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Importance of biomass burning

Biomass burning is an important source of atmospheric CO₂, 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 (an estimation from *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 (~90%) 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 CO₂ (IPCC, 2001), 39% of tropospheric O₃, and 10 % of CH₄.

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], using a non-linear regression inverse radiative transfer model based on the Multi-Layer Perceptron [Rumelhart et al., 1986], showed that upper air CO₂ 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 μ m mostly depend on the temperature of the atmosphere but also, although weakly [Chédin et al., 2002], on the CO₂ concentration. Also sensitive to the temperature of the atmosphere, the observations made simultaneously by MSU are not sensitive to CO₂. This allows separating the two signals. Figure 1 shows that the mean normalized CO₂ Jacobian (partial derivative of the satellite observations with respect to atmospheric layer CO₂ variations) of the HIRS-2 CO₂ sensitive channels exhibits maximum sensitivity at around 200 hPa.

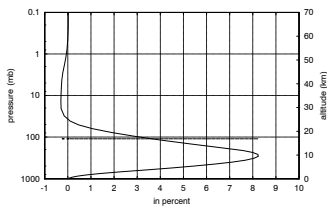


Figure 1
 Mean normalized CO₂ Jacobian (partial derivative of the TOVS observations with respect to CO₂ variations) of the HIRS CO₂ sensitive channels (in %). Dashed line: mean tropical tropopause level.

Diurnal variation of upper tropospheric CO₂ concentration

Four years of NOAA-10 observations at 7.30 am and 7.30 pm, from July 1987 to June 1991, have been interpreted in terms of mid to upper tropospheric CO₂ column. Individual cloud free daily retrievals at a spatial resolution of 1°x1° are binned into monthly maps at a spatial resolution of 15°x15° at 7.30 am and at 7.30 pm, over the latitude band 20N-20S.

For each month, we compute the difference in column-averaged upper tropospheric CO₂ between 7.30 pm and 7.30 am by averaging daily differences. In Figure 2, monthly 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 CO₂ 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 (see Figs.4-6), again averaged over the four years, a weaker regional enhancement of N-DD can be seen during February over northern Africa and during September over southern Africa and southern America.

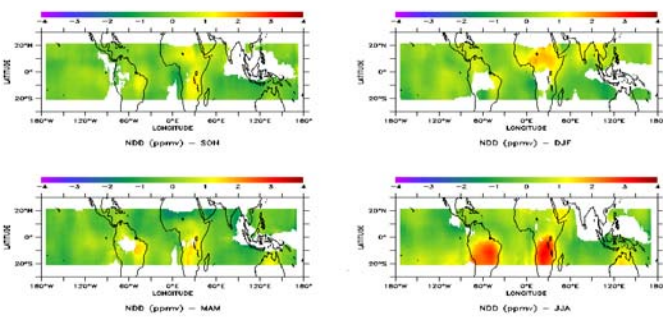


Figure 2: Seasonal mean difference between 7.30 pm and 7.30 am, local time, of mean upper tropospheric mixing ratios of CO₂ over the tropics (20N-20S) averaged over the period July 1987-June 1991. Spatial resolution: 15°x15°, 1° by 1° moving average.

