on the scene against such measurements or on the basis of measurements of tracer gases. In this way the absolute accuracy and uncertainty of the model outputs can be used to provide a measure of confidence of their validity. Not only can models be used to describe the spatial structure of the plume of contaminants, but they can also be used to forecast the impact of changing weather or emission conditions. Thus, the effect of shifting wind directions or changing wind speeds can be quantified. When actions such as vent-and-burn are contemplated, models can be helpful in describing the impacts and selecting the optimum meteorological conditions. Models are available that can easily be adapted to this application, but they need to be integrated into a real-time assessment system that incorporates on-site meteorological data, terrain features, emission estimates and concentration measurements (for validation), and weather forecast data.

CONCLUDING REMARKS

The number of hazardous spills from transport accidents has steadily increased over the past decade in response to the availability of new chemicals and increased demand. Risk to the nearby population is initially greatest as a result of atmospheric transport. The need is pressing to provide first-responder groups with instrumentation and other resources that will enable them to assess the magnitude and extent of the hazard rapidly and to develop effective control or protective actions. This paper does not present solutions. Rather, it attempts to organize the considerations that must be made in acquiring or specifying an appropriate system of response instrumentation, and it provides a brief introduction to the general types of measurement techniques available and their advantages.

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Applications of Remote Sensing to Hazardous Spill Incidents

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Remote sensing techniques may be particularly well suited for monitoring the distribution of hazardous spill concentrations. These techniques provide the means for real-time viewing of large atmospheric volumes over remote distances that have extremely high spatial and temporal resolution. Atmospheric remote sensing has been used extensively in air pollution research programs and is currently being developed for the military for toxic agent applications. This paper discusses some previous studies that demonstrate capabilities that should be considered for application to hazardous spill incidents.

Remote sensing techniques are classified as either active or passive and capabilities differ greatly between these classifications. Active systems provide their own energy sources; passive systems point at naturally occurring energy sources (e.g., sunlight, thermal radiation from terrain, and atmospheric species). Most active systems used for atmospheric observation use laser transmitters and optical receivers; passive systems have only optical receivers. Because lasers operate at only a finite number of wavelengths and because the cost of the sensor increases greatly as the number of wavelengths increases, only one or two wavelengths are typically used.

Passive sensors can perform wavelength scans economically over large wavelength intervals and thus are well suited for discriminating between agents that have different wavelength-dependent absorption or emission spectra. The major advantages of the active system are that the energy can be transmitted in pulse form (hence, range information can be obtained by using radar principles) and discrimination against background radiation is simplified. Because of the differences in active and passive sensor techniques, they are complementary and their combined capabilities are being considered in several development programs.

REMOTE SENSING EXAMPLES

SRI International has pioneered laser radar concepts since 1963, when the first observations in the lower atmosphere were conducted. Earlier light detection and ranging (lidar) systems were typically single wavelength and observed range-resolved energy backscattered from atmospheric particulate material. These systems did not realize their potential because of limitations in band pass and the dynamic range of electronic circuits for processing high-speed signals (∿0.000 000 01 s). Later systems have evolved that can measure particulate concentrations with high spatial resolution. These particulate backscatter systems have evolved so that 1.5 m of spatial resolution is now possible.

Gaseous-measuring laser radar systems (termed differential absorption lidar) have been developed recently. They depend on absorption of laser radiation at two frequencies by the gas being measured. Their emergence has depended on advances in tunable laser technology. Both van-mounted and aircraft-based lidar systems that measure particulates and gases are being routinely applied on air pollution and military programs. As an example of an existing system, the Mark IX mobile lidar (shown in Figure 1) can scan across a pollution plume downwind of the source and display the cross plume signature data in the form presented in Figure 2. In this figure the lidar is located at the lower left corner of the picture and is scanned in elevation at an azimuth direction that intersects the plume nearly perpendicular to the transport direction. Picture brightness is proportional to the logarithm of plume backscatter and therefore is a measure of relative aerosol concentration. Concentration profiles at several distances from the lidar are plotted in Figure 2. A plume cross section can be obtained in about 1 min (greatly reduced with new systems) so that the three-dimensional distribution of plume constituents can be determined rapidly.

A second example illustrates the capabilities of the airborne lidar plume and haze analyzer (ALPHA-1), a two-wavelength, downward-directed lidar operated from the SRI Queen Air aircraft (Figure 3). In this example (shown in Figure 4) the lidar was flown across a smoke plume about 500 m downwind of a small forest fire. Relative concentration patterns provide quantitative information on transport and diffusion downwind of the source. Surface returns have been analyzed in terms of vertical plume transmission, and the two-wavelength (0.53 and 1.06 μm) transmissions provide information on particle size needed for estimates of absolute concentration (1).

