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P3.28 Regional Comparisons of Satellite (AVHRR) and Space Shuttle (MAPS) Derived Estimates of CO and Aerosol Concentrations

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1. INTRODUCTION

Biomass burning is considered to be a major source of trace gas species and aerosol particles (Logan *et al.*, 1981) which play a vital role in tropospheric chemistry and climate (Crutzen and Andreae, 1990). Anthropogenic biomass burning has largely expanded in the last 15 years, due to increased deforestation practices in the Amazon Basin, as well as to clear land for shifting cultivation in South America, southeast Asia, and Africa. Biomass burning produces large amounts of carbon dioxide, carbon monoxide (CO), water, hydrocarbons, nitrous oxides, and smoke particles (Crutzen *et al.*, 1979).

Recent estimates have shown that about 114 Tg of aerosol particles is produced yearly in the tropics through biomass burning (Penner *et al.*, 1992). These particles affect boundary layer cloud microphysics by increasing the amount of available cloud condensation nuclei (CCN) (Radke, 1989), and by decreasing the cloud drop size (Kaufman and Nakajima, 1993). Aerosol particles have a cooling effect on climate, both directly scattering the incoming solar radiation and indirectly by modifying the shortwave reflective properties of clouds by acting as cloud condensation nuclei (Charlson *et al.*, 1987).

Biomass burning is also an important source of carbon monoxide, which is one of the main reactive trace gases in the atmosphere, and which plays an important role in tropospheric chemistry (Badr and Probert, 1994 a,b). Carbon monoxide is produced naturally through oxidation of methane and other hydrocarbons, and by anthropogenic activities. At this time, it is believed that the amount of CO produced by natural sources is comparable to the amount of CO produced by anthropogenic sources (Badr and Probert, 1994 b). The technological activities in the northern hemisphere and biomass burning in the tropics are considered to be the main anthropogenic sources. It has also been estimated that the amount of CO emitted from biomass burning equals the CO emitted from industrialized pollution (Logan *et al.*, 1981; Watson *et al.*, 1990).

In 1994 measurements of CO mixing ratios were performed using the MAPS (Measurement of Air Pollution from Satellites) instrument, installed onboard the space shuttle, during the 9 through 19 April, and 30 September through 11 October , missions. Large fires were observed over southeast Asia, Indonesia (New Guinea and Borneo), and much of Australia. Scattered fires were also observed in central South America, and Africa. Satellite images and space shuttle photographs show giant smoke and haze clouds produced by these fires, which extended over thousands of kilometers. Over these regions MAPS also detected enhanced CO mixing ratios over and downstream of the burning areas. In this study, the April and October data from MAPS measurements are compared with the satellite (AVHRR) estimates of CO mixing ratios using the method proposed by Kaufman *et al.* (1990). Coincident AVHRR LAC data is used to detect fires and smoke produced through biomass burning. The geostationary satellite data and the ECMWF model results will be used to examine the conditions necessary for the transport and redistribution of the CO from the boundary layer into the free troposphere.

Section 2 presents the data used in this study, section 3 includes the methodology and preliminary results, and section 4 summarizes this present work.

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2. DATA

In this study, selected AVHRR LAC images coinciding with the April 1994 MAPS mission are used to accurately detect fires and smoke. The area studied is the border of India with Burma, and north and central Burma, where large fires were reported by the astronauts. The nominal spatial resolution is about 1.1 km at nadir, which is adequate for smoke and fire detection (Kaufman and Nakajima, 1993).

The MAPS instrument, installed onboard the space shuttle, is a nadir-viewing, gas filter correlation radiometer that is designed to measure the global distribution of middle tropospheric carbon monoxide mixing ratios (Reichle *et al.*, 1986, 1990). This passive remote sensor maintains high effective spectral resolution in the 4.67 μm fundamental band of CO. The instantaneous field of view (FOV) is 20 km^2 at the surface of the Earth, and the data are sampled once each second. The combination of FOV, sampling rate, instrument response time, and spacecraft speed are such that essentially independent measurements are obtained every 50 km along the sub-satellite track. A detailed description of the instrument technique and calibration has been reported in several papers (Reichle *et al.*, 1986, 1990; Wallio *et al.*, 1992).

