NPS61-78-007

NAVAL POSTGRADUATE SCHOOL

Monterey, California

ATMOSPHERIC MARINE BOUNDARY LAYER MEASUREMENTS
IN THE VICINITY OF SAN NICOLAS ISLAND
DURING CEWCOM-78

C.W. Fairall, G.E. Schacher
K.L. Davidson, and T.M. Houlihan

September 1978

Approved for public release; distribution unlimited

Prepared for: Naval Air Systems Command (AIR 3706)
Washington, DC 20360

NAVAL POSTGRADUATE SCHOOL
Monterey, California

Rear Admiral T.W. Dedman
Superintendent

J.R. Borsting
Provost

The work reported herein was supported in part by the Naval Air Systems Command (AIR 370) and Naval Ocean Systems Center (EOMET).

This report was prepared by:

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: NPS61-78-007	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): Atmospheric Marine Boundary Layer Measurements in the Vicinity of San Nicolas Island During CEWCOM-78	5. TYPE OF REPORT & PERIOD COVERED: April - September 1978 Technical Report
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): C.W. Fairall, G.E. Schacher, K.L. Davidson, T.M. Houlihan	8. CONTRACT OR GRANT NUMBER(s): N00019-78-WR-81002; N66001-78-WR-00156
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Naval Postgraduate School, Monterey, CA 93940	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS: Naval Air Systems Command (AIR 3706), Washington, DC 20360	12. REPORT DATE: September 1978
	13. NUMBER OF PAGES: 74
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): Unclas
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Optical propagation, boundary layer, turbulence

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This is a report on the boundary layer aspects of the NPS participation in CEWCOM-78. The primary purpose of the experiment was to determine how representative San Nicolas Island is of an open ocean marine boundary layer and to examine the validity of boundary layer measurements at the NRL tower on the NW tip of the island. Under favorable wind conditions (NW) the turbulence and profile structure of the boundary layer near SNI was characterisitic of typical marine conditions. A comparison of simultaneous measurements at the NRL tower and the R/V ACANIA indicated considerable shoreline influence on the velocity fluctuations (U_* or ε)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

#20. and the mean wind speed (U) but essentially no influence on temperature fluctuations (C_T^2). Using the bulk method to calculate T_* and ξ from the ACANIA data, the actual measurements of C_T^2 could be predicted to within about a factor of two.

ATMOSPHERIC MARINE BOUNDARY LAYER MEASUREMENTS IN THE VICINITY OF SAN NICOLAS ISLAND DURING CEWCOM-78

C. W. Fairall, G. E. Schacher, K. L. Davidson
and T. M. Houlihan
Environmental Physics Group
Naval Postgraduate School
Monterey, California 93940

ABSTRACT

This is a report on the boundary layer aspects of the NPS participation in CEWCOM-78. The primary purpose of the experiment was to determine how representative San Nicolas Island is of an open ocean marine boundary layer and to examine the validity of boundary layer measurements at the NRL tower on the NW tip of the island. Under favorable wind conditions (NW) the turbulence and profile structure of the boundary layer near SNI was characteristic of typical marine conditions. A comparison of simultaneous measurements at the NRL tower and the R/V Acania indicated considerable shoreline influence on the velocity fluctuations (U_* or ε) and the mean wind speed (U) but essentially no influence on temperature fluctuations (C_T^2). Using the bulk method to calculate T_* and ξ from the Acania data, the actual measurements of C_T^2 could be predicted to within about a factor of two.

TABLE OF CONTENTS

APPENDICES

A. MOS Stability Functions

B. R/V Acania Boundary Layer Data

C. NPS Data From the Tower Site on SNI

D. Acoustic Sounder Data

FIGURES

TABLES

I. Primary data periods relevant to R/V Acania evaluations of SNI.

II. Comparison of turbulence (C_T^2 and U_*) and mean wind speed (U) measurements taken simultaneously at the NRL tower and aboard the R/V Acania. The Acania data are in Z=10 meter equivalent values The SNI C_T^2 and U data are from the Z=11.4 meter level. The U_* values from both sites are obtained by combining multi-level ε data.

III. Ratio of SNI to Acania measurements (r) for C_T^2, U_* and U.

REFERENCES

1. Businger, J. A., J. C. Wyngaard, Y. Izumi and E. F. Bradley, "Flux Profile Relationships in the Atmospheric Surface Layer", J. Atmos. Sci. 28, 181-189 (1971).

2. Davidson, K. L., T. M. Houlihan, C. W. Fairall, G. E. Schacher and D. Hinsman, "Description of Optically Relevant Turbulence Parameters", Proc. of Optical-Submillimeter Atmos. Propagation Conf., Colorado Springs, CO (1971).

3. Davidson, K. L., T. M. Houlihan, C. W. Fairall, and G. E. Schacher, "Observations of the Temperature Structure Function Parameter, C_T^2, Over the Ocean", NPS Report (1978).

4. Fairall, C. W., K. L. Davidson, T. M. Houlihan, and G. E. Schacher, "Atmospheric Turbulence Measurements in Marine Fog During CEWCOM -76", NPS Report NPS61-77-004 (1977).

5. Friehe, C. W., J. C. LaRue, F. H. Champagne, C. H. Gibson, and G. F. Dryer, "Effects of Temperature and Humidity Fluctuations on the Optical Refractive Index in the Marine Boundary Layer", J. Opt. Soc. Amer., 65, 1502-1511 (1975).

6. Haugen, D. Workshop on Micrometeorology, American Meteorology Society [Science Press] 392 pp (1974).

7. Wyngaard, J. C., Y. Izumi and S. A. Collins, "Behavior of the Refractive Index Structure Parameter Near the Ground", J. Opt. Soc. Amer., 61, 1646-1650 (1971).

8. Wyngaard, J. C. and O. R. Cote, "The Budgets of Turbulent Kinetic Energy and Temperature Variance in the Atmospheric Surface Layer", J. Atmos. Sci., 28, 181-189 (1971).

I. SUMMARY

A. Introduction

This is a report on atmospheric measurements made by the Naval Postgraduate School Environmental Physics Group aboard the R/V Acania in the vicinity of San Nicolas Island (SNI) in May of 1978. The primary goal of these measurements was to examine the open ocean "representativeness" of SNI and to evaluate the validity of measurements made at the NRL tower site on the north west tip of the island. This report will focus on the turbulence and boundary layer data, leaving the aerosol evaluation for a later report. In addition, the NPS group provided direct micrometeorological support for optic experiments and a rather conclusive study of the bulk method scaling law predictions of turbulence parameters in the surface layer.

B. Conclusions

How representative SNI is of the marine condition is more of an aerosol question than a turbulence question. However, the turbulence aspect is important. During CEWCOM-76 it was found that coastal areas exhibited diurnal variations of temperature structure function, C_T^2, characteristic of overland sites (minima in C_T^2 at sunrise and sunset) whereas open ocean areas exhibited almost no diurnal variation. Under the W-NW wind conditions that predominated during the turbulence evaluation periods of CEWCOM-78, the C_T^2 measurements near SNI showed no obvious diurnal variation.

The Naval Research Laboratory (NRL) tower site measurement made by NPS personnel using identical equipment to that being employed on the R/V Acania have been compared to simultaneous shipboard measurements. For data taken when the Acania was in the immediate vicinity of the tower site (primarily anchored within .3 miles) the C_T^2 comparison showed excellent agreement. Neglecting a few low wind speed cases, the average disagreement was only 7% for 23 periods with a single measurement standard deviation of 64%. Given the combined measurement uncertainty of about 30% and the uncertainty introduced by the stochastic nature of atmospheric turbulence, it may be quite difficult to do significantly better. Although only a few periods were available, C_T^2 measurements made at the NRL tower compared fairly well with shipboard measurements made when the Acania was 30 to 50 miles upwind of the island. This indicates that SNI is in a region of good horizontal homogeneity under NW wind conditions.

Comparisons of wind speed, U, and the rate of disipation of turbulence kinetic energy, ε, were not nearly as favorable as the C_T^2 comparison. The values of ε were used to calculate the friction velocity U_* (the surface stress is proportional to U_*^2). On average, the tower measurements of U_* were 2.5 times greater than the ship measurements with a standard deviation of 93%. The tower measurements of wind speed (at Z=11 meters) were, on average, 16% lower than the ship measurements with a standard deviation of 10%. The lower wind speed and higher surface stress at the tower is a result of the increased drag imposed by the surf and land. This means that neither turbulence nor profile measurements at the tower can be used to determine the atmospheric stability and Monin-Obukhov scaling parameters over the immediate ocean area.

The estimation of C_T^2 (as well as ε) using Monin-Obukhov scaling parameters not only requires a validation of the C_T^2 parameterization formulae, but also requires a practical method of obtaining the scaling parameters. Employing only four physical quantities (sea surface temperature and wind speed, air temperature and relative humidity at some reference height above the sea surface) the bulk method is not only the simplist but is also the least demanding in terms of accuracy. Using data from several cruises, the NPS group has shown that Wyngaard et al.'s (1971) C_T^2 parameterization is valid over the ocean and that the bulk method provides an excellent rendition of the scaling parameters [Davidson et al. (1978)]. Included in this report is a comparison of bulk predictions with observations obtained during CEWCOM-78, demonstrating the applicability of this technique.

C. General Comments and Recommendations

1. Obviously the NRL tower site location is most suitable for NW wind conditions. During CEWCOM-78 we did find good tower data for winds from 240 to 320 degrees (this does not necessarily exclude other wind directions). However, there is evidence of land influence under light wind conditions. In view of this, it would be prudent to limit the tower data to wind speeds greater than 2.5 m/sec.

2. We feel that atmospheric stability and Monin-Obukhov scaling parameters should be calculated using the bulk method with the updated coefficients and techniques given in the text. This will require supplementing the tower measurements with a sea surface or bulk ocean temperature measurement. Also, the tower measured wind speed should be increased to account for the surface drag effects.

3. Given the importance of the humidity contribution to C_N^2, the temperature-humidity covariance, C_{Tq}, should be measured at the tower site. Based on bulk estimates, during CEWCOM-78 the average relative contribution of C_T^2 and C_N^2 was 70%, the C_{Tq} contribution was 24% and the C_q^2 contribution was 6%.

II. SHIP MOVEMENTS

The primary movements of the R/V Acania are shown in Figures 1 and 2. Anchorage locations at SNI are shown in Figure 3. A summary of data periods relevant to SNI evaluations is given in Table I. Periods of running downwind and periods inside the Channel Islands have been excluded.

