7. METEOROLOGY

D.G. Fox, H.C. Humphries, K.F. Zeller, B.H. Connell, and G.L. Wooldridge
Rocky Mountain Forest and Range Experiment Station
Fort Collins, Colorado

GLEES is contained within the Snowy Range Observatory. This Observatory consists of many weather stations, precipitation monitors, and stream gages scattered throughout the Snowy Range. These sites have been operated by the Wyoming Water Research Center (WWRC) since 1968. Data from the sites are available from the WWRC and were last summarized by Wesche (1982).

While this long-term record of meteorological information is useful to set the control for GLEES, it is insufficient to characterize meteorological influences on the site. The ecosystems of GLEES are driven by radiation inputs, precipitation inputs, and chemical inputs that are strongly controlled by wind and temperature distributions across the site. Both macro and micro influences of these meteorological quantities are obvious on GLEES. In order to measure representative atmospheric inputs to GLEES, it is necessary to combine a detailed measurement program along with physically based models to expand the spatial detail of the measurements. At this writing, all the techniques to accomplish this are not available. Rather, one objective of the GLEES research will be the refinement of modeling techniques, as well as verification of these techniques using GLEES data.

In this chapter we describe the general climate of GLEES; the atmospheric measurement program and its results through February 1989; and a wind model that has been used to generate a detailed wind pattern over the site.

General Climate

Historical data from the Snowy Range Observatory meteorological stations have been summarized by Wesche (1982). It indicates that mean winter minimum temperatures at Little Brooklyn Lake (fig. 1.3) range from −23°C to −1°C over the years of record. Summer temperatures exhibit means as low as −7°C to a high of 21°C. Freezing temperatures can occur at any time throughout the year, although they are not common in July and August.

Precipitation occurs mostly as snow that can occur anytime during the year, although accumulations are not common in July and August. Summer precipitation occurs primarily as thunderstorms that are common in afternoons. Precipitation measurements at GLEES have been made since 1976, as noted in table 7.1. These measurements are made with Wyoming-shielded collectors, which are standard weighing rain gages surrounded by concentric rings of netting to reduce the deleterious wind effects. Studies have shown that these shields allow collection of approximately 60% of the actual precipitation deposited under the high winds that are common at GLEES (Goodison and Metcalfe 1982).

Winds are very strong and consistent at GLEES as evidenced by the presence of flagged trees and krummholz patterns (see Chapter 2). Wooldridge et al. (1993) used these trees to determine surface wind distributions over the watershed. The Snowy Range Observatory wind measurements are not representative of GLEES because the nearest site is located in a forest canopy in the vicinity of Brooklyn Lakes.

Table 7.1.—Precipitation at the Snowy Range Observatory, Glacier Lakes precipitation collector. Data provided courtesy of University of Wyoming, Wyoming Water Research Center.

	Total monthly precipitation, inches of water											
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1976								2.21	0.41	1.55	0.74*	1.89*
1977	1.60*	1.18*	0.77*	2.66*	3.58	0.08	2.54	2.46	0.81	1.34*	1.84*	4.22*
1978	1.29	0.78	2.30	nd	nd	nd	nd	nd	0.00*	1.62	0.92*	nd
1979	0.34*	2.74*	1.79*	2.15*	1.89*	1.58	0.74	4.23	0.91	2.55	5.47	3.41
1980	8.11*	5.77*	7.38	5.48	4.75	0.20	1.13	1.61	2.28	2.97	1.72	2.26
1981	2.33	4.88	4.01	3.02	7.23	0.73	2.04	1.41	1.23	3.60	3.03	7.40*
1982	1.83*	2.81	8.80	3.80*	4.59	2.22	3.16	1.63	3.73	3.71	4.57	5.68
1983	6.38	5.19	9.60	4.70	2.96	3.24	1.91	0.61	0.40	2.25	7.00	7.01
1984	1.87	1.76	3.64	3.34	1.79	1.19	5.20	3.53*	2.76	2.96	4.96	6.30
1985	3.85	2.51	5.69	5.51	2.25	1.27	2.49	0.72	3.22	3.17	9.16	6.24
1986	4.25	7.88	3.35	5.10	2.20	3.72	1.81	1.09	2.53	3.40	3.53	0.36
1987	2.34	1.46	2.24	1.16	2.87	2.27	4.17	1.98	0.46	2.15	2.12*	3.88
1988	6.23	3.58	6.26	1.91	3.69	0.96	0.83	0.84	2.00	0.69	5.15	3.00
1989	2.84	3.99	3.84	2.74								

nd — no data available.
** — includes periods with missing data.*

GLEES Atmospheric Measurements

Meteorological measurements are currently made at the following sites at GLEES:

Brooklyn Lakes meteorological tower (fig. 1.3)

Glacier Lakes meteorological tower (fig. 1.3)

NADP site (fig. 1.3)

Table 7.2 lists the parameters measured at the Glacier Lakes and Brooklyn Lakes sites. At the NADP site, precipitation and net radiation are recorded year round, while wind run and direction and pan evaporation are recorded at ground level during the growing season.

