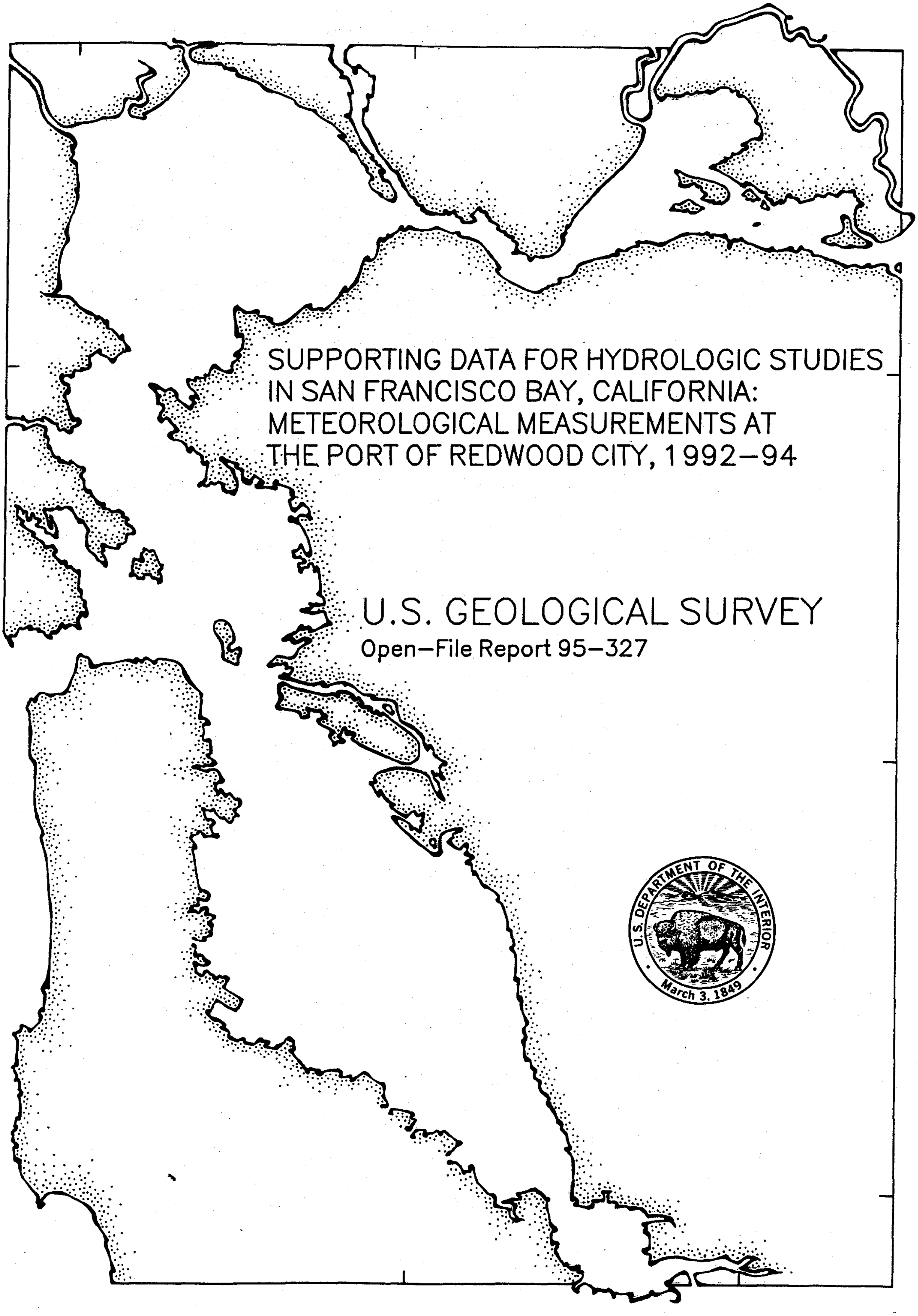

SUPPORTING DATA FOR HYDROLOGIC STUDIES IN SAN FRANCISCO BAY, CALIFORNIA: METEOROLOGICAL MEASUREMENTS AT THE PORT OF REDWOOD CITY, 1992–94

U.S. GEOLOGICAL SURVEY

Open–File Report 95–327

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By Laurence E. Schemel

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CONVERSION FACTORS

Metric and inch-pound units are used in this report. Conversion factors to other commonly used units are provided below for the measurements made in this study.

Multiply	By	To obtain
statute miles per hour	0.447	meters per second
Millibars	0.0295	inches of mercury
Millibars	0.0145	pounds per square inch

Temperature is given in degrees Celsius (°C) and can be converted to degrees Fahrenheit (°F) using the following equation:

$$(°F) = 1.80\ (°C) + 32$$

The use of brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

SUPPORTING DATA FOR HYDROLOGIC STUDIES IN SAN FRANCISCO BAY, CALIFORNIA: METEOROLOGICAL MEASUREMENTS AT THE PORT OF REDWOOD CITY DURING 1992-94

By Laurence E. Schemel

ABSTRACT

Meteorological data were collected during 1992-94 at the Fort of Redwood City, California, to support hydrologic studies in southern San Francisco Bay. The meteorological variables that were measured were air temperature, atmospheric pressure, quantum flux (insulation), and four parameters of wind speed and direction: scalar mean horizontal wind speed, (vector) resultant horizontal wind speed, resultant wind direction, and standard deviation of the wind direction. Hourly mean values based on measurements at five-minute intervals were logged at the site, then transferred to a portable computer monthly. Daily mean values were computed for temperature, insulation, pressure, and scalar wind speed. Hourlymean and daily-mean values are presented in time-series plots and daily variability arid seasonal and annual cycles are described. All data are provided in ASCII files on an IBM-formatted disk.

Observations of temperature and wind speed at the Port of Redwood City were compared with measurements made at the San Francisco International Airport. Most daily mean values for temperature agreed within one- to two-tenths of a degree Celsius between the two locations. Daily mean wind speeds at the Port of Redwood City were typically half the values at the San Francisco International Airport. During summers, the differences resulted from stronger wind speeds at the San Francisco International Airport occurring over longer periods of each day. A comparison of hourly wind speeds at the Palo Alto Municipal Airport with those at the Port of Redwood City showed that values were similar in magnitude.

INTRODUCTION

The U.S. Geological Survey collects many types of environmental data to support hydrologic studies of the San Francisco Bay estuarine system. Among these is the collection of meteorological data, because weather and climate affect physical, biological and chemical processes in bay waters. In the southern reach of San Francisco Bay (South Bay), meteorological data from the San Francisco International Airport (SFO) and other locations are useful for studies in the area of the bay between the Bay Bridge and San Mateo Bridge (fig. 1). In the area bounded by the San Mateo Bridge and Dumbarton Bridge, however, small airports and other meteorological stations are either located too far from the bay or do not provide data for the entire day. This is particularly important with regard to wind speed and direction variables, because the identification of wind-driven circulation and mixing is a primary research objective. Consequently, a temporary meteorological station was established in April 1992 at the Port of Redwood City (RWC) to support research and monitoring activities in this region.

This report presents measurements made during 1992-94 at the Port of Redwood City, and provides a brief overview of some daily and seasonal patterns exhibited by these data. Hourly and daily (mean or total) measurements are provided in comma-delimited, ASCII files on the enclosed IBM-formatted disk. This data set has proven useful in identifying links between weather and climate and hydrologic variables in studies conducted by the U.S. Geological Survey for the California Department of Water Resources (Sacramento, CA), the California State Water Resources Control Board, and the Regional Water Quality Control Board (Oakland, CA). In addition, the data are utilized in on-going studies of San Francisco Bay by the U.S. Geological Survey National Research Program and by researchers at Stanford University.

Acknowledgments

Cooperation and assistance by the U.S. Geological Survey Office of Pacific Marine Geology, in particular S.L. Wallace, is greatly appreciated. I gratefully acknowledge the assistance of S.K. Gallanthine in the initial phase of developing the program for the data logger. Sherry Byrd graciously provided data from the Palo Alto Municipal Airport, and D.H. Schoellhamer and R.E. Smith helped in acquiring hourly values for wind variables at both airports. Reviews of this report by C.C. Chang and S. Shapley are appreciated.

INSTRUMENTS AND METHODS

Meteorological variables were measured at the Port of Redwood City (RWC), which is located near the west side of South Bay. The selection of meteorological variables for this site was influenced by two major factors. For some variables, such as temperature and wind speed, values measured near the bay can be greatly different from those measured at inland locations. Therefore, data collected at inland locations might not be representative of conditions over the bay. Additionally, other sources of data for the reach between the San Mateo and Dumbarton Bridges either were not readily available or did not provide data over the entire day.

The meteorological variables that were measured from April 1992 through December 1994 are listed in Table 1 in the order that they are provided in the files containing hourly-mean data. Similarly, column headers for data files containing daily-mean and daily-total values are listed in Table 2. All data are based on measurements made at five-minute intervals.

Instruments were mounted on a 2m-high tripod located on the roof of the Office of Pacific Marine Geology (PMG) port facility building. This building is approximately 100m west of the Port of Redwood City administration building. The elevation of the instrument array above mean sea level was approximately 10 m. A large topographic obstruction, such as the PMG building is expected to have some effect on wind speed and perhaps other meteorological variables. Although this is not expected to cause large errors in this location, effects were not quantified.

All instruments and sensors were factory calibrated, and no further calibrations or assessments of the quality of the data were made (Table 3). Measurements were made at five-minute intervals, then averaged or otherwise processed (see below) to provide the value for the preceding 60 minutes. Data were logged on the hour (Pacific Standard Time) at the site by a Campbell Scientific Company, CR10, then downloaded monthly to a personal computer. Program development and communications utilized software provided by the manufacturer.

Data for wind speed and direction were collected according to recommendations made by the Environmental Protection Agency for regulatory modeling applications. This procedure provides scalar mean horizontal wind speed as well as (vector) resultant mean horizontal wind speed. Resultant mean wind direction and the standard deviation of wind direction are also provided by the output processing instruction.

A quantum sensor was used to measure insolation (solar irradiance). This sensor measures quantum fluxes in moles (6.02 x 1023 photons = one einstein) over the visible spectrum.

Table 1. Column headers for ASCII files of hourly mean values

Column Number (in sequence)	Measurement	Units
1	Program version	none
2	Day of calendar year	none
3	Pacific Standard time	hours
4	Insolation (quantum flux)	10^{-6} moles m^{-2} s^{-1}
5	Temperature	degrees Celsius
6	Barometric pressure	10^{-3} bars
7	Scalar mean wind speed	statute miles h^{-1}
8	Unit vector mean wind direction	degrees true
9	Resultant mean wind speed	statute miles h^{-1}
10	Standard deviation of direction	degrees

Table 2. Column headers for ASCII files of daily mean values

Column Number (in sequence)	Measurement	Units
1	Day of calendar year	none
2	Mean irradiance (quantum flux)	10^{-6} moles m^{-2} s^{-1}
3	Temperature	degrees Celsius
4	Barometric pressure	10^{-3} bars
5	Scalar mean wind speed	statute miles h^{-1}
6	Total insolation	moles m^{-2} d^{-1}

Table 3. Components of the temporary meteorological station at the Port of Redwood City, California

Components	Manufacturer
Wind Monitor, Model 05103	
	R.M. Young Company 2801 Aero-Park Drive Traverse City, MI 49884
Barometric Pressure Sensor, Model PTA-427	
	Visalia Sensor Systems 100 Commerce Way Woburn, MA 01801
Quantum Flux (Irradiance) Sensor, Model LI-190SZ	
	LI-COR, Inc P.O. Box 4425 Lincoln, Nebraska 68504
Temperature Probe, Model 107 Measurement and Control Module, Model CR10 Tripod with cross arm and irradiance sensor platform, Model CM6 Optically Isolated RS232 Interface, Model SC32A PC208 data logger support software package	
	Campbell Scientific P.O. Box 551 Logan, UT 84321

RESULTS

Data files *containing hourly-mean* and daily-mean values are provided on the IBM-formatted disk. Description of the data here is limited largely to identification of major *annual, seasonal,* and event-scale (a few days) variations. The reader is referred to other sources for additional *information on* the seasonal weather and microclimatology of the San Francisco Bay area (for example: Gilliam, 1962; Elford, 1970). Time-series plots of daily mean values for temperature, insolation (quantum flux), pressure, and (scalar) wind speed are shown for each year in figures 2-4. Time series plots of the hourly-mean values are provided for three-month intervals in the appendix (figs. 11-21).

