains 10.6% DBC ( $\pm 0.7\%$ , on a 95% confidence level,  $n$  = 15 DOC concentration groups). The intercept of the regression was not significantly different from zero. If the original ungrouped data are used for the regression, the resulting slope and intercept are statistically not different from the grouped data, but the estimates for the error margins (confidence intervals) are lower because of the higher number of data points ( $n$  = 109 data points). The major world river samples followed the regression of the whole data set, suggesting that natural integration occurs in big watersheds.

We took advantage of this highly significant relationship between DBC and DOC concentrations to convert published data for global river loads of DOC into DBC loads. The estimated annual DBC flux from land to ocean is about  $26.5 \pm 1.8$  MMT(mega-metric tons) of carbon per year, based on a flux of riverine DOC of 250 MMT of carbon per year (27). The global DOC flux contains considerable margins of uncertainty. As refinements of global DOC flux estimates become available, updates on global DBC fluxes can be easily made on the basis of the observed relationship between DOC and DBC.”

The authors end their paper as follows:

“Bio-char applications to soils have been proposed as an effective means of carbon sequestration (30). This activity may further enhance the translocation and export of DBC to marine systems. The environmental consequences of this are presently unknown but may be reflected in the reduction of DOC bioavailability and associated effects on microbial loop dynamics and aquatic food webs. Our data suggest that we apply our existing knowledge on DOC production, storage, and movement in soils to ensure that biochar applications are implemented sustainably and managed in ways to minimize riverine DBC fluxes.”

Reference (30) is:

Bio-Char Sequestration In Terrestrial Ecosystems A Review  
Johannes Lehmann, John Gaunt and Marco Rondon,

Mitigation and Adaptation Strategies for Global Change (2006) 11: 403427.

The next three slides show a  
PERSPECTIVES note, under ECOLOGY,  
that discusses our present paper from the note's authors' perspective. They point out that riverine DOC, and even DBC, can be transformed chemically in the ocean before joining a carbon pool.

These will be followed by an NSF news release, four slides, that gives a “local (Florida)” account of our present paper's background.

Finally, two slides give a perspective from Finland...



# Fire in the Ocean

C. A. Masiello<sup>1</sup> and P. Louchouart<sup>2,3</sup>

One of the great challenges of modern organic geochemistry is the determination of the chemical composition of Earth's largest active carbon pools: marine sediments, soils, and dissolved organic carbon (DOC) in both marine and terrestrial systems. Together these reservoirs are much larger than the atmospheric CO<sub>2</sub> pool, and they exchange carbon with the atmosphere, making them potential CO<sub>2</sub> sources or sinks in a changing climate. Rivers play a central role in the carbon exchange between all these reservoirs.

<sup>1</sup>Department of Earth Science, Rice University, 6100 Main Street, MS 126, Houston, TX 77005, USA. <sup>2</sup>Department of Marine Science, Texas A&M University at Galveston, Galveston, TX 77553, USA. <sup>3</sup>Department of Oceanography, Texas A&M University, College Station, TX 77853, USA. E-mail: masiello@rice.edu

On page 345 of this issue, Jaffé *et al.* (1) shed new light on the chemical composition of riverine DOC.

Earth's organic carbon reservoirs are thought to derive from living terrestrial and marine organic matter, altered through biotic and abiotic processes. However, once organic matter enters soils, rivers, and the ocean, its chemistry diverges rapidly from the easily characterized chemistry of fresh plant matter (2). Fire may be partly responsible for this: Burning alters the chemistry of biomass, rendering its organic chemical composition undetectable by standard analytical techniques. Black carbon (BC), carbonaceous material altered by fire, can be transported globally through the atmosphere, rivers, and oceans. Because exposure to fire can reduce biomass decompos-

Exposure to fire alters the properties of dissolved organic carbon in ways that affect how it decomposes in rivers and in the ocean.

ability, BC becomes an increasing fraction of carbon pools as they age.

Quantitating BC is analytically hard, and it has been particularly challenging to measure dissolved BC (DBC). Jaffé *et al.* have applied a novel DBC method to a large suite of river samples. With this method, which measures a highly recalcitrant fraction of DBC that is enriched in condensed polycyclic aromatic units, the authors identified more than 10% of DOC in rivers as DBC. It does not detect other DBC fractions such as levoglucosan (3). This means that the 10% value reported by Jaffé *et al.* is a low estimate of fire-altered DOC in rivers.

An even more interesting result is the strong correlation between DBC and DOC concentrations in their river samples, indicating that fire does not create a distinct



fraction of DOC with unusual properties. Instead, in the 27 rivers and wetlands analyzed by Jaffé *et al.*, DBC behaves like the bulk DOC pool, which suggests that fire-altered carbon is an intrinsic component of the reservoir.