3. METHODOLOGY AND PRELIMINARY RESULTS

3.1 Fire and Smoke Detection using AVHRR DATA

Fire detection is performed based on the method described by Kaufman *et al.*(1990). The mid-IR (3.7 μm - channel 3, "T3") and the infrared channels (10.8 μm - channel 4, "T4") of the AVHRR data are used to monitor the number of fires. The first condition (T3≥319°K) requires that a pixel be close to the 320K saturation level. The second condition (T3≥T4+10°K) requires that the radiative temperature in channel 3 be much larger than that of channel 4, in order to ensure that the pixel is not a warm surface; and the third condition (T4>255°K) overrules the possibility of saturating the pixel from highly reflective clouds.

For a selected satellite image (not shown) of about 800km x 800km, over Burma, 489 pixels are identified as fires. The fire areas stand out distinctly, having higher temperatures at 3.7 than at 10.8 μm. Figure 1 shows a west to east cross section through a portion of the studied area. Over fires, the 3.7-μm signature increases sharply when compared to 10.8 μm signal.

Most aerosol detection schemes require a dark uniform background to discriminate aerosols from the underlying terrain. The detection of aerosol over land

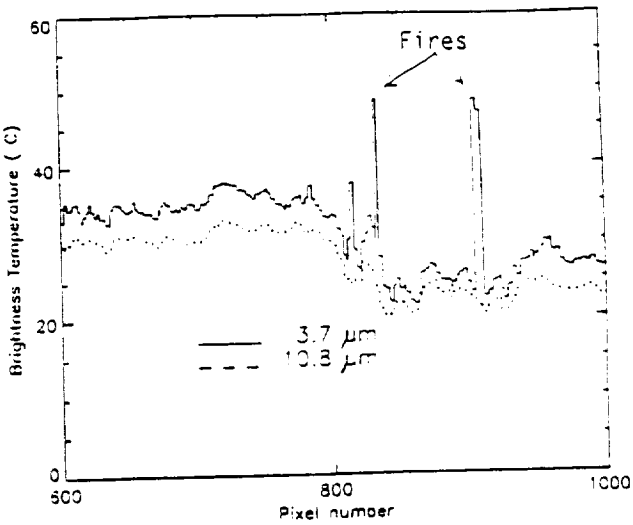

Figure 1. West to east cross section through the area studied in Burma (April 11, 1994 - AVHRR data)

is often more difficult due to the high albedo of the underlying background. In this study, a new technique based on a combination of spectral and textural measures is used for aerosol detection over land. The spectral combinations that were examined include AVHRR channels 2/1, (1-4)/(1+4), 1-2, 4-5, 3-4, and (3-4)/(3+4). Based on the Gray Level Difference Vector (GLDV) approach (e.g., Welch *et al.*, 1988), several textural features were calculated for a group of 9x9 AVHRR LAC pixels, which include 1) contrast, 2) local homogeneity, 3) angular second moment, 4) entropy, 5) mean, 6) difference cluster shade, and 7) difference cluster prominence. For smoke detection, the combinations that produced good results were obtained with channel 1 in red, channel (1-4)/(1+4) in green, and the textures MEAN or CONTRAST of channel (1-4)/(1+4).

3.2 *Computation of CO Mixing Ratios Using MAPS Data*

Figure 2 shows the locations of the detected fires over north and central Burma using AVHRR data, the high CO measurements (CO/Average CO over Central Pacific ≥ 2) recorded by MAPS instrument, and the pictures taken by the astronauts.

