accident of maximum actual composition LSA. Radiation doses to the skin from beta-emitting nuclides were calculated for each scenario and waste composition. For the average and maximum actual compositions, beta skin exposure is not a significant problem.

For maximum theoretical shipment of LSA under the present regulations, skin doses as high as 20 rad to the emergency worker could result from the partial-truckload accident. Although this does not exceed recommended emergency dose limits, the doses under the proposed regulations could be higher. Skin deposition is a more significant problem for emergency workers than for members of the general public.

CONCLUSIONS AND RECOMMENDATIONS

The primary potential hazard of concern would be the external gamma radiation from shipments near the maximum permitted concentrations. In actual shipments, concentrations approach maximum permitted levels only for spent resins and materials solidified in cement. If these materials are excluded from the LSA category, this potential hazard is not excessive.

The foregoing analyses have considered the potential hazards due to theoretical maximum shipment accidents under current and proposed regulations, as well as the hazards of typical and maximum actual shipments that might be better indicators of the range of likely hazards given an accident involving a shipment of LSA. By studying the survey of materials currently shipped we can determine whether current regulations or generator practice limits shipping activities. We suspect that generator practice limits shipping activity because few shipments even approach the permitted maximum.

If such is the case, the proposed changes in the regulations would allow increased flexibility of operations without materially affecting public safety. Isolated shipments that have one isotope at a higher activity than now permitted would not result in a significant increase in the average activity per shipment. On the other hand, if the shipment activity were regulation limited, a change in regulations could affect the actual hazards of shipment of LSA significantly.

As a more general comment on hazard assessments, we would suggest the use of the probabilistic approach in future efforts. It is possible to postulate hazardous situations under either the present or proposed regulations for transport of LSA. It would be appropriate, however, to temper these conclusions with information on the likelihood of such unusual events. This is the basis of probabilistic risk assessment, a tool that would be applied beneficially to such efforts in support of regulatory decisions.

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Aerometric Instrumentation for Real-Time Monitoring at Hazardous Spill Sites: Overview of Needs and Resources

WALTER F. DABBERDT

The last decade has seen a fourfold increase in the number of casualties from transportation incidents involving hazardous materials. Responder groups often cannot manage such incidents effectively because they lack knowledge of the chemicals involved, the peak concentrations present in the atmosphere, or the spatial extent of the hazardous zone. A systematic approach to providing responder groups with appropriate instrumentation needs to be developed. An introduction to the categorization of user needs is presented in terms of four types of constraints: time available for response, nature of the spill and the chemicals involved, responder expertise, and spatial extent of the impacted area. An overview is also provided of the general classes of instrumentation that should be considered.

Over the past decade, there has been a fourfold increase in the number of casualties from transportation incidents involving hazardous materials. In turn, the number of reported incidents over the same period has increased about eightfold (perhaps partly the result of stricter reporting pressures). Figure 1 illustrates the increases in incidents and casualties according to mode--(a) highway and rail and (b) air and water. Figure 2 provides corresponding information on the distribution of the hazardous materials (a) involved in the incidents and (b) responsible for the associated fatalities, respectively.

The distribution and concentration of toxic and hazardous substances in the air (and, correspondingly, the dangers) at a spill site are often poorly understood or simply unknown. The many possible reasons include the following--the identity of the chemicals is often unknown, in one-third of all railroad incidents it was impossible to read the placard on the car, and manifests could not be obtained for one-half of these incidents. Even if the chemicals are known, instruments to detect them in the field at the concentrations present may not exist or may be unavailable to the responders. In some cases the hazard potential may be too great to risk obtaining in situ samples. Remote sensors, however, may not exist for the particular chemical or they may require special expertise not available in the normal makeup of the on-scene response team or logistics may delay their transport and deployment to the point where they are no longer useful. Beyond these limitations, the nature of the atmosphere itself, coupled with the often dynamic nature of the incident (e.g., fire or explosion), compound and exacerbate the problem. The speed and direction of the wind, together with its turbulence intensity and stability, determine where and when the chemicals will be transported; they also determine their concentration or dilution and control the production of secondary products through chemical reactions in the air. The unsteady nature of the atmosphere and the modifying influence of local topographic and terrain conditions further complicate the problems of understanding existing conditions and forecasting future conditions.

