

1.5. METEOROLOGICAL MEASUREMENTS

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1.5.1. METEOROLOGY OPERATIONS

Introduction

The climatology of surface meteorological observations at the four CMDL observatories is based on hourly averaged measurements of the vector wind direction and speed, barometric pressure, ambient and dewpoint temperatures, and precipitation amount. The meteorological sensors used were selected for their high accuracy, as well as their ability to withstand the extreme conditions of the polar regions. Data are recorded as 1-min averages, so the variability within the hourly averages can be determined. To the extent that is possible, World Meteorological Organization (WMO) siting standards [WMO, 1969] are followed. Thermometers are also positioned at the top of the sampling towers at BRW, MLO, and SPO to measure the temperature gradient and to determine the stability of the surface boundary layer.

A detailed description of the PC-based data acquisition system may be found in *Peterson and Rosson* [1994]. Table 1.5 describes the instrument deployment as of December 31, 1999.

At BRW the complement of sensors measuring meteorological variables remained unchanged. In early 1998 and again in early 1999, the aspirator fan on the dewpoint hygrometer was replaced. In mid-June 1999 the dewpoint hygrometer sensor head was replaced since the old one failed at the beginning of June. In December 1999 a filter capacitor on the main power supply of the dewpoint hygrometer was replaced.

At MLO the RS-485 card, which is used by the meteorological

data acquisition computer to communicate with the sensor interface modules, was replaced in March 1998. In March 1999 the sensor interface modules in the dewpoint hygrometer and the anemometer that measures the 10-m winds were replaced. In August 1999 the wind speed transmitter on the Bendix aerovane was replaced.

At SMO the biggest change was the move of the anemometer, the dewpoint hygrometer, and the platinum resistance probe from the meteorological sampling tower to the newly constructed cellular phone tower near the main building. This move took place between July 8 and 24, 1999. Table 1.6 describes the heights of the sensors before and after the move to the new tower. The pressure transducer and the rain gauge remained in the same locations.

At SPO the RS-485 card was replaced in early January 1998. The aspirator fan in the dewpoint hygrometer was replaced in early April 1998 and then again later in the month.

Data Management

The meteorological data acquisition system gathers data from sensors that operate continuously at each of the four CMDL observatories. Data are transferred to Boulder on a daily basis via the Internet, except for SMO. The SMO data are transferred to Boulder on a weekly basis. Preliminary hourly averages of vector wind direction and speed, barometric pressure, ambient and dewpoint temperatures, and precipitation amounts are sent to the stations on a daily basis except for SMO, where it is sent on a weekly basis.

A comparison of the number of data points recorded against that expected for the year was used to monitor the system's performance. Table 1.7 shows the performance of each system in 1998 and 1999. On average the meteorological data acquisition system for the four observatories operated 95.62% and 92.03% of

TABLE 1.5. CMDL Meteorological Sensor Deployment December 31, 1999

| Sensor | BRW | | MLO | | SMO | | SPO | |
|-----------------------|------------|--------------|------------|--------------|------------|--------------|------------|--------------|
| | Serial No. | Elevation, m | Serial No. | Elevation, m | Serial No. | Elevation, m | Serial No. | Elevation, m |
| Primary anemometer† | 14584 | 10.5 | 23186 | 10.2 | 15945 | 22.9 | 14583 | 10.0 |
| Secondary anemometer† | | | 15946 | 38.2 | | | | |
| Pressure transducer‡ | 374199 | 9.5 | 374198 | 3398.4 | 374200 | 78.5 | 358960 | 2841.0 |
| Mercurial barometer | 641 | 9.5 | 278 | 3398.4 | 961 | 78.5 | 1215A | 2841.0 |
| Air temperature A§ | | 2.4 | | 2.0 | | 18.9 | | 1.6 |
| Air temperature B¶ | | 15.7 | | 37.4 | | 18.9 | | 22.0 |
| Air temperature C** | | 2.9 | | 2.0 | | 18.9 | | 2.0 |
| Dewpoint temperature | G0001 | 2.9 | G0004 | 2.0 | G0008 | 18.9 | G0007 | 2.0 |
| Rain gauge | | ~4 | | 0.8 | | ~4 | | |

Heights are in meters above surface, except for the pressure transducer and mercurial barometer, which is with respect to mean sea level.

†Propeller Anemometer, model no. 05103, R. M. Young Company, Traverse City, Michigan.

‡Pressure Transducer, model no. 270, Setra Systems, Acton, Massachusetts.

§Platinum Resistance Probe, Logan 4150 Series, Logan Enterprises, Liberty, Ohio.

¶Thermometer, positioned at the top of the local sampling tower to facilitate an estimation of boundary layer stability, except at SMO where both sensors were at the same height.

**Hygrometer, Technical Services Laboratory model no. 1088-400, Fort Walton Beach, Florida.

TABLE 1.6. SMO Sensor Instrument Heights on the Old Sampling Tower and the New Cellular Phone Tower

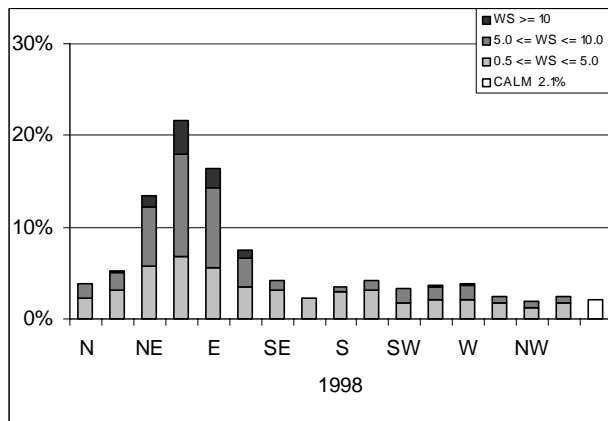
| Instrument | Old Sampling Tower Sensor Heights (m) | New Cellular Phone Tower Sensor Heights (m) |
|----------------------|--|---|
| Primary anemometer | 13.7 | 22.9 |
| Air temperature A | 14.0 | 18.9 |
| Air temperature B | | 18.9* |
| Air temperature C | 12.8 | 18.9 |
| Dewpoint temperature | 12.8 | 18.9 |

*Second Platinum Resistance Probe was installed on October 22, 1999.

TABLE 1.7. CMDL Meteorological Operations Summary

| Station | Expected Number of Data Points | Percent Data Capture | Number of Missing Data Points |
|---------|-----------------------------------|-------------------------|----------------------------------|
| 1998 | | | |
| BRW | 4,204,800 | 99.51% | 20,716 |
| MLO | 6,832,800 | 91.06% | 611,062 |
| SMO | 3,679,200 | 95.02% | 183,258 |
| SPO | 4,204,800 | 96.89% | 130,940 |
| Average | | 95.62% | |
| 1999 | | | |
| BRW | 4,204,800 | 98.70% | 54,832 |
| MLO | 6,832,800 | 89.82% | 695,350 |
| SMO | 3,778,560 | 83.60% | 619,545 |
| SPO | 4,204,800 | 96.01% | 167,660 |
| Average | | 92.03% | |

the time for 1998 and 1999, respectively. Because of the remoteness of the observatories, power outages are common and are the main reason for data loss. Hardware failure, system restarts, and system maintenance are the other reasons for data loss. At BRW, during the winter time periods, rime, snow, and ice occasionally would build up on the sensors and have to be removed by the station personnel.



