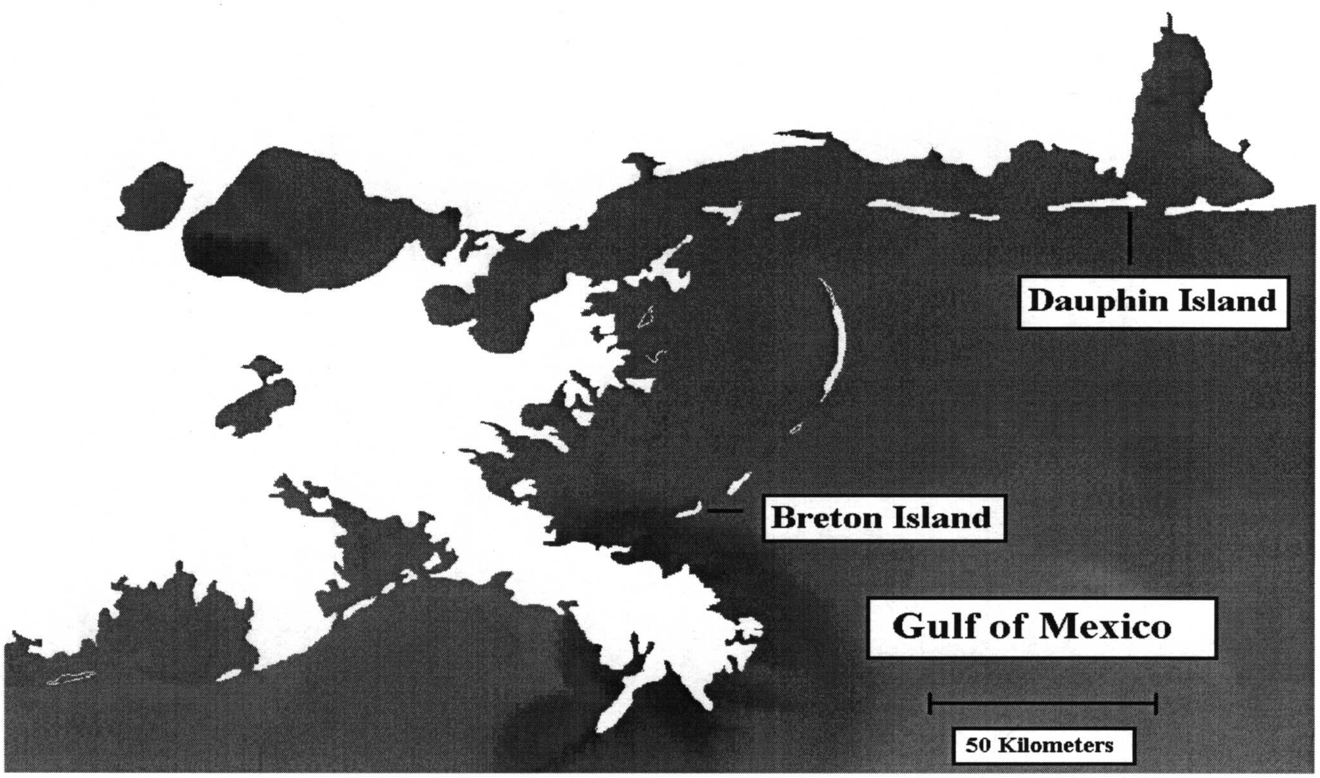
OCS Study
MMS 2000-014

Coastal Marine Institute

Air Quality and Dispersion Meteorology over the Northeastern Gulf of Mexico: Measurements, Analyses, and Syntheses



U.S. Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region

Cooperative Agreement
Coastal Marine Institute
Louisiana State University

OCS Study
MMS 2000-014

Coastal Marine Institute

Air Quality and Dispersion Meteorology over the Northeastern Gulf of Mexico: Measurements, Analyses, and Syntheses

Authors

S. A. Hsu
and
B. W. Blanchard

March 2000

Prepared under MMS Contract
14-35-0001-30660-19925
by
Coastal Marine Institute
Louisiana State University
Baton Rouge, Louisiana 70803

Published by

U.S. Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region

Cooperative Agreement
Coastal Marine Institute
Louisiana State University

DISCLAIMER

This report was prepared under contract between the Minerals Management Service (MMS) and the Coastal Studies Institute, Louisiana State University. This report has been technically reviewed by the MMS and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Service, nor does mention of trade names or commercial products constitute endorsement or recommendation for use. It is, however, exempt from review and compliance with MMS editorial standards.

REPORT AVAILABILITY

Extra copies of the report may be obtained from the Public Information Office (Mail Stop 5034) at the following address:

U.S. Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region
Attention: Public Information Office (MS 5034)
1201 Elmwood Park Boulevard
New Orleans, Louisiana 70123-2394

Telephone Number: 1-800-200-GULF or
504-736-2519

CITATION

Suggested citation:

Hsu, S. A. and B. W. Blanchard. 2000. Air Quality and Dispersion Meteorology Over the Northeast Gulf of Mexico: Measurements, Analyses, and Syntheses. OCS Study MMS 2000-014. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. 188 pp.

FRONT COVER

Advanced Very High Resolution satellite infrared image of our study area in the northeast Gulf of Mexico captured on 3 March 1997 0859 GMT (courtesy of the Earth Scan Lab, Louisiana State University).

ABSTRACT

Meteorological and air quality data recorded during the period of May 1997 through July 1998 is reduced and presented in this final report. The data was acquired from monitoring stations located on Dauphin and Breton Islands in the northeast Gulf of Mexico. It was found that the hourly average pollutant (SO_2 and NO_2) concentrations at both sites were less than 6 ppb during over half of this reporting period. Weak seasonal and diurnal trends were exhibited at Dauphin Island; the seasonal trend was less evident at Breton Island and diurnal peaks were generally not distinguishable. Maximum concentrations of both SO_2 and NO_2 at Dauphin Island were primarily associated with wind flow from the north and northeast; maximum SO_2 concentrations at Breton were also seen with northerly winds, but NO_2 maximums were often recorded under flow from the south and southwest. Unstable atmospheric conditions dominated over the Breton Sound area throughout the year, with free convection being observed as often as 15% of the time. Methods for determining the stability category, turbulence intensity, drag coefficient, and mixed heights from routinely available measurements are described. Computed values are in good agreement with observed data. Both air quality and meteorological results are consistent with findings from datasets previously obtained in this area.

TABLE OF CONTENTS

LIST OF FIGURES

List of Figures continued.

List of Figures continued.

List of Figures continued.

List of Figures continued.

List of Figures continued.

List of Figures continued.

LIST OF TABLES

List of Tables continued.

ACKNOWLEDGMENTS

The successful execution and completion of this field measurement program would not have been possible without the assistance of both the Alabama Marine Resources Division and the Kerr-McGee Corporation, who provided facilities for our monitoring stations. We especially recognize Kerr-McGee for preparing a second location for us following damage from Hurricane Danny. The staffs of Southern Seaplane and the fishing camp Chandeleur Islander provided logistic support for our service trips to Breton Island. The field technicians of the Coastal Studies Field Support Group deserve our gratitude for their efforts to install and maintain the monitoring stations - particularly Mr. Bill Gibson and Mr. Steve Dartez, the Chief Technicians for Dauphin and Breton Islands, respectively. Finally, thanks to Dr. William Hutzell and Dr. Alexis Lugo-Fernandez, our COTRs at the MMS New Orleans for their guidance and support.

I. Introduction

Ambient air quality conditions existing over coastal areas bordering the northeast Gulf of Mexico have come under greater scrutiny in recent years. Increases in both the population along the coast and in offshore energy production have raised concerns that emissions from these various source areas may be impacting the fragile habitats indigenous to these shoreline environments. This is especially critical as portions of this coastal region contain protected wildlife areas, and have been designated as Class I (the Breton National Wildlife Area (BNWA)) by the U.S. Congress. For these areas, the Prevention of Significant Deterioration (PSD) restrictions are applicable.

Since 1993, the Coastal Studies Institute of Louisiana State University has deployed several field programs to measure ambient air quality and meteorology at stations in the Delta National Wildlife Refuge, the BNWA, and the Gulf Islands National Seashore. The majority of this data record has been analyzed and discussed in three previous Minerals Management Service Reports (e.g., Hsu, 1995b; Hsu, 1996; and Hsu and Blanchard, 1998). The first two Reports documented data collected during short-term summer deployments (July to September 1993 and 1994, respectively). The last of these was an Interim Report which detailed aspects of the long term records obtained at Breton (October 1994 to April 1997) and Dauphin (March 1996 to April 1997) Islands in the northeast Gulf of Mexico (see Fig. 1 for locations). This document will build upon those prior findings by presenting data collected during the period of May 1997 through July 1998, the final phase of our field program.

The annual arithmetic means of SO_2 and NO_2 concentration recorded at Dauphin Island during the study period were 2.3 ppb and 4.4 ppb, respectively. These values are less than 10% of the National Ambient Air Quality Standards. For both pollutants, hourly concentrations were less than 4 ppb over 50% of the time. Annual trends show slight increases in both SO_2 and NO_2 during the fall and winter months. Median SO_2 values show little variation diurnally, while NO_2 often exhibits a peak in the morning hours. Maximum 1- and 3-hour average concentrations of both pollutants are mostly associated with north and northeast wind directions, and occasionally west winds (particularly for NO_2).

For the Breton Island monitoring station, calculated annual arithmetic means were 1.2 ppb and 6.2 ppb for SO_2 and NO_2, respectively. During more than half the study period, hourly concentrations of both pollutants were less than 6 ppb. The NO_2 data, however, showed greater frequency of higher concentrations than at Dauphin, with values more than 20 ppb recorded about 5% of the time. Annual trends of average concentrations for SO_2 and NO_2 show a very slight increase in the fall and winter months. Median SO_2 values are very low and are generally consistent throughout the day, while median NO_2 usually shows a slight morning peak. An opposite dependency of maximum concentrations and wind direction is observed here, with peak SO_2 associated with north winds, and peak NO_2 with winds from southwest and west. Higher SO_2 concentrations are more likely to be observed under Continental High and Frontal Overrunning synoptic conditions (see, e.g., Muller 1977); and higher NO_2 under Gulf Return, Frontal Overrunning, or Continental High. All average and maximum values obtained at Breton are well below the National Standards. Note that comparisons of the observed pollutant concentrations with

PSD increments are not valid since the baseline concentrations were unavailable for Breton and Dauphin Islands.

Concentrations of SO_2 at Dauphin were higher than those at Breton for both averages and maximums. Average NO_2 values were similar, with maximums frequently being higher at Breton. The Breton NO_2 maximums often result from short-duration (less than one day) episodes of high NO_x, with NO_2 concentrations exceeding 30 to 40 ppb. These events are observed several times each month.

Characteristics of dispersion and the atmospheric boundary layer prevailing over the BNWA are detailed. Included are methods for determining the drag coefficient, stability category, vertical and cross-wind turbulence intensities, the vertical eddy diffusivity, and the mixed layer height under both stable and unstable conditions. Slightly unstable conditions are shown to dominate in the study area with free convection occurring nearly 4 to 15% of the time. Monthly mean mixed heights ranged from about 375 to 775 m. Analysis of radiosonde data obtained over Breton Island verifies a relationship between surface dewpoint depression and lifting condensation level, or mixed height, at this location.

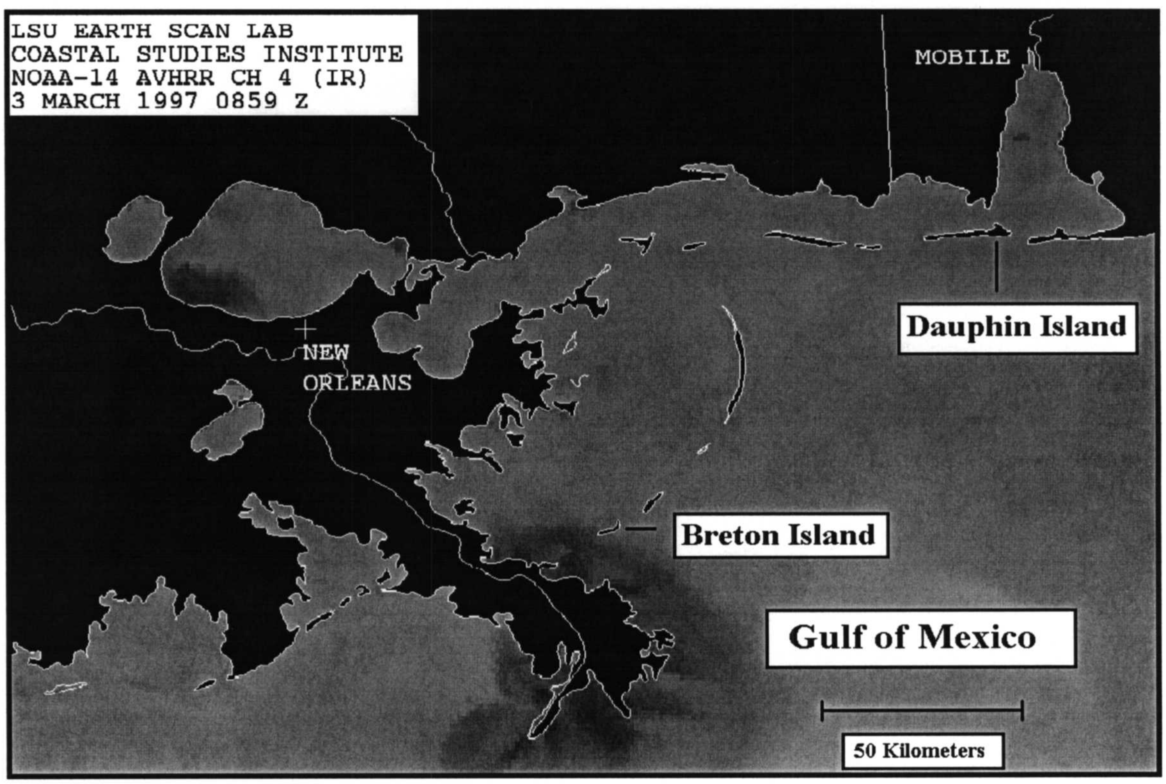


Figure 1. Advanced Very High Resolution Radiometer (AVHRR) satellite thermal image showing the approximate locations of our two air quality monitoring stations (courtesy of Buddy Martin, Earth Scan Lab, Louisiana State University).

II. Data Acquisition and Processing

A. Overview

During the period of May 1997 through July 1998, near-continuous monitoring of ambient air quality (SO_2 and NO_x) was conducted at two near-shore stations; one at Breton Island in the Chandeleur chain, and the other at Dauphin Island near the opening of Mobile Bay (see Fig. 1). Measurements at Breton Island were further complemented by a suite of standard meteorological sensors. The stations were designed to operate autonomously by employing Campbell Scientific CR-10 dataloggers with high capacity storage modules. The air quality monitors were scanned at 10-second intervals, and a five-minute average was recorded (giving 12 samples / hour). Most meteorological parameters were recorded on the hour; however several intervals were applied for the turbulence (uvw) data (15 and 30 minute averages). The storage modules were downloaded during regular service trips, at which time the memory would be cleared and the system re-initialized.

These stations were located in an attempt to best capture the spatial and temporal characteristics of ambient air quality and meteorology over the northeast Gulf of Mexico. In reality, site selection was primarily governed by the instrumentation's requirements for power and environmental control. While Dauphin Island is near enough to the mainland for commercial power, facilities at Breton Island were dependent upon power produced by diesel generators on site. Surface and marine vehicular traffic was also present at both locations. Hence, it is inevitable that these factors contributed to the recorded air quality records to some degree.

B. Dauphin Island

Air quality instrumentation at Dauphin Island was housed within the Alabama Marine Resources Division building on the east end of the island (see Fig. 2 for an approximate layout of the facility). Primary station components were Monitor Labs, Inc. ML 9850 SO_2 analyzer, ML 9841A NO_x analyzer, and an Environics Series 100 Multi-Gas Calibrator. All of these units are designated as an "equivalent method" for monitoring by the U.S. EPA, as defined in 40 CFR Part 53 (1994). Minimal detectable concentrations by the analyzers was approximately 1 ppb.

A Coastal-Marine Automated Network (C-MAN) station, DPIA1, is maintained by NOAA at Dauphin Island, less than 3 miles from our air quality monitors. Meteorological records obtained during this reporting period at DPIA1 were downloaded from the National Data Buoy Center (NDBC) website, and integrated with the air quality files during post-processing.

Calibration of the air quality monitors was achieved through gas phase titration, in which a traceable gas standard is diluted with pure air or ozone to generate multiple known concentrations (see, e.g., 40 CFR, App. B, 1994). If functioning properly, the monitor should produce a linear response, hence accuracy is consistent from low to high concentrations. For a more detailed description of servicing routines and calibrations, see the Interim Report (Hsu and Blanchard, 1998).

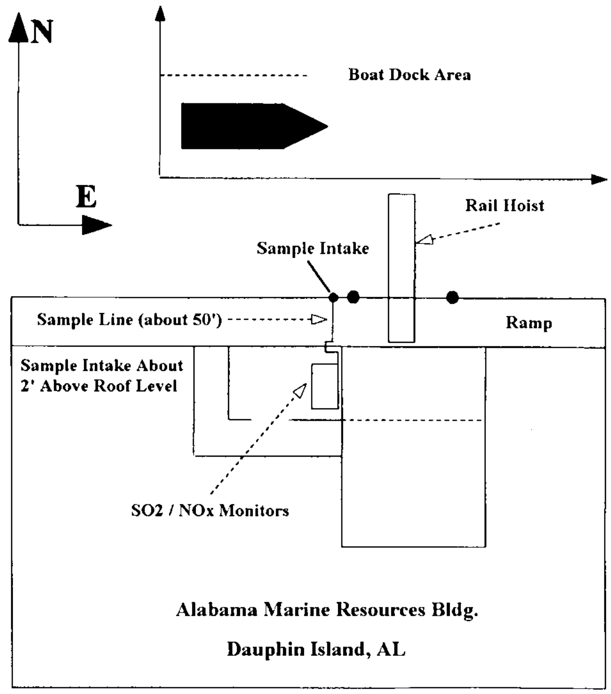


Figure 2. Layout of air quality monitoring station at Dauphin Island (distances are approximated).

Dauphin Island servicing dates and significant operational notes recorded during this reporting period are as follows:

May 13, 1997	Filters changed and cleaned, calibration.
June 12, 1997	Filters changed and cleaned, calibration.
July 16, 1997	UV filters cleaned, internal and external filters changed, charcoal changed, leak test, flow check, calibration.
September 12, 1997	Calibration.
September 26, 1997	Filters replaced and cleaned, flow check, calibration.
November 6, 1997	Units cleaned and leak tested, vacuum pump on NO_x monitor weakening but still within acceptable limits, calibration.
November 25, 1997	Discovered bad o-rings while working on NO_x monitor pump, one replaced, calibration.

December 11, 1997	O-rings replaced, improved vacuum reading on NO_x monitor, calibration.
January 8, 1998	Remaining o-rings replaced, clean and replaced filters, calibration.
January 22, 1998	Cleaned both monitors, leak test, flow check on SO_2 monitor, flow check on calibrator, calibration.
February 4, 1998	Replaced filters, failure of ozone generator in NO_x monitor, unit offline, calibration of SO_2 monitor.
February 13, 1998	Ozone generator installed in NO_x monitor, leak test, calibration.
February 27, 1998	Filters changed, calibration.
March 15, 1998	Filters changed, calibration.
April 2, 1998	Filters changed, calibration.
April 16, 1998	Filters changed, calibration.
May 9, 1998	Flow check on calibrator and SO_2 monitor, calibration, end of monitoring.

Results of the SO_2 monitor calibrations are given in Tables 1 to 3, and those for the NO_x monitor in Tables 4 to 8. Exceptional accuracy is obtained, with mean errors being less than 5%. No significant zero or span drift is evident for either monitor.

The SO_2 monitor has a built-in function for performing a daily background cycle and electronic zero check, hence no zero offsets were applied to the data. Periods in which known power outages occurred were removed from the record. Other negative values were either removed or converted to zero, depending on the magnitude and duration. Field experience has shown that minor power fluctuations can cause this monitor to re-initialize, sometimes producing intervals of bogus values until the unit stabilizes. Removed data periods were generally less than 24 hours in duration.

A consistent offset of 2 - 3 ppb was present in the NO_2 channel (see Table 4) during most of the study period. In an analysis of air quality data recorded from these stations prior to April 1997, this was addressed by subtracting the offsets from the recorded values (see Interim Report). This method can produce excessive negative values; also, since NO, NO_2, and NO_x each has an offset, subtraction may not remove the discrepancies (as evidenced by NO_2 / NO_x ratios > 1). It was found that subtracting the hourly averaged NO concentration from the NO_x concentration produced a value (computed NO_2) whose difference from the recorded NO_2 was nearly equivalent to the zero offset. Applying this technique to the previous dataset presented in the Interim Report resulted in monthly and annual averages within about 1 ppb of those listed. Therefore, for this analysis, the computed NO_2 value is used.

Table 1.
Dauphin Island SO_2 Monitor Zero Values

Date	Actual SO_2
13 May 1997	2
12 June 1997	0
17 July 1997	6
12 September 1997	-1
26 September 1997	0
6 November 1997	1
25 November 1997	1
10 December 1997	1
8 January 1998	1
22 January 1998	0
4 February 1998	1
13 February 1998	1
27 February 1998	1
15 March 1998	-1
2 April 1998	1
16 April 1998	0
8 May 1998	1

Table 2.
Dauphin Island SO_2 Monitor Precision Values

Date	Expected	Actual SO_2	% Error
6 November 1997	107	107	0.00
22 January 1998	107	106	-0.93
8 May 1998	107	102	-4.67
Sum			-5.60
Mean			-1.87
Standard Deviation			2.47
Upper 95% Limit			2.97
Lower 95% Limit			-6.71

Table 3.
Dauphin Island SO_2 Monitor Accuracy Values

Date	Expected	Actual SO_2	% Error
13 May 1997	207	207	0.00
	428	425	-0.70
12 June 1997	207	205	-0.97
	428	424	-0.94
18 July 1997	312	315	0.96
	207	210	1.45
	428	428	0.00
12 September 1997	230	230	0.00
	477	475	-0.42
26 September 1997	230	233	1.30
	477	480	0.63
6 November 1997	331	330	-0.30
	230	232	0.87
	477	477	0.00
25 November 1997	230	229	-0.44
	477	477	0.00
10 December 1997	230	228	-0.87
	477	475	-0.42
8 January 1998	230	229	-0.44
	477	475	-0.42
22 January 1998	331	331	0.00
	230	231	0.44
	477	478	0.21

Table 3 continued

Date	Expected	Actual SO_2	% Error
4 February 1998	230	229	-0.44
	477	473	-0.84
13 February 1998	230	228	-0.87
	477	471	-1.26
27 February 1998	230	227	-1.30
	477	471	-1.26
15 March 1998	230	226	-1.74
	477	467	-2.10
2 April 1998	230	228	-0.87
	477	469	-1.68
16 April 1998	230	226	-1.74
	477	466	-2.31
8 May 1998	331	317	-4.23
	230	221	-3.91
	476	454	-4.62
Sum			-29.23
Mean			-0.77
Standard Deviation			1.36
Upper 95% Limit			1.90
Lower 95% Limit			-3.44

Table 4.
Dauphin Island NO_x Monitor Zero Values

Date	Actual NO	Actual NO_2	Actual NO_x
13 May 1997	1	2	1
12 June 1997	1	2	1
18 July 1997	1	2	1
12 September 1997	1	2	2
26 September 1997	0	3	1
6 November 1997	1	2	1
25 November 1997	0	3	1
11 December 1997	-1	3	-1
8 January 1998	0	3	1
22 January 1998	0	2	0
13 February 1998	1	2	-1
27 February 1998	0	0	-3
15 March 1998	-1	-1	-3
2 April 1998	0	-1	-3
16 April 1998	0	-1	-3
8 May 1998	1	-1	-2

Table 5.
Dauphin Island NO_x Monitor Precision Values

Date	Expected	Actual NO	Actual NO_x	% Error	% Error
6 November 1997	100	96	98	-4.00	-2.00
22 January 1998	100	97	98	-3.00	-2.00
8 May 1998	100	98	96	-2.00	-4.00
Sum				-9.00	-8.00
Mean				-3.00	-2.67
Standard Deviation				1.00	1.15
Upper 95% Limit				-1.04	-0.40
Lower 95% Limit				-4.96	-4.93

Table 6.
Dauphin Island NO_x Monitor Accuracy Values

Date	Expected	Actual NO	Actual NO_x	% Error	% Error
13 May 1997	214	213	215	-0.47	0.47
	443	439	448	-0.90	1.13
12 June 1997	214	219	222	2.34	3.74
	443	455	461	2.71	4.06
18 July 1997	323	322	328	-0.31	1.55
	214	211	214	-1.40	0.00
	443	441	447	-0.45	0.90
12 September 1997	215	212	216	-1.40	0.47
	445	441	452	-0.90	1.57
26 September 1997	215	218	224	1.40	4.19
	445	462	473	3.82	6.29
6 November 1997	309	307	312	-0.65	0.97
	215	213	216	-0.93	0.47
	445	442	446	-0.67	0.22
25 November 1997	215	211	216	-1.86	0.47
	445	441	450	-0.90	1.12
11 December 1997	215	213	216	-0.93	0.47
	445	442	450	-0.67	1.12
8 January 1998	215	213	215	-0.93	0.00
	445	443	447	-0.45	0.45
22 January 1998	309	308	312	-0.32	0.97
	215	213	215	-0.93	0.00
	445	443	448	-0.45	0.67

Table 6 continued.

Date	Expected	Actual NO	Actual NO_x	% Error	% Error
13 February 1998	215	214	215	-0.47	0.00
	445	444	448	-0.22	0.67
27 February 1998	215	213	213	-0.93	-0.93
	445	444	446	-0.22	0.22
15 March 1998	215	213	215	-0.93	0.00
	445	443	449	-0.45	0.90
2 April 1998	215	213	214	-0.93	-0.47
	445	445	448	0.00	0.67
16 April 1998	215	214	215	-0.47	0.00
	445	448	450	0.67	1.12
8 May 1998	309	304	306	-1.62	-0.97
	215	211	212	-1.86	-1.40
	445	438	443	-1.57	-0.45
Sum				-14.25	30.66
Mean				-0.40	0.85
Standard Deviation				1.22	1.53
Upper 95% Limit				1.97	3.85
Lower 95% Limit				-2.77	-2.15

Table 7.
Dauphin Island NO_2 Precision Values

Date	Expected	Actual NO_2	% Error
13 May 1997	101	106	4.95
12 June 1997	103	109	5.83
18 July 1997	100	103	3.00
12 September 1997	93	103	10.75
26 September 1997	96	107	11.46
6 November 1997	95	100	5.26
25 November 1997	102	104	1.96
11 December 1997	98	103	5.10
8 January 1998	95	99	4.21
22 January 1998	98	99	1.02
13 February 1998	99	100	1.01
27 February 1998	98	99	1.02
15 March 1998	101	103	1.98
2 April 1998	98	100	2.04
16 April 1998	99	100	1.01
8 May 1998	98	100	2.04
Sum			62.64
Mean			3.92
Standard Deviation			3.27
Upper 95% Limit			10.33
Lower 95% Limit			-2.49

Table 8.
Dauphin Island NO_2 Accuracy Values

Date	Expected	Actual NO_2	% Error
13 May 1997	339	343	1.18
12 June 1997	354	356	0.56
18 July 1997	340	344	1.18
12 September 1997	336	344	2.38
26 September 1997	348	358	2.87
6 November 1997	343	348	1.46
25 November 1997	354	355	0.28
11 December 1997	353	359	1.70
8 January 1998	345	349	1.16
22 January 1998	341	343	0.59
13 February 1998	349	350	0.29
27 February 1998	345	346	0.29
15 March 1998	352	355	0.85
2 April 1998	334	337	0.90
16 April 1998	347	349	0.58
8 May 1998	348	351	0.86
Sum			17.13
Mean			1.07
Standard Deviation			0.74
Upper 95% Limit			2.52
Lower 95% Limit			-0.38

Table 9 lists the monthly air quality data capture rate for Dauphin Island after processing. Only February 1998 falls below 85% complete for NO_x, due to failure of the ozone generator as described above. Other missing data is a result of station maintenance and calibrations, and power outages.

Table 9.
Percent Data Return for Air Quality - Dauphin Island
(* indicates < 75% complete)

Month	% SO_2	% NO_x
May 1997	95.7	98.4
June 1997	99.6	99.6
July 1997	86.6	86.6
August 1997	98.8	99.7
September 1997	96.5	96.5
October 1997	100.0	100.0
November 1997	92.5	92.1
December 1997	96.2	96.6
January 1998	97.7	98.1
February 1998	95.5	65.3*
March 1998	98.0	98.0
April 1998	95.8	99.0

C. Breton Island

During this reporting period, several changes were made both to instrumentation and operating procedures at the Breton Island station. These modifications were brought about to enhance our measurement capability, and in response to damage incurred from environmental conditions, natural and man-made.

The air quality measurements suite consisted of identical Monitor Labs, Inc. analyzers as deployed at Dauphin Island; here a Monitor Labs, Inc. ML 8550 Gas Calibrator was used. Wind speed and direction was obtained from a roof-mounted RM Young Wind Sensor. The air quality monitors and datalogging system were located on the third floor of the Kerr-McGee building, with the air intake facing roughly northeast (see Fig. 3 for schematic).

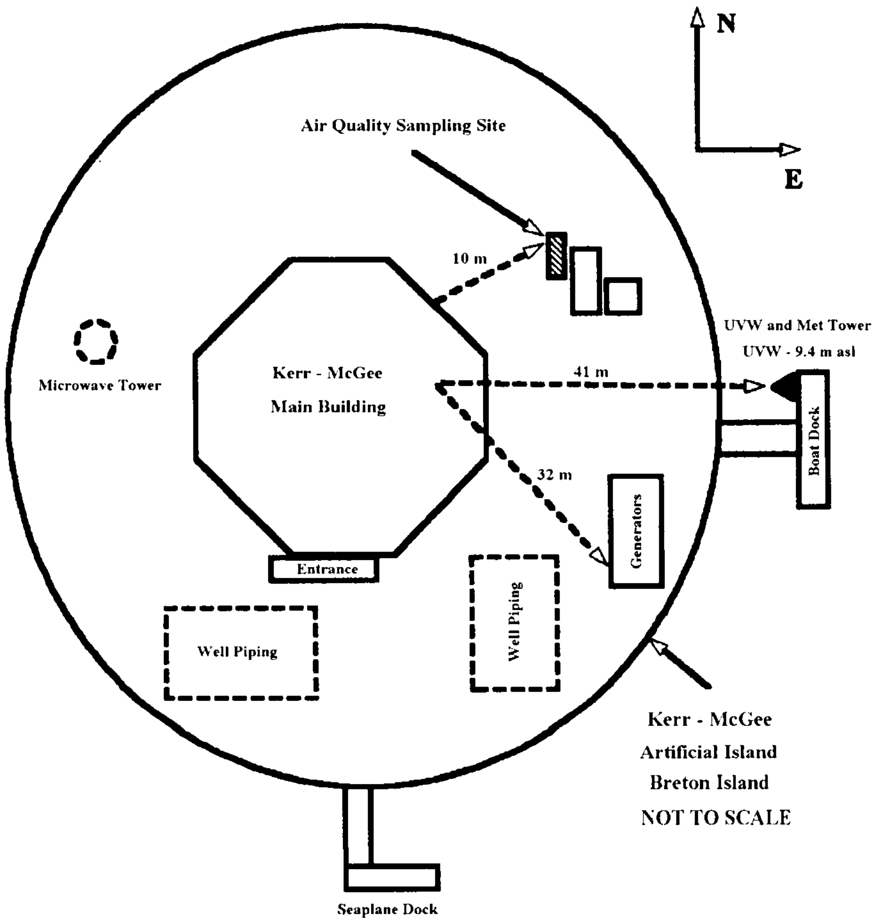


Figure 3. Schematic of the Kerr-McGee facility on Breton Island showing location of monitoring site following Hurricane Danny.

In early June 1997, a meteorological tower was installed inside of the large pier extending from Kerr-McGee. It was instrumented with a RM Young Gill UVW sensor (~9.4 m asl), air temperature and relative humidity sensors (~7.9 m asl), atmospheric pressure (~6 m asl), and water temperature at approximately -1 m depth. These sensors were connected to a separate datalogger within a weatherproof box on the pier.

Approximately six weeks later, Breton Island endured the full force of Hurricane Danny. Five-minute average wind speeds of over 30 m s^{-1} were recorded for several hours. The storm inflicted considerable damage to the Kerr-McGee facility, as well as to several houseboats and camps present nearby. Significant changes to the island's topography were produced. Power was lost early, but fortunately the only damage to our equipment was bent mounts on the wind sensors. On the other hand, in view of condition of the Kerr-McGee main building, it was decided that no repairs would be made and power would not be restored. Major equipment was removed from the island.

By the end of August, 1997, Kerr-McGee had prepared another location for our monitoring station - a small portable building which they had powered and air-conditioned specifically for our study program. The air quality intake was nearer to ground level (about 4 m) and to the generator shed (to the south-southeast); but the building was much better regulated both for power and environmental conditions. The meteorological tower was re-deployed, with the addition of the RM Young Wind Sensor to the tower (about 4.9 m asl).

As described in the Interim Report, fluctuations in voltage and power outages continued to affect operations at Breton Island. Much of May and June 1997 NO_x data was lost due to electronic damage to the monitor. Power spikes were better controlled following installation in the new building, however prolonged outages were noted in February and July 1998.

Like Dauphin Island, monitoring at Breton was scheduled to conclude at the end of April 1998. Considering the generally low data capture rate obtained at Breton, monitoring was allowed to continue through July 1998. A data gap occurred in June 1998 due to full memory between servicings.

Service dates and notes from the Breton Island station log are as follows:

May 9, 1997	Both monitors found malfunctioning, changed power inverter, SO_2 corrected, NO_x offline, SO_2 calibration.
June 4, 1997	NO_x re-installed, meteorological tower installed, calibration.
June 10, 1997	Discovered logging software error, no air quality data collected since 3 June, corrected.
June 24, 1997	Flow check of calibrator, calibration.
July 10, 1997	Installed new mast and RM Young Wind Sensor on roof of building, calibration.
July 23, 1997	Site inspection following Hurricane Danny on 18 July. All power lost; data downloaded and systems disconnected.
August 28, 1997	Station re-deployed in new location. Flow check of calibrator and monitor calibration.
September 19, 1997	Calibration.
November 4, 1997	Calibration begun but failure of zero air pump.
November 7, 1997	Repaired pump installed - problem remains. Discovered low line voltage. Kerr-McGee personnel adjust generator. Calibration begun and pump stops again. Power drop seen. Found that generator has worn spot near 110 volts,

vibration of unit keeps output voltage fluctuating. Generator set up to 115 VAC. All electronic setting on SO_2 monitor re-set. Calibration completed.

December 20, 1997	NO_x monitor pump changed, leak test, calibration.
January 18, 1998	Flow check of calibrator, calibration.
February 5, 1998	Calibration.
February 18, 1998	No communication with meteorological datalogger. Logging program lost - reloaded. Recorded data ended on 11 February. Air quality monitor's lens cleaned, ozone generator in NO_x replaced, leak test, calibration.
March 13, 1998	Found electronic settings on SO_2 monitor zeroed - reset. Monitor appeared to have lost settings following repeated power outages at end of February. NO_x monitor also required adjustment, calibration.
April 21, 1998	Meteorological program re-installed, zero offset on SO_2 adjusted, replaced PMT, ozone generator, and vacuum pump in NO_x monitor, calibration.
June 22, 1998	Calibration gas cylinder changed and quick purge of system attempted, flow check of calibrator, resulting calibration bad due to insufficient time for system purge, linearity of monitors good; no setting changed on either unit.
August 3, 1998	Final calibration before station removal.

Results of the monitor calibrations are given in Tables 10 - 17. As expected, slightly higher errors are seen throughout the record, however mean errors remain below 5%. As described above, the highest errors occurred following installation of a new span gas cylinder before the system could be completely purged.

Data processing routines applied to this dataset were the same as for Dauphin, i.e., removal of data during known power outages, conversion of negative values to zero, and calculation of NO_2 from hourly NO_x - NO. Negative values were generally less than 3 ppb. Several data spikes were observed following power outages or fluctuations; these were also removed since they were likely due to impurities in the sample line and / or instability in the monitor following re-start.

Corrective actions were required on the SO_2 and wind records on multiple occasions. After experiencing power failures in February 1998, the SO_2 monitor would not hold its electronic zero setting. Time series of the raw data combined with operator notes showed a negative displacement of 13.5 ppb during 1 - 13 May, 1998, and 5.7 ppb from May 14 to April 21, 1998, at which time the problem was corrected. These offsets were added to the affected data.

Table 10.
Breton Island SO_2 Monitor Zero Values

Date	Actual SO_2
9 May 1997	0
4 June 1997	0
24 June 1997	-1
10 July 1997	0
19 September 1997	0
7 November 1997	1
20 December 1997	1
18 January 1998	1
5 February 1998	1
18 February 1998	1
13 March 1998	0
21 April 1998	1
22 June 1998	0
3 August 1998	1
29 August 1998	1

Table 11.
Breton Island SO_2 Monitor Precision Values

Date	Expected	Actual SO_2	% Error
9 May 1997	95	93	-2.11
24 June 1997	100	96	-4.00
10 July 1997	100	98	-2.00
19 September 1997	114	118	3.51
7 November 1997	114	108	-5.26
20 December 1997	114	115	0.88
18 January 1998	117	115	-1.71
5 February 1998	117	113	-3.42
18 February 1998	117	115	-1.71
13 March 1998	117	115	-1.71
21 April 1998	117	115	-1.71
22 June 1998	109	82	-24.77
3 August 1998	109	100	-8.26
Sum			-52.27
Mean			-4.02
Standard Deviation			6.83
Upper 95% Limit			9.37
Lower 95% Limit			-17.41

Table 12.
Breton Island SO_2 Monitor Accuracy Values

Date	Expected	Actual SO_2	% Error
9 May 1997	494	493	-0.20
4 June 1997	494	490	-0.81
	162	158	-2.47
24 June 1997	416	416	0.00
	274	269	-1.82
	168	160	-4.76
10 July 1997	416	416	0.00
19 September 1997	414	415	0.24
	222	222	0.00
7 November 1997	414	416	0.48
20 December 1997	414	414	0.00
18 January 1998	417	416	-0.24
	350	349	-0.29
	223	220	-1.35
5 February 1998	417	407	-2.40
18 February 1998	417	416	-0.24
13 March 1998	417	416	-0.24
21 April 1998	417	416	-0.24
22 June 1998	386	293	-24.09
	328	251	-23.48
	208	157	-24.52
3 August 1998	386	365	-5.44
	328	306	-6.71
	208	192	-7.69
29 August 1998	414	415	0.24
	222	220	-0.90
Sum			-106.93
Mean			-4.11
Standard Deviation			7.66
Upper 95% Limit			10.90
Lower 95% Limit			-19.12

Table 13.
Breton Island NO_x Monitor Zero Values

Date	Actual NO	Actual NO_2	Actual NO_x
4 June 1997	1	3	3
24 June 1997	1	2	2
10 July 1997	0	2	1
19 September 1997	1	1	2
7 November 1997	1	2	2
20 December 1997	1	1	1
18 January 1998	-1	2	0
5 February 1998	-1	-1	0
18 February 1998	0	0	-1
13 March 1998	0	2	0
	0	2	0
21 April 1998	-2	6	2
22 June 1998	-1	5	2
3 August 1998	0	6	3
29 August 1998	1	2	1

Table 14.
Breton Island NO_x Monitor Precision Values

Date	Expected	Actual NO	Actual NO_x	% Error	% Error
24 June 1997	71	69	71	-2.82	0.00
10 July 1997	71	70	70	-1.41	-1.41
19 September 1997	108	106	108	-1.85	0.00
7 November 1997	108	103	104	-4.63	-3.70
20 December 1997	108	108	108	0.00	0.00
18 January 1998	112	113	112	0.89	0.00
5 February 1998	112	123	122	9.82	8.93
18 February 1998	112	110	114	-1.79	1.79
13 March 1998	112	91	92	-18.75	-17.86
	112	111	111	-0.89	-0.89
21 April 1998	112	110	113	-1.79	0.89
22 June 1998	112	82	85	-26.79	-24.11
3 August 1998	112	97	100	-13.39	-10.71
Sum				-63.40	-47.07
Mean				-4.88	-3.62
Standard Deviation				9.48	8.87
Upper 95% Limit				13.70	13.77
Lower 95% Limit				-23.46	-21.01

Table 15.
Breton Island NO_x Monitor Accuracy Values

Date	Expected	Actual NO	Actual NO_x	% Error	% Error
4 June 1997	477	477	477	0.00	0.00
	151	146	146	-3.31	-3.31
24 June 1997	388	385	388	-0.77	0.00
	233	229	230	-1.72	-1.29
	118	113	115	-4.24	-2.54
10 July 1997	388	388	388	0.00	0.00
19 September 1997	501	499	502	-0.40	0.20
	348	346	348	-0.57	0.00
	241	240	243	-0.41	0.83
7 November 1997	501	498	501	-0.60	0.00
20 December 1997	501	501	502	0.00	0.20
18 January 1998	417	417	419	0.00	0.48
	308	316	313	2.60	1.62
	177	176	175	-0.56	-1.13
5 February 1998	417	470	473	12.71	13.43
18 February 1998	417	415	416	-0.48	-0.24
13 March 1998	417	351	351	-15.83	-15.83
	417	415	417	-0.48	0.00
21 April 1998	417	417	417	0.00	0.00
22 June 1998	416	294	303	-29.33	-27.16
	307	218	227	-28.99	-26.06
	177	123	128	-30.51	-27.68
3 August 1998	416	379	381	-8.89	-8.41
	307	282	283	-8.14	-7.82
	177	158	161	-10.73	-9.04
29 August 1998	501	499	505	-0.40	0.80
	241	239	242	-0.83	0.42
Sum				-131.88	-112.53
Mean				-4.88	-4.17
Standard Deviation				10.19	9.57
Upper 95% Limit				15.09	14.59
Lower 95% Limit				-24.85	-22.93

Table 16.
Breton Island NO_2 Precision Values

Date	Expected	Actual NO_2	% Error
4 June 1997	101	108	6.93
24 June 1997	93	91	-2.15
10 July 1997	89	88	-1.12
19 September 1997	81	81	0.00
7 November 1997	77	77	0.00
20 December 1997	78	76	-2.56
18 January 1998	68	67	-1.47
5 February 1998	79	76	-3.80
18 February 1998	76	76	0.00
13 March 1998	58	55	-5.17
	81	80	-1.23
21 April 1998	71	71	0.00
3 August 1998	50	49	-2.00
29 August 1998	95	90	-5.26
Sum			-17.83
Mean			-1.27
Standard Deviation			2.97
Upper 95% Limit			4.55
Lower 95% Limit			-7.09

Table 17.
Breton Island NO_2 Accuracy Values

Date	Expected	Actual NO_2	% Error
4 June 1997	430	433	0.70
24 June 1997	343	345	0.58
10 July 1997	240	239	-0.42
19 September 1997	236	238	0.85
7 November 1997	218	224	2.75
20 December 1997	348	346	-0.57
18 January 1998	183	179	-2.19
5 February 1998	320	321	0.31
18 February 1998	293	293	0.00
13 March 1998	240	238	-0.83
	307	310	0.98
21 April 1998	293	295	0.68
3 August 1998	232	234	0.86
29 August 1998	367	366	-0.27
Sum			3.43
Mean			0.25
Standard Deviation			1.13
Upper 95% Limit			2.47
Lower 95% Limit			-1.97

Several versions of the meteorological datalogging program were produced during development and testing. On 28 August 1997 and 18 February 1998, a version containing an error in the wind speed logging was loaded accidentally while in the field. The error resulted in recorded wind speed values being off by a factor of 10. Affected periods were 1 September to 7 November 1997, and 18 February to 20 March 1998. The corrected wind data, along with the rest of the wind record, was found to be in good agreement with observations from NOAA buoy 42007 located at the northern end of the Chandeleurs.

As described previously, re-location of the equipment helped to produce a much improved data return rate at Breton, as shown in Table 18. Low values in July and August 1997 were due to Hurricane Danny, while June 1998 resulted from a full storage module between servicing. Other missing data is from monitor failure, power outages, and station maintenance.

Table 18.
Percentage Air Quality Data Return - Breton Island
(* indicates < 75% complete)

Month	% SO_2	% NO_x
May 1997	79.7	7.3*
June 1997	75.3	66.9*
July 1997	34.5*	51.2*
August 1997	0*	0*
September 1997	83.2	83.2
October 1997	98.9	98.9
November 1997	99.0	99.0
December 1997	99.5	99.5
January 1998	99.2	99.2
February 1998	79.2	81.9
March 1998	99.3	99.3
April 1998	93.6	93.6
May 1998	100.0	100.0
June 1998	56.8*	56.8*
July 1998	88.3	88.3

III. Analysis and Results

This section will present a summary of the air quality records obtained at Dauphin and Breton Islands during the period of May 1997 through July 1998. All air quality analysis is based on 1-, 3-, and 24-hour block averaged data. Station records will be compared, and case studies of simultaneous high concentrations discussed. Synoptic weather patterns associated with pollutant peaks at Breton Island are determined. Finally, a detailed analysis of boundary layer and dispersion meteorology over the BNWA is explained.

A. Dauphin Island Air Quality

Hourly air quality data were merged with meteorological records from the NOAA C-MAN station DPIA1. Figures 4 - 15 depict the monthly time series for wind direction, SO_2, and NO_2, along with servicing days. The majority of SO_2 and NO_2 values fall within the 0 - 10 ppb range, with NO_2 concentrations being slightly higher in general. A frequency distribution of all hourly values shows that almost 70% of the SO_2 values are less than 2 ppb, while NO_2 concentrations were less than 4 ppb approximately 60% of the time (Fig. 16).

Annual statistics were based on 8417 samples for SO_2 (96.1% complete) and 8267 samples for NO_2 (94.4% complete). The annual arithmetic mean SO_2 concentration was 2.28 ppb with a standard deviation of 3.18 ppb and a 95% confidence level of 0.068. For NO_2, the mean was 4.38 ppb with a standard deviation of 4.02 ppb and 95% confidence level of 0.087. These values compare well with those listed in the Interim Report (i.e., 1.86 ppb for SO_2 and 4.58 ppb for NO_2) (Hsu and Blanchard, 1998).

Monthly averages and maximums for SO_2 and NO_2 are listed in Tables 19 and 20, respectively. A slight increase in average concentration of both pollutants is seen during the late fall - early winter months of October - December 1997. The wintertime peaks, particularly for NO_2, were also evident in the 1996-1997 data as shown in Figs. 17 - 20, the 3- and 24-hour average time series for SO_2 and NO_2.

First, second, and third quartile values are used to show the diurnal variations of SO_2 and NO_2 concentrations in Figs. 21 and 22, respectively. Median (2^{nd} quartile) SO_2 values are generally 1 - 2 ppb; a slight peak is often observed in the mid-morning to mid-day hours. Median NO_2 values range from 1 - 7 ppb. A distinct peak is seen in the early morning (about 0700 CST), with minimum values in the late afternoon. This distribution is expected due to photoabsorption of solar radiation, which can cause NO_2 to dissociate into NO and O molecules (Bouble et al., 1994).

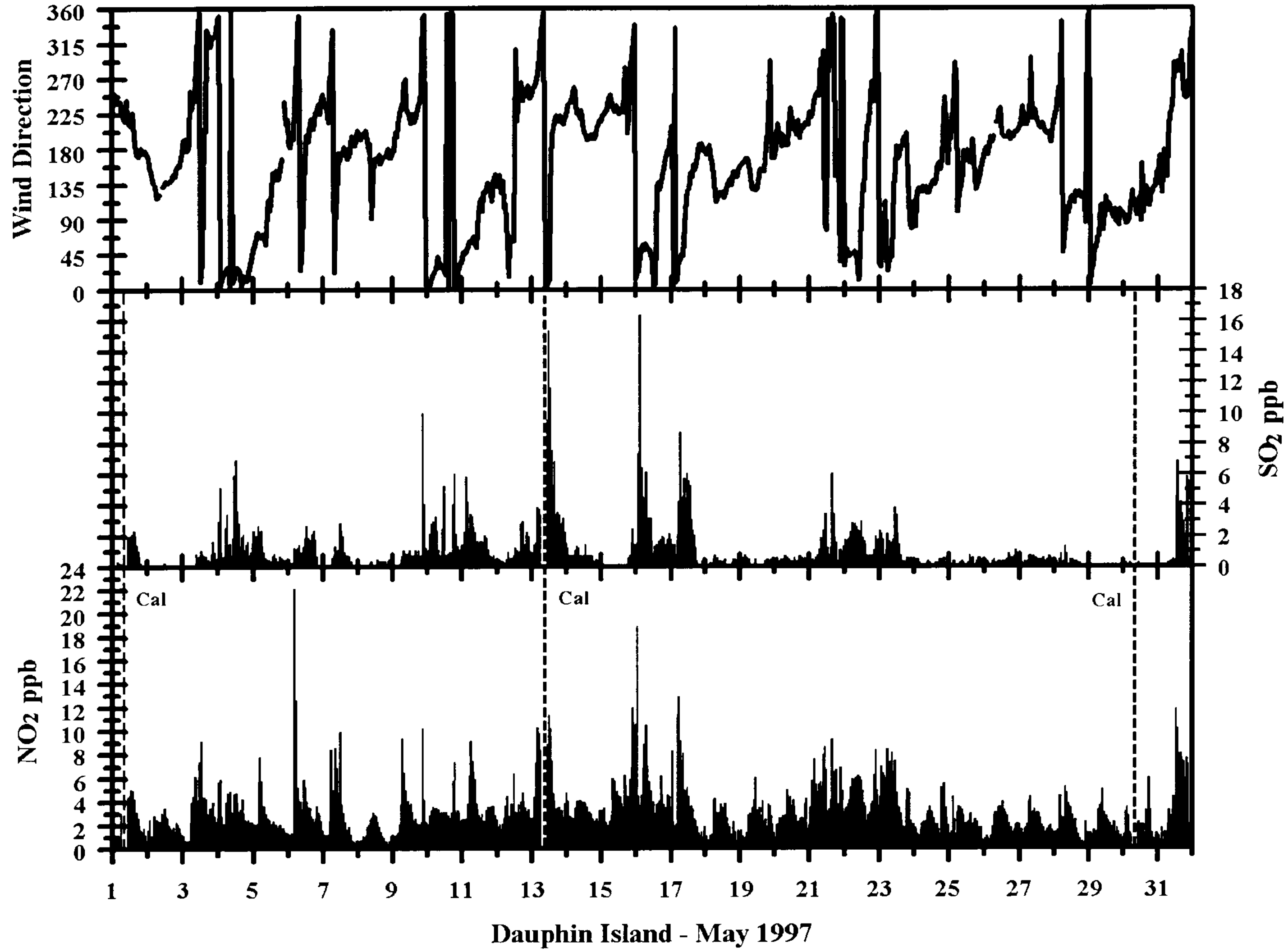


Figure 4. May 1997 time series of Dauphin Island hourly-averaged concentrations and wind direction from DPIA1. SO_2 missing on 15 May.

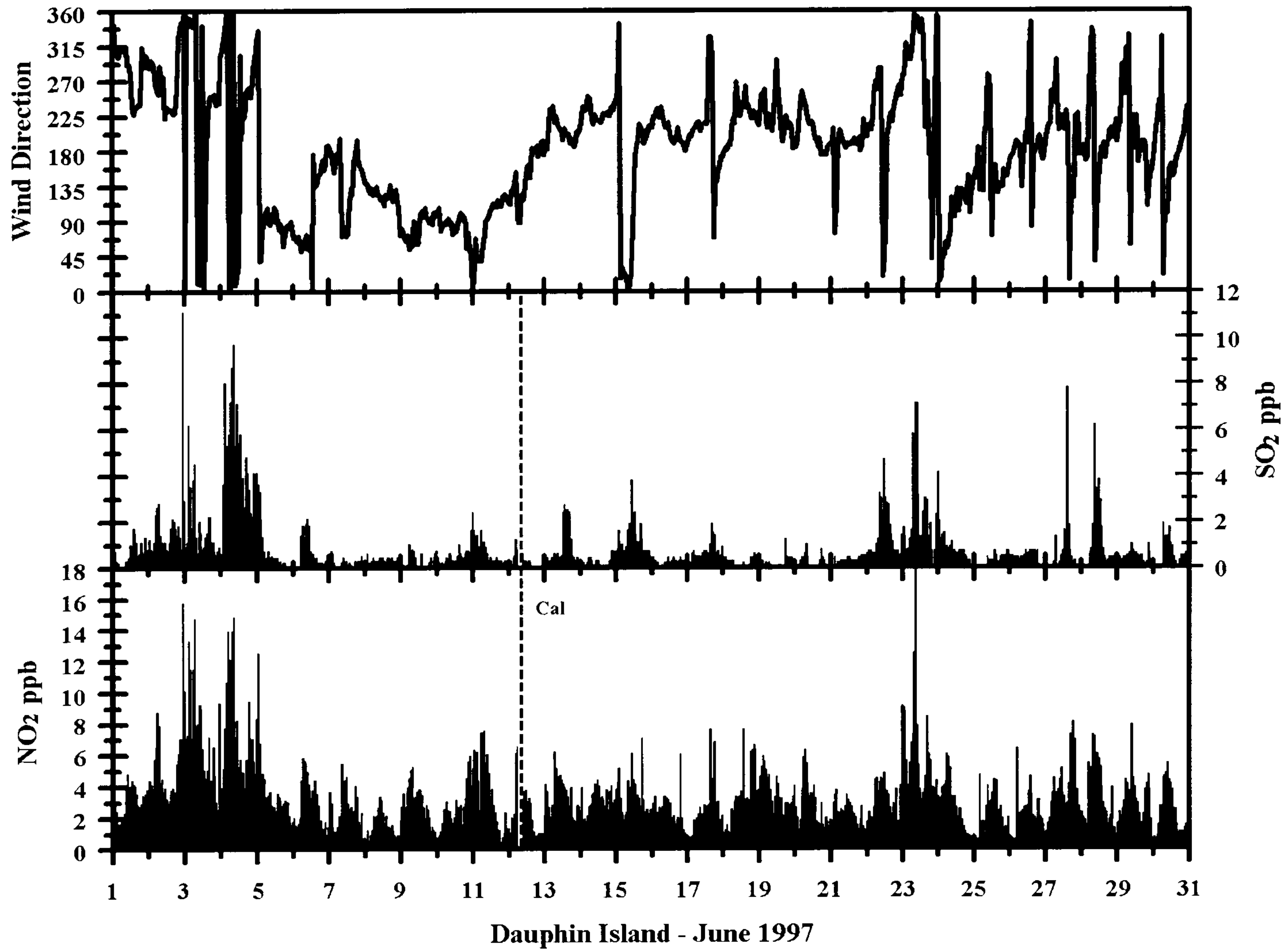


Figure 5. June 1997 time series of Dauphin Island hourly-averaged concentrations and wind direction from DPIA1.

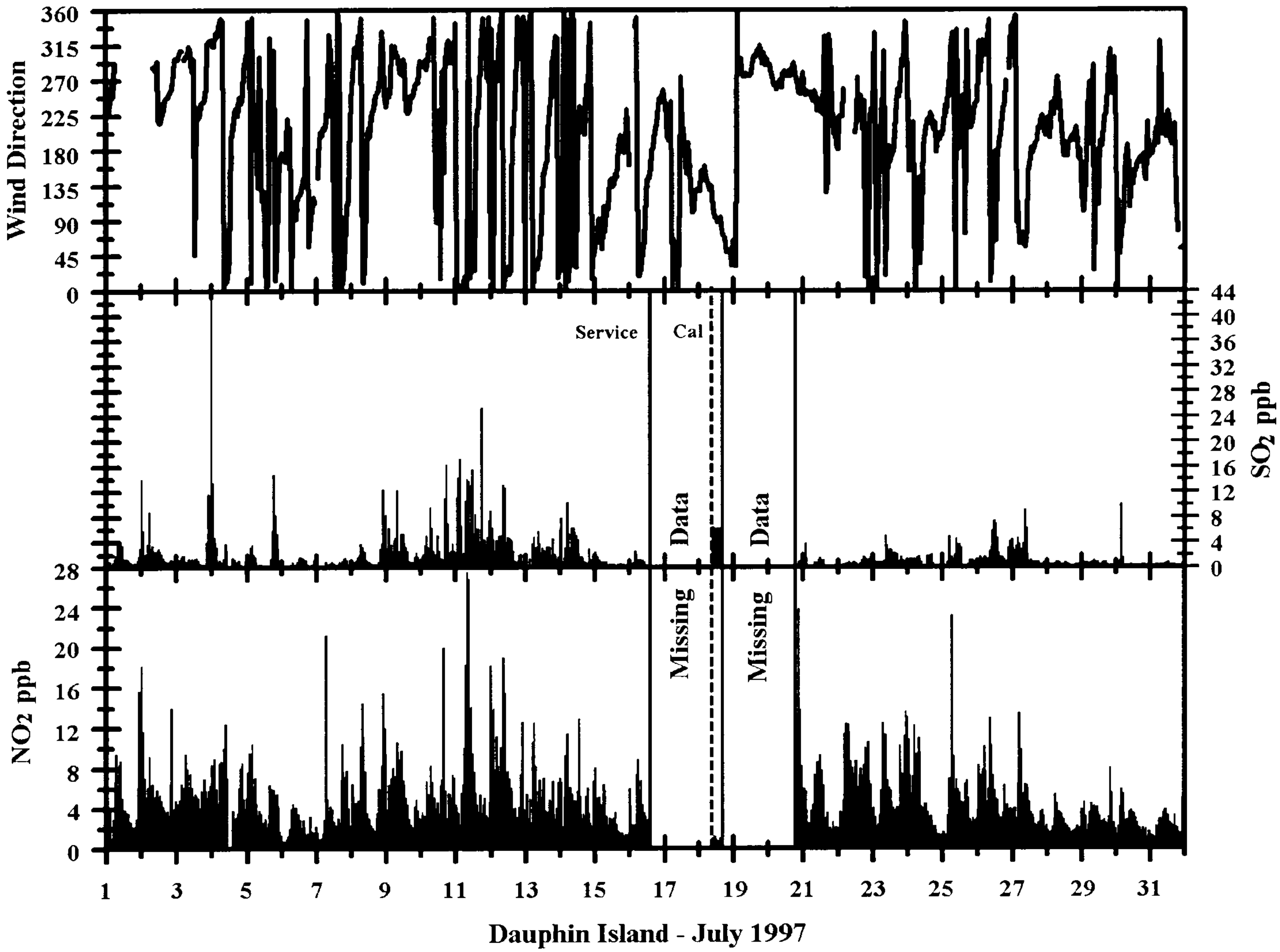


Figure 6. July 1997 time series of Dauphin Island hourly-averaged concentrations and wind direction from DPIA1. Air quality data missing on 4 July and in mid-month as depicted.

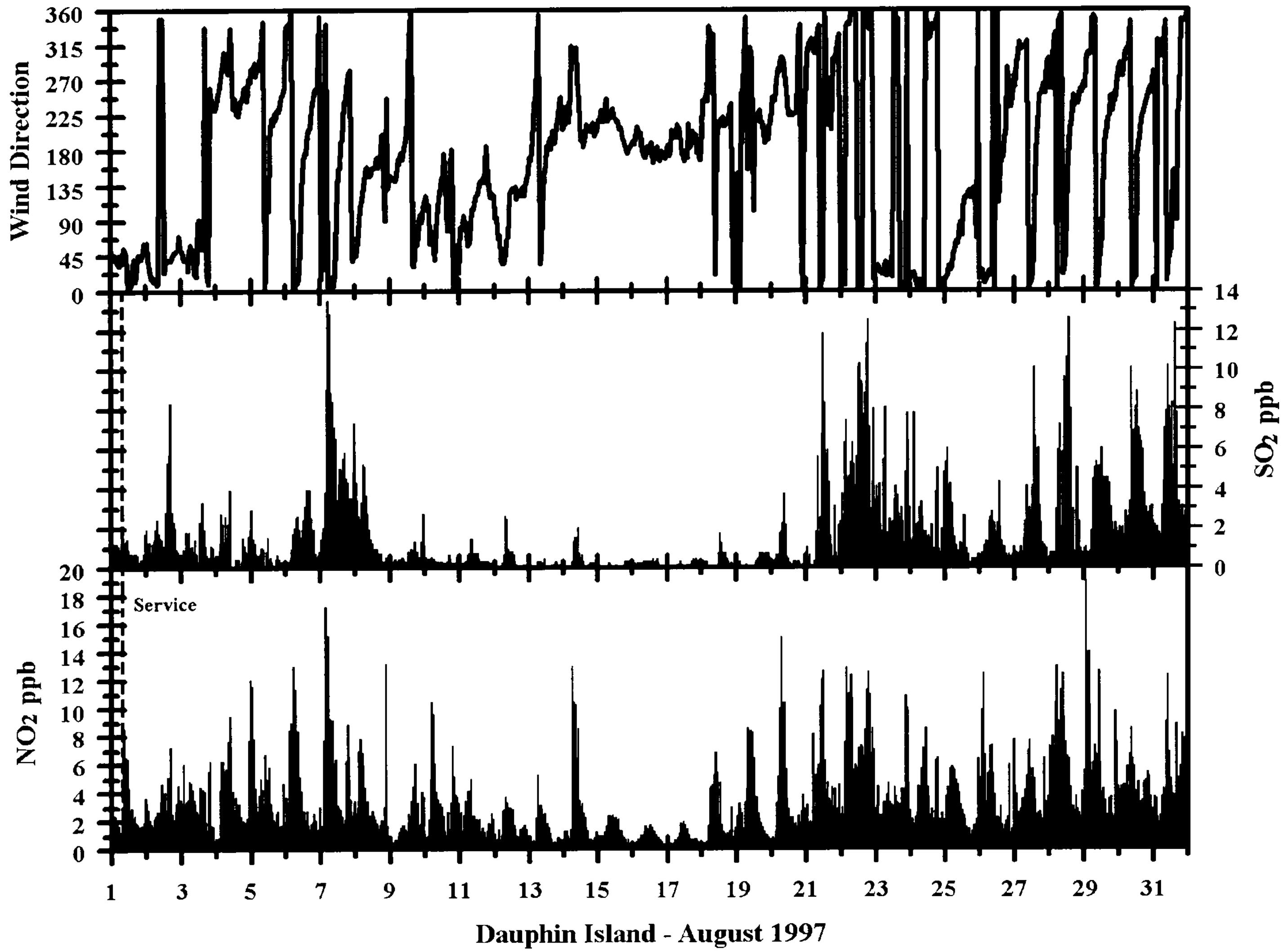


Figure 7. August 1997 time series of Dauphin Island hourly-averaged concentrations and wind direction from DPIA1. SO_2 data missing on 18 August.

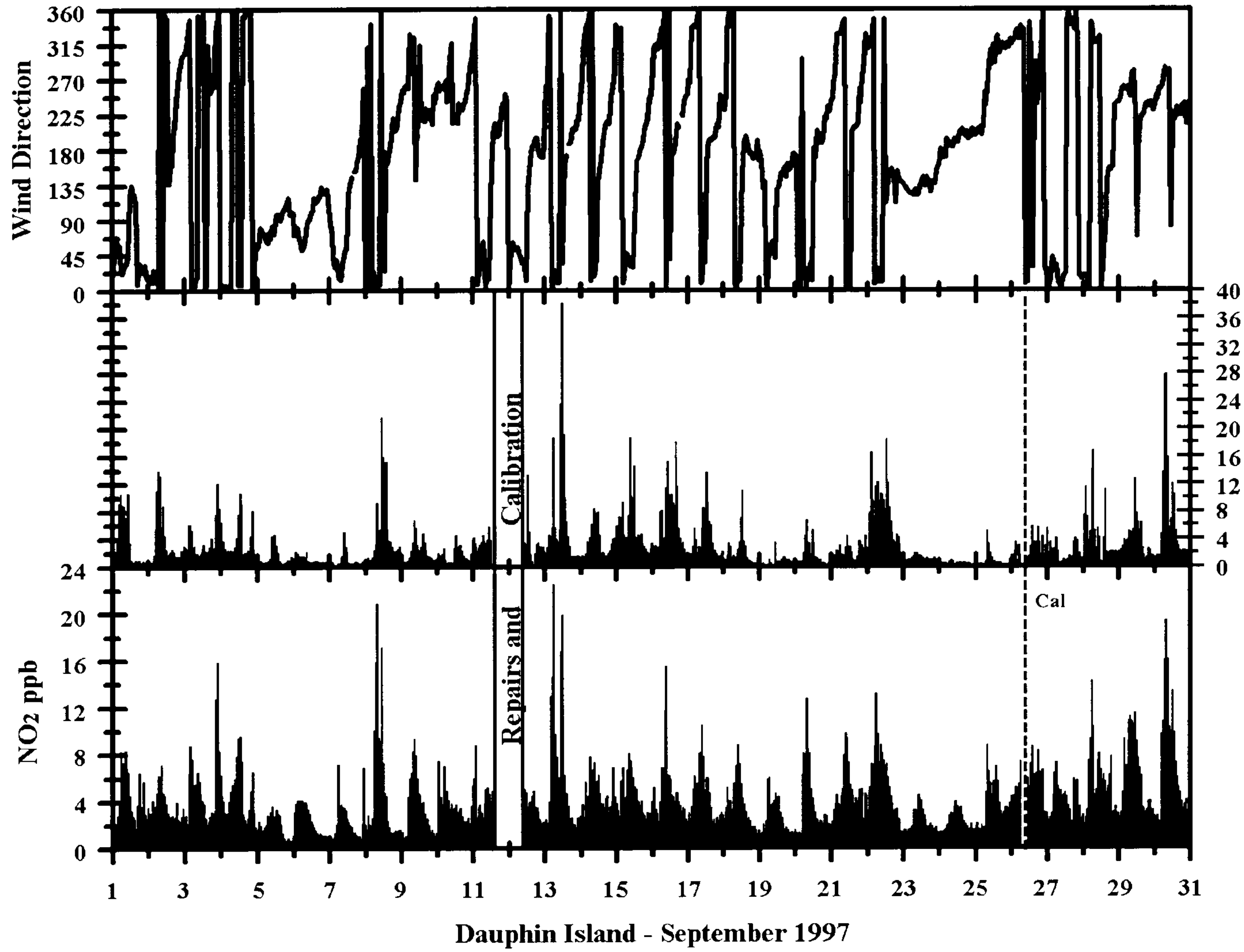


Figure 8. September 1997 time series of Dauphin Island hourly-averaged concentrations and wind direction from DPIA1.

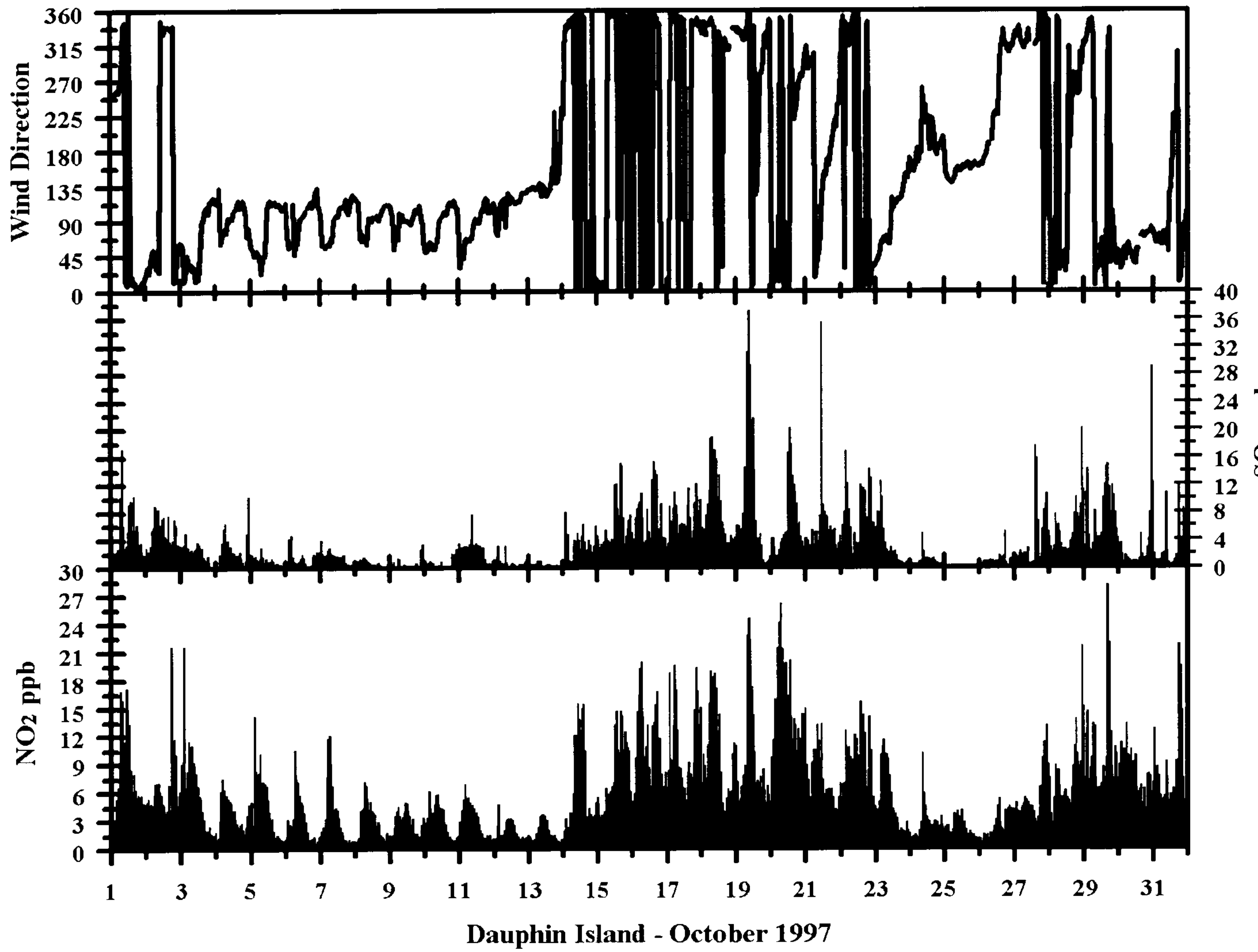


Figure 9. October 1997 time series of Dauphin Island hourly-averaged concentrations and wind direction from DPIA1.