A National Dry Deposition Network (NDDN) monitoring site was established near the Centennial Work Center (fig. 1.2) in 1989, and moved to a site near the Brooklyn meteorological tower in 1991. This site includes a 10 m tower with meteorological and air quality measurements (table 7.3) and filter pack for SO_2, SO_4, NO_3, NO_x, and HNO_3.

Figures 7.1–7.3 present monthly summaries of the data from Glacier Lakes tower for January, March, and August of 1991. The presentation illustrates monthly trends in all parameters. Figures 7.4–7.9 present the same information from the Brooklyn Lakes site. Temperature and winds are measured at 10 m and 30 m heights. Meteorological data are available in the PARADOX database for all months since installation of the systems in 1987.

Table 7.2.—Meteorological monitoring measurements at GLEES.

Sensor:	Temperature	Relative humidity	Wind speed	Wind direction	Pyra	Precip	Wet/dry	Ozone*
Type:	Thermistor	Carbon resistance	Switch	Potentiometer	Silicon photodiode	Weighing	Conductivity	Photometric
Dimensions:	°C	%	m/sec	degrees	watt/m²	mm	% of time	
Manufacturer:	Fenwal Electronics	Phy-Chem Scientific	MetOne	MetOne	LiCor	Belfort	Campbell Scientific	Thermo Electron
Model:	UUT51J1	PCRC-11	013	023	LI-200s	500mm	231	49
Calibration Schedule:	Biweekly	Biyearly	Biyearly	Biyearly	2 Years	Random	None	Daily
Calibration Method:	Vaisala	Salts	Wind Tunnel	Ohm Meter	Epply	Weights	Unit Gen.	
Sensor Height Glacier Lakes+	20 m	20 m	20 m	20 m	20 m	2 m	10 m	
Brooklyn Lake# Upper/Lower:	10 m/30 m	10 m/30 m	10 m/30 m	10 m/30 m	30 m	2 m	11 m	3 m

** Ozone monitored only at Brooklyn Lake.*
+ Glacier Lakes site elevation 3286 m.
 # Brooklyn Lake site elevation 3182 m.

Table 7.3.—Measurement specifications from ESE, operator of the NDDN (1987).

Measurement	Averaging time	Sampling frequency	Measurement method	Nominal lower quantifiable limit	Manufacturer's precision
Ozone	1 hr	24 hr/day	Ultraviolet photometric	2 ppb	±2 ppb
Windspeed	1 hr	24 hr/day	3-cup anemometer	0.22 m/sec threshold	±0.07 m/sec or ±1%
Wind direction	1 hr	24 hr/day	Wind vane threshold	0.22 m/sec	±2°
Temperature at two levels, (T)	1 hr	24 hr/day	Thermistor in motor-aspirated shield	NA	±0.1°C
Dewpoint	1 hr	24 hr/day	Lithium chloride dew cell	NA	±0.5°C
Solar radiation	1 hr	24 hr/day	Photovoltaic pyranometer	NA	±5% max
Precipitation	1 hr	24 hr/day	Rain gage, weighing type	0.25 mm	±0.25 mm
Wet deposition	1 week	1/week	Wet-dry sampler		
pH			pH electrode	NA	±0.1 pH
volume			Balance	1 cm³ (1 g)	±1 cm³ (±1 g)
Conductivity			Conductivity electrode	1 umho/cm	±2%

Note: ° = degrees; hr/day = hours per day; °C = degrees Celsius; mm = millimeter; cm³ = cubic centimeter; m/sec = meters per second; g = gram; ppb = parts per billion; hr = hour; umho/cm = micromhos per centimeter.

