BIOMASS BURNING AND GLOBAL CHANGE

March 13-17, 1995 Willaimsburg, Virginia
Convener: Joel S. Levine, Atmospheric Sciences Division, NASA Langley Research Center

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AGU Chapman Conference
Biomass Burning and Global Change

March 13 - 17, 1995 **Williamsburg, Virginia**

CONVENER: Joel S. Levine, Atmospheric Sciences Division,
NASA Langley Research Center

The aim of this Chapman Conference is to assess the role and importance of biomass burning as a process for global change. The conference will consider the impact of gaseous and particulate emissions from biomass burning on atmospheric chemistry, on the biogeochemical cycling of elements, and on climate.

LOCATION: Colonial Williamsburg, the restored capital of Colonial Virginia and an historic meeting venue, is the site for this conference. Located 2 1/2 hours south of Washington, D.C., and in close proximity to two international airports, Williamsburg is one of the major tourist attractions on the east coast. It is the home of the College of William and Mary, and the NASA Langley Research Center. Nearby attractions include the Yorktown Battlefield, Busch Gardens and the Old Country theme parks, excellent golf courses and retail shops, and extensive gardens that should be in full bloom in March.

REGISTRATION: Everyone attending this conference must register and pay the registration fee. The registration fee covers the cost of the program with abstracts, admittance to the scientific sessions, and all scheduled social activities. Guests who wish to participate in any of the social events or evening activities, must register at the guest rate of $150.00. This rate includes all refreshment breaks, the Sunday reception, and the Thursday dinner.

SOCIAL EVENTS

Sunday, March 12	6:00 P.M.	Opening Reception
Thursday, March 16	7:00 P.M.	Conference Dinner

MEETING FORMAT: The meeting will have both oral and poster presentations. In addition, there will be free time for participants to get together for discussions on topics of interest.

For presenters, the meeting room will be equipped with a 35mm slide projector and an overhead projector. Presenters requiring further equipment may be required to pay an additional fee.

CONFERENCE COSPONSORS: NASA Langley Research Center; NASA Headquarters; U.S. Environmental Protection Agency, International Global Atmospheric Chemistry Project; College of William and Mary, Science Museum of Virginia; Public Broadcast System (PBS) Television Station, WHRO/TV; Virginia Quality Education in Science and Technology (VQUEST).

MEETING AT A GLANCE

All meeting activities will be held at the Williamsburg Lodge in the Auditorium

Sunday, March 12, 1995

Registration	5:00 p.m. - 7:30 p.m.
Opening Reception	6:00 p.m. - 7:30 p.m.

Monday, March 13, 1995

Introduction/Welcome	8:00 a.m. - 8:30 a.m.
Session I	8:30 a.m. - 10:00 a.m.
Coffee Break	10:00 a.m. -10:30 a.m.
Session I Continues	10:30 a.m. -12:00 p.m.
Break for Lunch	12:00 p.m. - 1:30 p.m.
Session I Continues	1:30 p.m. - 3:45 p.m.
Refreshment Break	3:45 p.m. - 4:15 p.m.
Session II	4:15 p.m. - 6:00 p.m.
Public Lecture	7:30 p.m. - 10:00 p.m.

Tuesday, March 14, 1995

Session II Continues	8:00 a.m. - 10:00 a.m.
Coffee Break	10:00 a.m. -10:30 a.m.
Session II Continues	10:30 a.m. -11:30 a.m.
Session III	11:30 a.m. -12:00 p.m.
Break for Lunch	12:00 p.m. - 1:30 p.m.
Session III Continues	1:30 p.m. - 2:00 p.m.
Session IV	2:00 p.m. - 3:15 p.m.
Refreshment Break	3:15 p.m. - 3:45 p.m.
Session IV Continues	3:45 p.m. - 5:15 p.m.
Evening Activity and Poster Session	7:30 p.m. - 10:00 p.m.

Wednesday, March 15, 1995

Session IV Continues	8:00 a.m. - 9:15 a.m.
Session V	9:15 a.m. - 10:00 a.m.
Coffee Break	10:00 a.m. -10:30 a.m.
Session VI	10:30 a.m. -12:00 p.m.
Break for Lunch	12:00 p.m. - 1:30 p.m.
Session VI Continues	1:30 p.m. - 3:00 p.m.
Session VII	3:00 p.m. - 3:30 p.m.
Refreshment Break	3:30 p.m. - 4:00 p.m.
Session VII Continues	4:00 p.m. - 5:15 p.m.
Evening Activity and Poster Session	7:30 p.m. - 10:00 p.m.

Thursday, March 16, 1995

Session VII Continues	8:00 a.m. - 9:00 a.m.
Session VIII	9:00 a.m. - 9:45 a.m.
Session IX	9:45 a.m. - 11:30 a.m.
Session X	11:30 a.m. -12:00 p.m.
Break for Lunch	12:00 p.m. - 1:30 p.m.
Session X Continues	1:30 p.m. - 3:15 p.m.
Refreshment Break	3:15 p.m. - 3:45 p.m.
Session XI	3:45 p.m. - 6:00 p.m.
Conference Banquet	7:30 p.m. - 9:30 p.m.

Friday, March 17, 1995

Session XI Continues	8:00 a.m. - 9:00 a.m.
Session XII	9:00 a.m. - 9:30 a.m.
Session XIII	9:30 a.m. - 11:00 a.m.
Session XIV	11:00 a.m. -12:00 p.m.
Break for Lunch	12:00 p.m. - 1:30 p.m.
Session XIV Continues	1:30 p.m. - 2:15 p.m.
Conference Adjourns	2:15 p.m.

SCIENTIFIC PROGRAM

AGU Chapman Conference on Biomass Burning and Global Change

March 13-17, 1995 *Williamsburg, Virginia*

Convener: Joel S. Levine, Atmospheric Sciences Division,
NASA Langley Research Center

SUNDAY, MARCH 12, 1995

5:00 - 7:30 P.M. **Registration**

6:00 - 7:30 P.M. **Opening Reception**

MONDAY, MARCH 13, 1995

8:00 A.M. **Welcoming Remarks**

J S Levine, Convener
P F Holloway, Director, NASA Langley Research Center
R C Harriss, Director, Science Division, Mission to Planet Earth, NASA Headquarters
R G Zepp, U.S. Environmental Protection Agency
R G Prinn, Chair, International Global Atmospheric Chemistry Project

SESSION I: **REMOTE SENSING OF BIOMASS BURNING**
Chairs: D C Cahoon, J-P Malingreau, A W Setzer

8:30 A.M.	**J-P Malingreau**, J-M Grégoire	Developing a Global Vegetation Fire Monitoring System for Global Change Studies: Current Possibilities and Perspectives
8:45 A.M.	**C O Justice**, J D Kendall, Y J Kaufman	Global Fire Mapping Using Satellite Data: An Overview
9:00 A.M.	B J Stocks, **D R Cahoon**, J G Goldammer, R J Bauer	Documenting the Seasonal Distribution of Vegetation Fires in Eastern Africa Using DMSP and NOAA-AVHRR Satellite Imagery
9:15 A.M.	**P R Dowty**, B Stocks	The Use of Simulated AVHRR Data to Validate Fire Detection Algorithms
9:30 A.M.	**J D Kendall**, R J Scholes, C O Justice	A Multi-Sensor Approach to Estimation of the Areal Extent of Biomass Burning in Southern Africa
9:45 A.M.	**J R de A França**, J Fontan, M-M Brustet	The Use of Multispectral NOAA-AVHRR to Determine an Improved Budget in Intertropical Africa
10:00 A.M.	**COFFEE BREAK**	
10:30 A.M.	**B Koffi**, J-M Grégoire, P Legeay-Janvier, A Tournier	Satellite Monitoring of Multiannual Biomass Burning Activity for the African Continent

10:45 A.M.	**A W Setzer**, E M Miranda	AVHRR Operational Detection of Fires in Brazil Since 1987 - A Summary of the Experience and Results
11:00 A.M.	**J A Brass**, P J Riggan, V G Ambrosia, R N Lockwood, J A Pereira, R G Higgins	Brazil Fire Characterization and Burn Area Estimation Using the Airborne Infrared Disaster Assessment (AIRDAS) System
11:15 A.M.	C A Hlavka, V G Ambrosia, **J A Brass**, A Rezendez, S Alexander, L S Guild	Mapping Fire Scars in the Brazilian Cerrado Using AVHRR Imagery
11:30 A.M.	E M Prins, **W P Menzel**	Monitoring Biomass Burning With the Next Generation of Geostationary Satellites
11:45 A.M.	**E M Prins**, W P Menzel	Investigation of Biomass Burning and Aerosol Loading and Transport in South America Utilizing Geostationary Satellite Data
12:00 P.M.	**LUNCH BREAK**	
1:30 P.M.	**P Le Canut**, J S Levine, D R Cahoon	Biomass Burning in Western Europe in 1987
1:45 P.M.	**D R Cahoon**, B J Stocks, J S Levine, W R Cofer, J A Barber	Monitoring the 1992 Forest Fires in the Boreal Ecosystem Using NOAA AVHRR Satellite Imagery
2:00 P.M.	**B J Stocks**, D R Cahoon, W R Cofer, J S Levine	Monitoring Large-Scale Forest Fire Behavior in Northeastern Siberia Using NOAA-AVHRR Satellite Imagery
2:15 P.M.	L T Steyaert, F G Hall, B C Reed, D E Knapp, T R Loveland, P J Sellers, R A Pielke	Investigating Landscape Disturbance Patterns and Associated Vegetation Succession in the Boreal Forest with Multitemporal 1-Km AVHRR Data
2:30 P.M.	**E S Kasischke**, P Camille, N H French, L L Bourgeau-Chavez, H H Shugart	Estimating Carbon Storage and Release in a Fire-Disturbed Boreal Forest Using Multi-Sensor Satellite Data
2:45 P.M.	**C D Elvidge**, H K Kroehl, E A Kihn, K E Baugh, E R Davis	Algorithm for the Retrieval of Fire Pixels From DMSP Operational Line Scanner Data
3:00 P.M.	**E V Browell**, M P McCormick, C F Butler, M A Fenn, G D Nowicki, W B Grant, S Ismail	Airborne and Spaceborne Lidar Observations of Biomass Burning Plumes Over Africa and South America
3:15 P.M.	**E R Rignot**	On the Measurement of Aboveground Biomass Burning Using Imaging Radars

3:30 P.M.	**T L DeLiberty**, W P Menzel, E M Prins	An Investigation of the Hydrologic Cycle in the Amazon Using Remotely Sensed Variables
Poster	**C D Elvidge**	Survey of Fires in Southeast Asia and India During 1987
Poster	J G Goldammer, M R Helfert, J L Pfund	Vegetation Fires From Space: The use of the Earth Observation System in the Space Shuttle Program for Research and Documentation of Global Vegetation Fires: A Case Study From Madagascar
Poster	**E A Kihn**	Sub-Pixel Source Detection and Area Estimation Algorithms Applied to DMSP Operational Linescan System (OLS) Imagery
Poster	**H M Worden**, R Beer, C P Rinsland	Airborne High Resolution Infrared Spectroscopy of Western Wildfires
3:45 P.M.	**COFFEE BREAK**	

SESSION II: **GASEOUS EMISSIONS**
Chairs: M O Andreae, W R Cofer, R A Delmas

4:15 P.M.	**M O Andreae**, SAFARI/SA'ARI Science Team	*INVITED:* Emissions of Trace Gases and Aerosols From Fires in the Savannas of Southern Africa and Their Impact on the Atmospheric Environment
4:45 P.M.	**F S Rowland**	Hydrocarbon and Halocarbon Emissions During Biomass Burning
5:00 P.M.	**E Atlas**, W Pollock, A deKock	Characterization of Organic Compounds in Biomass Burning Plumes During SAFARI#'93
5:15 P.M.	**D Brocard**, C Lacaux, J P Lacaux, G Kouadio, V Yoboué, M Assa Achy, B Ahoua, M Koffi	Emissions From the Combustion of Biofuels in the African Tropics
5:30 P.M.	**R Koppmann**, A Khedim, J Rudolph, G Helas, M Welling	Emission of Medium Molecular Weight Organic Trace Gases From Savanna Fires in Southern Africa
5:45 P.M.	**J P Lacaux**, R Delmas	NO_x Emissions From African Savanna Burning
6:00 P.M.	**ADJOURN**	

7:30-10:00 P.M.	**EVENING ACTIVITY**	***PUBLIC LECTURE:*** BIOMASS BURNING AND GLOBAL CHANGE
	J S Levine	Moderator
	P J Crutzen	Biomass Burning, Greenhouse Gases, and Global Climate
	J E Penner	Biomass Burning, Particulates, and Global Climate
	M O Andreae	Biomass Burning and Tropospheric Chemistry
	F S Rowland	Biomass Burning and Stratospheric Chemistry
	S Brown	Biomass Burning and the World's Forests
	R C Harriss	Biomass Burning and NASA's Mission to Planet Earth
	R G Prinn	Biomass Burning and the International Global Atmospheric Chemistry Project

TUESDAY, MARCH 14, 1995

SESSION II: **GASEOUS EMISSIONS Continued**
Chairs: M O Andreae, W R Cofer, R A Delmas

8:00 A.M.	**P Le Canut**, M O Andreae, G W Harris, F G Wienhold, T Zenker	Pyrogenic Emission and Regional Distribution of Trace Gases and Aerosols Over Southern Africa During SAFARI-92
8:15 A.M.	**D L Mauzerall**, J A Logan, D J Jacob, B E Anderson, A S Bachmeier, G W Sachse, D R Blake, J D Bradshaw, H Fuelberg, B G Heikes	Relationships Between Biomass Burning Emissions and Photochemical Tracers Over Source Regions and the Tropical South Atlantic - Analysis of TRACE-A Expedition Measurements, September-October 1992
8:30 A.M.	**D E Ward**, R A Susott, W M Hao, C Doughty, R W Shea, J B Kauffman, E Chidumayo	Chitemene Agriculture in Southern Africa-Emissions and Sustainability
8:45 A.M.	**R E Babbitt**, W M Hao, R A Susott, D E Ward, S P Baker, G Olbu	Emissions of Trace Gases and Particulate Matter From Fires in Brazilian Forest and Savanna Ecosystems
9:00 A.M.	**P M Fearnside**	Land Use Change in Brazilian Amazonia: Annual Balance of Greenhouse Gas Emissions in 1990
9:15 A.M.	A Ezcurra, I Ortiz de Zárate, J P Lacaux, P Van Dihn	Atmospheric Impact of Cereal Waste Burning in Spain

9:30 A.M.	**L Trabaud**	Gaseous Emissions From Fires in Mediterranean Shrublands
9:45 A.M.	**J M Vose**, W T Swank, A E Major, C D Geron	Modeling Emissions From Forest Burning in the Southeastern United States
10:00 A.M.	**COFFEE BREAK**	
10:30 A.M.	**W R Cofer**, J S Levine, D R Cahoon, E L Winstead, B J Stocks, J G Goldammer	Trace Gas Chemistry of Canadian and Siberian Boreal Forest Fires
10:45 A.M.	**Y H Zhuang**, M Q Cao, X K Wang	Nitrous Oxide and Carbonyl Sulfide Emissions From Biomass Burning and the Spatial Distribution of Nitrous Oxide in China
11:00 A.M.	**D F Hurst**, D W T Griffith, G D Cook	Trace Gas Emissions From Savanna Burning in Australia
11:15 A.M.	**W M Hao**, M-H Liu, M Lorenzini, K D Singh, D E Ward	Spatial Distribution of Tropical Biomass Burning in 1990 with 1° x 1° Resolution
Poster	T Zenker, F G Wienhold, P Le Canut, M O Andreae, G W Harris, R Koppmann, A M Thompson, D P McNamara, T L Kuscera	Regional Trace Gas Distribution and Airmass Characteristics in the Haze Layer Over Southern Africa During the Biomass Burning Season (Sep./Oct. 92): Observations and Modeling From the STARE/SAFARI-92 DC-3

SESSION III: **BIOGENIC SOIL EMISSIONS**
Chairs: R G Zepp, R A Delmas

11:30 A.M.	**I C Anderson**, M A Poth, H S Miranda, A C Miranda	The Magnitude and Persistence of Soil NO, N_2O, CH_4, and CO_2 Fluxes From Burned Tropical Savannas
11:45 A.M.	**E L Winstead**, J S Levine, W R Cofer, D R Cahoon, D I Sebacher	Biomass Burning and Biogenic Soil Emissions of Nitric Oxide in the Boreal Forest
12:00 P.M.	**LUNCH BREAK**	
1:30 P.M.	**J S Levine**, W R Cofer, D R Cahoon, E L Winstead, D I Sebacher	Biomass Burning, Biogenic Soil Emissions, and the Global Nitrogen Budget
1:45 P.M.	**R G Zepp**, R A Burke, W L Miller, M A Tarr, D A B Parsons, M C Scholes	Soil-Atmosphere Exchange of Trace Carbon Gases in Southern African Savanna Fire Scars

SESSION IV: **PARTICULATE EMISSIONS**
Chairs: R G Prinn, D E Ward

2:00 P.M.	**P Artaxo**, F Gerab, M A Yamasoe, J V Martins, A Setzer, A H Miguel	Large Scale and Long Term Biomass Burning Monitoring in the Amazon Basin
2:15 P.M.	**W Maenhaut**, G Koppen, P Artaxo	Long-term Atmospheric Aerosol Study in Cuiaba, Brazil: Multielemental Composition, Sources, and Impact of Biomass Burning
2:30 P.M.	**J V Martins**, P Artaxo, C Liousse, H Cachier, Y Kaufman	Size Distribution, Elemental Composition and Carbon Measurement in Aerosols During the SCAR-C Experiment
2:45 P.M.	S J Piketh, H J Annegarn, M A Kneen	Regional Scale Impacts of Biomass Burning Aerosols Over Southern Africa
3:00 P.M.	F Echalar, A Gaudichet, H Cachier, P Artaxo	Trace Element Particulate Emissions in Tropical Savana and Forest Fire Plumes
3:15 P.M.	**COFFEE BREAK**	
3:45 P.M.	**M A Mazurek**, C Laterza, L Newman, P Daum, W R Cofer, J S Levine, E L Winstead	Molecular Composition of Carbonaceous Smoke Particles From Prescribed Burning of a Canadian Boreal Forest
4:00 P.M.	K L Carleton, D M Sonnenfroh, **W T Rawlins**, B E Wyslouzil	Activation of Carbon Aerosol by Deposition of Sulfuric Acid
4:15 P.M.	**S J Pyne**	*INVITED*: Flame and Fortune: Americans Fight Fire
5:15 P.M.	**ADJOURN**	
7:30-10:00 P.M.	**EVENING ACTIVITY**	BIOMASS BURNING EXPERIMENT (BIBEX) MEETING
	POSTER SESSION	All Posters Viewed

WEDNESDAY, MARCH 15, 1995

SESSION IV: **PARTICULATE EMISSIONS Continued**
Chair: R G Prinn, D E Ward

8:00 A.M.	**B R T Simoneit**, M Radzi bin Abas, G R Cass, W R Rogge, M A Mazurek, L M Hildemann	Natural Organic Compounds as Tracers for Biomass Combustion in Aerosols
8:15 A.M.	**L A Currie**	Biomass Burning Tracers: Elements, Isotopes, and Isomers

8:30 A.M.	T Novakov, C E Corrigan	Thermal and Optical characterization of Biomass Smoke Particles: Implications for Organic and Black Carbon Determination
8:45 A.M.	**V C Turekian**, S A Macko, W Gilhooly, R J Swap, D C Ballentine, M Garstang	Bulk and Molecular Level Isotope Analysis of Products of Vegetation Burns
9:00 A.M.	**C Liousse**, J E Penner, C Chuang, C R Molenkamp, J J Walton, H Eddleman, I Shult, H Cachier	Modeling Biomass Burning Aerosols
Poster	**D C Ballentine**, S A Macko, B Martincigh	Chemical and Isotopic Characterization of Aerosols Collected During Sugar Cane Burning in South Africa
Poster	**M A Yamasoe**, P Artaxo, A Miguel, A Allen	Aerosol Emissions From Forest and Cerrado Fires in the Amazon Basin
Poster	**R Serpolay**, P Van Dinh, J P Lacaux	Laboratory Investigations on Aerosols Produced by Combustion of Savanna Grass and Cereal Straw

SESSION V: **FUTURE EXPERIMENTS**
Chairs: R A Delmas, J G Goldammer

9:15 A.M.	**R A Delmas**, J P Lacaux, B Cros, P Zimmerman, G Brasseur, J P Malingreau, J-M Grégoire, M O Andreae, F Meixner	Overview of the EXPRESSO Project (EXPeriment for the Regional Sources and Sinks of Oxidants)
9:30 A.M.	**J G Goldammer**, FIRESCAN Science Team	Summary Results of the Bor Forest Island Fire Experiment, Fire Research Campaign Asia-North (FIRESCAN)
9:45 A.M.	J G Goldammer, M O Andreae, SAFARI and FIRESCAN Science Teams	State and Further Planning of the Regional Vegetation Fire Research Campaigns SAFARI, FIRESCAN, FIRESCHEME, and SEAFIRE
10:00 A.M.	**COFFEE BREAK**	

SESSION VI: **PARTICULATES AND SOLAR RADIATION**
Chairs: J E Penner, R P Turco

10:30 A.M.	**J E Penner**, C C Chuang, C Liousse, K Taylor	***INVITED*:** The Contribution of Aerosols From Biomass Burning to Climate Change
11:00 A.M.	**S A Christopher**, V S Connors, D V Vulcan, R M Welch	Biomass Burning as a Source of CO and Aerosols as Measured by Space Shuttle (MAPS) and Satellite (AVHRR) Measurements

11:15 A.M.	**Y J Kaufman**, L A Remer, P V Hobbs, D E Ward, R Ottmar, L Flynn	SCAR-C - Smoke Cloud and Radiation Experiment: California
11:30 A.M.	**P V Hobbs**, J A Herring, D A Hegg	Airborne in Situ and Remote Sensing Measurements of Smoke From Biomass Fires in the Pacific Northwest
11:45 A.M.	**F P J Valero**, I Sokolik, P Pilewskie	Airborne Measurements of the Radiative and Optical Properties of Smoke Produced by the Biomass Burning During the SCAR-C Field Mission
12:00 P.M.	**LUNCH BREAK**	
1:30 P.M.	P Artaxo, R Babbit, T Eck, **B Holben**, A Lucia, A Pereira, A Setzer, D Ward	Airborne and Ground Based Characterization of Regional Smoke Events From Biomass Burning in Alta Floresta Brazil
1:45 P.M.	**T F Eck**, B N Holben, I Slutsker	Measurements of the Effects of Biomass Burning Smoke in the Amazon Basin on Solar Radiation Incident at the Surface
2:00 P.M.	**B Holben**, T Eck, I Slutsker, W Newcomb, A Setzer, A Pereira	Aerosol Climatology During the Burning Season From Ground Based Spectroradiometer Measurements
2:15 P.M.	**L F Radke**, K K Laursen	Biomass Smoke in the Tropics: From Sources to Sinks
2:30 P.M.	**L A Remer**, Y J Kaufman, B Holben	Comparison of Smoke and Industrial Aerosol Optical Properties
2:45 P.M.	**C H Whitlock**, D R Cahoon, T Konzelmann	Effects of Biomass Burning on Satellite Estimates of Surface Radiation in Central Africa

SESSION VII: **FIRE CHARACTERISTICS, BIOMASS, FUEL, CHARCOAL**
Chairs: B J Stocks, S W Trollope

3:00 P.M.	**B Bilbao**, E Medina	Burn Types and Nitrogen in Tropical Savannas of Calabozo, Venezuela
3:15 P.M.	**M Moula**, J M Brustet, J Fontan, J-M Grégoire, H Eva	Contribution of Spread-Fire Model in the Study of Savannah Fires
3:30 P.M.	**COFFEE BREAK**	
4:00 P.M.	**M I Bird**, A R Chivas	The Carbon-Isotope Composition of Terrestrial Biomes
4:15 P.M.	**J B Kauffman**, R F Hughes, D L Cummings, D E Ward	Biomass Burning and Carbon Dynamics Along Anthropogenic Disturbance Gradients in the Amazon Basin

4:30 P.M.	**L M McKenzie**, D E Ward, W M Hao	Chlorine and Bromine in the Biomass of Tropical and Temperate Ecosystems
4:45 P.M.	**R W Shea**, B W Shea, J B Kauffman, D E Ward	Fuel Biomass and Nutrient Dynamics Associated With Savanna Fires in South Africa and Zambia
5:00 P.M.	**R A Susott**, S P Baker, G Olbu, D E Ward, J B Kauffman	Carbon, Hydrogen and Nitrogen Content of Tropical Ecosystem Fuels
5:15 P.M.	**ADJOURN**	
7:30-10:00 P.M.	**EVENING ACTIVITY**	GLOBAL EMISSIONS INVENTORY ON BIOMASS BURNING (IGAC/GEIA)
7:30 P.M.	**J S Levine**, D R Cahoon, W R Cofer, J G Goldammer, B J Stocks, K S Reightler, K P Lulla, C D Elvidge, J L McElroy, W S W Trollope, V W J H Kirchhoff, A W Setzer	A Global Inventory for the Geographical and Temporal Distribution of Biomass Burning and Its Gaseous and Particulate Emissions
7:45 P.M.	**J G Goldammer**, B J Stocks, Global Vegetation Fire Inventory Science Team	The Global Vegetation Fire Inventory (GVFI): Objectives and Progress Report
8:00 P.M.	**S Brown**, G Gaston	Spatial Distribution of Biomass Estimates of Forests of Tropical Africa
8:15 P.M.	**D W Sproles**	A Global Biomass Burning Data Repository
Poster	R C Dunkum, **J O Olson**, S E Sorlie	An Overview of the EOSDIS Langley Research Center Distributed Active Archive Center
	POSTER SESSION	All Posters Viewed

THURSDAY, MARCH 16, 1995

SESSION VII: **FIRE CHARACTERISTICS, BIOMASS, FUEL, CHARCOAL Continued**
Chairs: B J Stocks, S W Trollope

8:00 A.M.	**R Yevich**, J A Logan	Assessment of the Spatial Distribution of Biomass Fuel Consumption and Burning of Agricultural Waste
8:15 A.M.	**W S W Trollope**	Biomass Burning in the Savannas of Southern Africa With Particular Reference to the Kruger National Park in South Africa

8:30 A.M.	**T A J Kuhlbusch**, P J Crutzen	Black Carbon, the Global Carbon Cycle, and Atmospheric Carbon Dioxide
8:45 A.M.	D W T Griffith, **R J Yokelson**, W G Mankin, D E Ward	FTIR Studies of Laboratory Biomass Fires
Poster	**W P Gilhooly**, D J Verardo, S A Macko, V C Turekian, R J Swap, M Garstang	Stable Carbon Isotopic Analysis of Charcoal From Controlled and Natural Burns

***SESSION VIII*: TRANSPORT OF GASES AND PARTICULATES**
Chairs: A M Thompson, M Garstang

9:00 A.M.	**M Garstang**, P D Tyson, E Browell, R Swap	Determination and Verification of Atmospheric Transport of Biomass Burning Products
9:15 A.M.	**R J Swap**, M Garstang, S Macko, P D Tyson, P Källberg	Contributions of Biomass Burning Emissions vs. Biogenic Emissions to the Tropical South Atlantic
9:30 A.M.	**P D Tyson**, M Garstang, R Swap, M Edwards, P Källberg, E V Browell	Horizontal and Vertical Transport of Aerosols and Trace Gases From Southern Africa: Implications for Global Change

***SESSION IX*: CARBON DIOXIDE**
Chairs: P J Crutzen, J G Goldammer

9:45 A.M.	**E S Kasischke**	Fire, Global Warming, and the Carbon Balance of Boreal Forests
10:00 A.M.	**COFFEE BREAK**	
10:30 A.M.	**A Shvidenko**, S Nilsson, V Rojkov	Burning of Biomass in the Territories of the Former Soviet Eurasia: Impact on the Carbon Budget
10:45 A.M.	**X Wang**, Y H Zhuang, Z W Feng	Forest Fires in China: Carbon Dioxide Emission to the Atmosphere
11:00 A.M.	S F Iacobellis, R Frouin, H Razafimpanilo, **R C J Somerville**	Biomass Burning in the Savannas of North Africa and Atmospheric CO_2
11:15 A.M.	**A D Kambis**, J S Levine	A Numerical Model of the Global Carbon Cycle to Assess the Impact of Biomass Burning on Levels of Atmospheric Carbon Dioxide
Poster	F Mack, G Esser, **J G Goldammer**	The Influence of Vegetation Fires on the Global Carbon Cycle

SESSION X: **CARBON MONOXIDE AND METHANE**
Chairs: V W J H Kirchhoff, J A Logan

11:30 A.M.	**V S Connors**, H G Reichle, M Flood	Global Distribution of Biomass Burning and Carbon Monoxide in Middle Troposphere in April and October 1994
11:45 A.M.	**S A Christopher**, D V Vulcan, R M Welch	AVHRR and ERBE Investigations of Biomass Burning in the Tropics
12:00 P.M.	**LUNCH BREAK**	
1:30 P.M.	**D O Neil**	Refined Analysis of MAPS 1984 Global CO Measurements
1:45 P.M.	**J A Logan**, R Yevich, C M Spivakovsky, A D Alberts, P Novelli	An Analysis of the Causes of Recent Observed Decreases in the Concentrations of Carbon Monoxide Using a 3-Dimensional Chemical Tracer Model
2:00 P.M.	**R D Saylor**, R C Easter, E G Chapman, M K Brown	Estimates of Emissions Inferred From Satellite Measurements of Mid-Tropospheric Carbon Monoxide
2:15 P.M.	L N Yurganov, E I Grechko, E V Fokeeva	IR Solar Spectrocopy for Studying Total Column Carbon Monoxide Abundance: Manifestations of Biomass and Fossil Fuel Burnings on Global and Regional Scales
2:30 P.M.	**J M Conny**, L A Currie	The Isotopic Composition of Tropospheric CO in Brazil: A Model Scenario During the Biomass Burn Season
2:45 P.M.	**V W J H Kirchhoff**, M A da S Oliveira, P C Alvalá	Biomass Burning Effects on the Distribution of Atmospheric Methane in Brazil: Observations at the Atlantic Coast and Amazonian Cerrado
3:00 P.M.	**R G Prinn**, R F Weiss, B R Miller, J Huang, P G Simmonds, P B Fraser, F N Alyea, D M Cunnold, D E Hartley	Hydroxyl Radical Concentrations and Trends Based on 1978-1994 ALE/GAGE Trichloroethane Measurements: Implications for CO and CH_4 Emmissions
Poster	**A M Thompson**, K E Pickering, D P McNamara, C O Justice, J D Kendall, R J Scholes, R G Zepp, G W Sachse, M O Andreae, G T Helas, T Zenker	The Carbon Monoxide Budget in Southern Africa During TRACE-A/SAFARI-92
3:15 P.M.	**COFFEE BREAK**	

SESSION XI: **OZONE**
Chairs: F S Rowland, J Fishman

3:45 P.M.	**J Fishman**, E V Browell, V G Brackett, J R Olson	***INVITED***: Large-Scale Impact of Biomass Burning on the Composition of the Troposphere as Determined From Analysis of Satellite Measurements
4:15 P.M.	**A M Thompson**	***INVITED***: Model Evaluation of Biomass Burning Effects on Tropical Ozone and Oxidizing Capacity: Overview and Examples From Safari-92/Trace-A
4:45 P.M.	**J R Olson**	A Study of the Mass Transport of Enhanced Continental Ozone in the Tropics and Its Impact Over the Remote Southern Atlantic Ocean
5:00 P.M.	B Cros, **B N Ahoua**, D Nganga	Tropospheric Ozone on Both Sides of the Equator in Africa
5:15 P.M.	**K M Fakhruzzaman**, J Fishman, V G Brackett	Tropospheric Ozone Over Equatorial Atlantic: Ozonesonde-Trajectory Analysis
5:30 P.M.	**J H Kim**, R D Hudson, A M Thompson	A New Method of Deriving Time-Averaged Tropospheric Column Ozone in the Tropics Using TOMS Radiances: Intercomparison and Analysis
5:45 P.M.	**R D Hudson**, C Sieber, J H Kim	Comparison of Tropospheric Ozone Determined From TOMS Radiances Between October 1989 and October 1992
6:00 P.M.	**ADJOURN**	
7:00-9:30 P.M.	**CONFERENCE BANQUET**	

FRIDAY, MARCH 17, 1995

SESSION XI: **OZONE Continued**
Chairs: F S Rowland, J Fishman

8:00 A.M.	**V W J H Kirchhoff**	The Biomass Burning Sequence of the Brazilian Savanna and Observations of Atmospheric O_3 and CO.
8:15 A.M.	G P Brasseur, W M Hao, J F Muller, **C Granier**	Land Use Practices and Biomass Burning: Impact on the Chemical Composition of the Atmosphere

8:30 A.M.	**R B Chatfield**, J A Vastano	Explaining the Accumulation of Intercontinental Biomass-Burning Pollution: High vs. Low Processes, Africa vs. South America, Cooking vs. Mixing
8:45 A.M.	**K E Pickering**, A M Thompson, Y Wang, W-K Tao, D P McNamara, G W Sachse, G L Gregory, V W J H Kirchhoff, J D Bradshaw, D R Blake	Simulation of Convective Transport of Biomass Burning Emissions Over Brazil During TRACE-A: Effects on Tropospheric O_3 Production

SESSION XII: **GLOBAL CHANGE/ECOLOGY**
Chairs: J C Menaut, R G Zepp

9:00 A.M.	**C Li, C Lai**	The Impact of Deforestation on Eco-system Disasters in Yunnan Province, China
9:15 A.M.	**S Marshall**, R J Oglesby, J A Taylor, J W Larson, D J Erickson	Climatic Effects of Biomass Burning
Poster	**W G Egan**, A W Hogan	Carbon Dioxide, Water Vapor and Climate Change

SESSION XIII: **HISTORIC BIOMASS BURNING**
Chairs: J S Clark, J G Goldammer

9:30 A.M.	**J S Clark**	*INVITED*: What are the Spatial and Temporal Scales of Past Combustion Recorded in Sediments?
10:00 A.M.	**COFFEE BREAK**	
10:30 A.M.	**L C Ivany**, R J Salawitch	Ancient Wildfires: Biomass Burning at the Cretaceous-Tertiary Boundary
10:45 A.M.	**G H Miller**, B J Johnson	Is Persistent Drought in the Australian Outback Linked to Vegetation Change Caused by Late Pleistocene Aboriginal Burning?
Poster	J G Goldammer, P Cwielong, N Rodriquez, J Goergen	One Thousand Years of Fire History of Andino-Patagonian Forests Recovered From Sediments of the Rio Epuyén River, Chubut Province, Argentina
Poster	**K F Weiss**	Prehistoric Fire Regimes in East Africa by Lake Sediment Analysis

SESSION XIV: **KUWAIT OIL FIRES**
Chairs: P V Hobbs, W R Cofer

11:00 A.M.	**W R Cofer**, J S Levine, D R Cahoon, E L Winstead, J P Pinto, R K Stevens	Gaseous Composition of Kuwaiti Oil Fire Smoke Determined From Individual Wellfires
11:15 A.M.	**J A Herring**, R J Ferek, P V Hobbs	Heterogeneous Chemistry in the Smoke Plume From the 1991 Kuwait Oil Fires
11:30 A.M.	**I Sokolik**, F P J Valero, P Pilewskie	Spatial and Temporal Variations of the Radiative Characteristics of Airborne Smoke Clouds From the Kuwait Oil Fires
11:45 A.M.	**J A Herring**, P V Hobbs	Radiatively Driven Dynamics of the Plume From the 1991 Kuwait Oil Fires
12:00 P.M.	**LUNCH BREAK**	
1:30 P.M.	**P K Dowling**, J S Levine	The Kuwait Oil Fires and Their Regional Meteorological Impacts
1:45 P.M.	J L Ross, **R J Ferek**, P V Hobbs	Particle and Gas Emissions From an In-Situ Burn of Crude Oil on the Ocean During the Newfoundland Offshore Burn Experiment
2:00 P.M.	J L Ross, A P Waggoner, **P V Hobbs**	Lidar Measurements of a Smoke Plume Produced During the Newfoundland Offshore Burn Experiment
2:15 P.M.	**CONFERENCE ADJOURNS**	

ABSTRACTS

Monday, March 13, 1995

Morning
Session I: REMOTE SENSING OF BIOMASS BURNING
CHAIRS - D C CAHOON, J-P MALINGREAU, A W SETZER

Developing a global vegetation fire monitoring system for global change studies: current possibilities and perspectives.