A third data example illustrates the capabilities of a differential absorption lidar (DIAL) for observing the distribution of gaseous constituents. A DIAL system transmits energy at two closely spaced

Figure 1. Mark IX lidar system observing downwind distribution of smoke.

Figure 2. Example of computer-generated vertical plume density profile. Lidar is located in the lower left corner. Plume vertical concentrations (relative to clear air with a scale of 75 m/div) are plotted (lower left), and horizontal position associated with each photograph is plotted (upper right).

Figure 3. SRI Queen Air aircraft used to support ALPHA-1 lidar system.

Figure 4. Smoke plume distribution and vertical transmissions, based on surface returns, derived from ALPHA-1 observations.

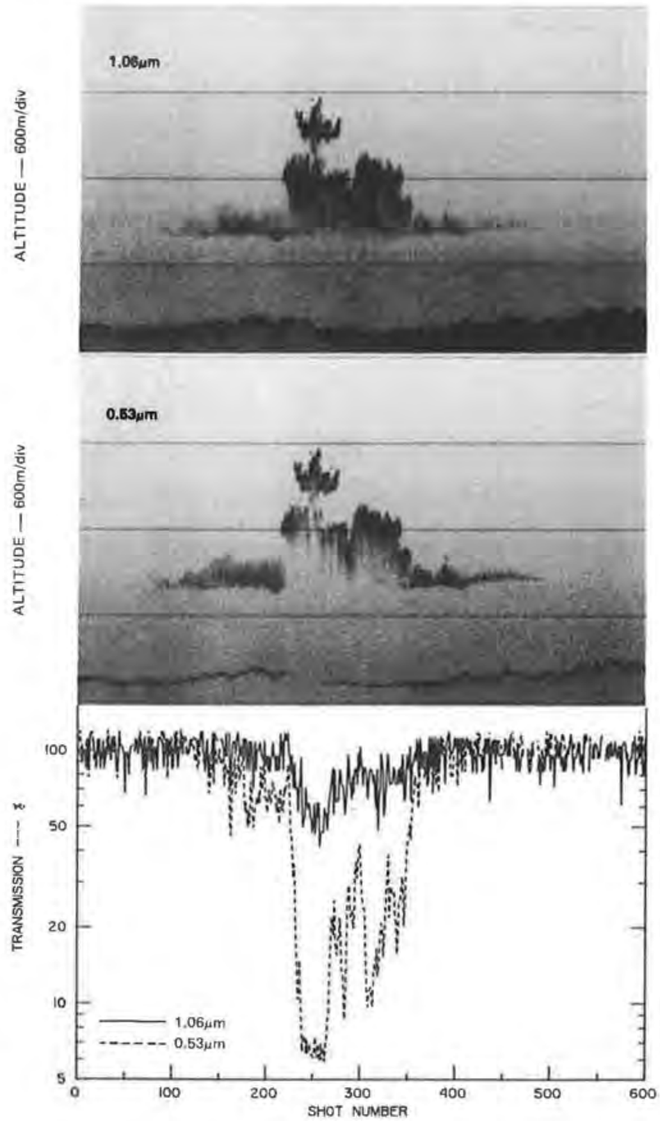


Figure 5. DIAL gas-measuring lidar system.

Figure 6. Horizontal cross section of sulfur dioxide concentrations derived downwind of Kincaid coal-burning power plant (3 km to right of lidar location) derived with the DIAL system.