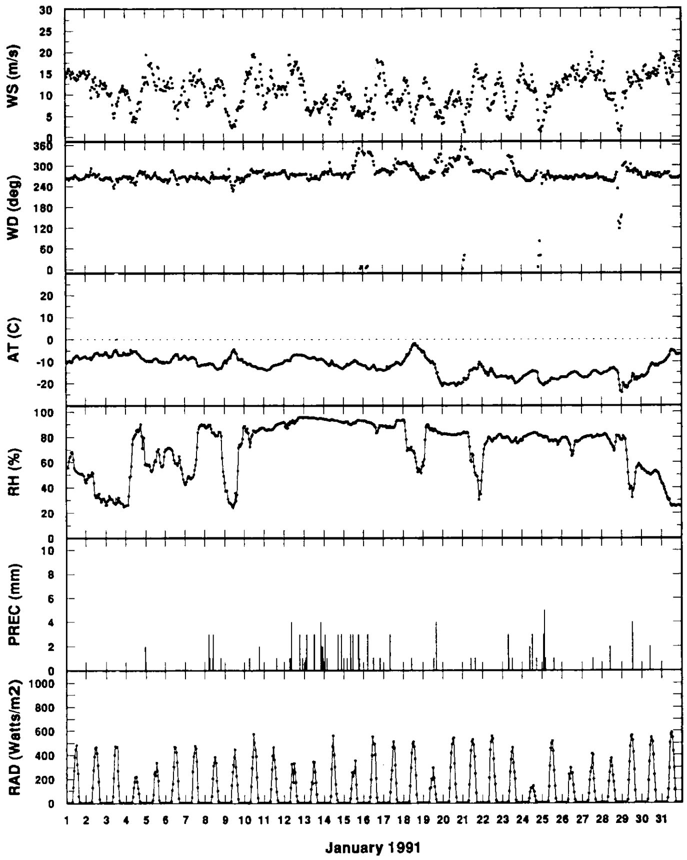

Figure 7.1.—Meteorological time plot, Glacier Lakes, January 1991, where PREC = precipitation, WS = wind speed, WD = wind direction, AT = air temperature

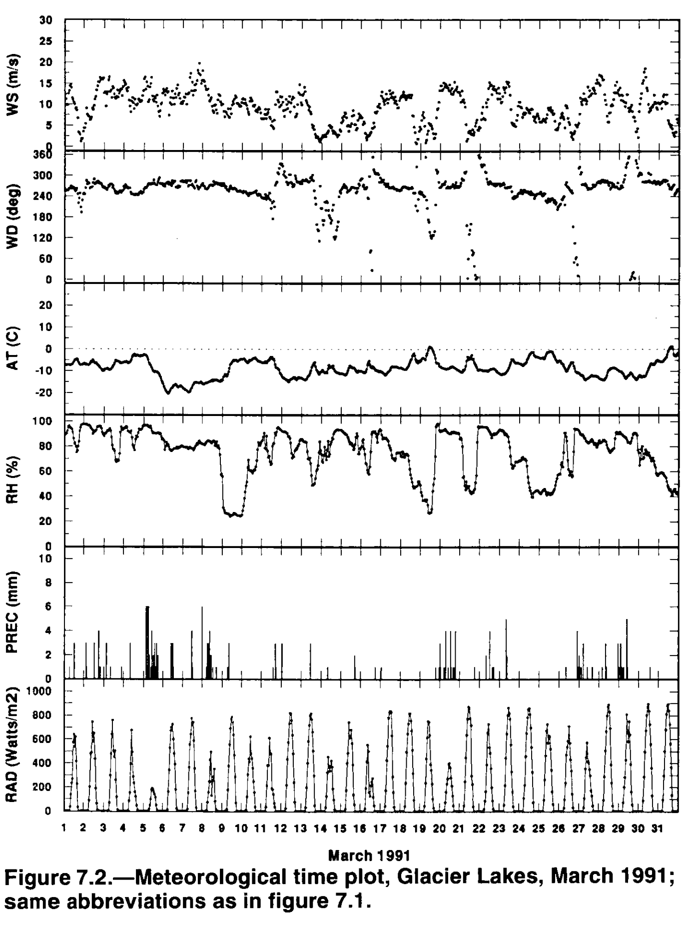

Figure 7.2.—Meteorological time plot, Glacier Lakes, March 1991; same abbreviations as in figure 7.1.