Jean-Paul Malingreau and Jean-Marie Grégoire, MTV/FIRE Project, Institute for Remote Sensing Applications, Joint Research Centre, European Commission, 21020 Ispra, Italy (Fax:39-332-789830; e-mail jean-paul.malingreau%cen.jrc.it).

While concentrated in fire prone ecosystems and during specific periods of time vegetation fires occur over a large fraction of the continental land masses and throughout the year. An observing system atuned to such an ubiquitous and dynamic element of the landscape must possess highly demanding technical characteristics in terms of fire detection, geographical coverage, frequency of data acquisition and data management capabilities. The present paper reviews the current feasibility of putting together a global fire information system using a range of satellite and non-satellite data sources. A stratification approach based upon the geographical probability of occurence is described; the objective is here to permanently adjust the geographical range and period of observation and to spatially fine tune detection algorithms applied to satellite data. The detection of unexpected events is also foreseen in the proposed scenario. Preliminary tests using limited sets of global data have been performed.

An expansion of the current capabilities for global monitoring of fire in ecosystems is proposed. It is based upon on current and foreseen developments in modelling, information system technologies and satellite observation instruments. The feasibility of developing such a system in the context of global change studies is assessed.

Global Fire Mapping Using Satellite Data: an Overview

C O Justice (University of Maryland, Code 923, NASA/GSFC, Greenbelt, MD 20771; ph. 301-286-7372; fax 301-286-1775; Internet: justice@kratmos.gsfc.nasa.gov); J D Kendall (SSAI, Code 923, NASA/GSFC, Greenbelt, MD 20771; ph. 301-286-6351; fax 301-286-1775; Internet: jackie@hades.gsfc.nasa.gov); Y J Kaufman (Code 913, NASA/GSFC, Greenbelt MD 20771; ph. 301-286-4866; fax 301-286-1759; Internet: kaufman@climate.gsfc.nasa.gov)

Regional studies have shown the utility of satellite remote sensing for mapping and monitoring fire events. For example, fire data from satellites are currently being used to support modeling of trace gas and particulate emissions and transport. In addition, the data are being used to examine the inter-annual variability of fire events. High and low, spatial and temporal resolution, sensing systems provide the means to characterize different aspects of fire. A comparison of the utility and synergy of existing sensing systems for fire monitoring is presented. A recent international initiative to develop a daily global 1 kilometer AVHRR data base provides the means to generate global distributions of fire events. However, the data volumes involved present new problems in data management. A preliminary evaluation of the IGBP 1 kilometer global data set for fire monitoring is presented. Experience with existing airborne and satellite sensing systems is being used to design future fire monitoring systems and data sets. The plans for an improved fire product from the MODIS sensor, due for launch by NASA in 1998, are discussed along with the associated research and development efforts.

Documenting the Seasonal Distribution of Vegetation Fires in Eastern Africa Using DMSP and NOAA-AVHRR Satellite Imagery

B.J. Stocks (Canadian Forest Service, Sault Ste. Marie, ON, Canada. D.R. Cahoon (NASA Langley Research Center, Hampton, VA, USA), J.G. Goldammer (Max Planck Institute for Chemistry, D-55020, Mainz, Germany), R. J. Bauer (NOAA National Snow and Ice Data Center, Boulder, CO, USA)

Recent large-scale international experiments (e.g. SAFARI-92) have determined that emissions from biomass burning throughout the African continent have a significant impact on regional and global atmospheric chemistry. While ground-based measurements during the SAFARI-92 Experiment were concentrated in arid savannas in South Africa, there is a growing consensus that emissions from various forms of burning in the subhumid savannas of southern Africa may be more significant. A SAFARAI-96 Experiment, with ground-based studies in Tanzania and Zambia, is being considered to address this issue.

An understanding of the spatial and temporal distribution of fires in this region is crucial to planning future research activities. This paper analyzes the pattern of burning in eastern Africa using data from the Defense Meteorological Satellite Program (DMSP) to determine the number and location of fires, and utilizing NOAA-AVHRR data to map the areal extent of burning.

The use of Simulated AVHRR Data to Validate Fire Detection Algorithms

Peter R. Dowty (Dept. of Environmental Sciences, University of Virginia, Charlottesville VA 22903; ph. 804-982-2195; fax 804- 982-2137; Internet: prd3r@virginia.edu); Brian Stocks (Great Lakes Forestry Centre, Natural Resources Canada, 1219 Queen St East, PO box 490, Sault St Marie, Ontario P6A 5M7 Canada; ph. 705-949-9461; fax 705-759-5700)

Remote sensing of vegetation fires with AVHRR data is performed at increasingly large scales, particularly with the recent availability of global data at 1km resolution. Validation efforts have been sparse and limited in scope for all of the various algorithms used. There is a need to quantify rates of correctly identified pixels, false detections, missed fires and bias due to non-uniform sensitivity across gradients of fire types (average fire size and temperature) and environmental conditions. It is not feasible to comprehensively meet these needs solely through field validation. An alternative approach evaluates fire detection algorithms using simulated data. The simulation model is validated using relatively limited field data but across a range of fire and environmental conditions.

Such a simulation model has been developed that represents a pixel as a three-element temperature field and incorporates calculations from the MODTRAN model to represent atmospheric effects. Surface reflection of solar radiation is also included. Uncertainty in georeferencing AVHRR 1km data precludes a pixel-by-pixel comparison of simulated and actual data. Instead, validation is accomplished by inverting the model to calculate fire characteristics from actual data for comparison with ground/aerial observations. A fire from the SAFARI experiment is used as an initial validation point.

A Multi-Sensor Approach to Estimation of the Areal Extent of Biomass Burning in Southern Africa.

J D Kendall (SSAI, Code 923, NASA/GSFC, Greenbelt, MD 20771; ph. 301-286-6351; fax 301-286-1775; Internet: jackie@hades.gsfc.nasa.gov); R J Scholes (Forestek, CSIR, Box 395, Pretoria 0001, South Africa; ph. 27-12-841-2045; fax 27-12-841-2689; Internet: BScholes@forestek.csir.co.za); C O Justice (University of Maryland, Code 923, NASA/GSFC, Greenbelt, MD 20771; ph. 301-286-7372; fax 301-286-1775; Internet: justice@kratmos.gsfc.nasa.gov)

The conventional methods used to calculate regional emissions from biomass burning involve assumptions on the frequency of burning and the area burned for the various vegetation strata. At the regional scale, assumptions of homogeneity with respect to these parameters are problematic and introduce large uncertainties in the final emissions estimates. Satellite data from the NOAA Advanced Very High Resolution Radiometer (AVHRR) have been used to systematically examine fire activity in the savannas of southern Africa at the regional scale. Daily one kilometer active fire surfaces have been generated for the 1989 and 1992 burning seasons, however these do not give a direct measure of the area burned.

In order to evaluate the AVHRR fire products a detailed analysis of multi-temporal high resolution satellite data was undertaken. Measurements of burn scars in Landsat Multispectral Scanner (MSS) and Thematic Mapper (TM) data revealed that the fraction of the savanna landscape burned annually is much smaller than previously estimated. In addition, the analyses have shown that the average fire size decreases with increasing rainfall, increasing Normalized Difference Vegetation Index (NDVI), and increasing number of AVHRR derived fires. The stratified high resolution satellite data sets provided a mechanism to relate AVHRR active fires to regional area burned, which is needed for modeling fire regimes and predicting emissions from biomass burning. Given the observed relationships between fire size, vegetation index, and AVHRR fires, a calibration scheme was devised. Using this method, the mean fraction of moist and arid African savanna landscapes burned in an average year were calculated.

The Use of Multispectral NOAA/AVHRR to Determine an Improved Budget in Intertropical Africa

J.Ricardo de A. França (Departamento de Meteorologia, Universidade Federal do Rio de Janeiro, Cidade Universitária - Ilha do Fundão - CEP:21949-900 Rio de Janeiro - Brazil - Fax:+55-21-5983280 e-mail: ricardo@geo.ufrj.br)
Jacques Fontan (Laboratoire d'Aérologie URA-CNRS-354- UPS - 118, Route de Narbonne, F31062-Toulouse Cedex - France - Fax: +33-62170988)
J-M Brustet (Laboratoire d'Aérologie URA-CNRS-354- UPS - 118, Route de Narbonne, F31062-Toulouse Cedex - France - Fax: +33-62170988)

The occurrence of fire events is related to a conjunction of factors among which the climate (local weather, and general circulation), and the biodiversity characteristics are predominant. In such a way, the atmospheric effects on remote sensing of biomass burning will be also related to these parameters and to their geographical vicinity (for exemple: West Africa savannas and Sahara desert).

In order to accurately estimate the active fires distribution in function of different sorts of bioclimatic zones, the West African region, savannas (Sahel, Sudan, and Guinean), and tropical forest have been considered, which represents an important natural biodiversity. Then, we have developed a multispectral methodology based on NOAA/AVHRR satellite data, which takes into account the atmospheric interference, with the purpose of eliminating as much as possible, the problems related to large surface heterogeneity, confusion and bias produced by clouds, smoke, haze, background emissivities, etc. These problems provide signals erroneously ascribed to the presence of fires when the fire detection is made by the current methods.

The fire pixels have been classified in a GIS file for the different bioclimatic zones, in association to the NDVI and meteorological analysis. The night images (at 3 am), have given a number of fires which is considerably reduced with respect to the number detected at daytime(> 1000). The principal causes of the observed reduction are: i) a strong cloud cover over this region, ii) an effective extinction of fires by people, iii) a reduction of fire propagation as a consequence of dew deposition.

A north-south temporal evolution was observed. NDVI analysis provided an important information about the fuel moisture content as well as evolution of fuel loading conditions. The fire activity starts in september/october for the northern zones (Sahel/Sudanian), and the maximum intensity was found in december, in agreement with ground chemical measurements. In addition, a more detailed study over Ivory Coast was made taking into account the hydrographical, roads, meteorological and ecological networks using a GIS file, which will provide an important contribution to regional emission estimates.

Satellite Monitoring of Multiannual Biomass Burning Activity for the African Continent

B.Koffi , J.-M.Grégoire, P.Legeay-Janvier, and A. Tournier (all at: MTV Unit, J.R.C, Institut for Remote Sensing Applications, I-21027 Ispra (Va), Italy)

Biomass burning is a phenomenon widely spread all over the tropical regions of the globe. In Africa, around 75% of the savannah burns annually, while, in the African rain forest, episodic fires are not uncommon and are thought to be on increase. Such a phenomenon of global proportions is capable of causing large and long lasting environmental changes, such as atmospheric chemistry alterations, deforestation and climate change. A systematic documentation on global biomass burning patterns and history is therefore needed.

Global Area Coverage (GAC) data, from the Advanced Very High Resolution Radiometer (AVHRR), are known to provide a good description of fire calendar and, on a continental scale, a good indicator of the locations of intense fire activity. In fact, the GAC data, available on a daily basis back to July 1981, is the only source of information actually usable to determine burning patterns, both on a continental scale and over long periods of time. The FIRE (*Fire In global Resource and Environmental monitoring*) project of the European Commission is carrying studies to define and to understand the geographical and temporal distributions of vegetation fires in tropical regions. It is actually involved in the analysis of the 10 years (1981-90) GAC archives, to characterize the dynamics of fire activity in Africa:

- Monthly and 10-days' maps of the distribution of active fires, have already been produced, for the whole african continent, from November 1984 to October 1989, and arranged in an unique database.
- The development of a geographic and meteo-climatic information system, has allowed to make this fire related database usable for the understanding of the biomass burning patterns, in relation to different environmental issues. A first analysis of the spatio-temporal dynamics of vegetation fires in Central Africa, in relation to pluviometric zones and vegetation types, is presented.
- The understanding of vegetation fire patterns constitutes a major step towards the assessment of biomass burning implications, in global change processes. An example is given here, for the localisation of intense fire activity in the savannah, as a source of chemical contamination of precipitations, in African equatorial forests.

AVHRR Operational Detection of Fires in Brazil Since 1987 - A Summary of the Experience and Results

Alberto W. Setzer (INPE/DSR, C.P.515, S.J.Campos, SP 12201, Brazil ++55-123-418977 asetzer@ltid.inpe.br)
Evaristo M. Miranda (Embrapa/NMA, C.P.491, Campinas, SP 13001,Brazil ++55-192-525977 postmaster@nma.embrapa.br)

The Brazilian experience in the operational detection of fires during the last seven years using thermal images from the Advanced Very High resolution Radiometer (AVHRR) on-board NOAA-series satellites is summarized. The technique developed is presented showing its major advantages and limitations. Feedback from fire control users who rely on the satellite data is discussed. Temporal and frequency distribution of fires in the country is sh ed in relation to deforestation,agricultural practices and weather patterns. Results from new efforts to estimate areas burned using AVHRR in regions of savannahs are also presented and analyzed. AVHRR fire detection is also related to recent airborne fire emission sampling in the troposphere and to derived estimates of fire emissions on synoptic scale.

Brazil Fire Characterization and Burn Area Estimation Using the Airborne Infrared Disaster Assessment (AIRDAS) System

J.A. Brass (NASA-Ames Research Center, M.S. 242-4, Moffett Field, CA 94035-1000, 415-604-5232; jbrass@gaia.arc.nasa.gov)
P.J. Riggan (USDA-Forest Service, Riverside Fire Lab, 4955 Canyon Crest Drive, Riverside, CA 92507, 909-276-6516)
V.G. Ambrosia (Johnson Controls World Service, Inc., M.S. 242-4, Ames Research Center, Moffett Field, CA 94035-1000; 415-604-6565; vambrosia@gaia.arc.nasa.gov)
R.N. Lockwood (USDA-Forest Service, Riverside Fire Lab, 4955 Canyon Crest Drive, Riverside, CA 92507; 909-276-6739)
J.A.Pereira (IBAMA/PREFOGO, 70.800-200-Brasilia-DF-Brazil, 055-061-223-6105)
R.G. Higgins (SIMCO Electronics, M.S. 240-6, Ames Research Center, Moffett Field, CA 94035-1000; 415-605-4038)

Remotely sensed estimations of regional and global emissions from biomass combustion have been used to characterize fire behavior, determine fire intensity, and estimate burn area. Highly temporal, low resolution satellite data have been used to calculate estimates of fire numbers and area burned. These estimates of fire activity and burned area have differed dramatically, resulting in a wide range of predictions on the ecological and environmental impacts of fires. As part of the Brazil/United States Fire Initiative, an aircraft campaign was initiated in 1992 and continued in 1994. This multi-aircraft campaign was designed to assist in the characterization of fire activity, document fire intensity and determine area burned over prescribed , agricultural and wildland fires in the savanna and forests of central Brazil. Using a unique, multispectral scanner (AIRDAS), designed specifically for fire characterization, a variety of fires and burned areas were flown with a high spatial and high thermal resolution scanner. The system was used to measure flame front size, rate of spread, ratio of smoldering to flaming fronts and fire intensity. In addition, long transects were flown to determine the size of burned areas within the cerrado and transitional ecosystems. The authors anticipate that the fire activity and burned area estimates reported here will lead to enhanced information for precise regional trace gas prediction.

Mapping Fire Scars in the Brazilian Cerrado Using AVHRR Imagery

C.A. Hlavka (NASA-Ames Research Center, M.S. 242-4, Moffett Field, CA 94035-1000; 415-604-3328, chlavka@gaia.arc.nasa.gov)
V.G. Ambrosia (Johnson Controls World Services Inc , Ames Research Center, M.S. 242-4, Moffett Field, CA 94035-1000; 415-604-6565; vambrosia@gaia.arc.nasa.gov)
J.A. Brass (NASA-Ames Research Center, M.S. 242-4, Moffett Field, CA 94035-1000; 415-604-5232; jbrass@gaia.arc.nasa.gov)
A. Rezendez (Civil Engineering Department, Stanford University, CA 94305; 415-325-0318; rezendez@leland.stanford.edu)
S. Alexander (National Research Council, Ames Research Center, M.S. 242-4, Moffett Field, CA 94035-1000, 415-604-6031;salexander@gaia.arc.nasa.gov)
L.S. Guild (Johnson Controls World Services Inc., Ames Research Center, M.S. 242-4, Moffett Field, CA 94035-1000; 415-604-3325; lguild@gaia.arc.nasa.gov)

The Brazilian cerrado, or savanna, spans an area of 1,800,000 km² on the great plateau of Central Brazil. Large fires covering hundreds of square kilometers, frequently occur in wildland areas of the cerrado, dominated by grasslands or grasslands mixed with shrubs and small trees, and also within areas in the cerrado used for agricultural purposes, particularly for grazing. Smaller fires, typically extending over areas of a few square kilometers or less, are associated with the clearing of crops, such as dry land rice. A method for mapping fire scars and differentiating them from extensive areas of bare soil with AVHRR bands 1 (.55 - .68μm) and 3 (3.5 - 3.9μm) and measures of performance based on comparison with maps of fires with Landsat imagery will be presented. Methods of estimating total area burned from the AVHRR fire scar map will be discussed and related to land use and scar size.

Monitoring Biomass Burning With the Next Generation of Geostationary Satellites

E. M. Prins (Cooperative Institute for Meteorological Satellite Studies, 1225 West Dayton St., Madison, WI 53706; elainep@ssec.wisc.edu)
W. P. Menzel (NOAA National Environmental Satellite Data and Information Service, 1225 West Dayton St., Madison, WI 53706; paulm@ssec.wisc.edu)

With the launch of GOES-8 in March 1994, a new capability for monitoring diurnal biomass burning activities in North and South America was introduced. The higher spatial resolution, greater radiometric sensitivity and improved navigation offer many advantages over GOES-7. The 1994 biomass burning season in South America and the United States provided many opportunities for the GOES-8 imager to detect fires and track smoke/aerosol transport regimes.

Although the GOES-8 was not yet operational during the 1994 burning season, several sample data sets were obtained in North and South America. These data sets are being used to develop the GOES-8 Automated Biomass Burning Algorithm (ABBA) which will be operational for the 1995 burning season. In South America, smoke palls were observed similar to those seen in August and September of 1988; they extended throughout the Amazon Basin and south into Bolivia, Paraguay, Uruguay, and Argentina. As in previous years, most of the burning occurred along the perimeter of the Amazon Basin and throughout the cerrado regions of southern Brazil and Bolivia. The diurnal signature was clearly evident with maximum burning occurring between 1500 and 1800 UTC. Comparisons with GOES-7 imagery reveal much more detail in the GOES-8 imagery, including surface features and individual fire activity. Throughout the wildfire season in North America only the largest fires were evident in GOES-7 imagery. Fires which displayed a strong brightness temperature signal in relation to the non-fire background temperatures in the GOES-8 data often showed no elevated signal in the GOES-7 data. For the first time it is possible to monitor diurnal variability in wildfire activity in North America.

Investigation of Biomass Burning and Aerosol Loading and Transport in South America Utilizing Geostationary Satellite Data

E. M. Prins (Cooperative Institute for Meteorological Satellite Studies, 1225 West Dayton St., Madison, WI 53706; elainep@ssec.wisc.edu)
W. P. Menzel (NOAA National Environmental Satellite Data and Information Service, 1225 West Dayton St., Madison, WI 53706; paulm@ssec.wisc.edu)

Recent modeling and analysis efforts have suggested that the direct and indirect radiative effects of aerosols from biomass burning may play a major role in the radiative balance of the earth and are an important factor in climate change calculations. One of the most active regions of burning is located in South America associated with deforestation in the selva (forest) and agricultural burning in the cerrado (grassland) regions of Brazil, Bolivia and Paraguay. The GOES VAS series of satellites which has been operational since 1981 and the next generation GOES-8 launched in the spring of 1994 offer the unique opportunity to monitor biomass burning activities and associated aerosol loading and transport in South America.

Currently the GOES Automated Biomass Burning Algorithm (ABBA) provides information concerning the location, temperature, and size of fires. An automated GOES multispectral thresholding algorithm is being developed to also catalogue the extent and transport of aerosols associated with biomass burning. GOES visible and infrared data at 3.9, 11.2 and

12.7 μm are used to distinguish smoke/haze associated with biomass burning from other multi-level clouds and low level moisture. The visible, 3.9 and 11.2 μm bands distinguish haze from clouds while the 11.2 and 12.7 μm bands distinguish haze from low level moisture. Furthermore, the temporal resolution of GOES data makes it possible to determine the prevailing circulation and transport of aerosols in South America in half-hourly visible and infrared images by tracking the motion of smoke, haze, and adjacent clouds. A preliminary analysis of GOES satellite imagery over South America during the dry seasons of 1983, 1988, 1989, 1991, and 1994 revealed numerous examples of aerosol transport associated with biomass burning in the selva and cerrado. Three major transport regimes were identified with smoke palls extending thousands of kilometers from the emission sources.

Biomass Burning in Western Europe in 1987

P Le Canut (Atmospheric Science Program, College of William and Mary, Williamsburg, VA 23185)
J S Levine and D R Cahoon Jr (Both at: NASA Langley Research Center, Atmospheric Sciences Division, VA 23681-0001)

In 1987, biomass burning around the world turned out to be more important than usual due to several very large fires in China and the former Soviet Union and an ever increasing worldwide deforestation. Nevertheless, this was not the case in Western Europe which experienced a below average year in terms of forest fires. Although trace gas emissions due to forest fires in western Europe are on average negligible compared to those around the world (<1%) and compared to the industrial emissions (1%) in this part of the world, their spatial and temporal distribution patterns are typical and related to the weather conditions. Each year, most of the burning (90%) occurs in four countries around the Mediterranean basin (Spain, Portugal, Italy, and Greece).

The regional spatial distribution with a better resolution than the country-scale, provided in the first part of this paper, can be obtained on a low cost basis with a regional remote sensing instrument like the Advanced Very High Resolution Radiometer (AVHRR) aboard the National Oceanographic and Atmospheric Administration satellite (NOAA-9). We describe here the method and the limitations of remote sensing forest fire scars in western Europe from space with the AVHRR sensor. An example of the processing is carried out on southern France. Our results suggest that this method can only provide a rough estimation of the spatial distribution of biomass burning in western Europe on a 1×1 degree scale. A much better precision could be obtained with an Earth resources satellite but at a much higher cost. Nevertheless, we do not consider this latter solution as appropriate for this particular case because biomass burning in western Europe accounts for such a small part of the total worldwide burning.

Monitoring the 1992 Forest Fires in the Boreal Ecosystem Using NOAA AVHRR Satellite Imagery

D R Cahoon, Jr. (NASA Langley Research Center, Atmospheric Sciences Division, Hampton, VA 23681-0001, USA, 804-864-5615)
B J Stocks (Canadian Forest Service, Ontario, Canada P6A 5M7)
J S Levine and W R Cofer, III (Both at: NASA Langley Research Center, Atmospheric Sciences Division, Hampton, VA 23681-0001)
J A Barber (Lockheed Engineering and Sciences Corporation, Hampton, VA 23666)

Forest fires are an integral part of the natural forces that shape the composition and evolution of the boreal forest. These fires, often very intense, commonly grow to sizes large enough for satellite monitoring using the National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) instrument. The AVHRR instrument produces 1-km resolution (at nadir) satellite imagery which has been used to monitor boreal forest fires throughout the 1992 forest fire season. The spatial distribution of the forest fires and an estimate of the total area effected by fire will be presented. The errors in the area estimate will be discussed. Comparison will be made with the 1987 fire season and the trace gas emissions to the atmosphere from all of the boreal fires in the 1992 fire season will be will be reported.

Monitoring Large-Scale Forest Fire Behavior in Northeastern Siberia Using NOAA-AVHRR Satellite Imagery

B.J. Stocks (Canadian Forest Service, Sault Ste. Marie, ON, Canada), D.R. Cahoon, W.R. Cofer III, and J.S. Levine (NASA Langley Research Center, Hampton, VA, USA)

Forest fires are the major disturbance regime in the world's boreal forests, burning from 5-10 million hectares annually in this biome, primarily in northern Canada and Siberia. Russian fire statistics have been unreliable and incomplete, particularly in remote regions of Siberia, where extreme fire weather ensures that large areas burn annually. In recent years satellite imagery has been increasingly used to determine the extent and geographical distribution of large boreal fires in Russia.

This paper deals with a severe fire situation in northeastern Siberia during the summer of 1991. A series of NOAA-AVHRR satellite images were used to track the development of numerous large fires in the vicinity of the Kolyma River over a two week period. Weather data from nearby meteorological stations was used, along with the Canadian Forest Fire Danger Rating System, to determine forest fire danger levels during this period, confirming that the extreme fire behavior observed was due to weather condition in that vicinity.

Investigating Landscape Disturbance Patterns and Associated Vegetation Succession in the Boreal Forest with Multitemporal 1-Km AVHRR Data

L T Steyaert[1], F G Hall[2], B C Reed[3], D E Knapp[2], T R Loveland[3], P J Sellers[2], and R A Pielke[4]

[1]U.S. Geological Survey, 521 National Center, Reston, VA 22092; 703-648-4515; FAX: 703-648-5542; lsteyaer@resdgs1.er.usgs.gov; [2]NASA/Goddard Space Flight Center, Code 923, Greenbelt, MD; 20771; [3]EROS Data Center, U.S. Geological Survey, Sioux Falls, SD 57198; [4]Colorado State Univ., Dept. of Atmos. Science, Fort Collins, CO 80523

A land cover classification based on multitemporal 1-km AVHRR data was used to characterize fire disturbance and subsequent vegetation succession patterns over a 1,000,000-km2 region within the boreal forest of central Canada. The study was part of the Boreal Ecosystem-Atmosphere Study (BOREAS). Monthly NDVI image composites (April-September 1992) of the BOREAS region were used in an unsupervised image cluster analysis algorithm to develop an initial set of seasonal land cover classes. Extensive ground data with GPS georeferencing, observations from selective low-level aerial flights over remote areas, and selected Landsat thematic mapper (TM) image composites (bands 5, 4, 3) for the 100-km by 100-km northern and southern study areas in the BOREAS region were analyzed to split, aggregate, and label the spectral-temporal clusters throughout the BOREAS region. The AVHRR classification was compared with Landsat TM land cover classifications for the BOREAS study areas. Both the TM and the 1-km AVHRR land cover classes were grouped to represent parametrically homogeneous classes used in regional-scale carbon, water,

and energy models. The classes were mixed vegetation mosaics, including wetland conifer, dry conifer, mixed deciduous and conifer, vegetation regeneration, and recent burns, as well as water classes. The AVHRR classes generally depict the decreases in tree size and stand density levels from south to north due to the effects of colder temperatures and decreasing growing degree day totals. Especially in the Canadian Shield Zone where fire suppression is minimal, the land cover classification shows a heterogeneous landscape characterized predominately by coniferous forest that is randomly broken by mixed forest vegetation patches of variable sizes from one to thousands of hectares. These patches (23 percent of total area) appear to be associated with fire and subsequent regenerating vegetation. These preliminary results suggest the potential for using multitemporal 1-km AVHRR to characterize the spatial distribution of forest fires and the associated forest successional patterns of regenerating vegetation over large regions. However, field observations, fire history records, and Landsat analysis are key data requirements for developing and validating this type of AVHRR land cover classification.

Estimating Carbon Storage and Release in a Fire-Disturbed Boreal Forest Using Multi-Sensor Satellite Data

E.S. Kasischke, P. Camille (School of the Environment, Duke University, P.O. Box 90328, Durham, NC 27708-0238; (919) 613-8039; email erick@env.duke.edu)
N.H. French, L.L. Bourgeau-Chavez (Center for Earth Sciences, Environmental Research Institute of Michigan, Ann Arbor, MI 48113-4001; (313) 994-1200; email french@erim.org)
H.H. Shugart (Environmental Sciences Department, University of Virginia, Charlottesville, VA 22903; (804) 924-7642; email HHS@virginia.edu)

The land surface encompassed by the world's boreal forests is one of the largest reservoirs of terrestrial-stored carbon; estimates range between 30% and 40%. Fire is a major disturbance regime in this biome, and is also a major factor in the exchange of carbon between biotic components and the atmosphere. The occurrence of fire in boreal forests is extensive, and individual events typically cover large areas, with fires between 1,000 and > 1,000,000 ha in size accounting for >98% of all area burned. The effects of large fires can easily be discriminated on a variety of satellite remote sensing system. Studies are underway to compare field data of surface characteristics in a fire-disturbed spruce forest in east-central Alaska to a variety of satellite data collected over this region. It has been shown that remote sensing data collected in different regions of the EM spectrum can be used to estimate different surface characteristics related to the effects of the fire. In this paper, we will discuss how satellite-derived surface parameters can be used to study patterns of carbon storage and release in fire-disturbed spruce forests. Three different aspects of the carbon cycle are being studied using multi-sensor satellite data: (1) the amount of carbon released during into the atmosphere via biomass burning during the fire event; (2) carbon flux rates after the fire due to aerobic (CO_2) and anaerobic (CH_4) decomposition; and (3) patterns of carbon storage in aboveground biomass during secondary succession.

Algorithm for the Retrieval of Fire Pixels From DMSP Operational Line Scanner Data

C.D. Elvidge (Solar and Terrestrial Physics Division, NOAA National Geophysical Data Center, Boulder, CO 80301; 303-497-6121; email: cde@ngdc.noaa.gov)
H.K. Kroehl (Solar and Terrestrial Physics Division, NOAA National Geophysical Data Center, Boulder, CO 80301; 303-497-6323; email: hwk@ngdc.noaa.gov
E.A. Kihn (Solar and Terrestrial Physics Division, NOAA National Geophysical Data Center, Boulder, CO 80301; 303-497-6121; email: eak@ngdc.noaa.gov)
K. E. Baugh (Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, CO 80309; 303-497-6945; email: kbaugh@ngdc.noaa.gov)
E. R. Davis (Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, CO 80309; 303-497-6945; email: edavis@ngdc.noaa.gov)

A system for the nightly inventory of active fires using data from the Defense Meteorological Satellite Program (DMSP) Operational Line Scanner (OLS) has been developed with sponsorship from the Strategic Environmental Research and Development Program (SERDP). The OLS sensor was designed for meteorological applications and has two broad spectral bands (VIS and TIR) covering the visible/NIR (0.4 to 1.1 um) and thermal infrared (10-13 um) regions. Light intensification of the VIS band at night makes it possible to detect surface emissions from active fires, city light and industrial facilities. A box filter is used to retrieve bright pixels relative to the local background, which are geolocated and placed in a reference grid. Fire pixels are then identified using a series of cascading steps, each of which removes a given set of extraneous features: 1) a land surface mask is applied to discard light sources on water, 2) a cloud mask is applied to eliminate pixels of heavy cloud cover (fires can be observed through thin cloud cover), 3) a city light mask is applied to remove permanent sources of light. Results from preliminary tests of the algorithm will be presented for the western U.S.A., Africa, and Brazil.