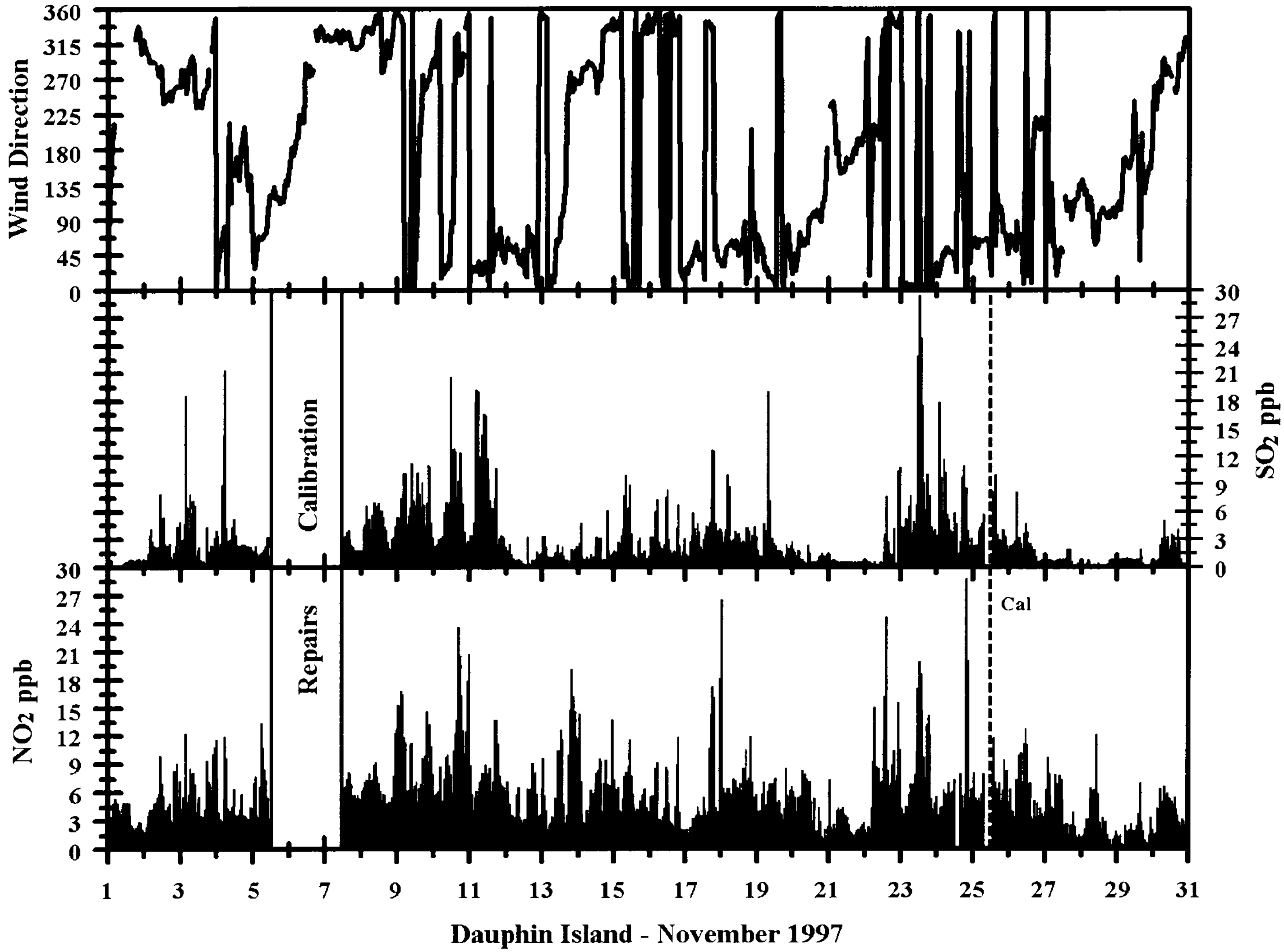


Figure 10. November 1997 time series of Dauphin Island hourly-averaged concentrations and wind direction from DPIA1. NO_x missing on 24 November.

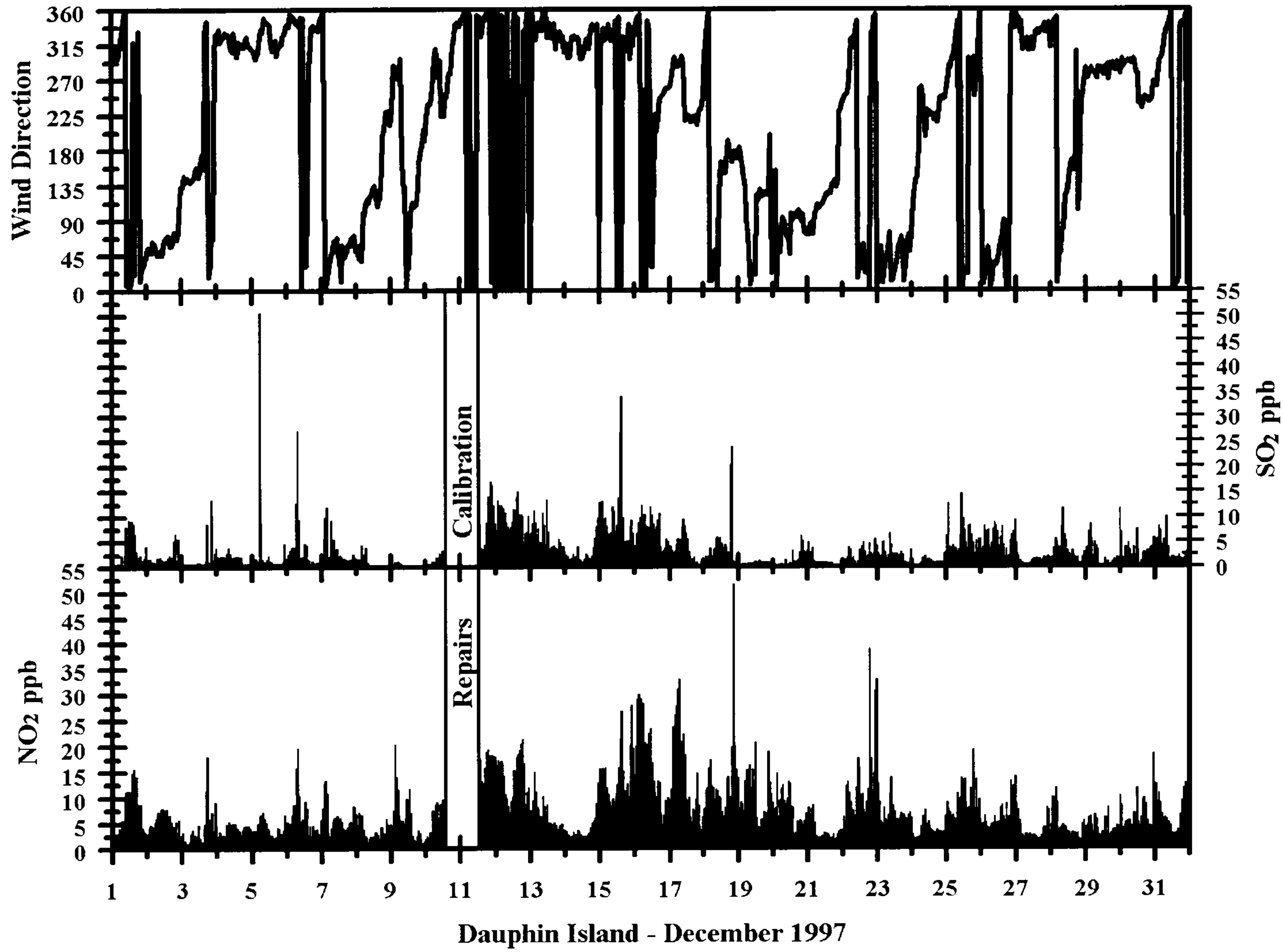


Figure 11. December 1997 time series of Dauphin Island hourly-averaged concentrations and wind direction from DPIA1. Missing SO_2 data on 29 December.

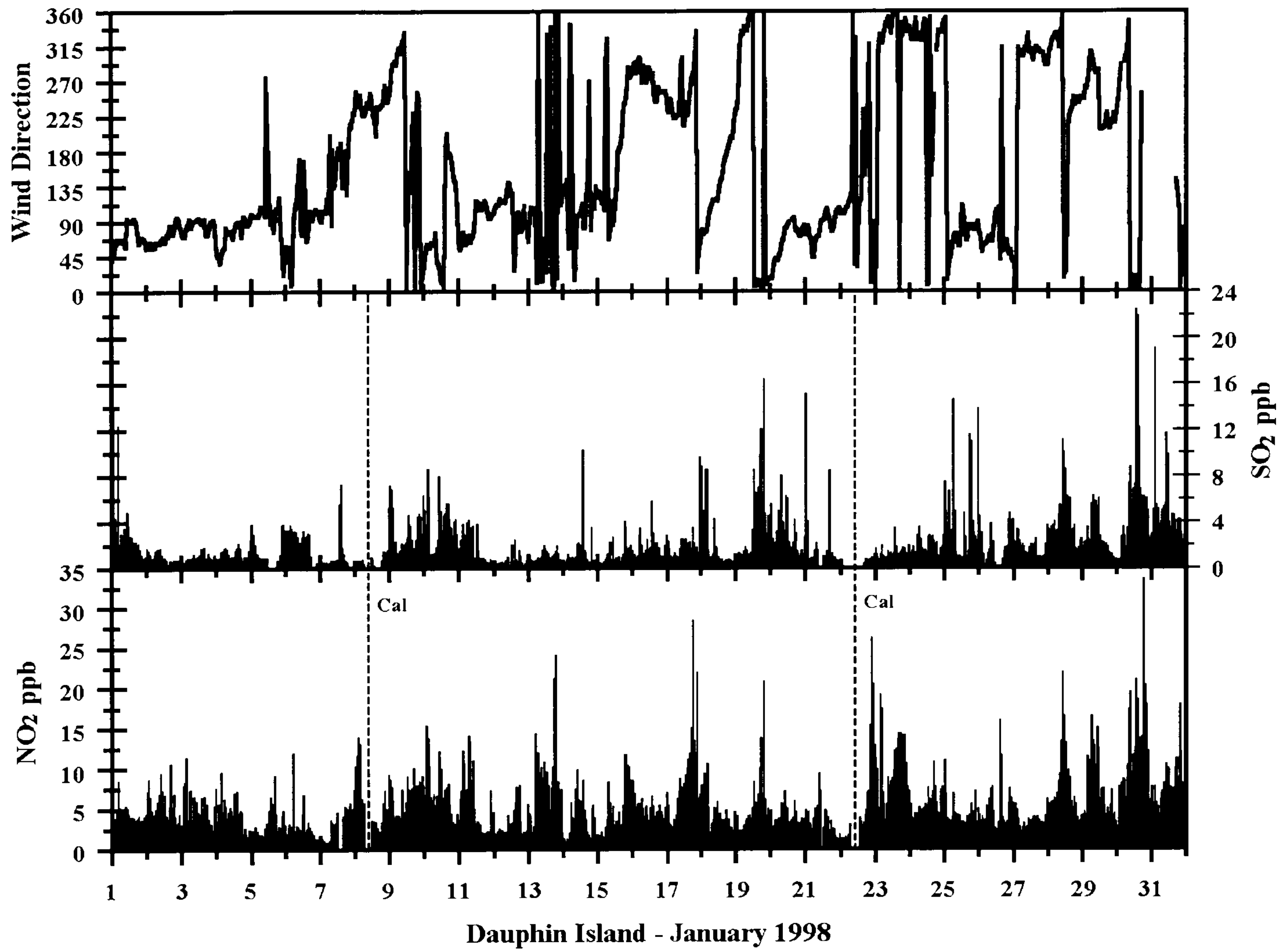


Figure 12. January 1998 time series of Dauphin Island hourly-averaged concentrations and wind direction from DPIA1. SO_2 data missing on 5 and 21 January, NO_x missing on 7 and 21 January.

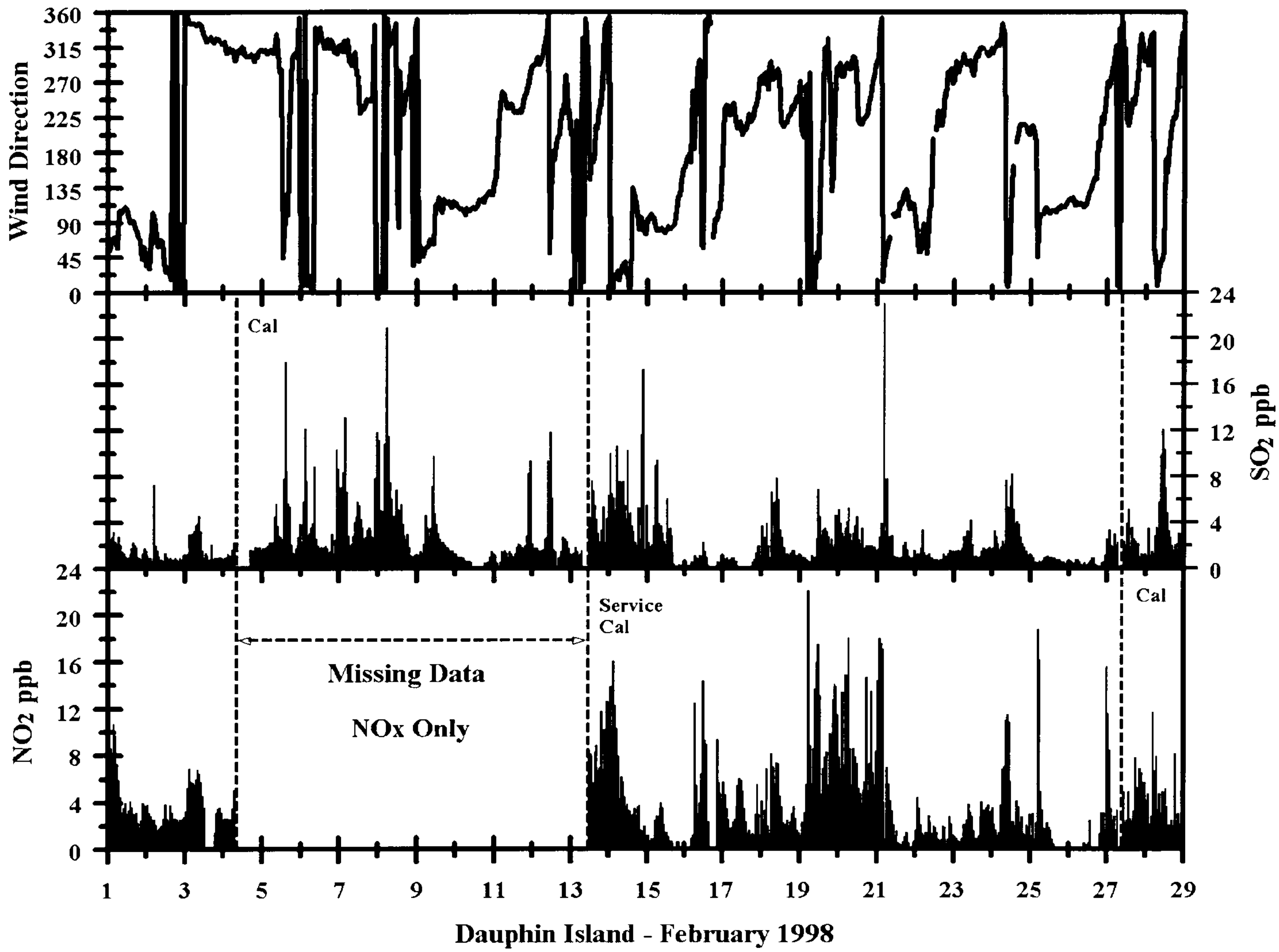


Figure 13. February 1998 time series of Dauphin Island hourly-averaged concentrations and wind direction from DPIA1. NO_x missing on 3 and 16 February, SO_2 on 16 and 17 February.

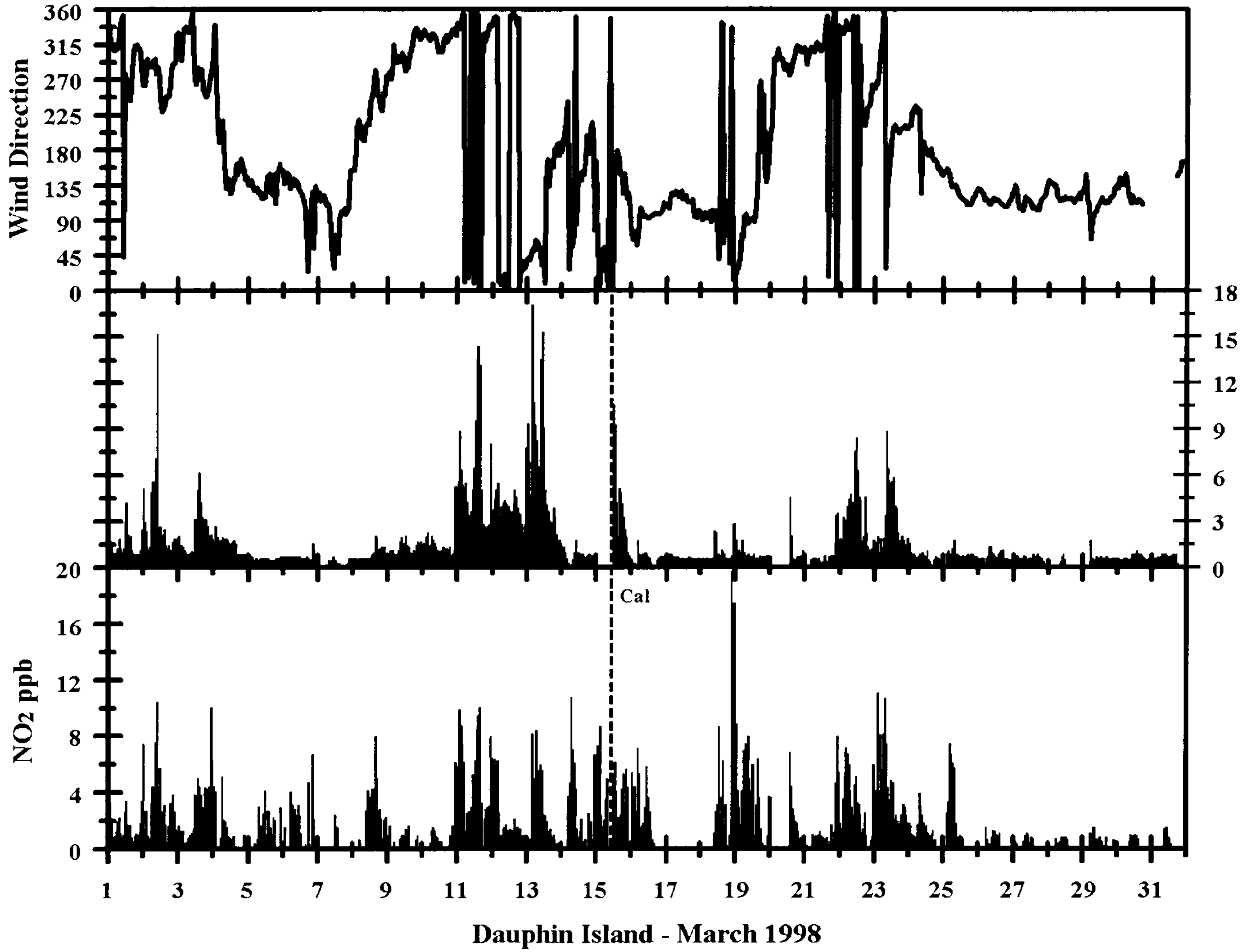


Figure 14. March 1998 time series of Dauphin Island hourly-averaged concentrations and wind direction from DPIA1. SO_2 and NO_x missing on 20 March.

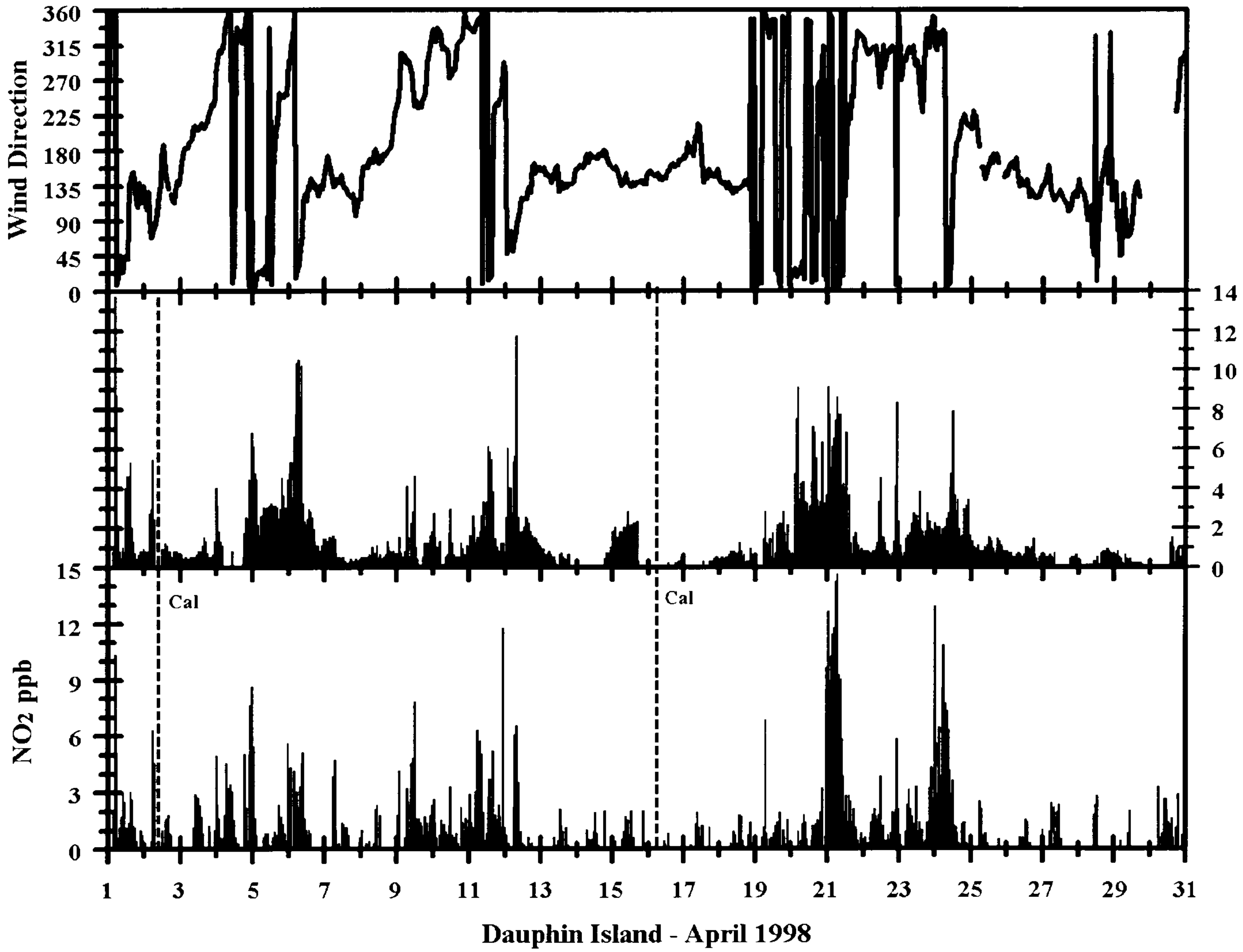
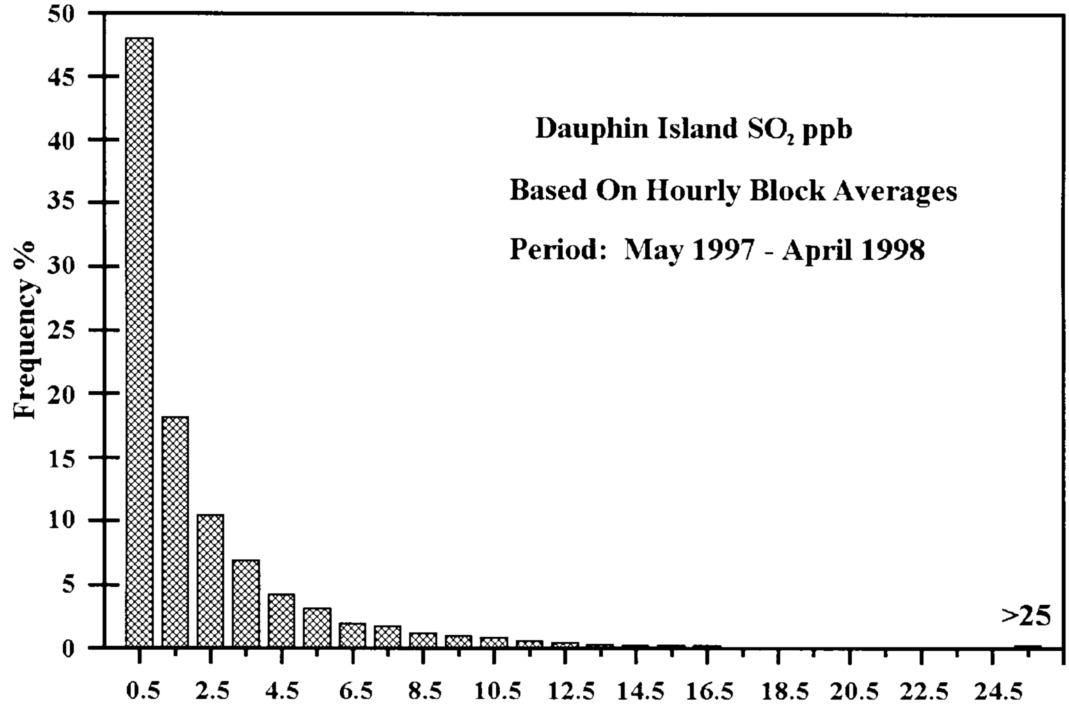


Figure 15. April 1998 time series of Dauphin Island hourly-averaged concentrations and wind direction from DPIA1. SO_2 data missing on 13 - 14 April.



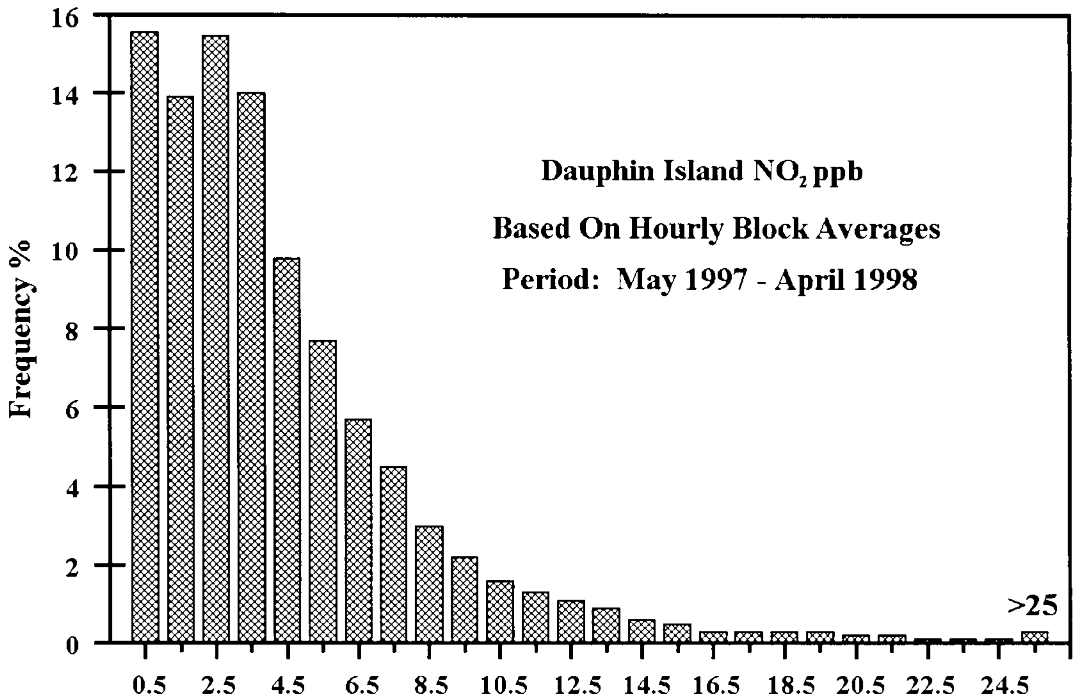


Figure 16. Frequency distribution of hourly-averaged SO_2 and NO_2 concentrations at Dauphin Island during the study period.

Table 19.
Dauphin Island SO_2 Maximums and Averages (ppb) based on 1 Hour Block Averages*

Day	May 1997		June 1997		July 1997		August 1997	
	Max	Avg	Max	Avg	Max	Avg	Max	Avg
1	2.3	0.8	1.7	0.6	4.3	1.4	1.4	0.8
2	0.2	0.0	11.1	1.8	13.9	2.8	8.3	2.2
3	1.6	0.4	6.2	1.8	11.5	1.8	3.3	1.1
4	6.9	2.2	9.7	4.7	42.5	4.0	3.9	1.1
5	2.6	1.0	4.1	0.8	14.7	2.2	2.9	0.7
6	2.6	1.1	2.1	0.6	1.5	0.5	3.9	1.7
7	2.8	0.6	0.7	0.2	1.4	0.5	13.5	5.4
8	0.4	0.2	0.6	0.3	12.3	2.0	7.3	2.1
9	9.9	1.1	1.0	0.3	12.2	3.3	2.7	0.6
10	6.0	2.0	1.6	0.5	16.2	4.0	1.1	0.4
11	5.8	1.9	2.4	0.7	25.3	8.6	1.4	0.5
12	2.9	1.0	1.2	0.3	13.0	4.2	2.6	0.4
13	15.3	4.6	2.7	0.9	5.6	2.4	0.4	0.1
14	1.5	0.8	0.7	0.2	10.2	3.3	2.0	0.4
15	2.4*	1.3*	3.8	1.3	2.3	0.6	0.3	0.1
16	16.3	3.2	0.4	0.2	2.4*	0.9*	0.4	0.2
17	8.7	2.8	1.9	0.6			0.4	0.1
18	0.7	0.3	0.9	0.2	6.3*	6.1*	1.7*	0.5*
19	0.7	0.3	1.2	0.2			0.7	0.3
20	0.6	0.4	1.0	0.2	1.4*	1.0*	3.7	0.7
21	6.0	1.5	0.5	0.3	3.6	0.6	11.8	2.8
22	2.9	1.7	4.7	1.5	1.5	0.6	12.5	6.6
23	3.8	1.3	7.1	2.3	5.0	1.5	8.1	3.5
24	0.5	0.2	4.1	0.9	2.0	0.9	7.8	2.2
25	0.7	0.2	0.7	0.3	4.8	1.3	6.0	1.9
26	1.0	0.4	0.7	0.4	7.4	2.4	4.3	1.4
27	0.7	0.4	7.8	0.7	9.1	2.3	10.1	2.7
28	1.3	0.3	6.2	1.2	0.8	0.4	12.6	4.0
29	0.1	0.0	1.0	0.5	1.1	0.6	6.0	3.0
30	0.3	0.1	1.9	0.5	9.9	0.6	10.1	4.3
31	6.8	1.7			0.7	0.3	12.3	4.7
# Hours	712		717		644		735	
Maximum	16.3		11.1		42.5		13.5	
Arith-Mean		1.1		0.8		2.0		1.8

* boxes indicate less than 75% (18 hours) complete.

Table 19 continued.

Day	September 1997		October 1997		November 1997		December 1997	
	Max	Avg	Max	Avg	Max	Avg	Max	Avg
1	10.6	3.6	17.2	5.1	0.9	0.5	9.3	3.1
2	13.8	3.7	8.9	5.1	7.9	2.5	6.5	2.1
3	12.0	3.7	5.0	2.3	18.5	3.9	13.2	1.7
4	10.6	3.8	10.2	2.6	21.3	4.3	3.8	1.9
5	4.6	1.3	2.8	0.9	3.2*	1.8*	50.5	3.6
6	2.1	1.1	4.6	1.2			27.0	3.8
7	5.0	1.0	3.9	1.6	3.9*	2.5*	11.8	3.4
8	21.6	5.2	1.4	0.6	7.0	4.5	4.3	0.8
9	6.6	2.2	3.3	0.5	11.2	7.4	1.0	0.2
10	4.5	1.6	2.6	0.7	20.6	6.5	3.1*	1.2*
11	5.7*	3.4*	7.6	2.7	19.1	8.8	16.9*	9.6*
12	13.2*	3.4*	3.1	0.7	3.2	1.0	14.9	9.8
13	38.0	7.1	0.9	0.4	3.3	1.5	13.3	6.1
14	8.3	3.5	8.0	3.2	6.1	1.8	9.7	2.7
15	18.6	6.0	15.0	6.3	9.9	3.1	33.8	10.2
16	18.0	6.8	15.2	7.4	8.3	3.2	12.1	7.4
17	13.6	4.0	12.0	7.2	12.6	4.2	9.3	3.6
18	11.0	2.2	18.9	8.8	9.9	3.8	23.8	4.5
19	3.4	0.7	37.1	9.9	19.0	3.0	1.1	0.6
20	6.6	1.7	20.1	6.8	2.7	1.1	6.0	1.2
21	4.4	2.2	35.4	6.3	0.8	0.5	4.8	1.1
22	18.3	7.8	16.8	7.3	10.4	1.6	5.4	2.3
23	1.9	1.1	12.5	3.3	29.3	8.8	6.5	2.4
24	0.8	0.4	4.9	1.0	17.8	5.9	3.3	0.9
25	5.1	0.7	0.5	0.0	9.9	4.1	14.5	5.5
26	5.7	2.7	5.1	0.9	8.0	2.3	8.6	5.4
27	5.4	1.9	17.5	4.1	1.9	0.7	9.2	1.6
28	16.7	4.8	20.1	5.5	0.8	0.3	11.4	3.3
29	12.6	3.8	14.9	7.8	1.9	0.7	8.3	2.5
30	27.8	6.6	29.0	3.2	5.0	1.9	11.4	3.5
31			12.2	3.2			9.8	3.4
# Hours	695		744		666		716	
Maximum	38.0		37.1		29.3		50.5	
Arith-Mean		3.3		3.8		3.2		3.5

Table 19 continued.

Day	January 1998		February 1998		March 1998		April 1998	
	Max	Avg	Max	Avg	Max	Avg	Max	Avg
1	20.0	4.2	3.1	1.7	4.2	1.5	13.7	2.2
2	1.7	1.0	7.2	1.1	15.1	3.0	5.4	1.3
3	1.8	0.9	4.5	1.7	6.1	2.3	1.5	0.7
4	2.1	1.2	2.2*	1.4*	2.6	1.5	4.4	1.1
5	3.8	1.5	17.9	3.8	0.9	0.5	6.8	3.4
6	3.7	2.3	12.1	3.7	1.5	0.6	10.5	4.1
7	7.2	1.0	13.1	4.8	0.6	0.2	1.6	0.7
8	1.5	0.6	20.9	5.8	2.0	0.8	1.3	0.6
9	7.1	3.2	9.7	2.7	2.0	1.2	4.6	1.2
10	8.6	4.0	1.4	0.5	5.2	1.5	2.9	1.0
11	4.1	1.8	9.3	1.9	14.3	5.9	6.1	2.3
12	2.4	0.6	11.8	3.0	5.4	3.8	11.7	2.9
13	1.9	1.0	7.6	3.2	17.0	6.5	1.0	0.6
14	10.2	1.4	17.2	6.3	1.7	0.8	1.0*	0.7*
15	4.0	1.2	9.4	2.9	10.5	2.4	2.8	1.5
16	5.8	1.8	2.2	0.6	1.7	0.5	0.5	0.1
17	3.5	1.8	1.9*	0.9*	0.8	0.6	0.5	0.1
18	9.6	2.6	7.8	2.7	2.7	0.8	1.2	0.6
19	16.4	4.2	6.8	2.1	2.8	0.9	2.8	1.2
20	8.0	3.1	5.2	2.9	4.5*	1.0*	9.1	4.1
21	15.1	2.3	23.0	2.8	3.5	0.7	9.1	4.3
22	0.8	0.3	3.3	1.1	8.4	3.4	8.3	1.6
23	3.4	1.3	4.1	1.8	8.8	3.0	3.8	1.9
24	3.5	1.9	8.1	3.2	1.8	0.7	7.9	2.7
25	14.6	4.1	1.0	0.7	1.7	0.7	1.5	1.0
26	13.8	2.3	0.8	0.5	1.3	0.7	1.4	0.7
27	4.1	1.8	5.1	2.4	0.8	0.5	0.7	0.3
28	11.1	4.5	12.0	3.6	0.8	0.1	0.9	0.3
29	6.2	2.8			1.7	0.5	0.8	0.3
30	22.4	6.1			1.0	0.6	1.5	0.3
31	19.0	5.2			0.8	0.5		
# Hours	727		642		729		690	
Maximum	22.4		23.0		17.0		13.7	
Arith-Mean		2.4		2.5		1.5		1.5

Table 20.
Dauphin Island NO_2 Maximums and Averages (ppb) based on 1 Hour Block Averages*

Day	May 1997		June 1997		July 1997		August 1997	
	Max	Avg	Max	Avg	Max	Avg	Max	Avg
1	5.0	2.4	4.8	3.1	15.6	4.4	8.5	2.8
2	3.4	2.1	15.7	5.3	18.1	6.8	7.2	3.3
3	9.1	3.4	14.7	7.5	9.3	5.7	6.2	3.5
4	5.8	3.5	14.8	7.5	12.3	6.6	9.4	3.8
5	7.7	2.7	12.5	3.8	10.3	4.9	12.0	4.3
6	22.1	4.2	5.8	2.9	4.4	2.1	12.9	4.5
7	9.9	3.1	5.4	2.6	21.1	4.4	17.2	6.0
8	3.0	1.4	3.3	1.5	15.4	5.9	13.1	3.6
9	10.1	3.3	5.2	2.9	10.5	5.6	6.0	2.0
10	7.3	3.2	5.9	2.5	19.9	5.8	10.4	3.6
11	9.1	3.8	7.5	3.8	27.4	8.0	4.9	2.3
12	6.3	3.2	6.5	2.3	18.9	8.6	3.7	1.7
13	11.3	5.7	6.2	3.4	12.4	5.3	5.2	1.5
14	4.7	3.2	4.4	3.1	12.8	5.5	12.9	3.2
15	11.9	4.6	7.0	3.5	8.0	3.2	2.4	1.3
16	18.8	5.7	6.0	2.5	8.8*	4.6*	1.7	0.8
17	12.8	4.4	7.6	2.5			1.9	0.8
18	4.2	2.2	7.6	3.3	1.2*	0.9*	6.8	2.3
19	6.0	2.6	5.9	3.7			8.5	3.3
20	4.9	2.8	6.3	2.9	23.8*	15.2*	15.0	3.9
21	9.2	5.5	3.7	2.3	9.2	4.5	12.6	4.8
22	8.3	4.6	4.8	3.1	12.3	7.6	12.8	7.9
23	8.4	4.8	17.9	6.4	13.6	6.2	10.8	4.0
24	5.5	2.5	6.0	2.7	13.0	5.6	8.5	3.7
25	4.3	2.3	4.7	2.3	23.1	5.2	6.3	3.2
26	3.9	2.1	6.4	2.3	12.9	5.8	12.4	4.2
27	4.3	2.2	8.1	3.8	13.4	4.6	7.7	4.0
28	5.2	2.4	7.2	3.5	5.3	2.5	12.9	6.4
29	5.0	2.1	7.9	3.1	8.0	3.5	19.0	6.4
30	6.0	2.0	5.4	2.4	5.8	2.8	8.5	4.7
31	11.8	4.2			5.0	2.5	12.3	5.3
# Hours	732		717		644		742	
Maximum	22.1		17.9		27.4		19.0	
Arith-Mean		3.3		3.4		5.1		3.7

* boxes indicate less than 75% (18 hours) complete.

Table 20 continued.

Day	September 1997		October 1997		November 1997		December 1997	
	Max	Avg	Max	Avg	Max	Avg	Max	Avg
1	8.3	4.6	17.1	8.0	7.0	3.9	15.4	7.6
2	7.1	3.7	21.5	6.6	9.8	5.0	7.8	5.4
3	15.8	5.3	21.5	6.5	12.2	6.4	17.9	4.1
4	9.5	4.7	7.5	3.7	11.9	5.0	5.2	3.9
5	3.6	1.9	14.1	4.6	13.3*	6.7*	7.0	4.1
6	4.1	2.4	10.5	3.0			19.5	6.3
7	7.1	2.2	12.0	3.5	8.1*	6.4*	13.2	6.1
8	20.8	5.2	7.1	3.0	12.2	6.7	7.0	3.7
9	9.3	3.6	4.9	2.8	16.7	10.2	20.2	5.9
10	7.4	3.5	6.1	3.1	23.5	10.3	9.5*	5.7*
11	8.7*	4.5*	6.8	3.2	20.6	8.3	19.2*	16.8*
12	5.0*	3.6*	4.7	2.0	9.0	5.0	21.2	14.3
13	22.4	6.6	3.7	1.8	19.0	7.9	14.8	6.7
14	7.7	4.7	15.4	6.6	14.3	7.0	12.7	3.8
15	8.0	4.5	14.6	8.3	11.5	5.9	27.8	14.4
16	15.4	5.1	19.8	11.0	11.8	5.0	29.8	16.8
17	10.4	4.6	19.5	10.9	17.2	5.1	32.8	15.0
18	8.7	3.8	18.9	10.7	26.4	8.3	51.4	12.9
19	6.0	2.6	24.5	9.9	8.5	5.4	20.5	10.3
20	12.7	3.9	26.1	14.9	8.3	4.7	14.4	7.9
21	9.7	4.7	14.9	7.7	7.3	2.9	8.3	3.5
22	13.1	5.7	15.6	9.7	24.6	8.4	38.8	12.1
23	4.5	2.3	11.5	5.2	19.8	8.9	32.8	8.1
24	3.9	2.2	10.1	2.8	28.7	7.3	7.4	3.5
25	8.7	3.8	4.0	2.2	11.7	6.9	19.0	9.4
26	8.6	5.7	5.2	2.5	12.7	6.0	13.1	6.4
27	7.2	4.0	13.0	5.5	9.7	4.4	13.8	4.1
28	14.2	5.7	21.5	7.8	12.0	3.2	11.5	4.4
29	11.4	6.1	28.0	10.7	6.9	1.9	7.8	4.1
30	19.3	7.1	13.2	8.1	6.6	4.1	18.2	6.6
31			21.7	8.2			12.5	6.7
# Hours	695		744		663		719	
Maximum	22.4		28.0		28.7		51.4	
Arith-Mean		4.3		6.3		6.1		7.6

Table 20 continued.

Day	January 1998		February 1998		March 1998		April 1998	
	Max	Avg	Max	Avg	Max	Avg	Max	Avg
1	8.5	4.3	10.6	4.7	5.7	1.7	10.3	1.7
2	10.5	5.7	3.8	2.6	10.4	3.3	6.3	0.9
3	11.3	5.3	6.8	4.5	10.0	2.6	2.9	0.7
4	9.5	4.6	5.0*	3.0*	6.2	1.3	7.6	2.2
5	9.1	3.3			4.1	1.2	8.6	1.3
6	11.9	3.0			6.7	1.5	5.6	1.8
7	5.7	3.0			2.4	0.2	4.7	0.6
8	13.8	6.0			7.9	2.0	2.3	0.4
9	10.0	6.8			1.6	0.5	7.8	1.9
10	15.3	7.2			6.1	0.8	3.3	1.2
11	14.0	5.9			10.0	5.0	11.7	3.0
12	7.9	3.4			6.4	2.3	6.5	1.0
13	24.1	8.9	12.5*	8.5*	8.3	2.6	2.1	0.3
14	9.8	3.9	16.0	5.9	10.7	2.4	2.0	0.4
15	11.7	4.9	3.9	1.4	8.6	4.0	2.0	0.5
16	8.5	5.2	14.3	4.4	7.1	2.0	0.8	0.1
17	28.4	9.0	6.0	3.3	0.0	0.0	1.9	0.4
18	10.5	4.8	8.1	3.7	19.6	3.0	1.8	0.4
19	20.7	5.7	22.0	8.8	17.4	4.4	6.8	0.8
20	7.1	4.1	18.0	8.6	6.8*	2.6*	3.2	0.8
21	9.3	3.8	17.9	4.5	7.9	1.1	14.6	5.8
22	26.2*	5.9*	4.3	1.7	7.1	3.0	5.8	1.4
23	19.1	10.9	4.0	2.1	11.0	4.6	4.3	1.5
24	10.7	5.7	11.4	3.9	3.9	1.3	12.9	3.8
25	10.9	4.6	18.7	2.6	7.4	1.6	2.5	0.3
26	15.9	5.3	3.1	0.6	1.5	0.4	1.5	0.2
27	5.6	3.5	15.5	5.1	1.1	0.3	2.4	0.5
28	21.9	7.9	11.6	4.1	0.8	0.2	2.8	0.3
29	16.4	7.7			1.5	0.4	2.0	0.1
30	33.5	12.5			1.0	0.2	3.3	0.9
31	17.8	8.2			1.5	0.3		
# Hours	730		439		729		713	
Maximum	33.5		22.0		19.6		14.6	
Arith-Mean		5.8		4.1		1.8		1.2

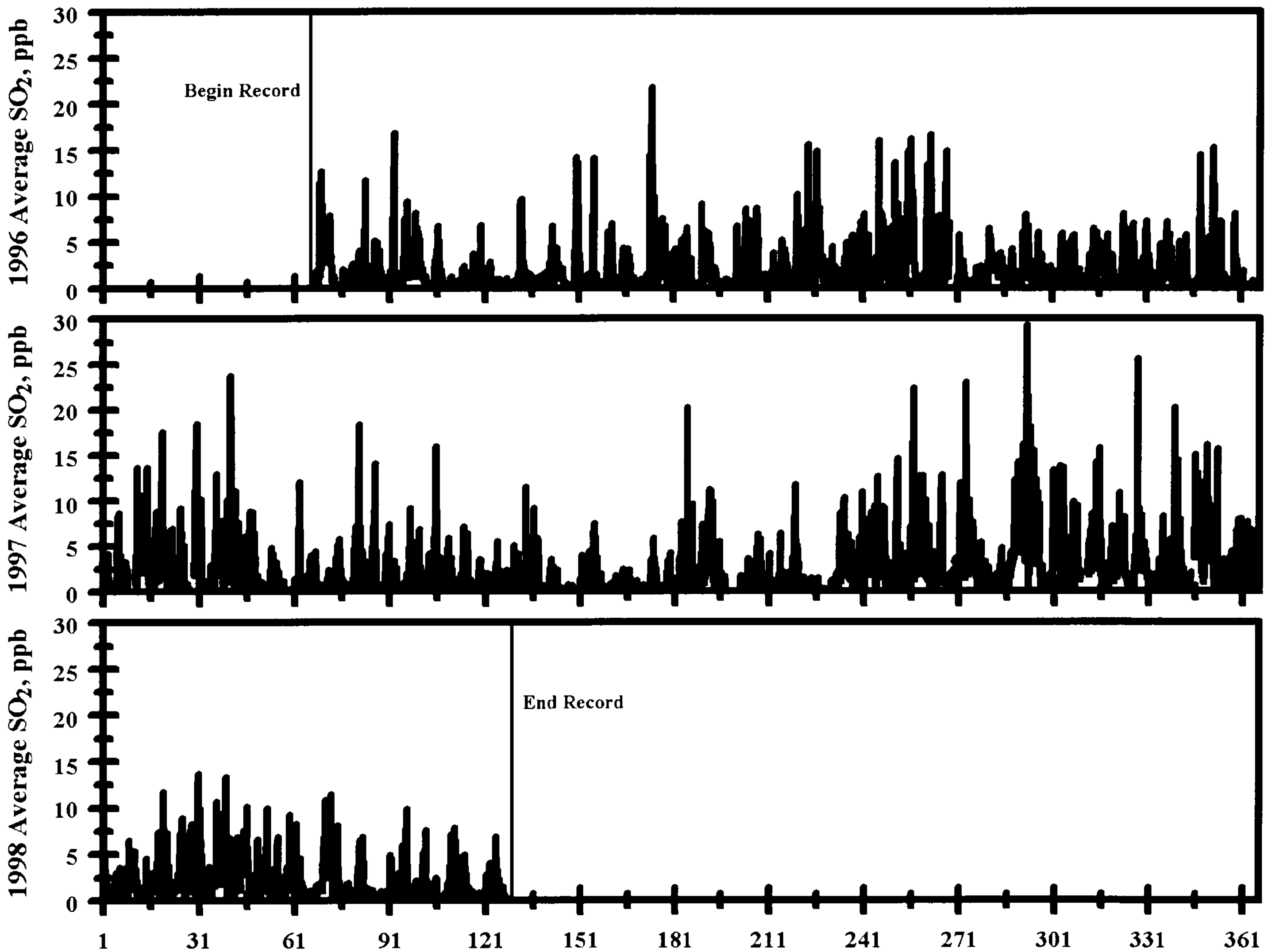


Figure 17. Dauphin Island 3-hour block average SO_2 annual trends.

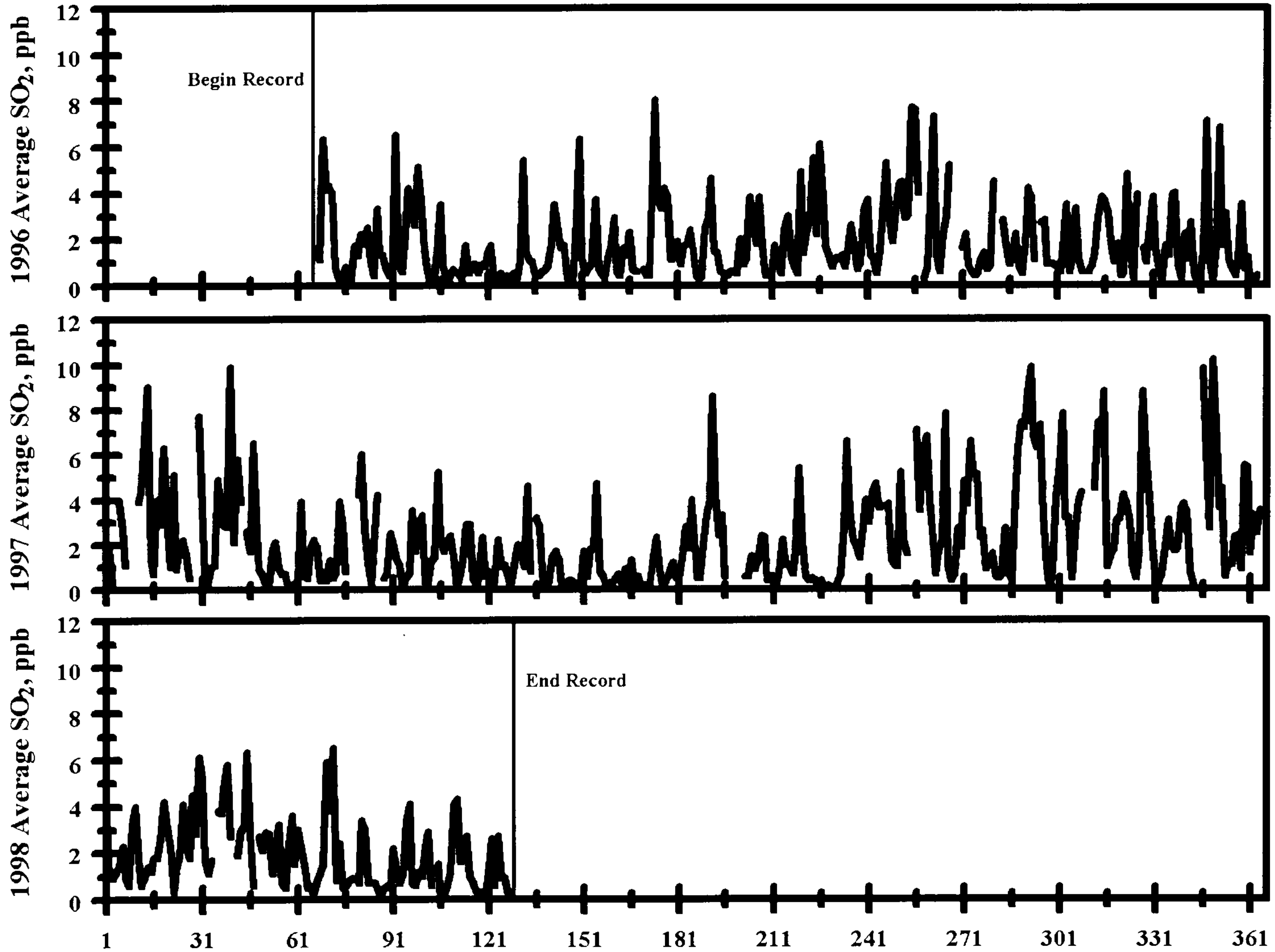


Figure 18. Dauphin Island 24-hour block average SO_2 annual trends.

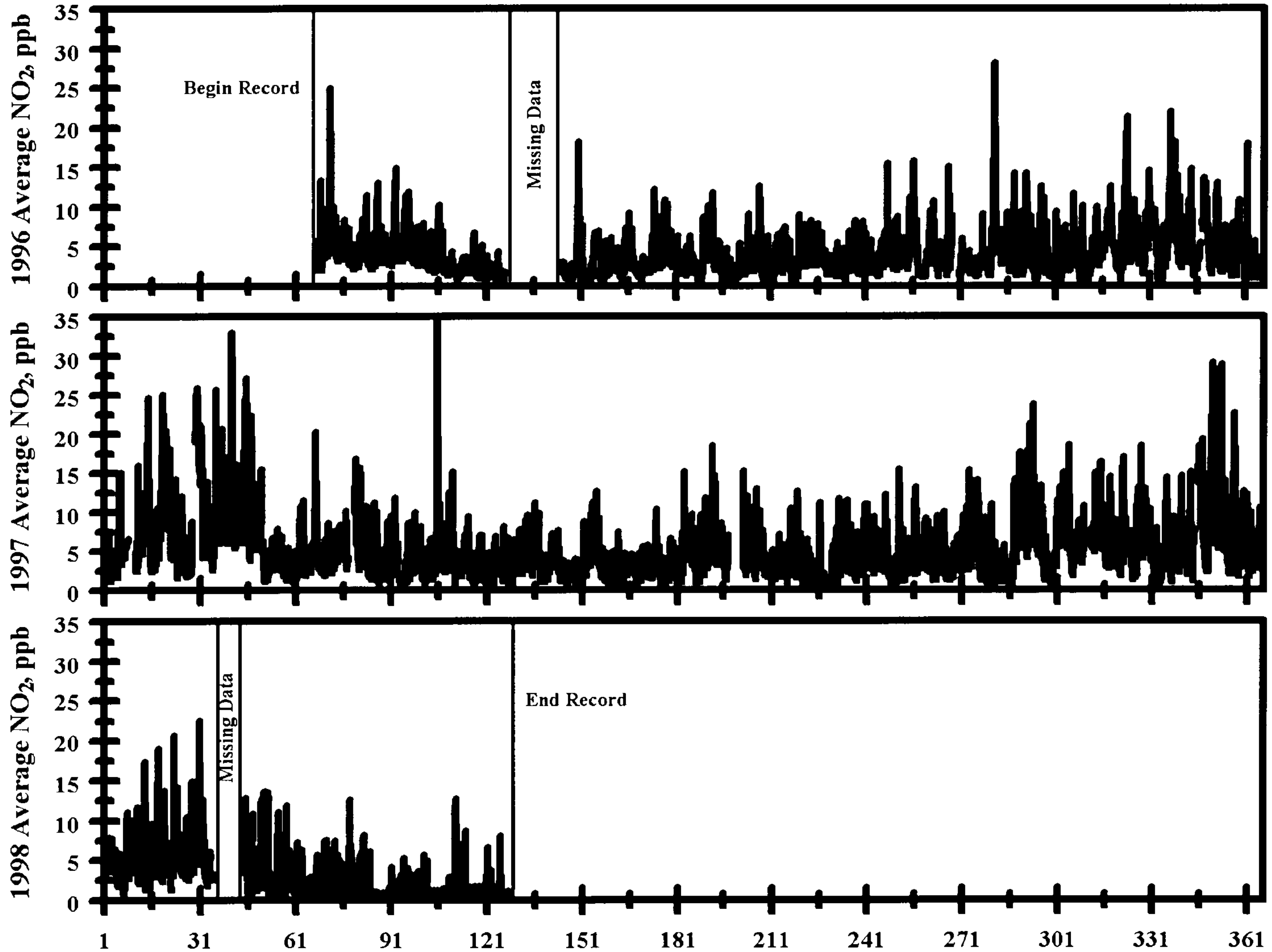


Figure 19. Dauphin Island 3-hour block average NO_2 annual trends.

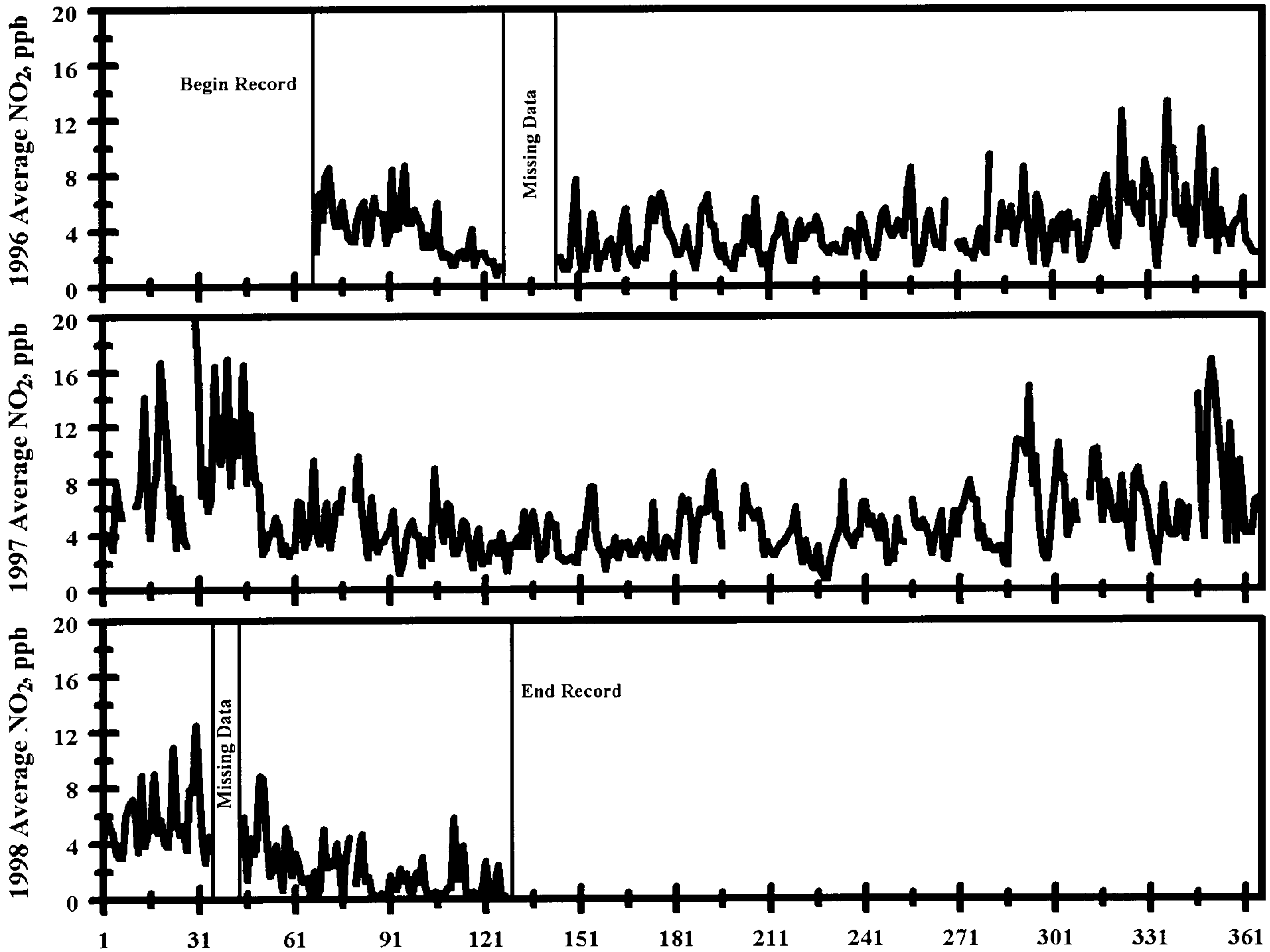


Figure 20. Dauphin Island 24-hour block average NO_2 annual trends.

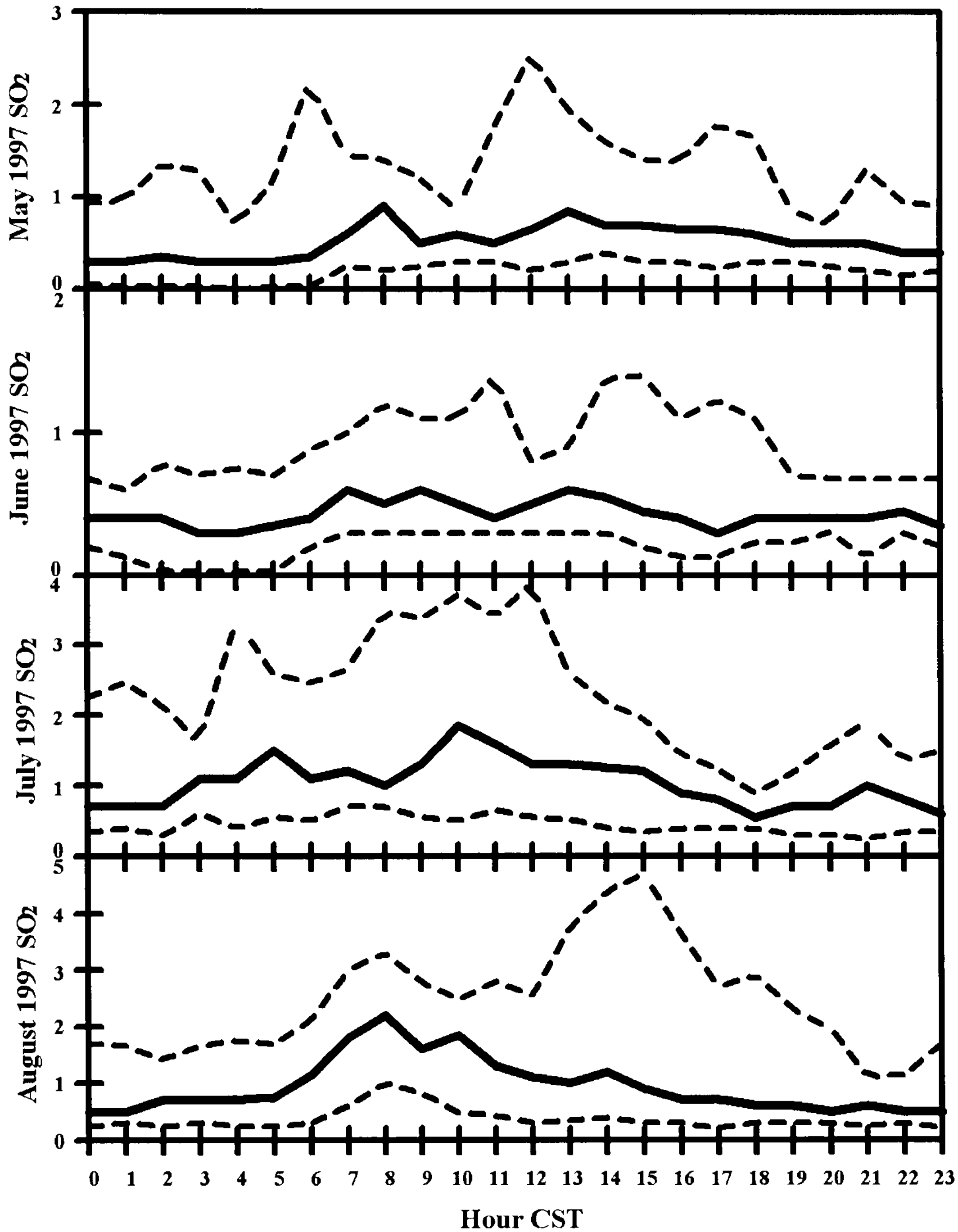


Figure 21. Dauphin Island diurnal SO_2 variations as represented by first (dashed), second (solid), and third (dashed) quartile lines.

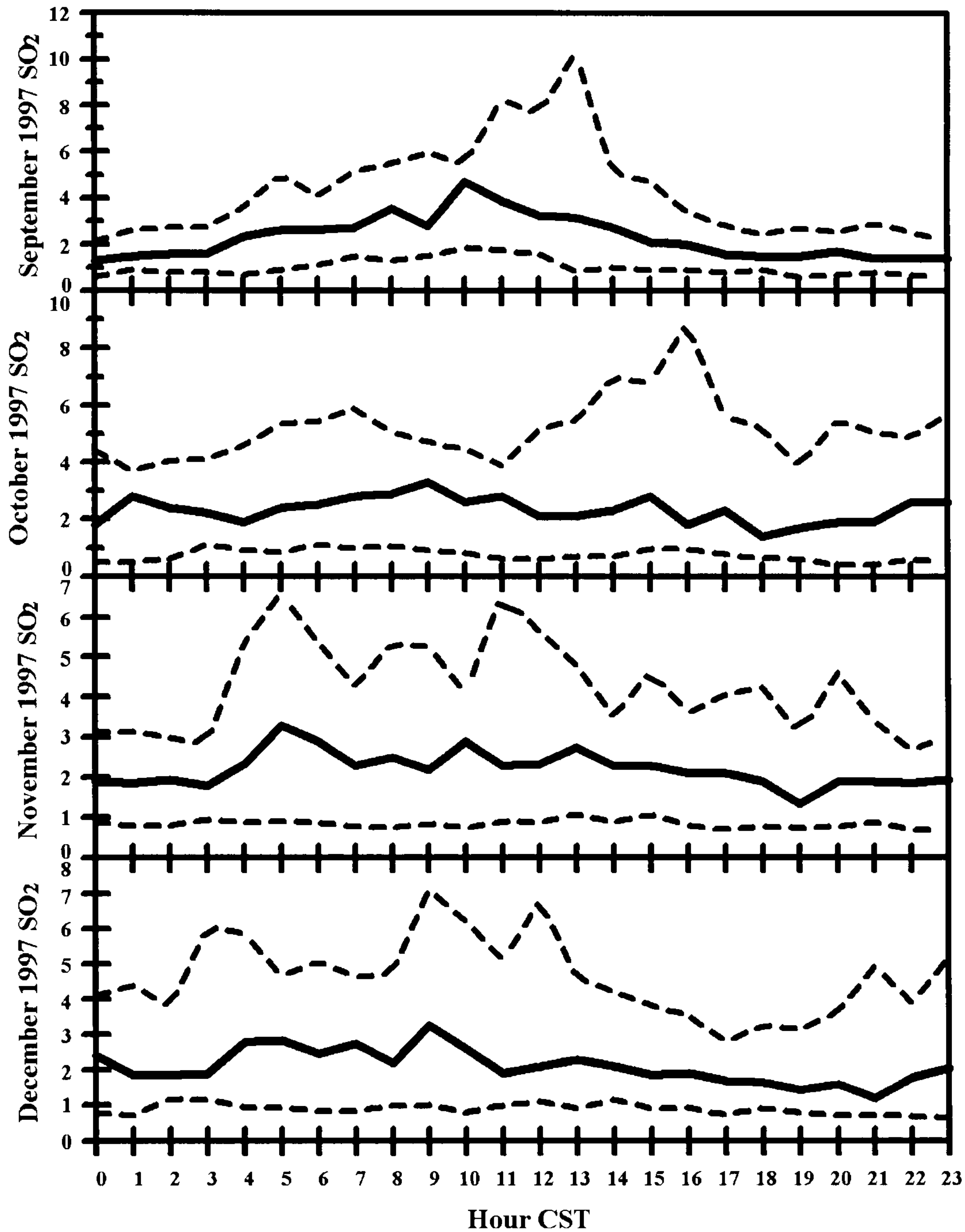


Figure 21 continued.

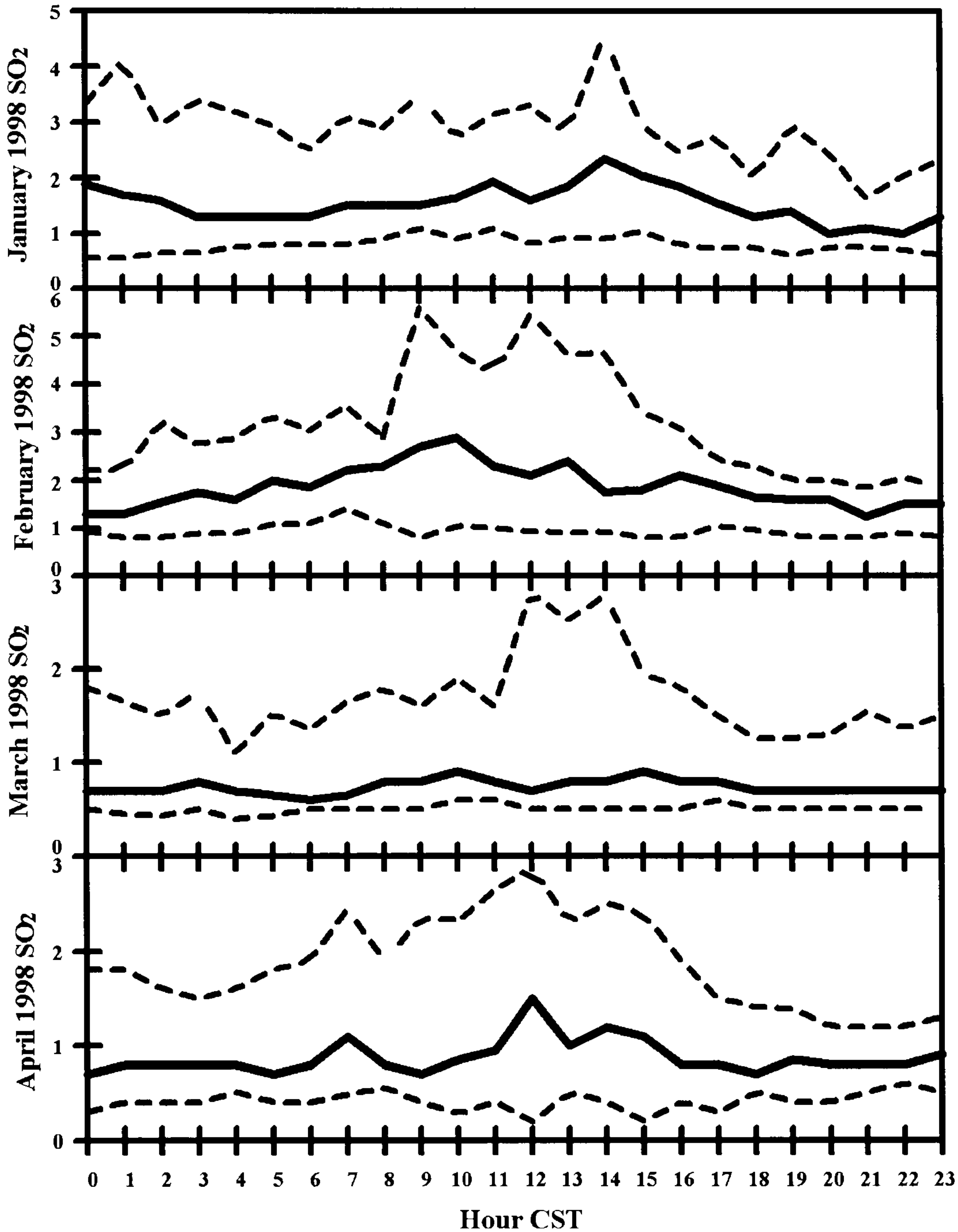


Figure 21 continued.

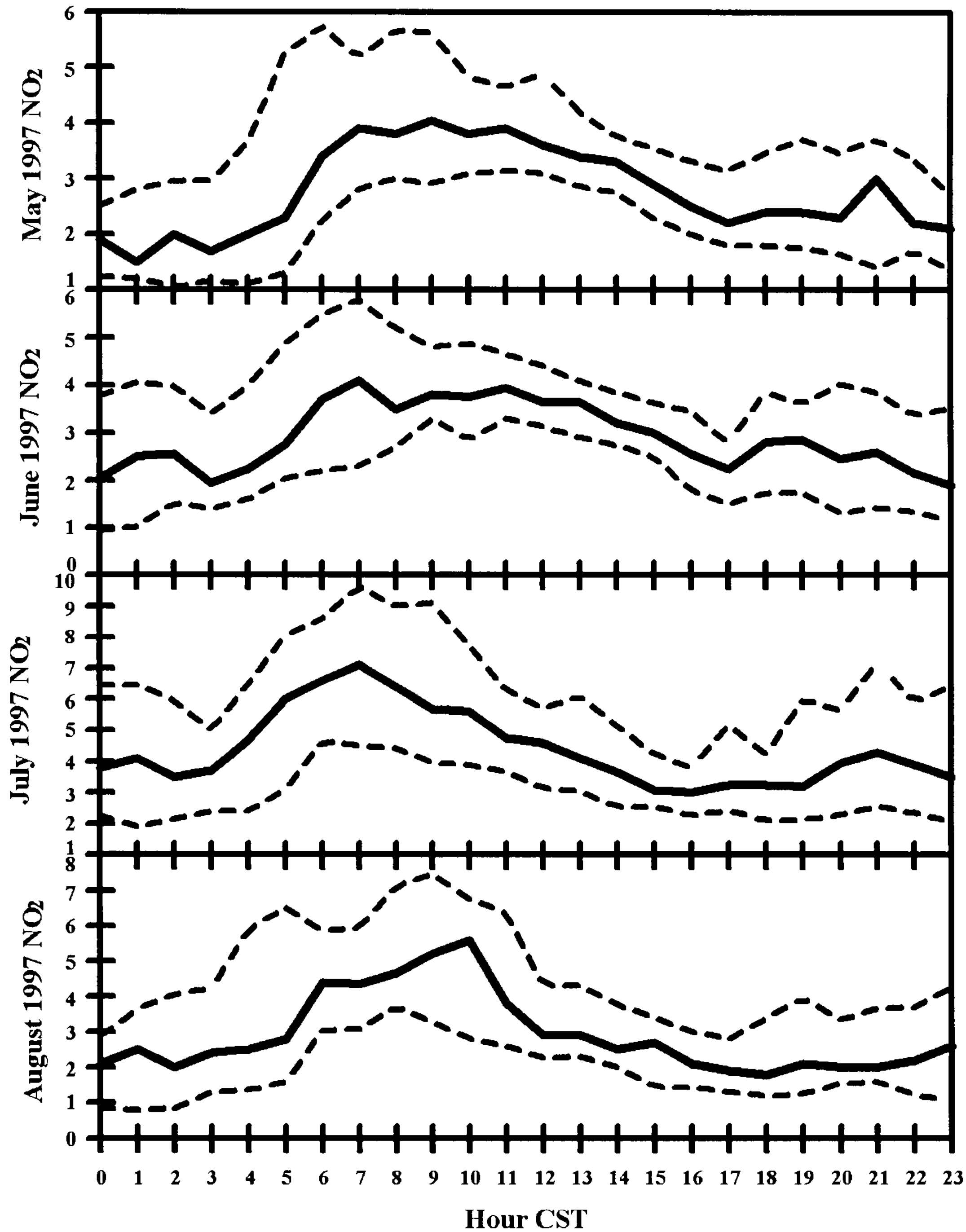


Figure 22. Dauphin Island diurnal NO_2 trends as represented by first (dashed), second (solid), and third (dashed) quartile lines.