1.5.2. STATION CLIMATOLOGIES

The 23-yr station climatologies are an important record for the interpretation of measured values of aerosols, trace gases, atmospheric turbidity, solar radiation, and the long-term changes in the records themselves. The records also serve to outline periods of local contamination.

Barrow

In Figure 1.1 histograms of hourly average vector wind direction and speed at BRW are presented in 16 direction classes and 3 speed classes. Winds from the “clean air” sector, north-northeast to southeast occurred 68.5% of the time in 1998 and 64% in 1999 as compared with 61.3% for the 21-yr period from 1977 through 1997 (Figure 1.2). Wind speeds in excess of 10 ms^{-1} in 1998 (8.7%) and 1999 (5.9%) were less frequent than in the 21-yr climatology (11.3%). The average wind speed of 5.5 ms^{-1} in 1998 was the fifth lowest average, while the 4.8 ms^{-1} in 1999 was the lowest average in the 23 years at the station (Table 1.8).

The average air temperature of -8.7°C in 1998 (Table 1.8), was considerably warmer than the 21-yr average of -12.4°C , while 1999 (-12.3°C) was very close to average. A new record high temperature was recorded in May 1998, and the record high temperature was tied in March 1998. The barometric pressure in 1998 was 1.8 hPa below the 21-yr average, while the average for 1999 was close to normal. September 1999 set a new record high pressure for the month, while new record lows were set in August 1998, January 1999, and May 1999. The summertime precipitation amounts for 1998 (54 mm) and 1999 (40 mm) were both below the long-term average of 61 mm.

Mauna Loa

The climatology of MLO is best understood when it is considered in two distinctive wind regimes, the night (downslope) period (1800–0559 Hawaiian Standard Time (HST)) and the day (upslope) period (0600–1759 HST). The 21-yr night and day wind histogram illustrate the two distinct wind regimes (Figure 1.3).

For the night regime, the 21-yr wind histogram (Figure 1.3) shows that 91.5% of all winds observed had a southerly component. The percentage of occurrence of southerly winds in 1998 was 90.4% (Figure 1.4) and 92.5% in 1999 (Figure 1.5).

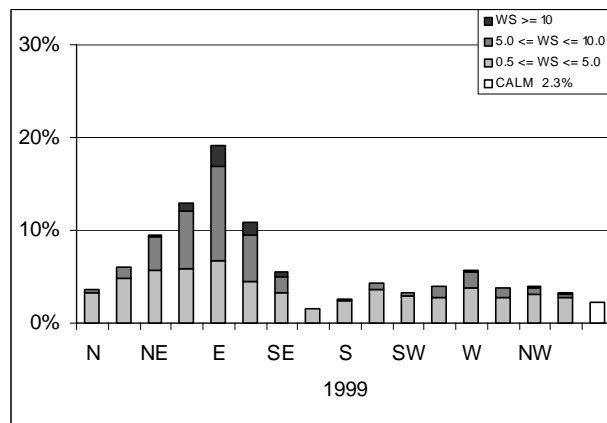


Fig. 1.1. Histogram of surface winds for BRW for 1998 (left) and 1999 (right). Percent frequency of winds is shown for each of 16 direction classes and 3 wind speed (WS) classes. Percent frequency of calm winds ($\text{WS} < 0.5 \text{ms}^{-1}$) is indicated in the legends and is shown as an open bar on each histogram.

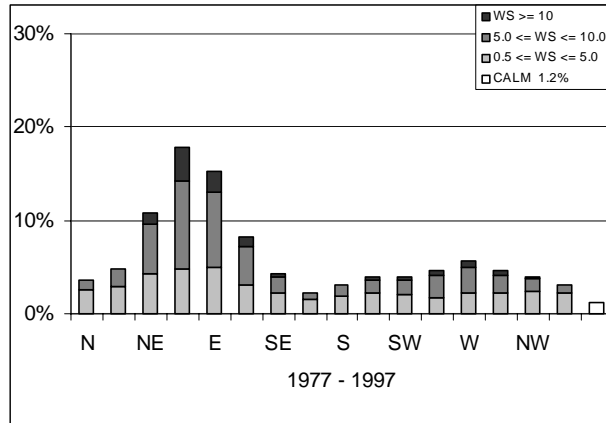


Fig. 1.2. Histogram of surface winds for BRW 1977 through 1997. Percent frequency of winds is shown for each of 16 direction classes and 3 wind speed (WS) classes. Percent frequency of calm winds ($WS < 0.5 \text{ ms}^{-1}$) is indicated in the legend and is shown as an open bar on the histogram.

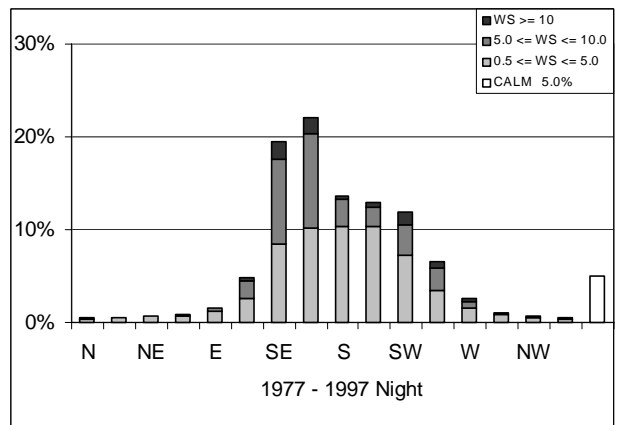
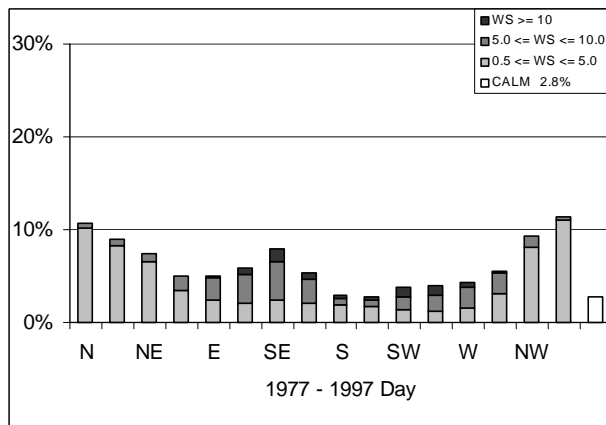


Fig. 1.3. Histograms of surface winds for MLO for 1977 through 1997 day (left) and night (right). Percent frequency of winds is shown for each of 16 direction classes and 3 wind speed (WS) classes. Percent frequency of calm winds ($WS < 0.5 \text{ ms}^{-1}$) is indicated in the legends and is shown as an open bar on each histogram.