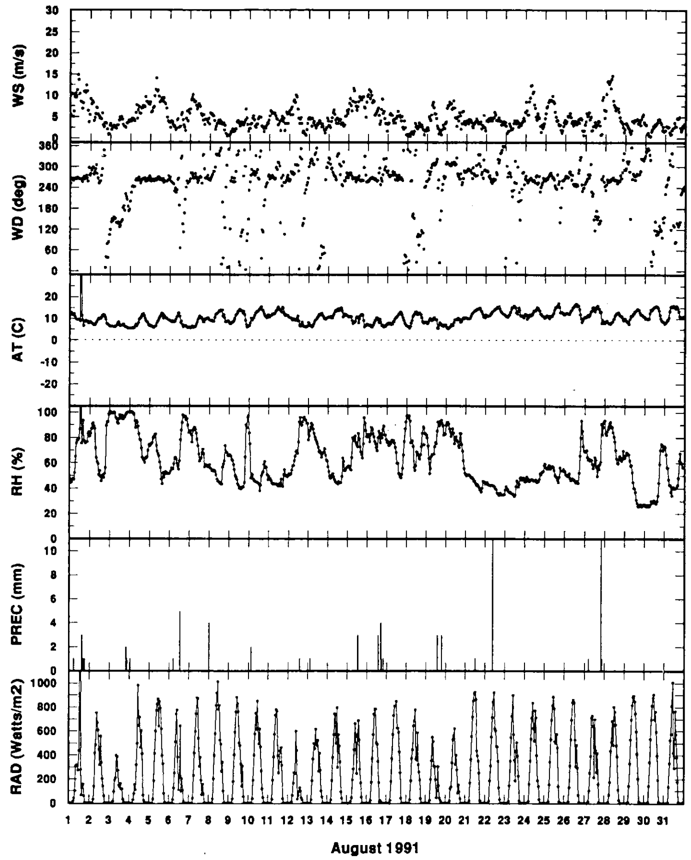

Figure 7.3.—Meteorological time plot, Glacier Lakes, August 1991; same abbreviations as in figure 7.1.

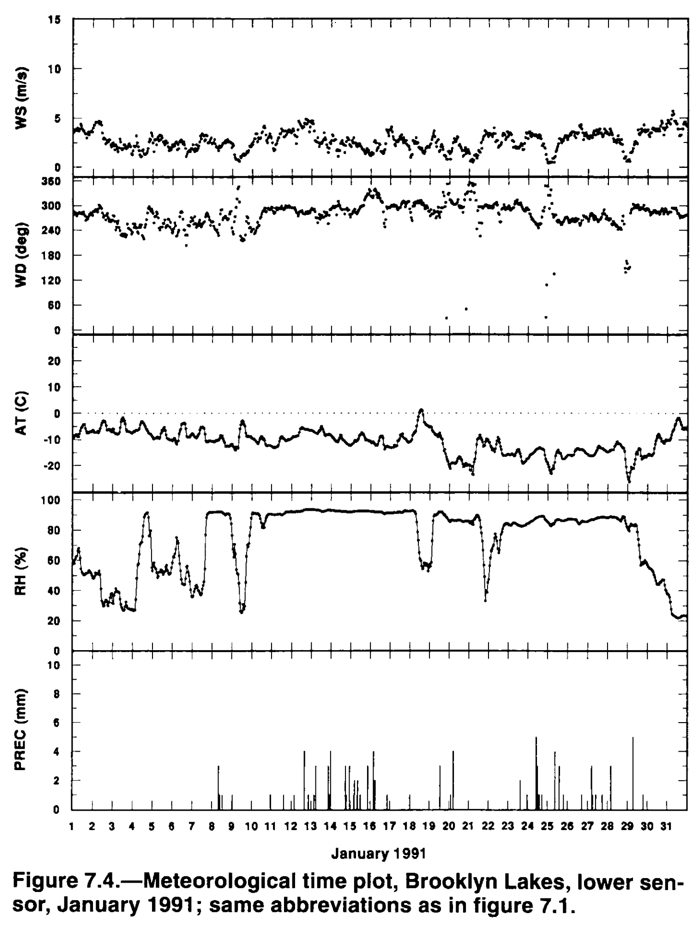

Figure 7.4.—Meteorological time plot, Brooklyn Lakes, lower sensor, January 1991; same abbreviations as in figure 7.1.

