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Goldstar 2016 Interim Report: Brief Introduction to Urban Dispersion

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This section describes ways in which an urban environment can affect the distribution of airborne radiological material. In an urban area, winds at street level are significantly more variable and complex than the prevailing winds above the buildings. Elevated winds may be uniform and representative of the general flow over the surrounding area, but buildings influence the local flow such that the winds below the building heights vary significantly in location and time (Hanna et al 2006). For a release of material near an individual building, the complex effect of the building on the airflow may locally enhance the air concentration of released material in some regions near the building and reduce it in others compared to a release in open terrain. However, the overall effect of an individual building is to induce a rapid enlargement and dilution of an incident plume from an isolated source upwind of the building (Hosker 1984). A plume spreading through an urban environment of multiple buildings will experience enhanced mixing and greater spreading of the contaminant plume in both the vertical and horizontal directions, compared to the same release in open terrain.

Consider first the more simplified case of a boundary layer flow (shear flow) normal to an isolated building. The presence of the building disrupts the incident boundary layer flow and several vortex structures develop around it, as illustrated in Figure 1 (Hosker 1984). As the flow approaches the building, it slows in the longitudinal direction, while accelerating in the cross-wind and vertical directions to pass around the building. In front of the windward face, a recirculation zone may develop. This recirculation is called a frontal eddy. Material carried by the incident flow can be trapped by the frontal vortex and enhance the concentration at the lower portion of the face. A standing horizontally-oriented horseshoe vortex develops near the ground upwind of the obstacle and wraps around the body. Downwind, this forms a counter-rotating vortex pair. Flow over the top and sides of the building usually separates from the surface and may reattach downstream depending on building geometry and flow conditions. If the flow over the top of the building reattaches, high concentrations of material on the roof may be observed, if not, the incident plume is deflected above the roof. Air concentrations in general are highly variable, with higher concentrations in some locations near a building and lower concentrations at other locations.

Directly behind the building, air recirculates in the cavity zone. A small standing vortex at the ground on the rear-face of the building may also be present. Material released or entrained behind a building is very well mixed in the cavity region, affected by complex turbulent flow in the near-body wake and enhanced by vertical vortices formed as flow wraps around the building corners. Concentrations over the rear face of the building will be relatively uniform. The material may then be detrained from this area after a wake residence time. After interaction with the building, material from a contaminant plume will exhibit enhanced spreading due to turbulence in the recovery region. Both material that was not entrained (deflected around the building) and material entrained and subsequently released from the near-body wake will exhibit this enhanced spreading.

When the incident flow is at an angle to the building, the location of the separation and reattachment of the flow at the sides of the building is affected. The building wake effects may be decreased compared to the above discussion since an angled building presents a more streamlined obstacle. Similarly, the upwind portion of the horseshoe vortex is not as large in diameter (Hosker 1984).