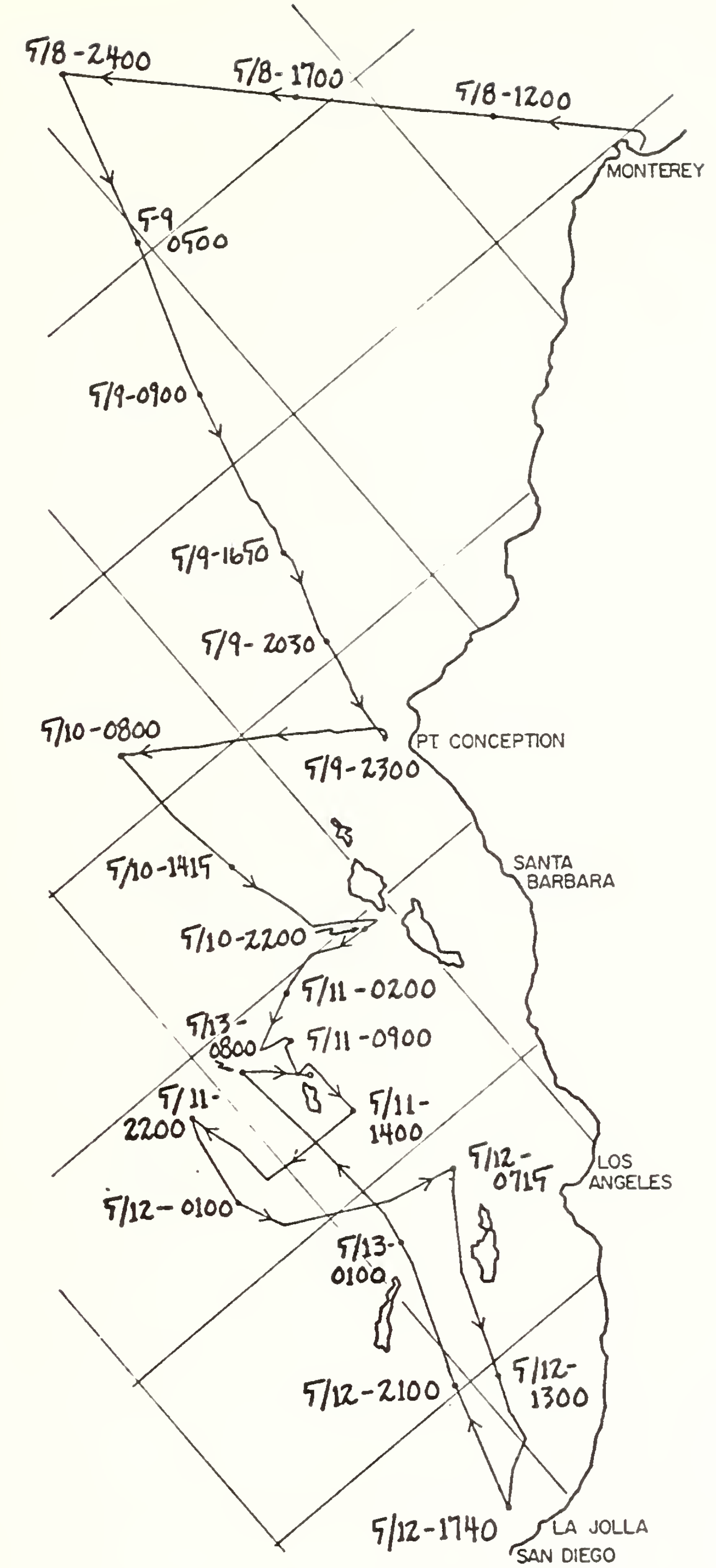


Figure 1. Positions of R/V Acania from 5/8/78 to 5/15/78

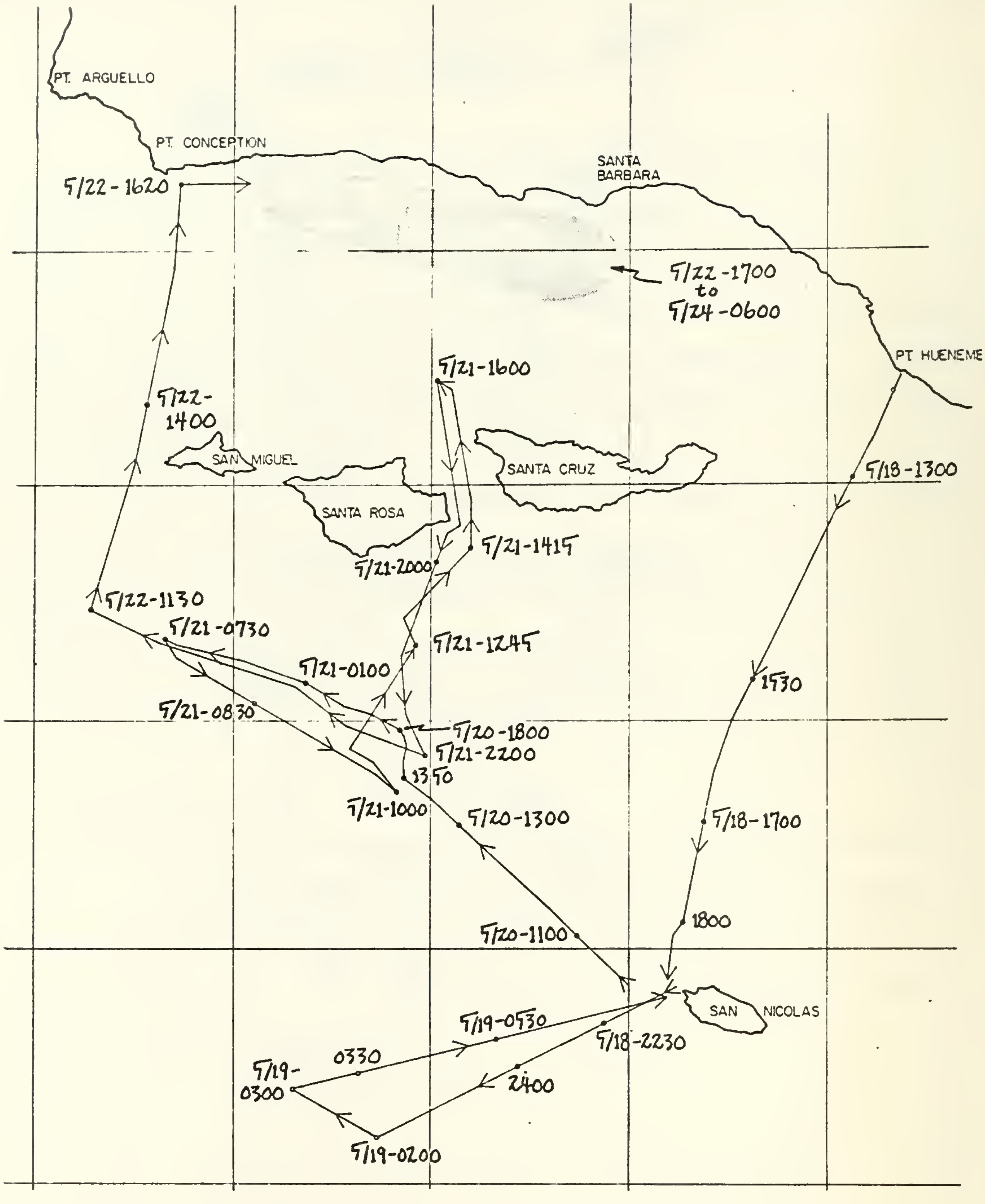


Figure 2. Positions of R/V Acania from 5/18/78 to 5/25/78

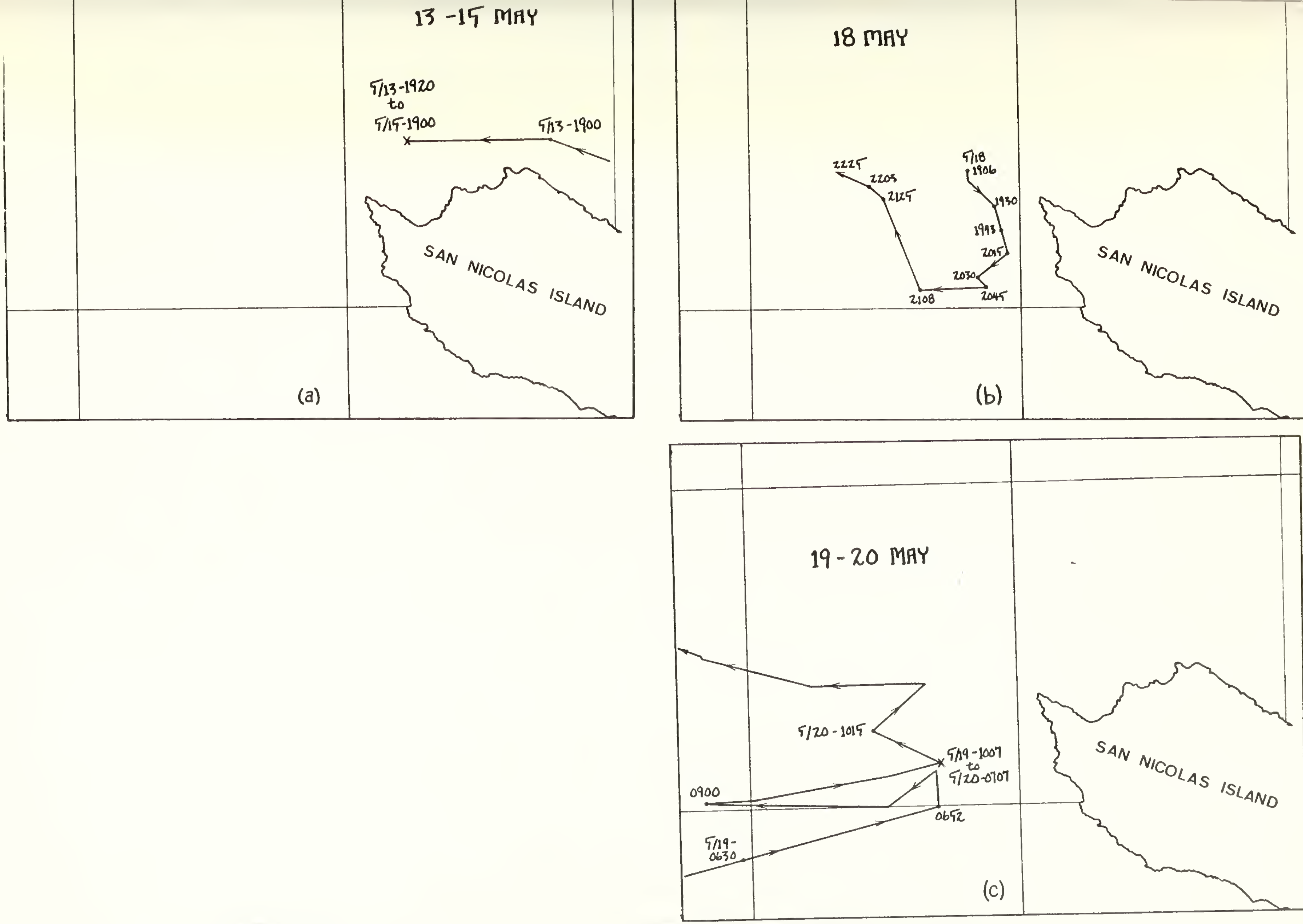


Figure 3. Positions and Anchorages (x) of R/V Acania in the Vicinity of San Nicolas Island; a) 5/13-15; b) 5/18; c) 5/19-20

TABLE I. PRIMARY DATA PERIODS RELEVANT TO R/V ACANIA EVALUATIONS OF SNI.

DATE	START	END	POSITION FROM SNI	MOVEMENT	SPEED
5/10	0300	1000	Upwind (70 miles)	V*	6 kts
5/11	0220	1230	Upwind	V	6-3 k
5/13	0100	0930	Downwind	U**	6 kts
	1820	1920	Parallel North Shore	U	6 kts
	1920	—	.3 mile NW	A***	0
5/14	—	—	.3 mile NW	A	0
5/15	—	1900	.3 mile NW	A	0
5/18	1800	2200	Near NW Point	V	3 kts
	2200	—	Upwind	U	varie
5/19	—	0300	Upwind	U	6 kts
	0700	0900	Near NW Point	V	3 kts
	1000	—	.3 mile NW	A	0
5/20	—	0800	.3 mile NW	A	0
	0800	1340	Upwind	U	6 kts
	1340	—	Upwind (30 miles)	U	2 kts
5/21	—	0700	Upwind (40 miles)	U	2 kts
	1000	1130	Upwind (30 miles)	U	2 kts
	2200	0000	Upwind (30 miles)	U	2 kts
5/22	—	1130	Upwind (40 miles)	U	2 kts

*V - Varied
**U - Upwind
***A - Anchored

III. THEORETICAL SUMMARY

A. Definitions

The optically relevant turbulence quantities measured were temperature structure function parameter, C_T^2, and the rate of dissipation of turbulent kinetic energy, ε. The refractive index structure function parameter, C_N^2, is related to C_T^2 by

$$C_N^2 = (79 \times 10^{-6} P/T)(C_T^2 + .11\, C_{Tq} + .0032\, C_q^2) \quad (1)$$

where C_{Tq} is the temperature - water vapor covariance parameter and C_q^2 is the water vapor structure function parameter. The microscale of turbulent functions, η, is related to ε by

$$\eta = (\nu^3/\varepsilon)^{1/4} \quad (2)$$

where ν is the kinematic viscosity of air.

B. Monin-Obukhov Similarity (MOS)

In the atmospheric surface layer ($Z \leq 50$ meters) C_T^2 and ε can be calculated from scaling parameters that are related to more easily measured atmospheric properties [see Haugen (1973) for a review]. The appropriate MOS formulae are

$$C_T^2 = T_*^2\, Z^{-2/3}\, f(\xi) \quad (3)$$

$$\varepsilon = (U_*^3/Kz)E(\xi) \quad (4)$$

Where T_* and U_* are the potential temperature and wind speed scaling parameters, $f(\xi)$ and $E(\xi)$ are dimensionless MOS functions (Appendix A), Z is the vertical coordinate and K is Von Karmon's constant (K = .35). The MOS dimensionless stability parameter, ξ, is related to the Monin-Obukhov length, L,

$$\xi = Z/L = \frac{KgZ}{T} \frac{(T_* + .61\ Tq_*)}{U_*^2} \tag{5}$$

where q_* is the water vapor mixing ratio scaling parameter, T is the temperature and g is the acceleration of gravity.

The vertical profile of the mean quantity X (where X = T, q, U) can be represented by

$$X(Z) = X(O) + \frac{X_*}{\alpha_X KZ} (\ln Z/Z_{ox} - \psi_X(\xi)) \tag{6}$$

where Z_{ox} is the roughness length for X and $\psi_X(\xi)$ is the profile function (Appendix A). The value of K is chosen so that α_u=1. We have assumed $\alpha_T = \alpha_q = 1.35$.

C. Bulk Method

One cannot calculate C_T^2 and ε from Equations 3 and 4 until one first obtains values for T_*, U_* and ξ. The bulk method of determining the MOS scaling parameters is based upon relating X_* to the air-sea X difference (ΔX) through the drag coefficient c_X.

$$X_* = c_X^{1/2}(X(Z) - X(O)) = c_X^{1/2} \Delta X \tag{7}$$

Using Equation 6 we can define the neutral value (ξ = 0) of the drag coefficient, c_{XN}

$$c_{XN}^{1/2} = \frac{\alpha_X K}{\ln Z/Z_{ox}} \tag{8}$$

and relate c_{XN} to c_X

$$c_X = \frac{c_{XN}}{(1 - (\alpha_X K)^{-1} c_{XN}^{1/2} \psi_X(\xi))^2} \tag{9}$$

Using Equation 5 and Equation 7 we can calculate

$$\xi = \xi_o \frac{(1 - K^{-1} c_{UN}{}^{1/2} \psi_U(\xi))^2}{(1 - (\alpha_T K)^{-1} c_{TN}{}^{1/2} \psi_T(\xi))} \qquad (10)$$

with

$$\xi_o = \frac{KgZ}{T} \; \frac{c_{TN}{}^{1/2}(\Delta T + .18\Delta q)}{c_{UN} U^2} \qquad (11)$$

where Δ T is the air-sea potential temperature difference (°C), Δq is the air-sea water vapor mixing ratio difference (gm/kg) and U is the wind speed (m/sec). c_{UN} varies with wind speed but is well approximated by $c_{UN} = 1.3 \times 10^{-3}$. Based upon Davidson et al.'s (1978) work, a good value for c_{TN} is $c_{TN} = 1.3 \times 10^{-3}$.

The actual bulk method process goes as follows:

1) From U calculate c_{UN}
2) From U, ΔT, Δq, c_{UN} calculate ξ_o (Equation 11)
3) From ξ_o, solve Equation 10 to find ξ
4) From ξ and c_{TN} calculate c_T (Equation 9)
5) From ΔT and c_T calculate T_* (Equation 7)
6) From T_* and ξ calculate $C_T{}^2$ (Equation 3)

The process can be greatly simplified by ignoring the wind speed dependence of c_{UN}. In this case (for z = 10 meters and T=15°C)

$$\xi_o = 3.3 \; (\Delta T + .18\Delta q)/U^2$$

We have solved Equation 10 for this case, allowing a simple algebraic relation between ξ_o and ξ.

$$\xi = \xi_o\ (1 - .03\xi_o^{.4}) \qquad \xi_o<0 \qquad (13a)$$

$$\xi = \xi_o(1 + .18\xi_o^{.8} + .13\xi_o^{3}) \qquad \xi_o>0 \qquad (13b)$$

This leads to the simplified bulk method process:

1) From U, ΔT and Δq calculate ξ_o (Equation 12)
2) From ξ_o calculate ξ (Equation 13)
3) From ξ and c_{TN} calculate c_T (Equation 9)
4) From ΔT and c_T calculate T_* (Equation 7)
5) From T_* and ξ calculate C_T^2 (Equation 3)

D. Application of Bulk Method to C_N^2

In order to calculate C_N^2 from Equation 1, one must have available estimations of C_T^2, C_{Tq} and C_q^2. Since the bulk method calculations have given us T_*, q_* and ξ, let us suppose that C_q^2 and C_{Tq} can be calculated from the MOS analagous form for Equation 3

$$C_q^2 = q_*^2\ Z^{-2/3}\ f(\xi) \qquad (14a)$$

$$C_{Tq} = T_*q_*Z^{-2/3}\ f(\xi) \qquad (14b)$$

From Equation 1, we now have

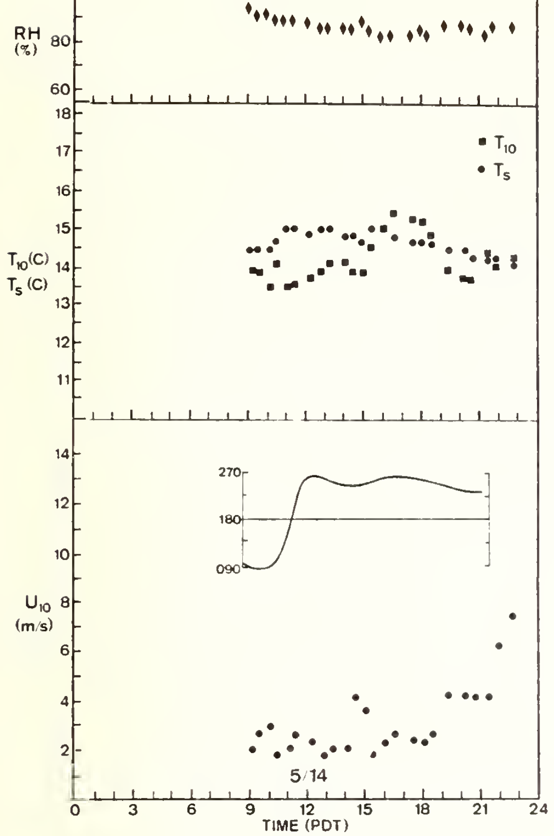
$$C_N^2 = (79 \times 10^{-6}P/T^2)^2(T_*^2 + .11\ T_*q_* + .0032q_*^2)Z^{-2/3}f(\xi) \quad (15)$$

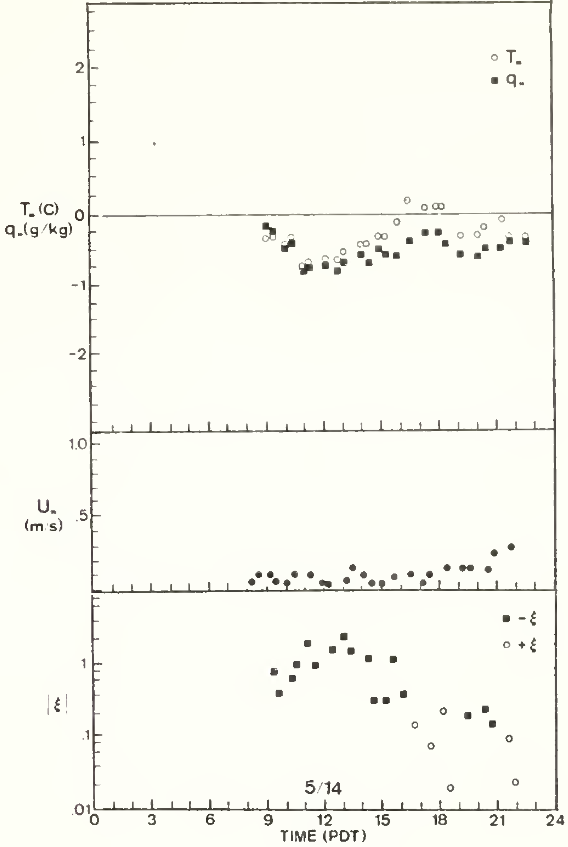
In Equations 14a and 14b we have assumed that C_q^2 and C_{Tq} obey Monin-Obukhov similarity and they have the same dimensionless structure function parameter $(f(\xi))$ as C_T^2.

IV. DATA

A. Surface Layer Data

The shipboard turbulence, mean and MOS scaling parameter data are shown in Figures 4 through 12. The turbulence





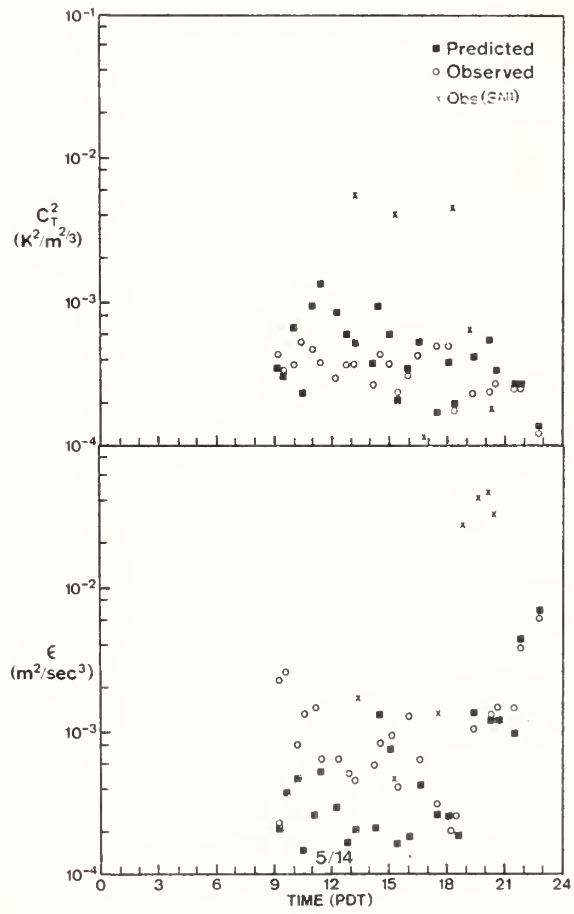
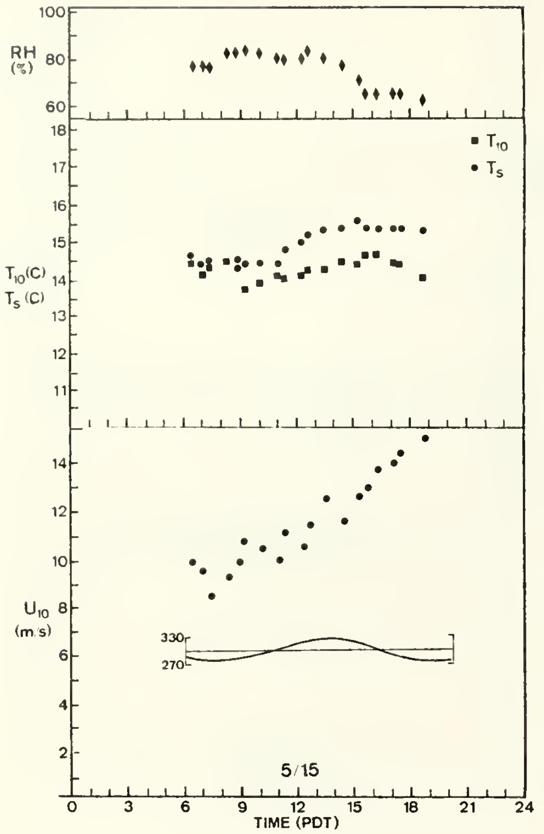
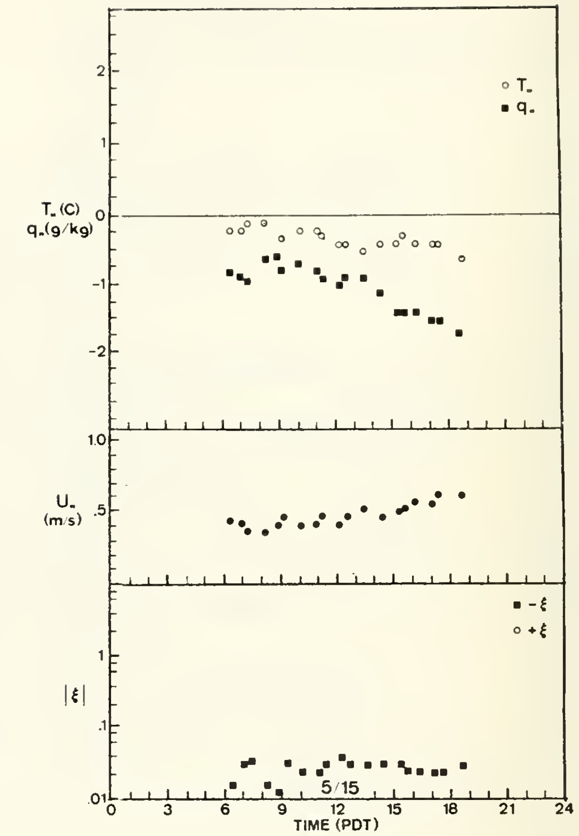


Figure 4. A/V Acania Atmospheric Surface Layer Data for 5/14/78.