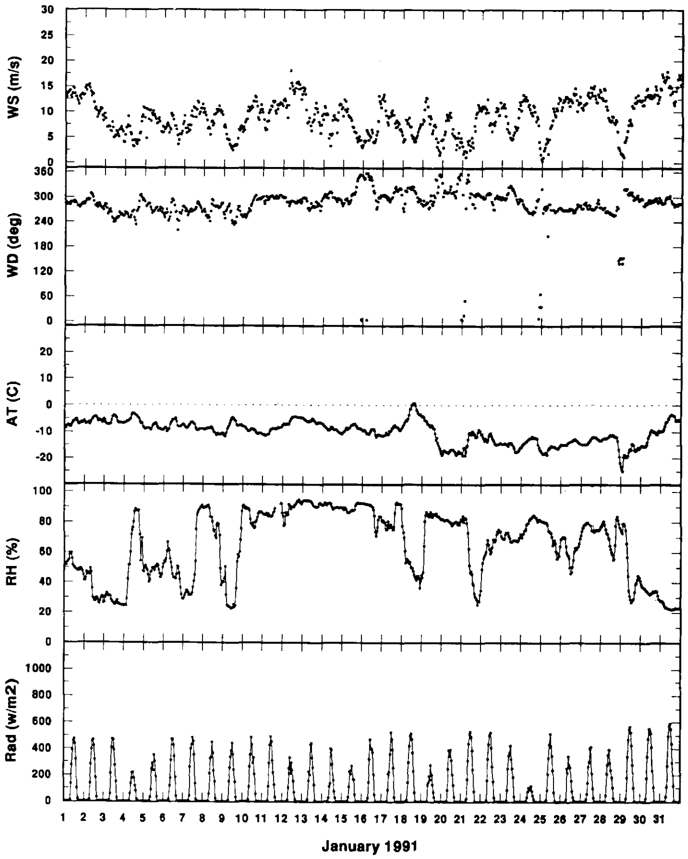

Figure 7.5.—Meteorological time plot, Brooklyn Lakes, upper sensor, January 1991; same abbreviations as in figure 7.1.

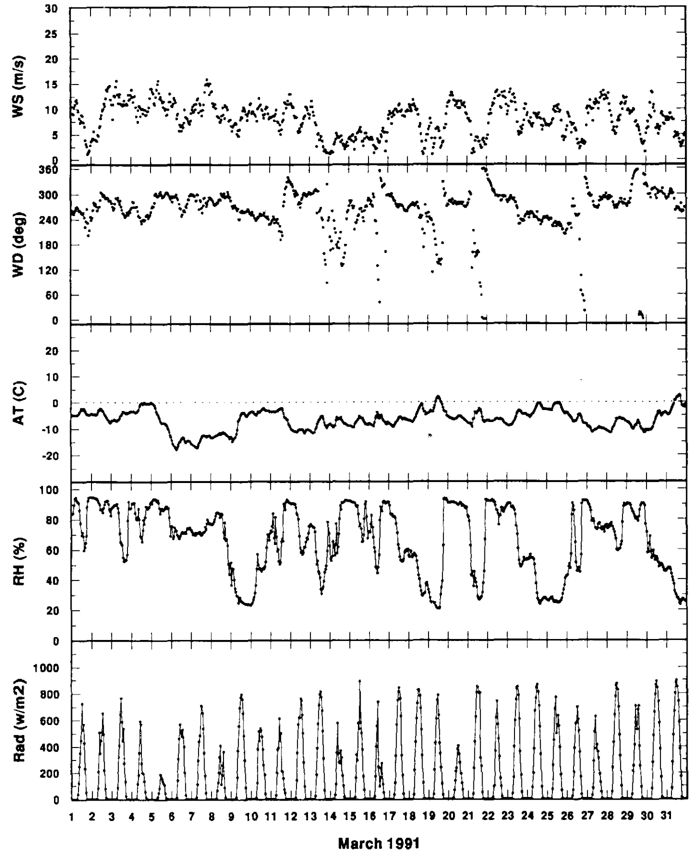

Figure 7.7.—Meteorological time plot, Brooklyn Lakes, upper sensor, March 1991; same abbreviations as in figure 7.1.