Time Scales of Variability

Although some differences in *annual patterns* among years were apparent in the meteorological variables (interannual variability), seasonal-scale changes were generally greatest, leading to strong annual cycles in most variables (figs. 2-4). Seasonal variations in temperature and *insolation (quantum* flux) followed the annual solar cycle. Warmest (daily mean) air temperatures occurred during summers and coolest temperatures occurred near the winter solstices. Differences between winter and summer were also observed in (atmospheric) pressure and (daily mean) wind speed, but not so much in the magnitudes of the values as in the amount of variability. Short-term variability in pressure during the winter storm season was generally much greater than during summer. Similarly, wind speeds showed greatest day-to-day variability over winter and spring, with the highest speeds most often corresponding to episodes of low pressure. Low pressures and high wind speeds were generally associated with the passage of storm fronts during winter and spring. This is evidenced by strong winds initially from the south (approx. 180 degrees true) then shifting to the north (see appendix figures). In general, however, daily mean wind speeds were highest during summer, a consequence of air circulation between the cool Pacific Ocean and the warm central valley of California.

Short-term variability on the order of hours to days was often related to the daily solar cycle, the daily cycle of coastal fog cover, and *intermittent cloudiness*. During late autumn, winter, and early spring, much of the short-term variability in the variables was associated with storm front activity. These storms usually occurred over a few days, and are identifiable in the records by high wind speeds, low pressures, and often lower values for temperature and irradiance.

Comparison with Values from San Francisco International Airport

Hourly meteorological measurements are collected at the San Francisco International airport (SFO) as part of a continuing program (National Oceanic and Atmospheric Administration, monthly and annual summaries). The San Francisco Bay region, however, comprises a wide variety of microclimate areas. Consequently, it was expected that some values at SFO might be quite different from those just a few miles away. As stated in the introduction, this was an important reason for establishing the station at the Port of Redwood City (RWC).

Air temperatures were similar for the two locations over the 1993 calendar year: differences are shown in figure 5. Most (278) of the 365 pairs of daily mean values were within 1°C, and nearly all of the values were within 2°C. Values at RWC were typically slightly less than those at SFO. Of the 96 cases when values at RWC were greater, 44 occurred from June through August, when air temperatures were generally greatest (see fig.3).

Daily mean values for (scalar) wind speed were greatly different between SFO and RWC. On the average, wind speeds at RWC were less than half the values at SFO (fig. 6). Winds at both locations, however, showed a strong annual cycle, which was even more pronounced at SFO (fig. 7). During summers, stronger winds were expected at SFO because it is in the path of airflow through a break in the coastal mountain range (Conomos, 1979). Examination of hourly values for July 24-25, 1994, showed that hourly mean wind speeds at SFO were greater than at RWC, and indicated the sometimes-great differences in the daily mean values were the result of winds blowing stronger for a longer part of the day at SFO (fig. 8). Hourly values over a winter storm event (March 2324, 1994) are shown in figure 9. Wind speeds were generally stronger at SFO, but they followed the same pattern as those at RWC.

Comparison with Values from Palo Alto Municipal Airport

Palo Alto Municipal Airport is located approximately six statute miles south-east of the Port of Redwood City (fig. 1). Instantaneous wind speed is recorded hourly during daylight hours at this location. Observations for five days during June 1993 were compared with hourly mean values for wind speed at RWC in figure 10. Most differences between the hourly means at RWC and the instantaneous values at the Palo Alto Municipal Airport were not unusually large. However, variability in the daily cycle of wind speed, as shown at RWC, was only partially represented by the instantaneous hourly observations. For example, winds were strong after midnight on calendar day 179 at RWC, but values were not recorded at Palo Alto.

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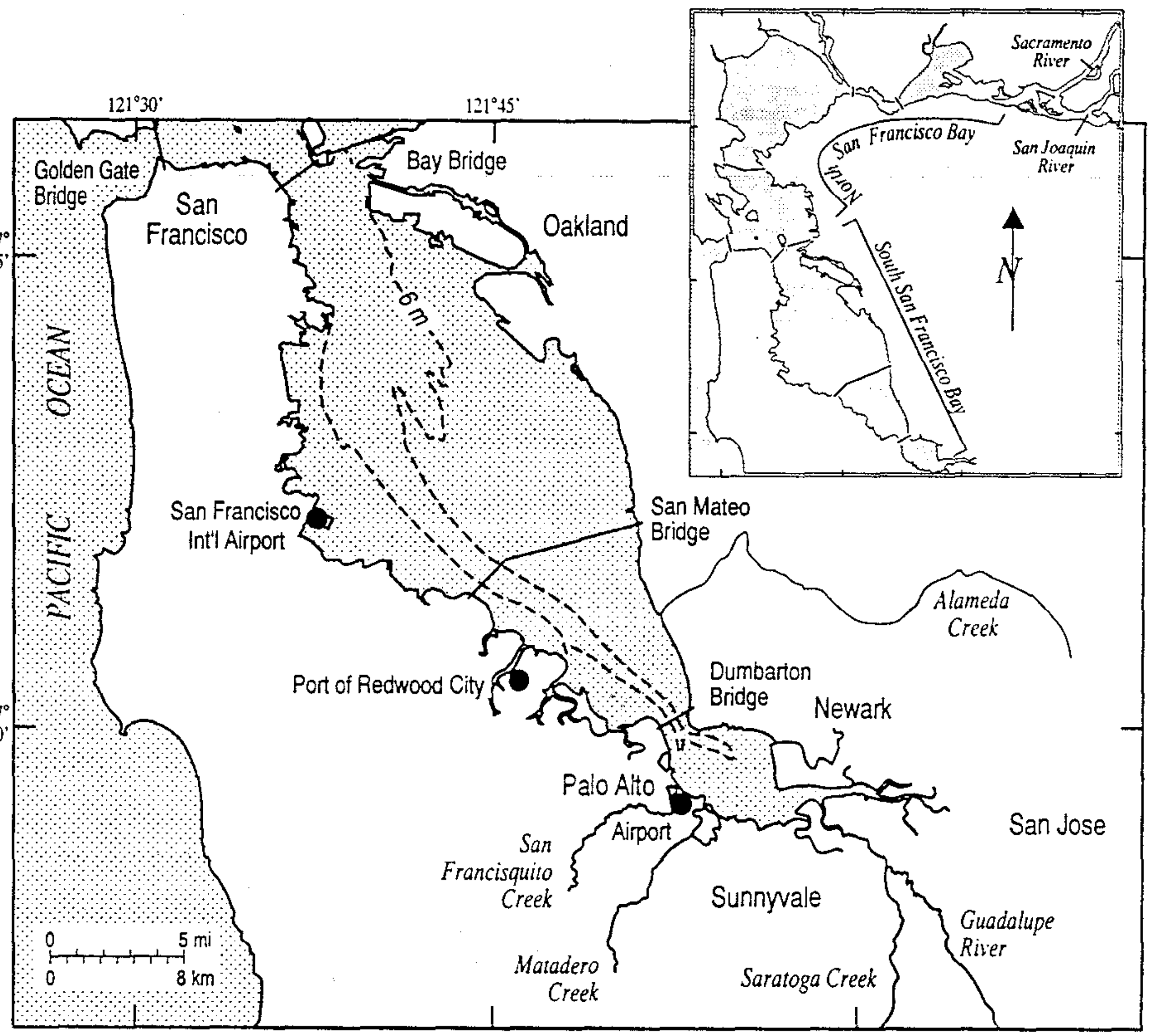

Figure 1. Map showing San Francisco Bay and locations in Southern San Francisco Bay.

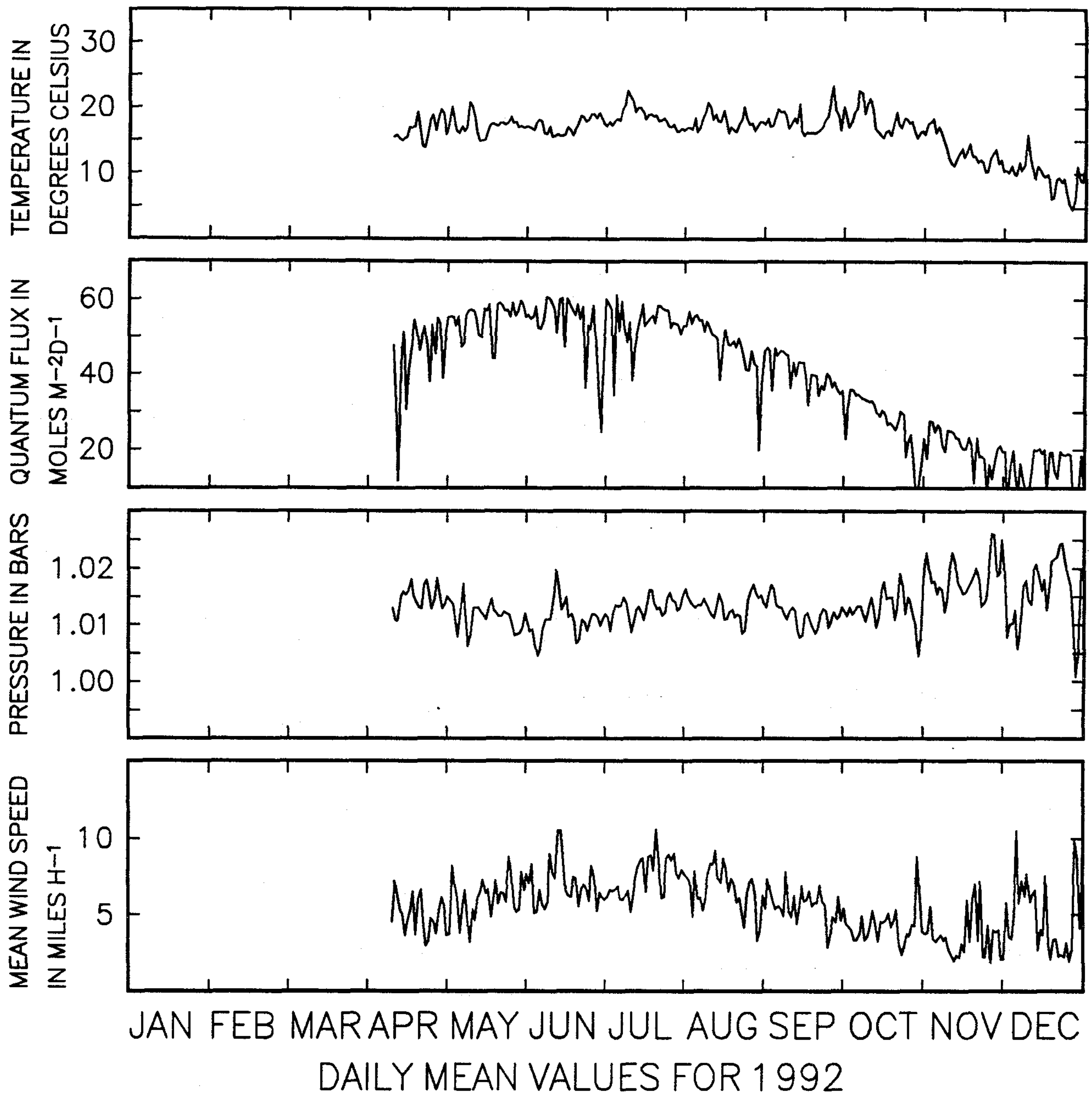

Figure 2. Time series plots of daily mean values of temperature, quantum flux (insolation), atmospheric pressure, and scalar wind speed at the Port of Redwood City, 1992.