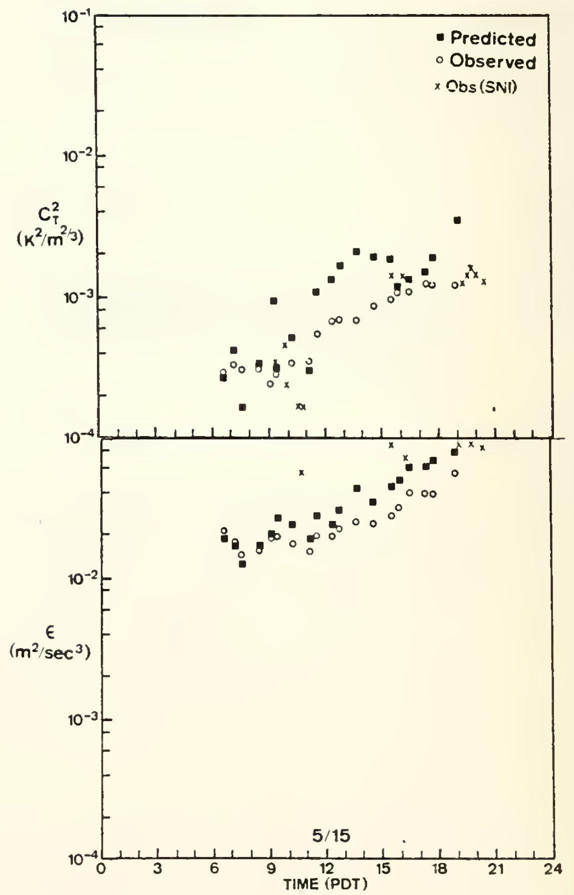
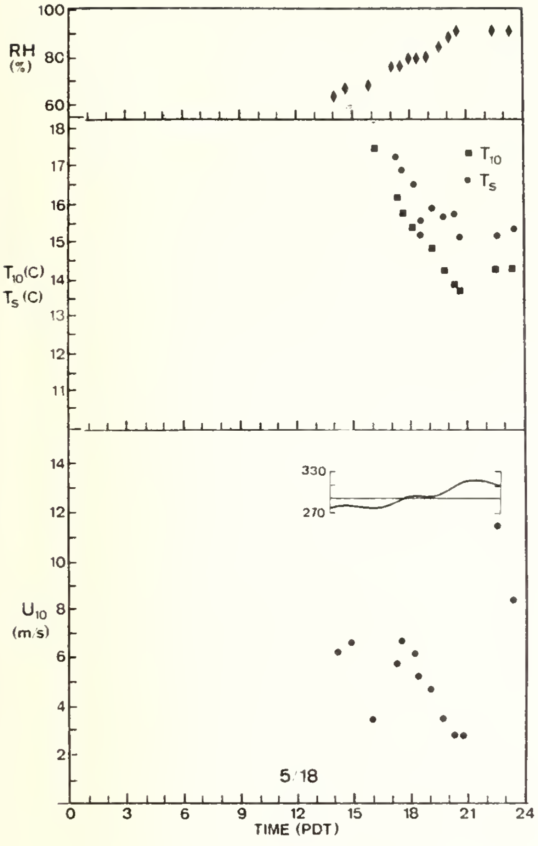
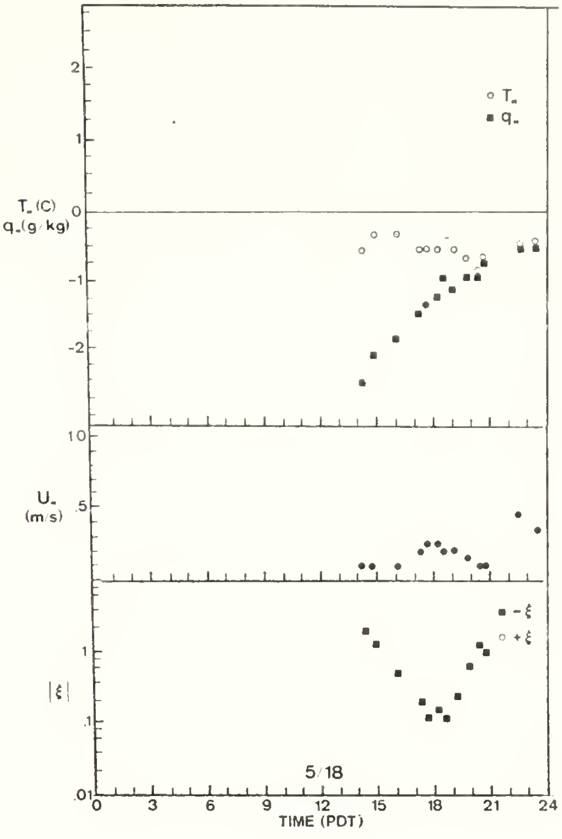


Figure 5. R/V Acania Atmospheric Surface Layer Data for 5/15/78.





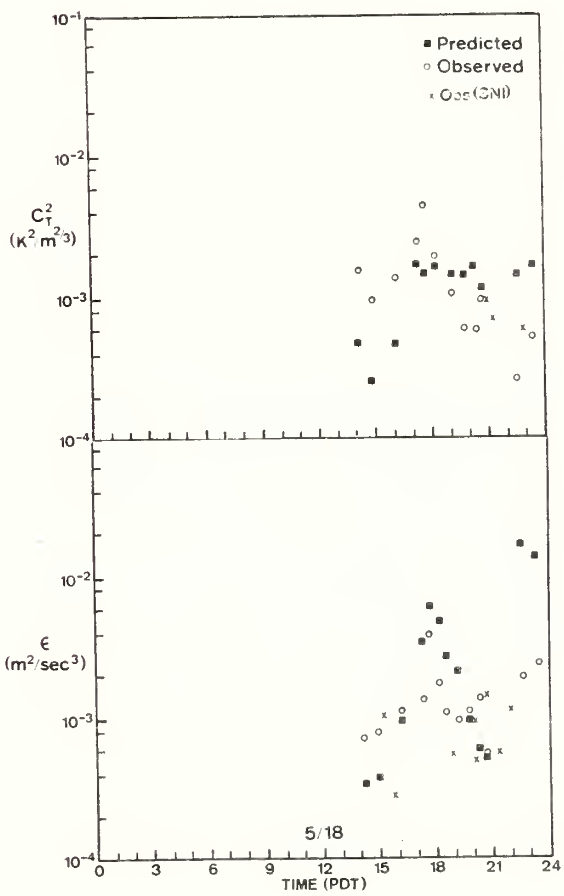
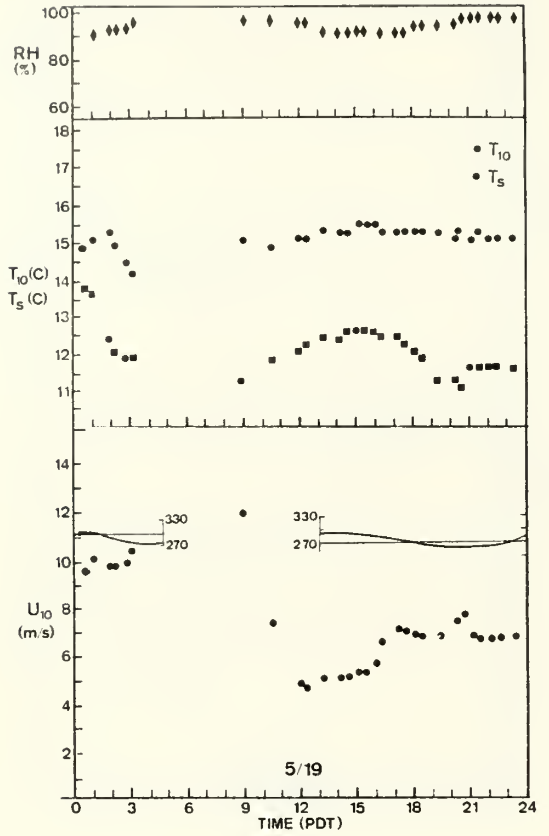
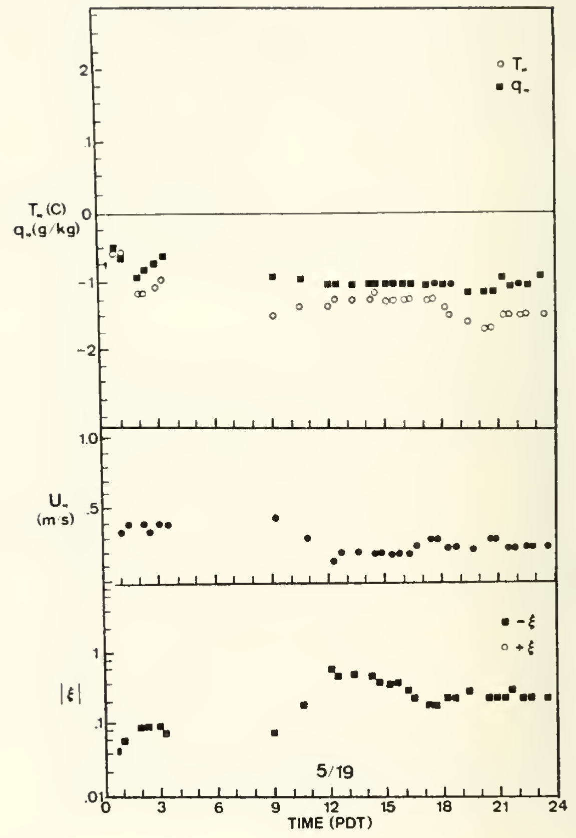


Figure 6. R/V Acania Atmospheric Surface Layer Data for 5/18/78.





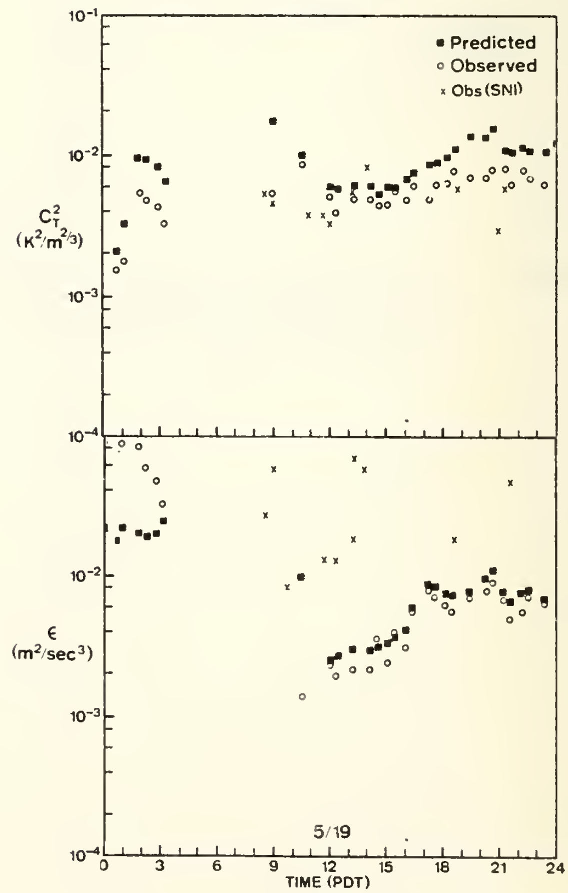
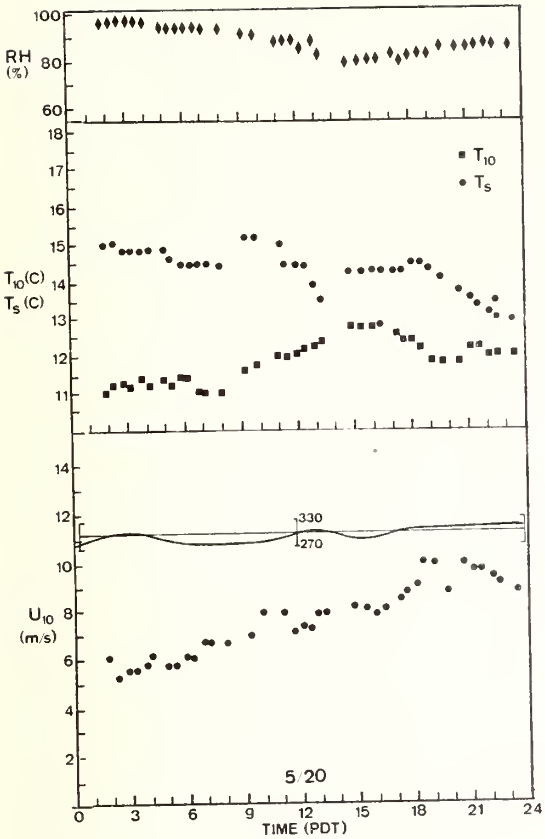


Figure 7. R/V Acania Atmospheric Surface Layer Data for 5/19/78.



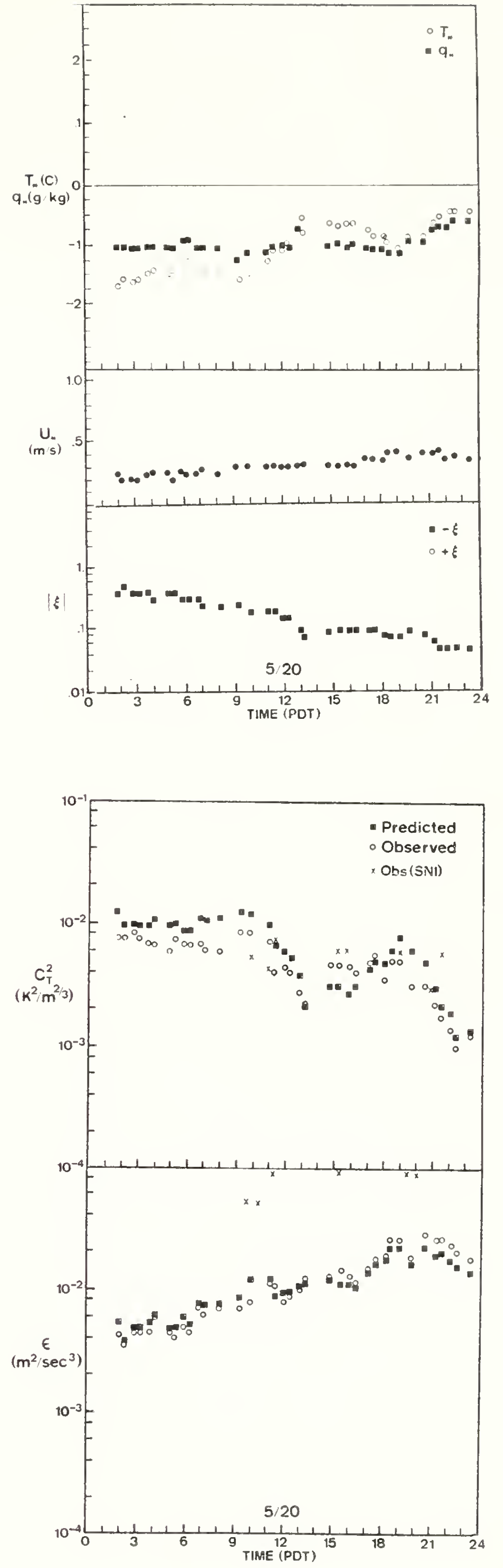
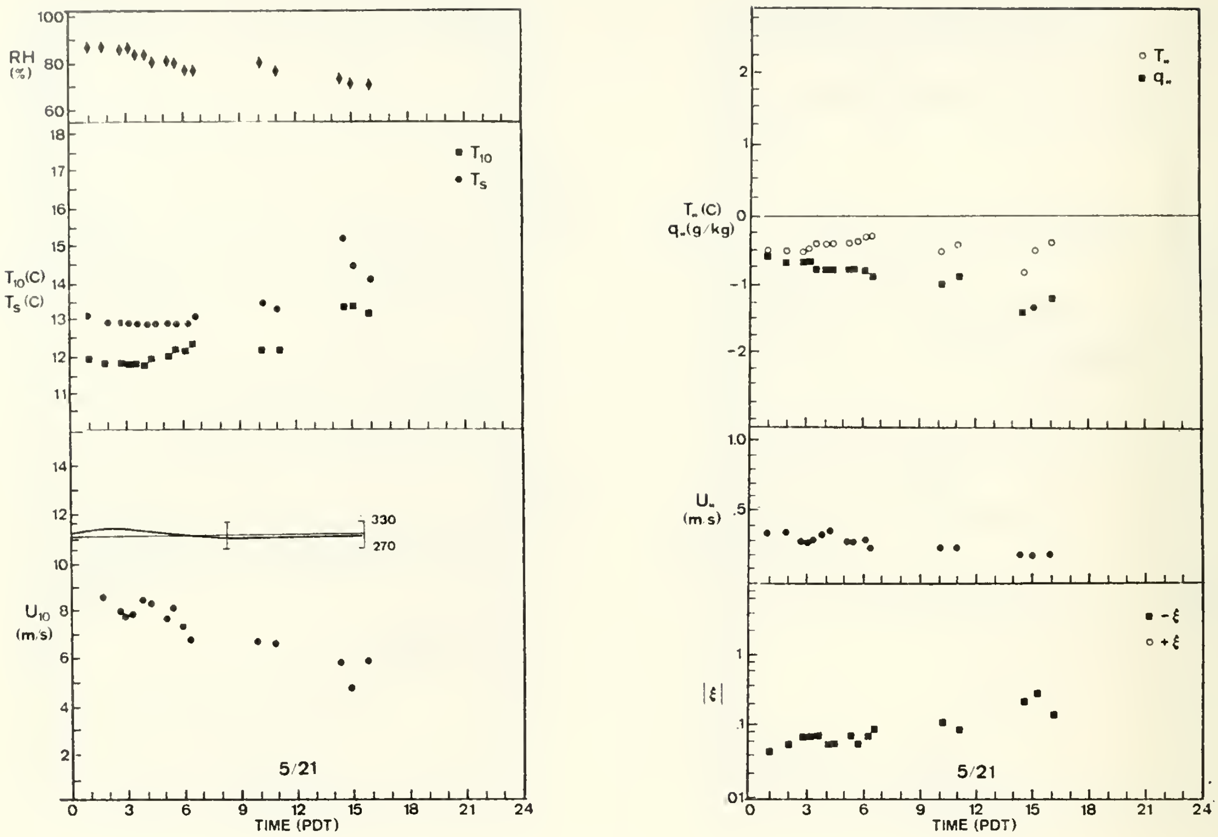


Figure 8. R/V Acania Atmospheric Surface Layer Data for 5/20/78.



