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Meteorological Monitoring at Los Alamos

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Cover: A meteorological observation tower in Mortandad Canyon in a sea of blooming Hoary Asters following the monsoon of 2006.

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Environmental Data and Analysis Group of the Waste and Environmental Services Division (WES-EDA)

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Introduction

Meteorological monitoring at Los Alamos began in 1910, when daily maximum and minimum temperatures, as well as precipitation data, were recorded and archived at the Los Alamos Boy's Ranch School. The Ranch School was closed to pave the way for the Manhattan Project which began in 1943, but weather data continued to be collected at various location around Los Alamos and the Los Alamos National Laboratory (LANL).

In 1979, a comprehensive tower network was installed at LANL to measure temperature, wind, humidity, pressure, precipitation, and insolation as required for DOE facilities. During the early 1990s, the network was revised, with additional towers sited throughout the facility to augment the data collection program, as well as to increase the spatial resolution of the observation domain. The LANL meteorology monitoring program has been described in several earlier incarnations of this document (Stone and Holt 1996, Baars et al 1998, Rishel et al 2003).

All measured data are archived continually and made accessible to Laboratory personnel for use in various projects and programs. For example, the collected data play a critical role in emergency planning in the event of a chemical or radiological release, demonstrating regulatory compliance in the areas of air quality, water quality, and waste management, as well as supporting monitoring programs in hydrology and health physics. Archived meteorological data are also used in numerous investigative studies and are the foundation of the comprehensive climatological study of Los Alamos by Bowen (1990, 1992).

Meteorological data requests come from a wide variety of customers, both internal and external to the Laboratory. The program's website, called the "Weather Machine" (http://weather.lanl.gov), is instrumental in servicing many of these requests, with its data request forms, graphical and tabular data displays, and relevant links to additional Web resources and tools. Other data requests typically require additional work and processing and are handled by program personnel via email, fax, or phone communication.

The meteorological monitoring program can be divided into five main components, each component playing an integral role in meeting the program's objectives:

Measurements. We maintain a continuous stream of high-quality, meteorological measurements from the program's extensive network of towers and instruments.

Data Management. We ensure the quality, integrity, and security of the extensive archive of meteorological data and associated data display products.

Data Analysis and Forecasting. Analyses are conducted per customer request and to increase knowledge of local weather phenomenon. Forecasting services are provided to support Laboratory operations.

Modeling. We support Laboratory emergency management and response in the event of an airborne release by providing real-time meteorological data and dispersion modeling.

Data Accessibility. We provide data access to internal and external customers, primarily by way of the program's website.

A. Rationale and Monitoring Requirements

Three DOE orders and guidance documents provide most of the rationale for the program: DOE Order 450.1 (DOE 2003), "Environmental Protection Program"; DOE Order DOE/EH-0173T (DOE 1991), the "Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance"; and DOE Order 151.1C (DOE 2005), "Comprehensive Emergency Management System." These orders state that DOE facilities are required to measure meteorological variables in sufficient detail to assess the impact of a release of hazardous material on the public and the environment. The three documents are described below:

- DOE Order 450.1 (DOE 2003) requires the implementation of an Environmental Management System at DOE sites to implement sound stewardship practices and to meet or exceed compliance with applicable environmental, public health, and resource protection laws, regulations, and DOE requirements. The Environmental Management System must be part of an Integrated Safety Management System (ISMS). As part of integrating an Environmental Management System into the site ISMS, an effluent monitoring and environmental surveillance program must be established.

- DOE/EH-0173T (DOE 1991) describes the elements of an acceptable effluent monitoring and environmental surveillance program at DOE sites, including meeting the meteorological data needs, which are in support of facility operations, environmental impact assessments, environmental surveillance activities, safety analyses, environmental restoration activities, and the consequence assessment element of emergency preparedness and response. DOE/EH-0173T frequently refers to EPA-454/R-99-005 "Meteorological Monitoring Guidance for Regulatory Modeling Applications" (EPA 2000) and ANSI/ANS-3.11-2005 "Determining Meteorological Information at Nuclear Facilities" (ANSI 2005) for further guidance.

- DOE Order 151.1C (DOE 2005) establishes policy and assigns and describes roles and responsibilities for the DOE Emergency Management System (EMS). The DOE EMS provides the framework for development, coordination, control, and direction of all emergency planning, preparedness, readiness assurance, response, and recovery actions. Meteorological monitoring support of EMS is broad in nature, and covers, for example, weather forecasting and airborne plume modeling.

Other DOE orders indirectly provide rationale for the program. For example, compliance with DOE Order 5400.5 (DOE 1993), "Radiation Protection of the Public and the Environment," requires the Laboratory to perform modeling calculations that require meteorological data gathered by the program.

B. Design Criteria

Los Alamos National Laboratory (LANL) covers 112 square kilometers of the Pajarito Plateau in north-central New Mexico. The Pajarito Plateau slopes from the west-northwest to the east-southeast, dropping 400 meters in elevation across the Laboratory. Canyons and mesas run along the slope of the plateau and drain to the broad Rio Grande Valley to the east. The Jemez Mountains, which extend up to about 900 meters above the plateau, are to the west. Vegetation varies from piñon/juniper at lower elevations of LANL to ponderosa pine forests found at higher elevations. These local and regional topographic features contribute to the complexity of the site and significantly influence the local meteorology and climatology at the Laboratory.

Many hazardous materials are used at the Laboratory, but most scenarios involving the release of these materials to the atmosphere do not pose a serious threat more than one or two kilometers from the facility. The town of Los Alamos could potentially be affected by a release from a Technical Area 3 (TA-3) facility, particularly during the day when the prevailing wind direction is from the south. The town of White Rock, which lies to the southeast of the Laboratory, could be affected by a release during the nighttime when northwesterly drainage flows are common.

For climatological applications, meteorological stations located at the easternmost and westernmost edges of the Laboratory would be sufficient to capture the east-west gradient in precipitation and temperature due to the elevation change and would be adequate for the formulation of a wind climatology. However, calculating a wind field for real-time plume calculations in the Laboratory's complex terrain setting requires a more elaborate tower network. Because it is impractical to erect numerous towers, the problem then is to determine the appropriate number of towers that will sufficiently resolve the wind field for plume modeling. Other limitations also play a role in siting the network, such as fiscal constraints, availability of suitable measurement sites, locations of potential sources, and site complexity.

The current meteorological network consists mainly of seven observation towers. Four towers are located on the plateau and are used principally for inferring atmospheric stability, as well as to interpolate a diagnostic wind field for the general area. Two towers are located in canyons—the TA-41 tower is located in Los Alamos Canyon and provides meteorological measurements that typify deep, "narrow" canyons, and the MDCN tower is located in Mortandad Canyon and is more representative of shallow, "open" canyons. The seventh tower is located on top of Pajarito Mountain and provides larger-scale wind conditions that can be used to predict wind shifts down on the plateau. There is also a Doppler sound detection and ranging (sodar) instrument located near the TA-6 tower to measure wind speed and direction at higher elevations, and an additional rain gauge located in the north community of Los Alamos.