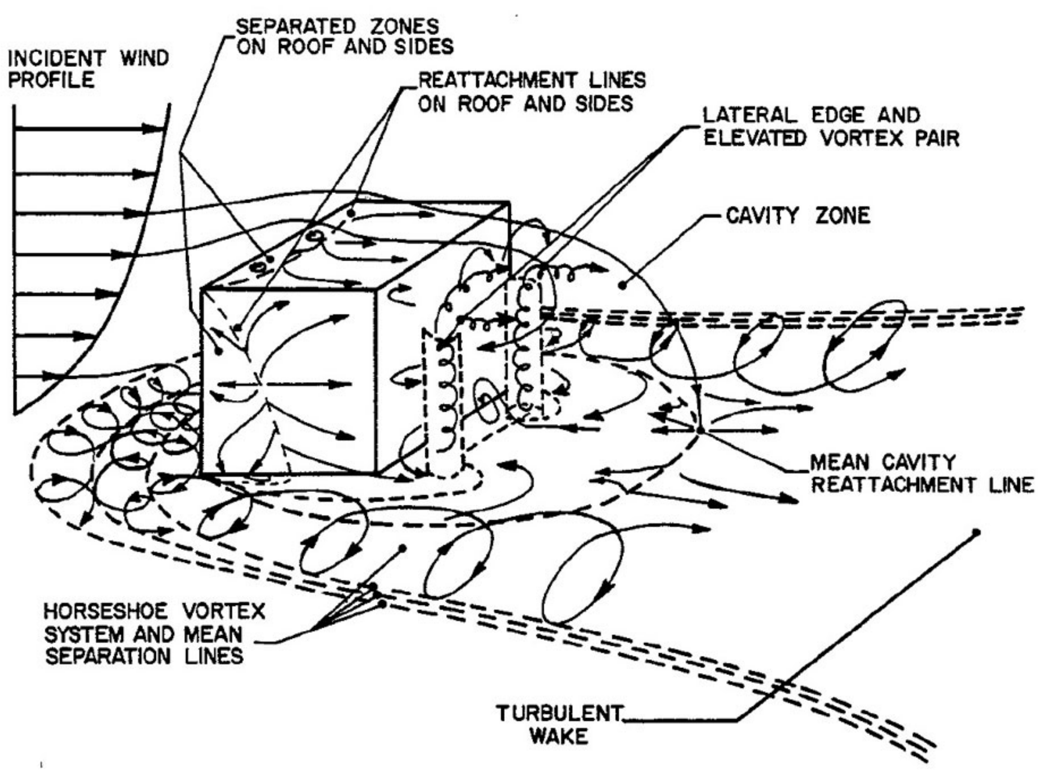

Figure 1: Flow near a three-dimensional building in a boundary layer (shear) flow. Figure from Hosker 1984

Next, consider an urban environment, which may consist of groups of many buildings of varying heights and orientations to each other and the wind field, and long streets bordered by dense buildings (urban canyons). It is evident that the effects of these structures on the behavior of the flow can be extremely complex. The primary effect of the buildings on aerosols and gases released in the urban environment is enhanced horizontal and vertical mixing of the contaminant near the source and greater spreading of the contaminant plume in the far-field. Near source behavior is very sensitive to wind and release location; slightly different release locations (of one block or less) can result in very different plume dispersion air concentration patterns (Allwine and Flaherty 2006). Urban plume dispersion patterns can be complex and non-intuitive as material travels around buildings and other urban structures.

Downtown urban areas often have complex urban canyons where long streets are flanked by dense rows of buildings. Two primary phenomena are observed in urban canyons: recirculation and channeling. The recirculation of air in the urban canyon is called either a cavity vortex (as above for a single building) or an in-canyon vortex. This vortex typically forms when wind is close to normal to the canyon. It rotates vertically with an axis parallel to the street canyon (Brown et al. 2000). When material is released into this flow configuration, it will be well mixed within the canyon. The material can build up in the vortex between the buildings and take a long time to be ejected from the area, leading to localized high concentration.

As the incident wind shifts from perpendicular, the flow pattern in a canyon goes from a cavity vortex to channeling. Channeling is when the flow is accelerated in the canyon and its trajectory is forced to follow the canyon geometry. Channeling in an urban environment can change the trajectory of a material plume compared to the prevailing wind direction. Even when a street aligns with the prevailing wind direction, contaminant may also be carried up side streets at an angle to the main flow due to channeling.

Depending on wind angle, material will either become trapped in the space between the rows of buildings making up the canyon or it will be forced to follow the path of the canyon. Cavity vortex and channeling phenomena are intermittent due to subtle changes in wind conditions. Flow in an urban canyon is a complex combination of vortices and channeling and will depend on incident wind angle, canyon configuration, presence of corner buildings and street intersections.

Street intersections further complicate urban flow behavior. In a four-way intersection, the flow may be moving in four different directions at each corner of the intersection (Brown 2004). Due to the variable wind trajectories and presence of one or more complex 3-D vortices, aerosol material concentrations in and across the intersection can vary significantly (Hoydysh and Dabberdt 1988). Local wind flow in street intersections is a result of many highly intermittent phenomena, so the concentration of material released within or blown through such an area can also be highly intermittent.

As illustrated in the single isolated building case, material can be transported “upwind” (in the opposite direction of the overall, prevailing flow) when it is entrained in the eddies generated by flow separation at the sidewall and roof or the cavity behind the building. For groups of buildings, this effect can be more pronounced as the material may travel between adjacent building eddies (Brown 2004).

Tall buildings deflect the local wind flow and can affect ground level winds significantly. The Goldstar test series has experimentally observed the effect that a building significantly taller than the other surrounding buildings can have on street-level winds, locally accelerating the flow field around the building. See section {put Aeolus wind validation section number or title here}. Material released near a tall building can experience enhanced vertical mixing in the vicinity of that building.