The current state of the art of ambient chemical instrumentation and meterological sensors offers many possibilities for improving the ability of response teams to assess (and predict) the intensity and location of dangerous substances. There are (at least) two ways in which the needs of the responders and the capabilities of the measuring devices can be matched.

1. Individual instruments that are potentially useful can be reviewed and the most promising candidates evaluated and ultimately made available to the responders. This approach focuses on the advantages of the individual instruments but suffers from its failure to address in a systematic way the specific needs of the responders.
2. The various needs of the responders (as a function of the time and personnel available and the nature of the chemicals and the affected groups of people) can be quantified and stratified into a hierarchy of monitoring requirements and then the candidate instruments reviewed and evaluated insofar as they can be assembled into systems that are designed for one or more of the various categories of user needs. For example, one set of needs might consider (a) phase 1 activities (<8 h after the incident) (1), (b) protection of workers at the accident site, (c) several known chemicals, and (d) technical expertise of local first responders, but not special engineers. This approach has the advantage of being user-oriented but may suffer if other useful, available techniques fall outside of the user-needs categories given first priority.

The optimum approach is one that follows the second method but also recognizes the particular advantages of promising candidate instruments and sensing techniques.

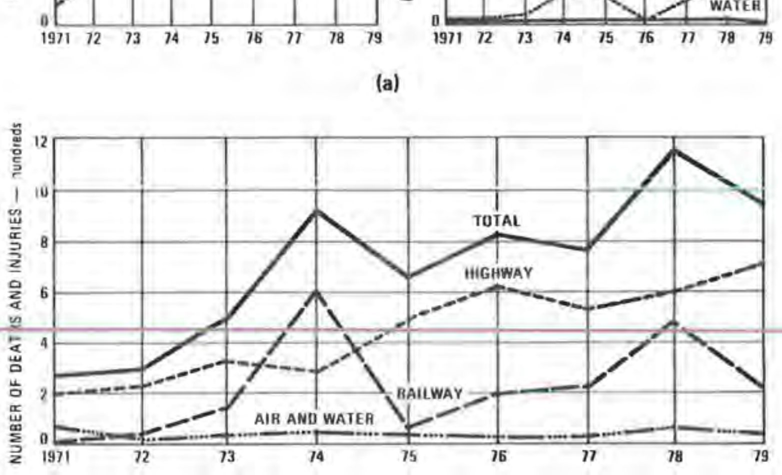
Much of the discussion in this paper may be abstract or esoteric. It is intended to provide an introduction to the type of framework that should first be established to best define the needs of the responders. With this in hand, the acquisition of useful instrumentation can proceed in an organized and focused way.

FRAMEWORK FOR DEFINITION OF USER NEEDS AND CONSTRAINTS

The types of instrumentation and other techniques that can be used at a spill site are governed by four classes or sets of constraints and considerations:

1. The time frame available for response,
2. The nature of the spill and the substances involved,
3. The expertise of the responders, and
4. The spatial extent of the impacted area.