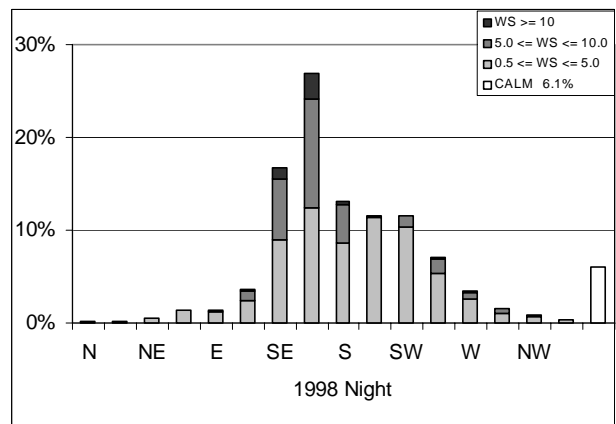
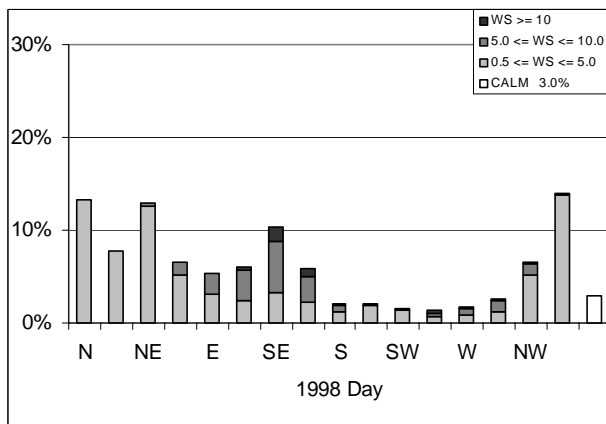


Fig. 1.4. Histograms of surface winds for MLO for 1998 day (left) and night (right). Percent frequency of winds is shown for each of 16 direction classes and 3 wind speed (WS) classes. Percent frequency of calm winds ($WS < 0.5 \text{ ms}^{-1}$) is indicated in the legends and is shown as an open bar on each histogram.

TABLE 1.8. BRW 1998 and 1999 Monthly Climate Summary

| | Jan. | Feb. | March | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Year |
|--|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| <i>1998</i> | | | | | | | | | | | | | |
| Prevailing wind direction | ENE | NE | E | ENE | ENE | E | E | E | ESE | ENE | ENE | SSW | ENE |
| Average wind speed (m s ⁻¹) | 6.4 | 5.2 | 5.0 | 4.8 | 6.1 | 4.4 | 6.4 | 5.4 | 5.0 | 6.5 | 6.7 | 3.3 | 5.5 |
| Maximum wind speed* (m s ⁻¹) | 13 | 14 | 13 | 14 | 14 | 9 | 12 | 16 | 14 | 21 | 15 | 12 | 21 |
| Direction of max. wind* (deg) | 76 | 56 | 108 | 80 | 62 | 88 | 92 | 219 | 103 | 55 | 64 | 79 | 55 |
| Average station pressure (hPa) | 1022.9 | 1014.4 | 1011.6 | 1008.2 | 1012.0 | 1015.4 | 1013.1 | 1003.9 | 1007.2 | 1010.1 | 1011.0 | 1019.1 | 1012.4 |
| Maximum pressure* (hPa) | 1037 | 1032 | 1038 | 1029 | 1023 | 1024 | 1023 | 1018 | 1021 | 1024 | 1028 | 1044 | 1044 |
| Minimum pressure* (hPa) | 998 | 994 | 994 | 993 | 997 | 1006 | 1000 | 983 | 987 | 983 | 998 | 991 | 983 |
| Average air temperature (°C) | -26.2 | -26.0 | -19.0 | -11.4 | -4.8 | 1.5 | 5.3 | 5.3 | 2.8 | -4.0 | -10.4 | -19.9 | -8.7 |
| Maximum temperature* (°C) | -19 | -11 | -1 | -2 | 8 | 18 | 15 | 14 | 9 | 3 | 0 | -1 | 18 |
| Minimum temperature* (°C) | -39 | -36 | -31 | -23 | -18 | -3 | -1 | -1 | -4 | -19 | -22 | -37 | -39 |
| Average dewpoint temperature (°C) | -29.0 | -29.0 | -21.3 | -12.9 | -6.2 | 0.6 | 4.3 | 4.0 | 1.3 | -6.1 | -12.5 | -22.0 | -11.0 |
| Maximum dewpoint temperature (°C) | -22 | -13 | -3 | -3 | 4 | 10 | 11 | 13 | 7 | 2 | 0 | -1 | 13 |
| Minimum dewpoint temperature (°C) | -42 | -40 | -34 | -26 | -21 | -4 | -2 | -3 | -8 | -22 | -25 | -41 | -42 |
| Precipitation (mm) | 0 | 0 | 0 | 0 | 1 | 1 | 15 | 21 | 14 | 1 | 0 | 0 | 54 |
| <i>1999</i> | | | | | | | | | | | | | |
| Prevailing wind direction | SW | NE | NE | E | E | E | E | E | E | E | ESE | SE | E |
| Average wind speed (m s ⁻¹) | 3.8 | 4.6 | 3.7 | 5.2 | 4.8 | 4.3 | 5.2 | 6.1 | 4.5 | 6.2 | 4.1 | 5.0 | 4.8 |
| Maximum wind speed* (m s ⁻¹) | 14 | 10 | 13 | 13 | 11 | 9 | 11 | 16 | 13 | 15 | 17 | 12 | 17 |
| Direction of max. wind* (deg) | 84 | 89 | 67 | 102 | 104 | 61 | 75 | 92 | 354 | 104 | 113 | 127 | 113 |
| Average station pressure (hPa) | 1015.4 | 1008.5 | 1019.3 | 1018.1 | 1016.6 | 1014.0 | 1014.6 | 1010.2 | 1008.9 | 1015.1 | 1010.6 | 1018.1 | 1014.2 |
| Maximum pressure* (hPa) | 1048 | 1026 | 1041 | 1037 | 1035 | 1020 | 1027 | 1021 | 1035 | 1031 | 1035 | 1041 | 1048 |
| Minimum pressure* (hPa) | 974 | 997 | 997 | 991 | 992 | 1001 | 997 | 1001 | 985 | 1000 | 993 | 997 | 974 |
| Average air temperature (°C) | -29.0 | -26.9 | -27.0 | -19.8 | -5.8 | 0.1 | 3.9 | 4.5 | 0.4 | -8.0 | -18.4 | -27.9 | -12.3 |
| Maximum temperature* (°C) | -9 | -18 | -17 | -4 | 1 | 6 | 17 | 20 | 8 | -1 | -9 | -17 | 20 |
| Minimum temperature* (°C) | -42 | -41 | -41 | -30 | -17 | -8 | -2 | -1 | -8 | -19 | -29 | -37 | -42 |
| Average dewpoint temperature (°C) | -31.7 | -29.5 | -29.7 | -21.8 | -6.9 | -0.4 | 2.2 | 3.0 | -1.4 | -10.7 | -20.9 | -30.7 | -14.8 |
| Maximum dewpoint temperature (°C) | -9 | -20 | -19 | -5 | 0 | 2 | 12 | 12 | 6 | -3 | -11 | -20 | 12 |
| Minimum dewpoint temperature (°C) | -46 | -45 | -46 | -33 | -19 | -4 | -2 | -4 | -10 | -21 | -32 | -40 | -46 |
| Precipitation (mm) | 0 | 0 | 0 | 0 | 1 | 6 | 9 | 19 | 4 | 0 | 0 | 0 | 40 |

Instrument heights: wind, 10.5 m; pressure, 9.5 m (MSL); air temperature, 2.9 m; dewpoint temperature, 2.9 m. Wind and temperature instruments are on a tower 25 m northeast of the main building.

