Management and Impacts of Climate Change Programme
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4/01 – Climatic impact of carbonaceous aerosols

Summary of Final Report

Coordinator: Cathy Liousse, LA

The climatic role of aerosols, although somewhat more difficult to assess than that of greenhouse gases, is now an established fact. What is more, it has become the object of several debates since Hansen *et al*. (2000) showed that climate warming control efforts should concern carbonaceous aerosols as well as greenhouse gas emissions. A more recent study (Jacobson, 2002) even suggested that it would be more efficient to reduce carbonaceous aerosol emissions than greenhouse gas emissions, as the lifetime of aerosols is somewhat shorter than that of greenhouse gases. Unfortunately, the 'cleanest' energies in terms of greenhouse gases are also the greatest emittors of carbonaceous particles. One may therefore understand the concern of politicians and businessmen, who had been advised to shift from 'petrol' energy to 'diesel' energy to limit greenhouse gas emissions and who realize today that the result of the operation would have been an increase in particle emissions! At the 'Pollution-Climate' workshop organized by J. Hansen in May 2002, the same lecturers were puzzled by this complexity, and sent researchers back to their studies to validate these hypotheses.

The aim of this programme is relevant to this issue, since our objective is to construct an inventory of carbonaceous particle emissions from 1860 to 2100. Our strategy, initially, is to improve and develop modern inventories (from 1950 to 2000) regarding fossil fuel emissions and biofuel emissions (combustion of wood, charcoal, farm wastes, etc.), to establish those of the past (1890-1950) and future (2030-2100 projections), and lastly to study the emissions of savannah and forest fires using satellite imagery.

The results were obtained using a methodology at the interface of experimentation and modelling and were produced thanks to the active cooperation of the main participating research units (LA, LSCE, IEPE and JRC-Ispra). They can be summarized as follows.

1) Revision of the algorithms for working out the distributions in time and space of emissions from fossil fuels and domestic fires. Establishment of emission inventories for fossil fuels (traffic, industries, etc.) and domestic fires (wood, coal, etc.) regarding black carbon (BC), primary organic carbon (OC_p) and total organic carbon (OC_{tot}) from 1950 through to 1997. This research has allowed us to revise the values of the emission factors

on the basis of recent literature data. It has also highlighted the significance of domestic fires as contributors to carbonaceous particle emissions, in particular in developing countries.

2) Inventory of BC, OC_p and OC_{tot} emissions from fossil fuels and domestic fires from 1860 through to 1997, taking into account variations in fuel consumption, type of activity and emission factors over time. For the 1860-1950 period, a new method was devised on the basis of Bairoch's (1991) data for the estimation of fuel consumption trends, of UNSTAT database data for fuel consumption trends, and of Pertuisot's (1997) data for emission factor trends. Comparisons were made between the UNSTAT-based inventory (see §1) and the Bairoch-based inventory for the overlapping years 1950-1985. At the same time, we were able to demonstrate the advantage of taking into account emission factor values that change with time.

3) Inventory of emissions from biomass fires on the basis of burnt areas detected using satellite imagery, in Africa (1981-1991 and 2000) and Asia (2000 and 2001). Results underline the importance of using remote sensing images of the burnt areas when calculating emissions, rather than the mean statistics that are commonly employed to this day. They also allowed us to draw a first comparison between inventories established on the basis of two different methods, both using satellite imagery, i.e. the 'fire scar' or 'burnt area' method and the 'fire pixels mapping' method. Our conclusions underline the importance of encouraging collaboration between research teams working on these two types of method. In the initial objectives of our programme, we had planned to identify a particular methodology for past and future projections. Our results show that past and future projections cannot be based solely on population maps, and must include climate indicators.

4) Inventory of emissions from fossil fuels and domestic fires for future projections. Initial inventories of emissions from fossil fuels were established for the period up to 2100 in the case of 'disaster' scenarios (scenario A2) and 'ideal' scenarios (scenario B1), on the basis of IPCC data. Given the many hypotheses assumed in order to derive the 2100 inventories and the non-inclusion of domestic fires, we developed other inventories for 2030 on the basis of socio-economic criteria more realistic than those on which the IPCC data relied and including the sources of fossil fuels and domestic fires. For the 1990-2030 period, fuel consumptions per activity were extracted from the POLES model data (P. Criqui research team) for two scenarios (a reference scenario 'ref' of the business-as-usual type and a 'ccc' scenario in conformity with the Kyoto Protocol criteria). The findings emphasize the importance of emission controls between the various scenarios. Depending on the scenario ('ref' or 'ccc'), BC emission estimates range from 5.8 to 13.7 TgC (in the case of 2100 B1 and 2100 A2 scenarios, BC budget ranges between 0.6 and 100 TgC, see Liousse & Cachier 2005).

5) Characterization of carbonaceous aerosol particles upon emission. For this purpose, we set up an experimental campaign in the combustion chamber on the LA premises in order to quantify and physico-chemically characterize emissions from the combustion of little-known fuels (domestic fires in India and China using various types of coal, charcoal,

wood, animal dung, etc., and fuels sent from India by our Indian colleague R. Gadi). We paid particular attention to the emission factor (EF) values and to the sizes of the carbonaceous particles. It must be noted that, contrary to what we expected, coal combustion produces mostly submicronic carbonaceous particles. The EF values, higher than those published in the literature, match those of uncontrolled domestic combustions typical of developing countries. With a wish to improve our data's integration (literature and recent experiments), we devised a theoretical formulation to obtain EF values as well as BC/OC ratios according to parameters that make it possible to describe the type of combustion involved (on the basis of the CO/CO_2 ratio, which is usually known). This relationship was validated in the course of our experiment on domestic fires.

6) Updating of discrepancies between inventory research results worldwide and their possible origin. We organized in June 2002 an international workshop where experts in this particular field met in order to look for the underlying causes of the great discrepancies observed between their various inventories – whether having to do with the definition of aerosols, the choice of emission factors or the methods used for sampling or analysis. The comparisons made at this workshop gave rise to a number of studies (Bond *et al*. 2004, Liousse *et al*. 2005, IIASAG book in preparation and IPCC chapter). In preparing a chapter for the IGAC-Emissions book edited by C. Granier on the emissions of biomass fires, C. Liousse, H. Cachier and J. Penner mentioned this coordination and revision effort at the international level on the subject of the choice of the EF in the case of savannah and forest fires (Liousse *et al*. 2004). However, clear recommendations are needed today, given the discrepancies that subsist between inventories. Within the framework of the ACCENT programme (network of excellence of the European programme FP6) and of GEIA (Global Emission Inventory Activities, http://weather.engin.umich.edu/geia), other experts' meetings are scheduled in 2005 in order to propose internationally consistent inventories for users.

N.B.: These inventories were constituted and completed in the form of a 'database' with the technical help of MEDIAS (CAPEDB: Database of Carbonaceous Aerosol Particle Emission) so as to be easily accessed and utilised. This research was undertaken in relationship with an ADEME-supported programme focusing on the development of regional and continental emission inventories. The database will be accessible as soon as the various papers in preparation have been published.