Airborne and Spaceborne Lidar Observations of Biomass Burning Plumes Over Africa and South America

E V Browell (Atmospheric Sciences Division, Mail Stop 401A, NASA Langley Research Center, Hampton, VA 23681; 804-864-1273; E-Mail: e.v.browell@larc.nasa.gov)
M P McCormick (NASA LaRC, Hampton, VA)
C F Butler, M A Fenn, and G D Nowicki (SAIC, Hampton, VA)
W B Grant, and S Ismail (NASA LaRC, Hampton, VA)

Airborne lidar measurements of aerosol and ozone (O_3) profiles have been made across plumes from biomass burning regions during the NASA Global Tropospheric Experiment - TRACE-A (TRansport and Atmospheric Chemistry near the Equator - Atlantic) conducted in September-October 1992 over Brazil, southern Africa, and the tropical Atlantic. Ozone profiles were obtained using the differential absorption lidar (DIAL) technique in the ultraviolet, and aerosol backscatter profiles were measured simultaneously at 300, 600, and 1064 nm. The lidar system was operated simultaneously below and above the NASA DC-8 aircraft to provide measurements from near the surface to above the tropopause. Plumes from extensive fires in Brazil were observed near their source and in outflow regions over the Atlantic. Gases were transported by convective storms into the upper troposphere where O_3 was photochemically produced and advected eastward over the Atlantic. In central Africa, the fires were widespread, and in the absence of convective storms, the fire plumes were advected westward at low altitudes (below ~6 km) over the Atlantic. A positive correlation was found between O_3 and aerosols in plumes that were not involved in convection.

Spaceborne lidar observations of biomass burning plumes were obtained by the LITE (Lidar In-space Technology Experiment) system during the Shuttle STS-64 mission in September 1994. The LITE system was the first lidar flown in space for measurements of aerosols and clouds. Lidar measurements were made simultaneously at 355, 532, and 1064 nm, and global distributions of aerosols and clouds were obtained in 53 hours of operation during the 11-day mission. The spatial distribution of plumes from extensive biomass burning regions in Africa and South America were observed

on several Shuttle overpasses. This paper discusses the biomass burning plume characteristics observed during the LITE mission and compares these measurements to the TRACE-A results.

On the Measurement of Aboveground Biomass Burning Using Imaging Radars

E R Rignot (Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109-8099; Ph. 818-354-1640; Fax 818-393-6943;#Internet: eric@adelie.jpl.nasa.gov)

Radar backscatter at the longer wavelengths is positively correlated with total aboveground woody biomass up to a biomass level of 20 kg/m2 at 68-cm wavelength. Cross-polarization radar returns are dominated by volume scattering from the tree branches, and provide information on crown biomass (foliage + branches), the burning fuels of the forest. Like-polarized radar returns are eventually dominated by ground-trunk coherent scattering and provide information on trunk biomass. Shorter wavelengths are more useful for measuring low biomass levels (grassland and shrubland) and detecting biomass changes in the upper canopy, e.g. consecutive to forest wildfires. Examples from various types of forests (boreal, temperate and tropical) are discussed. In areas of intense ground sampling, the results show that predicted total aboveground biomass levels from the radar are within 20 to 30 percent of the biomass values obtained from forest inventory, depending on the degree of complexity of the forest. In peruvian tropical rain forests, radar data separate major types of vegetation and provide reasonable estimates of forest biomass, confirming that the biomass of tropical forests has long been overestimated. In the case of the Yellowstone National Park, affected by major fires in 1988, no change in total aboveground biomass is detected - as indeed tree-trunks are still standing in burned areas - but crown biomass is strongly modulated by fire severity. The first spaceborne polarimetric radar images of the Park gathered in October 1994 by the SIR-C/X-SAR Experiment onboard the space shuttle Endeavour also demonstrate that imaging radars can detect forest regrowth from space in natural forest ecosystem, six years after a fire. To conclude, imaging radars offer a unique potential for monitoring biomass burning and the release of carbon into the atmosphere, as well as forest regrowth and the uptake of carbon from the atmosphere in the 20 years following a perturbance. A large number of existing radar images is now available to the research community. In addition, future radar coverage of other areas, e.g. using the three-frequency NASA/JPL polarimetric radar imager, can always be requested by interested users.

A Investigation of the Hydrologic Cycle in the Amazon Using Remotely Sensed Variables

T L DeLiberty (Department of Geography, University of Delaware, Newark, DE 19716; 302-831-2294
W P Menzel (NOAA National Environmental Satellite Data and Information Service, 1225 West Dayton St., Madison, WI 53706; paulm@ssec.wisc.edu)
E M Prins (Cooperative Institute for Meteorological Satellite Studies, 1225 West Dayton St., Madison, WI 53706; elainep@ssec.wisc.edu)

The hydrologic cycle in the Amazon Basin is investigated using data from a variety of sources to determine the spatial and temporal variability of the moisture budget and examine differences in forested versus deforested areas. Initially, the study is concentrating on two months, June and October in 1988 associated with the months prior to and following the biomass burning season documented in the Amazon. Since the majority of the research area is located in a data sparse region, the analysis is integrating datasets from a variety of unconventional sources to augment the existing surface and upper air data network including satellite data, surface meteorological observations, model variables and land surface information. Satellite derived variables of rainfall rates, total precipitable water, and land surface temperature changes are calculated from the GOES VAS data, while the vegetation state is characterized from the NOAA AVHRR NDVI. Conventional data (e.g., raingage and hydrologic data) is used to verify and supplement satellite derived parameters. The goal of this research is to provide a regional view of the moisture budget in the Amazon and characterize the effects of biomass burning and deforestation activities on the hydrologic cycle.

Survey of Fires in Southeast Asia and India During 1987

C.D. Elvidge (Solar and Terrestrial Physics Division, NOAA National Geophysical Data Center, Boulder, CO 80301; 303-497-6121; email: cde@ngdc.noaa.gov)

A survey of fires has been conducted for Southeast Asia and India for the year 1987 as part of the IGBP-IGAC Global Emission Inventory Activity (GEIA). The survey was conducted using nighttime analog images from the Defense Meteorological Satellite Program (DMSP) Operational Line Scanner (OLS) archives held by the University of Colorado. The OLS sensor was designed for meteorological applications and has two broad spectral bands (VIS and TIR) covering the visible/NIR (0.4 to 1.1 um) and thermal infrared (10-13 um) regions. Light intensification of the VIS band at night makes it possible to detect surface emissions from active fires, city light and industrial facilities. As the initial step in the survey, all of the available nighttime images of the region were visually examined. VIS and TIR which showed evidence of biomass burning and low cloud cover images of the same areas without burning were made into black and white prints from the analog film strips. The prints of images exhibiting fires were digitized using a flat bed scanner and the resulting images were georeferenced using a combination of coastlines and city lights. Using the non-fire images and an atlas for guidance, city lights and industrial lights were deleted from the digitized imagery, along with lighting and glare features. Then remaining lights are interpreted as fires. The results are summarized as a georeferenced grid showing the locations and frequency of OLS fire observations during 1987.

Vegetation Fires from Space: The use of the Earth Observation System in The Space Shuttle Program for Research and Documentation of Global Vegetation Fires: A Case Study from Madagascar

J G Goldammer (Max Planck Institute for Chemistry, Biogeochemistry Department, Fire Ecology and Biomass Burning Research Group, D-55020 Mainz, Germany)
M R Helfert (NASA Johnson Research Center, Code SN5, USA-Houston, Tx 77058)
J L Pfund (c/o Projet FNS ECO/BEF, Antananarivo, Madagascar)
(Sponsor: M O Andreae #000 930 274)

During the STS-60/61/62 Space Shuttle missions between December 1993 and April 1994 major emphasis was put on documentation of fires from space. Simultaneous ground-based observations and subsequent investigation of documented fires provide examples of the advantages and limitations of the Earth Observation System for fire research purposes. A case study from Madagascar shows that space photography may visualize phenomena which cannot be described by conventional ground, aerial and satellite sensors.

Sub-Pixel Source Detection and Area Estimation Algorithms Applied to DMSP Operational Linescan System (OLS) Imagery

E A Kihn (Solar-Terrestrial Physics Division, NOAA, National Geophysical Data Center, Boulder, CO 80303; tel. 303-497-6346; e-mail eak@ngdc.noaa.gov. Sponsor: H W Kroehl

Models of greenhouse gas emissions from biomass burning require fire location and burn area. Ground truth

estimates of burn area indicate that the OLS instrument is sensitive to subpixel sources at higher temperatures. OLS instruments measure visible/near- infrared (VNIR)=(.4 - 1.1 mm) and thermal infrared (TIR)=(10-13 mm) radiances .

Accurate burn area estimation is a key step in the modeling of greenhouse emmision. Thermal infrared temperatures observed by OLS are used to compute sub-pixel areas for fires thoughout the western United States, which are compared with US Forest Service estimates and presented.

Theoretical limits on sub-pixel fire detection for both the VNIR and TIR bands are established. These results are then compared with data from the Forest Service covering sub-pixel size fires occuring during fire season 1994.

This ground truth experiment is a precursor to a global inventory of biomass burning being undertaken by NGDC with support from SERDP.

Airborne High Resolution Infrared Spectroscopy of Western Wildfires

H M Worden and R Beer (Both at Jet Propulsion Laboratory, Pasadena, CA 91109; 818-354-0532)
C P Rinsland (NASA Langley RC, Hampton VA 23681)

In August 1994 the Airborne Emission Spectrometer was used to obtain high resolution (0.07 cm^{-1}) infrared spectra of a forest fire in northern Oregon and a brushfire in central California (San Luis Obispo) from the NASA DC8 aircraft flying at an altitude of 11 km.

Both measurement series were opportunistic. Therefore, the instrument and experimental plan were not optimized for these observations. However, we have been able to derive flame temperature, smoke/gas plume temperature, wind speed, wind direction and column densities for CO, CO_2, H_2O and NH_3. Other species are being sought but there are a number of unidentified features in the spectra that have so far defied interpretation.

Using these data and similar future observations (preferably with ground truth and/or correlative measurements), we hope to develop a retrieval method that will be applicable to space-based remote sensing of biomass burning episodes.

Monday, March 13, 1995

Afternoon/Evening Session II: GASEOUS EMISSIONS
CHAIRS - M O ANDREAE, W R COFER, R A DELMAS

Emissions of trace gases and aerosols from fires in the savannas of Southern Africa and their impact on the atmospheric environment

Meinrat O. Andreae and the SAFARI/SA'ARI Science Team

In the framework of the International Geosphere-Biosphere Programme/International Global Atmospheric Chemistry Project/Biomass Burning Experiment (IGBP/IGAC/BIBEX), an international research team from 14 countries investigated the impact of biomass burning on atmospheric chemistry over Southern Africa and the surrounding ocean areas. Emission measurements (airborne and ground-based) focused on the study of savanna fires, but also included sugar cane burning and forest fires. Regional-scale atmospheric composition was studied during airborne surveys spanning the region from Zambia to the Namibian Coast to Natal province. The first experiment, SAFARI-92 (Southern African Fire/Atmosphere Research Initiative 92), took place during the 1992 fire season (August-October 1992). The second experiment (SA'ARI-94 - "SAFARI without the Fire") coincided with the end of the wet season (May 1994), when only relatively few fires were present in the savannas.

During SAFARI-92, emission ratios and emission factors were obtained for many trace gases (CO_2, CO, CH_4, non-methane hydrocarbons, NO, NO_2, NH_3, N_2O, halogenated hydrocarbons, H_2, etc.) and particulate species (organic and elemental carbon, soluble ionic species, trace metals, etc.). Pyrogenic emissions were found to have a pronounced impact on the regional atmosphere during the fire season, with levels of atmospheric oxidants (especially ozone) and particulate matter resembling those in industrialized regions of the Northern Hemisphere. Significant levels of pollutants from biomass fires were found even during the SA'ARI-94 campaign in May, when the incidence of fires is relatively low. Detailed analysis of this data set is under way in order to deconvolute the influence of emissions from fossil fuel burning and biomass fires in the region. Transport of these materials to the surrounding ocean areas and beyond must be expected to result in an impact on atmospheric composition on a subhemispheric scale.

Hydrocarbon and Halocarbon Emissions During Biomass Burning

F. Sherwood Rowland, (Department of Chemistry, University of California, Irvine, CA 92717-2025; 714 824 6024; FAX 714 824 2905)

Atmospheric samples have been collected in two-liter canisters from the NASA Electra operating in northern Canada in summer 1990, from the NASA DC-8 aircraft operating in both Brazil and southern Africa during the September and October months of 1992 (TRACE-A), and with the NCAR King Air in the same months in both 1992 and 1994. The collection times coincided generally with the forest fire season in Canada, and with the biomass burning seasons in both Africa and South America. Numerous plumes were intercepted in each location. The gas chromatographic analytical system employed multi-column analysis, utilizing electron capture detection for the assay of halocarbons and flame ionization detection for hydrocarbons. The system underwent continual improvement over this period, but has provided measurements for 30 to 50 different hydrocarbons with sensitivities but mostly much less than 1 pptv. Unusually high hydrocarbon mixing ratios for the southern hemisphere (e.g. in ppbv, C_2H_6 above 1.0; C_2H_2 to 0.4) were also sometimes observed at DC-8 flight altitudes ever both continents and the South Atlantic, attributable to biomass burning. Within the plumes themselves, mixing ratios were observed from the Electra and DC-8 as high as (ppbv): C_2H_6, 15; C_2H_4, 21; C_2H_2, 8; 1,3 butadiene, 1; CH_3Cl, 1.3; the levels found with the King Air much closer to the actual fires were a factor of 10 higher. Emission factors relative to CO have been calculated for these locations for as many as 50 different compounds. Methyl chloride and methyl bromide have been observed in both African and South American plumes, and biomass burning probably accounts for 1/3 of the methyl bromide observed in the atmosphere. No evidence has been found for elevated quantities of chlorofluocarbon compounds in biomass burning plumes in any of these locations.

Characterization of Organic Compounds in Biomass Burning Plumes During SAFARI '93.

E Atlas and W Pollock (Both at: Atmospheric Chemistry Division, National Center for Atmospheric Research, Boulder, CO 80303; 303-497-1425; email: atlas@acd.ucar.edu);A deKock (PETCRU, Port Elizabeth, South Africa; email: adekock@ml.petech.ac.za)

Biomass burning emissions can contain a wide variety of organic trace gases with potential impact on regional and global atmospheric chemical processes. However, there have been few detailed studies of the

composition of naturally occurring fires from different ecosystems. As part of the SAFARI '93 campaign, samples were collected in stainless steel canisters and on charcoal cartridges for the identification and measurement of organic compounds associated with burning. Quantitative data were obtained using GC/MS with selected ion monitoring for a range of halogenated hydrocarbons and some sulfur species. Ratios of different emissions to CO and CO2 were calculated to estimate global impact of emission from savanna fires. Enhanced levels of methyl halides, chloroform, and OCS were observed in biomass burning plumes, while other halogenated species remained unaffected.

Full-scan GC/MS revealed the presence of a wide variety of organic compounds. Among the major species identified in the canister samples were mono-aromatic hydrocarbons, unsaturated hydrocarbons, and oxygenated hydrocarbons including aliphatic and aromatic carbonyl compounds and furans. Solvent extracts of the charcoal cartridges showed the presence of relatively large amounts of aliphatic acids and phenolic compounds which are apparently lost in the stainless canisters. These data indicate that multiple sampling strategies need to be employed to fully characterize organic emissions associated with biomass burning.

Emissions From the Combustion of Biofuels in the African Tropics

D Brocard C Lacaux and J P Lacaux (Laboratoire d'Aérologie, Université Paul Sabatier, 31062 Toulouse Cedex, France)
G Kouadio V Yoboué and M Assa Achy (Université d' Abidjan, Abidjan, FAST, Côte d'Ivoire)
B Ahoua and M Koffi (INSET, Yamoussoukro,Côte d'Ivoire)

Wood is the main source of domestic energy in Africa. Due to increasing demand and to urban growth, wood is more and more transformed into charcoal. More than 90 % of the African households use biofuels in the form of wood or charcoal for their domestic needs.

The yearly consumption of wood, in western Africa is estimated, from various data bases, to 117 Tg and the yearly consumption of charcoal to 3 Tg (11 Tg of wood with a carbonization rate of 28 %).

To estimate the atmospheric pollution caused by the use of wood as fuel, firewood and charcoal burning as well as wood carbonization for charcoal making were experimentally studied. For these three types of combustion, the production of carbon counpounds (CO_2, CO, CH_4, NMHC, organic acids) were quantified by determining, their emission ratio ($\Delta X/\Delta CO_2$), the different parameters of the combustion being controlled.

The CO/CO_2 ratio obtained, confirm that the processes involved in these three combustions are different: firewood is mostly flaming combustion ($\Delta CO/\Delta CO_2$ of the order of 5.7%) while charcoal making is basically smoldering combustion ($\Delta CO/\Delta CO_2$ of the order of 23%). For charcoal burning, $\Delta CO/\Delta CO_2$ is of the order of 16%.

From these emission ratios a set of emission factors is proposed. Combined with the estimate of burned biomasses, this shows that biofuel burning is a significant source of pollutants, compared with savannas fires.

Emission of Medium Molecular Weight Organic Trace Gases From Savanna Fires in Southern Africa

R Koppmann, A Khedim and J Rudolph (All at: Institut. für Atmosphärische Chemie, KFA Forschungszentrum Jülich, 52425 Jülich, Germany, +49-2461-615118, E-Mail: R.Koppmann@KFA-Juelich.de)
G Helas and M Welling (Both at: Max-Planck-Institute für Chemie, 55020 Mainz, Germany)

During the SAFARI 92 campaign in September/October 1992 about 180 whole air samples were collected inside and in the vicinity of the plumes of prescribed as well as uncontrolled savanna fires in South Africa. About 30 grab samples were collected in 6 dm^3 stainless steel canisters on board of a Cessna aicraft flying at low altitudes, 150 samples were pressurized in 2 dm^3 stainless steel canisters on board of a DC3 aircraft operating between 50 m and 4000 m altitude. In addition to CO, CO_2, CH_4 the samples were analysed in the laboratory for organic trace gases by FID/ECD gas chromatography and gas chromatography/mass spectrometry.
In the plume samples up to 150 different compounds could be identified by GC/MS. Besides alkanes and alkenes, ethers, esters, aldehydes, furanes and a variety of aromatic compounds could be found. While the mixing ratios of the sum of $>C_5$ organic trace gases outside the plumes varied between 2 and 6 ppbC, the mixing ratios in the plumes ranged from 40 ppbC up to 200 ppbC. The emission ratios of these compounds relative to CO_2 ranged from 0.01 % for the prescribed burnings to 0.6 % for the small uncontrolled fires. These emission ratios sometimes exceed those of light NMHC. Depending on the type of fire and the combustion processes the medium molecular weight organic trace gases may contribute as much as light nonmethane hydrocarbons to the emission of volatile organic carbon from biomass burning and thus may be very important for the photochemistry in the Southern Hemisphere.

NO_x Emissions From African Savanna Burning

J P Lacaux and R Delmas (Laboratoire d'Aérologie, UPS, 118 route de Narbonne, 31062 Toulouse, France)

The simultaneous measurements of the concentrations of CO, CO_2 and NO_x in the plumes of prescribed savanna fires during the FOS/DECAFE 91 and SAFARI 92 experiments, enabled the determination of the characteristics of the type of combustion and NO_x emissions of the African savannas.

These 2 experiments took place in 2 types of savanna having very different ecological properties: that of Lamto (FOS/DECAFE) in the guinean area is wet (80% water), dense (8 to 9 $T.ha^{-1}$) and has no litter (2% in mass), that of the Kruger park (SAFARI 92), on the contrary, is dry (10 to 20% water), has a low biomass (2 to 4 $T.ha^{-1}$) but 40% of its mass in the form of litter).

The mean carbon content of the 2 savannas is of the same order of magnitude (~43%). The nitrogen content of the 2 savannas can vary in a ratio of 2 to 3 (N = 0.3% in Lamto for 0.57 (0.14%) at the Kruger park), which implies different emission factors for the nitrogen compounds (NO_x, N_2O, NH_3...). The emission ratio $\Delta NO_x/\Delta CO_2$ and the nitrogen content of the plant are linearily linked ($\Delta NO_x/\Delta CO_2 = 0.66$ N% - 0.1) with a linear correlation coefficient of 0.93, which is statistically significant at better than the 99% confidence level. This important result enables the quantification of the emissions of NO_x from African savanna burning by measuring the nitrogen content of the plants and controlling the type of burning.

Tuesday, March 14, 1995

Morning
Session II: GASEOUS EMISSIONS - CONTINUES

Pyrogenic Emission and Regional Distribution of Trace Gases and Aerosols Over Southern Africa During SAFARI-92

P Le Canut, M O Andreae, G W Harris, F G Wienhold and T Zenker (All at: Max Planck Institute for Chemistry, D-55020 Mainz, Germany)

During the SAFARI-92 experiment (Southern Africa Fire/Atmosphere Research Initiative, September-October 1992), we flew an instrumented DC3 over southern Africa to study biomass burning emissions and atmospheric concentrations of trace gases and aerosols during the fire season. We discuss here the vertical distributions of several trace gases (CO, CO_2, and O_3), the absolute loadings of aerosols and their size distributions, as well as particle emission ratios relative to CO, and CO_2. Over 20 vertical soundings were carried out over the sub-continent. The lower troposphere almost always contained several layers with elevated concentrations of aerosols and trace gases. All the trace gas and aerosol concentrations decreased toward the end of the expedition, coinciding with the end of the fire season (from 3000 to 500 cm^{-3} for the aerosols with an average of 1000±500 cm^{-3}, from 200 to 80 ppb CO with an average of 130±40 ppb, from 360 to 353 ppm CO_2 with an average of 357±2 ppm, and from 70 to 40 ppb O_3 with an average of 60±13 ppb). High correlations between the aerosol concentrations and the trace gas mixing ratios enabled us to estimate the following average emission ratios: 10±4 cm^{-3} ppb^{-1} for $\Delta N/\Delta CO$ (Δ, concentrations in plume minus background concentrations), and 230±315 cm^{-3} ppm^{-1} for $\Delta N/\Delta CO_2$. The ozone production ratio, $\Delta O3/\Delta CO$, varied between a few hundredths, characteristic of very fresh smoke, to more than one, which is characteristic of aged layers with high initial $\Delta NO_x/\Delta NMHC$ ratios. Aerosol size distributions also varied from layer to layer, depending upon how long the layer had already aged. Back trajectories were used to estimate the origin and evolution of the air masses encountered. Our results on trace gas and particle concentrations, size distributions, and back trajectories support the concept of recirculation of air over southern Africa as an important determinant of airmass characteristics in the region.

Relationships between Biomass Burning Emissions and Photochemical Tracers over Source Regions and the Tropical South Atlantic - analysis of TRACE-A expedition measurements, September-October 1992.

DL Mauzerall, JA Logan, DJ Jacob (Dept. of Earth & Planetary Science, Harvard Univ., Cambridge, MA 02138; (617) 495-4577; e-mail: dlm@io.harvard.edu
BE Anderson, AS Bachmeier, GW Sachse (NASA Langley Research Center, Hampton, VA 22331)
DR Blake (Univ. of Calif. at Irvine, Irvine, CA 92717)
JD Bradshaw (Georgia Inst. of Tech., Atlanta, GA 30332)
H Fuelberg (Florida State Univ., Tallahassee, FL 32306)
BG Heikes (Univ. of Rhode Island, Narragansett, RI 02882)

The TRACE-A (TRansport and Atmospheric Chemistry near the Equator -Atlantic) expedition was conducted during the 1992 dry season to evaluate the contribution of biomass burning to the seasonal ozone maximum observed off the west coast of southern Africa. The chemical composition of biomass burning plumes over source regions and over the South Atlantic were measured. We use statistical analysis to determine and interpret enhancement ratios (e.g. $\Delta CO/\Delta CO2$, $\Delta NOy/\Delta CO$) observed during TRACE-A. Plume ages are determined from back trajectories and from the evolution of enhancement ratios between hydrocarbons. We use key enhancement ratios, e.g., $\Delta O_3/\Delta CO$, $\Delta O_3/\Delta(NOy-NOx)$, $\Delta H_2O_2/\Delta NO_y$, respectively, to indicate relative ozone production, ozone production efficiency, and hydrocarbon versus NO_x control over ozone production. We examine how these ratios evolve over time as a function of photochemical aging and dilution. Correlations between CH_4 and anthropogenic halocarbons as well as anti-correlations between $\Delta CH_4/\Delta CO$ are used as indicators of transport from the northern hemisphere.

Chitemene Agriculture in Southern Africa--Emissions and Sustainability

D E Ward, R A Susott, W M Hao, and C. Doughty (USDA Forest Service, Intermountain Research Station, PO Box 8089, Missoula, MT 59807)

R W Shea, J B Kauffman (Oregon State University, Corvallis, OR 97331)

E Chidumayo (University of Zambia, Lusaka, Zambia)

Chitemene slash and burn agriculture is widely used in northern parts of Zambia, southern Zaire, and Angola. After approximately seven years of production, the agricultural sites are abandoned and allowed to revert to natural vegetation. Fires reburn the fallow sites on almost a yearly frequency which restricts the recovery of the site to woodland. With increases in population, the fallow period has been shortened and the sustainability of using ash for fertilization is jeopardized. We measured the weight of biomass at 4 sites that were recently cut and harvested for nutrients as well as 6 other sites that had been placed in a fallow condition from 10 to 30 years. The areas were burned, smoke emissions were measured, and the amount of biomass before and after each fire was quantified along with the amount of trace gases and aerosol particles. We report the amount of observed biomass before and after the fire and emissions of trace gases from the fires by phase of combustion. We discuss implications of our research results on present land-use practices and the potential benefits that may accrue from implementing a few basic fire management practices.

Emissions of Trace Gases and Particulate Matter From Fires in Brazilian Forest and Savanna Ecosystems

R E Babbitt, W M Hao, R A Susott, D E Ward, S P Baker, and G Olbu (USDA Forest Service, Intermountain Research Station, PO Box 8089, Missoula, MT 59807)

Extensive field experiments of biomass burning were carried out in primary and secondary forests and cerrado ecosystems of Brazil in August and September of 1991, 1992 and 1993. About four hectares were burned at each site. The type of fuel, the elemental composition (carbon, hydrogen and nitrogen) of biomass, and the emissions of trace gases and aerosol particles according to the phase of combustion (flaming vs. smoldering) were investigated. The percentage of biomass burned in each combustion phase is estimated for different ecosystems. Emissions of CH_4 are linearly correlated with the combustion efficiency. The lower the combustion efficiency, the higher the emissions of CH_4. Production of C_2-C_6 alkanes and alkenes, and aromatic compounds is linearly correlated with that of CH_4. The linear relationships among emitted gases and particulate matter are compared for different phases of combustion in various ecosystems.

Land Use Change in Brazilian Amazonia: Annual Balance of Greenhouse Gas Emissions in 1990

P.M. Fearnside (Department of Ecology, National Institute for Research in the Amazon-INPA, C.P. 478, 69.011-970 Manaus, Amazonas, Brazil; 55-92-642-3300 Ext. 314)

Land use changes in 1990 in Brazil's 5 X 10^6 km^2 Legal Amazon Region included 13.8 X 10^3 km^2 of deforestation, approximately 5 X 10^3 km^2 of clearing in cerrado (savanna), 7 X 10^2 km^2 in "old" (pre-1970) and 19 X 10^3 km^2 in "young" (1970+) secondary forests; burning of 40 X 10^3 km^2 of productive pasture (33% of area

present), and regrowth in 121 X 10^3 km^2 of "young" secondary forests. No new hydroelectric flooding occurred in 1990, but decomposition continued in 4.8 X 10^3 km^2 of reservoirs already in place. Logging 24.6 X 10^6 m^3 was assumed, the 1988 official rate.

Estimated net emissions totaled 1404 X 10^6 t CO_2, 1.7 X 10^6 t CH_4, 31 X 10^6 t CO, and 0.1 X 10^6 t N_2O. These emissions are equivalent to 1454 X 10^6 t CO_2, using IPCC 1992 100-year GWPs. CO_2 emissions include 211 X 10^6 t from the initial burn, 824 X 10^6 t from decay and 57 X 10^6 t from subsequent burns of primary forest biomass; 45 X 10^6 t from decay and 57 X 10^6 t from burning of secondary forest biomass; 37 X 10^6 t from hydroelectric reservoirs, 30 X 10^6 t from soil to 20 cm, and 210 X 10^6 t from logging. Pastures released through burning (and assimilated in growth) 7 X 10^6 t, not counted in the above total. Secondary forest regrowth removed approximately 67 X 10^6 t (only 5% of the gross emission, excluding pasture). The total CO_2 emissions, excluding logging and hydro, are triple Brazil's official estimate, mainly because the latter omits decay and combustion after initial deforestation.

Atmospheric Impact of Cereal Waste Burning in Spain

A Ezcurra[1], I Ortiz de Zárate[1], J P Lacaux[2], and Pham Van Dihn[2]
[1]Euiti y T. Unv. País Vasco, Nieves Cano 12, 01006 Vitoria (Spain)
[2]Laboratoire d'Aérologie, CRA de Lannemezan, 65300 Lannemezan (France)

To eliminate cereal waste every year in Spain more than 5 10^6 ha of cereal fields are burned up in less than one month.

In order to attempt an evaluation of the environmental impact due to this source of pollution we followed an experimental approach to draw off some features of the phenomena.

From burning experiments on cereal waste carried out in a large combustion chamber (160 m^3), we deduce average emission factors of 0.8 g kg^{-1}(dm) for NO_x and TPM.

Continuous measurements carried out by means of a mobile laboratory in a rural area during burning periods, show that NO_x average concentrations increase in less than 5 hours from a background of 5 ppb to values of 40 ppb. Connected to this source, in a nearby city placed 40 km away from that area; average ozone concentration increase about 20% and episodes of high concentration of aerosol are produced.

Finally PCA analysis of pollution data measured in the 4 spanish EMEP/BAPMON stations allows us to identify the cereal waste burning as the sole source that affects simultaneously all the 4 stations.

Gaseous Emissions from Fires in Mediterranean Shrublands

L Trabaud (Centre d'Ecologie Fonctionnelle et Evolutive, CNRS, B.P. 5051, 34033 Montpellier, France; 33-6761-3293)

Wildfires are an ecological important phenomenon in the Mediterranean basin. Practically annually an average of 500 000 ha is burned in the European Community countries. How quantity of gaseous emissions is produced by them? An attempt was carried out through 3 experimental fires in a typical shrubland (garrigue). Plant biomass, in sampling plots, was measured before and after the burns. The amounts of nutrients present, remaining or lost were calculated from chemical analyses made on plant samples.

Nitrogen was the nutrient with the highest loss rates: more than 98% from the combustible material disappeared, probably by transformation of plant proteins into different gaseous nitrogen oxides. N amounts of 157-289 kg/ha were volatilized in the smoke. More than 97% of the carbon contained in combustible material was dissipated by burning, probably in the smoke as gaseous oxides; from 5 925 to 10 670 kg/ha of C were lost into the atmosphere.

Burnings released between 20-40 t/ha of CO_2, 2-3.5 t/ha of CO, and .1-1.3 t/ha of particulate matter. These rather high values are probably due to the character of woody shrubby vegetation which was burned.

Modeling Emissions from Forest Burning in the Southeastern United States

J.M. Vose, W.T Swank, A.E. Major (USDA Forest Service, Southeastern Forest Experiment Station, Coweeta Hydrologic Laboratory, Otto, NC 28763; 704-524-2128)
C.D. Geron (US-EPA, Atmospheric Research and Exposure Assessment Laboratory, Research Triangle Park, NC 27711; 919-541-4639)
(Sponsor: Alan Yeakley)

We developed a micro-computer based model (Regional Emissions from Forest Fires or "REFF") to estimate emissions of particulates (PM-10), CO_2, NO_x, N_2O, CH_4, CO, nonmethane hydrocarbons, and total hydrocarbons from wild- and prescribed fires in the southeastern United States by state, province, and month. A sub-model uses historical climatic data to predict fuel moisture content, which subsequently regulates fuel consumption in a separate sub-model. Emissions factors are fire and fuel type dependent and are applied in a weighted procedure depending on the distribution of fuel types (e.g., hardwood vs. pine) in each state and province. Historical forest fire data (prescribed acreage and wildfire acreage) were collected and summarized by state, county, and month for 1982 and 1988. These data, in combination with sub-models of of REFF, were used to estimate emissions by state, province, and fire type. Results showed there was substantial variation in emissions among states, provinces, and months which depended on climatic conditions (and related effects on fuel moisture and fire frequency and extent), fuel types, fire type and acreage burned. REFF allows for more accurate temporal and spatial resolution of emissions sources compared to currently used methods which apply average emissions factors (uncorrected for variation in fuel or fire type), and average consumption (uncorrected for variation in fuel moisture) over large geographical areas.