*Maximum and minimum values are hourly averages.

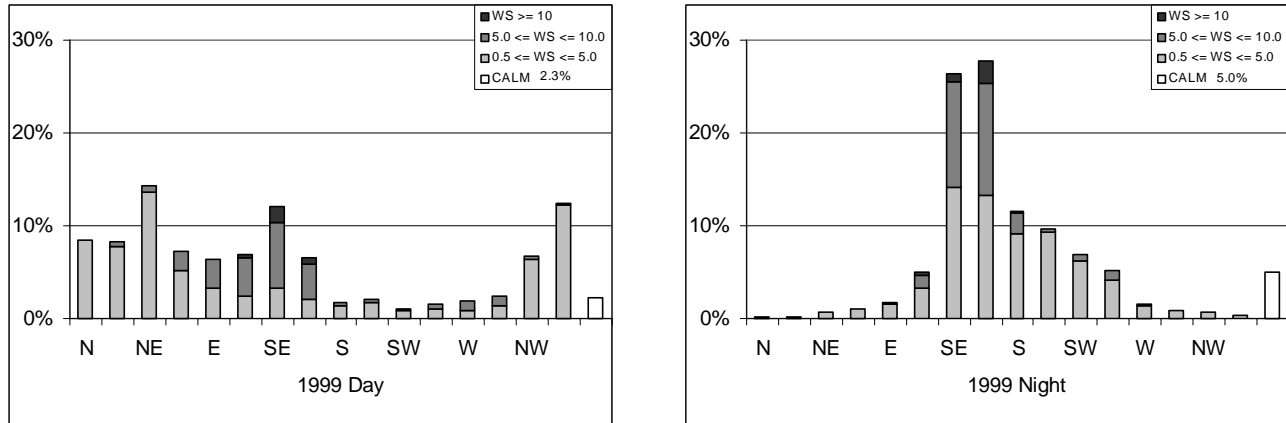


Fig. 1.5. Histograms of surface winds for MLO for 1999 day (left) and night (right). Percent frequency of winds is shown for each of 16 direction classes and 3 wind speed (WS) classes. Percent frequency of calm winds ($WS < 0.5 \text{ ms}^{-1}$) is indicated in the legends and is shown as an open bar on each histogram.

Pressure gradient controlled winds ($WS \geq 10 \text{ ms}^{-1}$) from predominately westerly and southeasterly directions, occurred 4.6% of the time in 1998 and 3.8% in 1999, both of which were below the 21-yr average of 7.3%. The annual average wind speeds for both 1998 and 1999 were below the long-term average (Tables 1.9 and 1.10). The upslope, or northerly component, winds (north-northwest through east-northeast) that occurred 2.5% of the time in 1998 and 1999, are the result of the daytime upslope flow extending into the early evening hours.

For the day regime the 1998 and 1999 wind histograms (Figures 1.4 and 1.5) indicate that winds from the west-northwest through east-southeast occurred 63.6% of the time in 1998 and 59.9% of the time in 1999 compared with 58.4% for the 21-yr climatology (Figure 1.3). Pressure gradient controlled winds ($WS \geq 10 \text{ ms}^{-1}$) occurred 3.6% of the time in 1998 and 2.9% of the time in 1999, both of which were lower than the 21-yr average of 6%. In 1998 and 1999 the pressure gradient winds, which are usually associated with storms, followed the expected pattern of fewer occurrences during the day regime. The day wind histogram is more uniformly distributed in the light wind classes than the night wind histogram. This is due to the variable wind directions during the transition periods at dawn and dusk, most of which are included in this regime.

The average ambient temperatures for 1998 and 1999 (Tables 1.9 and 1.10), combining both day and night regimes, were 8.2°C and 7.2°C , respectively, both of which were above the long-term average of 7.1°C . April 1999 and October 1999 both tied the minimum record temperature for the month. The average barometric pressure for 1998 (681.1 hPa) was above the long-term average of 680.4 hPa , while 1999 (680.0 hPa) was below the long-term average. The months of February, April, and July in 1998 each tied their maximum values for the month. The precipitation amounts in 1998 (66 mm) and 1999 (106 mm) were both much lower than the long-term average of 480 mm .

Samoa

A comparison of SMO's 1998 and 1999 wind histograms (Figure 1.6) to that of the 21-yr period (Figure 1.7) shows a considerably lower percentage (46%) of clean air sector winds (north-northwest through southeast) in 1998 while 1999

(72.4%) was considerably higher than the long-term average of 60.3%. The occurrence of winds in the 10 ms^{-1} or greater class was 5.4% in 1998 and 4.7% in 1999, while the expected occurrence based on the 21-yr average is 4.8%. The annual average wind speed for 1998 (5.9 ms^{-1}) was above normal, while 1999 (4.5 ms^{-1}) (Table 1.11) was slightly below the long-term-average of 4.9 ms^{-1} .

The average ambient temperatures for 1998 (26.2°C) and 1999 (26.7°C) were cooler than the 21-yr average of 27.1°C . Record minimum temperatures were tied in July 1998 and October 1999. The average barometric pressures for 1998 (1002.1 hPa) and 1999 (1001.8 hPa) were higher than the 21-yr average of 1000.3 hPa . High-pressure records were tied in the months of May, August, September, and October of 1998. A new high-pressure record was set in July 1998 that also ties the all time record high in 23 years of observations at SMO. The precipitation amounts in 1998 (1172 mm) and 1999 (1858 mm) were drier than the normal amount of 2108 mm .

South Pole

The distribution of the surface wind direction in 1998 and 1999 (Figure 1.8) shows a percentage of "clean air" sector (grid north-northwest through east-southeast) winds of 93.2% in 1998 and 92.7% in 1999 similar to the 21-yr average of 93.9% (Figure 1.9). The percentage of winds in the 10 ms^{-1} or greater class was 2.6% for both 1998 and 1999 compared to 3.9% for the long-term average. The annual average wind speeds for 1998 (5.2 ms^{-1}) and 1999 (5.0 ms^{-1}) were slightly less than the long-term average wind speed of 5.4 ms^{-1} .

The average temperatures for 1998 (-50.0°C) (Table 1.12) and 1999 (-49.9°C) were cooler than the long-term average of -49.0°C . January 1998 and December 1999 both tied their record minimum temperatures for the month. The minimum temperature in 1998 of -75°C occurred in May and September. The minimum temperature in 1999 of -74°C occurred in July. The annual average barometric pressure for 1998 (677.4 hPa) was 1.9 hPa lower than the 21-yr average of 679.3 hPa , while the average barometric pressure for 1999 was equal to the long-term average. May 1998 tied its record low-pressure record, and June 1999 set a new high pressure reading for the month, surpassing the old June record by 4 hPa .

