ESS5203.03 - Turbulence and Diffusion in the Atmospheric Boundary-Layer: Winter 2020

Further Considerations on Diffusion

Main Text (See Prof for copy): *Alex De Visscher*, Air Dispersion Modeling, Foundations and Applications, Wiley. 2014.

Also (from Library) *S. Pal Arya*, Air Pollution Meteorology and Dispersion, Oxford University Press. 1999 and *Akula Venkatram and John C. Wyngaard (eds).* Lectures on Air Pollution Modeling. American Meteorological Society. 1988.

0) Reviewed so far (Notes9): Gaussian plume models; Stability Classes; Reflection; Models.

$$\rho = \rho_{bg} + \frac{E}{2\pi U \sigma_y \sigma_z} \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right), \qquad \sigma_y = f_y(x,\varphi), \quad \sigma_z = f_z(x,\varphi)$$

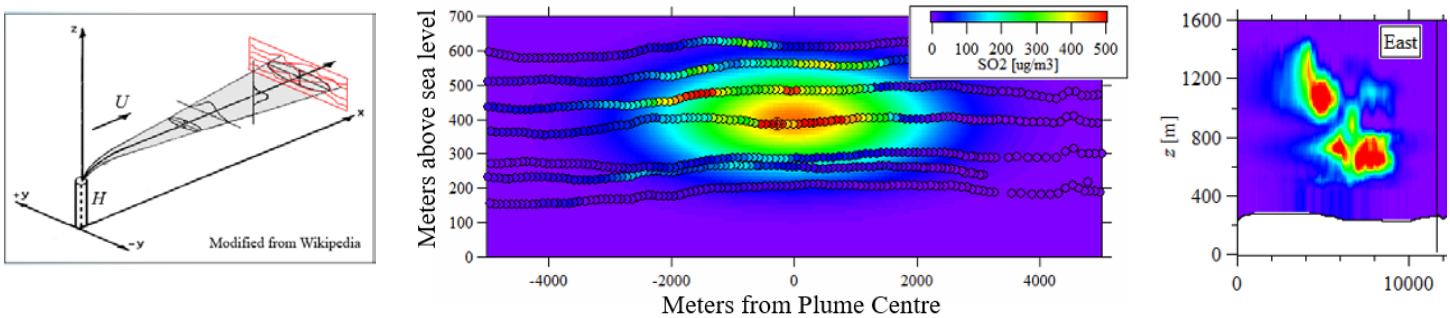

Figure 1. An example of a Gaussian versus a real plume (from the Alberta oil sands). Idealized case shown left. Fit to measurements centre. Kriging interpolation to measurements shown right. Note that source is three co-located stacks.

1) Point Source Plume Rise (Section 7.2 in De Visscher text)

Variables: $F_m = \left(\frac{\rho_s}{\rho}\right) r_s^2 w_s^2, \quad F_b = \left(1 - \frac{\rho_s}{\rho}\right) g r_s^2 w_s, \quad s = \frac{g}{T}\frac{d\theta}{dz}, \quad u, \quad t, \quad \Delta z$

The calculation of final plume rise ($\Delta h = \Delta z(t \to \infty)$) depending on the variables chosen for Pi-theorem, which depends on stability.

$$\Delta h = \pi_1^{-1/4} \left(\frac{F_b^2}{s^3}\right)^{1/8} \text{ and } \Delta h = \pi_2^{-1/4} \left(\frac{F_m}{s^3}\right)^{1/4} \text{ in stable conditions } (\pi_1^{-1/4} = 5.3, \pi_2^{-1/4} = 2.4).$$

$$\Delta h = \pi_1^{-1} \frac{F_b}{u^3} \text{ and } \Delta h = \pi_2^{-1/2} \left(\frac{F_m}{u^2}\right) \text{ in neutral conditions } (\pi_1^{-1} = 400, \pi_2^{-1/2} = 3).$$

For unstable conditions, theory predicts infinite plume rise, so a parameterization is used.