This study is part of a growing body of work deepening our understanding of the decomposability of BC. A simple model (2, 4) proposed a BC combustion continuum, where higher-temperature combustion creates larger aromatic ring clusters with longer environmental residence times. In terrestrial systems larger ring structures do appear to be more stable (5, 6), but once DBC leaves soils, larger ring clusters seem to be more photoreactive (7), leading to the accumulation of smaller aromatic structures in the oceans (see the figure) (8).

The chemical heterogeneity of DBC leads to a reactivity that does not mesh simply with the black carbon continuum model. Biomass combustion leads to structurally variable residues (9) that may degrade faster or slower than their precursor biomass (10). The soluble organics released by fire can be quite reactive (10, 11) and may further accelerate (prime) the decomposition of bulk DOC. Potential priming effects

induced by terrigenous DOC in inland and coastal waters have been identified as a gap in global carbon cycle models (12), and low molecular weight organics released from charcoals or from the photo-oxidation of larger DBC clusters may be priming substrates, impacting DOC cycling.

Research on the heterogeneity in BC environmental residence time is crucial for the widely applied carbon sequestration technique of biochar soil amendment. In this approach, biomass is converted into charcoal and added to soil, transferring carbon from fast-cycling biomass pools into the slow-cycling soil BC pool. Increased crop yields and altered soil hydrology have been observed in some biochar-amended systems (13). However, our understanding of the effectiveness of this technique is only as good as our understanding of the residence time of BC in soils, rivers, and the ocean.

Jaffé *et al.* mention that biochar soil amendment may have unintended consequences through increased transport of DBC into aquatic and marine systems, with downstream impacts on aquatic food webs. These possibilities must be taken seriously. The successful scaling-up of biochar soil amendment will require assessment of the

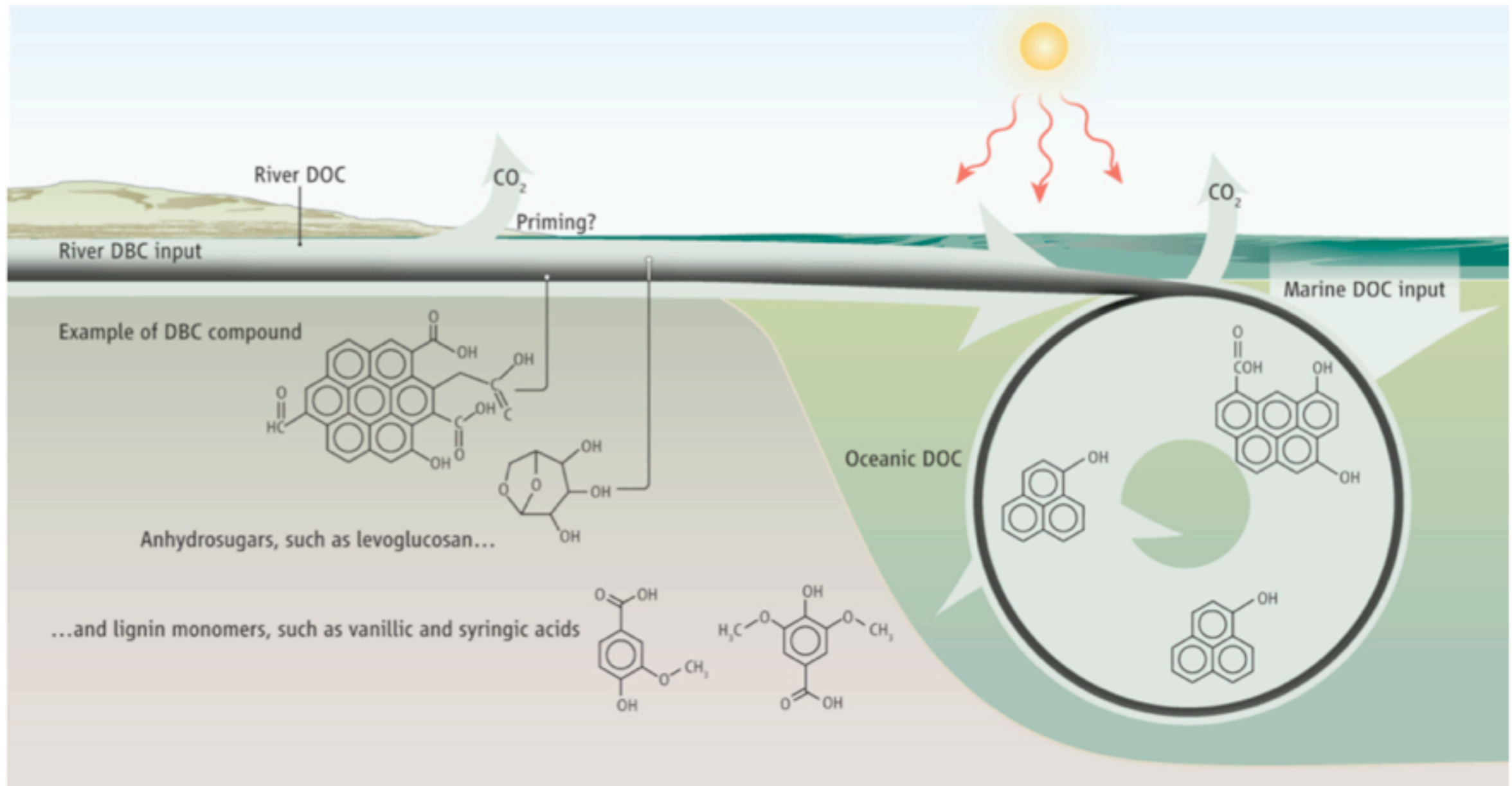
fate of biochar carbon both in the solid and dissolved phases. Jaffé *et al.*'s observation that the aromatic, dissolved fraction of BC behaves at least in part like bulk DOC may make tracking DBC that much easier.