TABLE 1.9. MLO 1998 Monthly Climate Summary

| | Jan. | Feb. | March | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Year |
|--|--------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| | <i>Night</i> | | | | | | | | | | | | |
| Prevailing wind direction | WSW | SW | SSE | SE | SSE | SSE | SSE | SSE | SSE | SSE | SSE | SSE | SSE |
| Average wind speed (m s ⁻¹) | 5.2 | 3.2 | 4.9 | 4.5 | 2.7 | 3.6 | 4.3 | 2.9 | 3.0 | 4.6 | 5.2 | 4.8 | 4.0 |
| Maximum wind speed* (m s ⁻¹) | 16 | 9 | 13 | 13 | 9 | 11 | 14 | 8 | 10 | 12 | 14 | 15 | 16 |
| Direction of max. wind* (deg) | 249 | 306 | 149 | 157 | 159 | 169 | 169 | 176 | 159 | 159 | 159 | 164 | 249 |
| Average station pressure (hPa) | 679.6 | 682.0 | 680.9 | 680.8 | 680.9 | 681.5 | 682.0 | 681.5 | 680.5 | 681.4 | 680.8 | 680.4 | 681.1 |
| Maximum pressure* (hPa) | 683 | 686 | 684 | 684 | 683 | 684 | 686 | 684 | 682 | 685 | 684 | 684 | 686 |
| Minimum pressure* (hPa) | 671 | 678 | 677 | 678 | 678 | 679 | 679 | 678 | 678 | 678 | 677 | 676 | 671 |
| Average air temperature (°C) | 5.4 | 6.1 | 5.2 | 5.2 | 6.5 | 8.1 | 6.9 | 6.8 | 6.6 | 6.4 | 5.4 | 4.8 | 6.2 |
| Maximum temperature* (°C) | 12 | 13 | 10 | 12 | 13 | 17 | 15 | 14 | 12 | 12 | 10 | 10 | 17 |
| Minimum temperature* (°C) | -3 | -2 | 1 | -1 | 0 | 2 | 1 | 1 | 2 | 1 | 1 | 0 | -3 |
| Average dewpoint temperature (°C) | -24.3 | -20.6 | -19.1 | -22.0 | -17.4 | -15.1 | -13.3 | -12.0 | -12.9 | -13.0 | -10.7 | -15.5 | -16.0 |
| Maximum dewpoint temperature (°C) | 1 | 7 | 2 | 3 | 5 | 5 | 6 | 8 | 7 | 6 | 6 | 4 | 8 |
| Minimum dewpoint temperature (°C) | -33 | -33 | -35 | -38 | -31 | -30 | -34 | -29 | -27 | -31 | -33 | -31 | -38 |
| Precipitation (mm) | 7 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 7 | 0 | 16 |
| | <i>Day</i> | | | | | | | | | | | | |
| Prevailing wind direction | NW | NNW | SE | N | NNW | NE | NE | NNW | NE | NE | SE | SE | NNW |
| Average wind speed (m s ⁻¹) | 4.6 | 3.1 | 4.3 | 4.2 | 2.9 | 3.3 | 4.3 | 3.0 | 2.7 | 3.8 | 4.4 | 3.9 | 3.7 |
| Maximum wind speed* (m s ⁻¹) | 15 | 12 | 13 | 13 | 9 | 10 | 12 | 10 | 8 | 11 | 13 | 14 | 15 |
| Direction of max. wind* (deg) | 256 | 310 | 132 | 159 | 137 | 155 | 169 | 141 | 157 | 164 | 149 | 162 | 256 |
| Average station pressure (hPa) | 679.7 | 681.9 | 681.1 | 681.1 | 681.1 | 681.7 | 682.2 | 681.7 | 680.6 | 681.4 | 680.8 | 680.3 | 681.2 |
| Maximum pressure* (hPa) | 683 | 686 | 685 | 685 | 684 | 684 | 685 | 684 | 683 | 685 | 683 | 684 | 686 |
| Minimum pressure* (hPa) | 672 | 678 | 677 | 678 | 678 | 679 | 679 | 678 | 678 | 678 | 677 | 676 | 672 |
| Average air temperature (°C) | 9.7 | 10.2 | 9.6 | 9.7 | 10.5 | 12.3 | 11.6 | 10.7 | 10.5 | 10.3 | 8.7 | 8.0 | 10.2 |
| Maximum temperature* (°C) | 17 | 17 | 15 | 15 | 17 | 20 | 18 | 17 | 18 | 17 | 15 | 15 | 20 |
| Minimum temperature* (°C) | -2 | 0 | 0 | 0 | 2 | 5 | 3 | 3 | 2 | 1 | 1 | 1 | -2 |
| Average dewpoint temperature (°C) | -17.0 | -12.7 | -11.2 | -11.6 | -7.7 | -7.1 | -7.4 | -3.4 | -2.8 | -6.3 | -7.3 | -9.3 | -8.3 |
| Maximum dewpoint temperature (°C) | 4 | 7 | 7 | 6 | 7 | 6 | 8 | 9 | 8 | 8 | 8 | 5 | 9 |
| Minimum dewpoint temperature (°C) | -32 | -31 | -32 | -34 | -30 | -30 | -32 | -28 | -27 | -29 | -33 | -31 | -34 |
| Precipitation (mm) | 1 | 0 | 0 | 1 | 3 | 0 | 4 | 17 | 3 | 13 | 7 | 0 | 50 |

Instrument heights: wind, 10.2 m; pressure, 3398.4 m (MSL); air temperature, 2.0 m; dewpoint temperature, 2.0 m. Wind and temperature instruments are on a tower 15 m southwest of the main building.

*Maximum and minimum values are hourly averages.