Trace Gas Chemistry of Canadian and Siberian Boreal Forest Fires

W R Cofer III, J S Levine, D R Cahoon Jr. (Atmospheric Sciences Division, NASA Langley Research Center, Hampton, VA 23681-0001; 804-864-5835)
E L Winstead (GATS/SAIC, One Enterprise Parkway, Hampton, VA 23666)
B J Stocks, Great Lakes Forestry Center, Sault Ste Marie, Ontario, Canada P6A 5M7
J G Goldammer, Max Planck Institute for Chemistry, C/O University of Freiburg, D-79085 Freiburg, Germany

Measurements of trace gases produced by vegetation fires were made from low-altitude helicopter penetrations of

smoke plumes above burning boreal forests in Canada and Siberia. Emission chemistry for biomass fires in the boreal system has been found to be highly complex and variable, producing the greatest range in potential chemical emissions of any major global ecosystem. Smoke compositions determined from prescribed fires in Canada are contrasted with emissions from a high-intensity experimental stand fire (Bor Forest Island Fire) in Siberian taiga. The Bor Island fire represents the first boreal fire in which crownfire emissions were isolated and captured for chemical analyses. Carbon dioxide (CO_2) normalized emission ratios (dX/dCO_2; V/V; where X = trace gas) for carbon monoxide (CO), hydrogen (H_2), and methane (CH_4) were determined from the Bor Fire and indicated lower combustion efficiencies during the intense stages of crowning than for flaming combustion in Canadian boreal slash fires. When this is coupled to the added greenhouse sensitivity at northern latitudes, the substantial buoyancy and potential height of convection columns typically generated by high-intensity crowning boreal fires in a region where the tropopause is already lower make direct stratospheric impacts possible, and indicate that additional research on crown fire behavior/emissions will be highly important to understanding global change processes.

Nitrous Oxide and Carbonyl Sulfide Emissions from Biomass Burning and the Spatial Distribution of Nitrous Oxide in China

Y H Zhuang M Q Cao and X K Wang (Research Center for Eco-Environmental Sciences, Academia Sinica, PO Box 2871, Beijing 100085, China; +86-1 255 9989; Fax +86-1 255 5381)
(Sponsor: National Natural Science Foundation)

The emission factors of nitrous oxide and carbonyl sulfide during the combustion of rice straw, wheat stalk and maize stalk have been determined in an experimental combustion chamber. The experimental errors in the determination of nitrous oxide and carbonyl sulfide concentrations by GC and in the sampling procedures have been discussed. Necessary measures have been taken to ensure the quality of analytical results.

The geographic distribution of nitrous oxide emission from biomass burning in mainland China has been estimated, and the results have been presented as a 1^0 x 1^0 grid map. The biomass formation in mainland China were calculated from the annual cereal production on the county level.

Trace Gas Emissions From Savanna Burning in Australia

D E Hurst (Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80303; 303-497-7003; Internet: hurst@cmdl.noaa.gov)
D W T Griffith (Department of Chemistry, University of Wollongong, Wollongong, New South Wales 2522, Australia; Internet: d.w.griffith@uow.edu.au)
G D Cook (Tropical Ecosystems Research Centre, Commonwealth Scientific and Industrial Research Organisation, Darwin, Northern Territory 0821, Australia; Internet: Garry.Cook@dwe.csiro.au)

Four smoke sampling campaigns were conducted during the dry seasons of 1990, 1991, and 1992 in the Northern Territory, Australia. The aim of these campaigns was to quantify the emissions of several trace gases from Australian savanna fires. Sampling was performed on the ground and aboard aircraft flying at low altitudes through the plumes of wild and prescribed fires. Various analytical methods (e.g. FTIR, NDIR, GC, chemiluminescence) were employed to measure CO_2, CO, CH_4, total NMHC, NO_x, NH_3, N_2O, HCN, CH_3CN, C_1-C_2 aldehydes, and selected hydrocarbons in the smoke samples. The mass loads and elemental contents of prefire fuel and postfire ash residue were also measured, allowing us to express trace gas emissions as emission factors relative to the fuel carbon or nitrogen that was burned. These emission factors illustrate how the burned fuel C and N were released to the atmosphere as different trace gases and deposited as ash. On average, 96% of the fuel carbon burned was released to the atmosphere, predominantly as CO_2 (87±3%) and CO (7.8±2.3%), with ~4% deposited in the ash. The measured emissions of NO_x and NH_3 represented 21±8% and 23±13% of fuel N burned, respectively. The sum total of measured N-containing emissions represented only ~50% of the fuel N released to the atmosphere during these fires. A model of vegetation distributions and fire behavior in northern Australia was used to estimate the annual emissions of several important trace gases from savanna burning in Australia.

Spatial Distribution of Tropical Biomass Burning in 1990 with 1° x 1° Resolution

W M Hao (USDA Forest Service, Intermountain Research Station, PO Box 8089, Missoula, MT 59807)
M-H Liu (School of Forestry, University of Montana, Missoula, MT 59812)
M Lorenzini and K D Singh (Forest Resources Assessment 1990 Project, Food and Agriculture Organization of the United Nations, 00100 Rome, Italy)
D E Ward (USDA Forest Service Intermountain Research Station, PO Box 8089, Missoula, MT 59807)

The area and the amount of biomass burned due to deforestation, shifting cultivation and savanna fires is quantified for Latin America, Africa and tropical Asia in 1990 with 1° latitude x 1° longitude resolution. They are estimated on the basis of high resolution vegetation maps, the area of land cleared owing to various land use practices, the amount of biomass density in different ecosystems, and the percentage of biomass burned in each ecosystem. The resolution of the vegetation map is 1 km x 1 km for tropical Asia and 2 km x 2 km for Latin America and Africa. The burned area is derived from the sub-national data of FAO 1990 Forest Resources Assessment, the Landsat images, and the previous survey data. Approximately 6.9 Pg (1 Pg = 10^{15} g) of biomass was burned in the tropics in 1990, which is close to the high estimates of previous studies. The largest source is savanna fires, followed by shifting cultivation and deforestation. Changes of land use practices and their impacts on the production of trace gases and aerosol particles also are discussed.

Regional trace gas distribution and airmass characteristics in the haze layer over southern Africa during the biomass burning season (Sep./Oct. 92): Observations and Modeling from the STARE/SAFARI-92 DC-3

T Zenker, F G Wienhold, P LeCanut, M O Andreae (Max Planck Institute for Biogeochemistry, Box 3060, Mainz D-55020, Germany; zenker@diane.mpch-mainz.mpg.de)
G W Harris (York University, 4700 Keele Street, North York, ONT, M3J 1P3)
R Koppmann (KFA-Jülich, Box 1913, Jülich D-52425, Germany)
A M Thompson, D P McNamara, T L Kuscera (NASA/GSFC/Code 916, Greenbelt, MD 20771)

Regional scale airborne trace gas measurements have been carried out in the haze layer over southern Africa in the biomass burning season during the STARE/SAFARI-92 experiment. We present vertical and regional scale trace gas distributions measured from the DC-3 series of flights over South Africa, Zimbabwe, Botswana, Namibia and Zambia in late September (24-28 September) and early Ocotber (1-6 October). In general, higher concentrations of O_3, CO, and NO_x were encountered in September than in October, but both sets of measurements were frequently elevated above background (non-polluted) levels due to biomass burning. Different airmass layers have been characterised according to age by ratios among particle density, CO, CO_2, O_3, NO_x, and NO_y. Possible origins of selected air masses have been investigated by back trajectory calculation. Additionally, photochemical "point" model calculations based on the measured trace gas mixing ratios are used to compute OH concentrations and net photochemical ozone production. These model results are compared to calculations based on DC-8 data collected during the STARE/TRACE-A mission in southern Africa from 6-18 October 1992.

Tuesday, March 14, 1995

Morning/Afternoon Session III: BIOGENIC SOIL EMISSIONS
CHAIRS - R G ZEPP, R A DELMAS

The Magnitude and Persistence of Soil NO, N2O, CH4, and CO2 Fluxes from Burned Tropical Savannas

I C Anderson (Virginia Institute of Marine Science, College of William and Mary, Gloucester Point VA 23062; ph. 804-642-7242; fax 804-642-7293; Internet: iris@vims.edu); M A Poth (USDA Forest Service Research, Riverside CA 92507; ph 909-276- 6571; fax 909-276-6426; Internet: /S=3DM.POTH/OU1=3DS27L05A@mhs fsbo.attmail.com); H S Miranda, A C Miranda (Departamento do Ecol=F3gia, Universidade de Bras=EDlia, 70910-900 Bras=EDlia D F, Brasil; ph 55-61-348-2326; fax 55-61-272-1053; Internet: hmiranda@guarany.cpd.unb.br) (AGU Sponsor: I C Anderson)

Tropical savannas represent the ecosystem most commonly impacted by anthropogenic burning. Interval of fire in cerrado, a type of tropical savanna covering 25% of Brazil, is 2 - 4 years. We measured soil fluxes of NO, N2O, CH4, and CO2 as well as soil mineralization and nitrification rates from cerrado sites that had been burned within the previous 2 days, 30 days, one-year, and from a control site, last burned in 1976. NO and N2O fluxes responded dramatically to fire with the highest fluxes observed from newly burned soils after addition of water. Fluxes were significantly correlated with soil NH4+ concentrations and pH. Emissions of N-trace gases post-burn were of similar magnitude to estimated emissions during combustion. NO fluxes immediately following burning are amongst the highest observed for any ecosystem studied to date. These rates declined with time after burning, and had returned to control levels one-year following the burn. Based upon annualized rates of NO emissions from cerrado normalized to time after burning, a six month rainy season, and assuming a burn frequency of two years it is suggested that tropical savanna compared to temperate ecosystems, agroecosystems, or boreal systems, burned or unburned, is a major source of NO to the troposphere. On the other hand, cerrado appears to be a minor source of N2O. Fire significantly increased fluxes of CO2 when water availability did not limit soil microbial activity. CO2 emissions were more persistent than NO emissions, remaining high throughout the year following a burn. There were no measurable fluxes of CH4 to/from unburned cerrado soils; however, burning increased CH4 uptake by soil with highest uptake observed 30 days following a burn. Annualized methane uptake extrapolated to all tropical soils represents 65% of the estimated total termite methane emission.

Biomass Burning and Biogenic Soil Emissions of Nitric Oxide in the Boreal Forest

E L Winstead (GATS Inc., Hampton, VA 23666, USA, 804-864-4209)
J S Levine, W R Cofer III, and D R Cahoon, Jr. (All at: NASA Langley Research Center, Atmospheric Sciences Division, Hampton, VA 23681-0001, USA)
D I Sebacher (SAIC, Hampton, VA 23666)

Enhanced biogenic soil emissions of nitric oxide have been measured following surface biomass burning in various ecosystems, including chaparral, savannas, and wetlands. Very little is known about the soil emissions of nitric oxide from boreal forests or the effect of fire on these emissions. Closed chamber flux measurements of nitric oxide were obtained in both unburned and burned soils. The burned sites were burned at time periods of one to seven years prior to the time of measurement. These measurements were made during the NASA Mission to Planet Earth, Boreal Ecosystem Atmosphere Study (BOREAS) conducted in the Canadian boreal forest near Thompson, Manitoba. Biogenic soil flux emissions of nitric oxide in the boreal system, the post-fire effects on the enhancement of nitric oxide emissions and how long this effect persists will be discussed.

Biomass Burning, Biogenic Soil Emissions, and the Global Nitrogen Budget

J S Levine, W R Cofer III, and D R Cahoon, Jr. (Atmospheric Sciences Division, NASA Langley Research Center, Hampton, VA 23681-0001, USA, 804-864-5692)
E L Winstead and D I Sebacher (SAIC, Hampton, VA 23665)

Biomass burning is an instantaneous source of nitrogen, nitric oxide and nitrous oxide to the atmosphere. Measurements also indicate that biomass burning has an additional impact on the global nitrogen budget. Burning stimulates enhanced biogenic soil emissions of nitric oxide, and in some ecosystems, of nitrous oxide. Closed chamber flux measurements of nitric oxide and nitrous oxide were obtained, both before and after burning, in diverse ecosystems, including a chaparral ecosystem in southern California, two savanna sites in South Africa--Kruger National Park during the IGAC/BIBEX/ SAFARI-92 experiment and Nylsvley Nature Reserve near Johannesberg during the IGAC/BATGE-94 experiment, and in the Canadian boreal forest during the BOREAS Project in 1993 and 1994. The impact of burning and wetting on the biogenic emissions of nitric oxide and nitrous oxide from soils in these diverse ecosystems will be reviewed. We believe that enhanced soil emissions of nitric oxide and nitrous oxide are related to enhanced concentrations of ammonium in the soil. Ammonium is an important component of the burn ash and is the substrate in the microbial production of nitric oxide and nitrous oxide via nitrification. A very surprising result is the very low soil emissions of nitrous oxide, both before and after burning, from these ecosystems. Soil emissions of nitric oxide exhibited a marked enhancement following burning. The implications of biomass burning on the global nitrogen budget will be discussed.

Soil-Atmosphere Exchange of Trace Carbon Gases in Southern African Savanna Fire Scars

R G Zepp, R A Burke, W L Miller, and M A Tarr (US Environmental Protection Agency, 960 College Station Road, Athens, GA 30605-2700; 706-546-3428; e-mail: erlath@uga.cc.uga.edu); D A B Parsons and M C Scholes, Department of Botany, University of Witwatersrand, P O Wits, Johannesburg, South Africa (27-11-716 2228)

The post-burning effects of fire on soil-atmosphere exchange of carbon dioxide, methane, and carbon monoxide were investigated in savanna sites located in the Kruger National Park (KNP) and Nylsvley Nature Reserve, South Africa. The KNP studies were conducted as part of the Southern African Fire-Atmosphere Research Initiative (SAFARI-92) during a period of extreme drought. Soil respiration (mean of 0.4 g CO_2 C m^{-2} d^{-1}) was little affected by burning of the dry savanna sites. On the other hand, simulated heavy rain (added 25 mm of deionized water) and a natural light rain (0.8 mm) strongly increased CO_2 fluxes in both burned and control sites. No methane source or sink activity was detected at the KNP sites during the SAFARI experiments (dry season). Burning and the addition of deionized water had no detectable effect on soil-atmosphere methane exchange over a two week period after moisture addition. However, methane consumption in both the KNP and Nylsvley soils was observed during the rainy season. CO fluxes were always observed to be from the soil to the atmosphere at the KNP during SAFARI-92. After burning, the CO fluxes rose nearly an order of magnitude, but dropped back to below pre-burn levels within a few days. Because

dead grasses and surface litter were a major source of CO from the savannas, removal of this plant matter by fire reduced net post-burn emissions of CO.

Tuesday, March 14, 1995

Afternoon/Evening Session IV: PARTICULATE EMISSIONS
CHAIRS - R G PRINN, D E WARD

Large Scale and Long Term Biomass Burning Monitoring in the Amazon Basin

P. Artaxo, F. Gerab, M. A. Yamasoe, J. V. Martins, (Instituto de Fisica, Universidade de Sao Paulo, Caixa Postal 20516, CEP 01452-990, Sao Paulo, SP, Brazil; Phone:[55](11)8187016; FAX:[55](11)8186749; internet: ARTAXO@IF.USP.BR; A. Setzer, Instituto Nacional de Pesquisas Espaciais, Caixa Postal 515, Sao Jose dos Campos, Sao Paulo, S.P., Brazil; A. H. Miguel, Instituto de Quimica, Universidade de Sao Paulo, S.P. Brazil.

Since 1990 three background monitoring stations in Brazil are continuously monitoring biomass burning in the Amazon Basin. Aerosol particles are being collected and analysed for trace elements, ionic components, and black carbon in three remote sampling stations in the Amazon basin (Cuiaba, Alta Floresta and Serra do Navio). Fine and coarse aerosol components were sampled using stacked filter units and cascade impactors. Trace elements (Al, Si, P, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Ni, Cu, Zn, Sr, Se, Zr, and Br) were measured by the PIXE (Particle Induced X-ray Emission) technique. Ion chromatography was used to measure K+, NH4+, NO3, PO4, Cl, SO4, Na+, Mg+, Ca++, CH3COO, HCOO and C204. Soot carbon was monitored continuously using an Aethalometer and also measured using a reflectance technique. Fine and coarse aerosol gravimetric mass concentration and aerosol size distribution using a MOUDI cascade impactor were measured. Multivariate statistical analysis identified three main aerosol components: The natural primary biogenic, gas-to particle conversion, the biomass burning and the soil dust component. For two of the sites there is a clear difference between the natural primary biogenic and the biomass burning component.

To assess the large scale distribution of aerosol particles in the Amazon basin during the biomass burning season, aerosol sampling using airborne platforms was performed. Two Brazilians aircrafts were used. The flights covered almost all different ecosystems in the Amazon region, including regions with very high frequency of primary forest biomass burning. Real time soot carbon determination was performed with Aethalometers with one minute time resolution. TSI CNC and PMS FSSP probes measured the number of particles. High aerosol concentrations up to 350 ug/m3 were observed. Sulphur, K, P and Zn were the elements associated with biomass burning plumes. Vertical profiles up to 10 Km of black carbon and total particle concentrations were performed in several regions, pointing to a maximum concentration at about 1.5 Km high. Remote sensing provided a framework to link ground based emissions with large scale concentrations. Size distribution on black carbon shows maximum concentrations at 0.35 micrometers.

Long-term Atmospheric Aerosol Study in Cuiaba, Brazil: Multielemental Composition, Sources, and Impact of Biomass Burning

W Maenhaut and G Koppen (Institute for Nuclear Sciences, B-9000 Gent, Belgium; maenhaut@inwchem.rug.ac.be)
P Artaxo (Univ. of Sao Paulo, CEP 01452-990, Sao Paulo, Brazil)

Atmospheric aerosol samples are collected continuously since July 1992 at Cuiaba, in the Brazilian savanna, south of the Amazon basin rain forest. The sampling device consists of a stacked filter unit, which separates the aerosol into a coarse and a fine fraction, and the collection time per sample is typically 3-5 days. All samples collected until 20 September 1993 were analyzed for the particle mass (PM), black carbon (BC), and up to 40 elements. The multielemental analyses are done by instrumental neutron activation analysis and particle-induced X-ray emission analysis.

PM, BC and virtually all elements exhibited clearly higher atmospheric concentrations during the dry (biomass burning) season (July-September) than during the rest of the year. During the dry season, the levels of fine and coarse PM were in the range of 5-30 and 10-50 $\mu g/m^3$, respectively. Absolute principal component analysis and chemical mass balance receptor modelling techniques were used to identify the major aerosol components (source types) in each of the two size fractions and to apportion PM and the various aerosol constituents to these components. In the coarse fraction, we identified a mineral dust component, a mixed crustal/biogenic component, with elevated concentrations of Ca, Mg, Mn, Cu, Zn and S, and a mixed crustal/pollution component, characterized by Sb, Pb, V and S. In the fine fraction, the components were mineral dust, a biomass burning component (with BC, S, Cl, K, Zn, Br, Rb, and I), and a pollution component (with Sb, Pb, V, and Cu). Possibly, the biomass burning component also contained some biogenic products. In fact, its multielemental profile showed at the same time some resemblance with pyrogenic profiles, derived from measurements near prescribed savanna fires, and with biogenic profiles, obtained in the Amazon basin during the wet season. Coarse PM was almost fully apportioned to the mineral dust, and the biomass burning component was the dominant contributor to the fine PM.

Size Distribution, Elemental Composition and Carbon Measurement in Aerosols During the SCAR-C Experiment

J V Martins, P Artaxo (Instituto de Fisica, Universidade de Sao Paulo, Caixa Postal 20516, CEP. 01452-990, Sao Paulo, Brazil; phone 55-11-8187016; fax 55-11-8186749; Internet: vanderlei@if.usp.br, artaxo@if.usp.br); C Liousse, H Cachier (Centre de Faibles Radioactivites Gif-Sur-Yvette, France); Y Kaufman (NASA Goddard Space Flight Center, Code 913, Greenbelt, Maryland 20771, USA);

During the SCAR-C (Smoke Cloud and Radiation) experiment, at September 1994, airborne sampling of aerosol particles was performed in different smoke plumes from forest biomass burning over Washington, Idaho and Oregon, in the US. The aerosols' samples were collected using the University of Washington C-131A aircraft. The measurements were obtained in different burning phases and positions, downwind and along the length of the plumes.

Nuclepore filters were used to measure the size distribution by scanning electron microscopy, trace elements composition by PIXE (Particle Induced X-ray Emission) and black carbon by reflectance technique. Quartz filters were used to measure carbon isotopic ratios and to obtain the organic carbon concentration. The simultaneous analyses of black carbon and organic carbon contents and the determination of xC-13 isotopic composition of particles are tested against other indicators of the combustion conditions. Some quantitative estimates of emission factors are proposed and compared to those previously obtained in various biomass burning experiments.

Atmospheric Hg in particulate and gaseous phases was collected using a gold trap sampler and was measured by a new fluorescence technique. Similar measurements were performed in aircraft experiments in the Amazon Basin, Brazil, during the biomass burning season. The data show clear evidences of Hg emissions from biomass burning in the United States and Brazil. Comparisons among data in background and high smoke conditions show different characteristics in the ratio gaseous to particulate Hg.

The aerosol data collected in the SCAR-C experiment are compared with ground based, direct emissions and aircraft results obtained in forest biomass burning in the Amazon Basin, in the last years.

Regional Scale Impacts of Biomass Burning Aerosols Over Southern Africa

S J Piketh,[1,2] H J Annegarn,[2] M A Kneen[2] ([1]Department of Geography and Environmental Studies, [2]Schonland Research Centre for Nuclear Sciences, University of the Witwatersrand, P. Bag 3, WITS, 2050, Johannesburg, South Africa; 27 11 716 3166; e-mail: 017gspp@witsvma.wits.ac.za)
(Sponsor: G Helas)

Research over the past decade has identified large scale biomass burning emissions as an important factor in regional scale atmospheric chemistry. The savanna regions of Southern Africa represent major source regions for pyrogenic emissions. A sampling program was initiated in 1993, to collect continuous aerosol particle samples at Elandsfontein (Transvaal Highveld), Misty Mountain (Transvaal Escarpment) and Ulusaba (Transvaal Lowveld). Samples taken during February, June and September were analysed. The months were chosen to represent different seasons to establish seasonal variability of biomass burning emissions. Samplers were PIXE International Inc circular streakers. Analysis of the samples was undertaken with Proton Induced X-ray Emissions (PIXE), in 4 hourly steps. Elements frequently observed above detection limits were Al, Si, S, Cl, K, Ca, Ti, Mn and Fe. The contribution of biomass burning to the total inorganic elements was calculated from the potassium concentration less the apportioned contribution of marine and soil related potassium. The distribution of the sampling sites made it possible to evaluate the regional scale impact of biomass burning. Biomass burning contributed to atmospheric particles throughout the year. During September the biomass burning emissions were the highest. The emissions were part of a well mixed air mass of industrial related pollutants (sulphate and heavy metal elements) and biomass burning related emissions. The prominent source direction of the biomass burning particles was from the north-north west. This indicated that prevailing synoptic scale conditions to be anticyclonic, thus making a first link to the continental scale gyres now known to exist over southern African. Biomass burning emissions from southern central Africa are thus transported southward by large scale continental anticyclonic flow, and impact at ground level sites across South Africa. Concentrations of biomass burning particles were not significantly different during February and June. Characteristics of the peak episodes revealed that local sources, probably domestic wood burning, and local forestry industries contributed the most.

Trace element particulate emissions in tropical savanna and forest fire plumes

F. Echalar, A.Gaudichet (Laboratoire Interuniversitaire des Systèmes Atmosphériques URA CNRS 1404 - Universités Paris 7 et Paris 12, 94010 Créteil CEDEX, France)
H. Cachier (Centre des Faibles Radioactivités, CNRS-CEA, 91198 - Gif sur Yvette CEDEX, France)
P. Artaxo (Institute of Physics, São Paulo University, Brazil)

Aerosol particles were collected in the amazonian forest and in african and brazilian savannas. Sampling was performed inside the plumes of vegetation fires and in the local background atmosphere. Samples were analysed for their elemental composition by Particle Induced X-Ray Emission (PIXE). Single particle studies were carried out on selected samples by means of a transmission electron microscope fitted with a microanalysis system. The microscopic study of savanna samples, where the flaming conditions are predominant, shows that microsoots emitted by flaming combustion are formed by 0.1 µm diameter spheres clustered in chains or grapes. The main trace elements detected by microanalysis are K, Cl, S and sometimes Zn. Forest samples, collected in smoldering conditions, show mainly isolated drop-like microsoots, where the presence of Cl is much less frequent. Regarding the bulk elemental results, enrichment factors of the plume aerosol relative to the local background were calculated. Savanna fire aerosols are characterized by enrichments in elements like K, P, Cl, Zn and Br, whereas forest fire emissions are enriched in Si and Ca. The unexpected low enrichment factor for potassium, which is usually considered an ubiquitous tracer of biomass burning, for forest fires could be due to the prevailing smoldering conditions, whereas the results for savanna fires could be associated with the predominant flaming conditions. We suggest, then, that potassium may be considered a good tracer of the flaming phase of fires only. Emission factors of P, S, Cl, K, Ca, Mn, Zn, Br and total particulate matter were calculated for african savanna fires. Our estimates of the annual potassium and zinc emissions by tropical savanna fires indicate that the contribution of this source should be taken into account to understand the biogeochemical cycles of these elements.

Molecular Composition of Carbonaceous Smoke Particles from Prescribed Burning of a Canadian Boreal Forest

M A Mazurek, C Laterza, L Newman, P Daum (Environmental Chemistry Division, Brookhaven National Laboratory, Upton, NY 11973; 516-282-3275 mail: mazurek@ bnl.gov)
W R Cofer, III, J S Levine (Atmospheric Sciences Division, NASA Langley Research Center, Hampton, VA 23681) E L Winstead (GATS/SAIC and SAIC, One Enterprise Parkway, Hampton, VA 23666)

In this study we examine the molecular organic constituents (C8 to C40 lipid compounds) collected as smoke particles from a Canadian boreal forest prescribed burn. Of special interest are (1) the molecular identity of polar organic aerosols, and (2) the amount of polar organic matter relative to the total mass of aerosol particulate carbon.

Organic extracts of smoke aerosol particles show complex distributions of the lipid compounds when analyzed by capillary gas chromatography/mass spectrometry. The molecular constituents present as smoke aerosol are grouped into non-polar (hydrocarbons) and polar ($\geq$2 oxygen atoms) subfractions. The dominant chemical species found in the boreal forest smoke aerosol are unaltered resin compounds (C20 terpenes) which are abundant in unburned conifer wood, plus thermally altered wood lignins and other polar aromatic hydrocarbons.

Our results show that smoke aerosols contain molecular tracers which are related to the biofuel consumed. These smoke tracers can be related structurally back to the consumed softwood and hardwood vegetation. In addition, combustion of boreal forest materials produces smoke aerosol particles that are both oxygen-rich and chemically complex, yielding a carbonaceous aerosol matrix that is enriched in polar substances. As a consequence, emissions of carbonaceous smoke particles from large-scale combustion of boreal forestland may have a disproportionate effect on regional atmospheric chemistry and on cloud microphysical processes.

ACTIVATION OF CARBON AEROSOL BY DEPOSITION OF SULFURIC ACID

K.L. Carleton, D.M. Sonnenfroh, W.T. Rawlins (Physical Sciences Inc., 20 New England Business Center, Andover, MA 01810; tel. 508-689-0003; e-mail: rawlins@psicorp.com
B.E. Wyslouzil (Worcester Polytechnic Institute, Dept. of Chemical Engineering, 100 Institute Rd., Worcester, MA 10609

Combustion-generated carbon particles affect atmospheric radiative properties through their large absorption cross sections, and can significantly alter cloud reflectivities if located in the interiors or surfaces of cloud droplets. Although black carbon is usually considered to be hydrophobic, the adsorption of combustion-generated SO_2 and/or H_2SO_4 could activate carbon particles for H_2O uptake, leading to the development of H_2SO_4/H_2O/carbon aerosol through heterogeneous nucleation processes. This process would then activate the particles as cloud condensation nuclei.

We have investigated the activation of single carbon particles under well controlled laboratory conditions, using a quadrupole electrodynamic trap housed in a temperature and humidity controlled cell. The experiments demonstrate that: (1) H_2SO_4 is readily adsorbed and retained on the carbon particles; (2) untreated carbon particles do not hydrate upon exposure to relative humidities between 0 and 80%; (3) particles treated with H_2SO_4 via vapor deposition readily hydrate under subsaturated conditions; (4) the hydration behavior of the treated particles is consistent with the hydration of pure H_2SO_4 in the presence of an inert substrate. The amount of acid adsorbed on the

carbon particles (soluble mass fraction) averaged 14±6 percent by weight, which corresponds to a surface coverage of ≈0.1-0.3 monolayer.

This work was supported by the NASA High Speed Research and Advanced Subsonic Technology Programs.

Flame and Fortune: Americans Fight Fire

S J Pyne (American Studies Department, Arizona State University West, P.O. Box 37100, Phoenix, AZ 85069-7100; 602 543-6013; iadsjp@asuvm.inre.asu.edu)

A century ago America was a developing country with a fire geography dominated by rural burning. The reservation of public lands for parks and forests, however, demanded a reconsideration of fire practices. Officials and particularly foresters trained in Europe began to suppress not only folk burning but fires of all kinds. But the ends were large and the means at hand small. The turning point came in the summer of 1910. Immense fires, a public debate over appropriate strategy, an activist generation eager for a life of strenuous endeavor - out of this collision emerged an American strategy of fire management based on fire control.

The fire establishment grew fitfully until the Roosevelt administration granted it almost unlimited manpower and support during the 1930s, and then it became allied with national security during World War II. The transfer of surplus military hardware reinforced an emerging cold war on fire. By the 1970s, however, economics, ecology, and a philosophy of wilderness forced a reevaluation of federal policy and led to an acceptance of controlled (or prescribed) burning. But a change of philosophy did not much change field operations. In practice the U.S. remains committed to aggressive fire suppression, even as the evidence mounts that such a strategy cannot succeed.

The American experience recommends that wildlands will burn: the issue is how, not whether. Controlled fire remains the best means of fire control.

Wednesday, March 15, 1995

Morning Session IV: PARTICULATE EMISSIONS - CONTINUED

Natural Organic Compounds as Tracers for Biomass Combustion in Aerosols

B R T Simoneit (College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR 97331-5503; 503-737-2215)
M Radzi bin Abas (Department of Chemistry, University of Malaya, Kuala Lumpur 59100, Malaysia)
G R Cass (Environmental Engineering Science Department, California Institute of Technology, Pasadena, CA 91125)
W F Rogge (Department of Civil and Environmental Engineering, Florida International University, University Park, FL 33199)
M A Mazurek (Environmental Chemistry Division, Brookhaven National Laboratory, Upton, NY 11973)
L M Hildemann (Department of Civil Engineering, Stanford University, Stanford, CA 94305)

Biomass combustion is an important primary source of carbonaceous particles in the global atmosphere. Although various molecular markers have already been proposed for this process, additional specific tracers need to be characterized.

The injection of natural product organic tracers to smoke occurs primarily by direct volatilization/steam stripping and by thermal alteration based on combustion temperature. The degree of alteration increases as the burn temperature rises and the moisture content of the fuel decreases. Although the molecular composition of organic matter in smoke particles is highly variable, the molecular structures of the tracers are generally source specific.

The homologous compound series and biomarkers present in smoke particles are derived directly from plant wax, gum and resin by volatilization and secondarily from pyrolysis of biopolymers (e.g., lignin, cutin, suberin), wax, gum and resin. The complexity of the organic components of smoke aerosol is illustrated with examples from controlled burns of temperate and tropical biomass fuels. The major organic components of smoke particles from tropical biomass are straight-chain, aliphatic and oxygenated compounds and triterpenoids. Several compounds (e.g., amyrones, friedelin, aromatic A-noroleananes and other thermal derivatives from triterpenoids, lignin phenols) are potential key indicators for smoke components from combustion of such biomass. Burning of biomass from temperate regions (i.e., conifers) yields characteristic tracers from diterpenoids as well as phenolics and other oxygenated species, which are recognizable in urban airsheds. The precursor to product approach of organic geochemistry can be applied successfully to provide tracers for studying smoke plume chemistry and dispersion.

Biomass Burning Tracers: Elements, Isotopes, and Isomers.

L. A. Currie (NIST, Gaithersburg, MD 20899)

Assessment of the chemical and climatic impacts of anthropogenic and natural sources of combustion aerosol requires quantitative source apportionment on regional and global scales. Commonly applied methods for the apportionment of tropospheric carbon depend on unique tracer species such as mineral-corrected potassium for biomass combustion sources; C-13 (abundance), for discrimination among C3, C4, and marine sources; C-14, for discrimination between fossil and "living" sources; and patterns among similar organic species, such as polycyclic aromatic hydrocarbons (PAH), for further discrimination between source types, such as soft and hardwood biomass. The complementarity of the several tracers brings very important benefits when elemental, isotopic, and organic tracers are used together: improved source resolution and detection of unsuspected sources may result; and apportionment based on different sets of assumptions – especially physical (isotopic) vs statistical (multivariate) – is important for model validation. Illustrations of multitracer studies will be reviewed, including dual isotopic (C-13, C-14) studies, isotopic-elemental, and isotopic-organic. The combination of C-14 with a multiple linear regression elemental (K, Pb) tracer model, for example, demonstrated that the use of potassium as a conservative tracer for biomass burning carbon is NOT always reliable; and linking C-14 with dimethyl phenanthrene isomers makes possible decomposition of carbonaceous aerosol into fossil, softwood, and hardwood combustion sources. Isotopic heterogeneity is another issue. In urban particle reference materials, for example, we have found the PAH fraction to be isotopically distinct (ca. 20% modern C-14) from the total carbon (ca. 60% modern).