#### References

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10.1126/science.1237688

**From rivers to ocean. Dissolved organic carbon (DOC) from rivers enters the ocean where it mixes into the larger marine DOC pool that travels through the ocean's thermohaline circulation.**



**C A Masiello, and P Louchouart Science 2013;340:287-288**







Press Release 13-069

## WHERE DOES CHARCOAL, OR BLACK CARBON, IN SOILS GO?

**Scientists find surprising new answers in wetlands such as the Everglades**



Charred boreal forest after a fire has raged: where does the "charcoal" go?

**Credit and Larger Version**

**April 18, 2013**

Scientists have uncovered one of nature's long-kept secrets--the true fate of charcoal in the world's soils.

The ability to determine the fate of charcoal is critical to knowledge of the global carbon budget, which in turn can help understand and mitigate climate change.

However, until now, researchers only had scientific guesses about what happens to charcoal once it's incorporated into soil. They believed it stayed there.

Surprisingly, most of these researchers were wrong.

The findings of a new study that examines the result of charcoal once it is deposited into the soil are outlined in a paper published this week in the journal *Science*.

The international team of researchers was led by scientists Rudolf Jaffe of Florida International University and Thorsten Dittmar of the German



The familiar look of charcoal; some charcoal is generated by wildfires and burning fossil fuels.

**Credit and Larger Version**



Alaska forest fire near NSF's Bonanza Creek LTER site; fires leave charcoal, or black carbon.

**Credit and Larger Version**



At NSF's Florida Coastal Everglades LTER site, charcoal is part of the dissolved organic carbon.

**Credit and Larger Version**



Charcoal, or black carbon, makes its way through Everglades wetlands and to the sea.

**Credit and Larger Version**

Max Planck Society.

"Most scientists thought charcoal was resistant," says Jaffe. "They believed that once it was incorporated into soils, it stayed there. But if that were the case, soils would be black."

Charcoal, or black carbon, is a residue generated by combustion including wildfires and the burning of fossil fuels.

When charcoal forms, it is usually deposited into the soil.

"From a chemical perspective, no one really thought it dissolved, but it does," Jaffe says.

"It doesn't accumulate for a long time. It's exported into wetlands and rivers, eventually making its way to the oceans."

It all started with a strange finding in the Everglades.

At the National Science Foundation (NSF) Florida Coastal Everglades Long-Term Ecological Research (LTER) site--one of **26 such NSF LTER sites in ecosystems around the world**--Jaffe studied the glades' environmental chemistry.

Dissolved organic carbon is known to be abundant in wetlands such as the Everglades and plays a critical role in the ecology of these systems.

Jaffe wanted to learn more about what comprised the organic carbon in the Everglades.

He and colleagues discovered that as much as 20 percent of the total dissolved organic carbon in the Everglades is charcoal.

Surprised by the finding, the researchers shifted their focus to the origin of the dissolved charcoal.

In an almost serendipitous scientific journey, Dittmar, head of the Max Planck Research Group for Marine Geochemistry at the University Oldenburg in Germany, was also tracing the paths of charcoal, but from an oceanographic perspective.

To map out a more comprehensive picture, the researchers joined forces. Their conclusion is that charcoal in soils is making its way into the world's waters.

"This study affirms the power of large-scale analyses made possible through international collaborations," says Saran Twombly, program director in NSF's Division of Environmental Biology, which funded the research along with NSF's Directorate for Geosciences.