TABLE 1.10. MLO 1999 Monthly Climate Summary

| | Jan. | Feb. | March | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Year |
|--|--------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| | <i>Night</i> | | | | | | | | | | | | |
| Prevailing wind direction | SE | S | SSE | SE | SSE | SE | SSE | SE | SSE | SE | SE | SE | SSE |
| Average wind speed (m s ⁻¹) | 4.5 | 2.5 | 4.6 | 3.2 | 3.6 | 3.6 | 4.6 | 5.1 | 3.5 | 4.6 | 4.4 | 5.2 | 4.3 |
| Maximum wind speed* (m s ⁻¹) | 14 | 5 | 13 | 10 | 10 | 9 | 13 | 14 | 15 | 13 | 11 | 13 | 15 |
| Direction of max. wind* (deg) | 130 | 180 | 157 | 156 | 163 | 143 | 156 | 126 | 117 | 151 | 161 | 137 | 117 |
| Average station pressure (hPa) | 679.4 | 679.7 | 678.9 | 679.1 | 680.4 | 680.9 | 680.5 | 681.2 | 680.1 | 680.5 | 680.2 | 678.7 | 680.0 |
| Maximum pressure* (hPa) | 683 | 683 | 682 | 682 | 683 | 684 | 683 | 684 | 683 | 683 | 683 | 682 | 684 |
| Minimum pressure* (hPa) | 675 | 677 | 676 | 676 | 678 | 678 | 678 | 678 | 678 | 675 | 678 | 673 | 673 |
| Average air temperature (°C) | 3.9 | 2.6 | 3.1 | 2.4 | 5.7 | 7.3 | 7.3 | 7.3 | 6.3 | 6.6 | 5.0 | 3.3 | 5.1 |
| Maximum temperature* (°C) | 10 | 9 | 8 | 11 | 12 | 14 | 14 | 12 | 12 | 11 | 10 | 8 | 14 |
| Minimum temperature* (°C) | 0 | -2 | -2 | -3 | 2 | 3 | 3 | 3 | 0 | 2 | 0 | -2 | -3 |
| Average dewpoint temperature (°C) | -13.5 | -11.7 | -13.7 | -13.4 | -11.6 | -13.4 | -17.3 | -10.9 | -15.2 | -13.3 | -14.4 | -6.2 | -12.9 |
| Maximum dewpoint | 5 | 6 | 6 | 3 | 5 | 5 | 6 | 8 | 6 | 5 | 4 | 5 | 8 |
| Minimum dewpoint temperature (°C) | -32 | -27 | -27 | -30 | -26 | -30 | -31 | -30 | -28 | -26 | -32 | -25 | -32 |
| Precipitation (mm) | 6 | 3 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 23 | 35 |
| | <i>Day</i> | | | | | | | | | | | | |
| Prevailing wind direction | SE | NE | SE | NNW | NE | NE | SE | SE | NW | NE | NE | SE | NE |
| Average wind speed (m s ⁻¹) | 4.6 | 1.8 | 3.7 | 3.1 | 3.4 | 3.6 | 3.9 | 4.7 | 3.3 | 3.9 | 4.0 | 5.2 | 3.9 |
| Maximum wind speed* (m s ⁻¹) | 18 | 5 | 11 | 8 | 10 | 10 | 12 | 15 | 13 | 13 | 12 | 14 | 18 |
| Direction of max. wind* (deg) | 145 | 201 | 147 | 161 | 156 | 32 | 136 | 122 | 115 | 148 | 152 | 152 | 145 |
| Average station pressure (hPa) | 679.3 | 679.7 | 679.0 | 279.2 | 680.5 | 680.9 | 680.7 | 681.2 | 680.1 | 680.4 | 680.1 | 678.6 | 680.0 |
| Maximum pressure* (hPa) | 683 | 683 | 682 | 682 | 683 | 684 | 684 | 685 | 683 | 683 | 682 | 682 | 685 |
| Minimum pressure* (hPa) | 675 | 676 | 677 | 677 | 678 | 678 | 679 | 678 | 678 | 676 | 677 | 673 | 673 |
| Average air temperature (°C) | 7.3 | 6.3 | 7.2 | 6.4 | 10.0 | 12.1 | 11.9 | 11.8 | 10.1 | 10.7 | 8.9 | 6.8 | 9.2 |
| Maximum temperature* (°C) | 16 | 13 | 12 | 14 | 15 | 17 | 18 | 18 | 17 | 18 | 14 | 14 | 18 |
| Minimum temperature* (°C) | -1 | -2 | -2 | -2 | 3 | 4 | 5 | 4 | 2 | 3 | 2 | -2 | -2 |
| Average dewpoint temperature (°C) | -8.6 | -6.7 | -7.5 | -6.5 | -6.3 | -7.5 | -8.3 | -4.5 | -4.5 | -6.1 | -9.2 | -5.3 | -6.7 |
| Maximum dewpoint temperature (°C) | 6 | 9 | 10 | 5 | 6 | 8 | 8 | 12 | 8 | 8 | 5 | 7 | 12 |
| Minimum dewpoint temperature (°C) | -29 | -28 | -26 | -28 | -24 | -30 | -27 | -29 | -29 | -25 | -26 | -25 | -30 |
| Precipitation (mm) | 2 | 23 | 1 | 9 | 11 | 2 | 1 | 0 | 0 | 5 | 0 | 16 | 71 |

Instrument heights: wind, 10.2 m; pressure, 3398.4 m (MSL); air temperature, 2.0 m; dewpoint temperature, 2.0 m. Wind and temperature instruments are on a tower 15 m southwest of the main building.

*Maximum and minimum values are hourly averages.

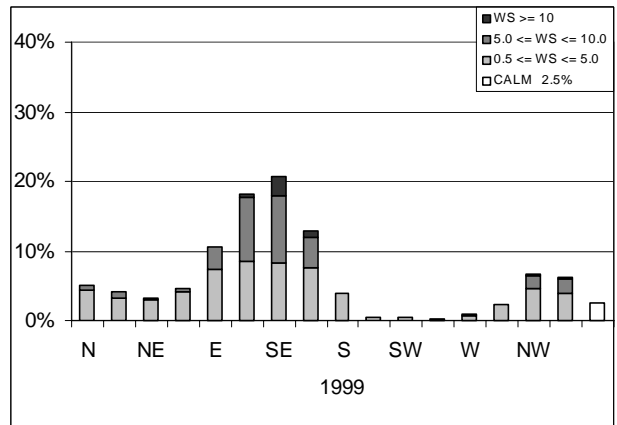
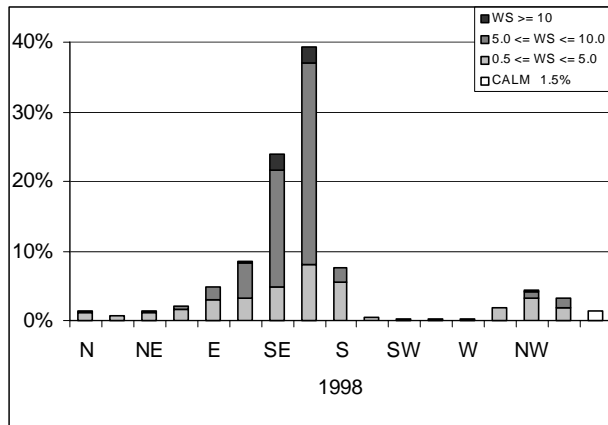


Fig. 1.6. Histograms of surface winds for SMO for 1998 (left) and 1999 (right). Percent frequency of winds is shown for each of 16 direction classes and 3 wind speed (WS) classes. Percent frequency of calm winds ($WS < 0.5 \text{ ms}^{-1}$) is indicated in the legends and is shown as an open bar on each histogram.

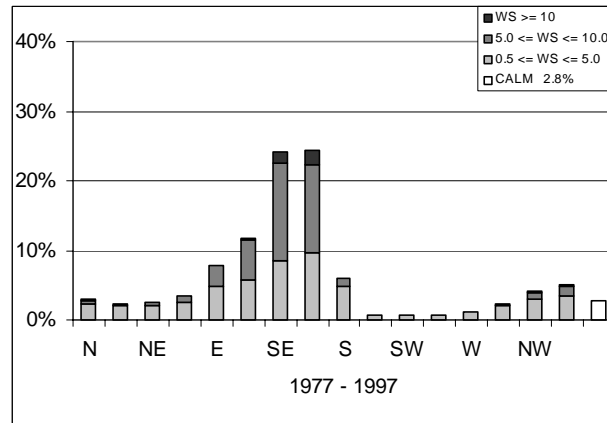


Fig. 1.7. Histogram of surface winds for SMO 1977 through 1997. Percent frequency of winds is shown for each of 16 direction classes and 3 wind speed (WS) classes. Percent frequency of calm winds ($WS < 0.5 \text{ ms}^{-1}$) is indicated in the legend and is shown as an open bar on the histogram.