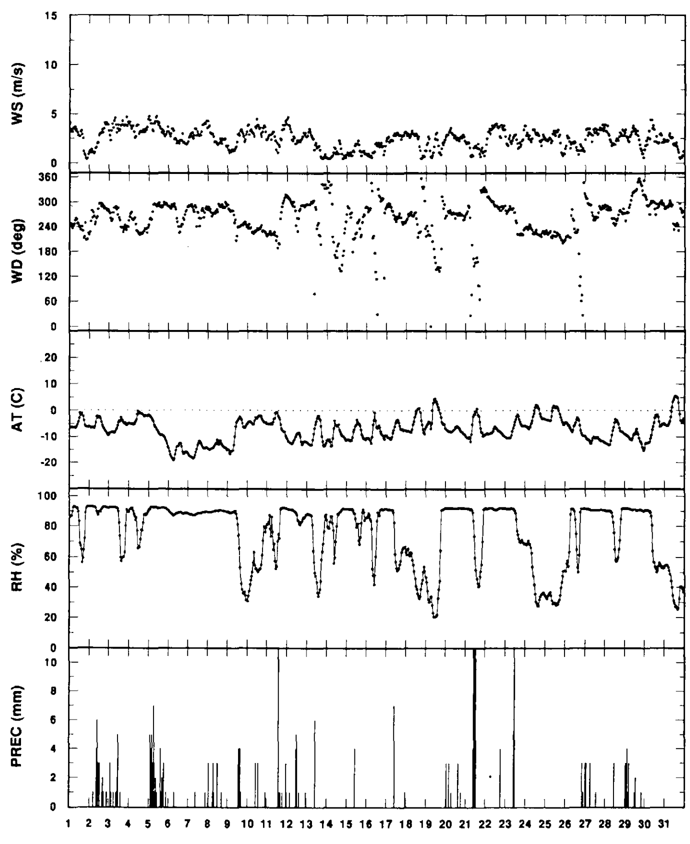

Figure 7.6.—Meteorological time plot, Brooklyn Lakes, lower sensor, March 1991; same abbreviations as in figure 7.1.

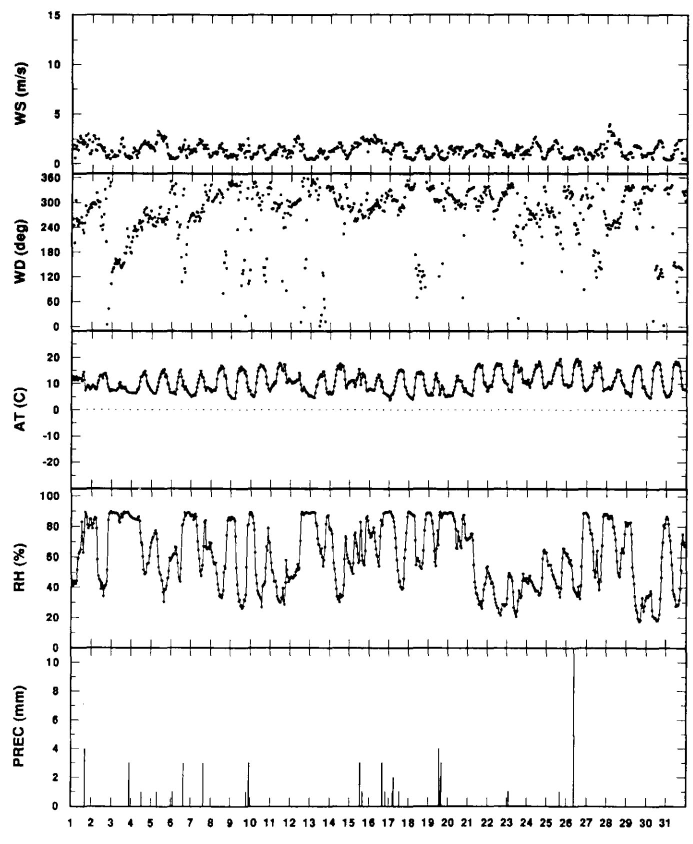

Figure 7.8.—Meteorological time plot, Brooklyn Lakes, lower sensor, August 1991; same abbreviations as in figure 7.1.

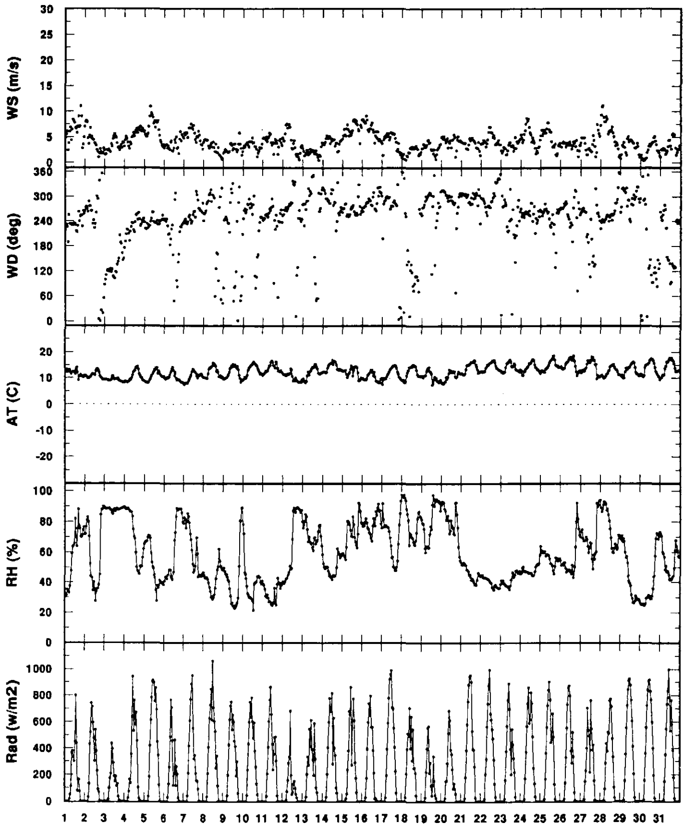

Figure 7.9.—Meteorological time plot, Brooklyn Lakes, upper sensor, August 1991; same abbreviations as in figure 7.1.