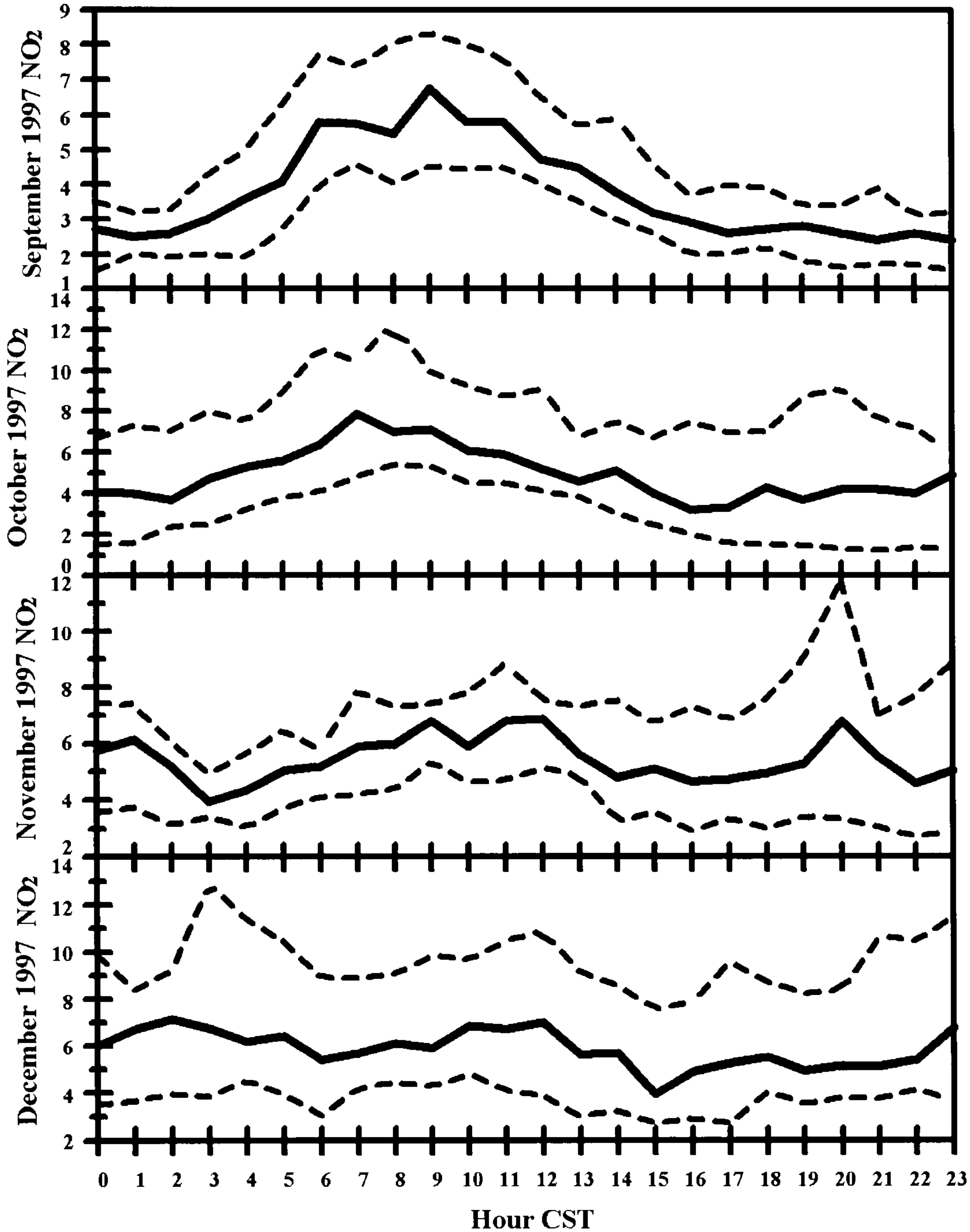


Figure 22 continued.

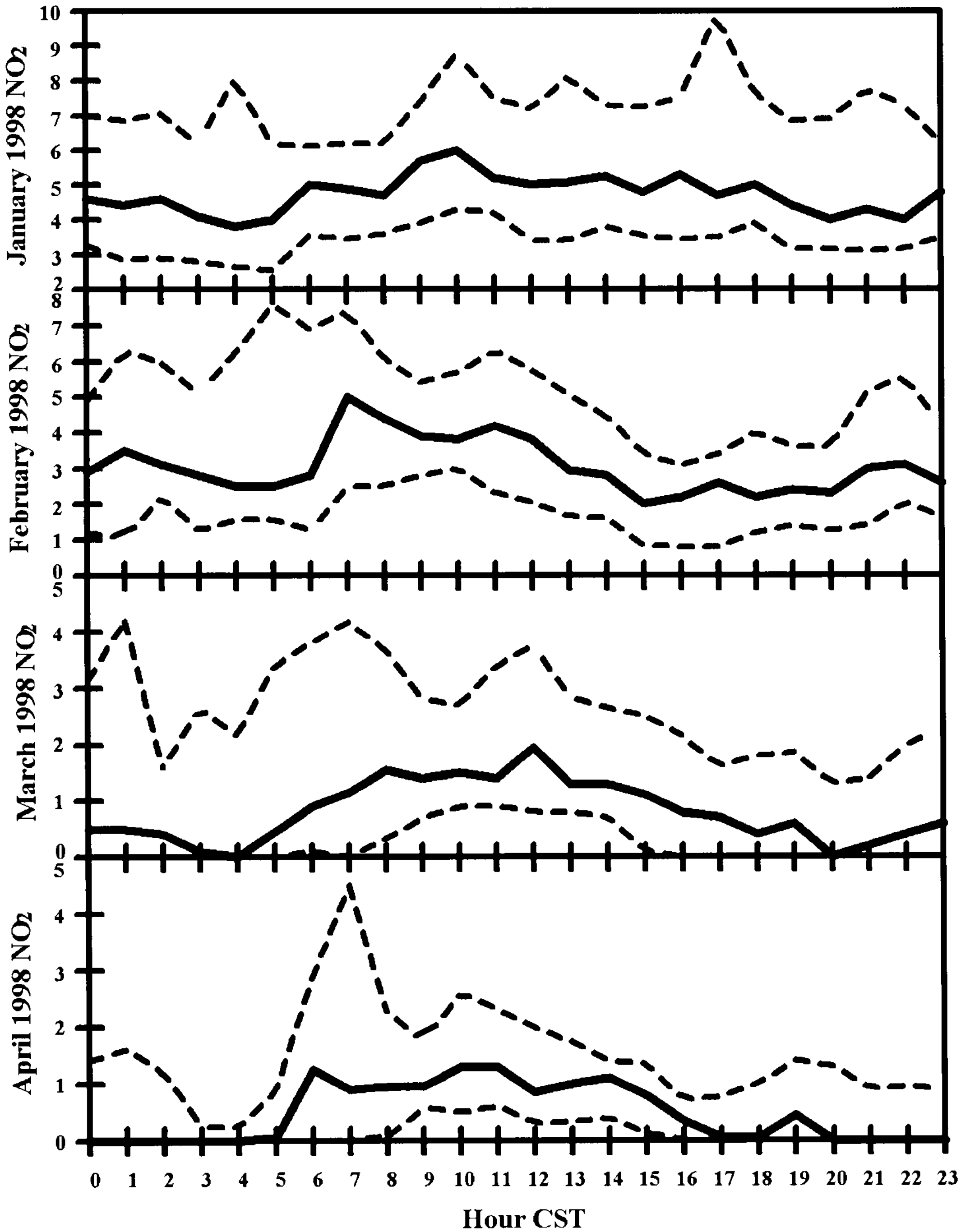


Figure 22 continued.

Using the combined air quality / meteorology data sets, monthly wind and pollution roses were created as shown in Figs. 23 - 34. The pollution roses represent the range of concentrations associated with a particular direction (i.e., direction from which the wind is blowing). Note that the February 1998 NO_2 rose is only 65% complete, due to failure of the NO_x monitor. SO_2 maximums are mostly associated with northerly wind directions; NO_2 maximums also occur mostly with northerly winds, however higher concentrations from the west and southwest are occasionally seen. This directional dependence is clear in Tables 21 and 22, which list the monthly 1, 3, and 24 hour block-averaged maximums for SO_2 and NO_2, respectively. NO_2 / NO_x ratios are included in Table 22. In general, the ratios are high, indicating a more aged air mass (and more distant source). For comparison to the National Ambient Air Quality Standard established by the U.S. EPA for SO_2 (see Table 23), the maximum 3 hour SO_2 concentration was 29.2 ppb and for 24 hours, 10.2 ppb.

The entire hourly air quality record for SO_2 and NO_2 obtained during this study period was ranked by concentration, and the top 10% selected for the analysis listed in Table 24. The greater frequency of high concentration measurements during the months of September to January is seen; even more striking is the clear association of high concentrations with north-northeasterly winds for both pollutants. Therefore, from this analysis it may be concluded that ambient air quality experienced at Dauphin Island is mostly dominated by land-based conditions, with little influence from offshore sources.

Table 21.
Dauphin Island SO_2 Maximums (ppb)

Month	Averaging Interval	Maximum	Day / Hour	Wind Direction / Speed
May 1997	1 hour	16.3	16 / 03	035 / 5.3
	3 hour	11.5 9.1	13 / 14 16 / 05	114 / 2.4 048 / 4.8
	24 hour	4.6		
June 1997	1 hour	11.1	2 / 23	342 / 7.6
	3 hour	7.4	4 / 11	008 / 4.1
	24 hour	4.7		
July 1997	1 hour	42.5	4 / 0	322 / 3.8
	3 hour	20.2	4 / 02	317 / 3.1
	24 hour	8.6		
August 1997	1 hour	13.5	7 / 06	006 / 4.5
	3 hour	11.7	7 / 08	012 / 4.1
	24 hour	6.6		
September 1997	1 hour	38.0	13 / 12	035 / 1.2
	3 hour	23.0	30 / 08	278 / 4.7
	24 hour	7.8		
October 1997	1 hour	37.1	19 / 09	355 / 6.4
	3 hour	29.2	19 / 11	360 / 5.9
	24 hour	9.9		
November 1997	1 hour	29.3	23 / 13	003 / 7.7
	3 hour	25.6	23 / 14	003 / 7.9
	24 hour	8.8		
December 1997	1 hour	50.5	5 / 06	326 / 9.5
	3 hour	20.2	5 / 08	331 / 9.2
	24 hour	10.2		

Table 21 continued.

Month	Averaging Interval	Maximum	Day / Hour	Wind Direction / Speed
January 1998	1 hour	22.4	30 / 14	005 / 2.8
	3 hour	13.6	30 / 17	332 / 1.0
	24 hour	6.1		
February 1998	1 hour	23.0	21 / 05	041 / 5.3
	3 hour	13.2	8 / 08	330 / 3.8
	24 hour	6.3		
March 1998	1 hour	17.0	13 / 04	054 / 6.6
	3 hour	11.4	13 / 11	043 / 3.8
	24 hour	6.5		
April 1998	1 hour	13.7	1 / 05	357 / 8.9
	3 hour	9.8	6 / 08	039 / 4.4
	24 hour	4.3		

Table 22.
Dauphin Island NO_2 Maximums (ppb)

Month	Avg. Int.	Maximum	Day / Hour	Wind Dir. / Speed	NO_2 / NO_x
May 1997	1 hour	22.1	6 / 05	239 / 1.6	0.73
	3 hour	11.2	16 / 02	019 / 4.4	0.98
	24 hour	5.7			
June 1997	1 hour	17.9	23 / 09	349 / 4.3	0.85
	3 hour	12.6	4 / 08	003 / 4.3	0.88
	24 hour	7.5			
July 1997	1 hour	27.4	11 / 08	003 / 3.3	0.88
	3 hour	18.5	11 / 08	008 / 3.1	0.90
	24 hour	8.6			
August 1997	1 hour	19.0	29 / 02	295 / 1.8	1.00
	3 hour	12.6	7 / 05	353 / 4.0	1.00
	24 hour	7.9			
September 1997	1 hour	22.4	13 / 06	011 / 4.9	0.97
	3 hour	15.5	8 / 08	011 / 5.0	0.90
	24 hour	7.1			
October 1997	1 hour	28.0	29 / 17	298 / 0.8	0.91
	3 hour	23.8	20 / 08	356 / 3.2	0.78
	24 hour	14.9			
November 1997	1 hour	28.7 26.4	24 / 20 18 / 01	000 / 0 030 / 4.7	1.00 0.82
	3 hour	18.4	23 / 14	003 / 7.9	0.66
	24 hour	10.3			
December 1997	1 hour	51.4	18 / 21	178 / 3.1	0.78
	3 hour	29.1	16 / 05	352 / 3.9	0.80
	24 hour	16.8			

Table 22 continued.

Month	Avg. Int.	Maximum	Day / Hour	Wind Dir. / Speed	NO_2 / NO_x
January 1998	1 hour	33.5	30 / 19	Missing	0.79
	3 hour	22.5	30 / 20	Missing	0.92
	24 hour	12.5			
February 1998	1 hour	22.0	19 / 06	282 / 1.6	0.96
	3 hour	13.6	20 / 08	288 / 4.4	0.83
	24 hour	8.8			
March 1998	1 hour	19.6	18 / 22	013 / 4.5	1.00
	3 hour	12.6	18 / 23	002 / 4.3	1.00
	24 hour	5.0			
April 1998	1 hour	14.6	21 / 07	003 / 5.6	0.80
	3 hour	12.7	21 / 08	004 / 5.2	0.83
	24 hour	5.8			

Table 23.
U.S. Federal Primary and Secondary Ambient Air Quality Standard
Source: 40 CFR § 50, July 1992
(From Bouble et al., 1994)

Pollutant	Type of Standard	Averaging Time	Frequency Parameter	Concentration $\mu g / m^3$	ppb
Sulfur Oxides (as sulfur dioxide)	Primary	24 hour	Annual Maximum*	365	138.7
		1 year	Arithmetic Mean	80	30.4
	Secondary	3 hour	Annual Maximum*	1300	494
Nitrogen Dioxide	Primary and Secondary	1 year	Arithmetic Mean	100	53

*Not to be exceeded more than once per year.

Table 24.
Frequency Distribution of Dauphin Island Top 10% Concentrations

Month	NO_2 (827 samples)	SO_2 (842 samples)
May 1997	18	20
June 1997	18	14
July 1997	69	58
August 1997	45	64
September 1997	42	103
October 1997	169	156
November 1997	95	106
December 1997	197	138
January 1998	108	58
February 1998	43	65
March 1998	11	30
April 1998	12	30
Direction		
0 - 45	246	296
46 - 90	75	103
91 - 135	16	24
136 - 180	16	36
181 - 225	21	34
226 - 270	75	32
271 - 315	104	65
316 - 360	255	239
Missing	19	13

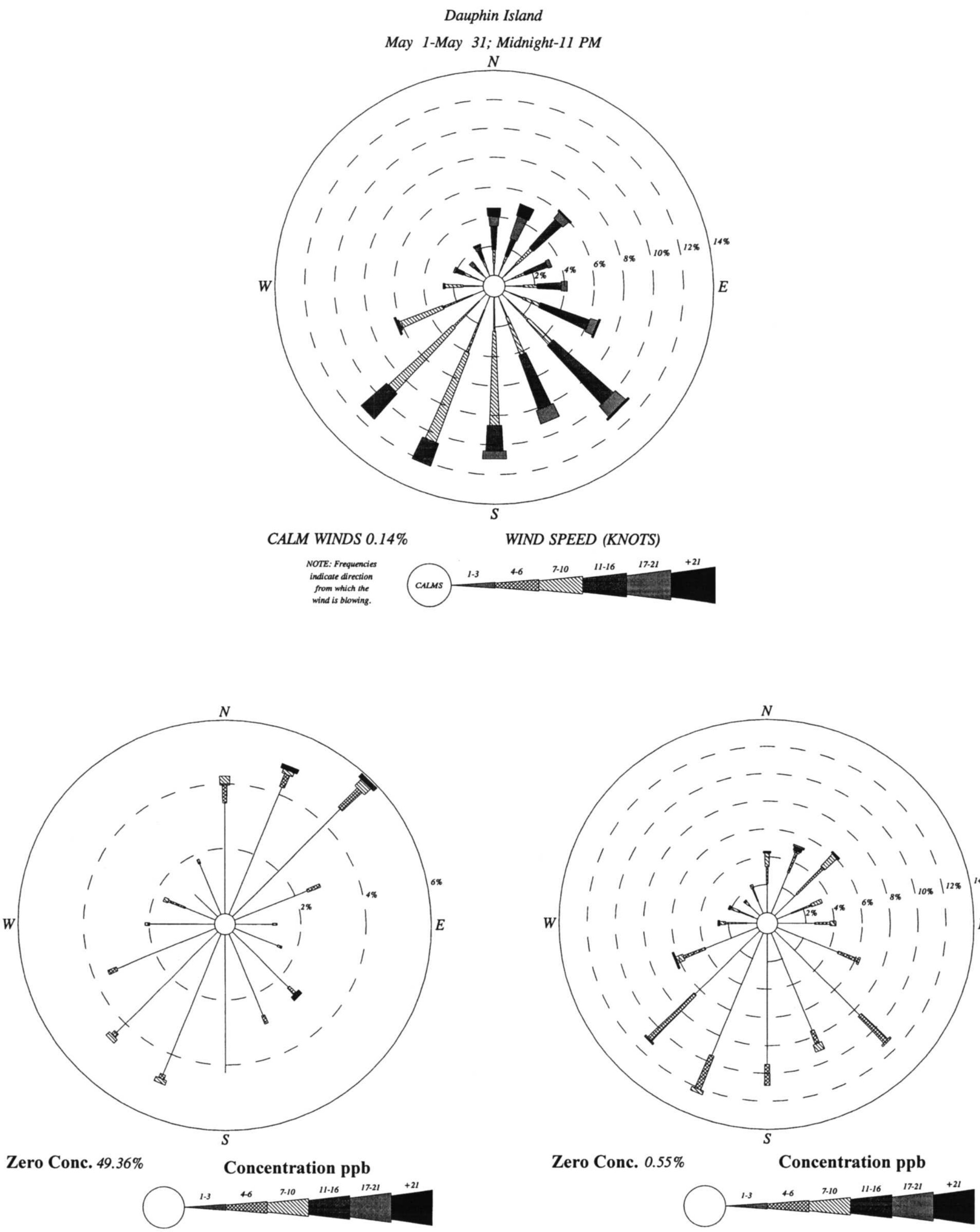


Figure 23. Dauphin Island May 1997 wind (top) and pollution roses (SO_2 bottom left, NO_2 bottom right).

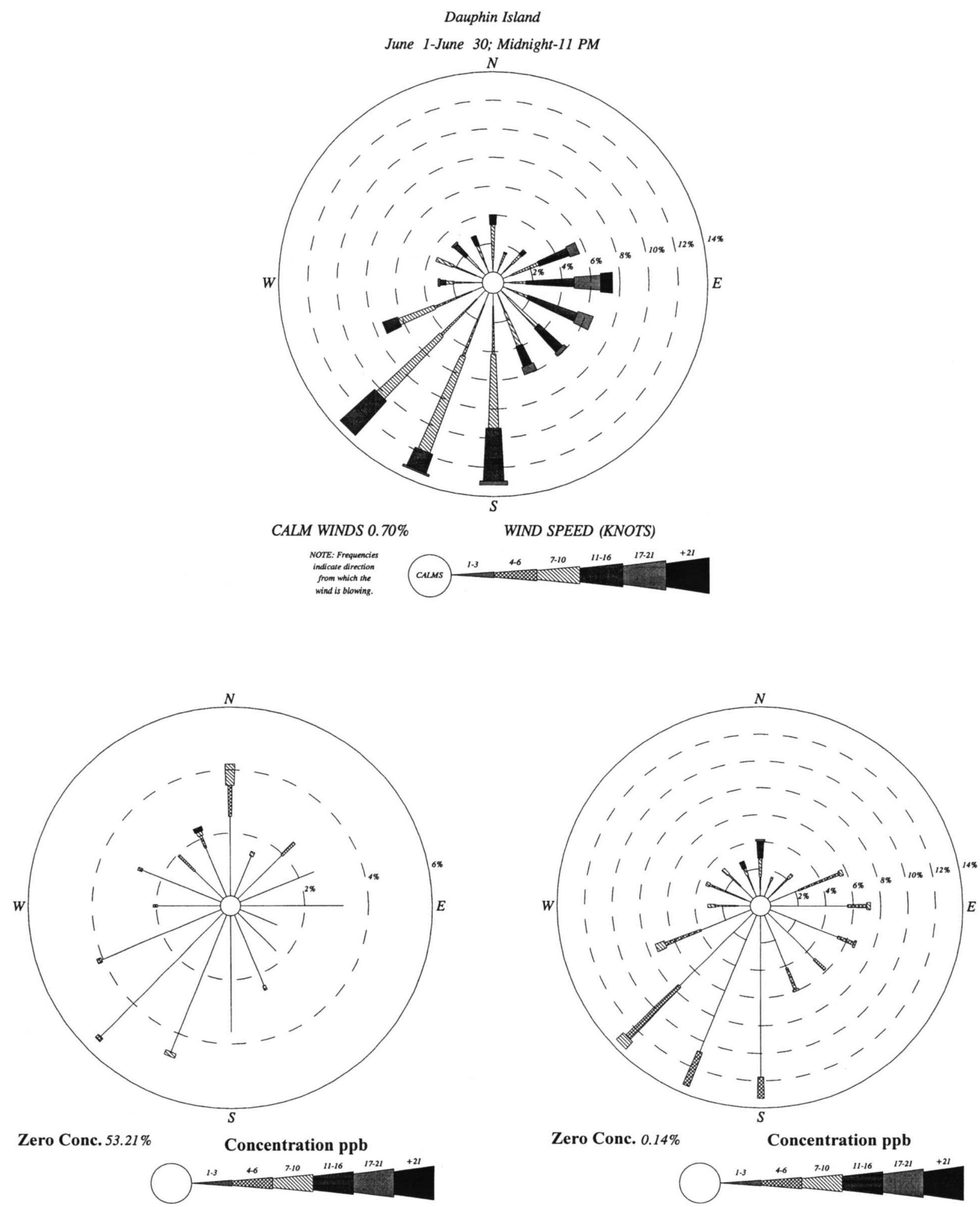


Figure 24. Dauphin Island June 1997 wind (top) and pollution roses (SO_2 bottom left, NO_2 bottom right).

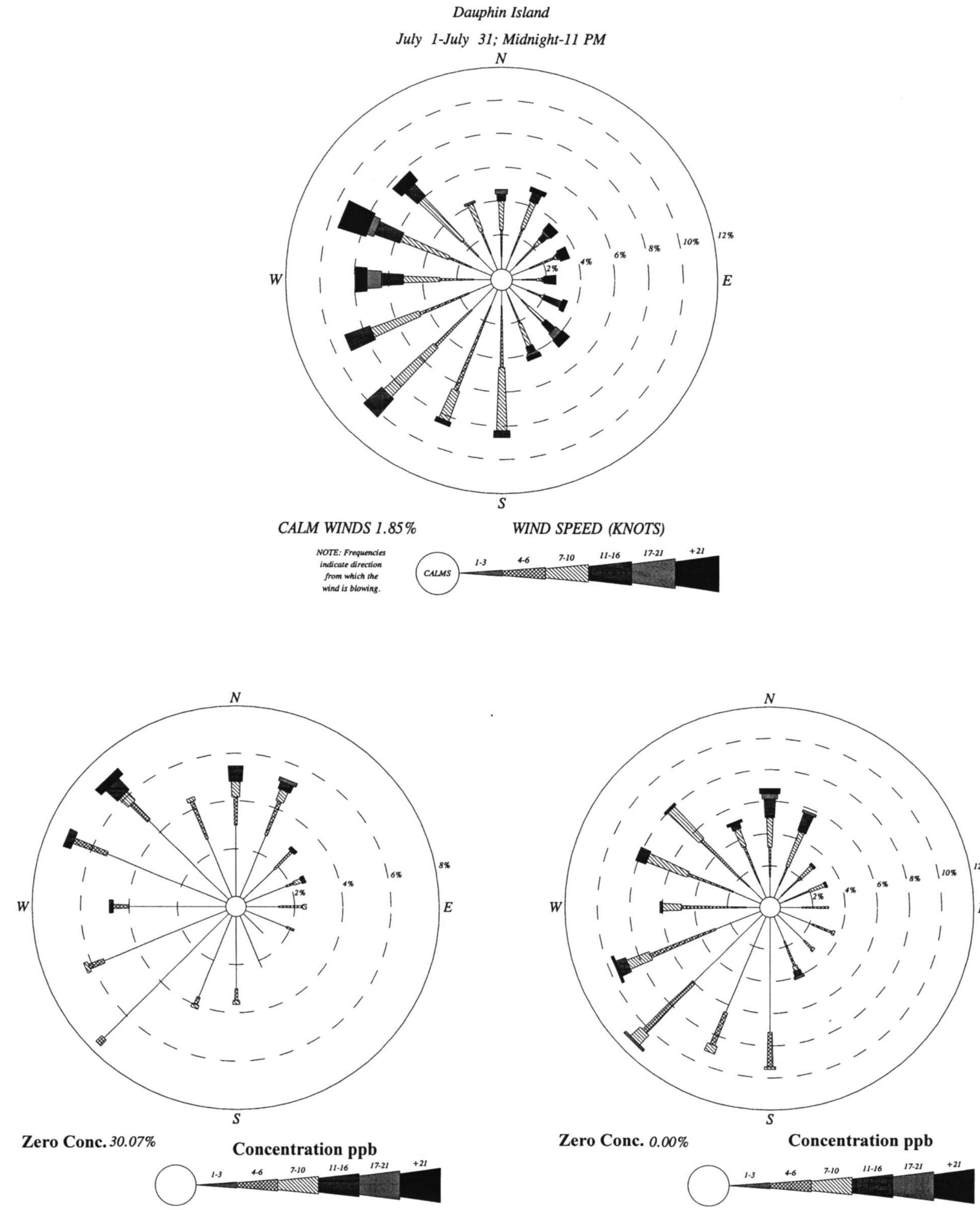


Figure 25. Dauphin Island July 1997 wind (top) and pollution roses (SO_2 bottom left, NO_2 bottom right).

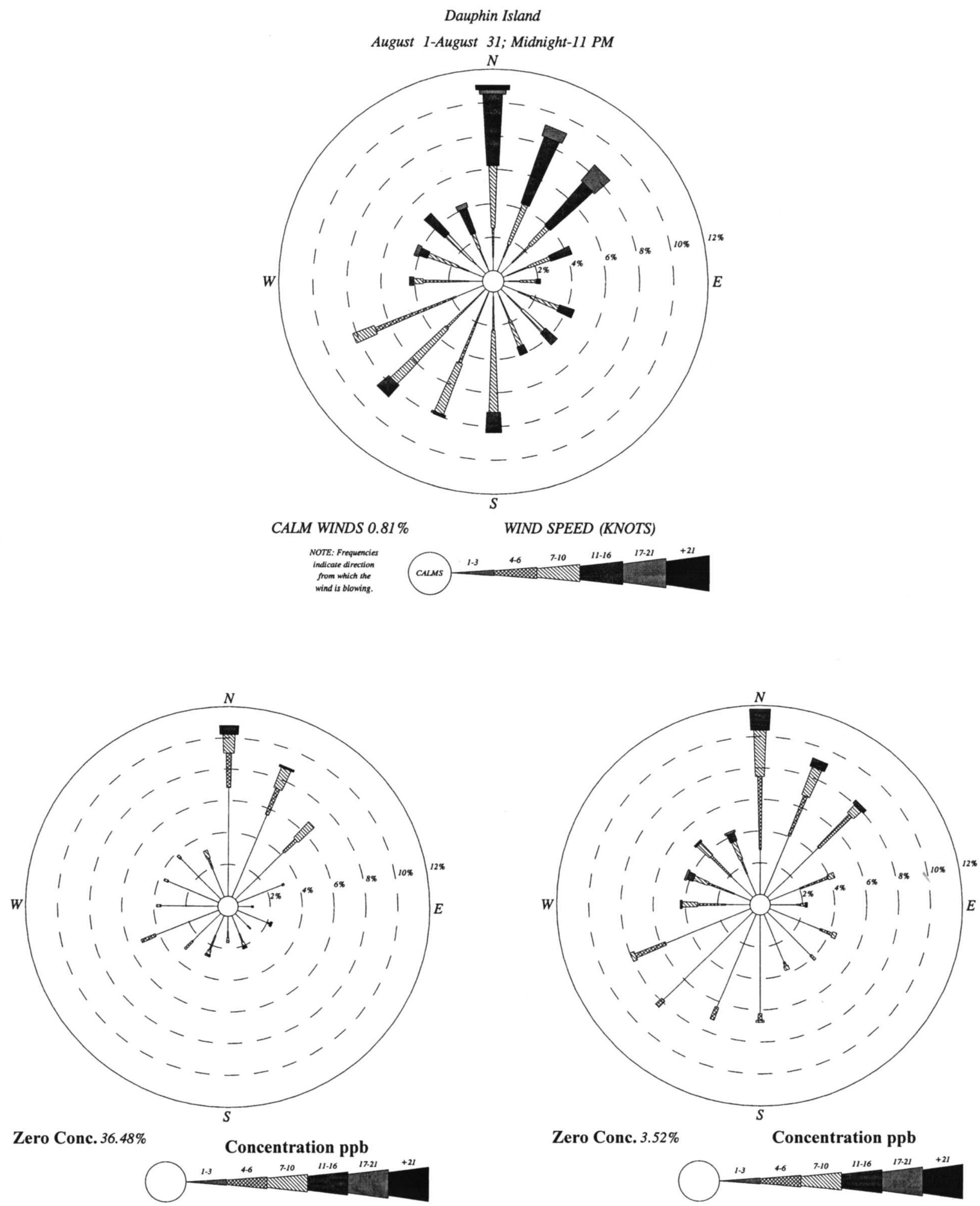


Figure 26. Dauphin Island August 1997 wind (top) and pollution roses (SO_2 bottom left, NO_2 bottom right).

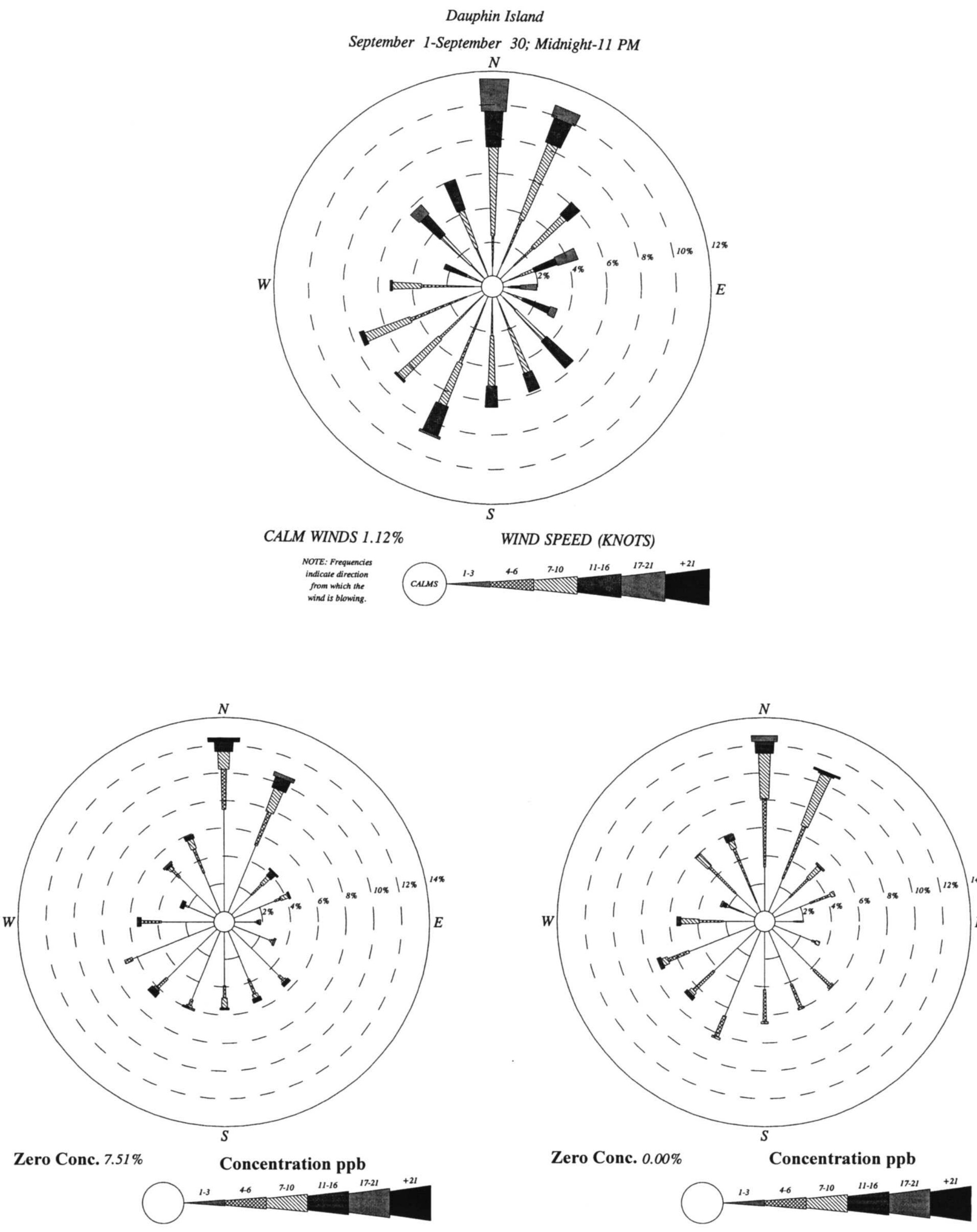


Figure 27. Dauphin Island September 1997 wind (top) and pollution roses (SO_2 bottom left, NO_2 bottom right).

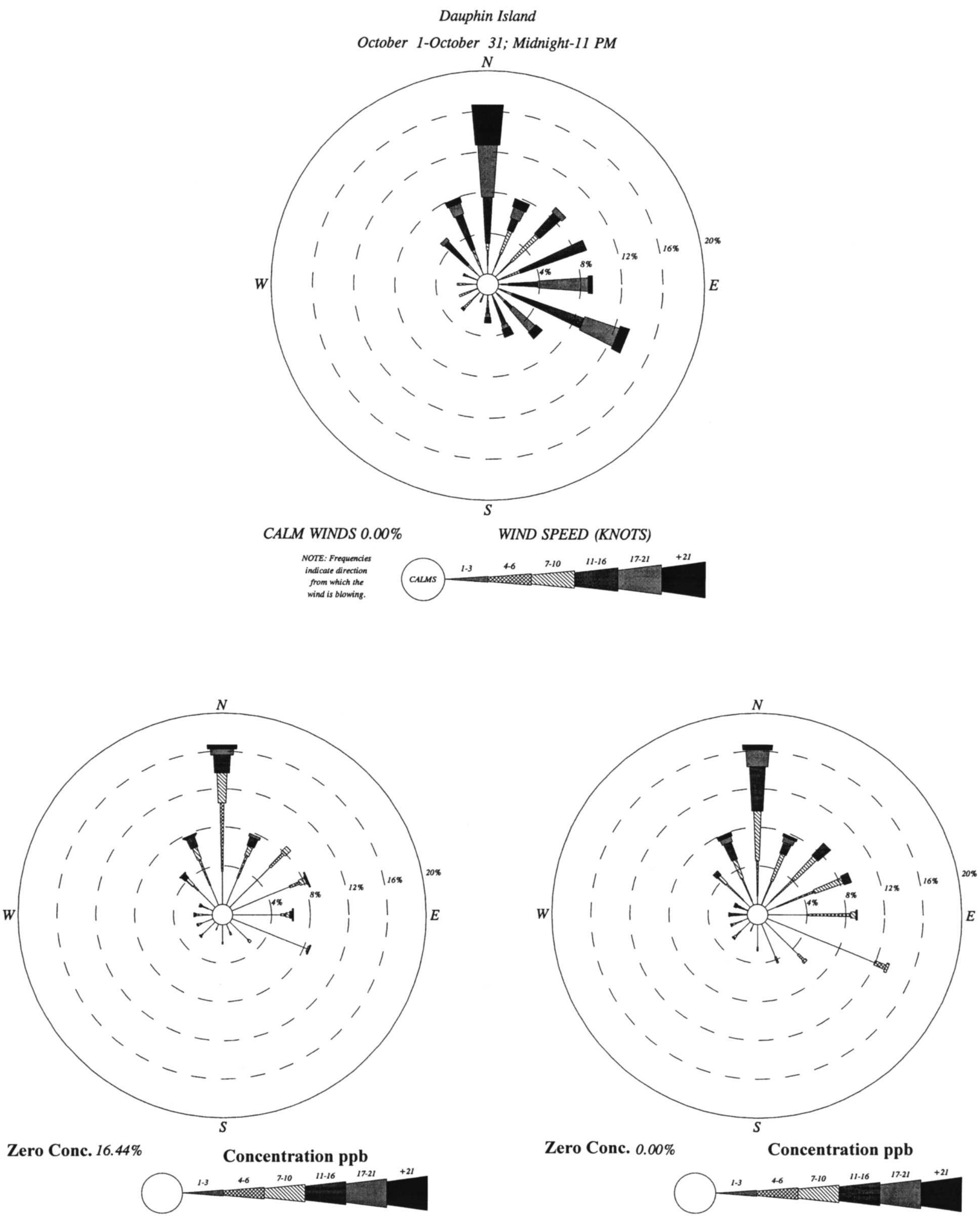


Figure 28. Dauphin Island October 1997 wind (top) and pollution roses (SO_2 bottom left, NO_2 bottom right).

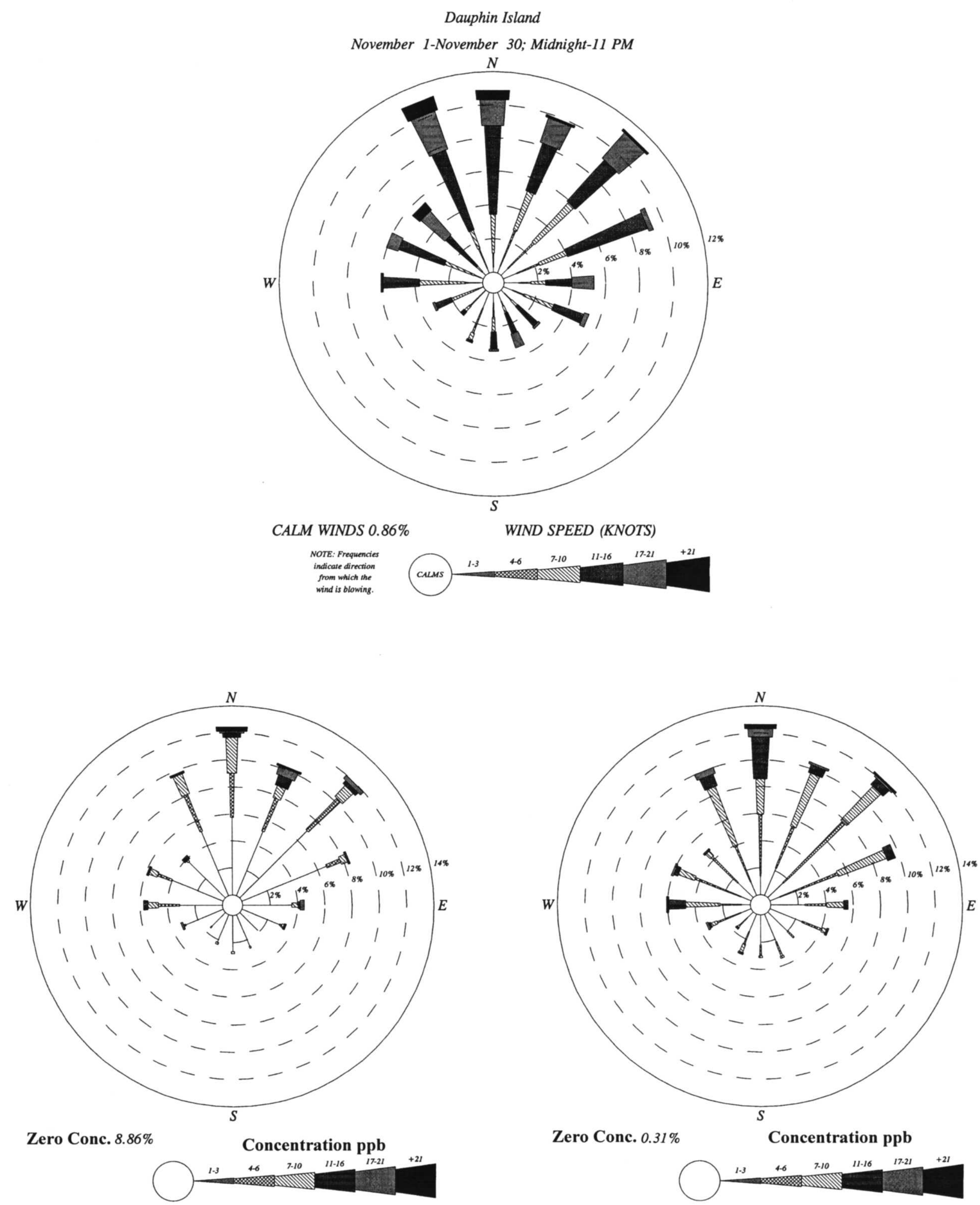


Figure 29. Dauphin Island November 1997 wind (top) and pollution roses (SO_2 bottom left, NO_2 bottom right).

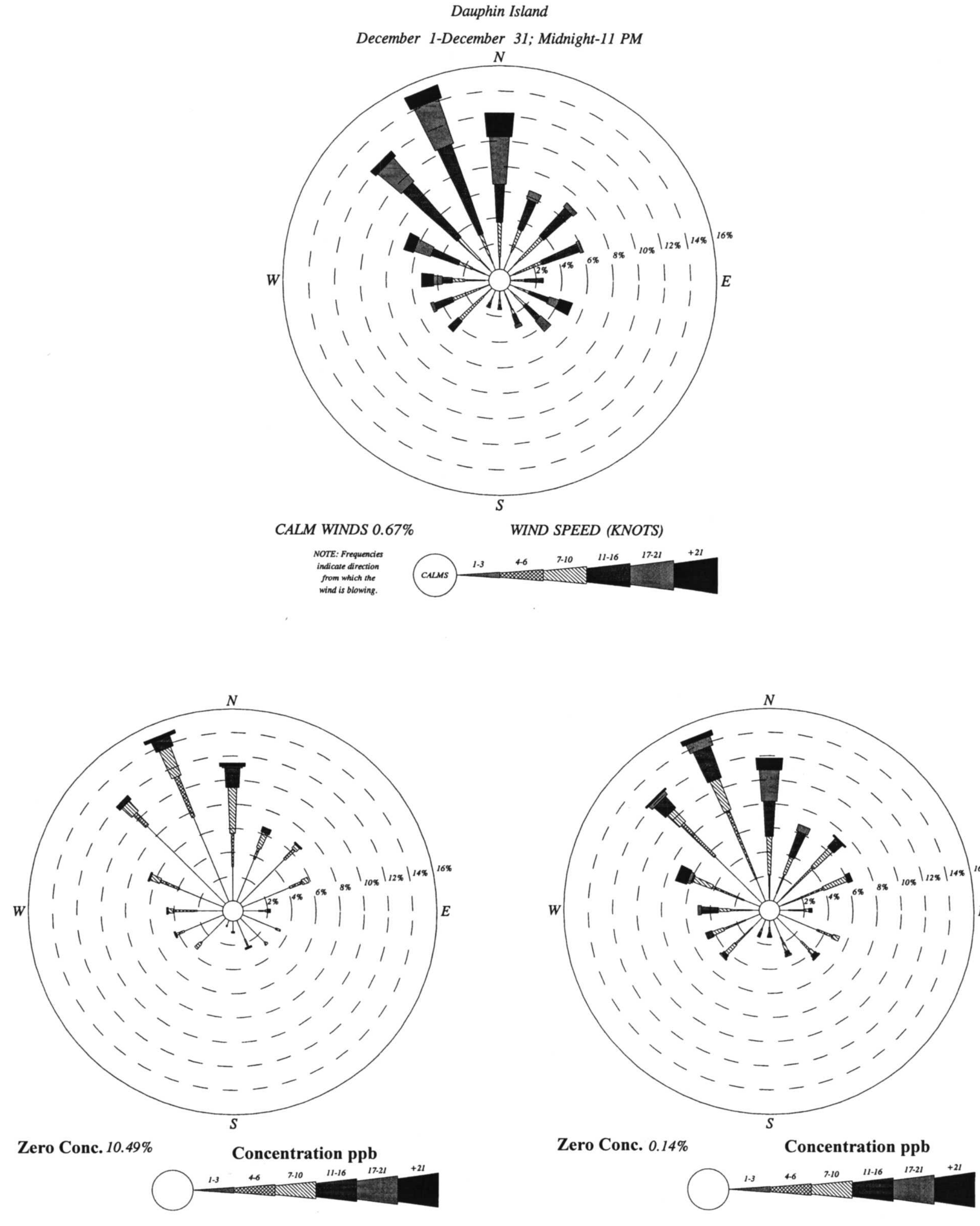


Figure 30. Dauphin Island December 1997 wind (top) and pollution roses (SO_2 bottom left, NO_2 bottom right).

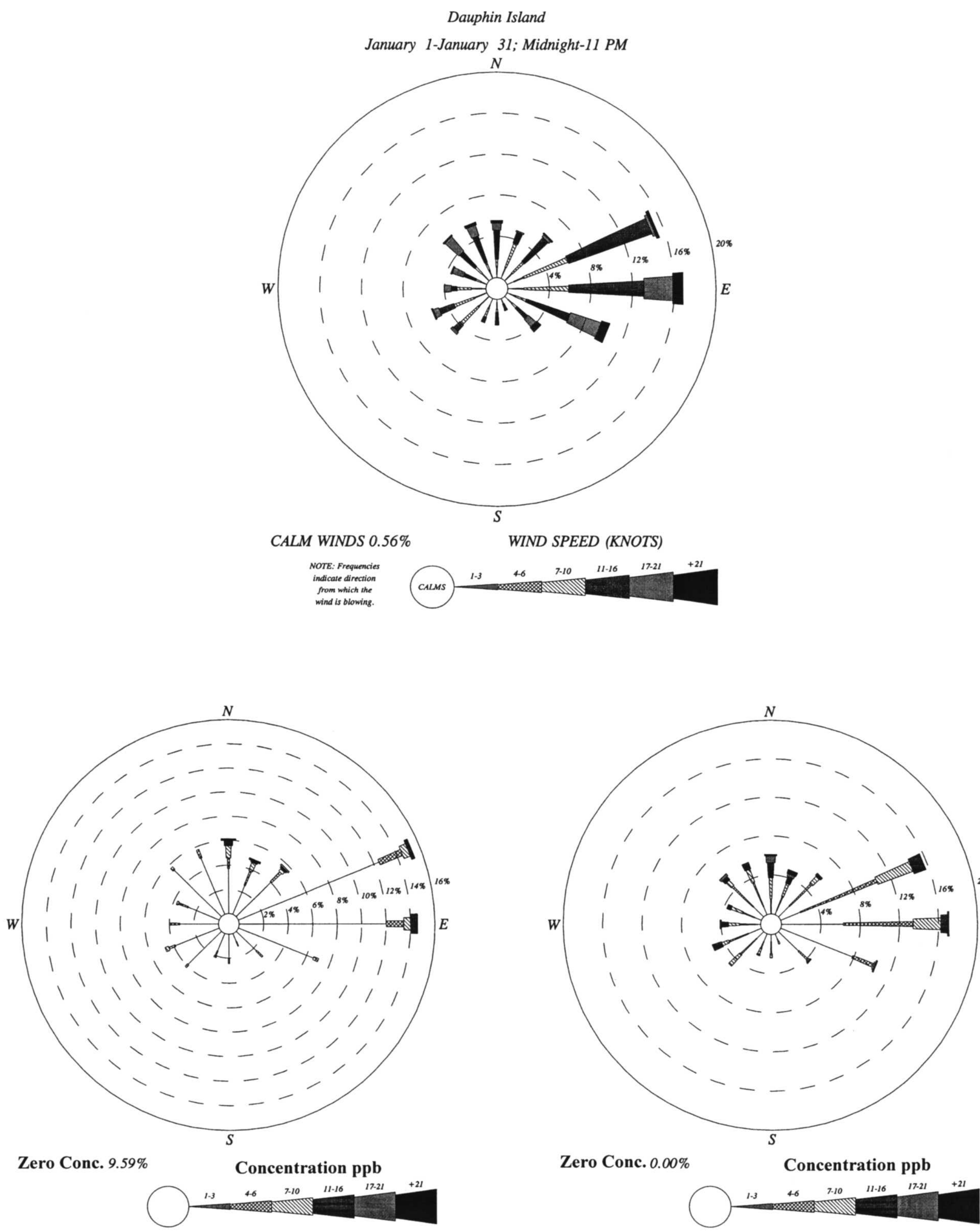


Figure 31. Dauphin Island January 1998 wind (top) and pollution roses (SO_2 bottom left, NO_2 bottom right).

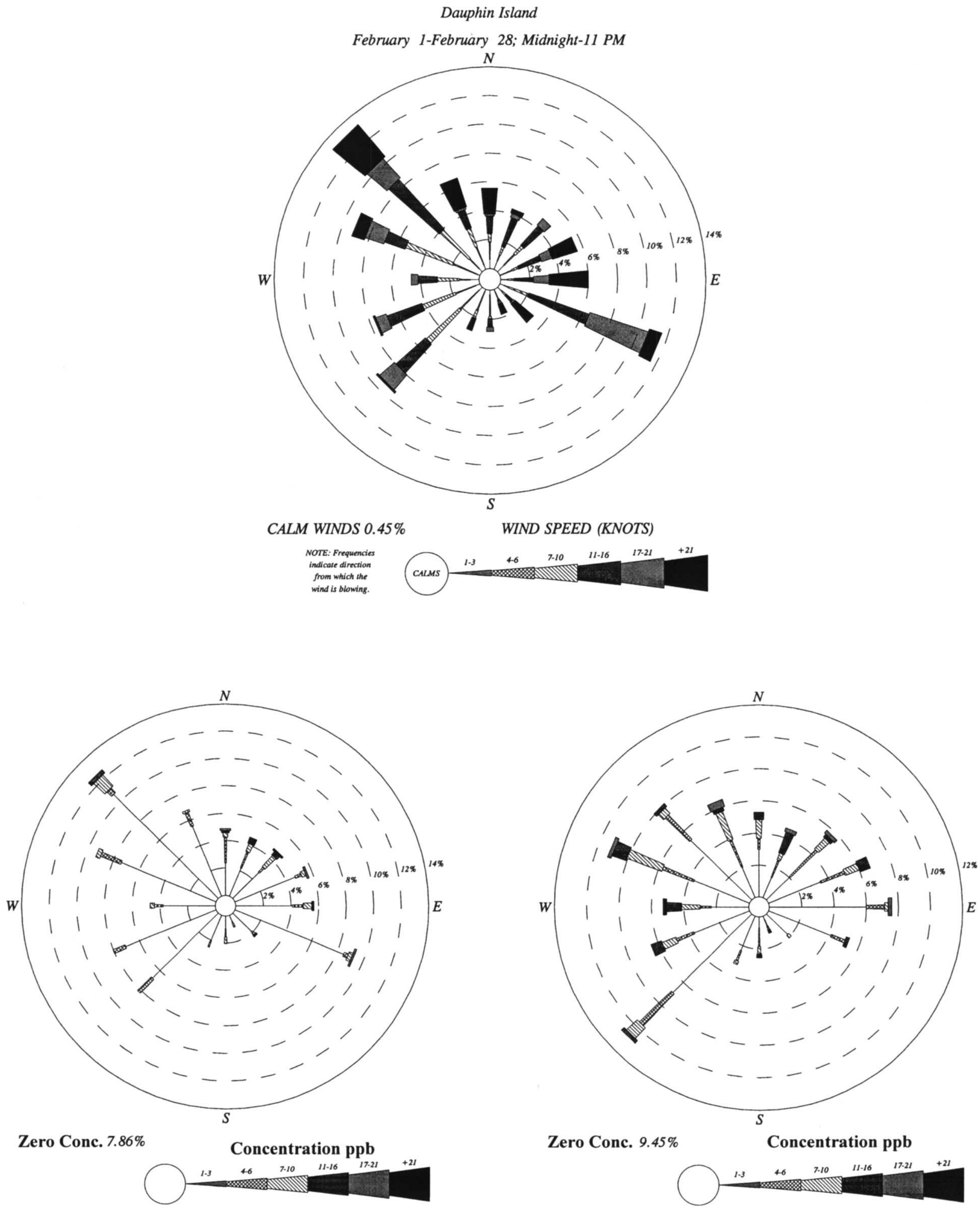


Figure 32. Dauphin Island February 1998 wind (top) and pollution roses (SO_2 bottom left, NO_2 bottom right).

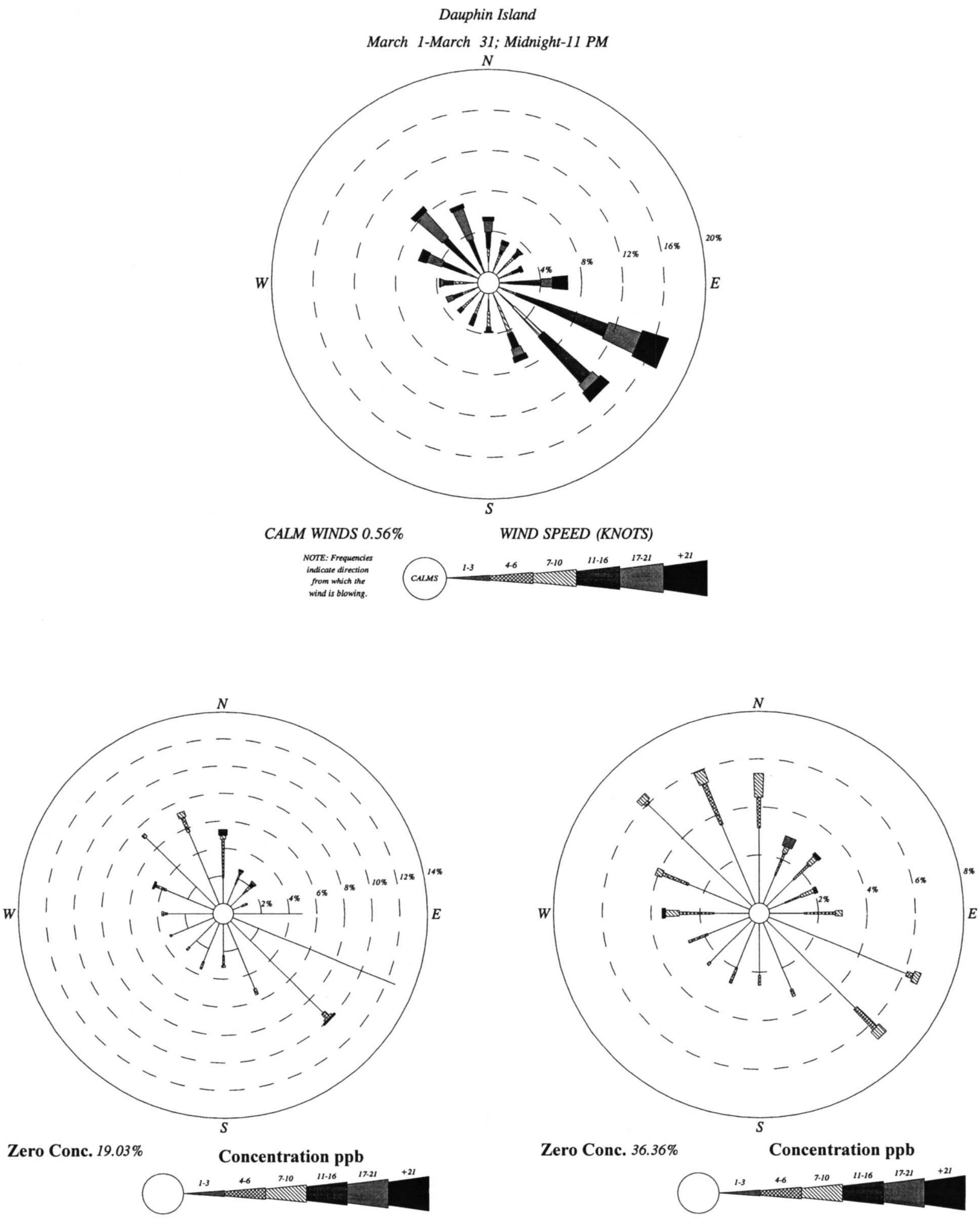


Figure 33. Dauphin Island March 1998 wind (top) and pollution roses (SO_2 bottom left, NO_2 bottom right).

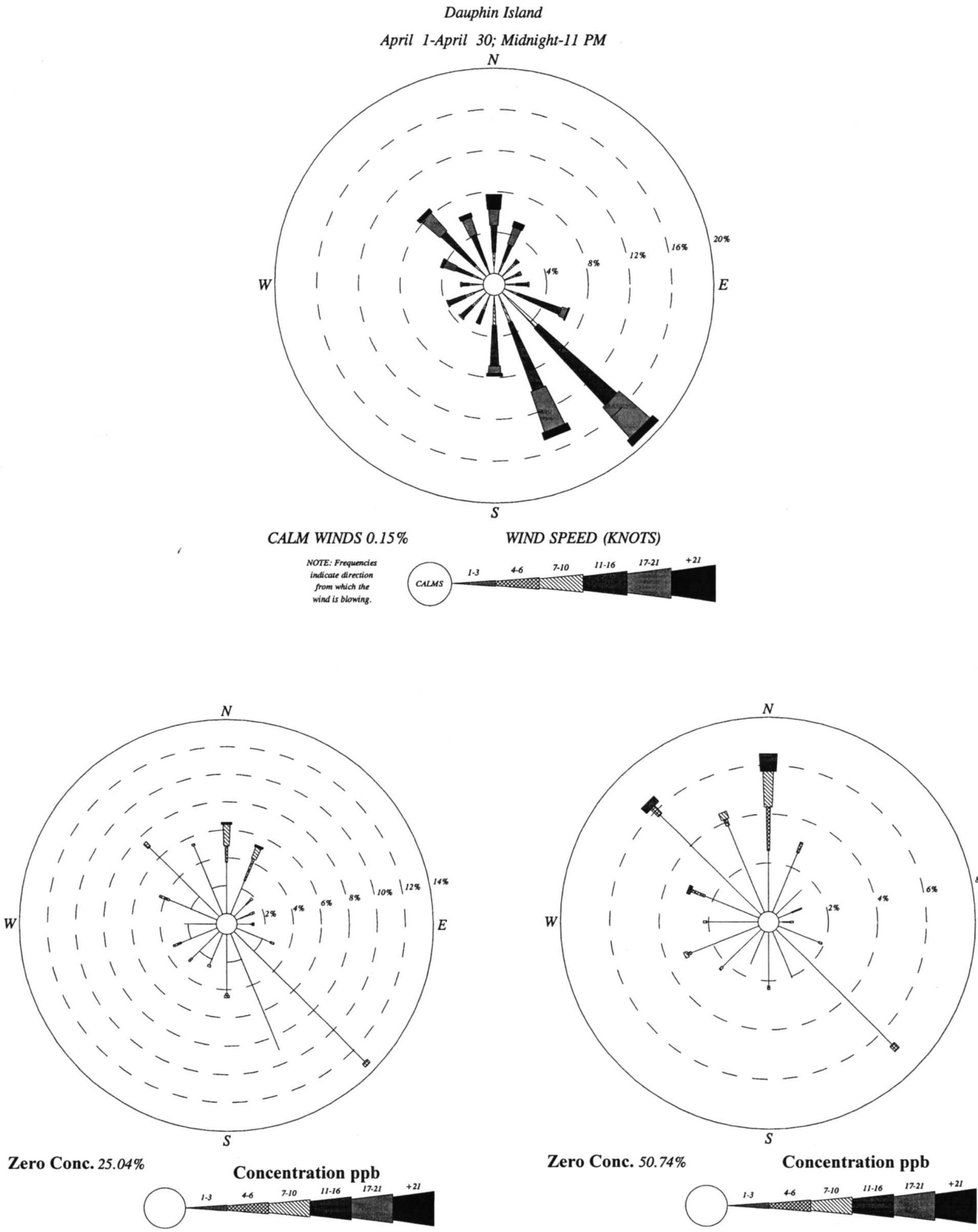


Figure 34. Dauphin Island April 1998 wind (top) and pollution roses (SO_2 bottom left, NO_2 bottom right).

B. Breton Island Air Quality

Wind measurements obtained on Breton Island by the RM Young Wind Monitor were merged with the hourly-averaged air quality data except for during the periods of 3 - 10 June, 1997 and 24 June to 11 July 1997; for these times winds were computed from the RM Young Gill UVW Anemometer. Monthly time series are presented in Figs. 35 - 48. Hourly SO_2 concentrations are generally within 2 - 3 ppb, while NO_2 mostly falls within 6 ppb. One notable feature is the greater frequency of short duration (hours to a day) high NO_2 concentration events, often reaching peaks in excess of 40 ppb.

Although the station monitoring was extended through July 1998, logistical concerns allowed only one servicing trip after 21 April 1998. As can be seen in Figs. 47 and 48, little variation is present in the SO_2 record while a slight positive drift may have entered the NO_2 (NO_x) data. Because an acceptable calibration was achieved at station removal, the data is presented here. However, for analysis purposes, the periods of May 1997 - April 1998 and June 1997 - May 1998 are selected for SO_2 and NO_2 annual statistics since they are most complete for the parameters.

The annual arithmetic mean SO_2 concentration found at Breton Island is 1.2 ppb with a 95% confidence level of 0.034 (based on 6863 samples, 78.3% complete). The annual arithmetic mean NO_2 concentration is 6.2 ppb with a 95% confidence level of 0.154 (based on 7096 samples, 81% complete). While the annual SO_2 statistics are in good agreement with previous findings listed in the Interim Report, the annual NO_2 is about 1 ppb higher. This may be accounted for primarily by the relocation of the monitor to ground level, and to a lesser extent by the use of computed NO_2 values.

Frequency distribution of the air quality data is depicted in Fig. 49. Approximately 80% of the SO_2 record is less than 2 ppb. NO_2 concentrations are below 5 ppb almost 60% of the record. On the other hand, higher concentrations are observed more frequently here than at Dauphin, with concentrations greater than 20 ppb recorded almost 5% of the time.

Breton Island monthly maximum and average SO_2 and NO_2 concentrations are listed in Tables 25 and 26, respectively. Slight peaks of both pollutants during the late fall - early winter months are evident here as at Dauphin. Note that the higher NO_2 averages at the end of the record may reflect the positive offset in the monitor. These seasonal trends are illustrated in Figs. 50 - 53, which show the annual 3- and 24-hour average trends. The improvement in data capture following relocation of the equipment is clear in these figures.

Diurnal quartile values are shown in Figs. 54 and 55 for SO_2 and NO_2, respectively. Median SO_2 is generally less than 1 ppb; a very slight increase is sometimes seen in late morning to midday hours. Median NO_2 values are higher at about 3 - 6 ppb. The morning peak observed at Dauphin Island is much less pronounced here, and often accompanied by an evening increase.

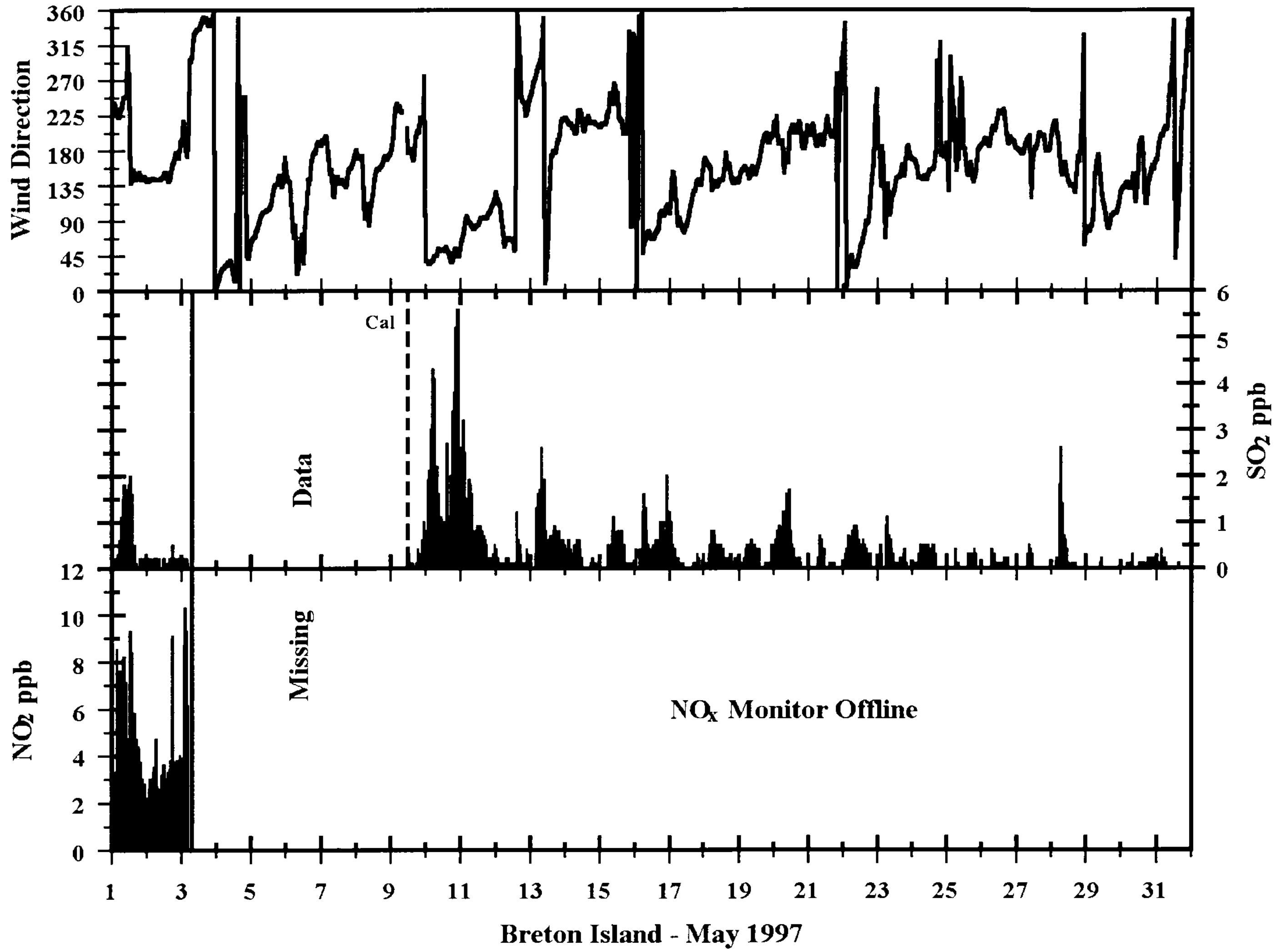


Figure 35. May 1997 time series of Breton Island hourly-averaged concentrations and wind direction.

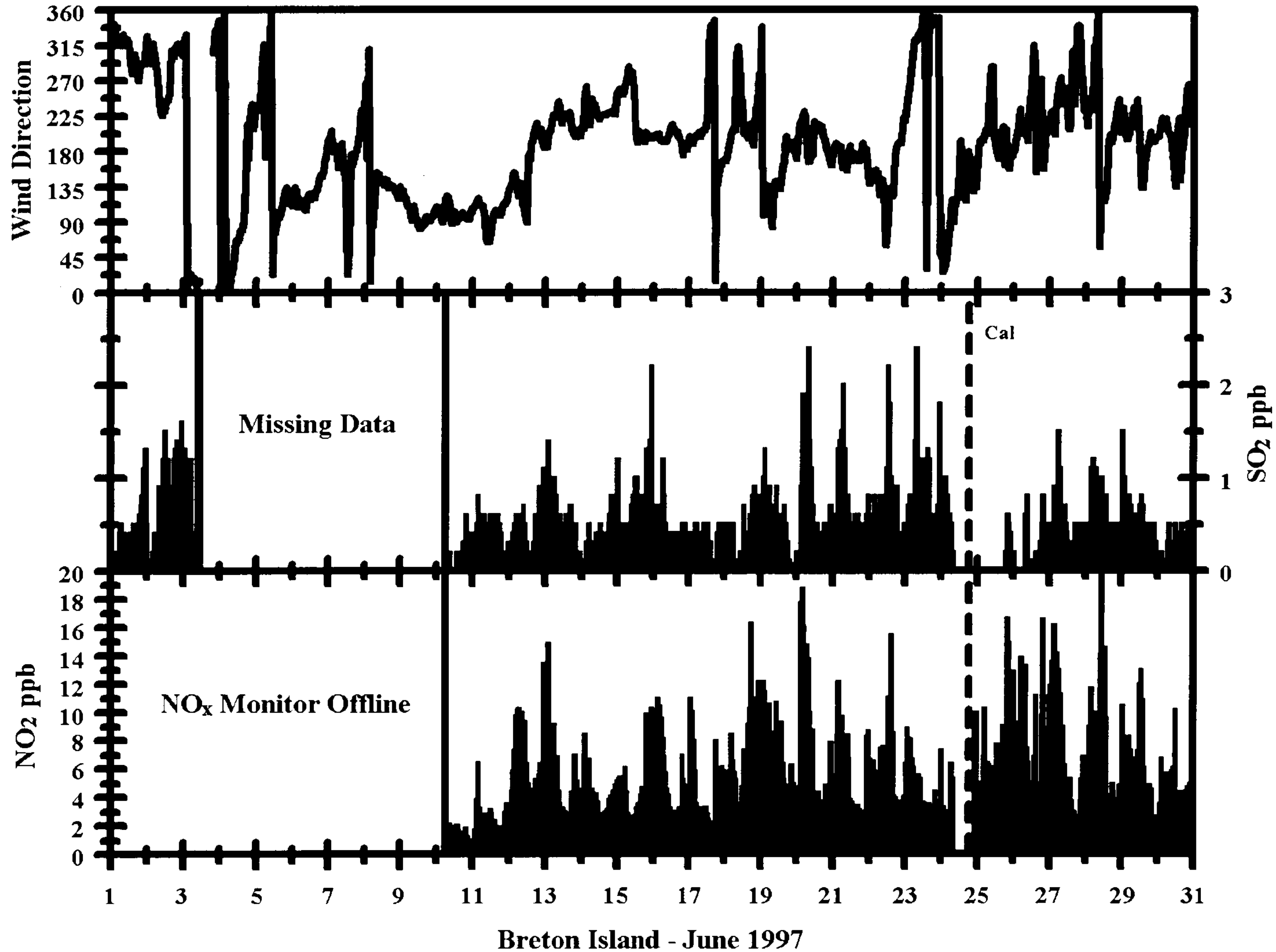


Figure 36. June 1997 time series of Breton Island hourly-averaged concentrations and wind direction.

