

# IMPACT OF TROPICAL BIOMASS BURNING EMISSIONS ON THE DIURNAL CYCLE OF MID TO UPPER TROPOSPHERE CO<sub>2</sub> RETRIEVED FROM NOAA-10 SATELLITE OBSERVATIONS

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## ABSTRACT

### Importance of biomass burning

Biomass burning is an important source of atmospheric CO<sub>2</sub>, aerosols and chemically important gases. It is as important to global chemistry as industrial activities in the developed world [Crutzen and Andreae, 1990]. Biomass burning is a key component of the global carbon budget, currently releasing 2.6 GtC from fires in the tropical and subtropical ecosystems (van der Werf *et al.* [2003], to be compared to the 5.6 GtC released from fossil fuels) to the atmosphere each year, most of it being emitted in the form of carbon dioxide, although there is important spread amongst various estimates. Biomass burning contributes up to 40% of gross atmospheric CO<sub>2</sub> (IPCC, 2001), 38% of tropospheric O<sub>3</sub>, and 10 % of CH<sub>4</sub>.

Fire activity is seasonal, generally lasting 3-4 months, with the burning season being longer in the southern hemisphere [Duncan *et al.*, 2003]. Fire activity generally undergoes a strong diurnal cycle. Using GOES-8 observations, Prins *et al.* [1998] report that, through the 1995 burning season in south America, a diurnal signature is clearly evident with peak burning occurring in the early to mid afternoon local time. The existence of a strong diurnal cycle of African savanna fires is also reported by Langaas [1993], using field observations and thermal satellite images.

## METHODOLOGY

Recently, Chédin *et al.* [2003] showed that upper air CO<sub>2</sub> concentration can be retrieved from observations of the TIROS-N Operational Vertical Sounder (NOAA/TOVS), which main mission is to measure atmospheric temperature and moisture at global scale. HIRS-2 radiances at 15 μm mostly depend on the temperature of the atmosphere but also, although weakly [Chédin *et al.*, 2002], on the CO<sub>2</sub> concentration. Also sensitive to the temperature of the atmosphere, the observations made simultaneously by MSU in the microwaves are not sensitive to CO<sub>2</sub>. This allows separating the two signals. The mean normalized CO<sub>2</sub> Jacobian (partial derivative of the satellite observations with respect to atmospheric layer CO<sub>2</sub> variations) of the HIRS-2 CO<sub>2</sub> sensitive channels exhibits maximum sensitivity at around 200 hPa.

## DIURNAL VARIATION OF UPPER TROPOSPHERIC CO<sub>2</sub> CONCENTRATION

Four years (July 1987 to June 1991) of NOAA-10 observations over the tropics (20N-20S), at 7.30 am and 7.30 pm, have been interpreted in terms of mid to upper tropospheric CO<sub>2</sub> column. For each month, we compute the difference in column-averaged upper tropospheric CO<sub>2</sub> between 7.30 pm and 7.30 am by averaging daily differences. Then, monthly "Night minus Day Difference" (N-DD) values have been lumped into seasons, and averaged over the four years considered. Contrary to our expectation of relatively smooth and weak upper troposphere CO<sub>2</sub> diurnal variations, the N-DD shows regional maxima of up to 3 ppm during June, July and August over southern Africa and southern America and of about 2 ppm during December, January and February over northern Africa (south Asia being obscured by persistent cloudiness), that is during the dry winter of each hemisphere. On a monthly basis, a weaker regional enhancement of N-DD can be seen during February over northern Africa and during September over southern Africa and southern America.

The seasonality of the N-DD maxima (Fig. 1a) follows that of fire activity, indicating that above burning areas, there is an important excess of CO<sub>2</sub> in the troposphere at 7.30 pm, several hours after the daily peak burning, compared to 7.30 am. Seasonal changes in the location of the N-DD maxima within the year compare well with emission maps derived by Duncan *et al.* [2003] or by van der Werf *et al.* [2003], although the periods analyzed are different.

The N-DD signal, based upon measurements of the concentration of CO<sub>2</sub> twice a day, is particularly well suited to depicting the seasonality of fires. Over southern Africa (0-20S), for example, the variations of CO<sub>2</sub> retrieved from TOVS (Fig. 1b) appear much less correlated with fires than the N-DD product (Fig. 1a). This is not surprising since

CO<sub>2</sub> variations are influenced both by regional sources and sinks and by long range transport acting on remote fluxes.