In the development of multivariate chemical and isotopic tracers, the importance of measurement and data quality cannot be overstated. This is especially of concern with complex materials such as atmospheric aerosols, and small concentrations such as those found in remote regions. In a recent C-13 imtercomparison, sponsored by the IAEA, involving premier international laboratories and well characterized pure substances, laboratory bias equal to -3.5 times the target precision was observed, as well as an outlier equal to +7 times that precision. Similarly, C-14 accelerator mass spectrometry (AMS) of tiny (microgram) atmospheric samples holds enormous promise, but valid results depend on strict attention to little

appreciated measurement artifacts, including sample size dependent efficiency, mass independent AMS isotopic fractionation, and the nature of the bivariate isotopic-chemical blank. The bottom line is that full advantage of the enormous discriminating power of trace isotopes and organic species in the atmosphere requires exhaustive attention the physics and chemistry of the respective measurement processes, supported by the demonstration of data quality through intercomparison and use of appropriate reference materials.

Acknowledgement: This work was supported in part by a grant from NASA.

Thermal and Optical Characterization of Biomass Smoke Particles: Implications for Organic and Black Carbon Determination*

T. Novakov and C. E. Corrigan (both at Energy and Environment Div., Lawrence Berkeley Laboratory, Berkeley, CA 94720; tel. 510-486-5319; e-mail tnovakov@lbl.gov)

In this paper we present results on characterization of filter-collected pine-needle and eucalyptus smoke particles by thermal, optical, and solvent extraction methods. Implications of these results on determinations of organic and black carbon concentrations and on absorption coefficients will be discussed. Our results show that black carbon (BC) and a significant fraction of organic carbon (OC) in biomass smoke particles have similar combustion temperatures. Combustion temperatures of both BC and this organic fraction depend critically on the concentrations of catalytically active metals such as Na and K. These metals may lower the combustion temperatures by more than 100°C. Consequently, thermal methods that rely on a specific temperature to separate organic from black carbon may either underestimate or overestimate the BC and OC concentrations, depending on the amounts of Na and K, and on the composition and concentration of the organic material present in a sample. Our measurements also demonstrate that optical absorption measured on filter samples remains unchanged upon removal of the organic component by solvent extraction. The specific mass absorption coefficient of black carbon, derived from black carbon concentration determined on solvent-extracted samples, was found to be 21.3 ± 0.6 m^2 g^{-1}, in agreement with the commonly accepted value. These results suggest that more than one method must be used to accurately determine the organic and black carbon concentrations.

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Bulk and Molecular Level Isotope Analysis of Products of Vegetation Burns

V C Turekian, S A Macko, W Gilhooly, R J Swap, D Ballentine and M Garstang (Dept. Environmental Sciences, University of Virginia, Charlottesville, VA 22903; 804-924-6845; vct8c@virginia.edu)

Isotopic signatures at the bulk and molecular level can be used to label products of vegetation burns. Isotopic analysis of bulk organic carbon and total nitrogen as well as fatty acids have been performed on biomass burning products. Aerosols and ash of parent vegetation exposed to controlled laboratory burns conserve the bulk carbon isotopic signal for smoldering burns and show an enrichment on the order of 2 $^{o}/_{oo}$ for samples experiencing both flame and smolder. Individual fatty acids analyzed by the new technology of gas chromatograph combustion isotope ratio mass spectrometry (GC-C-IRMS) indicate conservation of the carbon isotopic signal in the aerosols of controlled vegetation burns for Palmitic, Oleic and Stearic acid. Eucalyptus samples heated stepwise from 100-200°C at 20°C intervals and zea mays samples heated from 100-500°C at 100°C intervals, in a combustion furnace, show a conservation of the carbon isotope signal between the vegetation and the heated material. The eucalyptus samples showed a trend towards nitrogen isotope depletion from 100-120°C with isotopic enrichment from 120-200°C. Nitrogen isotope data for the zea mays showed a similar pattern with increasing isotopic depletion of the ash from 100-300°C and isotopic enrichment in the residue from 300-500°C. Data for carbon isotope fractionation in CO_2 as a function of flame temperature during controlled burns as well as the contributions of humic materials to aerosol loadings, are presented.

Modeling Biomass Burning Aerosols 160

C. Liousse (1,2), J.E. Penner (1), C. Chuang (1), C.R. Molenkamp (1), J.J. Walton (1), H. Eddleman (1), I. Shult (3) and H. Cachier (2) (1) (Global Climate Research Division, Lawrence Livermore National Laboratory, L-262, Livermore, CA, 94550 USA); (2) (Centre des Faibles Radioactivites, CNRS-CEA, Av de la Terrasse, 91198 Gif sur Yvette France); (3) (Max-Planck-Institute for Meteorology, Bundersstr 55, 20146 Hamburg, Germany)

Following an exhaustive literature survey, we have developed detailed emissions inventories for the amount of particulate matter from biomass burning, taking into account the savanna, forest, agricultural and domestic fires. We focused on black and organic carbon aerosols. Linked to the other sources (fossil fuel and natural sources), these emissions are used together with our global aerosol model to study the global distribution of total particulate matter. Our aerosol model has been linked to the Hamburg Climate Model, called ECHAM3, as well as to the NCAR Community Climate Model, CCM1.

The sensitivity of the predicted concentrations is tested by varying the aerosol removal rates by deposition. Observations of aerosol concentrations in the atmosphere and in precipitations in the Southern Hemisphere are able to constrain the model 's predicted biomass aerosols. Also, aerosol optical depths and single scattering albedos are calculated from the simulated particle distribution including black and organic carbon, sulfates and dust particles. These values are seen to be in agreement with previous observations.

Finally, from single scattering and surface albedos, a simple model is used to show the net cooling by atmospheric aerosols. The climate forcing derived from these simulations will be reported by Penner et al. (this issue).

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Chemical and Isotopic Characterization of Aerosols Collected During Sugar Cane Burning in South Africa

D.C. Ballentine (Department of Chemistry, University of Virginia, Charlottesville, Virginia 22903, USA; 804-924-6845; dcb8k@virginia.edu); S.A. Macko (Department of Environmental Sciences, University of Virginia, Charlottesville, Virginia 22903, USA); B. Martincigh (Department of Chemistry, University of Natal, Durbin, 4001, South Africa)

Emissions of organic materials during biomass burning have been suggested to influence the biogeochemical distribution of nutrients. Organic components that survive pyrolytic processes are of regional and global biogeochemical significance because they may serve as tracers for transport of biomass burning products. Two classes of compounds that are of interest in determining the transport of these products are polycyclic aromatic hydrocarbons (PAH) and fatty acids. Polycyclic aromatic hydrocarbons are stable to biodegradation and are typically produced during natural and anthropogenic combustion processes. Fatty acids are also stable to atmospheric degradation and have been implicated as useful biomarkers for atmospheric transport. In order to determine if these species are suitable biomarkers for the transport of biomass burning materials, the chemical and carbon isotopic composition of aerosols collected during sugar cane burning in South Africa have been investigated.

The production of PAH during sugar cane burning was confirmed with GC/MS in the selected ion monitoring (SIM) mode, but these species were in low abundance relative to other biogenic components. Fatty acids were found to survive the burning process and were significant components of the aerosol extract. Identified compounds included primarily even chain but also some odd and branched chain species. Similar investigations involving a controlled burn of Zea mays and a natural vegetation burn in southern Africa have also shown little or no PAH and the presence of both even and odd chain fatty acids in aerosol samples collected during burning. Bulk carbon isotopic ratios for the unburned sugar cane plant and the lipid extract were -13 and -28 per mil, respectively. The aerosol extracts were more depleted than the unburned plant, with isotopic ratios ranging from -28 to -23 per mil. This data indicates that isotopically light organic matter in soil may have contributed to the aerosols formed during sugar cane burning. The presence of odd chain fatty acids in the aerosols suggests that the extraneous organic matter may be bacterial in origin. Compound specific stable isotope analysis appears to be useful in confirming the origin of these components.

Aerosol Emissions from Forest and Cerrado Fires in the Amazon Basin

M A Yamasoe; P Artaxo (Instituto de Fisica, Universidade de Sao Paulo, C.P. 20516, CEP 01452-990, Sao Paulo, Brazil; ph. 55-11-8187016; fax 55-11-8186749; Internet: akemi@if.usp.br, artaxo@if.usp.br); A Miguel; A Allen (Instituto de Quimica, Universidade de Sao Paulo, Brazil)

Particulate matter emitted from biomass burning affects the atmospheric radiation budget and the geochemical cycles of several elements, besides other local and global effects. Those particles can either absorb or reflect the incoming solar radiation and are active as cloud condensation nuclei (CCN), possibly altering the atmospheric albedo and the hydrological cycles of tropical regions.

Aerosol particles were collected during direct emission over fires in cerrado and forested regions. Emphasis was given on characterizing the flaming and smoldering stages of combustion and establishing differences in emissions from cerrado and tropical rain forest. Analysis of samples from two long-term aerosols sampling stations was also performed, focusing on the impacts of fires. Samples were collected using Stacked Filter Units (SFU). Concentrations of Al, Si, P, S, Cl, K, Ca, Ti, Mn, Fe, Cu, Zn, Br and Pb were measured by Particle Induced X-ray Emissions (PIXE), ionic components (K+, NH4+, Na+, Ca++, Mg++, Cl-, NO3-, CH3COO-, HCOO-, SO4-- and C2O4--) concentrations were determined using ion chromatography, black carbon was quantified with a reflectance method and total mass concentration was measured by gravimetry.

Higher average concentrations, in percentage of mass, were obtained for sulfate, K, Zn and black carbon during flaming emissions, for cerrado and tropical rain forest burnings. Black carbon concentrations ranged, in percentage of mass, from 3.9% (during smoldering phase of tropical rain forest fires) to 12.6% (during flaming phase of cerrado fires). Cerrado emissions were enriched compared to forest emissions, specially for Cl, K and Zn. Chemical mass balance analysis showed the predominance of flaming emissions to the background cerrado station.

Laboratory Investigations on Aerosols Produced by Combustion of Savanna Grass and Cereal Straw

R Serpolay (OPGC/LaMP, Univ. Blaise Pascal, 12 av. des Landais, 63000 Clemont-Fd - France); Pham Van Dinh and J. P. Lacaux (OMP/CRA, Univ. Paul Sabatier, 65300 Lannemezan - France)
(Sponsor: Fred Rogers, AGU Member)

It is obvious that the huge amounts of biomass burned on the Earth surface are contributing to a large extent to the atmospheric aerosol and its further evolution. In order to get a better knowledge of that contribution from a qualitative as well as quantitative point of view, a set of equipments was built, developed and/or associated each others, the aim of which being:
-1°/ to reproduce such aerosols in controlled laboratory conditions - for instance capable of separating the flaming process from the smoldering one;
-2°/ to practice on them a number of analyses on their gaseous and particulate components and on the capability of the latters to act as Cloud Condensation Nuclei (CCN).

Till now the study has been carried out on two kinds of species: savanna grass and cereal straw.

In the aerosols produced from African savanna, the ratio $\Delta CPO/\Delta CO_2$. The Total Particulate Matter (TPM) and the number of particles with diameter $\geq 0{,}6\ \mu m$ are higher by smoldering than by flaming: respectively ~40% versus ~5%; 170 mg/g of dry matter (d.m.) burned versus 0.3 mg/g and almost three orders of magnitude higher.

An important amount of aerosol particles from each find of species are hygroscopic even at relative humidity quite below 100%. This is due to the fact that the most particles contain hydrophilic organic species and/or deliquescent mineral salts.

The emission factor of CN (Aiken Nuclei) appears to be the same for each mode of formation: it averages $3 \times 10^{12}\ g^{-1}$ of dry matter. But the emission factor for the CCN activated at 0.1% supersaturation is much higher in condition of smoldering than in condition of flaming: $0.6 \times 10^{11}\ g^{-1}$ of d.m versus $4 \times 10^{11}\ g^{-1}$ of d.m. This fact must be related to the production of a larger number of coarse particles in the smoldering mode.

Such emission factors lead to a global CCN production from these species comparable to those from the other natural or anthropogenic sources.

Wednesday, March 15, 1995

Morning
Session V: FUTURE EXPERIMENTS
CHAIRS - R A DELMAS, J G GOLDAMMER

Overview of the EXPRESSO Project (EXPeriment for Regional Sources and Sinks of Oxidants)

R A Delmas, J P Lacaux, B Cros, Laboratoire d'Aérologie, Université Paul Sabatier, 31062 Toulouse Cedex, France
P Zimmerman, G Brasseur, NCAR-ACD, PO Box 3000, Boulder Colorado 80307 USA
J P Malingreau, J M Gregoire, Institut for Remote Sensing Applications, CRC ECC, I 21010 Ispra Italy.
MO Andreae, F Meixner, MPI, Biogeochemistry Department, PO Box 3060 D-55020 Mainz Germany

EXPRESSO is an IGAC (BATGE-BIBEX) interdisciplinary experiment designed to investigate chemical processes in the tropical atmosphere. The purposes of the project are: (1) to better quantify the exchange fluxes of reactive trace gases and aerosols between the biosphere and the atmosphere in the tropics,i.e., biomass burning, biogenic emissions and deposition processes; (2) to analyze chemical interactions between the savanna and the tropical forest; (3) to isolate the respective roles of photochemical and meteorological processes; (4) to characterize the effects of ecological processes on trace gas fluxes; and, (5) to assess the impact of tropical sources on the global troposphere. To address these questions, an experimental programme will be implemented to quantify fluxes of numerous chemical species over a range of spatial scales. Several intensively-studied ground stations, each with a fully-instrumented tower and tethered balloon capability will be deployed in the savanna and in the forest. Biomass burning studies will be based on remote sensing of active fires and aircaft chemical measurements. Aircraft measurements along transects between the savannna and the forest and regional survey

flights over homogeneous ecosystems will serve to investigate atmospheric chemistry processes and tranfers from the surface to the middle troposphere. A strong modeling component including process level and chemistry/transport models will provide an assesment of the importance of tropical forest and savanna to the global chemical environment. The EXPRESSO Experiment will extend over the year 1996; it will represent an international collaboration in the framework of IGAC, to be led by European and U.S. scientists, and be conducted in collaboration with scientists in Africa.

Summary Results of the Bor Forest Island Fire Experiment, Fire Research Campaign Asia-North (FIRESCAN)

FIRESCAN Science Team (c/o J G Goldammer, Max Planck Institute for Chemistry, Biogeochemistry Department, Fire Ecology and Biomass Burning Research Group, D-55020 Mainz, Germany)
(Sponsor: M O Andreae #000 930 274)

In 1993 the first phase of the Fire Research Campaign Asia-North (FIRESCAN) was conducted in Krasnoyarsk Region, Central Siberia. The research campaign is designed to investigate hypotheses developed by the International Boreal Forest Research Association (IBFRA), Stand Replacement Fire Working Group. These hypotheses are related to quantitatively understanding boreal ecosystems, the role of fire in boreal ecosystems, and modeling and predicting forest dynamics. The involvement of atmospheric science through the structures of the International Global Atmospheric Chemistry (IGAC) Programme, a core project of the International Geosphere-Biosphere Programme (IGBP) gave additional insights into aspects of fire emissions and atmospheric chemistry. On 6 July 1993 an experimental high-intensity stand replacement fire was set in a light *taiga* coniferous forest dominated by a *Pinus silvestris* and a lichen-dominated ground cover (*Cladonia* sp.), on Bor Forest Island, Krasnoyarsk Region. Results are presented on fire characteristics and ecological and atmospheric chemical impacts. The medium- to long-term objectives of follow-up research and implications for fire research strategies are discussed.

State and Further Planning of the Regional Vegetation Fire Research Campaigns SAFARI, FIRESCAN, FIRESCHEME, and SEAFIRE

SAFARI and FIRESCAN Science Teams, c/o
J G Goldammer and M O Andreae (Max Planck Institute for Chemistry, Biogeochemistry Department, Fire Ecology and Biomass Burning Research Group, D-55020 Mainz, Germany)

A set of international fire research campaigns under the sponsorship of the IGBP/IGAC **Biomass Burning Experiment** (BIBEX) is being implemented or in the planning stage. They are designed to clarify the ecological, atmospheric chemical and climatic role of vegetation fires and other plant biomass burning on a regional and global scale. The results of following campaigns are evaluated:

o **Southern Tropical Atlantic Regional Experiment** (STARE), with the **Southern African Fire-Atmosphere Research Initiative** (SAFARI) and the **Transport and Atmospheric Chemistry Near the Equator** (TRACE-A) project

o **Fire Research Campaigns Asia-North** (FIRESCAN)

o **Fire Information Systems Research in the Socio-Culture, History and Ecology of the Mediterranean Environment** (FIRESCHEME)

o **South East Asian Fire Experiment** (SEAFIRE)

Further steps to integrate the findings of the regional research efforts into the IGBP activity **Global Analysis, Interpretation and Modelling** (GAIM) are discussed.

Wednesday, March 15, 1995

Morning/Afternoon Session VI: PARTICULATES AND SOLAR RADIATION CHAIRS - J E PENNER, R P TURCO

The Contribution of Aerosols From Biomass Burning to Climate Change

Joyce E. Penner, (Lawrence Livermore National Laboratory, Livermore, CA 94550; ph. 510-422-4140; fax 510-422-5844; Internet: penner1@llnl.gov); Catherine C. Chuang, (Lawrence Livermore National Laboratory, Livermore, CA 94550; ph. 510-423-2572; fax 510-422-5844; Internet: chuang1@llnl.gov); Catherine Liousse, (Lawrence Livermore National Laboratory, Livermore, CA 94550; ph. 510-423-5539; fax 510- 422-5844; Internet: lealliousse1@llnl.gov); and Karl Taylor (Lawrence Livermore National Laboratory Livermore, CA 94550; ph. 510-423#031#3623; fax 510-422-5844; Internet: taylor13@llnl.gov)
(AGU sponsor: Joyce Penner)

The contribution of aerosols from biomass burning to climate change results from two effects: clear-sky and cloudy-sky forcing. The clear-sky climate forcing by aerosols from biomass burning depends on the relative contribution of scattering and absorption by the aerosols which in turn depends on the fraction of aerosol mass associated with black carbon and its size distribution. In this paper, we review measurements relevant to these parameters and present new estimates of the clear-sky forcing by biomass aerosols, placing these estimates in the context of estimates for clear-sky forcing by anthropogenic sulfate aerosols, anthropogenic sources of black carbon from fossil fuel burning and anthropogenic sources of organic particulate matter from sources that are not associated with biomass burning.

The cloudy-sky forcing from biomass aerosols is more difficult to estimate because, among other factors, it depends on the amount of absorption by biomass aerosols in cloud. The factors controlling the cloudy-sky forcing by biomass aerosols will be reviewed and estimates of the plausible magnitude of the cloudy-sky forcing will be presented.

This work was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

Biomass Burning as a Source of CO and Aerosols as Measured by Space Shuttle (MAPS) and Satellite (AVHRR) Measurements

Sundar A. Christopher, (Institute of Atmospheric Sciences, SD School of Mines and Technology, Rapid City, SD 57701-3995 605-394-2291)
Vickie S. Connors, (National Aeronautics and Space Administration, Langley Research Center, Hampton, VA 23665-5225, 804-864-5849)
Donna V. Vulcan and Ronald M. Welch (Both at: Institute of Atmospheric Sciences, SD School of Mines and Technology, Rapid City, SD 57701-3995, 605-394-2291)
(Sponsor: A G U Member)

Biomass burning occurs across the planet as a result of both natural and anthropogenic factors. Once land is cleared either for shifting cultivation or to make space available for an expanding population, biomass burning takes on a seasonality regulated by the onset of the rainy season in the Tropics. In the boreal zone, both forest management practices and late summer thunderstorms act to cause forested regions to burn. Large amounts of carbon dioxide, carbon monoxide, water vapor, hydrocarbons, nitrogen oxide and smoke particles (Root, 1976) are released into the troposphere where they play a pivotal role in tropospheric chemistry and climate. Recent estimates have shown that about 114 Tg of smoke is produced per year in the tropics through biomass burning (Penner *et al.*, 1992). Several studies have shown that convective mixing redistributes the trace gases from the boundary layer into the free troposphere (e.g.: Connors *et al.* 1990). This could have an important effect on tropospheric chemistry since longer chemical lifetimes at higher altitudes would lead to longer horizontal distributions (Newell et al., 1988).

In the summer of 1994, large fires were reported over South East Asia, Indonesia (New Guinea and Borneo), and much of Australia. Scattered fires were also observed in central South America, Africa, British Columbia and Russia. Satellite images and shuttle photographs show the giant smoke and haze clouds produced by these fires, which extended over thousands of kilometers. The Space shuttle borne-measurements of Air Pollution from Satellites (MAPS) experiment detected enhanced CO mixing ratios over and downstream of the burning areas. Since the weighting function of the MAPS radiometer peaks around 7 to 8 km, this gives us an opportunity to examine the conditions leading to the vertical transport of carbon monoxide. Four years of drought conditions caused by the El Nino events, along with the increased biomass burning activities in the Tropics, could have significant implications on global climate.

The goal of this investigation is 1) to use AVHRR LAC data to accurately detect fires and smoke produced due to biomass burning using a combination of spectral and textural measures, 2) to utilize space shuttle measurements from the MAPS experiment to estimate carbon monoxide concentrations and, 3) to use geostationary satellite data in order to understand the influence of weather systems on the transport of trace gases from the boundary layer to the free troposphere. The analysis will be performed from the April and October 1994, MAPS missions.

SCAR-C - Smoke Cloud and Radiation experiment: California

Y. J. Kaufman (AGU member, NASA/GSFC, code 913, Greenbelt, MD 20771, Kaufman@climate.gsfc.nasa.gov 301-286-4866)
L. A. Remer (Science, System and Applications),
P. V. Hobbs (University of Washington),
D. E. Ward (USDA/USFS, MN),
R. Ottmar (USFS, WA)
L. Flynn (University of Hawaii)

The Smoke Cloud and Radiation experiment conducted in Sept., 1994 in the North West US, was one in a series of the SCAR experiments designed to measure the optical, physical and chemical properties of aerosol particles and their interaction with clouds and radiation. This information will serve in development of new satellite remote sensing techniques from MODIS on the Earth Observing System, and in assessing the impact of anthropogenic aerosol on climate. The SCAR-C experiment studied biomass burning from prescribed and natural fires. As part of its objectives it also measured the relationship between the fire apparent temperature distribution, the rate of biomass consumption and the emission factors of trace gases and particulates from the fire. Remote sensing of the fires and smoke from the AVIRIS and MAS imagers on the ER-2 aircraft was combined with a complete in situ characterization of the aerosol and trace gases from the C-131A of the U. of Washington and aerosol and trace gas measurements from the Forest Service Cesna. Simultaneous ground based measurements of the aerosol spectral optical thickness and size distribution were conducted using sun/sky radiometers. A description of the experiment and preliminary results of the remote sensing part of the experiment will be presented. In situ measurements are covered by other talks in this conference.

AIRBORNE IN SITU AND REMOTE SENSING MEASUREMENTS OF SMOKE FROM BIOMASS FIRES IN THE PACIFIC NORTHWEST

P. V. Hobbs, (Department of Atmospheric Sciences, AK-40, University of Washington, Seattle, WA 98195) J. A. Herring, D. A. Hegg

As part of the Smoke, Cloud and Radiation (SCAR-C) experiment carried out in September 1994, the University of Washington's Convair C-131A research aircraft was used to obtain detailed measurements on the smoke from both prescribed biomass burns of and wild fires in the Pacific Northwest. *In situ* measurements were obtained of particle and trace gases from the fires, from which aerosol size distributions, emission factors, aerosol mass light-scattering efficiencies, CCN mass efficiencies, and the optical properties of the smoke were derived. Measurements on plume dispersion, smoke mass concentrations, and the ratio of extinction-to-backscattering of light, derived from airborne lidar measurements, were also obtained.

Airborne Measurements of the Radiative and Optical Properties of Smoke Produced by the Biomass Burning During the SCAR-C Field Mission

F P J Valero (California Space Institute, Scripps Institution of Oceanography, University of California at San Diego, La Jolla, CA 92093; e-mail: fvalero@ucsd.edu)
I Sokolik (NASA Ames Research Center, Moffett Field, CA 94035; e-mail: irina@ra.arc.nasa.gov)
P Pilewskie (NASA Ames Research Center, Moffett Field, CA 94035; e-mail: pil@ra.arc.nasa.gov)

We have participated in the Smoke, Clouds, and Radiation (SCAR) field mission (9/21- 10/3/94) to provide measurements of radiation fields in the biomass burning environment. Total-direct-diffuse multichannel radiometers were installed in up- and downlooking positions on-board two aircraft: University of Washington C-131A and NASA ER-2. The radiometers allowed us to measure and retrieve the aerosol radiative and optical characteristics such as: spectral total, diffuse and direct fluxes; spectral optical depth; spectral upwelling flux; albedo of the underlying surface - atmosphere system; transmission; and radiative heating/ cooling rates. The data set to be presented was obtained during several research flights during the prescribed fires as well as during the wild forest fires.

Airborne and Ground Based Characterization of Regional Smoke Events from Biomass burning in Alta Floresta Brazil

P. Artaxo (Instituto de Fisica da USP; (55) (11) 818 7016; artaxo@if.usp.br,
R. Babbit (USFS, Fire Chemistry Lab Missoula, MT. 59807; 406 329-4862; ch_dew@lewis.umt.edu)
T. Eck and B. Holben (Both at GSFC, Greenbelt, MD, 20771; 301 286-7282)
A. Lucia (Instituto de Fisica da USP; (55) (11) 818 7016)
A. Pereira and A. Setzer (Both at INPE Sao Jose dos Campos, SP, Brazil; 55 (123) 41 89 77 x347)
D. Ward (USFS, Fire Chemistry Lab Missoula, MT. 59807; 406 329-4862; ch_dew@lewis.umt.edu)
(Sponsor: Yoram Kaufman)

A network of sun and sky scanning spectroradiometers have been monitoring aerosol concentrations and properties in the Brazilian Amazon Basin during the dry/burning seasons of '93 and '94. Alta Floresta located in Northern Matto Grosso, Brazil experienced extremely heavy aerosol loading from biomass burning in 1994 as compared to measurements from the previous year. An airborne and ground based campaign to monitor aerosol and trace gas emissions was made to characterize the vertical and horizontal extent in this source region. Collaboration from INPE, U. of Sao Paulo, the US Forest Service and NASA provided instrumentation and personel on INPE's Bandarante research aircraft. This included a nephelometer, CO, CO_2 and H_2O analyzer, air pressure, canister samples for trace gas analysis, mass flow filters for time integrated particulate concentrations, an aetholometer for black carbon analysis, CNC counter, a sun photometer for aerosol optical thickness and an SE590 for spectral measurements of upwelling radiance. A high density ground based network of spectral sun and sky scanning radiometers also measured the horizontal extent of the aerosol optical thickness for which size distributions were estimated from the spectral optical thickness.

Aerosol loading from biomass burning during the field campaign was the highest measured in the region during the two years of ground measurements. The results will be presented and compared to those of similar field campaigns conducted in the tropics.

Measurements of the Effects of Biomass Burning Smoke in the Amazon Basin on Solar Radiation Incident at the Surface

T.F. Eck, B.N. Holben, and I. Slutsker (All at: NASA/GSFC, Code 923, Greenbelt, MD, 20771; 301-286-6559; e-mail: teck@ltpsun.gsfc.nasa.gov)
(Sponsor: Y.J. Kaufman, NASA/GSFC)

Simultaneous measurements of aerosol optical properties and total incident solar radiation were made in biomass burning regions of Brazil in order to characterize the direct radiative effects of smoke aerosol on the solar radiation incident for cloudless or near cloudless conditions. Measurements were made in September 1992,September-October 1993, and August-October 1994 in cerrado (savanna) regions of the Amazon basin. Automatic sunphotometers were utilized to infer the spectral aerosol optical depth, wavelength exponent, total precipitable water and assymetry factor and pyranometers measured the total insolation for all dates and incident photosynthetically active radiation (PAR; 400-700 nm) for September 1992 and August-October 1994.

For a near solar noon solar zenith angle of 15^0, the measured reduction of solar radiation incident at the surface from a day of relatively low aerosol loading (aerosol optical depth at 440 nm, t_{a440}, of 0.43) to a day of high aerosol loading (t_{a440} of 1.72) was 16.4 % for total insolation and 18.9% for PAR incident at the surface. We utilized a simple clear sky flux model to estimate total insolation based on sunphotometer measurements and assumed single scattering albedo. By varying the single scattering albedo and fitting it to the measurements we computed an estimate of the single scattering albedo of the smoke aerosol ranging from 0.80 to 0.89 for total insolation and 0.90 to 0.92 for PAR. Calculated half-day totals of insolation for a day with "typical" aerosol loading for the burning season of t_{a440}=1.43, resulted in a reduction of total insolation by 17.9 % and 25.0% for PAR compared to a typical pre-burning season loading, t_{a440}=0.20. These computed reductions at a solar zenith angle of 76^0 are 37.1% for total insolation and 50.8% for PAR, while at 26^0 solar zenith the reduction is 15.4% for total insolation and 21.6% for PAR. The reductions of incident solar radiation at the surface due to biomass burning aerosols have implications for potential reductions of surface heating in the morning with resultant delayed onset and strength of convection.

Aerosol Climatology During the Burning season from Ground Based Spectroradiometer measurements

B. Holben; T. Eck , I. Slutsker and W. Newcomb (at GSFC, Greenbelt, MD, 20771; 301 286-7282), A. Setzer and A. Pereira (Both at INPE Sao Jose dos Campos, SP, Brazil; 55 (123) 41 89 77 x347) (Sponsor: Yoram Kaufman)

A network of sun and sky scanning spectroradiometers have been monitoring aerosol concentrations and properties in the Brazilian Amazon Basin during the dry/burning seasons of '93 and '94. Aerosol optical thickness, size distributions and phase functions are derived from these data.

The data were collected at three cerrado sites and four forest sites making a grided network with a spacing of approximately 500 km between sites that covers the southern and eastern boundary of the Amazon and provides for quantification of the advection of aerosols due to the counter clockwise circulation of the atmosphere.

The dry season data were clearly divided into a non burning and burning season for all sites. For example at Cuiaba in the cerrado region, the dry season began in June with an average aerosol optical thickness (AOT) of 0.19 at 440 nm and a wavelength exponent of 0.89. During the 60 day burning portion of the dry season the aerosol optical thickness averaged 1.36 at 440 nm with a wavelength exponent of 1.65 indicating the presence of small particles. These values are relatively typical for all sites during preburing and burning seasons but the duration varied greatly between sites and between years for the same sites. Size distributions were dominated by a Pinatubo mode during the pre burning season in '93 but was almost non existent in '94. Size distributions during the burning season showed distinct accumulation and coarse particle modes which dominated the Pinatubo mode. There was no distinction in aerosol properties between locations, either forest or cerrado, with respect to time of day, apparent age of smoke or precipitable water. It is speculated that the nature of the measurements and/ or inversion may bias the data towards that of a uniform well mixed smoke and that the smoke generated from the forest regions is more similar to that of cerrado as secondary growth/maintenance fires predominate. The spatial variability and aerial extent of the aerosol loading will be discussed.

Biomass Smoke in the Tropics: From Sources to Sinks

L F Radke (Research Aviation Facility, NCAR*, PO Box 3000, Boulder, CO 80307; tel: 303-497-1030; e-mail: radke@ncar.ucar.edu)
K K Laursen (Research Aviation Facility, NCAR*, PO Box 3000, Boulder, CO 80307; tel: 303-497-1030; e-mail: krista@ncar.ucar.edu)

The smoke source term for particles is increasingly well understood as are the particles' principle characteristics with regard to size, albedo and other optical properties, chemical composition, and the particles' efficiency as cloud condensation nuclei (CCN). However, the step from evaluating the source term to characterizing the atmospheric impact of the particles at increasing geographical scales remains highly uncertain. Indications of this uncertainty are especially evident in various studies in Brazil. Here, direct evidence of biomass smoke modifying clouds can easily be found. The impact is dramatic, yet efforts to detect such regional scale impact from satellite imagery remain controversial. Similarly, the primary control of smoke lifetime, cloud scavenging, remains quantitatively elusive. Local measurements suggest possibly rapid removal, far faster than theory predicts. Smoke lifetime issues bear heavily on the puzzling observation that while smoke from Africa seems quite evident in AVHRR optical depth analyses, smoke plumes from Brazil over the south Atlantic are almost imperceptible. Where has the smoke gone?

In this paper, we will review our measurements in Brazil and elsewhere at the local scale and will contrast these to larger scale satellite observations. We will then present a practical series of airborne measurements which should produce experimental closure between smoke sources and sinks.

* The National Center for Atmospheric Research is sponsored by the National Science Foundation.