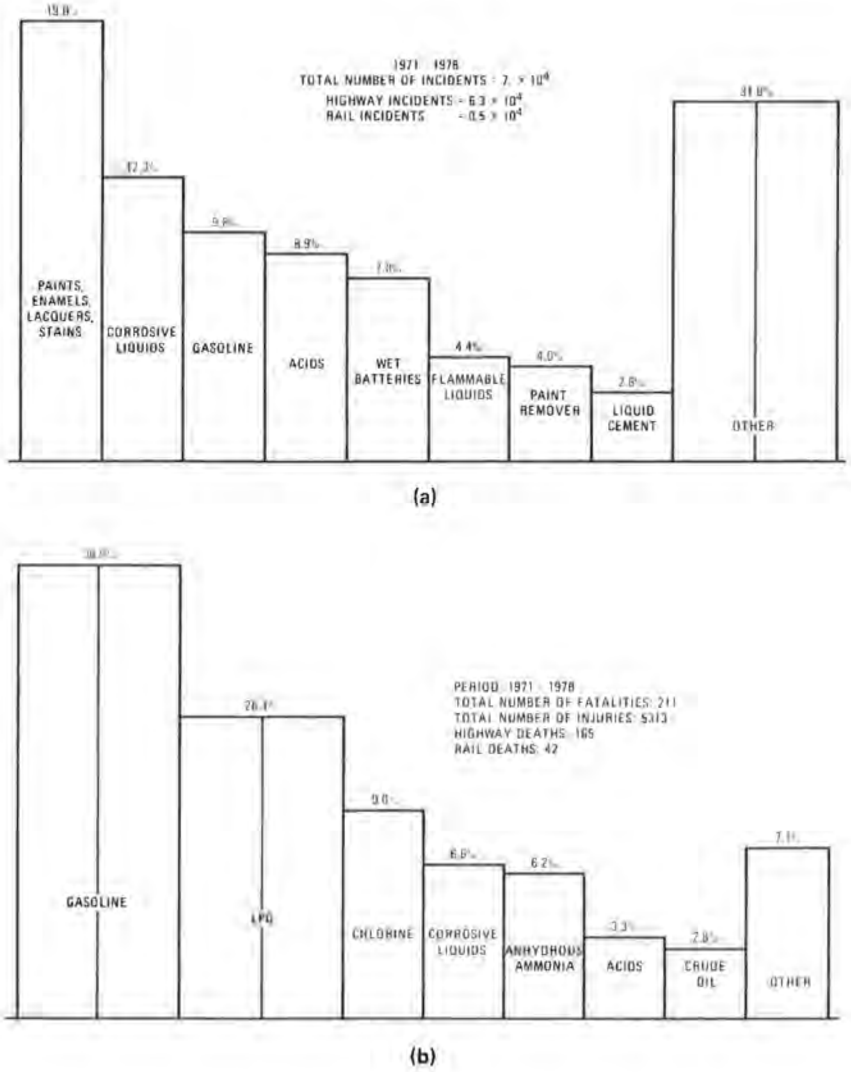
Figure 1. Yearly variation of incidents and casualties in U.S. by mode.



(a)

(b)

Figure 2. Hazardous materials involved in transportation incidents in U.S.



Spanning each of the four sets is the effect of the existing meteorological conditions and the way in which they may change with time (or location) (see Figure 3).

Time Frame

Time can be a factor in several ways but, basically, there is a need to consider what monitoring resources can be employed in each of the three logical phases of an accident, as introduced by Smith (1). Phase 1 is the initial period of response that lasts from 2 to 8 h and usually involves local responders. The principal object is to evaluate the emergency, contain it as much as is practical, and prevent injury to workers and the nearby population. Phase 1 instrumentation will of necessity be restricted to widely available devices that can be used easily by first responders. Phase 2 is the mature period of the incident and may last up to several days or more for major emergencies. Time is available to bring specialists and sophisticated hardware to the scene. Phase 2 is concluded when the emergency is controlled. Phase 3 may last several weeks (or more) and focuses on the restoration of the site. The purpose of monitoring during this phase is to assess potential residual effects that may involve long-term hazards.

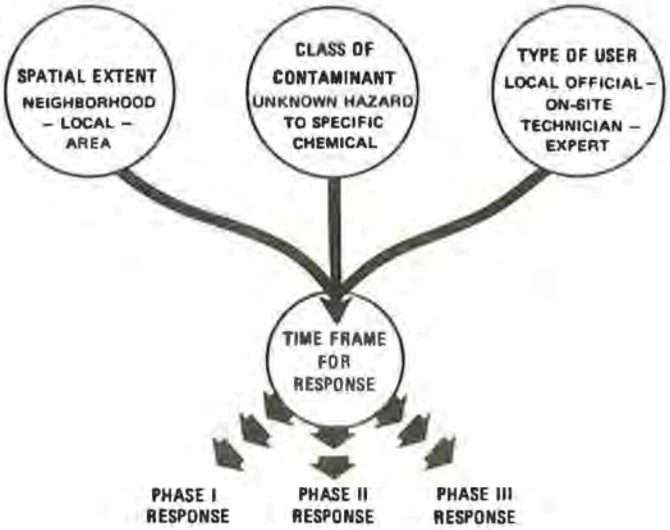
Nature of Spill

The hardware used to monitor during each of the three phases is a function of the nature of the primary or secondary contaminants. Two scenarios that must be considered are as follows: (a) the contaminants are either known with certainty or can be assumed to fall within a short list of possibles, or (b) the identity of the contaminants is virtually unknown. Even if the contaminant is known, appropriate instrumentation may not be available. Because the list of hazardous substances is so large, a priority listing will need to be prepared and appropriate methods considered according to the priority of the substance and the potential for obtaining a sensor that can serve in the field.

