Comments on "A General Gaussian Diffusion-Deposition Model for Elevated Point Sources"

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ABSTRACT

A comparison is made of the Gaussian diffusion-deposition models of Chamberlain (1953) and Overcamp (1976) with the exact solution of Horst (1977). Overcamp's model is found to be a useful improvement over Chamberlain's model at short distances downwind of the source. At large distances, however, Chamberlain's model is superior to that of Overcamp.

Csanady's (1955) model for the deposition of particulates with an appreciable settling velocity from a Gaussian diffusion plume has been extended by Overcamp (1976) to the case of gases and fine particulates, where the deposition velocity does not equal the settling velocity. This model selectively reduces the strength of the conventional image source to account for the loss of material due to dry deposition. Because it results in a relative depletion of the material near the ground, Overcamp's model is intended to be an improvement over the source depletion model of Chamberlain (1953) which distributes the loss throughout the entire vertical extent of the plume by reducing the strength of both the real and image sources.

As discussed by Csanady (1957), however, his model is only an approximate solution. In particular it neglects the transport due to the vertical gradient of material established by the deposition process. Horst (1977), on the other hand, has developed a surface depletion model which has been used to calculate exact solutions for the deposition of nonsettling particles from a Gaussian plume. Nevertheless, the models of Chamberlain and Overcamp are still of interest because they are computationally much less complex than that of Horst. It is the intent of this note to briefly compare the model predictions of Overcamp with those of Chamberlain and Horst.

For the case of gases and fine particulates with negligible settling velocities, Overcamp's model predicts that dry deposition reduces the surface air concentration by a factor of

$$\tfrac{1}{2}[1+\alpha_0(x)]=\left[1+\frac{v_d}{u}\left(\frac{h}{\sigma_z}\frac{d\sigma_z}{dx}\right)^{-1}\right]^{-1}, \tag{1}$$

where the coefficient $\alpha_0(x)$ specifies the fractional reduction of the image source strength, the x axis is aligned in the direction of the mean wind u, v_d is the deposition velocity, h the effective height of pollutant emission and σ_z the vertical standard deviation of a nondepositing Gaussian diffusion plume. Fig. 1 shows this quantity for $h=100$ m, $u=5$ m s^{-1}, $v_d=0.01$ m s^{-1}, and Pasquill stability categories A, C and E. Except for the addition of Pasquill category A, these conditions correspond to those used in Overcamp's Fig. 3. Also shown are the predictions of Chamberlain's source depletion model and Horst's surface depletion model. The σ_z values were calculated from the formulas given by Briggs (1974).

For all stabilities the models of both Horst and Overcamp correctly predict greater reductions in the surface air concentration than does Chamberlain's model. However, Overcamp's model still underpredicts the air concentration reduction at short distances and greatly overpredicts the reduction at large distances. For a release height of 100 m the crossover occurs at $x\approx 10^4$ m, and this distance is reduced by a factor of 5–10 for a release height of 10 m.

The underprediction at short distances is associated with the fact that, as in Chamberlain's model, Overcamp's model accounts for the material loss due to deposition by reducing the strength of a source at $x=0$. Thus the loss appears to propagate from $x=0$, rather than from the location x_d where the deposition actually occurs. At positions downwind of x_d, therefore, the effect of deposition on the surface air concentration is underestimated because the loss has been diluted by diffusion over the distance x rather than the smaller distance $x-x_d$. Nevertheless, at short distances downwind of the source Overcamp's model is an improvement over Chamberlain's model because reduction of only the image source strength results in relatively more depletion of the material near the surface.

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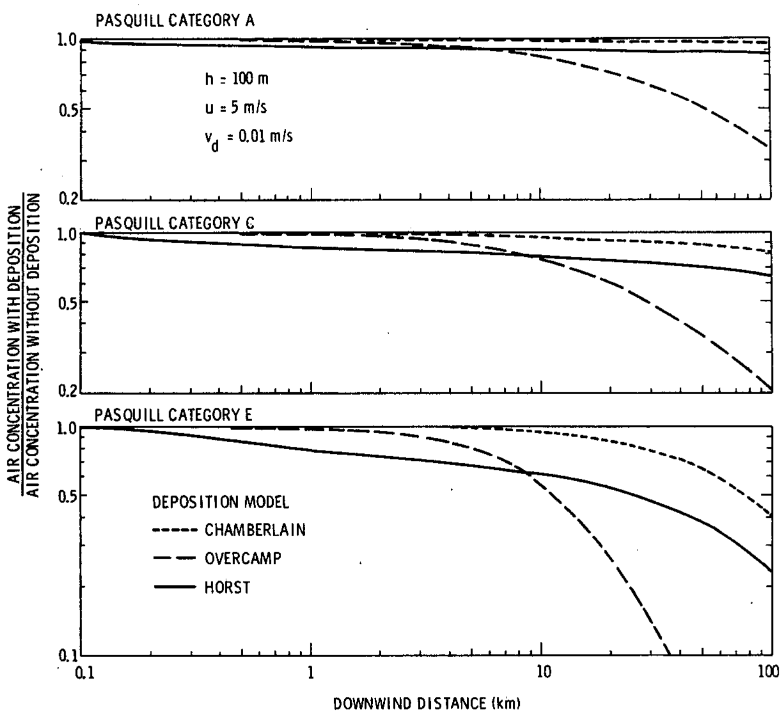

FIG. 1. The reduction of the surface air concentration due to deposition as predicted by several Gaussian models.

At large distances, however, Overcamp's model rapidly diverges from the other two, predicting a sharp decrease in the surface air concentration. This occurs because the model neglects the additional downward flux of material produced by the reduced air concentration at the surface. This flux limits the depletion of material near the surface by replacing it at a rate proportional to the magnitude of the vertical air concentration gradient.[1] The relative contribution of this flux increases with distance, and the effect of its neglect eventually overrides the underprediction discussed in the previous paragraph. Due to the resulting excessive depletion of the surface air concentration, Overcamp's model in fact predicts that deposition ceases at large downwind distances and the amount of undeposited material unrealistically approaches a constant value.

In summary, Overcamp's extension of Csanady's model to particles with a negligible settling velocity is a useful improvement over Chamberlain's model at short downwind distances. His predictions lie midway between those of Chamberlain's model and those of Horst's model. As a bonus, Overcamp's model does not require the computation of an integral and hence is even simpler to apply than that of Chamberlain. At large distances, however, Overcamp's model greatly overestimates the reduction of the surface air concentration and unrealistically predicts that the loss of material due to deposition has an upper limit. At these distances Chamberlain's model is superior to that of Overcamp.

[1] The deposition-caused vertical gradient of air concentration is reflected in the variation of α_0 with x and thus the additional transport could in principle be accounted for, but Csanady (1957) states that the resulting equations are excessively complicated.

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