The magnitude of errors in other model combinations depends on the functional form of the emissions model and the meteorological parameters used. Shen's[4] open landfill model includes a $u^{0.5}$ wind speed dependence which would result in larger errors than those presented. If evaporation rates are driven by mass transfer in both liquid and gas phase, error estimates require an examination of the effects on both liquid and gas phase mass transfer parameters. This results in estimates which are more complex to estimate but are likely to be large. Errors of this type and magnitude area also expected for meteorologically dependent initial dispersion models such as downwash models.

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Some Evaluations of the Effect of Ambient Temperature on Plume Rise

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The magnitude of plume rise above stack top, Δh, is known to be proportional to F_o^α, where F_o is the buoyancy flux at the stack top and α is a constant. The value of F_o is given by:

$$F_o = g\left(1 - \frac{T_a}{T_p}\right) V_o \qquad (1)$$

where g is the acceleration of gravity, T_a is the ambient temperature at the stack top, T_p is the temperature of the emitted gases at the stack top, and V_o is the plume volume flux at the stack top. Following Reference 1, $\alpha \cong 0.25$–0.33 for computations of Δh is the stable boundary layer and $\alpha \cong 0.6$ for the convective boundary layer.

Equation 1 suggests that the initial plume buoyancy flux, F_o, and, consequently, the relative plume rise may be noticeably modified when significant variations in T_a are involved. In the northeastern United States, for example, the differences in the daily-average shelter temperature between July and December are in the range of 25 K.[2] South-north temperature gradients are most pronounced during the winter. Figure 1a provides the January daily-average shelter temperature for the eastern half of the United States, indicating a change of ≈33 K between the southern and northern latitudes. Thus it is likely that during winter F_o is noticeably altered over mid-latitude locations due to the latitudinal variations of ambient temperature. Assume, a typical value of $T_p = 373$ K; then, in extreme situations, the variations in F_o may reach a factor of ≈1.5.

The values of T_a are considered in the routine computations of F_o and Δh when plume rise evaluations in a specific site are carried out. However, it is of a general interest to scale the effects of typical climatological variations in T_a on F_o and Δh. Such evaluations are provided in this Note, while suggesting a general scaling and a climatologically oriented illustration for the United States.

General Evaluations

The range of shelter temperatures typically observed in the populated areas of the Northern Hemisphere is 253 K to 308 K.[2] The relative increase in F_o, $F_o^{0.33}$, and $F_o^{0.6}$, when the ambient temperature, T_a, drops from a reference value, $T_{a_o} = 308$ K, was computed. Plume exit temperatures, T_p, in the range 323 K to 573 K were considered, while the same stack emission parameters were assumed for all computations. Figure 2a shows the relative change in F_o, η, with a change in T_a compared to that obtained for the reference ambient temperature. The value of η is given by:

$$\eta = \frac{F_{o|T_a}}{F_{o|T_{a_o}}} = \frac{\left(1 - \dfrac{T_a}{T_p}\right)}{\left(1 - \dfrac{T_{a_o}}{T_p}\right)} \qquad (2)$$

For a "cool" plume ($T_p = 323$ K), the value of F_o in a cold environment ($T_a = 253$ K) is larger by a factor of ≈4 compared to that in the reference environment temperature. For a "hot" plume ($T_p = 573$ K), this factor is only 1.2. The corresponding relative change in Δh with $\alpha = 0.33$ is presented in Figure 2b, reaching factors above 1.5 and 1.07 in the aforementioned situations, respectively. For the convective boundary layer, with $\alpha = 0.6$, the related ratios are above 1.8 and 1.12, respectively (see Figure 2c).

Some Specific Evaluations

The diurnal variation of the ambient temperature is usually too small to induce noticeable changes in the plume initial buoyancy flux. In the domain presented in Figure 1, the average diurnal range of the near surface temperature has a maximum value of ≈14 K in January and July.[2] Significantly larger diurnal variations of near surface temperatures may be related to the passage of synoptic systems. It is worth noting that the changes in air temperature due to passage of cold/warm air masses, for example, are typical to the entire atmospheric boundary layer. Likewise, the south-north variation in the climatological shelter temperature also should be assumed typical for the entire atmospheric boundary layer. Thus, in these cases, the presented computations are also applicable when very tall stacks are considered.

In the stable boundary layer the plume rise is proportional to $\beta_o^{-1/2}$, where β_o is the potential temperature lapse rate. One may suggest that the cold winter environments (i.e., northern latitudes) are involved with more stable nocturnal boundary layers compared to these in the warmer environments (i.e., southern latitudes). Examining, however, the intensities of wintertime early morning temperature inversions in the United States suggests that they are nearly similar in both southern and northern latitudes (see Reference 3, p. 80), although the temperature inversions tend to be deeper in the northern latitudes. This implies a tendency towards somewhat higher nocturnal plume rise in the northern latitudes for relatively low stacks. When tall stacks are considered, the related effective heights may exceed the depth of the nocturnal temperature inversions. In these situations the neutral case plume rise formula is more appropriate than the stable case formula.