Spatial Extent

Monitoring requirements for emergency situations will vary with the spatial aspects of the problem. Conditions immediately adjacent to the accident may necessitate different instrumentation from that used to assess the extent of the public evacuation zone further downwind. At the accident site concentrations are apt to vary rapidly in time and space and require the use of one or more continuous or near-continuous sensors to protect workers. Further

Figure 3. Four classes of constraints that dictate nature of atmospheric emergency response system.



downwind harmful secondary products may form that do not exist at the accident site or ambient levels may need to be monitored to assess the likelihood of chronic effects to unprotected citizens.

User Expertise

The personnel available to operate the instrumentation (and perhaps interpret the output) is a major consideration in the selection process. Local first responders will often be unable to afford the more sophisticated hardware nor would they normally be skilled in its operation and maintenance. Accordingly, Phase 1 hardware will need to allow these users to assess whether the concentrations are hazardous, yet they will need to be relatively inexpensive, readily available, and easy to use properly. Phases 2 and 3 will usually provide enough time to bring instrumentation specialists to the scene.

Accident Scenarios

Taken together, the four classes of constraints define most accident scenarios and the associated aerometric instrumentation requirements. Summarized below is the broad range of scenarios that can exist at a major accident:

Time Frame	Spatial Extent	Nature of Spill	User Expertise
Phase 1	Accident scene	Known chemicals	Public safety officials
Phase 2	Downwind populated areas	Unknown chemicals	Trained response team
Phase 3			Specialists

Not all subdivisions are mutually exclusive. The tabulation indicates that 30 scenarios may come into play. The development of monitoring devices and systems should be done in the context of an integrated plan that recognizes the scope of the physical problem and the specific needs of the users.

EXAMPLES OF AVAILABLE RESOURCES

A wide range of different sampling and detection techniques is available, both for monitoring of gases and aerosols and for meteorological measurements. These are the range of resources potentially available to support the air-monitoring needs of the emergency response teams.

Grab Samples

Instrumentation for grab samples can vary from substance-specific detector tubes to highly sophisticated interferometers and gas chromatograph-mass spectrometers. Draeger tubes, for example, are well suited for a first-on-the scene responder or a phase 1 response team. These devices are simple to use, require minimal operator training, and can usually identify a chemical class but often are not capable of specific identification. In fact, they are already in use for environmental emergency situations.

More sophisticated instrumentation such as portable infrared (IR) or portable gas chromatographs (GCs) or photoionization detectors offers more specificity and sensitivity of detection but is less portable and more complex to operate. Where extremely toxic materials are involved in a spill, much more complex instrumentation is required to monitor these chemicals at the minute concentrations that can represent a health hazard. Examples of this latter instrumentation are IR interferometers; GCs with sensitive, specific detectors; and mass spectrometers (2). These sophisticated instruments can be installed in vehicles to provide some portability, but only at considerable expense and difficulty. The more sophisticated analytical tools are well suited for phase 2 response teams and have some usefulness in the longer-term, phase 3 responses.

Remote Sensing

One problem facing the emergency response team when hazardous gases are released into the atmosphere is to define the size and concentration of the plume. Surveillance of the plume is needed as soon as possible after the accident until later periods (phase 1,2), possibly weeks (phase 3), when effects are residual from the outgassing of soil and water. Definition of the plume is also critical when certain actions are contemplated, such as increasing the release rate or combusting the material. In addition, the plume may be laden with toxic aerosols or aerosols may form downwind. Remote sensing, because of wide area coverage, offers a way of defining these gas and aerosol plumes.

Remote measurement systems always make a measurement along a line of sight, and multidimensional mapping is made possible by moving the line of sight by motion or scanning. Van-mounted scannable systems and aircraft-mounted systems are used rou-

Table 1. Specifications for remotely controlled sampling aircraft.

Parameter	Requirement
Weight	Total weight, including all sampling, control, and support equipment not to exceed 35 lb
Size	Overall size, including all equipment and the sampling case not to exceed 2.5 ft^3
Control range	Maximum radio-control range to exceed 1.5 miles
Deployment	Deployable at wind speeds ≤ 35 knots
Altitude	Operable 20-500 ft above the surface
Speed	20-65 mph
Fuel	Should be powered by a nonpetroleum fuel
Flight duration	Should be 30 min before refueling or recharging of batteries
Safety	Sampling system shall not be a source of ignition for a flammable vapor
Crew	Transported, deployed, and operated by a single person
Maintenance	Maintainable in field by using commercially available materials and parts

tinely. The diversity of remote-sensing instrumentation is wide; however, these instruments may be classified in a simple four-parameter tabulation:

1. Active or passive,
2. Range resolved or range averaged,
3. Airborne or ground based, and
4. Material specific or nonspecific.