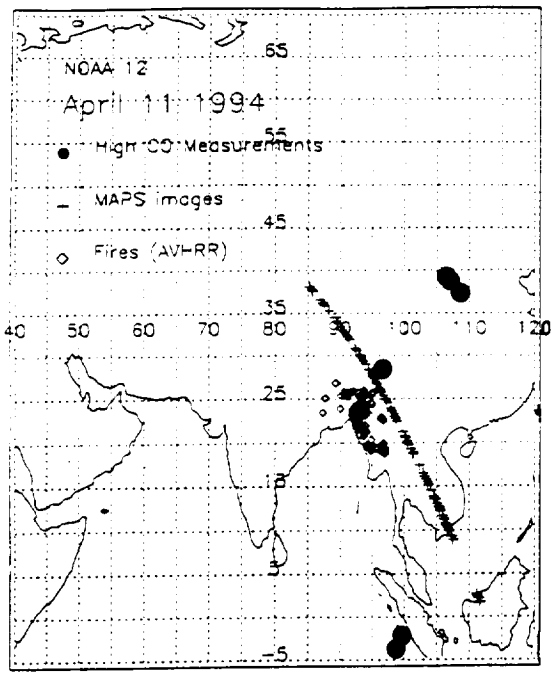

Figure 2: Locations of fires (489) detected using AVHRR channels 3 and 4; pictures taken by the astronauts on April 11, 1994; high CO mixing ratios over Burma, as recorded by MAPS instrument.

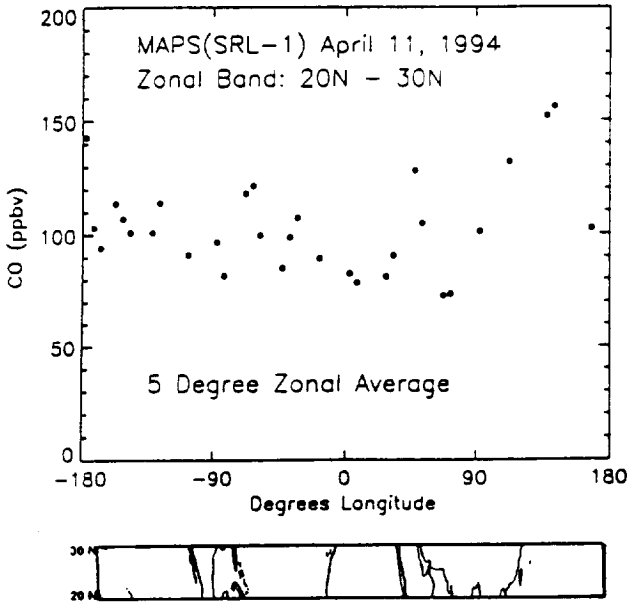

Figure 3: Carbon monoxide enhancement in 20N-30N latitude range as measured by MAPS on April 11, 1994.

Figure 3 shows the average CO mixing ratios recorded by MAPS instrument in the latitude band between 20N and 30N (which includes central and north Burma, and northeast of India), for each five degrees longitude during April 11, 1994. Since CO mixing ratios in the troposphere are maximum during Spring, it is not surprising that the average CO value in the middle troposphere, in the high northern latitudes, was 120 ppbv. In the 20N-30N zonal band on April 11, significant variability is shown in Figure 3, where the peak values (~130-160ppbv) are highly correlated with burning events in southeastern Asia or the plume being transported away from the local sources in China and South Vietnam. In areas removed from source regions, the CO mixing ratios decrease to about 80ppbv (ex. over Africa).

3.3. Estimation of the CO emission rate per fire using AVHRR LAC data.

The method proposed by Kaufman *et al.* (1990) is applied for estimating the total amount of particulates emitted due to biomass burning. First, AVHRR LAC imagery (3.7 μm and 10.8 μm channels) is used to determine the spatial and temporal distribution of fires which are observed during the satellite pass. Then the visible (0.63 μm) and near-IR (0.91 μm) channels are used to derive the aerosol optical thickness (aerosol mass loading in the atmosphere), its single scattering albedo (which is a measure of the presence of graphitic carbon in the aerosol), and the median particle size. Then an average dry aerosol emission per fire can be calculated. The amount of CO emitted per fire is estimated based on the relation between the amount of burned biomass, the emitted aerosol particles and the emitted trace gases (Kaufman et al, 1990; Ward, 1986). The CO emission rate is estimated for two fire conditions: smoldering and flaming. The results of this study will be presented at the conference.

4. SUMMARY

The amount of aerosol particles produced yearly in the tropics through biomass burning is estimated to be about 114 Tg (Penner *et al.*, 1992). It has also been estimated that the amount of CO emitted from biomass burning will continue to increase steadily, due to increased deforestation practices in the Amazon Basin, as well as to clear land for agricultural practices in South America, Southeast Asia, and Africa. In this study we compare the CO mixing ratios measured by the MAPS instrument during 1994 space shuttle missions, with estimated emissions of CO using coincident AVHRR data (Kaufman *et al.*, 1990). The new smoke detection technique is based on the combination of spectral and textural measures. The AVHRR channel 1 and (1-4)/(1+4) ratio along with the " mean or contrast" textural measures provided the best results. The geostationary satellite data and the ECMWF model results will also be used in determining the cor-

relation between the transport of CO from sources such as biomass burning and the high MAPS reading recorded during the April and October missions.