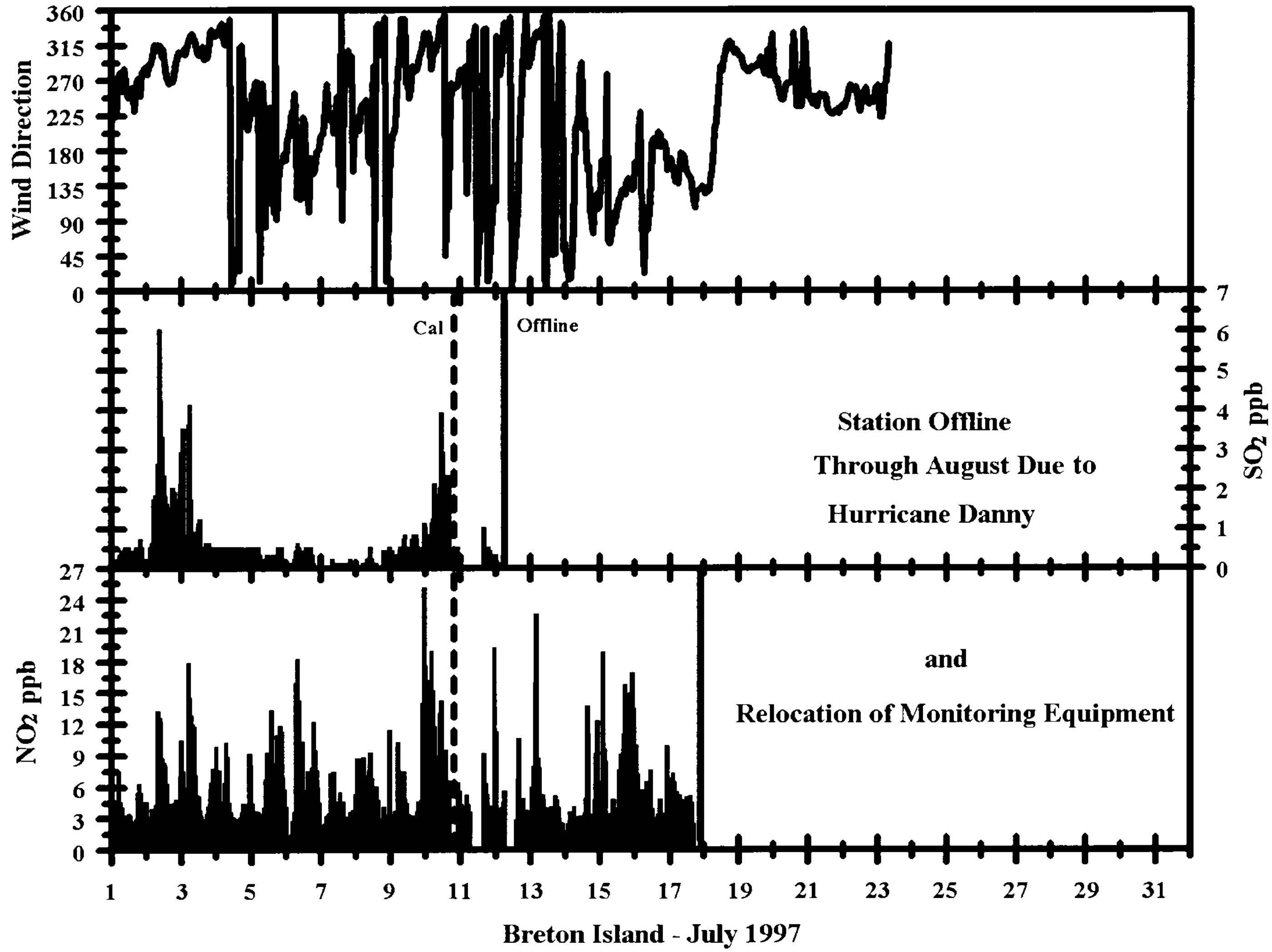


Figure 37. July 1997 time series of Breton Island hourly-averaged concentrations and wind direction. Missing SO_2 and NO_x on 11 and 12 July.

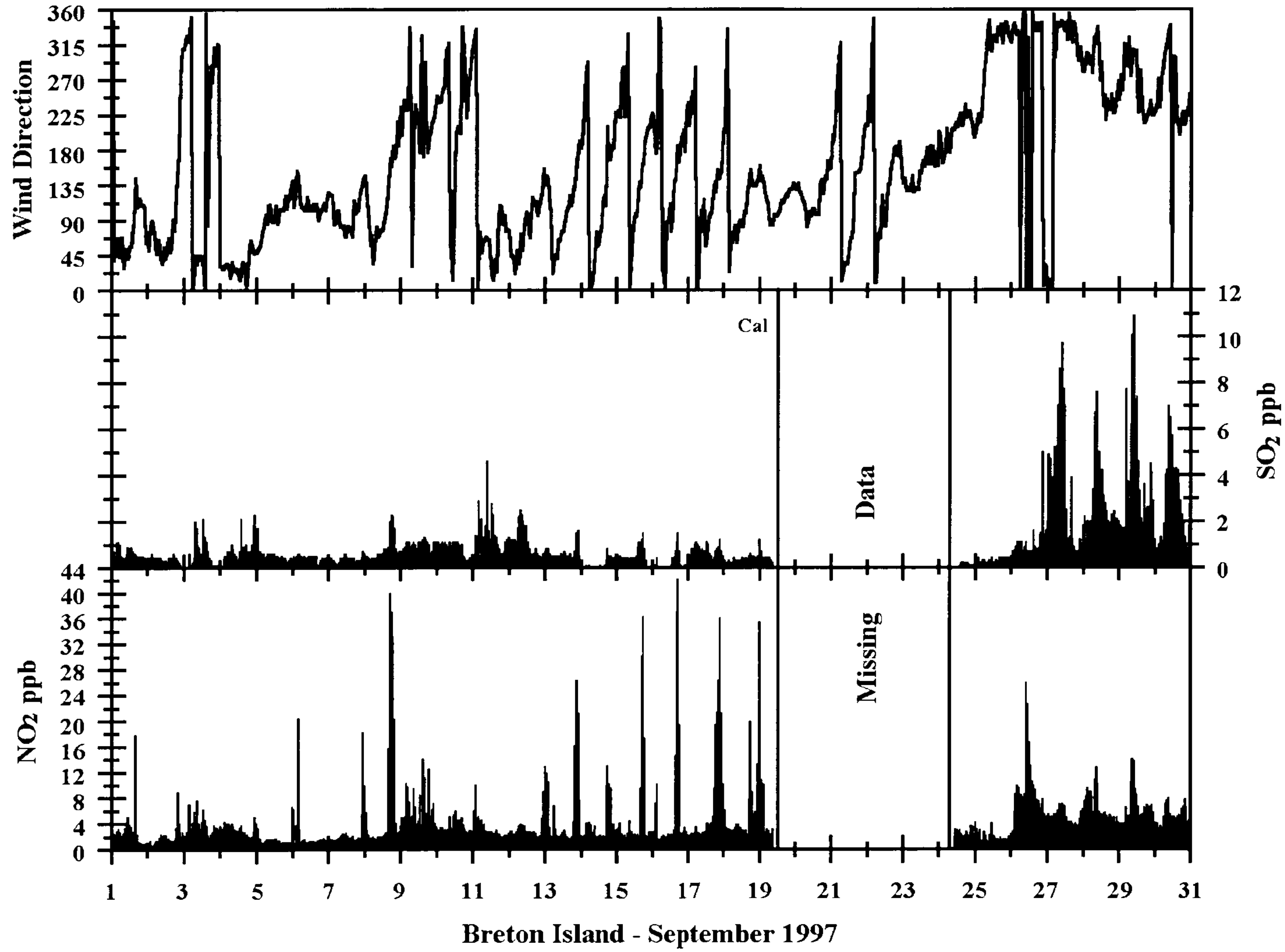


Figure 38. September 1997 time series of Breton Island hourly-averaged concentrations and wind direction.

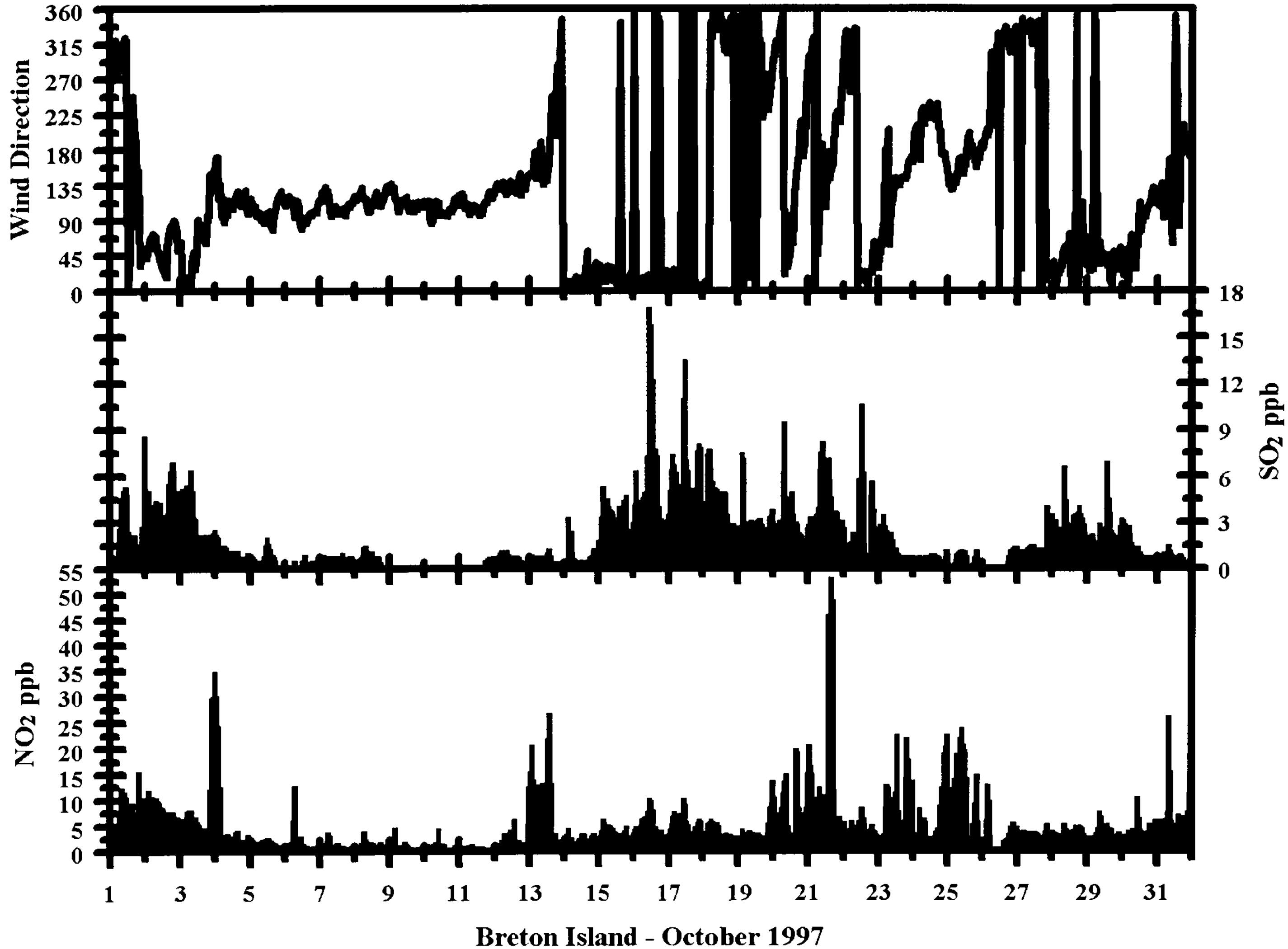


Figure 39. October 1997 times series of Breton Island hourly-averaged concentrations and wind direction. SO_2 and NO_x missing on 26 October.

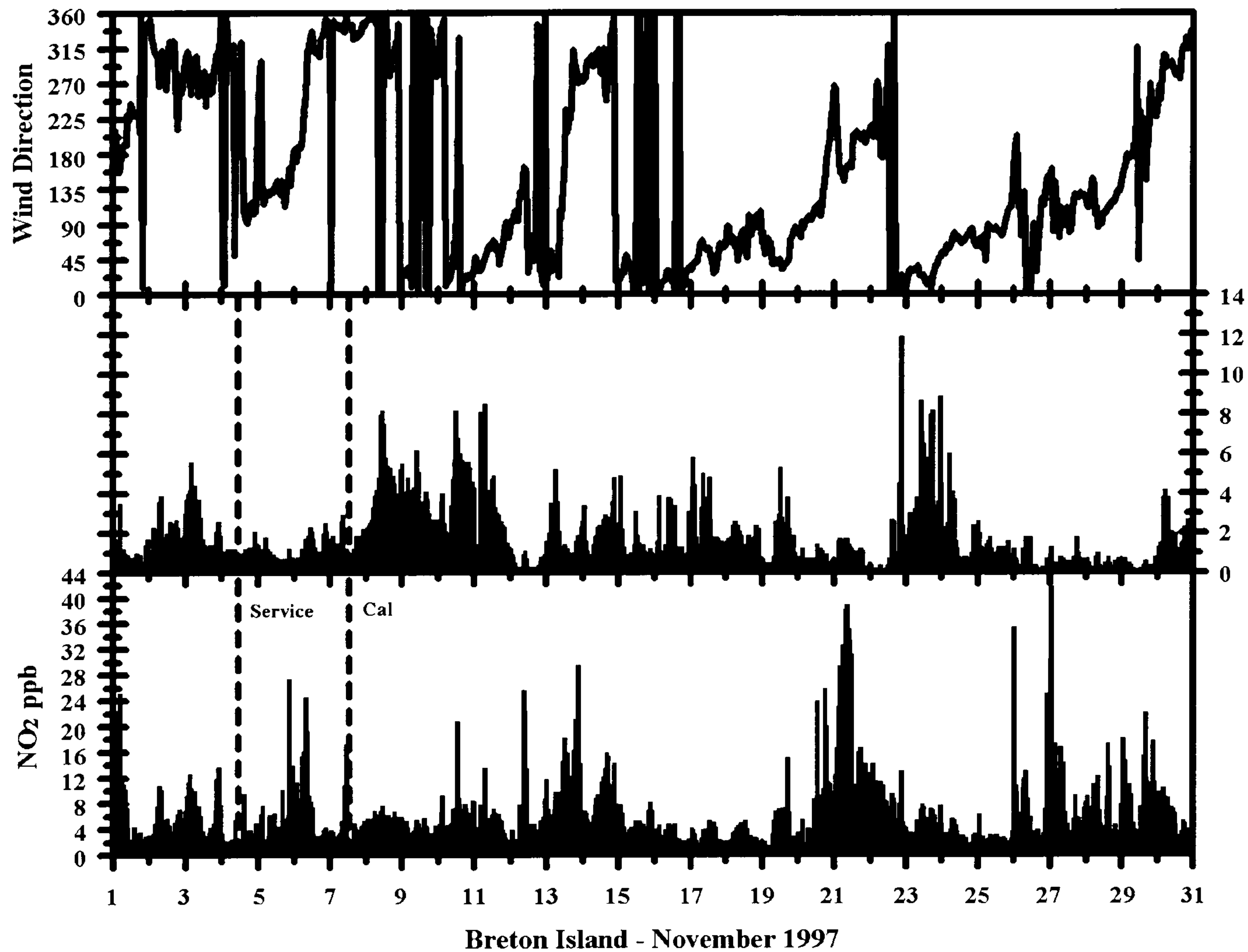


Figure 40. November 1997 time series of Breton Island hourly-averaged concentrations and wind direction.

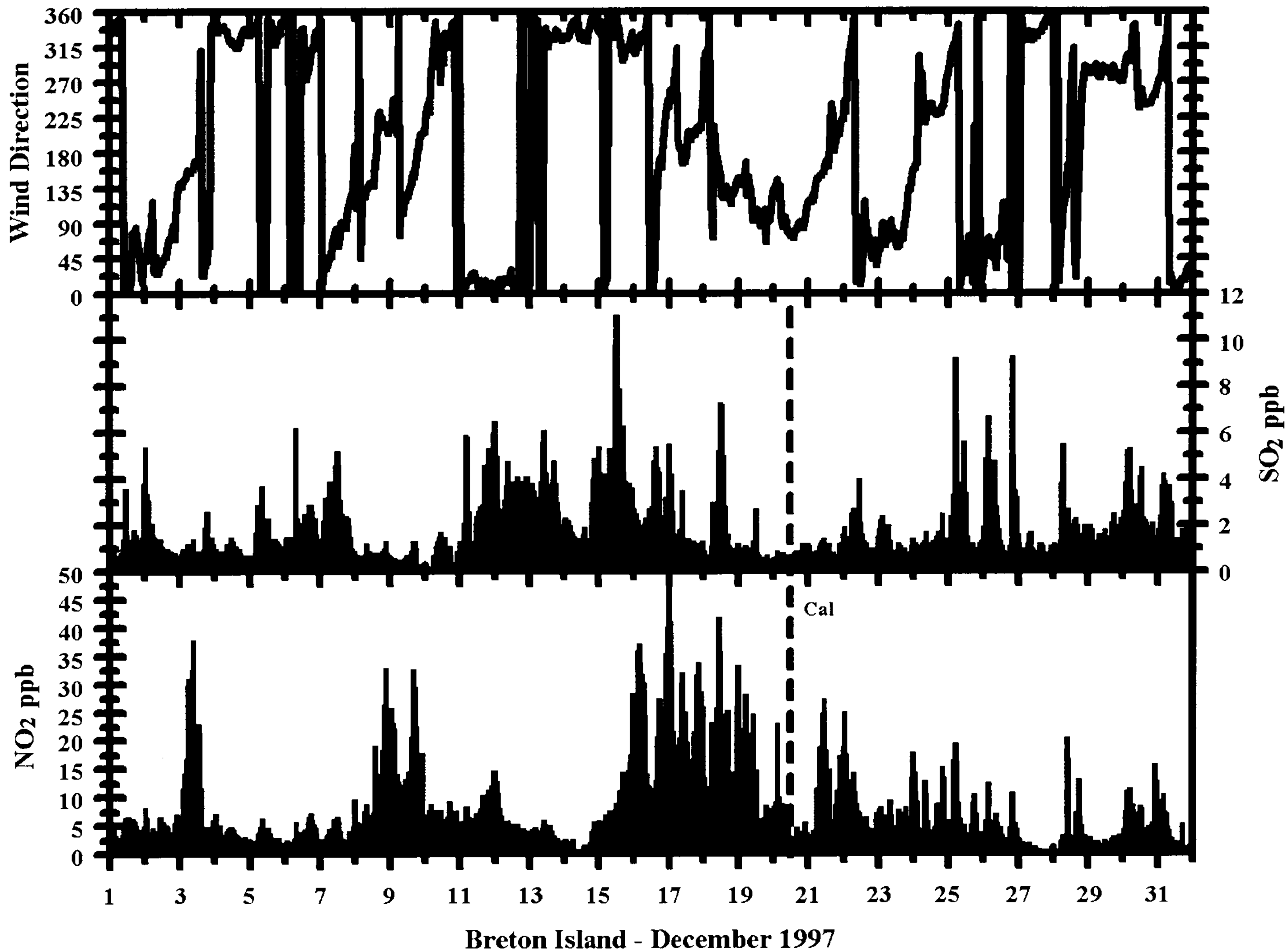


Figure 41. December 1997 time series of Breton Island hourly-averaged concentrations and wind direction.

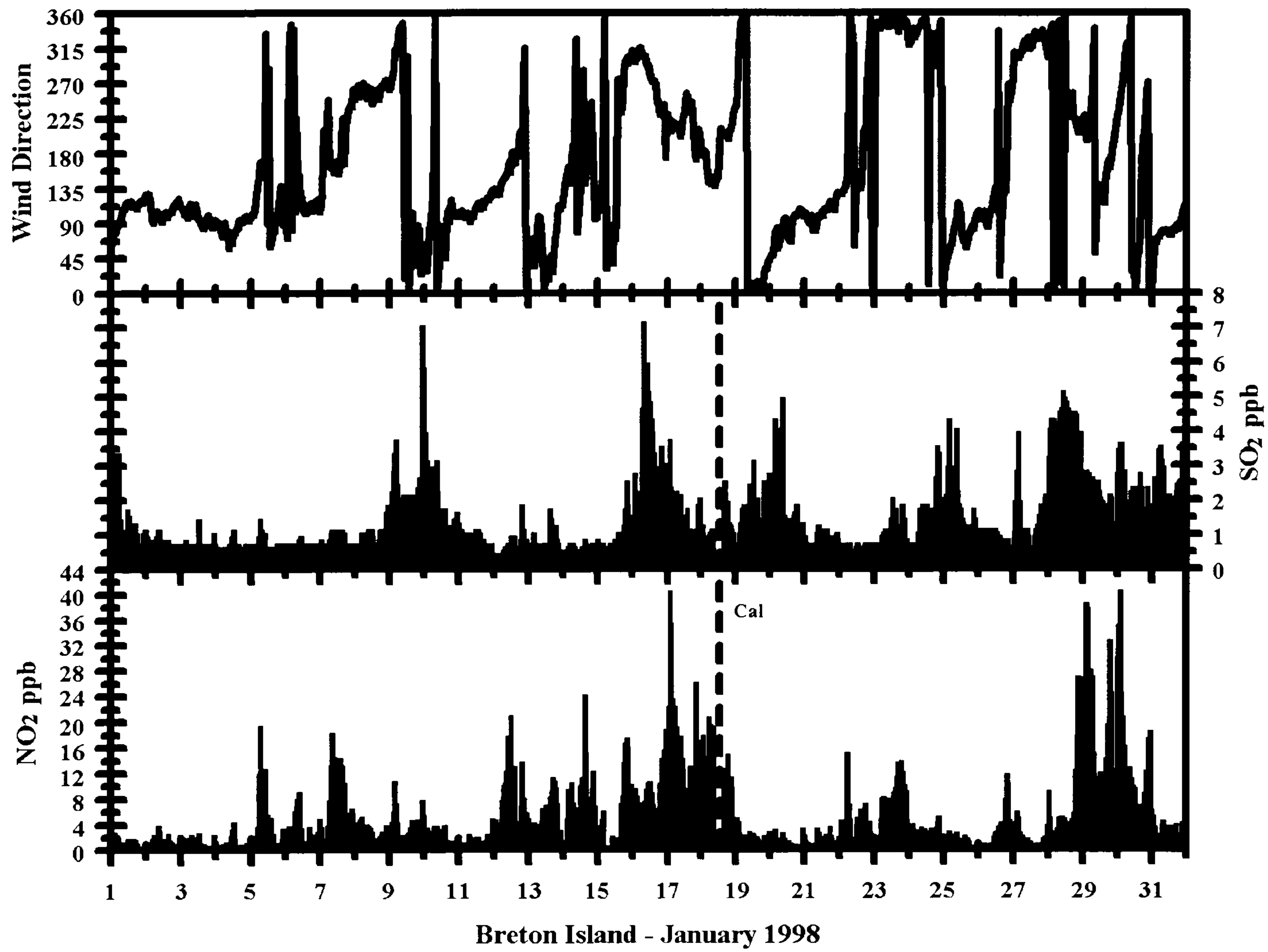


Figure 42. January 1998 time series of Breton Island hourly-averaged concentrations and wind direction.

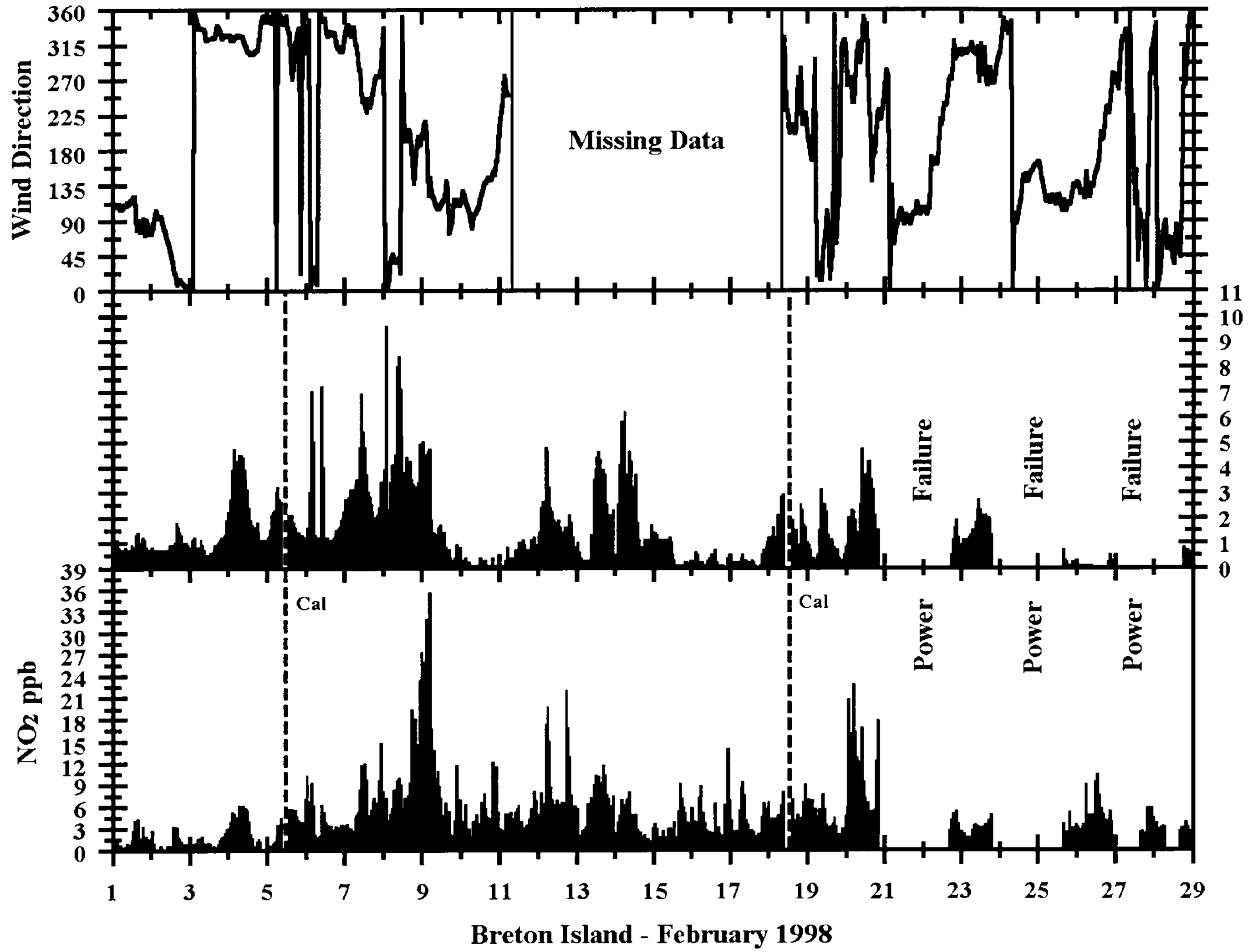


Figure 43. February 1998 time series of Breton Island hourly-averaged concentrations and wind direction. Missing air quality data on days 20 - 22, 23 - 25, 26 - 27, and 28.

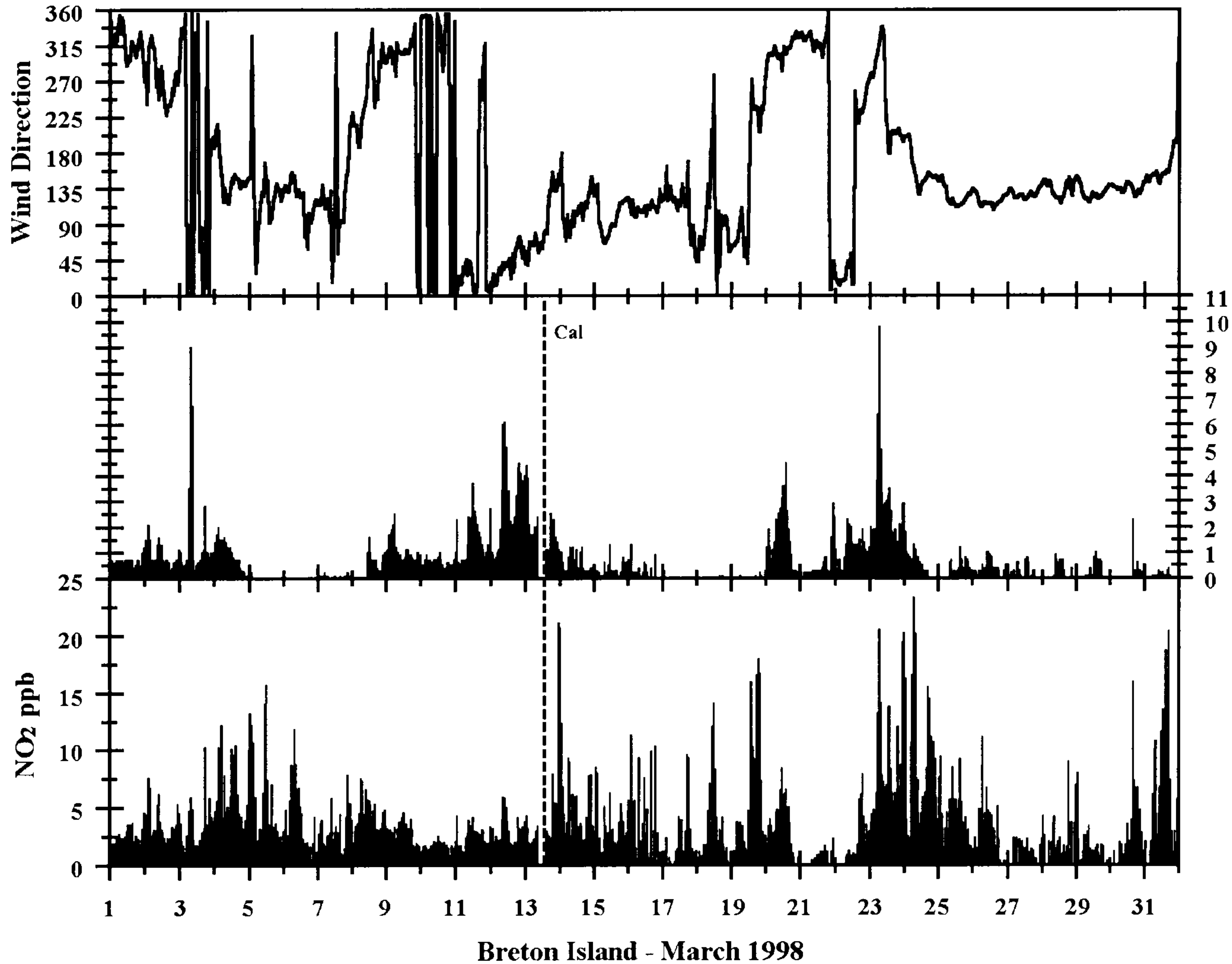


Figure 44. March 1998 time series of Breton Island hourly-averaged concentrations and wind direction. SO_2 data has been corrected for an offset.

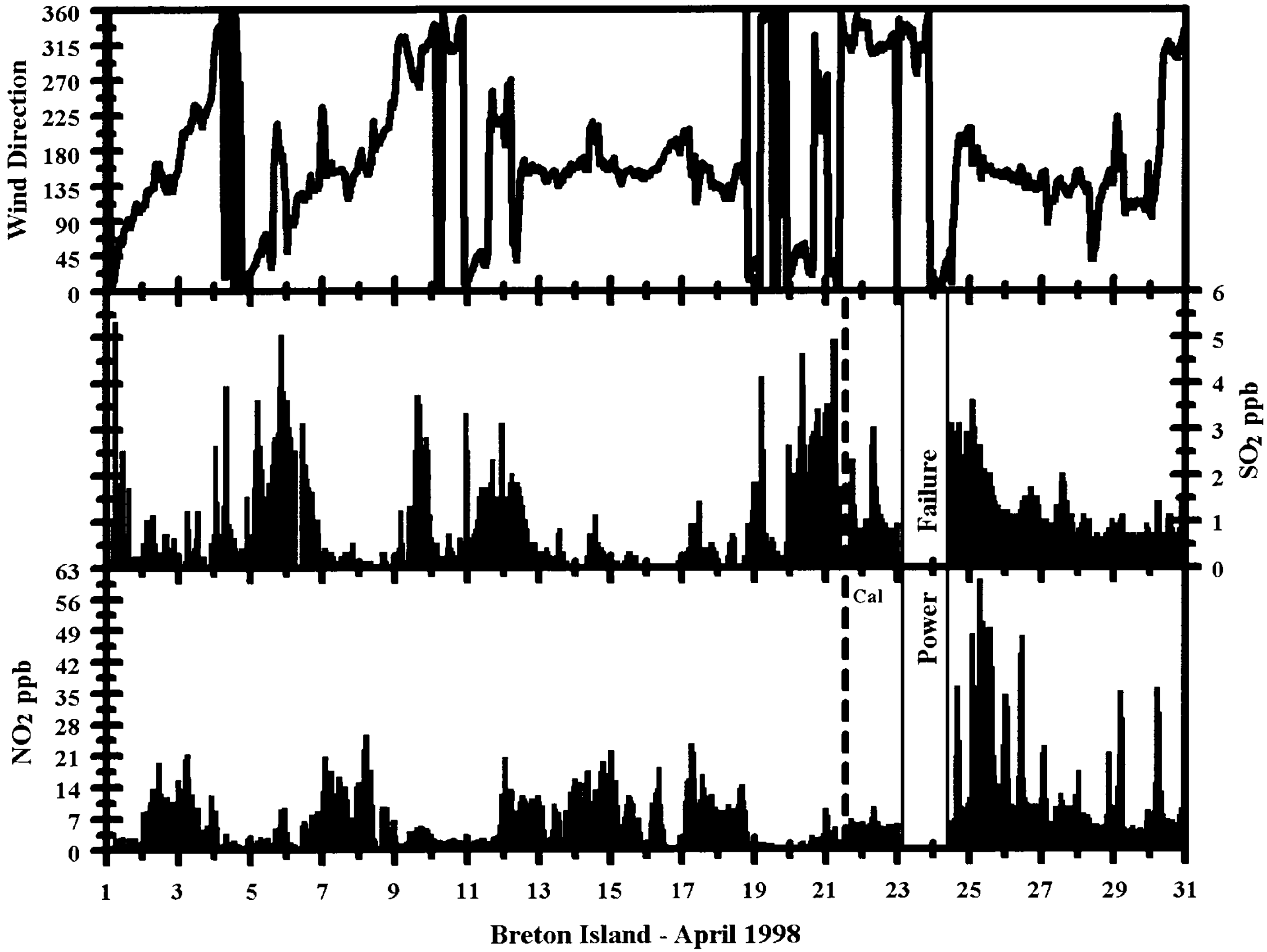


Figure 45. April 1998 time series of Breton Island hourly-averaged concentrations and wind direction. SO_2 and NOx data missing on days 6 and 23 - 24 April. SO_2 corrected for offset to 21 April.

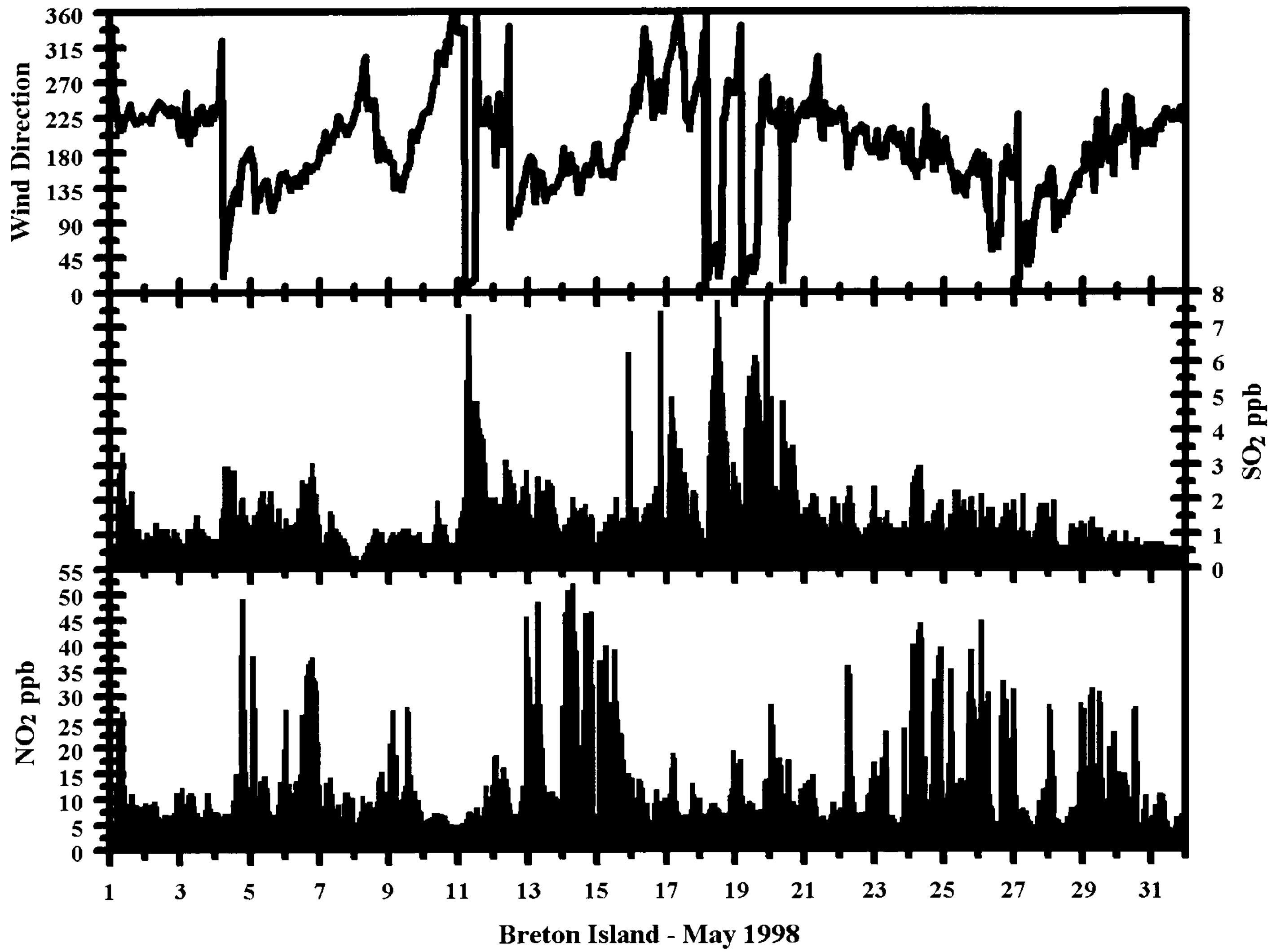


Figure 46. May 1998 time series of Breton Island hourly-averaged concentrations and wind direction.

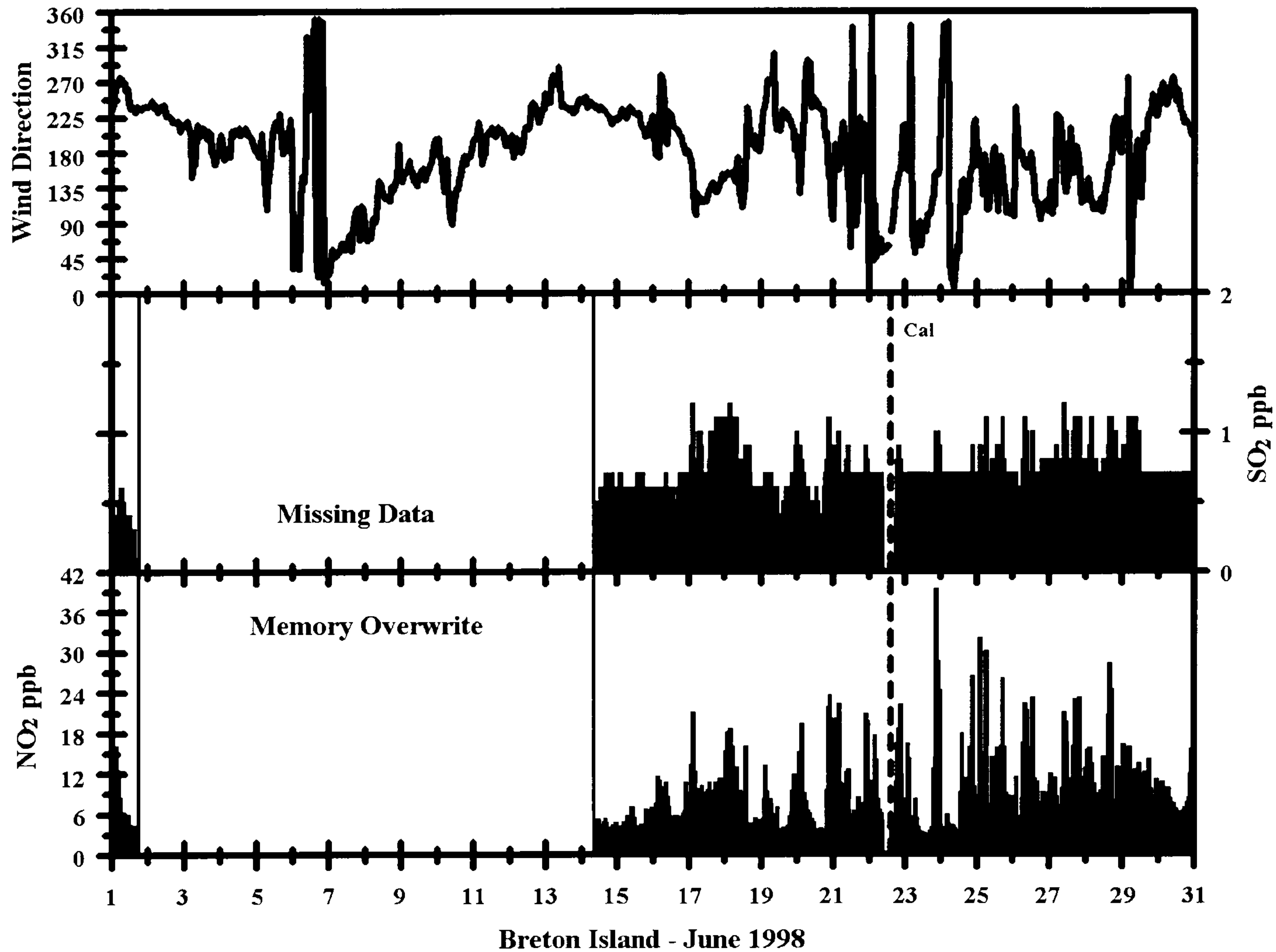


Figure 47. June 1998 time series of Breton Island hourly-averaged concentrations and wind direction.

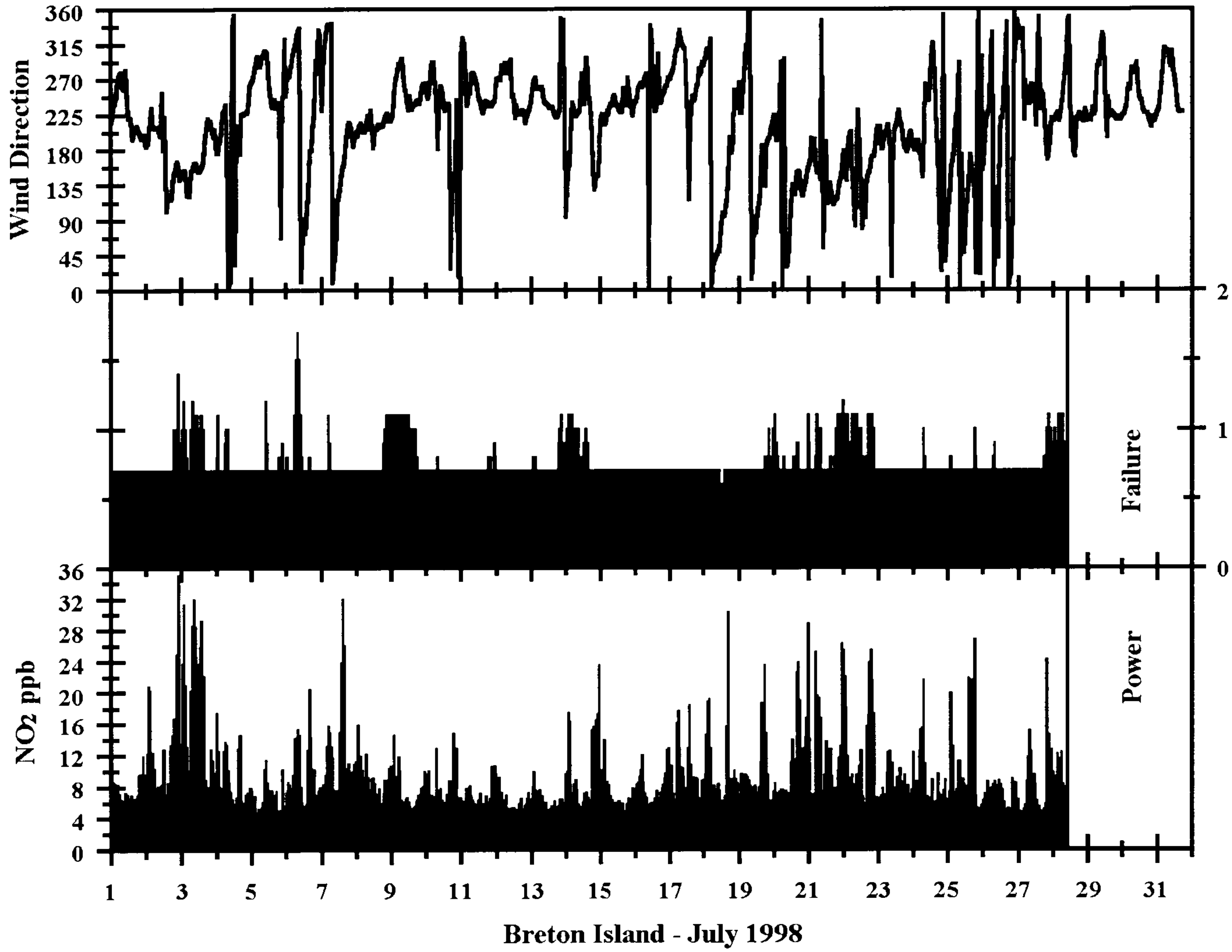


Figure 48. July 1998 time series of Breton Island hourly-averaged concentrations and wind direction.

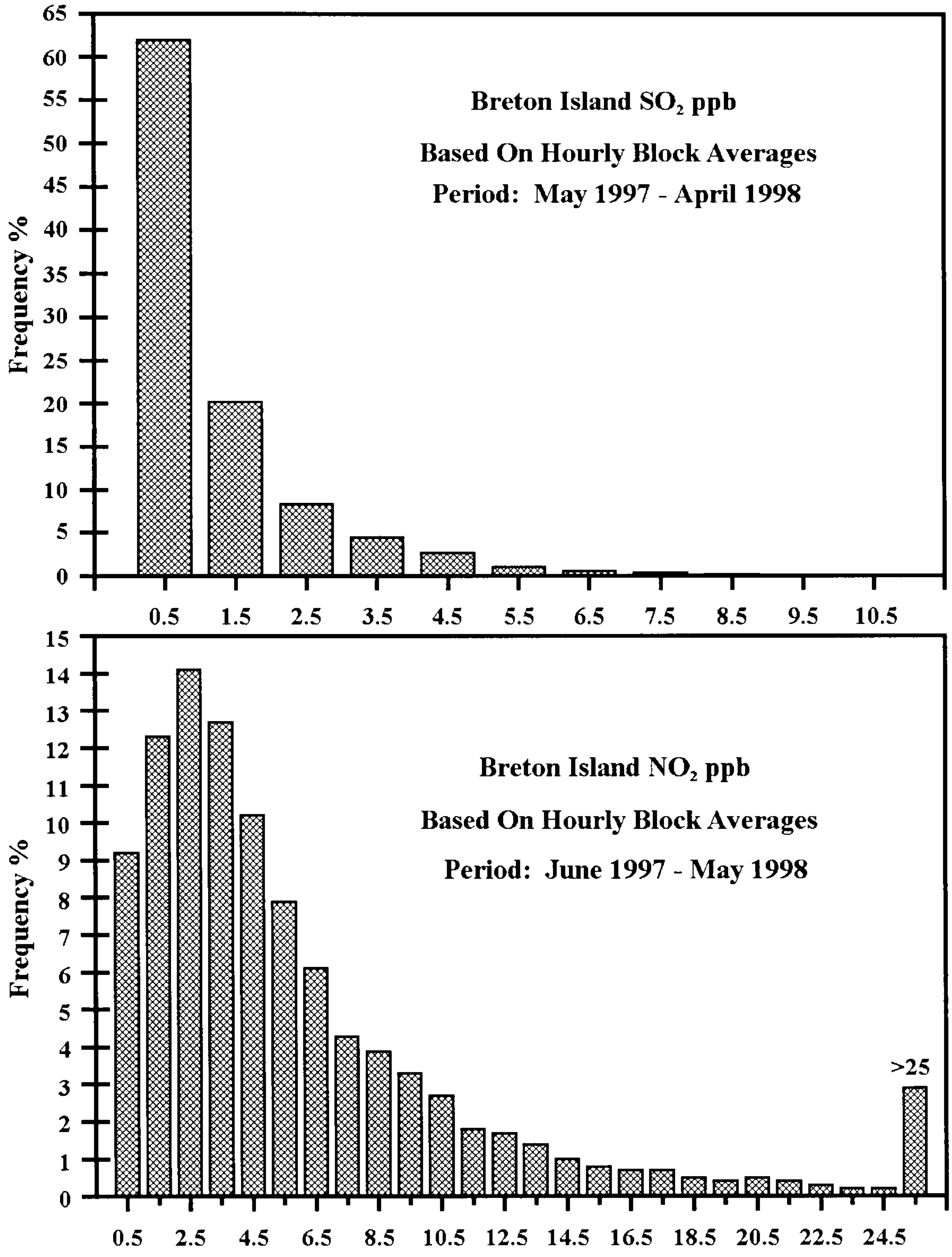


Figure 49. Frequency distribution of Breton Island hourly-averaged pollutant concentrations recorded during this study period.

Table 25.
Breton Island SO_2 Maximums and Averages (ppb) based on 1 Hour Block Averages*

Day	May 1997		June 1997		July 1997		September 1997	
	Max	Avg	Max	Avg	Max	Avg	Max	Avg
1	2.0	0.7	1.3	0.4	0.7	0.3	1.1	0.6
2	0.5	0.2	1.6	0.7	6.0	1.8	0.6	0.4
3	0.2*	0.2*	1.3*	0.6*	4.1	1.2	2.1	0.6
4					0.5	0.5	2.3	0.8
5					0.5	0.3	1.7	0.6
6					0.6	0.3	0.6	0.4
7					0.2	0.1	0.7	0.4
8					0.5	0.1	2.3	0.8
9	1.0*	0.3*			1.1	0.5	1.3	1.0
10	5.6	2.4	0.6*	0.2*	3.9	1.5	1.1	0.9
11	3.2	1.1	0.8	0.5	1.0*	0.2*	4.6	1.4
12	1.2	0.2	1.1	0.5	0.3*	0.1*	2.5	1.2
13	2.6	0.8	1.4	0.6			1.6	0.6
14	0.6	0.2	0.8	0.4			0.8	0.2
15	1.1	0.3	2.2	0.8			1.5	0.5
16	2.0	0.7	1.2	0.5			1.5	0.2
17	1.2	0.2	0.5	0.3			1.2	0.7
18	0.8	0.3	0.9	0.4			0.6	0.3
19	0.6	0.3	1.3	0.6			1.2*	0.5*
20	1.7	0.6	2.4	0.7				
21	0.7	0.1	2.0	0.7				
22	0.9	0.4	2.2	0.8				
23	1.1	0.3	2.4	0.9				
24	0.5	0.2	1.0	0.5			0.2*	0.1*
25	0.4	0.1	0.6	0.1			0.4	0.3
26	0.4	0.1	0.8	0.2			5.0	1.2
27	0.5	0.1	1.5	0.6			9.7	3.8
28	2.6	0.3	1.2	0.7			7.6	3.0
29	0.2	0.0	1.5	0.6			10.9	4.2
30	0.3	0.1	0.5	0.3			7.0	2.8
31	0.4	0.1						
# Hours	593		542		257		599	
Maximum	5.6		2.4		6.0		10.9	
Arith-Mean		0.4		0.5		0.6		1.1

* boxes indicate less than 75% (18 hours) complete.

Table 25 continued.

Day	October 1997		November 1997		December 1997		January 1998	
	Max	Avg	Max	Avg	Max	Avg	Max	Avg
1	5.2	2.2	3.4	1.0	3.5	1.2	3.3	1.5
2	8.5	4.5	3.8	1.8	5.3	1.5	1.1	0.8
3	6.3	3.4	5.5	2.4	2.5	0.9	1.4	0.7
4	2.4	1.2	2.0	1.1	1.4	0.8	1.1	0.6
5	1.9	0.6	1.7	0.9	3.6	1.3	1.4	0.7
6	0.8	0.2	2.4	1.2	6.1	1.9	0.9	0.7
7	0.9	0.6	2.8	1.5	5.1	2.4	1.1	0.8
8	1.4	0.6	8.1	4.4	1.2	0.7	1.8	0.9
9	0.1	0.0	6.1	3.7	1.2	0.5	7.0	2.4
10	0.1	0.0	8.1	4.2	1.6	0.7	5.8	2.1
11	0.6	0.1	8.4	3.1	5.9	2.7	1.3	0.9
12	1.1	0.6	1.1	0.4	6.4	3.7	1.8	0.6
13	1.2	0.5	5.1	1.8	6.0	3.4	1.7	0.8
14	3.2	0.7	4.7	2.0	4.8	2.1	0.8	0.6
15	5.2	3.3	4.8	1.3	11.0	4.9	2.5	0.9
16	16.8	5.7	3.8	1.6	5.3	2.6	7.1	3.3
17	13.4	6.0	5.7	2.6	5.4	1.7	3.7	1.7
18	7.6	4.3	2.5	1.6	7.2	1.9	2.5	1.3
19	7.4	3.1	5.2	1.5	2.6	0.7	3.1	1.6
20	9.4	3.1	1.3	0.7	1.1	0.7	4.9	1.9
21	8.1	4.3	1.6	0.9	1.3	0.9	1.2	0.9
22	10.5	2.9	11.8	1.2	3.9	1.4	0.8	0.6
23	3.4	1.4	8.8	4.2	2.3	1.1	2.0	1.1
24	1.1	0.6	5.9	1.9	2.4	1.2	3.5	1.5
25	1.1	0.4	2.5	1.2	9.1	2.3	4.3	2.0
26	1.3*	0.4*	1.7	0.5	9.2	2.7	1.1	0.9
27	3.9	1.3	1.7	0.5	1.6	0.9	3.9	1.4
28	6.5	2.9	0.9	0.3	5.4	1.8	5.1	4.1
29	6.8	2.4	0.7	0.2	2.4	1.5	2.8	2.0
30	3.1	1.4	4.1	1.9	5.2	2.6	3.6	2.3
31	1.4	0.7			4.1	2.0	3.6	2.3
# Hours	736		713		740		738	
Maximum	16.8		11.8		11.0		7.1	
Arith-Mean		1.9		1.7		1.8		1.4

*boxes indicate less than 75% (18 hours) complete.

Table 25 continued.

Day	February 1998		March 1998		April 1998		May 1998	
	Max	Avg	Max	Avg	Max	Avg	Max	Avg
1	2.1	0.9	1.0	0.7	5.3	0.7	3.3	1.3
2	1.8	0.9	2.1	0.9	1.1	0.4	1.3	0.9
3	1.9	0.9	9.0	1.5	1.2	0.3	1.5	0.9
4	4.7	2.7	2.0	1.0	3.9	0.8	2.9	1.6
5	3.2	1.9	0.2	0.0	5.0	2.3	2.2	1.4
6	7.2	2.1	0.0	0.0	3.6	1.9	3.0	1.7
7	6.9	3.2	0.2	0.1	0.5	0.2	1.6	0.8
8	9.6	4.5	1.6	0.4	0.3	0.0	1.1	0.6
9	5.0	1.9	2.5	1.1	3.7	1.4	1.1	0.8
10	0.8	0.2	1.0	0.6	3.3	0.4	1.9	0.9
11	1.2	0.6	3.7	1.5	3.1	1.4	7.3	3.3
12	4.8	2.0	6.1	2.9	2.0	1.2	3.1	2.0
13	4.6	2.1	4.4	2.1	0.8	0.2	2.6	1.7
14	6.2	2.6	1.2	0.6	1.1	0.2	2.0	1.3
15	1.4	0.7	1.3	0.4	0.3	0.1	6.2	1.5
16	0.7	0.2	1.3	0.3	0.1	0.0	7.4	1.8
17	1.0	0.3	0.3	0.0	1.4	0.4	4.9	2.3
18	2.9	1.6	0.1	0.0	1.2	0.2	7.7	3.4
19	3.1	1.0	0.2	0.0	4.1	0.9	7.7	3.9
20	4.7	2.5	4.5	1.7	4.6	2.4	4.9	2.6
21			2.9	0.5	4.9	2.2	2.1	1.4
22	1.9*	1.0*	2.4	1.2	3.0	1.1	2.3	1.3
23	2.7	1.7	9.8	2.9	0.9	0.9	2.3	1.2
24			2.9	0.6	3.1	2.6	2.9	1.7
25	0.7*	0.2*	1.2	0.3	3.6	1.9	2.2	1.4
26	0.5	0.1	1.0	0.4	1.7	1.2	2.1	1.3
27			0.8	0.2	2.0	1.0	2.1	1.2
28	0.8*	0.7*	0.9	0.2	1.1	0.7	1.9	1.0
29			1.0	0.2	1.1	0.7	1.4	0.9
30			2.3	0.2	1.4	0.8	1.0	0.7
31			0.4	0.1			0.7	0.6
# Hours	532		739		674		744	
Maximum	9.6		9.8		5.3		7.7	
Arith-Mean		1.5		0.9		0.9		1.5

*boxes indicate less than 75% (18 hours) complete.

Table 25 continued.

Day	June 1998		July 1998	
	Max	Avg	Max	Avg
1	0.6*	0.4*	0.7	0.7
2			1.4	0.8
3			1.2	0.9
4			1.1	0.8
5			1.2	0.7
6			1.7	0.9
7			1.1	0.7
8			1.1	0.8
9			1.1	1.0
10			0.8	0.7
11			0.9	0.7
12			0.8	0.7
13			1.1	0.8
14	0.7*	0.6*	1.1	0.9
15	0.7	0.6	0.7	0.7
16	0.7	0.6	0.7	0.7
17	1.2	0.9	0.7	0.7
18	1.2	0.8	0.7	0.7
19	0.9	0.6	1.0	0.7
20	1.1	0.7	1.1	0.8
21	1.0	0.7	1.1	0.9
22	0.9	0.6	1.2	1.0
23	1.0	0.7	0.7	0.7
24	0.9	0.7	1.0	0.7
25	1.1	0.8	1.0	0.7
26	1.1	0.7	0.9	0.7
27	1.2	0.9	1.1	0.8
28	1.1	0.8	1.1*	1.0*
29	1.1	0.8		
30	0.7	0.7		
31				
# Hours	409		657	
Maximum	1.2		1.7	
Arith-Mean		0.7		0.8

*boxes indicate less than 75% (18 hours) complete.

Table 26.
Breton Island NO_2 Maximums and Averages (ppb) based on 1 Hour Block Averages*

Day	May 1997		June 1997		July 1997		September 1997	
	Max	Avg	Max	Avg	Max	Avg	Max	Avg
1	9.3	5.8			7.4	3.7	17.8	3.1
2	9.1	3.3			13.1	5.6	9.0	2.0
3	10.3*	7.0*			17.7	7.0	7.7	4.0
4					10.1	4.8	5.0	3.2
5					13.2	6.0	4.0	1.5
6					18.1	6.8	20.3	2.7
7					7.3	3.7	18.2	2.6
8					11.3	5.4	40.0	8.3
9					25.0	5.5	14.1	6.8
10			2.1*	1.3*	18.9	10.3	5.9	3.6
11			6.4	2.5	19.2*	5.4*	10.0	3.3
12			13.4	6.6	11.2*	4.6*	8.9	3.1
13			14.8	5.5	22.4	5.5	26.3	6.3
14			8.4	3.9	13.6	4.3	13.0	4.1
15			10.2	4.8	18.8	8.3	36.3	6.0
16			10.9	5.7	9.9	4.5	42.1	7.2
17			10.9	4.3	7.2	4.9	36.0	7.8
18			16.2	7.0			19.9	5.4
19			12.1	7.6			35.4	7.6
20			18.7	7.6				
21			12.1	5.5				
22			15.4	6.1				
23			8.8	4.7				
24			9.9	5.0			3.7	2.6
25			16.6	7.0			4.2	2.0
26			16.5	8.0			26.0	9.4
27			16.1	7.4			7.0	5.1
28			19.9	7.4			12.7	6.8
29			12.9	6.1			14.1	6.6
30			10.1	4.5			7.9	5.3
31								
# Hours	54		482		381		599	
Maximum	10.3		19.9		25.0		42.1	
Arith-Mean		4.8		5.7		5.6		4.8

*boxes indicate less than 75% (18 hours) complete.

Table 26 continued.

Day	October 1997		November 1997		December 1997		January 1998	
	Max	Avg	Max	Avg	Max	Avg	Max	Avg
1	15.1	6.5	24.9	7.1	6.2	4.0	2.5	1.0
2	11.6	8.5	10.6	4.7	7.9	4.4	3.5	1.2
3	29.7	7.7	13.4	6.7	37.4	13.7	2.4	1.0
4	34.5	6.5	9.2	2.9	6.9	3.2	4.1	0.8
5	2.4	1.5	27.1	6.1	5.9	2.6	19.1	3.8
6	12.4	1.7	24.2	7.1	6.8	3.4	8.7	2.3
7	3.5	1.0	16.9	4.6	6.3	3.1	18.0	7.1
8	3.6	1.1	7.4	5.6	32.4	10.4	4.9	2.7
9	4.3	0.8	5.5	3.9	32.2	14.8	10.4	3.8
10	4.2	0.7	20.5	6.6	8.9	5.6	5.1	2.2
11	1.0	0.5	13.2	5.1	14.4	7.6	4.6	1.2
12	5.9	2.0	25.3	6.0	14.4	5.4	20.6	7.7
13	26.4	8.4	29.2	11.6	5.7	3.4	10.9	4.9
14	4.1	2.4	15.6	8.4	5.4	1.7	23.9	7.2
15	5.8	3.5	7.9	4.6	27.9	9.3	17.1	5.0
16	10.0	4.8	4.6	2.8	39.7	22.9	18.5	8.2
17	9.9	5.5	5.1	2.8	47.8	23.8	40.2	16.5
18	5.8	3.6	5.0	2.8	41.5	18.1	20.4	13.7
19	9.0	3.4	14.8	4.1	32.9	12.9	4.7	1.9
20	19.4	8.0	25.5	7.9	22.6	5.9	3.1	0.9
21	52.9	15.6	38.6	19.7	26.8	10.0	3.3	1.2
22	8.2	4.4	13.8	8.1	24.7	8.2	14.8	3.7
23	22.3	8.0	7.6	4.7	13.0	5.9	13.5	7.3
24	20.0	5.7	5.3	2.8	17.5	7.0	4.9	2.3
25	23.5	11.1	6.0	2.5	19.1	5.7	2.6	1.1
26	12.5*	4.1*	35.2	8.1	12.1	4.2	11.5	2.7
27	5.0	3.3	41.5	10.2	2.4	0.7	5.6	1.5
28	4.9	3.5	17.0	6.3	20.1	4.0	26.7	7.4
29	7.4	3.3	21.8	8.9	3.0	1.7	38.3	16.5
30	10.2	3.4	10.2	5.5	15.3	6.0	40.2	13.9
31	25.8	6.7			10.1	3.5	5.9	2.7
# Hours	736		713		740		738	
Maximum	52.9		41.5		47.8		40.2	
Arith-Mean		4.8		6.3		7.5		4.9

* boxes indicate less than 75% (18 hours) complete.

Table 26 continued.

Days	February 1998		March 1998		April 1998		May 1998	
	Max	Avg	Max	Avg	Max	Avg	Max	Avg
1	4.2	1.4	3.8	2.6	2.5	0.8	26.6	10.1
2	3.2	1.0	7.6	3.7	19.0	8.5	10.8	6.8
3	2.9	1.0	10.2	3.4	20.8	7.8	11.8	7.6
4	6.1	3.2	12.2	6.2	8.4	1.5	48.7	11.2
5	5.7	3.2	15.7	5.9	9.0	2.4	37.4	10.6
6	10.2	4.3	11.8	4.1	8.3	4.3	37.2	20.7
7	14.7	6.4	7.8	3.0	20.3	10.5	13.6	8.5
8	23.4	9.5	7.5	4.4	25.1	7.9	14.8	8.3
9	35.5	12.6	4.6	3.0	6.2	2.7	27.5	12.6
10	12.1	5.1	2.5	1.6	3.0	1.6	6.7	5.3
11	8.1	4.4	4.3	2.6	12.0	2.1	12.1	6.6
12	21.9	9.0	5.9	3.1	20.1	9.3	45.1	11.5
13	11.6	6.5	21.1	4.2	13.6	5.6	48.0	16.7
14	7.9	3.8	20.6	5.7	19.2	12.2	51.6	29.7
15	9.1	3.3	8.5	3.4	21.6	7.4	39.5	21.1
16	13.9	4.3	11.3	4.0	17.9	4.1	13.5	8.4
17	9.4	4.1	9.6	2.1	23.1	10.9	18.4	8.4
18	9.0	5.1	14.1	3.3	14.0	6.2	18.8	7.7
19	7.6	4.1	17.9	5.9	1.4	0.4	17.1	9.3
20	22.8	10.9	8.4	3.6	3.0	1.0	28.0	12.8
21			2.3	0.6	8.7	4.3	14.1	8.0
22	5.3	4.0	7.9	1.7	9.0	5.3	35.6	10.6
23	4.9	2.9	20.5	8.7	5.2	5.2	23.2	9.8
24			23.3	10.1	35.8	12.1	43.8	23.6
25	5.2*	3.0*	9.4	4.6	59.9	28.8	38.6	15.8
26	10.3	4.6	11.1	3.0	47.1	14.6	44.3	16.2
27	5.8*	4.0*	2.4	1.1	22.6	8.7	30.9	8.5
28	4.4*	3.0*	9.0	2.2	21.0	7.0	28.1	9.9
29			8.0	1.8	34.7	7.8	31.1	15.0
30			15.9	2.9	35.5	8.7	27.2	9.8
31			20.3	6.8			10.4	6.0
# Hours	550		739		674		744	
Maximum	35.5		23.3		59.9		51.6	
Arith-Mean		4.9		3.8		7.0		11.8

* boxes indicate less than 75% (18 hours) complete.

Table 26 continued.

Day	June 1998		July 1998	
	Max	Avg	Max	Avg
1	16.0*	7.2*	11.9	7.6
2			35.0	12.9
3			32.0	17.6
4			17.4	8.9
5			11.4	6.6
6			20.4	9.6
7			31.9	12.3
8			15.8	8.9
9			14.6	7.6
10			14.7	8.0
11			10.6	6.7
12			9.7	6.1
13			9.9	6.2
14	5.2*	4.3*	23.4	10.4
15	6.9	4.9	13.9	7.1
16	11.4	6.9	12.9	8.0
17	20.9	10.0	18.3	9.9
18	18.5	9.2	30.2	10.5
19	13.0	6.3	23.5	9.7
20	23.4	8.4	23.8	11.0
21	22.2	9.6	28.8	12.6
22	22.0	10.0	25.4	12.9
23	39.3	9.3	12.4	8.4
24	26.3	7.6	21.6	9.1
25	32.0	12.2	26.7	11.1
26	23.0	10.6	8.9	7.0
27	23.0	11.9	24.2	8.4
28	28.1	12.7	12.3*	10.2*
29	16.1	11.4		
30	15.4	8.2		
31				
# Hours	409		657	
Maximum	39.3		35.0	
Arith-Mean		9.1		9.5

*boxes indicate less than 75% (18 hours) complete.

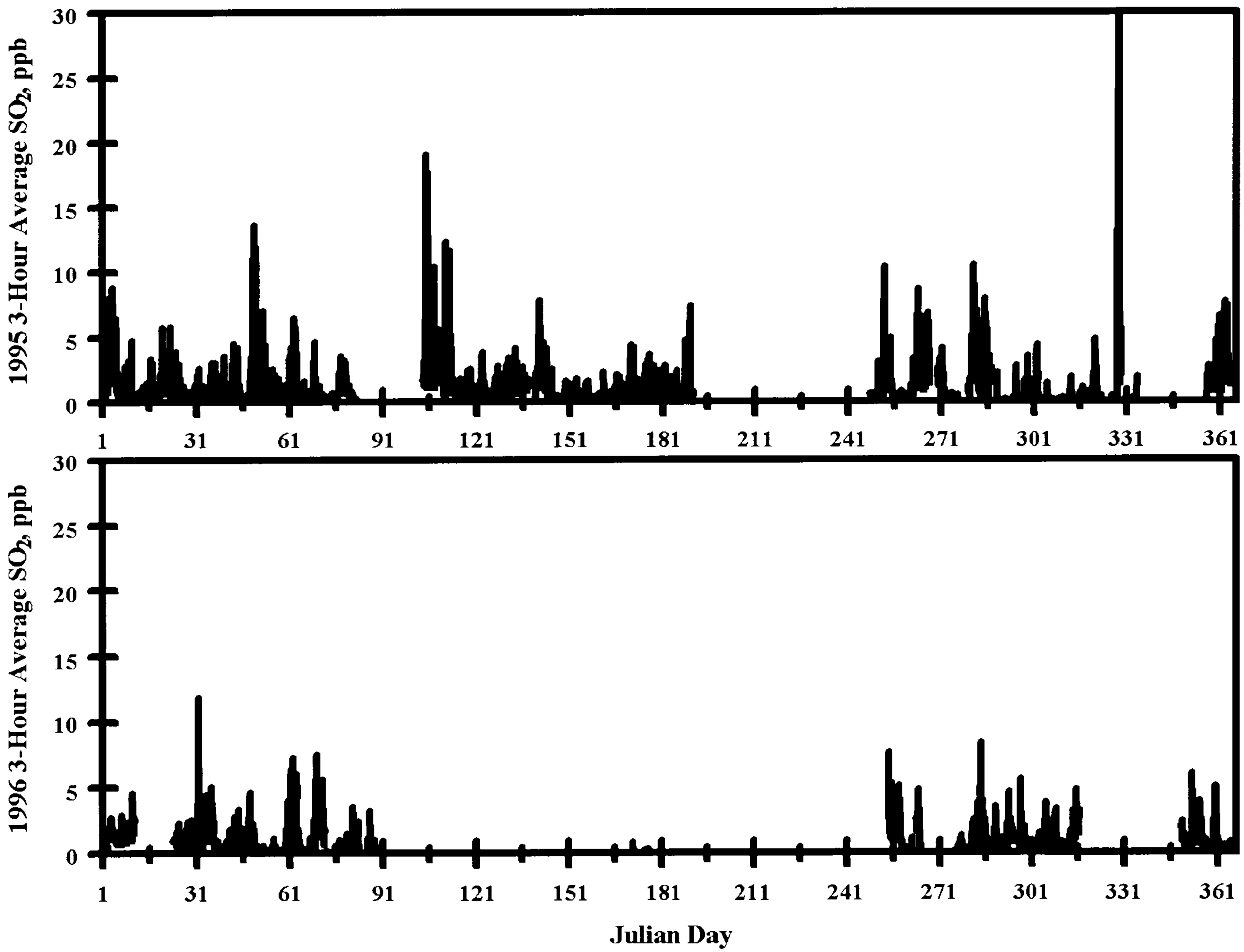


Figure 50. Breton Island annual SO_2 trends based on 3-hour block averages.