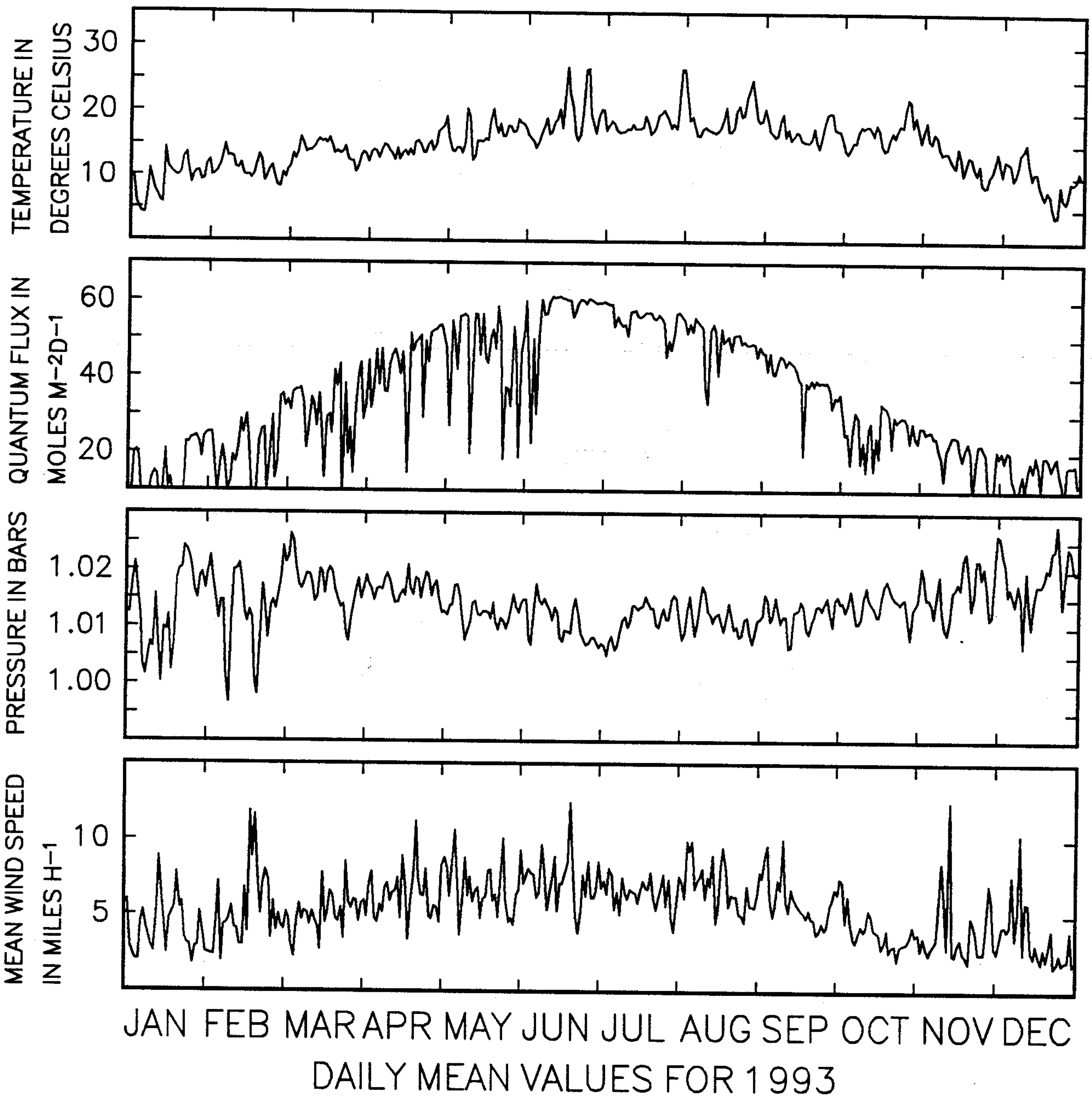

Figure 3. Time series plots of daily mean values of temperature, quantum flux (insolation), atmospheric pressure, and scalar wind speed at the Port of Redwood City, 1993.

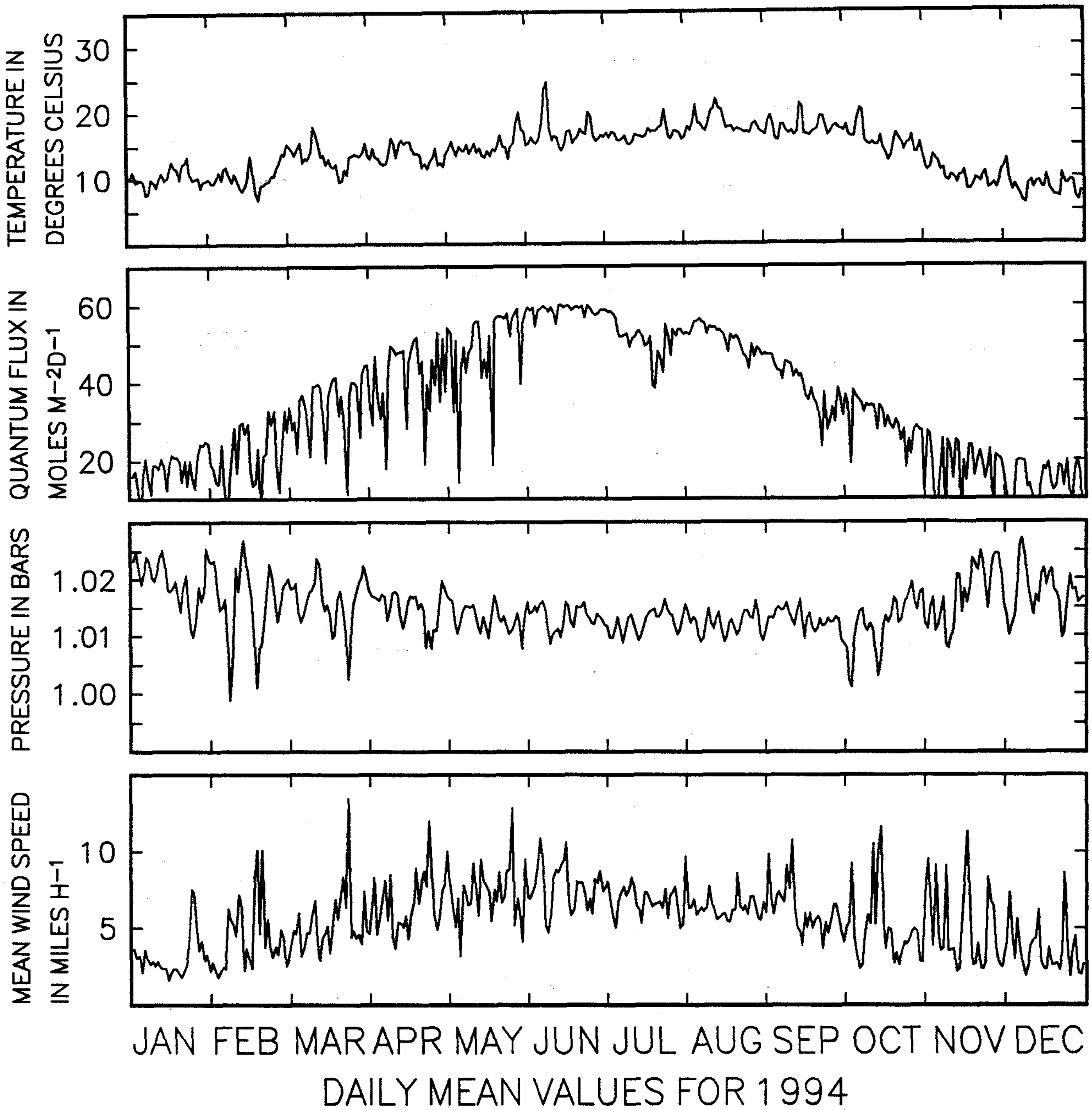

Figure 4. Time series plots of daily mean values of temperature, quantum flux (insolation), atmospheric pressure, and scalar wind speed at the Port of Redwood City, 1994.

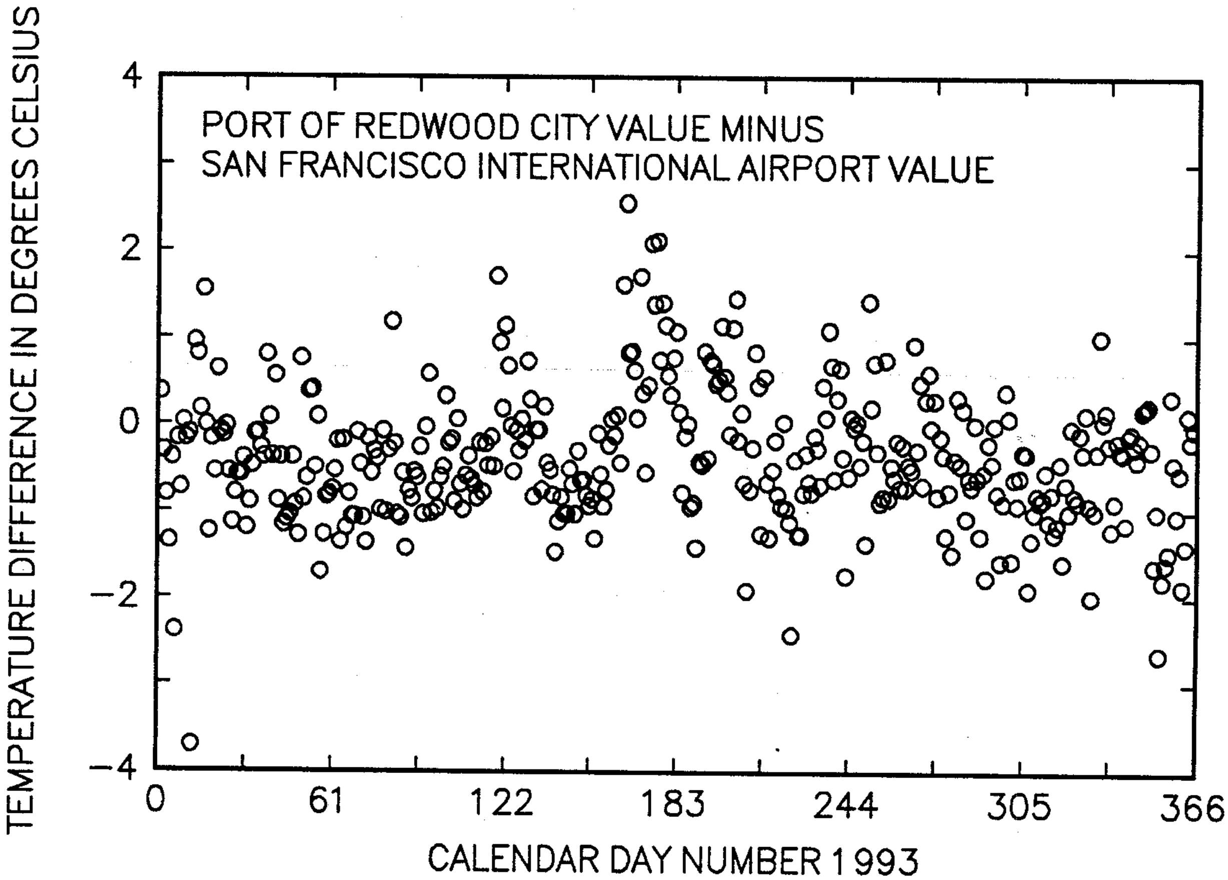

Figure 5. Differences between daily mean values for temperature at San Francisco International Airport and the Port of Redwood City during 1993