### INTERPRETATION OF THE N-DD SIGNAL

We explain the N-DD signal from the combination of diurnal fire-induced CO<sub>2</sub> emissions with two rapid transport mechanisms affecting the CO<sub>2</sub> emitted by the fires. First, a vigorous convective uplift of biomass burning plumes of CO<sub>2</sub> to the middle and upper troposphere occurring between morning and late afternoon, and thus detected by the satellite at 7.30 pm. Second, a rapid (within 12 hours) dispersal of the burning emission-laden air in altitude by the prevailing upper tropospheric flow during the night, before the next satellite pass in the morning. Fire-induced convection could be the key process that contributes to the uplifting of fire emissions. There is ample evidence that forest fires in boreal and temperate regions can generate enough energy to create a convection column which allows large amounts of fire emissions to reach the stratosphere [Fromm *et al.*, 2000, 2004]. Within the tropics, Andreae *et al.* [2004] report that “heavy smoke from forest fires in the Amazon was observed to reduce cloud droplet size and so delay the onset of precipitation from 1.5 kilometers above cloud base in pristine clouds to more than 7 kilometers in pyro-clouds. Suppression of low-level rainout and aerosol washout, by invigoration of the updrafts, allows transport of water and smoke to upper levels, where the clouds appear “smoking” as they detrain much of the pollution.” This conceptual model brings one possible transport mechanism able to explain the N-DD signals.

### DISCUSSION AND PERSPECTIVES

The most striking feature of this study is a strong increase in the night (7.30 pm, local time) minus day (7.30 am) difference of the retrieved CO<sub>2</sub> column over areas affected by intense fires. Both the seasonal and the interannual variability of this CO<sub>2</sub> difference follow the most recent studies on the distribution of fires. In particular, the agreement with the monthly Global Burnt Scar (GLOBSCAR) product, which is recognized as yielding reasonable estimates of burnt areas for larger and presumably more intense fires, is remarkable. It seems to indicate that the N-DD signature responds more to the burnt scar size, and presumably to the intensity of fire-induced convection, than to the number of fires. However, the magnitude of a few extreme N-DD values seems to point out a potential significant contamination of the N-DD signal by fire emission products other than CO<sub>2</sub>. It is concluded from a detailed sensitivity analysis that the main potential source of contamination may come from high altitude aerosols with a large infrared optical depth. Such an occurrence can only be explained by a vigorous injection of biomass burning emission products in the high troposphere, and would render the N-DD signal more a key indicator of the intensity and location of the fires than a quantitative measure of the injection of CO<sub>2</sub> in the upper troposphere.

Further analysis includes the processing of the whole NOAA-TOVS series from 1979 to now, as well as the assimilation of such data in atmospheric CO<sub>2</sub> flux inversions. Preliminary simulations using the general circulation model LMD-Z [F. Hourdin, private comm.] have also been started to further analyze the injection of biomass burning emissions into the upper troposphere.

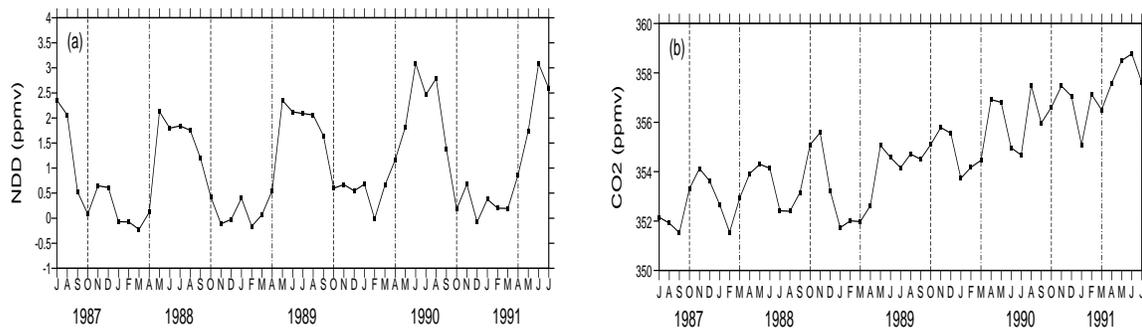


Fig. 1: (a) Monthly mean N-DD averaged over land for southern Africa (0-20S).  
(b): same as (a) but for the monthly mean concentration of CO<sub>2</sub>.