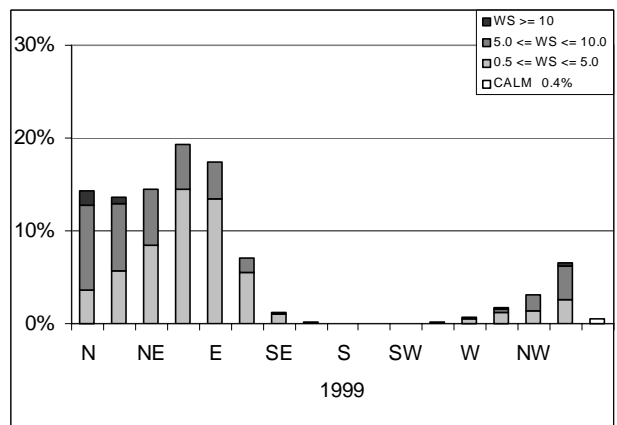
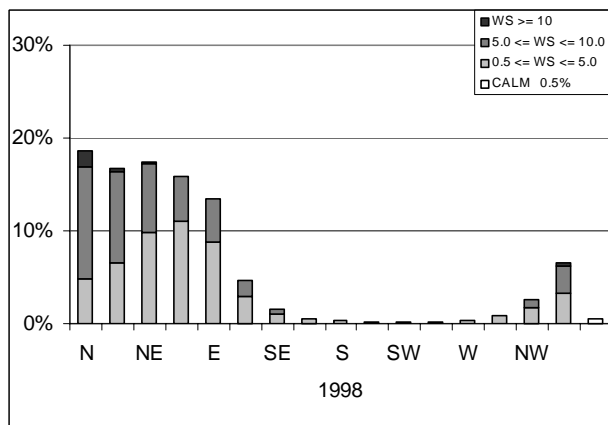


Fig. 1.8. Histograms of surface winds for SPO for 1998 (left) and 1999 (right). Percent frequency of winds is shown for each of 16 direction classes and 3 wind speed (WS) classes. Percent frequency of calm winds ($WS < 0.5 \text{ ms}^{-1}$) is indicated in the legends and is shown as an open bar on each histogram.

TABLE 1.11. SMO 1998 and 1999 Monthly Climate Summary

| | Jan. | Feb. | March | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Year |
|--|-------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| | <i>1998</i> | | | | | | | | | | | | |
| Prevailing wind direction | NW | SSE | SSE | SSE | SSE | SE | SSE | SSE | SSE | SE | SE | NNW | SSE |
| Average wind speed (m s ⁻¹) | 5.6 | 4.1 | 4.4 | 5.9 | 6.1 | 8.1 | 6.5 | 7.5 | 8.0 | 5.9 | 3.8 | 5.2 | 5.9 |
| Maximum wind speed* (m s ⁻¹) | 13 | 11 | 12 | 10 | 11 | 13 | 11 | 12 | 13 | 10 | 10 | 13 | 13 |
| Direction of max. wind* (deg) | 135 | 155 | 132 | 132 | 165 | 141 | 138 | 146 | 157 | 127 | 95 | 344 | 141 |
| Average station pressure (hPa) | 998.4 | 999.8 | 1000.1 | 1003.0 | 1003.7 | 1003.7 | 1004.6 | 1004.2 | 1004.1 | 1002.6 | 1000.8 | 999.4 | 1002.1 |
| Maximum pressure* (hPa) | 1002 | 1006 | 1004 | 1006 | 1007 | 1007 | 1009 | 1009 | 1009 | 1008 | 1004 | 1004 | 1009 |
| Minimum pressure* (hPa) | 992 | 995 | 996 | 999 | 1000 | 999 | 1000 | 1000 | 1000 | 999 | 998 | 995 | 992 |
| Average air temperature (°C) | 27.2 | 27.0 | 27.0 | 26.5 | 25.8 | 25.6 | 24.4 | 25.1 | 25.7 | 26.4 | 27.2 | 27.2 | 26.2 |
| Maximum temperature* (°C) | 29 | 30 | 30 | 29 | 27 | 27 | 26 | 27 | 27 | 29 | 29 | 30 | 30 |
| Minimum temperature* (°C) | 25 | 25 | 24 | 23 | 24 | 23 | 21 | 23 | 23 | 24 | 24 | 23 | 21 |
| Average dewpoint temperature (°C) | 25.0 | 23.8 | 23.5 | 22.9 | 22.0 | 22.4 | 20.0 | 22.2 | 22.7 | 23.0 | 23.6 | 23.5 | 22.8 |
| Maximum dewpoint temperature (°C) | 26 | 26 | 26 | 26 | 25 | 24 | 24 | 25 | 25 | 25 | 25 | 26 | 26 |
| Minimum dewpoint Temperature (°C) | 23 | 22 | 20 | 19 | 18 | 18 | 14 | 19 | 19 | 18 | 21 | 20 | 14 |
| Precipitation (mm) | 150 | 42 | 347 | 18 | 27 | 56 | 22 | 10 | 63 | 101 | 36 | 300 | 1172 |
| | <i>1999</i> | | | | | | | | | | | | |
| Prevailing wind Direction | SE | NNW | SE | ESE | SSE | SE | ESE | ESE | SE | ESE | SE | N | SE |
| Average wind Speed (m s ⁻¹) | 3.9 | 3.7 | 4.0 | 3.5 | 4.2 | 4.1 | 4.8 | 5.5 | 6.7 | 5.9 | 4.2 | 3.7 | 4.5 |
| Maximum wind Speed* (m s ⁻¹) | 11 | 10 | 9 | 10 | 14 | 12 | 9 | 13 | 19 | 13 | 10 | 9 | 19 |
| Direction of max. Wind* (deg) | 348 | 330 | 109 | 115 | 155 | 101 | 139 | 151 | 126 | 131 | 312 | 271 | 126 |
| Average station Pressure (hPa) | 1000.5 | 1000.2 | 1000.8 | 1001.5 | 1002.0 | 1002.9 | 1003.0 | 1004.0 | 1003.3 | 1002.6 | 1001.4 | 1000.3 | 1001.8 |
| Maximum pressure* (hPa) | 1004 | 1004 | 1004 | 1005 | 1005 | 1006 | 1006 | 1008 | 1007 | 1007 | 1005 | 1004 | 1008 |
| Minimum pressure* (hPa) | 997 | 995 | 997 | 998 | 999 | 1000 | 1000 | 1001 | 999 | 999 | 998 | 997 | 995 |
| Average air Temperature (°C) | 26.2 | 26.8 | 27.5 | 27.8 | 26.3 | 26.7 | 26.6 | 26.4 | 26.2 | 26.1 | 26.5 | 27.3 | 26.7 |
| Maximum temperature* (°C) | 29 | 29 | 30 | 30 | 30 | 29 | 28 | 28 | 28 | 28 | 28 | 29 | 30 |
| Minimum temperature* (°C) | 23 | 23 | 24 | 24 | 22 | 24 | 23 | 22 | 23 | 21 | 22 | 24 | 21 |
| Average dewpoint temperature (°C) | 24.3 | 24.7 | 25.0 | 25.4 | 24.4 | 24.5 | 23.9 | 22.7 | 22.4 | 22.7 | 22.9 | 22.9 | 23.8 |
| Maximum dewpoint temperature (°C) | 26 | 26 | 27 | 27 | 26 | 26 | 26 | 25 | 24 | 24 | 25 | 25 | 27 |
| Minimum dewpoint temperature (°C) | 21 | 22 | 22 | 23 | 21 | 22 | 22 | 19 | 18 | 20 | 20 | 18 | 18 |
| Precipitation (mm) | 228 | 160 | 87 | 38 | 360 | 97 | 33 | 75 | 282 | 147 | 195 | 155 | 1858 |

Instrument heights: wind, 13.7 m; pressure, 78.5 m (MSL); air temperature, 18.9 m; dewpoint temperature, 18.9 m. Wind and temperature instruments are on Lauagae Ridge, 110 m northeast of the main building.