1. Monitoring Stations

The seven meteorological observation towers, sodar, and north community rain gauge are listed in Table 1. Each station's name, alternate name(s), structure number, latitude and longitude coordinate, and elevation are given. The latitudes and longitudes shown assume the North American Datum of 1983 (NAD83) as the origin of the coordinate system. Conversions from latitude and longitude to state plane or UTM coordinates, and conversions from NAD83 into NAD27, can be made using a variety of software available on the internet.

Table 1. Current Meteorological Observing Stations

Station Name	**Alternate Name(s)**	**LANL Structure Number**	**Latitude/Longitude Coordinates (º)**		**Elevation (ft)**
			Latitude	**Longitude**	
TA-6	Official Los Alamos station	TA-06-0078	35.8615	106.3195	7424
sodar	none	TA-06-0100	35.8615	106.3187	7417
TA-41	Los Alamos Canyon	TA-41-0064	35.8764	106.2964	6914
TA-49	Bandelier	TA-49-0123	35.8133	106.2993	7045
TA-53	LANSCE	TA-53-1020	35.8701	106.2543	6990
TA-54	Official White Rock station	TA-54-0088	35.8259	106.2232	6548
PJMT	Pajarito Mountain	n/a	35.8864	106.3948	10360
MDCN	Mortandad Canyon	TA-05-0061	35.8597	106.2522	6750
NCOM	North Community	n/a	35.9009	106.3216	7420

Station locations are shown on a map in Figure 1. Spacing between the towers is relatively even with a mean distance of seven kilometers. Below is a brief description of each current station:

- The **TA-6 tower** is 92 meters tall and instrumented at five levels. It is located on the Pajarito Plateau in a natural meadow site that slopes downward about 1.5˚ to the east-southeast. The fetch within several hundred meters of the tower is over short grasses and widely scattered low shrubs. The tower is tall enough to characterize the azimuthal shear often present at night, but it is too short to see azimuthal shear that often occurs above the 200- to 500-meter deep upslope flow during the morning hours. This station is the official meteorological station for Los Alamos and the Laboratory. Observations from this site are reported to the Cooperative Observer Network of the National Weather Service (NWS) and are archived at the National Climatic Data Center (NCDC). Climate statistics for the upper Pajarito Plateau are compiled from observations at this site.

- The **TA-6 sodar** is located 78 meters east of the **TA-6 tower**. The sodar provides information on winds from the Pajarito Plateau up to approximately 2000 meters. These observations have been used to characterize upper level winds and inversion layer height for explosive shots.

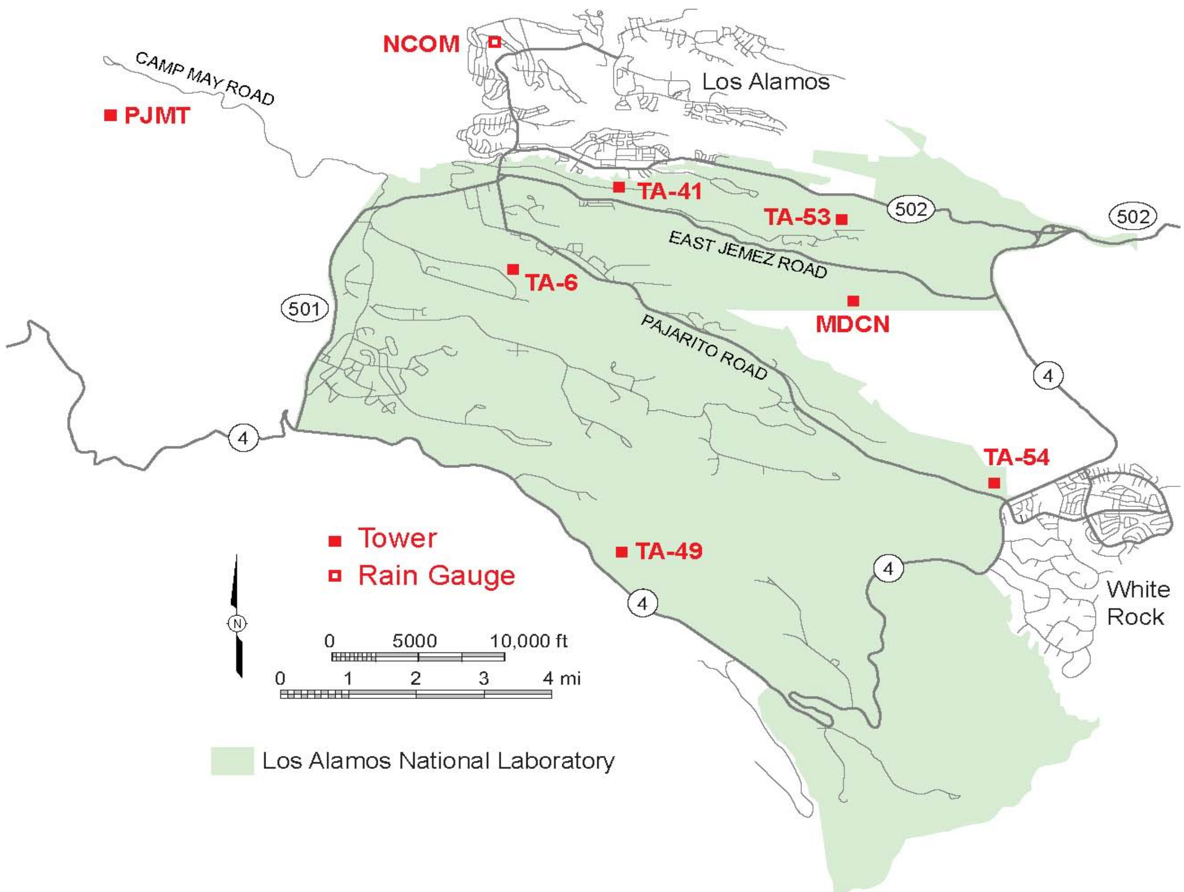

Figure 1. Map showing locations of meteorological observation stations.

- The **TA-41 tower** is 23 meters tall and instrumented at three levels. It is located in Los Alamos Canyon where the canyon is approximately 100 meters deep and 300 meters wide. The canyon runs west to east in the area of the tower. Observations from this tower indicate whether airborne material is likely to travel up- or down-canyon or be affected by a rotor inside the canyon.

- The **TA-49 tower** is 46 meters tall and instrumented at four levels. It is located on the Pajarito Plateau in an open meadow. The fetch within several hundred meters of this tower is over short grasses. The meadow site slopes downward 2˚ to the east-southeast. The tower is located close to technical areas where high-explosive experiments are conducted. The tower has also been used to characterize wind conditions at the old tritium facility at TA-33.
- The **TA-53 tower** is 46 meters high and instrumented at four levels. It is located on the narrow mesa between Sandia and Los Alamos Canyons. It is east-northeast of the Los Alamos Neutron Science Center (LANSCE) stack, which is the Laboratory's largest

routine emitter of radionuclides, primarily in the form of short-lived activated air products. This tower also characterizes wind conditions around TA-21.