5. ACKNOWLEDGMENTS

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6. REFERENCES

Badr, O., and S. D. Probert, 1994(a): Carbon-monoxide concentration in the Earth's atmosphere. *Appl. Energy*, **49**, 99-143. [Printed in Great Britain]

Badr, O., and S. D. Probert, 1994 (b): Sources of atmospheric carbon monoxide. *Appl. Energy*, **49**, 145-195. [Printed in Great Britain]

Charlson, R. J., J. E. Lovelock, M. O. Andreae and S. G. Warren, 1987: Oceanic phytoplankton, atmospheric sulphur, cloud albedo and climate. *Nature*, **326**, 655-661.

Crutzen, P. J., and M. O. Andreae, 1990: Biomass burning in the tropics: Impact on atmospheric chemistry and biogeochemical cycles. *Science*, **250**, 1669-1678.

Crutzen, P. J., L. E. Heidt, J. P. Krasnec, W. H. Pollock and W. Seiler, 1979: Biomass burning as a source of atmospheric gases. *Nature*, **282**, 253-256.

Kaufman, Y. J., C. J. Tucker and I. Fung, 1990: Remote sensing of biomass burning in the tropics. *J. Geophys. Res.*, **95**, 9927-9939.

Kaufman, Y. J., and T. Nakajima, 1993: Effect of Amazon smoke on cloud microphysics and albedo-analysis from satellite imagery. *J. Appl. Meteor.*, **32**, 729-744.

Logan, J. A., M. J. Prather, S. C. Wofsy and M. B. McElroy, 1981: Tropospheric chemistry: a global perspective. *J. Geophys. Res.*, **86**, 7210-7254.

Penner, J. E., R. E. Dickinson and C. A. O'Neill, 1992: Effects of aerosol from biomass burning on the global radiation budget. *Science*, **256**, 1432-1433.

Radke, L. F., 1989: Airborne observations of cloud microphysics modified by anthropogenic forcing. Paper presented at *Symposium on Atmospheric Chemistry and Global Climate*, Amer. Meteor. Soc., Anaheim, CA, Jan. 29 - Feb. 3.

Reichle, H. G., Jr., V. S. Connors, J. A. Holland, W. D. Hypes, H. A. Wallio, J. C. Casas, B. B. Gormsen, M. S. Saylor and W. D. Hesketh, 1986: Middle and upper tropospheric carbon monoxide mixing ratios as measured by a satellite-borne remote sensor during November 1981. *J. Geophys. Res.*, **91**, No. C9, 10,865-10,887.

Reichle, H. G., Jr., V. S. Connors, J. A. Holland, R. T. Sherrill, H. A. Wallio, J. C. Casas, E. P. Condon, B. B. Gormsen and W. Seiler, 1990: The distribution of middle tropospheric carbon monoxide during early October 1984. *J. Geophys. Res.*, **95**, D7, 9845-9856.

Wallio, H. A. C. C. Chan, B. B. Gormsen and H. G. Reichle, 1992: Differential correction technique for removing common errors in gas filter radiometer measurements. *Appl. Optics*, **31**, No. 36, 7716-7724.

Watson, C. E., J. Fishman and H. G. Reichle, 1990: The significance of biomass burning as a source of carbon monoxide and ozone in the southern hemisphere tropics: A satellite analysis. *J. Geophys. Res.*, **95**, No. D10, 16,443-16,450.

Ward, D. E., 1986: Field scale measurements of emission from open fires. Tech. Paper Presented at the Defense Nuclear Agency Global Effects Review, Defense Nuclear Agency, Washington, DC 20305-1000.

Welch, R. M., S. K. Sengupta and D. W. Chen, 1988: Cloud field classification based upon high spatial resolution textural features. Part I: Gray level cooccurrence matrix approach. *J. Geophys. Res.*, **93**, 12663-12681.