Comparison of Smoke and Industrial Aerosol Optical Properties

L.A. Remer (Science Systems and Applications Inc., code 913,Goddard Space Flight Center, Greenbelt, Maryland 20771; 301-286-8235; Internet remer@climate.gsfc.nasa.gov)

Y.J. Kaufman (Laboratory for Atmospheres, Goddard Space Flight Center, Greenbelt, Maryland 20771

B. Holben (Laboratory for Terrestrial Physics, Goddard Space Flight Center, Greenbelt, Maryland 20771

Two networks of automatic sun/sky photometers measured the total atmospheric column aerosol optical properties during 1993. One network, located in Brazil, observed smoke aerosol from biomass burning. The other network operated in the mid-Atlantic region of the eastern United States where aerosols from industrial/urban sources prevail. Aerosol optical thickness, aerosol size distribution and phase function are derived from the sun and sky radiance measured by these instruments. The networks remained in place, automatically collecting data for several months and provide a database of hundreds of size distributions and thousands of optical thickness

measurements. Despite the differences in origin and composition of the two aerosol types examined, we find several similarities in size distribution. For example, in both data sets, the accumulation mode varies as a function of aerosol optical thickness. However, there are also differences some of which may be due to the differences of cloud processes in the two regimes. Smoke aerosol properties derived from similar data measured recently in the western United States will also be presented.

Effects of Biomass Burning on Satellite Estimates of Surface Radiation in Central Africa

C H Whitlock and D R Cahoon (Atmospheric Sciences Division, NASA Langley Research Center, Hampton, Virginia 23681-0001,USA)
T Konzelmann, Geographisches Institut, Swiss Federal Institute of Technology, CH-8057 Zurich, Switzerland)
(Sponsor: J S Levine)

The World Climate Research Program has recently completed Version 1.1 satellite estimates of surface shortwave radiation over the globe (280 x 280 km equal-area grid) for a 46-month period. When compared with measurements from surface sites, the satellite product has large errors in the central African region during periods of extensive biomass burning. Time histories of the surface radiation errors correlated with satellite-detected fires indicate that biomass burning reduces surface irradiance by as much as 120 W m^{-2} when compared with background aerosol conditions during seasons with low burning.

Wednesday, March 15, 1995

Afternoon/Evening Session VII: FIRE CHARACTERISTICS, BIOMASS, FUEL, CHARCOAL
CHAIRS - B J STOCKS, S W TROLLOPE

Burn Types and Nitrogen in Tropical Savannas of Calabozo, Venezuela.

B. Bilbao(Centro de Ecologia y Ciencias Ambientales, Instituto Venezolano de Investigaciones Cientificas, Aptdo. 21827, Caracas 1020-A, Venezuela; ph. +58-2-5011193; fax +58-2-5011088; Internet: bbilbao@oikos.ivic.ve); E. Medina (Centro de Ecologia y Ciencias Ambientales, Instituto Venezolano de Investigaciones Cientificas, Aptdo. 21827, Caracas 1020-A, Venezuela; ph. +58-2-5011193; fax +58-2-5011088; Internet: emedina@oikos.ivic.ve)

Three types of experimental burns were found in the tropical savannas of Calabozo, Venezuela. The first type occurred on a savanna dominated by HYPARRHENIA RUFA(an African grass) which was submitted to a second burn after 30 years of fire protection. Maximum temperature (472C) was reached at soil level–where grass tussocks were 30 cm high. The rate of burn spread was 10 cm/s and the flame length was 1 m. In other area of the same savanna that had been submitted to frequent fires, we found the second type of burn. This one showed the same maximum temperature but less fire spread and a taller flame length (2m). The third one was associated with grasslands mainly dominated by native species seconded by H. RUFA The areas protected from fire over 30 years plus the ones that were burnt after this period showed the same burning behavior: maximum temperature of 389C (from 0 to 30 cm height), very slow fire spread and a flame length of 1.50 m.

The less N content in the ashes was consistent at the highest temperatures reached in H. RUFA savannas. Besides this, higher soil N content was found in those H. RUFA areas we left unburned, but "no differences were detected in those of native species".

There was no correlation amongst the biomass production, litter accumulation, or live/dead biomass ratio and fire behavior. Presumably the lower temperature and rate of fire spread in savannas dominated by native species was due to the fact that we found a higher biodiversity and equitatibility of the fuel material, while in H. RUFA savannas the homogeneity of the same and the fuel characteristics seemed to determine a higher fire intensity.

Contribution of Spread-Fire Model in the Study of Savannah Fires

M Moula , J M Brustet and J Fontan (Laboratoire d'Aérologie, U.P.S, U.R.A/CNRS-354, 118 Route de Narbonne 31062 Toulouse cedex , France)
J M Grégoire, H Eva (Joint Research Centre, Institute for Remote Sensing Applications I-21020 Ispra (Va) Italy)

Remote sensing techniques are often used to localize savannah fires, however they do not cover all needs because of the limited crossings of satellite over a specific area during one day (NOAA). To achieve an accurate estimation of the burned biomass over a short period (24 hours) fire behaviour models can be used.

The software BEHAVE, based on the Rothermel model was used to compute the ignition probability and the rate of spread of savannah fires. Atmospheric parameters (wind, cloud cover, temperature) and the fuel moisture content was shown to determine the ignition probability. It presents a daily cycle with a minimum of 0% at 6 a.m and a maximum of 80% at 3 p.m. The daily variation of fire density was obtained from the analysis of NOAA/AVHRR images taken over the Central African Republic.Over an area of 150.000km^2 the average number of fires varies (over 24hour) from 5 fires at 6 a.m to 974 at 3 p.m. The number of fires appears to be strongly correlated to the ignition probability. The results show that in the classical condition of satellite image acquisition (1 image/day) it is possible to use this combined remote sensing-modeling approach to compute the actual number of fires on a daily basis.

The Carbon-Isotope Composition of Terrestrial Biomes.

M I Bird and A R Chivas(Research School of Earth Sciences, Australian National University, Canberra, 0200, Australia: tel. 61-6-2493406; email: michael.bird@anu.edu.au)

Carbon isotopes ($\delta^{13}C$ values) are an important tracer of gaseous and particulate emissions from biomass burning. Unfortunately, individual plants exhibit a wide range of $\delta^{13}C$ values (>15‰) which can make the assignment of a 'bulk' $\delta^{13}C$ value to an ecosystem difficult. In contrast, surface soil organic carbon (SOC) $\delta^{13}C$ values provide an integrated measure of isotopic composition in at least the local area which can be more readily used to assign $\delta^{13}C$ values to a variety of biomass burning sources.
For this study, over 1000 surface SOC samples representing most major vegetation types have been collected and analysed. The samples span latitudes from 45°S to 78°N (tropical to arctic), an altitudinal range from 0-4600m a.s.l., and represent arid to perhumid climatic regimes.
The results for C_3 ecosystems (closed forests and tundra) show a consistent decrease in the average $\delta^{13}C$ value of C_3 ecosystems of

around 1-3‰ from high (arctic) to low (tropical) latitudes. The ^{14}C activities of these soils suggest that this variation is mostly due to faster organic matter turnover times in the tropics (i.e. sampling more recent atmospheric CO_2 which has a lower $\delta^{13}C$ value than in pre-industrial times due to the burning of fossil fuels).
Results from mixed C_3/C_4 ecosystems (savannas/grasslands/hot deserts) show a wide range of values from -13 to -26‰, as is to be expected from the heterogeneous distribution of C3 and C4 plants in savannas ecosystems. Sampling close to, and remote from, trees in C_3/C_4 ecosystems suggests that trees exert a disproportionate effect on the $\delta^{13}C$ of savanna soils which has not been previously recognized. A consistent relationship exists between the $\delta^{13}C$ value of SOC and the percentage of organic carbon in the sample (r^2=0.81), with high $\delta^{13}C$ values correlated with low organic carbon contents and vice versa.

Biomass Burning and Carbon Dynamics along Anthropogenic Disturbance Gradients in the Amazon Basin

J B Kauffman (Oregon State University, Corvallis, OR 97331; 503-737-1625)
R F Hughes, D L Cummings, and D E Ward (Oregon State University, Corvallis, OR 97331; 503-737-1626 and USDA Forest Service Int. Research Station, Missoula MT 59807; 406-329-4866)

Currently, areas of the Amazon Basin undergoing landuse changes are characterized as mosaics of primary forests, pastures, shifting cultivation, and regenerating forests. Few studies have quantified total aboveground biomass(TAGB), nutrient pools, losses and transformations in these cover types. In the states of Rondonia and Para, TAGB of primary forests ranged from 292 to 435 Mg ha^{-1}. TAGB of regenerating forests (Capoeira) and pastures ranged from 70-177 Mg ha^{-1} and 53-99 Mg ha^{-1}, respectively. The quantity of TAGB consumed is high relative to other reported combustion factors for tropical moist forest (38-57%, mean of 48%). Mean combustion factors in slashed regenerating forests and pastures were 63 and 59%, respectively. Similar proportions of C were lost during combustion processes with <3% remaining on site as combusted ash. Given the preponderance of fires in pastures and regenerating forests, the C dynamics of these cover types should be included in models of global C dynamics. In addition, these data suggest that inorganic C pools created by combustion processes are not likely significant long-term sinks of C.

Chlorine and Bromine in the Biomass of Tropical and Temperate Ecosystems

I. M McKenzie (Shafizadeh Center for Wood and Carbohydrate Chemistry, University of Montana, Missoula, MT 59812; 406-243-6166; E-mail smokie@selway.umt.edu)
D E Ward and W M Hao (Both at: Intermountain Fire Sciences Laboratory, Intermountain Research Station, Forest Service, U.S. Department of Agriculture, P.O. Box 8089, Missoula, MT 59807; 406-329-4862)

Biomass burning could be a significant source of atmospheric methyl chloride and methyl bromide. The amount of methyl chloride and methyl bromide emitted during a fire is hypothesized to depend on the concentrations of Cl and Br in the fuels burned. The concentrations of Cl and Br in fuel samples collected from savannah ecosystems in Zambia, primary and secondary forests in Brazil, and temperate forests in Oregon were determined by ion chromatography. Across all the ecosystems, wood had significantly less Cl and Br than other classes of biomass, such as foliage or grass. An approximate molar ratio of Cl:Br of 100 in wood remained constant for all ecosystems. Tropical wood had 50 to 100 times more Cl than temperate wood. Grass from Zambia had the most Cl, and the highest Cl:Br ratio. Duff and humus from the Oregon coast had the most Br and the lowest Cl:Br ratio. Gradients of Cl and Br exist for vegetation over a transect from western to eastern Oregon, with the highest concentrations near the coast. Fuel concentrations of Cl and Br, fuel loads, and percent fuel consumed were used to determine the contribution of each Zambian savannah fuel to the maximum possible Cl and Br released, which could be in the form of methyl chloride or methyl bromide, when the savannah was burned.

Fuel Biomass and Nutrient Dynamics Associated with Savanna Fires in South Africa and Zambia

R W Shea, B W Shea, J B Kauffman (Department of Rangeland Resources, Oregon State University, Corvallis, OR 97331; ph 503-737-3341; Internet: shear@heart.cor.epa.gov); D E Ward (Intermountain Fire Sciences Laboratory, USDA Forest Service, Missoula, MT 59807; ph 406-329-4866; Internet: CH_DEW@lewis.umt.edu)

Nutrient loss and redistribution associated with savanna fires was investigated during August and September 1992 at ten sites as part of the Southern Africa Fire-Atmosphere Research Initiative (SAFARI 92) experiment in the Kruger National Park, South Arica, and at four sites with distinct land-use patterns in the savanna woodlands of Zambia. Release of carbon dioxide, methane, and various species of nitrogen during savanna fires is suspected to contribute substantially to changes in global climate regimes, however limited quantitative data exist detailing the nutrient characteristics of fuel biomass, burning conditions, and the post-fire environment in African savannas. We quantified the concentration and mass of N, C, P, K, S, and Ca present in surface fuel biomass suscepatable to combustion from fires, and in residual fuels and ash following fire. Pre and post fire concentrations of P, K, Na, and Ca in soils between the depths of 0 to 2.5 cm and 2.5 to 10 cm were also determined.

Carbon, Hydrogen and Nitrogen Content of Tropical Ecosystem Fuels

R A Susott, S P Baker, G Olbu, and D E Ward (USDA Forest Service, Intermountain Research Station, PO Box 8089, Missoula, MT 59807)
J B Kauffman (Department of Rangeland Resources, Oregon State University, Corvallis, OR 97331)
(Sponsor: W M Hao)

Representative biomass fuel samples were collected from 1990 to 1993 at experimental fire sites in tropical ecosystems as part of the BASE-B, CARBON Cycling, and AEROSOL programs. Elemental carbon, hydrogen, and nitrogen contents were measured on over 950 of the samples from 19 sites in Brazil and 22 sites in Africa. Typical Cerrado, primary forest, second-growth forest and pasture burns were sampled in Brazil. Dryland savanna, dry and moist Miombo, Dambo, Chitemene, and Fallow Chitemene were sampled in South Africa and Zambia. Significant classes of aboveground biomass were sampled including grasses, dicot litter, leaves and stems of small shrubs, and woody debris in four size classes from <0.64 cm to >7.6 cm diameter. Carbon content (on a dry weight basis) ranged from 36% for some litter samples up to 54% for leaf samples. Hydrogen ranged from 4% to 6% and Nitrogen ranged from 0.2% to 3%. Africa biomass samples were generally more variable and lower in carbon content compared to Brazil samples. Thermogravimetric analysis of selected samples shows that variable inorganic ash content is an important factor contributing to uncertainty in carbon content.

Wednesday, March 15, 1995

Evening Activity
GLOBAL EMISSIONS INVENTORY ON BIOMASS BURNING (IGAC/GEIA)

A Global Inventory for the Geographical and Temporal Distribution of Biomass Burning and its Gaseous and Particulate Emissions

J S Levine, D R Cahoon, Jr., and W R Cofer III (Atmospheric Sciences Division, NASA Langley Research Center, Hampton, VA 23681-0001, USA, 804-8645692)
J G Goldammer (Fire Ecology and Biomass Burning Group, University of Freiburg, Freiburg, Germany)
B J Stocks (Canadian Forestry Service, Sault Ste. Marie, Ontario, Canada)
K S Reightler, Jr. Astronaut, and K P Lulla (NASA Johnson Space Flight Center, Houston, TX 77058)
C D Elvidge (NOAA National Geophys. Data Center, Boulder, CO)
J L McElroy (U.S. E. P. A., Las Vegas, NV 89193-3478)
W S W Trollope (University of Fort Hare, South Africa)
V W J H Kirchhoff and A W Setzer (Instituto Nacional de Pesquisas Espacias (INPE), Sao Jose dos Campos, SP, Brazil)

The global distribution (geographical and temporal) of biomass burning and its gaseous and particulate emissions is of critical importance to atmospheric chemistry and global climate modeling. A global distribution does not exist at the present time. To remedy this deficiency, a global distribution of biomass burning is being developed as part of the International Global Atmospheric Chemistry (IGAC) Project Global Emissions Inventory Activity (GEIA). The global biomass inventory will include data from a variety of sources including photographs and observations of burning and smoke plumes obtained by astronauts on the Space Shuttle and measurements from the NOAA Advanced Very High Resolution Radiometer (AVHRR) and the Defense Meteorological Satellite Project (DMSP) Block 5 satellites. This data will become part of the Earth Observing System (EOS) Data Information System (DIS) Distributed Active Archive Center (DAAC), which will be readily available to the world's scientists.The objectives, goals, and progress to-date of the Global Emission Inventory on Biomass Burning will be discussed.

The Global Vegetation Fire Inventory (GVFI): Objectives and Progress Report

Global Vegetation Fire Inventory Science Team (c/o J G Goldammer, Max Planck Institute for Chemistry, Biogeochemistry Department, Fire Ecology and Biomass Burning Research Group, D-55020 Mainz, Germany, and B J Stocks, Great Lakes Forestry Center, Forestry Canada Onatario Region, CDN-Sault Ste. Marie, Ontario P6A 5M7, Canada)
(Sponsor: M O Andreae #000 930 274)

Models of the global atmospheric chemical and climatic impacts of vegetation fires at present are based on crude estimates and weak databases. Reliable data are not available due to the lack of systematic fire monitoring by conventional methods and by remote sensing.

In 1994 the first phase of a Global Vegetation Fire Inventory (GVFI) was launched. The objectives of GVFI is to compile the available data on vegetation fires (forest and other wildland fires, agricultural burning) on a country-vegetation type base. The results of the inventory will be compared with a global vegetation fire model recently developed for the High Resolution Biosphere Model (HRBM). The outcome of this first phase of GVFI will be used to define the gaps of knowledge, the priorities and requirements for future research, and the development of a gridded emission inventories.

GVFI is considered to be integrated into a Global Vegetation Fire Information System (GVFI) which had been proposed by the Dahlem Conference on "Fire in the Environment" (Berlin, 1992).

An interim report on the state and prospects of the GVFI is given.

Spatial Distribution of Biomass Estimates of Forests of Tropical Africa

S Brown and G Gaston (US EPA, 200 SW 35th St, Corvallis, OR 97333; 503-754-4346)
(Sponsor: J S Levine)

Estimates of geographically referenced biomass densities of vegetation of tropical Africa were modeled in a geographic information system (GIS). Spatial data bases (3.75 km by 3.75 km resolution) of climate, soil, geomorphologic indices, and vegetation classes were first used to estimate the potential biomass densities (without human impacts). The resulting map was then modified to take into account the reduction in biomass (degradation) resulting from the cumulative effects of human disturbances such as sanctioned and unsanctioned logging, fuelwood gathering, grazing, and slash-and-burn-cultivation. For this step, we assumed that population density could be used as a surrogate index to account for the biomass reduction. We made estimates of actual biomass density from regression equations of degradation ratios vs. population density, stratified by either vegetation type or climatic regimes. Potential biomass densities (above and belowground) ranged from 300-600 Mg/ha for closed forests, 65-260 Mg/ha for woodlands, and 20-60 Mg/ha for savanna/grasslands. High human population densities, particularly in the drier zones, resulted in actual biomass densities of woodlands that were 70-80% of their potential. In constrast, most moist forests were typically reduced by about 30-50% of their potential biomass. This work represents some of first efforts at producing maps of biomass density suitable for use with maps of fires or deforestation.

A Global Biomass Burning Data Repository

D W Sproles (Computer Sciences Corporation, Applied Technology Division, Hampton, Va 23666-1379; pH. 804-865-1725; fax 804-865-1725; Internet: d.w.sproles@larc.nasa.gov)
(AGU Sponsor: Joel S. Levine)

Over the last five years the importance of the burning of various ecosystems has been shown to be comparable to the use of fossil fuels on global atmospheric pollution. A global data repository on burning would be a valuable research tool for atmospheric scientists.

New imaging techniques permit the detection of ecosystem burning from satellites. Data collection with a number of other methods is also ongoing. A Biomass burning data repository would offer a means for assembling data from the many available sources. A repository would provide researches a single site to search for and obtain data for their analysis. A distribution system would allow submittal and retrieval of this information.

Effort has been ongoing in this area to prove the feasibility of this concept. This effort includes the development of a prototype database as

the repository with relational database management systems. The database divided the globe into 1 degree by 1 degree elements. The database schema allowed for static and reported data. Static data included coordinates, land areas and ecosystem parameters. The variable data included information on gases, amount of carbon consumed by a fire, date of burning and percentage of area burned. Another area studied was in devising methods of distribution take into consideration possible data storage medium, computer platform availability, etc.

A repository must be designed with flexibility in mind; a database is one methodology considered. The many sources of data, data formats, the manner in which data is gathered for inclusion, and distribution medium are all variables. Developing an accessible tool requires input from the atmospheric scientists to define these variables. The other requirement will be their participation by submitting data to load such a repository.

An Overview of the EOSDIS Langley Research Center Distributed Active Archive Center.

R C Dunkum Jr, J O Olson and S E Sorlie (All at: NASA Langley Research Center,
Mail Stop 157-B, Hampton, VA 23681-0001, 804-864-8609;
Email: olson@magician.larc.nasa.gov)
Sponsor: Joel Levine (804) 864-6326

The Earth Observing System (EOS) is a long-term interdisciplinary and multidisciplinary research program to study global-scale processes that shape and influence the Earth as a "system". The EOS Data and Information System (EOSDIS) is a single, distributed system which will serve the Earth science community by archiving and distributing Earth Observations and related data. EOSDIS will provide easy and reliable access to the EOS data products derived from the EOS platforms, to Earth observations data previously archived at a number of data centers and to new data products derived from these data.

Science data products have been assigned to be archived in and distributed from a particular EOSDIS data center according to the scientific discipline associated with each particular data set. Nine Distributed Active Archive Centers (DAACs) have been selected based on their existing institutional Earth science discipline and research expertise, infrastructure, and commitment. The Langley DAAC, located at the National Aeronautics and Space Administration (NASA) Langley Research Center in Hampton, Virginia performs the data archival and distribution functions for the general science community in the areas of radiation budget, clouds, aerosols and tropospheric chemistry.

The overall goals of the Langley DAAC activities are to increase the use of existing data sets in the radiation budget, clouds, aerosols and tropospheric chemistry disciplines and to provide the general scientific community access to data retrieved from the EOS platforms that will be launched over the next 15 years.

Thursday, March 16, 1995

Morning
Session VII: FIRE CHARACTERISTICS, BIOMASS, FUEL, CHARCOAL - CONTINUED

Assessment of the spatial distribution of biomass fuel consumption and burning of agricultural waste

Rosemarie Yevich and Jennifer A Logan (Department of Earth and Planetary Sciences and Division of Applied Sciences, Harvard University, Cambridge, MA 02138; 617-495-4582; rmy@io.harvard.edu, jal@io.harvard.edu)

Biomass fuels are the major source of energy for rural populations in much of the developing world. We present an assessment of the consumption of the following biomass fuels on a country by country basis: wood, charcoal, dung, and agricultural residues. We have assessed also the burning of agricultural wastes in the fields on a crop-by-crop and national basis. Unlike earlier estimates that assumed a uniform fraction of burning for crop residues, we allow for different agricultural practices in different regions, for individual crops. Our results are based on the published and "gray" literature, and on consultations with many experts in energy consumption in developing countries, and in agricultural pratices.

Our approach allows for the use of emission factors specific to particular fuels and combustion practices, where known. Our results are spatially disaggregated on a grid of 1° latitude by 1° longitude for inclusion in 3-d models. We will present a comparison of emissions of trace gases from biomass fuels and agricultural residues with our own estimates of emissions from savanna burning, deforestation, and wildfires.

BIOMASS BURNING IN THE SAVANNAS OF SOUTHERN AFRICA WITH PARTICULAR REFERENCE TO THE KRUGER NATIONAL PARK IN SOUTH AFRICA

W.S.W. Trollope, (Department Livestock & Pasture Science, Faculty of Agriculture, University Fort Hare, Private Bag x402, Alice, 5700, South Africa).

Abstract

Africa is referred to as the ***Fire Continent*** as a result of the widespread occurrence of biomass burning, particularly in the savanna biome. This description is equally applicable to southern Africa where savanna is a major plant community. The early Portuguese explorers in the fifteenth century recorded in their ships logs that the interior of South Africa was ***"Terra dos fumos"*** - the land of smoke and fire. This capacity of Africa to support fire stems from the fact that climatic factors are the driving force of fire ecology and the main requirement for fire to occur anywhere on earth is to have lightning as the primary ignition source and climatic conditions that will permit the burning of vegetation and the spread of fires caused by lightning strikes. Africa is one of the continents that is highly prone to lightning storms and has a fire climate comprising dry and wet periods during which fires can burn the plant fuels during the dry period that have been produced and accumulated during the wet rainy period. Fire is recognised as an important ecological factor in the savanna ecosystems of southern Africa. Research investigating the effects of the fire regime on the biotic and abiotic components of the ecosystem has been conducted in South Africa since the early period of the twentieth century. This has led to a general understanding of the effects of the type and intensity of fire and season and frequency of burning on the grass and tree components of the vegetation. A major portion of this research has been conducted in the savannas of the Kruger National Park which are representative of a significant proportion of this type of vegetation on the subcontinent.

Black Carbon, the Global Carbon Cycle, and Atmospheric Carbon Dioxide

TAJ Kuhlbusch and PJ Crutzen (Max-Planck-Institut für Chemie, POBox 3060, 55020 Mainz, Germany; tky@mpch-mainz.mpg.d400.de)

Black carbon, certain forms of fire produced highly polymeric to graphitic carbon, is resistant to bacterial decay and is thus believed

to represent a sink of the active bio-atmospheric carbon cycle and hence of atmospheric CO_2. Several residues either derived from experimental fires in our burning apparatus or from a field campaign (SAFARI'92) were analysed with a newly developed method for their black carbon content. Measured production ratios of black carbon to CO_2 in savanna fire residues [(1.3 ± 0.6) %-C] and in the smoke [0.11 %-C; Cachier] clearly shows that black carbon by far most remains in the residues.

Using this ratio determined for different kind of vegetation fires and various estimates of carbon dioxide emitted by vegetation fires we obtain a first measurement-based estimate of annual global black carbon formation of 70-260 * 10^{12} g C. The global and regional source estimates will be used for comparison with coastal and marine deposition rates of black carbon to identify the main pools of black carbon.

Especially the burial of black carbon in deep sea sediment cores enables us to analyse past fire activities (going back millions of years) and if existent, any degradation processes of vegetation fire derived carbon. Any qualitative or even quantitative data of past fire activity are of great importance in evaluating the importance and impact of fires on past and present atmospheric composition and thus climate.

FTIR Studies of Laboratory Biomass Fires.

D W T Griffith (Department of Chemistry, University of Wollongong, Wollongong, NSW 2522 Australia; +61-42-213555, d.w.griffith@uow.edu.au)
R J Yokelson (Shafizadeh Center for Wood and Carbohydrate Chemistry, University of Montana, Missoula, MT 59812; 406-329-4812; byok@selway.umt.edu)
W G Mankin (National Center for Atmospheric Research, Boulder, CO 80307; 303-497-1403)
D E Ward (USDA Forest Service, Intermountain Research Station, PO Box 8089, Missoula, MT 59807; 406-329-4863)

A series of 8 fires, probing different forest and grassland fuel types, was burned in the IFSL combustion laboratory. Open path FTIR measurements of the mid-infrared spectrum of the smoke were acquired at 0.12 cm^{-1} resolution over a 3 meter cross-stack pathlength. The fuel mass loss, stack gas temperature, and flow were measured simultaneously. The IR data were analyzed using the MALT program to generate synthetic calibration spectra and a classical least-squares (CLS) multicomponent spectral fitting method. The results have yielded simultaneous concentrations for carbon dioxide, carbon monoxide, methane, methanol, formaldehyde, formic acid, ethane, ethene, acetylene, ammonia, nitrogen dioxide, nitric oxide, total water vapor, and fuel moisture desorption. It is confirmed that the oxides of nitrogen are released during the flaming phase with NH_3 being the dominant measured nitrogen product during the smoldering phase. The production of methanol and the desorption of bound water are nearly perfectly correlated with CO_2 release. Formaldehyde and acetylene emissions peak early in the fire during the flaming stage. Large differences in emissions are found to occur from different fuel types. For example, the CH_4/CO emission ratio for green pine needles is nearly 5 times that for sagebrush. Replicate runs are reproducible within a few percent. Derived quantities include emission ratios, emission factors, fuel moisture, combustion efficiency, and energy transfer terms. The technique is a valuable diagnostic tool for simultaneous analyses of many gases in smoke, providing an improved understanding of smoke composition and chemistry, fire behavior, carbon and nitrogen cycles, and impacts on atmospheric chemistry.

Stable Carbon Isotopic Analysis of Charcoal From Controlled and Natural Burns

W P Gilhooly, D J Verardo, S A Macko, V C Turekian, R J Swap, and M Garstang (Department of Environmental Sciences, University of Virginia, Charlottesville, VA 22903; 804-924-6846; wpg6n@faraday.clas.virginia.edu)

The study of charcoal formation can further the understanding of ancient fire regimes, global carbon sources and sinks, and climatic change. In this study, stable carbon isotopic analysis of charcoal isolated by a bulk assay technique was used to suggest the C3 and C4 character of the source plant material and to quantify the isotopic fractionation effects during charcoal formation. Vegetation samples collected on SAFARI 1992 from Etosha and Kruger National Parks provide an isotopic inventory of burned and unburned plant material. Controlled burn experiments were conducted on these samples and other plant materials. The ash and aerosol components produced during combustion were collected and charcoal was isolated from the material. Vegetation collected from Kruger has a mean carbon isotopic value of -12.7 per mil, indicating a C4 origin. A corresponding ash material produced during a natural fire event has a mean of -15.7 per mil and the charcoal a mean value of -14.1 per mil. The apparent isotopic depletion between unburned and burned vegetation may be attributable to mixing of C3 and C4 vegetation. Unburned litter from this area has a carbon isotopic signal of -24.7 per mil, which may account for the depletion seen in the collected ash. Carbon isotopic analysis of charcoal produced in these burns indicate a consistent 1 to 2 per mil enrichment in 13C between plant ash and charcoal. Through a quantification of fractionation effects during charcoal formation the utilization of this material as a paleoclimatic indicator of past carbon dioxide levels is enhanced. Charcoals isolated from marine sediments, for example, have values ranging from -14 to -22 per mil. A carbon isotopic inventory of charcoal isolated from plant ash and aerosol may also be used to suggest the source and photosynthetic pathway of the original plant which was pyrolized to become charcoal and eventually isolated from ancient marine sediments.

Thursday, March 16, 1995

Morning
Session VIII: TRANSPORT OF GASES AND PARTICULATES
CHAIRS - A M THOMPSON, M GARSTANG

Determination and Verification of Atmospheric Transport of Biomass Burning Products

Michael Garstang, (Dept. of Environmental Sciences, University of Virginia, Charlottesville, VA 22903), Peter D. Tyson (Climatology Research Group, University of the Witwatersrand, Johannesburg, South Africa), Edward Browell (NASA/Langley Research Center, Hampton, VA 23665) and Robert Swap (Dept. of Environmental Sciences, University of Virginia, Charlottesville, VA 22903)

A new approach to determine atmospheric transport is described. Large numbers of kinematic trajectories are calculated from a given point or points of origin. Atmospheric vertical velocity and stability is taken into account. Probability limits are placed on the 2-D (x,z) envelope of transport and travel times and distances from the location of origin provide the advection velocity of the plume. Volume and mass transports are calculated from the 2-D plume and the

advection velocity. Verification of the transport is sought through a comparison between direct observations of the vertical distribution of aerosols and ozone by means of airborne DIfferential Absorption Lidar (DIAL) and the calculated four-dimensional (x,y,z,t) plume position. A series of case studies from TRACE-A/SAFARI show excellent agreement between observations and calculations.

Contributions of Biomass Burning Emissions vs. Biogenic Emissions to the Tropical South Atlantic

Robert J. Swap, Michael Garstang and Stephen Macko (Dept. of Environmental Sciences, University of Virginia, Charlottesville, VA 22903), Peter D. Tyson (Climatology Research Group, University of the Witwatersrand, Johannesburg, South Africa) and Per Kållberg (Swedish Meteorological and Hydrological Institute, Norrköping, Sweden and ECMWF, Reading, England)

Aerosol and air parcel transports into the tropical south Atlantic, a region of enhanced mid-tropospheric ozone, are described during the austral spring of 1992. Results of three-dimensional backward trajectory anal ses from Ascension Island (8° S, 14° W) show the African continent south of 10° N to be the major source of air parcels (> 70%). The remaining fraction is supplied by the South American continent. The African source region extends over more than 30° of latitude with the primary source region being between the equator and 10° S. Concurrent rainfall distributions are out of phase with maximum biomass burning. Transport from African regions experiencing heightened biomass burning (Africa south of 15° S) to the Ascension Island region is approximately one-third of that from equatorial Africa. Simultaneous surface particulate aerosol measurements at Ascension Island indicate terrestrial as well as biomass burning signatures associated with this transport from southern Africa. These signatures are not observed with transport from equatorial Africa. Relative contributions of biogenic and biomass burning emissions to the total aerosol loadings of this region are computed, contrasted and compared. The results suggest that emissions into the south tropical Atlantic from the southern African continent consist of a mixture of biogenic and biomass burning products both subject to strong seasonality and both providing precursor gases to the production of O_3.

Horizontal and Vertical Transport of Aerosols and Trace Gases from Southern Africa: Implications for Global Change

P D Tyson (Climatology Research Group, University of the Witwatersrand), M Garstang and R Swap (Department of Environmental Sciences, University of Virginia), M Edwards (South African Weather Bureau), P Kallberg (Swedish Meteorological and Hydrological Institute and ECMF) and E V Browell (NASA Langley Research Center)

In large measure anthropogenically-induced global climatic change is a function of the changing composition of the atmosphere, which in turn depends on the integrated effect of regional and smaller scale contributions to the total loading of aerosols and trace gases. In this paper the mechanisms controlling horizontal and vertical transport of air over and away from southern Africa and into the northern South Atlantic and south-west Indian Ocean will be presented.

Circulation fields, atmospheric stability structures and their annual variation are considered. Case studies of aerosol and ozone transport during the southern hemisphere spring of 1992, as observed during the TRACE-A and SAFARI field experiment periods are used to illustrate the complexity of individual transport episodes. Thereafter, a transport climatology is developed by working, first, from a classification over a 5-year period of synoptic circulation types in which four modes are shown to be dominant. These are semi-permanent subtropical continental high pressure cells, transient ridging highs originating in the westerlies to the south of southern Africa, travelling mid-latitude westerly wave disturbances and quasi-transient tropical easterly wave disturbances occurring to the north of the subtropical highs. Over 1200 forward trajectories from seven localities are used to characterize vertically-integrated surface to 800hPa and 700-500hPa transport fields associated with each circulation type. Secondly, from the month-by-month annual variation of the circulation types, the annual variation of low- and middle-level transport are inferred to give an air transport climatology having a high degree of statistical significance. The degree of recirculation over the subcontinent associated with each transport mode is given, as well as the percentage transports exiting the subcontinent to the west through the 10° E meridian and to the east through 35° E, and thereafter much further afield.