"What started out as a puzzling result from the Florida Everglades engaged scientists at other LTER sites in the U.S., and eventually expanded worldwide," says Twombly. "The result is a major contribution to our understanding of the carbon cycle."

Fire is probably an integral part of the global carbon cycle, says Dittmar,



The researchers' findings are described in the April 19 issue of the journal *Science*.

**Credit and Larger Version**

its effects seen from land to sea.

The discovery carries significant implications for bioengineering, the scientists believe.

The global carbon budget is a balancing act between sources that produce carbon and sources that remove it.

The new findings show that the amount of dissolved charcoal transported to the oceans is keeping pace with the total charcoal generated by fires annually on a global scale.

While the environmental consequences of the accumulation of black carbon in surface and ocean waters are currently unknown, Jaffe said the findings mean that greater consideration should be given to carbon sequestration techniques.

Biochar addition to soils is one such technique.

Biochar technology is based on vegetation-derived charcoal that is added to agricultural soils as a means of sequestering carbon.

As more people implement biochar technology, says Jaffe, they should take into consideration the potential dissolution of the charcoal to ensure that these techniques are environmentally friendly.

Jaffe and Dittmar agree that there are still many unknowns when it comes to the environmental fate of charcoal, and both plan to move on to the next phase of the research.

They've proved where charcoal goes.

Now they'd like to answer how that happens, and what the environmental consequences are.

The more scientists can understand the process and the environmental factors controlling it, says Jaffe, the better the chances of developing strategies for carbon sequestration and mitigating climate change.

The research was also conducted at NSF's Bonanza Creek; Konza Prairie; Hubbard Brook; Coweeta; and Georgia Coastal Ecosystems LTER sites, and at other locations around the world.

Other authors of the paper are: Yan Ding of Florida International University; Jutta Niggemann of the Max Planck Research Group for Marine Geochemistry; Anssi Vahatalo of the University of Helsinki; Aron Stubbins of the Skidaway Institute of Oceanography in Savannah, Georgia; Robert Spencer of the Woods Hole Research Center in Massachusetts; and John Campbell of the USDA Forest Service.

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#### Related Websites

NSF Publication: Discoveries in Long-Term Ecological Research:  
[http://www.nsf.gov/pubs/2013/nsf13083](http://www.nsf.gov/pubs/2013/nsf13083/nsf13083.pdf?WT.mc_id=USNSF_25&WT.mc_ev=click)

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NSF Long-Term Ecological Research (LTER) Network:

<http://www.lternet.edu>

NSF Florida Coastal Everglades LTER Site: <http://fce.lternet.edu/>

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## Global Warming: 'Black Carbon' Flowing from Soil to Oceans

Apr. 19, 2013 — A smaller proportion of black carbon created during combustion will remain in soil than have been estimated before. Contrary to previous understanding, burying black carbon in the ground in order to restrain climate change will not create a permanent carbon reserve. Instead, a part of black carbon will dissolve from soil to rivers. The flux of dissolved black carbon from the rivers to the ocean was estimated in a research article published in *Science* on 19 April.

The burning of organic matter creates 40-250 million tons of black carbon every year. Black carbon is formed through the incomplete combustion of organic matter, e.g. in forest fires, slash-and-burn and controlled burning of fields. The general assumption has been that black carbon would remain in soil even for millions of years.

However, recently published research indicates that a remarkable proportion of black carbon in soil will dissolve to the water system. In the light of new research results, much discussed "bio-carbon" may not be that beneficial in terms of mitigating climate change. Carbon is given the prefix "bio" when it is used both for energy production and soil enrichment. In any case, the stability of carbon in soil has been a central factor of bio-carbon applications.

By sampling rivers all around the world, the researchers estimated that the annual amount of black carbon flowing via rivers to the ocean is 27 million tons per year.

"Each sample included a significant amount of black carbon," says a research participant Anssi Vähätalo, Senior Lecturer from the University of Jyväskylä.

"On average, the amount of black carbon was ten per cent of the amount of dissolved organic carbon. The results prove that the proportion of water soluble black carbon may be as much as 40 per cent of black carbon created annually.

## **Water samples from the largest rivers in the world**

The basis of the research was the 'Big river'-project started by Senior Lecturer Anssi Vähätalo while he was working as an Academy Research Fellow at the University of Helsinki before moving to the University of Jyväskylä. For this project, water samples were collected from the ten largest rivers in the world.

"These rivers carry one third of fresh water running to oceans, and their catchment area covers 28% of the whole land area in the world. Water samples were taken, e.g. from Amazon, the largest river in the world," says Vähätalo.

In addition to the samples used in the river project, the research published in Science was supplemented with samples from many other rivers all over the world. The total number of researched samples was 174.