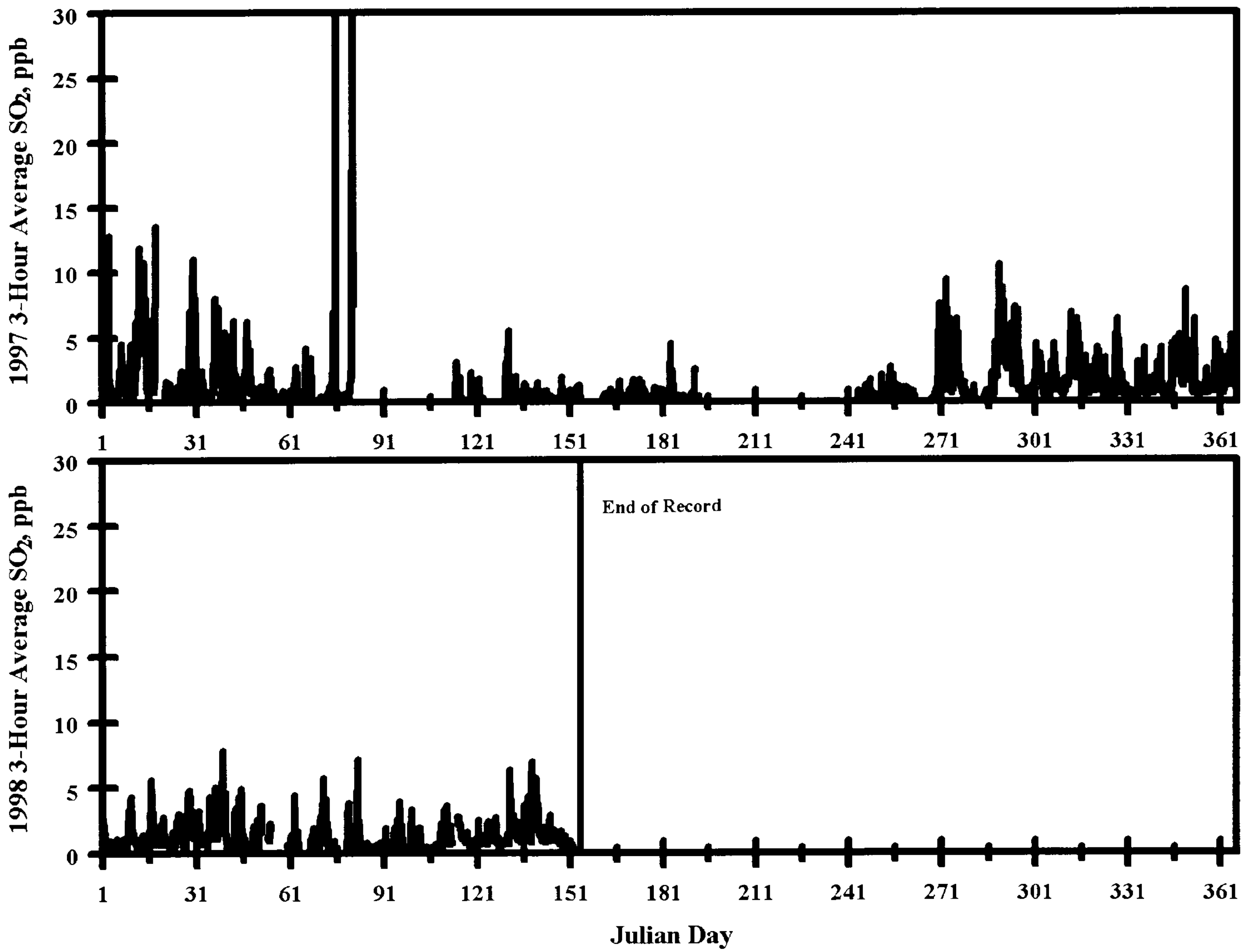


Figure 50 continued.

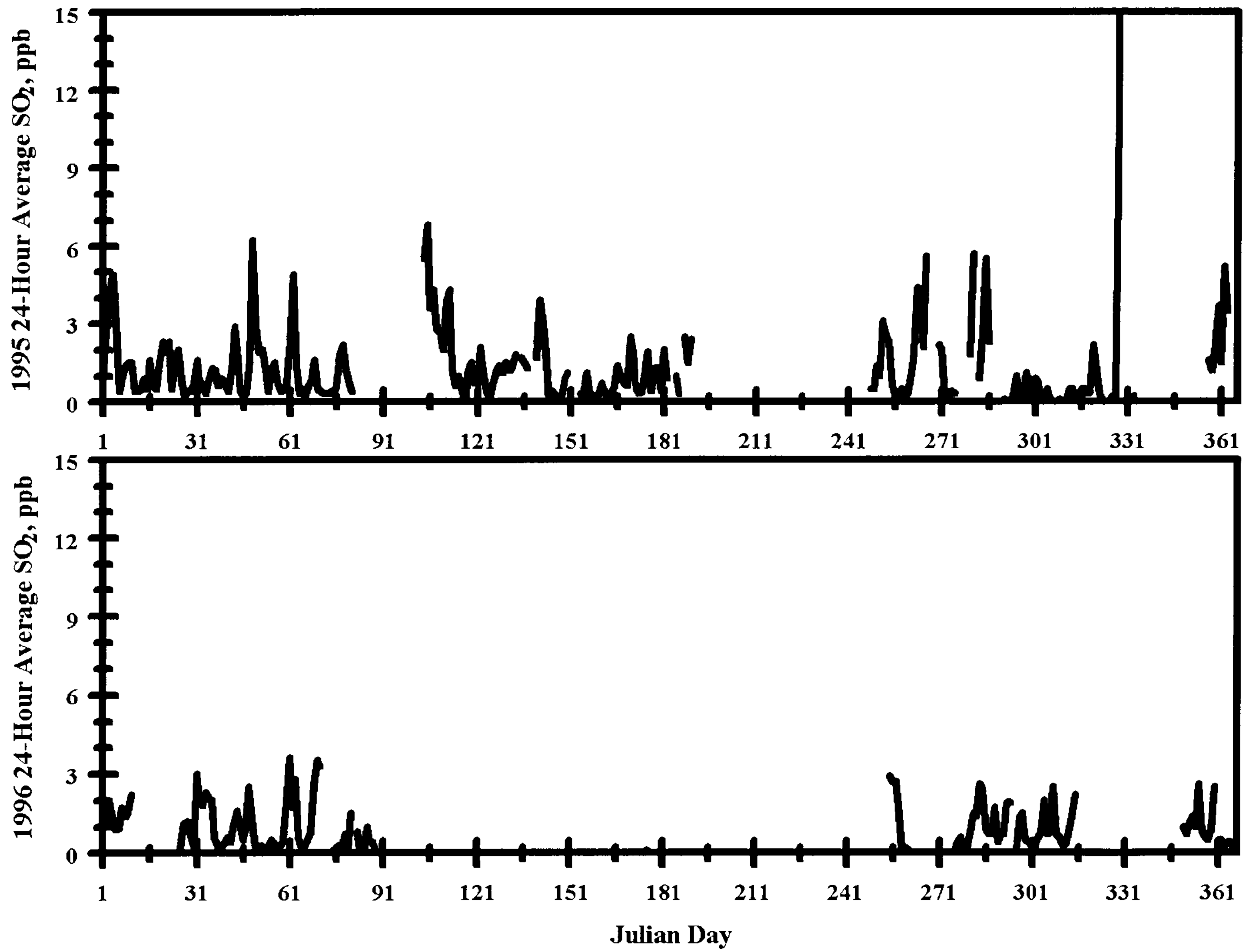


Figure 51. Breton Island annual SO_2 trends based on 24-hour block averages.

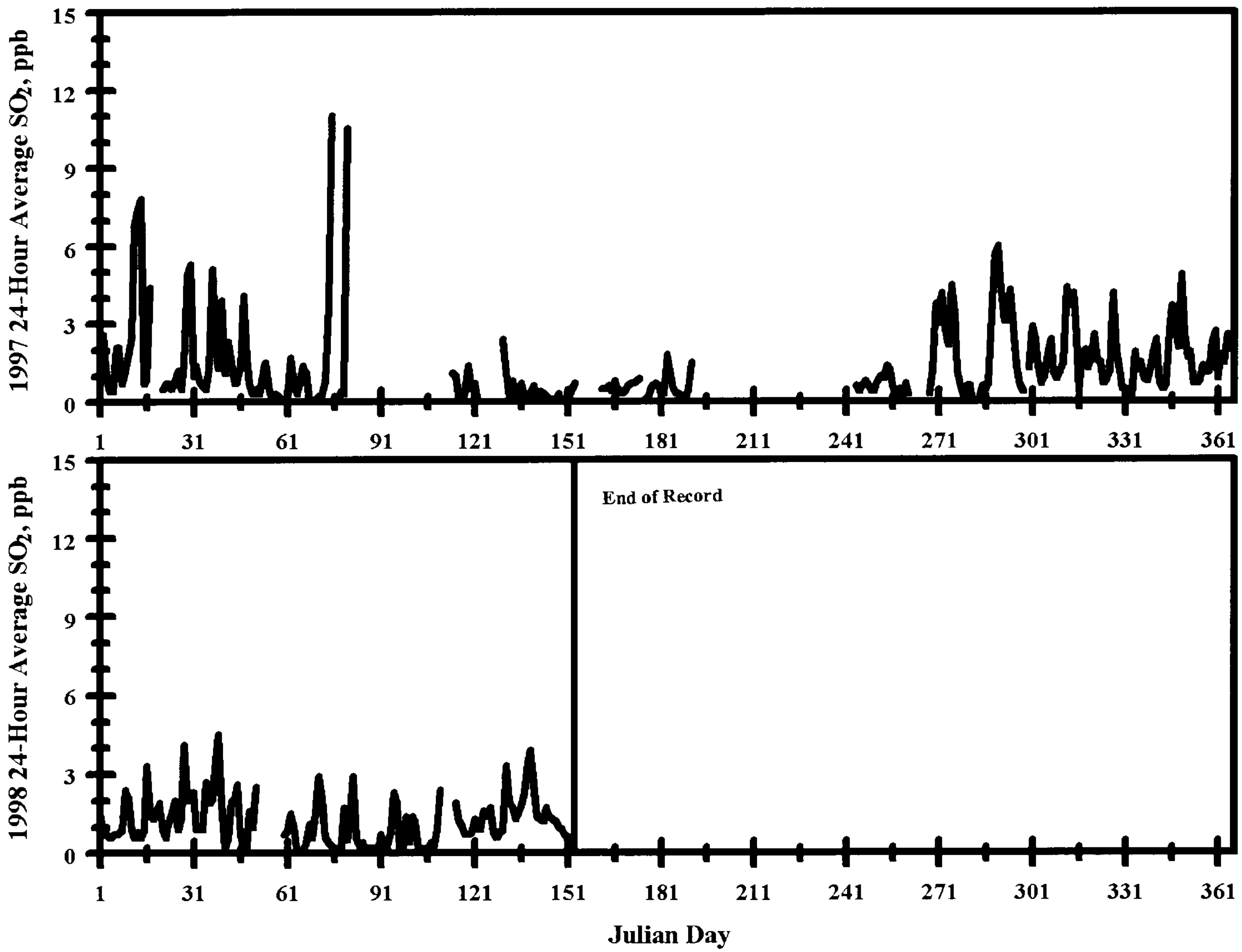


Figure 51 continued.

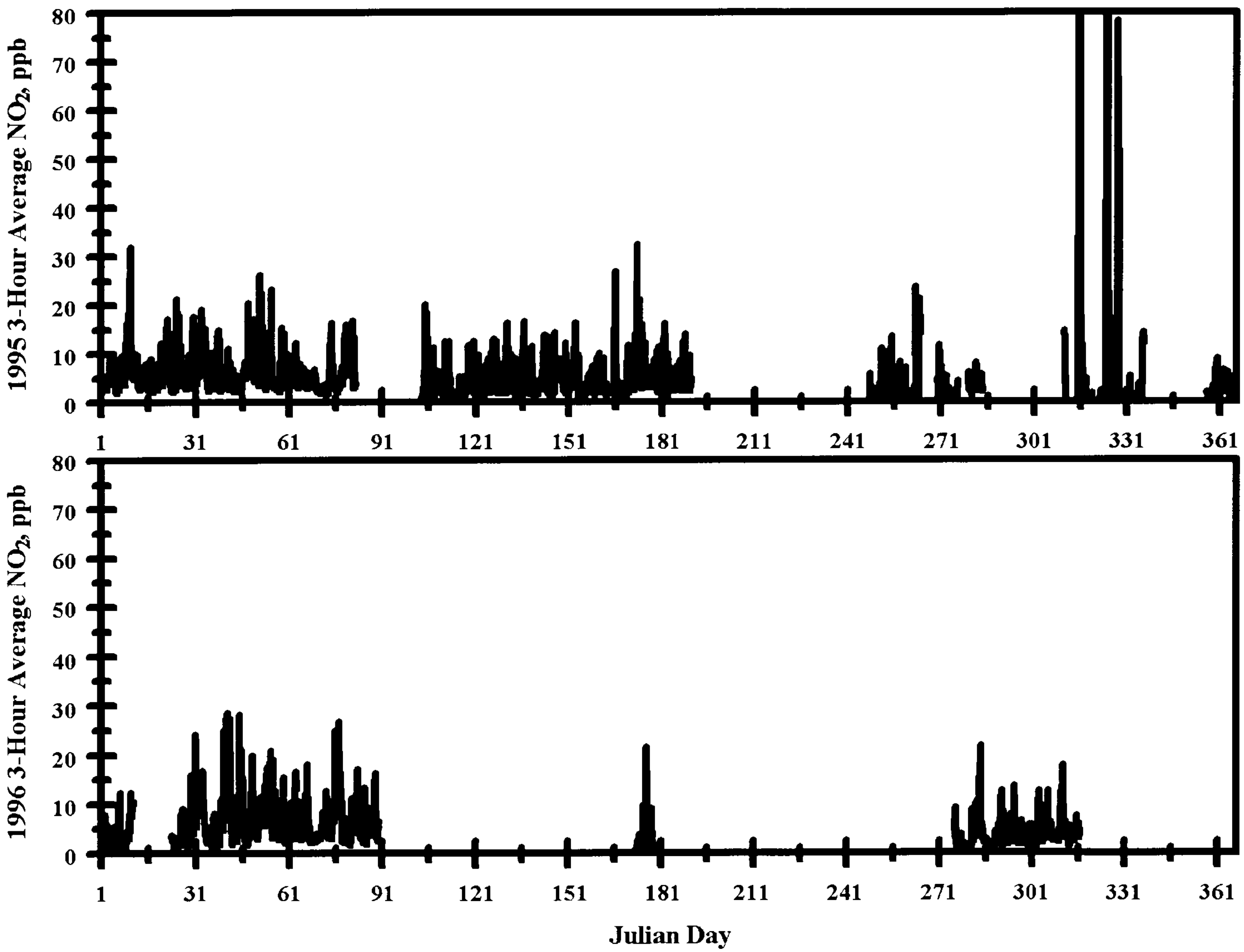


Figure 52. Breton Island annual NO_2 trends based on 3-hour block averages.

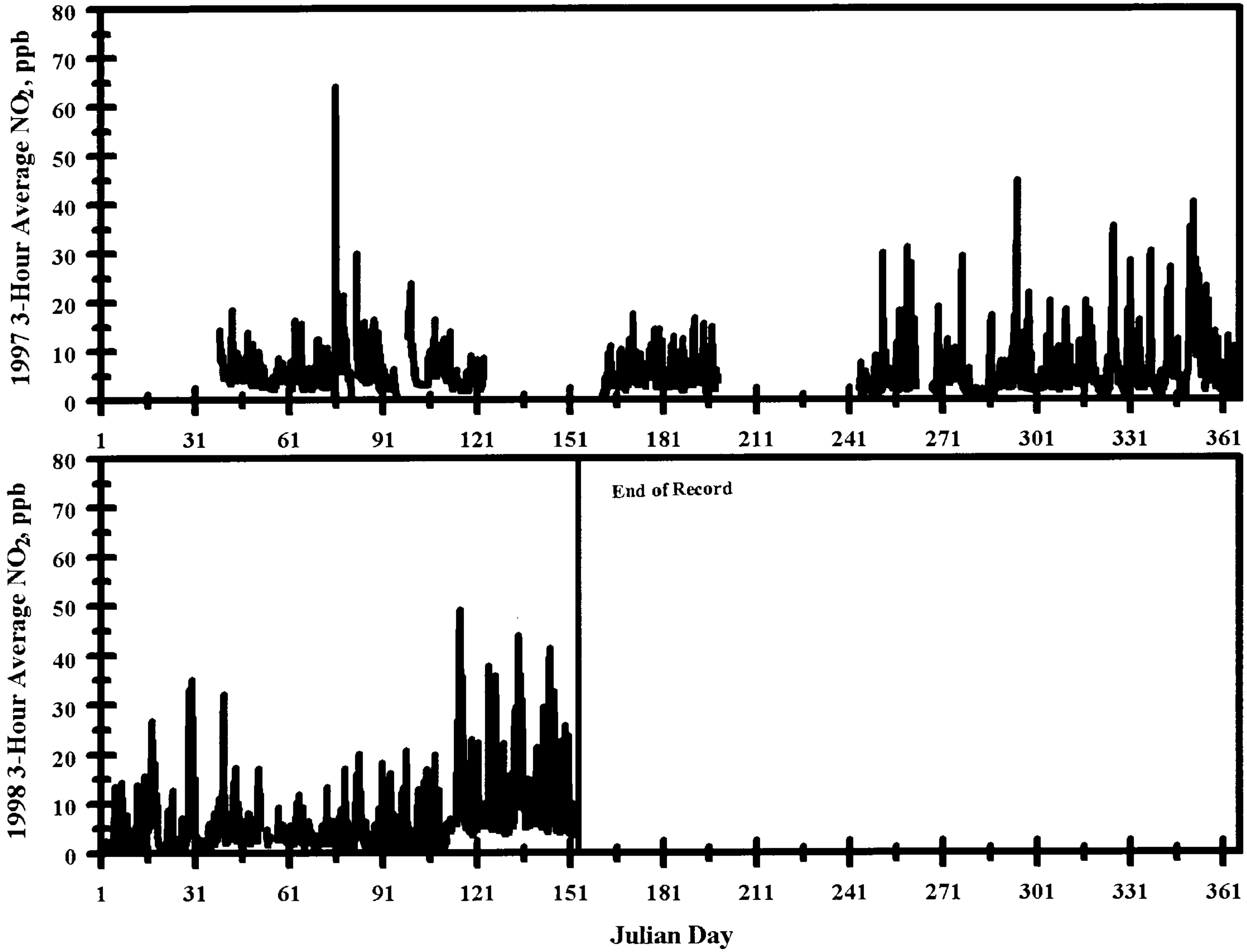


Figure 52 continued.

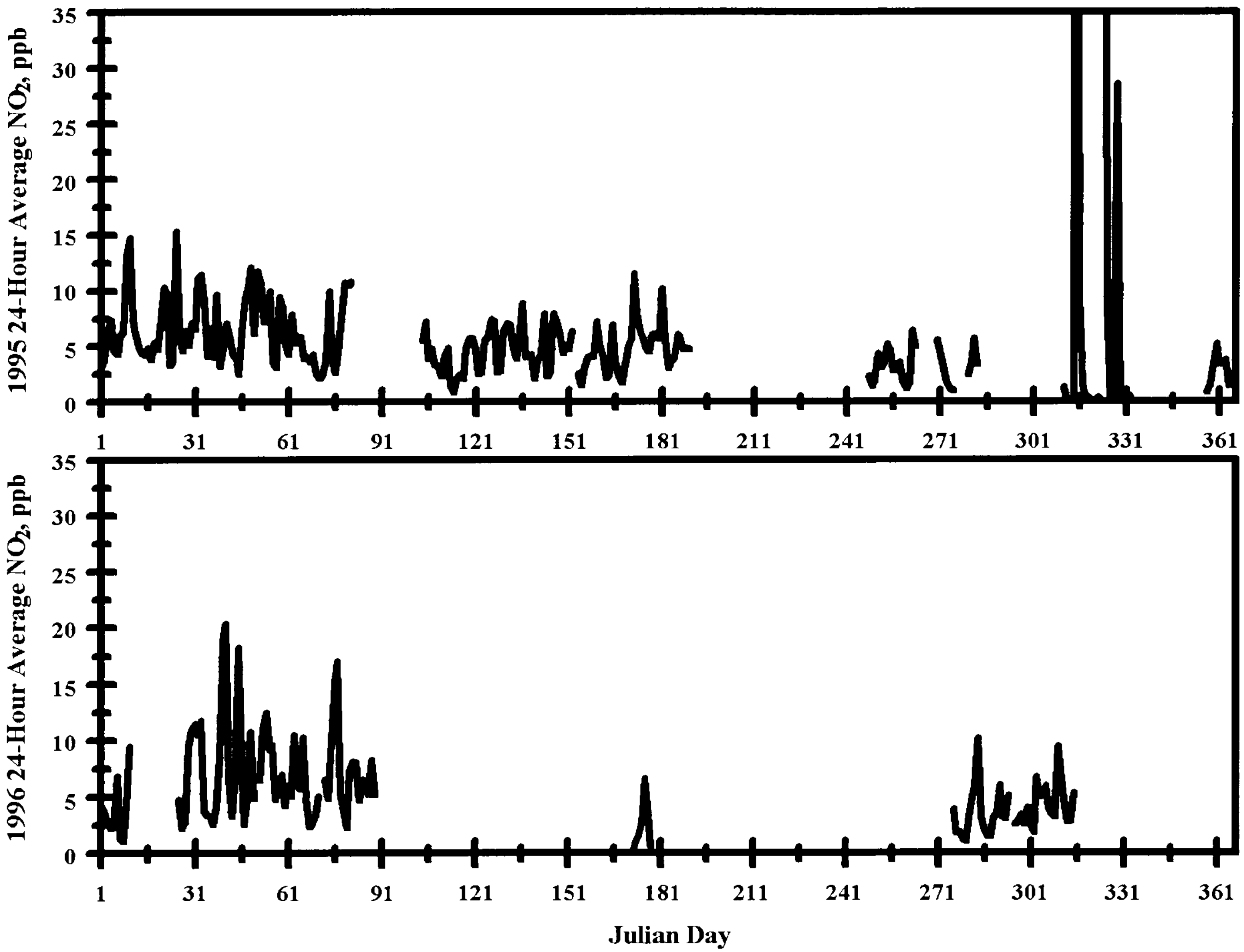


Figure 53. Breton Island annual NO_2 trend based on 24-hour averages.

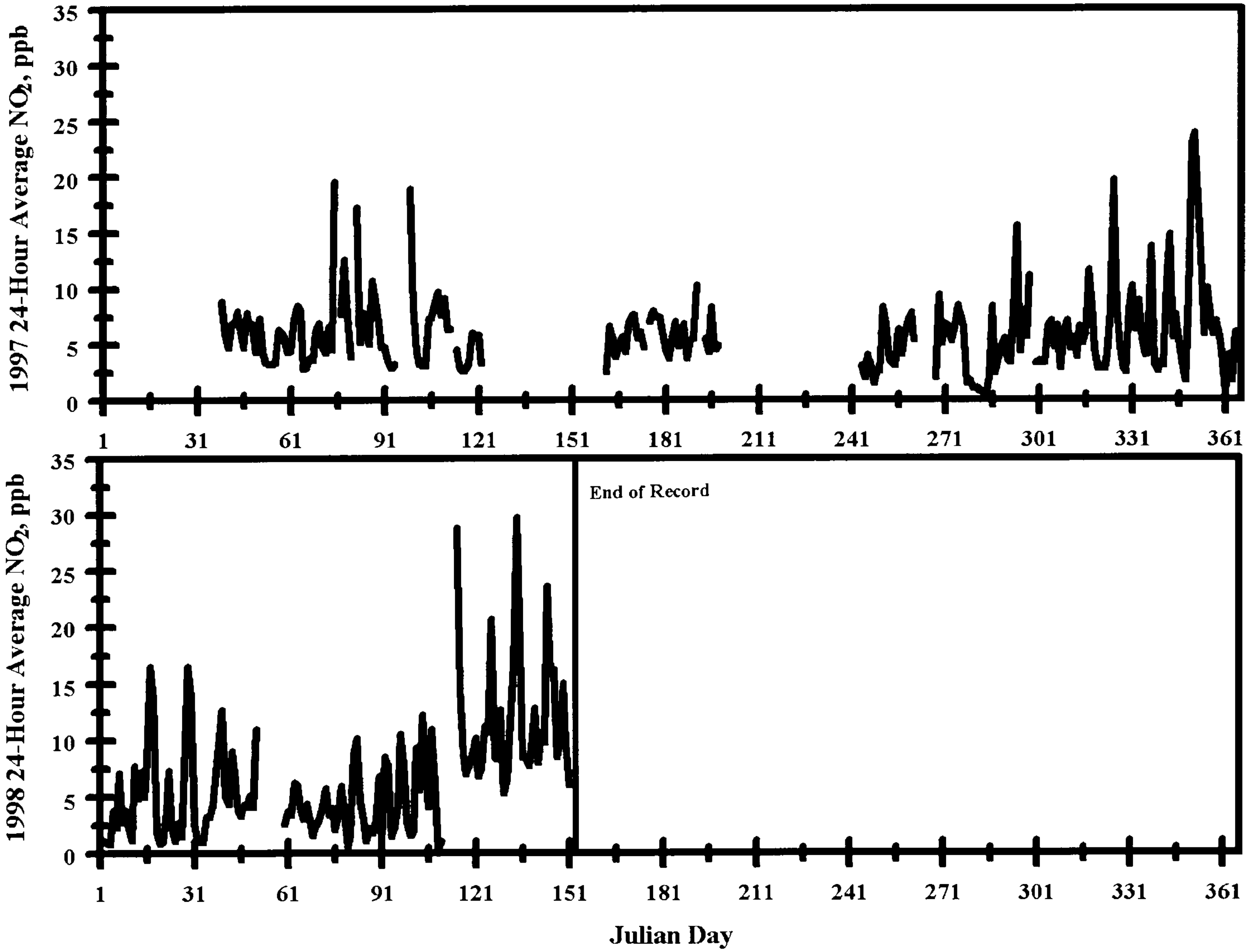


Figure 53 continued.

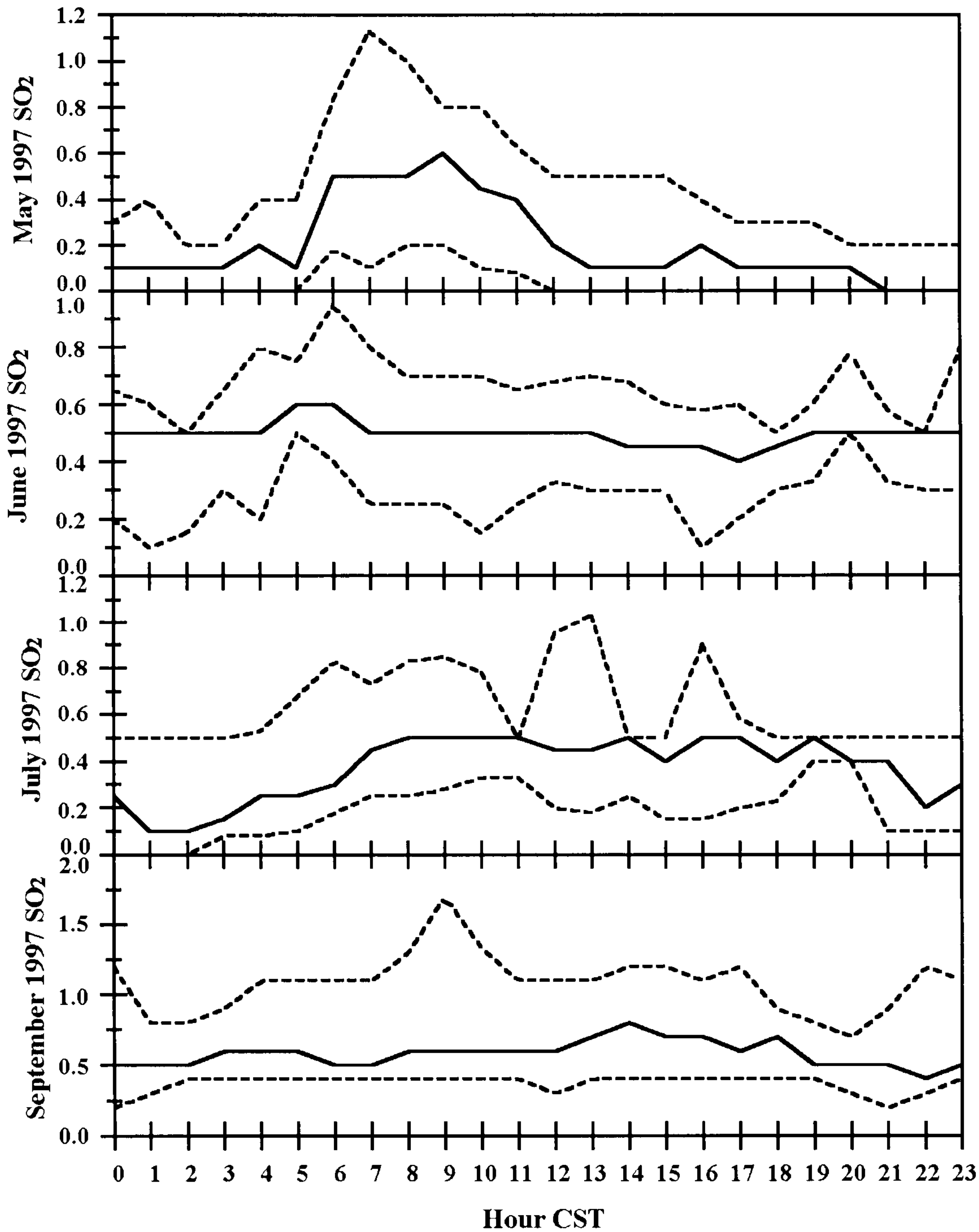


Figure 54. Breton Island diurnal SO_2 trends as represented by first (dashed), second (solid), and third (dashed) quartile lines.

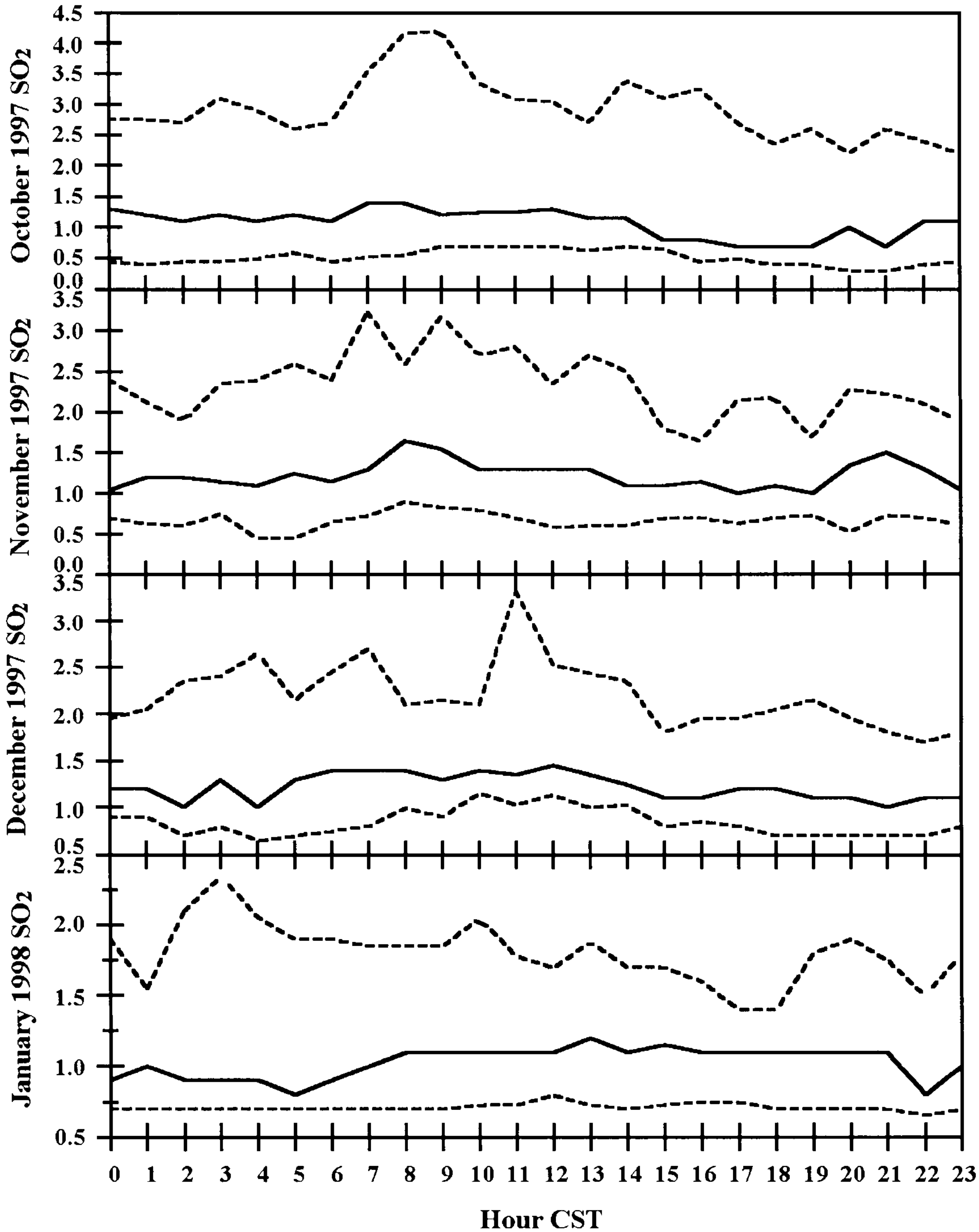


Figure 54 continued.

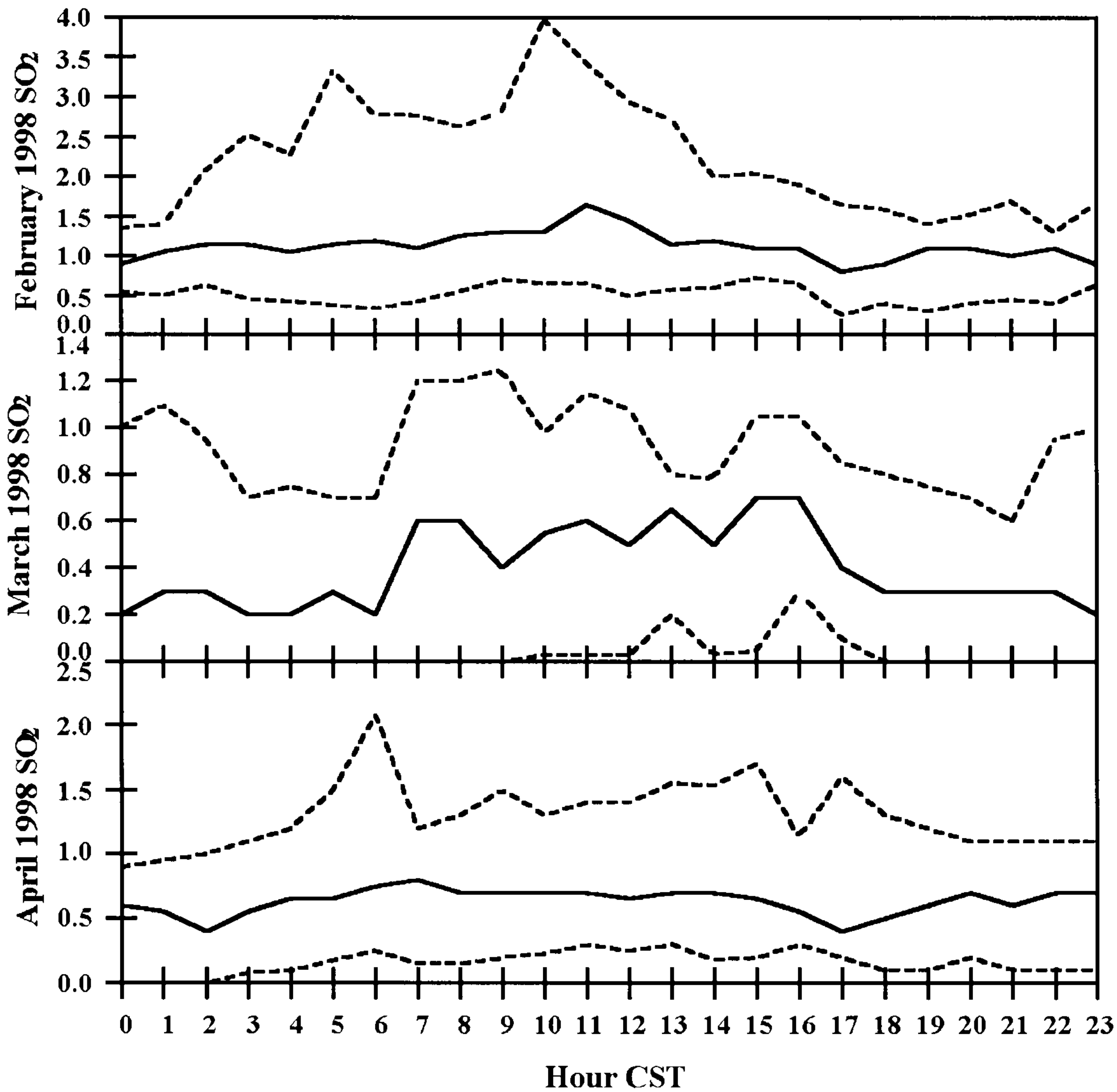


Figure 54 continued.

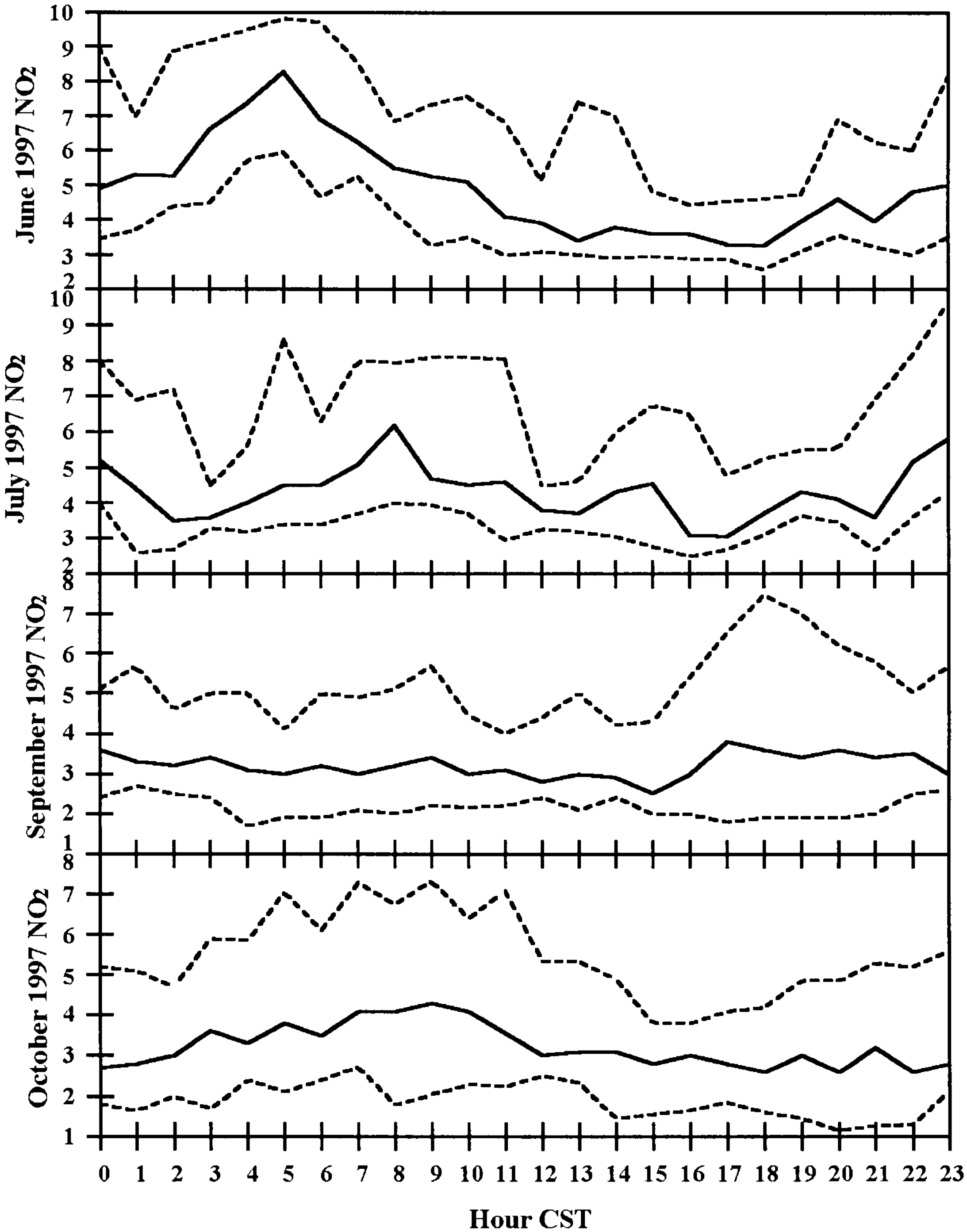


Figure 55. Breton Island diurnal NO_2 trends as represented by first (dashed), second (solid), and third (dashed) quartile lines.

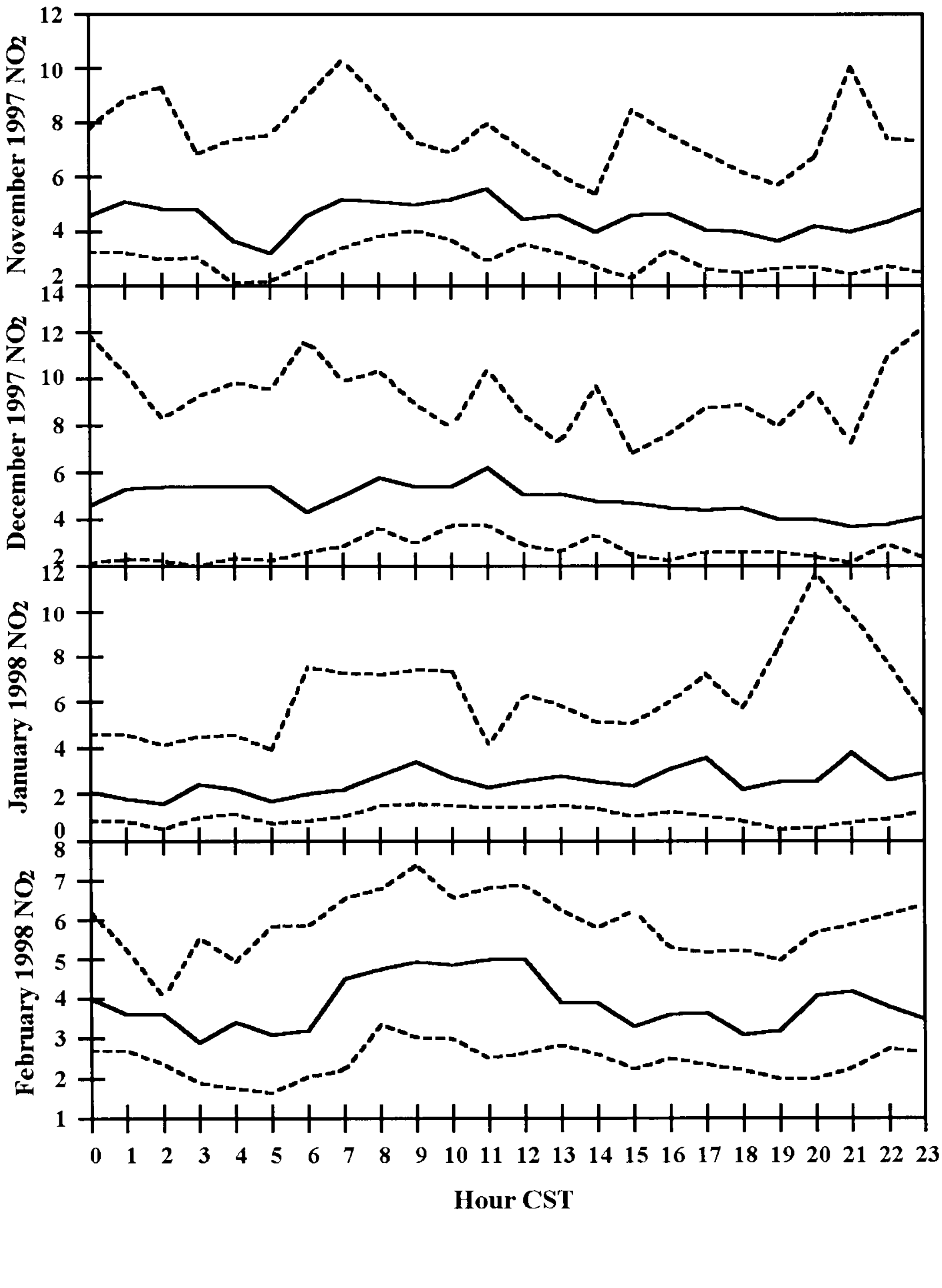


Figure 55 continued.

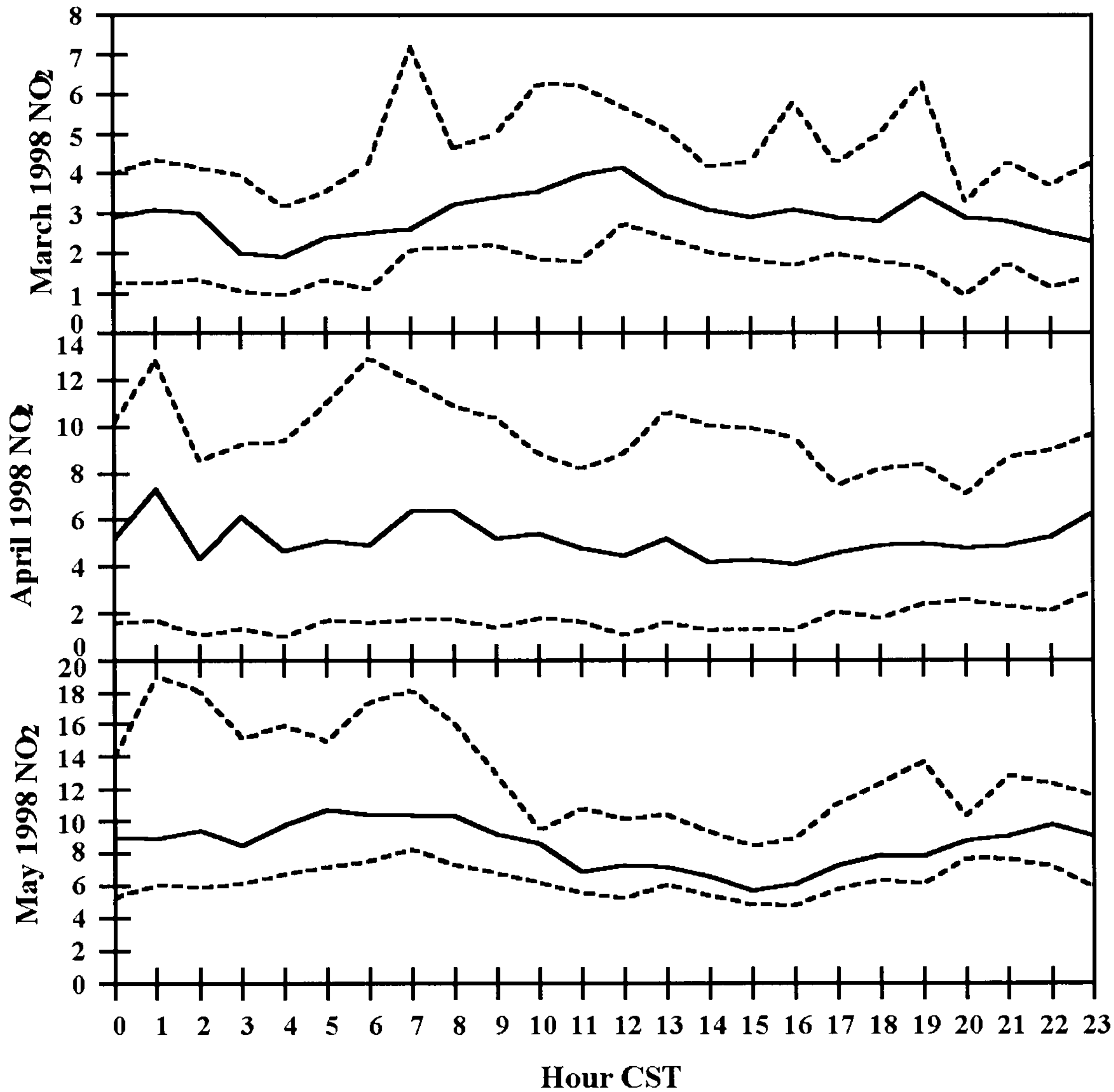


Figure 55 continued.

Monthly wind and pollution roses are given in Figs. 56 - 69. Higher SO_2 concentrations are very clearly associated with northerly wind directions, particularly north-northeast. High NO_2 concentrations are more distributed, often from west-northwest directions but mostly from southerly directions. Again, it must be noted that the Kerr-McGee generator shed was situated to the south-southeast of our monitoring station; however the peaks were often observed from the southwest and west. Maximum observed concentrations of SO_2 and NO_2 at Breton Island are listed in Tables 27 and 28, respectively. These directional relationships are further confirmed by the maximum values. Lower NO_2 / NO_x ratios are found here than at Dauphin, suggesting a much nearer source (less NO_x to NO_2 conversion). For comparison to the NAAQS (Table 23), maximum 3- and 24-hour SO_2 was 10.6 and 6.0 ppb; well below both the standard and similarly averaged values at Dauphin.

Table 29 lists the statistics for the top 10% of the Breton Island air quality data for this study period. The winter peak in SO_2 concentrations from October to January is pronounced; NO_2 exhibits dual peaks in early winter and late spring. More importantly, the opposite directional dependence of SO_2 to north and NO_2 to south is apparent. North and northeast of Breton Island is the Chandeleur Sound and eventually the Mississippi Gulf coast; to the south and southwest is the Breton Sound and the Mississippi River Delta. Numerous oil and gas platforms are active in these coastal waters. Obviously then, this location can be exposed to a wide variety of sources, both land-based and marine; however identification and quantification of sources is beyond the scope of this work.

In order to determine the synoptic weather regimes most frequently associated with high pollutant concentrations, the classification scheme of Muller (1977) is employed. A brief description of each synoptic type is as follows (see Fig. 70):

Pacific High (PH): following a "Pacific" cold front, this weather type is normally fair and mild with west to northwest winds. Ahead of the front, stronger southerly wind may prevail.

Continental High (CH): associated with polar or arctic outbreaks. North or northeasterly winds will prevail over a large section of the Gulf.

Frontal Overrunning (FOR): cloudy and rainy type occurs frequently when cold fronts become stationary along the Gulf coast or northern or central Gulf.

Coastal Return (CR): wind around high pressure over east Canada will bring southeasterly and southerly flow over Gulf.

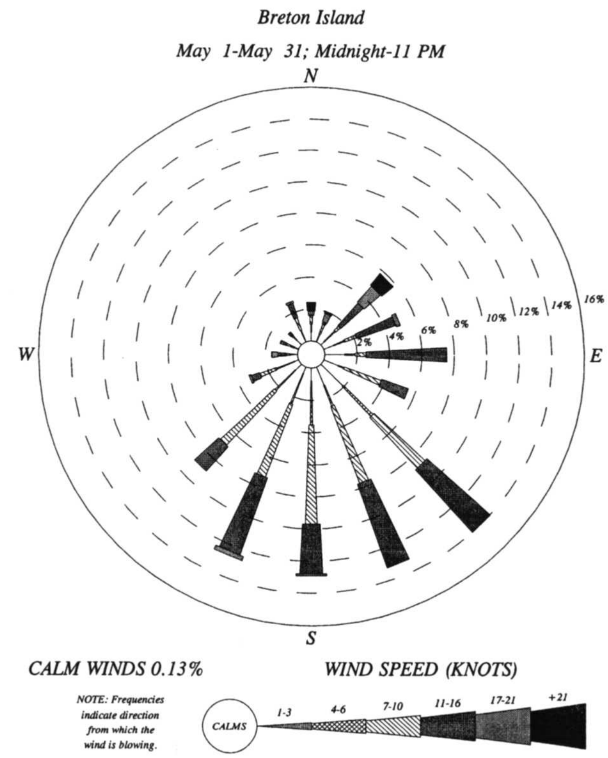
Gulf Return (GR): similar to CR, wind direction is mainly from southeast and south but speed is higher due to developing low pressure system over Texas.

Frontal Gulf Return (FGR): when cold front is approaching Gulf from northwest, return flow ahead of front becomes increasingly turbulent and stormy.

Gulf High (GH): high pressure system prevails over Gulf, calm weather results.

Gulf Tropical Disturbance (GTD): any tropical weather system prevails over Gulf.

The 1995 - 1998 annual records at Breton Island were ranked by 24-hour block average, and the top 20 days (about 5%) selected. The synoptic weather type present at New Orleans, Louisiana on these days as supplied by the "Louisiana Monthly Climate Review" (LOSC, 1995 - 1998) was determined. Table 30 lists these results. Maximums in SO_2 concentrations throughout the record are mostly associated with CH and FOR types; NO_2 maximums are more distributed but usually seen under GR, FGR, or CH types. This analysis is consistent with previous findings in that higher SO_2 occurs when wind blows from land to sea (CH), while high NO_2 is seen mostly when wind blows from sea to land (GR). It is interesting to see that a high percentage of NO_2 - CH cases are found, as the northerly wind - NO_2 relation was detected in the pollution rose analysis. Note that under FOR conditions, winds can either be from sea to land or land to sea, depending on location of the stationary front. This analysis may be slightly biased toward weather types commonly associated with the fall-winter seasons, since more of the air quality data was collected during those periods (from the time series depicted in Figs. 51 and 53, it is seen that the data return was higher during the winter seasons).



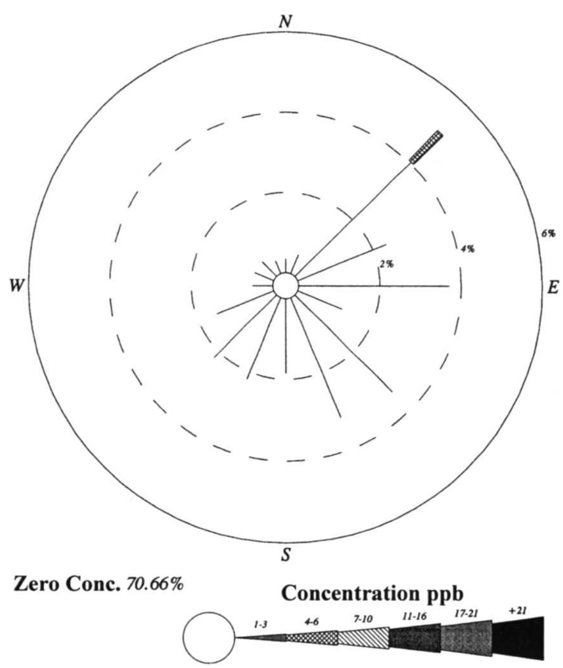
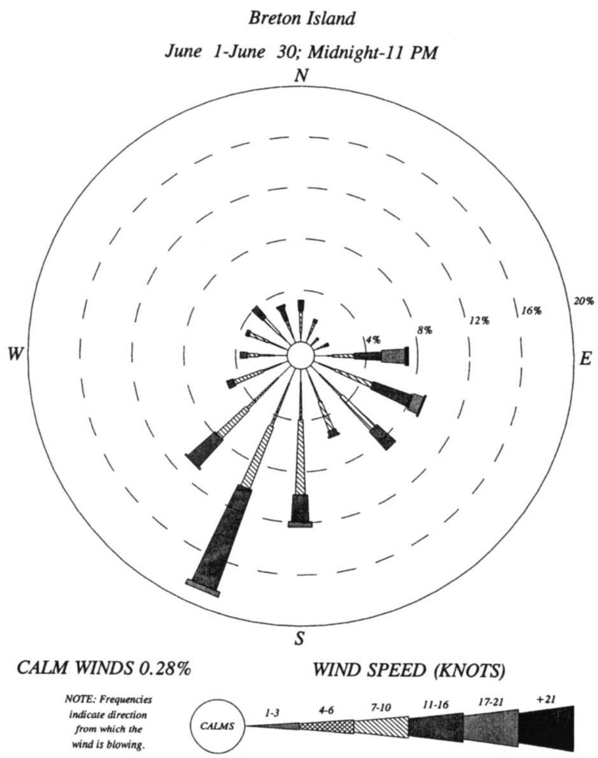
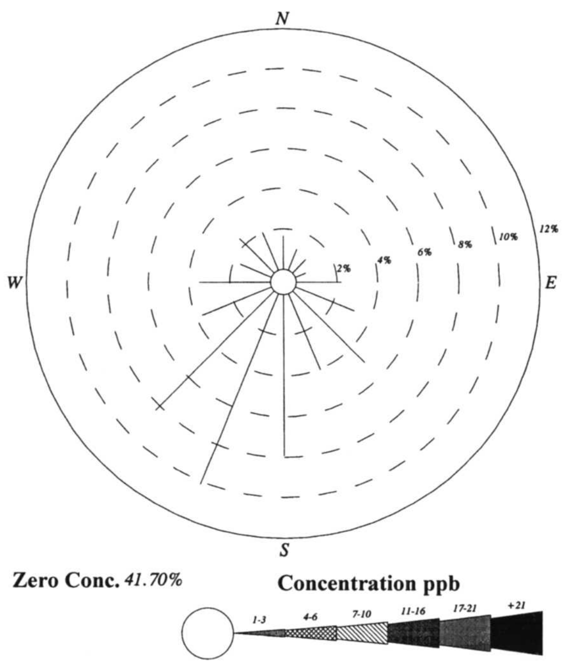


Figure 56. Breton Island May 1997 wind (top) and pollution roses (SO_2 bottom left, NO_2 missing).





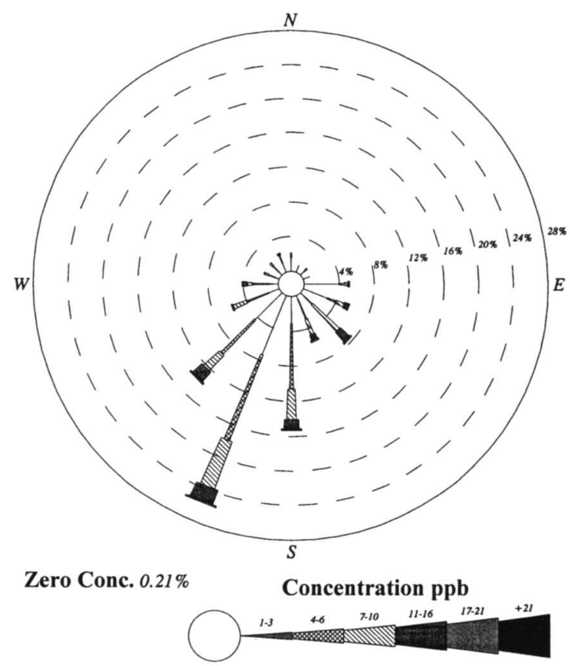


Figure 57. Breton Island June 1997 wind (top) and pollution roses (SO_2 bottom left, NO_2 bottom right).

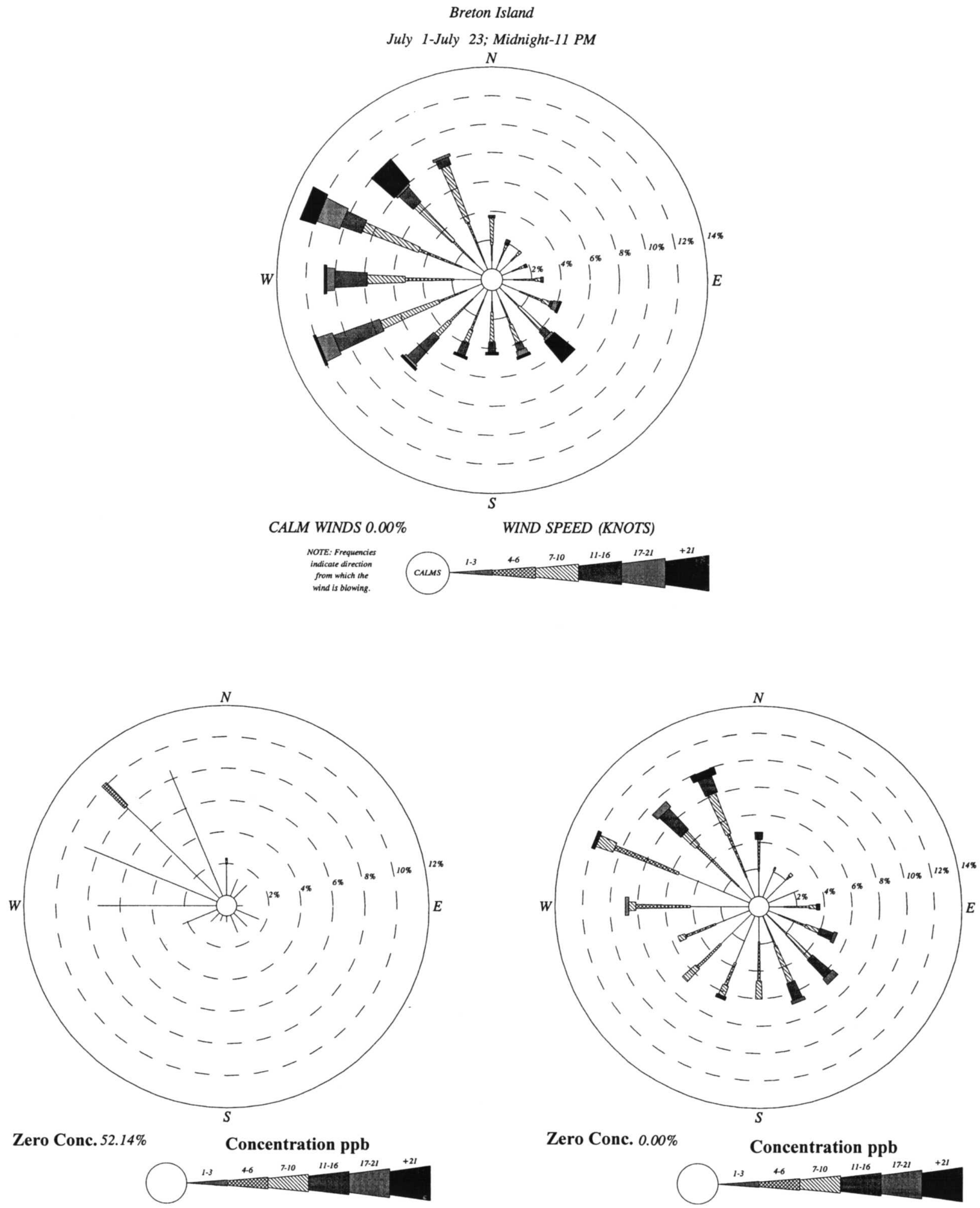


Figure 58. Breton Island July 1997 wind (top) and pollution roses (SO_2 bottom left, NO_2 bottom right). Note that Hurricane Danny occurred during this month.

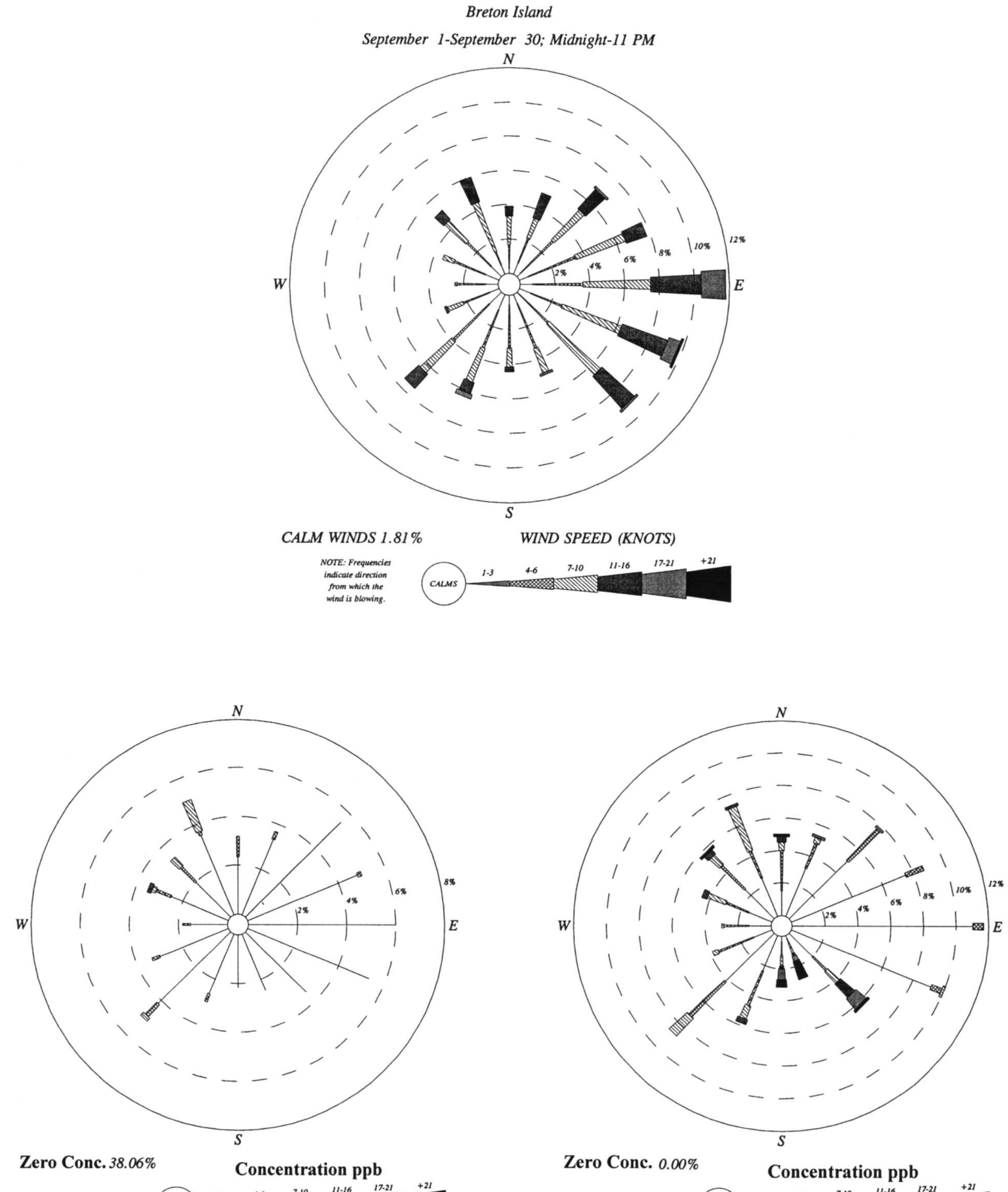
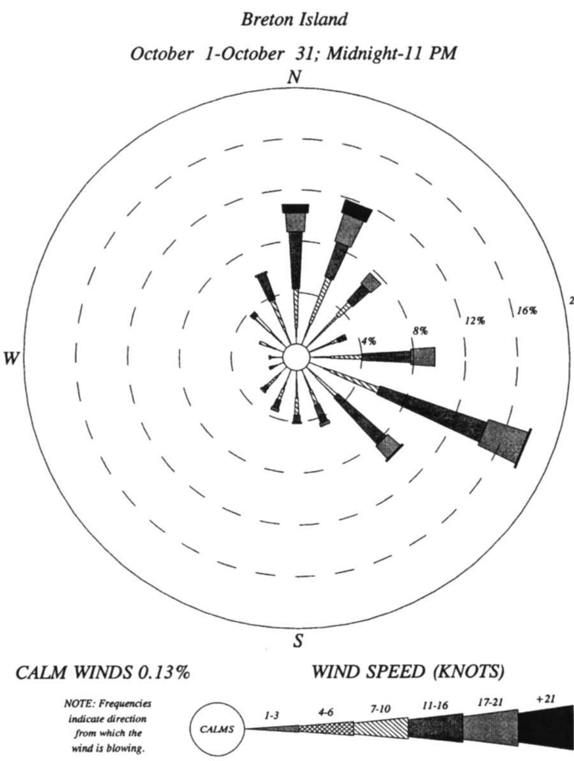
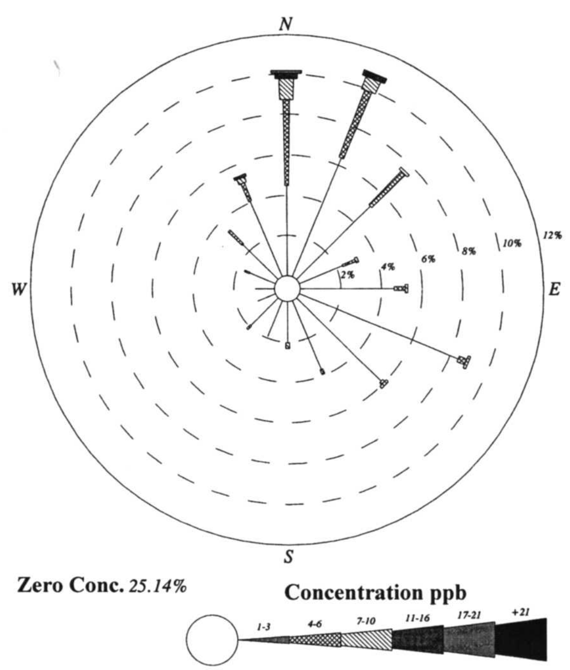


Figure 59. Breton Island September 1997 wind (top) and pollution roses (SO_2 bottom left, NO_2 bottom right).





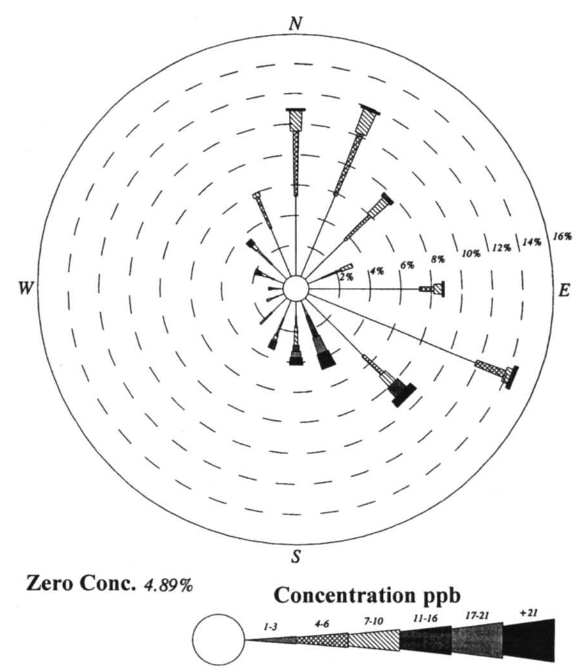
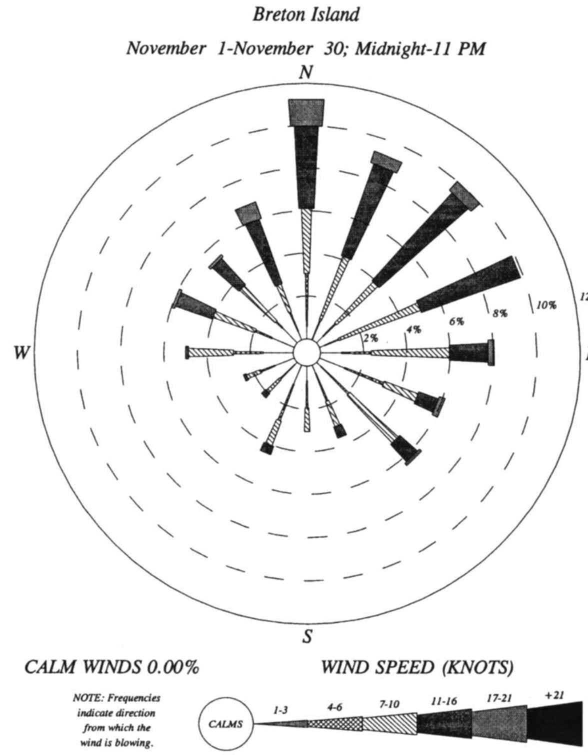
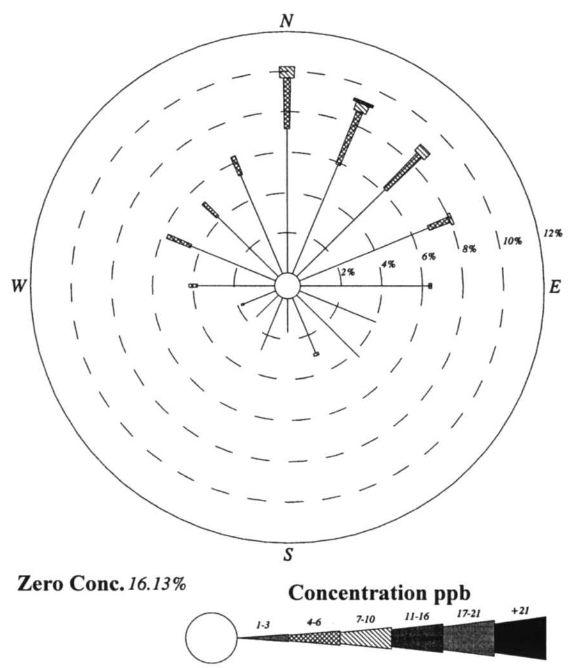


Figure 60. Breton Island October 1997 wind (top) and pollution roses (SO_2 bottom left, NO_2 bottom right).