Air transport balances for specific circulation types and the air transport climatology are used as a basis to provide for both physical and chemical modelling of the regional biogenic, biomass burning and industrial and urban air pollution aerosol and trace gas contributions from subtropical southern Africa to the atmosphere of the southern hemisphere.

Thursday, March 16, 1995

Morning
Session IX: CARBON DIOXIDE
CHAIRS - P J CRUTZEN, R G ZEPP

Fire, Global Warming, and the Carbon Balance of Boreal Forests

E.S. Kasischke (School of the Environment, Duke University, P.O. Box 90328, Durham, NC 27708-0238; (919) 613-8039; email erick@env.duke.edu)

Fire strongly influences carbon cycling and storage in boreal forests. In the near-term, if global warming occurs the frequency and intensity of fires in boreal forests is likely to increase significantly. A sensitivity analysis on the relationship between fire and carbon storage in the living-biomass and ground-layer compartments of boreal forests was performed to determine how the carbon stocks would be expected to change as a result of global warming. A model was developed to study this sensitivity. The model shows if the annual area burned in boreal forests increases by 50% as predicted by some studies, then the amount of carbon stored in the ground layer would decrease between 3.5 and 5.6 kg-m^{-2}, and the amount of carbon stored in the living biomass would increase by 1.2 kg-m^{-2}. There would be a net loss of carbon in boreal forests between 2.3 and 4.4 kg-m^{-2}, or 27.1 to 51.9 Pg on a global scale. Because the carbon in the ground-layer is lost more quickly than carbon is accumulated in living biomass, this could lead to a short-term release of carbon over the next 50 to 100 years at a rate of 0.33 to 0.8 Pg-C-yr^{-1}, dependent on the distribution of carbon between organic and mineral soil in the ground layer (which is presently not well understood) and the increase in fire frequency caused by global warming. The model developed for this study and results from a sensitivity study will be presented in this paper.

Burning of Biomass in the Territories of the Former Soviet Eurasia: Impact on the Carbon Budget

A Shvidenko and S Nilsson (Both at: International Institute for Applied Systems Analysis (IIASA), A-2361 Laxenburg, Austria; 43-2236-807430)
Vjacheslav Rojkov (V.V. Dockuchaev Soil Institute, Pyshevsky per. 7, Moscow; 07-095-231-09-25)
(Sponsor: IIASA)

Three means of greenhouse gas emissions caused by biomass burning in the vast (22 million km2) territory of the Former Soviet Union are considered: wild forest fires, various types of managed burning (in agriculture,

prescribed forestry burning), and use of biomass for energy production by industry and households.

Annual areas of wild forest fires are estimated to affect some 1.5 million ha of forested areas (closed forests) and additionally 2.0 million ha of other land-use categories (excluding agricultural lands). By employing model analyses and available data by ecoregions, the direct annual average forest fire flux in the early 1990s is estimated to be about 58 million tons C annually of which 22 million tons stem from peat fires. The average annual post-fire biogenic flux is estimated to be 92 million tons C in the early 1990s.

Data on managed burning as well as statistics of biomass consumption is limited in accessibility for the territories of the Former Soviet Union. Based on available statistics, analysis of recent historic use of the biomass fuel (wood, straw, peat, etc.), and some estimates on postharvest burning of agricultural products, estimates on burnt biomass for types of burning are presented for 14 aggregated ecoregions covering the Former Soviet Union. Calculations on the uptake of carbon in the atmosphere as well as estimates on the possible composition of the emitted gases (CO_2, CO, NH_4, NMHC) will be provided.

Forest Fires in China: Carbon Dioxide Emission to the Atmosphere

X K Wang Y H Zhuang and Z W Feng
(Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, P.O.Box 2871, Beijing 100085, China; e-Mail MX%"wangrs@bepc2.ihep.ac.cn")
(Sponsor: National Natural Science Foundation of China)

Forest fires have been considered as an important source of carbon dioxide in the atmosphere and their contributions to the global change have been intensively assessed. However, the contribution of forest fires in China has not been published yet, despite of the fact both the fire frequency and the area burned are significant. Hence, a significant carbon dioxide release to the atmosphere may be expected. On the basis of provincial statistical data on forest fires in the period of 1950-1991, we analyzed the forest fire frequency and distribution in China. Then the direct carbon release from forest fires was estimated according to forest biomass density distribution in China. From 1950 to 1991, the average frequency of forest fires is 14,879 per annum and the mean annual burned forest area is 8.64 x 10^5 ha. Over this period, both the frequency and burned forest area have a decreasing trend. The annual carbon emission from forest fires was estimated to be 6.21 x 10^7 tons C. Furthermore, an analysis on the distribution of carbon emission per hectare of forest area due to forest fires over China was made with the aid of geographical information system.

Biomass Burning in the Savannas of North Africa and Atmospheric CO_2

S F Iacobellis, R Frouin, H Razafimpanilo and R C J Somerville (All at: Scripps Institution of Oceanography, University of California, San Diego, La Jolla, CA 92093)

The effect on atmospheric CO_2 of biomass burning in the savannas of north Africa is investigated using a tracer transport model. The model uses winds from operational numerical weather prediction analyses and provides CO_2 concentrations as a function of space and time. After a spin-up period of several years, biomass burning sources are added, and model experiments are run for an additional year, utilizing various estimates of CO_2 sources.

The results demonstrate the strong remote effects of African biomass burning which, owing to the general circulation of the atmosphere, are felt as far away as South America. The effects are more pronounced during the period from January through March, when biomass burning in South America is almost non-existent. During this period, atmospheric CO_2 concentrations in parts of South America typically may increase by 0.5 to 0.75 ppm at 970 mb, the average pressure of the lowest model layer. These figures are above the probable uncertainty level, as model runs with biomass burning sources estimated from independent studies using distinct datasets and techniques indicate. From May through September, when severe biomass burning occurs in South America, the effect of north African savanna fires becomes generally small at 970 mb, but north of the equator it may be of the same magnitude or larger than the effect of South American fires. The CO_2 concentration increase in the northern and southern portions of South America, however, is mostly due to southern African fires, whose effect may be 2-3 times larger than the effect of South American fires at 970 mb. Even in the central part of the continent, where local biomass burning emissions are maximum, southern Africa fires contribute to at least 15% of the CO_2 concentration increase at 970 mb. At higher levels in the atmosphere, less CO_2 emitted by north African savanna fires reaches South America, and at 100 mb no significant amount of CO_2 is transported across the Atlantic ocean. The vertical structure of the CO_2 concentration increase due to biomass burning differs substantially, depending on whether sources are local or remote. A prominent maximum of CO_2 concentration increase in the lower layers characterizes the effect of local sources, whereas a more homogenous profile of CO_2 concentration increase characterizes the effect of remote sources.

A Numerical Model of the Global Carbon Cycle to Assess the Impact of Biomass Burning on Levels of Atmospheric Carbon Dioxide

A D Kambis (Department of Physics, College of William and Mary, Williamsburg, Virginia 23187)
J S Levine (Atmospheric Sciences Division, NASA Langley Research Center, Hampton, Virginia 23681-0001, USA)

A three-dimensional (2-1/2 x 2-1/2 degree latitude/longitude grid) coupled model of the global carbon cycle has been developed and the impact of biomass burning as a global source of carbon dioxide has been assessed. The model considers the production of carbon dioxide via fossil fuel combustion and biomass burning, the transport of carbon dioxide in the atmosphere, and the sinks for carbon dioxide, including the oceans and the biosphere. The ocean module includes both ocean circulation and ocean carbon chemistry. The biospheric module contains eight site-specific ecosystem models which represent over 80% of the net atmospheric exchange of carbon dioxide with the biosphere. The concentration of atmospheric carbon dioxide resulting from biomass burning as a function of geographical location and time has been assessed.

The Influence of Vegetation Fires on the Global Carbon Cycle

F Mack, G Esser (Both at: Institute for Plant Ecology, Justus Liebig University, D-35392 Giessen, Germany)
J G Goldammer Max Planck Institute for Chemistry, Biogeochemistry Department (Mainz), Fire Ecology and Biomass Burning Research Group, c/o Freiburg University, P.O. Box, D-79085 Freiburg, Germany)
(Sponsor: M O Andreae #000 930 274)

The objectiv of the study is the examination of extent and importance of global vegetation fires on the global carbon cycle, climate and vegetation. A model has been developed to consider feedback mechanism between biosphere, atmosphere, and the ocean. The model is driven by climatic parameters and can be adapted to any global carbon cycle model including a global vegetation model. Regarding the High Resolution Biosphere Model (HRBM) the global carbon content of the phytomass will be reduced by 23 %, of litter by 9 %, and of soil organic carbon by 16 %, if vegetation fires are considered. Approximately 4.8 Pg C are released anually into the atmosphere with a 46 % contribution of

savannas and tropical dry forests. The model can be utilized to estimate fire cycles, emissions of CO_2 and other trace gases and aerosols, and to reflect the replacement of woody by herbaceous vegetation types.

Thursday, March 16, 1995

Afternoon
Session X: CARBON MONOXIDE AND METHANE
CHAIRS - V W J H KIRCHHOFF, J A LOGAN

Global Distribution of Biomass and Carbon Monoxide in Middle Troposphere in April and October 1994

V S Connors (Atmospheric Sciences Division, NASA Langley Research Center, Mail Stop 401A, Hampton, VA 23681-0001; 804-864-5849; E-mail: vickie@stormy.larc.nasa.gov)
H G Reichle, Jr. and M Flood (Both at NASA Langley Research Center, Hampton, VA 23681; 804-864-5383)

Spaceborne measurements of tropospheric carbon monoxide were made by the Measurement of Air Pollution from Satellites (MAPS) experiment during April and October 1994 from the Space Shuttle Endeavour. During the two 10-day Space Radar Laboratory flights, extensive observations of the planet by the astronaut crews were recorded. Photography from hand-held cameras in the shuttle and videocameras in the payload bay provided further characterization of the surface and atmospheric conditions during the two missions. A global correlative measurement team contributed additional information e.g., CO (and other gases) mixing ratios, weather conditions, etc., at nearly 30 sites between 70°N and 67°S. All of these data together suggest a strong relationship between the distribution of biomass burning and enhancement of CO mixing ratios near and downstream from the areas being burning.

This paper will present an overview of the two missions and the global distribution of CO during April and October 1994. Next, the global distribution of burning events as reported by the astronaut crews will be presented. The two CO data sets with the maps of global burning will be compared and contrasted.

AVHRR and ERBE Investigations of Biomass Burning in the Tropics

Sundar A. Christopher, (Institute of Atmospheric Sciences, SD School of Mines and Technology, Rapid City, SD 57701-3995 605-394-2291)
Donna V. Vulcan and Ronald M. Welch (Both at: Institute of Atmospheric Sciences, SD School of Mines and Technology, Rapid City, SD 57701-3995, 605-394-2291)
(Sponsor: A G U Member)

Atmospheric aerosols play a pivotal role in the earth's radiative energy budget. They exert a net cooling influence on climate by directly reflecting the solar radiation to space and modifying the shortwave reflective properties of clouds. Each year increasing amounts of aerosol particles are released into the atmosphere due to biomass burning, dust storms, forest fires and volcanic activities. These particles significantly perturb the radiative balance on local, regional, and large scales.

Biomass burning which is widely prevalent in the tropics serves to clear land for the shifting and expanding population. It produces large amounts of trace gases and aerosol particles which play a pivotal role in atmospheric chemistry and climate. Aerosol particles emitted from biomass burning are also a major source of cloud condensation nuclei which affects the microphysics of boundary layer clouds and alter the radiation budget of the earth by increasing the albedo. The indirect effect of increasing cloud albedo may be as large in magnitude (but opposite in sign) as the greenhouse effect due to a doubling of carbon dioxide.

The goal of this investigation is 1) to accurately detect the aerosols produced due to biomass burning using a combination of spectral and textural measures using AVHRR data, 2) to determine the optical depth and particle size of these aerosols, and 3) to estimate the radiative impact of biomass burning using the Earth Radiation Budget Experiment (ERBE) data.

Refined Analysis of MAPS 1984 Global CO Measurements

D O Neil (Atmospheric Sciences Division, NASA Langley Research Center, Hampton, VA 23681-0001; 804-864-8171; d.o.neil@LaRC.NASA.GOV)

To prepare to reduce new MAPS (Measurement of Air Pollution from Satellites) data, the algorithms, models, and processes which had been used on the original MAPS data were reviewed. In addition, new measurements of spectral characteristics and new instrument calibration data were incorporated into the process. The revised algorithms and new test data were then applied to the existing (1984) MAPS global measurements of tropospheric CO. Significant improvements in data quality were obtained. These improvements were quantified by using the N2O distribution which MAPS measures simultaneously with its CO measurements as a systematic diagnostic of the data reduction process for the first time. (N2O is known to be uniformly mixed and single valued in the troposphere.) The global distribution pattern and the magnitude of the (1984) CO measurements are discussed and compared with the original values.

An Analysis of the Causes of Recent Observed Decreases in the Concentrations of Carbon Monoxide Using a 3-Dimensional Chemical Tracer Model.

Jennifer A Logan, Rosemarie Yevich, Clarisa M Spivakovsky and Amy D Alberts (Department of Earth and Planetary Sciences and Division of Applied Sciences, Harvard University, Cambridge, MA 02138; 617-495-4582; jal@io.harvard.edu)
Paul Novelli (Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, CO 80309-0449; 303-497-6974; pnovelli@cmdl.erl.gov)

Two recent studies have shown that concentrations of CO decreased significantly between 1990 and 1993 [Novelli et al., *Science, 263*, 1587, 1994; Khalil and Rasmussen, *Nature, 370*, 639, 1994]. A downward trend in biomass burning has been proposed to be the cause of the decrease in CO in the tropics and southern hemisphere. Other proposed causes of the global decrease in CO are the decrease in column ozone, causing enhanced removal of CO by OH, and decreases in the northern mid-latitude source of CO from fossil fuel combustion due to regulation of emissions in the US and Western Europe, and decreases in industrial output and energy consumption in eastern Europe and the former USSR.

We use a 3-dimensional Chemical Tracer Model to evaluate the effect of changes in sources and sinks of CO on the concentrations of CO, with a focus on quantifying the magnitude of the change in the source from

biomass burning consistent with the observed data. The lifetime of CO, less than 2 months in the tropics and in summer at mid-latitudes, but much longer in other seasons at mid-latitudes, allows for significant transport of CO away from its source regions. The model uses a new assessment of the sources of CO from fossil and biomass fuels, biomass burning, and isoprene oxidation. We can readily manipulate these sources to mimic hypothetical changes in sources in specific ecosystems or countries. Model results are evaluated using data from the NOAA/CMDL surface sites. We will assess independently the effect of changes in the sources of CO from biomass burning and fossil fuel, and the effect of decreases in column ozone, and changes in tropospheric ozone, on the spatial distribution of CO.

Estimates of Emissions Inferred from Satellite Measurements of Mid-Tropospheric Carbon Monoxide

Rick D. Saylor (Pacific Northwest Laboratory, Richland, WA 99352; ph. 509-372-6178; fax 509-372-6168; Internet: rd_saylor@pnl.gov); Richard C. Easter (Pacific Northwest Laboratory, Richland, WA 99352; ph. 509-372-6175; fax 509-372-6168; Internet: rc_easter@pnl.gov); Elaine G. Chapman (Pacific Northwest Laboratory, Richland, WA 99352; ph. 509-372-6181; fax 509-372-6168; Internet: eg_chapman@pnl.gov); Margaret K. Brown (Pacific Northwest Laboratory, Richland, WA 99352; ph. 509-372-4051; fax 509-372-6168; Internet: mk_brown@pnl.gov)

A three-dimensional tropospheric chemistry model has been used to analyze CO mixing ratio measurements from the Measurement of Air Pollution from Satellites (MAPS) experiment and to infer CO emissions, including the biomass burning contribution, that are consistent with these measurements. The MAPS experiments were designed and carried out by NASA to investigate the global tropospheric distribution of carbon monoxide (CO). In these experiments, a nadir-viewing gas-filter radiometer tuned to the fundamental spectral band of CO was placed on board the U.S. Space Shuttle and was able to obtain near global coverage of mid- to upper-tropospheric CO mixing ratios. This presentation reports on an analysis of data from the second MAPS experiment which took place during October 5-13, 1984. In our analysis, we have used a three-dimensional, Eulerian, atmospheric chemistry model to simulate CO emissions, transport and chemistry for the autumn of 1984 using observed meteorological data obtained from the European Centre for Medium Range Weather Forecasting. Using an objective inversion algorithm, we have used the model to infer emissions of CO that are consistent with MAPS measurements. The paper will describe features of the model and the inference process and will present comparisons of our emissions estimates with other studies. In particular, the fraction of CO emissions attributable to biomass burning activites will be compared to natural and anthropogenic sources.

IR Solar Spectrocopy for Studying Total Column Carbon Monoxide Abundance: Manifestations of Biomass and Fossil Fuel Burnings on a Global and Regional Scales.

L N Yurganov (Arctic and Antarctic Research Institute, St.Petersburg, 199397, Russia; 7-812-251-9758; e-mail: aaricoop@sovam.com) E I Grechko, E V Fokeeva (Institute of Atmospheric Physics, Russian Academy of Sciences, Moscow, 109017, Russia; 7-095-592-1221; e-mail:root@iaph.msk.su)

Measurements of total column abundances (vertically averaged mixing ratio) of carbon monoxide are being carried out in Russia since 1971 up to now. Since 1982 these data being collected at the Antarctic coastal station Mirny, in 1982-1988 total column CO was measured in the Arctic. A lot of data were gathered during 6 oceanic cruises. Regular measurements are being conducted in the center of Moscow to monitor anthropogenic sources of this gas. As a result a picture of global CO distribution in various seasons has been obtained. In the tropical latitudes all the cruises revealed enhanced CO mixing ratios, associated with a continental natural source (biomass burning and hydrocarbon photochemistry). In northern midlatitudes a CO maximum, well mixed zonally, is observed. In some cases comparing total column data with mixing ratios measured near the surface made it possible to assess indirectly the shape of vertical profile. In both polar regions in winter-spring an atmospheric steadyness prevents mixing, resulting in enhanced CO mixing ratios either in the boundary layer (the Arctic) or in the free troposphere (the Antarctic). In the former case man-made CO dominates, and in the latter it is produced most probably by biomass burning near the Equator. Forest fires in Northern midlatitudes as a rule influence spatial distribution and seasonal variations insignificantly (some signs of those could be seen in August). During catastrophic forest fires in Russia in 1972 a rise of about 20-30% comparing with "normal" years was detected. A regional increase of CO total column is measured over Moscow: the range for variations is from "background" to 2-3 times higher values. Measurements of the total column of a surface-generated trace gas are helpful for direct estimates of its upward flux.

The Isotopic Composition of Tropospheric CO in Brazil: A Model Scenario During the Biomass Burn Season

J M Conny and L A Currie (Atmospheric Chemistry Group, Surface and Microanalysis Science Division, NIST, Chemistry B364, Gaithersburg, MD 20899; 301-975-3932; Internet: JCONNY@ENH.NIST.GOV)

Isotopes such as carbon-13 and carbon-14 have become important tools for distinguishing sources of trace carbonaceous species in the atmosphere. This is due to isotopic differences among source emissions caused by isotope fractionation and the dependence of carbon-14 decay upon the age of the carbon source. The isotopic composition of trace carbonaceous species in the atmosphere reflects the flux-weighted isotopic composition of sources and the fractionation effects of sinks.

Presented are results from a three-dimensional transport and dispersion model of the carbon-13/carbon-12 composition of tropospheric CO in the rainforest and savanna of Brazil during the dry season. The purpose is to demonstrate the extent of CO isotopic variation in the regional troposphere due to isotopically distinct source emissions, and to develop strategies for predicting when and where to collect samples for isotopic measurements. The model considers advection of air masses to the rainforest carrying CO from burn sites mainly in the savanna where much of the biomass consists of relatively carbon-13-enriched C4 grasses. Sources of relatively carbon-13-depleted CO from the forest (e.g., oxidized isoprene) and oxidized methane are also included. Substantial horizontal and vertical variation among tropospheric carbon-13/carbon-12 ratios calculated at different altitudes shows the effect of burn CO carried long distances into the rainforest. Discussion will focus on model parameterization as well as results.

Biomass Burning Effects on the Distribution of Atmospheric Methane in Brazil: observations at the Atlantic Coast and Amazonian Cerrado

V W J H Kirchhoff, M.A. da S. Oliveira, P.C. Alvalá (PR/MCT - Instituto Nacional de Pesquisas Espaciais, Caixa Postal 515, 12201-970, Sao José dos Campos, SP, Brazil)

Measurements of atmospheric methane near the surface and from aircraft have been made in different environments in Brazil. Near the surface, about two years of observations are available at the Atlantic coast (Natal, 6 S, 35 W) where the lowest yearly averages are seen, around 1670 ppbv (parts per billion by volume) and at Cuiabá (16 S, 56 W), in the middle of the South American continent, where the yearly average is more variable and larger than at Natal, about 1750 ppbv. In order to investigate whether the systematic larger methane at Cuiabá is the result of nearby biomass burning, measurements were made at Cuiabá and also at Porto Nacional (11 S,48 W), a site located in the Brazilian cerrado, both being part of the Brazilian legal Amazon region. Aircraft was used at Cuiabá and Porto Nacional for in situ sampling of methane during the dry and wet seasons. There is a clear difference between these two opposite seasonal periods. Both Cuiabá and Porto Nacional show some 30-60 ppbv larger methane vertical profiles during the dry season, in comparison to the wet season, the difference at Cuiabá being larger. The possible influence of the Pantanal region, a yearly flooded complex about 100 km distant from Cuiabá is also investigated, as well as the possibility of Porto Nacional representing a sink in the dry season. It appears more probable, however, that the biomass

burning source near Cuiabá is the major factor, since it receives air masses that come from regions of slashed forest burns, where, contrary to the cerrado burnings, a major source contribution comes from the smoldering phase of the burning, where the release of methane is larger, in comparison to the flaming contribution.

Hydroxyl Radical Concentrations and Trends based on 1978–1994 ALE/GAGE Trichloroethane Measurements: Implications for CO and CH_4 Emissions

R.G. Prinn (MIT, Bldg. 54-1312, Cambridge, MA 02139; 617-253-2452; e-mail: rprinn@mit.edu) R. F. Weiss, B. R. Miller, J. Huang, P. G. Simmonds, P. B. Fraser, F. N. Alyea, D. M. Cunnold, and D. E. Hartley

Atmospheric measurements of 1,1,1-trichloroethane (methyl chloroform) made around the world at high frequency between 1978 and 1994 indicate that this species, which was steadily increasing at 4.4 ± 0.1% per year until mid-1990, has subsequently decreased at a rate of 2.6 ± 0.4% per year. This recent rapid decrease is the first actual atmospheric decrease observed for any halocarbon restricted under the Montreal Protocol, and the rates of decrease are consistent with reported industrial emission decreases resulting from the Protocol. The observed decreases began in early 1991 in the northern hemisphere and in mid-1992 in the southern hemisphere as expected from the predominantly northern hemispheric emissions of this industrial chemical and the known one to two year inter-hemispheric exchange times. The accurate determination of the lifetime of trichloroethane is very important because the hydroxyl radical concentrations and trends deduced from it are widely used to deduce the lower atmospheric lifetimes (removal rates) of almost all hydrogen-containing gases involved in the chemistry of the ozone layer and the radiative forcing of climate. The measured trichloroethane concentrations combined with independently estimated industrial emissions are used in an optimal estimation inversion method to deduce a globally averaged 1,1,1-trichloroethane lower atmospheric lifetime which is about 20% shorter than previously reported (Prinn *et al.*, 1992, *J. Geophys. Res.*, **97**, 2245). Assuming a lifetime for loss of trichloroethane to the oceans, we deduce globally averaged lower atmospheric hydroxyl radical concentrations which are then used together with CO and CH_4 observations to deduce the global emissions of these latter gases. We conclude that CO and CH_4 emissions are significantly greater than previous emission estimates. The rate of change of the above weighted average lower atmospheric hydroxyl radical concentration over the 1978–1994 time period is determined to differ insignificantly from zero, implying that the oxidation capability of the lower atmosphere was not changing significantly over this period. This removes increasing OH levels as an explanation for the recently observed decreases in CO and CH_4.

The Carbon Monoxide Budget in Southern Africa during TRACE-A/SAFARI-92

A M Thompson, K E Pickering, D P McNamara, C O Justice, J D Kendall (NASA/Goddard Space Flight Center, Greenbelt, MD; University of Maryland, JCESS* and Dept. of Geography, College Park, MD; 301-286-2629; thompson@gator1.gsfc.nasa.gov)
R J Scholes (FORESTEK, CSIR, Pretoria, RSA) and R G Zepp (EPA, Athens, GA), G W Sachse (NASA/Langley Research Center)
M O Andreae, G T Helas, and T Zenker (Max Planck Institut, Mainz, Germany)

Biomass burning is a significant source of atmospheric carbon monoxide. Elevated levels of CO (150 ppbv or more compared to background concentrations of 60-90 ppbv) were measured throughout southern Africa on STARE/SAFARI-92/TRACE-A (Sept.-Oct. 1992) from several platforms: the NASA DC-8, the MPI-sponsored Cessna near Kruger Park and DC-3. Fluxes of CO from biomass fires (monthly and gridded on a 0.5° basis; Justice et al, 1994; Scholes et al, 1992) and biogenic CO emissions [Zepp et al, 1994] have been determined from SAFARI-92. Simple photochemical models (box, point, 1-dimensional) are used to check consistency between TRACE-A/SAFARI-92 aircraft CO observations and the pyrogenic and biogenic CO flux estimates. These fluxes and model results are used to construct a CO budget for southern Africa during biomass burning. Additional sources include wood fuel burning, soils, plants and in-situ CO formation from photochemical oxidation of hydrocarbons (the latter determined parametrically from the models). The deep convective flux of CO from boundary layer to free troposphere is calculated using a statistical-dynamical method [Pickering et al, 1992; Thompson et al, 1994].

* Joint Center for Earth System Science (JCESS) is an institute of the University of Maryland and NASA/Goddard

Thursday, March 16, 1995

Afternoon/Evening Session XI: OZONE
CHAIRS - F S ROWLAND, J FISHMAN

Large-Scale Impact of Biomass Burning on the Composition of the Troposphere as Determined from Analysis of Satellite Measurements

J Fishman (Atmospheric Sciences Division, NASA Langley Research Center, Mail Stop 401A, Hampton, VA 23681-0001; 804-864-2720; e-mail: fishman@sparkle.larc.nasa.gov)
E V Browell, V G Brackett and J R Olson (all at NASA Langley Research Center, Hampton, VA 23681-0001)

NASA's TRACE-A (Transport and Atmospheric Chemistry near the Equator--Atlantic) experiment in September-October 1992 afforded the opportunity to investigate how emissions from widespread biomass burning perturbed the composition of the atmosphere. The use of satellite observations during this time to determine the distribution of tropospheric ozone has proven to be a powerful tool for quantifying the impact of these emissions on the composition of the atmosphere not only over Africa and Brazil, but also over the adjacent Atlantic and Indian Oceans. This paper will focus on the insights gained from these satellite analyses using the TOMS (Total Ozone Mapping Spectrometer) and SBUV (Solar Backscatter Ultraviolet) measurements to derive daily depictions of the distribution of tropospheric ozone over the experiment area. Aircraft measurements during TRACE-A are compared with these satellite depictions to determine the applicability of satellite measurements to studies on these temporal and spatial scales.

Model Evaluation of Biomass Burning Effects on Tropical Ozone and Oxidizing Capacity: Overview and Examples From Safari-92/Trace-A

A M Thompson (NASA/Goddard Space Flight Center, Greenbelt, MD and JCESS,* University of Maryland, College Park, MD; 301-286-2629; thompson@gator1.gsfc.nasa.gov)

Models on various scales (Table 1) are required to interpret chemical and physical measurements from biomass burning field campaigns and from spaceborne measurements of ozone, CO and fires. Several classes of models are described and examples of their application to satellite-derived data and in-situ observations from STARE/SAFARI-92 and TRACE-A are given. The consistency of results, from small-scale to regional (eastern South America across the Atlantic through southern Africa) to global, is examined with an emphasis on tropical OH and budgets of ozone and carbon monoxide.

Table 1. Models used for analysis of atmospheric chemical effects of biomass burning

Type	Scale	Data & Application
Chemical		
Instantaneous	Point	Use high-frequency trace gas data - test photochemical steady-state theory, compute O_3 formation rate
Box, 1D	Homogeneous	Simulate mean conditions, test region, consistency of concentrations, gradients air mass and fluxes, track air parcel
Dynamic		
Trajectory	Regional	Determine air mass origin and fate of biomass burning emissions
Mesoscale	Regional	Synoptic systems, simulation of mesoscale convective systems
Coupled Chemical-Transport (CTMs)		
CTMs	Multi	Coupled chemistry-dynamics - micro to global

* JCESS, the Joint Center for Earth System Studies, is a joint institute of the University of Maryland and NASA/Goddard Space Flight Center.

A Study of the Mass Transport of Enhanced Continental Ozone in the Tropics and Its Impact Over the Remote Southern Atlantic Ocean

J R Olson (NASA Langley Research Center, Mail Stop 401-A, Hampton, VA 23681, 804-864-5327; Email: richard@sparkle.larc.nasa.gov)
Sponsor: Jack Fishman (804-864-2720)

The Geophysical Fluid Dynamics Laboratory global scale Chemical Tracer Model was used to examine the effect on ozone (O_3) over the southern Atlantic Ocean from the mass transport of enhanced ozone produced from reactions of biomass burning emissions over tropical continents. A tracer was constrained in the model to reproduce the seasonal amplitude of O_3 determined from in situ ozonesonde measurements and from remote satellite data. The relative horizontal source strength of the tracer was based on published emissions grids for carbon release due to biomass burning. The temporal distribution of the source was based on information about precipitation climatology and cultural burning practices found in the literature.

The study found that no more than 30 to 50% of the observed seasonal amplitude over the southern Atlantic is likely to be due to the mass transport of enhanced continental O_3. An O_3 "deficit" is defined as the portion of the observed amplitude not explained by the model-predicted mass transport. The vertical distribution of the deficit in the central Atlantic suggests that at least two additional sources of O_3 are required: one in the upper troposphere above about 400 mb, and one at lower altitudes around 700 mb. Across the Tropics, there are two regions of maximum deficit: one in the center of the tropical Atlantic, and one located just off the west South American coast.

This study suggests that some other transport mechanism (such as from the stratosphere or middle latitudes) and/or that in situ photochemical production of O_3 from precursors emitted from biomass burning or other sources is responsible for most of the observed seasonal increases over the remote south Atlantic region.

Tropospheric Ozone on both sides of the Equator in Africa

B Cros, Laboratoire d' Aérologie,Université Paul Sabatier, 31062 Toulouse Cedex, France.
B N Ahoua, INSET, BP 1093,Yamoussoukro, Côte d'Ivoire.
Ph Rousselot, Observatoire de Bordeaux, BP 89, 33270 Floirac,France.
D Nganga, Laboratoire de Physique de l'Atmosphère, Université M Ngouabi, BP 69, Brazzaville, Congo.

Vertical Profiles of Ozone sondes in Brazzaville, Congo (4°20S, 16°E), during pre-TRACE and TRACE-A, and in Bangui, CAR (4°20N, 18°E) during a pre-campaign of EXPRESSO shown a similar seasonal behaviour.

The data indicate highest ozone tropospheric amounts during the dry season coincident with the presence of savanna burning. Although the sources of the ozone precursors seem equivalent in the both hemisphere the extension of this pollution is less important in the north than in the south. Many potential causes are examined, particularly meteorological considerations (ITCZ position, dry haze, shallow and deep convection,etc...) and land cover (equatorial forest).

However it will be necessary to wait complementary data from EXPRESSO to explain this apparent discrepancy of tropospheric ozone in the african tropics.

Tropospheric Ozone Over Equatorial Atlantic: Ozonesonde-Trajectory Analysis.

Khan M. Fakhruzzaman (Science Application International Corporation, Mail Stop 401A, Atmospheric Sciences Division, NASA Langley Research Center, Hampton, VA 23681-0001; ph. 804-864-2709; fax 804-864-7790; e- mail: zaman@lily.larc.nasa.gov); Jack Fishman (Atmospheric Sciences Division, Mail Stop 401A, NASA Langley Research Center, Hampton, VA 23681-0001); Vincent G. Brackett (SAIC, Mail Stop 401A, Atmospheric Sciences Division, NASA Langley Research Center, Hampton, VA 23681-0001); (AGU Sponsor: Khan M. Fakhruzzaman)

Several years of observations indicate an elevated amount of tropospheric ozone is present in the equatorial Atlantic during austral spring. Ozonesonde profiles for the region reveal that ozone enhancements frequently occur above the boundary layer in the lower half of the troposphere (between 1.5 km to 5.5 km.). Enhanced ozone at these altitudes is believed to be the result of biomass burning from the bordering continents. Isentropic trajectories can be used to identify the possible source regions of biomass burning emissions that are responsible for the enriched layers in these ozonesonde profiles. In this study, the authors present an analysis of the relationship between regions of widespread biomass burning, transport regimes and the higher ozone concentrations found in the ozonesonde measurements.