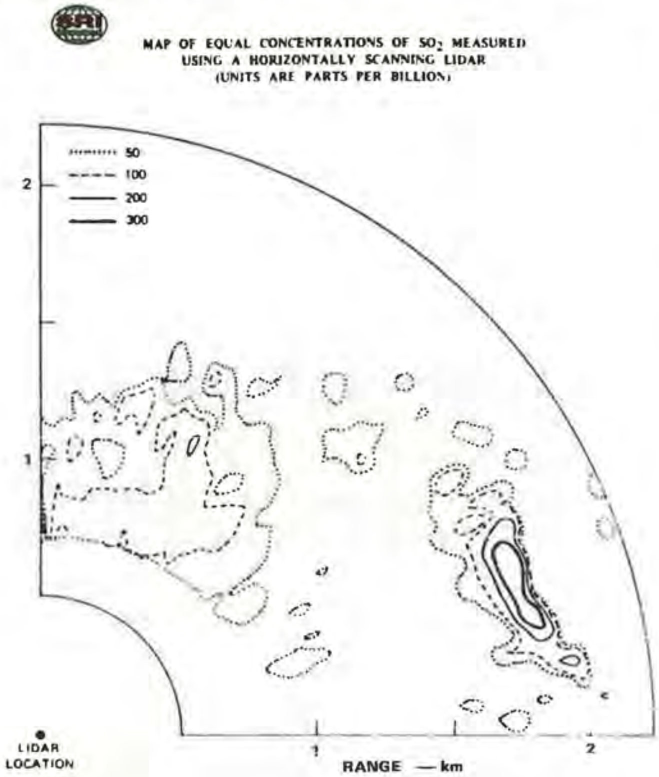
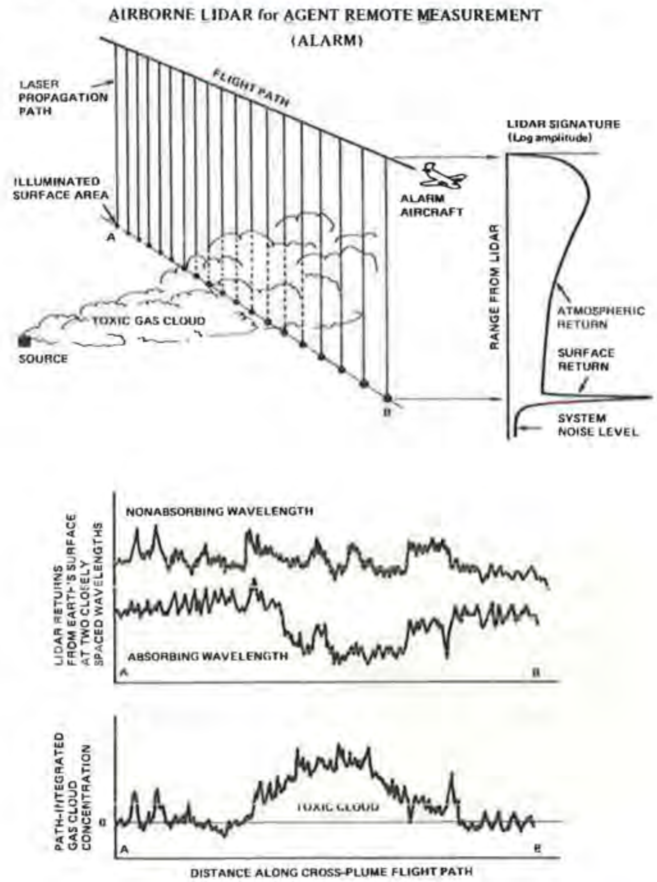


Figure 7. Application of proposed ALARM airborne lidar system.



wavelengths such that energy at one wavelength is absorbed by a gas species and the energy at the other wavelength is only minimally affected by the presence of gas. Because the wavelengths are closely spaced, aerosol effects can be eliminated and absolute profiles of gas concentrations can be evaluated. In this example, the mobile DIAL system constructed and operated by SRI (Figure 5) was used to map the distribution of sulfur dioxide near the surface downwind of a coal-burning power plant (Figure 6). The ultraviolet wavelength system has also been used to map distributions of ozone and nitrogen dioxide (2). Extension of this technique to infrared wavelengths would allow observation of many toxic chemicals that have unique infrared absorption spectra.

We have proposed to develop under Army support an airborne lidar system, airborne lidar for agent remote measurement (ALARM), that would use two infrared line-tunable lasers to combine the surface return analysis (example 2) with the DIAL technique (example 3) to map column content concentrations of military agents over large regional areas (Figure 7). Such a system would provide a strong tool for mapping the distribution of agents released from hazardous spill incidents.

Honeywell, Inc., has developed and demonstrated a system (XM-21) for toxic agent detection for the U.S. Army (3). The system makes rapid wavelength scans in the 8- to 12-m wavelength region and can make observations over large areas. However, application of the technique from a moving platform (e.g., aircraft) has not yet been demonstrated. Future programs may investigate the combined capabilities of the active and passive methods for improved detection, identification, and mapping of toxic agents suspended in the atmosphere.

CONCLUSIONS

Although remote sensing techniques have yet to be applied to the observation of hazardous spills, applications to observation of air pollution and military toxic agents have demonstrated their unique capabilities for detection, identification, and mapping of concentration distributions for particulate and gaseous materials. Remote sensing systems are available in ground mobile and airborne configurations to facilitate rapid movement to isolated incidents. Because of their ability to make observations in real time over extended remote distances with high spatial and temporal detail, remote sensors may be ideally suited for application to hazardous spill incidents.

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