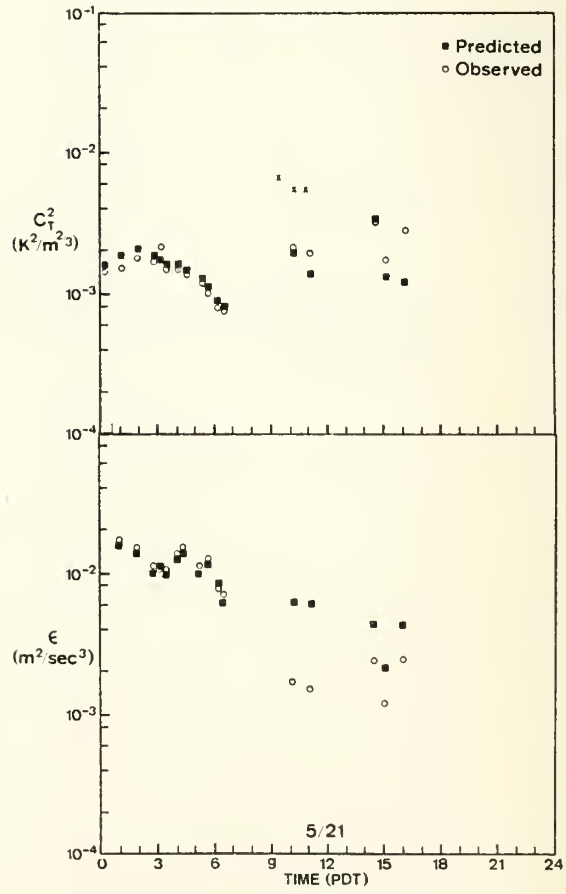
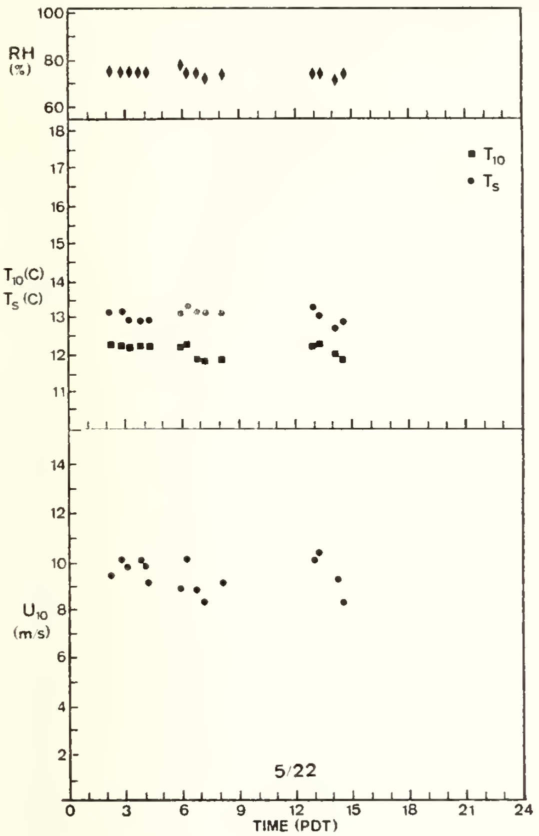
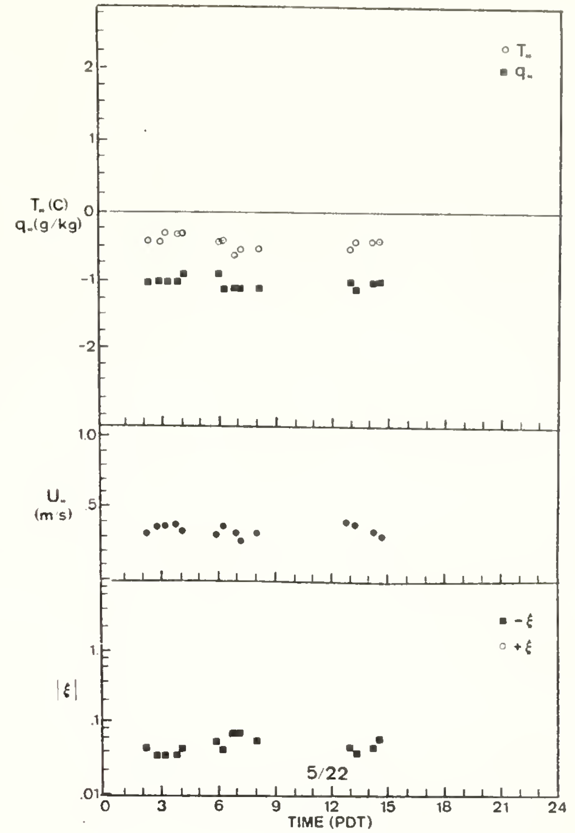


Figure 9. R/V Acania Atmospheric Surface Layer Data for 5/21/78.





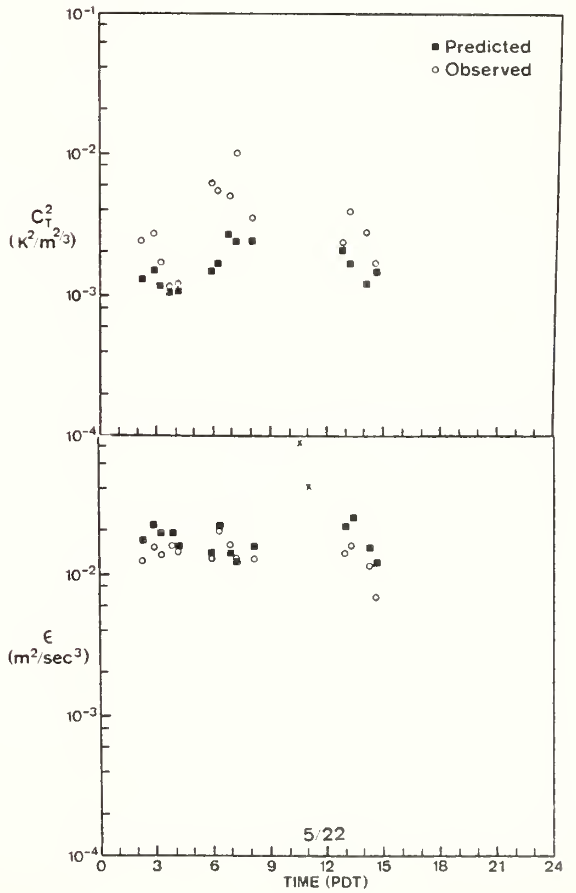
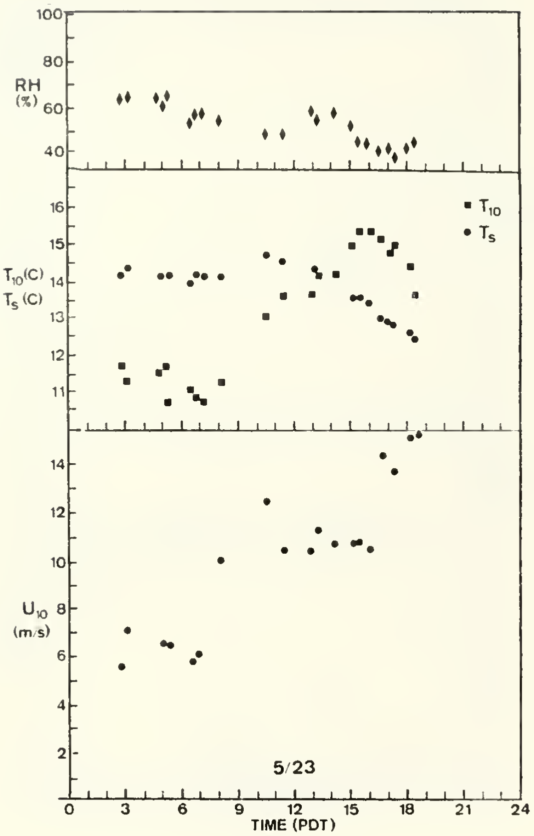
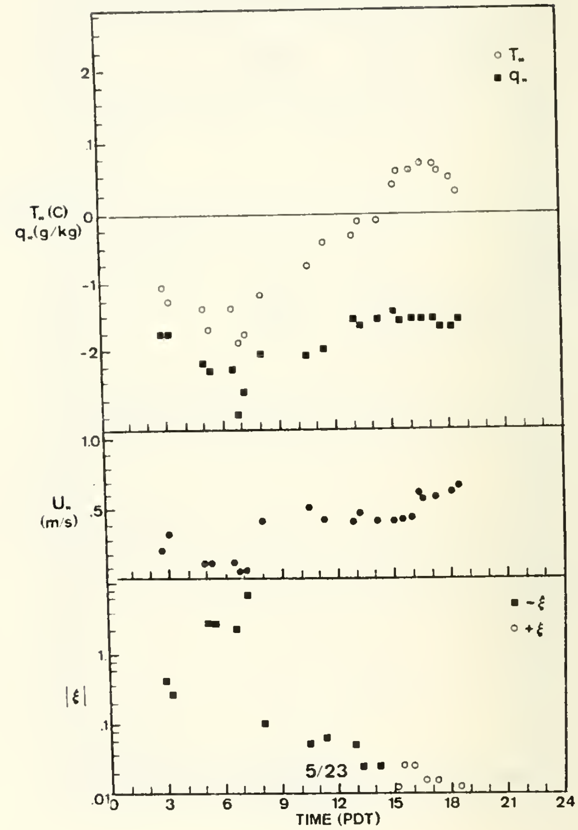


Figure 10. R/V Acania Atmospheric Surface Layer Data for 5/22/78.





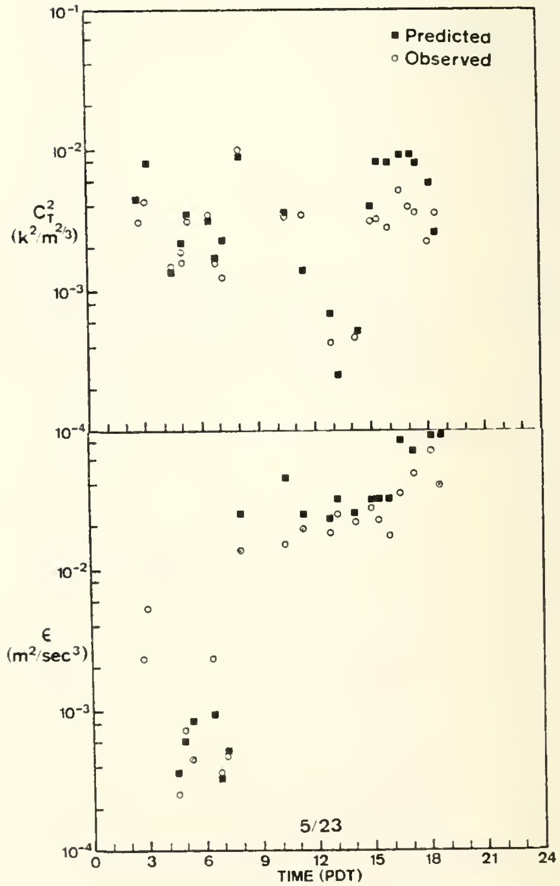


Figure 11. R/V Acania Atmospheric Surface Layer Data for 5/23/78.

figures include both the measured values and the values predicted on the basis of the bulk method MOS parameters. Data tables are given in Appendix B.

B. NRL Tower Site Evaluation

Although there is evidence that shore based measurements of C_T^2 can be poorly correlated with measurements made over the ocean [Davidson et al. (1976)], there is still hope that the NRL tower can provide meaningful data. The primary source of this optimism is the excellent location of the tower on a well exposed point of the island. In order to compare NRL tower measurements with R/V Acania measurements, NPS personnel installed and operated standard NPS C_T^2 and ε equipment on the NRL tower. In this way, measurements with identical equipment and procedures could be compared, thus eliminating (or reducing) one source of uncertainty. We did take the liberty of using the wind speeds measured by NRL equipment.

A table of the NPS measurements from the NRL tower is given in Appendix C. Table II is a compilation of data for those time periods when simultaneous SNI and Acania measurements are available. The data is further restricted to time periods when the Acania was either at anchor or underway immediately upwind of the tower site on the NW tip of SNI. Included at the end of the table is a comparison when the Acania was 30 miles to 50 miles upwind of SNI (5/20-1515 to 5/21-1045). The C_T^2 and U data from the Acania are Z = 10 meter equivalent values. The SNI C_T^2 and U data are from the Z = 11.4 meter level. Since the ε data is subject to greater statistical scatter, the

TABLE II. Comparison of turbulence (C_T^2 and U_*) and mean wind speed (U) measurements taken simultaneously at the NRL tower and aboard the R/V Acania.

DATE	TIME	φ,DEG	$C_T^2, 10^{-3}$ SNI	°$C^2/M^{2/3}$ ACANIA	U* SNI	M/SEC ACANIA	U SNI	M/SEC ACANIA
5/14	1315	254	5.76	.40	.19	.096	2.0	2.1
	1515	240	4.40	.25	.12	.094	1.5	2.0
	1745	257	.10	.49	.17	.072	3.3	2.4
	1845	241	4.63	.19	.48	.080	2.4	2.8
	1915	240	.51	.26	.55	.13	3.7	4.4
	2015	244	.17	.29	.50	.14	4.0	4.5
5/15	0845	276	.33	.38	1.0	.30	9.0	10.1
	0900	275	.22	.27	1.0	.34	10.5	10.7
	0945	279	.45	.32	.86	.33	10.0	11.6
	1000	277	.32	.37	1.0	.32	9.5	11.4
	1515	321	1.49	1.05	.71	.35	11.7	13.4
	1615	276	.148	1.17	.64	.41	11.9	14.7
	1915	279	1.13	1.44	.73	.45	14.4	17.3
	2000	271	1.72	1.65	.80	.50	14.3	19.6
5/18	2045	308	.96	1.01	.19	.10	2.4	3.0
	2200	307	.57	2.87	.13	.15	2.6	6.3
5/19	1045	300	.392	1.23	.33	.14	3.4	3.8
	1145	290	3.19	4.17	.43	.15	3.9	4.9
	1315	287	5.87	4.97	.45	.16	4.1	5.3
	1345	285	8.15	5.26	.58	.17	4.1	5.3
	1845	269	5.99	7.82	.46	.24	5.7	7.2
	2115	217	4.33	6.63	.54	.23	5.5	7.1
5/20	0945	326	5.11	8.00	.60	.25	5.7	7.6
	1045	304	4.24	7.24	.60	.30	5.7	8.4
	1115	297	7.26	4.25	.76	.30	5.4	7.6
5/20	1515	274	6.62	5.34	.80	.35	6.7	8.6
	1845	302	3.20	5.16	.90	.42	7.1	10.6
	1945	296	3.67	3.17	.80	.45	7.6	10.6
	2045	305	5.18	1.77	.76	.43	7.3	10.3
5/21	1015	398	5.83	2.57	.73	.17	5.8	7.2
	1045	304	5.53	1.90	.60	.16	---	7.2

multi-level measurements were combined (using Equation 4) into a single U_* value. Only the Z = 11.4 meter SNI C_T^2 data was used for the comparison since those measurements were available for the entire period from 5/14 to 5/21.

The C_T^2 comparison (Figure 12) indicates very reasonable agreement between the tower and shipboard measurements. A few cases of greater disagreement occurred during light winds (U~2 m/sec). The average ratio of the SNI to Acania values (Table III), excluding the light wind cases, indicates only a 7% average disagreement with a standard deviation of 64%. Given a single measurement error of about 20%, the combined instrumental error for this comparison is about 30%. On the last two days of the direct comparison (5/19 and 5/20) we also had available C_T^2 measurements at a second level on the NRL tower Z=17.5 meters). When converted to Z=10 meter equivalent, the level 2 values did not agree as well with the Acania values. For this period, a level 1 and 2 combined C_T^2 would have a 20% average disagreement with the Acania values, still a respectable result.

The velocity data shows significantly greater shoreline influence (Table III). The velocity scaling parameter comparison indicates U_* values 2.5 times greater at the tower than at the Acania (Figure 12), implying a considerably greater surface drag immediately upwind of the tower. This increased drag leads to 16% lower wind speeds at the tower (Figure 12) for the Z = 11.4 meter level. The average velocity drag coefficient measured at the tower was $c_{UN} = 1.0 \times 10^{-2}$, considerably greater than the typical ocean value of 1.3×10^{-3}.

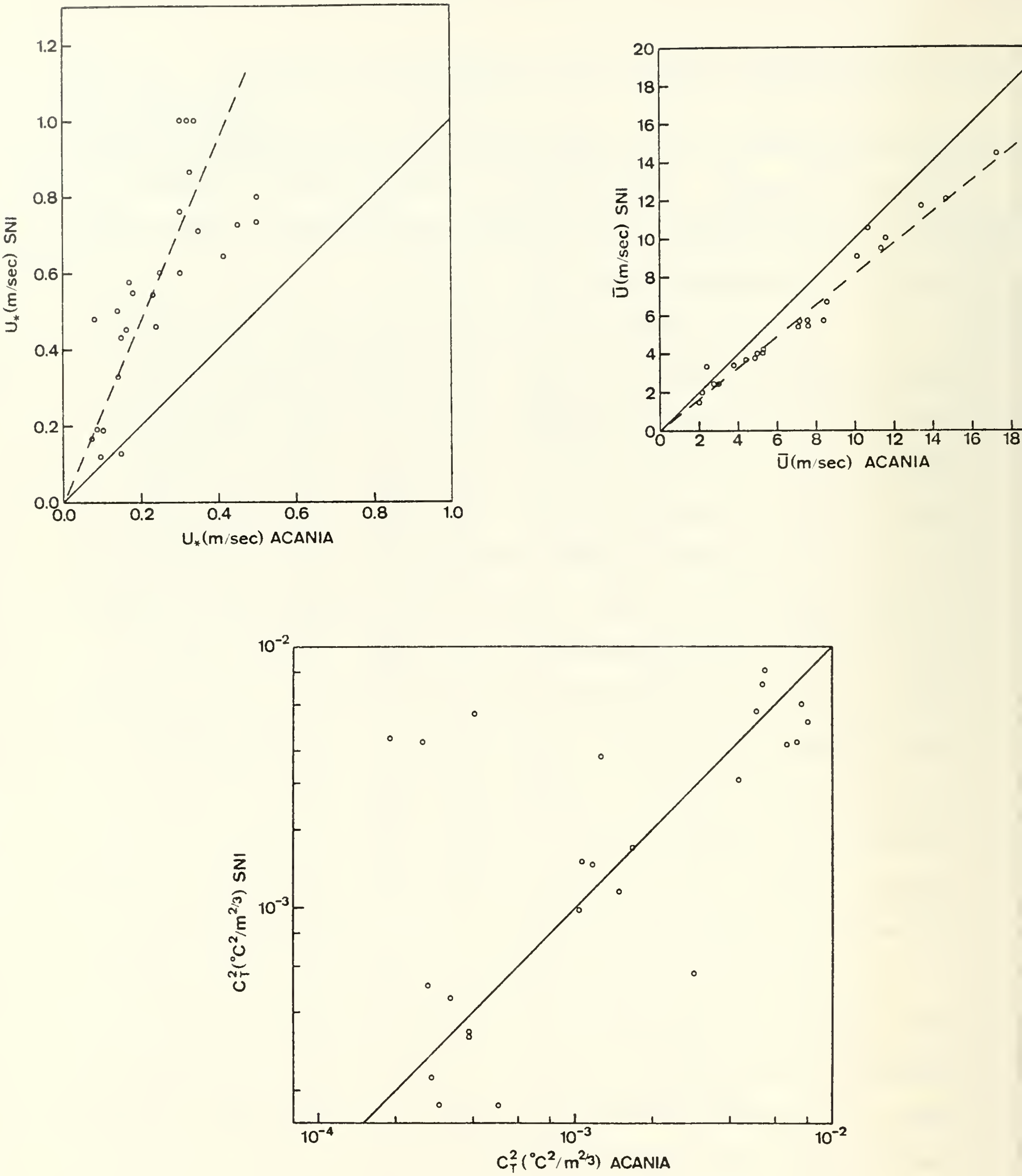


Figure 12. Comparison of Turbulence (C_T^2 and U_*) and Mean Wind (U) Data from the R/V Acania with NPS Measurements at NRL Tower on San Nicolas Island.