A New Method of Deriving Time-Averaged Tropospheric Column Ozone in the Tropics Using TOMS Radiances: Intercomparison and Analysis

J H Kim, R D Hudson (Department of Meteorology, University of Maryland, College Park, MD 20742: jwan@atmos.umd.edu)
A M Thompson (NASA/GSFC, Greenbelt, MD20771)

Daily total ozone maps for the tropics, from October 6-21, 1992, are derived from TOMS radiances following correction for errors in the maps. These daily maps, averaged together, are examined for longitudinal variations. Two dominant features are apparent. One is a wave with wave number 1, and the other is enhanced total ozone extending across Africa to South America. The wave pattern is used to construct the time-averaged stratospheric ozone field. Then a time-averaged tropospheric column ozone is derived by subtracting the stratospheric ozone field from the corrected total ozone. This derived tropospheric column ozone agrees within 10% with time-averaged ozonesonde measurements over Brazzaville, Congo, Ascension Island, and Natal, Brazil. Overall features of the derived tropospheric column ozone are (1) very high ozone from South America to Africa, presumably due to biomass burning and biogenic activity; (2) relatively low ozone over western South America and from the Indian Ocean to the western Pacific; (3) regional ozone enhancements over northern Australia and New Guinea due to biomass burning; (4) a plume-like structure of slightly elevated ozone extending from the eastern to central Pacific. Comparison with fire distributions during October 1992 suggests that tropospheric ozone produced from biomass burning in South America and Africa dominates the

ozone budget in the tropical southern hemisphere during the study period. We estimate the pyrogenic tropospheric ozone from South America, the Atlantic, and southern Africa to be 216 TgO_3 from June to October. Biogenic activity probably influences tropospheric ozone in tropical northern South America and central Africa

Comparison of Tropospheric Ozone Determined from TOMS Radiances between October 1989 and October 1992

R. D. Hudson, C. Sieber, and J. H. Kim
(Department of Meteorology, University of Maryland. College Park, MD 20742: hudson@atmos.umd.edu)

Since ozone budget from tropical biomass burning takes 86% of total biomass burning and 33% of all sources, measurements of tropospheric ozone in the tropics are necessitated to understand its impact on global atmospheric chemistry. Kim et. al. (1994)[1] have developed a new method, the so-called pattern recognition method, to determine time-averaged tropospheric ozone from radiances measured by Total Ozone Mapping Spectrometer (TOMS). In order to examine the accuracy of this algorithm for determining tropospheric ozone, we have selected two periods, October 1989 (non-QBO season) and October 1992 (QBO season), for which the stratospheric ozone field should be very different. We find that the amount of tropospheric ozone in October 1989 from South America to Africa is only about 5-10 DU less than in October 1992. The characteristics of the tropospheric ozone fields for these two periods will be presented, and the possible causes of the differences will be discussed.

1 J. H. Kim, R. D. Hudson, and A. Thompson, A new method of deriving time-averaged tropospheric column ozone over the tropics using TOMS radiances: Intercomparison and analysis , J. Geophys. Res., submitted, 1994.

reach values near 80 ppbv (parts per billion by volume), as shown by several field campaigns in different parts of the savanna. The carbon monoxide mixing ratios have an even larger variability between the wet and dry seasons, from about 100 to 1000 ppbv, and are more sensitive to the smoldering phase of the fires. Aircraft surveys measuring carbon monoxide over large areas show the spacial distribution of CO in the fire region, which normally maximizes downwind of the fires.

Land Use Practices and Biomass Burning: Impact on the Chemical Composition of the Atmosphere

G P Brasseur (Atmospheric Chemistry Division, National Center for Atmospheric Research, Boulder, Colorado 80307)
W M Hao (USDA Forest Service, Intermountain Research Station, PO Box 8089, Missoula, MT 59807)
J F Muller (Belgian Institute for Space Aeronomy, Brussels, Belgium)

Biomass burning is extensively used in the tropics for land use practices, such as deforestation, shifting cultivation, savanna burning, fuelwood use, and clearance of agricultural residues. The emission of chemical compounds into the atmosphere depends upon the type of vegetation, meteorology, and combustion conditions. We developed a global emission inventory of CO_2, CO, CH_4, other hydrocarbons, and NO_x produced from fires in different ecosystems. A three-dimensional chemical transport model of the global atmosphere is used to assess the impact on the chemical composition in the atmosphere from biomass burning in each ecosystem. We examine the transport of these compounds to the free troposphere and calculate their contribution to the production of tropospheric ozone.

Friday, March 17, 1995

Morning
Session XI: OZONE - CONTINUED

The Biomass Burning Sequence of the Brazilian Savanna and Observations of Atmospheric O3 and CO

V W J H Kirchhoff, (PR/MCT - Instituto Nacional de Pesquisas Espaciais, Caixa Postal 515, 12201-970, Sao José dos Campos, SP, Brazil)

The Brazilian savanna region is a large area of about 3 million square kilometers, which is seasonally affected by large fires during the local dry season, which may last for three to four month. The fire frequency, distribution and variation of its location has been followed usingg AVHRR data. The burning starts in June and peaks in August and September. Periodic accumulation of the total number of fires indicates favorable locations for sampling sites, aiming at observations of atmospheric perturbations in the concentration of ozone and carbon monoxide. Observations have been made at the surface, at fixed sites, and using sampling on aircraft, flown at strategic heights and locations in the savanna regions of central Brazil. Hourly averages in the savanna indicate maximum ozone concentrations near 3 pm local time, with mixing ratios near 45 ppbv, in contrast to maximum mixing ratios observed near the Atlantic coast of about 20 ppbv. Since most of the fires are events that last only for a few days, these near surface measurements, being the result of long term monitoring, usually underestimate short term (several days) events in which ozone concentrations in the lower troposphere may

Explaining the Accumulation of Intercontinental Biomass-Burning Pollution: High vs. Low Processes, Africa vs. South America, Cooking vs. Mixing

R B Chatfield (NASA Ames Research Center, Moffett Field CA 94305-1000; ph. 415-604-5490; fax 415-604-3625; Internet: chatfield@clio.arc.nasa.gov); J A Vastano, San Jose State University, San Jose, California, 95106-0760; ph 415-604-5519; fax 415-604-3625; Internet: vastano@clio.arc.nasa.gov)

The intercontinental buildup of tropospheric ozone, carbon monoxide, and other pollutants over the South Atlantic has been attributed to biomass burning over distant continents. We address several of the large questions regarding the nature and budget of this buildup have remained: What is the role of burning in South America or various portions of Africa in this accumulation? What are the relative roles of shallow and deep convection for emplacing various compounds in the free troposphere? Can we understand the ozone budget? We report the first simulations of a three-dimensional pollutant transport model, (GRACES) transport which is driven by fully reconstructed meteorology for the TRACE-A/SAFARI period of 1992. Greater detail is provided by a two-dimensional, detailed-chemistry model of more restricted regions of Africa. We find a predominant role for African emissions affecting the Atlantic during this period. Boundary-layer venting via PBL convection tends to build the observed carbon monoxide column over the ocean, while deep cumulonimbus processes tend to explain rather more of the ozone column.

Continuing examination of the pollutant ratios in our simulations reveals several outstanding questions. The reconciliation of carbon monoxide source strengths with observed atmospheric concentrations remains problematic; presumably this highlights uncertainties in the understanding of CO's smoldering-combustion source. Observed ratios of ozone and carbon monoxide enhancements in older polluted parcels tend to suggest higher ozone productivities than those parcels which are near sources, but sufficiently downwind that our model suggests most ozone production has ceased. We admit however, that regions with continuing burning emissions inputs, like the important Central Africa region, provide complex simulation results.

We use these insights to introduce the larger questions on the budget of ozone -- how much continued ozone production is there aloft, "mix and cook," downwind, compared to the results of simulations, which suggest ozone is the advected remains largely advected continental smog, "cook and mix." Chatfield and Delany [JGR, 1990] suggested a course of investigation on the venting mechanism (mixing) that emplace tropospheric ozone, resulting in our GRACES work. Now, our analysis suggests more investigation of the source and chemical (cooking) mechanisms.

Simulation of Convective Transport of Biomass Burning Emissions over Brazil during TRACE-A: Effects on Tropospheric O_3 Production

K E Pickering (Joint Center for Earth System Science*, University of Maryland, NASA/GSFC, Code 916, Greenbelt, MD 20771; 301-286-2097; pickering@gator1.gsfc.nasa.gov)
A M Thompson, Y Wang, W-K Tao, D P McNamara (All at: NASA/GSFC, Greenbelt, MD 20771)
G W Sachse and G L Gregory (NASA Langley Research Center), V Kirchhoff (INPE, Brazil), J D Bradshaw (Georgia Tech), D R Blake (University of California-Irvine)

A major outbreak of deep convection occurred during the Brazilian component of the TRACE-A experiment, which took place in the latter part of the 1992 cerrado burning season. Trace gas measurements in cloud-processed air were taken during Flight 6. We have used a mesoscale model (NCAR/Penn State Mesoscale Model - MM5) and a cloud-resolving model (Goddard Cumulus Ensemble Model - GCE) to extend these limited measurements to the regional scale. We used MM5 to simulate the sequence of convective storms that occurred over the region during a 24-hour period (26-27 Sept. 1992) and subsequently used the MM5 wind fields in a tracer advection model to transport burning-related species (e.g., CO). Simulated CO fields after the convective episode compare favorably with upper tropospheric CO data taken from the NASA DC-8. We used the GCE Model to simulate one of the specific cloud systems that produced the measured upper-level outflow of greatly enhanced CO, NO_y, and NMHCs. Eight-day forward trajectories from the upper portions of these clouds and from the measured trace gas maxima show transport in the westerlies to the region of satellite-detected ozone maxima over the South Atlantic. We used measured and simulated trace gas mixing ratios in a photochemical box model to estimate the amount of ozone production during the 8-day transport.

* JCESS is a joint institute of the University of Maryland and NASA Goddard.

Friday, March 17, 1995

Morning Session XII: GLOBAL CHANGE/ECOLOGY CHAIRS - J C MENAUT, J G GOLDAMMER

The Impact of Deforestation on Eco-system Disasters in Yunnan Province, China

Chungcheng Li (Kunming Weather Bureau, Meteorology Road Lurwick 50, Kunming, PRC 650034)
Cong Lai (Institute of Environmental Medicine, New York University Medical Center, Long Meadow Road, Tuxedo, NY 10987)
(Sponsor: Joel S. Levine)

Yunnan (N21°8' - 29°15', E97°31' - 106°11'), a landlocked province bordered by Burma, Laos and Vietnam in west-southern China, has rich and varied forest resources due to changes in topography. It is one of the largest forest area in China. Forest burning for cultivable land and wood burning for fuel, together with forest fires have caused many environmental changes. This research documents the relationship between biomass burning and a series of ecological disasters, such as landslides, mud-rock flows, floods, drought, frost injury and cold damage, by investigating the ancient literature and analyzing the present situation. By reviewing the previous 700 years we have shown that deforestation is associated with an increased frequency of ecological disasters. Our results indicate that when the forest covering ratio decreased from 70% in the 14th century to 31% in the 20th century, the frequency of large or medium scale landslides or mud-rock flows increased from 0.16 to 3.57 per year. The frequency of large scale floods increased during that time from 0.02 to 0.27 per year while the frequency of large scale drought increased from 0.09 to 0.27 per year. The relationship of deforestation and disaster occurrence frequency were analyzed using the correlation analysis method. Landslides and mud-rock flows, floods, frost injury and cold damage were found to be closely related.

Climatic Effects of Biomass Burning

Susan Marshall, (Dept. of Geog. and Earth Sciences, UNC-Charlotte, Charlotte, NC 28223, USA)
Robert J. Oglesby, (Dept. of Earth & Atmos. Sci., Purdue University, West Lafayette, IN 47907, USA)
John A. Taylor, Jay W. Larson (Centre for Res. and Environ. Studies, Australian National University, Canberra, Australia)
David J. Erickson III, (Atmospheric Chemistry Division, National Center for Atmospheric Research, Boulder, CO 80307 USA)

Biomass burning occurs as a result of natural causes or through the actions of humans. The indirect cooling effect of the smoke released from deforestation has, however, received little attention. Taylor and Zimmerman (1990) have developed a model to predict the distribution and intensity of biomass burning at a resolution of 2.5° latitude by 2.5° longitude. The model predicts that more than half of the emissions will occur in the southern hemisphere, which implies that biomass burning may be the most significant anthropogenic source of particulates affecting climate in that hemisphere. Biomass burning occurs predominately during the dry season when natural cloud formation will generally be at its lowest level. On satellite visible images and aerial photographs, the smoke plumes that result from biomass burning are nearly indistinguishable from low and mid-level clouds. The plumes, while dramatically obvious on visible wavelength satellite images, are virtually absent on infrared wavelength images. This is because the particulates strongly reflect short wave (solar) radiation, but are largely transparent to infrared (terrestrial) radiation. Biomass burning smoke plumes should therefore have a clear net cooling.

We have made a series of GCM simulations with the NCAR CCM1 in order to examine further the consequences of biomass burning. We imposed 'clouds' in the model whenever biomass smoke was predicted by the model of Taylor and Zimmerman and such a cloud was not already present. These smoke 'clouds' were only allowed to interact with the short-wave radiation scheme in the model. We found strong local coolings, and somewhat reduced regional-scale coolings, and also found that thse coolings resulted in subtle changes to the atmospheric circulation, especially in the southern hemisphere.

Carbon Dioxide, Water Vapor and Climate Change

W G Egan (Natural Sciences Department, York College/CUNY Jamaica, NY 11451; 718-441-6210;internet:EGAN@YCVAX.YORK.CUNY.EDU)
A W Hogan (US Army Cold Regions Research and Engineering Labortory, Hanover, NH 03755-1290; 603-646-4364)

A time difference has been shown in the hourly, daily, monthly, and annual variations in CO_2 and water vapor measurements at many stations. At several of these stations, the CO_2 variations have been shown to lag the water vapor variations. The inverse relationship of water vapor and CO_2 concentration magnitudes is not generally considered in radiation or climate models. Further, the geophysical CO_2 and water vapor variations are greatest in the northern hemisphere where the mass of water exceeds that in the southern hemisphere. Betts has shown that the major source of this water vapor is evapotranspiration. Also, when one steps from the geophysical to the local scale, even in relatively uncomplicated stations such as Barrow, Alaska,there is evidence that local condensation/precipitation processes modify the CO_2 concentration in the atmosphere. The disappearance of half of the fossil fuel CO_2 appears to be related to the local loss of CO_2 caused by these condensation/precipitation mechanisms. There is also a concurrent time dependent variation of condensation nuclei caused by local events, such as biomass burning. Biomass burning changes the local geophysical/bio-geochemical pattern as well as the synoptic and air mass patterns, and would be expected to influence world climate.

We propose a single point radiation model which could be combined to produce a synoptic scale model to characterize global response. The model would start with geophysical CO_2/water vapor variations,with bio-geochemical processes and events added.

Friday, March 17, 1995

Morning Session XIII: Historic Biomass Burning
Chairs - J S Clark, J G Goldammer

What are the spatial and temporal scales of past combustion recorded in sediments?

J S Clark (Center for Quaternary Studies, Duke University, Durham, NC 27706; ph. 919-660-7402; fax 805-893-2578; Internet: jimclark@sun1.botany.duke.edu)

Sediments contain a range of different combustion-derived constituents that result from sources at several scales. The different scales recorded by different constituents depends on their particle size and, hence, transport, and on the methods of analysis, that determines the degree of "smoothing" across time. "Small" particles have received much attention from atmospheric scientists and are the subject of several contributions to this workshop. Gasous emissions are widely dispersed and provide subcontiental scale records of past combustion. These include the NH4+ ice core records and other potential organic tracers. Aerosol size particles are also well-dispersed and scavenge PAH's that are also preserved in sedimentary environments. Other organic tracers may prove useful for reconstructing combustion at broad spatial scales.

I examine the way in which large particles that occur in sediments represent biomass burning at a range of spatial and temporal scales. These particles are extracted from sediment cores and analyzed in different particle size classes by optical microscopy. Large (100 to 100,000 microns) diameter particles have short residence times in the atmosphere and, thus, originate close to the point of sampling. Year-by-year records of biomass burning can be linked to local fires that burn within the lake catchment. Smaller particles (5 to 50 mm diameter) particles better reflect past combustion at a regional scale. These regional patterns are reconstructed from a network of dated sediment profiles and compared with patterns of landuse, climate, and vegetation. The data are most dense from eastern North America. They show geographic shift in the distribution of particle accumulation since European settlement, and they follow geographic trends in fire weather. Before widespread land clearance and fire suppression, substantial fractions of NPP were consumed by biomass burning in the Midwest. Large particles have declined since the 20th century in the Midwest, while small particles have increased throughout eastern North America. Results suggest the different particle sizes represent complementary records of biomass burning that can be analyzed together to resolve combustion sources at different scales.

Ancient Wildfires: Biomass Burning at the Cretaceous-Tertiary Boundary

L.C. Ivany and R.J. Salawitch (both at Dept. of Earth and Planetary Sciences, Harvard University, Cambridge, MA 02138)

A variety of indicators from the geologic record suggest that biomass burning occurred on a global scale at the Cretaceous-Tertiary (K/T) boundary, 65 million years ago. Carbon isotopic records from marine microfossils reveal that surface waters throughout the world's oceans became isotopically lighter than deep waters at the K/T boundary. Combustion of terrestrial biomass with subsequent transfer of isotopically light carbon to surface waters is the most likely cause of this anomaly. A biogeochemical model is used to explore the effects of global scale burning on the composition of the atmosphere and ocean. Combustion of roughly 25% of the above-ground biomass at the end of the Cretaceous is necessary to account for the observed isotopic signal.

Is persistent drought in the Australian Outback linked to vegetation change caused by Late Pleistocene aboriginal burning?

G H Miller and B J Johnson (INSTAAR and Geol Sci, Univ. Colorado, Boulder, CO 80309-0450; 303-492-6962

During the Late Quaternary the interior of Australia experienced prolonged intervals of alternately wetter and drier climate. These changes in moisture balance are registered in the Lake Eyre Basin (LEB), an interior basin draining one sixth of the continent, by the stratigraphic interfingering of fluvial, lacustrine and aeolian deposits. The observed wet/dry cycles reflect changes in global circulation due to forcing and feedback mechanisms outside Australia and provide an independent monitor of hemispheric changes in circulation.

A well dated record of environmental change across the LEB during the past 150 ka is now available. Moisture is delivered to the LEB primarily by the landward penetration of major tropical disturbances during the Australian summer monsoon. We argue that changes in monsoon strength are tied to the intensity of air flow from the Tibetan Plateau in the northern hemisphere winter. The strength of the Asian winter monsoon is, in turn, linked to insolation changes dictated by variations in Earth's orbital parameters. Periods

of minimum January insolation over the Tibetan Plateau produce the strongest pressure gradients with the adjacent ocean, and consequently the most intense outflow. An intense Asian winter monsoon, coupled with high eustatic sea level is hypothesized to produce the most intense Australian summer monsoons, and a wet interval throughout the Australian interior. High levels of Lake Eyre and enhanced fluvial activity in the basin observed between 60-70 and 90-130 ka ago coincide with high sea levels and January insolation minima over the Tibetan Plateau; desiccation and deflation observed between 15-25 and 70-80 ka ago occurred during weakened Asian monsoon (January insolation maxima) and sea level minima. In contrast, a strong Asian winter monsoon and high sea level between 5 and 10 ka ago resulted in only a limited moisture increase over the basin. The failure of the early Holocene monsoon instead may be tied to vegetation change induced by systematic burning of fire-sensitive vegetation with the arrival of people in Australia 50 to 60 ka ago. A reduction in vegetation and accompanying loss of soil-moisture-holding capacity across northern Australia would have decreased evapo-transpiration, resulting in a weakening of monsoon intensity and persistent aridity in the interior despite strong forcing by insolation and sea level.

One Thousand Years of Fire History of Andino-Patagonian Forests Recovered from Sediments of the Rio Epuyén River, Chubut Province, Argentina

J G Goldammer (Max Planck Institute for Chemistry, Biogeochemistry Department, Fire Ecology and Biomass Burning Research Group, D-55020 Mainz, Germany)
P Cwielong and N Rodriguez (Both at: Centro de Investigación y Extensión Forestál Andino Patagónico, ARG-9200 Esquel, Chubut, Argentina)
J Goergen (Cooperation Tecnica Argentino-Alemana, GTZ/INTA, ARG-8400 San Carlos de Bariloche, Argenitina)
(Sponsor: M O Andreae #000 930 274)

Charcoal indicating pre-Columbian forest fires in the Andino-Patagonian *Nothofagus* forests of Southern Argentina can be found in volcanic soils and river sediments. During an expedition in March 1993 the sediments of the Rio Epuyén estuary at Lago Puelo, Province of Chubut, Argentina, were investigated. Charcoal pieces embedded in a 6-m sand bank profile were recovered between the riverbed and a height of 2.2 m. ^{14}C dating revealed radiocarbon ages between 100 and 1200 years BP. High sedimentation rates during the ca. 1000-year period are probably due to extreme climate oscillations and natural (volcanic) and anthropogenic fire sources. Comparisons are made with recent droughts and fires in the Andino-Patagonian forests of Southern Argentina and Chile. The implications of periodic fire occurrence and selection of tree species and shaping of forest types and forest stand patterns of *Nothofagus pumilio, N.antarctica, N.dombeyi* and *Australocedrus chilensis* are discussed.

Prehistoric Fire Regimes in East Africa by Lake Sediment Analysis

K F Weiss (Max Planck Institute for Chemistry, Biogeochemistry Department, Fire Ecology and Biomass Burning Research Group, D-55020 Mainz, Germany)
(Sponsor: M O Andreae #000 930 274)

It is assumed that late Quaternary fire regimes in Africa have been influenced by climate and vegetation changes and increasing anthropogenic impacts. To investigate the fire regime of the last 30,000 years in East and Central Africa two lake sediment cores from Mobutu Sese Seko or Lake Albert (Uganda) and Ishiba Ngandu (Zambia) were examined for charcoal content. The cores were recovered in the 1960's and 70's and were made available by Dan Livingstone, Duke University, Durham, N.C.. The main interest is to investigate how late Pleistocene and Holocene fires correlate with fluctuating savanna areas. Charcoal particles of the sediment were analyzed by optical microscopy. Charcoal frequencies were compared to climatic and vegetation data and the available information on anthropogenic influences.

Palynological analysis and relative charcoal counting show that ancient fires are strongly correlated to the occurence of *Gramineae*. As compared to the last ca. 5,000 yrs, fire activities were lower during the periods ca. 5,000 - 10,000 B.P. and 15,000 - 25,000 B.P., higher during 10,000 - 15,000 B.P. and before 25,000 B.P.. For the period 30,000 to 15,000 B.P. results of the charcoal analyses are less consistent with vegetational and climatic data. For the last 15,000 yrs charcoal particle frequencies are in agreement with evidence from palynological data.

Friday, March 17, 1995

Morning/Afternoon Session XIV: Kuwait Oil Fires
Chairs - P V Hobbs, W R Cofer

Gaseous Composition of Kuwaiti Oil Fire Smoke Determined From Individual Wellfires

W R Cofer III, J S Levine, D R Cahoon Jr. (Atmospheric Sciences Division, NASA Langley Research Center, Hampton, VA 23681-0001; 804-864-5835)
E L Winstead (GATS/SAIC, One Enterprise Parkway, Hampton, VA 23666)
J P Pinto, R K Stevens (U.S. Environmental Protection Agency, Research Triangle Park, NC 27711)

Seven morning helicopter missions were conducted between July 31 and August 8, 1991, to collect and analyze samples of smoke from the Kuwaiti Oilfires. Flight profiles included both longitudinal and transverse penetrations of individual and mixed plumes at very low altitudes over the Sabriyah and Burgan oil fields. Concentrations of carbon dioxide (CO_2), carbon monoxide (CO), hydrogen (H_2), methane (CH_4), total nonmethane hydrocarbons, sulfur dioxide, and particulates, including black carbon, were measured. About 25-30% of the smoke plumes appeared white in color and were determined to contain high levels of sodium and calcium chloride. Despite the dramatic coloration of the plumes, combustion from the fires was found to be very efficient overall, with about a 93% conversion of carbon to CO_2.

Heterogeneous Chemistry in the Smoke Plume from the 1991 Kuwait Oil Fires

J. A. Herring, R. J. Ferek and P. V. Hobbs (All at Department of Atmospheric Sciences, AK-40, University of Washington, Seattle, WA 98195; 206-543-6027; E-mail: phobbs@atmos.washington.edu)

During late spring of 1991, airborne measurements in the smoke plume from the Kuwait oil fires indicated that SO_2 and NO_x were generally removed from the gas phase at rates of ~ 7 % h^{-1} and 10 % h^{-1}, respectively. Photochemical calculations indicate that homo-

geneous chemical reactions were responsible for < 1% h^{-1} of this removal. Heterogeneous removal of SO_2 on black carbon (soot) and salt aerosols produced by the fires also appeared to be relatively slow. The reaction between NO_x and salt particles was likely responsible for some of the observed removal of NO_x, as well as for the depletion of Cl^- from the salt particles at a rate of ~ 4 % h^{-1}. However, the highest rates of SO_2 and NO_x removal were associated with high concentrations of atmospheric soil dust. This was likely due to heterogeneous oxidation of the SO_2 and NO_x on the surfaces of soil dust particles. The removal of SO_2 and NO_x on soil dust was probably accelerated by the alkaline nature of the dust. Heterogeneous reactions on soil dust particles proceeded more rapidly in regions of dispersed smoke than in the core of the plume; this was probably due to the depletion of the available soil dust surface area in regions of dense smoke. Based on our measurements, we estimate that the quasi-second order reaction rates were $(9 \pm 2) \times 10^{-8}$ and $(10 \pm 5) \times 10^{-8}$ (mg soil dust $m^{-3})^{-1}$ s^{-1} for SO_2 and NO_x, respectively. For a soil dust concentration of 200 mg m^{-3}, this implies removal rates for SO_2 and NO_x on soil dust of 6.5 % h^{-1} and 7.2 % h^{-1}, respectively.

Spatial and Temporal Variations of the Radiative Characteristics of Airborne Smoke Clouds from the Kuwait Oil Fires.

I Sokolik (NASA Ames Research Center, Moffett Field, CA 94035; e-mail: irina@ra.arc.nasa.gov)
F P J Valero (California Space Institute, Scripps Institution of Oceanography, University of California at San Diego, La Jolla, CA 92093; e-mail: fvalero@ucsd.edu)
P Pilewskie (NASA Ames Research Center, Moffett Field, CA 94035; e-mail: pil@ra.arc.nasa.gov)

Airborne radiation measurements of smoke from the Kuwait oil fires were carried out between May 18 and June 2, 1991. A total-direct-diffuse multichannel radiometer (TDDR) and a multichannel flux radiometer were used to provide measurements of downwelling and upwelling hemispherical solar fluxes in narrow-band spectral regions: 380, 412, 500, 675, 778, and 1064 nm. The TDDR measurements also allow us to determine the direct solar spectral fluxes, thereby estimating the spectral optical depth.

The data set to be analyzed in the present paper was accumulated during five flights covering the area between 47°E - 51°E, and 26°N - 29°N. During each flight, measurements at several pressure levels in the range 950 mb-550 mb were taken. Where profiles of radiative fluxes were available we determined the instantaneous heating rates in the smoke plume, as well as spectral transmission and reflection.

Using the collected data we investigated spatial (horizontal and vertical) and temporal variations of the main radiative characteristics under the varied smoke conditions. Several cases can be distinguished: 'background' (clean) condition, stable supercomposite plume, and strongly varied smoke cloud. The measured radiative characteristics for each of the cases were analyzed along with the results of a radiative transfer model.

Radiatively Driven Dynamics of the Plume from the 1991 Kuwait Oil Fires

J. A. Herring and P. V. Hobbs (Both at Department of Atmospheric Sciences, AK-40, University of Washington, Seattle, WA 98195; 206-543-6027; E-mail: phobbs@atmos.washington.edu)

Optical properties of the aerosol from the 1991 Kuwait oil fires are calculated using measured aerosol size distributions and a spectral refractive index based on the measured chemical composition of the particulate matter. Radiative transfer calculations indicate maximum net daytime heating rates of 94 and 56 K day^{-1} for smoke 1 and 3 hours downwind of the fires, respectively. In the upper regions of the plume, where the calculated heating rates decrease with height, a radiative-convective mixed layer developed. There was no significant temperature inversion at the top of this layer, which allowed rapid entrainment of air into the top of the plume, causing it to thicken at an observed rate of ~ 0.1 m s^{-1}. In addition, radiative heating of the plume as a whole caused it to lift as a unit at a measured rate of ~ 0.1 m s^{-1} during the first few hours of plume evolution. Calculations, based on mixed-layer modeling and a scale analysis of the equations of motion, reproduce these two rates of vertical transport. This model of the dynamics of a radiatively heated plume can be used to predict the evolution and lofting of large composite smoke plumes, such as those from forest fires; it also has implications for the transport, lifetime and climatic importance of smoke generated on continental scales.

The Kuwait Oil Fires and Their Regional Meteorological Impacts

P K Dowling, Captain, USAF (1st Operations Support Squadron Weather Flight Commander, Langley Air Force Base, VA 23665-2299, USA)
J S Levine (Atmospheric Sciences Division, NASA Langley Research Center, Hampton, VA, 23681-0001, USA)

A joint Air Force/NASA study on the impacts of the Kuwait Oil Fires on meteorological phenomenon throughout Southwest Asia. The study compares recorded climatology prior to the ignition of Kuwaiti oil wells in 1991 and meteorological impacts both during the fires and after the last fire was extinguished. Significant environmental damage to the desert and Persian Gulf ecosystems was clearly evident during the ten months of oil fires and extensive oil spills. Selected locations are studied to evaluate the potential long term meteorological changes.

Particle and Gas Emissions from an In-situ Burn of Crude Oil on the Ocean During the Newfoundland Offshore Burn Experiment

J. L. Ross, R. J. Ferek, and P. V. Hobbs (All at Department of Atmospheric Sciences, AK-40, University of Washington, Seattle, WA 98195; 206-543-6027; E-mail: phobbs@atmos.washington.edu)

Burning is an effective way of removing oil spills from the ocean; the tradeoff is the potential for significant air pollution. Airborne measurements are described of particles and gases from two test burns of crude oil offshore of St. Johns Newfoundland. The smoke plumes from the burns initially rose 200-400 m high and then continued to rise and disperse laterally downwind. The concentrations of submicrometer, sized particles in the smoke was ~15,000 cm^{-3} 1.5 kilometers from the fire and remained as high as 4,000 cm^{-3} for tens of kilometers downwind. Total particle mass loadings were over 1000 mg m^{-3} near the fire; then decreased to ~100 mg m^{-3} 25 km downwind at plume level (500 m, MSL). After normalizing for plume dilution, particles in the size range 0.1 mm-0.3 mm increased in concentration downwind as the smoke aged.

Total particulate emission factors were measured to be ~9% of the fuel burned; This indicates significantly lower combustion efficiency than oil pool fires in Kuwait, and comparable, but generally lower, efficiency than pan fire tests. For each kg of fuel consumed, 767 g of carbon were released in the form of CO_2. The average ratio of the concentration of CO to CO_2 was 0.017. The smoke contained ~77% elemental carbon, and ~6% organic carbon.

Lidar Measurements of a Smoke Plume Produced During the Newfoundland Offshore Burn Experiment

J. L. Ross, A. P. Waggoner, and P. V. Hobbs (Department of Atmospheric Sciences, AK-40, University of Washington, Seattle, WA 98195; 206-543-6027; E-mail: phobbs@atmos.washington.edu)

An airborne lidar was used to study the smoke plume from the burning of a prescribed oil spill on the ocean. A unique method for determining the extinction-to-backscatter ratio of the smoke was used. In this technique the change in strength of the laser beam after it has passed through the smoke plume, been reflected from the ocean surface, and passed through the smoke plume again, is compared to the strength of the laser beam that is reflected directly from the ocean surface. The mass flux of smoke through four vertical cross sections of the plume are calculated. The spatial distribution of smoke mass concentrations along the long axis of the plume are derived from the lidar returns.

Smoke mass concentrations were found to be generally <300 μg m^{-3}, with a few isolated spots up to ~800 mg m^{-3}. The smoke mass fluxes calculated for the four cross sections were 161, 198, 466, and 464 g s^{-1}, compared to an estimated average smoke production rate of ~447 g s^{-1}. The optical depths of the smoke at a wavelength of 0.532 μm was determined to be typically between 0.2 and 0.5.

American Geophysical Union Meetings Calendar

Chapman Conference
Measurement Techniques for Space Plasmas: What Works and What Doesn't
April 3-7, 1995
Santa Fe, New Mexico

Spring Meeting - AGU, MSA, GS
May 29 - June 2, 1995
Baltimore, Maryland

AGU Fall Meeting
December 11-15, 1995
San Francisco, California

Ocean Sciences Meeting - AGU, ASLO
February 12-16, 1996
San Diego, California

Chapman Conference
Magnetic Storms
February 12-16, 1996
Pasadena, California

Spring Meeting - AGU, MSA, GS
May 20-24, 1996
Baltimore, Maryland

Western Pacific Geophysics Meeting
July 23-27, 1996
Brisbane, Australia

AGU Fall Meeting
December 9-13, 1996
San Francisco, California

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