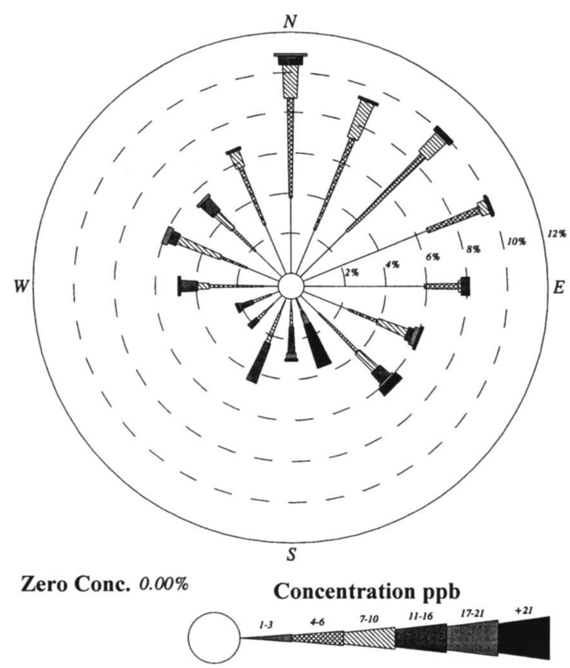


Figure 61. Breton Island November 1997 wind (top) and pollution roses (SO_2 bottom left, NO_2 bottom right).

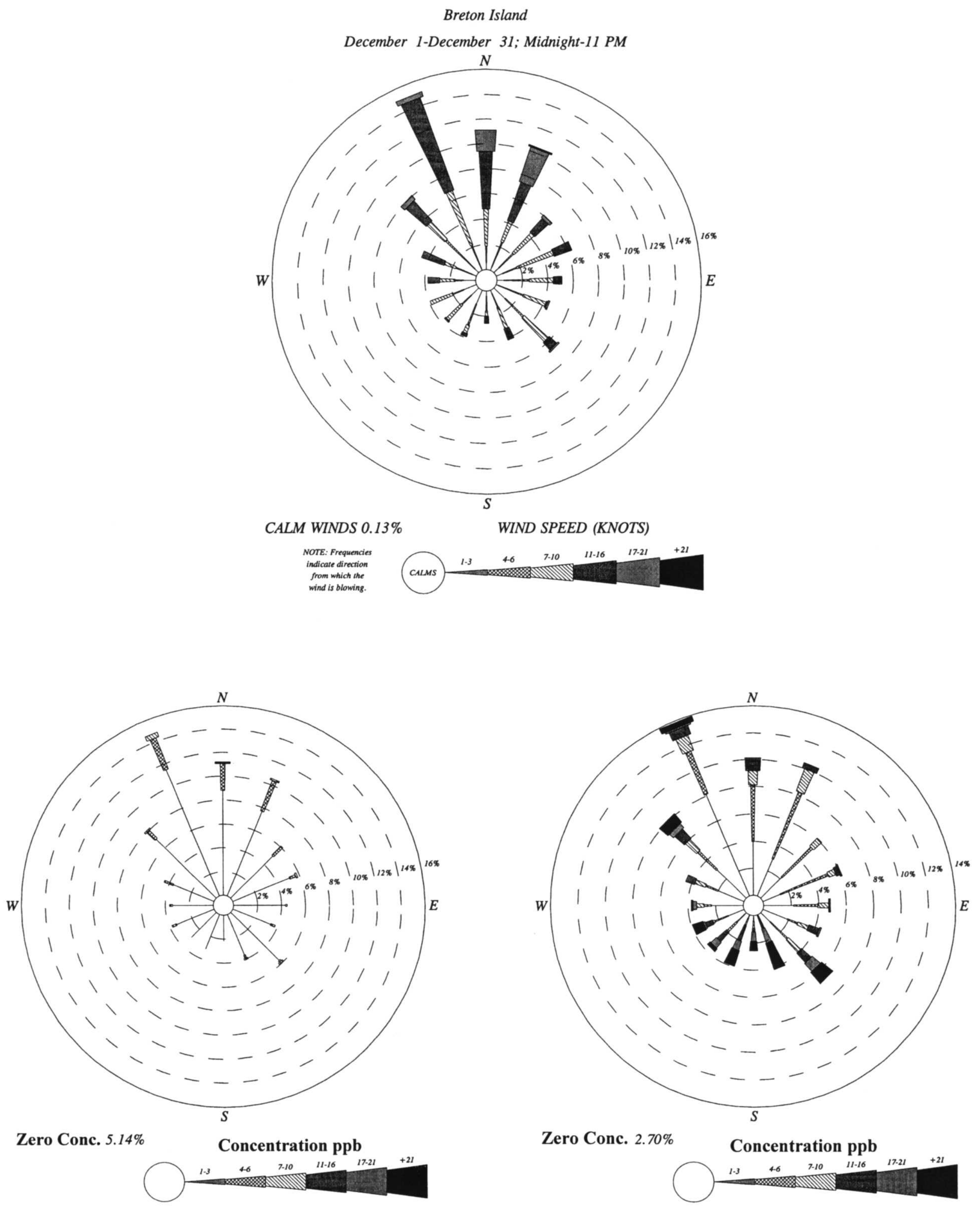


Figure 62. Breton Island December 1997 wind (top) and pollution roses (SO_2 bottom left, NO_2 bottom right).

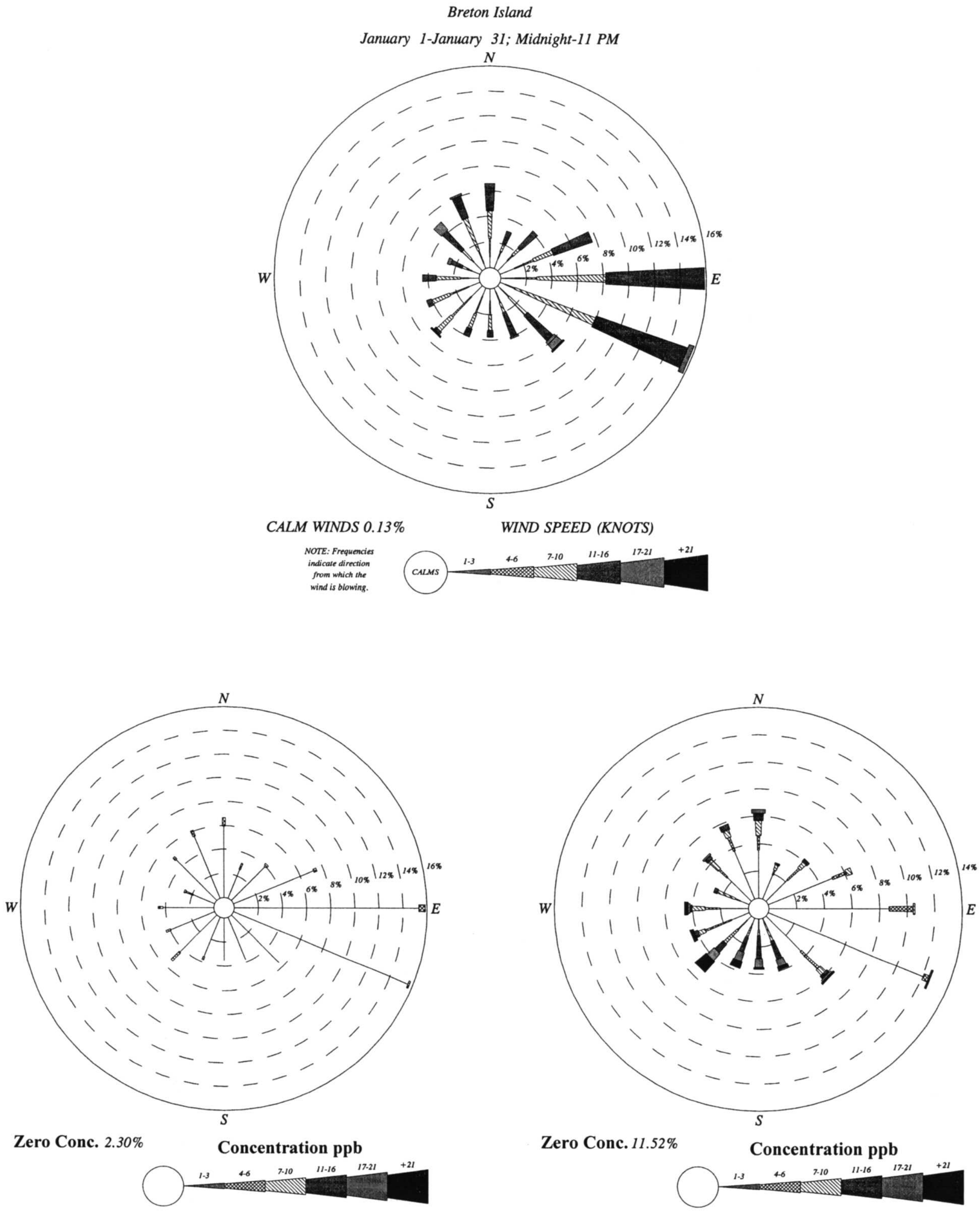


Figure 63. Breton Island January 1998 wind (top) and pollution roses (SO_2 bottom left, NO_2 bottom right).

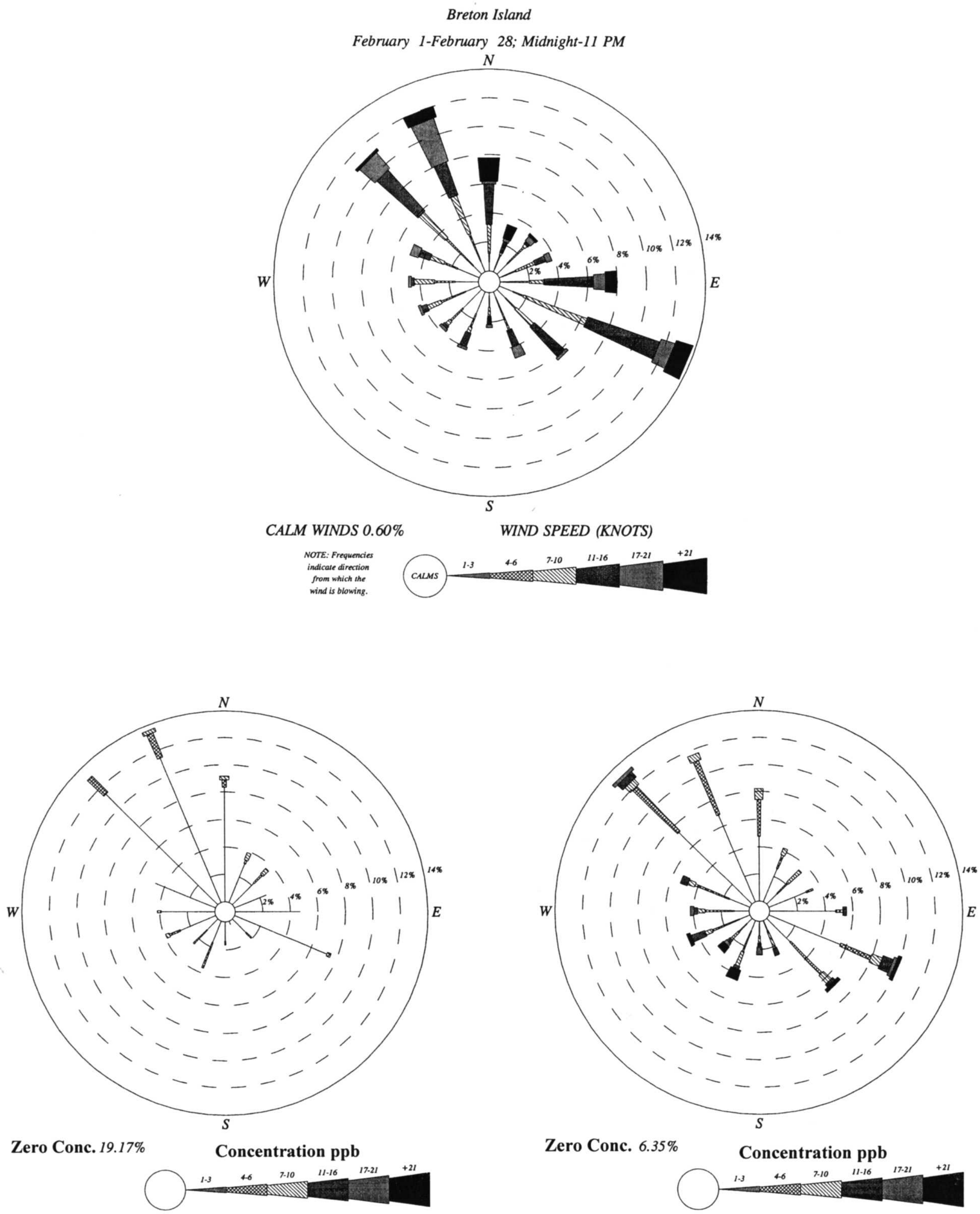


Figure 64. Breton Island February 1998 wind (top) and pollution roses (SO_2 bottom left, NO_2 bottom right).

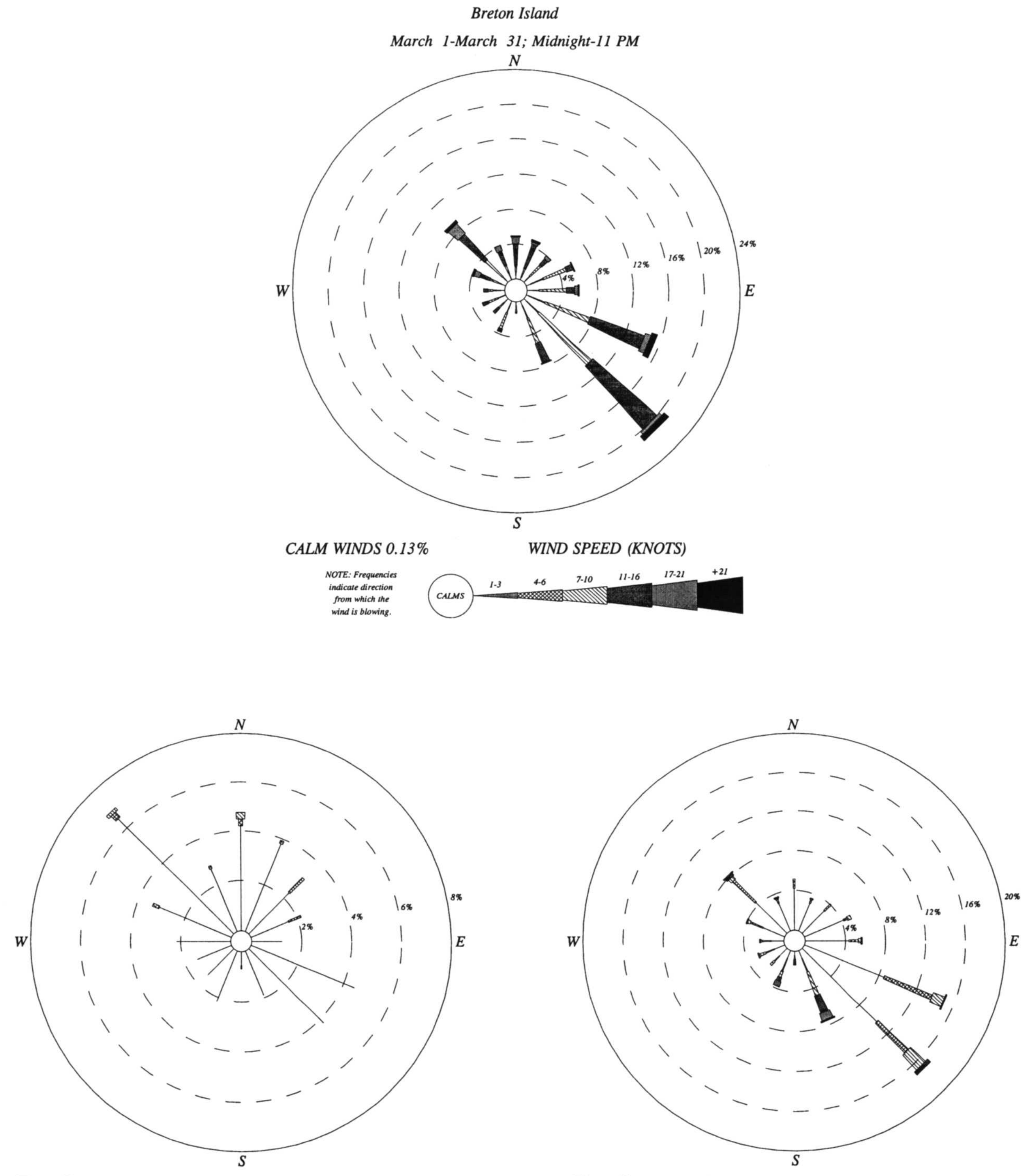


Figure 65. Breton Island March 1998 wind (top) and pollution roses (SO_2 bottom left, NO_2 bottom right).

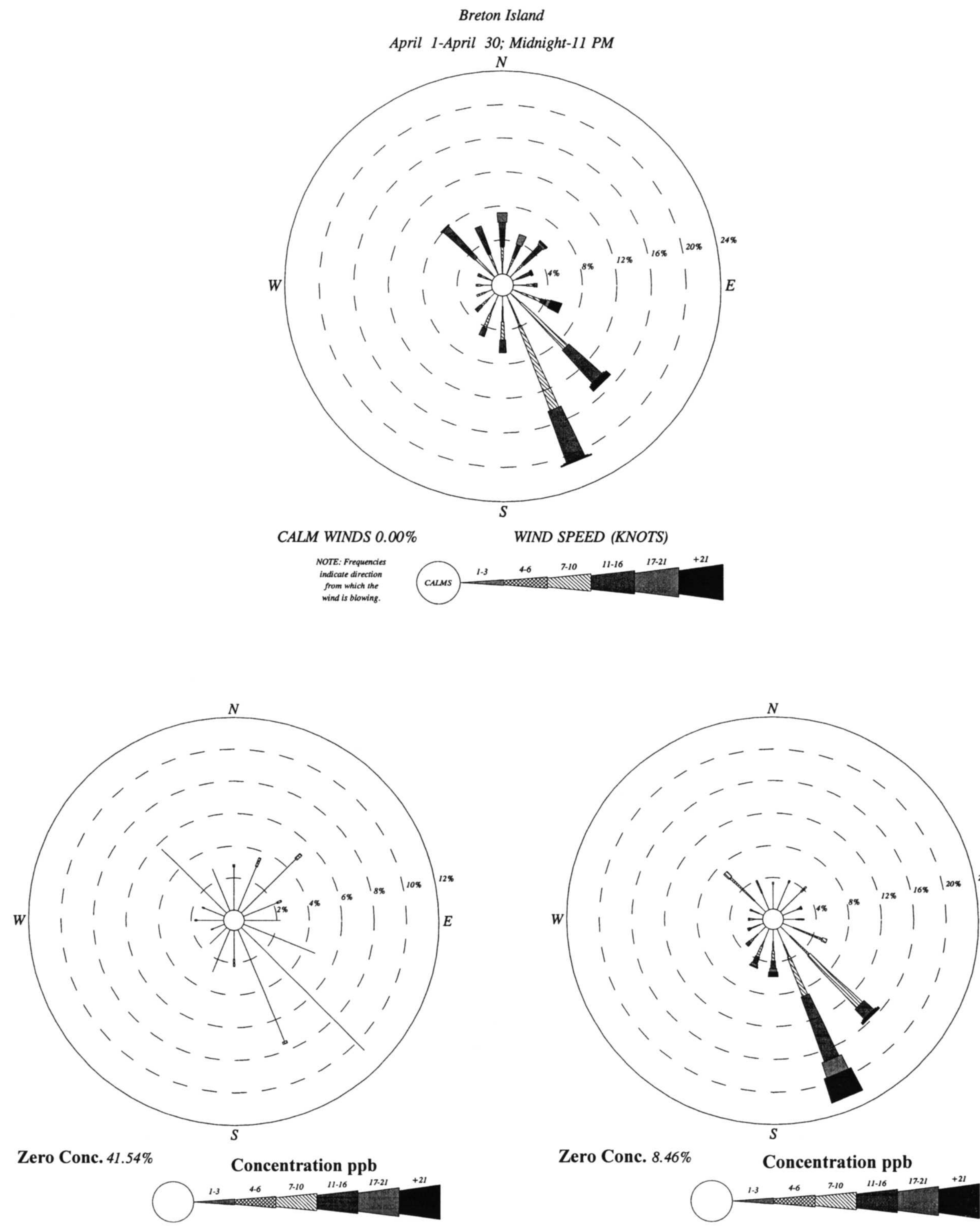
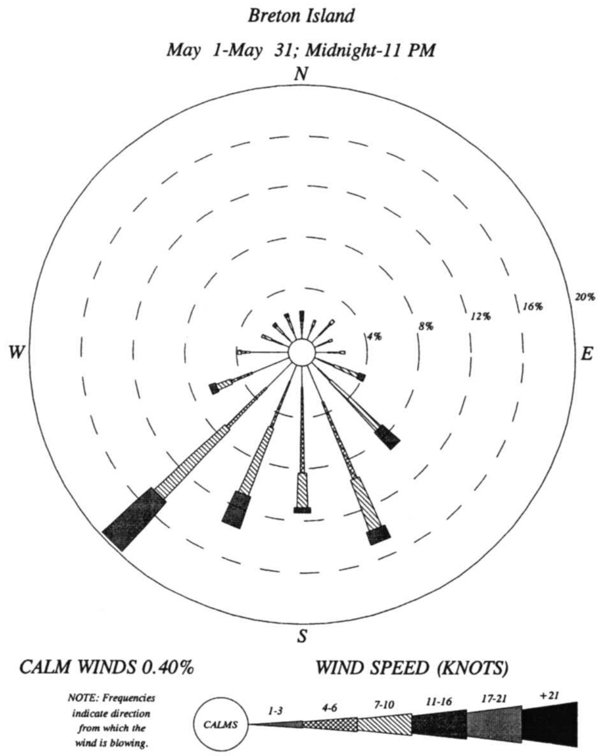
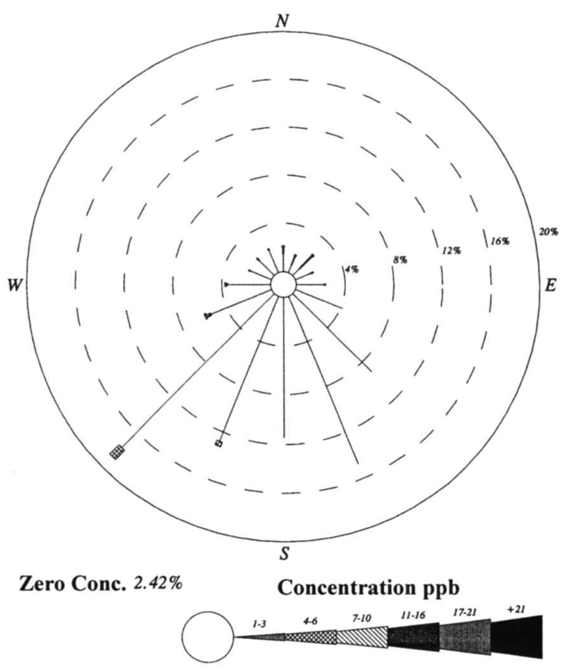


Figure 66. Breton Island April 1998 wind (top) and pollution roses (SO_2 bottom left, NO_2 bottom right).





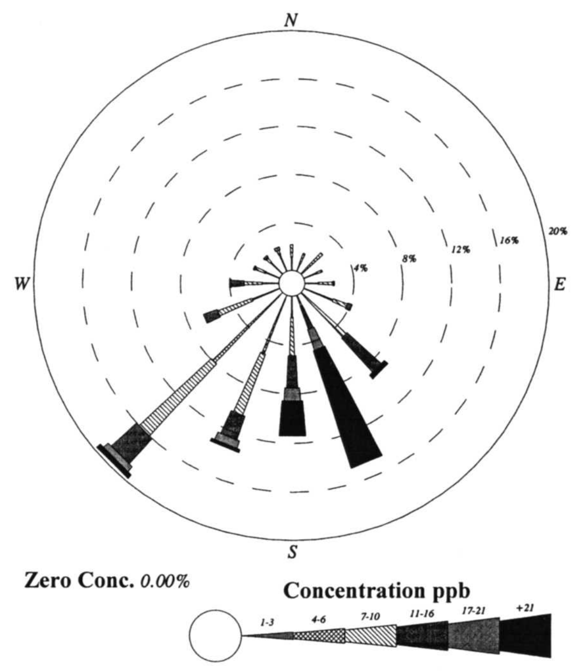


Figure 67. Breton Island May 1998 wind (top) and pollution roses (SO_2 bottom left, NO_2 bottom right).

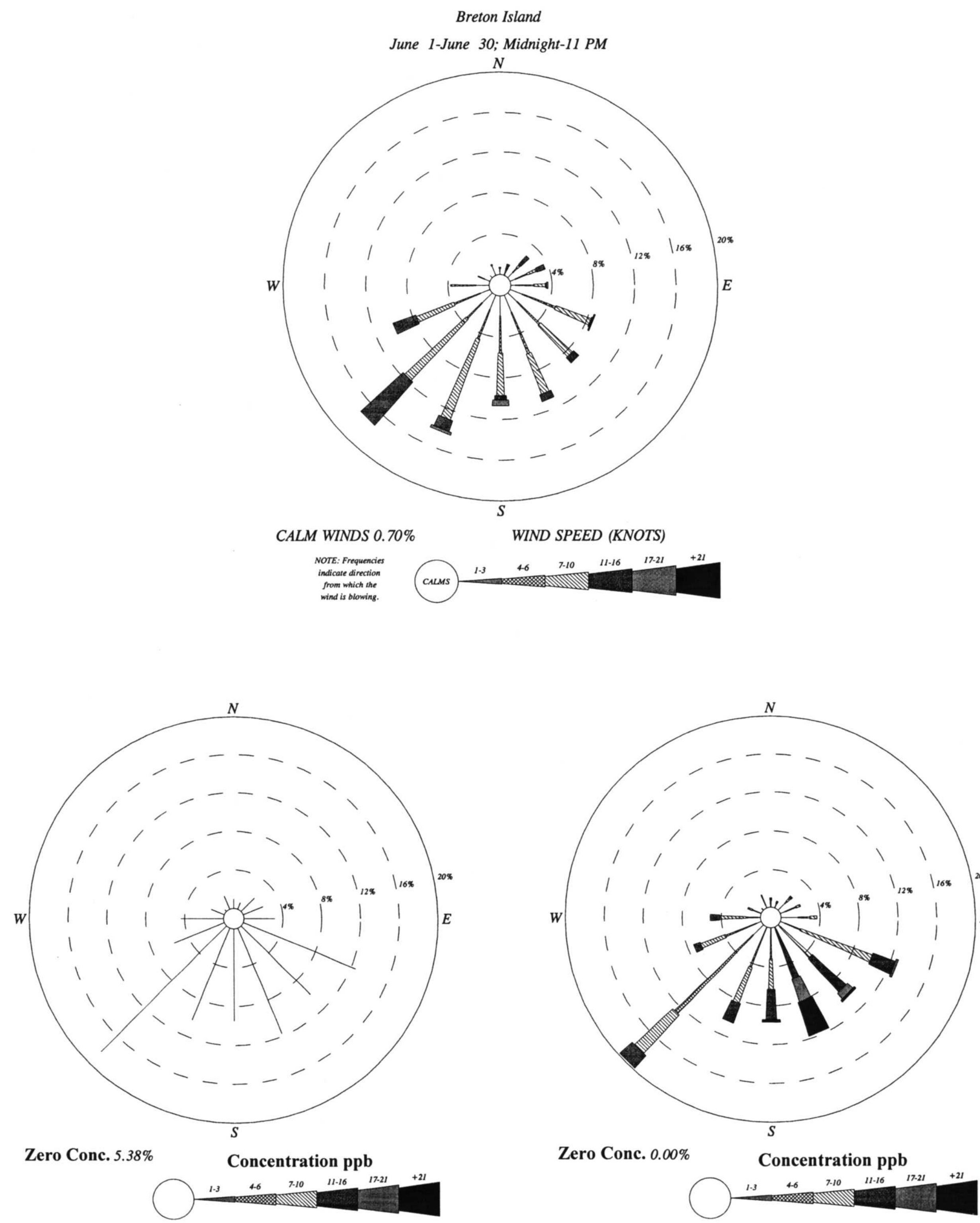


Figure 68. Breton Island June 1998 wind (top) and pollution roses (SO_2 bottom left, NO_2 bottom right).

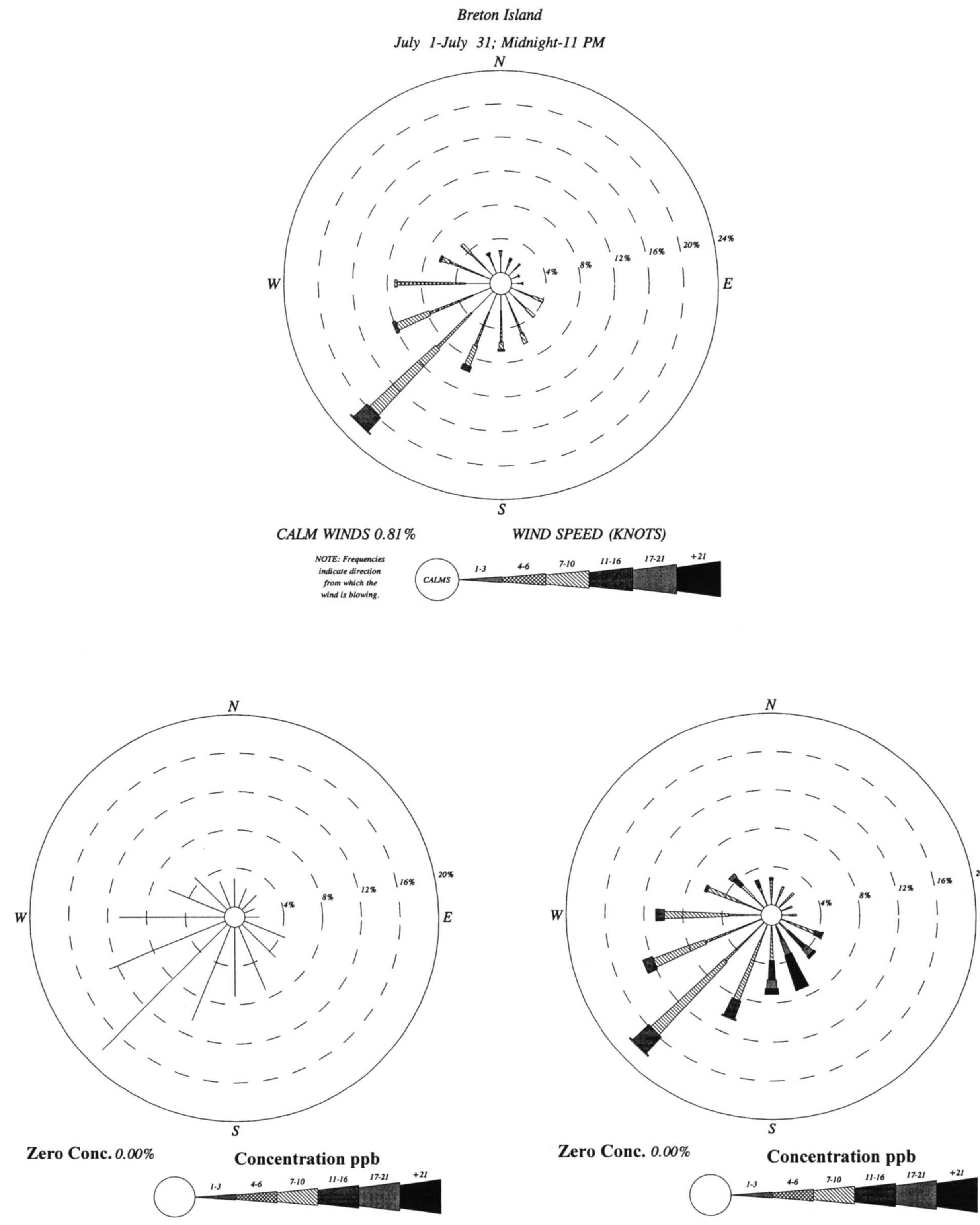


Figure 69. Breton Island July 1998 wind (top) and pollution roses (SO_2 bottom left, NO_2 bottom right).

Table 27.
Breton Island SO_2 Maximums (ppb)

Month	Averaging Interval	Maximum	Day / Hour	Wind Direction / Speed
May 1997	1 hour	5.6	10 / 22 10 / 23	046 / 6 048 / 7
	3 hour	5.5	10 / 23	048 / 6
	24 hour	2.4	10	
June 1997	1 hour	2.4	20 / 8 23 / 8	166 / 3 325 / 6
	3 hour	1.7	20 / 8 22 / 14	189 / 2 107 / 2
	24 hour	0.9	23	
July 1997	1 hour	6.0	2 / 9	312 / 6
	3 hour	4.5	2 / 11	309 / 5
	24 hour	1.8	2	
September 1997	1 hour	10.9	29 / 10	305 / 3
	3 hour	9.4	29 / 11	307 / 3
	24 hour	4.2	29	
October 1997	1 hour	16.8	16 / 11	000 / 6
	3 hour	10.6	16 / 14	007 / 6
	24 hour	6.0	17	
November 1997	1 hour	11.8	22 / 21	025 / 5
	3 hour	6.9	8 / 11	002 / 4
	24 hour	4.4	8	
December 1997	1 hour	11.0	15 / 12	355 / 4
	3 hour	8.6	15 / 14	343 / 4
	24 hour	4.9	15	

Table 27 continued.

Month	Averaging Interval	Maximum	Day / Hour	Wind Direction / Speed
January 1998	1 hour	7.1	16 / 08	304 / 6
	3 hour	5.6	16 / 11	296 / 4
	24 hour	4.1	28	
February 1998	1 hour	9.6	8 / 02	002 / 5
	3 hour	7.8	8 / 11	035 / 2
	24 hour	4.5	8	
March 1998	1 hour	9.8	23 / 07	324 / 3
	3 hour	7.1	23 / 08	325 / 3
	24 hour	2.9	12, 23	
April 1998	1 hour	5.3	1 / 06	027 / 7
	3 hour	3.9	5 / 23	161 / 2
	24 hour	2.4	20	
May 1998	1 hour	7.7	18 / 12 19 / 22	048 / 2 275 / 1
	3 hour	6.9	18 / 14	034 / 2
	24 hour	3.9	19	
June 1998	1 hour	1.2	17 / 03 18 / 04 27 / 10	154 / 2 153 / 3 143 / 3
	3 hour	1.1	17 / 21 to 18 / 05 29 / 08	145 / 3 087 / 1
	24 hour	0.9	17, 27	
July 1998	1 hour	1.7	6 / 08	330 / 2
	3 hour	1.4	6 / 08	322 / 3
	24 hour	1.0	9, 22	

Table 28.
Breton Island NO_2 Maximums (ppb)

Month	Avg. Int.	Maximum	Day / Hour	Wind Dir. / Speed	NO_2 / NO_x
June 1997	1 hour	19.9	28 / 11	136 / 1	0.37
	3 hour	17.5	20 / 05	222 / 4	0.72
	24 hour	8.0	26		
July 1997	1 hour	25.0	9 / 23	331 / 2	0.94
	3 hour	16.7	10 / 05	299 / 2	0.98
	24 hour	10.3	10		
September 1997	1 hour	42.1	16 / 17	164 / 3	0.38
	3 hour	31.2	16 / 17	164 / 3	0.40
	24 hour	9.4	26		
October 1997	1 hour	52.9	21 / 16	156 / 2	0.55
	3 hour	44.8	21 / 17	154 / 3	0.58
	24 hour	15.6	21		
November 1997	1 hour	41.5	27 / 01	160 / 2	0.35
	3 hour	35.5	21 / 11	165 / 5	0.32
	24 hour	19.7	21		
December 1997	1 hour	47.8	17 / 00	238 / 1	0.58
	3 hour	40.3	17 / 02	251 / 1	0.82
	24 hour	23.8	17		
January 1998	1 hour	40.2	17 / 02 30 / 02	221 / 3 246 / 2	0.98 0.95
	3 hour	34.9	30 / 02	237 / 2	0.98
	24 hour	16.5	17, 29		

Table 28 continued.

Month	Avg. Int.	Maximum	Day / Hour	Wind Dir. / Speed	NO_2 / NO_x
February 1998	1 hour	35.5	9 / 05	144 / 1	0.93
	3 hour	32.0	9 / 05	155 / 1	0.95
	24 hour	12.6	9		
March 1998	1 hour	23.3	24 / 07	157 / 2	0.79
	3 hour	20.0	24 / 08	157 / 3	0.82
	24 hour	10.1	24		
April 1998	1 hour	59.9	25 / 07	167 / 3	0.45
	3 hour	49.0	25 / 11	161 / 5	0.53
	24 hour	28.8	25		
May 1998	1 hour	51.6	14 / 07	161 / 2	0.52
	3 hour	43.9	14 / 05	158 / 2	0.54
	24 hour	29.7	14		
June 1998	1 hour	39.3	23 / 21	155 / 3	0.57
	3 hour	30.6	23 / 23	156 / 2	0.62
	24 hour	12.7	28		
July 1998	1 hour	35.0	2 / 22	156 / 4	0.42
	3 hour	28.0	3 / 11	161 / 3	0.47
	24 hour	17.6	3		

Table 29.
Breton Island Top 10% Frequency Distribution by Month and Direction

Month	NO_2 (710 samples)	SO_2 (686 samples)
May 1997	184	9
June 1997	22	0
July 1997	24	7
August 1997	Missing	Missing
September 1997	34	45
October 1997	43	182
November 1997	65	125
December 1997	124	121
January 1998	69	59
February 1998	27	83
March 1998	29	30
April 1998	89	25
Direction		
0 - 45	9	239
46 - 90	4	94
91 - 135	41	18
136 - 180	402	22
181 - 225	124	29
226 - 270	47	37
271 - 315	44	83
315 - 360	33	143
Missing	6	21

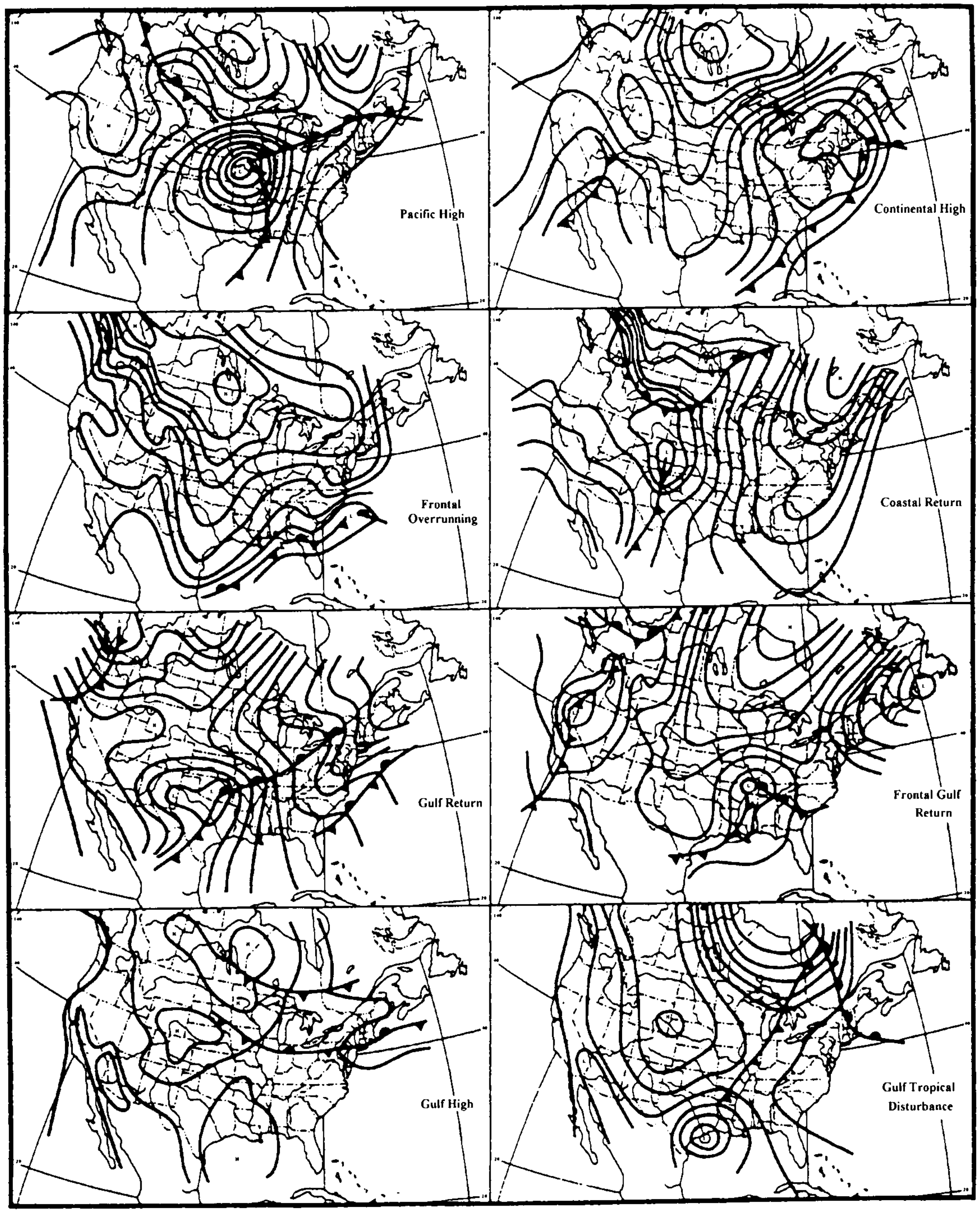


Figure 70. A classification scheme for synoptic weather types affecting New Orleans, Louisiana and the northeast Gulf of Mexico (after Muller, 1977).

Table 30.
Frequency of Occurrence of Synoptic Weather Types Associated
with Peak Pollutant Days at Breton Island

	Breton SO_2					
Synoptic Type	1995	1996	1997	1998	Total	%
PH	0.5	0	0.5	1.5	2.5	3.1
CH	5.5	14	12	10.5	42	52.5
FOR	6	3.5	5.5	0	15	18.8
CR	0	0.5	0.5	3	4	5
GR	2	1	0	0.5	3.5	4.4
FGR	4.5	0	0.5	1	6	7.5
GH	0.5	1	1	3.5	6	7.5
GTD	1	0	0	0	1	1.3
	Breton NO_2					
PH	1.5	0	0.5	0.5	2.5	3.1
CH	3.5	2.5	7	1.5	14.5	18.1
FOR	5	3.5	3.5	1	13	16.3
CR	1	0.5	1.5	2.5	5.5	6.9
GR	4.5	9.5	4	8.5	26.5	33.1
FGR	3	3	3	1.5	10.5	13.1
GH	1.5	1	0.5	4.5	7.5	9.4
GTD	0	0	0	0	0	0

C. Station Comparison

Monthly mean and maximum pollutant concentrations recorded at Breton and Dauphin Islands during the period of May 1997 through April 1998 are listed in Table 31 and graphed in Fig. 71. Mean SO_2 values at Dauphin are almost twice those observed at Breton, particularly during the winter months; maximum values are also much higher. With the exception of April 1998, mean NO_2 values are almost equivalent, while NO_2 peaks at Breton are generally higher.

From Figure 72a - e, there is good agreement between stations in simultaneous trends of the 24-hour average SO_2 data. Much less correlation is seen in the NO_2 trends. This suggests that the SO_2 maximums at both stations are often produced by the same air mass, while high NO_2 may be produced by different, more localized, conditions.

Four episodes were selected in which near simultaneous peaks of SO_2 and NO_2 were recorded at both Breton and Dauphin Islands; one with higher concentrations at Breton than Dauphin and the other with Dauphin greater than Breton. Meteorological conditions associated with these peaks are discussed as follows.

Table 31.
Summary of Breton and Dauphin Islands Monthly Air Quality Values (ppb)

	SO_2				NO_2			
	Dauphin Island		Breton Island		Dauphin Island		Breton Island	
Month	Max	Avg	Max	Avg	Max	Avg	Max	Avg
5/97	16.3	1.1	5.6	0.4	22.1	3.3	10.3*	4.8*
6/97	11.1	0.8	2.4	0.5	17.9	3.4	19.9*	5.7*
7/97	42.5	2.0	6.0*	0.6*	27.4	5.1	25.0*	5.6*
8/97	13.5	1.8			19.0	3.7		
9/97	38.0	3.3	10.9	1.1	22.4	4.3	42.1	4.8
10/97	37.1	3.8	16.8	1.9	28.0	6.3	52.9	4.8
11/97	29.3	3.2	11.8	1.7	28.7	6.1	41.5	6.3
12/97	50.5	3.5	11.0	1.8	51.4	7.6	47.8	7.5
1/98	22.4	2.4	7.1	1.4	33.5	5.8	40.2	4.9
2/98	23.0	2.5	9.6	1.5	22.0*	4.1*	35.5	4.9
3/98	17.0	1.5	9.8	0.9	19.6	1.8	23.3	3.8
4/98	13.7	1.5	5.3	0.9	14.6	1.2	59.9	7.0
Annual		2.3		1.2		4.4		6.2

* boxes indicate less than 75% complete.

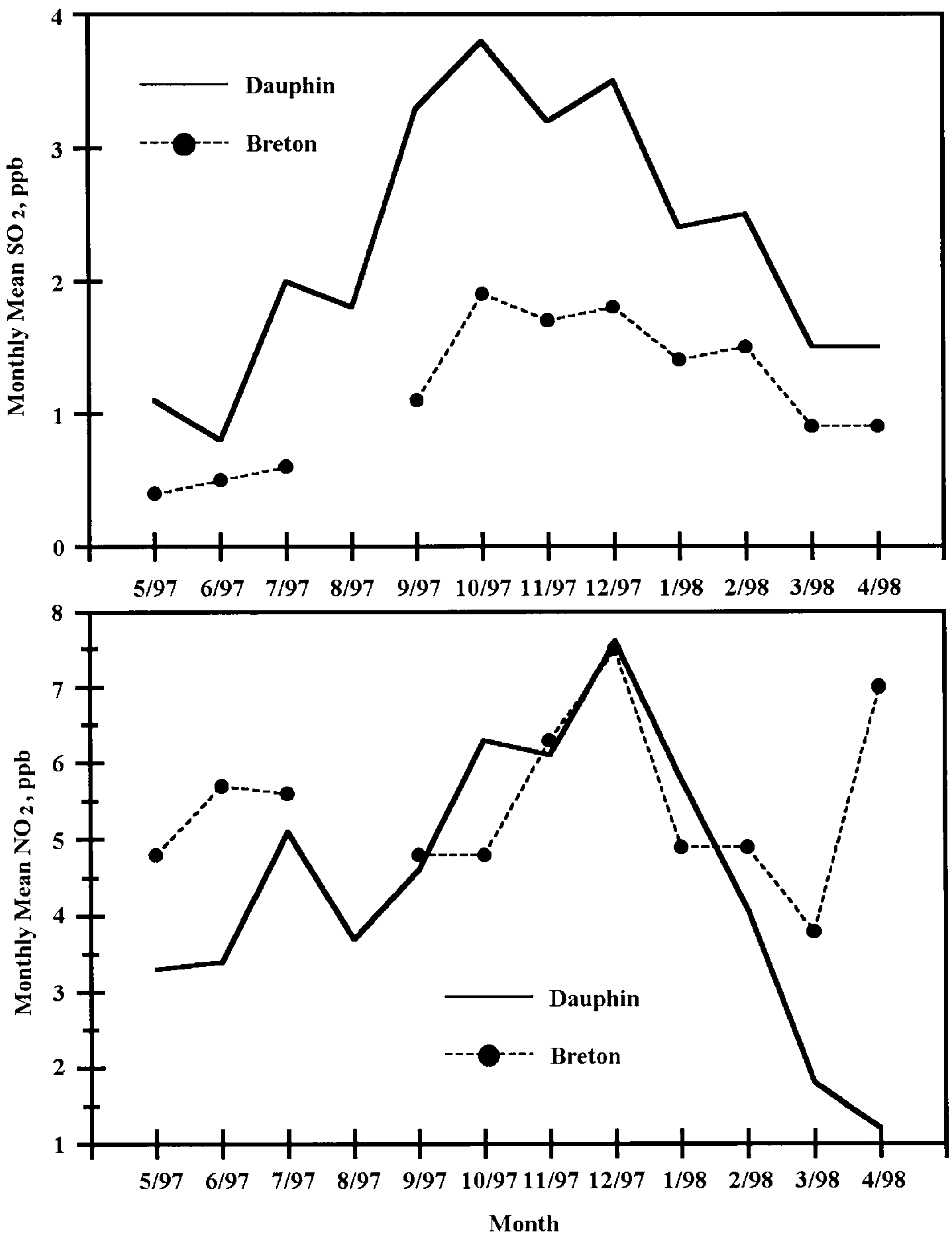


Figure 71. Comparison of monthly mean SO_2 (top) and NO_2 (bottom) values recorded at Breton and Dauphin Islands during the study period.

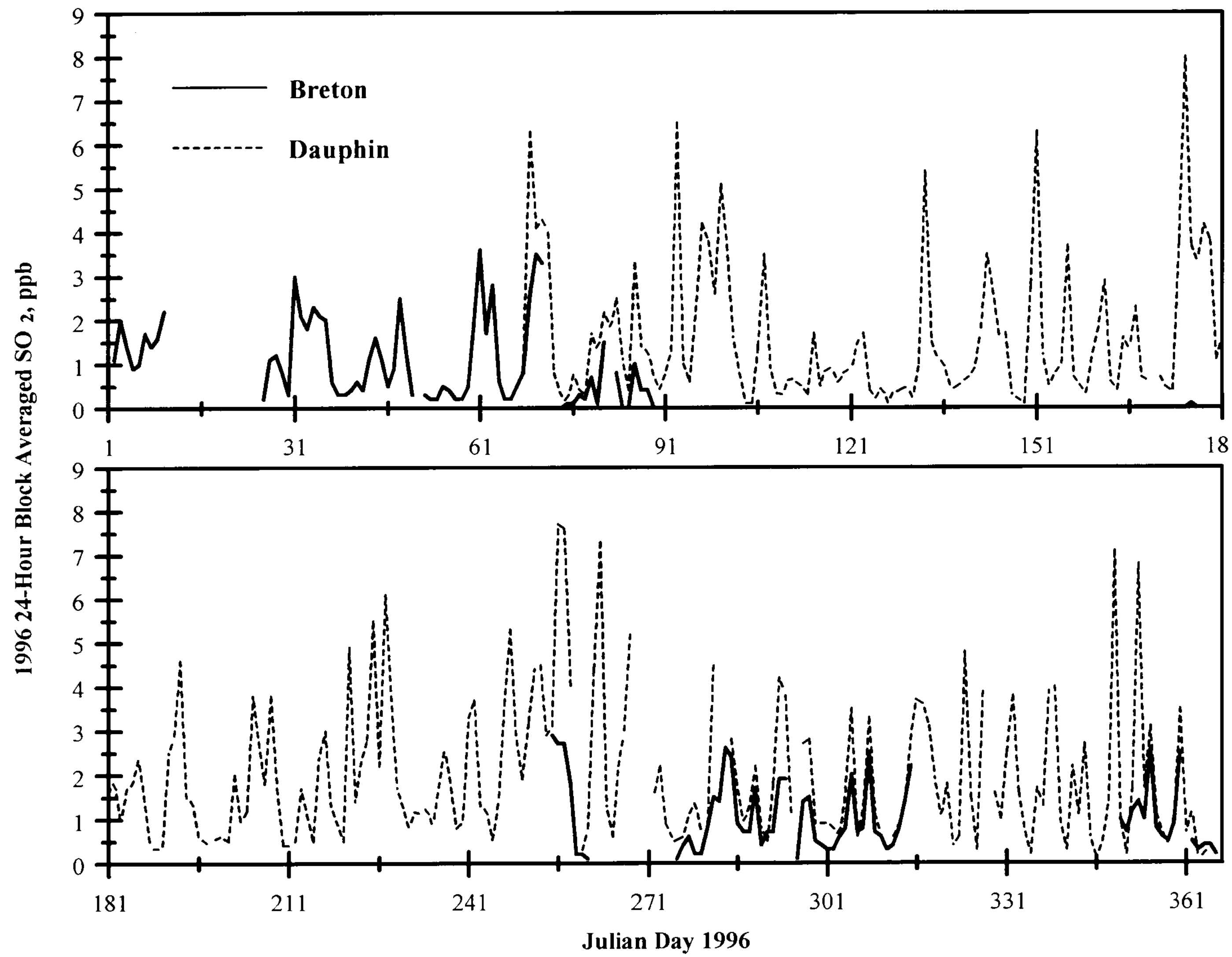


Figure 72a. Time series of 1996 24-hour block averaged SO_2 at Breton and Dauphin Islands.

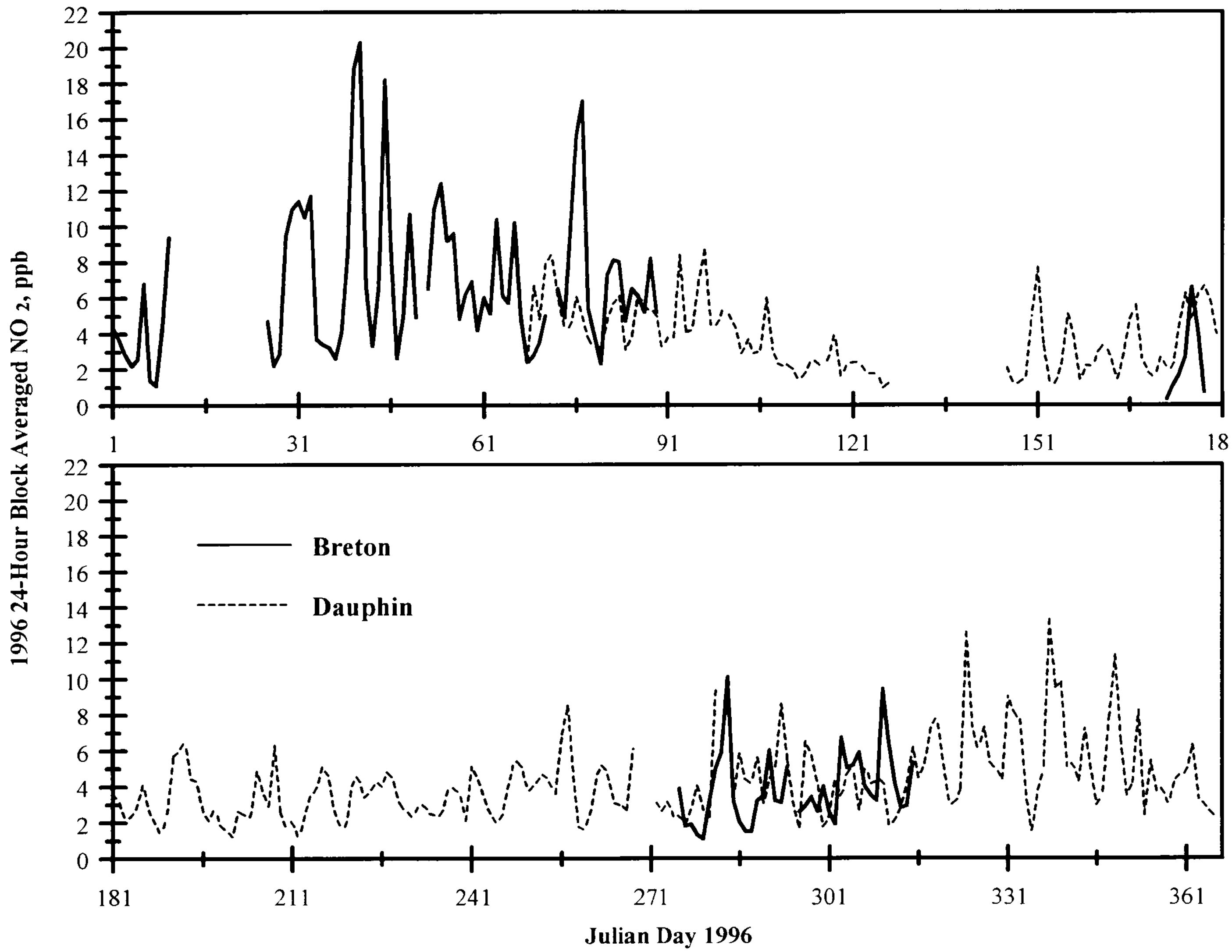


Figure 72b. Time series of 1996 24-hour block averaged NO_2 at Breton and Dauphin Islands.

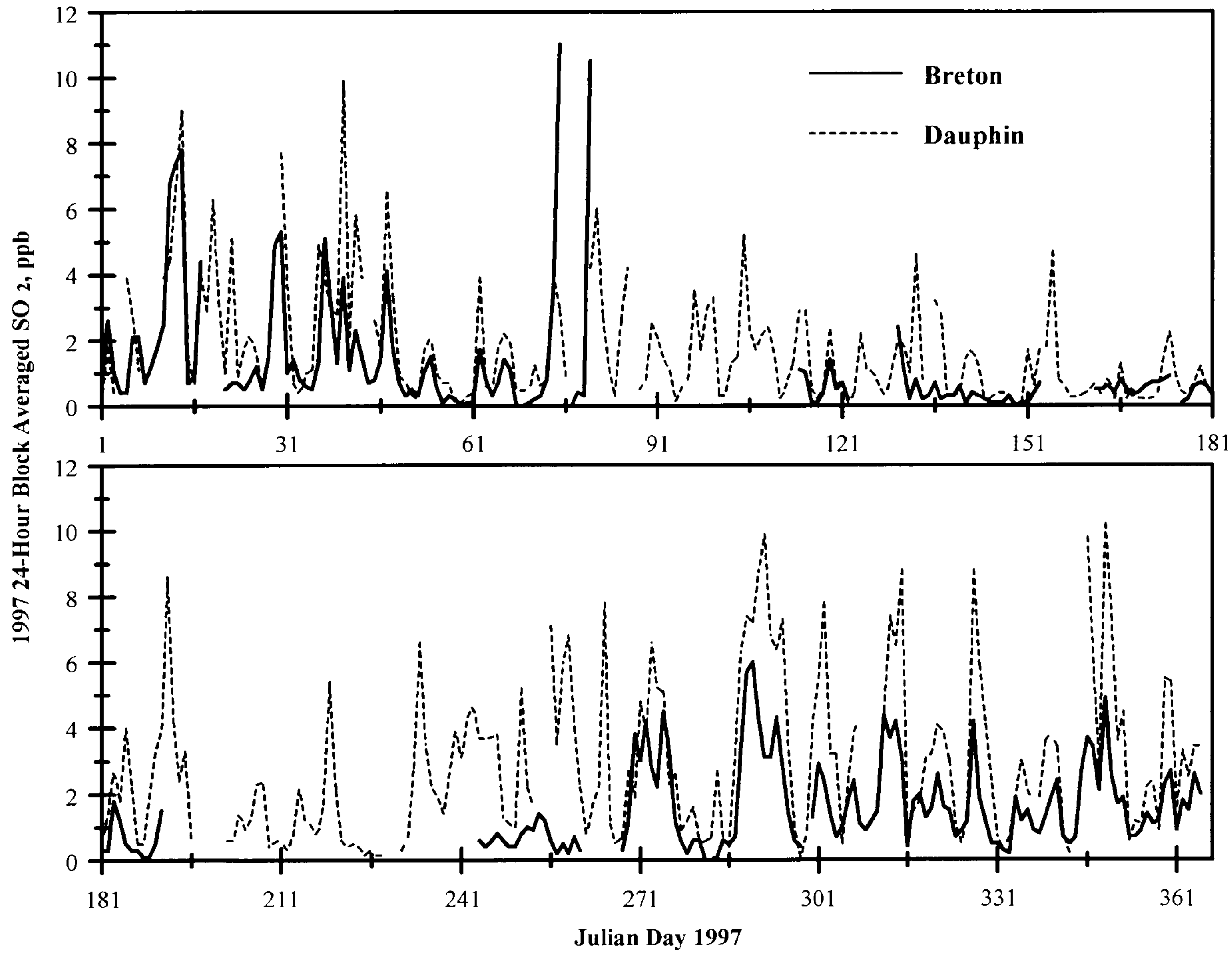


Figure 72c. Time series of 1997 24-hour block averaged SO_2 at Breton and Dauphin Islands.

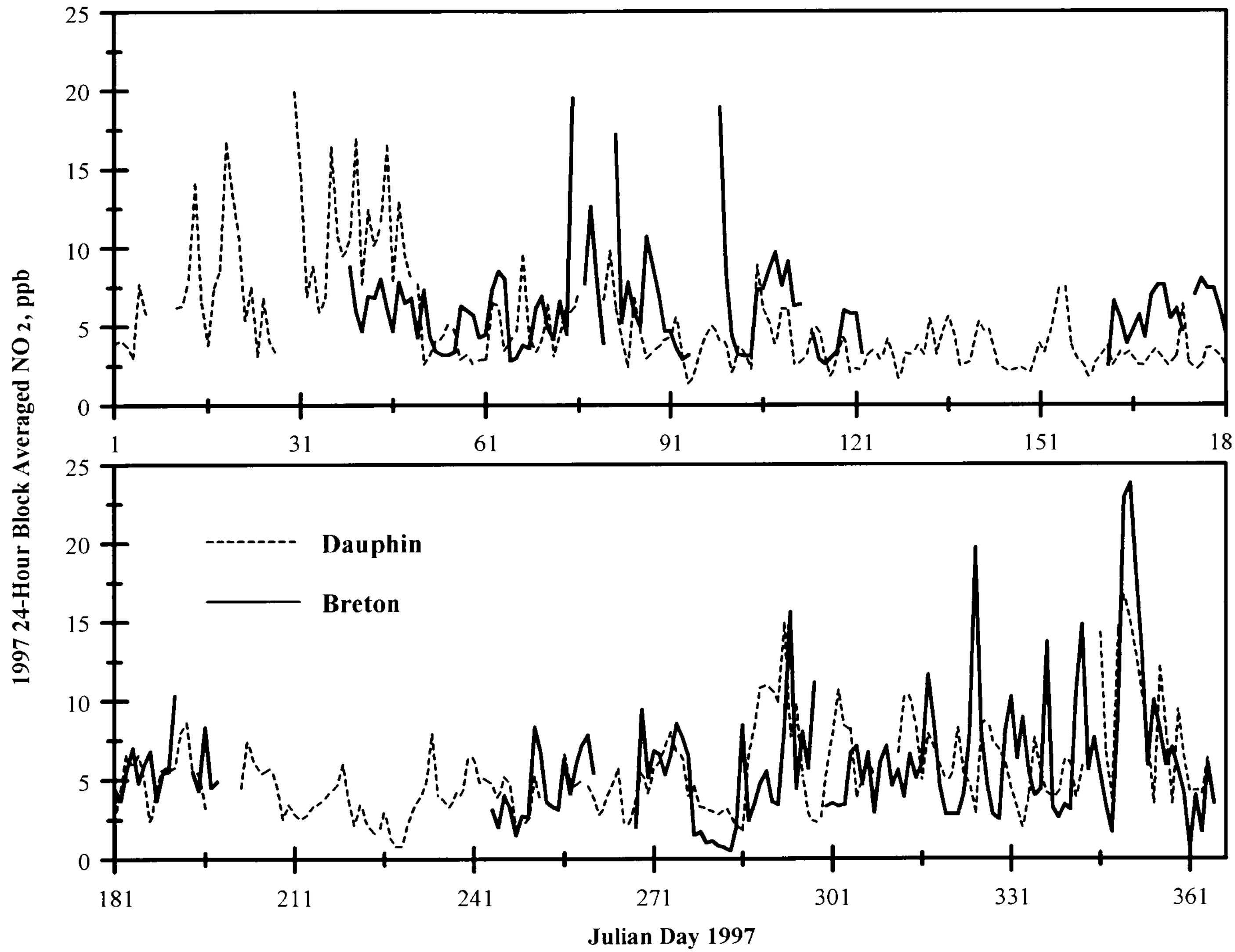


Figure 72d. Time series of 1997 24-hour block averaged NO_2 at Breton and Dauphin Islands.

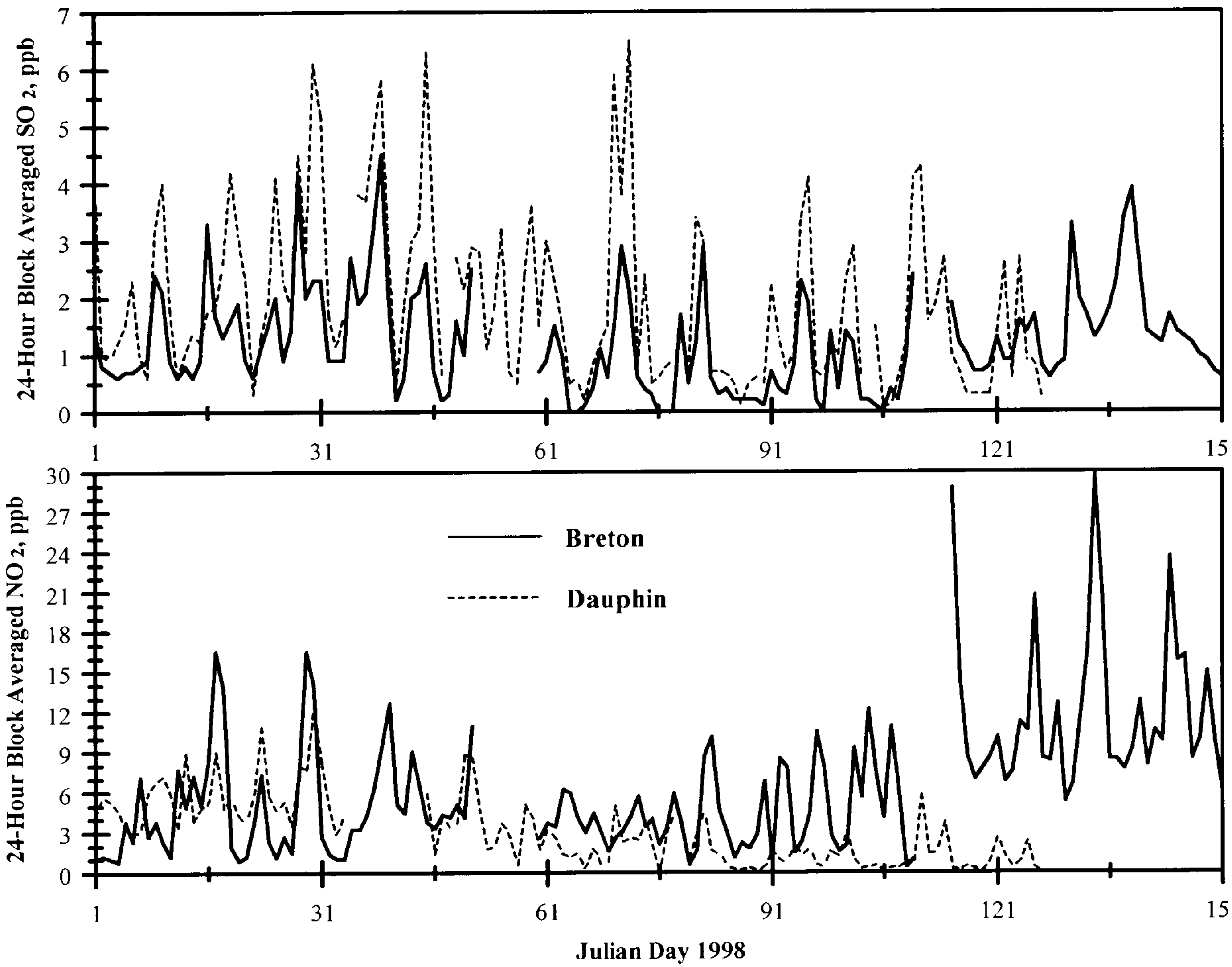
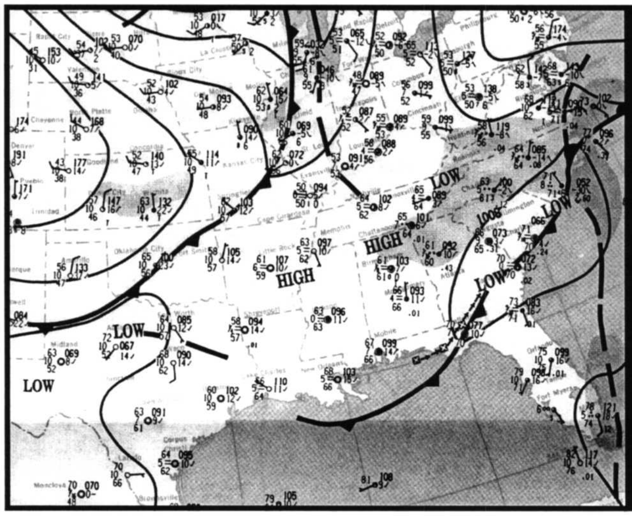
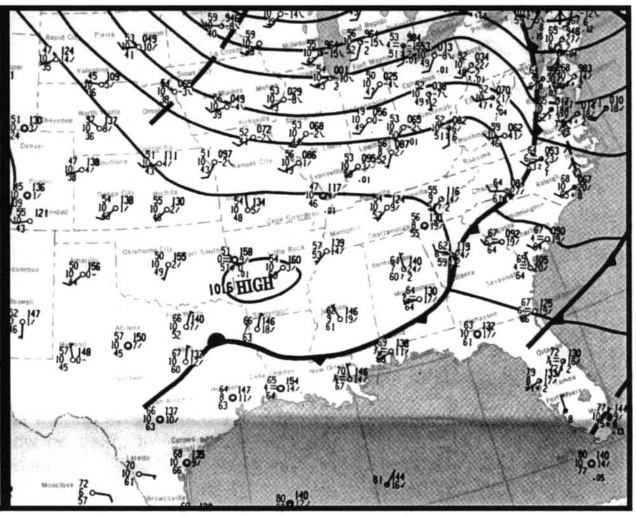


Figure 72e. Time series of 1998 24-hour block averaged SO_2 (top) and NO_2 (bottom) at Breton and Dauphin Islands.

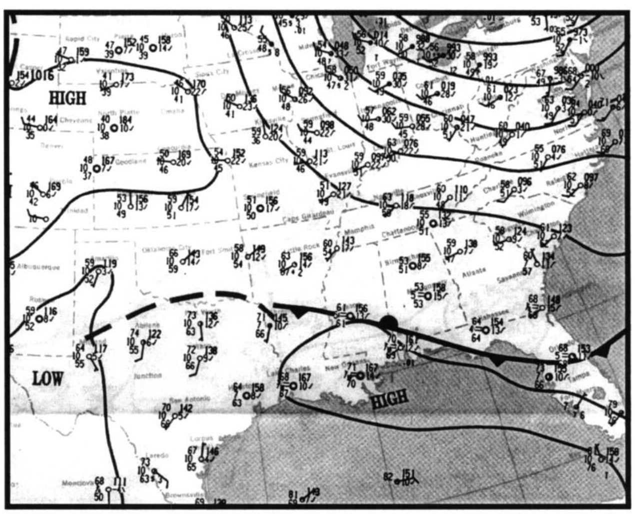
CH conditions prevail on 28 September 1997 behind a cold front over the northeast Gulf of Mexico. A second front attempts to push through on 29 September but becomes nearly stationary, and then retreats on 30 September allowing GR weather along the Gulf coast. Pressure rises throughout the period at both Breton and Dauphin stations, while surface winds are generally westerly. SO_2 rises rapidly on 29 September and peaks at about 14 ppb, with Breton maximum occurring slightly earlier than at Dauphin. A much higher peak is recorded at Dauphin on 30 September under westerly flow; Breton also peaks at about 8 ppb, and both decrease as the winds become more southwesterly.