TABLE III. RATIO OF SNI TO ACANIA MEASUREMENTS (r) FOR C_T^2, U_* AND U

	C_T^2	U_*	U
<r>	1.07	2.48	.84
σ	.64	.93	.10
N	23.0	25.0	25.0
$\sigma\sqrt{N}$	.13	.19	.02

We also compared SNI C_T^2 measurements to Acania values when the ship was 30 miles to 50 miles upwind of the island (Figure 13). Since only a few C_T^2 values were available from the SNI measurements; the comparison is rather incomplete but it is encouraging that no large disagreements were found.

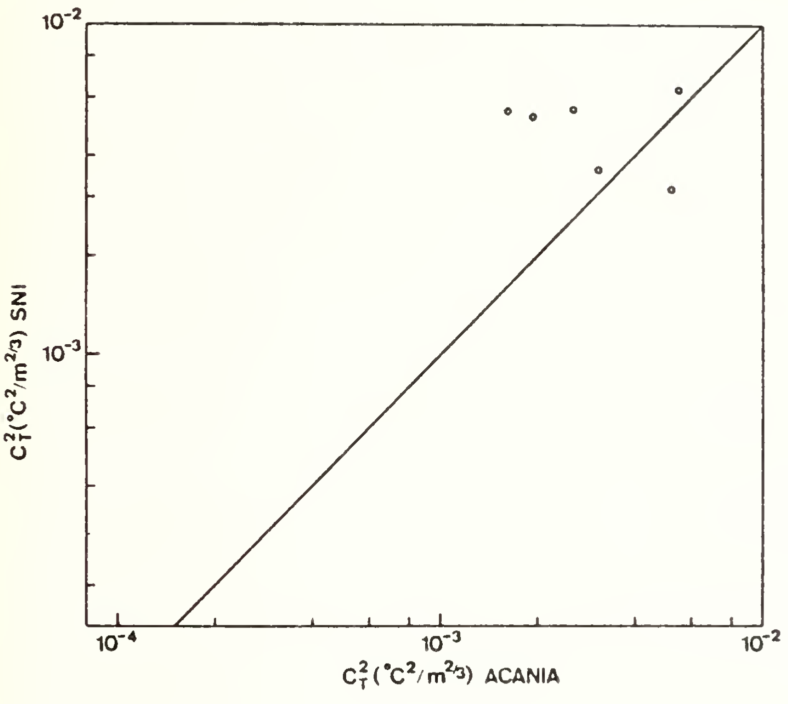


FIGURE 13. Comparison of C_T^2 Data from the R/V Acania with NPS Measurements at the NRL Tower on San Nicolas Island. For this data, the Acania was 30 miles to 50 miles upwind of SNI.

C. Acoustic Sounder Data

The NPS acoustic echosounder (Aeroenvironment Model 300) was mounted aboard the Acania and provided inversion height and plume structure data throughout the cruise. A tabulation of the sounder data is given in Appendix D.

V. CONCLUSIONS

A. Bulk Method

A brief examination of Figures 4 through 11 will reveal that the bulk method is a fairly good predictor of the measured values of C_T^2 and ε. A log average of the ratio of predicted C_T^2 to measured yields a single measurement standard deviation of 120% for CEWCOM-78. In other words, the bulk method predicted the measured value to within roughly a factor of 2 for a single half-hour averaging period. A considerable portion of this scatter is due to measurement problems (such as salt contamination of C_T^2 sensors) discussed in Davidson et al. (1978). Figure 14 [from Davidson et al. (1978)] indicates that excellent average agreement between the bulk method and measured values of C_T^2.

Included in the boundary layer data (Appendix B) is a calculation of C_N^2 (Equation 15) from bulk values of T_*, q_*, and ξ. The average relative magnitude of the terms contributing to C_N^2 were: C_T^2 (70%), C_{Tq} (24%) and C_q^2 (6%). This agrees well with the direct measurements during the BOMEX experiments [Friehe et al. (1975)].

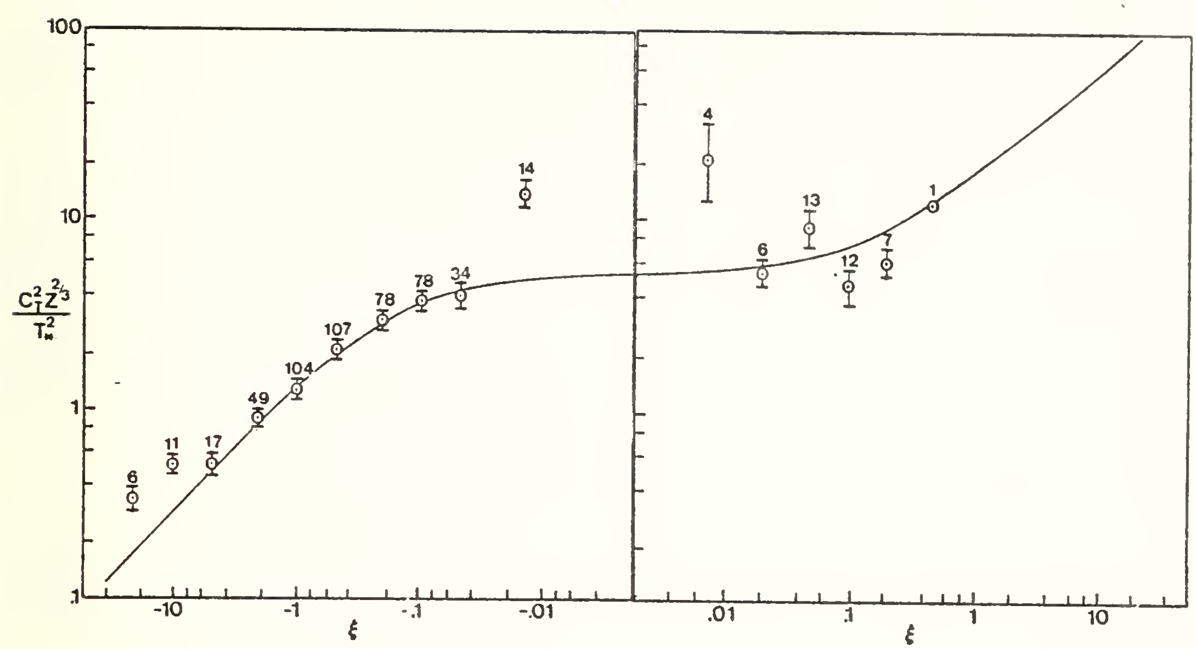


FIGURE 15. Dimensionless temperature structure function ($C_T^2\ Z^{2/3}/T_*^2 = f(\xi)$) vs. atmospheric stability (ξ). The circled points are data and the solid curve is Wyngaard et al's (1971) formulae for $f(\xi)$. The bulk method was used to calculate T_* and ξ.

B. SNI Boundary Layer Measurements at the NRL Tower

Comparison of the NPS measurements on the Acania and the NRL tower (Figure 12) used to evaluate the tower site data were summarized in Tables II and III. During the periods of the comparison the wind direction was most favorable (westerly to northerly) so be advised that our conclusions should be confined to those limits. Based on this data and the discussion of Section IV, we conclude the following about the NRL tower site:

1) The data is subject to land influence effects for

wind speeds less than about 2.5 m/sec.

2) The C_T^2 data is quite representative of the marine boundary layer.

3) The U_* (or ε) data is not representative of the marine boundary layer, presumably due to increased surface drag upwind of the tower.

4) The mean wind speed (U) is about 15% less than the marine boundary layer value at Z = 11.4 meters.

5) The marine boundary layer value of U_* cannot be obtained from wind speed profiles at the tower. This follows from 3 and 4.

In addition to these conclusions, we offer the speculation that T_* and q_* cannot be correctly inferred from tower measurements of temperature and humidity profiles. This opinion is based upon the known strong interaction between velocity structure and scalar structure. On the other hand, since the C_T^2 data seems to be unaffected at the tower, it is quite possible that the temperature and humidity profiles are similarly unaffected. Perhaps this question can be resolved by a comparison of NRL's profile data and the NPS R/V Acania data. Alternatively, one could use the bulk method with the tower data (requiring the addition of a suitable sea surface sensor) as has already been suggested by Carl Friehe.

C. SNI as a Representative Boundary Layer

From a turbulence and boundary layer point of view, SNI seemed to be a good example of a typical open ocean marine boundary layer during CEWCOM-78 (5/14-5/25). This is based primarily on the lack of diurnal variation of boundary layer parameters which is typical of open ocean conditions. A comparison of C_T^2 values (admittedly limited) showed a reasonble correlation between SNI values and values measured 30 miles to 50 miles upwind. Obviously this conclusion is limited to favorable wind directions.

ACKNOWLEDGEMENTS

The authors wish to thank Captain Reynolds and the crew of the R/V Acania, Tim Stanton, Ray Garcia, Ted Calhoun and Dale Leipper. A special thanks to Ted Blanc for providing facilities at the NRL tower on San Nicolas Island. Work supported by Naval Air Systems Command, AIR 370.

APPENDIX A
MOS STABILITY FUNCTIONS

The forms of the mean gradient functions (Businger et al., 1971)

$$\phi_U(\xi) - (1 - 15\xi)^{-1/4} \qquad \xi<0$$

$$\phi_U(\xi) = (1 + 4.7\xi) \qquad \xi>0$$

$$\phi_T(\xi) = (1 - 19\xi)^{-1/3} \qquad \xi<0$$

$$\phi_T(\xi) = (1 + 6.4\xi) \qquad \xi>0$$

The mean profile function

$$\psi(\xi) = 1-\phi(\xi)-3\ln\phi(\xi)+2\ln\left(\frac{1+\phi(\xi)}{2}\right) + 2\tan^{-1}\phi(\xi)-\pi/2+\ln\left(\frac{1+\phi^2(\xi)}{2}\right)$$

The dimensionless velocity dissipation function (Wyngaard and Cote, 1971)

$$E_U(\xi) = (1 + .51\xi^{2/3})^{3/2} \qquad \xi<0$$

$$E_U(\xi) = (1 + 2.5\xi^{2/3})^{3/2} \qquad \xi>0$$

The dimensionless temperature structure function parameter (Wyngaard et al., 1971).

$$f_T(\xi) = 4.9(1 - 7\xi)^{-2/3} \qquad \xi<0$$

$$f_T(\xi) = 4.9(1 + 2.4\xi^{2/3}) \qquad \xi>0$$

APPENDIX B

Marine boundary layer evaluation from R/V Acania measurements during CEWCOM-78 - bulk data, MOS scaling parameters, turbulence data and bulk calculation of C_N^2. The bulk and turbulence data are Z = 10 meter equivalent values. The MOS scaling parameters are calculated by the bulk method. The C_N^2 values are bulk estimates from Equation 15.

Date	PDT	TS (C)	T (C)	RH (%)	U (m/s)	Z/L	u* (m/s)	T* (C)	q* (g/Kg)	Ct^2 (C^2/m^2/3)	Eps (m^2/s^3)	Cn^2 (1/m^2/3)
05/14	0830	14.43	12.95	99.9	3.1	-6.12E-01	0.11	-0.06	-0.02	4.95E-04	1.77E-03	1.14E-15
05/14	0853	14.42	13.64	99.9	2.8	-3.66E-01	0.09	-0.03	-0.00	3.43E-04	1.50E-03	3.25E-16
05/14	0913	14.25	13.57	99.9	2.9	-2.96E-01	0.10	-0.02	-0.00	3.01E-04	1.21E-03	2.57E-16
05/14	0933	14.66	13.98	99.9	2.2	-5.35E-01	0.07	-0.02	0.00	5.37E-04	1.83E-03	2.02E-16
05/14	0953	14.60	14.08	97.3	2.8	-2.33E-01	0.09	-0.02	-0.01	3.70E-04	2.05E-03	1.50E-16
05/14	1013	14.60	13.73	95.3	2.9	-4.27E-01	0.10	-0.03	-0.02	3.99E-04	6.32E-04	4.24E-16
05/14	1051	14.84	14.31	94.4	1.9	-6.29E-01	0.06	-0.02	-0.02	6.02E-04	1.01E-03	1.17E-16
05/14	1121	15.28	13.73	93.4	2.0	-1.78E 00	0.07	-0.06	-0.06	5.07E-04	1.10E-03	8.27E-16
05/14	1151	15.20	13.59	93.4	2.8	-9.14E-01	0.10	-0.06	-0.05	4.30E-04	5.00E-04	1.21E-15
05/14	1224	15.08	13.79	93.3	2.3	-1.11E 00	0.08	-0.05	-0.05	3.18E-04	5.25E-04	6.91E-16
05/14	1300	15.20	14.00	91.3	1.8	-1.79E 00	0.06	-0.05	-0.06	4.25E-04	4.19E-04	4.88E-16
05/14	1330	15.20	14.17	91.0	2.0	-1.19E 00	0.07	-0.04	-0.05	3.98E-04	3.55E-04	4.24E-16
05/14	1400	15.04	14.27	91.2	2.2	-7.96E-01	0.07	-0.03	-0.04	2.86E-04	4.35E-04	2.68E-16
05/14	1430	14.98	13.98	90.1	4.3	-2.30E-01	0.15	-0.03	-0.05	4.49E-04	6.10E-04	7.68E-16
05/14	1500	14.75	14.01	92.4	3.6	-2.39E-01	0.12	-0.02	-0.03	4.00E-04	6.66E-04	3.81E-16
05/14	1530	15.13	14.56	91.2	2.0	-6.99E-01	0.07	-0.02	-0.04	2.47E-04	3.22E-04	1.44E-16
05/14	1600	15.30	15.32	86.2	2.3	-6.01E-02	0.07	0.00	-0.04	3.80E-04	9.99E-04	4.50E-18
05/14	1636	14.98	15.66	86.3	2.8	4.07E-01	0.08	0.02	-0.02	3.81E-04	4.98E-04	1.23E-15
05/14	1730	14.88	15.40	88.5	2.6	3.75E-01	0.07	0.02	-0.01	4.69E-04	2.38E-04	7.66E-16
05/14	1800	14.86	15.53	89.3	2.3	6.91E-01	0.06	0.02	-0.01	4.95E-04	1.65E-04	1.23E-15
05/14	1830	14.71	15.07	87.5	2.7	2.03E-01	0.08	0.02	-0.02	2.09E-04	1.97E-04	3.68E-16
05/14	1930	14.52	14.29	88.7	4.3	-5.85E-02	0.15	-0.00	-0.03	2.61E-04	8.48E-04	3.65E-17
05/14	2000	14.56	14.22	90.5	4.1	-8.59E-02	0.14	-0.01	-0.03	2.62E-04	8.98E-04	8.46E-17
05/14	2050	14.32	14.18	89.1	4.4	-3.58E-02	0.15	-0.00	-0.03	2.87E-04	1.16E-03	8.53E-18
05/14	2120	14.36	14.39	87.8	4.2	-9.95E-03	0.14	0.00	-0.03	3.06E-04	1.09E-03	7.18E-18
05/14	2150	14.14	14.24	88.8	6.5	4.12E-03	0.23	0.01	-0.03	2.79E-04	2.87E-03	3.28E-17
05/14	2240	14.19	14.40	88.8	7.7	9.24E-03	0.28	0.01	-0.03	1.42E-04	4.66E-03	1.03E-16
05/14	2310	14.12	14.37	87.0	7.6	1.00E-02	0.28	0.01	-0.03	1.76E-04	4.72E-03	1.29E-16
05/15	0002	14.13	14.24	87.4	7.0	2.76E-03	0.26	0.01	-0.03	2.90E-04	4.11E-03	3.55E-17
05/15	0651	14.63	14.70	78.9	10.3	-5.01E-03	0.39	0.01	-0.07	3.31E-04	1.48E-02	6.01E-18
05/15	0721	14.61	14.52	78.4	9.9	-1.04E-02	0.38	0.00	-0.07	3.83E-04	1.34E-02	1.49E-17
05/15	0751	14.58	14.68	78.3	8.9	-5.08E-03	0.34	0.01	-0.07	3.71E-04	1.10E-02	1.39E-17
05/15	0835	14.65	14.73	83.4	9.8	-1.87E-03	0.37	0.01	-0.05	3.82E-04	1.08E-02	1.48E-17
05/15	0909	14.62	14.73	83.5	10.4	-4.98E-04	0.40	0.01	-0.05	2.75E-04	1.50E-02	2.69E-17
05/15	0939	14.62	13.90	83.6	11.3	-2.13E-02	0.44	-0.02	-0.06	3.30E-04	1.48E-02	6.42E-16
05/15	1009	14.58	14.09	85.3	11.0	-1.56E-02	0.43	-0.01	-0.05	3.76E-04	1.30E-02	2.86E-16
05/15	1116	14.61	14.32	81.3	10.2	-1.44E-02	0.39	-0.01	-0.06	4.25E-04	1.17E-02	1.06E-16
05/15	1146	15.04	14.33	80.4	11.5	-2.20E-02	0.45	-0.02	-0.08	6.07E-04	1.49E-02	6.71E-16
05/15	1216	15.18	14.32	80.2	11.0	-2.84E-02	0.42	-0.03	-0.08	6.99E-04	1.42E-02	9.70E-16