Remote systems use the principle that the concentration of a gas or aerosol can be determined by the absorption or backscattering of light along the path. Passive systems use natural sources of radiation, such as sunlight, diffused sunlight, earth, and sky radiation. Active systems use artificial sources, such as lasers. Systems may also be range resolved or may estimate gas concentration averaged along the path. Passive systems usually have the latter characteristic. Systems may be flown, driven, or scanned across the plume. Finally, remote-sensing systems are classified as material specific or nonspecific. Many remote-sensing systems tend to be in the former category (see the paper by Uthe and Hawley in this Record).

Remote sensing could be of particular value when spills involve highly toxic materials or when toxic materials are combusted after the accident. Mapping can be accomplished at hazardous locations without the risks involved with grab sampling.

Remotely Controlled Sampling and Measurement Vehicles

An approach to collect grab samples safely in hazardous locations could make use of a remote-controlled land vehicle, boat, or model aircraft. The following discussion, however, is an example specific only to the application of a model aircraft.

A sampling aircraft suitable for use in this application should be easily transportable and carry an adequate payload for either sample collection in containers or for lightweight analytical instrumentation. Table 1 provides specific requirements for an existing model aircraft sampling platform that is suitable for use as a remotely piloted vehicle (RPV) operated by a phase 1 or 2 response team.

The RPV has an amphibious hull and can be adapted to collect either air or water samples. The RPV has a payload weight of 4.5 kg and payload volume of 17 L. Within the context of this design payload weight-volume constraint, several analysis techniques are practical:

1. Draeger tubes,
2. Photoionization detector,
3. Combustible gas detector,
4. Ion selective electrodes,
5. Conductivity detector,
6. Radioactivity detector, and
7. Particulate and gas collection.

Artificial Tracers

Artificial, gaseous tracers can be injected into the hazardous spill at a known rate to provide at least four types of useful information:

1. Definition of the distribution of the toxic gases and their dispersion by acting as a surrogate for the gases of concern;
2. Estimation of the actual concentration of the toxic gases (even when the latter cannot be measured), provided the rate of release of the toxic gases can be estimated;
3. Estimation of the rate of release of the toxic gases, provided there are simultaneous ambient measurements of the tracer gas and the toxic gases at one or more representative locations; and
4. Real-time evaluation of atmospheric dispersion models; with the tracer data to provide an objective measure of confidence, the models can be used for real-time in situ contingency planning.

Tracer gases such as sulfur hexafluoride can now be measured continuously at concentrations as low as 10^{-11}, and grab sampling and batch analysis can provide reliable measurements to 10^{-12}. Active remote-sensing systems for SF_6 that use infrared differentiatial absorption principles are now being developed.

Meteorological Data

Both large-scale (synoptic) and microscale meteorological data are vital to the protection of the response team and the citizenry. Synoptic data are available from the National Weather Service, although surface and upper air weather data available by teletype (e.g., Services A and C) can be obtained at the accident site most easily and quickly via telephone or terminal access to one of several private companies that offer this service around the clock. No special installation is required. Satellite and facsimile data are also invaluable and can easily be obtained in many locations that use receivers designed for marine use.

Microscale or local effects often dominate the observed weather conditions at the accident site, particularly when dispersion conditions are poorest. Local meteorological measurements are a necessity. These should include wind measurements at multiple heights and different locations, particularly when the terrain is hilly or the area heavily forested. Temperature stratification near the ground is also important to assess air drainage patterns and the rate of diffusion of the toxic plume. When the plume is buoyant due to fire or explosion, upper-level winds and temperatures will be important. These can most easily be obtained by tethersonde or Doppler acoustic radar.

Role of Dispersion Models

Properly used, dispersion models can provide valuable information to the on-scene coordinator for evaluating conditions that are potentially hazardous to cleanup and repair crews and for assessing the extent of public evacuation zones. Models are particularly useful for extending and supplementing the information obtained from several point measurements of gas or aerosol concentration. However, to be used with confidence, the models should be evaluated 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

EDWARD E. UTHE AND JAMES G. HAWLEY

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