Comments on "Lateral Dispersion from Tall Stacks"

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ABSTRACT

A few minor errors in a paper by Hanna are noted and several questions are raised about apparent inconsistencies. One question is why substantial enhancement of σ_y by buoyancy was noted for the Bull Run data but was unmentioned for the Kincaid data; information given in the paper suggests similar ranges of X^*/F_* at both plants, but much smaller F_* values at Kincaid, which may account for the lack of noticeable buoyancy effects there. The inconsistency between the recommended equation $\sigma_y/x = 0.6w_*/u$ and the σ_y/x values recommended for various stability classes (based on u/w^* ranges) can be removed by multiplying this σ_y expression by a factor which accounts for the effect of mechanical turbulence. Finally, it is noted that an identical equation was recently reported to give a good fit to σ_y from passive sources released above 0.3 h, albeit to much smaller distances than reported by Hanna.

The paper by Hanna (1986) on lateral dispersion provides very useful analyses of EPRI measurements of plumes from tall stack, large buoyancy sources. However, there are a few errors in the equations, and there are a few inconsistencies which beg further discussion.

The errors that I noticed all originate in section 3e, which pertains to buoyancy effects on σ_y. Equation (15) should be multiplied by u^{-1} on the right-hand side. In Eq. (16), the exponent of X^* should be preceded by a minus sign. Then we find that Eqs. (14) and (16) are equal when X^*/F_* equals $(1.6/0.6)^3 \approx 19$, not 17. (This erroneous calculation is carried over into the transition values of X^*/F_* recommended in the summary.)

I am puzzled by the fact that Hanna gives convincing evidence of enhancement of σ_y by buoyancy effects at Bull Run, yet says nothing about the presence or absence of such effects at Kincaid. He suggests that buoyancy effects dominate σ_y at smaller nondimensional distances, namely, at $X^*/F_* = xw_*^3/F < 17$ (or 19; see previous paragraph). Yet he reports that $F \approx 1000$ m^4 s^{-3} and $w_* \approx 1.5$ m s^{-1} at both power plants. Therefore, it would seem that $X^*/F_* \approx x/(300 \text{ m})$ at both plants, so the Kincaid database would also contain many $X^*/F_* < 17$ data points. Are these points consistent with Eqs. (15) and (16), or do they show no evidence of σ_y enhancement by F?

Perhaps the answer involves a second criterion necessary for buoyancy enhancement of σ_y, mentioned by Hanna in section 3e but omitted from the summary. That is, according to Briggs (1985), this enhancement of σ_y is noticeable at the surface only when $F_* > 0.06$. In such cases, plumes rise to the top of the mixing layer, at $z = h$, and are squeezed outward laterally by the force of their residual buoyancy (relative to the air below h) acting against the "ceiling" of overlying stable air (provided that this air has sufficiently higher potential temperature than does the lofted plume, so that penetration of the stable air is prevented). However, if $F_* < 0.06$, plumes do not evidence this effect on σ_y at the surface because most plume material is pushed downward by convective downdrafts before it reaches h; when the ambient turbulence can overpower buoyancy in this way, it also causes more lateral dispersion than does buoyancy. While X^*/F_* ranges may be roughly in the same range at both plants, F_* values may be generally smaller at Kincaid because $F_* \propto u^{-1}$ and wind speeds were substantially larger there than at Bull Run. I would like to see plots like Hanna's Fig. 12 for both plants with either data screened by F_* or identification of points by F_* range.

There is a hidden inconsistency between the recommended Eq. (14), $\sigma_y/x = 0.6\ w_*/u$, and the σ_y/x ratios recommended for various stability classes in section 3b. It should be emphasized that the stability classes used by Hanna (1986) are not the original Pasquill classes based on u and insolation, but are Weil and Brower's (1984) classes based on u/w_* ratios. [Because $w_* = (H^*h)^{1/3}$ and the surface buoyancy flux, H^*, is well correlated with insolation, there is substantial correlation of these classes with Pasquill's; however, the Pasquill scheme does not account for the influence of h on turbulence intensity.] Weil and Brower's u/w_* ranges corresponding to classes A, B, C, and D are <3.5, 3.5–6, 6–14, and >14, respectively. However, the σ_y/x ratios recommended by Hanna for the same classes agree with Eq. (14) only if $u/w_* = 2.5$, 3, 4, and 5, respectively. These ratios reasonably agree with Weil and Brower's for the A class but are disturbingly smaller for the less unstable classes, particularly C and D. If

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Hanna's σ_y/x recommendations are valid, then Eq. (14) very much underestimates σ_y in the latter classes.

This inconsistency is probably due to the effects of mechanical turbulence, neglected in Eq. (14). Hicks (1985) reports a good fit to turbulence measurements with $\sigma_v = (3.6u_*^2 + 0.35w_*^2)^{1/2}$, where u_* is friction velocity. If $\sigma_y \approx \sigma_v x/u$ and $u/u^* \approx 16$, say, at least in neutral and slightly unstable conditions, then we can use Hicks' σ_v to write

$$\sigma_y/x \approx 0.6(w_*/u)[1+(0.2u/w_*)^2]^{1/2}.$$

For example, in the C class, $u/w_* \approx 9$ and this equation yields a σ_y larger by a factor of 2.06 than that given by Hanna's Eq. (14): $\sigma_y/x \approx 0.6(2.06)/9 = 0.14$, which is reasonably in agreement with Hanna's recommendation of 0.15 for the C class. Even in the B class, the enhancement factor due to u_* ranges up to 1.56. Therefore, Eq. (14) should be recommended only for very unstable conditions. For moderately unstable to neutral conditions, modification of this equation, as suggested previously, should give a much better fit to data such as shown in Hanna's Fig. 6.

Apropos to Hanna's (1986) finding of near-linear σ_y growth in x at Kincaid, it is worthwhile to note that similar observations of σ_y behavior from *nonbuoyant* elevated sources were recently reported (Briggs et al., 1986). These data were from the CONDORS experiment, conducted in 1982 and 1983 at the Boulder Atmospheric Observatory in Colorado. They were collected in very unstable conditions, with a median value of $u/w_* = 1.5$. Although X^* values did not exceed 4, lateral diffusion from releases below 0.3 h approximately fit the Briggs (1985) expression, Eq. (13) in Hanna (1986). On the other hand, σ_y from the more elevated releases better fit the linear growth equation $\sigma_y = 0.6xw_*/u$, which is identical to Hanna's Eq. (14). However, unusually large wind direction shears were noted at this site (Briggs et al., 1986; Kaimal et al., 1986). These shears were thought to be due to the opposition of thermally induced upslope winds on the eastern slopes of the Rocky Mountains and the upper-level winds, and were suspected to be the cause of larger σ_y (at $X^* > 0.3$) for releases at $z > 0.3$ h at this site. Hanna (1986) raises the interesting possibility that, for quite elevated releases in unstable conditions, linear growth of σ_y occurs at sites distant from tall mountain ranges and to much larger distances than were monitored during CONDORS.

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