- The **TA-54 tower** is 46 meters tall and instrumented at four levels. It is located in a clearing in piñon/juniper woodland at the eastern edge of Mesita del Buey, an area where low-level radioactive wastes and mixed chemical wastes are handled and stored. Measurements from the TA-54 tower are used in environmental performance assessments of the waste site and would be used to characterize atmospheric transport and dispersion in the event of a release from operations at TA-54.

- The **PJMT tower** (Pajarito Mountain) is 36 meters tall and instrumented at two levels. The tower is a cellular phone tower located on top of Pajarito Mountain near the top of the Aspen Lift at the Pajarito Mountain Ski Hill. Instrumentation has been placed on top of the tower and near the ground at a position close to the tower. This site provides an "upstream" measurement of ambient wind conditions that can be used to predict winds on the plateau.

- The **MDCN tower** (Mortandad Canyon) is 10 meters tall and instrumented at two levels. It is located in Mortandad Canyon in a broad, shallow area of the canyon. The canyon runs, roughly, west to east in the area of the tower. The tower was installed in 2003 to provide meteorological data for the health and safety analysis of the proposed Advanced Hydrotest Facility (AHF). The data provide a second opinion on canyon flow in addition to the **TA-41 tower**.

- The **NCOM**, **North Community,** station is on the roof of the volunteer fire department's building at 4017 Arkansas. The building is approximately 12.2 meters tall. This station is used to determine precipitation along the northwestern edge of the Laboratory site.

Information about previous observation tower locations and data acquisition periods is presented in Table 2.

2. Adequacy of the Tower Network

A study by Lee et al. (1994) attempted to determine the adequacy of the tower network. The study modeled hypothetical particle trajectories from the Chemistry and Metallurgy Research (CMR) building at TA-3, using a $1/r^2$ interpolated wind field driven by data from the four plateau towers. The particle trajectories were then compared with trajectories using a wind field driven by data from an additional temporary tower erected north of the Los Alamos town site.

The conclusion from the study was that the benefits of adding an additional tower north of the town of Los Alamos would not significantly improve plume modeling. Evacuation decisions by emergency managers would be carried out for entire neighborhoods of Los Alamos, so the additional detail gained from the five-tower network would not change the response strategy.

Table 2. Historical Meteorological Observing Stations

Site	Dates	Comments	Latitude/Longitude Coordinates (º)		Elevation (ft)
			Latitude	Longitude	
Los Alamos weather stations					
Ranch School	11/1/1910 – 3/10/1946	Temperature records began 10/19/1918	35.883	106.3	7320
Townsite	3/19/1946 – 4/30/1950	Very close to previous site (Ranch School)	35.883	106.3	7320
Airport	5/1/1950 – 12/31/1951	Temperatures not representative (too high during 1950)	35.882	106.267	7150
Laboratory weather stations					
H/Ad	1/1/1952 – 3/20/1956		35.867	106.317	7045
SM-43	3/21/1956 – 8/31/1956	Temperature measured on roof	35.867	106.317	7400
SM-43	9/1/1956 – 1978	Temperature measurement moved to ground level	35.867	106.317	7400
TA-59	1978 – 7/1990		35.867	106.317	7380
TA-6	2/1/1990 – present	Current TA-6 site, station data feeds Los Alamos archive (LAarc)	35.8614	106.3196	7424
White Rock weather stations					
Fire Station	9/21/1964 – 1/28/1992	Data missing from 11/1979 – 6/1980 and 2/1981 – 3/1981	35.833	106.3948	6380
TA-54	1/29/1992 – present	Current TA-54 site, station data feeds White Rock archive (WRarc)	35.8258	106.2233	6548

C. Program Implementation

1. Measurements

a. Instrumentation

High-quality meteorological measurements are the foundation of the program. The objective is to deliver a continuous stream of data with a recovery of at least 90% (for in situ measurements). Program measurements strive to meet or exceed recommendations found in DOE 2004, EPA 2000, and ANSI 2005.

Over 100 instruments, consisting of about 15 different types of sensors, are used in the network. All instruments are of high quality and are purchased from reputable manufacturers. Automatic range checking is employed for a real-time verification of the incoming data. On a weekly basis, a meteorologist inspects all of the data, looking for possible instrument problems. The entire network also undergoes periodic calibration inspections and refurbishment as required by the instrumentation. External audits are performed periodically. Quality assurance is addressed in detail by Johnson (2007).

The types of instruments used in the network are given in Table 3. See Table 4 for definitions of variables and symbols. In general, instruments in the network operate continuously under local weather conditions. Occasionally, snowstorms cause icing on wind instruments and upward-facing radiometers. Considerable attention has been given to lightning protection, and although Los Alamos has a very high lightning flash density, data loss caused by lightning is rare.

All wind instruments are supported by towers of open-lattice construction with instruments mounted on booms. To reduce flow distortion from the tower, booms face westward into the prevailing wind direction and their lengths are more than twice the tower width. The booms are attached to an elevator that can be lowered for instrument inspection and replacement.

Table 3. Instruments Used Throughout the Network

Variable	Instrument Type	Number Used
Wind variables		
u	Propeller-driven AC tachometer	17
θ	Vane-driven potentiometer	17
w	Propeller-driven DC tachometer	16
Atmospheric state variables		
T	Thermistor (aspirated)	23
p	Variable ceramic capacitor	3
h	Hygroscopic capacitor	5
q	Infrared optical hygrometer	2
Precipitation variables		
r	Heated tipping bucket with wind screen	6
s_d	Ultrasonic measurement of distance to snow surface	2
l	Optical and rf sensors	1
Radiative fluxes		
$K\downarrow$	Pyranometer (aspirated)*	6
$K\uparrow$	Pyranometer	2
$L\downarrow$	Pyrgeometer (aspirated)	2
$L\uparrow$	Pyrgeometer	2
Subsurface measurements		
T_s	Thermistor	10
χ_w	Time domain reflectometer	4
Fuel moisture and temperature		
W_{10}	Capacitance of wood dowel	1
T_{fuel}	Thermistor (within wood dowel)	1

*The MDCN pyranometer is not aspirated.

Booms are not used for the Pajarito Mountain tower, which has its instrumentation situated on the top of an open-lattice, 36-meter, cellular phone tower. The Mortandad Canyon tower is a 10-meter tower (shown on cover). Towers, guy lines, and elevators are inspected periodically by a licensed tower erection contractor for wear and safe operation. Results of the last inspection, performed in 2005 by Advanced Tower Services, Inc. of Albuquerque, NM, are available in the meteorology instrumentation laboratory TA-59-001 rm 176.

b. Observed Variables

Meteorological variables measured by the program can be grouped into the categories of wind, atmospheric state, precipitation-related, radiative fluxes, subsurface measurements, and fuel moisture. Below is a brief description of each category, including its importance to the program.