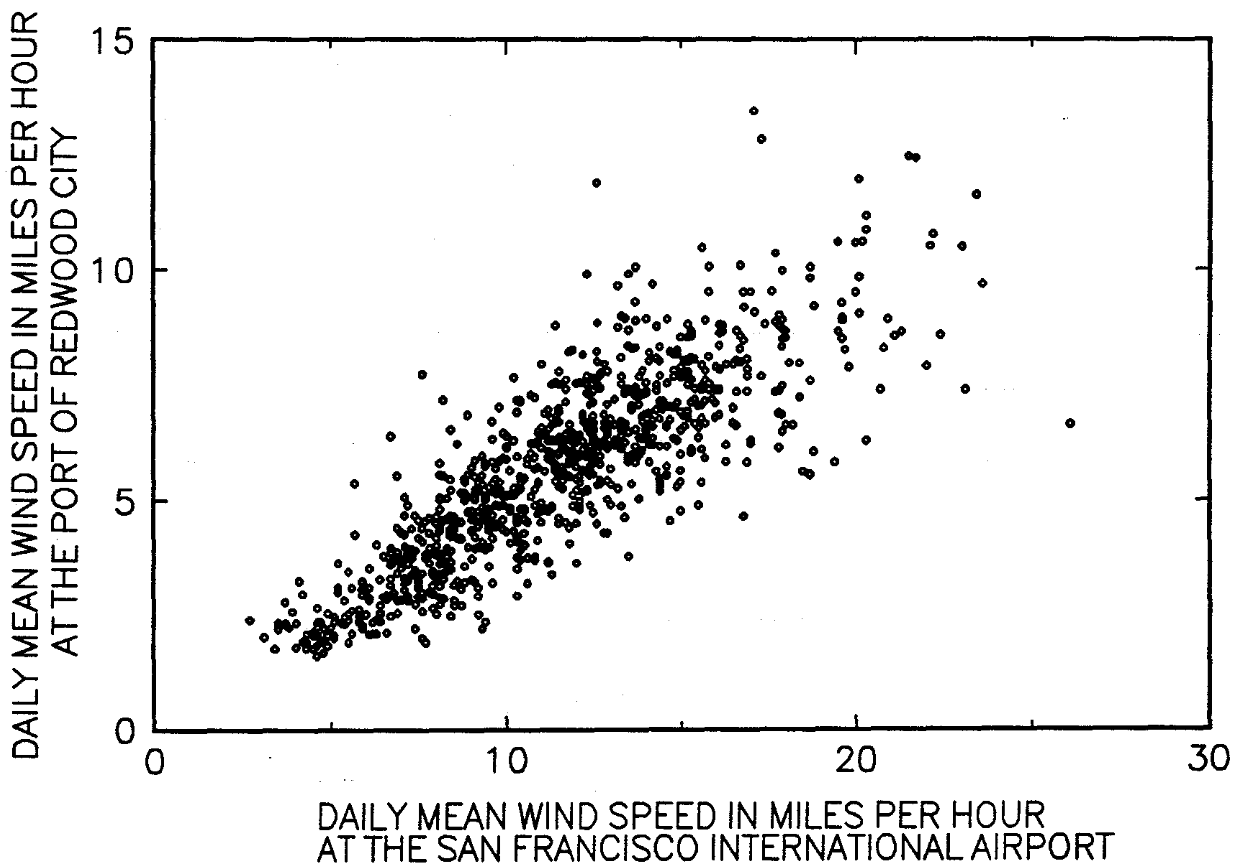

Figure 6. Plot of daily mean wind speed at the Port of Redwood City versus daily mean wind speed at the San Francisco International Airport.

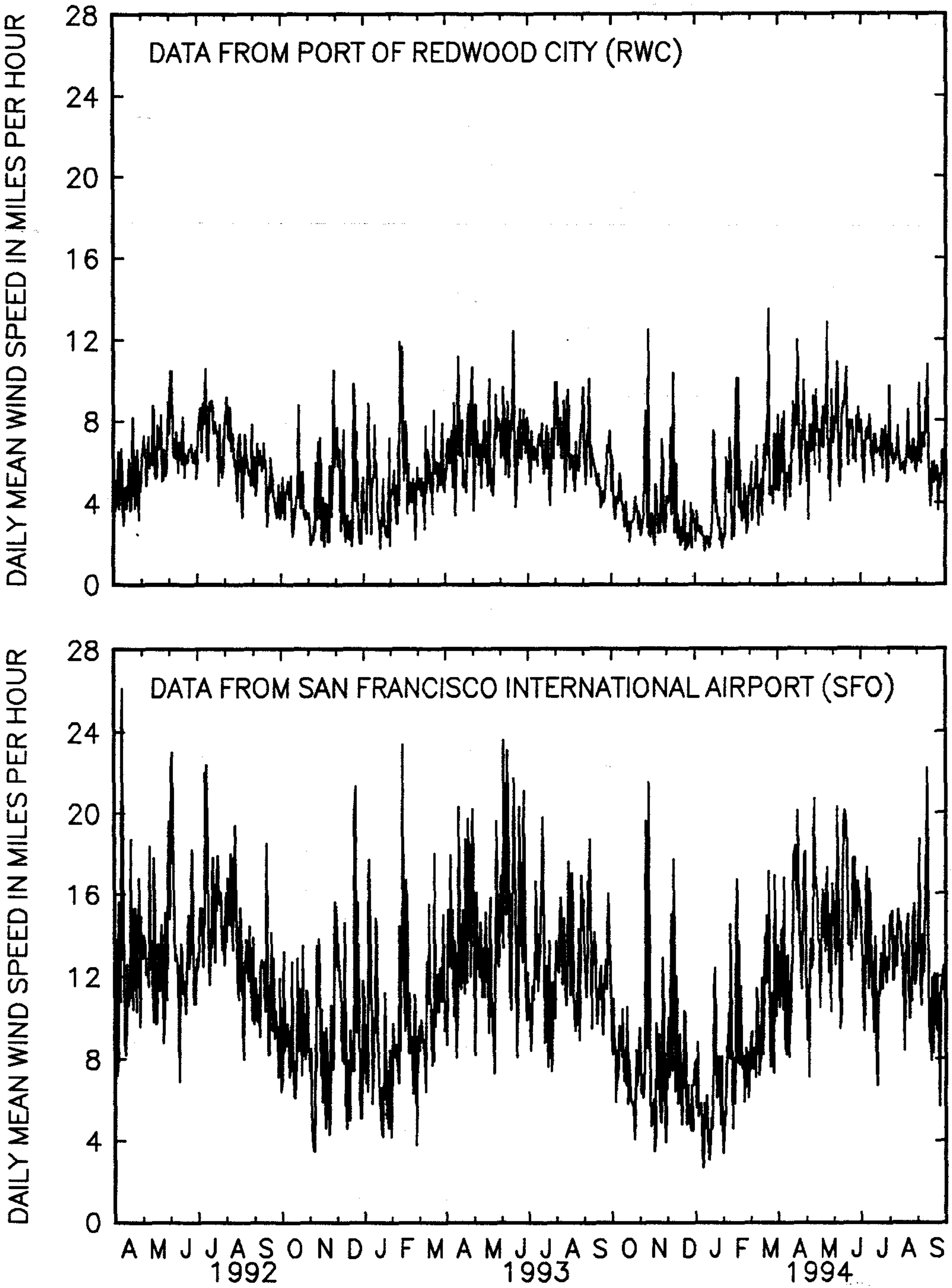

Figure 7. Time series plot of daily mean wind speeds at the Port Of Redwood City and the San Francisco International Airport, 1992-1994.

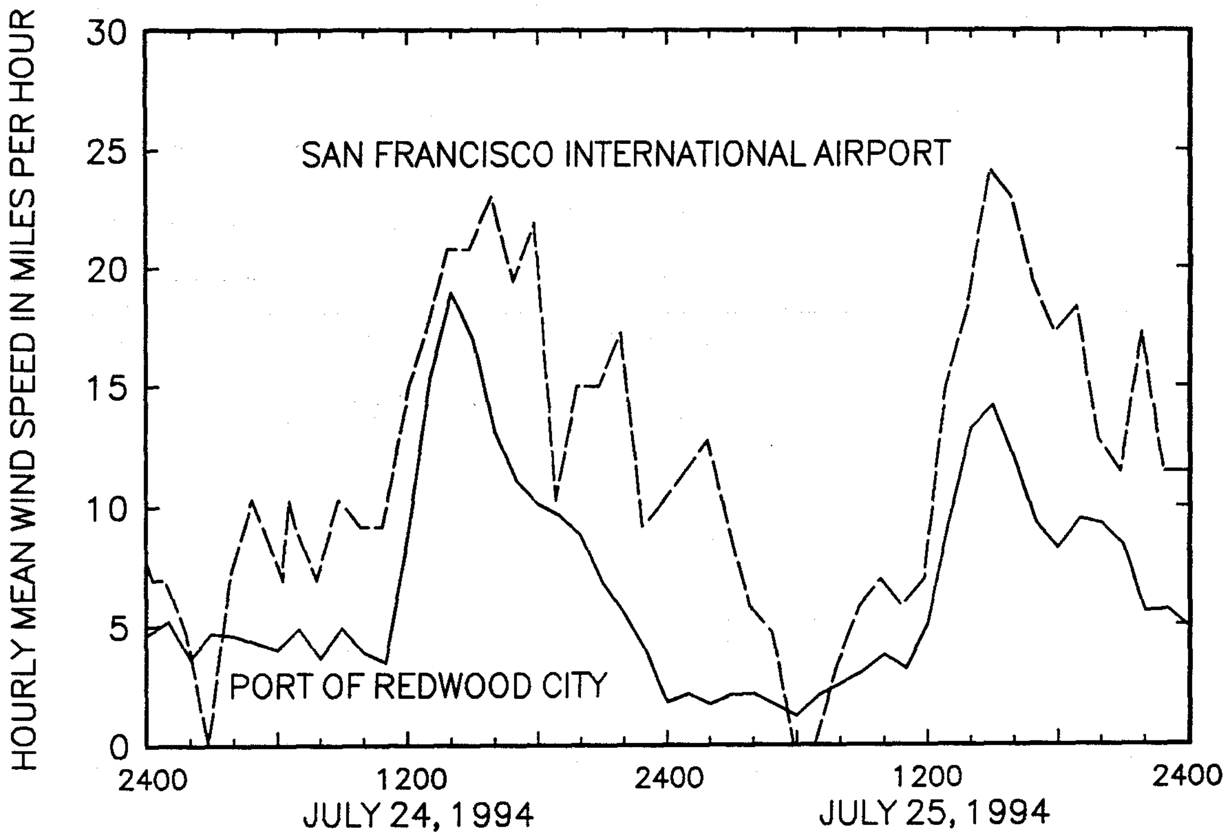

Figure 8. Comparison of hourly mean wind speeds at the Port of Redwood City and the San Francisco International Airport, July 24-25, 1994.

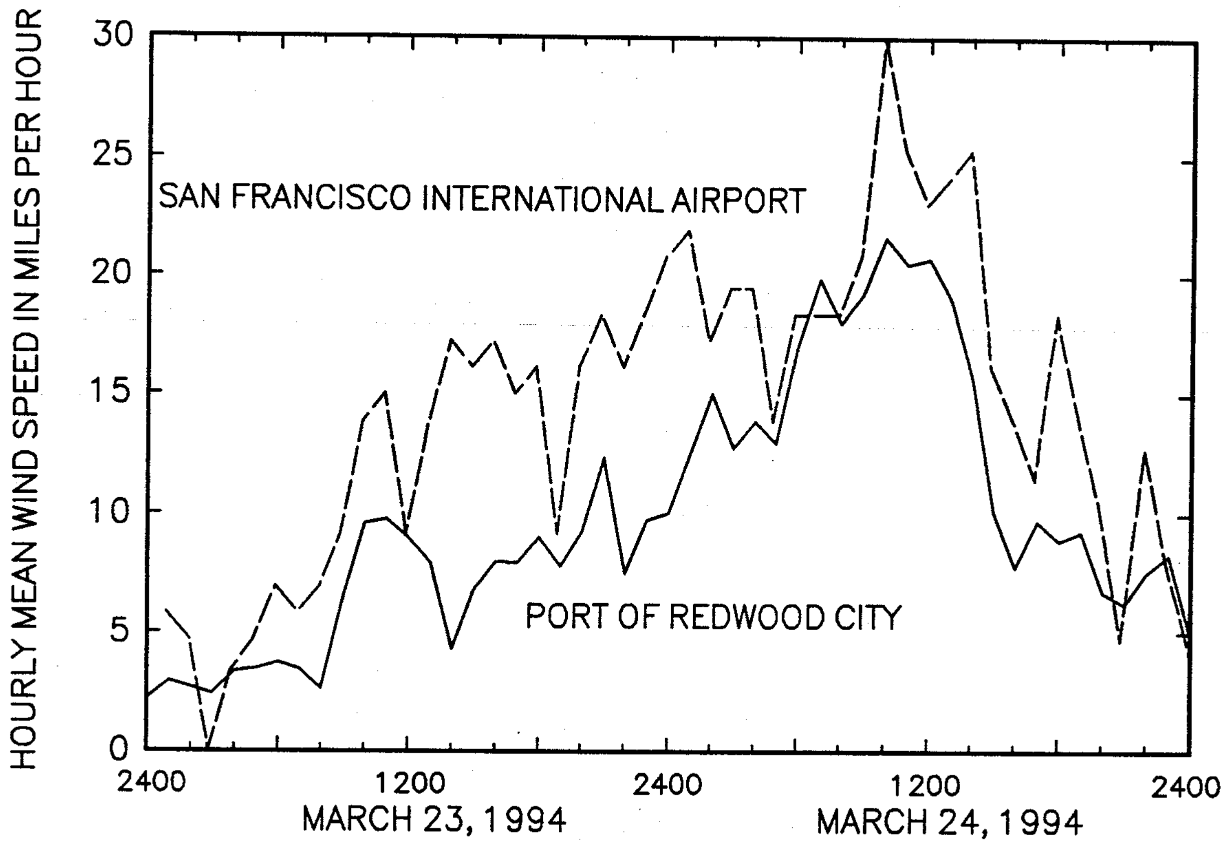

Figure 9. Comparison of hourly mean wind speeds at the Port of Redwood City and the San Francisco International Airport, March 23-24, 1994.