Modeling

Even a casual observer at GLEES is struck by the complexity of the wind distribution that directly affects vegetation growth (as evidenced by flagging and lack of regeneration on exposed locations) and indirectly affects the vegetation mosaic through snow distribution.

Since it is impossible to measure all microscale variation, we used a wind model to simulate distributions. NUATMOS is a three-dimensional diagnostic wind model (Ross et al. 1988) and is part of the TAPAS group of models (Fox et al. 1987). NUATMOS requires detailed input information to accurately depict the winds in complex terrain (Connell 1988). In order to provide such detailed input, free-flying constant volume balloons were released at GLEES and tracked by dual theodolites. Figure 7.10 displays an example of the sounding resulting from a balloon release on September 17, 1987. Using such input data, wind distributions for GLEES and the surrounding area were calculated. Figure 7.11 presents an example of results from this model. A vertical cross-section through the field as illustrated in figure 7.11 is shown in figure 7.12. These calculated wind patterns provide an opportunity to study micrometeorological influences on GLEES in detail.

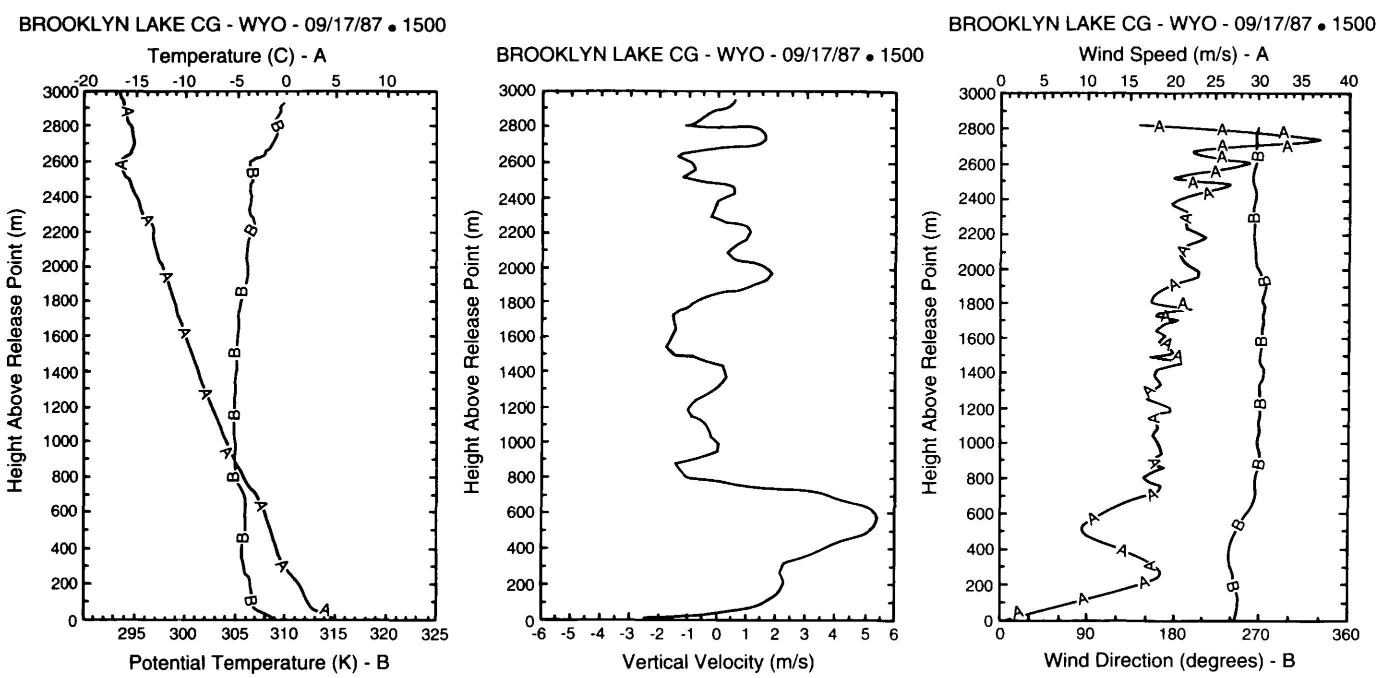

Figure 7.10.—Vertical profile data at Brooklyn Lake campground from sounding on September 17, 1987, at 1500 hours.