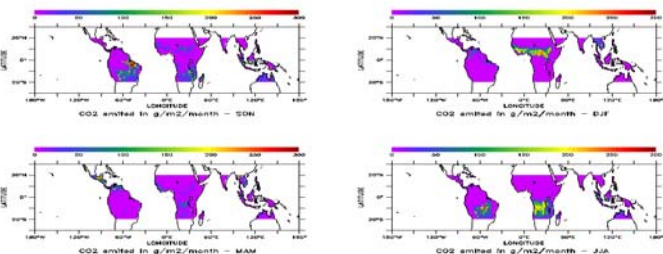
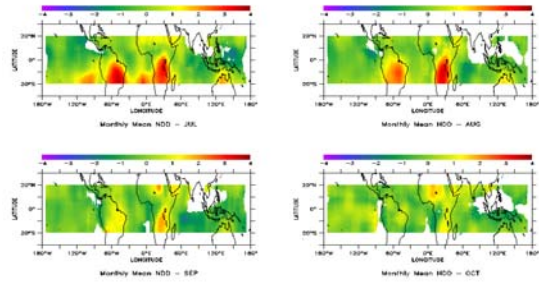
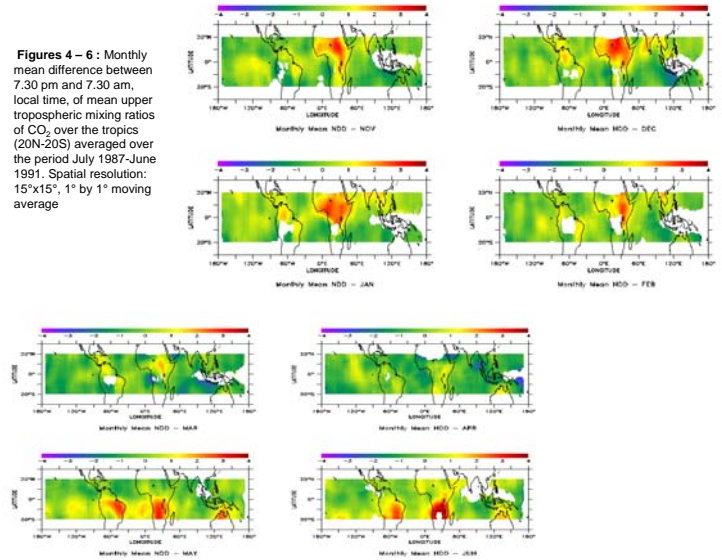


Figure 3: Seasonal mean fire emissions of carbon dioxide in g/m²/month from *van der Werf et al.* [2003] averaged over the period 1997-2002.

The seasonality of the N-DD maxima in Figs. 4 - 6 follows that of fire activity, indicating that above burning areas, there is an important excess of CO₂ in the upper 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] from aerosol indexes or ATSR fire counts or by *van der Werf et al.* [2003] from TRMM fire counts (see Figs. 2 and 3), keeping in mind that the periods analyzed are different and that the N-DD is a mid to upper tropospheric signal whereas TRMM fire counts describe a surface product.



Figures 4 - 6: Monthly mean difference between 7.30 pm and 7.30 am, local time, of mean upper tropospheric mixing ratios of CO₂ over the tropics (20N-20S) averaged over the period July 1987-June 1991. Spatial resolution: 15°x15°, 1° by 1° moving average



The N-DD signal, based upon measurements of the concentration of CO₂ twice a day, is particularly well suited to depicting the seasonality of fires. Over southern Africa (0-20S), for example, the variations of CO₂ retrieved from TOVS (Fig. 7b) appear much less correlated with fires than the N-DD product (Fig. 7a). This is not surprising since CO₂ variations are influenced both by regional sources and sinks and by long range transport acting on remote fluxes.

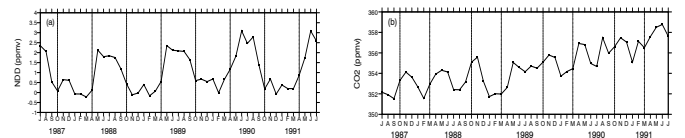


Figure 7: (a): Time series of the monthly mean N-DD averaged over land for southern Africa (0-20S). (b): same as (a) but for the monthly mean concentration of CO₂.

Interpretation of the N-DD signal

We explain the N-DD signal from the combination of diurnal fire-induced CO₂ emissions with two rapid transport mechanisms affecting the CO₂ emitted by the fires. First, a vigorous convective uplift of biomass burning plumes of CO₂ 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, feed directly on the smoke and heat from fires. 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, which validation motivated the Large-Scale Biosphere-Atmosphere Experiment in Amazonia-Smoke, Aerosols, Clouds, Rainfall, and Climate (LBA-SMOCC), brings one possible transport mechanism able to explain the N-DD signals of Figs. 2 and 4-6.

Discussion and perspectives

This study of mid to upper tropospheric column of CO₂ at 7.30 am and 7.30 pm local time in the tropics, shows unsuspected patterns in regions where almost no in-situ measurements exist. The most striking feature is a strong increase in the night (7.30 pm, local time) minus day (7.30 am) difference of the retrieved CO₂ column over areas affected by intense fires. Both the seasonal and the inter annual variability of this CO₂ difference follow the most recent studies on space and time 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 (for example over Africa in August 1990, of the order of more than 5 ppm locally), seems to point out a potential significant contamination of the N-DD signal by fire emission products other than CO₂. 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 frequency and location of the fires than a quantitative measure of the injection of CO₂ 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 CO₂ 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.