- *Wind variables*. The tower network provides continuous measurements of mean wind speed, wind direction, and turbulence at multiple levels over the Pajarito Plateau, on top of Pajarito Mountain, and in Los Alamos and Mortandad Canyons. These data are critical to emergency preparedness, dispersion modeling for regulatory compliance, and planning studies.

- *Sodar-derived winds*. Wind speed and direction are arguably the two most important variables that we measure. Under ideal conditions, the sodar determines wind speed and direction to an elevation of about 2000 meters above ground level. The sodar links wind measurements between the plateau tower network and Pajarito Mountain. The towers and the sodar also act as a redundant measurement mechanism for each other. In addition, backscatter intensity can provide information on the height of the mixed layer.

- *Atmospheric state variables*. Continuous measurements of temperature, pressure, and moisture variables are used to document the state of the atmosphere. Temperature applies to a wide range of planning studies and documentation. Pressure is used to calibrate several other environmental measurements and is required by a number of programs around LANL. Atmospheric moisture variables are used in engineering design. For dew point temperature, $T_d = f(VP(h, SVP(T,h)))$, where VP and SVP are vapor pressure and saturation vapor pressure. When $T < 0^{\circ}C$, T_d is the frost point.

- *Precipitation-related variables*. One of the most frequently requested data types is precipitation data. It is used by biologists, hydrologists, and those involved with regulatory compliance, and it is an input to the washout algorithm for modeling radioactive plumes. Total precipitation (liquid equivalent), snowfall, and snow depth measurements are reported to the NWS and are used for various forms of documentation. Snowfall is the only measurement that is not automatically measured and archived. Snowfall is manually measured using the snowfall.pro program, and only when measureable snow occurs.

  The lightning data represent the number of strokes detected in a given period over a range that depends on sky conditions and the natural variation in lightning flashes (estimated to be 5 kilometers to 50 kilometers). A lightning flash, which is often observed and commonly referred to as a strike, is composed of one to thirty strokes, with the average being four strokes per flash or strike. Lightning stroke rate is a sensitive indicator of the electrical power generated by a thunderstorm, and this power is closely related to the severity of the weather (wind, hail, and rain) associated with the storm. The lightning detector has early warning potential since it detects intracloud lightning which usually precedes the more dangerous cloud-to-ground lightning by 10 to 30 minutes. Dry thunderstorms occur when lightning is detected but no precipitation is measured. Dry thunderstorms have the potential for igniting wildfires.

- *Radiative fluxes*. The downward shortwave irradiance is used to estimate atmospheric stability, calculate evaporation, and document sky conditions for experiments. The upward shortwave irradiance provides information on the condition of the surface, or the albedo, such as determination of snow cover or ground wetness, which is also used in experiments. Shortwave irradiance includes diffuse and direct beam in the 0.285- to 2.800-micrometer waveband. The downward longwave irradiance provides cloud cover information at night.

- *Subsurface measurements*. Measurements of soil temperature and soil moisture document the response of the upper layers of the soil to atmospheric forcing.

- *Fuel moisture and temperature*. The variable fine-dead fuel moisture and temperature is directly related to the ignition potential and therefore is an important parameter for fire specialists in assessing various aspects of local fire danger. The 10-hour fuel moisture is measured, and a modified National Fire Danger Rating System (NFDRS) algorithm is then used to estimate the one-hour fuel moisture. The one-hour fuel moisture is especially important because it can change rapidly, and fires usually begin with the ignition of fuels in this category. The 10-hour fuel moisture is also important in determining the potential for ignition, as well as fire sustainability.

Table 4, parts (a) through (g), define all the meteorological variables measured or computed across the network. The tables are organized into sections corresponding to variable type: time, wind, atmospheric state, precipitation-related, radiative energy fluxes, subsurface measurements, and fuel moisture and temperature.

Table 4. Symbols, Variable Names, Units, and Definitions

Part (a) Time Variables

Symbol	Variable Name	Variable Definition
	year	Year
t	doy	Day of year (1 to 365 or 366 for a leap year)
	time	Mountain Standard Time (1min, ±1 min)

Table 4. Symbols, Variable Names, Units, and Definitions (continued)

Part (b) Wind Variables

Symbol	Variable Name	Units	Variable Definition
U	spdn	ms^{-1}	Horizontal scalar wind speed

			(0.1, ±0.2)
σ_u	sdspdn	ms^{-1}	Standard deviation of wind speed
$\overline{U}$	avgspdn	ms^{-1}	24-hour average wind speed
U_{mx}	mxgstn	ms^{-1}	Maximum instantaneous wind gust
t_{mx}	tgstn	hhmm	Time of occurrence of maximum gust
U_{mx1}	mx1gst	ms^{-1}	Maximum 1-minute wind gust during 24 hours based on non-overlapping 1-minute averages
t_{mx1}	t1gst	hhmm	Time of the maximum 1-minute gust
θ	dirn	degrees	Unit vector mean wind direction (1, ±3, measured clockwise from true north)
σ_θ	sddirn	degrees	Standard deviation of wind direction
θ_{mx}	dirgstn	degrees	Direction of the maximum instantaneous gust
θ_{mx1}	dir1gst	degrees	Direction of the maximum 1-minute gust
w	wn	ms^{-1}	Vertical velocity (0.01, ±0.1, positive upward)
σ_w	sdwn	ms^{-1}	Standard deviation of the vertical velocity

Part (c) Atmospheric State Variables

Symbol	Variable Name	Units	Variable Definition
T	tempn	˚C	Air temperature (0.1, ±0.3)
T_{mx}	mxtemp	˚C	Maximum instantaneous temperature
t_{mx}	tmxtemp	hhmm	Time of maximum temperature
T_{mn}	mntemp	˚C	Minimum instantaneous temperature
t_{mn}	tmntemp	hhmm	Time of minimum temperature
T_{mid}	midtemp	˚C	Midnight temperature (*LAarc* and *WRarc* only)
p	press	mb	Atmospheric pressure (0.1, ±0.6)
p_{mx}	mxpress	mb	Maximum instantaneous pressure
p_{mn}	mnpress	mb	Minimum instantaneous pressure
h	rh	%	Average relative humidity (1, ±2)
$\bar{h}$	avgrh	%	24-hour average relative humidity
h_{mx}	mxrh	%	Maximum relative humidity
h_{mn}	mnrh	%	Minimum relative humidity
h_{mid}	midrh	%	Midnight relative humidity (*LAarc* and *WRarc* only)
T_d	dewp	˚C	Dew-point temperature (0.1, **)
$\overline{T}_d$	avgdewp	˚C	24-hour average dew-point temperature
T_{dmx}	mxdewp	˚C	Maximum instantaneous dew point
T_{dmn}	mndewp	˚C	Minimum instantaneous dew point
q	ah	$g\ m^{-3}$	Absolute humidity (0.01, above 0˚C: 1.0˚C, below 0˚C: 1.5˚C
$\overline{q}$	avgah	$g\ m^{-3}$	24-hour average absolute humidity