Date	PDT	TS (C)	T (C)	RH (%)	U (m/s)	Z/L	u* (m/s)	T* (C)	q* (g/Kg)	Ct^2 (C^2/m^2/3)	Eps (m^2/s^3)	Cn^2 (1/m^2/3)
05/15	1246	15.39	14.39	82.7	11.7	-2.68E-02	0.46	-0.03	-0.08	6.93E-04	1.66E-02	1.28E-15
05/15	1348	15.53	14.36	82.3	13.0	-2.45E-02	0.51	-0.04	-0.08	7.15E-04	1.89E-02	1.77E-15
05/15	1440	15.67	14.56	78.0	12.3	-2.83E-02	0.48	-0.04	-0.10	8.80E-04	1.77E-02	1.66E-15
05/15	1520	15.75	14.71	70.6	13.0	-2.61E-02	0.51	-0.03	-0.13	1.05E-03	2.07E-02	1.60E-15
05/15	1550	15.69	14.88	67.5	13.3	-2.18E-02	0.53	-0.03	-0.14	1.17E-03	2.35E-02	1.05E-15
05/15	1620	15.66	14.84	67.5	14.3	-1.89E-02	0.57	-0.03	-0.14	1.19E-03	2.73E-02	1.09E-15
05/15	1700	15.66	14.69	65.0	14.4	-2.11E-02	0.58	-0.03	-0.15	1.24E-03	2.74E-02	1.50E-15
05/15	1730	15.66	14.60	64.8	14.8	-2.13E-02	0.59	-0.04	-0.15	1.28E-03	2.84E-02	1.77E-15
05/15	1855	15.66	14.25	62.8	15.4	-2.42E-02	0.62	-0.05	-0.16	1.35E-03	3.80E-02	3.02E-15
05/15	1925	14.90	13.85	65.7	16.8	-1.55E-02	0.68	-0.03	-0.14	1.46E-03	3.99E-02	1.72E-15
05/15	1955	0.00	13.71	63.5	18.9	1.11E-01	0.74	0.47	0.23	1.67E-03	5.03E-02	3.77E-13
05/18	1331	20.32	19.53	58.1	1.9	-2.09E 00	0.07	-0.03	-0.28	2.31E-03	6.75E-05	3.00E-16
05/18	1401	20.60	19.58	66.4	2.4	-1.44E 00	0.08	-0.04	-0.23	1.75E-03	1.79E-04	5.84E-16.
05/18	1459	19.73	19.07	68.7	2.6	-8.82E-01	0.09	-0.02	-0.19	1.17E-03	3.09E-03	3.22E-16
05/18	1600	18.61	17.92	68.2	3.6	-4.03E-01	0.13	-0.02	-0.17	1.67E-03	4.56E-03	4.68E-16
05/18	1700	17.62	16.40	76.8	6.0	-1.60E-01	0.22	-0.04	-0.13	2.75E-03	4.78E-03	1.56E-15
05/18	1730	17.19	16.06	77.5	6.8	-1.08E-01	0.26	-0.04	-0.12	5.37E-03	1.36E-02	1.46E-15
05/18	1800	16.83	15.68	79.9	6.2	-1.35E-01	0.23	-0.04	-0.10	2.39E-03	6.44E-03	1.51E-15
05/18	1820	15.89	15.49	81.7	5.5	-7.47E-02	0.20	-0.01	-0.07	4.81E-04	3.91E-03	1.84E-16
05/18	1900	16.30	15.42	82.2	4.9	-1.71E-01	0.18	-0.03	-0.08	1.19E-03	3.57E-03	7.36E-16
05/18	1948	15.98	14.80	87.7	3.6	-4.20E-01	0.13	-0.04	-0.07	6.30E-04	4.32E-03	9.20E-16
05/18	2018	15.92	14.42	90.5	2.9	-8.24E-01	0.10	-0.06	-0.07	6.68E-04	5.96E-03	1.12E-15
05/18	2049	15.32	14.25	93.5	2.9	-5.59E-01	0.10	-0.04	-0.04	1.02E-03	2.15E-03	6.17E-16
05/18	2218	15.32	14.45	93.5	11.9	-1.92E-02	0.46	-0.03	-0.03	2.89E-04	7.05E-03	8.53E-16
05/19	1057	15.10	11.78	98.0	7.7	-1.84E-01	0.30	-0.12	-0.07	1.24E-03	5.43E-03	9.68E-15
05/19	1200	15.22	12.06	95.2	4.7	-5.47E-01	0.17	-0.12	-0.08	6.30E-03	3.17E-04	6.01E-15
05/19	1230	15.28	12.21	94.6	4.9	-4.88E-01	0.18	-0.12	-0.08	4.19E-03	6.82E-03	5.93E-15
05/19	1300	15.33	12.33	93.6	5.3	-3.94E-01	0.20	-0.12	-0.09	0.00E 00	1.67E-02	6.17E-15
05/19	1330	15.40	12.41	93.1	5.2	-4.28E-01	0.19	-0.12	-0.09	4.97E-03	7.94E-03	5.97E-15
05/19	1400	15.49	12.51	93.0	5.2	-4.23E-01	0.19	-0.12	-0.09	5.30E-03	8.01E-03	5.94E-15
05/19	1430	15.49	12.68	93.0	5.2	-3.89E-01	0.19	-0.11	-0.08	4.83E-03	1.39E-02	5.45E-15
05/19	1500	15.52	12.65	92.6	5.4	-3.69E-01	0.20	-0.11	-0.09	4.79E-03	8.47E-03	5.79E-15
05/19	.1530	15.51	12.61	92.7	5.5	-3.52E-01	0.21	-0.11	-0.09	5.52E-03	1.55E-02	6.02E-15
05/19	1600	15.56	12.59	93.2	5.9	-3.14E-01	0.22	-0.11	-0.09	5.33E-03	1.07E-02	6.58E-15
05/19	1630	15.50	12.47	94.1	6.6	-2.44E-01	0.25	-0.11	-0.08	6.22E-03	1.98E-02	7.48E-15
05/19	1700	15.42	12.36	93.9	7.3	-1.97E-01	0.28	-0.11	-0.08	5.12E-03	2.69E-02	8.17E-15
05/19	1730	15.36	12.25	94.0	7.4	-1.95E-01	0.28	-0.12	-0.08	6.34E-03	2.43E-02	8.43E-15
05/19	1800	15.36	12.13	94.7	7.0	-2.28E-01	0.27	-0.12	-0.08	6.71E-03	2.16E-02	8.66E-15
05/19	1830	15.47	11.95	95.3	6.9	-2.52E-01	0.27	-0.13	-0.09	7.89E-03	2.05E-02	9.98E-15

Date	PDT	TS (C)	T (C)	RH (%)	U (m/s)	Z/L	u* (m/s)	T* (C)	q* (g/Kg)	Ct^2 (C^2/m^2/3)	Eps (m^2/s^3)	Cn^2 (1/m^2/3)
05/19	1930	15.34	11.65	97.0	7.1	-2.49E-01	0.27	-0.14	-0.09	7.42E-03	2.57E-02	1.10E-14
05/19	2000	15.30	11.50	97.2	7.6	-2.19E-01	0.29	-0.14	-0.09	6.92E-03	2.68E-02	1.21E-14
05/19	2030	15.37	11.41	97.8	7.8	-2.11E-01	0.31	-0.15	-0.09	7.81E-03	3.29E-02	1.34E-14
05/19	2100	15.27	11.71	98.1	7.0	-2.44E-01	0.27	-0.13	-0.08	7.77E-03	2.72E-02	1.03E-14
05/19	2130	15.35	11.72	98.2	6.9	-2.63E-01	0.26	-0.14	-0.09	6.67E-03	1.84E-02	1.04E-14
05/19	2200	15.29	11.56	98.1	7.1	-2.56E-01	0.27	-0.14	-0.09	8.00E-03	2.09E-02	1.12E-14
05/19	2230	15.26	11.65	98.2	7.0	-2.48E-01	0.27	-0.14	-0.08	7.19E-03	2.61E-02	1.05E-14
05/19	2300	15.25	11.60	98.4	6.9	-2.63E-01	0.26	-0.14	-0.08	6.74E-03	2.21E-02	1.06E-14
05/19	2330	15.26	11.42	98.3	6.7	-2.98E-01	0.26	-0.15	-0.09	6.73E-03	2.07E-02	1.12E-14
05/20	0130	15.21	11.40	98.8	5.8	-4.13E-01	0.22	-0.15	-0.09	7.25E-03	1.34E-02	9.77E-15
05/20	0200	15.20	11.12	98.7	6.3	-3.67E-01	0.24	-0.16	-0.10	7.32E-03	1.64E-02	1.18E-14
05/20	0230	15.17	11.30	98.6	5.5	-4.73E-01	0.21	-0.15	-0.09	7.51E-03	1.23E-02	9.57E-15
05/20	0300	15.08	11.27	98.3	5.9	-4.00E-01	0.22	-0.15	-0.09	7.95E-03	1.57E-02	9.92E-15
05/20	0330	15.09	11.26	98.2	5.9	-3.98E-01	0.22	-0.15	-0.09	7.37E-03	1.51E-02	1.01E-14
05/20	0400	15.06	11.38	98.1	6.2	-3.38E-01	0.24	-0.14	-0.09	6.41E-03	1.52E-02	9.84E-15
05/20	0430	15.01	11.30	97.7	6.5	-3.07E-01	0.25	-0.14	-0.09	6.62E-03	2.26E-01	1.03E-14
05/20	0500	14.96	11.40	97.3	6.1	-3.46E-01	0.23	-0.14	-0.09	5.75E-03	1.79E-02	9.10E-15
05/20	0530	14.86	11.35	97.0	6.0	-3.56E-01	0.22	-0.14	-0.09	6.95E-03	1.66E-02	8.78E-15
05/20	0600	14.65	11.43	96.9	6.5	-2.68E-01	0.25	-0.12	-0.08	6.84E-03	1.72E-02	8.11E-15
05/20	0630	14.60	11.41	96.6	6.2	-2.90E-01	0.24	-0.12	-0.08	6.44E-03	1.65E-02	7.75E-15
05/20	0700	14.68	11.31	96.4	6.9	-2.44E-01	0.26	-0.13	-0.08	6.56E-03	2.40E-02	9.17E-15
05/20	0730	14.69	11.26	96.3	7.1	-2.29E-01	0.27	-0.13	-0.08	5.83E-03	2.29E-02	9.71E-15
05/20	0800	14.69	11.39	96.3	7.1	-2.21E-01	0.27	-0.12	-0.08	6.02E-03	2.68E-02	9.07E-15
05/20	0930	15.49	11.64	93.6	7.3	-2.44E-01	0.28	-0.15	-0.10	8.12E-03	2.59E-02	1.22E-14
05/20	1000	15.46	11.82	92.9	8.1	-1.83E-01	0.32	-0.14	-0.10	8.20E-03	2.83E-02	1.19E-14
05/20	1100	15.26	12.02	90.5	8.1	-1.66E-01	0.32	-0.12	-0.10	7.29E-03	3.88E-02	9.74E-15
05/20	1130	14.67	12.01	89.4	7.4	-1.70E-01	0.28	-0.10	-0.09	4.31E-03	3.84E-02	6.45E-15
05/20	1200	14.59	12.10	88.7	7.7	-1.46E-01	0.30	-0.09	-0.08	4.68E-03	2.83E-02	5.92E-15
05/20	1230	14.52	12.35	87.0	7.7	-1.29E-01	0.29	-0.08	-0.08	4.11E-03	3.06E-02	4.63E-15
05/20	1300	14.05	12.32	90.4	8.1	-8.84E-02	0.31	-0.06	-0.06	2.85E-03	3.81E-02	3.11E-15
05/20	1330	13.62	12.44	84.4	8.3	-6.19E-02	0.32	-0.04	-0.07	2.47E-03	4.28E-02	1.55E-15
05/20	1400	14.18	12.68	82.9	7.9	-8.69E-02	0.30	-0.05	-0.08	0.00E 00	5.69E-02	2.45E-15
05/20	1455	14.32	12.78	81.2	8.3	-8.13E-02	0.32	-0.05	-0.09	5.34E-03	5.05E-02	2.64E-15
05/20	1530	14.44	12.88	80.7	8.3	-8.39E-02	0.32	-0.05	-0.09	5.37E-03	5.87E-02	2.72E-15
05/20	1600	14.40	12.87	80.5	8.3	-8.24E-02	0.32	-0.05	-0.09	4.96E-03	5.00E-02	2.61E-15
05/20	1630	14.37	12.82	81.4	8.1	-8.67E-02	0.31	-0.05	-0.09	4.67E-03	4.29E-02	2.65E-15
05/20	1700	14.43	12.58	82.7	8.9	-8.29E-02	0.34	-0.07	-0.09	5.08E-03	5.59E-02	3.79E-15
05/20	1730	14.47	12.51	82.4	9.0	-8.46E-02	0.35	-0.07	-0.09	5.68E-03	7.02E-02	4.25E-15
05/20	1800	14.51	12.46	84.4	9.4	-8.08E-02	0.36	-0.07	-0.09	3.46E-03	6.53E-02	4.65E-15

Date	PDT	TS (C)	T (C)	RH (%)	U (m/s)	Z/L	u* (m/s)	T* (C)	q* (g/Kg)	Ct^2 (C^2/m^2/3)	Eps (m^2/s^3)	Cn^2 (1/m^2/3)
05/20	1830	14.57	12.26	83.5	10.3	-7.40E-02	0.40	-0.08	-0.10	5.30E-03	1.01E-01	6.04E-15
05/20	1900	14.47	12.21	84.3	10.3	-7.21E-02	0.40	-0.08	-0.09	5.21E-03	1.01E-01	5.78E-15
05/20	1954	14.14	12.20	87.0	9.0	-8.11E-02	0.35	-0.07	-0.08	3.17E-03	6.71E-02	4.06E-15
05/20	2030	13.80	12.05	86.7	10.2	-5.58E-02	0.40	-0.06	-0.07	3.21E-03	1.18E-01	3.50E-15
05/20	2100	13.65	12.24	87.6	10.0	-4.77E-02	0.39	-0.05	-0.06	2.43E-03	9.69E-02	2.29E-15
05/20	2130	13.40	12.20	87.7	10.1	-4.03E-02	0.39	-0.04	-0.06	1.79E-03	9.96E-02	1.67E-15
05/20	2200	13.20	12.12	87.3	9.7	-4.01E-02	0.37	-0.04	-0.06	1.51E-03	9.25E-02	1.34E-15
05/20	2230	12.97	12.15	87.7	9.4	-3.29E-02	0.36	-0.03	-0.05	9.78E-04	7.98E-02	7.72E-16
05/20	2300	13.00	12.07	87.1	9.0	-4.00E-02	0.35	-0.03	-0.05	1.43E-03	6.93E-02	9.81E-16
05/20	2330	13.09	12.02	87.9	9.3	-4.25E-02	0.36	-0.04	-0.05	1.26E-03	6.80E-02	1.31E-15
05/21	0000	12.96	11.86	87.3	9.6	-4.11E-02	0.37	-0.04	-0.06	2.64E-03	7.67E-02	1.39E-15
05/21	0130	13.12	11.96	88.3	9.2	-4.72E-02	0.35	-0.04	-0.05	1.71E-03	6.22E-02	1.53E-15
05/21	0200	13.03	11.85	87.4	8.8	-5.28E-02	0.34	-0.04	-0.06	1.82E-03	5.74E-02	1.56E-15
05/21	0300	13.05	11.91	87.0	8.1	-6.13E-02	0.31	-0.04	-0.06	1.79E-03	4.66E-02	1.44E-15
05/21	0330	13.02	11.88	85.7	8.2	-6.07E-02	0.31	-0.04	-0.06	2.69E-03	4.11E-02	1.44E-15
05/21	0356	12.98	11.88	83.9	8.1	-6.13E-02	0.31	-0.04	-0.07	1.69E-03	3.78E-02	1.36E-15
05/21	0430	12.96	11.91	82.7	8.7	-5.21E-02	0.33	-0.04	-0.07	3.46E-03	5.10E-02	1.29E-15
05/21	0458	12.98	11.96	81.2	8.9	-4.95E-02	0.34	-0.03	-0.08	1.42E-03	5.20E-02	1.24E-15
05/21	0530	13.06	12.08	81.4	7.9	-6.04E-02	0.30	-0.03	-0.07	1.31E-03	4.33E-02	1.10E-15
05/21	0558	13.04	12.20	80.0	8.2	-5.09E-02	0.31	-0.03	-0.08	1.07E-03	4.80E-02	8.50E-16
05/21	0630	13.08	12.29	79.5	7.7	-5.57E-02	0.29	-0.03	-0.08	8.56E-04	2.84E-02	7.47E-16
05/21	0658	13.13	12.36	78.8	6.8	-7.26E-02	0.25	-0.02	-0.08	2.81E-02	2.83E-02	6.79E-16
05/21	1445	15.39	13.39	74.4	6.0	-2.38E-01	0.22	-0.07	-0.14	3.74E-03	8.81E-03	3.56E-15
05/21	1500	14.59	13.43	72.1	5.0	-2.33E-01	0.18	-0.04	-0.12	2.07E-03	4.41E-03	1.24E-15
05/21	1600	14.30	13.34	72.8	6.0	-1.28E-01	0.22	-0.03	-0.11	3.29E-03	9.38E-03	1.02E-15
05/21	1630	14.25	13.37	72.5	7.6	-6.96E-02	0.29	-0.03	-0.11	6.63E-04	1.03E-02	9.73E-16
05/21	2100	15.56	13.49	76.3	10.4	-7.00E-02	0.41	-0.07	-0.13	0.00E 00	7.14E-02	5.15E-15
05/21	2130	14.56	13.34	76.8	8.6	-6.64E-02	0.33	-0.04	-0.10	0.00E 00	3.75E-02	1.81E-15
05/21	2200	14.25	13.11	79.0	7.3	-8.72E-02	0.28	-0.04	-0.09	0.00E 00	2.70E-02	1.46E-15
05/21	2230	13.82	13.02	79.0	9.1	-4.02E-02	0.35	-0.03	-0.08	0.00E 00	2.48E-02	8.15E-16
05/21	2300	13.54	13.02	78.1	9.1	-2.92E-02	0.35	-0.02	-0.08	0.00E 00	2.39E-02	3.64E-16
05/21	2330	13.45	12.88	77.3	10.0	-2.57E-02	0.39	-0.02	-0.08	0.00E 00	3.22E-02	4.37E-16
05/22	0000	13.58	12.78	76.6	10.1	-3.33E-02	0.39	-0.03	-0.09	0.00E 00	3.46E-02	8.44E-16
05/22	0030	13.65	12.71	75.7	9.8	-4.05E-02	0.38	-0.03	-0.10	0.00E 00	3.66E-02	1.16E-15
05/22	0100	13.73	12.69	77.0	9.6	-4.50E-02	0.37	-0.03	-0.09	0.00E 00	3.58E-02	1.38E-15
05/22	0130	13.54	12.50	78.7	9.3	-4.72E-02	0.36	-0.03	-0.09	0.00E 00	3.18E-02	1.34E-15
05/22	0152	13.54	12.50	78.3	9.9	-4.14E-02	0.38	-0.03	-0.09	1.74E-04	3.20E-02	1.38E-15
05/22	0230	13.20	12.29	75.5	9.6	-4.11E-02	0.37	-0.03	-0.09	2.85E-03	4.51E-02	1.08E-15
05/22	0300	13.17	12.18	75.8	10.4	-3.68E-02	0.40	-0.03	-0.09	3.43E-03	5.61E-02	1.27E-15