After material from an aerosol release passes through an urban environment, the far-field concentrations will be reduced compared to the same release in an open terrain environment. Comparing the peach and red contours of concentration between the case with urban obstacles and the flat terrain case, it is clear that the extent of the highest concentration is reduced by the urban setting.

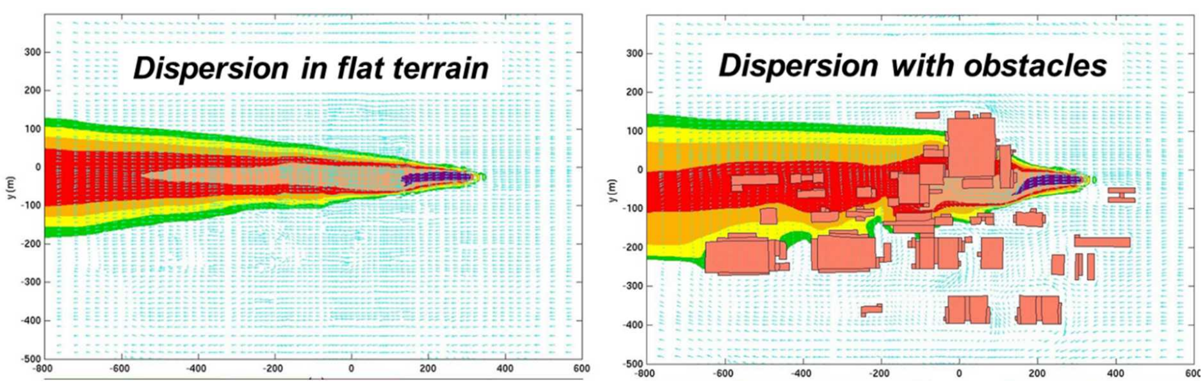

Figure 2: The effect of obstacles on plume spreading (right) compared to a release in flat terrain (left): The plume downwind from the obstacles is wider and the concentrations are lower. The small source of material is on the right side of the figure and the winds transport and disperse the material toward the left. Different contour colors represent different air concentration levels, with higher concentrations near the source. (Source: Stevens Chan, Lawrence Livermore National Laboratory)

When the release is in an urban area, transport in the direction of the predominant wind flow can be delayed as material is temporarily retained in recirculation zones around buildings and other urban structures. As a result, the transport of material in the prevailing downwind direction is slowed and delayed, compared to flow with no urban structures. Further, plume spreading due to interaction with the urban area persists far downstream. The resulting plume is more diffuse compared to an open terrain result.

Beyond buildings obstructing the flow field, other urban features can contribute to contaminant dispersion. The presences of trees in an urban canyon or in otherwise open areas between buildings may create drag that slows the near-surface wind and branches and leaves could capture aerosols (Brown 2004). Irregular building geometries, such as archways, alcoves and parking structures can also trap material. Vehicle traffic creates turbulence, alters the near-surface winds and may enhance near-wall concentration in a street canyon (Kastner-Klein et al. 2003). Heating of building faces changes the near-surface buoyancy which in turn changes the vertical flow structure (Brown 2004). These real-world effects are difficult to include in urban dispersion models.

The interaction of a rising buoyant cloud, such as the one formed by the detonation of a high explosive device, with buildings is an ongoing research question. The data gathered in the Goldstar test series reported here is a valuable contribution to the field, and can help the understanding of this phenomena.

Summary

- Wind flowing through an urban environment exhibits both large- and small- scale variability. The prevailing wind will change directions and/or speed significantly around the buildings. The local flow around urban structures can be highly intermittent, and small-scale wind variability more rapid.
- Changes in the wind flow affect the transport and dispersion of contaminant aerosol material release in urban environments. The complex flow around either isolated or clustered buildings can result in recirculation of material and delayed transport of material in the prevailing downwind direction.
- Variable local wind flow and features of urban structures can lead to locally higher or lower material concentrations in specific locations compared to a similar release in flat terrain.
- Channeling and recirculation effects can transport material upwind, down side streets, or otherwise different to with the prevailing winds above the urban area.
- In general, the presence of buildings will enhance the mixing of the material into the surroundings, leading to greater plume spread and thus more dilute plumes compared to an identical release which does not encounter building obstacles.

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