28 September



29 September



30 September

Figure 73a. 0700 EST surface weather maps for 28 - 30 September 1997 from NOAA Daily Weather Map Series.

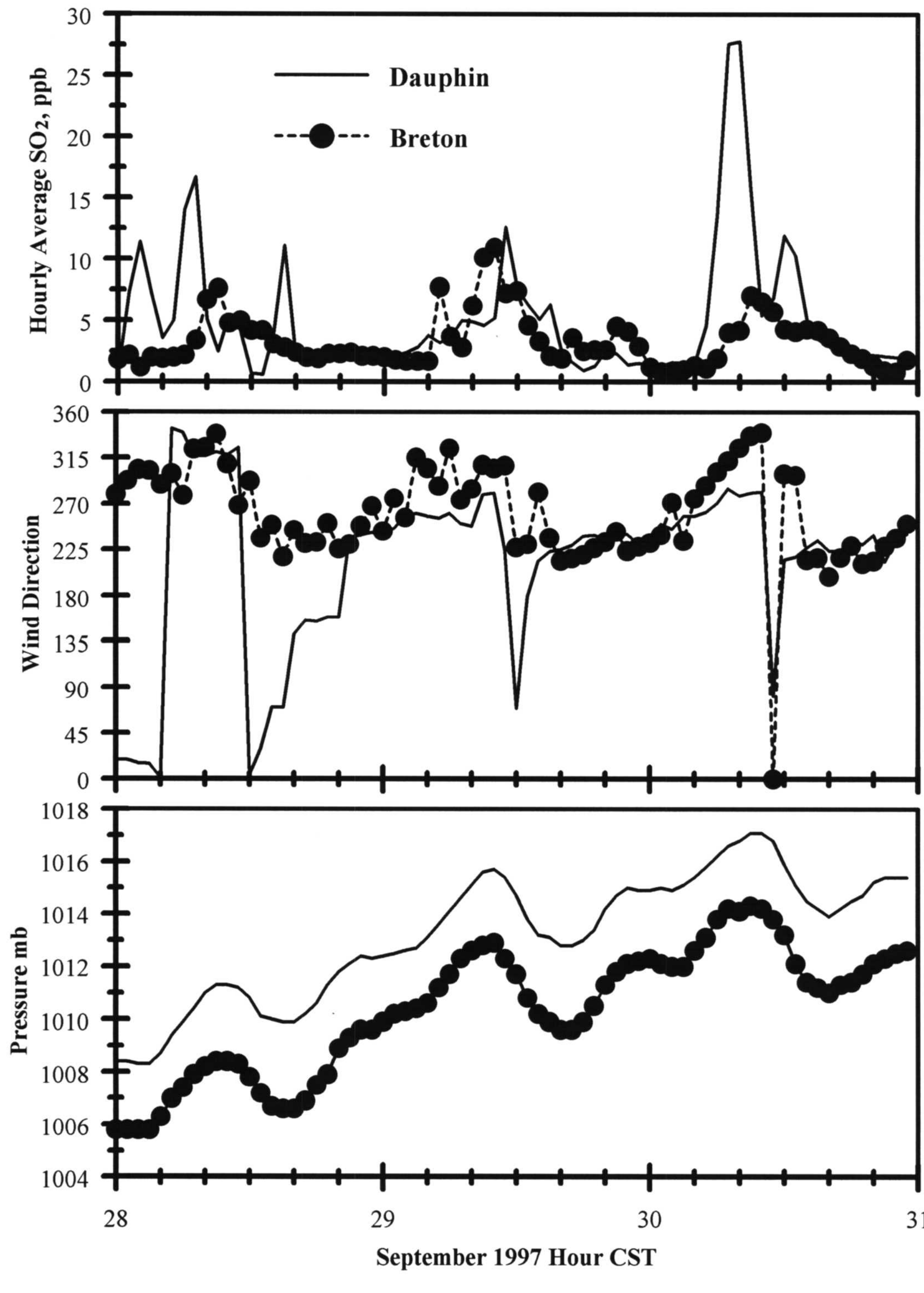
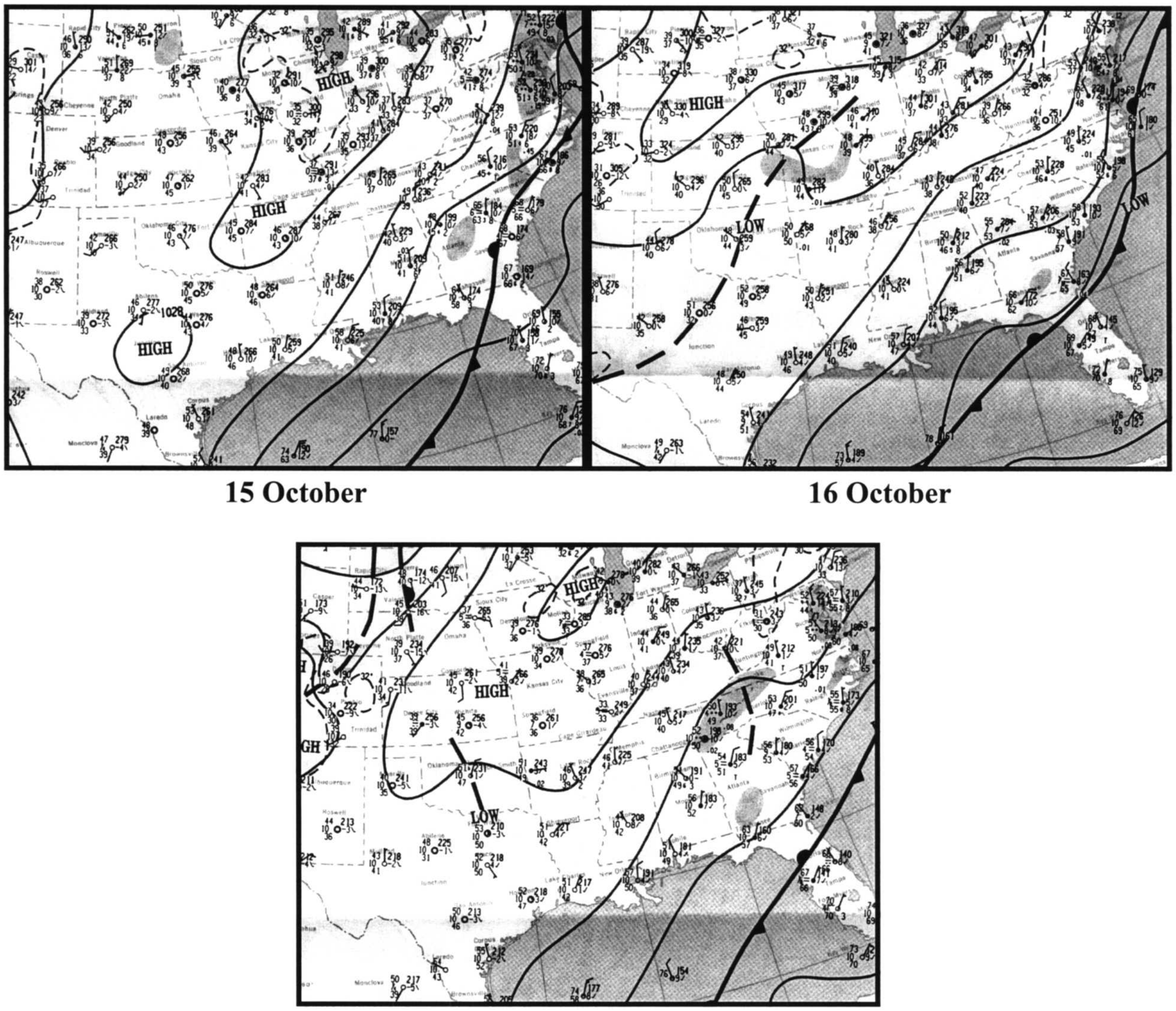


Figure 73b. Meteorological and air quality values observed at Breton and Dauphin Islands on 28 - 30 September 1997.

CH and northerly flow dominate during the period of 15 - 17 October 1997, although the pressure trend is falling. A SO_2 peak is seen at Dauphin on 15 October, but not at Breton. On the following day, Breton reaches a maximum of about 17 ppb almost four hours before a lesser peak at Dauphin. Note that multiple peaks are evident in the Dauphin record, whereas Breton often exhibits a single rise and fall.



15 October

16 October

17 October

Figure 74a. 0700 EST surface weather maps for 15 - 17 October 1997 from the NOAA Daily Weather Map Series.

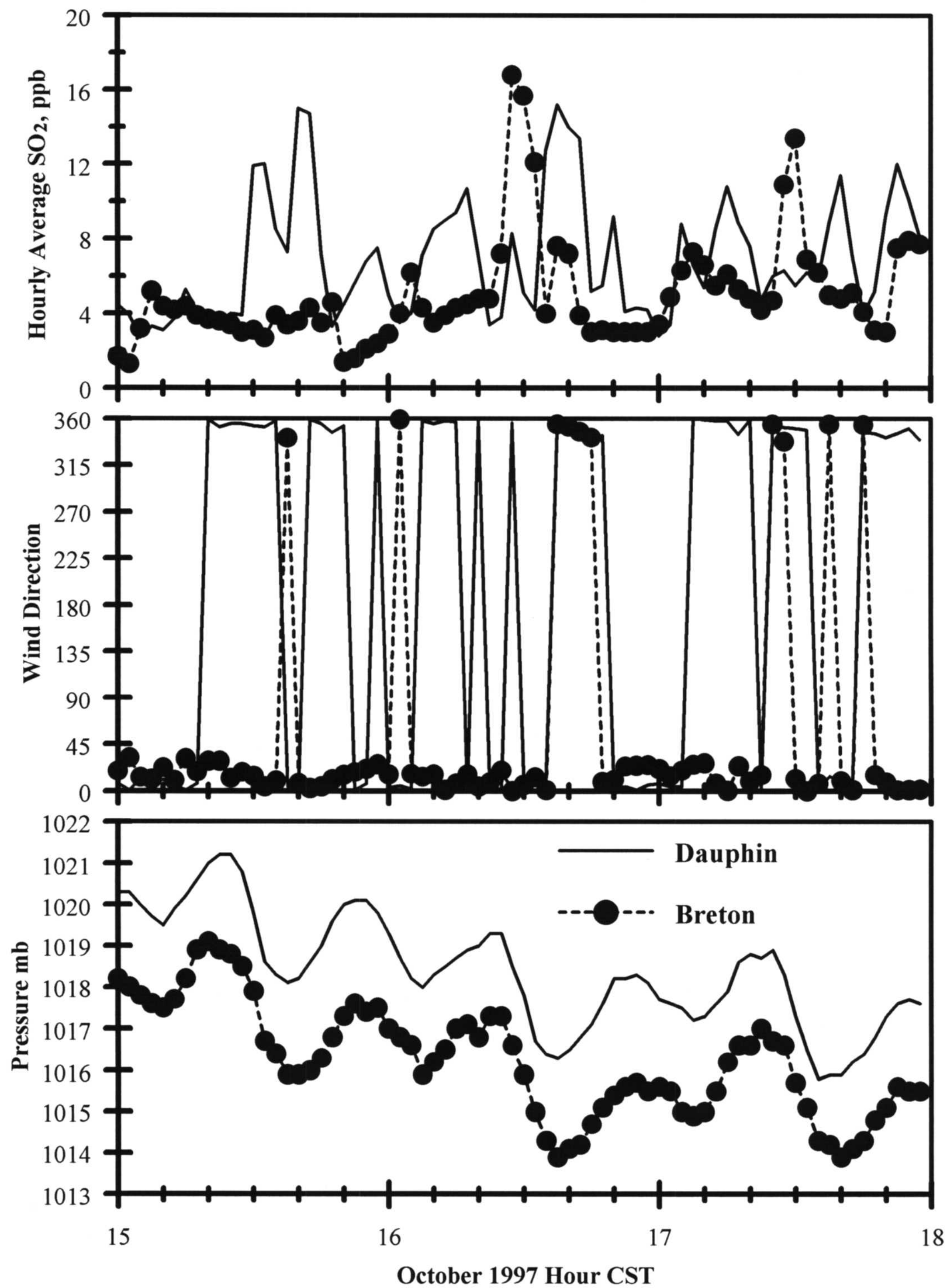
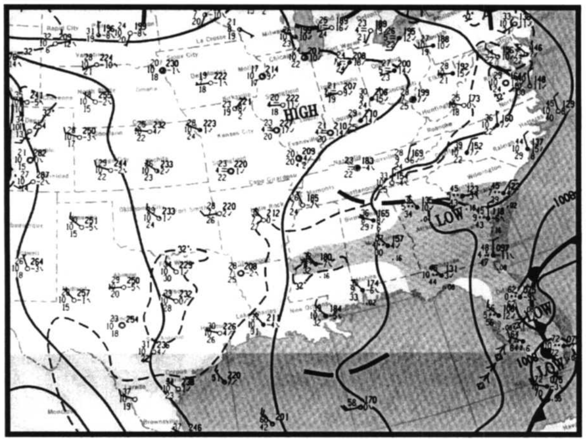
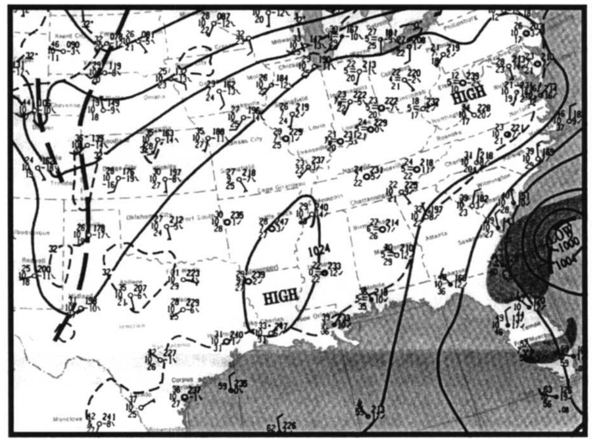


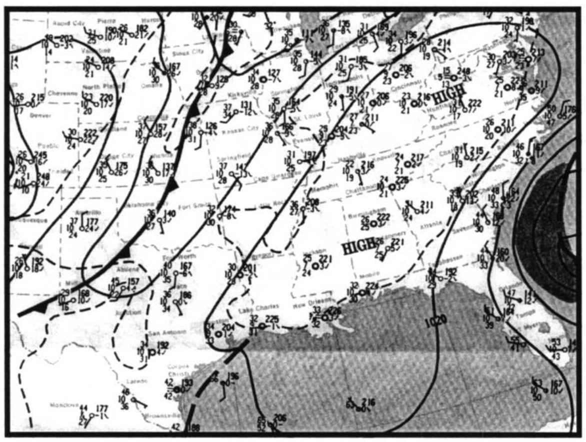
Figure 74b. Meteorological and air quality values observed at Breton and Dauphin Islands on 15 - 17 October 1997.



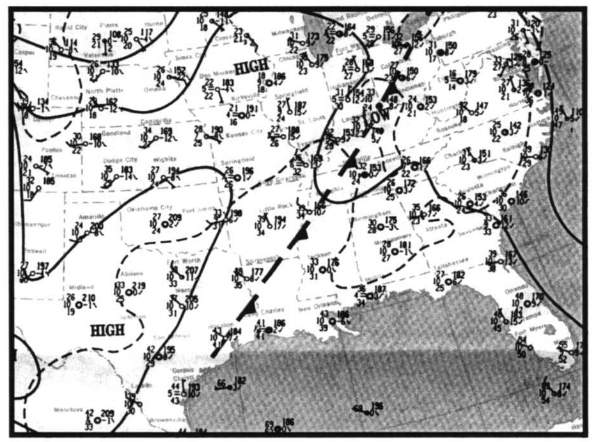
14 December



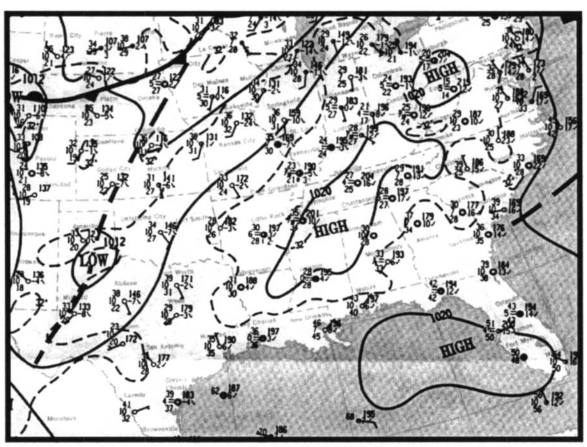
15 December



16 December



17 December



18 December

Figure 75a. 0700 EST surface weather maps for 14 - 18 December 1997 from NOAA Daily Weather Map Series.

A cold frontal system has reached the Florida peninsula on 14 and 15 December 1997, however FOR conditions remain along the Gulf coast as overcast conditions are seen. By the end of the 15th, the high has moved far enough to the southeast to bring about CH weather. As the high center moves eastward on the 16th, the surface winds rotate from northwest clockwise to westerly. Another front washes out over northeast Louisiana on the 17th, and FOR weather returns on the 18th as winds become more southerly along the coast. A gradual rise in NO_2 occurs at both stations, reaching a near simultaneous peak of 30 - 40 ppb early on the 16th with northerly winds. Concentrations then fall, but a second higher peak is seen at Breton in the evening under mostly westerly flow. Breton NO_2 generally remains higher (around 20 ppb) than at Dauphin through the 18th. NO_2 / NO_x ratios exhibit the expected minimums in the daytime hours, due to dissociation as described previously. The ratios are often lower at Breton, suggesting a nearer source, particularly the later peak on the 16th.

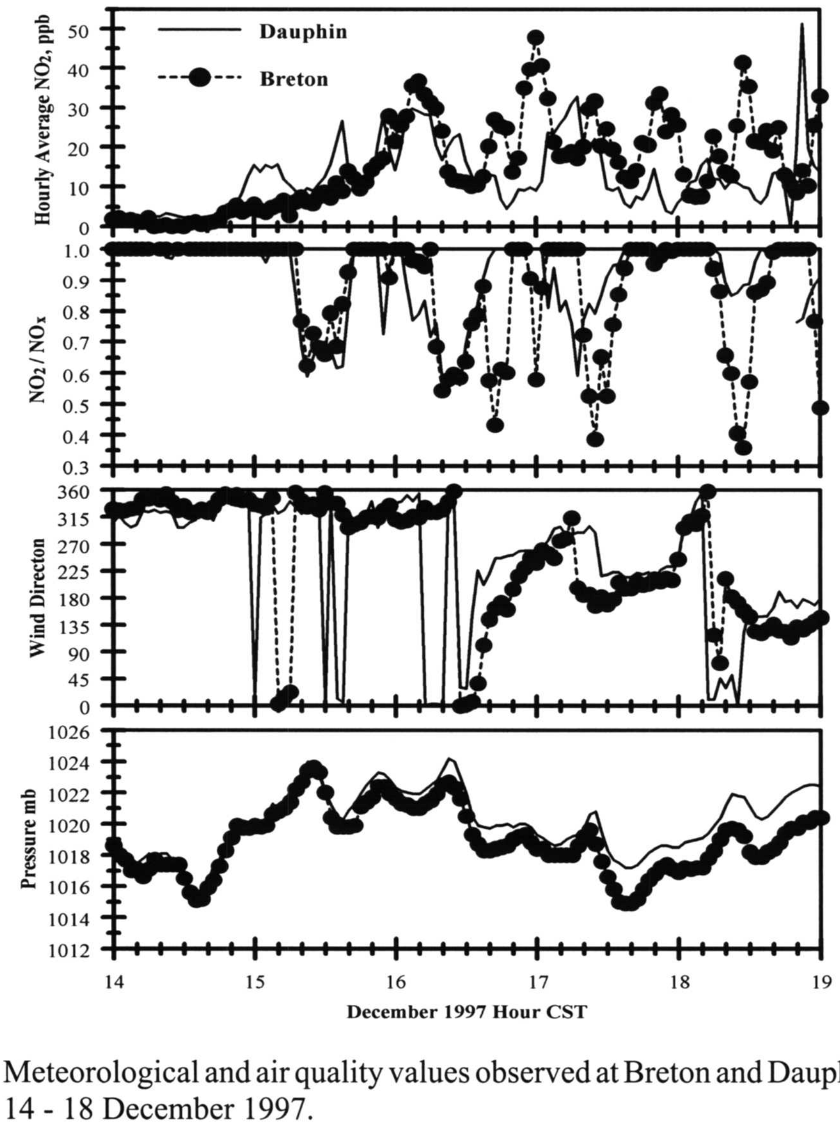
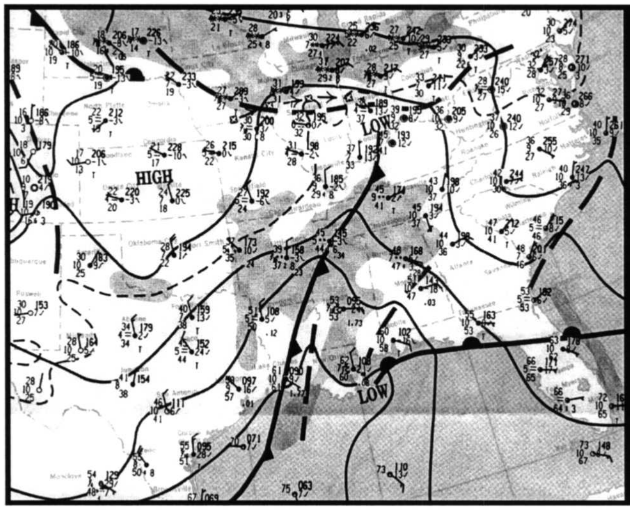
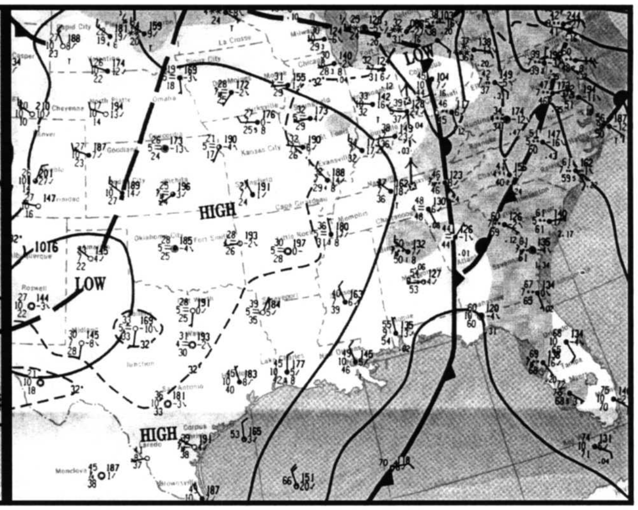


Figure 75b. Meteorological and air quality values observed at Breton and Dauphin Islands during 14 - 18 December 1997.

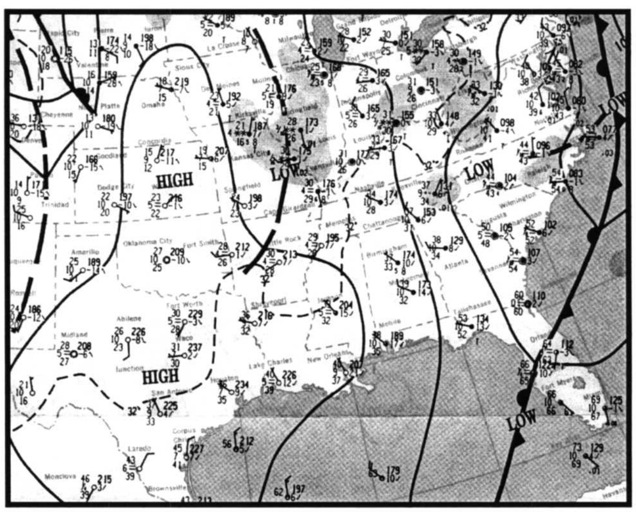
FGR weather precedes a front on 22 January 1998 as east-southeast winds are observed early in the day. A coastal low merges with the front and moves eastward, causing FOR (note overcast) on the 23rd and clearing to CH on the 24th with northerly flow and rising pressure. NO_2 peaks at Dauphin at the end of the 22nd are not observed at Breton; both stations show a gradual rise throughout the 23rd under northerly winds. NO_2 / NO_x ratios are similar, indicating a same-aged air mass at both locations.



22 January



23 January



24 January

Figure 76a. 0700 EST surface weather maps for 22 - 24 January 1998 from NOAA Daily Weather Map Series.

These examples further suggest that although similar synoptic meteorological conditions may be occurring at both stations, pollutant concentrations may be influenced more by localized sources.

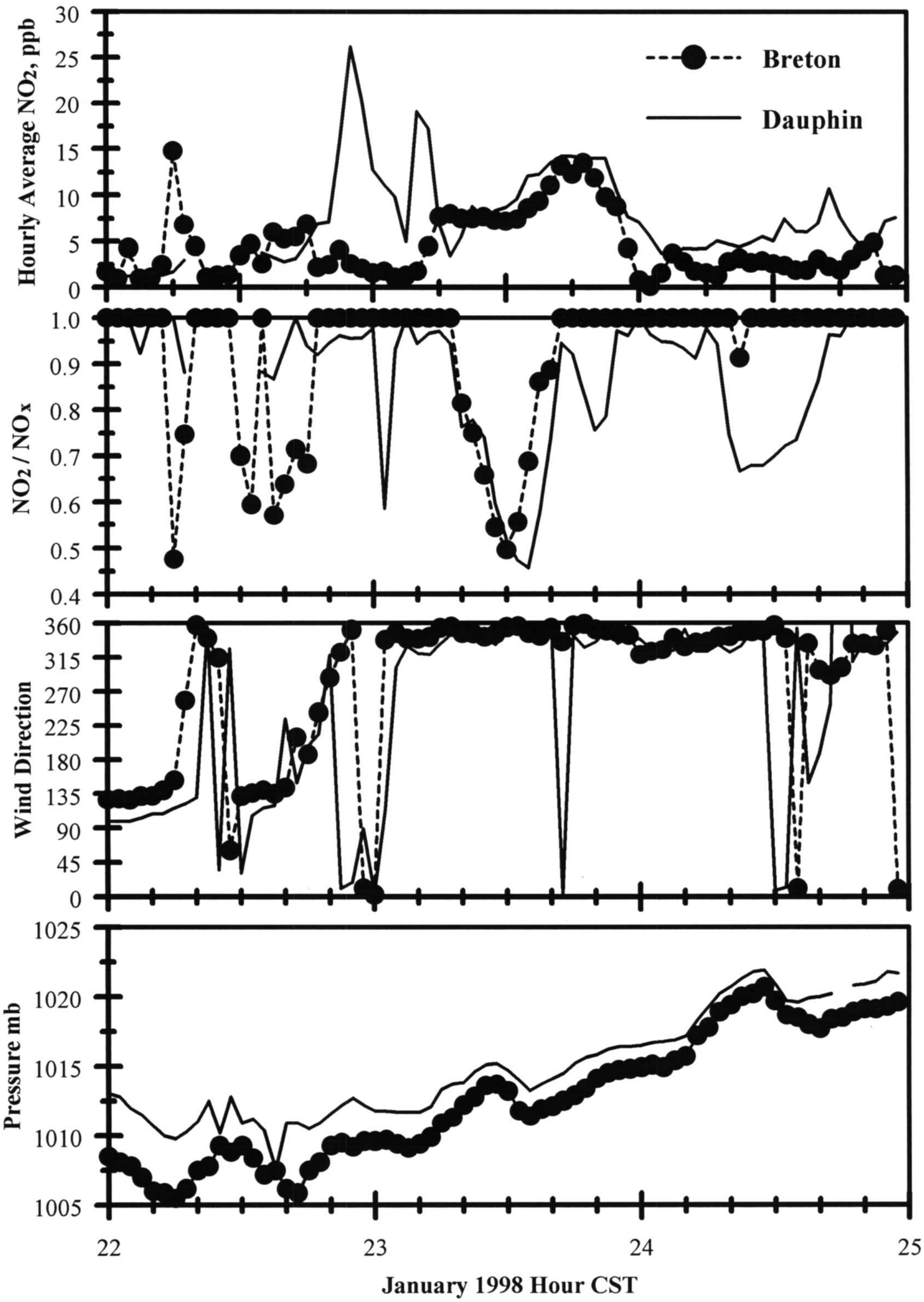


Figure 76b. Meteorological and air quality values observed at Breton and Dauphin Island on 22 - 24 January 1998.

D. Boundary Layer and Dispersion Meteorology Over Breton Island and Sound

1. Description of Key Processes in Pollutant Transport and Dispersion Over the Breton National Wilderness Area

a. Topography

The study area is flat and composed of barrier islands in a chain from Breton Island in the southwest (see Fig. 77 and Fig. 1) to the Chandeleur Islands in the northeast. The size of the main Breton Island is approximately 1 km wide and 6 km long. It is a relatively flat island. Because the islands are so low in elevation, storm surges can change the topography overnight. In fact, the overwash generated by Hurricane Danny in July 1997 temporally submerged much of Breton and left new cuts across the island. From the vegetative type map of the Louisiana coastal marshes published by the Louisiana Department of Wildlife and Fisheries in New Orleans in 1978, the entire Breton Island is classified as a saline marsh. The typical vegetation is oystergrass (Spartina alterniflora), Salicornia sp., blackrush (Juncus roemerianus), Batis maritima, black mangrove (Avicennia nitida), and saltgrass (Distichlis spicata).

Even though the island terrain is very low, it can still exert some drag to retard the air flow. In addition, the internal boundary layer may develop over this sea-island-sound system (see Hsu, 1988). Therefore, the results of turbulence intensity measurements via uvw sensors may not be the same as those of open water or further inland. The difference between this barrier island environment and the open water will be compared with results obtained from inland environments.

b. Air-Sea Exchange

Air-sea exchange includes momentum, heat, and moisture across the air-sea interface.

Meteorological transport processes in coastal marine environments are important from several points of view. For example, the wind stress or momentum flux is one of the most essential driving forces in water circulation. Heat and convection are the origin of some localized coastal weather systems. Sensible heat and water vapor fluxes are necessary elements in radiation and heat budget considerations, including computation of salt flux for a given estuarine system.

In the atmospheric surface boundary layer, the vertical turbulent transports are customarily defined as

$$\textit{Momentum flux} = -\rho\,\overline{u'w'} = \tau$$
$$= \rho K_m \left(\frac{\partial u}{\partial z} \right) = \rho\, C_d U_z^2$$

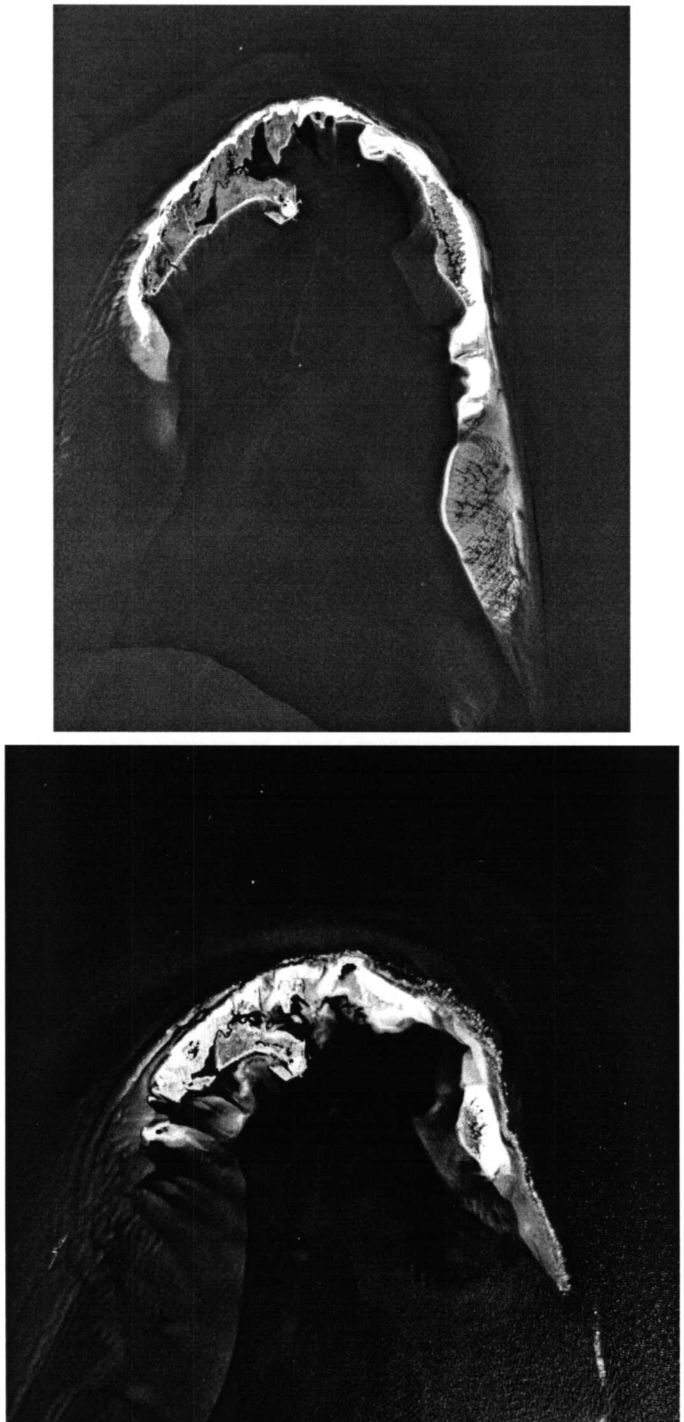


Figure 77. Aerial photographs (color infrared) of the northernmost part of Breton Island taken on 9 December 1996 (top) and 11 January 1999 (bottom). The Kerr McGee facility is visible as the small circular object on the inside of the island. Top of photos is oriented approximately to the northeast.

$$\begin{aligned} \textit{Sensible heat flux} &= -\rho\, c_p\, \overline{w'T'} \\ &= H_s = \rho\, c_p\, K_H \left(\frac{\partial \theta}{\partial z} \right) \\ &= \rho\, c_p\, C_H\, U_2\, \Delta T \end{aligned}$$

$$\begin{aligned} \textit{Moisture flux} &= -\rho\, \overline{w'q'} = E \\ &= -\rho\, K_E \left(\frac{\partial q}{\partial z} \right) = \rho\, C_E\, U_z\, \Delta q \end{aligned}$$

$$\textit{Latent heat flux} = H_L = L_v E$$

The primed values indicate deviations from mean values, which are designated by a horizontal bar; ρ is the air density; u and w are horizontal and vertical components of the wind; U_z is the mean horizontal wind at height z; T is the temperature; q is the specific humidity; c_p is specific heat at constant pressure; θ is the potential temperature; K_M, K_H, and K_E are eddy diffusivities for momentum, heat, and water vapor, respectively; ΔT is the difference between sea surface temperature and air temperature at a reference height (usually 10 m above the water surface); Δq is the corresponding mean moisture difference; C_d is the drag coefficient (which equals $(u_* / U_{10})^2$; where u_* is the shear or friction velocity); C_H and C_E are bulk aerodynamic coefficients, and L_v is the latent heat of vaporization. For practical reasons, averages over a 5- to 20-min measuring period are used.

Under fair (normal) weather conditions when the wind speed is below 10 to 12 m/sec, the transfer coefficient across the air-sea interface may be treated approximately as

$$C_d = C_H = C_E = 1.2 \; x \; 10^{-3}$$

Although the variation of C_H and C_E with wind speed and stability parameters may be considered small, the gradual increase of C_d with wind speed must be recognized, that is,

$$C_d = \left(A + B\, U_{10}\right) x \; 10^{-3}$$

where A = 0.80 and B = 0.065 are commonly used values.

c. Wind-Wave Interaction

Ocean surface waves are mainly generated by the wind. The relationship between nondimensionalized wind and wave parameters can be written as

$$\frac{g H_s}{U_{10}^2} = A \left(\frac{g T_p}{U_{10}} \right)^{\frac{3}{2}}$$

and

$$\frac{g H_s}{u_*^2} = B\left(\frac{g T_p}{u_*}\right)^{\frac{3}{2}}$$

where g is the gravitational acceleration, H_s is the significant wave height, and T_p is its corresponding peak period.

For a given region, values of A and B may be considered in equilibrium as constants so that wind, waves, and momentum flux are all related through the drag coefficient via

$$C_d = \left(\frac{A}{B}\right)^4$$

For example, in the Gulf of Mexico, on the average, A = 0.01155 and B = 0.062, so that $C_d = 1.2 \times 10^{-3}$. For the North Sea, A = 0.01048 and B = 0.054; therefore, $C_d = 1.4 \times 10^{-3}$.

For many air-sea interaction studies, e.g., oceanic current generation and Ekman pumping and the atmospheric mixing height for the overwater dispersion of pollutants, values of the wind stress τ ($= \rho u_*^2 = \rho C_d U_{10}^2$) are needed. Since direct measurements of u_* are not routinely available, C_d is commonly employed. Since τ is directly proportional to C_d, it is crucial to get as accurate a formulation as possible. Published equations of C_d vary greatly (see, e.g., Hsu, 1988, Fig. 6.11, p. 114). Most recently, Donelan et al. (1993) proposed a formulation in which the aerodynamic roughness, Z_0, is directly proportional to the wave height and inversely proportional to the wave age. These parameters are routinely available. Since C_d is proportional to Z_0, younger waves produce larger C_d values. Also, shorter fetch can generate younger seas and thus larger C_d.

At the air-sea interface the near-neutral stability may be assumed when the stability parameter $|Z/L| < 0.4$ (where Z is the reference height above the mean sea surface and L is the Monin-Obukhov stability length) (see Hsu, 1992). Under these conditions, the logarithmic wind profile law may be applied that

$$U_{10} = \frac{u_*}{\kappa} \ln\left(\frac{Z}{Z_0}\right) \tag{1}$$

Since u_* is not usually measured, the drag coefficient is employed in which

$$C_d = \left(\frac{u_*}{U_{10}}\right)^2 \tag{2}$$

Because there are two unknowns (i.e., u_* and Z_0) in Eq. (1) for a given wind speed, Donelan et al. (1993) proposed the following formula for operational applications

$$\frac{Z_0}{\sigma} = B_1\left(\frac{U_{10}}{C_p}\right)^{B_2} \tag{3}$$

where $B_1 = 6.7 \times 10^{-4}$, $B_2 = 2.6$, σ ($= H_s / 4$) in which σ is the root mean square wave height (where H_s is the significant wave height), and C_p ($= g T_p / 2\pi$) is the phase speed of the waves at the spectral peak (where T_p is the wave period at the spectral peak and g is the gravitational acceleration). Since

C_p / U_{10} is defined as the wave age, Z_0 is then directly proportional to H_s and inversely proportional to the 2.6 power of the wave age. In other words, for a given H_s and U_{10}, Z_0 is larger for younger seas (i.e., smaller magnitude of C_p / U_{10} or shorter wave period) and smaller for older seas (larger C_p / U_{10} or longer wave period).

From Eqs. (1) and (3) and by setting Z = 10 m and κ = 0.4, one gets

$$u_* = \frac{0.4\, U_{10}}{11.0 - \ln\left[\dfrac{H_s}{\left(\dfrac{C_p}{U_{10}}\right)^{2.6}}\right]} \tag{4}$$

Therefore, we can estimate u_* from the wind, U_{10}, and wave (H_s and C_p) information. Eq. (4) is referred to here as the wind-wave interaction method. Also, C_d may be obtained from this equation and Eq. (2) so that

$$C_d = \left[\frac{0.4}{11.0 - \ln\left[\dfrac{H_s}{\left(\dfrac{C_p}{U_{10}}\right)^{2.6}}\right]}\right]^2 \tag{5}$$

This is our recommended operational formula in which all parameters are routinely available from most data buoys. Verifications of Eqs. (4) and (5) in the Gulf of Mexico are provided in Hsu (1995a). It is shown that the agreement between these equations and the C_d formulation suggested by Wu (1982) and the WAMDI Group (1988) is within 95% such that

$$\begin{aligned} C_d &= 1.2875 \times 10^{-3} & U_{10} &< 7.5\ m/s \\ &= \left(0.8 + 0.065\, U_{10}\right) \times 10^{-3} & U_{10} &\geq 7.5\ m/s \end{aligned} \tag{6}$$

Since wave characteristics were not recorded at the Breton Island station, Eq. (6) is employed for determination of all drag coefficients in this analysis.

d. Atmospheric Turbulence

For pollution dispersion studies, atmospheric turbulence intensities in the horizontal and vertical directions are used. They are defined as (see, e.g., Zannetti, 1990)

$$\sigma_y = \sigma_v\, t\, S_y\left(\frac{t}{T_L}\right) \tag{7}$$

$$\sigma_z = \sigma_w\, t\, S_z\left(\frac{t}{T_L}\right) \tag{8}$$

where σ_v and σ_w are the standard deviations of the crosswind and vertical wind vector components, and S_y and S_z are universal functions of the diffusion (or travel) time t and the Lagrangian time scale T_L. Functions of S_y and S_z are provided in Zannetti (1990).

If we convert t to the downwind distance x with the wind speed U, we have

$$\sigma_y = \left(\frac{\sigma_v}{U_{10}} \right) x\, S_y \left(\frac{t}{T_L} \right) \tag{9}$$

$$\sigma_z = \left(\frac{\sigma_w}{U_{10}} \right) x\, S_z \left(\frac{t}{T_L} \right) \tag{10}$$

For overwater applications, the turbulence intensities are found to be (Geernaert et al., 1987)

$$\frac{\sigma_v}{U_{10}} = 0.0586 + 0.0012\, U_{10} \pm 0.015 \tag{11}$$

and

$$\frac{\sigma_w}{U_{10}} = 0.0369 + 0.0010\, U_{10} \pm 0.005 \tag{12}$$

Because σ_v and σ_w also vary with the atmospheric stability, we need the stability classification. Commonly, the Pasquill's Stability Classification scheme is employed (see, e.g., Panofsky and Dutton, 1984). For offshore regions, this classification may be obtained through the parameterization of Hsu (1992) that

$$\frac{Z}{L} = \kappa\, C_T\, C_d^{-\frac{3}{2}}\, R_b \tag{13}$$

and

$$R_b = \frac{g\, Z \left(T_{air} - T_{sea} \right)}{U_{10}^2 \left(T_{sea} + 273 \right)} \tag{14}$$

where Z is the height above the sea surface (normally set to 10 m), L is the Monin-Obukhov length, κ (= 0.4) is the von Kármán constant, C_T is the heat flux coefficient, C_d is the wind-stress drag coefficient, R_b is the bulk Richardson number, g (9.8 m s^{-2}) is the gravitational acceleration, T_{air} and T_{sea} are air and sea-surface temperatures in °C, and U_{10} (m s^{-1}) is the wind speed at 10 m height.

In Eq. (13), the heat flux coefficient, C_T, does not depend strongly on the wind speed, but is larger in unstable ($C_T = 1.10 \times 10^{-3}$) than in stable ($C_T = 0.83 \times 10^{-3}$) conditions (Smith, 1980). Garratt (1992, p. 102) suggests that under near-neutral conditions and for winds up to 25 m s^{-1}, $C_T = 1.1 \times 10^{-3}$ (± 15%).

e. Vertical Mixing

Vertical mixing includes eddy diffusivity and the mixing height.

1. The Vertical Eddy Diffusivity

In some K-diffusion models, the vertical eddy diffusivity, K_z, is required, e.g. (Hanna, 1984)

$$K_z = c\,u_* Z\left(1 - \frac{Z}{h}\right) \tag{15}$$

where u_* is the shear velocity defined above and h is the mixing height. For example, the Urban Airshed Model (UAM), the preferred model of the EPA for ozone studies, has a meteorological preprocessing subroutine which employs the gradient transport (K) modeling (Zannetti, 1990, p. 234). Since in the K-theory, u_* is required for the computation of vertical diffusivity, K_z, and concentration, χ, it is recommended that proper formulas to reflect the overwater variations in aerodynamic roughness length Z_0, or the drag coefficient C_d, be made in light of recent advances in the air-sea interaction field as shown in Eq. (5).

Note that if proper C_d values ($10^3C_d = 1.090 + 0.094\ U_{10}$) (obtained by buoy 42035 near Galveston, Texas using Eq. (5)) for the shallow water environment (such as Galveston Bay) are compared to those for the open Gulf of Mexico ($10^3C_d = 1.14$ based on open ocean conditions (Large and Pond, 1981) when U_{10} ranges between 4 to 11 m s^{-1}), the ratio of K_{zBay} / K_{zGulf} as well as H_{bay} / H_{gulf} is 1.18 when U_{10} = 5 m s^{-1}. This ratio increases to 1.32 when U_{10} increases to 10 m s^{-1}. On the other hand, the ratio of concentration χ_{Bay} / χ_{Gulf} is 0.85 and 0.76 when U_{10} is 5 and 10 m s^{-1}, respectively.

2. The Mixing Height

Due to potential evaporation, the air over the water is usually moister than that over land, and the top of the marine boundary layer is oftentimes capped by clouds (see, e.g., Garratt, 1992). On the basis of analysis of vertical soundings by research aircraft, rawinsondings, and radar wind profilers and Radio Acoustic Sounding Systems (RASS), it has been shown by Garratt (1992) that the mixing height h = LCL, the lifting condensation level under cumulus cloud conditions (where LCL = cloud base). The height of the LCL may be estimated by (see McIlveen, 1986, p. 126)

$$H_{sea} = 125\left(T_{air} - T_{dew}\right) \tag{16}$$

where H_{sea} is the mixing height over the water surface, and T_{air} and T_{dew} are the air and dewpoint temperatures (both in °C) over the water, respectively. However, if the clouds are stratiform (as is often the case over the U.S. west coast), the height of the cloud top rather than base is the mixing height (Garratt, 1992, p. 205). A method to obtain H_{sea} by using NOAA series or GOES satellite detection of cloud top temperature is shown in Fig. 78. Note that one may follow the saturation adiabat from the cloud top temperature downward and follow the dry adiabat from the surface air temperature upward. The point of intersection is the LCL. In this procedure, the height corresponding to the cloud top temperature must be determined beforehand from nearby routine rawinsonding station. If multi-layered stratus cloud, mid-level, or cirrus clouds are present, the warmest cloud-top temperature (CTT), which represents the clouds in the lowest layer, will be applied. Because the sea-surface temperature can be determined in the cloud-free region, the CTT in the first cloud layer away from the sea surface can be identified by the nephanalysis (see, e.g., Kidder and Vonder Haar, 1995).

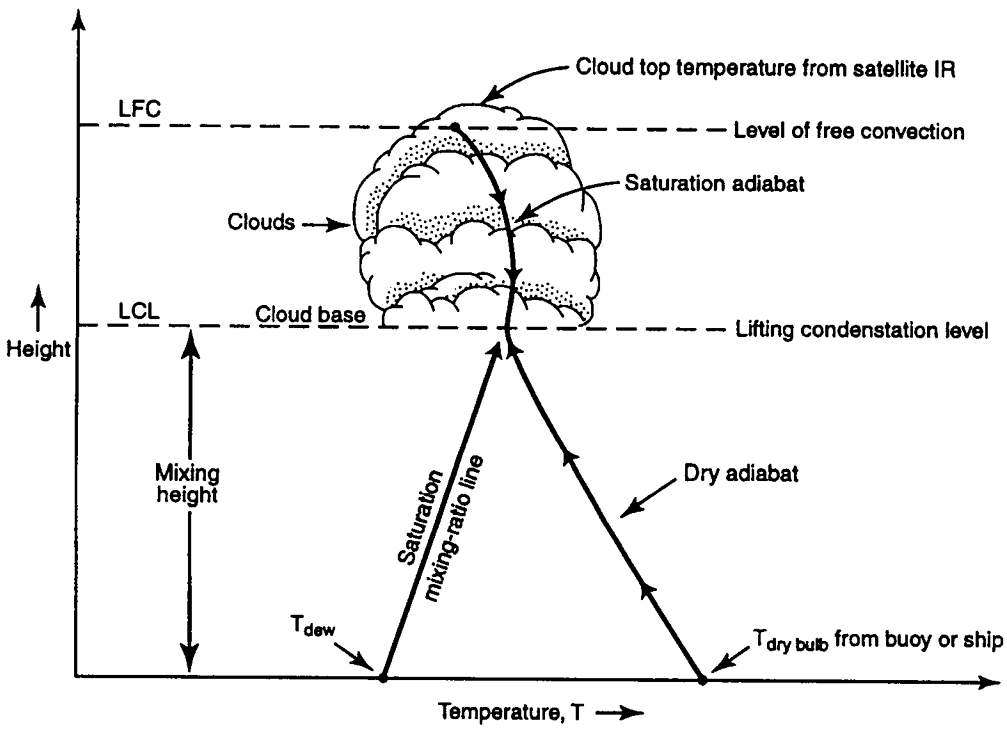


Figure 78. Determining overwater mixing height from the dewpoint depression at the surface or from surface and cloud-top temperatures based on atmospheric thermodynamics (see text for explanation).

Alternately, if we know the mixing height on land, H_{land} (in meters), and a barotropic boundary layer across the coastal zone exists, we may estimate the mixing height over the water, H_{sea} (in meters) by applying (Hsu, 1988, p. 183)

$$H_{sea} = H_{land} \left(\frac{C_{d\,sea}}{C_{d\,land}} \right) \left(\frac{U_{sea}}{U_{land}} \right)^2 \qquad \textbf{(17)}$$

where C_{dland} is the drag coefficient over land, C_{dsea} is based on Eq. (5), U_{sea} and U_{land} (both in m s^{-1}) are the windspeeds at sea and over land, respectively.

If the planetary boundary layer is baroclinic across the coastal zone, i.e., under land and sea breeze effects, according to Hsu (1988, p. 204),

$$H_{sea} = H_{land} - 123\left(T_{land} - T_{sea}\right) \qquad \textbf{(18)}$$

where T_{land} and T_{sea} (both in °C) are the air temperatures over land and sea, respectively.

2. Use of Observations to Compare Methods that Evaluate Parameters Associated with Key Processes

a. Determining Z/L

Hourly values of Z/L were calculated for NOAA buoys 42007 and 42040 and C-MAN GDIL1 (Grand Isle, Louisiana, see Fig. 79 for locations) as well as at Breton using Eqs. (6), (14), and (13) and setting $C_T = 1.1 \times 10^{-3}$. On first examination, stability was classified as unstable for $Z/L < -0.03$, neutral for $|Z/L| < 0.03$, and stable for $Z/L > 0.03$. Figure 80 shows the frequency of occurrence for each category. Breton Island stability characteristics most closely resemble those at buoy 42007; therefore this station's long-term record may be used to approximate conditions over the BNWA.

Investigation of the seasonal variations of meteorological and stability parameters over the study area was performed to further define their spatial and temporal characteristics. Monthly mean and standard deviation of Breton Island air and water temperatures are compared to the mean values at buoys 42007 and 42040 in Figure 81. Excellent agreement in air temperature amongst the three stations occurs throughout the year. As expected, sea surface temperatures at Breton and 42007 are well correlated, however wintertime (November - February) sea temperatures at buoy 42040 are considerably higher (4 - 6°C). From Eqs. (13) and (14), it can be inferred that this most offshore location is more unstable, as verified by Fig. 80. Note that the water temperature sensor at Breton was located in shallow water at the end of a concrete pier extending from the Kerr-McGee facility. Diurnal and seasonal heating and chilling of this shallow water body is likely more pronounced at this location than at the open-water buoys.

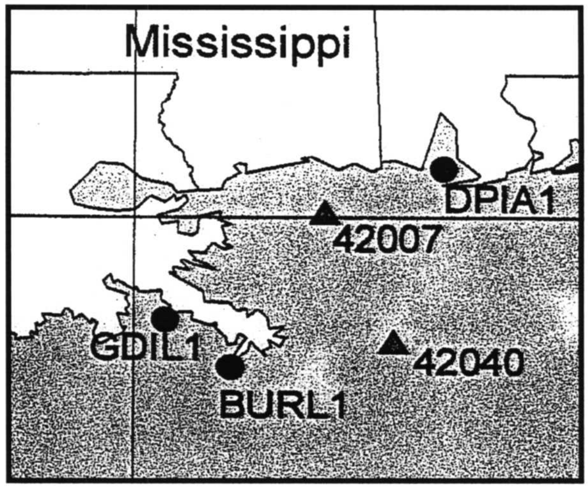


Figure 79. Approximate locations of NOAA buoys and C-MAN stations used in this analysis.

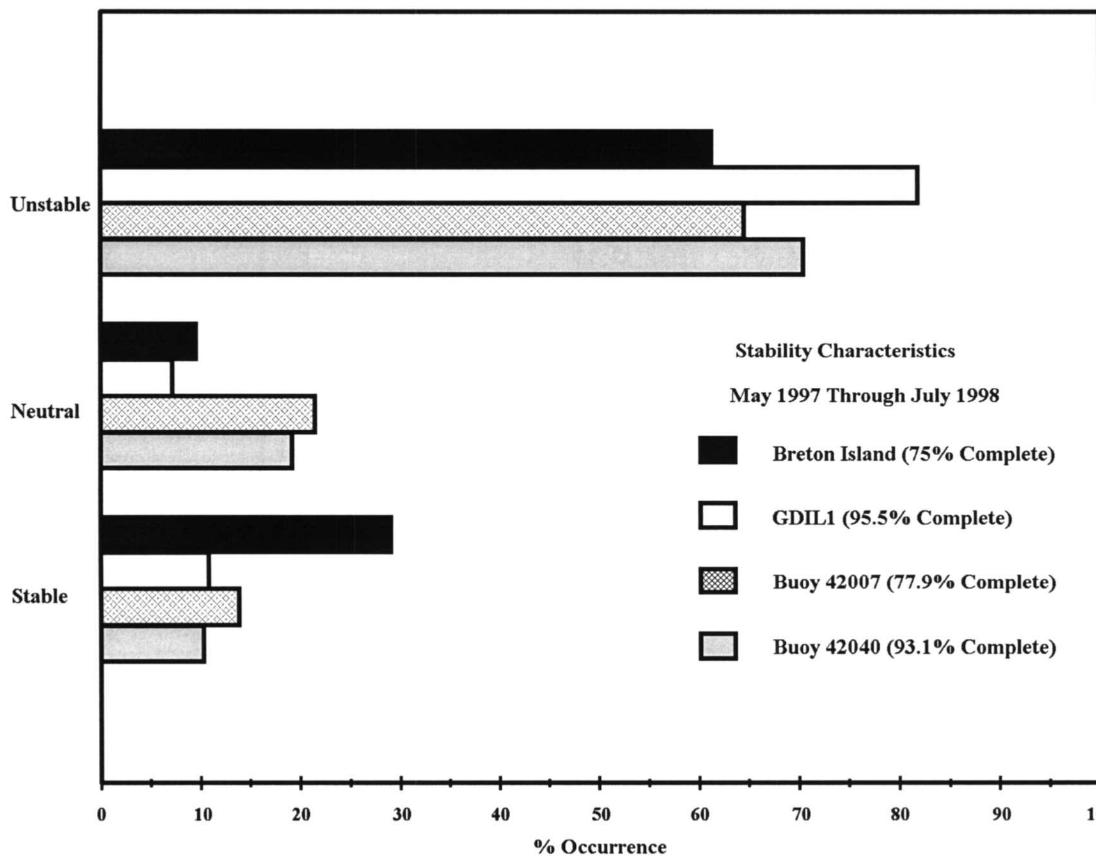


Figure 80. Frequency of occurrence of stability classes for three NOAA stations and Breton Island during the period of May 1997 through July 1998.

Monthly statistics of computed Z/L at all three offshore stations resulted in unrealistically large negative (unstable) mean values. This was found to be caused by a relatively small number of free convective cases (Stability Class B, Z/L < -1.0). A nomogram developed by Hsu (1992) to obtain Stability Class from routine measurements available at sea (Figure 82, proposed for use in air quality modeling, such as the OCS model (Hanna et al., 1985, Hsu, 1992)) was employed to identify hourly records which fell into Classes B and F. These records were then removed, since Monin-Obukhov theory is not applicable beyond |Z/L| > 1 (see, e.g, Kaimal and Finnigan, 1994); and monthly statistics were re-computed. Figure 83 depicts these results. Unstable (Z/L < 0) conditions exist at all locations throughout the year. Mean stability approaches free convective during the summer months, with Class B observed approximately 10 - 20% of the time (greater frequency at 42040). During the winter season, 42007 and Breton become more near-neutral, buoy 42040 responds much slower due to the abundant supply of warmer water further offshore. Again, the trend toward more stable conditions at Breton in the fall may be partially due to the chilling of the shallow waters.

A more convenient method for obtaining Z/L from readily available measurements is described as follows based on a comparative analysis of Z/L and R_b using data provided in Donelan et al. (1997). Parameters given in Donelan's extensive data set included U_{10N}, T_{air}, T_{sea}, L, and u_*. By setting Z = 10 m, the stability parameter Z/L was obtained.

For the first run, all records with Z/L < 0 were retained for a total of 96 samples. The bulk Richardson number, R_b, was given by Eq. (14). Values of Z/L extended to about -8, with 8 points being < -3. For these points, U_{10N} was ≤ 5 m s^{-1}, and T_{air} - T_{sea} $\approx$-8°C. These values were obtained under light wind conditions blowing almost directly against the 2 - 2.5 m swell following a cold frontal passage. This is extremely unstable, and therefore Monin-Obukhov theory does not apply. Thus, these 8 records were removed from the analysis.

From Eq. (13) and for Z/L < 0, R_b must be < 0. However, three points occurred where R_b > 0 and Z/L < 0. These values were recorded following the passage of another cold front, when T_{air} was still slightly warmer than T_{sea} and the winds brisk. These stability values approach near-neutral conditions (|Z/L| < 0.03) and were also excluded.

85 samples remained comprising Stablility Classes C and D (for Z/L < 0). For all samples, Z/L = 12.41 R_b with a correlation coefficient of 0.9. If only stability class D (-0.4 < Z/L < -0.03) is considered, 63 samples gives Z/L = 11.77 R_b with correlation of 0.93. Good fit is also obtained for Class D stable (Z/L > 0), however note that several points included in this regression fall into the near-neutral category. These results are summarized in Fig. 84. For those wind speed measurements taken a 5 m on NDBC buoys, correction to 10 m can be based on Hsu (1988, Table 8.5, p. 202).

b. Turbulence Intensity

Turbulence intensities derived from measurements of u, v, and w wind components under near-neutral conditions (|Z/L| < 1.0) at Breton Island were compared to the relationship found for the North Sea (Geernaert et al., 1987) (Eqs. (11) and (12)). Data observed under light wind conditions ($U_{10} < 5$ m s^{-1}) were excluded to ensure representation of stability class D conditions (see, e.g., Zannetti, 1990). In Fig. 85, good agreement is found for downwind (σu) and vertical (σw) intensities; however larger crosswind (σv) intensities are observed at Breton. As described previously, this may be partially due to topographical effects as well as the influence of man-made structures. Since the uvw sensor was fixed in the standard u = 90° (east), v = 360° (north) orientation, the dataset was narrowed down to only winds parallel to these directions for better delineation of the lateral variances. Closer agreement is achieved, as shown in Fig. 86. Note that westerly winds were excluded due to the presence of large structures in this direction. Further defining these relationships is essential for proper σ_y and σ_z calculations in dispersion modelling efforts over the BNWA.

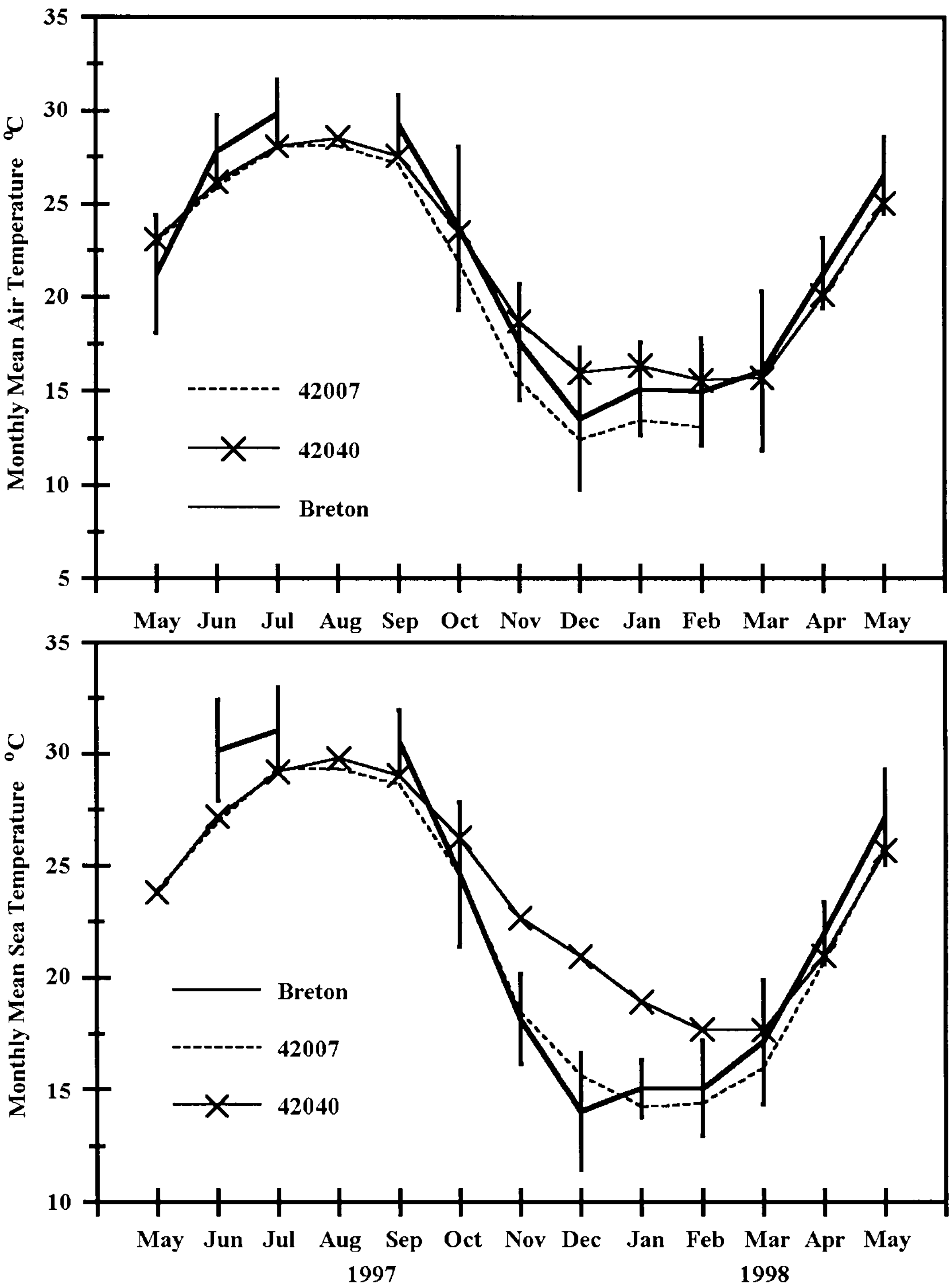


Figure 81. Monthly statistics of air and water temperatures at Breton Island and two NOAA buoys. Vertical lines are standard deviation at Breton.

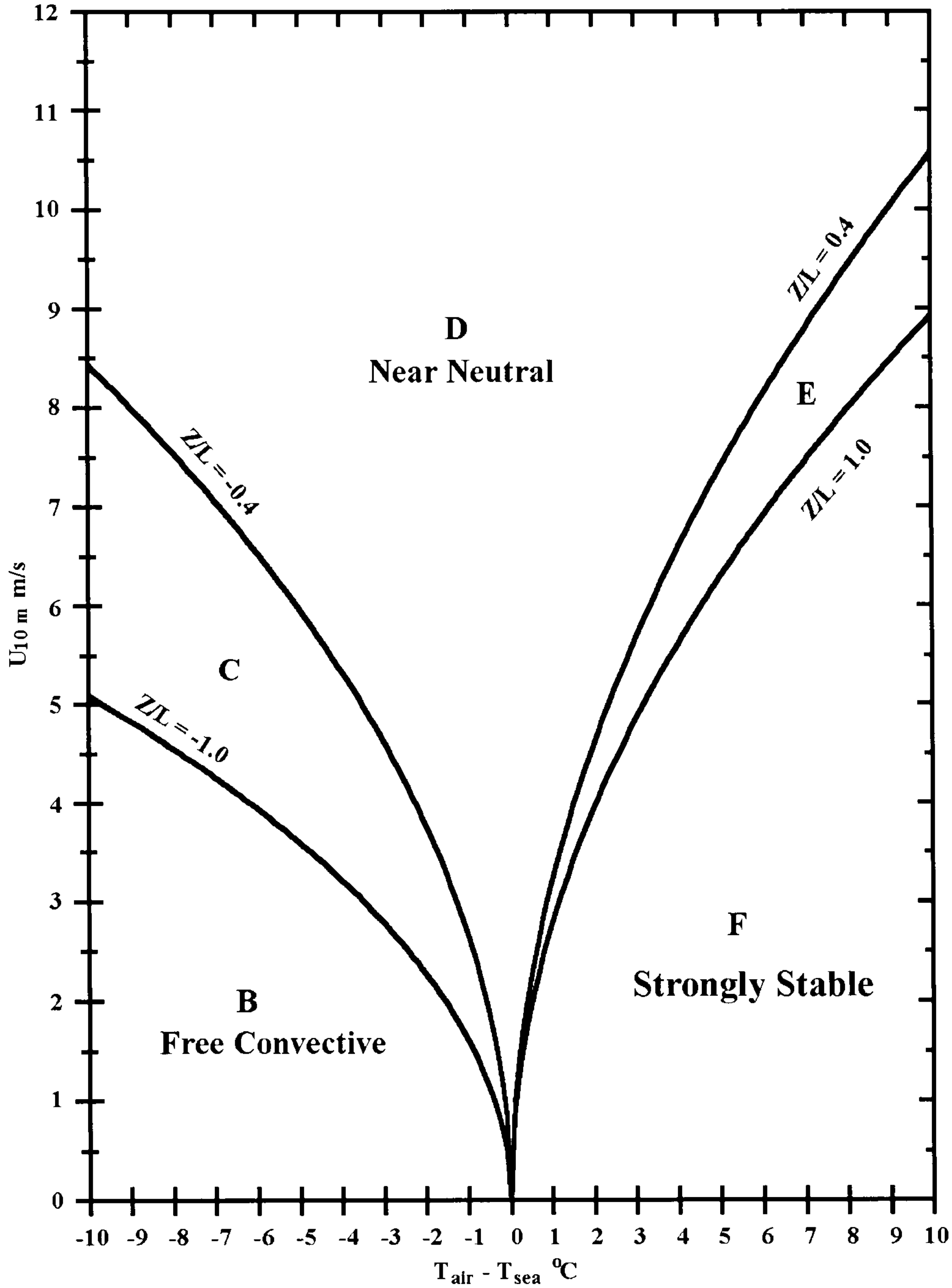


Figure 82. The stability classes as a function of wind speed and air-sea temperature difference (from Hsu, 1992).

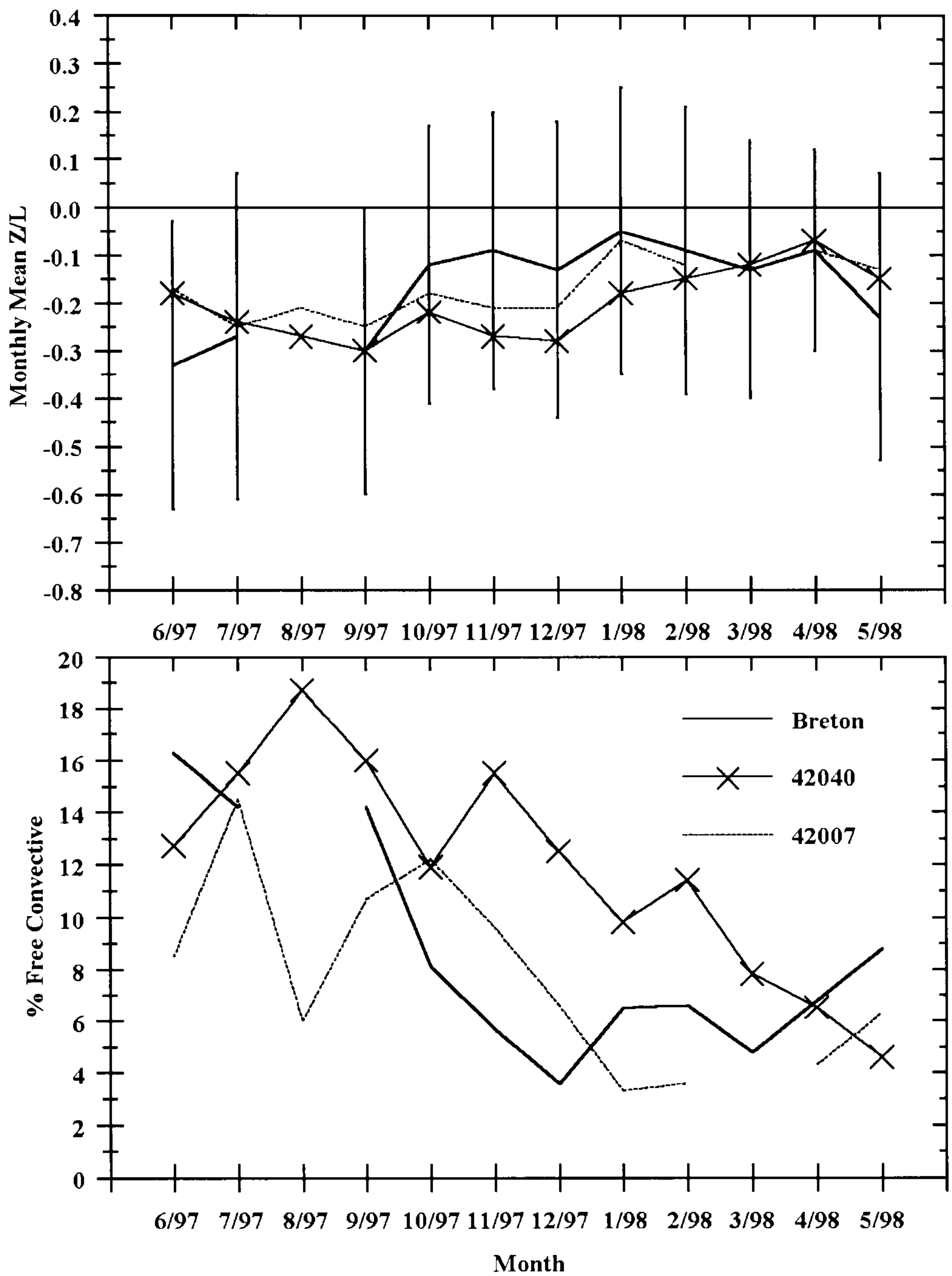


Figure 83. Monthly statistics of stability characteristics and frequency of occurrence of free convective conditions at Breton Island and two NOAA buoys. Vertical lines are standard deviation at Breton.