Table 4. Symbols, Variable Names, Units, and Definitions (continued)

Part (d) Precipitation-Related Variables

Symbol	Variable Name	Units	Variable Definition

r	precip	in.	15-minute total precipitation, includes rain and melted frozen precipitation (0.01, ±0.05r)
$\hat{r}$	tprecip	in.	24-hour total precipitation
s_d	snowd	in.	Snow depth (0.1, ±0.4)
s_{dmid}	midsnowd	in.	Midnight snow depth (0.1, ±0.4) (*laarc* only)
s_f	snowf	in.	Snowfall (0.1, ±0.4). Estimated from increases in snow depth when liquid precipitation is recorded
$\hat{s}_f$	tsnowf	in.	24-hour total snowfall (*laarc* only)
l	lstks	unitless	Number of lightning strokes in 15 minutes
$\hat{l}$	totlstks	unitless	Number of lightning strokes in 24 hours

Part (e) Radiative Energy Fluxes

Symbol	Variable Name	Units	Variable Definition
$K\downarrow$	swdn	W m^{-2}	Shortwave irradiance (1, ±0.035 $K\downarrow$ [zenith angle 0 to 70˚], ±0.065 $K\downarrow$ [zenith angle 70 to 90˚], positive downward)
$\hat{K}\downarrow$	swedn	MJ m^{-2}	24-hour total shortwave radiative energy (0.01, **) $K\downarrow = \int_0^{24} K\downarrow dt$
$K\uparrow$	swup	W m^{-2}	Reflected shortwave irradiance, positive upward
$\hat{K}\uparrow$	sweup	MJ m^{-2}	24-hour total reflected shortwave radiative energy $K\uparrow = \int_0^{24} K\uparrow dt$
$L\downarrow$	lwdn	W m^{-2}	Longwave irradiance in the 3.5 to 50 micrometer waveband (1, ±0.06*$L\downarrow$, positive downward)
$\hat{L}\downarrow$	lwedn	MJ m^{-2}	Downward longwave energy received in 24 hours (0.1, **) $L\downarrow = \int_0^{24} L\downarrow dt$
$L\uparrow$	lwup	W m^{-2}	Terrestrial irradiance, positive upward
$\hat{L}\uparrow$	lweup	MJ m^{-2}	Upward longwave energy received in 24 hours $L\uparrow = \int_0^{24} L\uparrow dt$
Q^*	netrad	W m^{-2}	Net irradiance (1, **, positive downward) $Q^* = K\downarrow + K\uparrow + L\downarrow + L\uparrow$
$\hat{Q}^*$	nete	W m^{-2}	24-hour net radiative energy received (0.1, **) $Q^* = \int_0^{24} Q^* dt$

Table 4. Symbols, Variable Names, Units, and Definitions (continued)

Part (f) Subsurface Measurements			
Symbol	**Variable Name**	**Units**	**Variable Definition**
T_s	stempn	˚C	Soil temperature (0.1, ±0.3)
χ_w	smoistn	%	Volumetric soil moisture content. For a given volume of soil, the volumetric soil moisture content is the percentage of that volume of soil that is water.
$\overline{\chi}_w$	avgsmoist	%	24-hour average soil moisture

Part (g) Fuel Moisture			
Symbol	**Variable Name**	**Units**	**Variable Definition**
W_{10}	fm10	%	10-hour fine-dead fuel moisture (1, when FM10 = 0 to 12%: 1.9%, when FM10 =12 to 30%: 3.6%, when FM10 > 30%: 16%). W_{10} is equal to the percent water (by weight) in a dead fuel of diameter < 1/4".
W_1	fm1	%	1-hour fine-dead fuel moisture, estimated from *fm10.* $W_1 = f(W_{10}, K\downarrow, T, h)$

Symbols given in the first column of Table 4 (a)–(g) are conventionally used in meteorological literature and are standard in program documentation. Symbols on the left side of the first column denote the primary variables, which are those obtained from an appropriately conditioned signal from an instrument's transducer. Indented symbols in the first column represent variables that are calculated, usually from the primary signal. In a few cases (e.g., dew-point temperature) these variables are calculated from multiple signals.

The second column shows the variable names used in locally developed data processing software. An *n* suffix, if present, denotes that measurements are made at multiple levels on the tower. The third column gives the units of measurement for the given variables. These are generally standard SI units although exceptions are found (e.g., millibars are used instead of Pascals for pressure).

The variables are defined in the fourth column. Unless otherwise noted, variables are based on a 15-minute sampling period. The integral means that the integrand has been integrated from 0000 to 2400 Mountain Standard Time (MST). Resolution of the archived data and estimated accuracy are given in parentheses. For example, (0.1, ±0.3˚C) means that the data are archived to the nearest 0.1˚C and the accuracy is estimated at ±0.3˚C. When the accuracy is undetermined, two asterisks (**) are inserted. Accuracy estimates are based on instrument accuracy as stated by the manufacturer, adjusted to reflect uncertainties in instrument alignment, exposure, and filtering and sampling effects, when appropriate.

Table 5 contains measurement level (*n*), measurement height above ground (*z*), and the set of variables measured every 15 minutes at each of the seven towers. Table 6 repeats Table 5 except for 24-hour data, and Tables 7 gives information on 15-minute and 24-hour surface and subsurface data.

Table 5. Meteorological Variables Measured (or Calculated) Every 15 Minutes at Height ***z***

Level	**z (m)**	**Wind**						**Atmospheric State**					**Precipitation**			**Radiative Energy Fluxes**				
n		u	σ_u	θ	σ_θ	w	σ_w	T	p	h	T_d	q	r	s_d	l	$K\downarrow$	$K\uparrow$	$L\downarrow$	$L\uparrow$	Q^*
										TA-6										
4	92.0	x	x	x	x	x	x	x												
3	46.0	x	x	x	x	x	x	x												
2	23.0	x	x	x	x	x	x	x												
1	11.5	x	x	x	x	x	x	x												
0	1.2							x	x	x	x	x	x	x	x	x	x	x	x	x
										TA-41										
2	23.0	x	x	x	x	x	x													
1	11.5	x	x	x	x	x	x	x												
0	1.2							x								x				
										TA-49										
3	46.0	x	x	x	x	x	x	x												
2	23.0	x	x	x	x	x	x	x												
1	11.5	x	x	x	x	x	x	x												
0	1.2							x		x	x		x			x				
										TA-53										
3	46.0	x	x	x	x	x	x	x												
2	23.0	x	x	x	x	x	x	x												
1	11.5	x	x	x	x	x	x	x												
0	1.2							x		x	x		x			x				
										TA-54										
3	46.0	x	x	x	x	x	x	x												
2	23.0	x	x	x	x	x	x	x												
1	11.5	x	x	x	x	x	x	x												
0	1.2							x	x	x	x	x	x			x	x	x	x	x
										PJMT										
1	36.6	x	x	x	x			x												
0	2.0							x	x	x	x		x	x						
										MDCN										
1	10.0	x	x	x	x	x	x	x												
0	1.2							x								x				

Table 6. Meteorological Variables Measured (or Calculated) Every 24 Hours at Height ***z***

Level ***n***	***z*** **(m)**	**Wind**			**Atmospheric State**								**Precipitation**			**Radiative Energy**				
		$\bar{u}$	u_{mx} θ_{mx} t_{mx}	u_{mx1} θ_{mx1} t_{mx1}	T_{mx} t_{mx}	T_{mn} t_{mn}	T_{mid}	p_{mx} p_{mn}	$\bar{h}$ h_{mx} h_{mn}	h_{mid}	$\bar{T}_d$ T_{dmx} T_{dmn}	$\bar{q}$	$\hat{r}$	$\hat{s}_f$ s_{mid}	$\hat{l}$	$\hat{K}\downarrow$	$\hat{K}\uparrow$	$\hat{L}\downarrow$	$\hat{L}\uparrow$	$\hat{Q}^*$
TA-6																				
4	92.0	x	x																	
3	46.0	x	x																	
2	23.0	x	x																	
1	11.5	x	x	x																
0	1.2				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
TA-41																				
2	23.0	x	x																	
1	11.5	x	x	x																
0	1.2				x	x										x				
TA-49																				
3	46.0	x	x																	
2	23.0	x	x																	
1	11.5	x	x	x																
0	1.2				x	x			x		x		x			x				
TA-53																				
3	46.0	x	x																	
2	23.0	x	x																	
1	11.5	x	x	x																
0	1.2				x	x			x		x		x			x				
TA-54																				
3	46.0	x	x																	
2	23.0	x	x																	
1	11.5	x	x	x																
0	1.2				x	x	x	x	x	x	x	x	x			x	x	x	x	x
PJMT																				
1	36.6	x	x	x																
0	2.0				x	x		x	x		x		x	x						
MDCN																				
1	10.0	x	x	x																
0	1.2				x	x										x				

Table 7. Surface and Subsurface Variables Measured (or Calculated) at Height or Depth ***z***

z (m)	χ_w	$\overline{\chi}_w$	T_s	W_{10}	W_1
TA-6					
0.30				x	x
-0.08					
-0.02			x		
-0.06			x		
-0.04	x	x			
-0.10			x		
-0.03 to -0.18	x	x			
TA-54					
0.30					
-0.08					
-0.02			x		
-0.06			x		
-0.04	x	x			
-0.10			x		
-0.03 to -0.18	x	x			

c. Sampling

The 15-minute sampling period recommended by the DOE "Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance" is used throughout the network. This period is long enough to give good estimates of mean quantities, yet short enough to provide adequate temporal resolution during periods of change for emergency response modeling.

The time associated with each datum is the ending time in MST of the standard 15-minute sampling period; for example, the datum for 1530 consists of averages or totals of data sampled from 3:15 until 3:30 in the afternoon. All maxima, minima, and other 24-hour summary values are based on the 0000–2400 MST period.

The sampling rate for most primary variables and their standard deviations is 0.33 hertz, or one sample every 3 seconds. This rate results in a 15-minute sample size of 300, which exceeds the ANSI standard of 180 samples during each 15-minute period. For the event-driven signals, such as precipitation and lightning, the 0.33-hertz sampling rate does not apply.

The sampling rate of the fuel moisture is one sample every minute for a total of 15 samples for every 15-minute period. This smaller sample rate is recommended by the manufacturer and is suitable because of the slow nature of change in the fuel moisture of a 10-hour fuel stick. The sampling rate for the subsurface measurements is one sample every 10 seconds.

Maxima and minima are generally based on data collected at the 0.33-hertz sampling rate. The exception is the 1-minute wind gust, which is based on non-overlapping 1-minute averages. The maximum instantaneous wind gust is actually a 1- to 2-second average gust because of the instrument's limited response. Slow instrument response also affects the extremes of temperature, pressure, and relative humidity.

2. Data Management

a. Description

The data management component of the program controls the processing of the meteorological data, from its measurement to its archiving and the automatic construction of graphics and tables. These end products are then made available to various applications and services, such as software for hazardous release modeling (NARAC, MIDAS, and others) or the program's website (called the Weather Machine).

The data management objectives are to (1) maintain a secure, high-quality data archive and (2) deliver data, statistical summaries, graphics, special data sets, and other weather products to a large customer base as efficiently as possible. A significant portion of the program's resources has been devoted to fulfilling these objectives, including a substantial investment in personnel, hardware and software, and maintenance contracts.

Standards for data management follow guidance when applicable, such as in the calculation of turbulence quantities and wind vector quantities (EPA 1987), stability categories (EPA 1978), and the formatting of model input files (EPA 1987). General guidance on data management by ANSI (2005) is also followed.

Improvements in the data management component during the mid 1990s have increased the program's visibility, improved accessibility to the data for customers, increased usage of the data, and increased the overall efficiency of the program. Significant changes include the establishment of a website (the Weather Machine) in 1993, the development of a local binary data archive and software to move data to and from this archive (1995), the creation of a common gateway interface (CGI) feature for the Weather Machine for distributing data (1996), and the addition of several graphics packages for such products as wind roses, annual summaries, and monthly summaries (1996 and 1997).

b. Hardware and Software

The program operates one Hewlett-Packard (HP) workstations, one x-terminal connected to the workstations, a host of Campbell Scientific, Inc. (CSI) data loggers, and accompanying peripherals such as printers, external disks, and additional IBM and Macintosh PCs. Figure 2 shows these hardware components and the associated linkages.

The program relies on several software packages, primarily in Hewlett-Packard's UNIX operating system, HP-UX (Version B.11.00). Below is a list of the software tools used by the program:

- **Cron** is a UNIX utility that runs many of the automatic processes.
- **Shell scripts** consist of a series of UNIX commands. Shell scripts are run by cron and control all routine, periodic data processing by calling C language executables and PV-Wave executables.
- **C** language executables convert datalogger data to binary data, allow access to binary data, perform data requests from the Web server, and construct model input data files.
- **PV-Wave** is a programming language designed for visual data analysis. PV-Wave generates all routine graphical displays for the Weather Machine and is used by the program staff to perform data analysis.

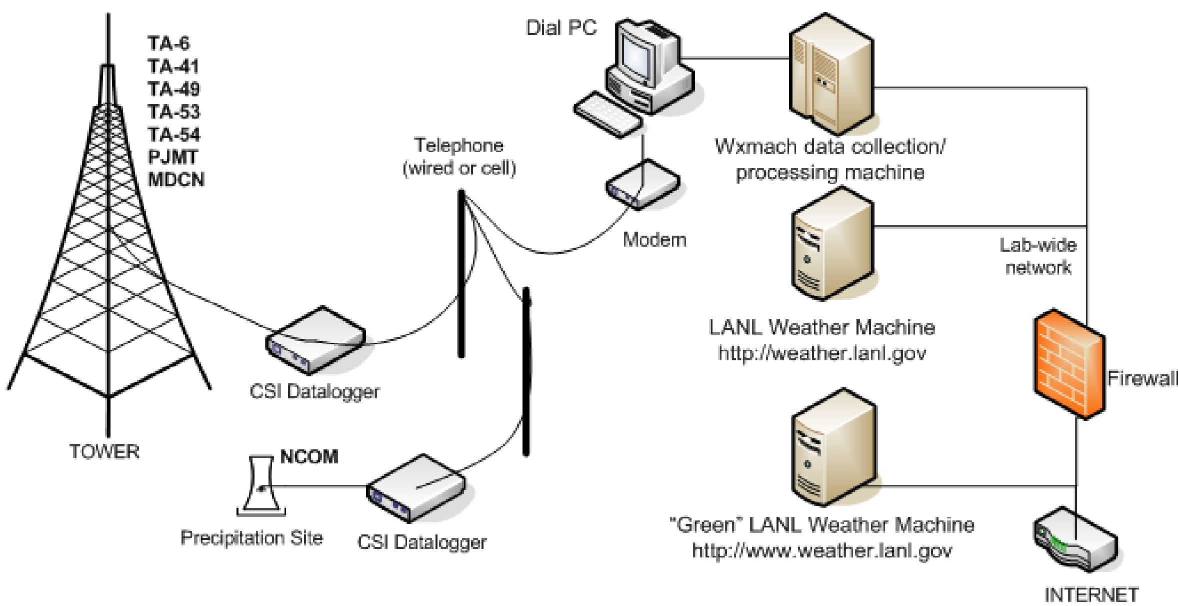

Figure 2. Main hardware components used in acquiring and processing meteorological data.

- **Perl** is a text processing language used in CGI applications. Perl scripts serve hypertext markup language (HTML) forms in Web browsers and pass information to and from clients. Perl is used by the program to manage raw data request forms and model input request forms on the Weather Machine, along with other functions requiring text processing.
- **ASP** is scripting technology that can be used to create dynamic and interactive web applications. ASP is used on the weather machine web page to parse and generate content both from local and remote data sources. ASP is used to parse and deliver content generated from perl scripts through data requests. ASP is also used to parse and deliver content from remote data sources such as NOAA.
- **Microsoft IIS and Apache** is the Web server software used to run the Weather Machine.

- **Campbell Scientific Datalogger programming language** is used by dataloggers to control sampling, perform signal conditioning, and carry out initial processing (such as the computation of means, variances, and daily totals).
- **PC208W** software communicates with the Campbell Scientific, Inc. data loggers. PC208W only runs in a PC environment. PC208W has a built in scheduler that performs all the dial-up and data collection from the weather towers.

c. Routine Data Acquisition and Processing

In 1996, the binary data format replaced the 80-column textual format as the primary form of data archive. All routinely processed data are placed into binary formatted files for storage. Other special, non-routine data sets are also formatted into binary files when possible.

The data record for each station consists of a series of annual binary files and a 90-day circular binary file for the 15-minute data; similarly, the 24-hour data are stored in annual files and a 90-day circular file. Data in the circular files are checked weekly for quality and then are moved over to the annual files. Thus the annual files contain only data that have been thoroughly checked and edited. Both circular and archive files are accessible through the CGI interface on the Weather Machine or through the PV-Wave custom application programming interface (API).

Data acquisition and processing operations are performed at regular intervals on several different time cycles. Below is a simple outline of these operations. All operations in the outline are automated except for the weekly, monthly, and annual tasks, which are performed manually.

1. On a 15-minute cycle,
   - The dial PC running PC208W, calls the data loggers (except Pajarito Mountain), and transfers the latest data from the data loggers to the HP workstation, Midas PC , and EOCPC;
   - Then a script runs that converts data logger files to UNIX files;
   - Then a C language is executed that reads the UNIX files, compares the data with expected ranges, and writes the data to binary circular files (data values falling outside predetermined ranges are entered with a standard “bad” value indicator, usually denoted by an asterisk [*] upon output);
   - Then scripts run PV-Wave executables that read the binary circular files and update graphical and tabular summaries of current conditions; and
   - Then a script runs a C language executable that uses the binary files to feed data to the Meteorological Information and Dispersion Assessment System (MIDAS) (see Section 4).

2. On an hourly cycle the same operations for the 15-minute cycle are performed when calling the cellular phone at the Pajarito Mountain station. The Pajarito Mountain station is called hourly, but a special utility can be invoked to call the Pajarito Mountain station every 15 minutes during emergency situations.

3. On a 24-hour cycle, cron (on the HP workstation)
    - calls a script that runs PV-Wave executables that generate tabular and graphical summaries for the previous day; and
    - runs a script that sends email to the program staff concerning the status of data collection and range checking for the previous day.

4. Weekly,
    - data collected during the previous week are reviewed;
    - the circular files are edited; and
    - edited circular file data are moved to their respective current annual files.

5. Monthly,
    - a PV-Wave executable is run to summarize the previous month's weather; and
    - a PV-Wave executable is run to update the daily and monthly extremes table.

6. In January, PV-Wave executables are run that construct an annual weather summary and wind rose plots for the previous year (for the Laboratory's Environmental Surveillance Report). This is done manually.

In addition to processing data from the local meteorological network, program software

- automatically retrieves meteorological data from other websites;
- analyzes the system status and log files;
- automatically handles raw data requests and model input data requests to the Weather Machine; and
- sends automatic email weather forecasts to a list of clients.

Figure 3 shows the locally constructed software components that control flow from the original raw data measurements to the final products. MDM.out, a C executable, controls flow to and from binary files and supports data requests to the Weather Machine. MS.out and STAR.out handle model input data requests. PV-Wave is used for producing routine summaries and graphics, as well as for special analyses.

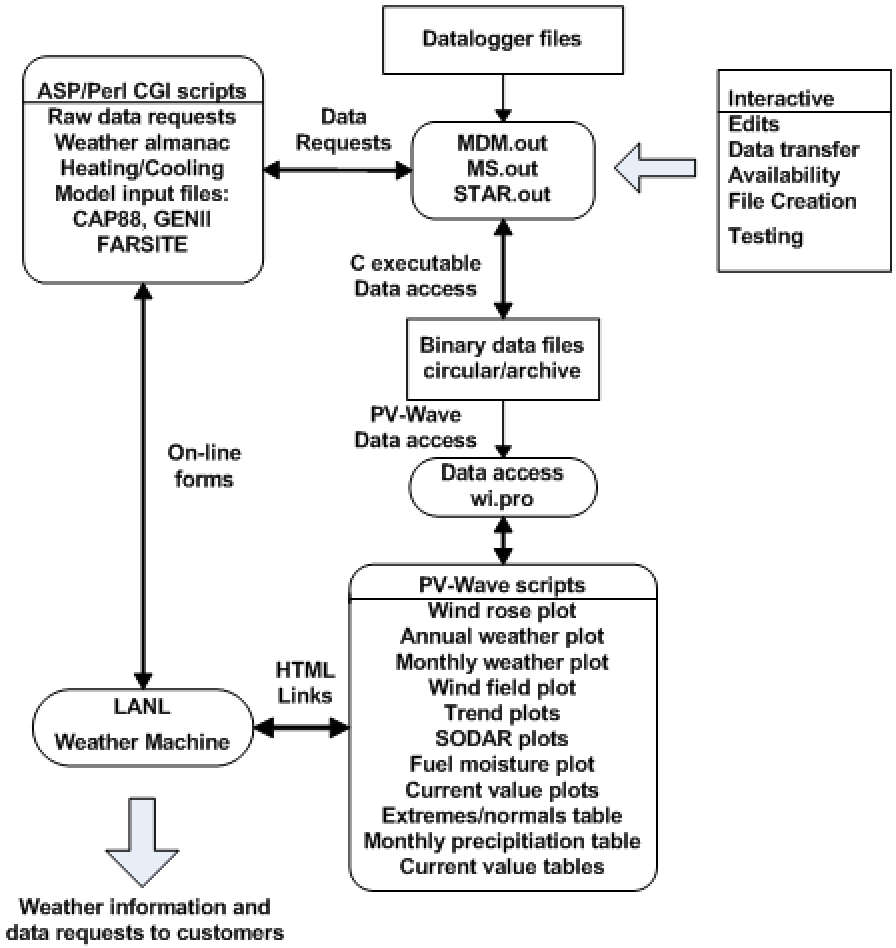

Figure 3. Main software components that control the flow of raw data from raw data files to the formatted products.

3. Data Analysis and Forecasting

Some program customers require more than access to raw meteorological data or standard summaries. Interpretation of raw data, computation of special quantities, or even measurement of special meteorological variables may be requested. The data analysis component of the program serves to fill this need.

Extensive analysis of the early tower data was conducted by Bowen in the mid-to-late 1980s, culminating in the document "Los Alamos Climatology" (Bowen 1990). Shortages in staffing led to a lull in analysis until the mid 1990s, when analysis again was feasible due to the addition of a staff member and improvements in data management. During this time many memorandums, reports, and draft reports were completed that aided in the understanding of the local meteorology of the Los Alamos area. A bibliography of local meteorological analysis studies made during that period can be found in a memorandum by Stone and Baars (1998). Other investigative studies by members of the meteorology program include Baars (1997), Bowen et al. (2000), Johnson and Balice (2006), and Stone (1998).

Weather forecasting is another type of analysis performed by the program. Forecasts are used primarily in the winter when snow storms affect construction projects, road crew scheduling, school busing, and airport operations. Forecasts of lightning are commonly requested during the summer. Forecasts support emergency response operations, explosives testing, and many other laboratory activities (even VIP visits). General forecast information is available on the Weather Machine. When a call or email is received requesting a weather forecasts or when inclement weather threatens, a frequent occurrence during winter, program staff develops their own forecasts. This is most frequent during winter, but also happens quite often during fair weather in support of, for example, explosives detonations.

4. Modeling

One of the primary purposes of conducting meteorological monitoring at DOE sites is to maintain a plume modeling capability in support of emergency planning and response. For many years the program provided this service using simple, straight-line Gaussian plume models. These models were deemed inadequate because they did not account for the Laboratory's complex terrain, multiple facilities, and numerous hazardous materials. Furthermore, the models did not take advantage of real-time meteorological data or provide a map-based, plume contour plot.

In 1993, the program purchased MIDAS (Meteorological Information and Dispersion Assessment System) to improve hazardous release dispersion modeling capabilities and to bring the Laboratory into compliance with DOE Order 5500.3A (DOE 1992). The model, developed by ABSG Consulting, Inc., calculates air concentrations and human dosages of hazardous materials released to the atmosphere. The rationale for choosing MIDAS over other available models at the time is given in Stone and Dewart (1992). In 2001, a new version of MIDAS was released that incorporates assessment of chemical and biological weapons releases.

DOE Order 151.1C (DOE 2005) mandates that the emergency plume modeling capability of NARAC (National Atmospheric Release Advisory Center) be used as a source of consequence assessment information at DOE facilities. NARAC is located at Lawrence Livermore National Laboratory (LLNL) in Livermore, CA. Thus, in 2006 we began using NARAC as well as MIDAS when modeling airborne releases.

Weather data including wind speed and direction, temperature, humidity, precipitation, and stability class are ftp'd to LANL's Emergency Operations Center and LLNL every 15 minutes. In this way, weather data current for LANL are always available when plume modeling becomes necessary.

The NARAC and MIDAS models can be run simultaneously from the Emergency Operations Center to provide advanced and redundant assessments during emergencies. When appropriate, relatively fast and simple models including EPIcode, ALOHA, and HOTSPOT are also utilized. These models are straight-line Gaussian plume models which do not take the complex terrain of LANL into account, and weather data must be manually entered.

Extensive studies have been performed on models similar to MIDAS. One such study for surface releases in complex terrain was performed in 1980 and 1981 during the atmospheric studies in complex terrain (ASCOT) study (Dickerson and Gudiksen 1984). When comparing the model results with actual measurements, the study found that model-predicted concentrations were within a factor of five 50% of the time and within a factor of 10 about 60% of the time. In our comparisons of MIDAS to straight-line Gaussian calculations and to field observations, MIDAS generally predicts impacts that exceed the Gaussian and observed doses and concentrations (Johnson 2004).

5. Data Accessibility

The program's website—the Weather Machine (http://weather.lanl.gov)—was established in 1993 as a means of distributing the tables and plots already in use for quality assurance and for emergency response applications. The Weather Machine has now developed into a useful tool for servicing routine data requests, providing information to the local weather-curious, promoting positive public relations, and making an extensive meteorological dataset more accessible.

The Weather Machine provides a variety of meteorological data, including local weather information, weather forecast products, regional and national weather information, and local climatological data. On-line documentation is accessible, making the Weather Machine a stand-alone meteorological service.

Also included in the Weather Machine are data request forms that provide access to the raw data archive and model input files for some of the frequently used atmospheric dispersion and dose assessment models (CAP88 and GENII). The actual data request forms are in an HTML format, and the data can be downloaded directly into a spreadsheet. The request forms are constructed according to data availability and user-specified information.

The users of the Weather Machine consist of internal Laboratory employees, DOE laboratories, universities, and the public sector. Internal Lab users are able to access the site's contents freely; however, the introduction of a firewall in 2000 between the Lab-wide network and publicly accessible Internet has restricted public availability of the Weather Machine. As a result, public data requests are typically serviced by phone and email communication.

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