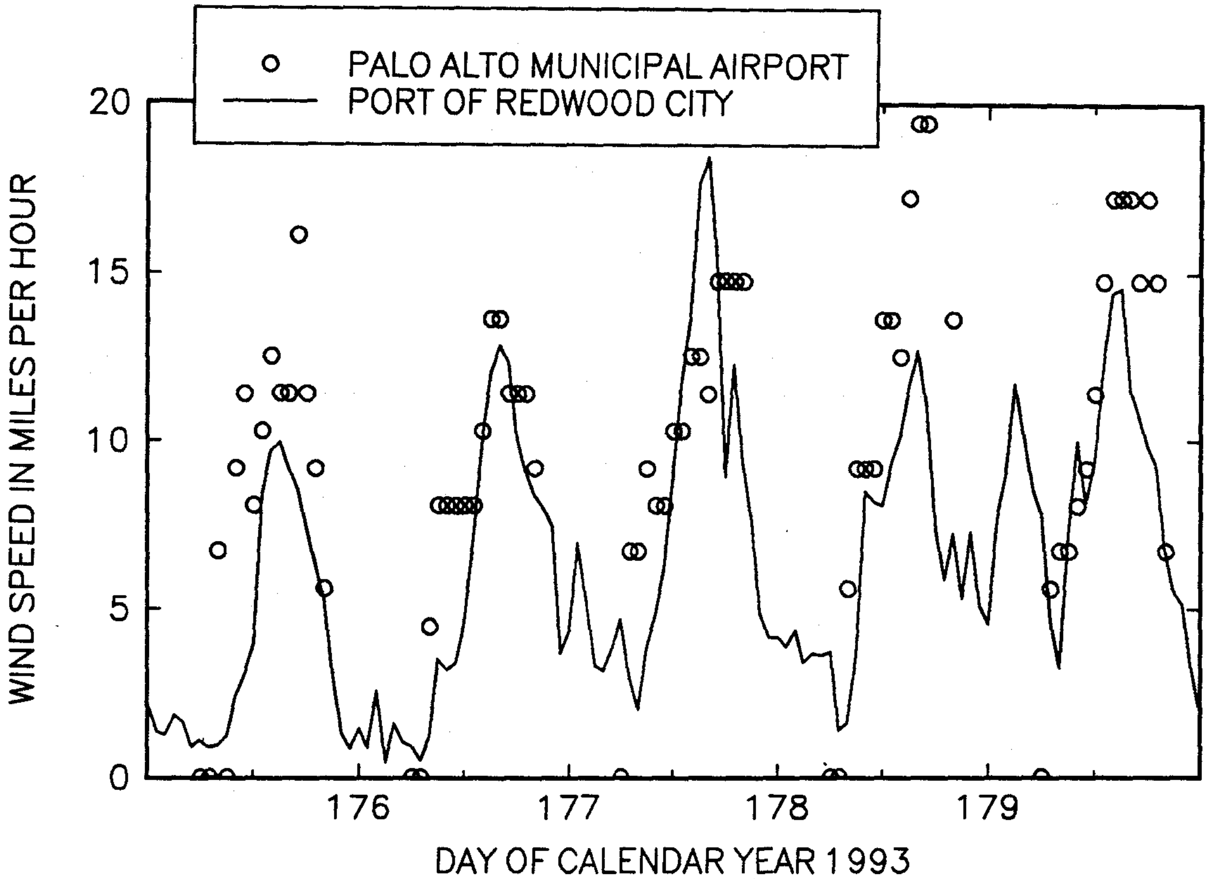

Figure 10. Comparison of hourly mean wind speeds at the Port of Redwood City with instantaneous measurements at the Palo Alto Municipal Airport, June 24-28, 1993.

APPENDIX

Figures 11-21 Time series plots of hourly mean temperature, quantum flux, pressure, wind speed, and wind direction at the Port of Redwood City: three-month periods 1992-94.

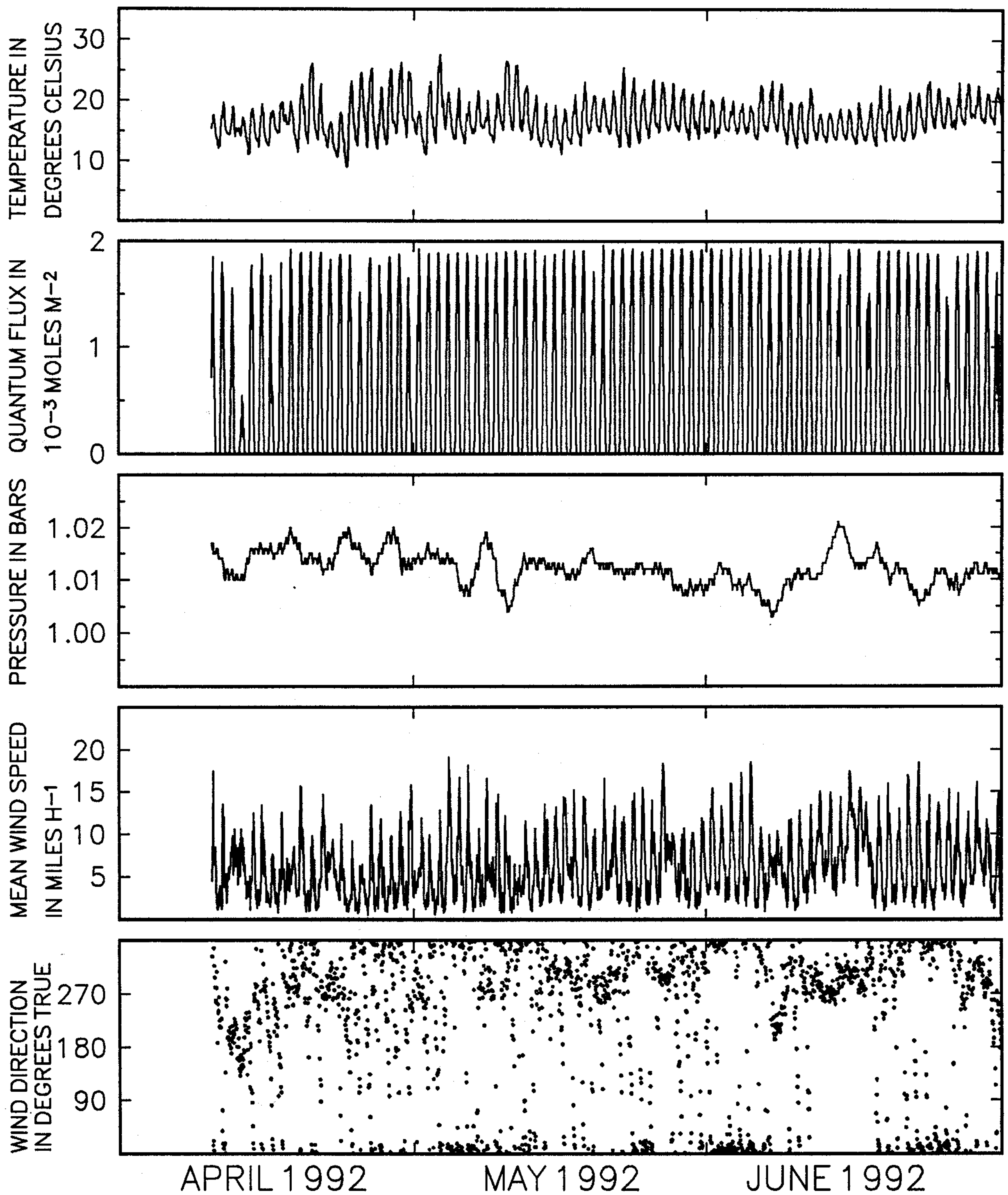

Figure 11. Time series plots of hourly mean temperature, quantum flux, pressure, wind speed, and wind direction at the Port of Redwood City, April-June, 1992.

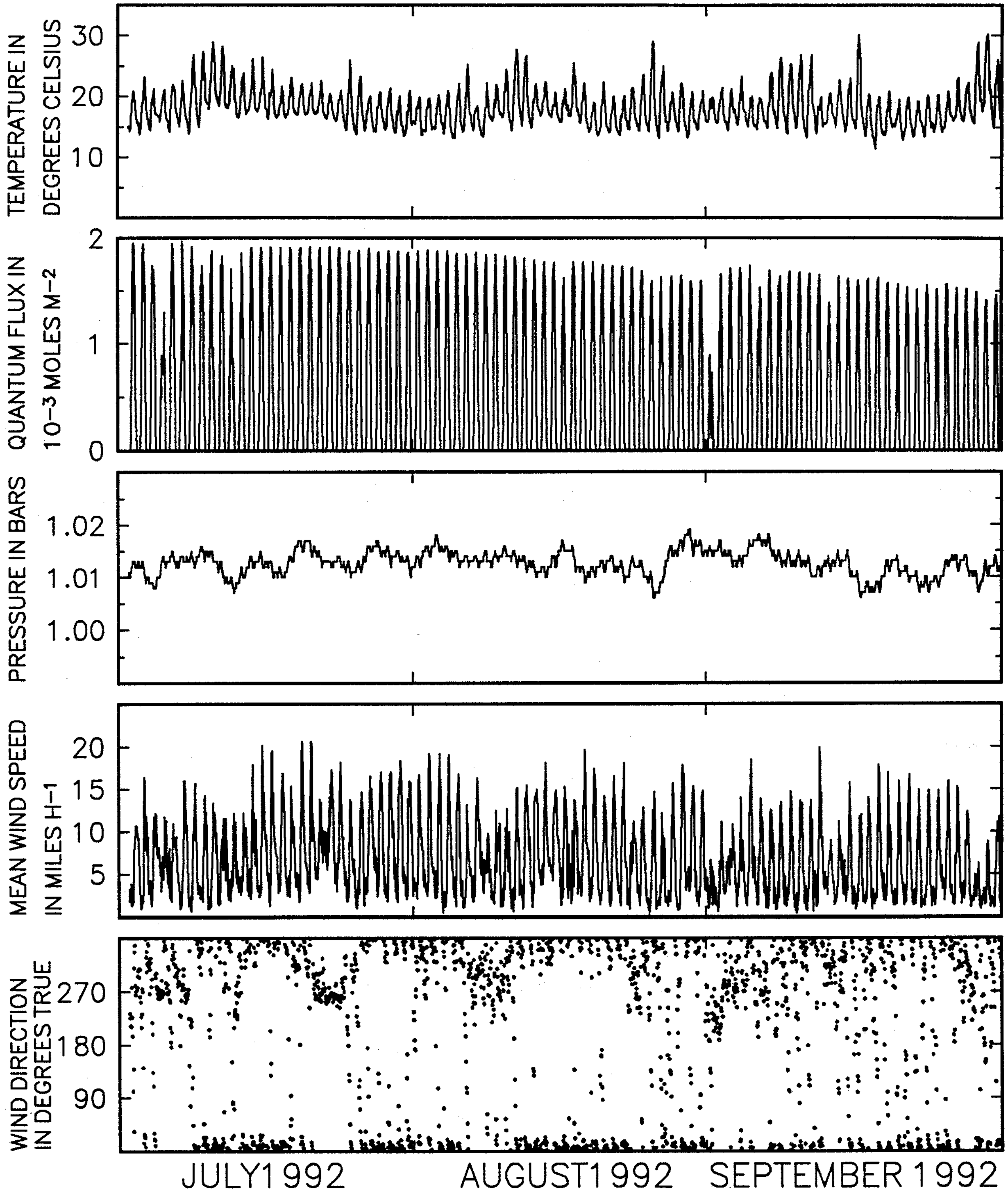

Figure 12. Time series plots of hourly means temperatures, quantum flux, pressure, wind speed, and wind direction at the Port of Redwood City, July - December 1992.