*Maximum and minimum values are hourly averages.

TABLE 1.12. SPO 1998 and 1999 Monthly Climate Summary

| | Jan. | Feb. | March | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Year |
|--|-------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| | <i>1998</i> | | | | | | | | | | | | |
| Prevailing wind direction | N | NE | NE | ENE | ESE | E | NNE | NE | ENE | NE | N | NNE | N |
| Average wind speed (m s ⁻¹) | 4.5 | 4.4 | 5.2 | 4.9 | 6.1 | 5.0 | 6.2 | 5.5 | 5.1 | 5.2 | 6.6 | 3.6 | 5.2 |
| Maximum wind speed* (m s ⁻¹) | 9 | 9 | 9 | 11 | 14 | 10 | 14 | 12 | 11 | 10 | 14 | 9 | 14 |
| Direction of max. wind* (deg) | 359 | 3 | 13 | 3 | 351 | 346 | 9 | 353 | 28 | 26 | 3 | 18 | 351 |
| Average station pressure (hPa) | 686.1 | 683.8 | 678.2 | 668.0 | 675.3 | 680.1 | 673.2 | 672.6 | 675.9 | 675.6 | 678.5 | 682.9 | 677.4 |
| Maximum pressure* (hPa) | 698 | 694 | 687 | 681 | 685 | 689 | 684 | 683 | 687 | 696 | 693 | 692 | 698 |
| Minimum pressure* (hPa) | 680 | 675 | 664 | 658 | 653 | 666 | 659 | 660 | 664 | 662 | 667 | 670 | 653 |
| Average air temperature (°C) | -27.5 | -38.4 | -53.0 | -62.2 | -58.0 | -54.6 | -59.1 | -63.0 | -62.2 | -53.8 | -36.4 | -28.6 | -50.0 |
| Maximum temperature* (°C) | -20 | -26 | -42 | -46 | -35 | -37 | -44 | -47 | -46 | -39 | -23 | -21 | -20 |
| Minimum temperature* (°C) | -38 | -52 | -62 | -73 | -75 | -69 | -74 | -73 | -75 | -66 | -48 | -34 | -75 |
| Average dewpoint temperature (°C) | -30.4 | -41.7 | -56.3 | -64.6 | -61.0 | -57.8 | -61.8 | -65.8 | -65.4 | -56.8 | -39.2 | -31.5 | -52.9 |
| Maximum dewpoint temperature (°C) | -23 | -29 | -45 | -49 | -37 | -40 | -46 | -49 | -49 | -41 | -26 | -24 | -23 |
| Minimum dewpoint Temperature (°C) | -42 | -55 | -66 | -76 | -78 | -73 | -76 | -76 | -79 | -69 | -50 | -37 | -79 |
| Precipitation (mm) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | <i>1999</i> | | | | | | | | | | | | |
| Prevailing wind Direction | NNW | E | ENE | NE | N | ENE | E | NE | E | N | NNE | E | ENE |
| Average wind Speed (m s ⁻¹) | 4.7 | 4.6 | 4.6 | 5.7 | 6.1 | 5.3 | 5.3 | 6.0 | 5.1 | 5.4 | 4.0 | 3.6 | 5.0 |
| Maximum wind Speed* (m s ⁻¹) | 12 | 12 | 10 | 12 | 12 | 11 | 12 | 14 | 12 | 12 | 9 | 8 | 14 |
| Direction of max. Wind* (deg) | 341 | 9 | 336 | 358 | 10 | 25 | 348 | 32 | 6 | 357 | 17 | 296 | 32 |
| Average station Pressure (hPa) | 690.5 | 685.1 | 681.0 | 671.5 | 674.5 | 688.8 | 675.0 | 674.8 | 679.4 | 671.9 | 679.9 | 679.1 | 679.3 |
| Maximum pressure* (hPa) | 703 | 695 | 692 | 686 | 692 | 711 | 690 | 691 | 699 | 688 | 698 | 693 | 711 |
| Minimum pressure* (hPa) | 680 | 674 | 673 | 660 | 658 | 673 | 660 | 657 | 665 | 659 | 662 | 669 | 657 |
| Average air Temperature (°C) | -26.0 | -41.0 | -54.0 | -60.6 | -56.8 | -58.2 | -62.7 | -56.4 | -62.0 | -51.1 | -39.4 | -31.5 | -49.9 |
| Maximum temperature* (°C) | -19 | -22 | -39 | -53 | -36 | -42 | -46 | -38 | -44 | -33 | -32 | -24 | -19 |
| Minimum temperature* (°C) | -34 | -49 | -69 | -72 | -73 | -71 | -74 | -69 | -72 | -69 | -51 | -41 | -74 |
| Average dewpoint temperature (°C) | -28.5 | -44.5 | -57.6 | -64.3 | -60.4 | -61.6 | -66.3 | -60.3 | -65.8 | -54.1 | -43.2 | -34.9 | -53.2 |
| Maximum dewpoint temperature (°C) | -19 | -24 | -42 | -56 | -38 | -45 | -50 | -41 | -47 | -35 | -34 | -27 | -19 |
| Minimum dewpoint temperature (°C) | -37 | -53 | -73 | -76 | -77 | -75 | -78 | -74 | -75 | -72 | -55 | -45 | -78 |
| Precipitation (mm) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Instrument heights: wind, 10.0 m; pressure, 2841 m (MSL); air temperature, 2.0 m; dewpoint temperature, 2.0 m. Wind and temperature instruments are on a tower 91.4-m grid north-northwest of the Atmospheric Research Observatory.

*Maximum and minimum values are hourly averages.

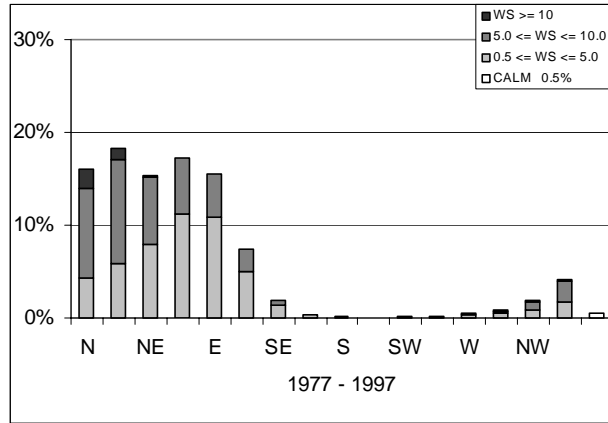


Fig. 1.9. Histogram of surface winds for SPO 1977 through 1997. Percent frequency of winds is shown for each of 16 direction classes and 3 wind speed (WS) classes. Percent frequency of calm winds ($WS < 0.5 \text{ ms}^{-1}$) is indicated in the legend and is shown as an open bar on the histogram.

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