Finally, it is suggested that in cold environments the gases' heat loss through stack walls is somewhat larger than in warmer environments. In the evaluation presented in this

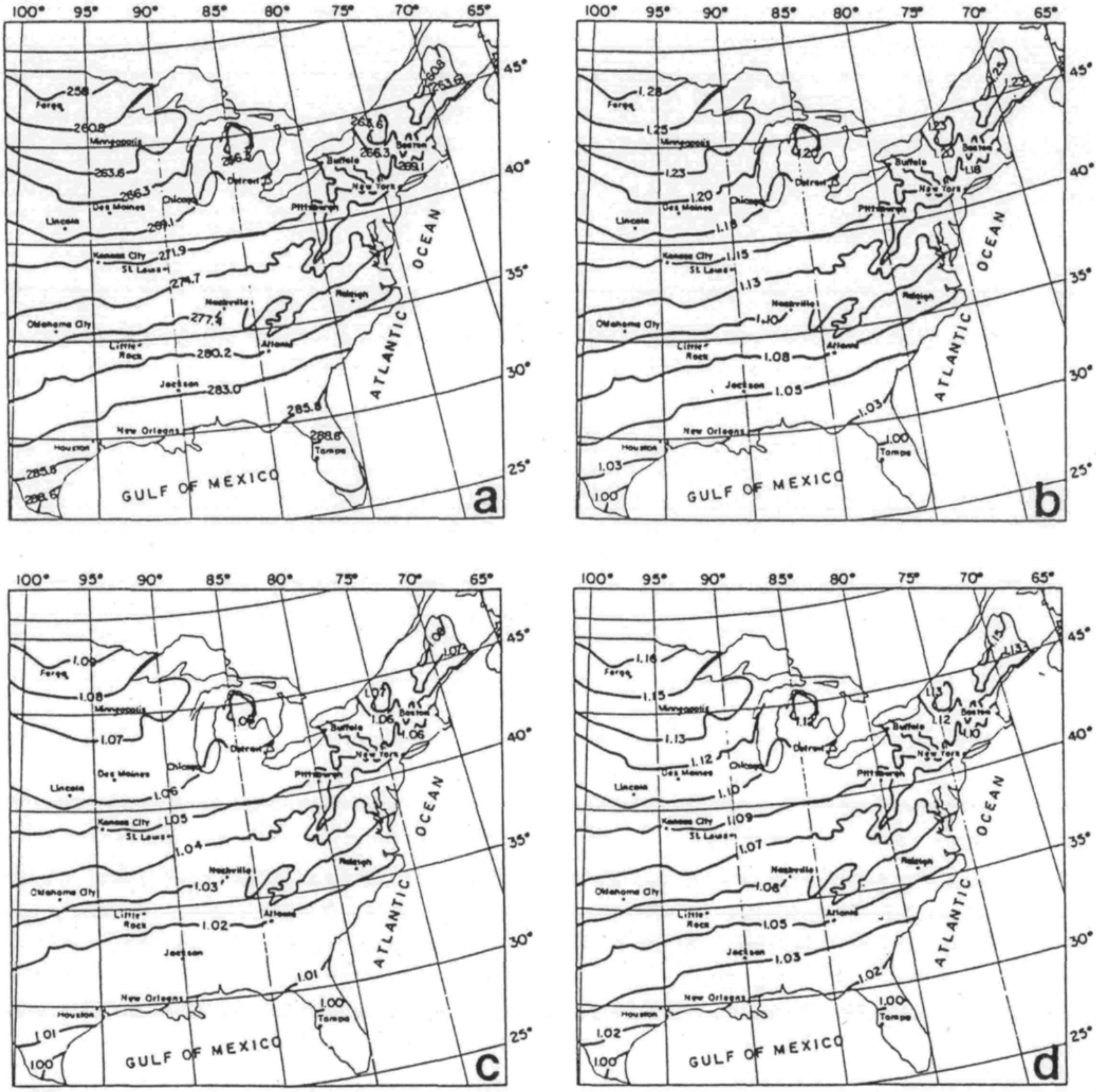

Figure 1. (a) January daily-average shelter temperature for the eastern half of the United States (in K) from Reference 2; (b) contours of η as a function of ambient temperatures where in (a) T_p = 398 K and the reference ambient temperature T_{a_o} = 288.6 K; (c) computed relative plume rise for a stable boundary layer (α = 0.33) corresponding to the η contours given in (b); and (d) computed relative plume rise for a convective boundary layer (α = 0.6) corresponding to the η contours given in (b).