Date	PDT	TS (C)	T (C)	RH (%)	U (m/s)	Z/L	u* (m/s)	T* (C)	q* (g/Kg)	Ct^2 (C^2/m^2/3)	Eps (m^2/s^3)	Cn^2 (1/m^2/3)
05/22	0330	13.01	12.17	74.5	10.1	-3.46E-02	0.39	-0.03	-0.09	1.99E-03	5.28E-02	9.38E-16
05/22	0400	12.97	12.18	75.5	10.2	-3.24E-02	0.39	-0.03	-0.09	1.18E-03	5.97E-02	8.37E-16
05/22	0430	12.99	12.21	76.2	9.4	-3.80E-02	0.36	-0.03	-0.09	1.47E-03	5.21E-02	7.96E-16
05/22	0500	13.16	12.20	77.7	9.2	-4.56E-02	0.35	-0.03	-0.09	1.09E-07	5.41E-02	1.16E-15
05/22	0530	13.22	12.20	78.2	9.8	-4.16E-02	0.38	-0.03	-0.09	4.58E-08	5.28E-02	1.31E-15
05/22	0600	13.30	12.25	78.4	9.0	-5.07E-02	0.35	-0.04	-0.09	7.35E-03	5.30E-02	1.36E-15
05/22	0630	13.36	12.26	73.6	10.3	-4.20E-02	0.40	-0.04	-0.10	6.78E-03	7.06E-02	1.59E-15
05/22	0700	13.21	12.08	73.8	9.0	-5.63E-02	0.35	-0.04	-0.10	5.61E-03	6.29E-02	1.59E-15
05/22	0730	13.13	12.15	73.5	8.5	-5.77E-02	0.32	-0.03	-0.10	1.16E-02	4.72E-02	1.20E-15
05/22	0800	13.16	12.14	75.0	9.3	-4.75E-02	0.36	-0.03	-0.09	4.02E-03	4.41E-02	1.31E-15
05/22	0830	13.10	12.11	72.6	9.0	-5.17E-02	0.34	-0.03	-0.10	0.00E 00	3.59E-02	1.25E-15
05/22	1130	13.59	12.15	78.6	8.8	-6.89E-02	0.34	-0.05	-0.09	0.00E 00	2.49E-20	2.41E-15
05/22	1300	13.50	12.26	76.3	10.4	-4.37E-02	0.40	-0.04	-0.10	2.38E-03	5.21E-02	1.94E-15
05/22	1330	13.23	12.21	73.7	10.7	-3.57E-02	0.41	-0.03	-0.10	4.42E-03	5.43E-02	1.37E-15
05/22	1400	12.85	11.98	73.3	9.5	-4.03E-02	0.37	-0.03	-0.10	3.16E-03	4.05E-02	9.87E-16
05/22	1430	12.94	11.95	74.1	8.6	-5.60E-02	0.33	-0.03	-0.10	1.87E-03	2.54E-02	1.22E-15
05/22	1500	13.35	12.00	74.8	10.0	-5.13E-02	0.39	-0.05	-0.10	0.00E 00	6.78E-02	2.27E-15
05/22	1600	13.21	12.09	73.5	12.3	-2.86E-02	0.48	-0.04	-0.10	0.00E 00	9.45E-02	1.70E-15
05/22	1630	12.81	12.40	70.5	10.9	-1.92E-02	0.42	-0.01	-0.10	0.00E 00	1.09E-01	2.69E-16
05/22	1850	14.10	13.50	60.8	11.4	-2.72E-02	0.44	-0.02	-0.15	0.00E 00	9.16E-02	6.47E-16
05/22	2055	14.75	13.97	64.5	6.2	-1.16E-01	0.23	-0.03	-0.14	1.94E-03	8.28E-03	7.96E-16
05/23	0004	14.78	12.53	63.9	3.9	-7.38E-01	0.14	-0.09	-0.19	0.00E 00	1.49E-03	3.05E-15
05/23	0103	14.65	12.43	63.7	5.6	-3.23E-01	0.21	-0.08	-0.18	0.00E 00	6.38E-03	4.09E-15
05/23	0230	14.50	11.93	63.3	3.3	-1.18E 00	0.12	-0.11	-0.20	3.98E-03	1.64E-03	3.21E-15
05/23	0300	14.47	11.89	65.8	5.7	-3.42E-01	0.21	-0.10	-0.18	3.65E-03	8.54E-03	5.30E-15
05/23	0330	14.54	11.50	66.7	7.4	-2.13E-01	0.29	-0.11	-0.18	5.19E-03	1.91E-02	8.57E-15
05/23	0500	14.40	11.80	65.6	1.8	-4.24E 00	0.07	-0.12	-0.21	2.28E-03	2.83E-03	1.84E-15
05/23	0524	14.35	11.56	64.2	2.5	-2.30E 00	0.09	-0.12	-0.21	1.82E-03	9.98E-04	2.77E-15
05/23	0548	14.40	10.91	64.8	2.7	-2.32E 00	0.10	-0.15	-0.22	3.62E-03	1.84E-03	4.27E-15
05/23	0645	14.28	11.33	58.3	3.1	-1.63E 00	0.11	-0.13	-0.23	4.15E-03	9.26E-03	3.67E-15
05/23	0700	14.38	11.35	59.3	1.2	-1.02E 01	0.05	-0.16	-0.27	1.86E-03	1.43E-03	1.74E-15
05/23	0725	14.33	11.23	60.0	1.8	-4.87E 00	0.07	-0.15	-0.25	1.48E-03	4.45E-04	2.47E-15
05/23	0810	14.33	11.48	56.0	10.2	-1.04E-01	0.40	-0.10	-0.20	1.13E-02	5.06E-02	9.43E-15
05/23	1048	15.03	13.34	52.1	12.8	-4.47E-02	0.51	-0.06	-0.20	1.42E-04	5.94E-02	4.21E-15
05/23	1130	14.88	13.77	51.2	10.6	-5.16E-02	0.41	-0.04	-0.20	4.23E-03	6.85E-02	1.98E-15
05/23	1200	14.03	13.87	51.3	12.8	-1.58E-02	0.50	-0.00	-0.17	0.00E 00	8.69E-02	1.39E-16
05/23	1230	14.76	13.74	58.4	11.5	-3.77E-02	0.45	-0.03	-0.17	0.00E 00	7.35E-02	1.64E-15
05/23	1300	14.69	13.91	61.1	10.5	-3.79E-02	0.41	-0.03	-0.15	5.22E-04	6.35E-02	1.00E-15
05/23	1330	14.62	14.44	57.5	11.6	-1.83E-02	0.45	-0.00	-0.16	2.96E-04	9.33E-02	1.36E-16

Date	PDT	TS (C)	T (C)	RH (%)	U (m/s)	Z/L	u* (m/s)	T* (C)	q* (g/Kg)	Ct^2 (C^2/m^2/3)	Eps (m^2/s^3)	Cn^2 (1/m^2/3)
05/23	1400	14.41	14.36	58.6	10.8	-1.69E-02	0.42	0.00	-0.15	6.07E-04	7.73E-02	4.35E-17
05/23	1430	13.89	14.50	59.4	10.4	1.88E-03	0.40	0.03	-0.13	0.00E 00	7.66E-02	3.71E-16
05/23	1500	13.83	15.32	53.7	10.9	2.20E-02	0.42	0.06	-0.14	3.10E-03	9.96E-02	2.94E-15
05/23	1540	13.71	15.73	47.3	10.8	3.40E-02	0.41	0.08	-0.15	2.88E-03	7.76E-02	5.72E-15
05/23	1600	13.54	15.65	46.7	10.5	3.88E-02	0.39	0.08	-0.15	2.57E-03	6.28E-02	6.37E-15
05/23	1620	13.30	15.63	46.3	12.3	3.18E-02	0.47	0.09	-0.15	0.00E 00	9.15E-02	7.71E-15
05/23	1640	13.20	15.39	45.1	14.4	2.00E-02	0.56	0.08	-0.16	4.58E-03	1.25E-01	6.47E-15
05/23	1700	13.03	15.15	46.0	14.0	2.08E-02	0.54	0.08	-0.15	3.60E-03	1.53E-01	6.10E-15
05/23	1720	13.05	15.28	42.7	14.0	2.14E-02	0.54	0.08	-0.16	3.87E-03	1.76E-01	6.65E-15
05/23	1800	12.82	14.58	45.2	15.5	1.21E-02	0.61	0.07	-0.16	2.14E-03	2.40E-01	3.90E-15
05/23	1830	12.69	13.86	48.7	16.0	5.35E-03	0.64	0.05	-0.15	3.42E-03	1.50E-01	1.54E-15
05/23	1900	12.67	13.78	46.0	12.2	7.76E-03	0.47	0.04	-0.16	2.83E-03	6.76E-02	1.36E-15
05/23	1930	12.70	13.23	47.1	10.8	-4.80E-03	0.41	0.02	-0.16	0.00E 00	5.74E-02	1.97E-16
05/23	2000	12.74	12.52	49.3	11.9	-1.93E-02	0.46	-0.00	-0.17	0.00E 00	5.36E-02	1.86E-16
05/23	2030	12.12	11.58	56.7	11.2	-2.61E-02	0.43	-0.02	-0.14	0.00E 00	5.96E-02	5.26E-16
05/23	2100	0.00	11.38	58.4	14.2	1.78E-01	0.52	0.38	0.17	4.81E-03	1.58E-01	2.79E-13
05/24	0206	12.36	11.96	58.8	3.9	-2.47E-01	0.13	-0.01	-0.14	7.99E-04	4.49E-03	2.10E-16
05/24	0250	11.73	13.19	49.4	4.7	1.47E-01	0.15	0.05	-0.13	8.80E-03	6.52E-03	3.55E-15
05/24	0324	11.49	12.80	47.3	3.0	3.38E-01	0.09	0.04	-0.13	5.79E-03	9.67E-04	3.10E-15
05/24	0344	12.17	13.09	43.7	3.4	5.97E-02	0.11	0.04	-0.16	8.28E-03	2.92E-03	9.97E-16
05/24	0404	12.41	13.11	36.6	4.3	-4.08E-02	0.15	0.03	-0.20	3.87E-03	6.48E-03	2.96E-16
05/24	0424	11.51	12.48	35.3	7.8	5.99E-03	0.29	0.04	-0.19	2.96E-03	3.09E-02	8.74E-16
05/24	0500	11.18	10.63	48.4	13.7	-1.85E-02	0.54	-0.02	-0.16	3.33E-03	2.28E-01	6.15E-16
05/24	0530	1.00	10.35	49.3	11.2	2.30E-01	0.40	0.31	-0.00	4.10E-03	1.33E-01	1.86E-13
05/24	1000	10.93	10.13	73.0	11.8	-2.31E-02	0.46	-0.03	-0.08	0.00E 00	1.03E-01	8.49E-16
05/24	1030	10.84	10.24	76.2	10.9	-2.10E-02	0.42	-0.02	-0.07	0.00E 00	8.25E-02	4.68E-16
05/24	1100	10.65	10.35	76.5	11.5	-1.12E-02	0.45	-0.01	-0.06	0.00E 00	9.12E-02	1.14E-16
05/24	1130	10.80	10.32	74.0	11.1	-1.76E-02	0.43	-0.01	-0.07	0.00E 00	7.35E-02	3.09E-16
05/24	1200	10.79	10.45	75.1	10.9	-1.44E-02	0.42	-0.01	-0.07	0.00E 00	7.21E-02	1.57E-16
05/24	1230	10.73	10.41	77.9	10.6	-1.35E-02	0.41	-0.01	-0.06	0.00E 00	6.43E-02	1.24E-16
05/24	1330	10.95	10.88	76.5	10.4	-7.42E-03	0.40	0.00	-0.06	0.00E 00	5.96E-02	6.12E-18
05/24	1400	11.09	11.16	74.4	10.6	-4.11E-03	0.41	0.01	-0.07	0.00E 00	5.95E-02	7.70E-18
05/24	1430	11.06	11.31	74.2	10.8	7.21E-04	0.41	0.01	-0.06	0.00E 00	6.35E-02	8.53E-17
05/24	1500	11.04	11.40	74.2	11.1	3.62E-03	0.43	0.02	-0.06	0.00E 00	7.42E-02	1.90E-16
05/24	1530	10.96	11.48	73.6	11.1	7.34E-03	0.43	0.02	-0.06	0.00E 00	1.34E-01	3.96E-16
05/24	1600	10.67	11.62	72.1	11.3	1.73E-02	0.43	0.04	-0.06	0.00E 00	8.30E-02	1.40E-15
05/24	1630	10.65	11.70	72.0	11.8	1.81E-02	0.45	0.04	-0.06	0.00E 00	9.74E-02	1.73E-15
05/24	1700	10.76	11.84	72.6	11.2	2.11E-02	0.43	0.04	-0.05	0.00E 00	8.03E-02	1.85E-15
05/24	1730	11.01	11.97	71.5	12.0	1.50E-02	0.46	0.04	-0.06	0.00E 00	9.36E-02	1.41E-15

Date	PDT	TS (C)	T (C)	RH (%)	U (m/s)	Z/L	u* (m/s)	T* (C)	q* (g/Kg)	Ct^2 (C^2/m^2/3)	Eps (m^2/s^3)	Cn^2 (1/m^2/3)
05/25	1400	11.00	10.47	79.0	3.3	-2.72E-01	0.11	-0.02	-0.07	0.00E 00	2.00E-02	2.11E-16
05/25	1429	11.00	10.54	79.9	3.3	-2.39E-01	0.11	-0.01	-0.06	0.00E 00	3.06E-02	1.61E-16
05/25	1454	11.00	10.72	79.8	3.3	-1.70E-01	0.11	-0.01	-0.06	0.00E 00	1.93E-02	6.45E-17
05/25	1600	10.50	10.87	78.8	3.3	9.44E-02	0.10	0.02	-0.04	0.00E 00	8.33E-03	2.89E-16
05/25	1630	10.25	11.47	75.7	3.3	4.67E-01	0.09	0.04	-0.03	0.00E 00	3.55E-03	3.50E-15
05/25	1720	11.00	11.65	76.6	3.8	1.46E-01	0.12	0.03	-0.05	3.02E-04	3.22E-02	8.94E-16
05/25	1745	11.25	11.80	78.2	3.8	1.15E-01	0.12	0.02	-0.04	1.23E-04	1.52E-02	6.35E-16

APPENDIX C

NPS data from the tower site at SNI. Level 1 is a Z=11.4 meters and level 2 is at Z=17.5 meters. The wind direction (ϕ) is from the Acania measurements. The drag coefficient (c_{10}) is from the NRL tower U_* data.

$$c_{10} = (U_*/U_{10})^2$$

DATE	TIME		U,m/sec	$C_T^2, 10^{-3}$ °$C^2/m^{2/3}$		$\varepsilon, 10^{-3}$ m^2/sec^3		U_*,m/sec	$C_{10}, 10^{-3}$
	START	END	1	1	2	1	2		
5/14	1310	1324	2.0	5.76		184.00		.19	9.0
	1520	1533	1.5	4.40		.43		.12	6.4
	1725	1745	3.3	.10		1.29		.17	2.7
	1835	1841	2.4	4.63		28.00		.48	40.0
	1919	1922	3.7	.61		42.00		.55	22.0
	1927	1930	3.7	.38		45.00		.56	23.0
	2011	2014	4.0	.17		31.00		.50	16.0
5/15	0846	0855	9.0	.33		280.00		1.00	12.0
	0854	0902	10.5	.22		250.00		1.00	9.1
	0946	0949	10.0	.45		160.00		.86	7.4
	0954	1000	9.5	.32		280.00		1.00	11.0
	1023	1030	8.6	.14		360.00		1.10	16.0
	1030	1045	8.8	1.14		56.00		.61	4.9
	1515	1630	11.7	1.49		88.00		.71	3.7
	1552	1614	11.9	1.48		67.00		.64	2.9
	1918	1930	14.4	1.14		96.00		.73	2.6
	1936	1939	14.3	1.72		130.00		.80	3.1
	1941	1951	15.1	1.52		120.00		.79	2.8
	2002	2019	15.7	1.35		85.00		.70	2.5
5/16	0947	1001	10.7	1.82		210.00		.94	7.7
	1004	1026	10.8	3.35		150.00		.84	6.2
	1108	1130	10.5	1.30		24.00		.46	1.9
	1335	1421	10.8	2.30		120.00		.79	5.4
	1443	1512	11.4	3.22		35.00		.52	2.1
	1540	1558	11.4	2.13		35.00		.52	2.1
5/17	1052	1112	4.8	2.98		5.30	7.80	.32	4.9
	1249	1315	2.0	5.07		.57	17.00	.30	22.0
	1520	1531	4.1	4.19	.68		13.00	.43	11.0
	1845	1856	1.5		.29		.57	.13	8.0