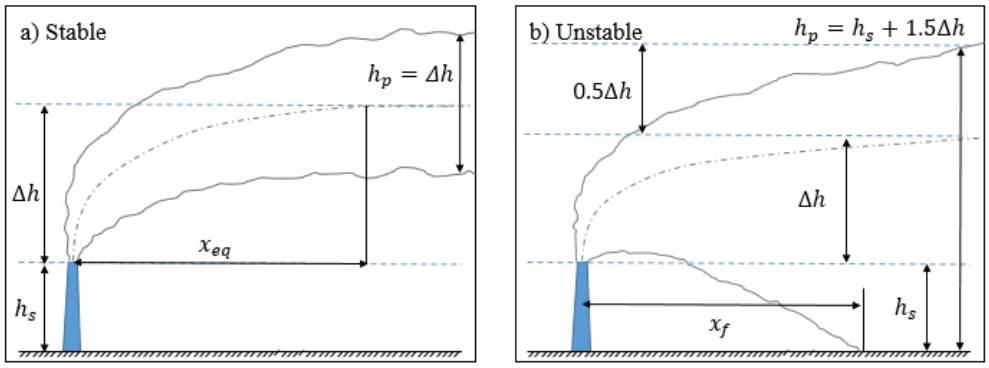

Figure 2. Plume rise for a) stable and neutral or b) unstable conditions, following Briggs (1984) Figs. 8.1 and 8.9. The stack height is h_s, the plume rise is Δh, the plume thickness is h_p, the horizontal distance to final plume rise in stable or neutral conditions is x_{eq}, and the average horizontal distance to plume touchdown is x_f.

2) Deposition (Section 7.5 in De Visscher text)

Dry deposition: Aerodynamic transport; Molecular transport, Surface uptake

$$F = \frac{-ku_*}{\ln(z/z_0)}(c - c_0) = -v_t(c - c_0) = -\frac{(c - c_0)}{r_a}$$

Wet deposition (scavenging): Rainout (in-cloud); Washout (below-cloud)

3) Line Sources and Highways. Venkatram, A. (2004) On estimating emission through horizontal fluxes. Atmos. Environ. 38, 1337-1344.

A system of equations to give concentration downwind of a highway. ρ: Concentration [kg]; E_V: Emissions [kg m^{-1}]; T: Traffic Flow [s^{-1}]; θ: Angle of Wind to Road; s: Stability Parameter; A, B, q: Functions of s only, f: Functions of s and p.

$$\rho = \rho_{bg} + \frac{E_V T A}{\overline{U}\,\overline{z}\cos\theta}\exp\left[-\left(\frac{Bz}{\overline{z}}\right)^s\right], \quad \overline{U} = fU_r\left(\frac{\overline{z}}{z_r}\right)^p, \quad p = \frac{u_*}{k\,U_r}\varphi, \quad \overline{z} = \frac{1}{q}\left[(p+1)kq\frac{u_*}{U_r}xz_r^p\right]^{\frac{1}{p+1}}$$

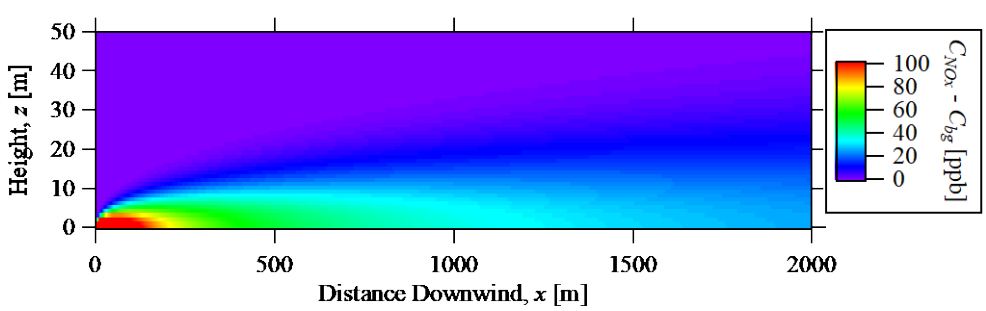

Figure 3. Simulated concentration field downwind of a highway using the Venkatram model.