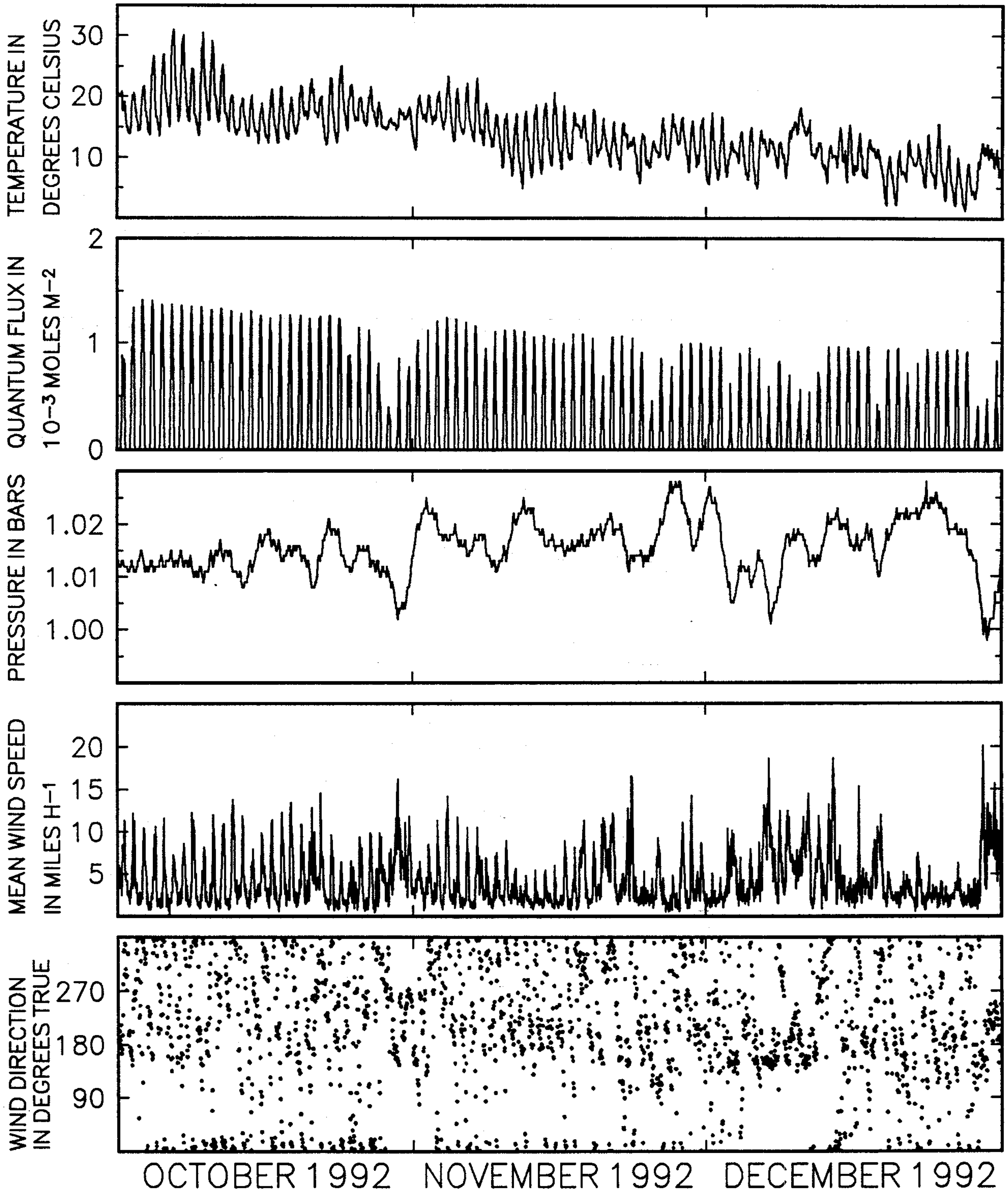

Figure 13. Time series plots of hourly mean temperature, quantum flux, pressure, wind speed, and wind direction at the Port of Redwood City, October- December 1992.

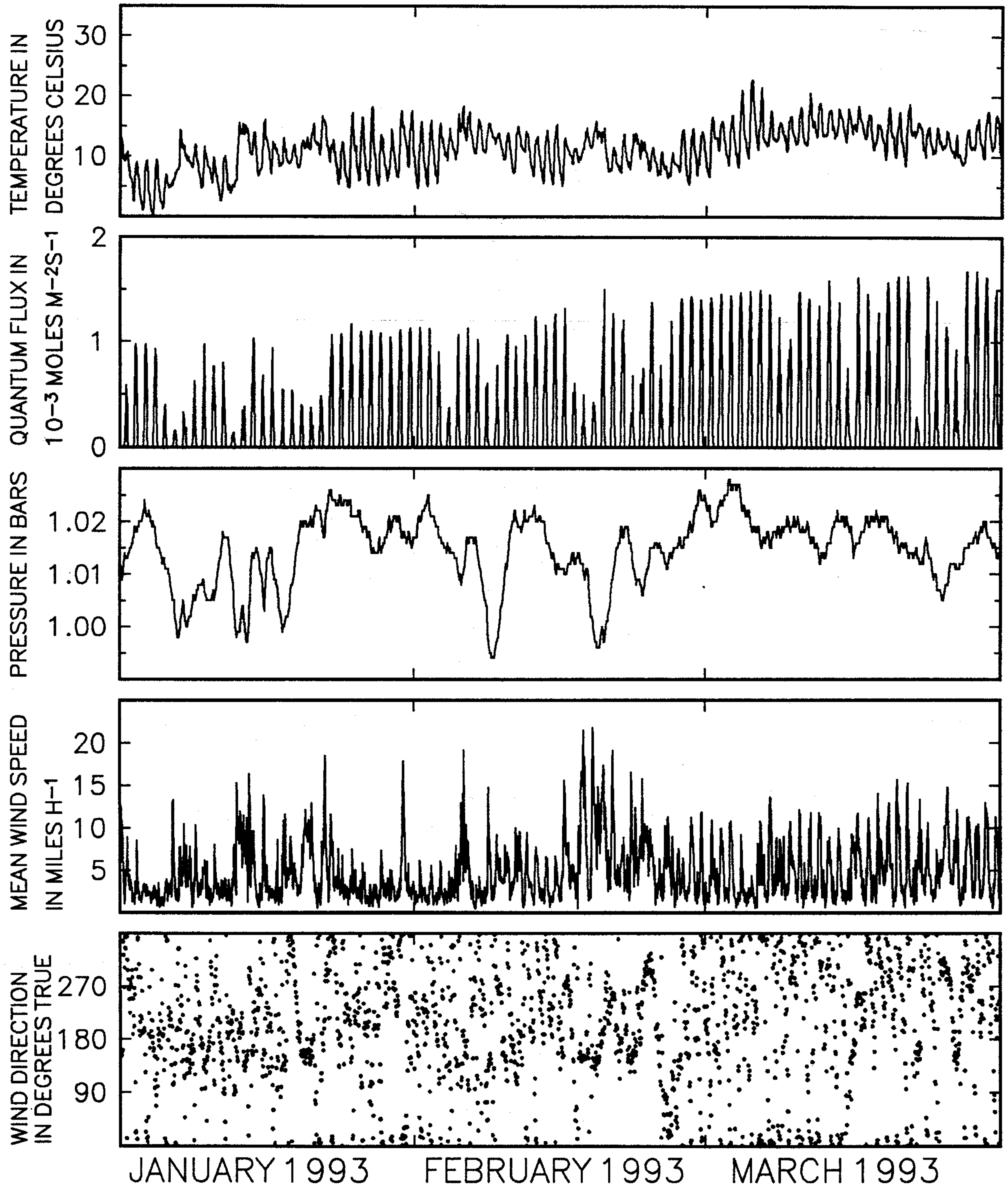

Figure 14. Time series plots of hourly mean temperature, quantum flux, pressure, wind speed, and wind direction at the Port of Redwood City, January-March, 1993.

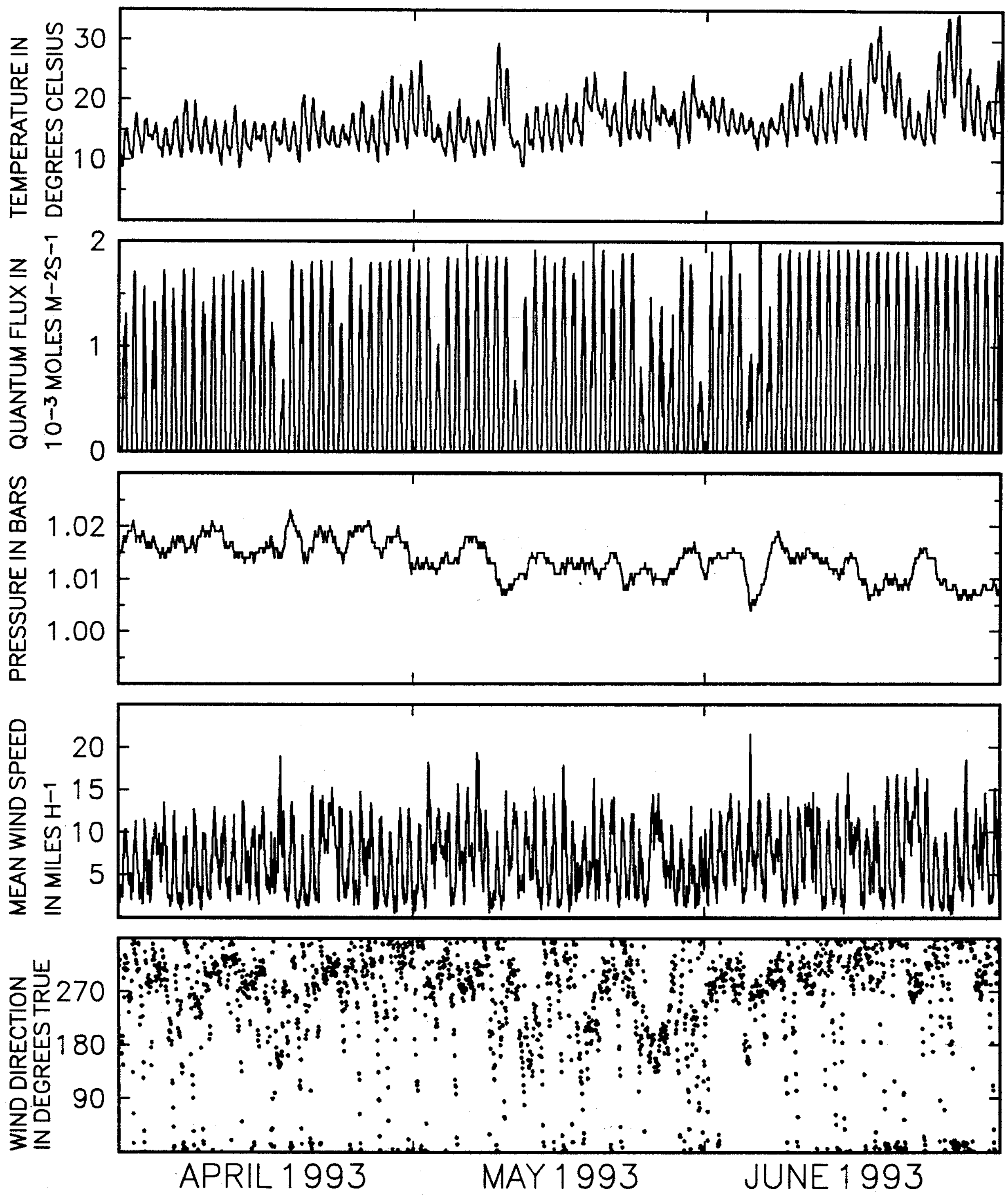

Figure 15. Time series plots of hourly mean temperature, quantum flux, pressure, wind speed, and wind direction at the Port of Redwood City, April-June, 1993.