DATE	TIME START	TIME END	U,m/sec 1	$C_T^2, 10^{-3}$ 1	$°C^2/m^{2/3}$ 2	$\varepsilon, 10^{-3}$ 1	m^2/sec^3 2	U_*,m/sec	$C_{10}, 10^{-3}$
5/18	0940	0947	2.6		.065		.090	.032	1.0
	1527	1540	3.7			1.0		.16	1.9
	1551	1600	3.4			.27		.10	1.0
	1906	1921	3.5			.54	.74	.15	1.9
	1730	1953	3.5			.96	.15	.13	1.4
	2011	2022	2.6			.48	.073	.10	1.5
	2031	2041	2.4	.96		1.34	1.56	.19	6.9
	2100	2129	2.4	.64	.10	.54	.11	.11	2.1
	2145	2207	2.6	.57		1.1	.22	.13	2.9
5/19	0830	0838	3.8	5.11	1.25	27.0	24.0	.50	17.0
	0840	0850	4.1	4.44	1.30	54.0	42.0	.62	23.0
	1025	1046	3.4	3.92	.56	8.1	6.2	.33	8.9
	1115	1140	3.9	3.88	.62	12.0	14.0	.40	11.0
	1145	1208	3.9	3.19	.58	12.0	13.0	.40	11.0
	1310	1332	4.1	5.87	.98	18.0	15.0	.40	11.0
	1350	1401	9.1	8.15	1.79	51.0	30.0	.58	20.0
	1835	1850	5.2	5.99	.57	18	24.0	.47	6.8
	2110	2115	5.5	2.03			14.0	.44	7.7
	2123	2133	5.3	5.76	1.52	46.0	66.0	.65	15.0
5/20	0945	1012	5.6	5.11	1.94	50.0	41.0	.60	11.0
	1015	1045	5.7	4.24	1.50	50 0	41.0	.60	11.0
	1108	1115	5.4	7.62	2.10	89.0	91.0	.76	17.0
	1507	1518	6.7	6.62	1.72	100.0	76.0	.76	17.0
	1525	1535	6.8	6.26	1.89	140.0	76.0	.80	14.0
	1840	1851	7.6	3.20	2.52	170.0	140.0	.90	14.0
	1933	1945	7.6	3.67	1.45	96.0	100.0	.80	12.0
	2025	2042	7.3	5.18	1.71	93.0	95.0	.78	11.0
5/21	0921	0935	5.8	6.78	2.70	120.0	100.0	.81	20.0
	1005	1016	5.5	5.83	2.02	94.0	65.0	.73	18.0
	1025	1040	5.2	5.53	1.32	40.0	41.0	.58	13.0

APPENDIX D
ACOUSTIC ECHOSOUNDER RESULTS FROM R/V ACANIA

P: Surface Plume Maximum Height (m)

In1: Lowest Inversion Height

In2: Second Lowest Inversion (m)

In3: Third Lowest Inversion (m)

In4: Fourth Lowest Inversion (m)

In5: Fifth Lowest Inversion (m)

In6: Sixth Lowest Inversion (m)

DATE	TIME	P	In1	In2	In3	In4	In5	In6
5/8	0000		70	110	280			
	0030		80	210	320			
	0100		80	220	300			
	0130	80	~80	270	320			
	0200							
	0230		surface	~150	~180	250		
	0300		70	merges	270	340		
	0330		70	merges		220		
	0400		70	merges		160	310W	
	0430		60	merges	110	merge		
	0500		surface	110	merges→			
	0530		80	100	180	260	440	
	0600		surface	merges	110	200	420	
	0630		70	120	200			
	0700		60	130	200			
	0730		70	110	180			
	0800		54	~110	180			
	0830		surface	100	180			
	0900		surface	←merge				
	0930		surfaces	←merges	140			
	1000		65	←merges				
	1030		surface	80	240			
	1100		60	100	160		possibly a 4th inversion	
	1130		surface	~100				
	1200		surface	120	← merges			
	1230		80	260				
	1300		100					
	1330		110					
	1400		130					
	1430		140					
	1500		130					

DATE	TIME	P	In1	In2	In3	In4	In5	In6
	1530		120					
	1600		160					
	1630		200					
	1700		210					
	1730		220					
	1800		200					
	1830		220					
	1900		220					
	1930		260					
	2000		300					
	2030		320					
	2100		340					
	2130		330					
	2200		340					
	2230		380					
	2300		400					
	2330		440					
	2400		420					
5/9	0030		440					
	0100		460					
	0130							
	0200							
	0230		~420					
	0300		400					
	0330		420					
	0400		400					
	0430		420					
	0500		~410					
	0530		400					
	0600		420					
	0630							

DATE	TIME	P	In1	In2	In3	In4	In5	In6
	0700							
	0730							
	0800		~300					
	0830		~316					
	0900		340					
	0930		340					
	1000		320					
	1030							
	1100		320					
	1130		300					
	1200		360					
	1230		460					
	1300		460					
	1330		520					
	1400		510					
	1430		460					
	1500		390					
	1530		360 (W)					
	1600		360					
	1630							
	1700							
	1730		~430 (W)					
	1800							
	1830		435					
	1900		440					
	1930							
	2000							
	2030		440					
	2100		450					
	2130		430					
	2200		410					

DATE	TIME	P	In1	In2	In3	In4	In5	In6
	2230		380					
	2300		420					
	2330		~320					
	2400		310					
5/10	0030		300					
	0100		300					
	0130		380					
	0200		460					
	0230		460					
	0300		510					
	0330		570					
	0400		580					
	0430		Too Weak					
	0500		580					
	0530		610					
	0600		660					
	0630		700					
	0700		700					
	0730		~700					
	0800		~700					
	0830							
	0900		640(W)					
	0930		640					
	1000		Too Weak					
	1030		↓					
	1100		↓					
	1130		↓					
	1200							
	1230		540					
	1300		480					

DATE	TIME	P	In1	In2	In3	In4	In5	In6
	1330		580					
	1400		560					
	1430		540					
	1500		510					
	1530		500					
	1600		440					
	1630		360					
	1700		340					
	1730		460					
	1800		500					
	1830		480					
	1900		500					
	1930							
	2000		420					
	2030							
	2100							
	2130		260					
	2200							
	2230							
	2300							
	2330							
	2400		440					
5/11	0030		440					
	0100		440					
	0130		440					
	0200		480					
	0230		440					
	0300		440					
	0330		440					
	0400		480					

DATE	TIME	P	In1	In2	In3	In4	In5	In6
	0430		460					
	0500		460					
	0530		440					
	0600		~400					
	0630		360					
	0700		260					
	0730		320					
	0800		260					
	0830		200					
	0900		100					
	0930		100					
	1000		surface	160	380			
	1030		160	← merges	360			
	1100		100	140	360			
	1130		80	280	360	610		
	1200		120	310	380	600		
	1230		100	~300 (W)	360			
	1300		80	200	240	340		
	1330		100	400				
	1400		80	400				
	1430		100					
	1500		100	300				
	1530							
	1600		100	420				
	1630		200					
	1700		220					
	1730							
	1800							
	1830							
	1900		200					
	1930		200					

DATE	TIME	P	In1	In2	In3	In4	In5	In6
	2000		240					
	2030		240					
	2100		260					
	2130		300					
	2200		280					
	2230		280					
	2300		240					
	2330		220					
	2400		200	260				
5/12	0030		100	180				
	0100		70	120				
	0130		60	110				
	0200		80	300 (W)				
	0230		100	320 (W)				
	0300		80	240				
	0330		200					
	0400		~190					
	1030		100	220				
	1100		100	260				
	1130		100	240	260			
	1200		80	240				
	1230		80	180				
	1300		80	140	260			
	1330		100	240				
	1400		60	240				
	1430		60	260				
	1500		60	300				
	1530		60	260				
	1600		60	120	240			
	1630		60	110	240			

DATE	TIME	P	In1	In2	In3	In4	In5	In6
	1700		80					
	1730							
	1800							
	1830		140					
	1900		140					
	2000		100					
	2030							
	2100		100	210				
	2130		120	240				
	2200		180					
	2230		200					
	2300		60	160	220			
	2330		260					
	2400		260					
5/13	0000		260					
	0030		60					
	0100		100					
	0130		140					
	0200		140					
	0230		80	160				
	0300		80					
	0330		80					
	0400		80					
	0430		80					
	0500		80					
	0530		80					
	0600		100					
	0630		120					
	0700		140					
	0730		140					

DATE	TIME	P	In1	In2	In3	In4	In5	In6
	0800		100					
	0830		100					
	0900		100					
	0930		60					
	1000		80					
	1030		60	120	150			
	1100		60	120	160	200		
	1130		60	120	160	200		
	1200		60	100	140			
	1700	100	120	140				
	1730	80	140	200	280			
	1800		80	200	~300			
	1830		80	120	220			
	1900							
	1930							
	2000							
	2030	80	70	180				
	2100		surface					
	2130	60	100	120				
	2200							
	2230							
	2300		80	160	200	340		
	2330		80	140	200	300		
	2400		surface	120	180	300		
5/14	0030		surface	80	120	160	220	300
	0100	100	110	140	240	280	260 (W)	
	0130	90	100	140	240	280	420 (W)	
	0200		80	160	260	34	460	
	0330		70	120				
	0400		70	100				

DATE	TIME	P	In1	In2	In3	In4	In5	In6
	0400		70	100				
	0430		60	120				
	0500		surface	120(W)	200			
	0530		80	140	240			
	0600		120	200(W)	200			
	0630		120	200	280			
	0700		110	200				
	0730		100	140				
	0800		surface	130	170			
	0830		80					
	0900		~100					
	0930		140	300				
	1000		100	180	280	400		
	1030							
	1100							
	1130							
	1200		80	160	220	260	300	
	1230		180					
	1300		280					
	1330		300					
	1400							
	1430							
	1500							
	1530							
	1600		320					
	1630		300					
	1700		280					
	1730		220					
	1800		200					
	1830		100	240				
	1900		80	100				

DATE	TIME	P	In1	In2	In3	In4	In5	In6
	1930		~160	240				
	2000		140	240				
	2030		140					
	2100		120					
	2130		140					
	2200		140					
	2230		180					
	2300		170					
	2330		~200					
	2400		160					
5/15	1600		340					
	1630		360					
	1700		360					
	1730		380					
	1800		400					
	1830		380					
	1900		400					
	1930		340					
	2000		320					
	2030		320					
	2100		340					
	2130		280					
	2200		300					
	2230		240					
	2300		240					
	2330		220					
	2400		260					

DATE	TIME	P	In1	In2	In3	In4	In5	In6
5/16	0030		160					
	0100		180					
	0130		160					
	0200		120					
	0230		120					
	0300		100					
	0330		140					
	0400		180					
	0430		180					
	0500		240					
	0530		220					
	0600		~260					
	0630							
	0700							
	0730							
	0800		280					
	0830		220					
	0900		200					
	0930		160					
	1000		120					
	1030		160					
	1100		400					
	1130		~300					
	1200							
	1230		240					
	1300		120					
	1330		220					
	1400		120					
	1430		150					
	1500		160	180				
	1530		140					

DATE	TIME	P	In1	In2	In3	In4	In5	In6
	1600		200					
	1630		100					
	1700		100					
	1730		120					
	1800		~160					
5/18	0630		70	180	200			
	0700		60	180	250			
	0730		70	140				
	0800		80	← merges				
	0830		110					
	0900		60	160				
	0930		60	100	160			
	1000		60	100	150	220		
	1130	120	260					
	1500		surface					
	1530		surface					
	1600		60					
	1630		60					
	1700		60					
	1730		60					
	1800		surface	190				
	1830		surface	150				
	1900		80	160				
	1930		80	160				
	2000		110	200				
	2030		120	260				
	2100		~90	210 (W)				
	2130		80	200 (W)				
	2200		surface	200 (W)				
	2230		surface					

DATE	TIME	P	In1	In2	In3	In4	In5	In6
	2300		~60					
	2330	80	90					
	2400	60	80					
5/19	0030	80	85					
	0100		80					
	0130	100	110					
	0200		100					
	0230	90	120					
	0300	100	140					
	0330	100	160					
	0400	110	180					
	0430	110	180					
	0500	140	180					
	0530	140	180					
	0600	130	200					
	0630	120	180					
	0700	160	200					
	0730	150	200					
	0800	140	200					
	0830	130	180					
	0900	120	180					
	0930	120	220					
	1000	110	180					
	1030	100	220					
	1100	100	200					
	1130	140	180					
	1200	140	210					
	1230	100	190					
	1300	120	170					
	1300	100	180					

DATE	TIME	P	In1	In2	In3	In4	In5	In6
	1400	100	190					
	1430	80	200					
	1500	80	~200					
	1530	100	180					
	1600	80	200					
	1630	80	210					
	1700	100	220					
	1730	150	240					
	1800	140	250					
	1830	100	230					
	1900	100	220					
	1930	~100	220					
	2000	150	260					
	2030	140	250					
	2100	90	280					
	2130	120	230					
	2200	100	230					
	2230	160	220					
	2300	120	240					
	2330	120	240					
	2400	100	250					
5/20	0030	120	270					
	0100	140	280					
	0130	140	330					
	0200	140	310					
	0230	140	360					
	0300	140	340					
	0330		370					
	0400	103	360					
	0430	100	350					

DATE	TIME	P	In1	In2	In3	In4	In5	In6
	0500	100	360					
	0530	100	370					
	0600	180	420					
	0630	210	420					
	0700	140	420					
	0730	220	460					
	0800	150	420					
	0830	100	410					
	0900	180	430					
	0930	100	430					
	1000	110	460					
	1030	90	440					
	1100	110	440					
	1130	100	420					
	1200	100	420					
	1230		440					
	1300		440					
	1300	100	430					
	1400	100	400					
	1430	110	410					
	1500	120	450					
	1530	120	420					
	1600	110	450					
	1630	80	420					
	1700	100	450					
	1730	~100	430					
	1800	120	440					
	1830	100	420					
	1900	100	420					
	1930	100	430					

DATE	TIME	P	In1	In2	In3	In4	In5	In6
	2000	80	360					
	2030		360					
	2100		360					
	2130		380					
	2200		400					
	2230		380					
	2300		410					
	2330		380					
	2400		420					
5/21	0030		460					
	0100		460					
	0130		500					
	0200		520					
	0230		510					
	0300		530					
	0330		580					
	0400		590					
	0430		600					
	0500		600					
	0530		620					
	0600		660					
	0630		700					
	0700		710					
	0730		~700(W)					
	0800		700(W)					
	0830		690(W)					
	0900		700(W)					
	0930		700					
	1000		700					
	1030		710					

DATE	TIME	P	In1	In2	In3	In4	In5	In6
	1100		720					
	1130		730					
	1200		710					
	1230		720					
	1300		400					
	1330		220					
	1400		surface					
	1430		300					
	1500		500	760				
	1530		420	750				
	1600		320	720				
	1630		140	240	680			
	1700		200	600				
	1730		~100	520				
	1800		100	500				
	1830		180					
	1900		80					
	1930		surface	~300				
	2000		200	~300				
	2030		320					
	2100		430					
	2130		460					
	2200							
	2230		600					
	2300		600					
	2330		640					
	2400		600					
5/27	0030		to dark					
	0100		to dark					
	0130		to dark					

DATE	TIME	P	In1	In2	In3	In4	In5	In6
	0200		540					
	0230		540					
	0300		580	620				
	0330		590					
	0400		too dark					
	0430		~700					
	0500		~700					
	0530		~700					
	0600		720					
	0630		780					
	0700		800					
	0730		860					
	0800		860					
	0830		860					
	0900		880					
	0930		880					
	1000		890					
	1030		900					
	1100		910					
	1130		920					
	1200		860					
	1230		760					
	1300		680					
	1300		600					
	1400		too dark					
	1430		500					
	1500		350					
	1530		250					
	1600		250					
	1630		too dark					

DATE	TIME	P	In1	In2	In3	In4	In5	In6
	1700		100	280				
	1730		100	340	-700			
	1800		surface	300	700			
	1830		340	merges w/ 1				
	1900		~300					
	1930		280					
	2000		surface					
	2030		surface	220				
	2100	100	160					
	2130		surface					
	2200		surface					
	2230	100						
	2300	120	~120					
	2330	180						
	2400		~ 80	~150				
5/23	0030		80	330				
	0100		80	300				
	0130		surface	120	~400			
	0200		surface	merges	340	470		
	0230		140	320	420			
	0300		80	260	410			
	0330	80	surface	300	680			
	0400	80	~120					
	0430		90					
	0500	100	180	330				
	0530	100	180	340				
	0600		270					
	0630		surface					
	0700		100					
	0730	200	~280					

DATE	TIME	P	In1	In2	In3	In4	In5	In6
	0800	160	260					
	0830	120	140					
	0900		320					
	0930		200					
	1000		160					
	1030		surface					
	1100		surface					
	1130		140					
	1200		160					
	1230		60					
	1300		70	250				
	1330		80	260				
	1400		surface	180				
	1430		surface	200				
	1500		surface	280				
	1530		surface					
	1600		surface					
	1630		surface	~200				
	1700		surface	180				
	1730	100	surface					
	1800	100	220					
	1830	80						
	1900	~ 90						
	1930	100						
	2000	100						
	2030	100	100					
	2100		200					
	2130		100	200				
	2200		200					
	2230		210					
	2300		200					
	2330	90	200					
	2400	120	260					

INITIAL DISTRIBUTION LIST

		No. of Copies
1.	Defense Documentation Center Cameron Station Alexandria, Virginia 22314	2
2.	Library, Code 0212 Naval Postgraduate School Monterey, California 93940	2
3.	Dean of Research, Code 012 Naval Postgraduate School Monterey, California 93940	1
4.	Asst. Professor C. W. Fairall, Code 61Fr Naval Postgraduate School Monterey, California 93940	5
5.	Professor K. E. Woehler, Code 61Wh Naval Postgraduate School Monterey, California 93940	1
6.	Dr. Ralph Markson Airborne Research Associates 46 Kendal Common Road Weston, Massachusetts 02193	1
7.	Assoc. Professor K. L. Davidson, Code 63Ds Naval Postgraduate School Monterey, California 93940	5
8.	Assoc. Professor T. Houlihan, Code 69Hm Naval Postgraduate School Monterey, California 93940	5
9.	Assoc. Professor G. Schacher, Code 61Sq Naval Postgraduate School Monterey, California 93940	5
10.	Mr. Murray Schefer Code Air-3706 Naval Air Systems Command Washington, D. C. 20360	1
11.	LT Michelle Hughes PM-22/PMS 405 Naval Sea Systems Command Washington, D. C. 20362	1

No. of Copies

12. Dr. Stuart Gathman
Code 8326
Naval Research Laboratory
Washington, D. C. 20375 — 1

13. Dr. Lothar Rohnke
Code 8320
Naval Research Laboratory
Washington, D. C. 20375 — 1

14. Dr. Barry Katz
Code 231
Naval Surface Weapons Center
White Oak Laboratory
Silver Spring, Maryland 20910 — 1

15. Professor Dale Leipper, Code 68Lr
Naval Postgraduate School
Monterey, California 93940

16. Eugene J. Mack
Calspan Corporation
Buffalo, New York 14221 — 1

17. Theodore V. Blanc
Code 8322B
Naval Research Laboratory
Washington, D. C. 20375 — 1

18. Dr. J. H. Richter
Code 813
Submarine Systems Division
Communications Systems and Technology Department
Naval Oceans Systems Center
San Diego, California 92152 — 1