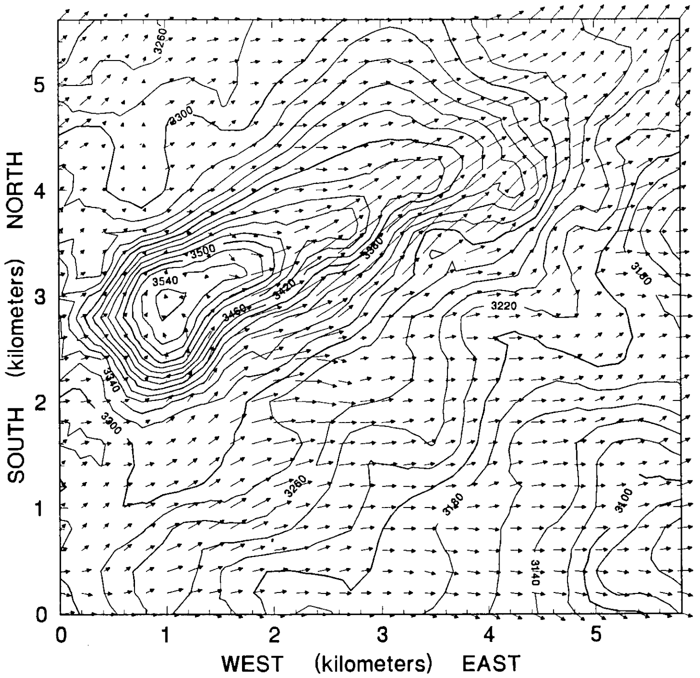

Figure 7.11.—Model output of wind distribution at GLEES and vicinity.

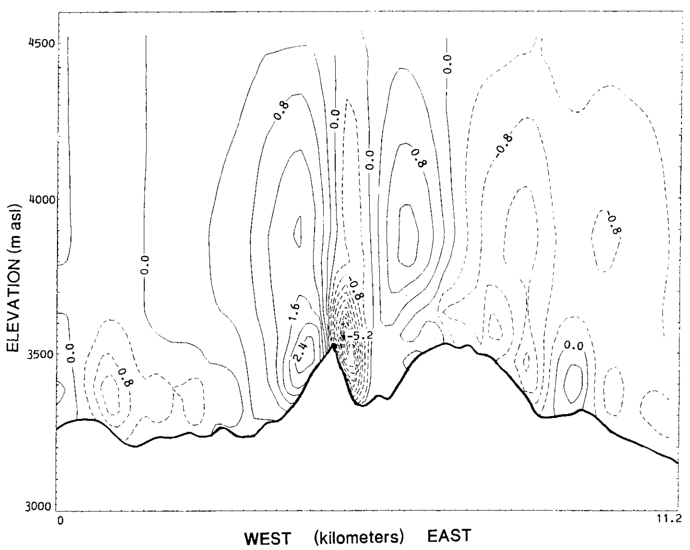

Figure 7.12.—Contours of vertical velocity (cross section through y=34). Solid lines denote positive values; dashed lines denote negative values. Contour increment = 0.4m/s.

References

Connell, B.H. 1988. Evaluation of a 3-D diagnostic wind model: NUATMOS. Fort Collins, CO: Colorado State University. 135 p. M.S. thesis.

Environmental Science and Engineering, Inc. 1987. NDDN measurement specifications. NDDN operating manual.

Fox, D.G.; Ross, D.G.; Dietrich, D.L.; Mussard, D.E.; Riebau, A. 1987. An update on TAPAS and its model components. In: Proceedings of the ninth conference on fire and forest management; 1987 April 21–24; San Diego, CA. Boston: American Meteorological Society: 1–6.

Goodison, B.E.; Metcalfe, J.R. 1982. Canadian snow gauge experiment, recent results. In: Proceedings of the Western Snow Conference: 1982 April 20–23; Reno, NV: 192–195.

Ross, D.G.; Smith, I.N.; Manins, P.C.; Fox, D.G. 1988. Diagnostic wind field modeling for complex terrain: Model development and testing. Journal of Applied Meteorology. 27: 785–796.

Wesche, T.A. 1982. The snowy range observatory: An update and review. Water Resources Series Report 81. Laramie, WY: University of Wyoming, Water Resources Research Institute. 310 p.

Wooldridge, G.I.; Musselman, R.C.; Sommerfeld, R.A.; Fox, D.G.; Connell, B.H. 1993. Mean wind patterns and snow depths in an alpine-subalpine ecosystem as measured by damage to coniferous trees. [Manuscript in preparation].