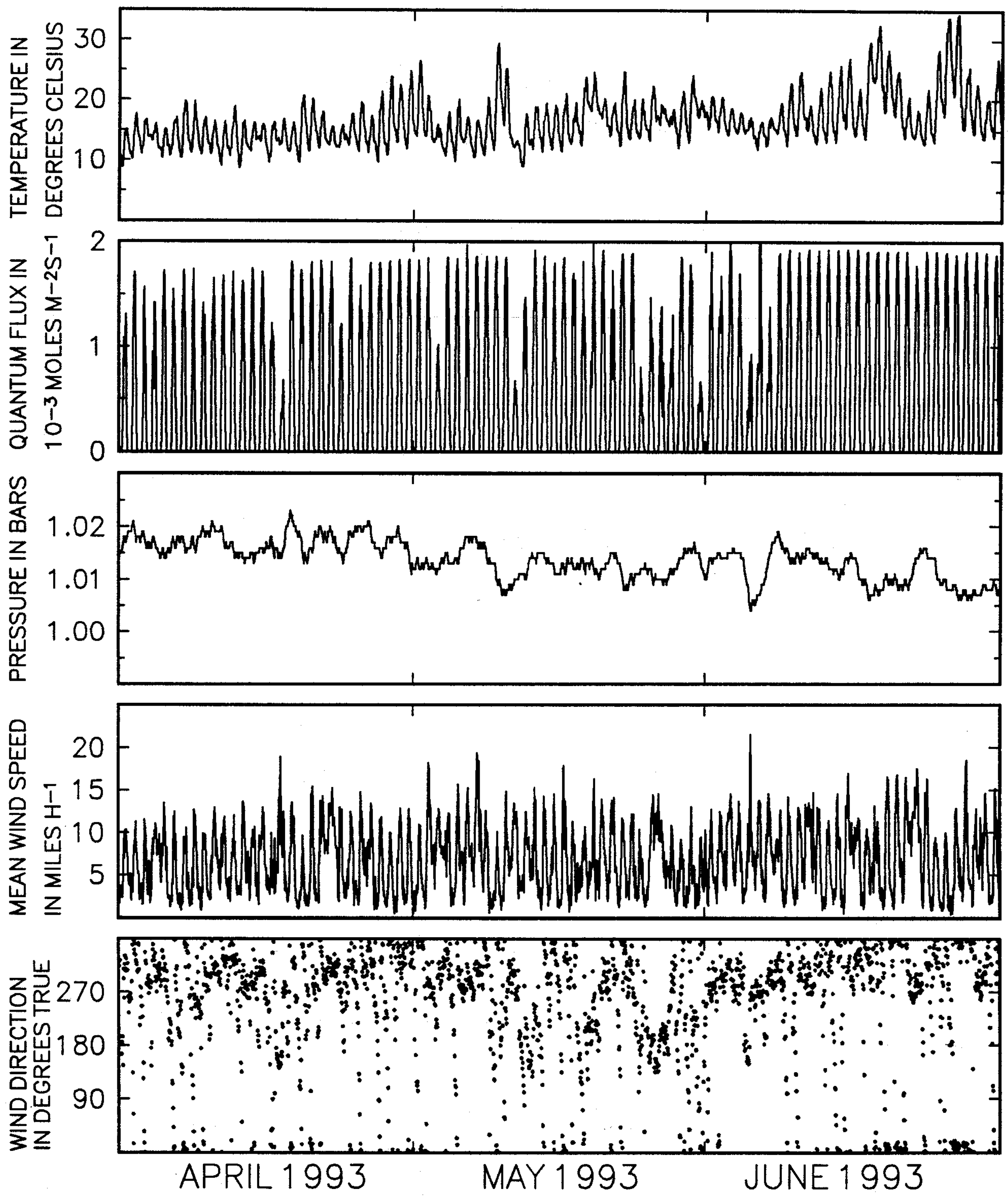

Figure 16. Time series plots of hourly mean temperature, quantum flux, pressure, wind speed, and wind direction at the Port of Redwood City, July-September, 1993.

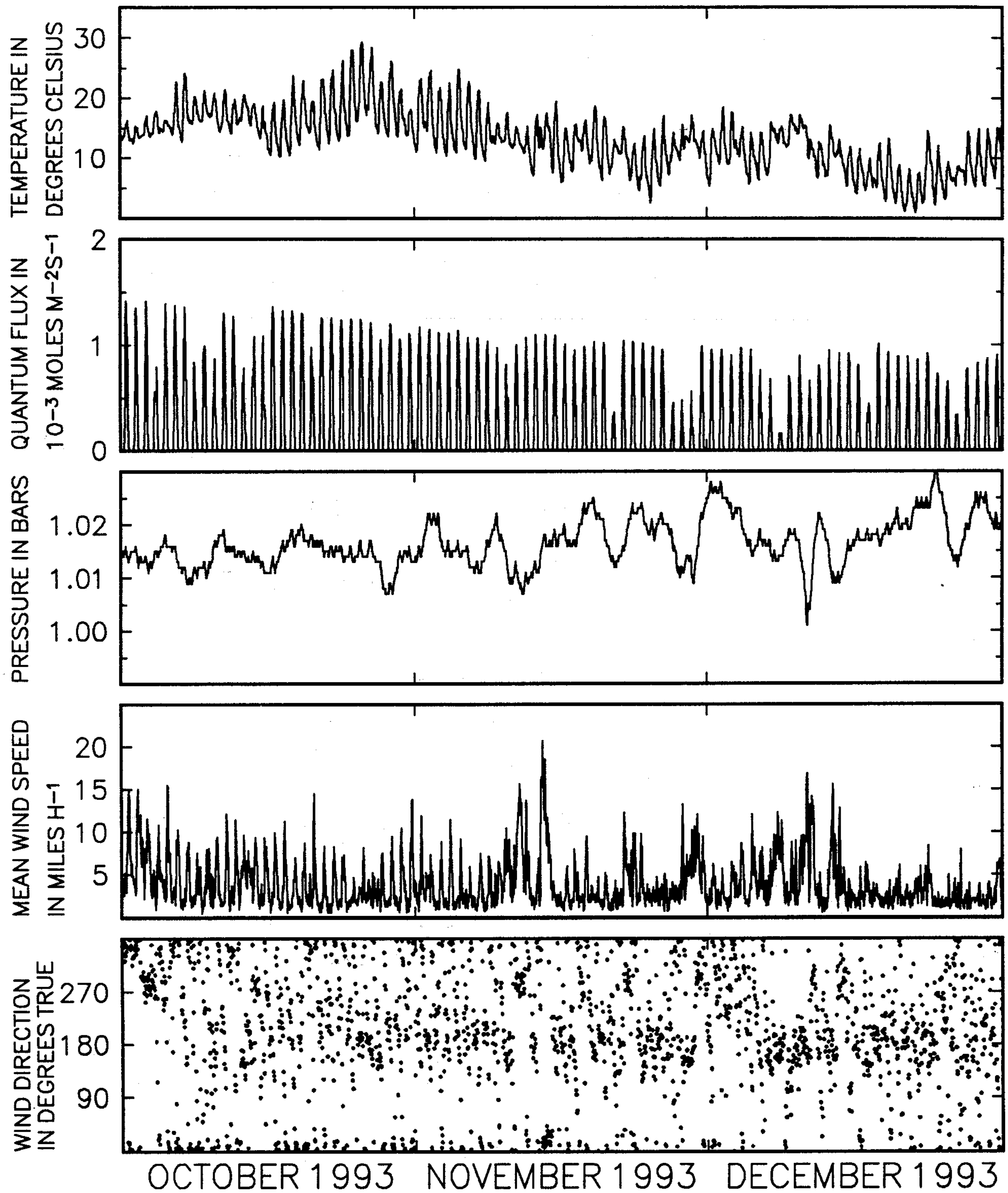

Figure 17. Time series plots of hourly mean temperature, quantum flux, pressure, wind speed, and wind direction at the Port of Redwood City, October-December, 1993.

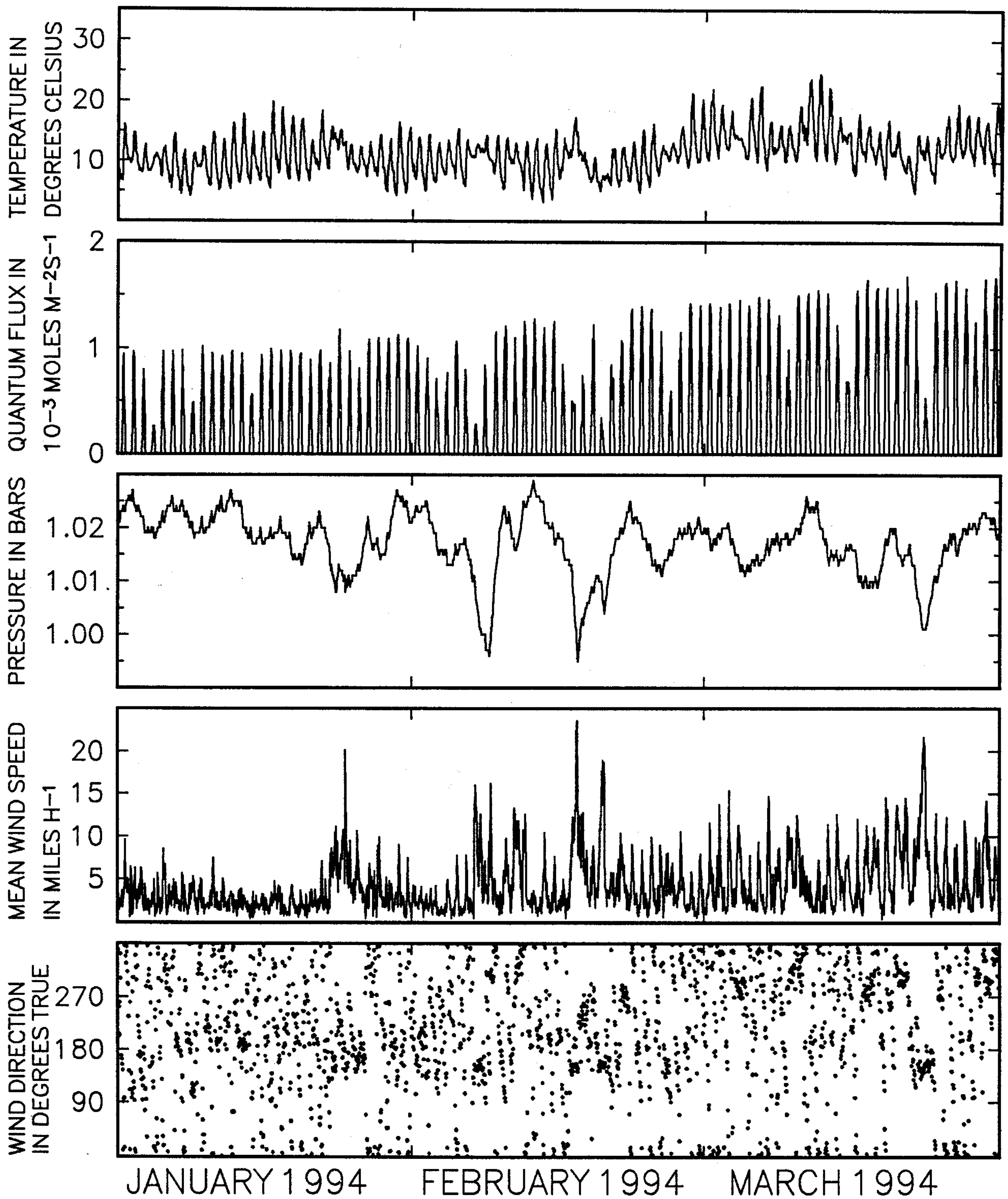

Figure 18. Time series plots of hourly mean temperature, quantum flux, pressure, wind speed, and wind direction at the Port of Redwood City, January-March, 1994.