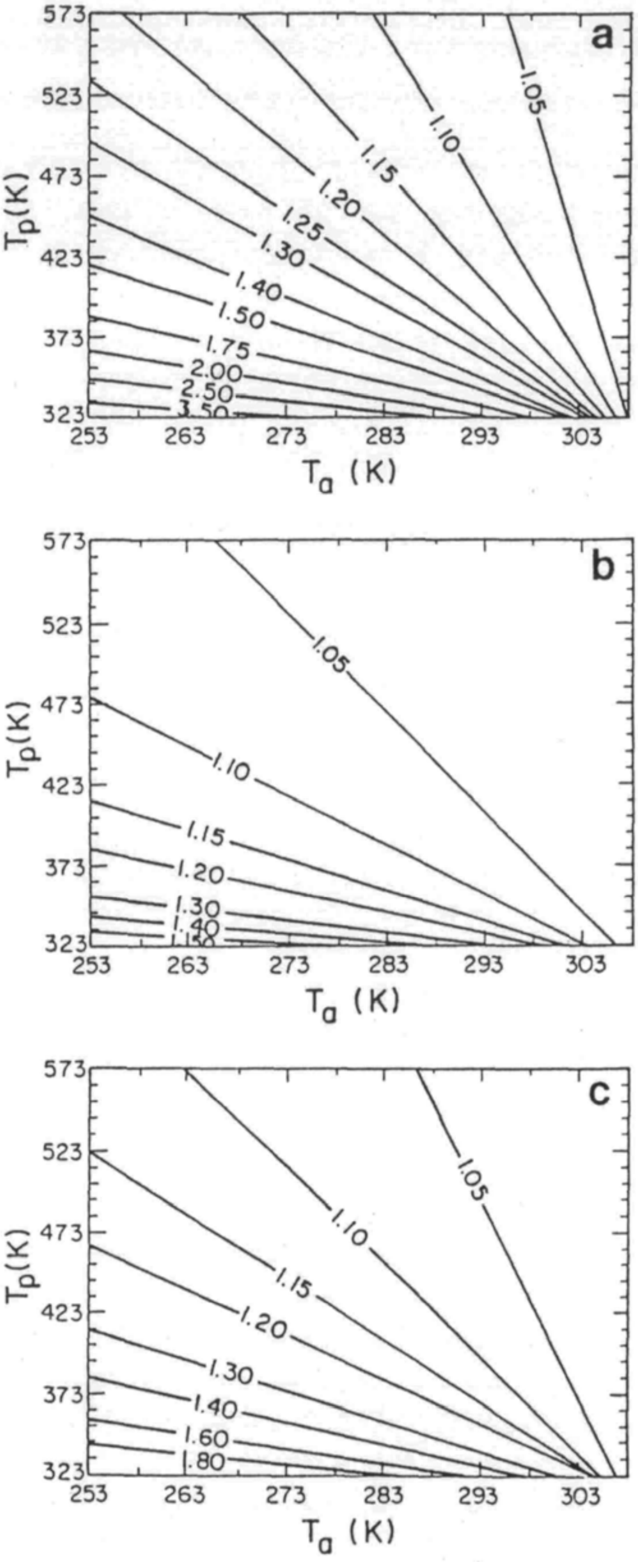

Figure 2. The values of η (see Equation 2) as a function of ambient temperature, T_a, and the plume exit gases temperature, T_p, for a reference ambient temperature T_{a_o} = 308 K; (b) the relative change in plume rise above stack top, Δh, in stable boundary layer conditions ($\alpha = 0.33$) for various values of T_a and T_p for the same T_{a_o} as above; and (c) the same as (b) except for convective boundary layer conditions ($\alpha = 0.6$).

Note, it is assumed that the corresponding effect on F_o is of secondary importance compared to that related to the variations in the ambient temperature.

Illustrations

The January daily-average shelter temperature, T_a over the eastern half of the United States was selected for illustrative purposes (Figure 2a). Adopting the maximum contour temperature (288.6 K, in southern Texas) as an ambient reference temperarture, T_{a_o}, the temperature contours in Figure 2a were relabeled by replacing values of T_a with values of η (Figure 2b). Thus the relative variation of the plume initial buoyancy flux while moving northward is illustrated. The relative increase of buoyancy for T_p = 398 K reached 28 percent when comparing the northern latitude and the southern reference latitude. The contours of $[F_{o|T_a}/F_{o|T_{ao}}]^{\alpha}$, with $\alpha = 0.33$ (i.e., reflecting the relative change of plume rise in a stable boundary layer), are presented in Figure 2c where an increase of 9 percent in the plume rise was inferred. Figure 2d is the same as Figure 2c except that $\alpha = 0.6$ (i.e., reflecting the relative change of plume rise in the daytime convective boundary layer). The corresponding increase estimated for the plume rise under these lower atmospheric conditions reached 16 percent.

Conclusion

Scaling of the potential impact of the ambient temperature on plume rise was provided in this Note. Climatological characteristics of the ambient temperature were considered for this purpose. The scaling results suggest that for climatologically sharp changes in the ambient temperature combined with a relatively low temperature plume, the impact on the plume rise in a stable or convective boundary layer is likely to be significant (reaching factor of ~2 in extreme cases). The effect also is noticeable, however less pronouncedly for high temperature plumes.

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