RESULTS FROM A CLIMATOLOGICAL MODEL OF HEAVY METALS IN EUROPE'S ATMOSPHERE

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INTRODUCTION

There is increasing observational evidence that heavy metals' air emissions cause not only local contamination, but also travel long distances in Europe and contribute to widespread, although low-level, contamination of the environment (e.g. Pacyna, et al, 1984; Ottar, et al, 1989). The *TRACE* model (*TR*ace toxic *A*ir *C*oncentrations in *E*urope) has been developed to compute the long range transport of various heavy metals (As, Cd, Pb, and Zn) on the European-scale. A preliminary version of this model was reported in Alcamo, et al (1991a) and model refinements and application are given in Alcamo, et al (1991b) and Bartnicki et al (1991).

This paper presents selected results of model testing and application. First we review the outcome of a sensitivity analysis of the dry deposition calculations of the model. Next we present calculations of the concentration of heavy metals in precipitation in Europe, and finally we report on estimates of the origin of the average atmospheric load of metals to various countries.

MODEL TESTING: UNCERTAINTY OF DRY DEPOSITION CALCULATIONS

Results of testing the model against observations are presented elsewhere (Alcamo, et al, 1991a and b), and are therefore not repeated here. In brief, model calculations agree fairly well with measured As and Pb air concentrations and wet deposition, but underestimate Cd and Zn data. Data from 1978 to 1985 were used for these comparisons.

There are, of course, many possible model/data uncertainties that can lead to discrepancies between model calculations and observations. In this paper, we focus

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on the uncertainties in computing dry deposition in the TRACE model because this information may be of general interest to other research efforts.

Dry deposition in the model is computed in the conventional way, as the product of air concentration at a receptor location, $c(x_r,y_r)$, and a dry deposition velocity v_d:

$$d_d = c(x_r,y_r) \cdot v_d \tag{1}$$

The dry deposition velocity is weighted according to particle size by:

$$v_d = \sum v_d (D_p, u*, z_o) f(D_p) \tag{2}$$

where v_d is computed from the semi-empirical model of Sehmel (1980) as a function of particle diameter (D_p), friction velocity ($u*$), and surface roughness (z_o). Sehmel's model is based on wind-tunnel experiments and theoretical removal rates via brownian diffusion and gravitational settling. Data for $u*$ and z_o are available in a European grid from the EMEP program. The variable $f(D_p)$ is the fraction of mass with diameter D_p in the particle size distribution of the different heavy metals. It is particularly difficult to obtain appropriate data for size distributions for all the heavy metals of interest because these data should be long-term averages and representative of wide geographic areas. This is a general problem in calculating regional budgets of heavy metals and other aerosol-based substances. Our provisional solution to the problem is to use the particle size distributions measured by Dulac et al (1989) in the Mediterranean for Cd and Pb because they are one-year averages collected at sites not affected by local sources but are nevertheless influenced by anthropogenic sources on the European continent. Dulac et al (1989) however, did not measure either the As or the Zn distribution. Consequently, as a first assumption, we assign the measured Cd mass size distribution also to As and Zn. This is consistent with the observation that As, Cd, and Zn have roughly the same source profile in Europe (Pacyna and Münch, 1987) and may therefore on the average have similar particle size distributions in the lower atmosphere. We examine this assumption below.

Uncertainties Regarding Particle Size Distributions. Uncertainty in estimating the dry deposition velocity with the preceding equations stems in part from:

- Uncertainty of assumptions about the characteristic particle size distribution.
- Uncertainties in Sehmel's model which is used to relate v_d to D_p, z_o, and $u*$.

These are obviously not the only sources of uncertainty in the procedure for calculating dry deposition, but we will examine them more closely because of their potential importance. We begin with an examination of the assumption that As, Cd and Zn have similar particle distributions, while Pb has a different distribution. As noted above, this is a very useful assumption because it is difficult to obtain appropriate particle size distribution data for all the heavy metals of interest in TRACE model calculations.

To test this assumption we compute the size-weighted v_d using equations (1) and (2) based on the particle distributions for As, Cd, Pb and Zn given in the literature review of Milford and Davidson (1985). (Most of these data are from North American cities, and hence unsuitable for routine use in the TRACE model.