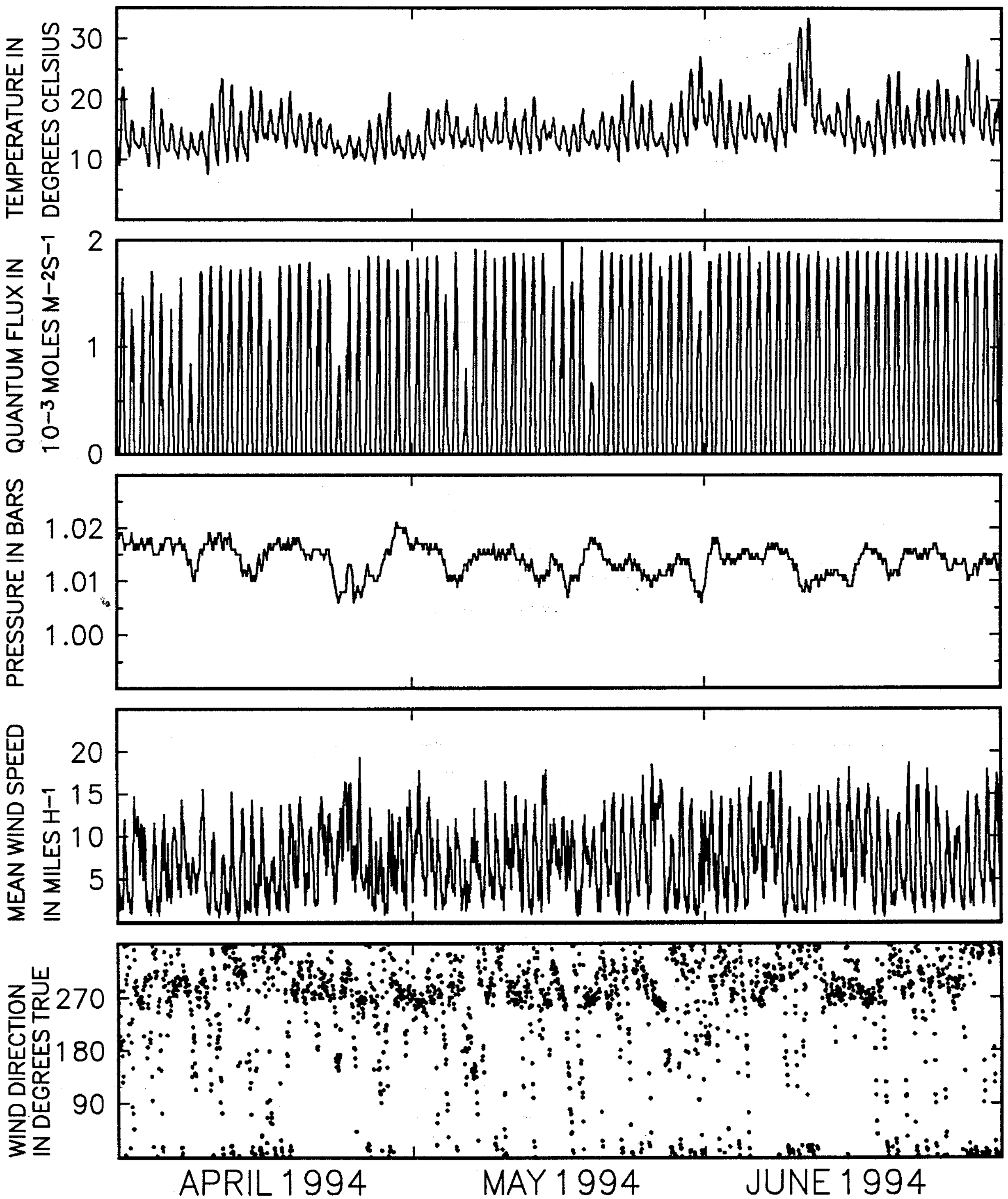

Figure 19. Time series plots of hourly mean temperature, quantum flux, pressure, wind speed, and wind direction at the Port of Redwood City, April-June, 1994.

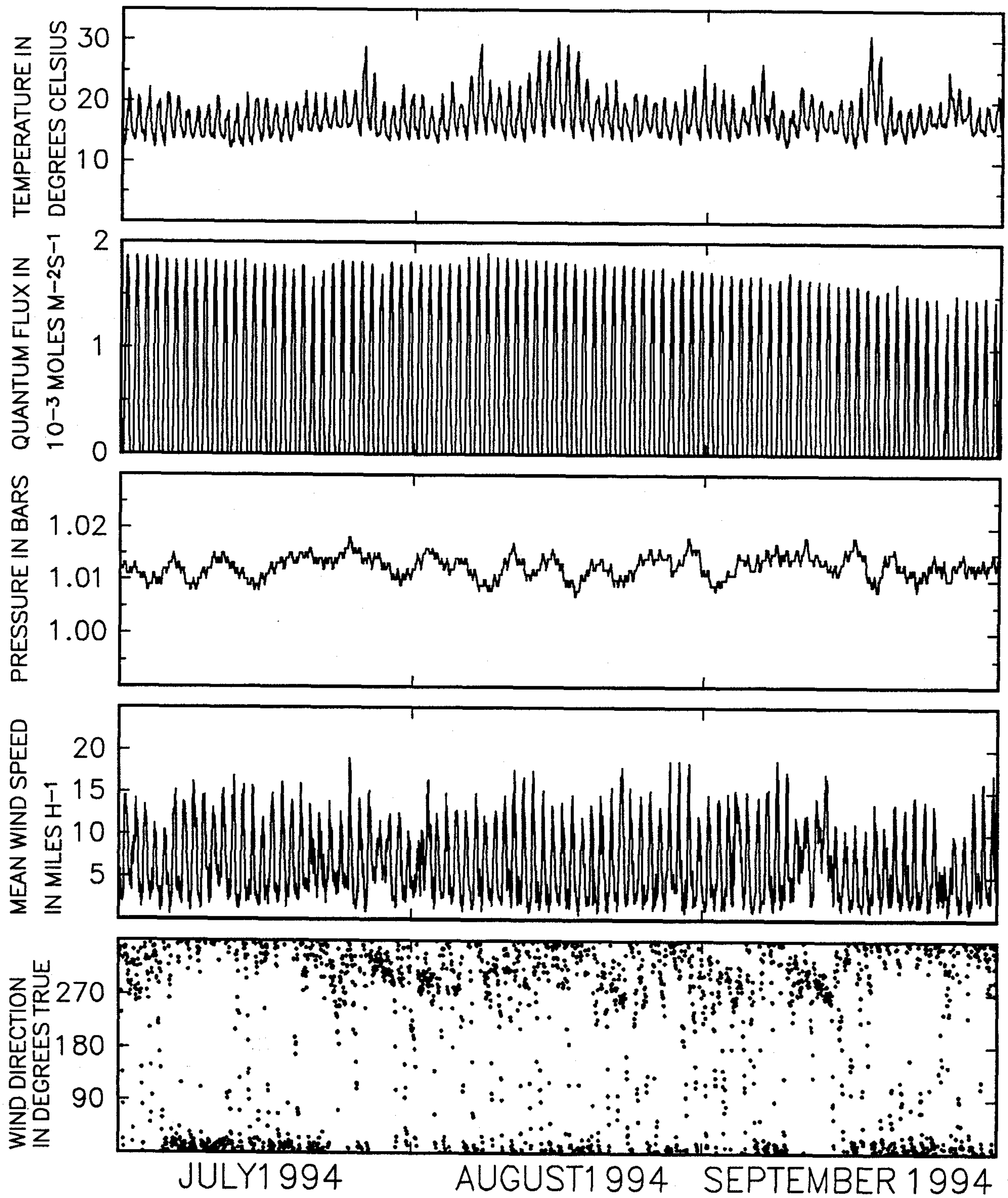

Figure 20. Time series plots of hourly mean temperature, quantum flux, pressure, wind speed, and wind direction at the Port of Redwood City, July-September, 1994.

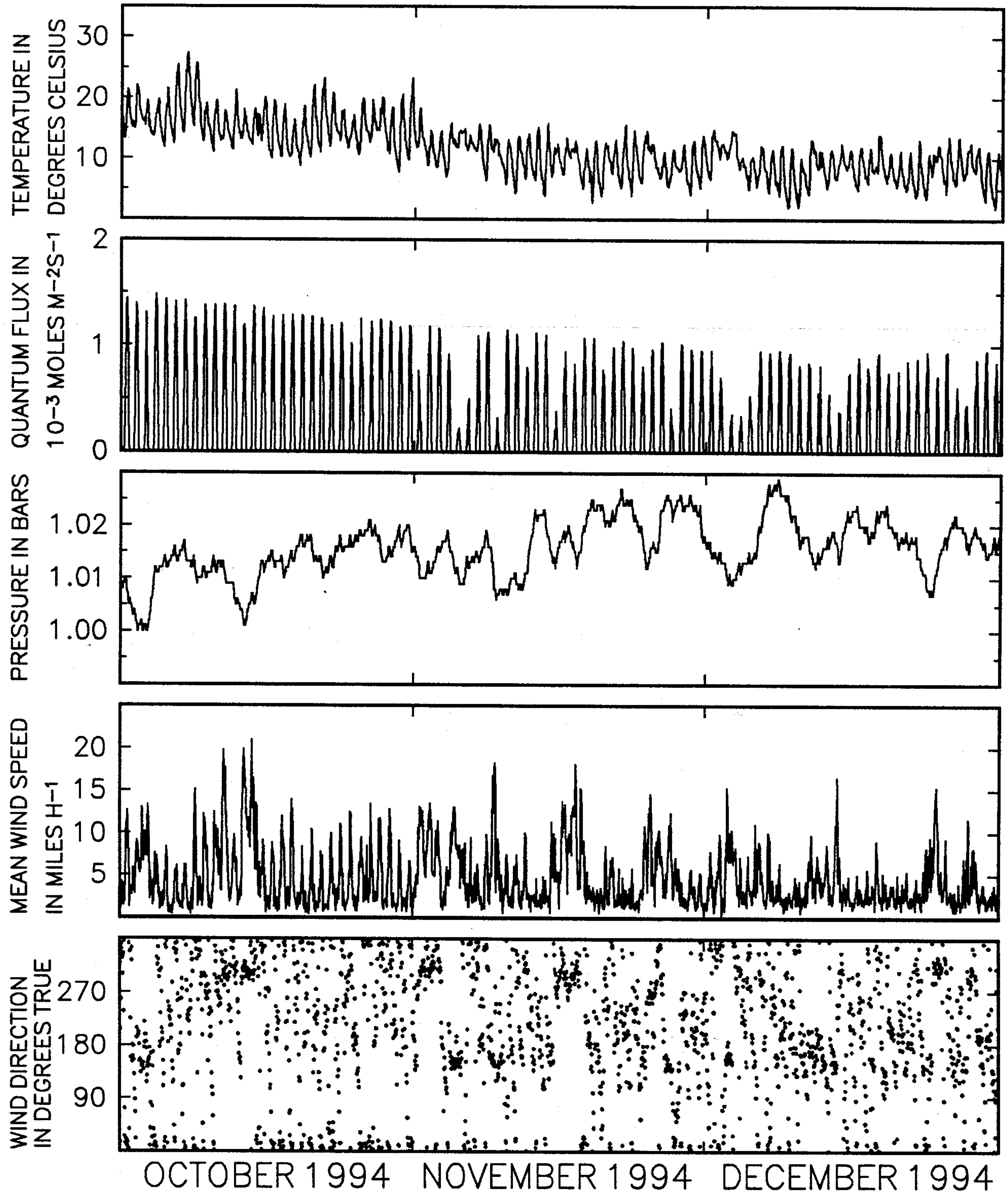

Figure 21. Time series plots of hourly mean temperature, quantum flux, pressure, wind speed, and wind direction at the Port of Redwood City, October-December, 1994.