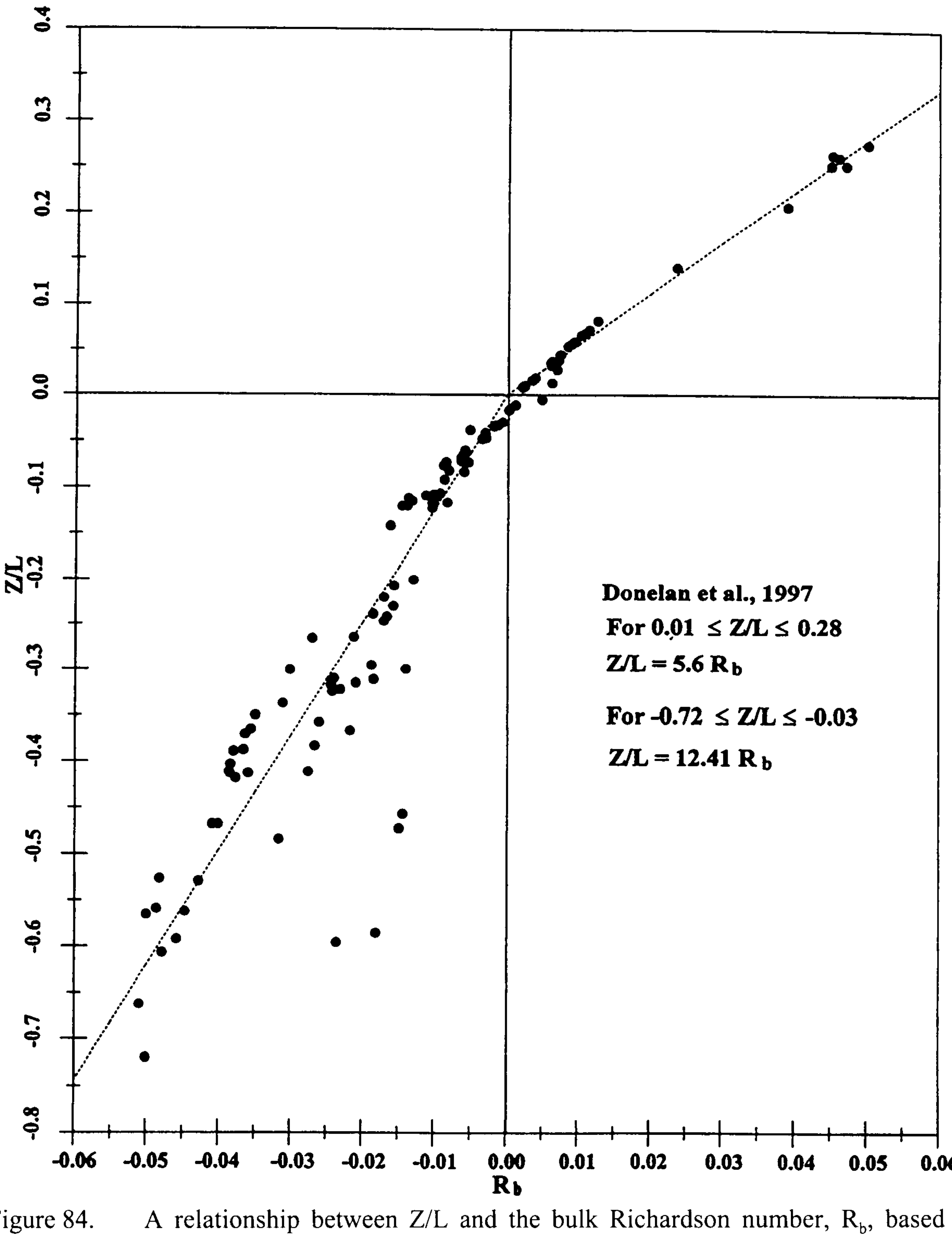


Figure 84. A relationship between Z/L and the bulk Richardson number, R_b, based on measurements from a continental shelf environment by Donelan et al. (1997).

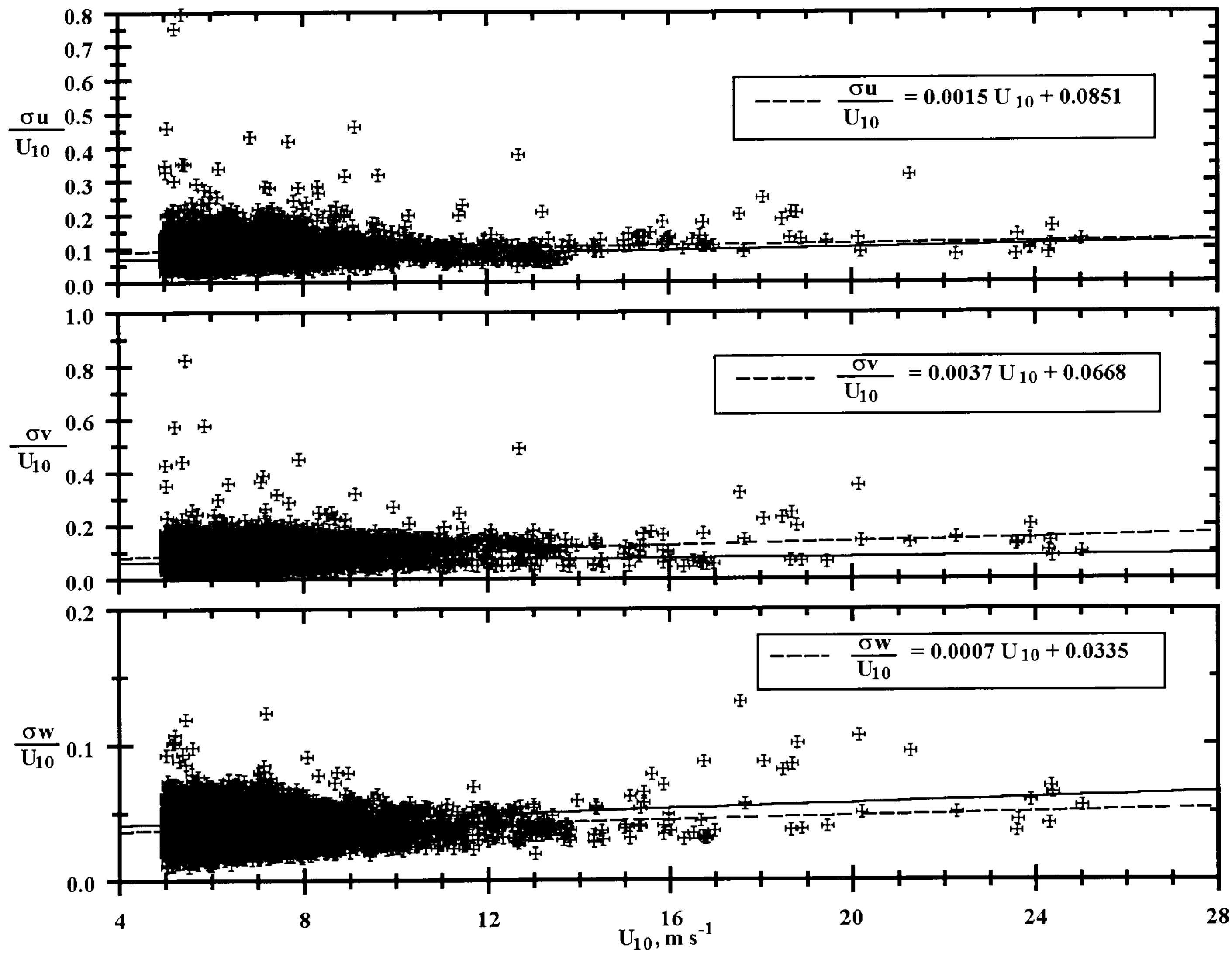


Figure 85. Observed turbulence intensities at Breton Island compared to the relationship found for the North Sea (denoted by solid line from Geernaert et al., 1987).

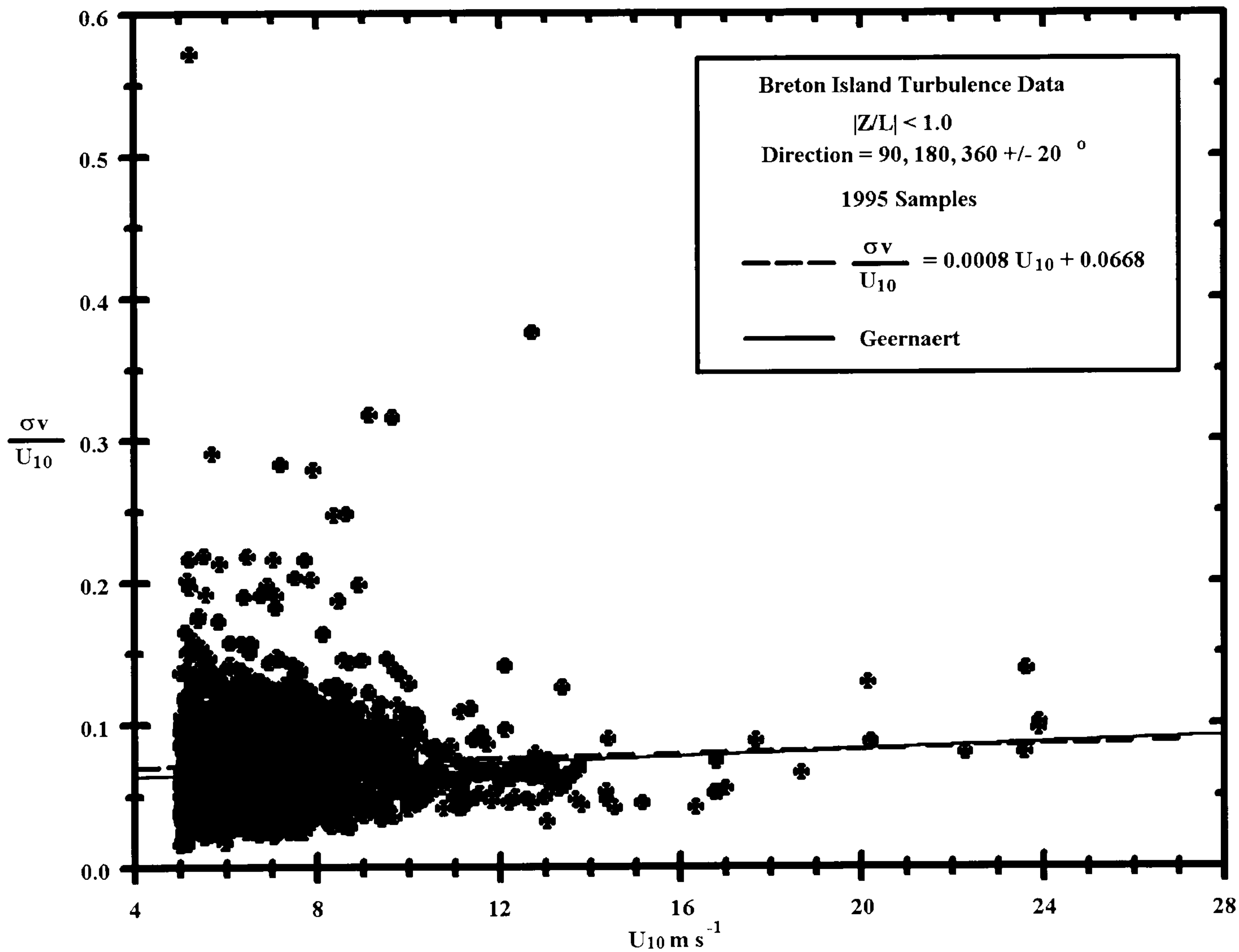


Figure 86. Lateral (crosswind) turbulence intensities at Breton Island compared to the relationship for the North Sea (see text for explanation).

c. The Mixing Height

New satellite systems scheduled to come online will provide accurate measurements of surface and cloud-top temperatures as well as heights of the cloud tops. Figure 87 shows an example for determining the mixed height from remotely-sensed data as described in Section III.D.1.e.2. and Figure 78. The computed LCL, or mixed height, from a radiosonde profile recorded at Breton Island on 4 August 1998 is shown to be in excellent agreement with that obtained from the satellite data.

While the Breton Island air quality station was being removed on 3 - 4 August 1998, several radiosondes were launched from the moored camp Chandeleur Islander nearby. Figures 88 through 96 display the standard Skew-T log P thermodynamic profiles for each launch, along with boundary layer profiles of potential temperature (θ), virtual potential temperature (θ_v), and mixing ratio (q). The latter profiles were used to estimate the mixing height as that point at which the lapse rate of both θ and q change abruptly (see, e.g., Hsu, 1988).

As discussed previously (Sec. III.D.1.e.2.), the mixed height over the marine environment may be equivalent to the lifting condensation level (LCL). Figure 97 shows a one-to-one comparison of LCL heights obtained through Skew-T analysis of the Breton radiosondes versus mixed heights calculated by Eq. (16) and estimated from boundary-layer profile. Root mean square errors for both methods are within 90 m; the error obtained from Eq. (16) is less than 20 m. Thus, Eq. (16) is recommended for operational use.

To visualize seasonal variations of the mixing height over the southeast Louisiana coast and eastward over the BNWA, Eq. (16) is applied to the records of C-MAN stations GDIL1 and BURL1, NOAA buoy 42040, and Breton Island. Dewpoint temperatures are recorded at the first three stations, for Breton dewpoints were calculated from air temperature and relative humidity by

$$E_s = 6.1078 \; x \; e^{\left(\frac{2.302 \; x \; 7.5 \; x \; T_{air}}{237.3 \; + \; T_{air}} \right)} \qquad \textbf{(19)}$$

$$E = \left(\frac{RH}{100} \right) E_s \qquad \textbf{(20)}$$

$$T_{dew} = \frac{(237.2 \; x \; Q)}{(7.5 \; - \; Q)} \quad where \quad Q = \log_{10}\left(\frac{E}{6.1078} \right) \qquad \textbf{(21)}$$

where E and E_s are the vapor pressure and saturation vapor pressure over water, respectivey; RH is the relative humidty; and T_{air} is the air temperature. Eq. (21) is valid for wet-bulb temperatures greater than zero. Since this parameter was not recorded, monthly minimum values of air temperature and relative humidity were input into psychometric tables; in no case was the corresponding wet-bulb temperature less than zero.

Figure 98 shows our results. Mean mixed heights range from about 250 m to 750 m, with peaks in August and April. Excellent agreement is found between Breton and GDIL1, while both BURL1 and 42040 generally are much lower. It is interesting to find the low mean heights at

BURL1 and 42040 from January through May 1998. A possible explanation may be localized effects caused by the discharge of cold Mississippi River water.

High concentrations of pollutants may be anticipated if a release were to occur during very stable conditions offshore. Stable mixed height may be approximated by (Panofsky and Dutton, 1984)

$$h_{stable} = 0.4\sqrt{\frac{u_* L}{f}} \quad \textbf{(22)}$$

where $f = 2\Omega \sin\varphi$. From Hsu (1998), when $T_{air} > T_{sea}$ (stable),

$$L = -\frac{u_*^3 C_p \rho T_{air}}{\kappa g H_s} \quad \textbf{(23)}$$

where H_s (sensible heat flux) $= \rho C_p C_T (T_{sea} - T_{air}) U_{10}$. Substituting back into Eq. (22) and reducing

$$h_{stable} = 0.4\, C_d U_{10}^2 \sqrt{\frac{T_{air}}{f \kappa g C_T (T_{air} - T_{sea}) U_{10}}} \quad \textbf{(24)}$$

Employing the WAMDI (1988) formulation for C_d (Eq. (6)), Figure 99 shows that an estimated mixed height of only 104 m was found under an episode of stable conditions at buoy 42007.

When the atmosphere is unstable, i.e., when $T_{sea} > T_{air}$, the formula proposed by Hsu (1997) may be applied that

$$Z_i = 369 + 6004\left(\overline{w'\theta_v'}\right)_0 \quad \textbf{(25)}$$

The Offshore and Coastal Dispersion (OCD) model proposed and evaluated by Hanna et al (1985) requires the Monin-Obukhov length to compute the stability class. Both wind shear and heat flux are needed for this computation. The previous discussions have presented several methods for estimating these parameters and others over the BNWA. According to Chang et al. (1998 - see MMS 98-0050), these newer parameterizations need to be further tested.

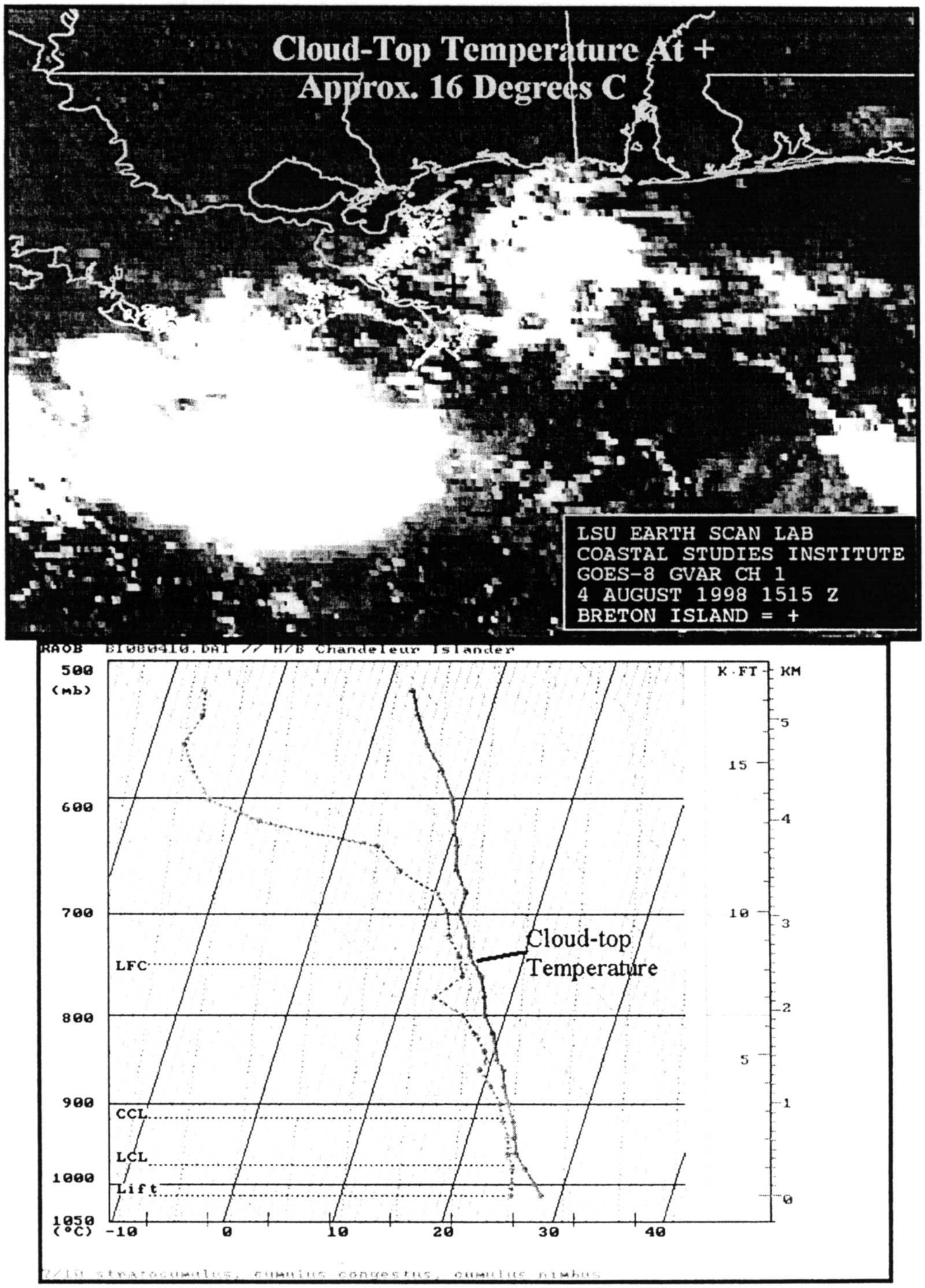


Figure 87. A demonstration of LCL (mixed height) from cloud-top temperature using data obtained over Breton Island on 4 August, 1998 at approximately 1500 GMT (1000 LT).

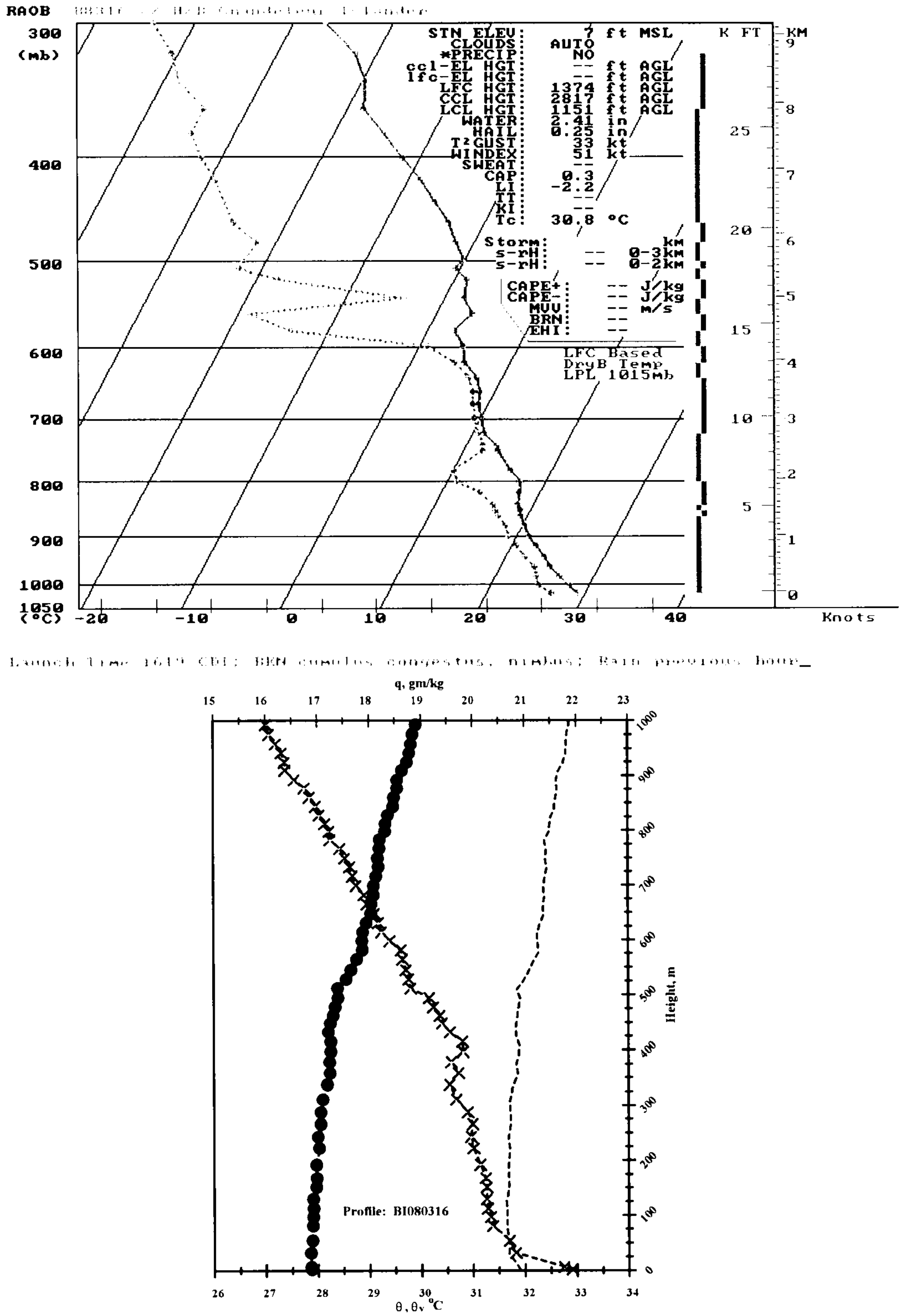


Figure 88. Thermodynamic and boundary layer profiles of 3 August 1998, 1619 CDT radiosonde over Breton Island. ●-line is θ, X-line is q, dashed line is θ_v.

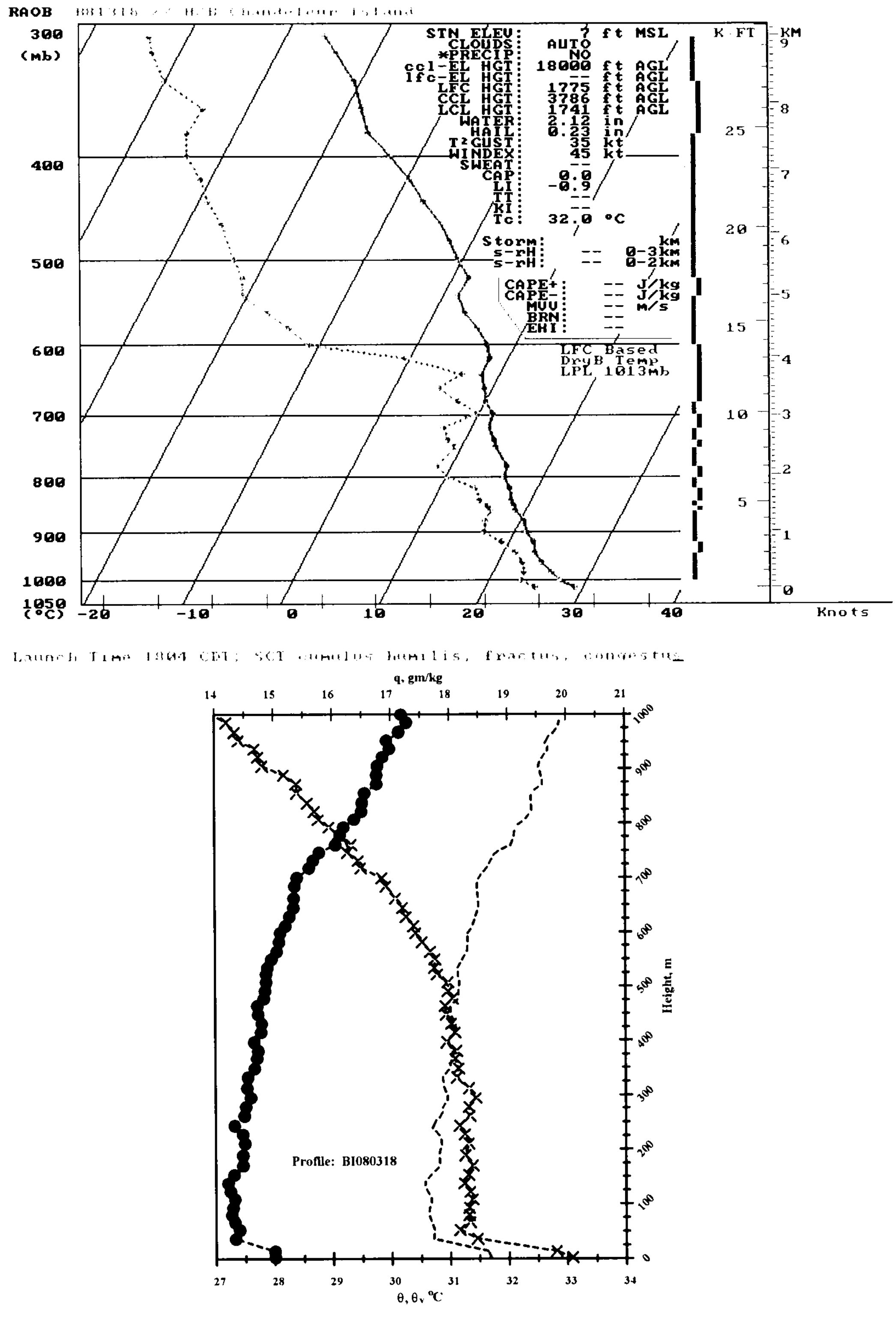


Figure 89. Thermodynamic and boundary layer profiles of 3 August 1998, 1804 CDT radiosonde over Breton Island. Lines as in Fig. 88.

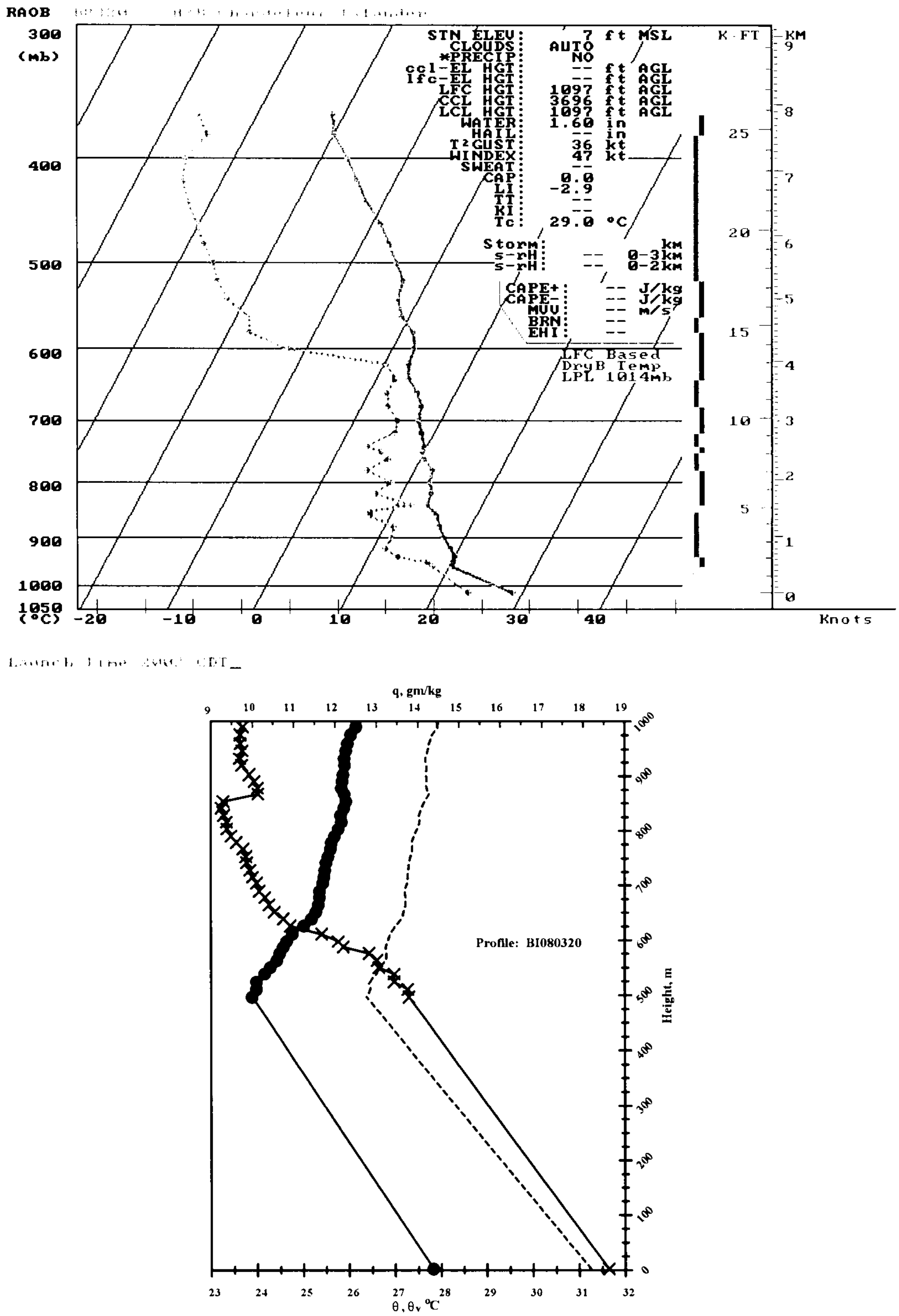


Figure 90. Thermodynamic and boundary layer profiles of 3 August 1998, 2002 CDT radiosonde over Breton Island. Lines as in Fig. 88.

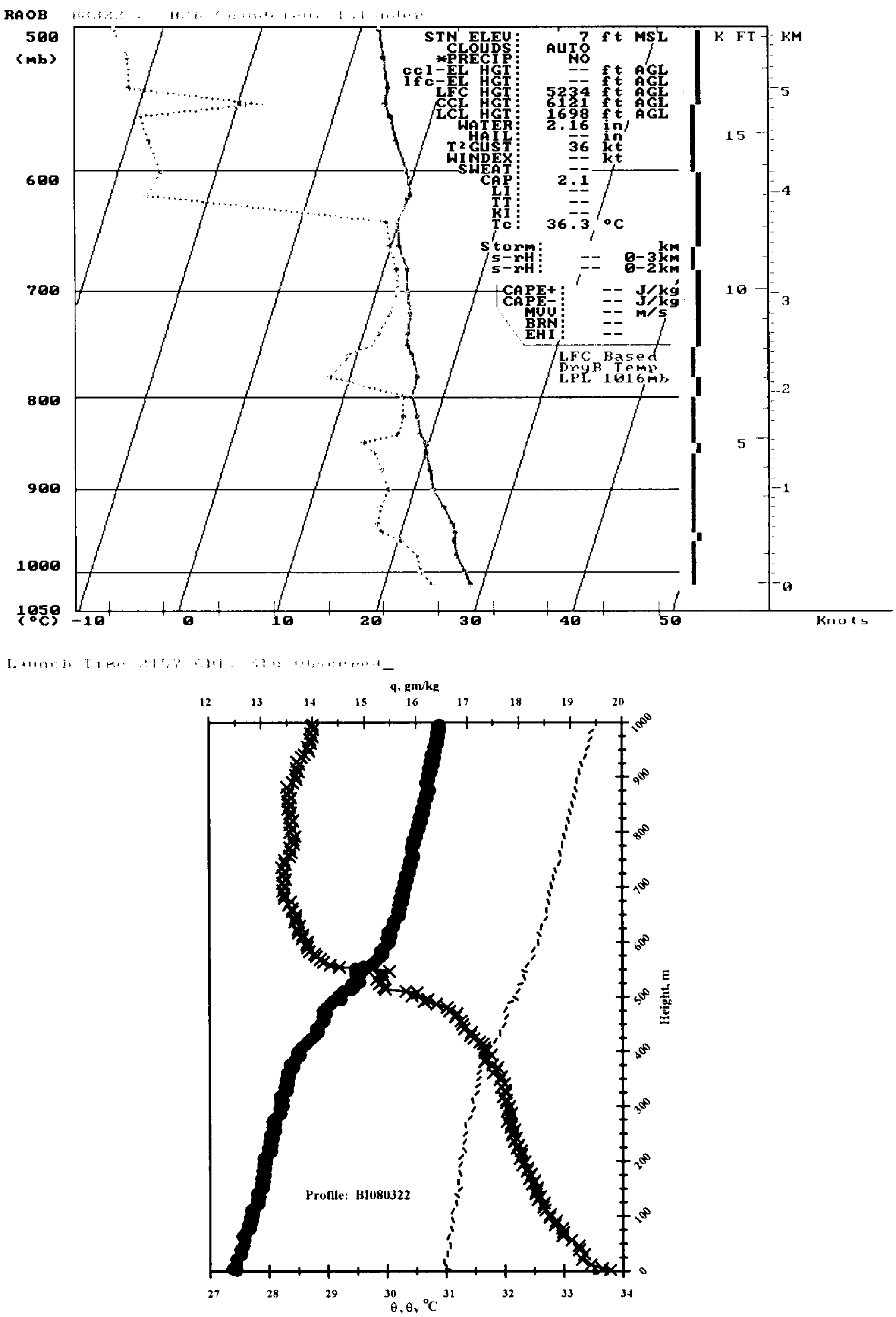


Figure 91. Thermodynamic and boundary layer profiles of 3 August 1998, 2157 CDT radiosonde over Breton Island. Lines as in Fig. 88.

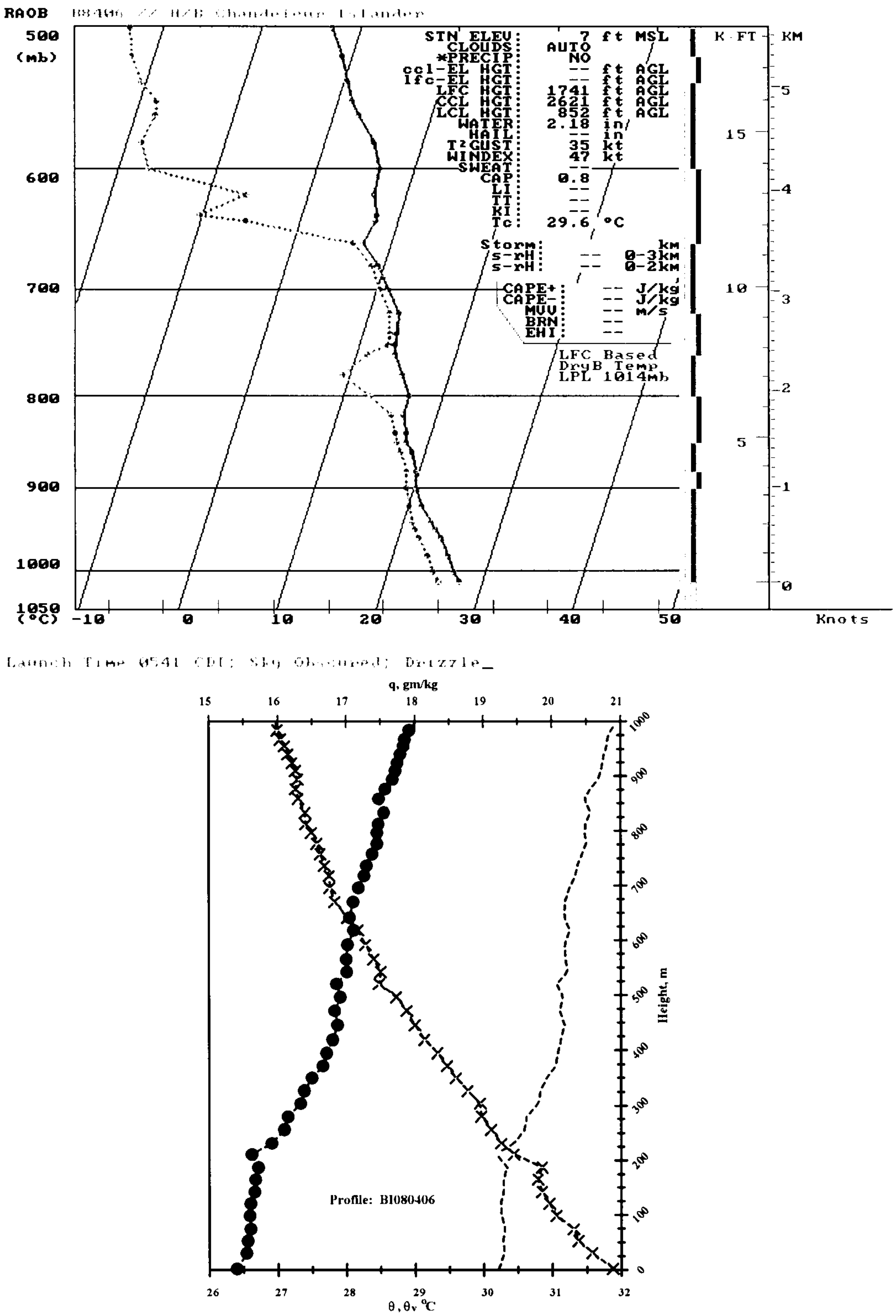


Figure 92. Thermodynamic and boundary layer profiles of 4 August 1998, 0541 CDT radiosonde over Breton Island. Lines as in Fig. 88.

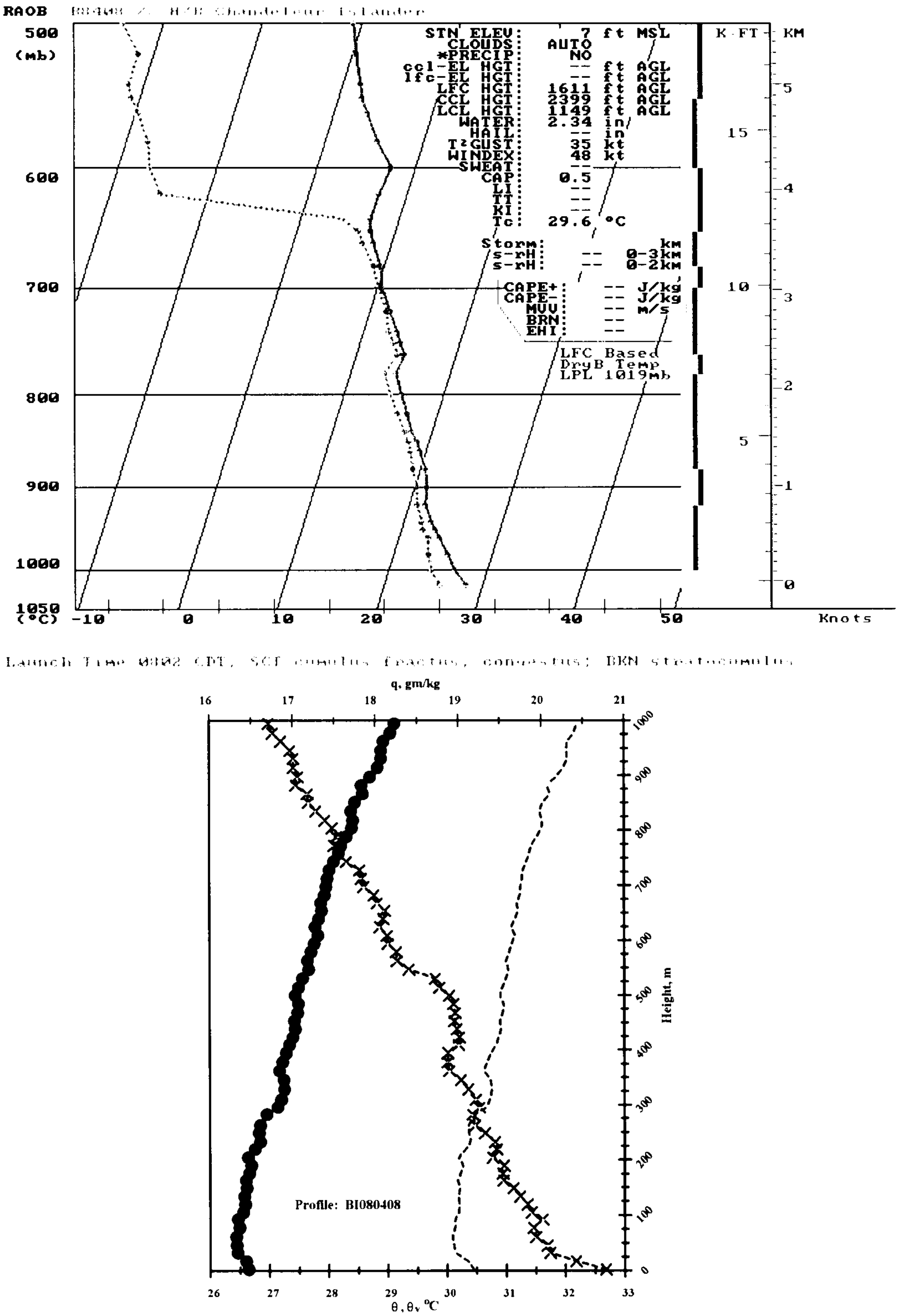


Figure 93. Thermodynamic and boundary layer profiles of 4 August 1998, 0802 CDT radiosonde over Breton Island. Lines as in Fig. 88.

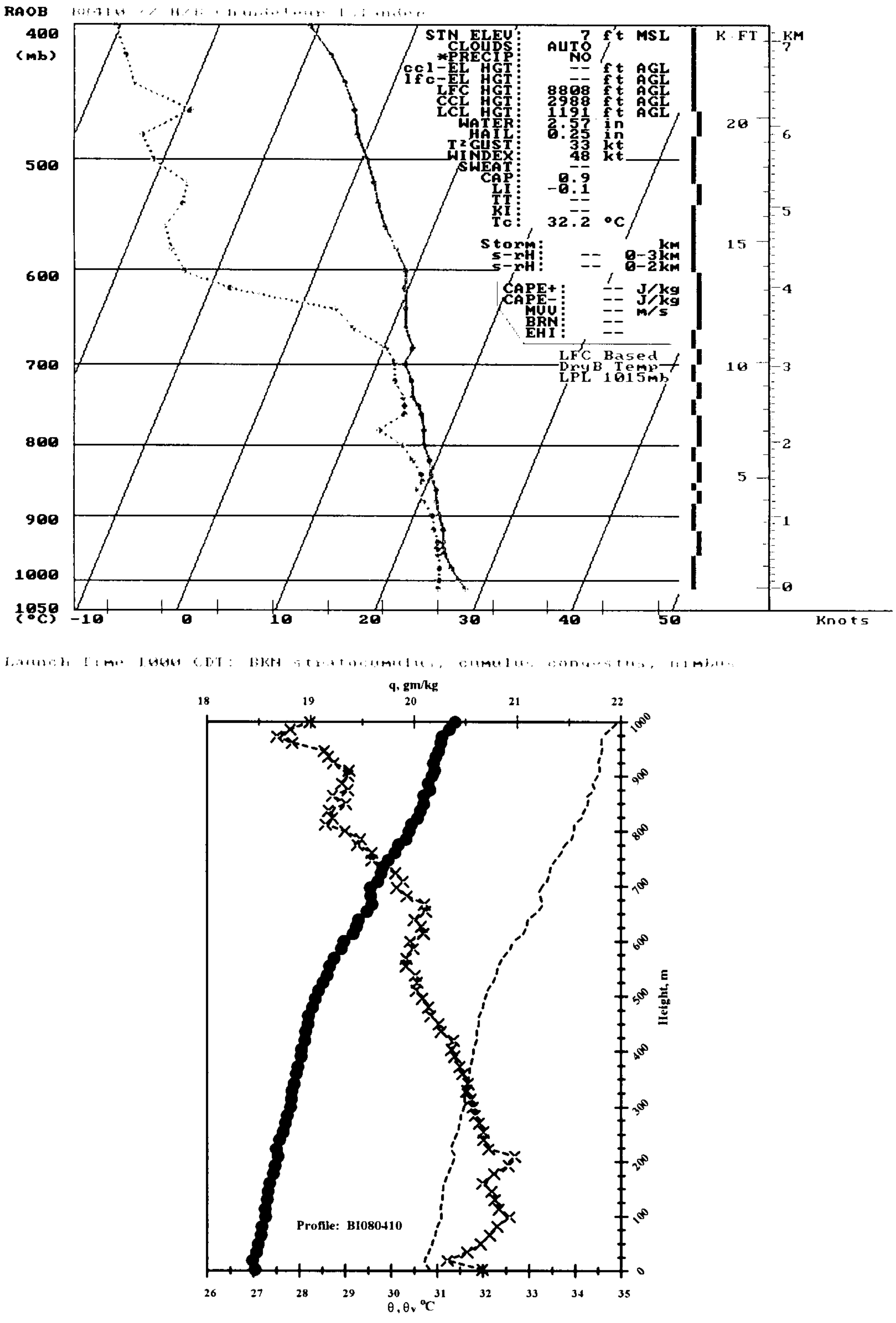


Figure 94. Thermodynamic and boundary layer profiles of 4 August 1998, 1000 CDT radiosonde over Breton Island. Lines as in Fig. 88.

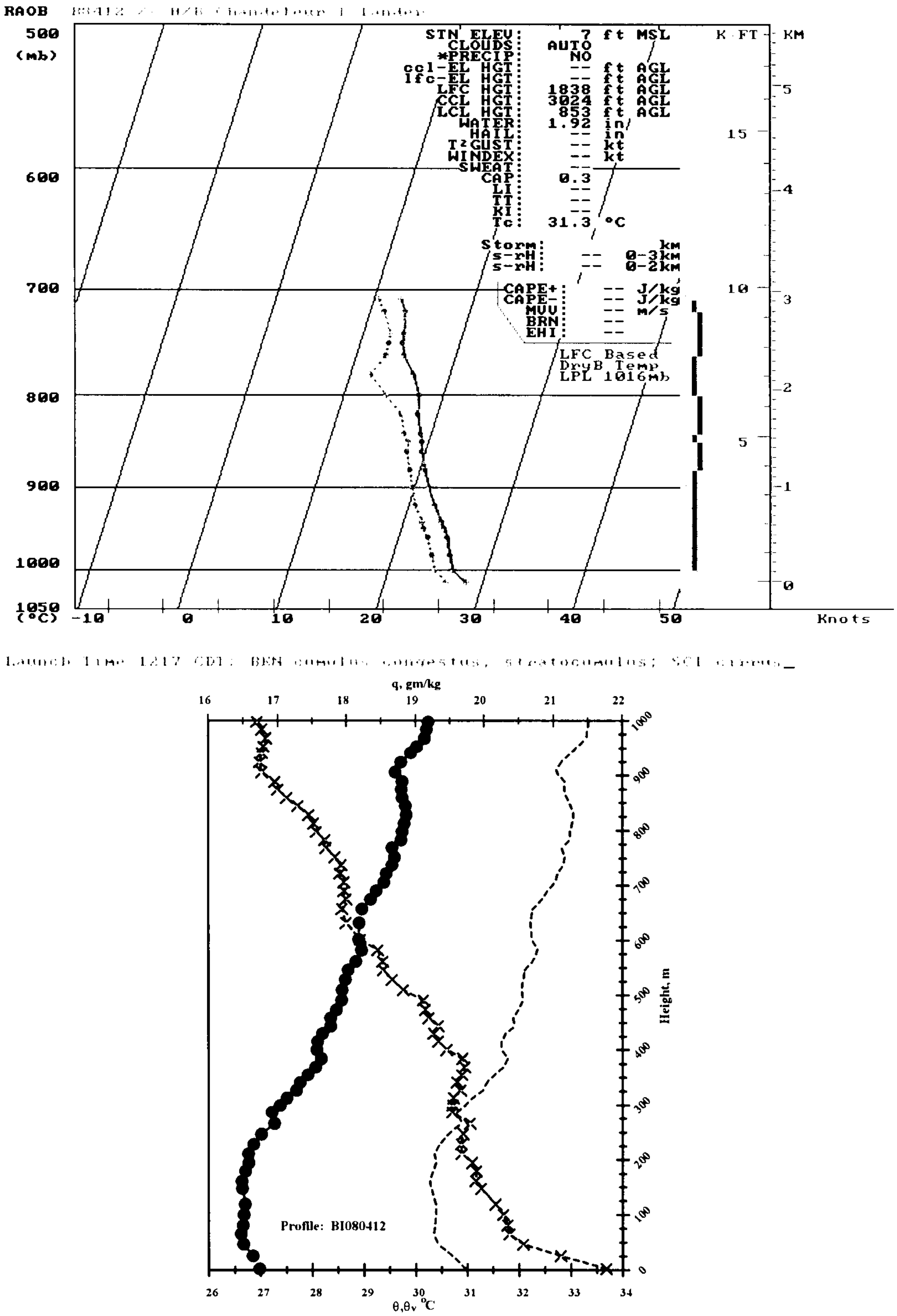


Figure 95. Thermodynamic and boundary layer profiles of 4 August 1998, 1217 CDT radiosonde over Breton Island. Lines as in Fig. 88.

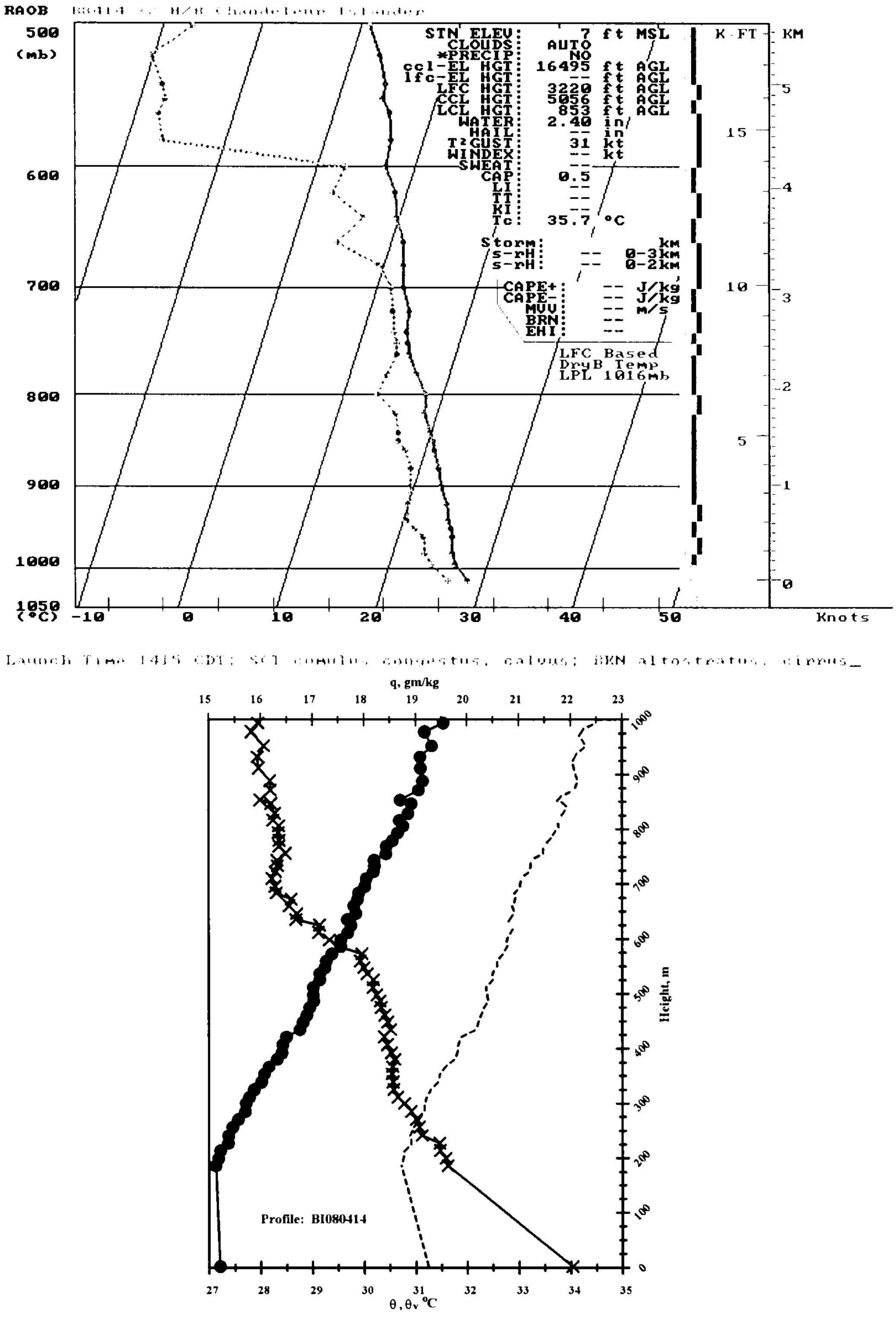


Figure 96. Thermodynamic and boundary layer profiles of 4 August 1998, 1415 CDT radiosonde over Breton Island. Lines as in Fig. 88.

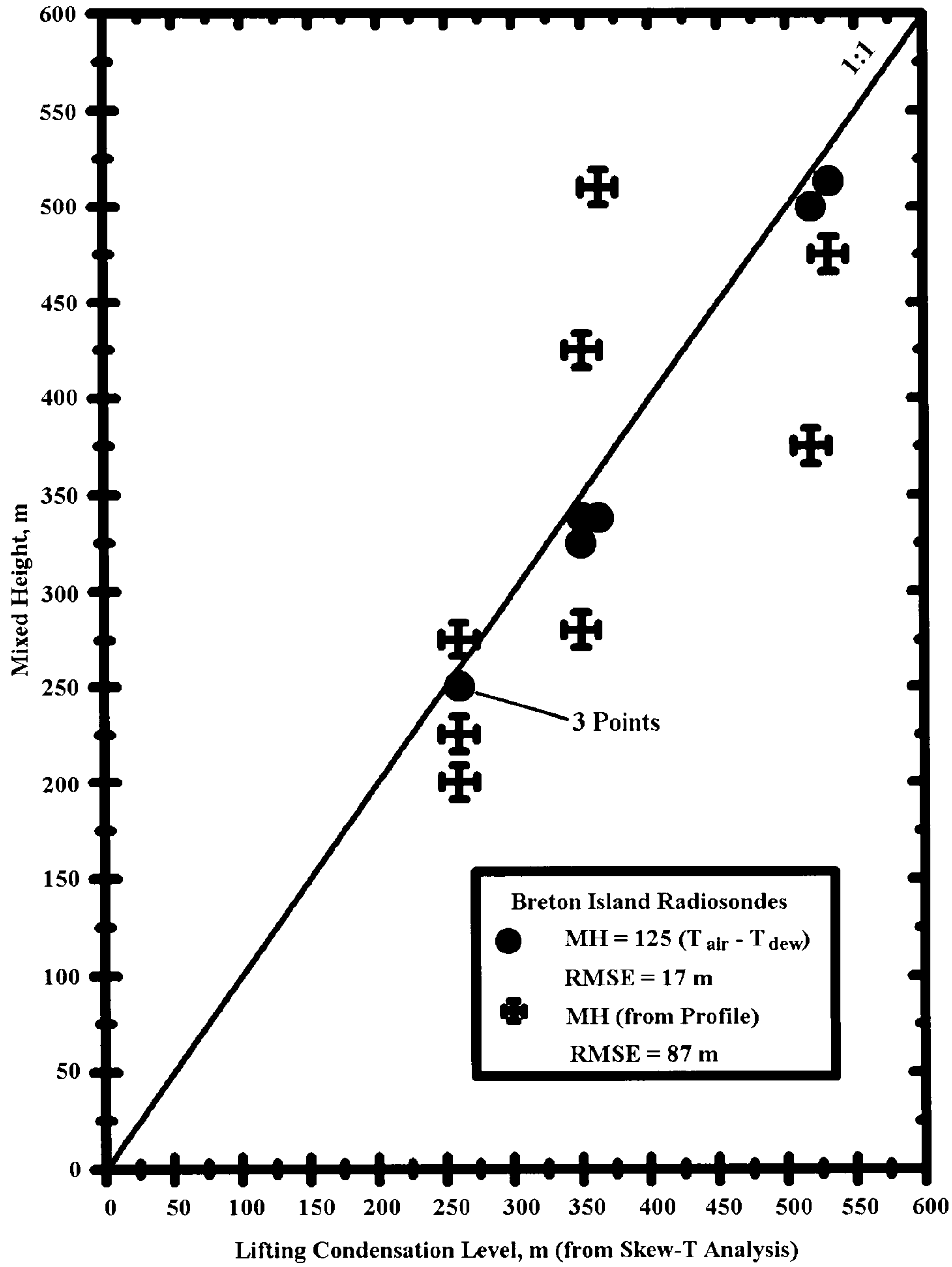


Figure 97. One-to-one comparison of LCL heights versus mixed heights from profile and computed by Eq. (16).

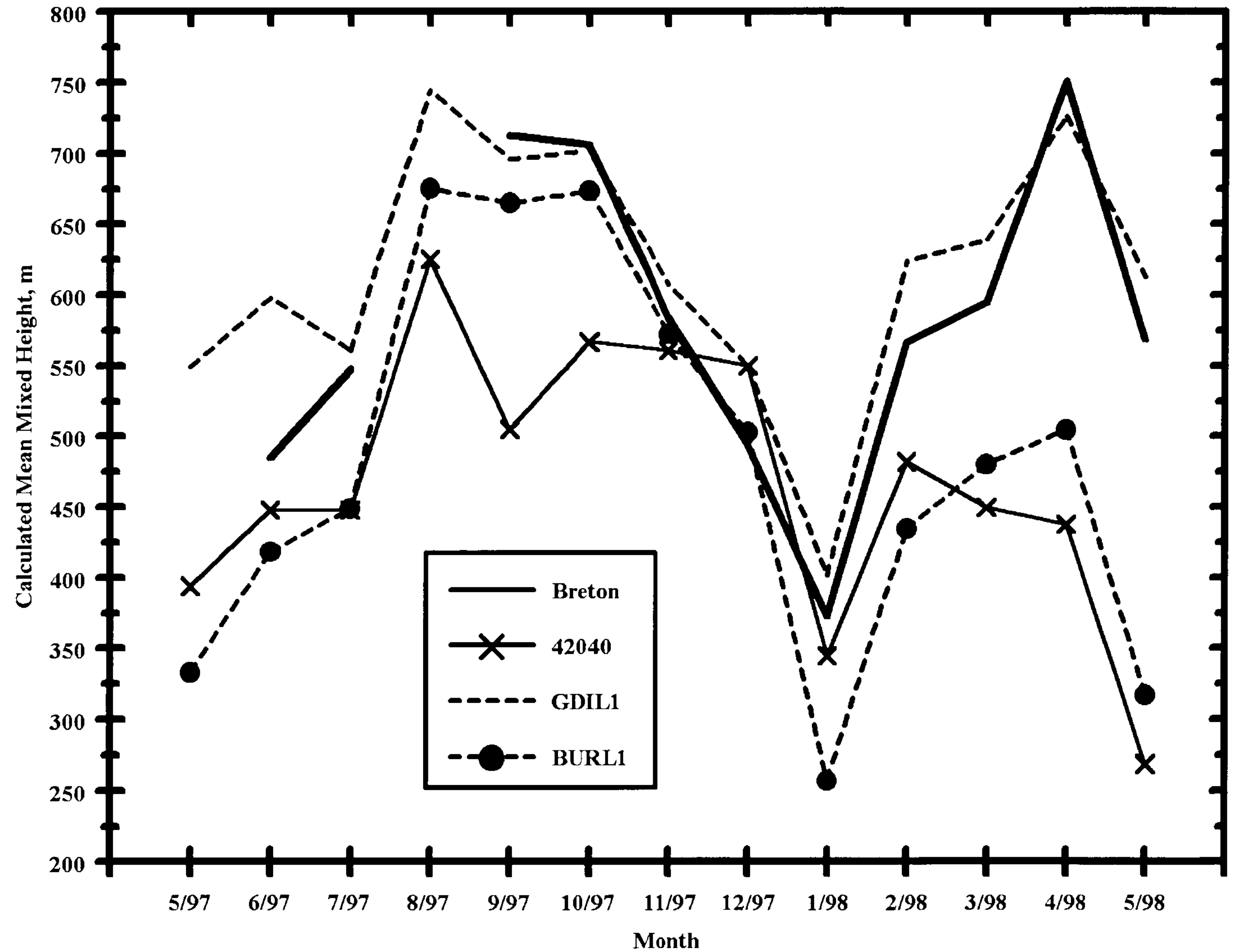


Figure 98. Variations of monthly mean mixed heights computed from Eq. (16) over the southeastern Louisiana coast and eastward over the BNWA.

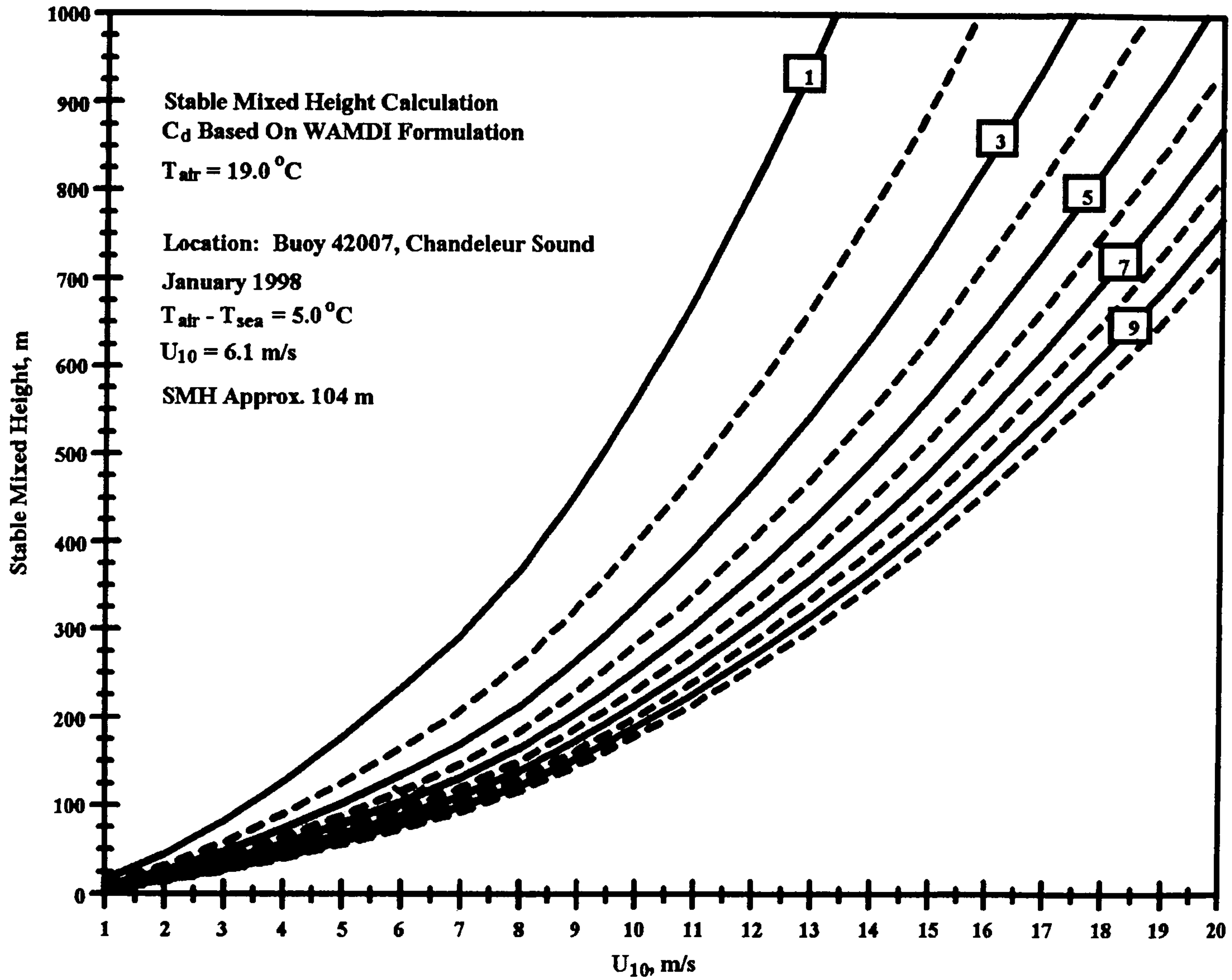


Figure 99. Stable mixed layer height nomogram for air temperature of 19°C. Lines indicate temperature difference (T_{air} - T_{sea}).

IV. Summary

Analysis of meteorological and air quality data records obtained during the period of May 1997 through July 1998 at Breton and Dauphin Islands yields many significant findings.

- Hourly concentrations of SO_2 and NO_2 at both stations were less than 6 ppb for over half of the study period.

- Average and maximum concentrations obtained were well below the National Ambient Air Quality Standard for both monitored pollutants.

- Concentrations are higher on average in the fall and winter months at both locations.

- No significant variations in the median SO_2 diurnal trends are evident at either location. Higher NO_2 is more likely in the early morning and, to a lesser extent, in the evening. This is an expected characteristic of NO_x, produced by chemical reactions fueled by solar radiation.

- Maximums of both pollutants are mostly associated with north-northeasterly winds at Dauphin Island.

- Breton SO_2 maximums are primarily seen with northerly winds, while NO_2 maximums are generally from the south-southwest.

- Continental High and Frontal Overrunning synoptic weather patterns are more likely to produce higher SO_2 over the BNWA, while Gulf Return, Frontal Overrunning, and Continental High conditions are mostly associated with higher NO_2.

- SO_2 concentrations are higher at Dauphin Island than at Breton; average NO_2 is nearly equivalent but higher maximums are observed at Breton.

- Short duration (about one day) high NO_x episodes are evident in the Breton data record, usually occurring several times each month.

- Accurate estimation of the drag coefficient, C_d, is essential for many air-sea applications. The wind-wave formulation (Eq. (5)) proposed by Hsu (1995a) is recommended for use.

- Turbulence intensities measured at Breton are in reasonable agreement with those found in the literature. However, even the very low elevation terrain of the islands can increase the turbulence.

- In the marine environment, the mixed height is equivalent to the lifting condensation level (LCL) under unstable conditions in the presence of cumulus clouds. Methods for estimating the LCL from surface parameters and from remotely-sensed input (satellite) are provided for use in the absence of in situ data.

- A nomogram for determining the stability category from routinely observed surface parameters is provided.

- Free-convective (defined here as $Z/L < -1.0$) stability was observed at Breton Island from 4 to 15% of the study period. Monthly mean stability was unstable throughout the year.

- Under stable conditions, mixed heights as low as approximately 100 m were observed over the BNWA. Methods for determining the mixed height under both stable and unstable conditions are provided.

The relatively short-term and non-continuous nature of these datasets makes comparison of the annual air quality statistics difficult. However, no significant change in pollutant characteristics between this study period and previously published results is evident at either location (with the slight increase of NO_2 at Breton attributed to station re-location). On the other hand, since the PSD Class I increments for SO_2 and NO_2 are only about 1 ppb (Boubel et al., 1994), continuous monitoring is strongly recommended to protect and preserve the environmental quality of these invaluable areas.

V. References

Boubel, R. W., D. L. Fox, D. B. Turner, and A. C. Stern. 1994. Fundamentals Of Air Pollution. San Diego: Academic Press. 574 pp.

Code of Federal Regulations. 1994. Title 40, Protection of Environment, Part 58, Appendix B, Quality assurance requirements for prevention of significant deterioration (PSD) air monitoring.

Chang, J. C., M. E. Fernau, J. S. Sire, and D. G. Strimaitis. 1998. A critical review of four types of air quality models pertinent to MMS regulatory and environmental assessment missions. OCS Study MMS 98-0050. Available from Minerals Management Service, Gulf of Mexico Region, New Orleans, LA.

Donelan, M. A., Dobson, F. W., Smith, S. D., and R. J. Anderson. 1993. On the dependence of sea surface roughness on wave development. J. Phys. Oceanogr., 23:2143 - 2149.

Donelan, M. A., W. M. Drennan, and K. B. Katsaros. 1997. The air-sea momentum flux in conditions of wind sea and swell. J. Phys. Oceanogr., 27:2087 - 2099.

Garratt, J. R. 1992. The Atmospheric Boundary Layer. Cambridge University Press. 316 pp.

Geernaert, G. L., S. E. Larsen, and F. Hansen. 1987. Measurements of wind stress, heat flux, and turbulence intensity during storm conditions over the North Sea. J. Geophys. Res., 92(C12): 13127 - 13139.

Hanna, S. R. 1984. Applications in air pollution modeling. Atmospheric Turbulence and Air Pollution Modeling. F. T. M. Nieuwstadt and H. van Dop, Eds., D. Reidel Publishing Co., pp. 275 - 310.

Hanna, S. R., L. L. Schulman, R. J. Paine, J. E. Pleim, and M. Baer. 1985. Development and evaluation of the offshore and coastal dispersion model. J. Air Poll. Contr. Assoc., 35:1039 - 1047.

Hsu, S. A. 1988. Coastal Meteorology. Academic Press, 260 pp.

Hsu, S. A. 1992. An overwater stability criterion for the offshore and coastal dispersion model. Boundary-Layer Meteorol., 60:397 - 402.

Hsu, S. A. 1995a. A proper wind-stress drag coefficient formulation for computer modeling of seas and coastal regions. In Computer Modeling of Seas and Coastal Regions II, C. A. Brebbia, L. Traversoni, and L. C. Wrobel (Editors), Computational Mechanics Publications, Boston, pp. 413 - 420.

Hsu, S. A. 1995b. Measurements of SO_2 concentration and atmospheric structure in Delta and Breton Wildlife Refuges. OCS Study MMS 95-0019. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. 74 pp.

Hsu, S. A. 1996. Analysis of ambient pollutant concentrations and meteorological conditions affecting EPA class I and II areas in southeastern Louisiana, Vol. 1: Technical Report. OCS Study MMS 96-0062. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. 156 pp.

Hsu, S. A. 1997. Estimating overwater convective boundary layer height from routine meteorological measurements for diffusion applications at sea. J. Appl. Meteor., 36:1245 - 1248.

Hsu, S. A. 1998. A relationship between the Bowen ratio and sea-air temperature difference under unstable conditions at sea. J. Phys. Oceanogr., 28:2222 - 2226.

Hsu, S. A., and B. W. Blanchard. 1998. Long-term measurements of SO_2 and NO_2 concentrations and related meteorological conditions in the northeastern Gulf of Mexico region. OCS Study MMS 98-0020. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. 308 pp.

Large, W. G., and S. Pond. 1981. Open ocean momentum flux measurements in moderate to strong winds. J. Phys. Oceanogr., 11:324 - 336.

Louisiana Office of State Climatology. 1995 - 1998. Louisiana Monthly Climate Review. Available from the Dept. of Geography and Anthropology, Louisiana State University, Baton Rouge, LA, 70803.

Kaimal, J. C. and J. J. Finnigan. 1994. Atmospheric Boundary Layer Flows. Oxford University Press, New York. 289 pp.

Kidder, S. Q., and T. H. Vonder Haar. 1995. Satellite Meteorology. Academic Press, San Diego, CA. 466 pp.

McIlveen, J. F. R. 1986. Basic Meteorology. Van Nostrand Reinhold (U.K.) Co., Ltd. 457 pp.

Muller, R. A. 1977. A synoptic climatology for environmental baseline analysis: New Orleans. J. Appl. Meteor., 16:20 - 33.

Panofsky, H. A. and J. A. Dutton. 1984. Atmospheric Turbulence. John Wiley. 397 pp.

Smith, S. D. 1980. Wind stress and heat flux over the ocean in gale force winds. J. Phys. Oceanogr., 10:709 - 726.

The WAMDI Group. 1988. The WAM model - a third generation ocean wave prediction model. J. Phys. Oceanogr., 18:1775 - 1810.

Wu, J. 1982. Wind-stress coefficients over sea surface from breeze to hurricane. J. Geophys. Res., 87(C12):9704 - 9706.

Zannetti, P. 1990. Air Pollution Modeling. Van Nostrand Reinhold. 444 pp.

The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

The Minerals Management Service Mission

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the **Offshore Minerals Management Program** administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS **Royalty Management Program** meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

The MMS strives to fulfill its responsibilities through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection.